Pilot Testing of a High-Rate Disk Filter for Water Recycling Applications and Title 22 Approval

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ABSTRACT

Pilot testing of the Nova Ultrascreen® (a high rate disk filter) was conducted at two water reclamation facilities in the Orlando, Florida area to demonstrate that the Ultrascreen® can produce an effluent that meets the California Title 22 Water Recycling Criteria turbidity requirements, at hydraulic loading rates ranging from 6 to 16 gpm/ft^2. The pilot testing was conducted at water reclamation facilities that utilize a continuous backwash and cloth media disk filters for the production of recycled water. During the pilot testing the influent and effluent turbidity of both the Ultrascreen® and the continuous backwash and cloth media disk filters were monitored. Influent and effluent grab samples were collected and analyzed for particle size distribution. The results from the pilot-scale testing demonstrate that the Ultrascreen® can consistently meet the Title 22 turbidity limit of 2 NTU while operating at hydraulic loading rates ranging from 6-16 gpm/ft^2. In addition the performance of the Ultrascreen® while operating at these higher loading rates of 6-16 gpm/ft^2 was similar to the performance of the full-scale continuous backwash and cloth media disk filters operating at hydraulic loading rates of <3 gpm/ft^2 and <5 gpm/ft^2, respectively.

KEYWORDS: Tertiary filtration, recycled water, high-rate disk filtration, Title 22.

INTRODUCTION

As the demand for water reuse increases in the United States so does the need for new cost effective technologies that can meet performance and regulatory requirements within a small footprint. The Ultrascreen® (a high rate disk filter) was introduced to the United States in April 2006 by Nova Water Technologies as an innovative approach to applying disk filters for tertiary treatment (U.S Patent No. 6,500,331). Preliminary results from the pilot testing conducted by Nova Water Technologies has indicated that the Ultrascreen® can produce an effluent with a turbidity of < 2 NTU while operating at a hydraulic loading rate of up to 16 gpm/ft^2, more than twice the hydraulic loading rate at which other commerically available disk filtration technologies operate.

Nova Water Technologies contracted with Carollo Engineers to conduct pilot testing on the Nova Ultrascreen® to determine if the filter could satisfy the California Title 22 recycled water turbidity limit while operating at a hydraulic loading rate of up to 16 gpm/ft^2. The ultimate goal of this testing was to obtain California Department of Public Health (CDPH) conditional acceptance (Title 22 aproval) for the use of this technology in the production of recycled water in California. Therefore, the focus of this paper will be to 1) provide a regulatory background on the Title 22 water recycling criteria, 2) to provide a description of the Ultrascreen®, 3) to provide a description of the experimental methodology, and 4) to describe the results of the Title 22 performance testing that was conducted.

TITLE 22 WATER RECYCLING CRITERIA

In California, the health laws related to the use of recycled water are found in Chapter 3 (Water Recycling Criteria) of Division 4 (Environmental Health) of Title 22 (Social Security) of the California Code of Regulations. The type of recycled water that is required for unrestricted irrigation, the highest non-potable quality of reuse water in California, is disinfected tertiary recycled water. Table 1 contains a summary of Title 22 water quality criteria for disinfected tertiary recycled water. The California water quality criteria and the treatment system requirements as specified in Title 22 (Section 60301 and 60304) are discussed below in detail.

Table 1. California Title 22 disinfected tertiary recycled water criteria.

Parameter	Required Limits	
Turbidity	2 NTU	24-hour period average
	5 NTU	5% of the time within a 24-hour period
	10 NTU	Never to exceed
Poliovirus [a]	5 log	Minimum log reduction during operation
Total Coliform [a] (MPN[b]/100 mL)	2.2	7 day median
	23	One sample in any 30 day period
	240	Not to exceed in any sample

[a] Reduction of microorganisms is achieved through filtration and subsequent disinfection.
[b] MPN is the most probable number.

"Disinfected tertiary recycled water," is defined in Title 22 as a "filtered and subsequently disinfected wastewater" (60301.230). Since the purpose of the Nova Ultrascreen® pilot testing was to determine if the performance of a filtration technology could meet the Title 22 requirements, the disinfection requirements of the Title 22 will not be discussed further. "Filtered wastewater" is defined in (60301.320) as an "oxidized wastewater that meets the criteria in subsection (a) or (b):"

a) Has been coagulated and passed through natural undistributed soils or a bed of filter media pursuant to the following:
   1) At a rate that does not exceed 5 gallons per minute per square foot of surface area in mono, dual, or mixed media gravity, upflow or pressure filtration systems, or does not exceed 2 gallons per minutes per square foot of surface area in traveling bridge automatic backwash filters; and
   2) So that the turbidity of the filtered wastewater does not exceed any of the following:
      a. Average 2 NTU within a 24-hour period;
      b. 5 NTU more that 5 percent of the time within a 24-hour period;
      c. 10 NTU at any time.
b) Has been passed through a microfiltration, ultrafiltration, nanofiltration, or reverse osmosis membrane so that the turbidity of the filtered wastewater does not exceed the following:
   1) 0.2 NTU more than 5 percent of the time within a 24-hour period; and
   2) Never to exceed 0.5 NTU at any time.

It should be mentioned that per section 60304 of the Title 22 criteria, coagulation need not be used as part of the treatment process provided that the filter effluent turbidity does not exceed 2 NTU, the turbidity of the influent to the filters is continuously measured, the influent turbidity does not exceed 5 NTU for more than 15 minutes and never exceeds 10 NTU, and there is the capability to automatically activate chemical addition or divert the wastewater should the filter influent turbidity exceed 5 NTU for more than 15 minutes.

Not all commercially available filtration technologies that have demonstrated their ability to meet the performance objectives of the current Title 22 regulations are specifically listed in the Title 22 Water Recycling Criteria. The CDPH, however, has published the "Treatment Technology Report For Recycled Water" (CDPH, 2009). This report lists those filtration technologies that have been given conditional acceptance for the production of recycled water and those operational conditions under which the filtration technology may operate. As shown in this document, all disk filtration technologies have received conditional acceptance to operate at a hydraulic loading rate of up to 6 gpm/ft^2. It should be mentioned that the CDPH has previously approved other filtration technologies to operate above the maximum 5 and 6 gpm/ft^2 hydraulic loading rate for granular and cloth media, respectively. As shown in the Treatment Technology Report for Recycled Water (CDPH, 2009), the Scrheiber Fuzzy Filter has been given conditional acceptance to operate at hydraulic loading rates up to 30 gpm/ft^2.

DESCRIPTION OF THE ULTRASCREEN®

The Ultrascreen® is an inside-out surface filtration system that consists of continuously rotating disk filters made of woven stainless steel mesh. The influent flow is directed into the center "inside" of the disk and flows out through the filter mesh to the effluent outlet (see Figure 1 and 2). The disks are continuously rotating throughout the filtration cycle as the filtration mesh is fed at angles less than 90 degrees, to achieve "dynamic tangential filtration". As shown in Figures 1b and 2, the effluent side of the filter is not partially submerged like other disk filtration technologies. Free filtrate discharge occurs with the Ultrascreen®.

Filter Mesh Characteristics

The disk of the Ultrascreen® is made of AISI 316 stainless steel micronic screen mesh. Due to the rotation of the disk and the "dynamic tangential filtration" it is claimed by the manufacturer that particles smaller than 10 micrometers (μm) can be removed with the 20 μm nominal size mesh screen. Figure 3 contains a photo of the filter media mesh. The filter media of the Ultrascreen® is similar to the approved cloth disk filter technology (Kruger Hydrotech Disk Filter) listed in "The Treatment Technologies Report for Recycled Water" (CDPH, 2009) except that the media is made of a woven stainless steel mesh instead of PET mono-filament weave. It is also claimed by the manufacturer that "dynamic tangential filtration" will lead to less solids accumulation on the media which will allows the filter to operate at a higher hydraulic loading rates while still meeting effluent turbidity limits. A proprietary silicone rubber blend seal sits against the disk sides and prevents short-circuiting. The silicone rubber blend seal allows the disks to rotate while preventing untreated effluent from passing the system. A schematic of the flow path through the Ultrascreen® is presented in Figure 1.

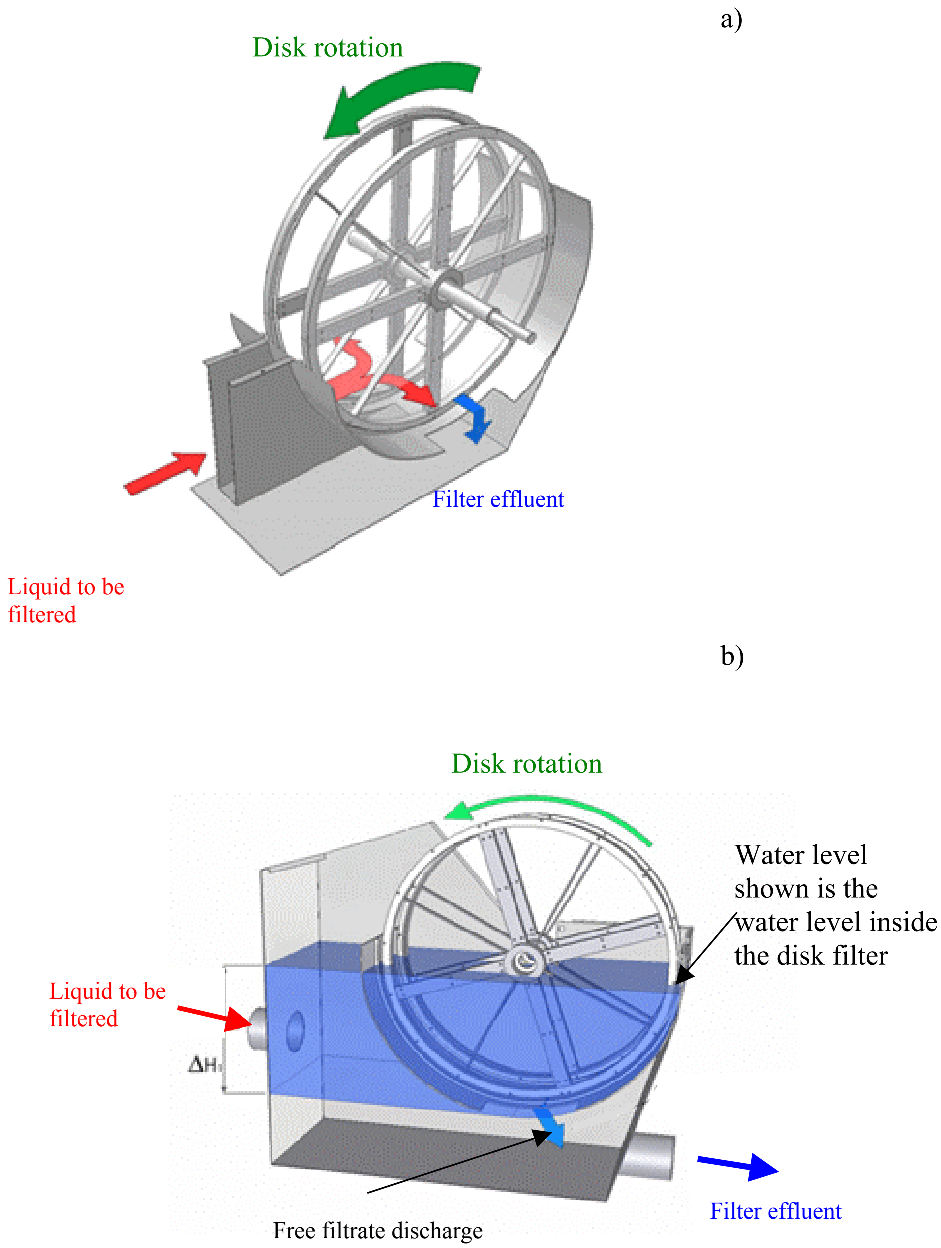


Figure 1. Schematic of the a) flow path and b) disk submergence through the Ultrascreen®.

Figure 2. Free filtrate discharge on the Ultrascreen®.

Figure 3. Picture of the Ultrascreen® media.

METHODOLOGY

Filter System Characteristics and Operation

The pilot unit Ultrascreen® consists of one set of disks (two disks) with a total of 17 square feet of dynamic filtration area. The Ultrascreen® utilized during this pilot is not a scaled down pilot unit but is instead the smallest capacity standard factory model regularly produced. A picture of the Ultrascreen® unit is presented in Figure 4. The pilot has an automatic data logger, an influent pump, and influent magnetic flowmeter, an influent and effluent turbidimeter, a centrifugal backwash water pump, and a variable speed filter drive unit. The automatic data logger records influent flow rate and effluent turbidity data. The filter drive unit, that controls the rotational speed of the disks, has a range of 0 to 28 rpm. The centrifugal backwash water pump cleans the screens intermittently with filtrate. Each disk has a dedicated spray header for washing.

Solids not passing through the mesh are removed during a backwash cycle and collect in a trough between the disks for discharge from the filter. As solids accumulate on the Ultrascreen® surface, the water level in the influent channel increases. When the level sensors detect the water level in the feed zone is above the pre-set level, a backwash cycle is initiated. During a backwash spray nozzles spray filtrate at 60 psig on the outside of the disks (Figure 5a) to remove solids. Solids that are cleaned from the filter mesh along with the backwash water are collected in a backwash trough between the disks and are discharged from the filter (Figure 5b). Once clean, the feed zone water level is reduced and another pre-set level limit deactivates the backwash water pump.

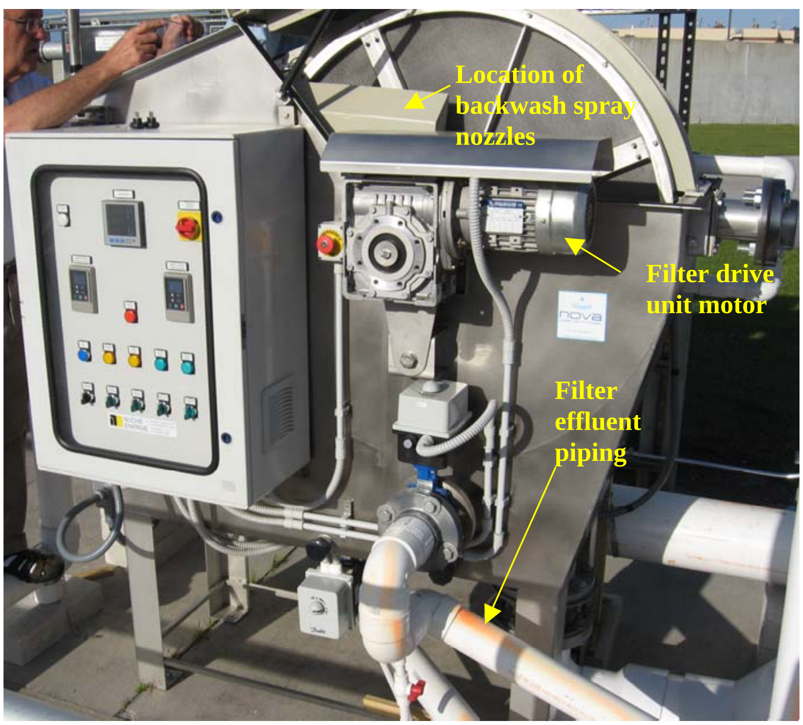


Figure 4. Picture of the Ultrascreen® pilot unit.

a) b)

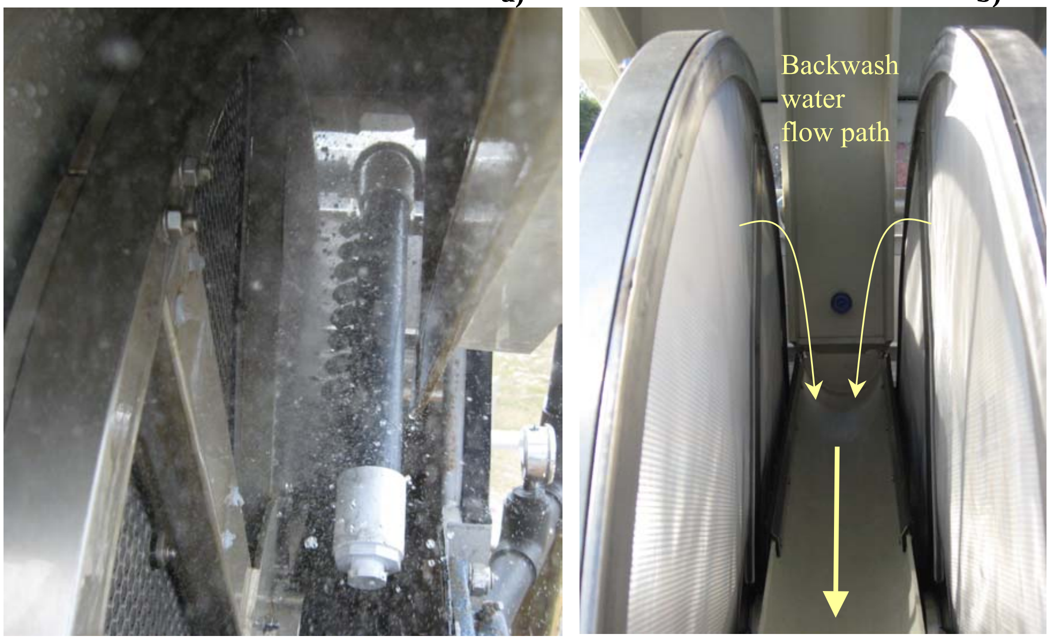


Figure 5. Picture of the a) backwash spray nozzles during a backwash and b) backwash water flow path to the wash water trough between the disks.

METHODS AND PROCEDURES

The purpose of the pilot testing was to demonstrate compliance with the California Title 22 Water Recycling Criteria as it relates to turbidity. The Title 22 performance testing took place at the Orange County Utilities South Water Reclamation Facility (WRF) and the Northwest WRF. The South WRF utilizes an AquaDisk® system (cloth media disk filter) for the production of recycled water. The Northwest WRF utilizes a continuous backwash filter (DynaSand®) for the production of recycled water. By performing the pilot testing at these two WRFs the performance of the Ultrascreen® at higher filtration rates could be compared to the performance of two filtration technologies that have already received conditional acceptance by the CDPH to be used for the production of recycled water.

Experimental Design

A summary of the experimental design for the pilot tests that were conducted at the two WRFs to demonstrate compliance with the California Title 22 Water Recycling Criteria is presented in Table 2.

Table 2. Summary of the experimental design.

Test Number	Hydraulic Loading Rate (gpm/ft^2)	Disk Rotational speed (rpm)
South WRF		
1A	6	5
1B	6	6
2B	10-12 [a]	8
3A	12	8
3B	12	12
Northwest WRF		
1A	6	5
1B	6	6
2A	8	6
2B	8	8
3A	12	8
4A	16	12
4A	16	16

[a] Clogging of the influent pump strainer with plastics resulted in a non-constant hydraulic loading rate.

Experimental Methods

Turbidity and flow data of the secondary effluent (pilot influent) were continuously measured at both WRF sites. The effluent turbidity of the Ultrascreen® effluent, and the host WRF tertiary filter effluent were also continuously monitored and recorded with data-logging devices at both pilot sites. In addition to the continuous data logging that was recorded during the experiments, grab samples were collected throughout the testing to monitor performance of the Ultrascreen® at the different experimental conditions listed in Table 2. During each day of testing an influent grab sample (secondary influent to both the pilot and full scale filtration units) and two filter effluent grab samples were collected and analyzed for particle size distribution (PSD), turbidity, and ultraviolet light transmittance (UVT). A list of the analytical methods used for the grab sample analysis is presented in Table 3. Twice a week grab samples were collected at the same time that the PSD samples and were analyzed for total suspended solids (TSS). On transition days a composite filter influent sample as well as three filter effluent samples were collected (i.e., after a backwash cycle, during the middle of the filtration cycle, and immediately before the backwash cycle) before and after changing operational conditions. The first set of three samples were collected at the existing set of operating conditions, the second set after the operating conditions had been changed, and the third set after a specified period (approximately 2 hours) of operation at the new conditions. The intent of these PSD samples was to help characterize filtration system performance during normal operation of the filter and to compare filter performance in terms of particle removal to the approved water recycling technologies.

Table 3. Analytical methods for grab samples.

Parameter	Method [a]
Turbidity	2130B
Particle Size Distribution	Modified version of proposed Method 2560C
UV Transmittance	Realtech UV Transmittance Meter measured @ 254 nanometers
Total Suspended Solids	2540D

[a] Unless otherwise indicated all methods are from Standard Methods.

RESULTS

As mentioned previously, the purpose of this testing was to evaluate the performance of the Ultrascreen® and determine the operational conditions under which the filter could meet the Title 22 water quality turbidity requirements of 2 NTU. During the testing the Ultrascreen® performance was compared to two full-scale filter technologies at the WRFs. The South WRF has AquaDisk® filters and the Northwest WRF has DynaSand® continuous backwash filters. Both of these filtration technologies have previously received conditional acceptance (i.e., Title 22 approval) by the CDPH for the production of recycled water. Originally, the goal was to run the full-scale filtration technologies at the maximum approved loading rates of 5 gpm/ft^2 and 6 gpm/ft^2 for the DynaSand® and the AquaDisk® filters, respectively, for comparison purposes. However, because the filters were part of operating WRFs that were producing recycled water for unrestricted reuse applications, there were some site specific operational limitations on the loading rates at which the full-scale filters could be operated. Therefore, the full-scale filters were operated at lower loading rates that were sometimes 2 to 8 times lower than the hydraulic loading rates for the Ultrascreen®.

Due to space constraints the results from the Title 22 performance testing conducted at hydraulic loading rates of 12 and 16 gpm/ft^2 will be presented in this manuscript. A description of the Ultrascreen® performance in terms of turbidity and PSD will be presented in the following sections.

Turbidity

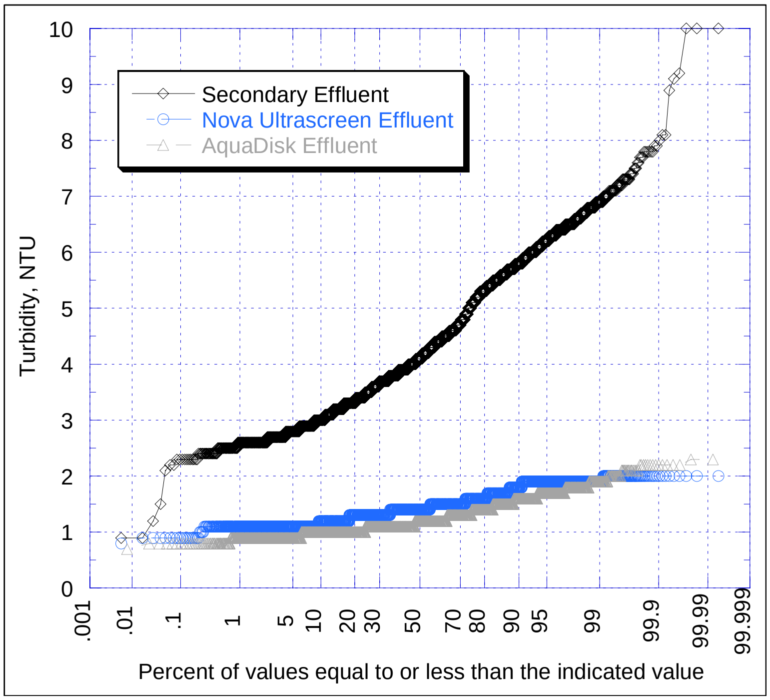
The influent and effluent turbidity of the Ultrascreen® and the full-scale filtration technologies were monitored continuously by on-line turbidimeters during the testing at both WRF's. Each test represents a different planned loading rate (i.e., 12 and 16 gpm/ft^2) for the Ultrascreen®. A probability plot of the influent (i.e., secondary effluent) and the filter effluents (i.e., Ultrascreen® and the on-site filtration technology) were developed for each test from the on-line data to show the percent of turbidity values that were equal to or less than 2 NTU. These probability plots have been used to evaluate the performance of the Ultrascreen® with regard to Title 22 turbidity requirements and to compare the performance to the full-scale filtration technologies. This evaluation is presented in the following subsection.

Target Loading rate of 12 gpm/ft^2

At the South WRF the Ultrascreen® operated at 11.92 to 11.97 gpm/ft^2 showed similar performance to the AquaDisk® that was operated at hydraulic loading rates of < 3 gpm/ft^2. The Ultrascreen® and the AquaDisk® achieved turbidity levels of less than 2 NTU for 99 percent (Figure 6) or 99.9 percent (Figure 7) of the time. At the Northwest WRF the Ultrascreen® operated at 12.37 gpm/ft^2 showed better performance than the DynaSand® filter operated at <2 gpm/ft^2 (Figure 8). The Ultrascreen® achieved effluent turbidity levels less than 2 NTU for 99 percent of the time and the DynaSand® filter achieved less than 2 NTU for 90 percent of the time. At a loading rate of approximately 12 gpm/ft^2, the Ultrascreen® performed similarly to the full-scale filtration technologies that were operated at hydraulic loading rates approximately 4 to 6 times lower than the Ultrascreen® filter.

Target Loading rate of 16 gpm/ft^2

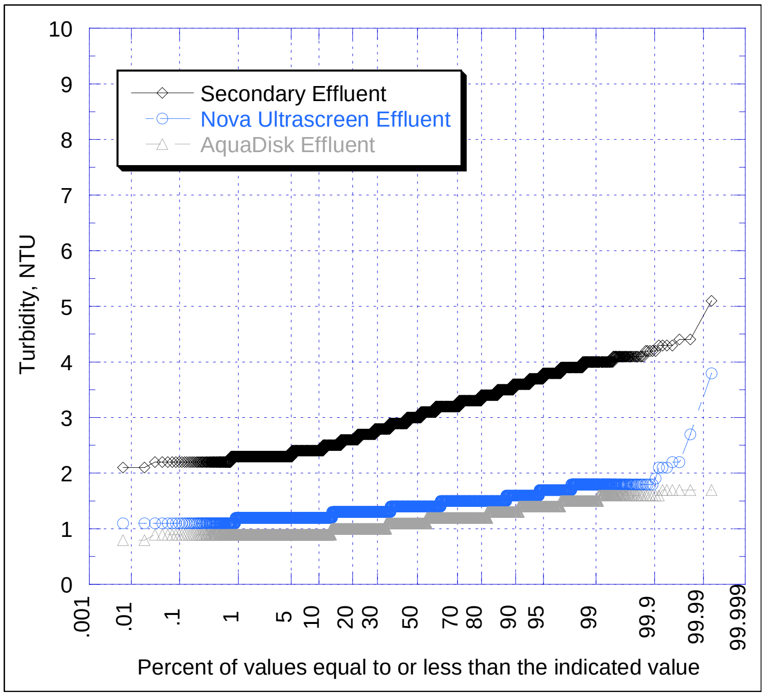
All of the testing at a loading rate of 16 gpm/ft^2 was performed at the Northwest WRF. The Ultrascreen® operated at an average hydraulic loading rate of 16.21 and 16.17 gpm/ft^2, respectively, for Tests 4a and 4b, performed better than the DynaSand® filter that was operated at <2 gpm/ft^2 (Figure 9 and 10). In Figure 9 and 10, the Ultrascreen® achieved effluent turbidity levels less than 2 NTU for 99.9 percent of the time and the DynaSand® filter achieved less than 2 NTU only 90 percent of the time.



Ultrascreen® Average Hydraulic Loading Rate 11.97 gpm/ft², 8 rpm

AquaDisk® Hydraulic Loading Rate <3 gpm/ft²

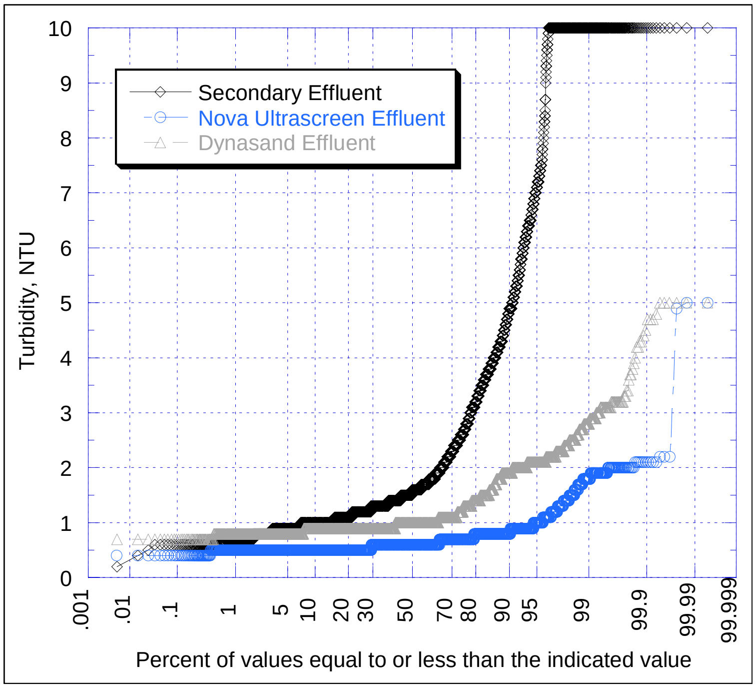
Figure 6. Turbidity performance during Experiment 3A (12 gpm/ft², 8 rpm) at the South WRF.



Ultrascreen® Average Hydraulic Loading Rate 11.92 gpm/ft², 12 rpm

AquaDisk® Average Hydraulic Loading Rate 1.9 gpm/ft²

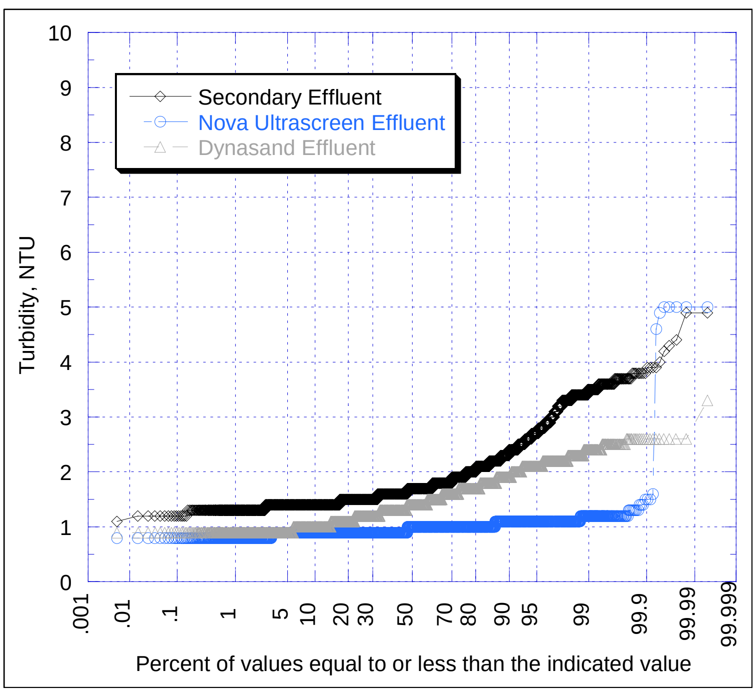
Figure 7. Turbidity performance during Experiment 3B (12 gpm/ft², 12 rpm) at the South WRF.



Ultrascreen® Average Hydraulic Loading Rate 12.37 gpm/ft², 8 rpm

DynaSand® Hydraulic Loading Rate < 2 gpm/ft²

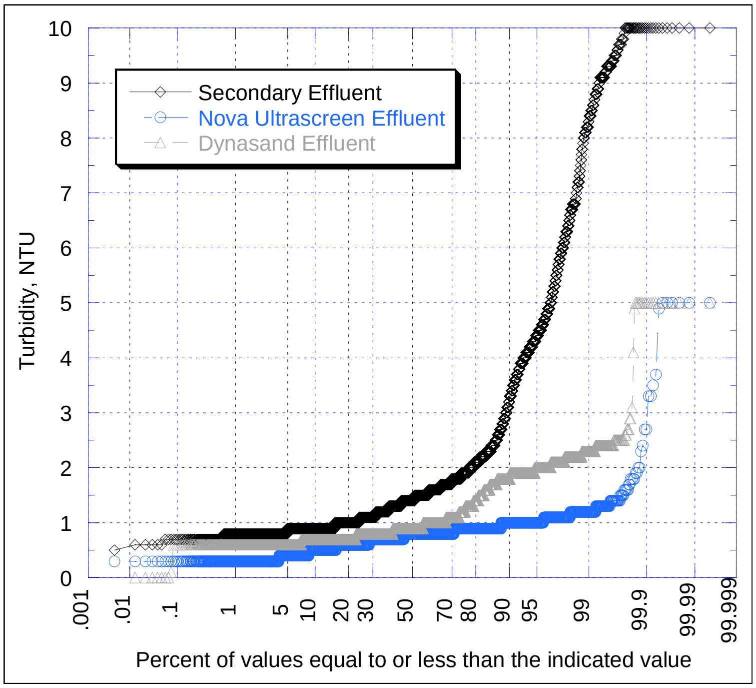
Figure 8. Turbidity performance during Experiment 3A (12 gpm/ft², 8 rpm) at the Northwest WRF.



Ultrascreen® Average Hydraulic Loading Rate 16.21 gpm/ft², 12 rpm

DynaSand® Hydraulic Loading Rate < 2 gpm/ft²

Figure 9. Turbidity performance during Experiment 4A (16 gpm/ft², 12 rpm) at the Northwest WRF.



Ultrascreen® Average Hydraulic Loading Rate 16.17 gpm/ft^2, 16 rpm

DynaSand® Hydraulic Loading Rate < 2 gpm/ft^2

Figure 10. Turbidity performance during Experiment 4B at the (16 gpm/ft^2, 16 rpm)at the Northwest WRF.

Particle Size Distribution

Samples were collected during testing at different loading rates and operational conditions for PSD analysis to compare the performance of the Ultrascreen® to the full-scale filtration technologies at each WRF. The PSD samples were also analyzed for turbidity and UVT. The average particle size distribution graphs of all grab samples are presented in Figures 11 to 15. In order to effectively view the large difference in particle concentration over the particle size ranges measured a log scale was utilized. It should be mentioned that the turbidity values listed on the average PSD graphs in Figures 11 to 15 are average values. All of these average turbidity values were found to be statistically similar based on the calculation of 95 percent confidence intervals except for those values listed in Figure 14. The average turbidity value of the Dynasand® filter effluent which is greater than the average Ultrascreen® filter effluent turbidity value was found to be statistically different.

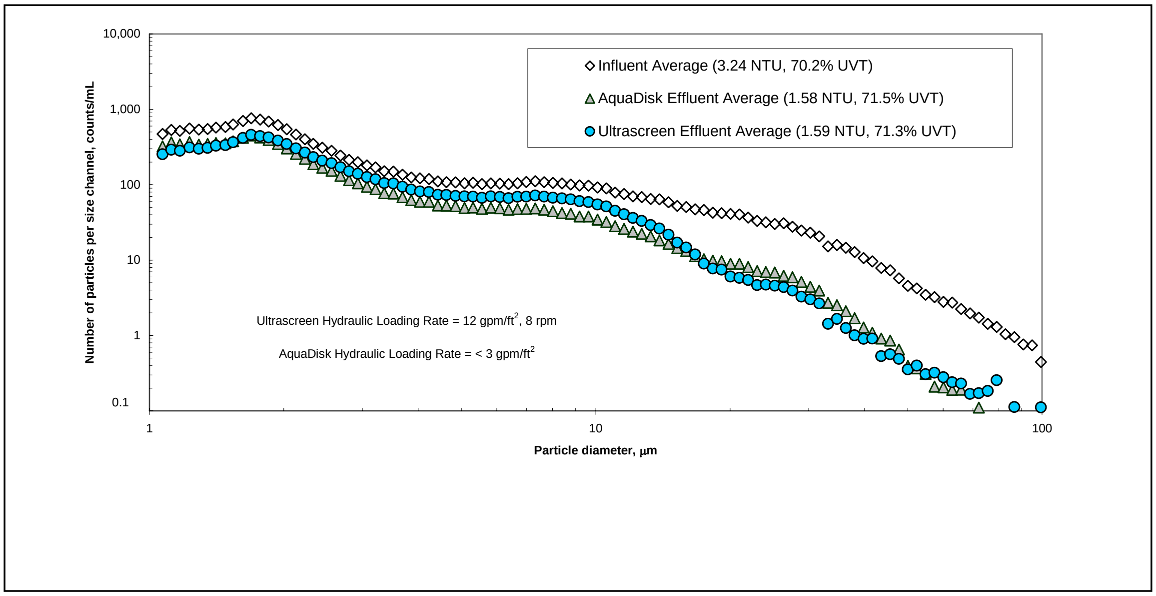


Figure 11. Average PSD graphs from Experiment 3A (12 gpm/ft^2, 8 rpm) at the South WRF.

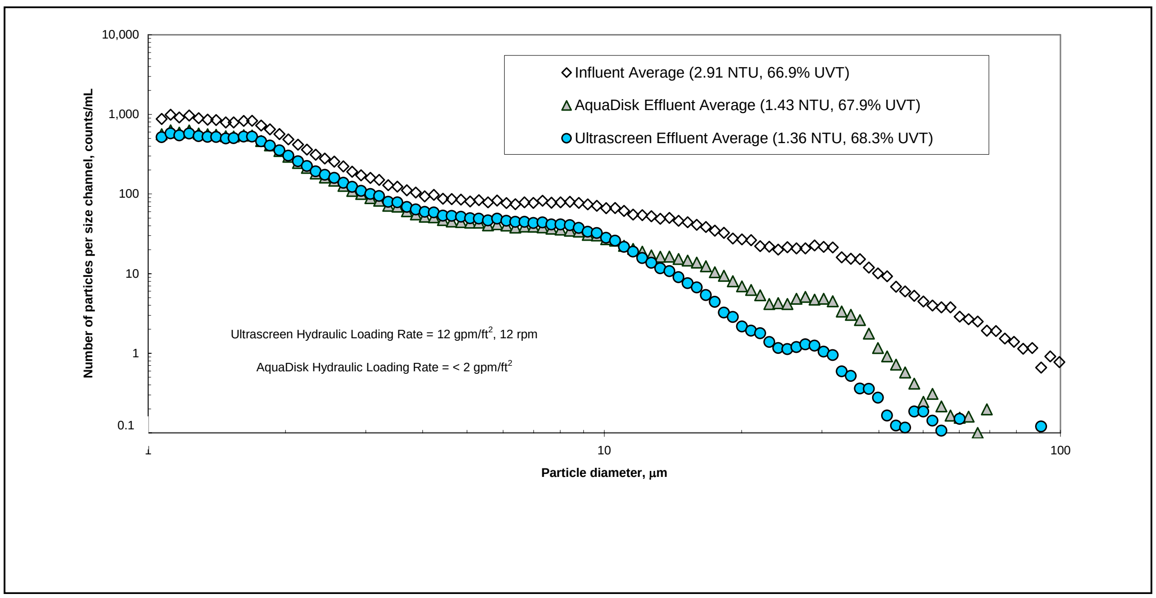


Figure 12. Average PSD graphs from Experiment 3B (12 gpm/ft^2, 12 rpm) at the South WRF.

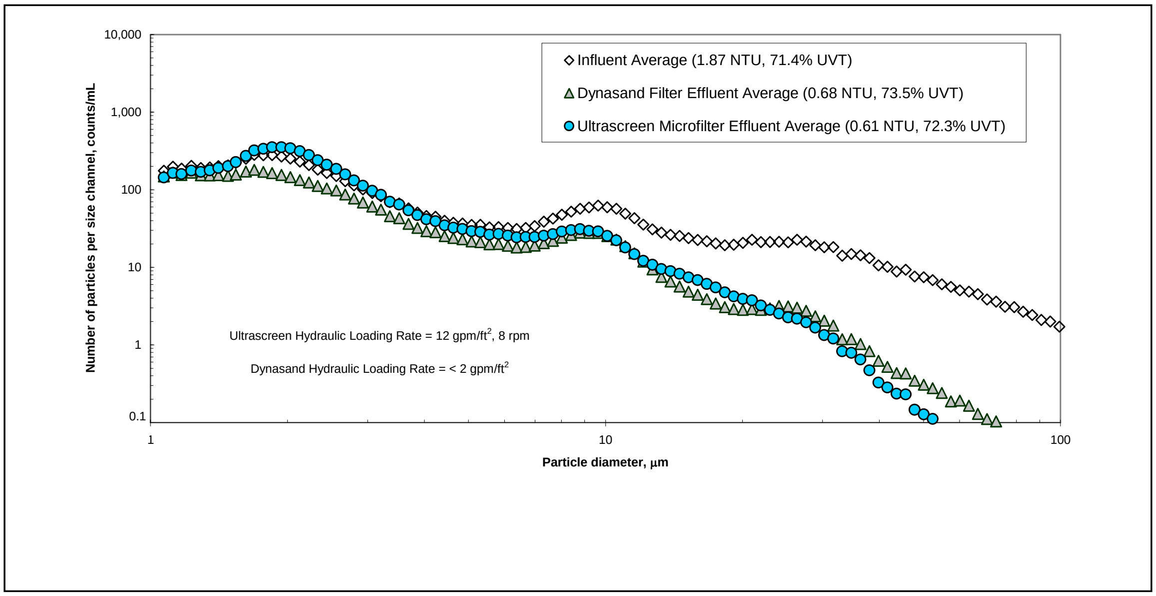


Figure 13. Average PSD graphs from Experiment 3A (12 gpm/ft^2, 12 rpm) at the Northwest WRF.

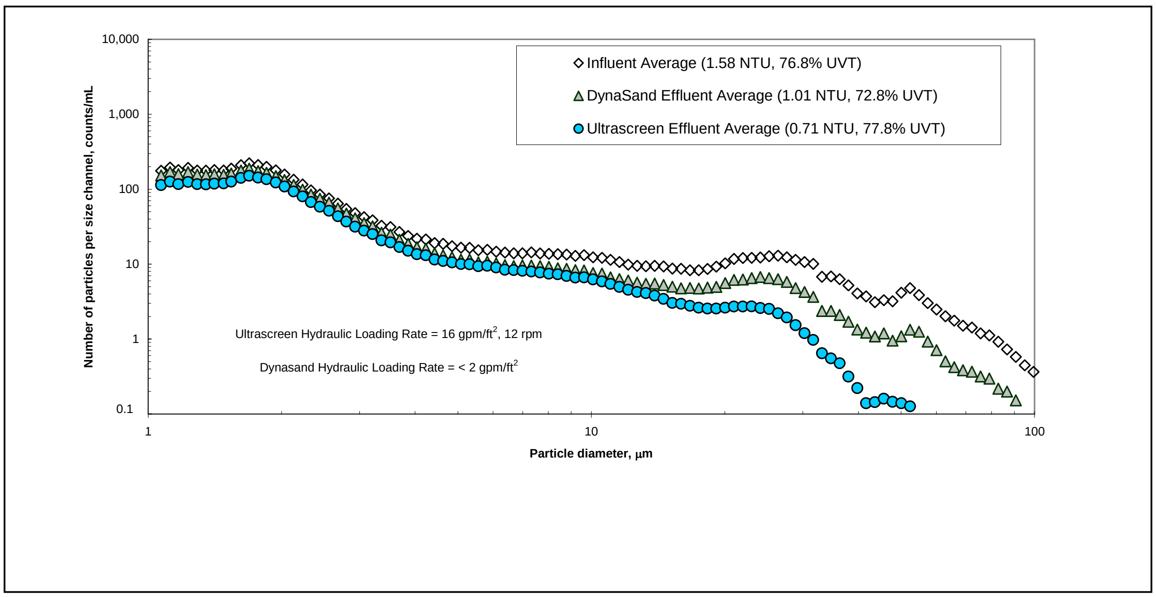


Figure 14. Average PSD graphs from Experiment 4A (16 gpm/ft^2, 12 rpm) at the Northwest WRF.

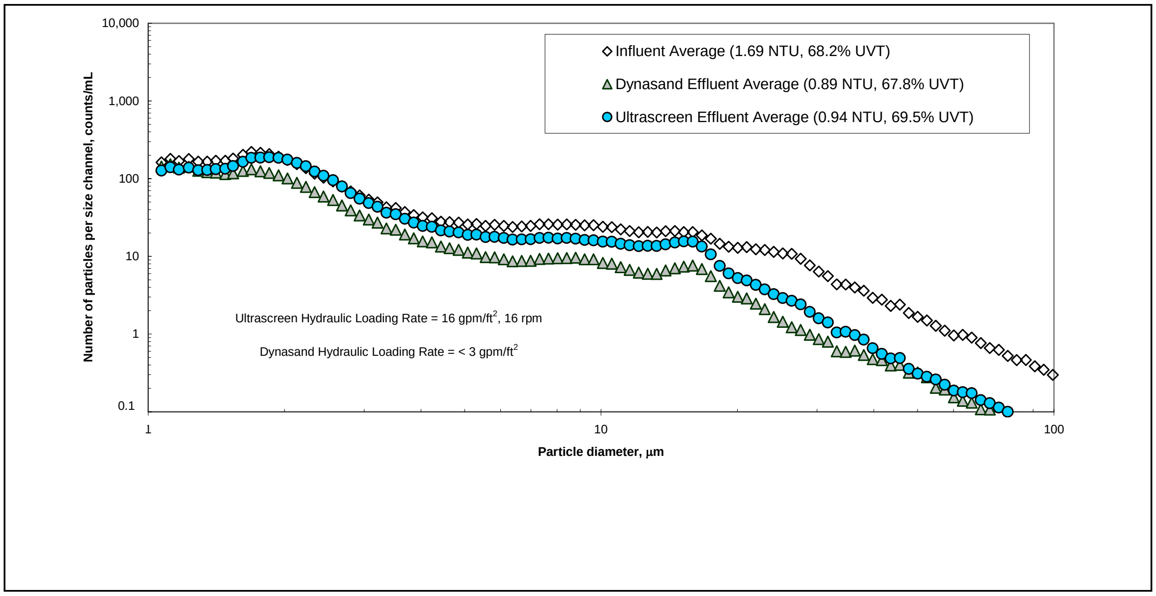


Figure 15. Average PSD graphs from Experiment 4B (16 gpm/ft^2, 16 rpm) at the Northwest WRF.

The average PSD graph from all of the effluent grab samples that were analyzed for PSD are presented in Figure 11 to 15. Although the presentation of the average PSD graphs are useful to summarize average filter performance, these figures do not characterize the variability in performance in terms of PSD that were observed in the testing. It is for this reason that bar charts (see Figures 16 to 20) were developed for each loading rate tested to compare the performance of the Ultrascreen® to the existing full-scale filtration technologies that are currently producing recycled water for unrestricted reuse applications. The particle sizes are separated into four ranges in the bar chart to compare the performance of the technologies. The statistical approach used for the PSD data was to sum the particle counts for each sample in the ranges depicted on the bar chart. The filter effluent sum of particles within a range were subtracted from the corresponding influent sum of particles within that range for a given day. The particle removals for the test period were averaged and a standard deviation and the 95 percent confidence intervals ($\alpha = 0.05$) were calculated. Each bar depicts the average removal with 95 percent confidence intervals on a log scale.

<u>Target Loading Rate of 12 gpm/ft^2</u>

As can be seen in Figure 16 for Experiment 3A at the South WRF, there was no statistical difference in the particle removal in the 15-30 µm and the 30-65 µm particle ranges while the AquaDisk® and the Ultrascreen® filters were operating at a hydraulic loading rate of <3 gpm/ft^2, and 12 gpm/ft^2, respectively. There were statistically significant differences in the particle removal in the 1-5 and 5-15 µm particle range. The difference in particle removal of the AquaDisk® and the Ultrascreen® was on average 58 and 56 percent. As mentioned previously even though there were statistically significant differences in particle removal in these two size ranges (i.e., 1-5 and 5-15 µm), these differences in particle removal did not affect the effluent turbidity values of the samples analyzed for PSD as these average turbidity values were found to be statistically similar (see Figure 11).

During Experiment 3B at the South WRF, it was found that there was no statistically significant differences between the particle removal obtained by the AquaDisk® (hydraulic loading rate of < 1.9 gpm/ft^2) and the Ultrascreen® (hydraulic loading rate of 11.92 gpm/ft^2, 12 rpm) filters in all size ranges measured (see Figure 17).

During Experiment 3A at the Northwest WRF, it was found that there was no statistically significant differences between the particle removal obtained by the DynaSand® (hydraulic loading rate of < 1.9 gpm/ft^2) and the Ultrascreen® (hydraulic loading rate of 11.92 gpm/ft^2, 12 rpm) filters in all size ranges measured (see Figure 18).

Target Loading Rate 16 gpm/ft^2

During Experiment 4A at the Northwest WRF, it was found that there was no statistically significant differences between the particle removal obtained by the DynaSand® (hydraulic loading rate of < 2 gpm/ft^2) and the Ultrascreen® (hydraulic loading rate of 16.21 gpm/ft^2, 12 rpm) filters in all size ranges measured (see Figure 19).

During Experiment 4B at the Northwest WRF, it was found that there was no statistically significant differences between the particle removal obtained by the DynaSand® (hydraulic loading rate of < 2 gpm/ft^2) and the Ultrascreen® (hydraulic loading rate of 16.17 gpm/ft^2, 16 rpm) filters in the size ranges of 1-5, 15-30, and 30-65 µm (see Figure 20). In the 5-15 µm particle range the difference in particle removal, which measured on average 50 percent, was found to statistically different. As mentioned previously, however these differences in particle removal did not affect the effluent turbidity values as the average turbidity of the effluent grab samples analyzed for PSD were found to be statistically similar (see Figure 15).

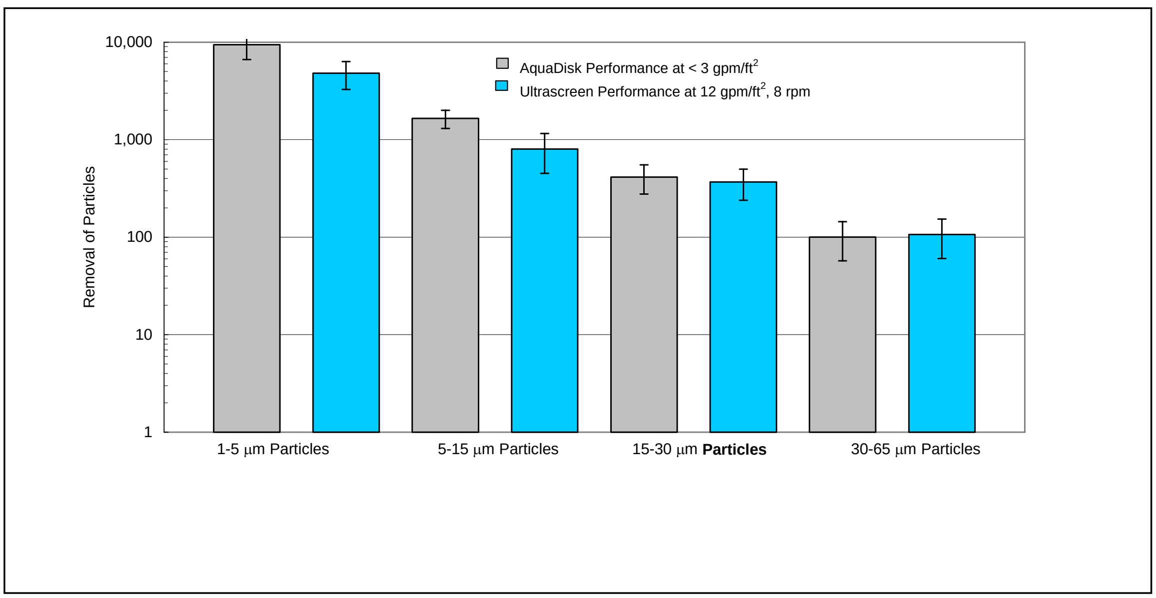


Figure 16. Ultrascreen Particle Removal during Experiment 3A (12 gpm/ft^2, 8 rpm) at the South WRF.

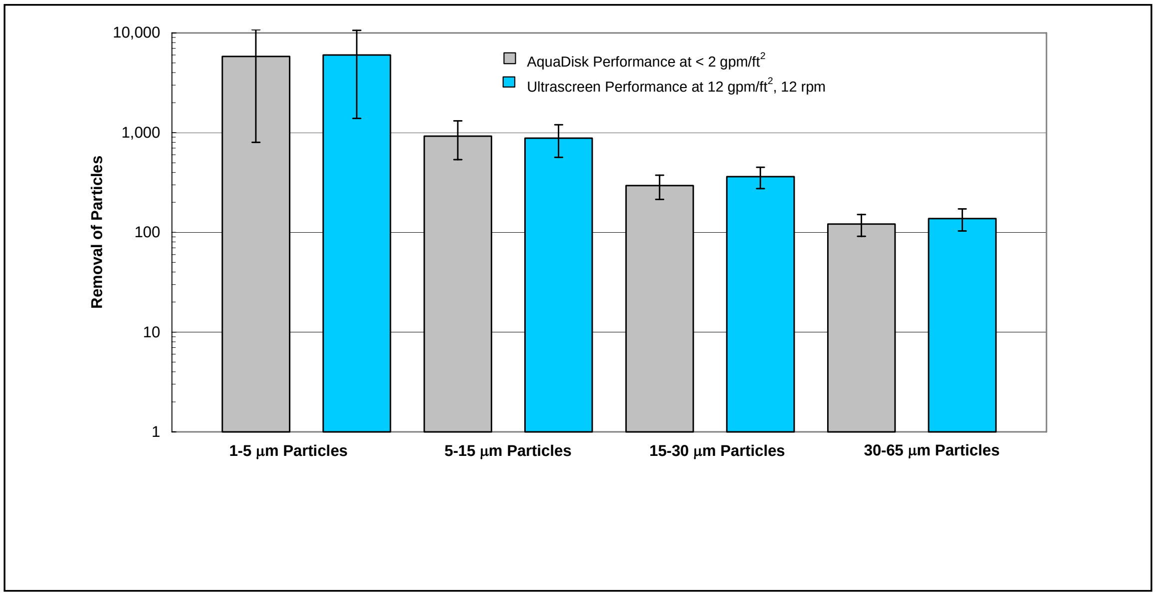


Figure 17. Ultrascreen Particle Removal during Experiment 3B (12 gpm/ft^2, 12 rpm) at the South WRF.

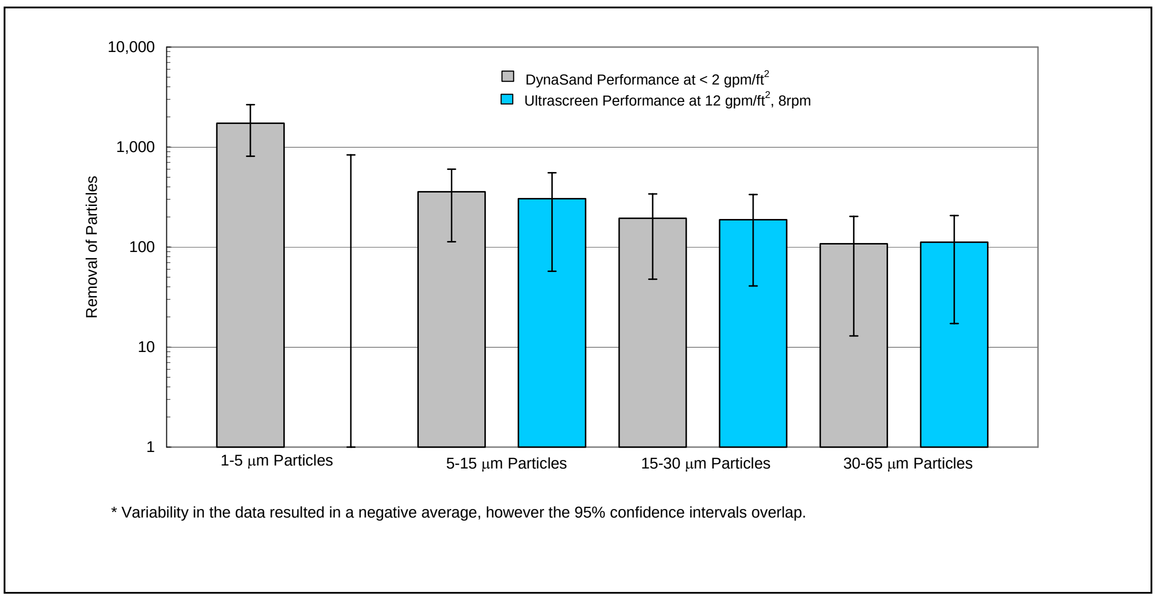


Figure 18. Ultrascreen Particle Removal during Experiment 3A (12 gpm/ft^2, 8 rpm) at the Northwest WRF.

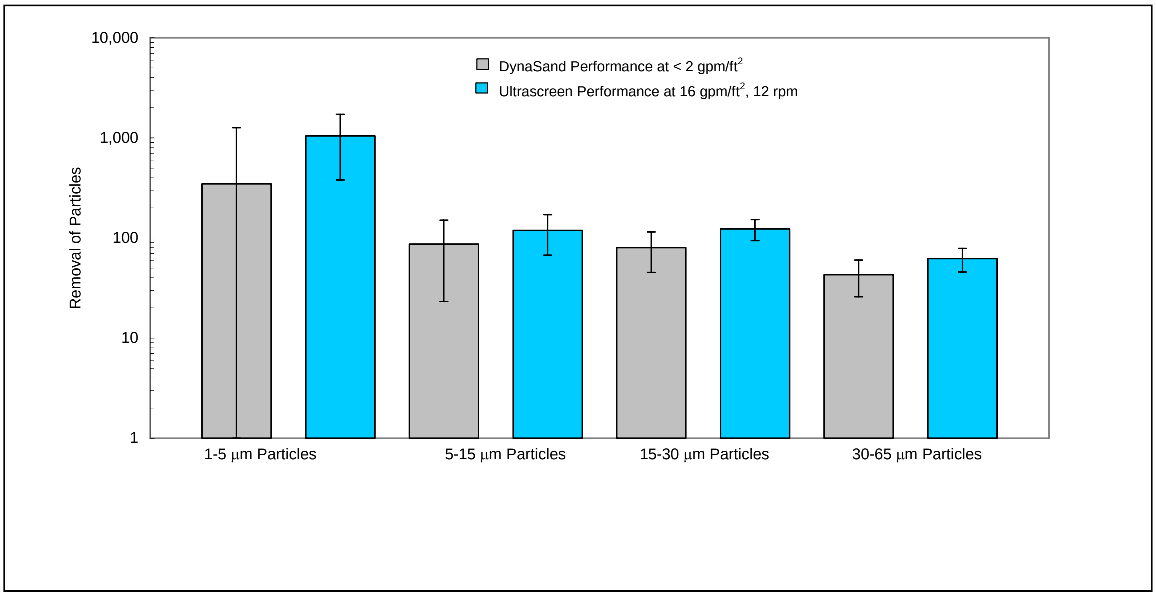


Figure 19. Ultrascreen Particle Removal during Experiment 4A (16 gpm/ft^2, 12 rpm) at the Northwest WRF.

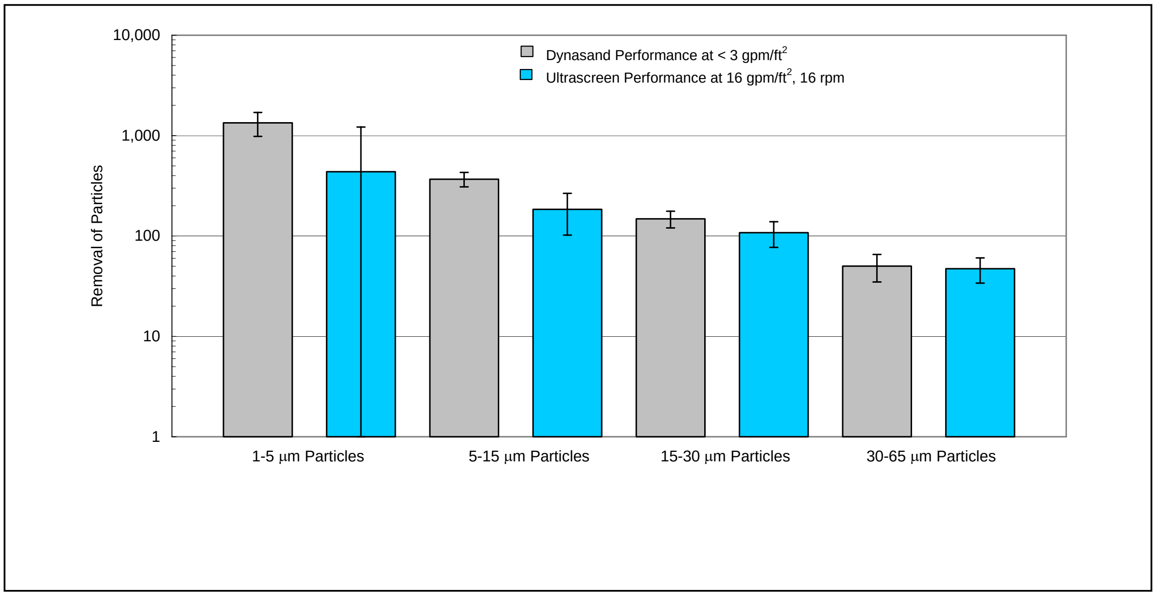


Figure 20. Ultrascreen Particle Removal during Experiment 4B (16 gpm/ft^2, 16 rpm) at the Northwest WRF.

CONCLUSIONS

Below is a list of the conclusions for this project

- The Ultrascreen® could meet the Title 22 turbidity requirements of 2 NTU while operating at hydraulic loading rates ranging from 6 to 16 gpm/ft^2
- Effluent turbidity of the Ultrascreen® while operating at hydraulic loading rates 3 to 6 times greater than the full-scale AquaDisk® and DynaSand® filters was found to be similar to the full-scale filter performance.
- At hydraulic loading rates of 12 and 16 gpm/ft^2 it was determined that there was no statistical differences in particle removal between the Ultrascreen®, AquaDisk®, and Dynasand® filters for 9 of the 12 particle ranges measured. For the 3 size ranges where the particle removal between the filters was found to be statistically different, the effluent turbidity values of these collected and analyzed grab samples were found to be statistically similar.

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