Performance Evaluation

This section evaluates water quality data based on treatment goals addressed in this TER.

Particle Size Distribution

The TAPE guidelines state that Pacific Northwest stormwater typically contains mostly silt-sized particles; thus, PSD results should be provided to indicate whether the stormwater runoff analyzed is consistent with particle sizes typically found in urban runoff in this region.

Two separate laboratories were used for PSD analysis. For the first 18 events, Chemoptix, Inc. was used, while Analytical Resources, Inc. was used for the last 10 events. The laboratories where switched due to inadequate service from the first laboratory and the fact that they could not bin the PSD data in the desired format. The separate PSD results obtained from the Chemoptix, Inc. and Analytical Resources, Inc. are shown in Figures 11 and 12, respectively.

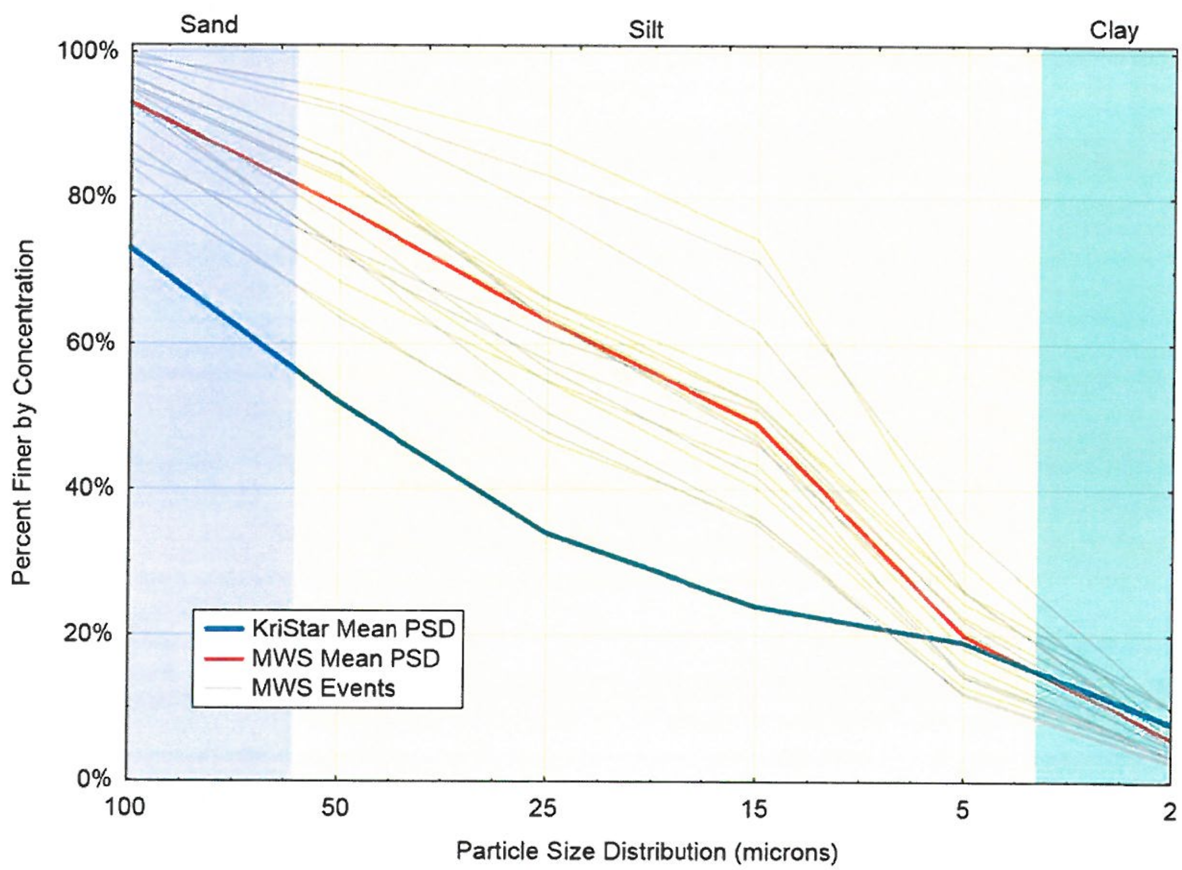

Figure 11. Influent PSD Results from Chemoptix (First 18 Samples).

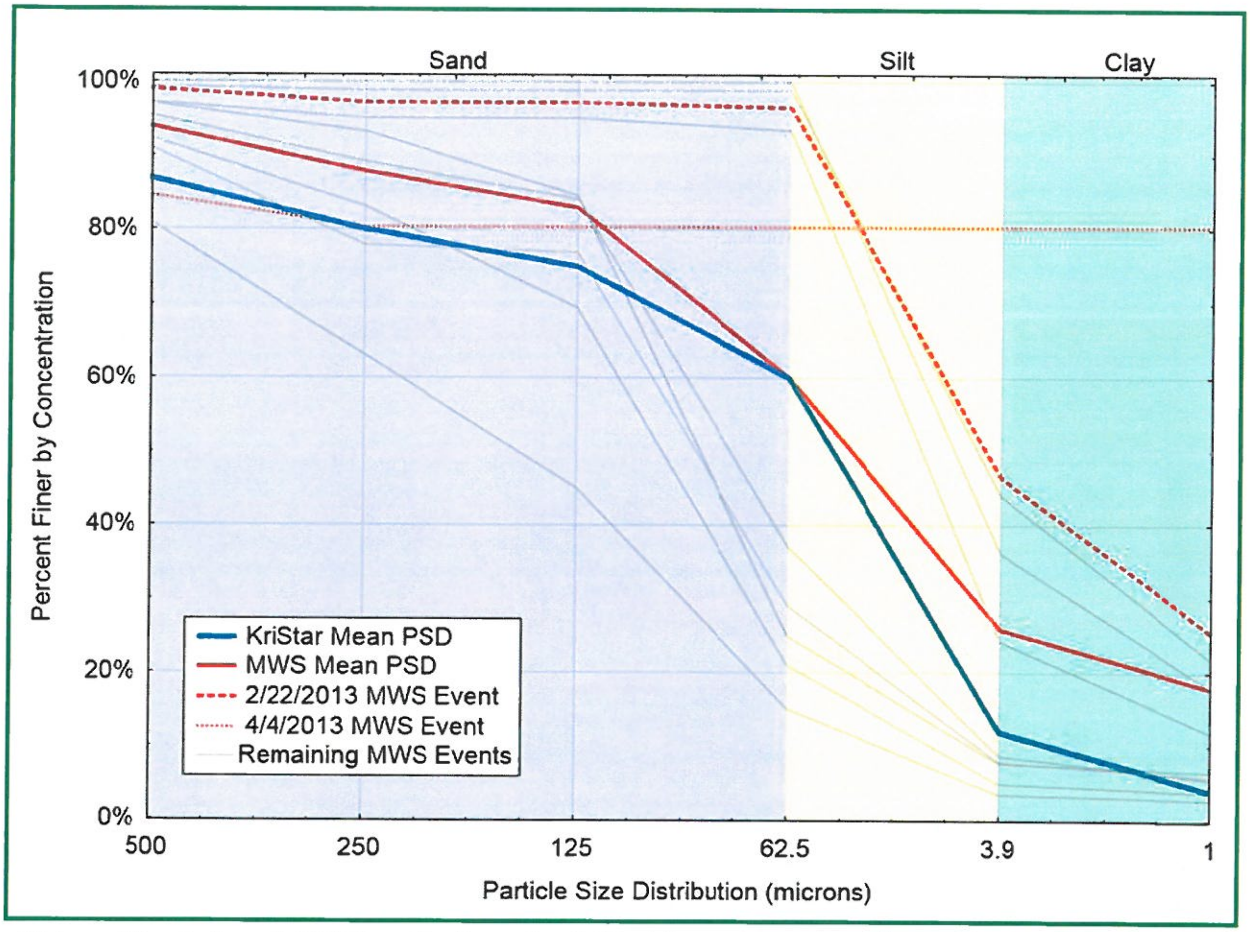

Figure 12. Influent PSD Results from Analytical Resources, Inc. (Last 10 Samples).

In Figure 11, it is apparent that the suspended solids in the stormwater are mostly comprised of silt sized particles. As was indicated in the *Maintenance Schedule* section above, the stormwater at the AMWS test site was unusually turbid. In order to quantify this, the mean PSD from a previous TAPE monitoring project (KriStar Perk Filter) was plotted with the AMWS data in Figure 11. As is apparent from Figure 11, there is 25 percent more silt at the AMWS site and an equivalent amount of clay when compared to the Kristar PSD. A somewhat similar pattern was observed with the PSD results from Analytical Resources, Inc. (Figure 12). Figure 12 shows there is, on average, equivalent silt content between AWMS and the KriStar data and 14 percent more clay at the AMWS site. In both cases, the data clearly show that significantly more fine sediment (either silt or clay) was being exported from the AMWS site than was from the KriStar site.

This comparison helps explains why the pre-filters were clogging at the AMWS site (see *Maintenance Schedule* and *Treated Flow Rate during Bypass* sections above). Figure 12 also highlights two events that produced PSD results that are considered outliers. The PSD results from the April 4, 2013, event indicated that 80 percent of the suspended solids were finer than clay (colloidal). This was deemed a spurious result and the PSD results were not used in calculating the mean PSD for the site; however, the chemistry results for the same sample appeared typical so they were included in the final analyses. Also noted on Figure 12 is the

PSD result from February 22, 2013. This sample exhibited the highest clay content (47 percent) of any of the accepted samples and was characterized by only 61 percent TSS removal (see *Basic Treatment* section below).

Basic Treatment

The basic treatment goal listed in the TAPE guidelines indicate that the bootstrapped 95 percent lower confidence interval (LCL95) of the mean total suspended solids (TSS) removal must be greater than or equal to 80 percent for influent concentrations ranging from 100 to 200 mg/L. For influent TSS concentrations less than or equal to 100 mg/L but greater than 20 mg/L, the upper 95 percent confidence interval (UCL95) of the mean effluent concentration must be less than or equal to 20 mg/L. There is no specified criterion for influent TSS concentrations less than 20 mg/L; consequently, those sample pairs (influent and effluent) cannot be used for assessment of TSS removal performance. For influent concentration that exceed 200 mg/L, the treatment goal is an LCL95 of greater than an 80 percent reduction. Additionally, it must be shown that a statistically significant difference between influent and effluent concentrations exists. Finally, pollutant removals that meet the TAPE goals must be shown for sample pairs across a range of treated flow rates up to and including the design flow rate. This section describes the sampling results in relation to these criteria based on data from 24 events where influent concentrations were greater than 20 mg/L.

Before any performance analyses were conducted, the dataset was analyzed in relation to the different pre-filters configurations that were installed during monitoring. Due to issues associated with the high clay content of the runoff, the pre-filter design had to be altered during the course of the monitoring project. This resulted in samples being collected with four different types of pre-filters: BioMediaGREEN blocks, ribbed BioMediaGREEN blocks, perlite, and finally BioMediaGREEN cubes. The manufacturer plans to use cubed BioMediaGREEN for all future MWS-Linear installations; consequently, a statistical test was run to indicate if the cubed BioMediaGREEN performed differently than the other pre-filters types. Specifically, a Mann-Whitney U-test was run on the 16 TSS percent removal results collected with the cubed BioMediaGREEN versus the 8 collected with the other pre-filter configurations. The test indicated that there was no significant difference between the datasets ($p = 0.110$). Consequently, the data collected under all pre-filter configurations were combined for use in the following analyses.

A one-tailed Wilcoxon signed-rank test performed on the total suspended solids data with influent concentrations ≥20 mg/L ($n = 24$) indicated there was a statistically significant ($p < 0.001$) decrease in effluent total suspended solids concentrations compared to influent total suspended solids concentrations. Consequently, this aspect of the Basic Treatment criteria for TAPE was met.

The majority of the samples collected at AMWS had influent concentrations below 100 mg/L (Table 9). Of the 28 sampled events, 18 had influent concentrations between 20 and 100 mg/L. The UCL95 mean concentration for these 18 samples was 12.8 mg/L, which is below the 20 mg/L threshold and consequently these samples also show the Basic Treatment criteria for TAPE was met.

Seven of the sampled events were characterized by influent concentrations greater than 100 mg/L, with three events exceeding 200 mg/L (Table 9). The mean TSS removal for these events was 84.9 percent (above the 80 percent reduction criteria). While the mean TSS removal for the events with influent from 100 to 200 mg/L and >200 mg/L, was 90.8 and 77 percent, respectively (Table 9). An LCL95 mean removal was not calculable for these samples, since at least 10 samples are required for a bootstrap analysis. However, these samples were used in the assessment of removal efficiency at various treatment flow rates.

Because flow-weighted composite sampling consists of combined samples collected across a wide range of flow rates through the entire storm hydrograph, the resultant average sampled treated flow rate for a given composite sample will almost always be below the design flow rate. In order to see how the system performed at higher flow rates discrete "peak flow" samples had to be collected (see Table 9). A potential ramification of having most of the samples collected below the design flow rate is that the average percent removal result will be biased high. This is based on the assumption that treatment will be more efficient at lower flow rates through the filter. Figure 13 displays percent removal as a function of treated flow rate. As can be seen from this figure, there is no trend indicating that lower treated flow rates produced higher percent removal results. Consequently, we posit that the sampling design is not biased and is sufficient to determine treatment performance across a range of flow rates.

To determine with what flow rates the TSS removals were associated, the flow rate at the point when each aliquot was collected was calculated. These flow rates were then averaged for each sampled event. As shown in Table 9, these results indicate the mean sampled treated flow rate was 17.3 gpm. As described in the *Test System Sizing* section above, the design flow rate for the system is 41 gpm. Figure 13 displays percent removal versus average treated flow rate for all of the 24 qualifying TSS sample pairs. For reference, the open blue dots on the figure are sample pairs with influent less than 100 mg/L while the solid red dots are sample pairs with influent TSS from 100 - 200 mg/L, and the black squares represent sample pairs with influent TSS > 200 mg/L. The TAPE (Ecology 2011) indicates that a regression analysis should be conducted to determine the treatment efficiency varies as function of treated flow rate. The results of the regression analysis indicated there is no significant relationship between treatment efficiency and treated flow rate ($p = 0.822$).

Visual examinations of the relationship between treatment efficiency and treated flow rate in Figure 13 highlight the anomalous results from the February 22, 2013, event. As indicated in the *Particle Size Distribution* section above, the influent sample for this event was characterized by 47 percent suspended clay, 21 percent more clay than the average for the site. This may explain why the TSS removal for this sample pair was so low. If this data point is removed, it is clear that the TSS removal is above 80 percent up to and through the design flow rate of 41 gpm. In addition, it appears as if the system is capable of removing TSS at flow rates up to 50 gpm.

Taken together, the above analyses indicate that the Basic Treatment criteria were met based on the data collected at the AMWS test site.

Table 9. Total Suspended Solids Concentrations and Removal Efficiency Estimates for Valid Sampling Events at the AMWS Test System.

Storm Start Date & Time	Influent Conc. (mg/L)	Qualifier	Effluent Conc. (mg/L)	Qualifier	Effluent Conc. (in = 20-100) (mg/L)	% Removal (in = 100-200)	% Removal (in >200)	Sampled Flow Rate (gpm) [b]	Max Treated Flow Rate (gpm)	Bypass?
4/15/2012 22:45	**26**		**2.8**		**2.8**			7	16.5	
4/17/2012 21:20	**100**		**2.3**		**2.3**	**98**		13	24.1	✓
4/19/2012 8:30	**46**		**4.8**		**4.8**			6	12.0	✓
4/25/2012 20:50	**20**		**3.2**		**3.2**			10	24.1	
5/2/2012 21:50	**32**		**3**		**3**			15	35.8	
5/21/2012 4:45	**70**		**12**		**12**			22	33.3	
10/14/2012 19:15	**26**		**7.4**		**7.4**			28	41.8	✓
10/15/2012 12:30	**67**		**17**		**17**			28	41.8	✓
10/28/2012 6:15	**22**		**4.1**		**4.1**			28	48.0	✓
10/29/2012 22:45	**57**		**12**		**12**			23	48.0	✓
10/31/2012 5:25	**30**		**11**		**11**			6	12.7	
11/23/2012 8:25	6.5		1.7					19	23.4	✓
11/29/2012 6:15	**34.2**		**16**		**16**			10	21.0	✓
12/2/2012 14:10	6.7		2.6					5	10.2	
12/3/2012 22:30	**22.8**		**5.7**		**5.7**			11	12.0	✓
12/11/2012 11:20	6.7		5					19	30.9	✓
12/19/2012 2:10	**48.7**		**5.5**		**5.5**			17	21.0	✓
1/23/2013 12:15	**42**		**26.7**		**26.7**			6	10.2	
1/24/2013 17:50	**41.2**		**14.3**		**14.3**			8	25.0	✓
2/22/2013 9:30 [a]	**339**		**132**				**61**	40	38.6	✓
3/19/2013 15:35 [a]	**209**		**47**				**78**	28	31.8	✓
4/4/2013 8:00	**145**	J	**19**			**87**		3	5.5	
4/6/2013 16:45	12		2.1					11	18.2	✓
4/10/2013 8:50	**153**		**17**			**89**		13	26.1	✓
4/18/2013 20:45	**20.6**		**2.6**		**2.6**			9	14.3	
4/29/2013 3:15	**186**		**21**			**89**		20	37.0	
5/16/2013 12:15 [a]	**251**		**20.8**				**92**	50	47.6	✓
5/21/2013 11:15 [a]	**79**		**20.5**		**20.5**			28	45.6	✓
n	28		28		18	4	3	28	28	
UCL95 Mean [c]					12.3					
Mean	75.0		15.7		9.5	90.8	77.0	17.3	27.0	
LCL95 Mean [d]										

[a] All sampled events were flow-weighted composite sampled except these events, which consisted of samples collected above a high flow rate threshold (per TAPE requirements).

[b] Sampled flow rate is calculated by averaging the instantaneous flow rate associated with each aliquot in the composite sample.

[c] Bootstrapped estimate of the upper 95% confidence limit of the mean. Only calculated for effluent concentration with influent between 20 and 100 mg/L per the TAPE (Ecology 2011).

[d] Bootstrapped estimate of the lower 95% confidence limit of the mean. Only calculated for percent removal when influent ≥100 mg/L per the TAPE (Ecology 2011). Not calculated for this data set because n value was too low for bootstrap procedure.

Bold values met influent screening criteria and were used in performance analyses.

J = estimated value based on water quality data (Appendix E)

gpm = gallons/minute

mg/L = milligram/liter

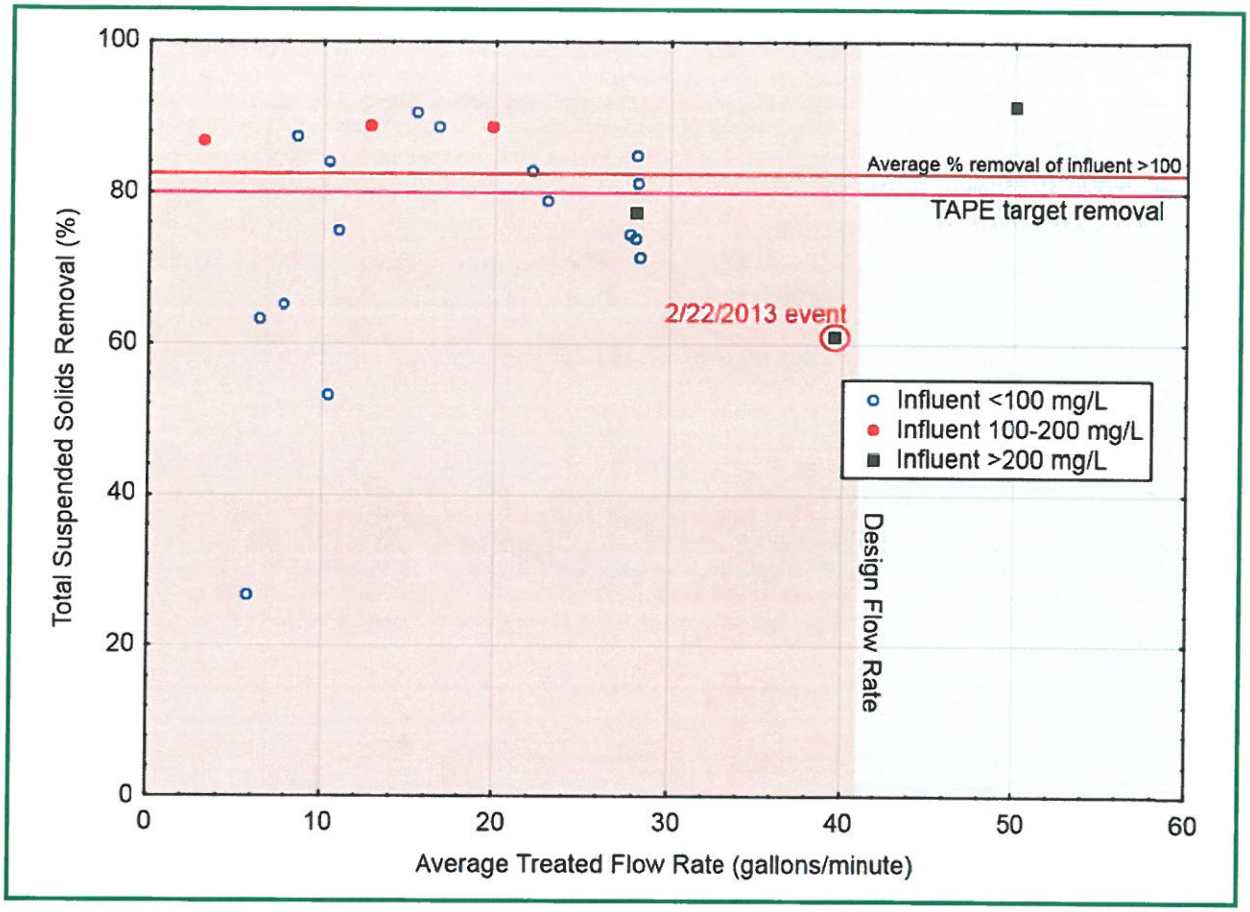

Figure 13. TSS Removal (%) as a Function of Average Treated Flow Rate.

Phosphorus Treatment

The phosphorus treatment goal listed in the TAPE guidelines indicates that the LCL95 of the mean removal must be greater than or equal to 50 percent for influent total phosphorus (TP) concentrations ranging from 0.1 to 0.5 mg/L. In addition, it must be shown that a statistically significant difference between influent and effluent concentrations exists. Finally, pollutant removals that meet the TAPE goals must be shown for sample pairs across a range of treated flow rates up to and including the design flow rate. This section describes the sampling results in relation to this criterion based on data from 17 events where influent concentrations were within the specified target range.

Before any performance analyses were conducted, the dataset was analyzed in relation to the pre-filters that were installed during monitoring. Specifically, a Mann-Whitney U-test was run on the 10 qualifying TP percent removal results collected with the cubed BioMediaGREEN versus the 7 collected with the other pre-filter configurations. The test indicated that there was no significant difference between the datasets ($p = 0.482$). Consequently, the data collected under all prefilter configurations were combined for use in the following analyses.

It should also be noted that one of the data points used in the analyses presented herein is an orthophosphorus result instead of a TP result. A high flow rate sample was collected on

May 16, 2013, but the sample was mistakenly not analyzed for TP. Orthophosphorus was used in lieu of TP for this event, which is a conservative approach as orthophosphorus is more difficult to treat and remove than is TP. This substitution was approved by Ecology in a meeting held on June 5, 2013.

A one-tailed Wilcoxon signed-rank test performed on the TP data with influent concentrations from 0.1 to 0.5 mg/L ($n = 19$) indicated there was a statistically significant ($p < 0.001$) decrease in effluent TP concentrations compared to influent concentrations. Consequently, this aspect of the Phosphorus Treatment criteria for TAPE was met.

The LCL95 mean percent reduction for the 17 qualifying TP sample pairs was 57.6 percent (Table 10), which is above the goal of ≥50 percent; consequently, these samples also show the Phosphorus Treatment criteria for TAPE was met.

To determine with what flow rates the TP removals were associated, the flow rate at the point when each aliquot was collected was calculated. These flow rates were then averaged for each sampled event. As shown in Table 10, these results indicate the mean sampled treated flow rate was 17.3 gpm. As described in the *Test System Sizing* section above, the design flow rate for the system is 41 gpm. Figure 14 displays percent removal versus average treated flow rate for all of the 17 qualifying TP sample pairs. Figure 14 indicates the high flow rate orthophosphorus result as well as all of the qualifying TP results. As is apparent, only one result fell below the 50 percent reduction threshold. It should be noted that in Figure 14, it is apparent that there is no trend indicating that there is increased TP removal at lower treated flow rates. Consequently, the LCL95 mean removal of 57.6 percent is not biased by the fact that the majority of the samples were collected below the design flow rate.

The results of the regression analysis on the percent removal versus flow rate data indicated there is no significant linear relationship between these variables ($p = 0.834$). A visual assessment of the data in Figure 14 also indicates treatment efficiency greater than 50 percent is evident up to and through the design flow rate; therefore, it can be safely assumed that the system can reduce TP by greater than 50 percent at the design flow rate of 41 gpm. In addition, it appears as if the system can effectively remove phosphorus at flow rates up to 50 gpm (Figure 14).

Taken together, the above analyses indicate that the Phosphorus Treatment criteria were met based on the data collected at the AMWS test site.

Enhanced Treatment

The TAPE enhanced treatment criteria indicate that the LCL95 of the mean dissolved zinc removal must be greater than 60 percent for influent concentrations ranging from 0.02 to 0.3 mg/L. In addition, the LCL95 of the mean dissolved copper removal must be greater than 30 percent for influent concentrations ranging from 0.005 to 0.02 mg/L. In addition, it must be shown that a statistically significant difference between influent and effluent concentrations exists. Finally, pollutant removals that meet the TAPE goals must be shown for sample pairs across a range of treated flow rates up to and including the design flow rate. Separate subsections below describe the sampling results in relation to these criteria based

Table 10. Total Phosphorus Concentrations and Removal Efficiency Estimates for Valid Sampling Events at the AMWS Test System.

Storm Start Date & Time	Influent Conc. (mg/L)	Qualifier	Effluent Conc. (mg/L)	Qualifier	% Removal (in= 0.1-0.5) [b]	Sampled Flow Rate (gpm) c	Max Treated Flow Rate (gpm)	Bypass?
4/15/2012 22:45	0.092		0.026		72	7	16.5	
4/17/2012 21:20	0.14	J	0.02	U	86	13	24.1	✓
4/19/2012 8:30	0.087	J	0.1	U		6	12.0	✓
4/25/2012 20:50	0.15		0.062		59	10	24.1	
5/2/2012 21:50	0.090		0.038		58	15	35.8	
5/21/2012 4:45	0.18		0.062		66	22	33.3	
10/14/2012 19:15	0.18		0.079		56	28	41.8	✓
10/15/2012 12:30	0.098		0.01		90	28	41.8	✓
10/28/2012 6:15	0.066		0.039			28	48.0	✓
10/29/2012 22:45	0.13		0.041		68	23	48.0	✓
10/31/2012 5:25	0.1		0.039		61	6	12.7	
11/23/2012 8:25	0.026		0.1	U		19	23.4	✓
11/29/2012 6:15	0.093		0.036		61	10	21.0	✓
12/2/2012 14:10	0.027		0.01			5	10.2	
12/3/2012 22:30	0.075		0.023			11	12.0	✓
12/11/2012 11:20	0.257		0.054		79	19	30.9	✓
12/19/2012 2:10	0.073		0.025			17	21.0	✓
1/23/2013 12:15	0.103		0.083		19	6	10.2	
1/24/2013 17:50	0.098		0.039		60	8	25.0	✓
2/22/2013 9:30 [a]	0.56		0.26			40	38.6	✓
3/19/2013 15:35 [a]	0.398		0.13		67	28	31.8	✓
4/4/2013 8:00	2.15	J	0.4			3	5.5	
4/6/2013 16:45	0.165		0.041		75	11	18.2	✓
4/10/2013 8:50						13	26.1	✓
4/18/2013 20:45						9	14.3	
4/29/2013 3:15						20	37.0	
5/16/2013 12:15 [a]	0.114 f		0.05 f		56 f	50	47.6	✓
5/21/2013 11:15 [a]	0.212		0.1		53	28	45.6	✓
n	25		25		17	28	28	
UCL95 Mean [d]								
Mean	0.231		0.076		63.9	17.3	27.0	
LCL95 Mean [e]					57.6			

[a] All sampled events were flow-weighted composite sampled except these events, which consisted of samples collected above a high flow rate threshold.
[b] Percent removal is only calculated for sample pairs with influent 0.1 - 0.5 mg/L.
[c] Sampled flow rate is calculated by averaging the instantaneous flow rate associated with each aliquot in the composite sample.
[d] Bootstrapped estimate of the upper 95% confidence limit of the mean. Only calculated for TSS effluent concentrations (not applicable for TP).
[e] Bootstrapped estimate of the lower 95% confidence limit of the mean. Used to compare to the TAPE TP criteria of at least 50 percent removal.
[f] Orthophosphorus results used in lieu of TP results for this event (due to missing TP data).
Bold values met influent screening criteria and were used in performance analyses
J = estimated value based on water quality data (Appendix E)
U = result at or below the reporting limit
gpm = gallons/minute
mg/L = milligram/liter

on data from 11 and 14 events where influent concentrations were within the specified ranges for dissolved zinc and copper, respectively.

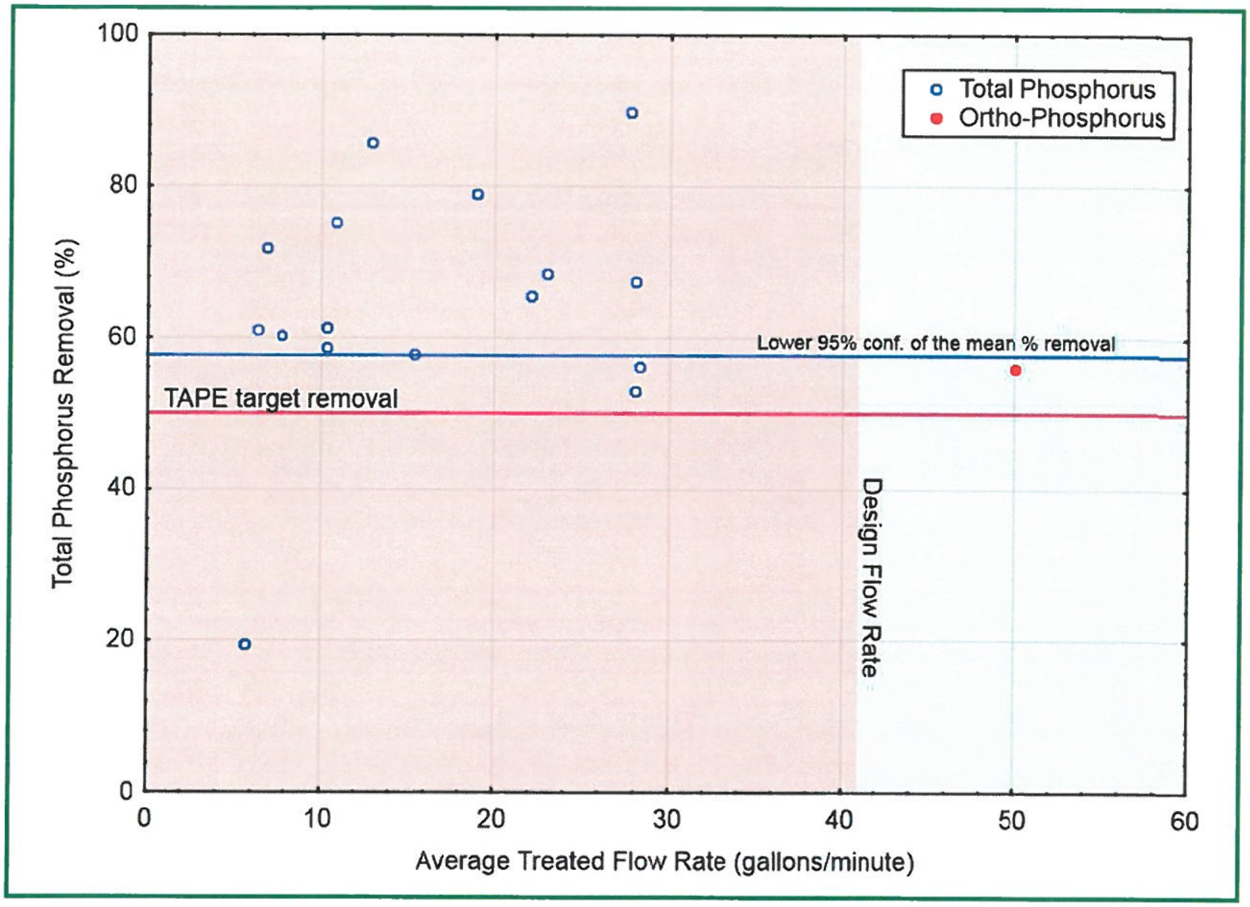

Figure 14. TP Removal (%) as a Function of Average Treated Flow Rate.

Dissolved Zinc Treatment

Before any performance analyses were conducted, the dissolved zinc dataset was analyzed in relation to the pre-filters, which were installed during monitoring. Specifically, a Mann-Whitney U-test was run on the 11 qualifying dissolved zinc percent removal results collected with the cubed BioMediaGREEN versus the 7 collected with the other pre-filter configurations. The test indicated that there was a significant difference between the datasets ($p = 0.004$). Consequently, only the data collected when the cubed BioMediaGREEN was installed were used in the final assessment. This results in a dataset with only 11 qualifying events. The TAPE indicates that 12 events are required. However, based on conversations with Douglas Howie of Ecology (June 5, 2013) and due to the challenging site conditions, 11 events was deemed adequate for this TER.

A one-tailed Wilcoxon signed-rank test performed on the dissolved zinc data with influent concentrations from 0.02 to 0.3 mg/L ($n = 11$) indicated there was a statistically significant ($p < 0.001$) decrease in effluent dissolved zinc concentrations compared to influent concentrations. Consequently, this aspect of the Enhanced Treatment criteria for TAPE was met.

The LCL95 mean percent reduction for the 11 qualifying dissolved zinc sample pairs was 60.5 percent (Table 11), which is above the goal of ≥60 percent; consequently, these samples also show the Enhanced Treatment criteria for TAPE was met.

To determine what flow rates were associated with the dissolved zinc removals, the flow rate was calculated at the point when each aliquot was collected. These flow rates were averaged for each sampled event. As shown in Table 11, these results indicate the mean sampled treated flow rate was 17.3 gpm. As described in the *Test System Sizing* section above, the design flow rate for the system is 41 gpm. Figure 15 displays percent removal versus average treated flow rate for all of the 11 qualifying dissolved zinc sample pairs (closed red dots). Figure 15 indicates the results from when the other pre-filters were installed (open blue circles) for reference purposes only. As is apparent, only three results from when the cubed BioMediaGREEN was installed fell below the 50 percent reduction threshold. These three results occurred at lower sampled flow rates. Closer to and through the design flow rate, the percent reduction results exceed 60 percent. The results of the regression analysis on the percent removal versus flow rate data also indicated there is no significant relationship between these variables ($p = 0.707$). Therefore, it can be safely assumed that the system can reduce dissolved zinc by greater than 60 percent at the design flow rate of 41 gpm. It should be noted that in Figure 15 it is apparent that there is no trend indicating that there is increased dissolved zinc removal at lower treated flow rates. Consequently, the LCL95 mean removal of 60.5 percent is not biased by the fact that the majority of the samples were collected below the design flow rate.

Taken together, the above analyses indicate that the Enhanced treatment criterion for dissolved zinc in TAPE was met based on the data collected at the AMWS test site.

Dissolved Copper Treatment

Before any performance analyses were conducted, the dissolved copper dataset was analyzed in relation to the pre-filters, which were installed during monitoring. Specifically, a Mann-Whitney U-test was run on the nine qualifying dissolved copper percent removal results collected with the cubed BioMediaGREEN versus the five collected with the other pre-filter configurations. The test indicated that there was no significant difference between the datasets ($p = 0.797$). Consequently, the data collected under all pre-filter configurations were combined for use in the following analyses.

A one-tailed Wilcoxon signed-rank test performed on the dissolved copper data with influent concentrations from 0.005 to 0.02 mg/L ($n = 14$) indicated there was a statistically significant ($p < 0.001$) decrease in effluent dissolved copper concentrations compared to influent concentrations. Consequently, this aspect of the Enhanced Treatment criteria for dissolved copper in TAPE was met.

The LCL95 mean percent reduction for the 14 qualifying dissolved copper sample pairs was 32.5 percent (Table 12), which is above the goal of ≥30 percent; consequently, these samples also show the Enhanced Treatment criterion for dissolved copper in TAPE was met.

Table 11. Dissolved Zinc Concentrations and Removal Efficiency Estimates for Valid Sampling Events at the AMWS Test System.

Storm Start Date & Time	Influent Conc. (mg/L)	Qualifier	Effluent Conc. (mg/L)	Qualifier	% Removal (in= 0.02-0.3) [b]	Sampled Flow Rate (gpm) [d]	Max Treated Flow Rate (gpm)	Bypass?
4/15/2012 22:45	**0.029**		**0.02**		**31 (NA)**	7	16.5	
4/17/2012 21:20	**0.020**		**0.011**		**45 (NA)**	13	24.1	✓
4/19/2012 8:30	0.011		0.01	U		6	12.0	✓
4/25/2012 20:50	**0.060**		**0.056**		**7 (NA)**	10	24.1	
5/2/2012 21:50	**0.022**		**0.012**		**45 (NA)**	15	35.8	
5/21/2012 4:45	**0.06**		**0.033**		**45 (NA)**	22	33.3	
10/14/2012 19:15	**0.031**		**0.012**		**61 (NA)**	28	41.8	✓
10/15/2012 12:30	**0.022**		**0.011**		**50 (NA)**	28	41.8	✓
10/28/2012 6:15	0.015		0.0046			28	48.0	✓
10/29/2012 22:45	**0.020**		**0.0074**		**63**	23	48.0	✓
10/31/2012 5:25	0.015		0.0068			6	12.7	
11/23/2012 8:25	0.0107		0.0034			19	23.4	✓
11/29/2012 6:15	0.0108		0.0099			10	21.0	✓
12/2/2012 14:10	0.0148		0.006			5	10.2	
12/3/2012 22:30	0.013		0.0109			11	12.0	✓
12/11/2012 11:20	**0.045**		**0.0133**		**70**	19	30.9	✓
12/19/2012 2:10	**0.0314**		**0.0072**		**77**	17	21.0	✓
1/23/2013 12:15	0.0156		0.0076			6	10.2	
1/24/2013 17:50	**0.0198**		**0.0069**		**65**	8	25.0	✓
2/22/2013 9:30 [a]	0.0022		0.0060			40	38.6	✓
3/19/2013 15:35 [a]	0.0104		0.0122			28	31.8	✓
4/4/2013 8:00	**0.352** [c]		**0.1940**		**45**[c]	3	5.5	
4/6/2013 16:45	**0.0338**		**0.0156**		**54**	11	18.2	✓
4/10/2013 8:50	**0.152**		**0.0652**		**57**	13	26.1	✓
4/18/2013 20:45	**0.299**		**0.0312**		**90**	9	14.3	
4/29/2013 3:15	**0.315** [c]		**0.0610**		**81**[c]	20	37.0	
5/16/2013 12:15 [a]	**0.0715**		**0.0238**		**67**	50	47.6	✓
5/21/2013 11:15 [a]	**0.0349**		**0.0136**		**61**	28	45.6	✓
n	28		28		11	28	28	
UCL95 Mean [e]								
Mean	0.0620		0.0240		66.4	17.3	27.0	
LCL95 Mean [f]					60.5			

[a] All sampled events were flow-weighted composite sampled except these events, which consisted of samples collected above a high flow rate threshold.
[b] Percent removal is only calculated for sample pairs with influent 0.02 - 0.3 mg/L. For exception see footnote c.
[c] Influent exceeded 0.3 mg/L but after discussions with Ecology on 6/5/2013, it was determined that these samples could be included for analysis.
[c] Sampled flow rate is calculated by averaging the instantaneous flow rate associated with each aliquot in the composite sample.
[d] Bootstrapped estimate of the upper 95% confidence limit of the mean. Only calculated for TSS effluent concentrations (not applicable to dissolved zinc).
[e] Bootstrapped estimate of the lower 95% confidence limit of the mean. Used to compare to the TAPE dissolved zinc criteria of at least 60 percent removal.
Bold values met influent screening criteria and were used in performance analyses

NA = not applicable. Percent removal results are associated with pre-filters which performed statistically worse than the cubed BioMediaGREEN. These results were not used in the final analysis.

U = result at or below the reporting limit

gpm = gallons/minute

mg/L = milligram/liter

Table 12. Dissolved Copper Concentrations and Removal Efficiency Estimates for Valid Sampling Events at the AMWS Test System.

Storm Start Date & Time	Influent Conc. (mg/L)	Qualifier	Effluent Conc. (mg/L)	Qualifier	% Removal (in= 0.005-0.02) [b]	Sampled Flow Rate (gpm) [d]	Max Treated Flow Rate (gpm)	Bypass?
4/15/2012 22:45	**0.0053**		**0.0027**		**49**	7	16.5	
4/17/2012 21:20	0.0026		0.002	U		13	24.1	✓
4/19/2012 8:30	0.0021		0.002	U		6	12.0	✓
4/25/2012 20:50	**0.011**		**0.0073**		**34**	10	24.1	
5/2/2012 21:50	0.0025		0.0021			15	35.8	
5/21/2012 4:45	**0.0066**		**0.0038**		**42**	22	33.3	
10/14/2012 19:15	**0.0057**		**0.0043**		**25**	28	41.8	✓
10/15/2012 12:30	**0.0049**		**0.0034**		**31**	28	41.8	✓
10/28/2012 6:15	0.0018		0.0016			28	48.0	✓
10/29/2012 22:45	0.0028		0.0021			23	48.0	✓
10/31/2012 5:25	0.0018		0.0011			6	12.7	
11/23/2012 8:25	0.0012		0.0016			19	23.4	✓
11/29/2012 6:15	0.0027		0.0019			10	21.0	✓
12/2/2012 14:10	0.0032		0.0046			5	10.2	
12/3/2012 22:30	0.0024		0.0028			11	12.0	✓
12/11/2012 11:20	**0.0051**		**0.0024**		**53**	19	30.9	✓
12/19/2012 2:10	0.001		0.0009			17	21.0	✓
1/23/2013 12:15	0.0041	J	0.0035			6	10.2	
1/24/2013 17:50	**0.0117**		**0.0053**		**54**	8	25.0	✓
2/22/2013 9:30 [a]	0.0025		0.0024			40	38.6	✓
3/19/2013 15:35 [a]	0.0026		0.0022			28	31.8	✓
4/4/2013 8:00	**0.034** [c]	J	**0.0275**		**19** [c]	3	5.5	
4/6/2013 16:45	**0.0144**		**0.0086**		**40**	11	18.2	✓
4/10/2013 8:50	**0.0205** [c]		**0.0090**		**56** [c]	13	26.1	✓
4/18/2013 20:45	**0.0225** [c]		**0.0090**		**60** [c]	9	14.3	
4/29/2013 3:15	**0.0471** [c]		**0.0354**		**25** [c]	20	37.0	
5/16/2013 12:15 [a]	**0.012**		**0.0093**		**23**	50	47.6	✓
5/21/2013 11:15 [a]	**0.0076**		**0.0056**		**26**	28	45.6	✓
n	28		28		14			
UCL95 Mean [e]								
Mean	0.0049		0.0059		38.4			
LCL95 Mean [f]					32.5			

[a] All sampled events were flow-weighted composite sampled except these events that consisted of samples collected above a high flow rate threshold.
[b] Percent removal is only calculated for sample pairs with influent 0.005 - 0.02 mg/L. For exception see footnote c.
[c] Influent exceeded 0.02 mg/L but after discussions with Ecology on 6/5/2013, it was determined that these samples could be included for analysis.
[d] Sampled flow rate is calculated by averaging the instantaneous flow rate associated with each aliquot in the composite sample.
[e] Bootstrapped estimate of the upper 95% confidence limit of the mean. Only calculated for TSS effluent concentrations.
[f] Bootstrapped estimate of the lower 95% confidence limit of the mean. Used to compare to the TAPE dissolved copper criteria of at least 30 percent removal.
Bold values met influent screening criteria and were used in performance analyses
J = estimated value based on water quality data (Appendix E)
U = result at or below the reporting limit
gpm = gallons/minute
mg/L = milligram/liter

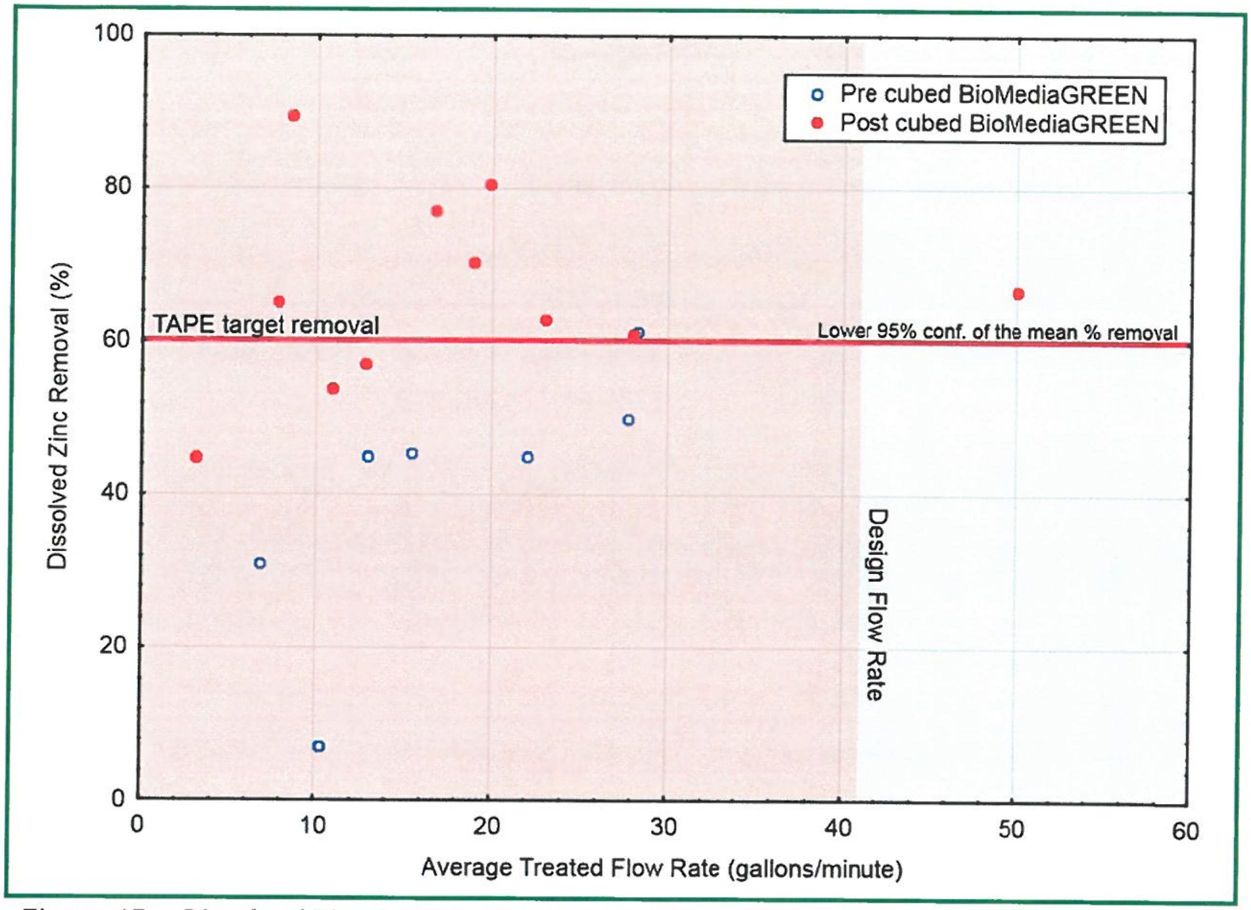

Figure 15. Dissolved Zinc Removal (%) as a Function of Average Treated Flow Rate.

To determine with flow rates were associated with dissolved copper removals, the flow rate at the point when each aliquot was collected was calculated. These flow rates were then averaged for each sampled event. As shown in Table 12, these results indicate the mean sampled treated flow rate was 17.3 gpm. As described in the *Test System Sizing* section above, the design flow rate for the system is 41 gpm. Figure 16 displays percent removal versus average treated flow rate for all of the 14 qualifying dissolved copper sample pairs (open blue circles). In addition, a data point from lab data collected in 2007 is included as a high flow rate reference point (red closed dot). The lab study data are summarized in the CULD application for the Modular Wetland System (Herrera 2011a). The TAPE indicates that lab data can be used to augment field data when determining performance at different flow rates. It should be noted that in Figure 16 it is apparent that there is no trend indicating that there is increased dissolved copper removal at lower treated flow rates. Consequently, the LCL95 mean removal of 32.5 percent is not biased by the fact that the majority of the samples were collected below the design flow rate.

The results of the regression analysis on the percent removal versus flow rate data indicated there is no significant relationship between these variables ($p = 0.079$); a visual assessment of the data in Figure 16 also show treatment above the TAPE target of 30 percent removal is evident until approximately 28 gpm. However, when the lab data point is included in the assessment, it is evident that the system (under less adverse conditions) can treat at a much higher efficiency at the design flow rate of 41 gpm. Given this, and considering the challenging site conditions at the Albina Maintenance Facility, we propose that Ecology grant dissolved copper removal certification at 41 gpm.

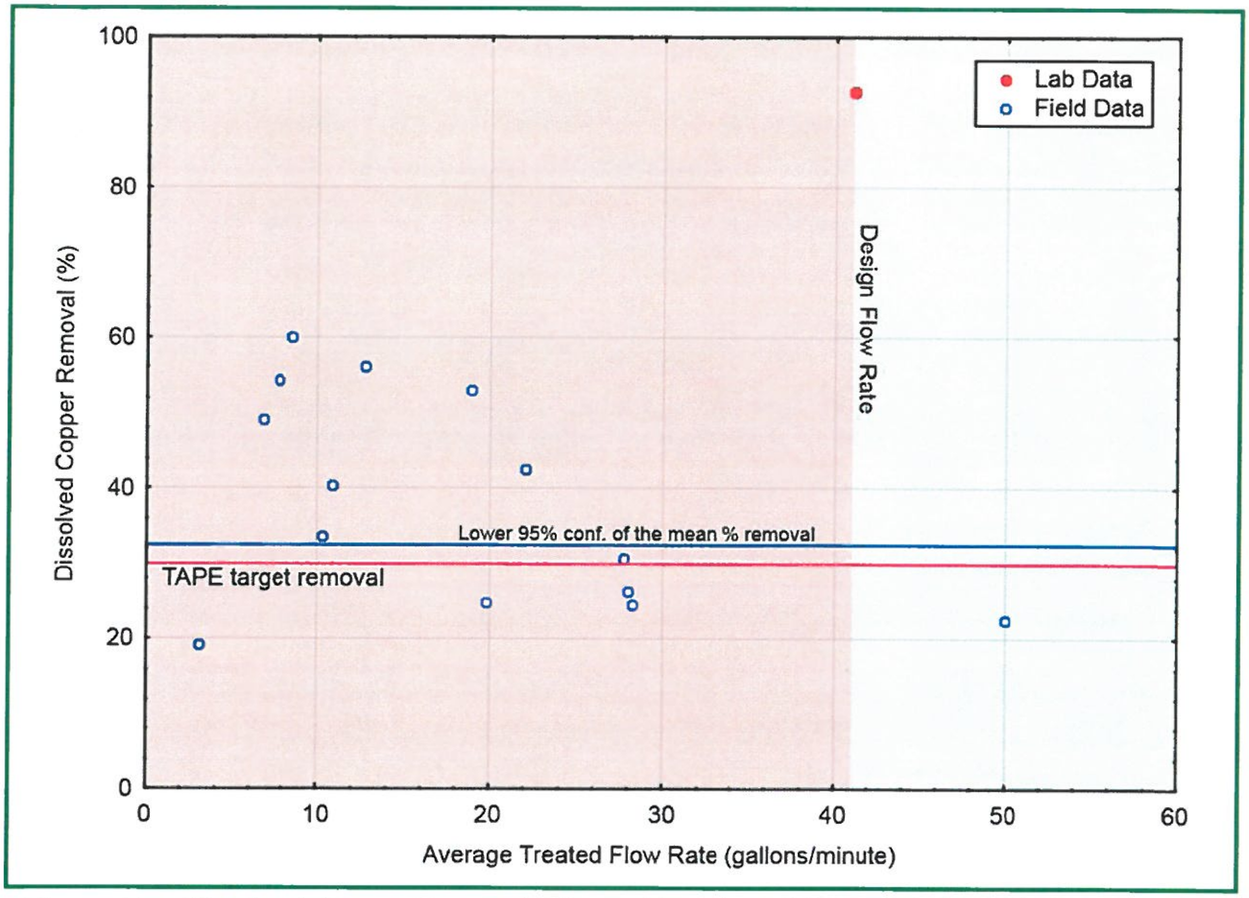

Figure 16. Dissolved Copper Removal (%) as a Function of Average Treated Flow Rate.

Taken together, the above analyses indicate that the Enhanced Treatment criteria for dissolved copper in TAPE was met. The flow rate at which dissolved copper is approved needs to be investigated further, but we propose approving dissolved copper at a flow rate of 41 gpm based on the lab data that indicates high removal at 41 gpm flow rate.

Other Parameters

The TAPE (Ecology 2011) indicates that in addition to required parameters mentioned above, screening parameters should be analyzed. The screening parameters consist of hardness, pH, and orthophosphate. The results for these parameters are presented in Table 13. The AMWS system had a negligible effect on hardness and pH. The average hardness concentrations were 37.6 and 40.6 mg $CaCO_3$/L at the inlet and outlet, respectively. The average pH concentrations were 7.6 and 7.5 at the inlet and outlet, respectively. TAPE guidelines indicate that the test system should not increase of decrease pH by more than one unit for any given event or export concentration less than 4 or greater than 9. The pH data presented in Table 13 indicate that these conditions were met for each sampled event.

Table 13. Summary Results for Screening Parameters.

Storm Start Date & Time	Influent Hardness (mg $CaCO_3$ /L)	QA	Effluent Hardness (mg $CaCO_3$ /L)	QA	Influent pH (std. units)	QA	Effluent pH (std. units)	QA	Influent ortho-P (std. units)	QA	Effluent ortho-P (std. units)	QA
4/15/2012 22:45	31		43		7.53		6.17		0.01		0.01	U
4/17/2012 21:20	37		51		7.54		7.51		0.01	U	0.01	U
4/19/2012 8:30	26		33		7.46		7.41		0.01	U	0.01	U
4/25/2012 20:50	39		48		7.51		7.54		0.069		0.024	
5/2/2012 21:50	26		31		7.4		7.29		0.016		0.01	U
5/21/2012 4:45	37		44		7.48		7.45		0.047		0.013	
10/14/2012 19:15	30		48		7.13		6.82		0.073		0.05	U
10/15/2012 12:30	35		42		7.3		7.2		0.059		0.08	
10/28/2012 6:15	29		31		7.57		7.45		0.05	H	0.05	UH
10/29/2012 22:45	35		35		7.41		7.36		0.05	U	0.05	U
10/31/2012 5:25	45		46		7.52		7.56		0.05	U	0.05	U
11/23/2012 8:25					7.29	J	7.41	J				
11/29/2012 6:15	33.2		30.4		7.74		7.32		0.05	U	0.05	U
12/2/2012 14:10	29.2		30		7.15		7.19		0.05	U	0.05	U
12/3/2012 22:30									0.05	U	0.05	U
12/11/2012 11:20	27.2		29.6		7.88	J	7.92	J	0.05	U	0.05	U
12/19/2012 2:10	19.6		25.2		7.86		7.71		0.05	U	0.05	U
1/23/2013 12:15	40		41.2		8.06		7.72		0.05	U	0.05	U
1/24/2013 17:50	38		34.8		7.71		7.81		0.05	U	0.05	U
2/22/2013 9:30 [a]	62.8		50.8		8.84		8.14		0.05	U	0.05	U
3/19/2013 15:35 [a]	36.8		39.2		7.86		7.77		0.05	U	0.05	U

Table 13 (continued). Summary Results for Screening Parameters.

Storm Start Date & Time	Influent Hardness (mg $CaCO_3$ /L)	QA	Effluent Hardness (mg $CaCO_3$ /L)	QA	Influent pH (std. units)	QA	Effluent pH (std. units)	QA	Influent ortho-P (std. units)	QA	Effluent ortho-P (std. units)	QA
4/4/2013 8:00	76		58.8		7.09	J	7.69	J	0.96		0.199	
4/6/2013 16:45	36		38.4		7.67		6.96		0.123		0.05	U
4/10/2013 8:50	43.2		41.6		7.83		8.13		0.426		0.05	U
4/18/2013 20:45	48		47.2		7.66		7.69		0.06		0.05	U
4/29/2013 3:15	42.4		47.6		7.33		7.52		0.156		0.05	U
5/16/2013 12:15 [a]	47.2		53.2		7.32		7.41		0.114		0.05	U
5/21/2013 11:15 [a]	28.4		34.4		7.65	J	7.57	J	0.062		0.05	U
Minimum	19.6		25.2		7.09		6.17		0.01	U	0.01	U
Mean	37.6		40.6		7.6		7.5		0.093		0.031	
Maximum	76		58.8		8.84		8.14		0.960		0.199	

[a] All sampled events were flow-weighted composite sampled except these events, which consisted of samples collected above a high flow rate threshold.

Ortho-P = Orthophosphorus

J = estimated value based on water quality data (Appendix E)

QA = quality assurance

The orthophosphorus data indicated that the AMWS system reduced orthophosphorus by 67 percent, on average. When compared with other treatment systems (Herrera 2006, 2009, 2010, 2011c), the AMWS exhibited a substantially higher orthophosphorus removal rate.

CONCLUSIONS

To obtain performance data to support the issuance of a GULD for the Modular Wetland System - Linear stormwater filtration system, Herrera conducted hydrologic and water quality monitoring at a test system in Portland, Oregon from April 14, 2012, to May 31, 2013. During this monitoring period, 28 separate storm events were sampled.

Of the 28 sampled events, 24 qualified for total suspended solids analysis. The data were segregated into sample pairs with influent concentration greater than and less than 100 mg/L. The UCL95 mean effluent concentration for the data with influent less than 100 mg/L was 12.8 mg/L, below the 20 mg/L threshold. In addition, the system exhibited TSS removal greater than 80 percent at flow rates up to and including the design flow rate of 41 gpm. Based on these results we recommend the system be granted Basic Treatment certification at 50 gpm (equivalent to 1.21 gpm/ft^2 of media).

Nineteen of the 28 sampled events qualified for total phosphorus analysis. The LCL95 mean percent removal was 61.7, well above the TAPE goal of 50 percent. Treatment above 50 percent was evident at flow rates up to and including the design flow rate of 41 gpm. Based on these results we recommend the system be granted Phosphorus Treatment certification at 50 gpm (equivalent to 1.21 gpm/ft^2 of media).

Eleven of the 28 sampled events qualified for assessment for dissolved zinc removal. The LCL95 mean removal was 60.5 percent while the TAPE goal is greater than 60 percent removal. Treatment above 60 percent was evident at flow rates up to and including the design flow rate of 41 gpm. Consequently, the MWS-Linear met the Enhanced Treatment criterion specified for dissolved zinc in TAPE at the design flow rate.

Fourteen of the 28 sampled events qualified for assessment for dissolved copper removal. The LCL95 mean removal was 32.5 percent while the TAPE goal is greater than 30 percent removal. Treatment above 30 percent was evident at flow rates up to 28 gpm. When lab data are used to augment the dataset, the results indicate the MWS-Linear met the Enhanced Treatment criterion specified for dissolved copper in TAPE at flow rates up to and including the design flow rate of 41 gpm.

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