Determining an appropriate chemical water quality improvement method for clarifying the water in the west lake at Lakes Regional Park.

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ABSTRACT

Alum and anionic polymer were tested to determine which of these chemicals provided the best results for improving water quality and clarity within the west lake at Lakes Regional Park when used in acoagulation/settling treatment process. The study was conducted using a small scale pilot plant. The pilot plant was designed to closely mimic the results that an actual full scale chemical water quality improvement project would provide. Numerous test runs were performed including; alum applications ranging from 10 to 150 ppm, anionic polymers (703d and 706d "Floc Logs" from Applied Polymer Systems, Inc.), and a combination of the alum and anionic polymer. Based on the results of the pilot project 100 ppm alum was determined to be the most effective chemical dosage for improving water quality and clarity.

INTRODUCTION

Lakes Regional Park is located within a portion of Section 26, Township 46 South, Range 24 East, in Lee County, Florida (26.5315150° N, 81.879421° W). Specifically, the park is situated north of Gladiolus Drive and west of Summerlin Road in Fort Myers.

Water quality monitoring data has documented increasing nutrient levels within the lakes at Lakes Regional Park since 1984. The lakes are divided into two systems, an east and west lake. The east lake serves as a flowway between incoming waters and Hendry Creek. The west lake receives overflow from the east lake through structures situated between the two lakes. The east and west lakes both discharge into Hendry Creek via control structures.

Due to the configuration of the west lake, there is very little to no circulation. As a result, the water in the west lake is near stagnant and the nutrients that enter the lake continually compound. The west lake is largely devoid of aquatic vegetation and there is little opportunity for excess nutrients to be absorbed.

The water quality problem within the west lake is further compounded by the presence of a wading bird rookery. "Waterbirds produce feces rich in phosphorus (P) and nitrogen (N) and are therefore often considered as important nutrient loaders for freshwater habitats" (Hahn et. al 2007). Per Frederick and Powell (1994) white ibis contribute 0.16 kg nitrogen and 0.06 kg phosphorus and on average other piscivorous waders contribute 36 kg nitrogen and 5 kg phosphorus per nesting attempt. In 2009 964 wading bird nests were identified on the islands located within the west lake. The nesting wading birds provide an additional source of nutrient loading in the west lake.

The high nutrient levels within the west lake, combined with saltwater intrusion caused by leaking control structures and/or extreme high tides overtopping the structures have created an ideal environment for *Prymnesium parvum* (a type of golden algae) which emits toxins harmful to gilled organisms. According to Jennifer Wolney with the FWC (personal communication, December 22, 2006) *Prymnesium* cell counts have been recorded as high as 6,561,300 cells/liter. The presence of the golden algae further complicates the nutrient issue by limiting light penetration and the ability of aquatic vegetation and other macrophytes to grow and remove nutrients.

As a result of the compounding high nutrient levels and the presence of the algae, it was hypothesized that a chemical water quality improvement process could provide improved water clarity and a reduction in excess nutrients in the west lake.

When the chemical water quality treatment process is successful in clarifying the lake water and light penetration is improved, then a natural water quality improvement measure, i.e. filter marsh, is proposed for construction. The filter marsh will be responsible for providing an ongoing, natural biological nutrient removal system within the Lakes. In addition, macrophytic vegetation would be able to re-establish throughout the lake, providing further opportunities for nutrient uptake and water quality improvement.

The chemicals that were tested as a part of this study include alum and anionic polymers. The purpose of this study was to test differing alum concentrations, APS Floc Logs 706d and 703d (anionic polymers) and alum/polymer combinations in order to determine which of these would provide the highest level of nutrient reduction as well as the greatest increase in water clarity within the west lake.

PILOT PROJECT DESIGN

In an attempt to obtain results similar to any future full scale application, a pilot plant was constructed adjacent to the west lake. The pilot plant, designed by AIM Engineering & Surveying, Inc., is shown schematically in Figure 1.

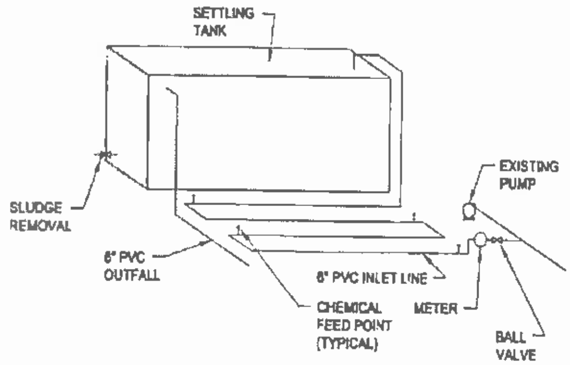


Figure 1: Pilot plant design

The pilot plant utilized an existing water pump, which fed a floating aerator (fountain) in the lake, to provide up to 100 GPM of lake water to the plant for treatment testing. Flow rate was controlled by manual valves, and a 2" water meter was installed on the inlet line to measure flow rate through the system. A small chemical feed pump (LMI Milton Roy, Series P1 Electronic Metering Pump) was used downstream of the water meter for injection of Aluminum Sulfate into the system. Flow then continued through 80 ft of serpentine PVC 6" diameter piping to provide mixing and contact time of at least 80 seconds before entering a rectangular, baffled steel tank where the resulting floc particles could settle. Wye fittings were installed on the serpentine PVC piping (mixing and contact zone) to allow insertion of the polymer "Floc Logs". Treated water from the tank overflowed to an outfall line and was returned to the lake by gravity. Sampling taps were installed before chemical injection (raw water), at the end of the serpentine piping (treated influent) and at the outfall (finished water).

The resulting pilot plant, fabricated by King Landscaping, Inc. is shown in Photos 1, 2 and 3.

Photo 1: Pilot plant, inlet view.

Photo 2: Pilot plant, outlet view.

Photo 3: Pilot plant, top view. The white pvc has jute mat attached. The green piping is a dewatering pump suction line used to drain the tank after test runs. During the actual test runs an additional jute mat was hung at the rear of the tank.

Jute mat "particle curtains" were initially installed across the tank at four (4) locations. The particle curtains were recommended to provide a substrate to which the polymer flocculent could adhere. Particle curtains were used for some of the alum runs in order to provide an equitable comparison.

METHOD

The morning of each trial, the pump was turned on at a rate of 100 GPM (gallons per minute). Typically, the tank was filled at 100 GPM, then throttled down to 25 GPM and chemical feed started. This operating flow rate allowed for a residence time of approximately 4.4 hours within the tank, which is more reflective of traditional wastewater treatment processes. Turbidity, pH and temperature readings were taken every 30 minutes. Approximately 4 hours after start of chemical feed, samples were taken for analysis by the Lee County Environmental Laboratory.

The samples were then analyzed for the following testing parameters; turbidity, total suspended solids, chlorophyll-A, color, othro-phosphorus, dissolved phosphorus, total phosphorus, ammonia, nitrite, nitrate, NOx, total nitrogen, total kjeldahl nitrogen, pH and iron.

Most of the samples were collected between 12:49 pm to 1:54 pm with the samples from the "extended runs" collected between 2:56 pm and 3:10 pm. The individual trails conducted per chemical water quality improvement method are summarized below.

Baseline

A baseline test was performed with no chemical application (raw water only) at a flow rate of 50 GMP, in order to account for any changes in the test parameters that may have resulted from the actual pilot plant (system) design.

Alum trials

A total of eleven alum trials were conducted. The initial set of trials included 10, 30, 50, 60, 70, 100 and 150 ppm alum applications operated at a 25 GPM flow rate with particle curtains installed in the settling tank. Additional trials included a 70 ppm trial at a 25 GPM flow rate without particle curtains, a 100 ppm trial at a 25 GPM flow rate without particle curtains, a 100 ppm trial at a 12.5 GPM (reduced) flow rate without particle curtains, and finally a 100 ppm alum trial at a 25 GPM flow rate without particle curtains operated for an extended period of time.

Polymer trials

Three polymer trials were conducted utilizing "Floc Log" polymers received from Applied Polymer Systems, Inc. (APS). The polymer types chosen were 706d and 703d. These specific polymers were chosen based on the results of the APS lab, a bench test conducted by the Lee County Environmental Sciences Laboratory and the recommendation of Eddie Snell - Environmental Specialist IV with the Reedy Creek Improvement District who regularly utilizes polymers for the treatment of surface water. The trials included one 706d log, four 706d logs and four 703d logs, all with particle curtains installed in the settling tank at a 25 GPM flow rate. A trial with one 703d log was originally proposed, however this trial was eliminated following inspection of the other Polymer-only trial results.

Alum and polymer combination trials

Two alum/polymer combination trails were conducted. These trails were run at a 25 GPM flow rate with particle curtains and included 100 ppm alum and 4 FLOCC logs (one trial used the 703d logs and the other trial used the 706d logs).

Since the trials were conducted over several days with varying influent concentrations, the percent reduction in the testing parameters was compared.

% reduction = ((influent conc. - effluent conc.) / influent conc.) x 100%

RESULTS

The test results were summarized for each trial by the individual testing parameters. The summaries below include turbidity (NTU), total suspended solids (TSS) (mg/L), chlorophyll A (mg/M^3), color (CU), total phosphorus (TP) (mg/L), total nitrogen (TN) (mg/L), total kjeldahl nitrogen (TKN) (mg/L), and pH.

The test results for ortho-phosphorus, dissolved phosphorus, ammonia, nitrate, nitrite, and nitrate and nitrite were at or below minimum detection levels during the laboratory analysis as a result, these testing parameters were inconclusive and are not summarized below.

Iron levels were monitored during each trial since an iron tank was utilized for the pilot plant. While the laboratory results did show increases in iron, there is no available evidence indicating that chemical reactions involving the presence of the iron were occurring that would alter our test results. Therefore iron levels were also excluded from the summaries below.

Alum Trials

Turbidity (NTU)

The alum trials conducted with particle curtains at a 25 GPM flow rate demonstrated the greatest reduction in turbidity during the 100 ppm alum application. The turbidity was reduced from 13.4 NTU to 2.46 NTU or 82%. The results of the baseline trial as well as each individual alum trial are included in Table 1 and a graph of the percent reduction per trial is included as Chart 1 below.

Turbidity			
Alum Concentration	Influent (NTU)	Effluent (NTU)	% reduction
0 ppm	14.9	14.4	3%
10 ppm	11.9	9.8	18%
30 ppm	11.8	7.27	38%
50 ppm	13.4	7.95	41%
60 ppm	12.5	5.4	57%
70 ppm	12.9	5.49	57%
100 ppm	13.4	2.46	82%
150 ppm	12.4	6.5	48%

Table 1: Turbidity results for the alum trials at 25 GPM with particle curtains.

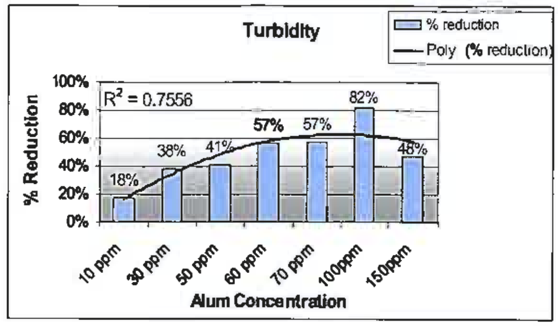


Chart 1: Comparison of the percent reduction in turbidity for the alum trials at 25 GPM with particle curtains.

Photo 4: Water from the influent and effluent taps treated with 100 ppm alum at 25 GPM with particle curtains.

Total Suspended Solids (TSS) (mg/L)

The greatest reduction in TSS observed during the alum trials conducted with particle curtains at a 25 GPM flow rate was the 100 ppm alum application. TSS were reduced from 17 NTU to 4.5 NTU or 74%. The results of the baseline trial as well as each individual alum trial are included in Table 2 and a graph of the percent reduction per trial is included as chart 2.

Chlorophyll A (mg/M^3)

Chlorophyll A levels were decreased by 95% and 94% respectively during the 70 ppm and 100 ppm alum trials conducted at a 25 GPM flow rate with particle curtains. The results of the baseline trial as well as the results of each individual alum trial are included in Table 3. A graph of the percent reduction in chlorophyll A per trial is included in chart 3.

Total Suspended Solids			
Alum Concentration	Influent (mg/L)	Effluent (mg/L)	% reduction
Baseline	21.5	20.7	4%
10 ppm	15.7	19.3	-23%
30 ppm	15.7	16.6	-6%
50 ppm	17.2	15.1	12%
60 ppm	15	8	47%
70 ppm	16.5	9.8	41%
100 ppm	17	4.5	74%
150 ppm	14	11.5	18%

Table 2: Total suspended solids results for the alum trials at 25 GPM with particle curtains.

Chlorophyll A			
Alum Concentration	Influent (mg/M3)	Effluent (mg/M3)	% reduction
Baseline	98.1	91.1	7%
10 ppm	64.4	53.1	18%
30 ppm	37.1	39.5	-6%
50 ppm	62.6	31.9	49%
60ppm	11.6	13.4	-16%
70 ppm	64.3	3.1	95%
100 ppm	43.9	2.8	94%
150 ppm	10.5	3.8	64%

Table 3: Chlorophyll A results for the alum trials at 25 GPM with particle curtains.

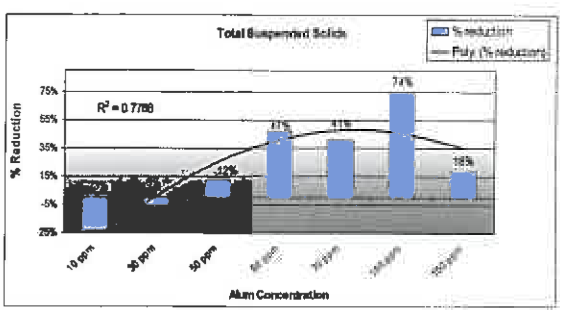


Chart 2: Comparison of the percent reduction in total suspended solids for the alum trials at 25 GPM with particle curtains.

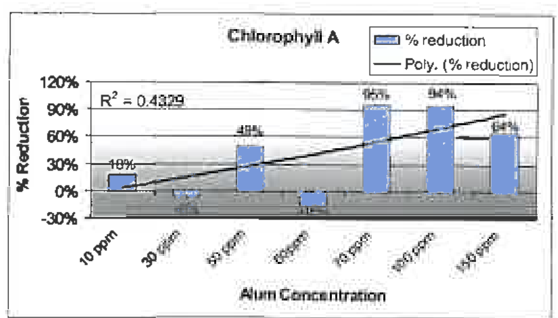


Chart 3: Comparison of the percent reduction in chlorophyll A for the alum trials at 25 GPM with particle curtains.

Color (CU)

During the alum trials conducted at a 25 GPM flow rate with particle curtains, the intensity of the water's color showed the greatest decline following the 100 ppm alum application, 81%. Table 4 includes the results of each trial and Chart 4 graphically presents the percent reduction for those trials.

Total Phosphorus (TP) (mg/L)

The greatest reduction in total phosphorus achieved during the alum trials at a 25 GPM flow rate was during the 70 ppm alum application, which resulted in a 78% reduction in total phosphorus levels. The results of the baseline trial and each individual alum trial for total phosphorus are included in Table 5 below. A graph of the percent reduction in total phosphorus levels per trial is included in Chart 5.

Color			
Alum Concentration	Influent (CU)	Effluent (CU)	% reduction
0 ppm	28.3	27.6	2%
10 ppm	30.2	24.3	20%
30 ppm	30.6	16.7	45%
50 ppm	34.7	14.7	58%
60 ppm	44.2	27.7	37%
70 ppm	29.9	11.6	61%
100ppm	36.5	6.77	81%
150ppm	40.1	14.9	63%

Table 4: Color results for alum trials at 25 GPM with particle curtains.

Total Phosphorus			
Alum Concentration	Influent (mg/L)	Effluent (mg/L)	% reduction
Baseline	0.031	0.04	-29%
10 ppm	0.022	0.02	9%
30 ppm	0.017	0.017	0%
50 ppm	0.022	0.021	5%
60 ppm	0.02	0.015	25%
70 ppm	0.036	0.008	78%
100 ppm	0.018	0.007	61%
150 ppm	0.022	0.012	45%

Table 5: Total phosphorus results for the alum trials at 25 GPM with particle curtains.

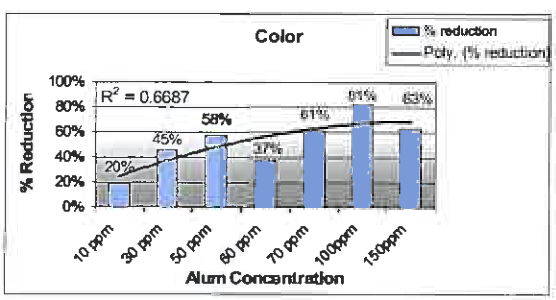


Chart 4: Comparison of the percent reduction in color for the alum trials at 25 GPM with particle curtains.

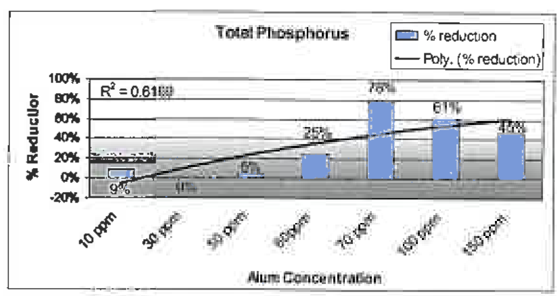


Chart 5: Comparison of the percent reduction in total phosphorus for the alum trials at 25 GPM with particle curtains.

Total Nitrogen (TN) (mg/L)

Of all alum trials conducted at a 25 GPM flow rate, the 150 ppm alum trial demonstrated the greatest reduction in total nitrogen (35%). The 70 ppm trial followed closely with a 33% reduction in total nitrogen. Table 6 includes the total nitrogen results for the baseline and each alum trial ran at 25 GPM with particle curtains. A graph of the percent reduction in total nitrogen for those trials is included as Chart 6.

Total Kjeldahl Nitrogen (TKN) (mg/L)

The greatest reductions in total kjeldahl nitrogen were demonstrated in the 150 ppm and the 50 ppm trials, both demonstrating a 35% reduction. The 70 ppm trial followed closely with a 31% reduction in total kjeldahl nitrogen. Table 7 includes the total kjeldahl nitrogen results of the baseline and the alum trials ran at 25 GPM with particle curtains. Chart 7 is a graph of the percent reduction in total kjeldahl levels for the alum trials.

Total Nitrogen			
Alum Concentration	Influent (mg/L)	Effluent (mg/L)	% reduction
Baseline	1.7	2.1	-24%
10 ppm	2	2.6	-30%
30 ppm	1.8	1.8	0%
50 ppm	1.7	1.7	0%
60 ppm	1.5	1.5	0%
70 ppm	2.7	1.8	33%
100 ppm	1.6	1.3	19%
150 ppm	1.7	1.1	35%

Table 6: Total nitrogen results for the alum trials at 25 GPM with particle curtains.

Total Kjeldahl Nitrogen			
Alum Concentration	Influent (mg/L)	Effluent (mg/L)	% reduction
Baseline	1.6	1.6	0%
10 ppm	2	2.6	-30%
30 ppm	1.8	1.8	0%
50 ppm	1.7	1.1	35%
60 ppm	1.5	1.5	0%
70 ppm	2.6	1.8	31%
100 ppm	1.3	1.1	15%
150 ppm	1.7	1.1	35%

Table 7: Total kjeldahl nitrogen results for the alum trials at 25 GPM with particle curtains.

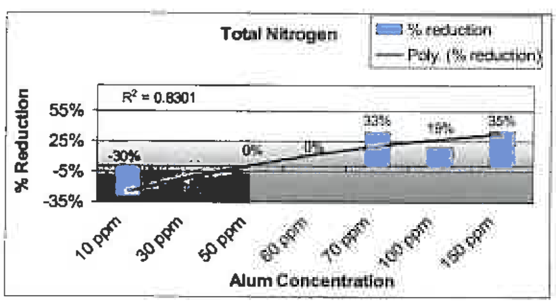


Chart 6: Comparison of the percent reduction in total nitrogen for the alum trials at 25 GPM with particle curtains.

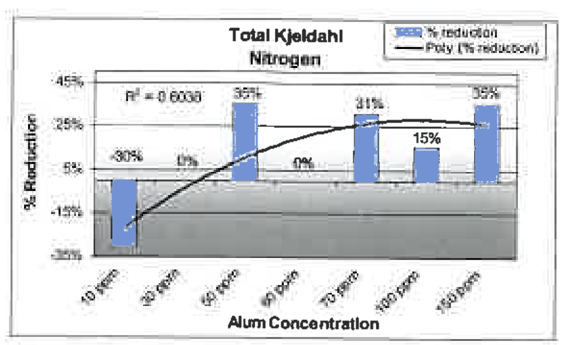


Chart 7: Comparison of the percent reduction in total kjeldahl nitrogen for the alum trials at 25 GPM with particle curtains.

pH

The pH levels declined with alum use as anticipated. The greatest decline in pH was demonstrated in the 100 ppm alum trial, in which the pH level dropped from 8.4 to 6.4 (24%). Water quality monitoring conducted by the Lee County Environmental Sciences Laboratory from November 2001 to August 2009 shows the mean pH of the lakes at Lakes Park to be 7.58. Per Ibanez, Hernandez-Esparza, Doria-Serrano & Singh, (2007) healthy lakes have a pH range between 6.5 and 8.5. pH levels during the trials did not fall below 6.4 which according to Ibanez et. al. is near the lower pH level of healthy lakes. Table 8 includes the pH levels of the baseline and each of the alum trials at 25 GPM with particle curtains. Chart 8 is a graph of the percent reduction in pH levels for those alum trials.

pH			
Alum Concentration	Influent	Effluent	% reduction
Baseline	8.5	8.5	0%
10 ppm	8.3	7.6	8%
30 ppm	8.4	7.1	15%
50 ppm	8.4	7	17%
60 ppm	8	6.9	14%
70 ppm	8	6.8	15%
100 ppm	8.4	6.4	24%
150 ppm	8	6.5	19%

Table 8: pH results for the alum trials at 25 GPM with particle curtains.

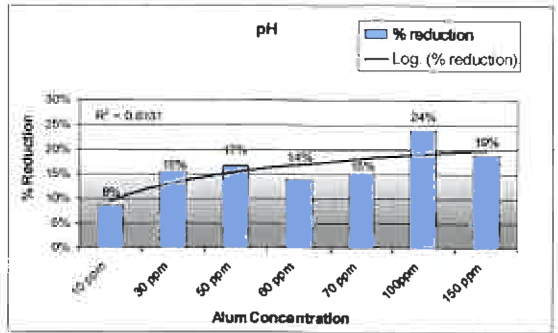


Chart 8: Comparison of the percent reduction in pH for the alum trials at 25 GPM with particle curtains.

Alum Variable Testing Parameters

Following the initial set of alum test trials, additional alum test trials were conducted in which operational parameters were varied. These variations included removing the Particle curtains and varying the flow rate through the system. The results of these tests are summarized in Tables 9-16 below.

Turbidity			
Alum Concentration	Influent (NTU)	Effluent (NTU)	% reduction
70 ppm	13.8	4.05	71%
100ppm	11.7	6.05	48%
100 ppm*	11.4	20.4	-79%
100ppm **	11.9	2.54	79%

Table 9: Turbidity test results for the alum trials with varied conditions. The 70 ppm trial was at 25 GPM without particle curtains, the 100 ppm trial was at a flow rate of 25 GPM without particle curtains, the 100 ppm* trial was at flow rate of 12.5 GPM without particle curtains and the final 100 ppm** trial was at a flow rate of 25 GPM without particle curtains and allowed to settle for an extended period of time.

Total Suspended Solids			
Alum Concentration	Influent (mg/L)	Effluent (mg/L)	% reduction
70 ppm	13.9	6.15	56%
100 ppm	13.5	10.6	21%
100 ppm*	15.9	17.1	-8%
100 ppm**	9.75	7.65	22%

Table 10: Total Suspended Solids test results for the alum trials with varied conditions. The 70 ppm trial was at 25 GPM without particle curtains, the 100 ppm trial was at a flow rate of 25 GPM without particle curtains, the 100 ppm* trial was at flow rate of 12.5 GPM without particle curtains and the final 100 ppm** trial was at a flow rate of 25 GPM without particle curtains and allowed to settle for an extended period of time.

Chlorophyll A			
Alum Concentration	Influent (mg/M3)	Effluent (mg/M3)	% reduction
70 ppm	36.7	13.1	64%
100 ppm	11.4	4.7	59%
100 ppm*	8.2	11.5	-40%
100 ppm**	70	18.6	73%

Table 11: Chlorophyll A test results for the alum trials with varied conditions. The 70 ppm trial was at 25 GPM without particle curtains, the 100 ppm trial was at a flow rate of 25 GPM without particle curtains, the 100 ppm* trial was at flow rate of 12.5 GPM without particle curtains and the final 100 ppm** trial was at a flow rate of 25 GPM without particle curtains and allowed to settle for an extended period of time.

Color			
Alum Concentration	Influent (CU)	Effluent (CU)	% reduction
70 ppm	26.3	26.6	-1%
100ppm	30.5	13.3	56%
100 ppm*	26.7	26.6	0%
100ppm **	29.3	6.81	77%

Table 12: Color test results for the alum trials with varied conditions. The 70 ppm trial was at 25 GPM without particle curtains, the 100 ppm trial was at a flow rate of 25 GPM without particle curtains, the 100 ppm* trial was at flow rate of 12.5 GPM without particle curtains and the final 100 ppm** trial was at a flow rate of 25 GPM without particle curtains and allowed to settle for an extended period of time.

Total Phosphorus			
Alum Concentration	Influent (mg/L)	Effluent (mg/L)	% reduction
70 ppm	0.013	0.008	38%
100 ppm	0.013	0.01	23%
100 ppm*	0.019	0.021	-11%
100 ppm**	0.014	0.006	57%

Table 13: Total Phosphorus test results for the alum trials with varied conditions. The 70 ppm trial was at 25 GPM without particle curtains, the 100 ppm trial was at a flow rate of 25 GPM without particle curtains, the 100 ppm* trial was at flow rate of 12.5 GPM without particle curtains and the final 100 ppm** trial was at a flow rate of 25 GPM without particle curtains and allowed to settle for an extended period of time.

Total Nitrogen			
Alum Concentration	Influent (mg/L)	Effluent (mg/L)	% reduction
70 ppm	1.4	1.4	0%
100 ppm	1.6	1.6	0%
100 ppm*	1.7	2	-18%
100 ppm**	1.6	0.98	39%

Table 14: Total Nitrogen test results for the alum trials with varied conditions. The 70 ppm trial was at 25 GPM without particle curtains, the 100 ppm trial was at a flow rate of 25 GPM without particle curtains, the 100 ppm* trial was at flow rate of 12.5 GPM without particle curtains and the final 100 ppm** trial was at a flow rate of 25 GPM without particle curtains and allowed to settle for an extended period of time.

Total Kjeldahl Nitrogen			
Alum Concentration	Influent (mg/L)	Effluent (mg/L)	% reduction
70ppm	1.4	1.4	0%
100 ppm	1.6	1.6	0%
100 ppm*	1.7	2	-18%
100 ppm**	1.6	0.98	39%

Table 15: Total Kjeldahl Nitrogen test results for the alum trials with varied conditions. The 70 ppm trial was at 25 GPM without particle curtains, the 100 ppm trial was at a flow rate of 25 GPM without particle curtains, the 100 ppm* trial was at flow rate of 12.5 GPM without particle curtains and the final 100 ppm** trial was at a flow rate of 25 GPM without particle curtains and allowed to settle for an extended period of time.

pH			
Alum Concentration	Influent	Effluent	% reduction
70 ppm	8.4	6.9	18%
100 ppm	8.4	6.6	21%
100 ppm*	7.9	8.2	-4%
100 ppm**	7.8	5.9	24%

Table 16: pH test results for the alum trials with varied conditions. The 70 ppm trial was at 25 GPM without particle curtains, the 100 ppm trial was at a flow rate of 25 GPM without particle curtains, the 100 ppm* trial was at flow rate of 12.5 GPM without particle curtains and the final 100 ppm** trial was at a flow rate of 25 GPM without particle curtains and allowed to settle for an extended period of time.

Polymer FLOCC Logs Trials

Turbidity

The polymer trials resulted in minimal reductions in turbidity levels. The greatest reduction in turbidity for the polymer trials was 4% during the 706d single log trial. The turbidity results for each of the polymer trials are included in Table 17 and a graph of the percent reduction in turbidity is included in Chart 9 below.

Turbidity (NTU)			
Polymer Application	Influent (NTU)	Effluent (NTU)	% reduction
706d 1 log	15.5	14.9	4%
706d 4 logs	16.3	16.1	1%
703d 4 logs	14.9	14.4	3%

Table 17: Turbidity test results for the polymer trials at 25 GPM with particle curtains.

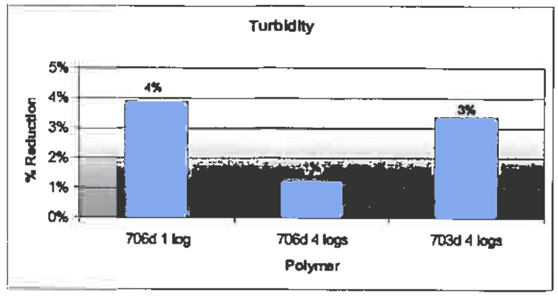


Chart 9: Comparison of the percent reduction in turbidity for the polymer trials at 25 GPM with particle curtains.

Total Suspended Solids (TSS)

The polymer trial that resulted in the greatest reduction in total suspended solids was the four log 703d run with a 25% reduction. The total suspended solids results for each of the polymer trials is included in Table 18 and a graph of the percent reduction in total suspended solids is included in Chart 10.

Total Suspended Solids			
Polymer Application	Influent (mg/L)	Effluent (mg/L)	% reduction
706d 1 log	19.4	17.5	10%
706d 4 logs	17.7	22.9	-29%
703d 4 logs	28.2	21.1	25%

Table 18: Total Suspended Solids test results for the polymer trials at 25 GPM with particle curtains.

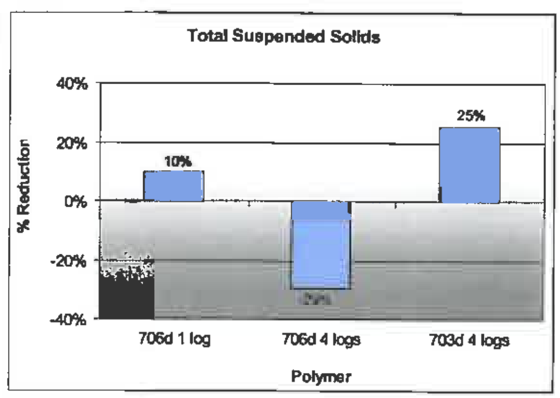


Chart 10: Comparison of the percent reduction in total suspended solids for the polymer trials at 25 GPM with particle curtains.

Chlorophyll A

The highest reduction in chlorophyll A levels for the polymer trials was during the four log 706d application. This trial showed an 81% reduction in chlorophyll A levels. This is assumed to be an anomaly because the same reduction in turbidity, total suspended solids and/or color was not observed. The chlorophyll A levels for each of the polymer trials are included in Table 19. A graph of the percent reduction in chlorophyll A per polymer trial is included in Chart 11.

Color

The polymer applications conducted at a 25 GPM flow rate with particle curtains demonstrated little effect on color. The highest reduction of 7% was observed during the 706d single log trial. The 706d four (4) log trial demonstrated the lowest reduction of -9%, which represents an increase in color. The results of the polymer trials are included in Table 20 and a comparison graph of the percent reduction of color is included in Chart 12.

Chlorophyll A			
Polymer	Influent (mg/M3)	Effluent (mg/M3)	% reduction
706d 1 log	59.9	44.3	26%
706d 4 logs	94.8	18	81%
703d 4 logs	53.8	60.5	-12%

Table 19: Chlorophyll A test results for the polymer trials at 25 GPM with particle curtains.

Color			
Polymer Application	Influent (CU)	Effluent (CU)	% reduction
706d 1 log	33	30.7	7%
706d 4 logs	30.5	33.1	-9%
703d 4 logs	31.3	30.2	4%

Table 20: Color results for the polymer trials at 25 GPM with particle curtains.

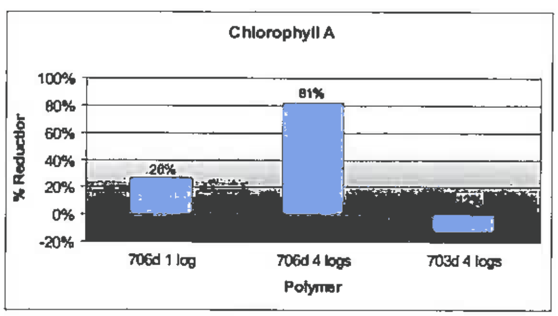


Chart 11: Comparison of the percent reduction in chlorophyll A for the polymer trials at 25 GPM with particle curtains.

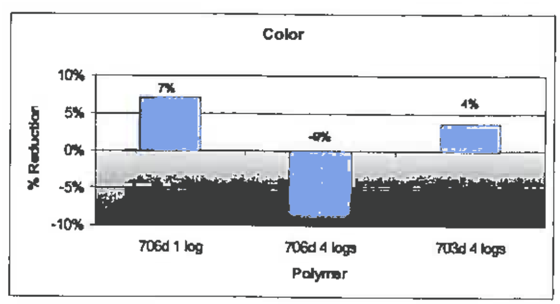


Chart 12: Graphically representation of the percent reduction in color during the polymer trials at 25GPM with particle curtains.

Total Phosphorus (TP)

The only polymer trial that demonstrated a reduction in total phosphorus levels was the four-log 706d trial with an 18% reduction. The other trials demonstrated increases in total phosphorus. The total phosphorus results of each of the polymer trials are included in Table 21. A graph of the percent reduction in total phosphorus levels per polymer trial is included in Chart 13.

Total Nitrogen (TN)

The polymer trials did not demonstrate a reduction in total nitrogen levels. The results of each polymer trial are shown in Table 22 below, and graph of the percent reduction in total nitrogen levels is included in Chart 14.

Total Phosphorus			
Polymer	Influent (mg/L)	Effluent (mg/L)	% reduction
706d 1 log	0.021	0.11	-424%
706d 4 logs	0.017	0.014	18%
703d 4 logs	0.015	0.016	-7%

Table 21: Total phosphorus test results for the polymer trials at 25 GPM with particle curtains.

Total Nitrogen			
Polymer	Influent (mg/L)	Effluent (mg/L)	% reduction
706d 1 log	1.6	6	-275%
706d 4 logs	1.7	1.9	-12%
703d 4 logs	1.6	2	-25%

Table 22: Total nitrogen test results for the polymer trials at 25 GPM with particle curtains.

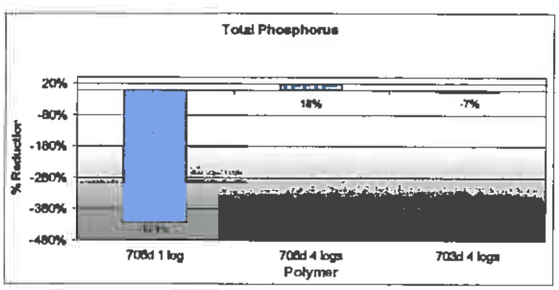


Chart 13: Comparison of the percent reduction in total phosphorus for the polymer trials at 25 GPM with particle curtains.

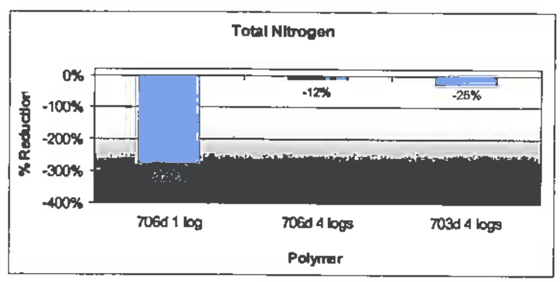


Chart 14: Comparison of the percent reduction in total nitrogen for the polymer trials at 25 GPM with particle curtains.

Total Kjeldahl Nitrogen (TKN)

The polymer trials did not demonstrate a reduction in total kjeldahl nitrogen levels. The results of each polymer trial are shown in Table 23 below and graph of the percent reduction in total kjeldahl nitrogen levels is included in Chart 15.

Total Kjeldahl Nitrogen			
Polymer	Influent (mg/L)	Effluent (mg/L)	% reduction
706d 1 log	1.6	6	-275%
706d 4 logs	1.7	1.9	-12%
703d 4 logs	1.6	2	-25%

Table 23: Total kjeldahl nitrogen test results for the polymer trials at 25 GPM with particle curtains.

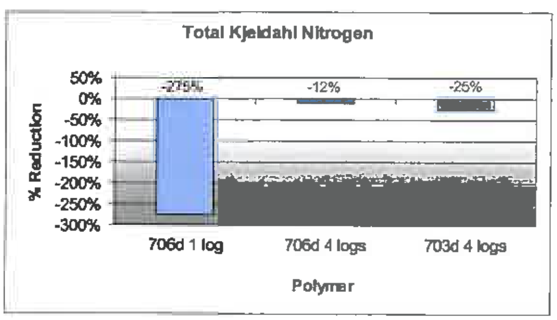


Chart 15: Comparison of the percent reduction in total kjeldahl nitrogen for the polymer trials at 25 GPM with particle curtains.

pH

The polymer trials did not demonstrate a significant change in pH levels. The greatest decline in pH levels was 2% during the single-log 706d trial. Water quality monitoring conducted by the Lee County Environmental Sciences Laboratory from November 2001 to August 2009 shows the mean pH of the lakes at Lakes Park to be 7.58. The pH results for each of the polymer trials are included in Table 24 and a graph of the percent reduction in pH is included in Chart 16.

pH			
Polymer Application	Influent	Effluent	% reduction
706d 1 log	8.6	8.4	2%
706d 4 logs	8.5	8.4	1%
703d 4 logs	8.4	8.3	1%

Table 24: pH test results for the polymer trials at 25 GPM with particle curtains.

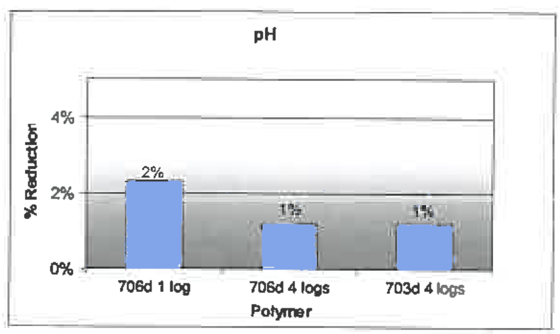


Chart 16: Comparison of the percent reduction in pH for the polymer trials at 25 GPM with particle curtains.

Polymer and Alum Combination Trials

Turbidity

The 100 ppm alum and single-log 703d combination trial demonstrated the greatest reduction (69%) in turbidity during the alum and polymer combination tests. However, this reduction is less than the turbidity reduction observed during the 100 ppm alum trial without polymers. Table 25 includes the turbidity results for each of the combined alum and polymer trials. A graph of the percent reduction in turbidity levels per the combined alum and polymer trial is included in Chart 17.

Total Suspended Solids (TSS)

The 100 ppm alum and single-log 703d combination trial demonstrated the greatest reduction (51%) of total suspended solids during the alum and polymer combination trials. However, the combination trials demonstrated a smaller reduction in total suspended solids than the alum trials without polymers. Table 26 includes the results of the total suspended solid levels during each of the alum and polymer combination trials and Chart 18 is a graph of the percent reduction from those trials.

Turbidity (NTU)			
Treatment	Influent (NTU)	Effluent (NTU)	% reduction
100 ppm Alum & 1 703d log	12.6	3.9	69%
100 ppm Alum & 1 706d log	13.9	7.6	45%

Table 25: Turbidity test results for the 100 ppm alum and polymer trials at 25 GPM with particle curtains.

Total Suspended Solids			
Treatment	Influent (mg/L)	Effluent (mg/L)	% reduction
100 ppm Alum & 1 703d log	14.4	7.1	51%
100 ppm Alum & 1 706d log	14	8.7	38%

Table 26: Total suspended solids test results for the 100 ppm alum and polymer trials at 25 GPM with particle curtains.

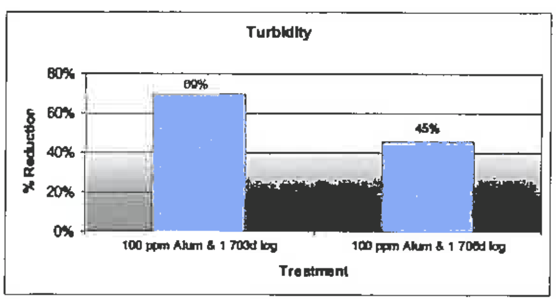


Chart 17: Comparison of the percent reduction in turbidity for the 100 ppm alum and polymer trials at 25 GPM with particle curtains.

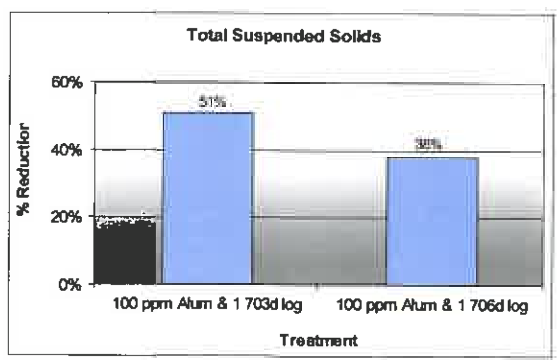


Chart 18: Comparison of the percent reduction in total suspended solids for the 100 ppm alum and polymer trials at 25 GPM with particle curtains.

Chlorophyll A

The 100 ppm alum and single-log 703d combination trial demonstrated the greatest reduction (70%) in Chlorophyll A levels during the alum and polymer combination trials. Table 27 includes the results of each of the alum and polymer combination trials on chlorophyll A levels and Chart 19 documents the percent reduction in chlorophyll A for those trials.

Chlorophyll A			
Treatment	Influent (mg/M3)	Effluent (mg/M3)	% reduction
100 ppm Alum & 1 703d log	60.7	18.5	70%
100 ppm Alum & 1 706d log	50.9	24.4	52%

Table 27: Chlorophyll A test results for the 100 ppm alum and polymer trials at 25 GPM with particle curtains.

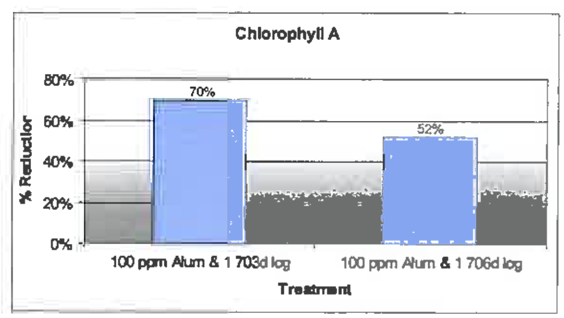


Chart 19: Comparison of the percent reduction in chlorophyll A for the 100 ppm alum and polymer trials at 25 GPM with particle curtains.

Color

The 100 ppm alum and single-log 703d combination trial demonstrated the greatest reduction (75%) in Color during the alum and polymer combination trials. Table 28 includes the results of the combination trials and Chart 20 is a graphical presentation of the percent reduction from those trials.

Color			
Treatment	Influent (CU)	Effluent (CU)	% reduction
100 ppm Alum & 1 703d log	31.3	7.93	75%
100 ppm Alum & 1 706d log	31.6	10.8	66%

Table 28: Color results for the 100 ppm alum and polymer trials at 25 GPM with particle curtains.

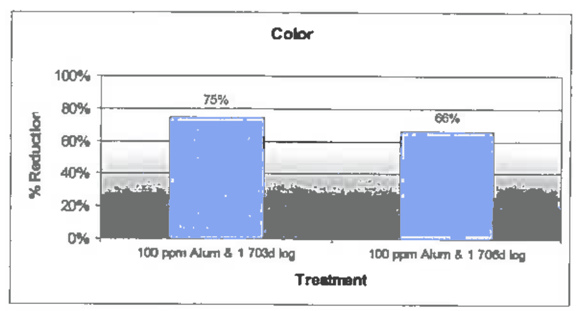


Chart 20: Comparison of the percent reduction in color from the combination trials.

Total Phosphorus (TP)

The 100 ppm alum and single-log 706d combination trial demonstrated the greatest reduction (36%) in Color during the alum and polymer combination trials. However, total phosphorus levels were not reduced during the 100 ppm Alum and single-log 703d combination trial. Table 29 includes the results of both combination trials and Chart 21 graphs the percent reduction in total phosphorus levels for the combination trials.

Total Nitrogen (TN)

Total nitrogen levels were reduced by 35% during the 100 ppm alum and single-log 706d combination trial. The total nitrogen results for each of the alum and polymer combination trials is included in Table 30 and a graph of the percent reduction in total nitrogen levels is included in Chart 22.

Total Phosphorus			
Treatment	Influent (mg/L)	Effluent (mg/L)	% reduction
100 ppm Alum & 1 703d log	0.015	0.02	-33%
100 ppm Alum & 1 706d log	0.042	0.027	36%

Table 29: Total phosphorus test results for the 100 ppm alum and polymer trials at 25 GPM with particle curtains.

Total Nitrogen			
Treatment	Influent (mg/L)	Effluent (mg/L)	% reduction
100 ppm Alum & 1 703d log	1.6	1.4	13%
100 ppm Alum & 1 706d log	2.6	1.7	35%

Table 30: Total nitrogen test results for the 100 ppm alum and polymer trials at 25 GPM with particle curtains.

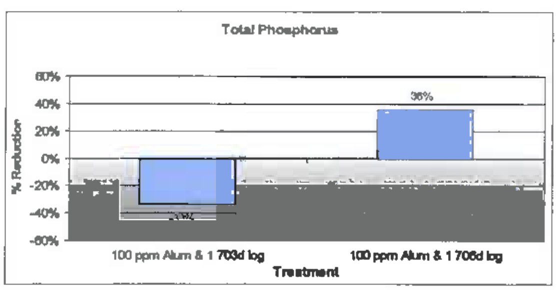


Chart 21: Comparison of the percent reduction in total phosphorus for the 100 ppm alum and polymer trials at 25 GPM with particle curtains.

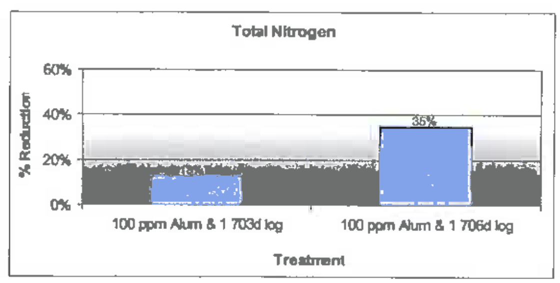


Chart 22: Comparison of the percent reduction in total nitrogen for the 100 ppm alum and polymer trials at 25 GPM with particle curtains.

Total Kjeldahl Nitrogen (TKN)

Total kjeldahl nitrogen levels were reduced by 35% during the 100 ppm Alum and single-log 706d combination trial. However, total kjeldahl nitrogen levels were increased during the 100 ppm alum and single-log 703d combination trial. Table 31 includes the total kjeldahl nitrogen levels resulting from each of the alum and polymer combination trials and Chart 23 documents the percent reduction in total kjeldahl nitrogen for those trials.

Total Kjeldahl Nitrogen			
Treatment	Influent (mg/L)	Effluent (mg/L)	% reduction
100 ppm Alum & 1 703d log	1.4	2.6	-86%
100 ppm Alum & 1 706d log	2.6	1.7	35%

Table 31: Total kjeldahl nitrogen test results for the 100 ppm alum and polymer trials at 25 GPM with particle curtains.

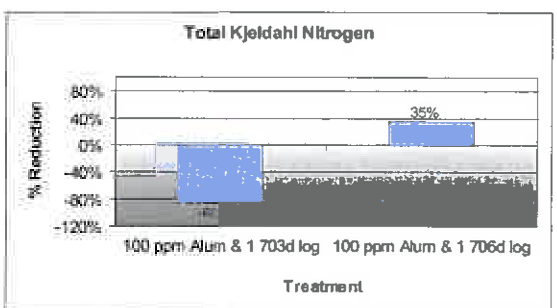


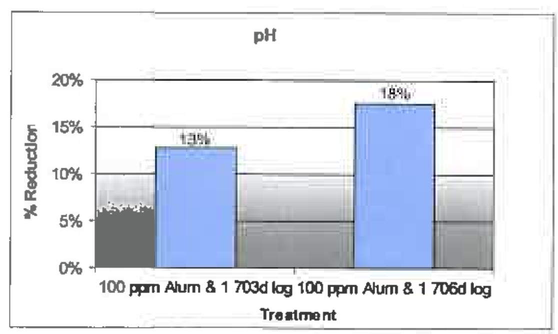
Chart 23: Comparison of the percent reduction in total kjeldahl nitrogen for the 100 ppm alum and polymer trials at 25 GPM with particle curtains.

pH

The 100 ppm Alum and single-log 706d combination trial demonstrated the greater pH reduction of 18%, from 8 to 6.6. This pH of 6.6 is still above the minimum pH level of healthy lakes-6.5 according to Ibanez et al. (2007). Water quality monitoring conducted by the Lee County Environmental Sciences Laboratory from November 2001 to August 2009 shows the mean pH of the lakes at Lakes Park to be 7.58. The results of the alum polymer combination trials on pH levels are included in Table 32. Chart 24 is a comparison graph of the percent reduction in pH for each of those trials.

pH			
Treatment	Influent	Effluent	% reduction
100 ppm Alum & 1 703d log	7.8	6.8	13%
100 ppm Alum & 1 706d log	8	6.6	18%

Table 32: pH test results for the 100 ppm alum and polymer trials at 25 GPM with particle curtains.



Graph 24: Comparison of the percent reduction in pH for the 100 ppm alum and polymer trials at 25 GPM with particle curtains.

Discussion

Based on the observed results of the pilot project test trials, it is concluded that an alum application with an initial application concentration of approximately 100 ppm would provide the greatest increase in water clarity with significant nutrient removal. During the trial, the 100 ppm alum application resulted in an 82% reduction in turbidity and a 74% reduction in total suspended solids.

As expected, the 100 ppm alum application provided a reduction in pH levels. Utilizing any alum treatment will require regular monitoring of pH. If the pH levels are lowered significantly (below the minimum for healthy lakes) Calcium Hydroxide and/or Sodium Hydroxide may be added in order to regulate the pH to a more appropriate level thereby mitigating any decline in pH levels.

While the 100 ppm alum trial did not demonstrate the greatest observed reduction in TP, TN and TKN levels during the trials, the 100 ppm alum application did demonstrate significant reductions in TP, TN and TKN of 61%, 19% and 15% respectively. As stated above, the 100 ppm also demonstrated the greatest increase in water clarity, through the greatest reduction in turbidity and TSS. The significant nutrient reductions combined with increased water clarity achieves the overall goals of nutrient reduction and promoting the growth of nutrient consuming macrophytes.

The polymer trials and the alum polymer combination trials were not as effective as the individual alum trials. We hypothesize that the charge on the cell wall of the algae inhibited the algae from binding with the anionic polymer. This is similar to the results that Golueke and Oswald observed when passing pond algae through anionic exchange resin columns (1970).

Particle curtains were incorporated into the pilot project plant design primarily to assist with polymer adsorption for the trials that utilized polymer, and the curtains were installed during construction and initial set-up of the plant. The particle curtains were not anticipated to provide a benefit in the alum-only trials, as the alum flocculent is primarily removed through settling in the main tank. However, the particle curtains were in place during the initial alum-only trials of 10, 30, 50, 60, 70, 100, 150 ppm, and were used through the polymer only trials and the alum-polymer combination trials.

In preparing for the final alum-only trials in which operational parameters were to be varied (flow rate, run time), the project team questioned whether the continued use of the particle curtains was necessary. As stated above, the particle curtains were primarily utilized in order to assist with polymer adsorption; however the team questioned if the particle curtains may have improved flocculent capture and settlement in the tank during the initial alum-only trials. A decision was made to remove the particle curtains in the final alum-only trials so the results could be compared with the initial alum-only trials (with particle curtains). The results of the alum trials with varied operational parameters and no particle curtains demonstrated that similar results could be obtained.

FURTHER DESIGN CONSIDERATIONS

In considering design for a full-scale chemical water quality treatment facility for Lakes Park, we have identified several factors that should be considered in the design process:

- Final placement of the full-scale facility should consider several factors, including minimizing the potential for public access, using natural features to "camouflage" the facility, and placing the facility near the south end of the west lake to treat water nearest the lake outlet (most impaired water).

- Size of the facility should be validated by a bathymetric survey of the West Lake system.

- The full-scale facility should include a pumped, recirculation line to transport treated water back up to the north end of the west lake, where it will receive further treatment through the newly proposed west lake filter marsh, and will "push" untreated water south to the treatment facility. The recirculation line should have features to provide aeration and multiple discharge points to improve circulation.

- The pilot project suggested 100ppm alum as the most appropriate concentration for the Lakes Park water. However, the full-scale facility should be designed to allow for varying concentrations of alum application, as the west lake water chemistry will change as the treatment process continues, and different alum concentrations my be appropriate at different times to maximize effectiveness.

- Sludge processing, handling, and removal will have to be determined in the full-scale design. The different options include variations on cost, staff, and other park-affecting requirements.

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