Sludge Pilot Study

Barb Duff, Dennis McAllister - 2006

I. Introduction:

Des Moines Water Works (DMWW) produces an average of 50,000 tons of dewatered residual lime sludge each year. This lime sludge consists of by-products from the water treatment softening process. These by-products may contain some river silt, clay, algae, organics and treatment chemicals (ferric chloride, powdered activated carbon, alum and soda ash). However, the sludge is primarily composed of calcium carbonate. Variable amounts of magnesium hydroxide may also be present depending on the pH of the operation. This residue contains approximately 3% solids before dewatering or 50% solids after dewatering.

The challenge for DMWW has been how to dispose of this lime sludge. From 1948 until 1995 the lime sludge was pumped across the Raccoon River to storage lagoons. This practice was stopped in 1995 because the storage lagoons had reached their capacity.

Since 1995, DMWW has contracted with Kelderman Manufacturing to haul away roughly 3,000 semi truck loads of lime sludge residual per year at a cost of $570,000. Therefore, for each $1,000,000 of treatment lime purchased, DMWW is paying roughly half that amount again to dispose of treatment residue.

Two studies were initiated to evaluate this situation. The first was a static flow study designed to determine if lime sludge could be effectively applied to the surface of ponds to settle cyanobacteria, reduce turbidity and lower phosphorous concentration. The second study was designed to determine if lime sludge could be used to effectively enhance cyanobateria and turbidity removal in the pre-sedimentation basin.

II. Study 1 - Static Flow

A static flow study was conducted to determine the dosage and practicality of spraying lime sludge on the ponds to settle cyanobacteria. Applications where this concept might have merit:

1. Emergency application on ponds to reduce cyanobacteria populations during algae blooms.
2. Periodic application for taste and odor control caused by cyanobacteria, if the water is used as a source of drinking water.
3. Creation of a high-pH layer on the bottom of storage lagoons to bind up phosphorus in the water.
4. Creation of an impermeable layer to decrease the leakage of a pond or basin.
5. Increased buffering capacity.

Evaluation of lime sludge alone, coagulant alone, and lime sludge in conjunction with a coagulant was conducted.

Depending on how the material behaved in a pond situation, it could also provide an aesthetic improvement to thousands of ponds on country homesteads throughout the area. This would provide a business opportunity for use of the lime sludge.

A. Method:

The testing was conducted in a 10'x 8" clear plastic column which was filled with pond water.

The depth of the column simulated what is observed in the DMWW pond system. Sampling ports were located every three feet on the column from the water surface. A control pond water sample was analyzed. Samples were collected at 0', 3', 6' and 9'depths at the following time intervals after chemical addition: 3

hours, 6 hours and 24 hours. The selected intervals were chosen to represent the real-time effects of the chemical settling in a static pond environment.

Three separate treatments were used:

1. Lime sludge only
2. Lime sludge + Ferric chloride
3. Ferric chloride only

Untreated pond water was used as a control.

The pond water in the column was spiked with Phosphate-P (PO4-P) to a final concentration of 2mg/L P. Phosphate was added to determine if calcium in the sludge would bind to P and precipitate it out of the solution.

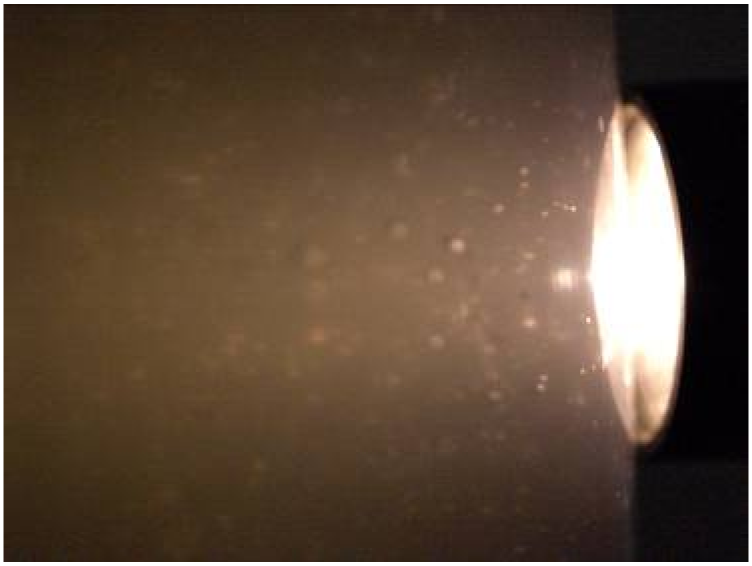
Lime sludge residual was collected from the center ring of the sludge settling building at the DMWW dewatering facility. The lime sludge was sprayed on top of the pond water in the column for seven seconds which equated to about 46 ml of sludge, 3% of the total volume in the column. This calculation was based on the amount of sludge, nozzle size and boat speed that would be used in a real world situation.

Ferric chloride (2.5 ml) was also sprayed on the top of the pond water in the column. This amount is the equivalent of the average dosage of ferric chloride applied in the full scale operation (10 mg/L).

B. Results

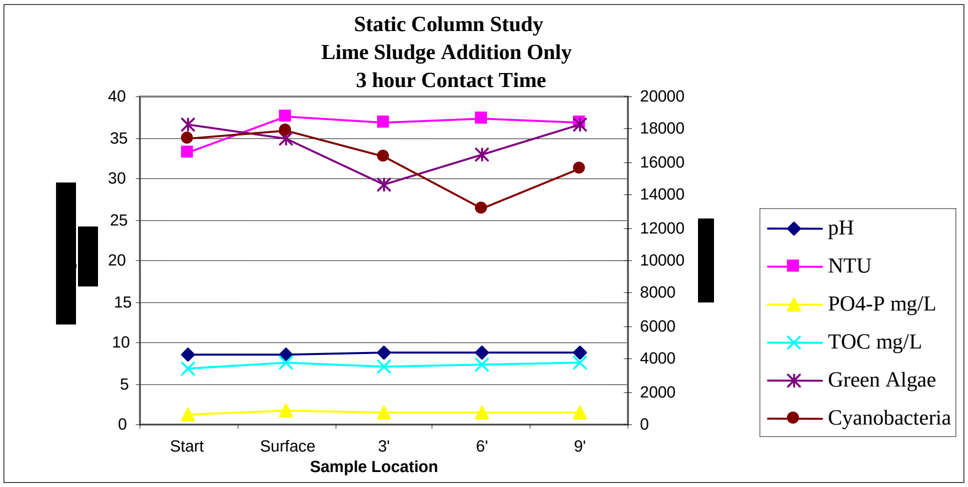
1. Sludge only

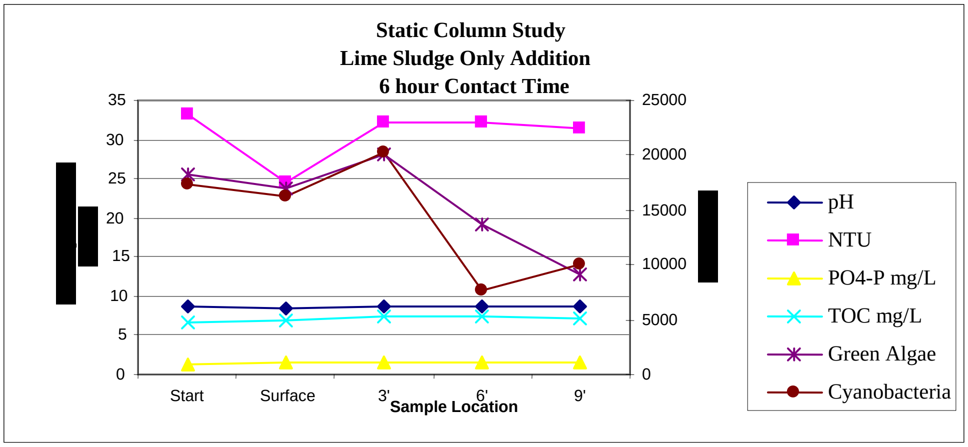
A 7-second spray of 0.03 g/L solids sludge (46.3 mL of lime sludge total) was applied to the surface of the water column containing pond water spiked to 2.0 mg/L of PO4-P.

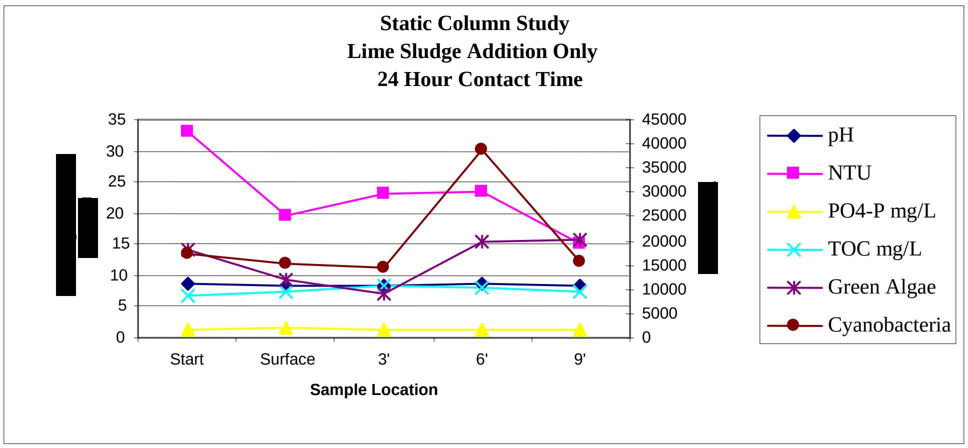


Shortly after chemical addition, particle formation was observed. However, the particles didn't have the snowflake appearance of the floc particles observed during the lime softening treatment process. The particles settled quickest in the middle of the column. The surface effect of the cylinder appeared to take over, slowing down the majority of the particles due to side adhesion. All large particles settled within 2 hours.

Result Graphs (Summary Table located in Appendix A)







a. Results Summary of Sludge Only Study

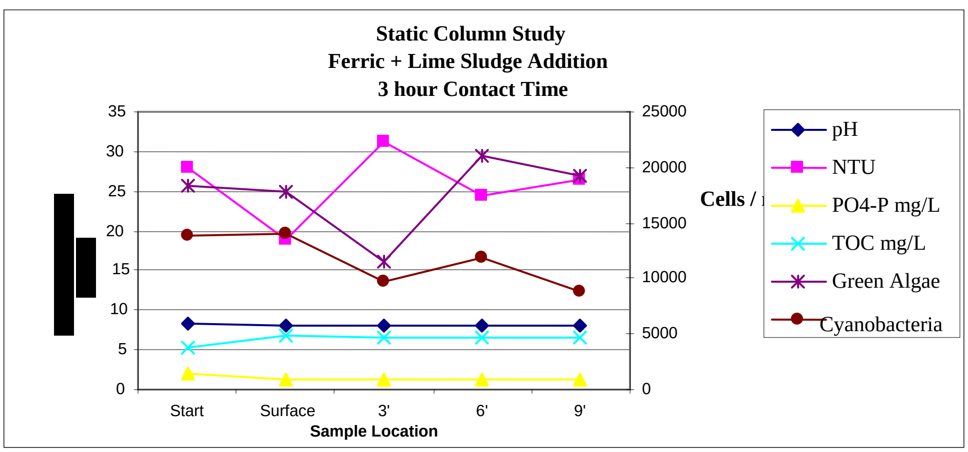
In the experiment where only lime sludge was added, TOC increased slightly during the 3, 6, and 24 hour contact periods. Turbidity did decrease after the 6 and 24 hour period. PO4-P appeared to remain constant throughout the study. This may indicate that any available Ca capable of binding with P sites was depleted. Cyanobacteria and green algae counts were reduced after the 6 hour contact time.

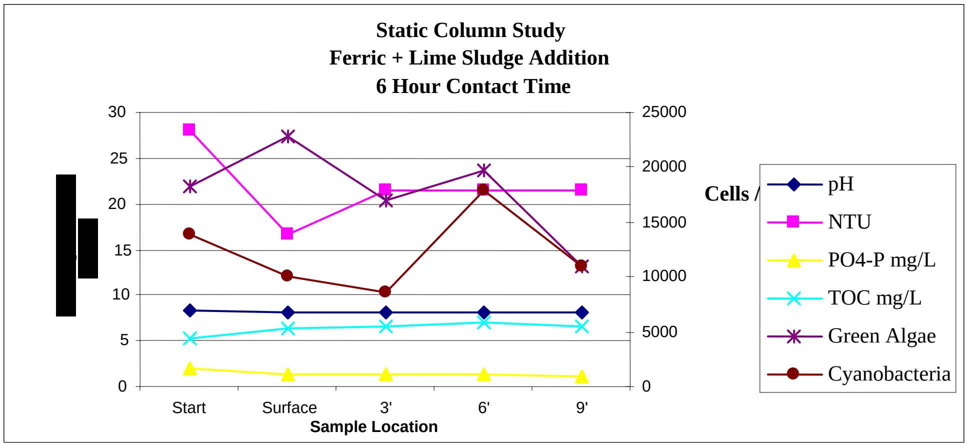
2. Sludge + Ferric

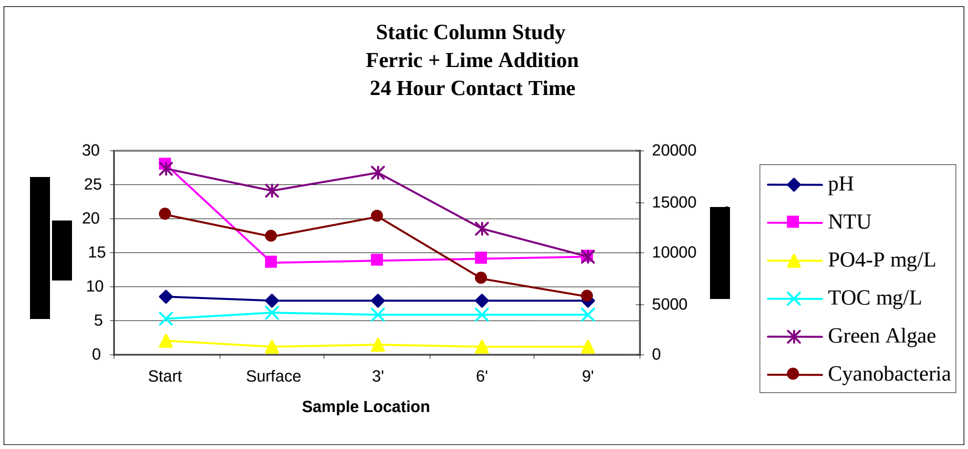
A 7-second spray of 0.03 g/L solids sludge (46.3 mL of lime sludge total) was applied to the surface of the water column containing P-spiked pond water (2 mg/L) simultaneous with a 7 second spray of 10 mg/L ferric chloride (2.12 mL total).

There was immediate coagulation upon chemical addition with large floc formation similar to formation in a lime softening treatment process. All the floc particles appeared to settle to the bottom of the column within 1 hour.

Results Graphs (Results tables located in Appendix B):







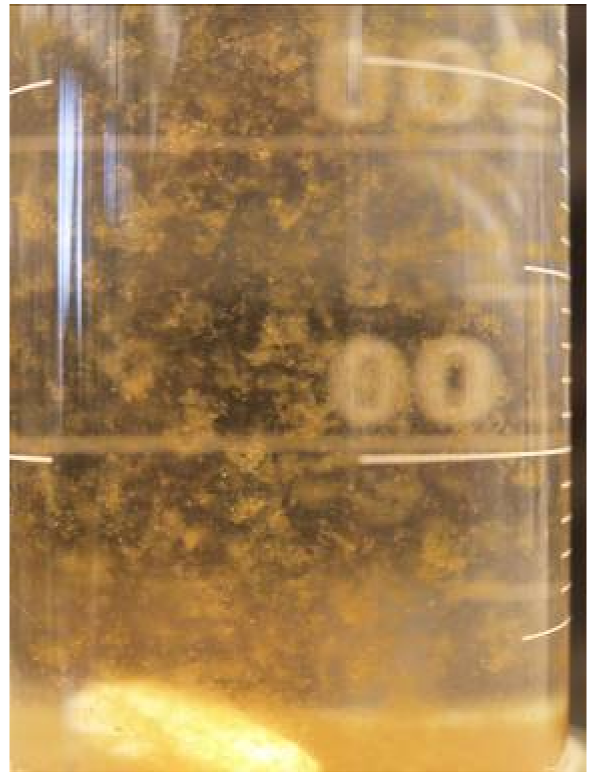
a. Results Summary of Sludge + Ferric Addition Study

Both turbidity and PO4-P removal were observed with this study at all sample locations regardless of contact time. One hypothesis for the phosphate removal is that the calcium in the lime sludge was liberated by the acidity of the ferric chloride addition, allowing this calcium to bind with the phosphate. TOC increased at all time periods. There was a slight decrease in green algae and cyanobacteria regardless of contact time.

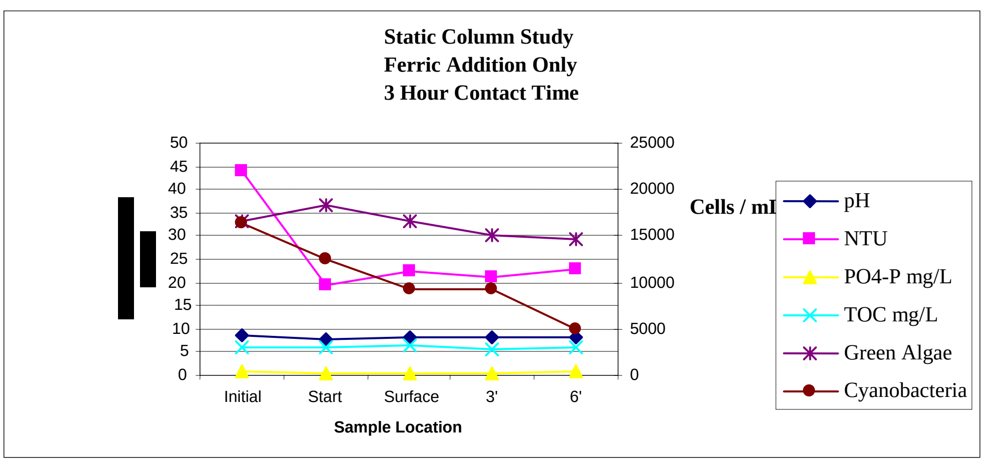
3. Ferric only

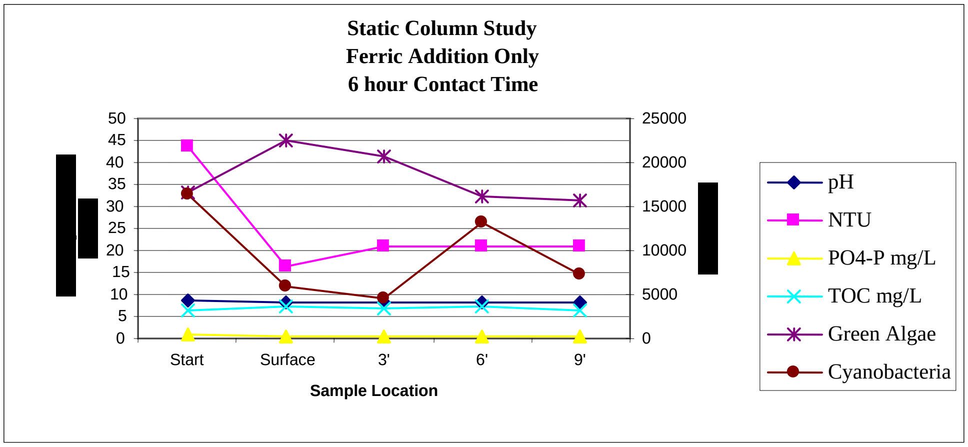
A 7-second spray of 10 mg/L ferric chloride (2.12 mL total) was applied to the surface of the water column. The water column was also spiked to a final concentration of 1.0 mg/L PO4-P.

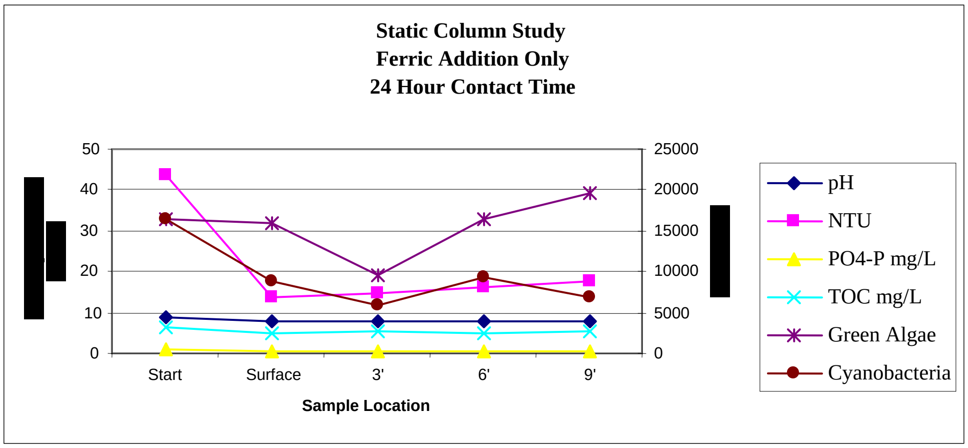
Floc formation was observed approximately 15 minutes later. A gelatinous floc of increasing size was noted after that time. Precipitation appeared complete within 1 hour.



Result Graphs (Data Table in Appendix C)







a. Results Summary of Ferric Addition Only Study

The ferric chloride only addition appeared beneficial in the removal of turbidity and cyanobacteria regardless of contact time. No significant reduction of TOC, PO4-P or green algae was observed during any of the collection periods. The ferric chloride did impart an iodine color to the pond water. This iodine color could potentially impair the water for recreational uses.

C. Summary:

Result Table

STATIC COLUMN LIME SLUDGE STUDY

VALUES = AVERAGE % REMOVAL OF ALL 4 DEPTHS

Bold= best in category

3 HOUR CONTACT - SETTLING TIME			
	SLUDGE ONLY	SLUDGE + FERRIC	FERRIC ONLY
NTU	-11.90	9.91	51.08
PO4-P mg/L	-15.27	36.24	18.00
TOC mg/L	-9.50	-25.09	2.02
GREEN ALGAE	8.75	5.00	2.08
CYANOBACTERIA	9.47	19.46	45.07

6 HOUR CONTACT - SETTLING TIME			
	SLUDGE ONLY	SLUDGE + FERRIC	FERRIC ONLY
NTU	9.49	27.77	55.14
PO4-P mg/L	-14.69	36.99	14.67
TOC mg/L	-7.38	-24.48	-11.98
GREEN ALGAE	18.13	3.75	-13.19
CYANOBACTERIA	22.03	13.75	52.46

23 HOUR CONTACT - SETTLING TIME			
	SLUDGE ONLY	SLUDGE + FERRIC	FERRIC ONLY
NTU	38.78	50.36	64.38
PO4-P mg/L	-8.59	34.22	24.33
TOC mg/L	-16.28	-12.55	17.70
GREEN ALGAE	16.88	23.75	6.25
CYANOBACTERIA	-20.92	30.83	52.46

The following is a summary of the static column studies:

1. The addition of *lime sludge only* increased the turbidity in the 3 and 6 hour study. There didn't appear to be any active sites on the lime sludge particles to act as a coagulant for the turbidity. The 39% turbidity removal in the 23 hour study may not be significant (the same removal may be noted by naturally settling). The other studies, *lime + ferric* and *ferric only* appeared beneficial for the removal of turbidity. An average turbidity removal of 30% with *ferric + sludge* was observed. The addition of ferric to the lime sludge appeared to reactivate some of the sites on the lime sludge making these reactivated sites capable of coagulating with turbidity.

2. An average PO4-P removal of 35% was observed independent of depth of sampling in the *lime sludge + ferric* study. As stated previously; the

mechanism behind this removal may be that the acidity of the ferric chloride converted the carbonate in the lime sludge to bicarbonate thus releasing calcium into solution. The now available calcium could then combine with the phosphorous and drop out of solution. Of note is that the P concentration in the *ferric only* was 1 mg/L, rather than 2 mg/L in the other two experiments. It is unlikely this difference affected the removal percentage during this experiment.

3. There was no apparent removal of TOC in any of the studies. In the *sludge addition only* and the *sludge + ferric* addition it appeared organics were being added to the pond water with the lime sludge. In the case of the *sludge + ferric* addition study, the increase in organics may be explained by the acidity of the ferric chloride. This acidity may have broken up the lime floc which in turn caused the trapped organics in the floc to be released. As for the addition of organics in the *lime sludge only experiment*, some of the trapped organics in the recycled lime sludge may have been detected. The average TOC of the spent lime sludge was 250 mg/L. Analyzing for DOC would have perhaps been a better indicator of organics in solution. Enhanced coagulation (pH 11 and/or 30mg/L ferric chloride) may be required in order to remove organics. The pH of the spent lime sludge added to the water column averaged 9 units.
4. There was less than 20 % removal of green algae in all three studies. The algae counts at the time of this study were relatively low compared to algae counts that have been observed during prolonged periods of elevated temperatures and sun. At this time, we do not know if the relative abundance of green algae in pond water are a factor in removal effectiveness.
5. The average relative percent removal of cyanobacteria was <10% for the *sludge only* pilot, 21% for the *ferric and sludge* addition pilot and 50% for the *ferric only* addition pilot study. As mentioned previously, ferric chloride addition only may impair the water with unwanted color.

C. Conclusion:

The static column study indicated that the potential of lime sludge applied to ponds to the settle cyanobacteria, reduce turbidity or reduce organics is limited. Co-application with ferric chloride enhances P removal.

The issues not addressed in these studies, which may be addressed at a later time, include:

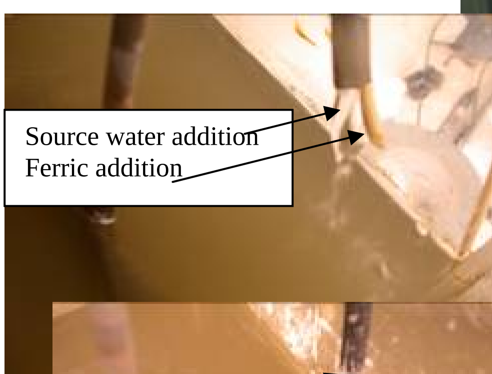
1. Utilizing lime sludge to form an impermeable layer to decrease leakage of a pond or basin.
2. Utilizing lime sludge as a means to increase buffering capacity.

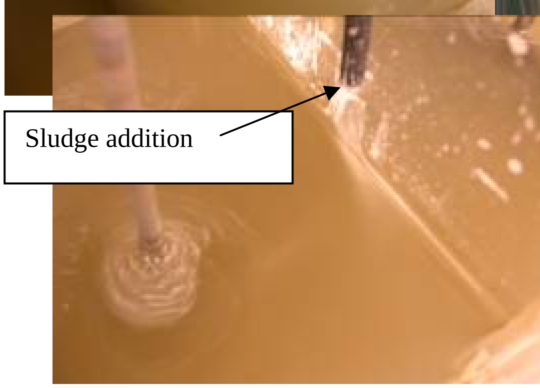
II. Study 2 - Continuous Flow:

This study was to determine the practicality of adding lime sludge to the pre-sedimentation basin for settling cyanobacteria, reducing turbidity, and finding alternative uses for residuals produced by DMWW.

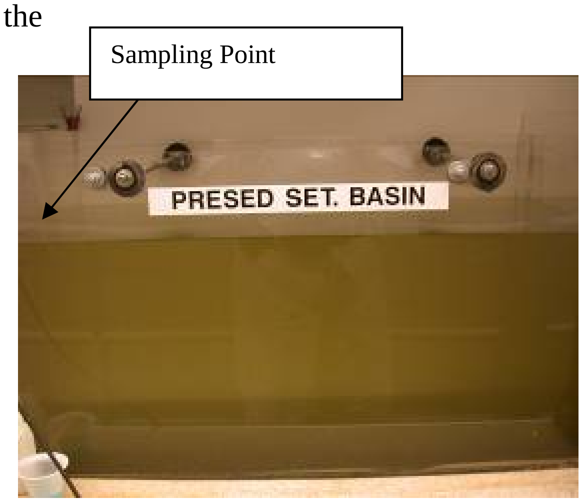
A. Method:

The pre-sedimentation portion of the DMWW water treatment pilot plant was used for this study. The pilot plant was modeled after the full scale plant (three flocculation rooms and a sedimentation basin). Each flocculation room was separated by a baffle designed to replicate the baffles in the full scale operation. Mixing was varied by altering paddle size and speed. When ferric chloride was fed, it was added directly the water entering the pilot basin. Source water flow and treatment chemical addition to the pilot simulated the full scale operation.





Full scale plant pre-sedimentation water, which included 10mg/L carbon, was run through the pilot treatment plant at a rate of 500 mL/min. At the time of this study, the source water to the full scale pre-sedimentation basin was Raccoon River Water. Ferric chloride was added at the beginning of the first flocculation room in the pilot at the rate of 10 mg/L. Varying concentrations of lime sludge (0.09, 0.24, 0.36, 0.6, 1.2, and 2.4g/L) were fed into the second flocculation room at flows representative to the concentrations. (The

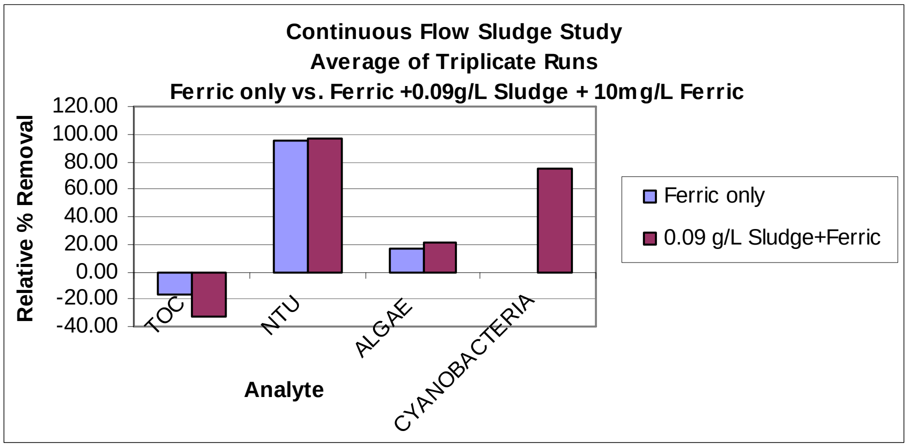


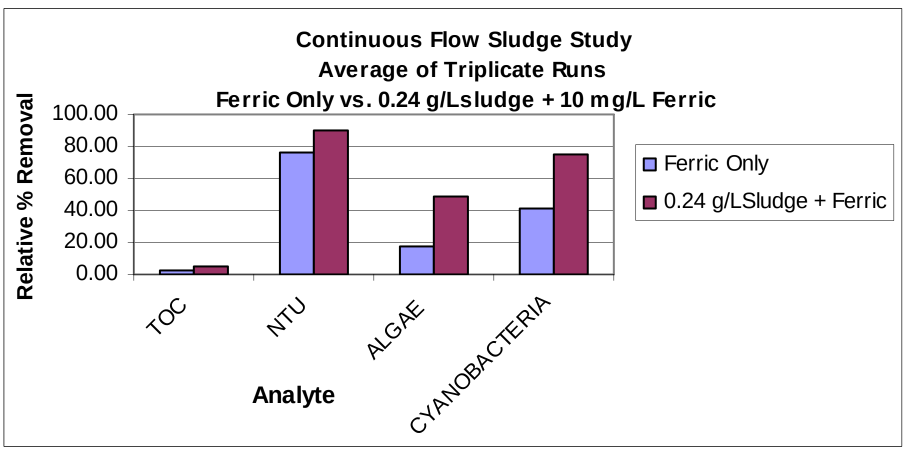
actual flows of the varying lime sludge concentrations into the pilot were: 0,1.5, 4, 6, 10, and 20 ml/min respectively). Samples were collected at the end of the pre-sedimentation settling basin and evaluated for cyanobacteria, turbidity and organic removal. Each study was performed in triplicate to check for reproducibility. (Both rain events and dry periods were included in the studies.)

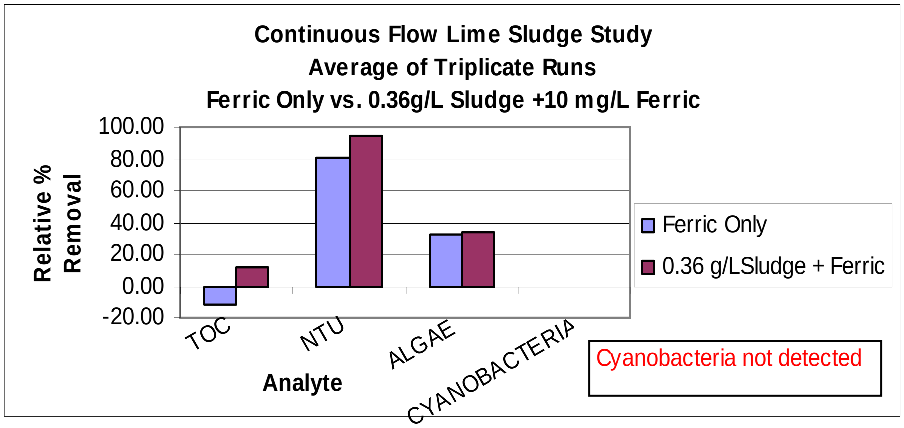
B. Results

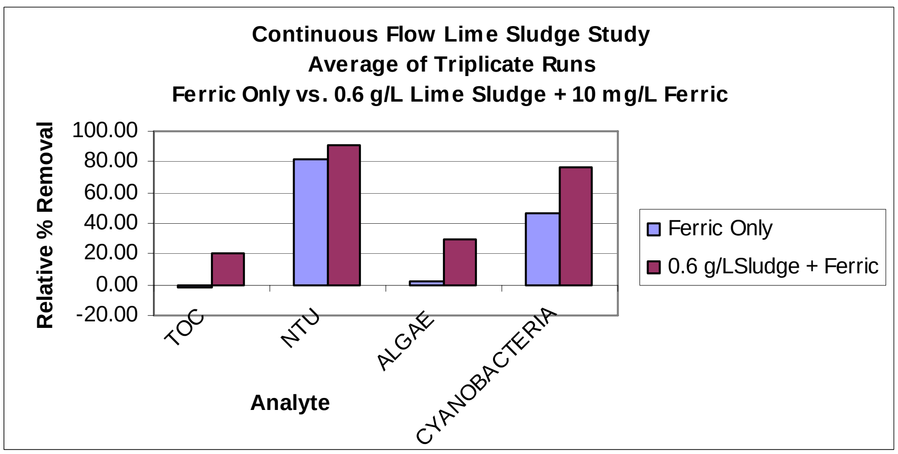
Results are presented as an average of the triplicate analysis of the varying amounts of lime sludge addition.

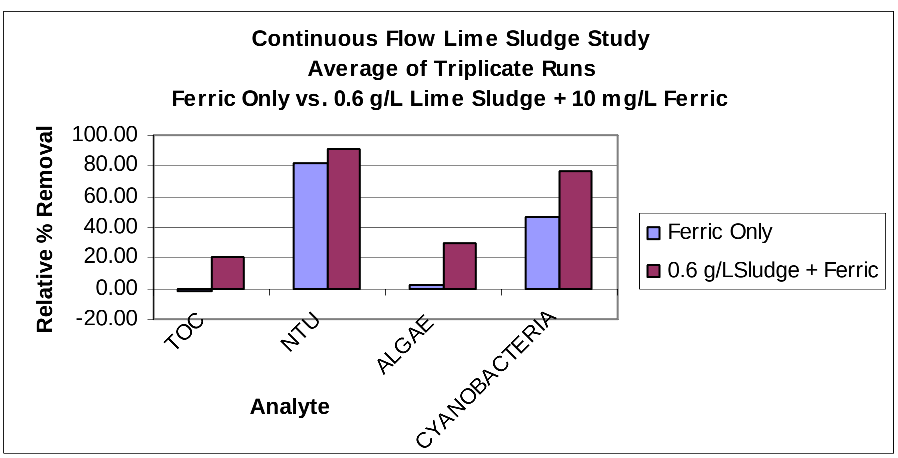
Results Graphs (Results tables located in Appendix D):

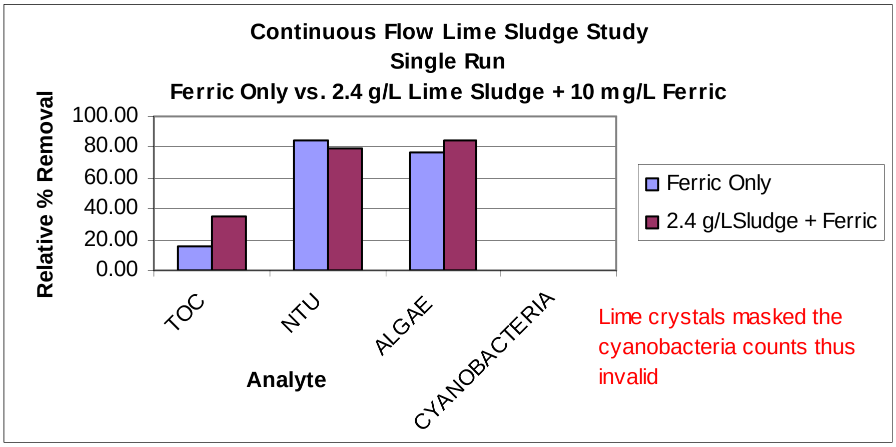





Continuous Flow Lime Sludge Study
Average of Triplicate Runs
Ferric Only vs. 0.36g/L Sludge +10 mg/L Ferric
Relative % Removal
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
TOC
NTU
ALGAE
CYANOBACTERIA
Analyte
Ferric Only
0.36 g/LSludge + Ferric
Cyanobacteria not detected


Continuous Flow Lime Sludge Study
Average of Triplicate Runs
Ferric Only vs. 0.6 g/L Lime Sludge + 10 mg/L Ferric
Relative % Removal
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
TOC
NTU
ALGAE
CYANOBACTERIA
Analyte
Ferric Only
0.6 g/LSludge + Ferric


Continuous Flow Lime Sludge Study
Average of Triplicate Runs
Ferric Only vs. 0.6 g/L Lime Sludge + 10 mg/L Ferric
Relative % Removal
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
TOC
NTU
ALGAE
CYANOBACTERIA
Analyte
Ferric Only
0.6 g/LSludge + Ferric



C. Results Summary

The addition of 0.09 g/L of sludge did not appear to enhance the removal of the turbidity, algae or TOC. Cyanobacteria increases in the pre-sedimentation basin with the addition of ferric chloride only appeared anomalous, and this data were not included. The addition of 0.09 g/L of lime sludge did not enhance TOC or turbidity removal enough for it to be utilized at DMWW.

The addition of 0.24 g/L of sludge did appear to enhance the removal of the cyanobacteria, algae and the total organic carbon. Turbidity removal remained unaffected by the lime sludge addition. This phenomenon has been noted in the full-scale plant on occasion when the recycle water accidentally overflowed into the pre-sedimentation basin. The addition of 0.24 g/L of lime sludge may be an effective dose at DMWW for enhanced turbidity, cyanobacteria, algae, and TOC removal.

The addition of 0.36 g/L of sludge did not enhance the removal of the algae, turbidity, or TOC as well as the smaller dose of 0.24 g/L. Cyanobacteria were not detected in the influent water at the time of these studies. TOC removal was negative in the pre-sedimentation basin with the addition of ferric only. A likely explanation is that the lime sludge itself is adding organics to the pre-sedimentation water. The lime sludge contained approximately 250 mg/L TOC.

The addition of 0.6 g/L of sludge did not appear to enhance the removal of the turbidity. Algae and cyanobacteria counts decreased with the addition of this dose and there appeared to be a slight reduction in TOC. The addition of 0.6 g/L of lime sludge may possibly enhance removal of the cyanobacteria and the algae enough for it to be utilized at DMWW in case of a bloom.

The addition of 1.2 g/L of sludge did not appear to enhance the removal of turbidity, cyanobacteria or TOC. Algae counts were reduced with the addition of lime sludge. Addition of this dose does not appear practical for DMWW.

The addition of 2.4 g/L of sludge did not appear to enhance the removal of turbidity, algae or cyanobacteria. TOC removal was noted but not considered significant. Cyanobacteria and algae were difficult to differentiate from lime crystals due to what appeared to be an overload of lime sludge. The addition of 2.4 g/L of lime sludge appeared to overload the system and thus would be considered an excessive dosage for use at DMWW.

D. Conclusion:

The continuous flow study indicated that a lime sludge addition of 0.24 g/L may be beneficial in achieving up to an additional 50% reduction of algae and cyanobacteria in the pre-sedimentation basin. This dosage would be recommended in the case of a cyanobacterium bloom which could potentially cause taste and odor concerns. However, any addition of lime sludge to the pre-sedimentation basin for the sole purpose of reducing residuals throughput in the lime sludge dewatering facility removed would likely increase TOC of the water treated in this fashion. This may be insignificant if the extra TOC is removed during softening.

Appendix A

Lime Sludge Addition Only Result Table

10/9/2006			Surface	3’	6’	9’
Elapsed Time	**0:00hr**					
	pH	8.65				
	NTU	33.2				
	PO4-P mg/L	1.31	* question mixing			
	TOC mg/L	6.74				
	Green Algae	18320				
	Cyanobacteria	17404				
Elapsed Time	**2 hr 56 min**		Surface	3’	6’	9’
	pH		8.65	8.7	8.7	8.69
	NTU		37.6	36.8	37.4	36.8
	PO4-P mg/L		1.68	1.5	1.41	1.45
	TOC mg/L		7.5	7.11	7.4	7.51
	Green Algae		17404	14656	16488	18320
	Cyanobacteria		17940	16330	13110	15640
Elapsed Time	**5 hr 56 min**		Surface	3’	6’	9’
	pH		8.5	8.68	8.68	8.7
	NTU		24.4	32.3	32.2	31.3
	PO4-P mg/L		1.47	1.54	1.5	1.5
	TOC mg/L		7.01	7.48	7.3	7.16
	Green Algae		16946	20152	13740	9160
	Cyanobacteria		16330	20240	7590	10120
Elapsed Time	**22 hr 56 min**		Surface	3’	6’	9’
	pH		8.42	8.46	8.51	8.5
	NTU		19.6	23.1	23.5	15.1
	PO4-P mg/L		1.5	1.41	1.43	1.35
	TOC mg/L		7.42	8.45	8.03	7.45
	Green Algae		11908	9160	19694	20152
	Cyanobacteria		15180	14490	38870	15640

Appendix B

Ferric + Lime Sludge Addition Results Table

10/11/2006			Surface	3’	6’	9’
Elapsed Time	**0:00 hr**					
	pH	8.41				
	NTU	28				
	PO4-P mg/L	1.98				
	TOC mg/L	5.32				
	Green Algae	18320				
	Cyanobacteria	13800				
Elapsed Time	**3 hrs 21 min**		Surface	3’	6’	9’
	pH		8	8.01	8.03	8.04
	NTU		18.8	31.2	24.5	26.4
	PO4-P mg/L		1.28	1.2	1.3	1.27
	TOC mg/L		6.83	6.59	6.61	6.59
	Green Algae		17862	11450	21068	19236
	Cyanobacteria		14030	9730	11960	8740
Elapsed Time	**6 hrs 09 min**		Surface	3’	6’	9’
	pH		8	8.01	8.01	8.03
	NTU		16.6	21.4	21.4	21.5
	PO4-P mg/L		1.23	1.28	1.29	1.19
	TOC mg/L		6.33	6.64	7.02	6.5
	Green Algae		22900	16946	19694	10992
	Cyanobacteria		10120	8510	17940	11040
Elapsed Time	**22 hrs 38min**		Surface	3'	6'	9'
	pH		7.93	7.94	7.94	7.95
	NTU		13.4	13.9	14	14.3
	PO4-P mg/L		1.29	1.33	1.32	1.27
	TOC mg/L		6.17	5.89	5.98	5.91
	Green Algae		16030	17862	12366	9618
	Cyanobacteria		11500	13570	7360	5750

Appendix C

Ferric Only Results Table

			Surface	3'	6'	9'
Elapsed Time	**0:00 hrs**					
	pH	8.75				
	NTU	43.8				
	PO4-P mg/L	0.75				
	TOC mg/L	6.2				
	Green Algae	16488				
	Cyanobacteria	16330				
Elapsed Time	**3hrs 30 min**		Surface	3'	6'	9'
	pH	8.75	7.93	8.15	8.16	8.17
	NTU	43.8	19.2	22.5	21.3	22.7
	PO4-P mg/L	0.75	0.52	0.63	0.64	0.67
	TOC mg/L	6.2	6.14	6.36	5.75	6.05
	Green Algae	16488	18320	16488	15114	14656
	Cyanobacteria	16330	12420	9200	9200	5060
Elapsed Time	**6 hrs 02 min**	Surface	3'	6'	9'	
	pH		8.3	8.18	8.19	8.19
	NTU		16.2	20.9	20.7	20.8
	PO4-P mg/L		0.64	0.64	0.64	0.64
	TOC mg/L		7.12	6.62	7.46	6.57
	Green Algae		22442	20610	16030	15572
	Cyanobacteria		5980	4600	13110	7360
Elapsed Time	**23 hrs 15 min**	Surface	3'	6'	9'	
	pH		8.07	8.04	8.04	8.01
	NTU		13.7	14.9	16.2	17.6
	PO4-P mg/L		0.57	0.58	0.59	0.53
	TOC mg/L		4.97	5.23	5.06	5.15
	Green Algae		16030	9618	16488	19694
	Cyanobacteria		8740	5980	9430	6900

Appendix D

CONTINUOUS FLOW PILOT Average of Triplicate Runs

R%R= RELATIVE % REMOVAL

FERRIC ONLY

FERRIC AMOUNT SLUDGE AMOUNT	**10 mg/L** **0**	R%R	**10 mg/L** **0**	R%R	**10 mg/L** **0**	R%R	**10 mg/L** **0**	R%R	**10 mg/L** **0**	R%R	**10 mg/L** **0**	R%R
	TOC	-16.40	**TOC**	2.90	**TOC**	-11.36	**TOC**	-1.46	**TOC**	-30.09	**TOC**	15.05
	NTU	95.83	**NTU**	76.65	**NTU**	81.03	**NTU**	81.69	**NTU**	80.45	**NTU**	83.97
	ALGAE	17.14	**ALGAE**	17.14	**ALGAE**	31.97	**ALGAE**	2.08	**ALGAE**	9.84	**ALGAE**	76.85
	CYANO.	0.00	**CYANO.**	40.94	**CYANO.**	NO CYANO.	**CYANO.**	47.06	**CYANO.**	-100	**CYANO.**	-200.00

SLUDGE+FERRIC

FERRIC AMOUNT SLUDGE AMOUNT	**10 mg/L** **0.09 g/L**	R%R	**10 mg/L** **0.24g/L**	R%R	**10 mg/L** **0.36g/L**	R%R	**10 mg/L** **0.6g/L**	R%R	**10 mg/L** **1.2g/L**	R%R	**10 mg/L** **2.4g/L**	R%R
	TOC	-32.12	**TOC**	5.10	**TOC**	12.28	**TOC**	20.47	**TOC**	-5.39	**TOC**	35.45
	NTU	97.22	**NTU**	90.08	**NTU**	94.62	**NTU**	91.23	**NTU**	86.23	**NTU**	78.77
	ALGAE	20.91	**ALGAE**	48.30	**ALGAE**	33.12	**ALGAE**	29.17	**ALGAE**	34.43	**ALGAE**	84.90
	CYANO.	75.00	**CYANO.**	74.60	**CYANO.**	NO CYANO.	**CYANO.**	76.47	**CYANO.**	-100	**CYANO.**	could not count too many crystals

RELATIVE % REMOVAL WITH SLUDGE ADDITION TO FERRIC

FERRIC AMOUNT SLUDGE AMOUNT	**10 mg/L** **0.09 g/L**	R%R	**10 mg/L** **0.24g/L**	R%R	**10 mg/L** **0.36g/L**	R%R	**10 mg/L** **0.6g/L**	R%R	**10 mg/L** **1.2g/L**	R%R	**10 mg/L** **2.4g/L**	R%R
	TOC	-48.94		43.15		192.51		107.13		458.09		57.56
	NTU	1.43		14.91		14.36		10.46		6.70		-6.60
	ALGAE	18.02		64.52		3.48		92.87		71.42		9.49
	CYANO.	75.00		45.12		NO CYANO.		38.46		0		#VALUE!