APPENDIX A

Phosphorus Removal by Minnesota Municipal Wastewater Treatment Facilities

Introduction:

This appendix presents a comparison of total phosphorus processed by Minnesota municipal wastewater treatment facilities (WWTFs) for the 2005 calendar year. Site specific differences between WWTFs, including influent characteristics, unit sizing, facility configurations and remaining hydraulic and organic treatment capacity are such that each WWTF's situation is unique and it is not possible to generalize about any individual facility's treatment capabilities. The average, minimum and maximum total phosphorus influent, effluent and percent removal reported here are intended to provide an overview of the range of performance reported by municipal wastewater treatment facilities in 2005. These comparisons may be useful for wastewater treatment facility operators seeking to benchmark the performance of their systems with respect to other similar types of WWTFs.

Data Collection:

The following is a comparison of total phosphorus influent, effluent and percent removal performance of 284 municipal wastewater treatment facilities. Data reported here represent annual averages calculated from monthly average data reported to the Minnesota Pollution Control Agency (MPCA). Only WWTFs that reported twelve months worth of monthly average data are included in this analysis.

Percent removal data has been calculated based on reported influent and effluent concentrations. This is particularly significant for controlled discharge stabilization pond WWTFs because the volumes of water received and discharged during one calendar year can vary substantially. A load based percent removal calculation for these types of facilities would be significantly biased by any difference between influent and influent flow volumes during the calendar year.

Continuously discharging WWTFs (mechanical facilities and aerated ponds) have been listed separately from controlled discharge WWTFs (stabilization ponds). WWTFs that include phosphorus removal processes (biological and/or chemical) were listed separately from WWTFs that do not incorporate specific phosphorus treatment processes.

Facilities providing phosphorus treatment are separated into biological and chemical treatment categories. No attempt has been made to determine whether combined biological/chemical phosphorus removal is being provided although it is likely that most biological phosphorus removal systems have the capability to provide supplemental chemical treatment.

WWTF type has been established on the basis of the MPCA's records of the major secondary treatment unit (activated sludge, trickling filter, etc.) in place for each WWTF. These data were derived from an incomplete MPCA database which may have resulted in the misclassification of some types of WWTFs.

Summary by WWTF Category:

Tables 1A through 1E report average Total Phosphorus values reported for the 2005 calendar year. These are the arithmetic mean, minimum and maximum annual average values calculated for the entire group of facilities and in each category. WWTFs are listed by continuously discharging and controlled discharge categories, both with and without phosphorus treatment. The average value represents the arithmetic mean. Unusually high or low values contained in the data set will tend to skew the arithmetic mean up or down. The minimum and maximum values show the range of the data set.

Influent concentrations for all 284 WWTFs average 5.86 mg/L. Projected to an average annual per capita influent phosphorus loading value, assuming a discharge rate of 100 gallons/capita/day, it is equivalent to 0.81 Kg/capita/year. This correlates well with the MPCA's predicted annual per captia phosphorus load of 0.8 Kg/capita/year. Any specific commercial, industrial or institutional phosphorus contribution to these WWTFs has not been take into account.

Table 1A: All 284 WWTFs	Influent Concentration	Effluent Concentration	Percent Removal
Average	5.86 mg/L	2.23 mg/L	61%
Minimum	1.17 mg/L	0.08 mg/L [1]	-17%
Maximum	25.05 mg/L	15.38 mg/L	99%

Table 1B: 53 Continuous Discharge With Phosphorus Removal	Influent Concentration	Effluent Concentration	Percent Removal
Average	6.28 mg/L	0.75 mg/L	88%
Minimum	2.77 mg/L	0.13 mg/L	45%
Maximum	14.99 mg/L	7.17 mg/L	98%

Table 1C: 12 Controlled Discharge With Phosphorus Removal	Influent Concentration	Effluent Concentration	Percent Removal
Average	5.18 mg/L	0.68 mg/L	85 %
Minimum	1.23 mg/L	0.08 mg/L [1]	71%
Maximum	10.88 mg/L	1.75 mg/L	99%

Table 1D: 99 Continuous Discharge Without Phosphorus Removal	Influent Concentration	Effluent Concentration	Percent Removal
Average	6.36 mg/L	3.68 mg/L	42%
Minimum	2.63 mg/L	0.95 mg/L	0%
Maximum	25.05 mg/L	15.38 mg/L	77%

Table 1E: 120 Controlled Discharge Without Phosphorus Removal	Influent Concentration	Effluent Concentration	Percent Removal
Average	5.34 mg/L	1.84 mg/L	63%
Minimum	1.17 mg/L	0.17 mg/L	-17%
Maximum	14.31 mg/L	5.93 mg/L	96%

[1] The minimum value of 0.08 mg/L is well below the minimum expected range of effluent concentrations .

Summary by WWTF Type:

The following figures and tables report average, minimum and maximum influent and effluent concentrations and percent removal by WWTF type. All continuously discharging WWTFs with phosphorus removal have been listed as either biological or chemical phosphorus removal facilities regardless of any other type of treatment provided. All controlled discharge WWTFs with phosphorus removal provide chemical treatment.

Continuously discharging WWTFs without phosphorus treatment have been separated based on the major secondary treatment technology in use at the facility. Trickling filter facilities that also operate rotating biological contactors (RBCs) or activated sludge units have been listed separately.

A few general observations:

For all WWTF types higher influent concentrations seem to be associated with higher effluent concentrations and lower removal efficiencies. Although the degree to which this occurs varies by facility type, the trend highlights the value of source reduction work.

Of the 65 WWTFs that provide phosphorus removal, only 6 of the chemical removal facilities reported annual average effluent values below 0.3 mg/L. This is significant because 0.3 mg/L is currently the lowest phosphorus effluent limitation currently in effect in the state (Ely and Bemidji WWTFs).

Controlled discharge stabilization ponds have excellent phosphorus removal capabilities. 19% of the stabilization ponds without phosphorus treatment had annual average effluent concentrations of less than 1 mg/L and 62% had effluent concentrations of less than 2 mg/L.

Of the various activated sludge configurations, extended air facilities showed relatively high and stable removal efficiencies throughout a range of influent concentrations. Percent removal averaged 53% and ranged from 44% to 62%.

The various configurations of trickling filter facilities showed the lowest removal efficiencies of all types of WWTFs reviewed. It is interesting to note that the group of trickling filter/RBC facilities combined the lowest removal efficiencies (averaging 28%) with some of the highest influent concentrations (averaging 8.58 mg/L). As a group these facilities produced some of the worst effluent quality averaging 6.10 mg/L total phosphorus.

Figure 1A:

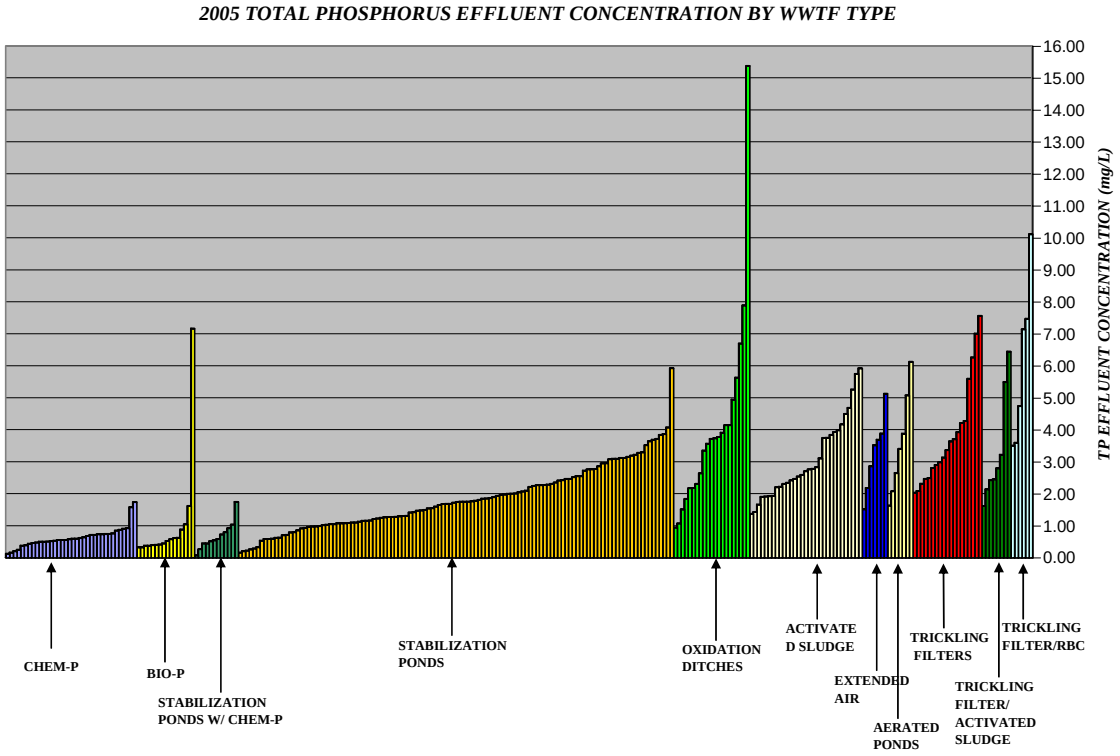


Figure 1B:

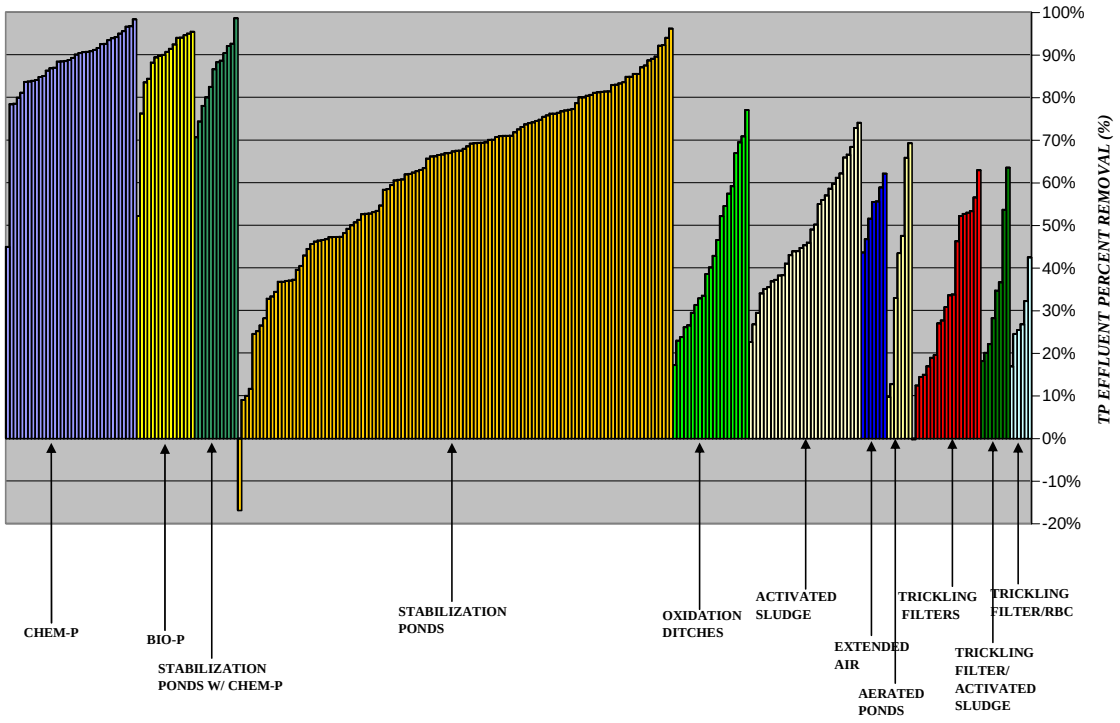


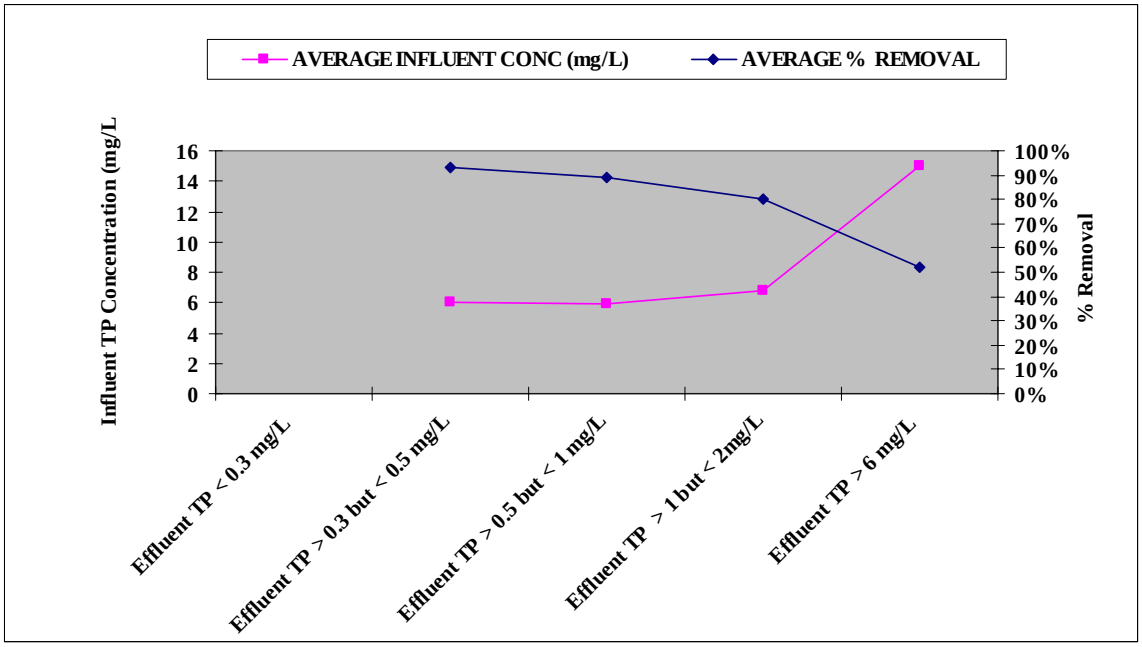
Table 2A: CONTINUOUS DISCHARGE BIOLOGICAL PHOSPHORUS REMOVAL

	Influent Concentration	Effluent Concentration	Percent Removal
Average	6.66 mg/L	1.01 mg/L	88%
Minimum	3.22 mg/L	0.33 mg/L	52%
Maximum	14.99 mg/L	7.17mg/L	95%

Table 2B: CONTINUOUS DISCHARGE BIOLOGICAL PHOSPHORUS REMOVAL

	NUMBER OF WWTPs	% OF TOTAL	AVERAGE INFLUENT CONC. (mg/L)	AVERAGE % REMOVAL
Effluent TP < 0.3 mg/L	0	0%		
Effluent TP 0.3 to 0.5 mg/L	8	50%	6.06	93%
Effluent TP 0.5 to 1.0 mg/L	5	31%	5.89	89%
Effluent TP 1.0 to 2.0 mg/L	2	13%	6.79	80%
Effluent TP > 6 mg/L	1	6%	14.99	52%
Total	16			
Average			6.66	88%

Figure 2: CONTINUOUS DISCHARGE BIOLOGICAL PHOSPHORUS REMOVAL



Observations:

- ⊕ All Bio-P WWTFs exceeded 0.3 mg/L effluent TP annual average.
- ⊕ 50% report effluent TP annual averages of less than 0.5 mg/L.
- ⊕ 81% report effluent TP annual averages of less than 1.0 mg/L.
- ⊕ Percent removal range from 52% to 95%.
- ⊕ The facility reporting an annual average total phosphorus concentration of 7.17 mg/L has experienced significant operational difficulties in 2005.

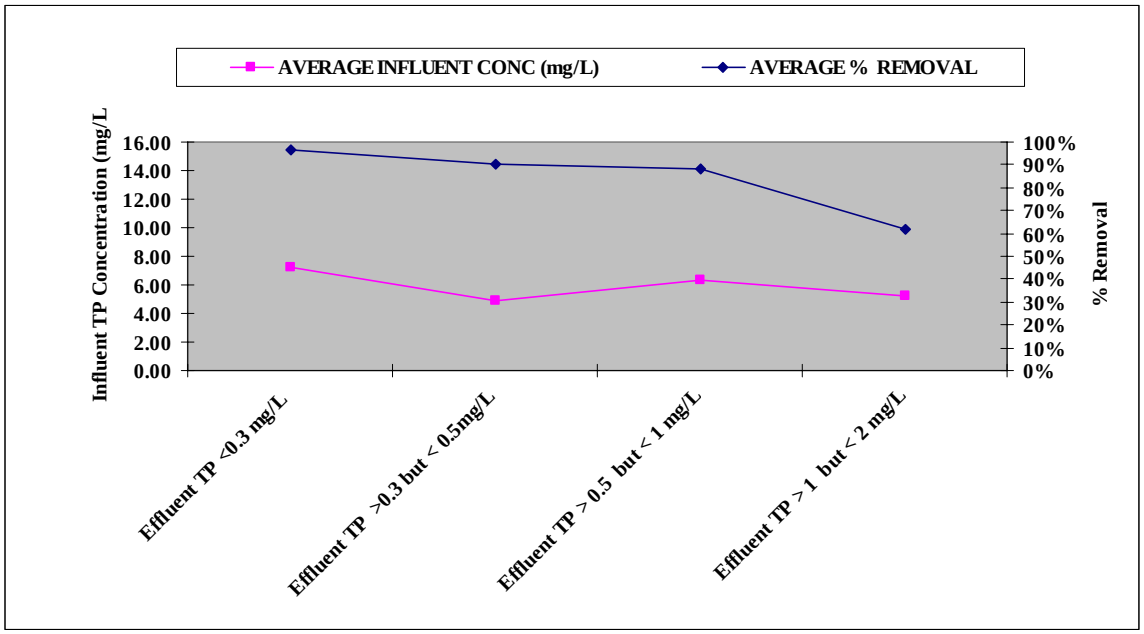
Table 3A: CONTINUOUS DISCHARGE CHEMICAL PHOSPHORUS REMOVAL

	Influent Concentration	Effluent Concentration	Percent Removal
Average	6.12 mg/L	0.63 mg/L	88%
Minimum	2.77 mg/L	0.13 mg/L	45%
Maximum	12.85 mg/L	1.75 mg/L	98%

Table 3B: CONTINUOUS DISCHARGE CHEMICAL PHOSPHORUS REMOVAL

	NO. OF WWTPs	% OF TOTAL	AVERAGE INFLUENT CONC. (mg/L)	AVERAGE PERCENT REMOVAL
Effluent TP < 0.3 mg/L	4	11%	7.19	97%
Effluent TP 0.3 to 0.5 mg/L	6	16%	4.88	90%
Effluent TP 0.5 to 1.0 mg/L	25	68%	6.31	88%
Effluent TP 1.0 mg/L to 2.0 mg/L	2	5%	5.27	62%
Total	37			
Average			6.12	88%

Figure 3: CONTINUOUS DISCHARGE CHEMICAL PHOSPHORUS REMOVAL



Observations:

- ⊕ 11% report effluent TP annual averages of less than 0.3 mg/L.
- ⊕ 27% report effluent TP annual averages of less than 0.5 mg/L.
- ⊕ 95% report effluent TP annual averages of less than 1.0 mg/L.
- ⊕ Percent removal range from 45% to 98%.
- ⊕ Very low effluent concentrations can be achieved through chemical addition.

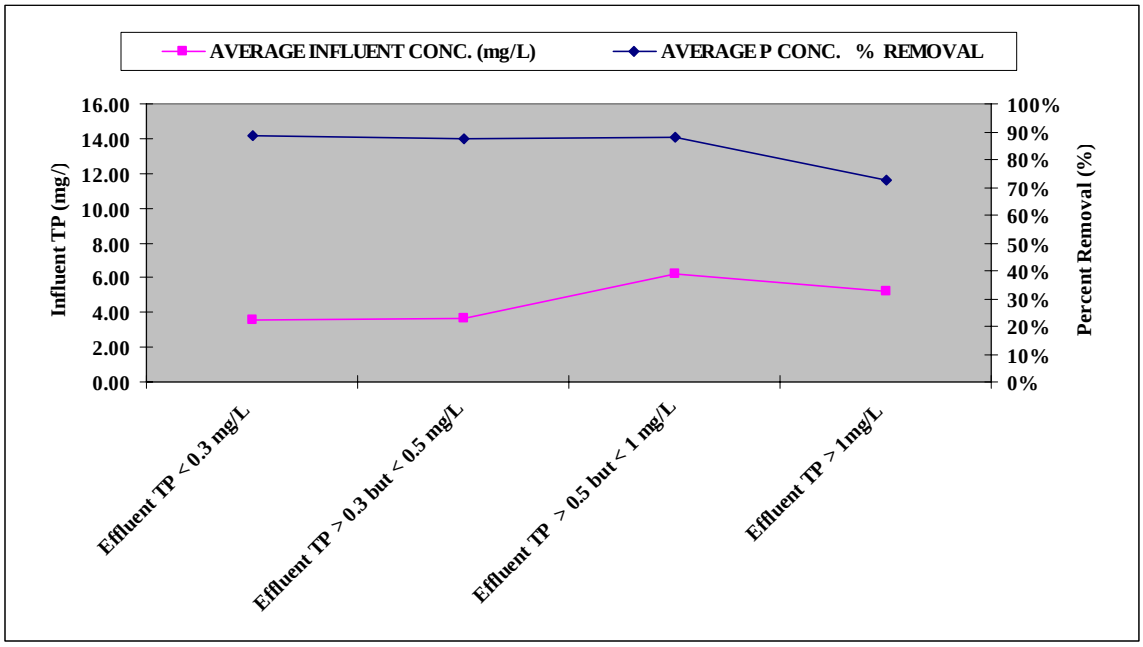
Table 4A: CONTROLLED DISCHARGE CHEMICAL PHOSPHORUS REMOVAL

	Influent Concentration	Effluent Concentration	Percent Removal
Average	5.18 mg/L	0.68 mg/L	85%
Minimum	1.23 mg/L	0.08 mg/L	71%
Maximum	10.88 mg/L	1.75 mg/L	99%

Table 4B: CONTROLLED DISCHARGE CHEMICAL PHOSPHORUS REMOVAL

	NO. OF WWTPs	% OF TOTAL	AVERAGE INFLUENT CONC. (mg/L)	AVERAGE P CONC. % REMOVAL
Effluent TP < 0.3 mg/L	2	17%	3.54	88%
Effluent TP 0.3 to 0.5 mg/L	2	17%	3.67	88%
Effluent TP 0.5 to 1.0 mg/L	6	50%	6.22	88%
Effluent TP > 1.0 mg/L	2	17%	5.19	72%
Total	12			
Average			5.18	85%

Figure 4: CONTROLLED DISCHARGE CHEMICAL PHOSPHORUS REMOVAL



Observations:

- ⊕ 17% report effluent TP annual averages of less than 0.3 mg/L.
- ⊕ 34% report effluent TP annual averages of less than 0.5 mg/L.
- ⊕ 84% report effluent TP annual averages of less than 1.0 mg/L.
- ⊕ Percent removal range from 45% to 98%.
- ⊕ The combination of relatively low influent concentrations, long detention times and chemical addition can achieve extremely good phosphorus removal.

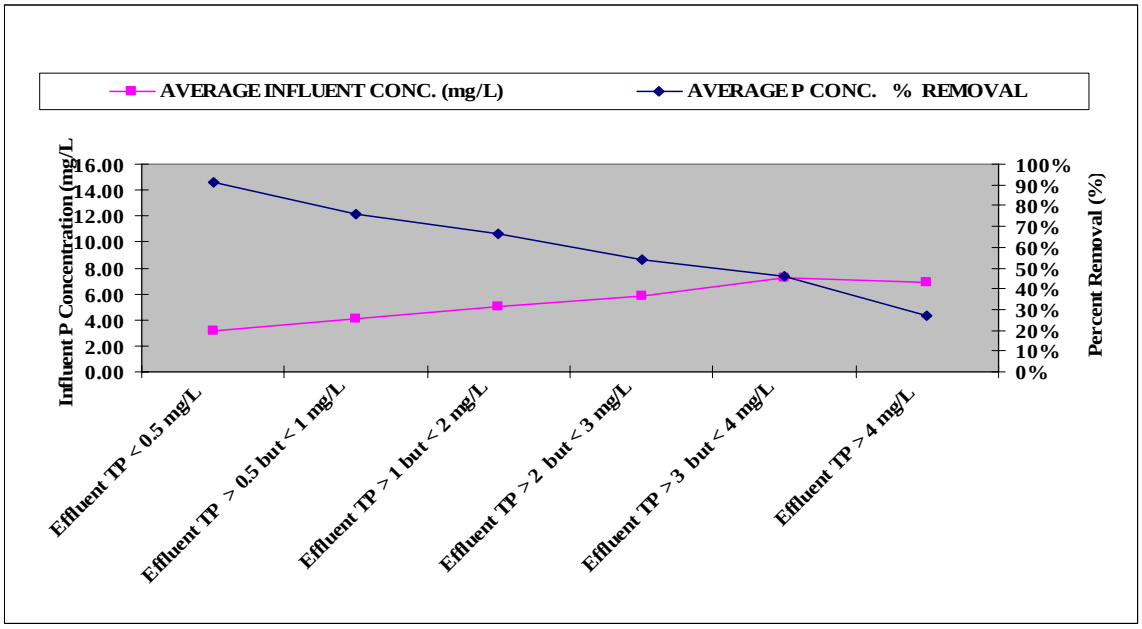
Table 5A: CONTROLLED DISCHARGE NO PHOSPHORUS TREATMENT

	Influent Concentration	Effluent Concentration	Percent Removal
Average	5.34 mg/L	1.84 mg/L	63%
Minimum	1.17 mg/L	0.17 mg/L	-17%
Maximum	14.31 mg/L	5.93 mg/L	96%

Table 5B: CONTROLLED DISCHARGE NO PHOSPHORUS TREATMENT

	NUMBER OF WWTPs	% OF TOTAL	AVERAGE INFLUENT CONC. (mg/L)	AVERAGE P CONC. % REMOVAL
Effluent TP < 0.5 mg/L	6	5%	3.18	91%
Effluent TP 0.5 to 1.0 mg/L	17	14%	4.08	76%
Effluent TP 1.0 to 2.0 mg/L	51	43%	5.05	66%
Effluent TP 2.0 to 3.0 mg/L	28	23%	5.87	54%
Effluent TP 3.0 to 4.0 mg/L	16	13%	7.27	46%
Effluent TP > 4.0 mg/L	2	2%	6.93	27%
Total	120			
Average			5.34	62.62%

Figure 5: CONTROLLED DISCHARGE NO PHOSPHORUS TREATMENT



Observations:

- ⊕ 5% report effluent TP annual averages of less than 0.5 mg/L.
- ⊕ 19% report effluent TP annual averages of less than 1.0 mg/L.
- ⊕ 62% report effluent TP annual averages of less than 2.0 mg/L.
- ⊕ Percent removal range from -17% to 96%.
- ⊕ Overall stabilization ponds provide excellent treatment TP treatment.
- ⊕ The facility reporting an annual average -17% removal rate experienced construction related operational problems in 2005.

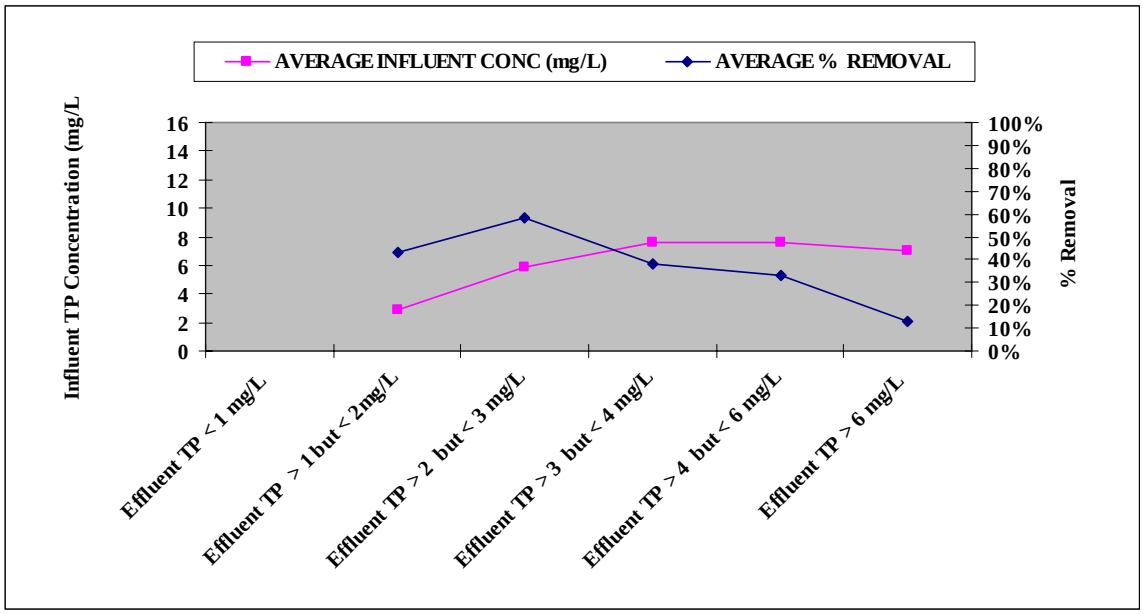
Table 6A: AERATED PONDS

	Influent Concentration	Effluent Concentration	Percent Removal
Average	6.35 mg/L	3.55 mg/L	40%
Minimum	2.90 mg/L	1.64 mg/L	10%
Maximum	11.37 mg/L	6.13 mg/L	69%

Table 6A: AERATED PONDS

	NO. OF WWTPs	% OF TOTAL	AVERAGE INFLUENT CONC. (mg/L)	AVERAGE PERCENT REMOVAL
Effluent TP < 1 mg/L	0	0%		
Effluent TP 1.0 to 2.0 mg/L	1	14%	2.90	43%
Effluent TP 2.0 to 3.0 mg/L	2	29%	5.92	58%
Effluent TP 3.0 to 4.0 mg/L	2	29%	7.58	38%
Effluent TP 4.0 to 6.0 mg/L	1	14%	7.58	33%
Effluent TP > 6.0 mg/L	1	14%	7.02	13%
Total	7			
Average			6.36	40%

Figure 6: AERATED PONDS



Observations:

- All exceeded effluent TP annual averages of 1.0 mg/L.
- 14% report effluent TP annual averages of less than 2.0 mg/L.
- 43% report effluent TP annual averages of less than 3.0 mg/L.
- 72% report effluent TP annual averages of less than 4.0 mg/L.
- Percent removal range from 10% to 69%.

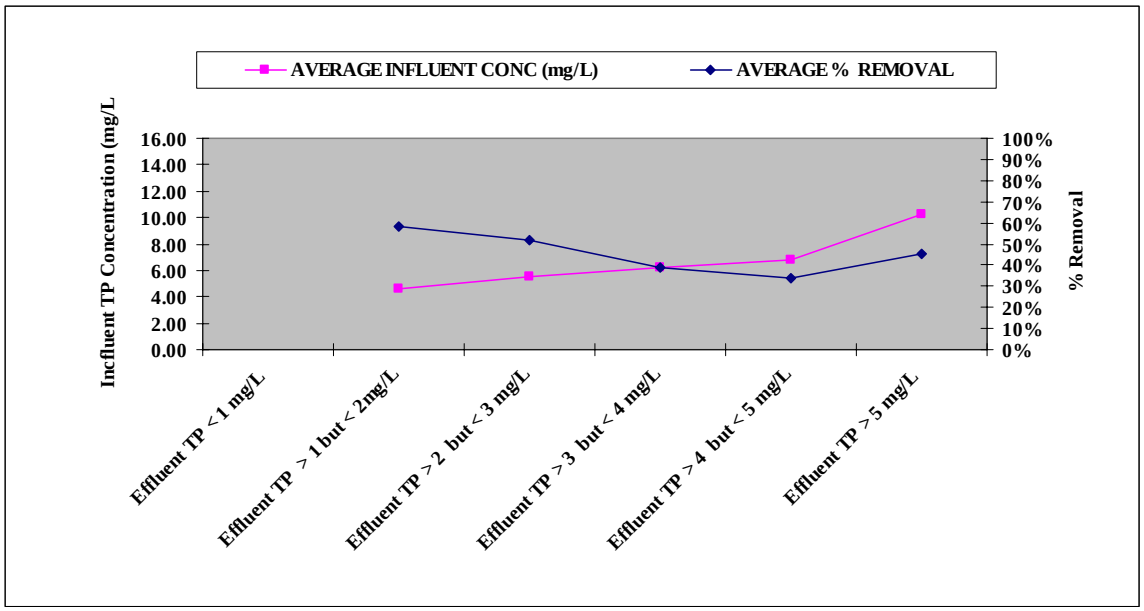
Table 7A: ACTIVATED SLUDGE

	Influent Concentration	Effluent Concentration	Percent Removal
Average	5.99 mg/L	3.07 mg/L	48%
Minimum	2.63 mg/L	1.38 mg/L	23%
Maximum	10.53 mg/L	5.93mg/L	74%

Table 7B: ACTIVATED SLUDGE

	NO. OF WWTPs	% OF TOTAL	AVERAGE INFLUENT CONC. (mg/L)	AVERAGE PERCENT REMOVAL
Effluent TP < 1 mg/L	0	0%		
Effluent TP 1.0 to 2.0 mg/L	7	23%	4.55	58%
Effluent TP 2.0 to 3.0 mg/L	12	39%	5.48	52%
Effluent TP 3.0 to 4.0 mg/L	6	19%	6.18	39%
Effluent TP 4.0 to 5.0 mg/L	3	10%	6.75	34%
Effluent TP > 5.0 mg/L	3	10%	10.30	45%
Total	31			
Average			5.99	48%

Figure 7: ACTIVATED SLUDGE



Observations:

- ⊕ All exceeded effluent TP annual averages of 1.0 mg/L.
- ⊕ 23% report effluent TP annual averages of less than 2.0 mg/L.
- ⊕ 62% report effluent TP annual averages of less than 3.0 mg/L.
- ⊕ 81% report effluent TP annual averages of less than 4.0 mg/L.
- ⊕ Percent removal range from 23% to 74%.

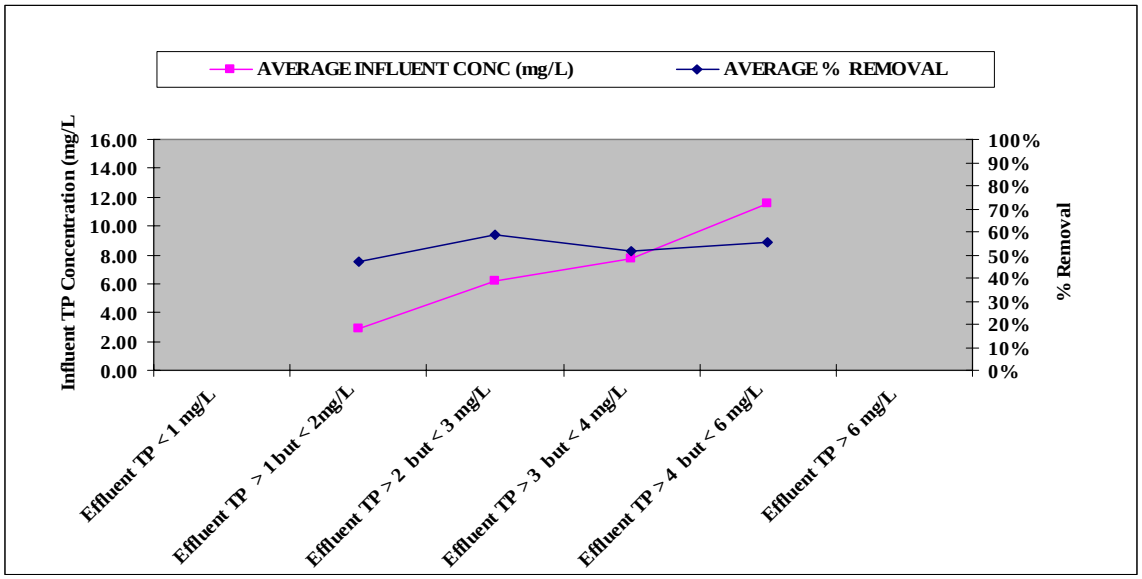
Table 8A: EXTENDED AIR

	Influent Concentration	Effluent Concentration	Percent Removal
Average	7.18 mg/L	3.26 mg/L	53 %
Minimum	2.86 mg/L	1.52 mg/L	44%
Maximum	11.57 mg/L	5.13 mg/L	62 %

Table 8B: EXTENDED AIR

	NO. OF WWTPs	% OF TOTAL	AVERAGE INFLUENT CONC. (mg/L)	AVERAGE PERCENT REMOVAL
Effluent TP < 1 mg/L	0			
Effluent TP 1.0 to 2.0 mg/L	1	14%	2.86	47%
Effluent TP 2.0 to 3.0 mg/L	2	29%	6.24	59%
Effluent TP 3.0 to 4.0 mg/L	3	43%	7.78	51%
Effluent TP 4.0 to 6.0 mg/L	1	14%	11.57	56%
Effluent TP > 6.0 mg/L	0			
Total	7			
Average			7.18	53%

Figure 8: EXTENDED AIR



Observations:

- ⊕ All exceeded effluent TP annual averages of 1.0 mg/L.
- ⊕ 14% report effluent TP annual averages of less than 2.0 mg/L.
- ⊕ 43% report effluent TP annual averages of less than 3.0 mg/L.
- ⊕ 86% report effluent TP annual averages of less than 4.0 mg/L.
- ⊕ Percent removal range from 44% to 62%.
- ⊕ Robust TP removal throughout range of influent concentrations.

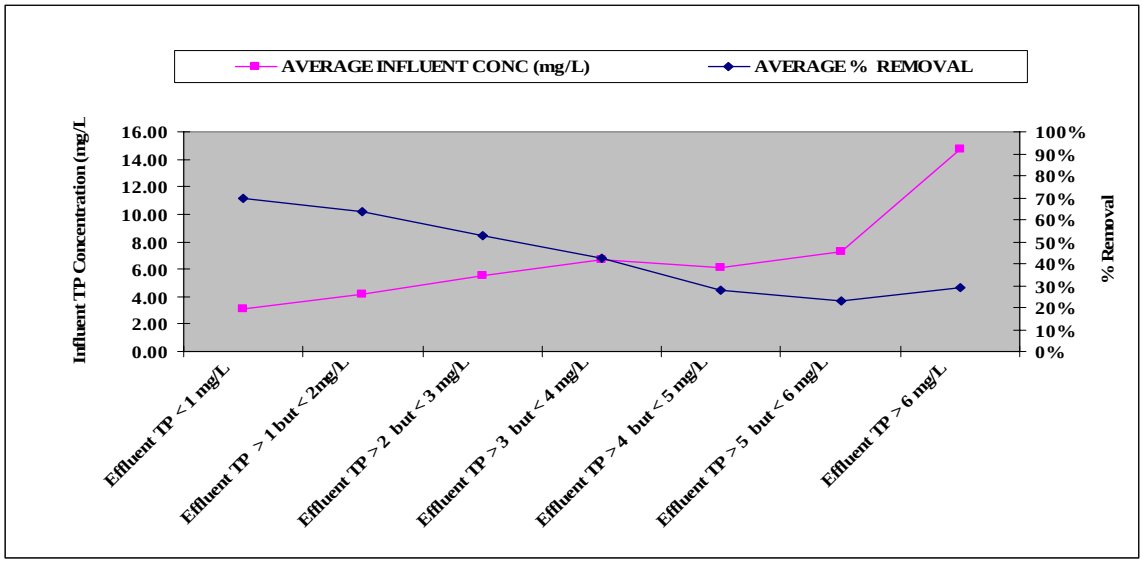
Table 9A: OXIDATION DITCHES

	Influent Concentration	Effluent Concentration	Percent Removal
Average	7.03 mg/L	4.08 mg/L	44%
Minimum	3.11 mg/L	0.95 mg/L	17%
Maximum	25.05 mg/L	15.38 mg/L	77%

Table 9B: OXIDATION DITCHES

	NO. OF WWTPs	% OF TOTAL	AVERAGE INFLUENT CONC. (mg/L)	AVERAGE PERCENT REMOVAL
Effluent TP < 1 mg/L	1	5%	3.11	69%
Effluent TP 1.0 to 2.0 mg/L	3	14%	4.16	64%
Effluent TP 2.0 to 3.0 mg/L	4	19%	5.49	53%
Effluent TP 3.0 to 4.0 mg/L	6	29%	6.66	42%
Effluent TP 4.0 to 5.0 mg/L	3	14%	6.12	28%
Effluent TP 5.0 to 6.0 mg/L	1	5%	7.31	23%
Effluent TP > 6.0 mg/L	3	14%	14.78	29%
Total	21			
Average			7.03	44%

Figure 9: OXIDATION DITCHES



Observations:

- ⊕ 5% report effluent TP annual averages of less than 1.0 mg/L.
- ⊕ 19% report effluent TP annual averages of less than 2.0 mg/L.
- ⊕ 38% report effluent TP annual averages of less than 3.0 mg/L.
- ⊕ 67% report effluent TP annual averages of less than 3.0 mg/L.
- ⊕ Percent removal range from 17% to 77%.

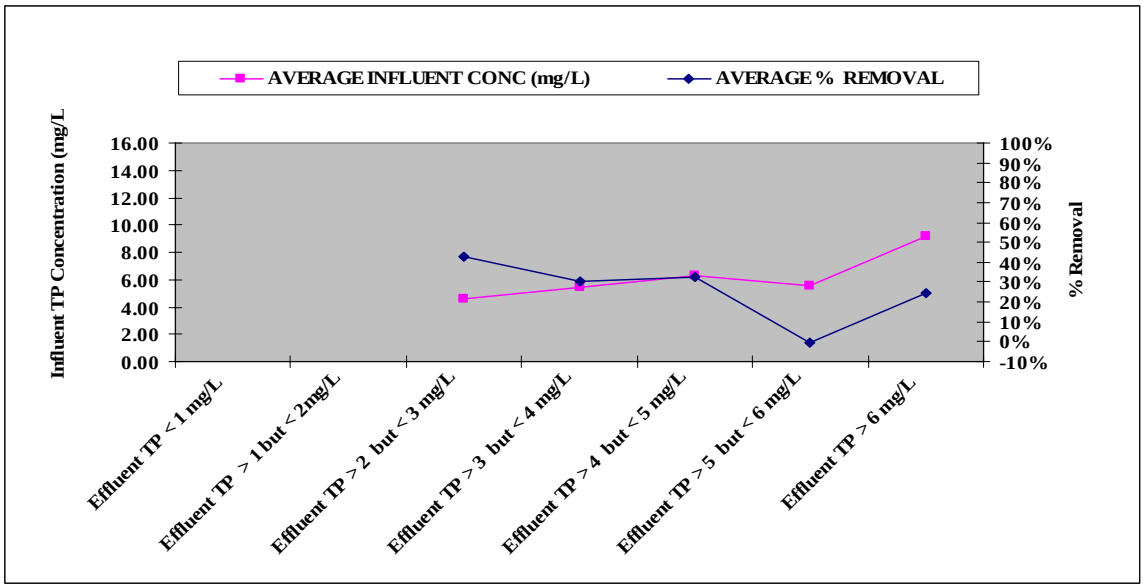
Table 10A: TRICKLING FILTERS

	Influent Concentration	Effluent Concentration	Percent Removal
Average	5.78 mg/L	3.83 mg/L	33%
Minimum	3.30 mg/L	2.04 mg/L	0%
Maximum	10.58 mg/L	7.56 mg/L	63%

Table 10B: TRICKLING FILTERS

	NO. OF WWTPs	% OF TOTAL	AVERAGE INFLUENT CONC. (mg/L)	AVERAGE PERCENT REMOVAL
Effluent TP < 1 mg/L	0			
Effluent TP 1.0 to 2.0 mg/L	0			
Effluent TP 2.0 to 3.0 mg/L	8	42%	4.61	43%
Effluent TP 3.0 to 4.0 mg/L	5	26%	5.47	30%
Effluent TP 4.0 to 5.0 mg/L	2	11%	6.28	32%
Effluent TP 5.0 to 6.0 mg/L	1	5%	5.58	0%
Effluent TP > 6 mg/L	3	16%	9.16	33%
Total	19			
Average			5.78	33%

Figure 10: TRICKLING FILTERS



Observations:

- ⊕ All exceeded effluent TP annual averages of 2.0 mg/L.
- ⊕ 42% report effluent TP annual averages of less than 3.0 mg/L.
- ⊕ 68% report effluent TP annual averages of less than 4.0 mg/L.
- ⊕ Percent removal range from 0% to 63%.
- ⊕ Extreme variability in removal efficiency

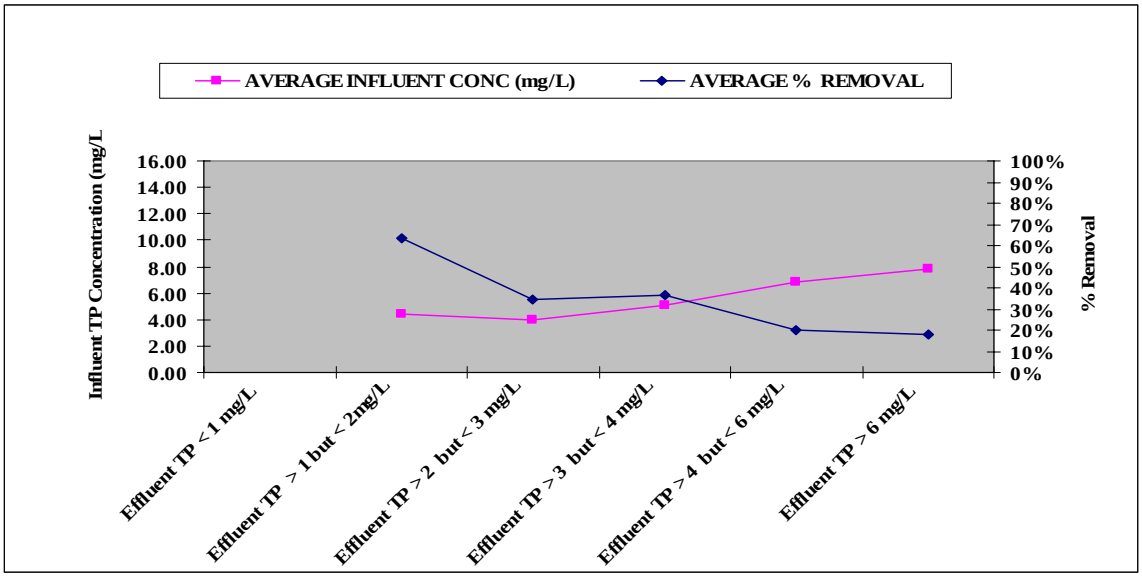
Table 11A: TRICKLING FILTER/ACTIVATED SLUDGE

	Influent Concentration	Effluent Concentration	Percent Removal
Average	5.00 mg/L	3.33 mg/L	35%
Minimum	2.99 mg/L	1.62 mg/L	18%
Maximum	7.88 mg/L	6.45 mg/L	64%

Table 11B: TRICKLING FILTER/ACTIVATED SLUDGE

	NO. OF WWTPs	% OF TOTAL	AVERAGE INFLUENT CONC. (mg/L)	AVERAGE PERCENT REMOVAL
Effluent TP < 1 mg/L	0			
Effluent TP 1.0 to 2.0 mg/L	1	13%	4.45	64%
Effluent TP 2.0 to 3.0 mg/L	4	50%	3.92	35%
Effluent TP 3.0 to 4.0 mg/L	1	13%	5.09	37%
Effluent TP 4.0 to 6.0 mg/L	1	13%	6.88	20%
Effluent TP > 6.0 mg/L	1	13%	7.88	18%
Total	8			
Average			5.00	35%

Figure 11: TRICKLING FILTER/ACTIVATED SLUDGE



Observations:

- ⊕ All exceeded effluent TP annual averages of 1.0 mg/L.
- ⊕ 13% report effluent TP annual averages of less than 2.0 mg/L.
- ⊕ 63% report effluent TP annual averages of less than 3.0 mg/L.
- ⊕ 76% report effluent TP annual averages of less than 4.0 mg/L.
- ⊕ Percent removal range from 18% to 64%.
- ⊕ Extreme variability in removal efficiency.

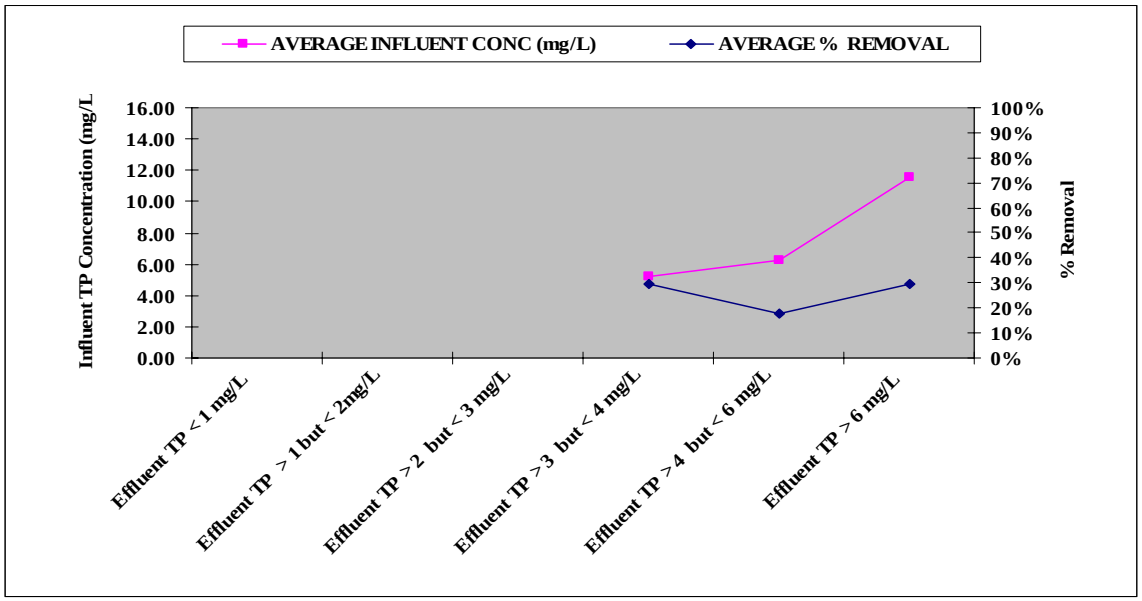
Table 12A: TRICKLING FILTER/RBC

	Influent Concentration	Effluent Concentration	Percent Removal
Average	8.58 mg/L	6.10 mg/L	28%
Minimum	4.23 mg/L	3.51 mg/L	17%
Maximum	14.93 mg/L	10.12 mg/L	43%

Table 12B: TRICKLING FILTER/RBC

	NO. OF WWTPs	% OF TOTAL	AVERAGE INFLUENT CONC. (mg/L)	AVERAGE PERCENT REMOVAL
Effluent TP < 1 mg/L	0			
Effluent TP 1.0 to 2.0 mg/L	0			
Effluent TP 2.0 to 3.0 mg/L	0			
Effluent TP 3.0 to 4.0 mg/L	2	33%	5.24	30%
Effluent TP 4.0 to 6.0 mg/L	1	17%	6.28	18%
Effluent TP > 6 mg/L	3	50%	11.57	30%
Total	6			
Average			8.58	28%

Figure 12: TRICKLING FILTER/RBC



Observations:

- ⊕ All exceeded effluent TP annual averages of 3.0 mg/L.
- ⊕ Only 33% report effluent TP annual averages of less than 4.0 mg/L.
- ⊕ Influent concentrations tend to be higher than other WWTF categories.
- ⊕ Percent removal range from 17% to 43%.
- ⊕ Lowest removal efficiencies of all facility types reviewed.