

## **STRESS TESTING OF FINAL CLARIFIER AND POLYMER USE FOR FLOW MAXIMIZATION**

**Jurek Patoczka, PE, PhD, HMM\***  
**James F. Lauria, PE, Bergen County Utilities Authority**  
**John J. Scheri, PE, HMM**  
**Jerome F. Sheehan, PE, Bergen County Utilities Authority**

**\*Hatch Mott MacDonald, Infrastructure and Environment**  
**27 Bleeker St., Millburn, NJ 07041 USA (973-912-2541)**

*Presented at 71<sup>st</sup> Annual Water Environment Federation Conference and Exposition,  
Orlando, FL, 1998*

### **ABSTRACT**

This paper presents results from stress tests on an activated sludge final clarifier conducted with and without polymer addition. The site of the tests was a large (30,000 m<sup>3</sup>/day or 80 MGD average flow during the test period), municipal wastewater treatment plant, which was evaluating the potential for flow maximization through the secondary system under storm flow conditions. The stress tests were conducted by diverting a disproportionately high fraction of the plant flow to one of 16 clarifiers under controlled flow and polymer addition regimes. Each of 10 tests lasted several hours during relatively stable, mid-day flow conditions. Clarifier performance was evaluated by measuring effluent TSS, sludge blanket level and by visual observation. In some tests polymer addition was initiated and stopped repeatedly, thereby facilitating evaluation of the clarifier's response time.

The major conclusion is that polymer addition extends the flow range of acceptable performance of the final clarifier by at least 30 percent. Response to polymer addition was quite rapid (30 to 45 minutes), corresponding well with the hydraulic retention time under the test conditions. This rapid response facilitates the use of polymer on a stand-by basis. The polymer dose required for positive control of clarifier performance was 1.5 mg/l in this application and it was 50% higher than the optimal dose determined in jar tests.

### **KEY WORDS**

final clarifier, polymer, stress testing, clarification failure, bypass, storm flow

### **INTRODUCTION**

The site of the stress experiments was a 30,000m<sup>3</sup>/day (80 MGD) (average flow during the test period) contact-stabilization wastewater treatment plant operated by Bergen County Utilities Authority (BCUA) in northern New Jersey. Several of the member communities have combined sewers; additionally, this relatively old collection system has significant infiltration/inflow (I/I) problems. The plant is able to accept flows of up to 160 MGD; at higher flows biosolids wash-out occurs. In order to protect the biomass, the plant was forced, on occasion, to bypass the treatment system and discharge directly to the Hudson Bay through an overflow located upstream of grit chambers.

In 1991 the Authority entered into an Administrative Consent Order (ACO) with the New Jersey Department of Environmental Protection (DEP) which required elimination of overflows (plant bypass). Two approaches were evaluated by the Authority in order to achieve this mandate. One was maximization of the plant's treatment capacity and the second involved reduction of the I/I component. The flow maximization approach is the subject of this paper.

As mentioned above, the limiting unit process in the treatment train is final clarification. Since there is inadequate space for construction of additional clarifiers, efforts focused on maximizing flow through the existing final clarifiers. Evaluation of chemical addition during periods of high flow was an obvious choice for investigation to accomplish this objective.

## LITERATURE REVIEW

Polymer use in a secondary clarification application has been practiced for a long time; however, available data quantifying the benefits of this technique is scarce. Most of the reported applications address sludge settling and foaming problems, such as those caused by filamentous bulking and *Nocardia*. On the other hand, a substantial body of recent literature is available detailing development and application of a protocol for evaluating activated sludge secondary clarifier performance, as sanctioned by American Society of Civil Engineers Clarifier Research Technical Committee (CRTC) (Wahlberg *et al.*, 1994a). This has been geared, however, towards understanding and modeling clarifier performance with an emphasis on potential improvements through modification of physical structures. Such design improvements were summarized by Stukenberg *et al.* (1983) and Albertson and Alfonso (1995).

It has been recognized also that microbiology and aeration-induced floc break-up and flocculation in the aeration tank, conveyance structures and clarifier are important for clarifier performance (Das *et al.*, 1993, Parker and Stenquist, 1986). The microbiological state of the sludge in terms of its impact on the allowable loading of the clarifier was quantified by Daigger and Roper (1985). In their paper, building upon the classic flux theory, they presented a method to predict maximum solids loading/overflow rates as a function of zone settling velocity (through sludge volume index, SVI) and MLSS concentration. This allows a more realistic estimate of the critical loading (at which biomass loss occurs), as compared to the conventional straight overflow rate.

Floc break-up and flocculation was documented and quantified by Wahlberg *et al.* (1994b). It was shown that clarifier effluent suspended solids concentration (below a critical load) depends on the flocculation state of the mixed liquor. In batch tests activated sludges from different treatment plants reached an equilibrium supernatant suspended solids concentration at a low level within a maximum of 10 minutes of mechanical flocculation. This underscores the importance of mixing intensity and opportunities to flocculate either in the conveyance structures upstream of the clarifier or in the clarifier itself (flocculating center well).

Polymer can improve a clarifier's performance in two interrelated but distinct ways. First, by creating larger and tighter agglomerates polymers effectively increase zone settling velocity and decrease SVI increasing critical, allowable solids loading/overflow rate of the clarifier, as predicted by the flux theory. Secondly, polymers facilitate flocculation and capture of the dispersed solids from the supernatant resulting in a lower effluent TSS. This may be of particular benefit when inadequate flocculation opportunities exists in the treatment structures (e.g. lack of flocculating center well or functionally similar structures).

## LABORATORY SCREENING TESTS

Initially, on-site screening of both dry and emulsion polymers was conducted by vendors representing major manufacturers (Allied Colloids, Stockhausen, Cytec Industries and Chemtol). Subsequently, the most effective products recommended by vendors were compared side by side in three rounds of tests conducted by Killam Associates' staff.

For the comparative testing, fresh mixed liquor samples were dosed with polymer in one liter beakers, flash mixed for 30 seconds, flocculated at 20 rpm for 3 minutes and settled for 10 minutes. The polymers were visually evaluated *in situ* for dose-response characteristics in respect to SVI, size of the floc generated, signs of overdosing, sludge mounding effect, generation of floatables/ash and turbidity and TSS of the supernatant.

Most of the polymers tested showed an expected dose-response characteristics, i.e. initially lowering the TSS as dose increases, than reaching a plateau and deteriorating upon overdosing due to increased supernatant turbidity and/or sludge floating. Typical improvement in estimated SVI was 10 to 30% at optimal polymer dose.

Table 1 (**See Table 1 "Polymer Selection Criteria**) summarizes results from a comparative round of testing and presents polymer selection criteria and resulting ranking. The most effective product

overall was Pollu-Treat C-116, a high molecular weight, 45% charge, dry cationic polymer manufactured by Chemtol (SNF), and distributed by Pollu-Tech, Inc. This polymer was selected for full scale demonstration tests at an optimal dose in 0.7 to 1.0 mg/l range. As noted in Table 1, all 6 polymers which were observed to float the sludge upon overdosing were emulsions, while both dry polymers used did not float the sludge.

**Table 1 - Polymer Selection Criteria**

Polymer		TSS - Based Information				Behavior Upon Overdosing (a)
No.	Type	Dose to Reach 10 mg/l TSS	Unit Cost \$/lb.	Polymer Cost @100 MGD, \$/day	Cost Rank	
A	Emulsion	2 (b)	1.25	2,085	3	Floating
B	Emulsion	2.2	1.26	2,312	6	Floating
C	Emulsion	(c)	1.61	-	-	Floating
D	Emulsion	1.2	1.82	1,821	2	Floating
E	Dry	1.5	1.80	2,250	4	No Floating
F	Emulsion	(c)	1.00	-	-	Floating
G	Emulsion	2.7 (b)	1.35	2,252	5	Floating
H	Dry	0.5	1.75	730	1	No Floating

- (a) Overdosing defined when large clumps of solids formed and settled during mixing, sludge blanket uneven with significant mounding.
- (b) Questionable optimum dose.
- (c) Product Not Effective.

**Figure 1 - Effect of Flocculation Time on Supernatant TSS**

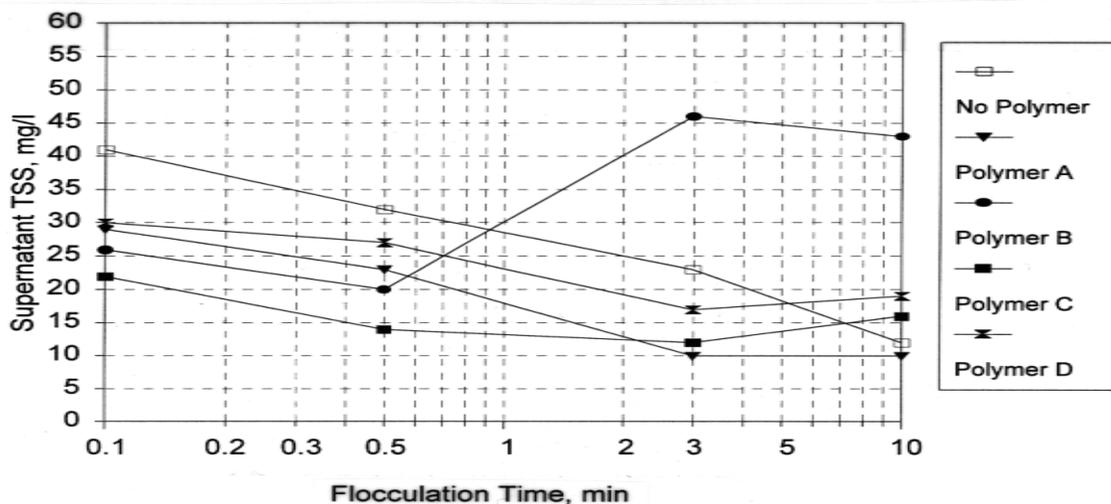


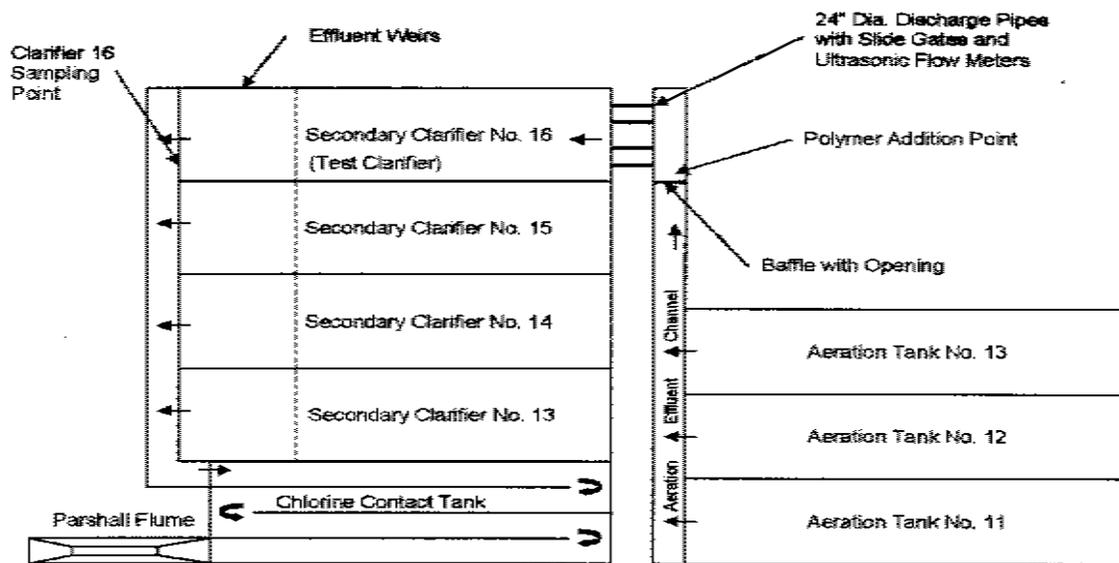
Figure 1 (See Figure 1 “Effect of Flocculation Time on Supernatant TSS”) illustrates the effect of slow mixing (flocculation) following addition of different polymers at their respective optimum doses. A minimum of 3 minutes of slow mixing (flocculation) was necessary to minimize supernatant suspended solids, with or without polymer addition. Actually, flocculation of mixed liquor without polymer addition, as recently documented by Wahlberg *et al.* (1994a), was as effective as flocculation with polymer aid in minimizing supernatant suspended solids. The very limited data presented in Figure 1 appear to suggest that synthetic polymers’ primary advantage over natural flocculation mechanisms of mixed liquor might be a speeding-up of the flocculation process.



## METHODOLOGY OF STRESS TESTS

**Site.** The site of the stress experiments was a 30,000m<sup>3</sup>/day (80 MGD) (average flow during the test period), contact-stabilization wastewater treatment plant operating with sixteen final clarifiers in four banks. Each bank of four clarifiers is followed by a chlorine contact tank and final effluent metering chamber using a Parshall flume. The clarifiers, each 170 ft long, 36 ft wide with 8.5 ft side water depth, are equipped with longitudinal sludge collectors with the hopper and cross-collectors located at the effluent end. Mixed liquor is transferred from the aeration (contact) tank to the final clarifiers via an aerated effluent channel, common for all clarifiers (Figure 2). (See Figure 2 “Schematic of Pilot Plant

**Figure 2 - Schematic of Pilot Plant Site**



**Site)**

**Flow Control.** The tests were conducted by diverting a disproportionately high fraction of the plant flow to one of the clarifiers by adjusting a sluice gate. The end section of the aerated effluent channel leading to the test clarifier (No. 16) was isolated by inserting a baffle with overflow (Figure 2). The baffle created a turbulent zone convenient for polymer addition and prevented backflow of polymer-dosed mixed liquor to the other clarifiers thus facilitating control over polymer dose.

Total flow to Clarifier No.16 was measured by four Doppler-type Controlotron System 190P flow meters clamped on the exterior of each of the four 24" pipes leading from the aeration effluent channel to the clarifier. Accuracy of the meters was verified by temporarily shutting down flow to the other three clarifiers in this bank, thus diverting all flow to Clarifier No.16. The Parshall flume metering final effluent from the isolated bank of clarifier (minus return and waste sludge rates) was then compared with the Doppler flow meters readings.

**Polymer Addition.** Polymer addition was accomplished by using a trailer mounted PolyBlend DP-500 system which automatically prepared batches of 0.25% solution. During the tests the polymer dose was manually adjusted to match flow changes to the clarifier. Accuracy of the metering pump was verified on several occasions by measuring the time to fill a graduated cylinder. Polymer was then post-mixed with approximately 20 gpm of treated effluent in the polymer solution delivery pipe. Polymer dosage rates discussed in the paper are at the point of polymer addition, i.e. base flow includes return sludge.

**Tests Execution.** Analysis of the diurnal flow patterns indicated that the plant had a fairly stable, mid-day period of peak flow lasting for 3-5 hours (approximately 11 am to 4 pm) with a typical peaking factor of 1.2. The morning flow (8 am to 9 am) was fairly close to the daily average. Consequently, sluice gates to clarifier No. 16 and other three clarifiers in this bank were adjusted in the morning, so to achieve the target flow rate later in the day. Test clarifier performance, with or without polymer addition, was monitored during the several hour, mid-day period of relatively stable flow rate. A total of 10 stress tests were conducted in this manner under varying conditions of flow and polymer addition.

Test progress was monitored by visual observation of the clarifier performance (effluent clarity) and sludge blanket level measurements using a stationary ultrasonic (Royce) sludge blanket detector and portable photometric probe (sludge judge). To document the clarifier's performance, effluent composite samples for TSS were collected by an automatic sampler in the effluent trough and complemented by manually collected grab samples as dictated by changing conditions in the clarifier.

## DETAILS OF INDIVIDUAL TEST RUNS

The initial three tests were conducted without polymer addition at progressively increasing flow rates. As illustrated on Figures 3 through 5 (**See Figure 3 "Test No. 1," Figure 4 "Test No. 2" and Figure 5 "Test No. 3"**) and summarized in Table 2 (**See Table 2 "Summary of Tests Results"**), the increasing flow had an expected and dramatic impact on the clarifier's performance. In the 11 to 11.4 MGD range, the clarifier performed satisfactorily, as demonstrated by the results from 3-hr effluent composite TSS which averaged 11 mg/l. Flow in the 13.8-14.8 MGD range caused unacceptably high effluent TSS (74 mg/l composite average), while total failure of the clarifier, with effluent TSS of 304 mg/l, was observed as the flow approached 16 MGD. Upon reaching such a condition, commonly referred to as "boil," the tests were terminated by reducing the flow to clarifier No. 16 to normal levels.

In test No. 4 polymer was added at a dose of 0.7 mg/l, corresponding to the optimum dose determined in a jar test conducted on that day. The clarifier flow averaged 17 MGD (see Figure 6). (**See Figure 6 "Test No. 4"**) Approximately one hour after the flow exceeded 16 MGD, the effluent quality deteriorated with composite effluent TSS at 71 mg/l. However, the clarifier's performance was better than during the previous test without polymer addition when total clarifier failure was caused at a similar flow rate. During the test the clarifier proximity switches tripped on several occasions resulting in intermittent operation of the rake chain and increased height of the sludge blanket. Since this was judged, and later confirmed, to be an artificial problem caused by faulty controls, the proximity switches in Clarifier No.16 were disconnected for the remainder of the tests.

The No. 5 test was conducted at a higher initial polymer dose of 1.0 mg/l and a flow rate averaging 14.8 MGD (Figure 7). (**See Figure 7 "Test No. 5"**) Polymer addition improved the clarifier's performance over that achieved in test No. 2 with a similar flow rate but without polymer addition.

During test No. 6, the clarifier's response to changing polymer addition was examined. With flows in a relatively narrow range from 14.9 to 15.3 MGD, polymer was added for several hours at a 1.5 mg/l dose with excellent effluent clarity and TSS remaining at or below 23 mg/l (Figure 8). (**See Figure 8 "Test No. 6"**) When polymer addition was stopped at 1:30 p.m., deterioration of the effluent quality was observed within 20 minutes. Gradually increasing effluent turbidity resulted in a TSS concentration of 95 mg/l in a composite sample collected between 3 and 4 pm. Upon reaching the point of clarifier "boil," the test was terminated.

Later that evening the operators noticed that the sludge draw-off line from test clarifier No. 16 was clogged, thereby causing an accumulation of sludge in the clarifier. Therefore, clarifier No. 16 had to be taken out of operation the following day, until the draw-off line was unclogged. While normal sludge blanket levels and operation of the draw-off line were observed throughout the test, including more than two hours following termination of the polymer addition, it is suspected that the higher density and more viscous sludge with polymer was the cause of the problem. This suspicion was reinforced when the flow in the draw-off line was restored the next day by lowering the sleeve on No.16's telescopic valve and

lowering the water level in the sludge wet well. The initial portions of sludge from clarifier No. 16 underflow had a viscous and thick appearance, as may be caused by a relatively high polymer dose.

In the next test (No. 7) the clarifier was initially operated without polymer addition at a flow rate of 13.2 MGD. Following visual deterioration of the effluent quality (Figure 9), (**See Figure 9 "Test No. 7"**) the polymer addition unit was activated at a dose of 1.5 mg/l resulting in clarifier performance improvement within 30 minutes.

The following day the test was repeated at a slightly higher flow rate of 14.3 MGD. This time a total failure of the clarifier was initially observed (Figure 10). (**See Figure 10 "Test No. 8"**) Within 35 minutes from the activation of the polymer addition unit, the effluent TSS dropped from above 200 to 22 mg/l. After the dramatic performance improvement was evident, the polymer addition was stopped. Again, the clarifier responded rapidly reaching the "boiling" state within 50 minutes (Figure 10).

Due to some problems with flow meters, absolute flow data from the test No.9 are uncertain. However, following activation of polymer addition, an improved performance of the clarifier in terms of effluent TSS was noted in this test as well (Figure 11). (**See Figure 11 "Test No. 9"**)

The final test (No. 10) was conducted with the flow rate ranging from 16.3 to 18 MGD (Figure 12). (**See Figure 12 "Test No. 10"**) When the clarifier appeared on the verge of boiling, polymer addition was activated resulting in a marked performance improvement within 35 minutes. Two hours later polymer addition was stopped, resulting in clarifier effluent deterioration within half an hour.

Later that evening the sludge draw-off line of the test clarifier was discovered to be clogged, similarly as after test No. 6.

## **SUMMARY OF THE RESULTS**

Test clarifier No. 16's performance under varying flow conditions and polymer addition is summarized in Table 2. Figure 13 (**See Figure 13 "Summary of Tests Results"**) presents the same information in a graphical form, categorizing clarifier performance as good (TSS < 30 mg/l), poor (TSS from 30 to 100 mg/l) and total failure (TSS > 100 mg/l).

The safe operational range without polymer addition appears to be below 1,200 gpd/sq ft. This, incidentally, is a common, recommended, maximum design rate for the hourly peak anticipated flow (Ten State Standards). Higher overflow rates could cause performance deterioration while all tests performed without polymer addition at overflow rates higher than 1,600 gpd/sq ft caused poor clarifier performance. Polymer addition at an adequate rate appears to extend the acceptable operational range to as much as 2,400 gpd/sq ft, or an increase of up to 50%. It should be emphasized that this is based on a short duration (several hours) performance with polymer addition.

Polymer addition at a dose lower than 1.5 mg/l (based on flow at the point of polymer addition) was not as effective, despite parallel jar tests indicating the optimum dose to be in 0.7 to 1 mg/l range. This confirms our previous experience, as well as others (J. Gatch, personal communication), that in full scale applications the required polymer dose is approximately 50% higher than the optimal dose determined in jar tests. This is most likely a result of less than perfect mixing available in full scale structures, inefficiencies of continuous polymer preparation units and/or factors such as temperature and dilution water quality.

The ability of the BCUA plant to treat storm flows on a sustained basis with polymer addition appears to be presently restricted by lack of positive withdrawal of settled sludge from the clarifiers. The polymer generates more dense and viscous sludge. Twice following completion of runs with polymer addition, the sludge draw-off line from the test clarifier became clogged. While the sludge draw-off lines at BCUA plant are occasionally plugged by rags or other debris, timing of the two failures in Clarifier No.16 and the thick appearance of the underflow sludge upon restoration of the sludge flow strongly suggests that polymer addition was the cause.

On the other hand, the fact that polymer was added to only one out of four interconnected clarifiers could have compounded the sludge withdrawal problems on these two occasions. From the sludge hopper with cross-collectors, the sludge flows by gravity to a wet well common for all four clarifiers. The discharge is through a telescopic valve with an adjustable sleeve (one per clarifier). However, the valves typically operate with sleeves submerged, partially due to the mechanical problems with the sleeve level adjustment gear boxes. This causes the same head for sludge withdrawal from all four clarifiers. With a more viscous, polymer-laden sludge in the test clarifier, higher friction losses in that draw-off line will cause lower flows, resulting in eventual complete clogging. Should all clarifiers be dosed with polymer, equal friction losses may evolve resulting in a more uniform sludge withdrawal although more head may be required to convey the sludge.

Experience from these tests underscores the importance of positive control of the sludge withdrawal at high flow rates and with polymer addition. This includes the ability of the rakes and chain mechanism to transport an increased load of thick sludge along the floor of a long clarifier.

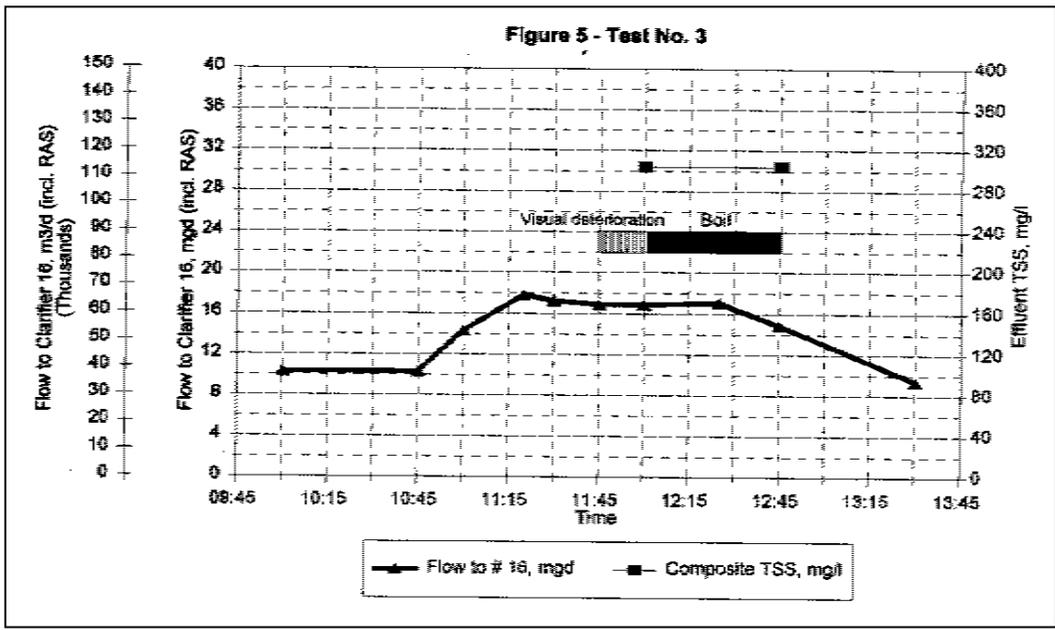
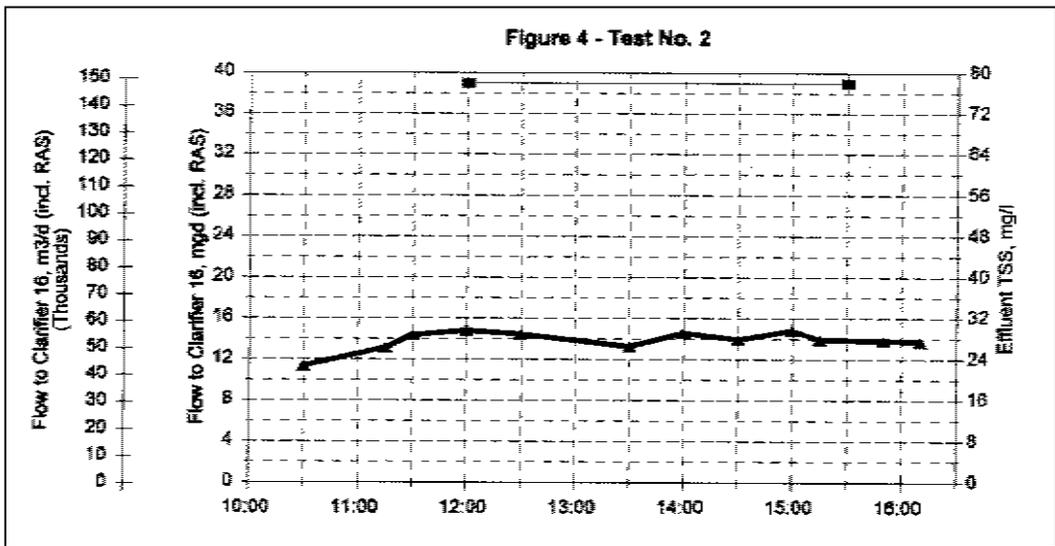
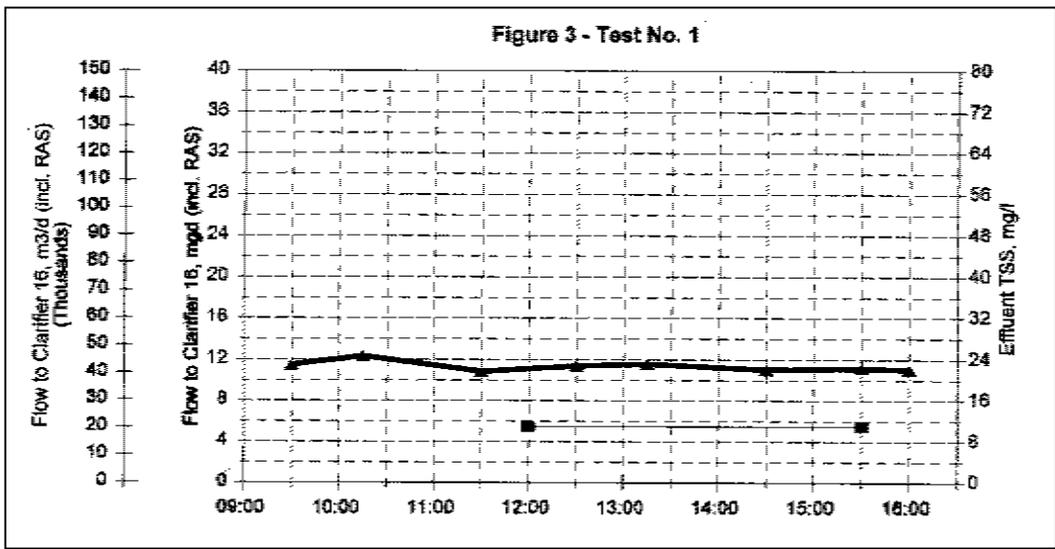
**Table 2 - Summary of Tests Results**

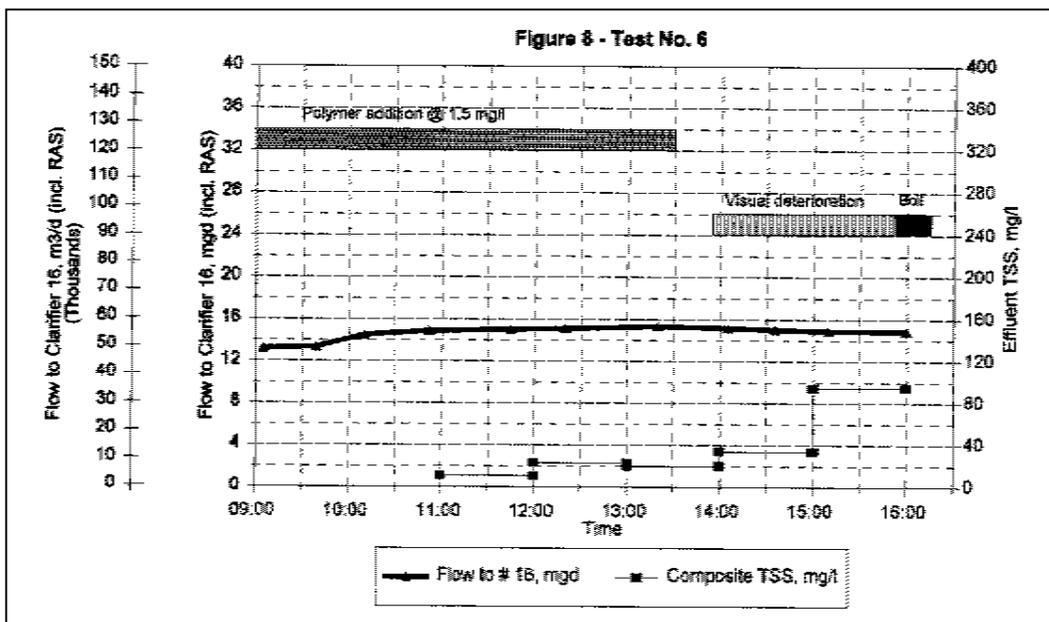
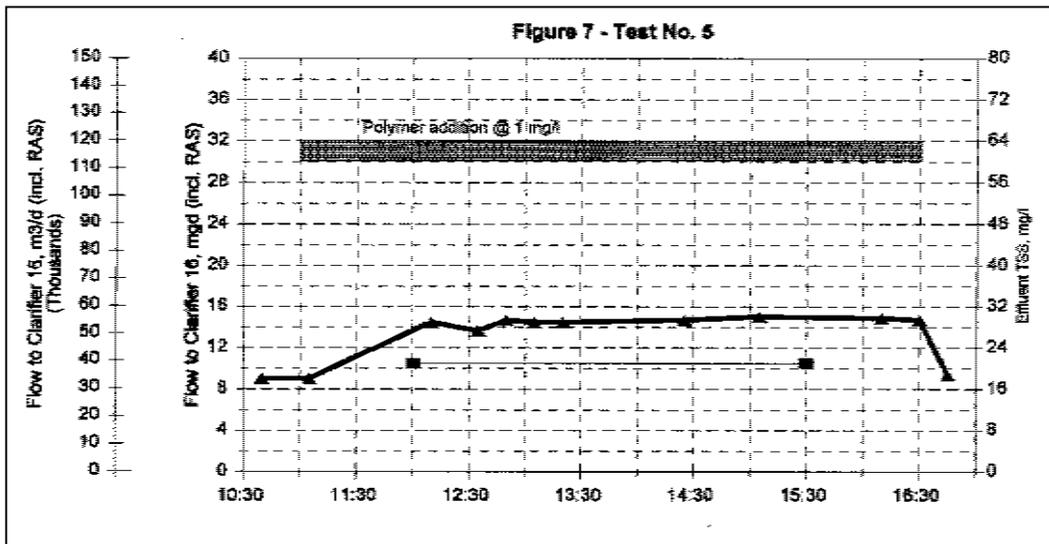
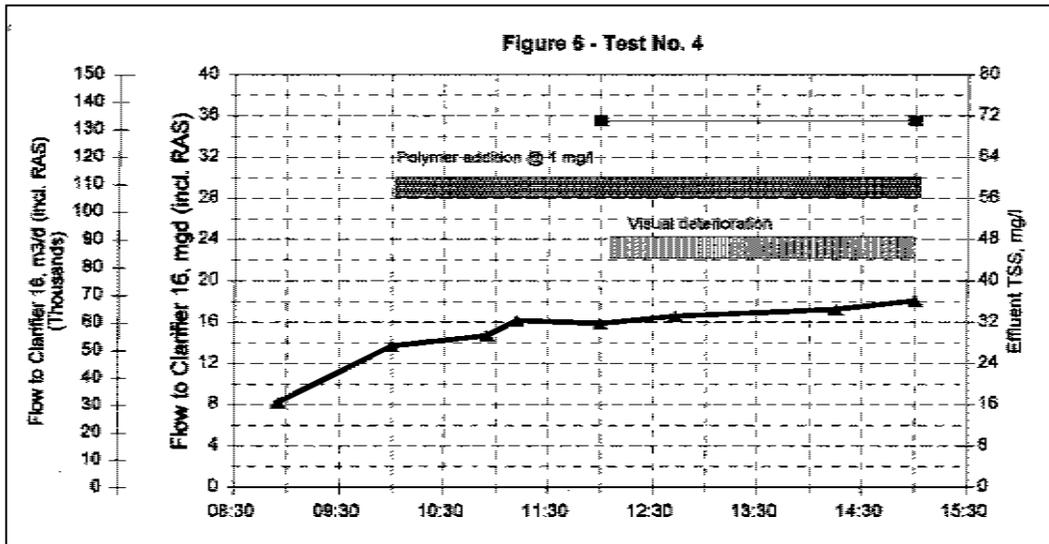
Test No.	Average Flow (1), MGD	Overflow Rate, gpd/sq ft	Polymer Addition (dose, mg/l)	Clarifier Performance (effluent TSS, mg/l)	Comments
1	11.2	1,220	No	Good (11)	
2	14.3	1,670	No	Poor (78)	
3	17.4	2,030	No	Total Failure (304)	
4	17.0	1,980	Yes (0.7)	Poor (71)	Clarifier rakes tripping - high sludge blanket
5	14.8	1,680	Yes (1.0)	Good (21)	
6	15.5	1,830	Yes (1.5)/No	Good (18)/Poor (95)	Sludge return lines plugged that evening
7	13.2	1,620	Yes (1.5)	Good (21.5)	
8	14.3	1,510	No/Yes (1.5)/No	Total Failure (206)/Good (25)/Poor (64)	Quick response to polymer addition
9	15.6	2,110	No/Yes (1.5)	Visual deterioration/Good (24)	Flow measurements uncertain
10	17.2	2,380	No/Yes (1.5)/No	Satisfactory (34)/Good (23)/Poor (50)	Sludge return line plugged that evening

(1) Total mixed liquor flow to clarifier No. 16, including RAS & WAS.

## CONCLUSIONS

1. Polymer addition extended the flow range of acceptable performance of final clarifier by up to 50 percent.
2. Clarifier effluent quality responded to polymer addition within 30 to 45 minutes which approximates the hydraulic retention time under the test conditions. This facilitates use of polymer on a stand-by basis.
3. The polymer dose required for a positive control of clarifier's performance (1.5 mg/l in this application) was 50% higher than the optimal dose determined in jar tests.
4. Limited, comparative jar tests indicate that emulsion polymers might have a tendency to cause floating of the sludge upon overdosing, while dry polymers did not exhibit this characteristic.





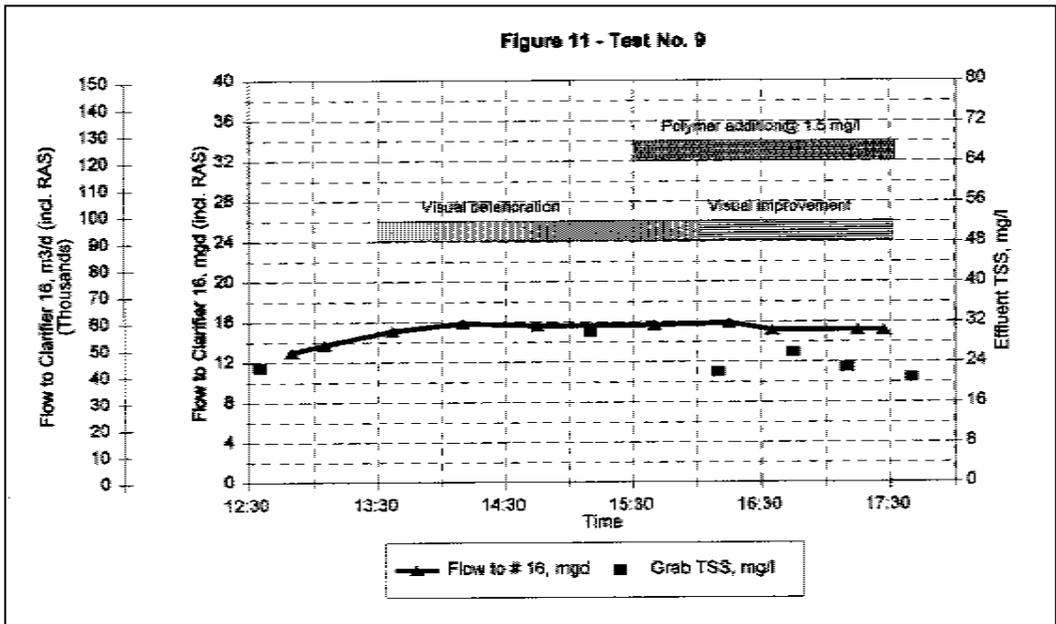
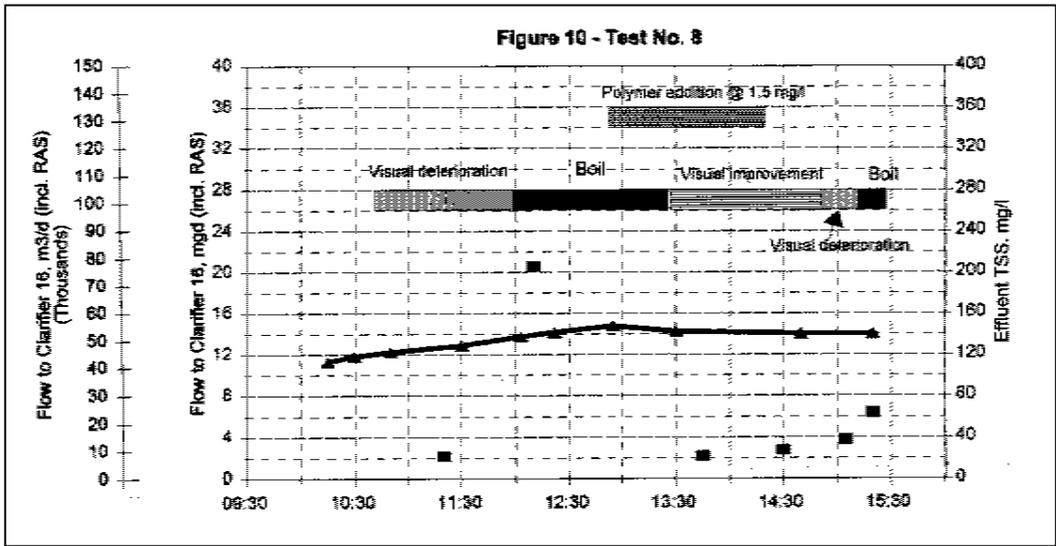
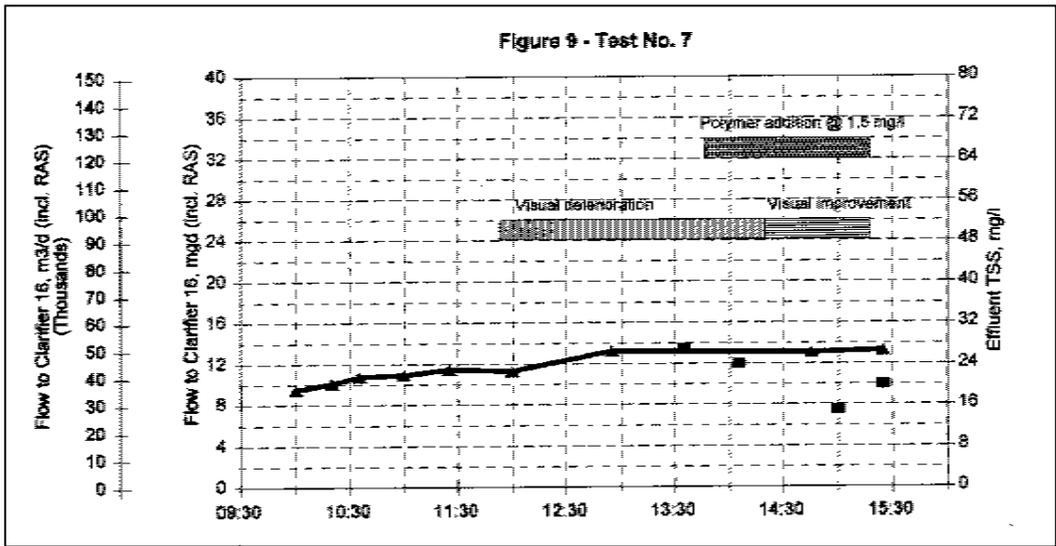


Figure 12 - Test No. 10

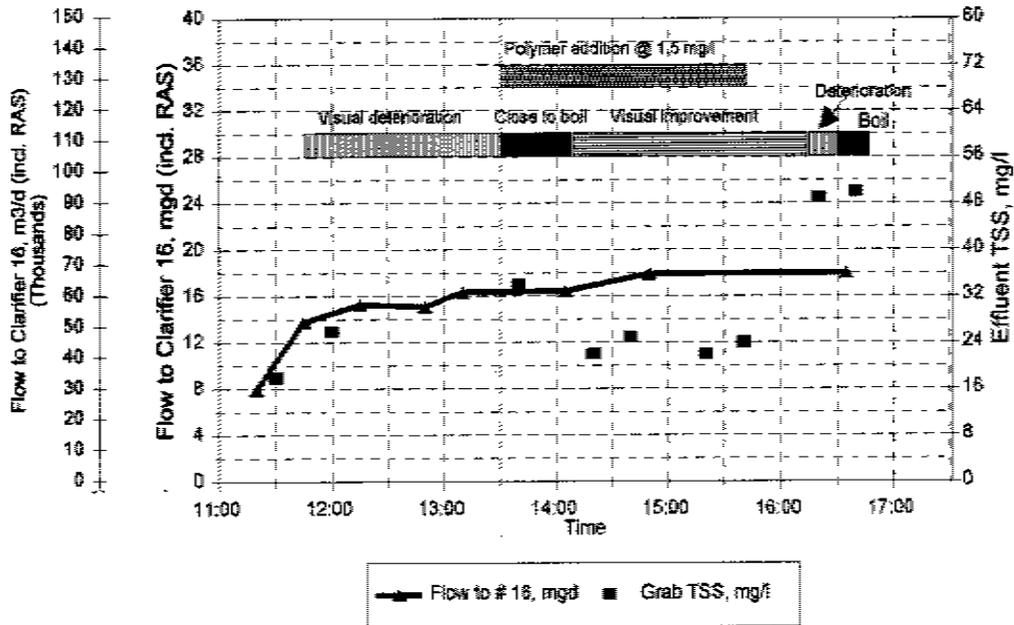
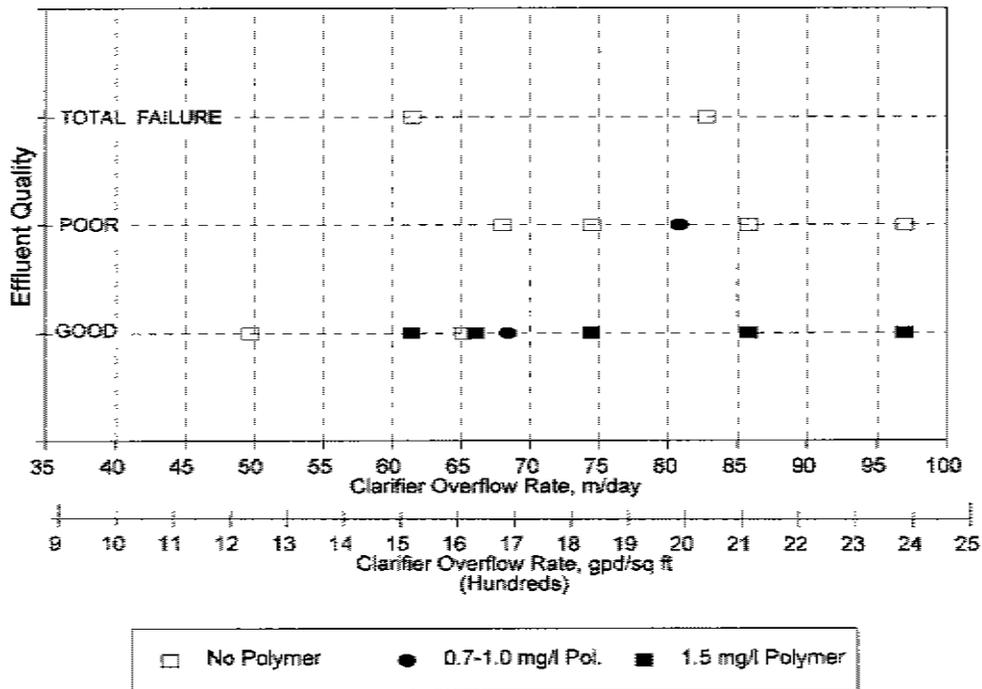


Figure 13 - Summary of Tests Results



## REFERENCES

- Albertson, O. E. and P. Alfonso (1995) "Clarifier Performance Upgrade," *Water Environment and Technology*, March 1995, pp. #56-59.
- Daigger, G. T. and R. E. Roper, Jr. (1985) "The Relationship between SVI and Activated Sludge Settling Characteristics," *J. Water Pollut. Control Fed.*, Vol 57, No. 8, pp. #859-866.
- Das, D., T. M. Keinath, D. S. Parker and E. J. Wahlberg (1993) "Floc Breakup in activated Sludge Plants," *Water Environ. Res.*, Vol. 65, No. 2, pp. #138-145.
- Gatch, J., Personal Communication, 1996.
- Parker, D. (1983) "Assessment of Secondary Clarification Design Concepts," *J. Water Pollut. Control Fed.*, Vol 55, No. 4, pp. #349-359.
- Parker, D. and R. Stenquist (1986) "Flocculator-clarifier Performance," *J. Water Pollut. Control Fed.*, Vol 58, No. 3, pp. #214-219.
- Stukenberg, J. R., L. C. Rodman and J. E. Touslee (1983) "Activated Sludge Clarifier Design Improvements," *J. Water Pollut. Control Fed.*, Vol 55, No. 4, pp. #341-348.
- Wahlberg, E. J., M. Augustus, D. T. Chapman, C. Chen, J. K. Elser, T.M. Keinath, D. S. Parker, R. J. Tekippe and T. E. Wilson (1994a) "Evaluating Activated Sludge Secondary Clarifier Performance Using the CRTS Protocol: Four Case Studies," Paper presented at WEF 67th Annual Conference, Chicago, Illinois.
- Wahlberg, E. J., T. M. Keinath and D. S. Parker (1994b) "Influence of Activated Sludge Flocculation Time on Secondary Clarification," *Water Environ. Res.*, Vol. 66, No. 6, pp. #779-786.