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**CHITOSAN, METAL SALT, AND POLYACRYLAMIDE  
JAR TESTS AT THE GLOUCESTER WATER  
POLLUTION CONTROL FACILITY**

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AT THE GLOUCESTER WATER POLLUTION CONTROL FACILITY**

by

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and**

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**October, 1991**

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## INTRODUCTION

This report grew out of a proposal submitted to MIT Sea Grant by Professor Donald Harleman and Susan Murcott of Parsons Laboratory, Massachusetts Institute of Technology, to conduct a series of jar tests to determine the efficacy of chitosan as a coagulant in wastewater treatment and to compare chitosan with metal salts in improving primary effluent quality. The testing took place at the Gloucester Water Pollution Control Facility thanks to the cooperation and assistance of Lynn Brown, Assistant Engineer, City of Gloucester.

The report consists of 2 sections:

1. A review of the basic plant data for the Gloucester primary treatment plant and a performance analysis of that facility;
2. Jar test results for 2 testing periods.



**SECTION 1**

## **1.0 THE GLOUCESTER WATER POLLUTION CONTROL FACILITY -- PERFORMANCE ANALYSIS**

### **1.1 PLANT DATA**

The Gloucester Water Pollution Control Facility (GWPCF), owned and operated by the City of Gloucester, is a primary municipal wastewater treatment plant with an average flow of 3.3 mgd and a peak flow of over 10 mgd. The facility was designed by Macquire Engineering Inc. of Waltham, Massachusetts, and came on line in May, 1984. In June, 1986, the U.S. EPA issued the City of Gloucester a National Pollutant Discharge Elimination System (NPDES) permit and a 301(h) waiver from secondary treatment, as allowed under the 1977 amendments to the Clean Water Act. This waiver expired in 1990 and the City has received verbal approval from the U.S. EPA of a new 301(h) waiver, but has not received the actual document.

#### **1.11 SEWERAGE AND STORM WATER COLLECTION SYSTEM**

The population of Gloucester is 27,000 year round and 37,000 in summer. Between 17,000 - 18,000 people are sewered, which is 50 to 66% of the residential population or 20% of the land area. A total of 16 sewage pumping stations operate at various points in the system. The remaining population is on septic systems, many of which are located on granite ledge. A number of these discharge into Gloucester Harbor or northern Massachusetts Bay. In spite of the pollution problem caused by faulty septic systems, there is some public opposition to sewerage because of the expense (estimated as high as \$20,000 per household) and because of the concern that sewerage will lead to expanded development and a ruining of local character.

Of the 17,000 acres of land that comprises Gloucester, 375 acres contain combined sewers.<sup>1</sup> Approximately 20-30% of the sewered areas are serviced by combined sewers, including all the downtown commercial establishments plus several of the harbor-front industries.

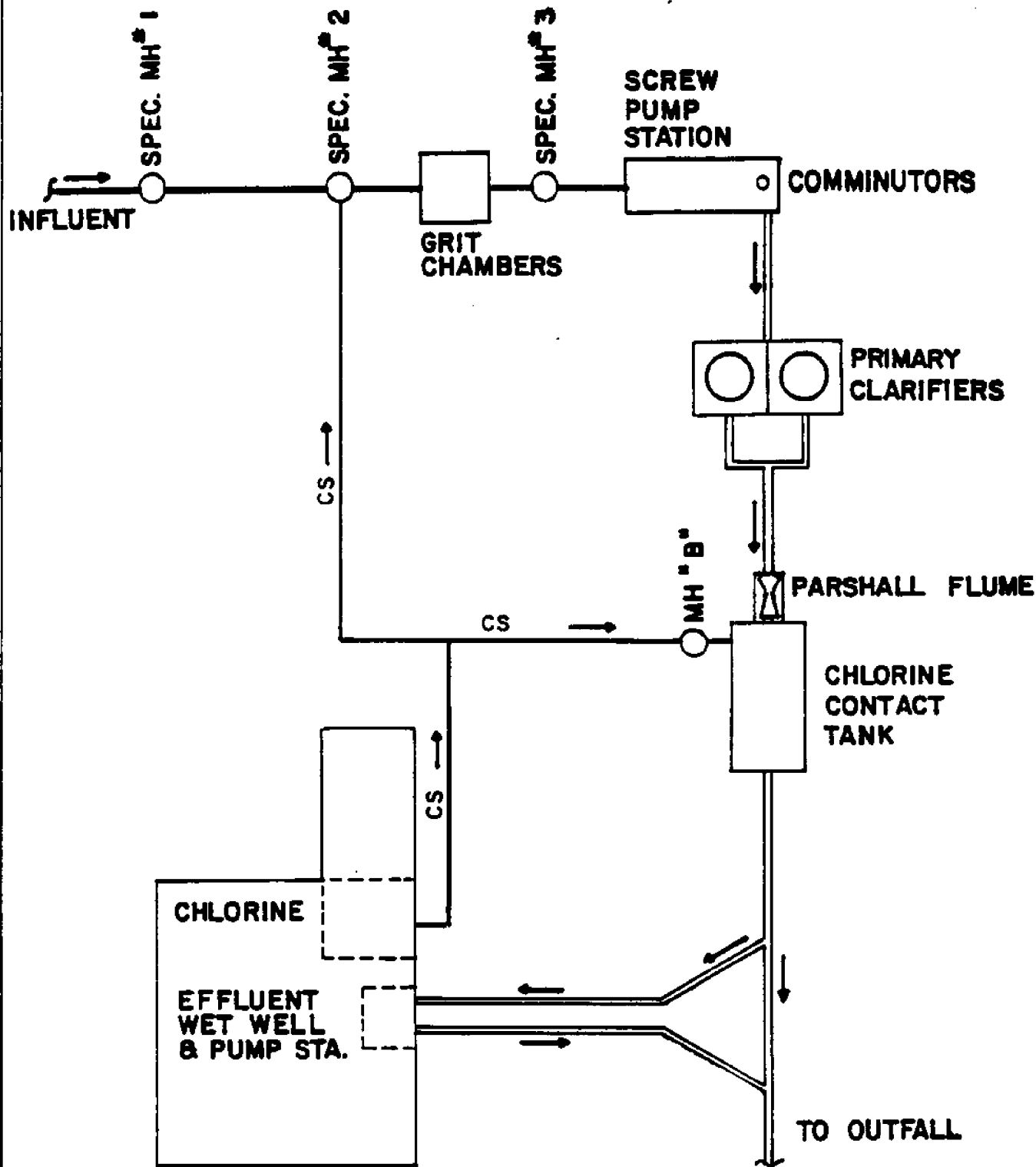
#### **1.12 PRIMARY TREATMENT PLANT**

The primary treatment plant consists of bar racks, a grit chamber, a screw pump station, comminutors, two 70 'x 70' primary clarifiers, a chlorine contact chamber and sludge dewatering facilities. The sludge handling facilities include 2 gravity thickeners and a belt filter press. Sludge is sent to a landfill.

Figure 1 shows a schematic of the plant. Table 1 gives basic plant data.

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<sup>1</sup>Personal communication, Lynn Brown. October 4, 1991.



**SCHEMATIC - WASTEWATER FLOW**

GLOUCESTER WATER POLLUTION CONTROL FACILITY	
OPERATION AND MAINTENANCE MANUAL	
SCHEMATIC WASTEWATER FLOW	
C E MAGUIRE, INC., WALTHAM, MA.	FIG. 1

**TABLE 1  
GLOUCESTER WATER POLLUTION CONTROL FACILITY -- PLANT DATA**

	INITIAL	DESIGN-2000
<b>Grit Chamber</b>		
Number	2	2
Capacity, mgd	7.5	7.5
<b>Bar Rack</b>		
Number	2	
Bar Spacing, in	1-1/2	1-1/2
<b>Septage Holding Tank</b>		
Number	1	1
Capacity, gal	14,200	14,200
<b>Primary Clarifiers</b>		
Number	2	2
Flow per tank,mgd	3.05	3.62
Tank surface dimensions, ft	70 x 70	70 x 70
Surface area per tank	4,900	4,900
Overflow Rate	623	740
Tank side water depth	10	10
<b>Sludge Handling Facilities</b>		
Number	2	2
Capacity, gpm (each)	220	220

**1.13 PERMIT LIMITS**

The effluent limits required under Gloucester's current NPDES permit are:

**TABLE 2  
GWPCF -- NPDES EFFLUENT PERMIT LIMITS**

	Effluent (mg/l)
TSS (max day)	140
BOD5 (max day)	245
FOG (monthly average)	15

Plant personnel analyze TSS, BOD5, and FOG, 3 times per week and fecal coliform 1 time per week in their in-house lab. TSS and BOD5 are collected as composite samples. FOG and fecal coliform are grab sample. Settleable solids, chlorine residuals, and pH are analyzed 3 times per day, 5 days per week. The plant is typically in compliance with its requirements. However, the U.S. EPA has stated that once it issues GWPCF its new NPDES permit, it will have 2 years to come into compliance with a 30% BOD5 removal requirement. If this new requirement is imposed, the plant would want to consider chemical addition as a means of increasing BOD5 % removal. This need was the motivating factor behind the pilot study of enhanced primary treatment at GWPCF (Brown, 1989).

#### 1.14 WASTESTREAM CHARACTERISTICS

Table 3 summarizes the plant's wastestream characteristics:

**TABLE 3  
SUMMARY OF GWPCF WASTESTREAM CHARACTERISTICS**

	Minimum	Maximum	Average	Std. Dev.
Flow Rate (mgd)	1.4	10.5	3.3	1.2
Overflow Rate (gpd/sf)	276	1327	670	214
Influent TSS (mg/l)	71	1213	201	135
Effluent TSS (mg/l)	23	200	81	26
Removal TSS (%)	9	92	55	15
Influent BOD5 (mg/l)	60	355	197	71
Effluent BOD5 (mg/l)	29	299	161	52
Removal BOD5 (mg/l)	-30	63	17	22
Influent Soluble BOD5* (mg/l)	43	154	89	43
Effluent Soluble BOD5* (mg/l)	38	116	90	31
Effluent FOG (mg/l)	9.3	27.8	14.7	4.9

(1990 Daily Average Data)

\*Influent and Effluent soluble BOD based on 3 month average.

Note that on average the ratio of soluble BOD5/total BOD5 effluent is 90/197 mg/l or approximately 46% of the total effluent BOD5. Typically, soluble BOD5 is about 40% of total BOD5. Soluble BOD5 can be as high as 75% of total effluent BOD5.<sup>2</sup> High solubility at GWPCF is related to 2 factors: the large number of fish processing industries discharging to the plant and the plant design feature where supernatant from the gravity thickeners and filtrate from the belt filter press is returned to the front of the grit chambers. This high soluble BOD5 component is a contributing factor to the plant's low BOD5 removal efficiency. Also, as the industrial pretreatment program has improved the quality of the incoming wastestream, particularly in terms of reducing BOD5 influent concentrations, it has been harder to achieve good BOD5 removal rates.

### **1.15 INDUSTRIAL AND COMMERCIAL CONTRIBUTION TO GWPCF'S WASTESTREAM**

Fish processing industries, which process both fresh and frozen seafood, comprise 14 of the 19 industries in Gloucester's industrial pretreatment program. Industrial discharge comprises about 11% of the wastestream, the remaining 89% is domestic and commercial. In addition to fishing and fish processing, tourism is the other major business in Gloucester.

### **1.16 OUTFALL**

Primary treated effluent is discharged through a 36-inch diameter outfall pipe which extends 13,500 feet into northern Massachusetts Bay. The outfall reaches 4,500 feet beyond the mouth of Gloucester Harbor. This new construction, completed in 1990, extended the old outfall by 9,000 feet. Whereas the original outfall's discharge was located in 30 feet of water, the newly extended outfall discharges in 90 feet of water. There is a diffuser at the end of the new outfall.

### **1.2 GRAPHS OF PERFORMANCE**

The performance analysis consists of 16 graphs of key variables including flow, time, TSS, BOD5, and overflow rate.

Graph 1: Flow Rate versus Day of the Year. The flow rate pattern over the 365 days of the year are shown in this graph. Typical of the Northeast, the flow is quite variable, the result of inflow and infiltration. The maximum flow rate is 10.5 mgd (not shown on the graph) and the minimum is less than 2 mgd. Maximum flows occur seasonally, during the spring and the fall rains.

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<sup>2</sup> Personal communication, Lynn Brown. January, 1991.

Graph 2: TSS Influent and Effluent Concentration versus Overflow Rate. This graph presents TSS influent and effluent concentrations as a function of overflow rate. Influent concentration averages 200 mg/l; effluent concentration averages 80 mg/l. This is typical performance for conventional primary treatment. However, the maximum effluent concentration recorded is 200 mg/l which is out of compliance with the permit limit of 140 mg/l. Several other data points are also out of compliance. The average overflow rate is 670 gpd/sf, again typical for a primary treatment plant. Influent and effluent concentrations are somewhat lower at higher overflow rates.

Graph 3: TSS % Removal versus Day of the Year. This graph shows the variation in % removal throughout the year. The average TSS removal is 55%; standard deviation is 15%. There is no clear correlation between removal efficiency and day of the year.

Graph 4: TSS % Removal versus Overflow Rate. This graph shows the variation in TSS removal rates as a function of overflow rate. No obvious correlation between TSS removal rate and overflow rate is evident.

Graph 5: TSS % Removal versus TSS Influent Concentration. This graph does show a correlation between TSS % removal and TSS influent concentration. There is a higher % removal with higher TSS influent. TSS influent concentrations above 200 mg/l give higher % removals.

Graph 6: TSS Influent and Effluent Concentration - Monthly Average Data. Whereas all the graphs up until now have presented daily average data, this graph depicts TSS influent and effluent concentration based on monthly average data. It shows that TSS effluent concentrations are quite consistent over the entire 12 month period, whereas influent concentrations are more variable in the winter and spring months of January through May.

Graph 7: TSS % Removal versus Month, 1990. Graph 7 is a different presentation of the same data shown in Graph 3. Whereas Graph 3 shows daily average data, Graph 7 gives monthly average data. Graph 7 gives a sharper view of TSS removal efficiency. The error bars show the monthly standard deviation.

Graph 8: TSS % Removal versus Overflow Rate - Monthly Average Data. Graph 8 gives TSS % removal versus overflow rate in terms of the monthly average data. Error bars shows monthly standard deviation.

Graph 9: BOD5 Influent and Effluent Concentration versus Overflow Rate. This graph presents BOD5 influent and effluent concentrations as a function of overflow rate. Influent BOD5 concentration averages 200 mg/l, about the same as TSS influent concentration; effluent BOD5 concentration, averaging 160 mg/l, is double TSS effluent concentration. BOD5 effluent concentration is somewhat higher than expected from a conventional primary treatment plant. The BOD5 effluent permit limit of 245 mg/l is generally met, but with exceptions. The maximum BOD5 effluent concentration recorded was 299 mg/l. Removal efficiency of BOD5 is limited. Influent and effluent concentrations are somewhat lower at higher overflow rates.

Graph 10: BOD5 % Removal versus Day of the Year. This graph shows the variation in BOD5 percent removal during 1990. Average percent removal is 17%, well below a possible future 30% BOD5 removal requirement. The standard deviation is 22%. There is no clear correlation between BOD5 removal efficiency and day of the year. Negative % removals, if not due to testing errors, indicate that the effect of treatment is to increase rather than decrease the BOD5 concentration. This is a problem that should be investigated and corrected.

Graph 11: BOD5 % Removal versus Overflow Rate. This graph shows the variation in BOD5 removal rates as a function of overflow rate. No obvious correlation between BOD% removal rate and overflow rate is evident.

Graph 12: BOD5 % Removal versus BOD5 Influent Concentration. This graph shows a correlation between BOD5 influent concentration and BOD5 removal efficiency. There is a higher removal of BOD5 at higher influent concentrations.

Graph 13: BOD5 Influent and Effluent Concentration - Monthly Average Data. This graph depicts BOD5 influent and effluent concentration based on monthly average data. It shows that BOD5 influent and effluent concentrations are quite variable over the entire 12 month period. It also shows many months where effluent concentrations are only slightly improved over influent concentrations.

Graph 14: BOD5 % Removal versus Month, 1990. Graph 14 is a different presentation of the same data shown in Graph 10. Whereas Graph 10 shows daily average data, Graph 14 gives monthly average data. It presents a sharper view of BOD5 removal efficiency. The error bars show the monthly standard deviation.

Graph 15: BOD5 % Removal versus Overflow Rate - Monthly Average Data. Graph 15 gives BOD5 % removal versus overflow



rate in terms of the monthly average data. Error bars shows monthly standard deviation.

Graph 16: BOD5 % Removal versus TSS Percent Removal.

This graph shows BOD5 % removal as a function of TSS % removal. One would expect a steep slope to the best fit line if most of the organic material was associated with settleable particles (> 40 micron). The fact that there is not a steep slope to this line suggests that most of the BOD5-related organic material is associated with colloidal (0.1 - 10 microns) or soluble material (< 0.07 microns).

### 1.3 CONCLUSIONS

- \* There is considerable variability in both flow and loading at GWPCF.
- \* The average TSS effluent concentration of 80 mg/l and TSS removal rate of 55% is characteristic of a well-functioning primary treatment plant.
- \* The average BOD5 effluent concentration of 160 mg/l and BOD5 removal rate of 17% is less than optimal for a well-functioning primary treatment plant. The BOD5 problem is likely a function of high industrial BOD5 contributions to the system and to the relatively high percent of soluble BOD5 in the influent BOD5.
- \* The existing plant is unable to consistently meet its effluent FOG permit limit of 15 mg/l.
- \* Assuming the renewal of the 301(h) waiver, chemical addition to the primary stage is a potentially viable option in any future upgrade to this facility in that it could increase BOD5 and FOG removal at a relatively nominal cost.

**SECTION 2**

## 2.0. JAR TESTS OF CHITOSAN, METAL SALTS, AND POLYACRYLAMIDES AT THE GLOUCESTER WATER POLLUTION CONTROL FACILITY

### 2.1 BACKGROUND AND PURPOSE

During the 1980s, the effectiveness of the addition of small quantities of metal salts plus polymers in increasing the removal of TSS, BOD5 and phosphorus has been demonstrated in full plant testing and operation at a number of primary wastewater treatment facilities in the United States, Canada, and Scandinavia. (Harleman and Morrissey, 1990; Morrissey, 1990). In Massachusetts, the Gloucester Water Pollution Control Facility (GWPCF) undertook a full-scale chemical addition test during the late summer and fall of 1989 and the South Essex Sewerage District (SESD) undertook a one year study of chemical addition as a part of a consent decree from October 1990 - 1991.

Chemical addition is relevant for the GWPCF because it is a cost-effective method to improve effluent quality. At present, the City of Gloucester has received verbal approval from EPA of their 301(h) waiver application. The 301(h) waiver allows them to discharge primary treated effluent through a newly constructed extended ocean outfall. Chemically-enhanced treatment could be useful for GWPCF if they have problems meeting compliance limits of their new NPDES permit or if they are required to upgrade to a higher form of treatment.

Jar tests are often used as the first step in determining the applicability of chemical addition at a particular wastewater treatment facility. Jar tests are used to screen various chemicals either alone and in combination to determine their efficacy, appropriate concentrations, order of addition, and mixing speed.

In December 1990, MIT submitted a proposal to Lynn Brown, Engineer, City of Gloucester, to conduct chemical addition tests at GWPCF. The program of jar testing decided on for GWPCF was patterned after the larger study of chemical addition that was occurring concurrently at the South Essex Sewerage District (SESD) also under the direction of Professor Donald Harleman of MIT. At GWPCF, MIT originally proposed conventional batch jar tests (stage one), continuous flow reactor tests (stage two), and a possible full scale test of chemically-enhanced treatment (stage three). However, mid-year results at SESD showed that the conventional batch jar testing method was sensitive to changes in chemical concentrations and a good indicator of plant performance. This coupled with the ease of running the conventional jar tests resulted in eliminating the use of the continuous flow reactor test from further investigation at SESD (Morrissey and Harleman, 1991b) and therefore from GWPCF.

A second insight gained at SESD that informed the conduct of testing and analysis at Gloucester was the use of COD instead of BOD5 as the chief indicator of organic pollution. COD was chosen

because the analysis time was relatively brief, a matter of hours, whereas BOD5 requires a 5 day waiting period.

Based on this experience, we decided to conduct two full weeks of conventional jar testing at GWPCF and, in the second test, to emphasize COD sample analysis. This testing took place on January 22 - 28, 1991, and on September 23-30, 1991.

The purpose of conducting a series of conventional batch jar tests at GWPCF was threefold:

1. To determine the efficacy of various metal salts, chitosan, and/or synthetic cationic and anionic polymers in promoting coagulation, flocculation, and sedimentation of Gloucester's raw influent;
2. Specifically, to test the effect of chitosan on municipal wastewater, which had not been done before, and which might be an appropriate coagulant in a community such as Gloucester that produces significant quantities of shellfish waste that could be recycled in the manufacture of chitosan;
3. To ascertain an appropriate chemical treatment regime for possible full scale chemical treatment at GWPCF based on the results of the jars tests in conjunction with a performance analysis and an evaluation of the plant design.

## **2.2 CHEMICALS TESTED AND CHEMICAL CHARACTERISTICS**

Tables 4 gives the chemicals tested during the two testing periods and Table 5 gives their chemical characteristics. Three types of chemicals have been used in this process: coagulants, coagulant aids and flocculants. Coagulation is the change of colloidal-sized particles into a denser solid mass. This change is effected by a coagulant and sometimes assisted by a coagulant aid. Because wastewater is often negatively charged, the coagulant and coagulant aid are typically positively charged particles, called cations. A second step in chemical wastewater treatment is called flocculation and is accomplished by a negatively charged particle, or anion, which enables the solids to form into assemblages of particles, called flocs. Because of their size and weight, flocs readily settle out of solution to the bottom of the reactor.

**TABLE 4 -- CHEMICALS TESTED**

COAGULANT	COAGULANT AID (cation)	FLOCCULANT (anion)
chitosan	chitosan	Delta # 2540 VHL
ferric chloride	Delta # 4701	Delta # S149-36
aluminum sulfate	Delta # 6395	Delta # S149-40
polyaluminum chloride	Delta # 6595H	Delta # S149-42
	Delta # 6795	
	Delta # 7004	
	Delta # 7394	

**TABLE 5 -- CHEMICAL CHARACTERISTICS**

COAGULANT	% SOLIDS	MOLECULAR WEIGHT	CHARGE DENSITY
	%	daltons	mole %
chitosan	100	161 - 2M	
ferric chloride	97	161	
aluminum sulfate	48.86	600	
polyaluminum chloride	100		
<b>COAGULANT AIDS (cation)</b>			
Delta # 4701	14		~60
Delta # 6395	38.2	8M	60
Delta # 6595H	35.5	10M	40
Delta # 6795	33.8	9M	20
Delta # 7004	41	14M	100
Delta # 7394	40	14M	60
<b>FLOCCULANTS (anion)</b>			
Delta # 2540 VHL	0.75	20M	40
Delta # S149-36	0.50	N/A	N/A
Delta # S149-40	0.50	N/A	N/A
Delta # S149-42	0.50	N/A	N/A

Toxicity is a chemical characteristic of concern not included on Table 5. The toxicity of polyacrylamides is one potential obstacle to the acceptance of new methods of chemically enhanced treatment by the environmental community. Unfortunately, the composition of many polyacrylamides is considered to be proprietary information by the manufactureres and purveyors, and an assessment of the toxicity of polyacrylamides is not a straightforward undertaking.

Facts generally known about polyacrylamides are that they have several undesirable characteristics:

- \* Cationic polyacrylamides (e.g. Delta #4701, 6395, 6595H, 6795, 7004,7394) may contain hazardous monomers (McCollister, D. 1989);
- \* The LD50 concentration for polyacrylamides in water treatment is 1,750 mg/kg +/- 219 for rats and 3,000 +/- 91 mg/kg body weight for mice (Lazareva, G. 1970). Lazareva recommends a dose of 0.2 mg/l in potable water.
- \* The cost of polyacrylamides, in common with most of the synthetic polymers, are tied to costs of energy and can be expected to rise according.

In contrast, chitosan is a natural polymer from chitin, which makes up at least 25% of shellfish waste. It is both non-toxic and biodegradeable. As a fisheries waste product, chitin offers opportunites for large scale waste recovery and reuse, which in turn could help invigorate the failing U.S. fisheries industry.

## 2.3 SET-UP

### 2.31 SOLUTION PREPARATION

#### COAGULANTS

(1) Chitosan: An 0.8% solution was prepared daily by dissolving 1.6 grams of chitosan (100% solids) in 200 ml of 1% acetic acid tap water solution (10ppm/cc).

(2) Ferric Chloride: An 0.8% solution was prepared daily by dissolving 1.64 grams of ferric chloride (97% solids) in 200 ml of tap water (10ppm/cc)

(3) Aluminum Sulfate: An 0.8% solution was prepared daily by dissolving 2.5 ml of aluminum sulfate (48.86% solids) in 200 ml of tap water (10ppm/cc).

(4) Polyaluminum Chloride: An 0.8% solution was prepared daily by dissolving 1.33 ml of polyaluminum chloride (100% solids) in 200 ml of tap water (10ppm/cc).

#### COAGULANT AIDS

(1) Chitosan: An 0.08% solution was prepared daily by dissolving 0.16 grams of chitosan (100% solids) in 200 ml of 1% acetic acid tap water solution (1ppm/cc).

(2) Delta #4701: An 0.08% solution was prepared daily by dissolving 1.1 ml of Delta #4701 (14% solids) in 200 ml of tap water (1ppm/cc).

(3) Delta #6395: An 0.008% solution was prepared daily by dissolving 0.042 ml of Delta #6395 (38.2% solids) in 200 ml of tap water (0.1ppm/cc).

(4) Delta #6595H: An 0.008% solution was prepared daily by dissolving 0.045 ml of Delta #6595H (35.5% solids) in 200 ml of tap water (0.1ppm/cc).

(5) Delta #6795: An 0.008% solution was prepared daily by dissolving 0.047 ml of Delta #6795 (33.8% solids) in 200 ml of tap water (0.1ppm/cc).

(6) Delta #7004: An 0.008% solution was prepared daily by dissolving 0.039 ml of Delta #7004 (41% solids) in 200 ml of tap water (0.1ppm/cc).

(7) Delta #7394: An 0.008% solution was prepared daily by dissolving 0.040 ml of Delta #7394 (40% solids) in 200 ml of tap water (0.1ppm/cc).

#### FLOCCULANTS

(1) Delta # 2540VHL: An 0.008% solution was prepared daily by dissolving 2.1 ml of Delta #2540 (0.75% solids) in 200 ml of tap water (0.1ppm/cc).

(2) Delta #S149-36: An 0.008% solution was prepared daily by dissolving 3.2 ml of Delta #S149-36 (0.50% solids) in 200 ml of tap water (0.1ppm/cc).

(3) Delta #S149-40: An 0.008% solution was prepared daily by dissolving 3.2 ml of Delta #S149-40 (0.50% solids) in 200 ml of tap water (0.1ppm/cc).

(4) Delta #S149-42: An 0.008% solution was prepared daily by dissolving 3.2 ml of Delta #S149-42 (0.50% solids) in 200 ml of tap water (0.1ppm/cc).

### **2.32 APPARATUS**

The jar tests were conducted using a Philips Bird gang stirrer with six mixing paddles.

### **2.33 SAMPLE COLLECTION**

The medium for the jar tests was the influent to the Gloucester Water Pollution Facility. During the January test, grab samples were collected for every one or two series of tests using a bucket. During the September test, grab samples were collected in the same way on Day 1. For the remainder of the September test (Day 2 - Day 5), grab samples were collected for the entire day (6-7 series) at the beginning of each day. Four buckets were combined into one large plastic garbage can. The change in sampling procedure was motivated by the fact that in combining the samples, the number of influent samples for analysis per day was minimized. However, this latter method of sample collection may have negatively contributed to some of the results, as will be discussed below. Once collected, the raw samples were distributed among the six 1000 ml beakers.

### **2.34 PROCEDURE**

The following testing procedure was used:

- 1) Fill 1000 ml beaker with 800 ml raw influent.
- 2) Mix at 100 RPM.
- 3) Inject coagulant and coagulant aid and mix at 100 RPM for 1 minute.
- 4) Stop stirrer and allow water to slow down. Inject anionic polymer and stir at 100 RPM for 30 seconds.
- 6) Slow to 40 RPM. Stir for 1 minute.
- 7) Stop. Allow to settle for 3-5 minutes.
- 8) Using a 60 ml syringe, draw samples from below the surface. Decant approximately 150 ml for TSS analysis, 50 ml for BOD5 analysis, 50 ml for P analysis.

### **2.35 ANALYSES PERFORMED**

The standard practice at GWPCF is for plant personnel to perform 3 sets of TSS and BOD tests per week on both the influent and effluent. They also take daily readings of pH, settleable solids, and chlorine residuals. During the January test period, jar test sample analysis was performed by GWPCF in-house staff which required that person work overtime to perform 4 TSS analyses per day for each of four days, and 8 BOD5 analyses on the final day for the MIT tests.



During the September testing period, TSS and COD analyses were performed on a daily basis by MIT's lab technician at SESD. On the final day of the September testing period, all samples were also analyzed for phosphorus.

Table A-1 and A-2 (see Appendix A) give plant performance data for test weeks 1 and 2. These tables are meant to serve as a guide regarding what took place at the plant itself during the 2 jar test weeks. These weekly plant summaries can in turn be compared to Table 3 in Section 1.14, which show GWPCF's 1990 daily average data.

#### Total Number of Samples Analyzed:

TSS: A total of 20 samples were analyzed during Test 1 (Jan 22-28, 1991) and 53 samples were analyzed during Test 2 (September 23-30) for a total of 73 samples analyzed.

BOD5: A total of 8 samples were analyzed for BOD5 during Test 1 on Day 5 of the test. These results were poor due to salt water infiltration on that day.

COD: A total of 53 samples were analyzed during Test 2 for COD. COD was used instead of BOD5, based on good experience with this method as a substitute for BOD5 at SESD. At SESD, COD removal was found to correlate well with BOD5 removal (Morrissey and Harleman, 1991).

## **2.4 CONDUCT OF JAR TESTS**

The jar tests were performed at the GWPCF laboratory over 2 five day periods from Tuesday, January 22 - Monday, January 28, 1991 and from Monday, September 23 - Monday, September 30, 1991. Between 6 - 8 series of tests of six jars per test could be accomplished on each of the five days. A specific goal was set for each day, based on the results of the previous day and all relevant information was recorded on a daily basis in a lab notebook. The characteristics of each jar in each series was visually observed for floc size, clarity, settleability. These observations were recorded on separate "Jar Test Data Sheets" which had been prepared in advance. One sheet was filled out for each series. (A sample "Jar Test Data Sheet" is given as Appendix B.) During the January test, the last run was intended to imitate the best experience of the day and the 4 best jars were then selected for analysis. During the September test, the best jar or jars for each run of each day were selected for analysis.

There were several problems that occurred during the test:

Rain: There were torrential rains on Day 5 of the January test, and Day 3-4 of the September test. The rains created significant inflow and infiltration into the wastestream. On Day 5 of the January test, the rains

coincided with astronomically high tides, which in turn meant significant salt water infiltration. Many of the results obtained during these rainy days turned out to be useless.

Low Influent Concentration: Due possibly to the sampling procedure followed during the September test (see discussion above), the blanks analyzed on Day 5 of the September test had unusually low influent concentrations (in spite of good weather). These results were less than optimal.

Cation Solution Preparation: During Day 2 - Day 4 of the September test, the cationic polyacrylamide coagulant aids were incorrectly made up. Instead of 0.008% solutions, 0.8% solutions were prepared. These results were not considered in the overall analysis presented here.

## 2.5 RESULTS

The results are examined below in two different ways, first on a day-by-day basis and then as a combined set of results.

### Day-by-Day Analysis:

For the total of 73 samples analyzed, the results have been tabulated as follows. (All tables are provided in Appendix A.) First, results are listed by test period and test day. Given that there were so few results for the January test, Tables A-3 presents all the analyzed results of that test. For the September test, each day's results were screened for the best results and this sub-set is presented. Table A-4 gives the test day, a jar identification number, and the chemical doses used during the September test. Table A-5a presents the TSS data and Table A-5b presents the COD and P data for these samples. Table 6 sorts the Table 5 TSS % improvement results in decreasing order.

### % Removal versus % Improvement:

The reader should note the distinction made throughout this section of the report between % removal and % improvement, because it is the basis by which all the results are evaluated.

$$\% \text{ removal} = \frac{\text{influent conc.} - \text{jar test sample result conc.}}{\text{influent conc.}}$$

$$\% \text{ improvement} = \frac{\text{conc. of blank} - \text{jar test sample result conc.}}{\text{conc. of blank}}$$

During both test periods, the influent concentration was available from the regular analyses performed by plant personnel. It is an average daily value. It was available on selected days only. The jar testing analyses were a separate activity. The jar testing sample blank was analyzed along with the jar test sample results. This blank should be roughly the equivalent of the plant effluent, as, in the jar test procedure, it is subjected to mixing and gravity settling, as is the primary effluent. Tables and graphs discussed below will specify % removal and/or % improvement for each result.

## TEST 1

Day 1: No tests. This day was considered a dry run. No samples were taken for analysis.

Day 2: On this day, the optimal SESD chemical regime of 50 mg/l alum + 5 mg/l 4701 + 0.2 mg/l 2540 was tested against the other metal salts at the same or similar concentrations and against a good chitosan dosage. This test, on the first day of sample analysis, gave the most impressive chitosan results in terms of TSS % removal. Graph 17 shows these results.

Day 3: On Day 3, chitosan was tested as a primary coagulant in the dose range of 5 - 50 mg/l. 10 mg/l seemed to be an optimal chitosan dose. Graph 18 shows that the previous day's successful dose of 15 mg/l chitosan with a lower cationic dose performed quite poorly. However, doses of 10 mg/l chitosan performed comparatively better in terms of both TSS % removal and TSS % improvement.

Day 4: On Day 4, chitosan was tested as a coagulant aid. Chitosan worked quite well as a coagulant aid, albeit in higher concentrations of 5 - 10 mg/l. In contrast, optimal synthetic cation concentrations during the January test was in the 2 - 5 mg/l range. Graph 19 shows these results.

Day 5: On this day, the best results from Day 4 (a metal salt as the primary coagulant + chitosan as the coagulant aid) were repeated and these regimes were compared to the best chitosan results from Day 2 and Day 3. The new variable on this day was torrential rains with astronomically high tides and salt water infiltration as great as 50% of the total influent flow, according to the plant manager. On this, the final day of the first test, BOD5 analyses were performed in addition to TSS analyses. Where BOD5 results were fairly identical from sample to sample, TSS results showed the metal salts outperforming chitosan by a considerable margin. Where the 10 mg/l metal salt + 10 mg/l chitosan + 0.5 mg/l 2540 doses gave over 90 % TSS % removal under the normal plant conditions of the previous Day 4, TSS %

improvement on Day 5 was under 70% for those same regimes. Graph 20 shows these results.

## TEST 2

Day 1: On the first day of the second test, a two chemical procedure was tested. (A coagulant + an anion. No coagulant aid.) The best results are given in Graph 21. Visual results had shown that the higher dosage of 60 mg/l FeCl<sub>3</sub> was more or less comparable to low doses of chitosan in the 8 - 10 mg/l range. With these FeCl<sub>3</sub> and chitosan doses, TSS % improvements are almost identical. FeCl<sub>3</sub> does somewhat better on COD removal.

Day 2: No results considered due to incorrect solution make-up.

Day 3: Heavy rain. On this day, a very low pH of 4.0 was recorded at 8 am. Grab samples for the jar tests were collected at 9 am and a standard regime using ferric chloride was compared to a standard regime using alum. FeCl<sub>3</sub> performed considerably better than alum in the low pH wastewater (Graph 22). In further tests, a standard dose of FeCl<sub>3</sub> with chitosan as a coagulant aid and a new anionic polymer was tested (Graph 23). We see in these results a situation which occurred with some regularity where the best TSS % improvement corresponded with the worst COD % improvement (see also, Graph 24).

Day 4: Heavy rains continued. Again, the optimal FeCl<sub>3</sub> dose was tested with chitosan as a coagulant aid and various different anions. The intent of both Day 3 and Day 4 of Test 2 was to try to come up with a good regime for handling a weak influent. Also, the purpose of this day was to test a variety of different anionic polymers in different concentrations. The 4 results in Graph 24 indicate that there is little difference in the performance of the several anionic polymers, when all other factors are held constant.

Day 5: Once again the final day of the test period, intended as the grand finale, fell short of expectation. Although it was a beautiful sunny day, influent TSS was 65 mg/l, influent COD was 187 mg/l, both very atypical for GWPCF. Given these low influent values, the interpretation of this day's results must be taken with a grain of salt. One interesting result is evident when the samples analyzed are arranged by TSS % improvement (Table A-6). By this arrangement, all of the metal salts outperform the chitosan regimes. Graph 25 shows some of the best results. Table A-6 also shows that metal salts perform better than chitosan in terms of COD % improvement.

Phosphorus analyzes were done on this day (Table A-7). The data indicates that all of the metal salts regimes outperform all of the chitosan regimes, suggesting that chitosan is not

useful in the removal of phosphorus, at least in conditions of low influent strength.

Based on Table A-7, the following chemical regimes were effective in P removal and also appeared on the TSS and COD optimal lists:

**TABLE 6  
CHEMICAL REGIMES FROM P LIST  
COMMON TO TSS OR COD SHORT LISTS**

Coagulant	Coagulant Aid	Flocculant
50 mg/l FeCl <sub>3</sub>	0.2 mg/l 6545H	0.5 mg/l 2540
20 mg/l FeCl <sub>3</sub>	10 mg/l chitosan	0.5 mg/l 2540
40 mg/l FeCl <sub>3</sub>	0.5 mg/l 6595H	0.5 mg/l 2540
40 mg/l FeCl <sub>3</sub>	0.2 mg/l 6540H	0.5 mg/l 2540

Complete Set Analysis:

A second way of examining the data is to combine all the best results and note any patterns. This is what has been done in Table A-8 and A-9. Beginning with the master lists (Tables A-3 and A-4) and with TSS as the lead parameter (because it was the only parameter for which all samples were analyzed), Table A-8 is comprised of the best results from that master list, screened on the basis of a minimum of 65% improvement. The table is then arranged from best to worst by TSS % improvement.

Table A-9 is comprised of the same optimal regimes as Table A-8, except it is a shorter list because there are fewer COD results. Table A-9 is ordered according to COD % improvement.

These two arrangements of the best jar test results show that chitosan and alum as primary coagulants appear on the list 6 and 7 times respectively. FeCl<sub>3</sub> shows up with twice that frequently. These arrangements also indicate 3 dominant types of successful chemical regimes:

- (1) 40 - 60 mg/l metal salt (FeCl<sub>3</sub> or alum) + 0.2 - 0.5 mg/l cation (#4701, #6595H, #7394) + 0.2 - 0.5 mg/l #2540. This is essentially the SESD standard chemical regime. (Graph 25 and Tables A-8 and A-9);
- (2) 10 - 20 mg/l metal salt (FeCl<sub>3</sub> or alum) + 5 -10 mg/l chitosan + 0.5 mg/l anion (#2540, #S149-40) (Graphs 19 and 20);
- (3) 10 mg/l chitosan + 0.5 - 1.5 mg/l #2540 (with the possible addition of 5 mg/l # 4701 or 7394) (Graphs 17 and 18).

That the first of these successful regimes is close to the standard SESD chemical regime should not come as a surprise. The correspondence between an efficient chemical regime at both sites may be due to the fact that SESD and Gloucester, as geographically proximate communities with similar industries and commercial establishments and similar wastestream characteristics may respond to the similar chemical regimes.

The second successful regime uses chitosan as a coagulant aid. That chitosan works well as a coagulant aid is a new and interesting result. The dosage in the 5 - 10 mg/l range permits the use of lower dosages of metal salts in the 10 - 20 mg/l range.

The third successful regime shows that chitosan may have a role to play in chemically enhanced primary treatment. That chitosan worked well as a primary coagulant at 1/4 - 1/5 the typical metal salt dosage and did so with a anionic polymer only, or with a cation and an anion, is another interesting result.<sup>3</sup>

## 2.6 SUMMARY AND CONCLUSIONS:

There was so much variability during these two test periods: stormy weather, astronomically high tides with high inflow and infiltration, unusually low pH, unusually low influent concentrations even under sunny skies, and my own error of incorrect cationic sample preparation during part of Test 2, that it is difficult to draw hard and fast conclusions. Nevertheless, some conclusions are offered below and where conclusions are not possible, one can make some observations:

\* Chitosan performs optimally at about 1/5 the dosage of metal salts.

\* Chitosan outperformed all the metal salts by a significant margin on Day 2 of Test 1 in terms of TSS % removal. However, the same chitosan dose with a lower anionic dose on the next day performed poorly.

\* Chitosan could be used successfully as a coagulant aid, allowing lower doses of metal salts to be applied.

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<sup>3</sup>When all the testing was over, the author came upon a reference in which a buffer of potassium phosphate was used in order to optimize the performance of chitosan in flocculation/coagulation (Johnson, R.; Gallanger, S. 1984). The use of a buffer should be tried in future testing of chitosan.

\* Metal salts outperform chitosan as a primary coagulant in weak influent conditions.

\* Chitosan appears not to be useful in phosphorus removal, at least in weak influent conditions (Table A-7).

\* In terms of TSS % removal, FeCl<sub>3</sub>, alum, and polyaluminum chloride performed identically on Day 2 of Test 1 and FeCl<sub>3</sub> and alum performed similarly on Day 4 and Day 5 of Test 1 when pH was in a normal range. During conditions of low pH during Test 2, FeCl<sub>3</sub> worked better than alum.

\* COD could be used as a substitute for BOD<sub>5</sub>; COD/BOD<sub>5</sub> % removal was in the 40 % range, not higher, probably because of the high soluble BOD<sub>5</sub> in the influent due to fish processing industrial discharge and the recycle of sludge processing water to the head of the plant.

\* Little difference was observed in the performance of anionic polymers.

\* Significant differences were observed between the various cationic polymers when used in high doses with chitosan.

\* 3 types of chemical regimes are worth further investigation at GWPCF and in other municipal wastewater treatment applications:

**TABLE 7  
CHEMICAL REGIMES APPROPRIATE FOR GWPCF**

Coagulant	Coagulant Aid	Flocculant
5 - 15 mg/l chitosan	5 mg/l 4701 or 7394	0.5 - 1.5 mg/l 2540
40 - 60 mg/l FeCl <sub>3</sub> or other metal salt	0.2 - 0.5 mg/l synthetic cation	0.2 - 0.5 mg/l 2540
10 - 20 mg/l FeCl <sub>3</sub> or other metal salt	5 - 10 mg/l chitosan	0.5 mg/l 2540

While jar test results tend to give performance results which are not reproducible at the same high level in full plant application, they are nonetheless a good method of screening chemicals and evaluating their relative merits. If we compare yearly average performance at GWPCF and the best jar tests results we see striking differences:

**TABLE 8**  
**COMPARISON OF 1990 PLANT TSS AND BOD5/COD REMOVALS**  
**WITH OPTIMAL JAR TEST RESULTS**

	GWPCF - 1990 Data (% Removal)	Optimal Jar Tests (% Improvement)
TSS	55%	85 - 95 %
BOD5/COD	17%	40 - 50 %

Experience at SESD has confirmed that jar test results can serve to predict performance at the full plant scale. That same experience has also shown that significant improvements are possible: TSS removal was improved by 24 percentage points and BOD efficiency was improved by 25- 45 percentage points during the Spring 1991 testing period (Morrissey and Harleman, 1991a)

As the performance and cost benefits of chemically enhanced primary treatment become more widely known, new chemicals such as chitosan will be increasingly tested. This type of testing is and will be an important area for potential innovation in wastewater treatment. Especially as the problems associated not only TSS and BOD5 loading, but with nutrients, toxics and heavy metals loading become more pronounced, increased attention will be paid to testing these untried chemical regimes and processes.

Although the efficacy of chitosan relative to metal salts in the removal of metals and toxics was not a subject of this test, recent work has shown chitosan to be highly effective in the removal of PCBs (Thome and Van Daele, 1988) and various heavy metals (Sigon, 1989). That it has performed well in removing conventional pollutants and that it holds promise in removing hard to manage toxics contaminants shows that chitosan is worthy of further investigation in municipal wastewater treatment and beyond.



### 3.0 REFERENCES

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**APPENDIX A - TABLES**

Gloucester WPCF pH, TSS, and BOD5 Data - Jan. 22-28, 1991

		pH Inf	pH Eff	TSS Inf mg/l	TSS Eff mg/l	TSS Rem %	BOD5 Inf mg/l	BOD5 Eff mg/l	BOD5 Rem %
DAY 1	Tues	1/22/91	7.2	7.1					
DAY 2	Wed	1/23/91	7.2	7	115	5	132	199	-50
DAY 3	Thur	1/24/91	7.1	7	86	30	188	203	-8
DAY 4	Fri	1/25/91	7	6.9	92	55	230	184	20
DAY 5	Mon	1/30/91	6.8	6.7					
		AVERAGE	7	7	98	30	183	195	-13
		STD. DEV.	0.17	0.15	15	25	49	10	35

TABLE A-1

Gloucester WPCF pH, TSS, and BOD5 Data - Sept. 23-30, 1991

		pH Inf	pH Eff	TSS Inf mg/l	TSS Eff mg/l	TSS Rem %	BOD5 Inf mg/l	BOD5 Eff mg/l	BOD5 Rem %	
DAY 1	Mon	9/23/91	6.9	6.7						
DAY 2	Tues	9/24/91	7	6.8						
DAY 3	Wed	9/25/91	5.6	6.1	176	82	53	166	139	16
DAY 4	Thur	9/26/91	6.5	6.4	27	19	30	69	37	46
DAY 5	Mon	9/30/91	6.9	6.7						
		AVERAGE	7	7	102	51	42	118	88	31
		STD.DEV.	0.58	0.29	105	45	16	69	72	21

TABLE A-2

TABLE A-3: Gloucester Jar Test Results - Jan. 23-28, 1991

DATE	Jar #	Conc mg/l	Coagulant	Coag. Aid Conc mg/l	Floc. mg/l	TSS mg/l	TSS % Improvement	TSS Rem %	BOD5 mg/l	BOD5 % Improvement	
DAY 1 1/22/91 (Tues)			NO TEST								
	DAY 2 1/23/91 (Wed)		INFLUENT			122					
		1	60	FeCl3	5	4701	0.5	2540		84	
		2	50	Alum	5	4701	0.5	2540		84	
3		50	PAC	5	4701	0.5	2540		84		
DAY 3 1/24/91 (Thur)	4	15	Ch	5	4701	0.5	2540		96		
			INFLUENT								
			BLANK								
	5					122					
DAY 4 1/25/91 (Fri)	6	15	Ch	2	4701	0.5	2540		47		
	7	10	Ch			1.5	2540		60		
	8	10	Ch			1	2540		84		
						12			90		
DAY 5 1/28/91 (Mon)			INFLUENT								
	9	30	FeCl3	10	Ch	0.5	2540		206		
	10	10	FeCl3	10	Ch	0.5	2540		25		
	11	50	Alum	10	Ch	0.5	2540		21		
DAY 5 1/28/91 (Mon)	12	10	Alum	10	Ch	0.5	2540		5		
						12			12		
			BLANK								
	13					145			179		
DAY 5 1/28/91 (Mon)	14	10	Ch			132			NT		
	15	10	Ch								
	16	10	FeCl3	10	Ch	0.5	2540		9		
	17	10	Alum	10	Ch	0.5	2540		63		
DAY 5 1/28/91 (Mon)	18	10	Ch			48			67		
	19	30	Ch			48			110		
	20	15	Ch	5	4701	0.5	2540		126		
						120			17		
DAY 5 1/28/91 (Mon)						153			134		
						128			108		
						AVE.			83		
						ST.DEV.			25		
						41		15			
						32		6			

TABLE A-3

Sept, 1991 Test Period - Chemical Dosages

DATE	Jar #	Conc mg/l	Coagulant	Conc mg/l	Coagulant Aid	Conc mg/l	Flocculant
9/23/91	1	60	FeCl3			0.5	2540
(Mon)	2	114	Alum			0.5	2540
	3	10	Ch			0.5	2540
9/24/91	4	10	Ch	20	6595H	0.5	2540
(Tues)	5	50	FeCl3	20	6595H	0.5	2540
	6	80	FeCl3	20	6595H	0.5	2540
	7	6	Ch	20	7394	0.5	2540
	8	8	Ch	20	7394	0.5	2540
	9	40	FeCl3	20	7394	0.5	2540
9/25/91	10	40	FeCl3	20	6595H	0.5	2540
(Wed)	11	40	FeCl3	5	Ch	0.5	S149-40
	12	40	FeCl3	10	Ch	0.5	S149-40
	13	30	FeCl3	5	Ch	0.5	S149-40
9/26/91	14	40	FeCl3	5	Ch	0.2	S149-40
(Thur)	15	40	FeCl3	5	Ch	0.5	S149-40
	16	40	FeCl3	30	6595H	0.5	2540
	17	40	FeCl3	3	Ch	0.5	2540
9/30/91	18	40	FeCl3	0.2	6595H	0.5	2540
(Mon)	19	40	FeCl3	0.5	6595H	0.5	2540
	20	50	FeCl3	0.2	6595H	0.5	2540
	21	50	FeCl3	0.5	6595H	0.2	2540
	22	40	Alum	0.5	6595H	0.5	2540
	23	30	Alum	0.5	6595H	0.5	2540
	24	20	FeCl3	10	Ch	0.5	S149-40
	25	30	Alum	0.3	7394	0.5	2540
	26	40	Alum	10	Ch	0.5	S149-40
	27	10	Ch	0.2	6595H	0.5	S149-40
	28	10	Ch	0.2	6595H	0.2	S149-40
	29	10	Ch	0.2	7394	0.5	2540
	30	10	Ch	0.5	7394	0.5	S149-40
	31	10	Ch	0.4	7394	0.5	S149-40
	32	10	Ch	0.6	7394	0.5	S149-40

TABLE A-4

Gloucester.WPCF Optimal TSS Test Results: Sept, 1991

	DATE	Jar #	TSS Inf mg/l	TSS Blank mg/l	TSS Eff mg/l	TSS % Improvemt	TSS Rem %
<b>DAY1</b>	<b>9/23/91</b>						
	<b>(Mon)</b>			133			
		1			40	70	
		2			18	86	
		3			40	70	
<b>Day 2</b>	<b>9/24/91</b>						
	<b>(Tues)</b>			106			
		4			32	70	
		5			30	72	
		6			32	70	
		7			4	96	
		8			16	85	
		9			24	77	
<b>Day3</b>	<b>9/25/91</b>						
	<b>(Wed)</b>		176	40			
		10			12	70	93
		11			10	75	94
		12			6	85	97
		13			14	65	92
<b>Day 4</b>	<b>9/26/91</b>						
	<b>(Thur)</b>		27	48			
		14			14	71	48
		15			8	83	70
		16			6	88	78
		17			10	79	63
<b>Day 5</b>	<b>9/30/91</b>						
	<b>(Mon)</b>			65			
		18			2	97	
		19			10	85	
		20			2	97	
		21			12	82	
		22			10	85	
		23			18	72	
		24			8	88	
		25			14	78	
		26			28	57	
		27			34	48	
		28			40	38	
		29			36	45	
		30			32	51	
		31			30	54	
		32			34	48	
	<b>AVE</b>		<b>102</b>	<b>78</b>	<b>16</b>	<b>80</b>	<b>79</b>
	<b>STD. DEV.</b>		<b>105</b>	<b>40</b>	<b>11</b>	<b>9</b>	<b>18</b>

TABLE A-5a

Gloucester WPCF Optimal COD P Test Results: Sept, 1991

	DATE	Jar #	COD Blank mg/l	COD Eff mg/l	COD % Improvement	P Blank mg/l	P Eff mg/l	P % Improvement
<b>DAY1</b>	<b>9/23/91</b>							
	(Mon)		457					
		1		270	41			
		2		247	46			
		3		407	11			
<b>Day 2</b>	<b>9/24/91</b>							
	(Tues)		406					
		4		258	36			
		5		209	49			
		6		216	47			
		7		210	48			
		8		246	39			
		9		213	48			
<b>Day3</b>	<b>9/25/91</b>							
	(Wed)		86					
		10		79	8			
		11		50	42			
		12		79	8			
		13		70	19			
<b>Day 4</b>	<b>9/26/91</b>							
	(Thur)		104					
		14		88	15			
		15		94	10			
		16		85	18			
		17		79	24			
<b>Day 5</b>	<b>9/30/91</b>							
	(Mon)		187			7.2		
		18		110	41		1.9	74
		19		107	43		0.6	92
		20		141	25		0.3	96
		21		145	22		0.7	90
		22		142	24		2.6	64
		23		122	35		1.3	82
		24		146	22		2.5	65
		25		145	22		2.2	69
		26		157	16		6.6	8
		27		194	-4		NT	
		28		180	4		NT	
		29		184	2		7	3
		30		146	22		NT	
		31		196	-5		6.2	14
		32		205	-10		6.5	10
	<b>AVE</b>		<b>248</b>	<b>158</b>	<b>30</b>	<b>7.2</b>	<b>1.5</b>	<b>79</b>
	<b>STD. DEV.</b>		<b>173</b>	<b>85</b>	<b>14</b>		<b>0.9</b>	<b>13</b>

TABLE A-5b



TEST 2: Day 5 Results, Sorted by TSS % Improvement

Jar #	Conc mg/l	Coag	Conc mg/l	Coag Aid	Conc mg/l	Flocculant	TSS Eff mg/l	TSS % Improve	COD Eff mg/l	COD % Improve	P Eff mg/l	P % Improvement
18	40	FeCl3	0.2	6595H	0.5	2540	2	97	110	41	1.9	74
20	50	FeCl3	0.2	6595H	0.5	2540	2	97	141	25	0.3	96
24	20	FeCl3	10	Ch	0.5	S149-40	8	88	146	22	2.5	65
19	40	FeCl3	0.5	6595H	0.5	2540	10	85	107	43	0.6	92
22	40	Alum	0.5	6595H	0.5	2540	10	85	142	24	2.6	64
21	50	FeCl3	0.5	6595H	0.2	2540	12	82	145	22	0.7	90
25	30	Alum	0.3	7394	0.5	2540	14	78	145	22	2.2	69
23	30	Alum	0.5	6595H	0.5	2540	18	72	122	35	1.3	82
26	40	Alum	10	Ch	0.5	S149-40	28	57	157	16	6.6	8
31	10	Ch	0.4	7394	0.5	S149-40	30	54	196	5	6.2	14
30	10	Ch	0.5	7394	0.5	S149-40	32	51	146	22	NT	
27	10	Ch	0.2	6595H	0.5	S149-40	34	48	194	-4	NT	
32	10	Ch	0.6	7394	0.5	S149-40	34	48	205	-10	6.5	10
29	10	Ch	0.2	7394	0.5	2540	36	45	184	2	7	3
28	10	Ch	0.2	6595H	0.2	S149-40	40	38	180	4	NT	

TABLE A-6

Best Jar Test Results Arranged by Total P % Improvement

Conc mg/l	Coag	Conc mg/l	Coag. Aid	Conc mg/l	Floc.	TSS mg/l	TSS % Improvem	COD mg/l	COD % Improvem	P mg/l	P % Improvem
50	FeCl3	0.2	6595H	0.5	2540	2	97	141	25	0.3	96
40	FeCl3	0.5	6595H	0.5	2540	10	85	107	43	0.6	92
50	FeCl3	0.5	6595H	0.2	2540	12	82	145	22	0.7	90
30	Alum	0.5	6595H	0.5	2540	18	72	122	35	1.3	82
40	FeCl3	0.2	6595H	0.5	2540	2	97	110	41	1.9	74
30	Alum	0.3	7394	0.5	2540	14	78	145	22	2.2	69
20	FeCl3	10	Ch	0.5	S149-40	8	88	146	22	2.5	65
40	Alum	0.5	6595H	0.5	2540	10	85	142	24	2.6	64
					<b>AVERAGE</b>	<b>10</b>	<b>85</b>	<b>132</b>	<b>29</b>	<b>1.51</b>	<b>79</b>
					<b>STD.DEV.</b>	<b>6</b>	<b>9</b>	<b>17</b>	<b>9</b>	<b>0.91</b>	<b>13</b>

TABLE A-7

Best Jar Test Results Arranged by TSS % Improvement

Conc	Coag.	Conc	Coag. Aid	Conc	Floc.	TSS Final mg/l	TSS % Imprvmt	COD Final mg/l	COD % Imprvmt
50	Alum	10	Ch	0.5	2540	5	98		
40	FeCl3	0.2	6595H	0.5	2540	2	97	110	41
50	FeCl3	0.2	6595H	0.5	2540	2	97	141	25
15	Ch	5	4701	0.5	2540	5	96		
10	Alum	10	Ch	0.5	2540	12	94		
10	FeCl3	10	Ch	0.5	2540	21	90		
30	FeCl3	10	Ch	0.5	2540	25	88		
20	FeCl3	10	Ch	0.5	S149-40	8	88	146	22
40	FeCl3	10	Ch	0.5	S149-40	6	85	79	8
40	FeCl3	0.5	6595H	0.5	2540	10	85	107	43
40	Alum	0.5	6595H	0.5	2540	10	85	142	24
60	FeCl3	5	4701	0.5	2540	19	84		
50	Alum	5	4701	0.5	2540	19	84		
50	PAC	5	4701	0.5	2540	19	84		
40	FeCl3	5	Ch	0.5	S149-40	8	83	94	10
10	Ch			1	2540	12	82		
50	FeCl3	0.5	6595H	0.2	2540	12	82	145	22
40	FeCl3	3	Ch	0.5	2540	10	79	79	24
30	Alum	0.3	7394	0.5	2540	14	78	145	22
40	FeCl3	5	Ch	0.5	S149-40	10	75	50	42
40	FeCl3	5	Ch	0.5	S149-40	10	75	50	42
30	Alum	0.5	6595H	0.5	2540	18	72	122	35
10	Ch			1.5	2540	19	71		
40	FeCl3	5	Ch	0.2	S149-40	14	71	88	15
60	FeCl3			0.5	2540	40	70	270	41
10	Ch			0.5	2540	42	68	320	30
10	Ch			0.5	2540	42	68	335	27
10	FeCl3	10	Ch	0.5	2540	48	67	(BOD)115	36
10	Alum	10	Ch	0.5	2540	48	67	(BOD)110	39
10	Ch			1	2540	53	63	(BOD)112	37
					<b>AVERAGE</b>	<b>14</b>	<b>83</b>	<b>131</b>	<b>28</b>
					<b>STD.DEV.</b>	<b>10</b>	<b>9</b>	<b>72</b>	<b>12</b>

TABLE A-8

**Best Jar Test Results Arranged by COD % Improvement**

Conc	Coag	Conc	Coag. Aid	Conc	Floc.	TSS Final mg/l	TSS % Imprvmt	COD Final mg/l	COD % Imprvmt
40	FeCl3	0.5	6595H	0.5	2540	10	85	107	43
40	FeCl3	5	Ch	0.5	S149-40	10	75	50	42
40	FeCl3	0.2	6595H	0.5	2540	2	97	110	41
60	FeCl3			0.5	2540	40	70	270	41
10	Alum	10	Ch	0.5	2540	48	67	(BOD)110	39
10	Ch			1	2540	53	63	(BOD)112	37
10	FeCl3	10	Ch	0.5	2540	48	67	(BOD)115	35
30	Alum	0.5	6595H	0.5	2540	18	72	122	35
10	Ch			0.5	2540	42	68	320	30
10	Ch			0.5	2540	42	68	335	27
50	FeCl3	0.2	6595H	0.5	2540	2	97	141	25
40	Alum	0.5	6595H	0.5	2540	10	85	142	24
40	FeCl3	3	Ch	0.5	2540	10	79	79	24
50	FeCl3	0.5	6595H	0.2	2540	12	82	145	22
30	Alum	0.3	7394	0.5	2540	14	78	145	22
20	FeCl3	10	Ch	0.5	S149-40	8	88	146	22
40	FeCl3	5	Ch	0.2	S149-40	14	71	88	15
40	FeCl3	5	Ch	0.5	S149-40	8	83	94	10
40	FeCl3	10	Ch	0.5	S149-40	6	85	79	8
					<b>AVERAGE</b>	<b>26</b>	<b>77</b>	<b>158</b>	<b>19</b>
					<b>STD DEV.</b>	<b>19</b>	<b>11</b>	<b>89</b>	<b>8</b>

TABLE A-9

**APPENDIX B**

JAR TEST DATA

Circle One:    Trial Preliminary Final Confirmation

Jar	Chemicals Used & Concentration (mg/l)					Color	pH	TSS (mg/l)	Clarity and Visual Observations
	Lime	Alum	ferric	Cationic	Anionic				
1									
2									
3									
4									
5									
6 Control	0	0	0	0	0				

Polymer Manufacturer: \_\_\_\_\_

Comments:

Mixing:    ✓

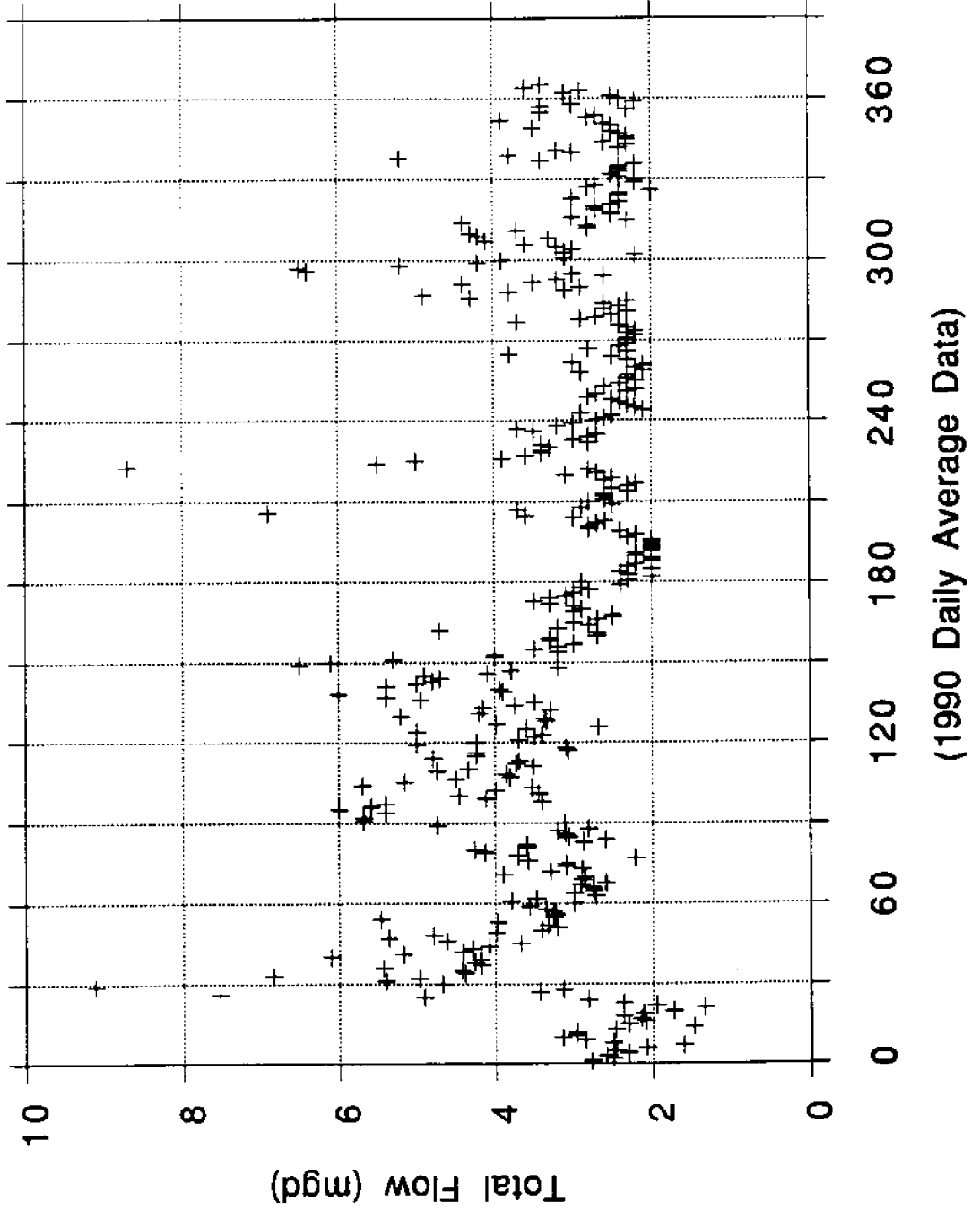
Sequence/Time of Chemical Addition:

\_\_\_\_\_ Min. @ \_\_\_\_\_ RPH  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

**APPENDIX C - GRAPHS**

# GRAPH 1

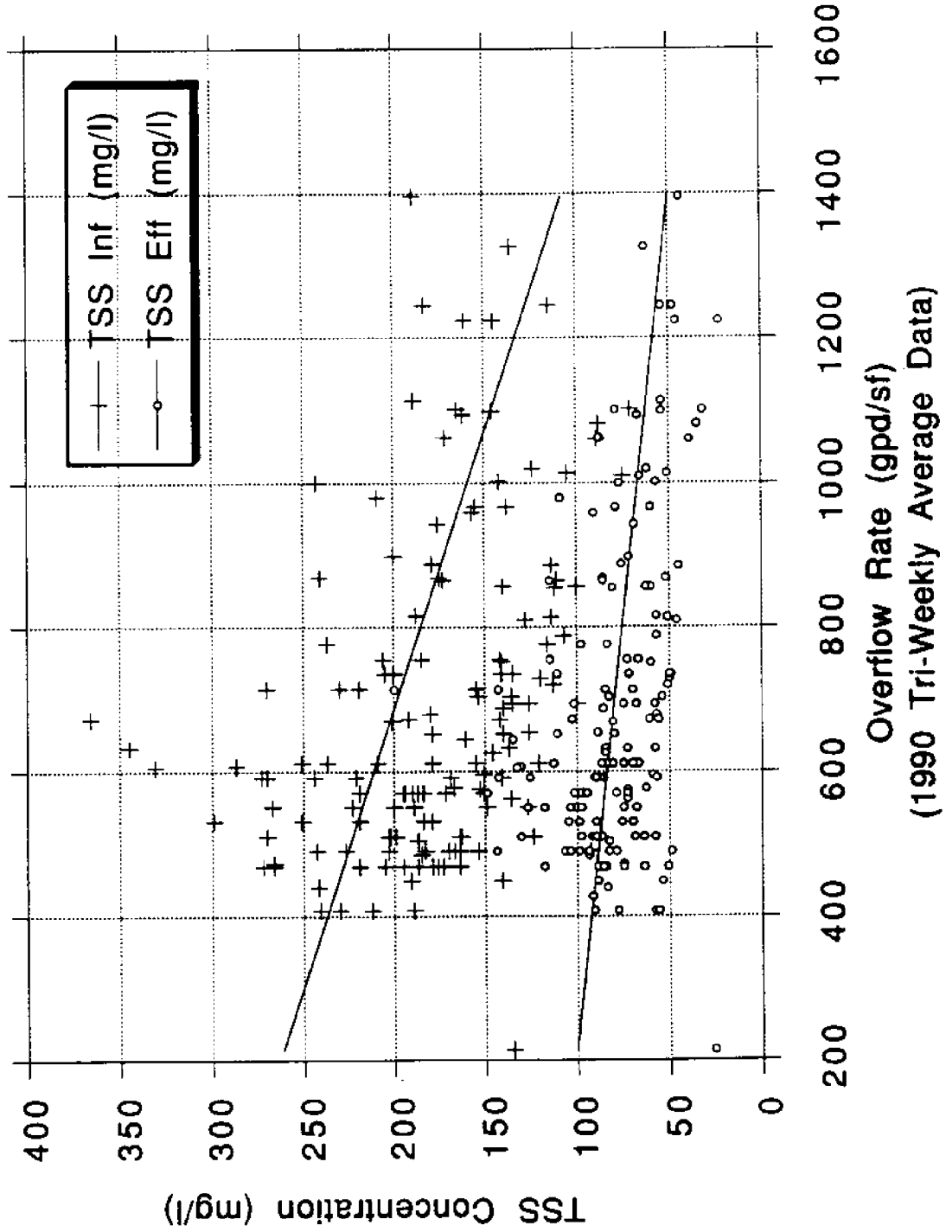
**Flow Rate vs. Day of the Year - 1990  
Gloucester Water Pollution Control Facility**





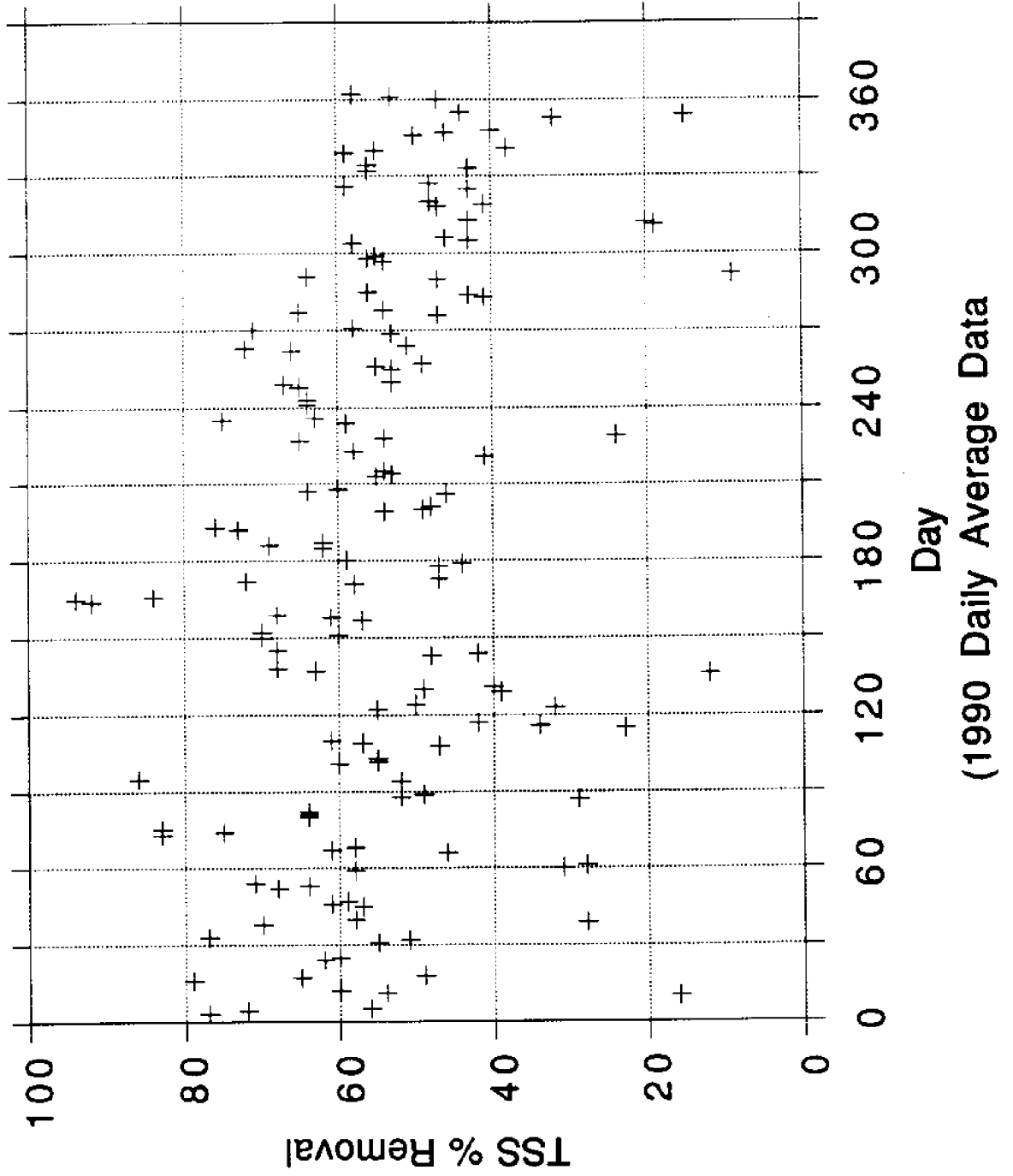
# TSS Influent and Effluent Concentration vs. Overflow Rate Gloucester Water Pollution Control Facility

## GRAPH 2



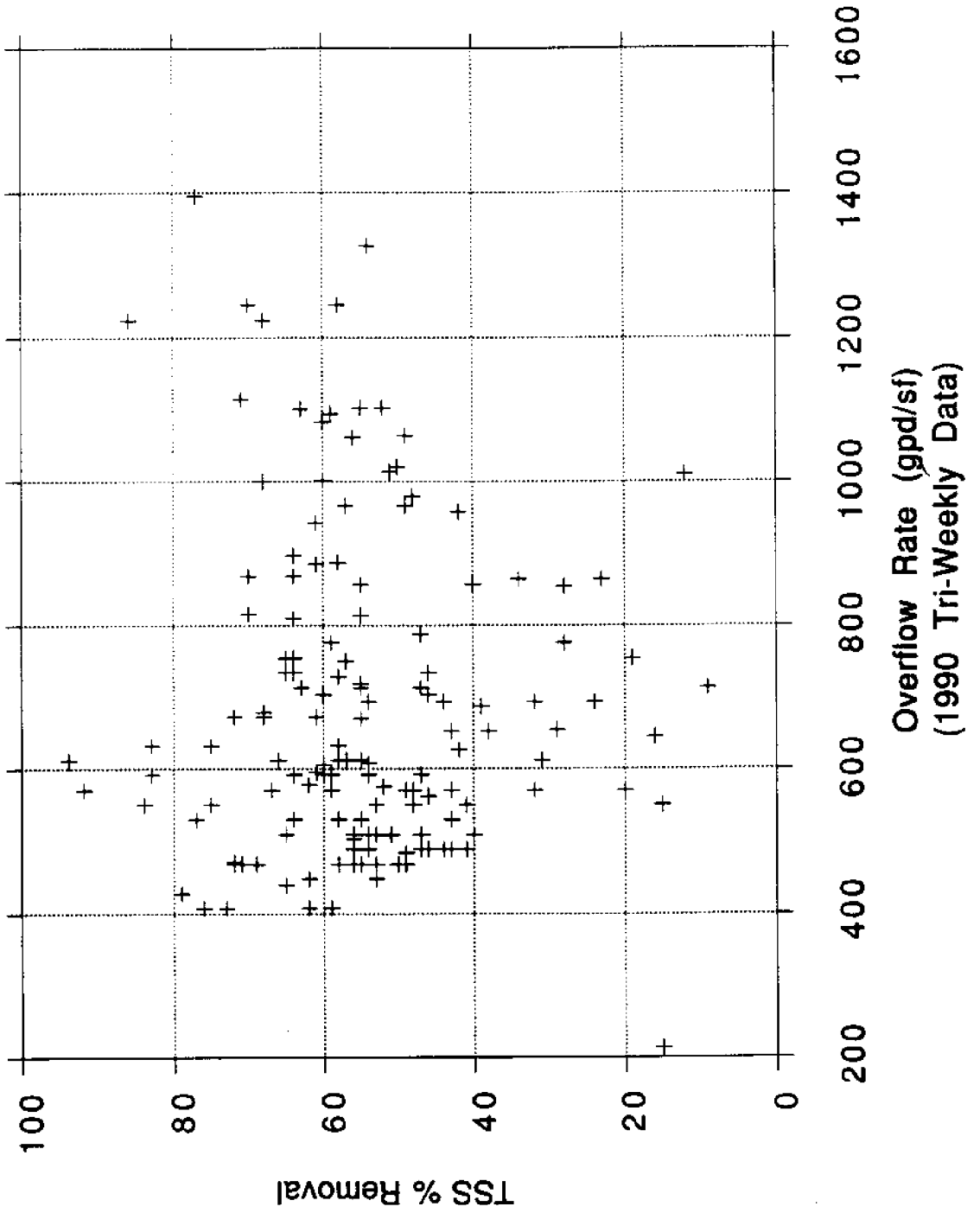
# GRAPH 3

TSS % Removal vs. Day of the Year - 1990  
Gloucester Water Pollution Control Facility



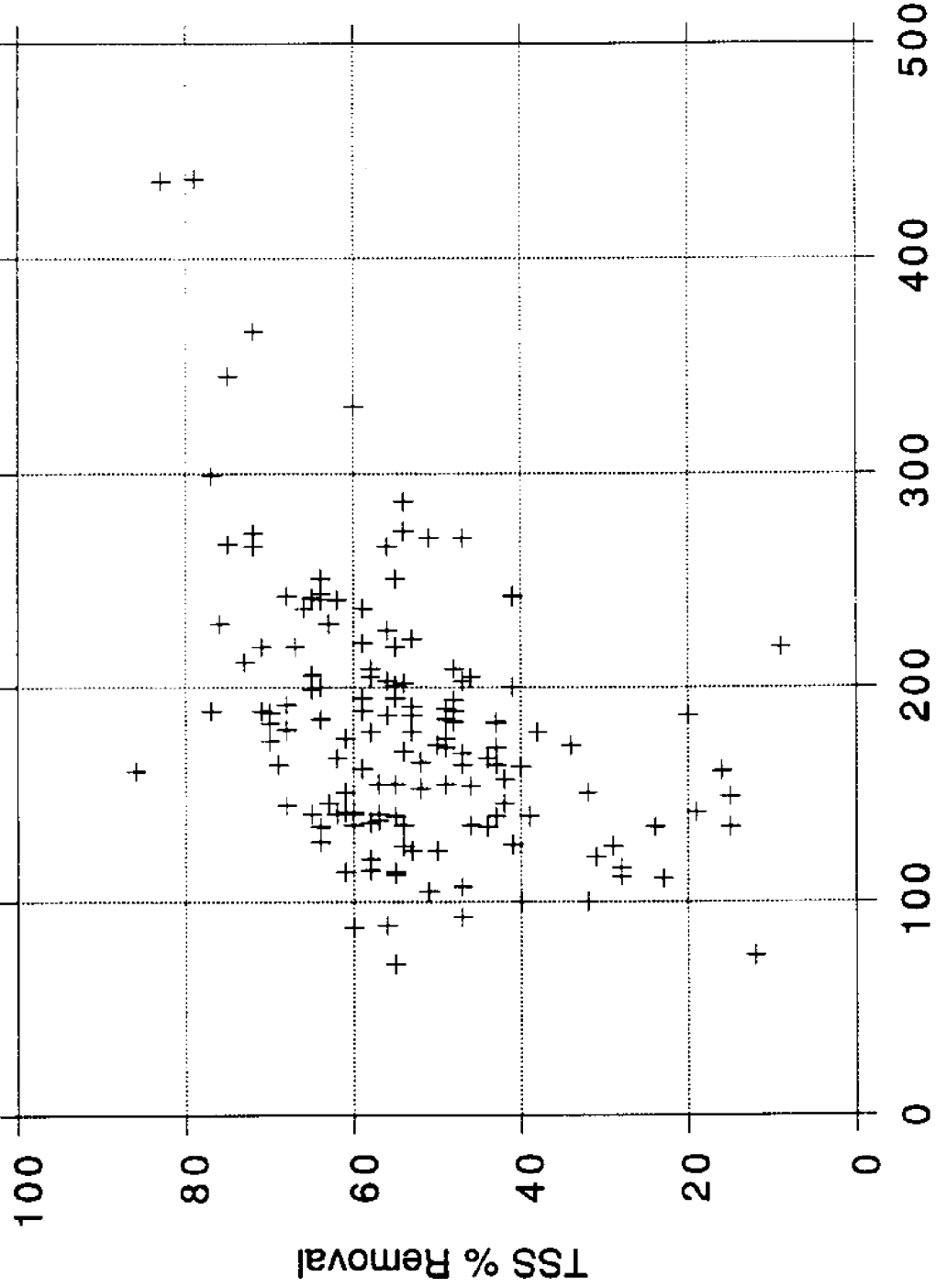
# GRAPH 4

TSS Percent Removal vs. Overflow Rate  
Gloucester Water Pollution Control Facility



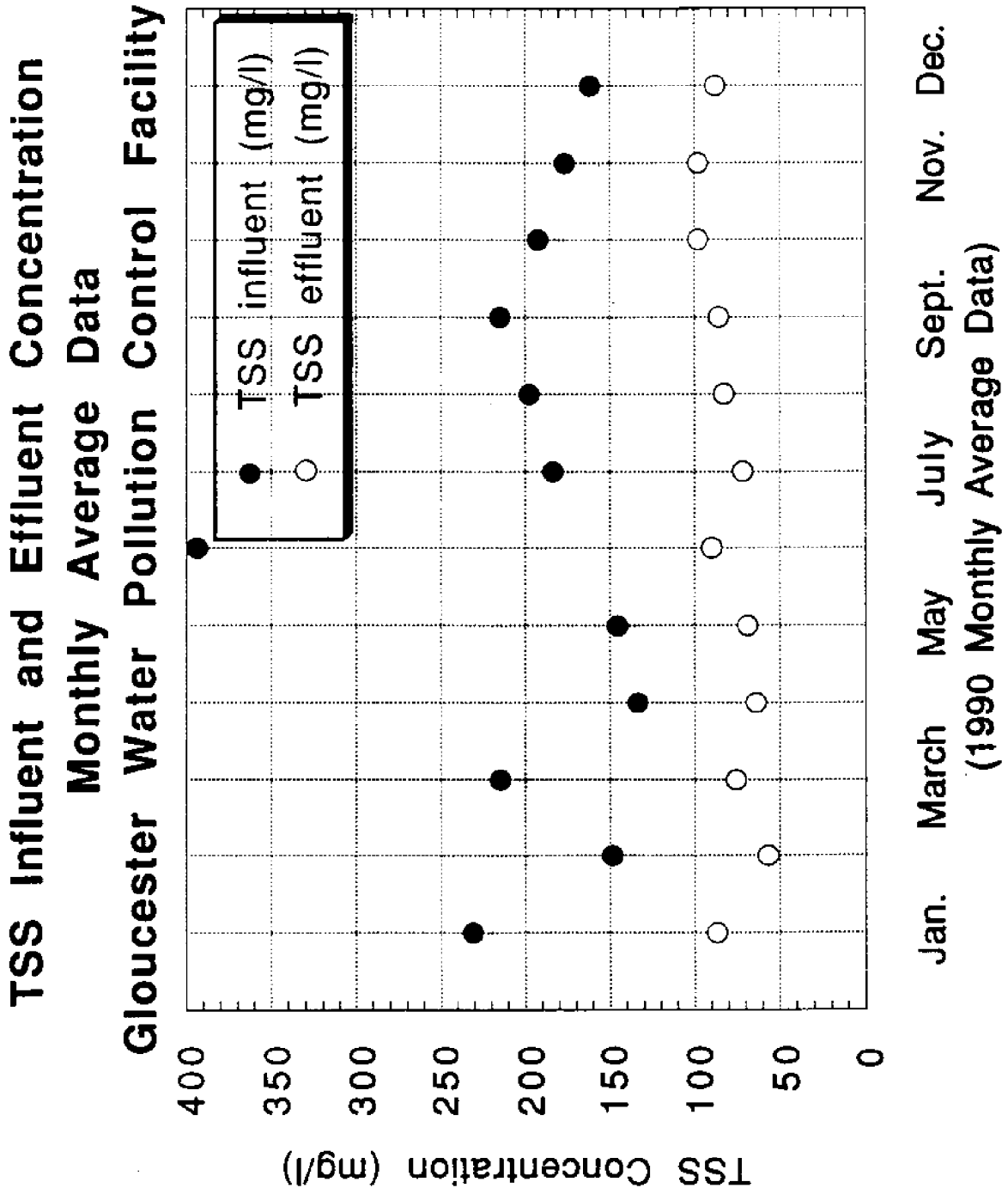
# GRAPH 5

**TSS % Removal vs. TSS Influent Concentration  
Gloucester Water Pollution Control Facility**



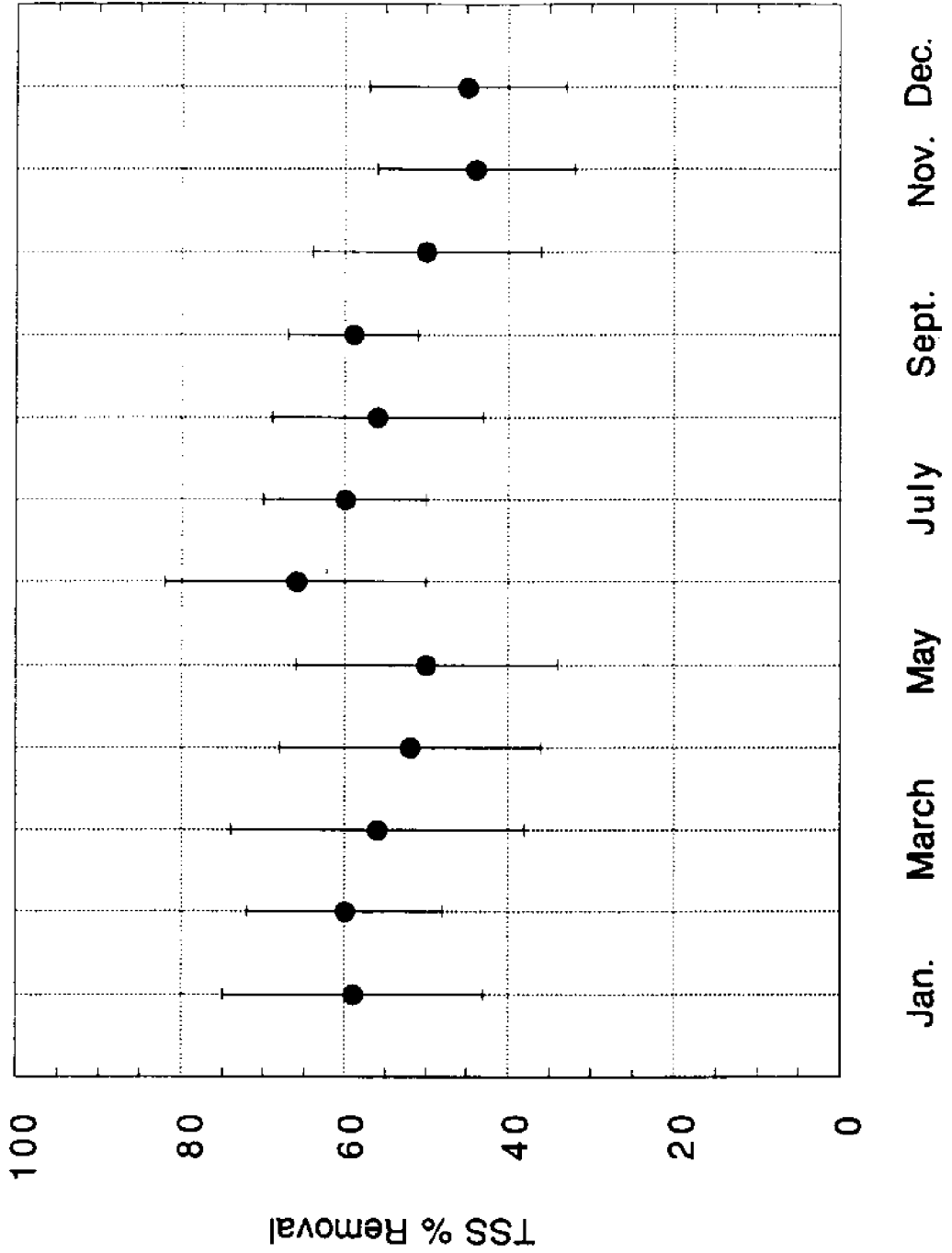
**TSS Influent Concentration (mg/l)  
(1990 Tri-Weekly Average Data)**

# GRAPH 6



# GRAPH 7

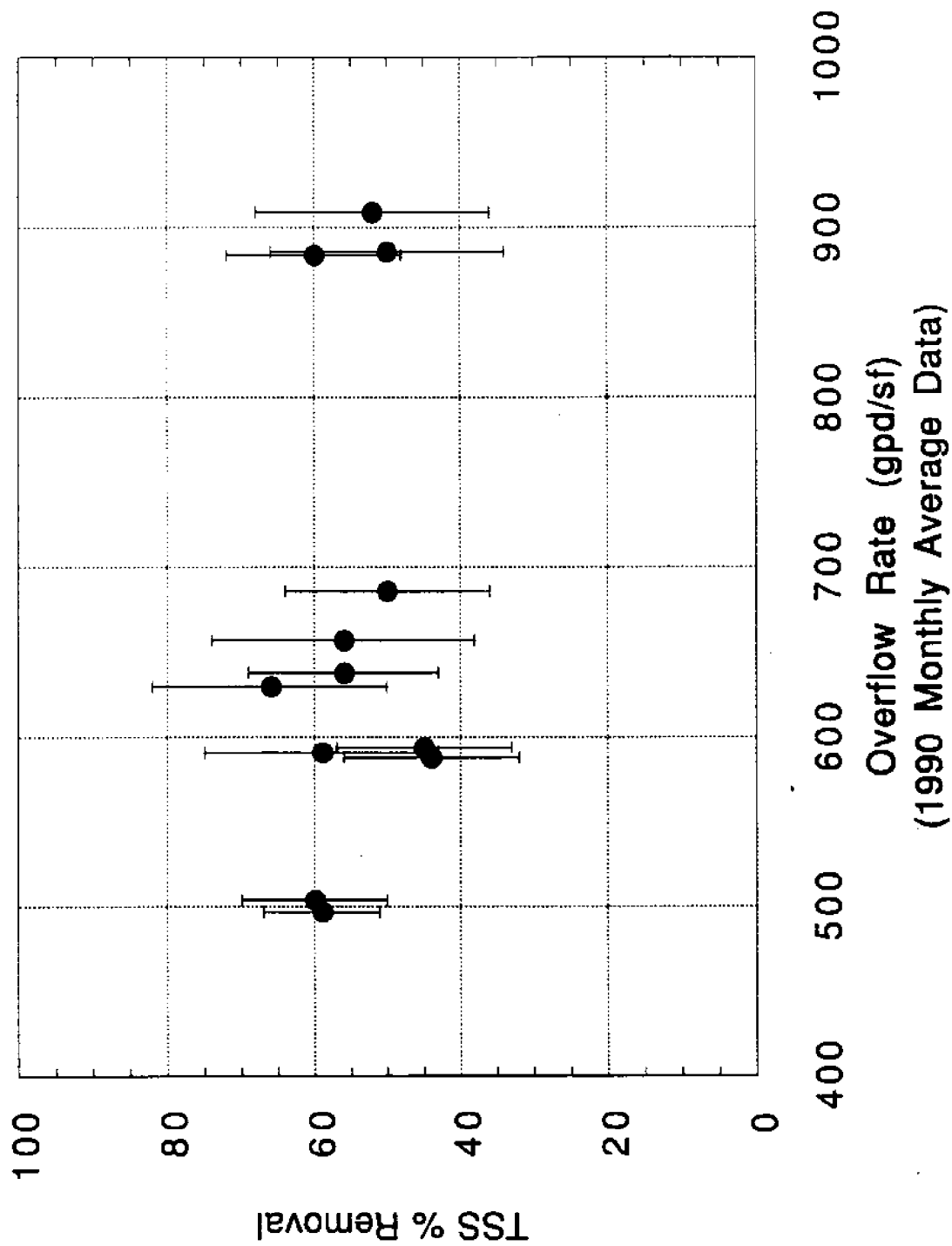
**TSS % Removal vs. Month - 1990  
Gloucester Water Pollution Control Facility**



(1990 Monthly Average Data)

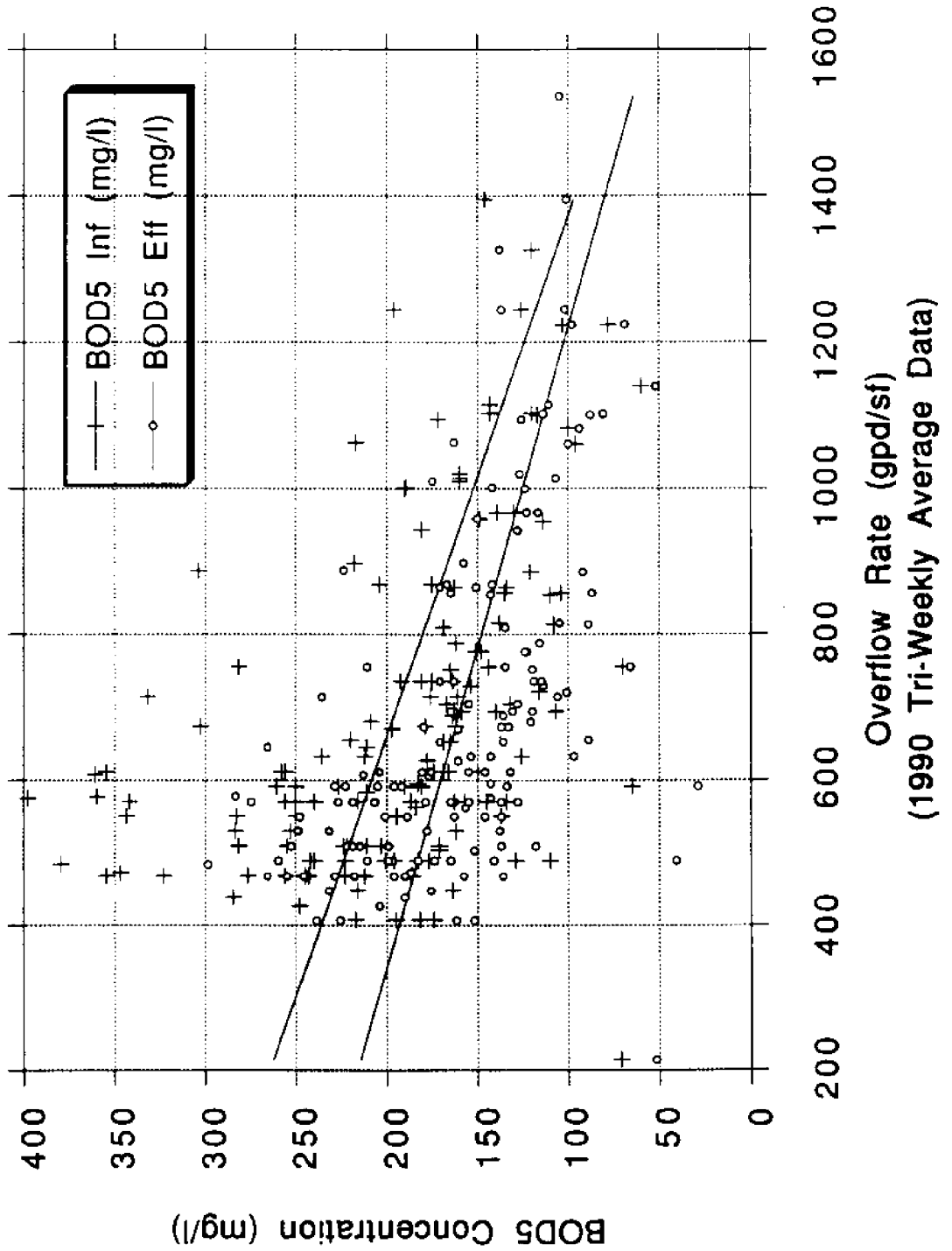
# GRAPH 8

## TSS % Removal vs. Overflow Rate Gloucester Water Pollution Control Facility



# BOD5 Influent and Effluent Concentration vs. Overflow Rate Gloucester Water Pollution Control Facility

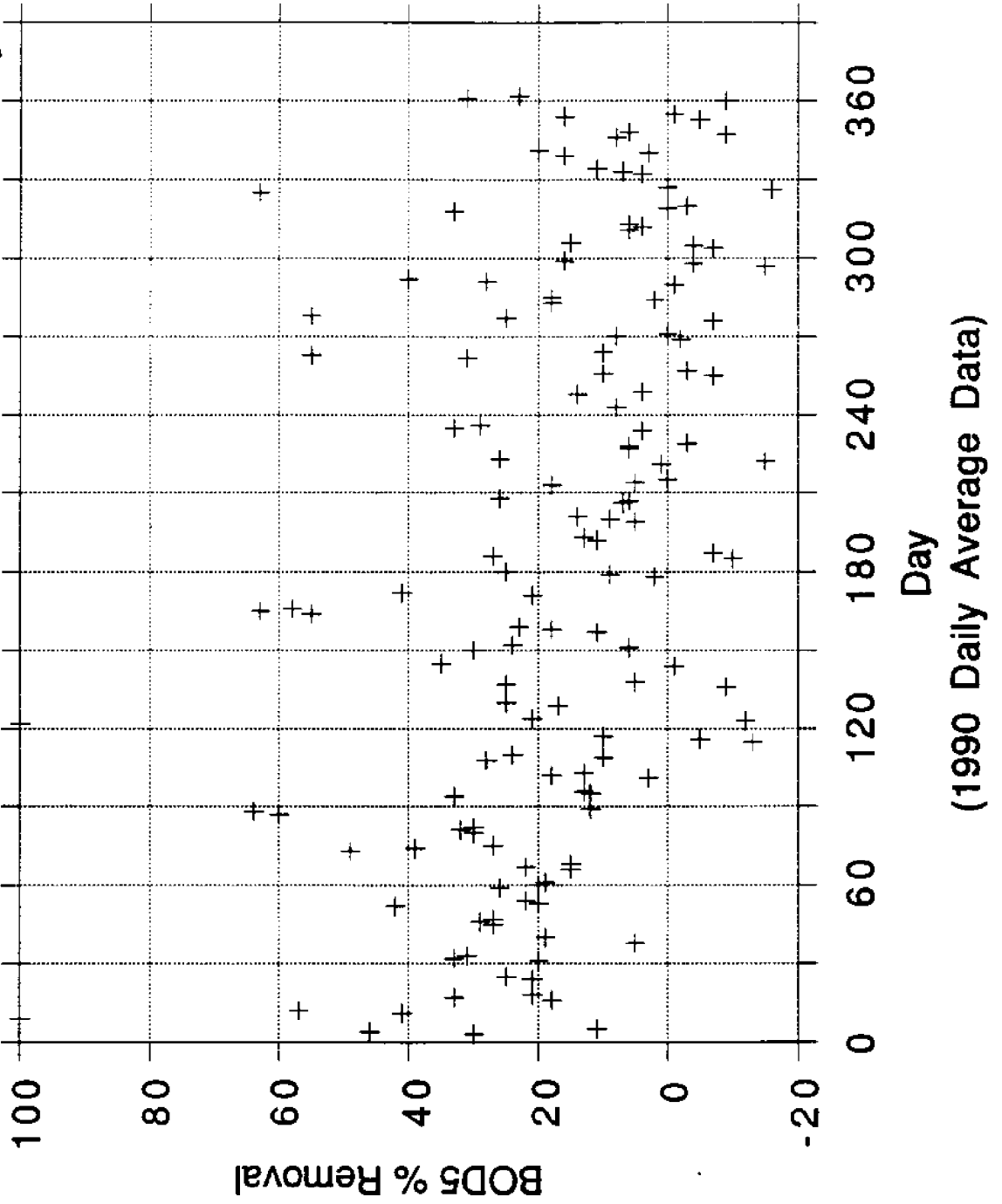
## GRAPH 9



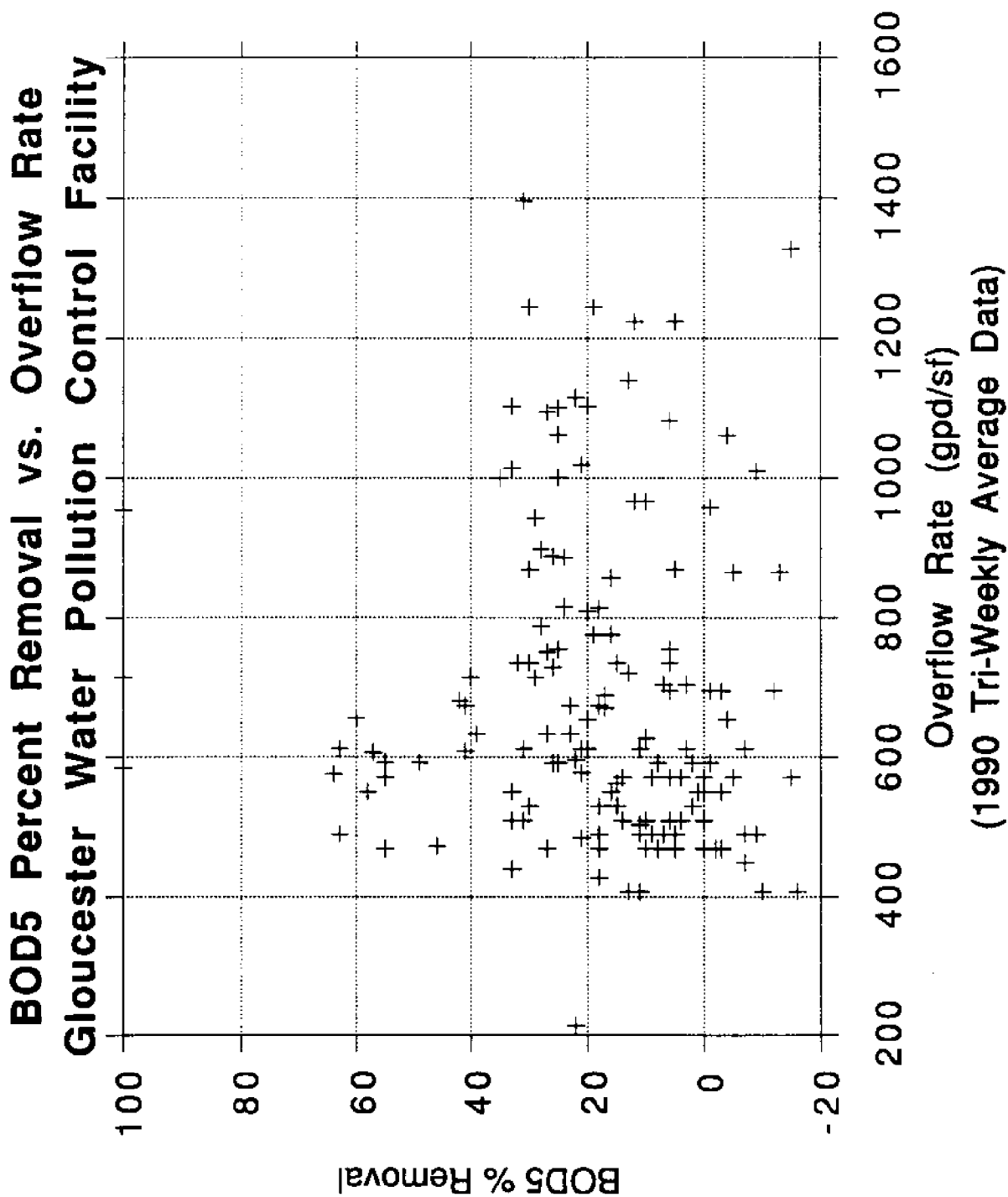


# GRAPH 10

**BOD5 % Removal vs. Day of the Year - 1990  
Gloucester Water Pollution Control Facility**

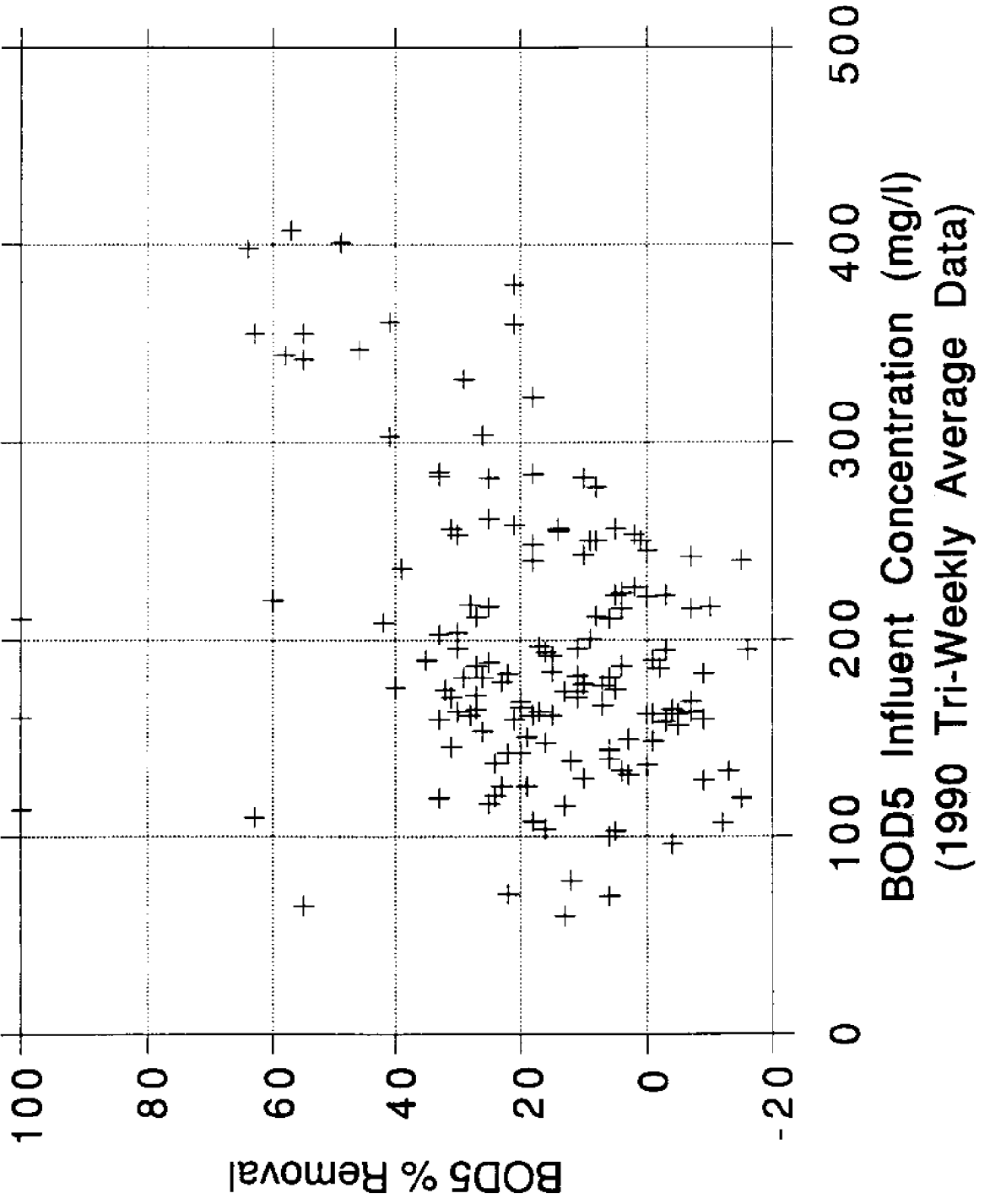


# GRAPH 11



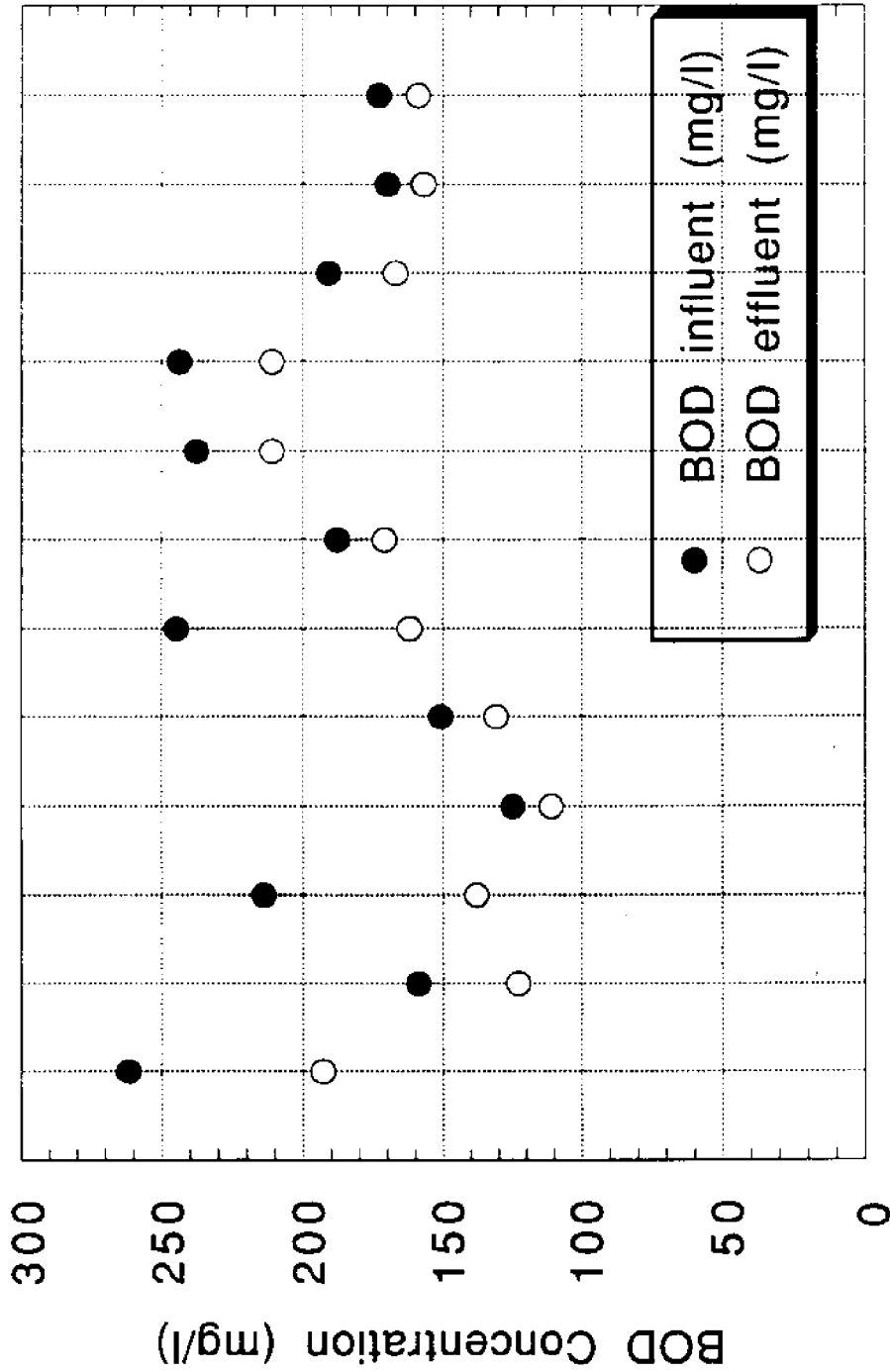
# BOD5 % Removal vs. BOD5 Influent Concentration Gloucester Water Pollution Control Facility

## GRAPH 12



# GRAPH 13

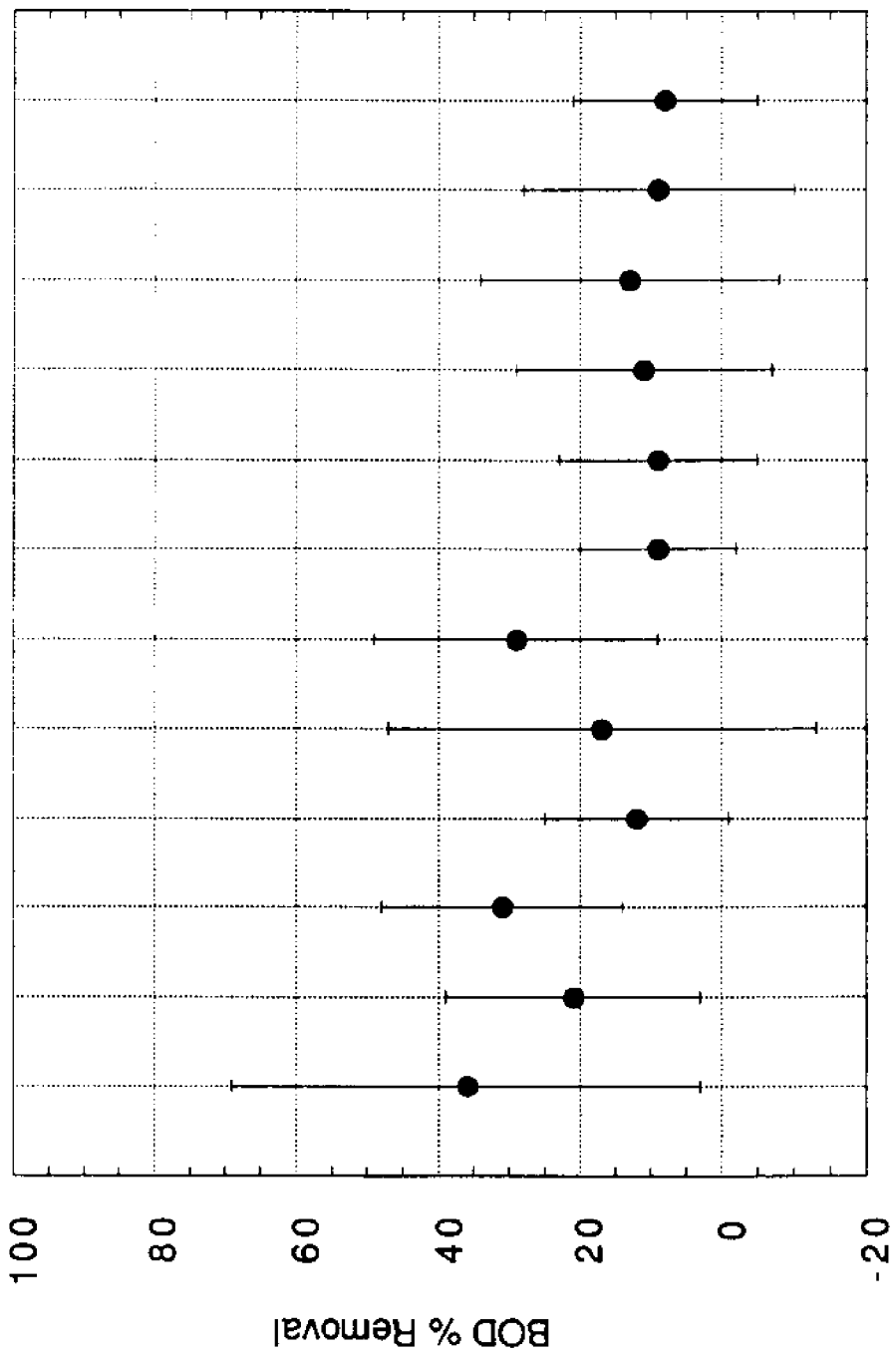
## BOD5 Influent and Effluent Concentration Monthly Average Data Gloucester Water Pollution Control Facility



Jan. March May July Sept. Nov. Dec.  
(1990 Monthly Average Data)

# GRAPH 14

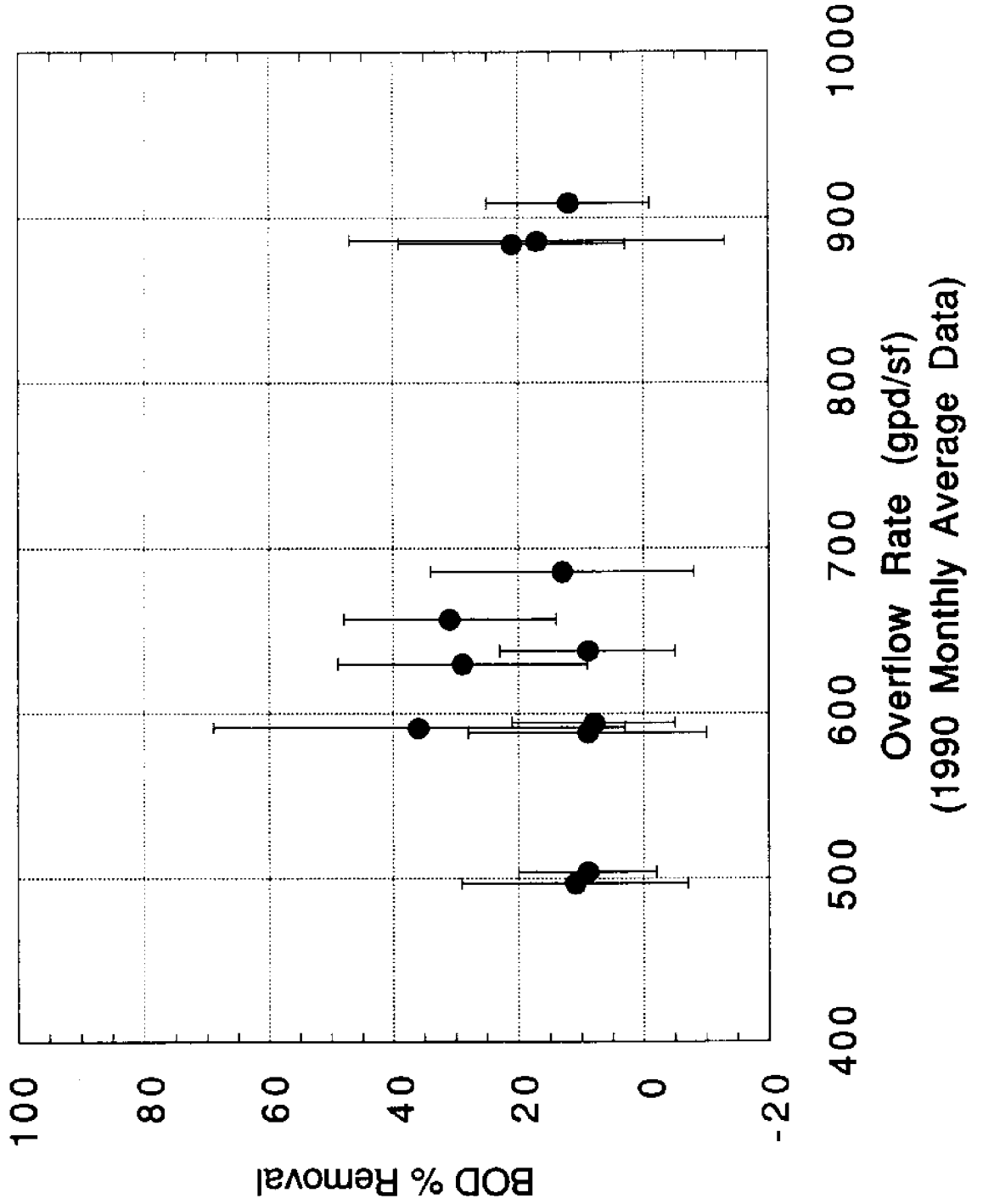
**BOD5 % Removal vs. Month - 1990**  
**Gloucester Water Pollution Control Facility**



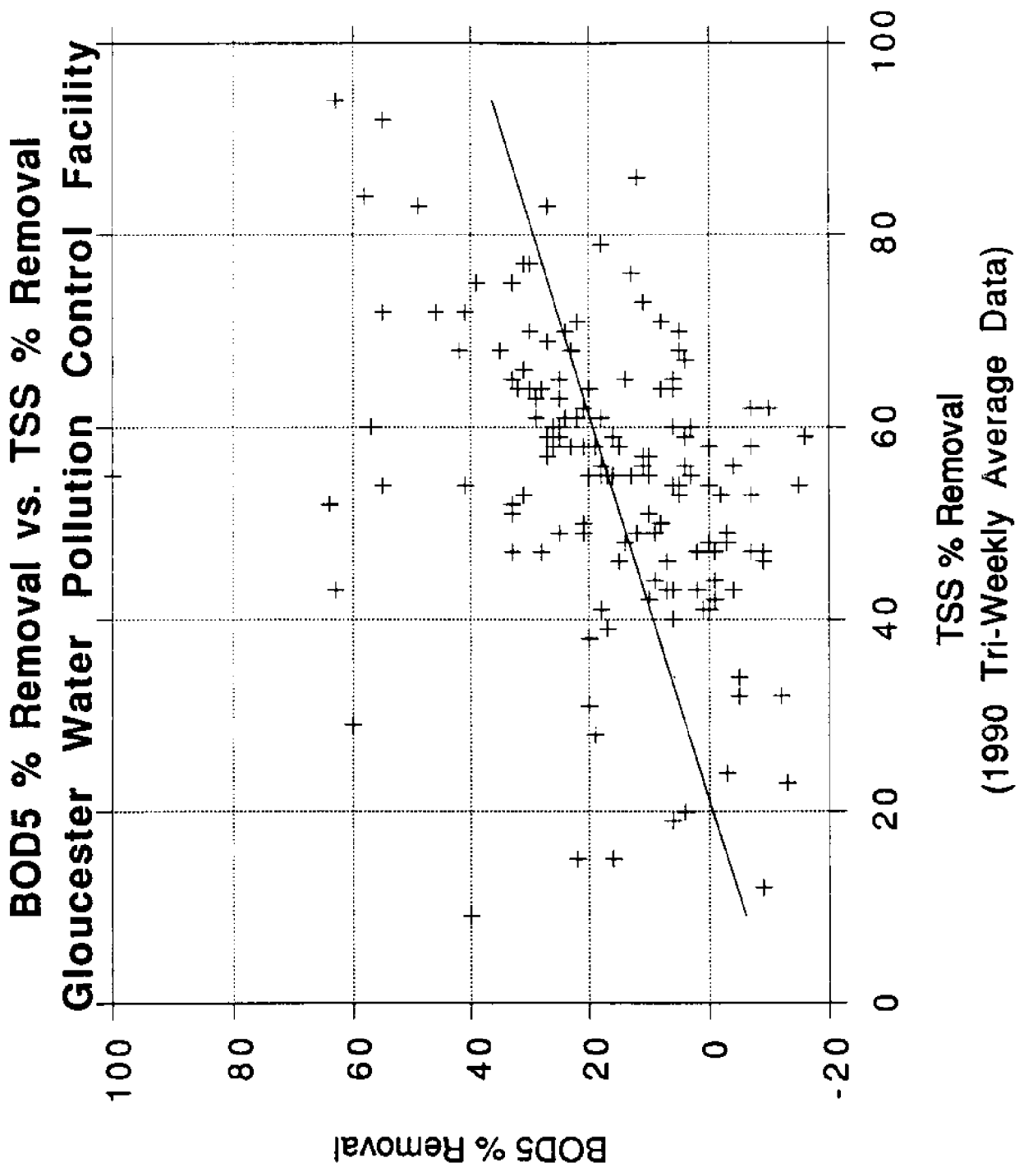
(1990 Monthly Average Data)

# GRAPH 15

**BOD5 % Removal vs. Overflow Rate  
Gloucester Water Pollution Control Facility**

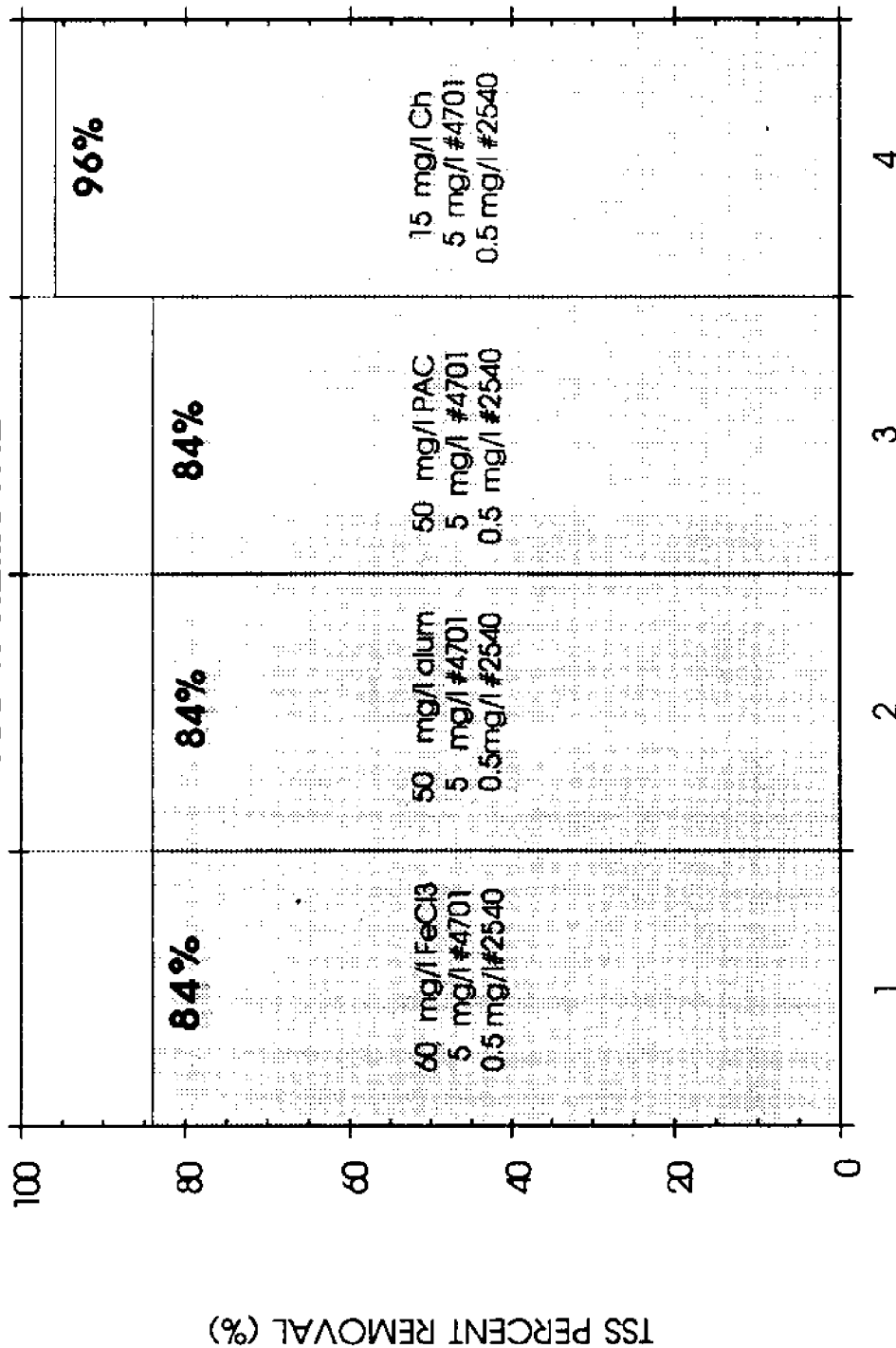


# GRAPH 16



# GRAPH 17

TEST 1 - DAY 2 RESULTS  
 JANUARY 23, 1991  
 TSS % REMOVAL

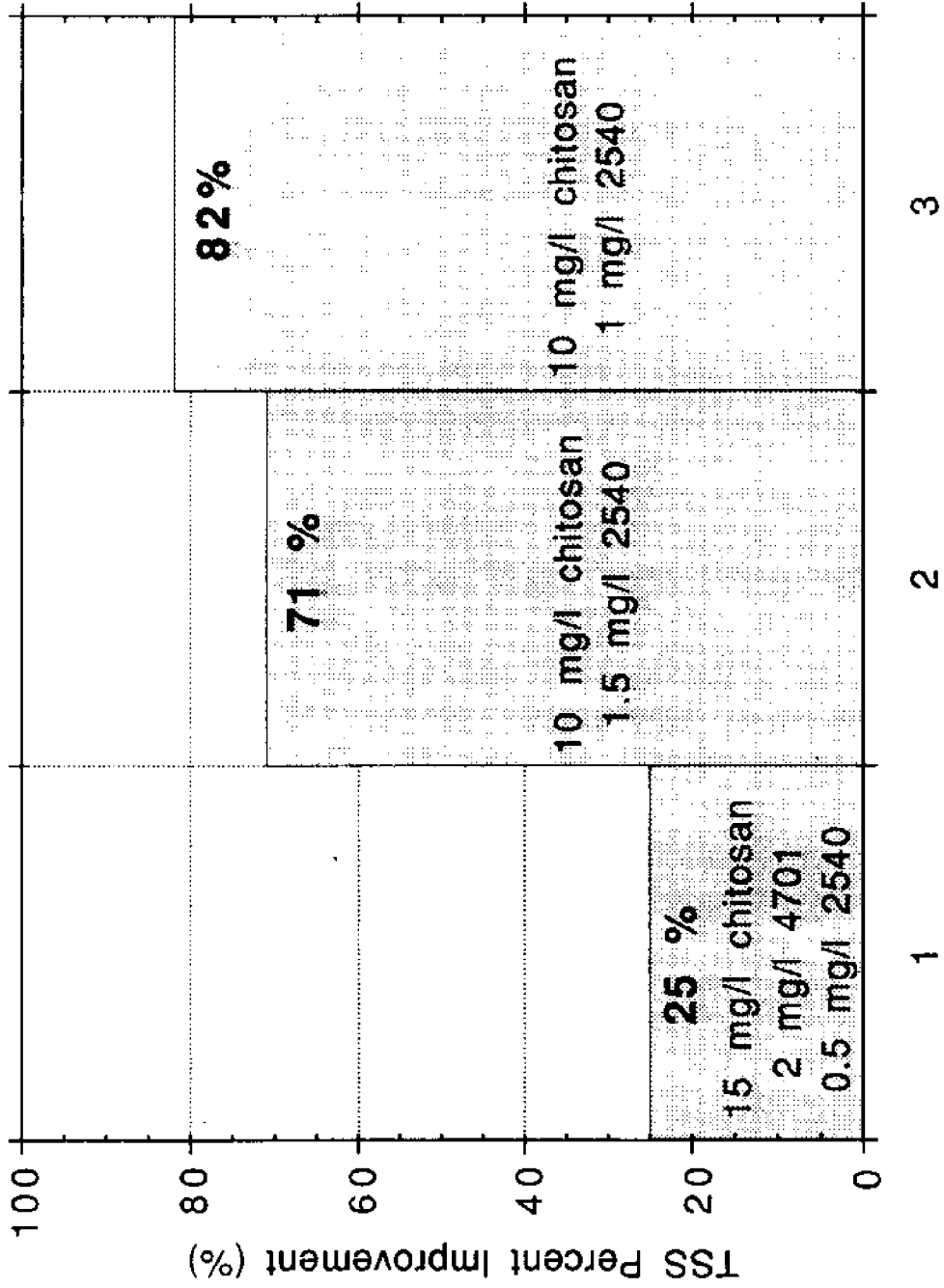


FeCl<sub>3</sub> = ferric chloride; AlSO<sub>4</sub> = alum  
 PAC = polyaluminum chloride; Ch = chitosan  
 #4701 = Delta Chemicals cationic polyacrylamide  
 #2540 = Delta Chemicals anionic polyacrylamide



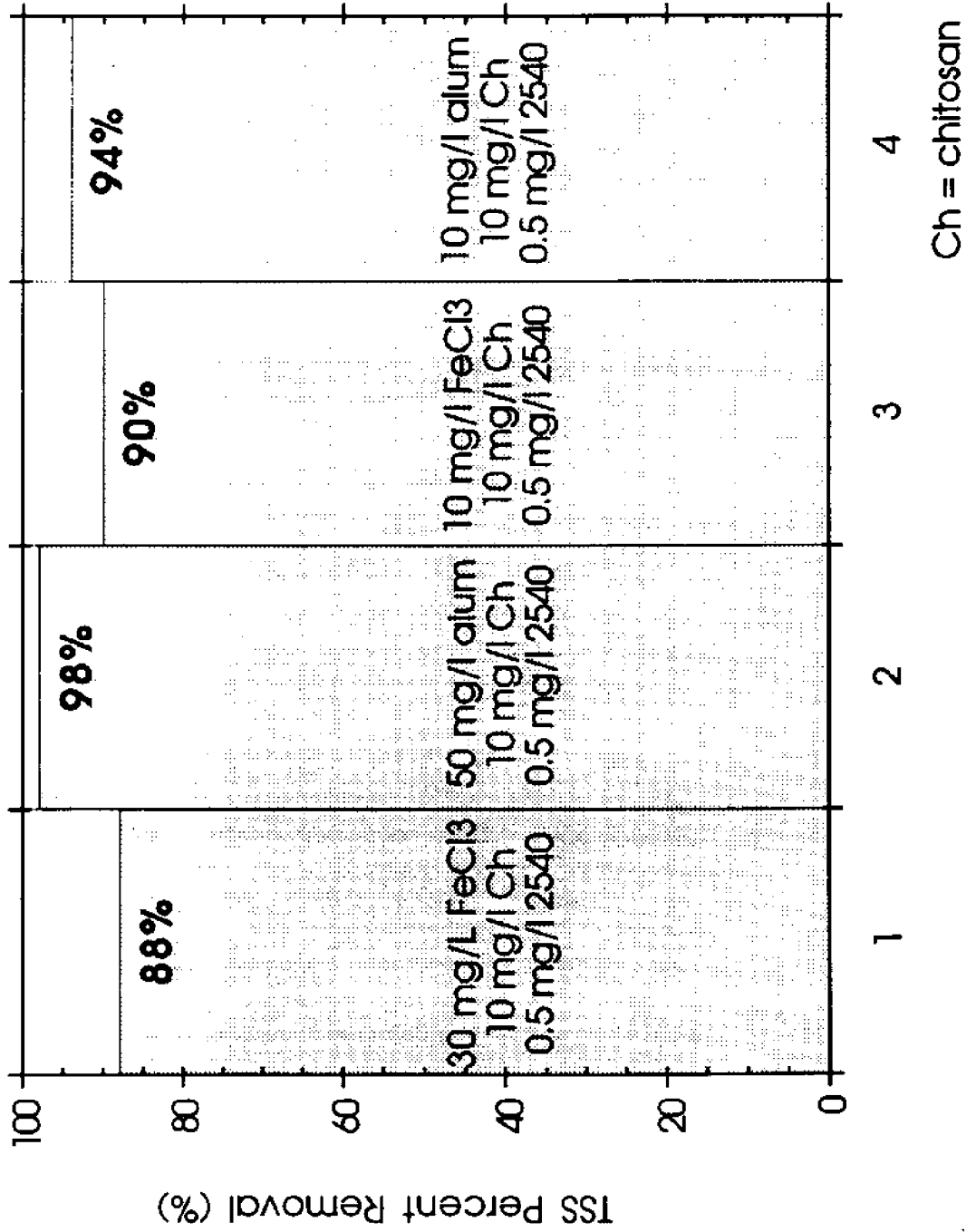
**TEST 1 - DAY 3 RESULTS  
JANUARY 24, 1991  
TSS % IMPROVEMENT**

**GRAPH 18**



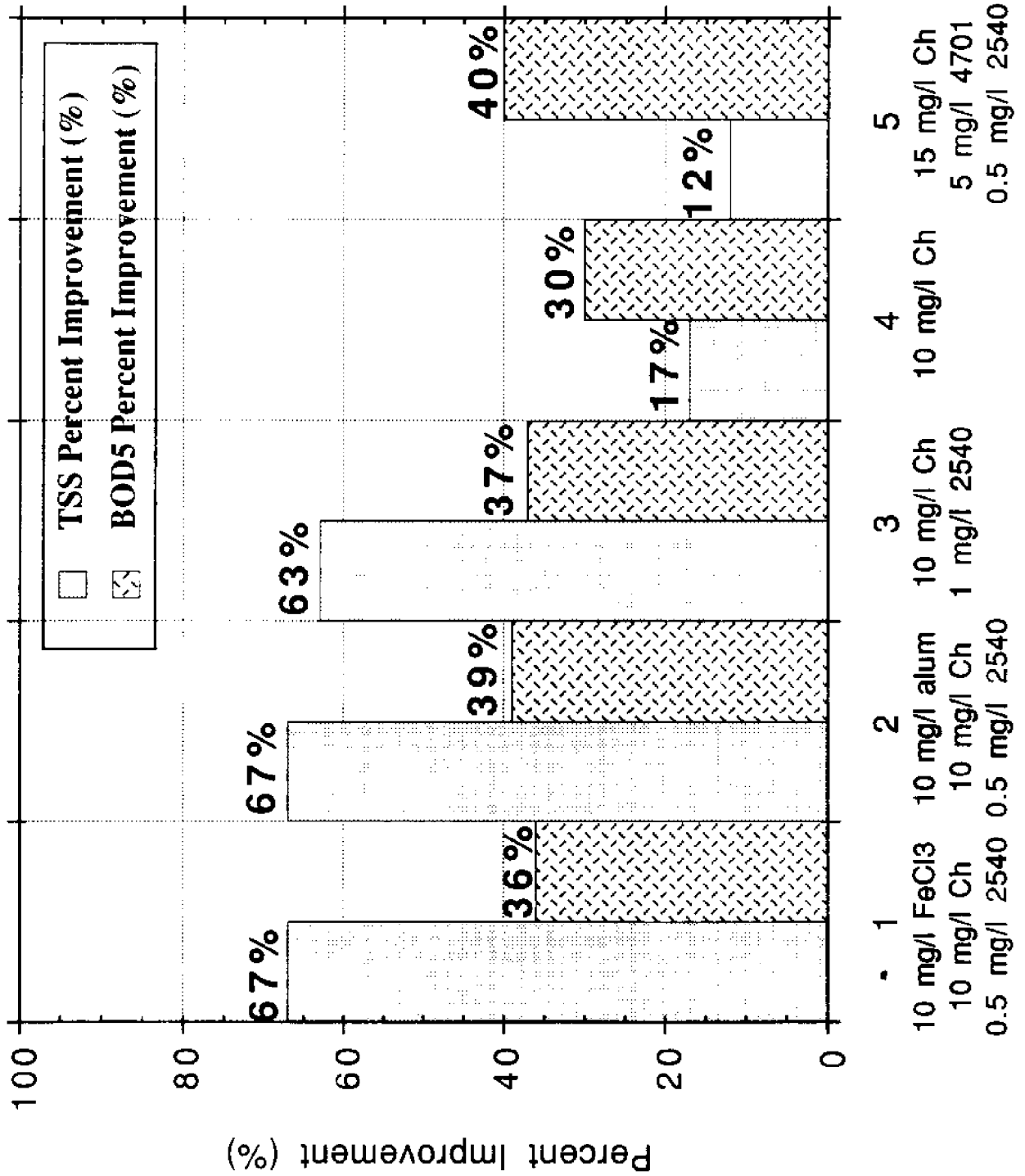
**TEST 1 - DAY 4 RESULTS  
 JANUARY 25, 1991  
 TSS % REMOVAL**

**GRAPH 19**



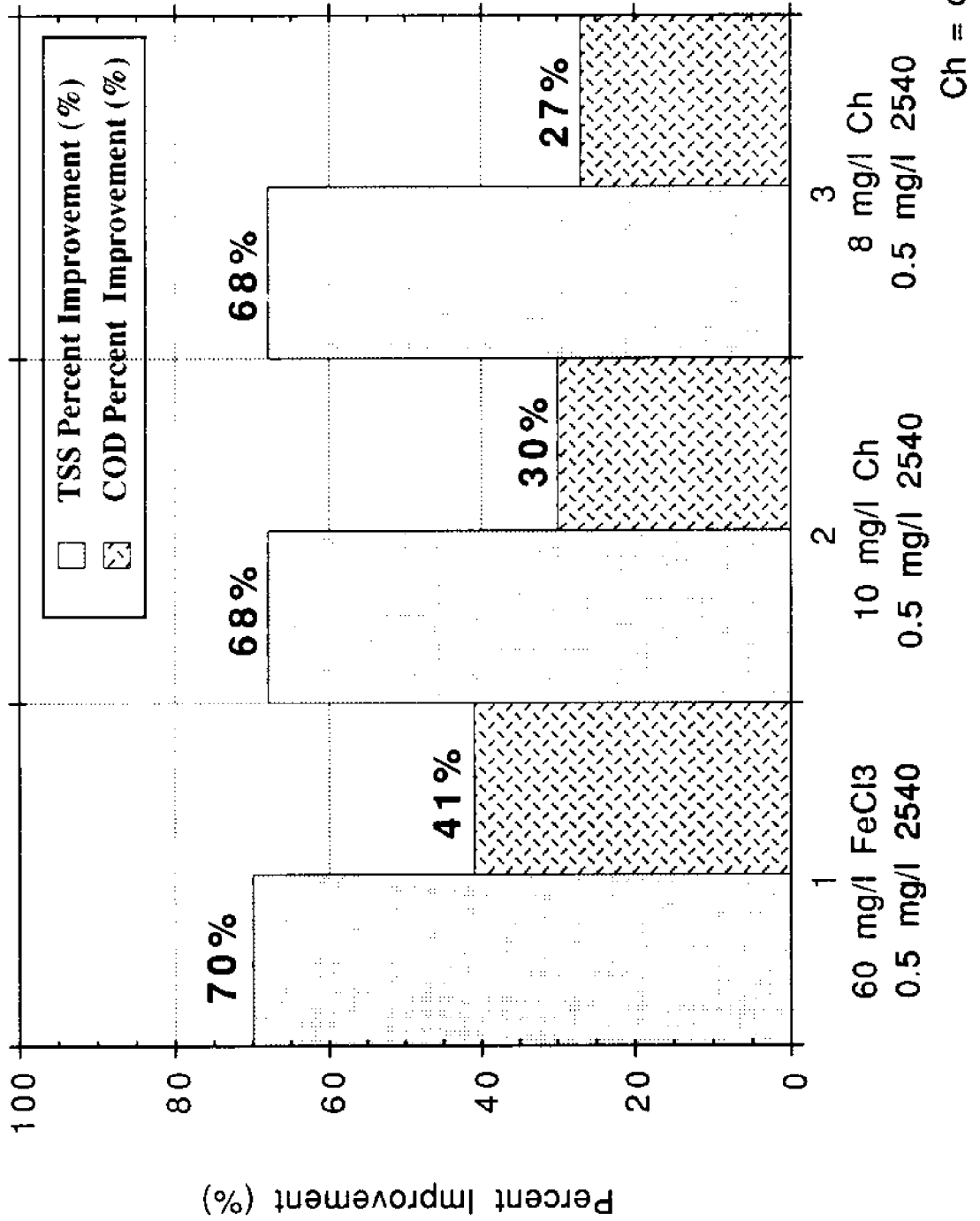
**TEST 1 - DAY 5 RESULTS  
 JANUARY 28, 1991  
 TSS & BOD5 % IMPROVEMENT**

**GRAPH 20**



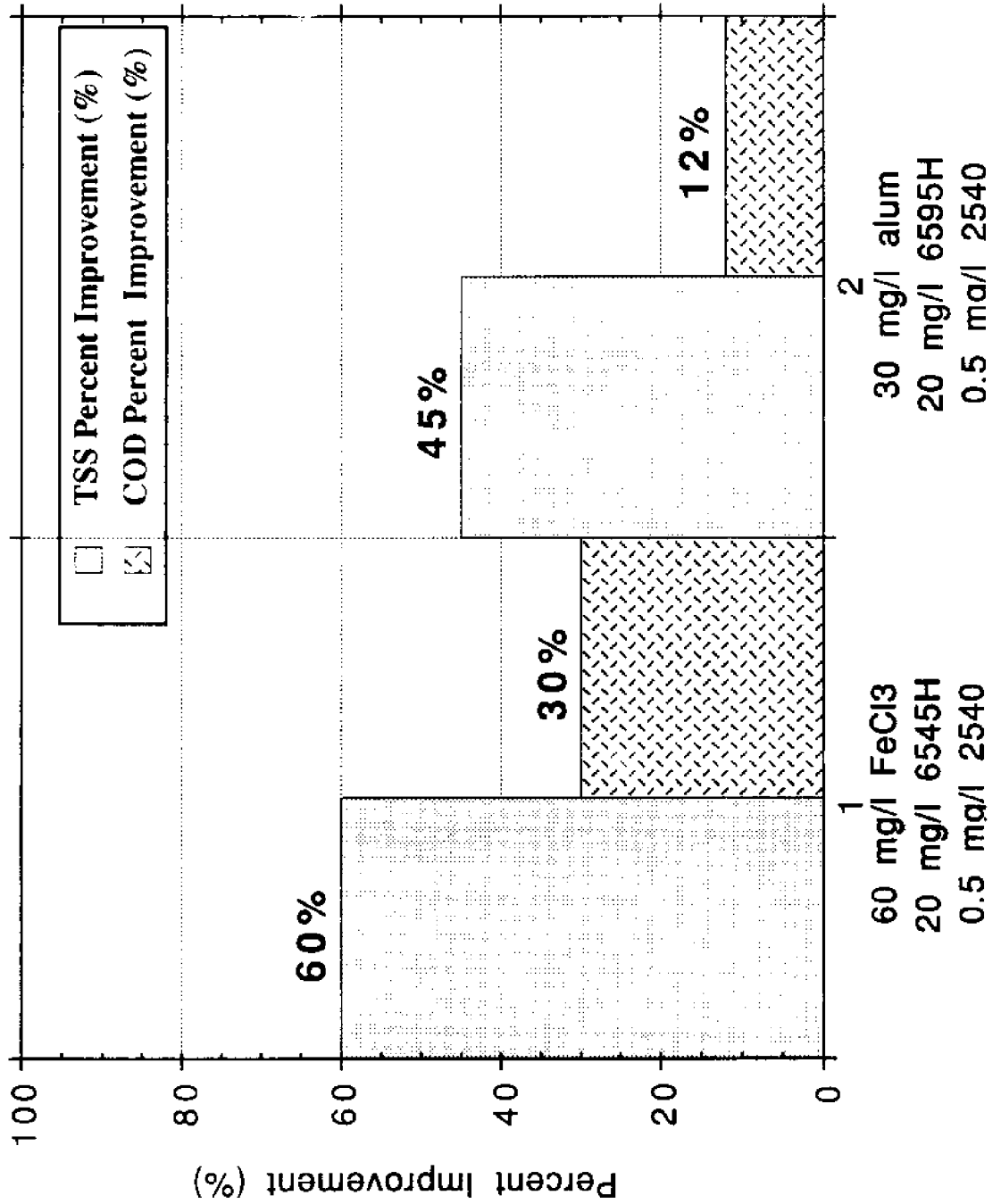
**TEST 2 - DAY 1 RESULTS  
 SEPTEMBER 23, 1991  
 TSS & COD % IMPROVEMENT**

**GRAPH 21**



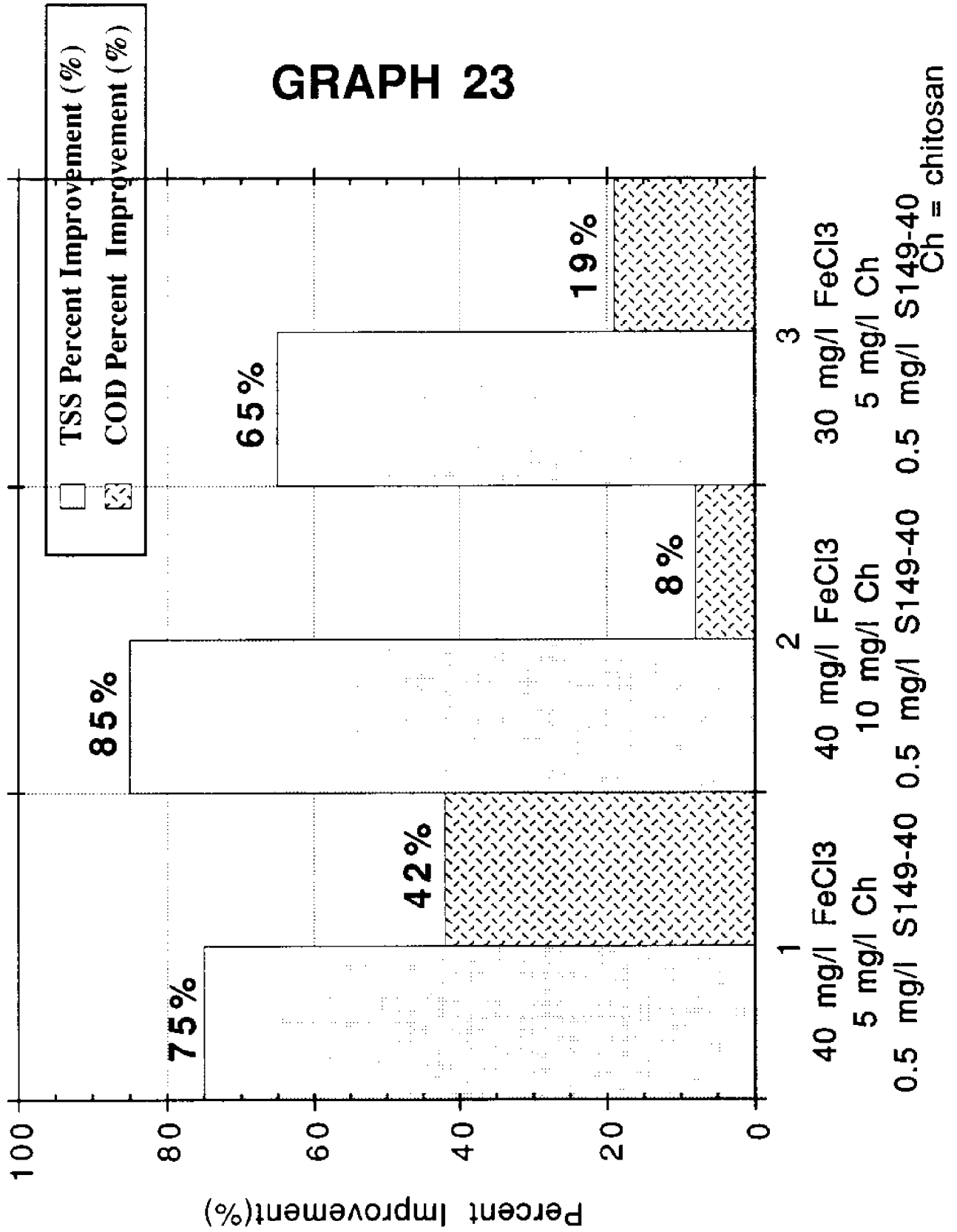
**COMPARISON OF FECL3 & ALUM UNDER LOW pH CONDITIONS  
 TEST 2 - DAY 3 RESULTS  
 SEPTEMBER 25, 1991**

**GRAPH 22**



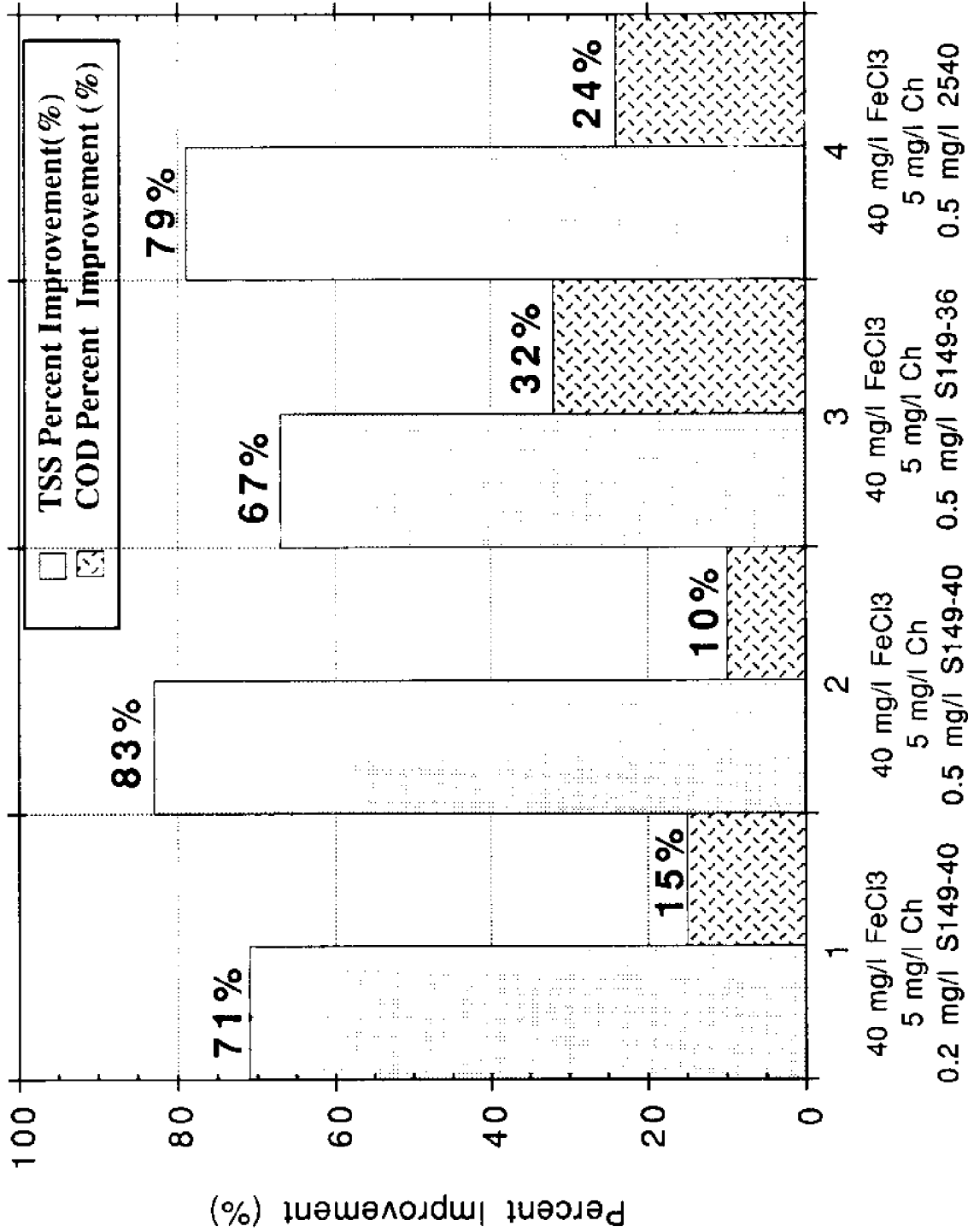
**TEST 2 - DAY 3 RESULTS  
 SEPTEMBER 25, 1991  
 TSS & COD % IMPROVEMENT**

**GRAPH 23**



**TEST 2 - DAY 4 RESULTS  
 SEPTEMBER 26, 1991  
 TSS & COD % IMPROVEMENT**

**GRAPH 24**



Ch = chitosan

**TEST 2 - DAY 5 RESULTS**  
**SEPTEMBER 30, 1991**  
**TSS & BOD5 or COD % IMPROVEMENT**

**GRAPH 25**

