


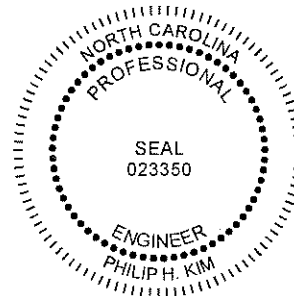
Color and THMFP Removal Pilot Test at Dare County Water Treatment Facilities

COUNTY OF DARE

Robert Oreskovich
Client Representative
Water Department Director

 6/8/98

Philip H. Kim, PhD, PE
Project Manager



BK-D01-200-00

June 1998



BOYLE ENGINEERING CORPORATION

2601 F Street, Bakersfield, CA 93301

Color and THMFP Removal Pilot Test at Dare County Water Treatment Facilities

County of Dare

Client Representative Robert Oreskovich
Water Department Director

Project Manager Philip H. Kim, PhD, PE

BK-D01-200-00

April 1998

BOYLE

2601 F Street, Bakersfield, California 93301

Section I - Summary

An earlier pilot test at the Buxton water treatment plant using anion exchange (ANIX) resins demonstrated an economical method of controlling organic content in treated water. The ANIX process was further pilot tested at Dare County's other water treatment facilities: Rodanthe, Skyco, and Kill Devil Hills.

The Dare County wanted to increase its water production by blending as much raw water as possible with treated water. However, their blending practice is limited by high THM potential in the raw water. By removing THM precursors selectively, the blending ratio can be increased dramatically.

The pilot test results indicated the Rodanthe and Skyco water treatment plants would be good candidates for application of the ANIX process for removal of organic materials from the raw water. High salt content in the raw water at the Kill Devil Hills water treatment plant, on the other hand, rendered the ANIX process less attractive.

It is recommended that hydrophilic ANIX resins (*i.e.*, acrylic based resins) be used for easier regeneration and fouling resistance although the advantage could not be demonstrated because of the short pilot testing period.

Estimated capital cost for 0.43 MGD (Rodanthe) and 4.5 MGD (Skyco) facilities are \$648,000 and \$2,484,000, respectively. Annual operation and maintenance cost is estimated as \$21,000 and \$172,000, respectively.

Section II - Pilot Test

This section discusses the findings, conclusions, and recommendations of the color/organic removal pilot test conducted at Dare County's water treatment facilities. The following headings are included in this section.

- Background
- Objectives
- Approach
- Pilot Setup and Equipment
- Test Results and Discussion
- Conclusions
- Recommendations
- Cost Estimate

Background

Dare County, NC, operates several water treatment facilities that treat both shallow and deep well waters using various technologies including reverse osmosis, ion exchange, and conventional clarification processes.

Previous studies determined the need for a new water treatment facility serving communities on Hatteras Island from Avon southward. Dare County's conventional water treatment plant located at Buxton experiences high concentrations of naturally occurring organic materials in shallow well waters. The well waters also contain high concentrations of iron and manganese. These materials cause the water to be highly colored.

Naturally occurring organic materials, often expressed collectively as total organic carbon (TOC), constitute the major precursor materials for trihalomethanes (THMs) when they are chlorinated. Therefore, removal of the precursor materials before they make contact with any oxidant/disinfectant is the most logical approach to complying with the disinfectants/disinfection byproduct (D/DBP) rule.

The anion exchange (ANIX) process was considered for removal of the organic materials from the shallow well water. Because of the anionic nature of natural organic materials at natural pH levels (pH 6 to 8), ANIX resins have been used for the removal of the organic materials.

The ANIX process was pilot tested at Dare County's four water treatment facilities: Buxton, Rodanthe, Skyco, and Kill Devil Hills.

At the Skyco water treatment plant, the groundwater is being treated with cation exchange resin for hardness removal. Their blending practice is limited by high THM potential in the groundwater (this is also the case at Buxton). By removing THM precursors selectively, the blending ratio can be increased dramatically. The water treatment practices at Rodanthe and Kill Devil Hills target the control of seawater intrusion in their groundwater using reverse osmosis (RO) technology. Both places seek the selective removal of THM precursor materials from their source water.

Objectives

The good organic removal performance demonstrated by three different ANIX resins tried at the Buxton water treatment supported the possibility that the ANIX process might be applicable at other Dare County water treatment plants. Therefore, the objectives of this pilot test were:

- To verify and duplicate the good organic removal performance by the ANIX process at other water treatment plant sites.
- To compare different types of ANIX resins for removal of color and TOC.
- To develop capital and O & M cost information.

Approach

Anticipated treatment processes at Buxton plant will be a combination of RO, ANIX, and iron and manganese removal. The RO treated water will be blended with the ANIX and iron/manganese treated water. The theory behind this treatment scheme is that the RO process will remove most dissolved constituents in the raw water producing a product rich in sodium chloride. On the other hand, the ANIX will remove only nonvolatile organic materials and anions. Hardness-causing cations such as calcium and magnesium will not be removed during the ANIX process. Based upon the current estimation, about 66 percent of raw water will be treated with RO, and the rest of the raw water will be treated with the ANIX and iron/manganese treatment processes. By blending the two process waters, the hardness and alkalinity removed during the RO process will be compensated by the hardness and alkalinity present in the ANIX and iron/manganese treated water. In addition, any remaining organic materials present in the ANIX and iron/manganese treated water will be diluted to produce lower THMs in the finished water. A dilution factor of about three for hardness and THMFP will result from blending the treated water.

At the Rodanthe and Kill Devil Hills desalination water treatment plants, treated water production can be increased dramatically by removing organic material selectively from the blending water. At the Skyco water treatment plant, hardness removal using cation exchange process is being practiced. Again, organic content in the blending water limits its treated water capacity. Therefore, if organic removal by ANIX is provided, overall water production rates for the above mentioned water treatment facilities can be increased by blending more water without violating THM regulations.

Pilot Setup and Equipment

Boyle Engineering Corporation (Boyle) partially assembled the ion exchange test equipment in Bakersfield, California and shipped it to the pilot test site at Buxton, North Carolina. The original equipment was used throughout the pilot testing period. Detailed information about the pilot setup and equipment can be found in the "Cape Hatteras Pilot Plant Study of the Shallow Groundwater Aquifer" (March 1997).

Test Results and Discussion

In this report, test results from Rodanthe, Skyco, and Kill Devil Hills water treatment plants are presented and discussed. Each treatment plant has unique raw water quality in terms of TOC, total dissolved solids (TDS), and color level.

Raw Water Quality

Raw water qualities of the three water treatment plants vary significantly. Some of the major water quality parameters are summarized in **TABLE II-1**.

TABLE II-1
DARE COUNTY PILOT TEST
RAW WATER QUALITY SUMMARY

| | Rodanthe | Skyco | Kill Devil Hills |
|--|--------------------------------|--------------|------------------|
| TOC (mg/L) | 7.5 (Well #1) 7.8 (Well #2) | 2.9 ± 0.5 | 3.5 ± 1.4 |
| Color (unit) | 18 ± 2 | 18 ± 4 | 23 ± 7 |
| pH | 8.0 ± 0.1 | 7.7 ± 0.1 | 7.8 ± 0.1 |
| TDS (mg/L) | 1,218 ± 67 | 299 ± 24 | 3,715 ± 154 |
| Sulfate (mg/L) | Not detected | Not detected | 212 ± 41 |
| Chloride (mg/L) | 485 ± 34 | 54 ± 13 | 2,275 ± 172 |
| Total Hardness (mg CaCO ₃ /L) | 95 ± 6 | 183 ± 12 | 567 ± 57 |

(Note: all figures reported are average ± standard deviation)

Among the parameters, very wide variations in concentrations of inorganic constituents (e.g., chloride, sulfate, and TDS) exist. The TOC concentrations at Rodanthe were much higher than Skyco and Kill Devil Hills water treatment plants as shown in **TABLE II-1**.

Rodanthe Water Treatment Plant

TOC Removal Performance

Pilot testing for the removal of organic matter was conducted at Rodanthe water treatment plant from March 24 to July 1, 1997. A total of three service cycles were tested during the period. The TOC breakthrough histories are presented in **FIGURES II-1**. The first run stopped at treated water throughput of 456 bed volumes as shown in **FIGURE II-1**. The second run after a regeneration removed only about 50 to 60 percent of the incoming TOC. This indicates incomplete regeneration of the ANIX resins. After the short second run (333 bed volumes), another regeneration was performed. The third run produced more than 1,150 bed volumes of treated water. The TOC of the treated water was 31 to 37 percent of the raw water TOC content.

Color Removal Performance

In **FIGURES II-2** through **II-4**, color removal performance of the three different ANIXs are compared. Although color breakthrough through the ANIX vessel should be gradual, numerical averages of all treated water color measurements are reported in **TABLE II-2**.

TABLE II-2
RODANTHE PILOT TEST
AVERAGE COLOR REMOVAL

| Average Color (unit) | | | |
|----------------------|------------|-----------|-----------|
| | 1st Run | 2nd Run | 3rd Run |
| Raw Water | 18 | 19 | 18 |
| SIR-22P-HP | 2.0 (89 %) | 3.9 (79%) | 2.3 (87%) |
| Tanex | 1.6 (91 %) | 1.6 (92%) | 1.4 (92%) |
| IRA-900-CL | 1.9 (89 %) | 2.1 (89%) | 1.2 (93%) |

(Note: Percent TOC removals are shown in parentheses)

FIGURE II-1
EFFLUENT TOC PROFILE AT RODANTHE

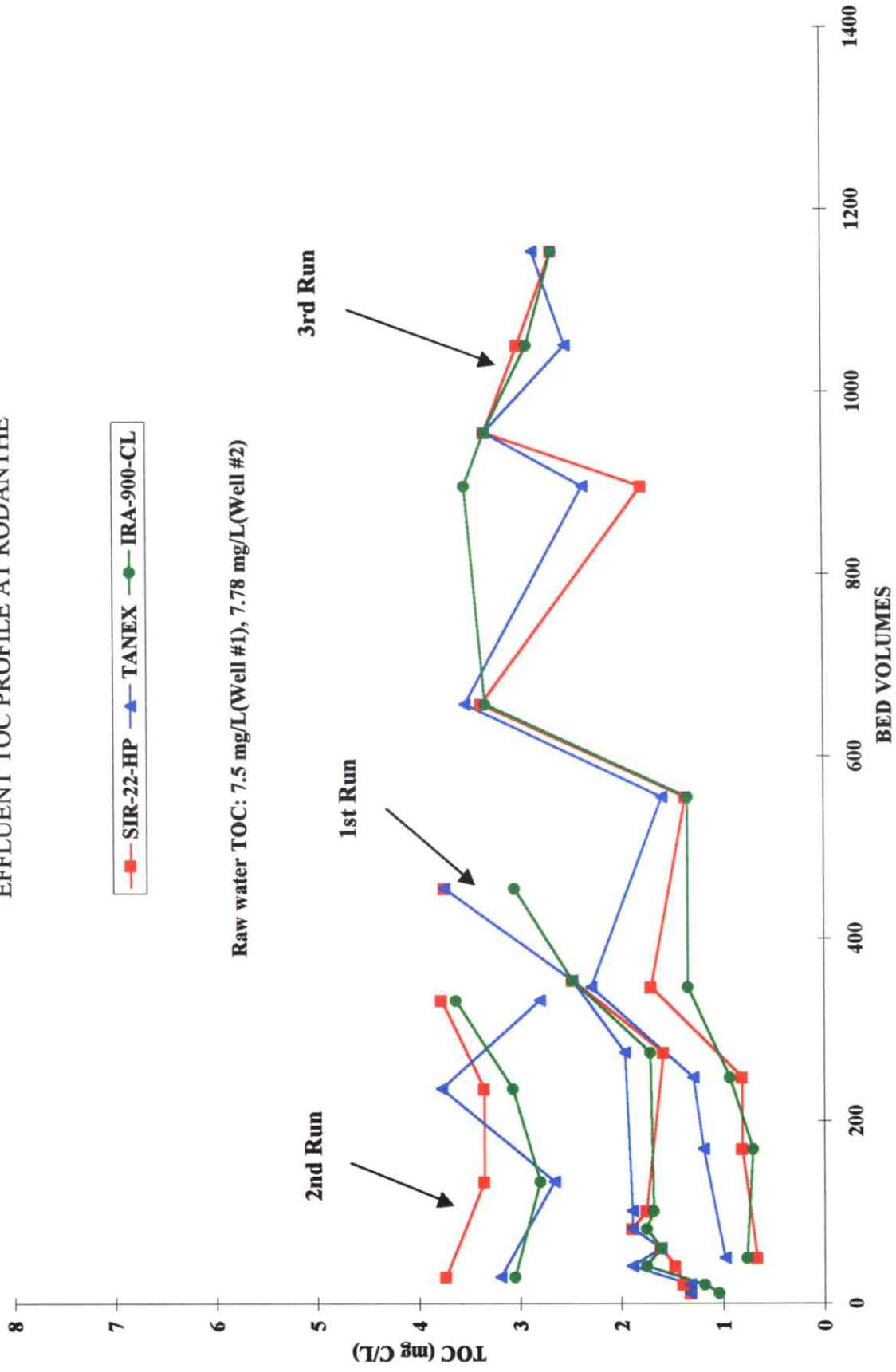


FIGURE II-2
EFFLUENT COLOR PROFILE AT RODANTHE - 1ST RUN

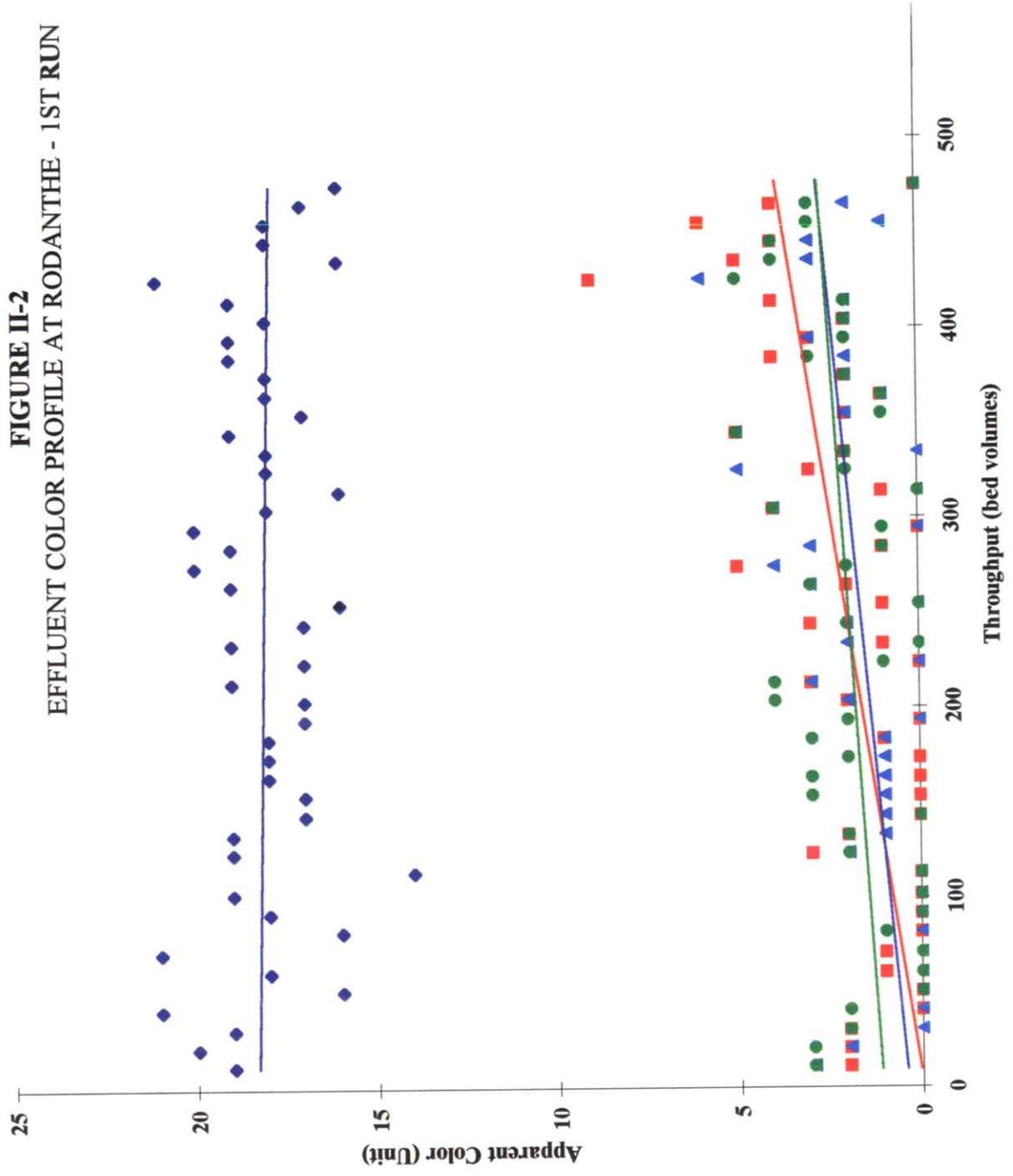


FIGURE II-3
EFFLUENT COLOR PROFILE AT RODANTHE - 2ND RUN

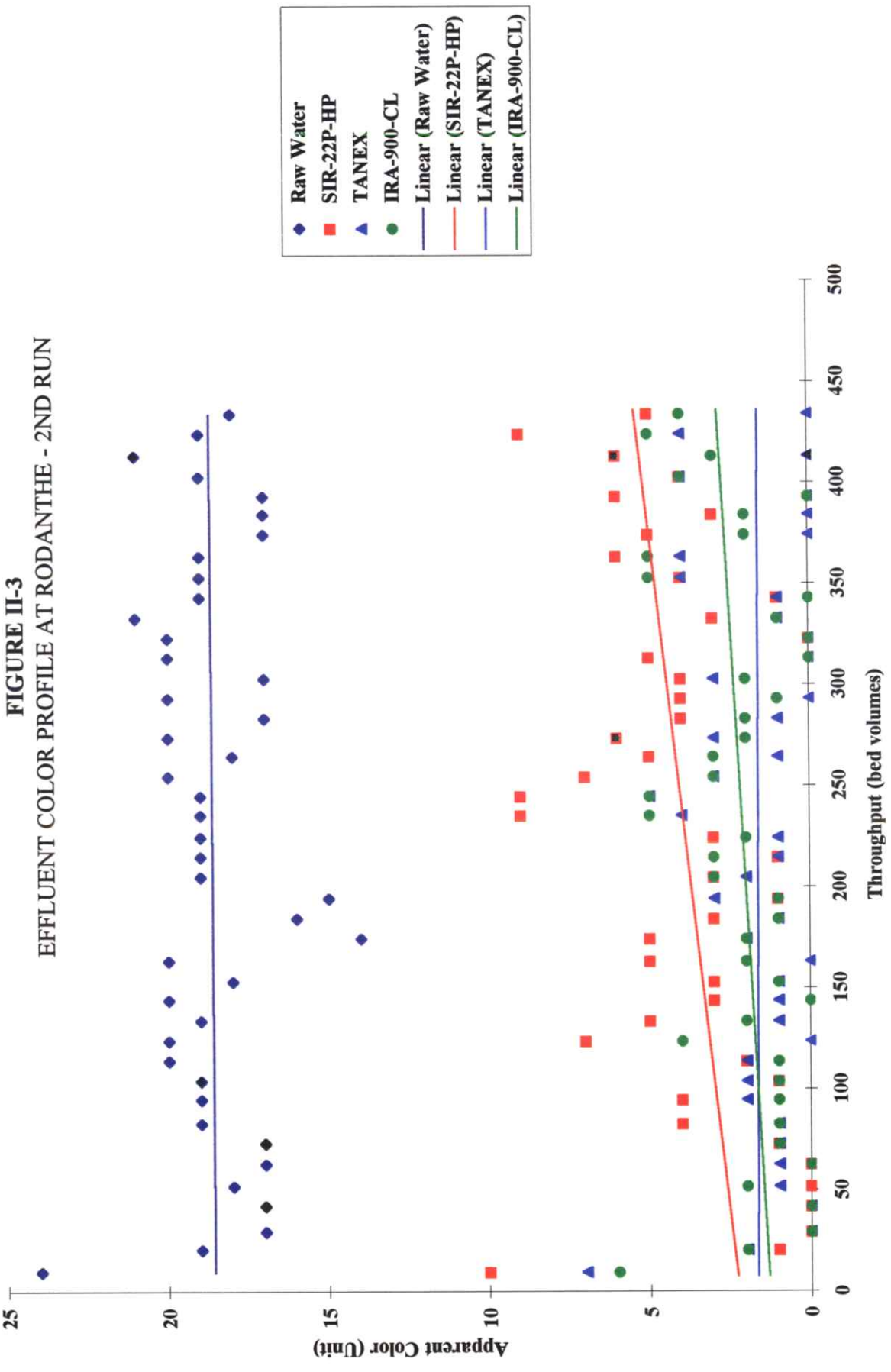
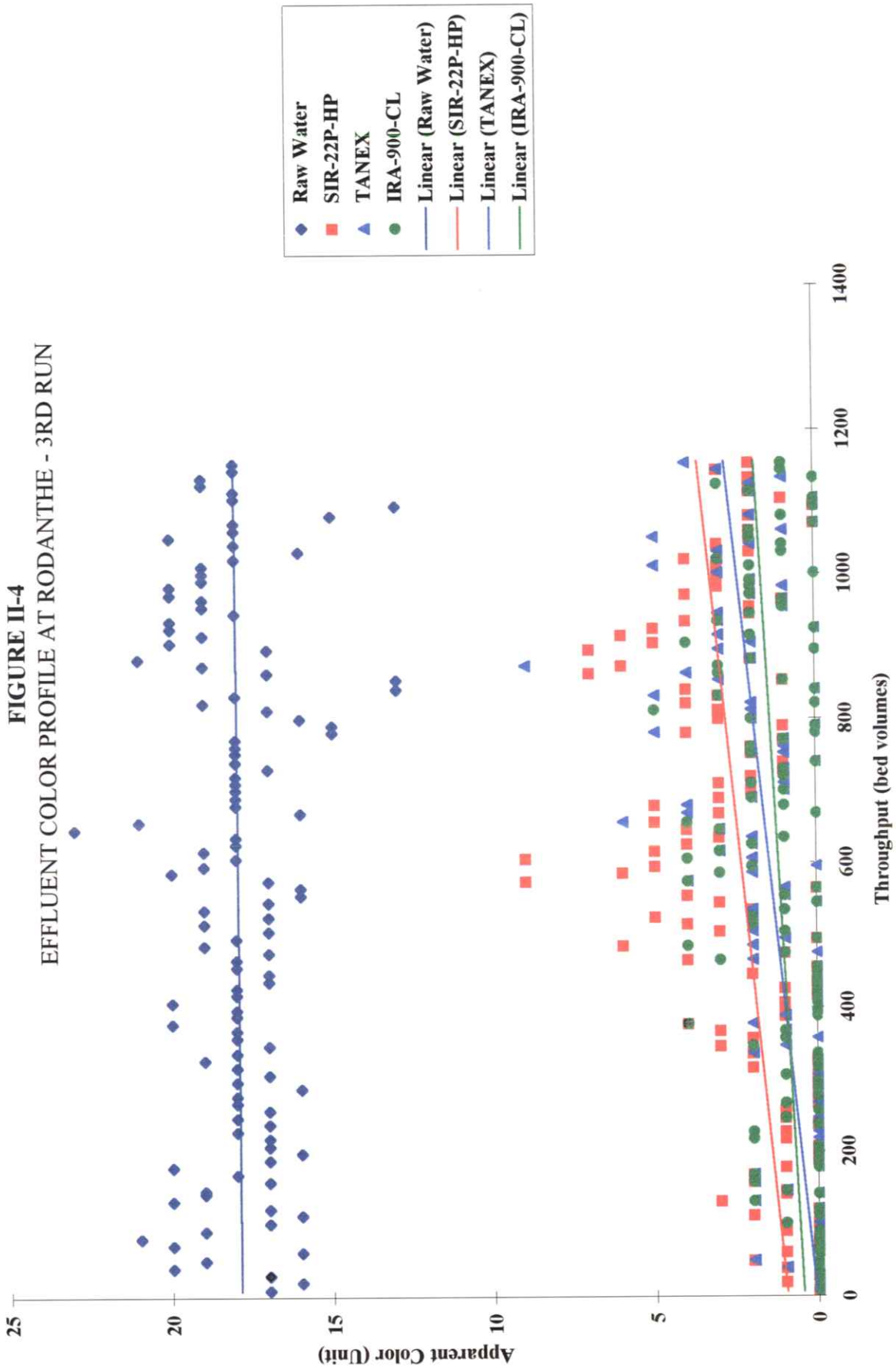


FIGURE II-4
EFFLUENT COLOR PROFILE AT RODANTHE - 3RD RUN



Color removal performance by ANIX resins was much higher than TOC removal performance as shown in **TABLE II-2**. This indicates that color bodies can be removed by ANIX resins much more efficiently than organic matters expressed in TOC.

Skyco Water Treatment Plant

After completion of the pilot test at the Rodanthe water treatment plant, the pilot unit was transferred to the Skyco water treatment plant. The pilot system, including the ANIX resins, was shock chlorinated with 50 ppm chlorine. The ANIX resins were further treated with a mixture of NaCl and NaOH.

TOC Removal Performance

Three service cycles were performed during the pilot test period (8/20/97 to 11/15/97). The effluent TOC profiles for the service cycles are shown in **FIGURES II-5** through **II-7**. In between the service cycles, the ANIX resins were regenerated with 12 percent brine.

The first service cycle (see **FIGURE II-5**) was terminated by the pilot operator at a treated water throughput of about 480 bed volumes. This early termination of the service cycle was precipitated by elevated iron concentrations in the ANIX effluents. All three ANIX resins were removing about 75 percent of the influent TOC when the first service cycle was terminated. The ANIX process does not remove cations such as iron, calcium, and magnesium. The iron removal mechanism by the ANIX resins during the pilot testing is not clearly defined. No effort was given to clarify the iron removal by the ANIX process.

The second service cycle (see **FIGURE II-6**) was stopped at a throughput of about 860 bed volumes. The service termination was caused by 14 days of well shut down. After the two-week shut down, the ANIX pilot system was put back into service.

The third and final service cycle (see **FIGURE II-7**) lasted over 1,650 bed volumes of throughput.

Color Removal Performance

Color breakthrough profiles during the three service cycles are presented in **FIGURES II-8** through **II-10**. As can be seen from the

FIGURE II-5
EFFLUENT TOC PROFILE AT SKYCO - 1ST RUN

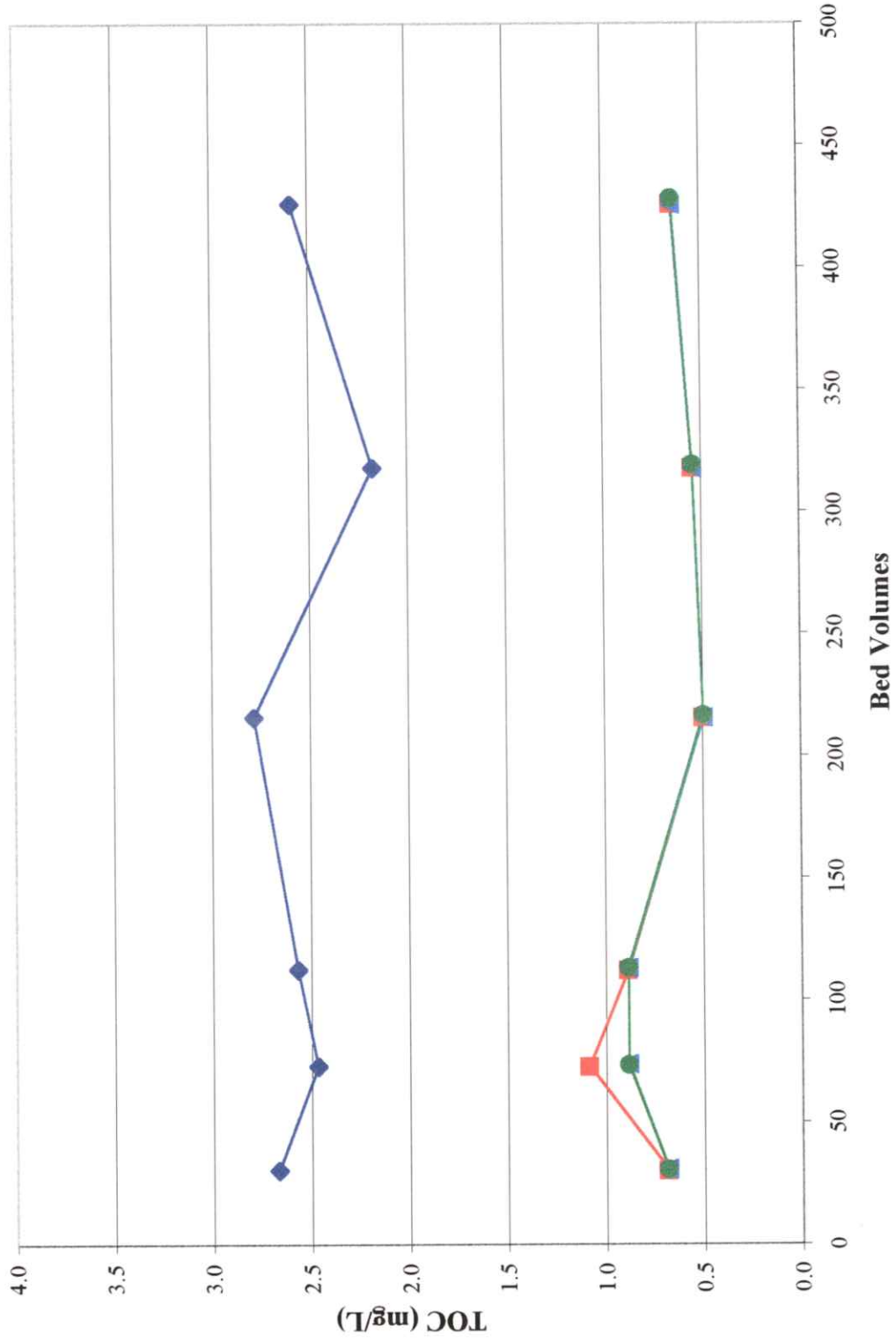


FIGURE II-6
EFFLUENT TOC PROFILE AT SKYCO - 2ND RUN

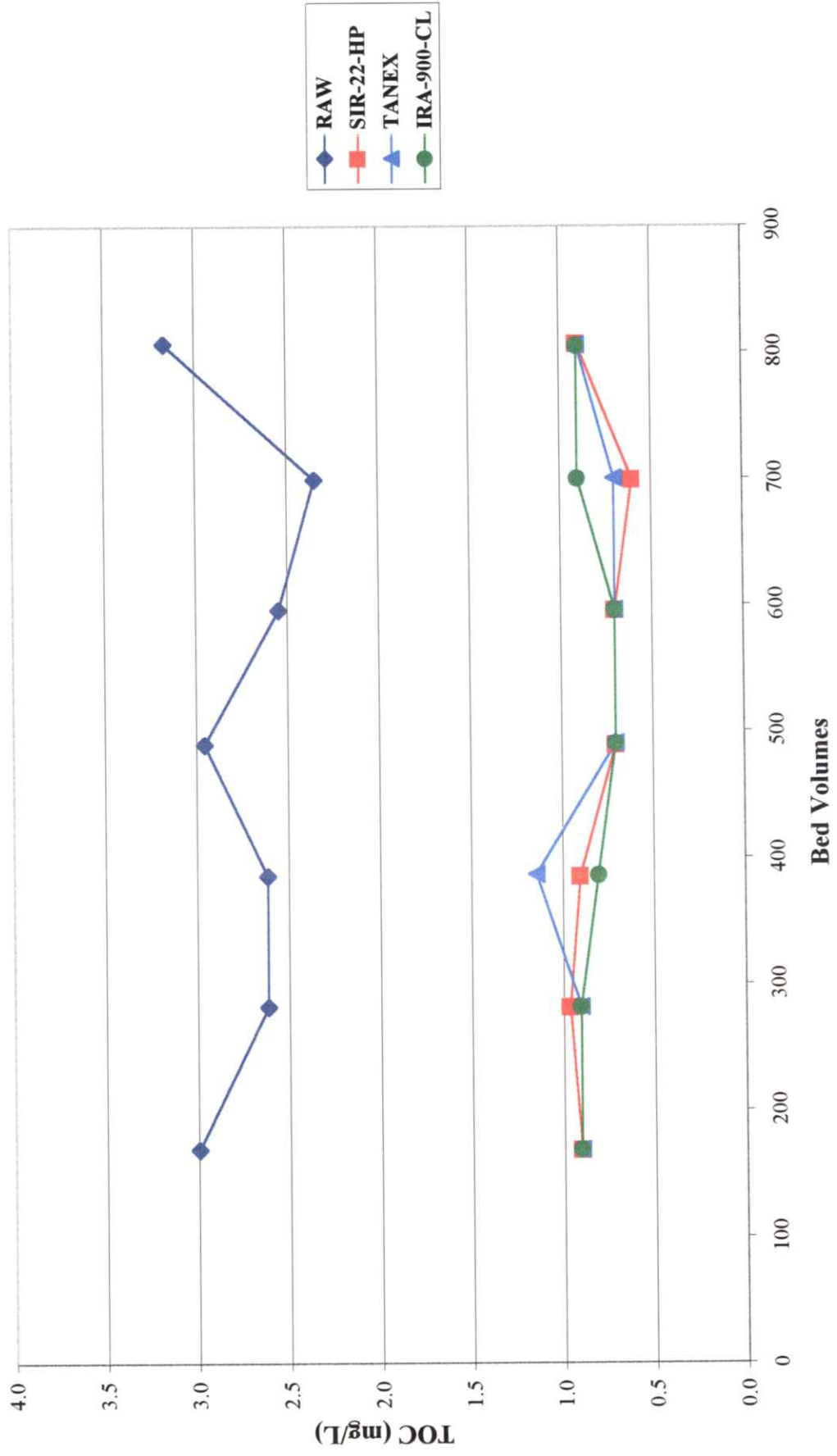


FIGURE II-7
EFFLUENT TOC PROFILE AT SKYCO - 3RD RUN

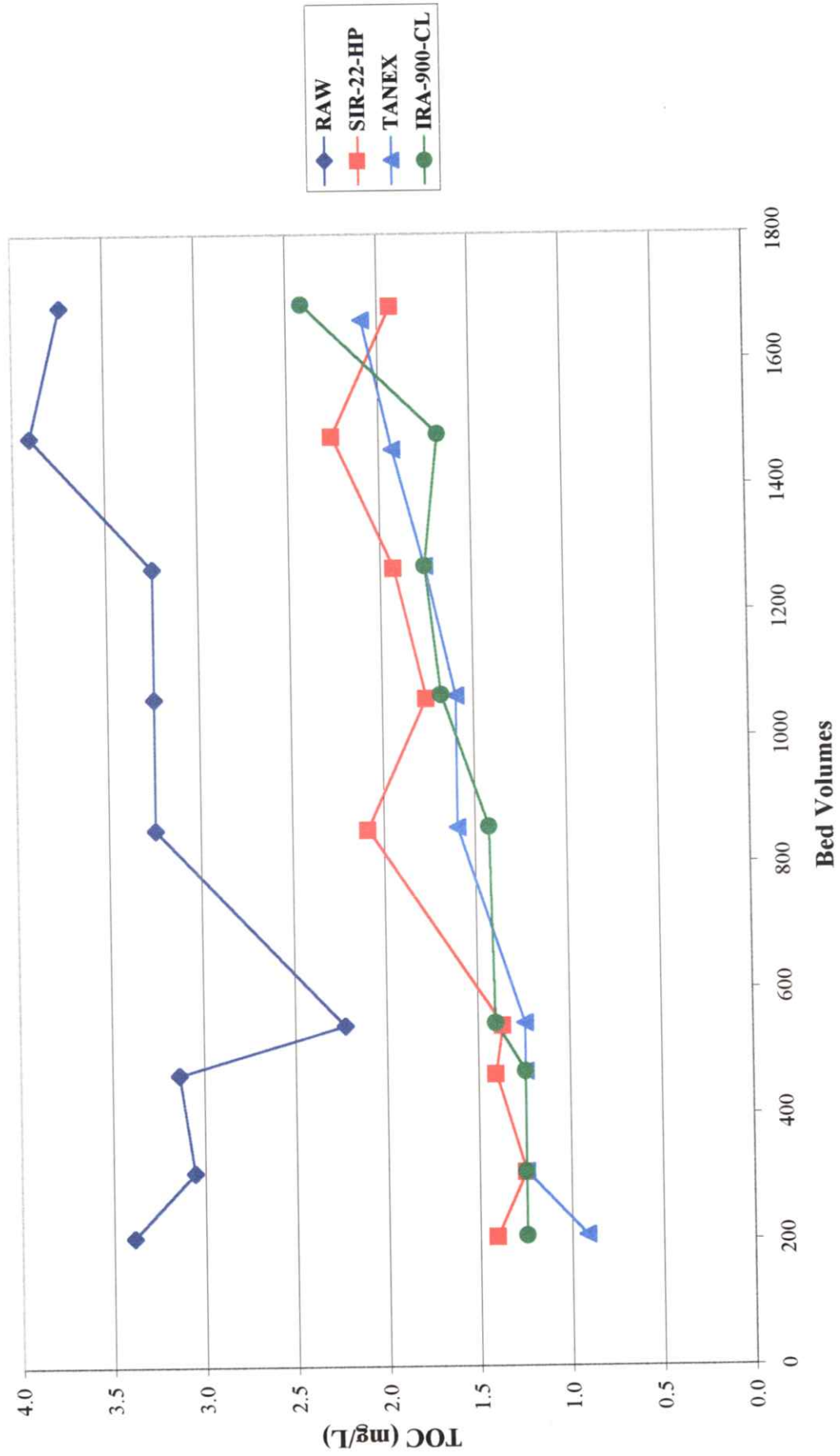


FIGURE II-8
EFFLUENT COLOR PROFILE AT SKYCO - 1ST RUN

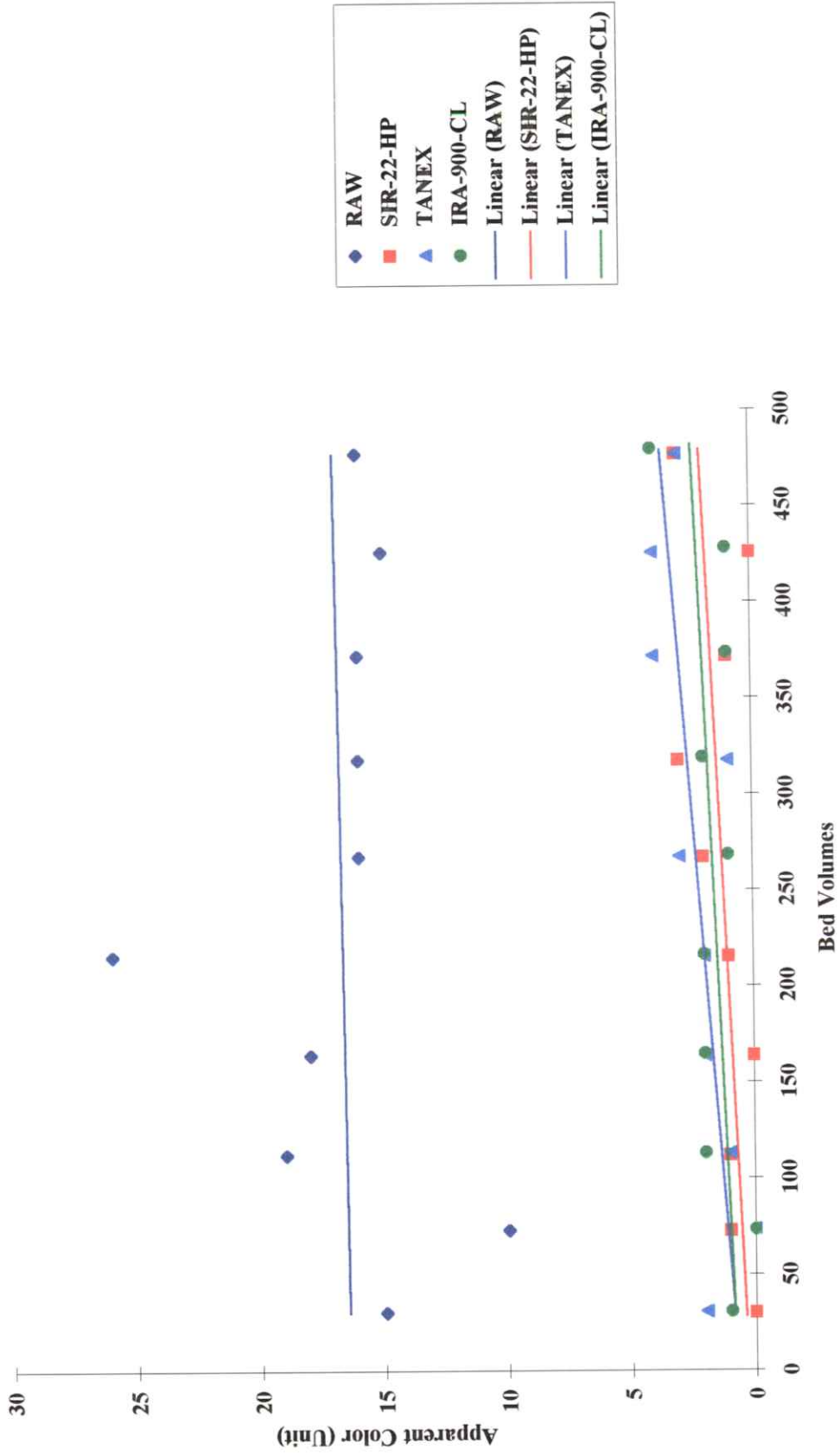


FIGURE II-9
EFFLUENT COLOR PROFILE AT SKYCO - 2ND RUN

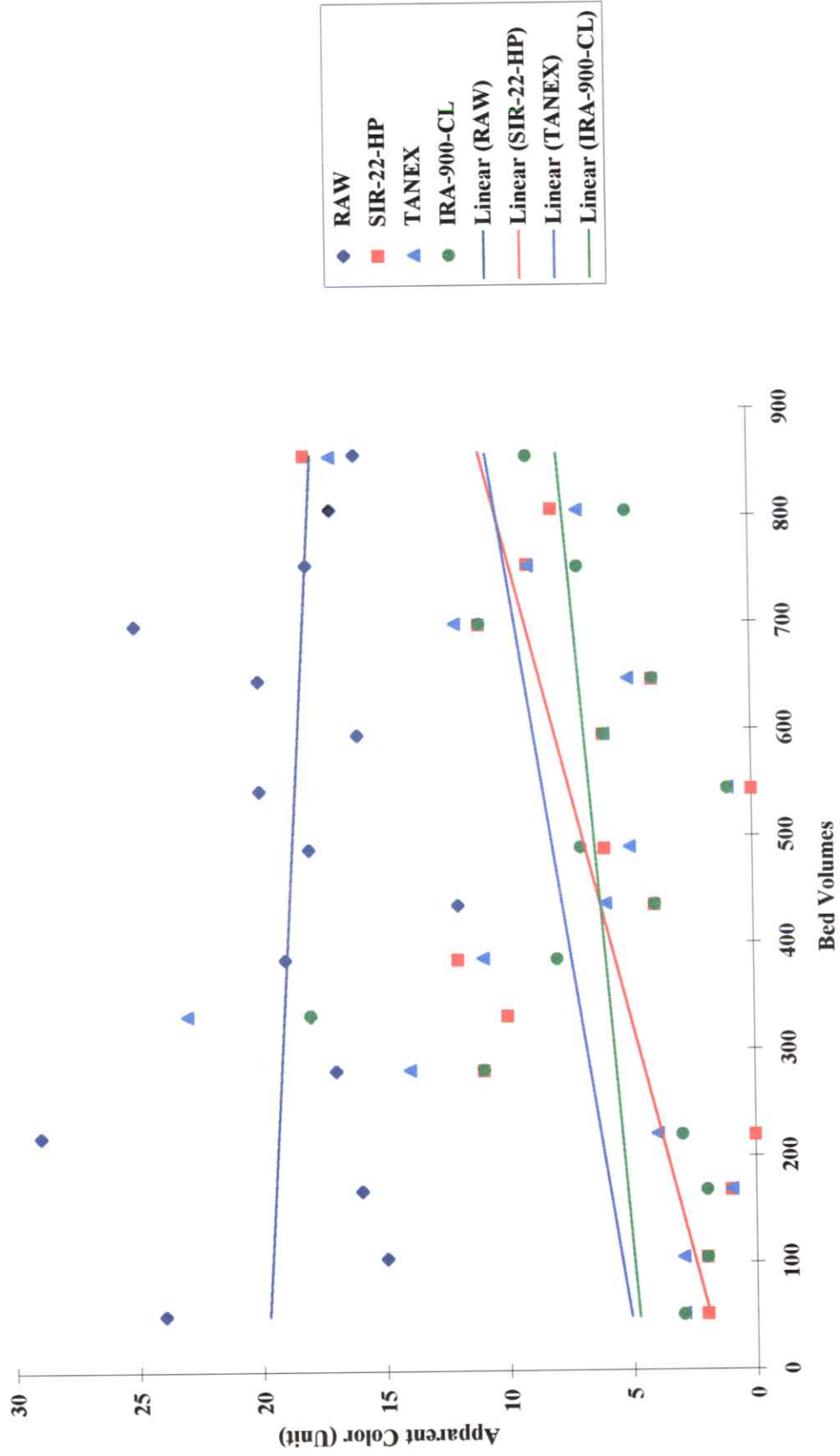
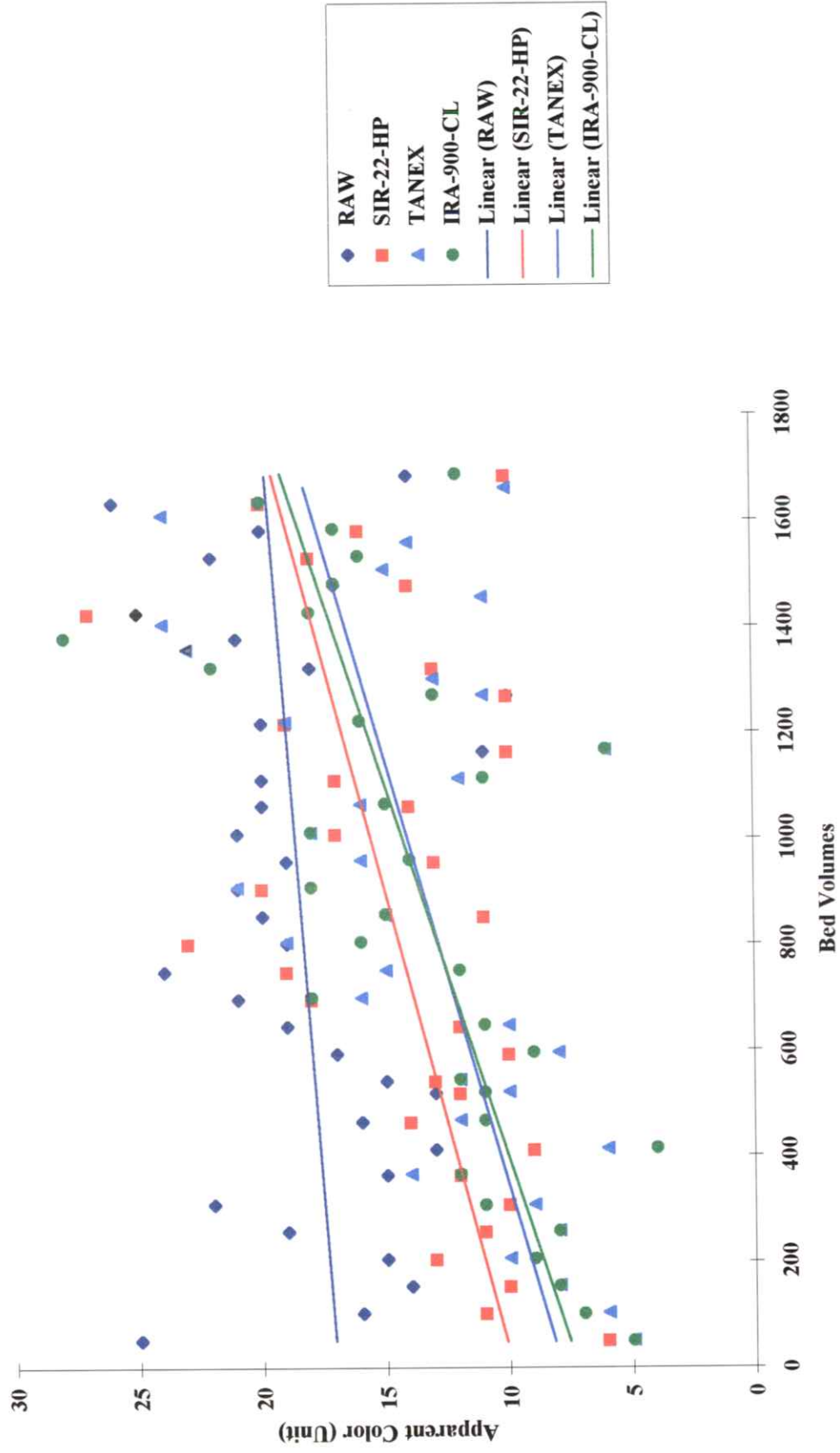


FIGURE II-10
EFFLUENT COLOR PROFILE AT SKYCO - 3RD RUN



breakthrough profiles, the effluent color data are scattered widely. Linear regression lines are added to the data points for easier distinction among the data series.

Contrary to the results observed from the Rodanthe testing, the color removal efficiencies were lower than corresponding TOC removal efficiencies. For example, when the organic content in the ANIX resins increased as the number of service cycles increased (see **FIGURE II-10**), the TOC removal efficiency decreased from about 60 percent to 49 percent toward the end of the service. The color removal efficiency, on the other hand, decreased from about 50 percent to almost no removal toward the end of the service cycle.

Kill Devil Hills Water Treatment Plant

After completion of the Skyco water treatment pilot test, the ANIX pilot unit was again moved to Dare County's Kill Devil Hills reverse osmosis water plant. The ANIX pilot system was shock chlorinated with 70 percent HTH. The ANIX resins were then regenerated with a 12 percent NaCl/25 percent NaOH by soaking for 24 hours.

It was expected that the organic removal efficiencies would be low because of high TDS (*e.g.*, over 3,800 mg/L) in the raw water. Only one service run was practiced during the pilot test.

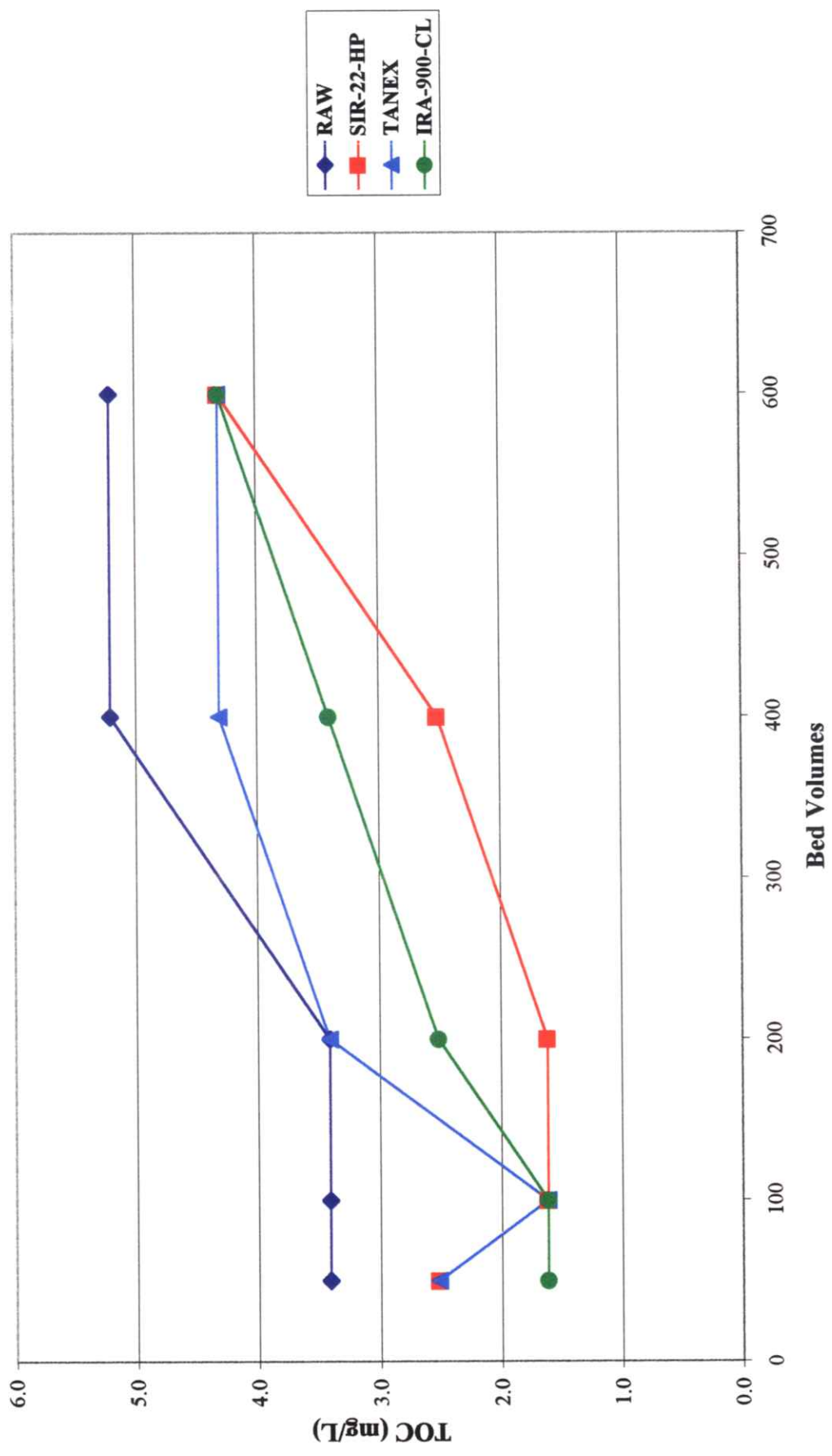
TOC Removal Performance

Treated effluent TOC profiles from the ANIX resins are compared in **FIGURE II-11**. The ANIX pilot test lasted for over three weeks before shutting down and produced about 2,300 bed volumes of treated water. The TOC samples, however, were taken only up to 600 bed volumes of throughput as can be seen in **FIGURE II-11**.

According to the TOC data in **FIGURE II-11**, the incoming TOC was removed throughout the sampling period of up to 600 bed volumes. At 600 bed volumes of throughput, all three ANIX system were removing about 17 percent of the TOC in the raw water.

As indicated in **TABLE II-1**, sulfate concentration in the raw water for the Kill Devil Hills water treatment plant averaged 212 mg/L. Although natural organic matters are generally more preferred than sulfate ions by ANIX resins, the sulfate ions still compete with organic

FIGURE II-11
EFFLUENT TOC PROFILE AT KILL DEVIL HILLS

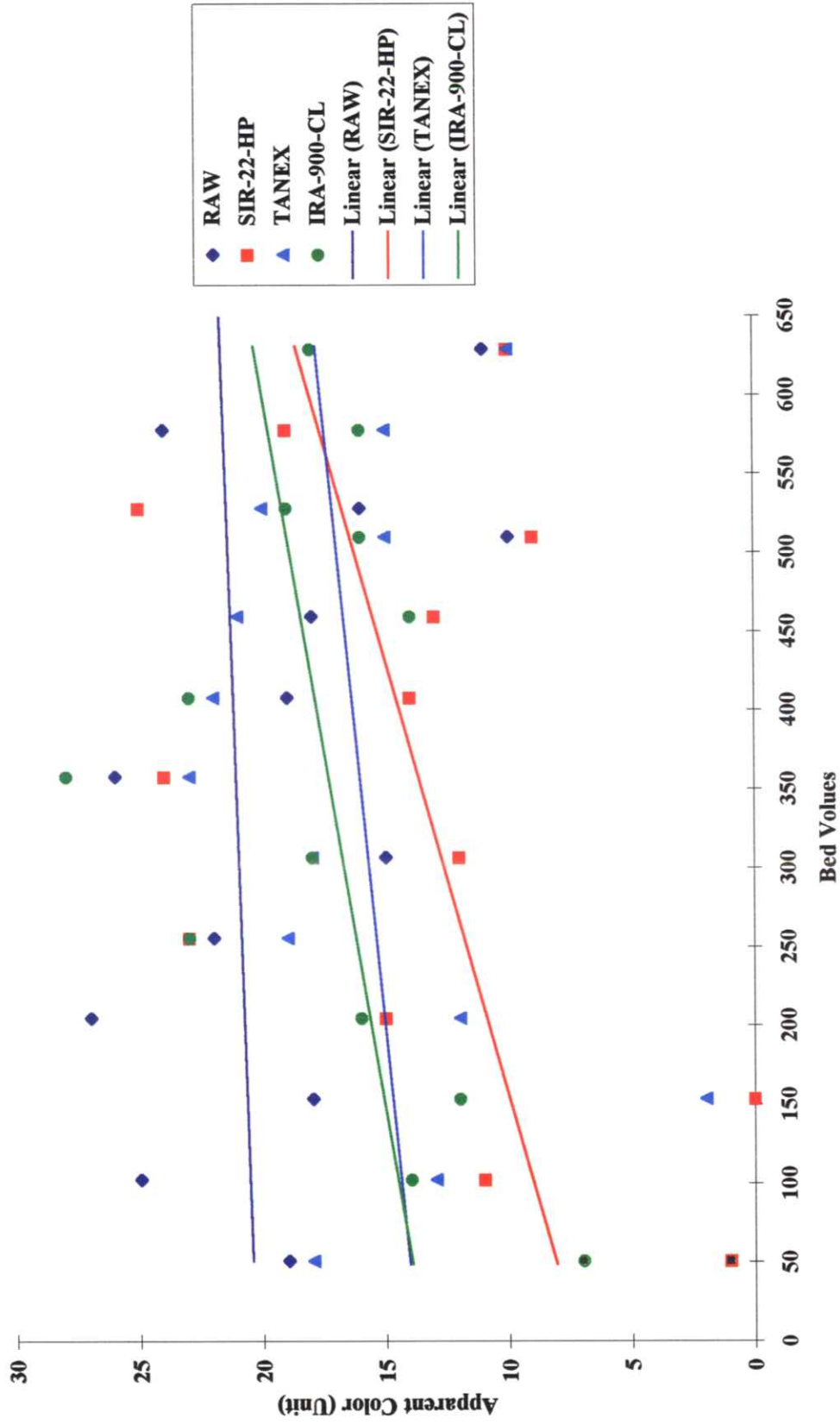


matters for the adsorption sites. Also, the higher the raw water TDS, the shorter the service run time expected for ion exchange systems.

Color Removal Performance

Effluent color data are presented in **FIGURE II-12** up to 650 bed volumes of throughput. The color breakthrough pattern is similar to the TOC breakthrough profile. Although not shown, after 650 bed volumes, treated color was virtually indiscernible from the raw water counterpart.

FIGURE II-12
EFFLUENT COLOR PROFILE AT KILL DEVIL HILLS



Conclusions

Based on the results and observations made during the pilot test for the removal of color and organic materials using ANIX resins, the following conclusions can be made:

1. All three ANIX resins performed well. No clear distinctions could be made regarding TOC and color removal performance.
2. By treating blend water with the ANIX process, overall water production from Rodanthe and Skyco water treatment plants can be dramatically increased.
3. Treating blend water with the ANIX process at Kill Devil Hills treatment plant appears economically not feasible because of high TDS and short service run time.
4. Selective removal of color and TOC by ANIX resins was observed depending on the raw water color or organic materials.
5. Service run time and treated water throughput are strongly dependent on regeneration level.
6. Iron removal at Skyco water treatment plant might have been caused by its association with organic materials in the water. No effort was made to clarify the removal mechanism during the project.

Recommendations

Based on the conclusions drawn, the following recommendations are made:

1. Because of the very low sulfate concentration in the raw water, "true" color or ultraviolet light absorbency should be used to detect color breakthrough for proper regeneration timing.
2. Difference in TOC and color removal performance among various types ANIX resins are not readily discernable because of the short duration of the pilot test. As service/regeneration cycles increase, however, hydrophilic ANIX resins should outperform hydrophobic resins. This is because the hydrophilic resins can be more efficiently regenerated than hydrophobic resins. Therefore, it is strongly recommended that hydrophilic resins (*i.e.*, acrylic based resins) be used for this application.
3. Exhausted ANIX resins should be regenerated with brine at a minimum salt loading rate of 10-lb NaCl per cubic foot of resin. Caustic can be added to raise the regenerant pH for a regeneration that is more complete.

Cost Estimate

Among the three water treatment plants (*i.e.*, Rodanthe, Skyco, and Kill Devil Hills), Rodanthe and Skyco water treatment plants seem to be good candidates for ANIX process for the removal of TOC and THMFP. Raw waters of both places contain extremely low sulfate and produced over 1,000 bed volumes of treated water throughput before regeneration was practiced.

The proposed ANIX system capacity for the Rodanthe water treatment plant is 300 gpm (or about 0.4 MGD). At the Skyco water treatment plant, on the other hand, the ANIX system capacity can be varied depending on desired finished water THM quality. During the pilot testing at Skyco, only TOC samples were collected. Based upon an assumption of similar percent THMFP reduction to percent TOC reduction (70 percent), it appears to be necessary to treat over 85 percent of the plant capacity by the ANIX system to meet the Phase 2 D/DBP rule (40 μg TTHM/L). Therefore, the ANIX system capacity for the purpose of the preliminary cost estimate is 4.5 MGD.

The capital cost of the ANIX system depends substantially on the number and size of ANIX vessels and amount of resin required. Based upon the pilot test result, preliminary equipment designs have been prepared and are shown in the following **TABLE II-3**.

TABLE II-3
DARE COUNTY ORGANIC REMOVAL ANIX SYSTEM
EQUIPMENT DESIGN

| Item | Rodanthe | Skyco |
|---------------------------------------|----------|-------|
| Design Flow, gpm | 300 | 3,125 |
| Vessel Diameter, ft | 7 | 12 |
| Resin Depth, ft | 3.5 | 6 |
| Number of Vessels | 3 | 6 |
| EBCT, minutes | 10 | 9.7 |
| Resin Volume, ft ³ | 405 | 4,100 |
| Volume Treated (est), MG/regeneration | 3 | 30.7 |
| Vessel Shell Height, ft | 8 | 12 |

In the following **TABLE II-4**, a cost estimate for Rodanthe and Skyco ANIX systems is presented. Estimated annual operation and maintenance cost is also presented in **TABLE II-5**.

TABLE II-4
DARE COUNTY ORGANIC REMOVAL ANIX SYSTEM
CAPITAL COST ESTIMATE

| Item | Rodanthe | Skyco |
|------------------------------------|------------------|--------------------|
| ANIX System Capacity | 0.43 MGD | 4.5 MGD |
| ANIX Vessels w/ face piping | \$150,000 | \$600,000 |
| Resin | \$80,000 | \$820,000 |
| Brine Tanks, Pumps, etc. | \$70,000 | \$70,000 |
| Instrumentation & Control | Manual | Manual |
| Pipe, Valves, Fitting | \$30,000 | \$60,000 |
| Electrical | \$10,000 | \$15,000 |
| Site Work | \$20,000 | \$25,000 |
| Building | \$120,000 | \$250,000 |
| Estimated Construction Cost | \$480,000 | \$1,840,000 |
| Engineering (15%) | \$72,000 | \$276,000 |
| Contingency (20%) | \$96,000 | \$368,000 |
| Estimated Capital Cost | \$648,000 | \$2,484,000 |

TABLE II-5
DARE COUNTY ORGANIC REMOVAL ANIX SYSTEM
ESTIMATED ANNUAL O & M COST ESTIMATE

| Item | Rodanthe | Skyco |
|--------------------------------------|-----------------|------------------|
| Salt (@ \$60/ton) | \$6,500 | \$65,000 |
| Maintenance (@ 1% capital) | \$6,500 | \$25,000 |
| ANIX Resin Replacement (@ 10%/Yr) | \$8,000 | \$82,000 |
| Estimated Yearly O&M Cost | \$21,000 | \$172,000 |