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TREATABILITY STUDY TO EVALUATE AEROBIC BIOREMEDIATION OF CONTAMINATED SITE GROUNDWATER WAUKEGAN MANUFACTURED GAS AND COKE PLANT SITE WAUKEGAN, ILLINOIS

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EXECUTIVE SUMMARY

The Waukegan Manufactured Gas and Coke Plant Site Technical Committee conducted a laboratory treatability study to determine the applicability of in-situ aerobic biodegradation as a remedial alternative for compounds of concern (COCs) present in Site groundwater.

The Treatability Study was conducted in three phases. Phase I, using deionized water with concentrations of compounds of concern (COCs) similar to Site groundwater, was designed to confirm the biodegradability of mixtures of phenol and ammonia and to finalize the experimental protocol. Phase II, using Site groundwater, was designed to confirm the viability of biodegradation and to determine the relative level of dilution needed to achieve biodegradation of the COCs. Phase III, using both synthetic and Site groundwater, was designed to provide an understanding of the biodegradation processes by measuring contaminant loss and determining the degradation kinetics. All three phases used an inoculum of ammonia and phenol degraders to provide sufficient levels of bacteria to accelerate the study so that data could be obtained in a reasonable period of time.

Results of the treatability study indicate the following:

1. The MW-7D Site groundwater, undiluted, does not support any biological activity.

2. Phenol degradation is unimpeded when the MW-7D groundwater is diluted at a ratio of 2:1 (MW13S:MW7D) or greater, for which the rate of phenol degradation is independent of the degree of dilution. Phenol degradation also is uninhibited by ammonia or thiocyanate at levels relevant to the Site.

3. Thiocyanate degradation occurs when the MW-7D groundwater is diluted at a ratio of 2:1 (MW13S:MW7D) or greater. Unlike phenol, thiocyanate kinetics continue to increase as the MW-7D groundwater is diluted to lower strengths. This finding indicates that components in the groundwater matrix are inhibitory to thiocyanate-degrading bacteria.

4. Ammonia was nitrified when MW-7D groundwater was diluted at a ratio of 2:1 (MW13S:MW7D) or greater, provided that nitrifying bacteria were present and that inhibition from phenol, thiocyanate, and components in the groundwater matrix was reduced by dilution or aerobic biodegradation. The inhibitory effect on nitrification could be explained by an accelerated die-off of the nitrifiers.

5. Once biodegradation was able to begin, the kinetics for each of the three compounds of concern was consistent with previously published work.

6. Active phenol- and thiocyanate-degrading bacteria were present in the Site soil.

In summary, the results of the laboratory treatability study support a conclusion that aerobic biodegradation of phenol and thiocyanate may be feasible at the Site provided the Site groundwater is sufficiently diluted or properly mixed prior to treatment. The results also suggest that nitrification of ammonia is possible, as long as nitrifying bacteria are present when toxicity from phenol, thiocyanate, and matrix components is relieved by a combination of aerobic biodegradation and dilution.

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1.0 INTRODUCTION

1.1 Study Purpose and Objectives

The lower portion of the shallow aquifer at the Waukegan Manufactured Gas and Coke Plant (WMGCP) Site has a chemical composition resembling that of coal conversion or coal gasification wastewaters. Three major groundwater compounds of concern (COC) at the Site are phenol, thiocyanate, and ammonia. The literature describing the aerobic biological treatment of coal conversion wastewaters suggests that these three COCs are biodegradable under the appropriate environmental conditions. The literature also indicates that the three COCs are self-inhibitory at high concentrations and that the interactions among the three compounds can adversely affect the rate at which specific compounds are biodegraded. The success of engineered systems in treating coal conversion wastewaters suggests that a properly designed aerobic biological treatment process should be an effective means of addressing these three COCs.

To determine if aerobic bioremediation is a viable remedy for the Site's aquifer, a laboratory treatability study was conducted to examine the aerobic biodegradation of these three COCs under simulated Site conditions. The major objectives of the biotreatability study were to evaluate the aerobic biodegradation of phenol, thiocyanate, and ammonia, and to assess the fate of other COCs. The biotreatability study progressed in three phases from tests using simulated groundwater (*i.e.*, spiked deionized water) to actual Site groundwater. The biotreatability study was designed to answer the following questions:

1. Are phenol, thiocyanate, and ammonia biodegradable when present together? In particular, what concentrations, singularly or in combination, are inhibitory to biodegradation?

2. Is there a matrix effect from Site groundwater that inhibits biodegradation?

3. What are the kinetic expressions and parameters that represent the kinetics of biodegradation for the three major COCs, including inhibitory interactions?

4. Does the Site soil contain bacteria capable of biodegrading the major COCs under aerobic conditions?

1.2 Literature Review of Treatment of Coal Conversion Wastewater

The deep groundwater at the Site closely resembles wastewater generated during coal conversion or coal gasification processes. The source of the deep groundwater contamination appears to have been the treatment ponds that received wastewater from the coal gasification and coking processes that were conducted on site.

A review of literature that discusses the biological treatment of coal conversion wastewaters was conducted to assist in the interpretation of data generated from this treatability study and to provide possible explanations for the difficulties encountered in the treatability test. The paragraphs below summarize findings from the literature pertaining to the biological treatment of coal conversion wastewaters. The literature reviewed focuses on biological processes for relatively high-strength coal conversion wastewaters.

The activated sludge process is the most widely used technology for the treatment of coal conversion wastewaters. This treatment process generally results in good reductions in COD and thiocyanate and very low effluent levels of phenols. However, long hydraulic detention times are usually necessary for adequate treatment.

Kostenbader and Flecksteiner (1969) conducted a treatability study on weak ammonia liquor (WAL) produced at the Bethlehem Steel Plant using the activated sludge process. A full scale activated sludge plant received an average of 112,000 gallons per day (gpd) of WAL at an average hydraulic detention time of 2-3 days. The average phenol concentrations was 1,400 mg/l and the phenol load to the plant was 1,300 lb/day. The phenol concentration in the clarifier effluent remained under 0.1 mg/l and BOD removal efficiency ranged from 85 to 95 percent during 2.5 years of operation. Thiocyanate oxidation ranged from 20 to 99 percent efficiency and averaged 70 percent during the same time period.

Barker and Thompson (1973) presented the results of a one-year pilot plant study that examined the biological removal of carbon and nitrogen compounds from coke plant wastes. The pilot plant consisted of two completely mixed activated sludge units in series. The first tank was used for organic carbon removal, while the second unit was for nitrification. A one-day hydraulic detention time was used for each unit, and the flow rate to the system was set at 1 gpm. The treatment system was operated for 40 days. During this period, the influent COD, phenol, and thiocyanate concentrations were 3,000 mg/l, 570 mg/l, and 310 mg/l, respectively, and associated removal efficiencies were 76, 99, and 10 percent, respectively. The second stage nitrification tank was fed a mixture of diluted first stage effluent and a supplemental ammonia solution. Under these conditions, 75 to 90 percent of the ammonia was nitrified. System upsets and the short term of operation of the process prevented the development of cultures capable of effective cyanide and thiocyanate oxidation.

Ganczarczyk and Elion (1978) examined the ability of an extended aeration activated sludge process to treat the coke plant effluent at Dominion Foundries and Steel Limited (DOFASCO) facility in Hamilton, Ontario. After equalization and stripping for ammonia reduction, the wastewater was fed to a single-stage activated sludge treatment plant. Phenol removal averaged 99 percent for influent phenol concentrations ranging between 2.9 and 288 mg/l and an aeration detention time of 13.8 hours. The activated sludge system was operated at a sludge age of 41.4 days with solids wasting over the effluent weir. Upon doubling the aeration detention time, the phenol removal efficiency increased to 99.3 percent, with the sludge age remaining essentially constant at 41.3 days. Thiocyanate removal was

roughly 50 percent. In spite of the high sludge age and elevated reactor temperature, nitrification of the unstripped portion of the influent ammonia did not occur.

Adams et al. (1974) conducted laboratory studies examining the biological treatment of two coke plant wastes. The wastewater contained a BOD_5 concentration of 4,140 mg/l, ammonia of 143 mg/l, phenol of 1,160 mg/l, and cyanide of 4.5 mg/l. Three identical activated sludge units were operated using hydraulic detention times of 6.6 days, 2.6 days, and 1.8 days, respectively. The mixed liquor suspended solids were maintained at roughly 2,500 mg/l in each of the three aeration tanks. Removal efficiencies for BOD, ammonia, phenol, and cyanide were 96.7, -3.5, 85.7, and 82.6 percent, respectively, for the 6.6 day hydraulic detention time unit. The 2.6 day hydraulic detention time unit yielded removal efficiencies for the above parameters of 97.6, 10.5, 84.6, and 79.8 percent, respectively, while a detention time of 1.8 days resulted in removal efficiencies of 88.9, 21.7, 76.8, and 70.9 percent, respectively. A second wastewater containing BOD_5 levels of 2,050 mg/l, ammonia of 110 mg/l, phenol of 430 mg/l, and cyanide of 3 mg/l was treated in two activated sludge units using hydraulic detention times of 4.1 and 2.2 days. A mixed liquor suspended solids concentration of 2,400 mg/l was maintained in each unit. Removal efficiencies for BOD, ammonia, phenol, and cyanide for the plant operated at a 4.1 day hydraulic detention time were 96.5, -101.8, >99.9, and 80.3 percent, respectively. Slightly lower removal efficiencies were observed for the plant operated at a hydraulic detention time of 2.2 days. Removal efficiencies for BOD, ammonia, phenol, and cyanide in this plant were 93.7, -60.0, 99.9, and 78.7 percent, respectively. The increase in ammonia concentrations after treatment could be attributed to the ammonia formed as an end product of the oxidation of thiocyanate and cyanide.

Luthy and Jones (1980) reported on the biological oxidation of an undiluted coke plant effluent. The COD, phenol, ammonia, cyanide, and thiocyanate concentrations of the waste ranged from 3,880-4,600 mg/l, 750-1,010 mg/l, 35-92 mg/l, 3.2-4.4 mg/l, and 280-554 mg/l, respectively. Seven identical reactors were operated at sludge ages ranging from 10 to 40 days and hydraulic detention times of 2.7 to 9.2 days. Phenol removal efficiencies were consistently greater than 99 percent for all systems, while thiocyanate removal efficiencies ranged from 90 to 99 percent. Cyanide, on the other hand, was only slightly removed. Nitrification occurred only in the reactor operated at a 40 day sludge age and a 9.2 day hydraulic retention time. The authors concluded that a well managed activated sludge treatment plant operated at a 40 day sludge age and a 9.2 day hydraulic detention time could treat an undiluted coke plant waste and produce an effluent that approaches best available technology (BAT).

Luthy and Tallon (1978) evaluated the biological treatability of HYGAS coal gasification process condensate at full strength and at a 50 percent dilution. This study demonstrated that at hydraulic detention times of 2 and 3 days and sludge ages ranging between 10 and 40 days, it was possible to remove 80 percent of the COD, 99 percent of the phenol, and 85 percent of the thiocyanate from the 50 percent diluted waste. However, the full-strength wastewater inhibited biological treatment.

Luthy et al. (1980) conducted activated sludge treatability studies examining the biological treatment of effluent from a slagging fixed-bed coal gasification pilot plant operated by the Grand Forks Energy Technology Center of the Department of Energy. Their findings reinforced previous work in which ammonia-stripped wastewater was processed reliably at 33 percent strength. It should be pointed out, however, that even at this dilution the organic content of the wastewater, which averaged 8,380 mg/l COD, was the highest reported for this type of wastewater. In a continuing study, Luthy and coworkers (1983) evaluated the treatability of the same wastewater after that water had been pretreated. Phenols were removed by solvent extraction with methylisobutyl ketone and the ammonia was steam stripped. The pretreated wastewater was treated with activated sludge and powdered activated carbon-activated sludge using aeration times of 12.6 and 11.7 days and sludge ages of 30 and 20 days, respectively. This study revealed that the solvent extracted and ammonia-stripped wastewater did not require dilution prior to biological treatment. Also, solvent extraction resulted in lower COD, TOC and color for both of the systems.

The relatively unstable operation reported for activated sludge systems during the treatment of coal conversion wastewaters can be explained by the presence of certain organic and inorganic compounds in the wastewater. Thiocyanate, cyanide, ammonia and phenol are all usually found in coal conversion wastewater at various concentrations. All of these compounds exhibit toxic effects above certain concentrations and may cause severe inhibition of the activated sludge process. Juntgen and Klein (1977) presented data on the co-inhibition of phenol, thiocyanate and ammonia during the aerobic treatment of coke oven and coal gasification wastewaters. Phenol degradation was inhibited by concentrations of ammonia, thiocyanate and sulfide in excess of 1,700, 250, and 25 mg/l, respectively. Thiocyanate degradation was completely halted at ammonia, thiosulfate, and phenol levels of 1,000, 100, and 25 mg/l, respectively. Nitrification, on the other hand, was inhibited at levels of phenol, thiocyanate, and cyanide as low as 50, 10, and 10 mg/l, respectively.

In conclusion, the biological treatment of relatively high-strength coal conversion wastewaters is achievable under controlled treatment processes. Organic constituents, such as phenol, were relatively easily degraded, yet degradation of other constituents such as ammonia, thiocyanate, and cyanide is significantly more difficult. Nitrification was possible in a single-stage reactor, but only under extremely long hydraulic and solids retention times or in a second-stage reactor devoted to nitrification. The relative unstable performance of the evaluated treatment processes in treating coal conversion wastewaters can be attributed to the presence of certain inhibitory organic and inorganic compounds.

1.3 Overview of Treatability Study Program

The Treatability Study was conducted in three phases. Phase I, using simulated groundwater (deionized water plus mineral nutrients) was designed to confirm the biodegradation of mixtures of phenol and ammonia in deionized water and to finalize experimental procedures. Phase II, using Site groundwater, was designed to determine the relative level of dilution required to achieve biodegradation in site groundwater. Phase III, using both simulated and Site groundwater, was designed to provide a

quantitative comparison of ammonia removal for different levels of dilution by tracking and measuring contaminant loss in reactors containing either spiked deionized water or actual Site groundwater. All three phases used an inoculum of ammonia and phenol degraders. The purpose of the inoculum was to provide sufficient levels of bacteria so that data could be obtained in a reasonable period of time. A description of each phase follows in Sections 2, 3, and 4 of this report.

2.0 PHASE I GROUNDWATER CHARACTERIZATION AND INOCULA SCREENING

Phase I consisted of two parts. The first part was an initial characterization of Site groundwater samples to determine maximum ammonia and phenol levels. This analysis was the basis for the levels of dilution used in the subsequent inoculum tests. The second part was a microbial inoculation screening to determine effective ammonia and phenol degrader inoculum levels.

2.1 Initial Groundwater Characterization

Two Site groundwater samples were collected and submitted to Fluor Daniel GTI's, Remediation Technology Testing Facility, Concord, California on July 18 and 19, 1996. One sample (MW-13S) was collected from the shallow groundwater, and a second sample (MW-7D) was collected from the deep groundwater. A total of three 2.5-gallon bottles of groundwater labeled MW-7D and three 2.5-gallon bottles labeled 13-S were collected. Sample aliquots from each 2.5-gallon bottle were composited to obtain an individual well composite sample. Samples were collected and submitted to CH2M Hill Analytical Services for chemical analyses. The results of the analyses are shown in Table 2.1.

In general, the deep groundwater contained high levels of phenol (480 mg/l), ammonia (620 mg/l), and cresols (446 mg/l) and moderate levels of dissolved arsenic (19 mg/l). Benzene concentration was fairly low (0.66 mg/l). Thiocyanate was not analyzed. The shallow groundwater contained low levels of ammonia (3.4 mg/l) and arsenic (0.15 mg/l), and contained no phenol or cresols. With the exception of cyanide, all the COCs were 3 to 5 orders of magnitude lower in the shallow groundwater than in the deep aquifer.

2.2 Microbial Inocula Screening

The microbial screening test was designed to determine the microbial inoculum size required to ensure measurable phenol and ammonia oxidation within a desirable time frame. Three sets of three tubes each were set up at three dilution levels. The first set was "undiluted", with phenol and ammonia concentrations set at what was present in MW-7D. The second set "diluted" these concentrations by a factor of 3; and the last set diluted these concentrations by a factor of 10. All three were made up by adding ammonia and phenol to mineral salt medium (i.e., inorganic nutrient medium without a carbon source). Inocula (phenol and ammonia degraders) was added to each set of tubes at three levels (10^4, 10^5, 10^6 colony forming units (CFU/ml). Both types of microbial inocula were obtained from NALCO Chemical Company (Chicago, IL). The ammonia degrading culture (INOC 8166 Plus) was

supplied in liquid suspension. The phenol degrading culture (INOC 7161) was supplied as a dry powder mixed with a bran carrier. A poisoned control tube was run based on the 10^5 inoculum size and 10:1 dilution level.

2.2.1 Experimental Protocol

The Phase I microbial inoculation screening study consisted of a series 10-day long batch tests. The batch tests contained high, medium, or low concentrations of two COCs, and either an estimated 10^4, 10^5, or 10^6 CFU/mL inocula of each phenol-degrading bacteria and of ammonia-oxidizing bacteria. The batch tests performed with deionized water spiked the low concentration of COCs initially contained 305 mg/L of ammonia and 90 mg/L of phenol. The medium concentration reactors initially contained 366 mg/L of ammonia and 250 mg/L of phenol, while the high concentration reactors had 1220 mg/L ammonia and 750 mg/L phenol. In addition to the added phenol, ammonia, phenol-degrading inocula, and the nitrifying inocula, the reactor media also contained various inorganic nutrients and a phosphate buffer. The initial pH of all systems was adjusted to between 7.5 and 8.0. The headspace of each test bottle was flushed with pure oxygen to increase the availability of oxygen for microbial activity.

The bottle reactors were equipped with septum caps and incubated on a reciprocating shaker table at room temperature. Individual bottle reactors from the experimental system (e.g., high concentration of COCs with the inocula consisting of 10^4 CFU/mL of phenol-degrading bacteria and the10^4 CFU/ of ammonia-oxidizing bacteria) were sacrificed for analysis of the remaining phenol and ammonia concentrations and for analysis of the produced concentrations of nitrite and nitrate. Bottle reactors were sacrificed three times a week during the course of the 10-day long batch tests.

HACH test kits were utilized for measuring ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, and total phenolic concentrations. These kits use a colorimetric procedure with a low detection range to determine compound concentrations. While the kits have the advantage that only small sample volumes are required, they do have the disadvantage that samples containing high concentration of the analyzed compound must be diluted to fall within the calibrated range. Also, the results were determined by visual comparison with a color wheel. Any coloration of the water can interfere with the results. The ranges for the test kits were ammonia-nitrogen (0 to 1.0 mg/L), nitrite-nitrogen (0 to 0.5 mg/L), nitrate-nitrogen (0 to 50 mg/L), and total phenolics (0 to 5.0 mg/L).

2.2.2 Discussion of Results

As illustrated in Tables 2.2, 2.3, and 2.4, and Figures 2-1, 2-2, and 2-3, the extent of phenol and ammonia degradation during the 10-day long batch tests was affected by the concentration of COCs (high, medium, or low) and the level of bacterial inoculation. Because of an unexplainable loss of ammonia from the control bottle reactors (Figure 2-1) and presumably from the other bottle reactors, the extent of nitrification was quantified only in terms of nitrite and nitrate production and not in terms of ammonia disappearance. With no significant loss of phenol from the control reactors, the extent of phenol biodegradation was quantified in terms of phenol disappearance.

The batch tests performed with the low initial concentrations of COCs (80 mg/L phenol and 305 mg/L ammonia nitrogen) showed complete phenol removal and significant nitrification. Regardless of inocula size, the 80 mg/L of phenol was removed within 1 day. Based on the accumulation of nitrite and nitrate, the extent of nitrification in the 10^4 CFU/mL bottles was 216 mg NH_3-N/L, in the 10^5 CFU/mL bottles was 130 mg NH_3-N/L, and in the 10^6 CFU/mL bottles was 220 mg NH_3-N/L.

The batch tests performed with the medium initial concentrations of COCs (250 mg/L phenol and 366 mg/L ammonia nitrogen) still showed complete phenol removal within 10 days, but showed virtually no nitrification. The time required for the complete removal of phenol decreased with increasing inocula size. For example, phenol removal occurred within 10 days for an initial inocula of 10^4 CFU/mL of phenol-degrading bacteria, while phenol removal occurred within 3 days with an initial inocula of 10^6 CFU/mL. The coal conversion wastewater literature indicated that phenol inhibits nitrification. Because the phenol persisted longer in the medium-concentration batch tests than the low-concentration batch tests, less nitrification was expected. This was the observed result. Because the difference in initial ammonia concentrations is small between the low- and medium-concentration batch tests (305 and 366 mg N/L, respectively), the lack of nitrification in the medium concentration batch tests is probably due to phenol inhibition rather than an increased intensity of self-inhibition.

The high-concentration batch tests (750 mg/L phenol and 1220 mg/L ammonia) showed incomplete phenol removal and no nitrification. Higher initial concentrations of phenol-degrading bacteria resulted in greater extents of phenol removal during the 10-day long batch tests. The 10^4 CFU/mL inocula showed no phenol removal, the 10^5 CFU/mL inocula showed a 25 percent reduction in phenol concentration, and the 10^6 CFU/mL inocula showed a 36 percent reduction. The presence of phenol during the entire 10-day long high-concentration batch tests precludes any nitrification, because of the reported inhibition of nitrification by phenol.

2.3 Phase I Conclusion

The 10-day long Phase I batch tests showed a reduction in the extent of phenol removal and nitrification with increasing initial concentrations of phenol and ammonia. The decreased removal of phenol with increasing initial phenol concentrations is consistent with the known self-inhibition of phenol biodegradation (*i.e.*, phenol inhibits its own biodegradation at higher concentrations). The reduction in the extent of nitrification with increased initial phenol and ammonia concentrations is primarily due to inhibition by phenol. However, a fraction of the observed reduction in nitrification could also be due to ammonia self-inhibition.

The Phase I batch test results suggest that at least a 10^5 CFU/mL of phenol-degrading bacteria and a 10^5 CFU/mL of ammonia-oxidizing bacteria are required to achieve complete phenol and ammonia removal within 10 days. Higher inocula sizes would be required for concentrations above those used in the low-concentration batch tests.

3.0 PHASE II MICROBIAL INHIBITION TESTS USING SITE GROUNDWATER

The purpose of Phase II was to determine if microorganisms could grow and could utilize phenol and ammonia in groundwater from the lower portion of the shallow aquifer at the WMGCP Site. While phenol and ammonia are amenable to aerobic biological treatment as demonstrated in Phase I, the high concentrations of these and other chemicals found in the deep groundwater could be inhibitory or toxic to the required types of microorganisms. The specific objective of the Phase II study was to determine the degree of dilution required to ensure the growth of the phenol and ammonia degraders when exposed to deep groundwater. Dilution was accomplished by adding appropriate proportions of the shallow groundwater to the deep groundwater.

Phase II was run in two parts. The first part, using four levels of dilution, did not yield any ammonia results due to the interference of the site groundwater with ammonia test kits and ion selective electrodes. In the second part, site groundwater and deionized water amended with mineral salt, and spiked with ammonia were tested to determine if ammonia degradation was measurable by the distillation method.

3.1 Experimental Procedures

Four systems were used to determine the degree of dilution required to ensure the viability of nitrifying and phenol-degrading microorganisms in groundwater from the deep aquifer. The systems were undiluted MW-7D (deep groundwater) and 1:1, 1:2, and 1:5 dilutions of MW- 7D with MW-13S. Inorganic nutrients (in the form of a mineral salts solution supplying manganese, calcium, magnesium and iron ions for growth) without ammonia and phosphate buffer were added. All systems were inoculated to microbial populations of 10^5 CFU/ml with ammonia and phenol oxidizing bacteria. The 50 ml head space was flushed with pure oxygen at times Day 0, Day 4, and Day 6. Multiple reactors were used for each condition. Individual reactors were then sacrificed at the appropriate time point for the analyses of phenol, ammonia, nitrate, and nitrite.

The ammonia analytical procedure had to be modified during the test due to the groundwater color interference with the HACH test kit. The groundwater was too dark in color to allow for accurate readings from the test kits. Samples from the four systems were sent to Sequoia Analytical Lab (Walnut Creek, California) to be analyzed for ammonia (using selective ion electrode), nitrate, and nitrite. The results, shown in Table 3.1, were higher than expected. After receiving the results from Sequoia Lab, the MW-7D composite was sent to be analyzed for ammonia by EPA 350.1 (distillation). The ammonia concentration was 410 mg/L, closer to what had been previously analyzed. These results indicated that the Site groundwater caused an interference to the ion selective electrode and that a distillation method was the only reliable method for determining the ammonia concentration in Site groundwater.

3.1.1 Experiment to Verify Activity of the Nitrifier Culture

The initial Phase II results showed a high degree of variability in the ammonia results. Little nitrate or nitrite was observed, which suggested a possibility that the nitrifier culture was not viable. To determine if the high degree of variability in the Phase II ammonia degradation results was an analytical problem and not a biological problem (i.e., an inactive nitrifier culture), two systems were set up in two separate one-liter bottles. Each bottle contained 150 ml of deionized water spiked with 200 mg/L ammonia. Minerals salt were added to support the microbial activity. One system was inoculated with 10^7 CFU/ml nitrifier bacteria. The second system, the control, was not inoculated. The pH was adjusted to 8.1 for both systems. The headspace for both systems was flushed with pure oxygen, sealed, and put on a reciprocating shaker table overnight. The results of this test are presented in Table 3.2. The test confirmed the viability of the nitrifier inoculum.

3.1.2 Phase IIb - Modification of Protocol

A second set of batch tests were performed to determine if ammonia degradation was measurable by the distillation method. Two 2.5-liter bottles were set up with 1.5 L of water. One used groundwater at a 2:1 dilution (MW-13S: MW-7D). Assuming that the MW-7D ammonia concentration was 410 mg/L, based on the distillation analysis, ammonia was added to make up the ammonia-nitrogen concentration representative of MW-7D (i.e., 600 mg/L). This sample was then diluted with MW-13S water to result in a target ammonia concentration of 200 mg/L. The second bottle used deionized water amended with mineral salt (without ammonia). The deionized water system was used as the control and was spiked with 200 mg/L ammonia. Both systems were inoculated with 10^6 CFU/ml of phenol degrading and nitrifying bacteria. The headspace for both systems was flushed with pure oxygen, and the pH was adjusted to 7.7 with Tris (hydroxymethlyl) aminomethane, or Tris buffer. Tris buffer was added to the control system, but not the Site groundwater system. Both bottles were sealed and put on a shaker. Dissolved oxygen was checked and recorded daily, and headspace was flushed with pure oxygen daily.

3.2 Discussion of Results

The phenol results (Table 3.3) showed substantial activity, which was dependent on the level of dilution. After 14 days, the phenol loss observed was 0%, 25%, 97%, and 100% for dilution levels of 0:1, 1:1, 2:1, and 5:1 (MW-13S: MW-7D). The phenol degradation at the 1:1 dilution appeared to stop after 9 days, indicating questionable or marginal activity. However, at dilution levels of 2:1 and 5:1, phenol degradation was virtually complete within 14 days.

The ammonia results for the initial Phase II experiments (Table 3.3) are not interpretable due to color interference between the groundwater and the test kits. However, none of the systems showed any significant production of nitrite or nitrate (as measured using HACH test kits), indicating that little ammonia oxidation was occurring at any dilution. There did, however, appear to be some appreciable levels of nitrate at the 5:1 dilution, and the dissolved oxygen (DO) concentrations were depressed, suggesting that some nitrifying activity may have occurred.

The Phase IIb results, Table 3.4, indicate that a 2:1 dilution of Site groundwater gave no nitrification. The ammonia concentration did not drop, and production of nitrate or nitrite was not evident. The deionized water control, however, showed loss of ammonia and, more significantly, the production of nitrate and nitrite. This difference in nitrate and nitrite products between the experimental and control batch tests suggests the inhibition of nitrification by the chemicals found in the Site groundwater.

3.3 Conclusions

The Phase II batch tests indicate that dilution of the MW-7D groundwater is required before phenol biodegradation will occur. The 14-day long Phase II batch tests performed with undiluted deep-aquifer groundwater (MW-7D) showed no phenol removal and no accumulation of nitrification products. This suggests that the undiluted deep-aquifer groundwater will not support the aerobic biodegradation of phenol and ammonia. However, dilution ratios of 2:1 and 5:1 (MW13S:MW-7D both) showed virtually complete phenol removal within 14 days. Thus, a certain amount of dilution of the MW-7D groundwater is required for aerobic phenol biodegradation to occur.

Unlike phenol, the dilution of the MW-7D groundwater from a 100 percent solution down to a 5:1 dilution (MW13S:MW7D) had no apparent effect on nitrification. None of the dilutions resulted in a continual accumulation of nitrite and nitrate. Although nitrate could have been consumed via denitrification due to the sometimes low dissolved oxygen concentrations, the lack of a continuous accumulation of nitrite and nitrate suggests a lack of nitrification. This lack of nitrification could be due to combination of three factors: (1) ammonia self-inhibition was a likely minor component, (2) inhibition of nitrification by phenol was a likely important component, and (3) inhibition of nitrification by other compounds found in the MW-7D groundwater was a likely component.

The Phase II batch tests indicate that any subsequent batch tests performed with actual site groundwater should use the distillation method. Also, the batch tests should be longer than 2 weeks and be inoculated with concentrations of bacteria greater than 10^5 CFU/mL in order to assess the aerobic biodegradation of COCs in the groundwater.

4.0 PHASE III - PHENOL AND AMMONIA BIODEGRADATION STUDY

The Phase III experiments consisted of two parts - a short-term study and a long-term study. The Phase III short-term study was intended to develop rate kinetics for the comparison of the effects of ammonia, phenol, and thiocyanate concentrations on biodegradation, specifically nitrification. The Phase III long-term study was intended to provide data to investigate the selective loss of phenol, ammonia, thiocyanate, organic nitrogen, and other contaminants, to verify the time frames necessary for significant contaminant concentration reduction, and to establish preliminary limits on potential treatment end points.

The Phase III protocol is based on the "Phenol and Ammonia Biodegradation Study" presented in the June 28, 1996, "Treatability Study Work Plan". The protocol was modified to incorporate the results of Phases I, II, and IIb. The short and long term studies were conducted in two parts, the original protocol and a test extension. Short-term and the long-term parts of the Phase III study were extended because nitrification was slow or not measurable in many of the test bottles. The studies were extended in length and/or the bottles were reinoculated with heterotrophs and nitrifying bacteria.

Because of the extensions, there were a total of four parts to the Phase III study: 1) initial short term study, 2) short term test extension, 3) initial long term study, and 4) long term study extension and re-inoculation test.

4.1 General Experimental Methods

4.1.1 Sample Receipt

Approximately 15 gallons of groundwater from monitoring well MW-13S and 10 gallons of water from monitoring well MW-7D were received by Fluor Daniel GTI, Remediation Technology Testing Facility, Trenton, New Jersey, in February, 1997 for use in the short and long term studies. Unused MW-7D water was frozen, and unused MW-13S water was refrigerated to minimize loss of COCs.

4.1.2 Nitrifier Inocula Calibration Test

Because nitrifiers do not respond to routine plate count methods, ammonia degradation rates were used to estimate the quantity of nitrifiers in the inoculum. The calibration procedure is described in Appendix A. A known concentration of ammonia was added to buffered deionized water. The rate of ammonia loss was measured and used to estimate the quantity of nitrifiers in the inocula. This procedure was used to calibrate the nitrifier inocula used during the various Phase III batch tests.

4.1.3 Analytical Methods

The analytical methods and the minimum detection limits of the analyses that were used for the Phase III Study are listed in Table 4.1.

4.1.4 Experimental Setup

Twenty liter glass bottles were used for all experiments in Phase III. Each bottle was filled with six liters of test solution. The test solution, depending on the particular experiment, was either spiked deionized water or a mixture of Site groundwater from monitoring wells MW-7D and MW-13S. Buffer and inocula were added as described in Tables 4.2, 4.4 and 4.6 and Appendix A. All experiments using deionized water were spiked with ammonia, phenol, and thiocyanate as specified in Tables 4.2, 4.4 and 4.6. The headspace of each bottle was periodically flushed with a stream of oxygen gas. All bottles were continuously stirred and covered with aluminum foil for the duration of the test to avoid light penetration, photochemical oxidation, and photosynthesis.

4.2 Phase III Short Term Study

The Phase III short term study was performed to provide data on the rate kinetics for biodegradation of contaminants and specifically nitrification, and to determine and verify the interaction among ammonia, phenol, and thiocyanate concentrations during the aerobic biodegradation process.

4.2.1 Initial Short-Term Study Protocol

Six testing bottles, identified as IIIST-1 through IIIST-6, were used for the short-term batch tests. Bottles IIIST-1 through IIIST-3 used spiked deionized water. Bottles IIIST-4 through IIIST-6 used Site groundwater. The experimental setup and purpose of the six short-term studies are summarized in Table 4.2 and described in detail in Appendix A.

The bottles were sampled twice weekly and analyzed for ammonia nitrogen (NH_3-N), thiocyanate (SCN^-), nitrate nitrogen (NO_3-N), nitrite nitrogen ($N0_2$-N), total Kjeldahl nitrogen (TKN), phenol, alkalinity, chemical oxygen demand (COD), and dissolved organic carbon (DOC). Thiocyanate and phenol were analyzed twice weekly until the concentrations were at or below detection limits. The pH and DO were monitored and recorded during every sampling interval. All samples for chemical analysis were sent to CH2M Hill Analytical Services.

4.2.2 Phase III Short-Term Test Extension

The short term study bottles using site groundwater (IIIST-4, IIIST-5, and IIIST-6) did not show appreciable ammonia removal at the end of 4½ weeks. Because of this, the study was extended. There were three modifications to the experimental protocol. First, all the test bottles with Site groundwater were continued. Second, test bottle IIIST-5, the 9:1 dilution (MW-13 to MW-7), was split, and one split was reinoculated. Third, two new short term studies using deionized water, IIIST-7 and IIIST-8, were set up and run to confirm the nitrification kinetics and an active nitrified inocula. The test protocol changes are summarized in Table 4.3 and discussed in more detail in Appendix A.

4.3 Phase III Long-Term Study

The Phase III Long Term Study was conducted to investigate the fate of phenol, ammonia, thiocyanate, total nitrogen, and other contaminants over a 12-week test period in Site groundwater. This testing was designed to determine the time frames necessary for significant contaminant degradation, determine if there were matrix inhibition effects in the Site groundwater, and establish preliminary performance limits and potential treatment endpoints. The initial experimental setup, including volumes of Site groundwater from MW7-D and MW13-S used, are summarized in Table 4.4 and discussed in more detail in Appendix A.

4.3.1 Initial Long-Term Study Protocol

Seven test bottles were used. IIILT-1 through IIILT-3 and IIILT-6 examined the effect of dilution and used dilutions ranging from 2:1 (MW-13S to MW-7D) to 9:1. Test bottle IIILT-4 was undiluted MW-7D water. Test bottle IIILT-5 used Site soil as an inoculum. Test bottle IIILT-7 was a poisoned control.

4.3.2 Long-TermTest Extension Protocol

The six active test bottles were reinoculated or split and reinoculated. None of the long-term test bottles showed any nitrification after 85 days. IIILT-7(poisoned control) was not reinoculated. Several of the bottles (IIILT 5, 6 and 9) were split or diluted to a new level. A 600 mL sample aliquot was withdrawn from test bottle IIILT-1 and diluted with 2400 ml of stored MW 13-S groundwater to make a 19:1 dilution test bottle. This bottle was designated IIILT-9i. The contents of test bottle IIILT-6 were split into two equal volumes (IIILT-6i and IIILT-6n).

Two new test bottles using deionized water, IIILT-8 and IIILT-10, were set up to confirm the ammonia biodegradation baseline kinetics and the concentration of active nitrifiers in the inocula. The sampling frequency for both test bottles IIILT-8 and IIILT-10 was three times a week.

A duplicate of test bottle IIIST-3, identified as IIIST-3D, was also run to reconfirm the synergistic inhibition of nitrification by phenol and thiocyanate.

The revised analytical procedure for the long term test extension are listed in Table 4.7.

4.4 *Nitrosomonas* Die-Off in the Presence of Phenol and Thiocyanate

An examination of the data from the short and long term studies indicated that inhibition of nitrification could possibly be explained by an initial biomass die-off of the *Nitrosomonas*, which occurs during the time when both phenol and thiocyanate were present. After the phenol was degraded, ammonia degradation occurred and followed the uninhibited nitrification kinetics with the viable, but reduced nitrifier population that remained after the initial die off. The lag time for nitrification observed was due to the regrowth of the nitrifying bacteria. A comparison of deionized water studies spiked with phenol and thiocyanate indicated that a matrix inhibition could also exist after phenol and thiocyanate have been degraded.

An experiment was conducted to verify that a die-off of the nitrifiers had occurred. Thirty mL aliquots were withdrawn from test bottles IIIST-3D, IIILT-2i, and IIILT-3i, and the biomass present was concentrated, washed, and resuspended in 50 mL ammonia assay buffer solution (0.955 g/L NH_4Cl; 0.46 g/L KH_2PO_4; 3.7 g/L K_2HPO_4; and 0.35 g/L $NaHCO_3$). The reason for the washing was to remove any toxic or inhibitory compounds. Three aliquots were taken from each bottle for assay at time intervals of 1, 3, and 6 hours. Nitrate and nitrite concentrations were measured using HACH test kits. Ammonia concentration was measured using an ammonium ion specific electrode. The nitrite and nitrate production data and ammonia degradation data obtained from these assays was analyzed using

standard mechanistic growth models to determine the growth of active *Nitrosomonas* biomass in each assay flask.

4.5 Results and Discussion

The analytical and monitoring results from the Short-Term and Long-Term Studies are presented in Appendix A and summarized in Tables 4.8 and 4.9, which present the number of days required for the removal of the key groundwater constituents, ammonia (NH_3-N), phenol, and thiocyanate (SCN^-). Discussion of the results is divided between pure compound/deionized water studies and Site groundwater studies.

4.5.1 Pure Compound/Deionized Water Studies

A series of studies was conducted using deionized water amended with ammonia, phenol, and thiocyanate. These pure compound studies were designed to examine the effect, individually and in combination, of these constituents on biodegradation processes. The following discussion will first examine the degradation of the primary COCs, ammonia, phenol, and thiocyanate. Second it will examine changes in the general water quality parameters during the biodegradation process.

4.5.1.1 Ammonia, Phenol and Thiocyanate A parameter that can be used to assess biodegradation is the length of time, in days, that it took for complete removal of a constituent. The time required for complete ammonia, thiocyanate and phenol degradation for the deionized water studies are summarized in Table 4.8 and depicted in Figures 4-1, 4-2, and 4-3. There are several observations that can be drawn from this data. See Appendix B for the complete data tabulations.

1. *All three constituents were aerobically biodegradable.*
2. *Phenol degradation was uninhibited by either ammonia or by thiocyanate. (Table 4.8, compare No. 5 and 7; Figure 4-3).*
3. *Ammonia degradation was inhibited by the presence of either phenol (Table 4.8, compare No. 1&2 with 5) or thiocyanate, (Table 4.8, compare No. 1&2 with 6). Phenol was a stronger inhibitor of nitrification than was thiocyanate. (Table 4.8, compare No. 5 and 6).*
4. *There was a synergistic inhibition of ammonia degradation when phenol and thiocyanate were present together (Table 4.8, compare No. 5&6 with 7; Figure 4.-1).*
5. *When all three were present, the order of complete degradation was phenol followed by thiocyanate then ammonia. (Table 4.8, No. 7).*
6. *The bacterial population level shortens the observed lag times (Table 4.8, compare No. 1&2 with 3&4) in roughly a first order manner.*

4.5.1.2 General Parameters A number of other parameters were monitored in addition to the loss of ammonia, phenol, and thiocyanate. Several of these show apparent response to biodegradation. The following summarizes the observations of these parameters. See Appendix B.

Nitrite/Nitrate - When ammonia oxidation occurred, nitrite levels increased first. After the ammonia was gone, the nitrite was converted to nitrate. The oxidation of ammonia in these pure compound studies was sequential: $NH_3 \rightarrow NO_2^- \rightarrow NO_3^-$, which is consistent with the fact that two different microbial populations are necessary to carry out the two steps.

TKN - Total Kjeldahl nitrogen is a measurement of free NH_3-N plus organic nitrogen. It slowly decreased in these studies which is a reflection of the ammonia oxidation.

Alkalinity - pH decreases or loss of alkalinity was evident during active nitrification. To compensate for the loss of alkalinity and corresponding decrease in pH, NaOH was added. Therefore, total alkalinity remained relatively constant throughout the test period due to the addition of base to maintain optimum pH levels for nitrification.

DOC - Dissolved organic carbon concentrations were variable during the study. It increased sometimes and decreased other times. There doesn't appear to be any obvious correlation to any processes.

COD - Chemical oxygen demand gradually decreased during the course of the studies, most likely due to the bio-oxidation of the major organic constituents. Phenol removal had the greatest impact on COD reduction. The COD was highest when phenol was present, and dropped rapidly when the phenol was removed.

DO - Dissolved oxygen was very sensitive to the degradation processes. The general pattern that was observed when oxidation occurred was an initial drop in DO while phenol was degraded, followed by an increase when the phenol was depleted, (due to oxygen flushing) and then a second drop as the ammonia was oxidized. The ammonia oxidation caused the greatest reduction in DO.

Nitrogen Balance - A total nitrogen balance was conducted on the pure compound/deionized study test bottles and the results are presented in Table 4.10. The sum of the TKN-nitrogen, nitrate-nitrogen, nitrite-nitrogen, and thiocyanate-nitrogen concentrations was calculated at two sampling points, specifically the initial sampling event and a sampling event near the end of the test. Changes in concentration due to the addition of acid or base and/or microbial inoculum was not accounted for in the calculation. With the exception of test bottle IIILT-8, the total nitrogen concentrations stayed relatively constant for the duration of the study indicating that the analytical as well as the experimental procedures were technically sound.

4.5.2 Site Groundwater Studies

Site groundwater was used to study the interaction among ammonia, phenol and thiocyanate and to determine if there was a matrix effect due to other constituents in the Site groundwater. The experiments were set up by diluting water from MW-7D with water from MW-13S. The MW-7D water was highly contaminated, while MW-13S was slightly contaminated. The level of dilution ranged from none to 20 fold. For a number of experiments, multiple inoculations were used to counteract apparent

toxicity and to maintain a high level of bacteria. The following discussion will first examine the degradation of the primary contaminants - ammonia, phenol, and thiocyanate. Second it will examine changes in the general water quality parameters during the biodegradation process. See Appendix B for tables of data collected during Phase III.

4.5.2.1 Ammonia, Phenol and Thiocyanate The key parameter that was tracked was the length of time in days that was required for the complete removal of ammonia, thiocyanate, and phenol. The results are summarized in Table 4.9 and depicted in Figures 4-4, 4-5, and 4-6.

Several observations about the oxidation of ammonia, phenol and thiocyanate can be made from these data:

1. The MW-7D Site groundwater, undiluted, did not support any aerobic biological activity . (Table 4.9 no. 13).

2. With a single inoculation, ammonia oxidation did not occur at less than a dilution level of 9 Parts MW-13S: 1 part MW-7D. (Table 4.9 compare nos. 3, 9, and 10; Figure 4.4) .

3. With multiple inoculations, ammonia oxidation occurred at up to a 2:1 dilution (MW13S: MW7D). Ammonia degradation increased as dilution increased. (Table 4.9 nos. 8, 10, and 12; Figure 4.4).

4. Phenol degradation was unimpeded at a 2:1 dilution (MW13S:MW7D) and was independent of the dilution level for greater dilutions. (Table 4.9 nos. 10, 11, and 12; Figure 4.5). Phenol degradation appears to have been uninhibited by either ammonia levels or thiocyanate levels.

5. Thiocyanate degradation occurred at dilution levels of 2:1 (MW13S:MW7D), and the degradation rate increased with greater dilutions. (Table 4.9 nos. 6, 9, 10, and 12; Figure 4.6).

6. When all three compounds were present, the order of complete degradation was phenol followed by thiocyanate and then ammonia. (Figure 4.7).

7. Active phenol and thiocyanate degraders were present in the Site soil . (Table 4.9 no. 7).

8. The degradation rates for ammonia and thiocyanate were slower in the Site groundwater than they were in DI water. This suggests an inhibitory matrix effect. (Compare Tables 4.8 and 4.9).

4.5.2.2 General Parameters A number of other parameters were monitored in addition to the loss of ammonia, phenol, and thiocyanate. Several of these show apparent response to biodegradation. The following summarizes the observations of these parameters.

Nitrite/Nitrate - The production of nitrate and nitrite appeared to be affected by the dilution level. At high dilutions, the oxidation of ammonia in these pure compound studies was sequential: NH_3 → NO_2^- → NO_3^-. When ammonia oxidation occurred, the nitrite levels generally increased first. After the ammonia was gone, the nitrite was then converted to nitrate. At low dilutions, accumulation of nitrite was small, and ammonia was more quickly oxidized to nitrate.

TKN - Total Kjeldahl nitrogen is a measurement of NH_3-N as well as organic nitrogen, such as biomass. It slowly decreased in these studies, a reflection of the ammonia oxidation. The drop in TKN was much slower in the Site groundwater than in the DI water studies. This may be due to the presence of organic molecules that contain nitrogenous species and are poorly degraded.

Alkalinity - pH decreases or loss of alkalinity was evident during active nitrification. To compensate for the loss of alkalinity and control pH, NaOH was added. Therefore, total alkalinity remained relatively constant throughout the test period due to the addition of base to maintain optimum pH levels for nitrification.

DOC - the most common pattern for dissolved organic carbon during the study was an initial increase followed by a period of "stability" and then a final decrease. This may reflect partial oxidation of groundwater constituents. The control showed a more random behavior.

COD - Chemical oxygen demand gradually decreased during the course of the studies, mainly due to the bio-oxidation of the major organic constituents. The degradation of phenol had the greatest impact on COD reduction. The COD was highest when phenol was present and dropped rapidly when the phenol was removed. However, as compared to the DI water studies, there was a residual COD after the primary constituents were removed. This may be due to the production of biomass or intermediates that are eventually oxidized, but at a slower rate than the primary constituents or, it may reflect some refractory or recalcitrant organic matter. The control also showed a drop in COD.

BOD - Biological oxygen demand generally decreased during the course of the study.

DO - Dissolved oxygen was very sensitive to the degradation processes. The general pattern that was observed when oxidation occurred was an initial drop in DO while phenol was degraded. After the phenol was removed DO increased (due to oxygen flushing). When ammonia degradation started there was a second drop in DO as the ammonia was oxidized. The ammonia oxidation caused the greatest reduction in DO. This is parallel to the observation made in the DI water studies.

Arsenic, Cyanide, Iron - The concentrations of these inorganic components were essentially unchanged during the studies.

Nitrogen Balance - A total nitrogen balance was conducted on the Site groundwater study test bottles and the results are presented in Table 4.11. The sum of the TKN-nitrogen, nitrate-nitrogen, nitrite-

nitrogen, and thiocyanate-nitrogen concentrations was calculated at two sampling points, specifically the initial sampling event and a sampling event near the end of the test. Changes in concentration due to the addition of acid or base and/or microbial inoculum was not accounted for in the calculation. With the exception of test bottles IIIST-5i, IIILT-6n, and IIILT-7, the total nitrogen concentrations stayed relatively constant (± 20%) for the duration of the study, indicating that the analytical as well as the experimental procedures were technically sound. Approximately one-half of the test bottles experienced an increase in the total nitrogen concentration from the beginning to the end of the study. Matrix interferences for certain analytical methods may also have contributed to the differences between the initial and final total nitrogen concentrations.

5.0 INTERPRETATION OF RESULTS

5.1 Introduction

The previous sections of this report describe the results of the biotreatability tests in terms of lag times and the time required for the complete removal of a substrate. This section interprets the Phase III experimental results in terms of a mechanistic microbial growth model. The development and calibration of the model is described in Appendix C. The calibrated model explicitly accounts for the inhibitory and toxic effects associated with the aerobic biodegradation of the phenol, thiocyanate, and the ammonium cation (hereafter referred to as ammonia or ammonia nitrogen) found in the Site groundwater.

As microbial substrates, phenol, thiocyanate, and ammonia are reported to be self-inhibitory when subject to aerobic biodegradation, *(i.e.*, the biomass-specific rate of aerobic biodegradation slows as the contaminant concentration increases beyond an inhibitory threshold concentration). Haldane kinetics can be used to describe the relationship between self-inhibitory substrate concentration and the resulting biodegradation rates. Based on Haldane kinetics, the calibrated mechanistic growth model suggests that rates of phenol, thiocyanate, and ammonia nitrogen will start to decrease above concentrations of 9, 39, and 79 mg/L, respectively. As illustrated in Figure 5-1, the maximum specific growth rates for the thiocyanate degraders and ammonia oxidizers are about a factor of 10 slower than the maximum growth rate for the phenol degraders. Thus, based solely on the self-inhibition kinetics of the three substrates, the expected pattern of complete substrate removal from batch tests containing all three substrates would be phenol first, followed by thiocyanate or ammonia.

In addition to an inhibitory threshold concentration, Haldane kinetics allows calculation of the maximum steady-state substrate concentration that will support a population of capable microorganisms (S_{max}). Theoretically, the determination of the S_{max} value for phenol, thiocyanate, and ammonia degrading microorganisms allows a quick determination of whether a particular concentration of substrate can be biodegraded. For example, if the concentration of phenol in the undiluted groundwater from monitoring well MW–7D is 1200 mg/L and the S_{max} for the heterotrophic inocula for a Phase III batch test is 6800 mg/L, then the Haldane kinetic model suggests that the phenol should be biodegradable. If this is not

the observed experimental result, then additional factors such as interaction between substrates and groundwater matrix toxicity can be precluding phenol biodegradation.

A comparison of the calculated S_{max} values to the substrate concentrations measured in the undiluted groundwater from monitoring well MW-7D suggests that phenol, thiocyanate, and ammonia should be biodegradable in the undiluted groundwater. As shown in Table 5.1, the observed substrate concentrations in the MW-7D groundwater are at least a factor of 3 below the calculated respective S_{max} values. This suggests that if the biodegradation of phenol, thiocyanate, and ammonia were only subject to self-inhibition, then the biological removal of phenol, thiocyanate, and ammonia from the undiluted MW-7D groundwater is expected. However, Figure 5-2 indicates no phenol, thiocyanate, and ammonia removal during the IIILT-4 batch test, which contained undiluted MW-7D groundwater. Thus, the aerobic biodegradation of phenol, thiocyanate, and ammonia in MW-7D groundwater is not solely defined by substrate self-inhibition. Additional factors such as substrate interaction and groundwater matrix toxicity are involved. One objective of this section is to quantify the interactions among phenol, thiocyanate, and nitrification, and to assess the groundwater matrix effects on the aerobic biodegradation of the target substrates. Another objective is to determine the concentration of indigenous microorganisms in an aquifer soil sample capable of biodegrading the target substrates.

5.2 Phenol Biodegradation Kinetics

Of the three evaluated substrates, the biokinetic evaluation of phenol biodegradation was the most straightforward. Besides being a self-inhibitory substrate (Figure 5-1), phenol is reported to be weakly inhibited by thiocyanate. The aerobic biodegradation of phenol was insensitive to the presence of groundwater from monitoring well MW-7D, in that groundwater dilutions of up to 2:1 (MW-13S:MW-7D) had little impact on phenol removal beyond those impacts predicted by phenol self-inhibition. The aerobic biodegradation of phenol is a rapid and robust process at MW13S:MW-7D dilutions of 2:1 or greater. If phenol was just subject to self-inhibition, then its removal should have occurred in the undiluted MW-7D groundwater (Table 5.1). Because there was no observed phenol removal in the IIILT-4 (undiluted) batch test (Figure 5-2), this suggests that the MW-7D groundwater is inhibitory to phenol-degrading bacteria at some concentration greater than a 2:1 dilution.

5.3 Thiocyanate Biodegradation Kinetics

The aerobic biodegradation of thiocyanate results in the release of ammonia nitrogen. As with phenol, the complete removal of thiocyanate was observed in all Phase III batch tests containing MW-7D groundwater, except during the IIILT-4 batch test which contained undiluted MW-7D groundwater. Figure 5-3 illustrates that the calibrated mechanistic model is able to predict the thiocyanate decay curve at low concentrations of MW-7D groundwater. However, Figure 5-4 suggests that, at MW-7D groundwater dilutions of 3:1 (MW-13S:MW-7D) and greater, thiocyanate is being removed at rates slower than expected based on Haldane kinetics. This observation suggests that additional factors,

such as groundwater matrix inhibition, is responsible for the slower than expected rates of thiocyanate removal at the higher concentrations of MW-7D groundwater.

5.4 Ammonia Biodegradation Kinetics

The oxidation of ammonia to nitrite by *Nitrosomonas* was adversely influenced by several mechanisms during the Phase III batch tests. These mechanisms may include the following:

1. Self-inhibition, although the self-inhibitory effect is weak until ammonia concentrations are well above 1000 mg N/L.

2. Reversible inhibition of nitrification by phenol, which acts as a strong non-competitive inhibitor. Once the phenol is removed by heterotrophic activity, nitrification appears to occur at its uninhibited rate.

3. Accelerated loss of active *Nitrosomonas* biomass when phenol and thiocyanate are present together.

4. Accelerated loss of active *Nitrosomonas* biomass upon initial exposure to all dilutions of WMGCP Site groundwater obtained from monitoring well MW-7D.

Because of these inhibitory and toxic interactions, the modeling of nitrification in the WMGCP Site groundwater requires the simultaneous tracking of ammonia, phenol, and thiocyanate concentrations.

To account for variations in toxicity among the different dilutions of MW-7D groundwater, a *matrix time factor* was determined. The concept is that an unknown toxic agent in the MW-7D groundwater exerts its toxic effect for a length of time called the matrix time factor. The matrix time factor depends on the MW-7D groundwater concentration and the length of time the MW-7D groundwater had been subjected to aerobic treatment prior to inoculation with *Nitrosomonas*. As illustrated in Figure 5-5, higher MW-7D groundwater concentrations increased the matrix time factor, while longer periods of aerobic treatment prior to inoculation with *Nitrosomonas* reduced the matrix time factor. The latter observation demonstrates that the initial toxicity of the MW-7D groundwater to *Nitrosomonas* can be reduced by aerobic treatment.

The Phase III studies were able to define a constant first-order biomass loss rate coefficient (b_N) for the various environmental conditions at which the batch tests were run. A detailed description of how the various b_N values were determined is presented in Appendix C. As provided in Table 5.2, the value of b_N for active *Nitrosomonas* biomass varied from 0.1 to 2.42 1/day depending on environmental conditions. The largest b_N value corresponds to a 50 percent reduction in active *Nitrosomonas* biomass concentration every 7.2 hours, a condition corresponding to the presence of phenol and thiocyanate in any concentration of untreated MW-7D groundwater.

The relative impacts of the various inhibitory and toxic effects on ammonia decay curves are illustrated in Figure 5-6. The four plotted ammonia decay curves were generated by the mechanistic model based on the initial substrate and biomass concentrations for the IIIST-6 (19:1 dilution) batch test. Complete ammonia removal occurred within 56 days during the IIIST-6 batch test. The model indicated that complete ammonia removal would require 8 days based solely on Haldane kinetics. When the inhibition of nitrification by phenol was added to the model, complete removal required 9 days. The time required for complete ammonia removal increased to 15 days when the model considered Haldane kinetics, inhibition by phenol, and the phenol/thiocyanate toxic effect. When a matrix time factor of 18 days was added to the model, the time required for complete ammonia removal jumped to 55 days. Thus, these simulations of a batch test containing a 19:1 dilution of MW-7D groundwater indicate that the most important factor in determining the time requirements for ammonia removal is the toxicity of the MW-7D groundwater toward *Nitrosomonas*.

In summary, the Phase III batch test results suggest that nitrification is sensitive to several factors related to the WMGCP Site groundwater. These factors include phenol inhibition, the loss of active biomass when phenol and thiocyanate are present together, and the toxicity of the MW-7D groundwater toward *Nitrosomonas*. Of these factors, the modeling results suggest that the undefined toxicity of the groundwater is the most limiting. Aerobic treatment of the groundwater may be required to protect unacclimated indigenous populations of *Nitrosomonas* during the bioremediation of the aquifer.

5.5 Indigenous Microorganisms

The IIILT-5 (5:1 dilution MW-13S:MW-7D) batch test was initially inoculated with 100 grams of aquifer soil obtained from the WMGCP Site near the water table. Complete phenol removal occurred sometime within the first 13 days of the batch test. Thiocyanate removal required about 41 days. No nitrification was observed. The thiocyanate decay curve allows the back calculation of the thiocyanate biomass concentrations associated with soil inoculum. The rapid removal of the phenol and the 2 weeks between sampling points precludes the back calculation of the initial concentration of phenol-degrading microorganisms. Instead, the mechanistic model was used to determine if the rapid removal of phenol could be due to biomass concentrations typically associated with sandy aquifer materials. The reported range of total bacterial cells associated with natural groundwater environments is from 10^5 to 10^7 cells per gram of dry soil.

Development of a predicted phenol decay curve for the IIILT-5 (5:1 dilution) batch test assumes that the 100 grams of aquifer sand contained 10^5 CFU/gram of phenol-degrading bacteria. This assumed soil inoculum corresponds to an initial phenol-degrading biomass concentration of $1.7 \cdot 10^3$ CFU/mL in the 6-liter batch reactor. Figure 5-7 indicates that this initial concentration of phenol-degrading microorganisms can account for the observed disappearance of phenol within 13 days of inoculation.

A trial-and-error approach was taken to calculate the initial population of thiocyanate-degrading microorganisms that were associated with the 100 gram of soil inoculum. As shown in Figure 5-7, an

initial water-phase concentration of thiocyanate-degraders equal to $5 \cdot 10^2$ CFU/mL allowed the mechanistic model to describe the observed thiocyanate decay curve. This water-phase concentration corresponds to a soil concentration of $3 \cdot 10^4$ CFU/gram soil.

In summary, the observed removal of phenol from the IIILT-5 (5:1 dilution) batch test within 13 days of inoculation with soil can be accomplished when the inoculum is assumed to contain a number of bacterial cells typically found in groundwater soils. The observed thiocyanate decay curve can be described by the model when the soil is assumed to contain $3 \cdot 10^4$ CFU/gram soil. The two sets of calculations suggest that a good number of indigenous microorganisms that are capable of biodegrading phenol and thiocyanate are associated with the sandy WMGCP aquifer near the water table.

5.6 Conclusions

In conclusion, the biokinetic evaluation of the Phase III batch tests suggests that contaminants of concern in the WMGCP aquifer (*i.e.*, phenol, thiocyanate, and ammonia) are biodegradable under aerobic conditions provided that sufficient dilution of the MW-7D groundwater is achieved to prevent complete inhibition of the respective microorganisms. The Phase III batch tests did not determine the maximal concentration of MW-7D groundwater that can support the biodegradation of phenol and thiocyanate, but the phenol and thiocyanate were completely removed from a 2:1 dilution (MW-13S:MW-7D) of MW-7D groundwater within 90 days. Nitrification was more sensitive to the adverse effects associated with the groundwater matrix than was the biodegradation of phenol and thiocyanate, but prior aerobic treatment of the groundwater appeared to reduce the intensity of the adverse effect. As with the biological treatment of coal gasification waste waters, the aerobic biological treatment of the WMGCP groundwater appears possible provided that the various chemical and biological interactions are considered in process design and operation.

6.0 TREATABILITY TEST SUMMARY AND CONCLUSIONS

The three primary parameters that were monitored in the treatability study were ammonia, phenol, and thiocyanate. In addition, several other constituents and several general groundwater parameters were also monitored. These included cyanide, arsenic, BTEX, alkalinity, TKN (Total Kjeldahl Nitrogen), BOD_5 (five day biological oxygen demand), COD (chemical oxygen demand), DOC (Dissolved Organic Carbon), iron, phosphorous, nitrate, nitrite, and pH. The following summarizes the results for the primary constituents, the minor constituents, and the general groundwater parameters.

6.1 Phenol Degradation

Phenol degradation was observed in virtually all studies (Phases I through III) except the one using undiluted deep Site groundwater (MW-7D). The undiluted deep groundwater was devoid of biological

activity. Phenol degradation was also observed in the experiment using Site soil as an inoculum, indicating the viable phenol degraders are present on Site.

Phenol degradation was rapid and complete at 2:1 dilution (MW-13S:MW-7D) and greater dilutions of MW-7D groundwater. Within the accuracy of measurement, there was no difference in phenol degradation in deionized water versus Site groundwater. It was the first primary constituent removed. Its degradation did not appear to be affected by the presence of other constituents or by the groundwater matrix. Once sufficient dilution was applied, phenol degradation occurred at the same rate for all experimental conditions. The time observed was generally a function of the sampling interval. The phenol degraded within the first sampling period. For the IIIST (short term) experiments, which had a short (2 day) sampling interval, phenol degradation occured between day 4 and day 6. For the IIILT (long term) experiments, which had a 14 day sampling interval, phenol degradation occured between day 0 and day 14.

The aerobic biodegradation of phenol is a rapid and robust process up to MW13S:MW-7D dilutions of 2:1. Besides being a self-inhibitory substrate (Figure 5-1), phenol is reported to be weakly inhibited by thiocyanate. The aerobic biodegradation of phenol was insensitive to the presence of groundwater from monitoring well MW-7D, in that groundwater dilutions of up to 2:1 (MW-13S:MW-7D) had little impact on phenol removal beyond those impacts predicted by phenol self-inhibition.

The key conclusions are:

1. No phenol degradation occurs in undiluted deep groundwater sample (i.e. 100% MW-7D).
2. Phenol degradation is consistently observed at 2:1 dilutions or greater of MW-13S: MW-7D).
3. Site soil contained phenol degraders.
4. Phenol degradation rates were quantitatively consistent with literature values at all successful dilutions.

6.2 Thiocyanate Degradation

Thiocyanate degradation was also observed in virtually all studies except undiluted deep Site groundwater (MW-7D). The undiluted deep groundwater was devoid of biological activity. Thiocyanate was not added in the Phase I studies and was not monitored in the Phase II studies. In Phase III studies at dilution levels of 3:1 (MW-13S:MW-7D) or greater, thiocyanate degradation was observed. Also thiocyanate degradation was observed in the Phase III experiment using Site soil as an inoculum, indicating that viable thiocyanate degraders are present on Site.

In the Phase III experiments where all three primary constituents were present, thiocyanate was the second constituent to degrade completely. It degraded slower than phenol, but faster than ammonia. The rate of thiocyanate degradation in Site groundwater was a function of dilution level. Generally the

more concentrated the Site groundwater the slower the rate of thiocyanate degradation. The time for complete removal varied from 51 days for a 3:1 dilution to 9 days for a 19:1 dilution.

The aerobic biodegradation of thiocyanate results in the release of ammonia nitrogen. As with phenol, the complete removal of thiocyanate was observed in all Phase III batch tests that contained less than 33% MW-7D groundwater (2:1 MW13S:MW7D). Thiocyanate was removed at rates slower than expected based on Haldane kinetics. This observation suggests that additional factors, such as groundwater matrix inhibition, is responsible for the slower than expected rates of thiocyanate removal at the higher concentrations of MW-7D groundwater.

The key conclusions are:

1. No thiocyanate degradation was observed in undiluted deep groundwater sample (i.e. 100% MW-7D).
2. Thiocyanate degradation was observed at 2:1 dilution MW-7D groundwater (2 parts MW-13S: 1 part MW-7D) or more diluted.
3. Thiocyanate degradation rates were quantitatively consistent with literature values at all successful dilutions greater than a 2:1 ratio of MW13S:MW7D. At less dilution, thiocyanate degradation rates were reduced.
4. Ammonia-nitrogen is a thiocyanate degradation product (i.e., thiocyanate degradation releases ammonia-nitrogen). Thus, the oxidation of thiocyanate can increase the ammonia concentration.

6.3 Ammonia Degradation

Ammonia degradation, even in DI water was quite complex. It was markedly inhibited by phenol and by the combination of phenol and thiocyanate. Phenol, by itself, had a moderate inhibitory affect on the time required for complete ammonia removal - 20 days for NH_3 removal in the presence of phenol versus 11 to 13 days for pure ammonia. Thiocyanate, by itself, may have had a slight inhibitory affect on ammonia degradation - 15 days for NH_3 removal in the presence of thiocyanate versus 11 to 13 days for pure ammonia. The combination of phenol and thiocyanate had the greatest inhibitory effect - 34 days for NH_3 removal in the presence of phenol and thiocyanate versus 11 to 13 days for pure ammonia.

Ammonia degradation studies using Site groundwater were complicated by the observation that biological activity in the Site groundwater could result in an increase in ammonia due to the conversion of thiocyanate and/or other nitrogen containing species present in Site groundwater to ammonia. Thus, the fate of ammonia requires tracking of thiocyanate.

The Site groundwater studies of ammonia degradation had two primary variables - the level of dilution and the number of inoculations. In general, the lag time associated with ammonia degradation

decreased with increasing dilution and with a greater number of inoculations. With only 1 inoculation, only the 19:1 and 9:1 dilutions evidenced ammonia degradation. The 9:1 dilution required approximately 3 times as much time as the 19:1 dilution for complete ammonia removal (158 days versus 50 days).

The oxidation of ammonia to nitrite by *Nitrosomonas* was adversely influenced by several mechanisms during the Phase III batch tests. These mechanisms may include self-inhibition, reversible inhibition of nitrification by phenol, accelerated loss of active *Nitrosomonas* biomass when phenol and thiocyanate are present together, and accelerated loss of active *Nitrosomonas* biomass upon initial exposure to all dilutions of groundwater from monitoring well MW-7D.

The key conclusions were:

1. No ammonia-nitrogen conversion occurred in undiluted deep groundwater sample (i.e. 100% MW-7D).
2. Phenol was moderately inhibitory to ammonia-nitrogen conversion.
3. Thiocyanate was weakly inhibitory to ammonia-nitrogen conversion.
4. Phenol and thiocyanate were synergistically inhibitory to ammonia-nitrogen conversion. Inhibition could be represented as ammonia degrader (nitrifiers) biomass loss.
5. Ammonia-nitrogen conversion was dependent on two variables: 1) dilution of MW-7D groundwater, and 2) pre-treatment time before ammonia conversion takes place.
6. Ammonia conversion rates, when successful, were quantitatively consistent with literature values.
7. Ammonia-nitrogen is a thiocyanate degradation product (i.e., thiocyanate degradation releases ammonia-nitrogen). The oxidation of thiocyanate can increase the apparent ammonia concentration.

6.4 Other Parameters

A number of other constituents and several general groundwater parameters were also monitored. These included cyanide, arsenic, BTEX, alkalinity, TKN (Total Kjeldahl Nitrogen), BOD_5 (five day biological oxygen demand), COD (chemical oxygen demand), DOC (Dissolved Organic Carbon), iron, phosphorous, nitrate, nitrite, and pH.

When oxidation occurred, there were observable changes in some of these parameters. Generally, during biodegradation, all reduced nitrogen species decreased, COD and BOD decreased, and DO was consumed. Nitrate and nitrite increased in response to ammonia oxidation. There were no discernable changes in arsenic, iron, or cyanide levels during the studies. BTEX degraded completely during the studies. The pH dropped while oxidation occurred and was adjusted with base to remain between 7.0 and 8.0.

6.5 Groundwater Matrix Effect

There appeared to be a non-specific matrix inhibition caused by the Site groundwater. Higher concentrations of MW-7D groundwater caused longer delays in the onset of ammonia conversion. This matrix inhibition was independent of the concentrations of major constituents.

The concept is that an unknown toxic agent in the MW-7D groundwater exerts its toxic effect for a length of time called the matrix time factor. The matrix time factor depends on the MW-7D groundwater concentration and the length of time the MW-7D groundwater had been subjected to aerobic treatment prior to inoculation with *Nitrosomonas*. Higher groundwater concentrations increased the matrix time factor, while longer periods of aerobic treatment prior to inoculation with *Nitrosomonas* reduced the matrix time factor. The latter observation demonstrates that the initial toxicity of the MW-7D groundwater to *Nitrosomonas* can be reduced by aerobic treatment.

6.6 Summary

In summary, the results of the laboratory treatability study support the conclusion that aerobic biodegradation of phenol and thiocyanate is feasible at this Site. The results for ammonia suggest that nitrification also is possible, as long as nitrifying bacteria are present when toxicity from phenol, thiocyanate, and matrix components is relieved by a combination of biodegradation and dilution.

FIGURES

Figure 2-1 Ammonia Degradation
Phase I, 10 Days

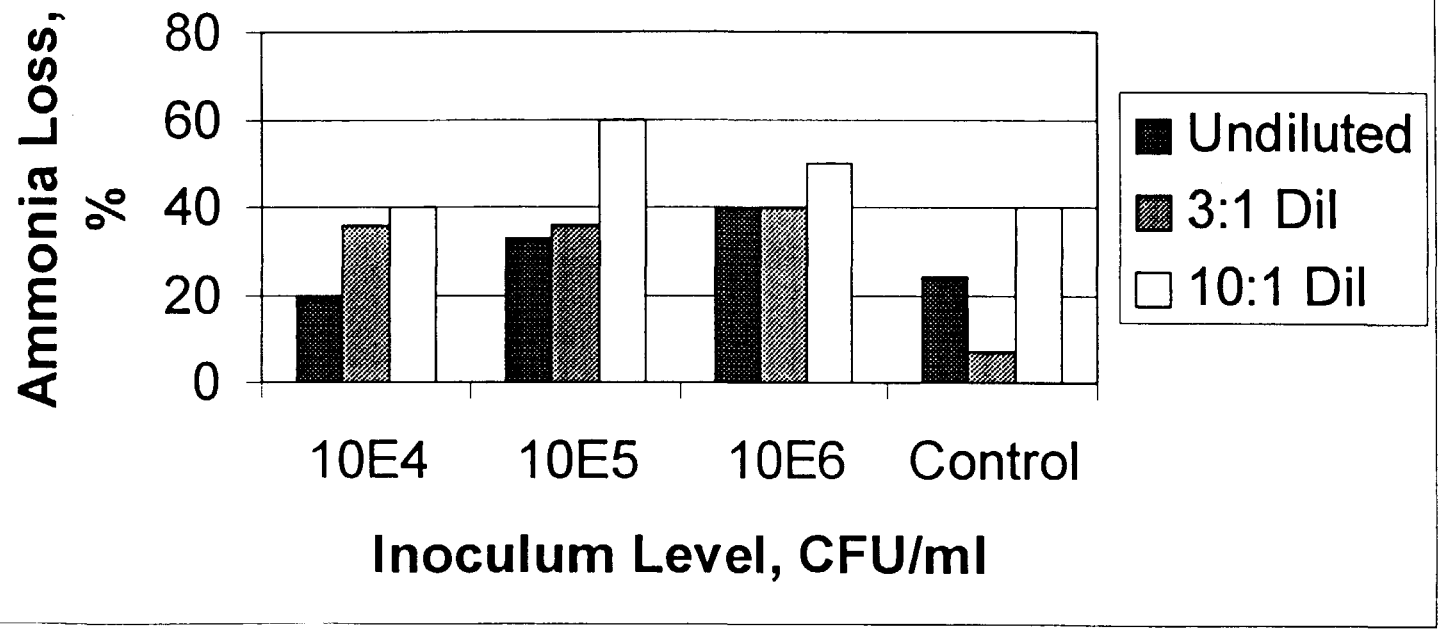


Figure 2-2 Phenol Degradation
Phase I, 3 Days

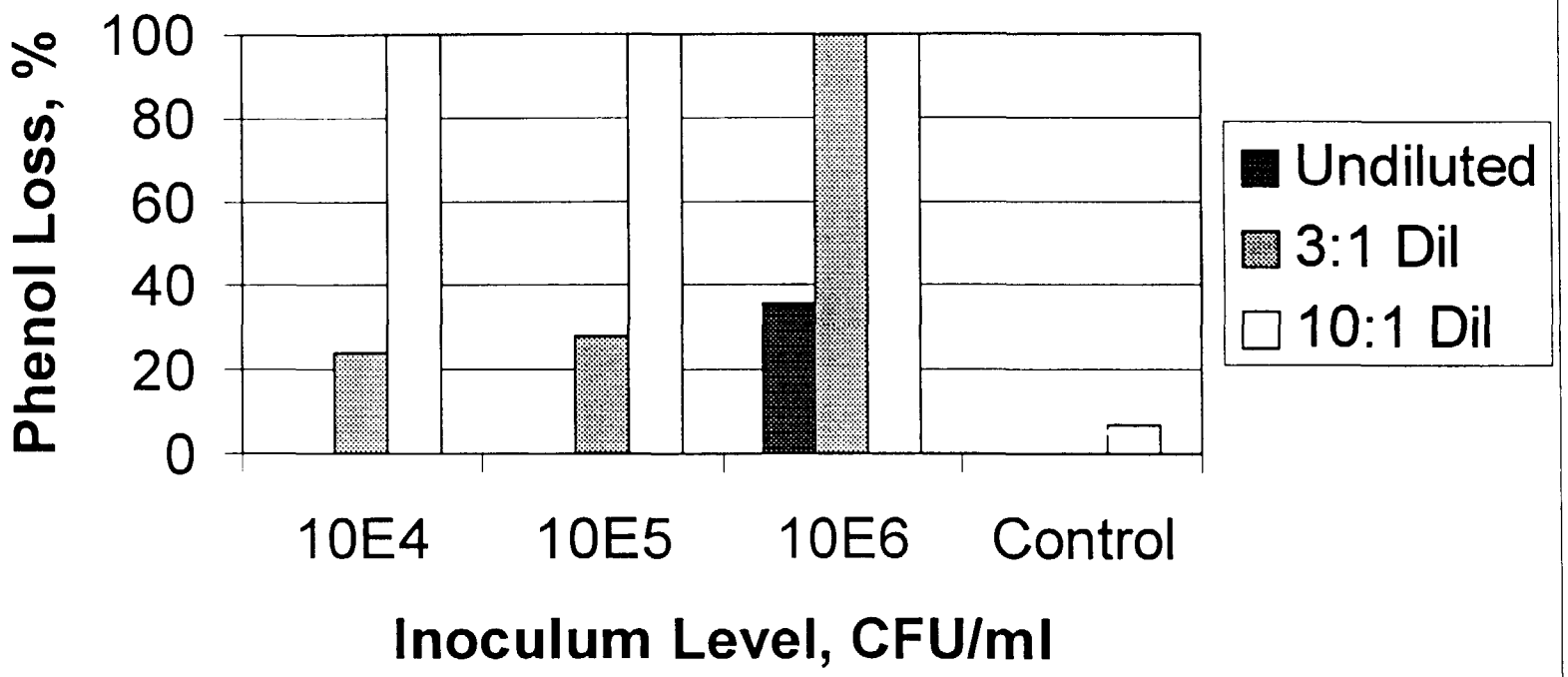


Figure 2-3 Nitrite & Nitrate Production Phase I, 10 Days

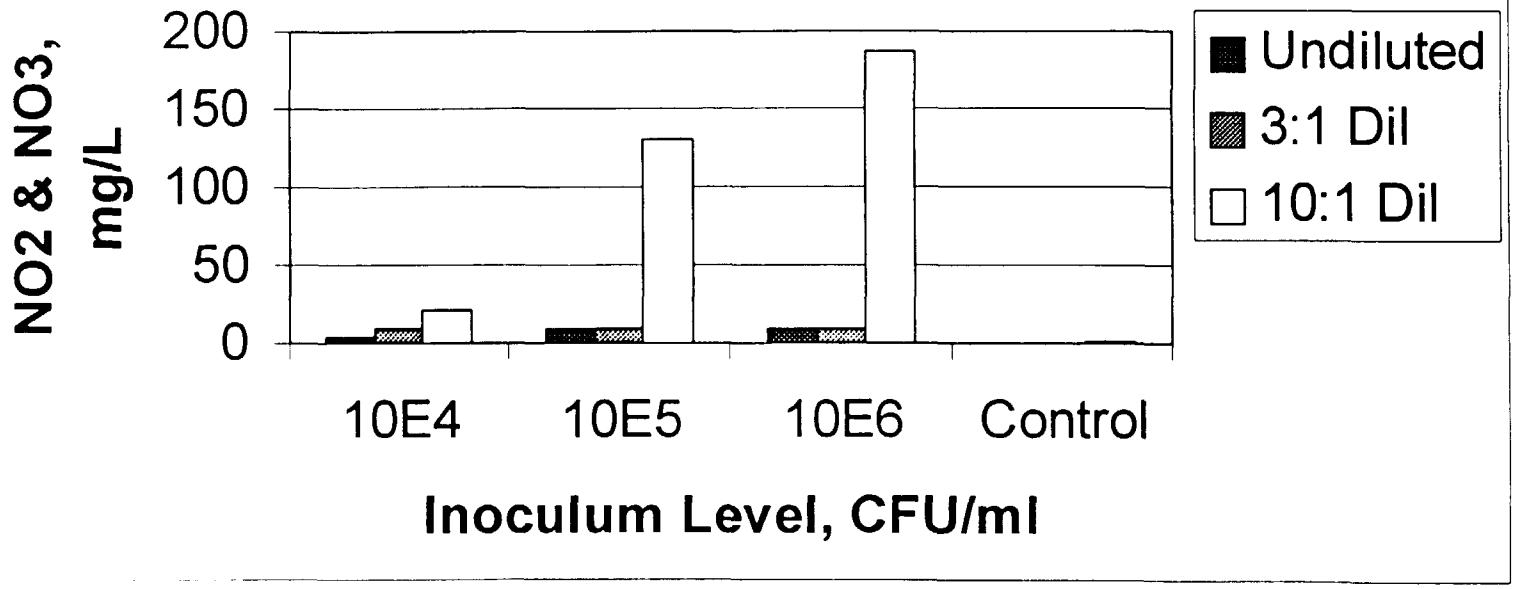


Figure 4-1 Days Required for Complete NH3 Removal

Phase III - DI Water

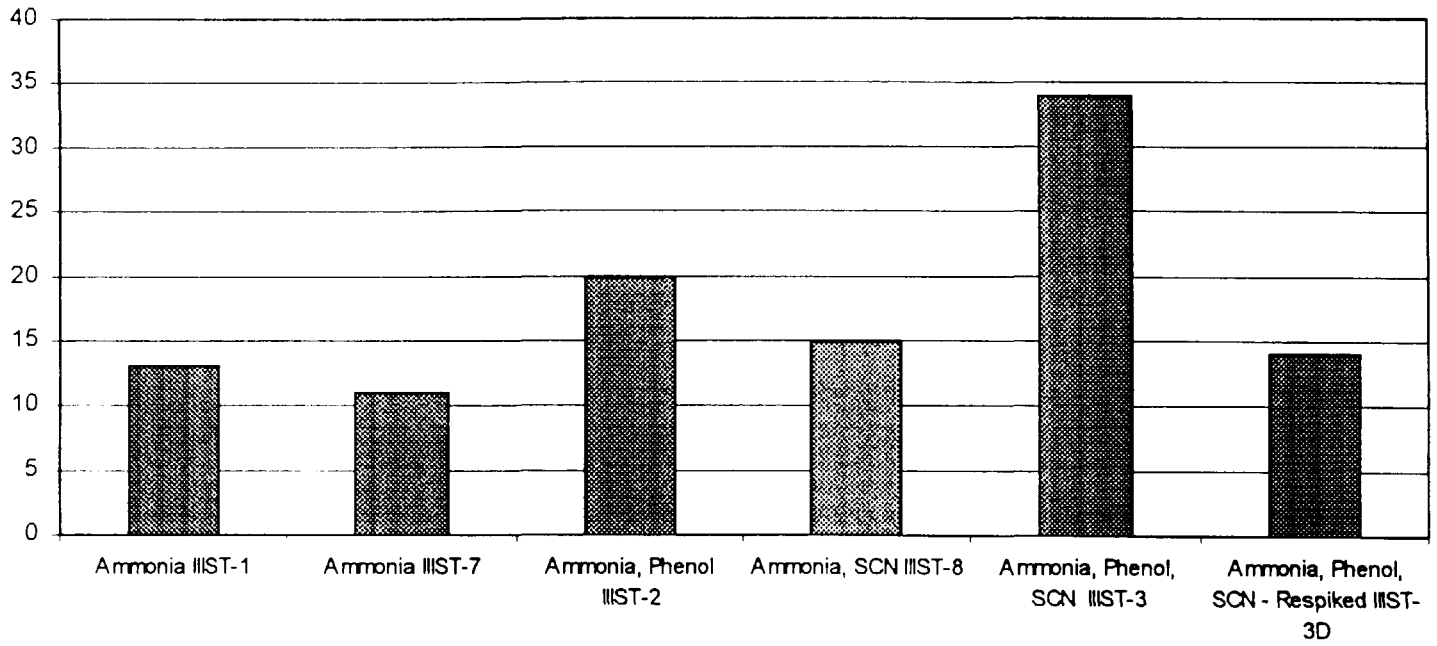


Figure 4-2 Days Required for Complete SCN Removal

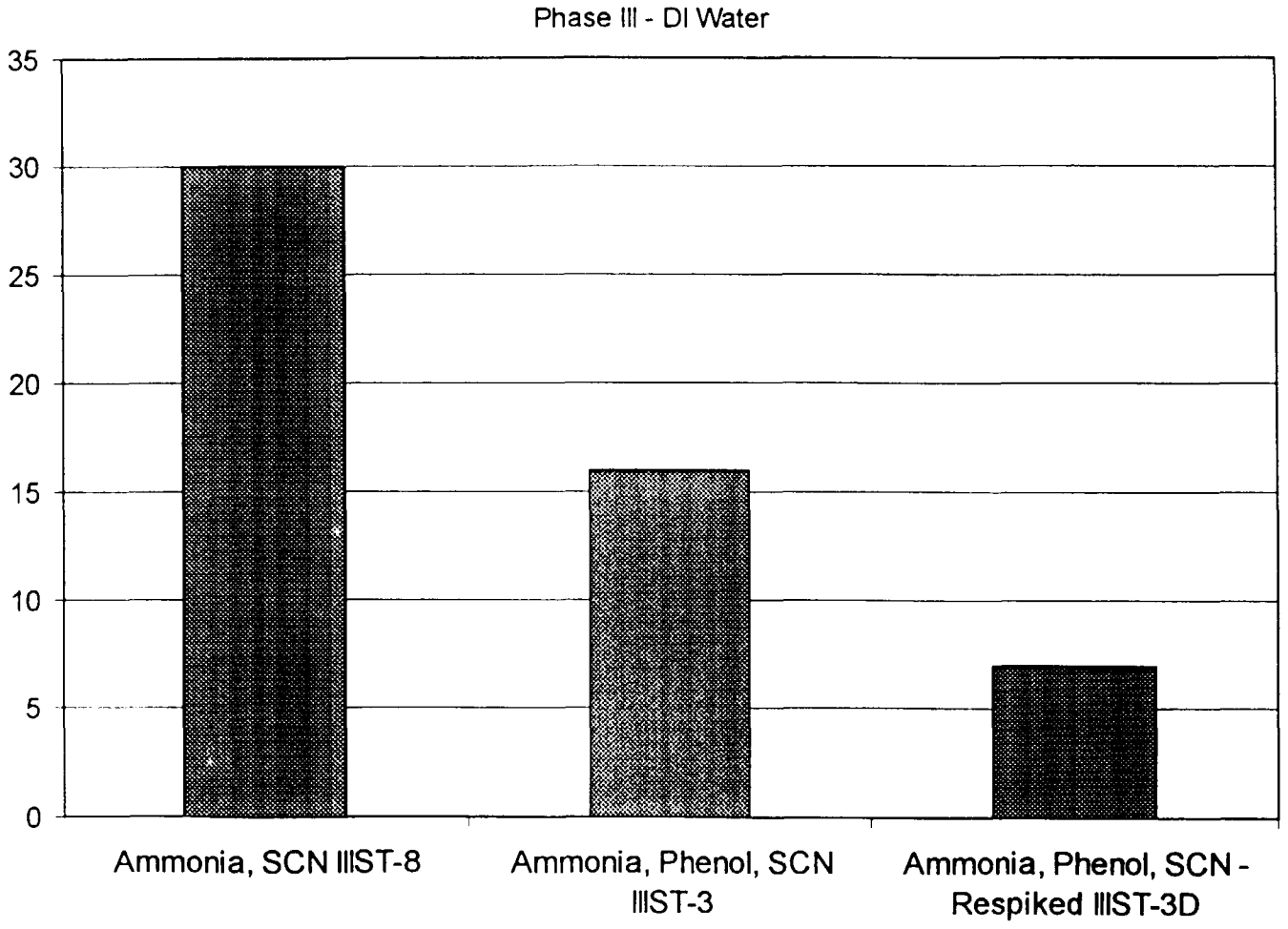


Figure 4-3 Days required for complete phenol removal

Phase III - DI Water

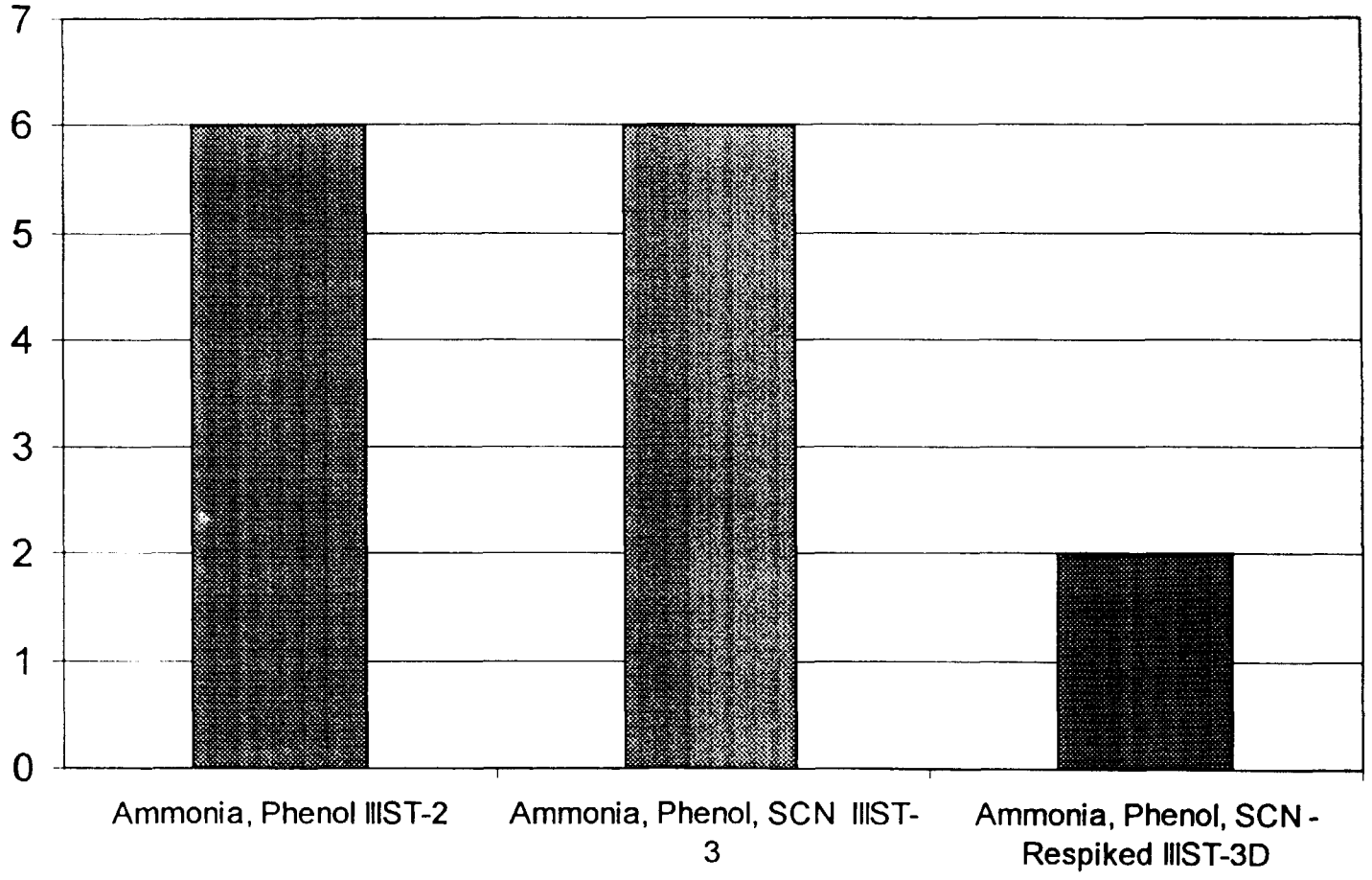


Figure 4-4 Days Required for Complete NH3 Removal

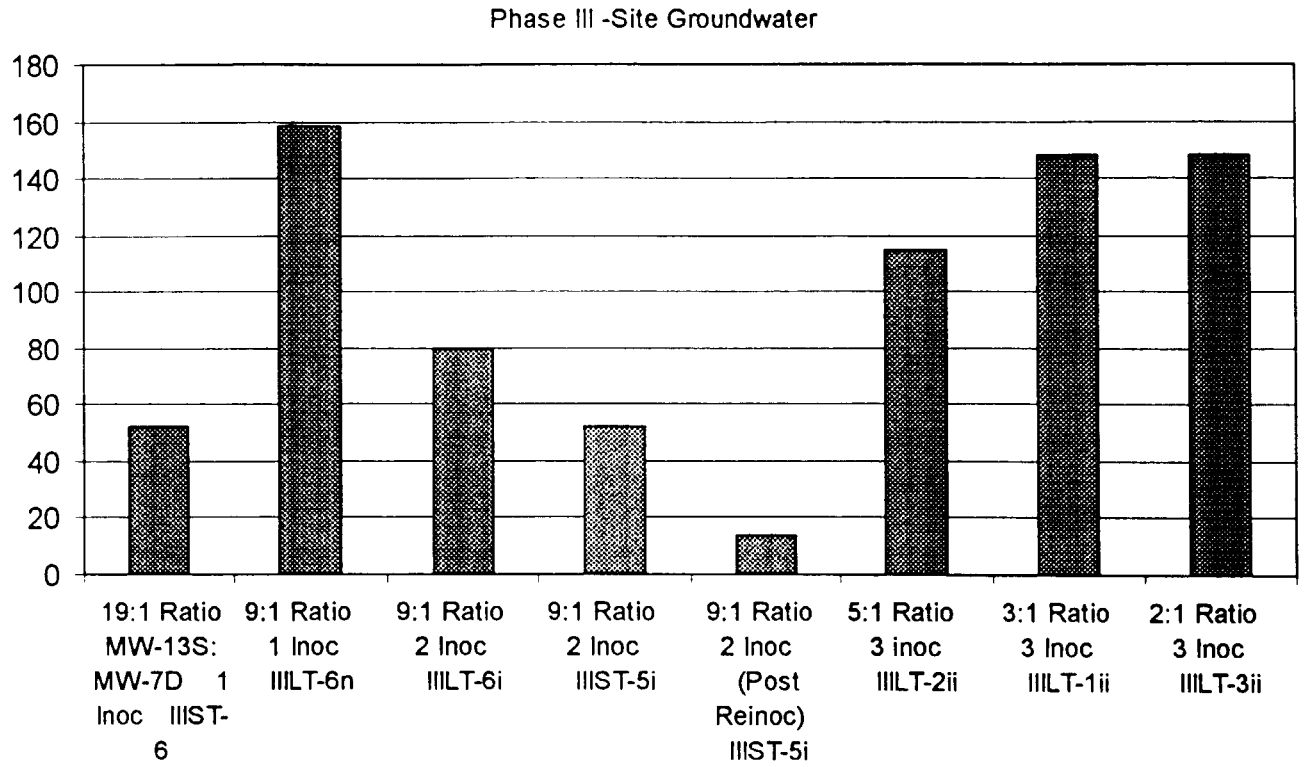


Figure 4-5 Days for Complete Phenol Removal

Site Groundwater

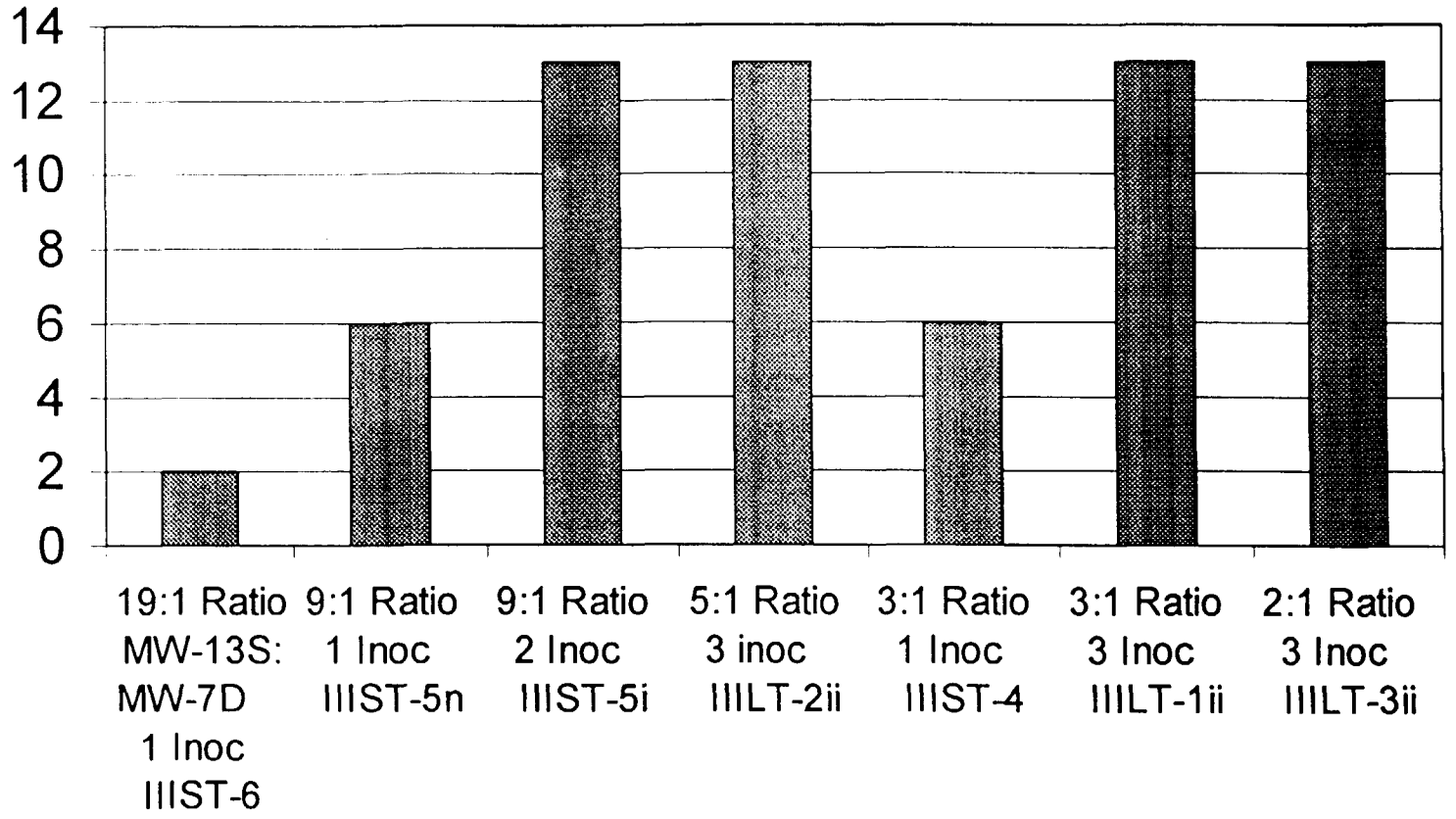


Figure 4-6 Days Required for Complete SCN Removal
Site Groundwater

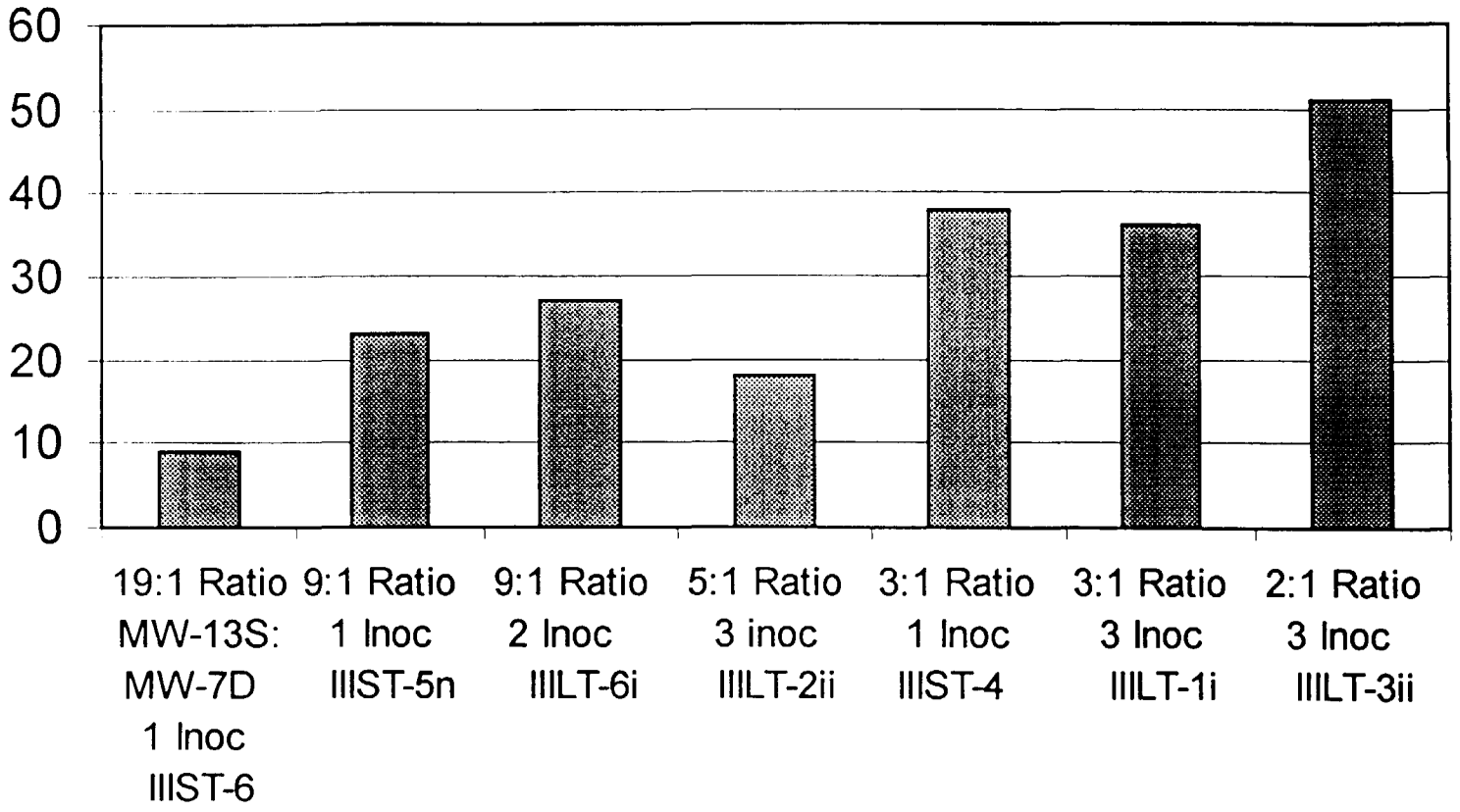
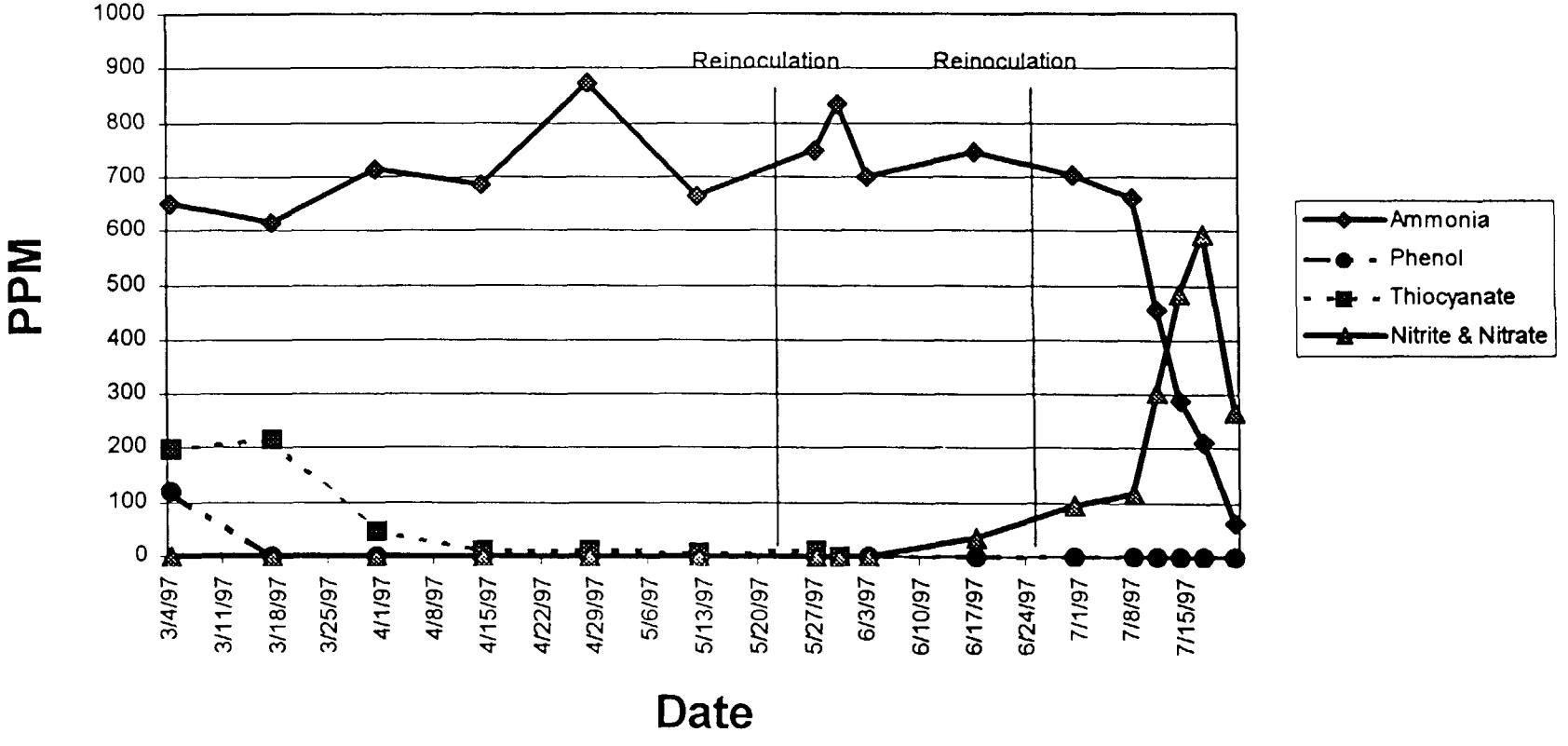


Figure 4-7 IIILT-1 3:1 MW-13S:MW-7D



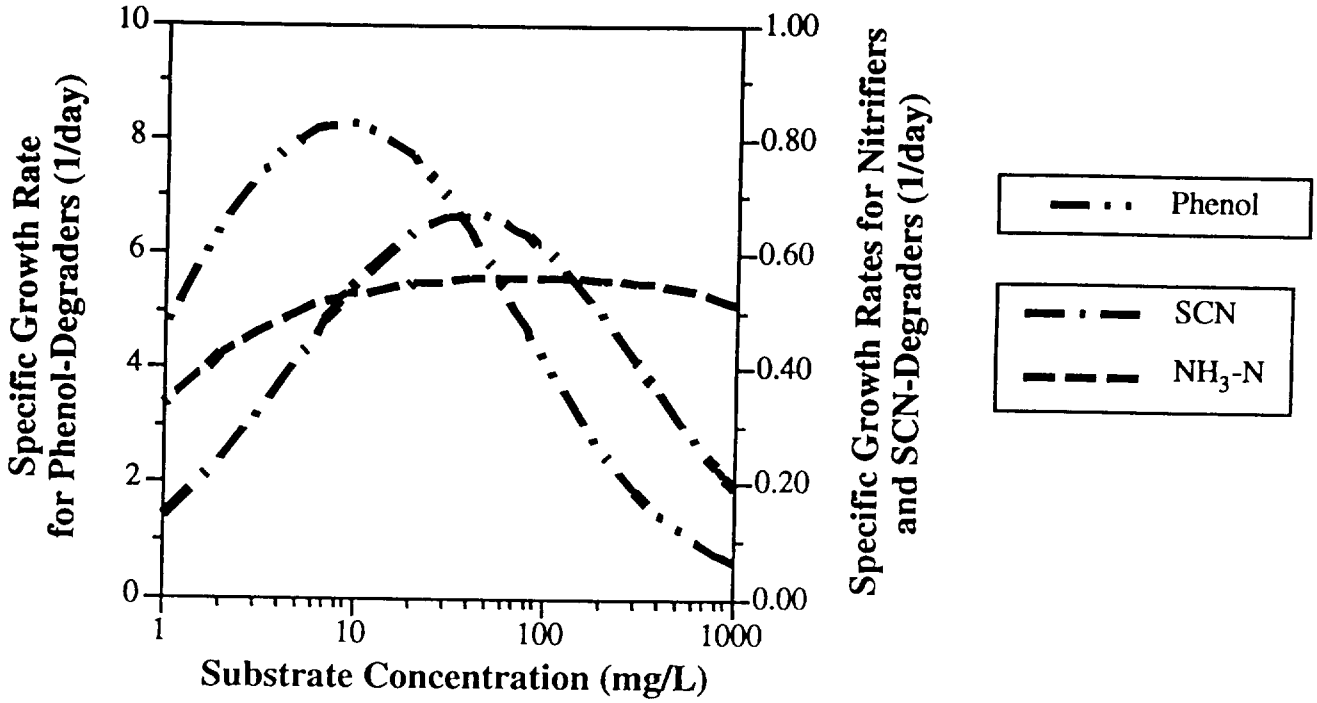


Figure 5-1. Comparison of specific growth rates as a function of substrate concentration.

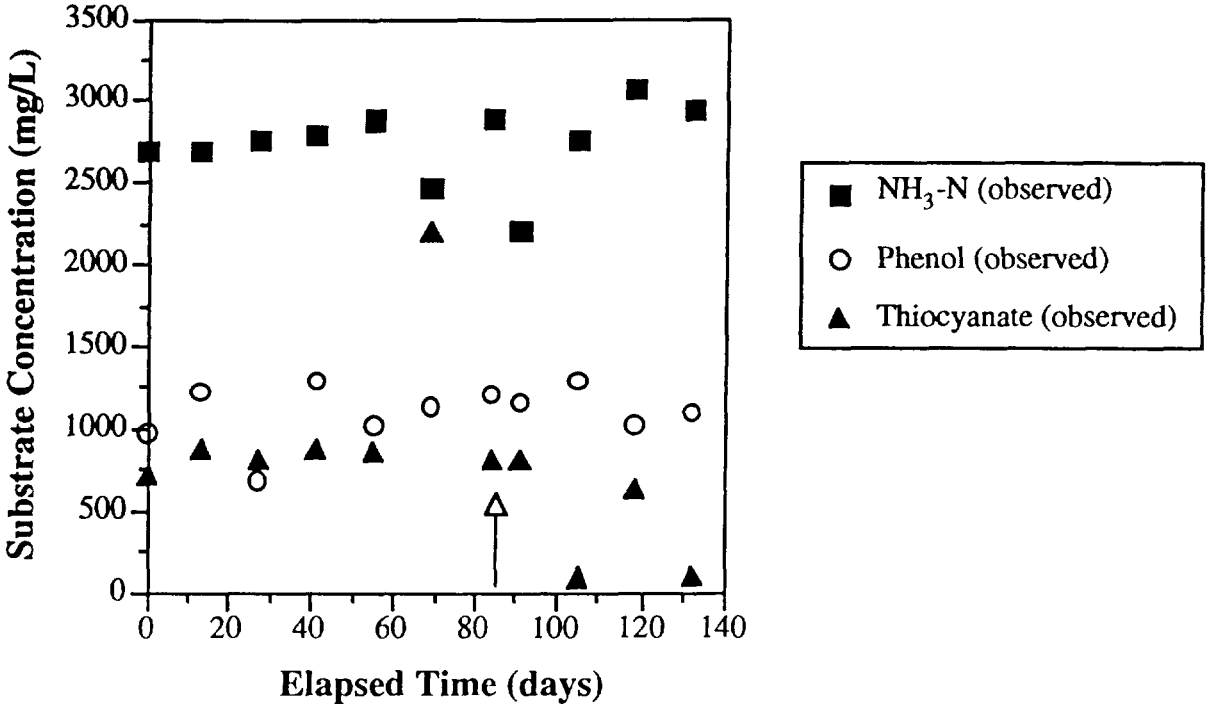


Figure 5-2. Observed decay curves for ammonia nitrogen, phenol, and thiocyanate during the IIILT-4 (0:1 MW-13S:MW-7D) batch test. The arrow represents the reinoculation of the batch test reactor with *Nitrosomonas* and heterotrophic microorganisms on day 85.

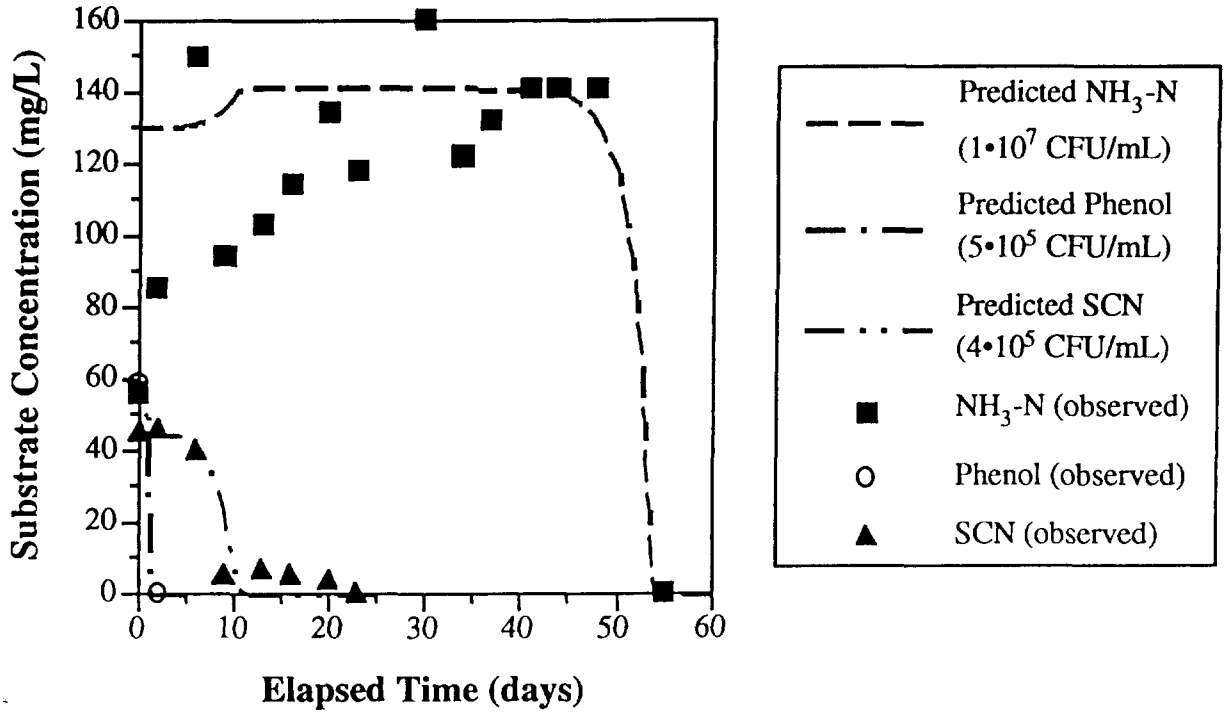


Figure 5-3. Comparison of the predicted and observed decay curves for ammonia nitrogen, phenol, and thiocyanate during the IIIST-6 (19:1 MW-13S:MW-7D) batch test. The ammonia decay curve assumes a matrix time factor of 18 days and includes the phenol/thiocyanate toxic effect.

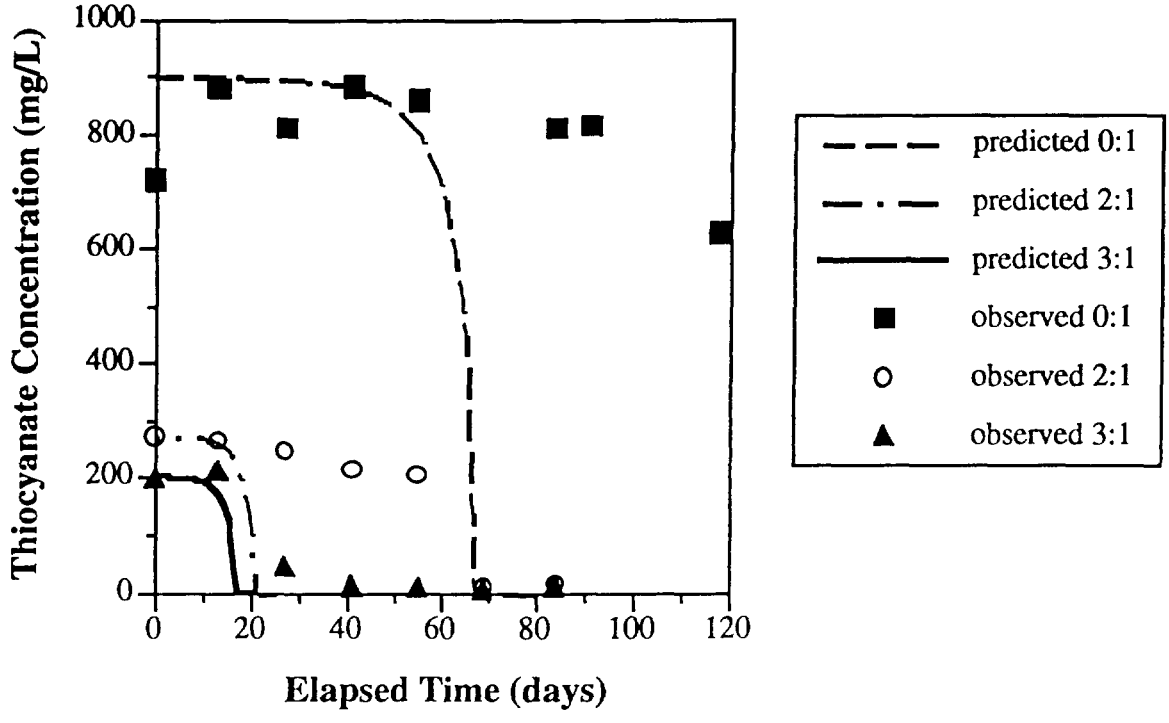


Figure 5-4. Comparison of the predicted and observed thiocyanate decay curves as a function of the MW-13S to MW-7D dilution ratio. The two outlier "0:1" data points at days 105 and 132 are not plotted (they are plotted in Figure 5-2).

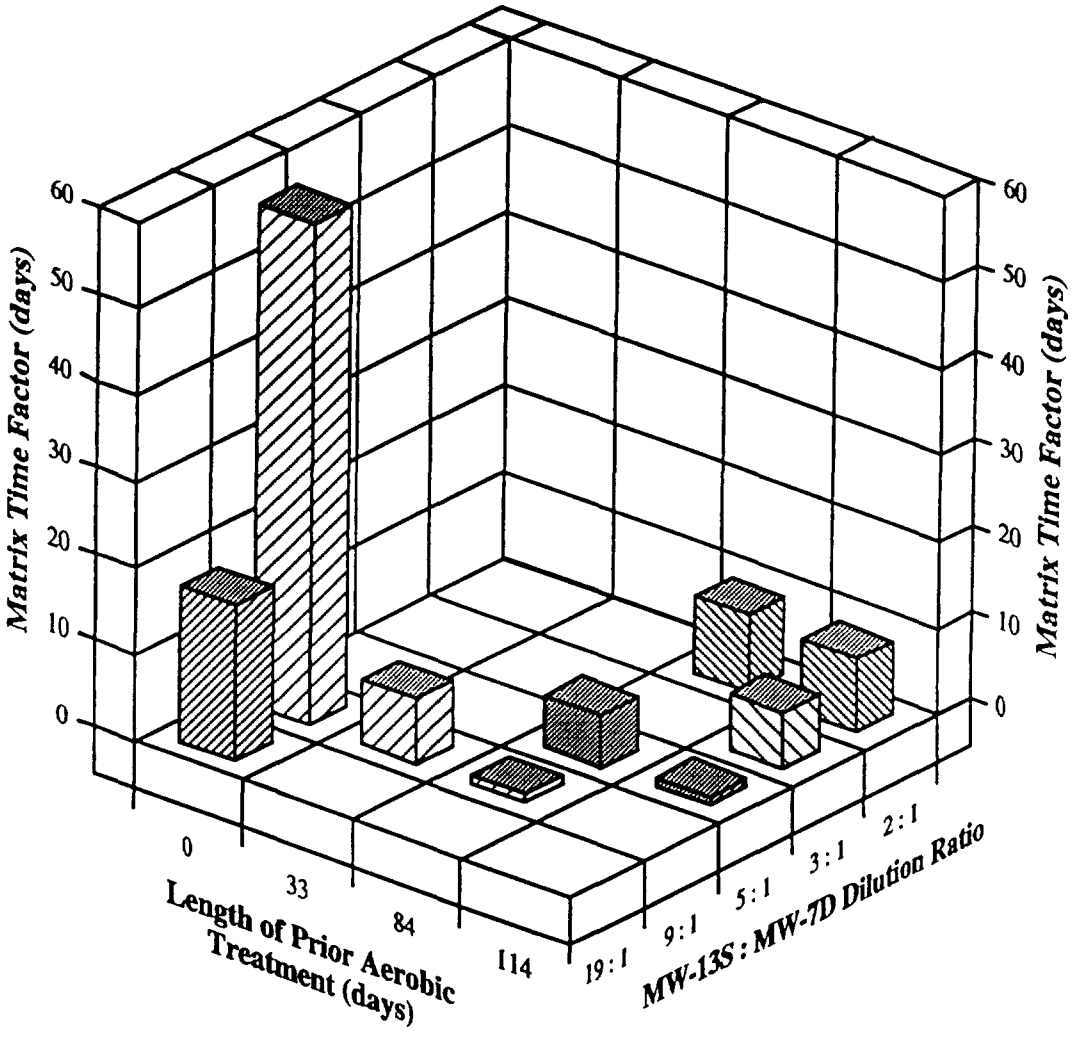


Figure 5-5. Matrix time factors as a function of MW-13S to MW-7D dilution ratio and the length of aerobic treatment prior to the addition of an unacclimated *Nitrosomonas* inoculum.

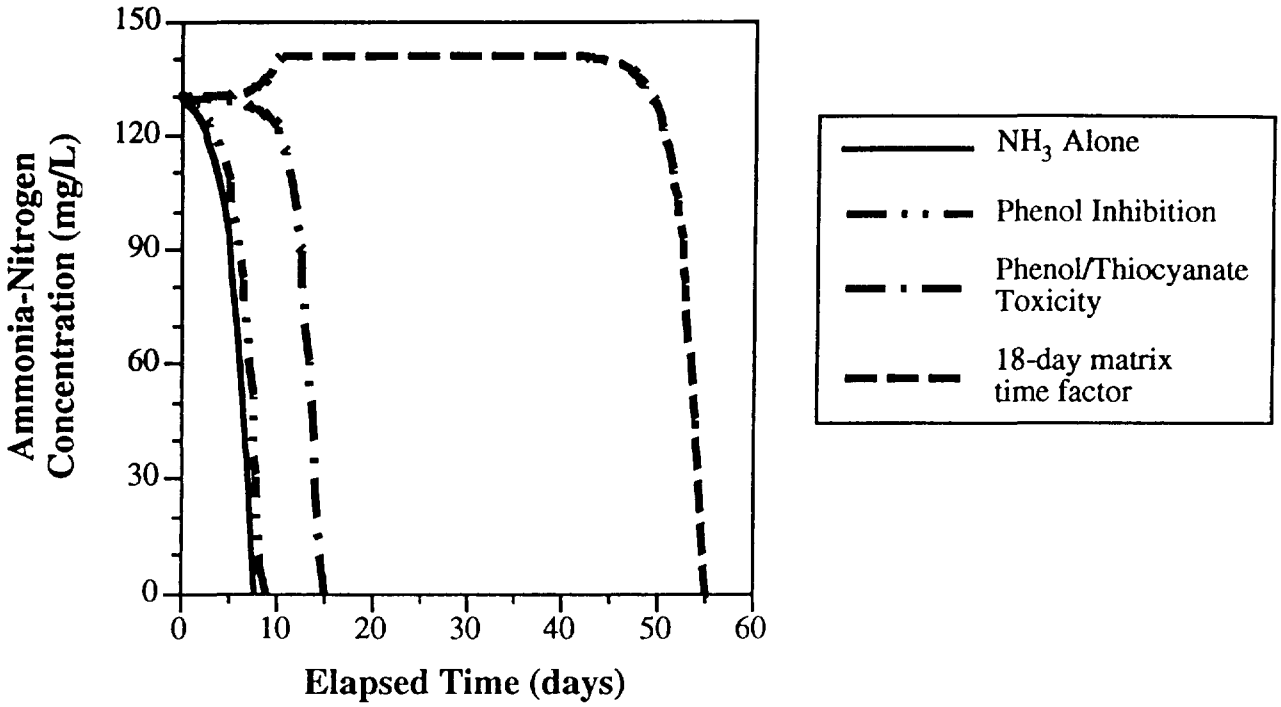


Figure 5-6. Ammonia decay curves predicted as a function of the inhibitory and toxic processes included in the model. Note that each plotted line also includes the mechanisms located above its name in the legend. The concentration increase between days 6 and 12 is from the release of ammonia during thiocyanate biodegradtion.

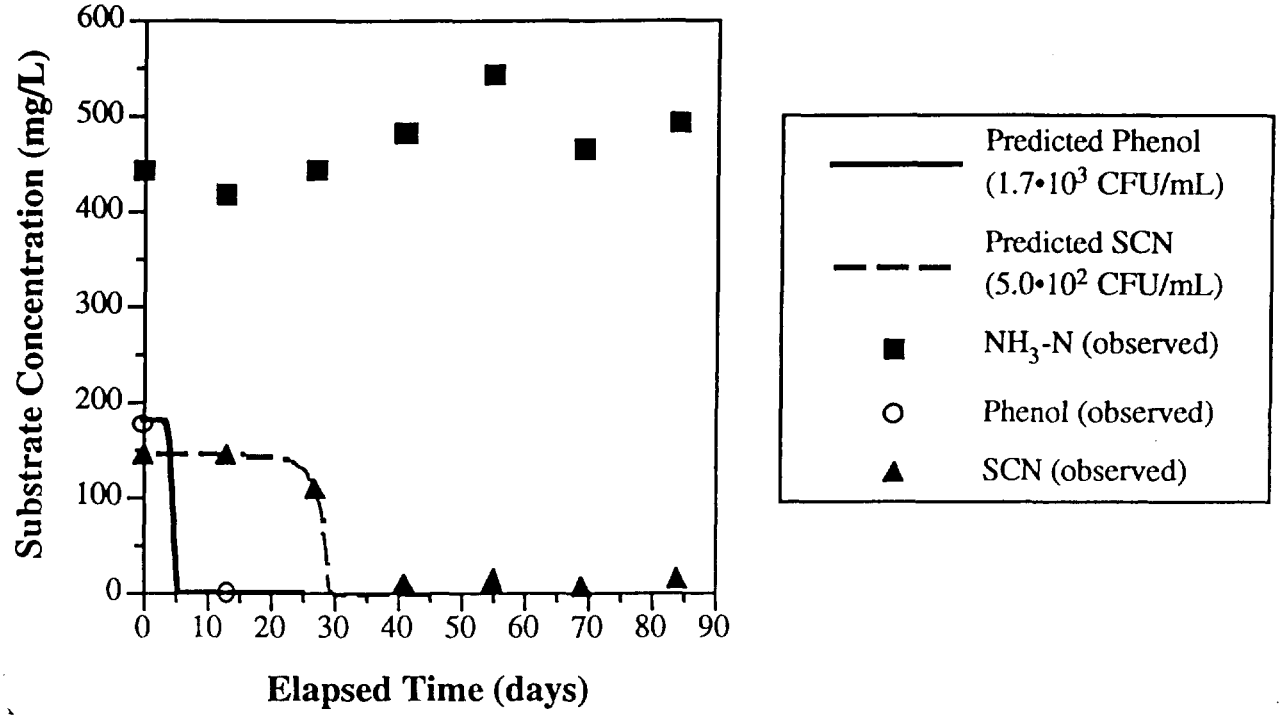


Figure 5-7. Comparison of the predicted and observed decay curves for phenol and thiocyanate during the IIILT-5 (5:1 MW-13S:MW-7D) batch test that was inoculated with 100 grams of aquifer soil.

TABLES

Table 2.1.
Waukegan Phase I Groundwater Analytical Results (mg/L)

Parameter	MW-7D (composite)	MW-13S (Composite)
Phenol	480	<0.01
Ammonia	620	3.4
Total Arsenic	20	0.18
Dissolved Arsenic	19	0.15
Nitrate Nitrogen	<5.0	0.06
Nitrite Nitrogen	<5.0	<0.05
Cyanide	<0.04	7.2
Creosol	446	<0.01
Benzene	0.66	<0.0005
Dissolved Oxygen	3.5	4.2
pH	8.8	7.2

1. The detection limit is used where the parameter is reported as not detected.

TABLE 2.2
Waukegan Phase I Analytical Results in mg/L
Deionized Water Spiked with Ammonia/Phenol
Undiluted

Phenol- and Ammonia-oxidizing culture inoculum size (CFU/mL)	Parameter	Day 0 8-20-96	Day 1 8-21-96	Day 3 8-23-96	Day 6 8-26-96	Day 8 8-28-96	Day 10 8-30-96
10^{4*}	NH_3	1220	976	1220	1025	976	976
	phenol	750	875	750	750	800	880
	NO_3	ND	0.09	ND	ND	ND	4.4
	NO_2	ND	0.03	0.07	0.07	0.07	0.03
10^{5*}	NH_3	1220	976	1220	1074	780	780
	phenol	750	750	750	625	640	560
	NO_3	ND	ND	ND	4.4	8.8	8.8
	NO_2	ND	0.1	0.07	0.1	0.07	0.03
10^6	NH_3	1220	976	927	1025	586	732
	phenol	750	750	500	500	580	480
	NO_3	ND	ND	4.4	8.8	8.8	8.8
	NO_2	ND	0.27	0.1	0.07	ND	0.03
10^5 *poison control	NH_3	1220	1070	1220	1220	1220	927
	phenol	750	750	750	750	840	1200
	NO_3	ND	ND	ND	ND	ND	ND
	NO_2	ND	ND	ND	ND	ND	ND

ND = Not Detected
* Number indicates the concentration of colony-forming units/ml of commercial phenol and ammonia-oxidizing cultures in each bottle

TABLE 2. 3
Waukegan Phase I Analytical Results in mg/L
Deionized Water Spiked with Ammonia/Phenol
3:1 Dilution Simulation

Phenol- and Ammonia- oxidizing culture inoculum size (CFU/mL)	Parameter	Day 0 8-20-96	Day 1 8-21-96	Day 3 8-23-96	Day 6 8-26-96	Day 8 8-28-96	Day 10 8-30-96
10^{4*}	NH_3	366	366	342	342	244	244
	phenol	250	250	190	275	5	ND
	NO_3	ND	ND	ND	ND	ND	8.8
	NO_2	ND	0.03	0.1	0.07	0.07	0.03
10^{5*}	NH_3	366	366	342	317	244	232
	phenol	250	250	180	ND	ND	ND
	NO_3	ND	ND	ND	4.4	ND	8.8
	NO_2	ND	0.13	0.1	0.07	0.07	0.03
10^6	NH_3	366	293	293	268	244	146
	phenol	250	30	ND	ND	ND	ND
	NO_3	ND	ND	4.4	4.4	8.8	8.8
	NO_2	ND	0.03	0.1	ND	0.07	0.03
10^5 *poison control	NH_3	366	366	342	366	366	342
	phenol	250	275	250	300	225	380
	NO_3	ND	ND	ND	ND	ND	ND
	NO_2	ND	ND	ND	ND	ND	ND

ND = Not Detected
* Number indicates the concentration of colony-forming units/ml of commercial phenol and ammonia-oxidizing cultures in each bottle

TABLE 2.4
Waukegan Phase I Analytical Results in mg/L
Deionized Water Spiked with Ammonia/Phenol
10:1 Dilution Simulation

Phenol- and Ammonia- oxidizing culture inoculum size (CFU/mL)	Parameter	Day 0 8-20-96	Day 1 8-21-96	Day 3 8-23-96	Day 6 8-26-96	Day 8 8-28-96	Day 10 8-30-96
10^{4*}	NH_3	305	244	244	183	183	183
	phenol	80	<0.1	<0.1	<0.1	<0.1	ND
	NO_3	<4.4	<4.4	<4.4	<4.4	22	178
	NO_2	<0.03	<0.03	0.17	0.83	7.3	38
10^{5*}	NH_3	305	244	244	183	183	183
	phenol	80	<0.1	<0.1	<0.1	<0.1	ND
	NO_3	<4.4	13.2	35.2	88	96.8	110
	NO_2	<0.03	0.83	16.7	29	35.8	20
10^6	NH_3	305	232	232	159	171	151
	phenol	80	<0.1	<0.1	<0.1	<0.1	ND
	NO_3	<4.4	154	163	176	154	154
	NO_2	<0.03	2.8	37.6	45	41.6	33
10^5 *poison control	NH_3	305	256	256	220	220	183
	phenol	80	75	75	75	75	75
	NO_3	<4.4	<4.4	<4.4	<4.4	<4.4	ND
	NO_2	<0.03	<0.03	<0.03	<0.03	<0.03	ND

ND = Not Detected

* Number indicates the concentration of colony-forming units/ml of commercial phenol and ammonia-oxidizing cultures in each bottle

Note: Additional ammonia was added through a nutrient salt solution - contributing to the elevated T-0 ammonia spike bottle.

Table 3.1. Ammonia Results with Ion Selective Electrode.

Sample ID	Ammonia mg/L	Nitrate mg/L	Nitrite mg/L
MW-7D	3000	ND	ND
1:1 (MW-7D:13S)	1400	ND	ND
1:2 (MW-7D:13S)	860	ND	ND
1:5(MW-7D:13S)	580	ND	ND

ND= Not Detected

Table 3.2: Confirmation of Ammonia Degradation, Phase II.

Ammonia, mg/L

	T=0	T=22 Hrs	T=72Hrs
Inoculated	195[1]	49	37
Control	195[1]	127	127

1. The initial analyses for ammonia by HACH kit was 195 mg/L. The solution was checked the next day; ammonia was 195 mg/L.

TABLE 3.3
Waukegan Phase II Preliminary Results in (mg/L)

System ID	Parameter	Day 0	Day 2	Day 4	Day 7	Day 9	Day 11	Day 14
	Date	9/9	9/11	9/13	9/16	9/18	9/20	9/23
Full concentration MW-7D	NH_3	488	195	146	156/151	156	146	146
	phenol	1400	1400	1400	1400/1320	1400	1400	1400
	NO_3	ND	ND	ND	ND/ND	ND	ND	ND
	NO_2	ND	ND	ND	ND/ND	ND	ND	ND
	DO	NA	NA	5.1	5.4	8.9	5.9	5.3
1:1 MW-13S:MW-7D	NH_3	244	244	244	200	224	205	'205
	phenol	800	800	720	680	600	600	600
	NO_3	ND	ND	18	31	44	1.1	13
	NO_2	ND	0.13	0.13	ND	ND	ND	ND
	DO	NA	NA	2.0	5.5	6.2	6.7	5.3
2:1 MW-13S:MW-7D	NH_3	162	293	205/195	268	215	215	216
	phenol	500	480	440/480	440	240	14	13
	NO_3	4.4	8.8	18/18	31	ND	30	31
	NO_2	ND	0.2	0.13/0.13	ND	ND	0.17	ND
	DO	NA	NA	0.7	5.5	1.1	2.6	0.1
5:1 MW-13S:MW-7D	NH_3	98	293	210	254	259/254	273/250	254/244
	phenol	270	200	44	2.1	1.1/1	1.0/1.0	2.0/2.0
	NO_3	ND	ND	13	8.8	ND/ND	19/11	31/22
	NO_2	ND	0.07	ND	ND	0.2/0.13	ND/ND	ND/ND
	DO	NA	NA	1.0	5.2	2.6	3.7	4.0

ND = Not Detected
NA = Not Analyzed

TABLE 3.4
Waukegan Phase IIb Results (mg/L)

	Mon., Oct. 21	Wed., Oct. 23	Fri., Oct. 25	Mon., Oct. 28	Wed., Oct. 30	Fri., Nov. 1	Mon., Nov. 4	Wed., Nov. 6	Fri., Nov. 8	Mon., Nov. 18	Wed., Dec. 4*	Wed., Dec. 18**
1:2 MW-7D:MW-13S Groundwater												
Ammonia (EPA 350.1)	280 (5x Dilution)	270 (5x)	360 (4x)	500 (4x)								320 (5x)
Nitrate (EPA 353.1)	<5 (100x Dilution)	<5 (100x)	<5 (100x)	<5 (100x)								<5 (100x)
Nitrite (EPA 353.1)	<5 (100x)	<5 (100x)	<5 (100x)	<5 (100x)	<5 (100x)	<5 (100x)	<5 (100x)	<5 (100x)	<5 (100x)	<5 (100x)	<5 & <5 (100x)	<5 (100x)
Phenol (EPA 8270B)												<48 ug/L (1x)
Control - Deionized Water												
Ammonia (EPA 350.1)	180 (5x)	230 (5x)	240 (4x)	290 (4x)	480 (5x)	310 (5x)	290 (5x)	300 (5x)	280 (5x)	110 (5x)	250 & 300 (5x)	110 (5x)
Nitrate (EPA 353.1)	<0.05 (1x)	2.7 (1x)	5.3 (1x)	3.7 (1x)	6.6 (1x)	5.2 (1x)	5.1 (1x)	3.8 (1x)	9.4 (1x)	32 (1x)	27 & 30 (1x)	29 (1x)
Nitrite (EPA 353.1)	20 (1x)	23 (1x)	26 (1x)	30 (1x)	27 (1x)	28 (1x)	30 (1x)	31 (1x)	28 (1x)	<0.05 (1x)	<0.05 & <0.05 (1x)	<0.05 (1x)
Phenol (EPA 8270B)												<57 ug/l (1x)

Table 4.1
Parameters and Analytical Methods for Sample Analysis

Parameter	Method	Min. Detection Limit	IMST[1]	IMLT[2]	IMLT[3]
Alkalinity	EPA 310.1	15 mg/L	X	X	X
Ammonia-N	EPA 350.2 (w/distillation)	10 mg/L	X	X	X
Total Kjedahl Nitrogen	EPA 351.3 (w/distillation)	10 mg/L	X	X	X
Nitrate-N	EPA 353.2	10 mg/L	X	X	X
Nitrite-N	EPA 353.2	10 mg/L	X	X	X
Phenolics (4AAP)	EPA 420.2	20 mg/L		X	
Phenolics (GC)	EPA 8040	5 mg/L	X	X	X
BOD, 5 Day	EPA 405.1	50 mg/L		X	
COD	EPA 410.4	20 mg/L	X	X	X
DOC	EPA 415.2	5 mg/L	X	X	X
BTEX	EPA SW-846 8020 (MOD)	1 mg/L		X	
Phosphorus-P, Total	EPA 365.1	0.5 mg/L		X	
Cyanide, Distilled	EPA 335.2	1 mg/L		X	
Thiocyanate	SM 4500-CNM	10 mg/L	X	X	X
Arsenic,	EPA 200.7/SW6010	0.1 mg/L		X	
Arsenic, Dissolved	EPA 200.7/SW6010	0.1 mg/L		X	
Iron, Total	EPA 200.7/SW6010	0.1 mg/L		X	
Total Hardness	EPA 130.1	15 mg/L		X	

Notes: [1] All sampling intervals.
[2] Initial and final sampling points.
[3] Intermediate sampling points.

TABLE 4.2
Phase III Short Term Study Set Up

	Water Volumes (liters)			Spiked Concentrations (mg/L)			Buffer Addition (grams)			Microbial Culture Inoculation (mL)		
Bottle ID	MW 7-D	MW 13-S	DI H_2O	NH_3-N	Phenol	SCN	KH_2PO_4	K_2HPO_4	$NaHCO_3$	Nitrifiers	Phenol Degraders	Purpose
IIIST-1	0.0	0.0	6.0	300	0	0	3.3	26.7	5.0	0.86	60	Develop baseline ammonia kinetics
IIIST-2	0.0	0.0	6.0	300	250	0	3.3	26.7	5.0	0.86	60	Verify effects of phenol on nitrification
IIIST-3	0.0	0.0	6.0	300	250	180	3.3	26.7	5.0	0.86	60	Verify effects of phenol and SCN on nitrification
IIIST-4	1.0	3.0	0.0	0	0	0	2.2	17.8	0.0	0.57	40	Verify effects of matrix on nitrification
IIIST-5	0.4	3.6	0.0	0	0	0	2.2	17.8	0.0	0.57	40	High dilution to determine if nitrification is achievable with Site groundwater
IIIST-6	0.2	3.8	0.0	0	0	0	2.2	17.8	0.0	0.57	40	Higher dilution to determine if nitrification is achievable with Site groundwater
Total Volume	1.6	10.4	18.0									

Table 4.3
Phase III Short Term Test Extension

Bottle ID	Description of Test Modifications
IIIST-1	None, Test Completed.
IIIST-2	None, Test Completed.
IIIST-3	None, Test Completed
IIIST-4	Continue test, maintain pH and D.O.; periodic sampling.
IIIST-5i	Split IIIST-5 for re-inoculation test; twice-weekly sampling.
IIIST-5n	Split IIIST-5 for re-inoculation test; twice-weekly sampling.
IIIST-6	Continue test, maintain pH and D.O.; sample weekly.
IIIST-7	New test bottle. Ammonia degradation kinetics baseline; twice-weekly sampling.
IIIST-8	New test bottle. Ammonia / thiocyanate kinetics baseline; twice weekly sampling.

Table 4.4
Phase III Long Term Study Set Up

	Water Volumes		Buffer Addition (grams)			Microbial Culture Inoculation (mL)			
Bottle ID	MW7-D	MW13-S	KH_2PO_4	K_2HPO_4	$HgCl_2$	Site Soil	Nitrifiers	Phenol Degraders	Purpose
IIILT-1	1.5 L	4.5 L	3.3	26.7	0.0	0.0	0.86	60	Medium dilution
IIILT-2	1.0 L	5.0 L	3.3	26.7	0.0	0.0	0.86	60	High dilution
IIILT-3	2.0 L	4.0 L	3.3	26.7	0.0	0.0	0.86	60	Low dilution
IIILT-4	6.0 L	0.0 L	3.3	26.7	0.0	0.0	0.86	60	Undiluted groundwater sample
IIILT-5	1.0 L	5.0 L	3.3	26.7	0.0	100 gm	0.0	0	High dilution with Site soil inoculum
IIILT-6	0.6 L	5.4 L	3.3	26.7	0.0	0.0	0.86	60	Higher dilution to confirm biotreatment possible with Site groundwater
IIILT-7	1.5 L	4.5 L	3.3	26.7	1.2*	0.0	0.0	0	Medium dilution poison control
Total Volume	13.6 L	28.4 L							

* 1.2 gm $HgCl_2$ added again after six weeks

Table 4.5
Phase III Long Term Modification Study

Bottle ID	Modification Description
IIILT-1i	Re-inoculate
IIILT-2i	Re-inoculate
IIILT-3i	Re-inoculate
IIILT-4i	Re-inoculate
IIILT-5i	Re-inoculate with Site soil
IIILT-6i	Split test bottle contents, re-inoculate
IIILT-6n	Split test bottle contents, no inoculation
IIILT-7	None
IIILT-8	New test bottle. Ammonia degradation kinetics baseline (300 mg/L); daily sampling.
IIILT-9i	Dilution of IIILT-1 aliquot to 5% solution and re-inoculate
IIILT-10	New test bottle. Ammonia degradation kinetics baseline at a higher ammonia conc. (700 mg/L); daily sampling.
IIIST-3D	New test bottle. Duplicate of IIIST-3 run previously. 300 mg/L NH_3-N, 250 mg/L phenol, and 180 mg/L thiocyanate.

Table 4.6
Phase III Long Term Extension Study Set Up

	Water Volumes (L)				Microbial Culture Inoculation (mL)			Buffer Addition (grams)				Other Additions (gm)		
Bottle ID	Est. Vol.	Water from III LT-1	MW 13-S	DI H2O	Nitrifiers	Phenol Degraders	Site Soil (gm)	$HgCl_2$	KH_2PO_4	K_2HPO_4	$NaHCO_3$	NH_4Cl	Phenol	NaSCN
III LT-1i	3.94	—	—	—	110	39	—	—	—	—	—	—	—	—
III LT-2i	4.58	—	—	—	128	46	—	—	—	—	—	—	—	—
III LT-3i	4.58	—	—	—	128	46	—	—	—	—	—	—	—	—
III LT-4i	4.54	—	—	—	127	45	—	—	—	—	—	—	—	—
III LT-5i	4.54	—	—	—	—	—	227.4	—	—	—	—	—	—	—
III LT-6i	2.34	—	—	—	66	23	—	—	—	—	—	—	—	—
III LT-6n	2.34	—	—	—	—	—	—	—	—	—	—	—	—	—
III LT-7	4.45	—	—	—	—	—	—	0.91	—	—	—	—	—	—
III LT-8	6.00	—	—	6.00	168	60	—	—	3.325	26.705	2.52	6.892	—	—
III LT-9i	3.00	0.60	2.40	—	84	30	—	—	1.33	10.679	—	—	—	—
III LT-10	6.00	—	—	6.00	168	60	—	—	3.305	26.72	5.892	16.120	—	—
III ST-3D	6.00	—	—	6.00	168	60	—	—	3.308	26.722	2.53	6.882	1.511	1.523

Table 4.7
Sampling and Analysis Protocol for Phase III Long Term Modification Study

	Proposed Sampling Frequency Parameters and Test Duration											
Bottle ID	Sampling Freq.	Duration	Alk	SCN	NH_3-N	NO_3-N	NO_2-N	TKN	COD	DOC	Phenols	Recommended Sampling Days
IIILT-1i	Once/2 weeks	6 weeks	X	—	X	X	X	X	X	X	—	Tu
IIILT-2i	Once/2 weeks	6 weeks	X	—	X	X	X	X	X	X	—	Tu
IIILT-3i	Once/2 weeks	8 weeks	X	X	X	X	X	X	X	X	—	Tu
IIILT-4i	Once/2 weeks	8 weeks	X	X	X	X	X	X	X	X	X	Tu
IIILT-5i	Once/2 weeks	8 weeks	X	—	X	X	X	X	X	X	—	Tu
IIILT-6i	Once/2 weeks	4 weeks	X	—	X	X	X	X	X	X	—	Tu
IIILT-6n	Once/2 weeks	6 weeks	X	—	X	X	X	X	X	X	—	Tu
IIILT-7	Once/2 weeks	8 weeks	X	X	X	X	X	X	X	X	—	Tu
IIILT-8	Daily	1 week	X	—	X	X	X	X	—	—	—	Mo, We, Sa
IIILT-9i	Once/2 weeks	4 weeks	X	—	X	X	X	X	X	X	—	Mo, Th
IIILT-10	Daily	1 week	X	—	X	X	X	X	—	—	—	Mo, We, Sa
IIIST-4	Once/2 weeks	8 weeks	X	—	X	X	X	X	X	X	—	Tu
IIIST-3D	Once/week	4 weeks	X	X	X	X	X	X	X	X	X	Tu

Table 4.8
Pure Compound, DI Water Studies

Experiment		Inoculum Level	Days Required		
RefNo	Description	CFU/ml	NH_3 Removal	Phenol Removal	SCN^- Removal
1	IIIST-1, 300 PPM NH_3	10^6	13		
2	IIIST-7, 300 PPM NH_3	10^6	11		
3	IIILT-7, 300 PPM NH_3	10^8	4		
4	IIILT-10, 600 PPM NH_3	10^8	6		
5	IIIST-2, 300 PPM NH_3, 250 PPM Phenol	10^6	20	6	
6	IIIST-8, 300 PPM NH_3, 180 PPM SCN^-	10^6	12		30[1]
7	IIIST-3,300 PPM NH_3, 250 PPM Phenol 180 PPM SCN^-	10^5	34	6	16
8	IIIST-3D, 300 PPM NH_3,250 PPM Phenol 180 PPM SCN^- (Respiked & Reinoculated ST-3)	10^6	14	2	7

Notes: 1. Estimated. Actual day to removal not known. Experiment terminated after NH_3 disappearance. SCN^- concentration essentially unchanged during entire test.

Table 4.9
Site Groundwater Studies

Experiment		Inoculation		Ratio	Days Required		
Ref No.	Description	No	Days After Start	MW13S: MW7D	NH_3 Removal	Phenol Removal	SCN^- Removal
1	IIIST-6	1		19:1	56	2	10
2	IIILT-9i[1]	2	75	19:1 Diluted from 3:1	3 (78)[1]	(14) [3,6] None Present after Dilution to 5%	(88)[3] None Present after Dilution to 5%
3	IIIST-5n[2]	1		9:1	NL [4]	6	23
4	IIIST-5i	2	2nd - 35	9:1	52	6	23
5	IIILT-6n [5]	1		9:1	158	14[6]	27
6	IIILT-6i	2	2nd - 75	9:1	80	14[6]	27
7	IIILT-5 (Soil Inoculum)	2	2nd - 75	5:1	NL [4]	14[6]	45
8	IIILT-2ii	3	2nd - 75 3rd - 105	5:1	115	14[6]	45
9	IIIST-4	1		3:1	NL [4]	6	38
10	IIILT-1ii	3	2nd - 75 3rd - 107	3:1	148	14[6]	88
11	IIILT-7(Killed Control)	2	2nd - 80	3:1	NL [4]	NL [4]	NL [4]
12	IIILT-3ii	3	2nd - 75 3rd - 105	2:1	135	14[6]	51
13	IIILT-4	2	2nd - 75	0:1	NL [4]	NL [4]	NL[4]

Notes:
1. IIILT-1 (25% MW-7D) was diluted to give 5% MW-7D after 78 days run time.
2. IIIST-5 was split into two bottles after 35 days. One of the splits was inoculated (IIIST-5i) and one was not (IIIST-5n)
3. The phenol and thiocyanate degradation times are those for IIILT-1. When IIILT-9i was setup there was no phenol or thiocyanate present.
4. " NL" Indicates that no degradation or loss was observed over the course of the study.
5. IIIT-6 was split into two bottles after 75 days. One of the splits was inoculated (IIILT-6i) and one was not (IIILT-6n)
6. The 14 days is reprted because of sampling schedule. Phenol degradation was probably faster.

Table 4.10
Nitrogen Balance
Pure Compound, DI Water Studies

Description	Initial Total Nitrogen (mg/L-N)	Final Total Nitrogen (mg/L-N)	Final Nitrogen / Initial Nitrogen
III ST-1	281	280	0.996
III ST-2	322	276	0.857
III ST-3	404	323	0.800
III ST-3D	467	439	0.940
III ST-7	299	279	0.933
III ST-8	367	397	1.082
III LT-8	409	273	0.667
III LT-10	839	650	0.775

Note: Total Nitrogen = TKN-N + NO_3-N + NO_2-N + SCN-N
(TKN-N includes Ammonia)

Table 4.11
Nitrogen Balance
Site Groundwater Studies

Description	Initial Total Nitrogen (mg/L-N)	Final Total Nitrogen (mg/L-N)	Final Nitrogen / Initial Nitrogen
III ST-4	811	958	1.181
III ST-5a	391	380	0.972
III ST-5i	391	300	0.767
III ST-6	201	179	0.891
III LT-1ii	778	909	1.168
III LT-2ii	518	597	1.152
III LT-3ii	1,076	1,041	0.967
III LT-4	3,164	3,341	1.056
III LT-5i	613	735	1.199
III LT-6n	315	437	1.387
III LT-6i	315	279	0.886
III LT-7	810	1,097	1.354
III LT-9i	156	122	0.782

Note: Total Nitrogen = TKN-N + NO_3-N + NO_2-N + SCN-N
(TKN-N includes Ammonia)

Table 5.1. Comparison of the S_{max} values for phenol, thiocyanate, and ammonia to their measured concentrations in the undiluted groundwater obtained from monitoring well MW-7D.

Substrate	S_{max} (mg/L)	Concentration in Undiluted MW-7D Groundwater* (mg/L)
Phenol	6,800	980
Thiocyanate	2,200	720
Ammonia	42,300	2,690

* = initial substrate concentrations in the IIILT-4 batch test

Table 5.2. First-order biomass loss rate coefficients for active *Nitrosomonas* biomass (b_N) as a function of environmental conditions.

Value of b_N (1/day)	Characteristic or When Used by Model
0.1	endogenous decay coefficient with no toxicity
0.62	biomass loss coefficient while the toxicity of the MW-7D groundwater remains, but phenol and thiocyanate are not present
1.9	biomass loss coefficient that describes the toxic effect created when phenol and thiocyanate are present together in solution, but no MW-7D groundwater is present
2.42	biomass loss coefficient while the toxicity of the MW-7D groundwater remains, and when phenol and thiocyanate are present together in solution

APPENDIX A

PHASE III - BIODEGRADATION STUDY EXPERIMENTAL METHODS

Appendix A
Phase III Biodegradation Study
Experimental Methods

Sample Receipt

Approximately 15 gallons of water from monitoring well MW-13S and 10 gallons of water from monitoring well MW-7D were received by Fluor Daniel GTI, Remediation Technology Testing Facility, Trenton, New Jersey, in February, 1997. Waters from monitoring well MW-7D that were not used in the initial set up of this study were frozen to ensure no loss of contaminants during storage. Waters from monitoring well MW-13S there were not used in the initial set up of this study were refrigerated for later use. .

Initial Nitrifier Inocula Calibration Test

Because nitrifiers do not respond to routine plate count methods. Ammonia degradation rates were used to estimate the quantity of nitrifiers in the inoculum. The calibration protocol consisted of preparing a 500 mL test bottle containing 200 mg/L NH_3, a phosphate buffer, sodium bicarbonate, and an estimated inocula size of 10^7 CFU/mL of nitrifiers. A control bottle was prepared with all the chemicals described above but which received no nitrifier inoculum. Both bottles were sealed and dissolved oxygen was maintained above 5 mg/L in both bottles for the duration of the test. The pH was adjusted and maintained between 7.0 and 8.0 in both bottles by adding either 6N HCl or 10N NaOH. Ammonia (NH_3), nitrate ($N0_3^-$), and nitrite ($N0_2^-$) were analyzed after one and two days from both bottles using HACH test kits. The rate of ammonia loss was then used to estimate the quantity of nitrifiers in the inocula.

Initial Phase III Short Term Study Protocol

The six 20 L glass testing bottles used for this study are identified IIIST-1 through IIIST-6. Bottles IIIST-1 to IIIST-3 used deionized (DI) water. Bottles IIIST-4 to IIIST-6 used Site groundwater. $NaHCO_3$ was added to the DI water bottles as an inorganic carbon source for nitrification. The pH was adjusted in all bottles to between 7.0 and 8.0 with either 6N HCl or 10N NaOH. All bottles were then buffered to a pH of approximately 8.0 using phosphate buffers. All bottles were inoculated to approximately 10^5 CFU/mL each of heterotroph and nitrifier concentrations as determined in the inocula calibration test. The pH was maintained between 7.0 and 8.0 in all bottles at all times by adding either standardized 6N HCl or 10N NaOH (calibrated). All bottles were continuously stirred, and covered with aluminum foil for the duration of the test to avoid light penetration, photochemical oxidation, and photosynthesis.

The headspace of each bottle was periodically flushed with a stream of oxygen gas (1.2 liter/minute) for 15 minutes and then sealed. Dissolved oxygen was maintained above 5 mg/L in all bottles at all times, by replenishing the headspace of the bottle with oxygen as needed. The sampling interval was twice weekly for ammonia (NH_3-N), thiocyanate (SCN^-), nitrate (NO_3-N), nitrite ($N0_2$-N), total Kjeldahl nitrogen (TKN), phenol, alkalinity, COD, and DOC. Thiocyanate and phenol analyses were conducted until the concentrations were at or below detection limits. The pH and DO were monitored and recorded during every sampling interval. The volume extracted for each sampling event for each test bottle was measured

and recorded. All samples for chemical analysis were sent to CH2M Hill Analytical Services (Montgomery, Alabama).

Phase III Short-Term Test Extension Protocol

Several observations were made during the short term study. First, thiocyanate appeared to increase the inhibition of nitrification. Second, the short term study bottles using Site groundwater did not show appreciable ammonia removal at the end of 4 ½ weeks. As a result of these observations, the study was extended in three ways. First, incubation of all the Site groundwater bottles was continued. Second, the 9:1 (MW-13 to MW-7) dilution, IIIST-5 was split and one split was reinoculated. Third, two new short term studies were set up and run to confirm the nitrification kinetics, both using DI water.

The remaining volume from IIIST-5 was split into two equal volumes. IIIST-5i (I for re-inoculated) , was inoculated with 10^6 CFU/mL nitrifier concentration, as determined from IIIST-1 calibration. Ten milliliters of the heterotrophic stock culture was used per liter of test volume. The second split of IIIST-5, IIIST-5n, was not reinoculated and continued as before. The test extention was four weeks.

An ammonia biodegradation baseline kinetic bottle, IIIST-7, was started at the same time that IIIST-5i was started. Test bottle IIIST-7 was similar to bottle IIIST-1. Test bottle IIIST-7 was inoculated with 10^6 CFU/mL nitrifier concentration. Test bottle IIIST-8, was an ammonia/thiocyanate baseline kinetic bottle. It was started at the same time IIIST-5i. Test bottle IIIST-8 was spiked to 300 mg/L NH_3 and 180 mg/L SCN^-. Test bottles IIIST-7 and IIIST-8 also received phosphate buffer and sodium bicarbonate.

Test bottle IIIST-8 was analyzed twice weekly for SCN. Sampling was normally Mondays, with the second sampling of the week on Thursdays. Test bottle IIIST-4 was sampled periodically for the primary parameters based on the laboratory results from previous sampling events.

Short Term Test Inocula Calibration

Based on the results of the IIIST-1 inocula calibration test, the stock solution of the nitrifier culture contained approximately $7x10^8$ CFU/mL and yielded approximately 10^5 CFU/mL in each test bottle. Approximately 1.4 mL of nitrifier stock solution per liter of test solution was used for any reinoculations to get a nitrifier concentration of 10^5 to 10^6 CFU/ml.

One sample of the nitrifier culture and one sample of the heterotrophic culture were submitted to the laboratory for testing to see if they contributed background levels of ammonia. The sample of nitrifier culture was diluted to a 10 percent concentration for submission to laboratory. The heterotrophic culture was prepared as a 10 percent slurry, allowed to mix three hours, and screened through glass wool. After the 10 percent slurry preparation was completed, a sample of the slurry was diluted further to a 1% solution for submittal to the laboratory. Neither culture contributed any significant quantities of ammonia nitrogen.

Phase III Initial Long-Term Test Protocol

All bottles were covered with aluminum foil after set-up for the duration of the test to avoid light penetration and photo oxidation of the contaminants, and photosynthesis. All bottles were buffered to a pH of

approximately 8.0. The pH was adjusted in all bottles to between 7.0 and 8.0 with either 6N HCL or 10N NaOH. The pH was periodically adjusted during the course of the study to between 7.0 and 8.0 by adding either standardized 6N HCL or 10N NaOH.

All sample bottles except IIILT-5 and IIILT-7 were inoculated to approximately 10^6 CFU/mL heterotroph and nitrifier concentrations. Bottle IIILT-5 was inoculated with 100 grams of Site soil. Bottle IIILT-7, a poison control, received no inoculum and was dosed with 1.2 grams (200 mg/L) of mercuric chloride. After 6 weeks, bottle IIILT-7 was again dosed with an additional 1.2 grams of mercuric chloride. Bottles IIIST-1 (containing ammonia), IIIST-2 (containing ammonia and phenol), and IIIST-3 (containing ammonia, phenol and thiocyanate) served as positive controls to confirm inocula viability and to determine baseline kinetics.

The headspace of each bottle was periodically flushed with a stream of oxygen gas (2.0 liter/minute) for 15 minutes and then each bottle sealed. Dissolved oxygen was maintained above 5 mg/L in all bottles at all times by replenishing the bottle headspace with oxygen as needed.

The sampling interval for the primary contaminants was every 14 days. The pH and DO levels were monitored and recorded twice weekly. The detection limits shown represent the minimum values that would meet the data quality and quantity objectives. An aliquot of bottle IIILT-4 was spiked with nitrate and nitrite at approximately 1.0 mg/L to determine if there was a matrix interference for these analyses. The initial sample collected from IIILT-4 was also analyzed for phenol using the GC/MS method and the results were compared to the GC results to verify that the analytical substitution of the GC method for the GC/MS method was reasonable.

The total liquid volume in each test bottle was monitored and recorded before and after each sampling event or at any time when liquids were added to or extracted from the test bottle. The volume extracted for each sampling event for each test bottle was measured and recorded. The total volume measured for each test bottle is accurate to +/- 50 mL. Each test bottle was calibrated in 100 mL increments to allow for direct measurement of the liquid in the bottle. The test duration was 11 ½ weeks.

Long Term Test Extension and Re-inoculation Protocol

The test extension protocol was a modification of the Phase III Long-Term Study program. It was based on observations from the Short Term Test and Test Extension. The objective of the Long-Term Study Extension was to determine if nitrification of Site groundwater could occur at Site groundwater dilutions other than the 9:1 dilution (IIIST-5i) and 19:1dilution (IIIST-6).

The results of the Phase III Short-Term Test indicated a probable die-off of the active nitrifying culture. The results of the Short Term Test Extension, specifically the reinoculation of test bottle IIIST-5i, demonstrated that nitrification could be achieved in Site groundwater, provided an active culture of nitrifiers was present after significant removal of organic species occurs. In order to achieve this in the study program reinoculation was required.

The following discusses the Phase III Long Term Study Extension and Re-inoculation Test. All of the original test bottles were reinoculated with the exception of IIILT-7(poisoned control). Two new bottles, IIILT-8 and IIILT-10, were set up to confirm the ammonia biodegradation baseline kinetics. They were

started when the long term test bottles were re-inoculated. Test bottle IIILT-8 was set up to parallel the previous ammonia baseline kinetic studies, specifically IIIST-1 and IIIST-7. It contained 300 mg/L NH_3. Test bottle IIILT-10 was dosed with 700 mg/L NH_3 to see if significant self-inhibition of nitrifiers would be observed. The sampling frequency for both test bottles IIILT-8 and IIILT-10 was three times a week.

In addition to the baseline ammonia kinetics studies, a duplicate of test bottle IIIST-3, identified as test bottle IIIST-3D, was run. This test bottle contained 300 mg/L NH_3-N, 250 mg/L phenol, and 180 mg/L thiocyanate (SCN) in DI water. It was run to reconfirm the synergistic inhibition of nitrification by phenol and thiocyanate.

Several of the bottles were split or diluted to a new level. A 600 mL sample aliquot was withdrawn from test bottle IIILT-1 and diluted with 2400 ml of stored MW 13-S groundwater to make a 5 percent dilution test bottle. This bottle was designated IIILT-9i. The contents of test bottle IIILT-6 were split into two equal volumes (IIILT-6i and IIILT-6n).

Test bottles IIILT-1i, IIILT-2i, IIILT-3i, IIILT-4i, IIILT-6i, IIILT-8, IIILT-9i, IIILT-10, and IIIST-3D were re-inoculated with the nitrifier stock solution containing approximately $1.8x10^{10}$ CFU/mL of *Nitrosomonas* at day 75 to a concentration of $5x10^8$ CFU/mL *Nitrosomonas*. Test bottles IIILT-1i, IIILT-2i, IIILT-3i, IIILT-4i, IIILT-6i, IIILT-8, IIILT-9i, IIILT-10, and IIIST-3D were also inoculated with the heterotrophic culture, containing approximately _ CFU/mL of heterotrophs to a concentration of 10^6 heterotrophs. Test bottle IIILT-5i was re-inoculated with 227.4 grams of Site soil per liter of test solution. Bottle IIILT-7, the poisoned control, was not reinoculated but was redosed with 200 mg of mercuric chloride per liter of test solution. Short-Term test bottle IIIST- 4 served as a live control and did not receive inocula. In addition to receiving the inoculum, test bottles IIILT-8, IIILT-10, and IIIST-3D were dosed with a phosphate buffer and sodium bicarbonate.

Dissolved oxygen and pH were monitored a minimum of three times per week. If the DO in any test bottle fell below 5 mg/L, the headspace was flushed with pure oxygen. The pH was also adjusted to be between 7.0 and 8.0. Test duration was 9 weeks.

Sampling frequency for the primary long-term test parameters were once every two weeks with the exception of test bottles IIILT-8, IIILT-10, and IIIST-3D which were sampled three times per week. A supplement to the normal sampling frequency described above should be noted. More frequent samples were collected and analyzed from each test bottle when laboratory monitoring suggested that nitrification was occurring in a test bottle. Dissolved oxygen and pH were monitored as criteria that indicated nitrification. When a decrease of 0.2 pH units and a decrease in DO occurred, a sample was collected immediately and every other day thereafter until the pH stabilized. The samples collected during these periods were analyzed for NH_3N, NO_3^-N, NO_2^-N, and TKN.

Long Term Test Inocula Calibration

Based on the results of the IIIST-1 and IIIST-7 inocula calibration tests, the stock solution of the nitrifier culture contained approximately $1.8x10^{10}$ CFU/mL of *Nitrosomonas*. Approximately 28 mL of nitrifier stock solution per liter of test solution was added to IIILT-1i, IIILT-2i, IIILT-3i, IIILT-4i, IIILT-6i, IIILT-8, IIILT-9, IIILT-10, and IIIST-3D to achieve a concentration of $5x10^8$ CFU/mL of *Nitrosomonas*.

Verification of Nitrosomonas Die-Off in the Presence of Phenol and Thiocyanate

To verify that a die-off of the nitrifiers was actually occurring, 30 mL aliquots were withdrawn from test bottles IIIST-3D, IIILT-2i, and IIILT-3i on Day 3, and the biomass present was concentrated, washed, and resuspended in 50 mL Ammonia Assay Buffer solution (0.955 g/L NH_4Cl; 0.46 g/L KH_2PO_4; 3.7 g/L K_2HPO_4; and 0.35 g/L $NaHCO_3$) to determine the number of viable nitrifiers present at this time. Three aliquots were taken from each bottle for assay at time intervals of 1, 3 and 6 hours. At each of the these time intervals, one aliquot was sacrificed for analysis. Nitrate and nitrite concentrations were measured using HACH test kits. Ammonia concentration was measured using an ammonium ion specific electrode.

APPENDIX B

ANALYTICAL RESULTS

			IIIST-1			IIIST-2			IIIST-3			IIIST-4		
Elapsed days	Date	sampling event	Amount added (ml)	amount removed (ml)	total volume (ml)	Amount added (ml)	amount removed (ml)	total volume (ml)	Amount added (ml)	amount removed (ml)	total volume (ml)	Amount added (ml)	amount removed (ml)	total volume (ml)
0	03-Mar-97				6000			6000			6000			**4000**
1	04-Mar-97	1	60.9	200	5861	60.9	200	5861	60.9	200	5860.9	42.6	195	**3848**
3	06-Mar-97	2		115	5746		140	5721		165	5695.9	10	165	**3693**
7	10-Mar-97	3	8	120	5634	5	155	5571	4	175	5524.9	5	170	**3528**
10	13-Mar-97	4	13.5	115	5532	6	135	5442	4	175	5353.9	2	170	**3360**
14	17-Mar-97	5	3.5	115	5421	10	145	5307		170	5183.9	1	170	**3191**
17	20-Mar-97	6		115	5306	6	140	5173	1	170	5014.9	1	170	**3022**
21	24-Mar-97	7		170	5136	2	195	4980		220	4794.9	1	220	**2803**
24	27-Mar-97	8		170	4966		220	4760		220	4574.9		230	**2573**
29	01-Apr-97	9			4966			4760	10.5	190	4395			**2573**
31	03-Apr-97	10			**4966**			**4760**	6	190	4211			**2573**
35	07-Apr-97	11							4	195	4020		85	**2488**
36	08-Apr-97		*Measured Amount*		***5020***	*Measured Amount*		***4365***			4020			**2488**
38	10-Apr-97	12							1	90	3931		85	**2403**
42	14-Apr-97	13									**3931**	0.5	85	**2318**
45	17-Apr-97	14										0.5	90	**2229**
49	21-Apr-97	15							*Measured Amount*		***4070***		90	**2139**
52	24-Apr-97	16											90	**2049**
56	28-Apr-97	17											80	**1969**
59	01-May-97													**1969**
63	05-May-97													**1969**
66	08-May-97													**1969**
70	12-May-97	18											80	**1889**
74	16-May-97													**1889**
78	20-May-97													**1889**
80	22-May-97													**1889**
85	27-May-97	19											90	**1799**
88	30-May-97											0.25		**1799**
91	02-Jun-97											0.6		**1799**
92	03-Jun-97	2 (1)										0.2	100	**1700**
94	05-Jun-97													**1700**
96	07-Jun-97													**1700**
98	09-Jun-97											0.2		**1700**
101	12-Jun-97											0.4		**1700**
106	17-Jun-97											0.2		**1700**
109	20-Jun-97											0.2		**1701**
112	23-Jun-97													**1700**
115	26-Jun-97													**1700**
119	30-Jun-97	11 (1)											85	**1615**
126	07-Jul-97													**1615**
129	10-Jul-97													**1615**
133	14-Jul-97	14 (1)											100	**1515**
136	17-Jul-97													**1515**
140	21-Jul-97													**1515**
143	24-Jul-97													**1515**
147	28-Jul-97	final											600	**915**
													Measured Amount	***1150***

(1) Became part of longterm extension

			IIIST-5			IIIST-5n			IIIST-5l		
Elapsed days	Date	sampling event	Amount added (ml)	amount removed (ml)	total volume (ml)	Amount added (ml)	amount removed (ml)	total volume (ml)	Amount added (ml)	amount removed (ml)	total volume (ml)
0	03-Mar-97				4000						
1	04-Mar-97	1	40.57	195	3846						
3	06-Mar-97	2		165	3681						
7	10-Mar-97	3	2	180	3503						
10	13-Mar-97	4	2	170	3335						
14	17-Mar-97	5		170	3165						
17	20-Mar-97	6		180	2985						
21	24-Mar-97	7		220	2765						
24	27-Mar-97	8		220	2545						
29	01-Apr-97	9			2545						
31	03-Apr-97	10		170	2375						
35	07-Apr-97	11						1235			1235
36	08-Apr-97		*Measured Amount*		*2470*			1235			1235
38	10-Apr-97	12				1.75	85	1152		85	1150
42	14-Apr-97	13				0.5	85	1067		85	1065
45	17-Apr-97	14				0.5	90	978		90	975
49	21-Apr-97	15					85	893	1	90	886
52	24-Apr-97	16					80	813	0.75	75	812
56	28-Apr-97	17					80	733	1	80	733
59	01-May-97						150	583	0.25	130	603
63	05-May-97										
66	08-May-97					*Measured Amount*		*430*	*Measured Amount*		*480*
70	12-May-97	18									
74	16-May-97										
78	20-May-97										
80	22-May-97										
85	27-May-97	19									
88	30-May-97										
91	02-Jun-97										
92	03-Jun-97	2 (1)									
94	05-Jun-97										
96	07-Jun-97										
98	09-Jun-97										
101	12-Jun-97										
106	17-Jun-97										
109	20-Jun-97										
112	23-Jun-97										
115	26-Jun-97										
119	30-Jun-97	11 (1)									
126	07-Jul-97										
129	10-Jul-97										
133	14-Jul-97	14 (1)									
136	17-Jul-97										
140	21-Jul-97										
143	24-Jul-97										
147	28-Jul-97	final									

(1) Became part of longterm extension

			IIIST-6			IIIST-7			IIIST-8		
Elapsed days	Date	sampling event	Amount added (ml)	amount removed (ml)	total volume (ml)	Amount added (ml)	amount removed (ml)	total volume (ml)	Amount added (ml)	amount removed (ml)	total volume (ml)
0	03-Mar-97				4000						
1	04-Mar-97	1	40.57	200	3841						
3	06-Mar-97	2		165	3676						
7	10-Mar-97	3	1	180	3497						
10	13-Mar-97	4	2	170	3329						
14	17-Mar-97	5		170	3159						
17	20-Mar-97	6		170	2989						
21	24-Mar-97	7		225	2764						
24	27-Mar-97	8		225	2539						
29	01-Apr-97	9			2539						
31	03-Apr-97	10		170	2369						
35	07-Apr-97	11		170	2199	1	170	6000	1	190	6000
36	08-Apr-97				2199			6000			6000
38	10-Apr-97	12		85	2114	5	85	5920	4	110	5894
42	14-Apr-97	13		90	2024	11	90	5841	9	110	5793
45	17-Apr-97	14	0.5	90	1934	5	90	5756	6	110	5689
49	21-Apr-97	15		85	1849	0.5	90	5667	2	110	5581
52	24-Apr-97	16	1.5	90	1761	1	90	5578	1	90	5492
56	28-Apr-97	17	2.25	80	1683						
59	01-May-97		0.75		1684		*Measured Amount*	*5570*		*Measured Amount*	*5425*
63	05-May-97		0.75		1684						
66	08-May-97				1684						
70	12-May-97	18		80	1604						
74	16-May-97				1604						
78	20-May-97										
80	22-May-97			*Measured Amount*	*1830*						
85	27-May-97	19									
88	30-May-97										
91	02-Jun-97										
92	03-Jun-97	2 (1)									
94	05-Jun-97										
96	07-Jun-97										
98	09-Jun-97										
101	12-Jun-97										
106	17-Jun-97										
109	20-Jun-97										
112	23-Jun-97										
115	26-Jun-97										
119	30-Jun-97	11 (1)									
126	07-Jul-97										
129	10-Jul-97										
133	14-Jul-97	14 (1)									
136	17-Jul-97										
140	21-Jul-97										
143	24-Jul-97										
147	28-Jul-97	final									

(1) Became part of longterm extension

IIIST-1

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Nitrate mg/L	Nitrite mg/L	Ammonia mg/L	TKN mg/L	Total N_2 (Calc) mg/L	SCN (as N) mg/L	SCN mg/L
0	03-Mar-97												
1	04-Mar-97	1			>20	1670	<0.50	<0.50	216	266	266	<1	<5.0
3	06-Mar-97	2	7.6		>20	1610	<0.50	5.54	235	275	281	NA	NA
7	10-Mar-97	3	6.73	7.68	17.0	1550	<0.50	132	160	162	294	NA	NA
10	13-Mar-97	4	6.19	7.82	15.9	1640	6.45	282	56.4	56.9	345	NA	NA
14	17-Mar-97	5	7.05	7.69	16.9	1770	20.7	285	<9.4	<9.4	306	NA	NA
17	20-Mar-97	6	7.62		13.2	1710	122	202	<9.4	<9.4	324	NA	NA
21	24-Mar-97	7	7.69		12.9	1670	49.8	243	<9.4	<9.4	293	NA	NA
24	27-Mar-97	8	7.68		13.5	1690	280	<0.50	<9.4	<9.4	280	NA	NA
29	01-Apr-97	9											
31	03-Apr-97	10	7.67		12.7	NA	NA	NA	NA	NA	NA	NA	NA
35	07-Apr-97	11	7.61		12.3	NA	NA	NA	NA	NA	NA	NA	NA

Elapsed days	Date	sampling event	COD mg/L	DOC mg/L	Phenol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97								
1	04-Mar-97	1	153	56.2	<0.10	<0.10	<0.10	<0.10	<0.10
3	06-Mar-97	2	NA	NA	NA	NA	NA	NA	NA
7	10-Mar-97	3	NA	NA	NA	NA	NA	NA	NA
10	13-Mar-97	4	NA	NA	NA	NA	NA	NA	NA
14	17-Mar-97	5	NA	NA	NA	NA	NA	NA	NA
17	20-Mar-97	6	NA	NA	NA	NA	NA	NA	NA
21	24-Mar-97	7	NA	NA	NA	NA	NA	NA	NA
24	27-Mar-97	8	NA	NA	NA	NA	NA	NA	NA
29	01-Apr-97	9							
31	03-Apr-97	10	NA	NA	NA	NA	NA	NA	NA
35	07-Apr-97	11	NA	NA	NA	NA	NA	NA	NA

IIIST-2

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Nitrate mg/L	Nitrite mg/L	Ammonia mg/L	TKN mg/L	Total N_2 (Calc) mg/L	SCN (as N) mg/L	SCN mg/L
0	03-Mar-97												
1	04-Mar-97	1			>20	1630	<0.50	<0.50	245	275	279	3.9	16.1
3	06-Mar-97	2	7.62		>20	1670	<0.50	<0.50	254	322	322	NA	NA
7	10-Mar-97	3	7.09	7.69	>20	2080	<0.50	1.57	254	256	258	NA	NA
10	13-Mar-97	4	6.9	7.78	>20	2230	3.3	34.7	282	284	322	NA	NA
14	17-Mar-97	5	6.56	7.83	14.2	1770	11.6	226	56.4	56.9	295	NA	NA
17	20-Mar-97	6	6.97	7.84	15.1	2110	52.4	279	<9.4	<9.4	331	NA	NA
21	24-Mar-97	7	7.41	7.83	11.0	2240	47.3	271	<9.4	18.8	337	NA	NA
24	27-Mar-97	8	7.82		10.4	2200	276	<0.50	<9.4	<9.4	276	NA	NA
29	01-Apr-97	9											
31	03-Apr-97	10	7.68		10.2	NA	NA	NA	NA	NA	NA	NA	NA
35	07-Apr-97	11	7.63		10.0	NA	NA	NA	NA	NA	NA	NA	NA

IIIST-2

Elapsed days	Date	sampling event	COD mg/L	DOC mg/L	Phenol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97								
1	04-Mar-97	1	893	120	92	<5.0	<5.0	<5.0	<5.0
3	06-Mar-97	2	543	50.5	88	<5.0	<5.0	<5.0	<5.0
7	10-Mar-97	3	137	135	<0.2	<0.2	<0.2	<0.4	<0.2
10	13-Mar-97	4	160	40.8	<0.1	<0.1	<0.1	<0.1	<0.1
14	17-Mar-97	5	224	92.5	<0.1	<0.1	<0.1	<0.1	<0.1
17	20-Mar-97	6	185	10.4	<0.1	<0.1	<0.1	<0.1	<0.1
21	24-Mar-97	7	147	7.3	<0.1	<0.1	<0.1	<0.1	<0.1
24	27-Mar-97	8	124	86.8	<0.1	<0.1	<0.1	<0.1	<0.1
29	01-Apr-97	9							
31	03-Apr-97	10	NA	NA	NA	NA	NA	NA	NA
35	07-Apr-97	11	NA	NA	NA	NA	NA	NA	NA

IIIST-3

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Nitrate mg/L	Nitrite mg/L	Ammonia mg/L	TKN mg/L	Total N_2 (Calc) mg/L	SCN (as N) mg/L	SCN mg/L
0	03-Mar-97												
1	04-Mar-97	1			18.3	1650	<0.50	<0.50	254	360	403	43.4	180
3	06-Mar-97	2	7.59		>20	1670	0.53	<0.50	273	360	404	43.9	182
7	10-Mar-97	3	7.21	7.59	>20	2060	0.53	<0.50	245	275	318	42.4	176
10	13-Mar-97	4	6.97	7.71	>20	2360	<0.50	<0.50	254	313	356	42.9	178
14	17-Mar-97	5	7.63		>20	2380	<0.50	<0.50	245	332	367	35.2	146
17	20-Mar-97	6	7.52	7.72	18.5	2460	0.52	<0.50	266	294	295	<1	<5.0
21	24-Mar-97	7	7.68		18.1	2420	<0.50	0.67	273	348	349	<1	<5.0
24	27-Mar-97	8	7.7		17.7	2360	0.66	9.29	263	291	301	<1	<5.0
29	01-Apr-97	9	6.72	7.82	7.61	1940	1.59	209	113	113	324	<1	<5.0
31	03-Apr-97	10	6.97	7.9	8.6	2090	16.1	297	56.4	65.8	379	<1	<5.0
35	07-Apr-97	11	7.07	7.85	8.0	NA	<10.0	349.0	<9.4	<9.4	349	<1	<5.0
36	08-Apr-97												
38	10-Apr-97	12	7.49	7.72	3.4	NA	136	187	<9.4	<9.4	323	NA	NA

Elapsed days	Date	sampling event	COD mg/L	DOC mg/L	Phenol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97								
1	04-Mar-97	1	850	111	93	<5.0	<5.0	<5.0	<5.0
3	06-Mar-97	2	755	53.2	97	<5.0	<5.0	<5.0	<5.0
7	10-Mar-97	3	352	46.8	<0.1	<0.1	<0.1	<0.1	<0.1
10	13-Mar-97	4	288	62.8	<0.1	<0.1	<0.1	<0.1	<0.1
14	17-Mar-97	5	235	49	<0.1	<0.1	<0.1	<0.1	<0.1
17	20-Mar-97	6	104	11.6	<0.1	<0.1	<0.1	<0.1	<0.1
21	24-Mar-97	7	141	7.2	<0.1	<0.1	<0.1	<0.1	<0.1
24	27-Mar-97	8	80	210	.68b	0.1	0.24	0.13	<0.1
29	01-Apr-97	9	247	140	NA	NA	NA	NA	NA
31	03-Apr-97	10	368	150	NA	NA	NA	NA	NA
35	07-Apr-97	11	205.0	208	NA	NA	NA	NA	NA
36	08-Apr-97								
38	10-Apr-97	12	NA	NA	NA	NA	NA	NA	NA

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Nitrate mg/L	Nitrite mg/L	Ammonia mg/L	TKN mg/L	Total N_2 (Calc) mg/L
0	03-Mar-97										
1	04-Mar-97	1	8.17	7.8	>20	2000	<0.50	<0.50	649	759	811
3	06-Mar-97	2	7.93	7.75	>20	2000	<0.50	<0.50	649	702	754
7	10-Mar-97	3	7.19	7.86	>20	2260	0.56	<0.50	621	711	759
10	13-Mar-97	4	7.21	7.81	12.3	2660	0.69	<0.50	630	683	731
14	17-Mar-97	5	7.56	7.84	11.4	2740	<0.50	<0.50	734	740	789
17	20-Mar-97	6	7.52	7.82	10.5	2700	0.59	<0.50	635	702	729
21	24-Mar-97	7	7.55	7.85	9.9	2760	<0.50	<0.50	621	743	767
24	27-Mar-97	8	7.75		9.9	2720	<0.50	<0.50	640	696	716
29	01-Apr-97	9									
31	03-Apr-97	10	7.75		9.1						
35	07-Apr-97	11	7.66		8.8						
36	08-Apr-97										
38	10-Apr-97	12	7.7		9.1	NA	0.65	<0.50	687	696	697
42	14-Apr-97	13	7.93	7.8	>20	NA	<0.50	<0.50	715	753	753
45	17-Apr-97	14	7.9	7.75	>20	NA	0.52	<0.50	696	734	735
49	21-Apr-97	15	7.86		>20	NA	0.57	<0.50	715	818	819
52	24-Apr-97	16	7.76		>20	NA	NA	NA	NA	NA	NA
56	28-Apr-97	17	7.83		>20	NA	<0.50	<0.50	721	825	825
59	01-May-97		7.85		>20						
63	05-May-97		7.85		>20						
66	08-May-97		7.76		>20						
70	12-May-97	18	7.85		>20	NA	<0.50	<0.50	882	910	910
74	16-May-97		7.78								
78	20-May-97		7.79		>20						
80	22-May-97		7.82		>20						
85	27-May-97	19	7.84		>20	NA	0.51	<0.50	844	872	873
88	30-May-97		7.96	7.81	>20						
91	02-Jun-97		8.21	7.89	18.5						
92	03-Jun-97	2 (1)	7.97	7.89	>20	2490	<0.5	<0.5	901	1030	1030
94	05-Jun-97		7.86		>20						
96	07-Jun-97		7.9		>20						
98	09-Jun-97		7.94	7.87	>20						
101	12-Jun-97		7.96	7.84	>20						
106	17-Jun-97		7.93	7.88	>20	NA	<0.50	<0.50	782	865	865
109	20-Jun-97		7.95	7.89	>20						
112	23-Jun-97		7.88		>20						
115	26-Jun-97		7.87		>20						
119	30-Jun-97	11 (1)	7.91		>20	NA	0.53	<0.50	828	958	958.53
126	07-Jul-97		7.89		>20						
129	10-Jul-97		7.9		>20						
133	14-Jul-97	14 (1)	7.9		>20	NA	<0.50	<0.50	800	1000	1000
136	17-Jul-97		7.89		>20						
140	21-Jul-97		7.88		>20						
143	24-Jul-97		7.92		>20						
147	28-Jul-97	final	7.93		>20						

(1) Became part of longterm extension

Elapsed days	Date	sampling event	SCN (as N) mg/L	SCN mg/L	COD mg/L	DOC mg/L	Phenol (GC) mg/L	Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97										
1	04-Mar-97	1	52	216	1690	413	110	19	42	18	5.3
3	06-Mar-97	2	52	214	1600	350	120	19	42	17	5.8
7	10-Mar-97	3	47	195	1040	109	<0.1	<0.1	<0.1	<0.1	<1.0
10	13-Mar-97	4	47	197	935	110	<0.1	<0.1	<0.1	<0.1	<1.0
14	17-Mar-97	5	49	202	787	1750	<0.1	<0.1	<0.1	<0.1	<1.0
17	20-Mar-97	6	26	109	732	69.4	<2.0	<2.0	<2.0	<2.0	<2.0
21	24-Mar-97	7	24	98.2	586	103	<2.0	<2.0	<2.0	<2.0	<2.0
24	27-Mar-97	8	20	82.3	555	358	1.1b	0.18	0.36	0.18	<1.0
29	01-Apr-97	9									
31	03-Apr-97	10									
35	07-Apr-97	11									
36	08-Apr-97										
38	10-Apr-97	12	NA	NA	NA	NA	NA	NA	NA	NA	NA
42	14-Apr-97	13	NA	NA	NA	NA	NA	NA	NA	NA	NA
45	17-Apr-97	14	NA	NA	NA	NA	NA	NA	NA	NA	NA
49	21-Apr-97	15	NA	NA	NA	NA	NA	NA	NA	NA	NA
52	24-Apr-97	16	NA	NA	NA	NA	NA	NA	NA	NA	NA
56	28-Apr-97	17	NA	NA	NA	NA	NA	NA	NA	NA	NA
59	01-May-97										
63	05-May-97										
66	08-May-97										
70	12-May-97	18	NA	NA	NA	NA	NA	NA	NA	NA	NA
74	16-May-97										
78	20-May-97										
80	22-May-97										
85	27-May-97	19	NA	NA	NA	NA	NA	NA	NA	NA	NA
88	30-May-97										
91	02-Jun-97										
92	03-Jun-97	2 (1)	NA	NA	291	322	NA	NA	NA	NA	NA
94	05-Jun-97										
96	07-Jun-97										
98	09-Jun-97										
101	12-Jun-97										
106	17-Jun-97		NA	NA	NA	NA	NA	NA	NA	NA	NA
109	20-Jun-97										
112	23-Jun-97										
115	26-Jun-97										
119	30-Jun-97	11 (1)	NA	NA	341	49.6	NA	NA	NA	NA	NA
126	07-Jul-97										
129	10-Jul-97										
133	14-Jul-97	14 (1)	NA	NA	NA	NA	NA	NA	NA	NA	NA
136	17-Jul-97										
140	21-Jul-97										
143	24-Jul-97										
147	28-Jul-97	final									

(1) Became pa

IIIST-5

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Nitrate mg/L	Nitrite mg/L	Ammonia mg/L	TKN mg/L	Total N_2 (Calc) mg/L	SCN (as N) mg/L
0	03-Mar-97											
1	04-Mar-97	1	7.85		>20	1690	<0.50	<0.50	235	370	391	21.4
3	06-Mar-97	2	7.78		>20	1650	0.59	<0.50	226	256	279	22.3
7	10-Mar-97	3	7.34	7.86	>20	1980	<0.50	<0.50	235	256	276	19.6
10	13-Mar-97	4	7.16	7.89	>20	2100	<0.50	<0.50	226	294	312	17.8
14	17-Mar-97	5	7.6		>20	2720	<0.50	<0.50	235	246	246	<5.0/6.9
17	20-Mar-97	6	7.71		>20	2130	0.53	<0.50	303	310	311	14.4/6.9
21	24-Mar-97	7	7.69		>20	2120	<0.50	<0.50	226	301	302	1.5
24	27-Mar-97	8	7.7		>20	2100	<0.50	<0.50	235	254	254	<1
29	01-Apr-97	9										
31	03-Apr-97	10	7.74		>20	2120	<0.50	0.58	310	320	321	NA
35	07-Apr-97	11	7.68		>20	NR	<0.50	0.6	263	273	274	NA

IIIST-5

Elapsed days	Date	sampling event	SCN mg/L	COD mg/L	DOC mg/L	Phenol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97									
1	04-Mar-97	1	89	829	135	46	8.7	17.9	8.1	3.2
3	06-Mar-97	2	92.4	563	77.8	36	7.2	8*	8*	<5.0
7	10-Mar-97	3	81.5	394	62.8	<0.1	<0.1	<0.1	<0.1	<0.2
10	13-Mar-97	4	73.9	373	45.1	<0.1	<0.1	<0.1	<0.1	<0.2
14	17-Mar-97	5	<5.0/6.9	224	49.2	<0.1	<0.1	<0.1	<0.1	<0.2
17	20-Mar-97	6	14.4/6.9	239	35	<0.1	<0.1	<0.1	<0.1	<0.1
21	24-Mar-97	7	6.02	220	34.5	<0.1	<0.1	<0.1	<0.1	<0.1
24	27-Mar-97	8	<5.0	209	161	<0.1	<0.1	<0.1	<0.1	<0.1
29	01-Apr-97	9								
31	03-Apr-97	10	NA	85	173	NA	NA	NA	NA	NA
35	07-Apr-97	11	NA	202	201	NA	NA	NA	NA	NA

IIIST-5n

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Nitrate mg/L	Nitrite mg/L	Ammonia mg/L	TKN mg/L	Total N_2 (Calc) mg/L	SCN (as N) mg/L	SCN mg/L
0	03-Mar-97												
1	04-Mar-97	1											
3	06-Mar-97	2											
7	10-Mar-97	3											
10	13-Mar-97	4											
14	17-Mar-97	5											
17	20-Mar-97	6											
21	24-Mar-97	7											
24	27-Mar-97	8											
29	01-Apr-97	9											
31	03-Apr-97	10											
35	07-Apr-97	11											
36	08-Apr-97				7.5								
38	10-Apr-97	12	8.24	7.9	7.43	NA	<0.50	1.48	282	329	330	NA	NA
42	14-Apr-97	13	8.3	7.83	>20	NA	0.53	<0.50	273	282	283	NA	NA
45	17-Apr-97	14	8.06	7.6	>20	NA	<0.50	<0.50	273	301	301	NA	NA
49	21-Apr-97	15	7.86		>20	NA	0.69	<0.50	329	414	415	NA	NA
52	24-Apr-97	16	7.72		>20	NA	<0.50	0.59	292	367	368	NA	NA
56	28-Apr-97	17	7.88		>20	NA	<0.50	0.61	379	455	456	NA	NA
59	01-May-97		7.86		>20	NA	<0.50	0.97	332	379	380	NA	NA

IIIST-5n

Elapsed days	Date	sampling event	COD mg/L	DOC mg/L	Phenol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97								
1	04-Mar-97	1							
3	06-Mar-97	2							
7	10-Mar-97	3							
10	13-Mar-97	4							
14	17-Mar-97	5							
17	20-Mar-97	6							
21	24-Mar-97	7							
24	27-Mar-97	8							
29	01-Apr-97	9							
31	03-Apr-97	10							
35	07-Apr-97	11							
36	08-Apr-97								
38	10-Apr-97	12	NA	NA	NA	NA	NA	NA	NA
42	14-Apr-97	13	NA	NA	NA	NA	NA	NA	NA
45	17-Apr-97	14	NA	NA	NA	NA	NA	NA	NA
49	21-Apr-97	15	NA	NA	NA	NA	NA	NA	NA
52	24-Apr-97	16	184	NA	NA	NA	NA	NA	NA
56	28-Apr-97	17	NA	NA	NA	NA	NA	NA	NA
59	01-May-97		NA	NA	NA	NA	NA	NA	NA

IIIST-5i

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Nitrate mg/L	Nitrite mg/L	Ammonia mg/L	TKN mg/L	Total N_2 (Calc) mg/L
0	03-Mar-97										
1	04-Mar-97	1									
3	06-Mar-97	2									
7	10-Mar-97	3									
10	13-Mar-97	4									
14	17-Mar-97	5									
17	20-Mar-97	6									
21	24-Mar-97	7									
24	27-Mar-97	8									
29	01-Apr-97	9									
31	03-Apr-97	10									
35	07-Apr-97	11									
36	08-Apr-97				7.5						
38	10-Apr-97	12	8.24	7.9	7.43	NA	<0.50	1.91	358	367	369
42	14-Apr-97	13	8.3	7.83	>20	NA	<0.50	6.63	282	282	289
45	17-Apr-97	14	8.06	7.6	>20	NA	2.71	11	263	301	315
49	21-Apr-97	15	7.86		>20	NA	32.4	13	273	292	337
52	24-Apr-97	16	7.72		>20	NA	161	1.16	150	179	341
56	28-Apr-97	17	7.88		>20	NA	282	<0.50	<9.4	<9.4	282
59	01-May-97		7.86		>20	NA	300	<0.50	<9.4	<9.4	300

IIIST-5i

Elapsed days	Date	sampling event	SCN (as N) mg/L	SCN mg/L	COD mg/L	DOC mg/L	Phenol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97										
1	04-Mar-97	1									
3	06-Mar-97	2									
7	10-Mar-97	3									
10	13-Mar-97	4									
14	17-Mar-97	5									
17	20-Mar-97	6									
21	24-Mar-97	7									
24	27-Mar-97	8									
29	01-Apr-97	9									
31	03-Apr-97	10									
35	07-Apr-97	11									
36	08-Apr-97										
38	10-Apr-97	12	NA	NA	NA	NA	NA	NA	NA	NA	NA
42	14-Apr-97	13	NA	NA	NA	NA	NA	NA	NA	NA	NA
45	17-Apr-97	14	NA	NA	NA	NA	NA	NA	NA	NA	NA
49	21-Apr-97	15	NA	NA	NA	NA	NA	NA	NA	NA	NA
52	24-Apr-97	16	NA	NA	174	NA	NA	NA	NA	NA	NA
56	28-Apr-97	17	NA	NA	NA	NA	NA	NA	NA	NA	NA
59	01-May-97		NA	NA	NA	NA	NA	NA	NA	NA	NA

IIIST-6

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Nitrate mg/L	Nitrite mg/L	Ammonia mg/L	TKN mg/L	Total N_2 (Calc) mg/L
0	03-Mar-97										
1	04-Mar-97	1			>20	1550	<0.50	<0.50	56.4	190	201
3	06-Mar-97	2	7.54		14.3	1530	<0.50	<0.50	84.7	104	115
7	10-Mar-97	3	7.45	7.65	>20	1670	0.66	<0.50	150	152	162
10	13-Mar-97	4	7.11	7.85	>20	1860	<0.50	<0.50	94.1	161	161
14	17-Mar-97	5	7.75		>20	1920	<0.50	<0.50	103	123	123
17	20-Mar-97	6	7.81		>20	1940	<0.50	<0.50	114	150	150
21	24-Mar-97	7	7.8		>20	1940	<0.50	<0.50	134	169	172
24	27-Mar-97	8	7.84		>20	1940	<0.50	<0.50	118	132	132
29	01-Apr-97	9									
31	03-Apr-97	10	7.88		>20	1940	<0.50	0.61	160	170	171
35	07-Apr-97	11	7.81		>20	NA	<0.50	0.58	122	132	133
36	08-Apr-97										
38	10-Apr-97	12	7.84		>20	NA	<0.50	0.6	132	160	161
42	14-Apr-97	13	7.84		19.7	NA	0.54	<0.50	141	160	161
45	17-Apr-97	14	7.94	7.74	18.8	NA	0.65	<0.50	141	169	170
49	21-Apr-97	15	7.72		18.2	NA	<0.50	2.65	141	207	210
52	24-Apr-97	16	7.33	7.72	17.2	NA	NA	NA	NA	NA	NA
56	28-Apr-97	17	6.96	7.84	15.5	NA	28.9	150	<9.4	<9.4	179
59	01-May-97		7.52	7.97	15.2						
63	05-May-97		7.68	7.91	14.6						
66	08-May-97		7.76		14.2						
70	12-May-97	18	7.8		14.2	NA	135	<0.50	<9.4	711	NA
74	16-May-97		7.83		14.2						

IIIST-6

Elapsed days	Date	sampling event	SCN (as N) mg/L	SCN mg/L	COD mg/L	DOC mg/L	Phenol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97										
1	04-Mar-97	1	10.9	45.4	468	48.6	26	4.5	10	4	1.5
3	06-Mar-97	2	11.1	46.2	242	45.4	0.072	<.10	<.10	<.10	<.20
7	10-Mar-97	3	9.7	40.4	203	72.8	<0.1	<0.1	<.10	<0.1	<0.1
10	13-Mar-97	4	<1	<5.0	143	41.6	<0.1	<0.1	<.10	<0.1	<0.1
14	17-Mar-97	5	0	<5.0/6.9	119	112	<0.1	<0.1	<.10	<0.1	<0.1
17	20-Mar-97	6	0	12.7/5.3	116	15.4	<0.1	<0.1	<.10	<0.1	<0.1
21	24-Mar-97	7	3.3	13.6	129	15.9	<0.1	<0.1	<.10	<0.1	<0.1
24	27-Mar-97	8	<1	<5.0	99	115	.85b	0.14	0.27	0.14	<0.1
29	01-Apr-97	9									
31	03-Apr-97	10	NA	NA	117	128	NA	NA	NA	NA	NA
35	07-Apr-97	11	NA	NA	106	129	NA	NA	NA	NA	NA
36	08-Apr-97										
38	10-Apr-97	12	NA	NA	NA	NA	NA	NA	NA	NA	NA
42	14-Apr-97	13	NA	NA	NA	NA	NA	NA	NA	NA	NA
45	17-Apr-97	14	NA	NA	NA	NA	NA	NA	NA	NA	NA
49	21-Apr-97	15	NA	NA	NA	NA	NA	NA	NA	NA	NA
52	24-Apr-97	16	NA	NA	NA	NA	NA	NA	NA	NA	NA
56	28-Apr-97	17	NA	NA	NA	NA	NA	NA	NA	NA	NA
59	01-May-97										
63	05-May-97										
66	08-May-97										
70	12-May-97	18	NA	NA	NA	NA	NA	NA	NA	NA	NA
74	16-May-97										

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Nitrate mg/L	Nitrite mg/L	Ammonia mg/L	TKN mg/L	Total N_2 (Calc) mg/L
0	03-Mar-97										
1	04-Mar-97	1									
3	06-Mar-97	2									
7	10-Mar-97	3									
10	13-Mar-97	4									
14	17-Mar-97	5									
17	20-Mar-97	6									
21	24-Mar-97	7									
24	27-Mar-97	8									
29	01-Apr-97	9									
31	03-Apr-97	10									
35	07-Apr-97	11	7.68	7.87		NA	<0.50	2.43	263	272	274
36	08-Apr-97										
38	10-Apr-97	12	7.11	7.85	0.7	NA	77.2	6.22	207	216	299
42	14-Apr-97	13	6.57	7.97	>20	NA	<10	247	65.8	75.3	322
45	17-Apr-97	14	7.15	7.83	>20	NA	47.2	259	<9.4	<9.4	306
49	21-Apr-97	15	7.63	7.7	15.4	NA	211	65.4	<9.4	<9.4	276
52	24-Apr-97	16	7.54	7.86	>20	NA	270	<0.50	<9.4	9.4	279

Elapsed days	Date	sampling event	SCN (as N) mg/L	SCN mg/L	COD mg/L	DOC mg/L	Phenol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97										
1	04-Mar-97	1									
3	06-Mar-97	2									
7	10-Mar-97	3									
10	13-Mar-97	4									
14	17-Mar-97	5									
17	20-Mar-97	6									
21	24-Mar-97	7									
24	27-Mar-97	8									
29	01-Apr-97	9									
31	03-Apr-97	10									
35	07-Apr-97	11	NA	NA	124	91.5	NA	NA	NA	NA	NA
36	08-Apr-97										
38	10-Apr-97	12	NA	NA	NA	NA	NA	NA	NA	NA	NA
42	14-Apr-97	13	NA	NA	NA	NA	NA	NA	NA	NA	NA
45	17-Apr-97	14	NA	NA	NA	NA	NA	NA	NA	NA	NA
49	21-Apr-97	15	NA	NA	NA	NA	NA	NA	NA	NA	NA
52	24-Apr-97	16	NA	NA	NA	NA	NA	NA	NA	NA	NA

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Nitrate mg/L	Nitrite mg/L	Ammonia mg/L	TKN mg/L	Total N_2 (Calc) mg/L	SCN (as N) mg/L
0	03-Mar-97											
1	04-Mar-97	1										
3	06-Mar-97	2										
7	10-Mar-97	3										
10	13-Mar-97	4										
14	17-Mar-97	5										
17	20-Mar-97	6										
21	24-Mar-97	7										
24	27-Mar-97	8										
29	01-Apr-97	9										
31	03-Apr-97	10										
35	07-Apr-97	11	7.67	77.87		NA	<0.50	2.56	254	263	306	41
36	08-Apr-97											
38	10-Apr-97	12	7.15	7.71	0.7	NA	5.11	67.2	216	254	367	40.7
42	14-Apr-97	13	6.7	7.89	>20	NA	<10	201	113	160	361	0
45	17-Apr-97	14	6.93	7.77	>20	NA	36.8	250	28.2	65.9	393	40.5
49	21-Apr-97	15	7.44	7.75	14.3	NA	90.4	198	<9.4	47	376	40.2
52	24-Apr-97	16	7.53	7.82	13.4	NA	180	102	<9.4	75.3	397	40.0

IIIST-8

Elapsed days	Date	sampling event	SCN mg/L	COD mg/L	DOC mg/L	Phenol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	,4-Dimethyl Phenol mg/L
0	03-Mar-97									
1	04-Mar-97	1								
3	06-Mar-97	2								
7	10-Mar-97	3								
10	13-Mar-97	4								
14	17-Mar-97	5								
17	20-Mar-97	6								
21	24-Mar-97	7								
24	27-Mar-97	8								
29	01-Apr-97	9								
31	03-Apr-97	10								
35	07-Apr-97	11	169	287	103	NA	NA	NA	NA	NA
36	08-Apr-97									
38	10-Apr-97	12	169	NA	NA	NA	NA	NA	NA	NA
42	14-Apr-97	13		NA	NA	NA	NA	NA	NA	NA
45	17-Apr-97	14	168	NA	NA	NA	NA	NA	NA	NA
49	21-Apr-97	15	167	NA	NA	NA	NA	NA	NA	NA
52	24-Apr-97	16	166	NA	NA	NA	NA	NA	NA	NA

			IIILT-1			IIILT-2			IIILT-3			IIILT-4		
Elapsed days	Date	sampling event	Amount added (ml)	amount removed (ml)	total volume (ml)	Amount added (ml)	amount removed (ml)	total volume (ml)	Amount added (ml)	amount removed (ml)	total volume (ml)	Amount added (ml)	amount removed (ml)	total volume (ml)
0	03-Mar-97				6000			6000			6000			6000
1	04-Mar-97	1	63.9	600	5464	62.9	550	5513	65.9	550	5516	80.9	560	5521
14	17-Mar-97	2	5	155	5314	6	155	5364	6	155	5367	1	160	5362
28	31-Mar-97	3	7	155	5166	4	155	5213	8	155	5220	1	155	5208
31	03-Apr-97		3		5169	2		5215	3		5223	0.5		5208
35	07-Apr-97		2		5171	1		5216	2		5225			5208
38	10-Apr-97				5171			5216	1		5226			5208
42	14-Apr-97	4		155	5016		155	5061	1	155	5072		160	5048
45	17-Apr-97				5016			5061			5072			5048
49	21-Apr-97				5016			5061			5072			5048
52	24-Apr-97		1		5017			5061			5072	1		5049
56	28-Apr-97	5		150	4867		150	4911		150	4922		150	4899
59	01-May-97				4867			4911			4922			4899
63	05-May-97				4867			4911	1.25		4923			4899
66	08-May-97				4867			4911			4923			4899
67	09-May-97				4867			4911			4923			4899
70	12-May-97	6		250	4617		255	4656	1	260	4664		280	4619
74	16-May-97				4617			4656			4664			4619
78	20-May-97				4617			4656			4664			4619
80	22-May-97				4617			4656			4664			4619
85	27-May-97	7		125	4492		130	4526		120	4544		135	4484
88	30-May-97	0 (1)	149	700	3941	175.5	100	4601	175.5	125	4595	172		4656
89	31-May-97				3941			4601			4595			4656
90	01-Jun-97	1			3941		80	4521		80	4515			4656
91	02-Jun-97				3941			4521			4515			4656
92	03-Jun-97	2		110	3831		105	4416		135	4380	1	180	4477
94	05-Jun-97	3	0.4		3831			4416	1	90	4291			4477
96	07-Jun-97	4			3831	1		4417	2	95	4198			4477
98	09-Jun-97	5			3831			4417	2	100	4100			4477
101	12-Jun-97	6			3831			4417	1	100	4001	3		4480
106	17-Jun-97	7		105	3726		105	4312	1.5	130	3872		170	4310
109	20-Jun-97	8			3726			4312	0.5	130	3743	0.5		4311
112	23-Jun-97	9			3726			4312	0.5	130	3613			4311
115	26-Jun-97	10		15	3711		327.8	3985	0.5	130	3484			4311
116	27-Jun-97				3711		15	3970			3484			4311
119	30-Jun-97	11	2	100	3613	7	85	3892	1.5	105	3380		125	4186
126	07-Jul-97		2.5		3616	10		3902	6		3386			4186
127	08-Jul-97	12		85	3531		85	3817		85	3301			4186
129	10-Jul-97		2.5		3533			3817	6.8		3308			4186
130	11-Jul-97	13		90	3443		90	3727			3308			4186
133	14-Jul-97	14	7.9	100	3351		100	3627	7.2	130	3185		170	4016
136	17-Jul-97	15	9	100	3260			3627	5	100	3090			4016
140	21-Jul-97	16	5.3	100	3166			3627	2.5	100	2993			4016
143	24-Jul-97		3		3169			3627	0.9		2994			4016
147	28-Jul-97	17	2	640	2531		640	2987	0.4	860	2134		860	3156
150	31-Jul-97	18												
154	04-Aug-97	19		*Measured Volume*	*2552*		*Measured Volume*	*2890*		*Measured Volume*	*2100*		*Measured Volume*	*3270*

(1) initiation of Long Term Extension

			IIILT-5			IIILT-6			IIILT-6n			IIILT-6l		
Elapsed days	Date	sampling event	Amount added (ml)	amount removed (ml)	total volume (ml)	Amount added (ml)	amount removed (ml)	total volume (ml)	Amount added (ml)	amount removed (ml)	total volume (ml)	Amount added (ml)	amount removed (ml)	total volume (ml)
0	03-Mar-97				6000			6000						
1	04-Mar-97	1	2	550	5452	60.9	550	5511						
14	17-Mar-97	2	5	160	5297	4	160	5355						
28	31-Mar-97	3	5	155	5147	2	155	5202						
31	03-Apr-97				5147	1		5203						
35	07-Apr-97		1		5148	1		5204						
38	10-Apr-97				5148			5204						
42	14-Apr-97	4		165	4983		160	5044						
45	17-Apr-97				4983			5044						
49	21-Apr-97				4983			5044						
52	24-Apr-97		2.5		4986	0.5		5044						
56	28-Apr-97	5		150	4836		150	4894						
59	01-May-97				4836			4894						
63	05-May-97				4836			4894						
66	08-May-97				4836			4894						
67	09-May-97				4836			4894						
70	12-May-97	6		255	4581		155	4739						
74	16-May-97		0.75		4581	0.5		4740						
78	20-May-97				4581			4740						
80	22-May-97		0.75		4582			4740						
85	27-May-97	7		120	4462		120	4620						
88	30-May-97	0 (1)			4462				0.7		2285	91.5	100	2374
89	31-May-97				4462		*Measured Volume*	*4570*			2285			2374
90	01-Jun-97	1			4462						2285	2	80	2296
91	02-Jun-97				4462						2285	2		2298
92	03-Jun-97	2	2	105	4359				0.4	105	2180	1	105	2194
94	05-Jun-97	3	1		4360				0.4		2181	1.3	105	2090
96	07-Jun-97	4			4360						2181	0.4	95	1996
98	09-Jun-97	5			4360						2181	0.3	100	1896
101	12-Jun-97	6			4360						2181		100	1796
106	17-Jun-97	7	1	105	4256				0.2	105	2076		105	1691
109	20-Jun-97	8			4256						2076			1691
112	23-Jun-97	9			4256					100	1976			1691
115	26-Jun-97	10			4256						1976			1691
116	27-Jun-97				4256						1976			1691
119	30-Jun-97	11		95	4161					86	1890			1691
126	07-Jul-97				4161						1890			1691
127	08-Jul-97	12			4161						1890			1691
129	10-Jul-97				4161						1890			1691
130	11-Jul-97	13			4161						1890			1691
133	14-Jul-97	14		100	4061					100	1790			1691
136	17-Jul-97	15			4061						1790			1691
140	21-Jul-97	16			4061						1790			1691
143	24-Jul-97				4061						1790			1691
147	28-Jul-97	17		860	3201				1.4	100	1691			1691
150	31-Jul-97	18							2.3	75	1619			
154	04-Aug-97	19		*Measured Volume*	*3315*				3	767	855		*Measured Volume*	*1695*

(1) initiation

Measured Volume *740*

			IIILT-7			IIILT-8			IIILT-9			IIILT-10		
Elapsed days	Date	sampling event	Amount added (ml)	amount removed (ml)	total volume (ml)	Amount added (ml)	amount removed (ml)	total volume (ml)	Amount added (ml)	amount removed (ml)	total volume (ml)	Amount added (ml)	amount removed (ml)	total volume (ml)
0	03-Mar-97				6000									
1	04-Mar-97	1	4	650	5354									
14	17-Mar-97	2		160	5194									
28	31-Mar-97	3		155	5039									
31	03-Apr-97		1		5040									
35	07-Apr-97				5040									
38	10-Apr-97		4		5044									
42	14-Apr-97	4	3	160	4887									
45	17-Apr-97		2		4889									
49	21-Apr-97		1		4890									
52	24-Apr-97		1.5		4892									
56	28-Apr-97	5		150	4742									
59	01-May-97				4742									
63	05-May-97				4742									
66	08-May-97				4742									
67	09-May-97			1	4741									
70	12-May-97	6		280	4461									
74	16-May-97				4461									
78	20-May-97				4461									
80	22-May-97		1		4462									
85	27-May-97	7		145	4317									
88	30-May-97	0 (1)			4317	17	150	6095	3	100	3119	16	100	6228
89	31-May-97				4317		90	6005			3119			6228
90	01-Jun-97	1			4317	9.5	80	5935	2	80	3041	16.5	80	6165
91	02-Jun-97				4317	2.3		5937	2		3043	16		6181
92	03-Jun-97	2	0.8	130	4187		195	5742		105	2938	11.1	105	6087
94	05-Jun-97	3			4187		105	5637		105	2833	5.4	105	5987
96	07-Jun-97	4			4187	0.4	100	5537			2833	1.4	100	5888
98	09-Jun-97	5			4187			5537			2833	1.4	100	5790
101	12-Jun-97	6			4187		100	5437			2833		100	5690
106	17-Jun-97	7		130	4057									
109	20-Jun-97	8			4057		*Measured Volume*	*6000*		*Measured Volume*	*2780*		*Measured Volume*	*5750*
112	23-Jun-97	9			4057									
115	26-Jun-97	10			4057									
116	27-Jun-97				4057									
119	30-Jun-97	11		105	3952									
126	07-Jul-97				3952									
127	08-Jul-97	12			3952									
129	10-Jul-97				3952									
130	11-Jul-97	13			3952									
133	14-Jul-97	14		130	3822									
136	17-Jul-97	15			3822									
140	21-Jul-97	16			3822									
143	24-Jul-97				3822									
147	28-Jul-97	17		860	2962									
150	31-Jul-97	18												
154	04-Aug-97	19		*Measured Volume*	*3115*									

(1) initiation

			IIIST-3D		
Elapsed days	Date	sampling event	Amount added (ml)	amount removed (ml)	total volume (ml)
0	03-Mar-97				
1	04-Mar-97	1			
14	17-Mar-97	2			
28	31-Mar-97	3			
31	03-Apr-97				
35	07-Apr-97				
38	10-Apr-97				
42	14-Apr-97	4			
45	17-Apr-97				
49	21-Apr-97				
52	24-Apr-97				
56	28-Apr-97	5			
59	01-May-97				
63	05-May-97				
66	08-May-97				
67	09-May-97				
70	12-May-97	6			
74	16-May-97				
78	20-May-97				
80	22-May-97				
85	27-May-97	7			
88	30-May-97	0 (1)	5	150	6228
89	31-May-97			130	6098
90	01-Jun-97	1	6	85	6019
91	02-Jun-97		6		6025
92	03-Jun-97	2	2	265	5762
94	05-Jun-97	3	2	175	5589
96	07-Jun-97	4	1.6	160	5431
98	09-Jun-97	5	3	170	5264
101	12-Jun-97	6	7	170	5101
106	17-Jun-97	7	3	170	4934
109	20-Jun-97	8	0.8	170	4764
112	23-Jun-97	9	0.1	175	4590
115	26-Jun-97	10			
116	27-Jun-97			*Measured Volume*	***4540***
119	30-Jun-97	11			
126	07-Jul-97				
127	08-Jul-97	12			
129	10-Jul-97				
130	11-Jul-97	13			
133	14-Jul-97	14			
136	17-Jul-97	15			
140	21-Jul-97	16			
143	24-Jul-97				
147	28-Jul-97	17			
150	31-Jul-97	18			
154	04-Aug-97	19			

(1) initiation

TABLE 1-1

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Cyanide mg/L	SCN mg/L	NH_3 mg/L	NO_3 mg/L	NO_2 mg/L	Phos. mg/L	TKN mg/L	BOD mg/L	COD mg/L	Phenol (4-APP) mg/L
0	03-Mar-97															
1	04-Mar-97	1	8.2	7.82	>20	2000	<0.5	199	649	<0.50	<0.50	1060	730	>350	1910	326
14	17-Mar-97	2	7.07	7.65	19.5	2490	NA	214	616	<0.50	<0.50	NA	702	NA	1040	
28	31-Mar-97	3	6.96	7.78	15	2680	NA	46.2	715	0.96	<0.5	NA	724	NA	483	
31	03-Apr-97		7.39	7.81	15.1											
35	07-Apr-97		7.51	7.84	15.3											
38	10-Apr-97		7.78		15.3											
42	14-Apr-97	4	7.71		15.4	3190	NA	11.9	687	<0.50	<0.50	NA	753	NA	469	
45	17-Apr-97		7.73		14.8											
49	21-Apr-97		7.79		14.5											
52	24-Apr-97		7.61	7.77	14.4											
56	28-Apr-97	5	7.89		13.6	3660	NA	10.6	872	<0.50	<0.50	NA	882	NA	477	
59	01-May-97		7.86		13.2											
63	05-May-97		7.8		13											
66	08-May-97		7.83		13											
67	09-May-97															
70	12-May-97	6	7.82		12.9	3520	NA	6.38	664	1.96	<0.50	NA	834	NA	418	
74	16-May-97		7.87		13											
78	20-May-97		7.84		11.8											
80	22-May-97		7.82		12.7											
85	27-May-97	7	7.82		12	3660	NA	11.9	749	1.04	<0.5		853		364	
88	30-May-97	0 (1)	7.66	7.82	>20	NA	NA	NA	834	2.05	22.8		893			
89	31-May-97															
90	01-Jun-97	1														
91	02-Jun-97		7.89		>20											
92	03-Jun-97	2	7.78		>20	3620	NA	NA	698	<1	24.6		949		416	
94	05-Jun-97	3	7.66	7.81	>20											
96	07-Jun-97	4	7.76		>20											
98	09-Jun-97	5	7.76		>20											
101	12-Jun-97	6	7.83		>20											
106	17-Jun-97	7	7.85		>20	NA	NA	NA	744	1.69	34.1		837			
109	20-Jun-97	8	7.88		>20											
112	23-Jun-97	9	7.82		>20											
115	26-Jun-97	10	7.8		>20											
116	27-Jun-97															
119	30-Jun-97	11	7.56	7.96	>20	NA	NA	NA	702	<10	94.7		810		622	
126	07-Jul-97		7.59	7.9	>20											
127	08-Jul-97	12				NA	NA	NA	661	116	2.48		782			
129	10-Jul-97		7.38	7.86	16.4											
130	11-Jul-97	13				NA	NA	NA	456	293	12.9		819			
133	14-Jul-97	14	6.64	7.83	8.7	NA	NA	NA	288	485	0.52		419			
136	17-Jul-97	15	6.74	7.77	17.8	NA	NA	NA	211	591	1.99		316			
140	21-Jul-97	16	6.85	7.84	16.7	NA	NA	NA	65.1	267	2.33		102			
143	24-Jul-97		7.18	7.8	16.1											
147	28-Jul-97	17	7.39	7.92	18.7											
150	31-Jul-97	18														
154	04-Aug-97	19														

(1) initiation of Long Term Extension

Elapsed days	Date	sampling event	DOC mg/L	hard-ness mg/L	BTEX mg/L	Dissolved Arsenic mg/L	Total Arsenic mg/L	Total Iron mg/L	Phenol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97												
1	04-Mar-97	1	408	140	0.153	3.54	4.22	0.897	120	20	44	19	6
14	17-Mar-97	2	97.4						<0.1	<0.1	<0.1	<0.1	<0.1
28	31-Mar-97	3	76.6						<0.1	<0.1	<0.1	<0.1	<0.1
31	03-Apr-97												
35	07-Apr-97												
38	10-Apr-97												
42	14-Apr-97	4	479						<0.1	<0.1	<0.1	<0.1	<0.1
45	17-Apr-97												
49	21-Apr-97												
52	24-Apr-97												
56	28-Apr-97	5	258						<0.1	<0.1	<0.1	<0.1	<0.1
59	01-May-97												
63	05-May-97												
66	08-May-97												
67	09-May-97												
70	12-May-97	6	525			3.29	2.25						
74	16-May-97												
78	20-May-97												
80	22-May-97												
85	27-May-97	7	469										
88	30-May-97	0 (1)	NA										
89	31-May-97												
90	01-Jun-97	1											
91	02-Jun-97												
92	03-Jun-97	2	499										
94	05-Jun-97	3											
96	07-Jun-97	4											
98	09-Jun-97	5											
101	12-Jun-97	6											
106	17-Jun-97	7											
109	20-Jun-97	8											
112	23-Jun-97	9											
115	26-Jun-97	10											
116	27-Jun-97												
119	30-Jun-97	11	60.6										
126	07-Jul-97												
127	08-Jul-97	12											
129	10-Jul-97												
130	11-Jul-97	13											
133	14-Jul-97	14											
136	17-Jul-97	15											
140	21-Jul-97	16											
143	24-Jul-97												
147	28-Jul-97	17											
150	31-Jul-97	18											
154	04-Aug-97	19											

(1) initiation

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Cyanide mg/L	SCN mg/L	NH_3 mg/L	NO_3 mg/L	NO_2 mg/L	Phos. mg/L	TKN mg/L	BOD mg/L	COD mg/L	Phenol (4-APP) mg/L
0	03-Mar-97															
1	04-Mar-97	1	8.01	7.74	>20	1810	<0.50	141	480	<0.50	<0.50	1060	484	>350	1280	225
14	17-Mar-97	2	6.95	7.62	>20	2120		135	398	<0.50	<0.50		455		521	
28	31-Mar-97	3	7.16	7.77	19.6	2420		5.74	470	<0.5	<0.5		480		310	
31	03-Apr-97		7.53	7.87	19.3											
35	07-Apr-97		7.65	7.84	19											
38	10-Apr-97		7.83		18.8											
42	14-Apr-97	4	7.83		18.9	2800		7.78	470	0.55	<0.50		508		343	
45	17-Apr-97		7.82		18.1											
49	21-Apr-97		7.86		17.8											
52	24-Apr-97		7.71		17.4											
56	28-Apr-97	5	7.87		16.6	3600		7.3	559	<0.5	<0.5		597		316	
59	01-May-97		7.87		15.9											
63	05-May-97		7.8		15.8											
66	08-May-97		7.81		15.7											
67	09-May-97															
70	12-May-97	6	7.82		15.7	3120		5.55	474	<0.5	<0.5		503		276	
74	16-May-97		7.88		15.2											
78	20-May-97		7.72		14.8											
80	22-May-97		7.8		15											
85	27-May-97	7	7.81		14.4	3180		7.77	626	<0.5	<0.5		645		223	
88	30-May-97	0 (1)	7.55	7.83	>20				474	3.74	25.8		568			
89	31-May-97															
90	01-Jun-97	1	7.73		>20				427	<0.5	3.57		642			
91	02-Jun-97		7.7		>20											
92	03-Jun-97	2	7.72		>20	3020			419	<1	29.7		567		465	
94	05-Jun-97	3	7.68		>20											
96	07-Jun-97	4	7.63	7.81	>20											
98	09-Jun-97	5	7.74		>20											
101	12-Jun-97	6	7.76		>20											
106	17-Jun-97	7	7.75		>20				521	<2.5	46.3		577			
109	20-Jun-97	8	7.77		>20											
112	23-Jun-97	9	7.73		>20											
115	26-Jun-97	10	7.66	7.83	>20											
116	27-Jun-97															
119	30-Jun-97	11	6.59	7.78	14				260	38.6	300		298		708	
126	07-Jul-97		6.52	7.82	10											
127	08-Jul-97	12							<9.4	456	<0.50		27.9			
129	10-Jul-97		7.79		>20											
130	11-Jul-97	13														
133	14-Jul-97	14	7.78		>20				<9.4	467	0.6		130			
136	17-Jul-97	15	7.72		>20											
140	21-Jul-97	16														
143	24-Jul-97															
147	28-Jul-97	17														
150	31-Jul-97	18														
154	04-Aug-97	19														

(1) initiation of Long Term Extension

Elapsed days	Date	sampling event	DOC mg/L	hardness mg/L	BTEX mg/L	Dissolved Arsenic mg/L	Total Arsenic mg/L	Total Iron mg/L	Phenol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97												
1	04-Mar-97	1	271	70	0.09	2.11	3.05	0.964	87	14	31	14	4.4
14	17-Mar-97	2	64.2						<0.1	<0.1	<0.1	<0.1	<0.5
28	31-Mar-97	3	42.7						<0.1	<0.1	<0.1	<0.1	<0.1
31	03-Apr-97												
35	07-Apr-97												
38	10-Apr-97												
42	14-Apr-97	4	346						<0.1	<0.1	<0.1	<0.1	<0.1
45	17-Apr-97												
49	21-Apr-97												
52	24-Apr-97												
56	28-Apr-97	5	274						<0.1	<0.1	<0.1	<0.1	<0.1
59	01-May-97												
63	05-May-97												
66	08-May-97												
67	09-May-97												
70	12-May-97	6	372			1.7	1.48						
74	16-May-97												
78	20-May-97												
80	22-May-97												
85	27-May-97	7	332										
88	30-May-97	0 (1)											
89	31-May-97												
90	01-Jun-97	1											
91	02-Jun-97												
92	03-Jun-97	2	375										
94	05-Jun-97	3											
96	07-Jun-97	4											
98	09-Jun-97	5											
101	12-Jun-97	6											
106	17-Jun-97	7											
109	20-Jun-97	8											
112	23-Jun-97	9											
115	26-Jun-97	10											
116	27-Jun-97												
119	30-Jun-97	11	32.5										
126	07-Jul-97												
127	08-Jul-97	12											
129	10-Jul-97												
130	11-Jul-97	13											
133	14-Jul-97	14											
136	17-Jul-97	15											
140	21-Jul-97	16											
143	24-Jul-97												
147	28-Jul-97	17											
150	31-Jul-97	18											
154	04-Aug-97	19											

(1) initiation

TABLE 1-3

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Cyanide mg/L	SCN mg/L	NH_3 mg/L	NO_3 mg/L	NO_2 mg/L	Phos. mg/L	TKN mg/L	BOD mg/L	COD mg/L	Phenol (4-APP) mg/L	DOC mg/L	hard-ness mg/L	BTEX mg/L
0	03-Mar-97																		
1	04-Mar-97	1	8.36	7.81	>20	2140	<0.50	273	931	<0.50	<0.50	1060	1010	>350	2500	439	552	80	0.18
14	17-Mar-97	2	7.04	7.67	17	2750		268	862	<0.50	<0.50		863		1270		165		
28	31-Mar-97	3	6.96	7.73	13	3060		248	903	<0.50	<0.50		922		826		98.3		
31	03-Apr-97		7.31	7.67	13.4														
35	07-Apr-97		7.41	7.7	13.4														
38	10-Apr-97		7.58	7.71	13.3														
42	14-Apr-97	4	7.66	7.8	13.3	3470		215	912	<0.50	<0.50		969		932		627		
45	17-Apr-97		7.73		13.1														
49	21-Apr-97		7.8		12.8														
52	24-Apr-97		7.77		12.5														
56	28-Apr-97	5	7.74		11.8	4330		207	891	<0.50	<0.50		1180		772		530		
59	01-May-97		7.73		11.2														
63	05-May-97		7.55	7.7	9.4														
66	08-May-97		7.82		10														
67	09-May-97																		
70	12-May-97	6	7.67	7.77	9.8	4100		9.7	920	<0.50	<0.50		1090		497		704		
74	16-May-97		7.84		9.7														
78	20-May-97		7.82		9.2														
80	22-May-97		7.78		9.7														
85	27-May-97	7	7.79		9.6	4200		16	939	<0.50	<0.50		1080		408		542		
88	30-May-97	0 (1)	7.55	7.8	>20			226	995	5.3	39.8		1120						
89	31-May-97																		
90	01-Jun-97	1	7.76		>20				1040	<2.5	50.3		1140						
91	02-Jun-97		7.73		18														
92	03-Jun-97	2	7.82		17.9	3790		15.2	837	<2.5	67.9		1200		230		580		
94	05-Jun-97	3	7.6	7.83	15.8														
96	07-Jun-97	4	7.53	7.79	14.9				790	<5.0	110		1030						
98	09-Jun-97	5	7.55	7.84	14.6				772	<10	148		791						
101	12-Jun-97	6	7.67	7.88	15														
106	17-Jun-97	7	7.68	7.79	13.4			11.4	837	<10	106		939						
109	20-Jun-97	8	7.68	7.84	12.9			10.8	763	<10	180		847						
112	23-Jun-97	9	7.68	7.8	9.2			10.8	847	33.8	180		1010						
115	26-Jun-97	10	7.69	7.87	16			15.8	698	122	180		921						
116	27-Jun-97																		
119	30-Jun-97	11	7.44	7.75	>20			11.6	558	341	1.17		689		568		61.8		
126	07-Jul-97		6.8	7.78	16.2														
127	08-Jul-97	12							502	594	1.56		568						
129	10-Jul-97		6.67	7.85	16.6														
130	11-Jul-97	13							279	1570	3.53		419						
133	14-Jul-97	14	6.6	7.9	9.4			20	298	832	<0.5		372						
136	17-Jul-97	15	6.98	7.83	>20				130	873	1.68		168						
140	21-Jul-97	16	7.16	7.8	>20				55.8	681	<0.50		83.7						
143	24-Jul-97		7.5	7.84	13.7														
147	28-Jul-97	17	7.66	7.83	13.3														
150	31-Jul-97	18																	
154	04-Aug-97	19																	

(1) initiation of Long Term Extension

Elapsed days	Date	sampling event	Dissolved Arsenic mg/L	Total Arsenic mg/L	Total Iron mg/L	Phenol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97									
1	04-Mar-97	1	4.22	4.88	0.798	140	22	48	21	6
14	17-Mar-97	2				<5.0	21	<5.0	<5.0	3.4
28	31-Mar-97	3				.79b	0.14	0.26	0.14	<0.4
31	03-Apr-97									
35	07-Apr-97									
38	10-Apr-97									
42	14-Apr-97	4				<0.1	<0.1	<0.1	<0.1	<0.2
45	17-Apr-97									
49	21-Apr-97									
52	24-Apr-97									
56	28-Apr-97	5				<0.1	<0.1	<0.1	<0.1	<0.1
59	01-May-97									
63	05-May-97									
66	08-May-97									
67	09-May-97									
70	12-May-97	6	5.72	4.15						
74	16-May-97									
78	20-May-97									
80	22-May-97									
85	27-May-97	7								
88	30-May-97	0 (1)								
89	31-May-97									
90	01-Jun-97	1								
91	02-Jun-97									
92	03-Jun-97	2								
94	05-Jun-97	3								
96	07-Jun-97	4								
98	09-Jun-97	5								
101	12-Jun-97	6								
106	17-Jun-97	7								
109	20-Jun-97	8								
112	23-Jun-97	9								
115	26-Jun-97	10								
116	27-Jun-97									
119	30-Jun-97	11								
126	07-Jul-97									
127	08-Jul-97	12								
129	10-Jul-97									
130	11-Jul-97	13								
133	14-Jul-97	14								
136	17-Jul-97	15								
140	21-Jul-97	16								
143	24-Jul-97									
147	28-Jul-97	17								
150	31-Jul-97	18								
154	04-Aug-97	19								

(1) initiation

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Cyanide mg/L	SCN mg/L	NH_3 mg/L	NO_3 mg/L	NO_2 mg/L	Phos. mg/L	TKN mg/L	BOD mg/L	COD mg/L	Phenol (4-APP) mg/L
0	03-Mar-97															
1	04-Mar-97	1	8.61	7.77	>20	3370	<0.50	721	2690	<0.50	<0.50	1040	2990	>350	7120	1280
14	17-Mar-97	2	7.92	7.79	>20	3210		879	2690	<0.50	<0.50		2800		6470	
28	31-Mar-97	3	7.65	7.77	>20	3290		911	2760	<0.50	0.55		2870		6590	
31	03-Apr-97		7.96	7.78	>20											
35	07-Apr-97		7.69		>20											
38	10-Apr-97		7.73		>20											
42	14-Apr-97	4	7.74		>20	3330		883	2790	0.5	<0.50		2800		7460	
45	17-Apr-97		7.74		>20											
49	21-Apr-97		7.78		>20											
52	24-Apr-97		7.68	7.73	>20											
56	28-Apr-97	5	7.82		>20	4170		859	2880	<0.50	<0.50		3050		6690	
59	01-May-97		7.8		>20											
63	05-May-97		7.74		>20											
66	08-May-97		7.82		>20											
67	09-May-97															
70	12-May-97	6	7.76		>20	4030		2200	2470	<0.50	0.54		3190		6450	
74	16-May-97		7.82		19.9											
78	20-May-97		7.72		18.8											
80	22-May-97		7.78		19.6											
85	27-May-97	7	7.83		19.2	3690		810	2890	<0.50	0.59		3090	6530		1920
88	30-May-97	0 (1)	7.86		>20											
89	31-May-97															
90	01-Jun-97	1														
91	02-Jun-97		7.89		>20											
92	03-Jun-97	2	7.99	7.84	>20	2590		817	2200	<0.5	<0.5		2960		6890	
94	05-Jun-97	3	7.85		>20											
96	07-Jun-97	4	7.75		>20											
98	09-Jun-97	5	7.9		>20											
101	12-Jun-97	6	8.07	7.86	>20											
106	17-Jun-97	7	7.9		>20			92.9	2760	<0.50	<0.50		3140			
109	20-Jun-97	8	7.91	7.87	>20											
112	23-Jun-97	9	7.81		>20											
115	26-Jun-97	10	7.78		>20											
116	27-Jun-97															
119	30-Jun-97	11	7.83		>20			628	3060	<0.50	<0.50		3190		10300	
126	07-Jul-97		7.78		>20											
127	08-Jul-97	12														
129	10-Jul-97		7.77		>20											
130	11-Jul-97	13														
133	14-Jul-97	14	7.78		>20			98.1	2930	<0.50	<0.50		4560			
136	17-Jul-97	15	7.76		>20											
140	21-Jul-97	16	7.72		19.5											
143	24-Jul-97		7.7		19.9											
147	28-Jul-97	17	7.74		>20											
150	31-Jul-97	18														
154	04-Aug-97	19														

(1) initiation of Long Term Extension

Elapsed days	Date	sampling event	DOC mg/L	hard-ness mg/L	BTEX mg/L	Dissolved Arsenic mg/L	Total Arsenic mg/L	Total Iron mg/L	Phenol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97												
1	04-Mar-97	1	1690	30	0.48	14	14.2	0.814	430	71	153	67	20
14	17-Mar-97	2	1680						540	90	193	87	<4.0
28	31-Mar-97	3	1500						300	48	117	43	<20
31	03-Apr-97												
35	07-Apr-97												
38	10-Apr-97												
42	14-Apr-97	4	2190						570	72	200	60	8.7
45	17-Apr-97												
49	21-Apr-97												
52	24-Apr-97												
56	28-Apr-97	5	1810						450	52	144	46	20
59	01-May-97												
63	05-May-97												
66	08-May-97												
67	09-May-97												
70	12-May-97	6	2280			1.75	1.45		500	68	146	64	17
74	16-May-97												
78	20-May-97												
80	22-May-97												
85	27-May-97	7							530	82	210	90	<40
88	30-May-97	0 (1)											
89	31-May-97												
90	01-Jun-97	1											
91	02-Jun-97												
92	03-Jun-97	2	2350						510	77	200	72	<40
94	05-Jun-97	3											
96	07-Jun-97	4											
98	09-Jun-97	5											
101	12-Jun-97	6											
106	17-Jun-97	7							570	70	76	170	<40
109	20-Jun-97	8											
112	23-Jun-97	9											
115	26-Jun-97	10											
116	27-Jun-97												
119	30-Jun-97	11	1740						450	61	71	150	<40
126	07-Jul-97												
127	08-Jul-97	12											
129	10-Jul-97												
130	11-Jul-97	13											
133	14-Jul-97	14							480	66	43	150	<40
136	17-Jul-97	15											
140	21-Jul-97	16											
143	24-Jul-97												
147	28-Jul-97	17											
150	31-Jul-97	18											
154	04-Aug-97	19											

(1) initiation

MLT-5

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Cyanide mg/L	SCN mg/L	NH_3 mg/L	NO_3 mg/L	NO_2 mg/L	Phos. mg/L	TKN mg/L	BOD mg/L	COD mg/L	Phenol (4-APP) mg/L
0	03-Mar-97															
1	04-Mar-97	1	8.01	7.75	>20	1830	<0.50	144	442	<0.50	<0.50	1040	578	>350	1240	227
14	17-Mar-97	2	7.28	7.68	>20	2130		144	417	<0.50	<0.50		455		543	
28	31-Mar-97	3	7.29	7.83	>20	2440		109	442	<0.50	0.54		480		473	
31	03-Apr-97		7.7		>20											
35	07-Apr-97		7.58	7.77	19.8											
38	10-Apr-97		7.69		18.8											
42	14-Apr-97	4	7.66		18.9	2640		9.42	480	0.51	<0.50		489		430	
45	17-Apr-97		7.68		18.3											
49	21-Apr-97		7.71		18											
52	24-Apr-97		7.54	7.9	17.3											
56	28-Apr-97	5	7.9		16.7	3060		13	541	0.73	<0.50		626		330	
59	01-May-97		7.9		16											
63	05-May-97		7.98		16											
66	08-May-97		7.9		16											
67	09-May-97															
70	12-May-97	6	7.85		15.5	3490		5.55	465	<0.50	<0.50		540		314	
74	16-May-97		7.93	7.8	15.3											
78	20-May-97		7.77		14.6											
80	22-May-97		7.94	7.74	14.8											
85	27-May-97	7	7.78		14	3010		13.5	493	<0.50	<0.50		560		270	
88	30-May-97	0 (1)	7.88		>20											
89	31-May-97															
90	01-Jun-97	1														
91	02-Jun-97		7.89		>20											
92	03-Jun-97	2	8.06	7.8	>20	2660			270	<0.50	<0.50		884		244	
94	05-Jun-97	3	7.92	7.77	>20											
96	07-Jun-97	4	7.72		>20											
98	09-Jun-97	5	7.76		>20											
101	12-Jun-97	6	7.87		>20											
106	17-Jun-97	7	7.9	7.78	>20				642	<0.50	<0.50		661			
109	20-Jun-97	8	7.85		>20											
112	23-Jun-97	9	7.82		>20											
115	26-Jun-97	10	7.83		>20											
116	27-Jun-97															
119	30-Jun-97	11	7.85		>20				707	0.65	<0.50		735		318	
126	07-Jul-97		7.88		>20											
127	08-Jul-97	12														
129	10-Jul-97		7.89		>20											
130	11-Jul-97	13														
133	14-Jul-97	14	7.91		>20				558	<0.50	<0.50	651				
136	17-Jul-97	15	7.89		>20											
140	21-Jul-97	16	7.89		>20											
143	24-Jul-97		7.87		>20											
147	28-Jul-97	17	7.89		>20											
150	31-Jul-97	18														
154	04-Aug-97	19														

(1) initiation of Long Term Extension

TABLE 5-5

Elapsed days	Date	sampling event	DOC mg/L	hardness mg/L	BTEX mg/L	Dissolved Arsenic mg/L	Total Arsenic mg/L	Total Iron mg/L	Phenol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97												
1	04-Mar-97	1	273	30	0.09	2.11	2.8	0.904	78	14	29	13	4.4
14	17-Mar-97	2	72.6						<0.1	<0.1	<0.1	<0.1	<0.1
28	31-Mar-97	3	54.1						<0.1	<0.1	<0.1	<0.1	<0.1
31	03-Apr-97												
35	07-Apr-97												
38	10-Apr-97												
42	14-Apr-97	4	348						0.25	<0.1	<0.1	<0.1	<0.1
45	17-Apr-97												
49	21-Apr-97												
52	24-Apr-97												
56	28-Apr-97	5	329						0.27	<0.1	<0.1	<0.1	<0.1
59	01-May-97												
63	05-May-97												
66	08-May-97												
67	09-May-97												
70	12-May-97	6	363			1.72	1.55						
74	16-May-97												
78	20-May-97												
80	22-May-97												
85	27-May-97	7	315										
88	30-May-97	0 (1)											
89	31-May-97												
90	01-Jun-97	1											
91	02-Jun-97												
92	03-Jun-97	2	324										
94	05-Jun-97	3											
96	07-Jun-97	4											
98	09-Jun-97	5											
101	12-Jun-97	6											
106	17-Jun-97	7											
109	20-Jun-97	8											
112	23-Jun-97	9											
115	26-Jun-97	10											
116	27-Jun-97												
119	30-Jun-97	11	32.5										
126	07-Jul-97												
127	08-Jul-97	12											
129	10-Jul-97												
130	11-Jul-97	13											
133	14-Jul-97	14											
136	17-Jul-97	15											
140	21-Jul-97	16											
143	24-Jul-97												
147	28-Jul-97	17											
150	31-Jul-97	18											
154	04-Aug-97	19											

(1) initiation

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Cyanide mg/L	SCN mg/L	NH_3 mg/L	NO_3 mg/L	NO_2 mg/L	Phos. mg/L	TKN mg/L	BOD mg/L	COD mg/L	Phenol (4-APP) mg/L
0	03-Mar-97															
1	04-Mar-97	1	7.86		>20	1730	<0.50	88.2	254	<0.50	<0.50	1070	294	>350	781	129
14	17-Mar-97	2	7.19	7.7	>20	1910		46.2	246	<0.50	<0.50		246		277	
28	31-Mar-97	3	7.32	7.66	>20	2000		<5	273	<0.50	<0.50		273		189	
31	03-Apr-97		7.61	7.79	>20											
35	07-Apr-97		7.63	7.87	>20											
38	10-Apr-97		7.8		>20											
42	14-Apr-97	4	7.81		>20	2320		6.1	301	<0.50	<0.50		310		235	
45	17-Apr-97		7.83		>20											
49	21-Apr-97		7.84		>20											
52	24-Apr-97		7.69	7.8	>20											
56	28-Apr-97	5	7.9		>20	2490		5.6	341	2.61	<0.50		370		202	
59	01-May-97		7.9		>20											
63	05-May-97		7.96		>20											
66	08-May-97		7.9		19.5											
67	09-May-97															
70	12-May-97	6	7.86		19.3	2510		<5.0	284	<0.50	<0.50		332		200	
74	16-May-97		7.91	7.83	19											
78	20-May-97		7.78		18.4											
80	22-May-97		7.85		18.5											
85	27-May-97	7	7.83		18.5			8.6	341	<0.50	<0.50		379		161	
88	30-May-97	0 (1)														
89	31-May-97															
90	01-Jun-97	1														
91	02-Jun-97															
92	03-Jun-97	2														
94	05-Jun-97	3														
96	07-Jun-97	4														
98	09-Jun-97	5														
101	12-Jun-97	6														
106	17-Jun-97	7														
109	20-Jun-97	8														
112	23-Jun-97	9														
115	26-Jun-97	10														
116	27-Jun-97															
119	30-Jun-97	11														
126	07-Jul-97															
127	08-Jul-97	12														
129	10-Jul-97															
130	11-Jul-97	13														
133	14-Jul-97	14														
136	17-Jul-97	15														
140	21-Jul-97	16														
143	24-Jul-97															
147	28-Jul-97	17														
150	31-Jul-97	18														
154	04-Aug-97	19														

(1) initiation of Long Term Extension

Elapsed days	Date	sampling event	DOC mg/L	hard. ness mg/L	BTEX mg/L	Dissolved Arsenic mg/L	Total Arsenic mg/L	Total Iron mg/L	. nol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97												
1	04-Mar-97	1	164	150	0.06	0.947	1.46	0.77	43	8.1	15.4	7.6	3
14	17-Mar-97	2	57.8						<0.1	<0.1	<0.1	<0.1	<0.1
28	31-Mar-97	3	26.8						<0.1	<0.1	<0.1	<0.1	<0.1
31	03-Apr-97												
35	07-Apr-97												
38	10-Apr-97												
42	14-Apr-97	4	145						0.5	<0.1	<0.1	<0.1	<0.1
45	17-Apr-97												
49	21-Apr-97												
52	24-Apr-97												
56	28-Apr-97	5	223						1.1	1.2	0.202	0.98	<0.1
59	01-May-97												
63	05-May-97												
66	08-May-97												
67	09-May-97												
70	12-May-97	6	252			1.19	1						
74	16-May-97												
78	20-May-97												
80	22-May-97												
85	27-May-97	7											
88	30-May-97	0 (1)											
89	31-May-97												
90	01-Jun-97	1											
91	02-Jun-97												
92	03-Jun-97	2											
94	05-Jun-97	3											
96	07-Jun-97	4											
98	09-Jun-97	5											
101	12-Jun-97	6											
106	17-Jun-97	7											
109	20-Jun-97	8											
112	23-Jun-97	9											
115	26-Jun-97	10											
116	27-Jun-97												
119	30-Jun-97	11											
126	07-Jul-97												
127	08-Jul-97	12											
129	10-Jul-97												
130	11-Jul-97	13											
133	14-Jul-97	14											
136	17-Jul-97	15											
140	21-Jul-97	16											
143	24-Jul-97												
147	28-Jul-97	17											
150	31-Jul-97	18											
154	04-Aug-97	19											

(1) initiation

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Cyanide mg/L	SCN mg/L	NH_3 mg/L	NO_3 mg/L	NO_2 mg/L	Phos. mg/L	TKN mg/L	BOD mg/L	COD mg/L	Phenol (4-APP) mg/L
0	03-Mar-97															
1	04-Mar-97	1	7.86		>20	1730	<0.50	88.2	254	<0.50	<0.50	1070	294	>350	781	129
14	17-Mar-97	2	7.19	7.7	>20	1910		46.2	246	<0.50	<0.50		246		277	
28	31-Mar-97	3	7.32	7.66	>20	2000		<5	273	<0.50	<0.50		273		189	
31	03-Apr-97		7.61	7.79	>20											
35	07-Apr-97		7.63	7.87	>20											
38	10-Apr-97		7.8		>20											
42	14-Apr-97	4	7.81		>20	2320		6.1	301	<0.50	<0.50		310		235	
45	17-Apr-97		7.83		>20											
49	21-Apr-97		7.84		>20											
52	24-Apr-97		7.69	7.8	>20											
56	28-Apr-97	5	7.9		>20	2490		5.6	341	2.61	<0.50		370		202	
59	01-May-97		7.9		>20											
63	05-May-97		7.96		>20											
66	08-May-97		7.9		19.5											
67	09-May-97															
70	12-May-97	6	7.86		19.3	2510		<5.0	284	<0.50	<0.50		332		200	
74	16-May-97		7.91	7.83	19											
78	20-May-97		7.78		18.4											
80	22-May-97		7.85		18.5											
85	27-May-97	7	7.83		18.5			8.6	341	<0.50	<0.50		379		161	
88	30-May-97	0 (1)														
89	31-May-97															
90	01-Jun-97	1														
91	02-Jun-97															
92	03-Jun-97	2														
94	05-Jun-97	3														
96	07-Jun-97	4														
98	09-Jun-97	5														
101	12-Jun-97	6														
106	17-Jun-97	7														
109	20-Jun-97	8														
112	23-Jun-97	9														
115	26-Jun-97	10														
116	27-Jun-97															
119	30-Jun-97	11														
126	07-Jul-97															
127	08-Jul-97	12														
129	10-Jul-97															
130	11-Jul-97	13														
133	14-Jul-97	14														
136	17-Jul-97	15														
140	21-Jul-97	16														
143	24-Jul-97															
147	28-Jul-97	17														
150	31-Jul-97	18														
154	04-Aug-97	19														

(1) initiation of Long Term Extension

Elapsed days	Date	sampling event	DOC mg/L	hard. ness mg/L	BTEX mg/L	Dissolved Arsenic mg/L	Total Arsenic mg/L	Total Iron mg/L	.ol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97												
1	04-Mar-97	1	164	150	0.06	0.947	1.46	0.77	43	8.1	15.4	7.6	3
14	17-Mar-97	2	57.8						<0.1	<0.1	<0.1	<0.1	<0.1
28	31-Mar-97	3	26.8						<0.1	<0.1	<0.1	<0.1	<0.1
31	03-Apr-97												
35	07-Apr-97												
38	10-Apr-97												
42	14-Apr-97	4	145						0.5	<0.1	<0.1	<0.1	<0.1
45	17-Apr-97												
49	21-Apr-97												
52	24-Apr-97												
56	28-Apr-97	5	223						1.1	1.2	0.202	0.98	<0.1
59	01-May-97												
63	05-May-97												
66	08-May-97												
67	09-May-97												
70	12-May-97	6	252			1.19	1						
74	16-May-97												
78	20-May-97												
80	22-May-97												
85	27-May-97	7											
88	30-May-97	0 (1)											
89	31-May-97												
90	01-Jun-97	1											
91	02-Jun-97												
92	03-Jun-97	2											
94	05-Jun-97	3											
96	07-Jun-97	4											
98	09-Jun-97	5											
101	12-Jun-97	6											
106	17-Jun-97	7											
109	20-Jun-97	8											
112	23-Jun-97	9											
115	26-Jun-97	10											
116	27-Jun-97												
119	30-Jun-97	11											
126	07-Jul-97												
127	08-Jul-97	12											
129	10-Jul-97												
130	11-Jul-97	13											
133	14-Jul-97	14											
136	17-Jul-97	15											
140	21-Jul-97	16											
143	24-Jul-97												
147	28-Jul-97	17											
150	31-Jul-97	18											
154	04-Aug-97	19											

(1) initiation

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Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Cyanide mg/L	SCN mg/L	NH_3 mg/L	NO_3 mg/L	NO_2 mg/L	Phos. mg/L	TKN mg/L	BOD mg/L	COD mg/L	Phenol (4-APP) mg/L
0	03-Mar-97															
1	04-Mar-97	1														
14	17-Mar-97	2														
28	31-Mar-97	3														
31	03-Apr-97															
35	07-Apr-97															
38	10-Apr-97															
42	14-Apr-97	4														
45	17-Apr-97															
49	21-Apr-97															
52	24-Apr-97															
56	28-Apr-97	5														
59	01-May-97															
63	05-May-97															
66	08-May-97															
67	09-May-97															
70	12-May-97	6														
74	16-May-97															
78	20-May-97															
80	22-May-97															
85	27-May-97	7														
88	30-May-97	0 (1)	8.2	7.86	>20											
89	31-May-97															
90	01-Jun-97	1														
91	02-Jun-97		8.15	7.86	>20											
92	03-Jun-97	2	7.99	7.85	>20	2230			195	<0.5	<0.5		419		779	
94	05-Jun-97	3	7.93	7.79	>20											
96	07-Jun-97	4	7.82		>20											
98	09-Jun-97	5	7.72		>20											
101	12-Jun-97	6	7.87		>20											
106	17-Jun-97	7	7.91	7.84	>20				363	<0.50	<0.50		400			
109	20-Jun-97	8	7.88		>20											
112	23-Jun-97	9	7.87		>20				363	<0.50	<0.50		419			
115	26-Jun-97	10	7.87		>20											
116	27-Jun-97															
119	30-Jun-97	11	7.92		>20				400	<0.50	<0.50		530		232	
126	07-Jul-97		7.9		>20											
127	08-Jul-97	12														
129	10-Jul-97		7.9		>20											
130	11-Jul-97	13														
133	14-Jul-97	14	7.92		>20				326	<0.50	<0.50		437			
136	17-Jul-97	15	7.91		>20											
140	21-Jul-97	16	7.87		>20											
143	24-Jul-97		7.8		>20											
147	28-Jul-97	17	7.22	7.78	>20											
150	31-Jul-97	18	6.84	7.81	14.7											
154	04-Aug-97	19	7.08	7.8	14.1											

(1) initiation of Long Term Extension

Elapsed days	Date	sampling event	DOC mg/L	hardness mg/L	BTEX mg/L	Dissolved Arsenic mg/L	Total Arsenic mg/L	Total Iron mg/L	...ol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97												
1	04-Mar-97	1											
14	17-Mar-97	2											
28	31-Mar-97	3											
31	03-Apr-97												
35	07-Apr-97												
38	10-Apr-97												
42	14-Apr-97	4											
45	17-Apr-97												
49	21-Apr-97												
52	24-Apr-97												
56	28-Apr-97	5											
59	01-May-97												
63	05-May-97												
66	08-May-97												
67	09-May-97												
70	12-May-97	6											
74	16-May-97												
78	20-May-97												
80	22-May-97												
85	27-May-97	7											
88	30-May-97	0 (1)											
89	31-May-97												
90	01-Jun-97	1											
91	02-Jun-97												
92	03-Jun-97	2	245										
94	05-Jun-97	3											
96	07-Jun-97	4											
98	09-Jun-97	5											
101	12-Jun-97	6											
106	17-Jun-97	7											
109	20-Jun-97	8											
112	23-Jun-97	9											
115	26-Jun-97	10											
116	27-Jun-97												
119	30-Jun-97	11	23.5										
126	07-Jul-97												
127	08-Jul-97	12											
129	10-Jul-97												
130	11-Jul-97	13											
133	14-Jul-97	14											
136	17-Jul-97	15											
140	21-Jul-97	16											
143	24-Jul-97												
147	28-Jul-97	17											
150	31-Jul-97	18											
154	04-Aug-97	19											

(1) initiation

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Cyanide mg/L	SCN mg/L	NH_3 mg/L	NO_3 mg/L	NO_2 mg/L	Phos. mg/L	TKN mg/L	BOD mg/L	COD mg/L	Phenol (4-APP) mg/L
0	03-Mar-97															
1	04-Mar-97	1														
14	17-Mar-97	2														
28	31-Mar-97	3														
31	03-Apr-97															
35	07-Apr-97															
38	10-Apr-97															
42	14-Apr-97	4														
45	17-Apr-97															
49	21-Apr-97															
52	24-Apr-97															
56	28-Apr-97	5														
59	01-May-97															
63	05-May-97															
66	08-May-97															
67	09-May-97															
70	12-May-97	6														
74	16-May-97															
78	20-May-97															
80	22-May-97															
85	27-May-97	7														
88	30-May-97	0 (1)	7.23	7.8	>20				190	<10	143		288			
89	31-May-97															
90	01-Jun-97	1	7.01	7.7	>20				114	12.4	217		186			
91	02-Jun-97		7.09	7.84	>20											
92	03-Jun-97	2	7.34	7.75	>20	1960			<9.4	<25	280		<9.4		280	
94	05-Jun-97	3	7.44	7.85	>20				<9.4	78.2	197		<9.4			
96	07-Jun-97	4	7.56	7.87	>20				<9.4	282	<0.50		<9.4			
98	09-Jun-97	5	7.6	7.84	>20				<9.4	289	<0.50		<9.4			
101	12-Jun-97	6	7.81		>20											
106	17-Jun-97	7	7.84		>20				<9.4	260	0.72		18.6			
109	20-Jun-97	8	7.83		>20											
112	23-Jun-97	9														
115	26-Jun-97	10														
116	27-Jun-97															
119	30-Jun-97	11														
126	07-Jul-97															
127	08-Jul-97	12														
129	10-Jul-97															
130	11-Jul-97	13														
133	14-Jul-97	14														
136	17-Jul-97	15														
140	21-Jul-97	16														
143	24-Jul-97															
147	28-Jul-97	17														
150	31-Jul-97	18														
154	04-Aug-97	19														

(1) initiation of Long Term Extension

Elapsed days	Date	sampling event	DOC mg/L	hardness mg/L	BTEX mg/L	Dissolved Arsenic mg/L	Total Arsenic mg/L	Total Iron mg/L	...ol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97												
1	04-Mar-97	1											
14	17-Mar-97	2											
28	31-Mar-97	3											
31	03-Apr-97												
35	07-Apr-97												
38	10-Apr-97												
42	14-Apr-97	4											
45	17-Apr-97												
49	21-Apr-97												
52	24-Apr-97												
56	28-Apr-97	5											
59	01-May-97												
63	05-May-97												
66	08-May-97												
67	09-May-97												
70	12-May-97	6											
74	16-May-97												
78	20-May-97												
80	22-May-97												
85	27-May-97	7											
88	30-May-97	0 (1)											
89	31-May-97												
90	01-Jun-97	1											
91	02-Jun-97												
92	03-Jun-97	2	188										
94	05-Jun-97	3											
96	07-Jun-97	4											
98	09-Jun-97	5											
101	12-Jun-97	6											
106	17-Jun-97	7											
109	20-Jun-97	8											
112	23-Jun-97	9											
115	26-Jun-97	10											
116	27-Jun-97												
119	30-Jun-97	11											
126	07-Jul-97												
127	08-Jul-97	12											
129	10-Jul-97												
130	11-Jul-97	13											
133	14-Jul-97	14											
136	17-Jul-97	15											
140	21-Jul-97	16											
143	24-Jul-97												
147	28-Jul-97	17											
150	31-Jul-97	18											
154	04-Aug-97	19											

(1) initiation

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Cyanide mg/L	SCN mg/L	NH_3 mg/L	NO_3 mg/L	NO_2 mg/L	Phos. mg/L	TKN mg/L	BOD mg/L	COD mg/L	Phenol (4-APP) mg/L
0	03-Mar-97															
1	04-Mar-97	1	8.24	7.74	>20	1980	<0.50	212	687	<0.50	<0.50	1110	759	>350	1820	338
14	17-Mar-97	2	7.82		>20	1950		216	664	<0.50	<0.50		825		1800	
28	31-Mar-97	3	7.75		>20	1960		222	706	<0.50	<0.50		724		1820	
31	03-Apr-97		8.04	7.8	>20											
35	07-Apr-97		7.62		>20											
38	10-Apr-97		7.14	7.72	11.3											
42	14-Apr-97	4	7.25	7.68	14.8	2540		220	687	0.52	<0.50		762		1090	
45	17-Apr-97		7.49	7.83												
49	21-Apr-97		7.62	7.79	14.5											
52	24-Apr-97		7.56	7.84	14.6											
56	28-Apr-97	5	7.86		13.9	3160		212	711	<0.50	<0.50		796		958	
59	01-May-97		7.86		13.5											
63	05-May-97		7.89		13.3											
66	08-May-97		7.84		13.2											
67	09-May-97															
70	12-May-97	6	7.78		13.2	3390		220	635	0.52	<0.50		796		953	
74	16-May-97		7.82		12.7											
78	20-May-97		7.79		12.3											
80	22-May-97		8	7.71	12.8											
85	27-May-97	7	7.71		12.3	3220		216	787	<0.50	0.53		863		898	
88	30-May-97	0 (1)	7.81		>20											
89	31-May-97															
90	01-Jun-97	1														
91	02-Jun-97		7.82		>20											
92	03-Jun-97	2	7.98	7.83	>20	2820		224	540	<0.5	<0.5		921		786	
94	05-Jun-97	3	7.87		>20											
96	07-Jun-97	4	7.78		>20											
98	09-Jun-97	5	7.75		>20											
101	12-Jun-97	6	7.89		>20											
106	17-Jun-97	7	7.9		>20			226	744	<0.50	0.83		884			
109	20-Jun-97	8	7.9		>20											
112	23-Jun-97	9	7.87		>20											
115	26-Jun-97	10	7.86		>20											
116	27-Jun-97															
119	30-Jun-97	11	7.94		>20			245	875	<0.50	<0.50		903		896	
126	07-Jul-97		7.89		>20											
127	08-Jul-97	12														
129	10-Jul-97		7.89		>20											
130	11-Jul-97	13														
133	14-Jul-97	14	7.91		>20			235	782	<0.50	0.73		1040			
136	17-Jul-97	15	7.84		>20											
140	21-Jul-97	16	7.79		>20											
143	24-Jul-97		7.75		>20											
147	28-Jul-97	17	7.73		>20											
150	31-Jul-97	18														
154	04-Aug-97	19														

(1) initiation of Long Term Extension

Elapsed days	Date	sampling event	DOC mg/L	hard ness mg/L	BTEX mg/L	Dissolved Arsenic mg/L	Total Arsenic mg/L	Total Iron mg/L	ol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97												
1	04-Mar-97	1	388	60	0.13	3.78	4.65	0.962	130	20	44	20	6.1
14	17-Mar-97	2	390						150	23	50	22	6.6
28	31-Mar-97	3	578						64b	11	26	11	<10
31	03-Apr-97												
35	07-Apr-97												
38	10-Apr-97												
42	14-Apr-97	4	420						1.1	16	<1.0	<0.1	3.1
45	17-Apr-97												
49	21-Apr-97												
52	24-Apr-97												
56	28-Apr-97	5	425						2.2	16	<1.0	<0.1	2
59	01-May-97												
63	05-May-97												
66	08-May-97												
67	09-May-97												
70	12-May-97	6	614			3.94	2.07		0.98	14	<1.2	<1.2	2.4
74	16-May-97												
78	20-May-97												
80	22-May-97												
85	27-May-97	7	456						<1	13	<1	<1	2.3
88	30-May-97	0 (1)											
89	31-May-97												
90	01-Jun-97	1											
91	02-Jun-97												
92	03-Jun-97	2	503										
94	05-Jun-97	3											
96	07-Jun-97	4											
98	09-Jun-97	5											
101	12-Jun-97	6											
106	17-Jun-97	7											
109	20-Jun-97	8											
112	23-Jun-97	9											
115	26-Jun-97	10											
116	27-Jun-97												
119	30-Jun-97	11	127										
126	07-Jul-97												
127	08-Jul-97	12											
129	10-Jul-97												
130	11-Jul-97	13											
133	14-Jul-97	14											
136	17-Jul-97	15											
140	21-Jul-97	16											
143	24-Jul-97												
147	28-Jul-97	17											
150	31-Jul-97	18											
154	04-Aug-97	19											

(1) initiation

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Cyanide mg/L	SCN mg/L	NH_3 mg/L	NO_3 mg/L	NO_2 mg/L	Phos. mg/L	TKN mg/L	BOD mg/L	COD mg/L	Phenol (4-APP) mg/L
0	03-Mar-97															
1	04-Mar-97	1														
14	17-Mar-97	2														
28	31-Mar-97	3														
31	03-Apr-97															
35	07-Apr-97															
38	10-Apr-97															
42	14-Apr-97	4														
45	17-Apr-97															
49	21-Apr-97															
52	24-Apr-97															
56	28-Apr-97	5														
59	01-May-97															
63	05-May-97															
66	08-May-97															
67	09-May-97															
70	12-May-97	6														
74	16-May-97															
78	20-May-97															
80	22-May-97															
85	27-May-97	7														
88	30-May-97	0 (1)	6.04	7.87	15	997			94	<10	232		177		209	
89	31-May-97															
90	01-Jun-97	1	6.73	7.88	18.9				<9.4	<10	289		<9.4			
91	02-Jun-97		7.37	7.73	18.9											
92	03-Jun-97	2	7.86		18.7	2130			<9.4	272	5.61		<9.4			
94	05-Jun-97	3	7.76		16.5				<9.4	25.9	250		<9.4			
96	07-Jun-97	4	7.68	7.79	9.4				<9.4	166	107		<9.4			
98	09-Jun-97	5	7.84		>20											
101	12-Jun-97	6	7.84		>20											
106	17-Jun-97	7														
109	20-Jun-97	8														
112	23-Jun-97	9														
115	26-Jun-97	10														
116	27-Jun-97															
119	30-Jun-97	11														
126	07-Jul-97															
127	08-Jul-97	12														
129	10-Jul-97															
130	11-Jul-97	13														
133	14-Jul-97	14														
136	17-Jul-97	15														
140	21-Jul-97	16														
143	24-Jul-97															
147	28-Jul-97	17														
150	31-Jul-97	18														
154	04-Aug-97	19														

(1) initiation of Long Term Extension

Elapsed days	Date	sampling event	DOC mg/L	hardness mg/L	BTEX mg/L	Dissolved Arsenic mg/L	Total Arsenic mg/L	Total Iron mg/L	...ol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97												
1	04-Mar-97	1											
14	17-Mar-97	2											
28	31-Mar-97	3											
31	03-Apr-97												
35	07-Apr-97												
38	10-Apr-97												
42	14-Apr-97	4											
45	17-Apr-97												
49	21-Apr-97												
52	24-Apr-97												
56	28-Apr-97	5											
59	01-May-97												
63	05-May-97												
66	08-May-97												
67	09-May-97												
70	12-May-97	6											
74	16-May-97												
78	20-May-97												
80	22-May-97												
85	27-May-97	7											
88	30-May-97	0 (1)	21										
89	31-May-97												
90	01-Jun-97	1											
91	02-Jun-97												
92	03-Jun-97	2											
94	05-Jun-97	3											
96	07-Jun-97	4											
98	09-Jun-97	5											
101	12-Jun-97	6											
106	17-Jun-97	7											
109	20-Jun-97	8											
112	23-Jun-97	9											
115	26-Jun-97	10											
116	27-Jun-97												
119	30-Jun-97	11											
126	07-Jul-97												
127	08-Jul-97	12											
129	10-Jul-97												
130	11-Jul-97	13											
133	14-Jul-97	14											
136	17-Jul-97	15											
140	21-Jul-97	16											
143	24-Jul-97												
147	28-Jul-97	17											
150	31-Jul-97	18											
154	04-Aug-97	19											

(1) initiation

111LT-9

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Cyanide mg/L	SCN mg/L	NH_3 mg/L	NO_3 mg/L	NO_2 mg/L	Phos. mg/L	TKN mg/L	BOD mg/L	COD mg/L	Phenol (4-APP) mg/L
0	03-Mar-97															
1	04-Mar-97	1														
14	17-Mar-97	2														
28	31-Mar-97	3														
31	03-Apr-97															
35	07-Apr-97															
38	10-Apr-97															
42	14-Apr-97	4														
45	17-Apr-97															
49	21-Apr-97															
52	24-Apr-97															
56	28-Apr-97	5														
59	01-May-97															
63	05-May-97															
66	08-May-97															
67	09-May-97															
70	12-May-97	6														
74	16-May-97															
78	20-May-97															
80	22-May-97															
85	27-May-97	7														
88	30-May-97	0 (1)	7.07	7.89	>20				28	<10	116		65.1			
89	31-May-97															
90	01-Jun-97	1	7.23	7.84	>20				<9.4	9.67	132		<9.4			
91	02-Jun-97		7.39	7.84	>20											
92	03-Jun-97	2	7.83		>20	2330			<9.4	130	6.14		<9.4		219	
94	05-Jun-97	3	7.77		>20				<9.4	49.7	72.3		<9.4			
96	07-Jun-97	4	7.71		>20											
98	09-Jun-97	5	7.7		>20											
101	12-Jun-97	6	7.68		>20											
106	17-Jun-97	7														
109	20-Jun-97	8														
112	23-Jun-97	9														
115	26-Jun-97	10														
116	27-Jun-97															
119	30-Jun-97	11														
126	07-Jul-97															
127	08-Jul-97	12														
129	10-Jul-97															
130	11-Jul-97	13														
133	14-Jul-97	14														
136	17-Jul-97	15														
140	21-Jul-97	16														
143	24-Jul-97															
147	28-Jul-97	17														
150	31-Jul-97	18														
154	04-Aug-97	19														

(1) initiation of Long Term Extension

Elapsed days	Date	sampling event	DOC mg/L	hard-ness mg/L	BTEX mg/L	Dissolved Arsenic mg/L	Total Arsenic mg/L	Total Iron mg/L	[illegible]ol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97												
1	04-Mar-97	1											
14	17-Mar-97	2											
28	31-Mar-97	3											
31	03-Apr-97												
35	07-Apr-97												
38	10-Apr-97												
42	14-Apr-97	4											
45	17-Apr-97												
49	21-Apr-97												
52	24-Apr-97												
56	28-Apr-97	5											
59	01-May-97												
63	05-May-97												
66	08-May-97												
67	09-May-97												
70	12-May-97	6											
74	16-May-97												
78	20-May-97												
80	22-May-97												
85	27-May-97	7											
88	30-May-97	0 (1)											
89	31-May-97												
90	01-Jun-97	1											
91	02-Jun-97												
92	03-Jun-97	2	156										
94	05-Jun-97	3											
96	07-Jun-97	4											
98	09-Jun-97	5											
101	12-Jun-97	6											
106	17-Jun-97	7											
109	20-Jun-97	8											
112	23-Jun-97	9											
115	26-Jun-97	10											
116	27-Jun-97												
119	30-Jun-97	11											
126	07-Jul-97												
127	08-Jul-97	12											
129	10-Jul-97												
130	11-Jul-97	13											
133	14-Jul-97	14											
136	17-Jul-97	15											
140	21-Jul-97	16											
143	24-Jul-97												
147	28-Jul-97	17											
150	31-Jul-97	18											
154	04-Aug-97	19											

(1) initiation

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Cyanide mg/L	SCN mg/L	NH_3 mg/L	NO_3 mg/L	NO_2 mg/L	Phos. mg/L	TKN mg/L	BOD mg/L	COD mg/L	Phenol (4-APP) mg/L
0	03-Mar-97															
1	04-Mar-97	1														
14	17-Mar-97	2														
28	31-Mar-97	3														
31	03-Apr-97															
35	07-Apr-97															
38	10-Apr-97															
42	14-Apr-97	4														
45	17-Apr-97															
49	21-Apr-97															
52	24-Apr-97															
56	28-Apr-97	5														
59	01-May-97															
63	05-May-97															
66	08-May-97															
67	09-May-97															
70	12-May-97	6														
74	16-May-97															
78	20-May-97															
80	22-May-97															
85	27-May-97	7														
88	30-May-97	0 (1)	6.17	7.82	>20	1030			502	<10	271		568		257	
89	31-May-97															
90	01-Jun-97	1	6.17	7.88	15.5				279	60	371		428			
91	02-Jun-97		6.56	7.84	7.4											
92	03-Jun-97	2	6.93	7.87	>20	2160			<9.4	617	12.9		<9.4			
94	05-Jun-97	3	7.12	7.87	16				<9.4	<25	666		<9.4			
96	07-Jun-97	4	7.52	7.79	>20				<9.4	<25	685		<9.4			
98	09-Jun-97	5	7.67	7.87	>20				<9.4	<25	650		<9.4			
101	12-Jun-97	6	7.88		18.6											
106	17-Jun-97	7														
109	20-Jun-97	8														
112	23-Jun-97	9														
115	26-Jun-97	10														
116	27-Jun-97															
119	30-Jun-97	11														
126	07-Jul-97															
127	08-Jul-97	12														
129	10-Jul-97															
130	11-Jul-97	13														
133	14-Jul-97	14														
136	17-Jul-97	15														
140	21-Jul-97	16														
143	24-Jul-97															
147	28-Jul-97	17														
150	31-Jul-97	18														
154	04-Aug-97	19														

(1) initiation of Long Term Extension

Elapsed days	Date	sampling event	DOC mg/L	hardness mg/L	BTEX mg/L	Dissolved Arsenic mg/L	Total Arsenic mg/L	Total Iron mg/L	nol (GC) mg/L	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Methyl Phenol mg/L	2,4-Dimethyl Phenol mg/L
0	03-Mar-97												
1	04-Mar-97	1											
14	17-Mar-97	2											
28	31-Mar-97	3											
31	03-Apr-97												
35	07-Apr-97												
38	10-Apr-97												
42	14-Apr-97	4											
45	17-Apr-97												
49	21-Apr-97												
52	24-Apr-97												
56	28-Apr-97	5											
59	01-May-97												
63	05-May-97												
66	08-May-97												
67	09-May-97												
70	12-May-97	6											
74	16-May-97												
78	20-May-97												
80	22-May-97												
85	27-May-97	7											
88	30-May-97	0 (1)	23.2										
89	31-May-97												
90	01-Jun-97	1											
91	02-Jun-97												
92	03-Jun-97	2											
94	05-Jun-97	3											
96	07-Jun-97	4											
98	09-Jun-97	5											
101	12-Jun-97	6											
106	17-Jun-97	7											
109	20-Jun-97	8											
112	23-Jun-97	9											
115	26-Jun-97	10											
116	27-Jun-97												
119	30-Jun-97	11											
126	07-Jul-97												
127	08-Jul-97	12											
129	10-Jul-97												
130	11-Jul-97	13											
133	14-Jul-97	14											
136	17-Jul-97	15											
140	21-Jul-97	16											
143	24-Jul-97												
147	28-Jul-97	17											
150	31-Jul-97	18											
154	04-Aug-97	19											

(1) initiation

Elapsed days	Date	sampling event	Initial pH	Final pH	D.O. (mg/L)	Alkalinity mg/L	Nitrate mg/L	Nitrite mg/L	Ammonia mg/L	TKN mg/L	Total N_2 (Calc) mg/L	SCN (as N) mg/L	SCN mg/L	COD mg/L	DOC mg/L	Phenol (GC) mg/L
0	03-Mar-97															
1	04-Mar-97	1														
14	17-Mar-97	2														
28	31-Mar-97	3														
31	03-Apr-97															
35	07-Apr-97															
38	10-Apr-97															
42	14-Apr-97	4														
45	17-Apr-97															
49	21-Apr-97															
52	24-Apr-97															
56	28-Apr-97	5														
59	01-May-97															
63	05-May-97															
66	08-May-97															
67	09-May-97															
70	12-May-97	6														
74	16-May-97															
78	20-May-97															
80	22-May-97															
85	27-May-97	7														
88	30-May-97	0 (1)	7.1	7.84	0.47	<508	0.81	3.9	275	419	467	43	179	694	210	<0.1
89	31-May-97															
90	01-Jun-97	1	7	7.83	13.8		35.7	35.6	223	335			124			
91	02-Jun-97		7.31	7.85	18.2											
92	03-Jun-97	2	7.54	7.85	>20	2720	85	9.51	228	344	439			348	250	.058b
94	05-Jun-97	3	7.45	7.82	16.4		<5	98.4	186	307	405		<5			<0.1
96	07-Jun-97	4	7.6	7.87	14.4		<5	118	251	391	509		<5			<0.1
98	09-Jun-97	5	7.34	7.8	5.3		<10	216	83.7	288	504		<5			<0.1
101	12-Jun-97	6	6.94	7.72	>20		10.3	253	<9.4	<9.4	265		5.65			<0.1
106	17-Jun-97	7	7.35	7.84	>20		<10	123	<9.4	<9.4	123		<5			<0.1
109	20-Jun-97	8	7.61	7.87	>20		<10	309	37.2	130	439	0	<5			<0.1
112	23-Jun-97	9	7.76	7.81	17.9		33.2	242	<9.4	<9.4	275	0	<5			<0.1
115	26-Jun-97	10														(b)
116	27-Jun-97															
119	30-Jun-97	11														
126	07-Jul-97															
127	08-Jul-97	12														
129	10-Jul-97															
130	11-Jul-97	13														
133	14-Jul-97	14														
136	17-Jul-97	15														
140	21-Jul-97	16														
143	24-Jul-97															
147	28-Jul-97	17														
150	31-Jul-97	18														
154	04-Aug-97	19														

(1) initiation of Long Term Extension

Elapsed days	Date	sampling event	2-Methyl Phenol mg/L	3-Methyl Phenol mg/L	4-Met Phenol mg/L	,4-Dimethy Phenol mg/L
0	03-Mar-97					
1	04-Mar-97	1				
14	17-Mar-97	2				
28	31-Mar-97	3				
31	03-Apr-97					
35	07-Apr-97					
38	10-Apr-97					
42	14-Apr-97	4				
45	17-Apr-97					
49	21-Apr-97					
52	24-Apr-97					
56	28-Apr-97	5				
59	01-May-97					
63	05-May-97					
66	08-May-97					
67	09-May-97					
70	12-May-97	6				
74	16-May-97					
78	20-May-97					
80	22-May-97					
85	27-May-97	7				
88	30-May-97	0 (1)	<0.1	<0.1	<0.1	<0.1
89	31-May-97					
90	01-Jun-97	1				
91	02-Jun-97					
92	03-Jun-97	2	<0.1	<0.1	<0.1	<0.1
94	05-Jun-97	3	<0.1	<0.1	<0.1	<0.1
96	07-Jun-97	4	<0.1	<0.1	<0.1	<0.1
98	09-Jun-97	5	<0.1	<0.1	<0.1	<0.1
101	12-Jun-97	6	<0.1	<0.1	<0.1	<0.1
106	17-Jun-97	7	<0.1	<0.1	<0.1	<0.1
109	20-Jun-97	8	<0.1	<0.1	<0.1	<0.1
112	23-Jun-97	9	<0.1	<0.1	<0.1	<0.1
115	26-Jun-97	10	*Potential false positive*			
116	27-Jun-97					
119	30-Jun-97	11				
126	07-Jul-97					
127	08-Jul-97	12				
129	10-Jul-97					
130	11-Jul-97	13				
133	14-Jul-97	14				
136	17-Jul-97	15				
140	21-Jul-97	16				
143	24-Jul-97					
147	28-Jul-97	17				
150	31-Jul-97	18				
154	04-Aug-97	19				

(1) initiation

APPENDIX C

BIOKINETIC EVALUATION OF INDIVIDUAL PHASE III BATCH TESTS

Appendix C: Biokinetic Evaluation of Individual Phase III Batch Tests

Table of Contents

$$\frac{dS}{dt} = \frac{-q_{max} X S}{K_S + S + \frac{S^2}{K_i}} \qquad \text{(C-1)}$$

in which S is the substrate concentration (mg_S/L), t is time (days), q_{max} is the maximum specific substrate utilization rate coefficient ($mg_S/(mg_X \cdot day)$), X is the active biomass concentration able to biodegrade the substrate (mg_X/L), K_s is the Monod or half-velocity coefficient (mg_S/L), and K_i is the Haldane inhibition coefficient (mg_S/L). Literature values of self-inhibitory kinetic parameters for ammonia, phenol, and thiocyanate can be obtained from Gee *et al.* (1990), Sáez and Rittmann (1993), and Neufeld *et al.* (1981), respectively. It should be noted that Neufeld *et al.* (1981) described the self-inhibition of thiocyanate by a non-Haldane kinetic expression, which did not fully capture the degree of thiocyanate self-inhibition observed during the Phase III batch tests. A Haldane expression for the aerobic biodegradation of thiocyanate was developed based on curve fitting the experimental data and on the values of q_{max}, Y (true yield, mg_X/mg_S), and K_s reported by Neufeld *et al.* (1981). The self-inhibitory nature of a substrate can be observed by the increasing lag times observed when a series of otherwise similar batch tests have increasing initial substrate concentrations. The phenomena of increased lag times with increasing initial thiocyanate concentrations is illustrated in Figure C-1. A similar approach was used to determine appropriate K_I values for phenol and ammonia, based on the Phase I, II, and III batch tests. The Haldane kinetic parameters used in this evaluation of the Phase III batch tests are provided in Table C-3. A comparison of the specific growth rates for ammonia oxidizers, phenol degraders, and thiocyanate degraders is provided in Figure C-2. The specific growth rate is defined by the following equation:

$$\mu = \frac{Y q_{max} S}{K_s + S + \frac{S^2}{K_i}} \qquad \text{(C-2)}$$

in which μ is the specific growth rate (1/day).

The literature indicates that three major interactions exist among nitrification, phenol biodegradation, and thiocyanate biodegradation. As illustrated in Figure C-3, the three previously defined interactions are:

1. the aerobic biodegradation of thiocyanate releases ammonia nitrogen, which is the initial substrate in nitrification (Luthy and Jones, 1980);

2. phenol is a strong non-competitive inhibitor of nitrification (Neufeld *et al.*, 1980); and

3. thiocyanate is a weak inhibitor of aerobic phenol biodegradation, and it has been described either as competitive inhibition (Neufeld and Valiknac, 1979) or as non-competitive inhibition (Kumaran and Paruchuri, 1997).

The aerobic biodegradation of thiocyanate can be represented by the following mass balance equation (Neufeld *et al.*, 1981):

$$SCN^- + 2\,H_2O + 2\,O_2 \rightarrow CO_2 + SO_4^{2-} + NH_4^+ \qquad \text{(C-3)}$$

Thus, each mg/L of thiocyanate degraded releases 0.24 mg/L of ammonia nitrogen. In the Phase III batch tests inoculated with both nitrifiers and heterotrophs, the ammonia nitrogen released by the thiocyanate degraders can be oxidized to nitrite and nitrate by the nitrifiers.

The non-competitive inhibition of *Nitrosomonas* activity by phenol can be described by the following equation (Neufeld *et al.*, 1980):

$$\frac{dS_N}{dt} = \left(\frac{4.4}{4.4 + \sqrt{S_P}}\right)\left(\frac{-q_{max,N} X_N S_N}{K_{s,N} + S_N + \frac{S_N^2}{K_{iN}}}\right) \qquad \text{(C-4)}$$

in which S_N is the ammonia nitrogen concentration (mg N/L), X_N is the active *Nitrosomonas* biomass concentration (mgx/L), S_P is the phenol concentration (mg/L), and the remaining kinetic coefficients are for the oxidation of ammonia nitrogen to nitrite nitrogen by *Nitrosomonas*. In non-competitive inhibition, increasing the concentration of the inhibitor (phenol) effectively decreases the value of the $q_{max,N}$. The degree of inhibition is independent of substrate concentration (ammonia nitrogen). Figure C-4 illustrates the decrease in q_{max} for ammonia nitrogen oxidation as a function of phenol concentration based on equation (C-4). The correlation of Neufeld *et al.* (1980) indicates that a phenol concentration of 100 mg/L reduces the rate of *Nitrosomonas* activity by about 70 percent.

The relatively weak inhibition of phenol degradation by thiocyanate has been described in terms of either competitive inhibition (Neufeld and Valiknac, 1979) or non-competitive inhibition (Kumaran and Paruchuri, 1997). The two reported descriptions of the inhibition of phenol biodegradation are compared in Figure C-5. At 100 mg/L of phenol, the reported competitive and non-competitive models predict virtually the same phenol utilization rates. However, at 10 mg/L phenol, the competitive model predicts a greater extent of inhibition than does the non-competitive model. The competitive inhibition approach of Neufeld and Valiknac (1979) was used in describing the Phase III batch test results, because it had the potential to predict the greatest degree of inhibition. The kinetic expression used to describe competitive inhibition of phenol biodegradation by thiocyanate had the following form (Neufeld and Valiknac, 1979) :

$$\frac{dS_P}{dt} = \frac{-q_{max,P} X_P S_P}{K_{s,P}\left(1 + \frac{\sqrt{S_T}}{1.26}\right) + S_P + \frac{S_P^2}{K_{iP}}} \qquad \text{(C-5)}$$

in which S_P is the phenol concentration (mg/L), S_T is the thiocyanate concentration (mg/L), and the other kinetic parameters are for phenol.

C.3 Non-Matrix Batch Test Results

The Phase III short-term batch tests contained only combinations of ammonia, phenol, and thiocyanate in laboratory water (*i.e.*, no groundwater from monitoring well MW-7D was used) and offered the opportunity to verify the ability of the kinetic coefficients listed in Table 5–3 and of a mechanistic microbial growth model to describe substrate disappearance. Biomass and substrate mass balance equations for each added compound were solved simultaneously. For each microorganism type, the substrate and biomass equations were of the form

$$\frac{dS}{dt} = \frac{-q_{max} X S}{K_s + S + \frac{S^2}{K_i}} \qquad \text{(C-6)}$$

$$\frac{dX}{dt} = \frac{Y\, q_{max}\, X\, S}{K_s + S + \frac{S^2}{K_i}} - b\, X \qquad \text{(C-7)}$$

in which Y is the true yield for the particular substrate (mg_x/mg_s) and b is the first-order biomass loss rate coefficient (1/day). The non-competitive inhibition of ammonia degraders by phenol and competitive inhibition by thiocyanate of phenol biodegradation used equations (C-4) and (C-5), respectively, instead of the simple Haldane terms in equations (C-6) and (C-7). (The complete mathematical expressions for each substrate are presented later in Section 5.3.d) Model inputs included the initial substrate and biomass concentrations. During the Phase III batch tests, initial *Nitrosomonas* concentrations were determined by monitoring the decrease in ammonia nitrogen concentration and the increase in nitrite- and nitrate-nitrogen concentrations during batch tests that contained only ammonia as a biodegradable substrate. Determining the distribution of added heterotrophic biomass into phenol-degrading and thiocyanate-degrading fractions was part of the model calibration process. The initial biomass concentrations used by the mechanistic model to describe the Phase III batch tests are presented in Table C-4.

C.3.a Batch Test IIIST-1 (ammonia alone)

The IIIST-1 short-term batch test consisted of adding inocula of nitrifying and heterotrophic microorganisms to nutrient media that also contained a targeted ammonia concentration of 300 mg N/L as the only substrate. This batch test had two objectives: (1) to verify that the nitrifying component of the inoculum was indeed active and (2) to provide an estimate of the initial nitrifier biomass concentration in all of the short- and long-term batch tests started on March 4, 1997. A trial-and-error approach of curve fitting the observed decrease in ammonia concentrations was used to estimate the initial nitrifier concentration, based on the kinetic parameters for *Nitrosomonas* listed in Table C-3. The predicted ammonia decay curve was obtained by simultaneously solving equations (C-6) and (C-7) via a fourth-order Runge-Kutta algorithm (Chapra and Canale, 1988). An initial ammonia concentration of 275 mg N/L was assumed, based on the measured initial concentration. Curve fitting suggested that the initial *Nitrosomonas* biomass concentration was about $1 \cdot 10^7$ CFU/mL (1 mg_x/L). The observed and predicted ammonia decay curves are compared in Figure C-6. The ability of the curve-fitted predicted curve to capture the general shape and magnitude of the observed data points suggests that the *Nitrosomonas* kinetic parameters obtained from the literature (Gee *et al.*, 1990) describe the activity of the nitrifying inoculum and that an initial *Nitrosomonas* biomass concentration of $1 \cdot 10^7$ CFU/mL is reasonable.

C.3.b Batch Test IIIST-2 (ammonia and phenol)

The IIIST-2 short-term batch test consisted of adding inocula of nitrifying and heterotrophic microorganisms to nutrient media that also contained a targeted ammonia concentration of 300 mg N/L and a targeted phenol concentration of 250 mg/L. The objective of the IIIST-2 batch test was to verify the reported inhibition of *Nitrosomonas* activity by the presence of phenol. The measured initial ammonia and phenol concentrations of 275 mg N/L and 209 mg/L, respectively, were used as the initial substrate concentrations for curve fitting of the two decay curves. The initial biomass concentrations of ammonia- and phenol-degraders were assumed equal to those for the IIIST-1 batch test and are listed in Table C-4.

The observed ammonia and phenol concentrations plotted in Figure C-7 confirm that phenol does inhibit *Nitrosomonas* activity. Comparison of Figure C-6 (the ammonia only IIIST–1 batch test) and Figure C-7 (the ammonia and phenol IIIST-2 batch test) suggests that *Nitrosomonas* activity is

sharply reduced when phenol is present. Complete removal of ammonia in the IIIST-1 batch test required about 13 days, while complete removal of ammonia in the IIIST-2 batch test (phenol present) required about 16 days. Phenol was present in the IIIST-2 batch test reactor for about 3 days before being completely removed by the phenol-degrading microorganisms. The additional lag time for ammonia removal in the IIIST-2 batch test is about equal to the length of time during which phenol remained present. Thus, the IIIST-2 batch test results suggest that phenol is an inhibitor of nitrification.

The predicted decay curves for ammonia and phenol during the IIIST-2 batch test were determined by simultaneously solving the mass balance equations for ammonia, nitrifier biomass, phenol, and phenol-degrading biomass. The ammonia and nitrifier biomass mass balance equations included terms for the non-competitive inhibition of nitrification by phenol as illustrated in equation (C-4). The observed and predicted decay curves for the IIIST-2 batch test are provided in Figure C-7. The good match between the observed and predicted phenol decay curves suggests that ammonia has no effect on phenol biodegradation. The good agreement between the observed and predicted ammonia decay curves suggests that the inhibition of nitrification by phenol follows the non-competitive relationship reported by Neufeld *et al.* (1980). Thus, the observed interactions between nitrification and phenol in the IIIST-2 batch test are consistent with those reported in the literature.

C.3.c Batch Test IIIST-8 (ammonia and thiocyanate)

The IIIST-8 short-term batch test consisted of adding inocula of nitrifying and heterotrophic microorganisms to nutrient media that also contained a targeted ammonia concentration of 300 mg N/L and a targeted thiocyanate concentration of 180 mg/L. The objective of the IIIST-8 batch test was to determine the presence of any additional interactions between nitrification and thiocyanate, other than the reported release of ammonia during the aerobic biodegradation of thiocyanate. The measured initial ammonia and thiocyanate concentrations were 283 mg N/L and 170 mg/L, respectively, and were used as the initial substrate concentrations for curve fitting the two decay curves. The initial *Nitrosomonas* biomass concentration was determined from the ammonia decay curve observed during the IIIST-7 batch test (an ammonia only batch test) and was equal to $2 \cdot 10^7$ CFU/mL (2 mg_x/L). The assumed initial thiocyanate-degrading biomass concentration was the value used in developing the predicted curves in Figure C-1 and was equal to $4 \cdot 10^5$ CFU/mL (0.04 mg_x/L).

The predicted decay curves for ammonia and thiocyanate during the IIIST-8 batch test were determined by simultaneously solving the mass balance equations for ammonia, nitrifier biomass, thiocyanate, and thiocyanate-degrading biomass. The only interaction included in the mass balance equations was the release of ammonia during the aerobic biodegradation of thiocyanate. Because the predicted lag time for thiocyanate removal occurred about a week after the predicted disappearance of ammonia nitrogen and about a week after the development of a large nitrifier population, the predicted removal of thiocyanate had no impact on the predicted IIIST-8 ammonia decay curve.

The observed and predicted ammonia and thiocyanate decay curves are compared in Figure C-8. The comparison yields two observations. First, although the predicted curve suggests that the thiocyanate should be gone within 16 days, the observed thiocyanate concentrations show no significant decrease within 17 days. The lack of any thiocyanate removal suggests that no active thiocyanate-degrading microorganisms were present (for an unknown reason) in the IIIST-8 batch test or that the required lag time is greater than 17 days. Without a significant active population of thiocyanate-degrading microorganisms, the IIIST-8 batch test can not confirm that the aerobic biodegradation of thiocyanate results in the accumulation of ammonia in solution.

The second observation from Figure C-8 is that the ammonia appears to be removed at a rate slower than predicted. Curve-fitting of the ammonia decay curve suggests that the exposure of the

Nitrosomonas population to a constant thiocyanate concentration of 170 mg/L inhibits the rate of nitrification by between 10 and 20 percent at 10 days. However, concentrations of nitrite- and nitrate-nitrogen that accumulated during the IIIST-8 batch test that the ammonia-nitrogen concentration at 10 days should be 0 mg N/L, instead of the observed 28 mg N/L. In this case, the ammonia decay curve would indicate no apparent inhibition of nitrification by thiocyanate. Because the nitrite/nitrate analysis tends to be more accurate than ammonia analysis, it is assumed that thiocyanate does not inhibit nitrification.

Although the IIIST-8 batch test was unable to confirm that the aerobic biodegradation of thiocyanate results in the release of ammonia, it suggests that a constant thiocyanate concentration of 170 mg/L has little effect on nitrification rates.

C.3.d Batch Test IIIST-3 (ammonia, phenol, and thiocyanate)

The IIIST-3 short-term batch test consisted of adding inocula of nitrifying and heterotrophic microorganisms to nutrient media that also contained a targeted ammonia concentration of 300 mg N/L, a targeted phenol concentration of 250 mg/L, and a targeted thiocyanate concentration of 180 mg/L. The objective of the IIIST-3 batch test was to confirm the reported interactions between nitrification, phenol, and thiocyanate that are illustrated in Figure C-3. The measured initial ammonia, phenol, and thiocyanate concentrations were 275 mg N/L, 211 mg/L, and 170 mg/L, respectively, which were used as the initial substrate concentrations for the curve fitting of the three substrate decay curves. The initial *Nitrosomonas* biomass concentration was determined from the ammonia decay curve observed during the IIIST-1 batch test (an ammonia only batch test) and was equal to $1 \cdot 10^7$ CFU/mL (1 mg_X/L). The assumed initial phenol-degrading and thiocyanate-degrading biomass concentrations were $5 \cdot 10^5$ CFU/mL (0.05 mg_X/L) and $4 \cdot 10^5$ CFU/mL (0.04 mg_X/L), respectively.

The predicted decay curves for ammonia and thiocyanate during the IIIST-8 batch test were determined by simultaneously solving the mass balance equations for ammonia, nitrifier biomass, phenol, phenol-degrading biomass, thiocyanate, and thiocyanate-degrading biomass. The mass balance equations included the interactions illustrated in Figure C-3 and described in Section 5.2 above. The complete set of mass balance equations is

$$\frac{dS_N}{dt} = \left(\frac{4.4}{4.4+\sqrt{S_P}}\right)\left(\frac{-q_{max,N}\, X_N\, S_N}{K_{s,N}+S_N+\frac{S_N^2}{K_{i,N}}}\right)+\gamma\left(\frac{q_{max,T}\, X_T\, S_T}{K_{s,T}+S_T+\frac{S_T^2}{K_{i,T}}}\right) \qquad \text{(C-8)}$$

$$\frac{dX_N}{dt} = \left(\frac{4.4}{4.4+\sqrt{S_P}}\right)\left(\frac{Y_N\, q_{max,N}\, X_N\, S_N}{K_{s,N}+S_N+\frac{S_N^2}{K_{i,N}}}\right) - b_N\, X_N \qquad \text{(C-9)}$$

$$\frac{dS_P}{dt} = \frac{-q_{max,P}\, X_P\, S_P}{K_{s,P}\left(1+\frac{\sqrt{S_T}}{1.26}\right)+S_P+\frac{S_P^2}{K_{i,P}}} \qquad \text{(C-10)}$$

$$\frac{dX_P}{dt} = \frac{Y_P\, q_{max,P}\, X_P\, S_P}{K_{s,P}\left(1+\frac{\sqrt{S_T}}{1.26}\right)+S_P+\frac{S_P^2}{K_{i,P}}} - b_P\, X_P \qquad \text{(C-11)}$$

$$\frac{dS_T}{dt} = \frac{-q_{max,T} X_T S_T}{K_{s,T} + S_T + \frac{S_T^2}{K_{i,T}}} \qquad \text{(C-12)}$$

$$\frac{dX_T}{dt} = \frac{Y_T q_{max,T} X_T S_T}{K_{s,T} + S_T + \frac{S_P^2}{K_{i,T}}} - b_T X_T \qquad \text{(C-13)}$$

in which γ is the mg of ammonia nitrogen released per mg of thiocyanate biodegraded (0.2414 mg N/mg SCN-), S is substrate concentration (mg/L), X is biomass concentration (mg_X/L), b is the first-order biomass loss coefficient (1/day), the subscript N refers to ammonia nitrogen, the subscript P refers to phenol, and the subscript T refers to thiocyanate. Equations (C-8) through (C-13) were solved simultaneously using a fourth-order Runge-Kutta algorithm (Chapra and Canale, 1988).

The ammonia, phenol, and thiocyanate decay curves predicted by the six mass balance equations are compared to the observed decay curves in Figure C-9. The agreement between the predicted and observed decay curves for phenol and thiocyanate suggests that the combination of the above mass balance equations and the kinetic coefficients listed in Table C-3 successfully describe the activity of the phenol- and thiocyanate-degrading microorganisms.

Figure C-9 also demonstrates that ammonia is released during the aerobic biodegradation of thiocyanate. As the thiocyanate is rapidly being biodegraded between days 15 and 17, the ammonia nitrogen increases by the appropriate stoichiometric amount, *i.e.*, the removal of about 180 mg/L of thiocyanate results in about a 43 mg N/L increase in ammonia nitrogen concentration.

In contrast to the phenol and thiocyanate comparisons, there is a poor agreement between the predicted and observed ammonia-nitrogen decay curves. For example, the predicted decay curve indicates that the ammonia should be gone within 13 days. The observed decay curve indicates that it required 34 days for the ammonia is disappear. A possible explanation for the apparent adverse effect is that an largely inactive *Nitrosomonas* inoculum was added to the batch test reactor, *i.e.*, an experimental artifact. However, the IIIST-1 and IIIST-2 batch tests demonstrated that the *Nitrosomonas* inoculum was active.

The inability of the mechanistic model to describe the ammonia decay curve suggests that the simultaneous presence of phenol and thiocyanate in solution has an adverse effect on nitrification. This adverse effect is much stronger than the non-competitive inhibition of nitrification by phenol alone. A rapid loss of biomass during the 3.5 days when phenol and thiocyanate were both present can explain the observed ammonia decay curve. Curve fitting indicated that an active *Nitrosomonas* biomass concentration of about 0.0025 mg_X/L at 3.5 days would allow the model to describe the observed ammonia decay curve for the IIIST-3 batch test. This suggests that the active *Nitrosomonas* concentration decreased 400-fold during the 3.5 days when both phenol and thiocyanate were present. For this to occur, the first-order biomass loss rate coefficient (b_N) for *Nitrosomonas* in equation (C–9) needs to be increased from 0.1 1/day to about 1.9 1/day when phenol and thiocyanate are present together.

C.3.e Batch Tests IIILT-8 and IIIST-3D (biomass assays)

The non-matrix batch tests IIIST-1, IIIST-2, and IIIST-3 demonstrated that the aerobic biodegradation of ammonia, phenol, and thiocyanate can be described by the mechanistic model, *except* when attempting to describe nitrification when phenol and thiocyanate are present together. Curve fitting of the observed ammonia decay curve from the IIIST-3 batch test suggests that the data could be explained by a 400-fold decrease in active *Nitrosomonas* biomass concentration during the initial 3.5 days of the batch test when phenol and thiocyanate were present together. The experimental results presented in this section confirm that the combination of phenol and thiocyanate is toxic to *Nitrosomonas*.

The IIIST-3 batch test was repeated, except that samples were withdrawn from the batch reactor and assayed for *Nitrosomonas* activity on days 3 and 6 (see Section 4.3.3 for protocol). This duplicate of the IIIST-3 batch test is called IIIST-3D. An ammonia-only batch test called IIILT-8 was run along side the IIIST-3D batch test to provide a basis of comparison, so that the phenol/thiocyanate effect could be demonstrated. A second ammonia-only batch test called IIILT-10 was used in combination with the IIILT-8 batch test to determine the initial active concentration of *Nitrosomonas* in all three batch tests.

The comparison of the predicted and observed ammonia decay curves for the IIILT-8 and IIILT-10 is provided in Figure C-10. An initial active *Nitrosomonas* biomass concentration of about $2.5 \cdot 10^8$ CFU/mL or 25 mg_x/L allows the mechanistic model to describe the two observed ammonia decay curves.

The active *Nitrosomonas* biomass concentrations predicted by the modeling and obtained from the biomass assays for IIILT-8 are compared in Figure C-11. The biomass assay results mirror the predicted increase in active biomass concentration during the first 3 days of the batch test. On day 6 of the batch test, the biomass assay results suggest a smaller residual active biomass concentration than is predicted by the modeling. This suggests that when the substrate is absent the first-order biomass loss rate coefficient for *Nitrosomonas* (b_N) is faster than the 0.1 1/day value listed in Table C-3. However, as long as substrate is available, the IIILT-8 batch test results suggest that the biomass assay and modeling approaches generate comparable active *Nitrosomonas* biomass concentrations.

Figure C-12 presents the predicted and observed substrate decay curves for the IIIST-3D batch test. The modeling predicts a faster rate of ammonia removal than is actually observed. The modeling suggests that ammonia should be removed within 5 days, while it actually required about 15 days. Thus, the IIIST-3D batch test appears to have captured the same adverse effect on nitrification as was observed in the IIIST-3 batch test. Curve fitting the observed ammonia decay curve suggests that the first-order biomass loss rate coefficient (b_N) for *Nitrosomonas* in equation (C-9) needs to be increased from 0.1 1/day to about 1.9 1/day when phenol and thiocyanate are present together. This is consistent with the IIIST-3 batch test. As illustrated in Figure C-13, when this elevated b_N value is incorporated into the model to address biomass loss when phenol and thiocyanate are present, the model successfully tracks the observed ammonia decay curve.

The biomass assay results suggest that the combination of phenol and thiocyanate are toxic to *Nitrosomonas*. The day-3 biomass assay results for the IIILT-8 and IIIST-3D batch tests are presented in Figure C-14. The biomass-containing water sample harvested from the ammonia-only IIILT-8 bioreactor generates nitrite- and nitrate-nitrogen at a faster rate than that harvested from the IIIST-3D reactor. The active *Nitrosomonas* biomass concentrations obtained from the biomass assays are provided in Table C-5. On day 3, the assay results indicate an active biomass concentration of about 100 mg_x/L in the IIIST-8 batch test, while the IIIST-3D batch test only had 30 mg_x/L. Compared to the ammonia-alone batch test, the combined presence of phenol and thiocyanate results in less biomass being generated.

The active *Nitrosomonas* biomass concentrations predicted by the modeling and obtained from the biomass assays are compared in Figure C-15. By assuming a b_N value of 1.9 when phenol and thiocyanate are present together, the modeling predicts that the active *Nitrosomonas* biomass concentration decreases from 25 mg_x/L to about 1 mg_x/L by day 3, while the day-3 biomass assay result is 30 mg_x/L. At day 6, the two approaches are in agreement: the predicted active biomass concentration is 4.5 mgx/L and the observed concentration from the biomass assay is 2.5 mg_x/L.

A possible explanation for the difference between the day-3 active biomass concentrations obtained by modeling and from the biomass assays is that the adverse phenol/thiocyanate effect remains reversible for the first several days. The biomass assay results listed in Table C-5 suggest that active *Nitrosomonas* biomass concentrations did not change significantly from 25 mg_x/L between day 0 to day 3. However, by day 6, the active biomass concentration dropped to 2.5 mg_x/L. This suggests that during the first 3 days the cells were inhibited by the phenol/thiocyanate mixture, resulting in no net growth. When removed from the mixture and placed in clean media, the cells returned to their initial level of activity. Somewhere between day 3 and 6, the adverse effect became irreversible and resulted in the loss of activity observed by the biomass assay. Thus, like most chemical toxicants, the adverse effect of phenol and thiocyanate on *Nitrosomonas* activity appears to be a function of toxicant concentration and exposure time.

C.3.f Summary of Non-Matrix Batch Tests

The Phase III non-matrix short-term batch tests did not contain diluted MW-7D groundwater. In general, the non-matrix batch tests demonstrated the ability of a mechanistic model to predict the biological removal of ammonia, phenol, and thiocyanate, when the substrates were present individually or in pairs. The model consisted of equations (C-8) through (C-13) and the literature-derived kinetic coefficients listed in Table C-3. However, when the mechanistic model attempted to describe the simultaneous removal of all three substrates, the model overestimated nitrification rates. Biomass assays and additional biokinetic modeling indicated inhibitory and eventually toxic effects on nitrification are associated with the combined presence of phenol and thiocyanate. Therefore, in addition to confirming the substrate interactions illustrated in the Figure C-3, the non-matrix batch tests indicated a combined toxic effect of phenol and thiocyanate on *Nitrosomonas*.

C.4 Matrix Batch Test Results

The matrix batch tests contained various dilutions of groundwater collected from the site's MW-7D well. Batch test media ranged from a 5 percent groundwater solution to a 100 percent groundwater solution. One objective of the matrix batch tests was to determine the fate of the contaminants of concern in an aerobic biological process. Another objective was to determine the potential for nitrification at various groundwater dilutions. Of particular interest was the determination of any additional adverse effects that the groundwater matrix may have on nitrification, beyond those observed during the non-matrix batch tests.

C.4.a Batch Tests IIIST-6 and IIILT-6 (5 and 10 percent solutions)

The IIIST-6 batch test consisted of adding nutrients, pH buffer, and inocula of nitrifying and heterotrophic microorganisms to a reactor containing a 5 percent solution of MW-7D groundwater. The IIILT-6 batch test was identical to the IIIST-6 batch test, except that the reactor contained a 10 percent solution of MW-7D groundwater. An objective of the two batch tests was to determine the ability of the initial inoculum to biodegrade aerobically the ammonia nitrogen, phenol, and

thiocyanate found in the diluted groundwater. Another objective was to evaluate the ability of the calibrated mechanistic model to predict the decay curves for the three compounds.

The predicted and observed compound decay curves for the IIIST-6 (5%-solution) batch test are compared in Figure C-16. The initial observed ammonia nitrogen, phenol, and thiocyanate concentrations were 56, 59, and 45 mg/L, respectively. Based on the cumulative generation of nitrite- and nitrate- nitrogen during the batch test, on the amount of ammonia nitrogen that can be stoichiometrically produced from the biodegradation of thiocyanate, and on the initial TKN concentration of 190 mg/L, the predicted ammonia decay curve assumed an initial ammonia concentration of 130 mg/L. The agreement between the predicted and observed decay curves for phenol and thiocyanate suggests that the biodegradation of these two organic compounds is as observed during the non-matrix batch tests, *i.e.*, the same kinetic coefficients and mass balance equations can be used to describe phenol and thiocyanate removal. However, even when the toxic effect associated with the combined presence of phenol and thiocyanate on nitrification is included in the mechanistic model, the model predicts a much shorter time for ammonia removal than is observed. The model predicts that the ammonia should be removed within 15 days, while ammonia removal actually occurred within 55 days. Thus, Figure C-16 suggests that something is inhibiting nitrification in addition to the phenol/thiocyanate toxic effect and the other known interactions illustrated in Figure 5-3.

The predicted and observed compound-decay curves for the IIILT-6 (10%-solution) batch test are compared in Figure C-17. The predicted ammonia decay curve assumed an initial ammonia concentration of 275 mg N/L. As with the 5%-solution batch test, the removal of phenol and thiocyanate in a 10%-solution batch test is successfully described by the calibrated mechanistic model, while ammonia removal is not described by the model. The model predicted that ammonia removal would occur within 20 days, while 80 percent removal of the assumed initial ammonia concentration required about 153 days. Figure C-17 supports the hypothesis that an additional factor is inhibiting nitrification beyond those quantified during the non-matrix batch tests. Because the lag time increased from about 55 days for the 5%-solution to about 153 days for the 10%-solution, the degree of inhibition or toxicity increases with the concentration of groundwater in the batch test reactor.

During the operation of the Phase III batch tests, it became obvious that the time frames required to demonstrate nitrification were much longer than originally anticipated. This was confirmed by the IIILT-6 (10%-solution) batch test, which had a lag time of about 153 days. Thus, the experimental protocol was modified such that selected short-term and long-term batch test reactors were re-inoculated with nitrifying and heterotrophic microorganisms. Also, because the inhibitory or toxic effect appears to be stronger at higher concentrations of groundwater in the reactor, the potential existed that virtually all of the initial nitrifying biomass could have been killed before the nitrifiers acclimated to the groundwater chemical matrix. The reinoculation protocols are described in Section 4.3.2.

To capture the long lag times for the ammonia decay curves observed during various matrix batch tests, the mechanistic model assumed that an undefined toxic agent in the MW-7D groundwater is responsible for the loss of active *Nitrosomonas* biomass. The reinoculation of matrix batch test solutions with *Nitrosomonas* after the phenol and thiocyanate are removed allowed the biomass loss rate coefficient b_N that corresponds to the matrix toxicity effect to be quantified.

The matrix toxicity b_N value was determined from biomass assays performed at 3 and 6 days following the reinoculation with *Nitrosomonas* of solutions obtained from the IIILT-2 (16%-solution) and IIILT-3 (33%-solution) batch tests. The objective of the biomass assays was to determine the initial die-off of *Nitrosomonas* biomass in a solutions containing MW-7D groundwater after the solution had be subjected to aerobic treatment for 85 days. As in the previous biomass assays, the initial *Nitrosomonas* biomass concentration in the reactors after reinoculation was assumed to be 25

mg_X/L, based on the IIILT-8 and IIILT-10 batch test results. As provided in Table C-5 and Figure C-18, active *Nitrosomonas* biomass concentrations decreased with exposure time to the groundwater solutions. This loss in active biomass occurred despite the fact that no phenol or thiocyanate remained in the IIILT-2 and IIILT-3 batch test reactors. Thus, some component of the MW-7D groundwater remains in solution after 85 days of aerobic treatment that is toxic to unacclimated *Nitrosomonas* cultures.

Figure C-18 suggests that the initial rate at which active *Nitrosomonas* biomass disappears is the same for the IIILT-2i and IIILT-3i batch reactors. (The small i refers to the batch test after reinoculation and ii refers to the batch test after a second reinoculation.) Despite having a factor of 2 difference in their initial concentration of groundwater, the loss of active biomass for both batch tests can be described by a first-order biomass loss coefficient (b_N) of 0.62 1/day. Of course, the concentration of the undefined toxic agent may be similar in the two reactors after 85 days of aerobic treatment.

To quantify the effect that the undefined toxic agent in the MW-7D groundwater had on active *Nitrosomonas* biomass, a *matrix time factor* was computed. The concept is that the toxic agent exerts its toxic effect for a length of time called the matrix time factor. Based on the results of Figure C-18, the added rate of biomass loss due to the toxic agent is 0.62 1/day. Table C-6 shows the various biomass decay rate coefficients used in the modeling of the non-matrix and matrix batch tests. Whenever the groundwater is toxic, the supplemental 0.62 1/day decay rate coefficient is in effect.

The matrix time factors for the IIIST-6 (5%-solution) and IIILT-6 (10%-solution) batch tests were determined by trial-and-error curve fitting. In other words, the time that the matrix toxicity was active was varied until the ammonia decay curves were fitted well. Figure C-19 illustrates that a matrix time factor of 18 days results in a predicted ammonia decay curve that matches the observed ammonia decay curve for the IIIST-6 (5%-solution) batch test. Figure C-20 illustrates that a matrix time factor of 58 days is appropriate for the IIILT-6 (10%-solution) batch test. Thus, the greater the concentration of MW-7D groundwater in the batch test, the greater is the calculated matrix time factor, and greater is the toxic effect on *Nitrosomonas*.

C.4.b Batch Tests IIIST-5 and IIIST-5i (10 percent solution)

The IIIST-5 batch test consisted of adding nutrients, pH buffer, and inocula of nitrifying and heterotrophic microorganisms to a reactor containing a 10-percent solution of MW-7D groundwater. An initial objective of the IIIST-5 batch test was evaluate the kinetic coefficients for ammonia, phenol, and thiocyanate biodegradation in the presence of a 10-percent groundwater solution. Although the phenol and thiocyanate had disappeared within the first 12 days of the batch test, the ammonia showed no signs of biodegradation after 33 days. On day 34, the remaining medium was split into two portions. The first portion was not modified in any way and was in essence a continuation of the original IIIST-5 batch test. The second portion was re-inoculated with nitrifying and heterotrophic microorganisms and was called the IIIST-5i batch test. The splitting of the media allowed the impact of reinoculation to be evaluated and provided a means of determining if any significant *Nitrosomonas* biomass developed after the initial exposure to the groundwater matrix.

The predicted and observed ammonia, phenol, and thiocyanate decay curves for the IIIST-5 and IIIST-5i batch tests are provided in Figure C-21. Once again, the mechanistic model captures the removal of phenol and thiocyanate. The blue line in Figure C-21 represents the predicted ammonia decay curve allowing for a possible phenol/thiocyanate toxicity, but the blue line does not consider any matrix effects. Without matrix effects, the model predicts that ammonia should be removed within about 19 days. Figure C-21 indicates that no ammonia removal occurred within 58 days. This confirms the observation from the IIIST-6 (5%-solution) and IIILT-6 (10%-solution) batch tests that

there is a potentially toxic agent to *Nitrosomonas* in the groundwater in addition to the previously evaluated phenol/thiocyanate toxic effect. The ammonia decay curve for the IIILT-6 (10%-solution) batch test had a lag time of over 150 days. Thus, the initial inoculum of *Nitrosomonas* in the IIIST-5 (10%-solution) batch test apparently had insufficient time to recover sufficiently from the initial exposure to the groundwater matrix to nitrify measurable amounts of ammonia within 58 days.

After 33 days of aerobic treatment, a portion of the IIIST-5 media was re-inoculated with *Nitrosomonas* and heterotrophic microorganisms. As shown in Figure C-21, nitrification removed all of the ammonia nitrogen within 21 days of reinoculation. If there was no matrix inhibition of nitrification, then the inoculation of the IIIST-5i batch test reactor with 25 mg_x/L of *Nitrosomonas* should only required 3 days to remove all of the ammonia nitrogen. Because no phenol or thiocyanate remained in solution at reinoculation, the inhibition must be due to matrix inhibition. Curve fitting indicated that a matrix time factor of 7.5 days is required for the mechanistic model to describe the observed ammonia decay curve for the IIIST-5i batch test. The resulting predicted ammonia decay curve is represented by the purple line in Figure C-21.

The matrix time factor for the IIIST-5i (10%-solution) batch test after 33 days of prior aerobic treatment is 7.5 days. A matrix time factor of 58 days is required for the model to describe the ammonia decay curve for the IIILT-6 (10%-solution), which received no aerobic treatment prior to inoculation. Thus, longer periods of aerobic treatment appear to reduce the toxicity of the MW-7D groundwater to unacclimated cultures of *Nitrosomonas*.

C.4.c Batch Test IIILT-6i (10 percent solution)

The IIILT-6 batch test consisted of adding nutrients, pH buffer, and inocula of nitrifying and heterotrophic microorganisms to a reactor containing a 10-percent solution of MW-7D groundwater. After no ammonia removal was observed during the first 84 days of the IIILT-6 (10%-solution) batch test, the remaining medium was split into two portions on day 85. The first portion was not modified in any way and was in essence a continuation of the original IIILT-6 batch test. The results of the continuing IIILT-6 batch test are described in Section 5.4.a. The second portion was re-inoculated with nitrifying and heterotrophic microorganisms and was called the IIILT-6i batch test. As shown in Figure C-22, nitrification removed all of the ammonia nitrogen within 6 days of reinoculation. Curve fitting indicated that a matrix time factor of 1.0 days is required for the mechanistic model to describe the observed ammonia decay curve for the IIILT-6i batch test. The resulting predicted ammonia decay curve is represented by the purple line in Figure C-22.

The calculated matrix time factor for the IIILT-6i batch test supports the trend that the shorter matrix time factors are associated with longer lengths to aerobic treatment prior to inoculation with unacclimated *Nitrosomonas* cultures. As provided in Table C-7, no prior aerobic treatment of a 10-percent solution of MW-7D groundwater results in calculated matrix time factor of 58 days. With 33 days of prior aerobic treatment (IIIST-5i), the matrix time factor is reduced to 7.5 days. With 84 days of aerobic treatment prior to reinoculation (IIILT-6i), the matrix time factor is reduced to 1.0 days. Thus, the longer a 10-percent solution of MW-7D groundwater is exposed to aerobic treatment, the less toxic the solution is to an unacclimated inoculum of *Nitrosomonas*.

C.4.d Batch Test IIILT-2 (16 percent solution)

The IIILT-2 batch test consisted of adding nutrients, pH buffer, and inocula of nitrifying and heterotrophic microorganisms to a reactor containing a 16-percent solution of MW-7D groundwater. The initial ammonia nitrogen, phenol, and thiocyanate concentrations were 480, 198, and 141 mg/L, respectively. Figure C-23 illustrates that the aerobic biodegradation of phenol and thiocyanate in a 16-percent solution of MW-7D groundwater can be described by the same kinetic coefficients and interactions used for the more dilute MW-7D groundwater batch tests and for the non-matrix batch tests. Thus, the 16-percent groundwater solutions does not alter the biokinetics of phenol and thiocyanate biodegradation.

The initial inoculum of *Nitrosomonas* did not oxidize significant amounts of ammonia nitrogen. The batch reactor was re-inoculated with microorganisms on day 85, but no significant nitrification was observed. The batch-test reactor was re-inoculated for a second time on day 114, which resulted in observable nitrification. As illustrated in Figure C-23, the second reinoculation was able to nitrify all of the ammonia within 12 days. Curve fitting indicated that a matrix time factor of 1.0 days allowed the model to describe the observed decay curve. The predicted decay curve for the second reinoculation, plotted in Figure C-23, assumes a matrix time factor of 1.0 days and an ammonia concentration of 500 mg N/L at the time of the second reinoculation. However, the model without any matrix toxicity also accurately described the decay curve.

The ability of the second reinoculation of *Nitrosomonas* to start nitrifying the remaining ammonia almost instantly suggests that the prior aerobic treatment of the 16-percent groundwater solution for 113 days removes almost all of the matrix toxicity. This interpretation discounts any generation of active biomass from the first reinoculation.

C.4.e Batch Test IIILT-1 (25 percent solution)

The IIILT-1 batch test consisted of adding nutrients, pH buffer, and inocula of nitrifying and heterotrophic microorganisms to a reactor containing a 25 percent solution of MW-7D groundwater. The initial ammonia nitrogen, phenol, and thiocyanate concentrations were 649, 273, and 199 mg/L, respectively. The comparison of the predicted and observed phenol and thiocyanate decay curves provided in Figure C-24 suggests that the mechanistic model and the kinetic coefficients listed in Table C-3 can describe the biological removal of phenol and thiocyanate in a 25-percent solution of MW-7D groundwater, although a close examination of the thiocyanate data suggests that thiocyanate was removed at rates slower than predicted by the model.

The IIILT-1 batch test results suggest that a 25-percent solution of MW-7D is toxic to *Nitrosomonas* and that this toxic effect can be mitigated by aerobic treatment. Figure C-24 illustrates that the initial inoculum of *Nitrosomonas* and the first reinoculation of *Nitrosomonas* on day 85 were unable to nitrify significant amounts of ammonia. The matrix time factor for the first reinoculation is at least 6 days (Figure C-18). The batch reactor was re-inoculated for a second time on day 118, which resulted in about a 90-percent removal of ammonia within 21 days of reinoculation. Figure C-24 indicates that the observed ammonia decay curve following the second reinoculation can be described by the mechanistic model when the model includes a matrix time factor of 6.5 days. As with the interpretation of the IIILT-2 (16%-solution) batch test, any impact of the first reinoculation on the resulting ammonia decay curve is not considered.

The IIILT-1 (25%-solution) batch test results support the hypothesis that prior aerobic treatment reduces the toxicity of the MW-7D groundwater solution. The initial inoculation and first reinoculation of the batch reactor with *Nitrosomonas* resulted in little or no nitrification. The second reinoculation was performed after the solution was subjected to 117 days of aerobic treatment. This

second reinoculation with 14 mg_x/L of *Nitrosomonas* resulted in nitrification with an apparent matrix time factor of 6.5 days. In comparison, the second reinoculation of the IIILT-2 (16%-solution) batch test had an apparent matrix time factor of only 1.0 days. Thus, removal of the toxicity from solutions containing MW-7D groundwater appears to require longer periods of aerobic treatment as the solution strength increases.

C.4.f Batch Test IIILT-3 (33 percent solution)

The IIILT-3 batch test consisted of adding nutrients, pH buffer, and inocula of nitrifying and heterotrophic microorganisms to a reactor containing a 33-percent solution of MW-7D groundwater. The initial ammonia nitrogen, phenol, and thiocyanate concentrations were 931, 318, and 273 mg/L, respectively. Comparisons of the predicted and observed decay curves for ammonia nitrogen, phenol, and thiocyanate are provided in Figure C-25. The mechanistic model was able to describe the phenol decay curve.

The observed thiocyanate decay curve indicated that complete thiocyanate removal occurred within 70 days of the initial inoculation. The model predicted that the thiocyanate would be entirely removed within about 20 days. Thiocyanate removal required an additional 50 days than the time predicted by the model. Based on the success of the model in describing thiocyanate at more dilute concentrations of MW-7D groundwater, Figure C-25 suggests inhibition of thiocyanate biodegradation in the 33-percent solution of MW-7D groundwater.

The IIILT-3 (33%-solution) batch test results suggest a slightly different explanation for the observed ammonia nitrogen decay curve than the previous long-term matrix batch tests. The initial inoculation of *Nitrosomonas* resulted in no observable nitrification. On day 85, the IIILT-3 batch test reactor was re-inoculated with 25 mg_x/L of unacclimated *Nitrosomonas*. By day 111, the *Nitrosomonas* population had recovered sufficiently such that 214 mg/L of ammonia nitrogen, or about 23 percent of the initial ammonia nitrogen concentration, had been nitrified to nitrite and nitrate. Such activity for the first reinoculation was not observed in the 16-percent (IIILT-2) and 25-percent (IIILT-1) solutions. It is not clear why the first reinoculation of the IIILT-3 (33%-solution) batch test with *Nitrosomonas* inoculum was able to reduce ammonia concentrations, while similar inocula added to less concentrated solutions were unable to reduce ammonia concentrations.

As illustrated in Figure C-18 and Table C-5, there was a rapid loss of active *Nitrosomonas* biomass immediately after this first reinoculation due to the toxicity of the 33-percent solution of MW-7D groundwater. The matrix time factor for this first reinoculation was at least 6 days (Figure C-18). Curve fitting based on varying only the matrix time factor alone did not provide a satisfactory description of the ammonia decay curve. However, a matrix time factor of 9 days combined with a 45 percent reduction in the value of $q_{max,N}$ was able to describe the ammonia decay curve following the first reinoculation. In addition to an initial loss of unacclimated *Nitrosomonas* biomass after reinoculation, the curve-fitting effort suggests that the growth rate of the surviving microorganisms and their progeny is inhibited by the 33-percent solution of MW-7D groundwater.

A second reinoculation of the IIILT-3 (33%-solution) batch test reactor with *Nitrosomonas* was performed on day 114. A 92-percent reduction in ammonia nitrogen concentration occurred within 25 days of this second reinoculation. Without considering any effects due to the carryover of active *Nitrosomonas* biomass from the first reinoculation, curve fitting of the ammonia decay curve following the second reinoculation suggests a matrix time factor of 6.5 days. While the use of this matrix time factor allows the model to describe when most of the ammonia nitrogen is gone, its use is not strictly correct, because active biomass carried over from the first reinoculation. This probably explains the poor description of the ammonia decay curve immediately after the second reinoculation (Figure C-25).

In summary, the IIILT-3 (33%-solution) batch test results provide the first evidence that the biodegradation of thiocyanate can be inhibited by the groundwater. The IIILT-3 batch test results also provide additional support for the hypothesis that the toxicity of the groundwater to unacclimated cultures of *Nitrosomonas* can be reduced by prior aerobic treatment.

C.4.g Batch Test: IIILT-4 (100 percent solution)

The IIILT-4 batch test consisted of adding nutrients, pH buffer, and inocula of nitrifying and heterotrophic microorganisms to a reactor containing undiluted MW-7D groundwater. The initial ammonia nitrogen, phenol, and thiocyanate concentrations were 2690, 977, and 721 mg/L, respectively. Comparisons of the predicted and observed decay curves for ammonia nitrogen, phenol, and thiocyanate are provided in Figure C-26. The observed ammonia, phenol, and thiocyanate concentrations suggested no significant biodegradation during the first 84 days. The reactor was re-inoculated on day 85. Observed compound removal after day 85 is questionable. The thiocyanate concentrations drop to about 100 mg/L on days 105 and 132, but the reported value of 628 on day 118 suggests that measured reduction in the thiocyanate may be just an analytical artifact. The model indicates that phenol and thiocyanate should be removed within 17 and 52 days, respectively. This is clearly not the case, which suggests that the matrix is inhibiting or is toxic to the added heterotrophic microorganisms in a much more intense manner than is described by the model. The predicted ammonia decay curve for the initial inoculum indicates that no ammonia removal is expected during the first 84 days due to the excessive phenol/toxicity effect caused by the slow predicted removal of phenol and thiocyanate. While the predicted decay curve agrees with the observed decay curve of no ammonia nitrogen removal, there is no reason to believe that model includes all of actual mechanisms responsible for no ammonia removal.

The IIILT-4 batch test results indicate that aerobic treatment is not likely to be effective in the biological treatment of solutions consisting almost entirely of MW-7D groundwater.

C.4.h Matrix Time Factors

Matrix time factors are an index of groundwater toxicity toward *Nitrosomonas*. The matrix time factors for the matrix batch tests are summarized in Figure C-27 in terms of groundwater concentrations and the length of time the matrix was subject to aerobic treatment prior to reinoculation. Those batch tests that only had an initial inoculation of *Nitrosomonas* had 0 days of prior aerobic treatment. Higher matrix time factors represent a more toxic solution. The general trends obtained from Figure C-27 are that the toxicity of the solution to *Nitrosomonas* increases with increased MW-7D groundwater concentration and the toxicity of the solution decreases with increased aerobic treatment prior to the addition of the unacclimated *Nitrosomonas* inoculum.

C.5 Summary

Phase III of the biotreatability study performed on groundwater collected from the monitoring wells MW-7D and MW-13S on the Waukegan Manufactured Gas and Coke Plant (WMGCP) site consisted of numerous batch tests that were designed to verify and quantify the interactions among phenol, thiocyanate, and nitrification, and to assess the groundwater matrix effects on aerobic biological activity. A biokinetic evaluation of individual Phase III batch tests had the following results:

- the aerobic biodegradation of phenol and thiocyanate by commercially-available microbial cultures can be described by Haldane inhibition kinetics when each compound is evaluated

separately in laboratory media (ammonia is reported to follow Haldane kinetics, but the Phase III batch tests did not allow verification);

- phenol is a strong inhibitor of nitrification (thiocyanate is reported to be a weak inhibitor of phenol biodegradation, but the Phase III batch tests did not allow verification);
- the combined presence of phenol and thiocyanate appears to have an initial inhibitory effect on nitrification that with time becomes a toxic effect resulting in the loss of active *Nitrosomonas* biomass;
- the chemical matrix of the groundwater collected from MW-7D had an adverse effect on nitrification at groundwater concentrations as low as 5 percent and batch tests performed at MW-7D groundwater concentrations of 15 and 33 percent demonstrated that the chemical matrix was toxic to the *Nitrosomonas* inocula;
- the chemical matrix of the groundwater collected from MW-7D appeared to inhibit thiocyanate biodegradation at concentrations possibly as low as 25 percent and completely inhibited thiocyanate biodegradation in the 100 percent MW-7D groundwater solution;
- the chemical matrix of the groundwater collected from MW-7D appeared to inhibit completely the aerobic biodegradation of phenol in the 100 percent MW-7D groundwater solution (sampling frequency precluded an assessment of matrix inhibition at lower groundwater concentrations); and
- prior aerobic treatment of the MW-7D groundwater appears to reduce the toxicity of the groundwater matrix to *Nitrosomonas*.

In conclusion, the biokinetic evaluation of the Phase III batch tests suggests that the contaminants of concern in the WMGCP aquifer (*i.e.*, phenol, thiocyanate, and ammonia) are biodegradable under aerobic conditions provided that sufficient dilution of the MW-7D groundwater is achieved to prevent complete inhibition of the respective microorganisms. The Phase III batch tests did not determine the maximal concentration of MW-7D groundwater that can support the biodegradation of phenol and thiocyanate, but the phenol and thiocyanate were completely removed from a 33 percent solution of MW-7D groundwater within 90 days. Nitrification was more sensitive to the adverse effects associated with the groundwater matrix than was the biodegradation of phenol and thiocyanate, but prior aerobic treatment of the groundwater appeared to reduce the intensity of the adverse effect. As with the biological treatment of coal gasification wastewaters, the aerobic biological treatment of the WMGCP groundwater appears possible provided that the various chemical and biological interactions are considered in process design and operation.

C.6 References

CHAPRA S. C. and CANALE R. P. 1988. *Numerical Methods for Engineers, Second Edition*. McGraw-Hill Book Company, New York, NY, 812 pp.

GEE S. C., SUIDAN M. T. and PFEFFER J. T. 1990. Modeling of nitrification under substrate-limiting conditions. *Journal of Environmental Engineering, ASCE* 116(1): 18-31.

KUMARAN P. and PARUCHURI Y. L. 1997. Kinetics of phenol biotransformation. *Water Research* 31(1): 11-22.

LUTHY R. G. and JONES L. D. 1980. Biological oxidation of coke plant effluent. *Journal of Environmental Engineering, ASCE* 106(4): 847-851.

NEUFELD R. D. and VALIKNAC T. 1979. Inhibition of phenol biodegradation by thiocyanate. *Journal Water Pollution Control Federation* 51(9): 2283-2291.

NEUFELD R. D., HILL A. J. and ADEKOYA D. O. 1980. Phenol and free ammonia inhibition to *Nitrosomonas* activity. *Water Research* 14: 1695-1703.

NEUFELD R. D., MATTSON L. and LUBON P. 1981. Thiocyanate bio-oxidation kinetics. *Journal of Environmental Engineering, ASCE* 107(5): 1035-1049.

SÁEZ P. B. and RITTMANN B. E. 1993. Biodegradation kinetics of a mixture containing a primary substrate (phenol) and an inhibitory co-metabolite (4-chlorophenol). *Biodegradation* 4: 3-21.

C.7 Tables

Table C-1. Description of the short-term Phase III batch tests.

Batch Test Name	Inoculation Dates	Description
IIIST-1	4 March 1997	300 mg N/L of NH_3 in laboratory water
IIIST-2	4 March 1997	300 mg N/L of NH_3 and 250 mg/L of phenol in laboratory water
IIIST-3	4 March 1997	300 mg N/L of NH_3, 250 mg/L of phenol, and 180 mg/L of thiocyanate in laboratory water
IIIST-3D	28 May 1997	300 mg N/L of NH_3, 250 mg/L of phenol, and 180 mg/L of thiocyanate in laboratory water
IIIST-4	4 March 1997	25 percent solution of MW-7D groundwater
IIIST-5	4 March 1997 7 April 1997	10 percent solution of MW-7D groundwater
IIIST-6	4 March 1997	5 percent solution of MW-7D groundwater
IIIST-7	7 April 1997	300 mg N/L of NH_3 in laboratory water
IIIST-8	7 April 1997	300 mg N/L of NH_3 and 180 mg/L of thiocyanate in laboratory water

Table C-2. Description of the long-term Phase III batch tests.

Batch Test Name	Inoculation Dates	Description
IIILT-1	4 March 1997 28 May 1997 30 June 1997	25 percent solution of MW-7D groundwater
IIILT-2	4 March 1997 28 May 1997 26 June 1997	16 percent solution of MW-7D groundwater
IIILT-3	4 March 1997 28 May 1997 26 June 1997	33 percent solution of MW-7D groundwater
IIILT-4	4 March 1997 28 May 1997	100 percent solution of MW-7D groundwater
IIILT-5	4 March 1997 28 May 1997	16 percent solution of MW-7D groundwater inoculated with site soil
IIILT-6	4 March 1997	10 percent solution of MW-7D groundwater
IIILT-7	none	poison control, 25 percent solution of MW-7D groundwater
IIILT-8	28 May 1997	300 mg N/L of NH_3 in laboratory water
IIILT-9	28 May 1997	a 5 percent solution of media from IIILT-1, which is equivalent to the reinoculation of a 1.25 percent solution of MW-7D groundwater
IIILT-10	28 May 1997	600 mg N/L of NH_3 in laboratory water

Table C-3. Kinetic coefficients used to develop the predicted substrate concentration curves for the Phase III batch tests.

Parameter	Symbol	Units	Substrate		
			NH_3-N	Phenol	Thiocyanate
True yield	Y	mg_x/mg_s	0.30	1.24	0.35
Maximum specific utilization rate	q_{max}	mg_s/mg_x•day	1.90	8.50	2.40
Half-velocity coefficient	K_s	mg_s/L	0.70	1.20	5.00
Haldane coefficient	K_i	mg_s/L	9000	65	300
Biomass loss coefficient	b	1/day	0.1	0.1	0.1
Minimum substrate concentration for steady-state growth	S_{min}	mg/L	0.15	0.01	0.68
Substrate concentration beyond which rates slow	S*	mg/L	79.4	8.8	38.7
Maximum substrate concentration for steady-state growth	S_{max}	mg/L	42,300	6,800	2,200

Table C-4. Assumed initial biomass concentrations for the Phase III short-term and long-term tests.

Approximate Inoculation Date	*Nitrosomonas* Calibration Batch Test	Initial *Nitrosomonas* Concentration (CFU/mL)	Initial *Nitrosomonas* Concentration (mg_x/L)	Initial Phenol-Degrading Bacteria Concentration (mg_x/L)	Initial Thiocyanate-Degrading Bacteria Concentration (mg_x/L)
3 April 1997	IIIST-1	$1.0 \cdot 10^7$	1.0	0.05	0.04
7 April 1997	IIIST-7	$2.0 \cdot 10^7$	2.0	0.05	0.04
28 May 1997	IIILT-8 IIILT-10	$2.5 \cdot 10^8$	25	1.25	1.40
30 June 1997	no-name	$1.4 \cdot 10^8$	14	0	0

Table C-5. Calculated active *Nitrosomonas* concentrations obtained from the biomass assays performed with samples harvested from the IIILT-8 (ammonia alone), IIIST-3D (ammonia, phenol, and thiocyanate), IIILT-2I (re-inoculated reactor containing a 16 percent solution of MW-7D groundwater), and IIILT-3i (re-inoculated reactor containing a 33 percent dilution of MW-7D groundwater) batch tests.

	Active *Nitrosomonas* concentration (mg/L)			
Exposure Time (days)	IIILT-8	IIIST-3D	IIILT-2i	IIILT-3i
0	25	25	25	25
0.83	*	*	*	15.5
3	100	30	3.0	3.0
6	20	2.5	0.6	0.75

* = not performed

Table C-6. First-order biomass loss rate coefficients for active *Nitrosomonas* biomass (b_N) used in equation (C-9) as a function of various assigned conditions.

Value of b_N (1/day)	Characteristic or When Used by Model
0.1	endogenous decay coefficient with no toxicity
0.62	biomass loss coefficient assumed during the initial length of elapsed time defined by the matrix time factor, when phenol and thiocyanate are not present together
1.9	biomass loss coefficient that describes the toxic effect created when phenol and thiocyanate are present together in solution, but no MW-7D groundwater is present
2.42	biomass loss coefficient assumed during the initial length of elapsed time defined by the matrix time factor, and when phenol and thiocyanate are present together in solution

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C.8 Figures

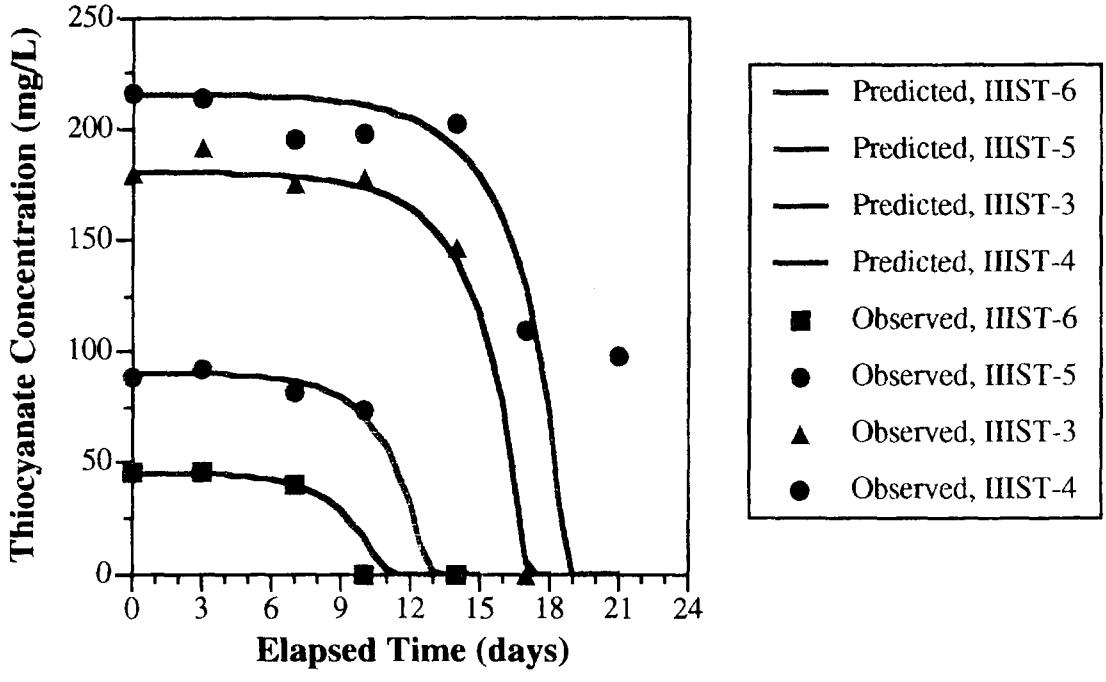

Figure C-1. Demonstration of increased lag times associated with increased initial concentrations of a self-inhibitory substrate. The predicted thiocyanate decay curves were calculated using the Haldane kinetic parameters listed in Table C-3 and an initial thiocyanate-degrading biomass concentration of 0.04 mg_x/L.

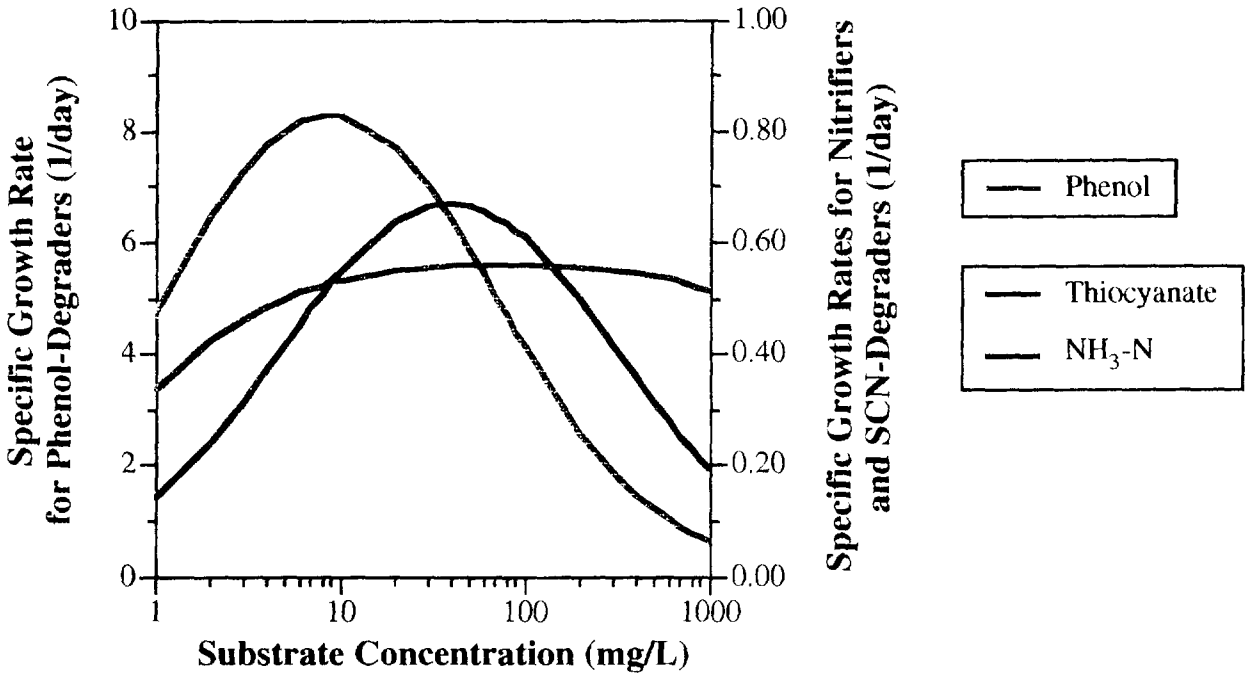

Figure C-2. Comparison of specific growth rates as a function of substrate concentration. Note that the above curves assume no interaction between substrates.

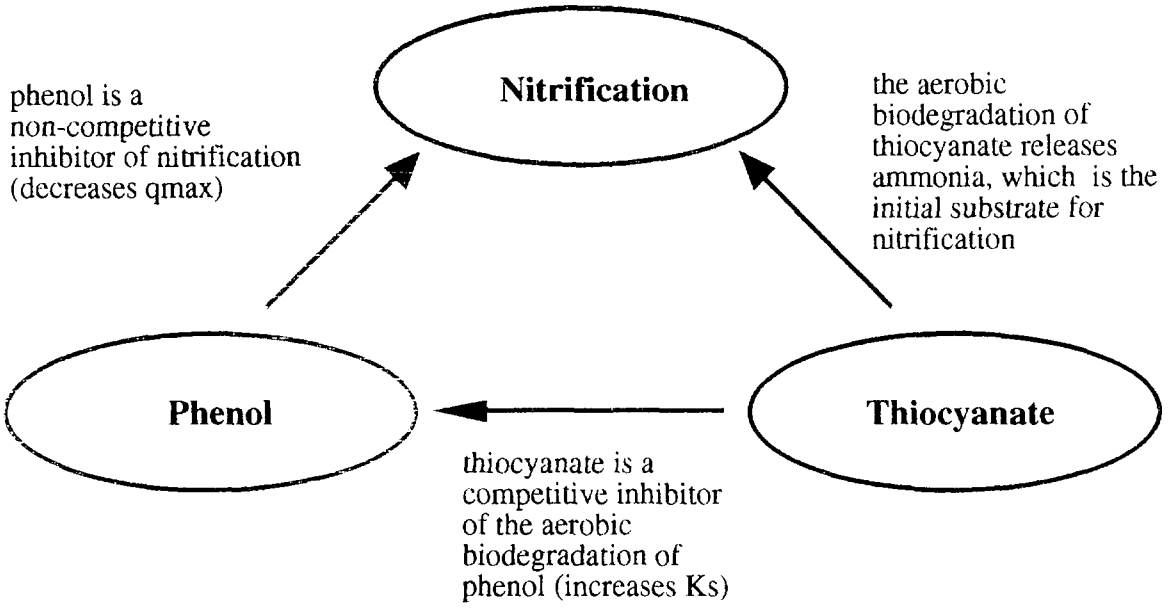

Figure C-3. Previously defined interactions among nitrification, phenol, and thiocyanate.

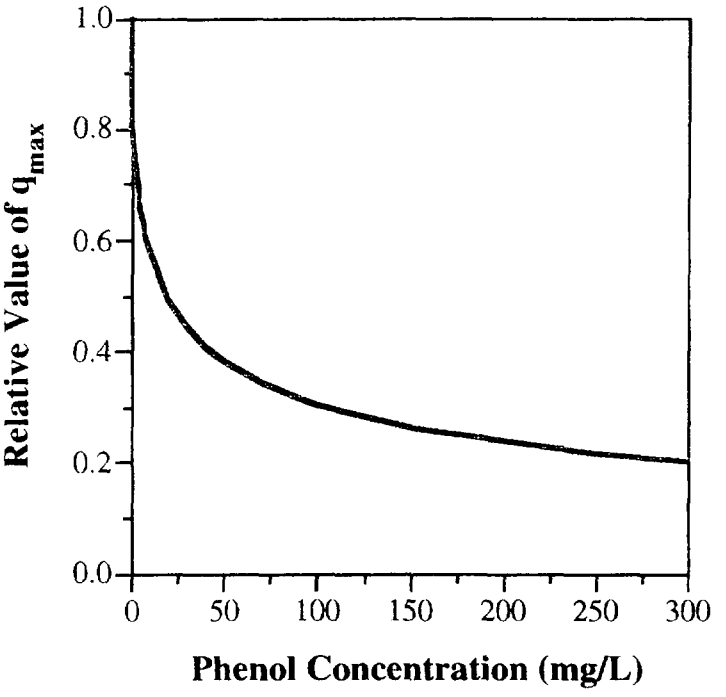

Figure 5.-4. Fractional effective q_{max} value for the oxidation of ammonia nitrogen to nitrite nitrogen by *Nitrosomonas* as a function of phenol concentration (Neufeld *et al.*, 1980).

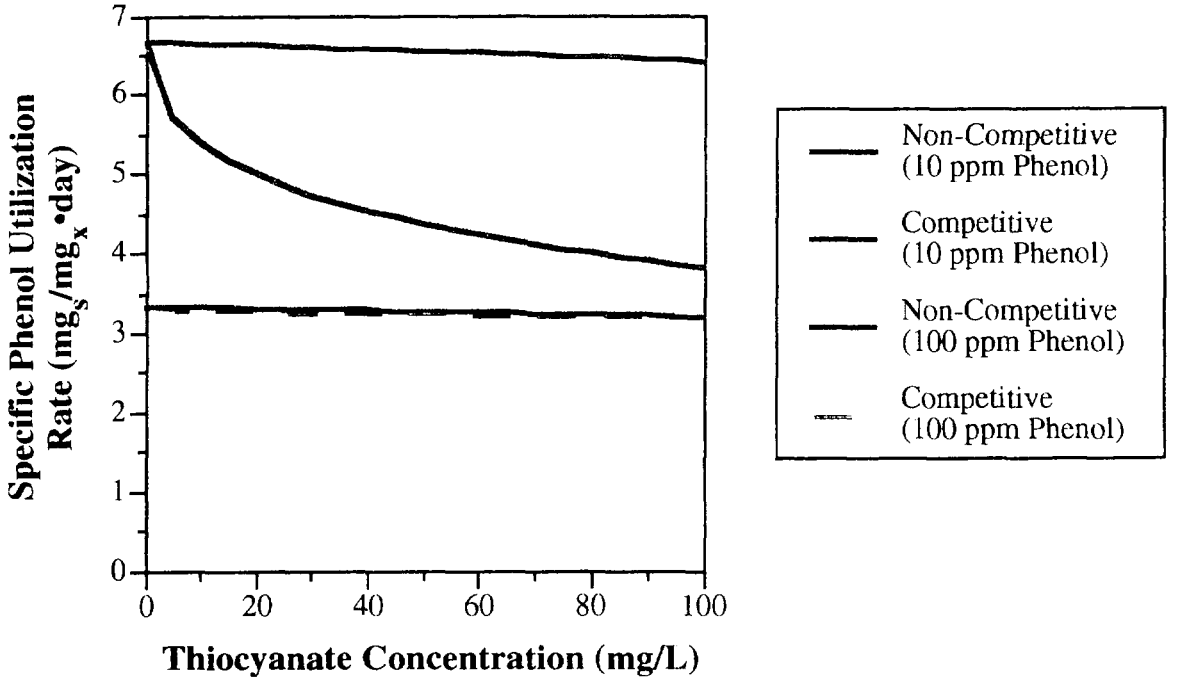

Figure C-5. Comparison of reported competitive and non-competitive inhibition of aerobic phenol biodegradation by thiocyanate as a function of thiocyanate and phenol concentrations.

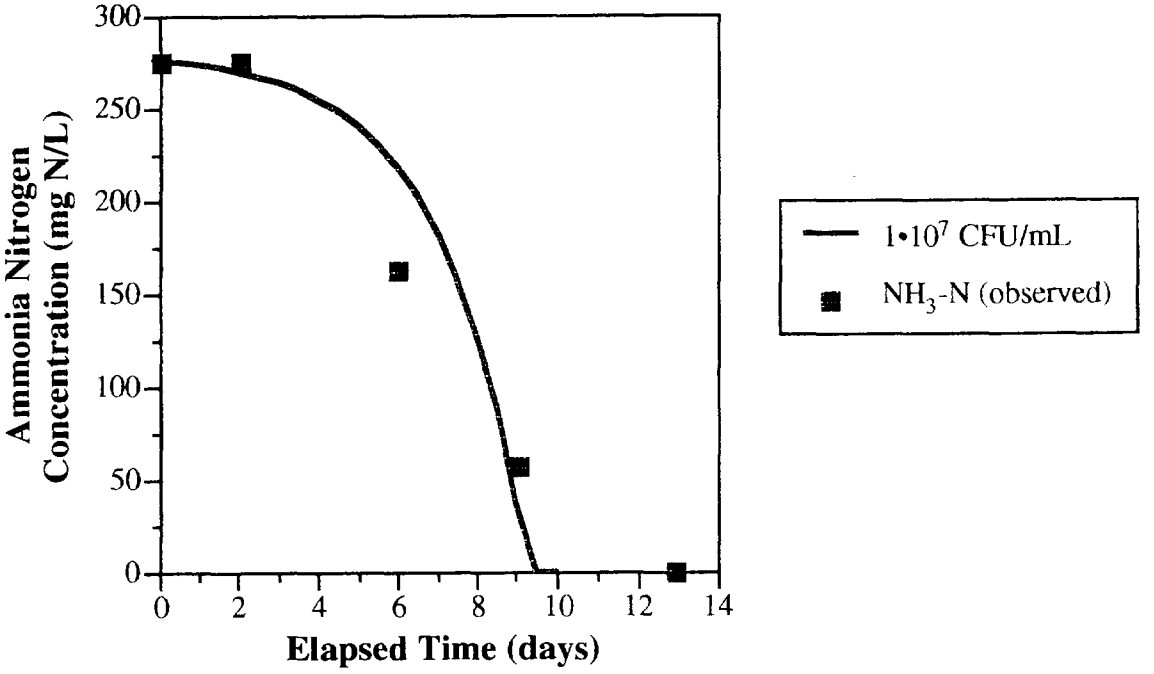

Figure C-6. Comparison of the predicted and observed ammonia nitrogen decay curves for the IIIST-1 batch test. The predicted curve assumes an initial *Nitrosomonas* biomass concentration of 1•10^7 CFU/mL or 1 mg_x/L.

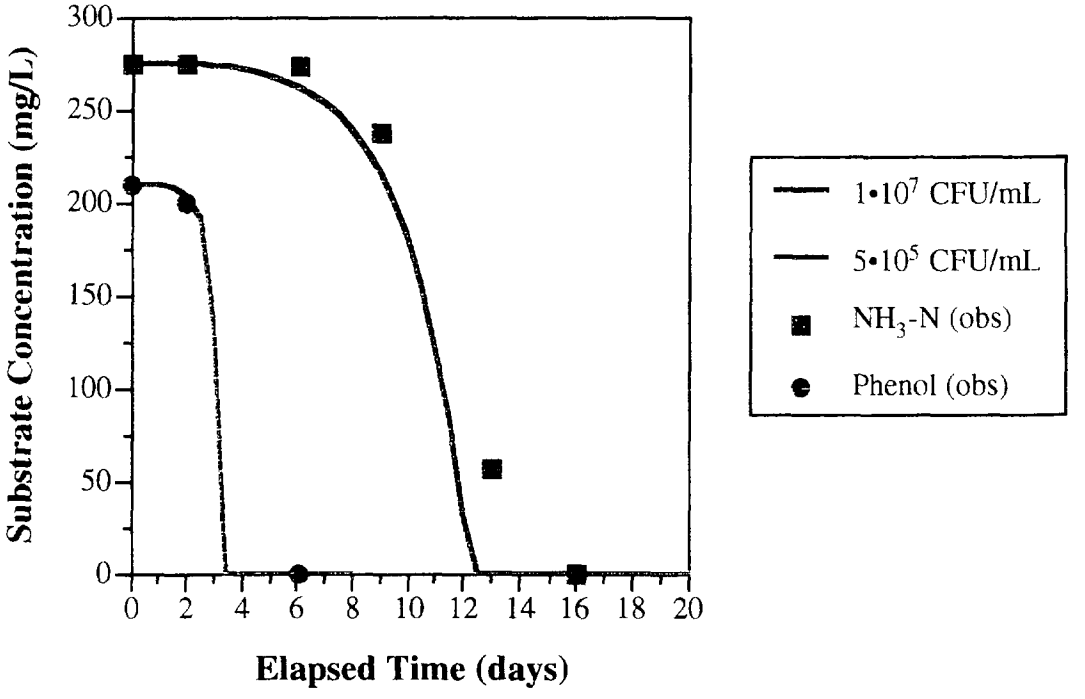

Figure C-7. Comparison of the predicted and observed decay curves for ammonia nitrogen and phenol during the IIIST-2 batch test. The assumed initial nitrifying and phenol-degrading biomass concentrations were 1•10^7 CFU/mL (1 mg_x/L) and 5•10^5 CFU/mL (0.05 mg_x/L), respectively.

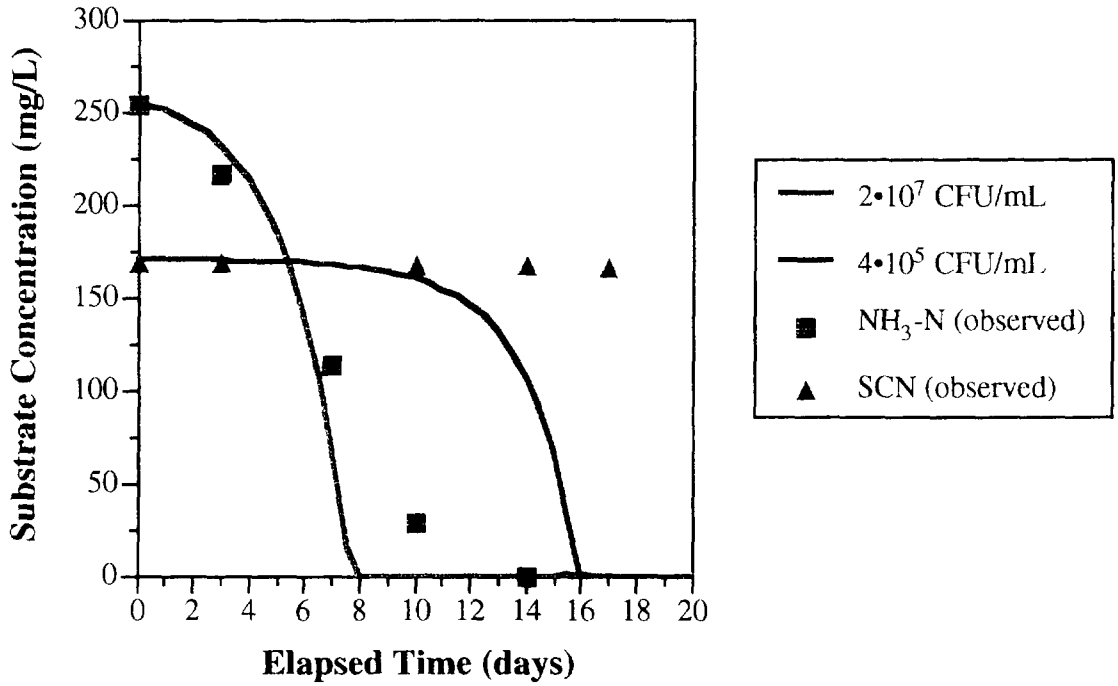

Figure C-8. Comparison of the predicted and observed decay curves for ammonia nitrogen and thiocyanate during the IIIST-8 batch test. The assumed initial nitrifying and thiocyanate-degrading biomass concentrations were $2 \cdot 10^7$ CFU/mL (2 mg_x/L) and $4 \cdot 10^5$ CFU/mL (0.04 mg_x/L), respectively.

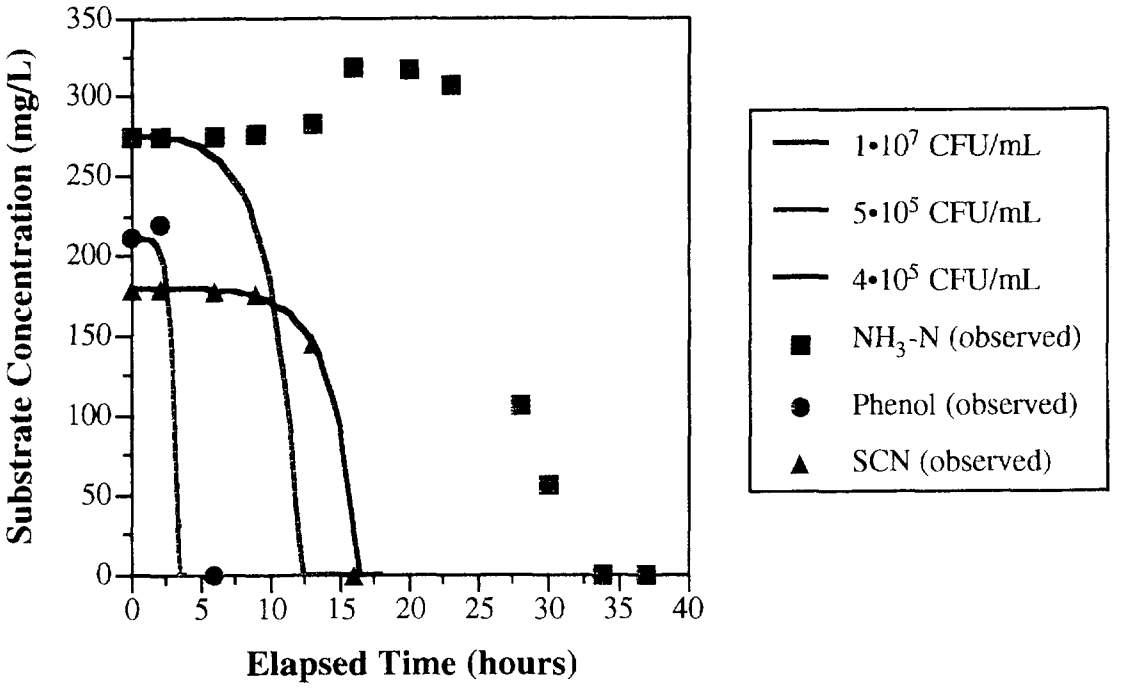

Figure C-9. Comparison of the predicted and observed decay curves for ammonia nitrogen, phenol, and thiocyanate during the IIIST-3 batch test. The assumed initial nitrifying, phenol-degrading, and thiocyanate-degrading biomass concentrations were $1 \cdot 10^7$ CFU/mL (1 mg_x/L), $5 \cdot 10^5$ CFU/mL (0.05 mg_x/L), and $4 \cdot 10^4$ CFU/mL (0.04 mg_x/L), respectively.

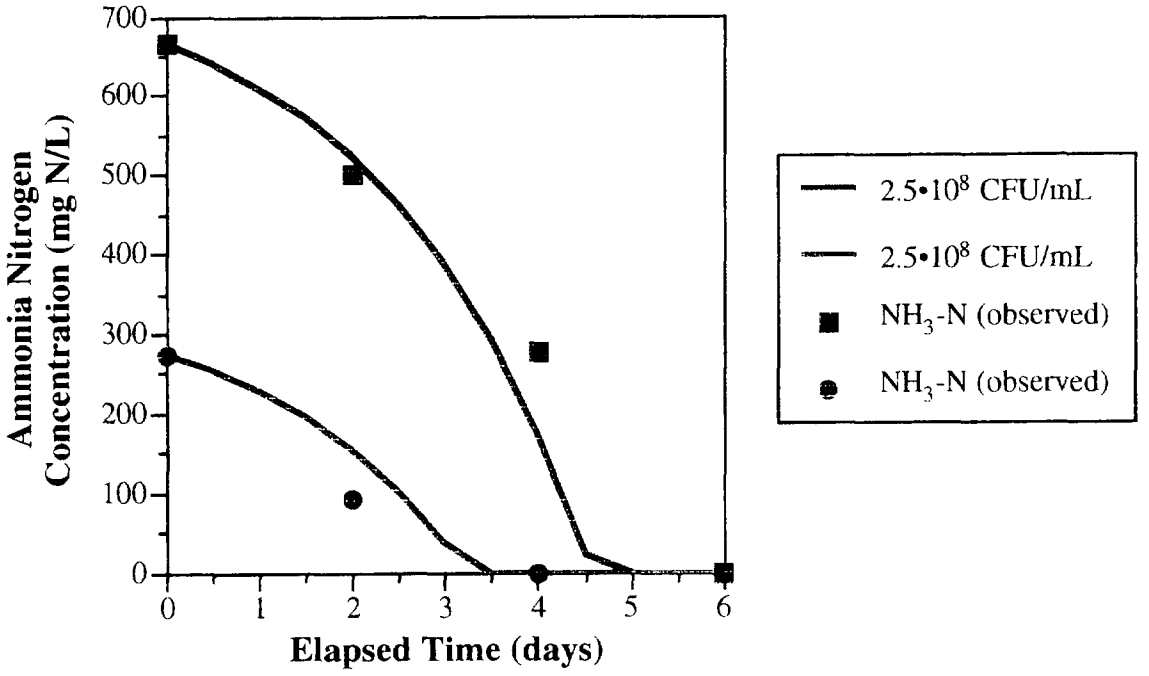

Figure C-10. Comparison of the predicted and observed ammonia nitrogen decay curves for the IIILT-8 (green) and IIILT-10 (blue) batch tests. Both predicted curves assume an initial *Nitrosomonas* biomass concentration of $2.5 \cdot 10^8$ CFU/mL or 25 mg_x/L.

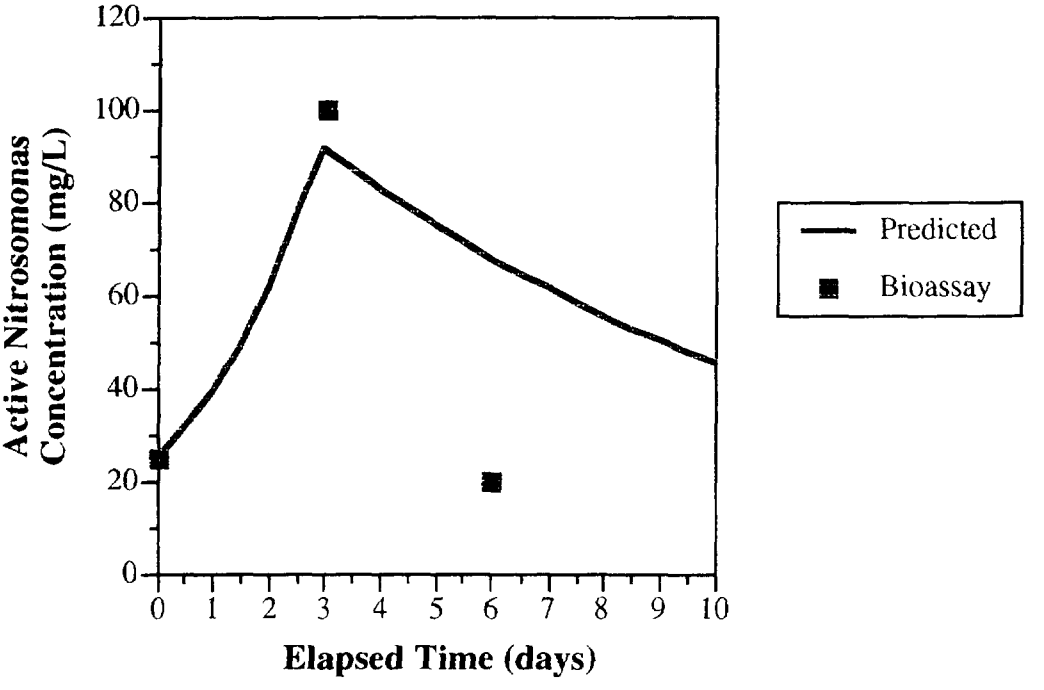

Figure C-11. Comparison of active *Nitrosomonas* biomass concentrations for the IIILT-8 batch test predicted by the biokinetic modeling and obtained from the biomass assays performed on days 3 and 6. Both sets of data assume an initial active *Nitrosomonas* biomass concentration of 25 mg_x/L.

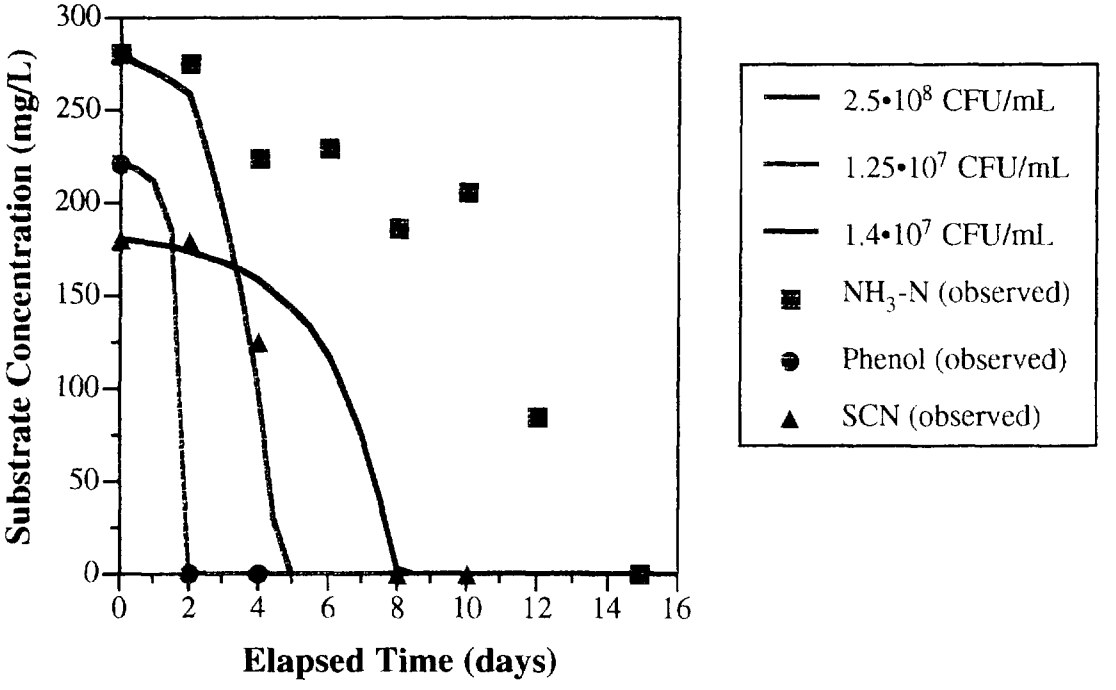

Figure C-12. Comparison of the predicted and observed decay curves for ammonia nitrogen, phenol, and thiocyanate during the IIIST-3D batch test with *no* adjustments for the phenol/thiocyanate effect on nitrification. The assumed initial nitrifying biomass concentration was $2.5 \cdot 10^8$ CFU/mL (25 mg_x/L). The initial phenol-degrading and thiocyanate-degrading biomass concentrations of $1.25 \cdot 10^7$ CFU/mL (1.25 mg_x/L), and $1.4 \cdot 10^7$ CFU/mL (1.4 mg_x/L), respectively, were obtained by curve fitting the observed decay curves.

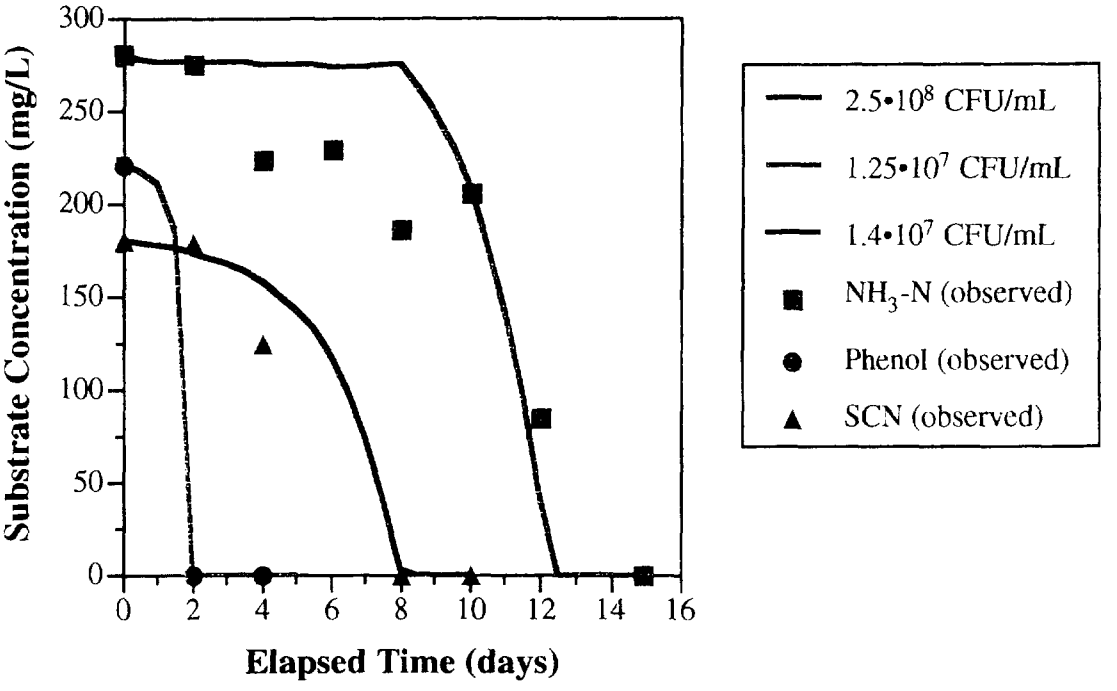

Figure C-13. Comparison of the predicted and observed decay curves for ammonia nitrogen, phenol, and thiocyanate during the IIIST-3D batch test assuming that b_N increases from the usual 0.1 1/day to 1.9 1/day when phenol and thiocyanate are present together. The initial biomass concentrations are as in Figure C-12.

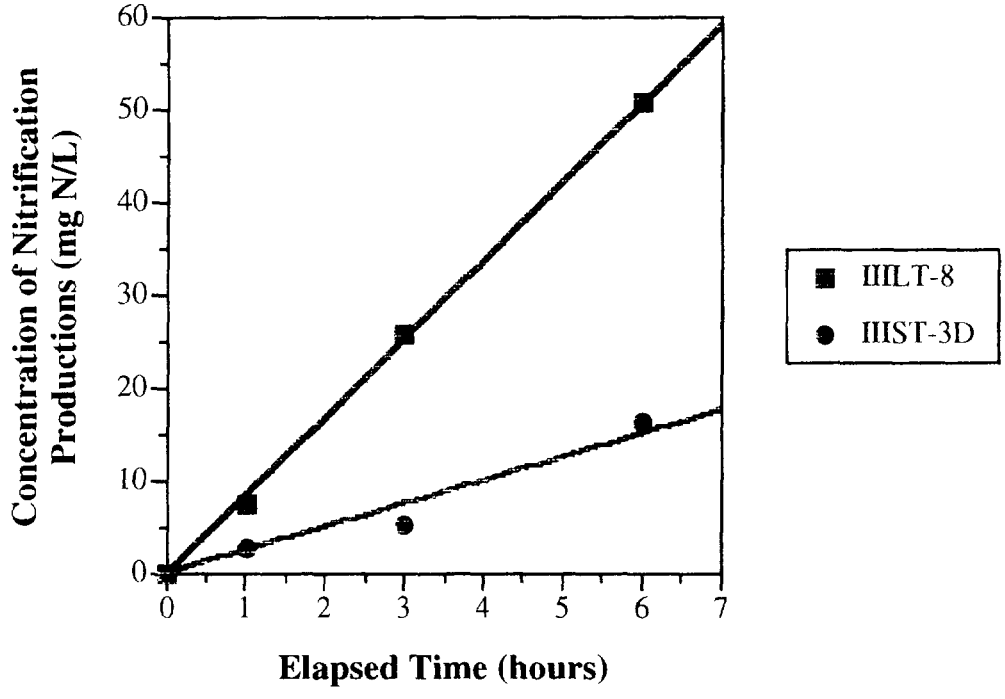

Figure C-14. Accumulation of nitrification products (nitrite-nitrogen and nitrate-nitrogen) for the biomass assays performed with biomass harvested from the IIILT-8 (ammonia) and IIIST-3D (ammonia, phenol, and thiocyanate) batch tests on day-3 of each batch test.

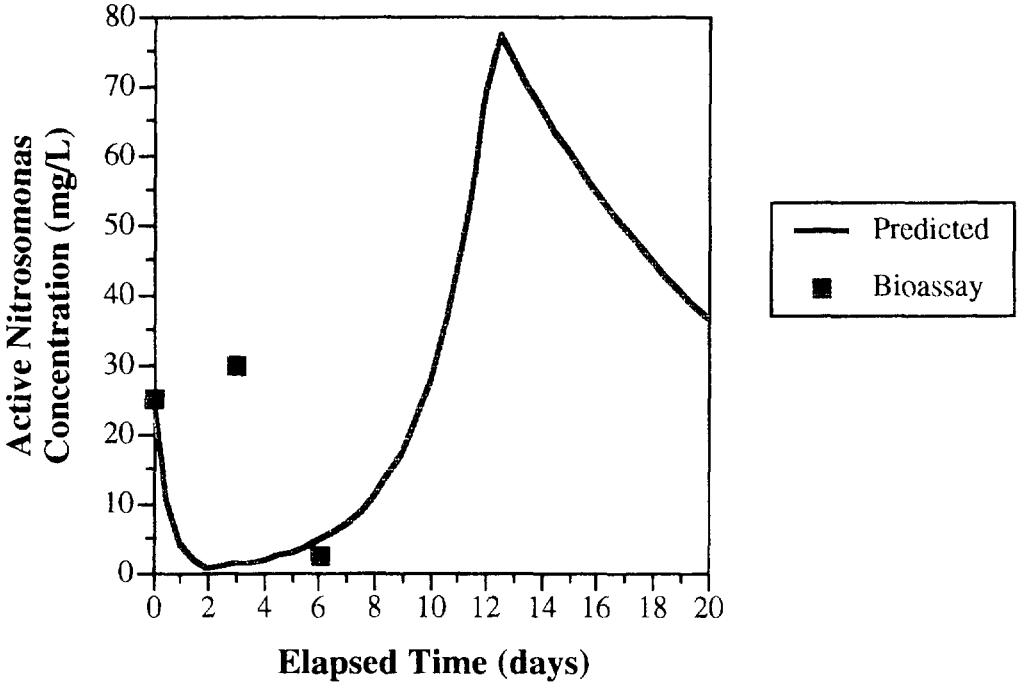

Figure C-15. Comparison of active *Nitrosomonas* biomass concentrations for the IIIST-3D batch test predicted by the biokinetic modeling and obtained from the biomass assays performed on days 3 and 6. Both sets of data assume an initial active *Nitrosomonas* biomass concentration of 25 mg_X/L.

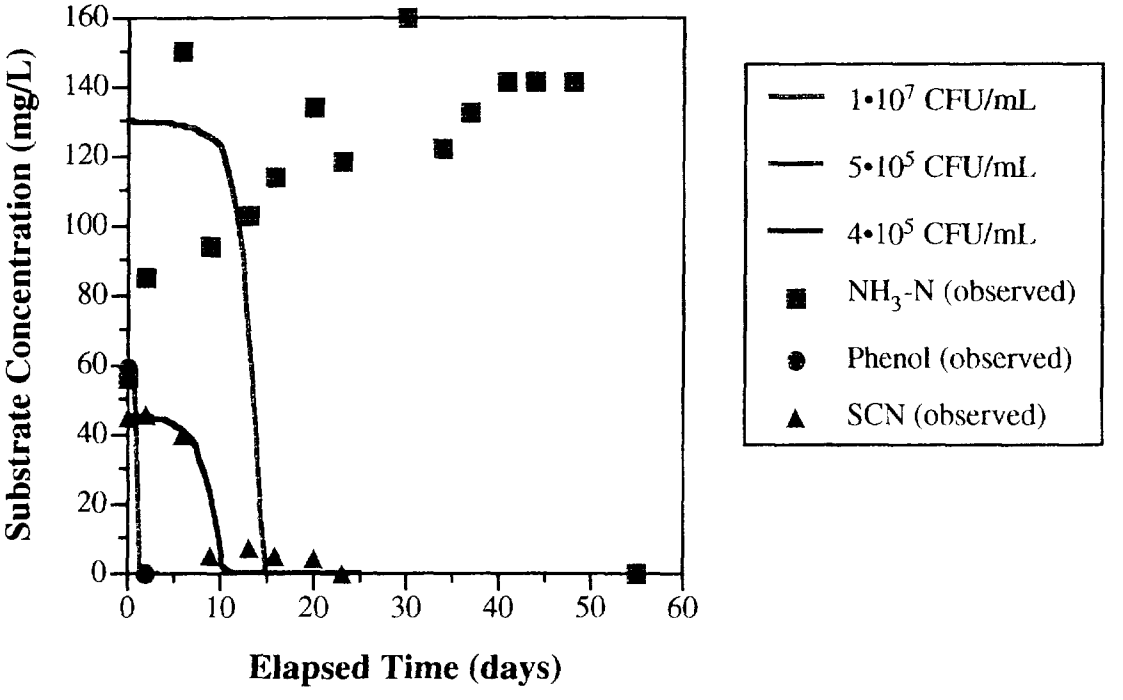

Figure C-16. Comparison of the predicted and observed decay curves for ammonia nitrogen, phenol, and thiocyanate during the IIIST-6 batch test which contained a 5 percent solution of MW-7D groundwater. The predicted ammonia decay curve includes the phenol/thiocyanate toxic effect quantified during the non-matrix batch tests.

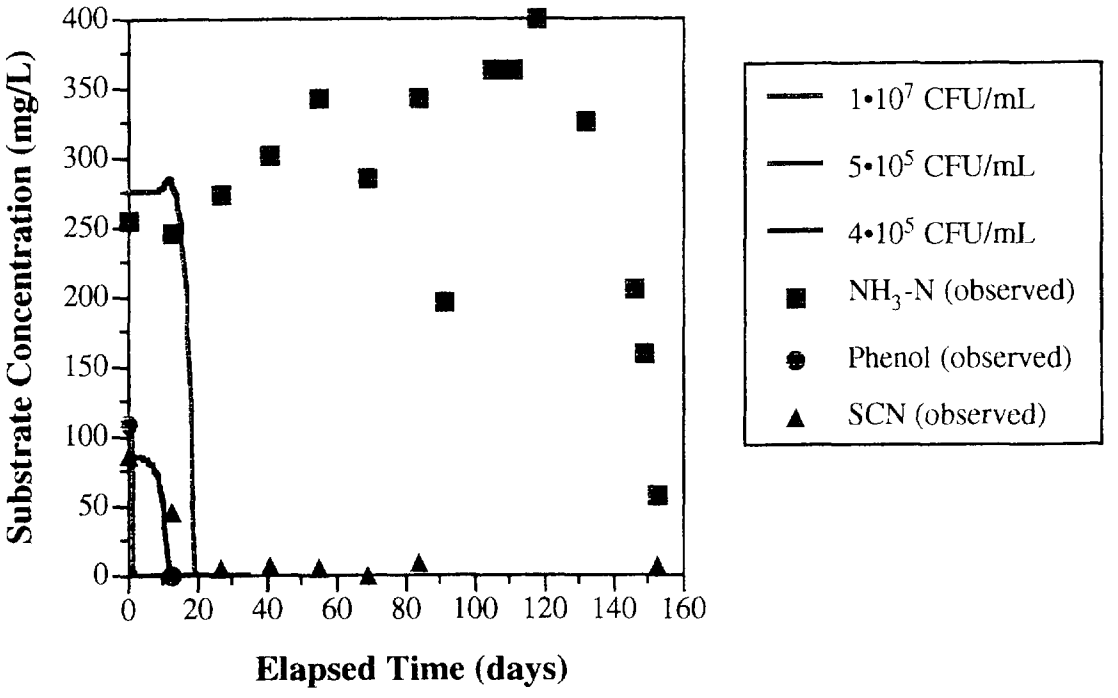

Figure C-17. Comparison of the predicted and observed decay curves for ammonia nitrogen, phenol, and thiocyanate during the IIILT-6 batch test which contained a 10 percent solution of MW-7D groundwater. The predicted ammonia decay curve includes the phenol/thiocyanate toxic effect quantified during the non-matrix batch tests.

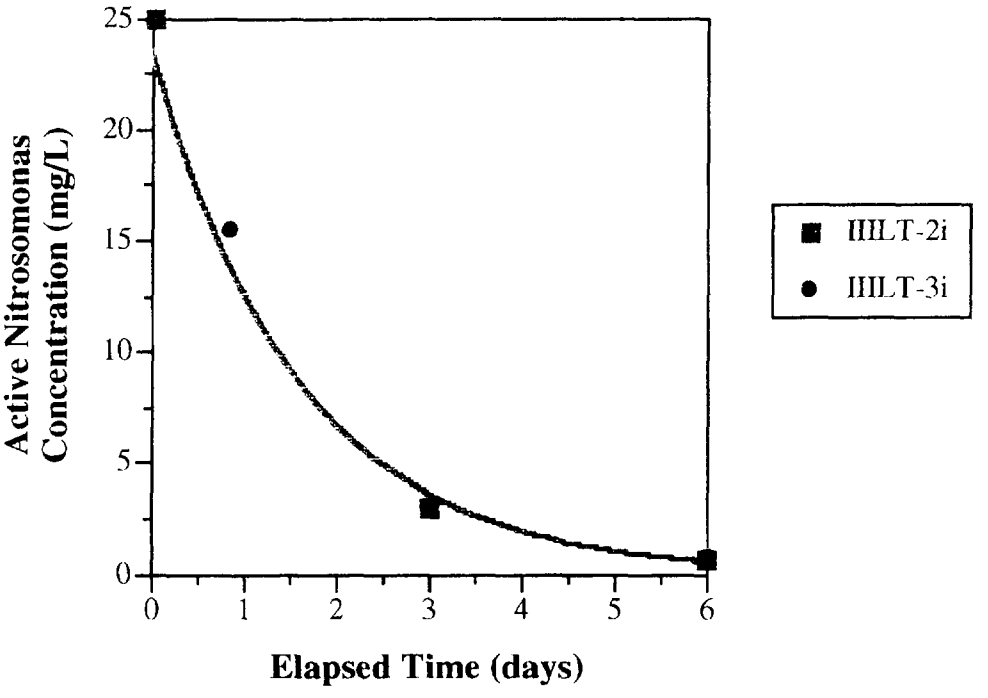

Figure C-18. Decay of active *Nitrosomonas* biomass concentration as a function of exposure time to a 16 percent (IIILT-2i) and 33 percent (IIILT-3i) solution of MW-7D groundwater. The net decay in active biomass can be described by a first-order biomass loss rate coefficient equal to 0.62 1/day (the green line).

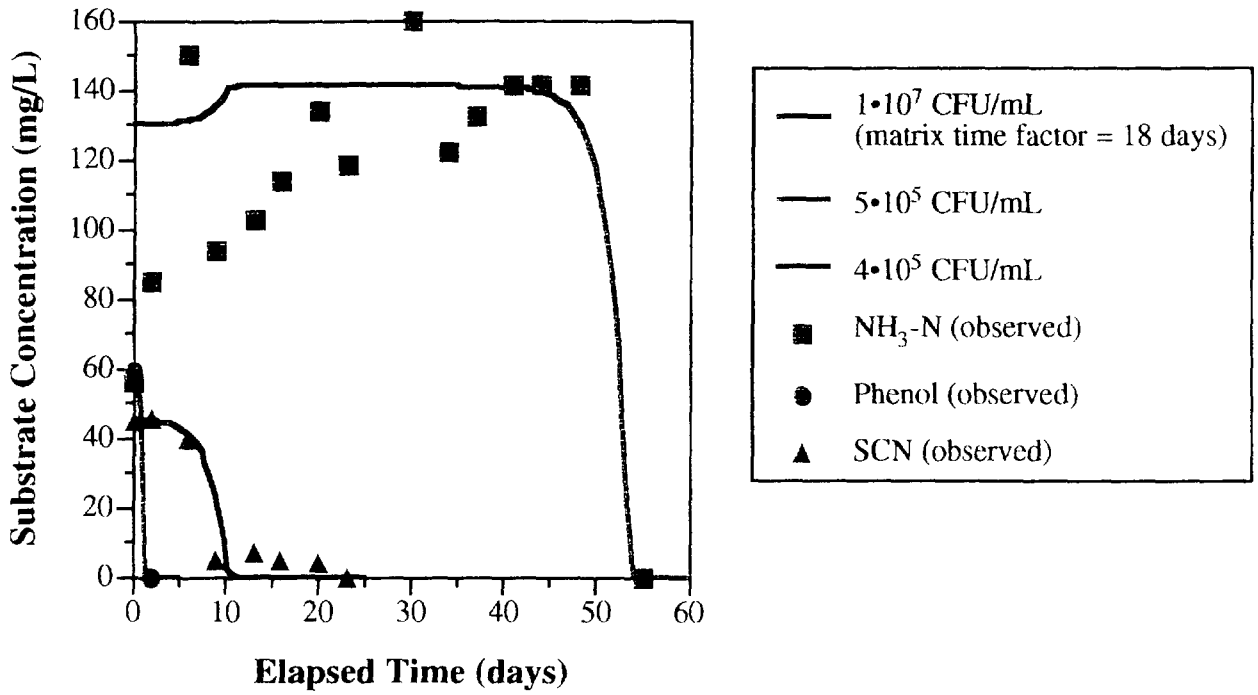

Figure C-19. Comparison of the predicted and observed decay curves for ammonia nitrogen, phenol, and thiocyanate during the IIIST-6 (5%-solution) batch test assuming a matrix time factor of 18 days. The ammonia decay curve also includes the phenol/thiocyanate toxic effect.

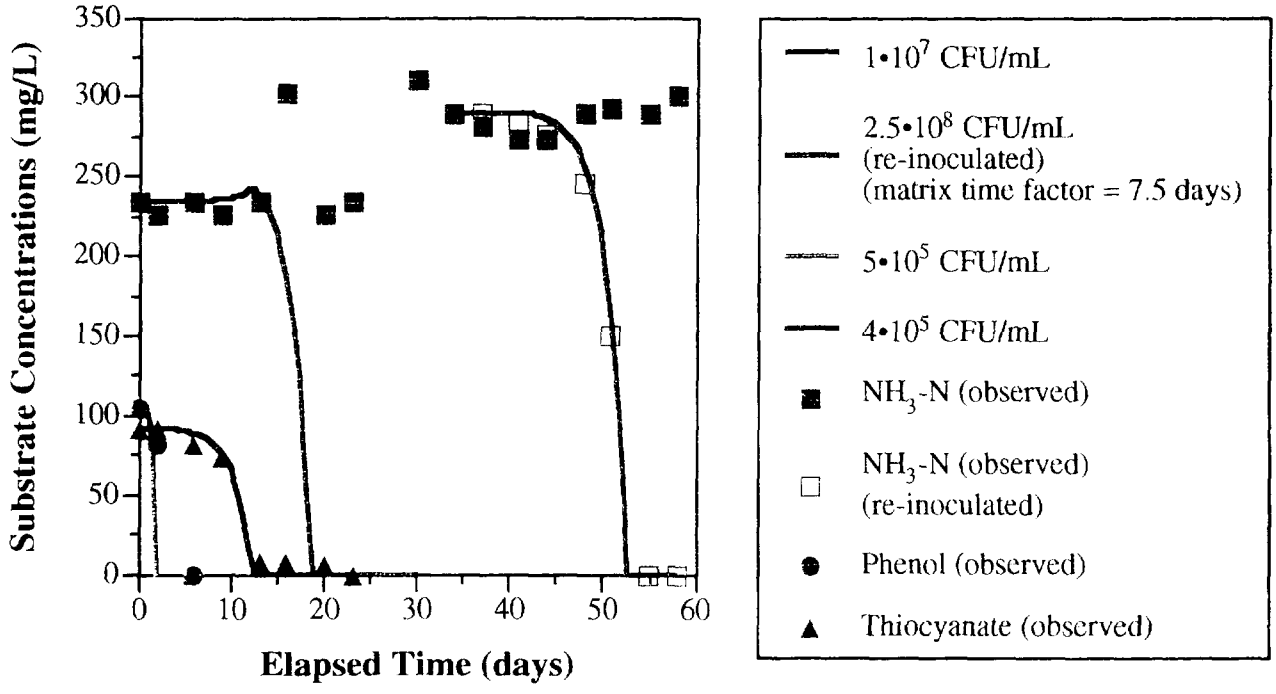

Figure C-21. Comparison of the predicted and observed decay curves for ammonia nitrogen, phenol, and thiocyanate during the IIIST-5 and IIIST-5i (10%-solution) batch tests. The IIIST-5i batch test was re-inoculated with *Nitrosomonas* and heterotrophic microorganisms on day 34. The blue line represents the predicted ammonia decay curve for the IIIST-5 batch test assuming only a phenol/thiocyanate toxic effect and no matrix effects. The purple line represents the predicted ammonia decay curve for the IIIST-5i batch test assuming a matrix time factor of 7.5 days and no phenol/thiocyanate toxic effect, because the phenol and thiocyanate were already biologically removed prior to the start of the IIIST-5i batch test.

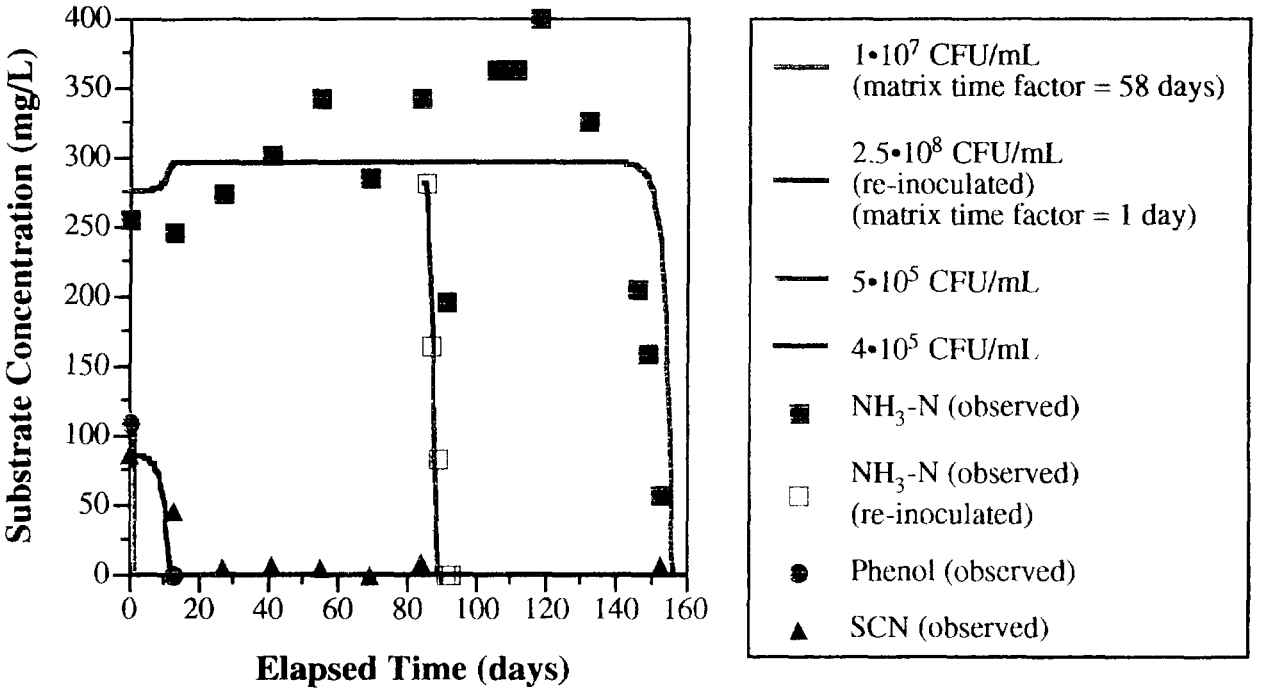

Figure C-22. Comparison of the predicted and observed decay curves for ammonia nitrogen, phenol, and thiocyanate during the IIILT-6 and IIILT-6i (10%-solution) batch tests. The IIILT-6i batch test was re-inoculated with *Nitrosomonas* and heterotrophic microorganisms on day 85. The blue line represents the predicted ammonia decay curve for the IIILT-6 batch test assuming a phenol/thiocyanate toxic effect and matrix time factor of 58 days. The purple line represents the predicted ammonia decay curve for the IIILT-6i batch test assuming a matrix time factor of 1.0 days and no phenol/thiocyanate toxic effect, because the phenol and thiocyanate were already biologically removed prior to the start of the IIILT-6i batch test.

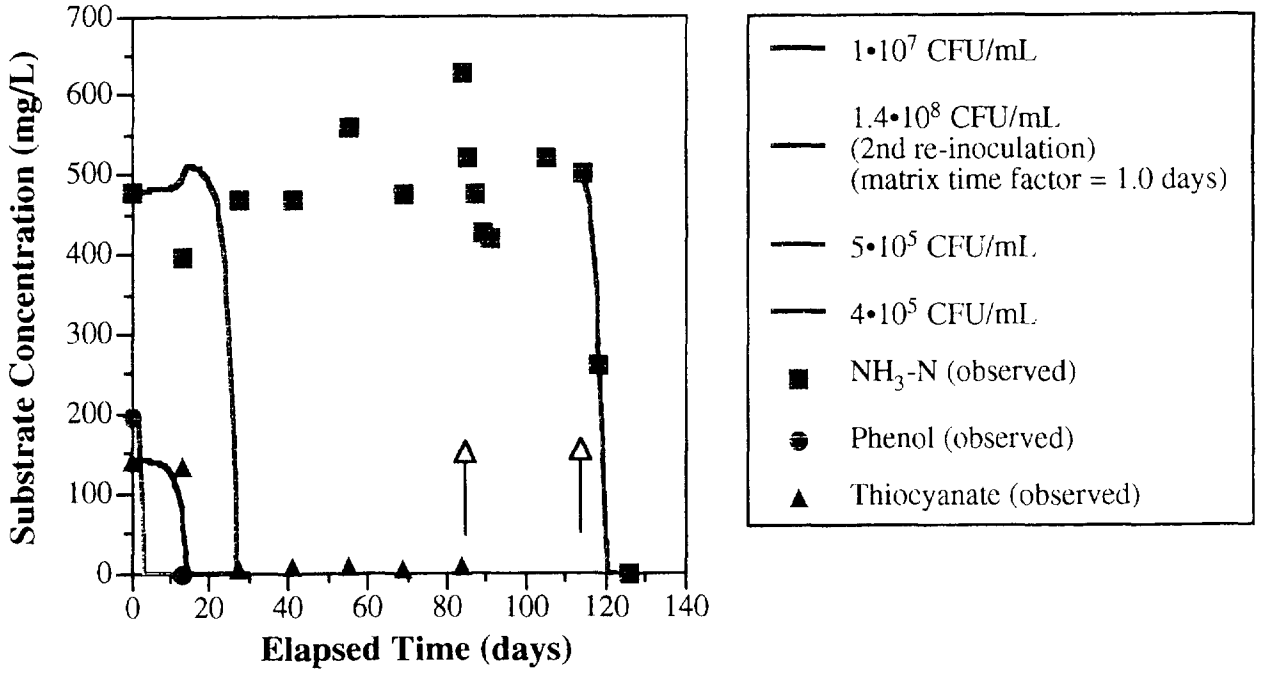

Figure C-23. Comparison of the predicted and observed ammonia nitrogen, phenol, and thiocyanate decay curves for the IIILT-2 (16%-solution) batch test. The arrows represent the two reinoculations of the batch test reactor with *Nitrosomonas* on days 85 and 114. A matrix time factor of 1.0 days was used to describe nitrification after the day 114-reinoculation.

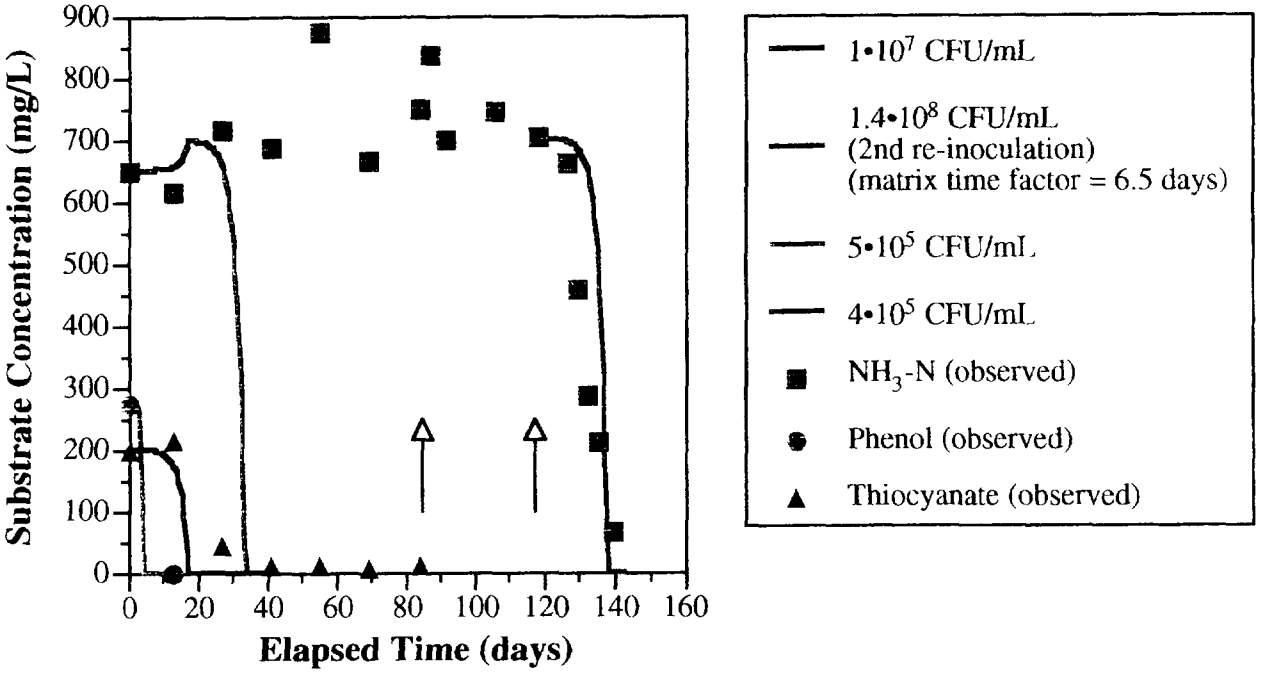

Figure C-24. Comparison of the predicted and observed ammonia nitrogen, phenol, and thiocyanate decay curves for the IIILT-1 (25%-solution) batch test. The arrows represent the two reinoculations of the batch test reactor with *Nitrosomonas* on days 85 and 118. A matrix time factor of 6.5 days was used to describe nitrification after the day-118 reinoculation.

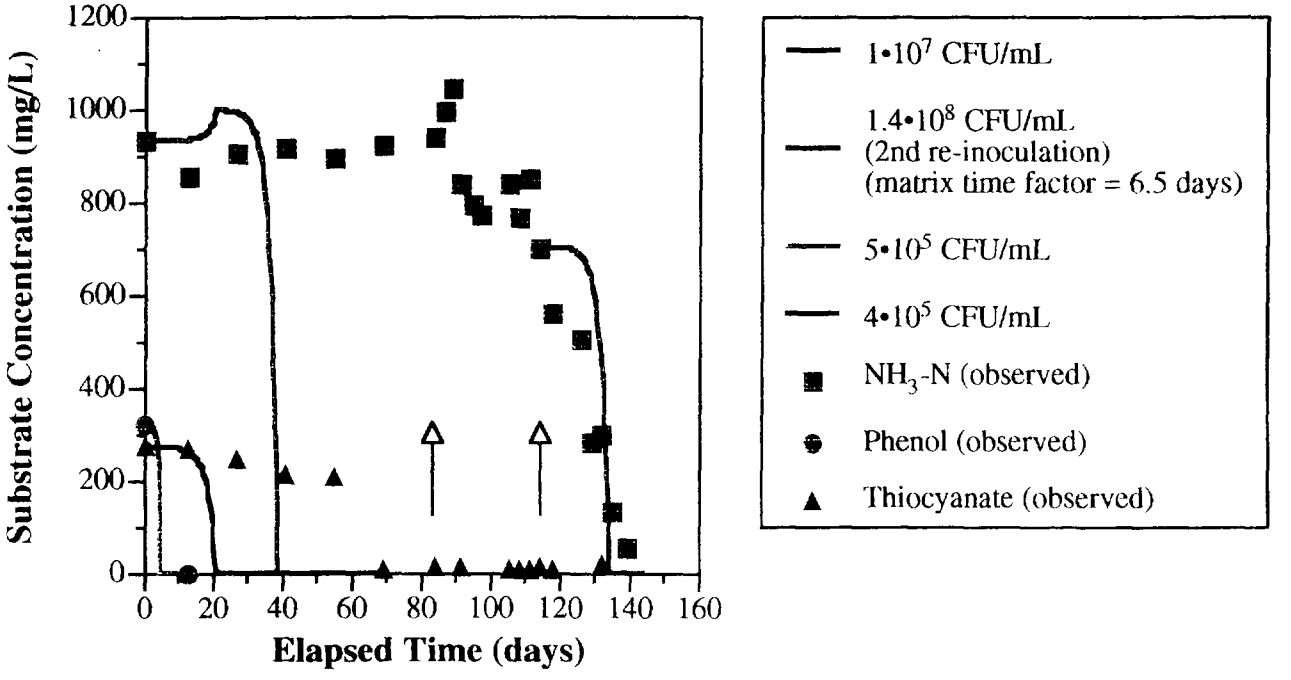

Figure C-25. Comparison of the predicted and observed ammonia nitrogen, phenol, and thiocyanate decay curves for the IIILT-3 (33%-solution) batch test. The arrows represent the two reinoculations of the batch test reactor with *Nitrosomonas* on days 85 and 114. A matrix time factor of 6.5 days was used to describe nitrification after the day 114-reinoculation.

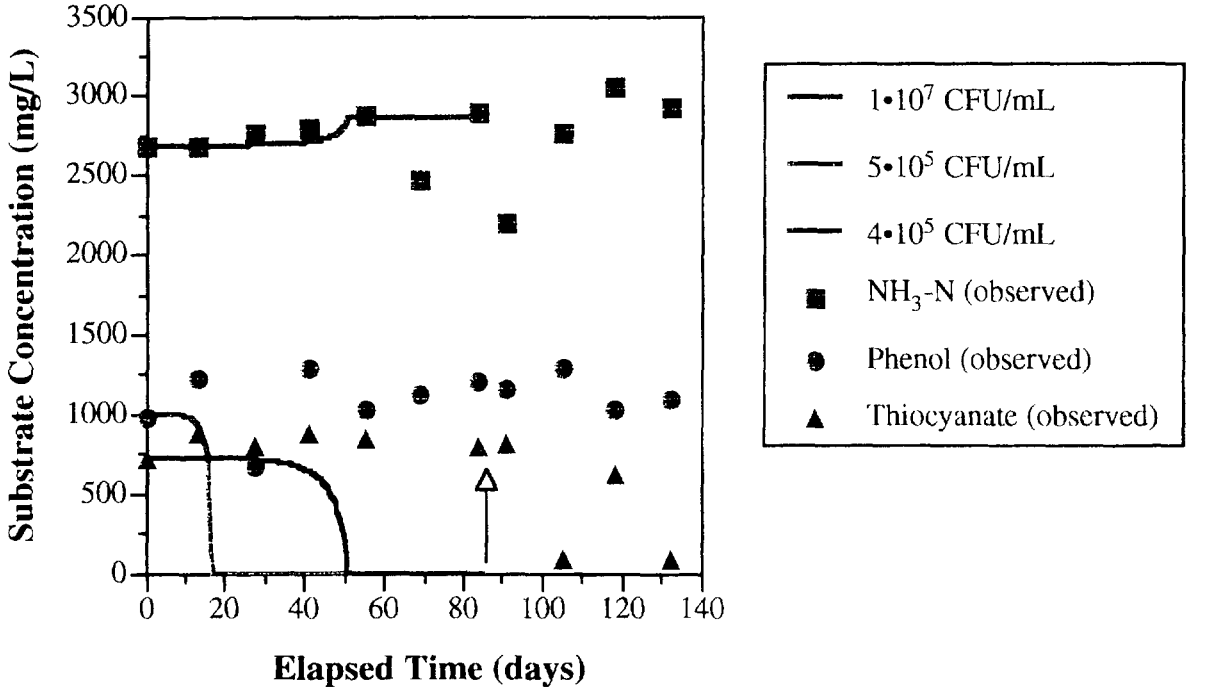

Figure C-26. Comparison of the predicted and observed decay curves for ammonia nitrogen, phenol, and thiocyanate during the IIILT-4 (100%-solution) batch test. The arrow represents the reinoculation of the batch test reactor with *Nitrosomonas* and heterotrophic microorganisms on day 85.

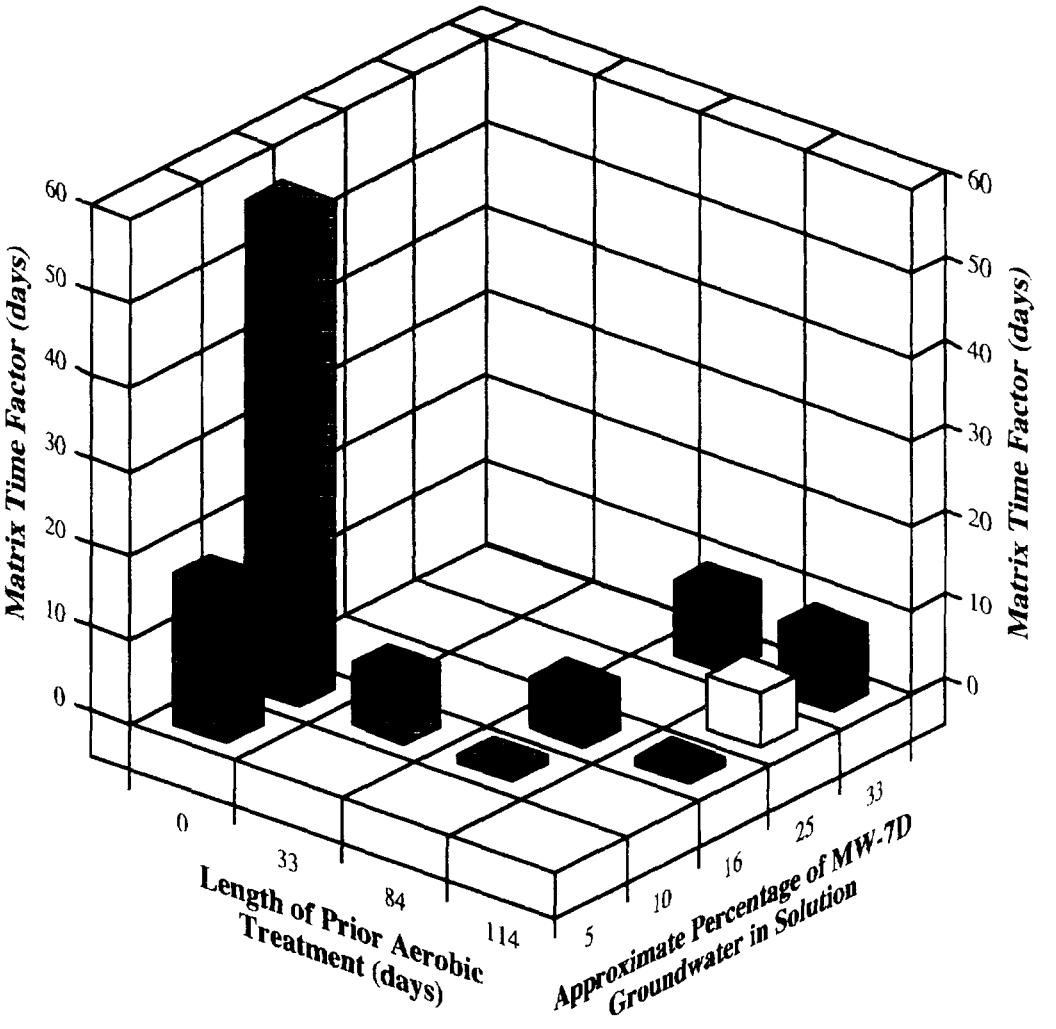

Figure C-27. Matrix time factors as a function of MW-7D groundwater concentration in solution and the length of aerobic treatment prior to the addition of the unacclimated *Nitrosomonas* culture. The matrix time factor for the 16%-solution with 84 days of prior aerobic treatment should be interpreted as something greater than 6 days. The matrix time factor for the 33%-solution with 84 days of prior aerobic treatment is plotted as 9 days, which is consistent with one curve fitting effort that assumed a 45 percent inhibition of $q_{max,N}$.