

IN-SITU TREATMENT OF CONTAMINATED SOIL BY  
EVAPORATION, SOIL WASHING, AND BIODEGRADATION  
WELLS, NEVADA

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ABSTRACT

The Environmental Response Team of the U. S. Environmental Protection Agency was established under the National Contingency Plan to provide federal, state, and local agencies with expertise and consulting in engineering studies, sampling and assessment, and alternative technologies. The ERT explored the feasibility of several innovative and alternative treatment options to remediate soil contaminated with phenol, ortho-cresol and meta- and para-cresol at the Poly-Carb Site in Wells, NV. Using bench scale experiments, this project explored three treatment technologies: passive evaporation, soil washing, and biodegradation.

After 3 weeks of passive evaporation, these studies showed the reduction of phenol, ortho-cresol, and meta- and para-cresol were 58 to 66, 55 to 80, and 36 to 43%, respectively. Contaminant decay plots indicate the half-lives of phenol, o-cresol, and m- and p-cresol were 1.5, 2.0 to 2.5, and 4.2 to 4.8 weeks, respectively. A direct relationship exists between the contaminant's evaporative half-life and its vapor pressure, therefore, only volatile or semi-volatile compounds can be treated in this manner.

In the soil washing tests, plain water was the preferred extractant. Water adjusted to pH 11.5 and 120°F show relative cleaning efficiencies of approximately 100 percent. Plain water performed nearly as well, while an aqueous surfactant extract had the lowest efficiencies.

Initial biotreatment experiments show that Pseudomonas cepacia AC1100, which has been shown to degrade 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), did not grow in a nutrient buffer containing 100 or 500 ppm phenol. Subsequent shake flask studies indicate that Alcaligenes eutrophus JMP134 may degrade phenol and cresol in soil. After four days of incubation, most JMP134 treated flasks showed nondetectable levels of contaminants. In addition, most JMP134-free control flasks also had nondetectable levels of contaminants after four days indicating that indigenous microbes can also degrade the contaminants in the presence of nutrients.

Based on the previous studies, an open, double-lined leach field was implemented to extract the Poly-Carb soil with plain water and to allow use of passive evaporation. A sprinkler system delivered leach water to the leach field. The leach field recovered leachate in a collection sump and recycled it through granulated activated carbon (GAC). The leach field reduced phenol concentration in soil by over 90%. This reduction of soil contamination was mirrored by the reduction of phenol in the leachate. The system was successfully operated during the Summer of 1987, closed during the cold months and will resume operation again in 1988.

#### KEY-WORDS INDEX

Phenol, cresol, contaminated soil, evaporation, soil washing, soil leaching, biodegradation.

## INTRODUCTION

The Environmental Response Team (ERT) was established in 1978 by the U.S. Environmental Protection Agency (U.S. EPA) in accordance with its disaster and emergency responsibilities under the National Contingency Plan. The ERT provides to federal, state, and local agencies expertise in, and resources for, engineering studies; sampling and assessment; analytical methods; alternative technologies; and, personnel training for hazardous waste sites and hazardous materials situations. U.S. EPA Region IX requested that the ERT provide sampling and engineering support at the Poly-Carb site in Wells, NV, a former waste recycling plant. The purpose of this project was to evaluate remediation methodologies for site clean-up.

The Poly-Carb site, a bankrupt waste recycling pilot plant, had soil contaminated with liquid refinery wastes including phenol and cresols, resulting from a spill. The site contained two PVC-lined and covered trenches, which held 850 cubic yards of soil (Figure 1). The site is located approximately 1 mile outside the town of Wells in northeastern Nevada in the high (5650 ft. elevation) basin and range desert. Wells was originally named for its dependable water. This site is in the re-charge zone for the aquifer used as sole source of drinking water for wells. Consequently, EPA initiated this soil remediation project to prevent pollution of this sensitive aquifer.

The 1986 Superfund Amendments and Reauthorization Act (SARA) mandated the use of innovative and alternative options over current remediation practices. In accordance with the spirit and letter of the law, U.S. EPA Region IX, the ERT, and the Response Engineering and Analytical Contractor (REAC) explored the feasibility of several innovative and alternative treatment options to decontaminate Poly-Carb soil. Using bench-scale experiments, this project explored three treatment technologies:

- o passive evaporation;
- o soil washing;
- o biological degradation.

Passive evaporation is the conversion of soil-bound contaminants into air-bound vapor using natural forces such as ambient temperature, wind velocity, and contaminant vapor pressure. Passive evaporation was explored because meteorological and geographical conditions at the Nevada site are favorable for this treatment method: hot (in summer), dry, windy, open, and outside of town. Furthermore, the site had no nearby population at exposure risk to the evaporated contaminants. All air samples taken at the site were below detection limit and the threshold limit value (TLV) of phenol is well below its odor threshold. The major advantages of this technique are design simplicity and low treatment cost.

Soil washing is the removal of contaminants from soil using liquid extraction agents. Soil washing consists of soil classification (the separation/segregation of soil by size or density into fractions), soil extraction, extractant recovery, and wastewater treatment. The extraction agents are basic (caustic), acidic (mineral or organic), organic (methanol, KPEG), surfactant, or chelating solutions.

Several extractants have been explored in soil washing studies. Researchers at Rutgers University used an alkaline aqueous extractant to remove organics from industrial sludges, and Dr. John Brugger at the U.S. EPA, Office of Research and Development, Releases Control Branch has explored a mobile treatment system using the Rutgers technology [1, 2]. Acidic extractants, both mineral and organic, have mobilized heavy metal contaminants from soil [3, 4, 5]. Bench-scale studies using an organic extractant, methanol, removed polychlorinated biphenyl (PCB) from Superfund site soil [6]. Another organic extractant, potassium polyethylene glycolate (KPEG) reduced polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) to less than 1 ppb required by regulation [7]. Using surfactants in a pilot study, researchers at the Texas Research Institute enhanced gasoline removal from sand to a 76% recovery rate [8]. A chelating agent, ethylenediaminetetraacetic acid (EDTA), removed 85 to 97% of the lead contamination from two Superfund site soils during bench-scale studies [9, 10, 11, 12, 13].

Biological degradation of phenolic wastes by acclimated microbes has been achieved with destructions as high as 99 percent [14, 15, 16]. Taking biodegradation to next level of sophistication, researchers at the U.S. EPA Hazardous Waste Engineering Research Laboratory (HWERL) in Cincinnati and the University of Illinois (UI) Health Sciences Center in Chicago have genetically engineered Pseudomonas cepacia AC1100 to allow it to degrade the recalcitrant chlorinated phenoxyacetate herbicides 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) and 2,4-dichlorophenoxyacetic acid (2,4-D) [17]. Similar degradations have been performed with Alcaligenes eutrophus JMP134 [18, 19].

## METHODOLOGY

### Sampling

To obtain representative soil for the studies, four evenly spaced vertical borings extracted soil from the center of each trench containing contaminated soil (see Figure 1). From each bore hole four discrete soil samples were taken: 1) above the upper PVC cover liner, 2) just below the upper liner, 3) mid-depth (2-4 ft), and 4) just above the lower trench liner. This sampling scheme represented a 4 x 4 sampling matrix. These discrete samples from each trench were composited to average contamination concentration, thus reducing the range of contamination found in discrete samples. A diagonal composite from four borings and a vertical composite from one boring were formulated and labeled for each trench: ED and EV for the east pit, and ND and NV for the north pit. In addition, a third composite was formulated from the remaining samples. Soil washing and biological degradation studies used the vertical and diagonal composites, while passive evaporation used the "remaining" composite.

### Analysis

Soil samples were analyzed for phenol, ortho-cresol and meta- and para-cresol by a modified method no. 625 using a Shimadzu GC 9-A gas chromatograph with a flame ionization detector (FID) [20]. Method modifications included FID capillary column Supelco cat. no. 2-3721, a

temperature program (80°C for 4 min, increased by 10°C/min to 230°C and held for 1 min, increased 30°C/min to 300°C and held 2 min.), and helium carrier gas at 18 ml/min. Actual detection limits for phenol, o-cresol, and m- and p-cresol were 1, 1, and 2 ug/ml, respectively.

### Passive Evaporation

Evaporation experiments were performed in a warehouse without sunlight at a relatively constant ambient temperature and humidity (50-60°F and 75-85%) to simulate poor evaporation conditions. This experiment set-up would give Region IX conservative results compared with the site's desert-like evaporation conditions. Soil was spooned into plastic petri plates (88 mm diameter X 18 mm high) and placed on a canopy-covered table to support and protect the samples from dust during passive evaporation. A 4 X 4 experimental matrix was designed for each trench. Four evaporation durations were used: 0 days (no evaporation); 7 days; 14 days; and 21 days. Four soil samples per duration yielded 16 samples per trench. At the end of each duration, the soil was analyzed for phenol, ortho-cresol, and meta- and para-cresol.

### Soil Washing

Before initiating soil washing experiments, the Poly-Carb site soil was characterized to determine particle size distribution. Wet sieve analysis classified the dry, flour-like soil by size.

For each soil washing, 10 g of soil was mixed with 200 ml of extractant and agitated for 10 min on an automatic shaker. After washing, a 100-ml aliquot was decanted into a centrifuge tube, spun for 20 min at 980G, and analyzed for phenol.

Soil washing experiments were performed under the auspices of Richard Traver, U.S. EPA, Office of Research and Development, Releases Control Branch, Edison, NJ [21].

### Biodegradation

Two organisms were explored for their contaminant degradation ability. The first culture tested, Pseudomonas cepacia AC1100 was initially grown on 2,4,5,T, harvested, resuspended in KPM 7 buffer solution (50 millimole KPO<sub>4</sub> and 0.1 millimole MgSO<sub>4</sub> in 100 ml adjusted to pH7) with either 100 or 500 ppm phenol and shaken at 200 RPM and 28°C for 1 or 2 days. The second culture, Alcaligenes eutrophus JMP134, was similarly grown but without the 2,4,5, T step. For soil biodegradation studies, 8 to 25 g of soil, 50 ml of KPM 7, 0.5 ml of 1.5M (NH<sub>4</sub>)<sub>2</sub> SO<sub>4</sub>, and 10 ml of cell suspension (at an absorbance of 5.0 at 600 nm in KPM 7) was placed into 125 ml flasks. The control flasks did not contain the cell suspension. Both experimental and control sample were shaken for up to 4 days and the soil slurry from the sacrificed flasks was quickly frozen to minus 20°F and stored for analysis.

This study utilized the expertise and resources of researchers at HWERL working with UI to biologically degrade the Poly-Carb soil contaminants with these plasmid-enhanced microorganisms.

## RESULTS

### Passive Evaporation

This study showed a significant reduction in the target contaminant due to passive evaporation. For east trench soil, the reduction of phenol, o-cresol, and m- and p-cresol after 21 days was 58, 55 and 43 %, respectively; for north trench soil, the reduction was 66, 80, and 36%. Even though there was a slight difference in contaminant reduction between trenches, there was little difference in the contaminant decay characteristics. This leads to a simplified mode of decay in passive evaporation dependent solely on contaminant concentration. If the decay or reduction of a contaminant depends only on its concentration, the decay is represented by

$$\frac{dC}{dt} = -kC \quad (1)$$

where C = contaminant concentration (ug/g)  
t = time (weeks)  
k = a rate constant (weeks<sup>-1</sup>)

Other factors, besides concentration, might affect decay, such as soil porosity differences, desorption from soil particles, temperature, etc. These factors appear to have a negligible effect on the rate and their contributions can be encompassed in the rate constant, k.

After integration of equation 1 and setting  $C = C_0$ , where  $C_0$  = concentration of C at  $t = 0$ , the exponential form of the equation becomes:

$$C = C_0 e^{-kt} \quad (2)$$

The decay of contaminant C can be represented by its half-life. The time at which  $C = 1/2 C_0$  is the components half-life,  $t_{1/2}$ , therefore

$$1/2 = e^{-kt_{1/2}}, \text{ or} \quad (3)$$

$$\ln(1/2) = -kt_{1/2} \quad (4)$$

$$kt_{1/2} = 0.6931 \quad (5)$$

The half-lives of phenol, ortho-cresol, and meta- and para-cresol were found to be 1.5, 2.0 to 2.5, and 4.2 to 4.8 weeks, respectively. To obtain these half-lives, the log concentration of each component versus evaporation duration was plotted in Figures 2, 3, and 4. From the slopes of each plot, the half-lives ( $t_{1/2}$ ) were found. The rate constant, k, can now be obtained by substituting the half-life value into equation 5.

After calculating the rate constants, equation 2 can be used to determine the evaporation duration for a contaminant to reach some targeted concentration. Conversely, this equation will also predict an expected contaminant concentration at a future time.

Physical factors have a marked effect on evaporation of chemical components. During passive evaporation, contaminant half-life is a function of that component's vapor pressure. The least squares fit line in Figure 5 shows a linear relationship between a compound's reciprocal half-life and its vapor pressure relative to phenol (i.e., the vapor pressure of phenol relative to phenol is one). The contaminant's half-life due to passive evaporation increases with a decreasing relative vapor pressure. Furthermore, a compound's vapor pressure is a function of temperature, therefore vapor pressure increases with rising temperature (Figure 6). Consequently, an ambient temperature increase will subsequently increase the evaporation rate of contaminants.

### Soil Washing

Particle size distribution analyses showed an average of 44.4% of the total soil is less than #150 mesh, 0.105 mm (Figure 7). This fine fraction has traditionally been the most difficult portion of the soil to treat due to materials handling and soil/liquid separation problems. In addition, the fraction less than #150 mesh contains nearly 90% of the factored surface area which provides sites for contaminant adsorption (Figure 8). Due to this large surface area and physical/chemical interactions between the soil particle and contaminants, the fine fraction usually has the greatest contaminant loading. Additional characterization found an average calcium carbonate content of 7.8 percent and a pH >8 for this soil.

The shake flask experiments demonstrated that soil washing was effective in removing phenol. Water adjusted to pH 11.5 with sodium hydroxide was the best extractant, however plain water was nearly as effective (Figure 9). The use of hot (120<sup>o</sup>) water also removed phenol effectively, while water with added surfactant showed a lower relative effectiveness. Finally, tap water removed 82 to 95% of the phenol. With such a high removal efficiency, tap water was the preferred extractant because its use precluded any additional extractant neutralization or removal step and it was the most cost effective.

The success of a plain water extraction may be predicted on the contaminant's hydrophilicity or hydrophobicity. Hydrophilicity is defined as having a solubility in water, at 25<sup>o</sup>C, over 10 g/l, while a hydrophobic compound possesses an octanol/water partition coefficient ( $K_{ow}$ ) greater than 100 [13]. One of the Poly-Carb contaminants, phenol, has solubility of 84 g/l and a  $K_{ow}$  of 29, making it hydrophilic and not hydrophobic. Consequently, phenol was a good candidate for a water wash or leach.

### Biodegradation

Pseudomonas cepacia AC1100, a plasmid-enhanced organism, was not able to use phenol as a carbon source. During the initial soil-free trials, AC1100 did not grow in the presence of 100 or 500 mg/l phenol in a nutrient buffer solution. In contrast, AC1100 has grown on various chlorinated phenolic compounds, such as 2,4,5-T and 2,4,5-Trichlorophenol (2,4,5-TCP). Since phenol is without substituted chlorines and is not an intermediate in the degradation pathway of 2,4,5-T or 2,4,5-TCP, phenol was not available to AC1100 as a carbon source.



Unlike AC1100, Alcaligenes eutrophus JMP134 apparently degraded phenol, o-cresol, and m- and p-cresol in contaminated soil. No degradation was observed in flasks after 2 days incubation. However, after 4 days, most flasks had nondetectable amounts of contaminants (Figure 10, 11, and 12). This result was also observed for the control flasks which contained the nutrient buffer and contaminated soil without the addition of the JMP134 culture. While apparently successful, biodegradation tests for soils do not have a standard protocol. Some questions remain as to what was really observed, biodegradation or evaporation. Additional testing may be required.

### System Design and Soil Treatment

The previous engineering studies found that evaporation reduced phenol, o-cresol, and m- and p-cresol at a predictable rate, and plain water recovered contaminants nearly as well as other extractants tested. From these results, an open leach field was designed, constructed, and operated at the Poly-Carb site to wash contaminants from soil with plain water and to make use of available passive evaporation.

The leach field was constructed to contain and monitor all contaminants. A half-acre pit was excavated, graded, and double-lined with 60 mil high density polyethylene (HDPE). Between these liners, a 12-inch layer of pea gravel was placed to act as leachate collection media (Figure 13). In the lined pit, a 12-inch base of clean backfill was placed under 24 to 30 inches of contaminated soil. More contaminated soil than expected was discovered during excavation, an increase of nearly 50% compared with the twelve to eighteen inch depth in the original design.

The leach field was designed with collection and monitoring sumps inside the system and production and monitoring wells outside. The collection sump was placed at the lowest end of the leach field to collect the leachate and transfer it for treatment. The monitoring sump inside the leach field consisted of a standpipe through the upper liner into the pea gravel to detect any leachate leakage or permeation of contaminants through the upper liner into the lower liner. The purpose of the production well was to add make up water lost by evaporation into the system. The well delivered 8 to 10 gallons per minute of water on demand and acted as a backup recovery well if contaminants migrated outside the field. The external monitoring well (Well No. 2 in Figure 14) monitored the groundwater for contaminants and served as an additional backup recovery well.

The soil extraction system of the leach field shown in Figure 14 contained:

- o a water supply;
- o an irrigation system to distribute the water;
- o a leachate collection system above the top liner;
- o a holding tank for contaminated leachate;
- o particulate filters;
- o three disposable, 55-gallon granular activated carbon (GAC) filters;
- o necessary pumps.

The contaminated soil was constantly irrigated by sprinklers in the middle of the leach field. The irrigation water leached through the soil, drained to the collection sump, and was transferred (at approximately 10 gpm) to the holding tank. From the holding tank, the water was first filtered for particulate removal, then for organics removal by GAC, and was recycled to the irrigation system. A well, outside the perimeter of the system, added makeup water to the system.

Soil leaching and passive evaporation reduced phenol concentrations in the soil by over 90%. Initial concentrations of phenol in soil taken from the storage trenches in January 1987 was 1020 ug/g (ppm), (Table 1 and Figure 15). When this soil was excavated for deposit into the leach field during July 1987, phenol levels measured 980 ug/g. Therefore, before treatment, little loss of contaminants occurred in the lined and covered storage trenches. However, after treatment phenol dropped below 100 ug/g during August and continued to decline in September, except for the last sample taken. Even though the soil was not tilled, evaporation of the leachate from the surface of the field was enhanced by the high temperatures, low humidity, long days, and windy conditions of summer.

The particulate and GAC filters removed most phenol from the leachate before recycling back to the leach field. Less than 1 ppm of phenol remained in the GAC effluent stream during September (Figure 16). The dark red to purple leachate influent to the filters turned clear after filtration. When the effluent turned yellow, this corresponded to an approximate 70% removal of phenol and cresol by the GAC so the carbon was replaced (three 55-gallon drums per week on the average). A local person was employed to change the carbon units and operate the system after receiving 40 hours of health and safety training. A knowledgeable operator was important to a successful operation. The leach field was operated without problems during the Summer of 1987, closed for the cold months, and will resume operation in 1988.

## DISCUSSION

This study showed a reduction of phenol, o-cresol, and m- and p-cresol contaminants in soil due to passive evaporation. The rate of contaminant reduction or decay can be expressed by contaminant half-life,  $t_{1/2}$ , and measured by the rate constant,  $k$ , and the initial concentration,  $C_0$ . These values can determine the time at which a soil contaminant will reach a target concentration or the concentration of the contaminant in the soil at some future time, provided all environmental parameters are relatively constant and the soil is regularly tilled to expose fresh soil. These predictions are useful for remedial project management.

The following example details the use of the previous equations to predict evaporation duration or contaminant reduction for remedial project management. First, bench-scale or pilot studies are necessary to find the decline of soil contaminants with evaporation time. After these values are plotted, a contaminant's half-life,  $t_{1/2}$ , can be obtained from the slope. Next, the value of  $t_{1/2}$  is substituted into equation 5 to determine the (decay) rate constant,  $k$ , for a particular set of

environmental conditions. Finally, the initial contaminant concentration,  $C_0$ , and the rate constant are substituted in equation 2. At this point, equation 2 can be solved for the predicted contaminant concentration,  $C$ , at a future time,  $t$ , or the evaporation duration to reach a targeted treatment level.

To determine contaminant half-lives in Figures 2, 3, and 4, only the initial slopes were used. The contaminant decay was linear during the first two weeks; however, the decay of the third week samples declined. This decline may be due to the absence of soil mixing during the bench-scale tests. This shows the importance of a regular soil mixing program to expedite remediation by allowing unevaporated components contact time with air since only the soil surface experiences evaporation. In the absence of mixing, evaporation occurs only at the soil surface. When the components at the surface have evaporated, the limiting factor for evaporation is internal diffusion. Subsurface contaminants in the soil must internally diffuse through the interstitial space. In another evaporation mechanism, these contaminants evaporate in the interstitial space, recondense on the soil particles above it, re-evaporate, and so on until reaching the surface. In both mechanisms, it is a tortuous path to the surface for the contaminant molecule.

Important variables affecting passive evaporation are vapor pressure, ambient temperature, barometric pressure, wind velocity, soil depth, and soil mixing. The contaminant half-life is directly related to vapor pressure. In soil with a mixture of contaminants, evaporation duration depends upon the compound with the lowest vapor pressure. If necessary, the vapor pressure of a contaminant can be increased by increasing soil temperature using natural or induced methods. A reduction in barometric pressure will also assist evaporation, therefore, the Poly-Carb site's mile high elevation was beneficial. Evaporation can also be expedited through the use of natural or forced convection (i.e., wind velocity, fans, etc.). And, as previously mentioned, soil depth and mixing are additional environmental factors affecting passive evaporation.

In most of the soil biodegradation studies, contaminants were not detectable 4 days after the addition of JMP134 culture and nutrients. The apparent lag time may reveal the organisms were adapting to the contaminants. In many of the control flasks containing only added nutrients (without JMP134), contaminant levels were also not detectable after four days incubation. This reduction of contaminants may be an indication that the indigenous microorganisms have adapted to the foreign substances during the two years of exposure in the soil trenches.

The plasmid enhanced AC1100 culture did not use phenol as a carbon source. Even though AC1100 has successfully degraded the recalcitrant chlorinated phenoxyacetate herbicides; 2,4-D and 2,4,5-T it was not able to cross-acclimate to the simpler phenol or cresol molecules.

Soil washing was an effective remediation technique for Poly-Carb soil. The pH 11.5 water was the best extractant. The increased extraction effectiveness of the basic water was due to the extraction of the hydroxyl proton on phenol and the subsequent greater solubility of the sodium phenate salt. Plain water was the extractant of choice because of the ease of operation, the elimination of extractant recovery or destruction problems, and lower treatment costs.

Even though plain water at 120°F yield excellent recovery in laboratory tests, the capital and operating cost of such a system precluded its use. The aqueous surfactant solution did not perform well enough in bench-scale studies to justify its use.

Because of the effectiveness of plain water over biodegradation and passive evaporation in removing contaminants from soil, process considerations of soil washing were explored further. To implement a soil washing system at the site, a process would have to be developed to excavate, handle, mix, dewater, and return the soil. Historically, material handling and soil/liquid separation problems have been experienced at several sites: Lee Farm, Woodville, WI; Church of God, Leeds, AL; and Shaffer Equipment, Minden, WV [9, 10, 13, 22]. To minimize these problems, the ERT used classification techniques in previous studies [9, 10] to separate the fine soil particles (<0.105 mm) from the coarse fraction (0.105 mm to 0.25 in). The separation, prior to extraction, of the hard-to-handle and difficult-to-dewater fine fraction allowed the coarse fraction to be successfully washed with separate treatment conditions for the fine. These fines can be separately washed or solidified. However, soil characterization tests found nearly half of the Poly-Carb soil was fines. With such a large fraction of the whole soil comprised of the fines, an alternative plan was proposed to use the advantages of a plain water extractant and to avoid the potential problems posed by this soil fraction. Therefore, to avoid process difficulties from this fraction, soil leaching was chosen over soil washing for site remediation.

The simple soil leach field and accompanying leachate treatment system reduced phenol contamination in the soil. After one, 2-month treatment season, phenol concentration dropped more than 90%. The concentration of phenol in the leachate influent (Figure 16) to the GAC shown in Figure 16, dropped considerably during treatment, which indicated the leach field removed phenol from the soil. This drop in phenol levels corresponds to the reduction of phenol levels in soil sampled throughout treatment, shown in Figure 15. However, the reduction in influent phenol also indicates that the soil must be mixed to expose new areas to the water leach.

A few operational aspects of the leach field are worth monitoring. The pea gravel drainage media transportation and installation proved time consuming and labor intensive. During the remediation phase, the treatment system performed reliably since, with the exception of several pumps, there were no moving parts.

A local resident was provided with the mandatory 40 hours of health and safety training and subsequently, acted as a part-time operator. This operator observed the operation of the system and changed GAC drums when the clear effluent turned yellow, correlating to a 70% phenol removal from the leachate. This knowledgeable and reliable operator reduced the amount of site management required by the EPA on-site coordinator (OSC) and reduced operating costs. Final cost projections predict treatment costs will be \$266 per cubic yard for the 1500 cubic yards treated.

## CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations based on the initial engineering study and the subsequent full-scale treatment system design and operation are:

- o Engineering studies are essential prior to soil remediation;
- o These studies show soil washing and passive evaporation are viable treatment options;
- o Biodegradation appeared to be successful; however, additional bench-scale studies and a full-scale treatment are necessary to demonstrate it;
- o Soil washing is an emerging technology. Soil leaching, a passive form of soil washing, was chosen because plain water was an effective extract;
- o A soil leaching system design must be flexible to accommodate any additional unexpected contaminated soil found in the excavation;
- o A gravel leachate collection media was difficult to construct, therefore a geo-textile would provide a faster treatment option implementation and possibly a lower overall cost;
- o Full-scale treatment, still on-going, appears to be validating the conclusions of the pilot study.

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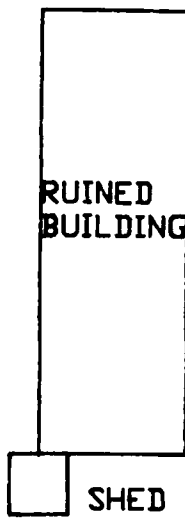
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TANKS



RUINED BUILDING



SHED

APPROX.  
200ft TO HWY.



TANKS



APPROX. 1 MILE  
TO WELLS, NV

CONTAMINATED  
SOIL TRENCHES

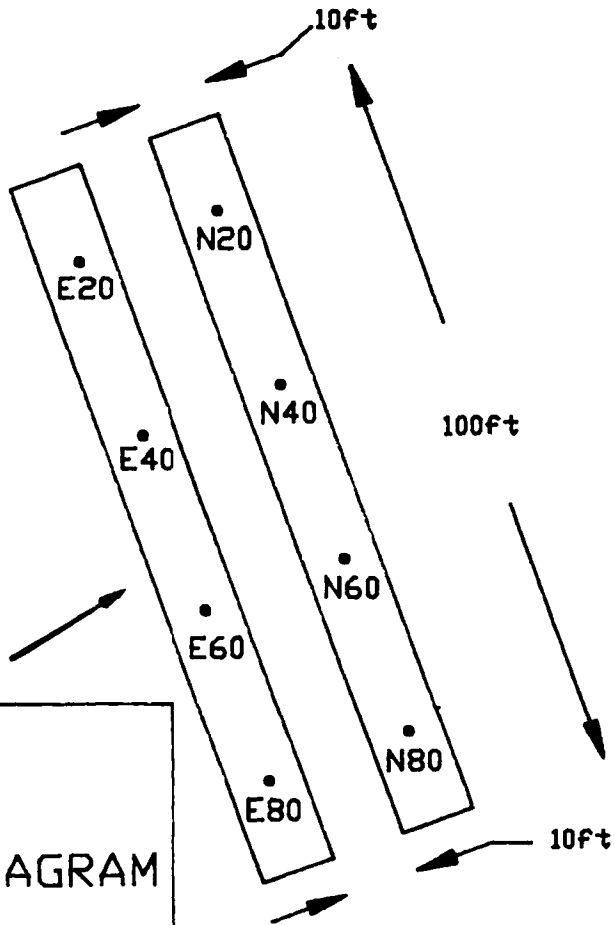


FIGURE #1

POLY-CARB SITE DIAGRAM

Figure 2. Phenol Evaporation

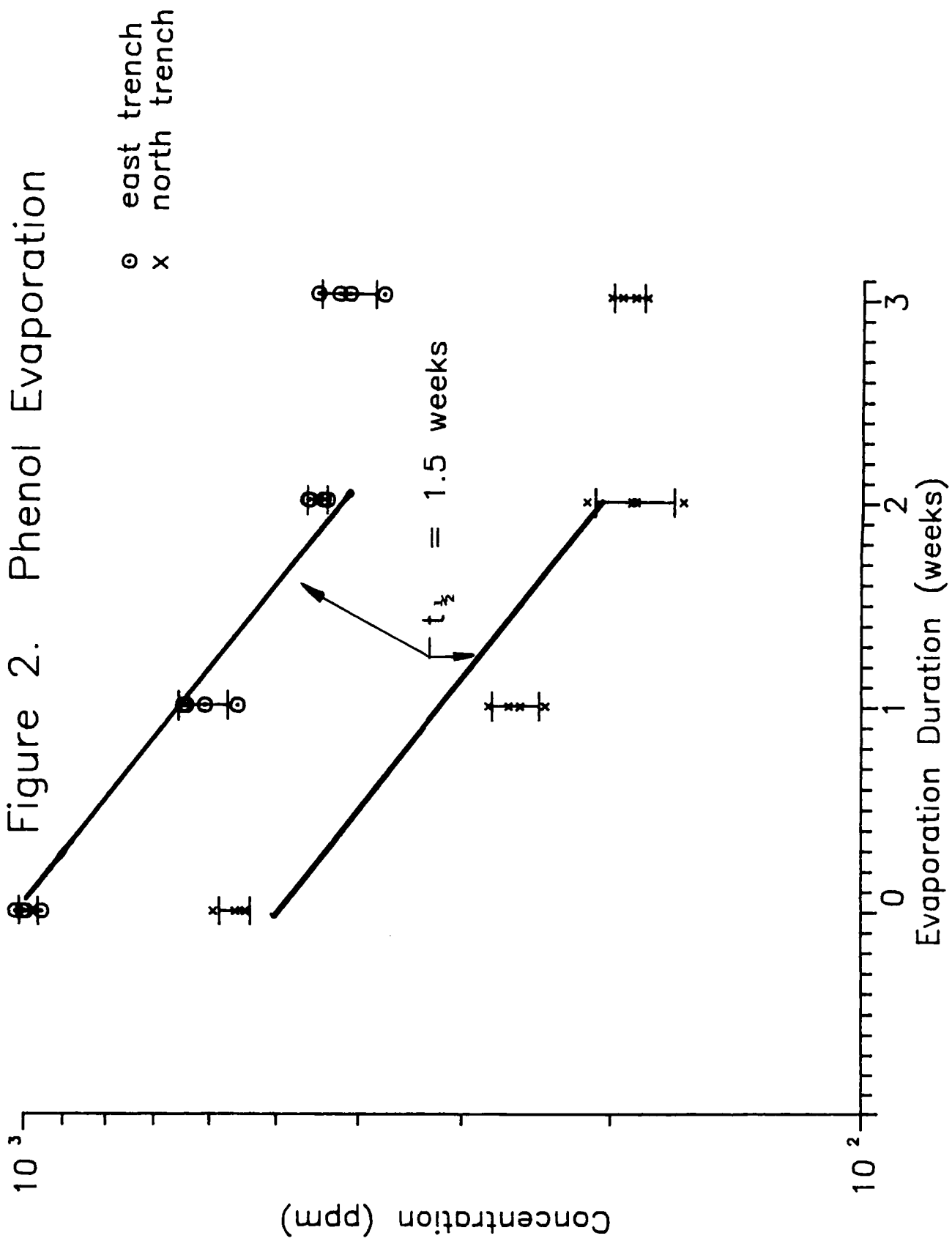


Figure 3. Ortho-cresol evaporation

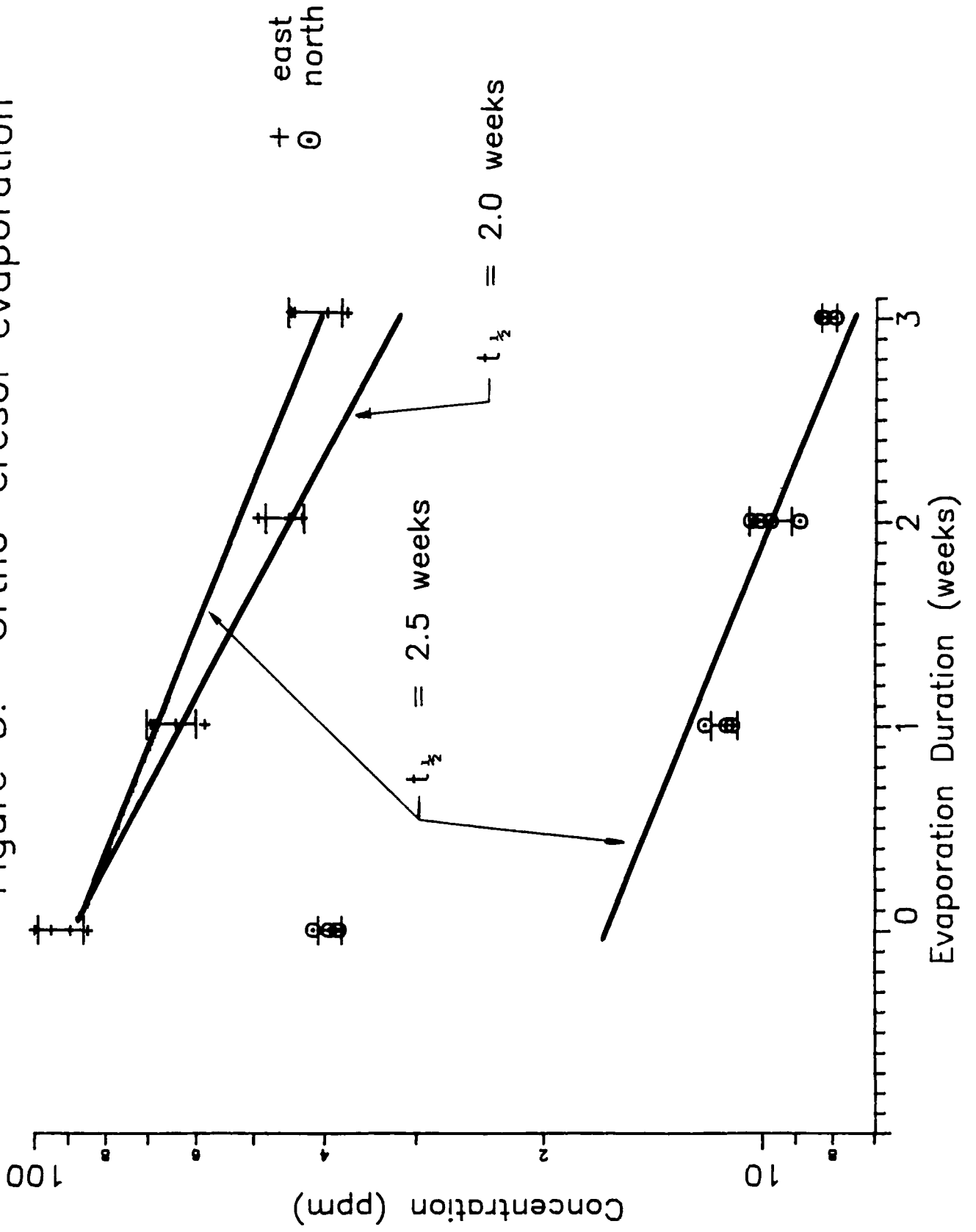


Figure 4. Para- & meta-cresol evaporation

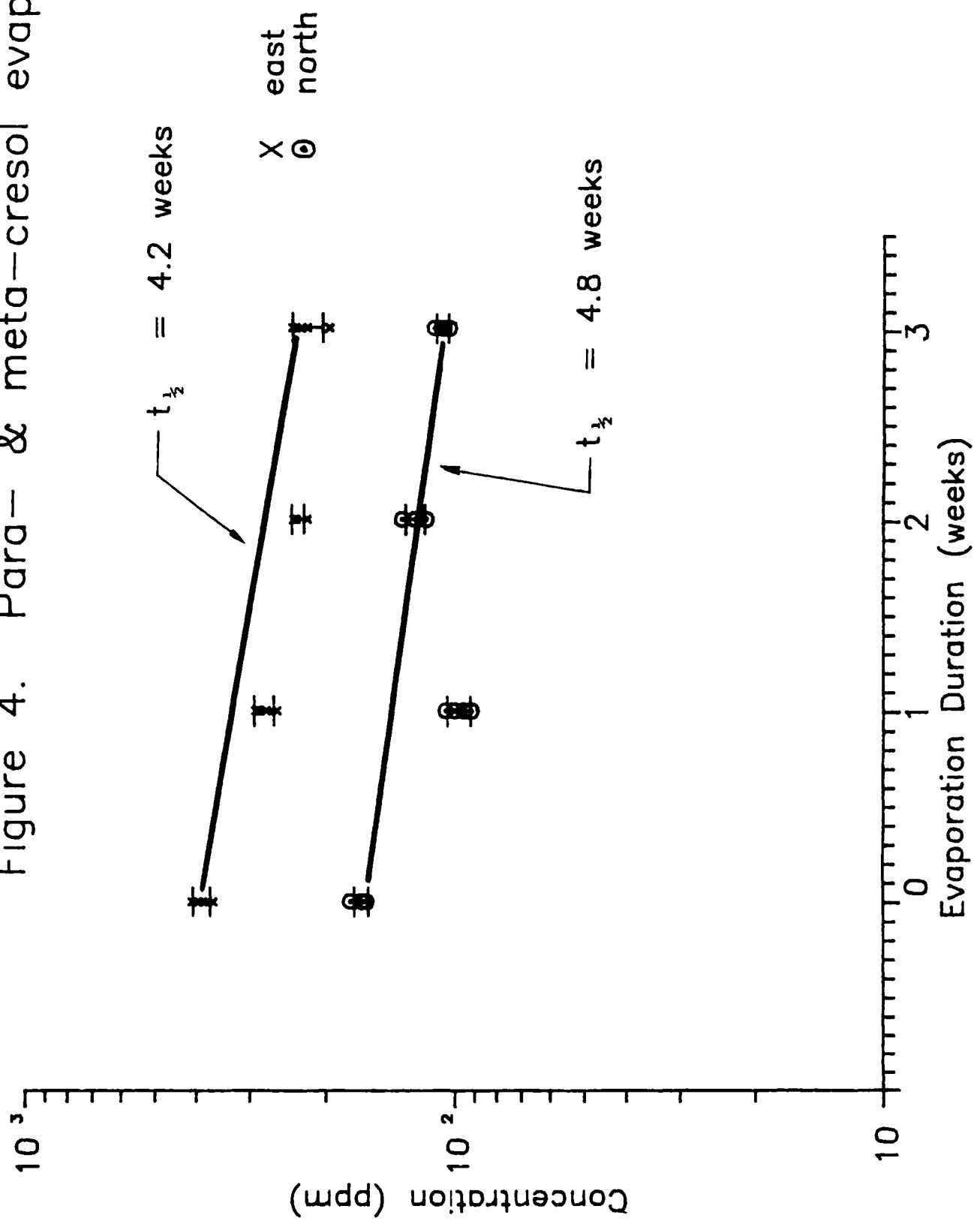


FIGURE 5. Relation of relative vapor pressure to reciprocal half life

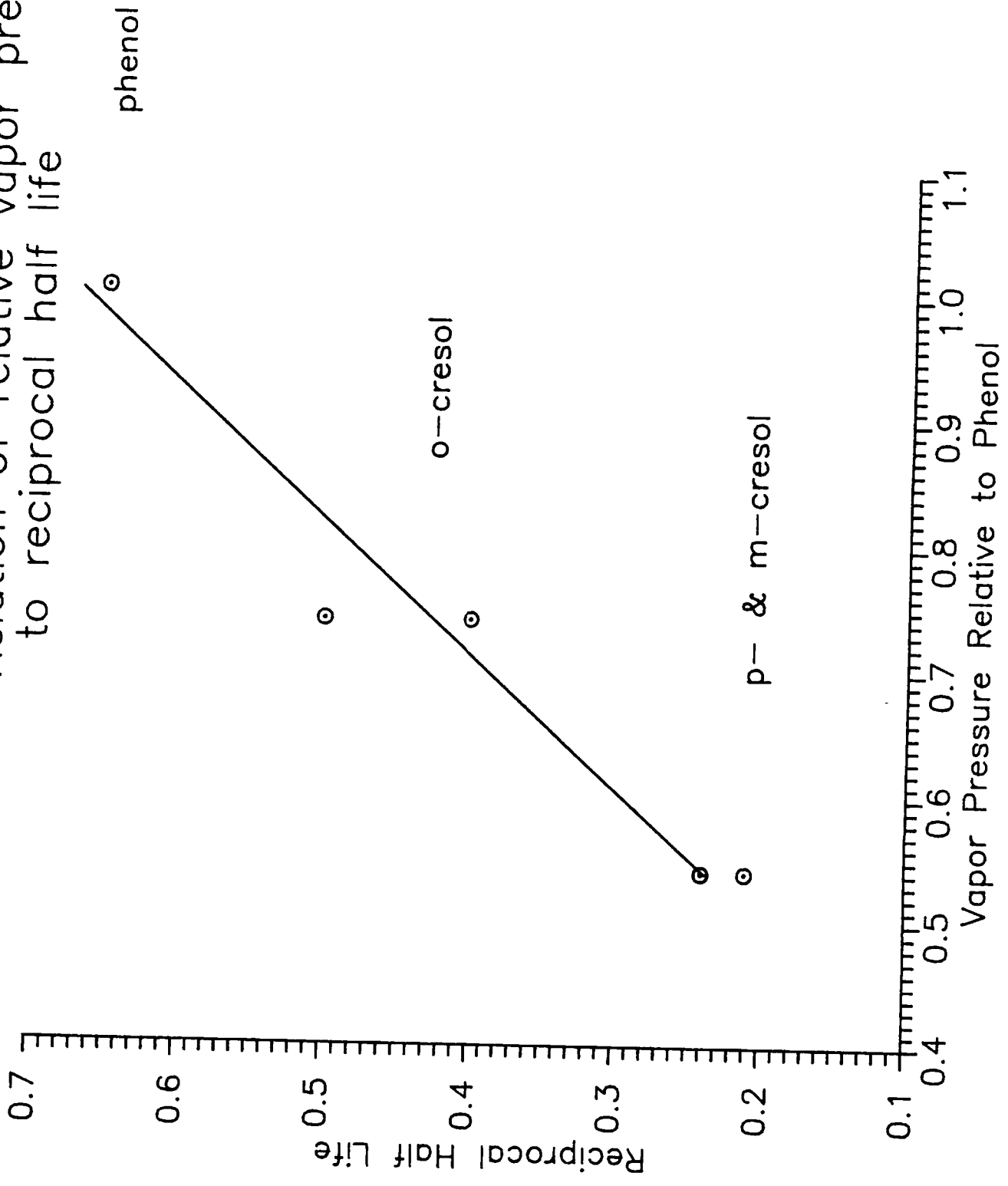


Figure 6. Relation of vapor pressure to temperature

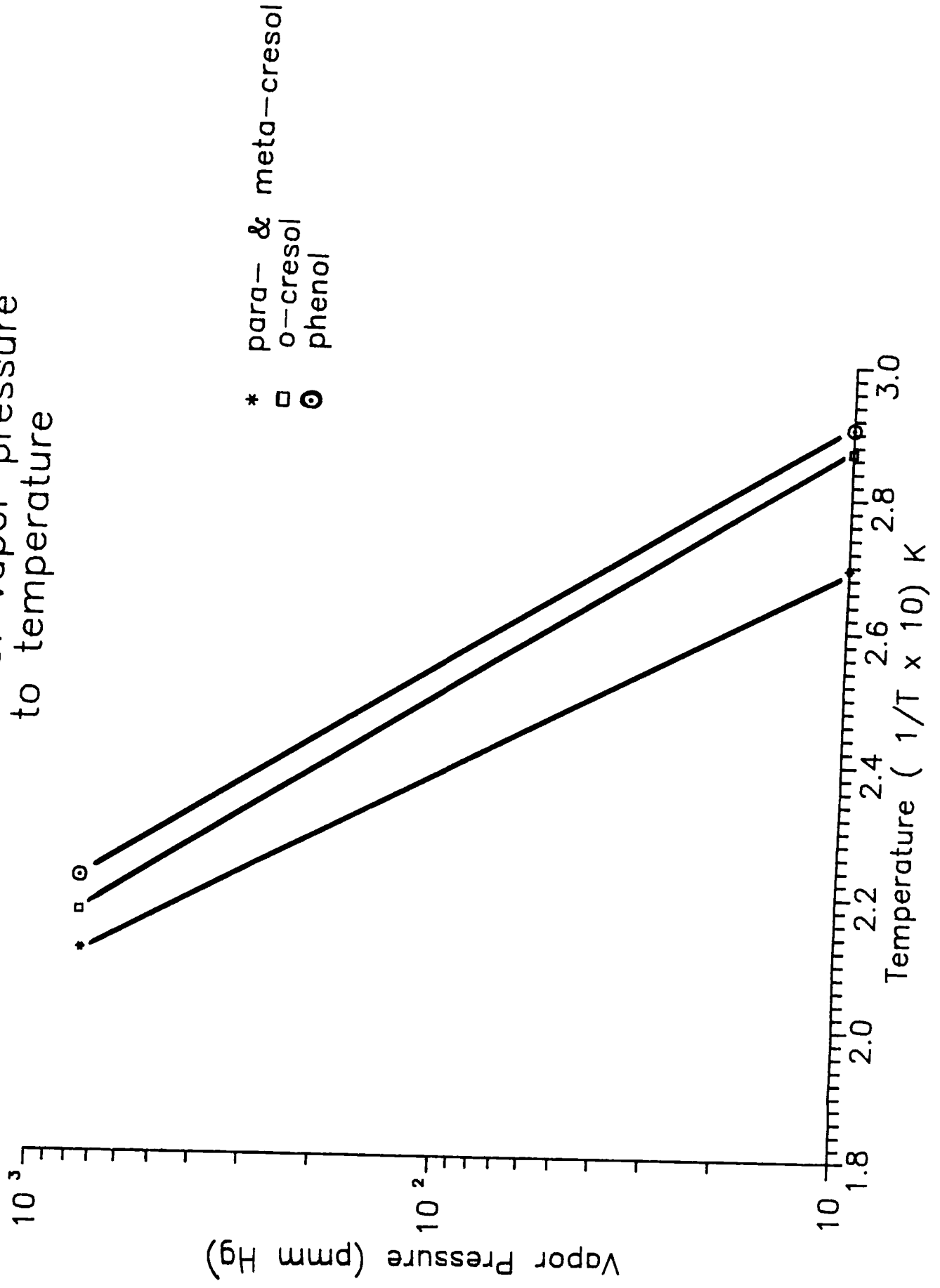


Figure 7. Soil particle size distribution amount retained on mesh

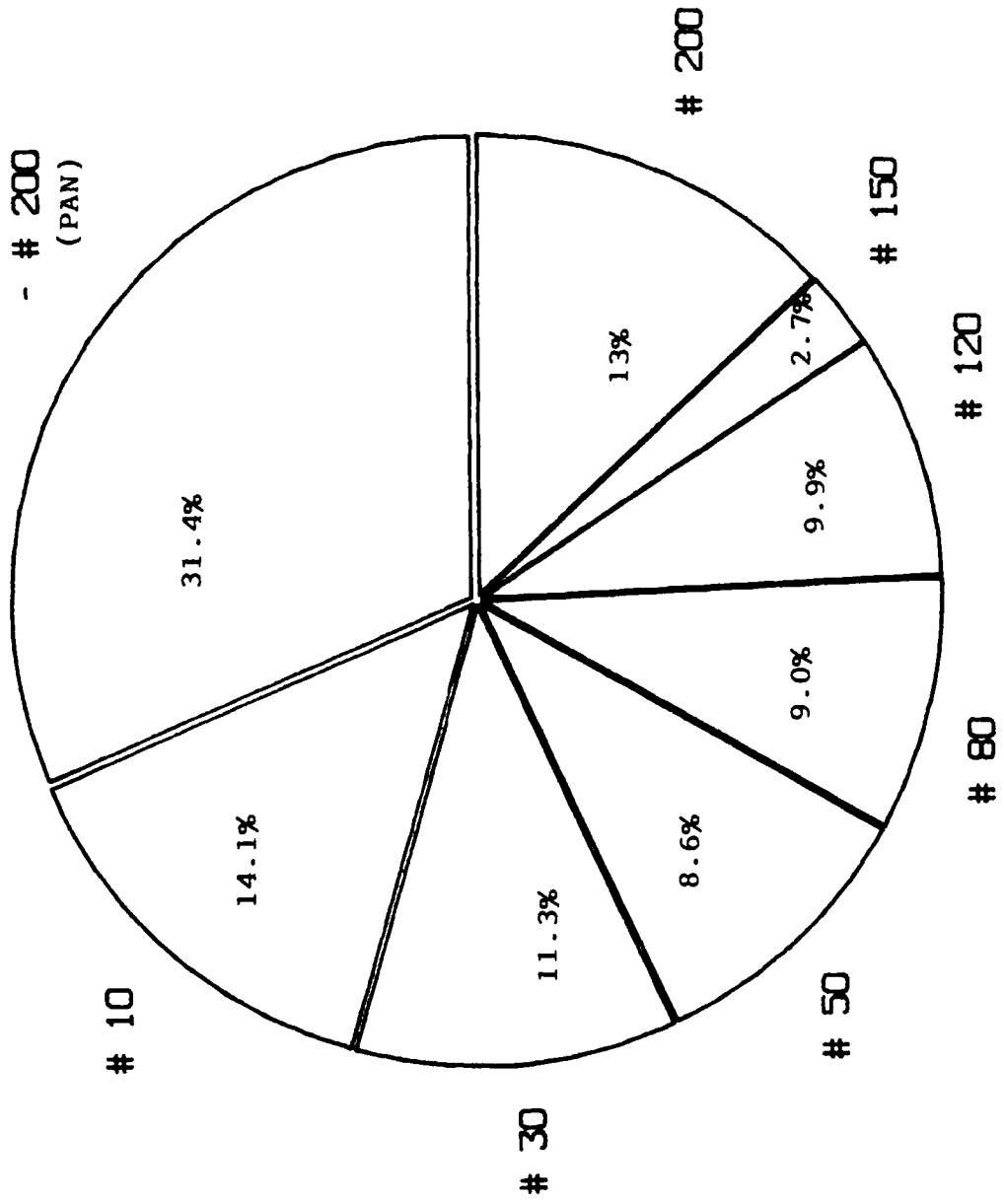


Figure 8. Factored surface area per soil fraction retained on mesh

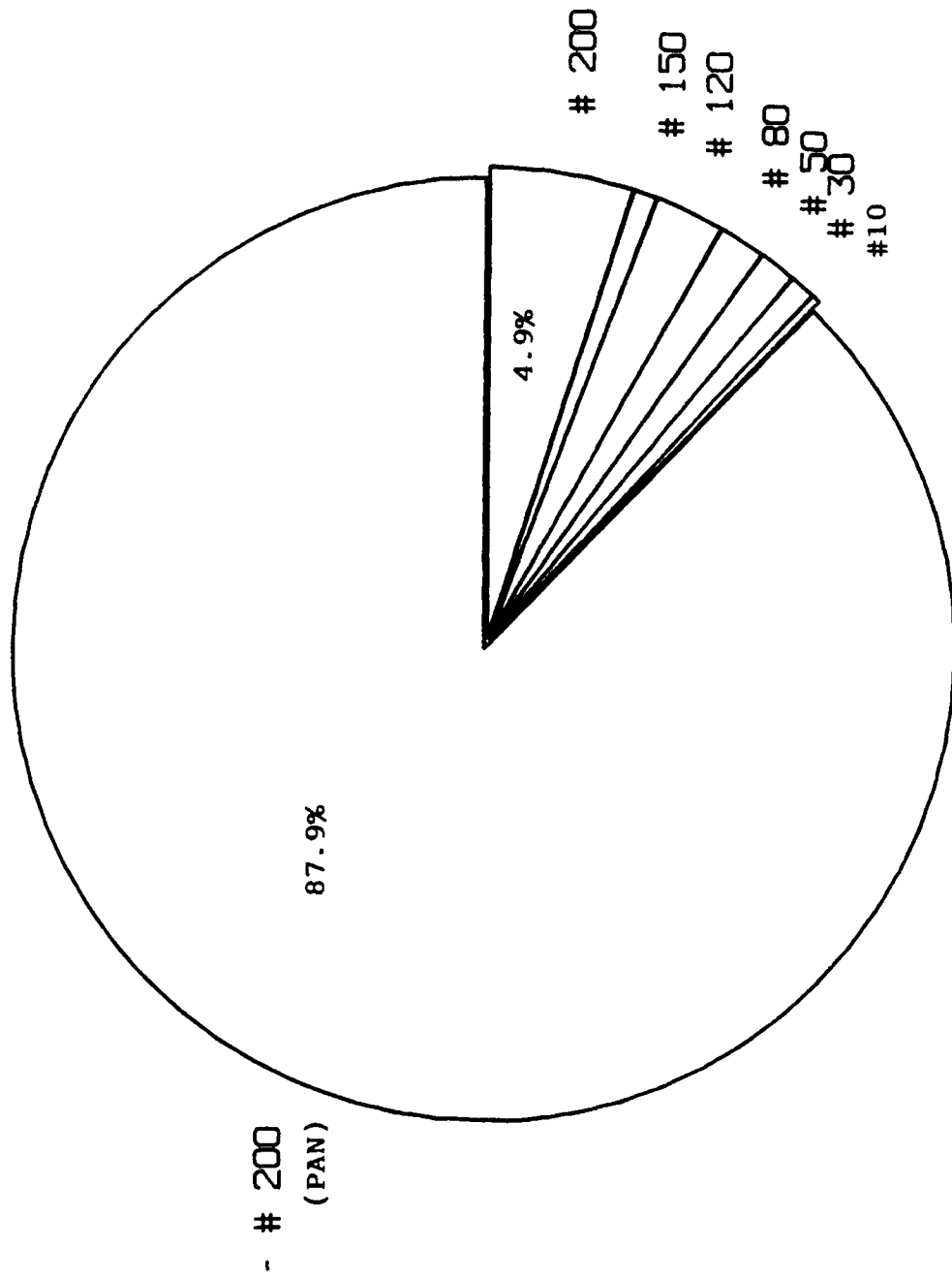




Figure 9. Relative phenol removal efficiency of soil washing

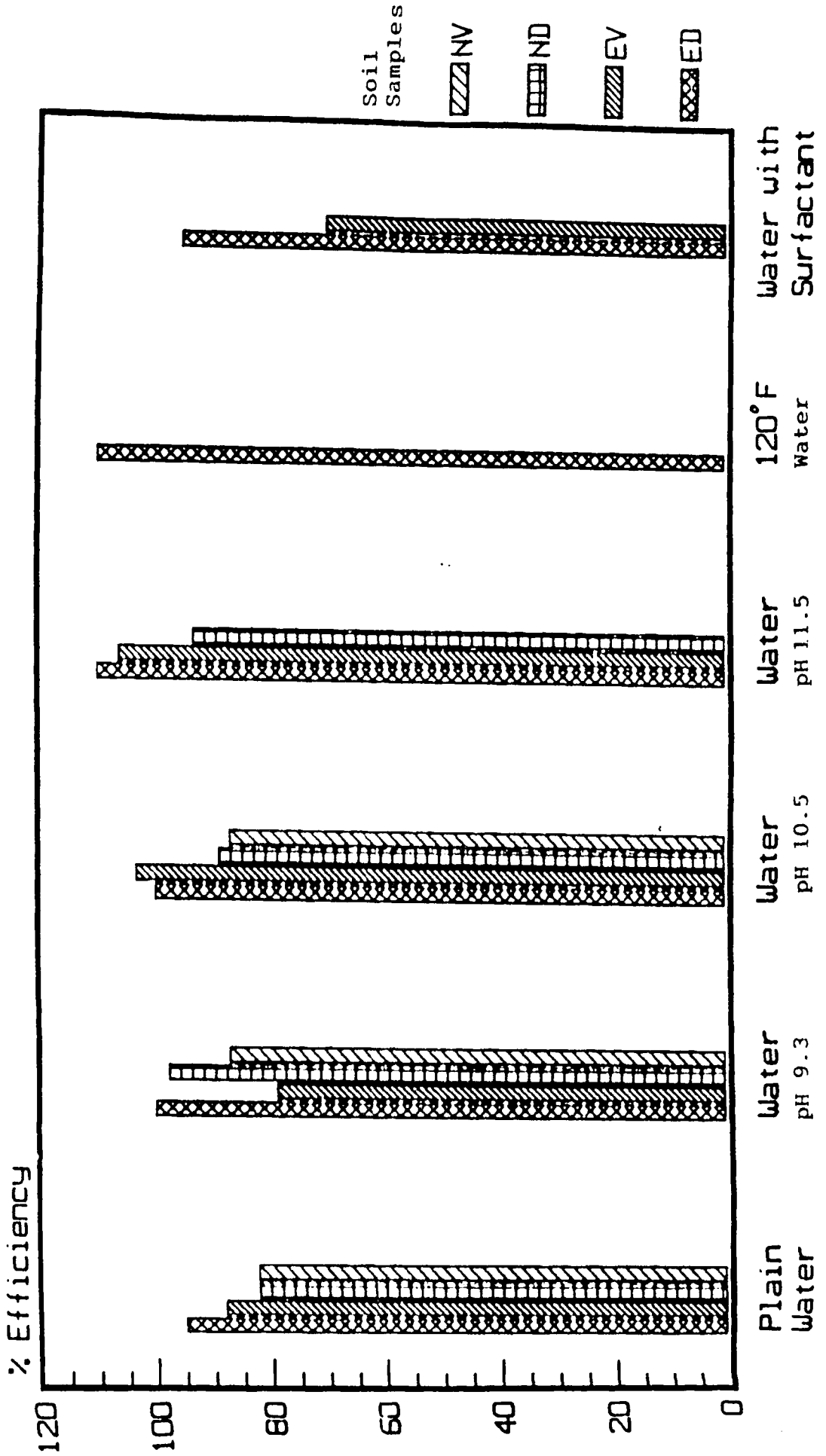


Figure 10. Phenol biodegradation

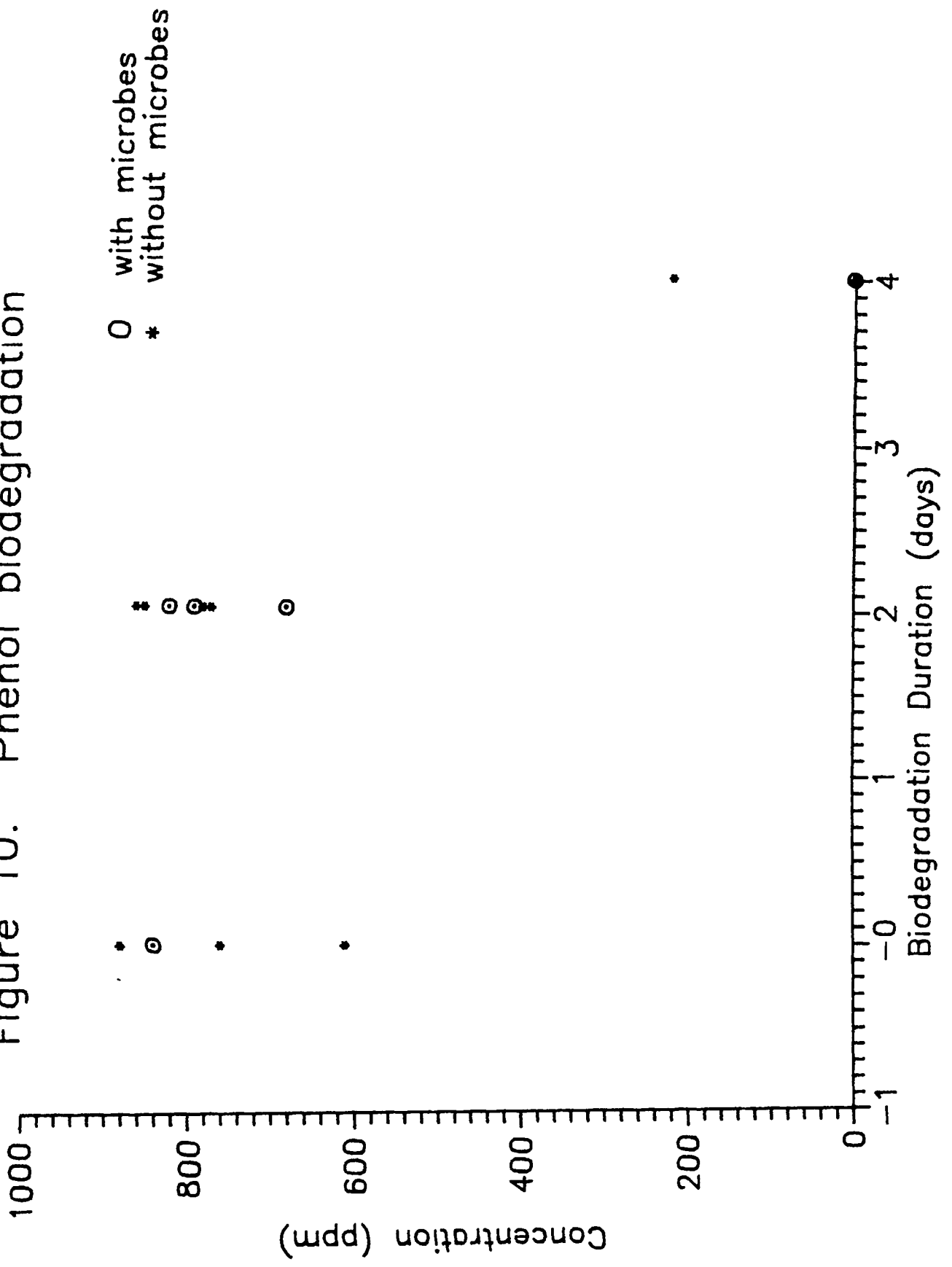


Figure 11. Ortho-cresol biodegradation

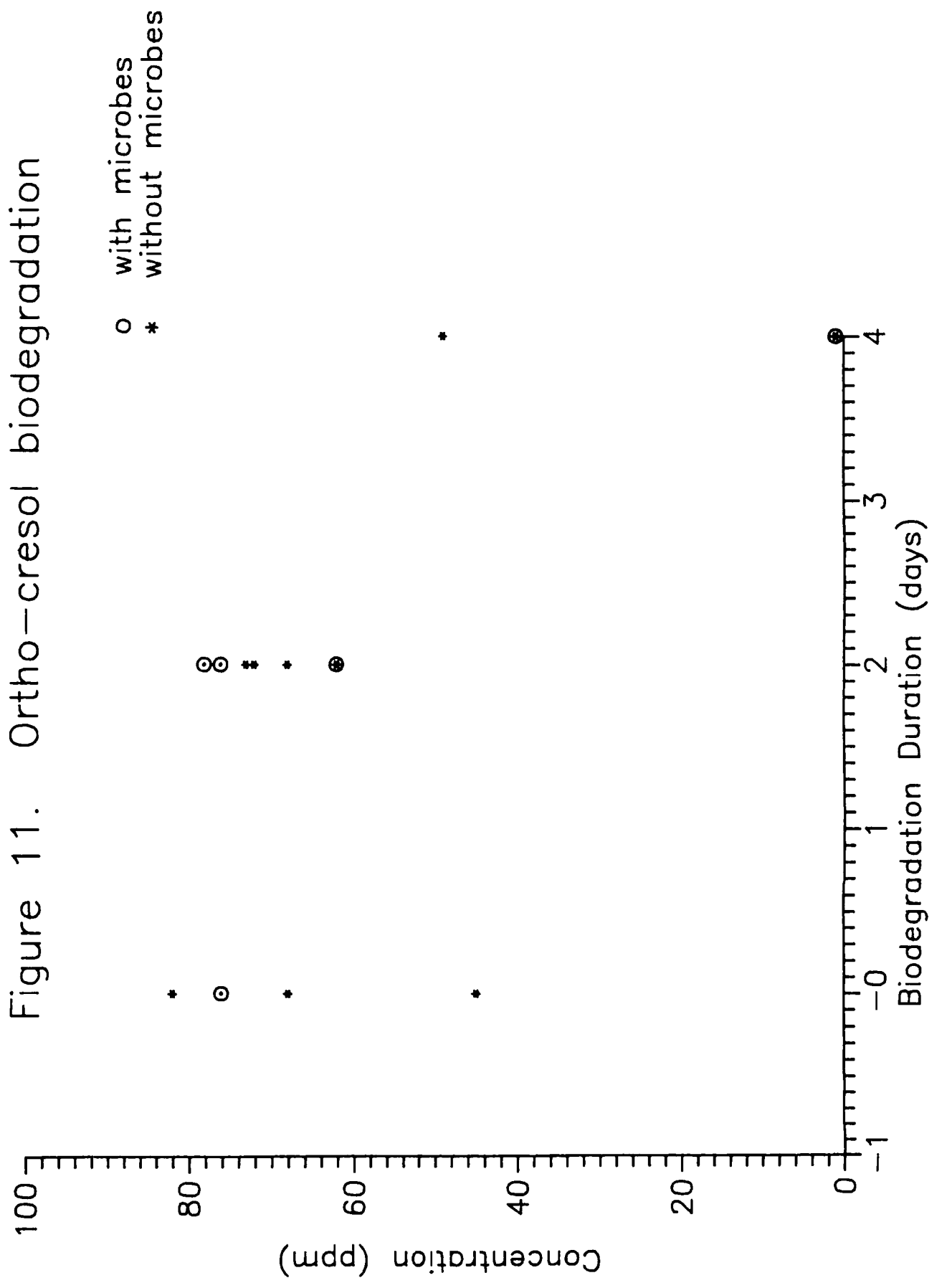
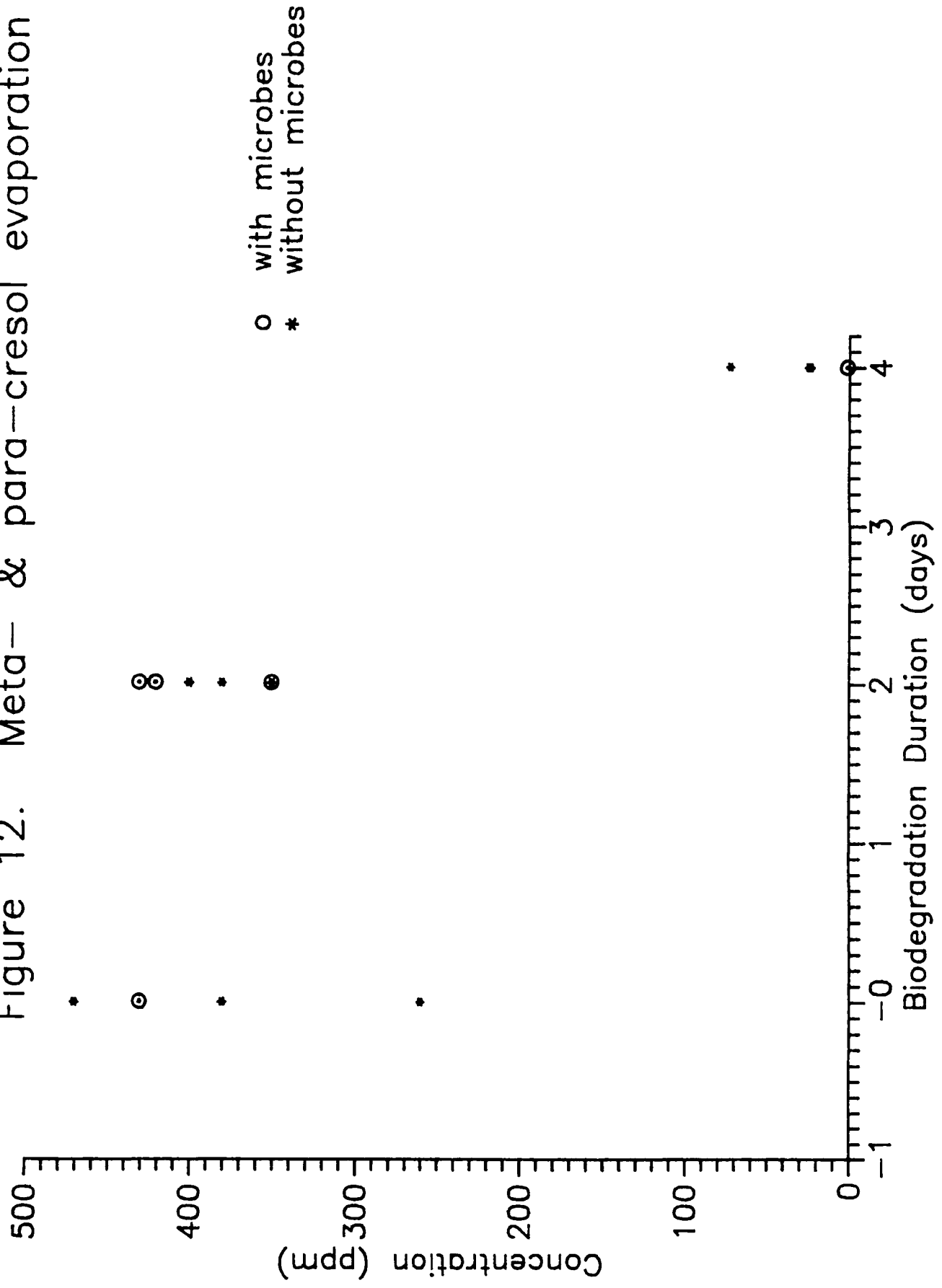


Figure 12. Meta- & para-cresol evaporation



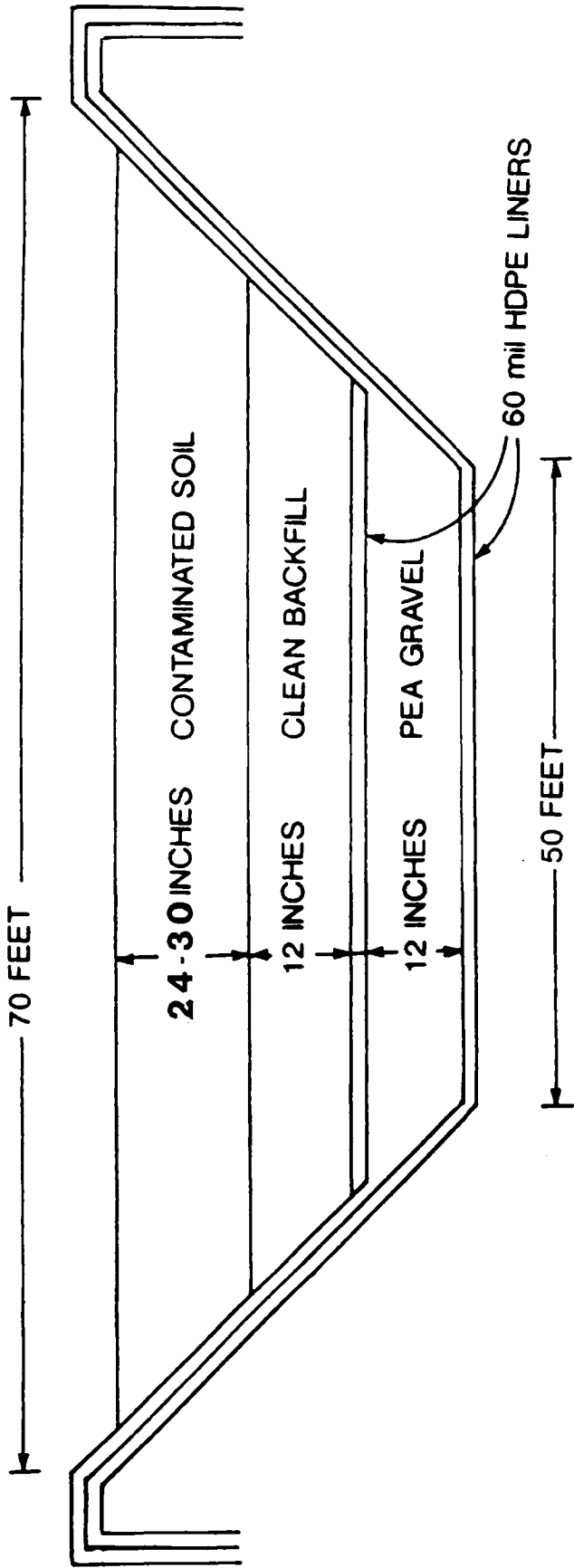


Figure 13. LEACH FIELD CROSS-SECTION

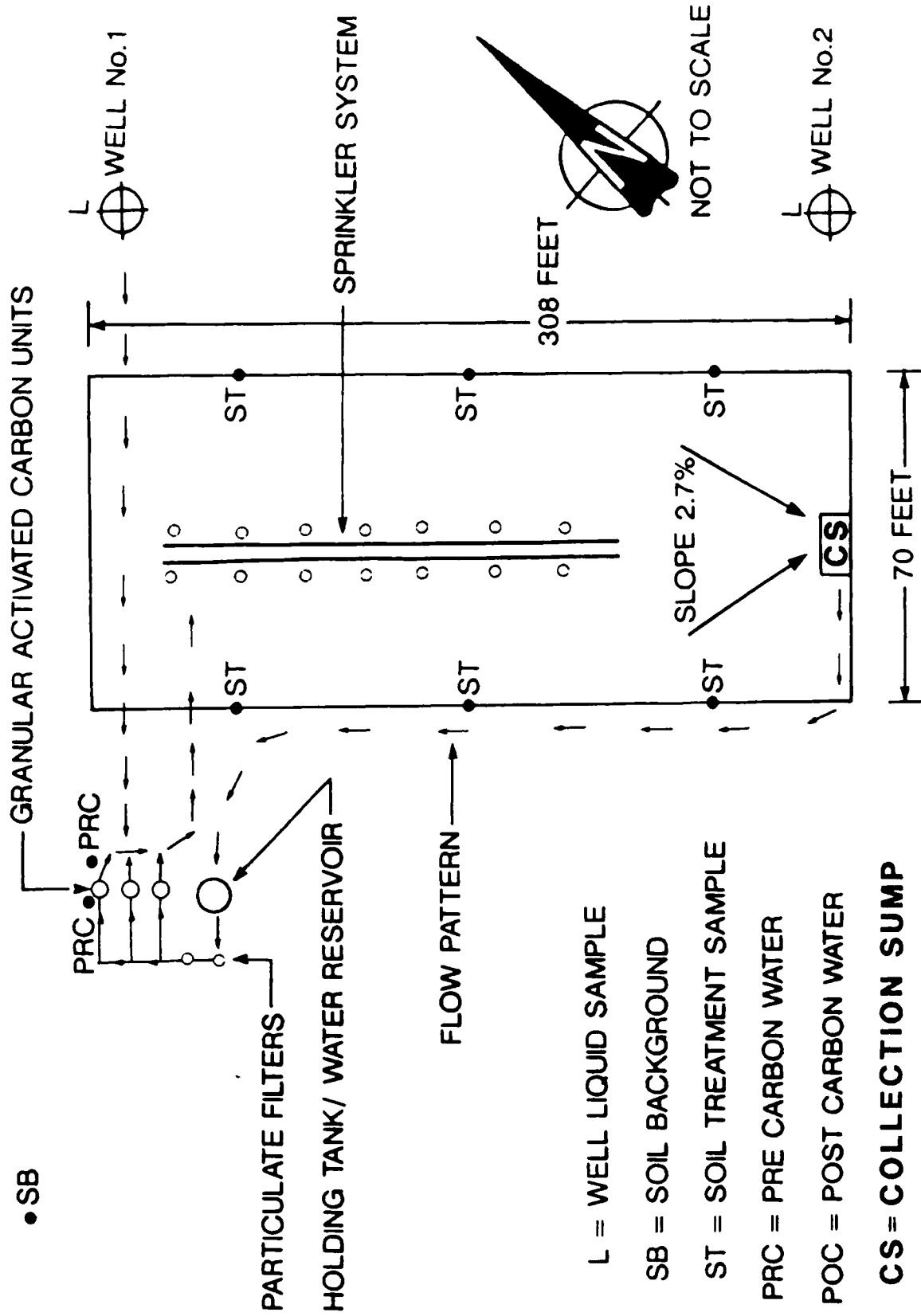


Figure 14. POLY CARB SITE

TABLE 1 - Sample Analysis Trends in Contaminated Soils, Influent and Effluent Leachate at Poly-Carb Site, Wells, Nevada

SAMPLE COLLECTION DATE	TARGET ANALYTE RESULTS - PHENOL (ppm)		
	CONTAMINATED SOIL	INFLUENT LEACHATE	EFFLUENT LEACHATE
JAN 1987	1020	N.T.	N.T.
JULY 8, 1987	980	N.T.	N.T.
AUGUST 5, 1987	43.2	37	11
SEPTEMBER 3, 1987	17	15	0.51
SEPTEMBER 29, 1987	350	5.2	.003

NOTE: N.T. = NO SAMPLE TAKEN

**Figure 15.** Sample Analysis Trends in Contaminated Soil  
at Poly-Carb Site, Wells, Nevada

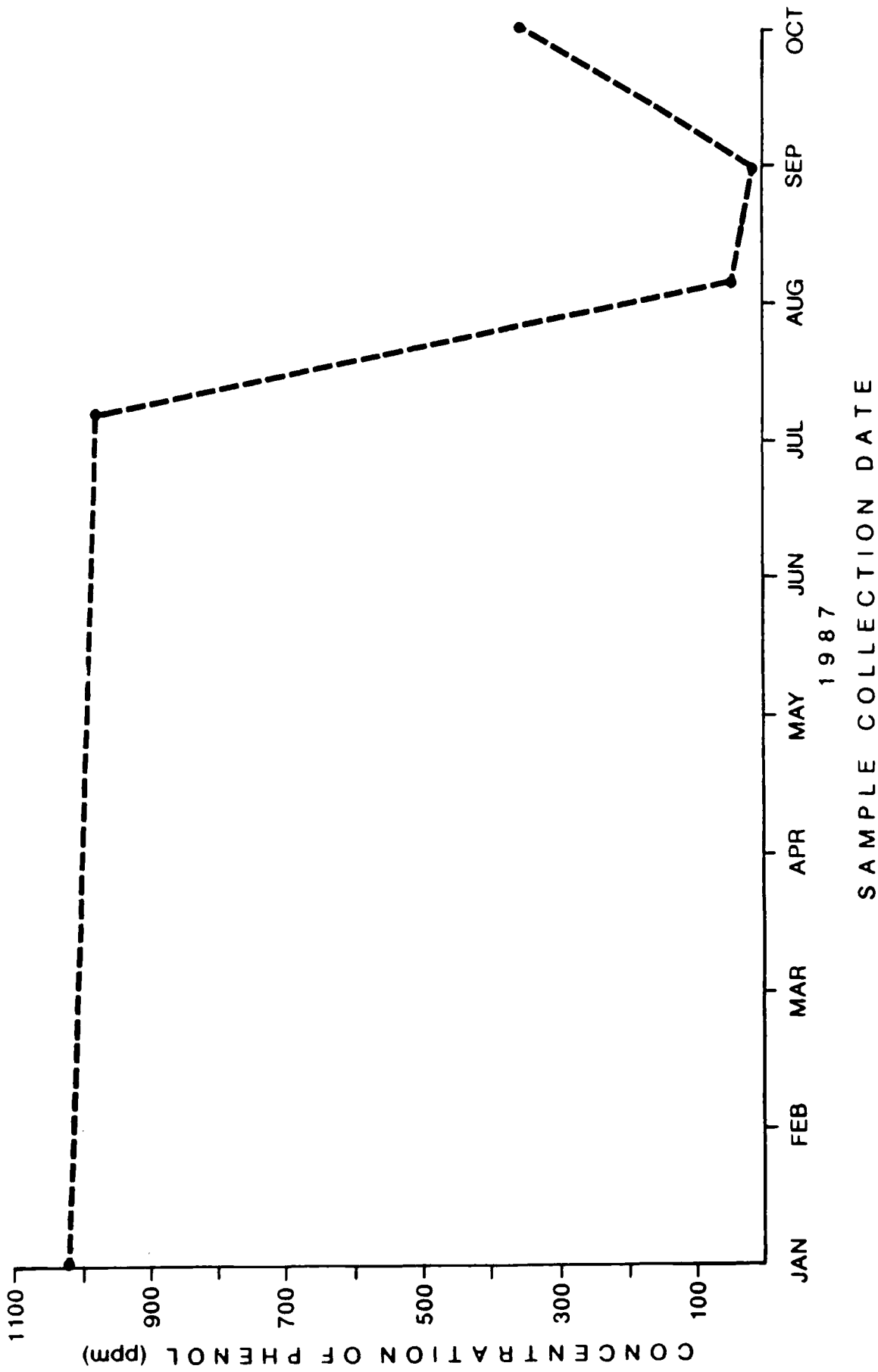




Figure 16. Sample Analysis Trends in Effluent and Influent Leachate at Poly-Carb Site, Wells, Nevada

