Statistical Support Documentation for the 40 CFR, Part 503

Final Standards for the Use or Disposal of Sewage Sludge

Volume I

Final Report
November 11, 1992

U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF SCIENCE AND TECHNOLOGY
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Final Report

Statistical Support Documentation for the 40 CFR, Part 503 Final Standards for the Use or Disposal of Sewage Sludge

Volume I

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PREFACE

Statistical methods and estimates that supported the development of the Final Standards for the Use or Disposal of Sewage Sludge (40 CFR, Part 503) are presented in this document. Estimates include the number of Publicly Owned Treatment Works (POTWs) in the Nation in 1988 practicing at least secondary treatment of wastewater and the estimated concentrations of pollutants of concern in the sewage sludge used or disposed in 1988 by these POTWs. Reported estimates were produced using data from the 1988 National Sewage Sludge Survey.

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1. INTRODUCTION

This document provides technical background, statistical methods, and resulting estimates of pollutant concentrations in sewage sludge from Publicly Owned Treatment Works (POTWs) in the Nation that practice at least secondary treatment of wastewater. Estimates were produced using data from the national probability sample of POTWs known as the 1988 National Sewage Sludge Survey (NSSS). Estimates in this document supported the development of pollutant limitations, regulatory impact analysis (RIA), and aggregate risk analysis in the Final Standards for the Use or Disposal of Sewage Sludge (40 CFR, Part 503).

Pursuant to Section 405(d) of the Clean Water Act (CWA) of 1977, as amended by the Water Quality Act of 1987, the Environmental Protection Agency (EPA) proposed a regulation for the final use and disposal of sewage sludge. For the purpose of the proposed Standards for the Use and Disposal of Sewage Sludge (40 CFR, Part 503) (54 *Federal Register* 5746-5902; February 6, 1989), the EPA used 1979-1980 pollutant-concentration data obtained from the "40 City Study." Although the "40 City Study" provided a reasonable data source for proposing the Part 503 regulation, the EPA believed that a current and reliable data base was required to support the final regulation. The EPA conducted the NSSS to fulfill this requirement.

The NSSS data collection effort began in August 1988 and was completed in September 1989. Samples of final process sewage sludge were collected just prior to use or disposal from 180 POTWs practicing at least secondary treatment of wastewater. These samples were analyzed for over 400 pollutants according to analytical protocols adapted specifically for the sewage sludge matrix. In addition, through the use of a detailed questionnaire, information on sewage sludge use and disposal and operational practices was collected from 462 secondary treatment POTWs. The Agency announced the availability of data and information resulting from the NSSS in a *Federal Register* notice titled "National Sewage Sludge Survey: Availability of Information and Data and Anticipated Impacts on 40 CFR, Part 503." Preliminary statistics estimated from NSSS data concerning the number of POTWs in the Nation using each of nine sewage sludge use and disposal practices in 1988 were reported on October 31, 1990, in the "Technical Support Documentation for Part I of the National Sewage Sludge Survey: Notice of Availability." Also reported in the notice were concentration estimates from the NSSS analytical survey for the 28 pollutants of concern listed in the proposed Final Standards for the Use or Disposal of Sewage Sludge (40 CFR, Part 503).

This document provides the technical background that supports the production of the final NSSS estimates to be reported in the final regulation. To introduce the technical portion of this document, a description of the NSSS and its design follows.

1.1 DESCRIPTION OF THE 1988 NATIONAL SEWAGE SLUDGE SURVEY (NSSS)

The 1988, the NSSS was conducted to collect sewage-sludge-quality and pollutant-detection data that describe sewage sludge just prior to use and disposal. Sewage-sludge-quality data were augmented with 1988 information concerning sewage sludge generation and treatment processes, current and alternate sludge use and disposal practices, and treatment and disposal cost data. These data, which resulted from a national probability sample of POTWs practicing secondary or advanced treatment of wastewater, provided reliable and current data that were used to evaluate risk-based pollutant limitations, conduct regulatory impact analysis (RIA), and develop the aggregate risk analysis (ARA) for the final regulation. These data will also be used to identify pollutants to be controlled in the subsequent amendments to Part 503.

1.2 DESIGN OF THE 1988 NATIONAL SEWAGE SLUDGE SURVEY (NSSS)

POTWs across the Nation practicing at least secondary wastewater treatment were selected as the target population for the NSSS and a national probability sample. Operationally, secondary treatment was defined as a primary clarification process followed by biological treatment and secondary clarification.

The sampling frame for the NSSS effort was defined by excluding POTWs with "Present Effluent Characteristics" codes of "No Discharge," "Raw Discharge," and "Advance Primary" from the EPA Office of Municipal Pollution Control's 1986 NEEDS survey. These exclusions resulted in a sampling frame of 11,407 secondary treatment POTWs in the 50 States, Puerto Rico, and the District of Columbia.

The NSSS effort consisted of two components—a questionnaire survey and an analytical survey. Each component survey had its own probability sample of POTWs selected from the sampling frame of 11,407 secondary treatment POTWs identified by the Agency. The two probability samples are related in that a POTW included in the probability sample for the analytical survey was also included in the questionnaire survey.

The sampling plan for the questionnaire survey was designed to allow survey results to be analyzed in two separate ways—by flow rate group and by sewage sludge use and disposal practice. The sampling frame was partitioned into 24 strata. These strata, created by joint stratification across four categories of wastewater flow rate (referred to as survey design groups) and six use and disposal practices created from data in the 1986 NEEDS survey, are defined below.

- **POTW Average Daily Flow Rate Categories:**

  1. Flow greater than 100 million gallons per day (MGD)
  2. Flow more than 10 MGD but less than or equal to 100 MGD
  3. Flow more than 1 MGD but less than or equal to 10 MGD
  4. Flow less than or equal to 1 MGD.

- **POTW Sewage Sludge Use and Disposal Practice Groups:**
  1. Land application
  2. Distribution and marketing

3. Incineration
4. Monofill (sewage-sludge-only landfill)
5. Co-disposal landfill and other
6. Ocean disposal.

The sample size for each of the 24 strata was statistically determined to minimize marginal coefficients of variation for estimating attributes under the assumption that a particular attribute is distributed hypergeometrically. A total of 479 POTWs was selected randomly from the sampling frame to comprise the questionnaire survey sample. Each POTW in the sample was sent a 50-page questionnaire containing questions about general operation and questions specific to use or disposal practices. The questionnaire gathered general information concerning service area, POTW operations, general sewage sludge use or disposal practices, pretreatment activities, wastewater and sewage sludge testing frequencies, and POTW financial information. POTWs also supplied information specific to their use or disposal practices and indicated which practice(s) would be likely alternatives. The data base created from returned questionnaires contains responses from 462 POTWs.

POTWs in the analytical survey were restricted to the contiguous States and the District of Columbia. All POTWs in the analytical survey were included in the questionnaire survey as well. A total of 208 POTWs from the four flow rate categories was selected for sampling and analysis. EPA contract personnel collected sewage sludge samples just prior to disposal from each POTW according to sampling and preservation protocols. Contract laboratories analyzed each sample for 412 pollutants. The list of tested organics, pesticides, metals, dibenzofurans, dioxins, and PCBs was compiled from the CWA Section 307(a) priority pollutants, toxic compounds highlighted in the "Domestic Sewage Study," RCRA Appendix VIII pollutants, and contaminants of suspected concern in municipal sludge. Analytical methods 1624 and 1625 were adapted from standard methods to allow volatile and semi-volatile organic pollutants to be quantified from the sewage sludge matrix. Pesticides and PCBs were analyzed by method 1618; dibenzofurans and dioxins were quantified using method 1613; and metals, other inorganics, and classicals were analyzed by standard EPA methods. All analytical methods were either developed, chosen, or adapted for the sewage sludge matrix to provide the most reliable and accurate measurement of the 412 pollutants. Analytical data from 180 POTWs are recorded in the NSSS analytical data base.

Printed or computer copies (9-track tape) of the questionnaire survey data base are available from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia, 22161. When ordering printed copies of the questionnaire data (PB 90-107509; cost $97.95) or the analytical data (PB 90-107491; cost $139.95), specify the PB number. Computer tapes, written under the OS operating system in SAS transportable code at 1600 bpi with logical record lengths of 80 and block sizes of 8000, should be readable by CMS, VSE, AOS/VS, PRIMOS, and VMS. The NTIS order number for the NSSS data tape is PB 90-501834 and the current price is $220. A data element dictionary containing definitions and specifications for all NSSS variables is also available (PB 90-198961; cost $23.)

1.3 NATIONAL SEWAGE SLUDGE SURVEY DATA BASES

The complete set of stored NSSS data is located in four component data bases; these are described below.

- **Questionnaire Data Base for the NSSS** contains questionnaire responses and followup responses published through the National Technical Information Service (NTIS) in 1990. These data are used as a historical reference. The EPA Statistical Analysis Section developed and maintains this data base.

- **Data Conventions Data Base for the NSSS** contains regulatory analytical (RA) use or disposal practice classifications, followup responses, and imputed values for missing or improbable responses for a select set of questions. These data are used in conjunction with the Questionnaire Data Base and the Analytical Data Base to describe sewage sludge use or disposal practices in 1988. The EPA Statistical Analysis Section developed and maintains this data base.

- **Regulatory Impact Data Base for the NSSS** contains questionnaire responses, followup responses, definition changes, additional information from the 1988 Needs Survey about POTWs that do not practice secondary or better wastewater treatment, and updated use or disposal information from POTWs legally required to change from ocean disposal after 1988. These data are used to support the aggregate risk analysis and the economic impact analysis required for promulgation of the final sewage sludge use or disposal regulation. The EPA Economic Analysis Section developed and maintains this data base.

- **Analytical Data Base for the NSSS** is the sole source of chemical analytical data used from the survey. These data are used in conjunction with the Revised Questionnaire Data Base for the NSSS to describe pollutant concentrations across the country in 1988, in conjunction with the Regulatory Data Base for the NSSS to estimate the environmental effect of current sewage sludge or disposal practices, and in conjunction with the Regulatory Impact Data Base for the NSSS to estimate the cost of compliance with the final sewage sludge use or disposal regulations. The EPA Sample Control Center developed and maintains this data base.

1.4 DOCUMENT ORGANIZATION AND TEXT CONVENTIONS

This document is divided into two volumes containing ten chapters and one appendix. Each chapter following this introduction is designed to stand alone. Therefore, it is sometimes necessary to repeat definitions and other information in more than one chapter. Throughout the report, certain text conventions are used to differentiate between NSSS survey responses (shown CAPITALIZED) and regulatory analytical (RA) use or disposal practice categories (shown in *CAPITALIZED ITALICS*). A summary of the contents of each section follows.

Volume I

- **Chapter 1. Introduction**—describes the National Sewage Sludge Survey, including its history and purpose, how it was designed, and how it supports the Final Standard for the Use or Disposal of Sewage Sludge (40 CFR, Part 503). The chapter also describes the four NSSS data bases and outlines the document's organization and text conventions.

- **Chapter 2. Estimation of the Number of Publicly Owned Treatment Works in the Nation Using Each of the Regulated Analytical (RA) Use or Disposal Practices in 1988**—provides technical background and estimates of the number of POTWs in the Nation practicing at least secondary treatment of wastewater and using each of the RA use or disposal practices in 1988. The chapter defines six categories of RA disposal practices—*LAND APPLICATION, INCINERATION, SURFACE DISPOSAL, DISPOSAL PRACTICE NOT COSTED FOR PART 503. UNKNOWN USE OR DISPOSAL PRACTICE, AND INELIGIBLE OR OUT OF BUSINESS;* describes data conventions; and estimates the national totals and variances of the total estimates.

- **Chapter 3. Estimation of the Number of Publicly Owned Treatment Works in the Nation for Each of Four Flow Rate Groups**—provides technical background and estimates of the number of POTWs in the Nation practicing at least secondary treatment of wastewater and using each of the RA use or disposal practices in 1988 in each of four flow rate groups. The chapter outlines data conventions and estimates national totals and variances of the total estimates.

- **Chapter 4. Stratum Weights**—provides both survey design stratum weights for the questionnaire and analytical surveys and adjusted stratum weights.

- **Chapter 5. National Estimates for the Total Dry Weight of Sewage Sludge Used or Disposed in 1988**—provides national estimates for the total dry weight of sewage sludge used or disposed in 1988 by RA use or disposal practice, by RA end use, and by average daily flow rate group.

- **Chapter 6. National Estimates for Selected Aspects of Regulated Analytical (RA) Use or Disposal Practices**—discusses several technical aspects of three RA use or disposal practices—*LAND APPLICATION* (preventing runoff to surface waters, maintaining control over the ultimate end use, and using alternative practices), *INCINERATION* (types of incinerators, afterburners, and where incinerator ash is disposed), and *SURFACE DISPOSAL* (monofills used per POTW, estimated depth to groundwater, release controls, owner of the monofill, and operator of the monofill).

- **Chapter 7. National Concentration Estimates for Pollutants**—describes physical analysis methods and reporting procedures, distributional estimation with censored data, fundamental units of analysis, distributional estimation of pollutant concentrations by POTW, and distributional estimation of pollutant concentrations by amount of sewage sludge used or disposed.

<u>**Volume II**</u>

- **Chapter 8. Comparison of Primary and Secondary Wastewater Treatment Sewage Sludges Using the "40 City Study"**—compares primary and secondary wastewater treatment sewage sludges.

- **Chapter 9. Data Integrity Assessments and Edits**—addresses data integrity and edits including use and disposal practices, individual POTW responses for total sewage sludge weight, and assessment and corrective actions to specific RA use and disposal practice responses.

- **Chapter 10. Lognormal Estimates from Stratified Random Samples**—presents study motivations, design, and results of the Monte Carlo simulation to illustrate the distributional properties associated with weighted mixtures of random variables that are lognormally distributed.

- **Appendix. Data Listings**—provides three data listings. Part A1 lists pollutant-concentration data from the analytical survey. Part A2 provides a listing of the Data Conventions Data Base containing RA use or disposal classifications and updated dry weights of sewage sludge used or disposed in 1988 for the POTWs in the NSSS. Finally, Part A3 lists pollutant-concentration data for the subset of 16 POTWs in the "40 City Study" used for statistical testing reported in Chapter 8.

A list of references is provided in both volumes.

2. ESTIMATION OF THE NUMBER OF POTWs IN THE NATION USING EACH OF THE REGULATORY ANALYTICAL (RA) USE OR DISPOSAL PRACTICES IN 1988

In accordance with the final regulation, the six 1986 NEEDS **survey disposal practices** and the nine 1988 National Sewage Sludge Survey (NSSS) **reported disposal practices** (which added three to the original six) were analyzed and reclassified into six new **regulatory analytical (RA) use or disposal practices.** Employing NSSS data, this chapter provides the technical background to produce point and interval estimates of the number of Publicly Owned Treatment Works (POTWs) in the Nation using each of the six RA use or disposal practices in 1988. Section 2.1 defines the six RA use or disposal practices and their subclassifications (see boxed definitions below). Section 2.2 provides data conventions and definitions of key variables. Section 2.3 cites the statistical formulae defining the point estimator of the total number of POTWs in the Nation from the NSSS stratified random sample data and the variance of the total estimate and also presents resulting estimates and confidence intervals for major RA use or disposal practices. Section 2.4 presents national total estimates for all RA use or disposal practices and end uses. Finally, Section 2.5 provides comments concerning a specific result.

2.1 REGULATORY ANALYTICAL (RA) USE OR DISPOSAL PRACTICES

Definitions for RA use or disposal practices, end uses, and analytical subclassifications are based on three specific questions asked in the NSSS. In particular, the six RA use or disposal practices were determined from question I-24 of the NSSS questionnaire; the Land Application end uses were determined from questions II-1 and III-1. The six major RA use or disposal practice categories are as follows:

1. *LAND APPLICATION*
2. *INCINERATION*
3. *SURFACE DISPOSAL*
4. *DISPOSAL PRACTICE NOT COSTED UNDER PART 503*
5. *UNKNOWN USE OR DISPOSAL PRACTICE*
6. *INELIGIBLE OR OUT OF BUSINESS.*

To differentiate the six RA **use or disposal practices** from the six NEEDS **survey disposal practices,** and the nine NSSS **reported disposal practices**, the RA use or disposal practices always appear in the text in *CAPITALIZED ITALICS.*

The boxed information that follows outlines the classifications resulting from the analysis of the NSSS questions, showing two outline levels and subclassifications. The first outline level describes the six RA use or disposal practices defined under the Final Standards for the Use or Disposal of Sewage Sludge (40 CFR, Part 503). The second outline level details the sewage sludge end uses. Subclassifications for analysis purposes are provided on both levels. CAPITALIZED words used to describe the subclassifications are paraphrases of possible responses from the three NSSS questions referred to above.

REGULATORY ANALYTICAL (RA) USE OR DISPOSAL PRACTICES

1. LAND APPLICATION

Includes POTWs classified as practicing LAND APPLICATION and DISTRIBUTION AND MARKETING.

1.1 Agricultural Land

Includes POTWs classified as practicing land application end uses ANIMAL FEED CROP LAND (NOT PASTURE), HUMAN FOOD CROP LAND, PASTURE LAND, and OTHER, as appropriate. Also includes the distribution and marketing end uses FARMERS and OTHER, as appropriate.

1.2 Forests

Includes POTWs classified as practicing land application end uses SILVICULTURE LAND and OTHER, as appropriate. Also includes the distribution and marketing end use OTHER, as appropriate.

1.3 Public Contact Sites

Includes POTWs classified as practicing land application end uses or distribution and marketing end uses GOLF COURSES, LANDSCAPE CONTRACTORS, MUNICIPAL PARKS, HIGHWAYS, and OTHER, as appropriate.

1.4 Reclaimed Land

Includes POTWs classified as practicing land application end uses LAND RECLAMATION and OTHER, as appropriate. Also includes the distribution and marketing end use OTHER, as appropriate.

1.5 Sale or Giveaway in a Bag or Similar Enclosure

This classification includes POTWs reporting DISTRIBUTION AND MARKETING to the end use GENERAL PUBLIC. All other POTWs are assumed to use some different RA use or disposal practice.

1.6 Undefined Land Application

Includes POTWs classified as practicing land application that could not be classified as to end use. Also includes distribution and marketing end use OTHER, as appropriate.

1.7 Compost Brokers/Contractors

Includes POTWs classified as practicing DISTRIBUTION AND MARKETING end use COMPOST BROKERS/CONTRACTORS.

2. INCINERATION

Includes POTWs classified as practicing INCINERATION.

REGULATORY ANALYTICAL (RA) USE OR DISPOSAL PRACTICES (con't)

3. SURFACE DISPOSAL

Includes POTWs classified as practicing DEDICATED LAND FOR SEWAGE SLUDGE DISPOSAL, MONOFILL, and SURFACE DISPOSAL. However, POTWs responding that they practice SURFACE DISPOSAL will be evaluated in relation to other survey responses on a case-by-case basis.

3.1 Dedicated Land

Includes POTWs classified as practicing DEDICATED LAND FOR SEWAGE SLUDGE DISPOSAL.

3.2 Monofill

Includes POTWs classified as practicing MONOFILL.

3.3 Other Surface Disposal

POTWs classified as practicing Surface Disposal that are not classified as practicing Dedicated Land or MONOFILL.

4. DISPOSAL PRACTICE NOT COSTED UNDER PART 503

Includes POTWs classified as practicing CO-DISPOSAL LANDFILL and CO-INCINERATION. The costs and benefits of using these disposal practices are not considered under Final Standards for the Use or Disposal of Sewage Sludge (40 CFR, Part 503).

5. UNKNOWN USE OR DISPOSAL PRACTICE

Includes POTWs classified as practicing OCEAN DISPOSAL, OTHER, WASTEWATER STABILIZATION POND, and NO SLUDGE. These facilities may, after implementation of the Final Standards for the Use or Disposal of Sewage Sludge (40 CFR, Part 503), use or dispose of sewage sludge in some fashion covered by the regulation.

5.1 Ocean Disposal

Includes POTWs classified as practicing OCEAN DISPOSAL.

5.2 Other

Includes POTWs classified as practicing OTHER that did not use or dispose of sewage sludge in 1988.

5.3 Unknown Transfer

POTWs whose OTHER practice is described as transfer and who cannot otherwise be classified.

6. INELIGIBLE OR OUT OF BUSINESS

POTWs found to practice less than secondary wastewater treatment and POTWs found to be out of business.

2.2 DATA CONVENTIONS

Prior to defining survey strata for sampling design purposes, the use or disposal practices of 11,407 secondary treatment POTWs were determined from information reported in the 1986 NEEDS survey. Six disposal practices were identified. These practices, referred to as survey disposal practices, are (1) Land Application, (2) Distribution and Marketing, (3) Incineration, (4) Monofill, (5) Co-disposal Landfill, and (6) Ocean Disposal. The cross-classification of these six disposal practices, along with the four levels of average daily flow rate, were multiplied to partition the sampling frame into 24 mutually exclusive strata. From these 24 strata, a total of 479 POTWs was randomly selected to comprise the NSSS questionnaire survey sample. Survey stratum identifications for each POTW in the sample are important to data analyses because (a) the stratum number indicates the sampling fraction to be assigned to the POTW's data for statistical estimation procedures, and (b) the disposal practice component of the stratum number indicates the POTW's disposal practice option reported in the 1986 NEEDS survey.

POTWs in the questionnaire survey reported the practice(s) used to dispose of sewage sludge in 1988 in question I-24 of the survey document. This question instructed the participant to record the wet weight of sewage sludge disposed by each of nine disposal practices. The first six of these nine practices are the same as the 1986 NEEDS survey disposal practices listed above. The remaining three are (7) Co-incineration, (8) Surface Disposal, and (9) Other. Answers to these nine questions were known as reported disposal practices. Sewage sludge disposal options for 1988 were expanded to include the three additional practices listed in question I-24 because not all of the POTWs responding to the survey used one of the six 1986 NEEDS survey-based disposal options. The box below summarizes the disposal practice questions asked in the two surveys.

NEEDS AND NSSS QUESTIONNAIRE CATEGORIES	
Survey Disposal Practices (1986 NEEDS) Included six categories.	1. LAND APPLICATION 2. DISTRIBUTION AND MARKETING 3. INCINERATION 4. MONOFILL 5. CO-DISPOSAL LANDFILL 6. OCEAN DISPOSAL
Reported Disposal Practices (1988 NSSS) Included the first six categories and added three more (numbers 7-9).	7. CO-INCINERATION 8. SURFACE DISPOSAL 9. OTHER

Definitions of the first eight reported disposal practices, just as they appeared in the NSSS questionnaire, are provided in Table 2-1.

TABLE 2-1
DEFINITIONS OF REPORTED SEWAGE SLUDGE USE OR DISPOSAL PRACTICES FROM THE 1988 NSSS SURVEY QUESTIONNAIRE

Land Application - The application of liquid, dewatered, dried, or composted sewage sludge to the land by surface spraying, surface spreading, or subsurface injection. Sludge may be applied to land intended for a number of end uses including, but not limited to, cropland, pasture, commercially grown turf, silviculture, land for reclamation, and dedicated sites. The sludge may be applied by the POTW or by a distributor or end user under a contract or similar control mechanism with the POTW. Note that in this definition, the POTW has direct control over the application of sewage sludge.

Distribution and Marketing - The give-away, transfer, or sale of sewage sludge or sewage sludge product (e.g., composted sludge product) in either bagged or bulk form. The POTW does not apply the sludge and the end-user applying the sludge is not under the direct control of the POTW. Note that a label or notice provided with the sewage sludge does not constitute direct control.

Sewage Sludge Incineration - The treatment of sewage sludge exclusively in an enclosed device using controlled flame combustion. Includes all sewage sludge incinerators on site and also, those facilities transporting sewage sludge to another facility that operates sewage sludge incinerators.

Monofill - A controlled area of land that contains one or more sewage sludge units. A sewage sludge unit is defined as a controlled area of land where only sewage sludge is placed. The sludge is covered with a cover material at the end of each operating day or at more frequent intervals.

Co-Disposal Landfill - An area of land or an excavation that is used for the permanent disposal of solid waste, residuals, and sewage sludges. These include, but are not limited to, municipal landfills that accept sewage sludge for disposal in conjunction with other waste materials.

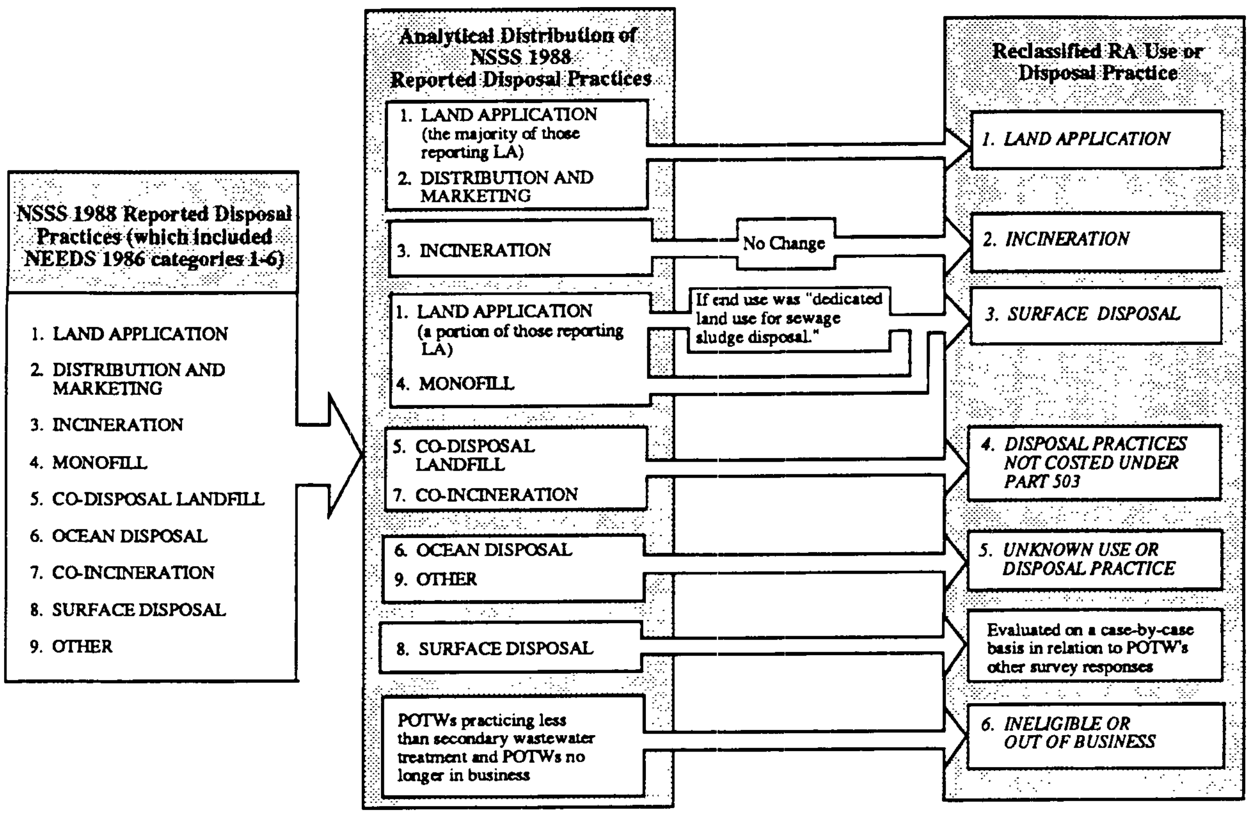
Ocean Disposal - Dumping or controlled release of sewage sludge from a barge or other vessel into marine water.

Co-Incineration - The combined treatment of sewage sludge and combustible waste materials (e.g., trash and other municipal solid waste) in an enclosed device using controlled flame combustion.

Surface Disposal - A controlled area of land where only sewage sludge is placed for a period of one year or longer. Sludge placed in this area is not provided with a daily or final cover. (Surface disposal areas may become naturally covered with vegetation as a result of seed drift). Surface disposal does not include areas where sludge has formed or is currently being formed and being deposited as a result of ongoing treatment (e.g., finishing ponds). Surface disposal can be a natural topographical depression, man-made excavation or diked area formed primarily of earthen material designed to store (not treat) sewage sludge for a period of one year or longer. Surface disposal also includes placement of sludge in piles for a period of one year or more, as a means of disposal.

For the final data estimates, the nine reported disposal practices were redefined into six regulatory analytical (RA) categories for analysis. As redefined, they are referred to throughout this report as RA use or disposal practices (defined in Section 2.1). Figure 2-1 provides an overview of how NSSS reported disposal practices were reclassified into RA use or disposal practices.

Figure 2-1. Overview of NSSS 1988 Reported Disposal Practice Categories and Their Reclassification Into Regulatory Analytical (RA) Use or Disposal Practices



Some POTWs that used wastewater stabilization ponds as a form of secondary wastewater treatment indicated in Question I-24 that their major disposal practice in 1988 was Surface Disposal. Other POTWs listed Sludge Lagoon under the Other reported disposal practice category of Question I-24. Upon further review of the data and schematics from these facilities, the majority were classified as using wastewater stabilization ponds—these were then categorized as *UNKNOWN USE OR DISPOSAL PRACTICE.*

The 1988 RA use or disposal practice for each of the 462 respondent POTWs (17 of 479 did not return completed questionnaires) was determined from Question I-24. If a POTW used multiple RA use or disposal practices, the practice used to dispose of the largest percentage of sewage sludge was assigned as the major RA use or disposal practice. When the use or disposal practice categories were reclassified, as detailed above, the reported volume of sewage sludge for each use or disposal practice was reclassified for each POTW. Following the reclassifications of the sewage sludge volumes, the major RA use or disposal practice was determined for each POTW.

Of the 17 POTWs that did not return a completed questionnaire, 4 POTWs were determined to be *OUT OF BUSINESS* and 2 POTWs were classified as being *INELIGIBLE* because they did not perform secondary treatment of wastewater. In addition, two POTWs that responded to the NSSS were classified as *INELIGIBLE* because they did not perform secondary treatment of wastewater and another POTW was determined to be *OUT OF BUSINESS* because it did not produce sewage sludge in 1988. No responses were obtained from 11 POTWs despite several followup contacts. The reported disposal practice for the 11 nonrespondent POTWs was assumed to be the same survey disposal practice reported in the 1986 NEEDS survey. That is, for the purpose of estimating the total number of POTWs in the Nation using each (reclassified) RA use or disposal practice in 1988, it was assumed that survey nonrespondents did not change their in disposal practice(s) between 1986 and 1988.

The number of POTWs for each of the six 1986 NEEDS survey disposal practices in the NSSS sample is recorded by major RA use or disposal practices in Table 2-2. This table displays the reclassifications of the POTWs from the six 1986 NEEDS categories to the six RA use or disposal practices, as defined in Section 2.1. Note that numbers 2 and 4 through 6 are missing in the major RA use or disposal categories because Distribution and Marketing (2) was reclassified as *LAND APPLICATION* (1), Monofill (4) was reclassified as *SURFACE DISPOSAL* (7), Co-disposal Landfill (5) was reclassified as *DISPOSAL PRACTICES NOT COSTED UNDER PART 503 (8)*, and Ocean Disposal (6) was reclassified as *UNKNOWN USE OR DISPOSAL PRACTICE* (9) (see boxed summary above).

2.3 ESTIMATION OF NATIONAL TOTALS AND VARIANCES OF THE ESTIMATES

Estimates of the total number of POTWs in the Nation in 1988 using each of the RA use or disposal practices and the variances of these total estimates were generated based on methods listed in Cochran (1977, p. 143, equations 5A.67 and 5A.68) for estimating totals over subpopulations. For a given RA use or disposal practice, first the number of POTWs in the Nation was estimated from NSSS data for each of the 24 design strata, then strata estimates were summed to produce national estimates. The equations from which these estimates were generated are defined below. However, notational conventions must be established first; these conventions follow.

Subscript Notation:

$i =$ Design flow rate group based on average daily flow rate reported in 1986 NEEDS survey where $\{i = 1, 2, 3, 4\}$ is defined as

$1 = \text{FLOW} > 100$ million gallons per day (MGD)

$2 = 10 < \text{FLOW} \leq 100$ MGD

$3 = 1 < \text{FLOW} \leq 10$ MGD

$4 = \text{FLOW} \leq 1$ MGD.

TABLE 2-2

1986 NEEDS DISPOSAL CLASSIFICATION VS REGULATORY ANALYTICAL (RA) USE OR DISPOSAL PRACTICE CLASSIFICATION

POTWs REPORTING SEVERAL RA USE OR DISPOSAL PRACTICES ARE CLASSIFIED ACCORDING TO THE PRACTICE USED TO DISPOSE OF THE MAJORITY OF SEWAGE SLUDGE

1986 NEEDS Based Survey Disposal Practice	Frequency / Percent / Row Pct / Col Pct	Major RA Use or Disposal Practice: 1	3	7	8	9	10	11	Total
1	Frequency	63	0	9	25	13	2	4	116
	Percent	13.15	0.00	1.88	5.22	2.71	0.42	0.84	24.22
	Row Pct	54.31	0.00	7.76	21.55	11.21	1.72	3.45	
	Col Pct	36.00	0.00	15.79	26.32	19.40	22.22	36.36	
2	Frequency	40	1	3	11	0	1	0	56
	Percent	8.35	0.21	0.63	2.30	0.00	0.21	0.00	11.69
	Row Pct	71.43	1.79	5.36	19.64	0.00	1.79	0.00	
	Col Pct	22.86	1.54	5.26	11.58	0.00	11.11	0.00	
3	Frequency	2	55	1	9	1	0	0	68
	Percent	0.42	11.48	0.21	1.88	0.21	0.00	0.00	14.20
	Row Pct	2.94	80.88	1.47	13.24	1.47	0.00	0.00	
	Col Pct	1.14	84.62	1.75	9.47	1.49	0.00	0.00	
4	Frequency	6	1	22	6	0	0	0	35
	Percent	1.25	0.21	4.59	1.25	0.00	0.00	0.00	7.31
	Row Pct	17.14	2.86	62.86	17.14	0.00	0.00	0.00	
	Col Pct	3.43	1.54	38.60	6.32	0.00	0.00	0.00	
5	Frequency	64	8	22	44	34	6	7	185
	Percent	13.36	1.67	4.59	9.19	7.10	1.25	1.46	38.62
	Row Pct	34.59	4.32	11.89	23.78	18.38	3.24	3.78	
	Col Pct	36.57	12.31	38.60	46.32	50.75	66.67	63.64	
6	Frequency	0	0	0	0	19	0	0	19
	Percent	0.00	0.00	0.00	0.00	3.97	0.00	0.00	3.97
	Row Pct	0.00	0.00	0.00	0.00	100.00	0.00	0.00	
	Col Pct	0.00	0.00	0.00	0.00	28.36	0.00	0.00	
Total	Frequency	175	65	57	95	67	9	11	479
	Percent	36.53	13.57	11.90	19.83	13.99	1.88	2.30	100.00

Disposal Practices:

1 = Land Application
2 = Distribution and Marketing
3 = Incineration
4 = Monofill
5 = Co-disposal Landfill
6 = Ocean Disposal
7 = Surface Disposal
8 = Not Costed Under Part 503
9 = Unknown
10 = Ineligible/Out of Business
11 = Nonrespondent

Subscript Notation (continued):

j = Design disposal practice group based on 1986 NEEDS survey responses where {j = 1, 2, 3, 4, 5, 6} is defined as

1 = Land Application

2 = Distribution and Marketing

3 = Incineration

4 = Monofill

5 = Co-disposal Landfill

6 = Ocean Disposal.

ij = Survey design stratum created by crossing the four levels of flow rate group with the six disposal practices. Thus, ij = 23 implies that the POTW was classified based on 1986 NEEDS survey data as having an average daily flow rate less than or equal to 100 MGD but more than 10 MGD and incinerating its sewage sludge {ij = 11, 12, 13,...,16, 21, 22,...,26,...,41,...,44, 45, 46}.

k = Designates the k^{th} POTW in the ij^{th} design stratum {k = 1, 2, 3,...,n_{ij}}.

r = Major RA use or disposal practice determined from the 1988 NSSS where {r = 1, 2, 3, 4, 5, 6} is defined as

1 = Land Application

2 = Incineration

3 = Surface Disposal

4 = Not Costed Under Part 503

5 = Unknown

6 = Ineligible/Out of Business.

Subscript Notation (continued):

Define

y_{ijkr} = 1 if the k[th] POTW in the ij[th] design stratum reported the r[th] practice as its major RA use or disposal practice
= 0 otherwise.

N_{ij} = the number of POTWs in the ij[th] stratum of the sampling frame.

n_{ij} = the number of POTWs in the ij[th] stratum of the sample.

f_{ij} = the sampling fraction for the ij[th] stratum where

$$f_{ij} = \frac{n_{ij}}{N_{ij}} .$$

Sampling fraction values for the 24 survey strata are listed in Table 2-3.

To estimate the total number of POTWs in 1988 using each of the major RA use or disposal practices, the number of POTWs using a given RA use or disposal practice was estimated for each survey stratum. The national estimate was then obtained by summing the strata estimates. That is,

$$\hat{Y}_r = \sum_{ij=11}^{46} \sum_{k=1}^{n_{ij}} \frac{Y_{ijkr}}{f_{ij}} .$$

Since y_{ijkr} equals 1 if the k[th] POTW in the ij[th] survey stratum reported the r[th] RA use or disposal practice in 1988 and is 0 otherwise, then the sum of y_{ijkr} over the index k determines the number of POTWs in the cell where the ij[th] row intersects the r[th] column in a cross tabulation of the survey stratum versus RA use or disposal practice. Denote the number of POTWs in this cell as n_{ijr} where $n_{ijr} \leq n_{ij}$.

Therefore, the equation for estimating the national total for the r[th] RA use or disposal practice in 1988 can be written as

$$\hat{Y}_r = \sum_{ij=11}^{46} N_{ij} \frac{n_{ijr}}{n_{ij}} .$$

TABLE 2-3

SAMPLING FRACTIONS FOR THE QUESTIONNAIRE SURVEY STRATA (f_{ij})

	Survey Strata Use Or Disposal Practice					
Flow Rate Group (MGD)	Land Application (1)	Distribution and Marketing (2)	Incineration (3)	Monofill (4)	Co-Disposal Landfill (5)	Ocean Disposal (6)
1: > 100	2/2	8/8	7/7	0	7/7	4/4
2: 10 - 100	13/61	10/18	33/74	9/11	31/148	11/12
3: 1 - 10	26/524	23/41	27/61	13/17	67/1295	3/3
4: 0 - 1	75/1646	15/27	1/2	13/17	80/7421	1/1

Subscript Notation (continued):

The variance for the r[th] RA use or disposal practice estimated total is

$$V(\hat{Y}_r) = \sum_{ij=11}^{46} \frac{N^2{}_{ij}}{n_{ij}(n_{ij}-1)}(1-f_{ij})\left[\sum_{k=1}^{n_{ij}} y^2{}_{ijk} - \frac{\left(\sum_{k=1}^{n_{ij}} y_{ijkr}\right)^2}{n_{ij}}\right].$$

The value $(1 - f_{ij})$ is the finite population correction factor. Again, since y_{ijkr} takes on the values of 1 or 0 to designate the use of the r[th] RA use or disposal practice, then the sum of $Y_{ijkr}{}^2$ over the index k is equal to n_{ijr}, which is also equal to the sum of Y_{ijkr} over the index k. Therefore, the variance estimator can be expressed as

$$V(\hat{Y}_r) = \sum_{ij=11}^{46} \frac{N_{ij}{}^2}{n_{ij}(n_{ij}-1)}(1-f_{ij})\left(n_{ijr} - \frac{(n_{ijr})^2}{n_{ij}}\right).$$

For computational simplicity, define

$$\hat{p}_{ijr} = \frac{n_{ijr}}{n_{ij}}$$

and

$$\hat{q}_{ijr} = (1-\hat{p}_{ijr}).$$

The variance of the total estimate can now be written as

$$V(\hat{Y}_r) = \sum_{ij=11}^{46} N^2{}_{ij}(1-f_{ij})\frac{(\hat{p}_{ijr}\hat{q}_{ijr})}{n_{ij}-1}.$$

This final expression of the variance of the estimate of the total was used for estimate computation.

Subscript Notation (continued):

Ninety-five percent confidence intervals were produced for the estimated total number of POTWs in the Nation using each of the major RA use or disposal practices in 1988 from the following formula:

$$\hat{Y}_r \pm 1.96 * V(\hat{Y}_r)^{1/2}.$$

Table 2-4 records resulting point and interval estimates.

2.4 NATIONAL ESTIMATES BY RA USE OR DISPOSAL PRACTICE

In addition to the national estimates by major RA use or disposal practice, estimates have also been calculated for the number of POTWs in the Nation using each of the RA use or disposal practices. These estimates are presented for the number of POTWs in specific RA use or disposal practice categories, including each of the RA use or disposal practices and each of the end uses. The formula used to calculate the national estimate of the number of POTWs in the r^{th} category is:

$$\hat{Y}_r = \sum_{ij=11}^{46} N_{ij} \frac{n_{ijr}}{n_{ij}}.$$

where,

N_{ij} = the number of POTWs in the ij^{th} stratum of the sampling frame
n_{ij} = the number of POTWs in the ij^{th} stratum of the sample
n_{ijr} = the number of POTWs in the ij^{th} stratum of the sample and in the r^{th} use or disposal practice category.

National estimates of the number of POTWs in the Nation by RA use or disposal practice are presented in Table 2-5. If a POTW uses two or more practices, the POTW is used in the estimate of each of these practices. The RA use or disposal practices used for these estimates (the r RA use or disposal practice categories) are defined below:

r = RA use or disposal practice determined from the 1988 NSSS where {r = 1, 2, 3, 4, 5, 6} are defined as

1 = Land Application
2 = Incineration
3 = Surface Disposal
4 = Not Costed Under Part 503
5 = Unknown
6 = Ineligible/Out of Business.

TABLE 2-4

ESTIMATES OF THE NUMBER OF POTWs IN THE NATION BY MAJOR USE OR DISPOSAL PRACTICE

Use or Disposal Practice	1986 NEEDS Classification	1988 Estimated	Variance of the 1988 Estimate	Lower 95% CI on 1988 Estimate	Upper 95% CI on 1988 Estimate
Land Application	2,233	3,929	146,366	3,179.15	4,678.85
Dist. and Marketing	94	.	.	.	.
Incineration	144	314	10,224	115.82	512.18
Monofill	45	.	.	.	.
Co-disposal Landfill	8,871	.	.	.	.
Ocean Disposal	20	.	.	.	.
Surface Disposal	.	1,128	67,912	617.22	1,638.78
Not Costed Under Part 503	.	2,317	116,901	1,646.86	2,987.14
Unknown	.	3,205	169,159	2,398.87	4,011.13
Ineligible/Out of Business	.	514	41,331	114.53	911.47
	11,407	11,407			

Note: Major use or disposal practice is defined as the practice that used or disposed of the greatest dry weight of sewage sludge in 1988 per POTW.

The national estimate of the number of POTWs using Land Application is divided into two subestimates in Table 2-5. Estimates are presented for the number of POTWs in the Nation that use the sale or giveaway of sewage sludge in a bag or similar enclosure as a Land Application end use, and for the number of POTWs that use any other Land Application end uses. For these estimates, r is defined as

r = 1 if POTW uses the sale or giveaway in a bag or similar enclosure
= 2 if POTW uses any other land application end use.

TABLE 2-5

ESTIMATES OF THE NUMBER OF POTWs IN THE NATION
BY REGULATED ANALYTICAL (RA) USE OR DISPOSAL PRACTICE

RA Use or Disposal Practice	Frequency in NSSS	National Estimate
Land Application	195	3,987
Sale or Giveaway	30	199
Others	194	3,967
Incineration	70	327
Surface Disposal	63	1,158
Not Costed Under Part 503	128	2,595
Unknown	79	3,534
Ineligible/Out of Business	9	513

Estimates of the number of POTWs in the Nation by each end use are presented in Table 2-6. If a POTW uses two or more end uses, the POTW is used in the estimate of each of these end uses. The end uses contained in these estimates (the r end use categories) are defined below:

r = RA use or disposal practice end use determined from the 1988 NSSS where {r = 1, 2, 3, ..., 16} are defined as

1 = LA: Agricultural Land
2 = LA: Compost Brokers/Contractors
3 = LA: Forests
4 = LA: Public Contact Sites
5 = LA: Reclamation Sites
6 = LA: Sale or Giveaway in a Bag or Similar Enclosure
7 = LA: Undefined
8 = Incineration
9 = SD: Dedicated Land
10 = SD: Monofill
11 = SD: Other
12 = Not Costed Under Part 503
13 = UNK: Ocean Disposal
14 = UNK: Transfer
15 = UNK: Other
16 = Ineligible/Out of Business.

TABLE 2-6

ESTIMATES OF THE NUMBER OF POTWs IN THE NATION BY END USE

RA Use or Disposal Practice	Frequency in NSSS	National Estimate
Land Application		
Agricultural Land	152	3,246
Compost Brockers/Contractors	19	145
Forests	4	30
Public Contact Sites	46	253
Reclamation Sites	14	68
Sale or Giveaway	30	199
Undefined	19	488
Incineration	70	327
Surface Disposal		
Dedicated Land	17	383
Monofill	34	320
Other	13	456
Not Costed Under Part 503	128	2,595
Unknown		
Ocean Disposal	21	115*
Transfer	1	22
Other	57	3,397
Ineligible/Out of Business	9	513

* A census of POTWs using ocean disposal in 1988 revealed a total of 28 POTWs.

National estimates of the number of POTWs in the Nation that use multiple RA use or disposal practices are presented in Tables 2-7a and 2-7b. Table 2-7a presents estimates of the number of RA use or disposal practices per POTW. Table 2-7b presents estimates of the number of POTWs using each combination of RA use or disposal practices. For the estimates in Table 2-7a, r is defined as

r = 1 if POTW uses one RA use or disposal practice
= 2 if POTW uses two RA use or disposal practices
= 3 if POTW uses three RA use or disposal practices.

For the estimates in Table 2-7b, r is defined by the combination of RA use or disposal practices used by each POTW. The possible values for r are

1 = Incineration
2 = Land Application
3 = Not Costed Under Part 503
4 = Ineligible/Out of business
5 = Surface Disposal
6 = Unknown
7 = Incineration and Land Application
8 = Incineration and Not Costed Under Part 503
9 = Incineration and Surface Disposal
10 = Incineration and Unknown
11 = Land Application and Not Costed Under Part 503
12 = Land Application and Surface Disposal
13 = Land Application and Unknown
14 = Not Costed Under Part 503 and Surface Disposal
15 = Not Costed Under Part 503 and Unknown
16 = Surface Disposal and Unknown
17 = Incineration, Land Application, and Not Costed Under Part 503
18 = Incineration, Land Application, and Surface Disposal
19 = Incineration, Land Application, and Unknown
20 = Incineration, Not Costed Under Part 503, and Surface Disposal
21 = Incineration, Not Costed Under Part 503, and Unknown
22 = Incineration, Surface Disposal, and Unknown
23 = Land Application, Not Costed Under Part 503, and Surface Disposal
24 = Land Application, Not Costed Under Part 503, and Unknown
25 = Land Application, Surface Disposal, and Unknown
26 = Not Costed Under Part 503, Surface Disposal, and Unknown.

TABLE 2-7a

ESTIMATES OF THE NUMBER OF POTWs IN THE NATION
USING MULTIPLE REGULATORY ANALYTICAL (RA) USE OR DISPOSAL PRACTICES

Number of RA Use or Disposal Practices	Frequency in NSSS	National Estimate
1 Practice	419	10,724
Single	419	10,724
2 Practices	55	659
3 Practices	5	24
Multiple	60	683

TABLE 2-7b

ESTIMATES OF THE NUMBER OF POTWs IN THE NATION USING EACH
REGULATORY ANALYTICAL (RA) USE OR DISPOSAL PRACTICE COMBINATION

RA Use of Disposal Practice Combinations	Frequency in NSSS	National Estimate
One Practice:		
Incineration	54	280
Land Application	149	3,439
Not Costed Under Part 503	88	2,276
Ineligible/Out of Business	9	513
Surface Disposal	52	1,011
Unknown	67	3,205
Two Practices:		
Incineration, Land Application	5	9
Incineration, Not Costed Under Part 503	9	36
Incineration, Surface Disposal	2	2
Land Application, Not Costed Under Part 503	25	257
Land Application, Surface Disposal	5	29
Land Application, Unknown	6	230
Not Costed Under Part 503, Surface Disposal	1	2
Surface Disposal, Unknown	2	95
Three Practices:		
Land Application, Not Costed Under Part 503, Surface Disposal	1	19
Land Application, Not Costed Under Part 503, Unknown	4	5

2.5 COMMENTS

As shown in Table 2-7b, the majority (87.5%) of POTWs use only one RA use or disposal practice. The greatest portion of those POTWs reporting one RA use or disposal practice reported *LAND APPLICATION*. Of the 12.5% that reported multiple RA use or disposal practices, most involved *LAND APPLICATION* and one other RA use or disposal practice. Nearly half of the POTWs who reported RA use or disposal practices, reported *LAND APPLICATION* and *NOT COSTED UNDER PART 503*.

Nineteen out of twenty POTWs reporting ocean disposal in the 1986 NEEDS survey were sampled for the NSSS. These POTWs were reclassified as *UNKNOWN USE OR DISPOSAL PRACTICE*, according to the RA use or disposal practice definitions. In view of this reclassification, the estimated total number of POTWs in the Nation using *UNKNOWN USE OR DISPOSAL PRACTICES* in 1988 appears excessive. The reason the estimate is excessive can be attributed primarily to one POTW. There are two POTWs that reported using ocean disposal in 1988 that were not identified in the category of Ocean Disposal from 1986 NEEDS survey information. One POTW that reported using ocean disposal in 1988 was classified as using incineration from 1986 NEEDS survey information. As the 1986 NEEDS survey classification determines the sampling fraction assigned to the POTW, the sampling fraction for this facility is $f_{33} = 27/61$. Therefore, this POTW added $1/f_{33}$ or 2 to the estimated total number of POTWs using the *UNKNOWN USE OR DISPOSAL CATEGORY PRACTICE* (Ocean Disposal) in 1988. However, the other POTW that reported using ocean disposal in 1988 was classified from the 1986 NEEDS survey as using Co-disposal Landfill. The sampling fraction for the survey stratum to which this POTW belonged was $f_{45} = 80/7421$. This POTW added $1/f_{45}$ or 93 POTWs to the estimated total of POTWs using *UNKNOWN USE OR DISPOSAL PRACTICES* (Ocean Disposal) in 1988. This change in disposal practice was noted while the questionnaire data base was being developed. Followup contact with the POTW indicated that, indeed, it used ocean disposal in 1988. A census of all POTWs that used ocean disposal in 1988 confirmed that there were 28 POTWs in the Nation that used this RA use or disposal practice in 1988.

3. ESTIMATION OF THE NUMBER OF PUBLICLY OWNED TREATMENT WORKS (POTWs) IN THE NATION IN EACH OF FOUR FLOW RATE GROUPS

This chapter provides point and interval estimates of the number of Publicly Owned Treatment Works (POTWs) in the Nation practicing at least secondary treatment of wastewater in 1988 in each of four flow rate groups—and also provides a basis for producing the reported estimates. Section 3.1 provides data conventions and definitions of key variables. Section 3.2 cites the statistical formulae defining the point estimator of the total number of POTWs from the stratified National Sewage Sludge Survey (NSSS) random sample and the variance of the total estimate; the section also presents estimates and confidence intervals.

3.1 DATA CONVENTIONS

For sampling purposes, each secondary treatment POTW in the NSSS sampling frame of 11,407 POTWs was categorized into one of four flow rate groups based on information reported in the 1986 NEEDS survey. These flow rate groups are referred to as **survey design groups** and are defined as

1 = FLOW $>$ 100 million gallons per day (MGD)

2 = $10 <$ FLOW ≤ 100 MGD

3 = $1 <$ FLOW ≤ 10 MGD

4 = FLOW ≤ 1 MGD.

The cross-classification of these four levels of average daily flow rate with the six survey disposal practices created from data in the 1986 NEEDS survey were multiplied to partition the sampling frame into 24 mutually exclusive strata. From these 24 strata, a total of 479 POTWs was randomly selected to comprise the questionnaire survey sample.

The average daily flow rate in 1988 for each of the 462 respondent POTWs in the questionnaire survey was extracted from Question 9B. These data were then categorized into one of four flow rate groups. The categories for 1988 reported flow rate groups are the same ones that were used to categorize the 1986 NEEDS survey flow rate groups. As reported in Chapter 2, four of the seventeen POTWs that did not return a completed questionnaire were determined to be *OUT OF BUSINESS*. Another two POTWs were classified as being *INELIGIBLE* because they did not perform secondary treatment of wastewater. No responses were obtained from 11 POTWs despite several followup contacts. The reported flow rate group for these 11 nonrespondents was assumed to be the flow rate group determined from the 1986 NEEDS survey data. That is, for the purpose of estimating the total number of POTWs in each flow rate group during 1988, it was assumed that the average daily flow rate classification did not change between 1986 and 1988 for survey nonrespondents.

Table 3-1 compares the number of POTWs in the NEEDS survey 1986-based flow rate group with the NSSS sample in each 1988-based reported flow rate group. Cells on the diagonal in Table 3-1 indicate the number of POTWs in the sample that did not change average daily flow rate categories from 1986 to 1988.

3.2 ESTIMATION OF NATIONAL TOTALS AND VARIANCES OF THE TOTAL ESTIMATES

Estimates of the total number of POTWs in the Nation in each of the four reported flow rate groups and the variances of these total estimates were generated based on methods listed in Cochran (1977, p. 143, equations 5A.67 and 5A.68) for estimating totals over subpopulations. For a given reported flow rate group, the number of POTWs in the Nation was first estimated for each of the 24 strata. Strata estimates were then summed to produce national estimates. The equations from which these estimates were generated are defined below. However, notational conventions must be established first; these conventions follow.

Subscript Notation:

i = Design flow rate group based on average daily flow rate reported in 1986 NEEDS survey where {i = 1, 2, 3, 4} is defined as

1 = FLOW > 100 million gallons per day (MGD)

2 = 10 < FLOW ≤ 100 MGD

3 = 1 < FLOW ≤ 10 MGD

4 = FLOW ≤ 1 MGD.

j = Design disposal practice group based on 1986 NEEDS survey responses where {j = 1, 2, 3, 4, 5, 6} is defined as

1 = Land Application

2 = Distribution and Marketing

3 = Incineration

4 = Monofill

5 = Co-disposal Landfill

6 = Ocean Disposal.

TABLE 3-1.

POTWS IN THE QUESTIONNAIRE SURVEY
1986 NEEDS FLOW RATE CLASSIFICATION VS. 1988 REPORTED FLOW RATE GROUP FREQUENCIES

1986 NEEDS Based Flow Rate Group (rows) by 1988 Reported Flow Rate Group (columns)

Frequency / Percent / Row Pct / Col Pct	1	2	3	4	5	6	7	total
1	24	2	2	0	0	0	0	28
	5.01	0.42	0.42	0.00	0.00	0.00	0.00	5.85
	85.71	7.14	7.14	0.00	0.00	0.00	0.00	
	96.00	1.87	1.17	0.00	0.00	0.00	0.00	
2	1	97	7	0	0	0	2	107
	0.21	20.25	1.46	0.00	0.00	0.00	0.42	22.34
	0.93	90.65	6.54	0.00	0.00	0.00	1.87	
	4.00	90.65	4.09	0.00	0.00	0.00	18.18	
3	0	7	139	11	0	0	2	159
	0.00	1.46	29.02	2.30	0.00	0.00	0.42	33.19
	0.00	4.40	87.42	6.92	0.00	0.00	1.26	
	0.00	6.54	81.29	6.92	0.00	0.00	18.18	
4	0	1	23	148	4	2	7	185
	0.00	0.21	4.80	30.90	0.84	0.42	1.46	38.62
	0.00	0.54	12.43	80.00	2.16	1.08	3.78	
	0.00	0.93	13.45	93.08	100.00	100.00	63.64	
TOTAL	25	107	171	159	4	2	11	479
	5.22	22.34	35.70	33.19	0.84	0.42	2.30	100.00

Average Daily Flow Rate Groups:
1 = Greater than 100 MGD
2 = 10 < FLOW <= 100
3 = 1 < FLOW <= 10
4 = FLOW <= 1
5 = Out of Business
6 = Ineligible
7 = Nonrespondents

Subscript Notation (continued):

ij = Survey design stratum created by crossing the four levels of flow rate group with the six disposal practices. Thus, ij = 23 implies that the POTW was classified based on 1986 NEEDS survey data as having an average daily flow rate less than or equal to 100 MGD but more than 10 MGD and incinerated its sewage sludge $\{ij = 11, 12, 13, \ldots, 16, 21, 22, \ldots, 26, \ldots, 41, \ldots, 44, 45, 46\}$.

k = Designates the k^{th} POTW in the ij^{th} design stratum $\{k = 1, 2, 3, \ldots, n_{ij}\}$.

r = Reported flow rate group determined form the 1988 NSSS where $\{r = 1, 2, 3, 4, 5, 6\}$ are defined as

1 = FLOW > 100 million gallons per day (MGD)

2 = 10 < FLOW ≤ 100 MGD

3 = 1 < FLOW ≤ 10 MGD

4 = FLOW ≤ 1 MGD.

Define

y_{ijkr} = 1 if the k^{th} POTW in the ij^{th} design stratum reported the r^{th} flow rate group
= 0 otherwise.

N_{ij} = the number of POTWs in the ij^{th} stratum of the sampling frame.

n_{ij} = the number of POTWs in the ij^{th} stratum of the sample.

f_{ij} = the sampling fraction for the ij^{th} stratum where

$$f_{ij} = \frac{n_{ij}}{N_{ij}} .$$

Sampling fraction values for the 24 survey stratum are listed in Chapter 2, Table 2-4.

To estimate the total number of POTWs in 1988 using each flow rate group, the number of POTWs used in a given flow rate group was first estimated for each survey stratum. The national estimate was then obtained by summing the strata estimates. That is,

Subscript Notation (continued):

$$\hat{Y}_r = \sum_{ij=11}^{46} \sum_{k=1}^{n_{ij}} \frac{Y_{ijkr}}{f_{ij}}.$$

Since y_{ijkr} equals 1 if the k^{th} POTW in the ij^{th} survey stratum was classified in the r^{th} flow rate group based 1988 average daily flow and is valued 0 otherwise, then the sum of y_{ijkr} over the index k determines the number of POTWs in the cell where the ij^{th} row intersects the r^{th} column in a cross tabulation of the survey stratum versus reported flow rate group. Denote the number of POTWs in this cell as n_{ijr} where $n_{ijr} \leq n_{ij}$. Therefore, the equation for estimating the national total for the r^{th} flow rate group in 1988 becomes

$$\hat{Y}_r = \sum_{ij=11}^{46} N_{ij} \frac{n_{ijr}}{n_{ij}}.$$

The estimated variance for the r^{th} flow rate group total is

$$V(\hat{Y}_r) = \sum_{ij=11}^{46} \frac{N^2{}_{ij}}{n_{ij}(n_{ij}-1)} (1-f_{ij}) \left[\sum_{k=1}^{n_{ij}} y^2{}_{ijk} - \frac{\left(\sum_{k=1}^{n_{ij}} y_{ijkr} \right)^2}{n_{ij}} \right].$$

The value $(1 - f_{ij})$ is the finite population correction factor. Again, since y_{ijkr} takes on the values of 1 or 0 to designate 1988 classification in the r^{th} flow rate group, then the sum of $Y_{ijkr}{}^2$ over the index k is equal to n_{ijr}, which is also equal to the sum of Y_{ijkr} over the index k. Therefore,

$$V(\hat{Y}_r) = \sum_{ij=11}^{46} \frac{N_{ij}{}^2}{n_{ij}} (n_{ij}-1)\ (1-f_{ij}) \left(n_{ijr} - \frac{(n_{ijr})^2}{n_{ij}} \right).$$

For computational simplicity, define

$$\hat{p}_{ijr} = \frac{n_{ijr}}{n_{ij}}$$

and

$$\hat{q}_{ijr} = (1-\hat{p}_{ijr}) .$$

The variance of the total estimate can now be expressed as

$$V(\hat{Y}_r) = \sum_{ij=11}^{46} N^2{}_{ij}(1-f_{ij}) \frac{(\hat{p}_{ijr}\hat{q}_{ijr})}{n_{ij}-1} .$$

Confidence intervals of 95% were produced for the 1988 estimated total number of POTWs in the Nation in each of the four flow rate groups using the following formula:

$$\hat{Y}_r \pm 1.96 * V(\hat{Y}_r)^{1/2} .$$

Resulting point and interval estimates are recorded in Table 3-2.

TABLE 3-2.

NATIONAL ESTIMATES OF POTWs BY AVERAGE DAILY FLOW GROUP

Reported Flow Group	1986 NEEDS Classification	1988 Estimated	Change 1988 Estimate -1986 NEEDS	Variance of the Estimate	Lower 95% CI on Estimate	Upper 95% CI on Estimate
> 100 MGD	28	26	-2	2.8	22.73	29.27
10 < FLOW <= 100	324	420	96	8,968.3	234.39	605.61
1 < FLOW <= 10	1,941	2,456	515	47,198.8	2,030.18	2,881.82
FLOW <= 1	9,114	8,090	-1,024	82,511.3	7,526.99	8,653.01
Out of Business	.	229	229	70,796.0	-292.51	750.51
Ineligible	.	186	186	16,808.7	-68.11	440.11
	11,407	11,407	0			

4. STRATUM WEIGHTS

A total of 11,407 POTWs practiced secondary or greater wastewater treatment in 1986 according to the EPA Office of Municipal Pollution Control's 1986 NEEDS survey. Because conducting a census of these 11,407 POTWS was impractical and cost-prohibitive, the 1988 NSSS survey components gathered data from a sample of the 11,407 eligible POTWs. This chapter defines stratum weights used to estimate the characteristics of the 11,407 POTWs based on the data gathered from the sample. Section 4.1 presents survey design stratum weights for each of the component surveys. Section 4.2 presents stratum weights adjusted for POTWs determined to be ineligible because they did not perform secondary treatment of wastewater. Categories classified under regulatory analytical (RA) use or disposal practices will appear in the text as *CAPITALIZED ITALICS*.

4.1 SURVEY DESIGN STRATUM WEIGHTS

Sampling designs for the 1988 NSSS were statistically structured to separate the analysis of survey results by flow rate group and sewage sludge use or disposal practice. The levels of flow rate group and sewage sludge use or disposal practice used to develop the survey sampling plan are defined below.

Survey Design Flow Rate Group and Use or Disposal Definitions:

- **POTW Average Daily Flow Rate Categories:**

  1. Flow greater than 100 million gallons per day (MGD)
  2. Flow more than 10 MGD but less than or equal to 100 MGD
  3. Flow more than 1 MGD but less than or equal to 10 MGD
  4. Flow less than or equal to 1 MGD.

- **POTW Sewage Sludge Use and Disposal Practice Groups:**

  1. Land Application
  2. Distribution and Marketing
  3. Incineration
  4. Monofill (sewage-sludge-only landfill)
  5. Co-disposal Landfill and Other
  6. Ocean Disposal.

Survey strata were created by applying these survey design definitions to the 11,407 POTWs eligible for sampling in the 1988 NSSS. Analysis of the number of POTWs in each stratum revealed that POTWs were mostly likely to be in the lowest flow rate group and were disproportionately distributed across the six disposal practices. A statistical sampling plan was developed to ensure that a sufficient number of POTWs from each stratum were in the survey while also minimizing the number of POTWs to be sampled. To ensure this goal, a statistical, stratified sampling plan was developed for each component survey.

POTWs for the questionnaire component of the NSSS were sampled from 24 strata. These strata represent all possible combinations of the four flow rate groups and six survey design use or disposal practices. A total of 479 of the 11,407 POTWs in the Nation were sampled for the questionnaire component of the NSSS. National estimates are produced first by summing the value of the variable being estimated across the data point values from the POTWs in a given survey stratum. Stratum estimates then are calculated as a function of the survey stratum sampling fraction. This sampling fraction, denoted as f_{ij} to designate the sampling fraction specific to the i^{th} flow rate stratum and the j^{th} survey design use or disposal practice, is a function of the number of POTWs in the sample from that stratum (n_{ij}) and the number of POTWs in the Nation in that stratum (N_{ij}.) Table 4.1 presents the sampling fraction values (f_{ij}) for the questionnaire component of the NSSS.

To illustrate the use of sampling fractions, suppose one wishes to estimate the total number of POTWs in the Nation with the attribute Y. Let Y take on the value of 1 if the attribute is present and 0 if the attribute is absent. First, sum the values of the variable Y for each stratum, then divide the sum of the variable Y by the sampling fraction. This sequence yields the estimated number of POTWs in the Nation with attribute Y in the stratum. The mathematical presentation of this operation is presented below.

$$\hat{Y}_{ij} = \sum_{k=1}^{n_{ij}} Y_{ijk}/f_{ij} = \sum_{k=1}^{n_{ij}} N_{ij}Y_{ijk}/n_{ij} = N_{ij}\overline{Y}_{ij}.$$

Obtain the estimated total number of POTWs in the Nation with attribute Y by summing the estimated total number of POTWs with the attributed across all strata.

To estimate the national average for a quantitative variable (Y), obtain the same stratum totals as illustrated previously. However, then divide the national total by the number of POTWs in the Nation. The formula for estimating a national average is presented below.

$$\overline{Y} = \frac{1}{N}\sum_{ij=1}^{24} \sum_{k=1}^{n_{ij}} Y_{ijk}/f_{ij} = \sum_{ij=1}^{24} \frac{N_{ij}}{N}\overline{Y}_{ij} = \sum_{ij=1}^{24} w_{ij}\overline{Y}_{ij}.$$

The far-right component of this equation indicates that a national average is the weighted sum of the strata averages. Stratum weights, designated as w_{ij}, are defined as the number of POTWs in the stratum (N_{ij}) divided by the number of POTWs in the Nation. Stratum weights for the questionnaire component of the NSSS appear at the bottom of Table 4-1.

TABLE 4-1

SAMPLING FRACTION VALUES FOR THE QUESTIONNAIRE SURVEY STRATA (f_{ij})

Survey Strata Use Or Disposal Practice

Flow Rate Group (MGD)	Land Application (1)	Distribution and Marketing (2)	Incineration (3)	Monofill (4)	Co-Disposal Landfill (5)	Ocean Disposal (6)
1= > 100	2/2	8/8	7/7	0	7/7	4/4
2= 10 - 100	13/61	10/18	33/74	9/11	31/148	11/12
3= 1 - 10	26/524	23/41	27/61	13/17	67/1295	3/3
4= 0 - 1	75/1646	15/27	1/2	13/17	80/7421	1/1

Stratum Weights for the Questionnaire Survey

Flow Rate Group (MGD)	Land Application (1)	Distribution and Marketing (2)	Incineration (3)	Monofill (4)	Co-Disposal Landfill (5)	Ocean Disposal (6)
1= > 100	2/11,407	8/11,407	7/11,407	0	7/11,407	4/11,407
2= 10 - 100	61/11,407	18/11,407	74/11,407	11/11,407	148/11,407	12/11,407
3= 1 - 10	524/11,407	41/11,407	61/11,407	17/11,407	1295/11,407	3/11,407
4= 0 - 1	1646/11,407	27/11,407	2/11,407	17/11,407	7421/11,407	1/11,407

A separate, but related stratified sample was drawn for the analytical component of the NSSS. In this case, the objective was to stratify POTWs with respect to the four flow rate groups. A total of 208 POTWs in the questionnaire component of the NSSS were statistically selected for inclusion in the analytical component of the NSSS. Because of logistics, POTWs for the analytical survey were restricted to the 11,346 POTWs located in the contiguous United States. The sampling fractions and stratum weights for the analytical survey are presented in Table 4-2.

TABLE 4-2

SAMPLING FRACTIONS AND STRATUM WEIGHTS FOR THE ANALYTICAL SURVEY

Stratum	Sampling Fraction (f_i)	Stratum Weights
FLOW > 100 MGD	20/28	28/11,346
10 < FLOW ≤ 100 MGD	56/324	324/11,346
1 < FLOW ≤ 10 MGD	65/1,927	1,927/11,346
FLOW ≤ 1 MGD	67/9,067	9,067/11,346

4.2 ADJUSTED STRATUM WEIGHTS

Analytical samples were obtained from 180 of the 208 POTWs selected for the analytic survey. Four POTWs were not sampled because they were classified as either *OUT OF BUSINESS* or *INELIGIBLE* under RA use or disposal practices. The remaining 24 POTWs were not sampled due to logistic difficulties. Population stratum sizes and the population total were adjusted to exclude POTWs that were classified as *OUT OF BUSINESS*, *INELIGIBLE*, or using wastewater stabilization ponds. In addition to the four POTWs that were not sampled because they were out of business or ineligible, a fifth POTW in the analytical survey (Episode 1488) was sampled in 1989 but was excluded from the survey because the facility was not operational during 1988, the time frame of the survey. Stratum weights were adjusted after excluding the following five POTWs which were classified as *OUT OF BUSINESS* or *INELIGIBLE*: 12-49-455, 25-38-345, 45-25-229, 45-42-387, and 45-42-392.

The number of POTWs that were classified as *OUT OF BUSINESS* and *INELIGIBLE* in each population stratum is determined in Table 4-3.

TABLE 4-3

ESTIMATED NUMBER OF POTWs CLASSIFIED AS INELIGIBLE/OUT OF BUSINESS

$Stratum_i$	ΣY_{ij}	$D_i\ 6=\Sigma Y_{ij}*N_i/n_i$	
1 = FLOW > 100 MGD	1	1*28/20 =	1
2 = 10 < FLOW ≤ 100 MGD	1	1*324/56 =	6
3 = 1 < FLOW ≤ 10 MGD	0	0*1927/65 =	0
4 = FLOW ≤ 1 MGD	3	3*9067/67 =	406
Total	5		413

The estimated number of POTWs that were *OUT OF BUSINESS* or *INELIGIBLE* in 1988 is 413. Therefore, the adjusted population total of POTWs in the contiguous United States and the District of Columbia is 10,933. The stratum weights are adjusted to reflect these exclusions as shown in Table 4-4.

TABLE 4-4.

STRATUM WEIGHTS EXCLUDING POTWs CLASSIFIED AS INELIGIBLE/OUT OF BUSINESS

$Stratum_i$	Adjusted N_i	Stratum Weight = w_i
1 = FLOW > 100 MGD	27	27/10,933 = 0.0024
2 = 10 < FLOW ≤ 100 MGD	318	318/10,933 = 0.0291
3 = 1 < FLOW ≤ 10 MGD	1,927	1,927/10,933 = 0.1763
4 = FLOW ≤ 1 MGD	8,661	8,661/10,933 = 0.7922
Total	10,933	1.0000

In addition to the 5 POTWs that were classified as *OUT OF BUSINESS* or *INELIGIBLE,* 18 POTWs from the analytical survey have been identified as using wastewater stabilization ponds. POTWs using wastewater stabilization ponds as a form of secondary treatment are excluded from national estimates of pollutant concentration because no sewage sludge samples were obtained from this treatment process during the NSSS analytical survey. Samples were not obtained from the POTWs due to sampling difficulty and because secondary treatment was not complete. These 18 POTWs that were excluded are listed in Table 4-5.

TABLE 4-5

POTWs IN THE ANALYTICAL SURVEY CLASSIFIED AS USING WASTEWATER STABILIZATION PONDS

Survey ID	Episode	Survey Stratum
45-02-005	0	4
45-11-064	0	4
45-13-083	0	4
45-13-089	0	4
45-14-092	0	4
45-15-112	0	4
45-16-130	0	4
45-17-131	0	4
45-19-154	0	4
45-23-208	0	4
45-24-220	0	4
45-25-231	0	4
45-26-237	0	4
45-28-246	0	4
45-29-248	0	4
45-30-253	0	4
45-45-415	0	4
45-50-474	0	4

The estimated number of POTWs in each population stratum using wastewater stabilization ponds or classified as *INELIGIBLE* or *OUT OF BUSINESS* is determined in Table 4-6.

The estimated number of POTWs classified as *OUT OF BUSINESS*, *INELIGIBLE*, or using wastewater stabilization ponds is 2,849. This reduces the adjusted population total of POTWs in the contiguous United States and the District of Columbia practicing at least secondary treatment of wastewater to 8,497. The adjusted stratum weights are in Table 4-7.

TABLE 4-6

ESTIMATED NUMBER OF POTWs CLASSIFIED AS INELIGIBLE/OUT OF BUSINESS AND USING WASTEWATER STABILIZATION PONDS

Stratum_i	ΣY_{ij}	$D_i = \Sigma Y_{ij} * N_i / n_i$
1 = FLOW > 100 MGD	1	1*28/20 = 1
2 = 10 < FLOW ≤ 100 MGD	1	1*324/56 = 6
3 = 1 < FLOW ≤ 10 MGD	0	0*1927/65 = 0
4 = FLOW ≤ 1 MGD	21	21*9067/67 = 2842
Total	23	2849

TABLE 4-7

STRATUM WEIGHTS EXCLUDING POTWs CLASSIFIED AS INELIGIBLE/OUT OF BUSINESS AND USING WASTEWATER STABILIZATION PONDS

Stratum_i	Adjusted N_i	Stratum Weight = w_i
1 = FLOW > 100 MGD	27	27/8,632 = 0.00318
2 = 10 < FLOW ≤ 100 MGD	318	318/8,632 = 0.03742
3 = 1 < FLOW ≤ 10 MGD	1,927	1,927/8,632 = 0.22679
4 = FLOW ≤ 1 MGD	6,225	6,225/8,497 = 0.73261
Total	8,497	1.00000

The adjusted stratum weights, presented above, were used in the calculation of the pollutant-concentration estimates presented in this document. Notice that, by applying these adjusted population stratum weights to the stratum estimates, it is implicitly assumed that the pollutant concentrations from the nonsampled POTWs not classified as *OUT OF BUSINESS*, *INELIGIBLE*, or using wastewater stabilization ponds would have to be quantified at the level of the estimated stratum statistic.

5. NATIONAL ESTIMATES FOR THE TOTAL DRY WEIGHT OF SEWAGE SLUDGE USED OR DISPOSED IN 1988

This chapter presents national estimates of the total dry weight of sewage sludge used or disposed in 1988. These estimates, shown in five tables, were produced using data from the National Sewage Sludge Survey (NSSS). Estimates of total dry weight of sewage sludge were calculated as weighted averages of survey strata dry weights. Definitions of subscript notations and variables are followed by comments specific to the production of estimates in each table, a table summary, and the tables themselves. References in the text to regulatory analytical (RA) use or disposal practice categories appear as *CAPITALIZED ITALICS*.

Subscript Notation:

d = Regulatory analytical (RA) use or disposal practice as classified from responses to the 1988 NSSS. The levels that subscript d can assume are listed in the box below. The second level of definition is the subcategory or end use definition. Capitalized words used in the subclassifications are paraphrases of possible responses from the NSSS questionnaire.

REGULATORY ANALYTICAL (RA) USE OR DISPOSAL PRACTICES

1. *LAND APPLICATION*

Includes Publicly Owned Treatment Works (POTWs) classified as practicing LAND APPLICATION and DISTRIBUTION AND MARKETING.

1.1 **Agricultural Land (LA: AGRI)**

Includes POTWs classified as practicing land application uses ANIMAL FEED CROP LAND (NOT PASTURE), HUMAN FOOD CROP LAND, PASTURE LAND, and OTHER, as appropriate. Also includes distribution and marketing end uses FARMERS and OTHER, as appropriate.

1.2 **Forests (LA: FORESTS)**

Includes POTWs classified as practicing land application end uses SILVICULTURE LAND and OTHER, as appropriate. Also includes the distribution and marketing end use OTHER, as appropriate.

REGULATORY ANALYTICAL (RA) USE OR DISPOSAL PRACTICES (Continued)

1. *LAND APPLICATION* (Continued)

1.3 Public Contact Sites (LA: PUBLIC)

Includes POTWs classified as practicing land application end uses or distribution and marketing end uses GOLF COURSES, LANDSCAPE CONTRACTORS, MUNICIPAL PARKS, HIGHWAYS, and OTHER, as appropriate.

1.4 Reclaimed Land (LA: RECLAIMED)

Includes POTWs classified as practicing land application end uses LAND RECLAMATION and OTHER, as appropriate. Also includes the distribution and marketing end use OTHER, as appropriate.

1.5 Sale or Giveaway in a Bag or Similar Enclosure (LA: SALE)

This classification includes POTWs reporting DISTRIBUTION AND MARKETING to the end use GENERAL PUBLIC. All other POTWs are assumed to use some different RA use or disposal practice.

1.6 Undefined Land Application (LA: UNDEFINED)

Includes POTWs classified as practicing land application that could not be classified as to end use. Also includes distribution and marketing end use OTHER, as appropriate.

1.7 Compost Brokers/Contractors (UNK: COMPOST)

Includes POTWs classified as practicing DISTRIBUTION AND MARKETING end use COMPOST BROKERS/CONTRACTORS.

2. *INCINERATION*

Includes POTWs classified as practicing INCINERATION.

3. *SURFACE DISPOSAL*

Includes POTWs classified as practicing DEDICATED LAND FOR SEWAGE SLUDGE DISPOSAL, MONOFILL, and SURFACE DISPOSAL. However, POTWs responding that they practice SURFACE DISPOSAL will be evaluated in relation to other survey responses on a case-by-case basis.

3.1 Dedicated Land (SD: DEDICATED)

Includes POTWs classified as practicing DEDICATED LAND FOR SEWAGE SLUDGE DISPOSAL.

REGULATORY ANALYTICAL (RA) USE OR DISPOSAL PRACTICES (Continued)

3. *SURFACE DISPOSAL* (Continued)

3.2 Monofill (SD: MONOFILL)

Includes POTWs classified as practicing MONOFILL.

3.3 Other Surface Disposal (SD: OTHER)

POTWs classified as practicing Surface Disposal that are not classified as Dedicated Land or MONOFILL.

4. *DISPOSAL PRACTICE NOT COSTED UNDER PART 503*

Includes POTWs classified as practicing CO-DISPOSAL LANDFILL and CO-INCINERATION. The costs and benefits of using these disposal practices are not considered under Final Standards for the Use or Disposal of Sewage Sludge (40 CFR, Part 503).

5. *UNKNOWN USE OR DISPOSAL PRACTICE*

Includes POTWs classified as practicing OCEAN DISPOSAL, OTHER, WASTEWATER STABILIZATION POND, and NO SLUDGE. These facilities may, after implementation of the Final Standards for the Use or Disposal of Sewage Sludge (40 CFR, Part 503), use or dispose of sewage sludge in some fashion covered by the regulation.

5.1 Ocean Disposal (UNK: OCEAN)

Includes POTWs classified as practicing OCEAN DISPOSAL.

5.2 Other (UNK: OTHER)

Includes POTWs classified as practicing OTHER that did not use or dispose of sewage sludge in 1988.

5.3 Unknown Transfer (UNK: TRANSFER)

POTWs whose OTHER practice is described as transfer and who cannot otherwise be classified.

6. *INELIGIBLE OR OUT OF BUSINESS*

POTWs found to practice less than secondary wastewater treatment and POTWs found to be out of business.

Subscript Notation: (continued)

f = Average daily flow rate group as determined from responses to the NSSS. The levels of the subscript f are as follows:

1 = FLOW > 100 million gallons per day (MGD)

2 = 10 < FLOW ≤ 100 MGD

3 = 1 < FLOW ≤ 10 MGD

4 = FLOW ≤ 1 MGD.

ij = The survey design stratum designation. There are 24 levels of the ij subscript. The design stratum from which a POTW was selected determines the probability that a POTW was included in the NSSS. The first letter, i, designates which of four design flow rate groups in the design stratum the POTW was sampled from, while the second letter, j, indicates to which of six 1986 NEEDS survey use or disposal practice categories the sample POTW belonged.

k = The k^{th} POTW from the ij^{th} design stratum using the d^{th} RA use or disposal practice in the f^{th} reported flow rate group.

Variable Definitions:

Y_{dfijk} = Dry weight of sewage sludge disposed using the d^{th} RA use or disposal practice by the k^{th} POTW in reported flow rate group f. The POTW reporting this dry weight was selected from the ij^{th} design stratum.

$Y_{dfij.}$ = Total observed dry weight of sewage sludge from sampled POTWs using the d^{th} RA use or disposal practice in 1988 reported flow group f from the ij^{th} design stratum. Dry weights are summed across the k POTWs.

$Y_{d.ij.}$ = Total observed dry weight of sewage sludge from sampled POTWs using the d^{th} RA use or disposal practice in 1988 in the ij^{th} design stratum. Dry weights are first summed across the k POTWs in the ij^{th} design stratum that belong to reported flow rate group f and are classified as using the d^{th} RA use or disposal practice. These dry weight totals are then summed across reported flow rate groups for POTWs in the ij^{th} design stratum using the d^{th} RA use or disposal practice.

$Y_{.fij.}$ = Total observed dry weight of sewage sludge from sampled POTWs in the f^{th} reported flow rate group from the ij^{th} design stratum. Dry weights are first summed across the k POTWs in the ij^{th} design stratum that belong to reported flow rate group f and are classified as using the d^{th} RA use or disposal practice. These dry weight totals are then summed across RA use or disposal practices for POTWs in the ij^{th} design stratum.

Subscript Notation: (continued)

N_{dfij} = Estimated number of POTWs in the nation using the d[th] RA use or disposal practice in reported flow rate group f from the ij[th] design stratum.

$N_{d.ij}$ = Estimated number of POTWs in the nation using the d[th] RA use or disposal practice in 1988 in the ij[th] design stratum. Totals are summed across reported flow rate groups for POTWs in the ij[th] design stratum using the d[th] RA use or disposal practice.

$N_{.fij}$ = Estimated number of POTWs in the nation in the f[th] reported flow rate stratum in 1988 from the ij[th] design stratum. Totals are then summed across RA use or disposal practices for POTWs in the ij[th] design stratum.

Table Descriptions and Estimation Methods:

Table 5-1 - Reports national estimates of total dry weight of sewage sludge by RA use or disposal practice. Multiple RA use or disposal practices were allowed for POTWs. The reported total dry weight of sewage sludge disposed in 1988 for the d[th] RA use or disposal practice was estimated as

$$\hat{Y}_d = \sum_{ij=1}^{24} N_{d.ij} * \frac{Y_{d.ij.}}{n_{d.ij}} = \sum_{ij=1}^{24} N_{d.ij} * \overline{Y}_{d.ij} .$$

Table 5-2 - Reports national estimates of total dry weight of sewage sludge by regulated end use. Multiple RA use or disposal practices were allowed for POTWs. The reported total dry weight of sewage sludge disposed in 1988 for the d[th] RA use or disposal practice was estimated as

$$\hat{Y}_d = \sum_{ij=1}^{24} N_{d.ij} * \frac{Y_{d.ij.}}{n_{d.ij}} = \sum_{ij=1}^{24} N_{d.ij} * \overline{Y}_{d.ij} .$$

Table 5-3 - Reports national estimates of total dry weight of sewage sludge by reported flow rate group. The total volume of dry weight sewage sludge disposed by a POTW was determined by summing sewage sludge volumes across the POTW's RA use or disposal practices (i.e., $Y_{.fijk}$). The reported total dry weight of sewage sludge disposed in 1988 for the f_{th} reported flow rate group was estimated as

$$\hat{Y}_f = \sum_{ij=1}^{24} N_{.fij} * \frac{Y_{.fij.}}{n_{.fij}} = \sum_{ij=1}^{24} N_{.fij} * \overline{Y}_{.fij} .$$

Subscript Notation: (continued)

Tables 5-4 and 5-5 - Report national estimates of total dry weight of sewage sludge by RA use or disposal practice and dichotomized flow rate group. That is, reported flow rates for the facilities were distinguished as being greater than one million gallons per day or less than or equal to one million gallons per day. Multiple RA use or disposal practices were allowed for POTWs. The reported total dry weight of sewage sludge disposed in 1988 for the d^{th} RA use or disposal practice in the f^{th} flow rate category was estimated as

$$\hat{Y}_{df} = \sum_{ij=1}^{24} N_{dfij} * \frac{Y_{dfij.}}{n_{dfij}} = \sum_{ij=1}^{24} N_{dfij} * \overline{Y}_{dfij} \quad .$$

The index d indicates RA use or disposal practice and end use for Tables 5-4 and 5-5, respectively.

Comments:

National estimates of total dry weight of sewage sludge used or disposed in 1988—obtained by summing total dry weight estimates across categories—reflect rounding errors. For example, the total volume of sewage sludge disposed in 1988 obtained by summing across RA use or disposal practices as reported in Table 5-1 is 5,032,834 U.S. Tons. Summing across regulated end use totals reported in Table 5.2, the estimated total volume of sewage sludge disposed in 1988 is 5,023,709 U.S. Tons. The RA use or disposal practice estimate exceeds the total end use estimate by 9,125 U.S. Tons or 0.2%.

Generally, the opportunity of rounding error increases as the number of categories being estimated increases. Discrepancies in the total dry weight estimates are also a result of the assumption that POTWs with missing values use or dispose of the average dry weight for their use or disposal/flow group category. Therefore, as the categories change, the average dry weight for each category, which replaces the missing values, also changes. This results in differences in the total dry weight estimates. National estimates of total sewage sludge obtained by summing estimated totals reported in the tables are presented in the Table Summary on the next page.

TABLE SUMMARY				
Table	Type of Estimates	National Estimate (U.S. Tons)	Percentage Difference as Compared to 5,053,424 U.S. Tons	Number of Estimated Categories
5-1	By RA Use or Disposal Practice	5,032,834	-0.41%	5
5-2	By Regulated End Use	5,023,709	-0.59%	15
5-3	By Reported Flow Group	5,053,424	0	4
5-4	RA Use or Disposal Practice and Reported Flow Group	5,036,107	-0.34%	10
5-5	Regulated End Use and Reported Flow Group	5,028,429	-0.49%	30

TABLE 5-1

NATIONAL ESTIMATES FOR TOTAL DRY WEIGHT OF SEWAGE SLUDGE USED OR DISPOSED IN 1988

BY REGULATORY ANALYTICAL (RA) USE OR DISPOSAL PRACTICE

RA Use or Disposal Practice	Estimated Number of POTWs[a]	Total Dry Weight (U.S. Tons)
INCINERATION	327	811,669
LAND APPLICATION	3,987	1,682,235
NOT COSTED UNDER PART 503	2,595	1,704,394
SURFACE DISPOSAL	1,158	519,589
UNKNOWN	3,534	314,947
UNKNOWN - ADJUSTED[1]	3,447	355,927

[a]A single POTW may employ more than one RA use or disposal practice. Therefore, the sum of the estimated number of POTWs across RA use or disposal practices is greater than the number of POTWs in the nation.

[1]UNKNOWN - ADJUSTED: Total estimates adjusted to reflect total sludge volumes from a census of 28 POTWs using Ocean Disposal.

TABLE 5-2

NATIONAL ESTIMATES FOR TOTAL DRY WEIGHT OF SEWAGE SLUDGE USED OR DISPOSED IN 1988

BY REGULATED END USE

RA Use or Disposal Practice	Estimated Number of POTWs[a]	Total Dry Weight (U.S. Tons)
INCINERATION	327	811,669
LA: AGRICULTURAL	3,246	1,098,970
LA: COMPOST	145	141,041
LA: FORESTS	30	29,409
LA: PUBLIC	253	155,891
LA: RECLAIMED	68	61,788
LA: SALE	199	66,707
LA: UNDEFINED	488	119,303
NOT REGULATED	2,595	1,704,394
SD: DEDICATED	383	242,892
SD: MONOFILL	320	147,705
SD: OTHER	456	128,993
UNK: OCEAN[1]	115	314,947
UNK: OTHER	3,397	0
UNK: TRANSFER	22	0

* LA = Land Application
SD = Surface Disposal
UNK = Unknown

[a] A single POTW may employ more than one end use. Therefore, the sum of the estimated number of POTWs across end uses is greater than the number of POTWs in the nation.

[1] A census of POTWs using ocean disposal in 1988 revealed that a total of 355,927 U.S. Tons of sewage sludge was disposed by 28 POTWs.

TABLE 5-3

NATIONAL ESTIMATES FOR TOTAL DRY WEIGHT OF SEWAGE SLUDGE USED OR DISPOSED IN 1988

BY REPORTED FLOW GROUP

REPORTED FLOW GROUP	NUMBER OF POTWs[a]		TOTAL DRY WEIGHT (U.S. Tons)	
	Estimated	Adjusted[b]	Estimated	Adjusted[b]
FLOW > 100 MGD -->	26	30	1,258,861	1,303,111
10 < FLOW ≤ 100 MGD	414	416	2,096,094	2,092,862
1 < FLOW ≤ 10 MGD	2,456	2,455	1,314,161	1,314,135
FLOW ≤ 1 MGD	7,997	7,905	384,308	384,625

[a]Excluding POTWs classified as Ineligible or Out of Business.
[b]Estimates adjusted to reflect data from a census of 28 POTWs using ocean disposal.

TABLE 5-4

NATIONAL ESTIMATES FOR TOTAL DRY WEIGHT OF SEWAGE SLUDGE USED OR DISPOSED IN 1988

BY REGULATORY ANALYTICAL (RA) USE OR DISPOSAL PRACTICE AND DICHOTOMIZED REPORTED FLOW GROUP

RA Use or Disposal Practice	Reported Flow Group	Estimated Number of POTWs[a]	Total Dry Weight (U.S. Tons)
INCINERATION	FLOW > 1 MGD	234	809,777
	FLOW ≤ 1 MGD	93	1,892
LAND APPLICATION	FLOW > 1 MGD	1,274	1,486,452
	FLOW ≤ 1 MGD	2,713	196,420
NOT COSTED UNDER PART 503	FLOW > 1 MGD	1,026	1,605,714
	FLOW ≤ 1 MGD	1,569	101,316
SURFACE DISPOSAL	FLOW > 1 MGD	391	429,676
	FLOW ≤ 1 MGD	766	89,913
UNKNOWN	FLOW > 1 MGD	262	314,896
	FLOW ≤ 1 MGD	3,272	51
UNKNOWN-ADJUSTED[1]	FLOW > 1 MGD	266	355,887
	FLOW ≤ 1 MGD	3,180	40

[a]A single POTW may employ more than one RA use or disposal practice. Therefore, the sum of the estimated number of POTWs across RA use or disposal practices is greater than the number of POTWs in the nation.

[1]Adjusted to reflect a census of 28 POTWs using ocean disposal.

TABLE 5-5

NATIONAL ESTIMATES FOR TOTAL DRY WEIGHT OF SEWAGE SLUDGE USED OR DISPOSED IN 1988

BY REGULATED END USE AND DICHOTOMIZED REPORTED FLOW GROUP

END USE*	REPORTED FLOW GROUP	ESTIMATED NUMBER OF POTWs[a]	TOTAL DRY WEIGHT (U.S. Tons)
INCINERATION	FLOW > 1 MGD	234	809,777
	FLOW ≤ 1 MGD	93	1,892
LA: AGRICULTURAL	FLOW > 1 MGD	993	954,271
	FLOW ≤ 1 MGD	2,253	144,699
LA: COMPOST	FLOW > 1 MGD	51	108,799
	FLOW ≤ 1 MGD	95	32,242
LA: FORESTS	FLOW > 1 MGD	8	28,356
	FLOW ≤ 1 MGD	22	1,053
LA: PUBLIC	FLOW > 1 MGD	200	150,845
	FLOW ≤ 1 MGD	53	5,046
LA: RECLAIMED	FLOW > 1 MGD	22	61,428
	FLOW ≤ 1 MGD	46	361
LA: SALE	FLOW > 1 MGD	99	66,609
	FLOW ≤ 1 MGD	100	98
LA: UNDEFINED	FLOW > 1 MGD	194	108,533
	FLOW ≤ 1 MGD	293	12,855
NOT COSTED UNDER PART 503	FLOW > 1 MGD	1,026	1,605,714
	FLOW ≤ 1 MGD	1,569	101,316

* LA = Land Application
SD = Surface Disposal
UNK = Unknown

[a] A single POTW may employ more than one end use. Therefore, the sum of the estimated number of POTWs across end uses does not represent the total number of POTWs.

TABLE 5-5 (con't)

NATIONAL ESTIMATES FOR TOTAL DRY WEIGHT OF SEWAGE SLUDGE USED OR DISPOSED IN 1988

BY REGULATED END USE
AND DICHOTOMIZED REPORTED FLOW GROUP

END USE*	REPORTED FLOW GROUP	ESTIMATED NUMBER OF POTWs[a]	TOTAL DRY WEIGHT (U.S. Tons)
SD: DEDICATED	FLOW > 1 MGD	207	205,541
	FLOW ≤ 1 MGD	176	37,350
SD: MONOFILL	FLOW > 1 MGD	124	125,045
	FLOW ≤ 1 MGD	196	22,659
SD: OTHER	FLOW > 1 MGD	61	99,090
	FLOW ≤ 1 MGD	394	29,903
UNK: OCEAN[1]	FLOW > 1 MGD	21	314,896
	FLOW ≤ 1 MGD	94	51
UNK: OTHER	FLOW > 1 MGD	240	0
	FLOW ≤ 1 MGD	3,157	0
UNK: TRANSFER	FLOW > 1 MGD	0	
	FLOW ≤ 1 MGD	22	0

* LA = Land Application
SD = Surface Disposal
UNK = Unknown

[a] A single POTW may employ more than one end use. Therefore, the sum of the estimated number of POTWs across end uses is greater than the number of POTWs in the nation.

[1] A census of POTWs using ocean disposal in 1988 revealed that a total of 355,927 U.S. Tons of sewage sludge was disposed by 28 POTWs. Dichotomized by reported flow group, the totals from the census are:

REPORTED FLOW GROUP	NUMBER of POTWs	TOTAL DRY WEIGHT
FLOW > 1 MGD	26	355,887
FLOW ≤ 1 MGD	2	40

6. NATIONAL ESTIMATES FOR SELECTED ASPECTS OF USE OR DISPOSAL PRACTICES

Chapter 6 discusses special issues concerning three separate sections of the National Sewage Sludge Survey (NSSS): Section II—Land Application, Section IV—Incineration, and Section V—Monofill. In these three areas of the NSSS, the Publicly Owned Treatment Works (POTWs) were instructed to complete multiple copies of Part B for situations described in the Part B instructions. In Section II, a Part B was to be completed for each Land Application practice employed at the POTW, in Section IV, for each Incinerator, and in Section V, for each Monofill. Multiple responses were also allowed in some of the questions in these sections. This chapter describes how national estimates were achieved accounting for these special circumstances. The national estimates provided herein are lower bounds. This is because estimates were generated using data only from POTWs that responded to the specific questions. No imputation was conducted for nonrespondents. Section 6.1 describes management practices used to prevent runoff to surface waters, Section 6.2 discusses incineration, and Section 6.3 covers surface disposal. References in the text to regulatory analytical (RA) use or disposal practice classifications appear as *CAPITALIZED ITALICS.*

6.1 MANAGEMENT PRACTICES USED TO PREVENT RUNOFF TO SURFACE WATERS

There are 195 POTWs in the NSSS that have been classified under RA use or disposal practice criteria as using *LAND APPLICATION* to dispose of sewage sludge in 1988. The estimated total number of POTWs in the Nation classified as using *LAND APPLICATION* is 3,987. Of the 195 POTWs in the NSSS, 161 POTWs responded to the followup question in the Land Application section. Therefore, national estimates for select aspects of the *LAND APPLICATION* category are based on those responses only. No assumptions were made about POTWs that did not respond to the survey.

The questions of concern from the Land Application section (Section II) are Part B, Questions II-23, II-28, and II-31. The following estimates, taken from responses to Question II-28 were computed for each POTW. That is, for each possible response, the POTW was considered to have responded "yes" if the POTW had responded affirmatively to that option for any of its end uses (i.e., any copy of Part B). Any POTW that did not answer a question was assumed not to have used any of the given options. The copies of Section II, Part B, relating to the category Dedicated Land, have been excluded from this analysis because Dedicated Land has been reclassified as *SURFACE DISPOSAL.*

II-28. What type of management practices were used to prevent runoff to surface waters?

a. None
b. Buffer zone
c. Conservation tillage
d. Maximum slope requirement
e. Sediment basin
f. Terracing/berming
g. Other

The following national estimates represent the number of *LAND APPLICATION* POTWs in the Nation that use each management practice in at least one of the end uses.

Estimated number of POTWs using None	635
Estimated number of POTWs using Buffer Zone	1,843
Estimated number of POTWs using Conservation Tillage	278
Estimated number of POTWs using Maximum Slope Requirement	1,632
Estimated number of POTWs using Sediment Basin	34
Estimated number of POTWs using Terracing/Berming	533
Estimated number of POTWs using Other Management Practices	169

The following management practices were reported under the category Other:

Site specific
Approved sediment and erosion control plans
Diversion ditch
Use flat areas
Mix with flyash
Injection
Flood plane
High bank containment
Containment of surface runoff
Site checks during storm events
Runoff recirculation
Vegetation
Seasonal restrictions
Hay bales
Sites approved
Land terraced.

6.1.1 Mechanisms Used to Maintain Control Over the Ultimate End Use

II-23. What type of arrangement or mechanism was used to maintain control over the ultimate end use of the sewage sludge?

a. Inter-agency agreements
b. Written contract
c. Other written agreement
d. Other
e. None

The following national estimates represent the number of *LAND APPLICATION* POTWs in the Nation that use each type of arrangement or mechanism for at least one of the end uses.

Estimated number of POTWs using Inter-Agency Agreements	214
Estimated number of POTWs using Written Contracts	930
Estimated number of POTWs using Other Written Agreements	478
Estimated number of POTWs using Other Mechanisms	384
Estimated number of POTWs using None	278

The other written agreements reported in Question II-23c include:

Land-lease agreement
Instructions prohibit certain end uses
Agreements with land owners
DER permits
State approval
State permit
Instructions/agreement
Land use agreement
Land owner/contractor agreements
State letter
Proof of ins. and letter agreement
Contracts
Permit
PADER permit
Hauling receipt
OEPA sludge management
DER agreement.

The other mechanisms reported in Question II-23d include:

IEPA permit limit
State permits
MWCC monitoring
No public or private involvement
Verbal agreement
Request from researcher and letter of approval from PADER
Permit from Maine Department Environmental Protection
POTW manages
Permits, supervision by metro
Oral agreement
In-house control
Land application permit
Set price
Verbal contract
County controls
Written site approval
Permit
Land owner.

6.1.2 Alternative Use Or Disposal Practices

> II-31. How would you use or dispose of the sewage sludge available as a result of reduced application rates?
>
> a. Increase acreage within this land application category
> b. Apply to other land application categories
> c. Pursue other disposal practices (not land application)
> d. Other

The following national estimates represent the number of *LAND APPLICATION* POTWs in the Nation that would use each alternative use or disposal practice for at least one of the end uses. Question II-31 was only to be answered if the response to Question II-29 was "Yes." However, in the NSSS questionnaire, there were 22 POTWs that responded to Question II-31 even though the response to Question II-29 was "No," "Not applicable," or was left blank. The responses from these POTWs are included in the following estimates.

Estimated number of POTWs using increased acreage within the land application category	810
Estimated number of POTWs applying to other land application categories	439
Estimated number of POTWs pursuing other disposal practices	314
Estimated number of POTWs using other options	26

The Other options specified under Question II-31d include:

Unknown
Recycle compost
Transfer to other.

6.2 INCINERATION

There are 68 POTWs in the NSSS questionnaire that have been classified as using *INCINERATION*. The estimated total number of POTWs using *INCINERATION* in the Nation is 307.

For Questions IV-16 and IV-22 in Part B, only one response was permitted per incinerator. However, there were four POTWs with missing data for these questions. Therefore, they were considered to have responded "no" to all the options. This accounts for the remaining incinerators which were not included in the estimates. For Question IV-26, multiple responses were permitted per incinerator. The estimates for this question represent the number of incinerators using each of the possible responses.

6.2.1 Types of Incinerators

IV-16a. Indicate below the incinerator type.

1. Electric furnace
2. Fluid bed
3. Multiple hearth
4. Rotary kiln
5. Other

The following estimates represent the number of each type of incinerator in the Nation. These estimates account for 296 of the estimated 431 incinerators in the Nation. The remaining incinerators are a result of the four POTWs that did not respond to Question IV-16a.

Estimated number of Electric Furnace incinerators	2
Estimated number of Fluid Bed incinerators	49
Estimated number of Multiple Hearth incinerators	242
Estimated number of Rotary Kiln incinerators	0
Estimated number of Other Types of incinerators	3

The other types of incinerators reported in Question IV-16a(5) were flash driers.

6.2.2 Afterburners

IV-22. Does this incinerator currently have an afterburner installed? a. No b. Afterburner with heat exchanger c. Afterburner without heat exchanger

The following estimates represent the number of incinerators in the Nation with each type of afterburner. These estimates account for 298 of the estimated 431 incinerators in the Nation. The remaining incinerators are a result of the 4 POTWs that did not respond to Question IV-22.

Estimated number of incinerators without an afterburner	186
Estimated number of incinerators with an afterburner with a heat exchanger	27
Estimated number of incinerators with an afterburner without a heat exchanger	85

6.2.3 Number of Incinerators

IV-1. How many individual incinerators were used to incinerate your sewage sludge during 1988? a. On-site incinerators b. Off-site incinerators c. Total number of incinerators

From the estimated 307 POTWs in the Nation that use *INCINERATION,* the estimated total number of incinerators in the Nation is 431.

6.2.4 Where Incinerator Ash is Disposed

IV-26. Where is this incinerator ash disposed? a. Co-disposal landfill b. Metal extraction processing c. Recycling (e.g., making bricks) d. Storage lagoon e. Waste pile f. Other

The following estimates represent the number of incinerators in the Nation using each of the ash disposal options. Each incinerator may use more than one location for ash disposal.

Estimated number of incinerators using Co-Disposal Landfill	152
Estimated number of incinerators using Metal Extraction Processing	0
Estimated number of incinerators using Recycling	6
Estimated number of incinerators using Storage Lagoons	136
Estimated number of incinerators using Waste Piles	12
Estimated number of incinerators using Other Locations	30

The other ash disposal locations specified in Question IV-26f include:

Cement manufacturing
Ash monofill
Ash landfill.

6.3 SURFACE DISPOSAL

In the NSSS questionnaire, 64 POTWs were classified as using *SURFACE DISPOSAL* to dispose of sewage sludge in 1988. The *SURFACE DISPOSAL* classification comprises all POTWs that reported on the NSSS questionnaire in the categories Surface Disposal, Monofill, or Dedicated Land for Sewage Sludge Disposal. However, only the POTWs that reported using monofills were required to answer the followup questions in Section V. Therefore, the following estimates are based only on POTWs reporting the use of monofills. Of the 64 POTWs classified as using *SURFACE DISPOSAL*, 33 reported the use of monofills. The estimated total number of POTWs in the Nation that use monofills is 320.

There are two POTWs that reported the use of monofills but did not respond to the followup questions in Section V. Because of the survey design strata of these two POTWs, the missing responses represent 112 POTWs in the Nation.

For Questions V-14, V-15, and V-21 in Part B, only one response per question was requested. However, some POTWs provided multiple responses to these questions. Therefore, the sum of the national estimates for Questions V-14, V-15, and V-21 (209), plus the estimated national number from the two POTWs with missing data (112), does not sum to the estimated total number of monofills (320). The difference is a result of the multiple responses from some POTWs.

For Question V-20 multiple responses were permitted for each monofill.

6.3.1 Monofills Used Per POTW

V-1.	How many monofills were used in 1988 to dispose of your sewage sludge?
	__ monofills

From the estimated 320 POTWs in the Nation that use monofills, the estimated total number of monofills in the Nation is 320. This represents one monofill per POTW. For the 31 POTWs in the NSSS questionnaire responding to Question V-1, each POTW used only one monofill.

6.3.2 Estimated Depth to Groundwater

> V-21. Estimate the depth to groundwater from the bottom of this monofill.
>
> a. No known groundwater source below monofill
> b. Monofill is located in groundwater
> c. 0 to 0.5 meters
> d. 0.6 to 2 meters
> e. 2.1 to 8 meters
> f. 8.1 to 12 meters
> g. Greater than 12 meters

The following estimates represent the number of monofills in the Nation that fall into each of the depth to groundwater categories. Two POTWs provided more than one response to this question.

Estimated number of monofills with no known groundwater source	3
Estimated number of monofills located in groundwater	1
Estimated number of monofills with depth between 0 and 0.5 meters	3
Estimated number of monofills with depth between 0.6 and 2 meters	53
Estimated number of monofills with depth between 2.1 and 8 meters	8
Estimated number of monofills with depth between 8.1 and 12 meters	2
Estimated number of monofills with depth greater than 12 meters	139

6.3.3 Release Controls

> V-20. Describe the discharge controls at this monofill.
>
> a. Cover practices
> b. Leachate collection systems
> c. Leachate treatment systems
> d. Liners, natural
> e. Liners, synthetic
> f. Methane controls
> g. Monitoring wells
> h. Runon/runoff controls
> i. No controls
> j. Other

The following estimates represent the number of monofills in the Nation that use each discharge control. Multiple responses per monofill are permitted.

Estimated number of monofills using Cover Practices	199
Estimated number of monofills using Leachate Collection Systems	11
Estimated number of monofills using Leachate Treatment Systems	4
Estimated number of monofills using Natural Liners	124
Estimated number of monofills using Synthetic Liners	5
Estimated number of monofills using Methane Controls	3
Estimated number of monofills using Monitoring Wells	41
Estimated number of monofills using Runon/Runoff Controls	125
Estimated number of monofills using No Controls	4
Estimated number of monofills using Other Controls	19

The only discharge control specified in the category Other Controls in Question V-20j was Lime Absorption.

6.3.4 Owner of the Monofill

V-14. Who is the owner of this monofill?

a. Your POTW
b. Other POTW
c. Municipality
d. Private party
e. State
f. Other

The following estimates represent the number of monofills in the Nation owned by each of the POTWs providing possible responses. Two POTWs provided more than one response to this question.

Estimated number of monofills owned by POTW	63
Estimated number of monofills owned by Other POTW	0
Estimated number of monofills owned by Municipality	124
Estimated number of monofills owned by Private Party	21
Estimated number of monofills owned by State	1
Estimated number of monofills owned by Other	0

6.3.5 Operator of the Monofill

V-14. Who is the operator of this monofill?

a. Your POTW
b. Other POTW
c. Municipality
d. Private party
e. State
f. Other

The following estimates represent the number of monofills in the Nation which are operated by each of the POTWs providing possible responses. One POTW provided more than one response to this question.

Estimated number of monofills operated by POTW	72
Estimated number of monofills operated by Other POTW	0
Estimated number of monofills operated by Municipality	96
Estimated number of monofills operated by Private Party	40
Estimated number of monofills operated by State	1
Estimated number of monofills operated by Other	0

7. NATIONAL CONCENTRATION ESTIMATES FOR POLLUTANTS OF CONCERN FROM THE NATIONAL SEWAGE SLUDGE SURVEY (NSSS)

This chapter presents estimates of the expected concentrations of pollutants of concern in sewage sludge used or disposed in 1988 from POTWs in the Nation practicing secondary or greater treatment of wastewater, excluding wastewater stabilization ponds. National estimates of the standard deviation of these pollutant concentrations and estimates of the 90^{th}, 95^{th}, 98^{th}, and 99^{th} percentile concentrations are also included. Concentration estimates are reported for the pollutants of concern because these are the pollutants that the Agency proposed to regulate in the February 6, 1989 *Federal Register*, based on toxicity, persistence, and health and environmental risk. All elements, compounds, or solids physically measured will be referred to in this chapter as pollutants. The term **pollutant** is used here to mean only that a substance, in certain quantities, <u>could</u> cause harm to the environment; not that it <u>will</u> cause harm to the environment. In particular, pollutants such as nitrogen and phosphorous are necessary for plant growth in soil as long as their concentrations in the soil under consideration are within an appropriate range.

Reported estimates were produced from National Sewage Sludge Survey (NSSS) pollutant-concentration data using a modified maximum-likelihood estimation technique with the assumption that pollutant concentrations follow a lognormal distribution. As a point of reference, nonparametric estimates are also presented. Pollutant concentrations are not assumed to follow any specific distribution for these nonparametric estimates. Procedures used to quantify and report pollutant concentrations from NSSS samples and the techniques used to estimate flow rate group and national pollutant concentrations from the data were discussed in this chapter.

Chemical analysis methods were adapted specifically for the NSSS to facilitate reliable measurement of pollutants from the sewage sludge matrix (US EPA, 1989B). Section 7.1 discusses these methods and the procedure for reporting results. Because some pollutants were not detected in concentrations above the minimum level of detection, NSSS analytical data contains censored observations. Section 7.2 presents an evaluation of the statistical methods available for analyzing data that contain quantitative and censored observations. Section 7.3 provides data conventions and aggregation schemes. Section 7.4 discusses the statistical procedures and assumptions used to estimate POTW-based pollutant concentrations from NSSS data. Section 7.4 also presents tabulated POTW-based pollutant-concentration estimates for the pollutants of concern and graphical presentations of results. Section 7.5 presents the statistical procedures and assumptions used to estimate mass-based pollutant concentrations and resulting estimates. Finally, Section 7.6 contains summary comments about the statistical methods used and the resulting estimates.

7.1 CHEMICAL ANALYSIS METHODS AND REPORTING PROCEDURES

Samples of final process sewage sludge, collected prior to use or disposal from the 180 secondary treatment POTWs, excluding POTWs using wastewater stabilization ponds, in the stratified NSSS analytical survey were tested by EPA contract laboratories for 412 pollutants. The list of tested pollutants, which includes volatile and semi-volatile organics, metals, pesticides, dibenzofurans, dioxins, and PCBs, was formed from the Clean Water Act (CWA) Section 307(a) priority pollutants, toxic compounds highlighted in the Domestic Sewage Sludge Study, Resource Conservation and Recovery Act (RCRA) Appendix VIII pollutants, and contaminants of suspected concern in municipal sewage sludge. Specific analytical protocols were developed for the NSSS to facilitate reliable measurement of pollutant concentrations from the sewage sludge matrix. Methods 1624 and 1625 for quantifying volatile and semi-volatile organic pollutants, respectively, were augmented with gel permeation procedures for sample cleanup. Likewise, ultrasonic techniques in conjunction with extraction procedures increased the precision and accuracy of pesticides, PCBs, dibenzofurans, and dioxin concentration determinations. Each pollutant was assigned a minimum level, a form of "detection limit" used by the Agency, in the analytical method protocol.

If a pollutant was quantified above the minimum level, as adjusted for interferences, the measured concentration in dry weight units is reported under the variable "AMOUNT" in the NSSS data base. However, if analytical testing did not yield a concentration above the minimum level, the dry weight value of the minimum level is recorded for the sample in the variable "DETLIMIT." Minimum level, as applied to the determination of pollutants by gas chromatography combined with mass spectrometry (GCMS), is defined by the EPA's Industrial Technology Division as the level at which "the entire analytical system shall give recognizable mass spectra and acceptable calibration points" (US EPA, 1989B, p. 41). For elemental pollutants, minimum level is defined "the minimum concentration of substance that can be measured and reported in 99% confidence that the value is above zero" (Ibid., p. 198). In the NSSS, the minimum level is roughly equivalent to the minimum concentration or amount of pollutant that could be measured.

NSSS pollutant concentrations and minimum levels were reported in dry weight units due to differences in the solids contents of sewage sludge samples. A pollutant-concentration reported in dry weight units is a function of the sample's percent solids. Percent solids range from less than 1% to 100% in NSSS samples. A standardized reporting unit allows all sewage sludge samples to be evaluated on the same basis with respect to pollutant loads. Implicit in this form of reporting is that pollutants are associated with the solid phase of sewage sludge.

Dry weight and wet weight NSSS pollutant concentrations are plotted against percent solids for each of the pollutants of concern in Figures 7-1 through 7-72. These graphics are located at the end of this chapter. A density of 1 is assumed for conversions. Odd-numbered figures present dry weight pollutant concentrations plotted against sample percent solids. Even-numbered figures present wet weight pollutant concentrations plotted against sample percent solids. For a given pollutant, the wet weight plot generally illustrates that pollutant concentrations detected above the minimum level tend to increase with increasing percent solids. However, when dry weight concentrations for the same pollutant are plotted against percent solids, this increasing trend is no longer evident. That is, dry weight pollutant concentrations appear to be dispersed randomly with respect to percent solids. Since the conversion from wet to dry weight concentration takes into account percent solids, this random dispersion of detected pollutant concentrations reinforces the assertion that sewage sludge samples with differing percent solids can be evaluated on the same basis with respect to pollutant load if dry weight measurements are used in the analyses.

For any given pollutant, the values recorded under the variable "DETLIMIT" are not constant. A constant value would imply that a fixed volume or amount was tested for all samples with no dilution of the sample or extract and that there was no matrix effect. A matrix effect is defined as analytical interference from the sewage sludge sample. This was not the case. All analytical protocols specified the volume or amount of sewage sludge to be tested. However, when matrix interferences prevented accurate determination of pollutant concentration, samples were diluted with reagent water and analyzed. The purpose of dilution was to negate matrix effects. The minimum level for a diluted sample was raised by the dilution factor, however. For instance, if a sample was diluted by a factor of 10, then the minimal level was raised by a factor of 10. Analytical protocols provided explicit guidance as to the limits of dilution.

Likewise, the reporting of analytical results in units per kilogram influences the values reported in the data base. As mentioned previously, the percent solids of NSSS samples range from 1 to 100%. Because the dry weight pollutant concentrations and minimum levels are a function of the percent solids in a sample, the range in percent solids also is reflected in reported pollutant concentrations or minimum levels. For example, assuming that there was no dilution of samples and that the same quantity of sewage sludge was tested, the value recorded under "DETLIMIT" for a sample with 1% solids would be 10 times higher than that reported for a sample with 10% solids. This is because it would take 10 times the quantity of the 1% solids sample to produce the same amount of solids in the 10% solids sample.

Figure 7-34 illustrates the wet weight of mercury for NSSS samples. Mercury concentrations detected above the minimum level are distinguished by the triangle symbol and defined in the exhibit key as "Above Minimum Level." This designation contrasts with the samples that were not measured above the minimum level that are identified by the symbol "x" and are listed in the exhibit key as minimum levels. Notice that the majority of "nondetect" samples have 0.01 mg/l as the minimum level. The effect of sample percent solids on the dry weight reporting of mercury minimum levels is illustrated by the plot of dry weight mercury concentrations in Figure 7-33.

Because POTWs in the NSSS were sampled according to flow rate strata, a test was performed to determine if there was a statistical association between flow rate group and a categorical variable created from percent solids data. The three levels of the percent solids categorical variable were greater than 30% solids, between 1% and 30% solids, and less than 1% solids. These 3% solids categories were selected to parallel the percent solids categories that differentiate sample preparation procedures in the analytical protocols. The cross-tabulation of these two variables is listed in Table 7-1.

The statistical test of association incorporated the ordinal nature of both variables. Specifically, a test statistic was calculated and a z-score determined from the difference in the number of concordant and discordant pairs. The number of concordant and discordant pairs was determined according to the method listed by Alan Agresti in his book entitled, *Analysis of Ordinal Categorical Data* (p. 180-181). Standard error for the estimate of the difference in concordant and discordant pairs was derived using the delta method under the assumption that the difference between concordant and discordant pairs is 0. This test is a consistent test against monotonic departures from the null hypothesis that the two variables are distributed independently.

TABLE 7-1.

FREQUENCY OF PERCENT SOLIDS IN NATIONAL SEWAGE SLUDGE SURVEY SAMPLES BY FLOW RATE GROUP

1986 NEEDS based Flow Rate Group	Frequency / Percent / Row Pct / Col Pct	Percent Solids >30%	1%-30%	<1%	Total
	>100 MGD	9 4.50 34.62 14.52	17 8.50 65.38 13.28	0 0.00 0.00 0.00	26 13.00
	10-100 MGD	16 8.00 26.23 25.81	45 22.50 73.77 35.16	0 0.00 0.00 0.00	61 30.50
	1-10 MGD	22 11.00 31.43 35.48	44 22.00 62.86 34.38	4 2.00 5.71 40.00	70 35.00
	≤1 MGD	15 7.50 34.88 24.19	22 11.00 51.16 17.19	6 3.00 13.95 60.00	43 21.50
	Total	62 31.00	128 64.00	10 5.00	200 100.00

The calculated z-score from this test was 0.5675. The attained significance value for this statistic is more than 0.5 but less than 0.9. Therefore, there is insufficient evidence to reject the null hypothesis that the distribution of percent solids and flow rate group are independent.

7.2 PARAMETER ESTIMATION WITH CENSORED DATA

When a pollutant is not measured above the minimum level, the data point recording the dry weight minimum level for that sample is considered "left censored." Left censoring implies that the pollutant concentration in a sample falls within a restricted range. That is, the concentration in the sample is less than, or "to the left of," the minimum-level value. When the censoring points (ie., dry weight minimum levels) differ because of differences in the sewage sludge matrix, the data were considered to be multicensored.

Several statistical methods are available for estimating pollutant concentration descriptive statistics when the data contain multiple censor points. The most commonly applied methods include (1) ignoring the censored observations, (2) setting all censored observations equal to 0, and (3) setting the censored observation to either the minimum limit of detection or some fraction of the limit of detection. Ignoring censored data will usually result in descriptive statistics that overestimate true pollutant concentration values. Setting censored data points to 0 will underestimate true pollutant-concentration levels. Equating censored points to the minimum level of detection will overestimate pollutant concentrations.

Other methods for estimating multicensored data exist but are used less frequently. Generally, these methods consist of "fill-in" and maximum-likelihood procedures. "Fill-in" procedures replace censored data points with pollutant concentrations that have been estimated from measured or noncensored data points. In maximum-likelihood procedures developed by Cohen (1959), pollutant concentrations are estimated by maximizing likelihood equations that incorporate both the data measured above the minimum level and censored data point values. Eight procedures for calculating descriptive statistics from data with a single censor point value were evaluated by Gilliom and Helsel of the U.S. Geological Survey (USGS) in 1986. These procedures included simple substitution, "fill-in," and maximum-likelihood techniques. Monte Carlo experiments with singularly censored data from distributions that mimic the distribution of water quality measures were used to evaluate the accuracy and reliability of the eight methods. Simulation results indicated that simple substitution methods produce biased and highly variable estimates. The maximum-likelihood procedure and a probability plotting "fill-in " procedure, performed on natural logarithm transformed data, produced the lowest errors of estimation. That is, estimated statistics were the closest to the known population values. The most reliable estimates of the mean and standard deviation were produced by the probability plotting procedure, while the maximum-likelihood technique produced the best median and percentile estimates. Application of these techniques to actual water quality data confirmed these conclusions.

In 1988, Helsel and Cohn of the USGS extended their study to include multiple censor points. Two approaches to producing estimates were used in this later study. In the first approach, the maximum value of the multiple censor points was determined, and single censor techniques were applied using this maximum value. In the second approach, methods were evaluated using multiple censor points. The methods using multiple censor points were shown to be better than the application of single censor methods. Conclusions in the presence of multiple censor points were the same as those drawn from the studies with single censor points. Although the "fill-in" procedure is more robust to departures from lognormality, the maximum-likelihood technique is more desirable when lognormality of the distribution of pollutants can be assumed. In their 1988 publication, Helsel and Cohn state, "When utilized correctly, 'less than' values frequently contain nearly as much information for estimating population moments and quantiles as would the same observation had the detection limit been below them."

7.3 DATA CONVENTIONS AND SCHEMES

7.3.1 Conventions

Pollutant-concentration data were collected from 180 POTWs during the analytical component of the 1988 NSSS. However, data from only 178 POTWs were used for these estimates. Data from Episode 1477 are available at EPA's Sample Control Center, but were not included in the data set at the time of these analyses. Data from Episode 1488 were determined to have been collected in 1989. Because the POTW was not operational in 1988, the data from this POTW were also excluded from these analyses. A listing of these data, by survey stratum, for each of the pollutants of concern is found the appendix to this report (in Volume II).

The national estimates were calculated for a total of 39 pollutants, including 11 metals, 7 organic pollutants, 16 pesticides, individual and composite pollutants of concern, phosphorus, total jkeldahl nitrogen, and percent solids. The composite pollutants consist of Aldrin/Dieldrin, DDT Composite (DDD, DDE, and DDT), and the PCB Aroclors (PCB-1016, PCB-1221, PCB-1232, PCB-1242, PCB-1248, PCB-1254, and PCB-1260). Estimates were calculated for each of the composite pollutants and each of the individual component pollutants.

Two sets of cadmium data were used in these analyses. A single cadmium concentration of 8,220 mg/kg from Episode-1492 was determined to be an extreme value, since the next largest observed cadmium concentration was 299 mg/kg. Therefore, the pollutant-concentration estimates for cadmium have been calculated including and excluding this extreme concentration value.

The pollutant-concentration data have been aggregated by POTW for these analyses. For each of the 29 POTWs with samples from multiple treatment trains, the mean concentration was determined by weighing each sample by the corresponding dry weight of sewage sludge disposed by the sample's treatment process. There was insufficient information to link the samples for 23 of the 29 POTWs with samples from multiple treatment trains with dry weight data. When the treatment process for each sample could not be determined, an arithmetic average across treatment train samples was used. Therefore, the data used for these estimates consists of a single pollutant concentration value per POTW for each pollutant. If the pollutant concentration was detected above the minimum level for one sample from a POTW and not detected above the minimum level for another sample from a POTW with multiple treatment trains, the minimum-level value was used for the nondetected sample when POTW concentrations were determined.

For the composite pollutants, the pollutant concentrations first were combined for each sample by summing the individual concentrations together. The samples then were aggregated for each POTW as stated above. This mathematical compositing was conducted because regulatory limits will be set for the related pollutants as opposed to the individual component pollutant.

7.3.2 Adjusted Stratum Weights

Analytical survey stratum weights (w_i) used to calculate national estimates have been adjusted to exclude the POTWs determined to have been *INELIGIBLE* or *OUT OF BUSINESS* in 1988 or classified as using wastewater stabilization ponds. The total number of POTWs (N_i) within each survey flow rate stratum, and the number of POTWs selected for the analytical survey (n_i) are tabulated below.

NUMBER OF POTWs IN THE NSSS ANALYTICAL SURVEY

$Stratum_i$	N_i	n_i
1 = Flow > 100 MGD	28	20
2 = 10 < Flow ≤ 100 MGD	324	56
3 = 1 < Flow ≤ 10 MGD	1,927	65
4 = Flow ≤ 1 MGD	9,067	67
Total	11,346	208

Five POTWs in the analytic survey were classified as *INELIGIBLE* or *OUT OF BUSINESS* in 1988. In addition to these five, there were eighteen POTWs classified as using Wastewater Stabilization Ponds. POTWs using wastewater stabilization ponds as a form of secondary treatment are excluded from national estimates of pollutant concentration because no sewage sludge samples were obtained from this treatment process during the NSSS analytical survey. Samples were not obtained from the POTWs due to sampling difficulty and because secondary treatment was not complete. The adjusted number of eligible POTWs in the Nation (N_i) and the number of POTWs sampled (n_i), after excluding these POTWs, along with the adjusted stratum weights (w_i), are presented below.

ADJUSTED NUMBER OF ELIGIBLE POTWs

$Stratum_i$	N_i	n_i	Stratum Weights=w_i
1 = Flow > 100 MGD	27	19	27/8,497 = 0.00318
2 = 10 < Flow ≤ 100 MGD	318	55	318/8,497 = 0.03742
3 = 1 < Flow ≤ 10 MGD	1,927	65	1,927/8,497 = 0.22679
4 = Flow ≤ 1 MGD	6,225	46	6,225/8,497 = 0.73261
Total	8,497	185	1.00000

The total number of eligible POTWs sampled was 185. However, pollutant-concentration data were available for only 178 POTWs. The remaining seven POTWs were considered eligible for the analytic survey, according to the disposal practices listed in the questionnaire responses, but six could not be sampled due to logistic difficulties, and data from the seventh was not added to the data base. For the calculation of the national pollutant-concentration estimates, it is assumed that these POTWs operate at the stratum mean concentration level.

7.4 POTW-BASED NATIONAL POLLUTANT-CONCENTRATION ESTIMATES

National estimates of POTW-based pollutant concentrations are presented in this section. Descriptive statistics for pollutant concentrations are generated from the distribution of pollutant concentrations across all POTWs in the Nation. Thus, the mean pollutant concentration in the Nation is actually the expected concentration of the given pollutant in sewage sludge from the "average" POTW. The concentration of a given pollutant in sewage sludge from 90% of the POTWs in the Nation will be less than or equal to the estimated 90^{th} percentile pollutant concentration.

The first set of estimates presented in this chapter were generated under the assumption that pollutant concentrations in sewage sludge follow a lognormal distribution. Statistical methods and strata and national estimates of pollutant-concentration means, standard deviations, and coefficients of variation under this distributional assumption are presented in section 7.4.1.

As a point of reference, two nonparametric statistical estimates of pollutant concentrations for the pollutants of concern are tabulated along with estimates, which were generated under the assumption that pollutant concentrations follow a lognormal distribution. Nonparametric statistical estimation procedures do not make any assumptions about the distribution of pollutant concentrations in sewage sludge. For one nonparametric estimate, sample-specific minimum-level values were substituted for those samples from which a pollutant concentration was not measured above the minimum level of detection. The value of zero was substituted for those samples from which a pollutant concentration was not measured above the minimum level of detection in the other nonparametric estimates.

Nonparametric and lognormal national estimates of pollutant concentrations are presented in section 7.4.2. Estimates include the mean, standard deviation, and coefficient of variation of pollutant concentrations in the Nation for the pollutants of concern and 95% confidence intervals about the estimated national mean pollutant concentrations--the latter are included in this document in response to public request.

Finally, section 7.4.3 presents the statistical methodology and results for nonparametric and lognormal estimates of the 50^{th}, 90^{th}, 95^{th}, 98^{th}, and 99^{th} percentile pollutant concentrations.

Three significant figures are reported for all pollutant-concentration estimates. To maintain a consistent format, tabulated estimates include two decimal places. If these digits are not significant, zeros are reported.

7.4.1 National Pollutant-Concentration Estimates—Assuming Pollutant Concentrations Follow a Lognormal Distribution

Pollutant concentration descriptive statistics for the NSSS were estimated as weighted functions of estimates from each of the four flow rate strata in the survey design. Stratum estimates were produced using the multiple censor point, maximum-likelihood technique. This technique, which requires the assumption that pollutant concentrations follow a lognormal distribution, was the statistical method of choice for two reasons: (1) the lognormal distribution is commonly used because it generally provides a good approximation of the distribution of pollutant concentrations, and (2) there was an insufficient number of samples detected above the minimum level to use the "fill-in" technique for some strata.

For the i^{th} flow rate stratum, maximum-likelihood estimates (MLE) of the mean (μ_i) and variance (σ^2_i) of pollutant concentration were obtained by minimizing the following loss function:

$$LOSS_i = -\prod_{j=1}^{n_i}\left[I(X_{ij}>ML_{ij})\frac{1}{X_{ij}\sqrt{2\pi\sigma^2_i}}\exp\left\{-\frac{1}{2}\left(\frac{\ln X_{ij}-\mu_i}{\sigma_i}\right)^2\right\} + I(X_{ij}\le ML_{ij})\,\Phi\left(\frac{\ln X_{ij}-\mu_i}{\sigma_i}\right)\right].$$

Note that minimizing this loss function is tantamount to maximizing the likelihood function. In the loss function expression, $\ln(X_{ij})$ is the natural logarithm transform of the pollutant concentration for the j^{th} sample from the i^{th} stratum. The first indicator function $I(X_{ij} > ML_{ij})$ takes on the value 1 if the pollutant concentration from the j^{th} sample from the i^{th} flow rate stratum is greater than the minimum level, and 0 if otherwise. The second indicator function, $I(X_{ij} \le ML_{ij})$, has a value of 1 if the pollutant concentration in the ij^{th} sample is not measured above the minimum level, and 0 if it is. Therefore, observations above the minimum level enter the loss function in the standard fashion. On the other hand, censored observations contribute to the loss function through the lognormal cumulative distribution function.

Iterative techniques were used to determine values of the mean (μ_i) and variance (σ^2_i) that minimize the loss function for pollutant concentrations from the i^{th} stratum. The first technique, known as the Simplex algorithm, employs direct search techniques and does not require a Hessian matrix of second derivatives to determine the step direction of each iteration. The second technique, the Quasi-Newton algorithm, makes use of information in the Hessian matrix. Quasi-Newton algorithms approximate the Hessian matrix at each iteration. A singular or nondefined Hessian matrix precludes parameter estimation.

Several runs were made using both of these minimization techniques to estimate the MLE concentrations for each stratum. The runs differed in the values of the mean and variance supplied to the algorithms as starting points. Regardless of the starting points, the same MLEs were produced from each run provided that the stratum had at least one noncensored data point. That is, for a given pollutant*stratum, the same MLEs resulted from both minimization techniques from each series of starting values. When all data points were censored, the resulting MLEs were not unique. These estimates are listed as missing.

Functions of the maximum-likelihood mean and variance estimates for each pollutant*stratum were exponentiated to determine the mean, or expected concentration value of X_i, and the variance of X_i. The variable X_i designates pollutant concentration from the i^{th} flow rate stratum from the survey design. Again, X_i is assumed to be distributed lognormally. For a given pollutant, the expected pollutant concentration $E(X_i)$ and variance $V(X_i)$ for each stratum were estimated as follows:

$$E(X_i) = \exp(\hat{\mu}_i + \frac{1}{2}\hat{\sigma}^2{}_i)$$

$$V(X_i) = \exp(2\hat{\mu}_i + \hat{\sigma}^2{}_i)(\exp(\hat{\sigma}^2{}_i) - 1) .$$

In this expression, $\hat{\mu}_i$ is the MLE of the i^{th} stratum mean, and $\hat{\sigma}^2_i$ is the adjusted MLE of the variance for the i^{th} stratum. The MLE of the variance (σ^2_i) was multiplied by a factor of $n_i/(n_i-1)$ where n_i is the number of POTWs sampled in the i^{th} stratum. This adjustment was made to correct for bias in the MLE estimate of the variance.

National pollutant-concentration estimates were calculated as weighted estimates of the expected pollutant concentrations and variances of each stratum. Adjusted stratum weights (w_i) used to generate national estimates are discussed earlier in Section 7.3. These weights have been adjusted to exclude ineligible POTWs and POTWs that use wastewater stabilization ponds as a form of secondary treatment. No samples of sewage sludge from these POTWs were analyzed in the NSSS survey.

National expected pollutant concentrations E(X) were calculated as

$$E(X) = \sum_{i=1}^{4} w_i E(X_i) .$$

Pollutant-concentration variance V(X) was estimated as a function of within- and between-strata variance components. The estimator used for NSSS pollutants will be motivated first by an expression of the unbiased estimate of population variance based on proportional stratified sampling. This expression, listed in *Sampling Survey Methods and Theory, Vol. II* (Hansen, Hurwitz, and Madow. p. 138), is

$$V(X) = \frac{1}{n}\sum_{h}^{L}\sum_{i}^{n_h}(x_{hi}-\bar{x})^2+\frac{1-f}{n}S^2{}_{wX}$$

where

$$S^2{}_{wX} = \frac{1}{n}\sum_{h}^{L} n_h S^2{}_{hX}.$$

The subscript h designates the stratum while the subscript i indicates the ith observation in the stratum. S^2_{wX} defines the weighted sum of within-stratum variances for the random variable X.

Under proportional stratified sampling

$$\frac{n_h}{n} = \frac{N_h}{N}$$

where n_h is the number of POTWs sampled for stratum h and n is the sum of POTWs sampled over all strata. Likewise, N_h is the number of elements in the sampling frame stratum and N is the total number of elements in the sampling frame. N is obtained by summing N_h over all strata.

The sampling fraction, f_h, is the same for all strata under proportional stratification since for every stratum

$$\frac{n_h}{n} = \frac{N_h}{N} \rightarrow \frac{n_h}{N_h} = \frac{n}{N} \rightarrow f_h = f.$$

Therefore,

$$\frac{1}{n} = \frac{N_h}{N}\frac{1}{n_h}$$

can be expressed as

$$\frac{1}{n} = \frac{w_h}{n_h}.$$

The variance, V(X), for a stratified sample becomes

$$V(X) = \sum_h^L \sum_{i=1}^{n_h} \frac{w_h}{n_h} (x_{hi}-\overline{x})^2 + \sum_h^L (1-f_h) \frac{w_h^2}{n_h} S^2{}_{hX}.$$

The first term in this variance expression can be written as

$$\sum_h^L \sum_{i=1}^{n_h} \frac{w_h}{n_h} (x_{hi}-\overline{x}_h+\overline{x}_h-\overline{x})^2$$

which equals

$$\sum_h^L \sum_{i=1}^{n_h} \frac{w_h}{n_h} (x_{hi}-\overline{x}_h)^2 + \sum_h^L w_h (\overline{x}_h-\overline{x})^2.$$

After combining like terms, the variance estimate is written as

$$V(X) = \sum_h^L S^2{}_{hX} \frac{w_h}{n_h} (n_h-1+w_h(1-f_h)) + \sum_h^L w_h (\overline{x}_h-\overline{x})^2.$$

where

$$S^2{}_{hX} = \sum_{i=1}^{n_h} \frac{(x_{hi}-\overline{x}_h)^2}{n_h-1}$$

defines the within-stratum variance component. The second term in the expression for the variance estimator is the between-strata sums of squares.

Therefore, pollutant-concentration variance was estimated from the NSSS as

$$V(X) = \sum_{i=1}^{4} V(X_i) \frac{w_i}{n_i} (n_i - 1 + w_i (1 - f_i)) + \sum_{i=1}^{4} w_i (E(X_i) - E(X))^2 .$$

Table 7-2 presents stratum and national pollutant-concentration estimates for the pollutants of concern. Individual pollutant estimates for the mathematically composited pollutants are presented in Table 7-3. Finally, stratum and national MLE estimates for Total Kjeldahl Nitrogen and Phosphorus are provided in Table 7-4.

7.4.2 Lognormal and Nonparametric Pollutant-Concentration Estimates

Due to the extremely low levels of detection, national estimates are not available for some pollutants under the parametric assumption that pollutant concentration follows a lognormal distribution. Nonparametric estimates do not require any distributional assumptions. Because of this, estimates can be generated for all pollutants. Nonparametric national estimates of pollutant concentration were calculated using two substitution methods for those samples from which a pollutant was not quantified above the minimum level of detection. In the first method, sample-specific values of the minimum level of detection were substituted for those samples from which a pollutant was not quantified above the minimum level of detection. Estimates produced according to this method are designated as "SM-ML." In the second nonparametric method, the value zero was substituted for those samples from which a pollutant was not quantified above the minimum level of detection. Estimates produced using this method are designated as "SM-0." Although these nonparametric methods yield estimates for all pollutants regardless of the rate of detection, the reader is cautioned to refer to the discussion in Section 7.2 regarding the pollutant statistical properties related to estimates resulting from these substitution methods.

TABLE 7-2.

STRATA AND NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
ASSUMING A LOGNORMAL DISTRIBUTION OF CONCENTRATION

POLLUTANTS OF CONCERN

Pollutant	Unit	Stratum	Number of POTWs	Detect Percent	Mean	Standard Deviation	Coefficient of Variation (CV)
Aldrin/Dieldrin[a]	µg/kg	> 100 MGD	19	0	.	.	.
		10 < FLOW <= 100	54	0	.	.	.
		1 < FLOW <= 10	63	0	.	.	.
		FLOW <= 1	41	0	.	.	.
		NATIONAL*	177	0	.	.	.
Aldrin/Dieldrin[b,c]	µg/kg	> 100 MGD	19	11	5.45	28.20	5.18
		10 < FLOW <= 100	54	4	14.50	17,300.00	1,200.00
		1 < FLOW <= 10	63	10	6.03	67.10	11.10
		FLOW <= 1	41	7	6.41	210.00	32.70
		NATIONAL*	177	8	6.63	3,320.00	501.00
Aldrin/Dieldrin[b,d]	µg/kg	> 100 MGD	19	11	8.83	11.60	1.32
		10 < FLOW <= 100	54	4	4.38	59.80	13.70
		1 < FLOW <= 10	63	10	7.40	15.20	2.06
		FLOW <= 1	41	7	5.68	24.10	4.24
		NATIONAL*	177	8	6.03	24.70	4.09
Arsenic	mg/kg	> 100 MGD	19	74	8.33	4.82	0.58
		10 < FLOW <= 100	54	91	10.60	12.60	1.19
		1 < FLOW <= 10	64	86	9.63	10.20	1.06
		FLOW <= 1	41	78	9.43	18.80	1.99
		NATIONAL*	178	80	9.52	16.90	1.78

. = Nonestimable.
* = National Estimates Determined as Weighted Sums of Stratum Estimates.
CV = Standard Deviation Divided by the Mean.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if At Least One Individual Pollutant is Measured Above the Minimum Level.
[c] Composite Pollutant Concentration Determined by Setting Maximum Nondetect Equal to the Highest Minimum Value and All Other Nondetects to Zero.
[d] Composite Pollutant Concentration Determined by Setting Nondetect Equal to the Minimum Level.

Note: Aldrin/Deildrin is a combination of Aldrin and Dieldrin.

TABLE 7-2. (Continued)

STRATA AND NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY ASSUMING A LOGNORMAL DISTRIBUTION OF CONCENTRATION

POLLUTANTS OF CONCERN

Pollutant	Unit	Stratum	Number of POTWs	Detect Percent	Mean	Standard Deviation	Coefficient of Variation (CV)
Benzene	µg/kg	> 100 MGD	19	11	98.80	2,700.00	27.30
		10 < FLOW <= 100	54	4	16.30	305.00	18.70
		1 < FLOW <= 10	64	0	.	.	.
		FLOW <= 1	41	0	.	.	.
		NATIONAL*	178	0	.	.	.
Benzo(A)pyrene	µg/kg	> 100 MGD	19	0	.	.	.
		10 < FLOW <= 100	54	6	.	.	.
		1 < FLOW <= 10	64	5	427.00	2,770.00	6.48
		FLOW <= 1	41	2	268.00	429.00	1.60
		NATIONAL*	178	3	.	.	.
Beryllium	mg/kg	> 100 MGD	19	37	0.51	0.14	0.27
		10 < FLOW <= 100	54	24	0.38	0.34	0.89
		1 < FLOW <= 10	64	38	0.52	0.47	0.90
		FLOW <= 1	41	17	0.34	0.36	1.07
		NATIONAL*	178	22	0.38	0.39	1.03
Bis(2-Ethylhexyl) Phthalate	µg/kg	> 100 MGD	19	100	160,000.00	415,000.00	2.60
		10 < FLOW <= 100	54	85	157,000.00	411,000.00	2.62
		1 < FLOW <= 10	64	89	145,000.00	648,000.00	4.47
		FLOW <= 1	41	54	46,900.00	399,000.00	8.50
		NATIONAL*	178	63	73,600.00	468,000.00	6.36
Cadmium	mg/kg	> 100 MGD	19	89	52.10	98.60	1.89
		10 < FLOW <= 100	54	100	22.30	39.20	1.76
		1 < FLOW <= 10	64	81	16.40	38.00	2.32
		FLOW <= 1	41	63	5.48	6.36	1.16
		NATIONAL*	178	69	8.74	21.80	2.49

. = Nonestimable.
* = National Estimates Determined as Weighted Sums of Stratum Estimates.
CV = Standard Deviation Divided by the Mean.

TABLE 7-2. (Continued)

STRATA AND NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY ASSUMING A LOGNORMAL DISTRIBUTION OF CONCENTRATION

POLLUTANTS OF CONCERN

Pollutant	Unit	Stratum	Number of POTWs	Detect Percent	Mean	Standard Deviation	Coefficient of Variation (CV)
Cadmium[a]	mg/kg	> 100 MGD	19	89	52.10	98.60	1.89
		10 < FLOW <= 100	54	100	22.30	39.20	1.76
		1 < FLOW <= 10	63	81	9.52	11.40	1.20
		FLOW <= 1	41	63	5.48	6.36	1.16
		NATIONAL*	177	69	7.18	12.80	1.78
Chlordane	µg/kg	> 100 MGD	19	0	.	.	.
		10 < FLOW <= 100	54	0	.	.	.
		1 < FLOW <= 10	63	2	23.10	403.00	17.40
		FLOW <= 1	41	0	.	.	.
		NATIONAL*	177	0	.	.	.
Chromium	mg/kg	> 100 MGD	19	100	480.00	596.00	1.24
		10 < FLOW <= 100	54	100	254.00	437.00	1.72
		1 < FLOW <= 10	64	100	189.00	363.00	1.92
		FLOW <= 1	41	88	95.50	302.00	3.17
		NATIONAL*	178	91	124.00	327.00	2.64
Copper	mg/kg	> 100 MGD	19	100	901.00	758.00	0.84
		10 < FLOW <= 100	54	100	746.00	629.00	0.84
		1 < FLOW <= 10	64	100	628.00	489.00	0.78
		FLOW <= 1	41	100	752.00	1,020.00	1.35
		NATIONAL*	178	100	724.00	909.00	1.25

. = Nonestimable.
* = National Estimates Determined as Weighted Sums of Stratum Estimates.
CV = Standard Deviation Divided by the Mean.

[a] Estimates Generated After Deleting an Extreme Outlier Observation from Stratum 3.

TABLE 7-2. (Continued)

STRATA AND NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
ASSUMING A LOGNORMAL DISTRIBUTION OF CONCENTRATION

POLLUTANTS OF CONCERN

Pollutant	Unit	Stratum	Number of POTWs	Detect Percent	Mean	Standard Deviation	Coefficient of Variation (CV)
DDT, Composite[a]	µg/kg	> 100 MGD	19	0	.	.	.
		10 < FLOW <= 100	54	0	.	.	.
		1 < FLOW <= 10	63	0	.	.	.
		FLOW <= 1	41	0	.	.	.
		NATIONAL*	177	0	.	.	.
DDT, Composite[b,c]	µg/kg	> 100 MGD	19	21	71.70	553.00	7.71
		10 < FLOW <= 100	54	6	13.10	62.50	4.76
		1 < FLOW <= 10	63	5	11.30	54.40	4.83
		FLOW <= 1	41	2	5.39	15.60	2.90
		NATIONAL*	177	3	7.22	43.90	6.08
DDT, Composite[b,d]	µg/kg	> 100 MGD	19	21	91.40	209.00	2.28
		10 < FLOW <= 100	54	6	33.50	48.00	1.43
		1 < FLOW <= 10	63	5	31.80	33.70	1.06
		FLOW <= 1	41	2	13.50	23.70	1.76
		NATIONAL*	177	3	18.60	31.10	1.67
Heptachlor	µg/kg	> 100 MGD	19	0	.	.	.
		10 < FLOW <= 100	54	2	3.32	4.73	1.42
		1 < FLOW <= 10	63	0	.	.	.
		FLOW <= 1	41	0	.	.	.
		NATIONAL*	177	0	.	.	.

. = Nonestimable.
* = National Estimates Determined as Weighted Sums of Stratum Estimates.
CV = Standard Deviation Divided by the Mean.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if At Least One Individual Pollutant is Measured Above the Minimum Level.
[c] Composite Pollutant Concentration Determined by Setting Maximum Nondetect Equal to the Highest Minimum Value and All Other Nondetects to Zero.
[d] Composite Pollutant Concentration Determined by Setting Nondetect Equal to the Minimum Level.

Note: DDT, Composite is a combination of 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT.

TABLE 7-2. (Continued)

STRATA AND NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
ASSUMING A LOGNORMAL DISTRIBUTION OF CONCENTRATION

POLLUTANTS OF CONCERN

Pollutant	Unit	Stratum	Number of POTWs	Detect Percent	Mean	Standard Deviation	Coefficient of Variation (CV)
Hexachlorobenzene	µg/kg	> 100 MGD	19	0	.	.	.
		10 < FLOW <= 100	54	0	.	.	.
		1 < FLOW <= 10	64	0	.	.	.
		FLOW <= 1	41	0	.	.	.
		NATIONAL*	178	0	.	.	.
Hexachlorobutadiene	µg/kg	> 100 MGD	19	0	.	.	.
		10 < FLOW <= 100	54	0	.	.	.
		1 < FLOW <= 10	64	0	.	.	.
		FLOW <= 1	41	0	.	.	.
		NATIONAL*	178	0	.	.	.
Lead	mg/kg	> 100 MGD	19	100	245.00	159.00	0.65
		10 < FLOW <= 100	54	100	241.00	284.00	1.18
		1 < FLOW <= 10	64	89	158.00	147.00	0.93
		FLOW <= 1	41	76	117.00	179.00	1.53
		NATIONAL*	178	80	131.00	179.00	1.36
Lindane (Gamma-BHC)	µg/kg	> 100 MGD	19	0	.	.	.
		10 < FLOW <= 100	54	2	2.68	28.80	10.70
		1 < FLOW <= 10	63	2	2.41	54.20	22.50
		FLOW <= 1	41	0	.	.	.
		NATIONAL*	177	0	.	.	.
Mercury	mg/kg	> 100 MGD	19	84	2.66	1.83	0.69
		10 < FLOW <= 100	54	87	2.98	2.61	0.88
		1 < FLOW <= 10	64	84	4.14	3.25	0.78
		FLOW <= 1	41	56	5.78	18.90	3.27
		NATIONAL*	178	64	5.30	16.30	3.07

. = Nonestimable.
* = National Estimates Determined as Weighted Sums of Stratum Estimates.
CV = Standard Deviation Divided by the Mean.

TABLE 7-2. (Continued)

STRATA AND NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
ASSUMING A LOGNORMAL DISTRIBUTION OF CONCENTRATION

POLLUTANTS OF CONCERN

Pollutant	Unit	Stratum	Number of POTWs	Detect Percent	Mean	Standard Deviation	Coefficient of Variation (CV)
Molybdenum	mg/kg	> 100 MGD	19	68	9.42	6.43	0.68
		10 < FLOW <= 100	54	80	12.80	16.20	1.26
		1 < FLOW <= 10	64	69	10.60	10.80	1.01
		FLOW <= 1	41	46	9.16	18.70	2.05
		NATIONAL*	178	53	9.63	17.10	1.78
N-Nitrosodimethylamine	µg/kg	> 100 MGD	19	0	.	.	.
		10 < FLOW <= 100	54	0	.	.	.
		1 < FLOW <= 10	64	0	.	.	.
		FLOW <= 1	41	0	.	.	.
		NATIONAL*	178	0	.	.	.
Nickel	mg/kg	> 100 MGD	19	95	104.00	124.00	1.19
		10 < FLOW <= 100	54	98	82.80	115.00	1.39
		1 < FLOW <= 10	64	83	48.90	48.60	0.99
		FLOW <= 1	41	61	42.90	114.00	2.66
		NATIONAL*	178	67	46.00	103.00	2.24
PCB, Composite•	µg/kg	> 100 MGD	19	0	.	.	.
		10 < FLOW <= 100	54	0	.	.	.
		1 < FLOW <= 10	63	0	.	.	.
		FLOW <= 1	41	0	.	.	.
		NATIONAL*	177	0	.	.	.

. = Nonestimable.
* = National Estimates Determined as Weighted Sums of Stratum Estimates.
CV = Standard Deviation Divided by the Mean.

• Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.

Note: PCB, Composite is a combination of PCB-1016, PCB-1221, PCB-1332, PCB-1242, PCB-1248, PCB-1254, and PCB-1260.

TABLE 7-2. (Continued)

STRATA AND NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY ASSUMING A LOGNORMAL DISTRIBUTION OF CONCENTRATION

POLLUTANTS OF CONCERN

Pollutant	Unit	Stratum	Number of POTWs	Detect Percent	Mean	Standard Deviation	Coefficient of Variation (CV)
PCB, Composite[b,c]	µg/kg	> 100 MGD	19	21	472.00	5,540.00	11.70
		10 < FLOW <= 100	54	15	415.00	12,700.00	30.70
		1 < FLOW <= 10	63	19	471.00	8,600.00	18.30
		FLOW <= 1	41	20	1,600.00	182,000.00	114.00
		NATIONAL*	177	19	1,300.00	155,000.00	120.00
PCB, Composite[b,d]	µg/kg	> 100 MGD	19	21	1,050.00	525.00	0.50
		10 < FLOW <= 100	54	15	737.00	701.00	0.95
		1 < FLOW <= 10	63	19	802.00	721.00	0.90
		FLOW <= 1	41	20	923.00	2,780.00	3.01
		NATIONAL*	177	19	889.00	2,400.00	2.70
Selenium	mg/kg	> 100 MGD	19	68	6.11	7.11	1.16
		10 < FLOW <= 100	54	87	5.25	4.93	0.94
		1 < FLOW <= 10	64	78	7.12	7.38	1.04
		FLOW <= 1	41	63	5.12	8.10	1.58
		NATIONAL*	178	68	5.58	7.86	1.41
Toxaphene	µg/kg	> 100 MGD	19	0	.	.	.
		10 < FLOW <= 100	54	0	.	.	.
		1 < FLOW <= 10	63	0	.	.	.
		FLOW <= 1	41	0	.	.	.
		NATIONAL*	177	0	.	.	.

. = Nonestimable.
* = National Estimates Determined as Weighted Sums of Stratum Estimates.
CV = Standard Deviation Divided by the Mean.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if At Least One Individual Pollutant is Measured Above the Minimum Level.
[c] Composite Pollutant Concentration Determined by Setting Maximum Nondetect Equal to the Highest Minimum Value and All Other Nondetects to Zero.
[d] Composite Pollutant Concentration Determined by Setting Nondetect Equal to the Minimum Level.

Note: PCB, Composite is a combination of PCB-1016, PCB-1221, PCB-1332, PCB-1242, PCB-1248, PCB-1254, and PCB-1260.

TABLE 7-2. (Continued)

STRATA AND NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY ASSUMING A LOGNORMAL DISTRIBUTION OF CONCENTRATION

POLLUTANTS OF CONCERN

Pollutant	Unit	Stratum	Number of POTWs	Detect Percent	Mean	Standard Deviation	Coefficient of Variation (CV)
Trichloroethene	µg/kg	> 100 MGD	19	5	10.80	10.10	0.93
		10 < FLOW <= 100	54	6	49.60	2,720.00	54.80
		1 < FLOW <= 10	64	5	21,900.00	33,900,000,000.00	1,540,000.00
		FLOW <= 1	41	0	.	.	.
		NATIONAL*	178	1	.	.	.
Zinc	mg/kg	> 100 MGD	19	100	1,470.00	859.00	0.59
		10 < FLOW <= 100	54	100	1,520.00	1,550.00	1.02
		1 < FLOW <= 10	64	100	1,700.00	2,260.00	1.33
		FLOW <= 1	41	100	1,060.00	1,280.00	1.21
		NATIONAL*	178	100	1,220.00	1,580.00	1.30

. = Nonestimable.
* = National Estimates Determined as Weighted Sums of Stratum Estimates.
CV = Standard Deviation Divided by the Mean.

TABLE 7-3.

STRATA AND NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
ASSUMING A LOGNORMAL DISTRIBUTION OF CONCENTRATION

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Stratum	Number of POTWs	Detect Percent	Mean	Standard Deviation	Coefficient of Variation (CV)
Aldrin/Dieldrin[a]	µg/kg	> 100 MGD	19	0	.	.	.
		10 < FLOW <= 100	54	0	.	.	.
		1 < FLOW <= 10	63	0	.	.	.
		FLOW <= 1	41	0	.	.	.
		NATIONAL	177	0	.	.	.
Aldrin/Dieldrin[b,c]	µg/kg	> 100 MGD	19	11	5.45	28.20	5.18
		10 < FLOW <= 100	54	4	14.50	17,300.00	1,200.00
		1 < FLOW <= 10	63	10	6.03	67.10	11.10
		FLOW <= 1	41	7	6.41	210.00	32.70
		NATIONAL	177	8	6.63	3,320.00	501.00
Aldrin/Dieldrin[b,d]	µg/kg	> 100 MGD	19	11	8.83	11.60	1.32
		10 < FLOW <= 100	54	4	4.38	59.80	13.70
		1 < FLOW <= 10	63	10	7.40	15.20	2.06
		FLOW <= 1	41	7	5.68	24.10	4.24
		NATIONAL	177	8	6.03	24.70	4.09
Aldrin	µg/kg	> 100 MGD	19	5	2.81	5.02	1.78
		10 < FLOW <= 100	54	4	6.35	1,480.00	234.00
		1 < FLOW <= 10	63	5	2.42	19.60	8.07
		FLOW <= 1	41	2	1.55	54.30	35.10
		NATIONAL	177	3	1.93	289.00	150.00

. = Nonestimable.
* = National Estimates Determined as Weighted Sums of Stratum Estimates.
CV = Standard Deviation Divided by the Mean.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.
[c] Composite Pollutant Concentration Determined by Setting Maximum Nondetect Equal to the Highest Minimum Value and All Other Nondetects to Zero.
[d] Composite Pollutant Concentration Determined by Setting Nondetects Equal to the Minimum Level.

Note: Aldrin/Dieldrin is a combination of Aldrin and Dieldrin.

TABLE 7-3. (Continued)

STRATA AND NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
ASSUMING A LOGNORMAL DISTRIBUTION OF CONCENTRATION

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Stratum	Number of POTWs	Detect Percent	Mean	Standard Deviation	Coefficient of Variation (CV)
Dieldrin	µg/kg	> 100 MGD	19	5	3.00	22.30	7.43
		10 < FLOW <= 100	54	0	.	.	.
		1 < FLOW <= 10	63	5	2.56	25.50	9.96
		FLOW <= 1	41	5	3.23	80.50	24.90
		NATIONAL	177	5	.	.	.
DDT, Composite[a]	µg/kg	> 100 MGD	19	0	.	.	.
		10 < FLOW <= 100	54	0	.	.	.
		1 < FLOW <= 10	63	0	.	.	.
		FLOW <= 1	41	0	.	.	.
		NATIONAL	177	0	.	.	.
DDT, Composite[b,c]	µg/kg	> 100 MGD	19	21	71.70	553.00	7.71
		10 < FLOW <= 100	54	6	13.10	62.50	4.76
		1 < FLOW <= 10	63	5	11.30	54.40	4.83
		FLOW <= 1	41	2	5.39	15.60	2.90
		NATIONAL	177	3	7.22	43.90	6.08
DDT, Composite[b,d]	µg/kg	> 100 MGD	19	21	91.40	209.00	2.28
		10 < FLOW <= 100	54	6	33.50	48.00	1.43
		1 < FLOW <= 10	63	5	31.80	33.70	1.06
		FLOW <= 1	41	2	13.50	23.70	1.76
		NATIONAL	177	3	18.60	31.10	1.67

. = Nonestimable.
* = National Estimates Determined as Weighted Sums of Stratum Estimates.
CV = Standard Deviation Divided by the Mean.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.
[c] Composite Pollutant Concentration Determined by Setting Maximum Nondetect Equal to the Highest Minimum Value and All Other Nondetects to Zero.
[d] Composite Pollutant Concentration Determined by Setting Nondetects Equal to the Minimum Level.

Note: DDT, Composite is a combination of 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT.

TABLE 7-3. (Continued)

STRATA AND NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY ASSUMING A LOGNORMAL DISTRIBUTION OF CONCENTRATION

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Stratum	Number of POTWs	Detect Percent	Mean	Standard Deviation	Coefficient of Variation (CV)
4,4'-DDD	µg/kg	> 100 MGD	19	5	1,260.00	42,400,000.00	33,700.00
		10 < FLOW <= 100	54	0	.	.	.
		1 < FLOW <= 10	63	0	.	.	.
		FLOW <= 1	41	0	.	.	.
		NATIONAL	177	0	.	.	.
4,4'-DDE	µg/kg	> 100 MGD	19	5	42.30	4,600.00	109.00
		10 < FLOW <= 100	54	2	14.50	7.85	0.54
		1 < FLOW <= 10	63	3	7.83	29.20	3.73
		FLOW <= 1	41	0	.	.	.
		NATIONAL	177	1	.	.	.
4,4'-DDT	µg/kg	> 100 MGD	19	16	11.60	22.10	1.91
		10 < FLOW <= 100	54	4	11.00	1,940.00	176.00
		1 < FLOW <= 10	63	2	1.82	9.13	5.02
		FLOW <= 1	41	2	2.15	6.55	3.05
		NATIONAL	177	2	2.44	371.00	152.00
PCB, Composite[a]	µg/kg	> 100 MGD	19	0	.	.	.
		10 < FLOW <= 100	54	0	.	.	.
		1 < FLOW <= 10	63	0	.	.	.
		FLOW <= 1	41	0	.	.	.
		NATIONAL	177	0	.	.	.

. = Nonestimable.
* = National Estimates Determined as Weighted Sums of Stratum Estimates.
CV = Standard Deviation Divided by the Mean.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.

Note: PCB, Composite is a combination of PCB-1016, PCB-1221, PCB-1232, PCB-1242, PCB-1248, PCB-1254, and PCB-1260.

TABLE 7-3. (Continued)

STRATA AND NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
ASSUMING A LOGNORMAL DISTRIBUTION OF CONCENTRATION

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Stratum	Number of POTWs	Detect Percent	Mean	Standard Deviation	Coefficient of Variation (CV)
PCB, Composite[b,c]	µg/kg	> 100 MGD	19	21	472.00	5,540.00	11.70
		10 < FLOW <= 100	54	15	415.00	12,700.00	30.70
		1 < FLOW <= 10	63	19	471.00	8,600.00	18.30
		FLOW <= 1	41	20	1,600.00	182,000.00	114.00
		NATIONAL	177	19	1,300.00	155,000.00	120.00
PCB, Composite[b,d]	µg/kg	> 100 MGD	19	21	1,050.00	525.00	0.50
		10 < FLOW <= 100	54	15	737.00	701.00	0.95
		1 < FLOW <= 10	63	19	802.00	721.00	0.90
		FLOW <= 1	41	20	923.00	2,780.00	3.01
		NATIONAL	177	19	889.00	2,400.00	2.70
PCB-1016	µg/kg	> 100 MGD	19	0	.	.	.
		10 < FLOW <= 100	54	0	.	.	.
		1 < FLOW <= 10	63	0	.	.	.
		FLOW <= 1	41	0	.	.	.
		NATIONAL	177	0	.	.	.
PCB-1221	µg/kg	> 100 MGD	19	0	.	.	.
		10 < FLOW <= 100	54	0	.	.	.
		1 < FLOW <= 10	63	0	.	.	.
		FLOW <= 1	41	0	.	.	.
		NATIONAL	177	0	.	.	.

. = Nonestimable.
* = National Estimates Determined as Weighted Sums of Stratum Estimates.
CV = Standard Deviation Divided by the Mean.

[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.
[c] Composite Pollutant Concentration Determined by Setting Maximum Nondetect Equal to the Highest Minimum Value and All Other Nondetects to Zero.
[d] Composite Pollutant Concentration Determined by Setting Nondetects Equal to the Minimum Level.

Note: PCB, Composite is a combination of PCB-1016, PCB-1221, PCB-1232, PCB-1242, PCB-1248, PCB-1254, and PCB-1260.

TABLE 7-3. (Continued)

STRATA AND NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY ASSUMING A LOGNORMAL DISTRIBUTION OF CONCENTRATION

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Stratum	Number of POTWs	Detect Percent	Mean	Standard Deviation	Coefficient of Variation (CV)
PCB-1232	µg/kg	> 100 MGD	19	0	.	.	.
		10 < FLOW <= 100	54	0	.	.	.
		1 < FLOW <= 10	63	0	.	.	.
		FLOW <= 1	41	0	.	.	.
		NATIONAL	177	0	.	.	.
PCB-1242	µg/kg	> 100 MGD	19	0	.	.	.
		10 < FLOW <= 100	54	0	.	.	.
		1 < FLOW <= 10	63	0	.	.	.
		FLOW <= 1	41	0	.	.	.
		NATIONAL	177	0	.	.	.
PCB-1248	µg/kg	> 100 MGD	19	11	91.20	139.00	1.52
		10 < FLOW <= 100	54	11	201.00	4,260.00	21.10
		1 < FLOW <= 10	63	13	144.00	1,060.00	7.39
		FLOW <= 1	41	7	47.40	118.00	2.50
		NATIONAL	177	9	75.10	965.00	12.80
PCB-1254	µg/kg	> 100 MGD	19	5	2,740.00	33,800,000.00	12,300.00
		10 < FLOW <= 100	54	2	47.30	10,700.00	227.00
		1 < FLOW <= 10	63	6	79.60	1,120.00	14.10
		FLOW <= 1	41	10	36,100.00	2,920,000,000.00	80,700.00
		NATIONAL	177	9	26,500.00	2,490,000,000.00	94,000.00
PCB-1260	µg/kg	> 100 MGD	19	16	147.00	433.00	2.95
		10 < FLOW <= 100	54	7	66.40	133.00	2.00
		1 < FLOW <= 10	63	10	105.00	841.00	7.97
		FLOW <= 1	41	10	120.00	1,940.00	16.20
		NATIONAL	177	10	115.00	1,710.00	14.90

. = Nonestimable.
* = National Estimates Determined as Weighted Sums of Stratum Estimates.
CV = Standard Deviation Divided by the Mean.

TABLE 7-4.

STRATA AND NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
ASSUMING A LOGNORMAL DISTRIBUTION OF CONCENTRATION

PERCENT SOLIDS, PHOSPHORUS, AND TOTAL KJELDAHL NITROGEN

Pollutant	Unit	Stratum	Number of POTWs	Detect Percent	Mean	Standard Deviation	Coefficient of Variation (CV)
Percent Solids	%	> 100 MGD	19	100	26.70	52.90	1.98
		10 < FLOW <= 100	54	100	26.60	34.60	1.30
		1 < FLOW <= 10	64	100	33.80	97.70	2.89
		FLOW <= 1	41	100	30.10	138.00	4.57
		NATIONAL	178	100	30.80	126.00	4.11
Phosphorus	mg/kg	> 100 MGD	19	100	2,510.00	4,660.00	1.86
		10 < FLOW <= 100	54	100	1,630.00	3,770.00	2.31
		1 < FLOW <= 10	64	100	4,800.00	23,300.00	4.84
		FLOW <= 1	41	100	8,140.00	48,700.00	5.99
		NATIONAL	178	100	7,120.00	43,100.00	6.06
Total Kjeldahl Nitrogen	mg/kg	> 100 MGD	19	100	63,700.00	77,100.00	1.21
		10 < FLOW <= 100	54	100	69,500.00	124,000.00	1.78
		1 < FLOW <= 10	64	100	53,300.00	66,400.00	1.25
		FLOW <= 1	41	100	48,100.00	56,800.00	1.18
		NATIONAL	178	100	50,100.00	62,800.00	1.25

* = National Estimates Determined as Weighted Sums of Stratum Estimates.
CV = Standard Deviation Divided by the Mean.

Once substitutions were made for censored data points, stratum estimates of the expected value of pollutant concentration $E(X_i)$ and variance $V(X_i)$ were generated arithmetically. That is, the stratum estimate of $E(X_i)$ was calculated as

$$E(X_i) = \sum_{j=1}^{n_i} \frac{X_{ij}}{n_i} = \overline{X}_i$$

and the variance of the pollutant concentration for the i^{th} stratum $V(X_i)$ as

$$V(X_i) = \frac{\sum_{j=1}^{n_i} (X_{ij} - \overline{X}_i)^2}{(n_i - 1)}.$$

The variable X_{ij} indicates the pollutant concentration value from the j^{th} POTW sampled in the i^{th} stratum. Likewise, n_i designates the number of POTWs sampled in the i^{th} flow rate stratum.

National, nonparametric pollutant concentrations means and variances are then estimated using the formulae for the respective national estimates presented in section 7.4.1.

Table 7-5 lists lognormal and nonparametric national estimates of the mean, standard deviation, and coefficient of variation for the pollutants of concern. Estimates designated as "MLE" indicate that the national estimate was generated under the assumption that pollutant concentrations follow a lognormal distribution. National estimates for the individual pollutants for those pollutants which have been mathematically composited are presented in Table 7-6.

Finally, parametric and nonparametric estimates of the mean, standard deviation, and coefficient of variation for total kjeldahl nitrogen and phosphorus are listed in Table 7-7.

TABLE 7-5.

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation	Coefficient of Variation (CV)
Aldrin/Dieldrin[a]	µg/kg	0	MLE	.	.	.
			SM-ML	26.70	27.00	1.01
			SM-0	1.65	6.44	3.90
			SM-COM	14.40	14.40	1.00
Aldrin/Dieldrin[b]	µg/kg	8	MLE-ML	6.03	24.70	4.09
			MLE-COM	6.63	3,320.00	501.5
			SM-ML	26.70	27.00	1.01
			SM-0	1.65	6.44	3.90
			SM-COM	14.40	14.40	1.00
Arsenic	mg/kg	80	MLE	9.52	16.90	1.78
			SM-ML	10.30	14.90	1.44
			SM-0	8.66	14.70	1.70
Benzene	µg/kg	0	MLE	.	.	.
			SM-ML	956.00	2,830.00	2.96
			SM-0	0.08	3.37	44.95

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
MLE-ML = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Nondetects Set Equal to the Minimum Level.
MLE-COM = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.
SM-COM = Weighted Nonparametric Substitution Method Stratum Estimates. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.

. = Nonestimable.

Note: Aldrin/Dieldrin is a combination of Aldrin and Dieldrin.

TABLE 7-5. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation	Coefficient of Variation (CV)
Benzo(A)pyrene	µg/kg	3	MLE	.	.	.
			SM-ML	9,620.00	13,100.00	1.36
			SM-0	76.90	1,100.00	14.28
Beryllium	mg/kg	22	MLE	0.38	0.39	1.03
			SM-ML	1.85	2.43	1.31
			SM-0	0.12	0.28	2.27
Bis(2-Ethylhexyl) Phthalate	µg/kg	63	MLE	73,600.00	468,000.00	6.36
			SM-ML	54,000.00	106,000.00	1.96
			SM-0	48,600.00	107,000.00	2.21
Cadmium	mg/kg	69	MLE	8.74	21.80	2.49
			SM-ML	39.40	489.00	12.42
			SM-0	36.00	490.00	13.58
Cadmium[c]	mg/kg	69	MLE	7.18	12.80	1.78
			SM-ML	10.30	26.20	2.53
			SM-0	6.96	26.20	3.77
Chlordane	µg/kg	0	MLE	.	.	.
			SM-ML	321.00	338.00	1.05
			SM-0	1.76	29.30	16.67
Chromium	mg/kg	91	MLE	124.00	327.00	2.64
			SM-ML	163.00	438.00	2.69
			SM-0	160.00	439.00	2.74

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.

[c] Estimates Generated After Deleting an Extreme Outlier Observation from Stratum 3.

. = Nonestimable.

TABLE 7-5. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation	Coefficient of Variation (CV)
Copper	mg/kg	100	MLE	724.00	909.00	1.25
			SM-ML	657.00	568.00	0.87
			SM-0	657.00	568.00	0.87
DDT, Composite[a]	µg/kg	0	MLE	.	.	.
			SM-ML	154.00	162.00	1.05
			SM-0	1.24	12.30	9.97
			SM-COM	65.30	68.10	1.04
DDT, Composite[b]	µg/kg	3	MLE-ML	18.60	31.10	1.67
			MLE-COM	7.22	43.90	6.08
			SM-ML	154.00	162.00	1.05
			SM-0	1.24	12.30	9.97
			SM-COM	65.30	68.10	1.04
Heptachlor	µg/kg	0	MLE	.	.	.
			SM-ML	25.60	27.00	1.06
			SM-0	0.02	0.59	38.00

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
MLE-ML = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Nondetects Set Equal to the Minimum Level.
MLE-COM = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.
SM-COM = Weighted Nonparametric Substitution Method Stratum Estimates. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.

. = Nonestimable.

Note: DDT, Composite is a combination of 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT.

TABLE 7-5. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation	Coefficient of Variation (CV)
Hexachlorobenzene	µg/kg	0	MLE	.	.	.
			SM-ML	9,560.00	13,100.00	1.37
			SM-0	0.00	0.00	0.00
Hexachlorobutadiene	µg/kg	0	MLE	.	.	.
			SM-ML	9,560.00	13,100.00	1.37
			SM-0	0.00	0.00	0.00
Lead	mg/kg	80	MLE	131.00	179.00	1.36
			SM-ML	135.00	122.00	0.91
			SM-0	109.00	128.00	1.18
Lindane (Gamma-BHC)	µg/kg	0	MLE	.	.	.
			SM-ML	32.30	33.80	1.05
			SM-0	0.16	2.46	15.26
Mercury	mg/kg	64	MLE	5.30	16.30	3.07
			SM-ML	6.58	8.77	1.33
			SM-0	3.83	8.48	2.21
Molybdenum	mg/kg	53	MLE	9.63	17.10	1.78
			SM-ML	14.70	14.50	0.98
			SM-0	6.66	11.80	1.78
N-Nitrosodimethylamine	µg/kg	0	MLE	.	.	.
			SM-ML	47,800.00	65,400.00	1.37
			SM-0	0.00	0.00	0.00

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.

. = Nonestimable.

TABLE 7-5. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation	Coefficient of Variation (CV)
Nickel	mg/kg	67	MLE	46.00	103.00	2.24
			SM-ML	58.20	95.10	1.63
			SM-0	44.00	97.60	2.22
PCB, Composite[a]	µg/kg	0	MLE	.	.	.
			SM-ML	2,030.00	2,070.00	1.02
			SM-0	279.00	992.00	3.56
			SM-COM	535.00	1,010.00	1.89
PCB, Composite[b]	µg/kg	19	MLE-ML	889.00	2,400.00	2.70
			MLE-COM	1,300.00	155,000.00	119.8
			SM-ML	2,030.00	2,070.00	1.02
			SM-0	279.00	992.00	3.56
			SM-COM	535.00	1,010.00	1.89
Selenium	mg/kg	68	MLE	5.58	7.86	1.41
			SM-ML	7.70	11.10	1.45
			SM-0	4.28	8.09	1.89

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
MLE-ML = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Nondetects Set Equal to the Minimum Level.
MLE-COM = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.
SM-COM = Weighted Nonparametric Substitution Method Stratum Estimates. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.

. = Nonestimable.

Note: PCB, Composite is a combination of PCB-1016, PCB-1221, PCB-1232, PCB-1242, PCB-1248, PCB-1254, and PCB-1260.

TABLE 7-5. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation	Coefficient of Variation (CV)
Toxaphene	µg/kg	0	MLE	.	.	.
			SM-ML	1,280.00	1,350.00	1.06
			SM-0	0.00	0.00	0.00
Trichloroethene	µg/kg	1	MLE	.	.	.
			SM-ML	968.00	2,840.00	2.93
			SM-0	17.10	212.00	12.37
Zinc	mg/kg	100	MLE	1,220.00	1,580.00	1.30
			SM-ML	1,430.00	4,560.00	3.19
			SM-0	1,430.00	4,560.00	3.19

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.

. = Nonestimable.

TABLE 7-6.

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation	Coefficient of Variation (CV)
Aldrin/Dieldrin[a]	µg/kg	0	MLE	.	.	.
			SM-ML	26.70	27.00	1.01
			SM-0	1.65	6.44	3.90
			SM-COM	14.40	14.40	1.00
Aldrin/Dieldrin[b]	µg/kg	8	MLE-ML	6.03	24.70	4.09
			MLE-COM	6.63	3,320.00	501.0
			SM-ML	26.70	27.00	1.01
			SM-0	1.65	6.44	3.90
			SM-COM	14.40	14.40	1.00
Aldrin	µg/kg	3	MLE	1.93	289.00	150.0
			SM-ML	13.10	13.50	1.03
			SM-0	0.58	3.40	5.88
Dieldrin	µg/kg	5	MLE	.	.	.
			SM-ML	13.50	13.90	1.02
			SM-0	1.07	5.58	5.20

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
MLE-ML = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Nondetects Set Equal to the Minimum Level.
MLE-COM = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.
SM-COM = Weighted Nonparametric Substitution Method Stratum Estimates. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.

. = Nonestimable.

Note: Aldrin/Dieldrin is a combination of Aldrin and Dieldrin.

TABLE 7-6. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation	Coefficient of Variation (CV)
DDT, Composite[a]	µg/kg	0	MLE	.	.	.
			SM-ML	154.00	162.00	1.05
			SM-0	1.24	12.30	9.97
			SM-COM	65.30	68.10	1.04
DDT, Composite[b]	µg/kg	3	MLE-ML	18.60	31.10	1.67
			MLE-COM	7.22	43.90	6.08
			SM-ML	154.00	162.00	1.05
			SM-0	1.24	12.30	9.97
			SM-COM	65.30	68.10	1.04
4,4'-DDD	µg/kg	0	MLE	.	.	.
			SM-ML	64.10	67.70	1.06
			SM-0	0.07	5.06	77.40
4,4'-DDE	µg/kg	1	MLE	.	.	.
			SM-ML	64.50	67.70	1.05
			SM-0	0.67	9.17	13.70

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
MLE-ML = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Nondetects Set Equal to the Minimum Level.
MLE-COM = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.
SM-COM = Weighted Nonparametric Substitution Method Stratum Estimates. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.

. = Nonestimable.

Note: DDT, Composite is a combination of 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT.

TABLE 7-6. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation	Coefficient of Variation (CV)
4,4'-DDT	µg/kg	2	MLE	2.44	371.00	152.0
			SM-ML	25.90	27.10	1.05
			SM-0	0.50	4.31	8.61
PCB, Composite[a]	µg/kg	0	MLE	.	.	.
			SM-ML	2,030.00	2,070.00	1.02
			SM-0	279.00	992.00	3.56
			SM-COM	535.00	1,010.00	1.89
PCB, Composite[b]	µg/kg	19	MLE-ML	889.00	2,400.00	2.70
			MLE-COM	1,300.00	155,000.00	120.0
			SM-ML	2,030.00	2,070.00	1.02
			SM-0	279.00	992.00	3.56
			SM-COM	535.00	1,010.00	1.89
PCB-1016	µg/kg	0	MLE	.	.	.
			SM-ML	256.00	270.00	1.06
			SM-0	0.00	0.00	0.00

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
MLE-ML = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Nondetects Set Equal to the Minimum Level.
MLE-COM = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.
SM-COM = Weighted Nonparametric Substitution Method Stratum Estimates. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.

. = Nonestimable.

Note: PCB, Composite is a combination of PCB-1016, PCB-1221, PCB-1232, PCB-1242, PCB-1248, PCB-1254, and PCB-1260.

TABLE 7-6. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation	Coefficient of Variation (CV)
PCB-1221	µg/kg	0	MLE	.	.	.
			SM-ML	256.00	270.00	1.06
			SM-0	0.00	0.00	0.00
PCB-1232	µg/kg	0	MLE	.	.	.
			SM-ML	256.00	270.00	1.06
			SM-0	0.00	0.00	0.00
PCB-1242	µg/kg	0	MLE	.	.	.
			SM-ML	256.00	270.00	1.06
			SM-0	0.00	0.00	0.00
PCB-1248	µg/kg	9	MLE	75.10	965.00	12.80
			SM-ML	277.00	310.00	1.12
			SM-0	32.50	187.00	5.75
PCB-1254	µg/kg	9	MLE	26,500.00	2490000000	94000
			SM-ML	427.00	747.00	1.75
			SM-0	184.00	744.00	4.04
PCB-1260	µg/kg	10	MLE	115.00	1,710.00	14.90
			SM-ML	307.00	371.00	1.21
			SM-0	62.30	287.00	4.61

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.

. = Nonestimable.

TABLE 7-7.

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

PERCENT SOLIDS, PHOSPHORUS, AND TOTAL KJELDAHL NITROGEN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation	Coefficient of Variation (CV)
Percent Solids	%	100	MLE	30.80	126.00	4.11
			SM-ML	21.00	24.60	1.17
			SM-0	21.00	24.60	1.17
Phosphorus	mg/kg	100	MLE	7,120.00	43,100.00	6.06
			SM-ML	4,480.00	9,960.00	2.22
			SM-0	4,480.00	9,960.00	2.22
Total Kjeldahl Nitrogen	mg/kg	100	MLE	50,100.00	62,800.00	1.25
			SM-ML	42,400.00	24,700.00	0.58
			SM-0	42,400.00	24,700.00	0.58

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.

Of the 19 individual pollutants for which national pollutant-concentration estimates were produced from the NSSS data using the maximum-likelihood method, pollutants with higher detection rates tended to have the smaller coefficients of variation. One pollutant, PCB-1254, had an unrealistic estimate. Although this pollutant was detected above the minimum level about 9% of the time, it was detected at concentrations about 10 times higher than the minimum-level values in each stratum. This resulted in large MLEs of strata variances that are used to produce estimates of both the expected value of the pollutant concentration E(X) and the variance of the pollutant concentration V(X). Review of the raw data strongly suggests that, in the case of PCB-1254, the assumption that pollutant concentration is distributed lognormally is not applicable.

Estimates of the mean pollutant concentration produced using the assumption of lognormality generally were found to be lower than estimates generated when the minimum level was substituted for censored data. On the other hand, the mean pollutant concentration estimated under the assumption of lognormality was higher than estimates produced when no pollutant was assumed to be present in samples from which the pollutant was not detected above the minimum level. The exceptions to this are bis(2-ethylhexyl) phthalate, copper, PCB-1254, and zinc.

Tables 7-8, 7-9, and 7-10 present 95% confidence intervals about the estimated national pollutant-concentration means resulting from each estimation method. These estimates are provided in response to public request. A negative lower confidence limit indicates that the value zero is statistically credible for the true mean pollutant concentration. Estimates of the standard deviation of the mean of pollutant concentrations for a given pollutant reported in Tables 7-8, 7-9, and 7-10 were generated as the square root of the estimated variance of the distribution of concentration means for that pollutant. The formula used to generate the variance of the estimated mean pollutant concentrations is that presented by William G. Cochran in of his book entitled, *Sampling Techniques* (Chapter 5A.14). Notice that the reported standard deviations of the mean estimates reported in Tables 7-8, 7-9, and 7-10 are much smaller than those shown in Tables 7-5, 7-6, and 7-7, respectively. That is because the standard deviations reported in Tables 7-5, 7-6, and 7-7 estimate the standard deviation across the distribution of a pollutant's concentrations. The standard deviations reported in Tables 7-8, 7-9, and 7-10, on the other hand, estimate the standard distribution across the distribution of a pollutant's mean concentrations.

7.4.3 Lognormal and Nonparametric Pollutant-Concentration Percentile Estimates

Three sets of national concentration percentiles for the pollutants of concern are presented in this section. The first set of estimates were generated assuming that pollutant concentrations follow a lognormal distribution. Multicensored maximum-likelihood statistical techniques discussed in section 7.4.1 were used to produce estimates under this assumption. The remaining two sets of nonparametric estimates made no assumption about the parametric distribution of pollutant concentrations. The two nonparamteric estimates differed with respect to assumptions made concerning censored pollutant-concentration data. For one set of nonparametric estimates, censored data were assumed to be present at the minimum level of quantitation. For the other set of nonparametric estimates, a pollutant was considered to be absent, as denoted by a concentration value of zero, for censored samples. For all three assumptions, estimates of the median (50^{th} percentile), 90^{th}, 95^{th}, 98^{th}, and 99^{th} percentile concentrations are reported for each pollutant.

TABLE 7-8.

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

STANDARD DEVIATION AND CONFIDENCE INTERVAL FOR THE MEAN

POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation of Mean Estimate	Lower 95% Conf. Limit	Upper 95% Conf. Limit
Aldrin/Dieldrin[a]	µg/kg	0	MLE	.	.	.	.
			SM-ML	26.70	3.04	20.70	32.60
			SM-0	1.65	0.69	0.30	3.00
			SM-COM	14.40	1.61	11.30	17.60
Aldrin/Dieldrin[b]	µg/kg	8	MLE-ML	6.03	2.63	0.87	11.20
			MLE-COM	6.63	82.50	-155.14	168.00
			SM-ML	26.70	3.04	20.70	32.60
			SM-0	1.65	0.69	0.30	3.00
			SM-COM	14.40	1.61	11.30	17.60
Arsenic	mg/kg	80	MLE	9.52	2.03	5.53	13.50
			SM-ML	10.30	1.55	7.26	13.30
			SM-0	8.66	1.59	5.53	11.80
Benzene	µg/kg	0	MLE	.	.	.	.
			SM-ML	956.00	189.00	587.00	1,330.00
			SM-0	0.08	0.03	0.03	0.12

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
MLE-ML = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Nondetects Set Equal to the Minimum Level.
MLE-COM = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.
SM-COM = Weighted Nonparametric Substitution Method Stratum Estimates. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.

. = Nonestimable.

Note: Aldrin/Dieldrin is a combination of Aldrin and Dieldrin.

TABLE 7-8. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

STANDARD DEVIATION AND CONFIDENCE INTERVAL FOR THE MEAN

POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation of Mean Estimate	Lower 95% Conf. Limit	Upper 95% Conf. Limit
Benzo(A)pyrene	µg/kg	3	MLE	.	.	.	.
			SM-ML	9,620.00	1,270.00	7,120.00	12,100.00
			SM-0	76.90	31.40	15.30	138.00
Beryllium	mg/kg	22	MLE	0.38	0.04	0.30	0.46
			SM-ML	1.85	0.26	1.34	2.37
			SM-0	0.12	0.03	0.07	0.17
Bis(2-Ethylhexyl) Phthalate	µg/kg	63	MLE	73,600.00	46,400.00	-17,418.38	165,000.00
			SM-ML	54,000.00	10,300.00	33,800.00	74,100.00
			SM-0	48,600.00	10,500.00	28,100.00	69,100.00
Cadmium	mg/kg	69	MLE	8.74	1.28	6.22	11.20
			SM-ML	39.40	28.50	-16.37	95.20
			SM-0	36.00	28.50	-19.75	91.80
Cadmium°	mg/kg	69	MLE	7.18	0.78	5.65	8.71
			SM-ML	10.30	1.37	7.65	13.00
			SM-0	6.96	1.32	4.37	9.55
Chlordane	µg/kg	0	MLE	.	.	.	.
			SM-ML	321.00	38.20	246.00	396.00
			SM-0	1.76	1.71	-1.58	5.10

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.

° Estimates Generated After Deleting an Extreme Outlier Observation from Stratum 3.

. = Nonestimable.

TABLE 7-8. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

STANDARD DEVIATION AND CONFIDENCE INTERVAL FOR THE MEAN

POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation of Mean Estimate	Lower 95% Conf. Limit	Upper 95% Conf. Limit
Chromium	mg/kg	91	MLE	124.00	34.10	57.20	191.00
			SM-ML	163.00	44.00	76.80	249.00
			SM-0	160.00	44.10	73.90	247.00
Copper	mg/kg	100	MLE	724.00	110.00	509.00	940.00
			SM-ML	657.00	65.20	529.00	784.00
			SM-0	657.00	65.20	529.00	784.00
DDT, Composite[a]	µg/kg	0	MLE	.	.	.	.
			SM-ML	154.00	18.30	119.00	190.00
			SM-0	1.24	0.59	0.08	2.39
			SM-COM	65.30	7.63	50.30	80.20
DDT, Composite[b]	µg/kg	3	MLE-ML	18.60	2.74	13.30	24.00
			MLE-COM	7.22	2.28	2.75	11.70
			SM-ML	154.00	18.30	119.00	190.00
			SM-0	1.24	0.59	0.08	2.39
			SM-COM	65.30	7.63	50.30	80.20

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
MLE-ML = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Nondetects Set Equal to the Minimum Level.
MLE-COM = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.
SM-COM = Weighted Nonparametric Substitution Method Stratum Estimates. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.

. = Nonestimable.

Note: DDT, Composite is a combination of 4,4'-DDD, 4,4'-DDD, and 4,4'-DDT.

TABLE 7-8. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

STANDARD DEVIATION AND CONFIDENCE INTERVAL FOR THE MEAN

POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation of Mean Estimate	Lower 95% Conf. Limit	Upper 95% Conf. Limit
Heptachlor	µg/kg	0	MLE	.	.	.	.
			SM-ML	25.60	3.06	19.60	31.60
			SM-0	0.02	0.01	-0.01	0.04
Hexachlorobenzene	µg/kg	0	MLE	.	.	.	.
			SM-ML	9,560.00	1,270.00	7,060.00	12,100.00
			SM-0	0.00	0.00	0.00	0.00
Hexachlorobutadiene	µg/kg	0	MLE	.	.	.	.
			SM-ML	9,560.00	1,270.00	7,060.00	12,100.00
			SM-0	0.00	0.00	0.00	0.00
Lead	mg/kg	80	MLE	131.00	19.70	92.80	170.00
			SM-ML	135.00	11.50	112.00	158.00
			SM-0	109.00	12.20	84.70	132.00
Lindane (Gamma-BHC)	µg/kg	0	MLE	.	.	.	.
			SM-ML	32.20	3.82	24.80	39.70
			SM-0	0.16	0.13	-0.10	0.42
Mercury	mg/kg	64	MLE	5.30	2.03	1.31	9.28
			SM-ML	6.58	1.04	4.54	8.63
			SM-0	3.83	1.04	1.79	5.88
Molybdenum	mg/kg	53	MLE	9.63	2.03	5.64	13.60
			SM-ML	14.70	1.54	11.70	17.70
			SM-0	6.66	1.25	4.20	9.12

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.

. = Nonestimable.

TABLE 7-8. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

STANDARD DEVIATION AND CONFIDENCE INTERVAL FOR THE MEAN

POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation of Mean Estimate	Lower 95% Conf. Limit	Upper 95% Conf. Limit
N-Nitrosodimethylamine	µg/kg	0	MLE	.	.	.	.
			SM-ML	47,800.00	6,370.00	35,300.00	60,300.00
			SM-0	0.00	0.00	0.00	0.00
Nickel	mg/kg	67	MLE	46.00	12.30	21.80	70.10
			SM-ML	58.20	10.10	38.30	78.10
			SM-0	44.00	10.50	23.50	64.50
PCB, Composite[a]	µg/kg	0	MLE	.	.	.	.
			SM-ML	2,030.00	238.00	1,570.00	2,500.00
			SM-0	279.00	121.00	40.90	517.00
			SM-COM	535.00	123.00	293.00	777.00
PCB, Composite[b]	µg/kg	19	MLE-ML	889.00	299.00	304.00	1,470.00
			MLE-COM	1,300.00	19,500.00	-36,926.19	39,500.00
			SM-ML	2,030.00	238.00	1,570.00	2,500.00
			SM-0	279.00	121.00	40.90	517.00
			SM-COM	535.00	123.00	293.00	777.00

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
MLE-ML = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Nondetects Set Equal to the Minimum Level.
MLE-COM = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.
SM-COM = Weighted Nonparametric Substitution Method Stratum Estimates. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.

. = Nonestimable.

Note: PCB, Composite is a combination of PCB-1016, PCB-1221, PCB-1232, PCB-1242, PCB-1248, PCB-1254, and PCB-1260.

TABLE 7-8. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

STANDARD DEVIATION AND CONFIDENCE INTERVAL FOR THE MEAN

POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation of Mean Estimate	Lower 95% Conf. Limit	Upper 95% Conf. Limit
Selenium	mg/kg	68	MLE	5.58	0.89	3.83	7.33
			SM-ML	7.70	1.26	5.24	10.20
			SM-0	4.28	0.87	2.57	5.99
Toxaphene	µg/kg	0	MLE	.	.	.	.
			SM-ML	1,280.00	153.00	980.00	1,580.00
			SM-0	0.00	0.00	0.00	0.00
Trichloroethene	µg/kg	1	MLE	.	.	.	.
			SM-ML	968.00	189.00	599.00	1,340.00
			SM-0	17.10	12.20	-6.74	41.00
Zinc	mg/kg	100	MLE	1,220.00	151.00	925.00	1,520.00
			SM-ML	1,430.00	281.00	877.00	1,980.00
			SM-0	1,430.00	281.00	877.00	1,980.00

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.

. = Nonestimable.

TABLE 7-9.

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

STANDARD DEVIATION AND CONFIDENCE INTERVAL FOR THE MEAN

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation of Mean Estimate	Lower 95% Conf. Limit	Upper 95% Conf. Limit
Aldrin/Dieldrin[a]	µg/kg	0	MLE	.	.	.	.
			SM-ML	26.70	3.04	20.70	32.60
			SM-0	1.65	0.69	0.30	3.00
			SM-COM	14.40	1.61	11.30	17.60
Aldrin/Dieldrin[b]	µg/kg	8	MLE-ML	6.03	2.63	0.87	11.19
			MLE-COM	6.63	82.50	-155.14	168.00
			SM-ML	26.70	3.04	20.70	32.60
			SM-0	1.65	0.69	0.30	3.00
			SM-COM	14.40	1.61	11.30	17.60
Aldrin	µg/kg	3	MLE	1.93	8.98	-15.67	19.50
			SM-ML	13.10	1.53	10.10	16.10
			SM-0	0.58	0.33	-0.07	1.23
Dieldrin	µg/kg	5	MLE	.	.	.	.
			SM-ML	13.50	1.56	10.50	16.60
			SM-0	1.07	0.62	-0.14	2.28

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
MLE-ML = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Nondetects Set Equal to the Minimum Level.
MLE-COM = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.
SM-COM = Weighted Nonparametric Substitution Method Stratum Estimates. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.

. = Nonestimable.

Note: Aldrin/Dieldrin is a combination of Aldrin and Dieldrin.

TABLE 7-9. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

STANDARD DEVIATION AND CONFIDENCE INTERVAL FOR THE MEAN

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation of Mean Estimate	Lower 95% Conf. Limit	Upper 95% Conf. Limit
DDT, Composite[a]	µg/kg	0	MLE	.	.	.	.
			SM-ML	154.00	18.30	119.00	190.00
			SM-0	1.24	0.59	0.08	2.39
			SM-COM	65.30	7.63	50.30	80.20
DDT, Composite[b]	µg/kg	3	MLE-ML	18.60	2.74	13.30	24.00
			MLE-COM	7.22	2.28	2.75	11.70
			SM-ML	154.00	18.30	119.00	190.00
			SM-0	1.24	0.59	0.08	2.39
			SM-COM	65.30	7.63	50.30	80.20
4,4'-DDD	µg/kg	0	MLE	.	.	.	.
			SM-ML	64.10	7.64	49.10	79.10
			SM-0	0.06	0.04	-0.00	0.13
4,4'-DDE	µg/kg	1	MLE	.	.	.	.
			SM-ML	64.50	7.65	49.50	79.50
			SM-0	0.67	0.51	-0.33	1.68

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
MLE-ML = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Nondetects Set Equal to the Minimum Level.
MLE-COM = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.
SM-COM = Weighted Nonparametric Substitution Method Stratum Estimates. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.

. = Nonestimable.

Note: DDT, Composite is a combination of 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT.

TABLE 7-9. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

STANDARD DEVIATION AND CONFIDENCE INTERVAL FOR THE MEAN

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation of Mean Estimate	Lower 95% Conf. Limit	Upper 95% Conf. Limit
4,4'-DDT	µg/kg	2	MLE	2.44	8.92	-15.04	19.90
			SM-ML	25.90	3.05	19.90	31.80
			SM-0	0.50	0.29	-0.06	1.07
PCB, Composite[a]	µg/kg	0	MLE	.	.	.	.
			SM-ML	2,030.00	238.00	1,570.00	2,500.00
			SM-0	279.00	121.00	40.90	517.00
			SM-COM	535.00	123.00	293.00	777.00
PCB, Composite[b]	µg/kg	19	MLE-ML	889.00	299.00	304.00	1,470.00
			MLE-COM	1,300.00	19,500.00	-36,926.19	39,500.00
			SM-ML	2,030.00	238.00	1,570.00	2,500.00
			SM-0	279.00	121.00	40.90	517.00
			SM-COM	535.00	123.00	293.00	777.00
PCB-1016	µg/kg	0	MLE	.	.	.	.
			SM-ML	256.00	30.60	196.00	316.00
			SM-0	0.00	0.00	0.00	0.00

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
MLE-ML = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Nondetects Set Equal to the Minimum Level.
MLE-COM = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.
SM-COM = Weighted Nonparametric Substitution Method Stratum Estimates. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.

. = Nonestimable.

Note: PCB, Composite is a combination of PCB-1016, PCB-1221, PCB-1232, PCB-1242, PCB-1248, PCB-1254, and PCB-1260.

TABLE 7-9. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

STANDARD DEVIATION AND CONFIDENCE INTERVAL FOR THE MEAN

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation of Mean Estimate	Lower 95% Conf. Limit	Upper 95% Conf. Limit
PCB-1221	µg/kg	0	MLE	.	.	.	.
			SM-ML	256.00	30.60	196.00	316.00
			SM-0	0.00	0.00	0.00	0.00
PCB-1232	µg/kg	0	MLE	.	.	.	.
			SM-ML	256.00	30.60	196.00	316.00
			SM-0	0.00	0.00	0.00	0.00
PCB-1242	µg/kg	0	MLE	.	.	.	.
			SM-ML	256.00	30.60	196.00	316.00
			SM-0	0.00	0.00	0.00	0.00
PCB-1248	µg/kg	9	MLE	75.10	37.50	1.56	149.00
			SM-ML	277.00	31.00	216.00	338.00
			SM-0	32.50	10.10	12.80	52.30
PCB-1254	µg/kg	9	MLE	26,500.00	313,000,000.00	-613,340,972.58	613,000,000.00
			SM-ML	427.00	91.60	247.00	606.00
			SM-0	184.00	92.10	3.48	365.00
PCB-1260	µg/kg	10	MLE	115.00	209.00	-296.03	525.00
			SM-ML	307.00	43.80	221.00	393.00
			SM-0	62.30	35.10	-6.42	131.00

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.

. = Nonestimable.

TABLE 7-10.

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

STANDARD DEVIATION AND CONFIDENCE INTERVAL FOR THE MEAN

PERCENT SOLIDS, PHOSPHORUS, AND TOTAL KJELDAHL NITROGEN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Mean	Standard Deviation of Mean Estimate	Lower 95% Conf. Limit	Upper 95% Conf. Limit
Percent Solids	%	100	MLE	30.80	15.00	1.39	60.20
			SM-ML	21.00	2.74	15.60	26.40
			SM-0	21.00	2.74	15.60	26.40
Phosphorus	mg/kg	100	MLE	7,120.00	5,270.00	-3,205.14	17,400.00
			SM-ML	4,480.00	1,220.00	2,080.00	6,870.00
			SM-0	4,480.00	1,220.00	2,080.00	6,870.00
Total Kjeldahl Nitrogen	mg/kg	100	MLE	50,100.00	6,380.00	37,600.00	62,600.00
			SM-ML	42,400.00	2,710.00	37,000.00	47,700.00
			SM-0	42,400.00	2,710.00	37,000.00	47,700.00

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.

If the variable X denotes pollutant concentration, the p^{th} percentile pollutant concentration is defined as the smallest value of X such that the cumulative distribution function of X , denoted as F(X), is greater than or equal to p. That is,

p^{th} percentile = X_p where X_p is the smallest value of X such that $F(X_p) \geq p$ ie., $F^{-1}(p) = X_p$.

Percentile estimates produced under the assumption that pollutant concentrations follow a lognormal distribution were generated using the maximum-likelihood technique. A pollutant's p^{th} percentile concentration is estimated under the assumption that the pollutant follows a lognormal distribution as follows:

$$\hat{X}_p = \exp(\hat{\mu} + Z_p * \hat{\sigma})$$

where Z_p is the largest z score from the standard normal distribution such that $F(z_p) \leq p$ and the estimates μ and σ are the estimates of the mean and standard deviation, respectively, for the national distribution of the pollutant's concentrations under the assumption of lognormality. The estimated values of μ and σ are determined from national estimates of the pollutant-concentration mean E(X) and the squared value of the estimated coefficient of variation (CV.)

For the percentiles reported in this section, the value of the Z score for the median is zero, while $Z_{0.90} = 1.282$, $Z_{0.95} = 1.645$, and $Z_{0.98} = 2.055$. With the appropriate Z score value, other percentile points may be calculated using the same method described in this section.

Pollutant concentration is distributed lognormally if the natural logarithm transformation of X (ln X) is distributed normally with mean μ and variance σ^2 (ie., $\text{lx}(X) \sim N(\mu,\sigma^2)$. Under these conditions, the mean (E(X)), the variance (V(X)), and the p^{th} percentile are estimated as follows:

$$E(X) = \exp(\hat{\mu} + \frac{1}{2}\hat{\sigma}^2)$$

$$V(X) = \exp(2\hat{\mu} + \hat{\sigma}^2)(\exp(\hat{\sigma}^2 - 1)$$

$$p^{th} percentile = \exp(\hat{\mu} + Z_p \hat{\sigma}).$$

Additionally, when X is distributed lognormally, the coefficient of variation (CV) is estimated as

$$CV(X) = [\exp(\hat{\sigma}^2 - 1)]^{1/2}.$$

In order to estimate the p[th] percentile, national estimates of μ and σ are needed. The national estimate of σ^2 for a given pollutant was obtained by equating the squared value of the estimated pollutant-concentration coefficient of variation (CV) to the lognormal expression for the squared coefficient of variation and solving for σ^2, as noted below.

$$CV^2 = \exp(\sigma^2) - 1 \rightarrow \hat{\sigma}^2 = \ln(\hat{CV}^2 + 1).$$

Likewise, the estimate of μ was obtained for a pollutant by equating the estimated national pollutant-concentration mean to the lognormal expression of the mean and solving for μ.

$$\overline{X} = \exp(\mu + \frac{1}{2}\sigma^2) \rightarrow \hat{\mu} = \ln(\overline{X}) - \frac{1}{2}\hat{\sigma}^2.$$

Because the NSSS was conducted as a stratified survey, national pollutant-concentration means (E(X)), and variances (V(X)), were estimated as weighted combinations of stratum estimates. Monte Carlo simulations to assess the appropriateness of this assumption are presented in Chapter 10.

Two sets of nonparametric estimates of pollutant concentrations were generated using substitution methods. Nonparametric estimates do not require any assumptions about the distribution of pollutant concentration. Assumptions for nonparametric estimates in these analyses regard the concentration of censored pollutant-concentration data. For the first set of nonparametric estimates, if a pollutant concentration was not measured above the minimum level (i.e., the value is censored) then it was assumed that the pollutant concentration occurred at the minimum level. For the second set of estimates, it was assumed that the pollutant was absent if it was not detected above the minimum level.

Nonparametric national pollutant concentration p[th] percentile estimate (X_p) were generated as a weighted combination of nonparametric stratum estimates. The equation for estimating the national p[th] percentile concentration is given below.

$$X_p = F(X) \geq p \text{ where } F(X) = \sum_{i=1}^{4} w_i F_i(X)$$

where

$$F_i(X) = \sum_{j=1}^{n_{ij}} \frac{I(X_{ij} \leq x)}{n_{ij}}$$

and $I(X_{ij} \leq x) = 1$ if $X_{ij} \leq x$ for $x \geq 0$
$= 0$ otherwise.

Estimates of the median, 90[th], 95[th], 98[th], and 99[th] percentile for the pollutants of concern are presented in Tables 7-11, 7-12, and 7-13. For a given pollutant, the first estimate presented is designated as "MLE." This indicates that the estimate was generated under the assumption that pollutant concentration follows a lognormal distribution. The other two estimates are the nonparametric estimates. Estimates recorded in the rows "SM-ML" indicate that the minimum level was substituted for censored pollutant concentration values. The estimates in rows designated "SM-0" were produced assuming that the pollutant was absent if it was not measured above the minimum level.

Also recorded in these tables are the national estimate of percent detection. This estimate was determined as a weighted linear combination of the four stratum estimates of percent detection. Ten of the pollutants, including the composite PCBs and DDTs, are not detected at all in the NSSS. For these pollutants, "MLE" estimates are not available because all of the data were censored. Additionally, MLE percentile estimates are not available for benzo(a)pyrene, dieldrin, and trichloroethene. This is because the pollutant was not detected in sewage sludge from any of the POTWS sampled from one or more of the flow rate strata. Thus, the national estimate was considered nonestimable.

TABLE 7-11.

NATIONAL POLLUTANT CONCENTRATION PERCENTILE ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Median	90th Percentile	95th Percentile	98th Percentile	99th Percentile
Aldrin/Dieldrin[a]	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	20.30	41.70	48.60	108.00	149.00
			SM-0	0.00	0.00	13.80	24.40	30.40
			SM-COM	10.30	23.30	40.90	56.80	75.40
Aldrin/Dieldrin[b]	µg/kg	8	MLE-ML	1.43	12.60	23.30	46.70	74.00
			MLE-COM	0.01	1.21	4.37	18.50	48.20
			SM-ML	20.30	41.70	48.60	108.00	149.00
			SM-0	0.00	0.00	13.80	24.40	30.40
			SM-COM	10.30	23.30	40.90	56.80	75.40
Arsenic	mg/kg	80	MLE	4.67	21.50	33.30	54.30	75.00
			SM-ML	5.80	21.10	41.30	61.50	61.60
			SM-0	4.38	19.50	41.30	60.40	61.60
Benzene	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	357.00	2,080.00	3,130.00	5,020.00	7,040.00
			SM-0	0.00	0.00	0.00	0.00	0.00
Benzo(A)pyrene	µg/kg	3	MLE	.	.	.	.	.
			SM-ML	4,700.00	28,600.00	32,900.00	42,800.00	43,300.00
			SM-0	0.00	0.00	0.00	750.00	965.00
Beryllium	mg/kg	22	MLE	0.27	0.79	1.07	1.52	1.92
			SM-ML	0.90	5.00	8.00	8.34	8.56
			SM-0	0.00	0.50	0.60	0.98	1.13

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
MLE-ML = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Nondetects Set Equal to the Minimum Level.
MLE-COM = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.
SM-COM = Weighted Nonparametric Substitution Method Stratum Estimates. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.

. = Nonestimable.

Note: Aldrin/Dieldrin is a combination of Aldrin and Dieldrin.

TABLE 7-11. (Continued)

NATIONAL POLLUTANT CONCENTRATION PERCENTILE ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Median	90th Percentile	95th Percentile	98th Percentile	99th Percentile
Bis(2-Ethylhexyl) Phthalate	µg/kg	63	MLE	11,400.00	135,000.00	273,000.00	603,000.00	1,020,000.00
			SM-ML	17,000.00	131,000.00	191,000.00	426,000.00	516,000.00
			SM-0	5,020.00	131,000.00	191,000.00	426,000.00	516,000.00
Cadmium	mg/kg	69	MLE	3.25	19.70	32.80	58.40	85.50
			SM-ML	6.50	19.90	21.50	41.70	153.00
			SM-0	3.60	9.39	17.00	25.30	153.00
Cadmium[c]	mg/kg	69	MLE	3.52	16.20	25.10	40.90	56.50
			SM-ML	6.50	19.00	21.30	25.30	87.70
			SM-0	3.60	9.35	16.70	24.40	87.70
Chlordane	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	241.00	505.00	568.00	1,360.00	1,860.00
			SM-0	0.00	0.00	0.00	0.00	0.00
Chromium	mg/kg	91	MLE	43.90	278.00	470.00	848.00	1,250.00
			SM-ML	40.10	273.00	930.00	1,980.00	2,040.00
			SM-0	38.10	273.00	930.00	1,980.00	2,040.00
Copper	mg/kg	100	MLE	451.00	1,570.00	2,240.00	3,330.00	4,330.00
			SM-ML	466.00	1,200.00	1,940.00	2,400.00	2,970.00
			SM-0	466.00	1,200.00	1,940.00	2,400.00	2,970.00
DDT, Composite[a]	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	118.00	241.00	274.00	651.00	893.00
			SM-0	0.00	0.00	0.00	12.30	27.90
			SM-COM	49.30	103.00	135.00	273.00	374.00
DDT, Composite[b]	µg/kg	3	MLE	9.57	41.90	63.90	102.00	140.00
			MLE	1.17	13.50	27.00	59.00	98.90
			SM-ML	118.00	241.00	274.00	651.00	893.00
			SM-0	0.00	0.00	0.00	12.30	27.90
			SM-COM	49.30	103.00	135.00	273.00	374.00

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.

[c] Estimates Generated After Deleting an Extreme Outlier Observation from Stratum 3.

. = Nonestimable.

TABLE 7-11. (Continued)

NATIONAL POLLUTANT CONCENTRATION PERCENTILE ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Median	90th Percentile	95th Percentile	98th Percentile	99th Percentile
Heptachlor	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	19.50	39.90	45.70	109.00	149.00
			SM-0	0.00	0.00	0.00	0.00	0.00
Hexachlorobenzene	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	4,570.00	28,600.00	32,900.00	42,800.00	43,300.00
			SM-0	0.00	0.00	0.00	0.00	0.00
Hexachlorobutadiene	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	4,570.00	28,600.00	32,900.00	42,800.00	43,300.00
			SM-0	0.00	0.00	0.00	0.00	0.00
Lead	mg/kg	80	MLE	77.70	289.00	419.00	639.00	843.00
			SM-ML	106.00	236.00	375.00	530.00	541.00
			SM-0	75.90	236.00	310.00	528.00	541.00
Lindane (Gamma-BHC)	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	24.40	52.00	57.00	136.00	186.00
			SM-0	0.00	0.00	0.00	0.00	0.00
Mercury	mg/kg	64	MLE	1.64	11.60	20.40	38.10	57.80
			SM-ML	4.30	12.80	16.80	42.80	44.80
			SM-0	1.70	6.39	8.54	40.20	44.80

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
MLE-ML = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Nondetects Set Equal to the Minimum Level.
MLE-COM = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.
SM-COM = Weighted Nonparametric Substitution Method Stratum Estimates. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.

. = Nonestimable.

Note: DDT, Composite is a combination of 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT.

TABLE 7-11. (Continued)

NATIONAL POLLUTANT CONCENTRATION PERCENTILE ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Median	90th Percentile	95th Percentile	98th Percentile	99th Percentile
Molybdenum	mg/kg	53	MLE	4.72	21.80	33.70	54.90	75.90
			SM-ML	11.20	34.80	42.50	56.40	59.40
			SM-0	2.26	14.10	29.40	55.30	58.30
N-Nitrosodimethylamine	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	22,800.00	143,000.00	164,000.00	214,000.00	217,000.00
			SM-0	0.00	0.00	0.00	0.00	0.00
Nickel	mg/kg	67	MLE	18.70	104.00	170.00	294.00	423.00
			SM-ML	29.20	110.00	209.00	438.00	460.00
			SM-0	14.60	107.00	180.00	438.00	460.00
PCB, Composite[a]	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	1,480.00	3,050.00	5,430.00	8,270.00	10,070.00
			SM-0	0.00	681.00	1,320.00	2,510.00	5,870.00
			SM-COM	220.00	1,250.00	1,700.00	2,860.00	6,050.00
PCB, Composite[b]	µg/kg	19	MLE	309.00	1,990.00	3,380.00	6,130.00	9,100.00
			MLE	10.80	568.00	1,760.00	6,240.00	14,400.00
			SM-ML	1,480.00	3,050.00	5,430.00	8,270.00	10,700.00
			SM-0	0.00	681.00	1,320.00	2,510.00	5,870.00
			SM-COM	220.00	1,250.00	1,700.00	2,860.00	6,050.00
Selenium	mg/kg	68	MLE	3.23	12.30	18.00	27.70	36.80
			SM-ML	4.80	12.50	26.00	50.40	56.30
			SM-0	3.50	6.80	9.43	28.60	41.40
Toxaphene	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	962.00	2,000.00	2,270.00	5,420.00	7,440.00
			SM-0	0.00	0.00	0.00	0.00	0.00

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.

. = Nonestimable.

TABLE 7-11. (Continued)

NATIONAL POLLUTANT CONCENTRATION PERCENTILE ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Median	90th Percentile	95th Percentile	98th Percentile	99th Percentile
Trichloroethene	µg/kg	1	MLE	.	.	.	.	.
			SM-ML	357.00	2,080.00	3,130.00	5,020.00	7,040.00
			SM-0	0.00	0.00	0.00	0.00	41.20
Zinc	mg/kg	100	MLE	746.00	2,660.00	3,820.00	5,730.00	7,500.00
			SM-ML	706.00	2,370.00	4,120.00	4,790.00	5,990.00
			SM-0	706.00	2,370.00	4,120.00	4,790.00	5,990.00

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.

. = Nonestimable.

TABLE 7-12.

NATIONAL POLLUTANT CONCENTRATION PERCENTILE ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Median	90th Percentile	95th Percentile	98th Percentile	99th Percentile
Aldrin/Dieldrin[a]	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	20.30	41.70	48.60	108.00	149.00
			SM-0	0.00	0.00	13.80	24.40	30.40
			SM-COM	10.30	23.30	40.90	56.80	75.40
Aldrin/Dieldrin[b]	µg/kg	0	MLE	.	.	.	.	.
			MLE-COM	0.01	1.21	4.37	18.50	48.20
			SM-ML	20.30	41.70	48.60	108.00	149.00
			SM-0	0.00	0.00	13.80	24.40	30.40
			SM-COM	10.30	23.30	40.90	56.80	75.40
Aldrin	µg/kg	3	MLE	0.01	0.74	2.35	8.61	20.30
			SM-ML	10.00	20.80	24.00	57.50	87.00
			SM-0	0.00	0.00	0.00	17.20	18.50
Dieldrin	µg/kg	5	MLE	.	.	.	.	.
			SM-ML	10.20	20.80	33.40	57.50	87.00
			SM-0	0.00	0.00	0.00	24.60	33.20

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
MLE-ML = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Nondetects Set Equal to the Minimum Level.
MLE-COM = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.
SM-COM = Weighted Nonparametric Substitution Method Stratum Estimates. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.

. = Nonestimable.

Note: Aldrin/Dieldrin is a combination of Aldrin and Dieldrin.

TABLE 7-12. (Continued)

NATIONAL POLLUTANT CONCENTRATION PERCENTILE ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Median	90th Percentile	95th Percentile	98th Percentile	99th Percentile
DDT, Composite(1)	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	118.00	241.00	274.00	651.11	893.00
			SM-0	0.00	0.00	0.00	12.30	12.30
			SM-COM	49.30	103.00	135.00	273.00	374.00
DDT, Composite(2)*	µg/kg	3	MLE-ML	9.57	41.90	63.90	102.00	140.00
			MLE-COM	1.17	13.50	27.00	59.00	98.90
			SM-ML	118.00	241.00	274.00	651.00	893.00
			SM-0	0.00	0.00	0.00	12.30	27.90
			SM-COM	49.30	103.00	135.00	273.00	374.00
4,4'-DDD	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	48.10	100.00	114.00	395.00	419.00
			SM-0	0.00	0.00	0.00	0.00	0.00
4,4'-DDE	µg/kg	1	MLE	.	.	.	.	.
			SM-ML	49.20	102.00	123.00	271.00	372.00
			SM-0	0.00	0.00	0.00	0.00	0.00
4,4'-DDT	µg/kg	2	MLE	0.02	0.93	2.94	10.80	25.50
			SM-ML	19.70	41.50	46.30	126.00	155.00
			SM-0	0.00	0.00	0.00	8.39	13.20
PCB, Composite[a]	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	1,480.00	3,050.00	5,430.00	8,270.00	10,700.00
			SM-0	0.00	681.00	1,320.00	2,510.00	5,870.00
			SM-COM	220.00	1,250.00	1,700.00	2,860.00	6,050.00

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
MLE-ML = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Nondetects Set Equal to the Minimum Level.
MLE-COM = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.
SM-COM = Weighted Nonparametric Substitution Method Stratum Estimates. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.

. = Nonestimable.

Note: DDT, Composite is a combination of 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT.

TABLE 7-12. (Continued)

NATIONAL POLLUTANT CONCENTRATION PERCENTILE ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Median	90th Percentile	95th Percentile	98th Percentile	99th Percentile
PCB, Composite[b]	µg/kg	0	MLE	.	.	.	.	.
			MLE-COM	10.80	568.00	1,760.00	6,240.00	14,400.00
			SM-ML	1,480.00	3,050.00	5,430.00	8,270.00	10,700.00
			SM-0	0.00	681.00	1,320.00	2,510.00	5,870.00
			SM-COM	220.00	1,250.00	1,700.00	2,860.00	6,050.00
PCB-1016	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	192.00	401.00	454.00	1,080.00	1,490.00
			SM-0	0.00	0.00	0.00	0.00	0.00
PCB-1221	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	192.00	401.00	454.00	1,080.00	1,490.00
			SM-0	0.00	0.00	0.00	0.00	0.00
PCB-1232	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	192.00	401.00	454.00	1,080.00	1,490.00
			SM-0	0.00	0.00	0.00	0.00	0.00
PCB-1242	µg/kg	0	MLE	.	.	.	.	.
			SM-ML	192.00	401.00	454.00	1,080.00	1,490.00
			SM-0	0.00	0.00	0.00	0.00	0.00

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
MLE-ML = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Nondetects Set Equal to the Minimum Level.
MLE-COM = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.
SM-COM = Weighted Nonparametric Substitution Method Stratum Estimates. Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

[a] Composite Pollutant Considered a Detect if All Individual Pollutants are Measured Above the Minimum Level.
[b] Composite Pollutant Considered a Detect if at Least One Individual Pollutant is Measured Above the Minimum Level.

. = Nonestimable.

Note: PCB, Composite is a combination of PCB-1016, PCB-1221, PCB-1232, PCB-1242, PCB-1248, PCB-1254, and PCB-1260.

TABLE 7-12. (Continued)

NATIONAL POLLUTANT CONCENTRATION PERCENTILE ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Median	90th Percentile	95th Percentile	98th Percentile	99th Percentile
PCB-1248	µg/kg	9	MLE	5.83	105.00	240.00	607.00	1,120.00
			SM-ML	209.00	428.00	673.00	1,510.00	1,660.00
			SM-0	0.00	0.00	231.00	354.00	598.00
PCB-1254	µg/kg	9	MLE	0.28	129.00	740.00	5,260.00	19,200.00
			SM-ML	209.00	859.00	1,580.00	2,530.00	3,580.00
			SM-0	0.00	0.00	1,250.00	2,460.00	3,530.00
PCB-1260	µg/kg	10	MLE	7.68	151.00	352.00	913.00	1,710.00
			SM-ML	209.00	462.00	828.00	1,910.00	2,110.00
			SM-0	0.00	0.00	493.00	654.00	1,350.00

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.

. = Nonestimable.

TABLE 7-13.

NATIONAL POLLUTANT CONCENTRATION PERCENTILE ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY USING LOGNORMAL AND NONPARAMETRIC SUBSTITUTION METHOD ESTIMATION PROCEDURES

PERCENT SOLIDS, PHOSPHORUS, AND TOTAL KJELDAHL NITROGEN

Pollutant	Unit	Percent Detect	Estimation Procedure*	Median	90th Percentile	95th Percentile	98th Percentile	99th Percentile
Percent Solids	%	100	MLE	7.28	64.00	119.00	239.00	378.00
			SM-ML	10.70	63.20	71.10	87.00	96.90
			SM-0	10.70	63.20	71.10	87.00	96.90
Phosphorus	mg/kg	100	MLE	1,160.00	13,300.00	26,600.00	58,100.00	97,400.00
			SM-ML	1,250.00	9,900.00	12,400.00	18,200.00	43,800.00
			SM-0	1,250.00	9,900.00	12,400.00	18,200.00	43,800.00
Total Kjeldahl Nitrogen	mg/kg	100	MLE	31,300.00	108,000.00	155,000.00	230,000.00	299,000.00
			SM-ML	40,600.00	74,200.00	83,600.00	94,300.00	97,900.00
			SM-0	40,600.00	74,200.00	83,600.00	94,300.00	97,900.00

* MLE = Weighted Functions of Stratum Multiple Censor Point MLEs. Lognormality Assumed.
SM-ML = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to the Minimum Level.
SM-0 = Weighted Nonparametric Substitution Method Stratum Estimates. Nondetects Set Equal to Zero.

A percentile estimate, denoted as "SM-COM" is included for the composite estimates of aldrin/dieldrin PCB and DDT. For the composite pollutant-concentration estimates, the maximum of all minimum-level values for all compounds in a sample's composite was retained. The remaining minimum-level values for the sample were set to zero. For a sample, these values then were summed across all compounds in the composite to produce the data point that was used to estimate "SM-COM."

Graphical presentations of cumulative distribution functions estimated under the assumption of lognormality and using the two nonparametric substitution procedures can be found in Figures 7-73 through 7-110, located at the end of this chapter. Plotted concentration values do not necessarily represent observed data points. Rather, they represent incremental pollutant concentration values that were chosen to span the full range of data for a pollutant. Therefore, plotted on the horizontal axis is the probability that pollutant concentration in sewage sludge is at most the corresponding concentration plotted on the vertical axis. That is,

$$\textit{fraction of POTWs less than concentration} = F_X(c) = P[X \leq c]$$

where X is the pollutant-concentration random variable and c is the pollutant concentration value plotted on the vertical axis.

The estimated lognormal cumulative distribution functions used to determine the fraction of POTWs with sewage sludge containing at most the concentration "c" of a pollutant assume that the concentration of a pollutant follows a national lognormal distribution. That is, it was assumed that the cumulative distribution function for a given pollutant could be expressed as

$$F_X(c) = \int_0^c \frac{1}{x\sqrt{2\pi\hat{\sigma}^2}} \exp\left\{-\frac{1}{2}\left(\frac{\ln x-\hat{\mu}}{\hat{\sigma}}\right)^2\right\} \partial x.$$

The nonparametric cumulative distributions were estimated for each substitution method as weighted linear combinations of the stratum cumulative distribution functions. That is,

$$\textit{fraction of POTWs less than concentration} = F_X(c) = \sum_{i=1}^{4} w_i F_{X_i}(c)$$

where

$$F_{X_i}(c) = \sum_{j=1}^{n_i} \frac{I(X_{ij} \leq c)}{n_i}.$$

The cumulative distribution plots clearly illustrate how the estimation method influences conclusions. For example, observe the cumulative distribution functions for beryllium in Figure 7-77. The national detection rate for this metal was 22%. When the minimum level is substituted for observations that are censored, the cumulative distribution defined by the triangle symbol indicates that approximately 53% of secondary treatment POTWs would dispose of sewage sludge containing at most 1 milligram per kilogram (mg/kg) of beryllium. On the other hand, the cumulative distribution function estimated under the multicensored lognormal assumption suggests that 93% of the POTWs dispose of sewage sludge containing at most 1 mg/kg of beryllium—this is determined from the plot defined by the symbol "x." Finally, when it is assumed that samples contained no pollutant if the pollutant was not measured above the minimum level, then the graph depicted by the symbol "o" suggests that 99% of secondary treatment POTWs in the Nation dispose of sewage sludge that contains at most 1 mg/kg of beryllium.

7.5 DISTRIBUTIONAL ESTIMATES OF POLLUTANT CONCENTRATION BY AMOUNT OF SEWAGE SLUDGE

National pollutant-concentration estimates, weighted by amount of sewage sludge disposed, are presented in Tables 7-14, 7-15, and 7-16 (presented at the end of this chapter). For each pollutant, the national mean pollutant concentration estimate is presented along with the standard deviation and 95% confidence interval about the mean.

Two substitution methods were used for pollutant-concentration samples measured below the minimum detection level. The first, SM-ML, sets the pollutant concentration for nondetects equal to the minimum detection level. The second, SM-0, sets the pollutant concentration for nondetects to zero. For the composite pollutants, a third substitution method is used, SM-COM. In this case, for each sample, the highest minimum detection level among the nondetected samples is determined from the individual pollutants. This value is substituted for the maximum nondetect, and the other nondetects are set equal to zero. For example, suppose, for a given sample, DDT is measured at 15 μg/kg, and DDD and DDE are not measured above the respective detection limits of 5 μg/kg and 10 μg/kg. The highest minimum detection level among these nondetects is 10 μg/kg, for DDE. This value is retained and the concentration for DDD is set equal to zero. Therefore, the values comprising the DDT composite pollutant are 15, 0, and 10 μg/kg. The DDT composite pollutant concentration for this sample would then be 25 μg/kg.

The dry weight of sewage sludge disposed by each POTW in 1988 was determined from the responses in the NSSS questionnaire. For each POTW in the analytical survey, the dry weight disposed by each disposal practice was summed together to produce a total dry weight of sewage sludge, in U.S. tons, disposed by each POTW. The dry weights, by regulatory analytical use (RA) or disposal practice for each POTW in the NSSS, are listed in Part A2 of the appendix. Because the quantity of sewage sludge disposed in 1988, did not pass certain data integrity assessment criteria for 27 POTWs, the quantity of sewage sludge disposed was imputed. These POTWs are identified in Chapter 9.

Estimates are presented for each of the applicable substitution methods. For some pollutants, the variance under method SM-0 cannot be calculated because, within at least one stratum, there are no concentration values above the minimum detection level. The resulting set of zero values precludes the calculation of

Pearson's product-moment estimate of correlation between the pollutant concentration and dry weight of sewage sludge. These correlations are presented in Tables 7-17, 7-18, and 7-19 (presented at the end of this chapter). A total of 291 tests of hypothesis were conducted. To control the Type I statistical error rate to a level of $\alpha = 0.05$ across all tasks, the null hypothesis of independence between pollutant concentration and the mass of dry weight of sewage sludge disposed was rejected for individual tests if the attained significance value (p-value) was 0.0001. Notice that the dry weight amount of sewage sludge disposed and pollutant concentration were statistically correlated for chromium in stratum 3 ($1 < \text{FLOW} \leq 10$ MGD) for both substitution methods for those samples not quantified above the minimum level. This number of statistically significant tests out of the 291 tests is insignificant.

For each of the pollutants of concern, each POTW has a single dry weight concentration value (X_{ij}) and a dry weight of sewage sludge disposed (Y_{ij}). In order to weight the pollutant concentrations by the amount of sewage sludge disposed, the concentration is multiplied by the sewage sludge dry weight to produce a "concentration*dry weight" value (Z_{ij}) for each POTW.

The estimate of the weighted pollutant-concentration mean is a ratio estimator of the estimated national "concentration*dry weight" mean over the estimated national sewage sludge dry weight mean. The formula for the estimated mean ($\hat{R}$) is

$$\hat{R} = \frac{\sum_{i=1}^{4} \hat{N}_i \cdot \overline{Z}_i}{\sum_{i=1}^{4} \hat{N}_i \cdot \overline{Y}_i}$$

where

X_{ij} = *dry weight pollutant concentration from the* j^{th} *POTW in stratum* i

Y_{ij} = *dry weight of sewage sludge disposed in* 1988 *by the* j^{th} *POTW in stratum* i

$Z_{ij} = X_{ij} \cdot Y_{ij}$

$\overline{Y}_i$ = *mean dry weight of sewage sludge disposed in* 1988 *in stratum* i

$\overline{Z}_i$ = *mean concentration*dry weight in stratum* i

$\hat{N}_i$ = *adjusted number of POTWs in the Nation in stratum* i.

The national estimate for the variance of this ratio estimator is

$$\hat{\sigma}_r^2 = \frac{1}{\hat{N}^2} \cdot \frac{1}{\overline{Y}^2} \sum_{i=1}^{4} (\hat{N}_i)^2 \cdot (1 - f_i) \cdot \frac{n_i}{(n_{ij})^2} \cdot \hat{s}_i^2$$

where

$\hat{N}_i$ = *adjusted number of POTWs in the Nation in stratum i*

$\hat{N}$ = *adjusted total number of POTWs in the Nation* (8,497)

n_i = *number of POTWs selected for the analytic survey in stratum i*

N_i = *number of POTWs in stratum i*

$$f_i = \frac{n_i}{N_i}$$

n_{ij} = *number of POTWs in stratum i using or disposing sewage sludge in* 1988

$$\overline{Y} = \frac{\sum_{i=1}^{4} \hat{N}_i \cdot \overline{Y}_i}{\hat{N}}.$$

The estimated stratum variance ($\hat{s}_i^2$) is calculated from the following formula:

$$\hat{s}_i^2 = s_{iX}^2 + R^2 \cdot s_{iY}^2 - 2 \cdot R \cdot \rho_{iXY} \cdot s_{iX} \cdot s_{iY}$$

where

$$s_{iX}^2 = \frac{\sum_{j=1}^{n_i} (X_{ij} - \overline{X}_i)^2}{n_{ij} - 1}$$

$$s_{iY}^2 = \frac{\sum_{j=1}^{n_i} (Y_{ij} - \overline{Y}_i)^2}{n_{ij} - 1}$$

ρ_{iXY} = *Pearson's product-moment correlation between X and Y in stratum i.*

The 95% confidence interval about the estimated mean is calculated as

$$95\%\ C.I. = \hat{R} \pm 1.96 \cdot \hat{\sigma}_r.$$

Empirical estimates of the median, 90th, 95th, and 98th percentile pollutant concentrations on a sewage sludge mass basis are presented in Tables 7-20, 7-21, and 7-22 (presented at the end of this chapter). Estimates are reported for each of the two substitution methods. For the estimated reported as SM-ML, the minimum-level value was substituted for those POTWs from which a pollutant was not quantified above the minimum level. The value zero was reported for those POTWs with a pollutant concentration not quantified above the minimum level for those estimates reported as SM-O.

For a given pollutant, sewage sludge mass-based percentile estimates were determined first by ordering POTW sewage sludge data from the smallest to the largest value of observed concentration values for a pollutant. The amount of sewage sludge disposed by each POTW then was multipled by its survey weight to estimate the amount of sewage sludge disposed in the Nation. The cumulative percent of sewage sludge disposed then was estimated for the j^{th} POTW by summing the weighted amounts of sewage sludge disposed by the $i=1$ through j^{th} ordered POTWs, and dividing this cumulative quantity by the total mass of sewage sludge disposed in the Nation. Concentration percentile estimates then were determined to be the pollutant concentration associated with the POTW that corresponded to the pth percentile of the cumulative mass of sewage sludge disposed.

7.6 SUMMARY COMMENTS CONCERNING STATISTICAL METHODS AND RESULTING ESTIMATES OF POLLUTANT CONCENTRATION FROM THE NSSS

The multicensored, maximum-likelihood estimation (MLE) procedure used to estimate pollutant concentrations under the assumption that pollutant concentrations follow a lognormal distribution was selected, as discussed in Section 7.2, because it is the most robust technique available for estimating the upper percentiles for the distribution. For those pollutants with low rates of censoring, particularly the metallic pollutants, this method works particularly well, as illustrated in the graphical presentations of the estimated cumulative distribution functions for each pollutant.

However, for those pollutants for which the rate of detection is either low or zero, MLE estimates are either unreliable or nonestimable. In the case where detection rates are low, such as PCB-1254, the data suggest it may not be valid to assume that pollutant concentrations follow a lognormal distribution. For these pollutants, the nonparametric method of estimating pollutant concentrations, which substitutes the sample-specific, minimum-level value for those samples from which a pollutant is not detected above the minimum level, is consistent with a conservative estimate of risk.

The statistical methods used to estimate pollutant concentrations in the presence of the multiple censoring points with the objective of producing the most statistically robust estimates were presented to the public for comment in the technical support document for the NSSS Notice of Availability. In general, comments from the public were favorable. In other cases, commentors referenced statistical techniques presented by Dennis Helsel in his article entitled, "Less than Obvious: Statistical Treatment of Data Below the Detection Limit"(p. 1766-1771). The methods presented by Dr. Helsel in this article were the methods considered by the Agency and discussed in Section 7.2. Other commentors responded with alternative statistical methods requiring the empirical measurement for those samples not quantified above the minimum level of detection. Unfortunately, these measurements were not available for the NSSS.

TABLE 7-14.

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
WEIGHTED BY AMOUNT OF SEWAGE SLUDGE DISPOSED

STANDARD DEVIATIONS AND CONFIDENCE INTERVALS FOR THE MEAN

POLLUTANTS OF CONCERN

Pollutant	Unit	Substitution Method*	Mean	Standard Deviation	Lower 95% Conf. Limit	Upper 95% Conf. Limit
Aldrin/Dieldrin	µg/kg	SM-ML	19.90	1.78	16.40	23.40
		SM-0	0.76	0.07	0.63	0.90
		SM-COM	10.50	0.94	8.63	12.30
Arsenic	mg/kg	SM-ML	11.00	0.99	9.04	12.90
		SM-0	8.88	0.80	7.32	10.50
Benzene	µg/kg	SM-ML	842.00	75.80	694.00	991.00
		SM-0	1.61	.	.	.
Benzo(A)Pyrene	µg/kg	SM-ML	13,800.00	1,250.00	11,400.00	16,300.00
		SM-0	21.50	.	.	.
Beryllium	mg/kg	SM-ML	0.99	0.09	0.81	1.16
		SM-0	0.16	0.02	0.14	0.19
Bis(2-Ethylhexyl)Phthalate	µg/kg	SM-ML	110000.00	9,890.00	90,500.00	129,000.00
		SM-0	107000.00	9,610.00	88,000.00	126,000.00
Cadmium	mg/kg	SM-ML	38.70	3.49	31.90	45.60
		SM-0	38.10	3.43	31.40	44.80
Cadmium•	mg/kg	SM-ML	38.10	3.41	31.40	44.80
		SM-0	37.50	3.35	30.90	44.00

* SM-ML = Nondetects Set Equal to the Minimum Level.
SM-0 = Nondetects Set Equal to Zero.
SM-COM = Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

• Estimates Generated After Deleting an Extreme Outlier Observation From Stratum 3.

. = Nonestimable.

Note: Aldrin/Dieldrin is a combination of Aldrin and Dieldrin.

TABLE 7-14. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
WEIGHTED BY AMOUNT OF SEWAGE SLUDGE DISPOSED

STANDARD DEVIATIONS AND CONFIDENCE INTERVALS FOR THE MEAN

POLLUTANTS OF CONCERN

Pollutant	Unit	Substitution Method*	Mean	Standard Deviation	Lower 95% Conf. Limit	Upper 95% Conf. Limit
Chlordane	µg/kg	SM-ML	243.00	21.70	200.00	285.00
		SM-0	0.00	.	.	.
Chromium	mg/kg	SM-ML	589.00	53.00	485.00	693.00
		SM-0	588.00	52.90	485.00	692.00
Copper	mg/kg	SM-ML	639.00	57.50	526.00	752.00
		SM-0	639.00	57.50	526.00	752.00
DDT, Composite	µg/kg	SM-ML	120.00	10.80	99.00	141.00
		SM-0	4.81	0.43	3.97	5.66
		SM-COM	53.20	4.76	43.80	62.50
Heptachlor	µg/kg	SM-ML	19.40	1.74	16.00	22.80
		SM-0	0.04	.	.	.
Hexachlorobenzene	µg/kg	SM-ML	13,800.00	1,240.00	11,400.00	16,300.00
		SM-0	0.00	.	.	.
Hexachlorobutadiene	µg/kg	SM-ML	13,800.00	1,240.00	11,400.00	16,300.00
		SM-0	0.00	.	.	.
Lead	mg/kg	SM-ML	204.00	18.40	168.00	240.00
		SM-0	200.00	18.00	164.00	235.00

* SM-ML = Nondetects Set Equal to the Minimum Level.
SM-0 = Nondetects Set Equal to Zero.
SM-COM = Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

. = Nonestimable.

Note: DDT, Composite is a combination of 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT.

TABLE 7-14. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
WEIGHTED BY AMOUNT OF SEWAGE SLUDGE DISPOSED

STANDARD DEVIATIONS AND CONFIDENCE INTERVALS FOR THE MEAN

POLLUTANTS OF CONCERN

Pollutant	Unit	Substitution Method*	Mean	Standard Deviation	Lower 95% Conf. Limit	Upper 95% Conf. Limit
Lindane	µg/kg	SM-ML	24.60	2.20	20.30	28.90
		SM-0	0.26	.	.	.
Mercury	mg/kg	SM-ML	3.24	0.29	2.66	3.81
		SM-0	2.62	0.24	2.16	3.08
Molybdenum	mg/kg	SM-ML	11.10	1.00	9.12	13.00
		SM-0	8.20	0.74	6.75	9.64
N-Nitrosodimethylamine	µg/kg	SM-ML	69,100.00	6,220.00	56,900.00	81,300.00
		SM-0	0.00	.	.	.
Nickel	mg/kg	SM-ML	90.60	8.16	74.70	107.00
		SM-0	87.40	7.86	72.00	103.00
PCB, Composite	µg/kg	SM-ML	1,530.00	137.00	1,260.00	1,800.00
		SM-0	197.00	17.70	163.00	232.00
		SM-COM	392.00	35.10	323.00	460.00
Selenium	mg/kg	SM-ML	6.14	0.55	5.06	7.22
		SM-0	3.45	0.31	2.84	4.06
Toxaphene	µg/kg	SM-ML	971.00	87.00	801.00	1,140.00
		SM-0	0.00	.	.	.

* SM-ML = Nondetects Set Equal to the Minimum Level.
SM-0 = Nondetects Set Equal to Zero.
SM-COM = Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

. = Nonestimable.

Note: PCB, Composite is a combination of PCB-1016, PCB-1221, PCB-1232, PCB-1242, PCB-1248, PCB-1254, and PCB-1260.

TABLE 7-14. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
WEIGHTED BY AMOUNT OF SEWAGE SLUDGE DISPOSED

STANDARD DEVIATIONS AND CONFIDENCE INTERVALS FOR THE MEAN

POLLUTANTS OF CONCERN

Pollutant	Unit	Substitution Method*	Mean	Standard Deviation	Lower 95% Conf. Limit	Upper 95% Conf. Limit
Trichloroethene	µg/kg	SM-ML	858.00	77.20	707.00	1,010.00
		SM-0	20.90	.	.	.
Zinc	mg/kg	SM-ML	1,490.00	134.00	1,230.00	1,750.00
		SM-0	1,490.00	134.00	1,230.00	1,750.00

* SM-ML = Nondetects Set Equal to the Minimum Level.
SM-0 = Nondetects Set Equal to Zero.

. = Nonestimable.

TABLE 7-15.

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
WEIGHTED BY AMOUNT OF SEWAGE SLUDGE DISPOSED

STANDARD DEVIATIONS AND CONFIDENCE INTERVALS FOR THE MEAN

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Substitution Method*	Mean	Standard Deviation	Lower 95% Conf. Limit	Upper 95% Conf. Limit
Aldrin/Dieldrin	µg/kg	SM-ML	19.90	1.78	16.40	23.40
		SM-0	0.76	0.07	0.63	0.90
		SM-COM	10.50	0.94	8.63	12.30
Aldrin	µg/kg	SM-ML	10.10	0.91	8.35	11.90
		SM-0	0.63	0.06	0.52	0.74
Dieldrin	µg/kg	SM-ML	9.78	0.88	8.07	11.50
		SM-0	0.13	.	.	.
DDT, Composite	µg/kg	SM-ML	120.00	10.80	99.00	141.00
		SM-0	4.81	0.43	3.97	5.66
		SM-COM	53.20	4.76	43.80	62.50
4,4'-DDD	µg/kg	SM-ML	50.40	4.52	41.60	59.30
		SM-0	2.16	.	.	.
4,4'-DDE	µg/kg	SM-ML	49.70	4.45	40.90	58.40
		SM-0	1.67	.	.	.
4,4'-DDT	µg/kg	SM-ML	20.00	1.79	16.50	23.50
		SM-0	0.98	0.09	0.81	1.15

* SM-ML = Nondetects Set Equal to the Minimum Level.
SM-0 = Nondetects Set Equal to Zero.
SM-COM = Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

. = Nonestimable.

Note: Aldrin/Dieldrin is a combination of Aldrin and Dieldrin.
DDT, Composite is a combination of 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT.

TABLE 7-15. (Continued)

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY
WEIGHTED BY AMOUNT OF SEWAGE SLUDGE DISPOSED

STANDARD DEVIATIONS AND CONFIDENCE INTERVALS FOR THE MEAN

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Substitution Method*	Mean	Standard Deviation	Lower 95% Conf. Limit	Upper 95% Conf. Limit
PCB, Composite	µg/kg	SM-ML	1,530.00	137.00	1,260.00	1,800.00
		SM-0	197.00	17.70	163.00	232.00
		SM-COM	392.00	35.10	323.00	460.00
PCB-1016	µg/kg	SM-ML	194.00	17.40	160.00	228.00
		SM-0	0.00	.	.	.
PCB-1221	µg/kg	SM-ML	194.00	17.40	160.00	228.00
		SM-0	0.00	.	.	.
PCB-1232	µg/kg	SM-ML	194.00	17.40	160.00	228.00
		SM-0	0.00	.	.	.
PCB-1242	µg/kg	SM-ML	194.00	17.40	160.00	228.00
		SM-0	0.00	.	.	.
PCB-1248	µg/kg	SM-ML	223.00	19.90	183.00	262.00
		SM-0	39.80	3.57	32.90	46.80
PCB-1254	µg/kg	SM-ML	317.00	28.40	261.00	372.00
		SM-0	132.00	11.80	109.00	155.00
PCB-1260	µg/kg	SM-ML	215.00	19.20	177.00	252.00
		SM-0	25.80	2.31	21.30	30.30

* SM-ML = Nondetects Set Equal to the Minimum Level.
SM-0 = Nondetects Set Equal to Zero.
SM-COM = Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

. = Nonestimable.

Note: PCB, Composite is a combination of PCB-1016, PCB-1221, PCB-1232, PCB-1242, PCB-1248, PCB-1254, and PCB-1260.

TABLE 7-16.

NATIONAL POLLUTANT CONCENTRATION ESTIMATES FROM THE NATIONAL SEWAGE SLUDGE SURVEY WEIGHTED BY AMOUNT OF SEWAGE SLUDGE DISPOSED

STANDARD DEVIATIONS AND CONFIDENCE INTERVALS FOR THE MEAN

PERCENT SOLIDS, PHOSPHORUS, AND TOTAL KJELDAHL NITROGEN

Pollutant	Unit	Substitution Method*	Mean	Standard Deviation	Lower 95% Conf. Limit	Upper 95% Conf. Limit
Percent Solids	%	SM-ML	26.80	2.41	22.00	31.50
		SM-0	26.80	2.41	22.00	31.50
Phosphorus	mg/kg	SM-ML	1,850.00	167.00	1,520.00	2,180.00
		SM-0	1,850.00	167.00	1,520.00	2,180.00
Total Kjeldahl Nitrogen	mg/kg	SM-ML	42,800.00	3,850.00	35,300.00	50,400.00
		SM-0	42,800.00	3,850.00	35,300.00	50,400.00

* SM-ML = Nondetects Set Equal to the Minimum Level.
SM-0 = Nondetects Set Equal to Zero.

TABLE 7-17.

ESTIMATED CORRELATION COEFFICIENTS
BETWEEN POLLUTANT CONCENTRATION AND SEWAGE SLUDGE DRY WEIGHT DISPOSED

POLLUTANTS OF CONCERN

Pollutant	Estimation Procedure*	Stratum	Correlation Coefficient	p-Value
Aldrin/Dieldrin	SM-ML	> 100 MGD	-0.4146	0.0776
		10 < FLOW <= 100	-0.0655	0.6411
		1 < FLOW <= 10	-0.1162	0.3727
		FLOW <= 1	-0.1225	0.4576
	SM-0	> 100 MGD	-0.1276	0.6025
		10 < FLOW <= 100	-0.0902	0.5205
		1 < FLOW <= 10	-0.0984	0.4504
		FLOW <= 1	-0.1032	0.5319
	SM-COM	> 100 MGD	-0.3044	0.2051
		10 < FLOW <= 100	-0.0856	0.5425
		1 < FLOW <= 10	-0.1362	0.2954
		FLOW <= 1	-0.1447	0.3794
Arsenic	SM-ML	> 100 MGD	-0.0934	0.7038
		10 < FLOW <= 100	-0.0390	0.7814
		1 < FLOW <= 10	-0.1249	0.3335
		FLOW <= 1	0.2218	0.1748
	SM-0	> 100 MGD	0.0930	0.7049
		10 < FLOW <= 100	-0.0480	0.7326
		1 < FLOW <= 10	-0.0829	0.5218
		FLOW <= 1	0.2035	0.2139
Benzene	SM-ML	> 100 MGD	-0.0318	0.8971
		10 < FLOW <= 100	-0.0152	0.9140
		1 < FLOW <= 10	-0.0955	0.4602
		FLOW <= 1	0.0054	0.9738
	SM-0	> 100 MGD	-0.1936	0.4271
		10 < FLOW <= 100	0.5136	0.0001
		1 < FLOW <= 10	.	.
		FLOW <= 1	.	.
Benzo(A)pyrene	SM-ML	> 100 MGD	0.1203	0.6238
		10 < FLOW <= 100	-0.0748	0.5946
		1 < FLOW <= 10	0.1592	0.2164
		FLOW <= 1	-0.0442	0.7891
	SM-0	> 100 MGD	.	.
		10 < FLOW <= 100	-0.2202	0.1132
		1 < FLOW <= 10	-0.0878	0.4976
		FLOW <= 1	-0.1091	0.5085
Beryllium	SM-ML	> 100 MGD	-0.2542	0.2937
		10 < FLOW <= 100	-0.0472	0.7374
		1 < FLOW <= 10	-0.1359	0.2923
		FLOW <= 1	-0.0123	0.9409

* SM-ML = Nondetects set equal to the Minimum Level.
SM-0 = Nondetects set equal to zero.
SM-COM = Maximum nondetect set equal to the highest minimum level; other nondetects set equal to zero.

Note: Aldrin/Dieldrin is a combination of Aldrin and Dieldrin.

TABLE 7-17. (Continued)

ESTIMATED CORRELATION COEFFICIENTS
BETWEEN POLLUTANT CONCENTRATION AND SEWAGE SLUDGE DRY WEIGHT DISPOSED

POLLUTANTS OF CONCERN

Pollutant	Estimation Procedure*	Stratum	Correlation Coefficient	p-Value
Beryllium	SM-0	> 100 MGD	0.2979	0.2154
		10 < FLOW <= 100	-0.0738	0.5994
		1 < FLOW <= 10	-0.1127	0.3833
		FLOW <= 1	-0.1107	0.5023
Bis(2-Ethylhexyl) Phthalate	SM-ML	> 100 MGD	0.2504	0.3012
		10 < FLOW <= 100	-0.1362	0.3310
		1 < FLOW <= 10	0.1131	0.3816
		FLOW <= 1	0.0331	0.8412
	SM-0	> 100 MGD	0.2509	0.3001
		10 < FLOW <= 100	-0.1088	0.4381
		1 < FLOW <= 10	0.1128	0.3828
		FLOW <= 1	0.0575	0.7280
Cadmium	SM-ML	> 100 MGD	0.2305	0.3424
		10 < FLOW <= 100	0.0556	0.6928
		1 < FLOW <= 10	-0.0688	0.5953
		FLOW <= 1	-0.1106	0.5026
	SM-0	> 100 MGD	0.2356	0.3315
		10 < FLOW <= 100	0.0563	0.6890
		1 < FLOW <= 10	-0.0678	0.6006
		FLOW <= 1	-0.2093	0.2010
Cadmium'	SM-ML	> 100 MGD	0.2305	0.3424
		10 < FLOW <= 100	0.0556	0.6928
		1 < FLOW <= 10	0.0264	0.8401
		FLOW <= 1	-0.1106	0.5026
	SM-0	> 100 MGD	0.2356	0.3315
		10 < FLOW <= 100	0.0563	0.6890
		1 < FLOW <= 10	0.0508	0.6971
		FLOW <= 1	-0.2093	0.2010
Chlordane	SM-ML	> 100 MGD	-0.3975	0.0919
		10 < FLOW <= 100	-0.0027	0.9847
		1 < FLOW <= 10	-0.0959	0.4622
		FLOW <= 1	-0.1041	0.5282
	SM-0	> 100 MGD	.	.
		10 < FLOW <= 100	.	.
		1 < FLOW <= 10	.	.
		FLOW <= 1	.	.
Chromium	SM-ML	> 100 MGD	0.5893	0.0079
		10 < FLOW <= 100	-0.1949	0.1620
		1 < FLOW <= 10	0.6846	0.0001
		FLOW <= 1	-0.0837	0.6123

* SM-ML = Nondetects set equal to the Minimum Level.
SM-0 = Nondetects set equal to zero.

' Estimates generated after deleting an extreme outlier observation from stratum 3.

TABLE 7-17. (Continued)

ESTIMATED CORRELATION COEFFICIENTS
BETWEEN POLLUTANT CONCENTRATION AND SEWAGE SLUDGE DRY WEIGHT DISPOSED

POLLUTANTS OF CONCERN

Pollutant	Estimation Procedure*	Stratum	Correlation Coefficient	p-Value
Chromium	SM-0	> 100 MGD	0.5893	0.0079
		10 < FLOW <= 100	-0.1949	0.1620
		1 < FLOW <= 10	0.6846	0.0001
		FLOW <= 1	-0.0883	0.5931
Copper	SM-ML	> 100 MGD	-0.0804	0.7435
		10 < FLOW <= 100	-0.2031	0.1447
		1 < FLOW <= 10	-0.1303	0.3130
		FLOW <= 1	-0.1016	0.5384
	SM-0	> 100 MGD	-0.0804	0.7435
		10 < FLOW <= 100	-0.2031	0.1447
		1 < FLOW <= 10	-0.1303	0.3130
		FLOW <= 1	-0.1016	0.5384
DDT, Composite	SM-ML	> 100 MGD	-0.2254	0.3535
		10 < FLOW <= 100	-0.0328	0.8154
		1 < FLOW <= 10	-0.1000	0.4432
		FLOW <= 1	-0.1056	0.5221
	SM-0	> 100 MGD	-0.1205	0.6230
		10 < FLOW <= 100	-0.0855	0.5425
		1 < FLOW <= 10	-0.0540	0.6794
		FLOW <= 1	-0.1091	0.5085
	SM-COM	> 100 MGD	-0.1646	0.5008
		10 < FLOW <= 100	-0.0615	0.6619
		1 < FLOW <= 10	-0.1092	0.4021
		FLOW <= 1	-0.1093	0.5079
Heptachlor	SM-ML	> 100 MGD	-0.3985	0.0910
		10 < FLOW <= 100	-0.0195	0.8897
		1 < FLOW <= 10	-0.0957	0.4630
		FLOW <= 1	-0.1038	0.5295
	SM-0	> 100 MGD	.	.
		10 < FLOW <= 100	-0.1249	0.3728
		1 < FLOW <= 10	.	.
		FLOW <= 1	.	.
Hexachlorobenzene	SM-ML	> 100 MGD	0.1203	0.6238
		10 < FLOW <= 100	-0.0474	0.7361
		1 < FLOW <= 10	0.1596	0.2153
		FLOW <= 1	-0.0432	0.7939
	SM-0	> 100 MGD	.	.
		10 < FLOW <= 100	.	.
		1 < FLOW <= 10	.	.
		FLOW <= 1	.	.

* SM-ML = Nondetects set equal to the Minimum Level.
SM-0 = Nondetects set equal to zero.
SM-COM = Maximum nondetect set equal to the highest minimum level; other nondetects set equal to zero.

Note: DDT, Composite is a combination of 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT.

TABLE 7-17. (Continued)

ESTIMATED CORRELATION COEFFICIENTS
BETWEEN POLLUTANT CONCENTRATION AND SEWAGE SLUDGE DRY WEIGHT DISPOSED

POLLUTANTS OF CONCERN

Pollutant	Estimation Procedure*	Stratum	Correlation Coefficient	p-Value
Hexachlorobutadiene	SM-ML	> 100 MGD	0.1203	0.6238
		10 < FLOW <= 100	-0.0474	0.7361
		1 < FLOW <= 10	0.1596	0.2153
		FLOW <= 1	-0.0432	0.7939
	SM-0	> 100 MGD	.	.
		10 < FLOW <= 100	.	.
		1 < FLOW <= 10	.	.
		FLOW <= 1	.	.
Lead	SM-ML	> 100 MGD	0.3697	0.1193
		10 < FLOW <= 100	-0.1255	0.3704
		1 < FLOW <= 10	-0.0772	0.5507
		FLOW <= 1	0.0016	0.9922
	SM-0	> 100 MGD	0.3697	0.1193
		10 < FLOW <= 100	-0.1233	0.3792
		1 < FLOW <= 10	-0.0199	0.8781
		FLOW <= 1	-0.0303	0.8549
Lindane(Gamma-BHC)	SM-ML	> 100 MGD	-0.3981	0.0914
		10 < FLOW <= 100	-0.0147	0.9165
		1 < FLOW <= 10	-0.0996	0.4452
		FLOW <= 1	-0.1054	0.5230
	SM-0	> 100 MGD	.	.
		10 < FLOW <= 100	-0.0353	0.8016
		1 < FLOW <= 10	-0.0453	0.7286
		FLOW <= 1	.	.
Mercury	SM-ML	> 100 MGD	-0.2905	0.2276
		10 < FLOW <= 100	-0.0878	0.5318
		1 < FLOW <= 10	-0.1434	0.2663
		FLOW <= 1	-0.0733	0.6573
	SM-0	> 100 MGD	-0.1092	0.6564
		10 < FLOW <= 100	-0.0330	0.8145
		1 < FLOW <= 10	-0.0714	0.5812
		FLOW <= 1	-0.0770	0.6411
Molybdenum	SM-ML	> 100 MGD	-0.0202	0.9347
		10 < FLOW <= 100	-0.2731	0.0478
		1 < FLOW <= 10	-0.1233	0.3398
		FLOW <= 1	-0.0395	0.8114
	SM-0	> 100 MGD	0.3298	0.1679
		10 < FLOW <= 100	-0.2635	0.0566
		1 < FLOW <= 10	0.0039	0.9761
		FLOW <= 1	-0.2112	0.1969
N-Nitrosodimethylamine	SM-ML	> 100 MGD	0.1203	0.6238
		10 < FLOW <= 100	-0.0474	0.7361
		1 < FLOW <= 10	0.1596	0.2153
		FLOW <= 1	-0.0432	0.7939

* SM-ML = Nondetects set equal to the Minimum Level.
SM-0 = Nondetects set equal to zero.

TABLE 7-17. (Continued)

ESTIMATED CORRELATION COEFFICIENTS
BETWEEN POLLUTANT CONCENTRATION AND SEWAGE SLUDGE DRY WEIGHT DISPOSED

POLLUTANTS OF CONCERN

Pollutant	Estimation Procedure*	Stratum	Correlation Coefficient	p-Value
N-Nitrosodimethylamine	SM-0	> 100 MGD	.	.
		10 < FLOW <= 100	.	.
		1 < FLOW <= 10	.	.
		FLOW <= 1	.	.
Nickel	SM-ML	> 100 MGD	0.3132	0.1916
		10 < FLOW <= 100	-0.1666	0.2332
		1 < FLOW <= 10	0.1236	0.3386
		FLOW <= 1	-0.1062	0.5198
	SM-0	> 100 MGD	0.3195	0.1823
		10 < FLOW <= 100	-0.1660	0.2349
		1 < FLOW <= 10	0.1691	0.1890
		FLOW <= 1	-0.1640	0.3186
PCB,Composite	SM-ML	> 100 MGD	0.0869	0.7235
		10 < FLOW <= 100	-0.1084	0.4397
		1 < FLOW <= 10	-0.1111	0.3938
		FLOW <= 1	-0.0974	0.5554
	SM-0	> 100 MGD	0.4476	0.0547
		10 < FLOW <= 100	-0.1018	0.4683
		1 < FLOW <= 10	-0.1017	0.4353
		FLOW <= 1	-0.0267	0.8720
	SM-COM	> 100 MGD	0.4226	0.0715
		10 < FLOW <= 100	-0.1028	0.4639
		1 < FLOW <= 10	-0.1487	0.2526
		FLOW <= 1	-0.0513	0.7564
Selenium	SM-ML	> 100 MGD	-0.2088	0.3910
		10 < FLOW <= 100	0.0230	0.8701
		1 < FLOW <= 10	-0.0748	0.5636
		FLOW <= 1	-0.0946	0.5669
	SM-0	> 100 MGD	-0.0077	0.9750
		10 < FLOW <= 100	-0.4204	0.0017
		1 < FLOW <= 10	-0.1138	0.3785
		FLOW <= 1	-0.1387	0.3997
Toxaphene	SM-ML	> 100 MGD	-0.3977	0.0917
		10 < FLOW <= 100	-0.0028	0.9843
		1 < FLOW <= 10	-0.0959	0.4623
		FLOW <= 1	-0.1041	0.5281
	SM-0	> 100 MGD	.	.
		10 < FLOW <= 100	.	.
		1 < FLOW <= 10	.	.
		FLOW <= 1	.	.

* SM-ML = Nondetects set equal to the Minimum Level.
SM-0 = Nondetects set equal to zero.
SM-COM = Maximum nondetect set equal to the highest minimum level; other nondetects set equal to zero.

Note: PCB, Composite is a combination of PCB-1016, PCB-1221, PCB-1232, PCB-1242, PCB-1248, PCB-1254, and PCB-1260.

TABLE 7-17. (Continued)

ESTIMATED CORRELATION COEFFICIENTS
BETWEEN POLLUTANT CONCENTRATION AND SEWAGE SLUDGE DRY WEIGHT DISPOSED

POLLUTANTS OF CONCERN

Pollutant	Estimation Procedure*	Stratum	Correlation Coefficient	p-Value
Trichloroethene	SM-ML	> 100 MGD	-0.0284	0.9080
		10 < FLOW <= 100	-0.0164	0.9072
		1 < FLOW <= 10	-0.0985	0.4463
		FLOW <= 1	0.0054	0.9738
	SM-0	> 100 MGD	-0.1475	0.5468
		10 < FLOW <= 100	-0.0403	0.7744
		1 < FLOW <= 10	-0.0349	0.7880
		FLOW <= 1	.	.
Zinc	SM-ML	> 100 MGD	0.3363	0.1592
		10 < FLOW <= 100	-0.2165	0.1194
		1 < FLOW <= 10	-0.0619	0.6325
		FLOW <= 1	-0.1599	0.3309
	SM-0	> 100 MGD	0.3363	0.1592
		10 < FLOW <= 100	-0.2165	0.1194
		1 < FLOW <= 10	-0.0619	0.6325
		FLOW <= 1	-0.1599	0.3309

* SM-ML = Nondetects set equal to the Minimum Level.
SM-0 = Nondetects set equal to zero.

TABLE 7-18.

ESTIMATED CORRELATION COEFFICIENTS
BETWEEN POLLUTANT CONCENTRATION AND SEWAGE SLUDGE DRY WEIGHT DISPOSED

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Estimation Procedure*	Stratum	Correlation Coefficient	p-Value
Aldrin/Dieldrin	SM-ML	> 100 MGD	-0.4146	0.0776
		10 < FLOW <= 100	-0.0655	0.6411
		1 < FLOW <= 10	-0.1162	0.3727
		FLOW <= 1	-0.1225	0.4576
	SM-0	> 100 MGD	-0.1276	0.6025
		10 < FLOW <= 100	-0.0902	0.5205
		1 < FLOW <= 10	-0.0984	0.4504
		FLOW <= 1	-0.1032	0.5319
	SM-COM	> 100 MGD	-0.3044	0.2051
		10 < FLOW <= 100	-0.0856	0.5425
		1 < FLOW <= 10	-0.1362	0.2954
		FLOW <= 1	-0.1447	0.3794
Aldrin	SM-ML	> 100 MGD	-0.3865	0.1022
		10 < FLOW <= 100	-0.0844	0.5481
		1 < FLOW <= 10	-0.1015	0.4362
		FLOW <= 1	-0.1077	0.5140
	SM-0	> 100 MGD	-0.0352	0.8862
		10 < FLOW <= 100	-0.0902	0.5205
		1 < FLOW <= 10	-0.0290	0.8246
		FLOW <= 1	-0.0119	0.9427
Dieldrin	SM-ML	> 100 MGD	-0.3692	0.1198
		10 < FLOW <= 100	-0.0023	0.9867
		1 < FLOW <= 10	-0.1252	0.3362
		FLOW <= 1	-0.1338	0.4166
	SM-0	> 100 MGD	-0.1207	0.6226
		10 < FLOW <= 100	.	.
		1 < FLOW <= 10	-0.0959	0.4620
		FLOW <= 1	-0.1086	0.5103
DDT, Composite	SM-ML	> 100 MGD	-0.2254	0.3535
		10 < FLOW <= 100	-0.0328	0.8154
		1 < FLOW <= 10	-0.1000	0.4432
		FLOW <= 1	-0.1056	0.5221
	SM-0	> 100 MGD	-0.1205	0.6230
		10 < FLOW <= 100	-0.0855	0.5425
		1 < FLOW <= 10	-0.0540	0.6794
		FLOW <= 1	-0.1091	0.5085
	SM-COM	> 100 MGD	-0.1646	0.5008
		10 < FLOW <= 100	-0.0615	0.6619
		1 < FLOW <= 10	-0.1092	0.4021
		FLOW <= 1	-0.1093	0.5079

* SM-ML = Nondetects set equal to the Minimum Level.
SM-0 = Nondetects set equal to zero.
SM-COM = Maximum nondetect set equal to the highest minimum level; other nondetects set equal to zero.

Note: Aldrin/Dieldrin is a combination of Aldrin and Dieldrin.
DDT, Composite is a combination of 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT.

TABLE 7-18. (Continued)

ESTIMATED CORRELATION COEFFICIENTS
BETWEEN POLLUTANT CONCENTRATION AND SEWAGE SLUDGE DRY WEIGHT DISPOSED

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Estimation Procedure*	Stratum	Correlation Coefficient	p-Value
4,4'-DDD	SM-ML	> 100 MGD	-0.1745	0.4750
		10 < FLOW <= 100	-0.0028	0.9842
		1 < FLOW <= 10	-0.0959	0.4623
		FLOW <= 1	-0.1051	0.5243
	SM-0	> 100 MGD	-0.1048	0.6693
		10 < FLOW <= 100	.	.
		1 < FLOW <= 10	.	.
		FLOW <= 1	.	.
4,4'-DDE	SM-ML	> 100 MGD	-0.2570	0.2882
		10 < FLOW <= 100	-0.0022	0.9873
		1 < FLOW <= 10	-0.1027	0.4312
		FLOW <= 1	-0.1051	0.5243
	SM-0	> 100 MGD	-0.1048	0.6693
		10 < FLOW <= 100	0.0635	0.6516
		1 < FLOW <= 10	-0.0426	0.7444
		FLOW <= 1	.	.
4,4'-DDT	SM-ML	> 100 MGD	-0.3430	0.1505
		10 < FLOW <= 100	-0.0838	0.5507
		1 < FLOW <= 10	-0.0999	0.4436
		FLOW <= 1	-0.1083	0.5117
	SM-0	> 100 MGD	-0.1636	0.5033
		10 < FLOW <= 100	-0.0954	0.4967
		1 < FLOW <= 10	-0.0611	0.6400
		FLOW <= 1	-0.1091	0.5085
PCB, Composite	SM-ML	> 100 MGD	0.0869	0.7235
		10 < FLOW <= 100	-0.1084	0.4397
		1 < FLOW <= 10	-0.1111	0.3938
		FLOW <= 1	-0.0974	0.5554
	SM-0	> 100 MGD	0.4476	0.0547
		10 < FLOW <= 100	-0.1018	0.4683
		1 < FLOW <= 10	-0.1017	0.4353
		FLOW <= 1	-0.0267	0.8720
	SM-COM	> 100 MGD	0.4226	0.0715
		10 < FLOW <= 100	-0.1028	0.4639
		1 < FLOW <= 10	-0.1487	0.2526
		FLOW <= 1	-0.0513	0.7564
PCB-1016	SM-ML	> 100 MGD	-0.3980	0.0915
		10 < FLOW <= 100	-0.0027	0.9847
		1 < FLOW <= 10	-0.0959	0.4624
		FLOW <= 1	-0.1043	0.5275

* SM-ML = Nondetects set equal to the Minimum Level.
SM-0 = Nondetects set equal to zero.
SM-COM = Maximum nondetect set equal to the highest minimum level; other nondetects set equal to zero.

Note: PCB, Composite is a combination of PCB-1016, PCB-1221, PCB-1232, PCB-1242, PCB-1248, PCB-1254, and PCB-1260.

TABLE 7-18. (Continued)

ESTIMATED CORRELATION COEFFICIENTS
BETWEEN POLLUTANT CONCENTRATION AND SEWAGE SLUDGE DRY WEIGHT DISPOSED

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Estimation Procedure*	Stratum	Correlation Coefficient	p-Value
PCB-1016	SM-0	> 100 MGD	.	.
		10 < FLOW <= 100	.	.
		1 < FLOW <= 10	.	.
		FLOW <= 1	.	.
PCB-1221	SM-ML	> 100 MGD	-0.3980	0.0915
		10 < FLOW <= 100	-0.0027	0.9847
		1 < FLOW <= 10	-0.0959	0.4624
		FLOW <= 1	-0.1043	0.5275
	SM-0	> 100 MGD	.	.
		10 < FLOW <= 100	.	.
		1 < FLOW <= 10	.	.
		FLOW <= 1	.	.
PCB-1232	SM-ML	> 100 MGD	-0.3980	0.0915
		10 < FLOW <= 100	-0.0027	0.9847
		1 < FLOW <= 10	-0.0959	0.4624
		FLOW <= 1	-0.1043	0.5275
	SM-0	> 100 MGD	.	.
		10 < FLOW <= 100	.	.
		1 < FLOW <= 10	.	.
		FLOW <= 1	.	.
PCB-1242	SM-ML	> 100 MGD	-0.3980	0.0915
		10 < FLOW <= 100	-0.0027	0.9847
		1 < FLOW <= 10	-0.0959	0.4624
		FLOW <= 1	-0.1043	0.5275
	SM-0	> 100 MGD	.	.
		10 < FLOW <= 100	.	.
		1 < FLOW <= 10	.	.
		FLOW <= 1	.	.
PCB-1248	SM-ML	> 100 MGD	-0.4132	0.0787
		10 < FLOW <= 100	-0.1118	0.4254
		1 < FLOW <= 10	-0.1274	0.3279
		FLOW <= 1	-0.1188	0.4711
	SM-0	> 100 MGD	-0.1717	0.4821
		10 < FLOW <= 100	-0.0922	0.5113
		1 < FLOW <= 10	-0.0868	0.5058
		FLOW <= 1	-0.1589	0.3339
PCB-1254	SM-ML	> 100 MGD	0.7399	0.0003
		10 < FLOW <= 100	-0.0680	0.6287
		1 < FLOW <= 10	-0.1050	0.4207
		FLOW <= 1	-0.0594	0.7196
	SM-0	> 100 MGD	0.7680	0.0001
		10 < FLOW <= 100	-0.0726	0.6053
		1 < FLOW <= 10	-0.0388	0.7663
		FLOW <= 1	-0.0363	0.8264

* SM-ML = Nondetects set equal to the Minimum Level.
SM-0 = Nondetects set equal to zero.

TABLE 7-18. (Continued)

ESTIMATED CORRELATION COEFFICIENTS
BETWEEN POLLUTANT CONCENTRATION AND SEWAGE SLUDGE DRY WEIGHT DISPOSED

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Estimation Procedure*	Stratum	Correlation Coefficient	p-Value
PCB-1260	SM-ML	> 100 MGD	-0.3774	0.1112
		10 < FLOW <= 100	-0.0152	0.9138
		1 < FLOW <= 10	-0.1159	0.3738
		FLOW <= 1	-0.0305	0.8536
	SM-0	> 100 MGD	-0.2165	0.3733
		10 < FLOW <= 100	-0.0188	0.8937
		1 < FLOW <= 10	-0.0670	0.6077
		FLOW <= 1	0.0347	0.8340

* SM-ML = Nondetects set equal to the Minimum Level.
SM-0 = Nondetects set equal to zero.

TABLE 7-19.

ESTIMATED CORRELATION COEFFICIENTS
BETWEEN POLLUTANT CONCENTRATION AND SEWAGE SLUDGE DRY WEIGHT DISPOSED

PERCENT SOLIDS, PHOSPHORUS, AND TOTAL KJELDAHL NITROGEN

Pollutant	Estimation Procedure*	Stratum	Correlation Coefficient	p-Value
Percent Solids	SM-ML	> 100 MGD	0.3408	0.1534
		10 < FLOW <= 100	-0.0285	0.8394
		1 < FLOW <= 10	0.1304	0.3124
		FLOW <= 1	-0.0549	0.7399
	SM-0	> 100 MGD	0.3408	0.1534
		10 < FLOW <= 100	-0.0285	0.8394
		1 < FLOW <= 10	0.1304	0.3124
		FLOW <= 1	-0.0549	0.7399
Phosphorus	SM-ML	> 100 MGD	-0.1739	0.4765
		10 < FLOW <= 100	-0.1102	0.4322
		1 < FLOW <= 10	-0.1099	0.3953
		FLOW <= 1	-0.0397	0.8102
	SM-0	> 100 MGD	-0.1739	0.4765
		10 < FLOW <= 100	-0.1102	0.4322
		1 < FLOW <= 10	-0.1099	0.3953
		FLOW <= 1	-0.0397	0.8102
Total Kjeldahl Nitrogen	SM-ML	> 100 MGD	-0.3412	0.1528
		10 < FLOW <= 100	-0.0728	0.6043
		1 < FLOW <= 10	-0.0616	0.6341
		FLOW <= 1	0.0854	0.6052
	SM-0	> 100 MGD	-0.3412	0.1528
		10 < FLOW <= 100	-0.0728	0.6043
		1 < FLOW <= 10	-0.0616	0.6341
		FLOW <= 1	0.0854	0.6052

* SM-ML = Nondetects set equal to the Minimum Level.
SM-0 = Nondetects set equal to zero.

TABLE 7-20.

NATIONAL SEWAGE SLUDGE MASS BASED POLLUTANT CONCENTRATION PERCENTILE ESTIMATES

POLLUTANTS OF CONCERN

Pollutant	Unit	Substitution Method*	Median	90th Percentile	95th Percentile	98th Percentile
Aldrin/Dieldrin	µg/kg	SM-ML	20.00	27.00	34.00	47.10
	µg/kg	SM-0	0.00	0.00	0.00	18.50
	µg/kg	SM-COM	10.00	15.10	22.00	32.50
Arsenic	mg/kg	SM-ML	6.70	15.00	23.70	41.20
	mg/kg	SM-0	5.20	14.90	19.50	41.20
Benzene	µg/kg	SM-ML	272.00	1,920.00	5,260.00	8,770.00
	µg/kg	SM-0	0.00	0.00	0.00	6.24
Benzo(A)pyrene	µg/kg	SM-ML	6,670.00	21,300.00	43,500.00	100,000.00
	µg/kg	SM-0	0.00	0.00	0.00	0.00
Beryllium	mg/kg	SM-ML	0.70	1.90	2.70	4.00
	mg/kg	SM-0	0.00	0.57	0.72	0.90
Bis(2-Ethylhexyl)Phthalate	µg/kg	SM-ML	63,300.00	235,000.00	264,000.00	379,000.00
	µg/kg	SM-0	61,700.00	235,000.00	264,000.00	379,000.00
Cadmium	mg/kg	SM-ML	8.95	128.00	128.00	210.00
	mg/kg	SM-0	8.80	128.00	128.00	210.00
Cadmium•	mg/kg	SM-ML	8.95	128.00	128.00	210.00
	mg/kg	SM-0	8.80	128.00	128.00	210.00

* SM-ML = Nondetects Set Equal to the Minimum Level.
SM-0 = Nondetects Set Equal to Zero.
SM-COM = Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

• Estimates Generated After Deleting an Extreme Outlier Observation From Stratum 3.

Note: Aldrin/Dieldrin is a combination of Aldrin and Dieldrin.

TABLE 7-20. (Continued)

NATIONAL SEWAGE SLUDGE MASS BASED POLLUTANT CONCENTRATION PERCENTILE ESTIMATES

POLLUTANTS OF CONCERN

Pollutant	Unit	Substitution Method*	Median	90th Percentile	95th Percentile	98th Percentile
Chlordane	µg/kg	SM-ML	250.00	311.00	416.00	556.00
	µg/kg	SM-0	0.00	0.00	0.00	0.00
Chromium	mg/kg	SM-ML	150.00	1,670.00	2,320.00	2,320.00
	mg/kg	SM-0	150.00	1,670.00	2,320.00	2,320.00
Copper	mg/kg	SM-ML	444.00	1,180.00	1,790.00	2,120.00
	mg/kg	SM-0	444.00	1,180.00	1,790.00	2,120.00
DDT,	µg/kg	SM-ML	120.00	156.00	206.00	272.00
	µg/kg	SM-0	0.00	0.00	0.00	30.30
	µg/kg	SM-COM	50.00	71.80	86.00	166.00
Heptachlor	µg/kg	SM-ML	20.00	24.80	33.10	44.00
	µg/kg	SM-0	0.00	0.00	0.00	0.00
Hexachlorobenzene	µg/kg	SM-ML	6,670.00	21,300.00	43,500.00	100,000.00
	µg/kg	SM-0	0.00	0.00	0.00	0.00
Hexachlorobutadiene	µg/kg	SM-ML	6,670.00	21,300.00	43,500.00	100,000.00
	µg/kg	SM-0	0.00	0.00	0.00	0.00
Lead	mg/kg	SM-ML	152.00	472.00	472.00	525.00
	mg/kg	SM-0	152.00	472.00	472.00	522.00

* SM-ML = Nondetects Equal to the Minimum Level.
SM-0 = Nondetects Set Equal to Zero.
SM-COM = Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

Note: DDT, Composite is a combination of 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT.

TABLE 7-20. (Continued)

NATIONAL SEWAGE SLUDGE MASS BASED POLLUTANT CONCENTRATION PERCENTILE ESTIMATES

POLLUTANTS OF CONCERN

Pollutant	Unit	Substitution Method*	Median	90th Percentile	95th Percentile	98th Percentile
Lindane	µg/kg	SM-ML	25.00	32.10	43.00	56.00
	µg/kg	SM-0	0.00	0.00	0.00	0.00
Mercury	mg/kg	SM-ML	2.30	6.70	8.70	11.30
	mg/kg	SM-0	1.90	5.55	7.00	8.30
Molybdenum	mg/kg	SM-ML	8.30	20.10	29.70	43.50
	mg/kg	SM-0	6.60	17.00	24.70	37.30
N-Nitrosodimethylamine	µg/kg	SM-ML	33,300.00	106,000.00	217,000.00	500,000.00
	µg/kg	SM-0	0.00	0.00	0.00	0.00
Nickel	mg/kg	SM-ML	46.50	236.00	236.00	390.00
	mg/kg	SM-0	40.60	236.00	236.00	390.00
PCB, Composite	µg/kg	SM-ML	1,460.00	2,020.00	2,390.00	3,120.00
	µg/kg	SM-0	0.00	822.00	1,470.00	1,470.00
	µg/kg	SM-COM	210.00	1,020.00	1,550.00	1,550.00
Selenium	mg/kg	SM-ML	4.50	13.00	16.90	23.50
	mg/kg	SM-0	3.00	6.60	10.60	15.70
Toxaphene	µg/kg	SM-ML	999.00	1,240.00	1,670.00	2,220.00
	µg/kg	SM-0	0.00	0.00	0.00	0.00

* SM-ML = Nondetects Set Equal to the Minimum Level.
SM-0 = Nondetects Set Equal to Zero.
SM-COM = Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

Note: PCB, Composite is a combination of PCB-1016, PCB-1221, PCB-1232, PCB-1242, PCB-1248, PCB-1254, and PCB-1260.

TABLE 7-20. (Continued)

NATIONAL SEWAGE SLUDGE MASS BASED POLLUTANT CONCENTRATION PERCENTILE ESTIMATES

POLLUTANTS OF CONCERN

Pollutant	Unit	Substitution Method*	Median	90th Percentile	95th Percentile	98th Percentile
Trichloroethene	µg/kg	SM-ML	272.00	1,920.00	5,260.00	8,770.00
	µg/kg	SM-0	0.00	0.00	0.00	24.20
Zinc	mg/kg	SM-ML	970.00	2,660.00	3,390.00	4,820.00
	mg/kg	SM-0	970.00	2,660.00	3,390.00	4,820.00

* SM-ML = Nondetects Set Equal to the Minimum Level.
SM-0 = Nondetects Set Equal to Zero.

TABLE 7-21.

NATIONAL SEWAGE SLUDGE MASS BASED POLLUTANT CONCENTRATION PERCENTILE ESTIMATES

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Substitution Method*	Median	90th Percentile	95th Percentile	98th Percentile
Aldrin/Dieldrin	µg/kg	SM-ML	20.00	27.00	34.00	47.10
	µg/kg	SM-0	0.00	0.00	0.00	18.50
	µg/kg	SM-COM	10.00	15.10	22.00	32.50
Aldrin	µg/kg	SM-ML	10.00	14.30	19.20	22.40
	µg/kg	SM-0	0.00	0.00	0.00	6.52
Dieldrin	µg/kg	SM-ML	10.00	12.90	16.60	22.30
	µg/kg	SM-0	0.00	0.00	0.00	0.00
DDT, Composite	µg/kg	SM-ML	120.00	156.00	206.00	272.00
	µg/kg	SM-0	0.00	0.00	0.00	30.30
	µg/kg	SM-COM	50.00	71.80	86.00	166.00
4,4'-DDD	µg/kg	SM-ML	50.00	64.30	83.70	113.00
	µg/kg	SM-0	0.00	0.00	0.00	0.00
4,4'-DDE	µg/kg	SM-ML	50.00	64.80	83.80	113.00
	µg/kg	SM-0	0.00	0.00	0.00	0.00
4,4'-DDT	µg/kg	SM-ML	20.00	27.50	34.30	45.40
	µg/kg	SM-0	0.00	0.00	0.00	0.00

* SM-ML = Nondetects Set Equal to the Minimum Level.
SM-0 = Nondetects Set Equal to Zero.
SM-COM = Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

Note: Aldrin/Dieldrin is a combination of Aldrin and Dieldrin.
DDT, Composite is a combination of 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT.

TABLE 7-21. (Continued)

NATIONAL SEWAGE SLUDGE MASS BASED POLLUTANT CONCENTRATION PERCENTILE ESTIMATES

INDIVIDUAL POLLUTANTS FOR COMPOSITE POLLUTANTS OF CONCERN

Pollutant	Unit	Substitution Method*	Median	90th Percentile	95th Percentile	98th Percentile
PCB, Composite	µg/kg	SM-ML	1,460.00	2,020.00	2,390.00	3,120.00
	µg/kg	SM-0	0.00	822.00	1,470.00	1,470.00
	µg/kg	SM-COM	210.00	1,020.00	1,550.00	1,550.00
PCB-1016	µg/kg	SM-ML	200.00	248.00	334.00	444.00
	µg/kg	SM-0	0.00	0.00	0.00	0.00
PCB-1221	µg/kg	SM-ML	200.00	248.00	334.00	444.00
	µg/kg	SM-0	0.00	0.00	0.00	0.00
PCB-1232	µg/kg	SM-ML	200.00	248.00	334.00	444.00
	µg/kg	SM-0	0.00	0.00	0.00	0.00
PCB-1242	µg/kg	SM-ML	200.00	248.00	334.00	444.00
	µg/kg	SM-0	0.00	0.00	0.00	0.00
PCB-1248	µg/kg	SM-ML	206.00	351.00	444.00	522.00
	µg/kg	SM-0	0.00	0.00	296.00	468.00
PCB-1254	µg/kg	SM-ML	206.00	446.00	1,370.00	1,370.00
	µg/kg	SM-0	0.00	0.00	1,370.00	1,370.00
PCB-1260	µg/kg	SM-ML	204.00	305.00	444.00	596.00
	µg/kg	SM-0	0.00	0.00	0.00	330.00

* SM-ML = Nondetects Set Equal to the Minimum Level.
SM-0 = Nondetects Set Equal to Zero.
SM-COM = Maximum Nondetect Set Equal to the Highest Minimum Level; Other Nondetects Set Equal to Zero.

Note: PCB, Composite is a combination of PCB-1016, PCB-1221, PCB-1232, PCB-1242, PCB-1248, PCB-1254, and PCB-1260.

TABLE 7-22.

NATIONAL SEWAGE SLUDGE MASS BASED POLLUTANT CONCENTRATION PERCENTILE ESTIMATES

PERCENT SOLIDS, PHOSPHORUS, AND TOTAL KJELDAHL NITROGEN

Pollutant	Unit	Substitution Method*	Median	90th Percentile	95th Percentile	98th Percentile
Percent Solids	%	SM-ML	20.40	64.00	66.00	71.40
	%	SM-0	20.40	64.00	66.00	71.40
Phosphorus	mg/kg	SM-ML	560.00	5,850.00	6,930.00	12,600.00
	mg/kg	SM-0	560.00	5,850.00	6,930.00	12,600.00
Total Kjeldahl Nitrogen	mg/kg	SM-ML	40,300.00	73,000.00	90,500.00	102,000.00
	mg/kg	SM-0	40,300.00	73,000.00	90,500.00	102,000.00

* SM-ML = Nondetects Set Equal to the Minimum Level.
SM-0 = Nondetects Set Equal to Zero.

FIGURES 1-110

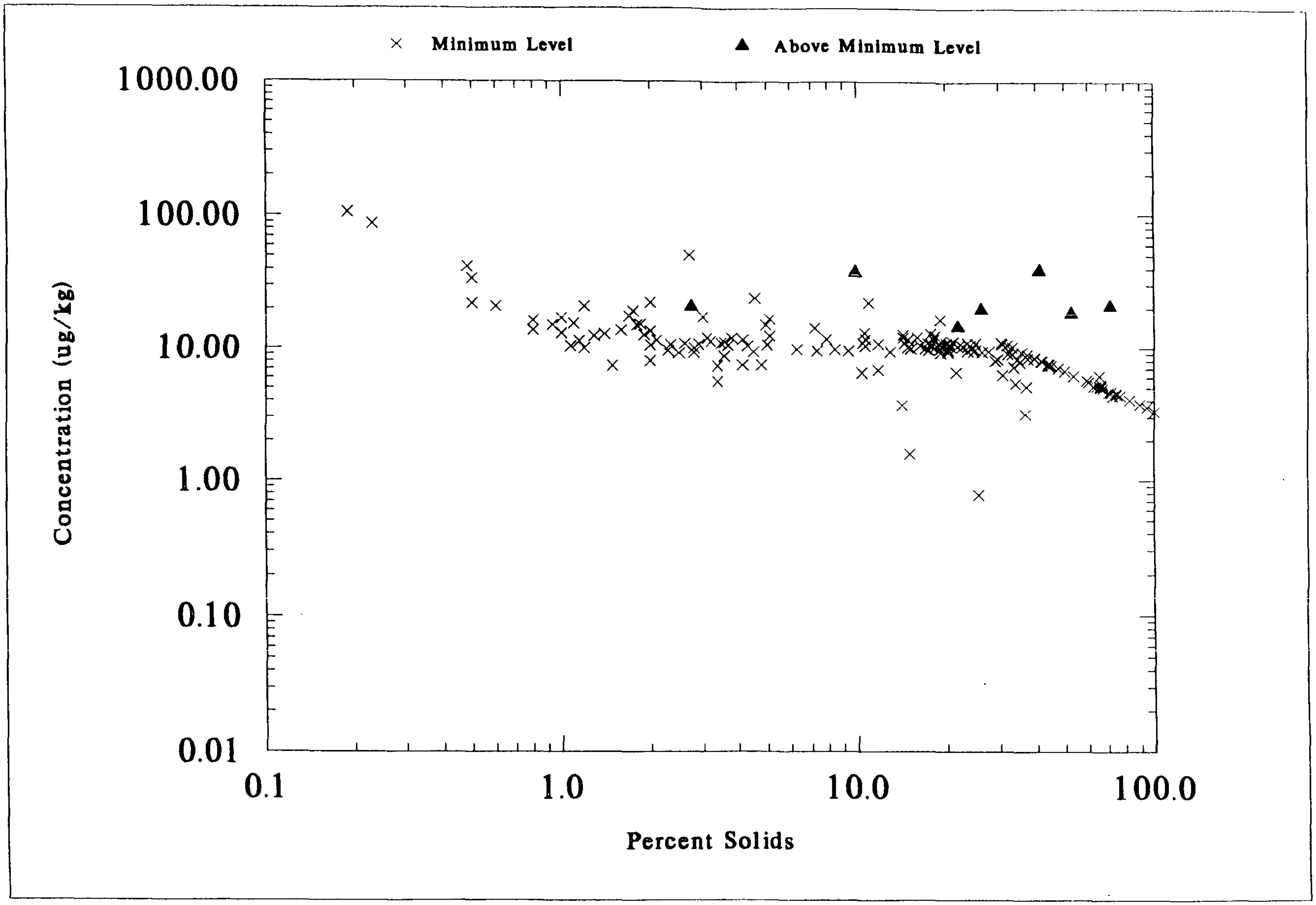


Figure 7-1. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of ALDRIN

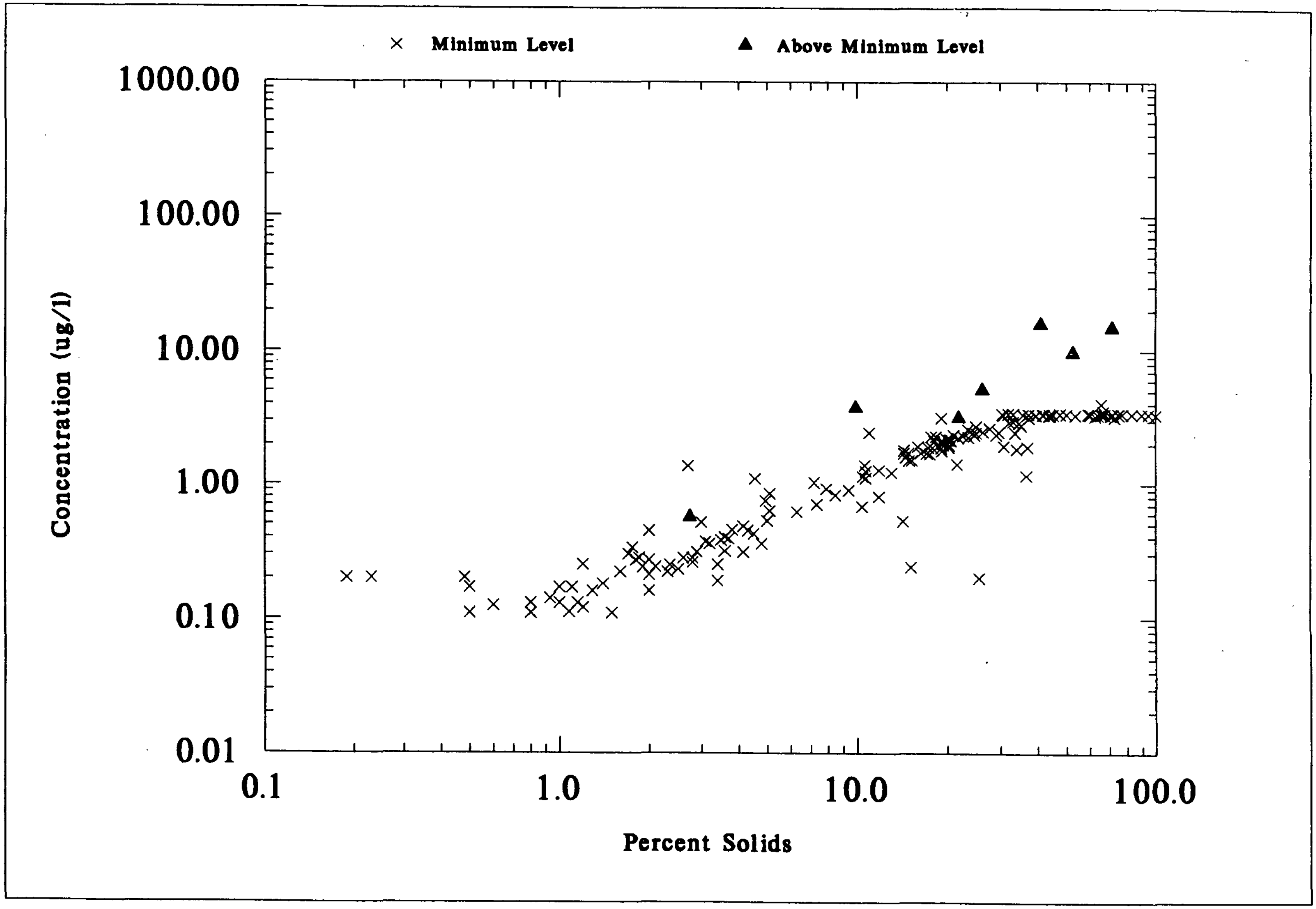


Figure 7-2. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of ALDRIN

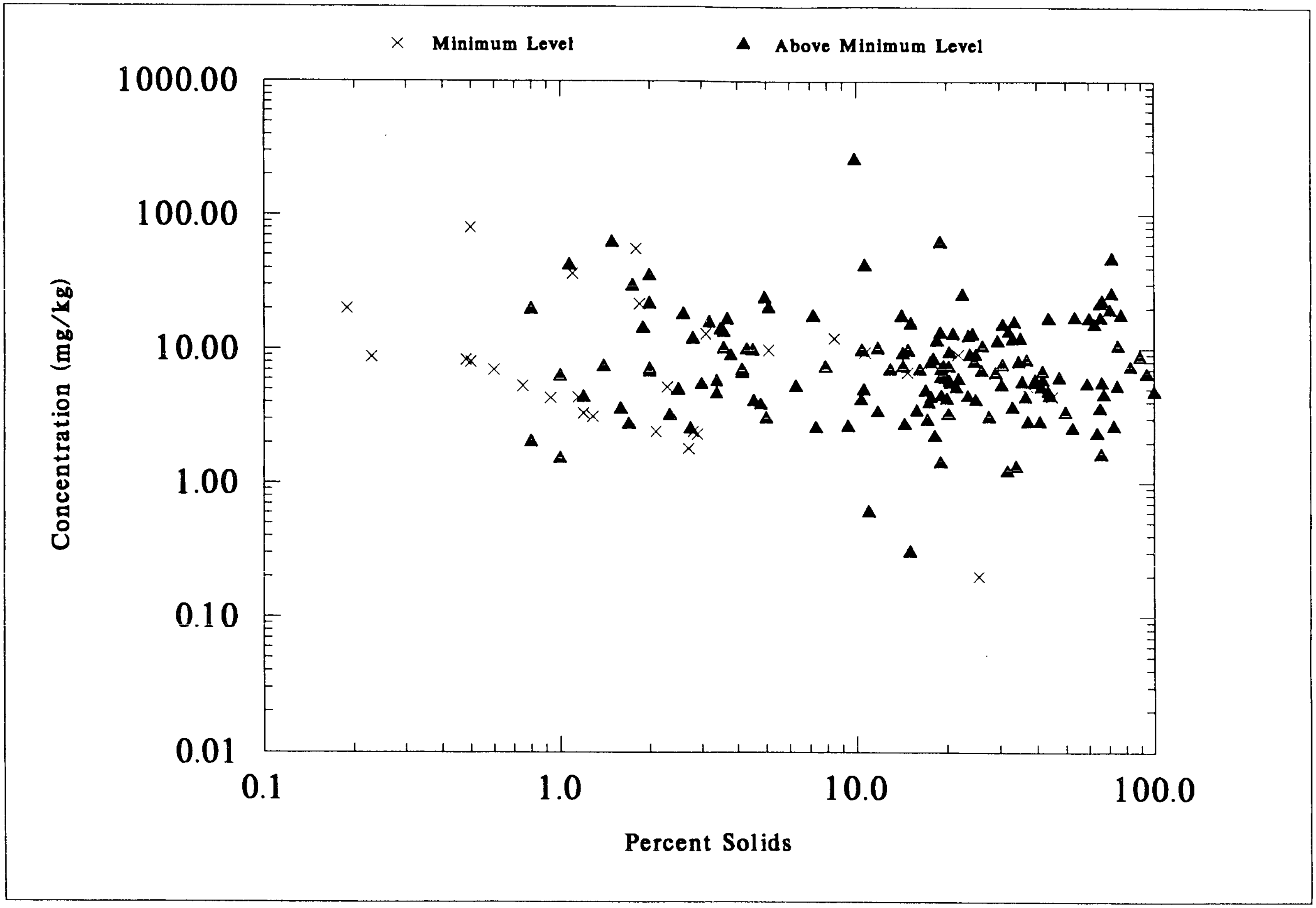


Figure 7-3. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of ARSENIC

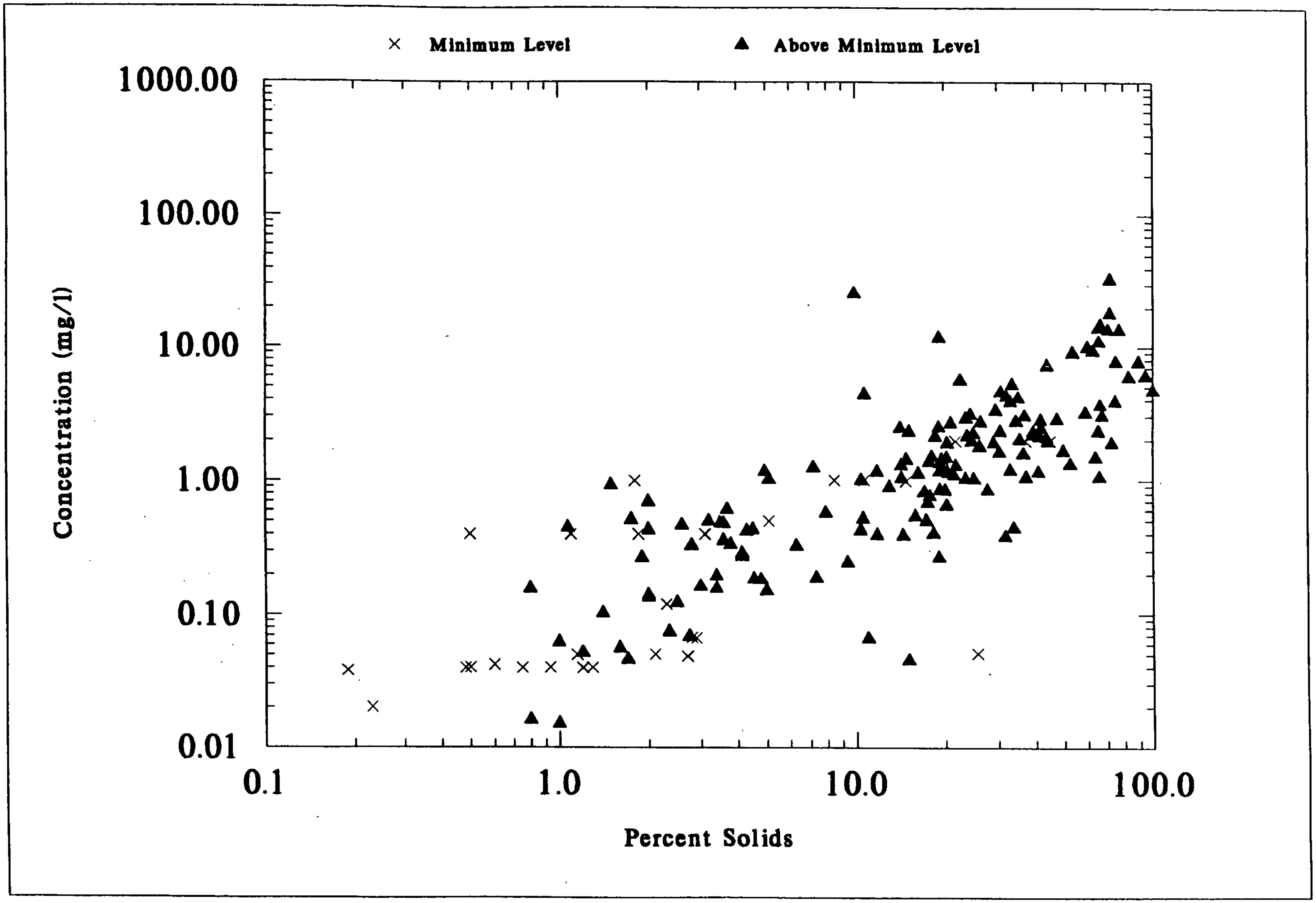


Figure 7-4. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of ARSENIC

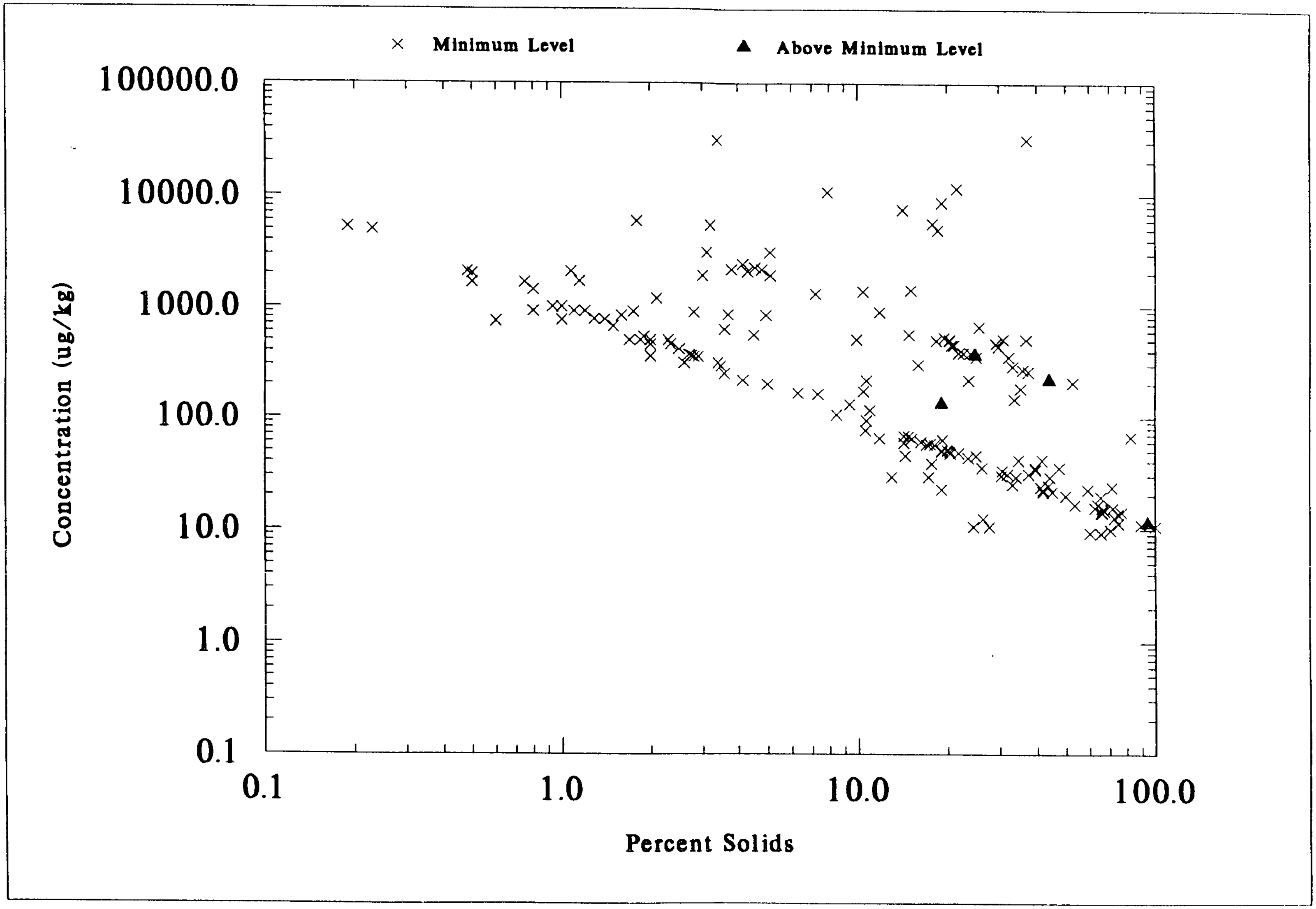


Figure 7-5. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of BENZENE

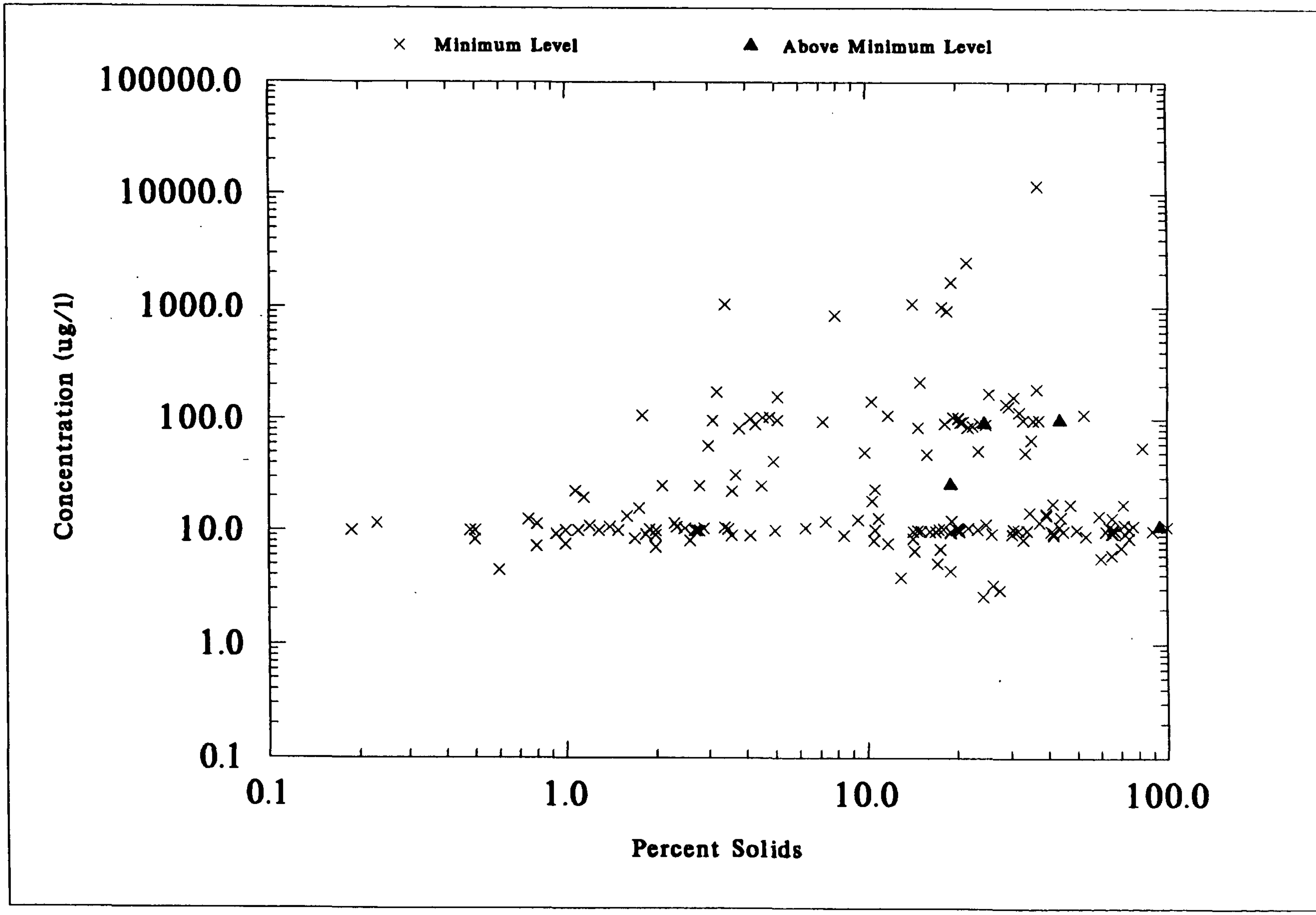


Figure 7-6. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of BENZENE

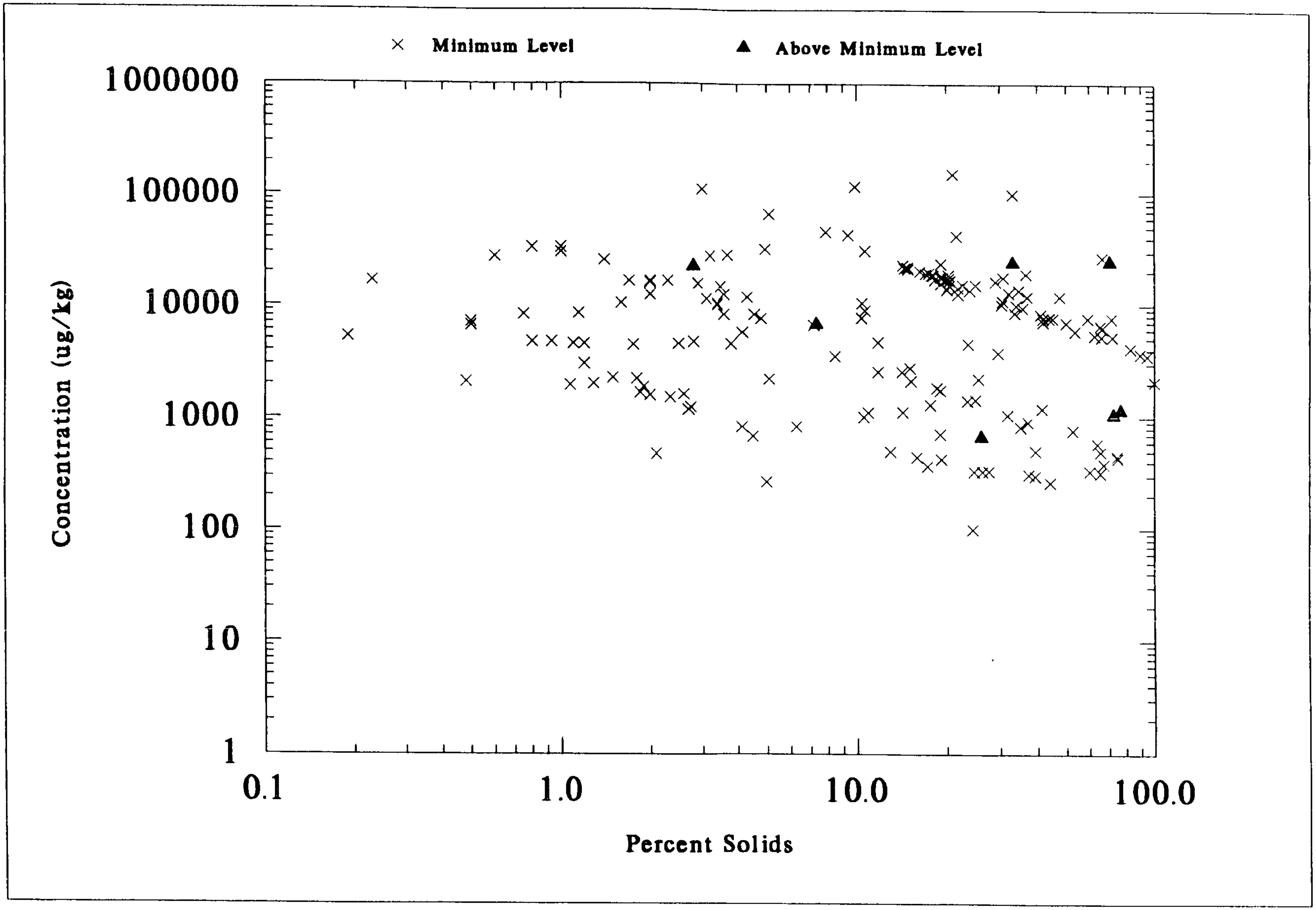


Figure 7-7. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of BENZO(A)PYRENE

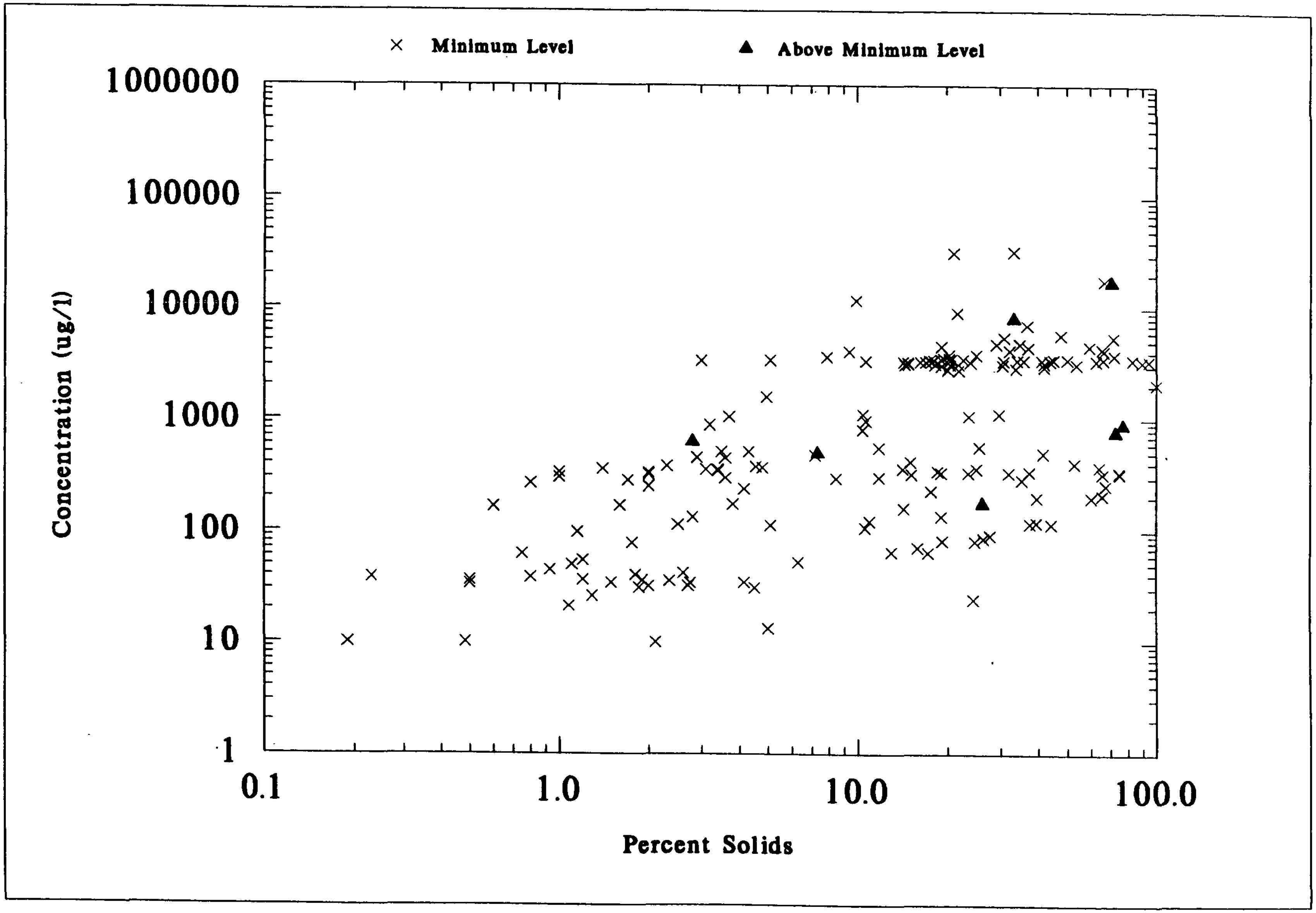


Figure 7–8. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of BENZO(A)PYRENE

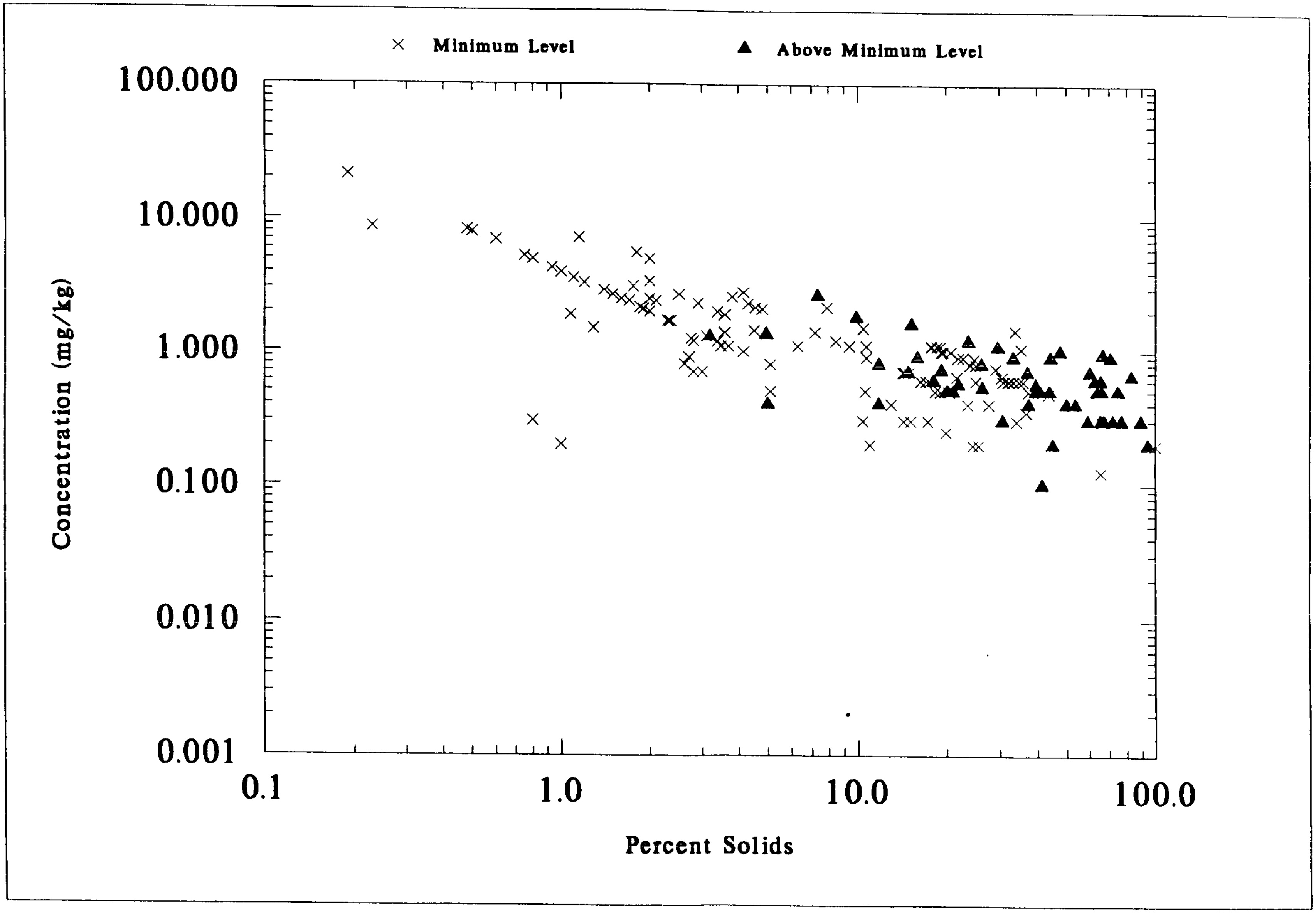


Figure 7-9. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of BERYLLIUM

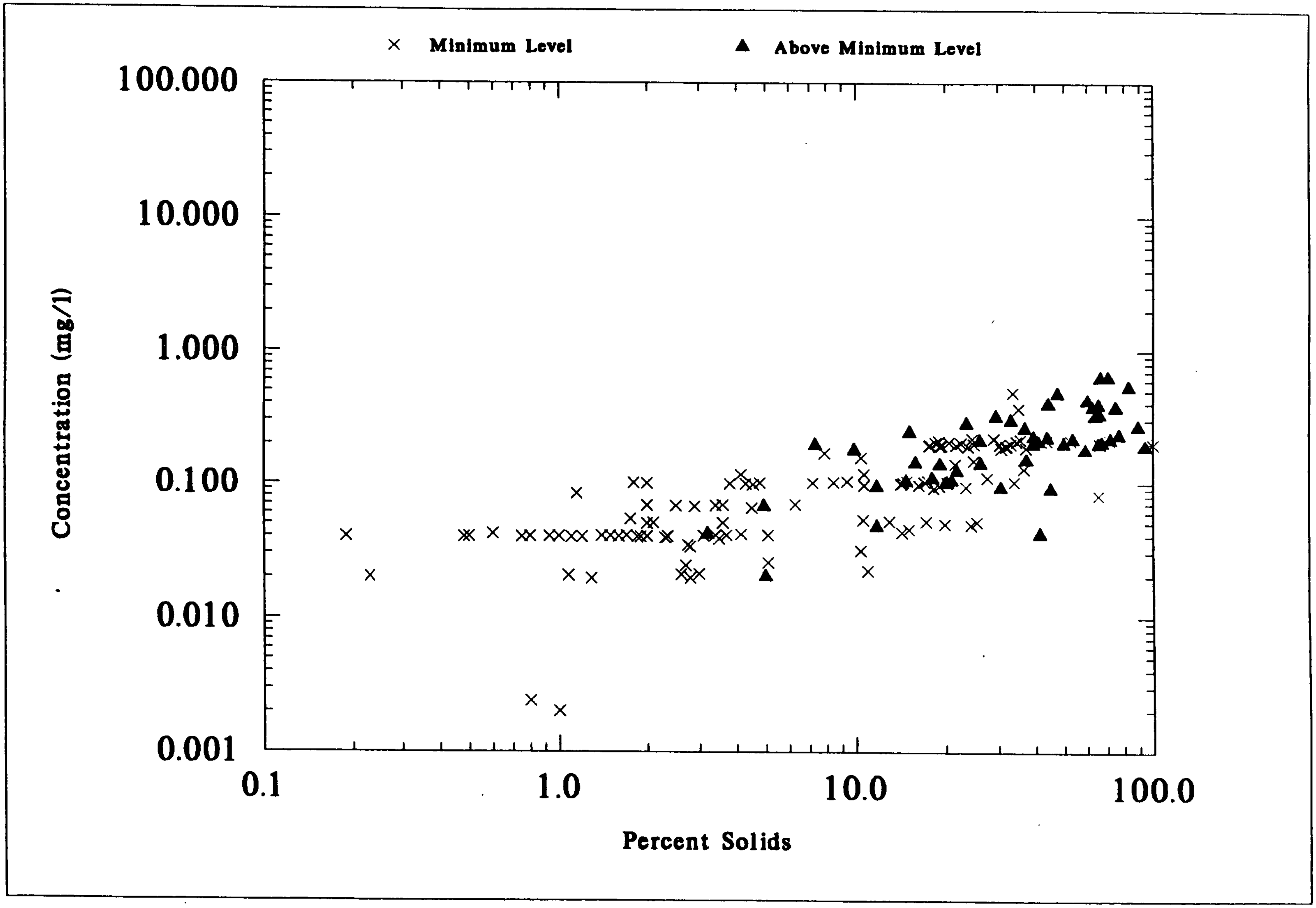


Figure 7-10. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of BERYLLIUM

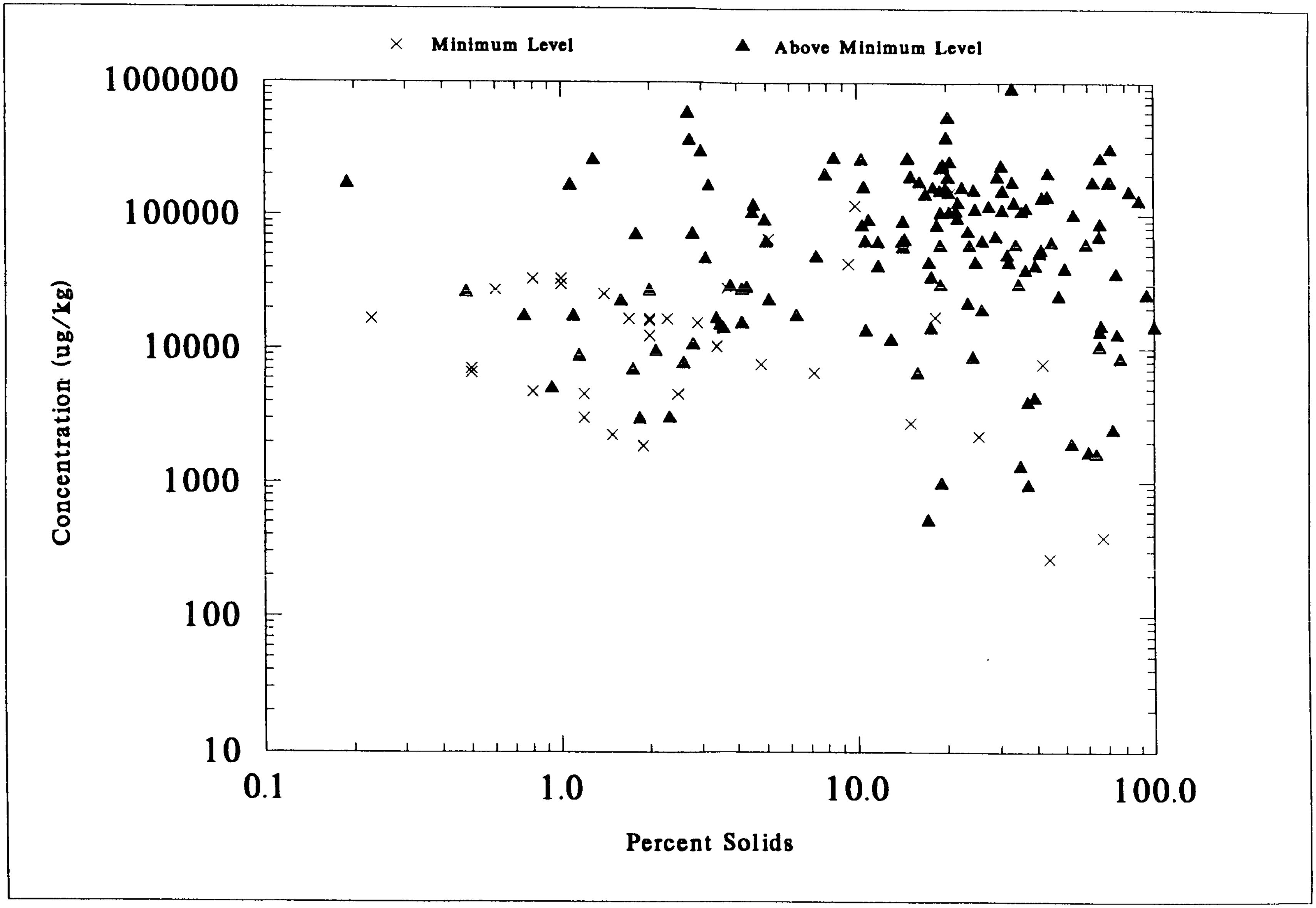


Figure 7-11. Percent Solids of NSSS Samples Versus
DRY WEIGHT Concentrations of BIS(2-ETHYLHEXYL) PHTHALATE

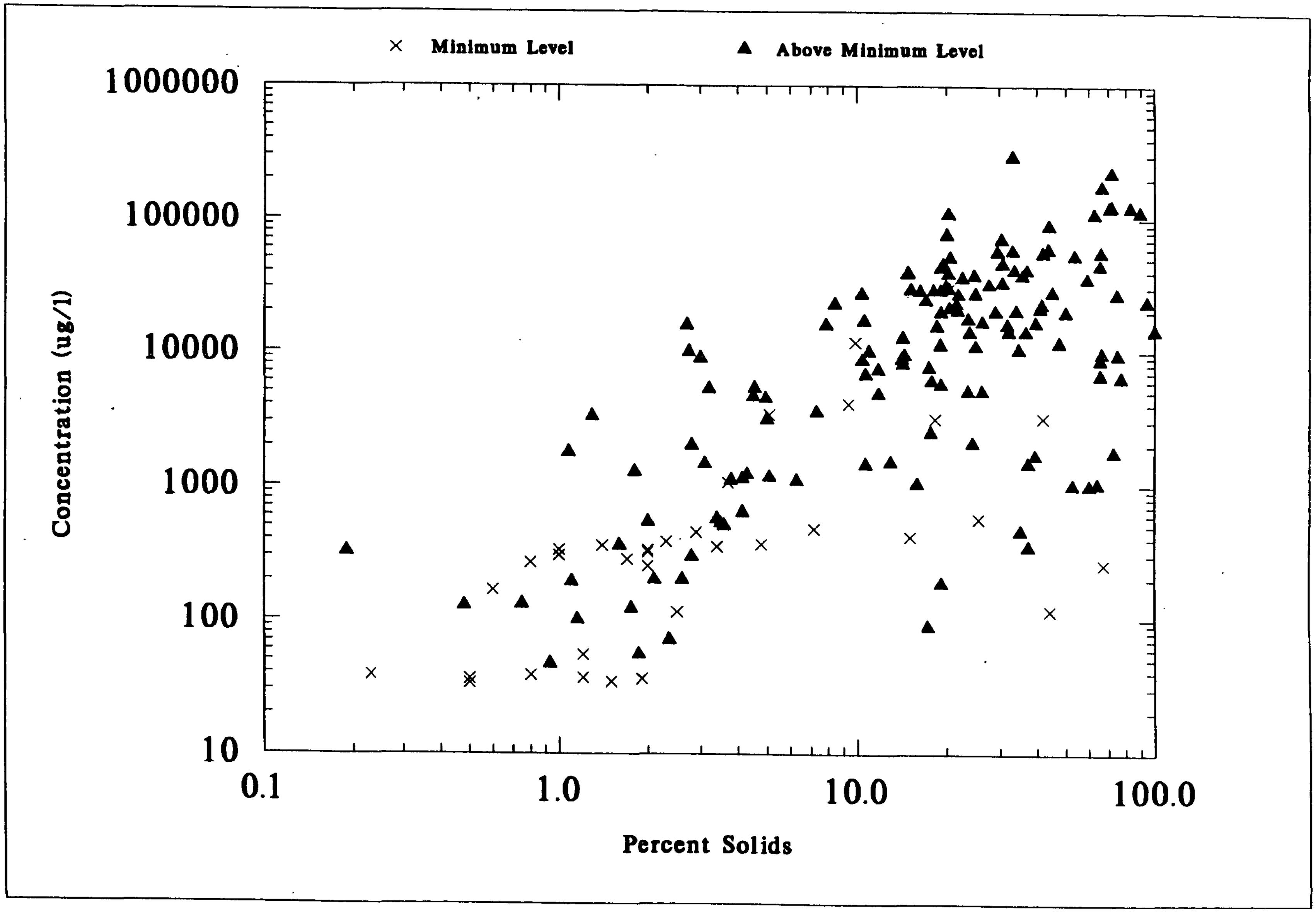


Figure 7-12. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of BIS(2-ETHYLHEXYL) PHTHALATE

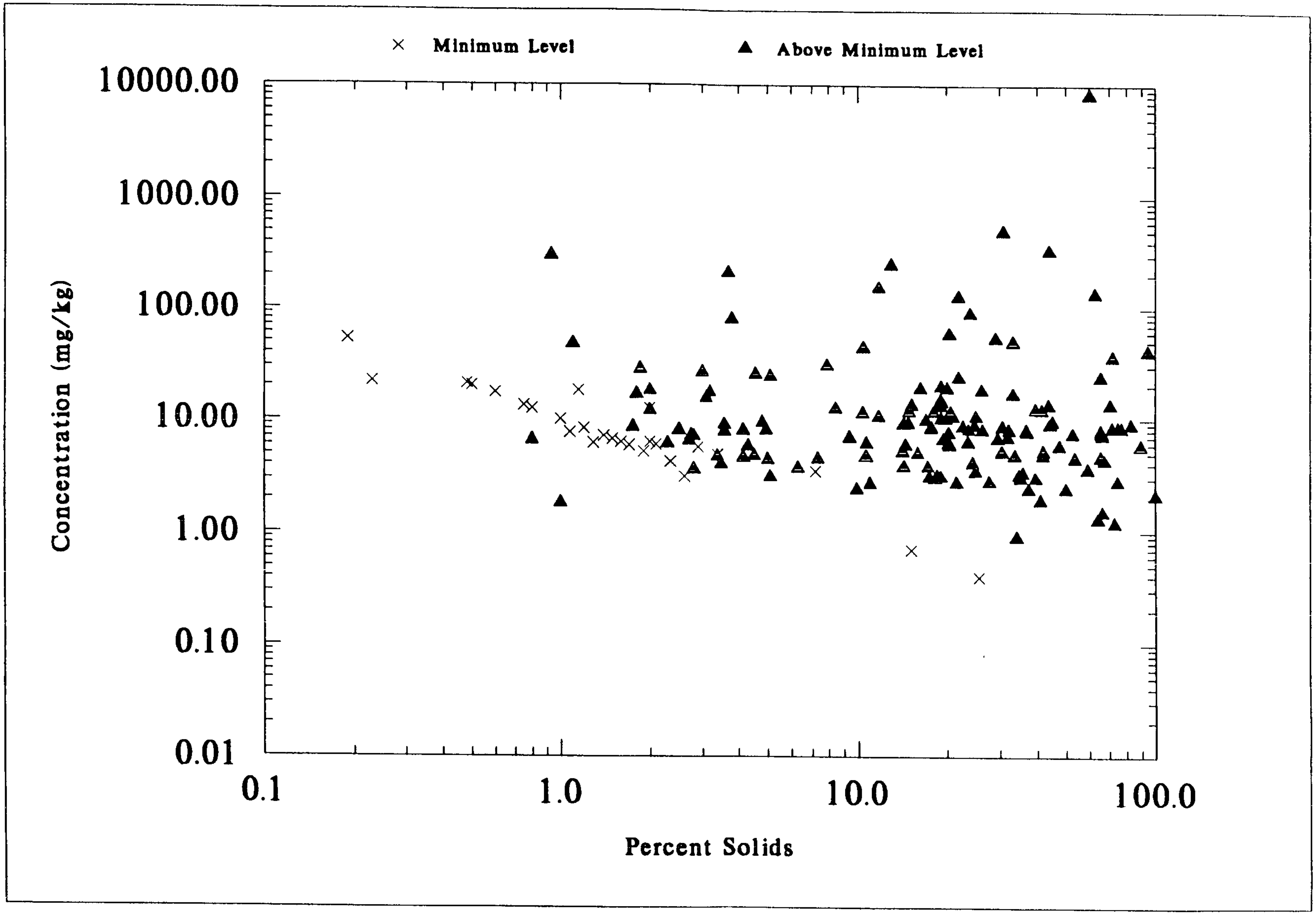


Figure 7-13. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of CADMIUM

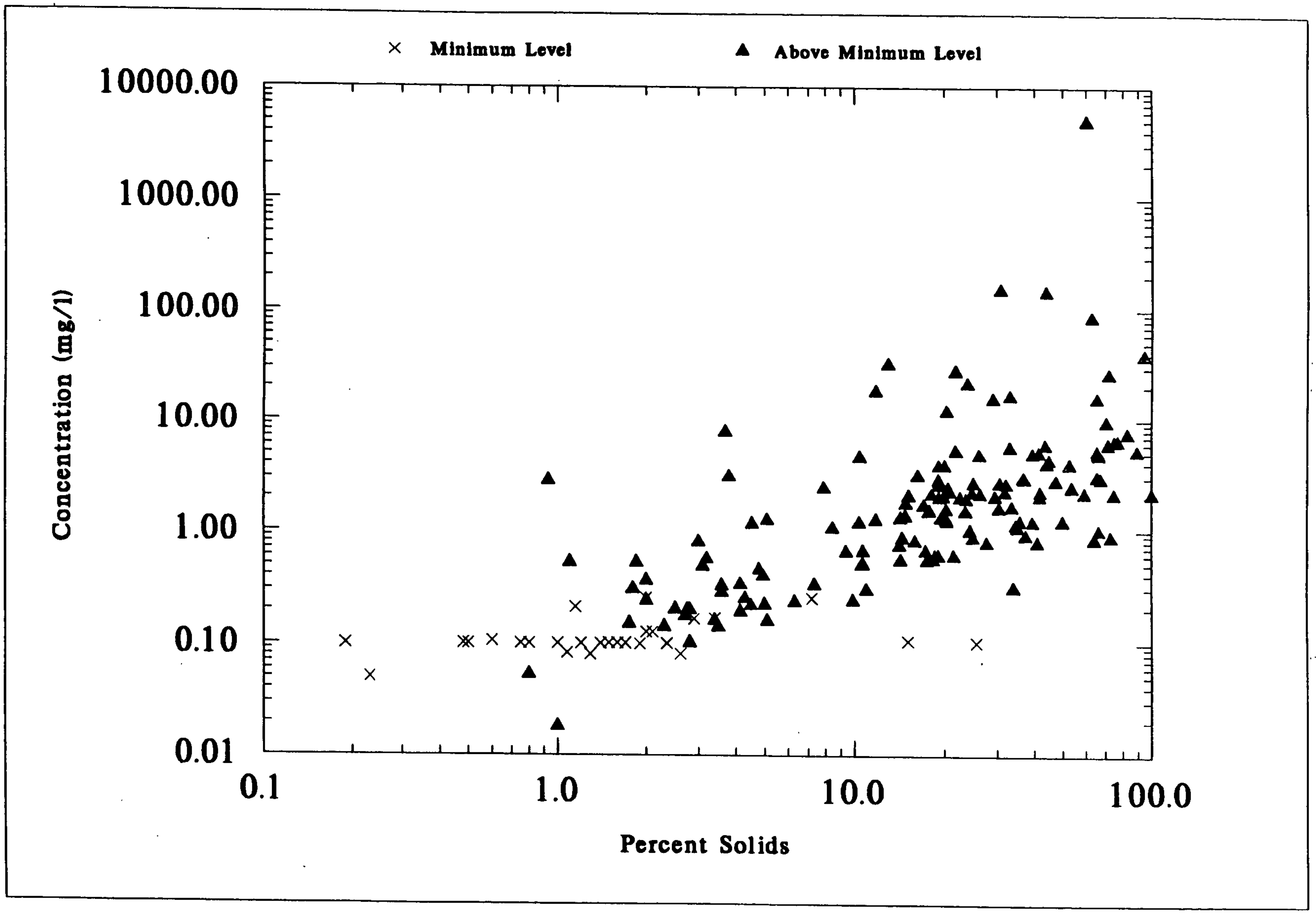


Figure 7-14. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of CADMIUM

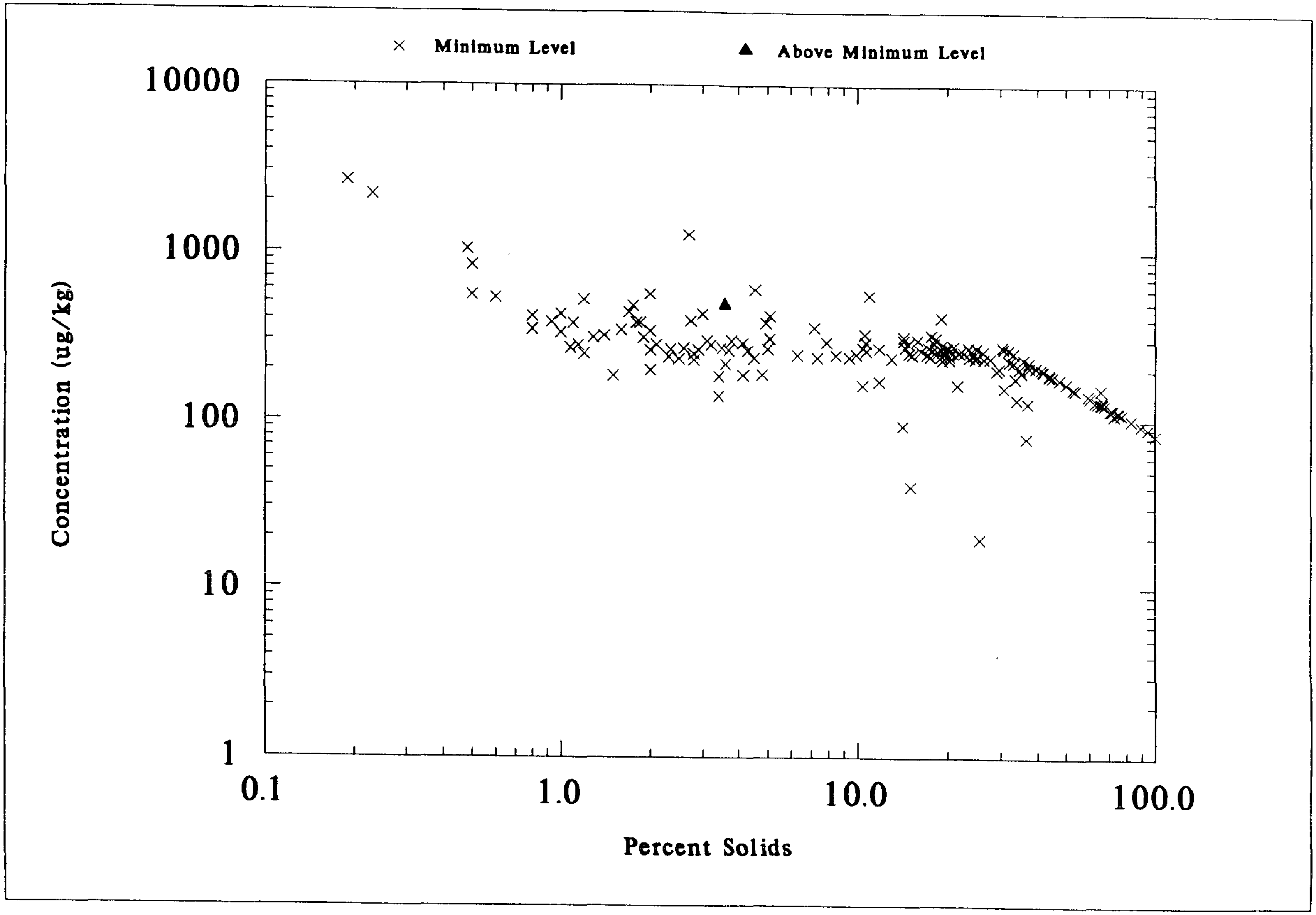


Figure 7-15. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of CHLORDANE

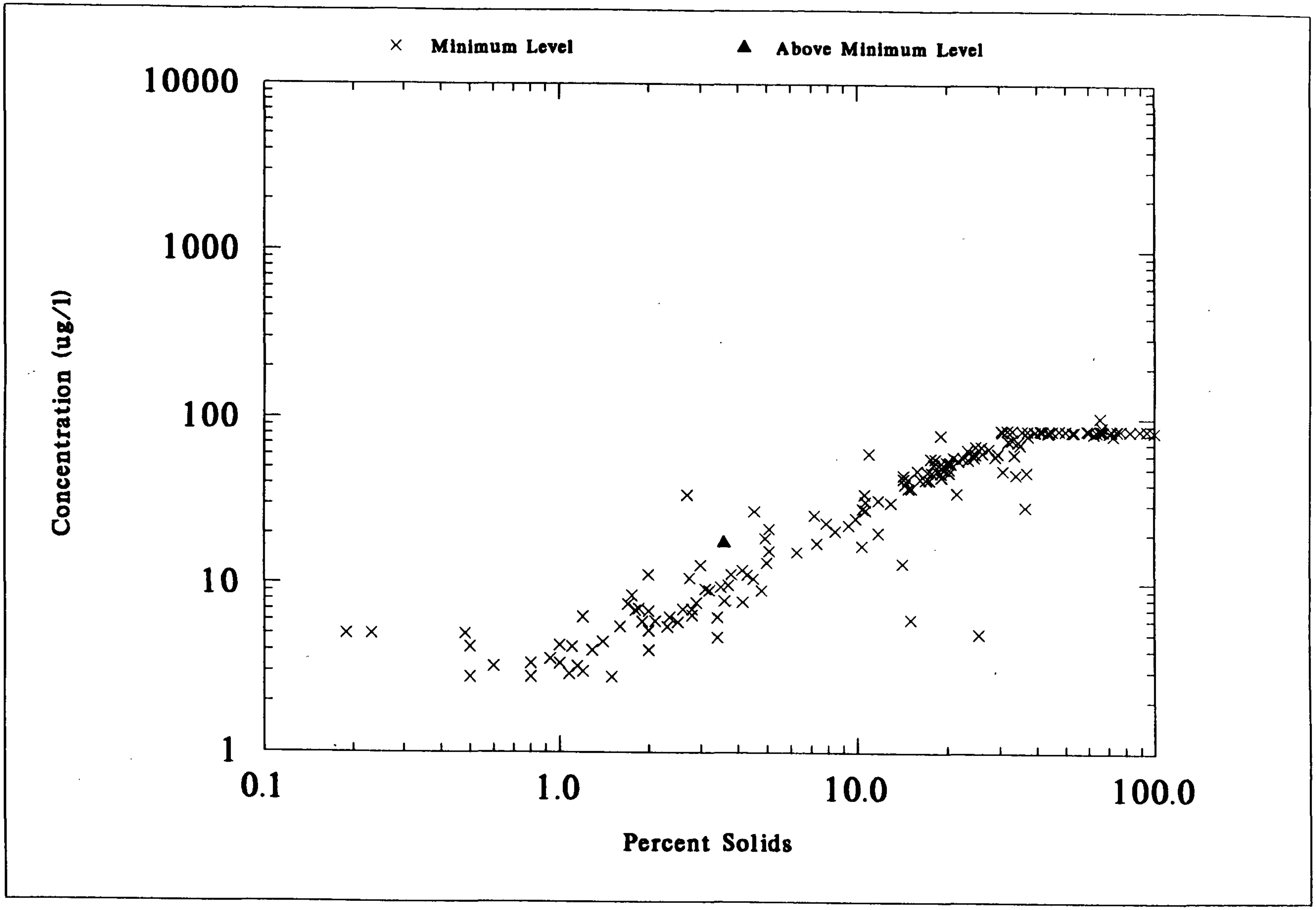


Figure 7-16. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of CHLORDANE

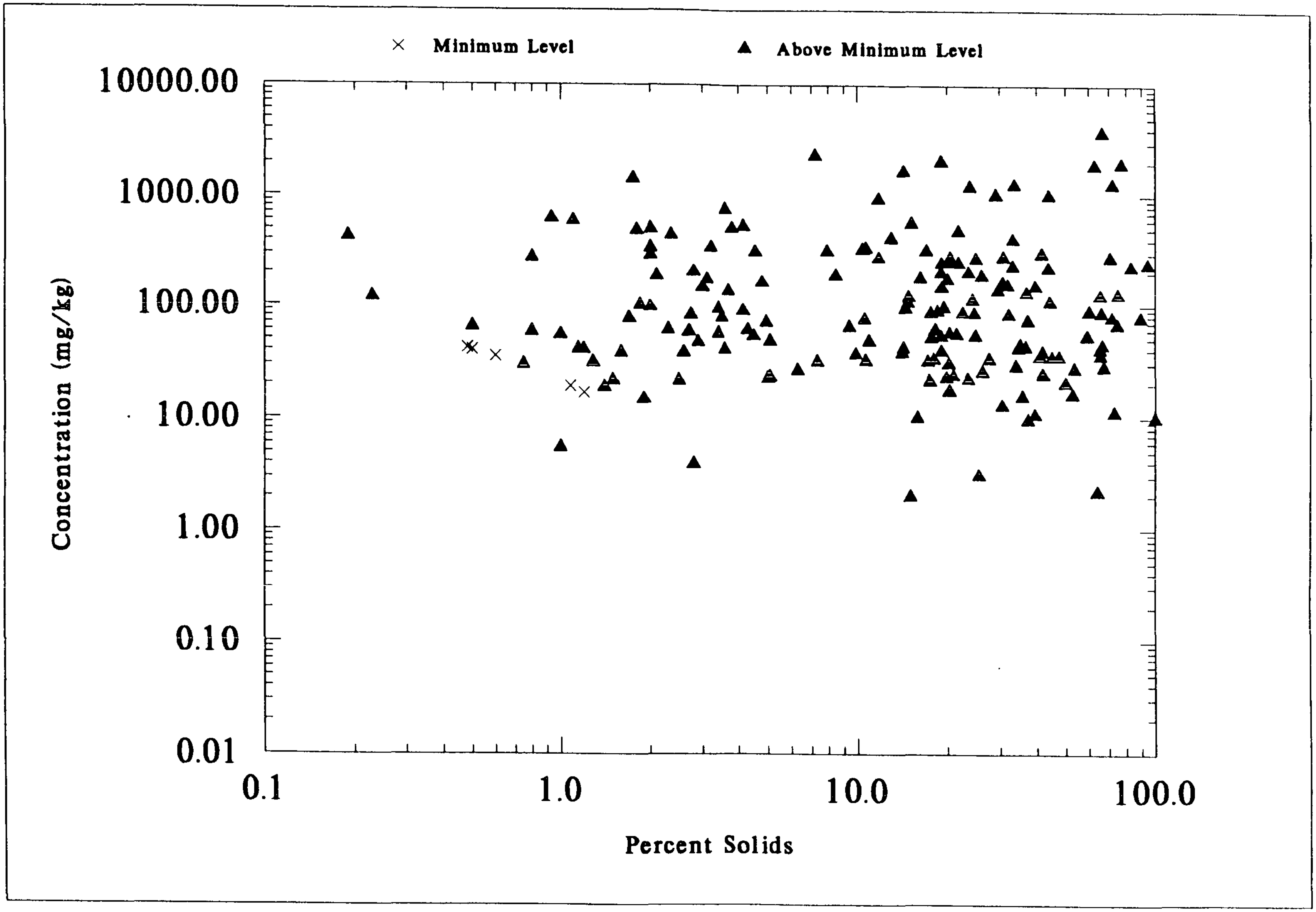


Figure 7-17. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of CHROMIUM

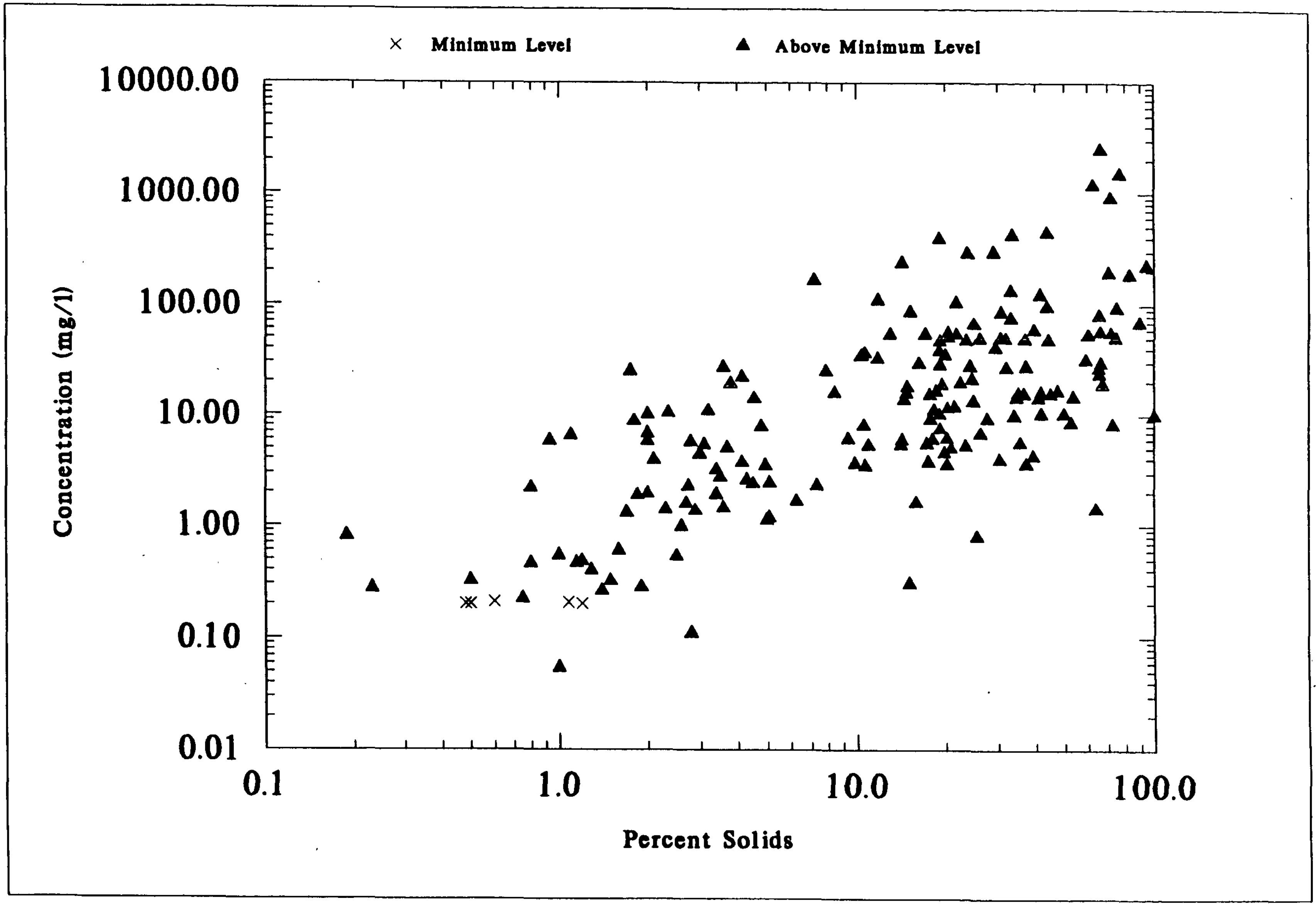


Figure 7-18. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of CHROMIUM

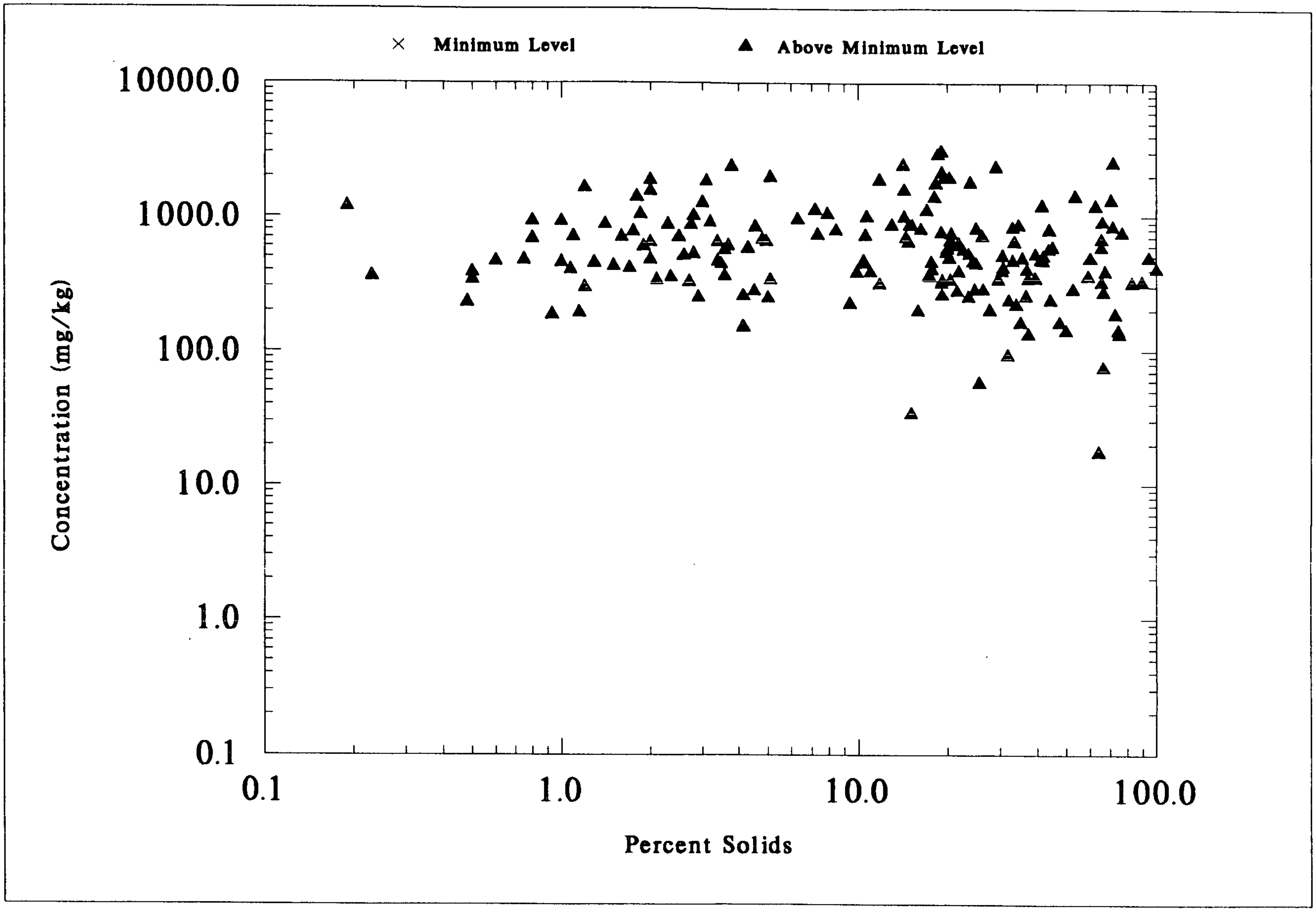


Figure 7–19. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of COPPER

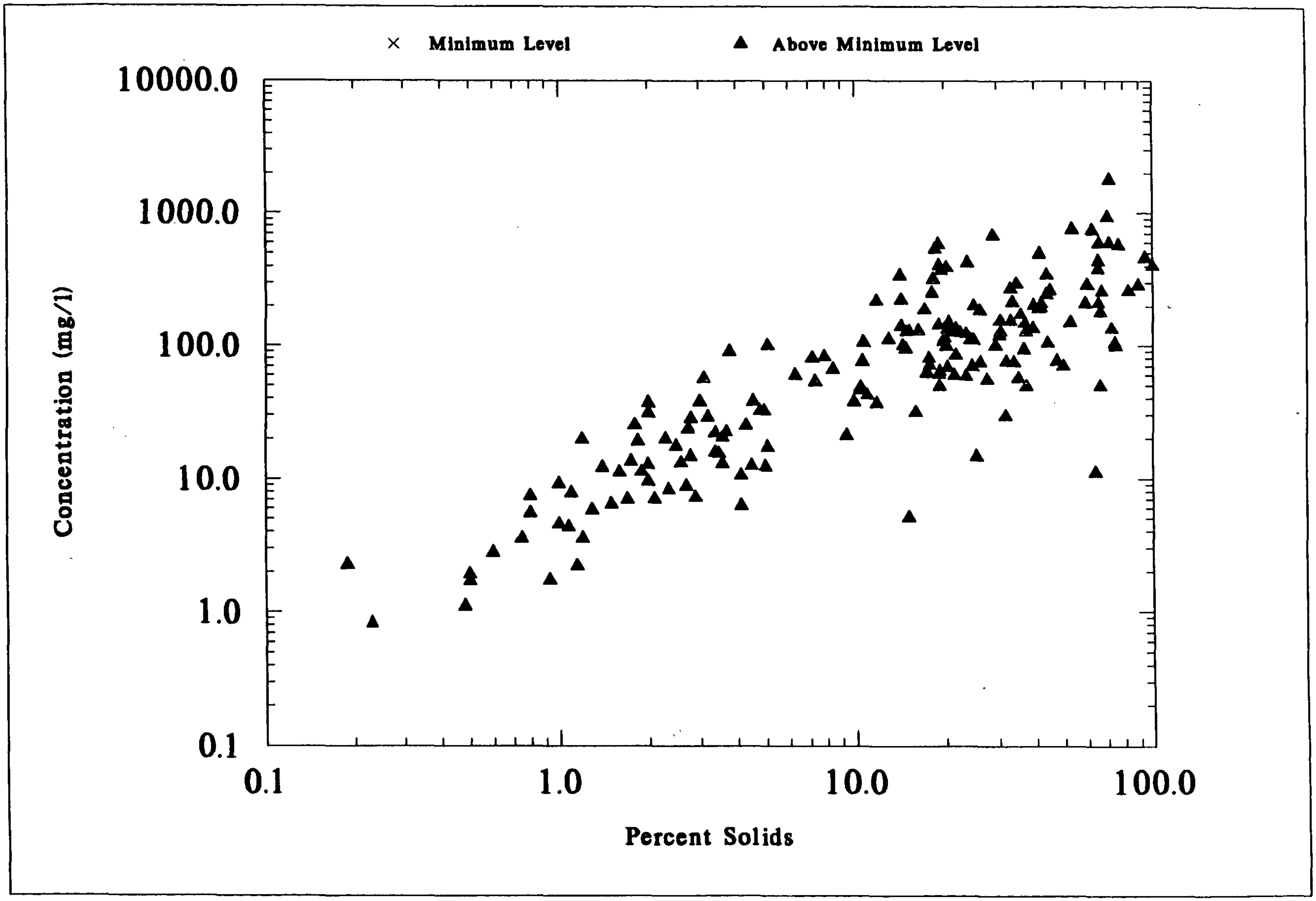


Figure 7-20. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of COPPER

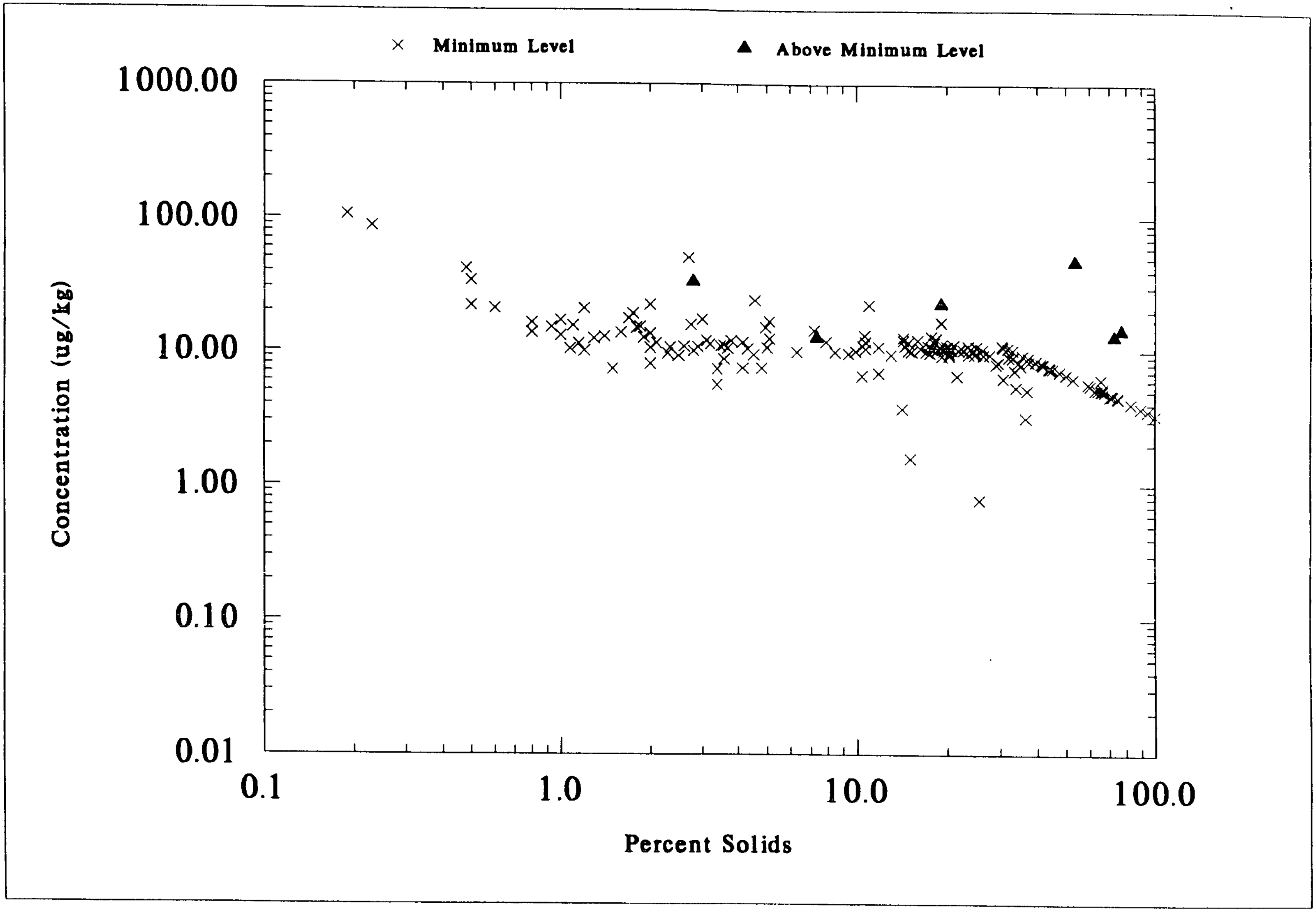


Figure 7-21. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of DIELDRIN

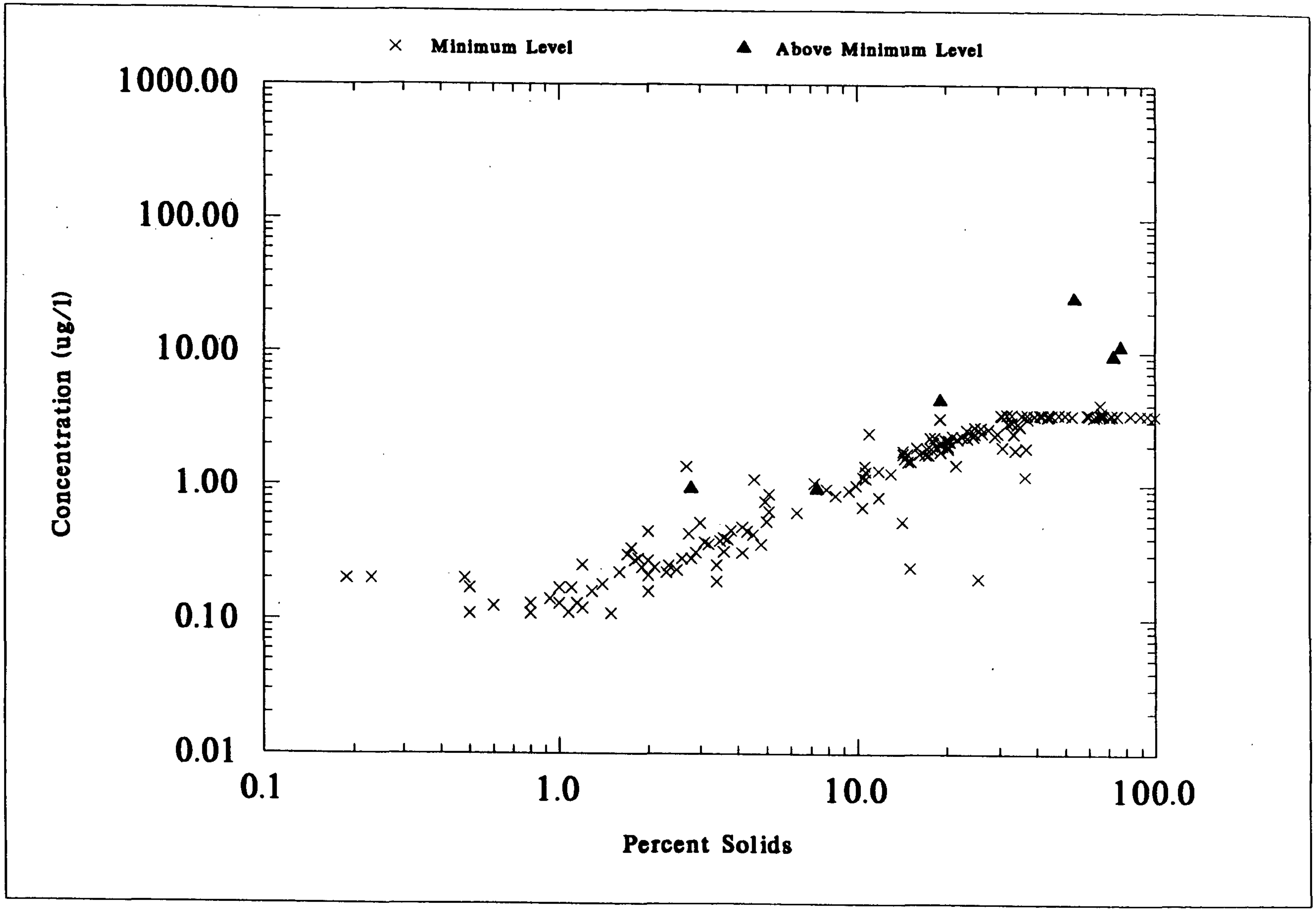


Figure 7-22. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of DIELDRIN

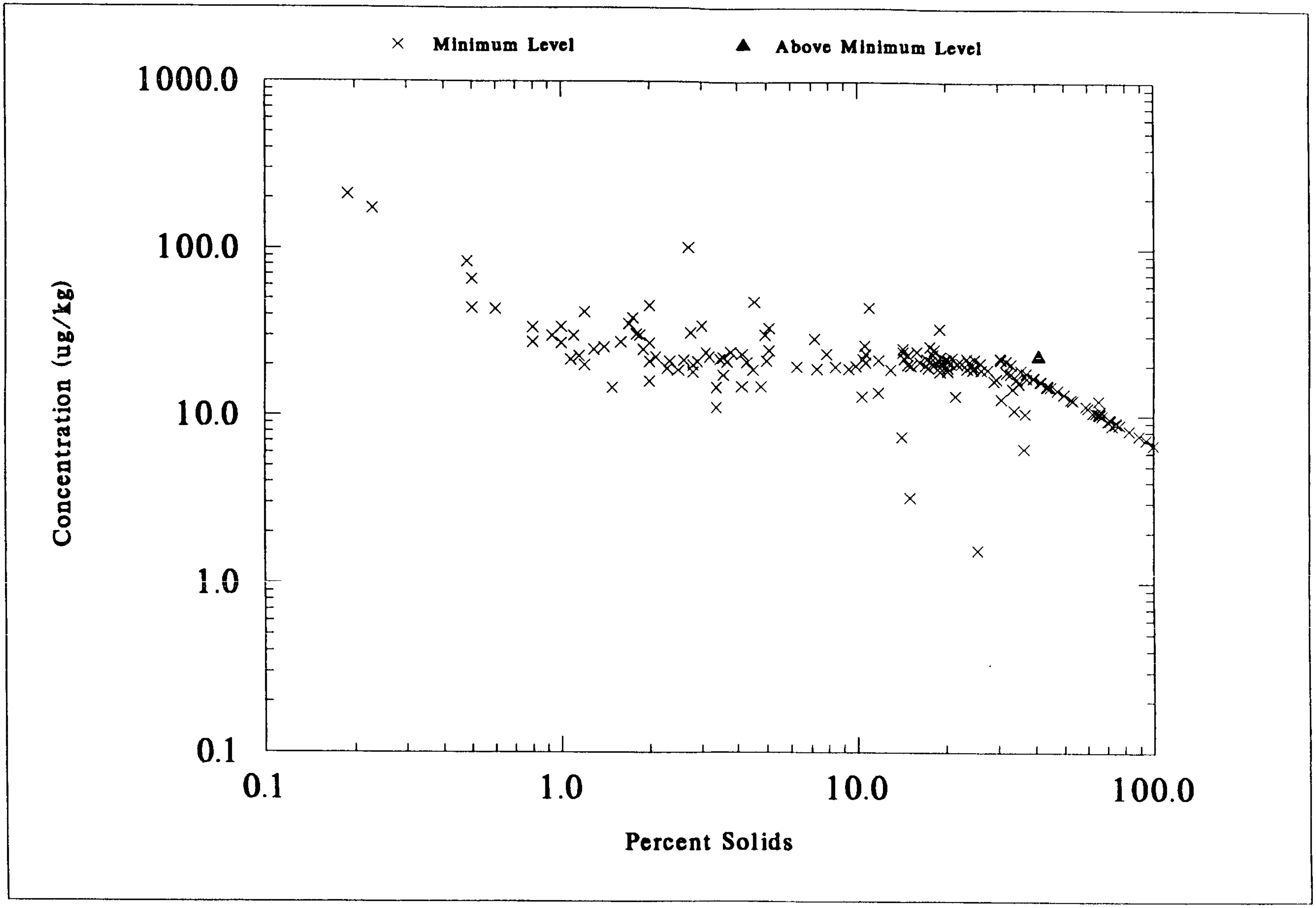


Figure 7-23. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of HEPTACHLOR

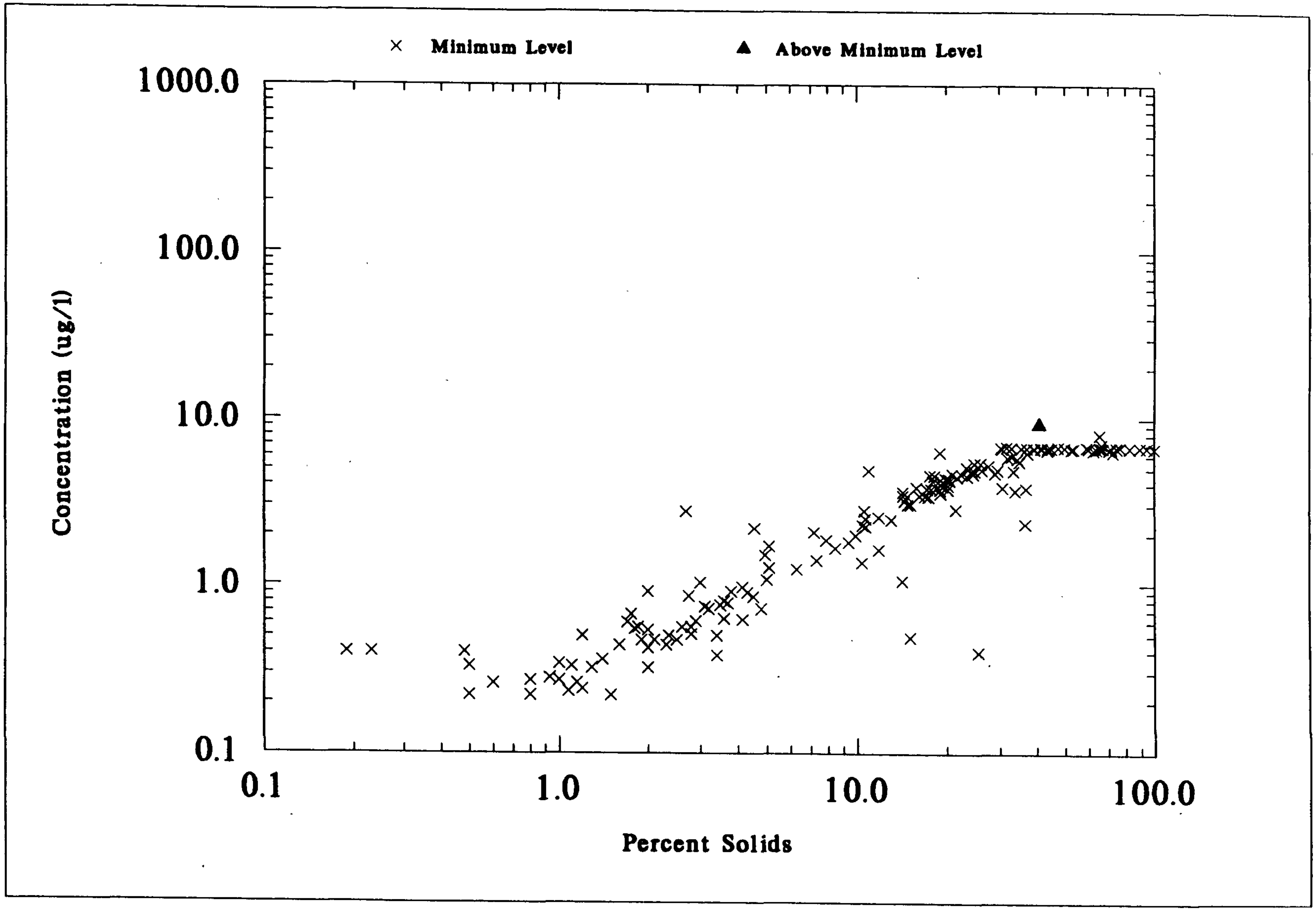


Figure 7-24. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of HEPTACHLOR

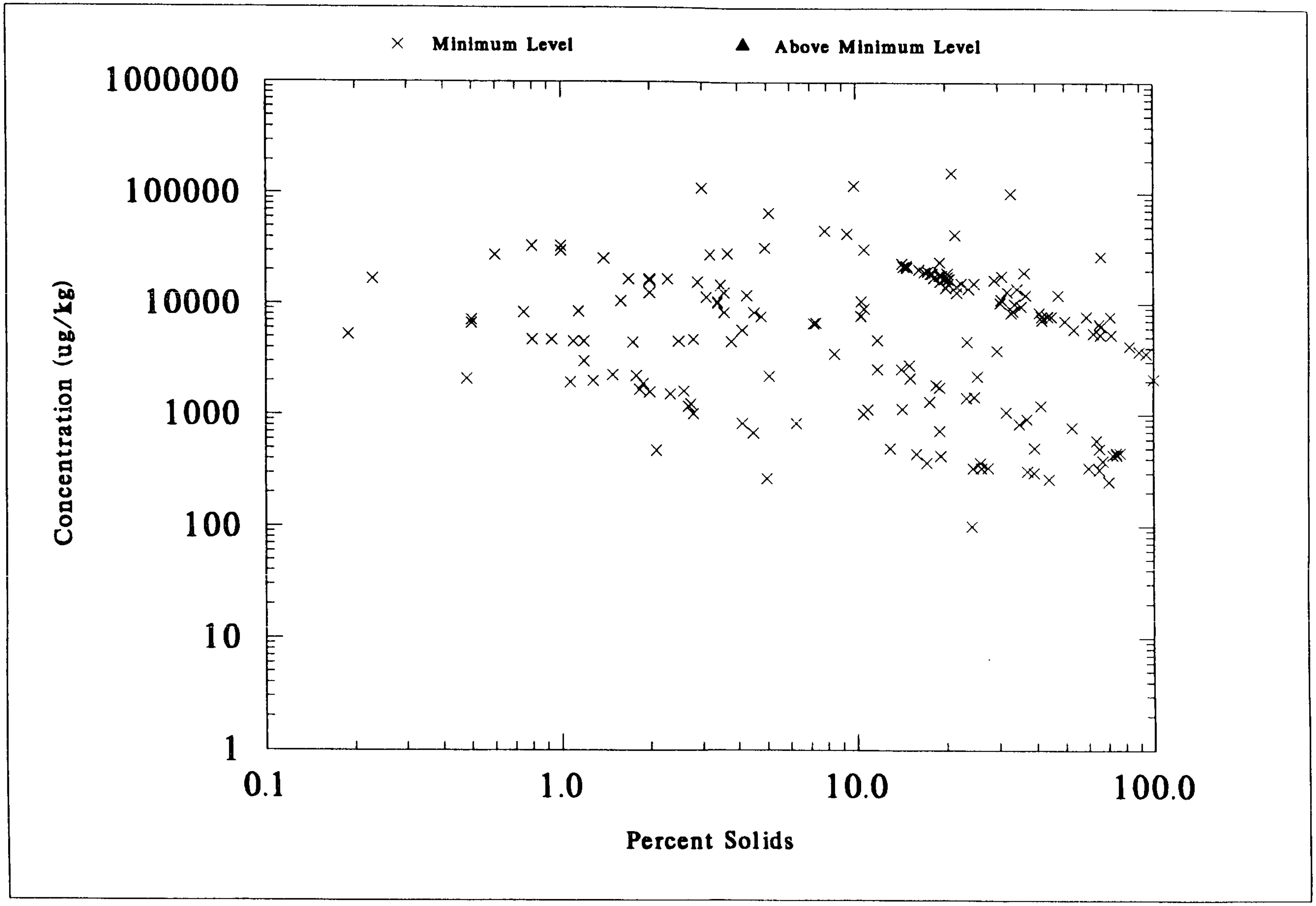


Figure 7–25. Percent Solids of NSSS Samples Versus
DRY WEIGHT Concentrations of HEXACHLOROBENZENE

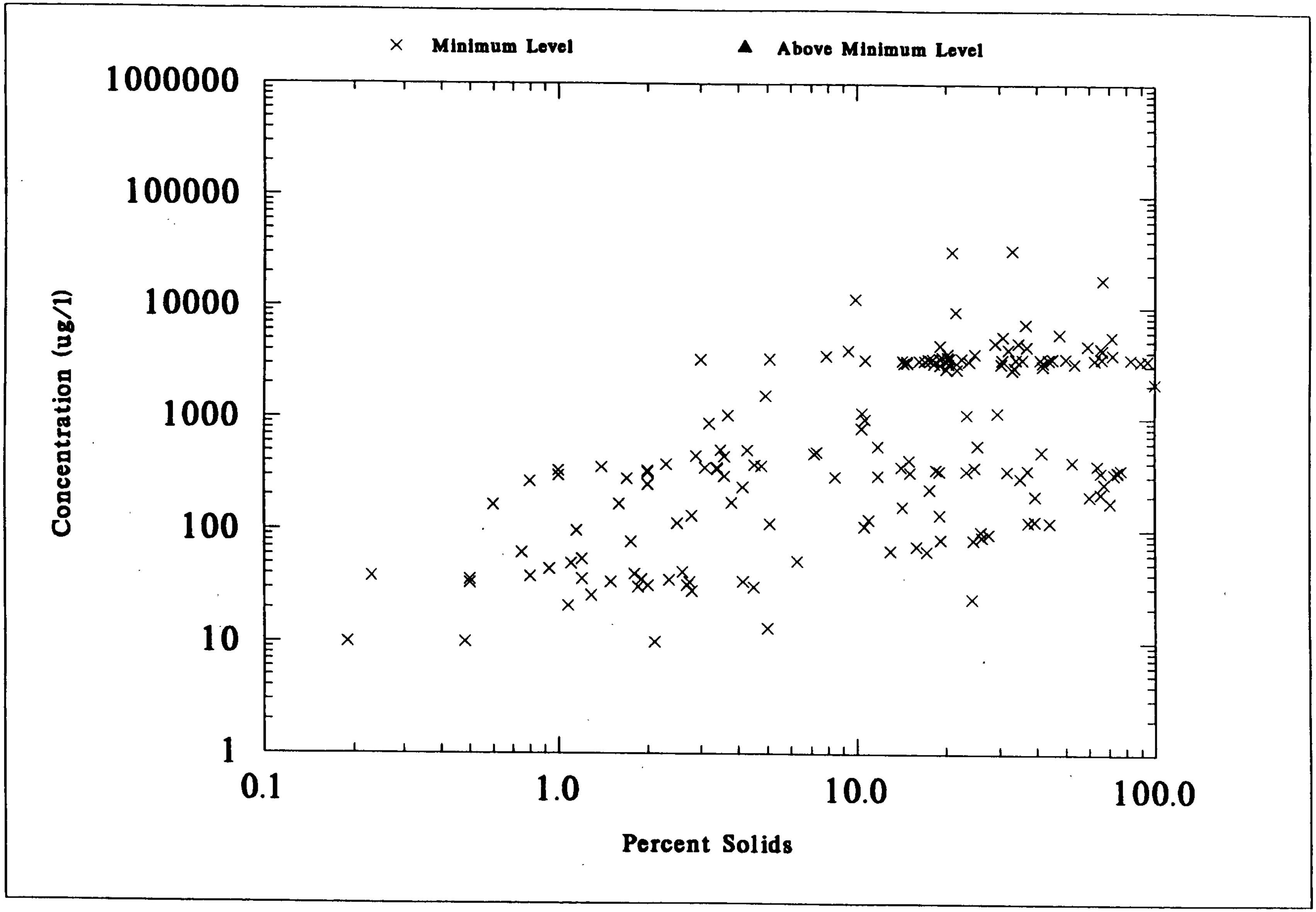


Figure 7-26. Percent Solids of NSSS Samples Versus
WET WEIGHT Concentrations of HEXACHLOROBENZENE

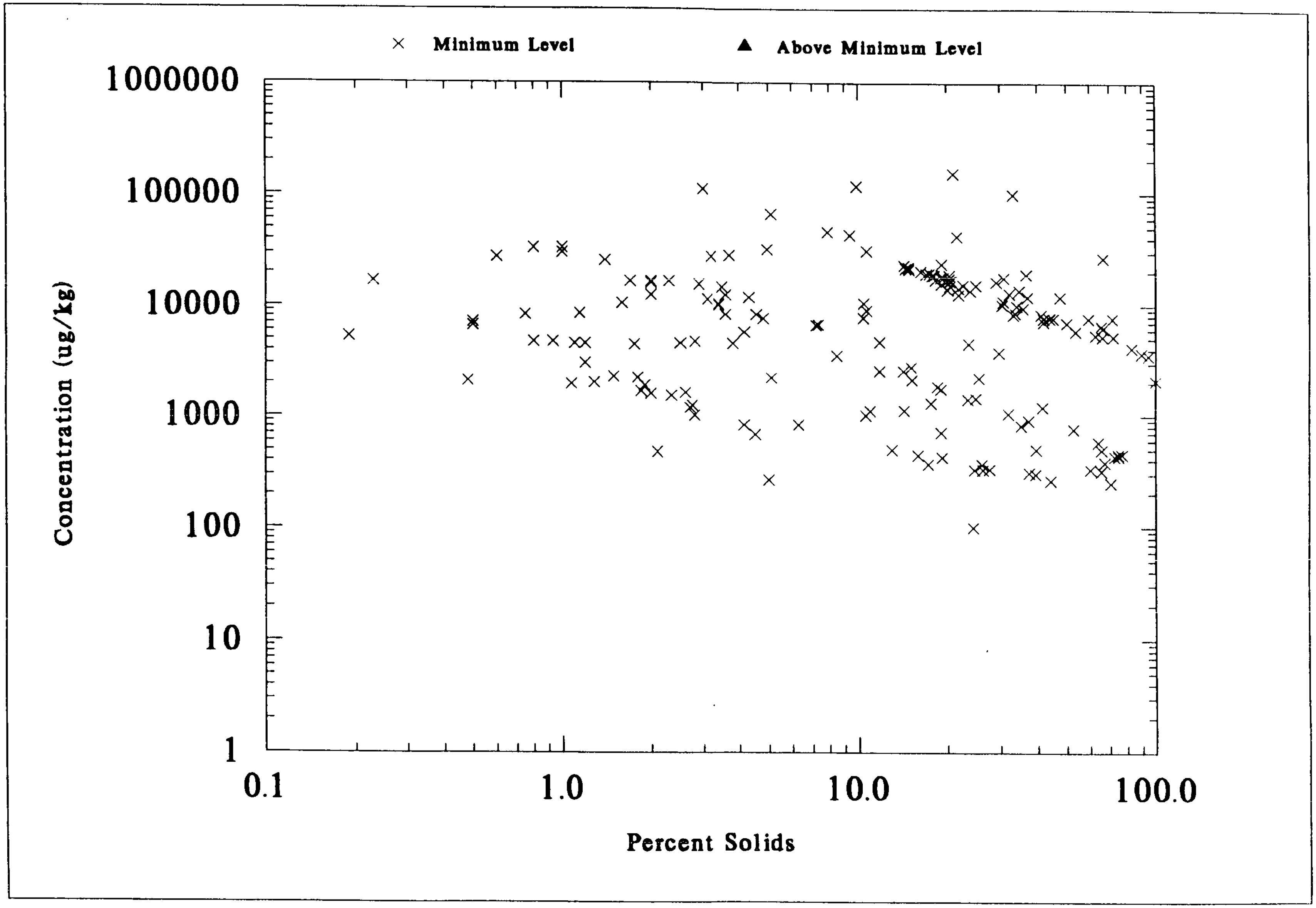


Figure 7-27. Percent Solids of NSSS Samples Versus
DRY WEIGHT Concentrations of HEXACHLOROBUTADIENE

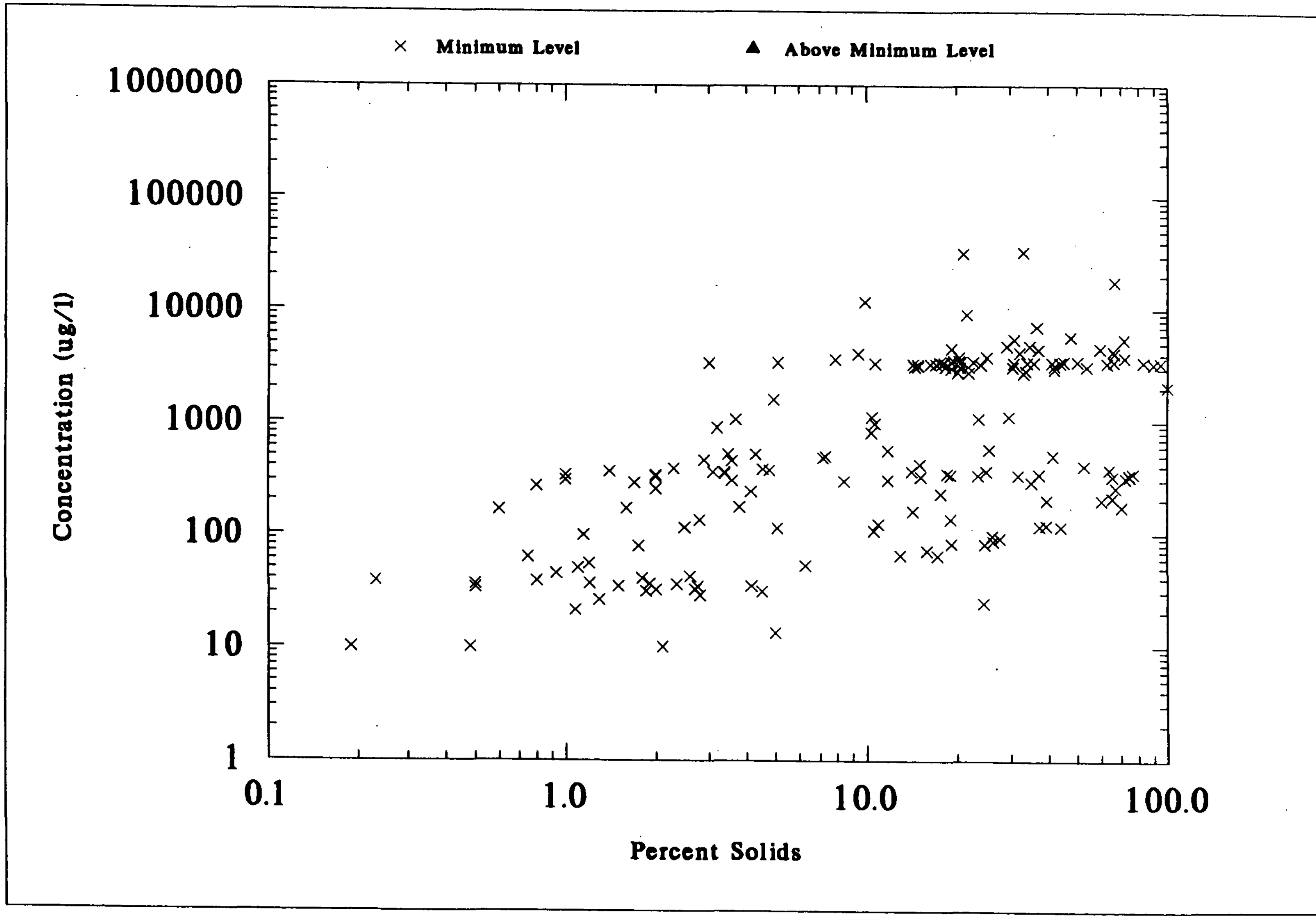


Figure 7–28. Percent Solids of NSSS Samples Versus
WET WEIGHT Concentrations of HEXACHLOROBUTADIENE

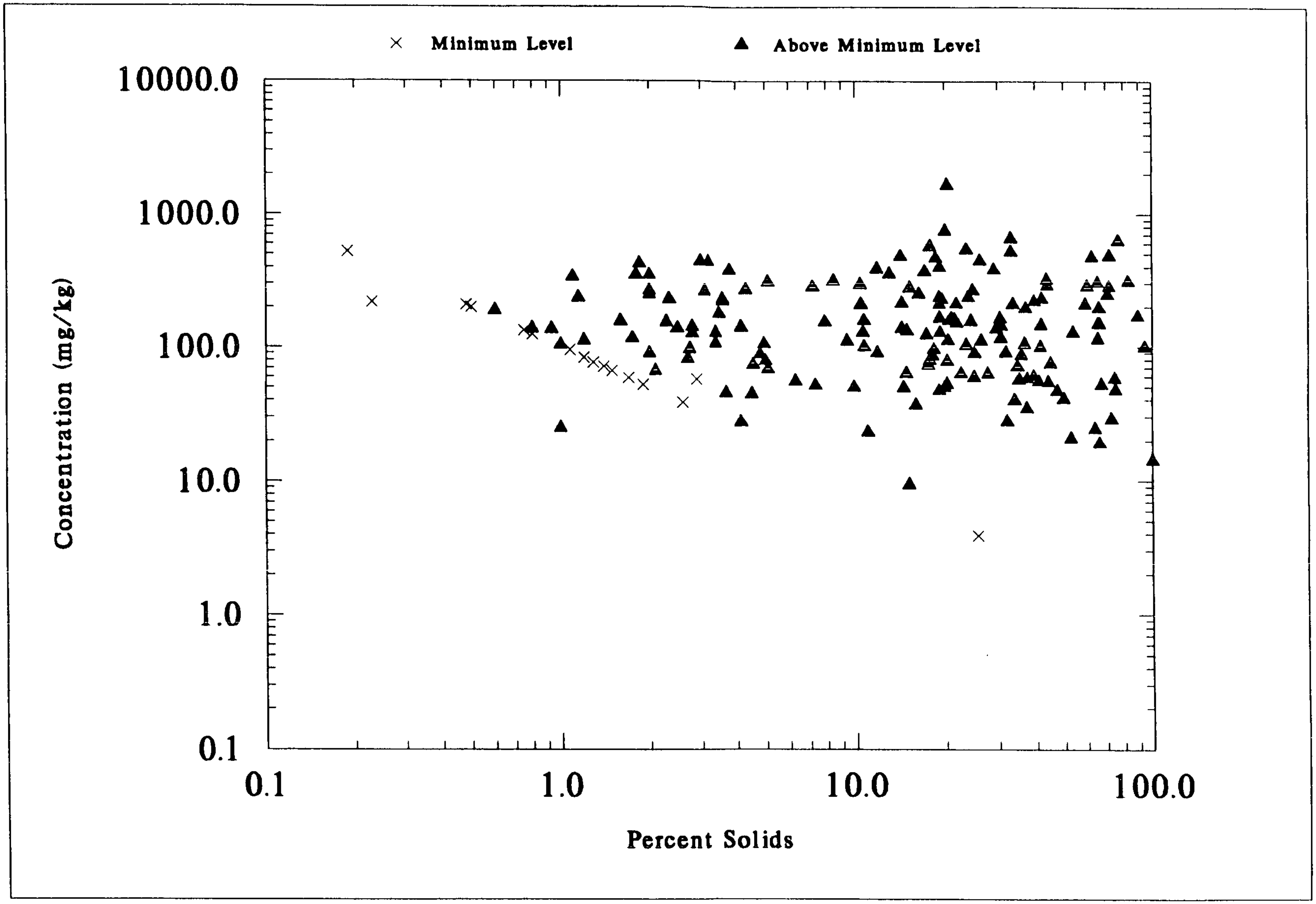


Figure 7-29. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of LEAD

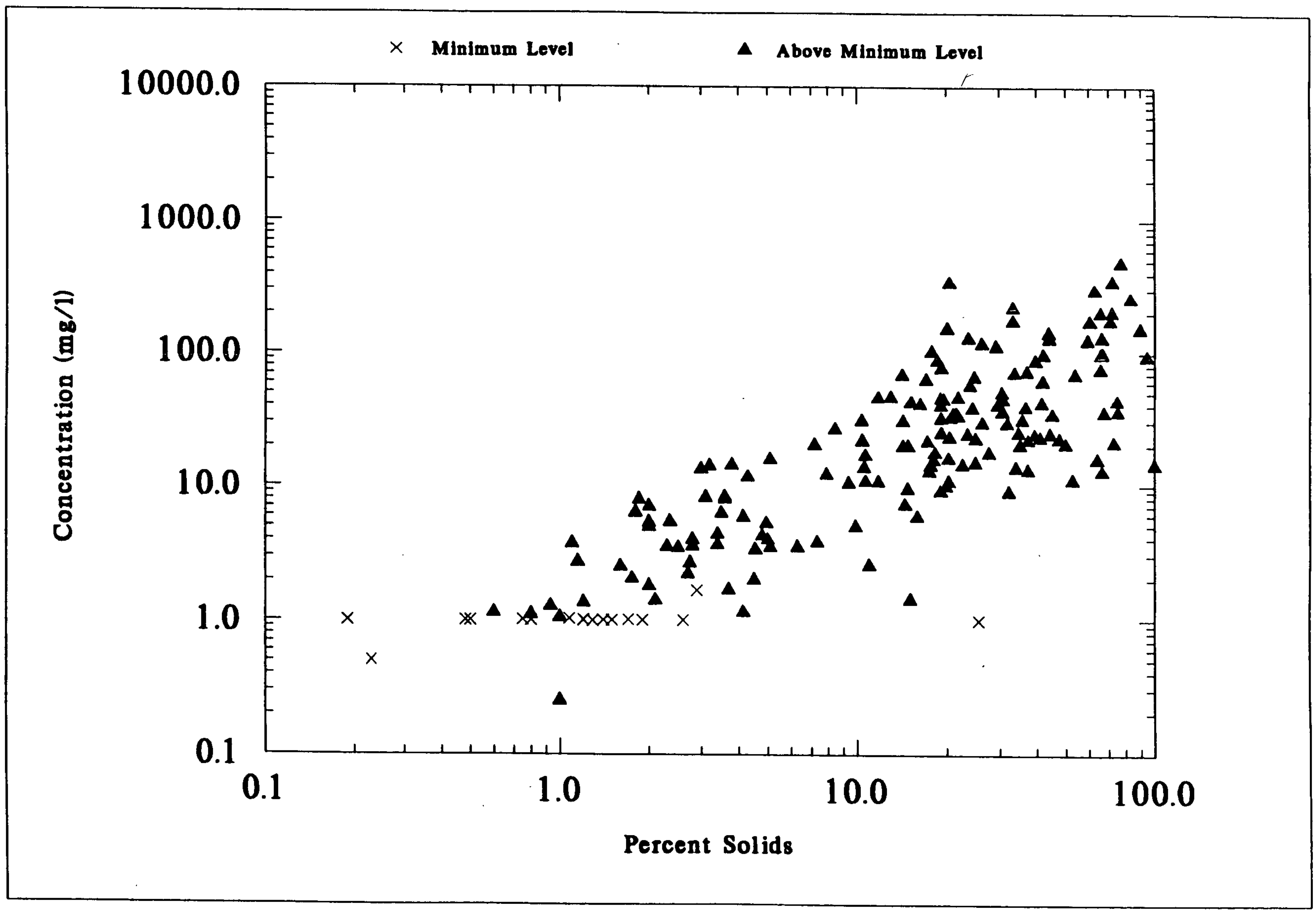


Figure 7-30. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of LEAD

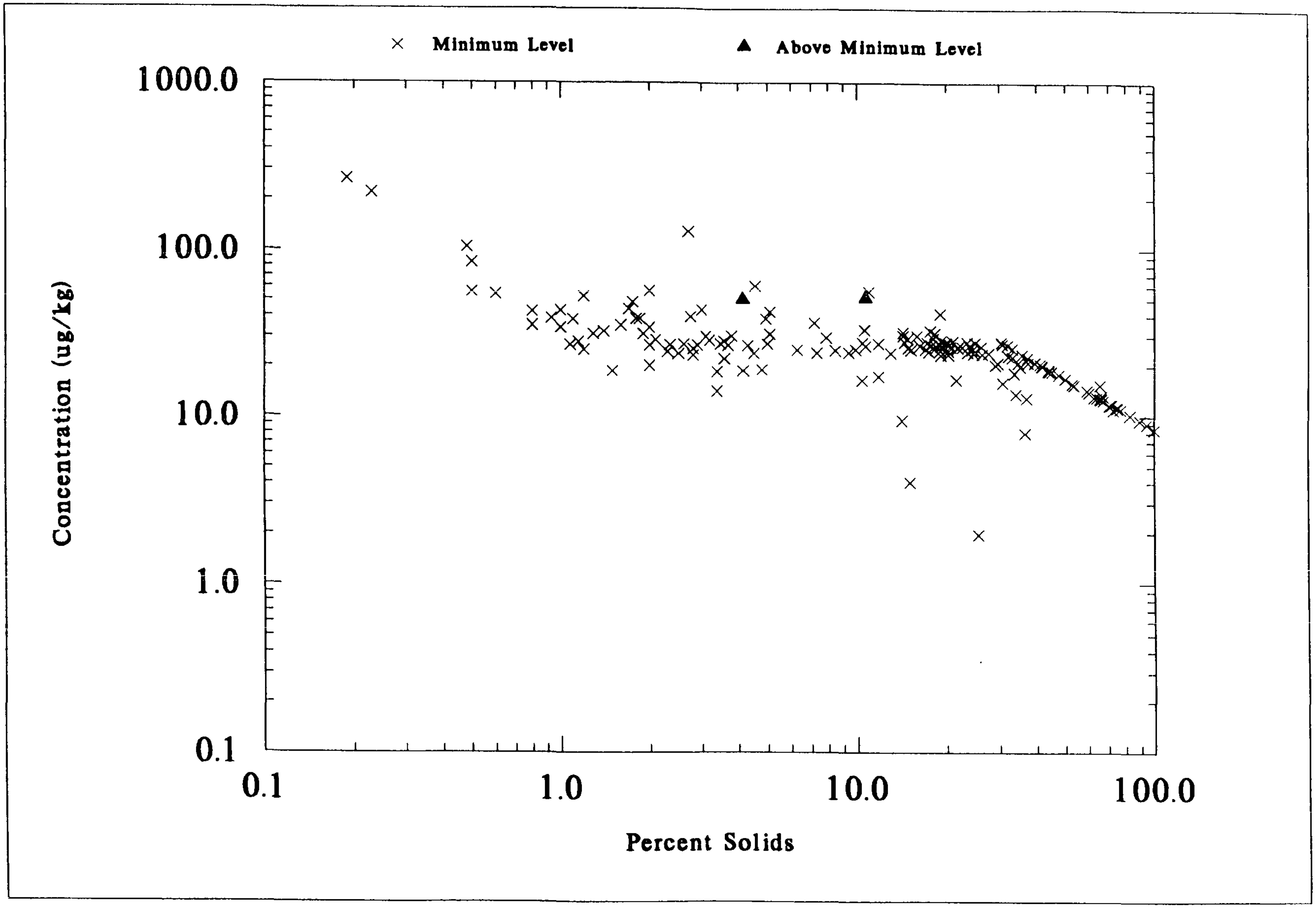


Figure 7-31. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of LINDANE (GAMMA-BHC)

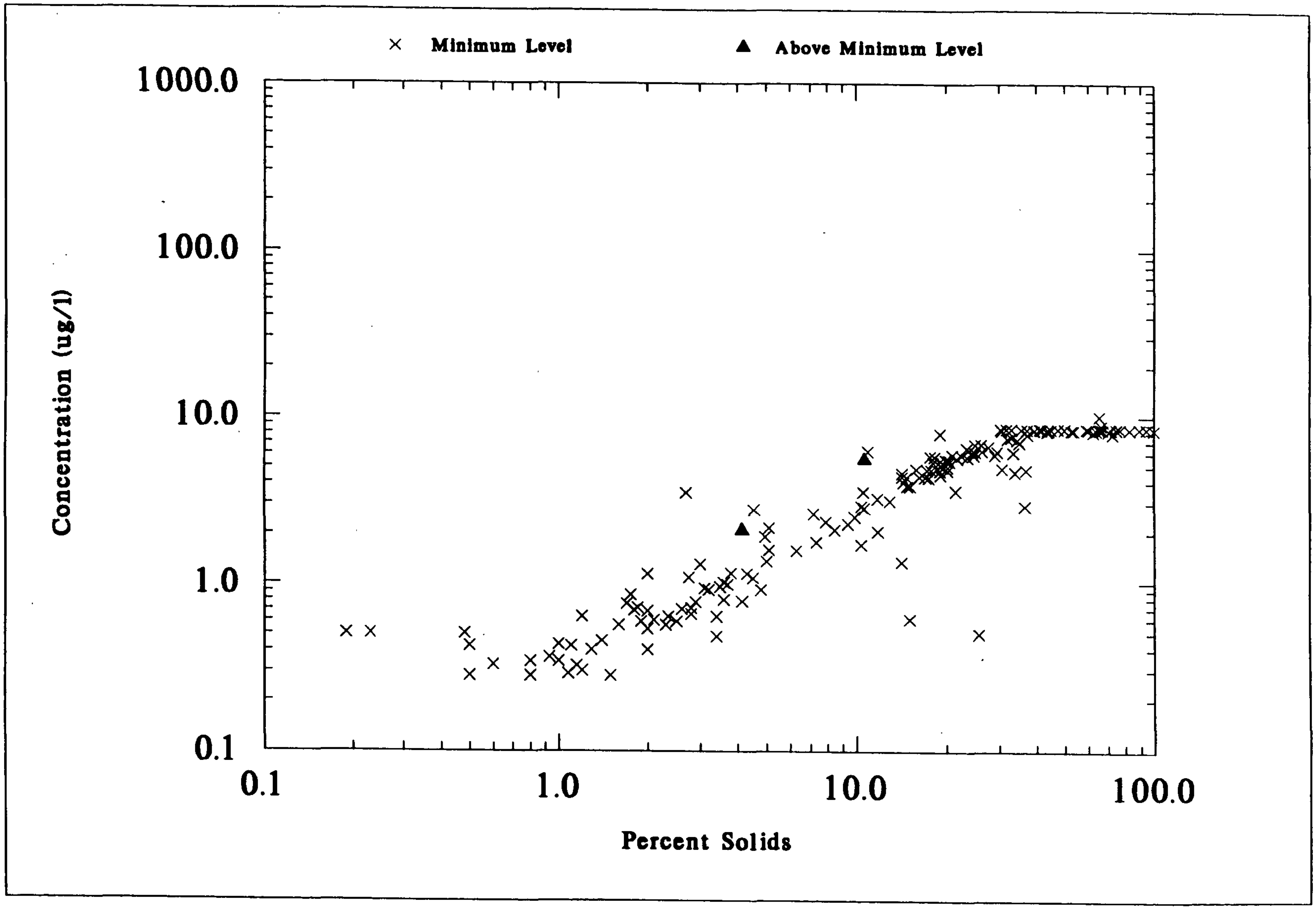


Figure 7-32. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of LINDANE (GAMMA-BHC)

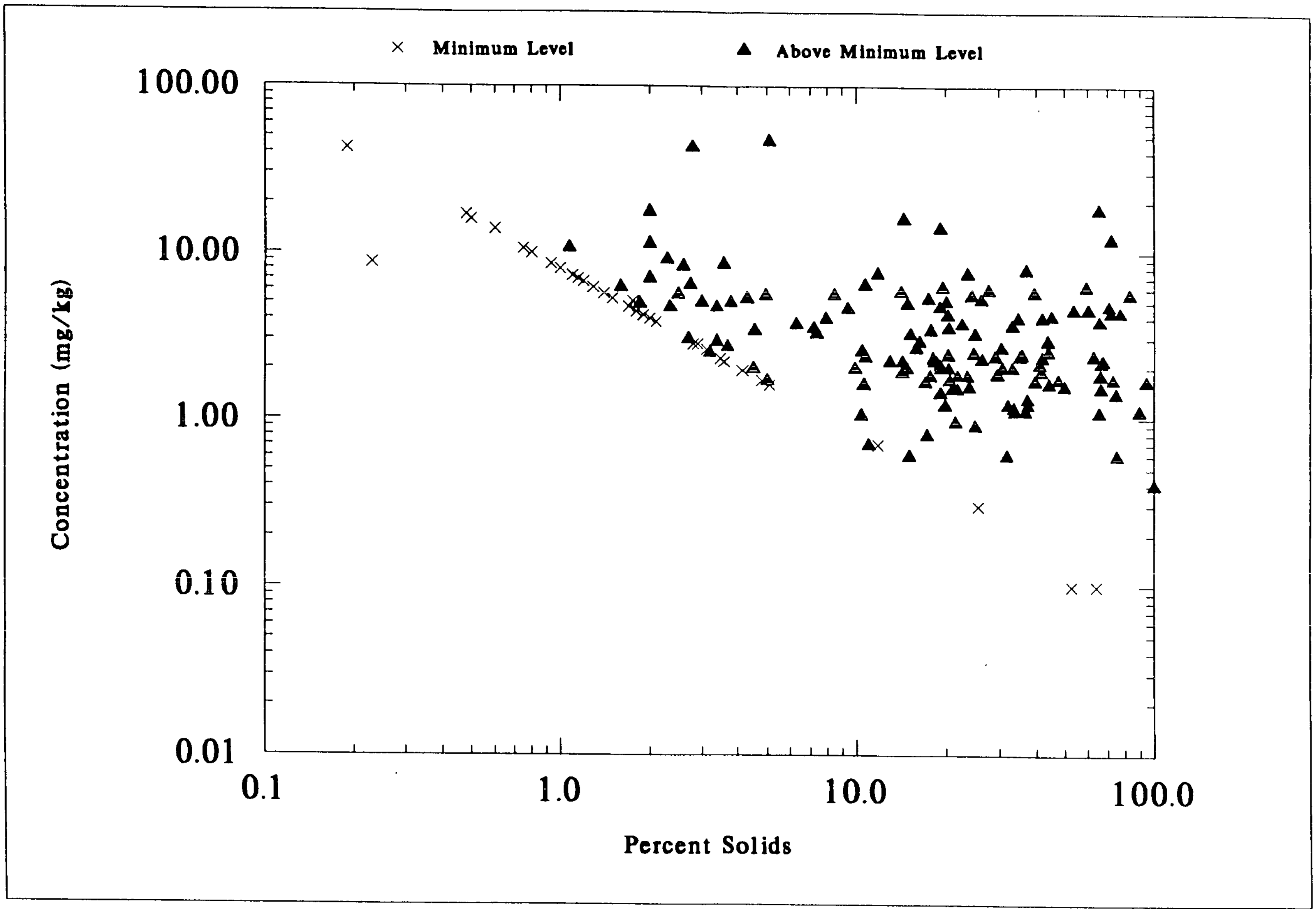


Figure 7-33. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of MERCURY

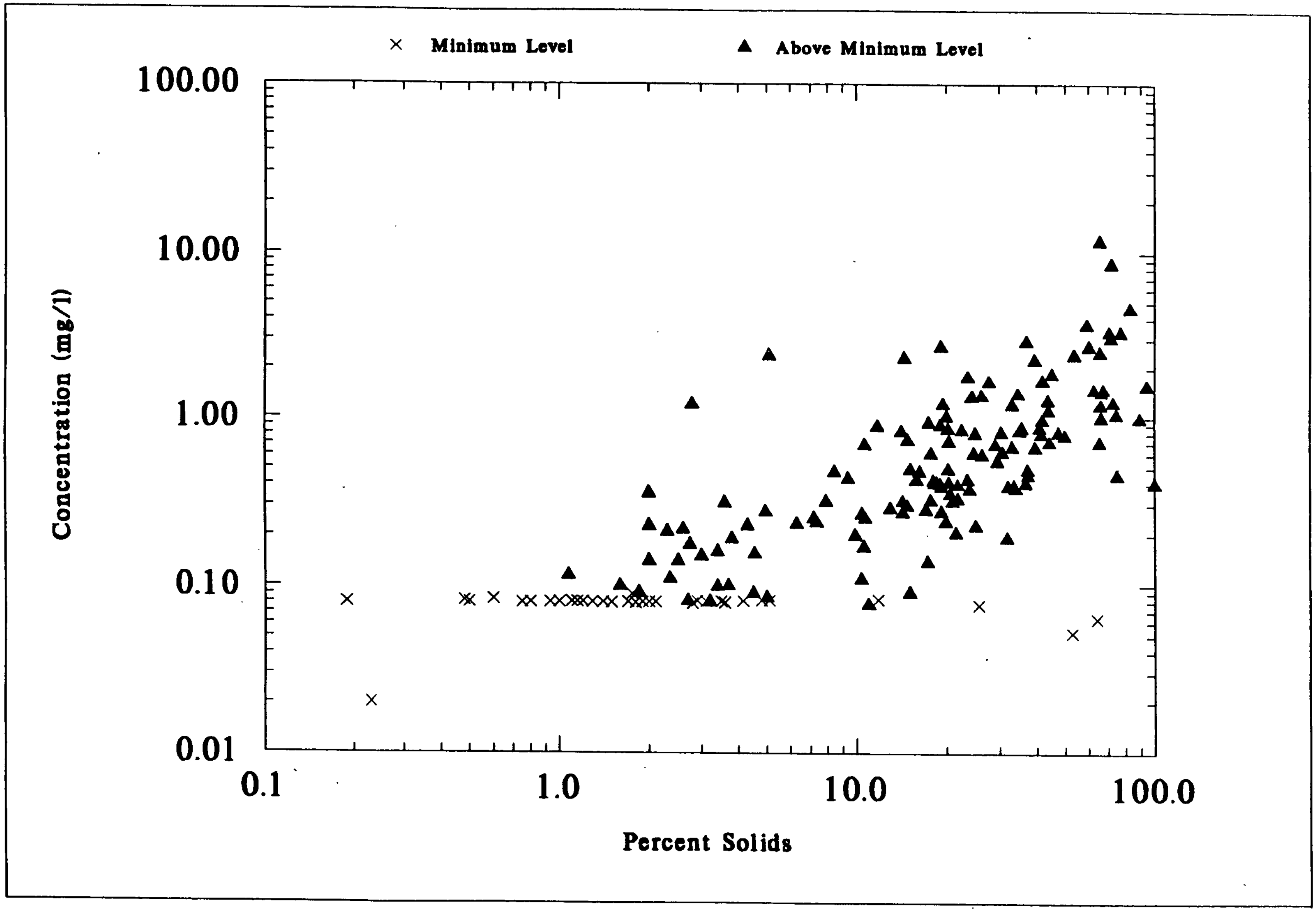


Figure 7-34. Percent Solids of NSSS Samples Versus
WET WEIGHT Concentrations of MERCURY

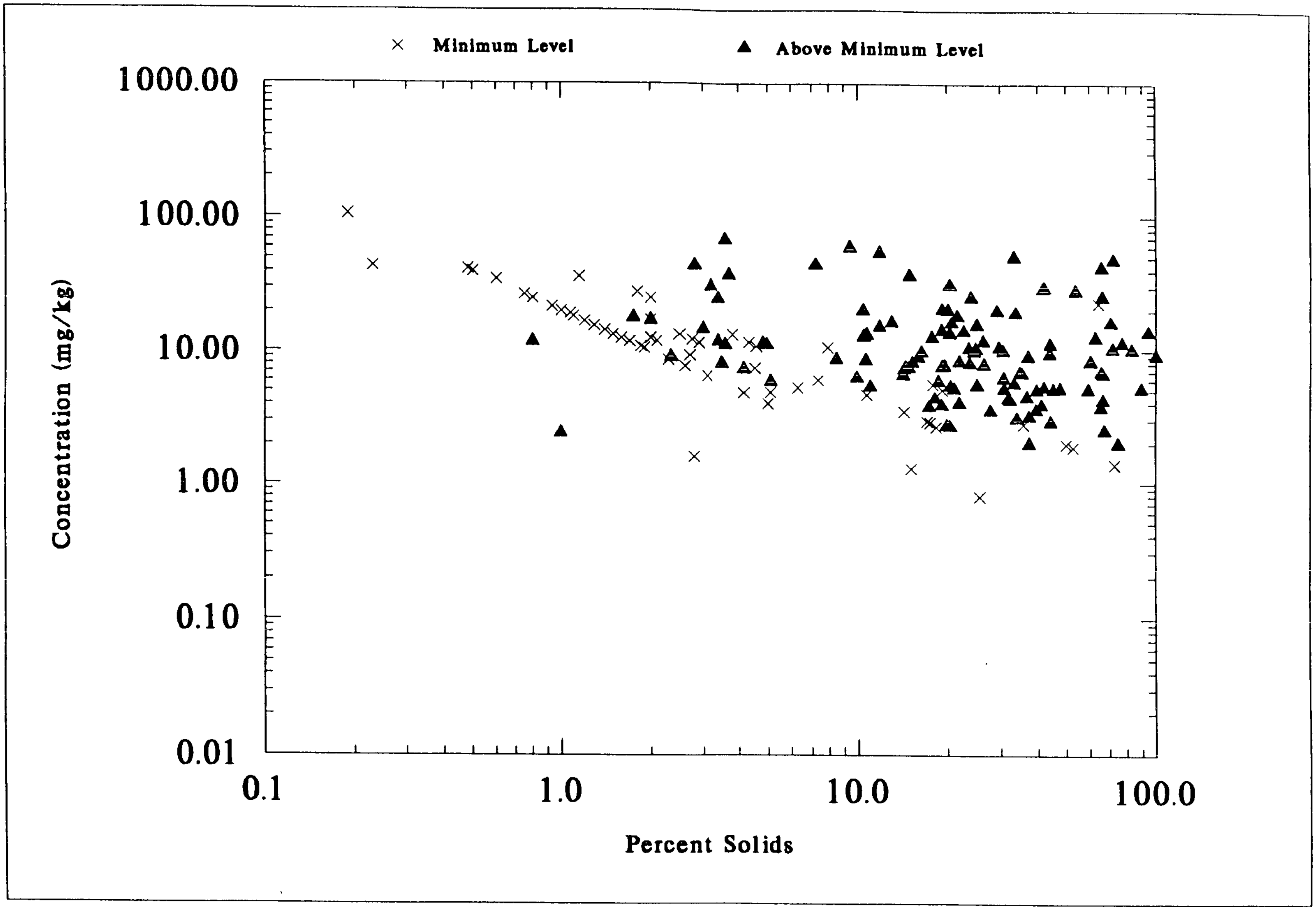


Figure 7-35. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of MOLYBDENUM

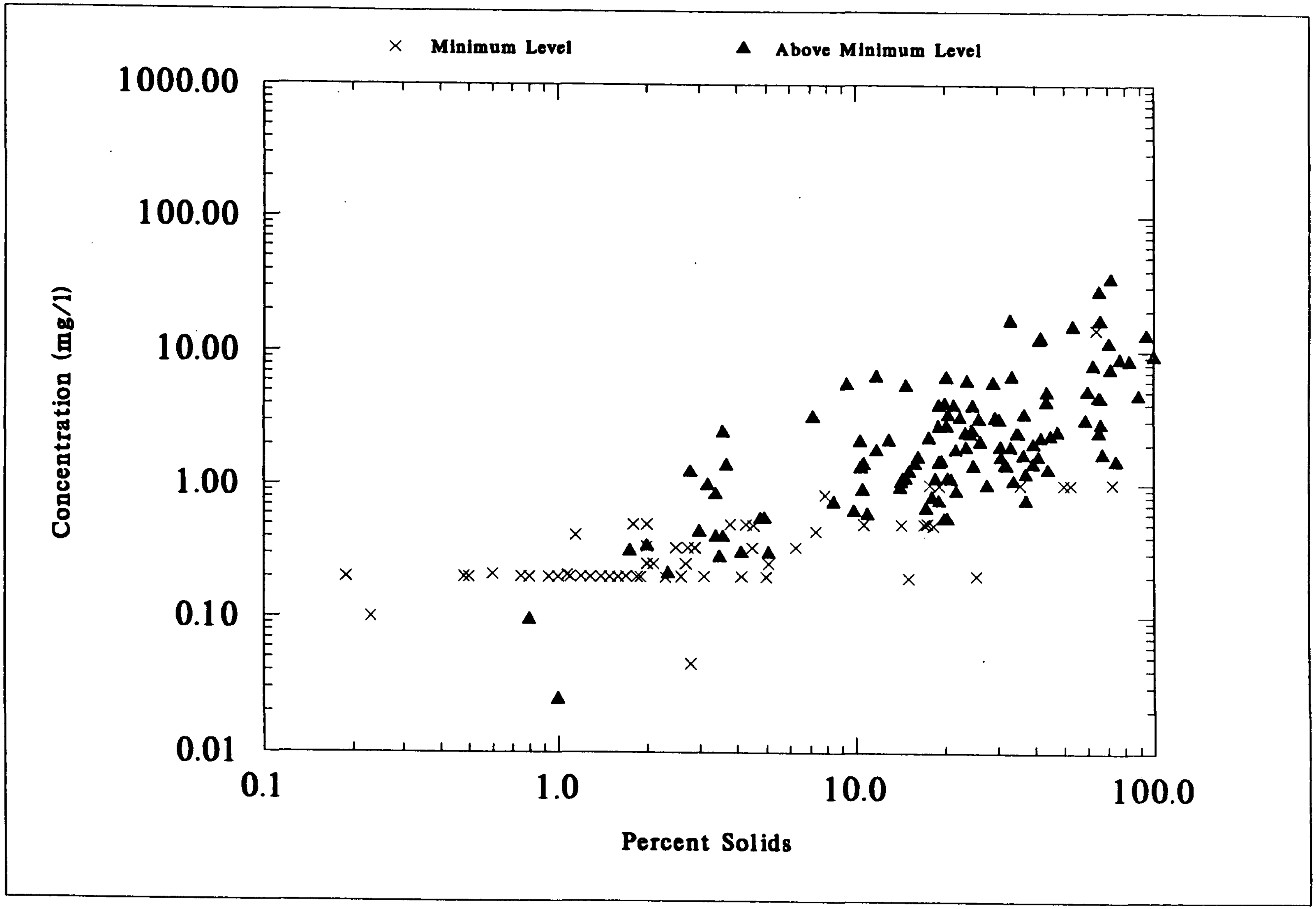


Figure 7–36. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of MOLYBDENUM

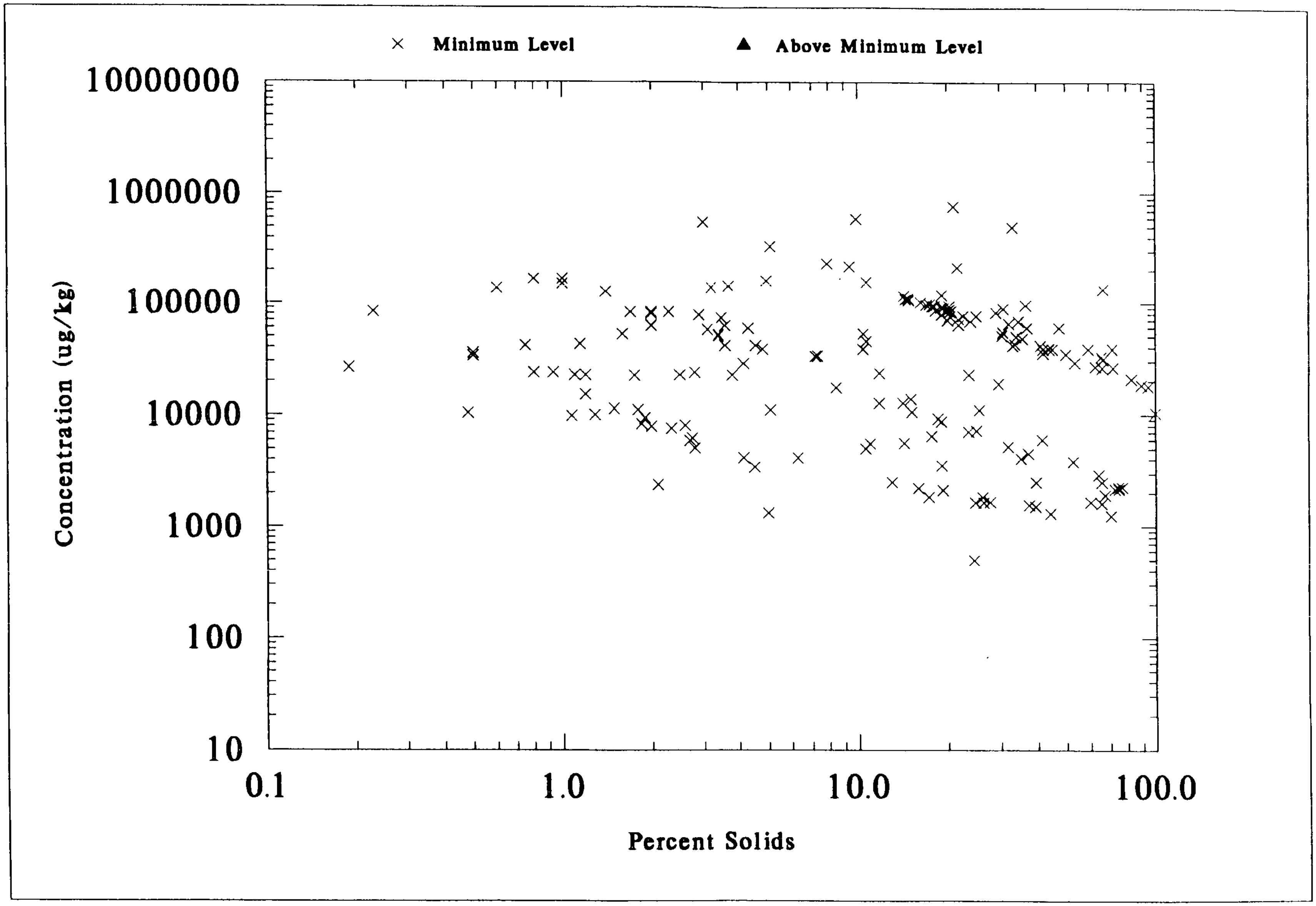


Figure 7-37. Percent Solids of NSSS Samples Versus
DRY WEIGHT Concentrations of N-NITROSODIMETHYLAMINE

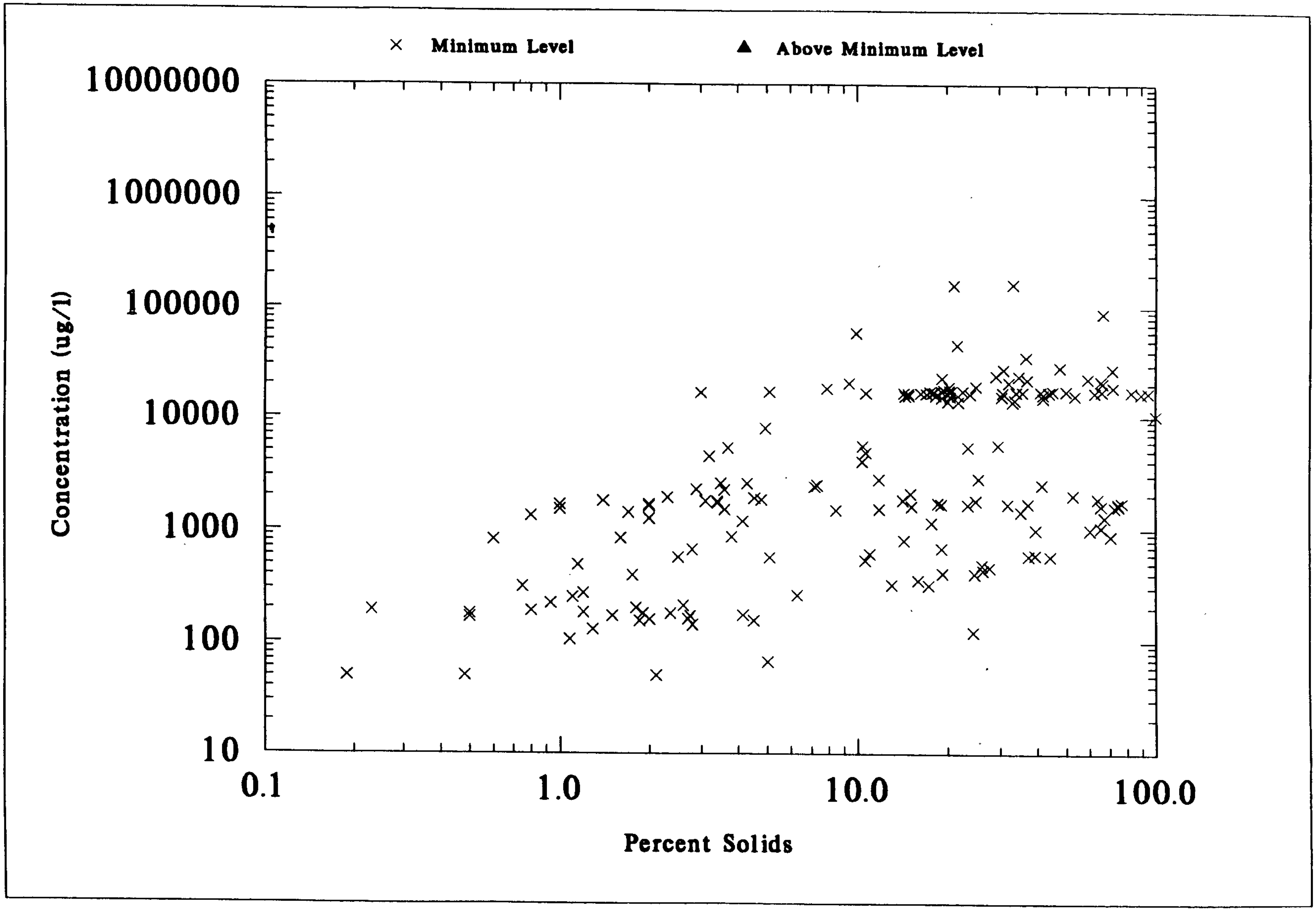


Figure 7-38. Percent Solids of NSSS Samples Versus
WET WEIGHT Concentrations of N-NITROSODIMETHYLAMINE

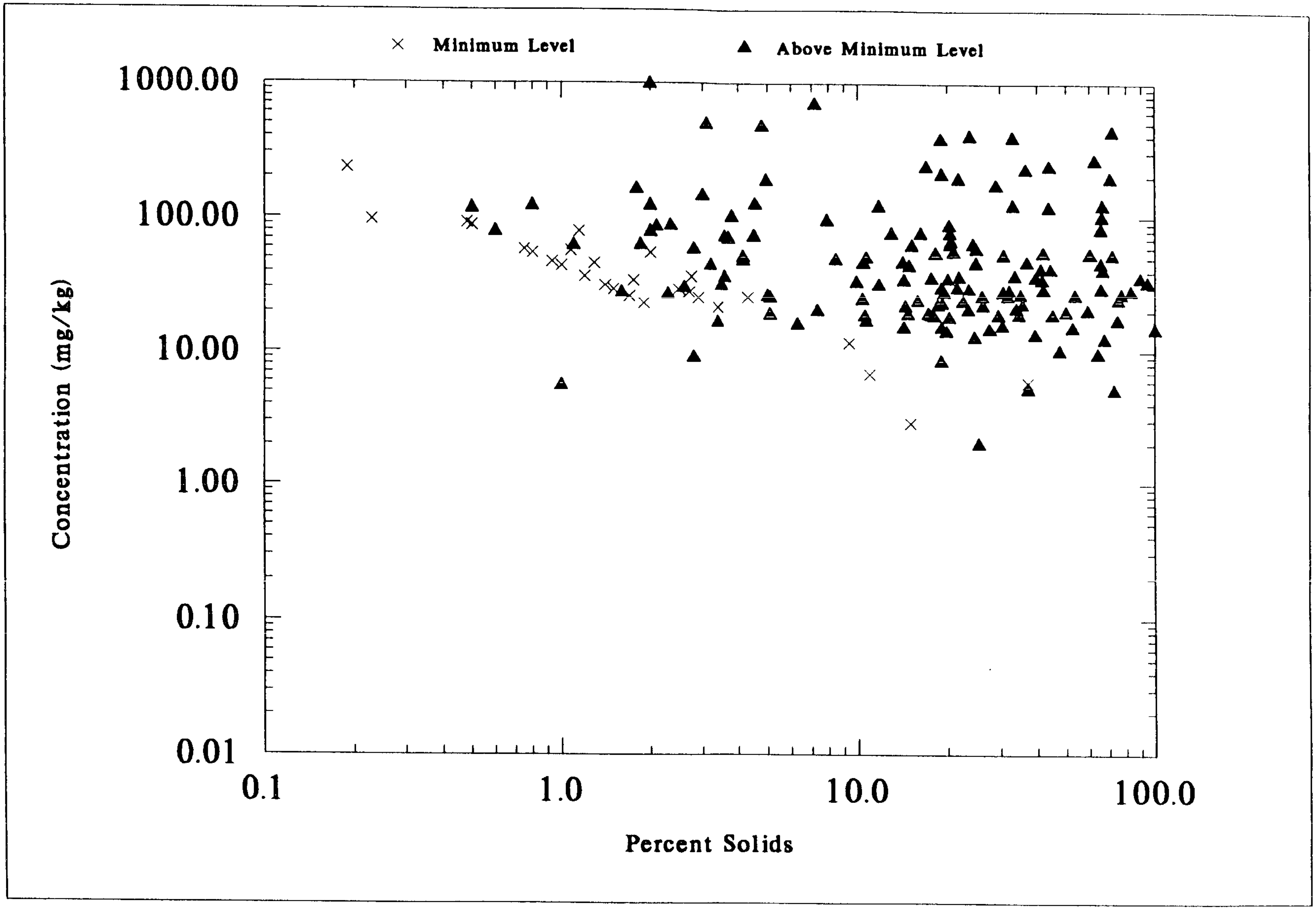


Figure 7–39. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of NICKEL

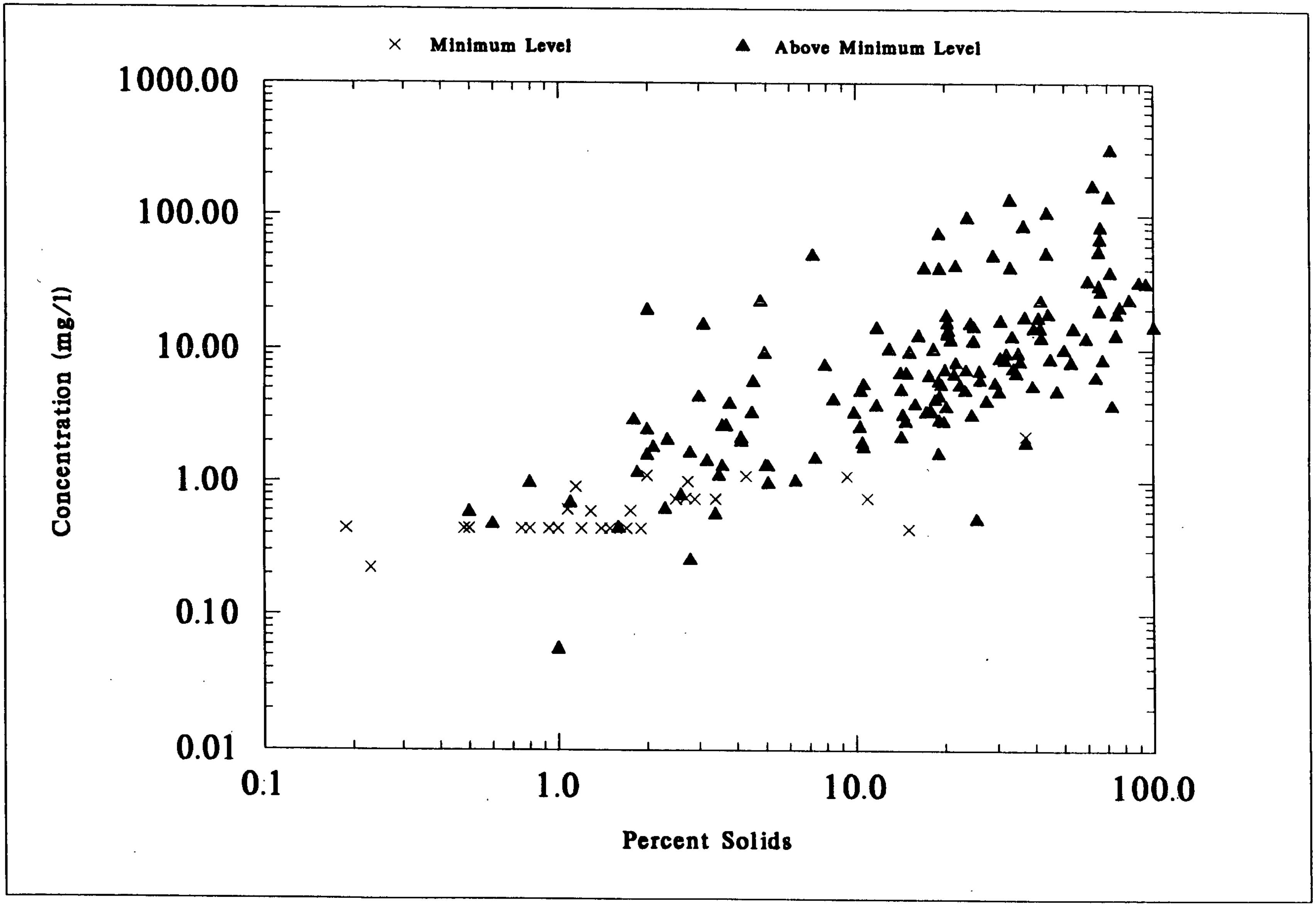


Figure 7-40. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of NICKEL

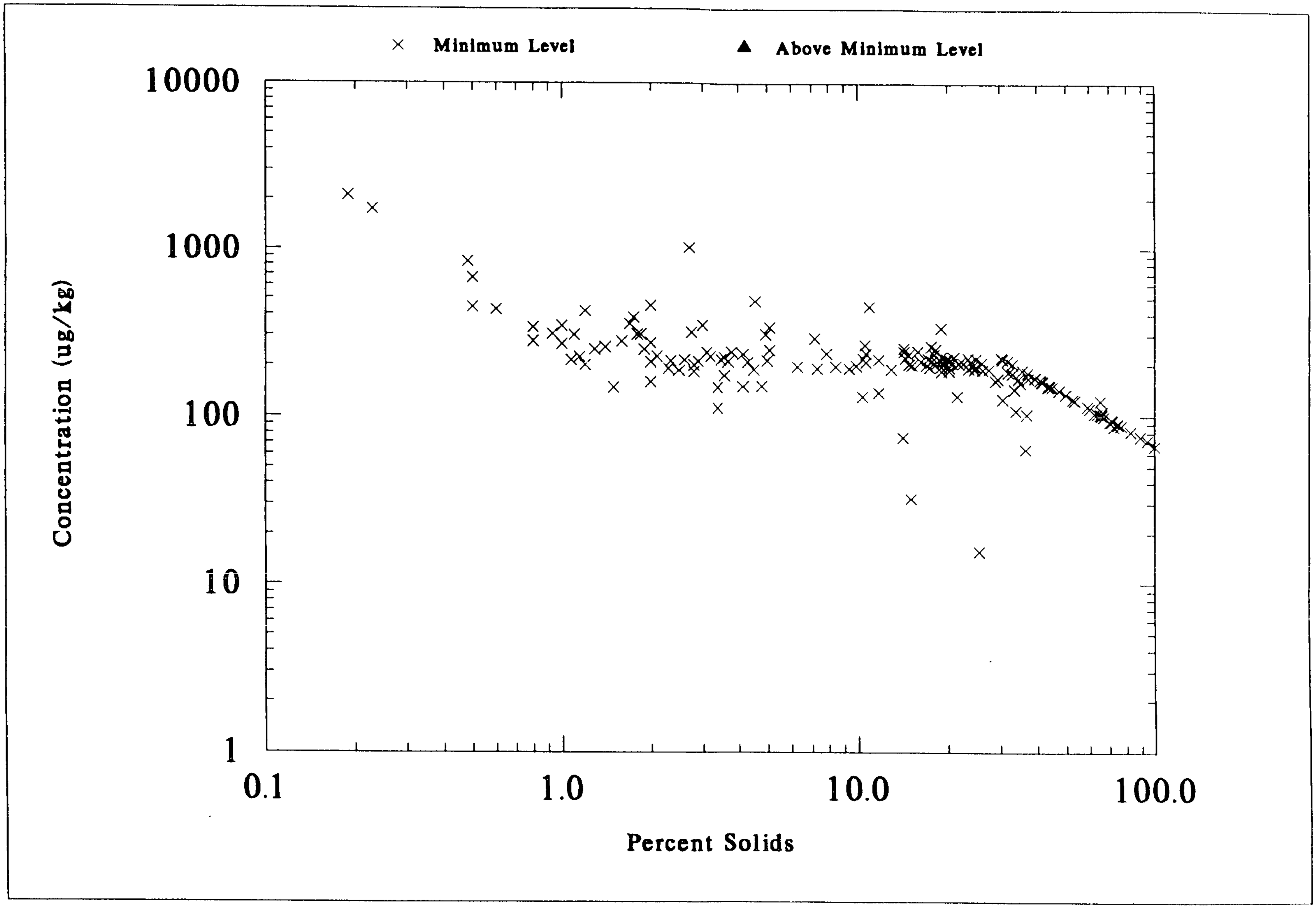


Figure 7-41. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of PCB-1016

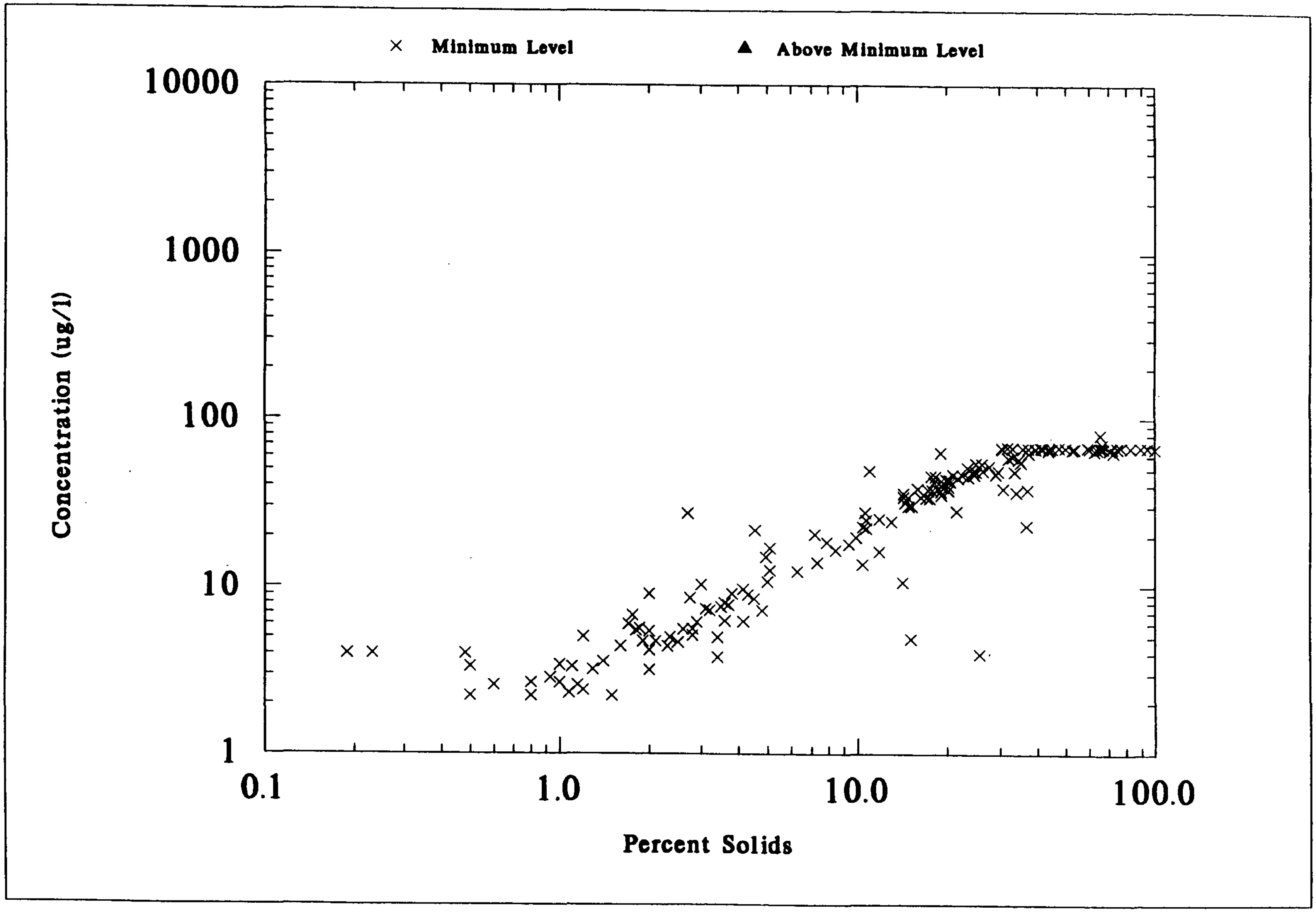


Figure 7-42. Percent Solids of NSSS Samples Versus
WET WEIGHT Concentrations of PCB-1016

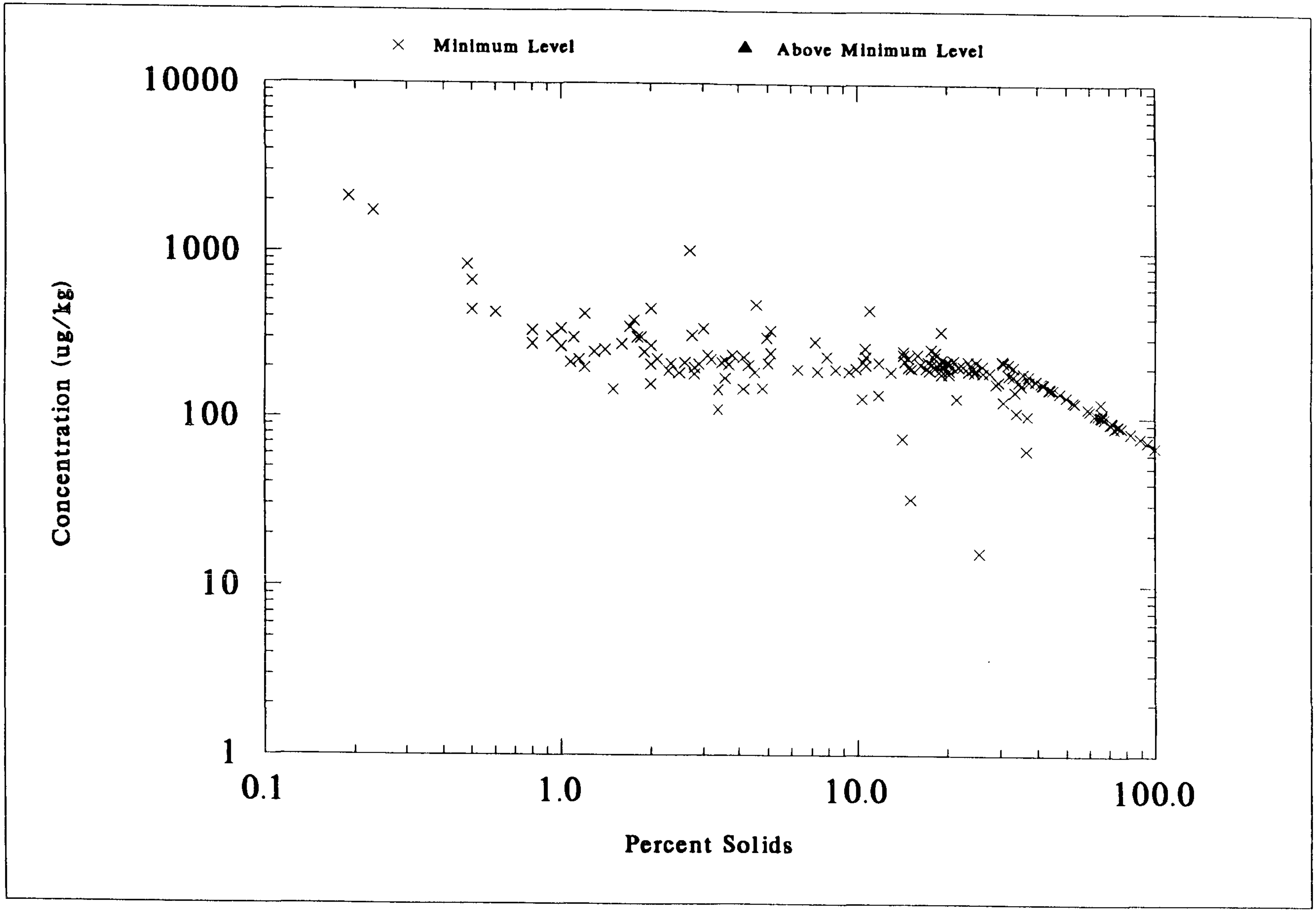


Figure 7-43. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of PCB-1221

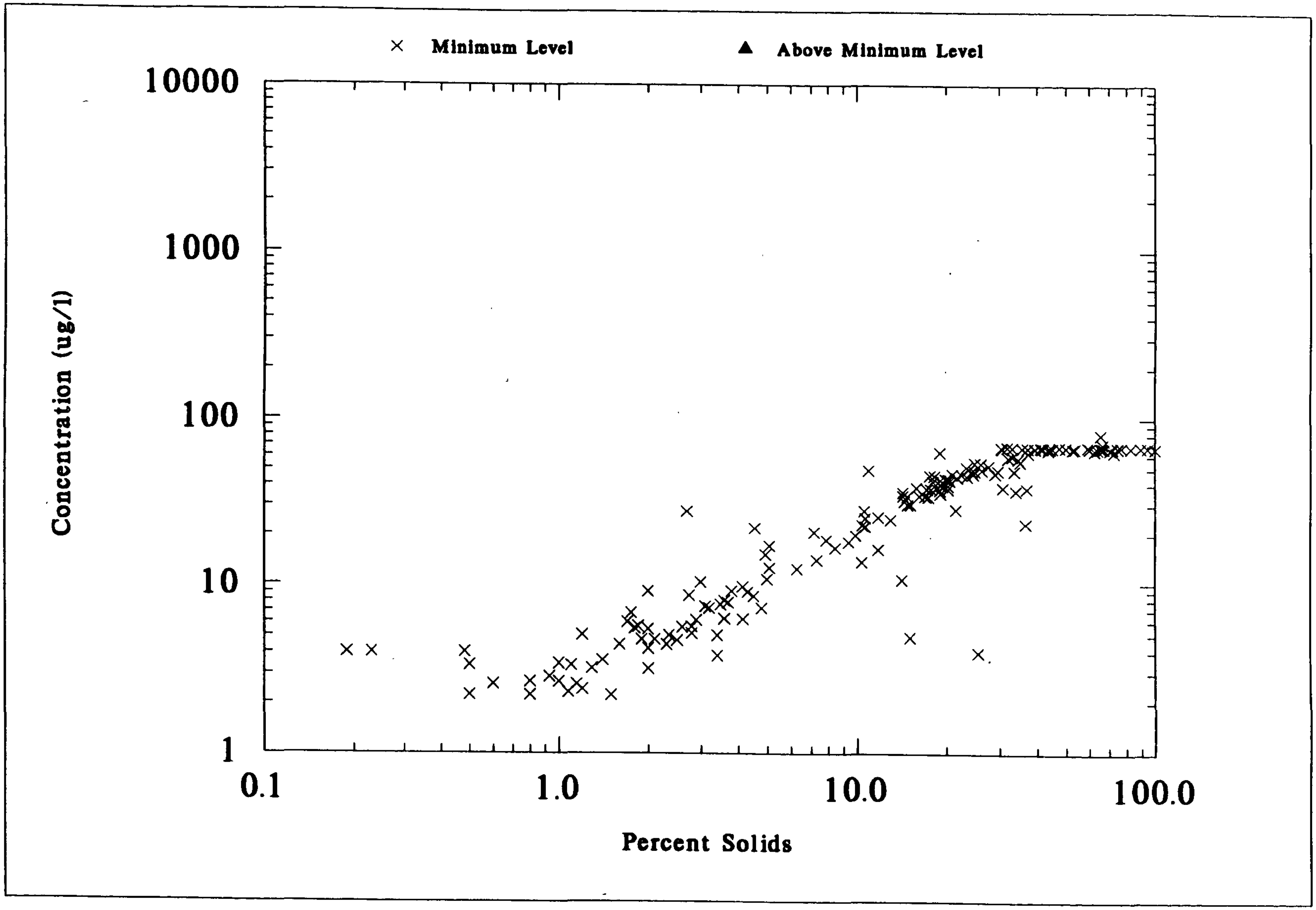


Figure 7-44. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of PCB-1221

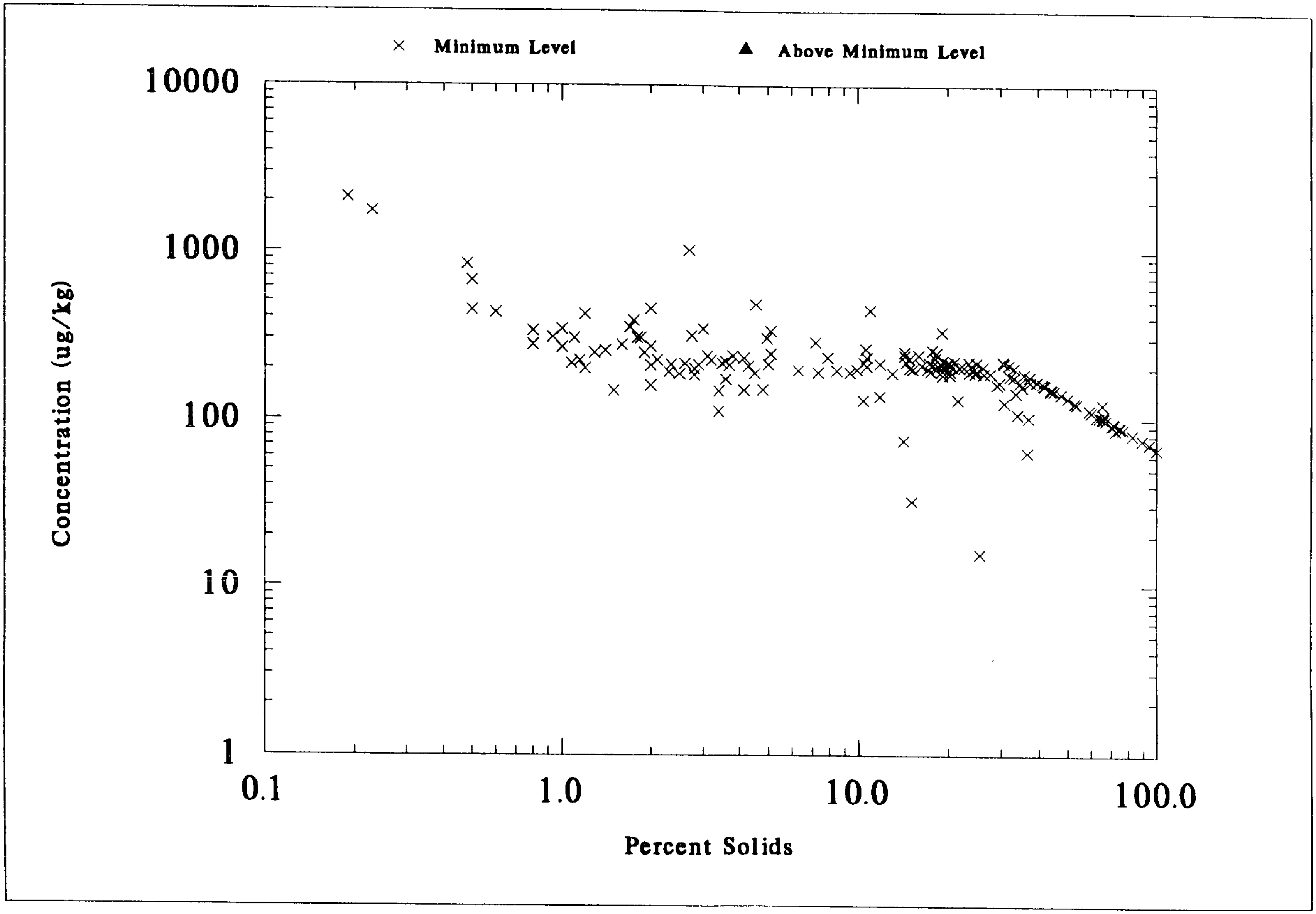


Figure 7-45. Percent Solids of NSSS Samples Versus
DRY WEIGHT Concentrations of PCB-1232

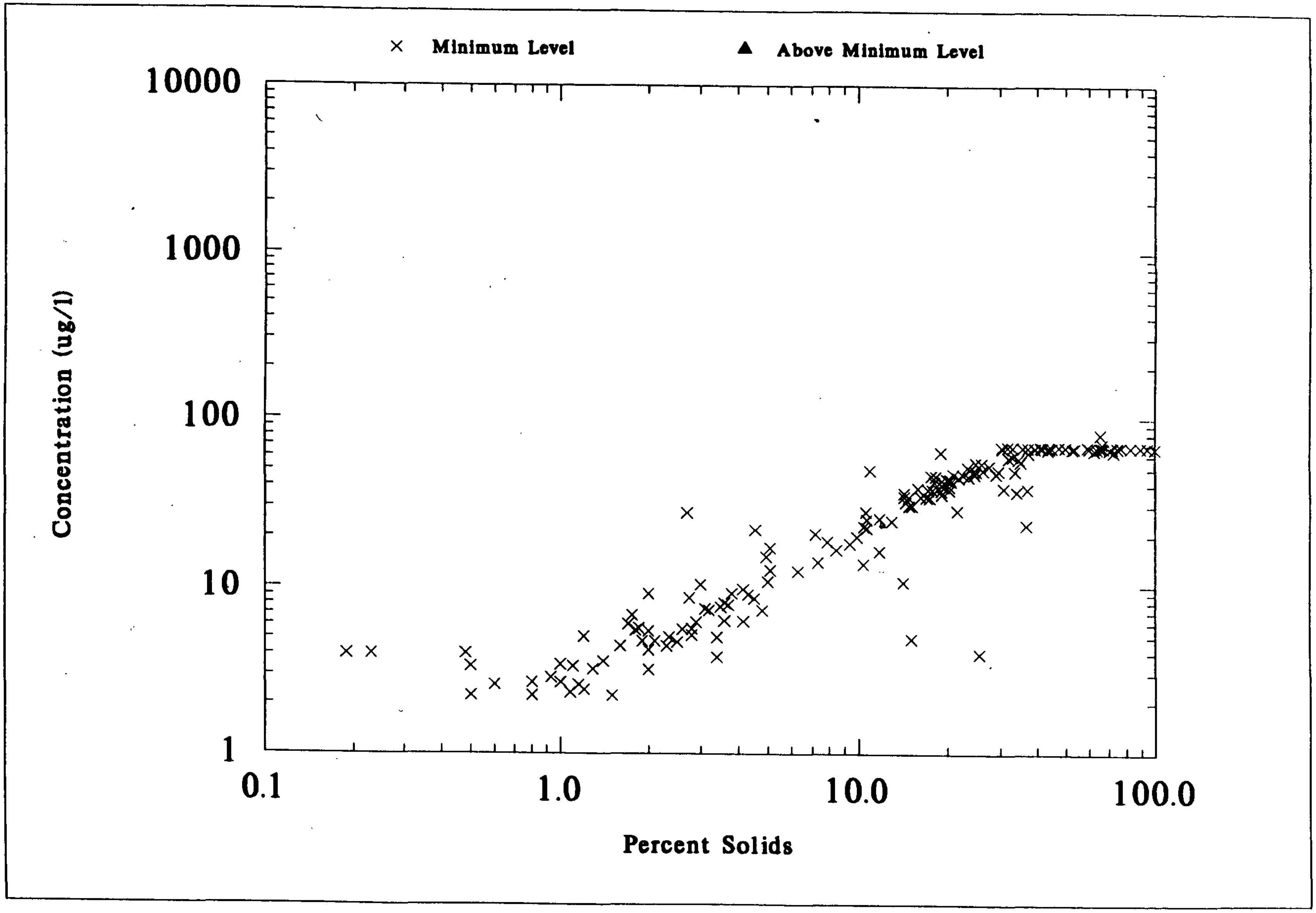


Figure 7-46. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of PCB-1232

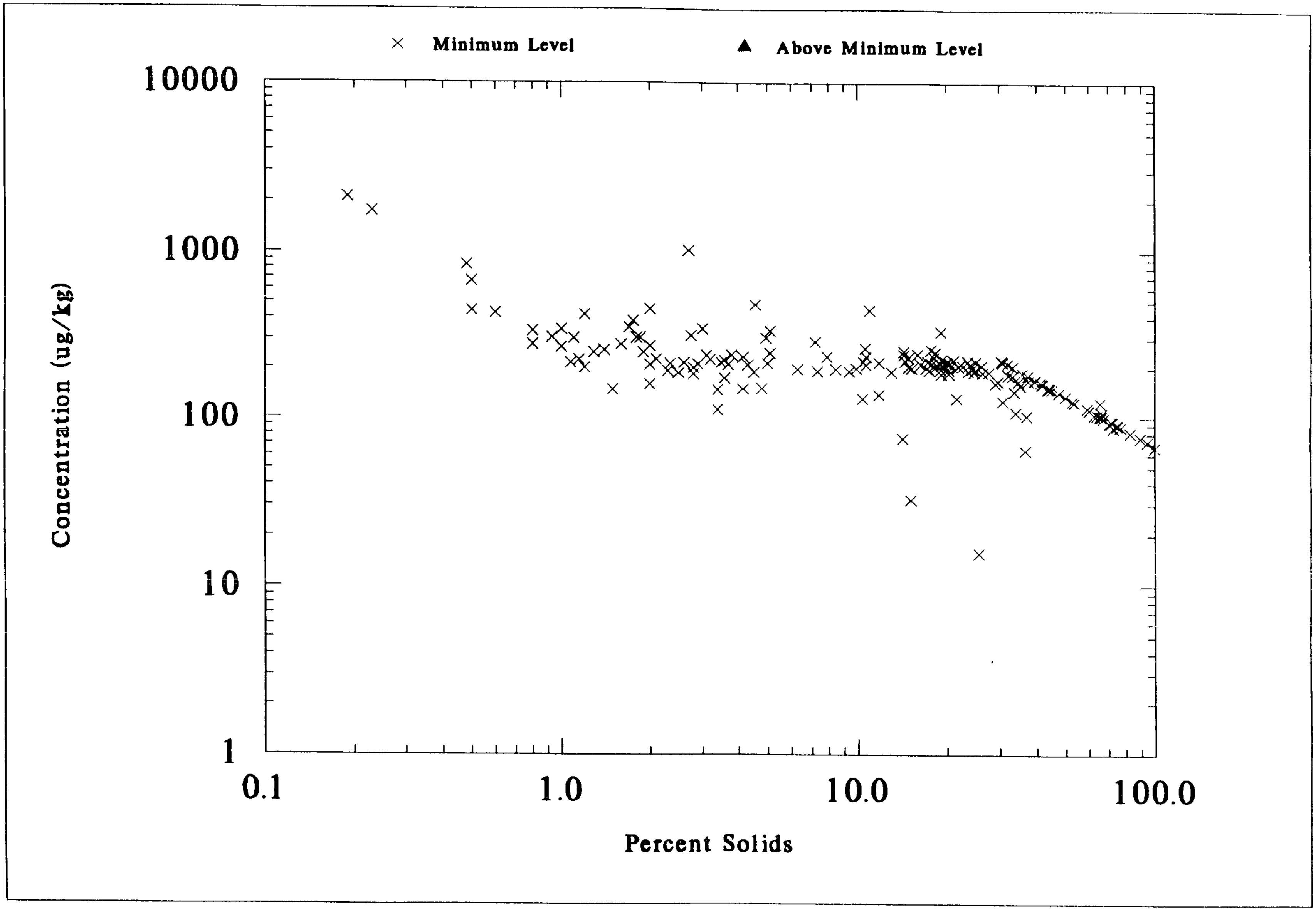


Figure 7-47. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of PCB-1242

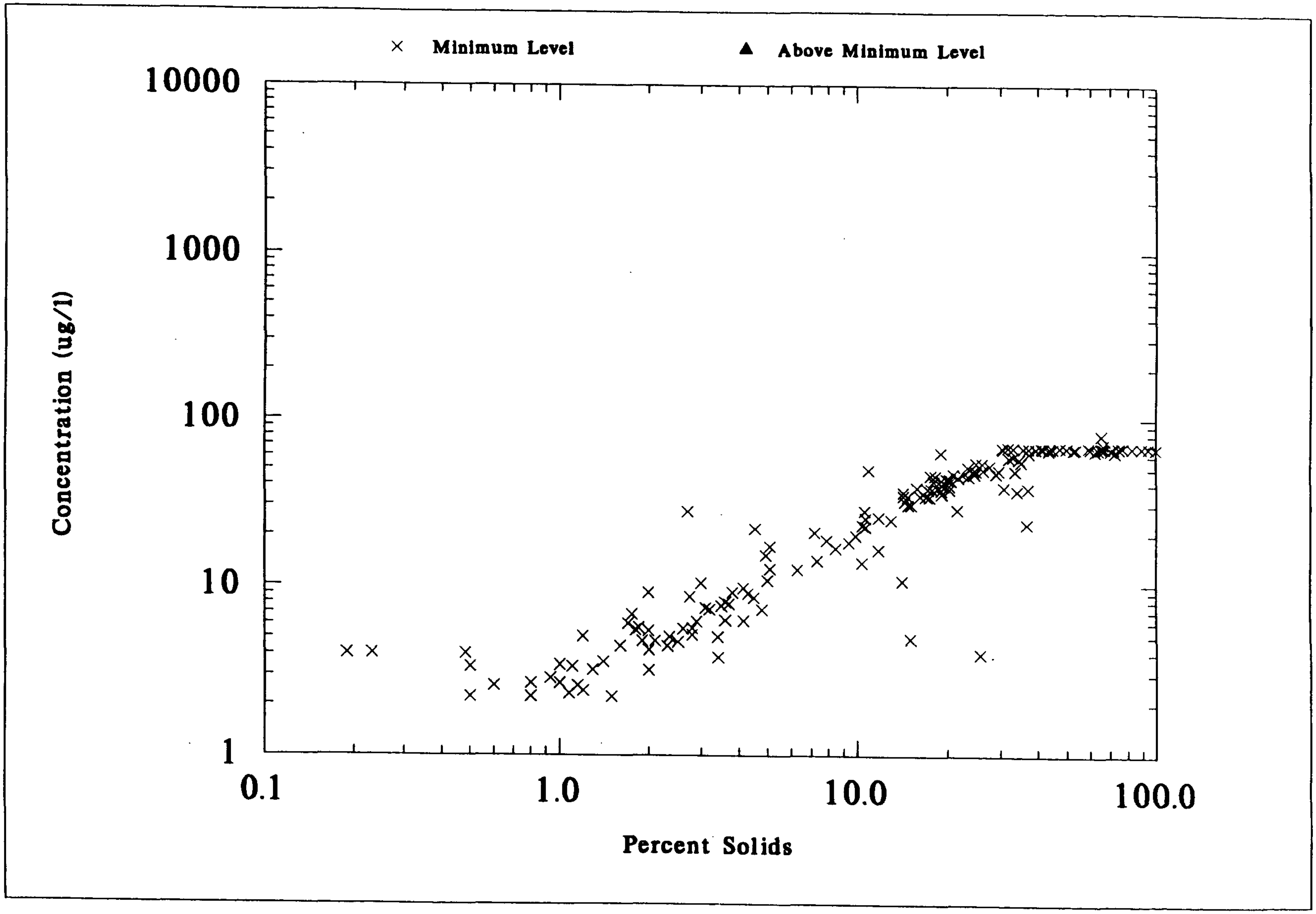


Figure 7-48. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of PCB-1242

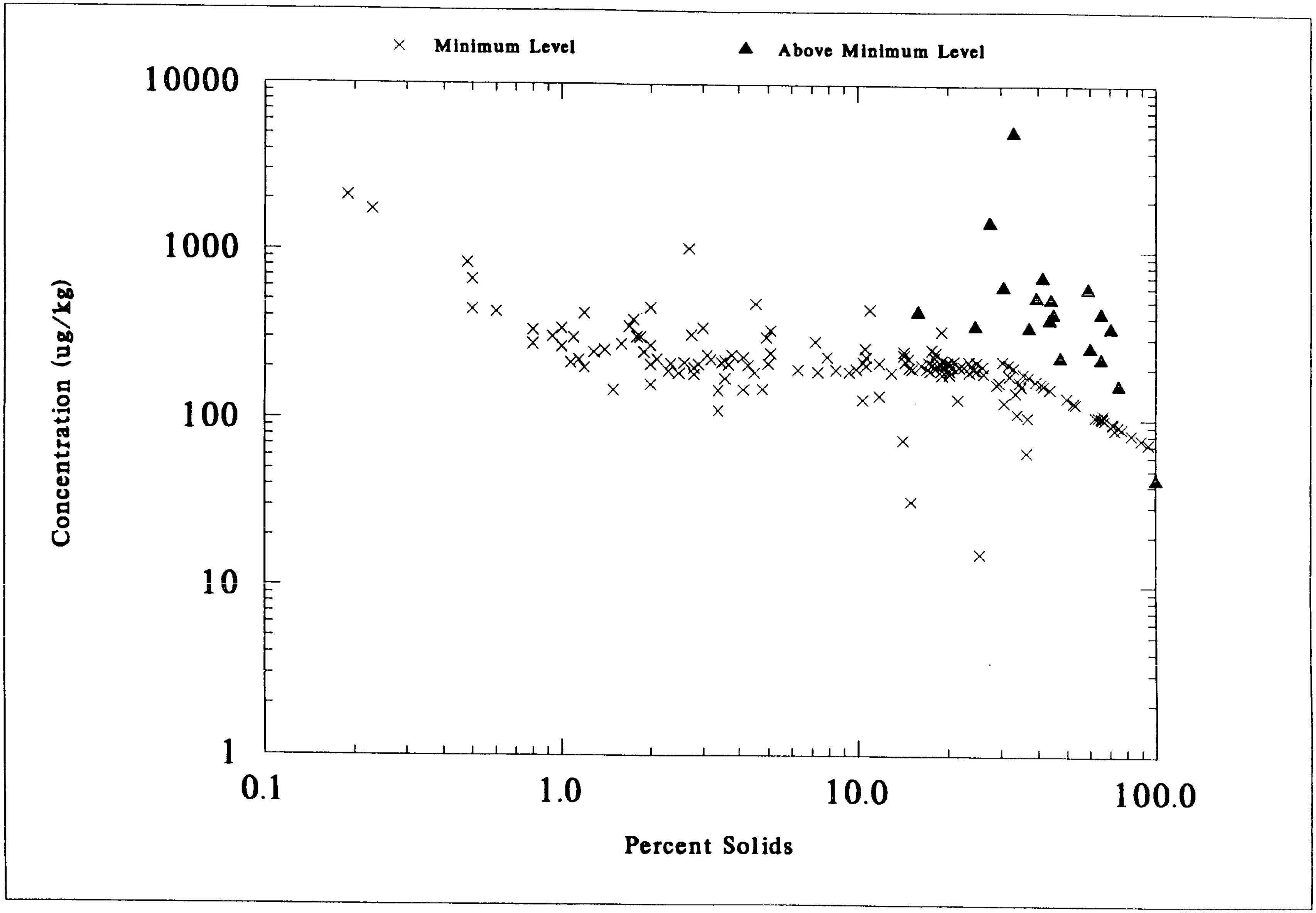


Figure 7-49. Percent Solids of NSSS Samples Versus
DRY WEIGHT Concentrations of PCB-1248

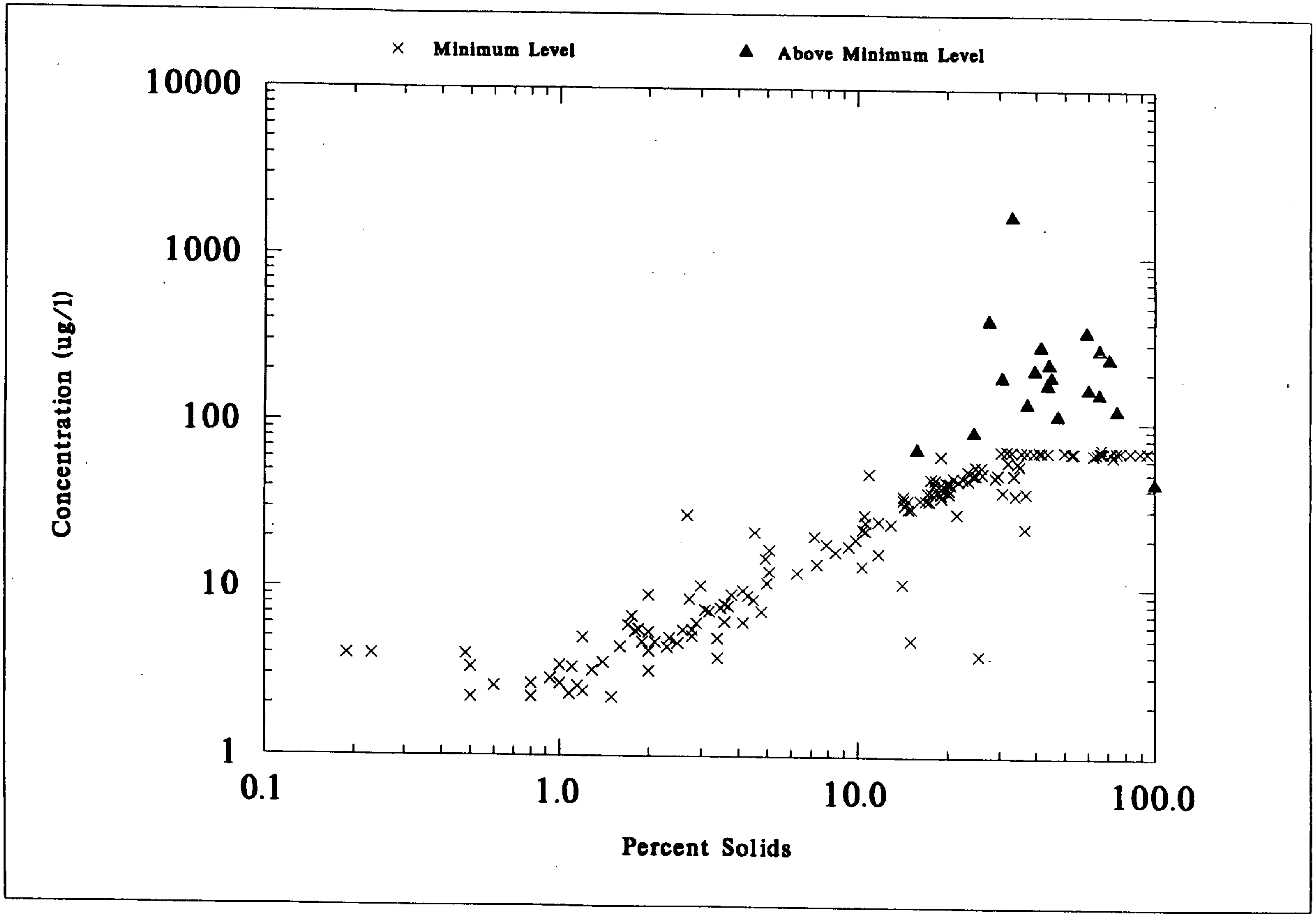


Figure 7-50. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of PCB-1248

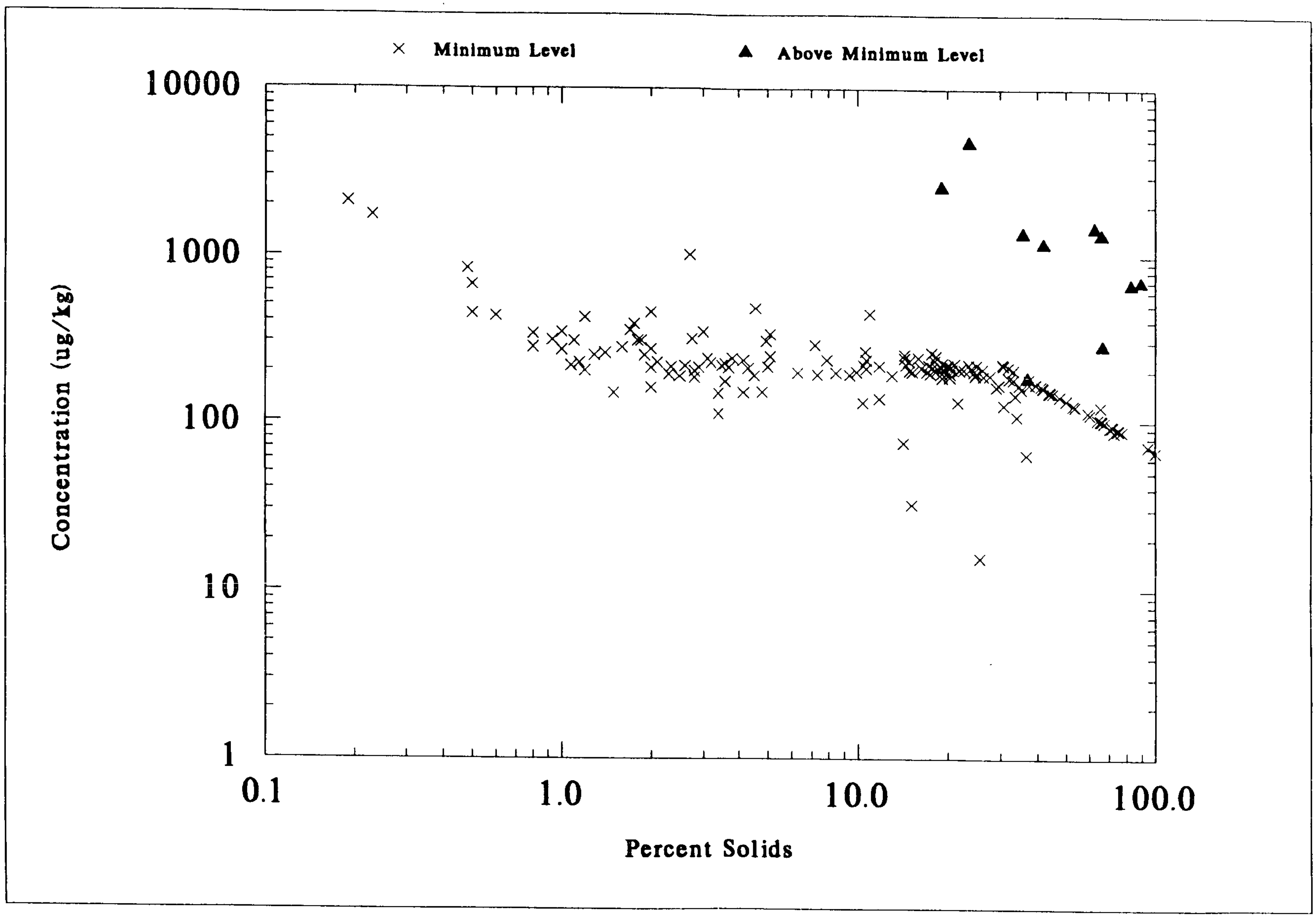


Figure 7-51. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of PCB-1254

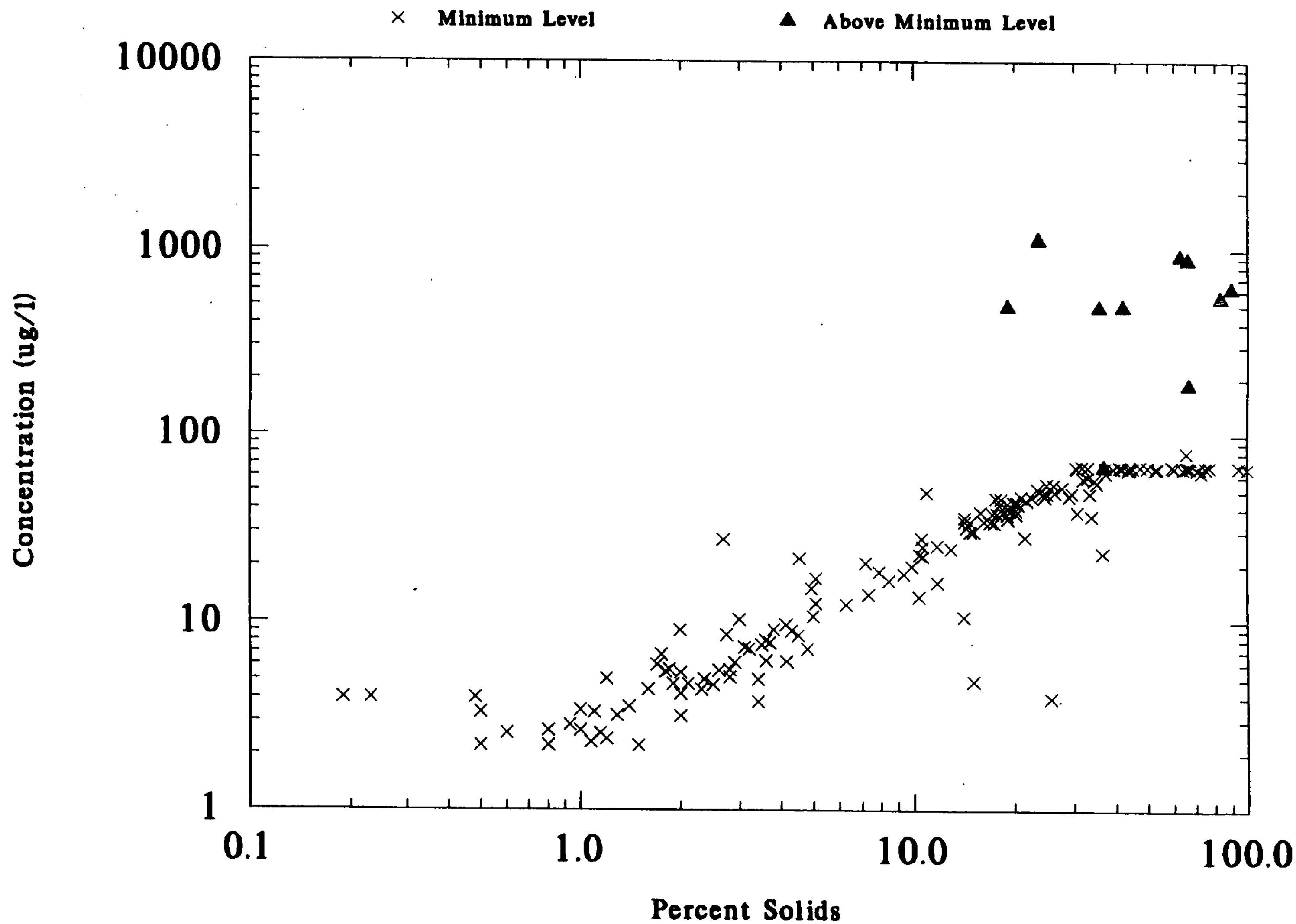


Figure 7-52. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of PCB-1254

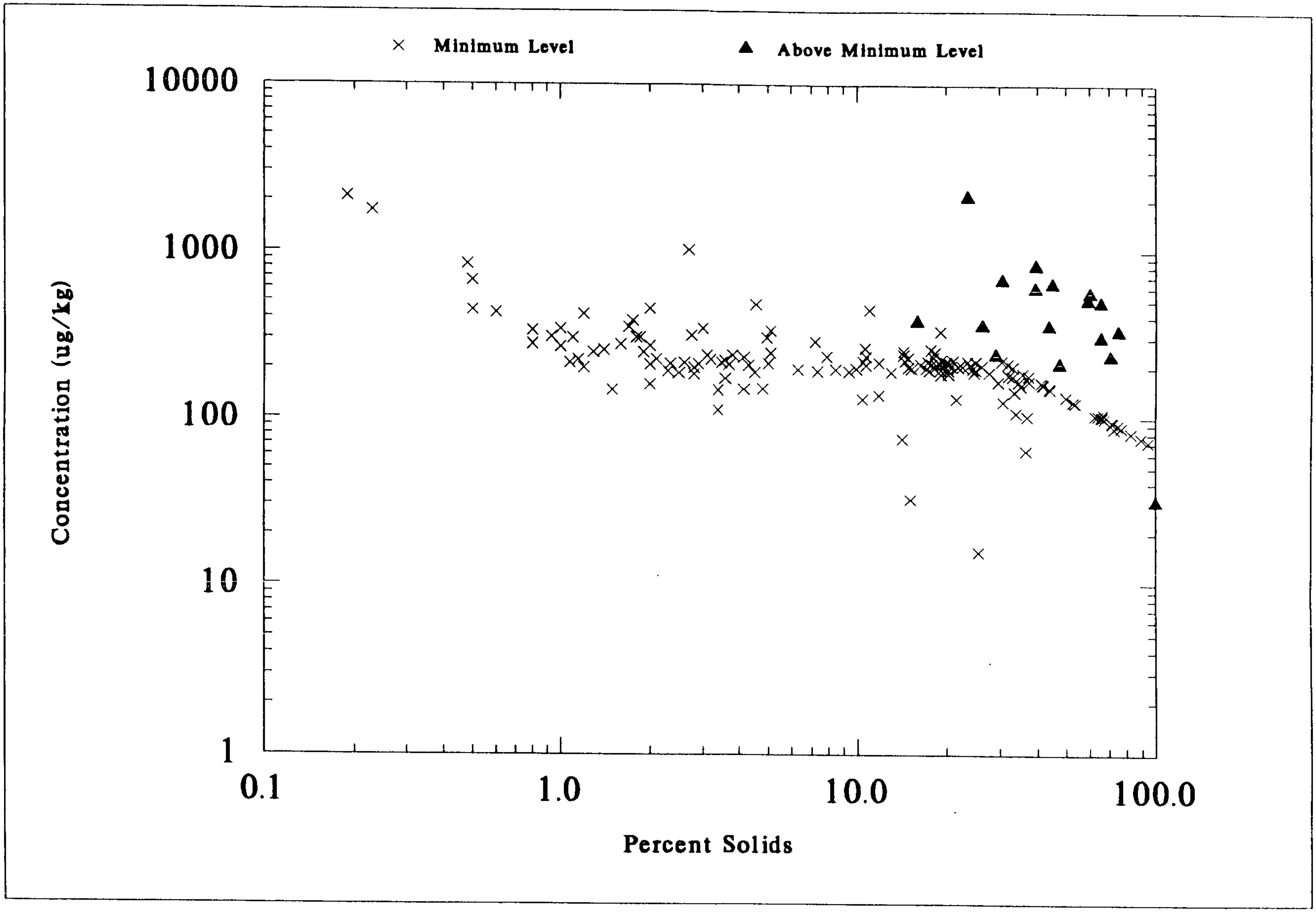


Figure 7-53. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of PCB-1260

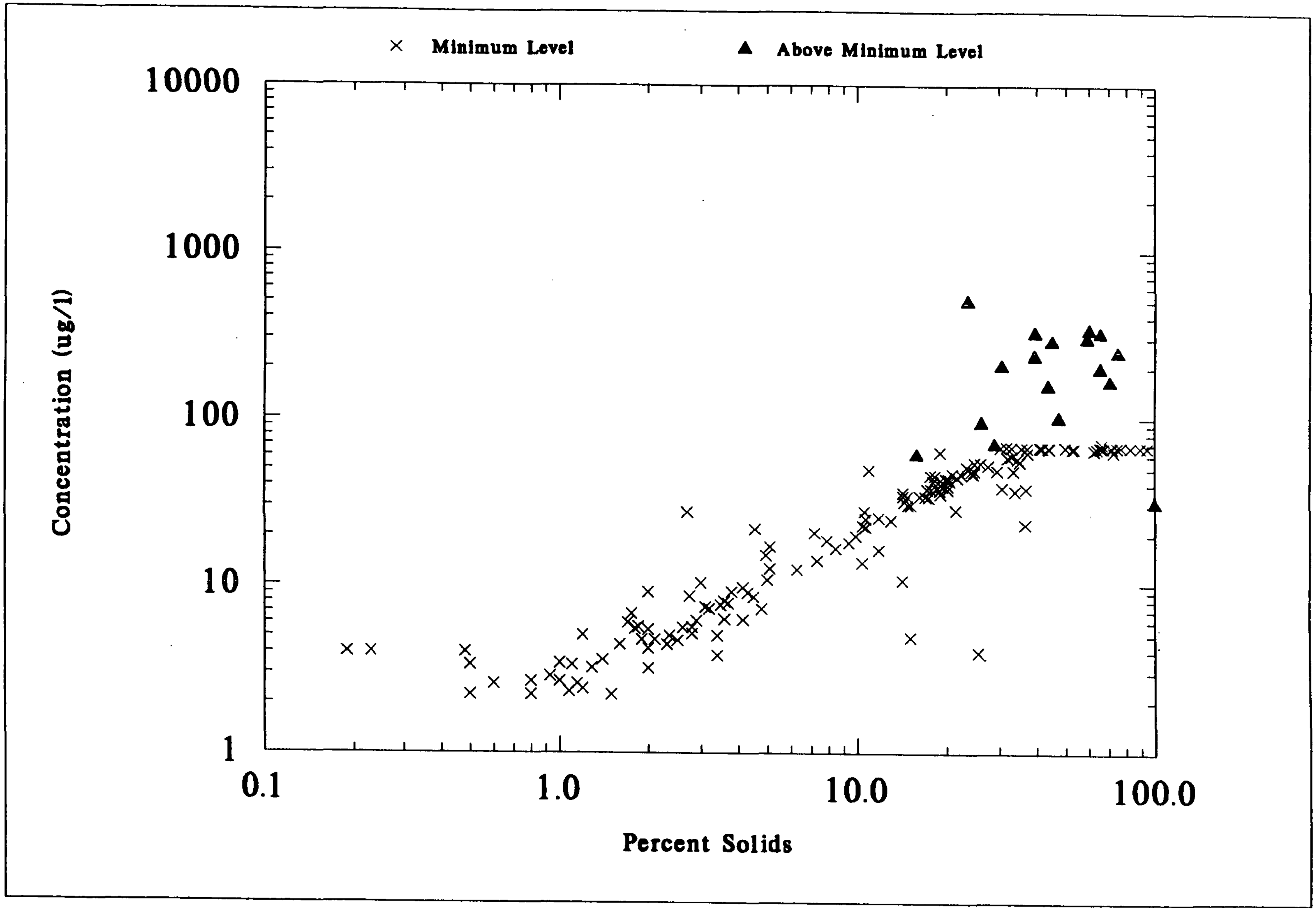


Figure 7-54. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of PCB-1260

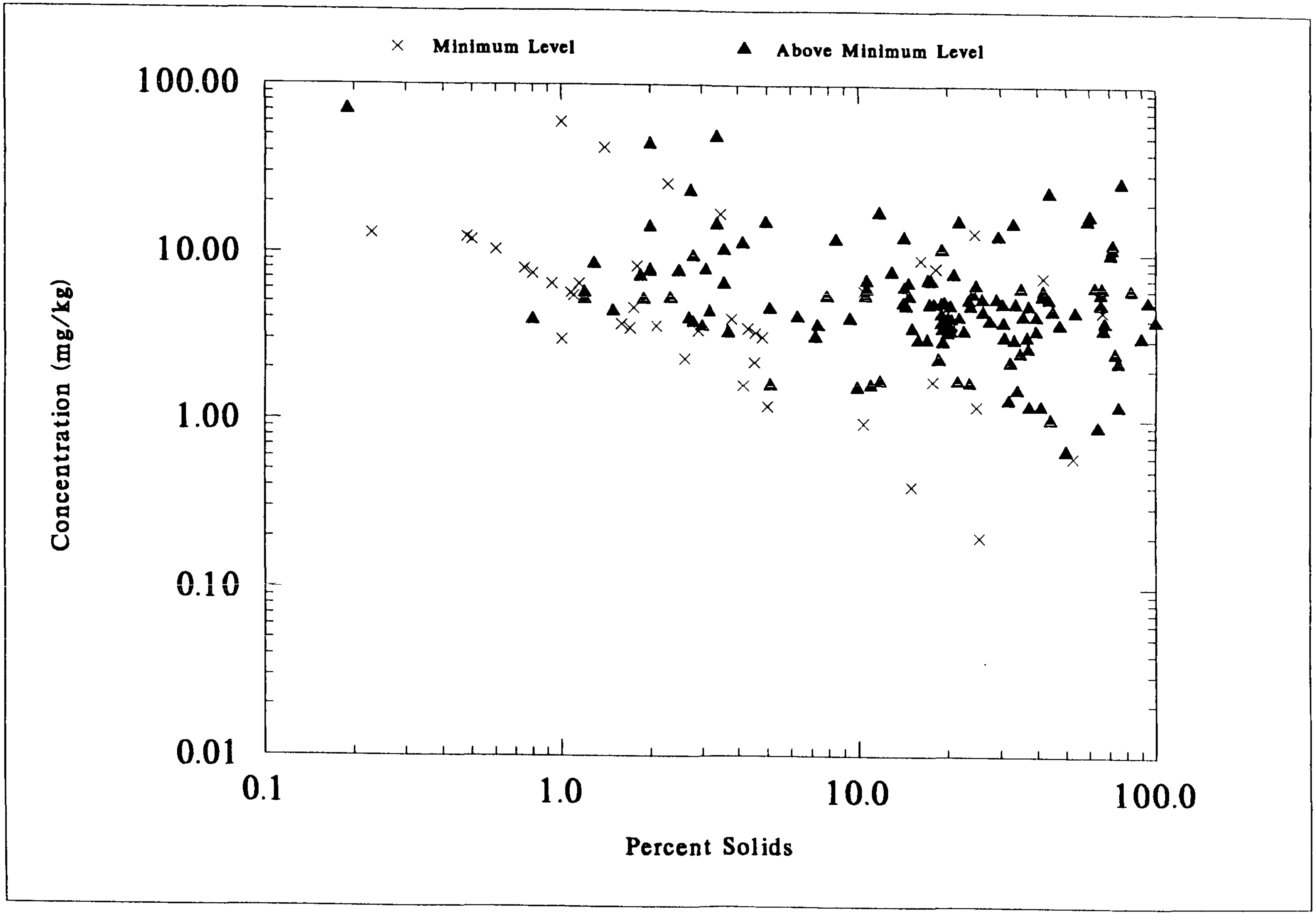


Figure 7-55. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of SELENIUM

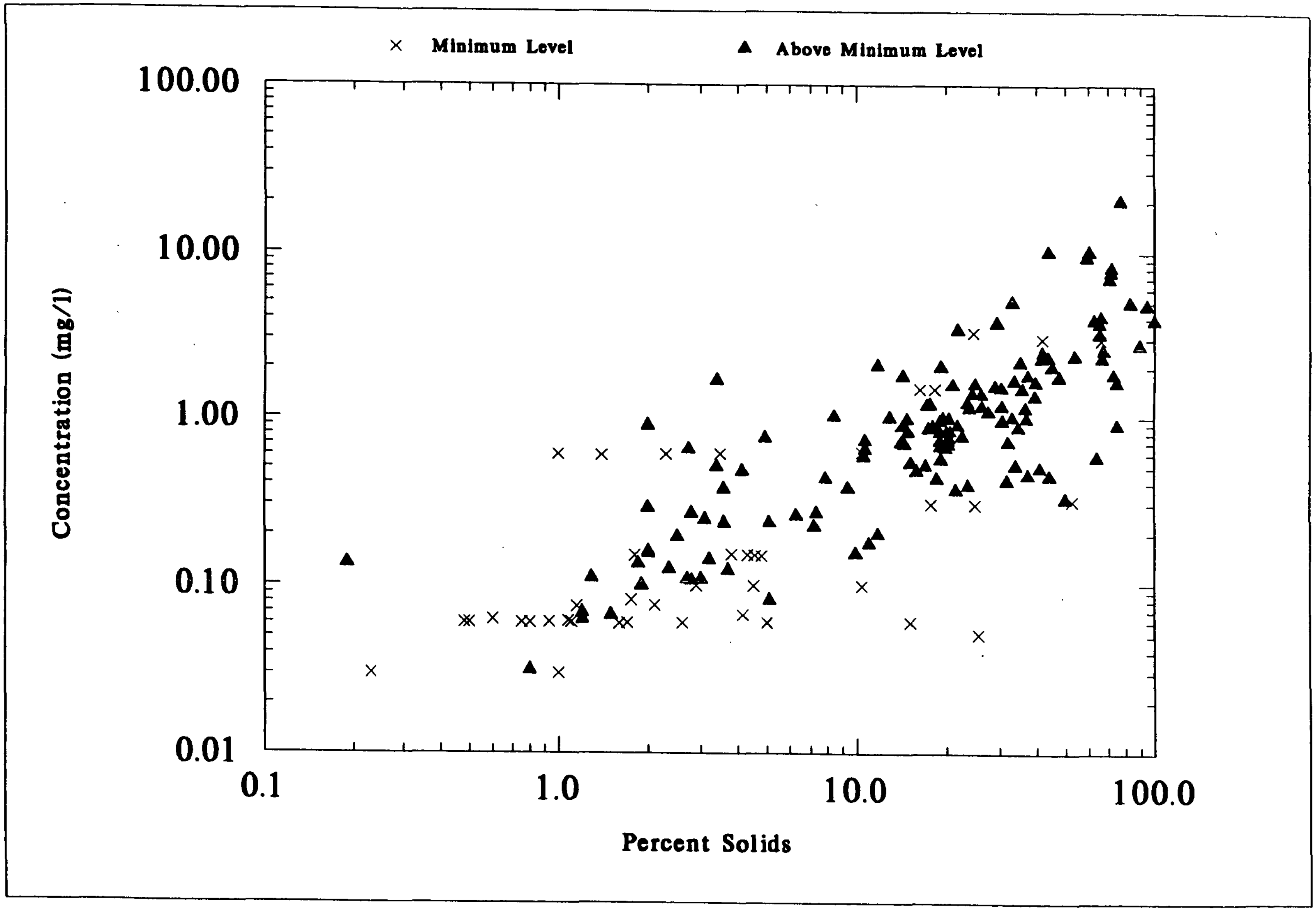


Figure 7-56. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of SELENIUM

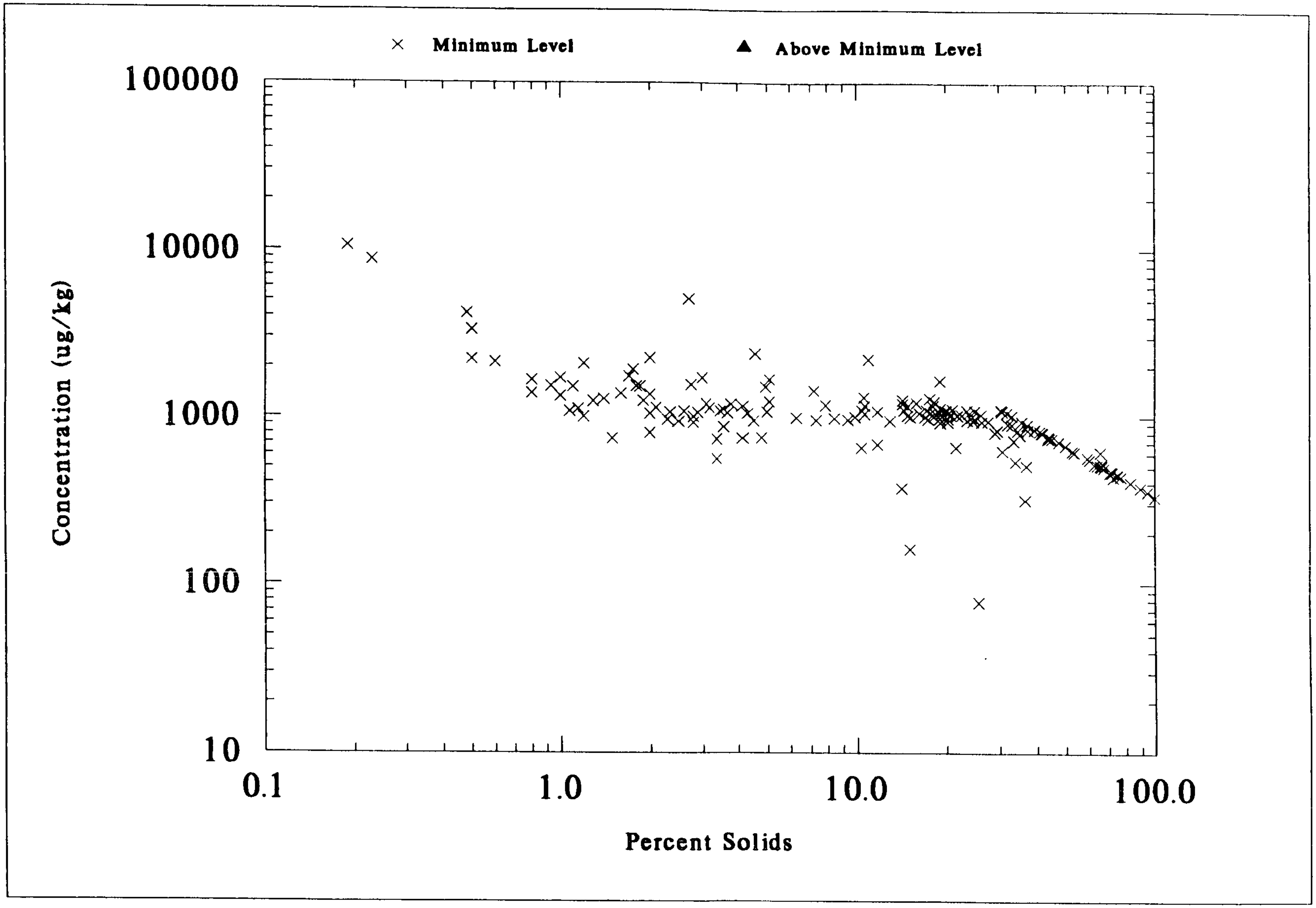


Figure 7-57. Percent Solids of NSSS Samples Versus
DRY WEIGHT Concentrations of TOXAPHENE

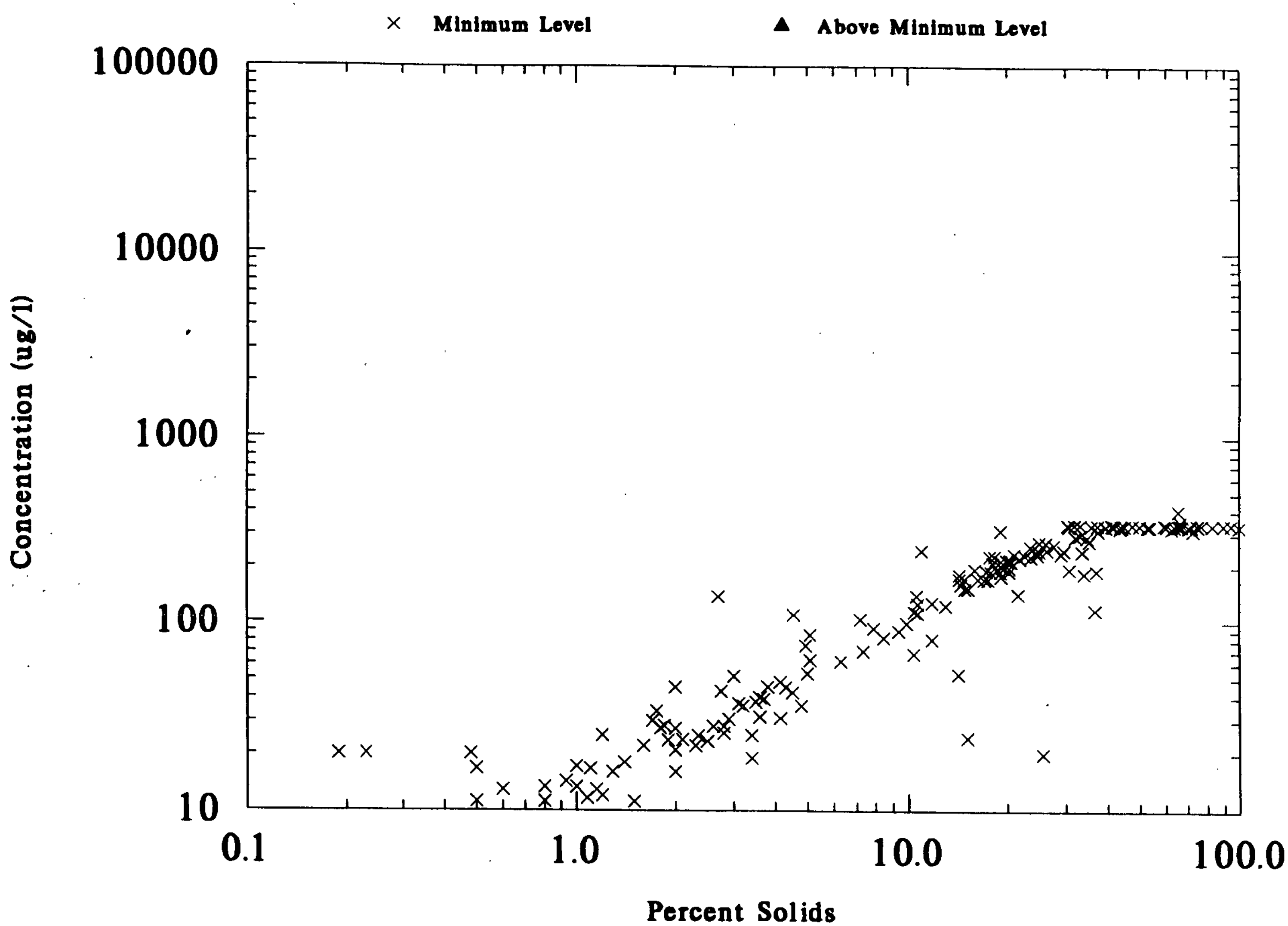


Figure 7-58. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of TOXAPHENE

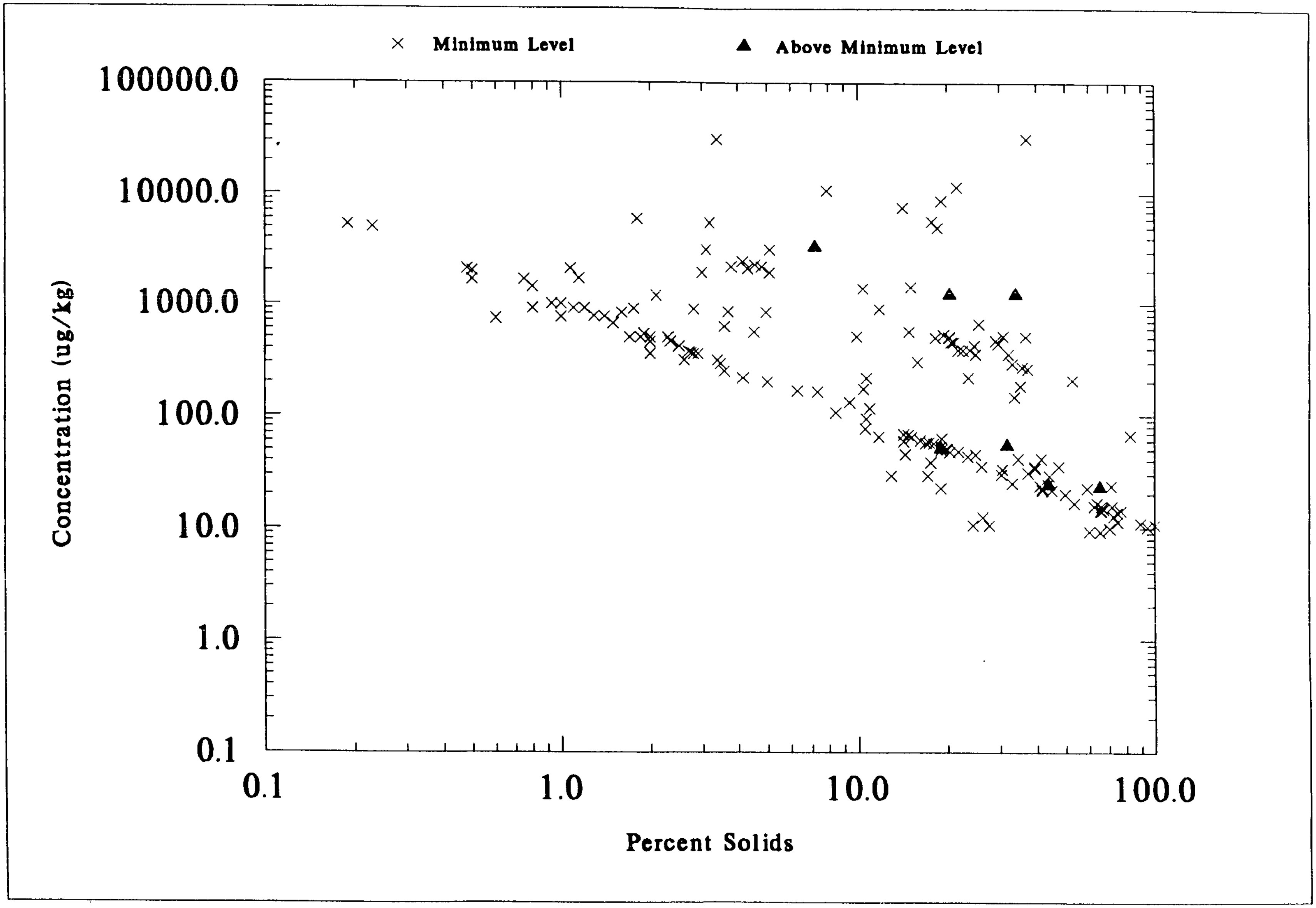


Figure 7-59. Percent Solids of NSSS Samples Versus
DRY WEIGHT Concentrations of TRICHLOROETHENE

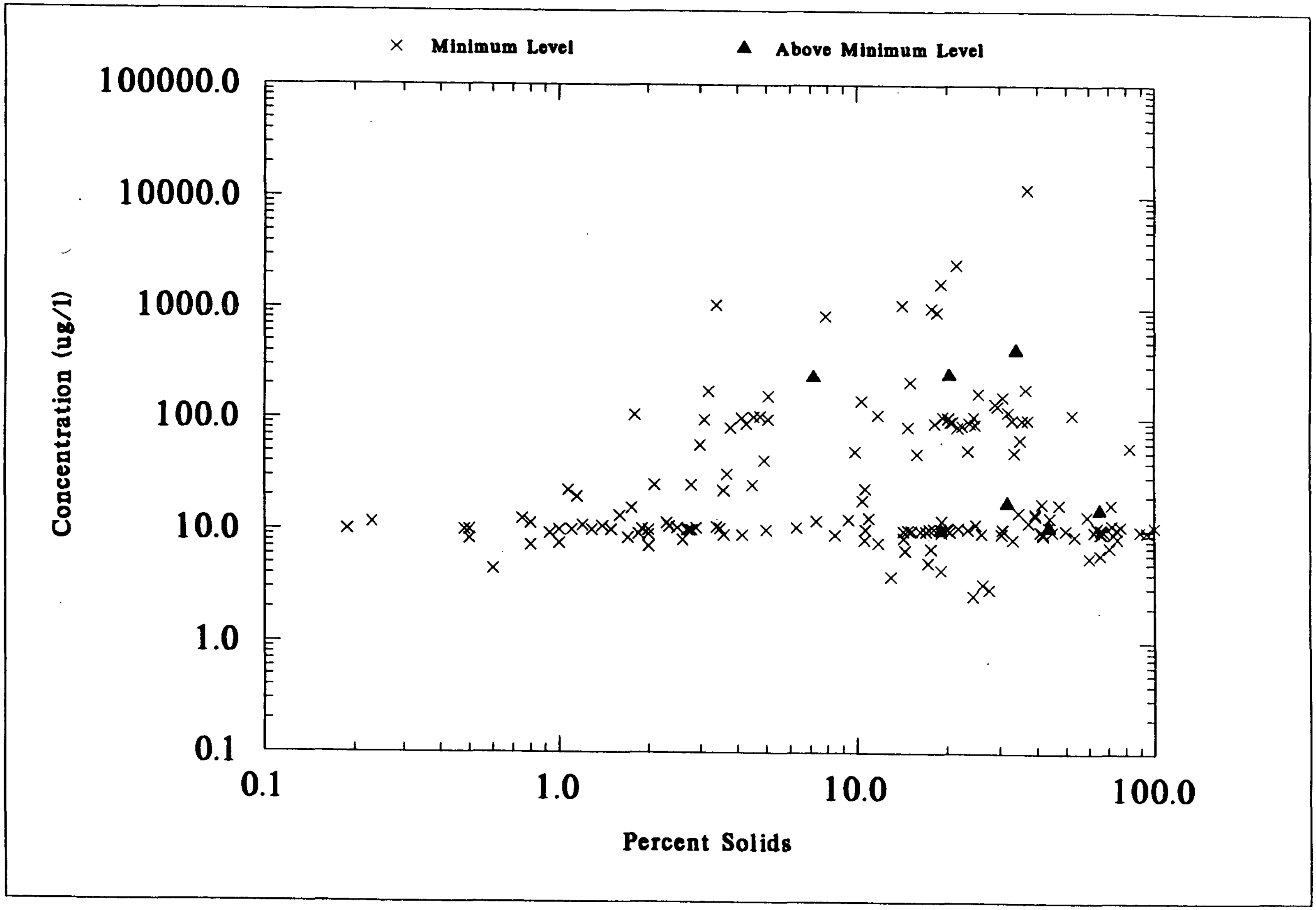


Figure 7-60. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of TRICHLOROETHENE

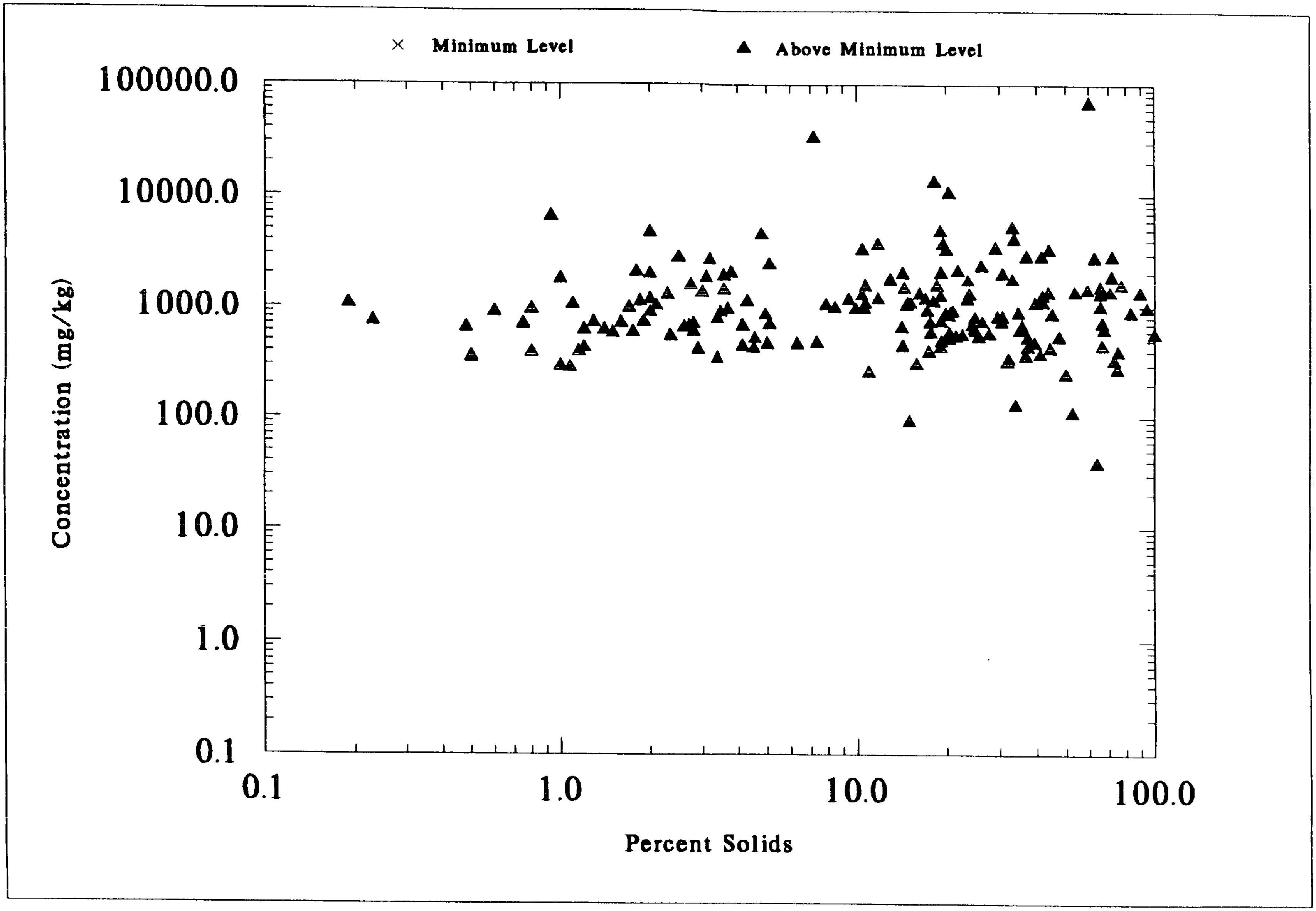


Figure 7-61. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of ZINC

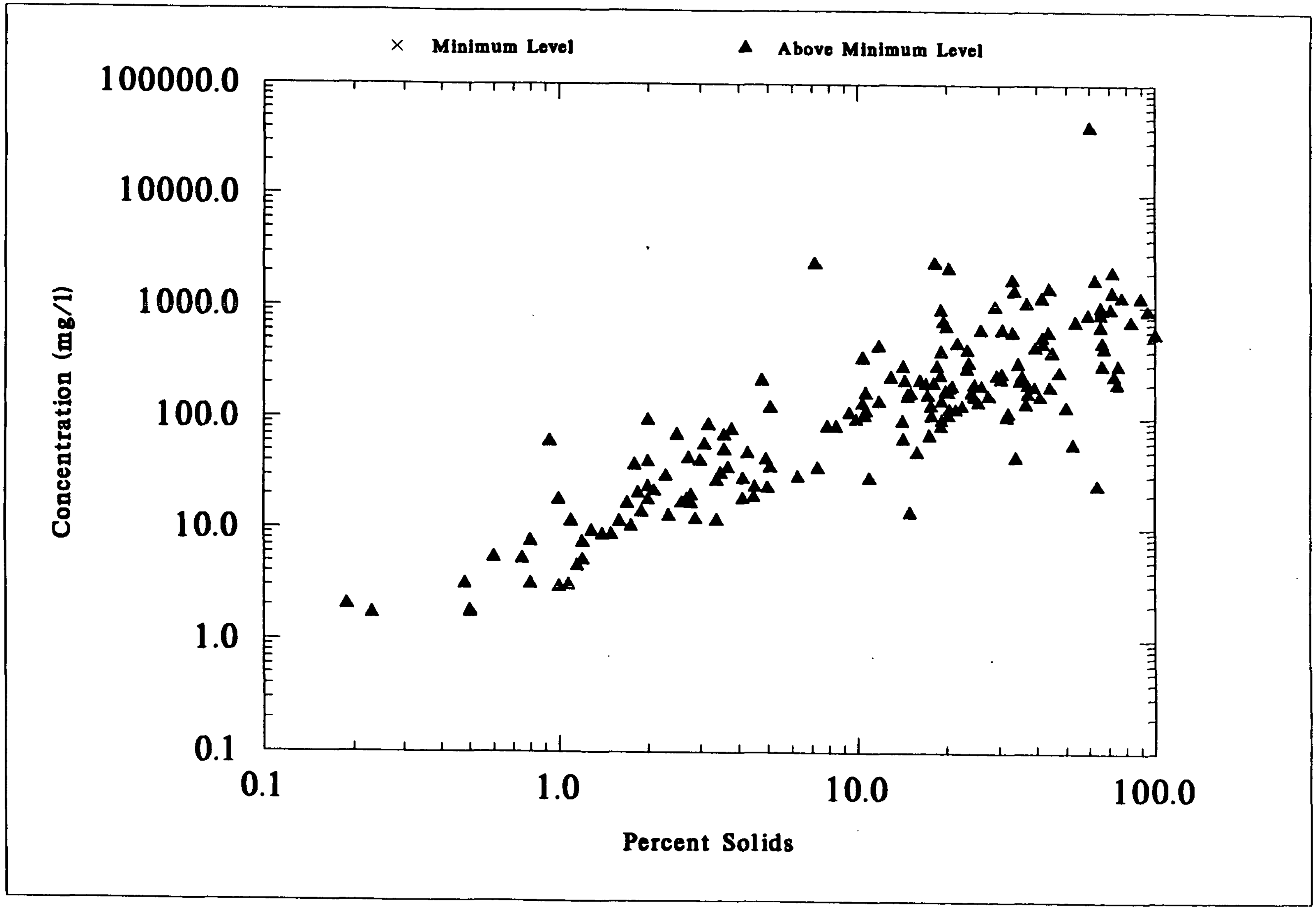


Figure 7-62. Percent Solids of NSSS Samples Versus
WET WEIGHT Concentrations of ZINC

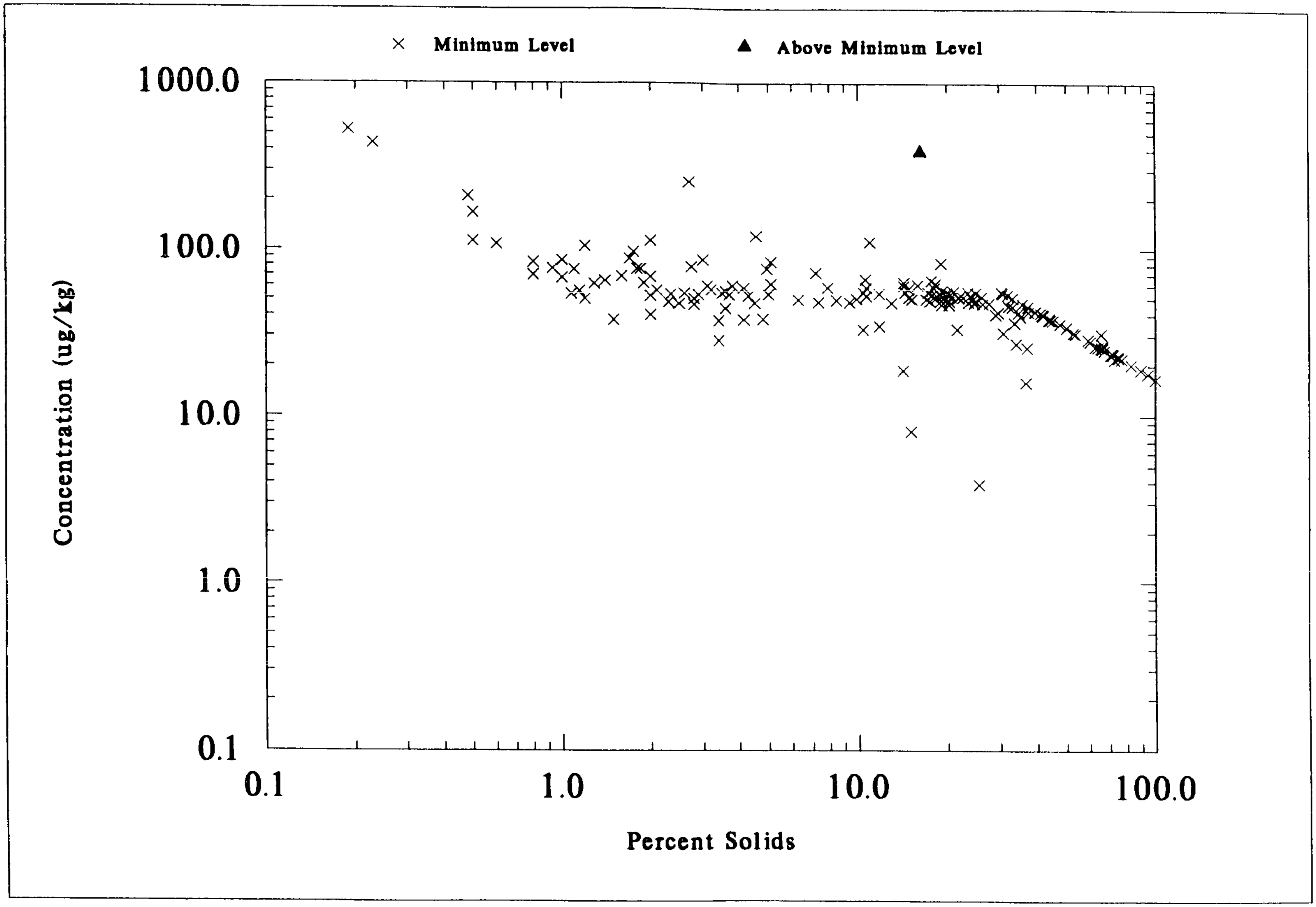


Figure 7-63. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of 4,4'-DDD

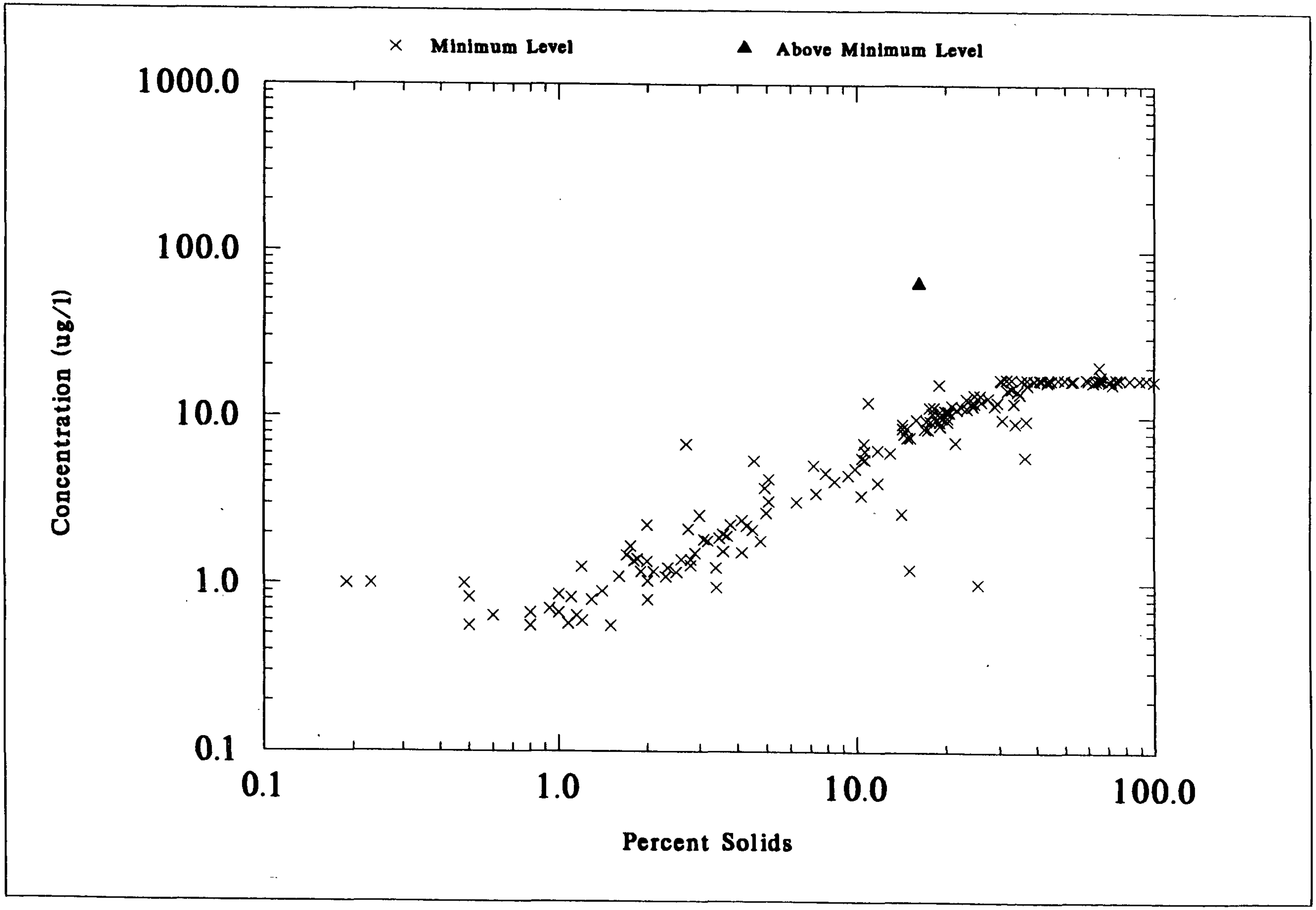


Figure 7-64. Percent Solids of NSSS Samples Versus
WET WEIGHT Concentrations of 4,4'-DDD

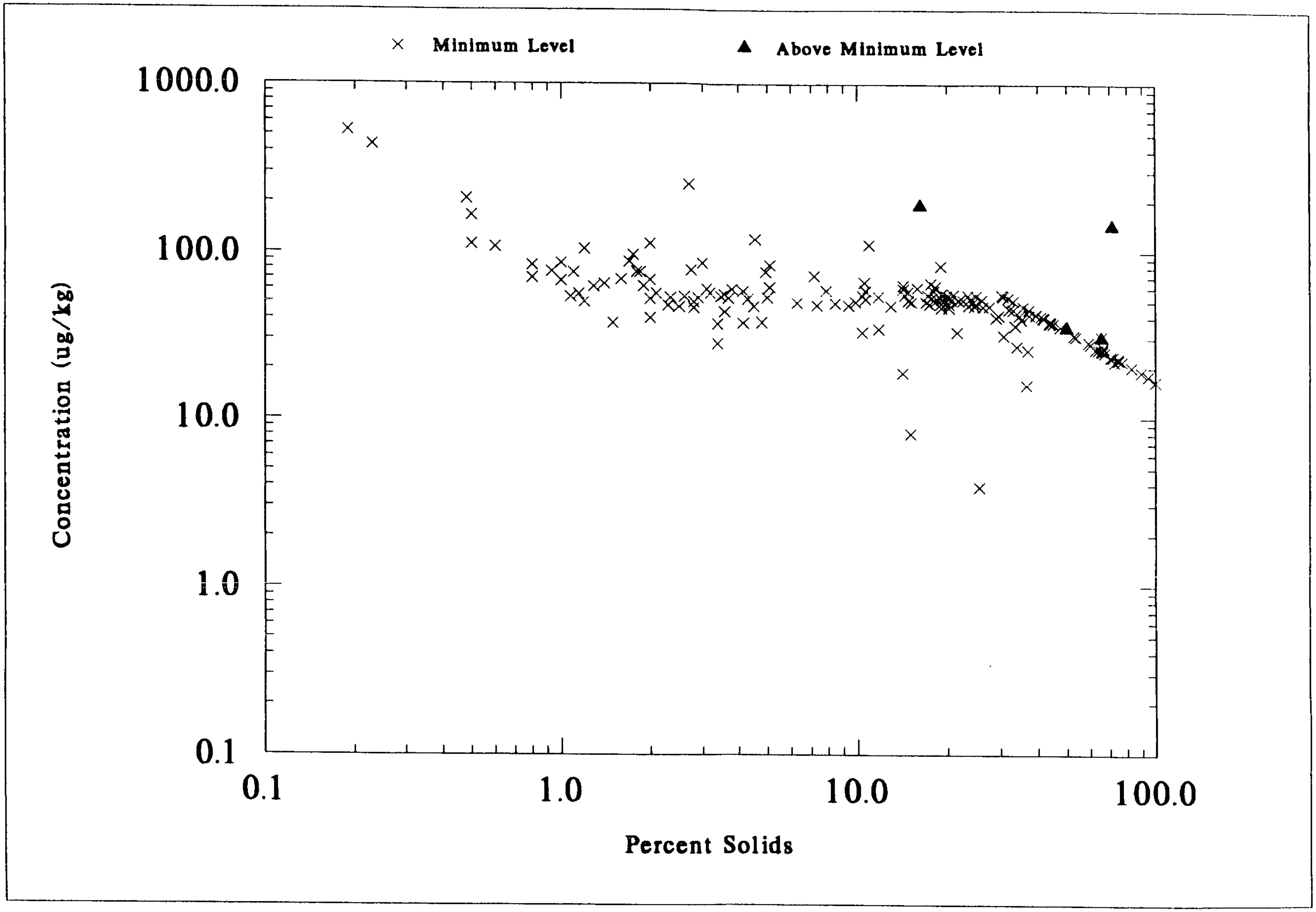


Figure 7–65. Percent Solids of NSSS Samples Versus
DRY WEIGHT Concentrations of 4.4'–DDE

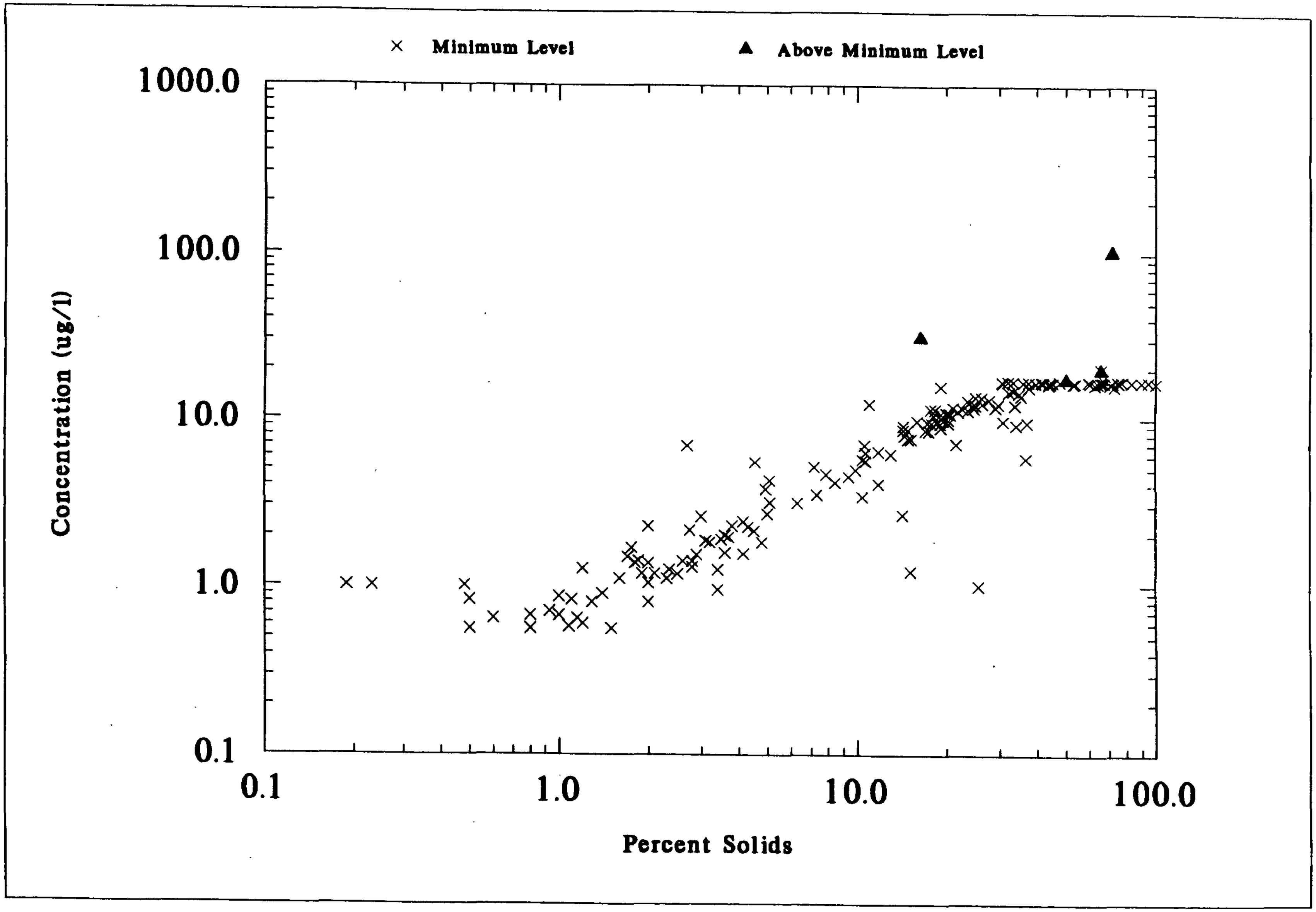


Figure 7-66. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of 4.4'-DDE

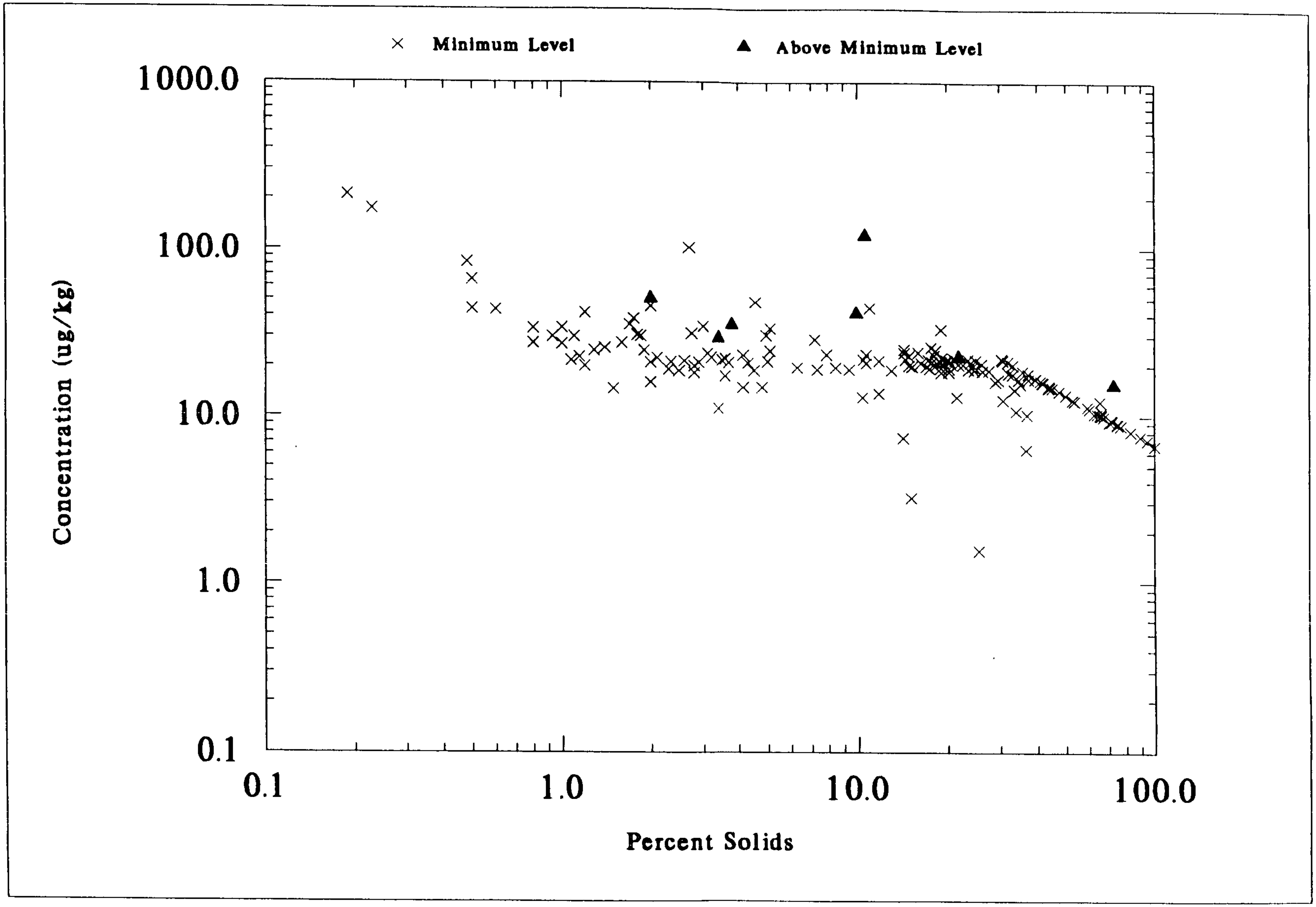


Figure 7-67. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of 4,4'-DDT

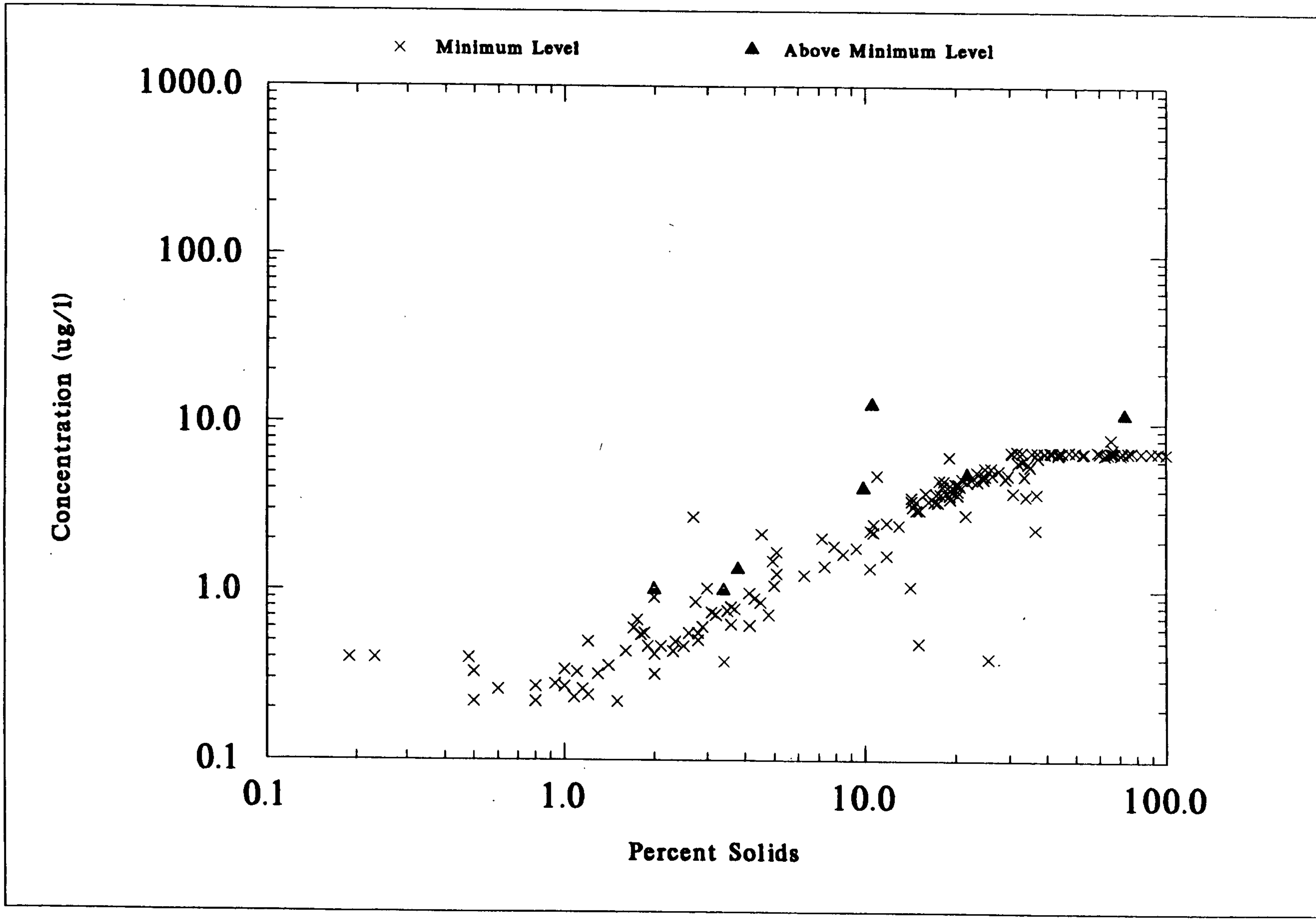


Figure 7-68. Percent Solids of NSSS Samples Versus WET WEIGHT Concentrations of 4,4'-DDT

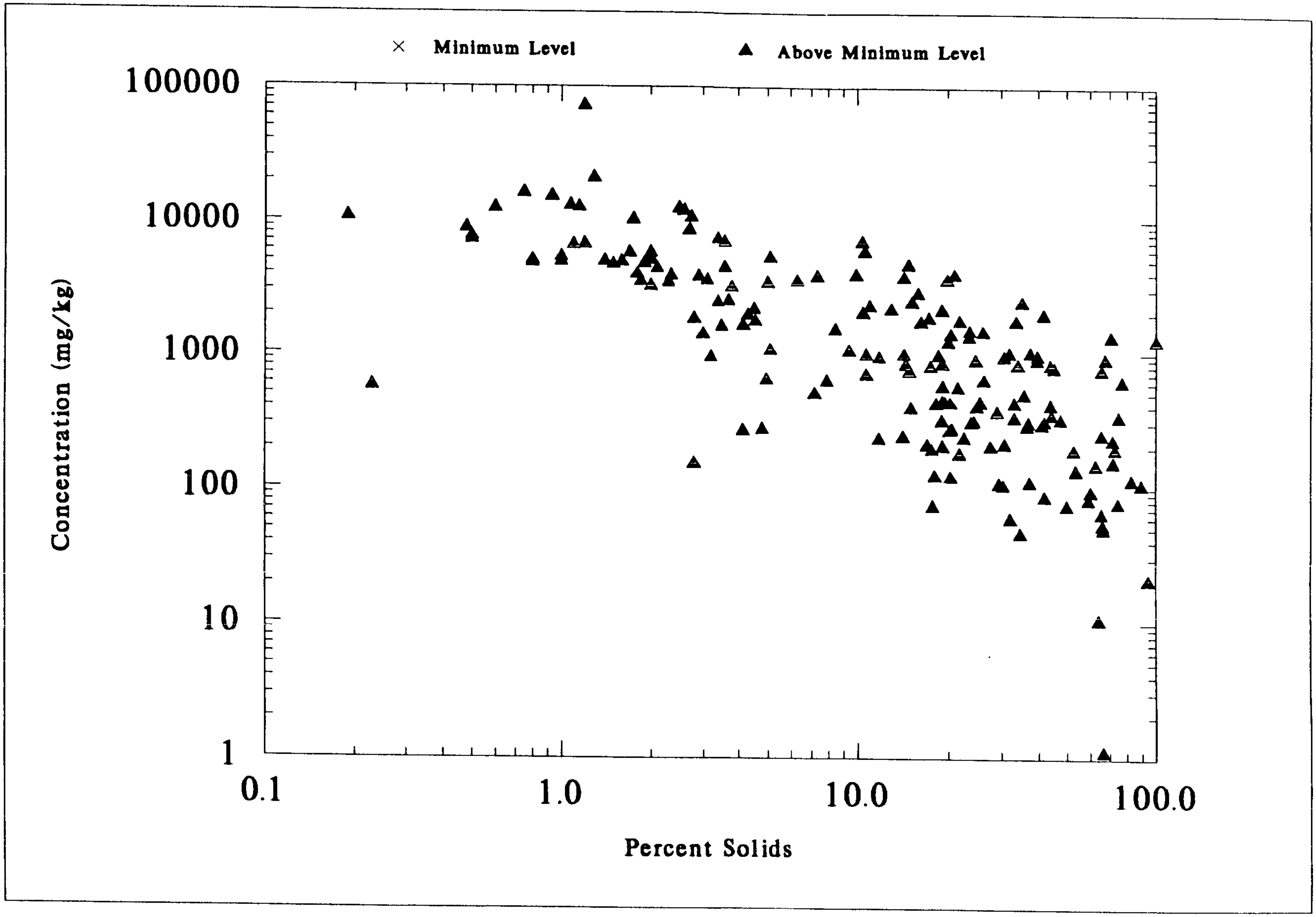


Figure 7–69. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of PHOSPHORUS

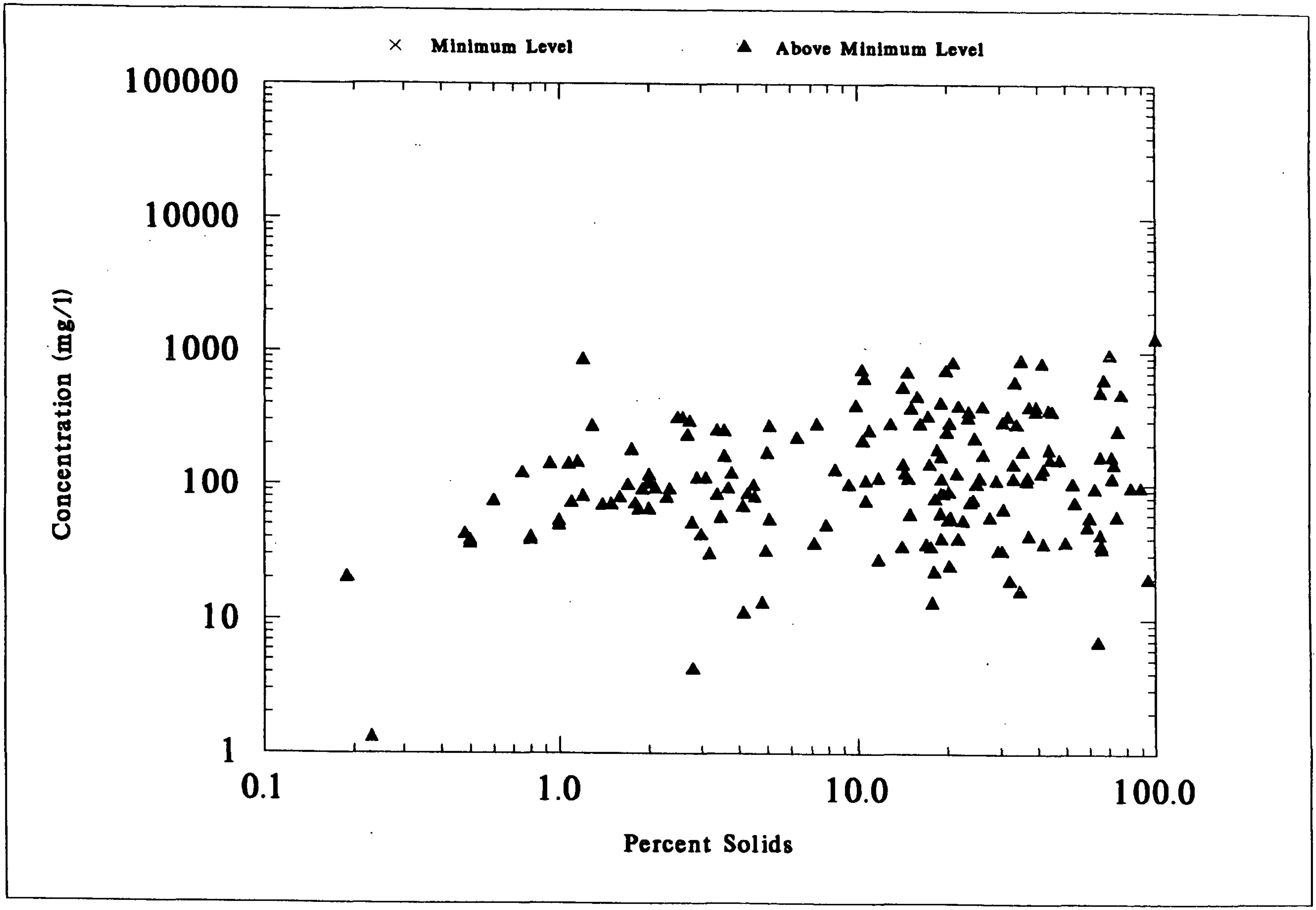


Figure 7-70. Percent Solids of NSSS Samples Versus
WET WEIGHT Concentrations of PHOSPHORUS

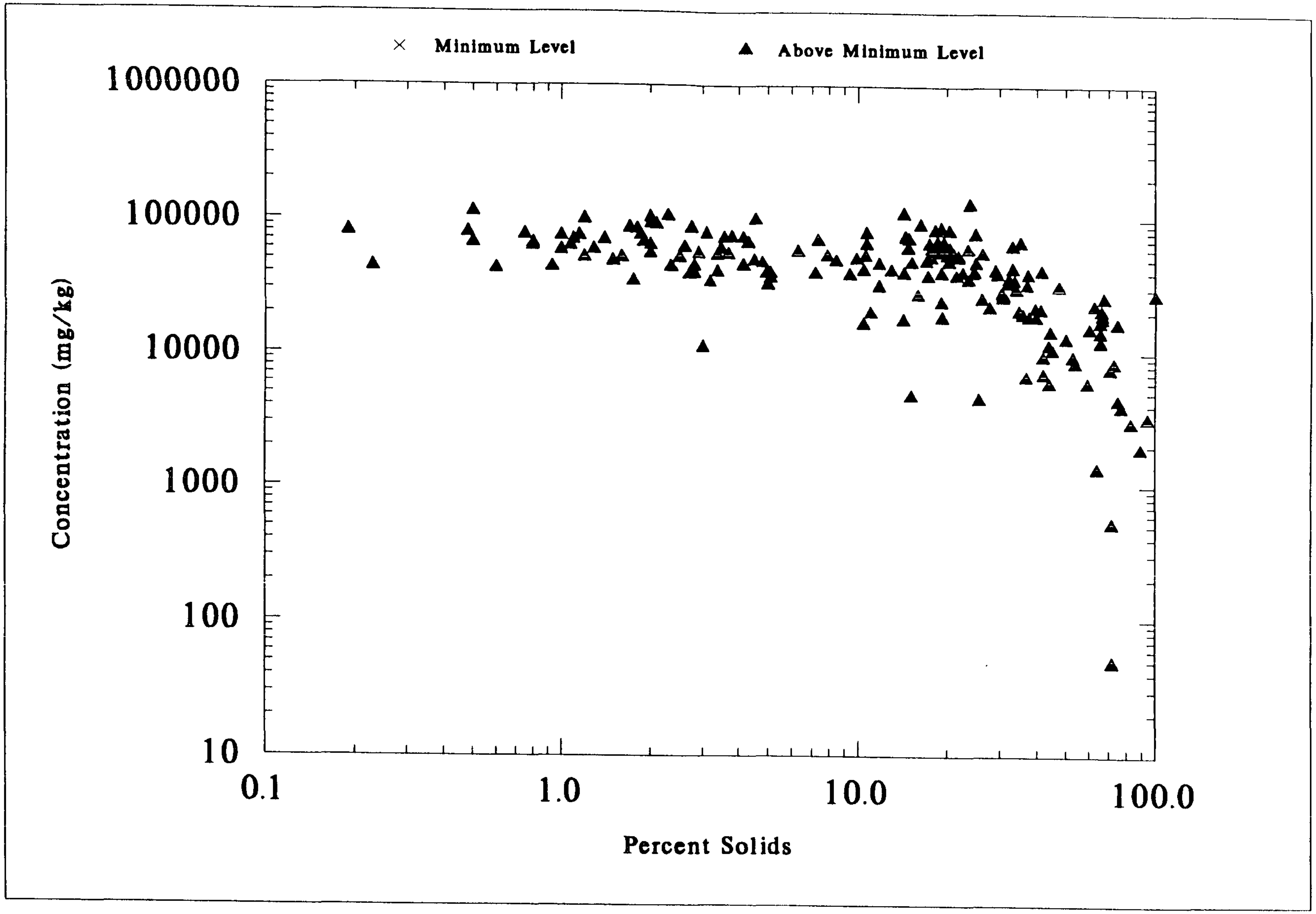


Figure 7-71. Percent Solids of NSSS Samples Versus DRY WEIGHT Concentrations of TOTAL KJELDAHL NITROGEN

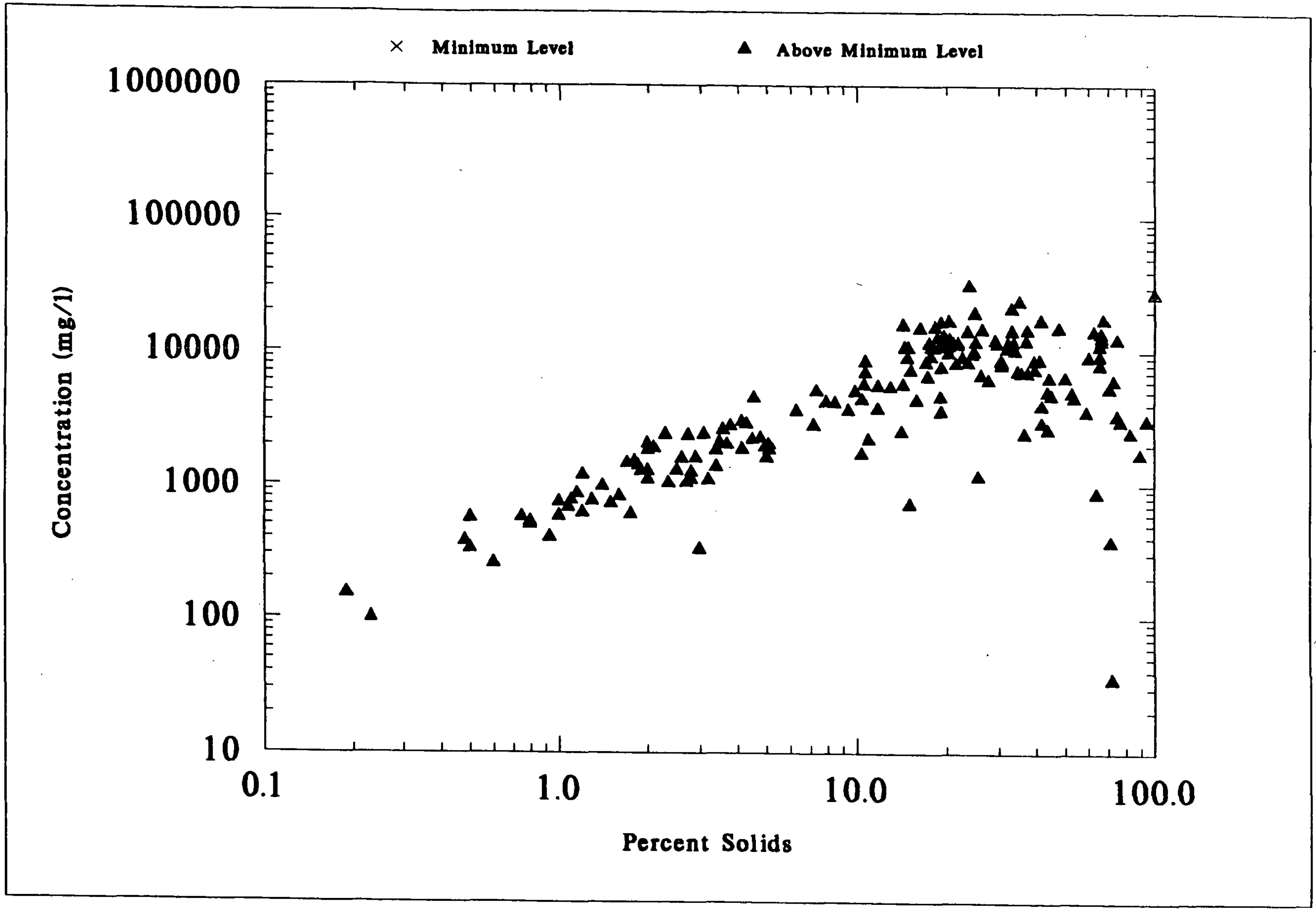


Figure 7-72. Percent Solids of NSSS Samples Versus
WET WEIGHT Concentrations of TOTAL KJELDAHL NITROGEN

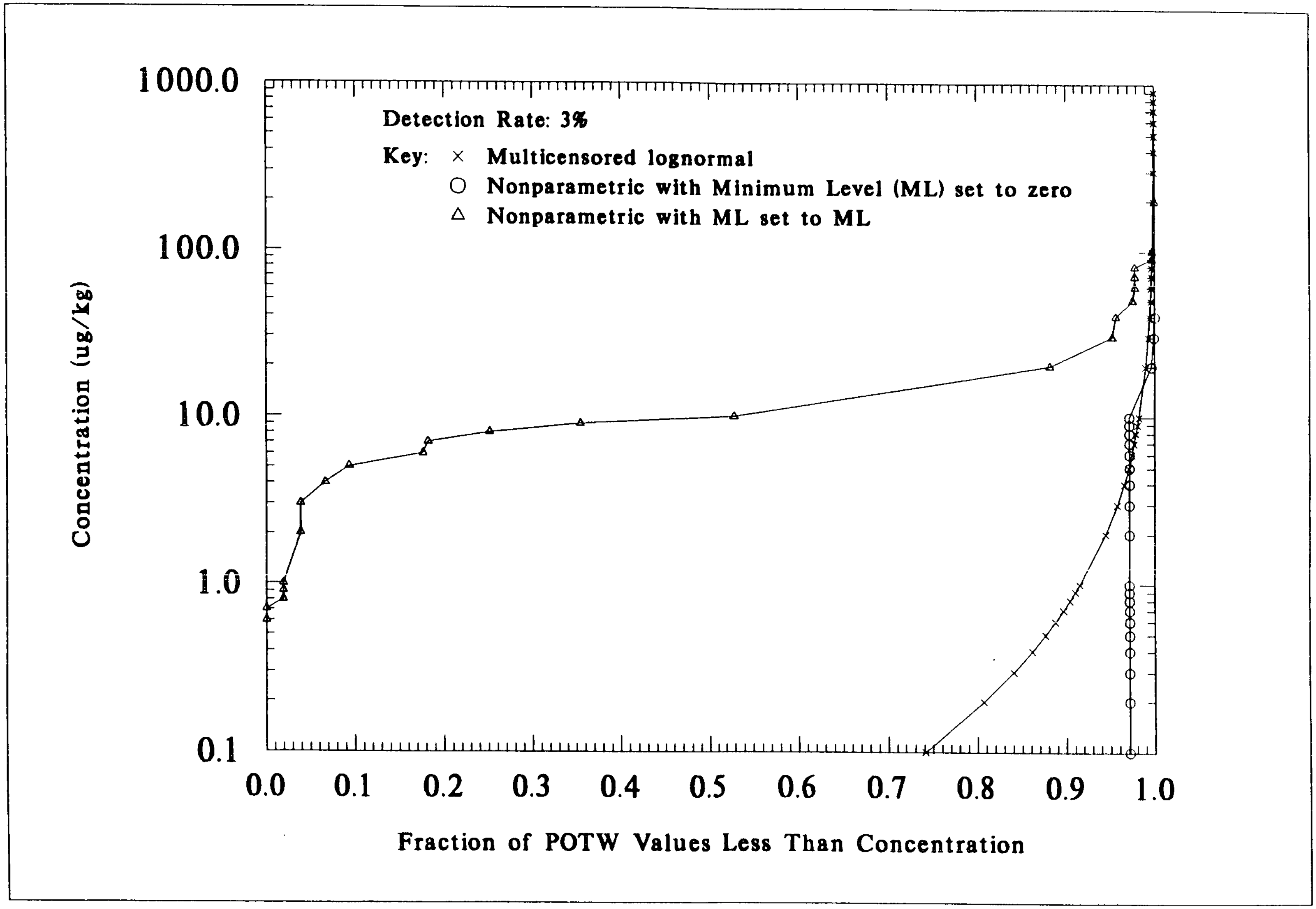


Figure 7-73. Cumulative Distribution Functions: ALDRIN

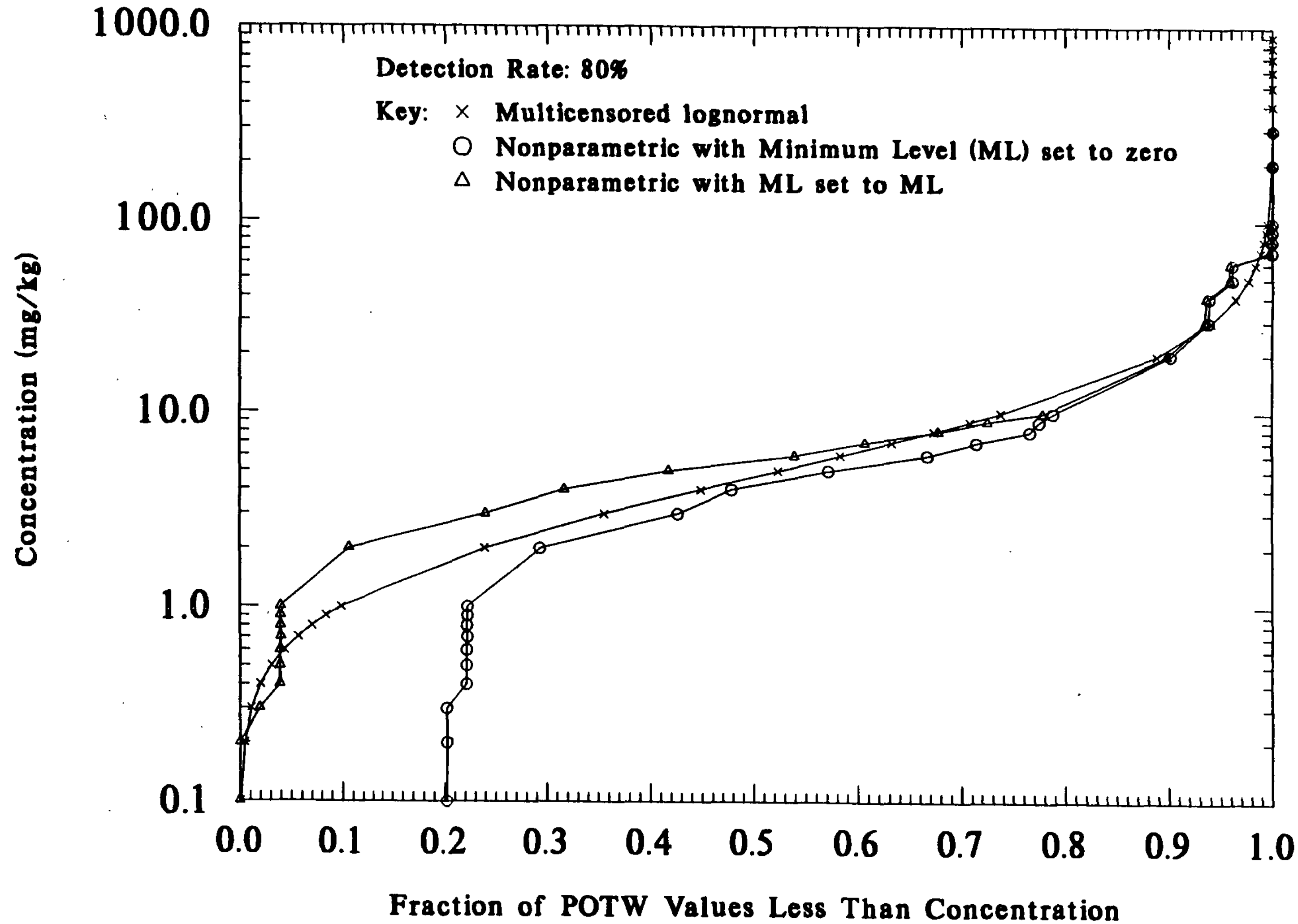


Figure 7-74. Cumulative Distribution Functions: ARSENIC

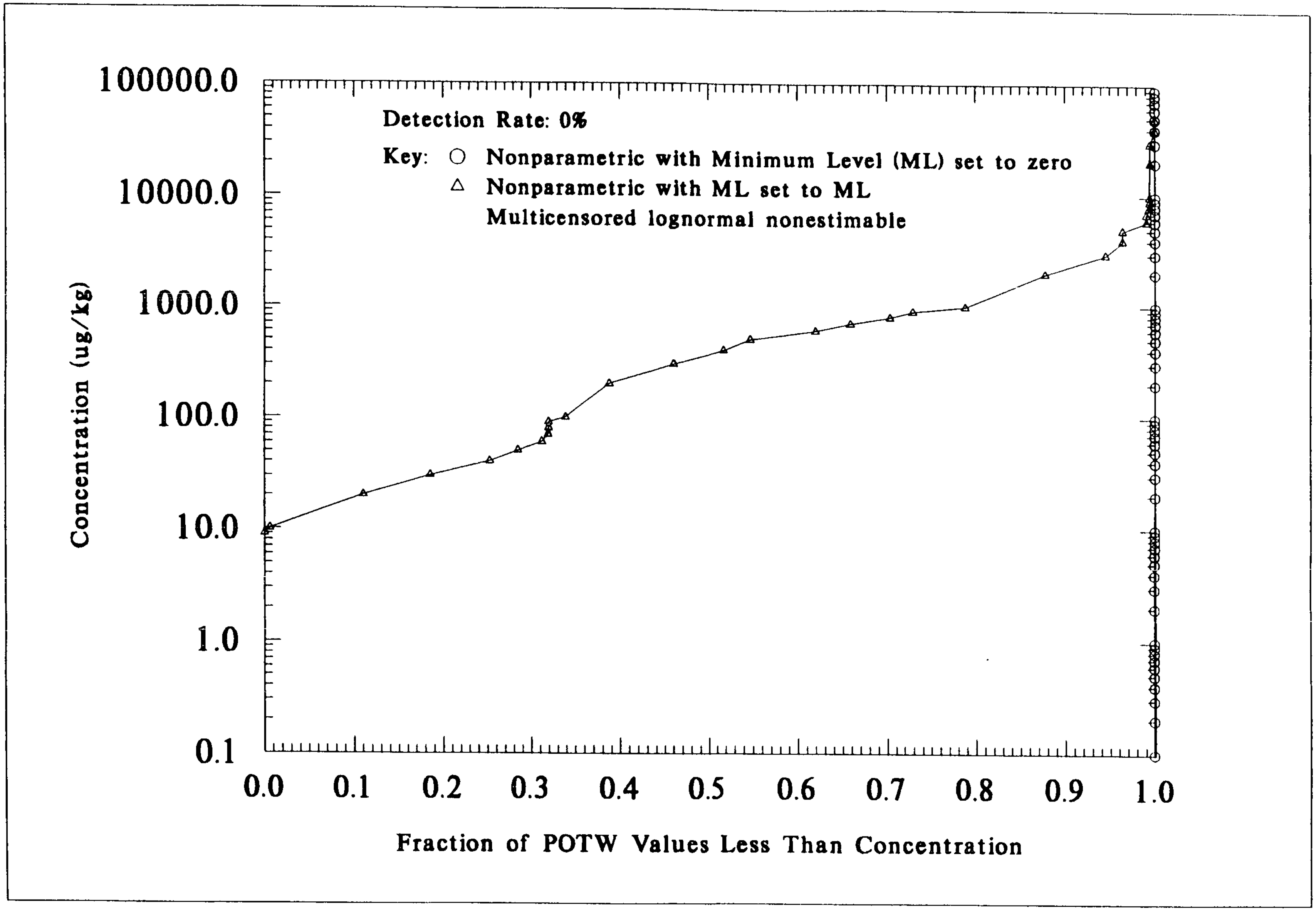


Figure 7-75. Cumulative Distribution Functions: BENZENE

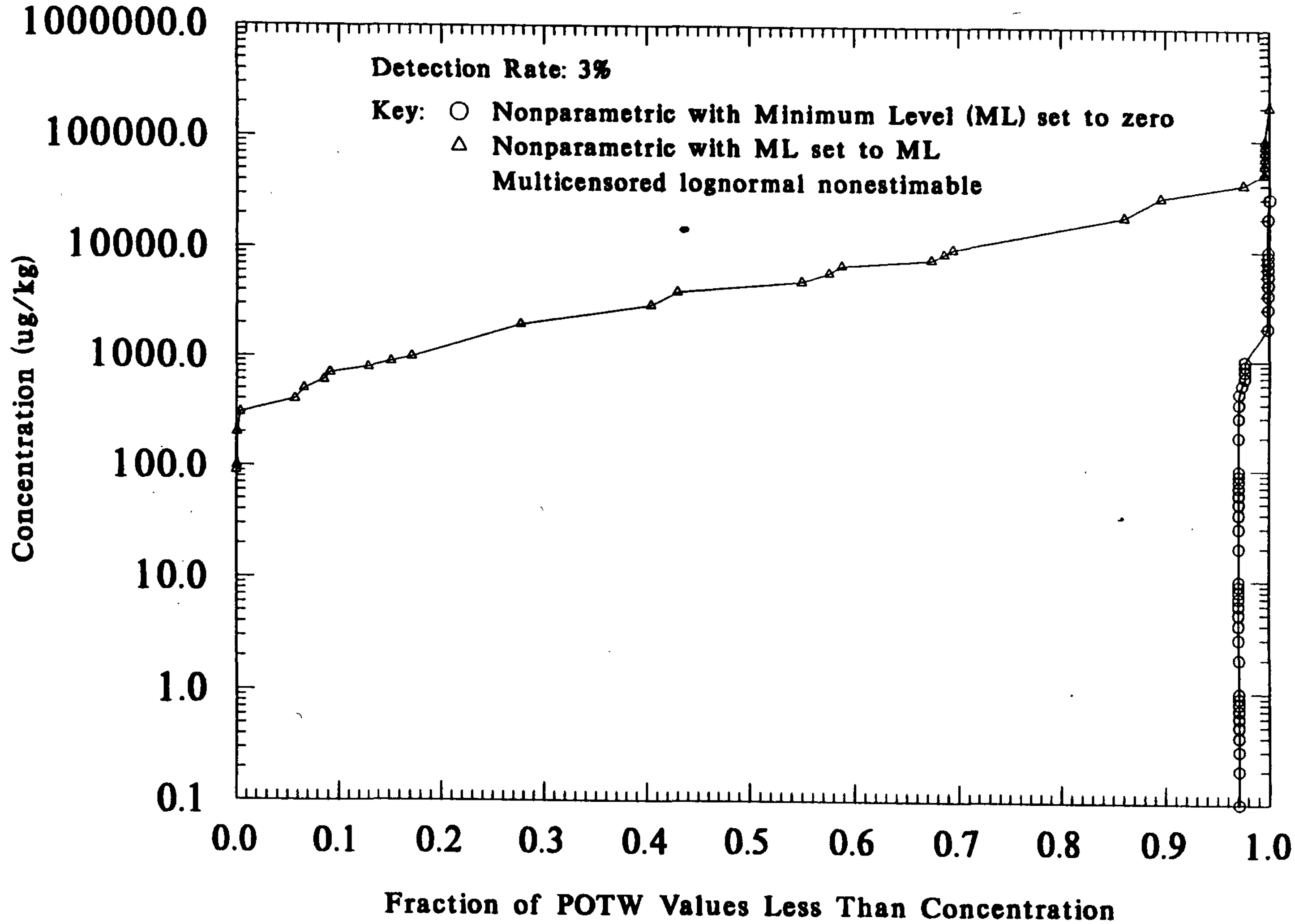


Figure 7-76. Cumulative Distribution Functions: BENZO(A)PYRENE

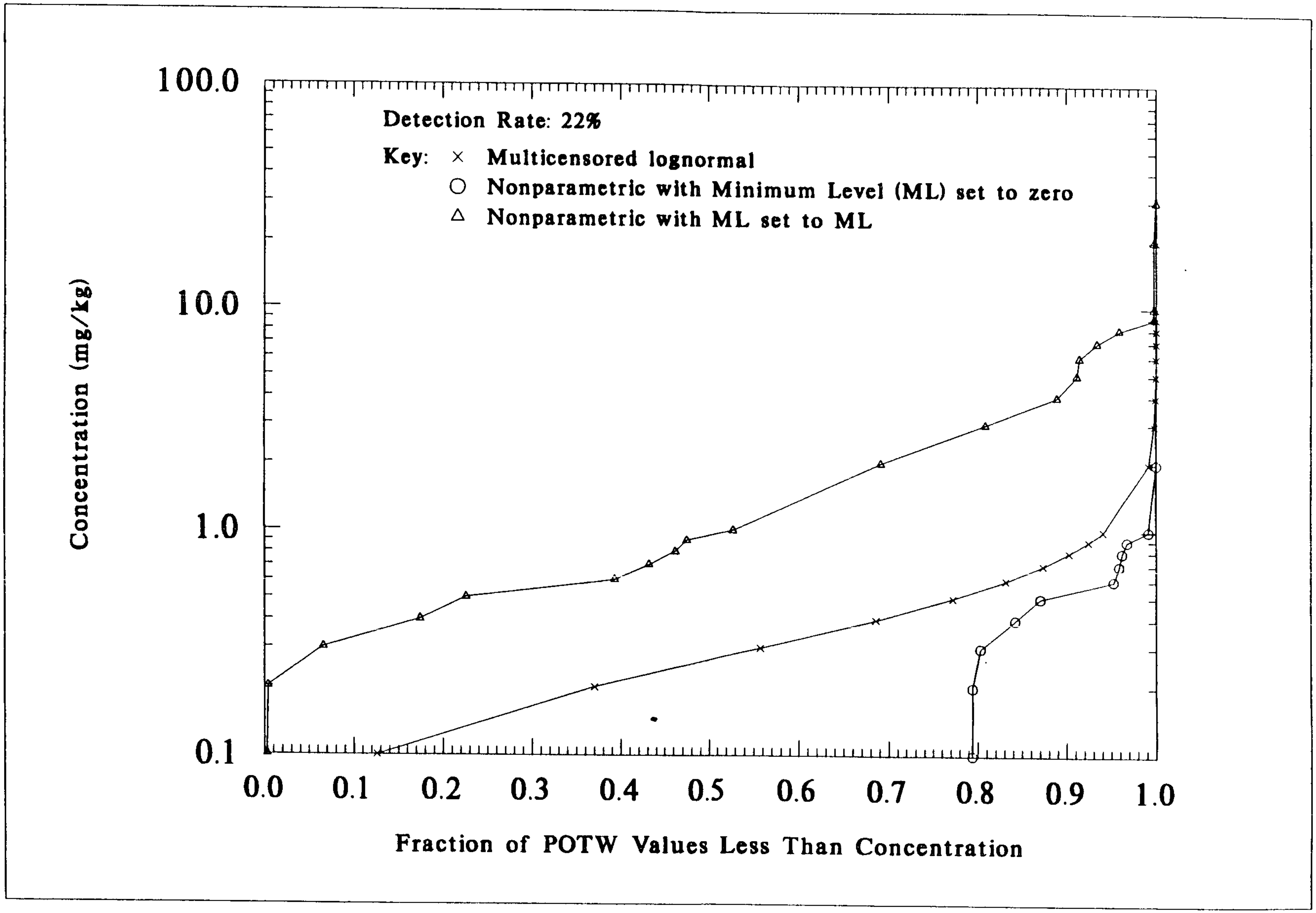


Figure 7-77. Cumulative Distribution Functions: BERYLLIUM

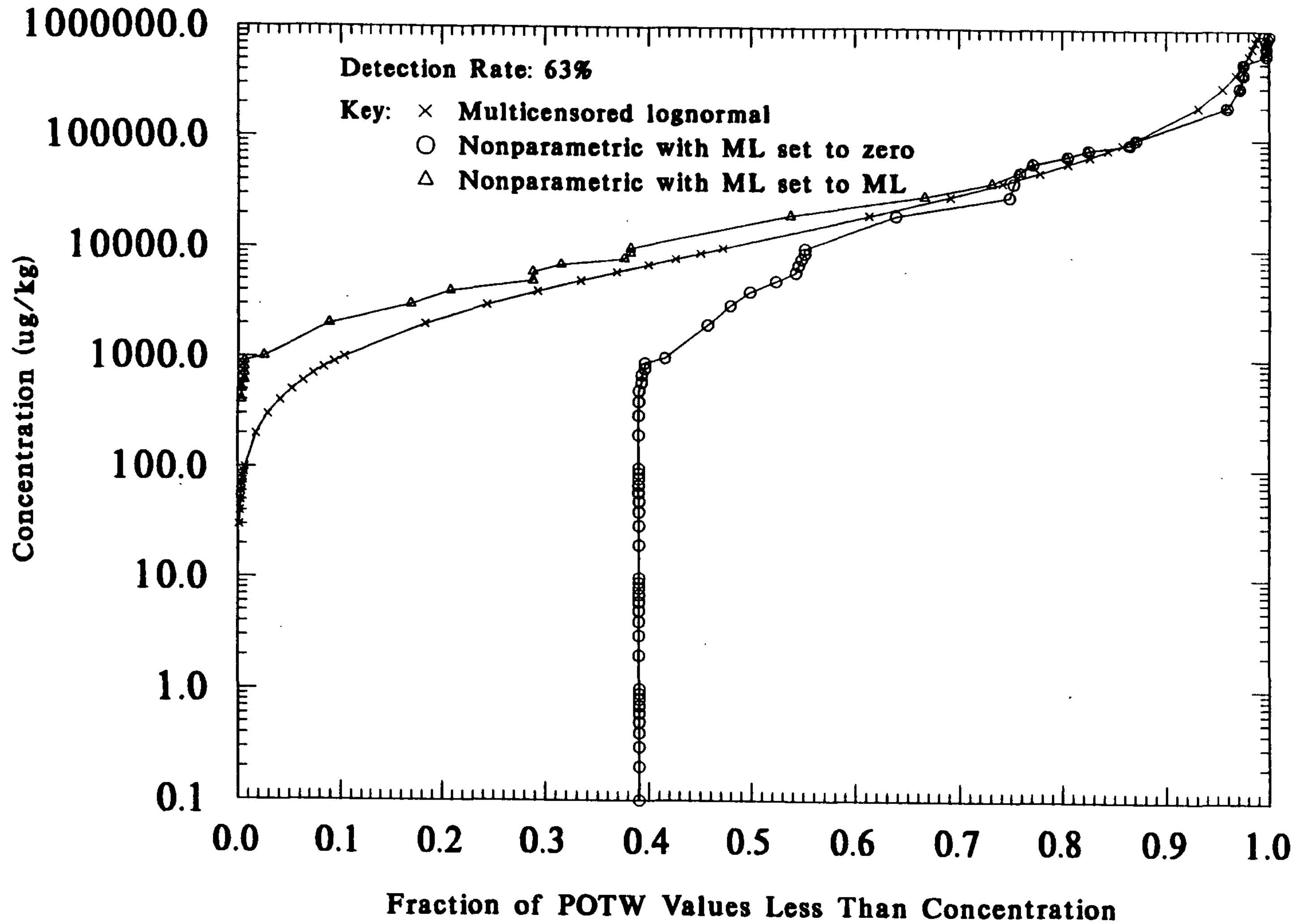


Figure 7-78. Cumulative Distribution Functions: BIS(2-ETHYLHEXYL) PHTHALATE

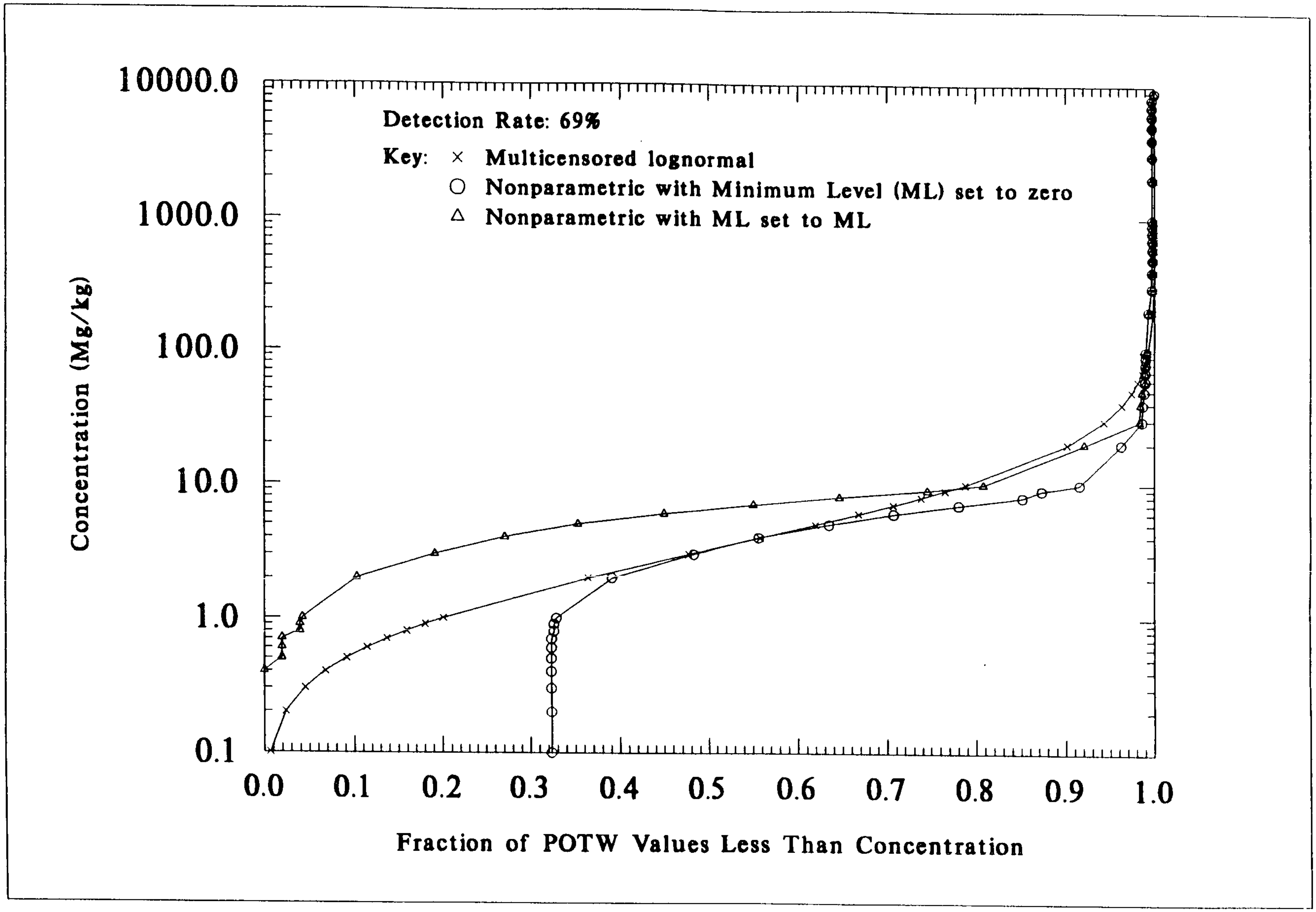


Figure 7-79. Cumulative Distribution Functions: CADMIUM

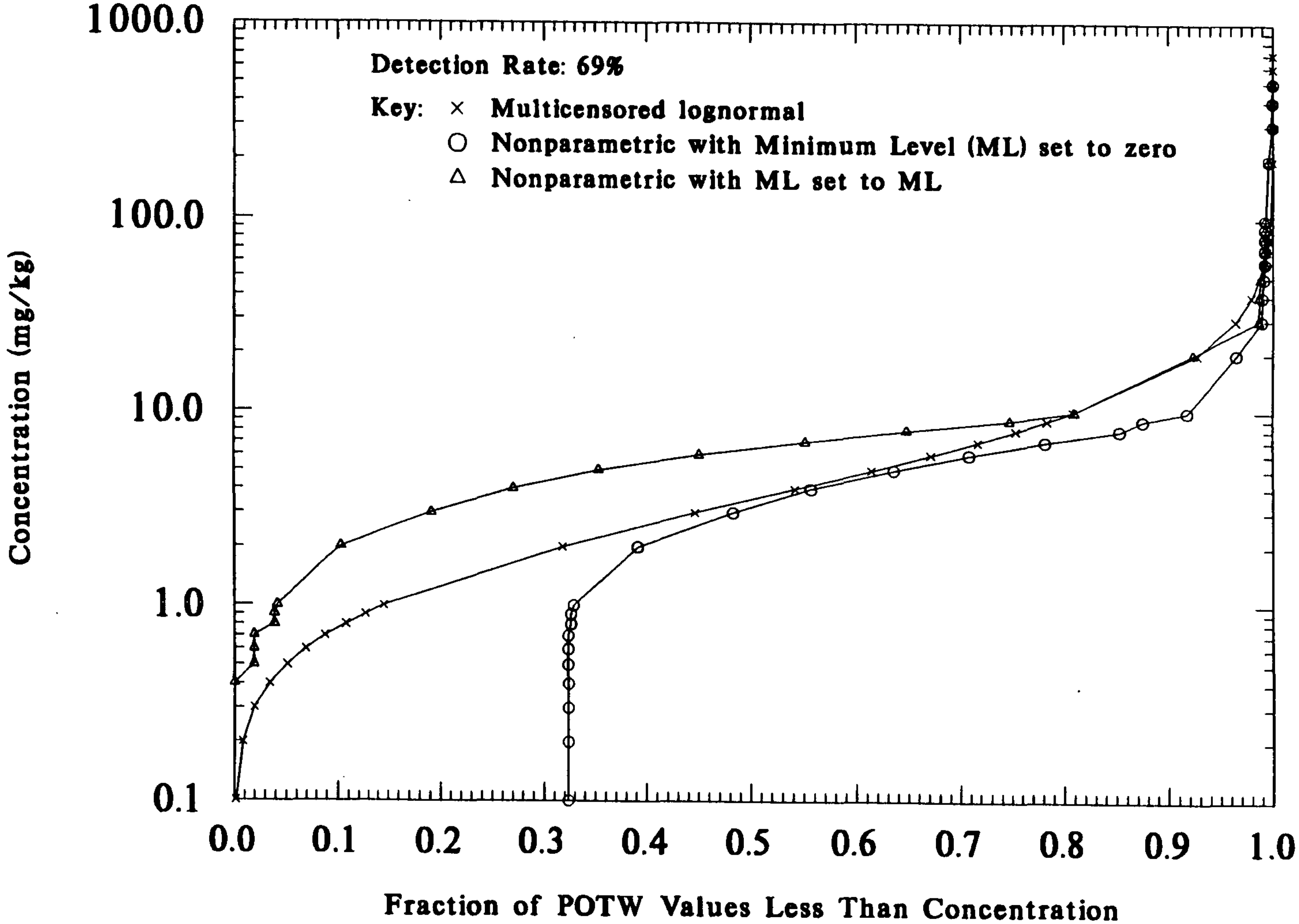


Figure 7-80. Cumulative Distribution Functions: CADMIUM*

* Excluding an Extreme Outlier Observation From Stratum 3

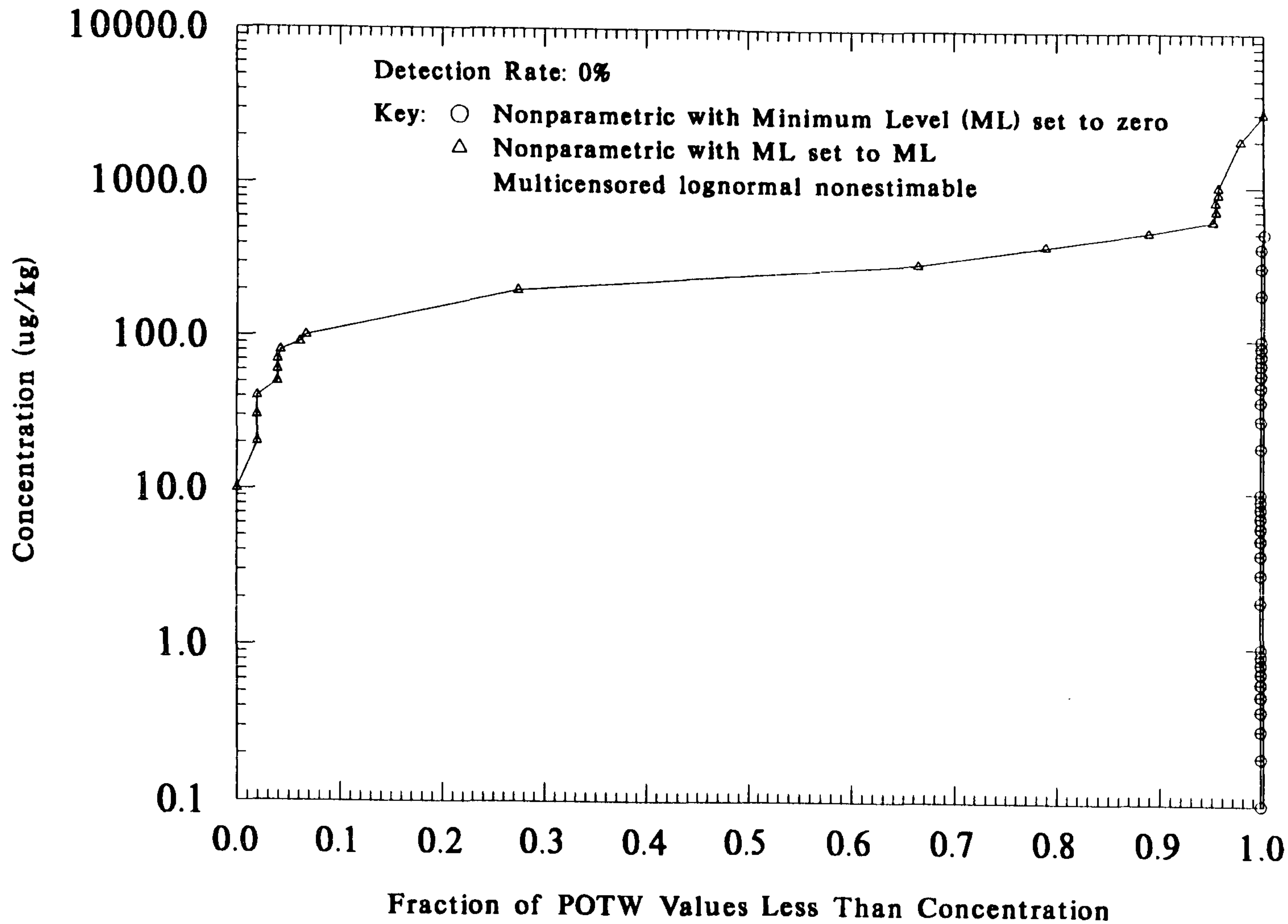


Figure 7-81. Cumulative Distribution Functions: CHLORDANE

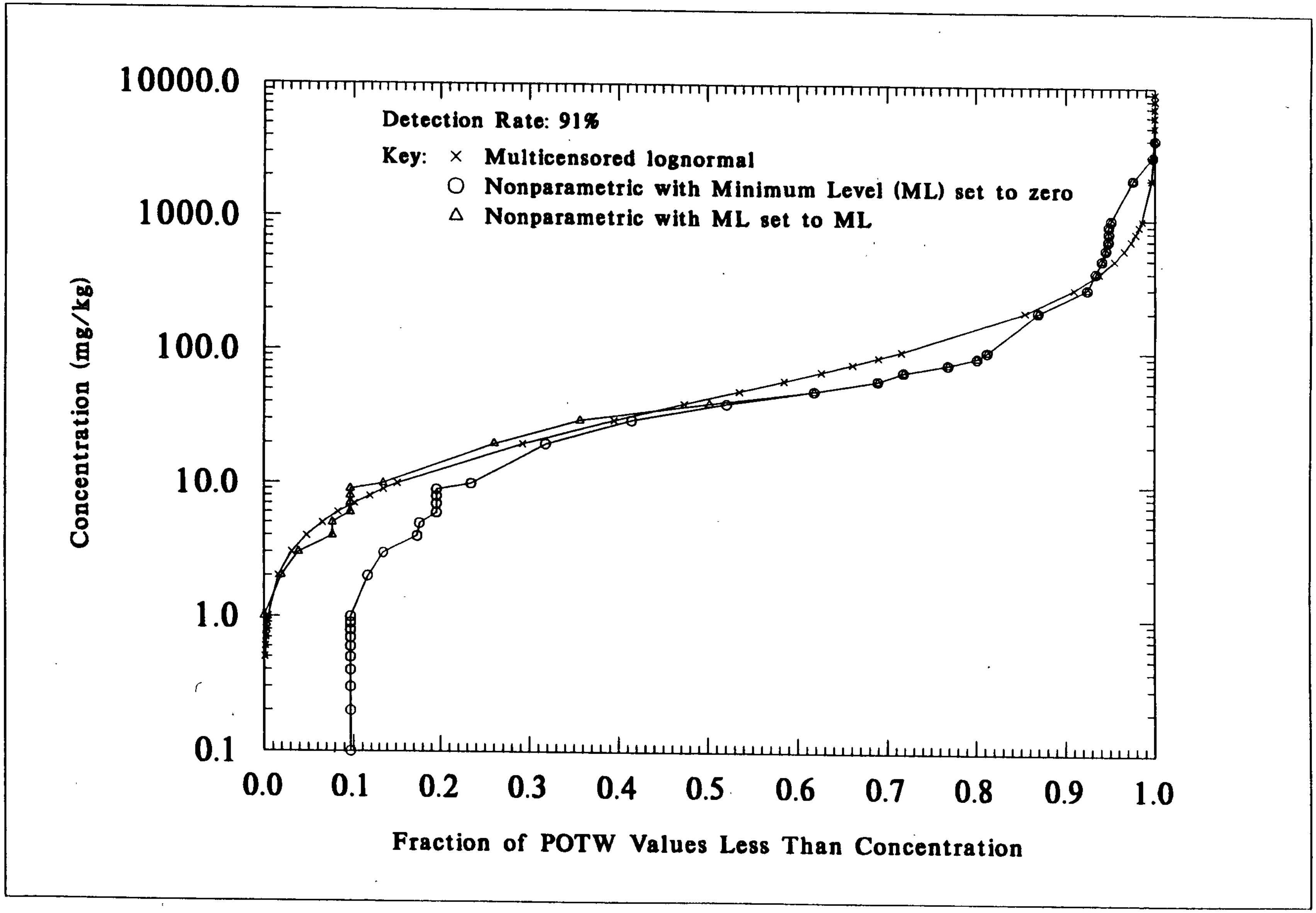


Figure 7-82. Cumulative Distribution Functions: CHROMIUM

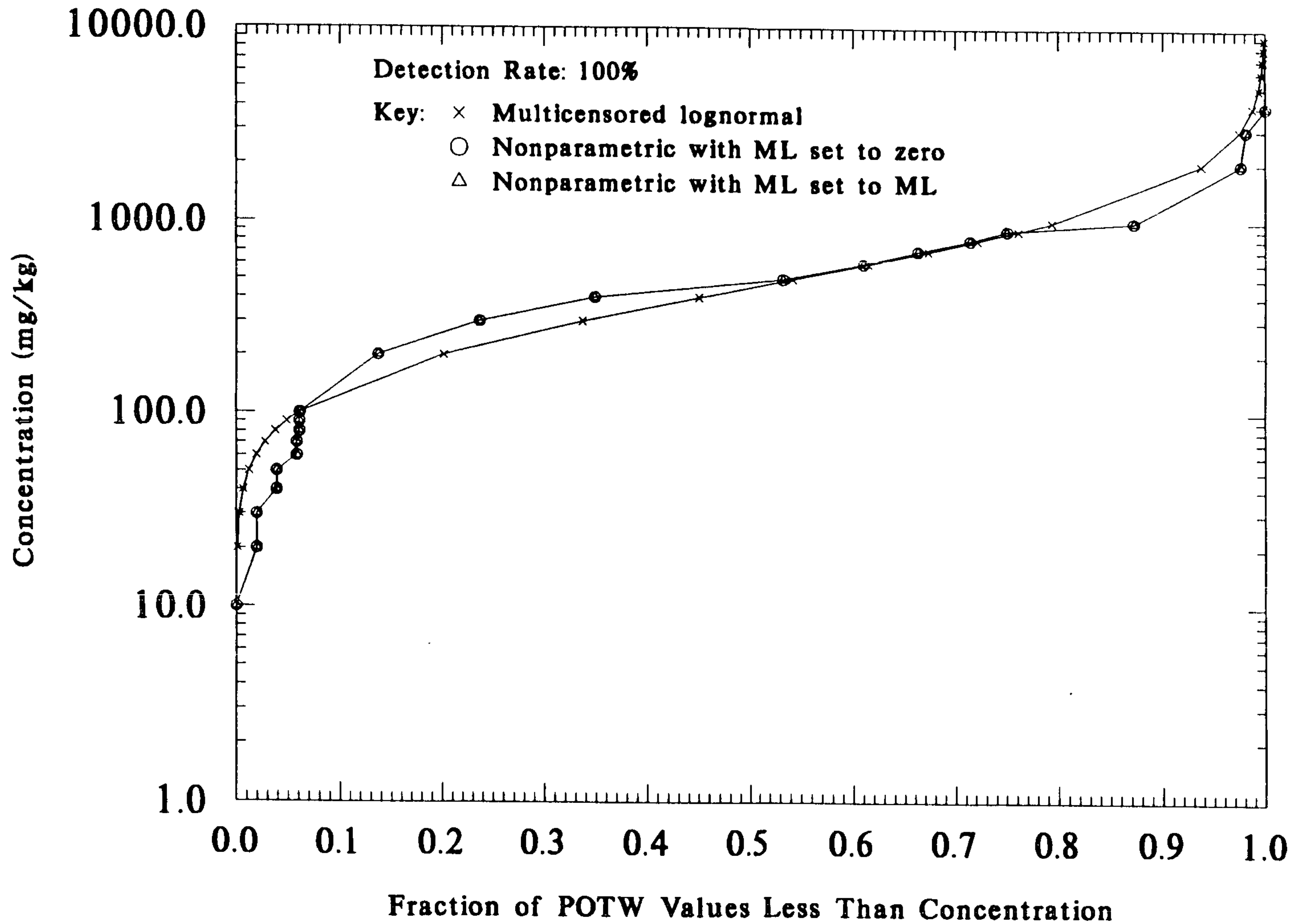


Figure 7-83. Cumulative Distribution Functions: COPPER

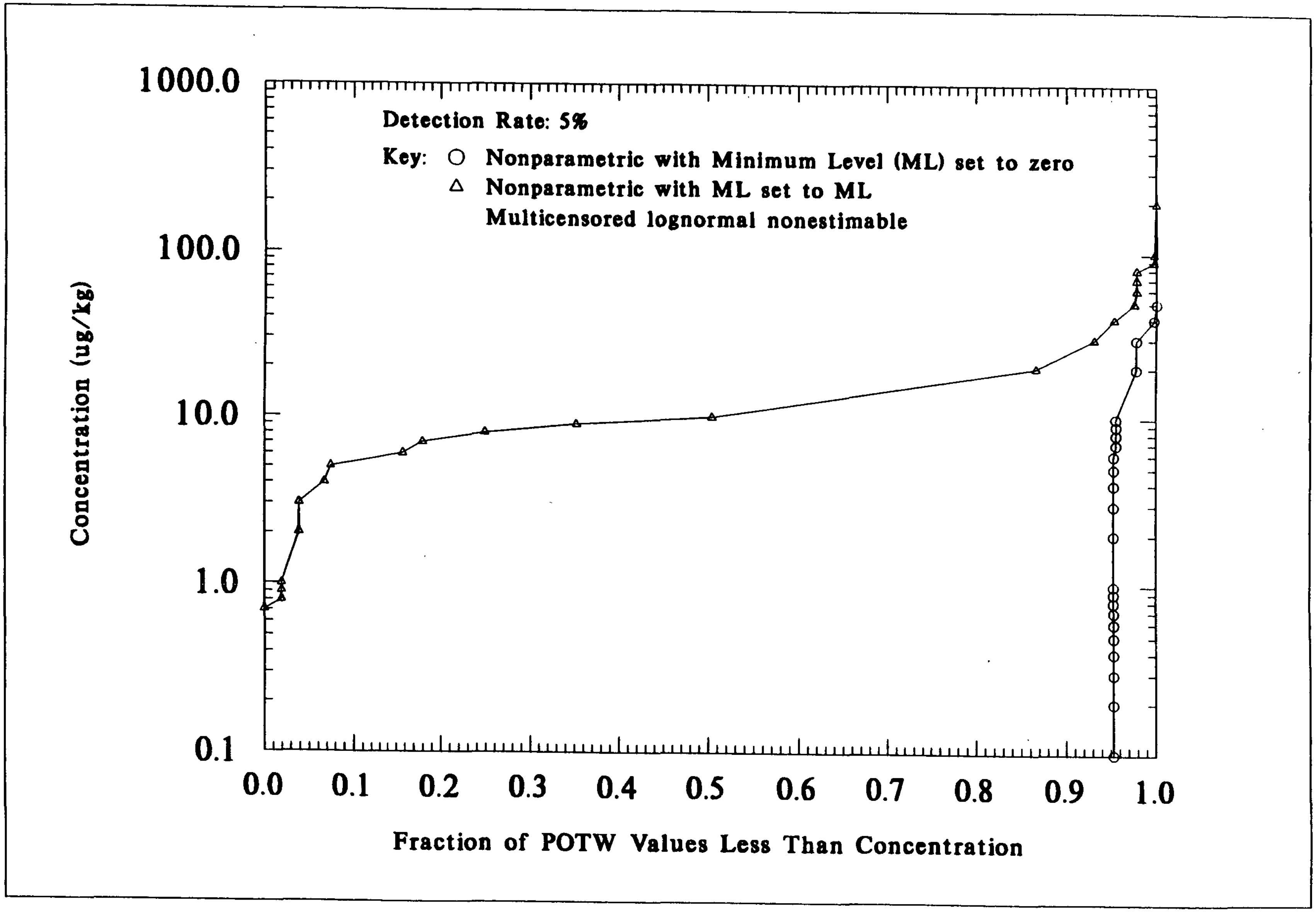


Figure 7-84. Cumulative Distribution Functions: DIELDRIN

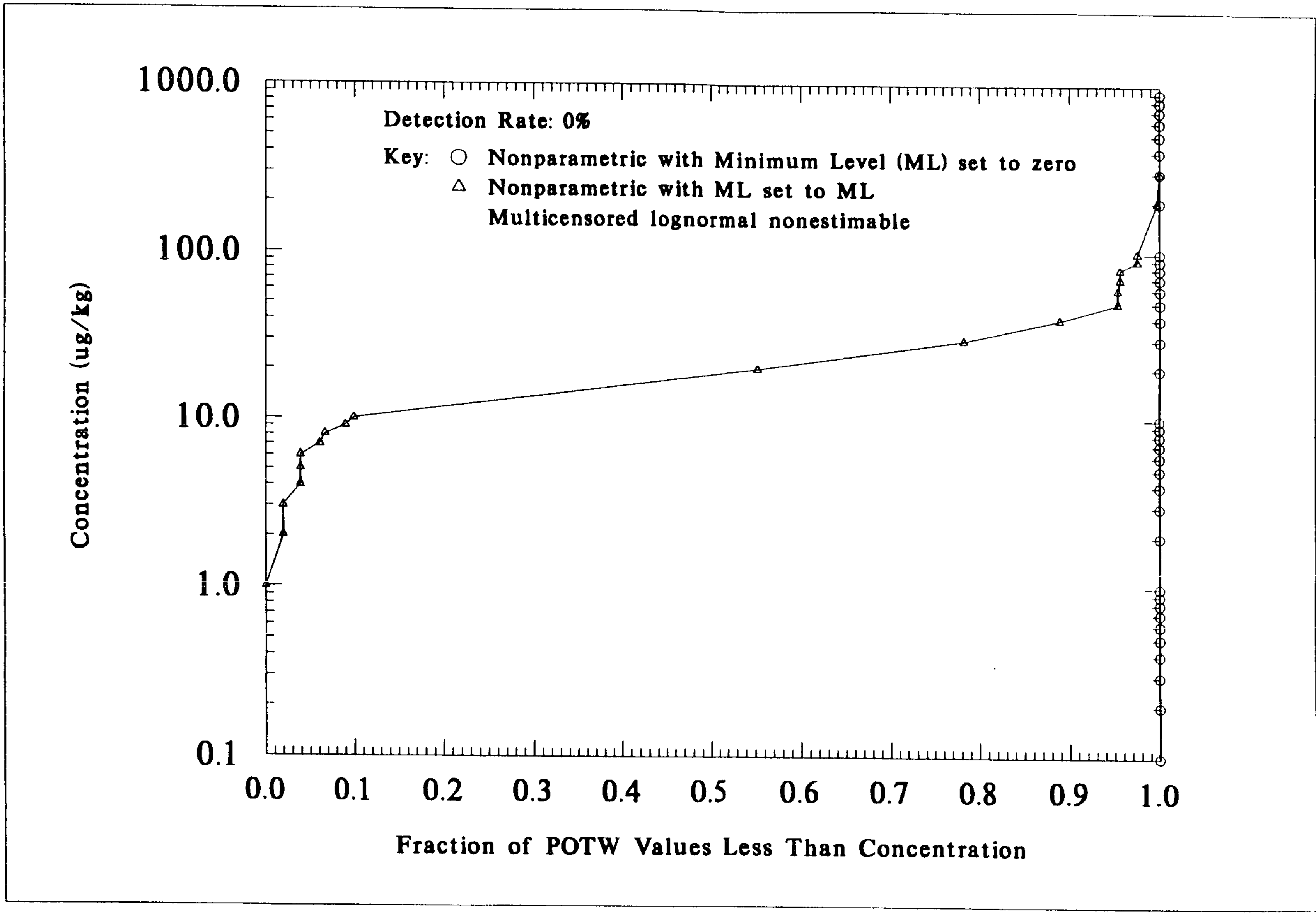


Figure 7-85. Cumulative Distribution Functions: HEPTACHLOR

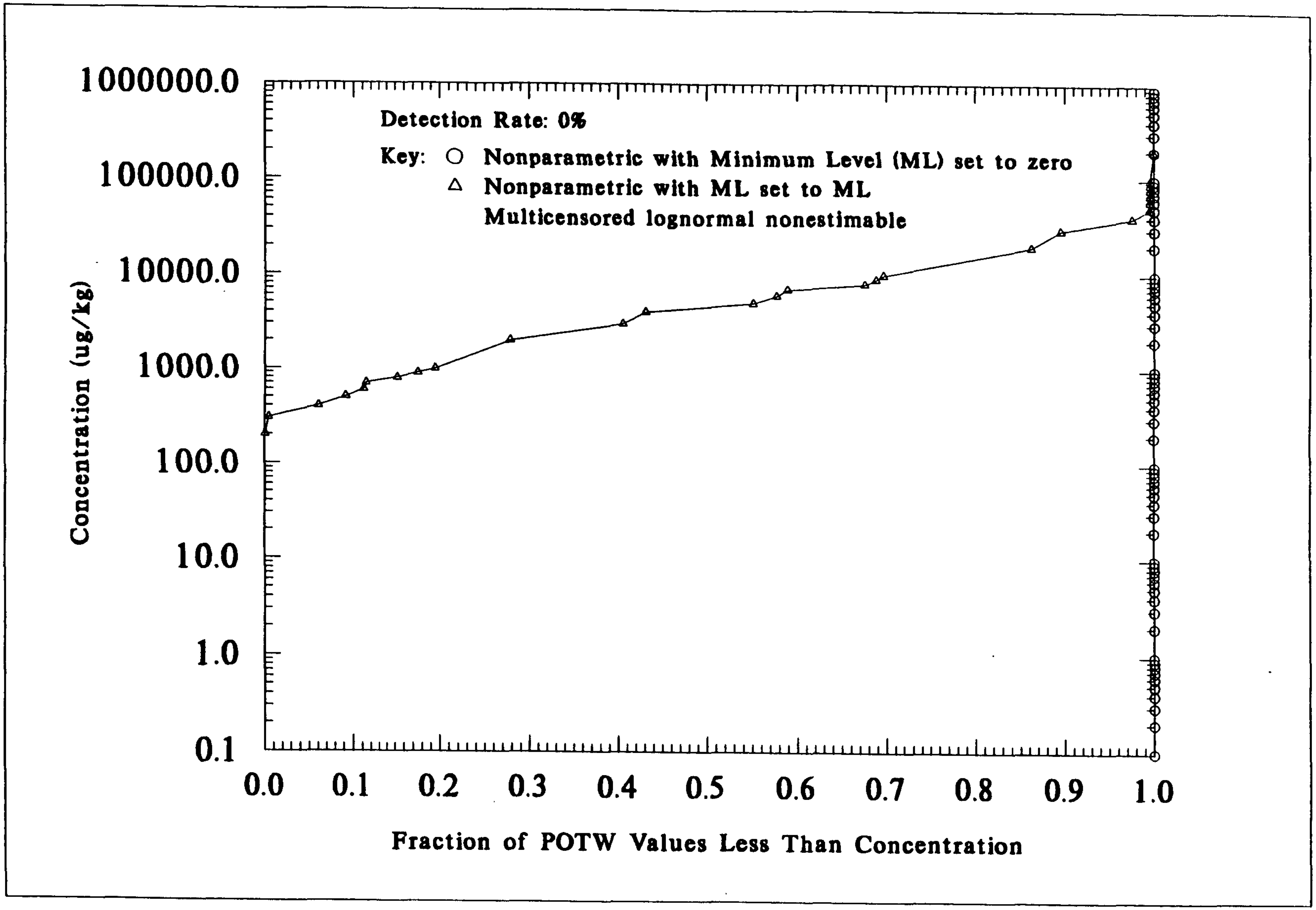


Figure 7-86. Cumulative Distribution Functions: HEXACHLOROBENZENE

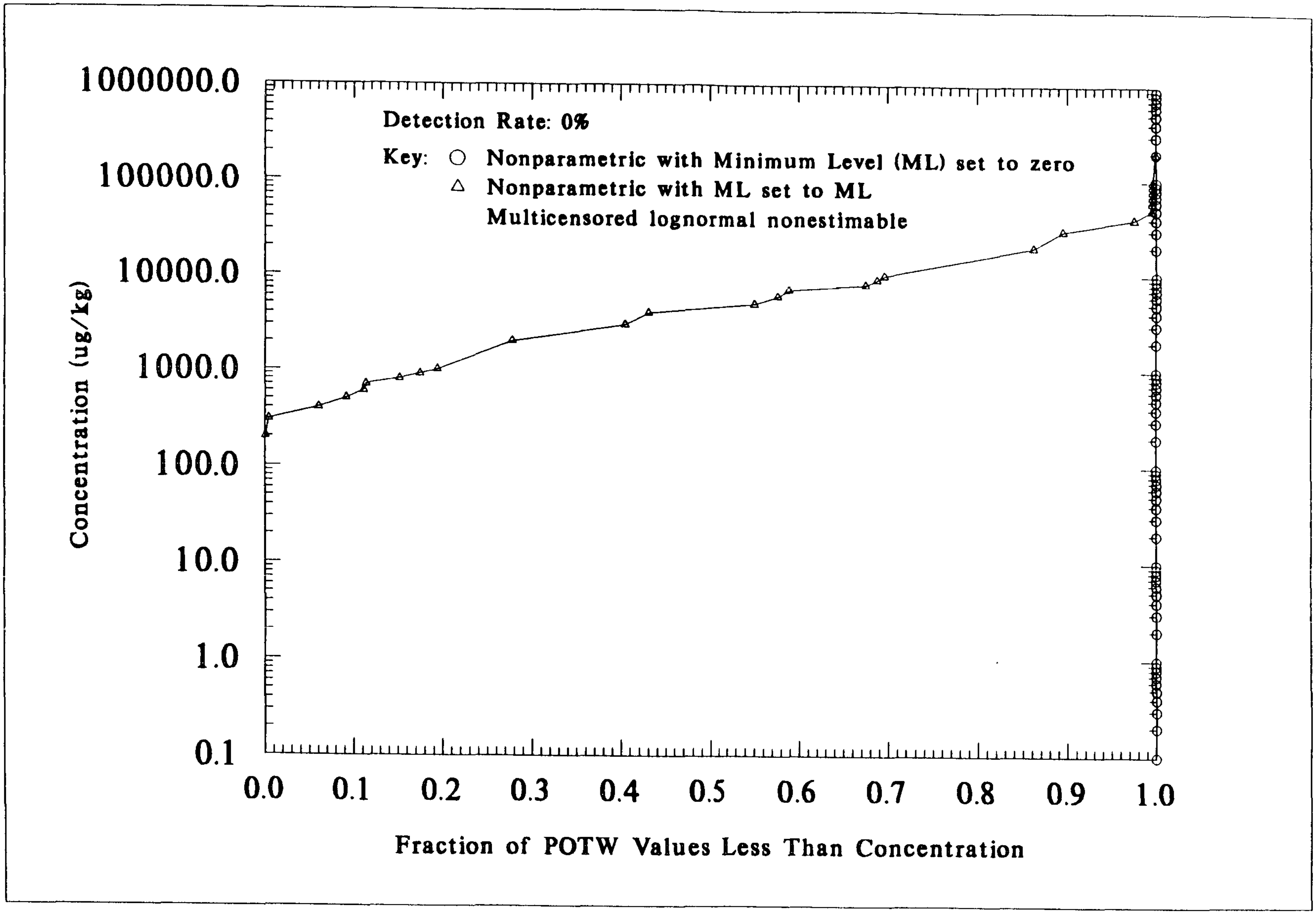


Figure 7-87. Cumulative Distribution Functions: HEXACHLOROBUTADIENE

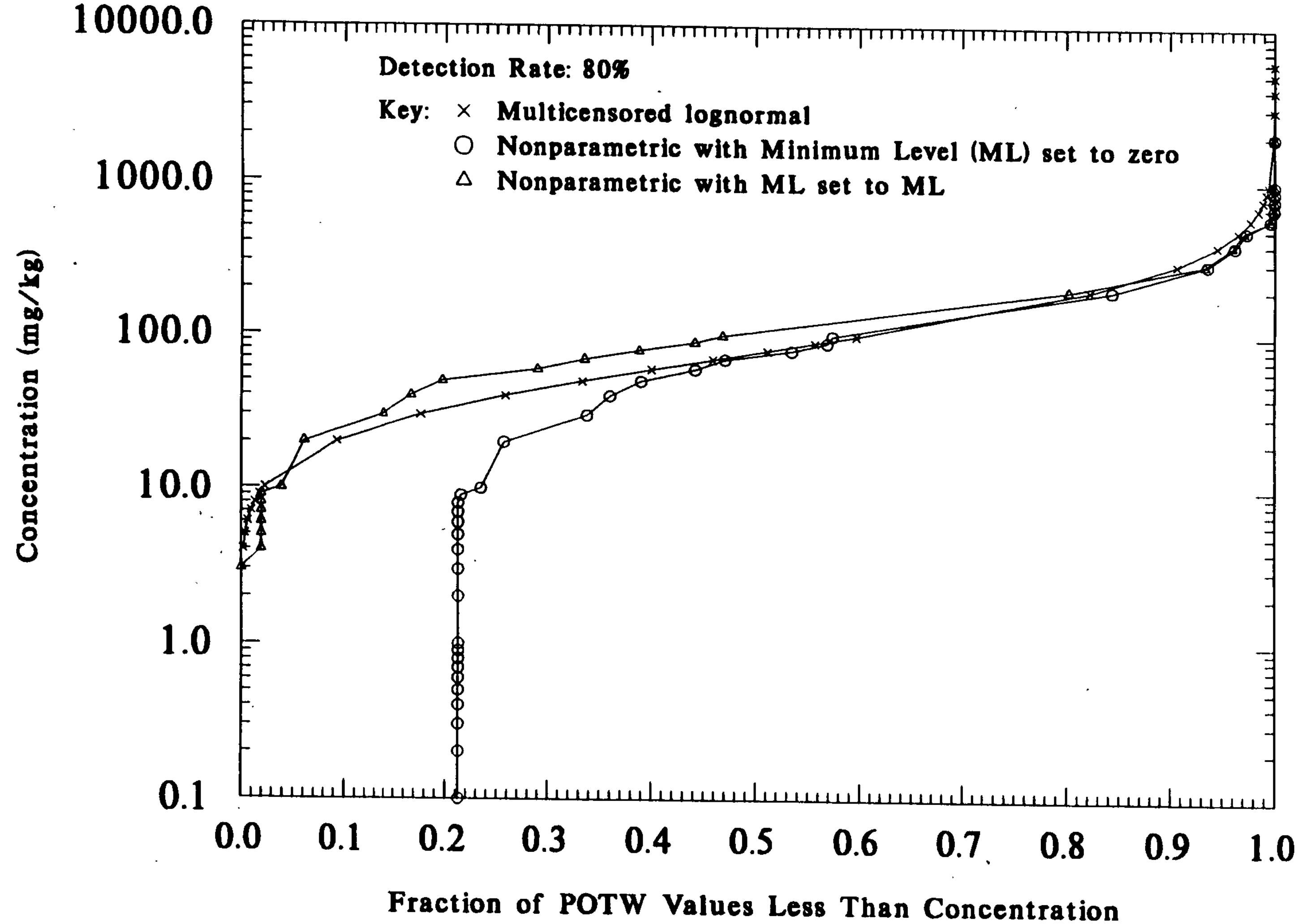


Figure 7–88. Cumulative Distribution Functions: LEAD

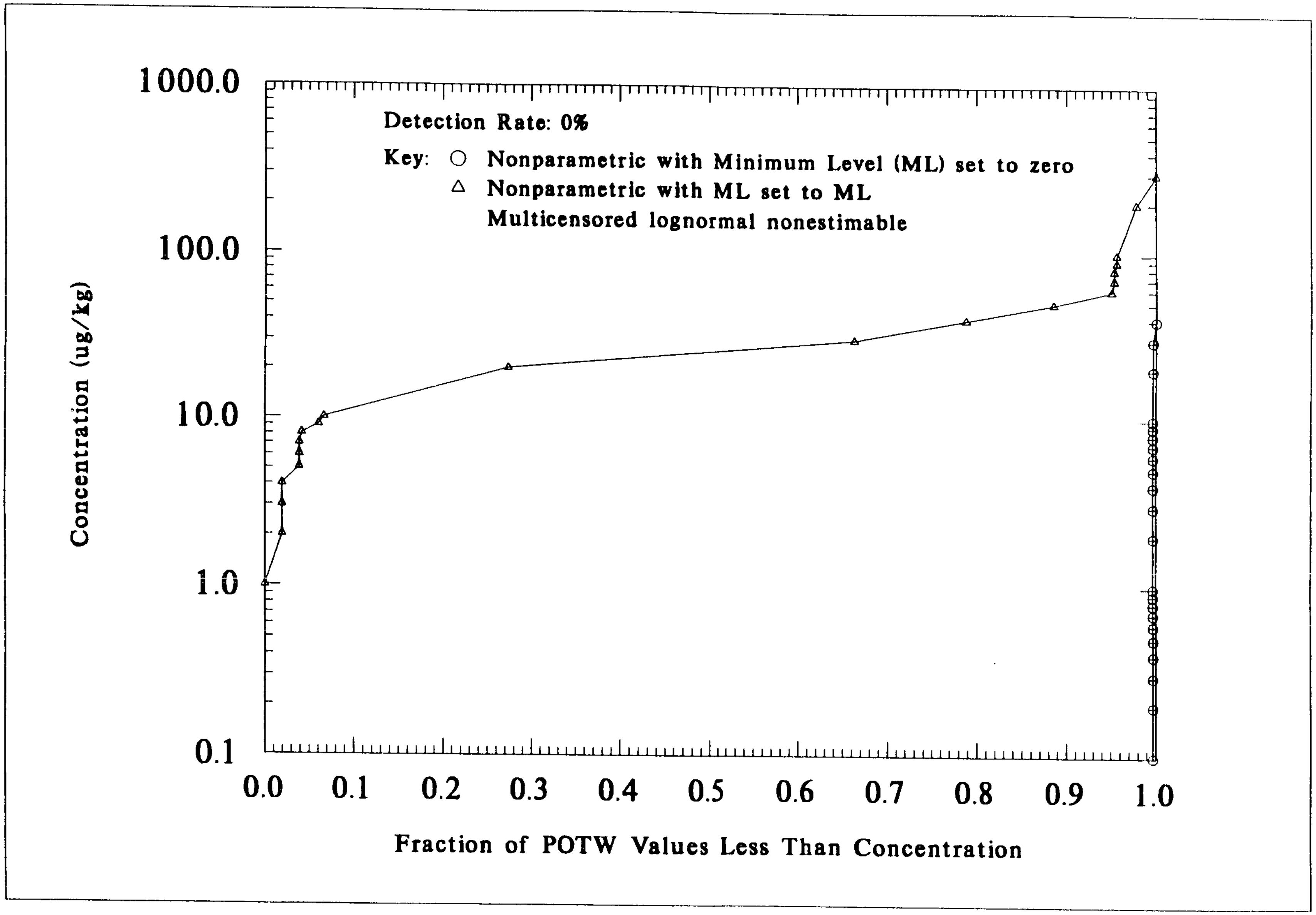


Figure 7-89. Cumulative Distribution Functions: LINDANE (GAMMA-BHC)

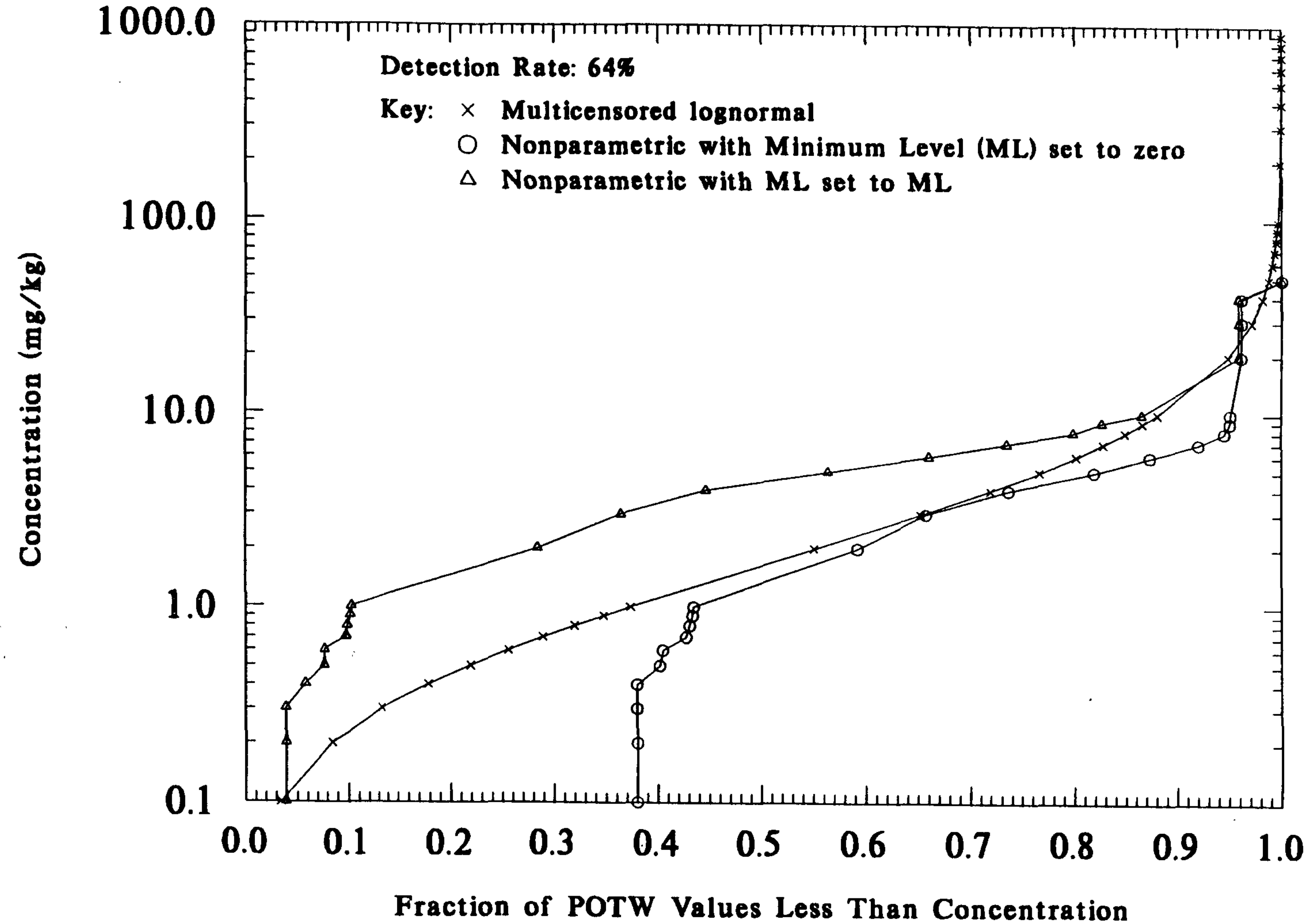


Figure 7-90. Cumulative Distribution Functions: MERCURY

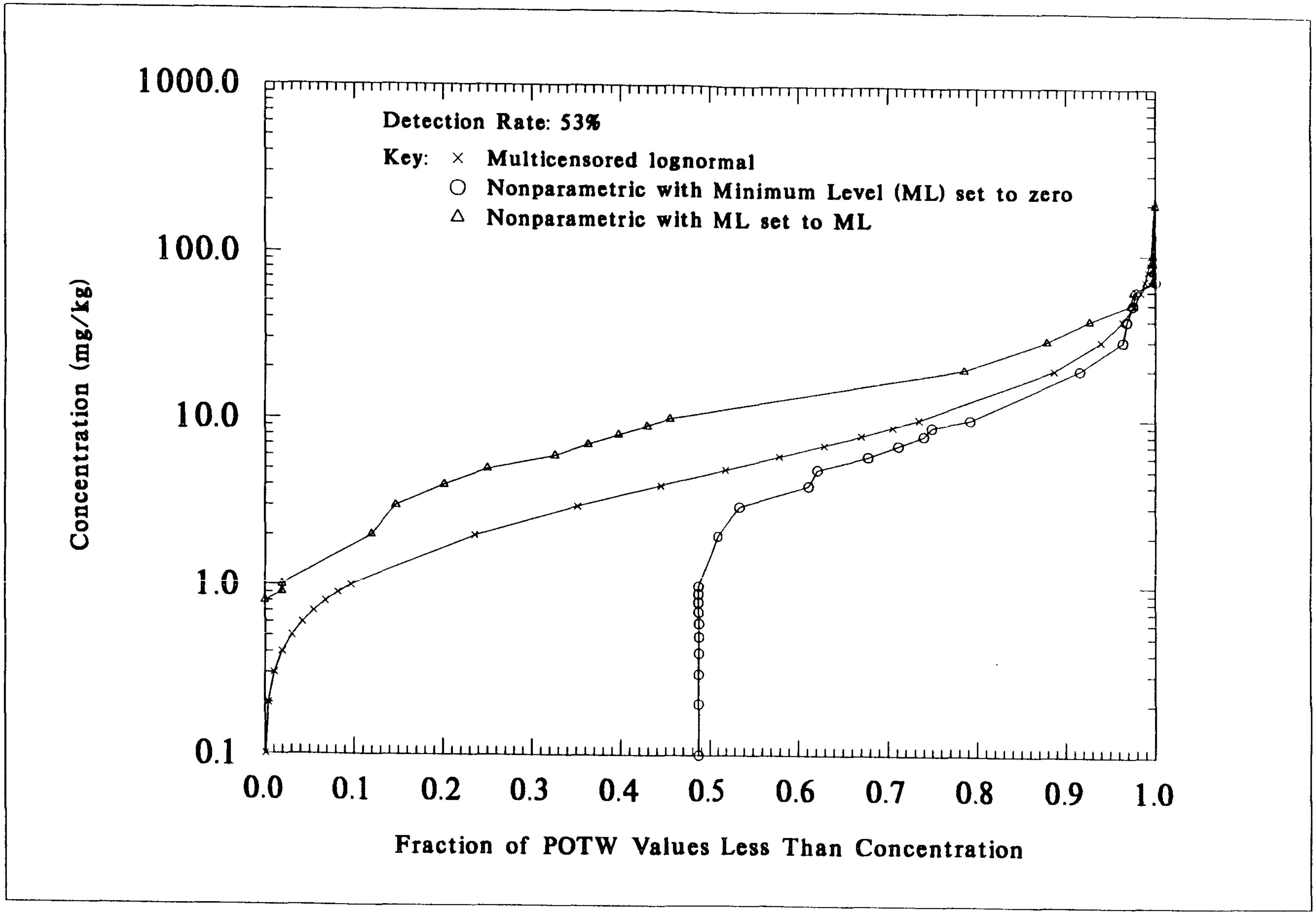


Figure 7-91. Cumulative Distribution Functions: MOLYBDENUM

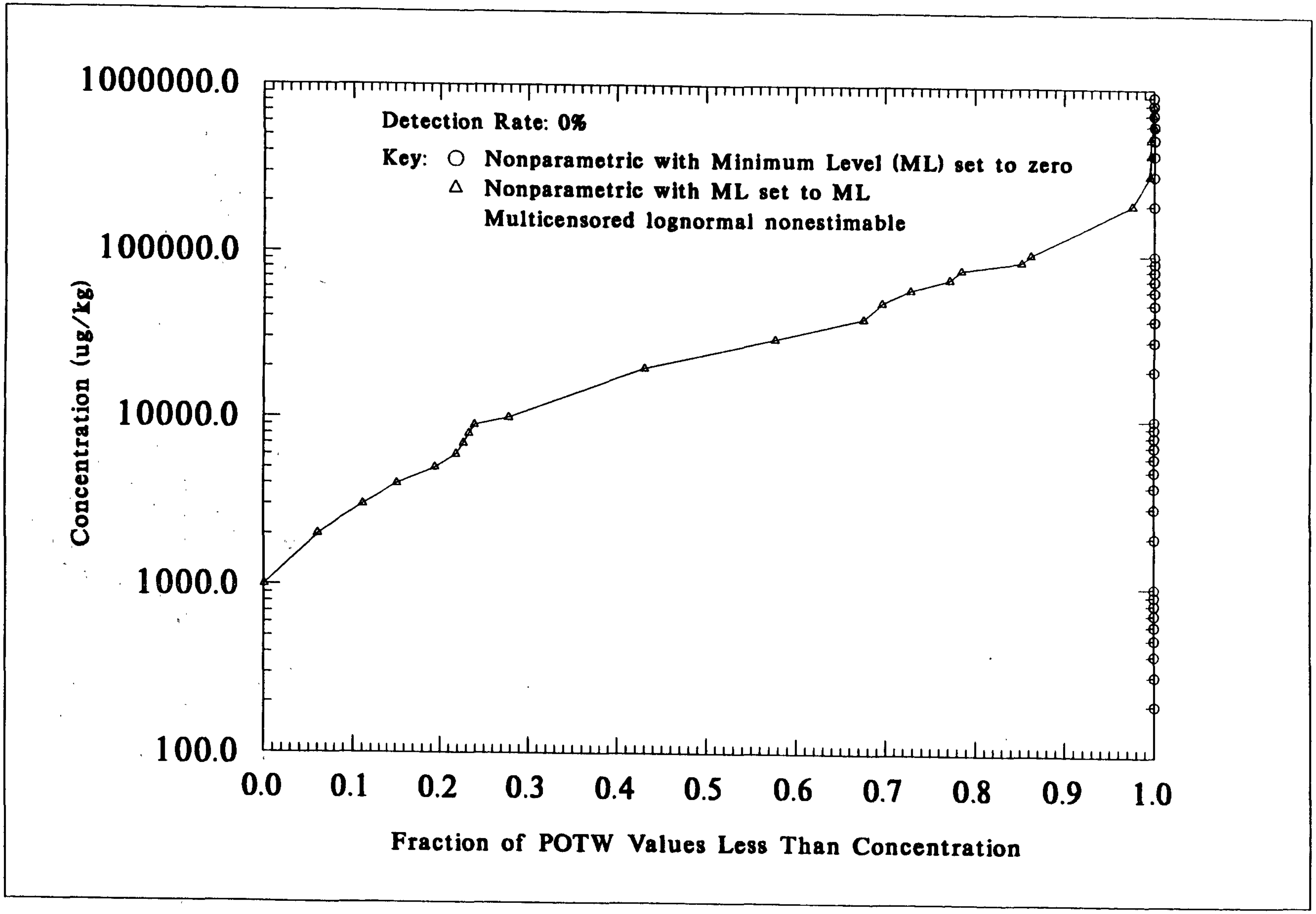


Figure 7-92. Cumulative Distribution Functions: N-NITROSODIMETHYLAMINE

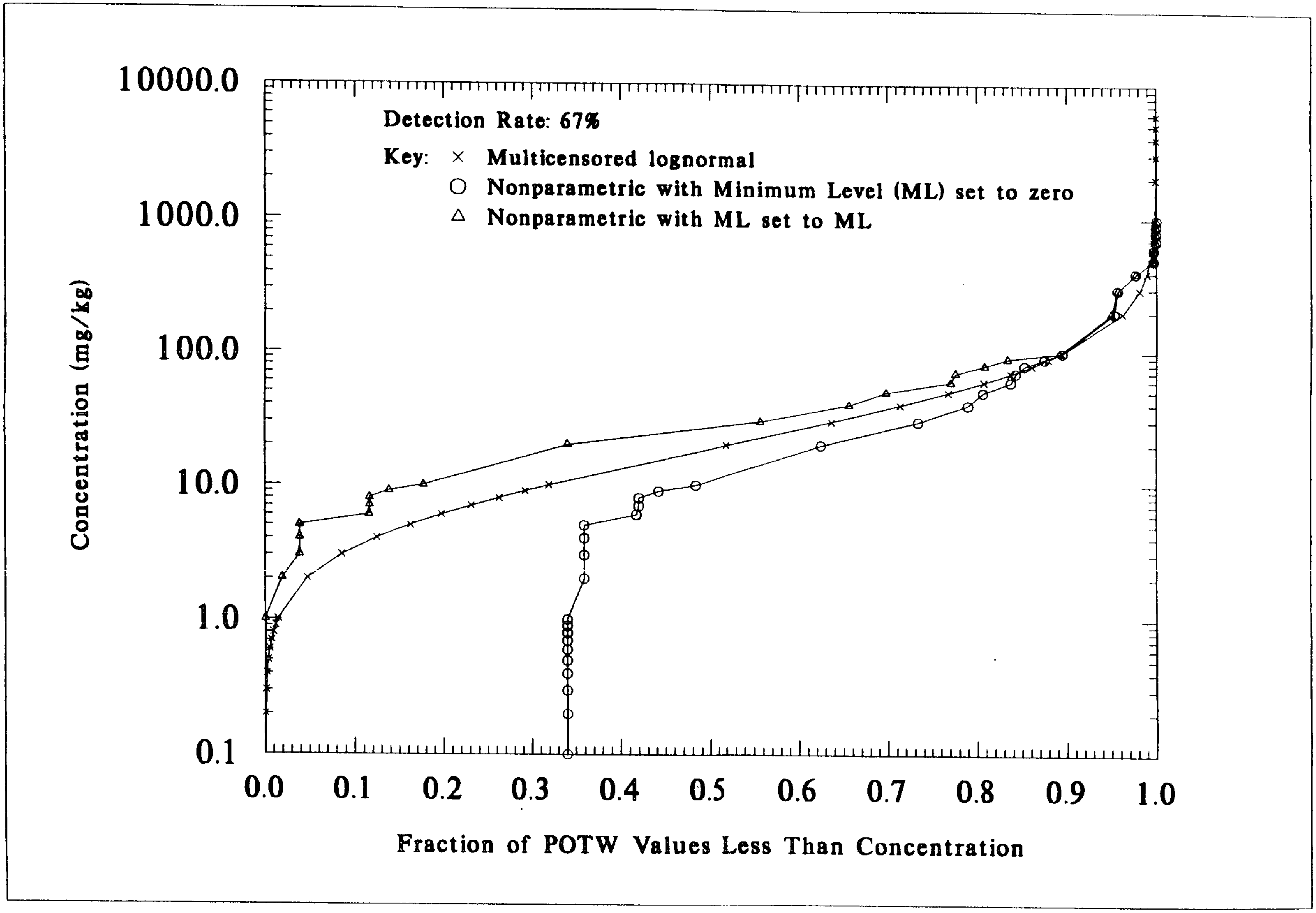


Figure 7–93. Cumulative Distribution Functions: NICKEL

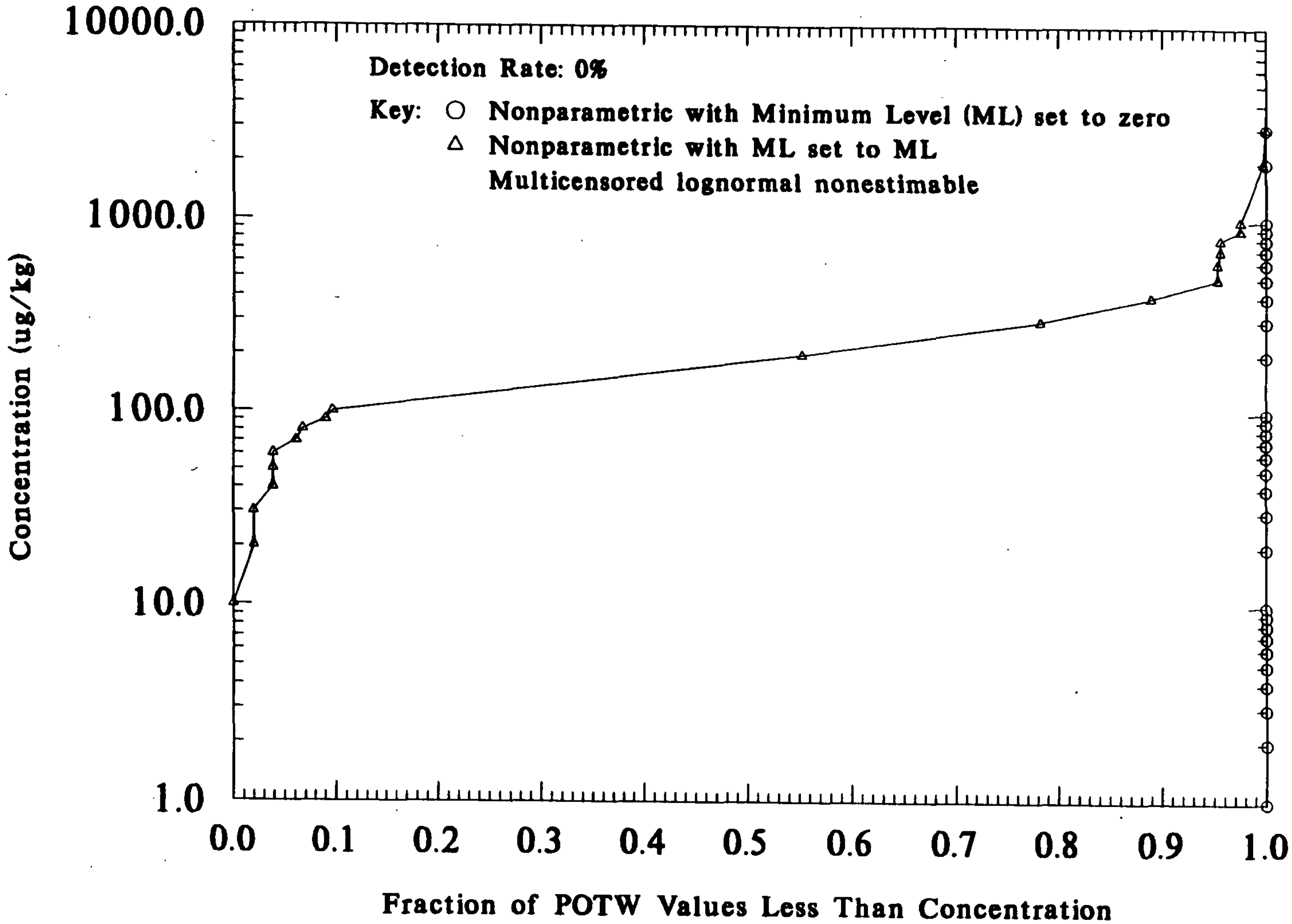


Figure 7-94. Cumulative Distribution Functions: PCB-1016

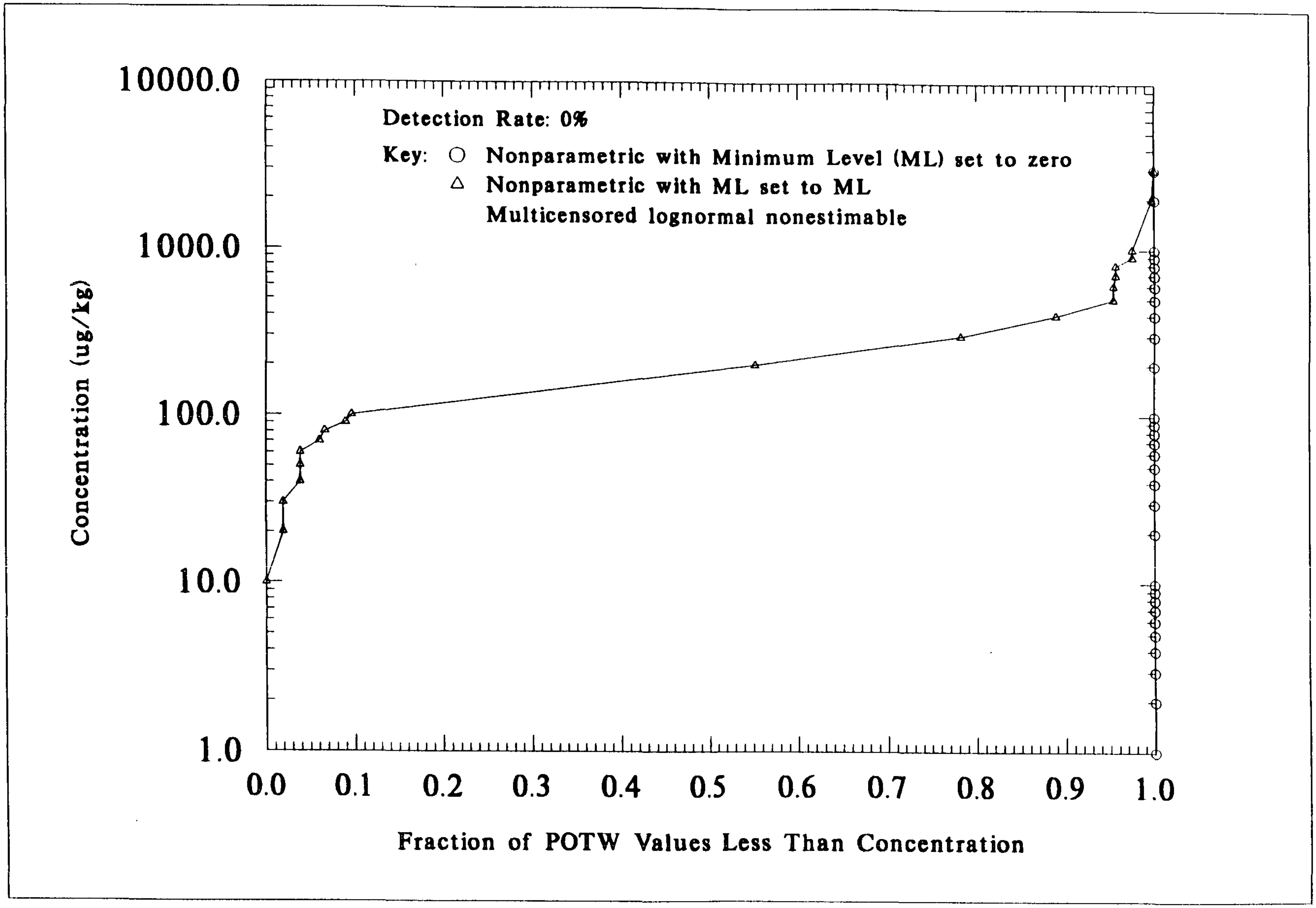


Figure 7-95. Cumulative Distribution Functions: PCB-1221

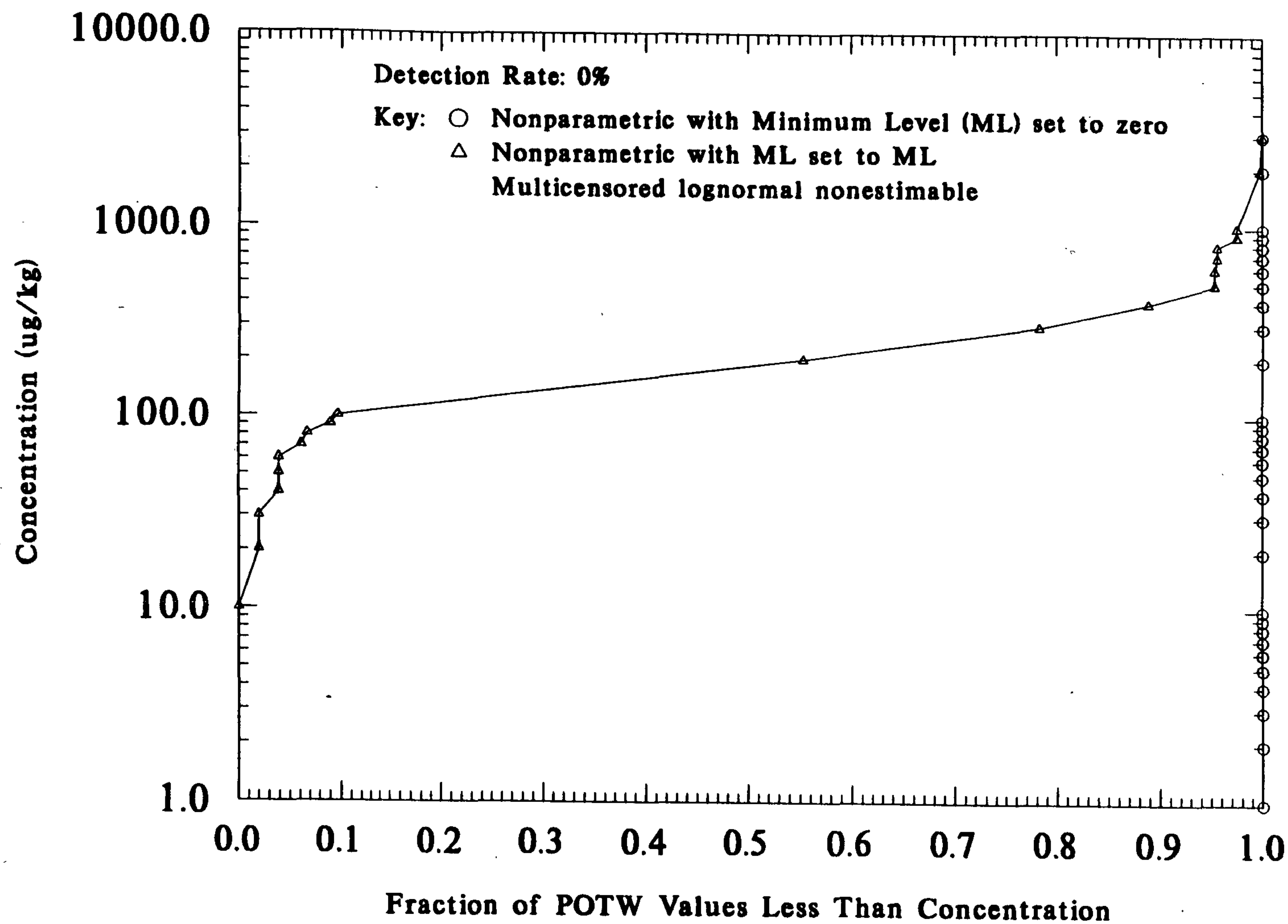


Figure 7-96. Cumulative Distribution Functions: PCB-1232

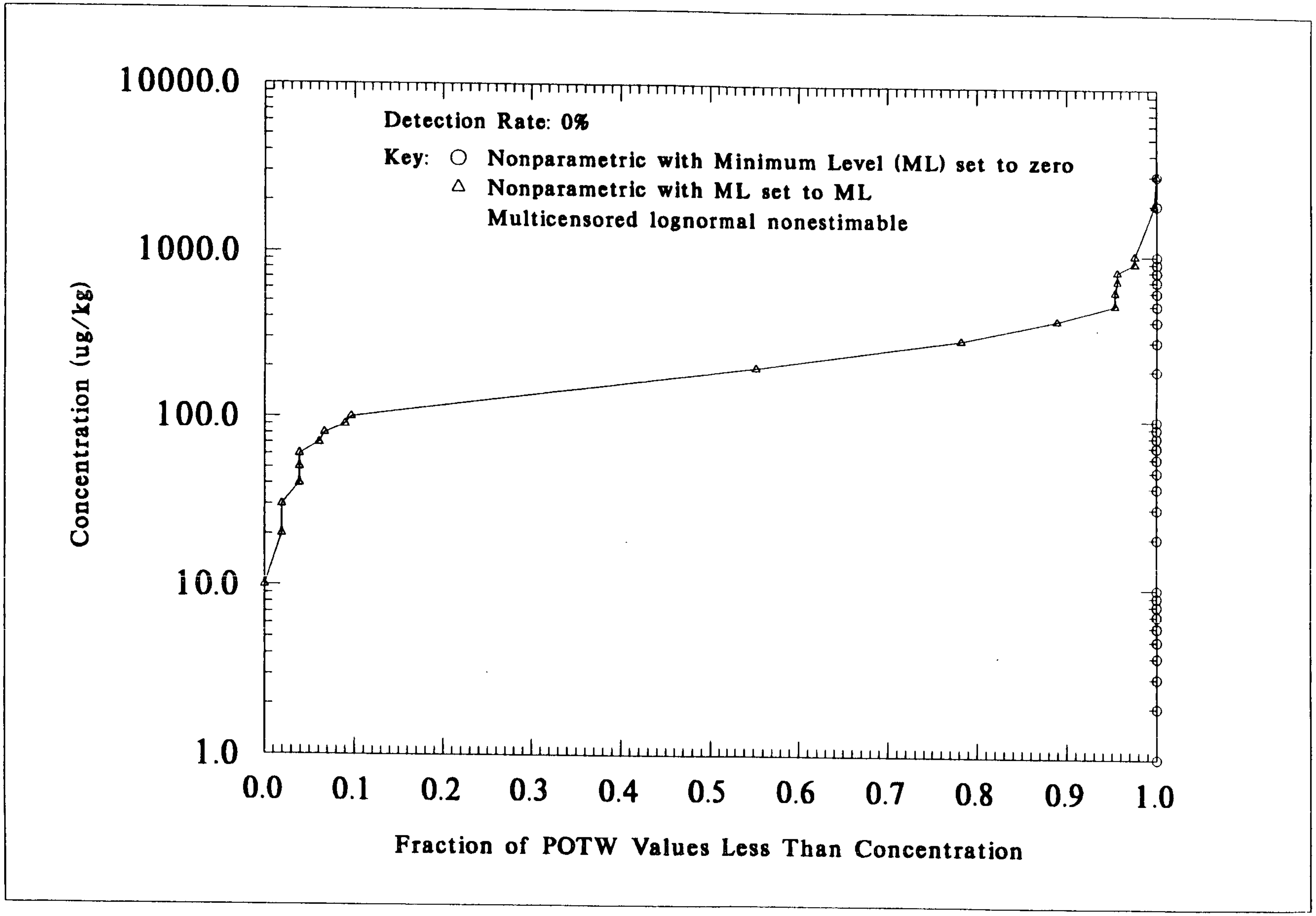


Figure 7-97. Cumulative Distribution Functions: PCB-1242

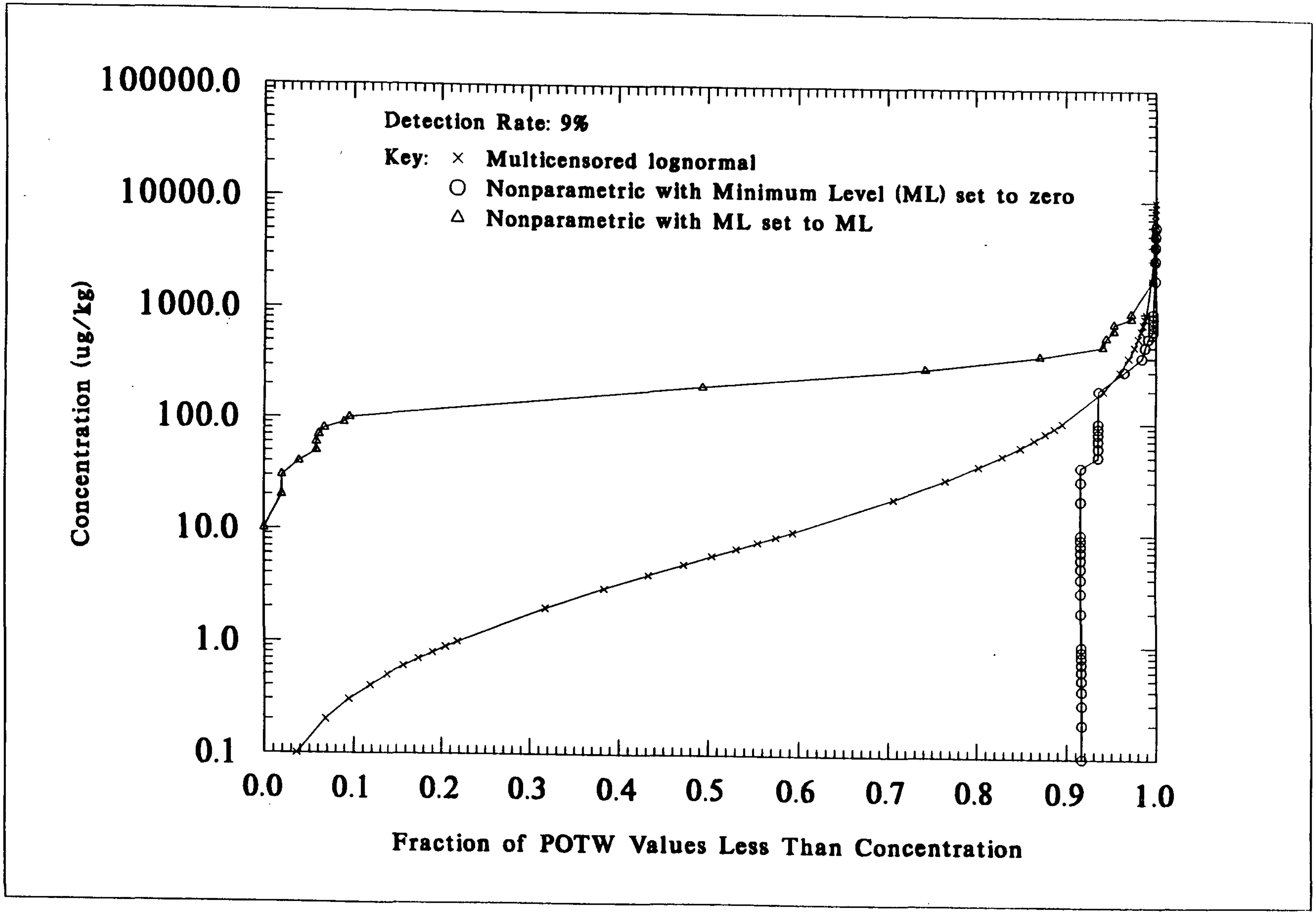


Figure 7-98. Cumulative Distribution Functions: PCB-1248

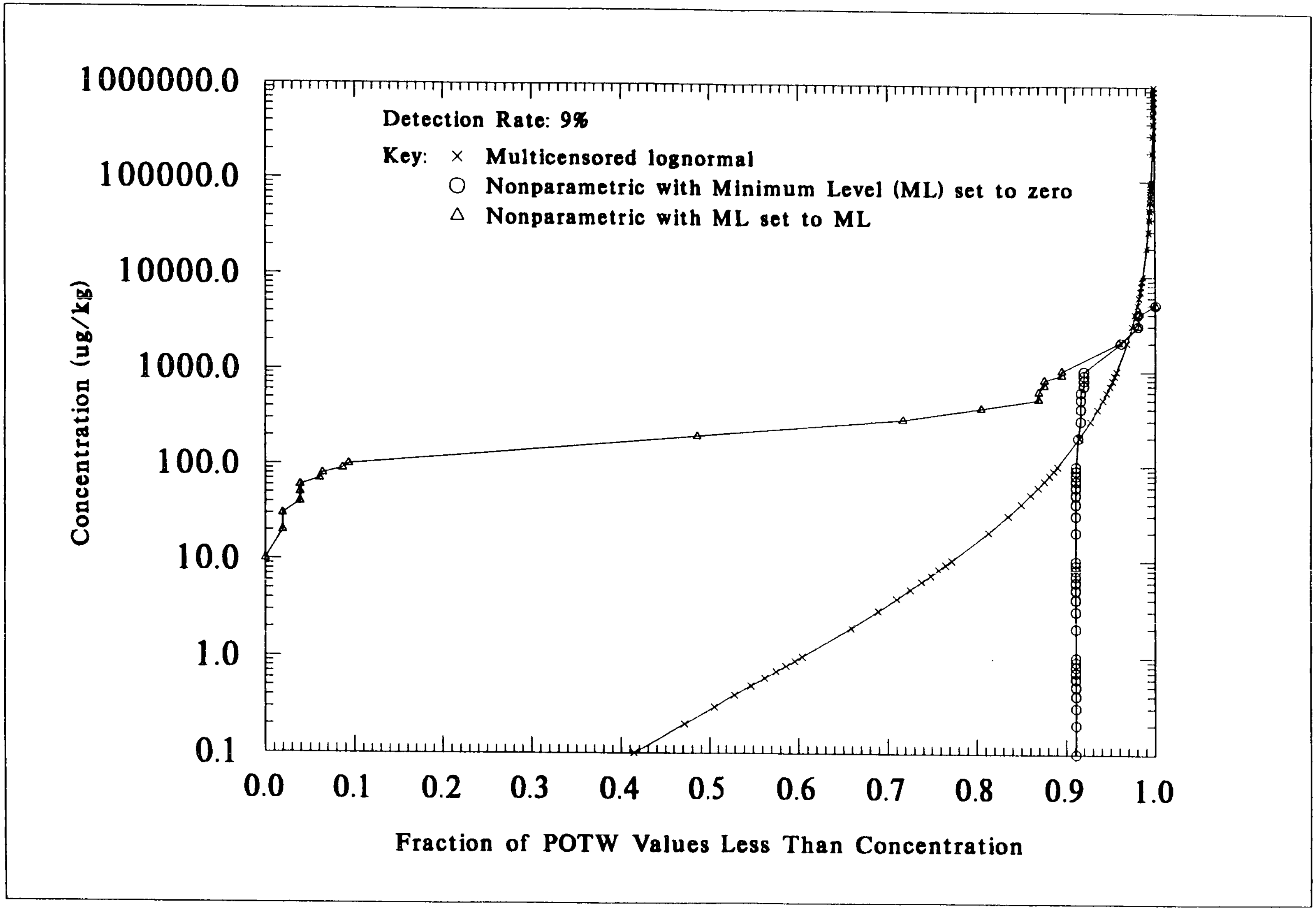


Figure 7-99. Cumulative Distribution Functions: PCB-1254

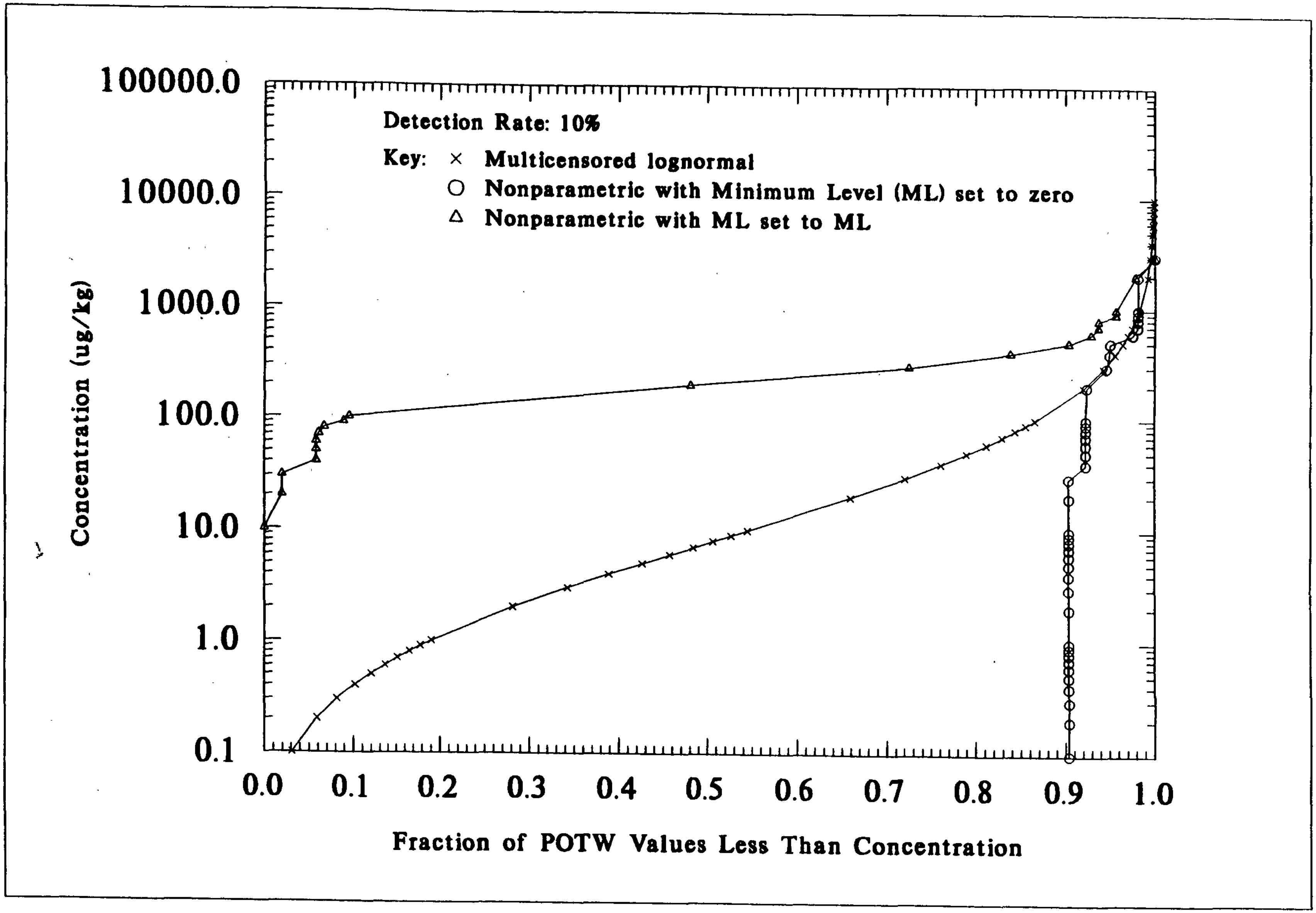


Figure 7-100. Cumulative Distribution Functions: PCB-1260

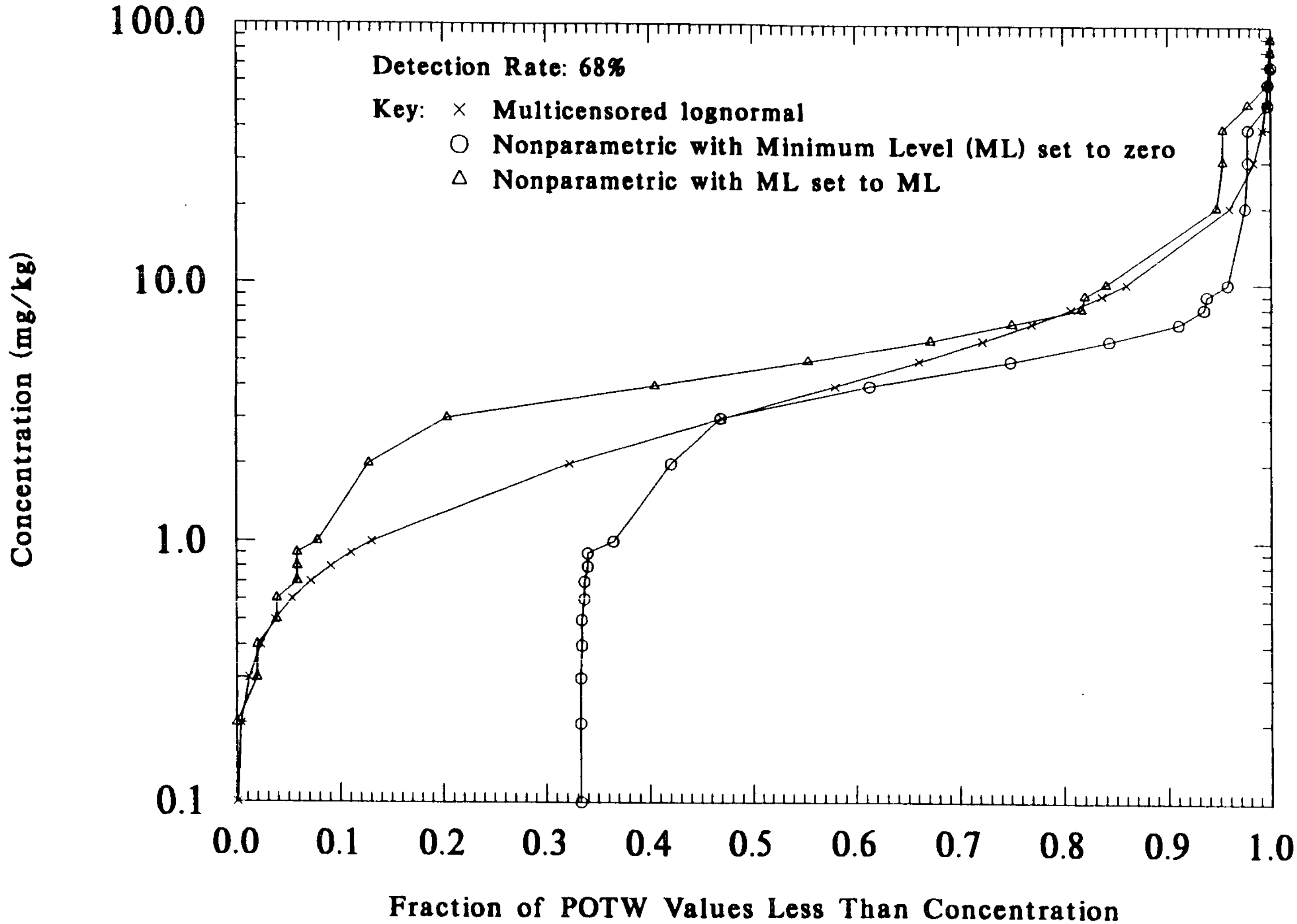


Figure 7-101. Cumulative Distribution Functions: SELENIUM

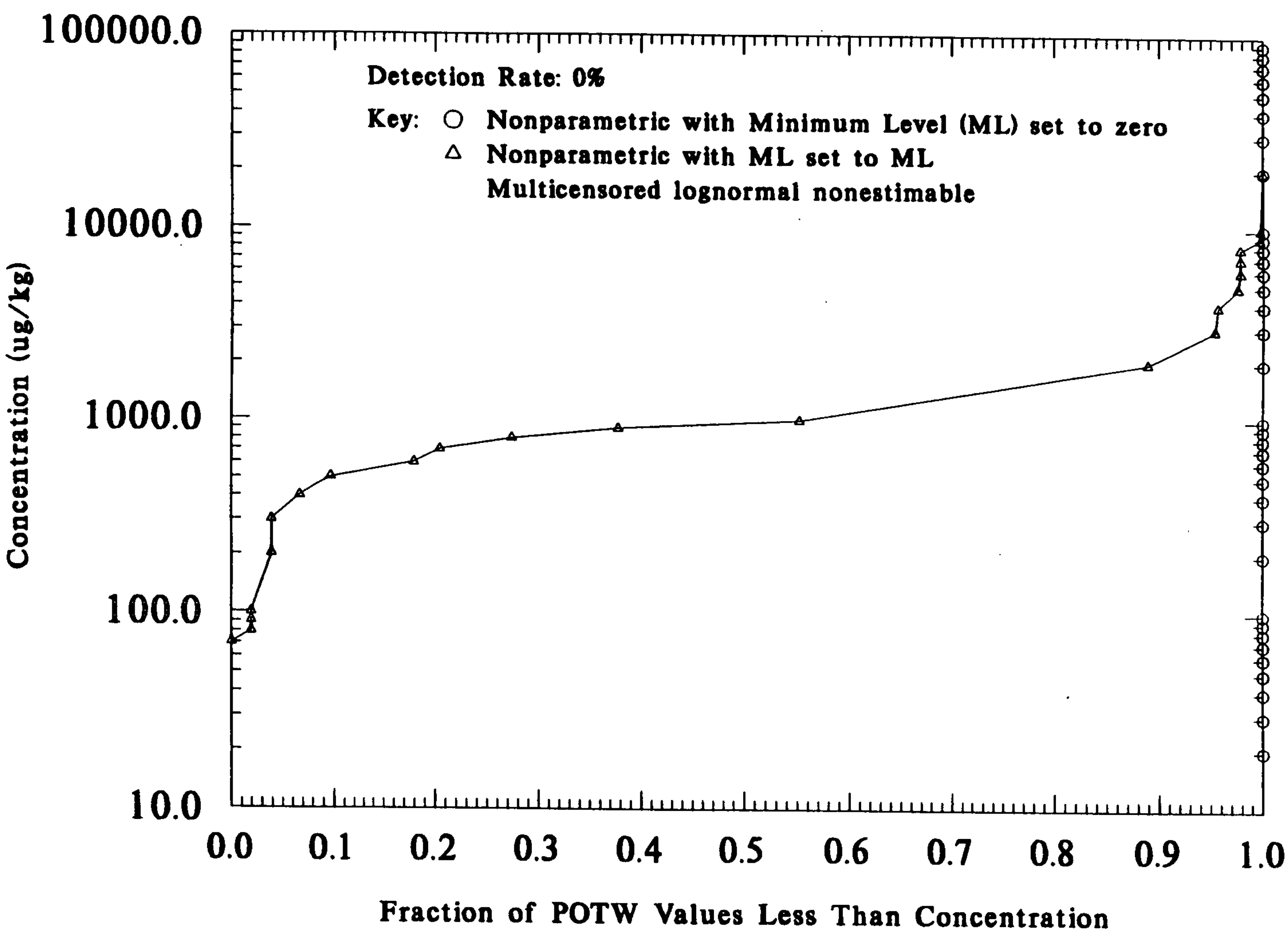


Figure 7-102. Cumulative Distribution Functions: TOXAPHENE

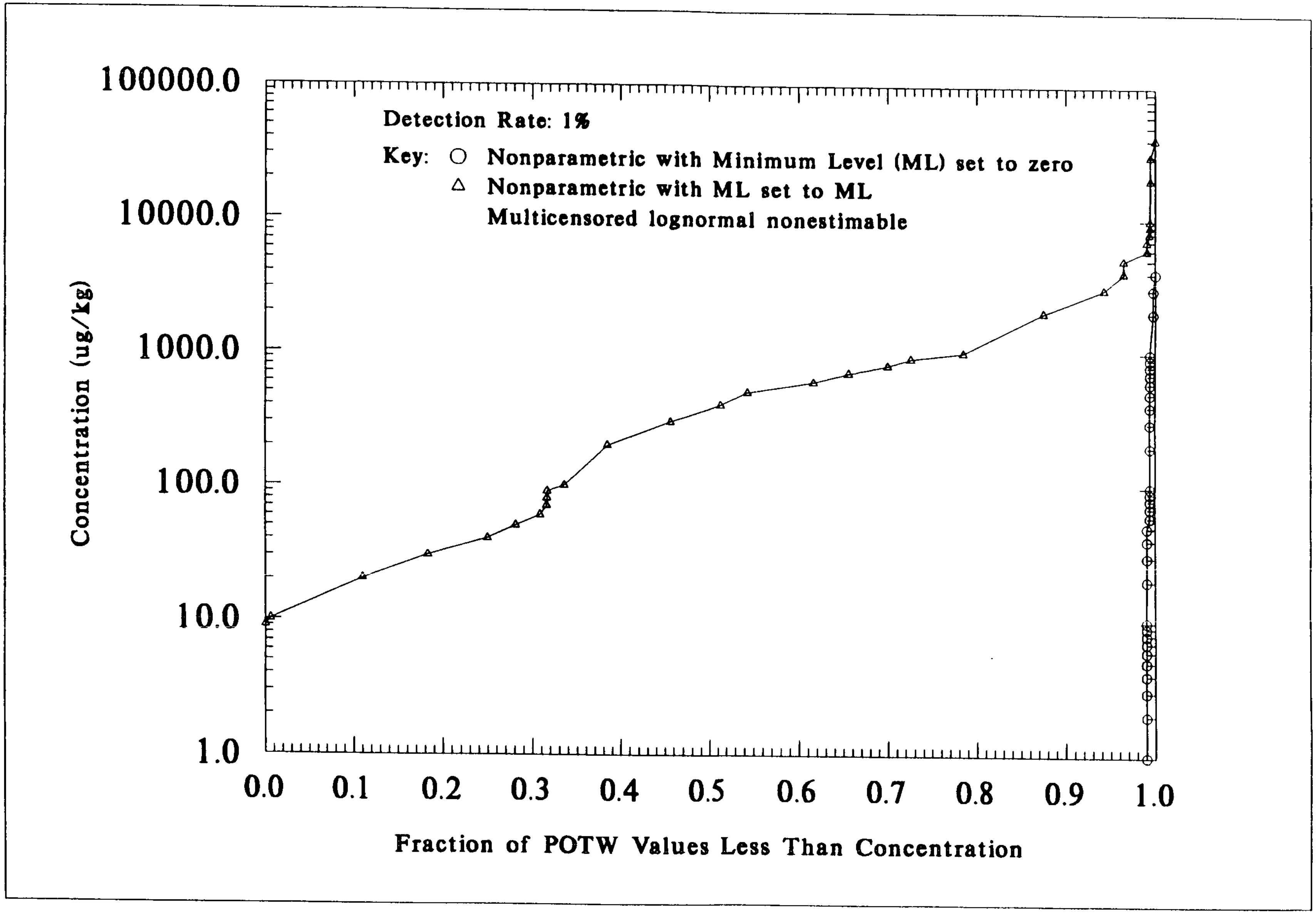


Figure 7-103. Cumulative Distribution Functions: TRICHLOROETHENE

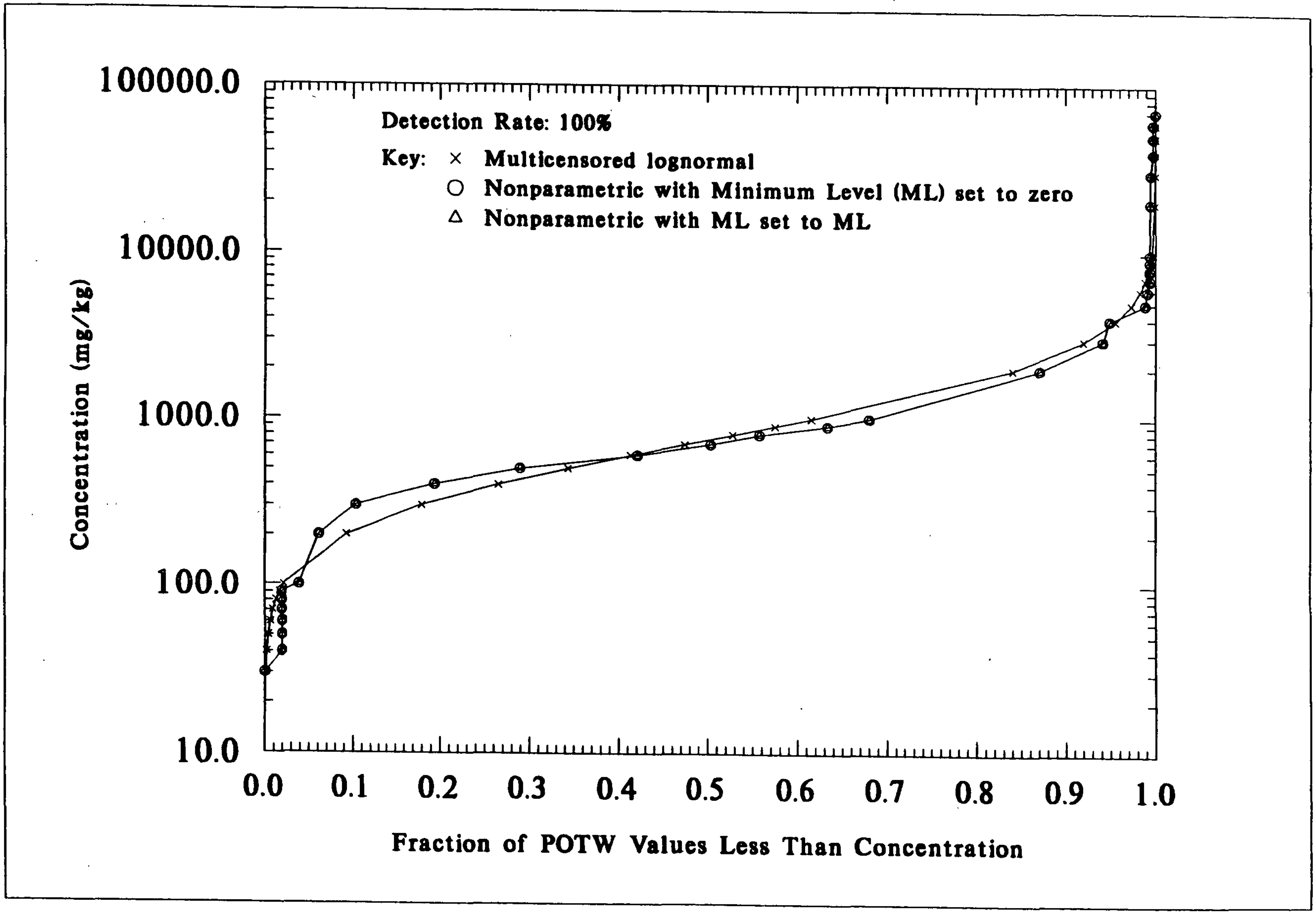


Figure 7-104. Cumulative Distribution Functions: ZINC

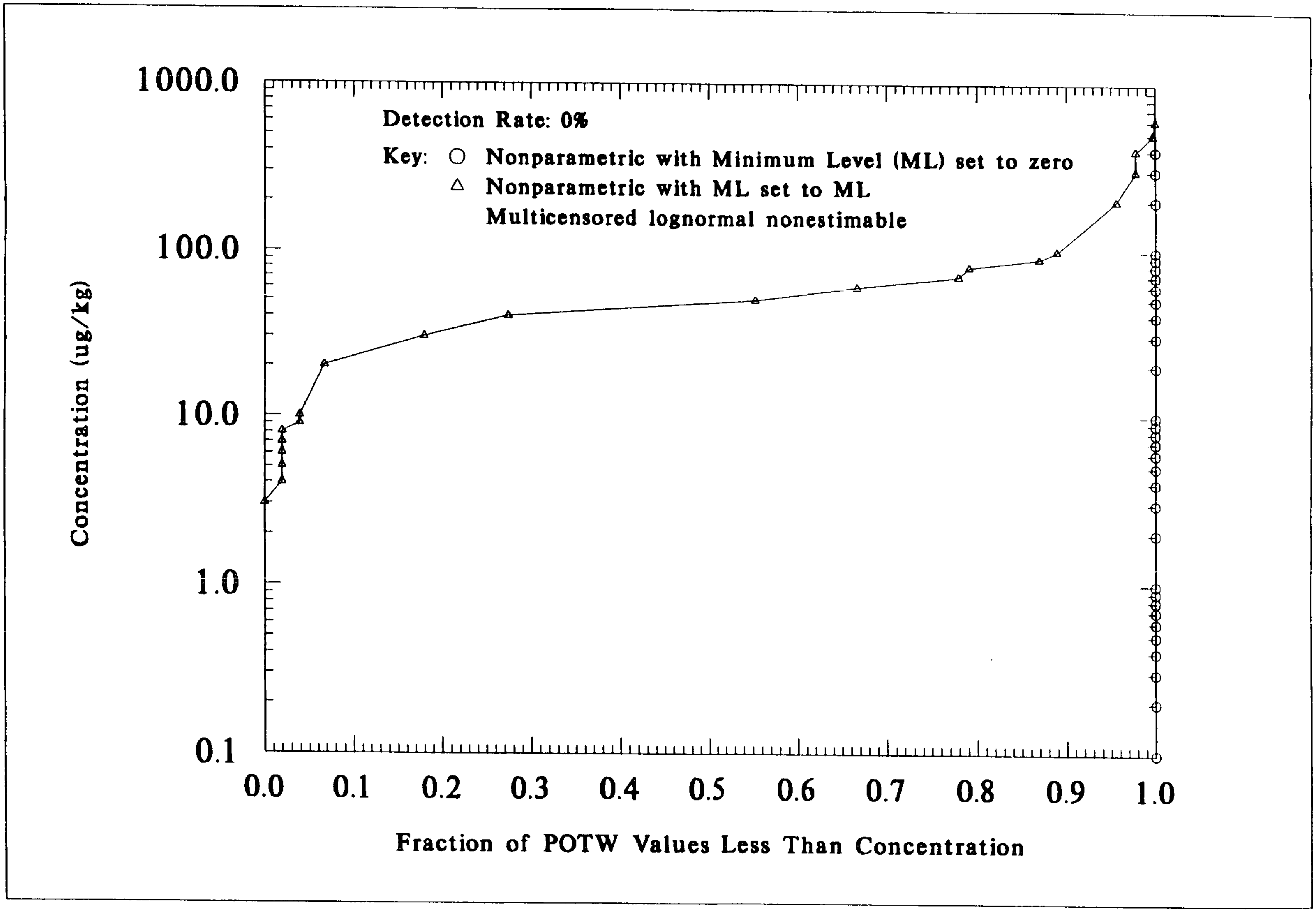


Figure 7-105. Cumulative Distribution Functions: 4,4'-DDD

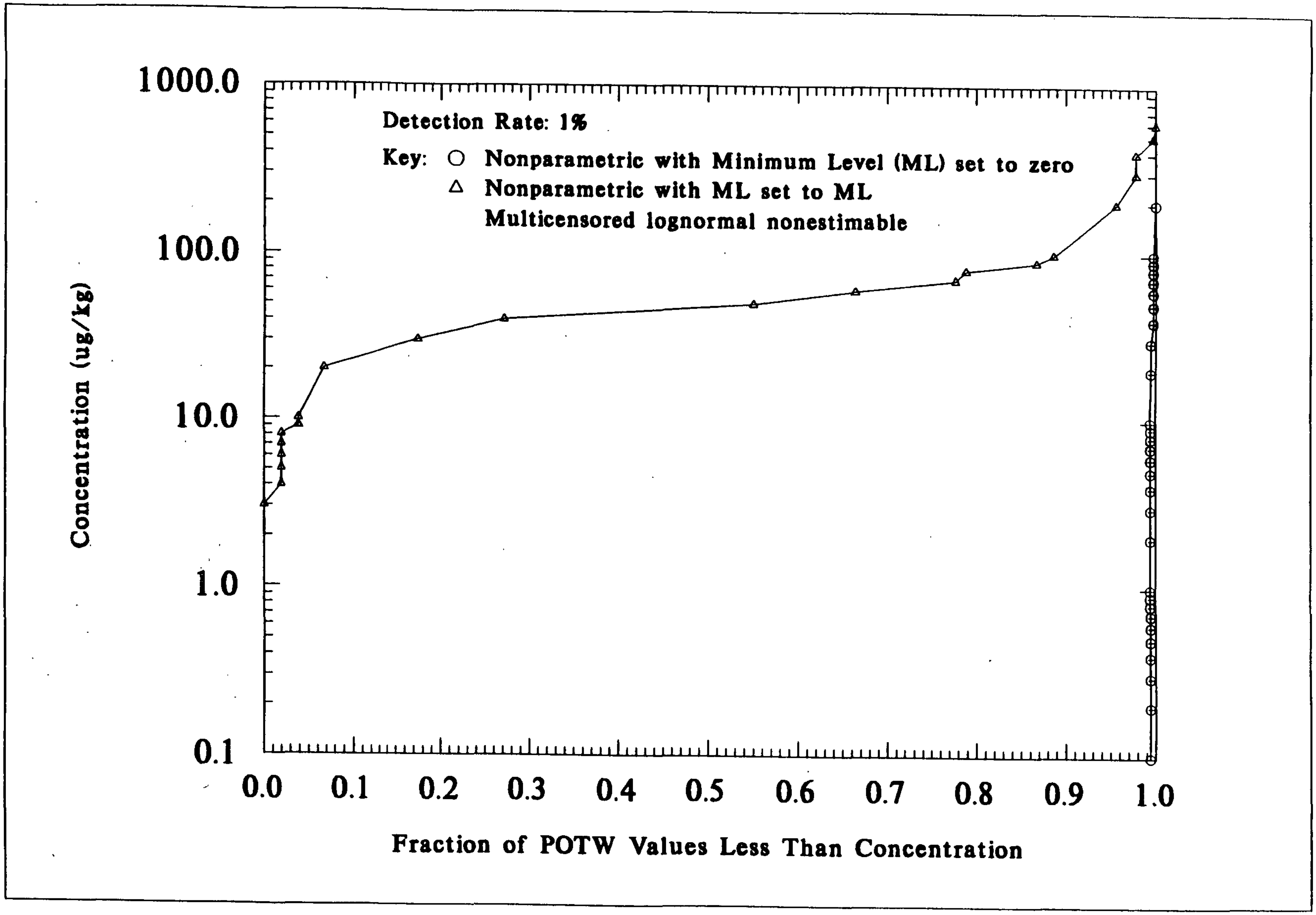


Figure 7-106. Cumulative Distribution Functions: 4,4'-DDE

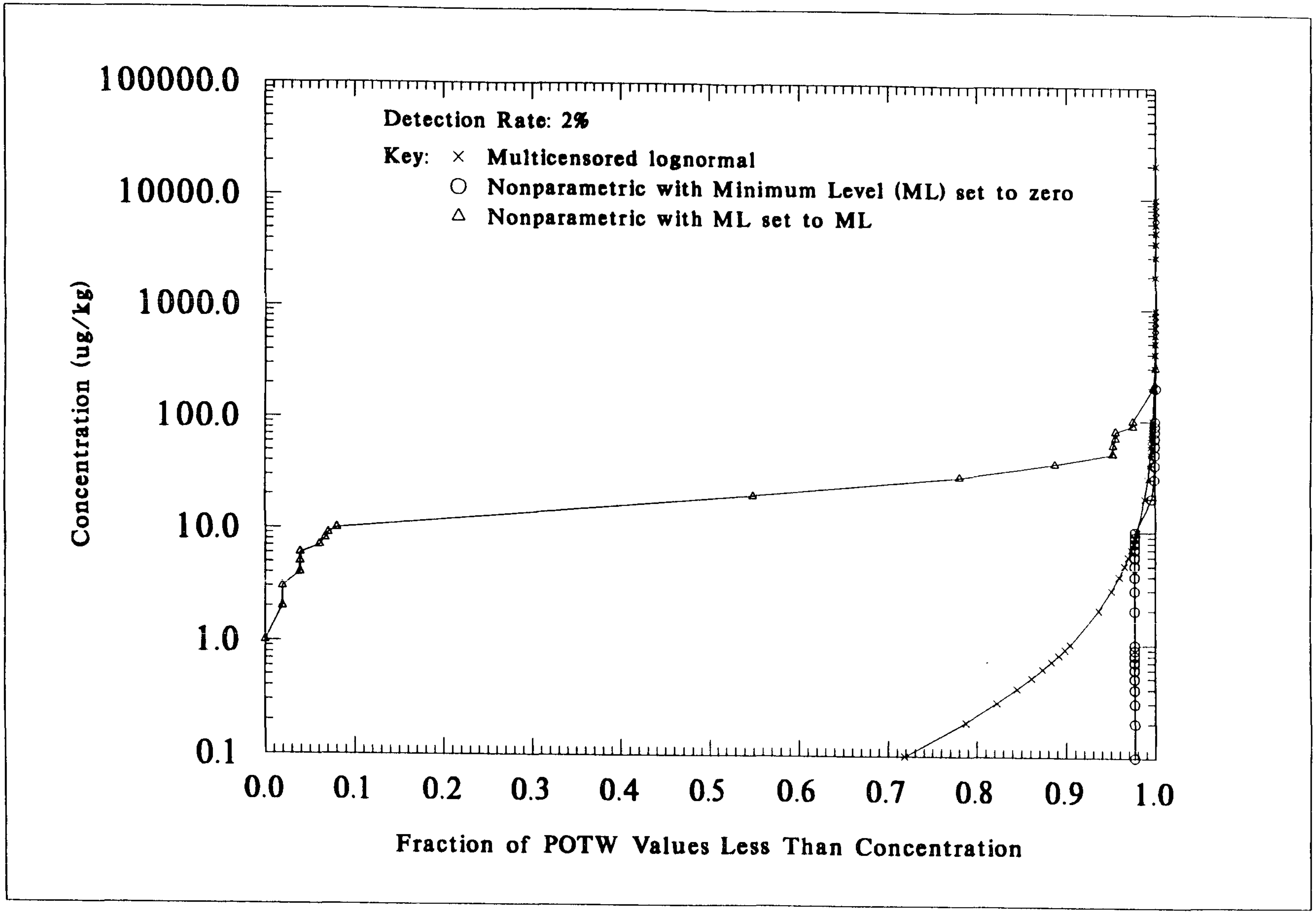


Figure 7-107. Cumulative Distribution Functions: 4,4'-DDT

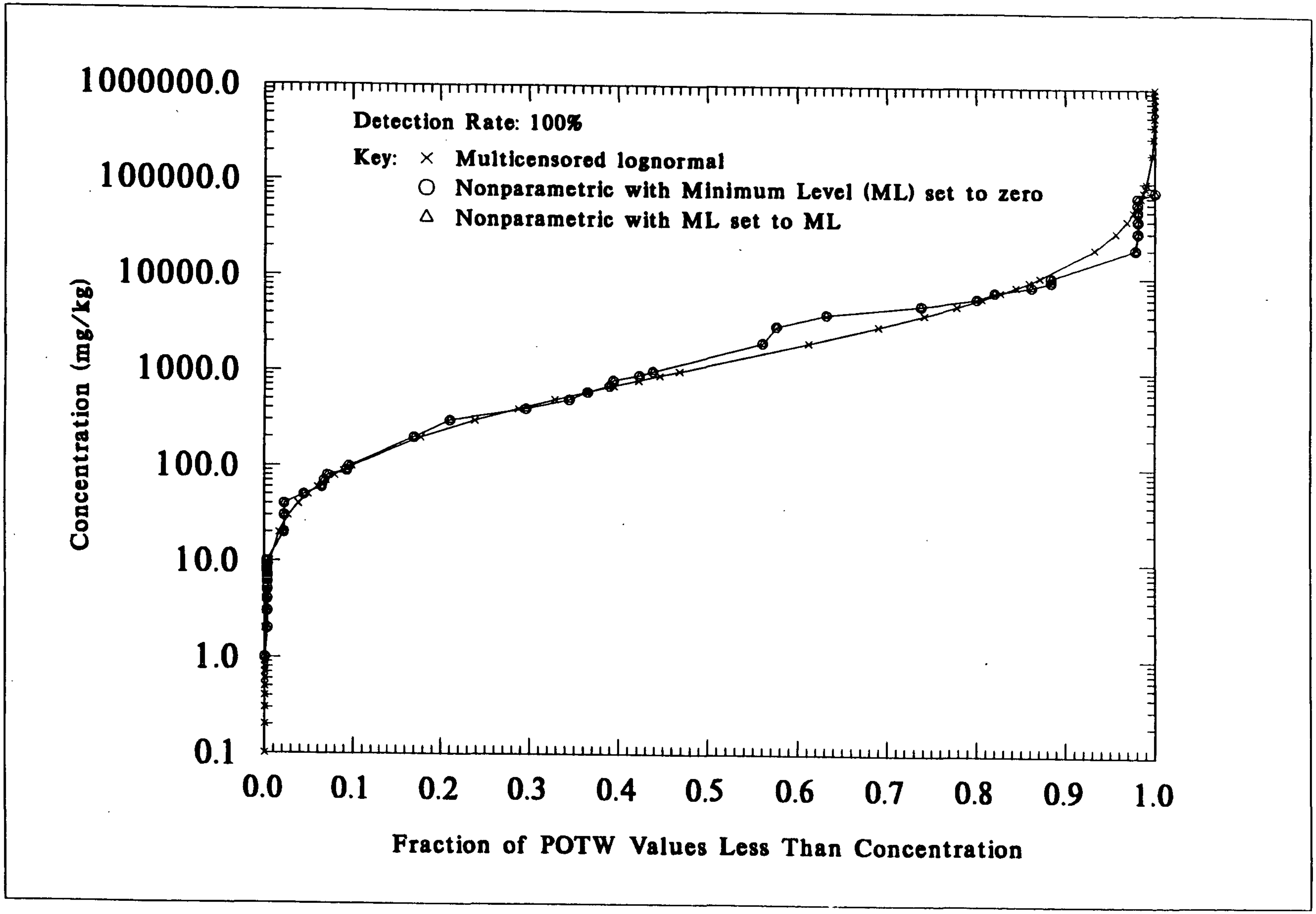


Figure 7-108. Cumulative Distribution Functions: PHOSPHORUS

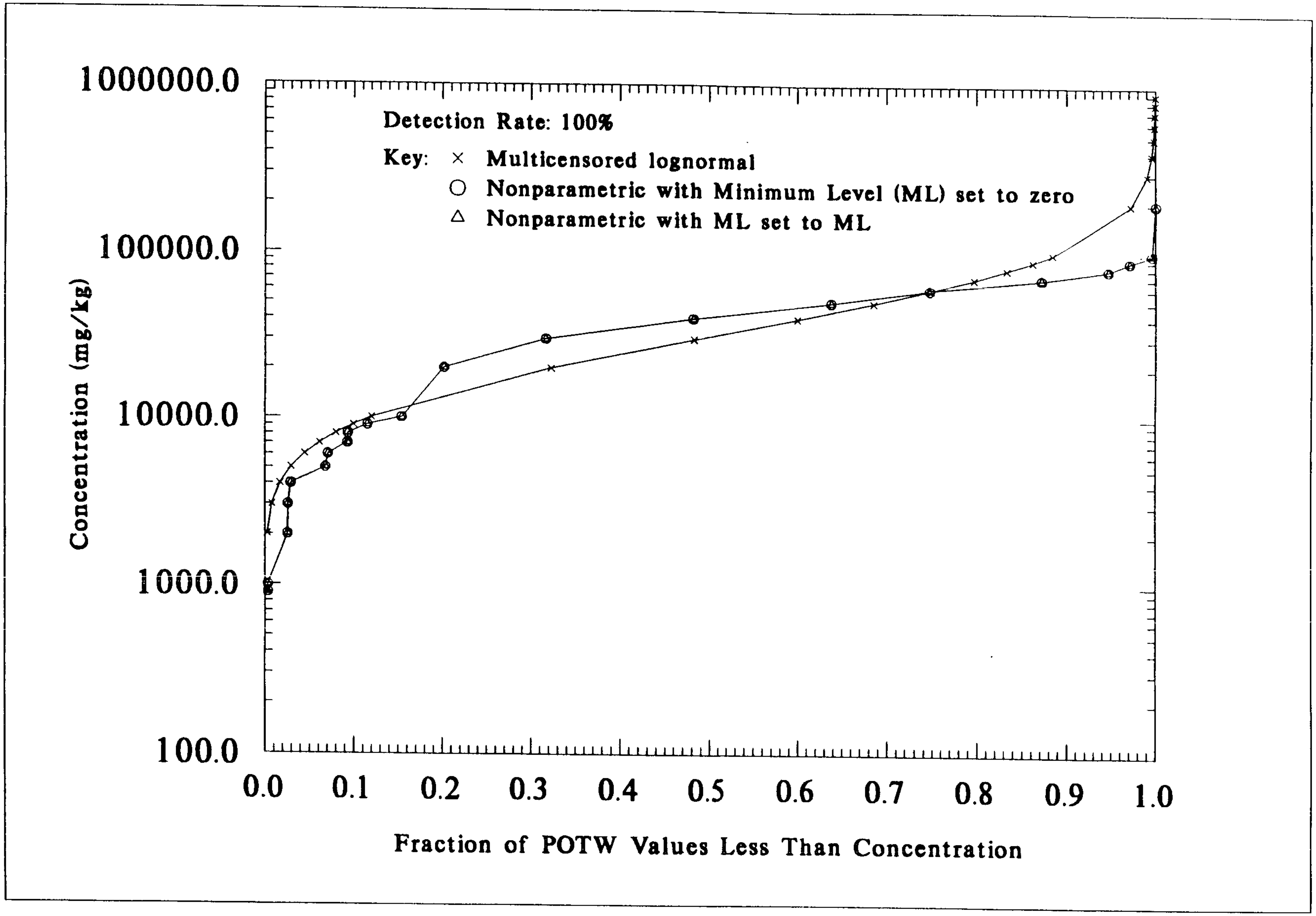


Figure 7-109. Cumulative Distribution Functions: TOTAL KJELDAHL NITROGEN

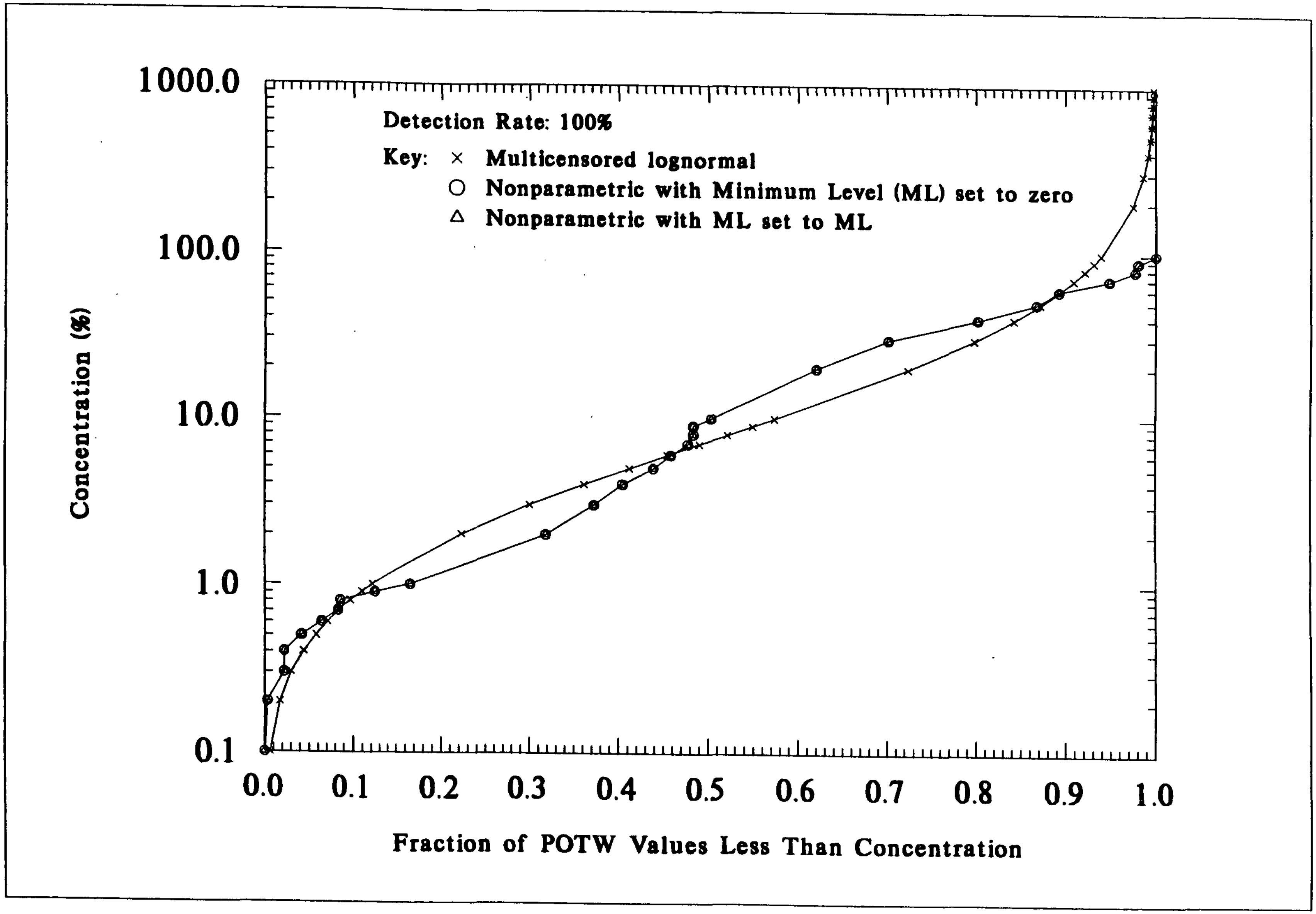


Figure 7-110. Cumulative Distribution Functions: PERCENT SOLIDS

REFERENCES

Volume I and Volume II

Agresti, Alan. 1984. *Analysis of Ordinal Categorical Data*. John Wiley & Sons, Inc., New York, NY.

Aitchison, J., and J.A.C. Brown. 1963. *The Lognormal Distribution*. Cambridge University Press, New York, NY.

Barakat, Richard. 1976. "Sums of Independent Lognormally Distributed Random Variables." *Journal of the Optical Society of America*. Vol. 66, No. 3 (March).

Cochran, W.G. 1977. *Sampling Techniques*. Third edition. John Wiley & Sons, Inc., New York, NY.

Cohen, A. Clifford, Jr. 1959. "Simplified Estimators for the Normal Distribution When Samples are Singly Censored or Truncated." *Technometrics*. Vol. 1, No. 3 (August).

Everitt, B.S. 1977. *The Analysis of Contingency Tables*. John Wiley & Sons, Inc., New York, NY.

Gilliom, Robert J. and D.R. Helsel. 1986. "Estimation of Distributional Parameters for Censored Trace Level Water Quality Data. 1. Estimation Techniques." *Water Resources Research*. Vol. 22, No. 2 (February).

Hansen, M.H., W.N. Hurwitz, and W.G. Madow. 1953. *Sample Survey Method and Theory Volume II: Theory*. John Wiley & Sons, Inc., New York, NY.

Helsel, D.R. and T.A. Cohn. 1988. "Estimation of Descriptive Statistics from Multi-Censored Water Quality Data." *Water Resources Research*. Vol. 24, No. 12. (December).

Helsel, D.R., and R.J. Gilliom. 1986. "Estimation of Distributional Parameters for Censored Trace Level Water Quality Data. 2. Verification and Applications." *Water Resources Research*. Vol. 22, No. 2 (February).

Helsel, Dennis. 1990. "Less than Obvious: Statistical Treatment of Data Below the Detection Limit." *Environmental Science Technology*. Vol. 24, No. 12.

Hollander, Myles, and D.A. Wolfe. 1973. *Nonparametric Statistical Methods*. John Wiley & Sons, Inc., New York, NY.

U.S. Environmental Protection Agency. 1988. "Supporting Statement for the National Sewage Sludge Survey." (August).

U.S. Environmental Protection Agency. 1989A. "Standards for the Disposal of Sewage Sludge; Proposed Rule (40 CFR, Parts 257 and 503)." (February).

REFERENCES

Volume I and Volume II (continued)

U.S. Environmental Protection Agency. 1990. "National Sewage Sludge Survey; Availability of Information and Data, and Anticipated Impacts on Proposed Regulations; Proposed Rule (40

CFR Part 503)." (November).U.S. Environmental Protection Agency. 1990. *Technical Support Documentation for Part 1 of the National Sewage Sludge Survey Notice of Availability.* (October).

U.S. Environmental Protection Agency, Industrial Technology Division, Office of Water Regulations and Standards. 1989B. "Analytical Methods for the National Sewage Sludge Survey."

U.S. Environmental Protection Agency, Office of Water. 1990. *Analytical Methods for the National Sewage Sludge Survey.* (September).

U.S. Environmental Protection Agency, Office of Water Program Operation, EPA-430/9-78-001. 1978. *Field Manual for Performance Evaluation and Troubleshooting at Municipal Wastewater Treatment Facilities.*