ENVIRONMENTAL ASSESSMENT OF SUBSURFACE DISPOSAL

OF MUNICIPAL WASTEWATER TREATMENT SLUDGE

Interim Report

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Foreword

A major concern in any solid waste management system is the disposal of wastewater treatment sludge. The quantities of sludge to be disposed are increasing and will continue to increase with the implementation of more strigent Federal water quality standards and best practicable treatment technology requirements. Currently 5.5 million dry tons of wastewater sludge are generated annually, and this quantity is expected to more than double by 1983.

Approximately 50 percent of the land disposal sites accepting residential and commercial wastes in this country also accept wastewater treatment plant sludge. An additional, but unknown, number of land disposal sites are specifically designed for wastewater treatment sludge only.

In order to assess the environmental effect of these sludge landfilling practices, especially on groundwater quality, the Office of Solid Waste awarded a contract to SCS Engineers. The study was designed to detect the presence or absence of leachate-contaminated groundwater in the immediate vicinity of the disposal sites. The results of the first 12 months of the study are presented in this interim report.

The study was not designed to evaluate whether such contamination represented a significant threat to local groundwater supplies or how far such contamination moved from the disposal site. This study was designed only to detect the presence or absence of groundwater contamination within several hundred feet of the site.

The effort to determine the areal extent of contamination and degree of attenuation is currently being evaluated under the second phase of this contract. When completed, this study will provide a more comprehensive understanding of the effects of sludge landfilling on groundwater quantity.

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I. INTRODUCTION

DESCRIPTION OF THE PROBLEM

The disposal of municipal wastewater treatment plant sludge is a growing problem in the United States. Communities throughout the country are experimenting with various procedures for the disposal of sludge in an attempt to evolve a method best suited to their requirements.

The prohibition of further discharges of municipal wastewater treatment sludge to the ocean has created predictable and staggering problems in several coastal areas of the country. Large quantities of sludge have been accumulated at treatment plants in several east coast locations. Compelled to stop disposal of municipal wastewater treatment sludge in the oceans, some communities have taken the most convenient and expeditious alternative, not necessarily conductive to protecting the environment.

Communities presently incinerating their sludge are finding this method to be increasingly costly because of energy cost escalations and more stringent air emission regulations. Whereas sludge incineration appeared quite attractive when capital costs were financed with federal and state funds, operating expenses are now a burden for the local taxpayer. Several such communities are seriously contemplating incinerator closure and implementation of another disposal procedure. Communities such as these are in need of advice and guidance as to the best alternative procedures to replace their present sludge disposal practices. Other past and present practices for the disposal of municipal wastewater treatment sludge have included:

- Various land burial procedures,
- Direct discharge to rivers and lakes,
- Placement in evaporative- or percolation-type lagoons and ponds,
- Agricultural utilization,
- Spray irrigation,
- Land and/or forest application.

Regulatory agencies overseeing wastewater treatment and solid waste disposal in 48 states were contacted for information concerning wastewater treatment sludge disposal facilities in their respective states. Leads and recommendations from these agencies, as well as other sources, led to a preliminary investigation of over 300 such facilities in the United States. Information provided by the regulatory agencies, as well as in-depth interviews and site visitations revealed a confusing picture of state and local regulatory agency requirements governing the handling and disposal of wastewater treatment sludge. Completely dichotomous disposal philosophies and regulations were apparent from state to state. The contradictory and seemingly arbitrary regulation of sludge disposal has spawned a patchwork of conflicting practices. In some instances, it has helped foster environmentally-unacceptable overt and covert practices.

Discussions with over 100 municipal officials revealed a general lack of knowledge on the method and location of sludge disposal in their respective communities. Oftentimes, officials had little knowledge or understanding of the attendant problems. The impression that remained was that water and wastewater were adequately regulated, but that wastewater treatment sludge disposal came under some ambiguous wastewater regulation. In addition, many state solid waste regulations arbitrarily excluded municipal wastewater treatment sludge or were vague concerning handling and disposal. Only a few states evidenced a comprehensive knowledge of the wastewater treatment sludge disposal practices in their state or had realistic and practical regulations governing the disposal of such material.

PROJECT DESCRIPTION

An organized program has been developed by the U.S. Environmental Protection Agency (EPA), Office of Solid Waste, to assess costs and the environmental impacts of different methods of sludge utilization and/or disposal. Disposal and utilization practices are to be carefully documented, costs established, and the associated environmental impacts evaluated through site investigations and monitoring work. From projects included in the overall program, guidelines will be developed to aid communities in selecting a cost-effective and environmentally acceptable sludge disposal method.

SCS Engineers was awarded EPA Contract No. 68-01-3108 in December 1974 to conduct an initial assessment of the environmental impact of wastewater treatment sludge burial practices. Other features to be assessed included the economics, operations, and aesthetics of such practices. To accomplish this overall objective, a series of tasks was delineated and performed. These included:

- Identification and selection of nine case study sites encompassing a representative range of sizes, soil characteristics, climatological conditions, operating techniques, sludge quantities and characteristics, and environmental impacts (actual and potential) for detailed field study.

- Conduct of field studies at each location to obtain site data; historical operating and cost information; aesthetic and environmental problems encountered and approaches to problem solution; sludge quantities and physical, chemical, and biological characteristics; and disposal site operating techniques.

- Location and installation of monitoring wells at each site to assess the physical and chemical characteristics of leachate and groundwaters, and composition of decomposition gases generated within the landfill.

The data obtained under this contract determined only the presence or absence of groundwater contamination. No effort was made to provide information on the level and areal extent of groundwater contamination at these sites. Another deficiency included the lack of truly representative background groundwater samples with which to compare down-gradient groundwater and to identify contamination. Further, this initial effort encompassed less than four data points, and further analyses were required to statistical confidence.

Accordingly, a second project was conceived and awarded to SCS Engineers under EPA Contract No. 68-01-4166 in August 1976 and scheduled for completion in early 1978. The latter project is intended to provide additional data on leachate and groundwater quality at eight of the case study sites of the initial project. Tasks delineated under the second project include:

- Monitoring leachate and groundwater quality at case study sites for a specified list of contaminants at two month intervals over a 12-month period.

- Measuring and evaluating changes in groundwater quality down-gradient from two disposal sites as a function of distance and hydrogeological parameters.

- Predicting possible future damage to the groundwater aquifer in the area of all sites, based on field information obtained.

- Preparing detailed case study reports for each of the eight sites.

- Correlating observed differences in concentrations and areal extent of pollutant contamination among the eight sites with the following parameters:

  - Types and quantities of wastes buried.
  - Climate.
  - Geology.
  - Hydrology.

- Assessing, where possible, the mechanism(s) of concentration or attenuation as the leachate passes from the waste/soil interface to groundwaters.

The initial study (Contract No. 68-01-3108) was conducted from December 1974 through January 1976. This current report discusses the project execution and data trends of the initial study and has been organized into the following topic areas:

- Identification of site selection criteria.

- Discussion of case study site selection process employed.

- Brief description of the individual case study sites highlighting climatological, geological, and topographical features; operating practices; description of refuse and/or sludge quantities, characteristics, and contributing sources of sludge; and other notable events which may impact on the environment.

- Discussion of scope and results of leachate, groundwater, soil, sludge, and gas monitoring at the case study sites.

- Data evaluation and discussion of trends and relationships observed.

- Description of sampling procedures.

- Delineation of laboratory analytical procedures.

TRENDS AND OBSERVATIONS

The following trends were derived from the analytical data and field survey work completed during the project. These trends rely heavily on experience, judgement, and inference; are derived from a limited data base consisting of only one, two, and sometimes three data points; and are subject to testing and confirmation.

1. Discernible groundwater contamination was detected within a distance ranging up to 300 ft (91 m) beyond the limits of the disposal area at all eight study sites. Lead, mercury, and iron were the principal heavy metal contaminants.

2. EPA Drinking Water Standards were equaled or exceeded in the shallow off-site groundwater monitoring wells indicated by X's in Table 1.

TABLE 1. OFF-SITE SHALLOW GROUNDWATER CONSTITUENTS ABOVE DRINKING WATER STANDARDS

	Constituent					
Site	SO_4	Cd	Cu	Fe	Hg	Pb
1	X			X		X
2		X		X	X	X
3				X	X	X
4	X				X	X
5				X	X	X
6				X	X	X
7				X		
8		X	X	X		X

3. Deep off-site groundwater sample concentrations equaled or exceeded EPA Drinking Water Standards at sites indicated by X's on Table 2.

TABLE 2. OFF-SITE DEEP GROUNDWATER CONSTITUENTS ABOVE DRINKING WATER STANDARDS

	Constituent				
Site	Cl	Cd	Fe	Hg	Pb
1		No deep well installed			
2	X	X	X	X	X
3		No deep well installed			
4		No deep well installed			
5		No deep well installed			
6			X	X	X
7			X		X
8			X		X

4. A detailed comparison of sites was of limited value since contaminant concentrations at the monitoring well locations are believed to be a function of distance from the leachate source, groundwater movement and direction, elevation of the groundwater table, waste composition, site age, climate factors, and soil types, all of which varied between study sites.

5. Sludge-only disposal sites have a potential for greater adverse environmental impact because of the high contaminant concentrations contained in the sludges, and the greater degree of contaminant mobility resulting from a higher moisture content. However, there was little discernible difference in off-site groundwater quality between sites receiving sludge only and those sites mixing sludge and refuse, except for somewhat higher lead concentrations at the sludge-only sites.

6. Methane concentrations in decomposition gases were higher at the sludge-only disposal sites.

7. None of the eight case study sites reported any discernible increase in the frequency of illness, accidents, injuries, or other health problems by site employees, site users, or the community as a result of the wastewater treatment sludge disposal operations.

8. From a visual and aesthetic viewpoint, certain disposal practices appeared more acceptable than others. However, the analytical results obtained from this limited study did not show that these

operational practices mitigated adverse impacts on local groundwaters.

9. The major aesthetic problems reported were odors and unattractive piles of exposed sludge.

10. Operational problems arose primarily from the difficulty experienced by equipment operators in handling the sludge piles. The high moisture content of the sludge caused wheels and tracks to spin and caused sludge to accumulate on equipment components. Soft spots occurred in the landfill where large quantities of sludge had been buried, resulting in depressions that trapped drainage or bogged down equipment.

11. The indicated cost of wastewater treatment ranged from $9.10 to $22.35 per dry ton ($10.03 to $24.63 per metric ton) at the sludge-only disposal facilities, and $2.80 to $41.85 per ton ($3.08 to $46.12 per metric ton) at the mixed refuse and sludge burial facilities. Costs reflect an actual or calculated "gate fee" at each disposal site and do not necessarily indicate the actual cost incurred for sludge disposal.

12. The proper handling and land disposal of septic tank pumpings was cited as a difficult problem by many site operators. The number and degree of problems encountered appear to increase with the proportion of septic tank pumpings received, primarily because the material is liquid, obnoxious, and often unstable.

13. A confusing picture of state and local regulatory agency requirements governing the handling and disposal of wastewater treatment sludge exists in the United States. Completely dichotomous disposal philosophies and regulations are apparent from state to state. This seemingly inconsistent regulation of wastewater treatment sludge disposal has spawned a patchwork of conflicting practices. In some instances, it has helped to foster environmentally-unacceptable overt and covert sludge disposal practices.

II. SITE SELECTION PROCEDURES

SITE SELECTION CRITERIA

Criteria used in the initial screening and selection of prospective case study sites were prepared at the onset of the project. Several mandatory criteria were stipulated in the contract, and other desirable criteria were identified to aid in ensuring a successful project. The mandatory criteria follow:

- Subsurface placement of wastewater treatment sludge needed to be practiced at the site for at least one year, and no site could have been closed for more than three years prior to the start of the survey.
- Three of the sites selected disposed of wastewater treatment sludge only, while the remainder disposed of wastewater treatment sludge together with municipal refuse.
- For those sites which disposed of both municipal refuse and wastewater treatment sludge, the sludge comprised at least 10 percent of the combined total quantity by weight.
- The disposal method used was either sanitary landfill or pit and trench method. (Liquid wastewater treatment sludge injection methods were specifically excluded.)
- The sludges were municipal wastewater treatment sludges and/or septic tank pumpings, or any combination of these wastes with municipal refuse. (Industrial sludges had been excluded.)
- As a group, the sites were selected to cover a representative range of sizes, soil characteristics, climatological conditions, operating techniques, sludge quantities and characteristics, and actual or potential environmental impacts.

- The entity responsible for the site agreed to cooperate during the monitoring program. (Such cooperation was essential if the contractor's personnel were to obtain samples from the site and additional information on site operations, handling procedures, and other pertinent information necessary to the goals of the project.)

The desirable criteria included the following:

- Good operational records existed for the disposal site. (Especially helpful in this regard were historical records of quantities and types of waste received, chemical and physical characteristics of the waste, the sources of sludge material, and the areas in the landfill where sludge was placed.)

- Data existed on area groundwater quality prior to start-up of the operation as well as climatological data from a nearby weather station.

- Sites which had previously been researched by university groups, and state or local regulatory agencies yielded useful background data for comparative purposes.

- Existing groundwater/leachate monitoring and/or gas sampling systems had been installed. (Such sites provided a longer-term historical data record to supplement and complement the information obtained during this study's short-term monitoring program.)

- Sites which had maintained current topographic maps of the site since the initiation of filling operations, as well as geological and/or engineering reports pertaining to the site and its developments were beneficial.

- The selection of exemplary sites was not considered essential. The selection of average or perhaps below-average operations provided a better indication of the possible severity of environmental contamination resulting from wastewater treatment sludge disposal. The selection of exemplary sites was not considered essential.

APPROACH TO SITE SELECTION

Several approaches were employed to locate prospective sites for possible inclusion in the study. These are capsulated below:

- A search of the literature was made for references to locations where various aspects of sludge disposal to landfills had been or were being investigated.

- A review was completed of U.S. Public Health Service Bulletin No. 1866, entitled "1968 National Survey of Community Solid Waste Practices."

- Letters of inquiry were sent to all State Solid Waste Management and Wastewater Quality Control Agencies to enlist assistance in locating prospective sites meeting the mandatory criteria stipulated above. Similar inquiries were made to all EPA Regional Offices.

- Wastewater treatment plants and/or public works departments in the largest 150 cities in the U.S. were contacted by telephone to ascertain how wastewater treatment sludge was being disposed in the respective communities.

The PHS Bulletin reports on field investigations of more than 6,000 land disposal sites in the U.S., and basic data pertaining to each site are tabulated, including the volume of wastewater treatment sludge disposed with other municipal solid wastes. A review of Volumes 1 and 2 (volumes for the central and western parts of the United Stated have not been published at the time of initial report presentation) was made to provide a quick initial screening of potential candidate sites along the east coast. Unfortunately, the document proved of less value than originally anticipated due to closure of many sites and changes in disposal practices over the interim seven-year period. Most of the data was found to be obsolete and no longer useful for the purposes of the project.

The letters of inquiry were followed up by telephone calls to any agency which had not responded or which indicated that additional sites could be identified. An initial list of approximately 200 prospective sites was generated from these telephone contacts as well as from completed letters of inquiry and literature and personal contacts. Telephone inquiries were then made for each of these sites. The contributing wastewater treatment plant was initially contacted. This source provided pertinent information on sludge types and quantities generated and on treatment plant operation. Later, the landfill operator was contacted. This source provided pertinent information on sludge types and quantities received, refuse types and quantities received, disposal site operation, and relevant historical data. Telephone contacts with more than one individual were useful in that they provided a cross-check on the validity of information obtained.

Unfortunately, upon further investigation, only a very few sites actually met all of the mandatory selection criteria. The major causes for site rejection in descending order of occurrence and importance follow:

- The relative weight or percentage of wastewater treatment sludge landfilled commonly was less than one or two percent of the total instead of the desired 10 percent or more.

- The disposal of wastewater treatment sludge at the site:

  - Had been conducted for less than one year, thus presenting little probability of any measurable environmental impacts,

  - Had been discontinued after a short time because of unspecified operating difficulties,

  - Had been sporadic in occurrence and thus deposited in unidentifiable locations in the landfill,

  - Had stopped more than three years ago, and/or

  - Had been used with soil cover and not buried.

- Inadequate records had been kept on the quantities of material deposited and other data considered useful in assessing and correlating the monitoring results.

- Many of the sites which accepted large quantities of wastewater treatment sludge also accepted industrial wastes, including industrial wastewater treatment sludges.

RESULTS OF SITE INVESTIGATIONS

Following a careful review of site data and selection criteria, the list of prospective sites totaled some 40 sites.

A total of 31 sites were subsequently field visited in an attempt to identify sites meeting the mandatory and desired criteria to the maximum possible degree.

The field visit encompassed a full man-day effort to assemble pertinent information with regard to the site. This covered two or three distinct areas as summarized below:

Wastewater Treatment Plant

At the treatment plant, the following information was solicited:

- Year plant started,
- Treatment or stabilization method for wastewater and sludge,
- Wastewater treatment sludge disposal practices since the plant became operational,
- Availability of quantity records for the years of operation,
- Chemical and physical characterization data on sludge, and
- Methods and frequency of sludge transport.

Disposal Site

The disposal site was visited and the site owner or operator queried as to the following information:

- Year site first operated,
- Year sludge first received and where disposed,
- Site plan and delineation of where sludge had been buried,
- Operational methods of handling and burial of refuse and/or sludge,
- Operational problems related to sludge handling,
- Current and past environmental monitoring programs, if any,

- Availability of hydrogeologic information, and
- Regulatory agency requirements with regard to landfill operations and/or sludge burial.

Other Information Sources

If a local or state regulatory agency had been active in establishing operating requirements or monitoring at the landfill site, the following information was solicited:

- Monitoring results with regard to environmental and health implications of the sludge-burial operation,
- Water quality data as well as geologic profiles for the area of the landfill, and
- Surface soil data from the Soil Conservation Service of the U.S. Department of Agriculture.

Information obtained from the site visit was evaluated nd compared with telephone-derived data, and recommendations for site inclusion or exclusion were derived. Nine case study sites* were ultimately selected.

* Monitoring wells at one location were inadvertently destroyed; thus only eight locations are discussed in the report.

III. DESCRIPTION OF CASE STUDY SITES

Selected comparative information is presented in this section to characterize and identify the range of conditions found at the case study site locations.

LOCATION

The eight case study sites were located in the midwest and northeastern sectors of the country. Three sites were located in Nebraska, two in New York State, and one each in the states of New Jersey, Arkansas, and Virginia.

CLIMATE

Selected climate characteristics of the eight sites are presented in Table 3 and were representative of the midwestern and eastern seaboard areas.

Normal precipitation of the four midwestern locations ranged from 23.4 to 42.4 in (59.4 to 108 cm) annually. Annual precipitation at the four eastern locations ranged from 32.5 to 45.4 in (82.6 to 115 cm). Site 1 in the midwest received the least annual precipitation, 23.4 in (59.4 cm) of the eight sites, while Site 6 on the eastern seaboard with 45.4 in (115 cm) had the highest average annual precipitation. All locations were subject to snow and ice in the winter months.

Maximum average daily temperatures of the four midwestern sites ranged from 62 to 70°F (16.7 to 21.1°C). Minimum average daily temperatures ranged from 38 to 47°F (3.3 to 8.3°C). Corresponding average daily maximum and minimum temperatures for the four sites located in the east ranged from 54 to 64°F (12.2 to 17.8°C), and 34 to 43°F (1.1 to 6.1°C) minimum, respectively.

Site 4 in the south-midwest had consistently higher average daily maximum and minimum temperatures, while Site 8 in the northeast experienced the lowest average daily maximum and minimum temperatures.

OWNERSHIP AND OPERATION

Table 4 compares ownership and operating information at each of the eight locations. Two locations, Sites 5 and 7, had formerly operated as open dumps with intermittent burning. Each has since been converted to sanitary landfill procedures.

TABLE 3. COMPARATIVE WEATHER DATA

	Precipitation (In.)*					
	Water Equivalent			Snow, Ice Pellets		Mean No. of Days Precipitation 0.01 in. or More
Site	Normal	Max. Monthly	Max. 24 Hrs.	Max. Monthly	Max. 24 Hrs.	
1	23.4	14.0	5.4	26.0	12.0	88
2	26.7	7.5	2.7	19.8	10.4	96
3	30.2	13.7	6.5	27.2	18.3	99
4	42.4	14.2	9.6	13.5		
5	40.1	18.2	11.9	24.2	15.4	111
6	45.5	13.1	6.5	35.2	14.4	112
7	33.4	9.0	4.5	57.5	21.9	135
8	32.5	11.5	3.6	56.7	16.5	152

Source: U.S. Department of Commerce

* Multiply tabulated values by 2.54 to obtain centimeters.

TABLE 3. (continued)

Site	Temperature °F			Mean Number of Days			
	Normal			Maximum		Minimum	
	Daily Max.	Daily Min.	Monthly	90°F & Above	32°F & Below	32°F & Below	0°F & Below
1	62.1	38.1	50.1	40	45	149	16
2	62.2	39.7	51.0	37	40	141	18
3	62.8	40.2	51.5	34	40	137	12
4	70.0	47.0	58.5	48	7	91	1
5	64.7	42.7	53.7	25	13	116	2
6	63.6	43.8	53.7	17	15	110	1
7	58.1	37.1	47.6	8	48	156	17
8	54.2	34.5	44.4	4	76	165	28

TABLE 4. SELECTED DESCRIPTIVE INFORMATION ON CASE STUDY SITES

Criteria	Case Study Site 1	2	3	4
Ownership	Municipal	Municipal	Municipal	Municipal
Operation	Private	Municipal	Municipal	Municipal
Year Opened	1969	1956	1939	1968
First Received Sludge	1969	1967	1939	1968
Remaining Life (Est. Years)	3	Late 1980	1	2-3
Open to Public	Yes	Yes	No	No
Scales	No	No	No	No
Gate Fee	Yes	No	No	No
Operating Personnel	3	3	1	1
Equipment (Number and Type)	Caterpillar 955 1-3/4 c.y. bucket Caterpillar 977 2-1/2 c.y. bucket	3 Caterpillar D-8 track dozers 1 c.y. dragline	I-H 175 loader 2-1/2 c.y. bucket J. Deere 3/4 c.y. dragline	Backhoe
One-Way Haul Distance (treatment plant to site) - Miles	5	4	2 Plants Plant adjacent to disposal site, Plant 10 miles from site	Plant adjacent to disposal site

TABLE 4. (continued)

Criteria	Case Study Site 5	6	7	8
Ownership	Municipal	Municipal	Municipal	Private
Operation	Municipal	Municipal	Municipal	Private
Year Opened	Dump 1925 Landfill 1972	1955	Dump 1947 Landfill 1960	1973
First Received Sludge	1973	1967	1973	1973
Remaining Life (Est. Years)	17	20	15-20	6
Open to Public	No	No	Yes	No
Scales	Yes	No	No	No
Gate Fee	No	Yes	No	No
Operating Personnel	35	3	2	1
Equipment (Number and Type)	2 compactors 4 dozers 6 scrapers 1 track loader 2 graders; 2 water flusher trucks 12 misc.	Front-end bucket dozer Loader	Front-end bucket loader 3 c.y. Rex Trash Master Model 330 Caterpillar D-5 dozer	Michigan 754 loader 2-1/2 c.y. bucket Caterpillar D-6 Dozer

TABLE 4. *(continued)*

Criteria	Case Study Site 1	2	3	4
Haul Vehicle	Open dump truck (6 c.y.)	Open dump truck (8 c.y.)	Open dump truck (6 c.y.)	Open dump trucks (6 - 10 c.y.)
Waste Types Received (annual quantities), Wet Basis	Sludge cake (17,300 c.y.) Paunch manure (430 c.y.) Industrial and commercial wastes (22,000 c.y.) Residential (78,100 c.y.)	Construction and demolition, municipal refuse, pretreated industrial plating sludges, paunch manure (220,210 T) Wastewater treatment sludge (28,527 T)	Dewatered grit and screenings, wastewater treatment sludge, paunch manure (Varies)	Sludge (7,950 T/yr - 5 yr average)
Disposal Method	Sludge spread with refuse, compacted and covered with soil	Trench, covered with refuse and soil	Pit, covered with soil	Trench, covered with soil
Disposal Cost, ($/dry ton)	$2.80	$4.61	$9.10	$15.82

TABLE 4. (continued)

Criteria	Case Study Site 5	6	7	8
One-Way Haul Distance (treatment plant to site) - Miles	Unknown (3 plants)	6-10 (2 plants)	3	12
Haul Vehicle	Tandem axle trucks, 8 c.y. roll-off containers	Vacuum tank truck	Open dump trucks 6 c.y.	Tandem axle truck 18-30 c.y. roll-on containers
Waste Types Received (annual quantities), Wet Basis	Sludge (86,736 T) Refuse (462,800 T)	Household and commercial refuse (167,000 c.y.) Septic tank pumpings (5,942 c.y.) Municipal wastewater treatment sludge (4,456 c.y.)	Domestic, commercial, Institutional and industrial (76,540 c.y.) Sludge (19,880 c.y.)	Sludge, screenings and grit (26,081 c.y.)
Disposal Method	Sludge spread with refuse, compacted and covered with soil	Sludge dumped on spread refuse, covered with soil	Sludge dried in piles, then spread with refuse, covered with soil	Sludge is lagooned, dried, and covered with soil
Disposal Cost, ($/dry ton)	$41.85	Not available	$8.25	$22.35

Only one site was owned and operated by a private firm. Of the remaining seven locations, all were municipally owned and operated except Site 1; here a private contractor operated the municipally-owned site.

Three of the eight sites accepted only sludge while the remaining five sites accepted both sludge and mixed refuse. The respective costs for sludge burial were calculated on the basis of gate fees, lump sum payments to contractors, or annual operating budgets. Cost per ton of dry sludge solids ranged from $2.80 at Site 1 to $41.85 at Site 5. (Cost data were unavailable at Site 6.)

Personnel employed at the sites generally ranged from one to three with the largest site operated by a staff of 35.

Wastes were delivered by open-top truck to all of the sites. Haul distances ranged up to 12 miles, one way.

SLUDGE DESCRIPTION

Table 5 provides comparative information on sludge type, sludge solids content, and estimated quantities of sludge and other wastes (if any) delivered to the case study sites.

Sludge received at six of the sites was described as dewatered raw primary and waste activated sludge. Site 6 received anaerobically digested sludge and large quantities of septic tank pumpings. Site 5 received a mixture of raw and digested primary and waste activated sludge along with minor quantities of incinerated sludge residue.

Solids content of the sludge as received for disposal ranged from about three percent at Site 6 to 40 percent at Sites 3 and 7. Site 3 receives relatively dry paunch manure while Site 7 receives Zimpro-processed sludge.

The relative proportion of sludge to all wastes received ranged from a low of 5.9 percent (volume basis) at Site 2 to 20.6 percent (volume basis) at Site 7.

GROUNDWATER DEPTH

The depths to groundwater at the monitoring well locations for each case study site are shown in Table 6. Calculated depths to groundwater below the bottom of the landfill are also presented.

TABLE 5. VARIATION IN WASTE COMPOSITION

Criteria	Case Study Site 1	2	3	4
Sludge Type	Raw primary and waste activated sludge, gravity thickened, vacuum filtered (polymers)	Raw primary and waste activated sludge, gravity and/or air flotation thickening, vacuum filtered (polymers)	Raw primary and waste activated sludge, vacuum filtered, paunch manure	Raw primary and waste activated sludge, gravity thickened, vacuum filtered (lime & ferric chloride)
Solids content of sludge (as delivered to site)	25-30%	20-25%	25-40%	18-25%
Annual Sludge Quantity (wet basis)	17,730 c.y. (5 yr average)	28,527 T	Varies radically due to incinerator breakdown	7,950 T (5 yr average)
Total Annual Quantity of Waste Delivered to Site	117,830 c.y.	248,737 T	Varies	7,950 T
Proportion of Sludge to Total Waste (wet basis)*	15.1%	11.5%	N.A.	100%

* Proportion based on either wet weight or wet volume basis depending on quantity data.

TABLE 5. (continued)

Criteria	Case Study Site 5	6	7	8
Sludge Type	Digested and lime & ferric chloride treated raw sludge, incinerator sludge residue	Anaerobically digested sludge, septic tank pumpings	Raw primary and waste activated sludge, Zimpro processed, vacuum filtered	Raw primary and waste activated sludge gravity thickened, centrifuged
Solids content of sludge (as delivered to site)	8-10%, average	3-5%	40% (Zimpro) 20% when Zimpro down	15%
Annual Sludge Quantity (wet basis)	86,736 T	10,398 c.y.	19,880 c.y. (3 yr average)	26,081 c.y.
Total Annual Quantity of Waste Delivered to Site	549,536 T	177,398 c.y.	96,420 c.y.	26,081 c.y.
Proportion of Sludge to Total Waste (wet basis)*	15.8%	5.9%	20.6%	100%

* Proportion based on either wet weight or wet volume basis depending on quantity data.

TABLE 6. DEPTHS TO GROUNDWATER

Site	Depth from Surface (ft)		Depth from Bottom of Landfill (ft)
	Refuse Well	Off-Site Wells	
1	35	18	11
2	27	7.5 to 13.5	-3
3	29.5	22	8.5
4	Drilling stopped upon reaching bedrock. Nearby potable water obtained from 150 - 200 ft depth.		
5	32	9.5	8
6	25	6	6
7	39	14 to 20	15
8	10	3.5	2

Only Site 2 had sludge deposited within the first 3 ft (0.9 m) of the seasonally-fluctuating groundwater table. The other locations ranged from 2 ft (0.6 m) above the groundwater table at Site 8 to an estimated 15 ft (4.6 m) above the groundwater at Site 7.

SURFACE AND SUBSURFACE SOILS

A general categorization of soil types found at each of the sites to bedrock or parent material is described in Table 7. Soil conditions were not homogeneous at any of the sites and exhibited considerable variation with depth.

TABLE 7. SOILS AND GEOLOGY

SITE 1	SITE 2
Alluvium Sand and gravel Coarse sand and gravel Bedrock	Silt Clayey silt Sand and sandy gravels Sandstone
SITE 3	**SITE 4**
Sandy silt and clay Silty clay Coarse unconsolidated alluvium Limestone	Loams Limestone Shale and calcareous sandstone Limestone
SITE 5	**SITE 6**
Unconsolidated sediments (fine sands, silts, clays, and gravel) Metamorphic and igneous rocks Granites	Gravel, sand, and clay Gray clay and fine gravel Sand
SITE 7	**SITE 8**
Glacial and alluvial deposits Shale	Gravelly sands Silt

IV. LEACHATE AND GAS MONITORING AND ANALYSIS

MONITORING OBJECTIVES AND SCOPE

Monitoring was performed at all eight case study sites to assist in completing an assessment of the environmental effects of wastewater treatment sludge disposal to landfills. The scope of the monitoring program was limited to a four-to-six month period during which measurements were made of decomposition gas composition, leachate quality immediately below the disposal site, and groundwater quality at two depths in the presumed downstream direction from the disposal site.

MONITORING WELLS

At each case study site, three monitoring wells were drilled to the groundwater table. One well was situated within the landfill area to facilitate sampling of leachate generated within the well proximity. Gas probes were placed at two different depths within the landfill at this same well location. Figure 1 illustrates the construction details for the in-refuse monitoring well

Two additional wells were to be located approximately 100 ft outside the limits of the disposal area in the presumed direction of groundwater migration. These wells were to intercept any leachate emanating from the landfill. One off-site well would intercept the groundwater in the first several feet of the groundwater aquifer. The second off-site well would penetrate a deeper stratum approximately 20 ft below the interception point of the first well, the purpose being to detect differences in groundwater quality with depth. Because of bedrock, caving sand, or other impediments, deep wells were not installed at four of the sites. Figure 2 illustrates construction details on the off-site wells.

Figures 1 and 2 also illustrate the locations of in-situ samples of waste material and soil taken, and the methods and materials used for backfilling and sealing the well.

During installation of the in-refuse monitoring well, the following soil and refuse samples were obtained:

- Cover soil for the determination of soil permeability,

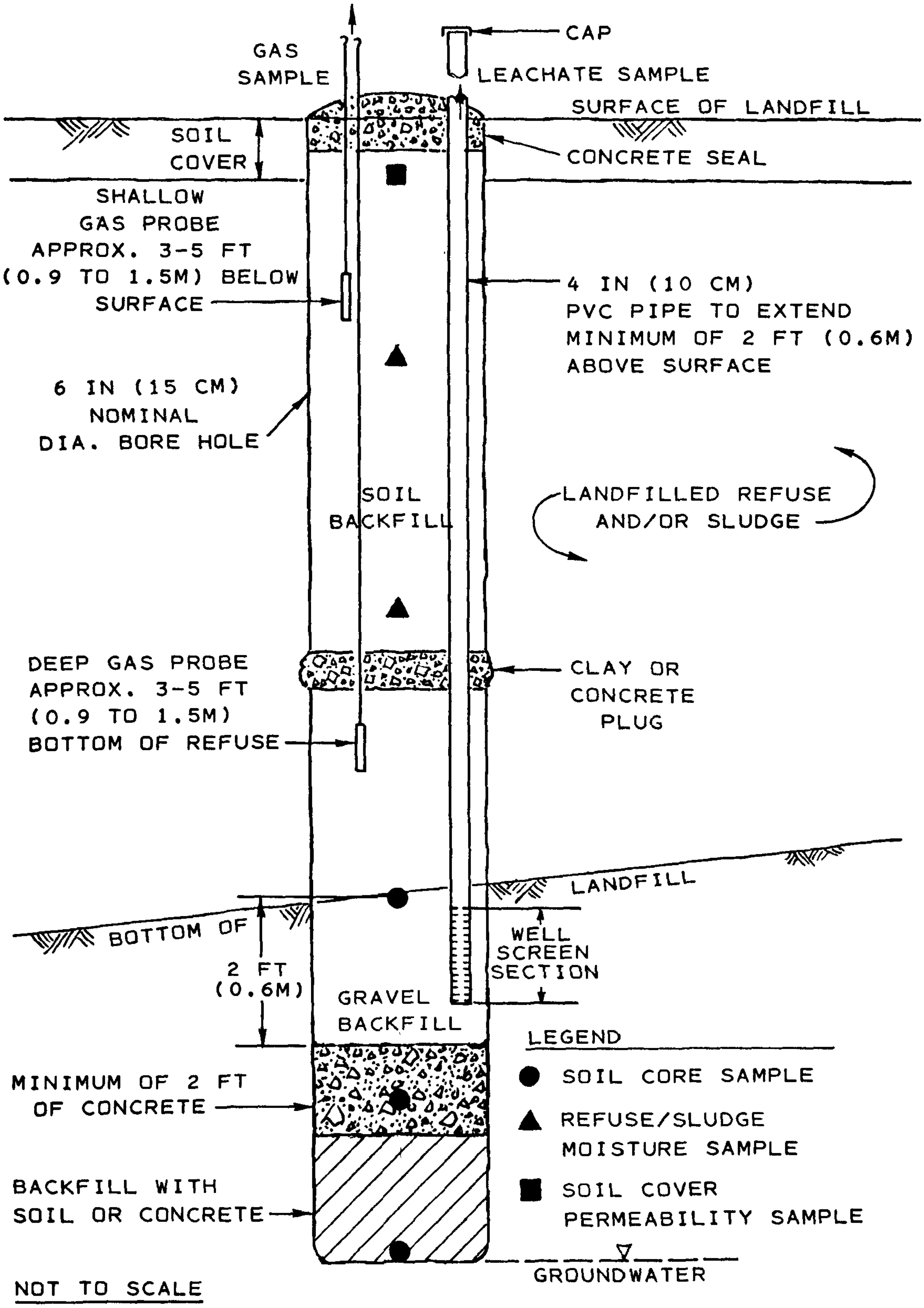


FIGURE 1
TYPICAL SAMPLING WELL DETAILS
(IN-REFUSE WELL)

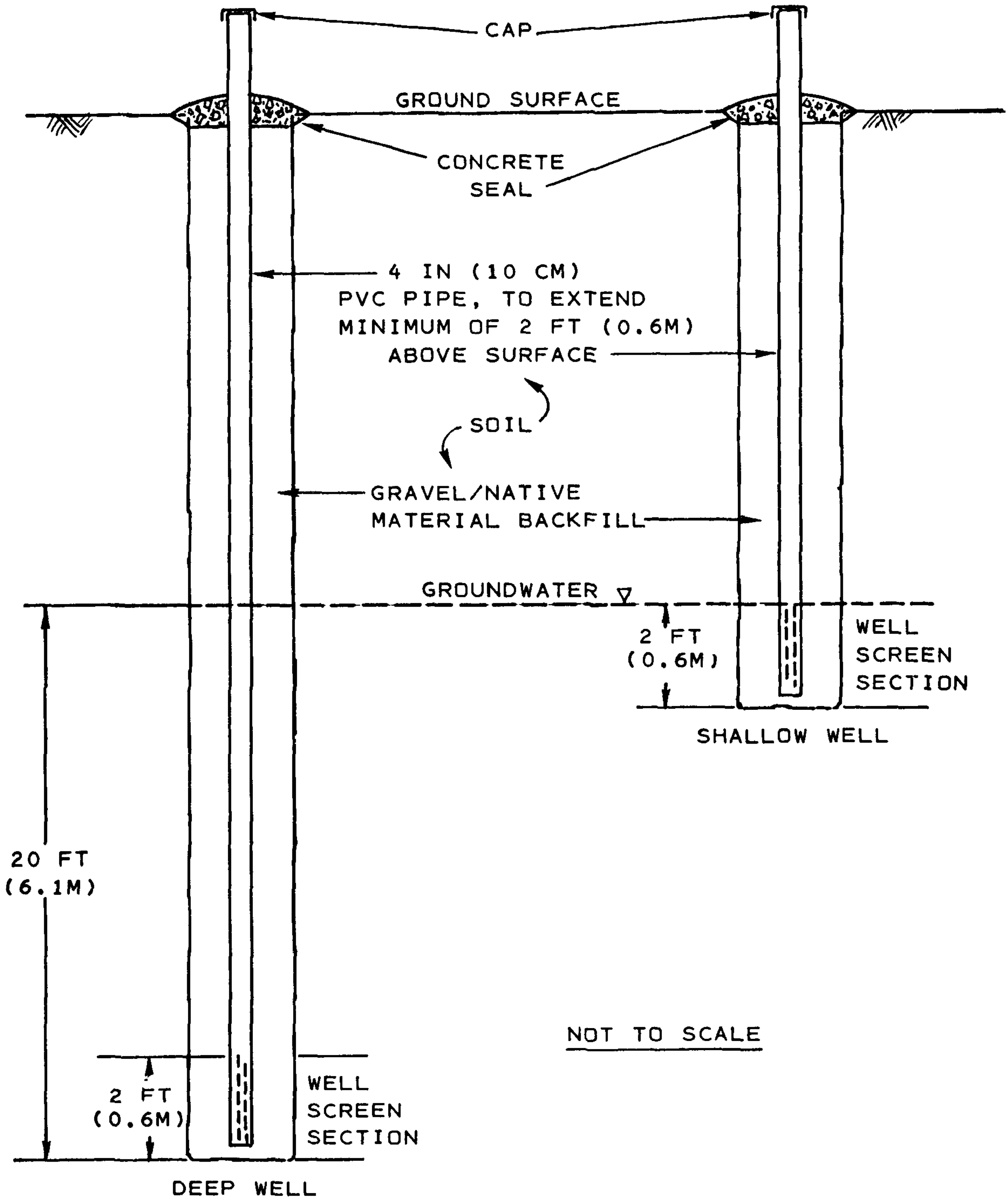


FIGURE 2
TYPICAL SAMPLING WELL DETAILS
(DOWNSTREAM PLUME WELLS)

- Refuse for determination of moisture content, and
- Core samples of soil at the landfill bottom, at a point halfway between the landfill bottom and the groundwater table, and at the soil-groundwater interface.

Detailed procedures for the installation of the monitoring wells were prepared. These procedures are included as Appendix A of this report.

MONITORING PROGRAM

The monitoring wells were to be sampled a total of three times over a period of from four to six months. At the time of the visit, samples of the following were obtained:

- Leachate from the in-refuse well,
- Groundwater from each of the downstream wells, and
- Gas samples from each of the two gas probes.

Detailed procedures for the field sampling activity and the preservation and shipping of samples were prepared. These procedures are described in Appendix B of this report.

All of the leachate and groundwater samples were analyzed for the same constituents. These constituents were:

- pH
- Total Solids
- Ammonia-Nitrogen (NH_4-N)
- Nitrate-Nitrogen (NO_3-N)
- Total Kjeldahl Nitrogen (TKN)
- Chloride (Cl)
- Sulfate (SO_4)
- Total Organic Carbon (TOC)
- Chemical Oxygen Demand (COD)
- Calcium (Ca)
- Cadmium (Cd)
- Chromium (Cr)
- Copper (Cu)
- Iron (Fe)
- Mercury (Hg)
- Lead (Pb)

Gas samples taken at two different depths in the refuse and/or sludge disposal area were analyzed for methane, carbon dioxide, oxygen, and nitrogen content.

Appendix C contains a detailed description of sample preparation and analysis methods utilized during the project.

V. DATA EVALUATION

The results of physical measurements and laboratory analyses obtained from the monitoring program at each of the eight case study disposal sites are summarized in Tables 8 to 16. Table 8 summarizes soil textures and horizontal and vertical permeability coefficients for the landfill cover soils found in the vicinity of the in-refuse monitoring wells. Soil cover permeabilities are expressed as a vertical and a horizontal factor for each soil sample tested. Two or more cover soil samples were tested for permeability at several sites.

The first page of each of Tables 9 to 16 presents analytical results for representative samples of background groundwater and wastewater treatment sludge. The sludge samples were obtained from the wastewater treatment plant with the exception of Site 2. At this location, the sample was obtained from material excavated during placement of the in-refuse monitoring well.

On the second and subsequent pages of each table, analytical results from leachate and groundwater sampling of the in-refuse well, the shallow off-site groundwater well, and the deep off-site groundwater well are presented. Results reflect four separate sampling dates encompassing a one-year monitoring period. Reasons for omissions are cited where appropriate on the respective tables.

Samples of gas were taken at times of leachate and groundwater monitoring from an upper and lower level gas probe (see Figure 1). Gas composition as percent methane, carbon dioxide, oxygen, and nitrogen by volume for the respective sampling dates at all eight study sites is presented in Table 17.

One or two grab samples of the background groundwater were taken at each site to provide a reference datum for comparison of water quality below the disposal site and with the off-site shallow and groundwater monitoring wells located in the presumed direction of groundwater movement.

The in-refuse monitoring well, as well as the shallow and deep off-site groundwater monitoring wells, were sampled on four separate occasions. On several occasions, there were insufficient samples to analyze.

Two wastewater treatment sludge samples, representative of those normally delivered to the disposal site, were also obtained

TABLE 8. SOIL TEXTURE AND PERMEABILITY COEFFICIENTS
COVER SOILS AT STUDY SITES

Site	Soil Texture*	Permeability Coefficient (cm/sec)	
		Horizontal	Vertical
1	Clayey sand	1.8×10^{-6} 1.4×10^{-7}	1.6×10^{-6} 1.1×10^{-7}
2	Silty clay	1.2×10^{-9}	1.2×10^{-9}
3	Silty clay	4.8×10^{-9}	9.4×10^{-9}
4	Silty clay	3.4×10^{-8}	7.4×10^{-9}
5	Clayey sand	4.1×10^{-6}	3.2×10^{-6}
6	Sand	4.5×10^{-4} 7.5×10^{-4}	1.7×10^{-3} 5.4×10^{-3}
7	Sand	1.2×10^{-3} 6.1×10^{-6}	2.0×10^{-4} 2.7×10^{-6}
8	Sand	4.5×10^{-5}	3.3×10^{-5}

* Visual classification (Unified Soil Classification System)

TABLE 9. ANALYTICAL RESULTS FOR SITE 1

Sample:	Sludge*				Background Groundwater	
Extract:	Water	Acid	Water	Acid		
Constituent**	7/8/75		6/4/76		10/14/75	6/4/76
pH					7.6	
Tot. Solids					598.1	
TOC	50000		45360		14	2.0
COD	173056				17	
MBAS			<0.1			<0.01
TKN	7145				0.2	
NH_4-N	687				0.2	
NO_3-N	1.1				0.65	
Cl	110		12		24	27
SO_4	<10		88		152	240
Ca	1740				46	
Cd	0.77			1.5	<0.001	.001
Cr	10.17			53	<0.01	<.01
Cu	108			200	0.008	.01
Fe	187			2000	0.10	.23
Hg	0.087			<0.003	0.0008	<.0002
Ni				2.9		<.01
Pb	21.0			72	0.020	.007
Zn				212		.49

TABLE 9. (continued)

Sample:	Refuse Well Leachate		Off-Site Well (Shallow)			
Constituent**		6/4/76	7/8/75	9/18/75	10/14/75	6/4/76
pH	Insufficient sample on 7/8/75, 9/18/75, and 10/14/75 for analysis		Insufficient sample	7.9		
Tot. Solids				609		
TOC		985		10	52	12
COD				30	83	
MBAS		<0.01				0.04
TKN				1.1	2.7	
NH_4-N				0.14	1.3	
NO_3-N				<0.02	0.25	
Cl		-		25	47	36
SO_4		8		238	430	315
Ca				70	87	
Cd		0.003		0.008	0.003	0.001
Cr		0.01		<0.01	0.03	0.07
Cu		<0.01		0.008	0.016	0.02
Fe		190		0.33	0.85	4.6
Hg		<0.0002		<0.0001	0.0004	<0.0002
Ni		0.04				0.02
Pb		0.10		0.056	0.035	0.02
Zn		11				0.09

* Sludge was extracted with water and conc. nitric acid. Sampling dates are also indicated. Moisture content for the 6/4/76 sample was 85%.

** Concentrations are expressed as mg/kg of wet sludge and mg/ℓ of groundwater or leachate.

TABLE 10. ANALYTICAL RESULTS FOR SITE 2

Sample:	Sludge*				Background Groundwater	
Extract: Constituent**	Water 6/17/75	Acid 6/17/75	Water 6/4/76	Acid 6/4/76	9/18/75	6/4/76
pH					8.2	
Tot. Solids					4029	
TOC	8250		42742		54	14
COD	31416				82	
MBAS			<0.1			0.15
TKN	608				2.4	
NH_4-N	122				1.6	
NO_3-N	2.4				<0.02	
Cl	256		10		1201	1500
SO_4	5450		38		375	360
Ca	19625	1775			76	
Cd	<0.03	0.66		3.6	0.014	0.001
Cr	<0.30	7.00		22	<0.01	<.01
Cu	<0.20	11.90		62	0.043	<.01
Fe	0.56	4933		1000	0.86	2.5
Hg	0.680			<0.003	0.0016	<0.0002
Ni				9.6		.01
Pb	1.2	48		55	0.040	.02
Zn				150		2.1

Refuse percent moisture (8 ft) 22.1
(9 ft) 29.0
(17 ft) 36.0
(20 ft) 41.0

TABLE 10. (continued)

Sample:	Refuse Well Leachate			
Constituent**	7/8/75	9/18/75	10/14/75	6/4/76
pH	6.9	7.8	7.9	
Tot. Solids	12465	5940	5433	452
TOC	2750	1067	1350	
COD	5637	2687	2000	
MBAS				<0.01
TKN	161	103.7	80	
NH_4-N	130	70	57	
NO_3-N	<0.02	0.02	0.02	
Cl	29	350	492	70
SO_4	1600	76	1	540
Ca	510	161	77	
Cd	0.009	0.025	0.011	0.003
Cr	0.14	0.01	0.47	0.01
Cu	0.100	0.02	0.015	<0.01
Fe	64	2.76	0.75	1.5
Hg	0.007	0.033	0.0005	<0.0002
Ni				0.08
Pb	0.310	0.200	0.263	0.10
Zn				0.01

TABLE 10. (continued)

Sample:	Off-Site Well (Shallow)			Off-Site Well (Deep)			
Constituent**	7/8/75		6/4/76	7/8/75	9/18/75	10/14/75	6/4/76
pH	7.6	Insufficient sample on 9/18/75 and 10/14/75 for analysis		7.7	7.9	7.6	
Tot. Solids	22548			29299	6887	2006	
TOC	700		14	350	32	68	9.2
COD	2746			1581	54	83	
MBAS			<0.01				<0.01
TKN	36			14.2	2.1	1.3	
NH_4-N	4.5			2.5	0.6	1.1	
NO_3-N	0.10			0.05	0.32	0.30	
Cl	234		132	687	273	360	580
SO_4	135		60	210	238	108	170
Ca	25			30	53	23	
Cd	0.015		0.002	0.030	0.009	0.004	0.003
Cr	0.65		< 0.01	0.98	0.02	0.02	0.02
Cu	0.330		0.01	0.540	0.008	0.009	<0.01
Fe	540		2.3	1090	0.42	0.23	0.44
Hg	0.003		< 0.0002	0.006	0.0003	0.0002	0.0002
Ni			< 0.01				<0.01
Pb	0.740		0.02	1.890	0.056	0.070	0.58
Zn			0.03				0.08

* Sludge was extracted with water and conc. nitric acid. Moisture content for the 6/4/76 sample was 86%.

** Concentrations are expressed as mg/kg of wet sludge and mg/ℓ of groundwater or leachate.

TABLE 11. ANALYTICAL RESULTS FOR SITE 3

Sample (Depth):	Sludge* (9')				Background Groundwater
Extract:	Water	Acid	Water	Acid	
Constituent**	10/14/75		6/3/76		9/19/75
pH	5.4				7.8
Tot. Solids					991
TOC	7333		65714		11
COD	11925				34
MBAS			1.0		
TKN	616				1.3
NH_4-N	375				1.0
NO_3-N	1.9				.91
Cl	51		120		38
SO_4	10		38		185
Ca	300	1000			230
Cd	<0.04	0.60		1.2	0.009
Cr	1.25	33.50		63	0.02
Cu	0.24	6.00		44	0.018
Fe	29	650		2125	1.24
Hg	0.0003	0.002		<0.004	0.0004
Ni				5.9	
Pb	0.5	31.0		75	0.036
Zn				238	
Percent moisture		89.9			

Sludge and paunch manure percent moisture (8 ft) 23.1
(21 ft) 23.1

TABLE 11. (continued)

Sample:	Refuse Well Leachate			
Constituent**	7/8/75	9/19/75	10/15/75	6/3/76
pH	6.7	7.6	7.5	
Tot. Solids	13290	8111	5805	
TOC	7200	11333	14267	1030
COD	19552	23283	20302	
MBAS				
TKN	759	3236	3545	
NH_4-N	605	2468	3407	
NO_3-N	<0.02	<0.02	<0.02	
Cl	28	112	31	1160
SO_4	430	2	1	8
Ca	2070	437	111	
Cd	0.007	0.021	0.008	0.002
Cr	0.15	0.10	0.17	0.04
Cu	0.050	0.020	0.054	<0.1
Fe	20.6	11.1	10.4	1.7
Hg	0.005	0.012	0.001	
Ni				0.15
Pb	0.37	0.73	0.18	0.03
Zn				0.08

TABLE 11. (continued)

Sample:	Off-Site Well (Shallów)			
Constituent**	7/8/75	9/19/75	10/15/75	6/3/76
pH	6.7	7.4	6.7	
Tot. Solids	2379	3403	2040	
TOC	550	33	17	40
COD	861	50	32	
MBAS				<0.01
TKN	0.3	6.6	0.9	
NH_4-N	<0.1	4.6	0.5	
NO_3-N	0.10	<0.02	0.28	
Cl	3	50	60	56
SO_4	35	30	40	30
Ca	196	170	290	
Cd	0.007	0.008	0.004	0.007
Cr	0.17	<0.01	0.03	0.02
Cu	0.100	0.150	0.020	0.08
Fe	87.4	0.33	2.58	30
Hg	0.005	0.0002	0.0004	<0.0002
Ni				0.11
Pb	0.16	0.09	0.10	0.09
Zn				0.32

* Sludge was extracted with water and conc. nitric acid. Moisture contents were 89.9 and 78% for the 10/14/75 and 6/3/76 samples, respectively.

** Concentrations are expressed as mg/kg of wet sludge and mg/ℓ of groundwater or leachate.

TABLE 12. ANALYTICAL RESULTS FOR SITE 4

Sample	Sludge*				Background Groundwater	
Extract	Water	Acid	Water	Acid		
	6/17/75		6/5/76		10/10/75	6/5/76
Constituent**						
pH	12.3				7.6	
Tot. Solids					201	
TOC	3600		30465		39	13
COD	4412				41	
MBAS			<0.1			<0.01
TKN	534				0.7	
NH_4-N	137				<0.1	
NO_3-N	0.7				0.36	
Cl	1187		3250		2	13
SO_4	230		625		11	870
Ca	5889	14000			12	
Cd	0.03	1.5		2.8	0.002	0.002
Cr	0.30	13.17		34	0.01	0.01
Cu	8.8	85		108	0.007	<0.01
Fe	3.3	5960		3750	1.32	1.4
Hg	<0.001	0.010		<0.003	0.001	<0.0002
Ni				8.6		0.02
Pb	1.2	28		16	0.010	0.04
Zn				88		0.02
	<30					
	210					
Percent Moisture	82.9					

TABLE 12. (continued)

Sample	Refuse Well Leachate			
Constituent**	7/8/75	10/10/75	11/13/75	6/5/76
pH	7.1	7.4	8.3	
Tot. Solids	5411	6948	23760	
TOC	4960	4320	4160	227
COD	8570	5443	10998	
MBAS				0.51
TKN	1459	1082	1058	
NH_4-N	1432	986		
NO_3-N	<0.02	<0.02		
Cl	508	624	596	680
SO_4	60	1		16
Ca	317		2248	
Cd	0.060	0.025	0.216	0.003
Cr	9.50	3.30	51.64	0.08
Cu	4.70	2.12	36.34	<0.01
Fe	124	42	350	12
Hg	0.005	0.0005	0.003	<0.0002
Ni				0.08
Pb	0.760	0.345	3.530	0.02
Zn				0.01

TABLE 12. (continued)

Constituent**	Off-Site Well (Shallow)			
	7/8/75	10/8/75	11/3/75	6/5/76
pH	7.2	7.9	7.6	
Tot. Solids	2087	1941	2066	
TOC	8	28	15	1.5
COD	19	30	20	
MBAS				<0.01
TKN	2.1	1.3	0.7	
NH_4-N	0.4	0.3	<0.1	
NO_3-N	0.10	0.45	0.85	
Cl	50	65	87	81
SO_4	900	912	825	1050
Ca	350	160	275	
Cd	0.006	0.004	0.004	0.003
Cr	0.05	0.01	0.02	<0.01
Cu	0.074	0.015	<0.006	<0.01
Fe	0.13	0.20	0.17	0.18
Hg	0.005	0.0001	<0.0001	<0.0002
Ni				0.02
Pb	0.120	0.062	0.070	0.02
Zn				0.02

* Sludge was extracted with water and conc. nitric acid. Moisture contents were 82.9 and 85% for the 6/17/75 and 6/5/76 samples, respectively.

** Concentrations are expressed as mg/kg of wet sludge and mg/ℓ of groundwater and leachate.

TABLE 13. ANALYTICAL RESULTS FOR SITE 5

Sample	Sludge*				Background Groundwater
Extract	Water	Acid	Water	Acid	
	9/10/75		6/7/76		9/10/75
Constituent**					
pH	7.7				6.8
Tot. Solids					258
TOC	687		25575		2
COD	2410				6
MBAS			0.49		
TKN	560				0.5
NH_4-N	429				0.3
Cl	584		450		8
SO_4	33		150		5
Ca	159	1955			2
Cd	0.03	2.83		1.5	<0.001
Cr	0.20	46.40		96	0.02
Cu	0.10	92.20		75	<0.01
Fe	17	92.60		13750	0.09
Hg	<0.001	0.011		0.011	0.001
Ni				5.1	
Pb	0.8	151		38	0.060
Zn				175	
Percent Moisture	70.4				

TABLE 13. (continued)

Sample	Refuse Well Leachate	Existing Off-Site Well		Off-Site Well (Shallow)			
Constituent**		9/10/75	6/7/76	5/28/75	9/10/75	10/29/75	6/7/76
pH	Insufficient sample on 5/28/75, 9/10/75, and 10/29/75 for analysis			6.7	6.8	Insufficient sample	
Tot. Solids				462	355		
TOC			12	300	8		16
COD				603	22		
MBAS			<0.01				<0.01
TKN		1.3		13.7	1.9		
NH_4-N		0.6		1.2	1.0		
NO_3-N		0.51		<0.02	1.68		
Cl		37	21	23	10		24
SO_4		32	33	11	3		30
Ca		24			2		
Cd		0.004	0.010	0.001	0.003		0.002
Cr		0.01	<0.01	0.02	0.02		<0.01
Cu		<0.006	<0.01	<0.006	0.008		0.01
Fe		0.31	23	1.98	0.39		32
Hg		<0.0001	<0.0002	0.002	<0.0001		<0.0002
Ni			<0.01				<0.01
Pb		0.028	0.009	<0.020	0.054		0.009
Zn			0.06				0.20

* Sludge was extracted with water and conc. nitric acid. Moisture contents were 70.4 and 85% for the 9/10/75 and 6/7/76 samples, respectively.

** Concentrations are expressed as mg/kg of wet sludge and mg/ℓ of groundwater or leachate.

TABLE 14. ANALYTICAL RESULTS FOR SITE 6

Sample	Sludge*				Background Groundwater	
Extract	Water	Acid	Water	Acid		
	6/4/75		6/8/76		10/29/75	6/8/76
Constituent**						
pH	5.5				6.1	
Tot. Solids					203	
TOC	587		13500		4	3.7
COD	937				9	
MBAS			14			<0.01
TKN	448				1	
NH_4-N	398				0.8	
NO_3-N	7				2.95	
Cl	123		1450		4	<2
SO_4	10		150		<1	<1
Ca	32	60			1	
Cd	0.04	0.12		0.12	<0.001	<0.001
Cr	1.88	3.75		225	<0.01	<0.01
Cu	0.20	11.2		36	0.010	0.69
Fe	4	181		1188	0.55	0.50
Hg	0.0004	0.002		<0.001	<0.0001	<0.0002
Ni				0.12		<0.01
Pb	0.5	2.6		6.2	0.026	<0.005
Zn				74		0.67
Percent Moisture	98.5					

TABLE 14. (continued)

Sample / Constituent**	Refuse Well Leachate	Off-Site Well (Shallow) 5/28/75	9/11/75	10/29/75	6/8/76
pH	Insufficient samples taken on 5/28/75, 9/11/75, 10/29/75, and 6/8/76	7.5	5.5	6.3	
Tot. Solids		148	52	126	
TOC			51	2	19
COD			116	11	
MBAS					<0.01
TKN			2.5	2.5	
NH_4-N			2.3	1.0	
NO_3-N			0.51	8.85	
Cl		26	41	5	5
SO_4		10	28	5	6.6
Ca		5	64	2	
Cd		<0.001	0.0003	0.001	<0.001
Cr		<0.01	<0.01	0.02	<0.01
Cu		0.050	0.050	0.010	<0.01
Fe		3.85	1.57	0.10	0.25
Hg		0.003		0.0001	<0.0002
Ni					<0.01
Pb		0.060	0.025	0.04	<0.005
Zn					0.18

TABLE 14. (continued)

Sample	Off-Site Well (Deep)			
Constituent**	5/28/75	9/11/75	10/29/75	6/8/76
pH	7.5	5.0	6.5	
Tot. Solids	200	359	66	
TOC		11	2	9.4
COD		21	4	
MBAS				0.10
TKN		4.3	0.5	
NH_4-N		31	0.4	
NO_3-N		1.94	4.15	
Cl	7	6	5	11
SO_4	53	4	5	2.9
Ca	9	3	2	
Cd	0.002	0.002	<0.001	<0.001
Cr	<0.01	0.01	<0.01	<0.01
Cu	0.090	<0.006	0.010	<0.01
Fe	3.85	0.41	0.05	0.12
Hg	0.043	0.0001	<0.0001	<0.0002
Ni				<0.01
Pb	0.050	0.015	0.016	<0.005
Zn				0.07

* Sludge was extracted with water and conc. nitric acid. Moisture contents were 98.5 and 95% for the 6/4/75 and 6/8/75 samples, respectively.

** Concentrations are expressed as mg/kg of wet sludge and mg/ℓ of groundwater or leachate.

TABLE 15. ANALYTICAL RESULTS FOR SITE 7

Sample	Sludge *				Background Groundwater
Extract	Water	Acid	Water	Acid	
	7/31/75		6/8/76		7/31/75
Constituent**					
pH					
Tot. Solids					
TOC	5000		116740		7
COD	32096				6
MBAS			15		
TKN	1490				0.1
NH_4-N	821				0.1
NO_3-N	4				8.7
Cl	340		1900		5
SO_4	90		2375		3
Ca	3778	30600			79
Cd	0.81	15.07		1.1	<0.001
Cr	628	8975		18750	<0.01
Cu	11.50	37.50		49	0.360
Fe	145	1511		3000	0.42
Hg	0.011	0.003		<0.01	<0.001
Ni				5.4	
Pb	25.0	284		338	0.030
Zn				106	

TABLE 15. (continued)

Sample	Refuse Well Leachate			
Constituent**	9/18/75	10/2/75	11/4/75	6/8/76
pH	7.5	7.7	7.6	
Tot. Solids	4413	3770	3736	
TOC	1083	1333	733	118
COD	2736	4505	1345	
MBAS				<0.01
TKN	544	555	510	
NH_4-N	521	517	482	
NO_3-N	0.03	0.11	0.12	
Cl	1090	1283	1123	1000
SO_4	<1	<1	<1	<1
Ca	164	198	115	
Cd	0.011	0.011	0.006	<0.001
Cr	0.14	2.93	1.91	0.05
Cu	0.040	0.063	0.130	0.02
Fe	96	126	104	1.1
Hg	0.0007	0.0002	0.0002	<0.0002
Ni				0.04
Pb	0.364	0.264	0.340	0.03
Zn				0.06

TABLE 15. (continued)

Sample	Off-Site Well (Shallow)			
Constituent**	9/18/75	10/2/75	11/4/75	6/8/76
pH	7.6		8.0	
Tot. Solids	4263		3511	
TOC	82	89	30	17
COD	127	195	37	
MBAS				0.26
TKN	51.4	38.0	47.6	
NH_4-N	38.8	33.0	47.6	
NO_3-N	0.02	0.59	1.10	
Cl	4	133	143	127
SO_4	12	18	13	16
Ca	83	59	88	
Cd	0.001	0.002	<0.001	0.002
Cr	0.01	0.25	0.04	0.01
Cu	0.010	0.030	0.020	<0.01
Fe	1.31	6.25	5.28	4.9
Hg	<0.0001	0.0002	0.0001	<0.0002
Ni				0.01
Pb	0.018	0.020	<0.010	<0.005
Zn				0.20

TABLE 15. (continued)

Sample	Off-Site Well (Deep)			
Constituent**	9/18/75	10/2/75	11/14/75	6/8/76
pH	7.9	8.1	8.2	
Tot. Solids	427	1630	396	
TOC	67	60	88	26
COD	135	141	110	
MBAS				<0.01
TKN	18.1	16.7	16.0	
NH_4-N	17.9	15.1	14.4	
NO_3-N	<0.02	0.78	1.0	
Cl	61	75	68	52
SO_4	21	24	22	9.1
Ca	67	52	63	
Cd	0.002	0.003	0.002	0.007
Cr	<0.01	<0.01	0.02	0.01
Cu	0.016	0.016	0.020	0.01
Fe	0.17	0.15	2.09	0.88
Hg	<0.0001	0.0002	<0.0001	<0.0002
Ni				0.24
Pb	0.052	<0.010	0.010	0.012
Zn				0.70

* Sludge was extracted with water and conc. nitric acid. Moisture content was 49% for the 6/8/76 sample.

** Concentrations are expressed as mg/kg of wet sludge and mg/ℓ of groundwater or leachate.

TABLE 16. ANALYTICAL RESULTS FOR SITE 8

Sample	Sludge*				Background Groundwater
Extract	Water	Acid	Water	Acid	
	6/30/75		6/8/76		9/17/75
Constituent**					
pH	7.1				
Tot. Solids					
TOC	4200		33300		31
COD	9135				95
MBAS			5.6		
TKN	408				0.6
NH_4-N	76				
NO_3-N	0.4				
Cl	48		13		2
SO_4	17		63		25
Ca	133	127			46
Cd	0.01	0.12		0.12	0.002
Cr	0.12	1.73		1050	<0.01
Cu	0.40	31.00		44	0.090
Fe	10	116		538	0.50
Hg	0.024	0.229		<0.003	0.0004
Ni				3.0	
Pb	0.2	3.6		24	0.080
Zn				75	
Percent Moisture	86.7				

* Sludge percent moisture (7 ft) 33.0

TABLE 16. (continued)

Sample	Refuse Well Leachate			
Constituent**	7/30/75	9/17/75	10/3/75	6/19/76
pH	6.2	7.2		
Tot. Solids	4965	19808		
TOC	3000	890	1160	2970
COD	8265	1194	5721	
MBAS				
TKN	254			
NH_4-N	198			
NO_3-N	0.28			
Cl	3			
SO_4	12			
Ca	617	43	47	
Cd	0.019	0.016	0.033	0.002
Cr	0.09	0.19	5.62	0.30
Cu	1.670	0.310	1.900	0.59
Fe	227	63	237	320
Hg	<0.001			<0.0002
Ni				0.02
Pb	0.680	0.770	0.700	0.08
Zn				0.26

TABLE 16. (continued)

Sample	Off-Site Well (Shallow)			
Constituent**	7/30/75	9/17/75	10/3/75	6/9/76
pH	7.5	7.8	8.2	
Tot. Solids	156	197	108	
TOC	320	38	50	29
COD	2698	91	66	
MBAS				<0.01
TKN	89	6.3	8.0	
NH_4-N	7.3	5.5	7.7	
NO_3-N	1.10	<0.02	0.62	
Cl	12	15	17	
SO_4	7	17	10	
Ca	907	77	77	
Cd	0.040	0.002	0.001	0.001
Cr	0.92	<0.01	0.19	<0.01
Cu	3.000	0.029	0.016	<0.01
Fe	1114	0.70	8.38	27
Hg	<0.001	0.0006	0.001	<0.0002
Ni				0.02
Pb	1.150	0.090	0.024	0.5
Zn				0.48

TABLE 16. (continued)

Sample	Off-Site Well (Deep)			
Constituent**	7/30/75	9/17/75	10/3/75	6/9/76
pH	7.0	7.8	7.8	
Tot. Solids	55534	32890	2170	
TOC	49	64	36	28
COD	83	135	104	
MBAS				0.02
TKN	1.4	6.2	1.3	
NH_4-N	0.8	0.7	0.3	
NO_3-N	0.20	<0.02	0.67	
Cl	4	9	10	10
SO_4	15	14	6	1.7
Ca	14	15	16	
Cd	<0.002	0.003	<0.001	0.001
Cr	<0.01	<0.01	<0.01	<0.01
Cu	0.430	0.009	0.018	<0.01
Fe	0.46	0.38	0.30	1.7
Hg	<0.001	0.0008	0.001	<0.0002
Ni				<0.01
Pb	0.050	0.231	0.024	0.02
Zn				0.15

* Sludge was extracted with water and conc. nitric acid. Moisture contents were 86.7 and 83% for the 6/30/75 and 6/8/76 samples, respectively.

** Concentrations are expressed as mg/kg of dry soil, mg/kg of wet sludge, mg/ℓ of groundwater or leachate, and most probable number/100 ml (100 g) for fecal bacterial counts.

TABLE 17. IN-REFUSE GAS COMPOSITION AT TWO DEPTHS

Site	Date	Gas Composition (%)							
		CH_4		CO_2		O_2		N_2	
		Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
1	7/8/75	55.1	51.5	41.5	39.0	0.7	2.1	2.7	7.4
	9/18/75	--	45.0	--	34.7	20.8	4.2	79.2	16.1
	10/14/75	50.5	52.3	39.9	39.3	2.0	1.8	7.5	6.6
2	7/8/75	*	*	*	*	*	*	*	*
	9/18/75	1.3	2.8	1.1	1.7	20.0	20.4	77.6	75.1
	10/14/75	39.5	49.9	37.1	37.2	5.2	2.3	23.0	10.5
3	7/8/75	--	56.3	0.1	39.6	21.2	0.9	78.7	3.2
	9/19/75	53.7	--	33.6	--	2.8	21.2	9.8	78.8
	10/15/75	5.8	62.6	1.4	34.3	16.4	0.6	76.4	2.5
4	7/18/75	--	*	0.25	*	21.8	*	78.0	*
	9/18/75	1.1	1.1	0.9	0.4	21.1	21.0	76.9	77.5
	10/10/75	--	--	--	--	21.7	21.7	78.2	78.2
	11/13/75	*	*	*	0.4	*	21.1	*	78.5
5	5/28/75	36.0	29.8	49.2	37.5	3.3	7.2	11.5	25.4
	9/10/75	28.5	43.0	67.2	50.4	0.7	1.1	3.6	5.4
6	6/8/75	57.9	52.6	30.5	30.8	0.6	3.5	10.9	13.2
	9/10/75	49.0	29.3	37.1	47.1	13.0	3.5	10.8	20.1
	10/30/75	*	58.7	*	40.6	*	0.2	*	0.5
7	10/6/75	*	53.6	*	32.4	*	3.3	*	10.6
	9/18/75	5.5	24.5	18.8	7.2	6.2	21.9	69.5	46.4
	10/30/75	48.0	*	20.0	*	7.4	*	24.7	*
8	7/30/75	14.1	**	22.1	**	13.5	**	50.3	**
	9/17/75	--	--	0.4	--	20.9	20.7	78.7	79.3
	10/6/75	**	42.7	**	39.8	**	3.6	**	13.9

-- below detection level
* buret broken in transit
** drew water

at almost one-year intervals for analysis and comparison purposes. A synopsis of indicated groundwater quality before and after the impact of refuse and/or wastewater treatment sludge disposal at the case study locations is depicted in Figures 3 to 18.

Each figure depicts a specific chemical constituent. Results are grouped by sites. The one or two horizontal lines for each site depict background groundwater quality for that particular constituent. The vertical bar graphs from left to right are: (1) sludge as shipped to landfill, (2) in-refuse leachate, (3) off-site shallow groundwater, and (4) off-site deep groundwater. Sites 1, 3, 4, and 5 do not have a deep off-site well. The top and bottom of a bar represent maximum and minimum observed concentration values. Additional results are shown as points within the bar. Where only a single value was available, it is shown as a point in the column space where a bar would have been.

Where an EPA Drinking Water Standard (see Appendix D) or an AWWA Potable Water Standard has been established, the respective value has been superimposed on the appropriate figure to provide a basis for evaluating the relative quality of the waters sampled. In addition, where sample concentrations were below the present state-of-the-art analytical detection levels, they are presented below the figure ordinate.

In addition to these graphical representations, the monitoring results have been further summarized in Tables 18 and 19. These tabulations identify the number of samples in which a specific constituent was above the EPA or AWWA Drinking Water Standard, the number of samples below present state-of-the-art detection levels, and the number of samples falling within incremental order of magnitude concentration ranges.

The constituent concentrations observed within the fill were high and determined to a large degree by the type and quantity of material disposed. However, the concentrations within the fill are immaterial to an assessment of the off-site environmental impact. For the purpose of the environmental assessment and evaluation, the analysis centered around the off-site groundwater quality in the direction of presumed ground-water movement.

With regard to the shallow off-site monitoring well results, all of the sites except Site 4 exceeded established drinking water standards for iron, and all the sites except Site 7 exceeded the allowable maximum lead concentration. Sites 2, 3, 4, and 6 exceeded the allowable mercury standard, while Sites 1 and 4 exceeded the sulfate standard. Sites 2 and 8 exceeded the allowable cadmium standard. Only Site 8 exceeded the allowable copper standard. In summary, all locations exceeded one or more of the allowable drinking water standards in the shallow off-site well.

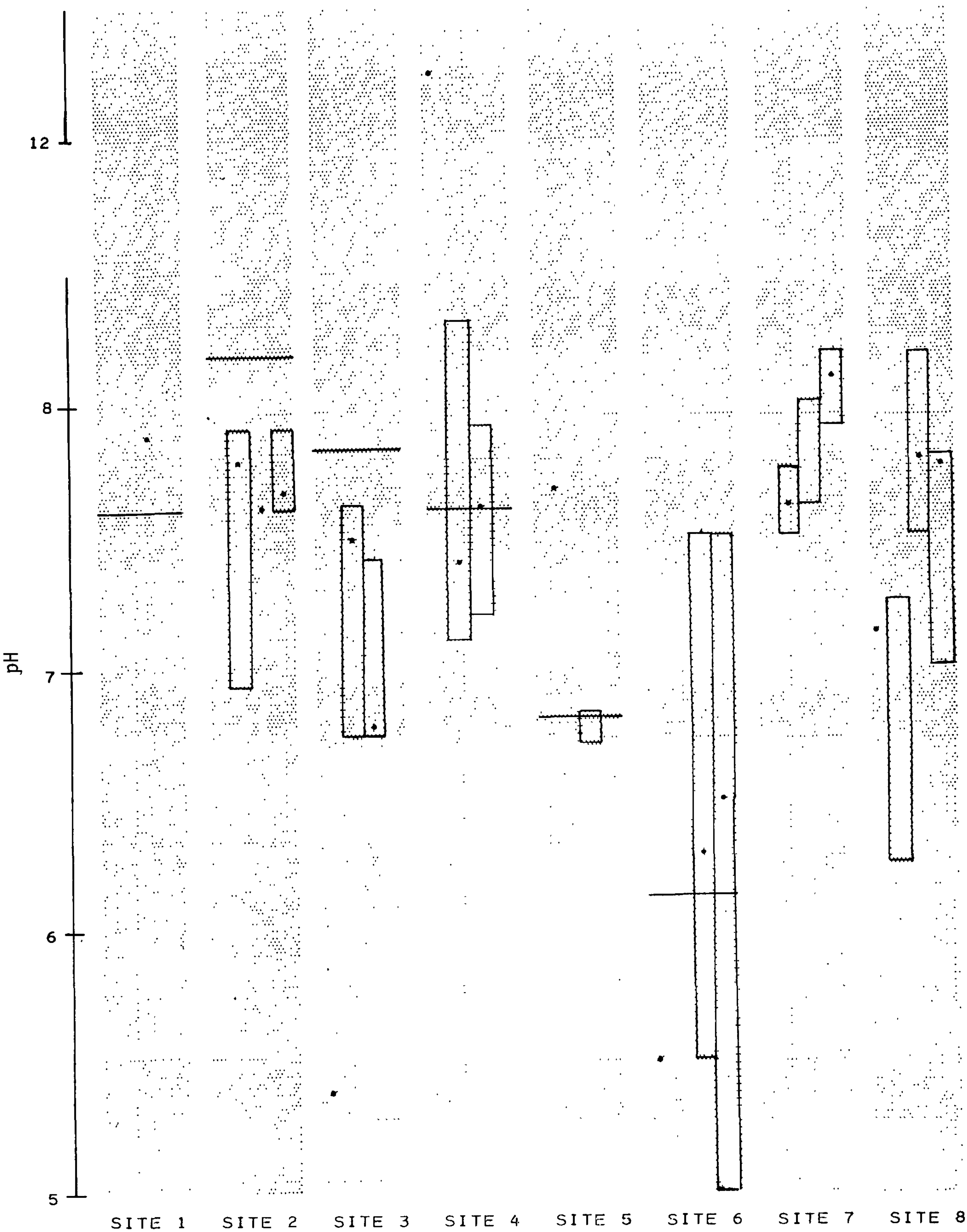
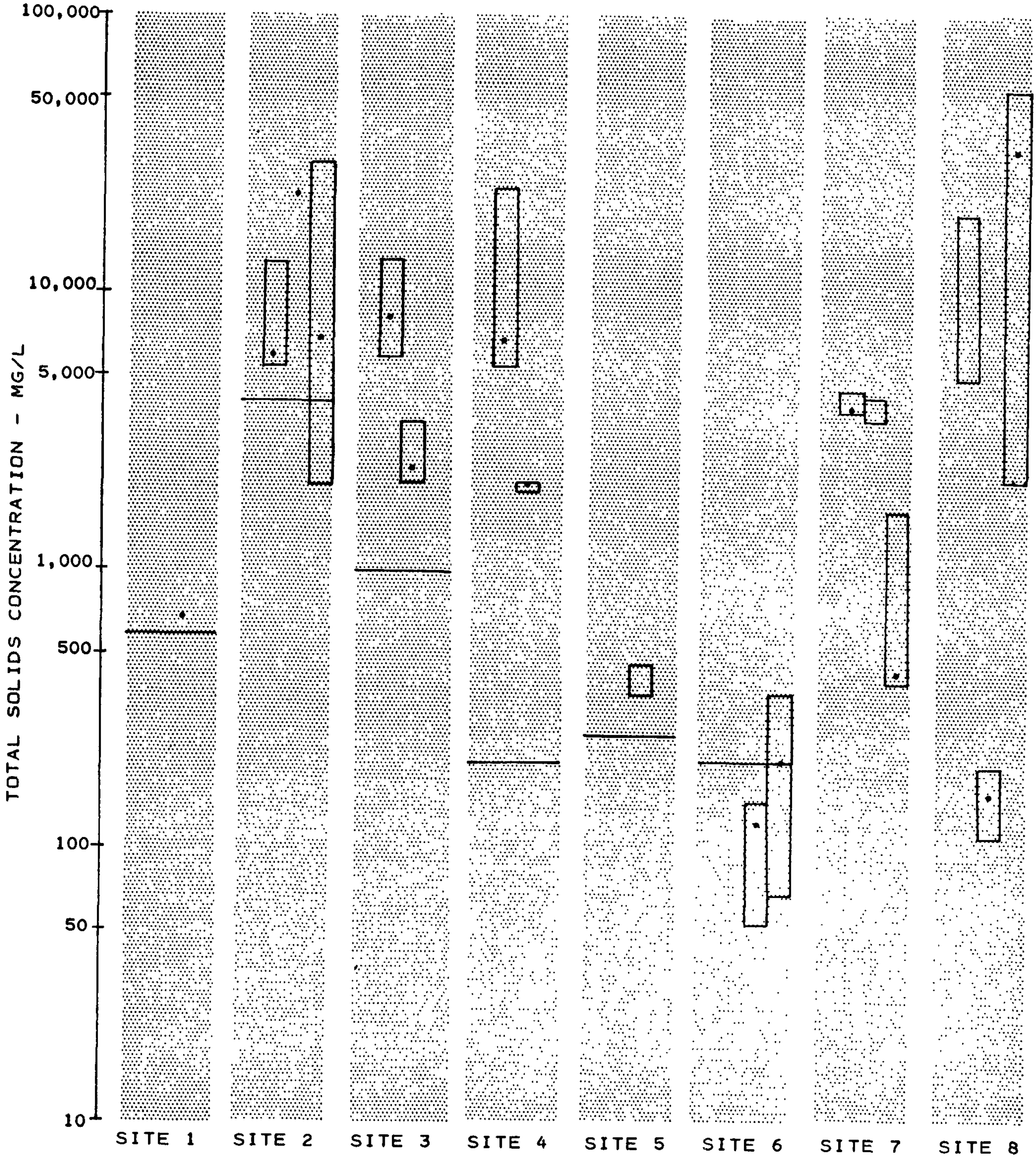


FIGURE 3



100,000
50,000
10,000
5,000
1,000
500
100
50
10
TOTAL SOLIDS CONCENTRATION - MG/L
SITE 1
SITE 2
SITE 3
SITE 4
SITE 5
SITE 6
SITE 7
SITE 8

FIGURE 4

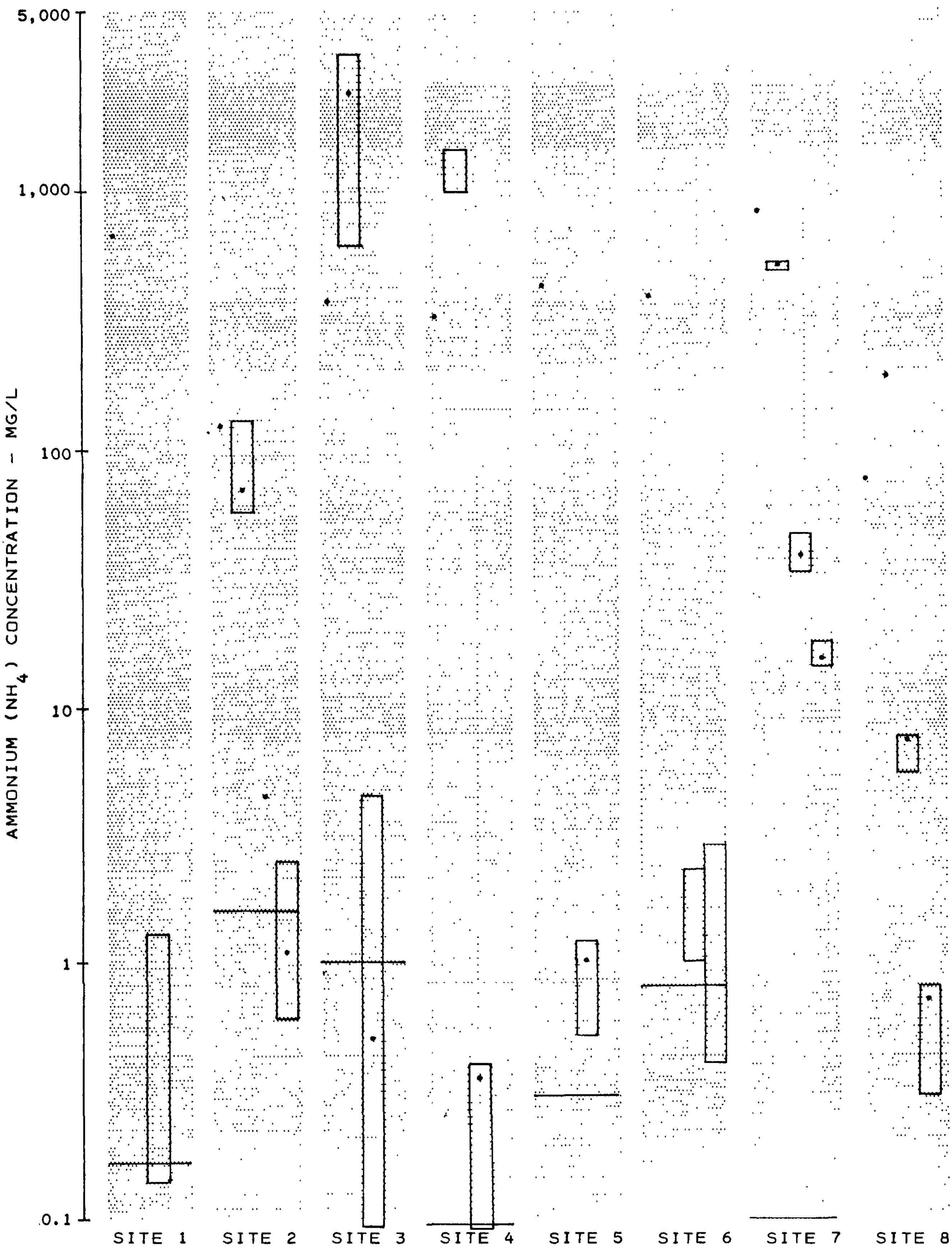
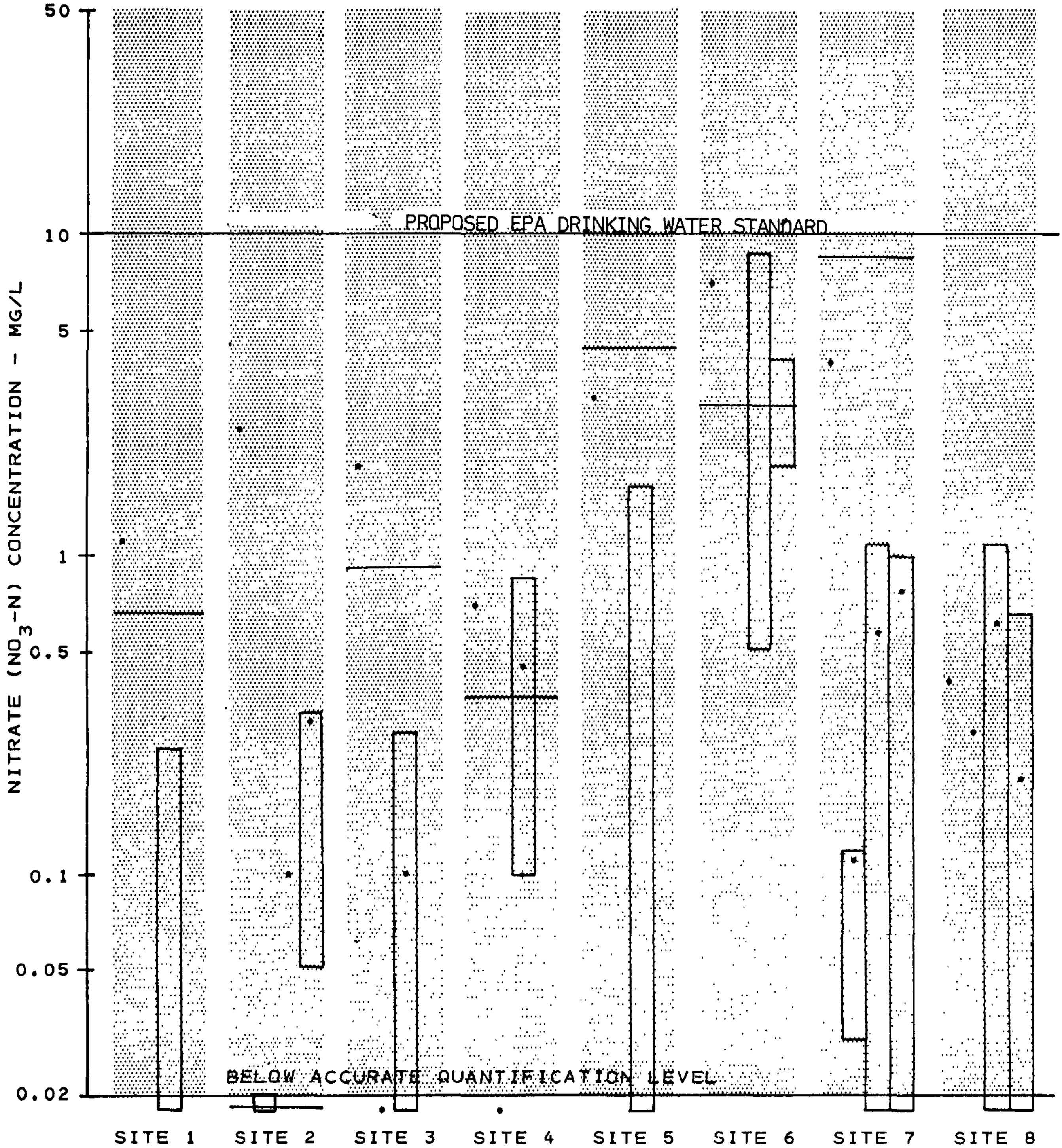
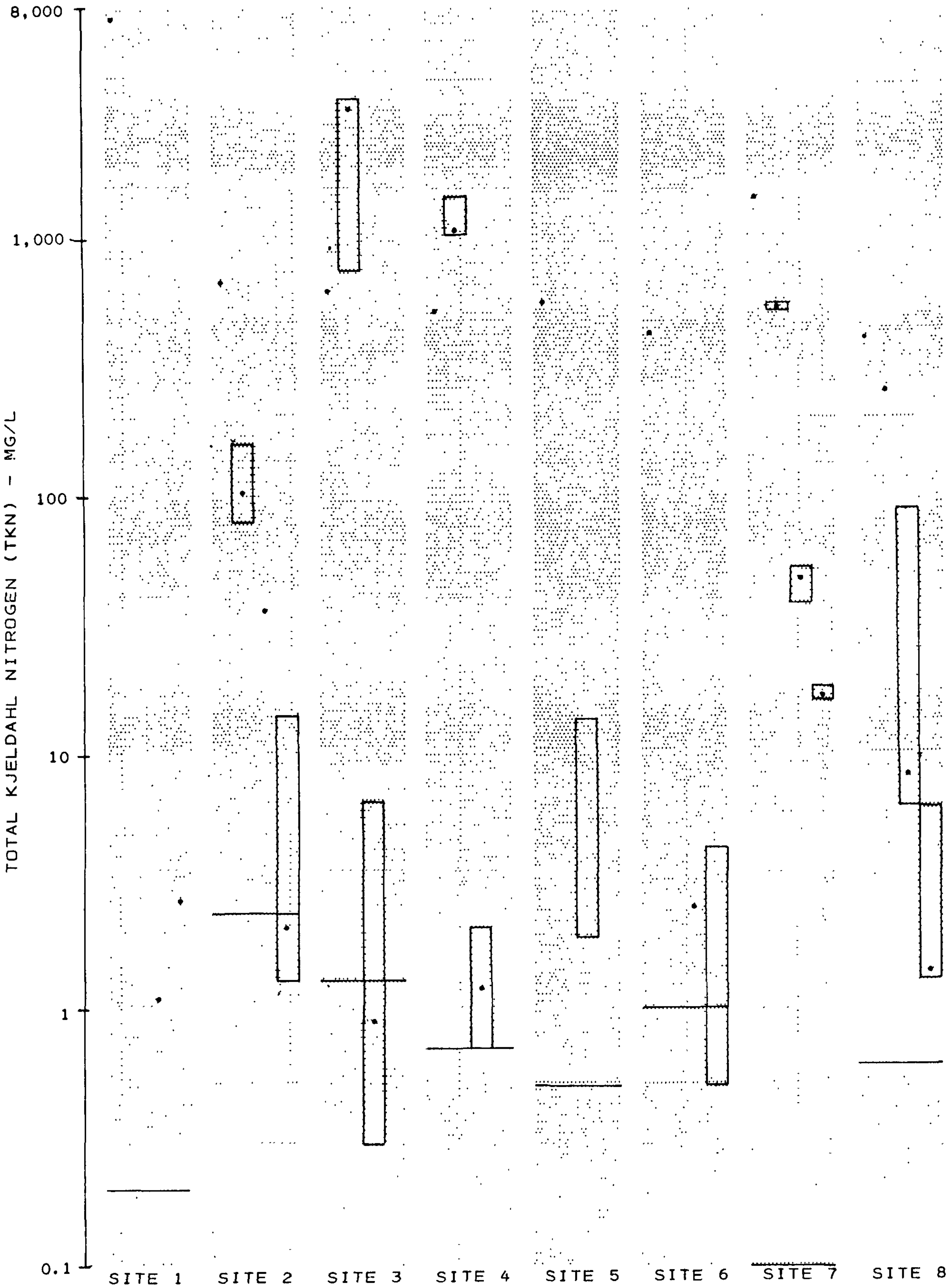

5,000
1,000
100
10
1
0.1
AMMONIUM (NH_4) CONCENTRATION - MG/L
SITE 1
SITE 2
SITE 3
SITE 4
SITE 5
SITE 6
SITE 7
SITE 8

FIGURE 5



50
10
5
1
0.5
0.1
0.05
0.02
NITRATE (NO_3-N) CONCENTRATION - MG/L
PROPOSED EPA DRINKING WATER STANDARD
BELOW ACCURATE QUANTIFICATION LEVEL
SITE 1
SITE 2
SITE 3
SITE 4
SITE 5
SITE 6
SITE 7
SITE 8

FIGURE 6



8,000
1,000
100
10
1
0.1
TOTAL KJELDAHL NITROGEN (TKN) - MG/L
SITE 1
SITE 2
SITE 3
SITE 4
SITE 5
SITE 6
SITE 7
SITE 8

FIGURE 7

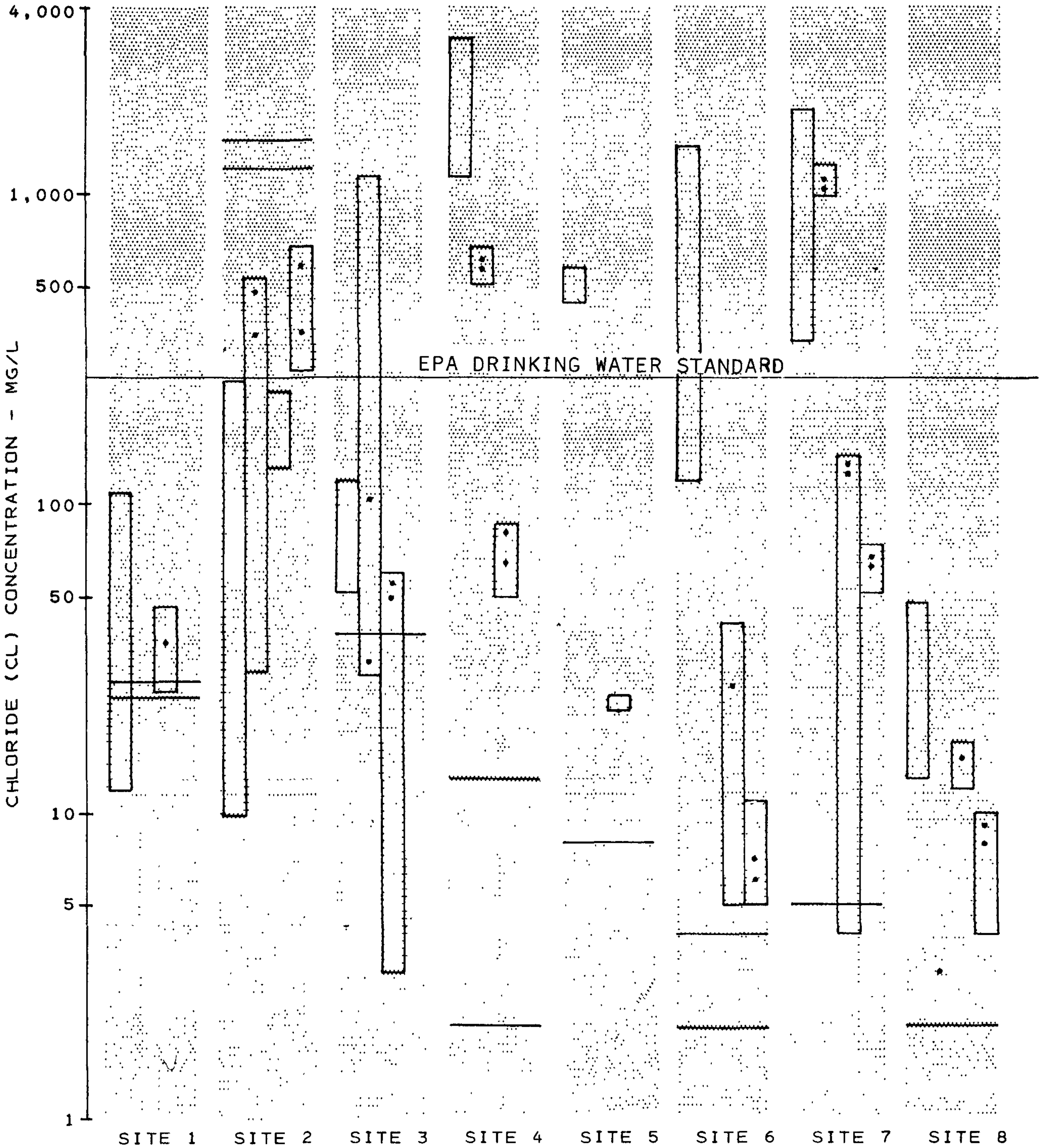

4,000
1,000
500
100
50
10
5
1
CHLORIDE (CL) CONCENTRATION - MG/L
EPA DRINKING WATER STANDARD
SITE 1
SITE 2
SITE 3
SITE 4
SITE 5
SITE 6
SITE 7
SITE 8

FIGURE 8

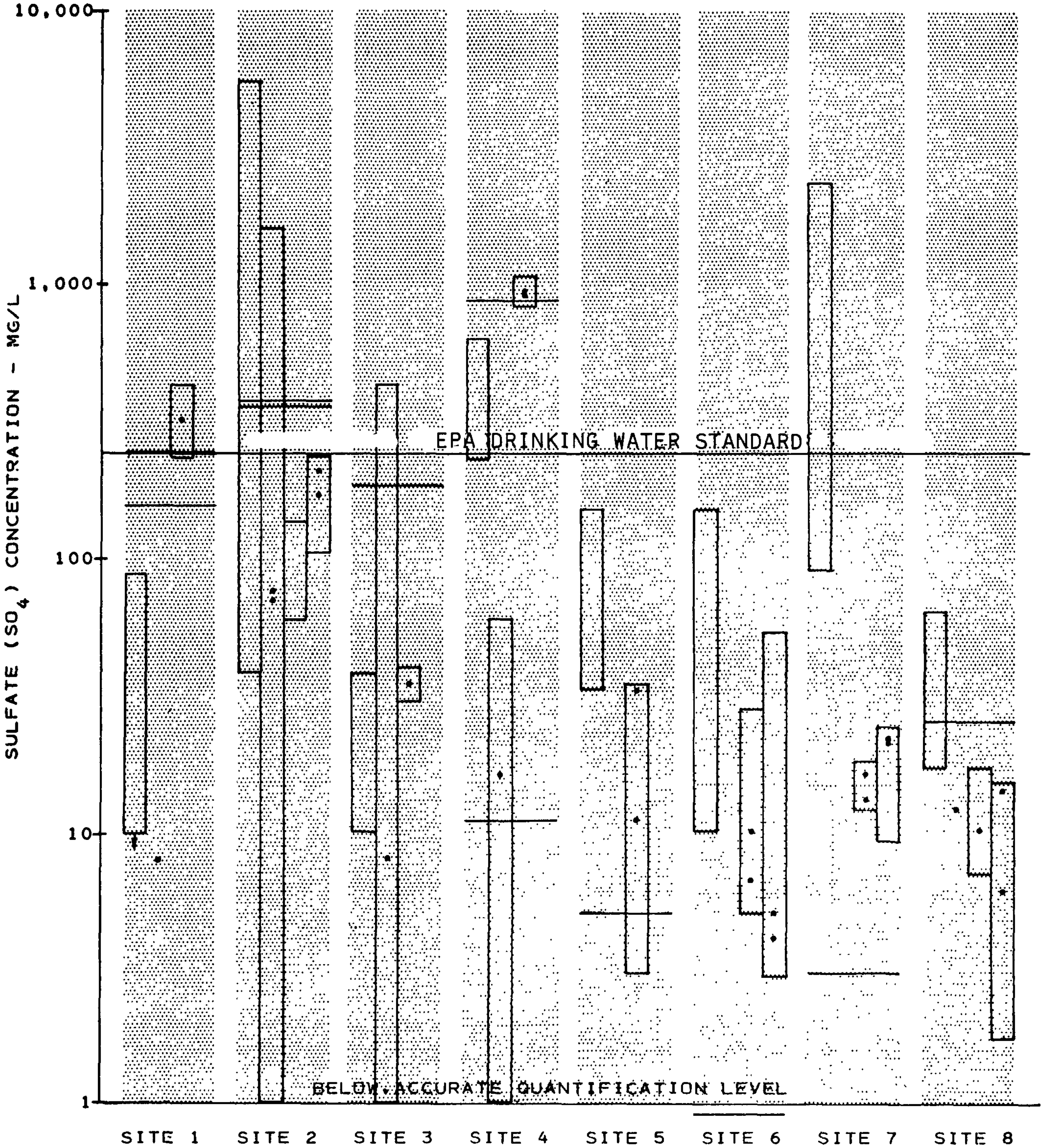

10,000
1,000
100
10
1
SULFATE (SO4) CONCENTRATION - MG/L
EPA DRINKING WATER STANDARD
BELOW ACCURATE QUANTIFICATION LEVEL
SITE 1
SITE 2
SITE 3
SITE 4
SITE 5
SITE 6
SITE 7
SITE 8

FIGURE 9

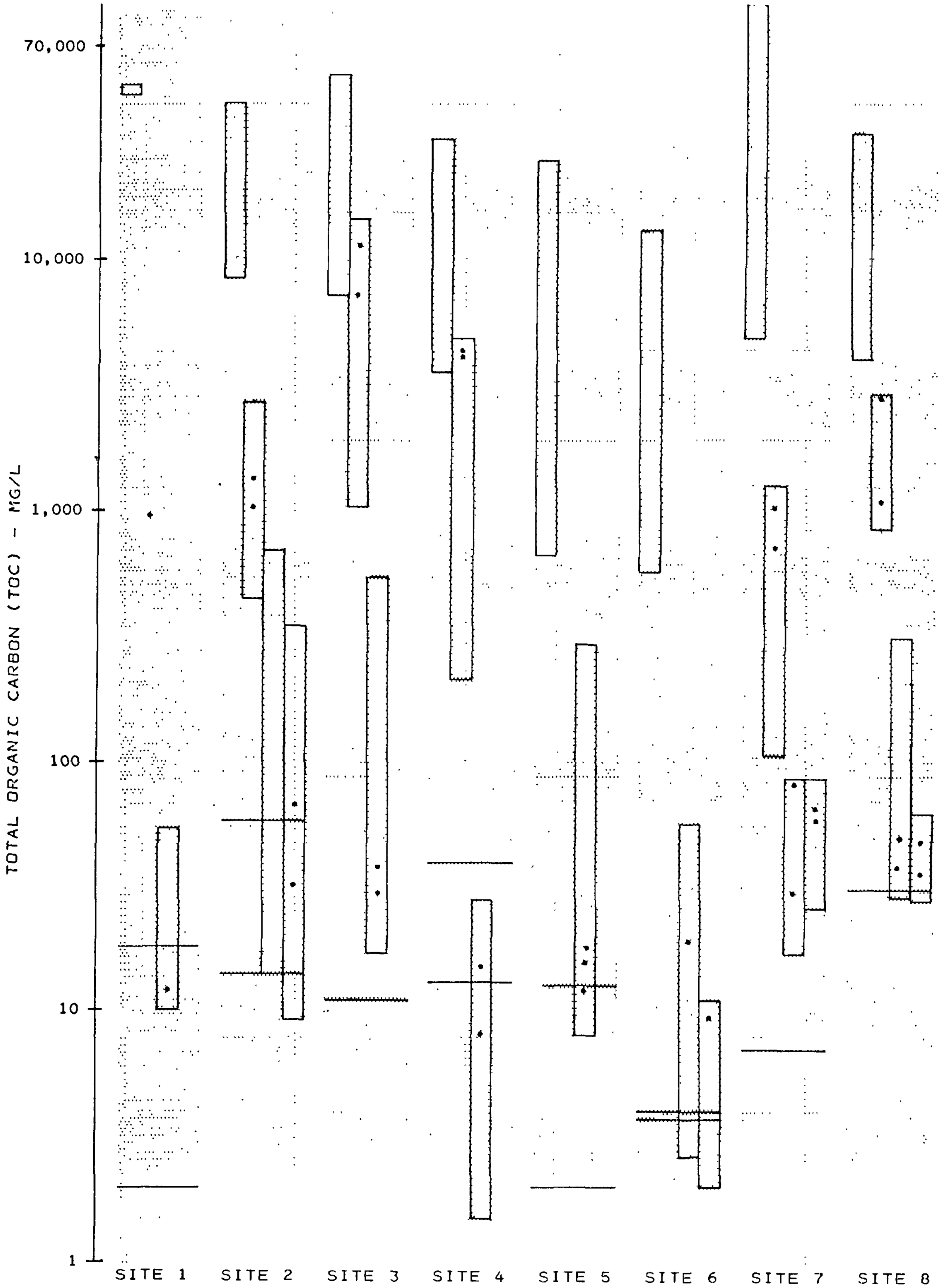

70,000
10,000
1,000
100
10
1
TOTAL ORGANIC CARBON (TOC) - MG/L
SITE 1
SITE 2
SITE 3
SITE 4
SITE 5
SITE 6
SITE 7
SITE 8

FIGURE 10

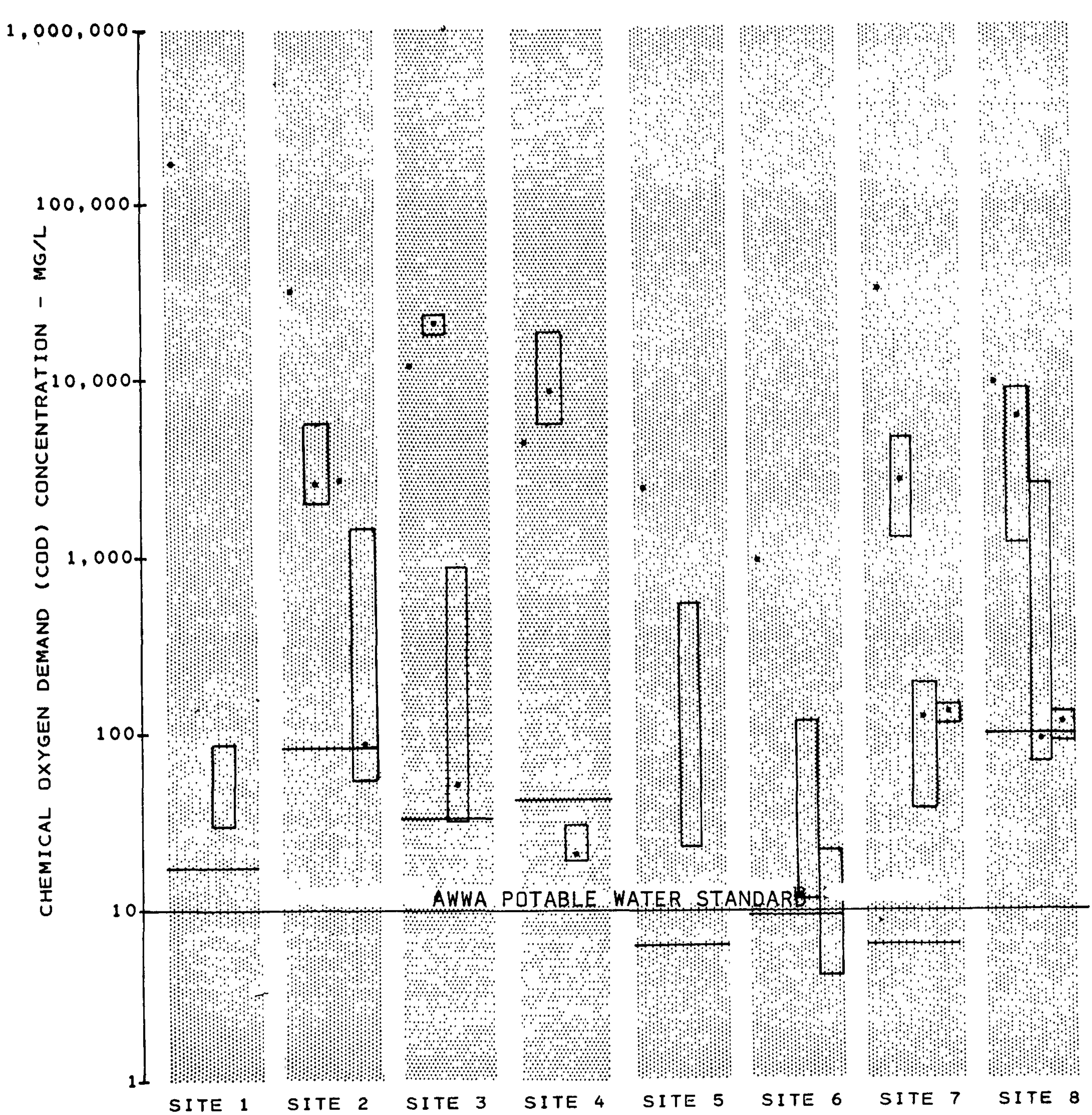

1,000,000
100,000
10,000
1,000
100
10
1
CHEMICAL OXYGEN DEMAND (COD) CONCENTRATION - MG/L
AWWA POTABLE WATER STANDARD
SITE 1
SITE 2
SITE 3
SITE 4
SITE 5
SITE 6
SITE 7
SITE 8

FIGURE 11

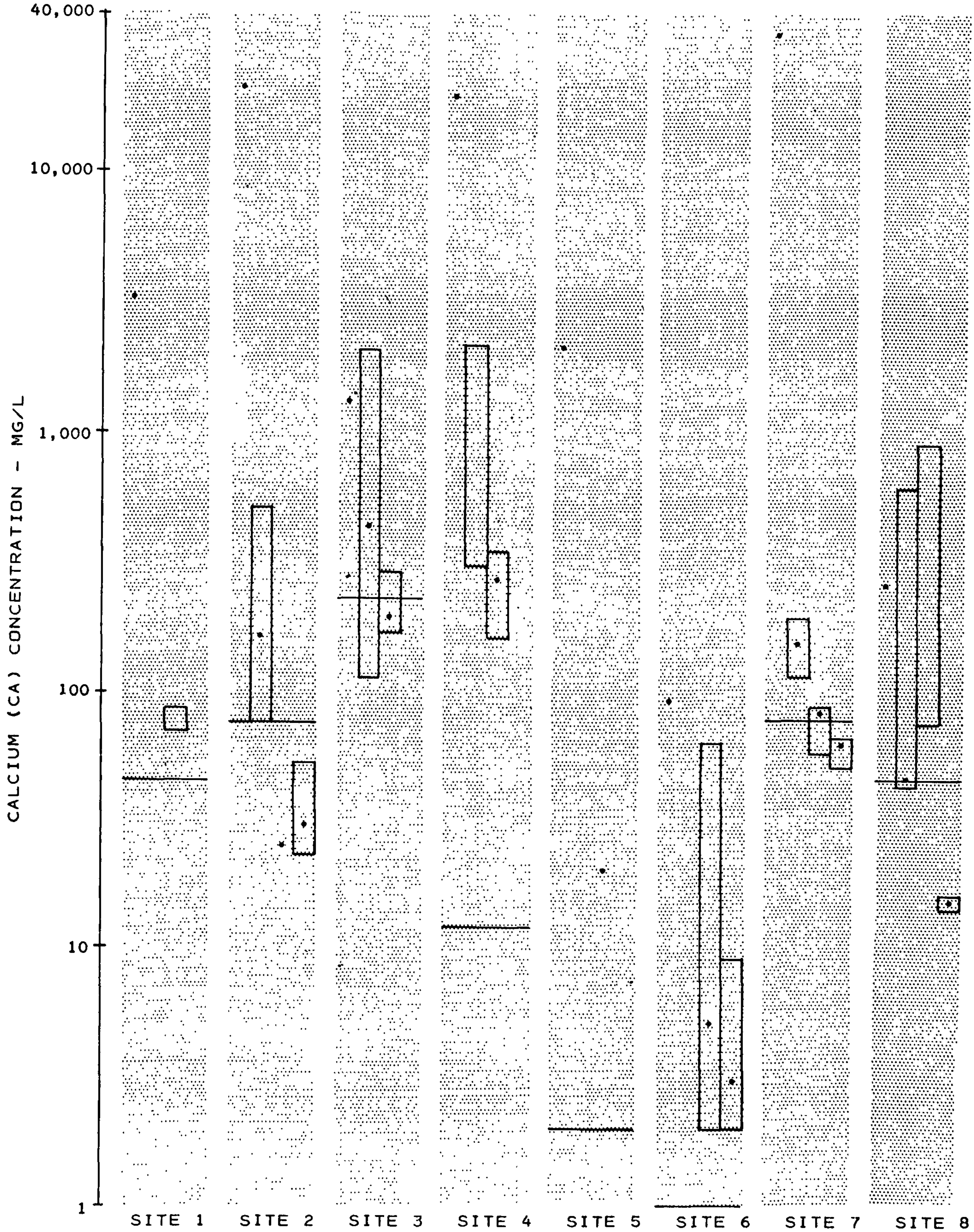
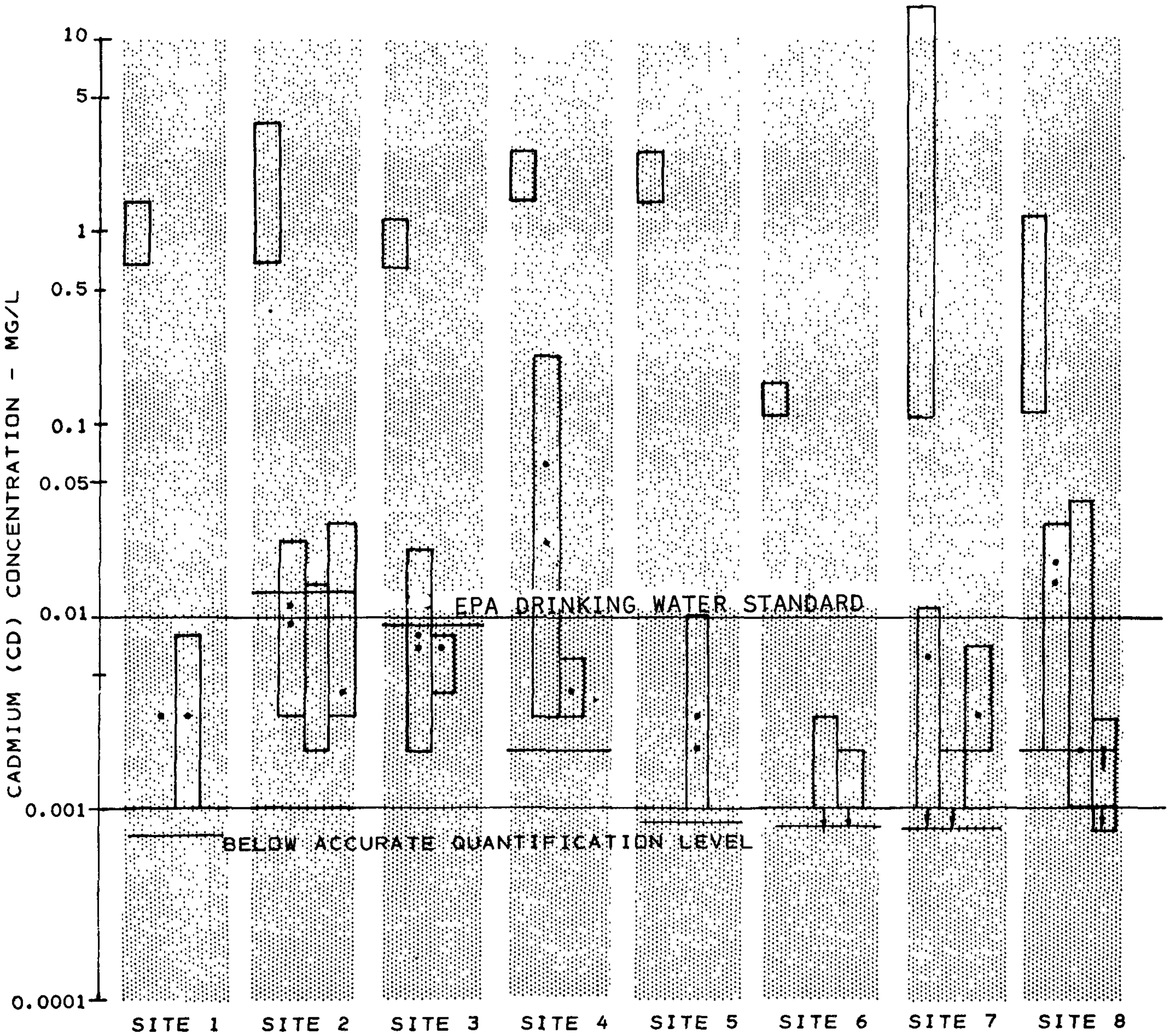
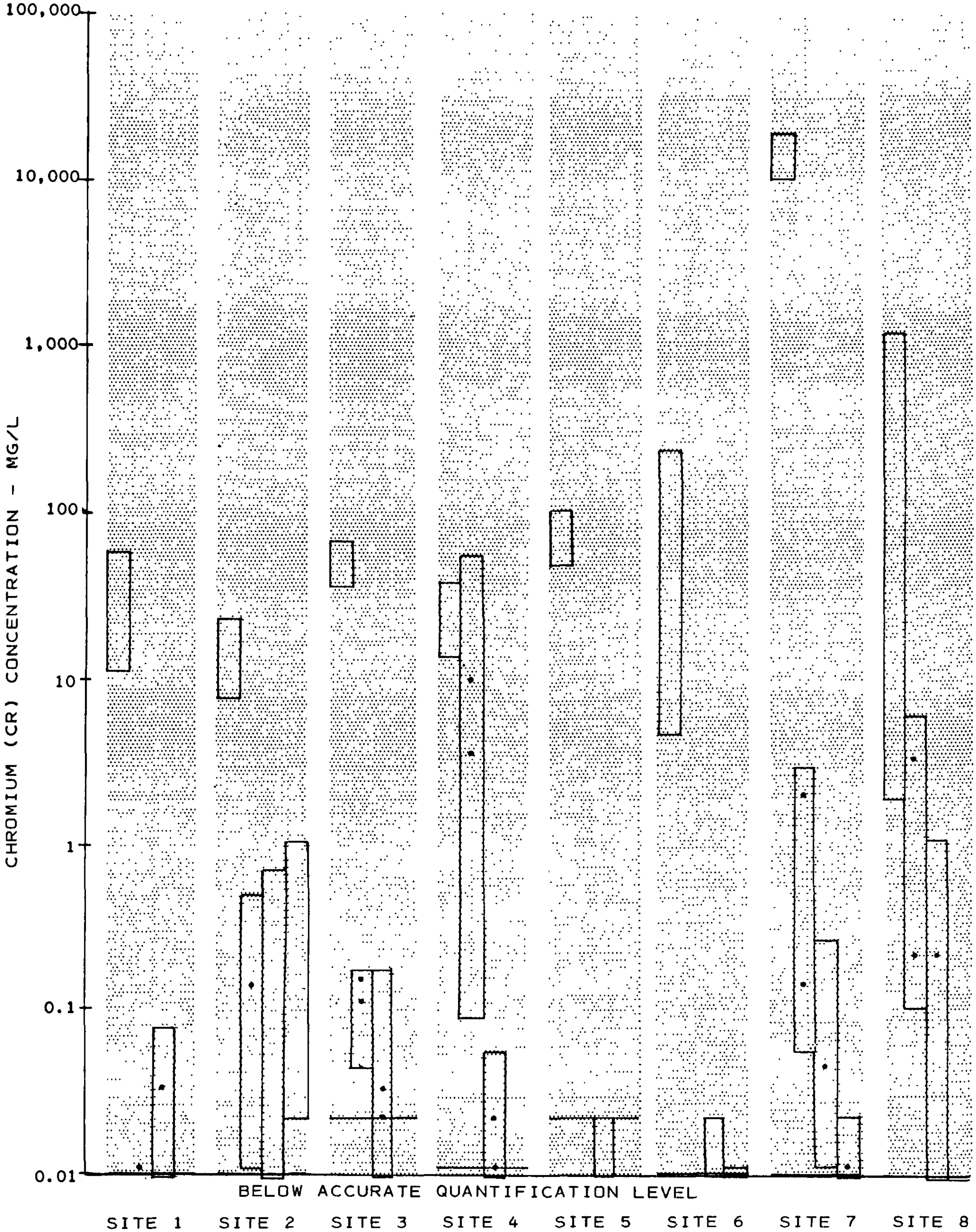

40,000
10,000
1,000
100
10
1
CALCIUM (CA) CONCENTRATION - MG/L
SITE 1
SITE 2
SITE 3
SITE 4
SITE 5
SITE 6
SITE 7
SITE 8

FIGURE 12



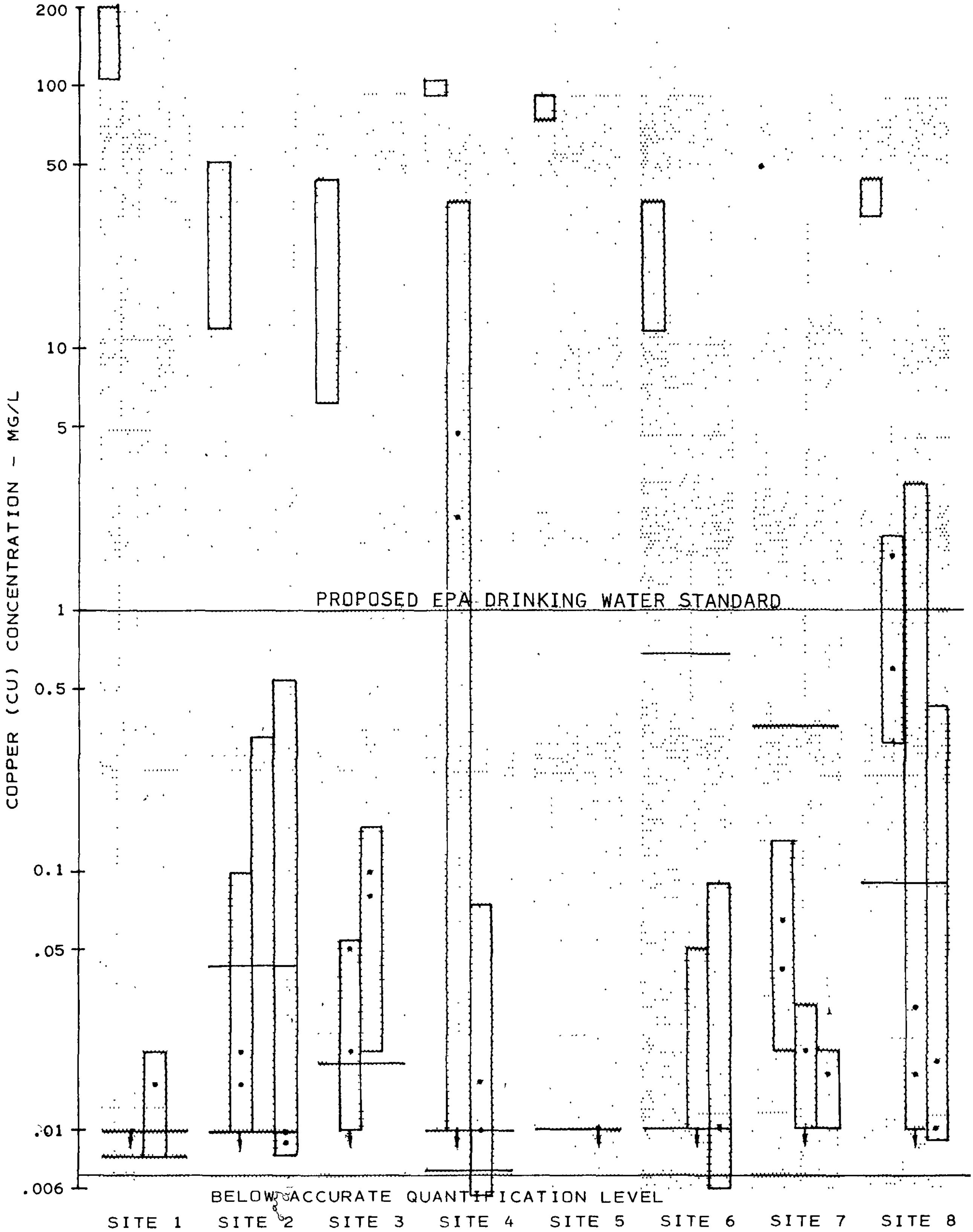
10
5
1
0.5
0.1
0.05
0.01
0.001
0.0001
CADMIUM (CD) CONCENTRATION - MG/L
EPA DRINKING WATER STANDARD
BELOW ACCURATE QUANTIFICATION LEVEL
SITE 1
SITE 2
SITE 3
SITE 4
SITE 5
SITE 6
SITE 7
SITE 8

FIGURE 13



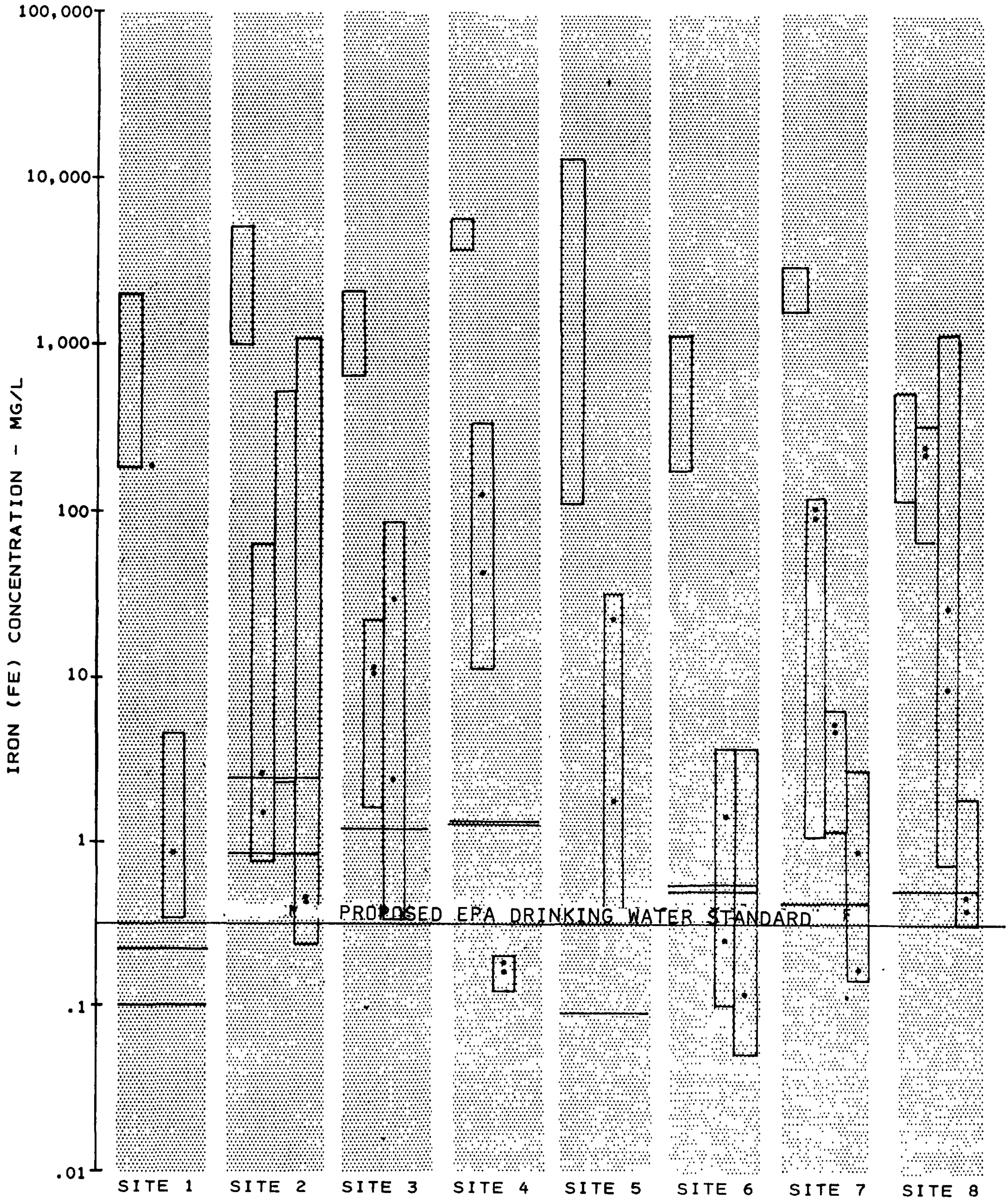
100,000
10,000
1,000
100
10
1
0.1
0.01
CHROMIUM (CR) CONCENTRATION - MG/L
BELOW ACCURATE QUANTIFICATION LEVEL
SITE 1
SITE 2
SITE 3
SITE 4
SITE 5
SITE 6
SITE 7
SITE 8

FIGURE 14



200
100
50
10
5
1
0.5
0.1
.05
.01
.006
COPPER (CU) CONCENTRATION - MG/L
PROPOSED EPA DRINKING WATER STANDARD
BELOW ACCURATE QUANTIFICATION LEVEL
SITE 1
SITE 2
SITE 3
SITE 4
SITE 5
SITE 6
SITE 7
SITE 8

FIGURE 15



100,000
10,000
1,000
100
10
1
.1
.01
IRON (FE) CONCENTRATION - MG/L
PROPOSED EPA DRINKING WATER STANDARD
SITE 1
SITE 2
SITE 3
SITE 4
SITE 5
SITE 6
SITE 7
SITE 8

FIGURE 16

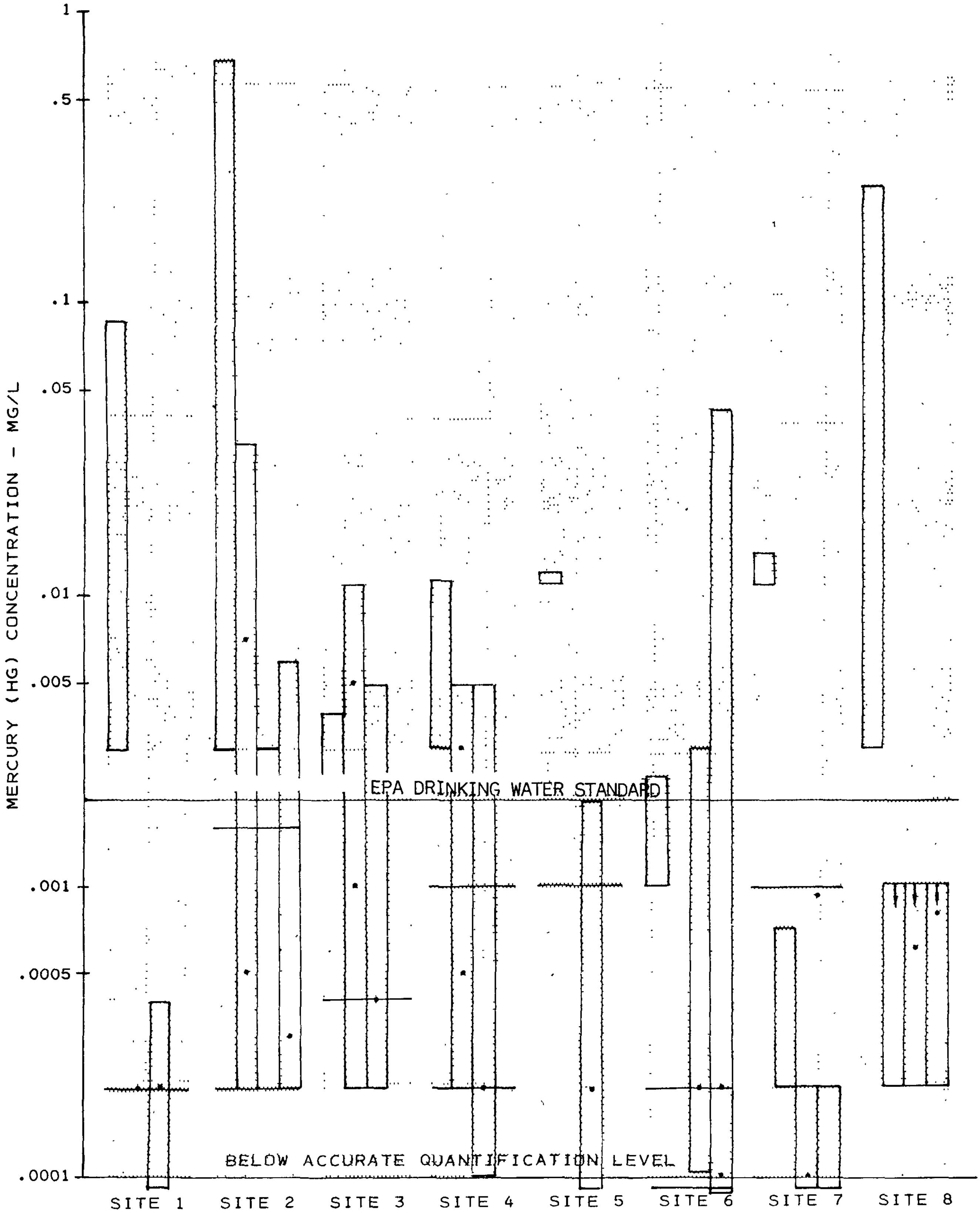

MERCURY (HG) CONCENTRATION - MG/L
1
.5
.1
.05
.01
.005
.001
.0005
.0001
EPA DRINKING WATER STANDARD
BELOW ACCURATE QUANTIFICATION LEVEL
SITE 1
SITE 2
SITE 3
SITE 4
SITE 5
SITE 6
SITE 7
SITE 8

FIGURE 17

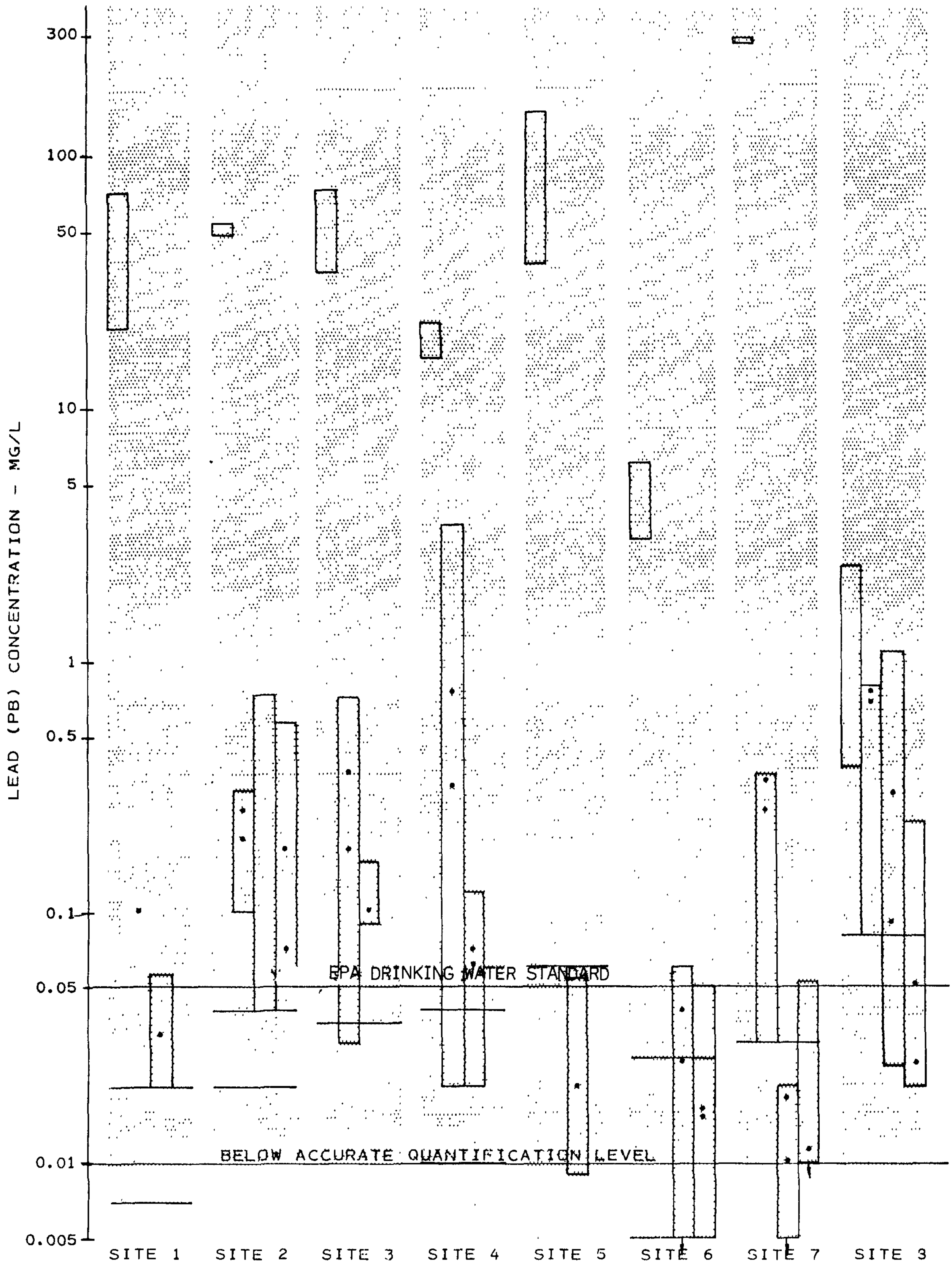

LEAD (PB) CONCENTRATION - MG/L
300
100
50
10
5
1
0.5
0.1
0.05
0.01
0.005
EPA DRINKING WATER STANDARD
BELOW ACCURATE QUANTIFICATION LEVEL
SITE 1
SITE 2
SITE 3
SITE 4
SITE 5
SITE 6
SITE 7
SITE 3

FIGURE 18

TABLE 18. SUMMARY OF SHALLOW OFF-SITE GROUNDWATER WELL ANALYTICAL RESULTS

Levels (mg/l)	Constituents																		
	Ca	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Zn	NH_4	NO_3	TKN	Cl	SO_4	TOC	COD	Fecal Coli	Strep	MBAS
Above maximum or recommended maximum USPHS drinking water standards		2	4	1	24	4		14						6					
Below accurate detection levels		3	11	8		17	3	3		2	5								7
0.0001 - 0.001		2				7													
0.001 - 0.01		16	1	4		5	1	1											
0.01 - 0.1		1	8	14			4	20	3		1								1
0.1 - 1			5	3	12		1	5	6	5	10	3							1
1 - 10	3			1	11			1		9	4	11	5	4	5		5	5	
10 - 100	10				5					3		6	19	18	20	13	7	8	
100 - 1000	7				1								6	6	4	5	3	4	
1000 - 10000					1											2	4	3	
10000 - 100000																			
100000+																			
Total number of samples	20	22	25	30	30	29	9	30	9	19	20	20	30	29	29	20	19	20	9

TABLE 19. SUMMARY OF DEEP OFF-SITE GROUNDWATER WELL ANALYTICAL RESULTS

Levels (mg/l)	Constituents																		
	Ca	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Zn	NH_4	NO_3	TKN	Cl	SO_4	TOC	COD	Coli	Fecal Strep	MBAS
Above maximum or recommended maximum USPHS drinking water standards		1			11	3	3	8					4						
Below accurate quantification levels		4	10	4		8		2			2								2
0.0001 - 0.001						6													
0.001 - 0.01		16		4		1													
0.01 - 0.1		1	9	6	1	2		11	2		1								2
0.1 - 1			1	2	11		1	2	2	5	5	1							
1 - 10	3				3			1		3	3	6	7	9	3	1	6	3	
10 - 100	9									3		4	5	3	11	4	1	3	
100 - 1000													4	4	1	5		3	
1000 - 10000					1											1	4	2	
10000 - 100000																			
100000+																			
Total number of samples	12	21	21	16	16	17	4	16	4	11	11	11	16	16	15	11	11	11	4

A lesser number of infractions occurred in the deep off-site groundwater wells. Four of the eight sites exceeded allowable levels on at least two constituents. Samples obtained at Site 2 exceeded five water quality tolerances (chloride, cadmium, iron, mercury, and lead). Site 6 exceeded the iron, mercury, and lead standards. Sites 7 and 8 both exceeded the iron and lead standard.

Iron appeared the most times in concentrations in excess of EPA Drinking Water Standards. Twenty-four of 30 shallow and 11 of 16 deep off-site groundwater sample results exceeded the the iron standard.

Lead emerged as the second most prevalent constituent monitored for which EPA Drinking Water Standards had been exceeded. Fourteen out of 30 shallow groundwater samples and eight of 16 deep off-site groundwater sample results violated maximum acceptable standards for lead.

Mercury in excess of EPA standards appeared four times in the shallow off-site groundwater and three times in the deep off-site groundwater.

In the shallow off-site groundwater, cadmium appeared twice, copper once, and sulfate six times above accepted limits. In the deep off-site groundwater, cadmium appeared once and chloride four times.

Using the EPA Drinking Water Standards as a measure of degradation of off-site groundwaters, it must be concluded that in the eight sites surveyed, there had been appreciable groundwater quality degradation beyond the limits of the immediate disposal area. Subsequent studies will be necessary to determine the areal extent of contamination which has occurred and to estimate the potential for future contamination.

Testing of statistical significance of data was not attempted because of the limited data, masking by seasonal variation, and limited degree to which one case study site could be reasonably compared to another.

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APPENDIX A

GAS PROBE AND MONITORING WELL PLACEMENT PROCEDURE

I. In-Refuse Well

A. The monitoring well in the landfill will be drilled to the groundwater table. Figure 1 shows a typical installation. The following samples will be taken at the time of drilling this well:

1. Core sample of soil cover material for permeability determination.

2. Two (2) samples of landfill material for determination of moisture content.

3. Three (3) soil cores spaced over the distance between the landfill bottom and the groundwater table for determination of leachate attenuation by soil.

A core auger or bucket rig is most desirable for drilling holes in refuse. An air rotary drill may be used but is subject to fouling in refuse.

Experience has indicated that for our typical 4-in diameter monitoring well, the well bore diameter should be a minimum of 6 in and preferably 8 in or greater. During the drilling, refuse is pulled loose and protrudes into the hole. This leads to difficulties during the placement of the gas probes attached to the outside of the well casing and in backfilling.

Carefully construct a soil boring log of the material brought to the surface during the well drilling operation.

B. Core Sample of Cover Soil. After the location of the well has been determined on the site and preferably before the well driller arrives, take a core sample of the cover soil material for determination of permeability. Refer to Field Sampling Instruction Manual for detailed instructions on obtaining the sample.

C. Moisture Content Samples of Refuse. Two refuse samples will be taken for determination of moisture content from each hole at the one-third and two-third overall landfill depth, respectively. Approximately one shovelful of refuse and/or sludge material will be placed in a plastic bag

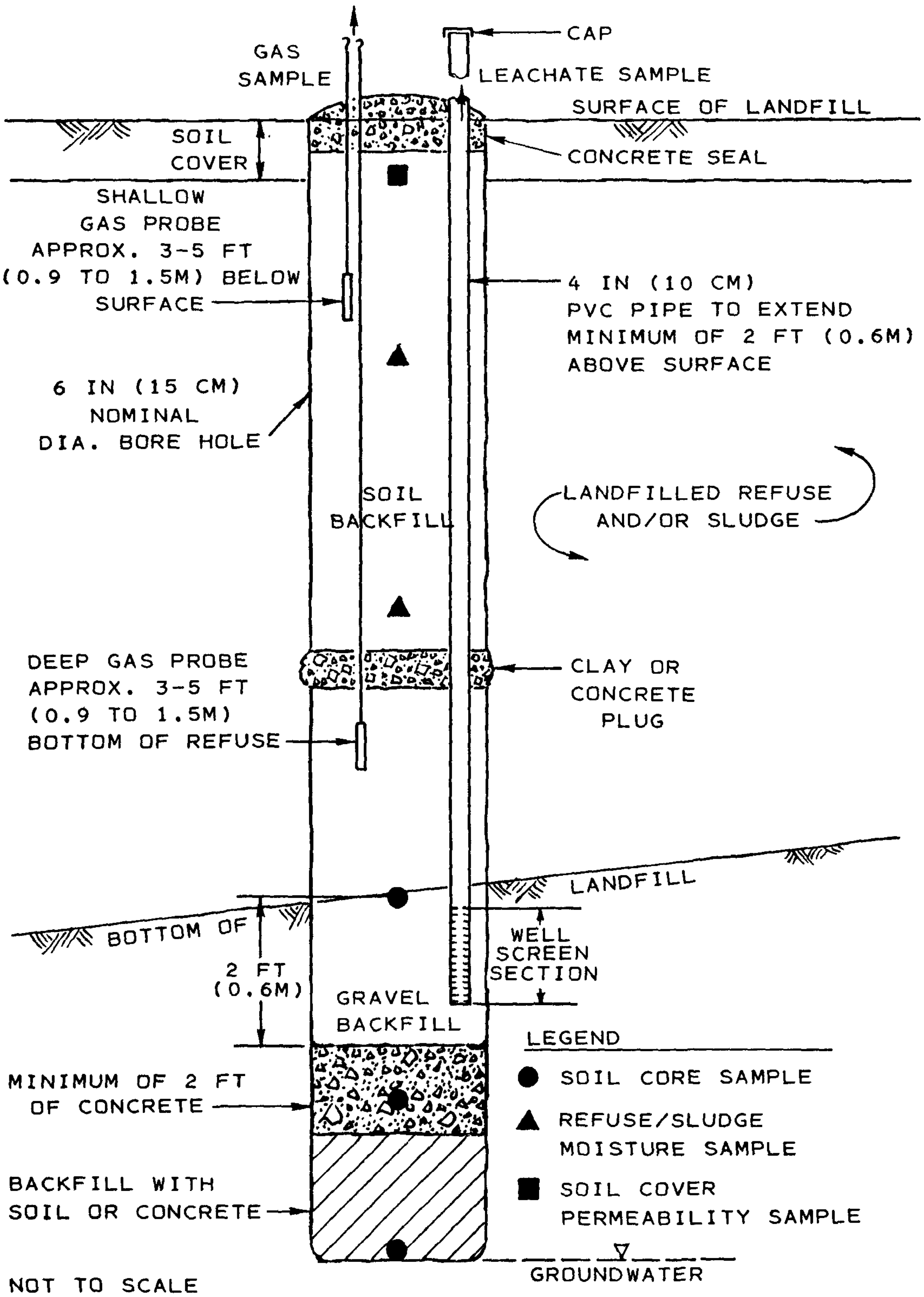

FIGURE 1
TYPICAL SAMPLING WELL DETAILS
(IN-REFUSE WELL)

and sealed. The bag containing the sample will be placed in a second plastic bag and again sealed. This double bagging is to minimize moisture loss.

D. Soil Below Landfill. Upon reaching the bottom of the landfill (when the auger brings up mostly soil), take a soil or core sample (approximately a shovelful) and place in a sterile plastic specimen bag. Label and place in a second bag.

Two additional samples will be taken following the same procedure, one halfway between the landfill bottom and the groundwater, and the other at groundwater level. Since the exact distance to groundwater may not be known, several samples around the presumed mid-depth may need to be obtained and retained until the midpoint location is established.

II. Plume Wells

Two wells will be placed in the presumed groundwater down-gradient direction from the in-refuse well described above. These wells should not penetrate any refuse, and should be approximately 100 ft from the in-refuse well if practical.

One well will penetrate the groundwater table elevation to a depth of 2 ft. This well will be termed the shallow well. The second well will penetrate the groundwater table elevation to a depth of about 20 ft (site conditions permitting). This well will be termed the deep well. Figure 2 illustrates typical construction details for each well.

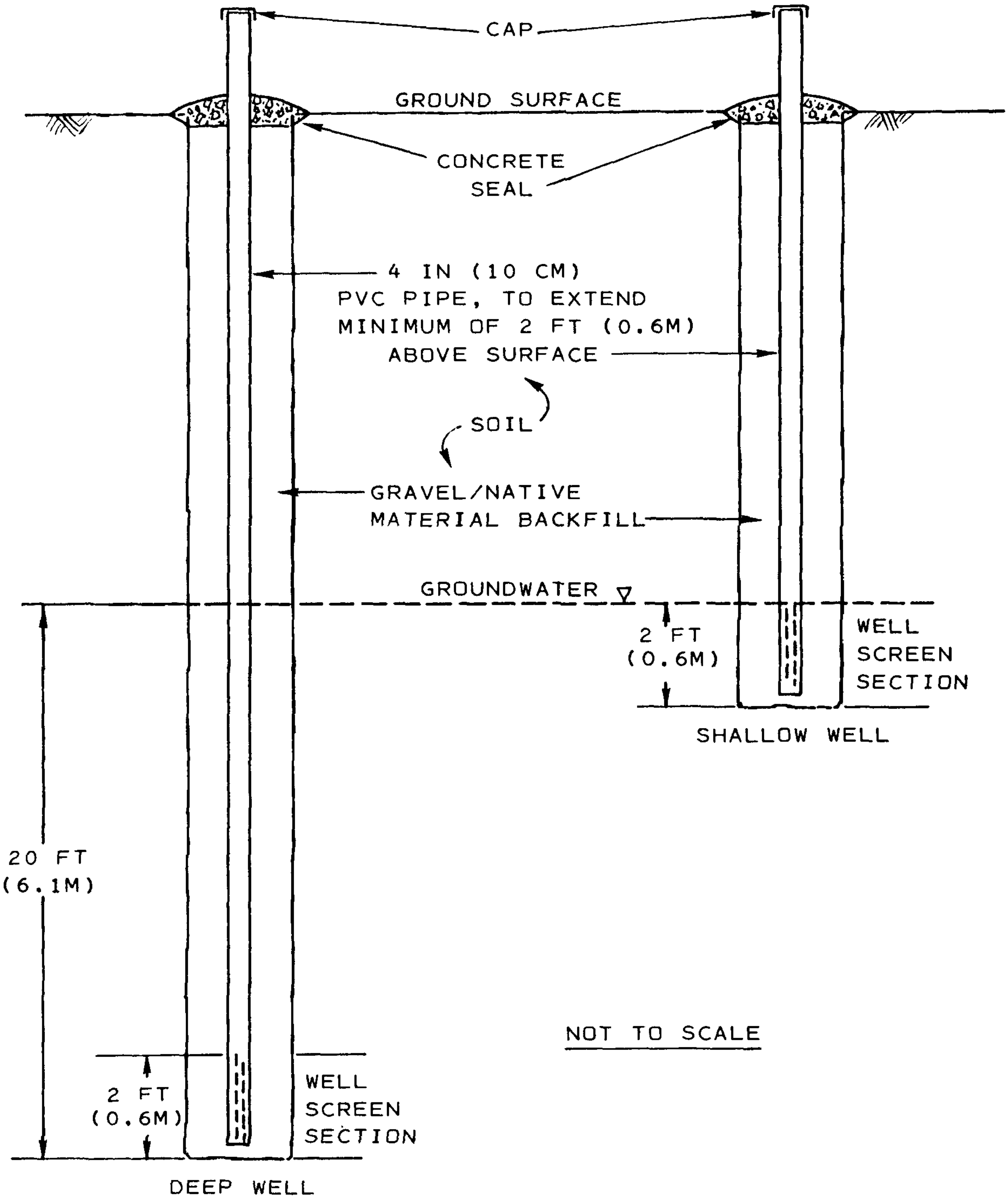

FIGURE 2
TYPICAL SAMPLING WELL DETAILS
(DOWNSTREAM PLUME WELLS)

APPENDIX B

FIELD SAMPLING INSTRUCTION MANUAL

The objective of field sampling is to obtain representative leachate, groundwater, gas, sludge, and mixed refuse-sludge samples from each of the case study sites. The accuracy and care taken during sampling cannot be overemphasized. An accurate analysis is directly dependent upon the care taken by field personnel in drawing and shipping the requisite samples.

This manual is intended to provide field personnel with a guide to the precise procedures to be employed as well as alternative procedures, where applicable, for coping with anticipated problems.

I. <u>Sampling Code Convention</u>

A. Labeling

The following information should appear on each sample container. (See Figures 1 and 2.)

1. Date: Month and day only, use number for months.

2. Sample sequence number: Each sample will be given a sequence number starting with 1 for the first sample. Consecutive numbers will be assigned for additional samples taken from each site. For example, the second leachate sample taken will be assigned the number "2."

3. Project code: This five-digit code uniquely identifies this specific project, i.e., SCS-34.

4. Location code: Sample site location codes are taken from the commercial airport nearest to the case study site.

5. Sample hole designation (for gas sampling): Each gas probe hole will be assigned a reference number.

6. Probe Depth (for gas sampling):
   A = shallow probe
   B = deep probe

7. Sample hole designation (for groundwater sampling):
   A = shallow well
   B = deep well

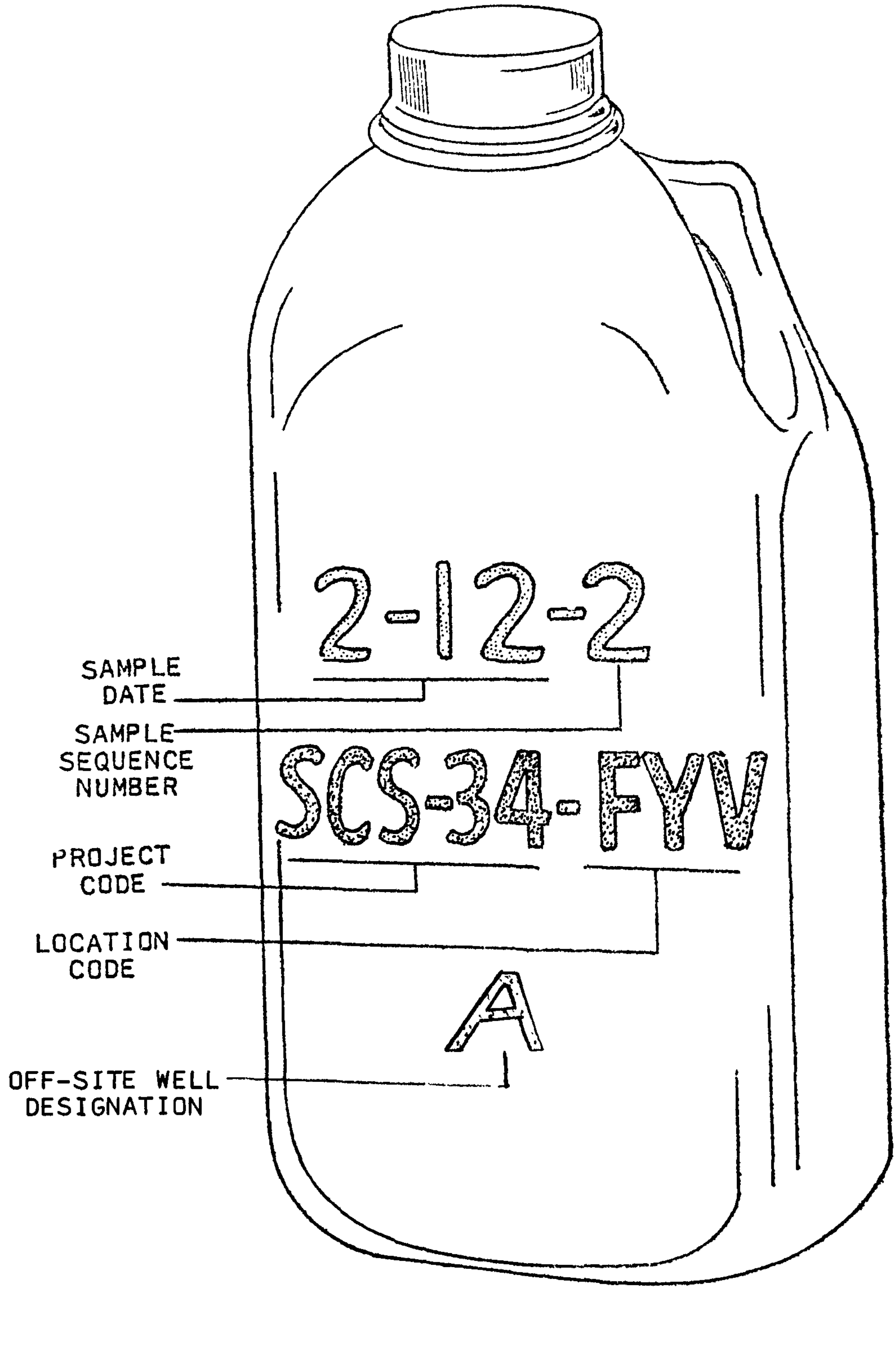

FIGURE 1

LEACHATE SAMPLE
CONTAINER LABELING

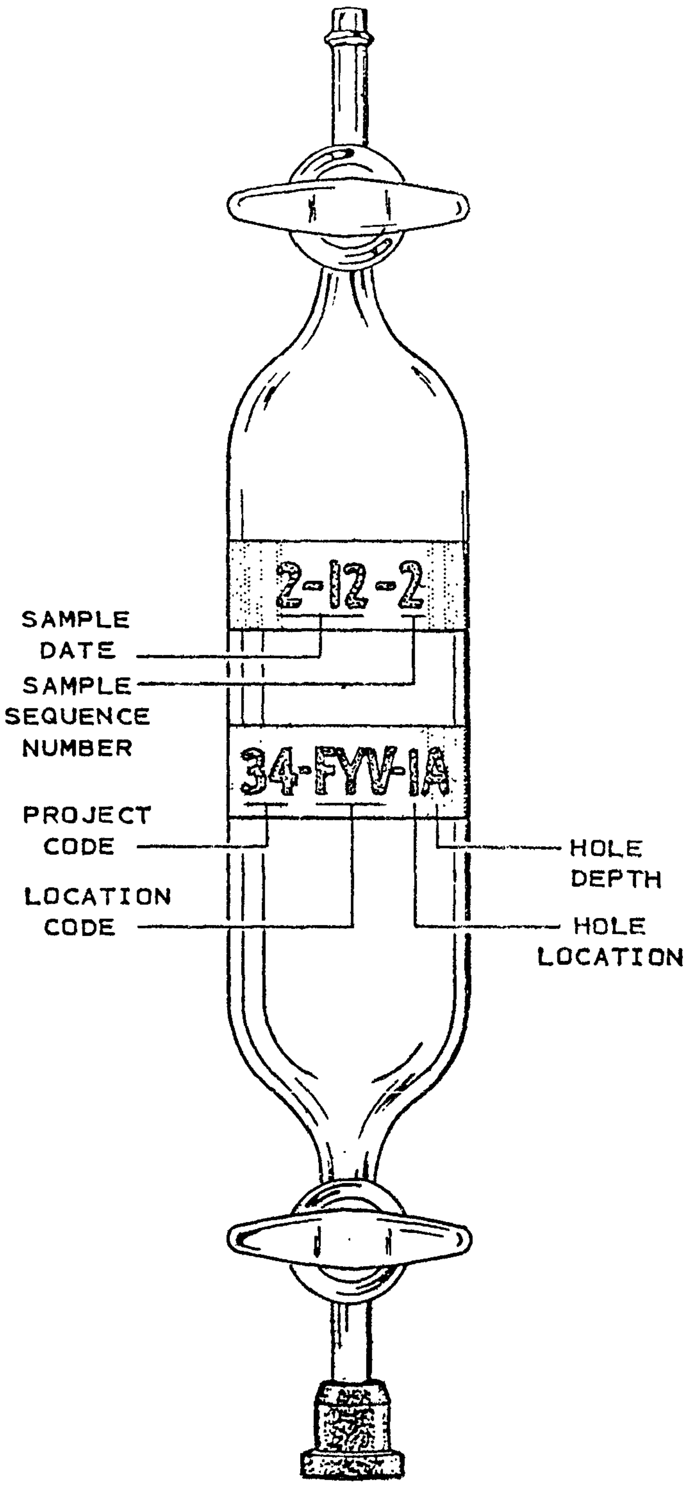

FIGURE 2

SAMPLE CONTAINER LABELING
FOR GAS SAMPLE BOTTLES

B. Leachate and Groundwater

Both sides of the sample bottles should be labeled with a waterproof marking pen. Mark each container in LARGE NEAT BLOCK LETTERS as in Figure 1. Use dashes (not slashes) to separate items. On groundwater sample containers for off-site wells, be sure to designate which well is being sampled (A for deep, B for shallow).

C. Gas Bottle Marking

Carefully place two strips of masking tape on the gas sample bottle as shown in Figure 2. Label the tape as per the above-mentioned procedure. Do not use waterproof pens directly on glass because the markings are almost impossible to remove.

D. Soil and refuse samples will be placed in polyethelene bags. Prior to sampling, the bag should be marked (with waterproof pens) with appropriate sample codes. All samples are to be double bagged and sealed to prevent moisture loss.

II. Leachate and Groundwater Sampling Procedure

A leachate sample will be obtained from the in-refuse well at each site. A groundwater sample will be obtained from each off-site well at each site.

A. Materials Required

1. One copy *Field Sampling Instruction Manual*
2. Styrofoam-lined corrugated shipping cartons
3. Adequate supply of plastic 2-liter bottles and lids*
4. Sampling unit with two sample bottles (Figure 3)
5. One thermometer with a range of 0 to 150^{o}C
6. Corning Model 3 pH meter (portable)
7. One plastic funnel
8. Black waterproof marking pens
9. Four packs minimum of "blue ice" for shipping. (The "blue ice" should be frozen prior to obtaining the leachate samples. Use motel ice machine or restaurant freezer).
10. Several rolls of fiber packing tape or duck tape
11. Notebook for field notes
12. Master list of sample sequence numbers and sampling dates by site

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* These containers are prepared for field use as follows: The polyethylene containers are first washed with hot tap water, cooled and rinsed with AA grade 1:1 Nitric and Hydrochloric Acid. Cold tap water is used to flush the acid remains from the bottles and finally, each bottle is rinsed several times with double-distilled deionized water. Caps are treated in a similar fashion. The bottles are then capped tightly and prepared for shipment to the field.

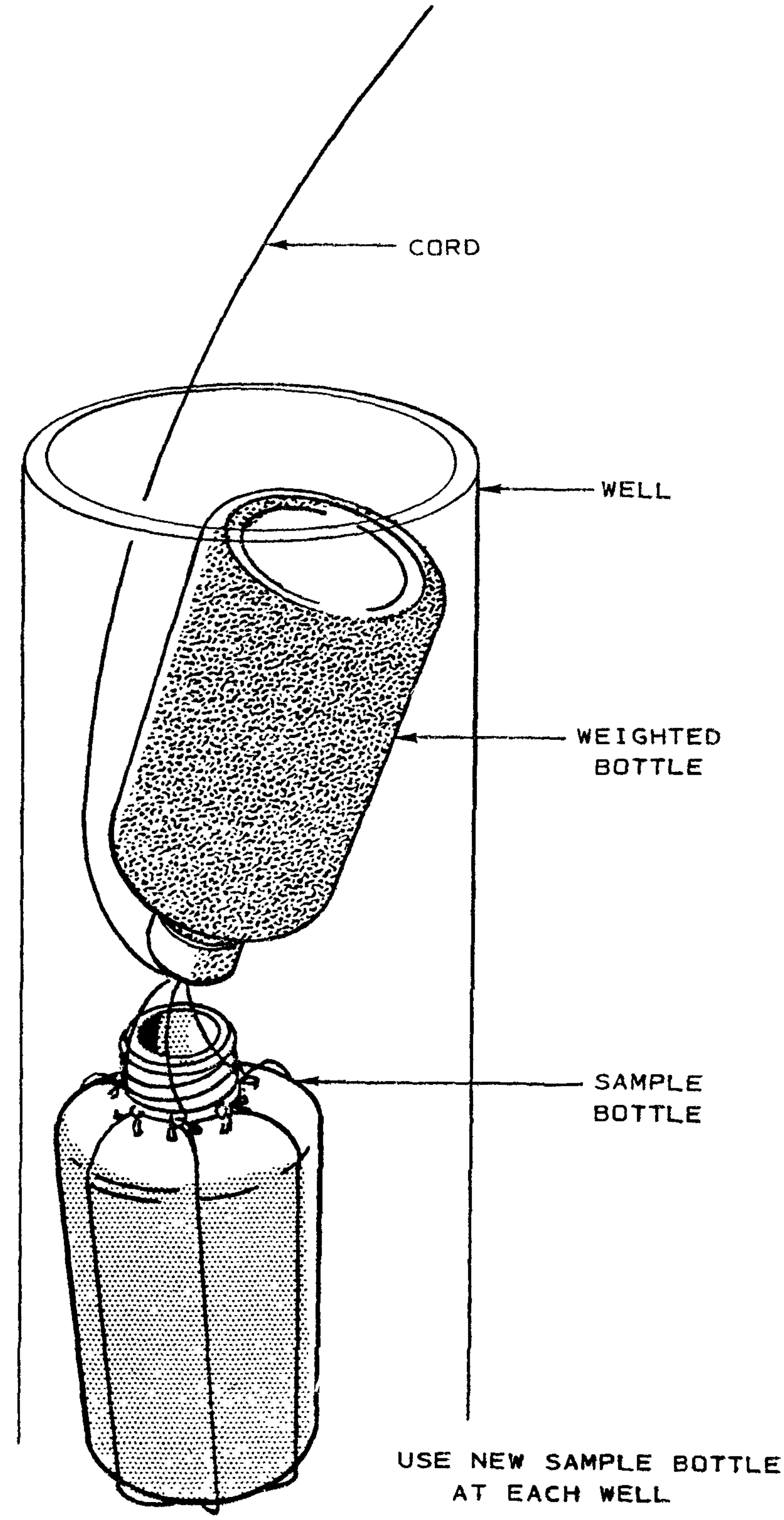

FIGURE 3
SAMPLING UNIT FOR LIQUID SAMPLES

13. One styrofoam ice chest

B. Field Sampling

Leachate and groundwater samples will be obtained using careful grab sample techniques to insure representative sampling. The sample sequence shall be as follows: deep off-site well, shallow off-site well, and in-refuse well.

1. Carefully label the outside of 2-liter bottles with the appropriate identifying codes, dates, etc., using a black waterproof marking pen (see Figure 1).

2. Place sampling bottle firmly attached to weighted bottle (see Figure 3) in well casing and lower to water level of well and submerse both bottles. When the sample container is filled, pull the container back to the surface and transfer sample to appropriate 2-liter bottle. Repeat procedure until the bottle is 90 percent filled. Record water temperature and pH and cap the sample bottle tightly.

3. After capping, place the 2-liter bottle in an ice water bath. Allow the sample temperature to equilibrate at 3-4^{o}C (usually 2 to 3 hours).

4. Repeat the above procedure at the remaining two wells after replacing the sample bottle on the sampling unit.

C. Shipment of Leachate and Groundwater Samples

All samples are to be sent to the SCS - Long Beach Office by air freight as soon as practical after field sampling has been completed. All project samples must be shipped in sturdy styrofoam-lined insulated corrugated cartons. All samples are to be wrapped in at least two layers of paper to prevent container damage and to prevent the sample codes from rubbing off.

"Blue ice" is to be packed with the samples to keep them at the proper temperature. If the transition time between the field and the SCS - Long Beach lab is expected to be more than three days, sufficient "blue ice" should be used to keep the samples adequately chilled. Dry ice <u>should not</u> be used for shipping purposes.

III. Soil and Refuse Sampling Procedure

Soil and refuse samples will be obtained from well locations during drilling and placement of the in-refuse well.

A. Materials Required

1. One copy Field Sampling Instruction Manual
2. Styrofoam-lined corrugated shipping cartons
3. Adequate supply of comercially-available polyethylene bags
4. Several black waterproof marking pens
5. Sufficient "blue ice" for shipping
6. Several roles of fiber-packing or duck tape
7. Notebook
8. Master list of sample sequence numbers and sampling dates by site
9. One 4 lb hammer
10. One shovel
11. Core sampling device
12. One tarp 8' x 8'

B. Soil Permeability Sampling

Locate an area of the site where soil cover has been placed over refuse for some time. With a shovel excavate the first inch or so of soil to remove grass, weeds, and organic material until the soil appears uniform in texture. Drive the sample device (with hammer) to a depth of about 12 in. Carefully excavate around the sampler and remove it, seal both ends and place in a double plastic bag. Seal bag and label with site designation.

C. Refuse Sampling from In-Refuse

Refuse samples will be taken from the bore hole at approximately one-third and two-thirds depths of the landfill, respectively. Place approximately one shovelful of refuse and/or sludge material in a double plastic bag, seal and label properly.

D. Soil Sampling from In-Refuse Well

Three soil core samples will be taken from each site. The first sample will be obtained from the bottom of the bore hole at the refuse/soil interface. The second and third samples will be taken half the distance to groundwater and at the soil/groundwater interface, respectively. A split-tube or Shelby tube sampler will be used depending on local well driller equipment capabilities. Place about 1/3 lb of soil sample in a double plastic bag, seal and label the bag properly.

E. Shipment of Soil and Refuse Samples

Soil and refuse samples will be shipped similarly to liquids as delineated in II(C).

VI. Background Groundwater Sampling Procedures

Sampling procedures for background groundwater are site specific. Whether samples are drawn from test facilities or domestic outlets, they should be taken in a method which will minimize any possible contamination of the samples. Example, if sampling from a tap, turn tap on and let run for five minutes before sampling to insure that the piping system has been thoroughly flushed. Again, sampling will be site-specific and procedures should be discussed with the Project Manager to determine the best method for each case study site.

A. Materials Required

1. Two plastic 2-liter bottles and lids

2. Shipping materials if sampling performed at a different time than site well sampling

B. Shipment of Samples

Refer to Shipment of Leachate and Groundwater Samples, II(C).

V. Gas Probe Sampling Procedure

Gas samples will be obtained from probes placed in the in-refuse well hole. Each probe is situated at a different depth within the hole.

A. Materials Required

1. 1/4" I.D. rubber hose (surgical tubing is adequate), 2 - 6-in lengths

2. Sample bottle(s) - 250 ml. (Corning #9500)*

3. Masking tape

4. Rubber suction bulb, aspirator type

5. One copy SCS Field Sampling Instructions

6. Styrofoam-lined corrugated shipping cartons

7. Several rolls of fiber-packing tape or duck tape

8. Notebook for field notes

9. Master list of sample sequence numbers and sampling dates by site

B. Gas Sampling (refer to Figure 4 while reading instructions)

1. Mark sample bottles as shown in Figure 2

2. Remove rubber stopper from the exposed end of one gas probe

3. Slip the end of one of the 6" pieces of rubber hose over the probe end

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* Gas burettes are to be immersed in a solution of detergent and water to remove residue soils or other foreign material. Insolubles will be removed by immersing burette in acetone. Residues that might have remained will be removed by soaking burettes in aqua regia. The burettes are then rinsed in distilled H_2O and dried in the oven at 103^oC for 30 minutes. The burettes are removed and placed in the desiccators for 30 minutes. Upon cooling, the stopcocks are greased with Apiezon N grease to insure a tight seal. The burettes are then evacuated with a vacuum pump just prior to shipment to the field.

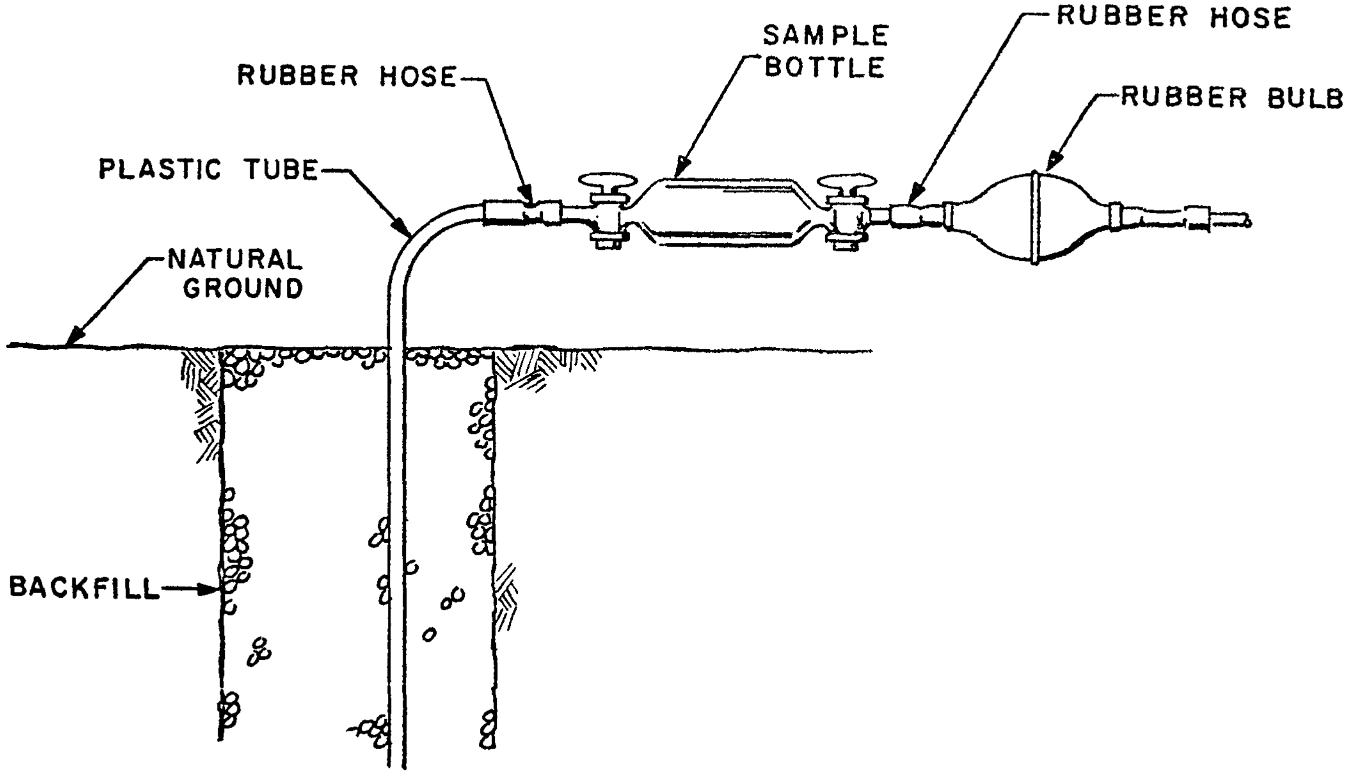


FIGURE 4

GAS SAMPLING PROCEDURE

4. Slip the other end of the same rubber hose over one end of the sample bottle.

5. Slip one end of the second piece of rubber hose over the other end of the sample bottle.

6. Slip the other end of the rubber hose onto the rubber bulb.

7. Open the sample bottle stopcock nearest the gas probe. Note: The sample bottle has been evacuated to remove any contaminants from the bottle. Thus, when the stopcock is opened, a brief hissing noise will be heard. This is the sound of the vacuum being filled. If the hissing sound is not heard, one of the stopcocks may have been opened during transport or at some other time prior to sample taking. Make a note of this fact and continue the prescribed sampling procedure.

8. Open the second stopcock.

9. Begin aspirating the rubber bulb to draw in gases within the probe's area of influence. The number of squeezes necessary varies with the probe depth. A rule of thumb: one squeeze is required for each two feet of probe depth.

10. When the appropriate number of squeezes have been taken, close the stopcock nearest the rubber bulb.

11. Close the other stopcock.

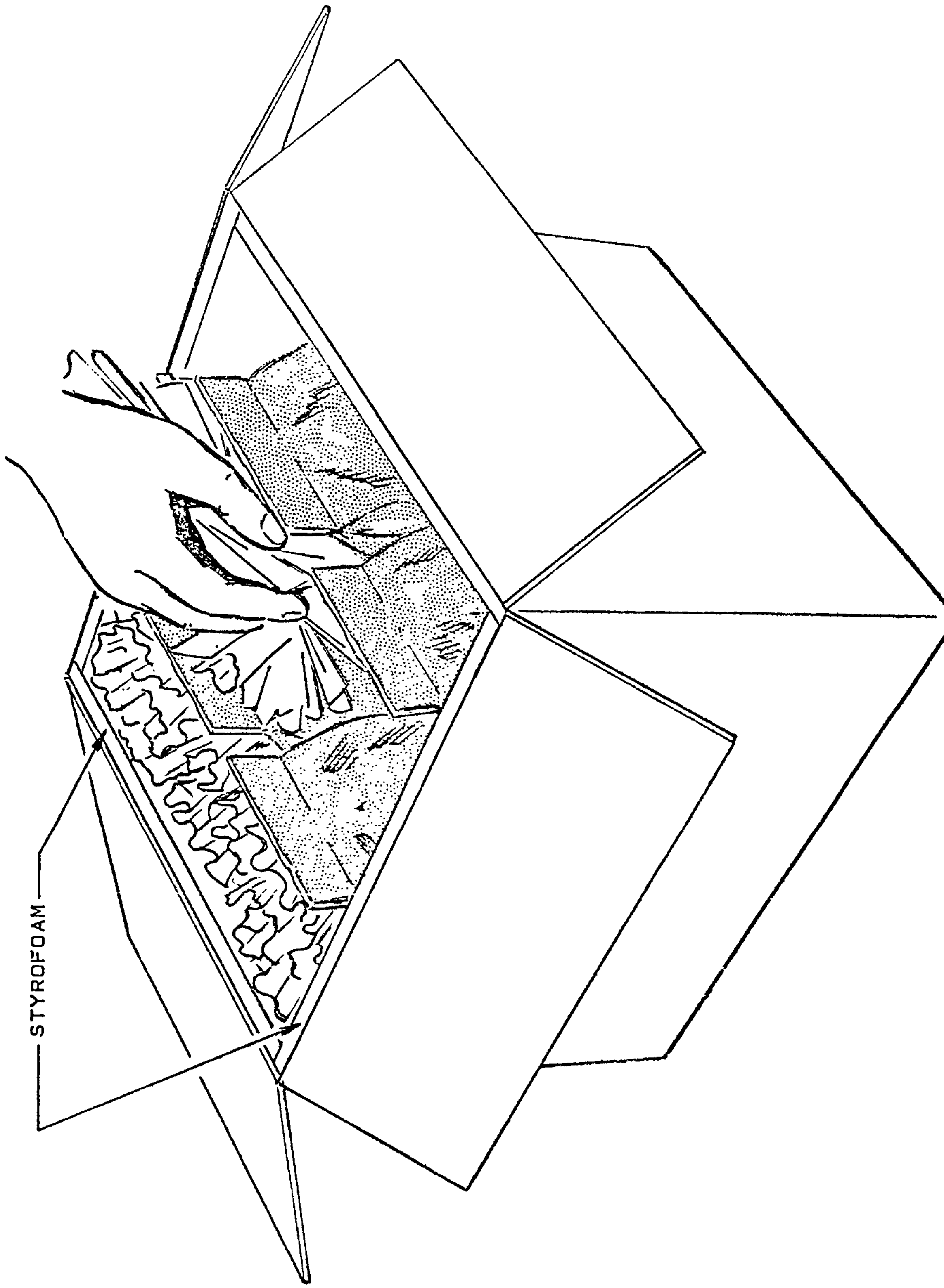
12. Remove the sampling apparatus from the gas probe and replace the rubber stopper (cap) on the gas probe end.

13. Follow steps numbers 1-11 until a sample is obtained from each of the gas probes.

C. Shipment of Gas Samples

All samples must be sent to SCS - Long Beach immediately after collection and packing for shipment (see Figure 5).

The gas sample bottles must be wrapped with multi-layers of paper or in packing sleeves to prevent



PACKING OF GAS SAMPLE BOTTLES

FIGURE 5

breakage and shipped in styrofoam-lined corrugated containers.

VI. Quality Control Procedures for the Arrival of Field Samples

All leachate, groundwater, and soil samples will be transferred from shipping containers to refrigeration immediately upon receipt. This interim storage before analysis insures temperature control of 3 to 4°C. Sample temperatures will be recorded for all arriving water and leachate. Analytical procedures are to start as soon as practical after receipt of samples.

All incoming samples will be assigned SCS lab sequence numbers. The numbers will be recorded in a log along with the date of receipt, sample identifier, description of sample, disposition of the sample, and the SCS project number.

Gas samples are analyzed upon receipt by gas chromatography.

This record is a necessary part of the SCS quality assurance program in which positive disposition of samples, sample destinations, and analytical results are effected.

APPENDIX C

METHODS FOR SAMPLE PREPARATION AND ANALYSIS

The following procedures were standardized for the preparation and analysis of sewage sludge, soil, leachate, and groundwater samples received from the case study sites.

Sample Preparation

I. Soils and Sludges

A. Sample preparation for water extraction of pH, Total Solids, COD, Ammonia Nitrogen, Nitrate Nitrogen, Organic Nitrogen, Chloride, Sulfate, TOC, Moisture, Heavy Metals and Bacteriological Tests.

1. A representative sample of 75 grams of soil or sludge was placed in a previously-sterilized mason glass jar.

2. 750 ml. of sterilized deionized water were added.

3. The contents of the jars were stirred for one-half hour with mixer. (The chrome plated mixer blades are flamed for sterilization.)

4. The slurry was allowed to settle.

5. The liquid portion was decanted through a fluted filter using paper equivalent to Whatman No. 1 or Whatman No. 42.

6. A liquid sample of the supernatant was pipetted into prepared microbiological tubes for determination of fecal coliform and fecal streptococcus.

7. A portion of the supernatant was preserved with several mls. of concentrated hydrochloric HCl) acid as a preservative prior to analysis for total organic carbon (TOC).

8. An aliquot for the COD determination was removed.

9. The supernatant was again used for total kjeldahl nitrogen, ammonia and nitrate nitrogens, chlorides and sulfates.

10. An aliquot of the supernatant was concentrated and analyzed for heavy metals (calcium, copper,

chromium, lead, iron, mercury, cadmium) by atomic absorption.

B. Sample preparation for acid extraction of soils and sludges for heavy metals (calcium, copper, chromium, lead, iron, mercury, cadmium) by atomic absorption.

1. An equal volume of nitric acid (HNO_3) was added to the soil or sludge residue volume remaining in the jar (following water extraction).

2. A teflon-coated stirring bar was placed in an agitating mixer on a hot plate and stirred for approximately 90 minutes (without boiling).

3. Sufficient water was added to the contents to make up to 750 ml. (Double distilled deionized water was used in all determinations.) Appropriate blanks were prepared for each group of determinations.

4. Mercury was determined by a separate procedure taking 50 ml. of the supernatant solution and 50 ml. of the solid residue, acidifying each and then run with flameless atomic absorption.

II. <u>Leachate</u>

A. Aliquots of well-shaken leachate were drawn for pH and total solids determination.

B. A liquid sample of the leachate was pipetted into prepared microbiological tubes for determination of fecal coliform and fecal streptococcus.

C. A portion of the leachate was preserved with several mls. of hydrochloric acid and analyzed for total organic carbon.

D. An aliquot of leachate was drawn for analysis of kjeldahl nitrogen, ammonia nitrogen, nitrate nitrogen, chlorides, and sulfates.

E. An aliquot of leachate was digested in nitric acid by gently refluxing. This process was repeated several times until the formation of a light-colored liquid residue. The residue was evaporated gently to dryness, taken up with 1:1 hydrochloric acid, the solution then heated, filtered and diluted with doubly distilled deionized water to a known volume. The solution was analyzed by atomic absorption spectroscopy for heavy metals.

Analytical Procedures

pH

All pH measurements were performed using an Orion Model 701 pH Meter with glass electrode in combination with a saturated reference calomel electrode. The pH meter was standardized periodically under conditions of temperature and concentration which were as close as possible to those of the sample, using various standard pH buffer solutions (pH 4, 7, and 10).

Total Solids

The procedure used to determine percent solids was evaporation at 180^{o}C in an air convection oven. Standard Methods (13th Edition, Section 148A, p. 288-289).

Chemical Oxygen Demand

Chemical oxygen demand was determined using the dichromate reflux method. Standard Methods (13th Edition, Section 220, p. 495).

Ammonia Nitrogen

Ammonia nitrogen was analyzed by distilling procedure. Standard Methods (13th Edition, Section 132, p. 222).

Nitrate Nitrogen

Nitrate nitrogen was determined by the brucine sulfate procedure. Standard Methods (13th Edition, Section 213C, p. 461).

Kjeldahl Nitrogen

Organic nitrogen was determined by the classic kjeldahl procedures. Standard Methods (13th Edition, Section 216, p. 469).

Chloride

Chlorides were determined via the mercuric nitrate procedure. Standard Methods (13th Edition, Section 112B, p. 97).

APPENDIX D

PROPOSED NATIONAL INTERIM PRIMARY DRINKING WATER STANDARDS

Maximum Contaminant Levels for Inorganic Chemicals

Contaminant	Level (mg/l)	Contaminant	Level (mg/l)
Arsenic	0.05	Lead	0.05
Barium	1.	Mercury	0.002
Cadmium	0.010	Nitrate	10.
Chromium	0.05	Selenium	0.01
Cyanide	0.2	Silver	0.05

Fluorides - When the annual average of the maximum daily air temperatures for the location in which the public water system is situated is the following, the corresponding concentration of fluoride shall not be exceeded:

Temperature (in degrees F)	(degrees C)	Level (mg/l)
50.0-53.7	10.0-12.0	2.4
53.8-58.3	12.1-14.6	2.2
58.4-63.8	14.7-17.6	2.0
63.9-70.6	17.7-21.4	1.8
70.7-79.2	21.5-26.2	1.6
79.3-90.5	26.3-32.5	1.4

Maximum Contaminant Levels for Organic Chemicals

The maximum contaminant level for the total concentration of organic chemicals is 0.7 mg/l.

Maximum Contaminant Levels for Pesticides

Chlorinated Hydrocarbons	Level (mg/l)
Chlordane	0.003
Endrin	0.0002
Heptachlor	0.0001
Heptachlor Epoxide	0.0001
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005

Chlorophenoxys	Level (mg/l)
2,4-D	0.1
2,4,5-TP Silvex	0.01

Maximum Microbiological Contaminant Levels

Two methods may be used:

(1) When membrane filter technique is used, coliform densities shall not exceed one per 100 milliliters as arithmetic mean of all samples examined per month and either

(i) Four per 100 milliliters in more than one standard sample when less than 20 are examined per month; or

(ii) Four per 100 milliliters in more than five percent of the standard samples when 20 or more are examined per month.

(2)(a) When fermentation tube method is used and 10 milliliter standard portions, coliforms shall not be present in more than 10 percent of the portions in any month; and either

(i) Three or more portions in one sample when less than 20 samples are examined per month; or

(ii) Three or more portions in more than five percent of the samples if 20 or more samples are examined per month.

(b) When fermentation tube method is used and 100 milliliter standard portions, coliforms shall not be present in more than 60 percent of the portions in any month; and either

(i) Five or more portions in more than one sample when less than five samples are examined; or

(ii) Five or more portions in more than 20 percent of samples when five samples or more are examined.

Supplier of water shall provide water in which there shall be no greater than 500 organisms per one milliliter as determined by the standard bacterial plate county.

Maximum Contaminant Level of Turbidity

The level at representative entry point(s) to the distribution system is one turbidity unit (TU) except that five or fewer turbidity units may be allowed if supplier can demonstrate to State that higher turbidity does not:

(a) Interfere with disinfection;

(b) Prevent maintenance of an effective disinfectant agent through the distribution system; and

(c) Interfere with microbiological determinations.

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