United States
Environmental Protection
Agency

Office of
Drinking Water (WH-550)
Washington, DC 20460

EPA 570/9-84-004(b)
June 1984

Water

EPA

National Statistical Assessment of Rural Water Conditions

Volume II

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA 570/9-84-004-B	2.
3. RECIPIENT'S ACCESSION NO.	PB8 4 222348
4. TITLE AND SUBTITLE National Statistical Assessment of Rural Water Conditions, Volume : II	5. REPORT DATE June 1984
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Department of Rural Sociology Cornell University	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Cornell University Department of Rural Socialocy	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Office of Drinking Water (WH-550) Washington, DC 20460	13. TYPE OF REPORT AND PERIOD COVERED
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Four Volume Set

16. ABSTRACT

This study considered five dominant dimensions of the status of domestic water: quality, quantity, availability, cost and affordability. Rural residents were asked about health effects but the results were modest in that very few rural residents reported adverse health conditions which they associated with the water supply.

With enactment of the Safe Drinking Water Act of 1974, Congress set in motion two major efforts to develop systematic, current data on rural water supplies across the nation. First, in response to growing concern with the quality of drinking water and its effects on human health, the Safe Drinking Water Act provided for a uniform, national set of water quality standards and extended the monitoring and regulatory responsibility of the US Government over smaller water supplies. Second, the Act mandated a one-time national statistical assessment of the current status of rural domestic water characteristics. This document fulfills that mandate.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Rural water drinking water Rural water conditions water supply systems water quality water quantity		

18. DISTRIBUTION STATEMENT Open distribution	19. SECURITY CLASS *(This Report)* non-sensitive	21. NO. OF PAGES 444
	20. SECURITY CLASS *(This page)*	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

V

Status of US Rural Water Supply

Congress recognized in the Safe Drinking Water Act that an assessment of rural water conditions required investigation of a number of interrelated components of water supply. All of those components—not just water quality—were studied in the NSA. This chapter, the central descriptive chapter of the NSA report, presents a comprehensive account of the status of household water conditions in rural America. Findings are arranged according to their relevance to the various dimensions of rural water supply. Later chapters of the report explore the relationships between these findings and other NSA data.

Congress sensed that rural water conditions were best described by water quality, quantity, and availability, and it specified that these three factors were to be studied in the rural water survey. At the same time, the Safe Drinking Water Act mandated national, legally enforceable actions affecting a number of aspects of public water supply. The broad scope of the legislation required an equally broad study of the technical, economic, and institutional aspects of water conditions. In view of that orientation, it became clear to EPA officials that the three designated factors—quality, quantity, and availability—would have to be defined comprehensively, and that other factors would have to be included in the study.

In light of these considerations, the status of rural water supplies was described in the NSA in terms of five primary factors: quality, quantity, availability, cost, and affordability. In addition, the survey questioned rural water users about the effects of water quality, quantity, and availability on their households. Each of these broad subjects is explored in detail in this chapter.

The status of rural water supplies described here was determined in the rural household. This emphasis was in keeping with the Congressional directive to obtain information on the number of rural residents who had inadequate service, limited access to supply, exposure to waterborne health risks, or outright waterborne illnesses. The new federal drinking water regulations reiterated this concern by requiring that most quality standards be met in the consumer's household, at his tap, rather than just at the supply facility or at the source. This approach recognized that conditions at other points along the distribution system were important, but that household water conditions had to be judged in the consumer's home.

In this chapter, as is the practice in the NSA, variables describing status include both laboratory-measured values (for water quality, for example) and perceived values (such as the user's evaluation of the water's taste and appearance). This approach allowed analysis of conditions which required laboratory measurement and of conditions which needed to be assessed by personal appraisal. Laboratory-measured values are discussed first, and perceived values second.

QUALITY

Of the five primary factors used in the NSA to delineate rural water conditions, quality is taken up first for both historical and pragmatic reasons.[1] Historically, from porous vessel filtration of water in ancient Egypt to deactivation of the infamous cholera-contaminated Broad Street well in nineteenth-century England, a major concern has been with the purity of drinking water. Even the NSA stemmed originally from worry about US waterborne disease outbreaks in the 1960s. This worry was intensified by the discovery of substandard drinking water in many community water supply facilities and in consumers' homes in 1969 during a nationwide study (the US Public Health Service Community Water Supply Survey, cited under Reference 1).

Pragmatically, household water quality was the factor which could be studied most thoroughly in the NSA. In this context, 'quality of water' referred to the suitability of water for human use. The major consideration was that the water not present a health threat to human beings. However, the NSA concept of water quality also included aesthetic and economic considerations. Overall, the NSA concept of quality was consistent with the definition of a "functionally ideal" public water supply as adopted by the Board of Directors of the American Water Works Association in 1968. The definition stated, in part: "Ideally, water delivered to the consumer should be clear, colorless, tasteless, and odorless. It should contain no pathogenic organisms and be free from biological forms which may be harmful to human health or aesthetically objectionable. It should not contain concentrations of chemicals which may be physiologically harmful, esthetically objectionable, or economically damaging. The water should not be corrosive or incrusting to, or leave deposits on, water-conveying structures through which it passes, or in which it may be retained, including pipes, tanks, water heaters, and plumbing fixtures."[2]

Major emphasis in the NSA was given to bacteriological, physical, and chemical water constituents which traditionally have characterized water quality (see Table V-1). Many of the NSA measurements were relevant to new federal drinking water regulations. The major focus was on measurements of health-related constituents of water, particularly in the subsample of 10 percent of the

Table V-1

Constituents Measured in NSA Survey

Category	Constituent	Has Primary (P), Secondary (S), or No (N) MCL	Measured in All NSA Household Samples or only in Group II Subsample
Microbial	Total coliform	P	All
	Fecal coliform	N	All
	Fecal streptococcus	N	All
	Standard plate count	N	All
	Fecal coliform/fecal streptococcus ratio	N	All
Physical and Chemical	Turbidity	P	All
	Color	S	All
	Temperature	N	All
	Specific conductance	N	All
	Total dissolved solids (as determined from conductance)	S	All
	Hardness (as determined from calcium and magnesium)	N	All
Inorganic	Calcium	N	All
	Magnesium	N	All
	Nitrate-N	P	All
	Sulfates	S	All
	Iron	S	All
	Manganese	S	All
	Sodium	N	All
	Lead	P	All
	Arsenic	P	Subsample
	Selenium	P	Subsample
	Fluoride	P	Subsample
	Cadmium	P	Subsample
	Mercury	P	Subsample
	Chromium	P	Subsample
	Barium	P	Subsample
	Silver	P	Subsample
Organic	Endrin	P	Subsample
	Lindane	P	Subsample
	Methoxychlor	P	Subsample
	Toxaphene	P	Subsample
	2,4-D	P	Subsample
	2,4,5-TP	P	Subsample

Table V-1 (continued)

Category	Constituent	Has Primary (P), Secondary (S), or No (N) MCL	Measured in All NSA Household Samples or only in Group II Subsample
Radioactive	Gross alpha	P	Subsample
	Gross beta	P	Subsample
	*Radium 226	P	
	*Radium 228	P	
	*Uranium	P	
	*Stontium-89	P	
	*Strontium-90	P	
	*Cesium-134	P	
	*Tritium	P	
	*Iodine-131	P	

*Measured only if the laboratory analyst considered gross alpha or gross beta readings sufficient to warrant further investigation.

NSA water specimens (see "Constituents Studied in NSA," below), but some determinations were related more to aesthetic and economic considerations.

The regulations provide one, but only one, body of standards for interpreting the implications of NSA findings. In this chapter, federal standards are compared with other existing criteria and standards in order to present a broader context for interpreting the NSA findings.

As to the specific terminology used in the federal regulations, there are two levels of standards which have been established. One level is the interim primary Maximum Contaminant Level (MCL). Primary MCLs are numbers which refer to specific concentrations of individual constituents. The specific concentrations cannot be exceeded in public drinking water supplies which have fifteen or more connections or which regularly serve 25 or more people. The requirement is mandatory since the constituents in question are regarded as possible health threats if they are present in excessive concentrations.

The other regulatory level is the secondary Maximum Contaminant Level. Secondary MCLs also are numbers which specify concentrations of constituents, but the specifications are recommended, not legally enforceable by the US government. The constituents involved are considered to have aesthetic or economic consequences, but only minor or uncertain health effects.

NSA WATER QUALITY REFERENCE VALUES

In order to assess household water quality, it was desirable to develop a set of reference values for all of the constituents studied in the NSA. The federal primary and secondary drinking water regulations (which were developed to assess the quality of community water systems) composed one set of standards which provided appropriate bases, but other standards also were consulted in developing the NSA reference values (see Table V-2).

Table V-2

NSA Reference Values for Constituents Measured in NSA Survey

Constituent	NSA Reference Value (milligrams per liter of water, unless otherwise noted)	*Basis for Reference Value	Purpose or Effect of Constituent
Total coliform bacteria	Not more than one bacterium per 100 milliliters of water	MCL(P)	Indicator of infectious disease potential
Fecal coliform bacteria	Complete absence of bacteria in a 100-milliliter sample	EPA	Indicator of infectious disease potential
Fecal streptococci	None		Indicator of possible infectious disease potential
Fecal coliform/ fecal strepto-coccus ratio	None		Indicator of human versus animal contamination
Standard plate count	500 colony-forming units per one milliliter of water	NRC	General indicator of bacteria level
Turbidity	None		Aesthetic, health
Color	15 color units	MCL(S)	Aesthetic
Temperature	None		Aesthetic
Specific conductance (normalized at 25^{o} C)	None		Used for estimating total dissolved solids
Total dissolved solids (as derived from specific conductance)	500	MCL(S)	Economic, aesthetic

Table V-2 (continued)

Constituent	NSA Reference Value (milligrams per liter of water, unless otherwise noted)	*Basis for Reference Value	Purpose or Effect of Constituent
Hardness	None		Economic
Calcium	None		Aesthetic, economic
Magnesium	125	Various	Aesthetic, economic, health
Nitrate-N	10	MCL(P)	Health
Sulfates	250	MCL(S)	Aesthetic, health
Iron	0.3	MCL(S)	Aesthetic
Manganese	0.05	MCL(S)	Economic, aesthetic
Sodium	More stringent: 20 Less stringent: 100	NRC	Health
Lead	0.05	MCL(P)	Health
Arsenic	0.05	MCL(P)	Health
Selenium	0.01	MCL(P)	Health
Fluoride	1.4	MCL(P)	Health
Cadmium	0.01	MCL(P)	Health
Mercury	0.002	MCL(P)	Health

Table V-2 (continued)

Constituent	NSA Reference Value (milligrams per liter of water, unless otherwise noted)	*Basis for Reference Value	Purpose or Effect of Constituent
Chromium	0.05	MCL(P)	Health
Barium	1	MCL(P)	Health
Silver	0.05	MCL(P)	Health
Endrin	0.0002	MCL(P)	Health
Lindane	0.004	MCL(P)	Health
Methoxychlor	0.1	MCL(P)	Health
Toxaphene	0.005	MCL(P)	Health
2, 4-D	0.1	MCL(P)	Health
2, 4, 5-TP	0.01	MCL(P)	Health
Gross alpha radioactivity	See Figure V-28	MCL(P)	Health
Gross beta radioactivity	50 pCi	MCL(P)	Health
Radium 226 Radium 228 Other radio-nuclides (uranium, strontium-89, strontium-90, cesium-134, tritium, iodine-131)	These constituents were not measured frequently enough to provide independent national estimates (See text for details about NSA reference values.)		Health

*See text for details: MCL(P) indicates interim primary Maximum Contaminant Level, MCL(S) indicates secondary Maximum Contaminant Level; EPA stands for US Environmental Protection Agency, NRC for the National Research Council, and "Various" for several sources which are described in the text.

As to the federal drinking water regulations, there was an important distinction between the requirements for arriving at measurements under the EPA regulations and the procedure followed in the NSA. Under the regulations governing administration of the interim primary MCLs,[3] sampling was to be done over designated periods of time, and compliance with the MCL requirement was judged not on the basis of just one finding, but on the basis of the average of several findings. The secondary drinking water regulations were not federally enforceable, but the same sort of sampling and averaging process was envisioned for their application.[4]

The sampling and averaging process is used to monitor public drinking water supplies systematically and to identify situations in which excessive concentrations of certain materials appear to pose persistent problems. The averaging provision reduces the chance that a single, temporary elevation of one substance would bring the supply into noncompliance with regulations. In the NSA, on the other hand, only one set of specimens was collected. All of the NSA findings thus were based on single-specimen values, not on average values for multiple collections. The MCL itself, however, had validity as a measure of health or aesthetic consequence. That value, then, frequently was used as the basis for the NSA reference value. The MCLs and other standards are discussed and compared where appropriate in this report, and the basis for the NSA reference value is stated.

As a note on terminology used in subsequent sections on laboratory findings, measured values which are larger than the NSA reference values are reported as exceeding (surpassing or being above) the reference values. Measured values which are equal to or less than the reference values may be reported as within or below the reference values. The terms "household" and "supply" are used interchangeably. In this regard, it is important to note that the set of specimens for quality studies was drawn from the one major water supply in each household.

In 97.0 percent of households, that supply provided drinking water as well as satisfying other domestic water requirements (see Chapter IV).

HEALTH-RELATED CHARACTERISTICS

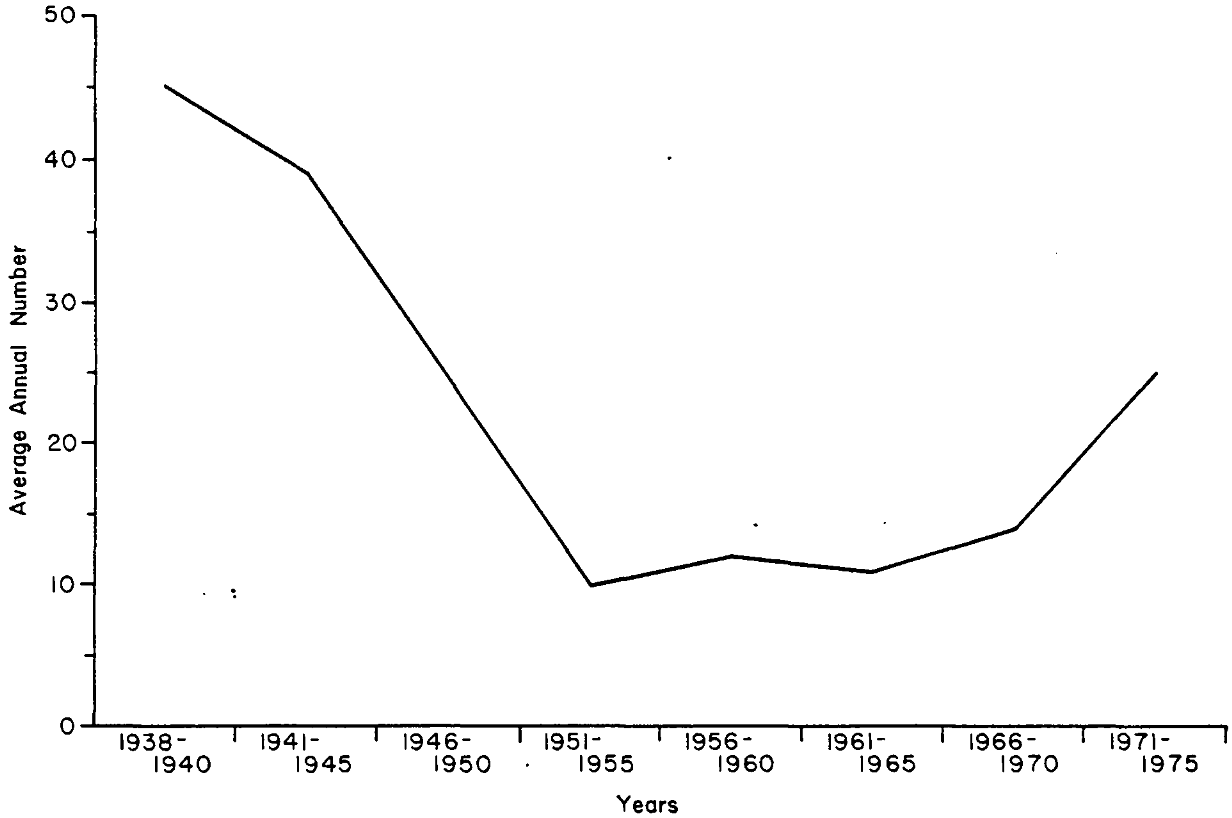
The emphasis on traditional health-related characteristics was felt to be in keeping with recent public health trends. Microorganisms have been the cause of the largest reported outbreaks of waterborne disease in the US during the past twenty years, even though chemical and radioactive contaminants have posed new problems. The number of outbreaks (defined as at least two cases of certain specified illnesses), after declining from 1938 through 1950, began to rise after 1950 (see Figure V-1).

Whatever the reason for the increase, the outbreaks were attributed primarily to microscopic organisms rather than to chemical contaminants. This tendency is apparent in the types of illness outbreaks from 1971 to 1974 (see Table V-3). During that period, 90.9 percent of the outbreaks were caused by microorganisms—only 9.1 percent of the outbreaks were caused by chemical contaminants. Nevertheless, the number of individual cases of chemical poisoning (474) was larger than the number for several infectious diseases.

A complication in considering chemical contamination is that effects of industrial pollutants, ranging from asbestos to exotic organic chemicals, may be serious but so subtle or delayed as to avoid detection by present methods. To add to the difficulty, only a small portion of organic contaminants in water have been identified at all. According to the NRC: "Although approximately 90 percent of the volatile organics in drinking water have been identified and quantified, these represent no more than ten percent of the total organic material. Only five to ten percent of the nonvolatile organic compounds, which comprise the remaining 90 percent of the total organic material in water, have been identified."[5]

Figure V-1

Average Annual Number of Waterborne Disease Outbreaks,* 1938 - 1975



*An outbreak consisted of at least two cases of certain reportable illnesses.

Source: *National Academy of Sciences. Drinking Water and Health. Washington,DC: National Academy of Sciences, 1977, p.64.*

Table V-3

Summary of Waterborne Illness Outbreaks and Cases, 1971-74

Illness	Outbreaks	Cases
Acute gastroenteritis (cause unknown)	46	7,992
<u>Bacterial</u>		
Shigellosis	13	2,747
Typhoid fever	4	222
Salmonellosis	2	37
<u>Viral</u>		
Infectious hepatitis	13	351
<u>Protozoan</u>		
Giardiasis (includes 4,800 cases in one outbreak at Rome, New York)	12	5,127
<u>Chemical</u>		
Chemical poisoning	9	474
Total	99	16,950

Source: Adapted from National Academy of Sciences. Drinking Water and Health. Washington, DC: National Academy of Sciences, 1977, p. 65.

As to radioactive contaminants, the NRC concluded that "the radiation associated with most water supplies is such a small portion of the normal background to which all human being are exposed that it is difficult, if not impossible, to measure any adverse health effects with certainty."

The pattern of federal regulations for drinking water is in keeping with the state of scientific knowledge about water contamination. Thus, heavy emphasis is on acceptable bacterial content of water, coupled with surveillance of public water supplies to ensure that the limits are not exceeded. Considerable emphasis also is given to traditional tests for water turbidity, an optical measure of suspended substances in water which may harbor or protect microorganisms. Less emphasis is given to surveillance for inorganic materials, although mandatory limits are established for those with apparent health effects, except in noncommunity systems where long-term exposure is assumed to be limited. The emphasis on organic materials (limited to insecticides and herbicides at the time of the NSA) is on substances known to have serious toxic properties. Emphasis also is given to surveillance for certain levels of radioactivity, with little expectation of finding significant levels in public drinking water except in isolated cases.

In a broader context, the relation of water quality to human health is complex, and it is necessary to identify those aspects of the relationship which were considered in the NSA study. Public health officials generally relate water quality to the occurrence of specific, potentially dangerous substances in drinking water supplies. Health nutritionists, on the other hand, often relate water quality as well to the presence of certain substances required in the human diet. The public health official's main concern is prevention of waterborne illness; the nutritionist's main concern is dietary adequacy.

The emphasis in the NSA investigation was on the traditional concern of public health officials with levels of materials that might have adverse health effects. Thus, even though a number of constituents measured in the NSA had potentially beneficial effects in small amounts, the emphasis was on the hazard they might create in larger amounts.

Despite the NSA focus on potential health hazards in water, it was not possible within the confines of the study to trace the implications of water conditions which indicated potential health problems. To do this would have required expensive, time-consuming epidemiological research to link particular health problems with conditions in household water supplies. In some cases, long periods of time would have been needed to identify cumulative, delayed, or interrelated health effects. Such research on a national scale would have been far beyond the scope of the project. In addition, it was possible to take only one set of specimens of water from each household at one particular point in time. This was adequate to provide an indication of overall national and regional situations. One sample could not represent the range of conditions which occurred during an entire year, however.

Faced with these problems, NSA investigators foresaw serious difficulties in one section of the Congressional mandate for the rural water survey. That section directed that the survey include "consideration of the number of residents in each rural area . . . who have experienced incidents of chronic or acute illness, which may be attributed to the absence or inadequacy of a drinking water supply system."

Possible methods for meeting this directive were reviewed by EPA and by NSA investigators. Advice was sought from the US Health Interview Survey, the Health Examination and Nutrition Survey, the Office of Vital Statistics, and the Center for Disease Control. These government organizations have had extensive experience with clinical and epidemiological techniques applicable to public health studies. Officials from these organizations pointed out the many obstacles to obtaining useful information in an extensive, one-time, cross-sectional survey such as the NSA. For example, clinical examination of respondents would be far too limited to provide meaningful public health conclusions. Available statistical data from health departments would be incomplete and outdated. Epidemiological studies would be of limited value without solid evidence of localized outbreaks. Perhaps most important, integration of data to provide a reliable national picture of public health problems related to drinking water would be risky and very likely misleading.

In view of these considerations, NSA investigators concluded that the NSA could not provide a direct, comprehensive assessment of the adverse health effects of rural water supplies. Nevertheless, questions about perceived water-related illness were included in the NSA interview schedule. Responses, however, may have been more significant indicators of the residents' awareness of possible links between health problems and water supplies than they were of actual health effects of the supplies. The results of these questions and others related to possible health effects of water supplies are discussed in the section of this chapter entitled "Effects of Quality, Quantity, and Availability."

In summary, the only measure of health effects in the NSA is strictly a measure of potential health hazards posed by constituents found in the water specimens collected at rural households. Measurement of the constituents provides an indication of the immediate risk to persons living in the households. In addition, the analysis of "at-risk" US rural households could contribute to public health statistical investigations and to assessment of the need for countermeasures.

WATER QUALITY DATA—PERSPECTIVES

Every scientific endeavor strives to collect, transport, process, synthesize, and report with minimal distortion. The practical hope is to reduce errors to small random perturbations.

From the time that the NSA was planned, a variety of procedures were included to minimize the possibilities for error. Interviewers were intensively trained on every aspect of the survey during a two-week training course. Their work in the field was checked by multiple independent examinations of their completed forms, through telephone follow-ups, and by actual on-site, follow-up visits by supervisors at randomly selected households. Water specimens were preserved at the time of collection—ice for microbiological samples, mercuric chloride for the nitrate samples and nitric acid for the metals and radiation samples. Every effort was made to insure that the collection was careful and consistent. Only EPA laboratories or EPA-approved laboratories were used to analyze the water.

Nevertheless, errors invariably arise in any large-scale study. Hence, even after data collection was completed, further checking was employed to uncover and correct errors. The effects of errors can be characterized in two ways. There are errors which leave the estimate of the mean unaffected but cause the data to be dispersed. This imprecision is reflected in large standard deviations. Errors of this nature are difficult to correct since they are not consistent in their effect. The second type of error is usually called bias. It causes the estimates of means to be displaced, but may not affect the standard deviation. The two types of error may occur together.

Two approaches were used throughout the NSA for assessing the presence of errors in the collected data. First, data sets with results that had some overlap with the content of the NSA were examined to see how well the overlapping results aligned. Second, extensive internal examinations were undertaken.

Regarding the first approach, comparisons of NSA results with independently collected studies of a similar nature were made. This was the approach used in part of Chapter III and Appendix B. Similar findings indicate either that (1) both efforts reasonably reflect the true situation or (2) both err but happen to arrive at the same result. Since the latter case was not likely, a pattern of consistent results was taken to mean that the total effect of error was not meaningful.

Since the NSA was the first national investigation of rural water conditions, there were no completely comparable data sets. Though the US Census had some overlap with NSA's socioeconomic data, comparable data sets of national rural water quality data did not exist. Other data sets differed from the NSA in important ways. Some were not national in scope. Most were not rural oriented. Some were not systematically taken. In some, water samples had not been appropriately preserved, or the water samples had been analyzed with incompatible techniques, were incompatibly reported, and so forth. (The EPA's federal reporting data system, FRDS, does collect water quality data for community water systems, including rural systems. It holds promise of becoming a comparable source for those systems affected by federal monitoring guidelines.) Though they were not directly comparable, these other data sets generally had lower values than the NSA, particularly among the metals readings. The lack of comparable data necessitated the use of the second, internal approach to detection of errors.

The second, more tedious approach involved an internal examination of NSA research procedures to try and identify sources of consistent error. An internal data examination is generally less desirable because it requires more effort and is necessarily inconclusive since all possible error sources cannot be examined. The best attainable conclusion from such an approach would be that of the possible problems examined, none showed a systematic error pattern.

The internal examination of the water quality data was crucial to some NSA water quality findings, especially the metals results, which generally had higher readings and a higher proportion of samples with high readings than was expected by many professionals. Lead, cadmium, and mercury were the most notable standouts. Work by other researchers (to be discussed later) provided a strong indication that the preservative ampules of nitric acid could have affected the lead and cadmium results. Internal detection of errors in the water quality data was conducted in two steps. Step one involved an examination of interviewer behavior, collection, and transporting of the water specimens. Step two involved an examination of laboratory procedures. The results of that examination, presented below, include qualifications and cautions which are appropriate in order to establish a realistic basis for interpreting the laboratory measures of water quality. More detailed documentation of the NSA's internal assessment of the laboratories' performance is contained in Appendix C. Appendix C is not bound with the NSA report but can be obtained by contacting the Director, The Office of Drinking Water, US Environmental Protection Agency, 401 M Street S.W., Washington, DC, 20460.

Quality assurance results

Investigation of interviewer, handling, and transporting procedures did not identify any systematic error source. There were no systematic patterns of inordinately high or low findings among interviewers that were inconsistent with readings for other interviewers in the same general geographic area.

Seven laboratories participated in the NSA water quality assessment. Each of the laboratories performed standard checks to assure consistency, accuracy, and validity. But, the results of these checks are not standardly requested by the data user. While NSA researchers did request these quality assurance data, they were not always available or interpretable for a variety of reasons. For those laboratories which could be checked, original laboratory notebooks were compared with NSA reporting forms, data key punched, and finally with the computer analysis tapes. An error rate ranging from 1 to 3 percent was apparent in comparing the laboratory notebooks to the computer tape (many of those errors were corrected in the checking process). Every number reported from the laboratories was independently checked at least twice, but usually four times. Some important transcription errors were discovered and corrected for mercury. Some metals specimens, preserved with nitric acid, sent to the EPA laboratory in

Las Vegas were inadvertently misplaced and were not analyzed for as long as nine months. These specimens were mistakenly transferred to an unrefrigerated warehouse. An examination of the readings for those misplaced specimens did not reveal an identifiable effect from the improper handling. However, a thorough resolution of that question was not possible without experimentation.

The course of investigating the validity and reliability of the data did not identify any procedure or laboratory effect which would suggest aberrant results. But again, some important avenues of inquiry were unavailable. For instance, randomly interspersed blank specimens of laboratory pure water were not sent to the laboratories. They could have indicated bias in drawing, handling, or analyzing the specimens. Specimens from the same household, drawn at the same time, were not sent to more than one laboratory. So no direct test of laboratory bias was available. A variety of other experiments testing storage time, container characteristics, preservation technique, and so on would have been useful but were not performed.

The following is a summary of specific findings of the quality assurance which was derived from laboratory records.

Microbiology

Three laboratories participated in the bacteriological investigation of NSA water specimens. The ERCO (Energy Resources Company, Inc.) of Boston, Massachusetts, did the bulk of the work. The Madison County Environmental Center of Edwardsville, Illinois, and the Colorado State Health Department of Denver, Colorado, were the other laboratories.

A polypropylene, autoclaved, sealed, one quart container was used to collect the water. During the collection, the bottle lid was held suspended face down. Neither it nor the interior of the bottle were allowed to come in contact with anything but the flowing tap water. The filled container was then sealed in a plastic bag and placed in a styrofoam shipping container. Ice, in a separate sealed plastic bag, was packed with the specimen. The styrofoam box was closed, sealed, and sent to the nearest of the three laboratories, usually by airplane. The laboratories picked up the incoming specimens and began the analysis within thirty hours from the time of collection. If this deadline was not met, the water was discarded and the interviewer instructed to collect a new water specimen.

A detailed system of checks was used to test the validity of the organism identification and the accuracy of the count. The EPA's Office of Research and Development, Environmental Monitoring and Support Laboratory (EMSL) followed the quality assurance data (QA) from the microbiological analyses and drew the following conclusion upon transmitting the detailed results of their monitoring:

> "The importance of a vigorous QA program was evidenced in the detection and resolution, early in the study, of technical problems and differences that occurred in laboratory operations and data reporting by participants. We believe the . . . QA protocol (for microbiology) was conscientiously followed. The quality control report forms were monitored regularly by EMSL. We conclude that the QA program (for microbiology) was appropriate for the study and did confirm the validity of the test data."

Radiation

All radiological investigations were conducted at the EPA Environmental Systems Monitoring Laboratory at Las Vegas. A reorganization of the laboratory following the NSA survey resulted in the dispersion of personnel and the loss of records. There were, therefore, no data available to describe the results of quality control efforts for the radiation results.

Chlorinated hydrocarbons

Two laboratories participated in the examination of chlorinated hydrocarbons: The South Carolina Epidemiologic Study Laboratory and the Mississippi State Chemistry Laboratory. As with the radiological examination, no quality control data were recovered regarding laboratory procedures with the NSA data. However, results on the EMSL check samples were available for the first month of the NSA data collection. While no examination of NSA specimens occurred in these laboratories until some time later, these were the only quality control data available. At the time the check samples were analyzed, the laboratory did perform within EPA's acceptance limits.

Physical, chemical, and inorganic analyses

Two laboratories participated in this segment of the NSA investigation. Both are EPA laboratories: one, the Environmental Monitoring Systems Laboratory, is located in Las Vegas, Nevada; the other, the Environmental Monitoring and Support Laboratory, is in Cincinnati, Ohio. Both laboratories performed analyses on the same constituents. The Cincinnati laboratory received about two-thirds of the specimens while the Las Vegas laboratory did one-third. The specimens were divided between the laboratories largely on the basis of which laboratory was closest to the sampled household.

Tables V-A, V-B, and V-C, at the end of this section, display results of quality assurance procedures for some of the data generated by the Cincinnati and Las Vegas laboratories.

There are three types of inquiry reflected in the tables. Table V-A displays the differences between the value reported for a household and a duplicate reading on a separate aliquot from the same sample. Ideally, the differences should tend toward a mean and standard deviation of zero. Assuming homogeneity throughout a particular water sample, the duplicate reading provided an indication of variability in the measuring process. The data shown were not for the entire NSA sample, but for the subset on which quality assurance data were aggregated. Thus, the columns showing ranges of data may not correspond to ranges presented elsewhere in the report when the full NSA data is discussed.

Table V-B reports percentages of spike recovery. Spiking involves purposefully adding a known amount of the substance being investigated to a tested aliquot, then retesting to see what percent of the spike is recovered in the new reading. The process can reflect both validity—whether the chemistry is measuring what is intended—and the precision of the range. The mean should tend toward 100 percent and the standard deviation to zero.

Table V-C displays the results of measuring known standard solutions interspersed with the test samples. The differences between the expected value and the measured result should tend toward a mean and a standard deviation of zero. These results were only for those analysis runs for which the measured standards were within the laboratory acceptance limits. All results from runs in which the standard readings were unacceptable were automatically discarded and the water retested.

The data in the tables came from a selected sample (usually 5 or 10 percent) of the cases reported in the NSA. Some of the apparent instability was directly a result of having few data points. This caution is particularly relevant for those constituents studied only in the NSA 10 percent subsample.

The lack of data in some parts of the tables does not necessarily mean the work was not done by the laboratory, rather that laboratory quality assurance procedures are not normally reported to the data users. Incomplete communication, unavailable records, lack of time, and the like made some of these data unavailable. Examination of some of the laboratory records suggested that less care was taken in transcribing quality assurance results than was taken for the primary findings. That may account for some but certainly not all of the variability reflected in the tables. Some of the quality assurance results suggest that more careful laboratory control could have been exercised.

The results for two parameters need some special qualification. Turbidity and color were measured at the laboratory—not in the field. Ideally, they should be assessed at the time the water is drawn. There can be precipitation or other physical, chemical, or biological actions from the time of drawing to laboratory analysis which could change the readings for both turbidity and color. The EPA considered that consistently accurate field readings by interviewers would be more of a problem than the possible inaccuracies induced by waiting to take the readings under controlled laboratory conditions. The effect of that decision upon the data is unknown.

Some of the constituents were measured on a 10 percent subsample of interviewed households. That reduction in data reduces the statistical confidence which can be associated with point estimates (such as means, medians, and standard deviations). Cadmium and mercury were among the subsample constituents and, as previously mentioned, they were found in greater concentrations and in greater proportions of household water supplies than expected by many professionals, suggesting a possible bias or that the smaller case base resulted in an unrepresentative sample, or both.

Edward Calabrese _et al_. reported in the _Bulletin of Environmental Contamination and Toxicology_ (September, 1979, pp. 107-111) that the preservative ampules purchased from the same corporation as those used in the NSA could bias lead and cadmium results in drinking water analyses. Apparently the thin line of blue paint marking the appropriate breakpoint on the ampule neck contained lead and cadmium. Shaking the acid from the opened ampule could contaminate the water sample with sufficient paint to alter subsequent measurement of the two metals. If the mean contamination elevation in NSA water samples was the same as discovered by Calabrese, then the NSA's estimates are artifically elevated by 36 parts per billion lead and 0.92 parts per billion cadmium. While there is no way to ascertain the true effect on each water sample, it is likely that the average effect was probably similar to that found by Calabrese. (The manufacturer no longer employs the painted marking line.)

Quality assurance summary and conclusions

Bias in the data will shift the estimated concentrations either higher or lower than what was actually present in the water. Two groups of data, radiation and chlorinated hydrocarbons, had uniformly low readings. There were no data available for inquiring whether these findings were biased. If they were biased high, then the implications are not serious. But, if they were biased low, then the NSA suggests inappropriate complacency. For the other water quality data, extensive quality assurance information was investigated but no bias (other than for lead and cadmium) was identified. Nevertheless, if the data are biased high, then the NSA suggests problems which are not real. If the data are biased low, then the NSA underestimates the severity of problems with rural domestic water supplies.

The extensive inquiry into sources of error in the data has not identified any problem which repudiates the findings, though the Calabrese report does qualify the NSA's lead and cadmium results. Still, not all the important possible error sources have been eliminated. Some of the results suggest water problems that do not square with some long-standing professional expectations. These data should therefore be viewed with realistic caution and the appropriate scientific scepticism. They should not be the basis for permanently definitive conclusions, neither should they be ignored. They represent the first nationally systematic investigation of rural domestic water supplies. They identify and clarify possible concerns for rural domestic supplies and can be a valuable guide for subsequent inquiries.

Table V-A

Water Chemistry Laboratory Quality Assurance Results. Original and Duplicate Readings

Constituent and Laboratory	Range of the Original Readings		Distribution Characteristics of the Original Readings Minus the Duplicate Readings		
	Lowest Value	Highest Value	Highest Absolute Value	Mean	Standard Deviation
Turbidity (NTU)					
Cincinnati	0.1	22.0	0.4	-0.03	0.08
Las Vegas	UA*	UA	UA	UA	UA
Color (std. color units)					
Cincinnati	2.0	50.0	UA	UA	UA
Las Vegas	UA	UA	UA	UA	UA
Specific Conductance (micromhos)					
Cincinnati	24.0	2131.0	4.0	-0.04	0.42
Las Vegas	UA	UA	UA	UA	UA
Calcium (mg/l)					
Cincinnati	0.5	58.0	21.4	-0.14	2.69
Las Vegas	0.1	582.5	94.9	-1.44	10.52
Magnesium (mg/l)					
Cincinnati	0.1	59.0	2.8	-0.01	0.52
Las Vegas	0.1	138.4	2.9	0.04	0.62
Nitrate-N (mg/l)					
Cincinnati	0.3	19.2	0.4	0.02	0.09
Las Vegas	0.0	18.6	0.7	0.02	0.17
Sulfates (mg/l)					
Cincinnati	15.0	320.0	10.0	0.17	1.13
Las Vegas	0.6	36.4	1.2	0.08	0.40
Iron (mg/l)					
Cincinnati	0.10	5.15	1.00	0.008	0.161
Las Vegas	0.00	7.35	1.00	0.109	0.128

Table V-A continued

Constituent and Laboratory	Range of the Original Readings: Lowest Value	Range of the Original Readings: Highest Value	Distribution Characteristics of the Original Readings Minus the Duplicate Readings: Highest Absolute Value	Mean	Standard Deviation
Manganese (mg/l)					
Cincinnati	UA	UA	UA	UA	UA
Las Vegas	0.00	1.73	0.02	-0.003	0.005
Sodium (mg/l)					
Cincinnati	1.0	254.0	4.0	0.00	0.63
Las Vegas	0.9	1025.0	29.0	0.95	4.91
Lead (mg/l)					
Cincinnati	0.005	0.200	0.012	-0.000	0.002
Las Vegas	0.002	0.131	0.030	-0.001	0.005
Arsenic (mg/l)					
Cincinnati	0.005	0.005	0.000	0.000	0.000
Las Vegas	0.001	0.021	0.006	0.000	0.006
Selenium (mg/l)					
Cincinnati	0.005	0.005	0.000	0.000	0.000
Las Vegas	0.005	0.014	0.005	0.000	0.004
Fluoride (mg/l)					
Cincinnati	UA	UA	UA	UA	UA
Las Vegas	0.10	0.91	1.62	-0.18	0.54
Cadmium (mg/l)					
Cincinnati	0.002	0.020	0.000	0.000	0.000
Las Vegas	0.002	0.012	0.000	-0.001	0.001
Mercury (mg/l)					
Cincinnati	0.001	0.006	0.004	0.000	0.000
Las Vegas	0.001	0.010	0.000	0.000	0.000
Chromium (mg/l)					
Cincinnati	0.005	0.005	0.000	0.000	0.000
Las Vegas	0.003	0.016	0.013	0.004	0.008

Table V-A continued

Constituent and Laboratory	Range of the Original Readings		Distribution Characteristics of the Original Readings Minus the Duplicate Readings		
	Lowest Value	Highest Value	Highest Absolute Value	Mean	Standard Deviation
Barium (mg/l)					
Cincinnati	0.2	0.3	0.1	-0.312	0.366
Las Vegas	0.0	0.4	0.0	-0.045	0.100
Silver (mg/l)					
Cincinnati	0.030	0.080	0.030	0.006	0.016
Las Vegas	0.010	0.020	0.000	-0.010	0.020

* UA - Unavailable.

Table V-B

Water Chemistry Laboratory Quality Assurance Results.
Recovery of Spikes

Constituent and Laboratory	Range of Spikes Used		Distribution Characteristics of the Percent of Recovered Spike			
	Lowest Value	Highest Value	Lowest Percent	Highest Percent	Mean	Standard Deviation
Turbidity (NTU)						
Cincinnati	NA*	NA	NA	NA	NA	NA
Las Vegas	NA	NA	NA	NA	NA	NA
Color (std. color units)						
Cincinnati	NA	NA	NA	NA	NA	NA
Las Vegas	NA	NA	NA	NA	NA	NA
Specific Conductance (micromhos)						
Cincinnati	UA**	UA	UA	UA	UA	UA
Las Vegas	UA	UA	UA	UA	UA	UA
Calcium (mg/l)						
Cincinnati	5.0	5.0	52.5	131.7	93.1	11.8
Las Vegas	2.0	20.0	57.7	124.8	93.0	14.1
Magnesium (mg/l)						
Cincinnati	1.0	1.0	76.8	131.3	101.8	7.8
Las Vegas	1.0	20.0	10.7	297.1	101.0	28.3
Nitrate-N (mg/l)						
Cincinnati	0.5	1.0	25.0	160.0	84.3	18.1
Las Vegas	0.3	7.5	3.26	254.14	64.2	48.9
Sulfates (mg/l)						
Cincinnati	10.0	40.0	44.4	105.3	90.8	13.0
Las Vegas	9.6	9.6	89.0	112.2	99.6	4.3
Iron (mg/l)						
Cincinnati	0.50	1.00	50.0	122.7	92.9	12.6
Las Vegas	0.50	2.00	2.5	210.8	89.7	31.7

Table V-B continued

Constituent and Laboratory	Range of the Spikes Used		Distribution Characteristics of the Percent of Recovered Spike			
	Lowest Value	Highest Value	Lowest Percent	Highest Percent	Mean	Standard Deviation
Manganese (mg/l)						
Cincinnati	0.50	1.00	20.2	179.2	97.5	13.4
Las Vegas	0.50	1.00	0.6	205.3	97.7	45.2
Sodium (mg/l)						
Cincinnati	5.0	10.0	27.2	186.1	102.1	18.3
Las Vegas	5.0	10.0	0.0	292.4	105.2	42.1
Lead (mg/l)						
Cincinnati	0.010	0.100	15.0	125.0	84.9	21.7
Las Vegas	0.020	0.200	14.3	177.1	81.3	33.0
Arsenic (mg/l)						
Cincinnati	UI***	UI	UI	UI	UI	UI
Las Vegas	0.200	0.400	84.6	117.0	99.2	16.5
Selenium (mg/l)						
Cincinnati	UA	UA	UA	UA	UA	UA
Las Vegas	0.200	0.400	11.1	73.6	49.8	27.0
Fluoride (mg/l)						
Cincinnati	0.50	1.00	83.3	116.7	96.5	11.6
Las Vegas	1.10	2.00	34.4	83.3	60.2	14.1
Cadmium (mg/l)						
Cincinnati	0.010	0.010	50.0	214.3	105.3	46.6
Las Vegas	0.050	0.050	83.1	101.9	92.5	13.3
Mercury (mg/l)						
Cincinnati	0.001	0.001	60.0	112.5	81.1	19.9
Las Vegas	0.001	0.005	75.7	103.7	95.3	7.1
Chromium (mg/l)						
Cincinnati	UI	UI	UI	UI	UI	UI
Las Vegas	0.200	0.200	97.0	218.9	128.6	60.2

Table V-B continued

Constituent and Laboratory	Range of the Spikes Used		Distribution Characteristics of the Percent of Recovered Spike			
	Lowest Value	Highest Value	Lowest Percent	Highest Percent	Mean	Standard Deviation
Barium (mg/l)						
Cincinnati	0.5	1.0	68.3	121.4	90.7	17.8
Las Vegas	1.0	1.0	78.0	156.1	109.9	41.0
Silver (mg/l)						
Cincinnati	0.500	0.500	49.1	128.3	83.9	24.6
Las Vegas	0.200	0.400	77.3	97.0	88.4	9.4

*NA - not applicable.
**UA - Unavailable.
***UI - Uninterpretable.

Table V-C

Water Chemistry Laboratory Quality Assurance Results. Performance Results on Laboratory Standard Solution Tests

Constituent and Laboratory	Range of Standard Solutions Used: Lowest Value	Range of Standard Solutions Used: Highest Value	Distribution Characteristics of Known Standard Solutions Minus the Measure of the Standard: Lowest Value	Highest Value	Mean	Standard Deviation
Turbidity (NTU)						
Cincinnati	UA**	UA	UA	UA	UA	UA
Las Vegas	10.0	10.0	0.0	0.5	0.08	0.10
Color (std. color units)						
Cincinnati	NA*	NA	NA	NA	NA	NA
Las Vegas	NA	NA	NA	NA	NA	NA
Specific Conductance (micromhos)						
Cincinnati	UA	UA	UA	UA	UA	UA
Las Vegas	586.0	720.0	-12.0	11.0	-0.04	4.30
Calcium (mg/l)						
Cincinnati	UA	UA	UA	UA	UA	UA
Las Vegas	5.0	100.0	-7.9	5.6	-0.61	2.02
Magnesium (mg/l)						
Cincinnati	UA	UA	UA	UA	UA	UA
Las Vegas	5.0	100.0	-4.9	6.1	-0.27	1.02
Nitrate-N (mg/l)						
Cincinnati	UA	UA	UA	UA	UA	UA
Las Vegas	1.0	1.0	0.0	0.1	0.01	0.01
Sulfates (mg/l)						
Cincinnati	UA	UA	UA	UA	UA	UA
Las Vegas	UA	UA	UA	UA	UA	UA
Iron (mg/l)						
Cincinnati	UA	UA	UA	UA	UA	UA
Las Vegas	0.50	10.00	-4.80	1.00	-0.033	0.521

Table V-C continued

Constituent and Laboratory	Range of Standard Solutions Used		Distribution Characteristics of Known Standard Solutions Minus the Measure of the Standard			
	Lowest Value	Highest Value	Lowest Value	Highest Value	Mean	Standard Deviation
Manganese (mg/l)						
Cincinnati	UA	UA	UA	UA	UA	UA
Las Vegas	0.20	5.00	-0.08	2.02	0.036	0.250
Sodium (mg/l)						
Cincinnati	UA	UA	UA	UA	UA	UA
Las Vegas	10.0	100.0	-6.0	3.8	-0.51	1.36
Lead (mg/l)						
Cincinnati	UA	UA	UA	UA	UA	UA
Las Vegas	UA	UA	UA	UA	UA	UA
Arsenic (mg/l)						
Cincinnati	UA	UA	UA	UA	UA	UA
Las Vegas	0.100	0.500	-0.023	0.035	0.000	0.015
Selenium (mg/l)						
Cincinnati	UA	UA	UA	UA	UA	UA
Las Vegas	UA	UA	UA	UA	UA	UA
Fluoride (mg/l)						
Cincinnati	UA	UA	UA	UA	UA	UA
Las Vegas	UA	UA	UA	UA	UA	UA
Cadmium (mg/l)						
Cincinnati	UA	UA	UA	UA	UA	UA
Las Vegas	UA	UA	UA	UA	UA	UA
Mercury (mg/l)						
Cincinnati	UA	UA	UA	UA	UA	UA
Las Vegas	UA	UA	UA	UA	UA	UA
Chromium (mg/l)						
Cincinnati	UA	UA	UA	UA	UA	UA
Las Vegas	0.100	0.500	-0.038	0.000	-0.012	0.011

Table V-C continued

Constituent and Laboratory	Range of Standard Solutions Used: Lowest Value	Range of Standard Solutions Used: Highest Value	Distribution Characteristics of Known Standard Solutions Minus the Measure of the Standard: Lowest Value	Highest Value	Mean	Standard Deviation
Barium (mg/l)						
Cincinnati	UA	UA	UA	UA	UA	UA
Las Vegas	1.0	5.0	-0.1	1.0	0.10	0.29
Silver (mg/l)						
Cincinnati	UA	UA	UA	UA	UA	UA
Las Vegas	0.100	0.500	-0.010	0.010	0.000	0.010

*NA - Not applicable.
**UA - Unavailable.

METHOD OF PRESENTATION

The NSA results which follow are grouped in four broad categories—(1) bacterial content, (2) physical or chemical properties (turbidity, color, temperature, specific conductance, or hardness), (3) inorganic and organic constituents, and (4) radioactivity. Background information for the results comes from a variety of sources (see References), but primarily from the national interim primary drinking water regulations and the 1977 report by the National Research Council (NRC) entitled Drinking Water and Health.[6] The NRC report reviews the subject of water quality in extensive detail and critically assesses recent regulatory approaches.

The focus in this report is on the findings for the various NSA constituents. Specific laboratory techniques used to obtain the findings are described only in general terms, if at all. Details about the laboratory procedures, beyond those cited in the preceding section, are found in Appendix C. In reviewing the NSA findings, it is helpful to keep in mind that some of the constituents were studied for each of the 2,654 NSA sample households, and the results were then projected to rural America. Some of the constituents, however, were studied only for a special 267-household, 10-percent subsample of the surveyed households. The groupings are set out in Table V-1. In reporting the laboratory results, there is a coincidental grouping in which constituents studied at the full sample of households are reported on in sequence, from the total coliform findings through the manganese findings. Then, in reporting the laboratory results for the constituents at the subsample households, there is a subsequent grouping which includes the arsenic findings through the radionuclide findings. One major consequence of the different sample sizes is the statistical confidence with which the results can be projected to all of rural America (see Appendix B).

Within the full-sample and subsample groupings, the presentation of the NSA findings follows the same order of reporting generally used in previous chapters. That is, findings are presented first for households in the nation as a whole; second, for households according to their location in different geographic regions; third, for households according to their location inside or outside of SMSAs (regardless of geographic region); fourth, for households according to their location in large rural communities, small rural communities, or other rural areas; and, fifth, for households according to the type of water system they use (community, intermediate, or individual). After the presentation of findings in these different groupings, the health-related implications of the findings are discussed, when warranted.

To supplement the narrative discussion of each constituent, graphs are presented which plot the distribution of most constituents in household supplies across the nation and within each of the four geographic regions. In addition, graphs on semilog scales are used to present the national distribution of values for certain constituents which were present in household supplies in a very wide range of concentrations. Graphs are not presented for the other subnational comparisons, but differences in the various groupings are set forth fully in the text.

As to the statistical analyses, there are several summary statistics which are employed routinely, most notably medians and percentages. Means generally are not used for two reasons. The first reason is that, for many of the constituents, the mean would be biased toward a slightly too-large reading. This is a result of the standard laboratory practice of reporting a lower limit of detection. That is, when concentrations become very small in relation to the measurement capacity of the laboratory instruments, the measurements begin to be unreliable. Rather than induce an artificial degree of precision into the data, a lower detection limit is established, and the limit is assigned to households when the measured quantity is lower than that detection limit. Hence, in calculating the mean, each household with very small concentrations gets a value which, though small (the lower detection limit), is usually larger than the true concentration, thereby slightly inflating the mean.

The second reason is that the mean, being the average of values for all households, would be strongly influenced by a few very large values, which sometimes occurred in the NSA. The median, being the midpoint between the highest and lowest values in a distribution, is not affected by extremely high or low values; nor is it affected by the lower limit of detection. The median is often more useful than the mean for summarizing data trends, and it is used almost exclusively in discussion of the NSA laboratory results. Since a formula is used for calculating the median, it is sometimes expressed as a fraction even though the counts may be in whole numbers.

Percentages are used to indicate relative proportions of households in a certain range of constituent values. They are especially helpful in establishing perspective for the overall situation. They do not directly indicate the numbers of households involved, however, and it should be kept in mind that relatively small percentages may actually refer to a large number of households—for example, 5.0 percent of households may be equivalent to as many as 1.1 million households.

Finally, a special note is required to aid interpretation of findings in one grouping—size of place. As explained in Chapter II, one grouping of households for analysis in the NSA was according to the size of place in which they were located: places with 1,000 to 2,500 people (sometimes referred to in this report as large rural places or large rural communities), places with fewer than 1,000 people (sometimes referred to as small rural places or small rural communities), and other rural areas—roughly, those areas which range from open country to informally recognized communities.

On the basis of the NSA findings, about 82 percent of rural households are located in other rural areas, compared to about 11 percent in large rural communities and 7 percent in small rural communities. Households within each of these three classifications are not distributed evenly throughout the US, however. In Chapter III, it was pointed out that about 70 percent of all rural households are located in two regions—the South (42.3 percent) and the North Central (28.3 percent). Therefore, rural households within the three size-of-place classifications are located predominantly in the South and North Central.

For a number of NSA constituents—calcium, magnesium, nitrates, arsenic, and others—size-of-place findings are influenced by the regional distribution of households. The presence of these constituents tends to be related at least in part to geological or environmental factors which vary from region to region. Thus, concentrations of the constituents are likely to be greatest in households located in size-of-place classifications which happen to be located predominantly in regions where the constituents are naturally present in greater-than-usual quantities. This situation is particularly apparent in findings for households in small rural communities. About one-half of all the households located in small rural communities are in the North Central. Coincidentally, the largest concentrations of a number of constituents also are in the North Central. Thus, as discussed in the reports which follow, households in small rural communities sometimes show larger-than-expected levels of constituents, not primarily because of some unique aspect related to small communities, but because of the geographic location of the households. On the other hand, some findings for households in small rural communities appear to indicate that the category has certain aspects which require special consideration.

BACTERIAL CONTENT

Four standard tests of bacteriological conditions were performed on all NSA household water specimens. The procedures measured content of total coliform bacteria, fecal coliform bacteria, fecal streptococcal bacteria, and total bacteria as determined by the standard plate count method. These tests had one feature in common: they did not measure content of disease-causing organisms directly; instead, they produced results which could determine, or at least indicate, whether there was disease potential.

This indirect approach to monitoring pathogens in water is the best available, despite its inability to measure disease threat directly. In the proceedings from the water quality workshop sponsored by the National Science Foundation, it is pointed out that: "For some pathogens, even the qualitative techniques for demonstration of their presence in water are quite unreliable and, even when the pathogens are found, there is no way to tell if they are viable and virulent enough to establish an infection."[7]

In view of this, an indirect method for specimen analysis is necessary: "The way around the problems of enumerating pathogens and establishing their virulence," the editor continues, "is to measure the degree of contamination of the water with fecal material. The amount of fecal material in the water is measured by enumerating nonpathogenic fecal bacteria for which reasonably accurate microbiological techniques are available. The basis for this is the assumption that if the water is contaminated with the feces of a large number of people, the person-to-person variation in excretion of pathogens and indicators will be averaged out, and there will be a more-or-less stable ratio of indicators to pathogens. The (numerical) value of the ratio of indicators to pathogens is a function of the number of excreters of the pathogen in the population which in turn should be related to the incidence of the disease."

Total coliform bacteria

Assay of coliform bacteria has been a standard test of drinking water quality for 70 years. The standard admittedly is imperfect, but it has been a reliable tool in drinking water sanitation. The coliform bacteria generally do not themselves cause disease. Rather, they are "indicator organisms" which are present in human and animal feces as well as in other organic materials and therefore are often indicative of fecal contamination. The fecal wastes, in turn, may contain disease organisms which can cause typhoid fever, salmonellosis, gastroenteritis, and other intestinal diseases. Technically, the coliform group includes all of the aerobic and facultative anaerobic, Gram-negative, non-spore-forming, rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35° C. (For the membrane filter technique described below, this definition is altered to the bacteria, as described here, which produce a dark colony with a metallic sheen within 24 hours of incubation.)[8]

To a much lesser extent, the coliform bacteria signal possible hazard from pathogenic protozoa or intestinal worms (helminths) excreted in human feces. Also, to a certain extent, the indicator bacteria may warn of possible viral disease, but in this regard, the test is especially weak. This is particularly so because many viruses can substantially outlast the coliform bacteria indicators. As long as the indicator bacteria survive with the viruses, the indicator warning tag is intact. If the viruses survive even though the bacteria die, however, the warning is lost.

Special care was used in handling the water specimens intended for bacteriological analysis. As soon as the water was drawn, the container was packed in ice and shipped by air to the laboratory. Any specimen which could not be analyzed within 30 hours was discarded, and a new specimen was taken from the same household. Despite these procedures, the count of viable organisms in each specimen was expected to be lower than when the water was first drawn.

The bacteriological results, therefore, were a conservative estimate of the number of indicator organisms which were actually present in the tap water.

Conceptually, the total coliform test is best regarded not as an indicator of water quality at all, but rather as an indicator of possible fecal contamination or of the effectiveness of disinfection, since potable water should be free of coliform organisms. According to the NRC: "It has been reported repeatedly in the literature that the presence of any type of coliform organism in drinking water is undesirable. The regulations essentially demand that coliform-free water be distributed to consumers. Wolf has ably summarized: 'The drinking water standard presently in use (approximately one coliform per 100 ml.) is, in a sense, a standard of expedience. It does not entirely exclude the possibility of acquiring an intestinal infection. It is attainable by the economic development of available water supplies, their disinfection, and, if need be, treatment in purification works by economically feasible methods. It is not a standard of perfection'."[9]

In assessing the NSA findings in terms of overall implications for health in rural America, it is important to keep in mind that the total coliform count is primarily useful as an indication of the status of sanitation in water supplies. That is, the presence of coliform organisms indicates pollution in the supply which should be corrected by measures such as treatment, protection of the supply source, or even change in the supply source. In addition to providing this warning, the total coliform count provides an indication of <u>possible</u> disease potential in the water supply.

Many attempts have been made to establish some direct relationship between a specific number of coliform organisms and the presence of disease organisms, but a consistent relationship has not been proven. It is impossible to predict how many, or what kind, of disease organisms can be expected at a particular coliform concentration. For this and a number of other reasons, there is little scientific evidence pointing to a reliable "threshold" at which the level of coliform bacteria is associated statistically with increased incidence of disease. It is possible, however—on theoretical grounds only—to state that water supplies with more than one coliform bacteria per 100 milliliters "can be responsible for waterborne disease, both gastroenteritis and typhoid fever."[10]

In addition to this theoretical conclusion, one 1953 study by Albert H. Stevenson indicates increased incidence of disease in water used for swimming when total coliform organisms in the water exceed at least 2,300 per 100 milliliters.[11] Although the Stevenson study is being reevaluated by the National Environmental Research Center, the study findings "added much weight to the rationale of establishing a coliform standard for drinking-water sources," according to the NRC.[12] A level of more than 2,300 coliform organisms per 100 milliliters thus is taken in the NSA as a possible indication of increased hazards to human health.

Most attempts to associate total coliform counts with some range of pathogen counts have been made with reference to water sources contaminated with feces from many people. Rural water supplies, which are often individual wells located on users' household premises, draw water from sources which generally are not subject to fecal contamination by large numbers of people. Coliform bacteria in such supplies are likely to originate from a few individuals or animals, or from decaying organic material. In this sense, the total coliform test is even less interpretable for rural households than for community water systems. Nevertheless, whenever viable coliforms occur in a water supply, they indicate that the supply is not completely protected. Their presence, regardless of origin, signals a possible health hazard to anyone who consumes the water. However, while such supplies constitute a continuing health risk, it is very possible for users to show no adverse health effects, even after many years of exposure.

The levels of total coliform bacteria in the NSA were determined by the membrane-filter technique. According to the technique, coliform organisms were those which produced a dark colony (generally purplish-green) with a metallic sheen within 24 hours of incubation on an appropriate culture medium. The colonies were counted under magnification, and the number counted was reported as the total number of coliform organisms (on the assumption that most of the colonies had each been produced by just one of the organisms originally present). In a very small number of samples, the membrane-filter technique was not usable for technical reasons, and the somewhat slower most-probable-number technique was used instead. This alternative technique was employed so infrequently that the following NSA results can be assumed to be based on the membrane-filter procedure.

In monitoring coliform levels, suppliers are given some leeway. The number of specimens to be taken depends on the size of the population served; when there are more than four coliform bacteria in a single 100-milliliter specimen, intensified monitoring is required until the average concentration in specimens is less than one coliform bacterium per 100 milliliters of water. Here, the interim primary MCL is assumed to be one coliform bacterium per 100 milliliters, and that value is taken as the NSA reference value.

— Total coliform bacteria levels in rural supplies

In rural America, 28.9 percent or 6.4 million households had major supplies with two or more coliform organisms per 100 milliliters of water (Figures V-2, V-2a). Thus, more than one out of every four rural households exceeded the NSA reference value and were served by water supplies which needed attention such as further water quality studies, disinfection, or some other protective measure.

When larger concentrations were considered, 3.7 percent of all rural households—a total of about 813,000—had total coliform levels exceeding 1,000 organisms per 100 milliliters. The levels exceeded 2,300 organisms at 2.4 percent of all rural households.

Figure V-2
Total Coliform in US Rural Household Supplies

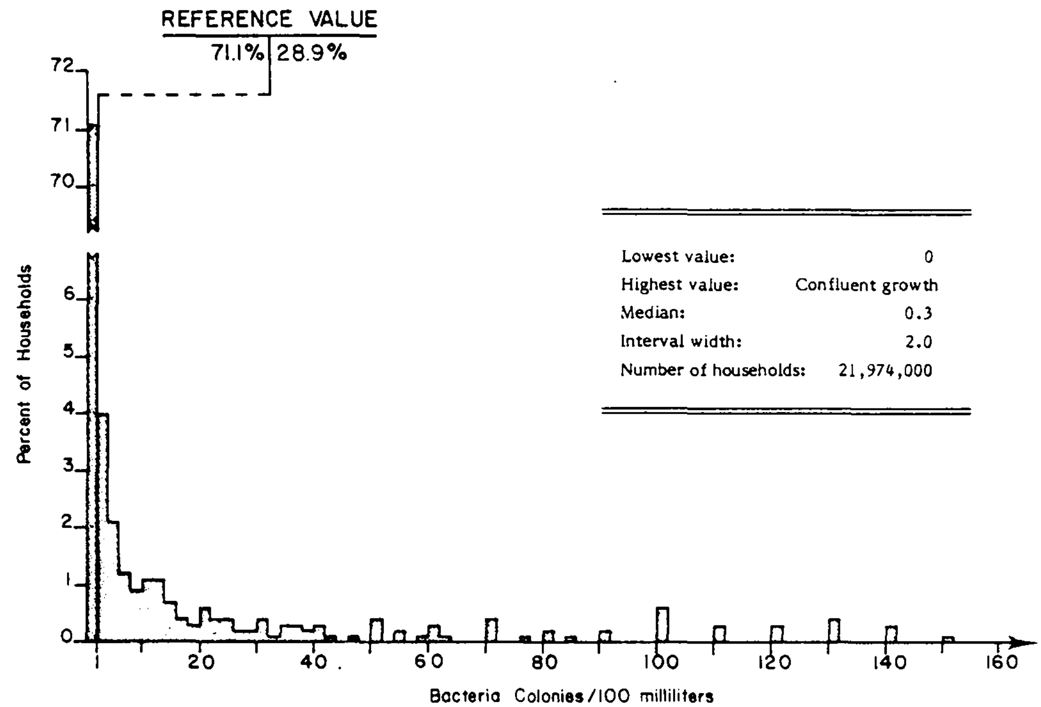
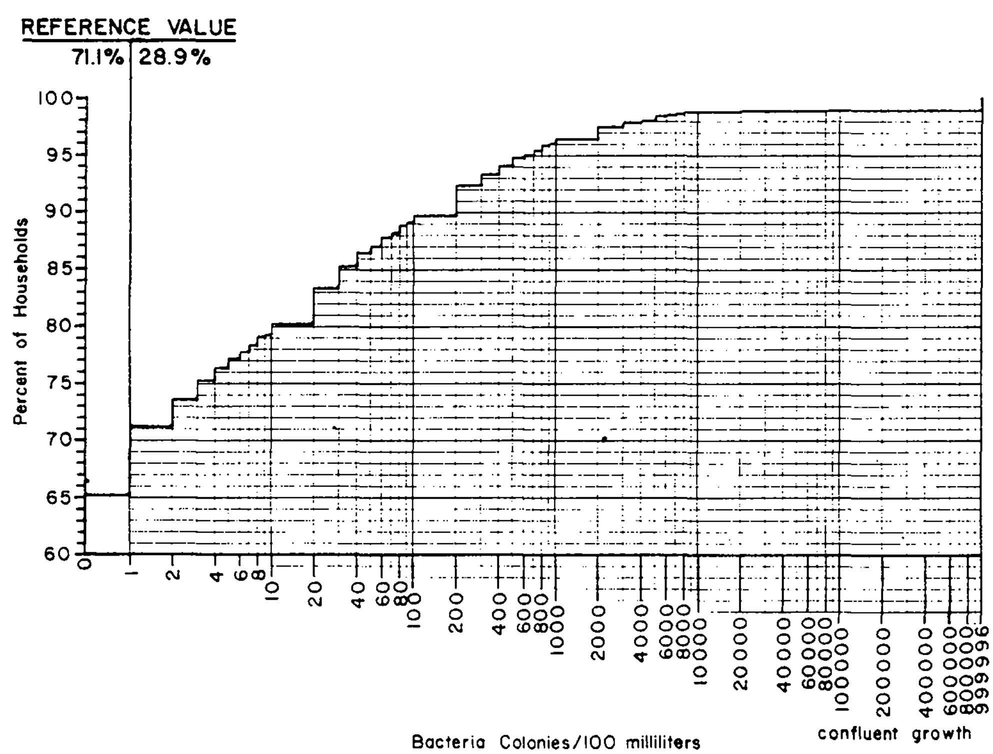


Figure V-2a. Cumulative Distribution of Total Coliform



NOTE: Cumulative distribution is plotted on semilog paper. Base: 21,974,000 households.

Although total coliform bacterial colonies were estimated in whole numbers (as were colonies of fecal streptococcal and fecal coliform bacteria, to be discussed shortly), the median and mean values were derived by formula, and they were not whole numbers. The median was the most meaningful summary number since the mean (10,500 total coliform bacterial colonies) was strongly influenced by very large values which occurred in a relatively small percentage of rural households. The median, then, was 0.3 (i.e., less than one) total coliform bacterial colonies in major household water supplies in rural America.

In terms of regional variations (Figures V-2b through V-2e), the NSA reference value was exceeded most commonly in the South and West. There, about 32 percent and 31 percent, respectively, of the rural households were above the reference value. The North Central had the lowest proportion of households above the reference value—24.4 percent. The results indicated, however, that the contamination was not localized in any one particular region, but rather was pervasive throughout rural America.

In comparing the results for SMSA and nonSMSA households, it was found that 18.3 percent of the SMSA households exceeded the NSA reference value, compared to 33.9 percent of the nonSMSA households. Similarly, supplies in other rural areas were contaminated more commonly than those in places of larger population. (About 31 percent of other-rural-area household supplies were above the reference value, compared to 20 percent of supplies in small communities and 18 percent of supplies in large communities.)

A striking contrast was that households served by intermediate or individual systems exceeded the reference value more than 40 percent of the time—nearly three times as often as households using community systems. Of the 6.4 million rural households above the NSA reference value, 4.7 million were served by these small water systems. At the same time, 1.7 million households using community systems also exceeded the reference value.

Regional Variation in Total Coliform in US Rural Household Supplies

Figure V-2b. Northeast

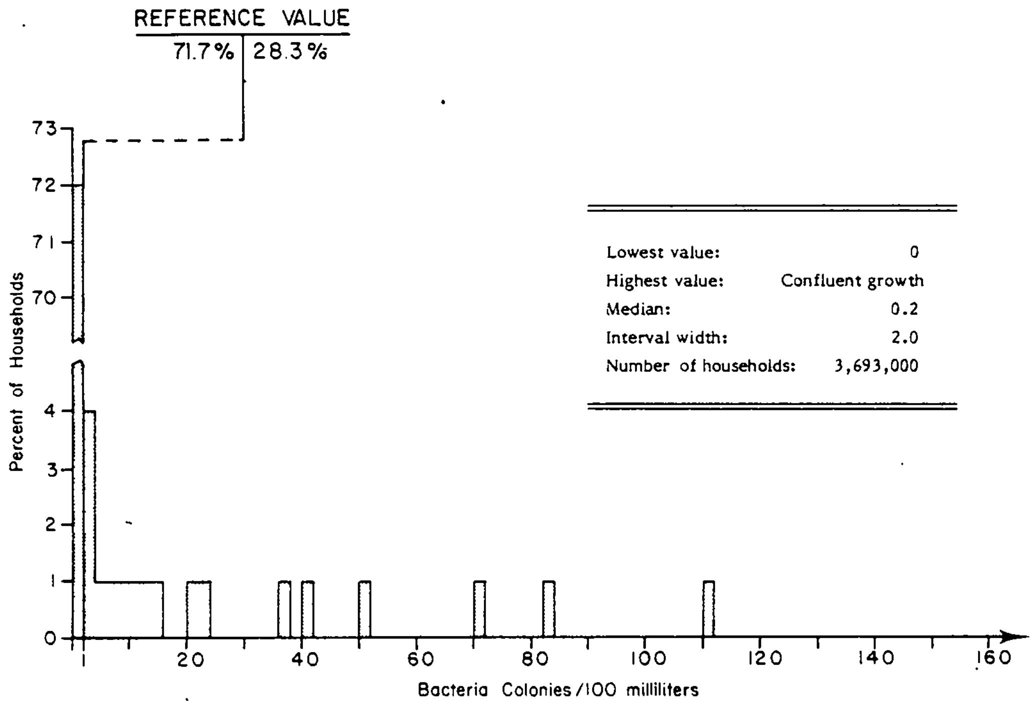
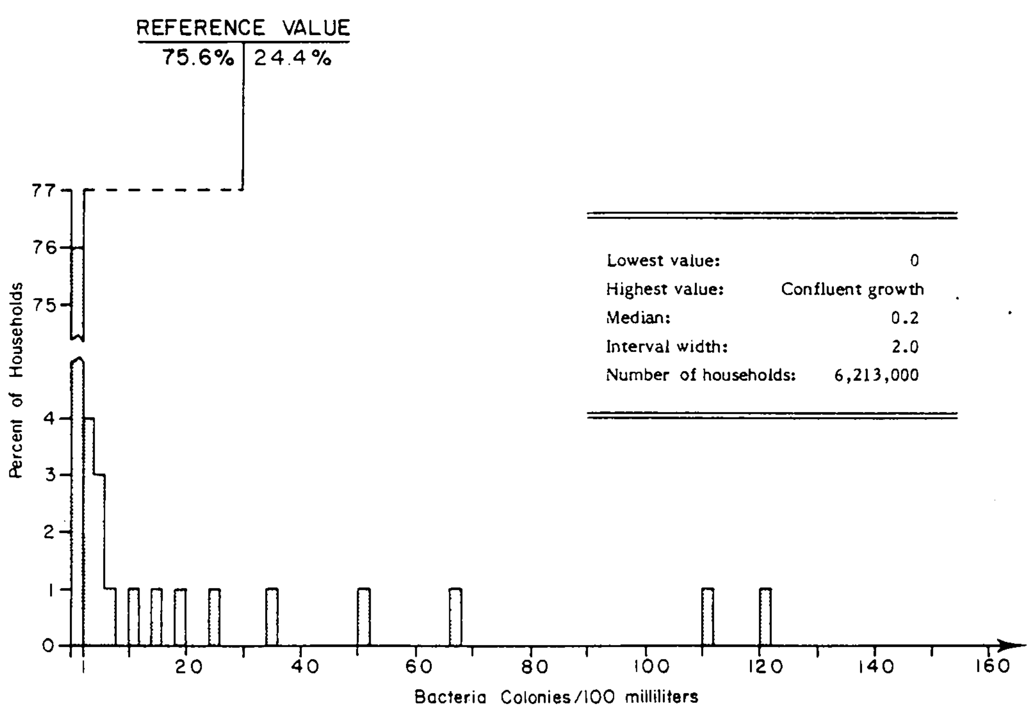


Figure V-2c. North Central



Regional Variation in Total Coliform (continued)

Figure V-2d. South

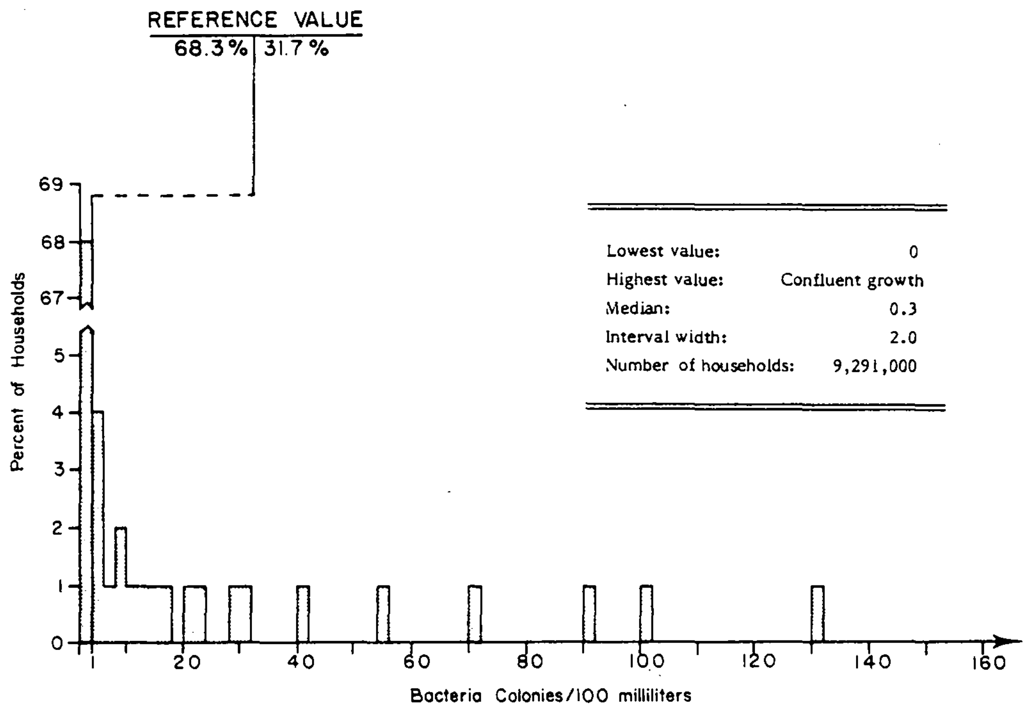
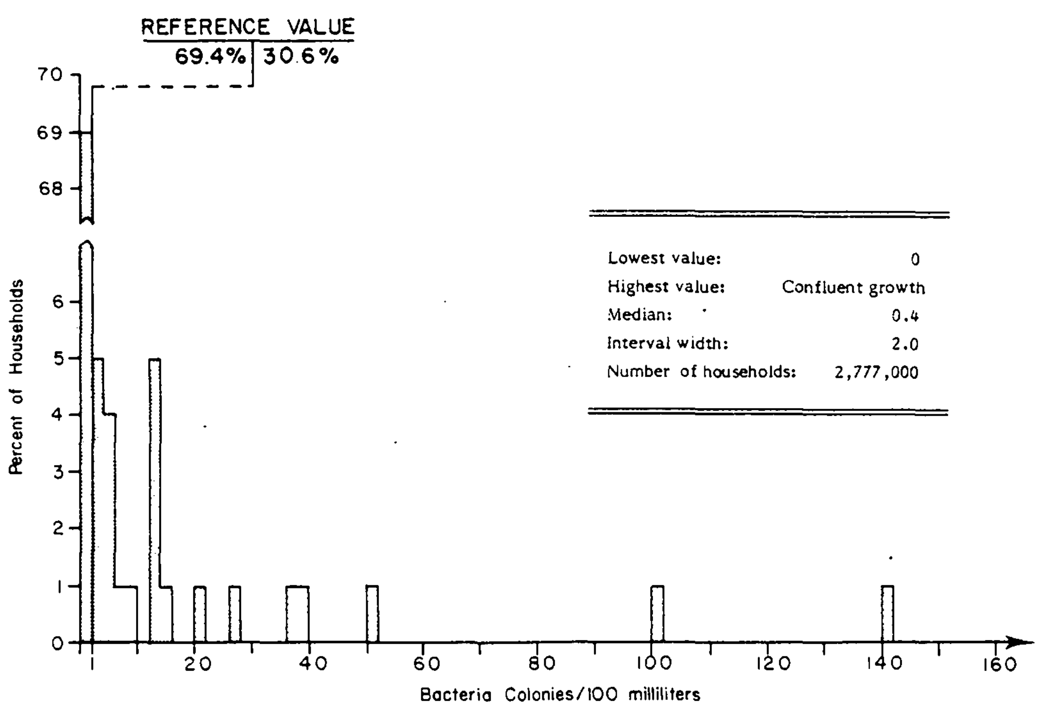


Figure V-2e. West



In terms of possible health implications for rural America, the values discussed in the introductory material above provide some perspective in assessing the NSA data. On theoretical grounds, then, there was the chance for waterborne, bacterially induced disease in some of the 6.4 million rural households with more than one coliform organism per 100 milliliters of water. The major implication for many of those households, however, was not that an immediate health threat existed (a hazard which could not be directly proven on the basis of the total coliform tests, as explained above), but rather that the supplies required further assessment to determine the need for remedial action. Considerable evidence points to increasing health risk as the concentration of total coliform bacteria rises, however, and in this light a number of rural American households had potentially serious conditions in their water supplies. For example, the 527,000 household supplies in the nation that had levels exceeding 2,300 coliform organisms were at levels even greater than those which have been associated with increased incidence of disease in some public bathing waters.

The potential problems from bacterial contamination were pervasive in rural America. They were not limited to any particular region of the country. On the other hand, the problems were most prominent in households in areas classified as other rural (mostly in open country) which were served by individual or intermediate systems. This pattern was consistent with other studies pointing to contamination being associated most often with individual wells in areas outside of major communities.[13]

Fecal coliform bacteria

Because of the generalized nature of the total coliform bacteria test, other tests have been proposed. In particular, a test for fecal coliforms has been favored to assess the recentness of fecal contamination in water supplies. The test has gained acceptance primarily for evaluation of recreational and shellfish waters rather than for drinking water, however.[14] The usual test for fecal coliforms is, in essence, an extension of the total coliform test, but with a different medium and with the incubation temperature raised from 35° C to 44.5° C. The advantage is that at the higher temperature, nonfecal coliform bacteria (such as those originating from soil and plants) generally do not grow well. These bacteria are included in the total coliform count (above), but they have less significance for human health. Although the test for fecal coliforms provides an indication of recent contamination from human or animal feces, fecal coliforms are less numerous than total coliforms, and thus provide a less sensitive indication of pollution than does the total coliform content.

Furthermore, as with other indicator tests, the one for fecal coliforms does not pinpoint specific pathogens. Rather, presence of fecal coliforms indicates the possibility of pathogens and accompanying health risks. However, fecal coliforms can die at a faster rate than some pathogens, a situation which diminishes their usefulness as indicator organisms.

As with total coliform organisms, various attempts have been made to establish a direct relationship between a specific number of fecal coliforms and the presence of disease organisms. For example, *Salmonella* bacteria are potential pathogens which can be detected fairly easily in water, and for convenience they have been studied in association with fecal coliforms. This has been done to give investigators a feeling for the possibility of a direct relationship between concentrations of fecal coliforms and the occurrence of disease organisms. The studies have not shown a precise, reliable relationship. However, Edwin E. Geldreich has reported that "field data from numerous fresh water and estuarine pollution studies indicate a sharp increase in the frequency of *Salmonella* detection when fecal coliform densities are above 200 organisms per 100 milliliters."[15]

This generalized finding does not mean that the incidence of waterborne disease will necessarily increase exactly at this threshold concentration of fecal coliforms. There is marked variation in the occurrence of *Salmonella* bacteria and other disease organisms regardless of the concentration of fecal coliforms, and there is great variation in susceptibility of persons exposed to the organisms. Nevertheless, Geldreich concludes that the evidence supports a limit of no more than 200 fecal coliforms per 100 milliliters for water to be used for recreation such as swimming.

There is no federal standard for concentration of fecal coliform bacteria in drinking water, but the presence of even one such organism is taken as indication of fecal contamination which requires attention. The EPA makes this statement: "Although the total coliform group is the prime measurement of potable water quality, the use of a fecal coliform measurement in untreated potable supplies will yield valuable supplemental information. Any untreated potable supply that contains one or more fecal coliforms per 100 milliliters should receive immediate disinfection."[16] In the NSA, the reference value was zero, or the complete absence of fecal coliform bacteria in a 100-milliliter sample.

— Fecal coliform bacteria levels in rural supplies

About 12.2 percent of all rural households (approximately 2.7 million) had supplies with one or more fecal coliform bacteria (Figures V-3, V-3a) and thus exceeded the NSA reference value. The level exceeded 200 organisms per 100 milliliters at about 350,000 households (1.6 percent of all households), and it ranged up to concentrations which were too dense to count (confluent growth) at 109,000 households (0.5 percent of all households). The median for the rural US was 0.1 fecal coliform colonies.

In terms of regional variations, the percentage of households showing fecal coliforms was the same (14.0 percent) in three regions: the Northeast, South, and West (Figures V-3b through V-3e). In the North Central, the proportion was six percentage points less. The evidence thus was that, as with total coliform

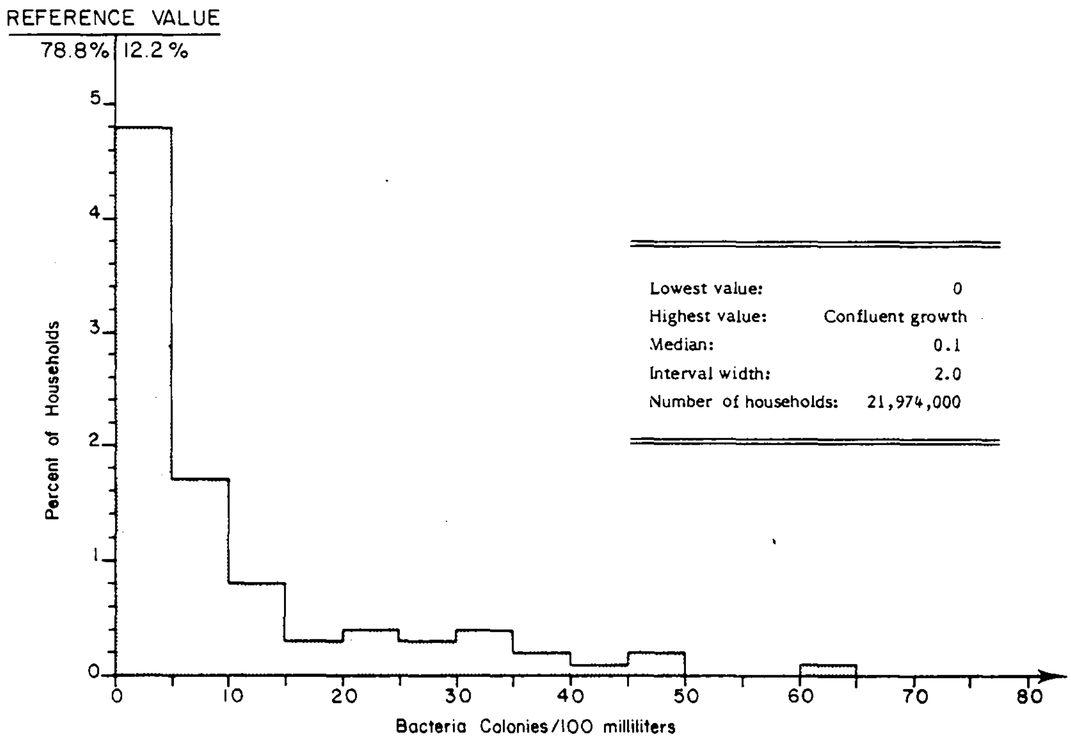
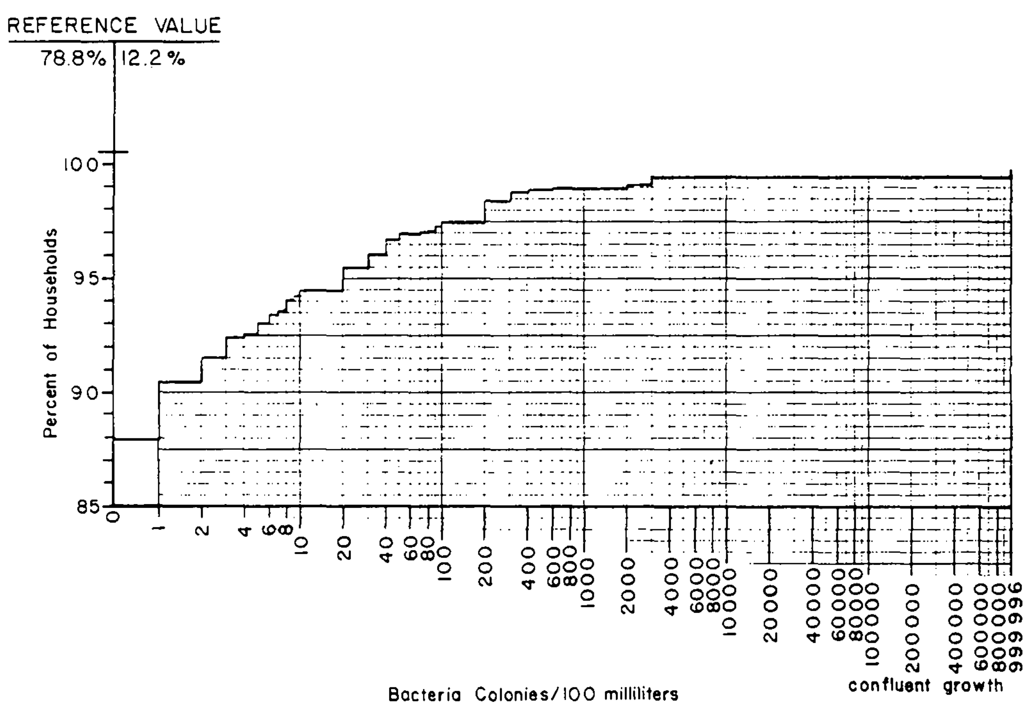


Figure V-3a. Cumulative Distribution of Fecal Coliform



NOTE: Cumulative distribution is plotted on semilog paper. Base: 21,974,000 households.

Regional Variation in Fecal Coliform in US Rural Household Supplies

Figure V-3b. Northeast

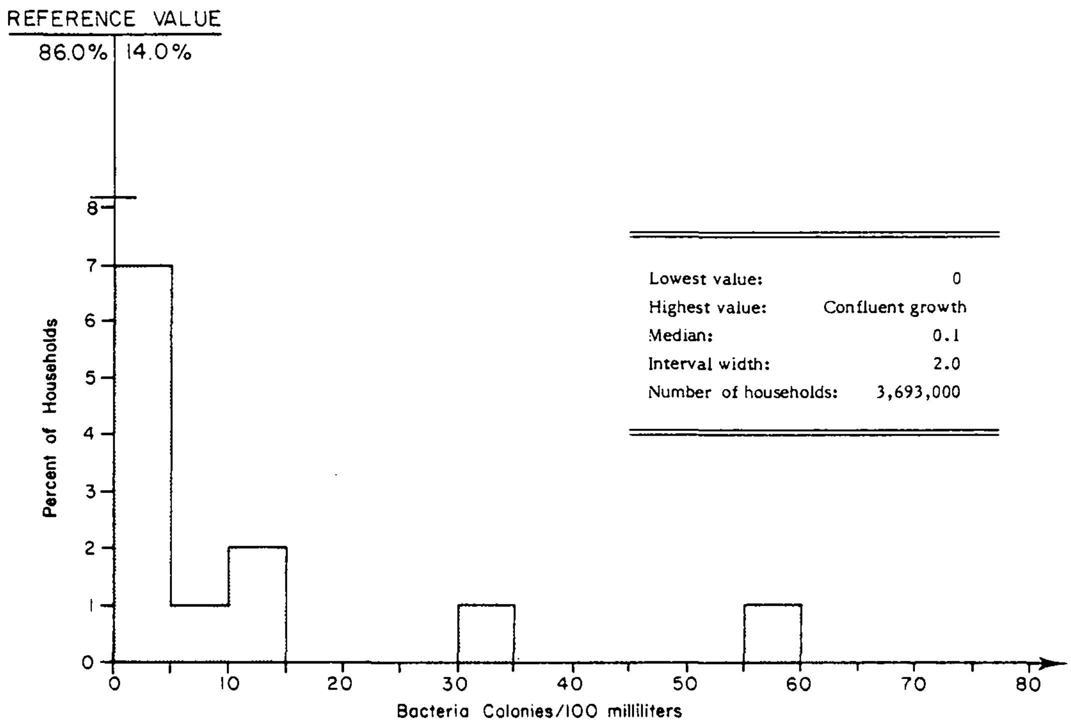
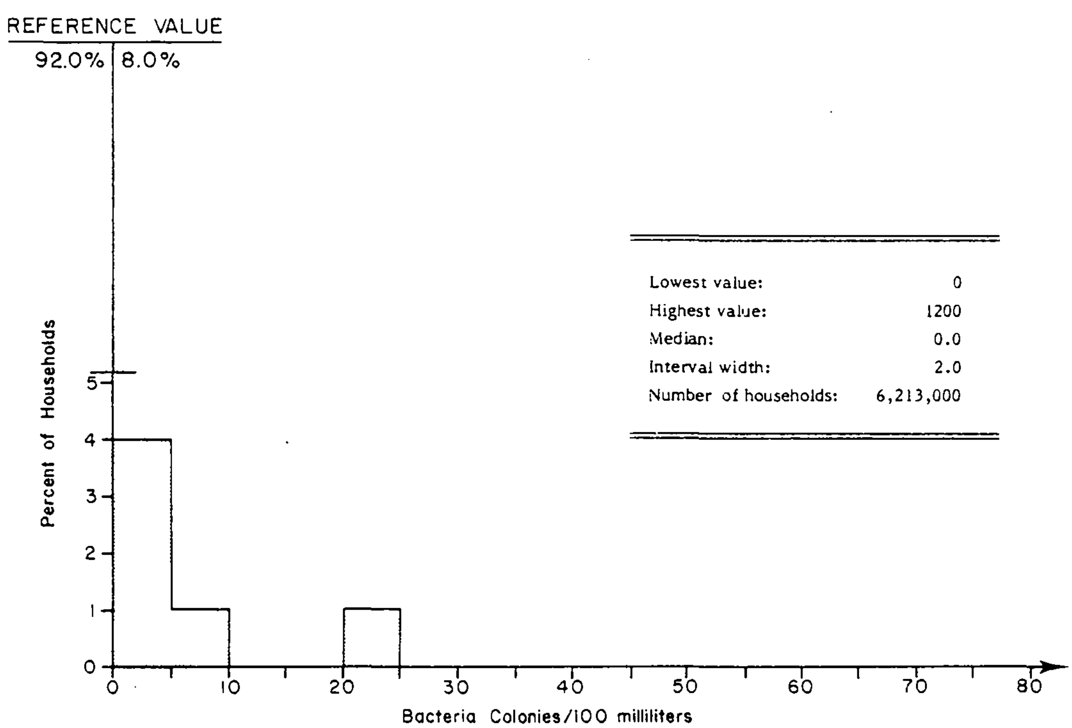


Figure V-3c. North Central



Regional Variation in Fecal Coliform (continued)

Figure V-3d. South

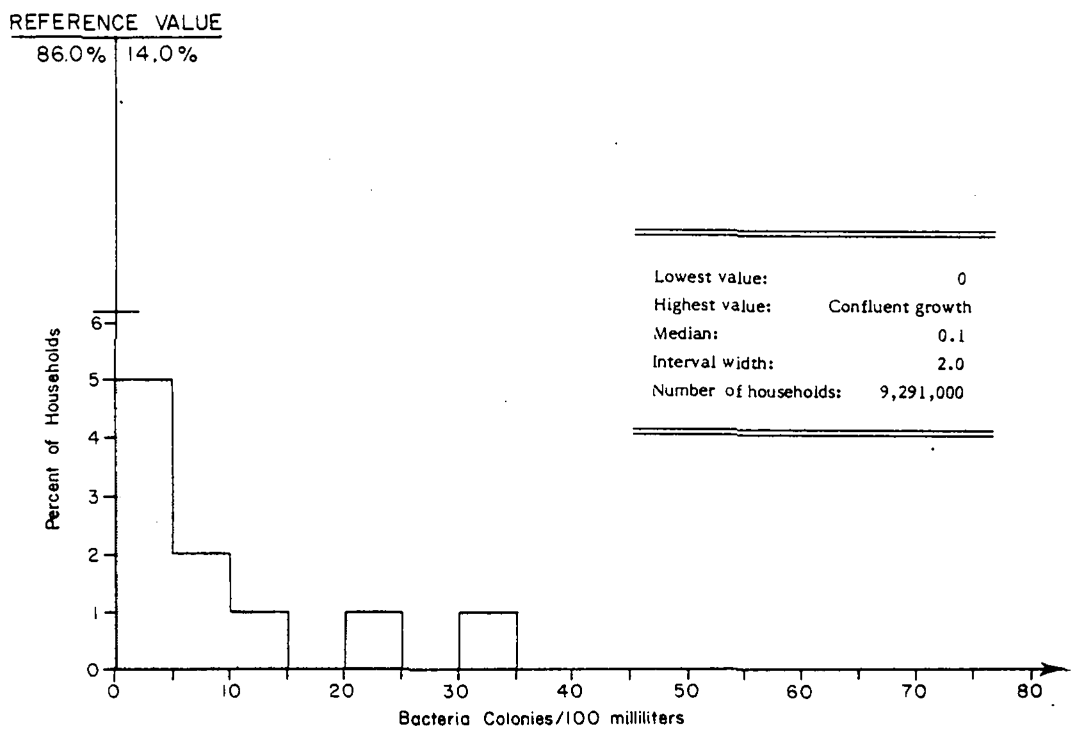
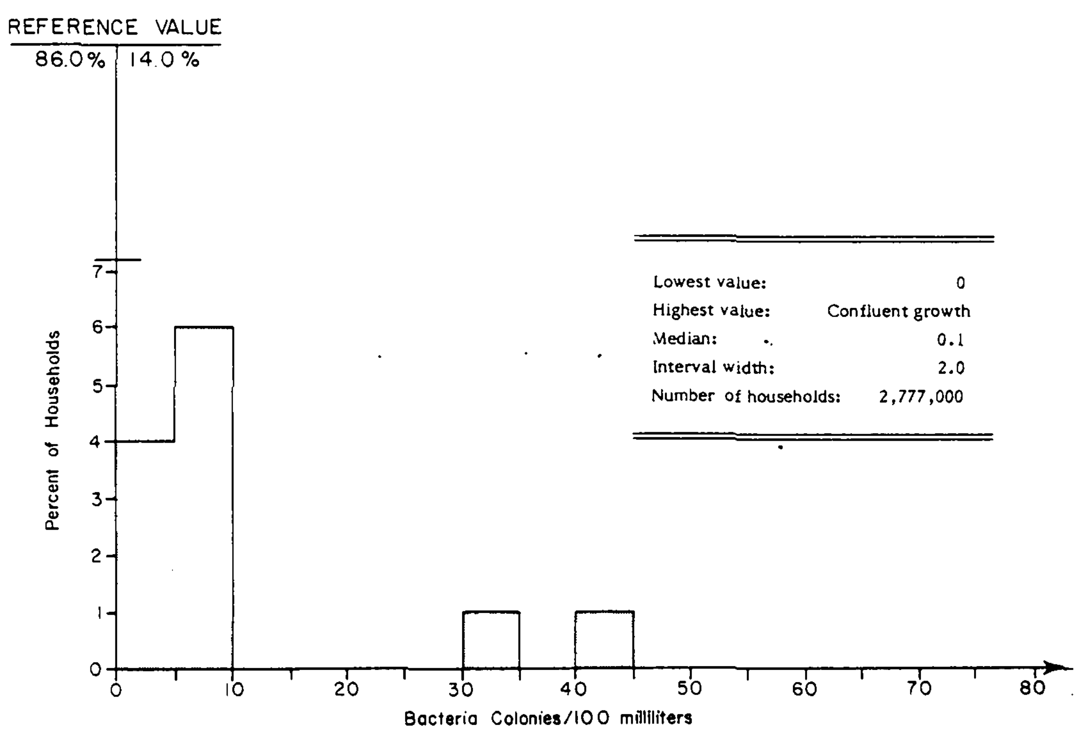


Figure V-3e. West



contamination, contamination from fecal coliform bacteria occurred across the US and was not localized in one region. Even in the North Central, although the percentage of households exceeding the reference value was smaller than elsewhere (8.0 percent), the number of households involved was about 400,000—more than in the West and Northeast.

There were one or more fecal coliforms per 100 milliliters in twice as large a proportion of nonSMSA households as SMSA households—in 15.0 percent of the former and 7.0 percent of the latter. Also, this contamination occurred about three times as frequently in households in other rural areas as in households in either of the other two size-of-place classifications (14.0 percent in other rural areas, compared to less than 5 percent in large and small rural communities).

Fecal coliform bacteria were found five times more frequently in rural households served by individual or intermediate systems as in households served by community systems. Specifically, 4.0 percent of households served by community systems had fecal coliforms, as opposed to 20.0 percent of households served by individual or intermediate systems.

As to the potential health effects of the fecal coliform levels in rural households, the presence of even one fecal coliform bacterium in a 100-milliliter specimen is viewed with concern by public health authorities. The supplies in 2.7 million households with at least one organism thus presented potentially significant problems. All of the supplies were candidates for prompt study and possible treatment. Furthermore, in about 350,000 of these households, the fecal coliform level was greater than 200 organisms per 100 milliliters. That concentration was in excess of the limit viewed by some authorities as excessive even for public swimming water (as noted before), and it represented a potentially serious sanitary problem.

Generally, variations in the degree of contamination by region and other groupings were similar to those for total coliform bacteria. Overall, the most serious contamination problems involving either total or fecal coliform bacteria existed in rural households which were outside of SMSAs, located in other rural areas, or served by intermediate or individual systems.

Fecal streptococci

Fecal streptococcal bacteria include a variety of strains which have different origins and survival rates. The organisms have been studied as possible indicator organisms, but they have not proven suitable for drinking water analysis because of low recovery rates, poor agreement between various assay procedures, and uncertainty about their health significance.[17] Thus, there is no NSA reference value for levels of fecal streptococcal bacteria. Values for concentration of fecal coliforms and fecal streptococci together, however, have been used in sanitary evaluations (see below).

— Fecal streptococci levels in rural supplies

At least one organism was found in water supplies of 19.0 percent of all rural households (about 4.2 million). There were ten or more fecal streptococci per 100 milliliters at about 10 percent of all rural households; 100 or more fecal streptococci at 3.5 percent of all rural households. The median value for the level of fecal streptococci in major household water supplies was 0.12 (Figures V-4, V-4a).

In terms of variations in the different NSA groupings, the medians were close to the national median of 0.12 in most classifications. The slight variations which did exist tended to repeat the pattern which was observed for other bacteriological indicators. That is, the values tended to be somewhat larger in rural households which were located in regions other than the North Central (Figures V-4b through V-4e), outside of SMSAs, in other rural areas, or which were served by intermediate or individual systems.

Figure V-4
Fecal Streptococcus in US Rural Household Supplies

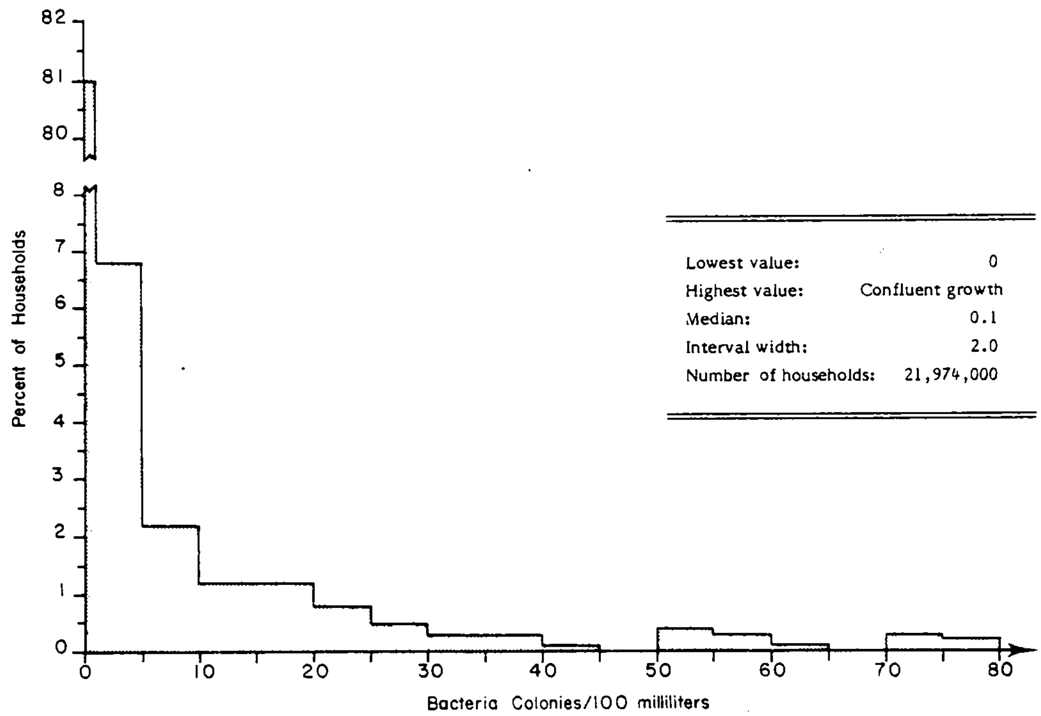
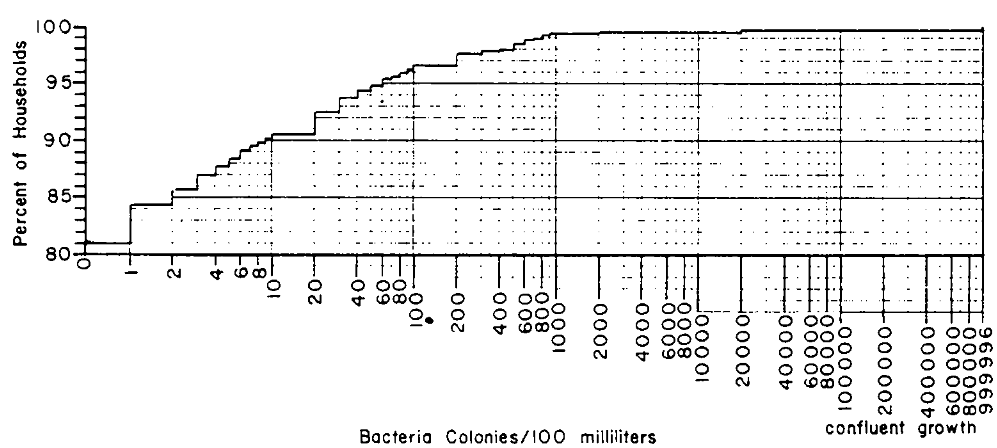


Figure V-4a. Cumulative Distribution of Fecal Streptococcus



NOTE: Cumulative distribution is plotted on semilog paper. Base: 21,974,000 households.

Regional Variation in Fecal Streptococcus in US Rural Household Supplies

Figure V-4b. Northeast

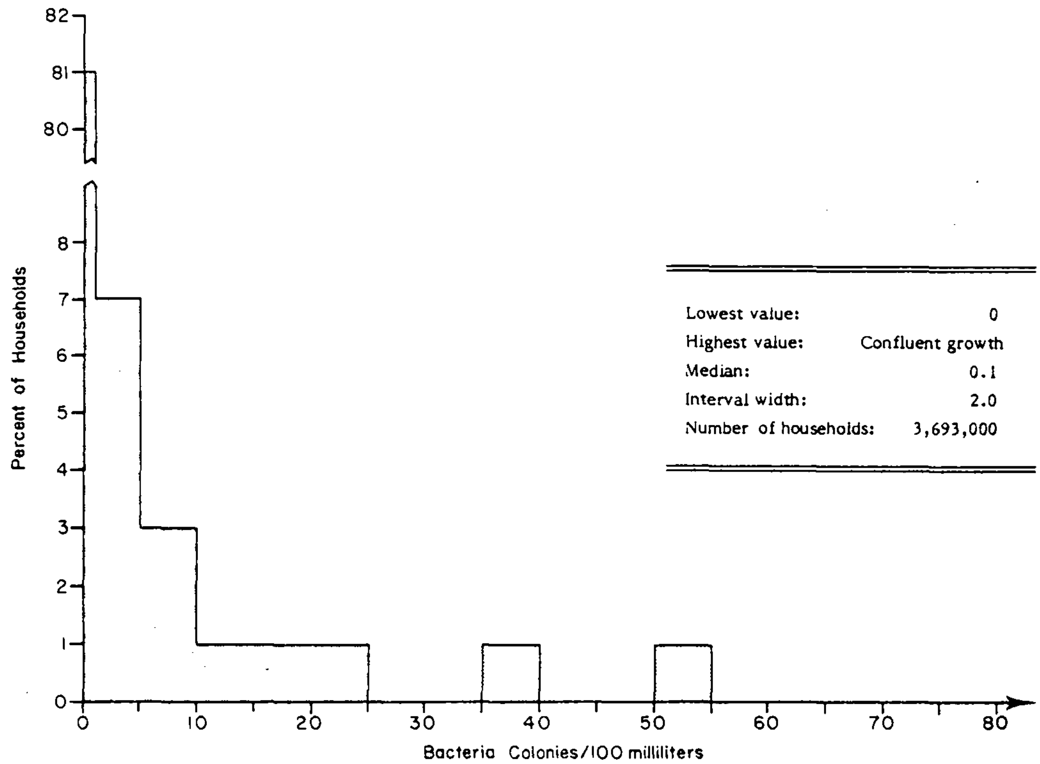
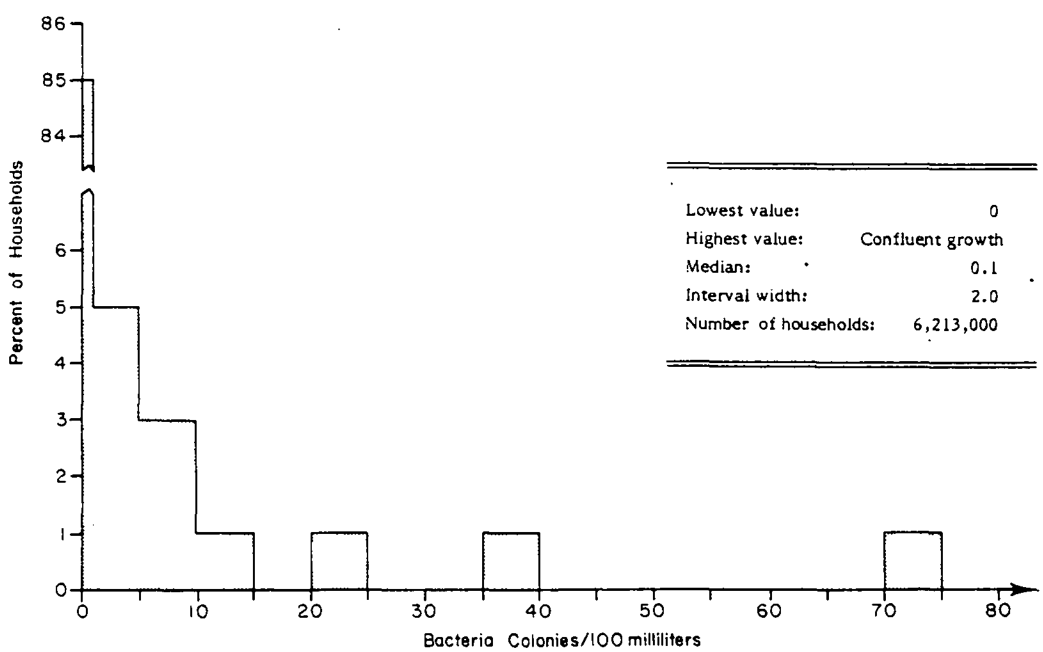


Figure V-4c. North Central



Regional Variation in Fecal Streptococcus (continued)

Figure V-4d. South

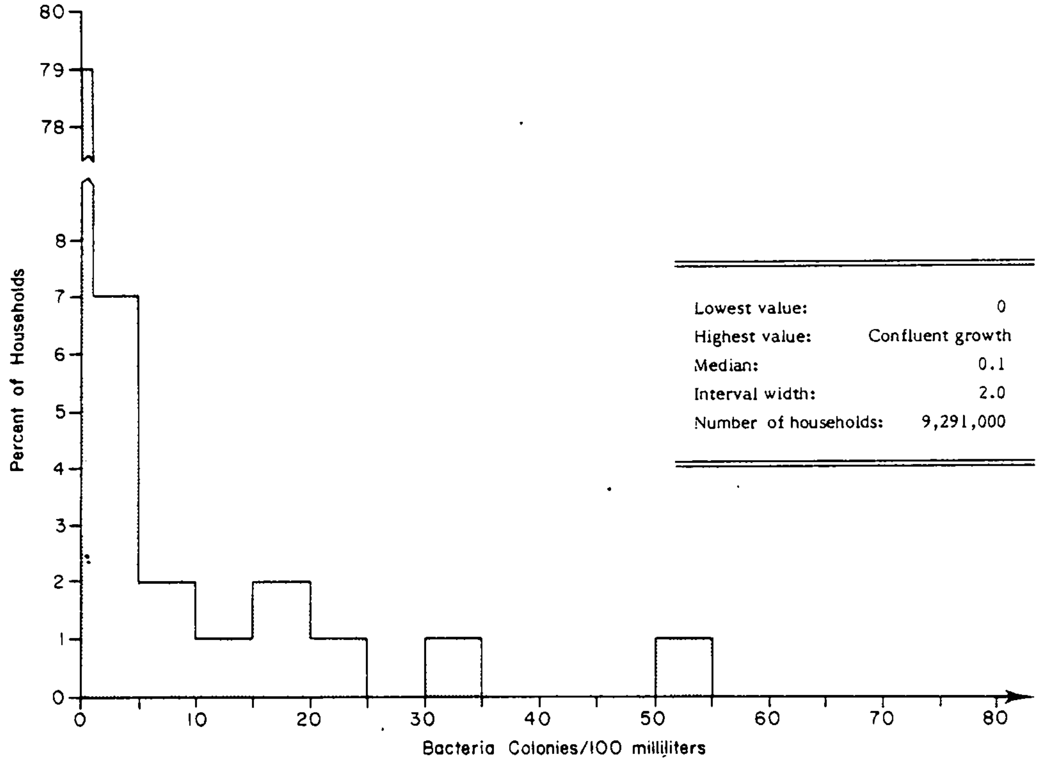
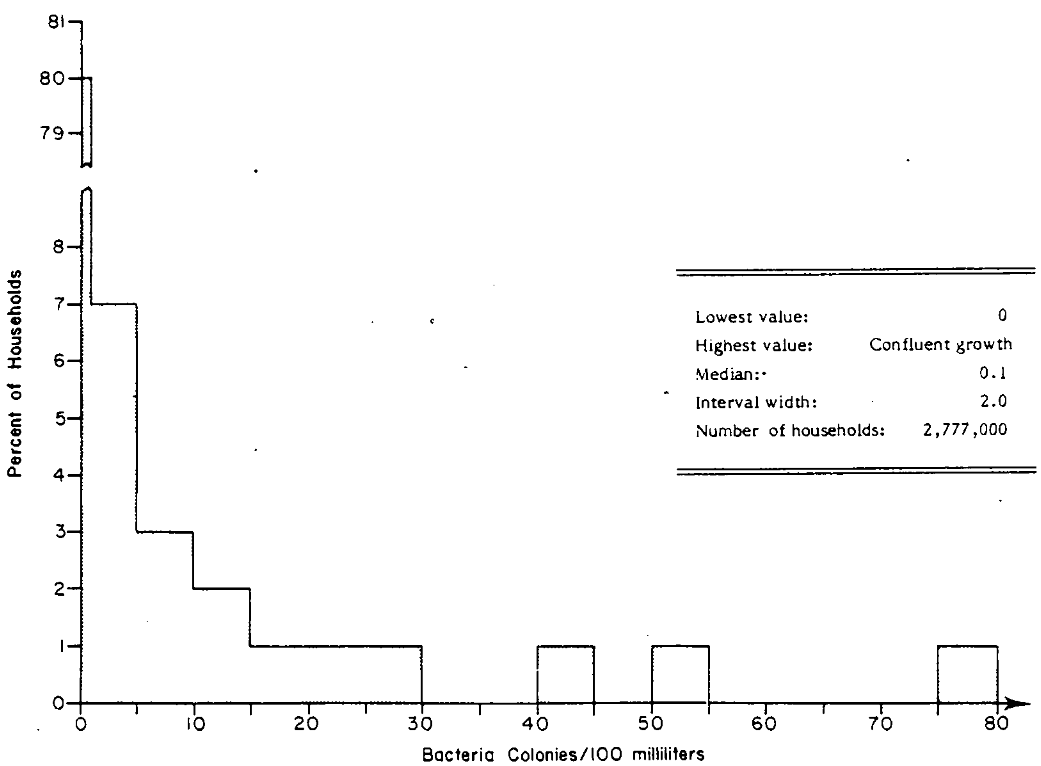


Figure V-4e. West



Fecal coliform/fecal streptococci ratio

The ratio of fecal coliforms to fecal streptococci (FC/FS ratio) in water specimens supplements the value obtained for total coliforms. As pointed out above, total coliform content may warn of contamination, but the contamination may be from a variety of fecal and plant materials. Furthermore, fecal contamination may be from either human beings or animals. Investigators have discovered, however, that the FC/FS ratio of the specimen helps indicate whether human or animal wastes are implicated. In some instances, even the type of animal can be suggested by the ratio.

As explained by EPA microbiologist Edwin E. Geldreich: "The ratio of fecal coliform to fecal streptococcus is four-to-one or higher in human fecal material. However, this ratio is reversed in the feces of other warm-blooded animals, so that the ratio of fecal coliform to fecal streptococcus would be 0.6 or less. When data are carefully developed through the use of sensitive media, this unique relationship can be a useful bacteriological tool to characterize fecal pollution sources of human origin through domestic sewage discharges, of farm animal origin through feedlot drainage, or of wildlife or pet animal origin in storm water runoff."[18]

To determine the FC/FS ratio in rural households, NSA investigators first tabulated independently the concentrations of fecal coliform and fecal streptococcal bacteria in water specimens studied for all surveyed households—as reported in the preceding sections. The investigators then compared the values for both constituents to obtain the FC/FS ratios, and the results were projected to rural American households. The ratios themselves did not indicate the magnitude of bacterial contamination in households since small numbers of the organisms could produce the same ratios as very large numbers. The ratios did provide an indication of the origin of the pollution, however.

— FC/FS ratios in rural supplies

Either fecal coliform or fecal streptococci—or both—appeared in five million, or 22.9 percent, of rural household water supplies. Concentrations of fecal coliforms and fecal streptococci were found together in 1.8 million rural households (8.3 percent of all rural households). The reported FC/FS ratios thus provided insight into the source of pollution only at those 1.8 million households. Put another way, in those households for which fecal coliform or fecal streptococci, but not both, were identified, no interpretation regarding the bacterial source was attempted. In those households, a meaningful ratio could not be formulated since only one of the two elements in the ratio was present.

Among the 8.3 percent of all rural households in which the ratio could be formulated, most (4.9 percent) had FC/FS ratios which were 0.6 or lower (Figure V-5), suggesting contamination from animal feces. At the other end of the scale, the FC/FS ratios were four-to-one or greater in 1.5 percent of all rural households, suggesting contamination from human feces. In addition, the ratios at 2.0 percent of all rural households suggested contamination of mixed animal and human origin or plant origin (the FC/FS ratios were between 0.6 and 4.0).

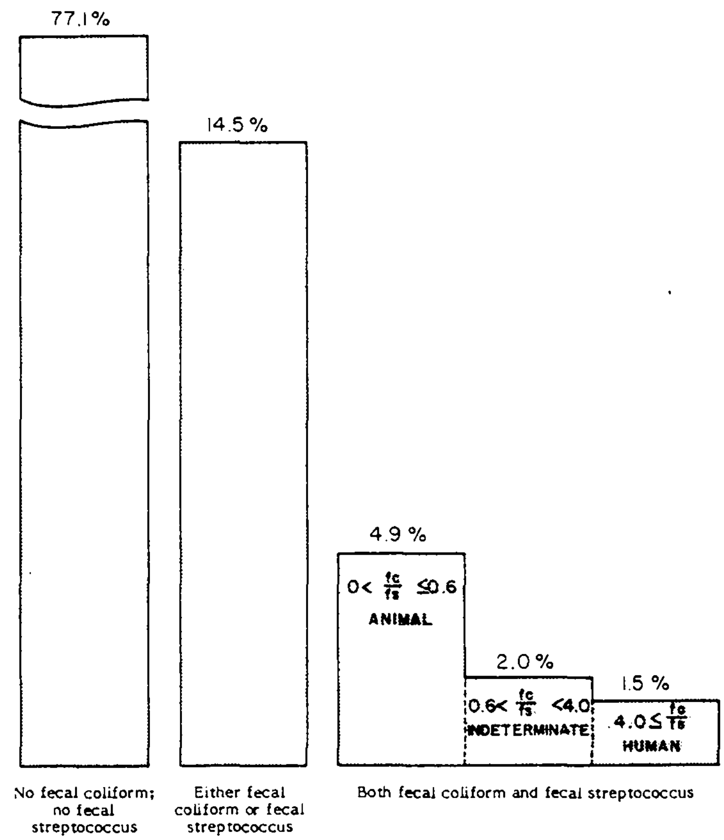
As was true for the nation as a whole, the evidence indicated a preponderance of contamination from animal or mixed origin as opposed to human origin in all regions of the US (Figures V-5a through V-5d).

In both SMSA and nonSMSA households with fecally contaminated supplies, the evidence pointed to contamination of animal or mixed origin. Specifically, the FC/FS ratios suggested contamination with animal feces in 2.6 percent of SMSA households as opposed to 5.9 percent of nonSMSA households. The ratios suggested human contamination in 1.0 percent of SMSA households as opposed to 1.6 percent of nonSMSA households.

Predominantly animal contamination also was implicated in households grouped according to size of place. The FC/FS ratios suggested animal

Figure V-5

Fecal Coliform/Fecal Streptococcus Ratios in US Rural Household Supplies



Regional Variation in Fecal Coliform/Fecal Streptococcus Ratios in US Rural Household Supplies

Figure V-5a. Northeast

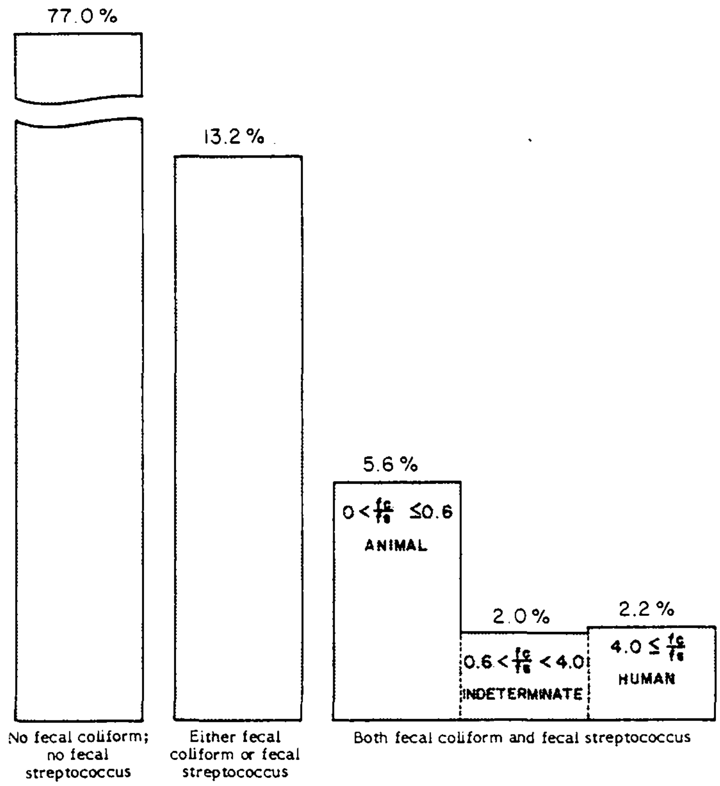
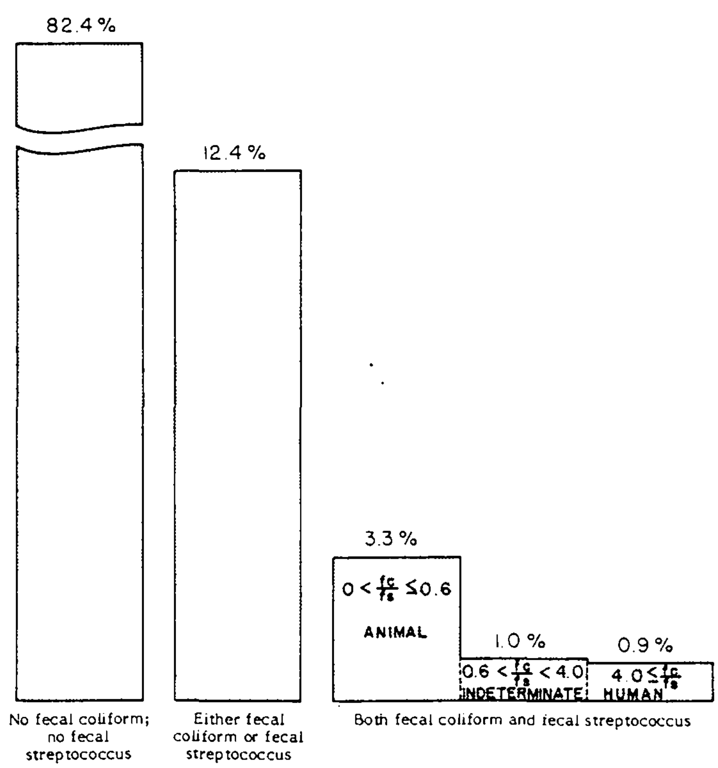


Figure V-5b. North Central



Regional Variation in Fecal Coliform/Fecal Streptococcus Ratios (continued)

Figure V-5c. South

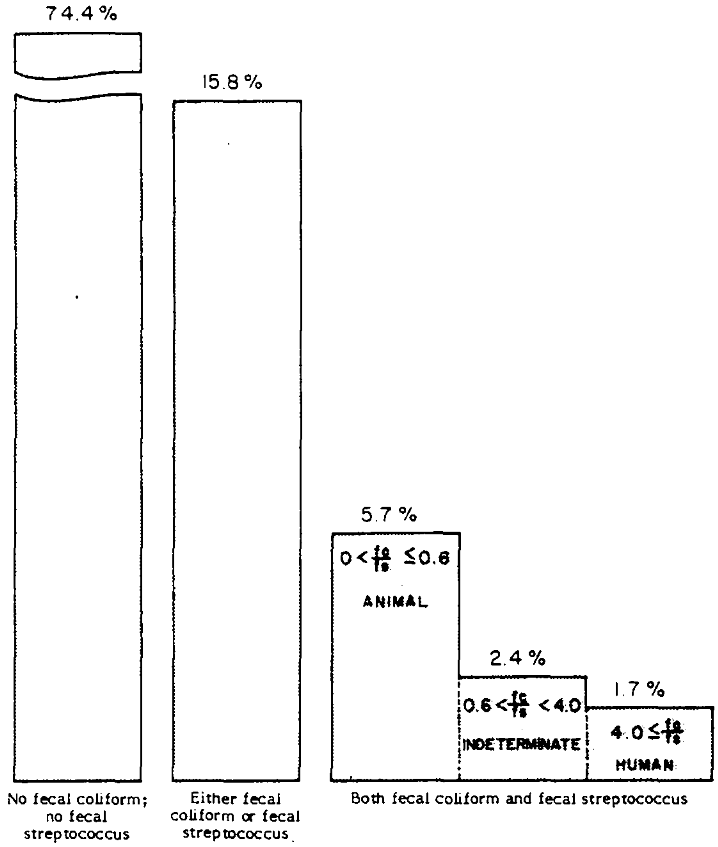
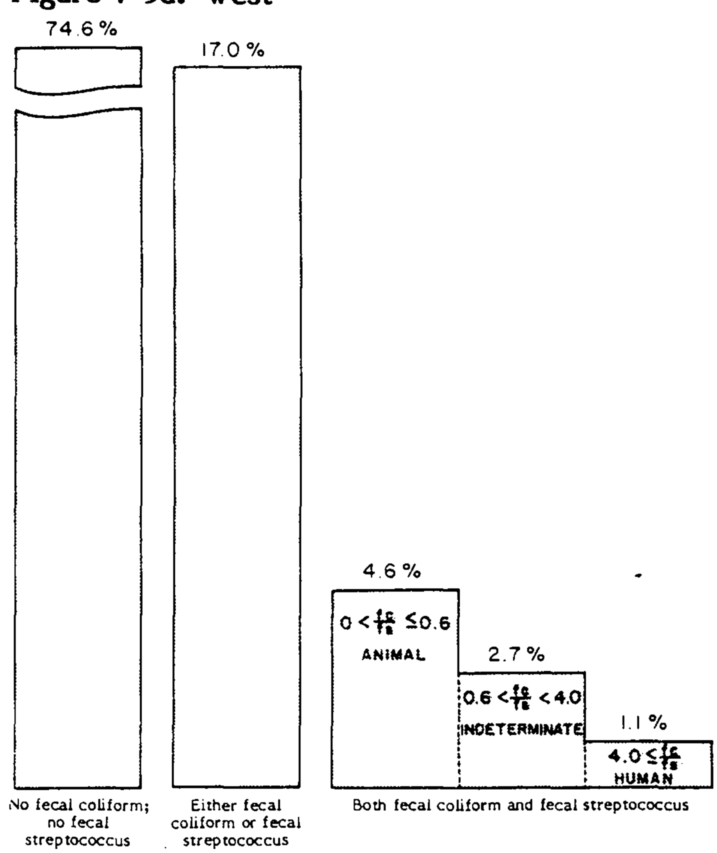


Figure V-5d. West



contamination at 1.0 percent of large-community households (about 24,000) and human contamination at 0.8 percent of those households (about 20,000); animal contamination at 2.5 percent of small-community households (about 38,000) and human contamination at 0.0 percent of those households; and animal contamination at 5.6 percent of households in other rural areas (about one million) with human contamination at 1.7 percent of those households (about 300,000).

The fecal bacteria also were much more prevalent in households served by individual or intermediate systems than in households served by community systems. The FC/FS ratios suggested that the contamination was primarily of animal or mixed origin in major household supplies from individual or intermediate systems. For major household supplies from community water systems, only 0.8 percent appeared to have predominantly animal fecal contamination, and just 0.6 percent appeared to have human fecal contamination. On the other hand, 9.2 and 7.9 percent of household supplies from individual and intermediate systems, respectively, were in the range indicating animal contamination. At the same time, 2.2 and 2.7 percent of the respective supplies were in the range indicating human contamination. The more favorable findings for community water systems were not surprising since larger systems generally have disinfection programs and usually exercise closer control over system maintenance.

The NSA findings generally were consistent with what one might expect in rural America. That is, fecal contamination in rural household supplies could be primarily from animal wastes contaminating wells. To a lesser extent, the contamination could be from local human waste disposal systems. Across the nation, about 23 percent of all households showed indications of fecal contamination (from fecal coliform, fecal streptococci, or both). According to the FC/FS ratio where it could be applied, the indication was that about 5 percent of the households were contaminated by animal fecal material, and 1.5 percent by human sewage.

As to the health implications of the NSA findings, the primary usefulness of the NSA data is to indicate potential contamination sources. Fecal contamination of human origin, of course, indicates a serious sanitary problem. On the other hand, fecal contamination from warm-blooded animals also can introduce organisms which cause illness in man.[19] Thus, the NSA findings cannot be taken as an indication of the relative seriousness of different types of fecal contamination in rural households. The findings may, however, help focus on the aspects of water supply systems which need attention.

Standard plate count

Another bacteriological test which is a useful supplement to the enumeration of coliform bacteria is the standard plate count (SPC). Technically, the SPC begins with inoculating a known volume of a water specimen in a culture dish containing a nutrient agar medium. The culture is incubated for 48 hours, and the organisms which grow as colonies on the agar plates represent a fraction of the total population of bacteria in the water. Allowable SPC bacterial numbers vary in different health department jurisdictions, but a limit of 500 colony-forming units per milliliter of water is recommended by the National Research Council.[20] This limit also is suggested, although not required, in the EPA's National Interim Primary Drinking Water Regulations.[21] The limit is used as the NSA reference value.

— Standard plate count values in rural supplies

The SPC values exceeded 500 colonies per milliliter of water in the supplies of 19.3 percent of all rural households; about 10 percent of all households had counts of 2,000 or more (Figures V-6, V-6a). The median SPC value in rural households was about 42 colonies per milliliter.

Figure V-6

Standard Plate Count in US Rural Household Supplies

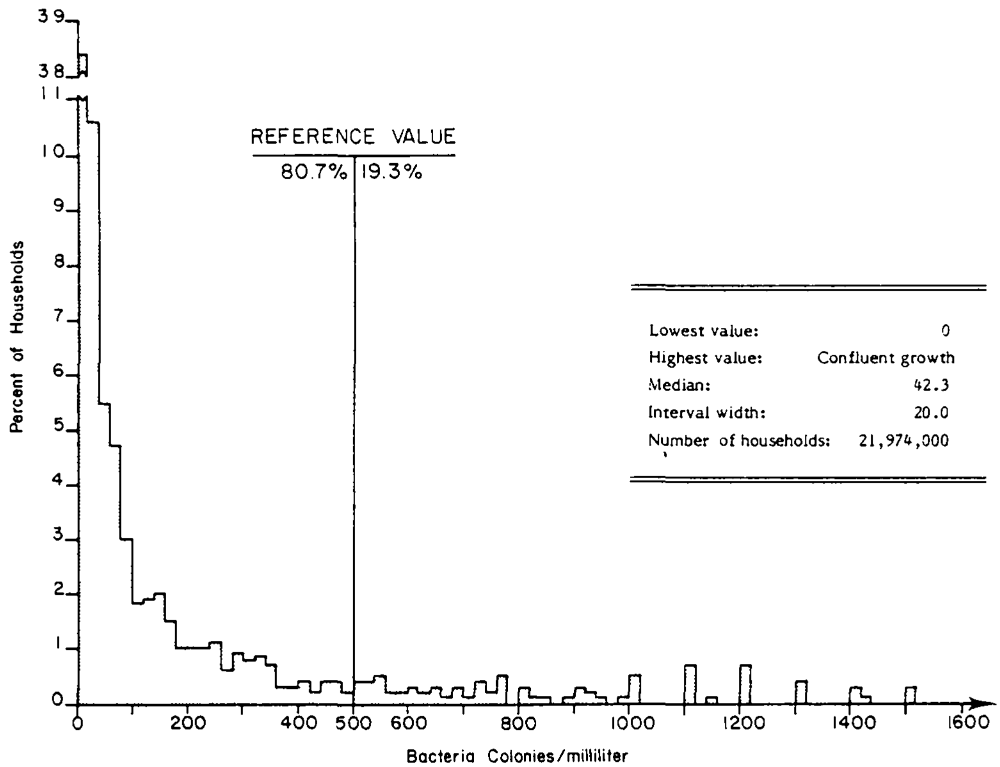
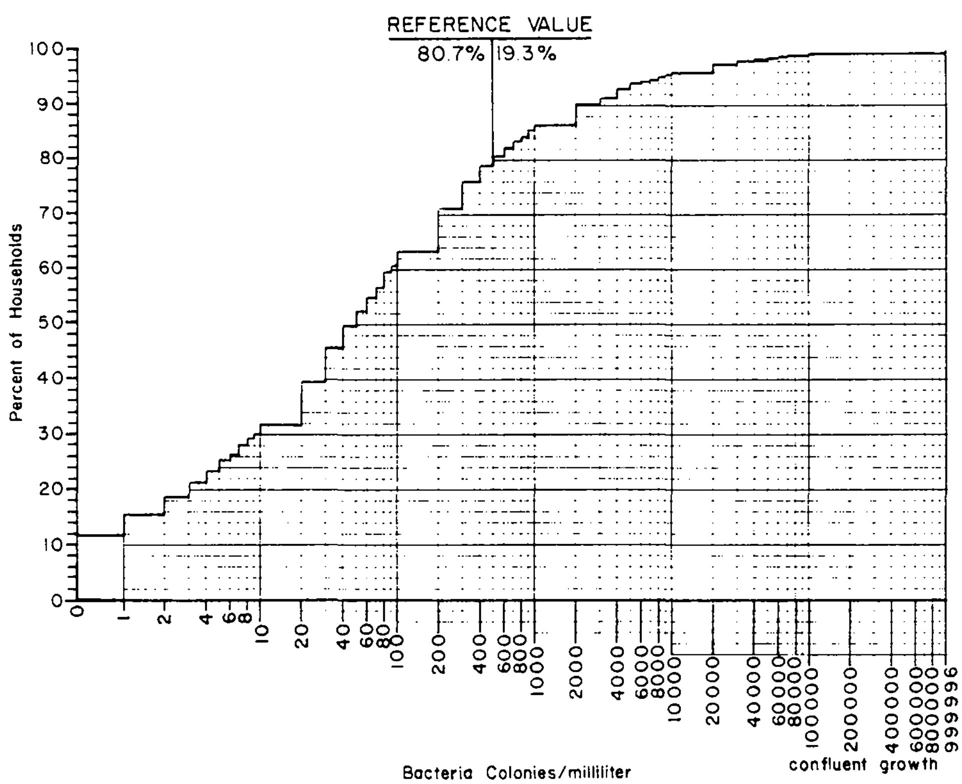


Figure V-6a. Cumulative Distribution of Standard Plate Count



NOTE: Cumulative distribution is plotted on semilog paper. Base: 21,974,000 households.

As to regional variations (Figures V-6b through V-6e), households exceeded the reference value most frequently in the West (in 24.8 percent of households there) and in the South (in 22.8 percent of households there). Households exceeded the reference value least often in the Northeast (in 10.2 percent of households there). In the North Central, 17.1 percent of rural households were above the reference value.

As was generally true for the results of other bacterial measurements, SPC values in excess of the NSA reference value occurred more often among nonSMSA households (22.0 percent, compared to 13.8 percent of SMSA households) and more often among households located in other rural areas (20.5 percent, compared to 15.0 percent in large rural communities and 11.7 percent in small communities). High values also occurred more often among households served by individual systems (26.6 percent) than among households served either by intermediate systems or community systems (17.8 percent and 13.9 percent, respectively).

Summary of bacteriological findings

Despite its shortcomings (discussed in more detail earlier in this chapter), the total coliform count is regarded by many professionals as the best available general indicator of bacteriological water quality. Accordingly, 28.9 percent of all rural households at the time of the NSA survey had supplies with total coliform levels (two or more bacteria per 100 milliliters of water) which exceeded the NSA reference value and which therefore probably required further assessment and possible remedial action. The levels in some of the supplies were high enough to raise the possibility of imminent health consequences. Rural supplies were above the reference value more often in the South and West than in other regions, more often outside of SMSAs than inside SMSAs, and more often in other rural areas than in large or small rural communities. High values also were much more common

Regional Variation in Standard Plate Count in US Rural Household Supplies

Figure V-6b. Northeast

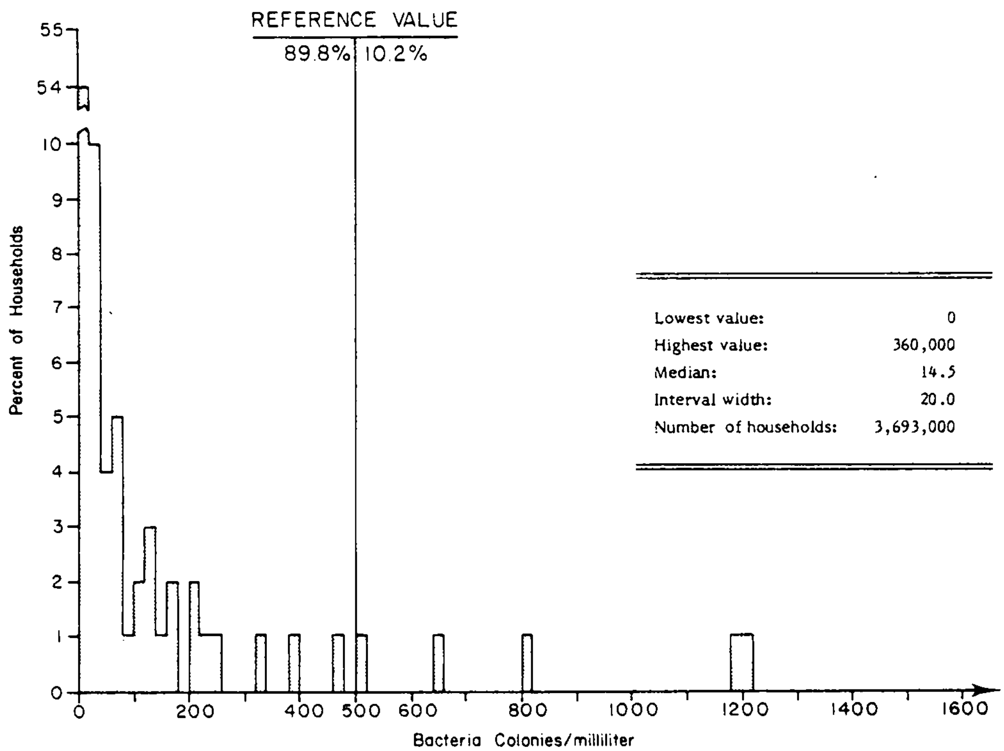
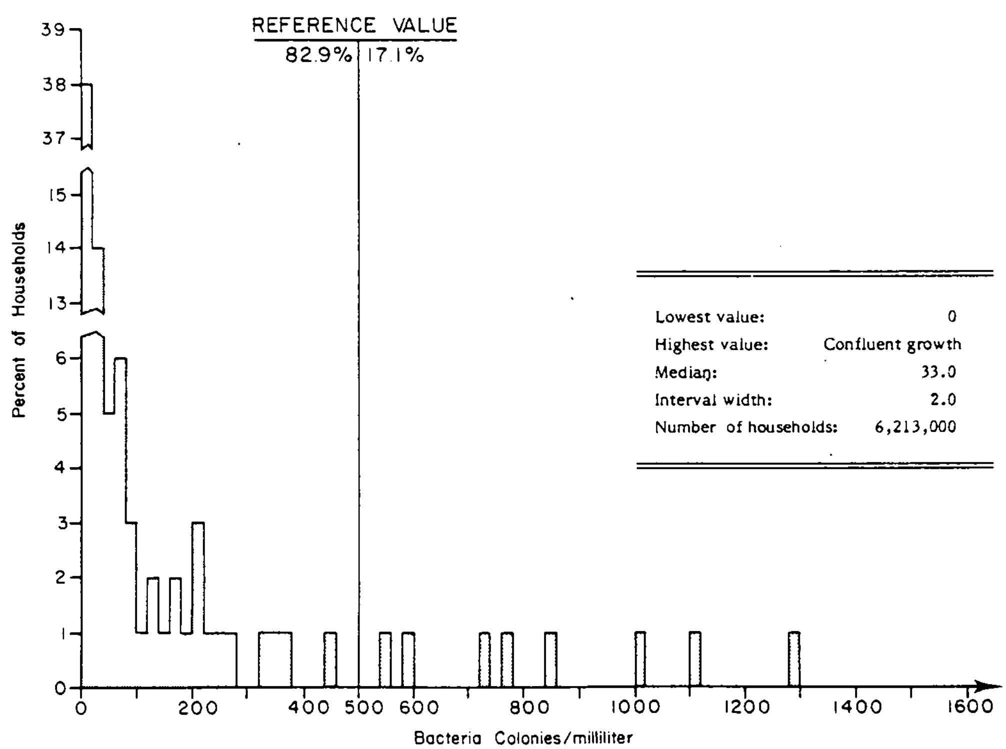


Figure V-6c. North Central



Regional Variation in Standard Plate Count (continued)

Figure V-6d. South

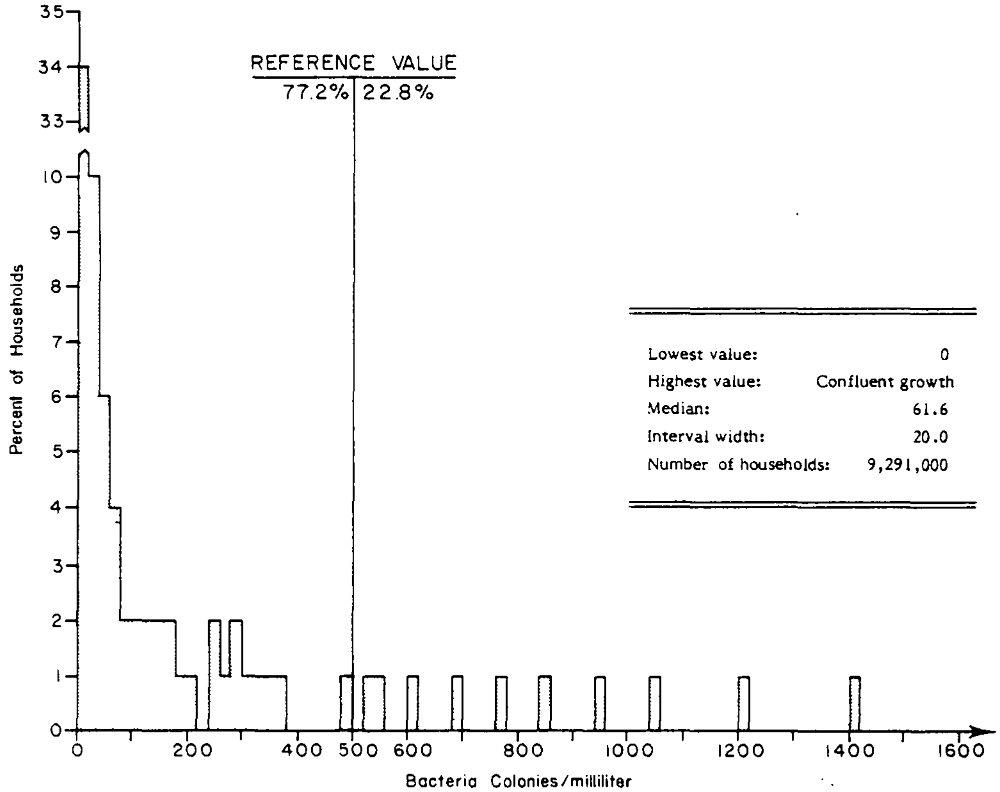
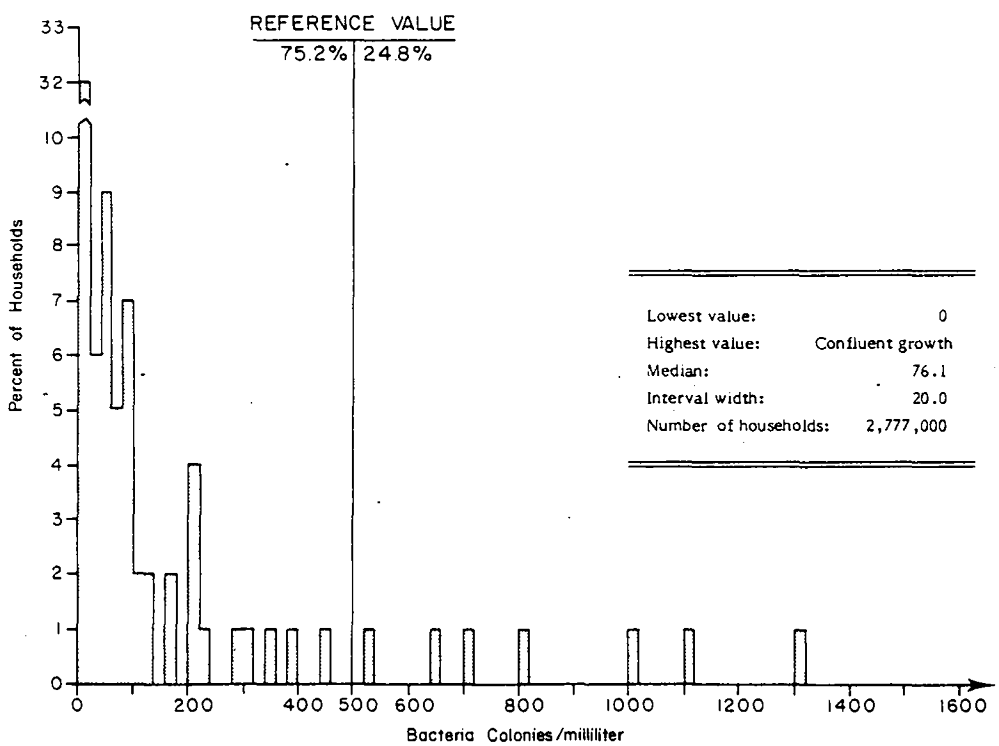


Figure V-6e. West



among supplies served by individual or intermediate systems than among supplies provided by community systems.

On the basis of NSA findings, 12.2 percent of all rural households had supplies which may have required attention because of the presence of at least one fecal coliform bacterium. In 1.6 percent of rural households (350,000), the fecal coliform level was higher than that which has been associated with increased occurrence of at least one organism with disease potential (200 colonies), indicating the possibility of heightened threat of disease. High values were proportionately most common outside of SMSAs, in other rural areas, and among households served by individual or intermediate systems.

Fecal streptococci were found in 1.8 million rural water supplies which also had fecal coliform bacteria. The ratio of these two organisms in the supplies suggested that contamination from animal wastes alone (a potential in 4.9 percent of all rural households) outweighed contamination from human wastes alone (a potential in 1.5 percent of all rural supplies). This trend was apparent in all regions of the US and also in households grouped by size of place and size of system.

In regard to general levels of bacteria as determined by the SPC, values exceeding 500 per milliliter of water were found most often in the West and South. The high values were more frequent among nonSMSA households, among households located in other rural areas, and among households served by individual systems.

PHYSICAL AND CHEMICAL CHARACTERISTICS

Three physical characteristics—turbidity, color, and temperature—were determined in all NSA water specimens, as were two general chemical characteristics—hardness and conductance. Measurements of turbidity, color, and specific conductance were made in EPA laboratories. The concentrations of calcium and magnesium in all NSA water specimens were used to measure hardness.

Temperature of the water was recorded by NSA interviewers before the specimens were collected from the households. All five characteristics represented important overall aspects of water quality.

Turbidity

Turbidity refers to the optical effect in water caused by suspended matter such as clay, silt, and organic particles, as well as by plankton and other microscopic organisms. These materials, in turn, may have direct health effects, or indirect effects resulting from reactions with other constituents (like chlorine, which can combine with some organic materials in the formation of trihalomethanes).[22] One of the important effects of the turbidity-chlorine interaction is the dissipation of the disinfecting power of chlorine through reactions with the suspended matter other than bacteria and viruses. The turbidity particles also can shield bacteria and viruses from the chlorine. An effective means of removing the risk associated with chlorine-resistant cysts of pathogenic protozoa and helminth eggs is sedimentation or filtration,[23] both of which remove turbidity to a great degree; therefore, turbidity suggests a potential for disease risk which treatment might alleviate. (Of course, clear water does not necessarily mean there is no health risk.)

Turbidity measurements in the laboratory are based on light scattering and absorbing properties of the suspended substances in the water. The amount of light scattered and detected depends on the number, size, shape, and refractive index of the particles, the wavelength spectrum of the incident light, and the geometry and detection characteristics of the analytic equipment. Turbidity results do not identify the substances in the water: more selective techniques must be used to test for specific substances. However, high levels of turbidity do provide an indication that adverse health effects are possible. Furthermore, the levels may make the water unattractive enough to prompt people to use another supply.

Unacceptably high turbidity can be an economic liability in its effects as well as in the cost of its removal.

The NRC does not recommend a specific standard for unacceptable turbidity. Instead, the council cautions that health department standards and equipment vary, and that the test requires standardization. Furthermore, the NRC advises, the nature of the test is such that low turbidity measurements do not guarantee that water is potable. Federal regulations, on the other hand, do set interim Maximum Contaminant Levels (MCLs) for turbidity for both community and noncommunity water supply systems using surface water. The MCL ranges from one to five turbidity units, depending on a number of factors.

The federal interim regulations, however, are difficult to apply as a direct gauge of NSA findings. For example, the regulations require testing in the distribution system between the water treatment plant and the main distribution pipes, but the NSA specimens were taken at the user's tap. The regulations strictly apply only to suppliers with surface water sources, but NSA water supplies were from a number of sources, some of which were not identified (as was noted in Chapter IV). Furthermore, turbidity measurements are best made on the day on which a specimen is obtained.[24] This procedure was not followed in the NSA, since all specimens were shipped to central laboratories for later analysis.

Water supplies that are to be treated with chlorine ideally should have very low turbidity levels—less than one nephelometric turbidity unit—in order to minimize interference with the disinfection. Turbidity becomes perceptible at about the level of five turbidity units. Turbidity constitutes a general indication of potential problems. In the NSA, however, more selective bacteriological, physical, and chemical measures were available to specify the substances present. No NSA reference value was chosen for turbidity, since NSA findings on particular constituents specify the problems which turbidity indicates in a general way.

NSA turbidity data will be divided and presented in two ways. First, conditions will be described according to the prevalence of rural water supplies with one turbidity unit. The object is to indicate the proportion of supplies that might require attention if chlorination were adopted. Second, the level of five turbidity units will be used to indicate the proportion of supplies with turbidity that is aesthetically perceptible.

Turbidity was measured in the NSA by use of an instrument called a nephelometer, and the measured findings were expressed in nephelometric turbidity units (NTUs).

— Turbidity levels in rural water supplies

Turbidity levels were one NTU or less in 83.5 percent of all rural households (Figures V-7, V-7a). For 16.5 percent—a total of 3.6 million households—turbidity exceeded one NTU. About one million of these households had turbidity of more than five NTUs. The latter households—4.8 percent of all rural households—had turbidity levels which were aesthetically perceptible. In all, the measured levels ranged from less than 0.05 NTU to 132 NTUs; the rural US median was 0.3 NTU.

Levels exceeded one and five NTUs most often in rural households in the North Central, where 23.8 percent were above one NTU and 6.8 percent were over five NTUs. The West had the lowest percentages: 8.5 percent exceeded one NTU and 1.7 percent exceeded five NTUs. Values larger than one NTU were discovered in 10.1 percent of households in the Northeast and 16.6 percent of households in the South (Figures V-7b through V-7e). There were 2.9 and 5.2 percent of households in the Northeast and South, respectively, above five NTUs.

As to results of other NSA comparisons, turbidity values were over one NTU in 18.2 percent of nonSMSA households and over five NTUs in 5.2 percent, compared to 12.9 and 3.9 percent of SMSA households. Supplies with high turbidity

Figure V-7
Turbidity in US Rural Household Supplies

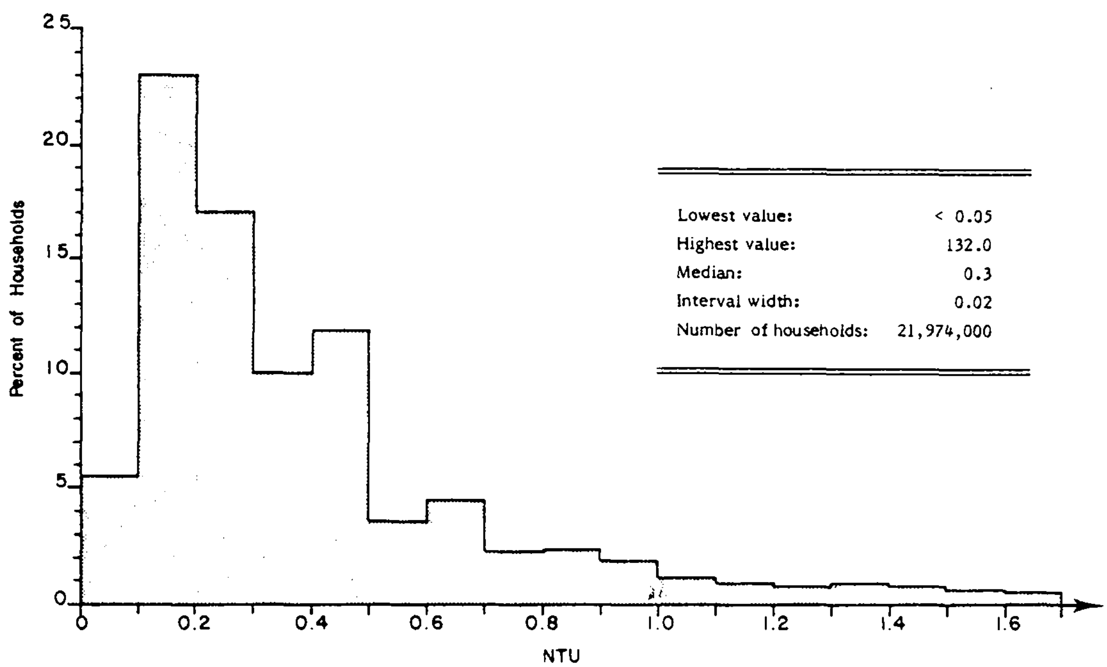
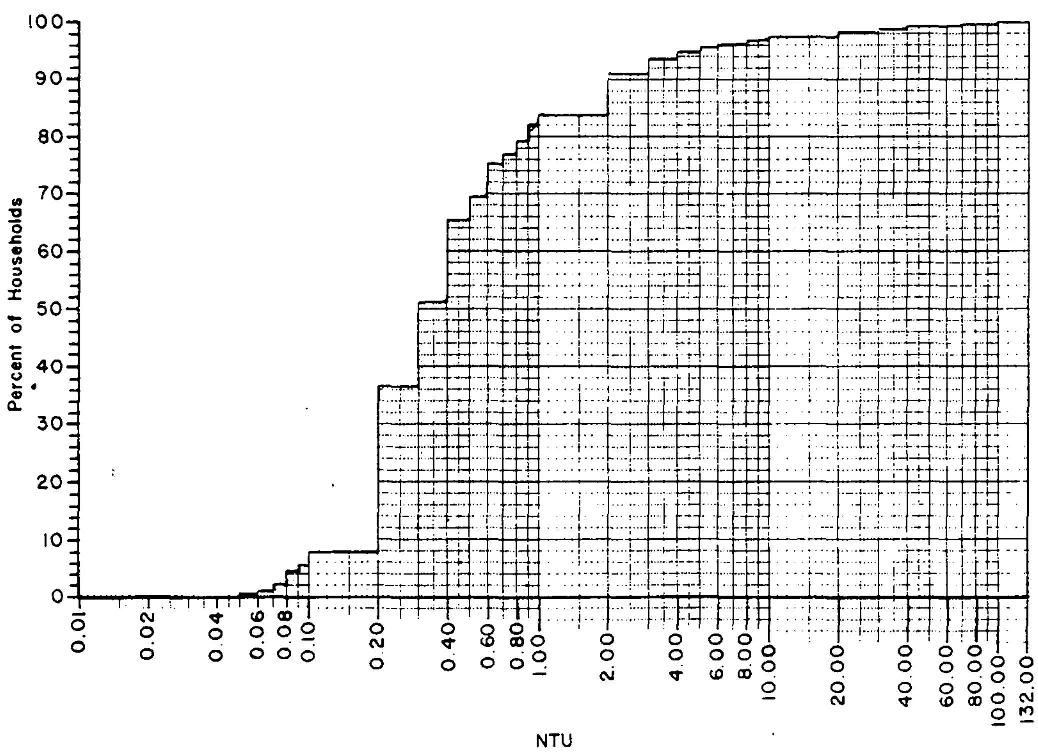


Figure V-7a. Cumulative Distribution of Turbidity



NOTE: Cumulative distribution is plotted on semilog paper. Base: 21,974,000 households.

Regional Variation in Turbidity in US Rural Household Supplies

Figure V-7b. Northeast

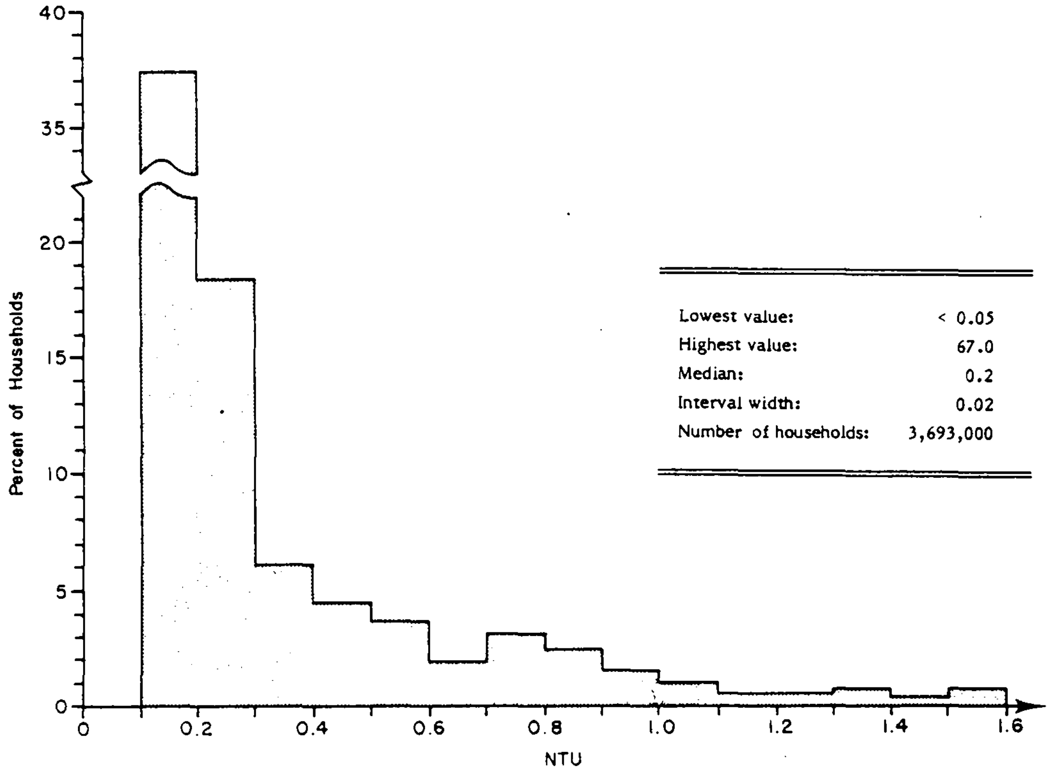
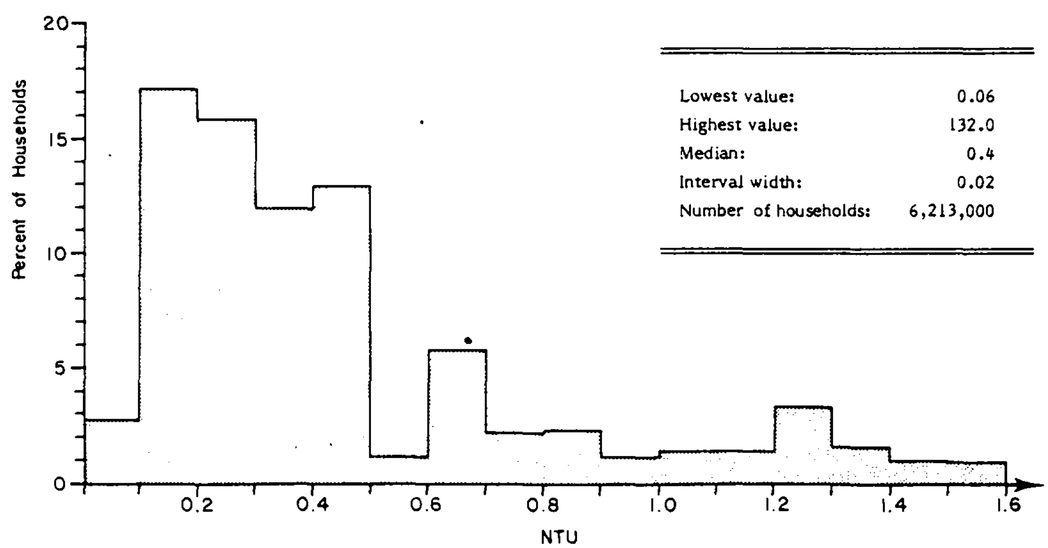


Figure V-7c. North Central



Regional Variation in Turbidity (continued)

Figure V-7d. South

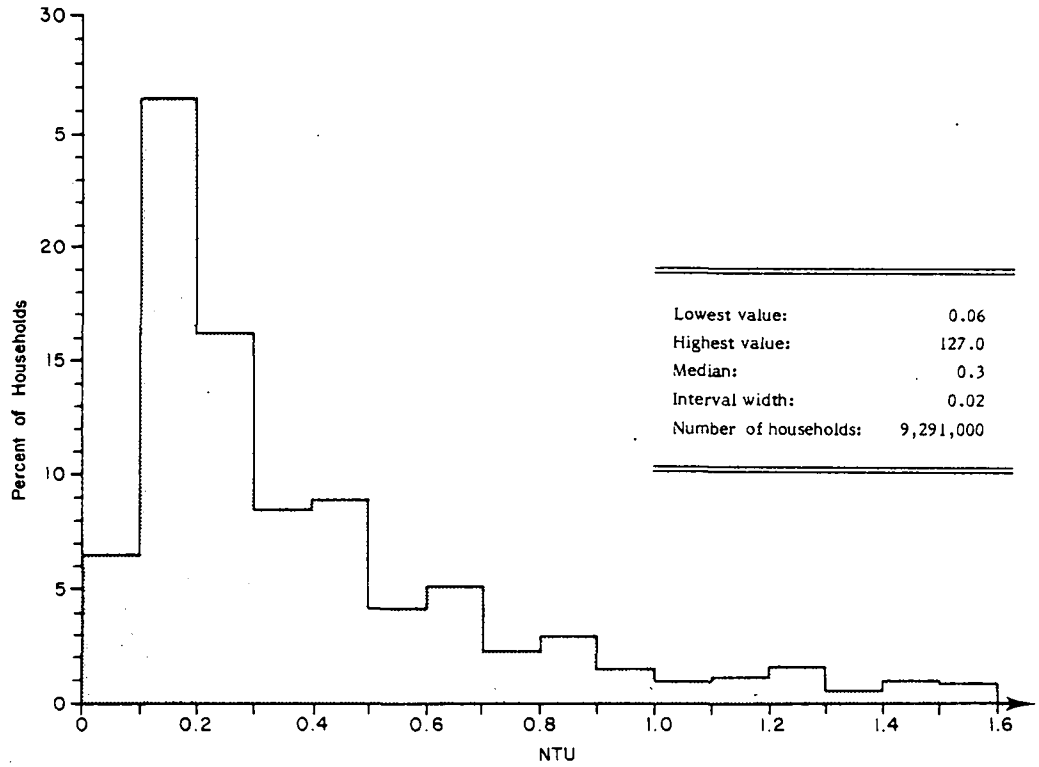
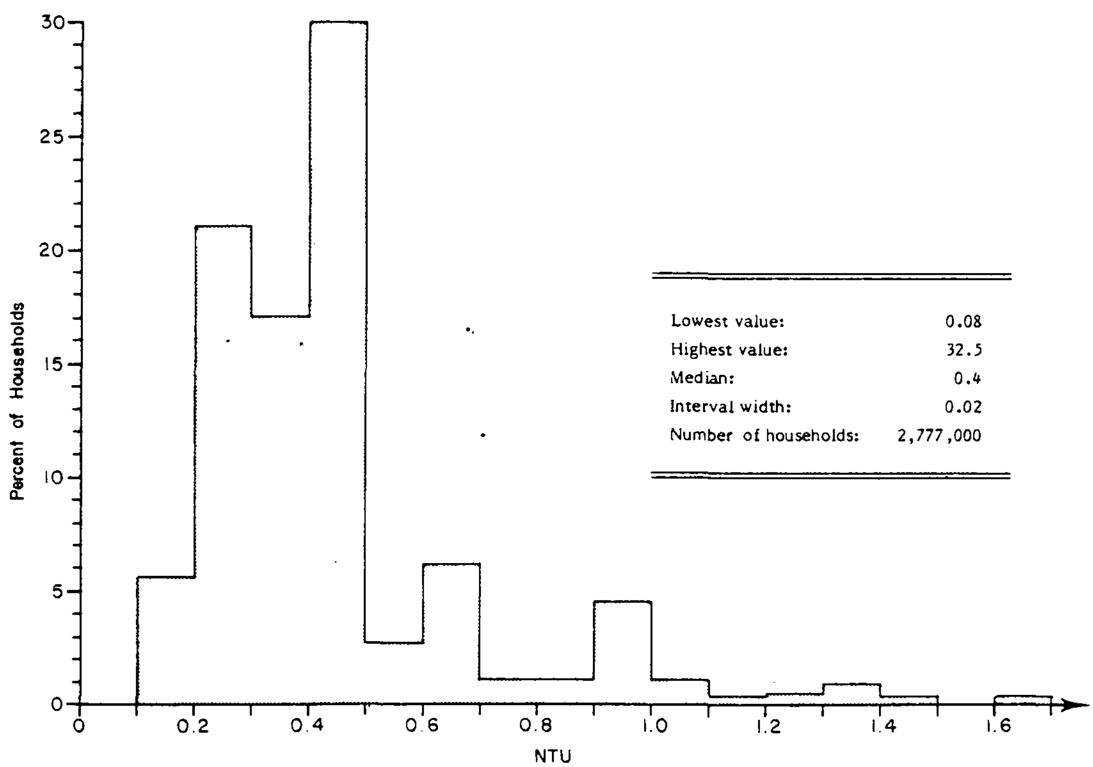


Figure V-7e. West



levels were found proportionately more often among households located in small rural communities (21.8 percent above one NTU and 5.0 percent above five NTUs). Comparable proportions were 10.8 and 1.7 percent among households in large rural communities, and 16.8 and 5.2 percent among households in other rural areas.

The difference in the size-of-place comparison probably was influenced by the distribution of rural households (discussed earlier, in the section entitled "Constituents Studied in NSA"). That is, rural communities with fewer than 1,000 people were concentrated in the North Central and the South, the two regions having the largest proportions of high-value households. If adjustment were made for this situation, it is likely that the proportion of households over one NTU in small rural communities would be similar to the proportion in other rural areas. The proportions over one NTU in these two classifications would be greater than the proportion in large rural communities, however.

In the size-of-system comparison, households served by individual and intermediate systems were more than twice as likely to have high values as households served by community systems. Specifically, there were 24.0 percent of households with individual systems, 24.7 percent of households on intermediate systems, and 8.9 percent of households on community systems above one NTU. Above five NTUs, the proportions were 8.7 percent for individual, 6.7 percent for intermediate, and 1.3 percent for community systems. The proportion of households served by individual systems with readings above five NTUs (8.7 percent) was almost as large as the percentage over one NTU (8.9 percent) among households served by community systems.

The relative differences in the NSA comparisons generally were anticipated. Correction of excessive turbidity may require treatment processes such as sedimentation, coagulation, and filtration which are used most extensively by community systems. Water provided by these systems would be expected to have fewer extreme levels of turbidity, and it is these larger systems which more often serve households in SMSAs and in larger communities. Nonetheless, because of the likelihood of chlorination among community systems and because of the negative interaction between chlorine and turbidity, the relatively low levels of turbidity found in households served by community systems are potentially significant. For the one million community-system households with turbidity levels over one NTU, chlorination would give rise to a potential hazard of trihalomethanes. In addition, the substances causing the turbid conditions may themselves constitute health hazards, as they would in supplies from systems of any size. All these risks would be even greater among those 1.1 million rural households with turbidity levels over five NTUs.

Despite the relative differences among proportions of households with high turbidity, the median level of turbidity in rural American households was similar throughout all of the groupings except the regional one. Specifically, the national median of 0.3 NTU held fairly steady in rural households whether they were in SMSAs or not, whether they were in rural communities or in other rural areas, or whether they were served by individual, intermediate, or community systems. The median was lower in the Northeast, however (0.2 NTU), than in other regions; in the South, it was at about the national level, while it was somewhat higher in the West and North Central (0.4 NTU in both regions).

Color

Water is colored primarily by natural organic matter, but also by certain industrial wastes and some metallic complexes. The standard laboratory procedure for measuring color is based on the use of solutions that contain known concentrations of a color-producing chemical. Solutions containing a range of concentrations of the chemical are assigned corresponding, arbitrary color values. Through the use of a color comparison device, the specimen to be studied is visually matched according to color intensity with the closest standard solution, and the scale value of the standard solution becomes the measured value for the specimen.

At less than five color units, color in water is not discernible, according to the EPA.[25] At more than fifteen color units, the color is displeasing to most people. In view of this, the EPA has promulgated a secondary MCL of fifteen color units. That standard was selected as the NSA reference value.

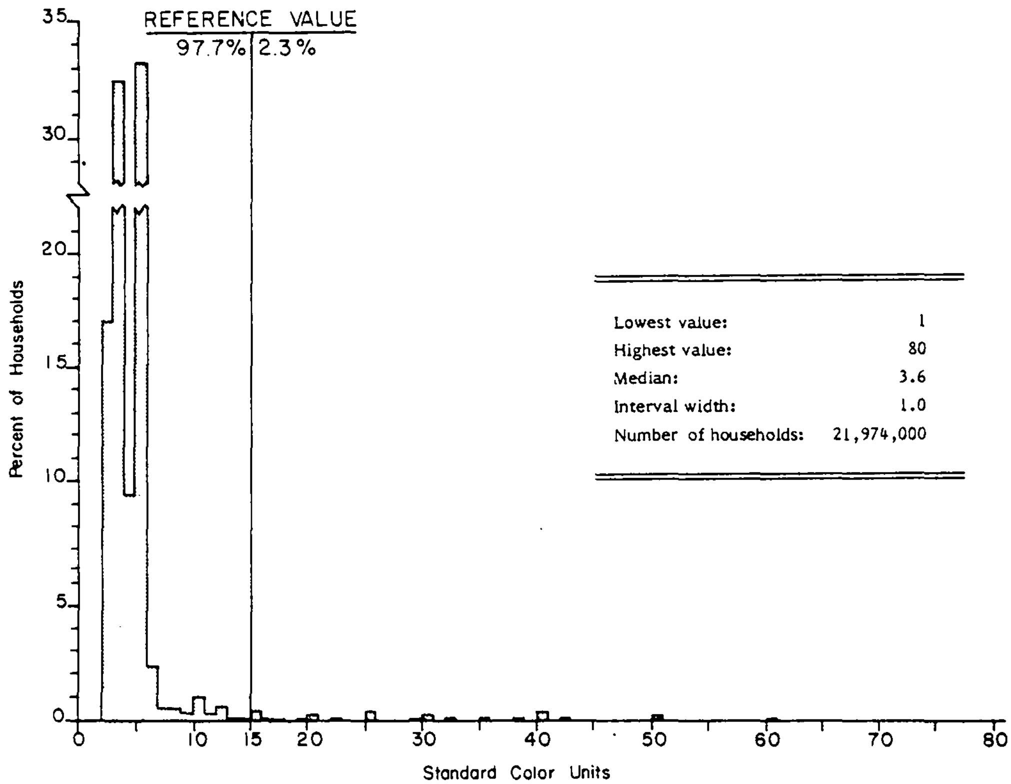
— Color unit values in rural supplies

Most rural water supplies were within the NSA reference value for color (Figure V-8). The reference value was exceeded in only 2.3 percent of all rural households (a total of about 513,000). The median value for the rural US was only 3.6 color units. The maximum value was 80 units, recorded for the supplies at about 25,000 rural households.

Among the relatively small number of households with color unit values surpassing the reference value, disproportionately more were located in the North Central and South (3.4 percent and 2.6 percent, respectively, compared to 1.6 percent in the West and 0.5 percent in the Northeast—see Figures V-8a through V-8d), and outside of SMSAs (2.8 percent, compared to 1.4 percent inside SMSAs). Although the proportion of households above the reference value was greater among households in small rural communities (5.4 percent) than in large communities (1.5 percent) or other rural areas (2.2 percent), the difference probably occurred because a disproportionately large number of small communities were in the North Central and South, which had the greatest proportions of over-reference-value households in the regional comparison. A slightly larger proportion of households served by individual as opposed to intermediate or community systems had color values exceeding fifteen standard color units (3.0 percent of individual-system households, compared to 1.9 percent of both intermediate-system and community-system households).

Figure V-8

Color in US Rural Household Supplies



Regional Variation in Color in US Rural Household Supplies

Figure V-8a. Northeast

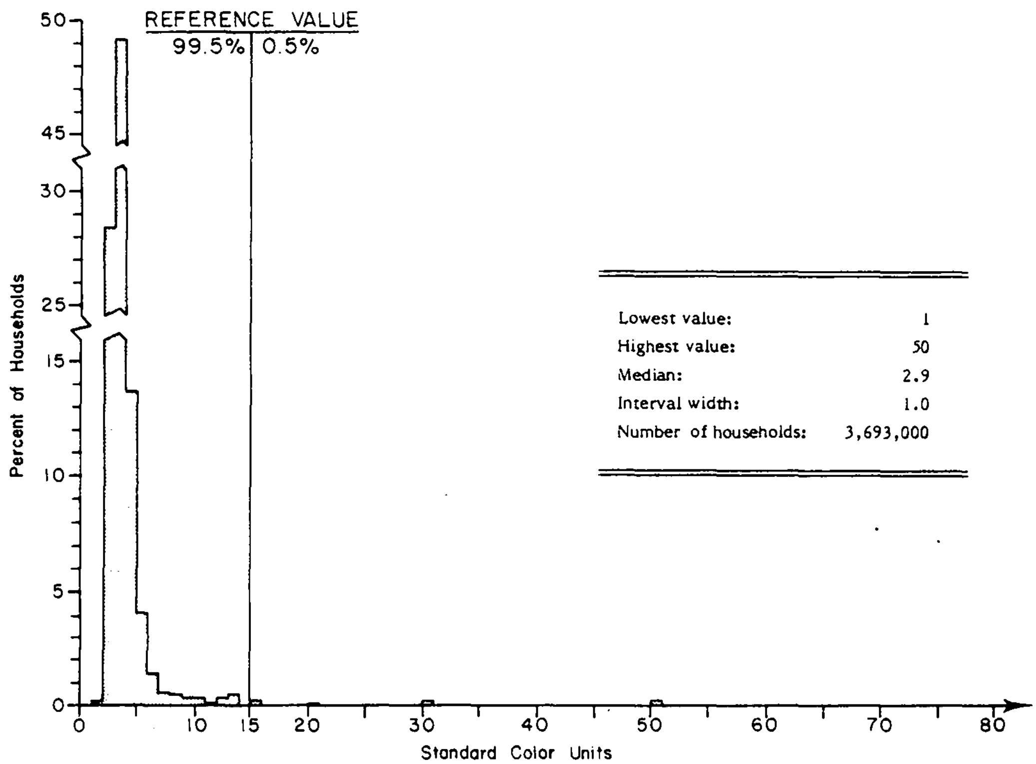
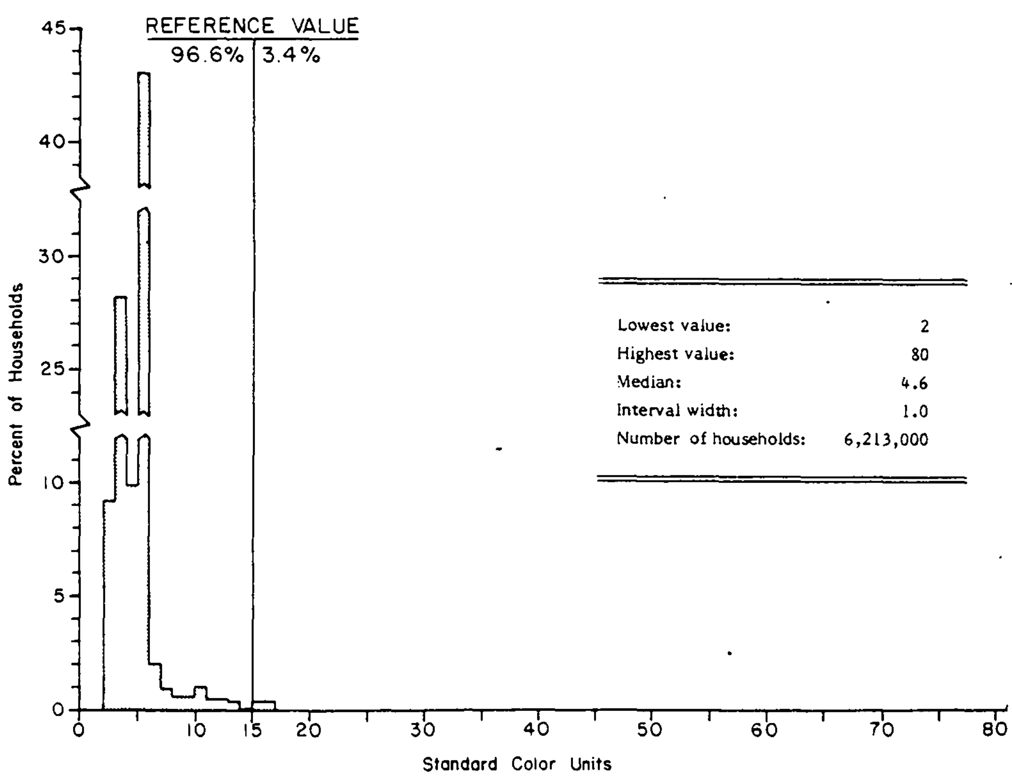


Figure V-8b. North Central



Regional Variation in Color (continued)

Figure V-8c. South

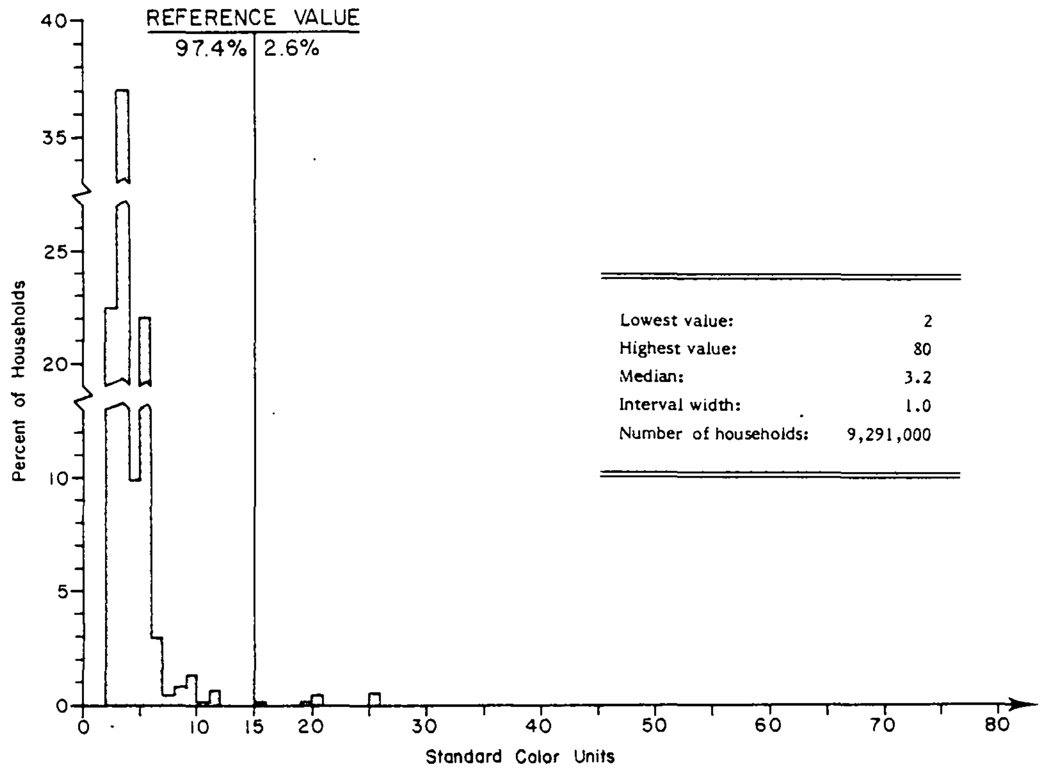
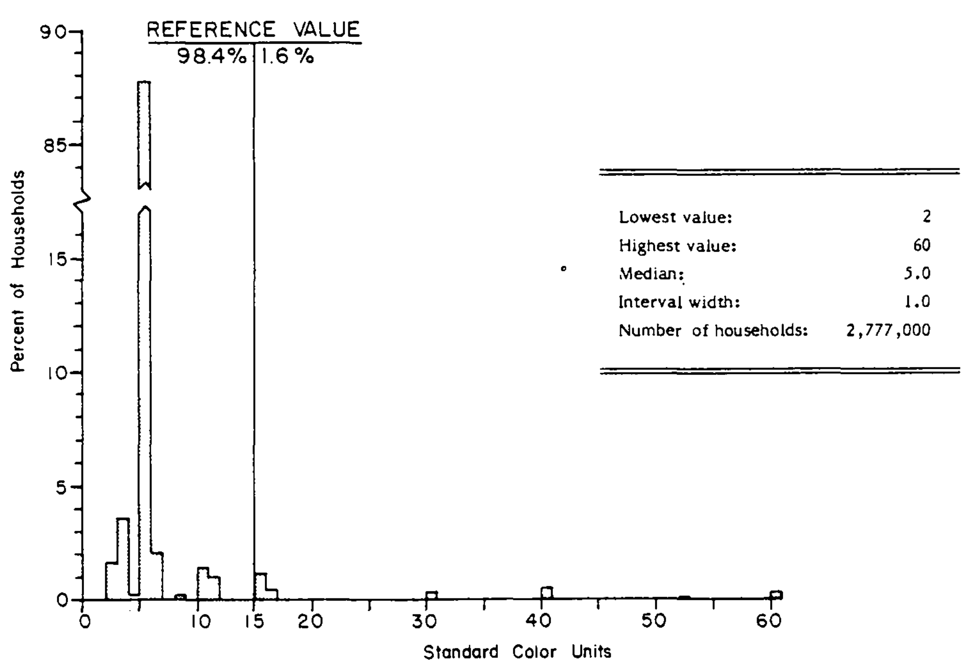


Figure V-8d. West



Temperature

Temperature influences the palatability of water, but it also may affect its healthfulness. The Drexel University Workshop Microbiology Panel observed that: "Water temperature especially influences survival of enteric organisms, with higher temperatures promoting inactivation and low temperatures promoting survival. In cold weather viruses introduced into aquatic environments may persist for several weeks to months, and become widely dispersed from the source of contamination. Coupling this longer viral persistence with the fact that disinfection action is slower in cold water temperatures, there may be some undefined increase in risk of viral breakthrough into potable water which was processed from poor quality raw water."[26]

NSA water samples were drawn from the cold water tap, but the temperature range did not seem great enough to warrant conclusions about possible survival of viruses, and no attempt was made to measure viral contamination. Also, though data collection spanned three seasons (summer and fall of 1978, and winter of 1978-79), only one set of specimens was drawn at any particular sampled household, and most specimens were obtained from June through October 1978. Therefore, conclusions about water supply temperature have to be qualified. Consequently, temperature values in the NSA were used mainly in reference to the aesthetic acceptability of the water supplies.

In regard to aesthetic acceptability, the EPA concludes that "most individuals find that water having a temperature between 50° and 60° F (10° to 16° C) is most palatable."[27] Authors of the State of California Water Quality Criteria state that "for drinking purposes, water with a temperature of 10° C is usually satisfactory. Temperatures of 15° C or higher are usually objectionable."[28] One report quoted in the Water Quality Criteria indicates that public water supply temperatures in excess of 19° C invariably result in complaints from consumers.

In the NSA, temperature was measured by opening the tap and inserting a thermometer into the flowing water until the temperature reading stabilized. This usually took about 30 seconds. The NSA temperature readings therefore are probably higher than would have been recorded if sufficient water had been run to flush the household plumbing. However, NSA temperatures do reflect the temperatures of household water as it generally was used during those periods of the year when households were visited for the NSA. Of course, there could be a large range of temperatures at any particular household, depending upon how long water was allowed to run. This makes it difficult to describe the household condition based on the NSA temperature readings. Consequently, 20^{o} C will be used as a descriptor for dividing the data and aiding in the presentation of results—but no formal reference value will be chosen for temperature.

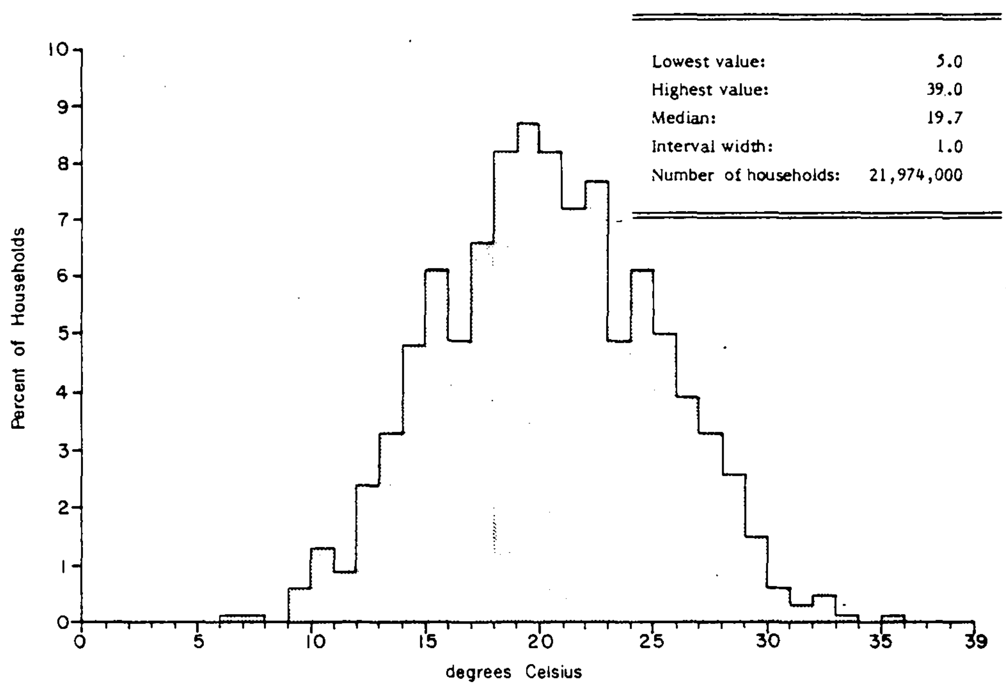
The possible health consequences of domestic water temperature cannot be assessed on the basis of the NSA data. Further, no criterion for a minimum temperature was considered in the NSA since the focus of professional attention has been on the agreeability of warm water rather than cold water. In fact, the lowest temperatures recorded in rural households were within 5^{o} C of the lower end of the range viewed as favorable by the EPA.

— Temperature levels in rural supplies

The temperature of major water supplies in rural households, as measured at the cold water tap, ranged from 5^{o} C through 39^{o} C. Both the mean and the median temperatures were nearly 20^{o} C. Supplies at 43.8 percent of all rural households (a total of 9.6 million) were above 20^{o} C (Figure V-9).

Mean and median temperatures were relatively warm in rural household water supplies in all regions (Figures V-9a through V-9d), but especially in the South and West. The median water temperature was 22.5^{o} C among Southern households, 19.9^{o} C among Western households. At the same time, the percentage

Figure V-9
Temperature in US Rural Household Supplies



Regional Variation in Temperature in US Rural Household Supplies

Figure V-9a. Northeast

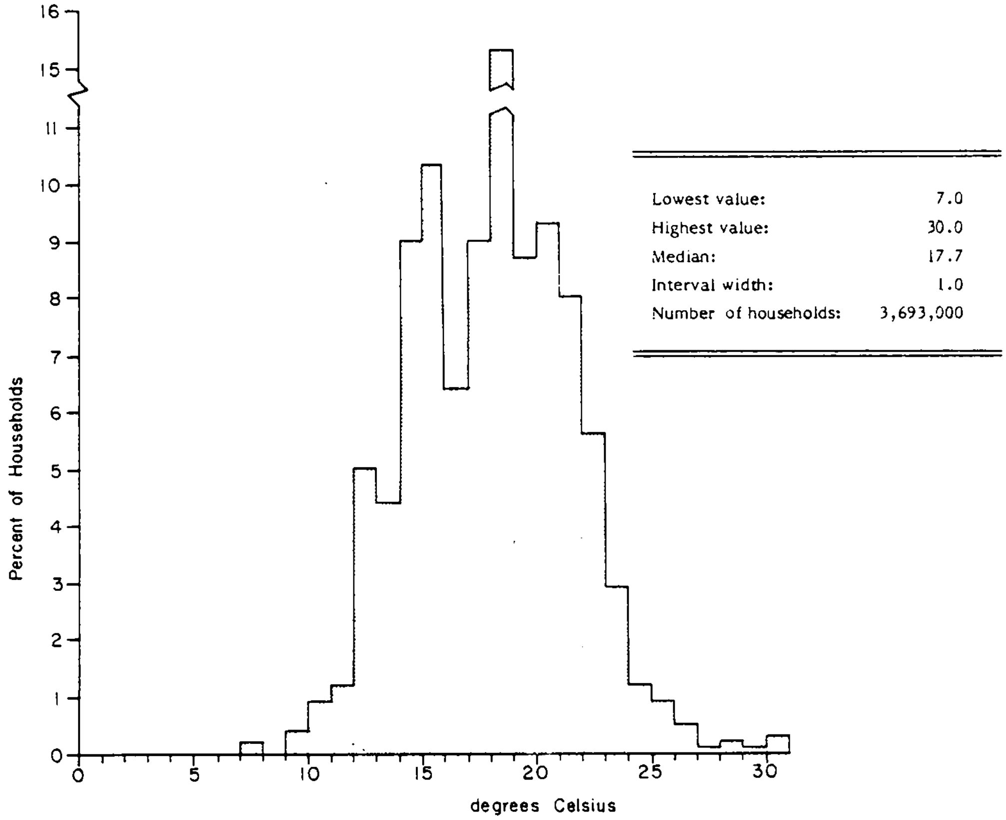
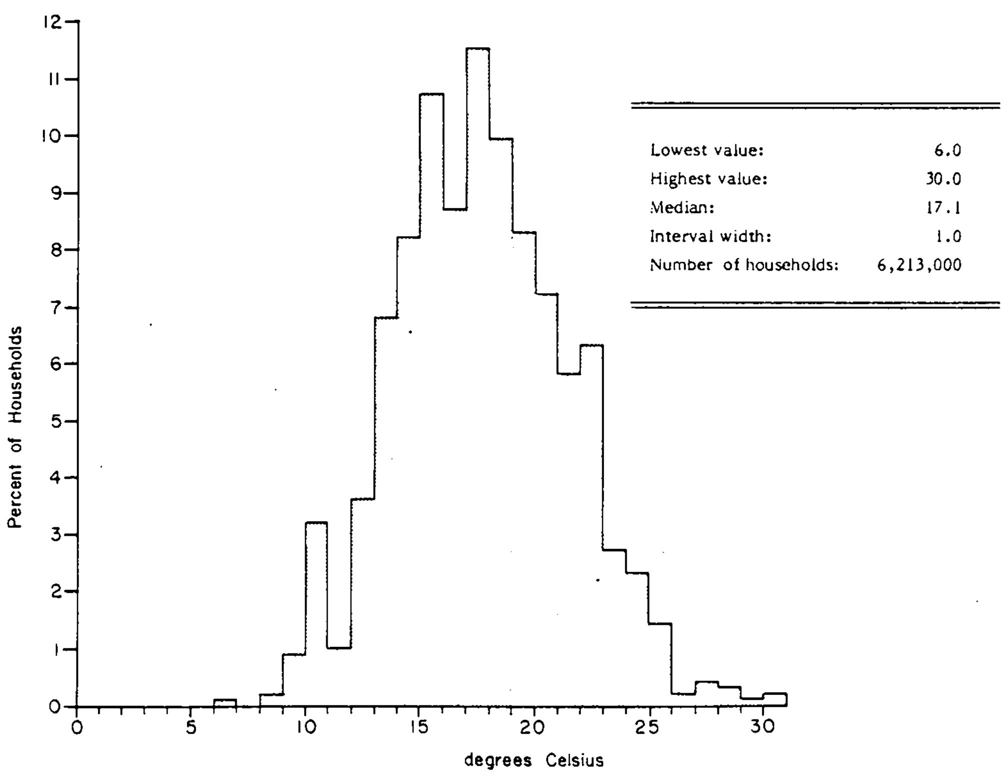


Figure V-9b. North Central



Regional Variation in Temperature (continued)

Figure V-9c. South

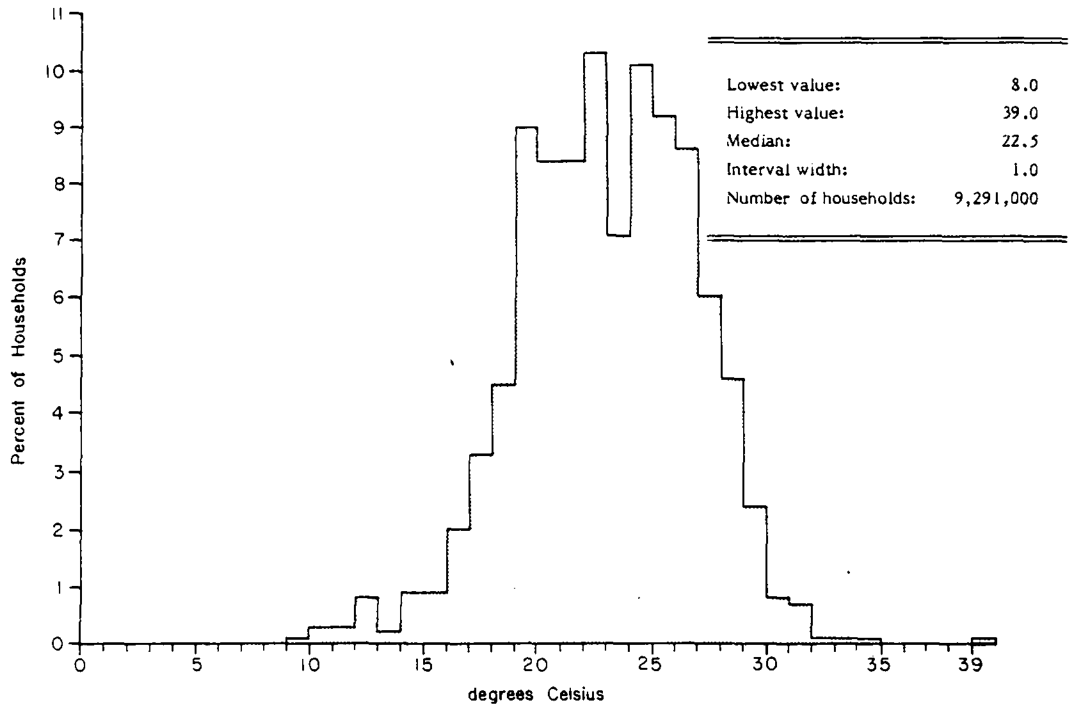
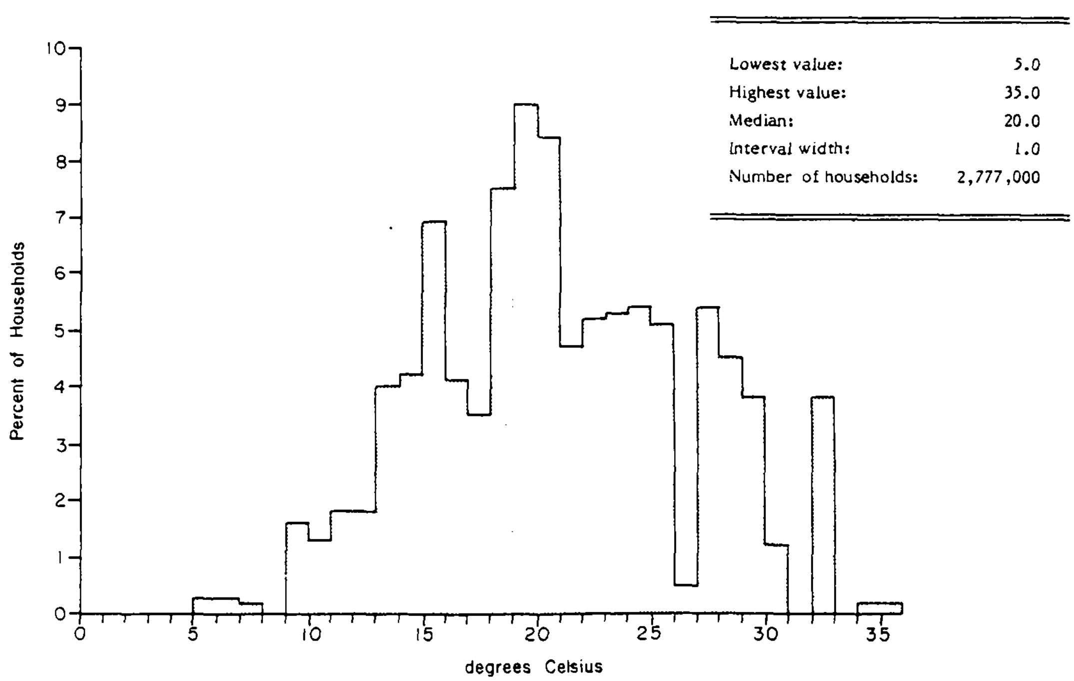


Figure V-9d. West



of households having water warmer than 20° C was much greater in the South than in any other region. The percentage above 20° C in the South was 69.0 percent—a total of 6.4 million households. In the West, about 45 percent of households were over 20° C, compared to about 20 percent in both the Northeast and North Central.

Water temperatures were similar among SMSA and nonSMSA households (the medians were 19.9° C and 19.7° C, respectively), but showed variation in the size-of-place and size-of-system comparisons. The median temperature was slightly warmer among households located in large rural communities (20.8° C) than among those in small rural communities (19.2° C) or other rural areas (19.7° C). Also, the percentage of households above 20° C in large rural communities was 53.0 percent, more than ten percentage points higher than for households in small communities or other rural areas. This finding was in part attributable to the large concentration (about 45 percent) of all rural large-community households in the South, where the water tended to be warmer.

Both the median temperature and the percentage of households over 20° C showed a progressive pattern in the size-of-system comparison: lowest among households served by individual systems, highest among those served by community systems. Specifically, median temperatures were about 18°, 19°, and 21° C, respectively, in households served by individual, intermediate, and community systems. The respective over-20° C rates were about 27 percent, 38 percent, and 59 percent.

In summary, the NSA data showed that domestic water in rural America tended to be unsuitably warm—at least by established criteria. This was particularly the case for households located in large rural communities and served by community systems. The situation was most prominent in the South and West.

Large community systems may deliver water from surface sources, and may transmit it for considerable distances, which may account for the higher water temperatures that were found in community supplies. Depth of pipes in the ground, the weather, latitude, and the source of the water are known to affect water temperature. Indeed, the NSA regional differences were consistent with the warmer climate of the South and with the predominance of community systems in the West (see Chapter IV).

Specific conductance

Specific conductance is an electrical measurement which provides an indication of the concentration of dissolved mineral salts. The measurement is particularly helpful in determining suitability of water for irrigation, but it also is generally useful in determining domestic water quality. For example, increasing conductance may indicate rising content of dissolved mineral salts from natural or industrial origin, but the source of the increase and the chemical composition of the substances must be determined by other tests. Specific conductance is the reciprocal of the electrical resistance measured between two electrodes one centimeter apart and one square centimeter in cross-section; conductance is measured at the existing water temperature and corrected to 25° C.

Conductance values can be related to drinking water quality only insofar as the values are indicative of the concentration of total dissolved solids in water. The dissolved solids are primarily mineral salts which, in large amounts, can increase water hardness, corrosivity, and an unpleasant, "salty" taste. The 1962 US Public Health Service standards suggested a limit of 500 milligrams of total dissolved solids per liter of drinking water. This same limit is proposed for a federal secondary MCL, and was used as the NSA reference value. Conductance in micromhos per centimeter can be converted to roughly equivalent values of total dissolved solids (in milligrams per liter) by multiplying the micromho values by 0.65.[29, 30]

The implications for water quality in terms of total-dissolved-solid content is taken up here after the discussion of conductance findings. The conductance findings themselves, presented immediately below, provide the background for the discussion of water quality. However, conductance is a general indicator rather than a precise measurement of water quality, and no reference value for conductance was set in the NSA.

— Conductance values in rural supplies

Specific conductance showed a wide range of values (Figures V-10, V-10a). At the lower end of the scale, the supplies in some 8,000 rural households had a conductance of seven micromhos per centimeter. At the other extreme, the supplies at about 7,000 households had a conductance of 9,152 micromhos. The mean in rural US households was 473.2; the median was 381.7.

Conductance values varied considerably from region to region (Figures V-10b through V-10e), as was to be expected on the basis of different geological and environmental features. The lowest median values in household supplies were in the Northeast and South (240.1 and 251.7, respectively); the highest values were in the North Central and West (600.4 and 444.0, respectively). Median values in the other NSA groupings (SMSA/nonSMSA, size of place, and size of system) showed some—but not necessarily meaningful—variation. The most prominent variation occurred in the size-of-place comparison. The median value among households in small rural communities (484.3) was higher than in either large rural communities (388.9) or other rural areas (368.1). The variation was partially attributable to a disproportionate number of small-community households being located in the North Central, where conductance values were highest.

— Levels of estimated total dissolved solids in rural supplies

As indicated above, values for specific conductance can be converted to approximately equivalent values of total dissolved solids by multiplying by 0.65. It must be emphasized that the conversion provides only an approximation of the

Figure V-10

Specific Conductance in US Rural Household Supplies

Lowest value:	7.0
Highest value:	9152.0
Median:	381.7
Interval width:	20.0
Number of households:	21,974,000

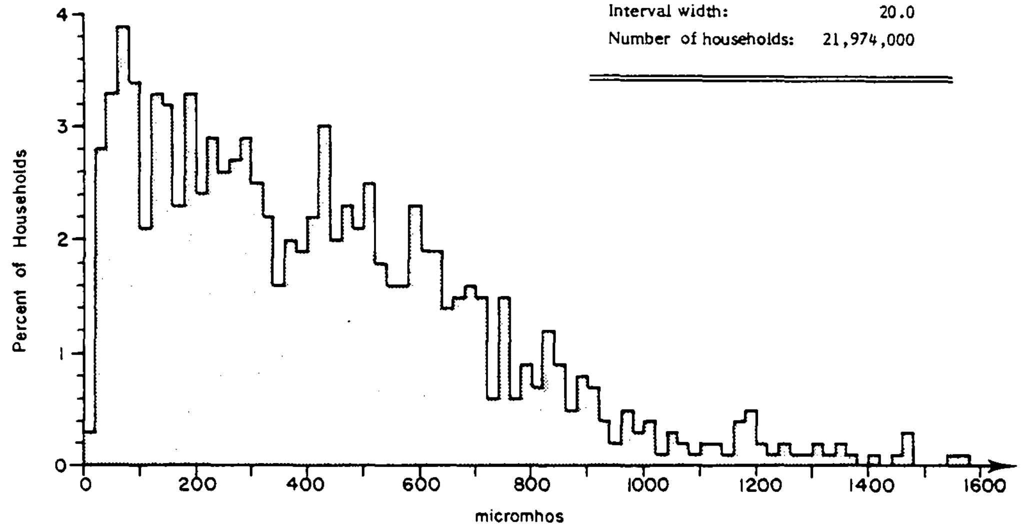
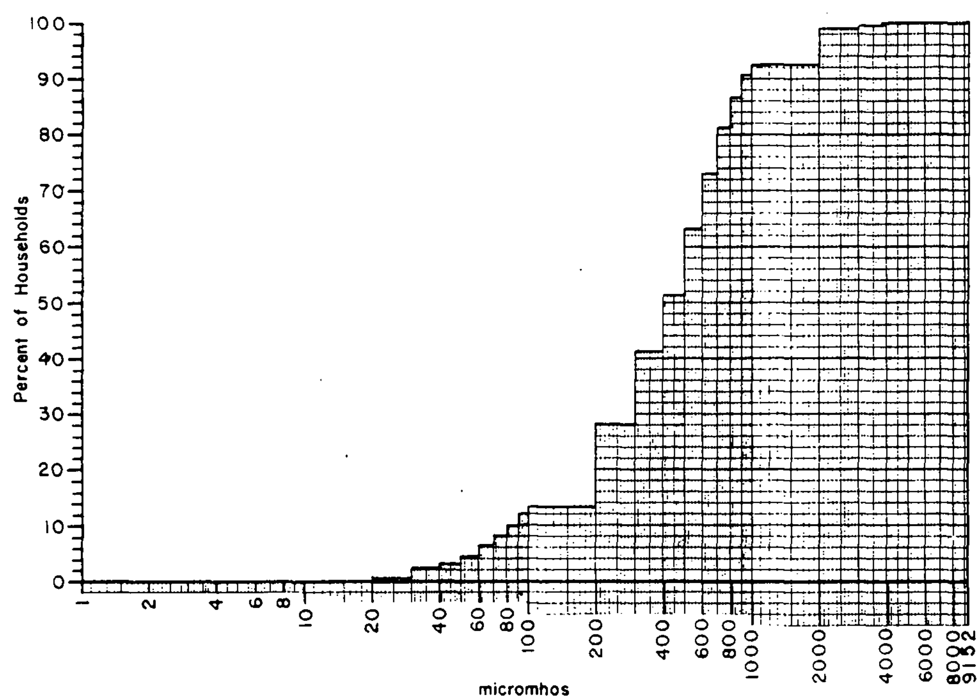


Figure V-10a. Cumulative Distribution of Specific Conductance



NOTE: Cumulative distribution is plotted on semilog paper. Base: 21,974,000 households.

Regional Variation in Specific Conductance in US Rural Household Supplies

Figure V-10b. Northeast

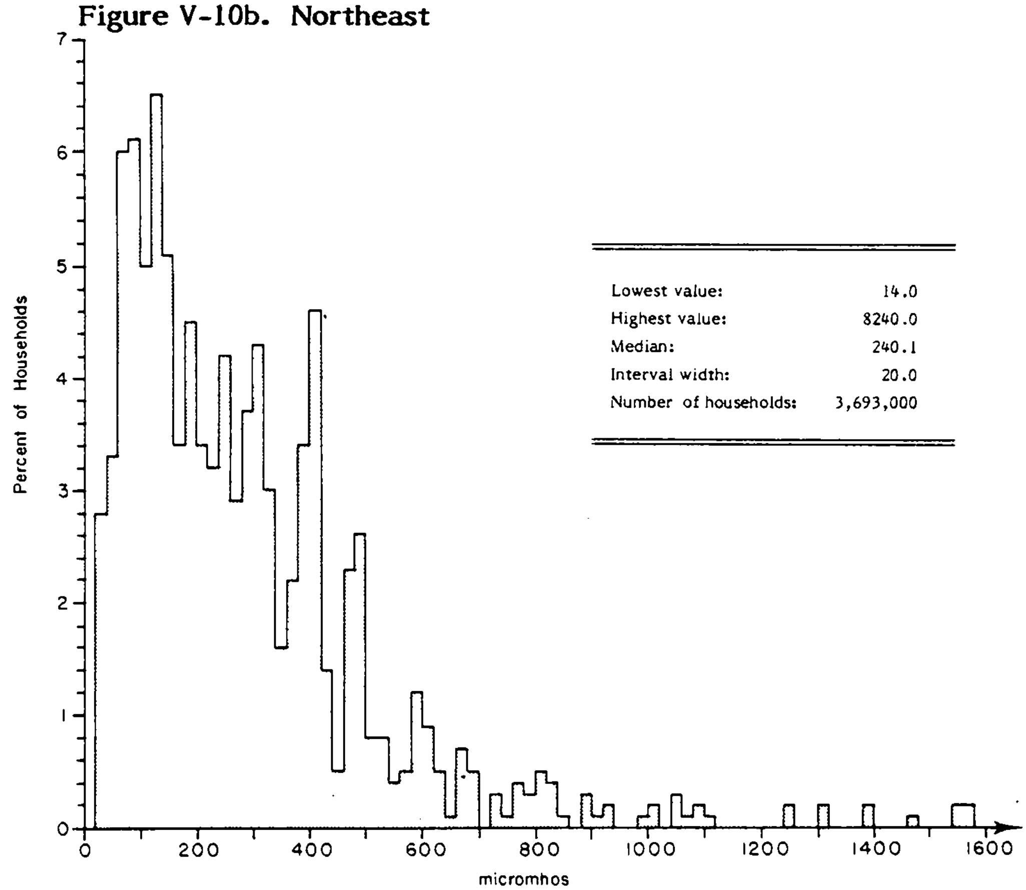
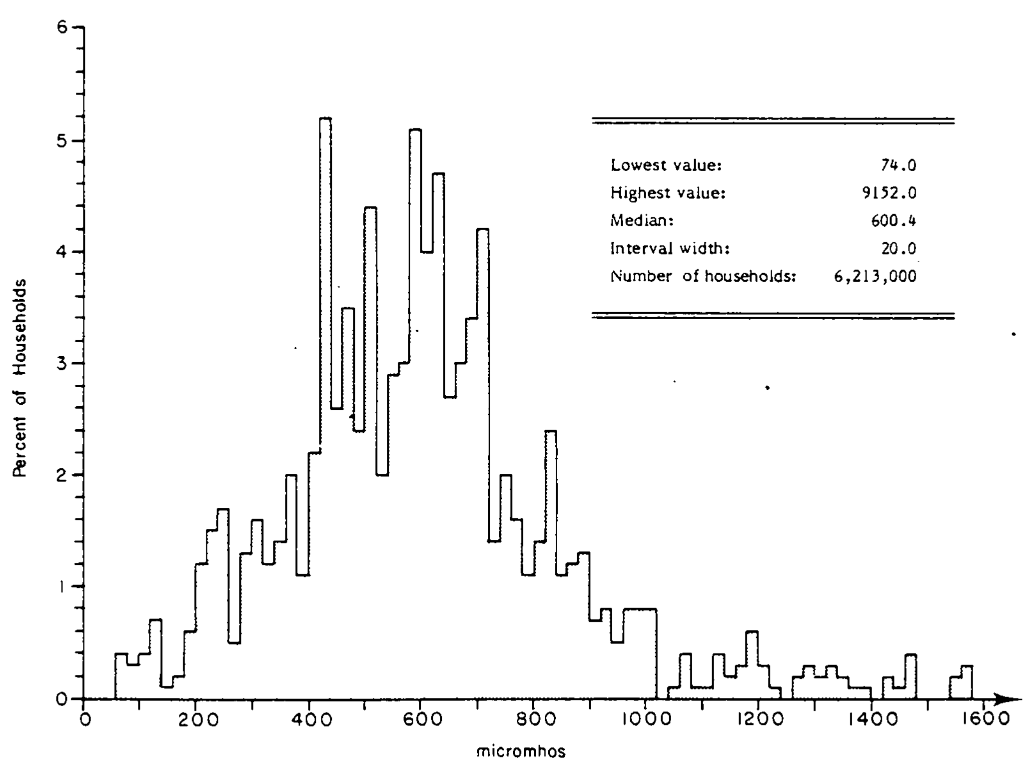


Figure V-10c. North Central



Regional Variation in Specific Conductance (continued)

Figure V-10d. South

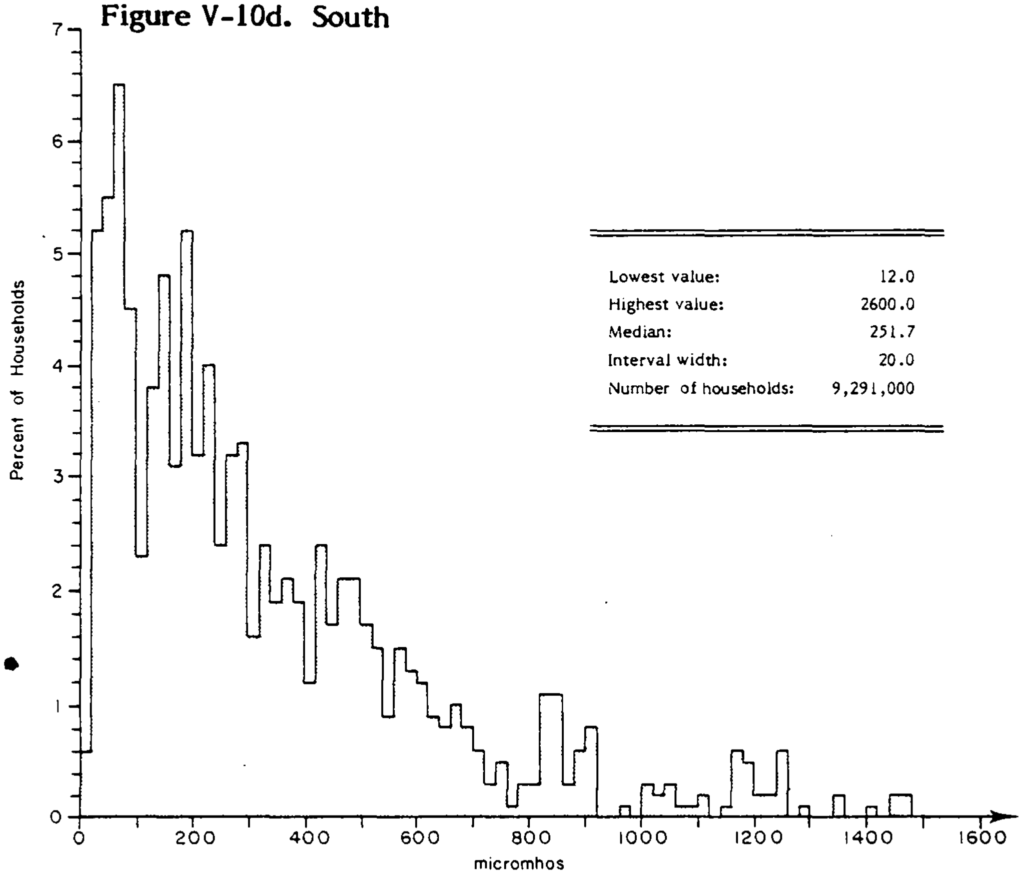
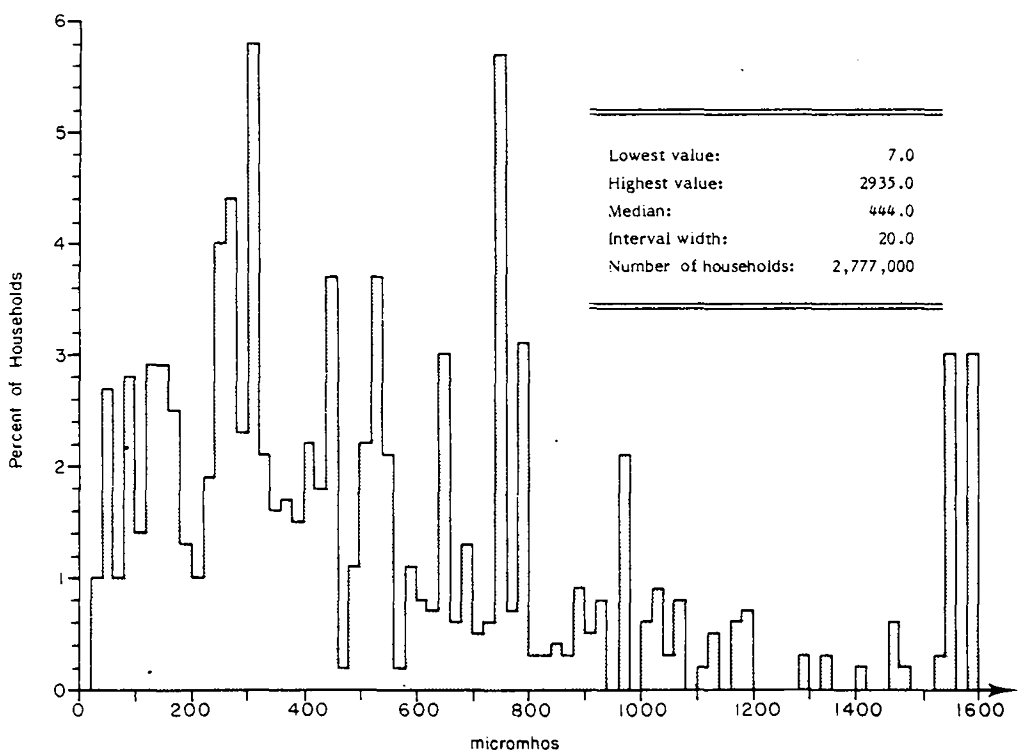


Figure V-10e. West



concentration of total dissolved solids in water supplies. The conductance values vary according to the specific mineral content of the water, and the more exact way to measure total dissolved solids is to allow a specimen of water to evaporate, then to weigh the solid residue. Despite this major qualification, the converted values for total dissolved solids provide a measure of water quality which is easier to assess than the conductance values alone. Specifically, the converted values can be compared to an NSA reference value based on the national secondary MCL for total dissolved solids. Again, the reference value provides only a rough comparison point since, among other things, the secondary MCL on which the reference value is based assumes testing by the evaporative method. The NSA reference value is 500 milligrams of total dissolved solids per liter of water.

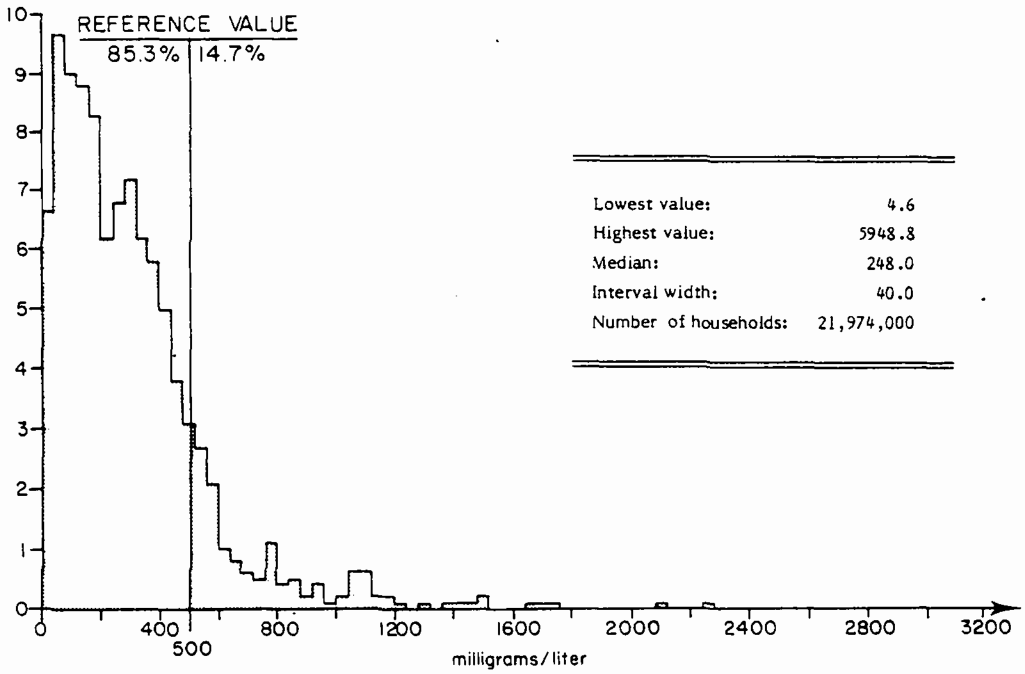
Rural US water supplies showed a median value of total dissolved solids that was about one-half of the reference value. Fully 85.3 percent of supplies were below the reference value, with values of 500 milligrams per liter or less (Figure V-11).

The proportion of supplies above the reference value varied notably from region to region (Figures V-11a through V-11d). The lowest percentage was in the Northeast, where only 5.0 percent of households had supplies with more than 500 milligrams of total dissolved solids per liter of water. In contrast, 23.9 percent of the households in the North Central and 22.2 percent of the households in the West had supplies which exceeded 500 milligrams per liter. In the South, 10.2 percent exceeded that level.

Although there were prominent regional differences, no substantial variation appeared in the other NSA comparisons (SMSA/nonSMSA, size of place, and size of system).

Figure V-11

Estimated Total Dissolved Solids in US Rural Household Supplies



Regional Variation in Estimated Total Dissolved Solids in US Rural Household Supplies

Figure V-11a. Northeast

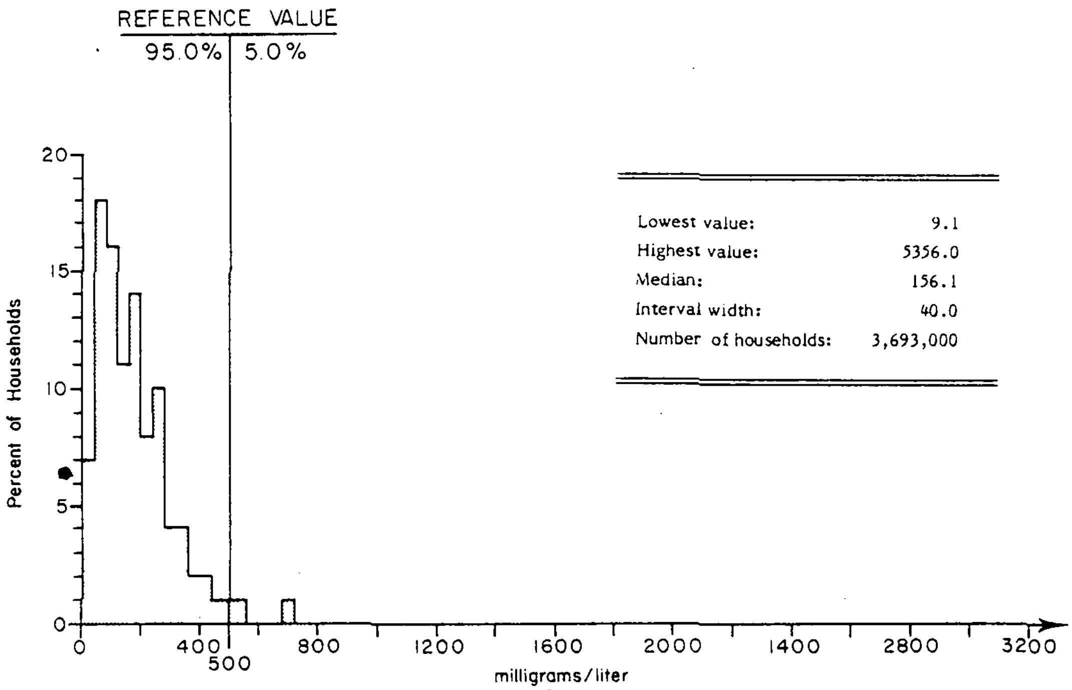
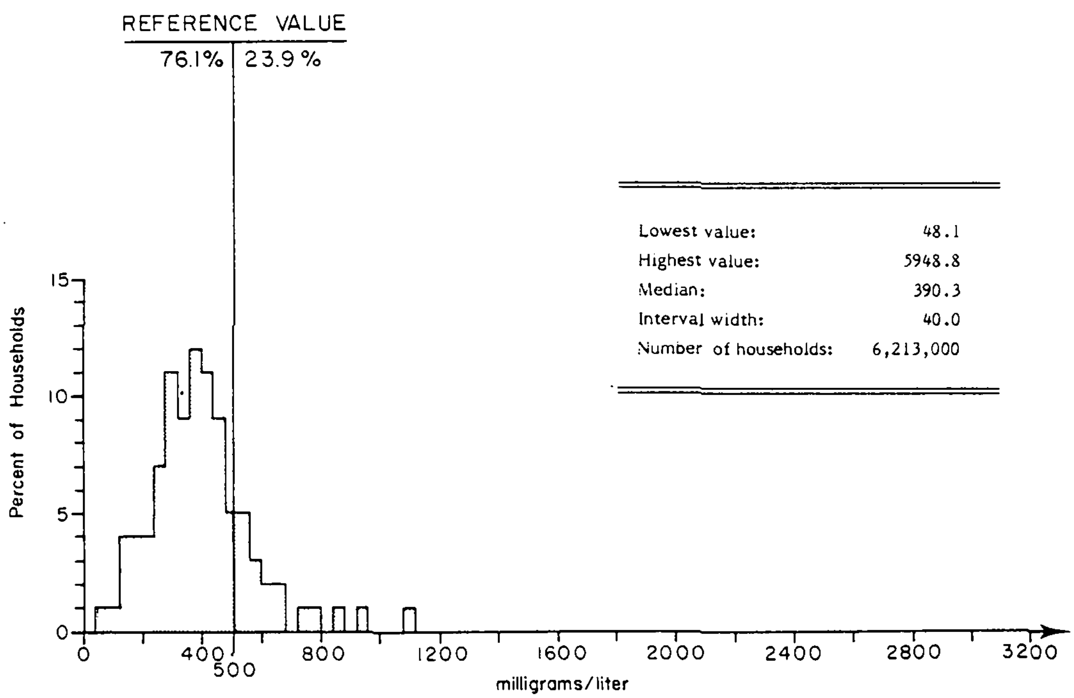


Figure V-11b. North Central



Regional Variation in Estimated Total Dissolved Solids (continued)

Figure V-11c. South

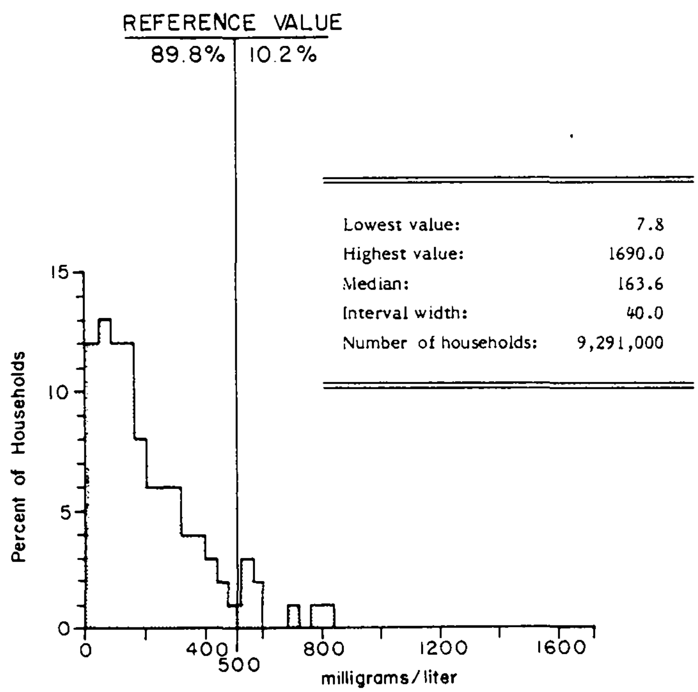
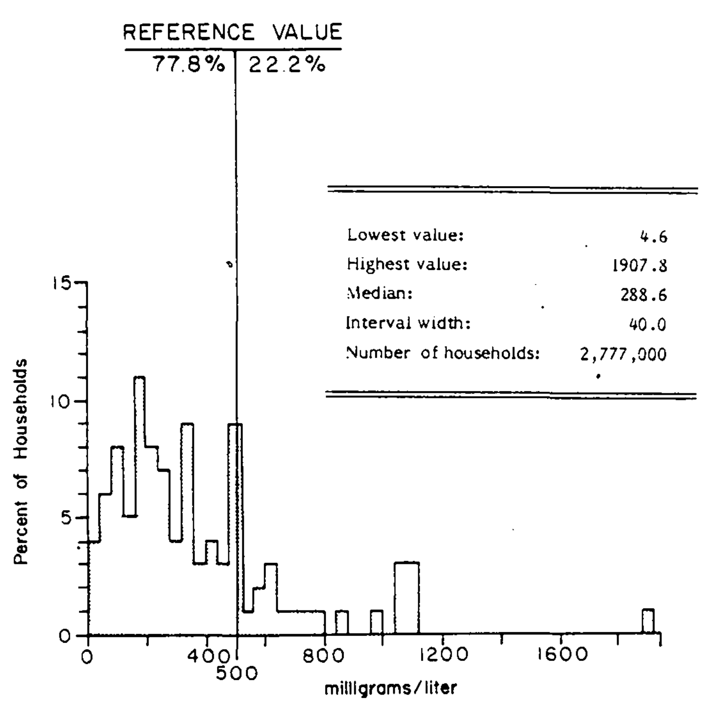


Figure V-11d. West



Hardness

Water's "hardness" refers to its capacity to neutralize soap; substances which form insoluble curds with soap cause hardness. The characteristic of hardness presents a dilemma for water users. On the one hand, hardness (caused most often by calcium and magnesium salts) retards the cleaning action of soaps and detergents and causes a buildup of scale deposits in hot water pipes and cooking pots. On the other hand, artificial "softening" of water by the ion-exchange or lime-soda ash processes may increase the sodium content of water and thus make it unsuitable for people restricted to low sodium diets.[31] Furthermore, naturally soft water tends to be more corrosive than hard water.[32] As a result, soft water can dissolve metals such as cadmium and lead from water pipes or other containers. These and other metals may have specific adverse health or aesthetic effects, some of which are described later.

In addition, the NRC reports that the preponderance of evidence indicates that the softer the water, the higher the incidence of cardiovascular disease.[33] Furthermore, investigators have attributed certain disease-protective effects to the very substances in hard water which are removed in water softeners—calcium and magnesium. All of the theories regarding soft-water problems, however, need extensive testing before final conclusions can be reached, the NRC observes.

According to the NRC, water with less than 75 milligrams of calcium carbonate equivalent per liter generally is considered soft, and water with more is considered hard. A more complete categorization has been done by researchers C. N. Durfor and Edith Becker:[34]

Hardness Range (in milligrams of calcium carbonate equivalents per liter of water)	Description
0 - 60	Soft
61 - 120	Moderately hard
121 - 180	Hard
More than 180	Very hard

Although hardness is caused most often by calcium and magnesium salts, small levels of hardness can be caused by metals, including iron and manganese.[35] Although these two metals were assayed in NSA specimens, their concentrations were not large enough to alter hardness to a prominent degree. In the NSA, hardness thus was calculated only on the basis of concentrations of calcium and magnesium in water. The combined concentrations of the two substances were converted into equivalent quantities of calcium carbonate, which were used to express hardness. To do this, the concentration of calcium in milligrams per liter was multiplied by 0.0499 to convert to milliequivalents per liter. Similarly, the concentration of magnesium in milligrams per liter was multiplied by 0.08226 to convert to milliequivalents per liter. The sum of the milliequivalent values was multiplied by 50 to obtain calcium carbonate equivalent values; those values were used to express hardness.[36]

An NSA reference value was not set for hardness because of the unresolved questions about its potentially contradictory aesthetic and health effects. In fact, the EPA considered establishing a secondary MCL for hardness, but concluded that "available information is not sufficient at this time to balance the aesthetic desirability of setting a limit for hardness against the potential health risk of water softening."[37]

Because of this uncertainty, no attempt is made to interpret the potential health effects of the NSA findings for hardness. However, the findings are compared in a general way with values in the hardness range estimates quoted above. This comparison provides some insight into potential aesthetic and economic effects of hardness, but not into health consequences.

— Hardness in rural supplies

Hardness, expressed as calcium carbonate equivalent units, ranged from a low of 0.1 to a high of just over 1,800 in rural US water supplies (Figures V-12, V-12a). The median was 111.6, which was in the "moderately hard" range according to the Durfor and Becker scale. Hardness at 36.6 percent of households was in the "soft" range (0 through 60). At the other end of the scale, a similar proportion of household supplies (35.3 percent) were in the "very hard" range (more than 180).

Hardness varied prominently according to region (Figures V-12b through V-12e). This was anticipated since the condition is influenced by geological characteristics. Medians were 55.9 and 68.5 in the South and Northeast, respectively. The supplies in those regions thus tended to be soft to moderately hard. In contrast, the medians in the West and North Central were 156.5 and 255.6, respectively. Supplies in those regions thus tended to be very hard—particularly in the North Central, where the median was more than twice that for the nation.

In contrast to the sharp differences that appeared in the regional comparison, few major differences were seen in the comparison of SMSA and nonSMSA households or in the size-of-system comparison. Medians were nearly identical (about 111) for both SMSA and nonSMSA supplies. Medians also were similar for households with individual, intermediate, and community systems—although those with intermediate systems tended to have slightly less hard water (a median of

Figure V-12
Hardness as Calcium Carbonate ($CaCO_3$) in US Rural Household Supplies

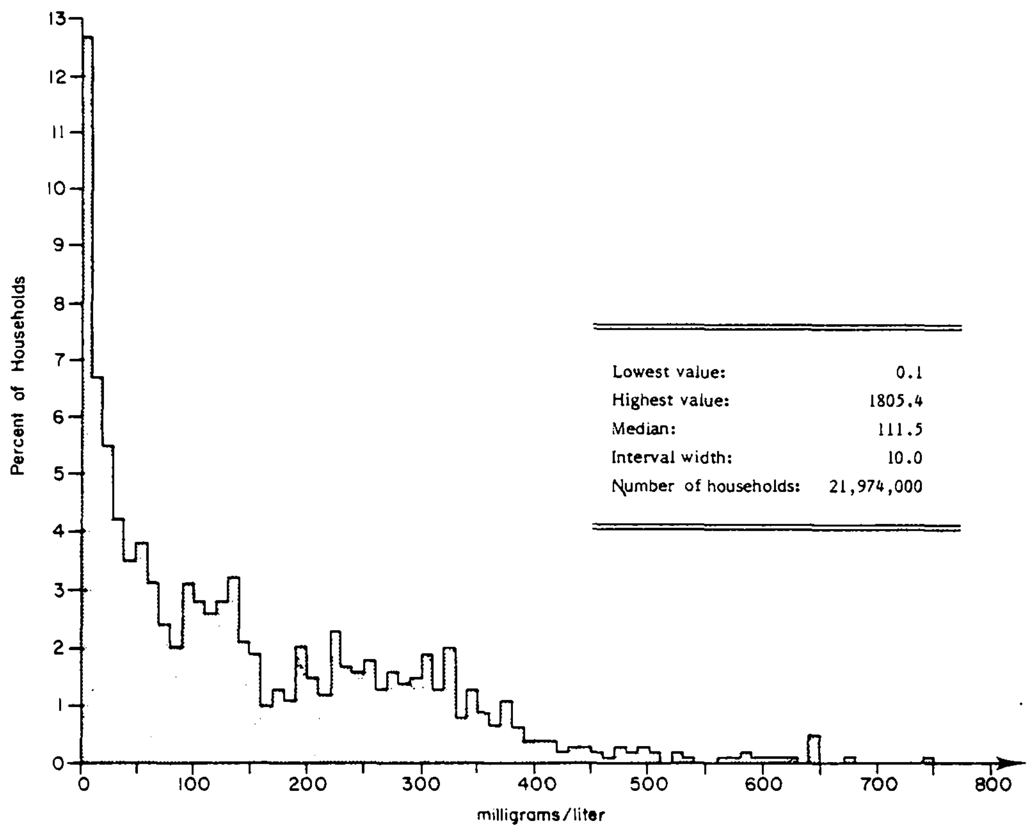
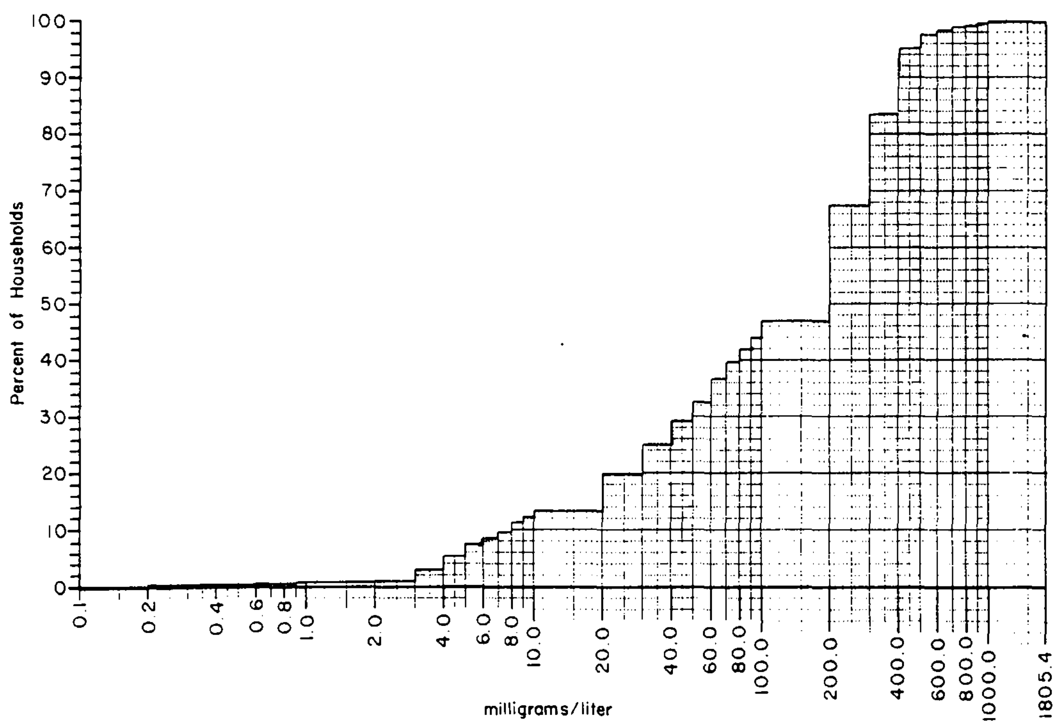


Figure V-12a. Cumulative Distribution of Hardness as Calcium Carbonate



NOTE: Cumulative distribution is plotted on semilog paper. Base: 21,974,000 households.

Regional Variation in Hardness as Calcium Carbonate ($CaCO_3$) in US Rural Household Supplies

Figure V-12b. Northeast

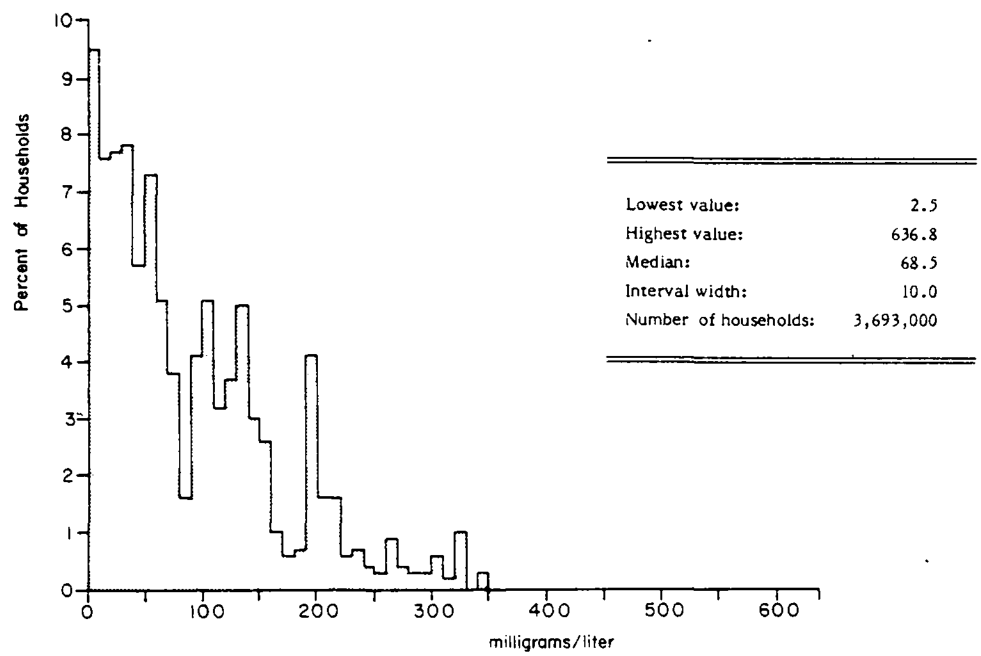
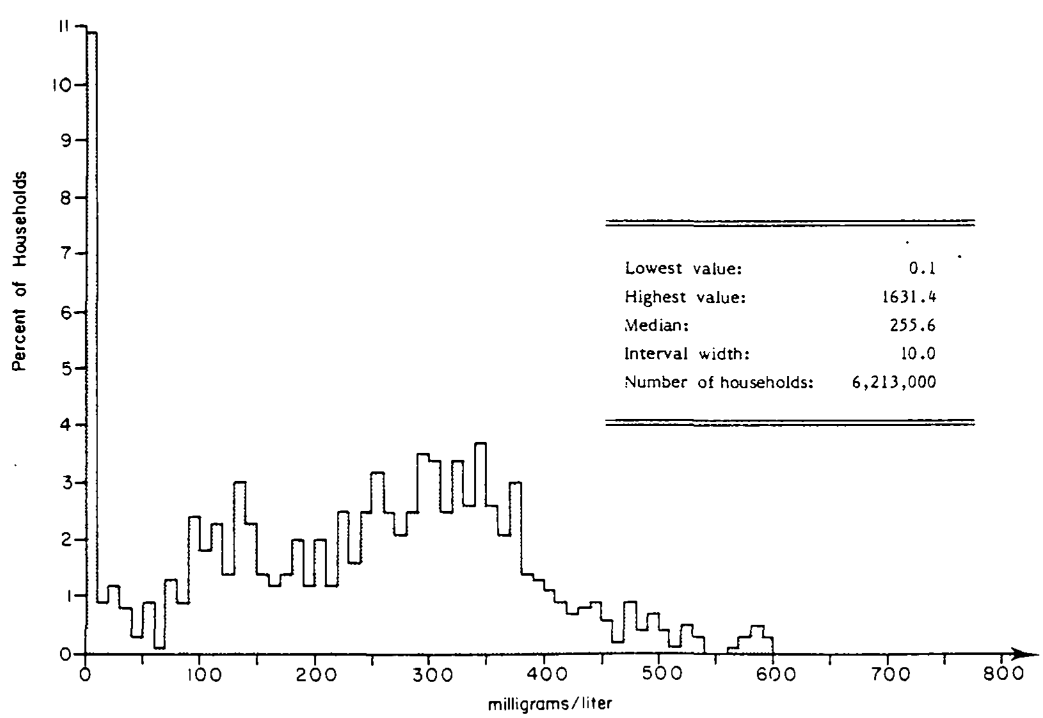


Figure V-12c. North Central



Regional Variation in Hardness as Calcium Carbonate (continued)

Figure V-12d. South

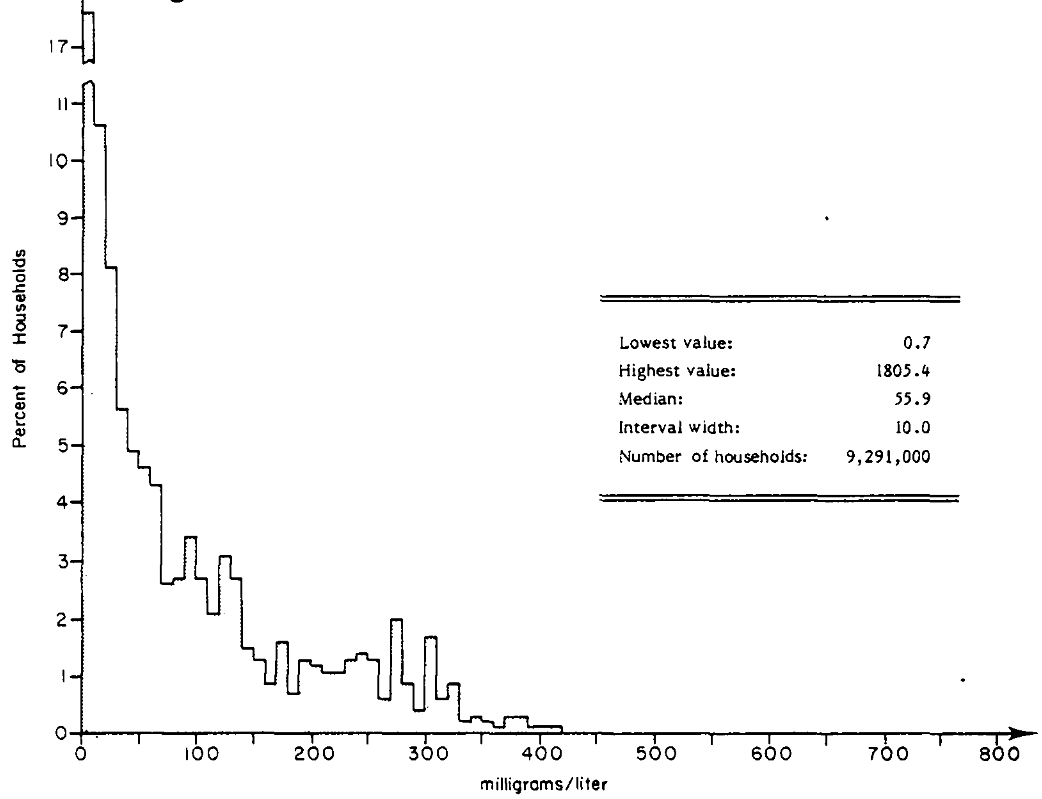
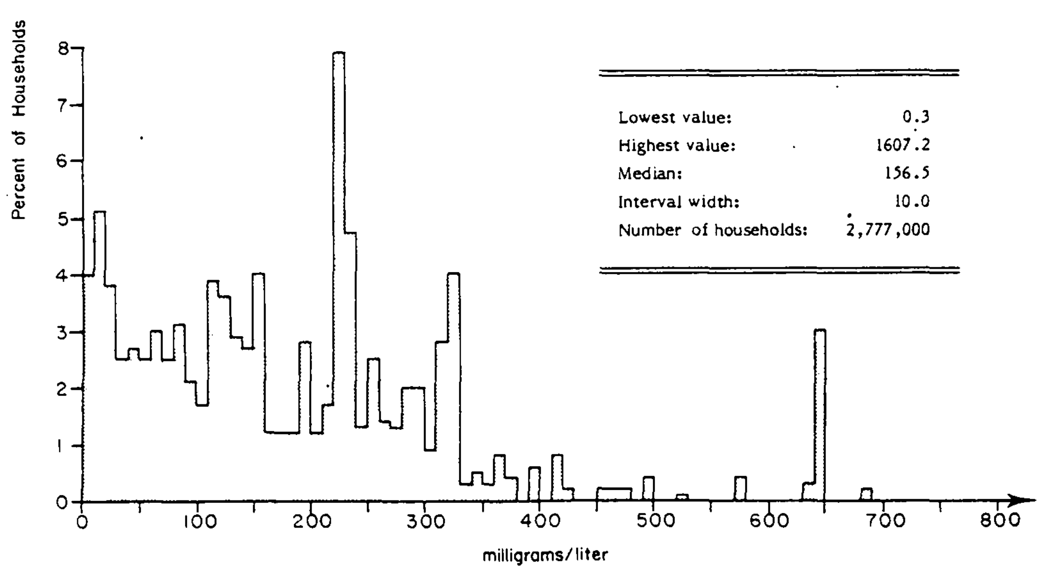


Figure V-12e. West



106.7, compared to about 112 for households with individual and community systems).

The size-of-place comparison showed more variation. The median for households in small rural communities was 195.4, more than twice the median value for households in large rural communities (91.8) and considerably larger than the value for households in other rural areas (109.2). Once again, this difference was at least in part attributable to a disproportionate number of small-rural-community households being located in the North Central, where water hardness was much greater than in other regions.

Summary of physical and chemical characteristics

Of the characteristics in this section of the NSA study, turbidity probably is the most comprehensive, but least specific, indicator of water quality. Generally, domestic water with low turbidity offers less interference to industrial and commercial applications, is easier to disinfect, offers less opportunity for proliferation of bacteria, and may be less susceptible to taste and odor problems.[38] Nearly 84 percent of rural household supplies had readings lower than one NTU. High values, on the other hand, were particularly prominent in the North Central and South, and in households served by individual or intermediate systems as opposed to community systems.

Households which had more than 500 milligrams per liter of total dissolved solids (as derived from specific conductance) also were most prominent in the North Central, where about one of every four households had excessive concentrations. The proportion above this reference value was nearly as large in the West, but much smaller in the South and Northeast.

As to water hardness, the North Central once again had more than its share of supplies with very hard water. The median in the North Central (255.6 calcium carbonate equivalent units) was more than twice the median value for the nation, and considerably larger than the median for any other region.

Color was not a problem in rural supplies. Water temperature, on the other hand, was a potential problem. Measured temperature was above 20° C at 43.8 percent of all rural households. The proportion of households with warm water was most prominent in the South, where about seven of every ten households had water temperatures over 20° C. The proportion over 20° C in the West was less than that in the South, but large in comparison to the Northeast and North Central. An important consideration, however, is that the 20° C mark was derived from conventional abstract measures of desirable water temperature. Household residents, on the other hand, may consider water that is warmer than 20° C acceptable.

INORGANIC CONSTITUENTS

A number of inorganic substances, ranging from chemical compounds to heavy metals, have recognized health effects. Standards for acceptable levels of a number of the substances have been established by public health authorities over the years. Constituents with potential health, economic, or aesthetic effects were studied in NSA water specimens. Some of the substances—calcium, magnesium, nitrates, sulfates, iron, manganese, sodium, and lead—were measured in all of the NSA specimens. Others—arsenic, barium, cadmium, chromium, mercury, selenium, silver, and fluoride—were measured only in a special subsample of the specimens. Specimens from this subsample, which were designated as "Group II," comprised 10 percent of the total number of specimens obtained in the study. The former (Group I) substances tended to be those which were traditionally acknowledged by public health experts as being important in public water supplies. Some (nitrates and lead) had federal interim primary Maximum Contaminant Levels (MCLs); some (sulfates, iron, and manganese) were included in the national secondary regulations;

and one (sodium) was under consideration by the EPA. The latter substances —those assayed in the Group II subsample—all had interim primary MCLs, but there was less expectation of finding them in problematic quantities. The federal MCLs for inorganic substances were used primarily as guides in determining NSA reference values, as explained earlier in this chapter.

Calcium

Calcium compounds are common in water. The element is essential to human nutrition, and the diet should include about seven-tenths to two grams of calcium per day, an amount considerably greater than that found in water—even hard water. Some evidence implicates excessive calcium and magnesium in drinking water as predisposing people to kidney or bladder stones, but other evidence points to deficiency of calcium in water as being a more serious problem.[39]

The situation is summarized in California's exhaustive reference source, Water Quality Criteria:[40] "So far as can be determined at the present time, calcium limits are desirable for domestic supplies not because of a hazard to health, but because calcium may be disadvantageous for other household uses, such as washing, bathing, and laundering, and because it tends to cause incrustations on cooking utensils and water heaters. Hibbard has recommended the following limiting concentrations of calcium in waters for domestic use:

Drinking and Cooking	30 milligrams per liter
Washing	10 milligrams per liter
Laundry	0 milligrams per liter."

Because of the uncertainty about the effects of specific levels of calcium in domestic water, the NSA findings were not compared directly to a reference value. The findings thus are presented without an attempt to analyze their significance for water quality.

— Calcium levels in rural supplies

Calcium was detected in US rural supplies in amounts ranging from less than 0.05 to 582 milligrams per liter of water (Figures V-13, V-13a). The median for the rural US was 30.0 milligrams of calcium per liter; the mean was 41.0.

Calcium was one of the two constituents used to determine hardness, and regional differences in calcium concentrations paralleled those reported for hardness (Figures V-13b through V-13e). Thus, median values were smallest among household supplies in the South (17.0 milligrams per liter) and in the Northeast (19.3 milligrams per liter), and largest among household supplies in the West (40.0 milligrams per liter) and in the North Central (68.0 milligrams per liter).

Results of other NSA groupings also paralleled those for hardness. Thus, the median concentration among both SMSA and nonSMSA households was about 30 milligrams of calcium per liter, as was the median concentration among households served by each size of system, whether individual, intermediate, or community.

The size-of-place differences also paralleled those for hardness, with median values largest among households located in places of less than 1,000 people (small rural communities). These differences were partially attributable to the regional distribution of households, as described in the discussion of hardness, above.

Magnesium

As one of the most abundant elements in the earth's crust, magnesium is widely distributed in ores and minerals. Magnesium salts generally are very soluble, and large concentrations are found in water.

Figure V-13

Calcium in US Rural Household Supplies

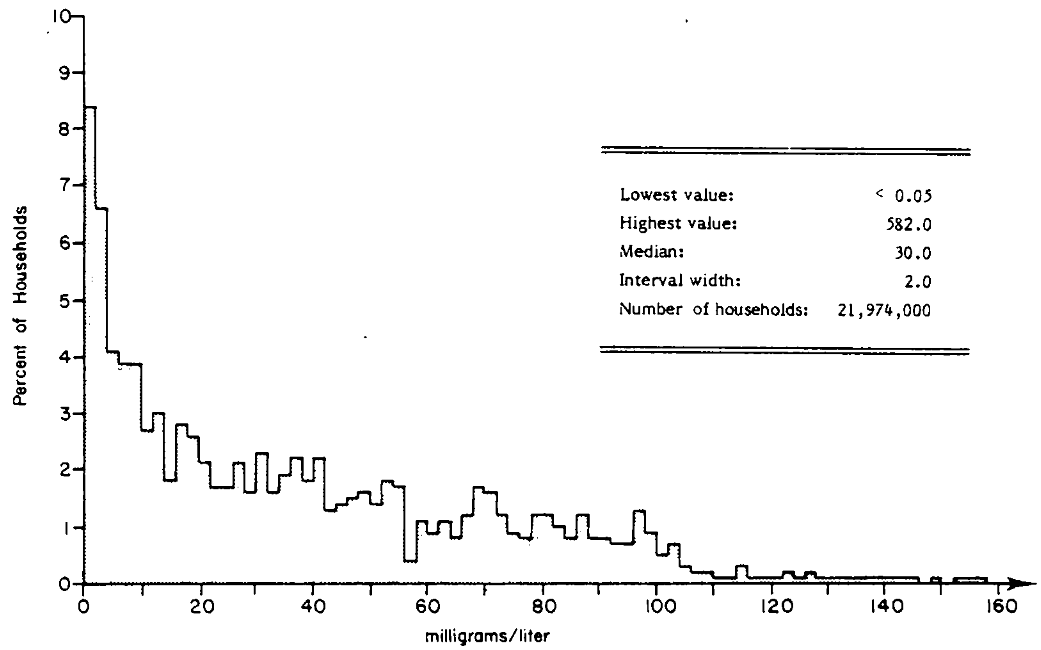
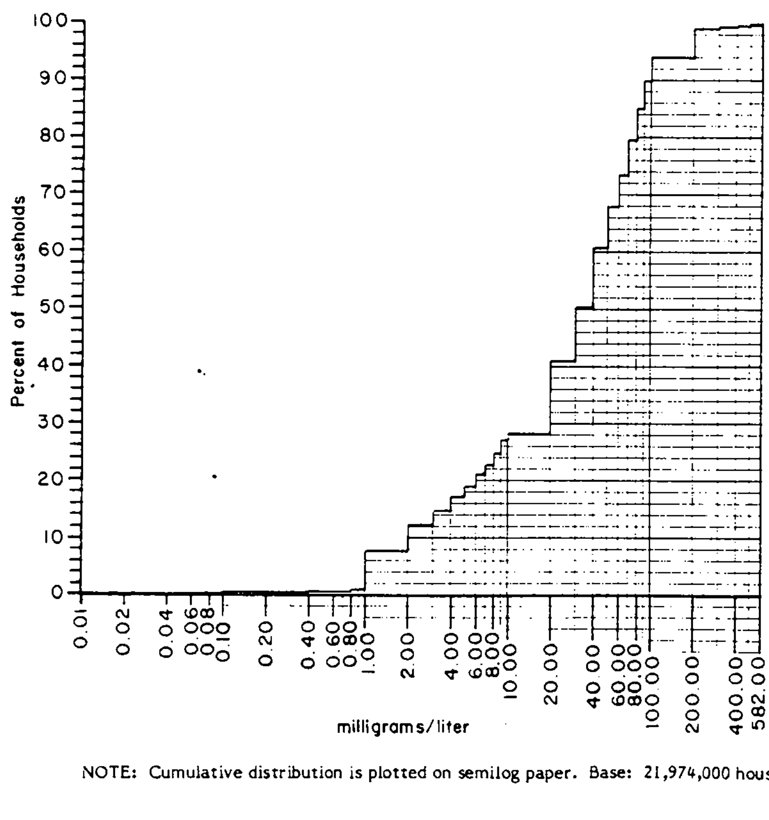


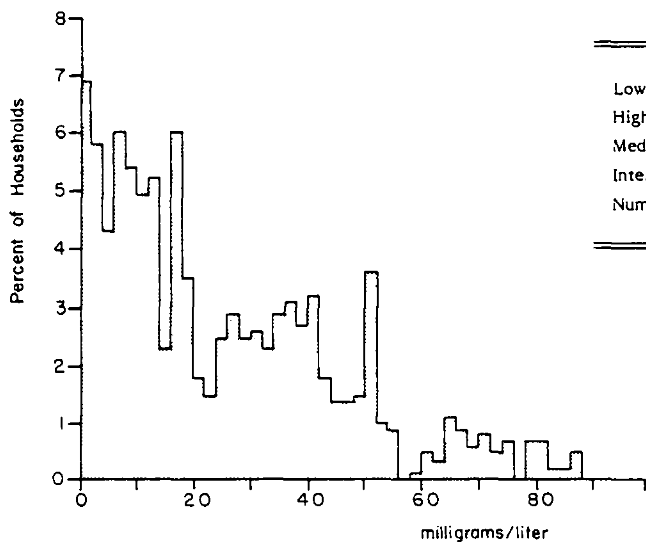
Figure V-13a. Cumulative Distribution of Calcium



NOTE: Cumulative distribution is plotted on semilog paper. Base: 21,974,000 households.

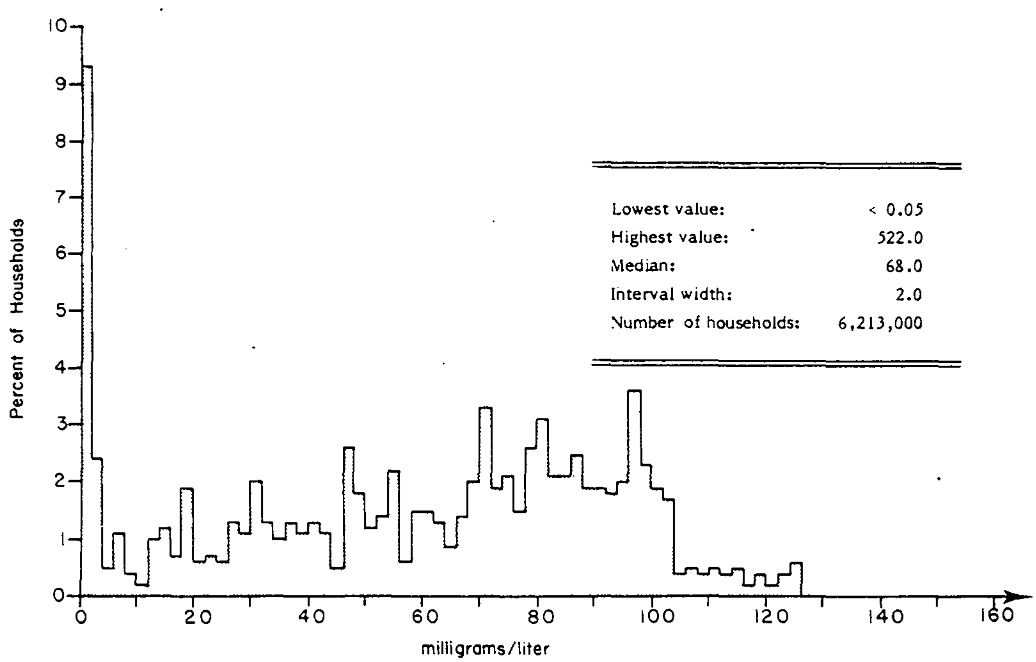
Regional Variation in Calcium in US Rural Household Supplies

Figure V-13b. Northeast



Lowest value:	1.0
Highest value:	199.0
Median:	19.3
Interval width:	2.0
Number of households:	3,693,000

Figure V-13c. North Central



Lowest value:	< 0.05
Highest value:	522.0
Median:	68.0
Interval width:	2.0
Number of households:	6,213,000

Regional Variation in Calcium (continued)

Figure V-13d. South

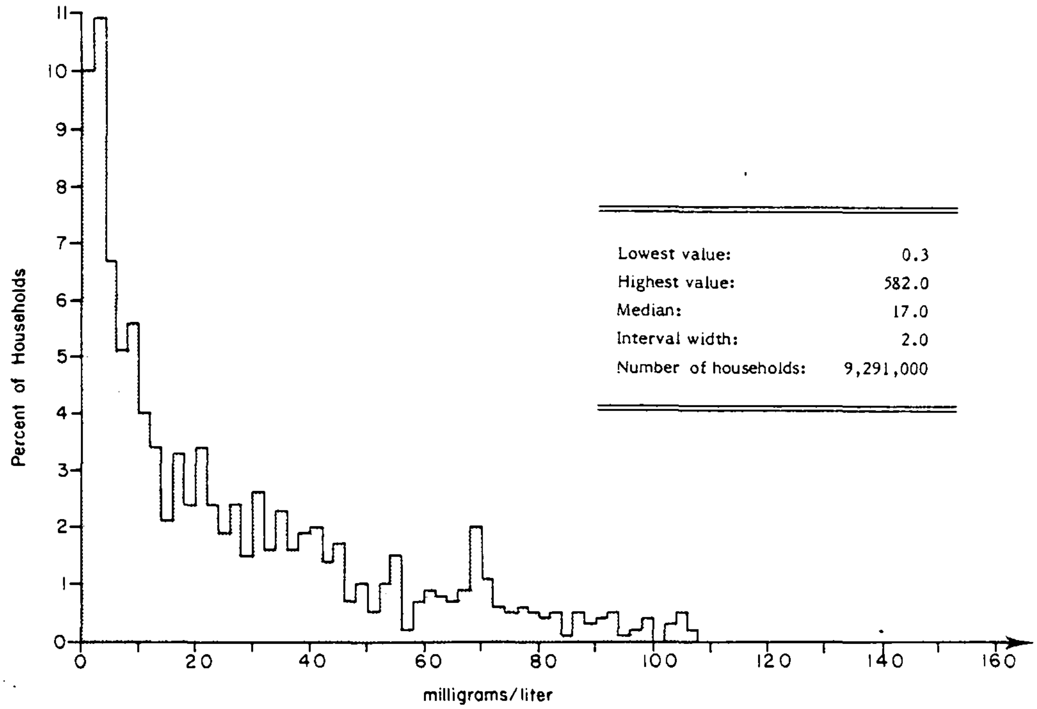
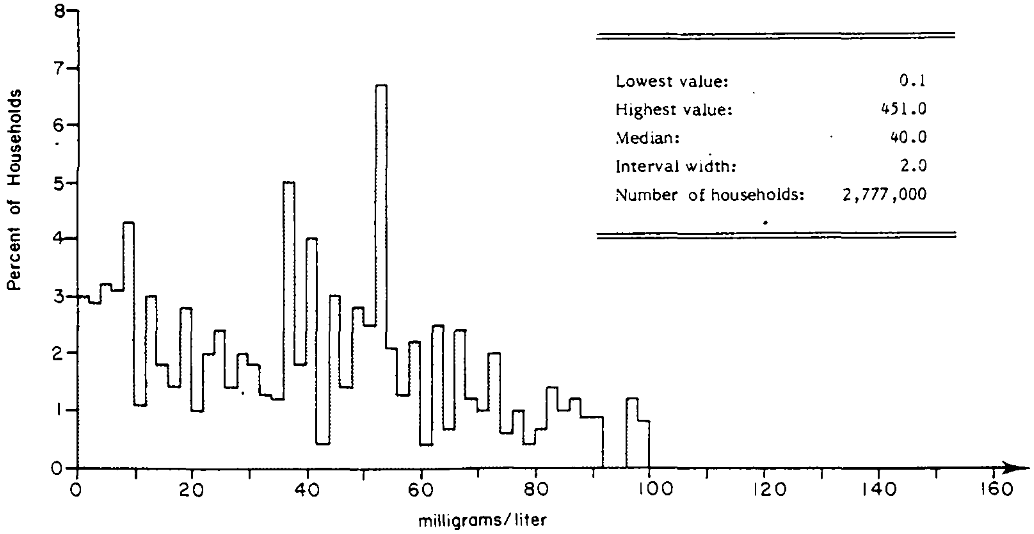


Figure V-13e. West



Magnesium is an essential element in the human diet; excessive amounts seldom are hazardous since they usually are excreted before harm is done. Large concentrations of magnesium sulfate in drinking water may cause diarrhea at first, but the body apparently counteracts the effect with time, as it does the laxative effect of sulfate (see below). In the past, the US Public Health Service has recommended a maximum concentration of 100 milligrams per liter of water (in 1925), and 125 milligrams per liter (in 1942 and 1946). The recommendation was dropped in 1962, however, and the new federal regulations do not set limits for the substance. The World Health Organization's international standards specify 150 milligrams of magnesium per liter of drinking water as excessive.[41]

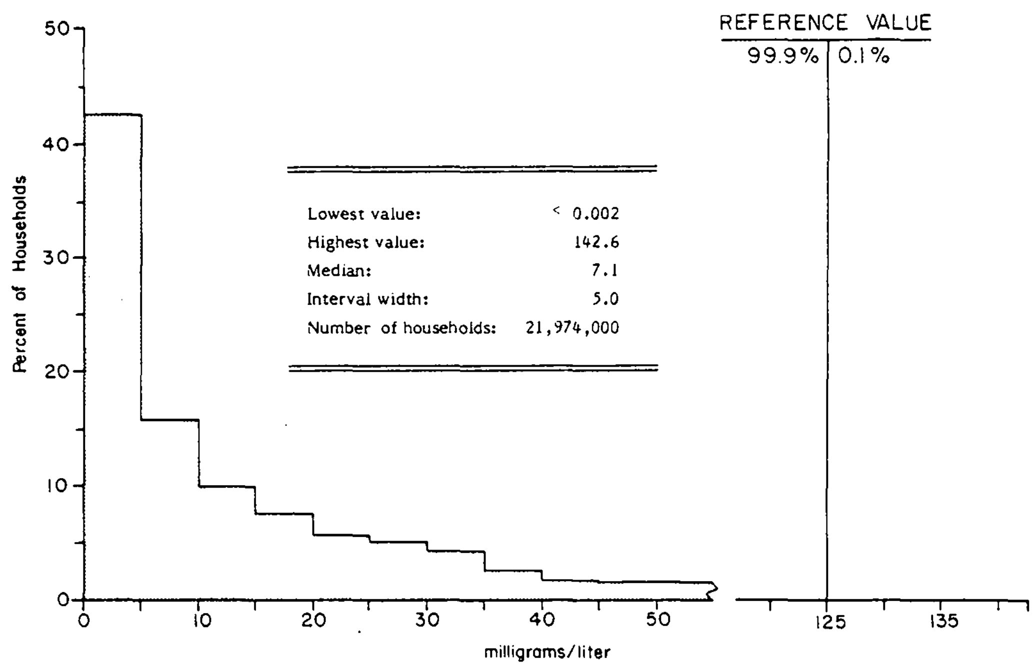
To provide a descriptive guide, NSA investigators selected a reference value of 125 milligrams of magnesium per liter of water. This level was the same as the former Public Health Service standard, but lower than the World Health Organization recommendation. Selection of the more stringent reference value was in accord with the general NSA procedure of using the more conservative measure, but the World Health Organization recommendation was also used as a reference in evaluating potential health consequences.

— Magnesium levels in rural supplies

As expected, magnesium was detected in nearly all rural water supplies. The concentrations varied greatly—from a low of less than 0.002 milligrams per liter to a high of 142.6 milligrams per liter (Figure V-14). However, only 0.1 percent of households (21,000) had supplies with values exceeding the NSA reference value of 125 milligrams per liter. The US median value was 7.1 milligrams of magnesium per liter.

Magnesium was one of the two constituents used to calculate hardness, and concentrations of the metal varied in a regional pattern similar to that for hardness. The smallest median values were observed among households in the

Figure V-14
Magnesium in US Rural Household Supplies



South (2.9 milligrams per liter) and in the Northeast (4.4 milligrams per liter); the largest values were found among households in the West (14.9 milligrams per liter) and in the North Central (19.1 milligrams per liter). In conjunction with these findings, household supplies exceeding the NSA reference value were found only in the West and North Central, where median values were highest (Figures V-14a through V-14d).

The medians and the proportions of households exceeding the NSA reference value were not strongly influenced by location of households inside or outside SMSAs. There were variations according to the size of system serving the household, but the variations were too small to be meaningful. Again, the most prominent variation occurred in the size-of-place grouping. There, the median value among households located in small rural communities was 11.3 milligrams of magnesium per liter, more than twice the value among households in large rural communities, and about one and one-half the value for households in other rural areas. This difference was in part attributable to the regional distribution of households, as explained in the discussion of hardness, above.

There did not appear to be serious health consequences associated with the NSA findings for magnesium. On the basis of present research knowledge, even the highest concentrations of magnesium appeared to present no imminent health hazard. That is, the highest concentration (142.6 milligrams per liter), which occurred in some 8,000 households, exceeded the NSA reference value but not the World Health Organization recommendation. High concentrations were found most often in the West and North Central.

Nitrates

Nitrogenous materials tend to be converted to nitrates in lakes, streams, and groundwater. Most naturally occurring nitrogenous compounds enter the water in organic matter. A small amount is in precipitation. Concentrated amounts

Regional Variation in Magnesium in US Rural Household Supplies

Figure V-14a. Northeast

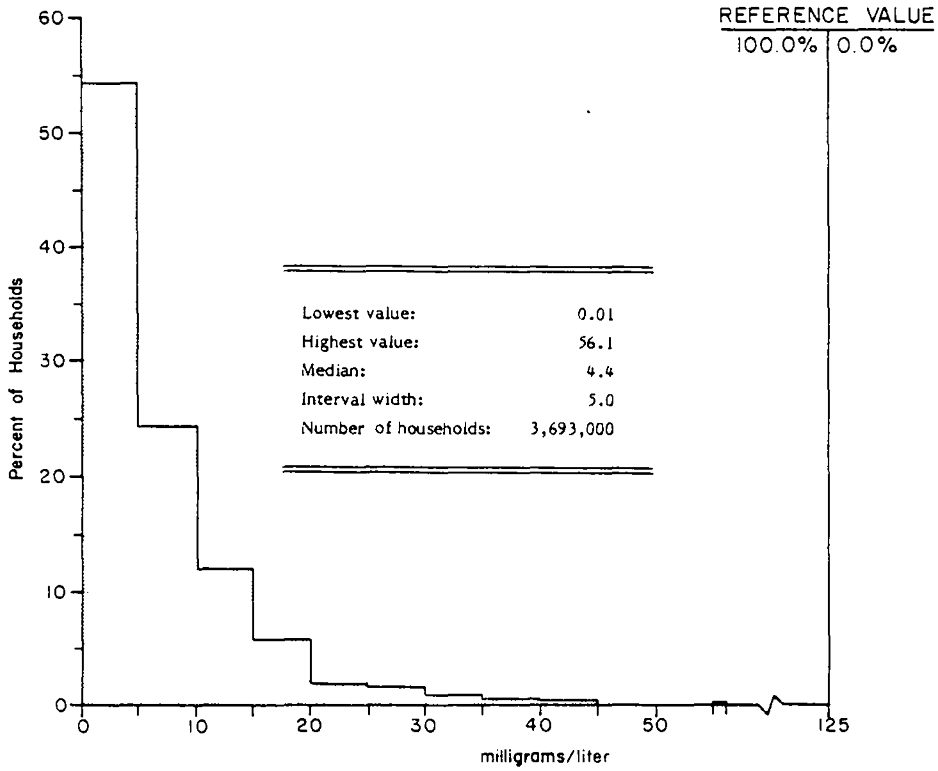
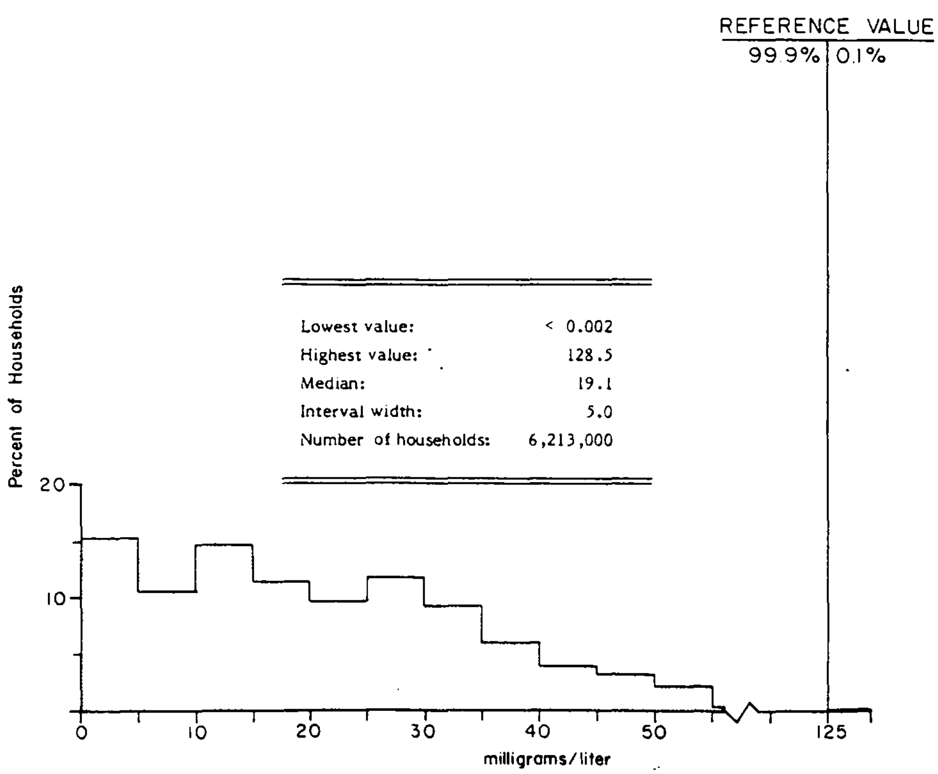


Figure V-14b. North Central



Regional Variation in Magnesium (continued)

Figure V-14c. South

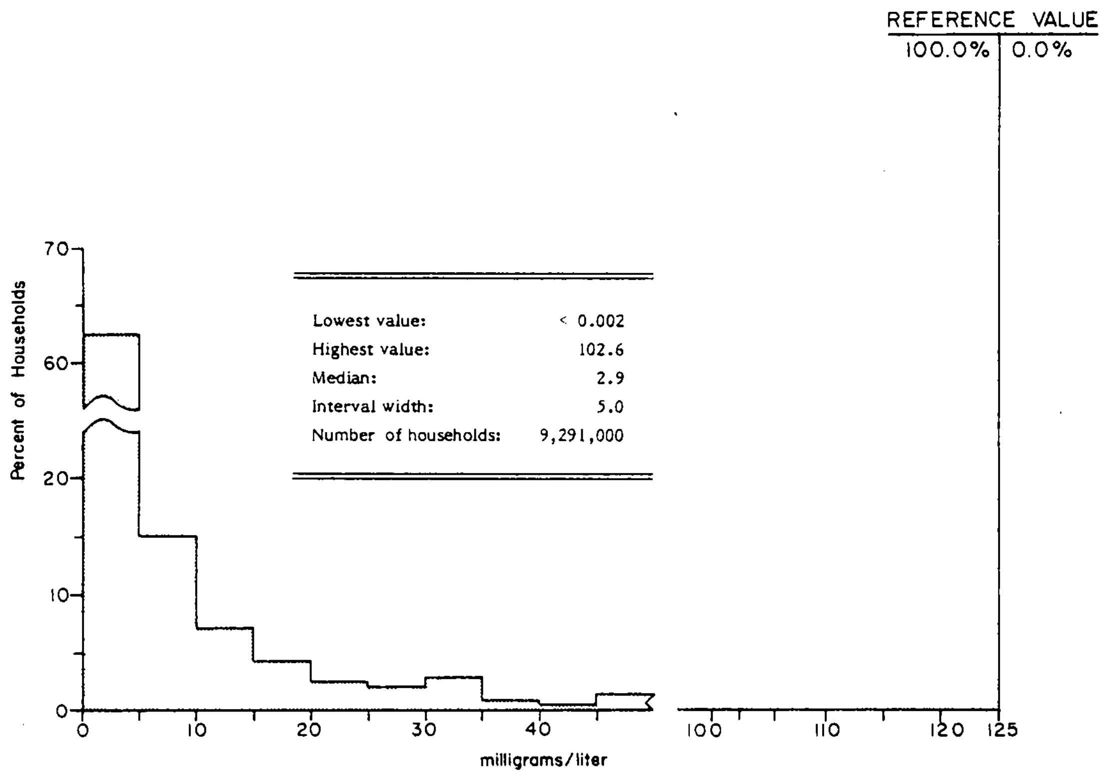
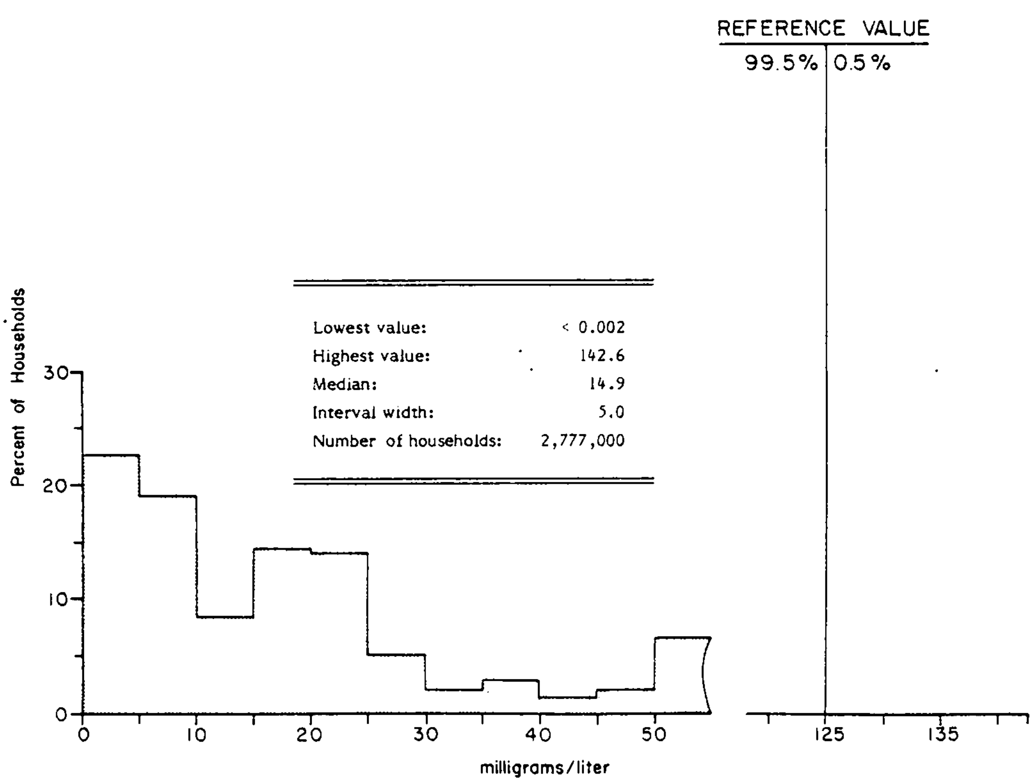


Figure V-14d. West



enter from municipal and industrial wastewater pipes, refuse dumps, animal feed lots, and septic tanks. Another, more diffuse source of nitrates is inorganic chemical fertilizer applied to the land.

Nitrates themselves generally are not direct health hazards. Nitrates in the human intestine, however, can be converted by bacterial action into nitrites. This is a particular problem in infants because the pH in the stomachs of infants tends toward alkalinity (pH of 5-7) because the acid secretion pattern found in older humans is not yet developed. As a consequence, nitrate-converting bacteria are able to inhabit areas of the small intestine closer to the stomach. The converted nitrites then have longer residence time, and therefore absorption time, in the intestine than if acidity from the stomach forced the bacteria farther down the tract.[42] Absorbed nitrites oxidize hemoglobin in the blood to methemoglobin, which blocks the crucial function of oxygen transport to the body's tissues. The result can be severe oxygen depletion (the "blue baby" syndrome).

Generally, standards for the maximum acceptable concentration of nitrates in drinking water are linked to the anoxic threat in infants. According to the NRC, a value of about ten milligrams of nitrate-N (nitrate content expressed as equivalent nitrogen) per liter of water is the maximum level at which no adverse health effects have been observed. This value is the same as the federal interim primary MCL. The NRC cautions, however, that "there is little margin of safety in this value."[43]

The NSA reference value was the same as the interim primary MCL—ten milligrams of nitrate-N per liter of water.

— Nitrate-N levels in rural America

Large concentrations of nitrate-N previously had been found in shallow wells, particularly in the Midwest,[44] and it was assumed that a fairly large number of rural supplies might exceed the NSA reference value. Fortunately, this was not the case. In the rural US, 97.3 percent of households were below the reference value; only 2.7 percent were above it (Figures V-15, V-15a). Despite some larger values, the mean level in rural America was only 1.7 milligrams of nitrate-N per liter, and the median was only 0.3.

As expected, those households above the reference value were predominantly in the North Central and West, regions which have been associated with excessive nitrate-N values in the past.[45] The percentage of North Central households above the reference value was 5.8, twice the national average. The percentage of Western households exceeding the reference value was 4.0. Only 1.3 percent of households in the South and 0.3 percent in the Northeast surpassed the reference value (Figures V-15b through V-15e). Also as anticipated, a larger proportion of nonSMSA households had values greater than the reference value —3.2 percent, compared to 1.7 percent for SMSA households.

As to size-of-place variation, the proportion of households above the reference value was close to the national average in other rural areas, but half again as large as the national average in both large and small rural communities (4.2 percent and 4.7 percent, respectively). This finding was surprising since in previous studies many of the supplies with excessive amounts of nitrates were on farms, which most often are located in other rural areas. Again, the difference may have been attributable in part to differential distributions in the NSA sample. That is, a disproportionately large number of small-rural-community households (about 48 percent) were located in the North Central, where the proportion of households beyond the nitrogen reference value was largest. At the same time, a disproportionately small number of small-rural-community households (about 8 percent) were located in the Northeast, where the proportion of households above the nitrogen reference value was smallest. The overall effect was to increase the over-reference-value rate in the small-rural-community category. A similar but

Figure V-15
Nitrate-N in US Rural Household Supplies

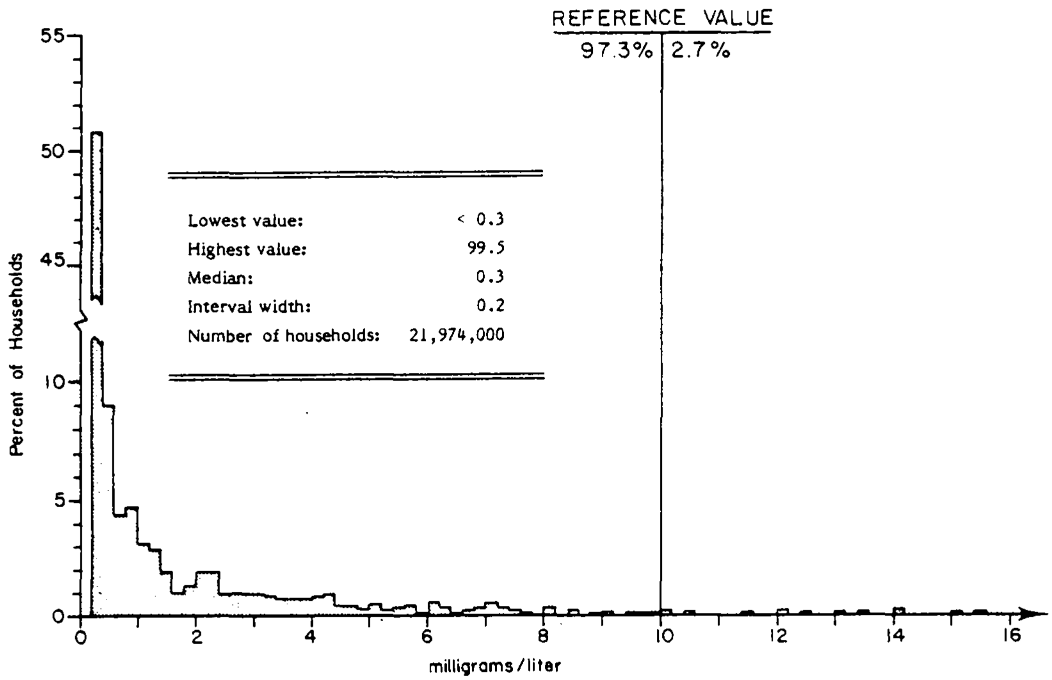
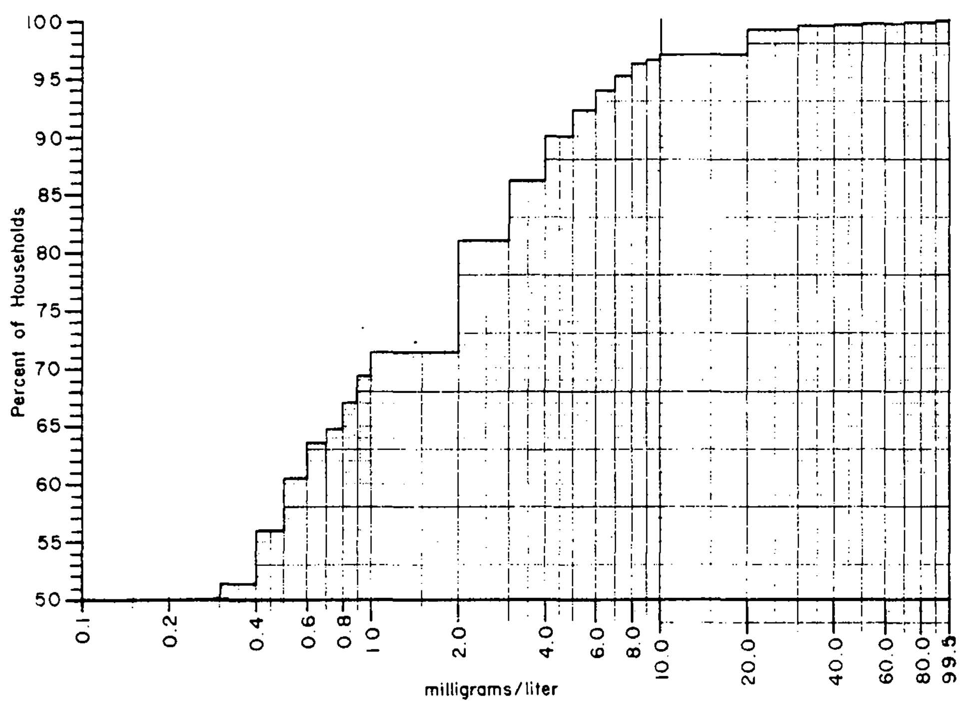


Figure V-15a. Cumulative Distribution of Nitrate-N



NOTE: Cumulative distribution is plotted on semilog paper. Base: 21,974,000 households.

Regional Variation in Nitrate-N in US Rural Household Supplies

Figure V-15b. Northeast

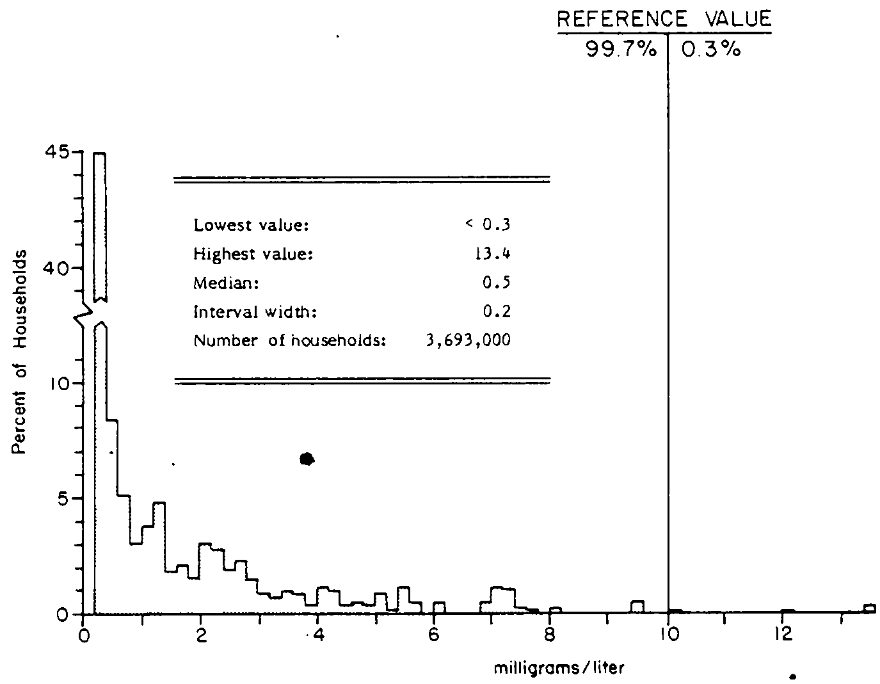
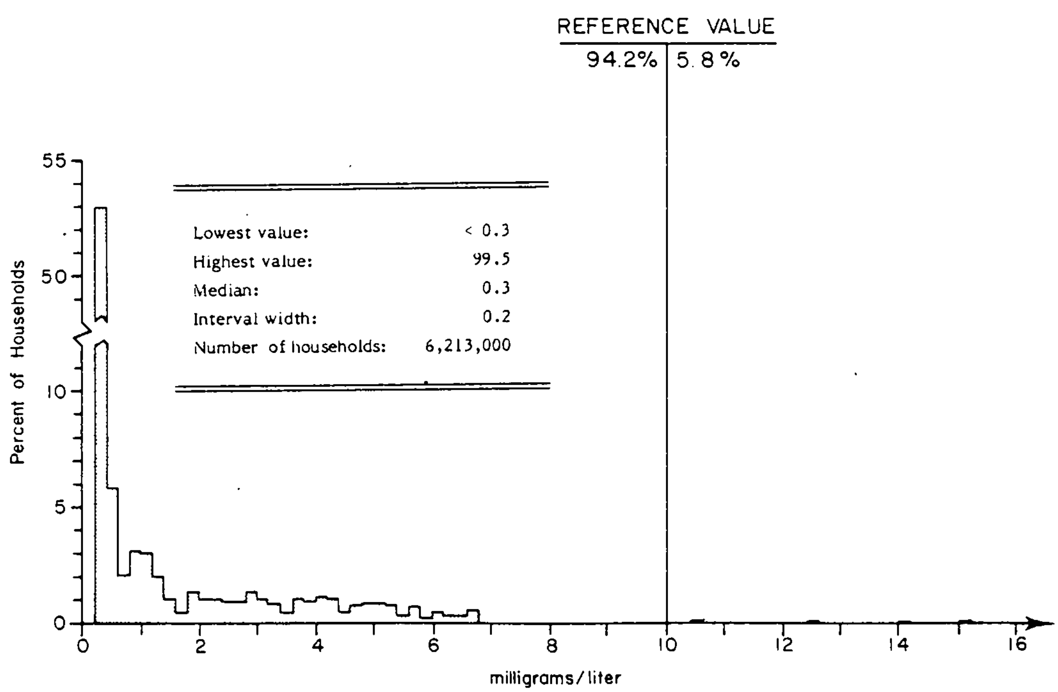


Figure V-15c. North Central



Regional Variation in Nitrate-N (continued)

Figure V-15d. South

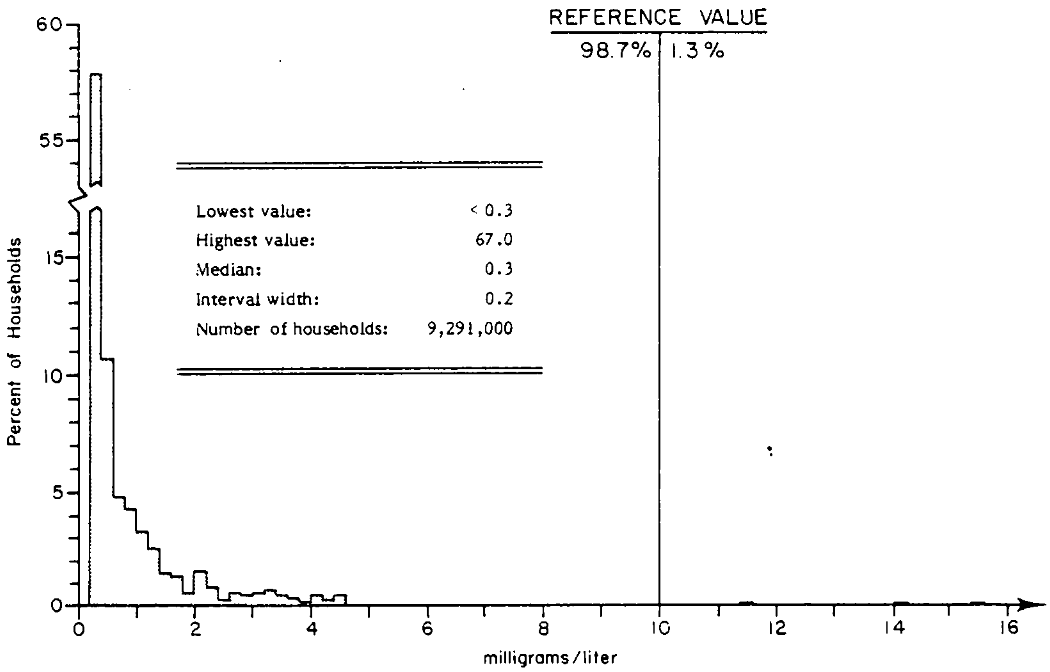
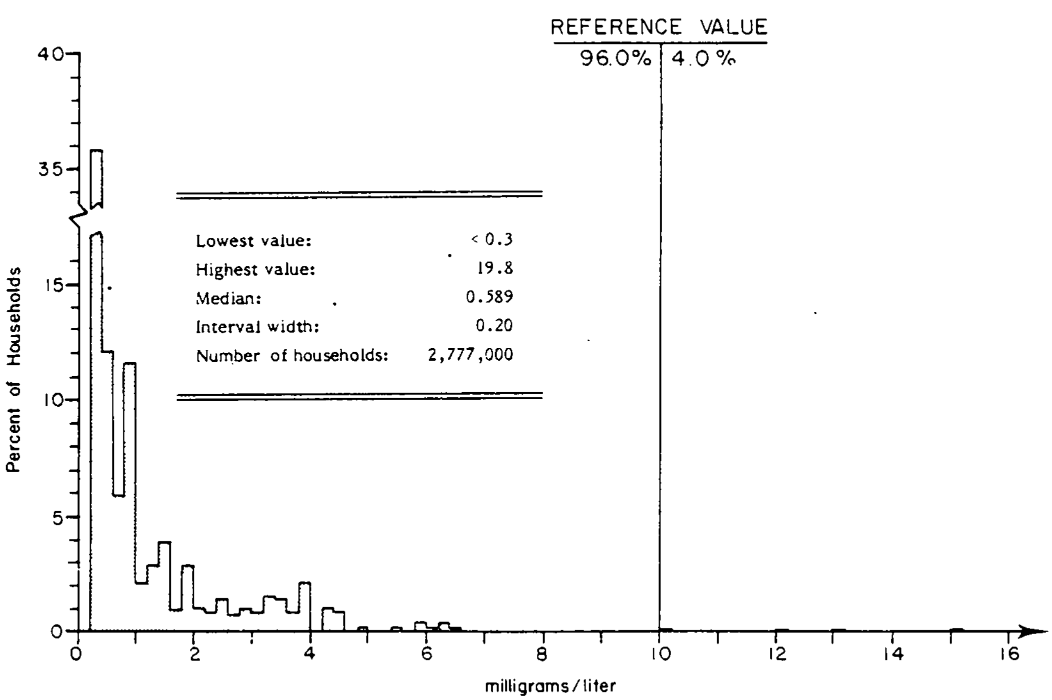


Figure V-15e. West



much weaker effect influenced the over-reference-value rate in the large-rural-community category.

Regarding the size-of-system findings, there was an inverse relationship between the proportion of households exceeding the reference value and the size of system serving the households. There were 4.1 percent of households served by individual systems above the reference value, compared to 3.0 percent of households served by intermediate systems and 1.6 percent served by community systems. Individual systems were most prevalent among households in other rural areas, less prevalent among households in small rural communities, and least prevalent among households in large rural communities. Community systems, on the other hand, were least common among households in other rural areas and most common among households in large rural communities. The overall pattern, then, indicated that the size of system was more important than the size of place in determining the over-reference-value rate. This was consistent with other findings pointing to a much higher incidence of large nitrate concentrations in individual wells in open country than in community systems in larger rural places.[46]

Although relatively few rural supplies surpassed the NSA reference value, it is important to keep in mind that those that did (about 603,000) could pose an important health threat in the form of increased risk to infants aged about four months or less. On the basis of NSA data, this risk of exposure to high nitrates was greatest among Western or North Central households served by individual or intermediate systems.

Sulfates

Sulfates are natural constituents of water. They also are generated by human activities. They enter the water from sediments, precipitation, domestic wastes, and industrial wastes. Sulfates tend to remain dissolved in water unless they are removed artificially.

In view of the prevalence and persistence of sulfates in drinking water, it is fortunate that the substances have relatively minor health effects. At concentrations exceeding 500 milligrams per liter of water, sulfates can cause diarrhea. The level at which this laxative effect occurs is assumed to be greater than 600 milligrams per liter of water in the national secondary drinking water regulations.[47] Sulfate compounds can cause detectable tastes at concentrations of 300 to 400 milligrams per liter, according to the regulations.

Regular users of sulfate-containing water apparently develop resistance to the laxative effect. The main hazard is to travelers or visitors who drink the water infrequently. Similarly, although excessive levels of sulfates may taint the water, the taste may be acceptable to those who use the water regularly.

The secondary MCL for sulfates, as well as the NSA reference value, is 250 milligrams of sulfate per liter of water.

— Sulfate levels in rural supplies

Concentrations of sulfates in rural supplies were generally well within the NSA reference value (Figures V-16, V-16a). Fully 96.0 percent of all rural households were below the reference value; only 4.0 percent were above it. The median sulfate level in rural US supplies was 17.0 milligrams per liter of water.

Median concentrations of sulfates were more than 30 milligrams per liter in both the North Central and West, but only half that great in the Northeast and South. The occurrence of over-reference-value supplies reflected this pattern: the rates were greater than 7 percent among major household supplies in the North Central and West, but smaller than 1 percent in the Northeast and South (Figures V-16b through V-16e). The rate was somewhat higher among nonSMSA households (4.8 percent) than among those located inside SMSAs (2.2 percent), and higher among households in small rural communities (7.5 percent) than among those in large rural communities (2.6 percent) or other rural areas (3.8 percent). However,

Figure V-16

Sulfates in US Rural Household Supplies

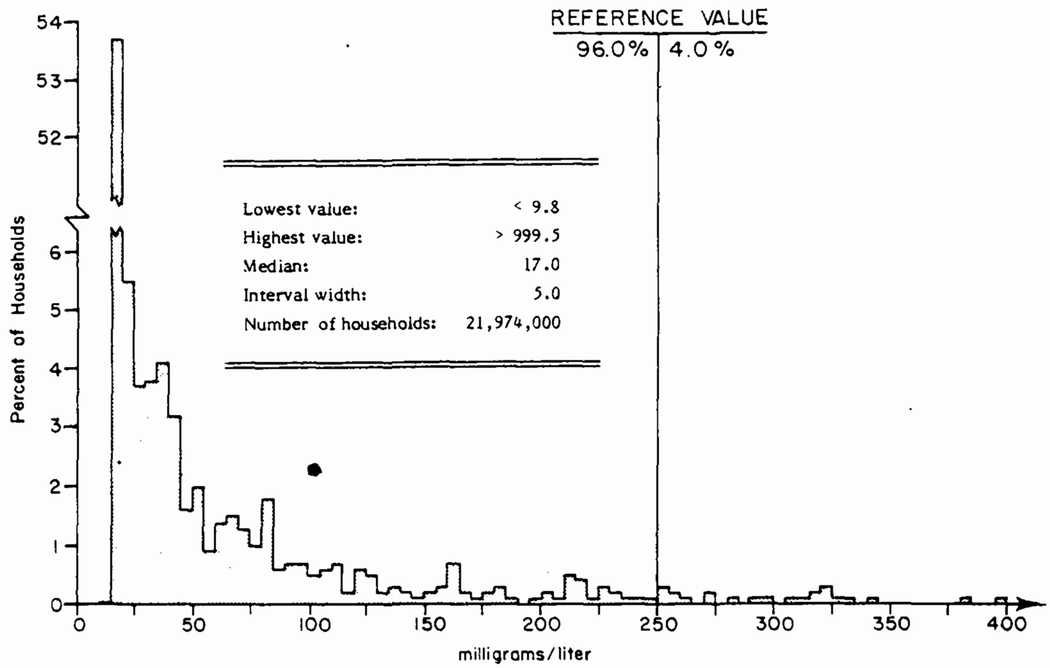
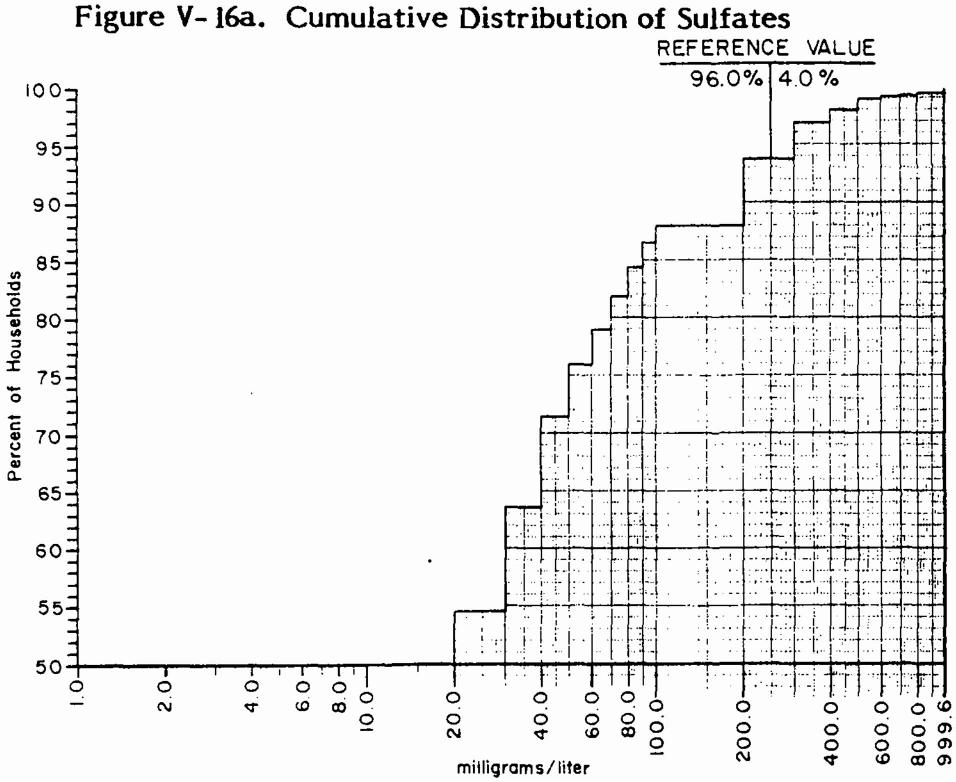


Figure V-16a. Cumulative Distribution of Sulfates



NOTE: Cumulative distribution is plotted on semilog paper. Base: 21,974,000 households.

Regional Variation in Sulfates in US Rural Household Supplies

Figure V-16b. Northeast

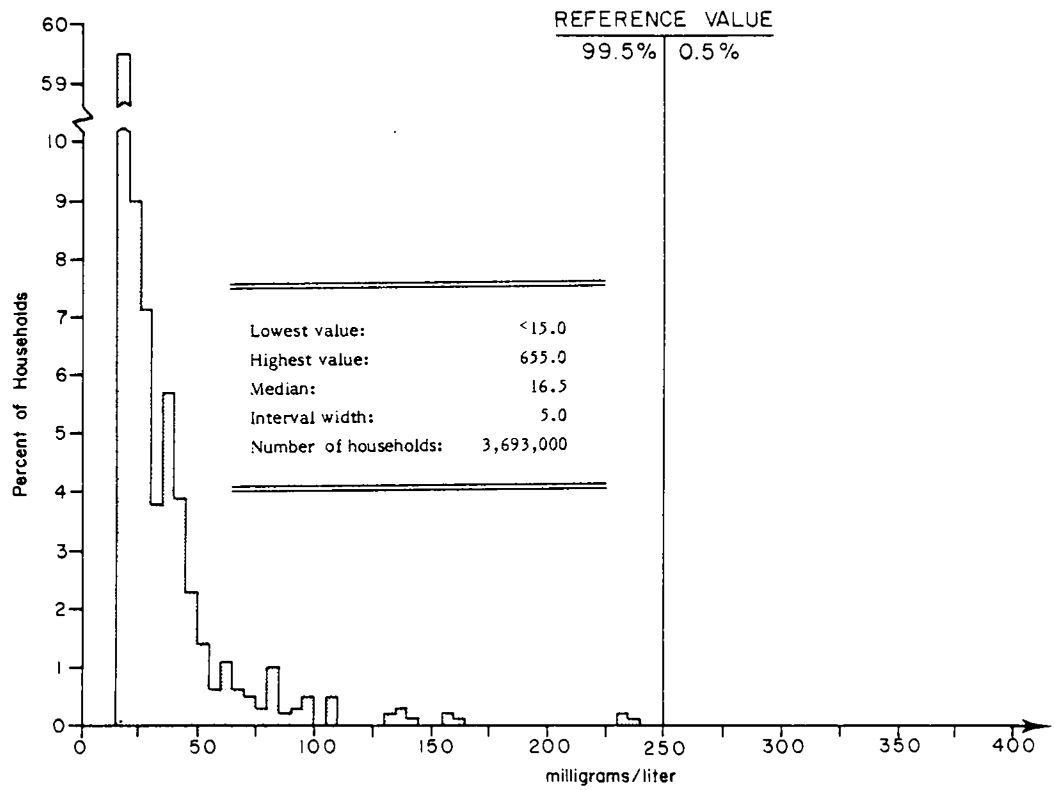
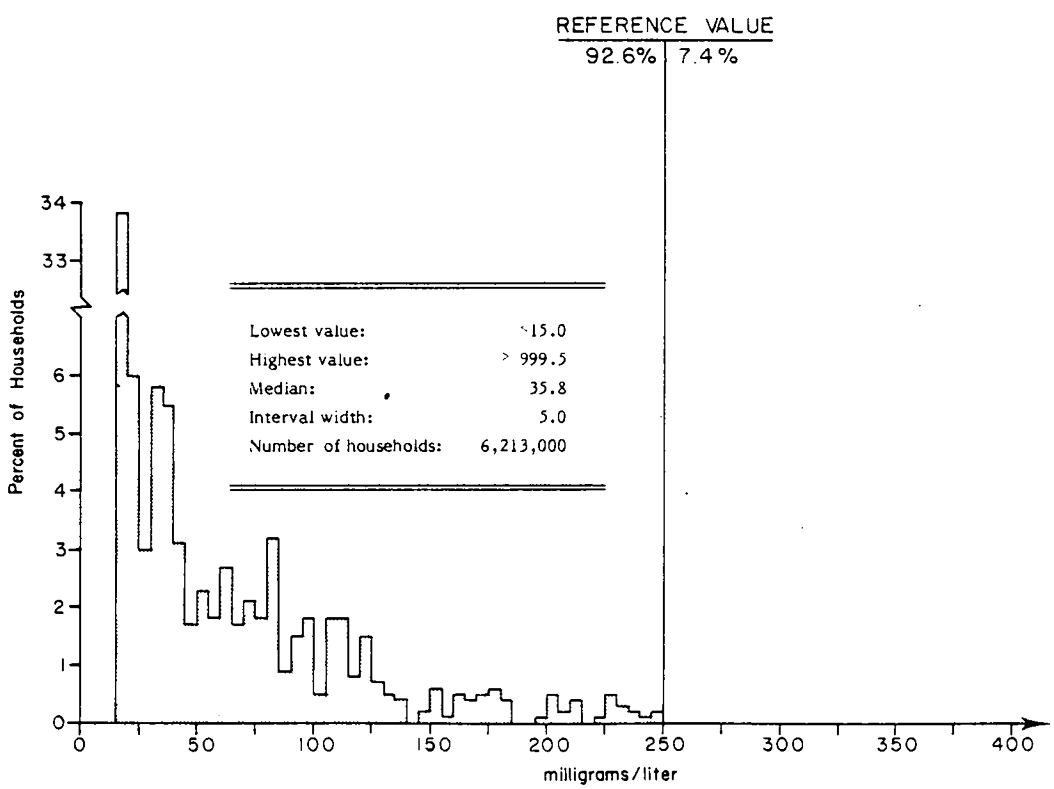


Figure V-16c. North Central



Regional Variation in Sulfates (continued)

Figure V-16d. South

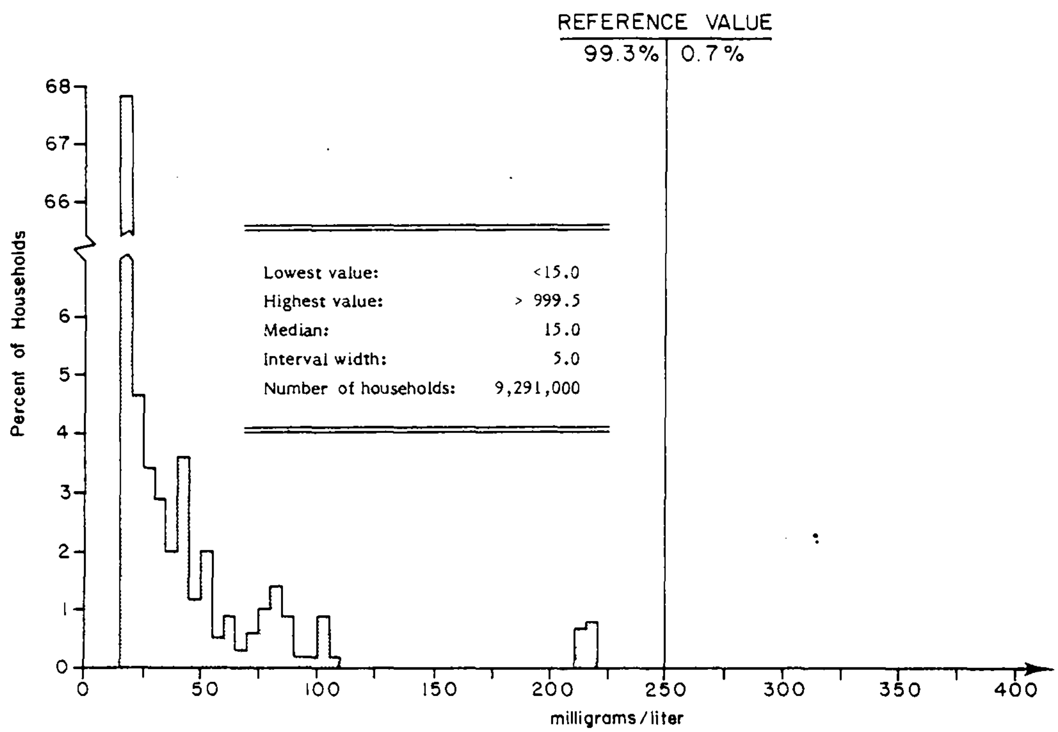
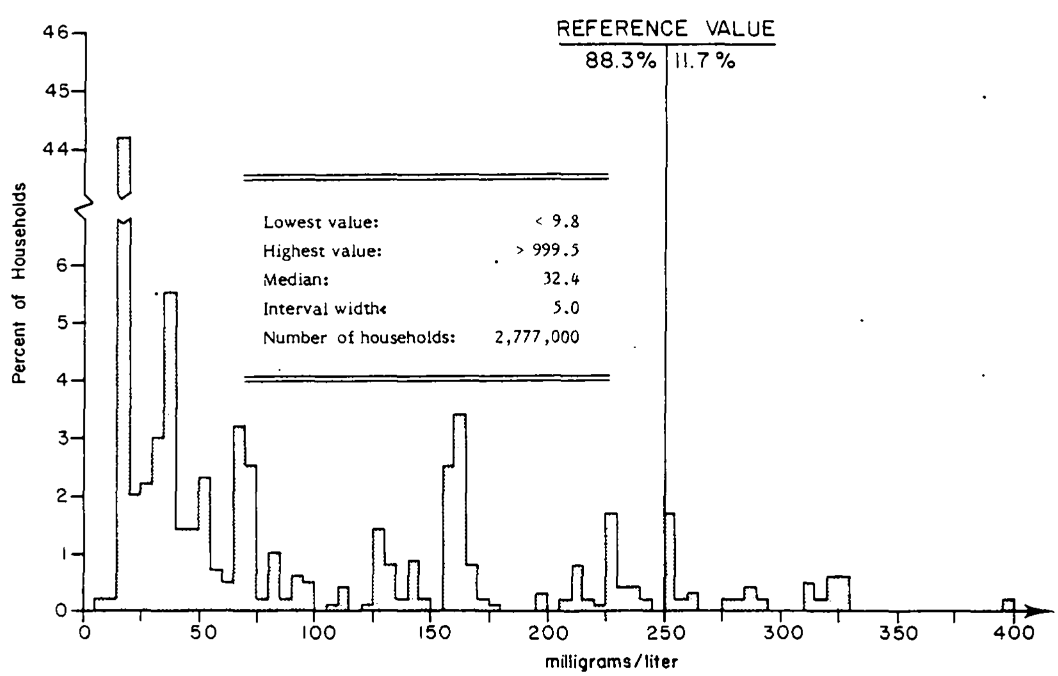


Figure V-16e. West



the size-of-place findings were influenced by a disproportionate number of small-community households being located in the North Central, where the median sulfate level was relatively high.

In regard to the size-of-system grouping, the incidence of households over the reference value was exactly the same for households using community systems (4.2 percent) as for those using individual systems; that rate was two and one-half times larger than for households served by intermediate systems (1.7 percent). Median concentrations, however, were the same for households with individual or intermediate systems (15.0 milligrams per liter of water), and greater for households with community systems (24.0 milligrams per liter).

Regardless of the size-of-system differences, the levels in excess of the reference value did not represent a serious health problem. Among those 4.0 percent of households (about 870,000) above the reference value, few had concentrations equal to those which were assumed by the EPA to be a potential cause of diarrhea. Specifically, in 0.9 percent of all rural households—roughly one out of four of the over-reference-value group—the concentrations were higher than 600 milligrams of sulfate per liter. In those households, visitors unaccustomed to the drinking water might have difficulties. The remaining 3.1 percent of the rural supplies with high levels had concentrations between 250 milligrams and 600 milligrams of sulfate per liter. In those households, supplies may have had objectionable tastes, but they would be expected to have posed few gastrointestinal problems.

Iron

Iron is a common natural constituent of water. The amount ingested from water is small in comparison to that consumed in food, however.[48] The concentrations of iron normally in water thus pose no known threat to human health. On the other hand, excessive amounts of iron in water promote a reddish-brown discoloration in laundry, stain water fixtures, and cause an astringent or bitter taste in drinking water. In view of these objectionable characteristics, EPA has established a secondary MCL of 0.3 milligrams per liter of water. That MCL value was used as the NSA reference value.

— Iron concentrations in rural supplies

Approximately eight out of ten rural households were below the NSA reference value for iron (Figures V-17, V-17a). In fact, the median for supplies in the rural US was only 0.10 milligrams of iron per liter—one-third of the reference value. Despite the favorable overall situation, supplies in 18.7 percent of rural households were above the reference value. In 2.6 percent of rural households (about 570,000), the concentration was more than ten times the reference value.

The reference value was exceeded most often in households in the North Central, where 28.2 percent of households were high. Over-reference values in the South and Northeast were 17.0 and 16.0 percent, respectively. In the West, by contrast, only 7.0 percent of households were above 0.3 milligrams per liter (see Figures V-17b through V-17e). Consistent with these findings, the highest median concentrations of iron occurred in household supplies in the Northeast, South, and North Central (0.1 milligrams per liter in each of the three regions) rather than in the West (0.05 milligrams per liter).

The proportion of nonSMSA households above the NSA reference value for iron was greater than that for SMSA households (21.0 percent versus 13.8 percent). In the size-of-place comparison, supplies with high values were located at least twice as often in small rural communities and other rural areas (23.3 percent and 19.5 percent, respectively) as in large rural communities (9.4 percent). In addition, households served by individual and intermediate systems were over the reference value about four times as often as households served by community systems. The exact proportions were 29.9 percent of households served by individual systems and

Figure V-17
Iron in US Rural Household Supplies

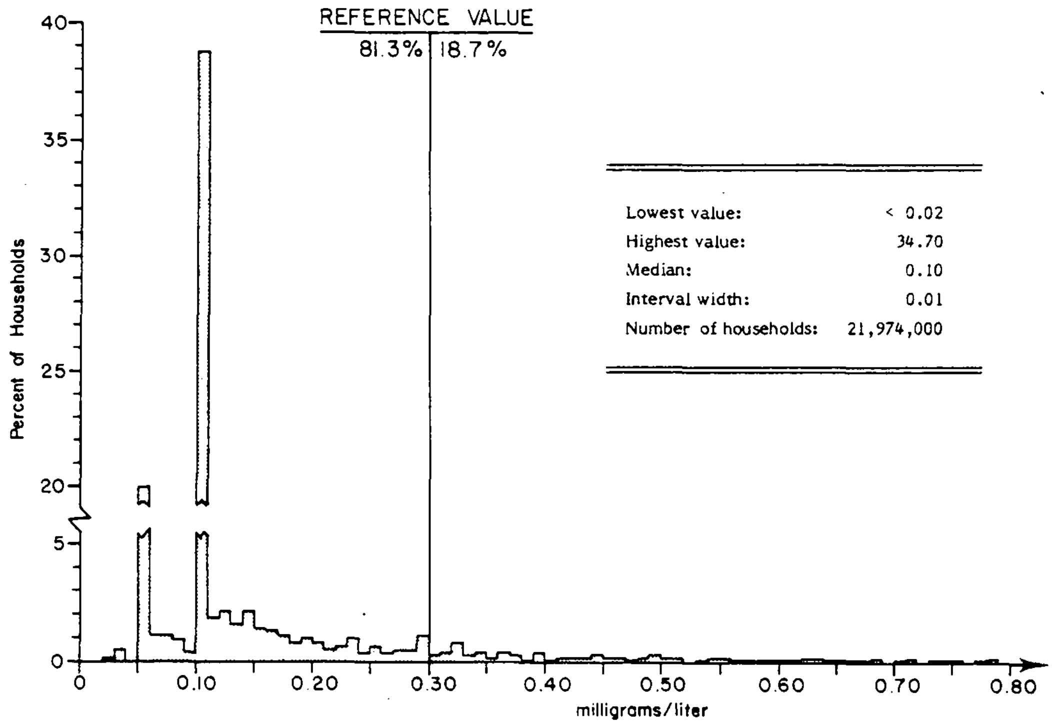
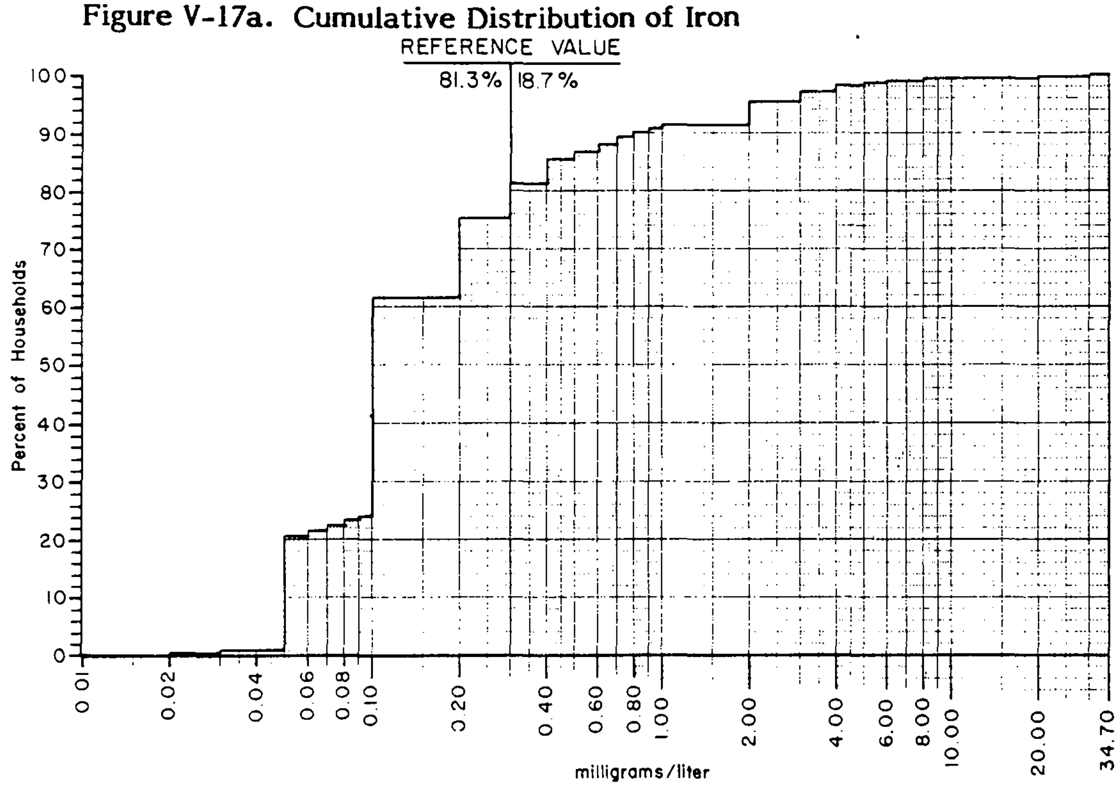


Figure V-17a. Cumulative Distribution of Iron



NOTE: Cumulative distribution is plotted on semilog paper. Base: 21,974,000 households.

Regional Variation in Iron in US Rural Household Supplies

Figure V-17b. Northeast

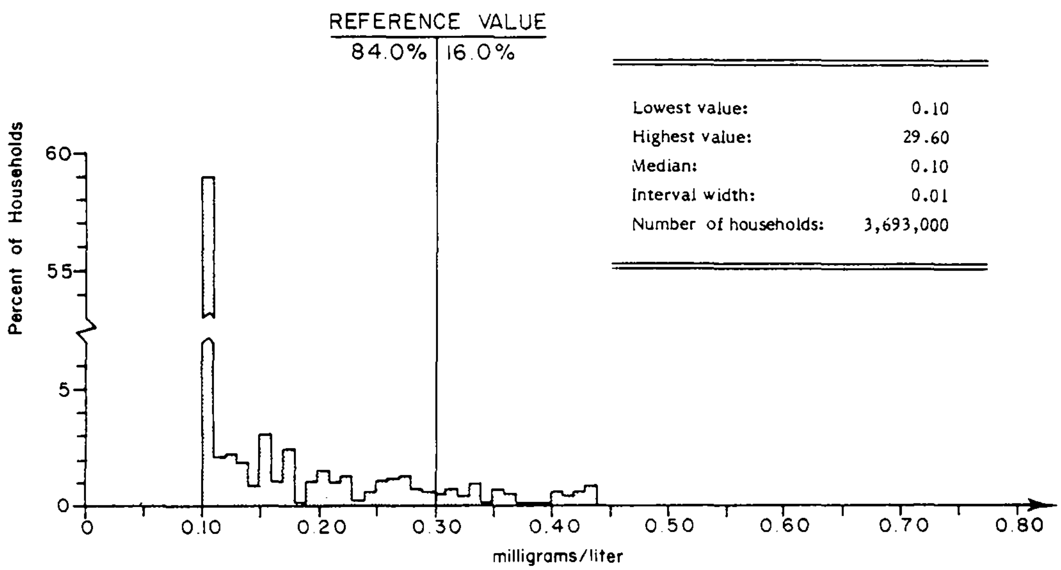
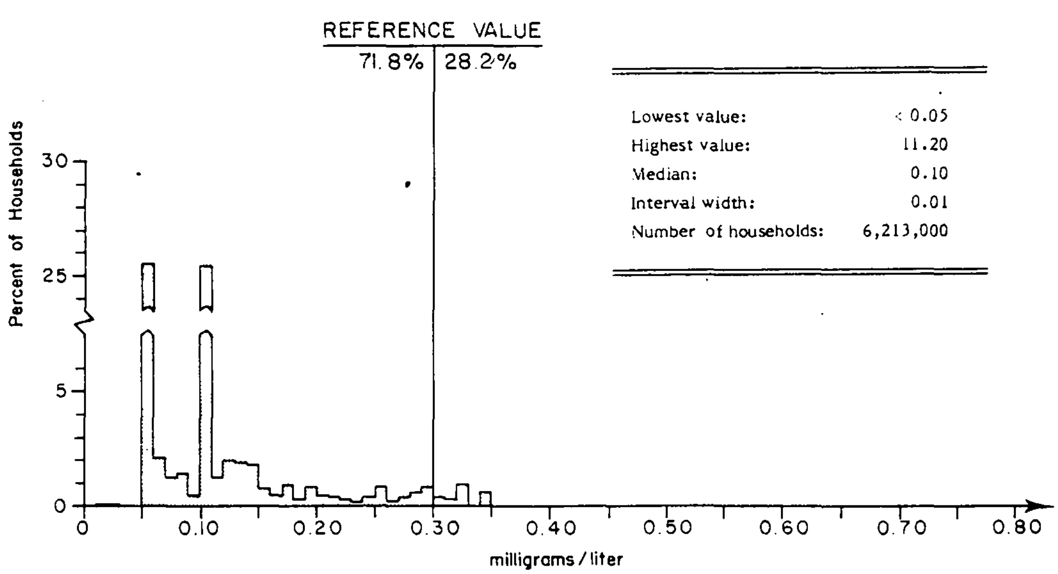


Figure V-17c. North Central



Regional Variation in Iron (continued)

Figure V-17d. South

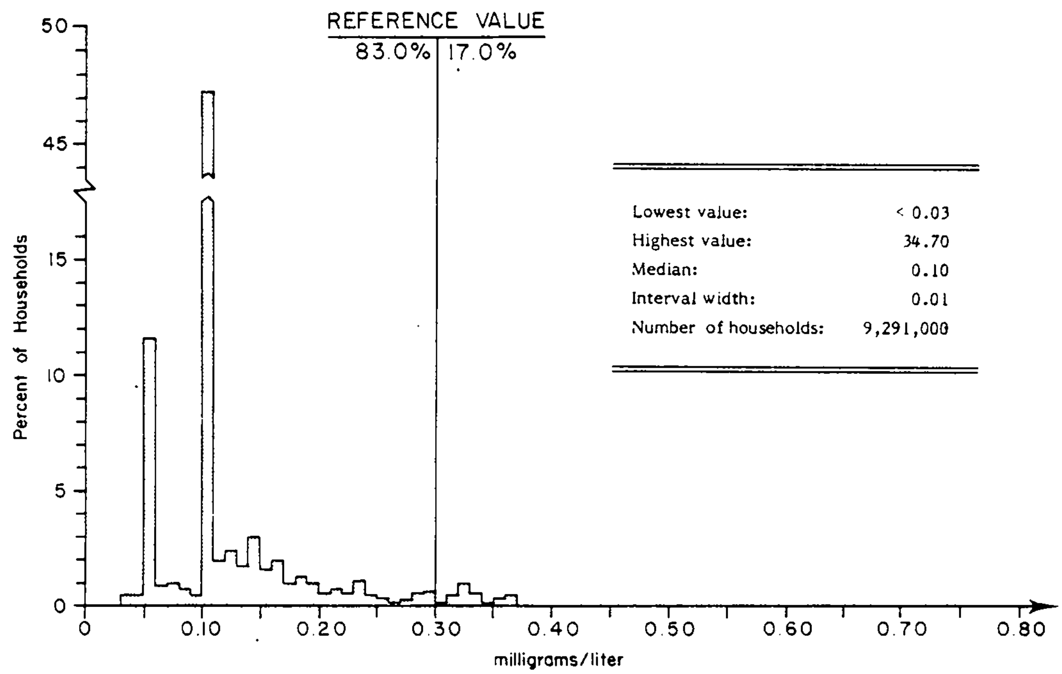
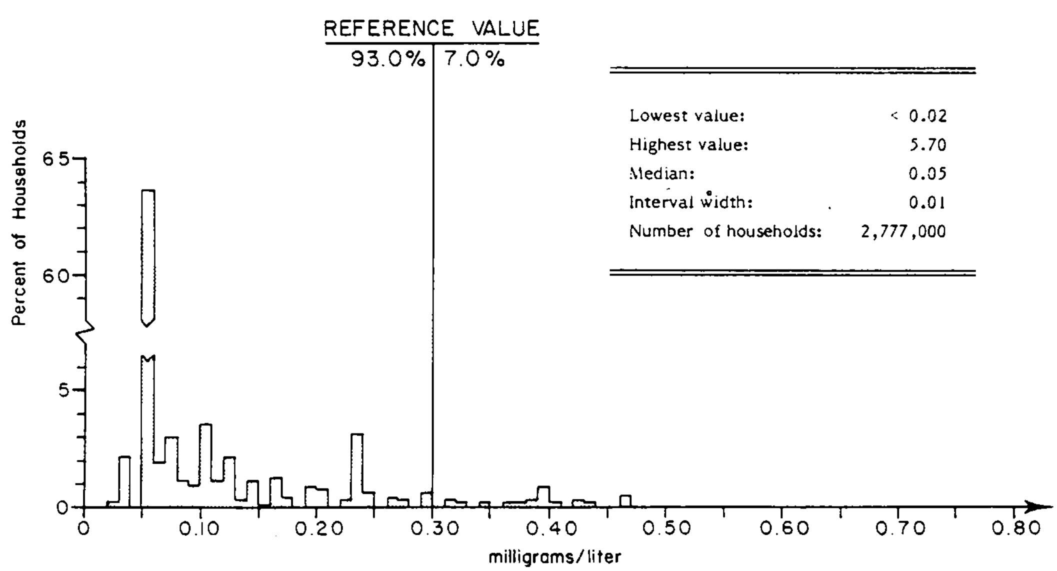


Figure V-17e. West



28.7 percent among those served by intermediate systems, compared to 7.7 percent of households served by community systems.

The NSA reference value for iron provided a dividing point in terms of non-health-related, objectionable characteristics of iron compounds in domestic water. In that regard, a fairly large number of rural households (4.1 million) had concentrations which exceeded the reference value, and residents therefore faced potential problems from discolored laundry or from bitter or astringent tastes. The overall situation in rural America, however, was not serious since so many rural supplies were within the reference value.

Manganese

Like iron, manganese is a natural constituent in water. This metal also poses little danger to health in concentrations which can be expected in water. In fact, manganese is an essential trace element which is important to proper enzyme function in human beings, as is iron.

Manganese is less abundant in waterborne compounds than is iron, but its objectionable characteristics are much the same: it stains laundry and water fixtures, and has an unpleasant taste. In view of these effects, the EPA has adopted a secondary MCL of 0.05 milligrams of manganese per liter of water. That also was the NSA reference value.

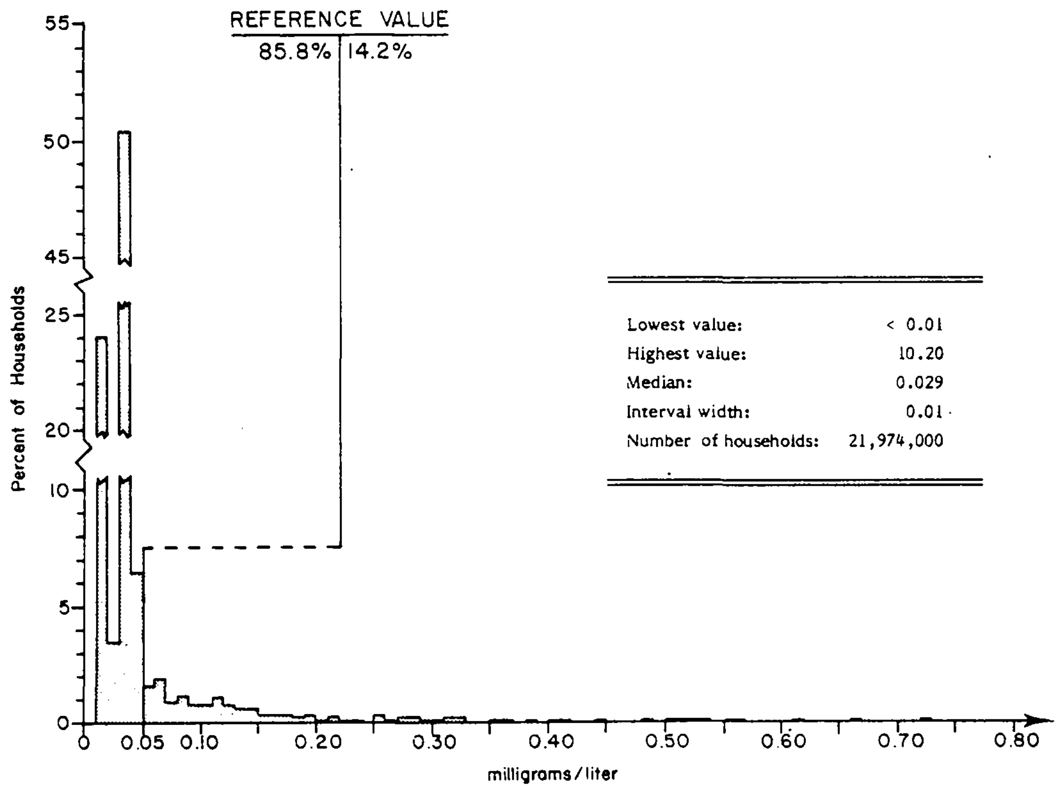
— Manganese levels in rural supplies

Manganese resembles iron in chemical behavior, and it frequently is found with iron in groundwater.[49] It is less abundant in rocks, however, and thus its concentration in water usually is less than that of iron.[50] This overall picture is consistent with that found in the NSA. The largest concentration of manganese in major household supplies of the rural US was 10.2 milligrams per liter—about one-third the highest concentration of iron. The median concentration of manganese in rural supplies was 0.029 milligrams per liter—compared to 0.1 milligrams for iron. Overall, 85.8 percent of rural households were below the manganese reference value; 14.2 percent of households were above it (Figures V-18, V-18a). By comparison, 18.7 percent of rural households were over the iron reference value.

The proportion of households with high manganese values varied in different NSA comparative groupings in a pattern similar to that for iron. As seen in Figures V-18b through V-18e, high readings occurred most often among households located in the North Central (19.9 percent) and Northeast (16.9 percent), less often in the South (12.3 percent), and least often in the West (4.7 percent). High readings were more frequent among nonSMSA households (16.3 percent) than among SMSA households (9.9 percent), and more frequent among households located in small rural communities (21.7 percent) or other rural areas (14.0 percent) than among households in large rural communities (11.4 percent). As with iron concentrations, manganese concentrations exceeding the reference value were proportionately more frequent (about three times so) among households served by individual or intermediate systems than among households served by community systems, which had an over-reference-value rate of 7.2 percent. Treatment methods to reduce manganese concentrations were not generally used by intermediate and individual systems, and rural households served by community systems were less likely to have excessive amounts of the metal, indicating that those systems were better able to deal with the problem.

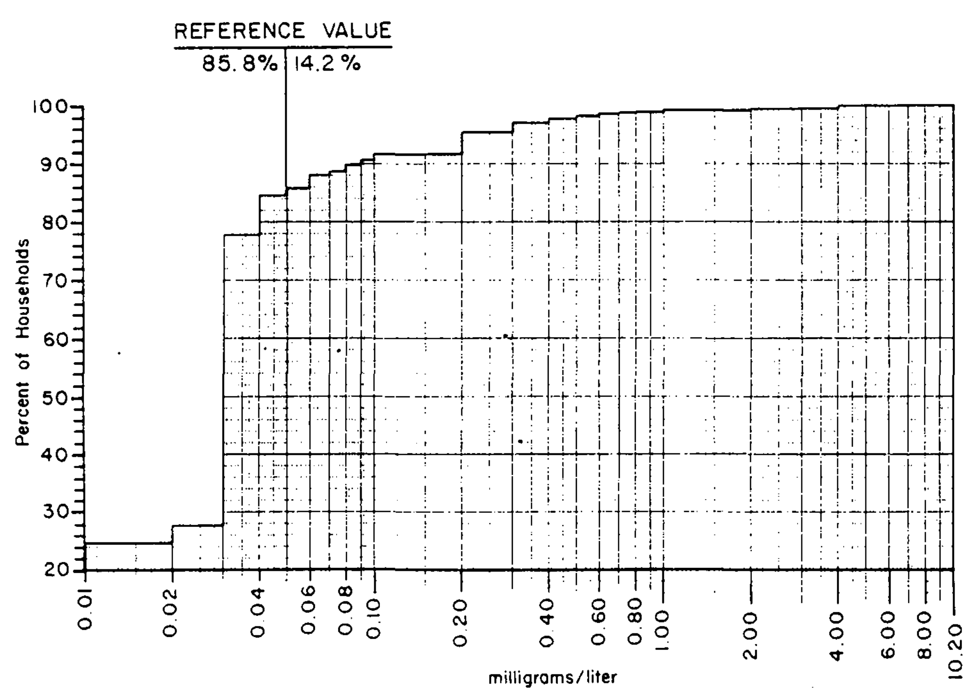
As with iron compounds, the reference value provided a dividing point for non-health-related, objectionable characteristics of manganese. From that perspective, there were potential problems with taste and staining properties in the supplies at 3.1 million rural households (those above the reference value). The general pattern of the extent of the problems was very similar to that for iron, and since iron and manganese frequently occur together, the two substances represent

Figure V-18
Manganese in US Rural Household Supplies



Lowest value:	< 0.01
Highest value:	10.20
Median:	0.029
Interval width:	0.01
Number of households:	21,974,000

Figure V-18a. Cumulative Distribution of Manganese



NOTE: Cumulative distribution is plotted on semilog paper. Base: 21,974,000 households.

Regional Variation in Manganese (continued)

Figure V-18d. South

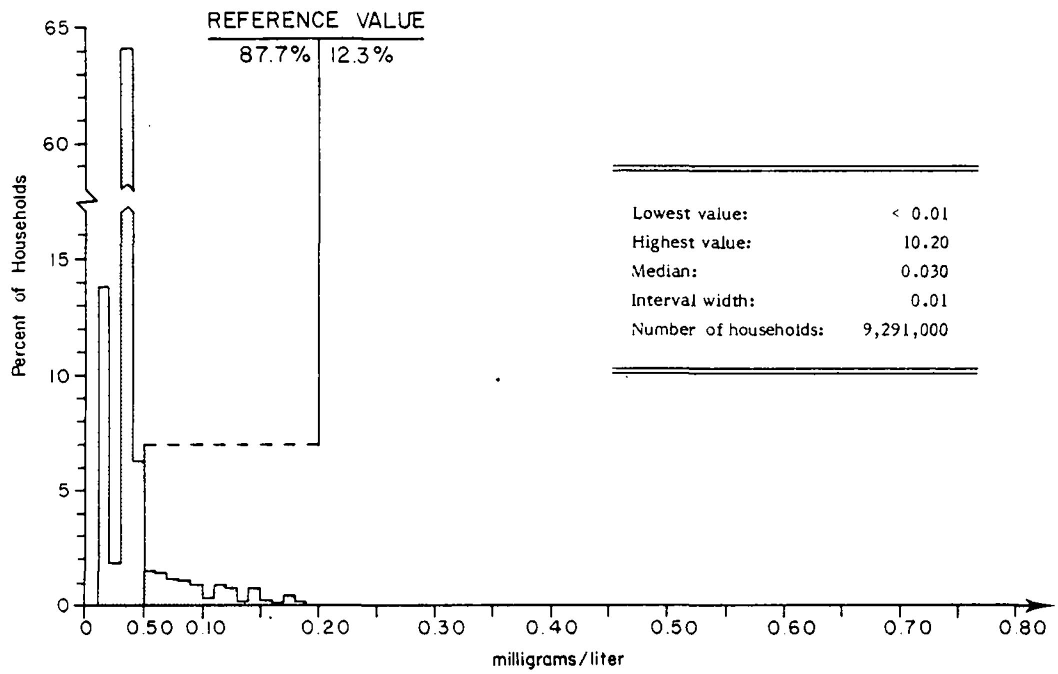
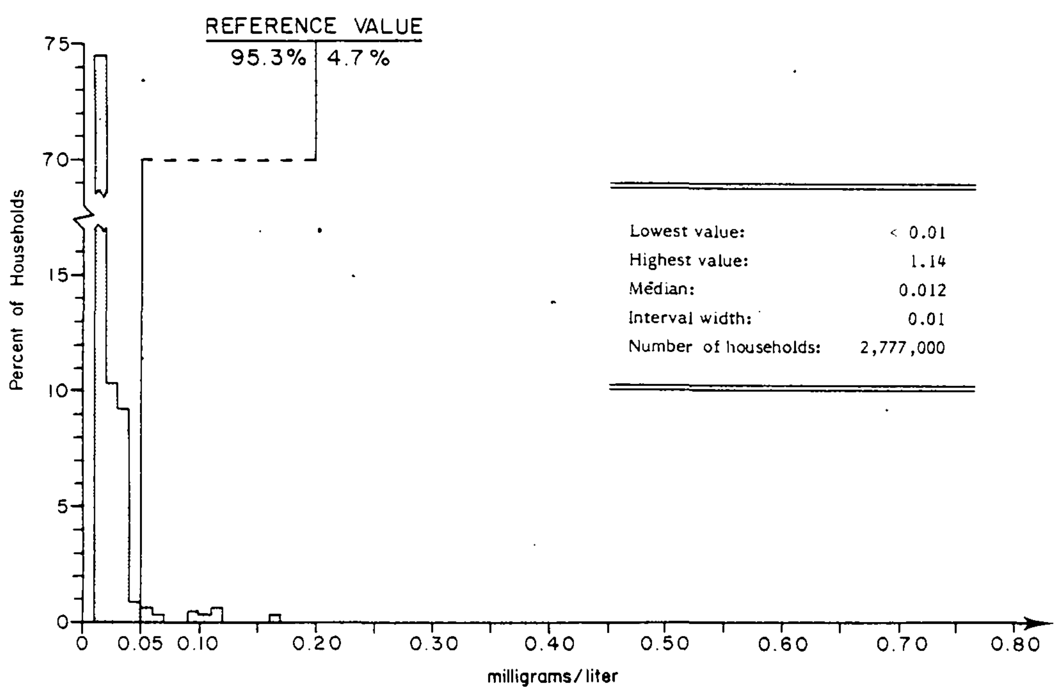


Figure V-18e. West



an aesthetic difficulty for a number of households in the rural US—particularly in the North Central.

Sodium

The sodium ion is ubiquitous in water. It comes naturally from surface and underground deposits of salts such as sodium chloride, from the sodium aluminum silicates and similar minerals, from rainfall which contains evaporated salt water particles, and from seawater which enters fresh water aquifers. It also comes from sodium chloride used to de-ice roads and from a number of substances in municipal and industrial wastewater. Other sources in domestic water supplies are the ion-exchange or the lime-soda ash water softening processes.

Sodium plays an essential role in the regulation of fluid balances in the body. Yet adults in the US apparently routinely take in more than ten times the amount of sodium which they require.[51] According to the NRC: "An impressive amount of evidence has accumulated over the last several decades that sodium taken in excess of physiologic need is important in inducing an age-related increase in blood pressure that culminates in hypertension in genetically susceptible people."

In view of this hazard, the NRC cautions: "Concentrations (of sodium) should be maintained at the lowest practicable levels, and trends toward increasing concentrations of sodium in water supplies as a result of deicing and water-softening procedures should be discouraged. Optimal concentrations of sodium should be regarded as the lowest feasible."[52]

A standard procedure in toxicology is to determine the highest concentration of a substance at which no adverse effect is observed. This "threshold" value is determined on the basis of animal experiments and public health experience. A safety factor then is applied, which produces a much lower value to be used as the one considered safe for humans. This value then can be used as a basis for maximum permissible concentrations of the substance in food, water, and air—based on a number of related considerations, such as total exposure to the substance and its rate of dietary intake. This approach was used in setting official standards which became the bases for NSA reference values regarding a number of inorganic substances, but the situation was more complicated for sodium. The NRC states: "Specification of a 'no-observed-adverse-health-effect' level in water for a substance like sodium for which the effect is associated with total dietary intake and for which food intake is already greater than a desirable level is impossible."

One arbitrary approach is to aim for an allowable maximum level which offers some protection to persons in the US who are required to use sodium-restricted diets because they have hypertension. Persons who must severely limit their sodium intake should not use drinking or cooking water which contains more than twenty milligrams of sodium per liter of water. The EPA recognizes the desirability of having supplies with a sodium content of less than twenty milligrams per liter, but the position of the agency is that "regulation of sodium by a maximum contaminant level is a relatively inflexible, very expensive means of dealing with a problem which varies greatly from person to person."[53] A massive control program would be necessary since, by EPA's estimate, about 40 percent of US public water supplies have a natural or added sodium content greater than twenty milligrams per liter. In view of this situation, the EPA advises that sodium monitoring programs are the most practical countermeasures: if excessive levels of sodium are found in domestic water, users can be warned and, if necessary, they can then use alternative water sources.

There clearly are problems with complete reliance on a monitoring program. For example, monitoring may be of uneven quality in different areas; users may not always receive sufficient warning about excessive amounts of sodium and, even if they are warned, there may be no practical alternative water sources for them to use. In view of these considerations, NSA investigators decided that the most useful approach in analysis of NSA data would be to use two reference values. One reference value selected was twenty milligrams of sodium per liter; the other was 100 milligrams. The former, more stringent, value was appropriate for persons who must limit their sodium intake in the extreme—to a total of about 500 milligrams of sodium each day from all sources.[54] Indeed, the "EPA suggests that sodium levels of 20 mg/l or less in drinking water be considered as optimal."[55] The latter, less stringent, value would offer some advantage to persons who require a less restrictive low-sodium diet.[56]

— Sodium levels in rural America

The median sodium concentration in rural households was about twelve milligrams per liter of water. In terms of the more stringent NSA reference value, the sodium concentration exceeded twenty milligrams per liter of water in 39.1 percent of rural households (Figures V-19, V-19a). This was consistent with the EPA's estimate that about 40 percent of all US public water supplies had concentrations of this amount. As to the less stringent NSA reference value, the sodium concentration was higher than 100 milligrams per liter in 14.3 percent of all rural households. This was consistent with data used by the EPA which indicated that 14.6 percent of all public water supplies had concentrations of this amount. The agreement between the NSA findings and earlier EPA estimates reinforced existing impressions of the scope of the potential problem in the US.

Household sodium concentrations varied prominently in different regions of the US (Figures V-19b through V-19e). Median concentrations were highest in the West (24.72 milligrams per liter) and in the North Central (20.05 milligrams per liter). Those median concentrations were more than twice as large as the ones in the South (9.29 milligrams per liter) and in the Northeast (8.2 milligrams per liter). The percentage of households exceeding either of the NSA reference values varied in a pattern similar to that for the median concentrations. That is, the proportion

Figure V-19

Sodium in US Rural Household Supplies

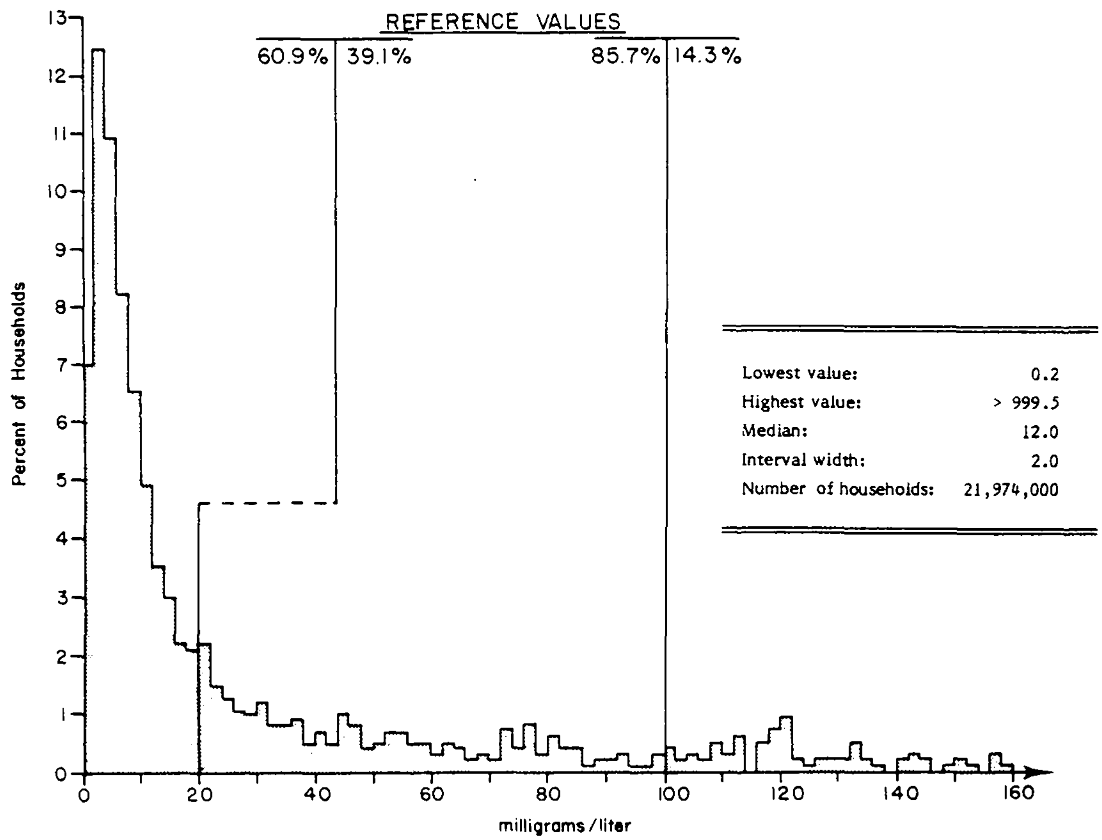
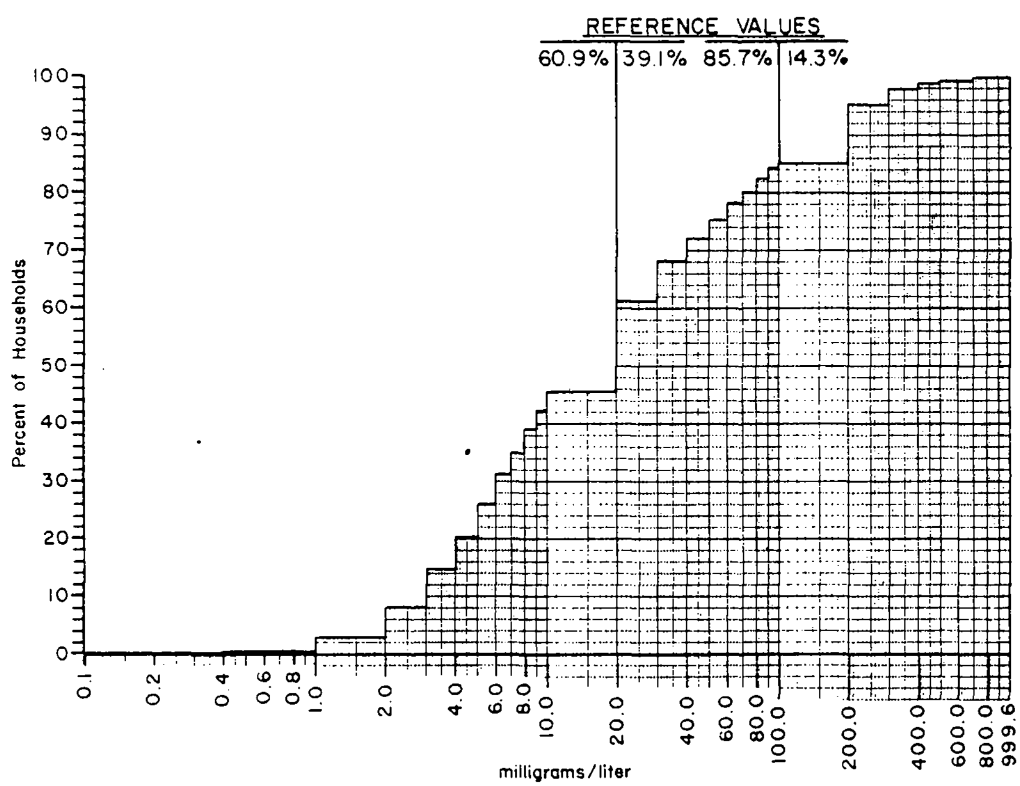


Figure V-19a. Cumulative Distribution of Sodium



NOTE: Cumulative distribution is plotted on semilog paper. Base: 21,974,000 households.

Regional Variation in Sodium in US Rural Household Supplies

Figure V-19b. Northeast

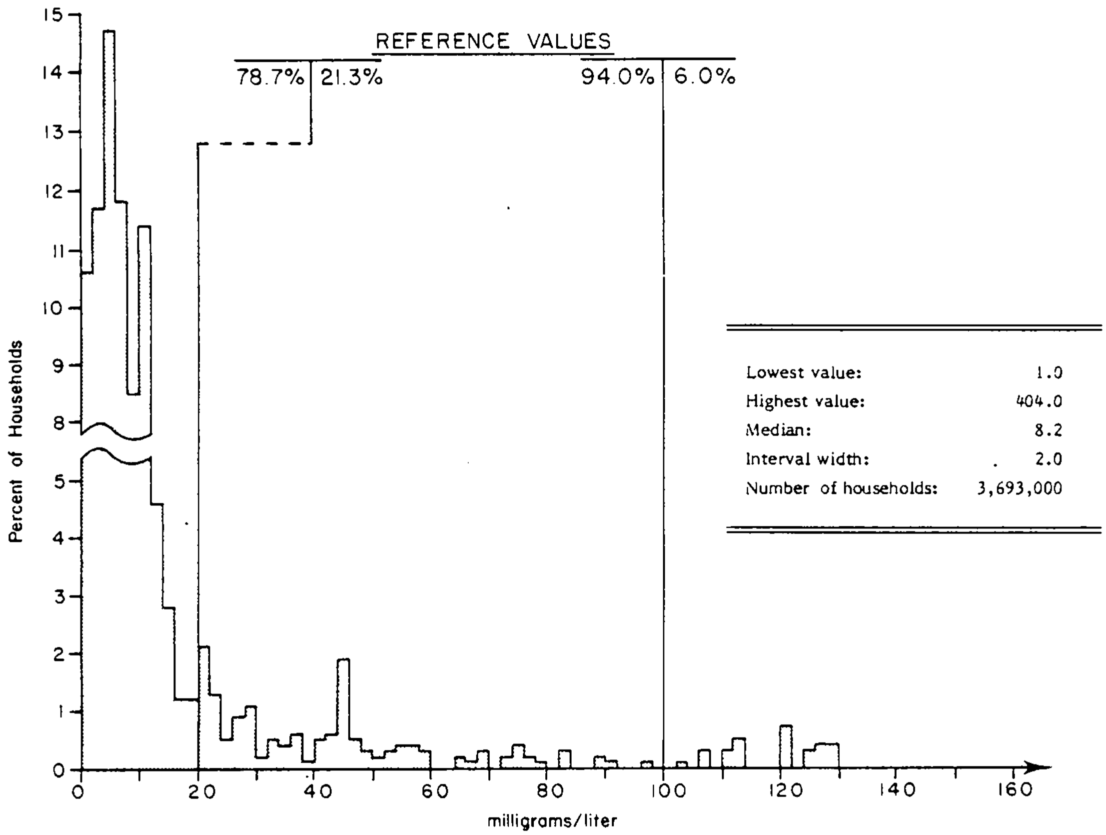
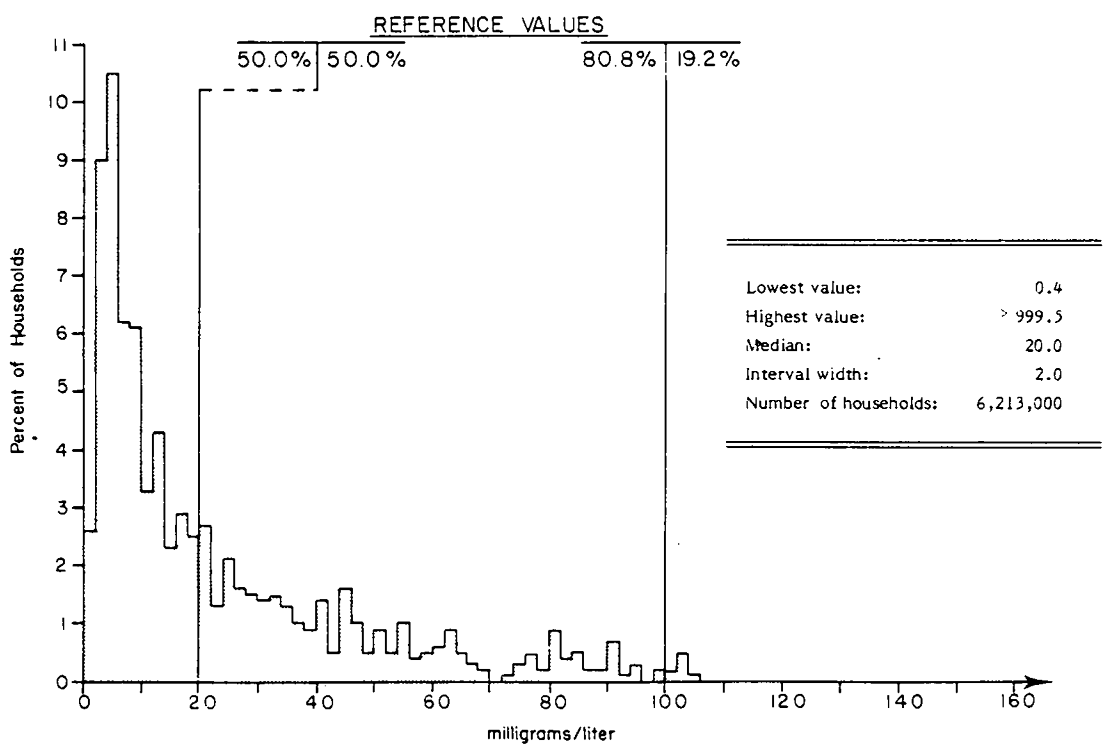
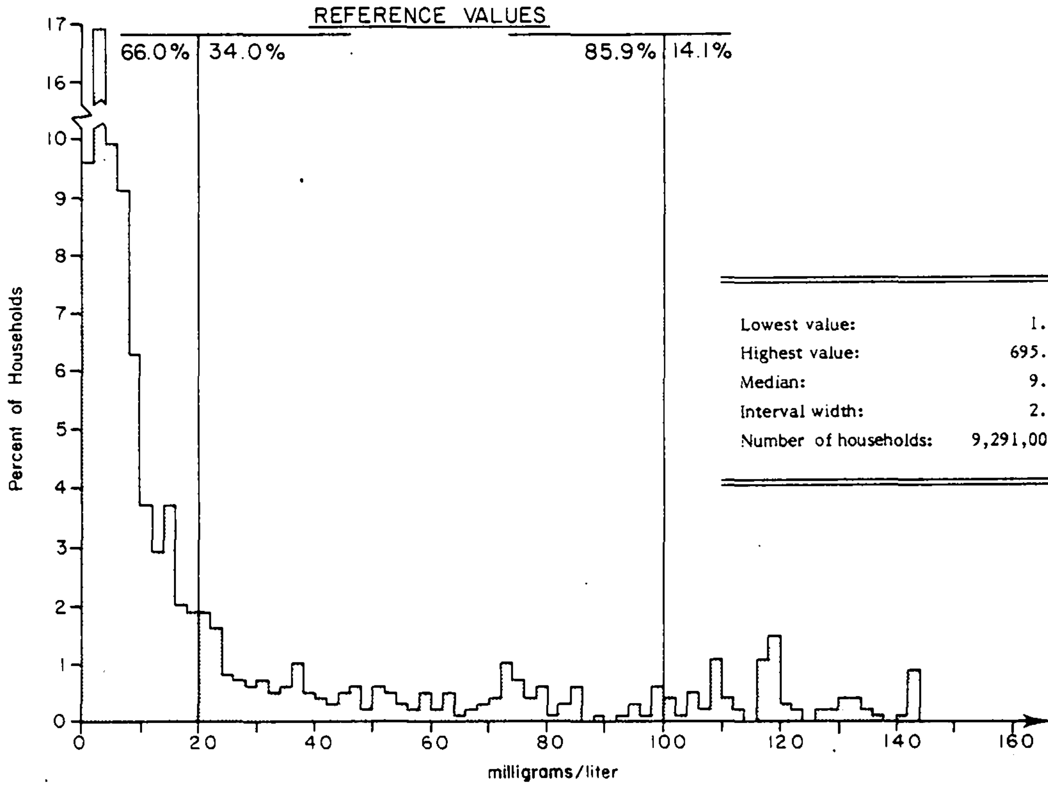


Figure V-19c. North Central



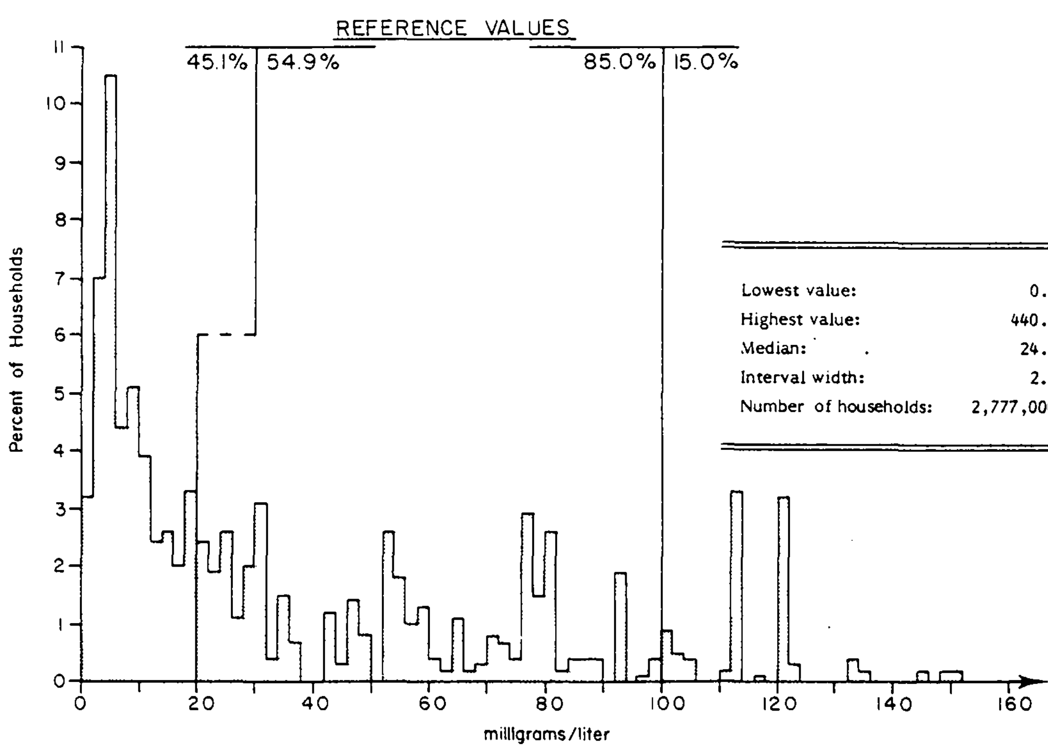
Regional Variation in Sodium (continued)

Figure V-19d. South



Lowest value:	1.0
Highest value:	695.3
Median:	9.3
Interval width:	2.0
Number of households:	9,291,000

Figure V-19e. West



Lowest value:	0.2
Highest value:	440.0
Median:	24.7
Interval width:	2.0
Number of households:	2,777,000

of households above either reference value was generally larger in the West and in the North Central than in the South and Northeast.

Variations in median sodium concentrations and in proportions of households exceeding either reference value were much less evident in other NSA groupings. One possible exception was a tendency for larger median concentrations and more values in excess of the reference values to be found among households served by community systems than among those served by individual or intermediate systems. This tendency was particularly apparent in regard to the reference value of twenty milligrams per liter: about 44 percent of households served by community systems (4.8 million) exceeded that reference value. The contrasting percentages were about 35 percent for households served by individual systems and 31 percent for households served by intermediate systems.

As noted above, the NSA reference values for sodium were health-related, but they did not represent a professional consensus on the level at which specific health risks could be expected in the general population. In addition, it would have been necessary to know something about the health status and dietary habits of individuals in NSA households to determine the possible consequences of large sodium concentrations in water supplies. That is, only a certain percentage of rural residents had the specific diseases (such as hypertension, renal disease, and cirrhosis of the liver) which require restricted sodium intake. Identification of these individuals and a study of their dietary experiences were far beyond the scope of the NSA.

Lead

Since Roman times, lead in water has been linked to health problems. In the centuries since then, investigators have found no beneficial effects for human health. They have found persistent quantities of the substance, however, in the air we breathe, food we eat, and water we drink.

Most of this exposure stems from sources related to human activities. Lead in the air in cities, for example, often comes from the exhaust of vehicles burning leaded gasoline. Ingested lead frequently is in the form of leaded paint peelings in old dwellings—children find the peelings attractive and eat them. Lead in domestic water most often comes from water pipes—naturally soft, acidic water dissolves lead from service connections, lead-lined household piping, and soldered joints.

Human exposure to lead must be limited since the metal can accumulate in the body and cause serious damage to the kidney, liver, brain, reproductive systems, and central nervous system. At subtoxic levels, lead interferes with the functioning of red blood cells; at toxic levels, it may destroy the red blood cells. Mental retardation in children is a common result of lead poisoning.

Permissible levels of this metal in air, food, and water are established in light of anticipated total intake of the metal as people go about their daily activities. This is the customary way to set limits for a number of toxic substances which have cumulative effects. Concentrations in each exposure source—air, food, and water—must be low enough to guard against dangerous overall accumulation of the substance in the human body.

In the case of lead, intake among city dwellers frequently is so large that the cumulative total—50 to 60 micrograms of lead per day—is at the theoretical level at which adverse effects can be expected. In view of this, the NRC cautions that existing US regulations for waterborne lead may not provide adequate protection: "Results of studies in the Boston area indicate that increased blood levels of lead will occur in children when the water supply contains 0.05 - 0.1 milligrams of lead per liter of water. Thus, the interim limit of 0.05 milligrams of lead per liter may not provide the margin of safety to safeguard the high-risk population of urban areas . . . It is concluded that the no-observed-adverse-health-effect level cannot be set with assurance at any value greater than 0.025 milligrams per liter of water."[57]

The NSA reference value for lead was the same as the interim primary MCL—0.05 milligrams of lead per liter of water.

— Lead levels in rural America

Large concentrations of several heavy metals studied in the NSA were much more pervasive in rural US water supplies than was anticipated. Lead was one of those metals—cadmium and mercury, discussed below, were the others.

The reference value for lead was exceeded in 16.6 percent of rural households—a total of 3.6 million (Figures V-20, V-20a). The range of US rural lead concentrations was from less than 0.005 milligrams of lead per liter of water to 0.97 milligrams; the median was 0.008 milligrams; the mean was 0.03 milligrams.

In the South, 23.1 percent of households were over the reference value —the largest proportion in any region. The lowest rate was in the Northeast (Figures V-20b through V-20e); nonetheless, 9.6 percent of household supplies in the Northeast had concentrations which exceeded the reference value. Moreover, although 9.6 percent was lower than the proportion in any other region, it was considerably higher than was anticipated on the basis of the EPA's experience. That experience had indicated that less than 4 percent of public water supplies had lead concentrations exceeding the reference value.[58] It might have been anticipated that large lead concentrations would be more common in households served by individual systems with lead pipes or lead-alloy-soldered pipes, and this might have led the EPA to expect larger concentrations among NSA samples (the EPA estimate was based on studies of community systems as opposed to rural household supplies). This expectation also would not have been borne out, however; in the NSA size-of-system comparison, a larger proportion—and a larger total

Figure V-20
Lead in US Rural Household Supplies

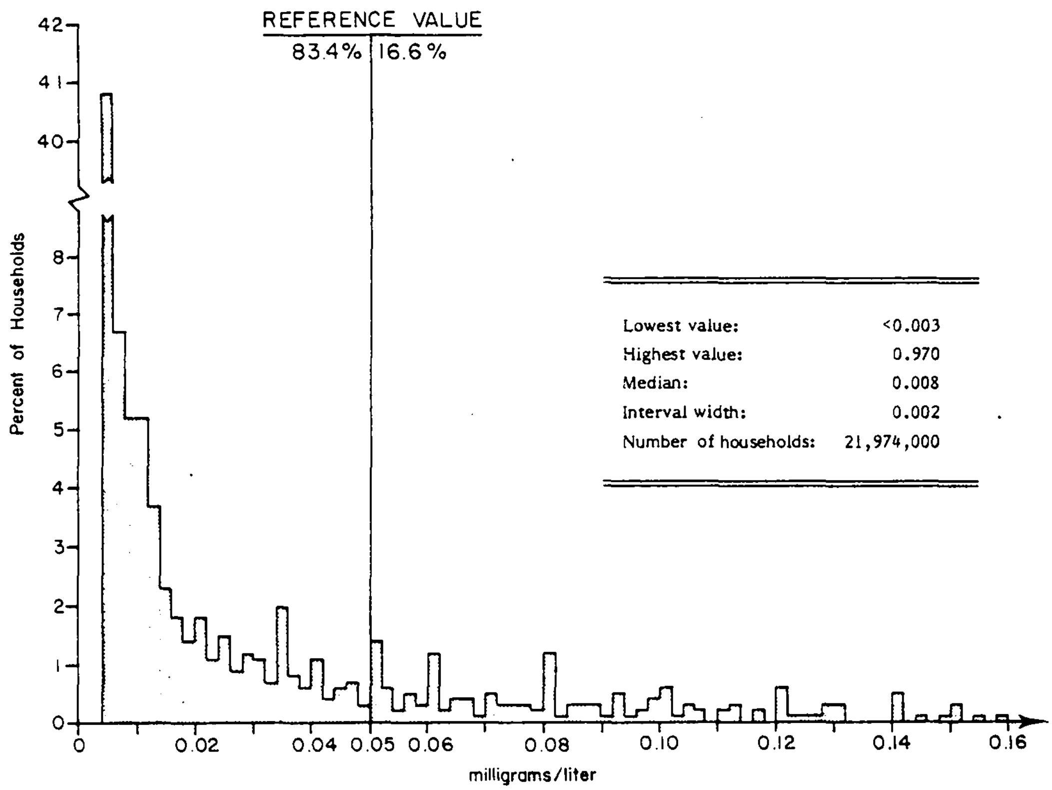
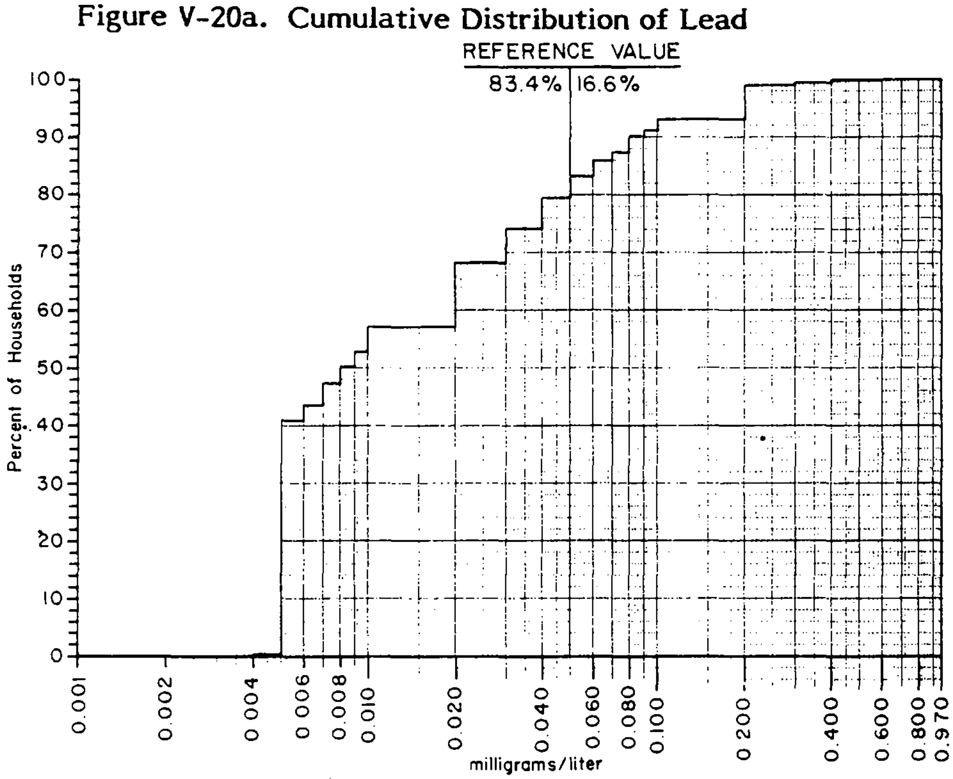


Figure V-20a. Cumulative Distribution of Lead



NOTE: Cumulative distribution is plotted on semilog paper. Base: 21,974,000 households.

Regional Variation in Lead in US Rural Household Supplies

Figure V-20b. Northeast

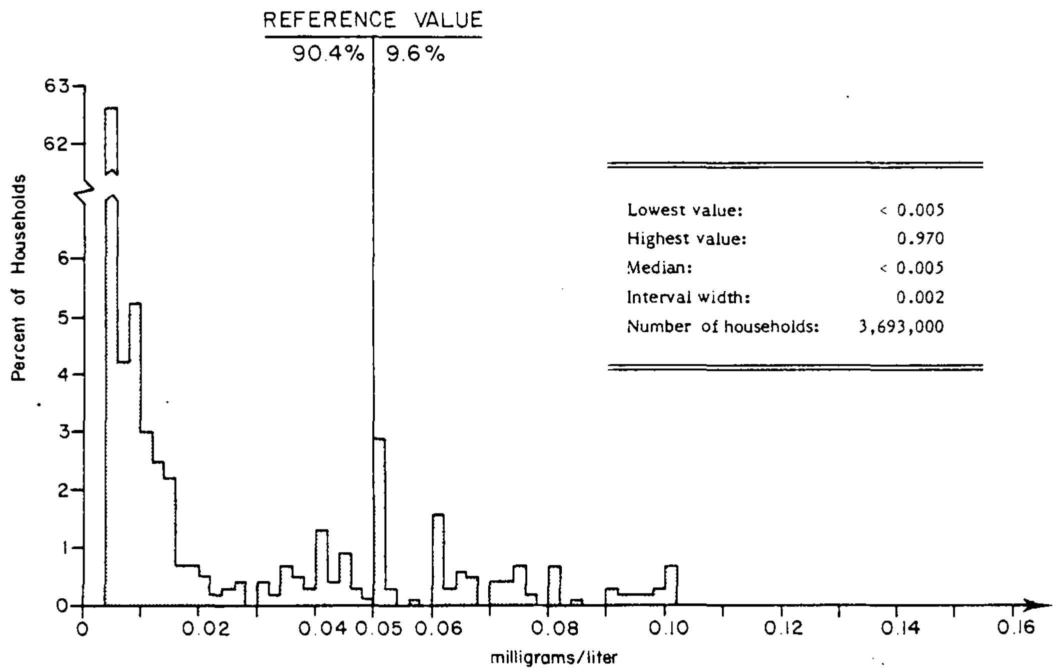
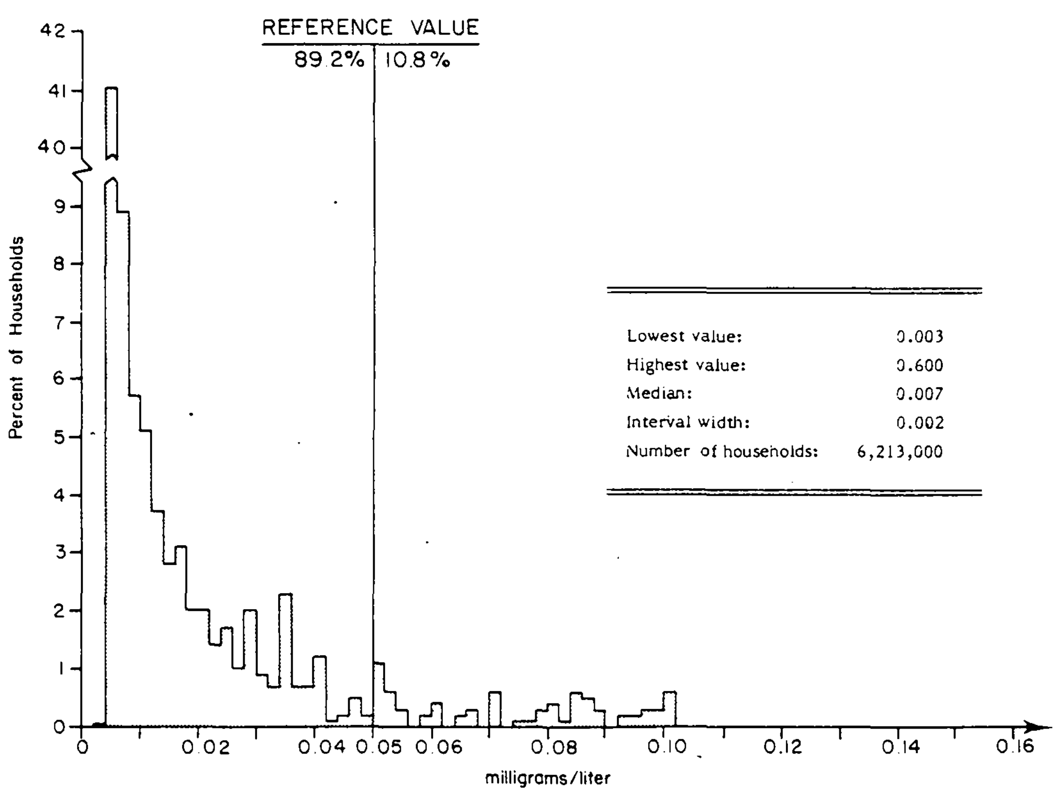


Figure V-20c. North Central



Regional Variation in Lead (continued)

Figure V-20d. South

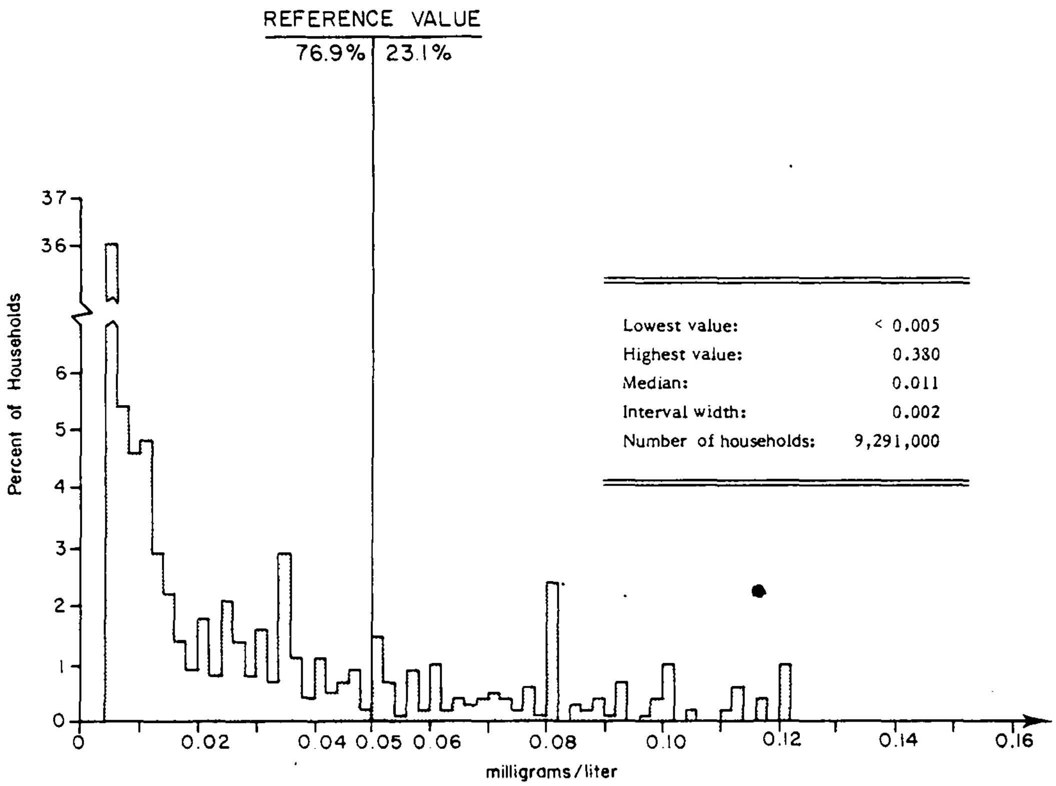
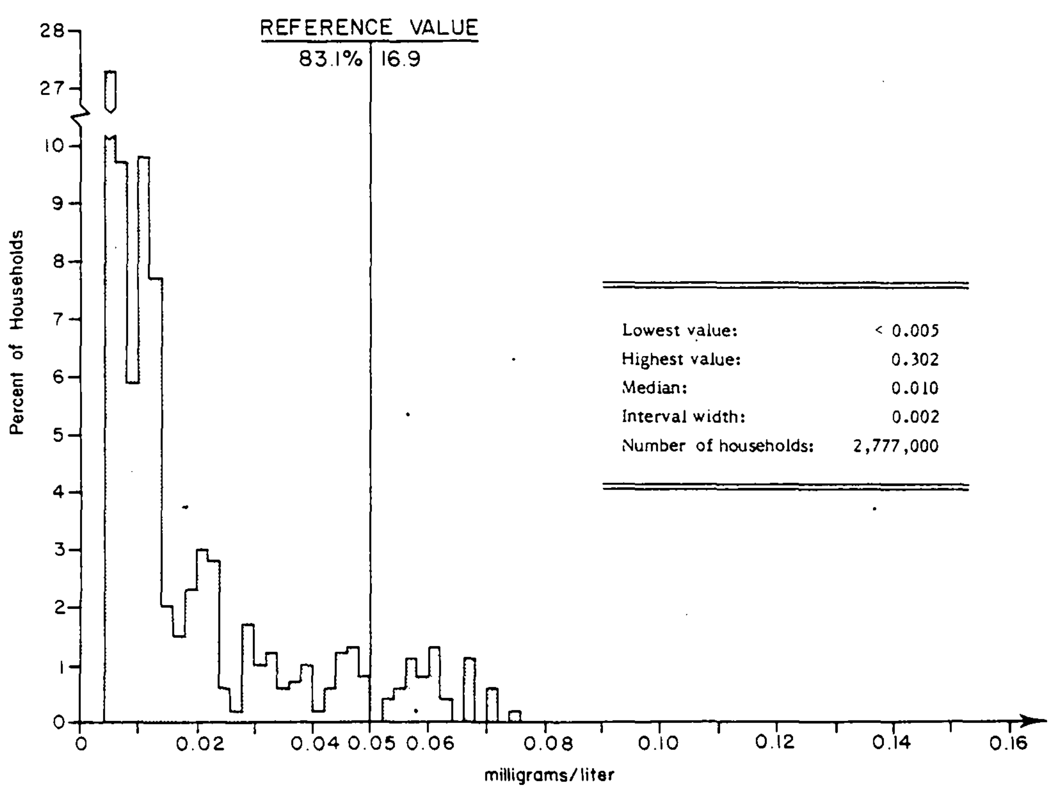


Figure V-20e. West



number—of households served by community systems were over the reference value, compared to households served by individual systems. Specifically, 17.7 percent of households served by community systems (1.9 million) were high with regard to the lead reference value, compared to 14.1 percent of households using individual systems (1.2 million). The largest proportion (20.5 percent)—but the smallest number (458,000)—of high-value households were served by intermediate systems.

As to variation in the other NSA groupings, proportions over the lead reference value were higher among nonSMSA households (18.3 percent, compared to 12.9 percent of SMSA households), and somewhat higher in small rural communities (18.1 percent, compared to 15.1 percent in large rural communities and 16.6 percent in other rural areas).

The health implications of the NSA findings are potentially serious. The risk from lead intake is dependent on several factors, but it is particularly troublesome for children who are exposed to large amounts of the metal. Such exposure is most common in urban areas, as noted above. In rural areas, where airborne lead levels usually would not be expected to be as large, total exposure would be lower. The NSA data provide no indication of total exposure to lead, and the findings about concentrations in the water thus must be interpreted in isolation from other relevant considerations. Nevertheless, the NSA findings indicate that lead intake could reach hazardous levels in some rural households.

The mean total dietary intake of lead by North American adults is estimated to be from 0.2 to 0.3 milligrams per day.[59] Roughly one-tenth of this intake (about 0.026 milligrams per day) is attributed to lead in water used for drinking or cooking. This estimate of the contribution from domestic water is based on the assumption that the average lead concentration in tap water is 0.013 milligrams per liter, and that daily water consumption by adults is two liters.[60] The NSA findings, however, showed a mean lead concentration in rural US household supplies of 0.03 milligrams of lead per liter—over two times the assumed average level. In fact, although the mean is influenced by relatively large concentrations in a small number of households, about 38 percent of rural households exceeded the anticipated level of 0.013 milligrams per liter. The concentrations in those households are not necessarily cause for concern until they approach the reference value of 0.05 milligrams per liter, but they demonstrate the potential for unexpectedly heavy exposure to lead in the diet of rural Americans.

That exposure becomes particularly noteworthy in rural households in which the lead concentration in the major water supply is large enough to push total dietary intake to relatively high levels. It has been estimated that total intake of appreciably more than 0.6 milligrams of lead per day on a regular basis and over a long period of time may lead to dangerous accumulation of the metal in the human body.[61] Assuming that a rural adult American eats about 0.2 milligrams of lead in food each day (the per capita estimate for North Americans, discussed above), the additional intake from water in a small proportion of rural households would be enough to raise total intake well above 0.6 milligrams per day. For example, supplies at about 110,000 households had concentrations of at least 0.3 milligrams of lead per liter. An adult in one of these households, then, might in the course of one day consume two liters of water with a total of 0.6 milligrams of lead, plus food containing 0.2 milligrams. His total intake that day would be 0.8 milligrams of lead, which could be hazardous if continued regularly even for as short a period as four years because of accumulation in the body.[62]

The situation probably is most serious in households with children aged one to three years. Children of this age drink only about half as much water as do adults, but they are more susceptible to adverse effects of lead.[63] As a result, their situation should be carefully evaluated in households with supplies over the reference value—a total of 3.6 million households in rural America.

Arsenic

This solid, brittle chemical element has a fearsome reputation as a poison. Yet its toxic effects differ strikingly according to the chemical compound, the route by which it is taken in, and the duration of the exposure. For example, the lethal dose of the more toxic arsenic compounds may be one to 25 milligrams per kilogram of body weight in animals; the lethal dose for less toxic compounds may be ten to 400 times this amount.

Small concentrations of arsenic are common in US waters. The material probably comes mostly from natural geological sources, although some is from industrial sources such as smelters.

Specific health effects of waterborne arsenic in the US are unclear, but there does appear to be a potential, yet-to-be-defined risk. According to the NRC: "The evidence for an association between arsenic and disease in some human populations has been further strengthened by recent epidemiological studies such as those conducted in the waters of Puget Sound, in local water supplies such as those in Lassen County, California; Perham, Minnesota; Lane County, Oregon; Antofagasta, Chile; and on the southwest coast of Taiwan. Skin lesions, including cancer, and a circulatory disorder referred to as 'blackfoot' are major clinical problems where chronic exposure to arsenic exists. Human disease associated with arsenic is not exactly duplicated in animals, although misuse of arsenicals results in disease in dogs and in cattle. . . The different forms of arsenic that exist in the environment may account for differences in clinical manifestations between different localities."[64]

In view of the indirect, epidemiological evidence of a link between skin cancer and large concentrations of arsenic in drinking water, the current US interim primary MCL of 0.05 milligrams per liter may not provide an adequate margin of safety, according to the NRC. The NRC does not specify a recommended level, however.

In the NSA survey, arsenic was one of eight inorganic substances studied exclusively in 10 percent of the household specimens—the Group II subsample. As noted previously, all the Group II constituents are reported on in sequence in the following pages, beginning with arsenic and ending with the radionuclides.

The reference value used for comparative purposes in the NSA was the same as the interim primary MCL of 0.05 milligrams of arsenic per liter of water.

— Arsenic levels in rural supplies

Arsenic was above the minimum detection limit in about 17 percent of rural supplies (Figures V-21, V-21a), but the concentrations rarely exceeded the reference value (0.05 milligrams per liter). In fact, detected concentrations in most supplies were half or less of that allowed by the reference value. Levels exceeded the reference value in only 0.8 percent of rural households. The highest value was 0.179 milligrams of arsenic per liter (in 0.3 percent of households).

The median value was consistently less than 0.005 milligrams of arsenic (less than one-tenth the reference value) in all rural households, regardless of NSA grouping. The only exception occurred in the West, where household supplies had a slightly higher median value, 0.008 milligrams of arsenic per liter of water (Figures V-21b through V-21e).

Consistent with the regional distribution of median values, the proportion of households exceeding the reference value was greatest in the West—2.1 percent of households there. The proportion was 1.8 percent in the North Central. Within the statistical limits of NSA findings, the results showed that the reference value was not exceeded in households in the Northeast or South.

The proportion of households over the reference value for arsenic was greater among nonSMSA households (1.2 percent, compared to 0.0 percent of SMSA households). Small rural communities had a much greater proportion of households above the reference value—6.6 percent, compared to 0.0 percent in large

Figure V-21
Arsenic in US Rural Household Supplies

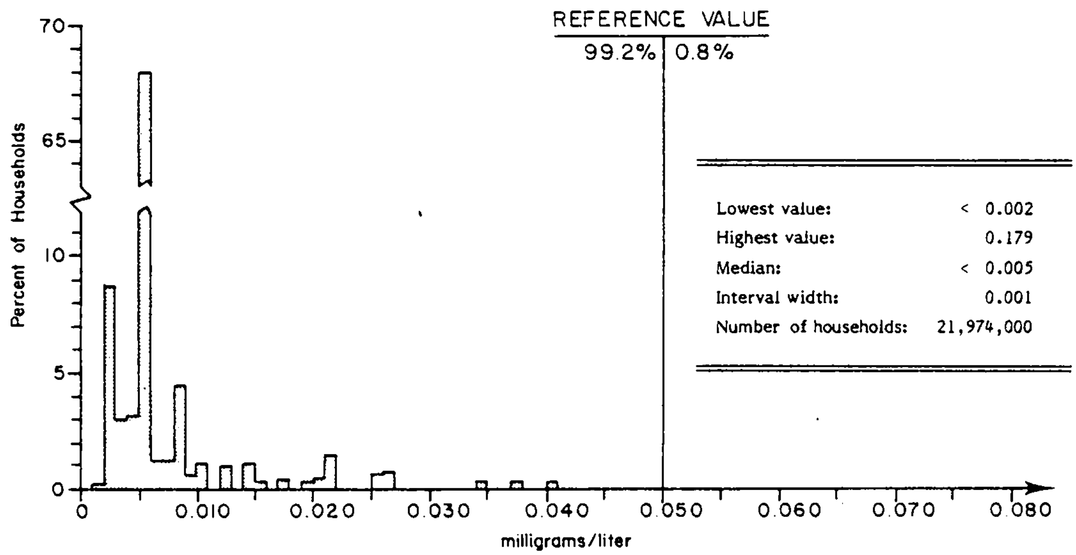
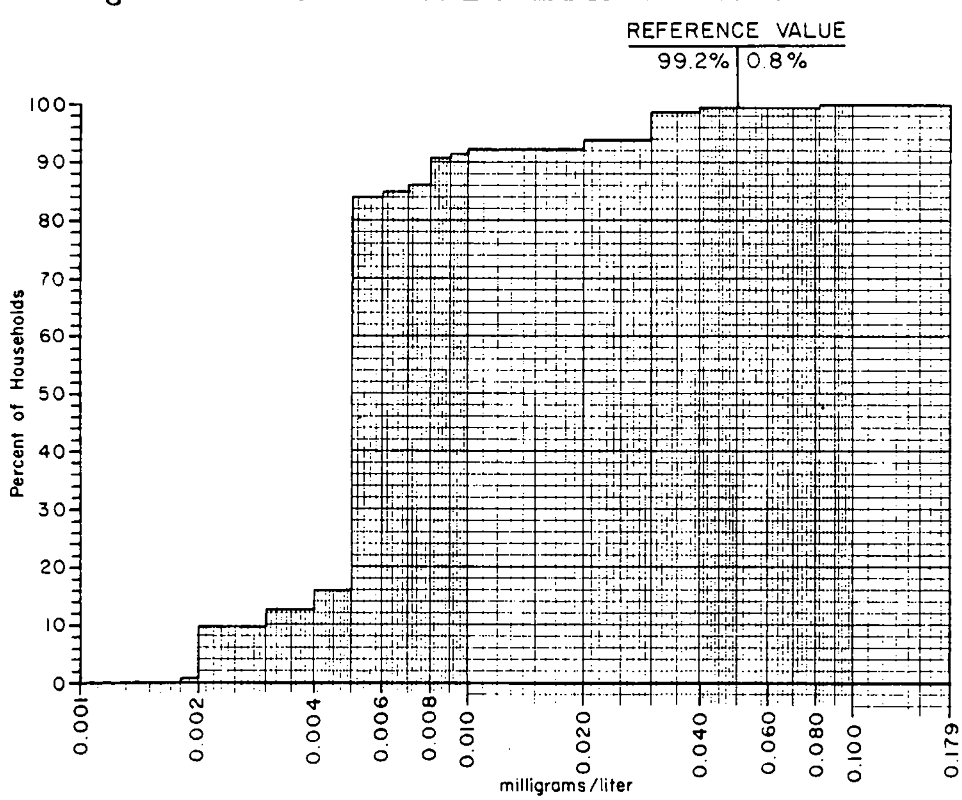


Figure V-21a. Cumulative Distribution of Arsenic



NOTE: Cumulative distribution is plotted on semilog paper. Base: 21,974,000 households.

Regional Variation in Arsenic in US Rural Household Supplies

Figure V-21b. Northeast

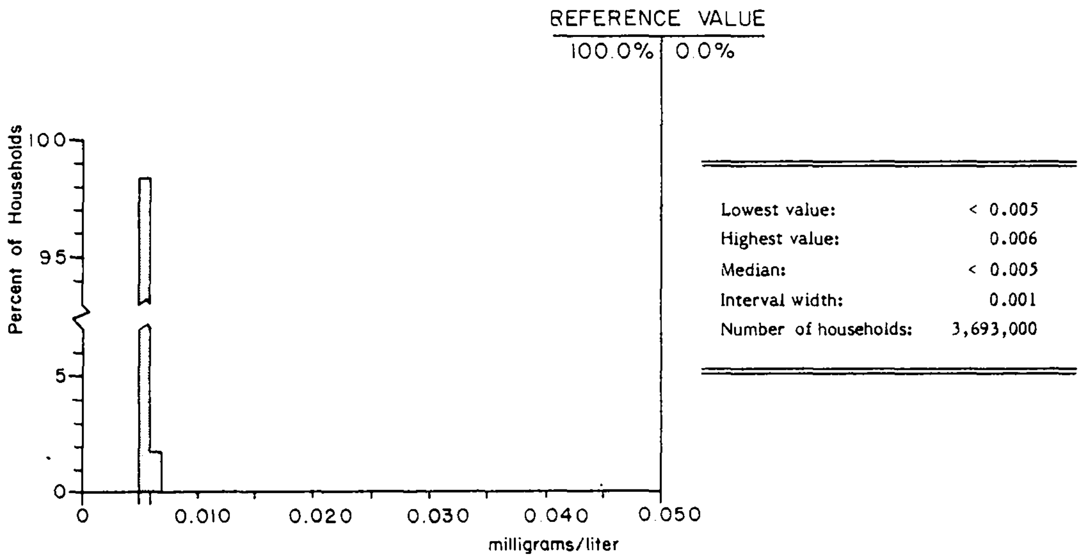
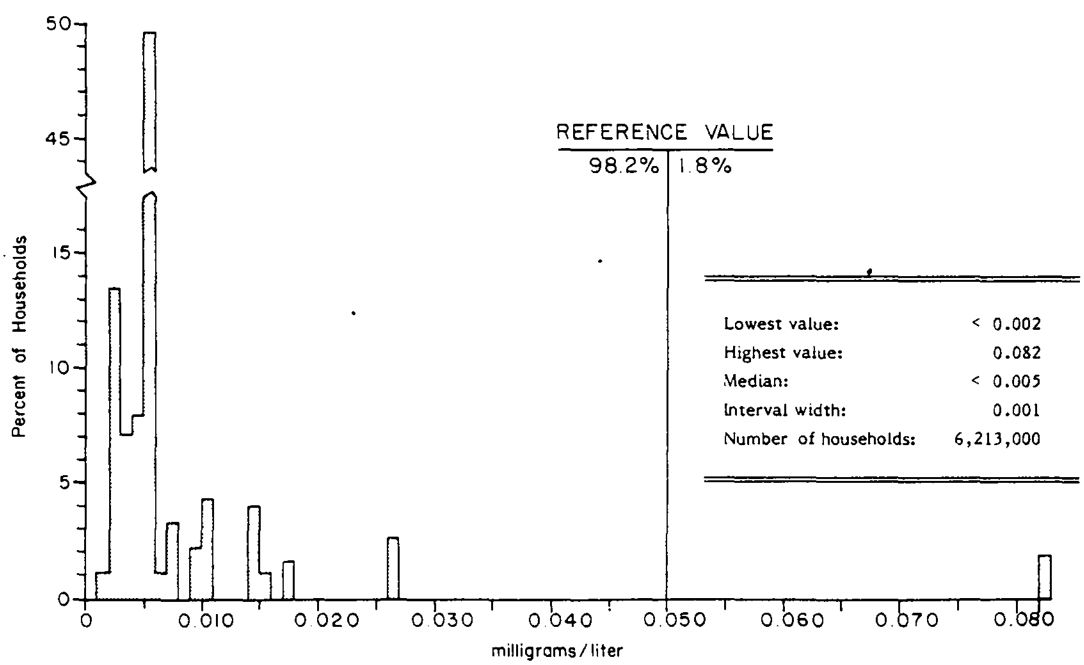


Figure V-21c. North Central



Regional Variation in Arsenic (continued)

Figure V-21d. South

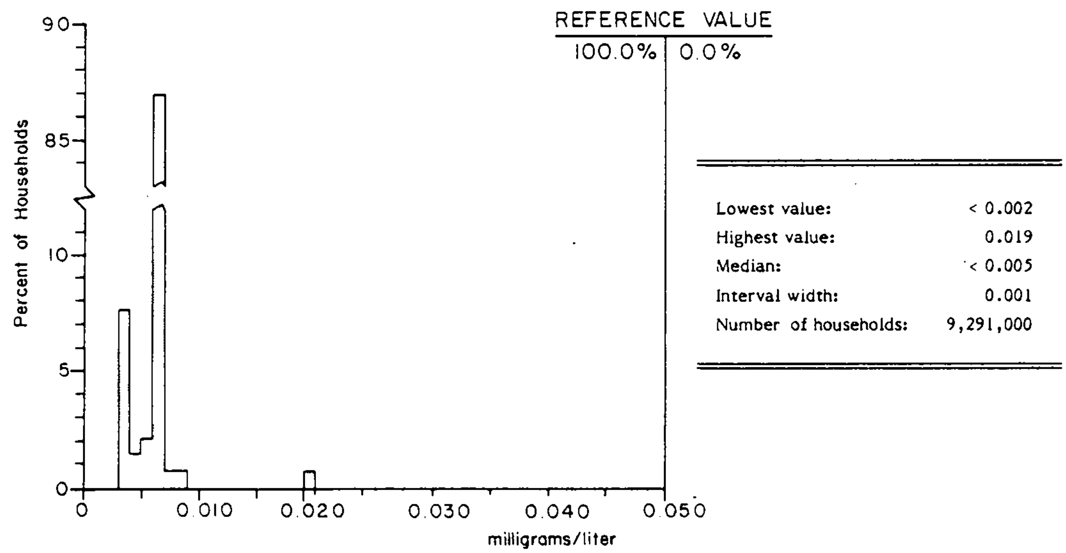
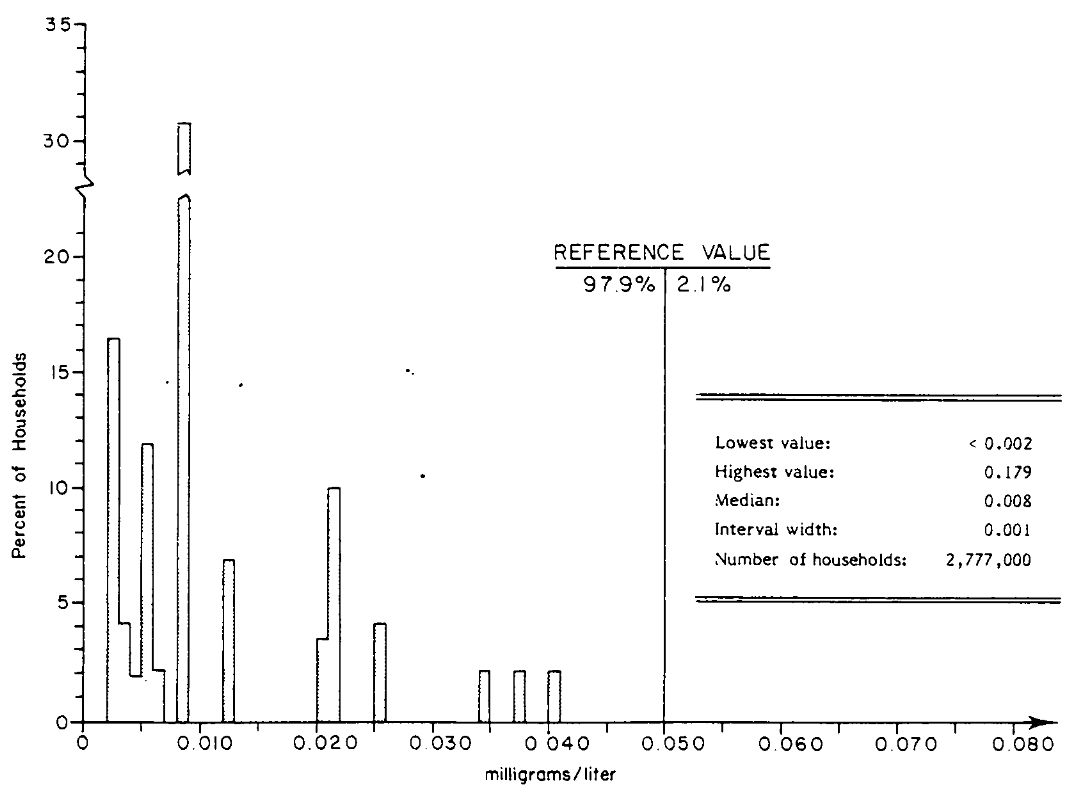


Figure V-21e. West



communities and 0.4 percent in other rural areas—but all of the high-value small-community households were located in the North Central, where the reference value was exceeded most often. The pattern of high values showed little variation in the size-of-system grouping.

On the basis of the NSA findings, arsenic was not pervasive in US rural household water supplies. When found, it appeared in relatively low concentrations. Even the highest concentrations posed no identifiable immediate health threat.

Selenium

This nonmetallic element resembles sulfur chemically. The substance is one of those which has a dual influence on human health: too little results in nutritional insufficiency; too much (in certain forms) produces a variety of adverse symptoms.

Selenium toxicity may be modified by the presence of other elements such as arsenic, mercury, cadmium, and thallium. In particular, selenium toxicity in laboratory animals is alleviated or prevented by administration of sodium arsenate.[65]

Water-soluble selenium compounds come from both natural and artificial sources. According to the NRC, "there is a wide variation in concentration of selenium, depending on geologic location. Thus, groundwaters and surface waters may contain significant amounts of selenium, particularly in areas where there is an excess of selenium in rocks and soils; in other areas, there may be little (if any) detectable selenium in the water."[66] Despite the likelihood of selenium in many water sources, the NRC adds "there is little in the literature to indicate that surface waters contain toxic amounts of selenium; in fact, it is likely that there is an insufficient amount of selenium in the water alone to provide the nutrient requirement of most animals, but concentrations may vary in different places."

In view of this, the NRC advises: "Rather than concern for toxicity, the literature indicates that there is a greater potential for a deficiency. Consideration should be given to raising the current permitted levels in water of the United States (the U.S. interim primary MCL is 0.01 milligrams of selenium per liter of water)."[67]

In the NSA, the interim primary MCL was used as the reference value.

— Selenium levels in rural supplies

Supplies at 86.3 percent of all rural households were below the selenium reference value; those at 13.7 percent were above (Figures V-22, V-22a). Selenium levels were as high as 0.114 milligrams per liter of water (in 0.3 percent of rural households). The median level in rural US households was less than 0.005 milligrams per liter.

As was frequently true for constituents studied in the NSA, variation among the total percentage of households exceeding the MCL was most pronounced according to region rather than other groupings (Figures V-22b through V-22e). Thus, 41.3 percent of the households in the West had supplies with selenium concentrations over the reference value. At the other extreme, no households in the Northeast and only 2.1 percent of households in the South had supplies with concentrations above the reference value. In the North Central, 25.7 percent of households had supplies exceeding the reference value.

In general, variations in the proportions of supplies exceeding the reference value were not prominent in other comparisons. One possible exception was that in households located in small rural communities, supplies exceeded the reference value less often (6.6 percent) than in households located in large rural places (16.5 percent) or in other rural areas (14.0 percent). Another possible exception was that supplies also exceeded the reference value less often in households served by

Figure V-22
Selenium in US Rural Household Supplies

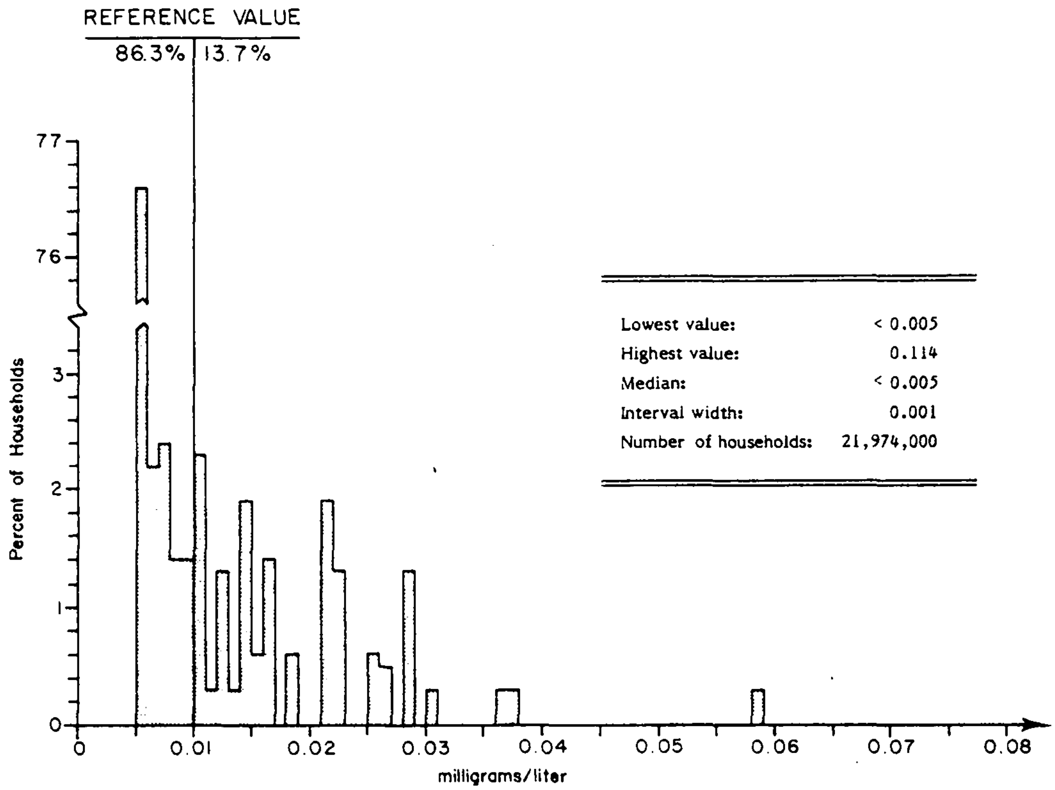
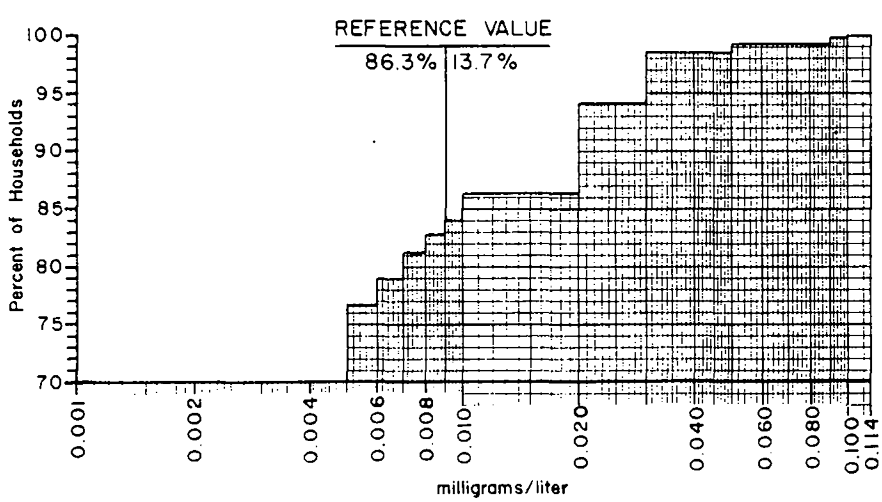


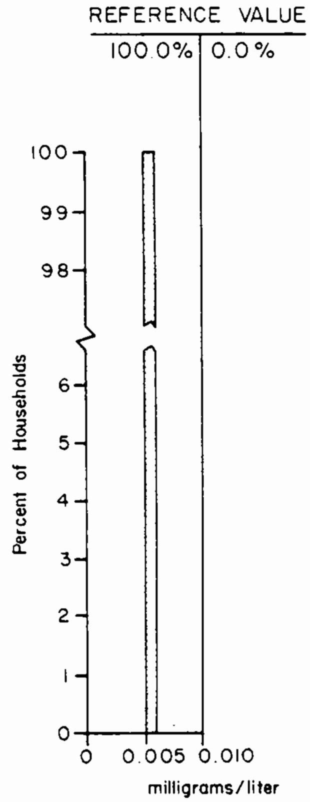
Figure V-22a. Cumulative Distribution of Selenium



NOTE: Cumulative distribution is plotted on semilog paper. Base: 21,974,000 households.

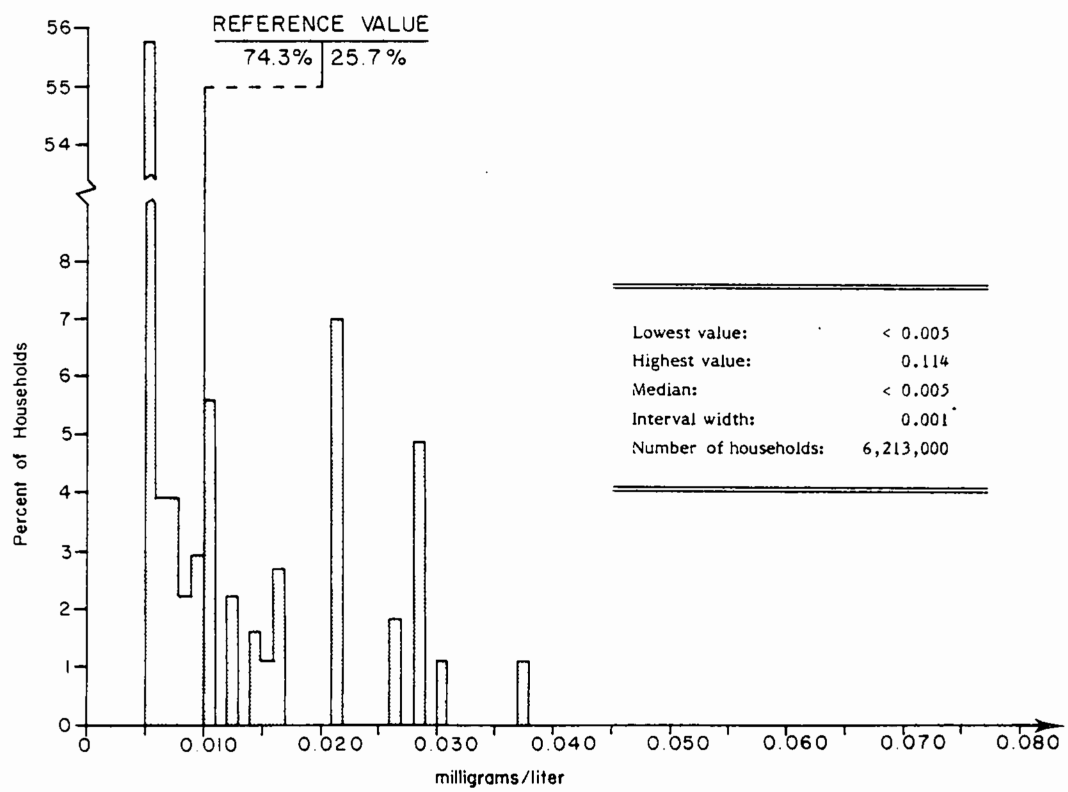
Regional Variation in Selenium in US Rural Household Supplies

Figure V-22b. Northeast



Lowest value:	< 0.005
Highest value:	< 0.005
Median:	< 0.005
Interval width:	0.001
Number of households:	3,693,000

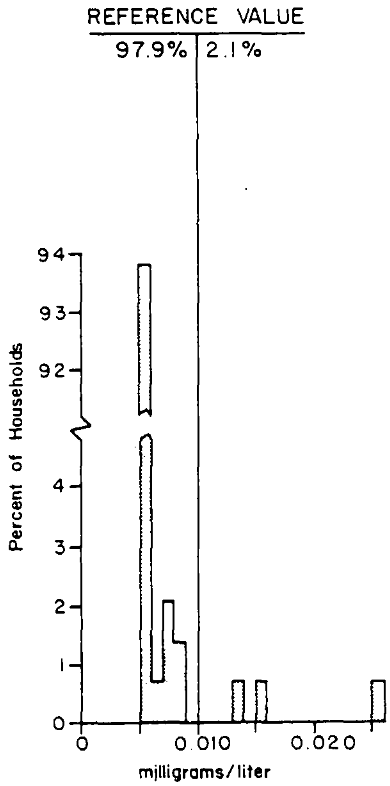
Figure V-22c. North Central



Lowest value:	< 0.005
Highest value:	0.114
Median:	< 0.005
Interval width:	0.001
Number of households:	6,213,000

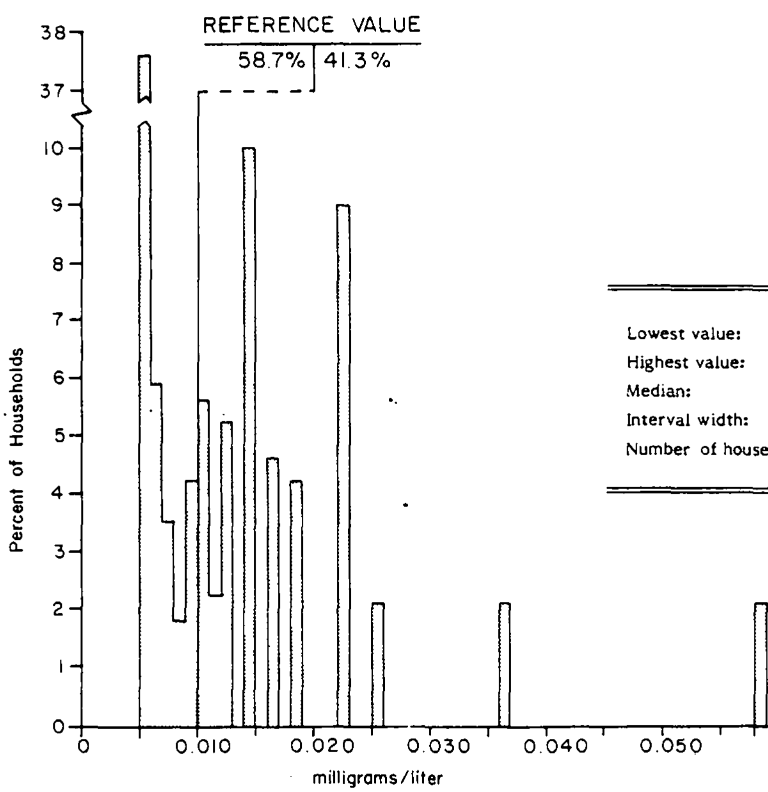
Regional Variation in Selenium (continued)

Figure V-22d. South



Lowest value:	< 0.005
Highest value:	0.025
Median:	< 0.005
Interval width:	0.001
Number of households:	9,291,000

Figure V-22e. West



Lowest value:	< 0.005
Highest value:	0.058
Median:	0.009
Interval width:	0.001
Number of households:	2,777,000

individual or community systems than in households served by intermediate systems.

As to possible health implications, the NSA findings indicated that selenium was not present in rural household supplies in sufficient quantities to pose a health threat. At the same time, the findings suggested the need for caution in raising the present interim primary MCL as is suggested by the NRC (see above). The highest concentration in the NSA was 0.114 milligrams of selenium per liter, a concentration which by itself did not represent a health threat. However, dietary intake of selenium from other sources totals about 0.2 milligrams a day.[68] Assuming that a person drinks two liters of water a day,[69] total daily selenium intake could be about 0.43 milligrams a day in households with 0.114 milligrams of selenium per liter of drinking water. According to data relied on by the EPA, signs of selenium toxicity have occurred at an estimated intake as low as 0.7 milligrams of selenium per day. There is still a margin of safety between this lower threshold danger point and the exposure level which could be anticipated in the households with the largest selenium concentrations, but the margin is not great, particularly if exposed persons drink more than two liters of water a day and eat food with more than average amounts of selenium.

Fluoride

Fluorine exists naturally as fluoride. The concentration of fluoride in water depends principally on the solubility of local fluoride-containing rocks. In addition, fluoride compounds such as sodium fluoride have been added to drinking water supplies for more than 30 years in the US as a countermeasure against tooth decay (caries).

The use of fluorides in drinking water has prompted a continuing public debate. Fluorides in appropriate concentrations reduce the incidence of tooth decay, but in excessive amounts fluorides can cause mottling of the teeth.

These conditions are not likely to develop, however, according to the NRC. The council offers this summation:

> "There is no generally accepted evidence that anyone has been harmed by drinking water with fluoride concentrations considered optimal for the annual mean temperatures in the temperate zones. It seems likely, however, that objectionable dental fluorosis mottling occurred in two children with diabetes insipidus. Bone changes, possibly undesirable, have been noted in patients being dialyzed against large volumes of fluoridated water. Similar changes can be expected in the rare renal patient with a long history of renal insufficiency and a high fluid intake that includes large amounts of tea. With this particular combination of circumstances, the lowest drinking-water concentration of fluoride associated with symptomatic skeletal fluorosis that has been reported to date is three ppm (equivalent to three milligrams per liter of water), outside of countries such as India. It should be possible for the medical profession to avoid the possible adverse effects of fluoride under the conditions described above, thereby making it unnecessary to limit the concentrations of fluoride in order to protect these rare patients. On the basis of studies done more than fifteen years ago, occasional objectionable mottling would be expected to occur in communities in the hotter regions of the United States with water that contains fluoride at one ppm or higher and in any community with water that contains fluoride at two ppm or higher. However, this may not be the case today; more liberal provisional limits seem appropriate while studies are conducted to clarify the subject.
>
> "The possibility of fluoride causing other adverse effects (allergic responses, mongolism, and cancer) or beneficial effects other than decreased dental caries has not been adequately documented to carry weight in the practical decision about the desirable levels of fluoride. The questions of mongolism and cancer have been raised on the basis of epidemiological data for which there is contrary evidence and the risk factors involved in any case are too low to establish a causal association. The allergic responses claimed by some reports are based on clinical observations and in some case double blind tests. The reservation in accepting these at face value is the lack of similar reports in much larger numbers of people who have been exposed to considerably more fluoride than was involved in the original observations. From a scientific point of view none of these effects can be ruled out, but the available data are rather limited or easily improved so further study is indicated."[70]

Interim primary MCLs for fluoride have been established by the EPA according to a schedule which takes into account local air temperature. (The hotter the climate, the more water consumed and thus the greater the amount of fluoride taken in—a situation of particular significance to children, whose teeth are most susceptible to fluoride mottling.) The maximum contaminant levels for fluoride are set according to the annual average of the maximum daily air temperatures for the location in which the community water system is situated:

Temperature (degrees, Fahrenheit)	Temperature (degrees, Celsius)	MCL (milligrams per liter)
53.7 and below	12.0 and below	2.4
53.8 to 58.3	12.1 to 14.6	2.2
58.4 to 63.8	14.7 to 17.6	2.0
63.9 to 70.6	17.7 to 21.4	1.8
70.7 to 79.2	21.5 to 26.2	1.6
79.3 to 90.5	26.3 to 32.5	1.4

In describing the background for the national regulations, the EPA states:

> "Excessive fluoride in drinking water supplies produces objectionable dental fluorosis which increases with increasing fluoride concentration above the recommended upper control limits. In the United States, this is the only harmful effect observed to result from fluoride found in drinking water. Other expected effects from excessively high intake levels are: (a) bone changes when water containing 8-20 mg fluoride per liter (8-20 mg/l) is consumed over a long period of time; (b) crippling fluorosis when 20 or more mg of fluoride from all sources is consumed per day for 20 or more years; (c) death when 2,250-4,500 mg of fluoride (5,000-10,000 mg sodium fluoride) is consumed in a single dose."[71]

Fluoride concentration was determined in water specimens from the Group II NSA subsample. The reference value used was the lowest allowable MCL value: 1.4 milligrams of fluoride per liter of water. Data on local air temperatures were not readily available, thus prohibiting the use of a set of reference values to parallel the MCL. The selection of 1.4 milligrams of fluoride per liter of water, the lowest value in the range of MCLs, was in line with the NSA policy of selecting the most conservative value when no other selection criterion was available. In the case of fluoride, the MCLs are very close to the concentrations at which known adverse health effects are noticed. The use of 1.4 milligrams per liter as a reference value provides the greatest margin of safety.

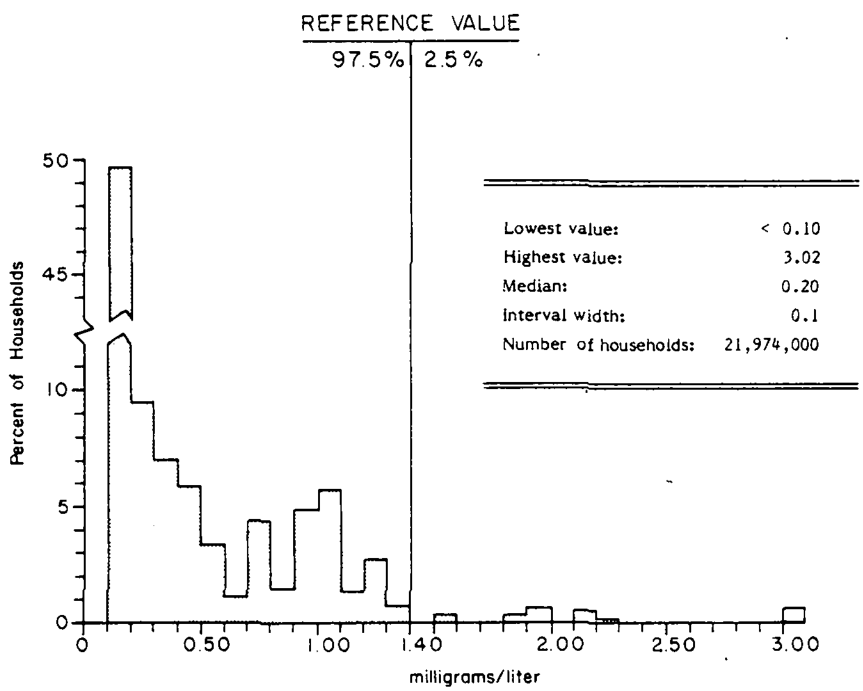
— Fluoride levels in rural supplies

Concentrations of fluoride generally were well below the MCL-related reference value of 1.4 milligrams per liter of water (Figure V-23). Only 2.5 percent of rural households had supplies with concentrations which exceeded that level. In fact, fewer than 1 percent of all rural households had values (3.02 milligrams per liter) which exceeded the maximum, temperature-based, interim primary MCL of 2.4 milligrams of fluoride per liter of water. The median value for rural US water supplies was 0.20 milligrams of fluoride per liter, or about one-third the reference value.

The reference value for fluoride was exceeded proportionately more often in the West than in other regions (Figures V-23a through V-23d). The reference value was exceeded somewhat more often among nonSMSA households than among SMSA households, and more than twice as often in households in small rural places than in households in large rural places or other rural areas.

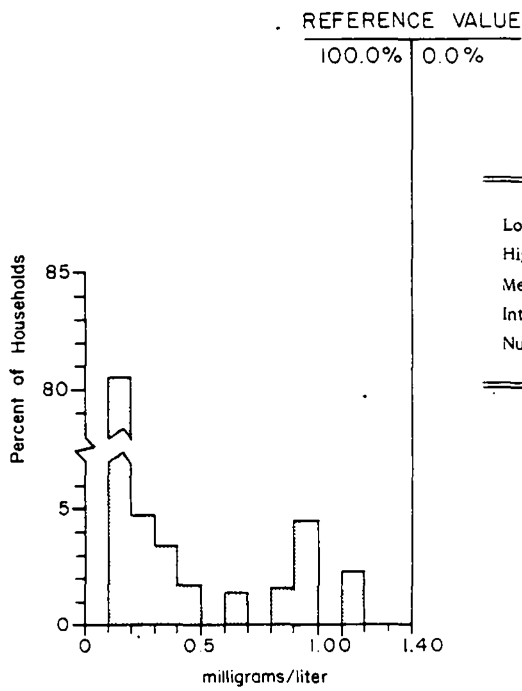
Pronounced variations occurred according to the size of system serving rural households. The fluoride reference value was exceeded most often in households served by intermediate systems (in about 7 percent of those households). The reference value was exceeded least often in households served by individual systems (in slightly less than 1 percent of those households). The reference value was exceeded in only about 3 percent of households using community systems. On the other hand, median fluoride values were lower among households served by individual systems and intermediate systems (0.10 milligrams per liter in both cases) than among households served by community systems (0.38 milligrams per liter). This finding may reflect the effect of fluoridation in some community systems.

Figure V-23
Fluoride in US Rural Household Supplies



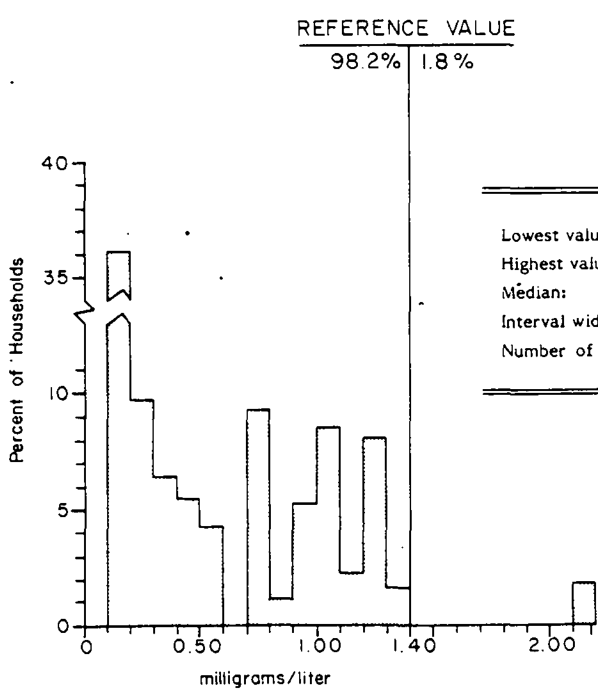
Regional Variation in Fluoride in US Rural Household Supplies

Figure V-23a. Northeast



Lowest value:	< 0.10
Highest value:	1.10
Median:	0.11
Interval width:	0.1
Number of households:	3,693,000

Figure V-23b. North Central



Lowest value:	< 0.10
Highest value:	2.18
Median:	0.33
Interval width:	0.1
Number of households:	6,213,000

Regional Variation in Fluoride (continued)

Figure V-23c. South

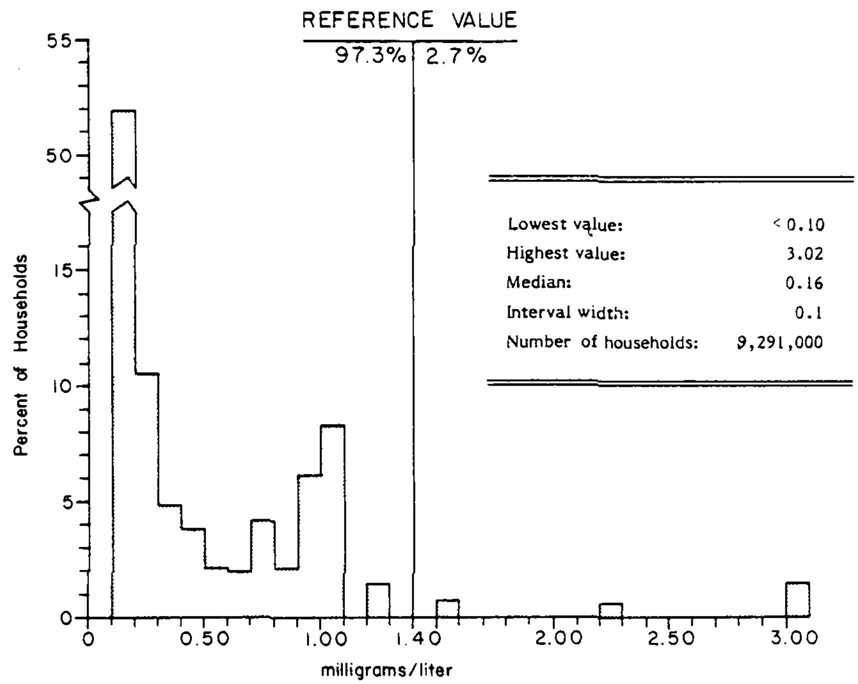
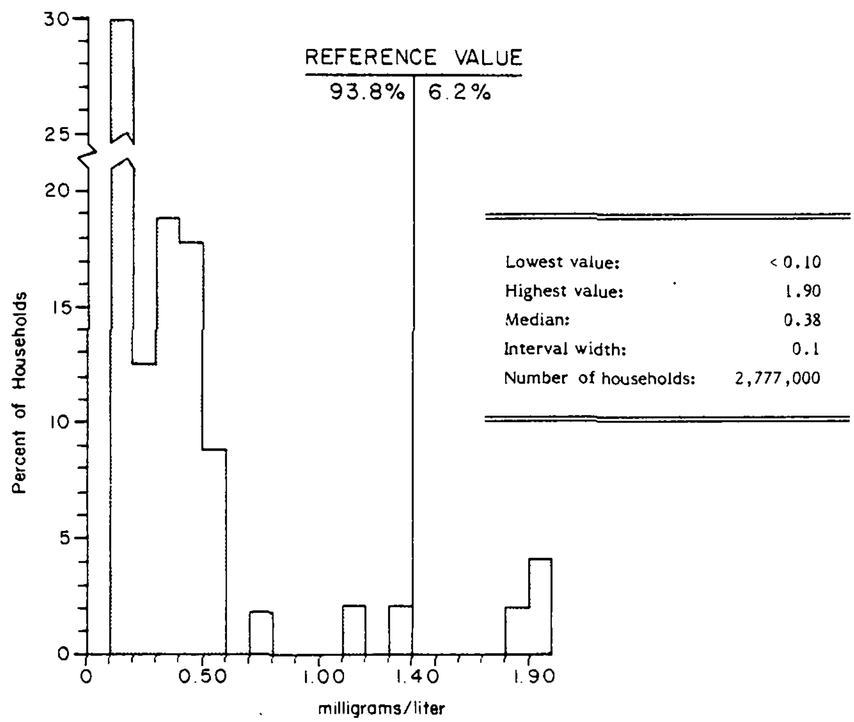


Figure V-23d. West



NSA findings suggested no serious health consequences from the levels of fluoride in rural water supplies. The highest concentration of the substance (3.02 milligrams per liter) was below the range at which long-term bone changes might be a hazard. The most prominent effect of excessive fluoride intake by human beings is mottling of the teeth, and this might be a problem in those households with concentrations higher than two milligrams of fluoride per liter.[72] That concentration is equivalent to the two ppm (parts per million) threshold which some research has linked to increased incidence of mottling (see above). The NSA findings revealed that only about 1 percent of rural households had concentrations of at least two milligrams of fluoride per liter. These levels were found only in the South and North Central—with the highest value (3.02 milligrams per liter) occurring in the South. This finding indicated that mottling of teeth was a potential but isolated problem primarily in the South and North Central, even though the largest proportion of households over the reference value was in the West. That is, although a larger proportion of households exceeded the reference value in the West than in the other regions, the largest values actually were found in the South and North Central.

Cadmium

Cadmium is a soft, silver-white, blue-tinged element that is chemically related to mercury. The main source of cadmium in source water has been assumed to be industrial discharges which release the metal into the water directly, or indirectly through atmospheric emissions which contaminate precipitation.[73] The most serious health risk is to persons who breathe the metal in industrial emissions or in cigarette smoke. Waterborne cadmium poisoning, however, has produced more than 200 cases of severe degenerative bone disease in Japan. In the US, the concern is centered primarily on possible long-term development of hypertension caused by continued exposure to cadmium.[74]

According to the EPA: "The average concentration of cadmium in drinking water from community supplies is 1.3 micrograms per liter in the United States. Slight amounts are common, with 63 percent of samples taken at household taps showing one microgram per liter or more."[75]

Despite the prevalence of the substance, the EPA estimates that "only 0.3 percent of tap samples would be expected to exceed the limits of ten micrograms per liter (equivalent to 0.01 milligrams per liter, the official interim primary MCL)." The NSA reference value was the same as the interim primary MCL—0.01 milligrams per liter.

— Cadmium levels in rural supplies

A far larger proportion of rural households exceeded the cadmium reference value than was anticipated on the basis of existing estimates. Fewer than 1 percent of US rural households were expected to have readings beyond the reference value (see above), but instead 16.8 percent did (Figures V-24, V-24a). The highest recorded concentration was 0.046 milligrams of cadmium per liter of water; the median for the rural US was less than 0.002 milligrams per liter.

Although the median values for cadmium concentrations were at or near the limit of detection in each region, the proportion of households over the reference value changed considerably from region to region (Figures V-24b through V-24e). By far the largest proportion of households with high levels was in the West, where supplies in 27.1 percent of rural households had levels in excess of the reference value. In sharp contrast, supplies in only 1.6 percent of Northeast rural households had concentrations that high. The reference value was exceeded in 20.7 percent of North Central households and in 17.3 percent of Southern households.

Supplies in excess of the reference value occurred in 21.4 percent of SMSA households, compared to 14.3 percent of nonSMSA households. The reference value was surpassed more than twice as often in large rural places (19.8 percent) and

Figure V-24

Cadmium in US Rural Household Supplies

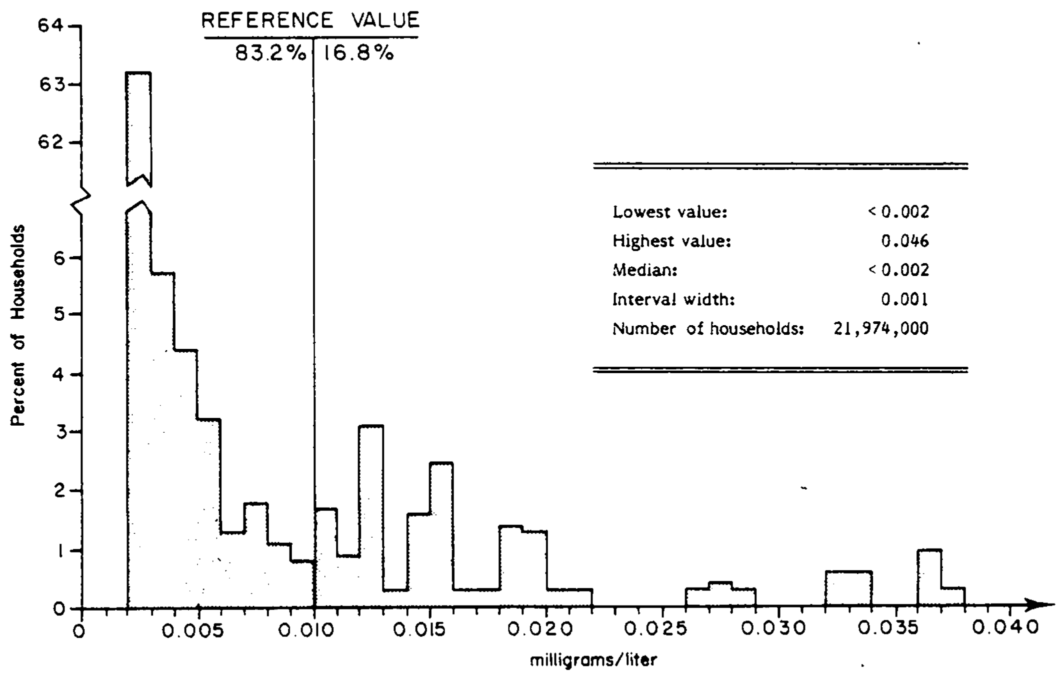
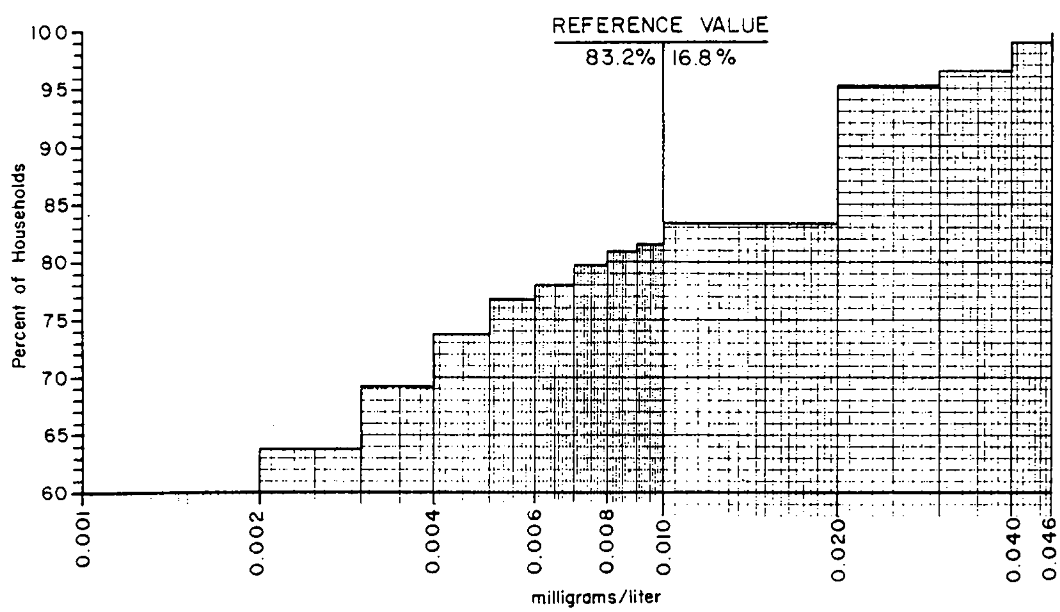


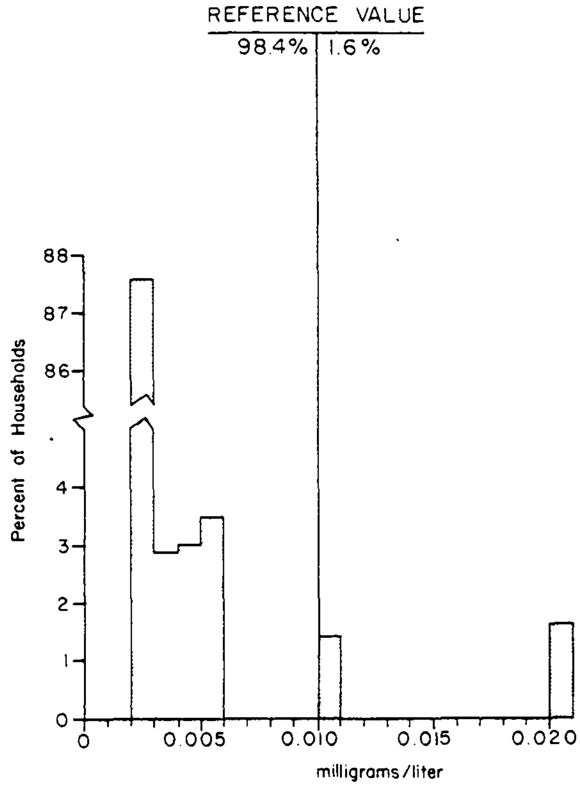
Figure V-24a. Cumulative Distribution of Cadmium



NOTE: Cumulative distribution is plotted on semilog paper. Base: 21,974,000 households.

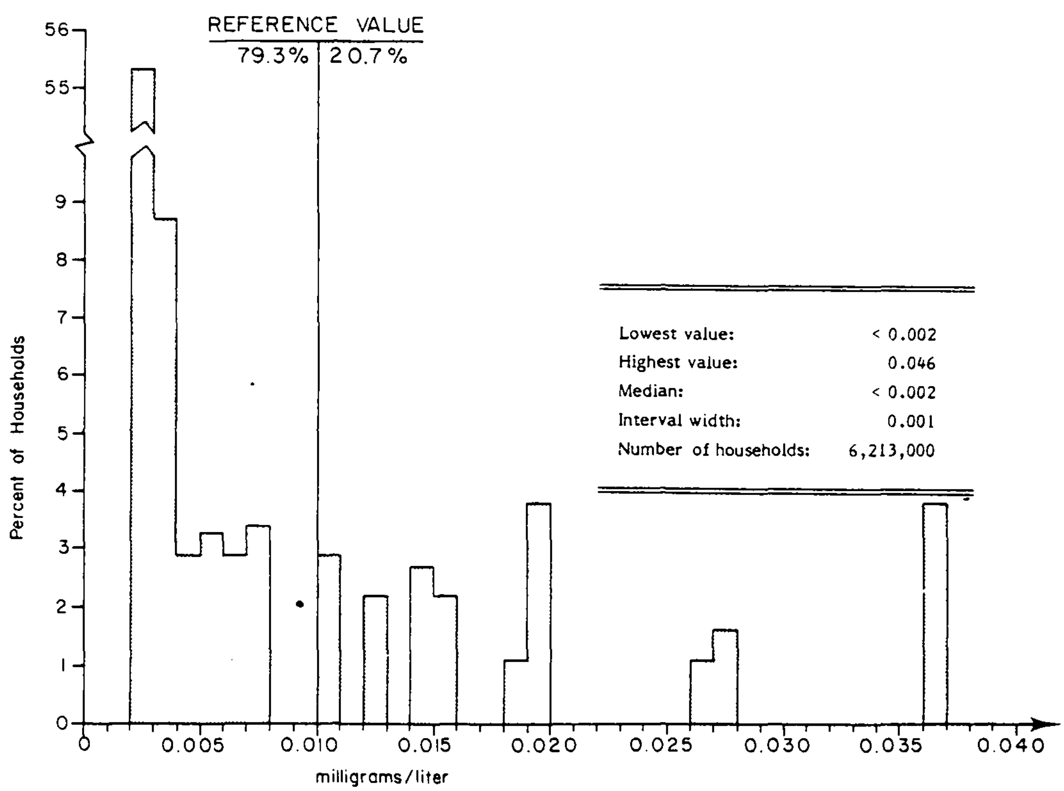
Regional Variation in Cadmium in US Rural Household Supplies

Figure V-24b. Northeast



Lowest value:	< 0.002
Highest value:	0.020
Median:	< 0.002
Interval width:	0.001
Number of households:	3,693,000

Figure V-24c. North Central



Lowest value:	< 0.002
Highest value:	0.046
Median:	< 0.002
Interval width:	0.001
Number of households:	6,213,000

Regional Variation in Cadmium (continued)

Figure V-24d. South

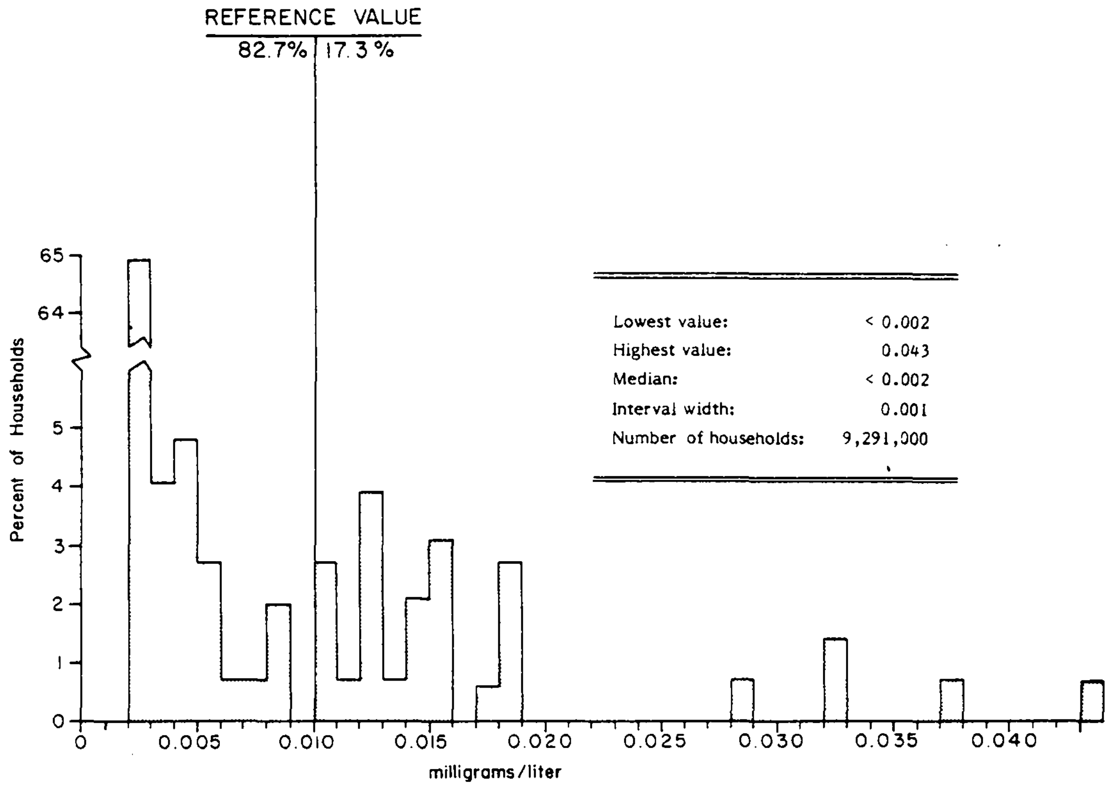
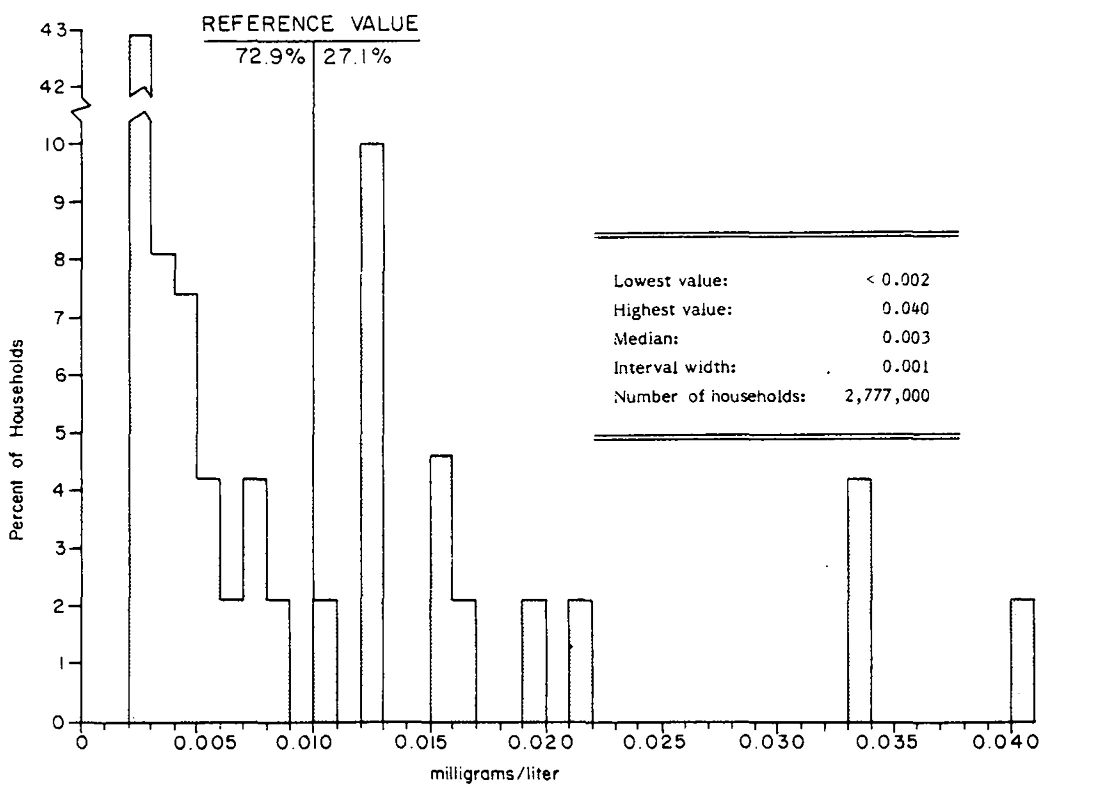


Figure V-24e. West



other rural areas (17.3 percent) than it was in small rural places (7.3 percent). Supplies exceeding the reference value were much more common among households served by community or intermediate systems than among those using individual systems. Specifically, the reference value was exceeded in only 7.9 percent of households served by individual systems, as opposed to 26.9 percent of households served by intermediate systems and 21.2 percent of households served by community systems.

Cadmium compounds enter the water from a number of sources.[76] Despite the many possible sources, one in particular is consistent with the NSA data—namely, the technological features of water transmission and distribution facilities. Cadmium frequently is an impurity in zinc, lead, and complex copper ores.[77] The metal also can be present as an impurity in zinc-galvanized pipes, and it is used itself as an anti-corrosion coating for some metallic parts.[78] Cadmium also is used in the formulation of silver-brazing alloys which are used to join iron, copper, nickel, and silver-base alloys.[79] The metal sometimes is used as an alloy with copper. Furthermore, cadmium compounds are used as stabilizers in some plastic products, and the metal has been shown experimentally to leach out into water in black polyethylene pipes.[80]

Water transmitted through the pipes of community systems, particularly in the West where long-range piping often is necessary, is in contact with transmission equipment for longer periods of time than is water in individual systems. Thus, there would be more opportunity for exposure to cadmium compounds in the equipment. Consistent with this consideration, supplies exceeded the reference value considerably more often among households served by intermediate and community systems than among those served by individual systems. Further, values in excess of the reference value also were most frequent in the West, where the proportion of households with community systems was substantially larger than in other regions (see Chapter IV).

As to overall health implications, the NSA results indicated the need for further assessment of cadmium contamination since a sizable proportion of rural households were over the NSA reference value in every region except the Northeast. As to immediate risk, even the highest recorded values were far below those which have caused direct toxic effects in human beings. Furthermore, even the largest concentrations were considerably lower than those which have been associated with chronic effects.[81] On the other hand, the potential long-term cumulative influence of cadmium ingestion on the scale occurring in the rural US is uncertain.[82]

Mercury

Mercury is one of the least abundant elements, and its presence in surface source water is associated mainly with industrial discharges. Historically, the toxicity of mercury became apparent when workers in the felt hat industry became mentally unstable after being exposed to the metal in their trade.

Mercury is present in soil and rock. The concentration usually averages only about 0.05 parts per million, but it can range from one to 30 parts per million in some geological areas with sediment and volcanic rock containing large amounts of cinnabar (HgS).[83] Weathering of rocks and deposits may contribute to the amount of mercurial compounds in the sediment of streams and lakes. Ground water, depending upon its aggressiveness and the geology of its surroundings, may pick up the compounds.

In addition to the natural sources of mercury, inorganic mercurial salts have been discharged by industry. The main concern has been that the natural or industrial inorganic mercurial compounds can be converted by naturally occurring microorganisms into organic methylmercury compounds, which are of greater hazard to human beings.[84] The greatest potential hazard is consumption of fresh-water fish which contain the methylmercury compounds. Contaminated fish flesh may contain concentrations of methylmercury which far exceed allowable federal limits.

On the other hand, there has been no historical indication that mercurial compounds in US drinking water supplies are present in sufficient quantities or in specific chemical forms which pose a threat to human health. (This is the conclusion of the NRC in reviewing information about the subject.)

In formulating the interim primary MCL for mercury in drinking water, the EPA took a more cautious approach. The background statement for the regulation begins: "Environmental exposure of the population to mercury and its compounds poses an unwarranted threat to man's health. Since conditions indicate an increasing possibility that mercurials may be present in drinking water, there is a need for a guideline that will protect the health of the water consumer."[85]

The interim primary MCL for mercury is 0.002 milligrams per liter of water. That is the reference value used in the NSA.

— Mercury levels in rural supplies

As with cadmium, the reference value for mercury was exceeded in a far larger proportion of rural households than had been anticipated. Fully 24.1 percent of households had more than the reference value level of 0.002 milligrams of mercury per liter (Figures V-25, V-25a). In fact, the median value for rural supplies was 0.001, a level relatively close to the reference value. Furthermore, the mean value for rural supplies was 0.003, or about one and one-half times the reference value. The largest recorded concentration was 0.25 milligrams per liter.

The median value for mercury concentrations was 0.001 milligrams per liter across all regions and across all other NSA groupings, indicating the pervasiveness of the metal in water supplies. The proportions of households above the reference value varied considerably from region to region, however (Figures V-25b through V-25e). Specifically, proportions exceeding the reference value for

Figure V-25
Mercury in US Rural Household Supplies

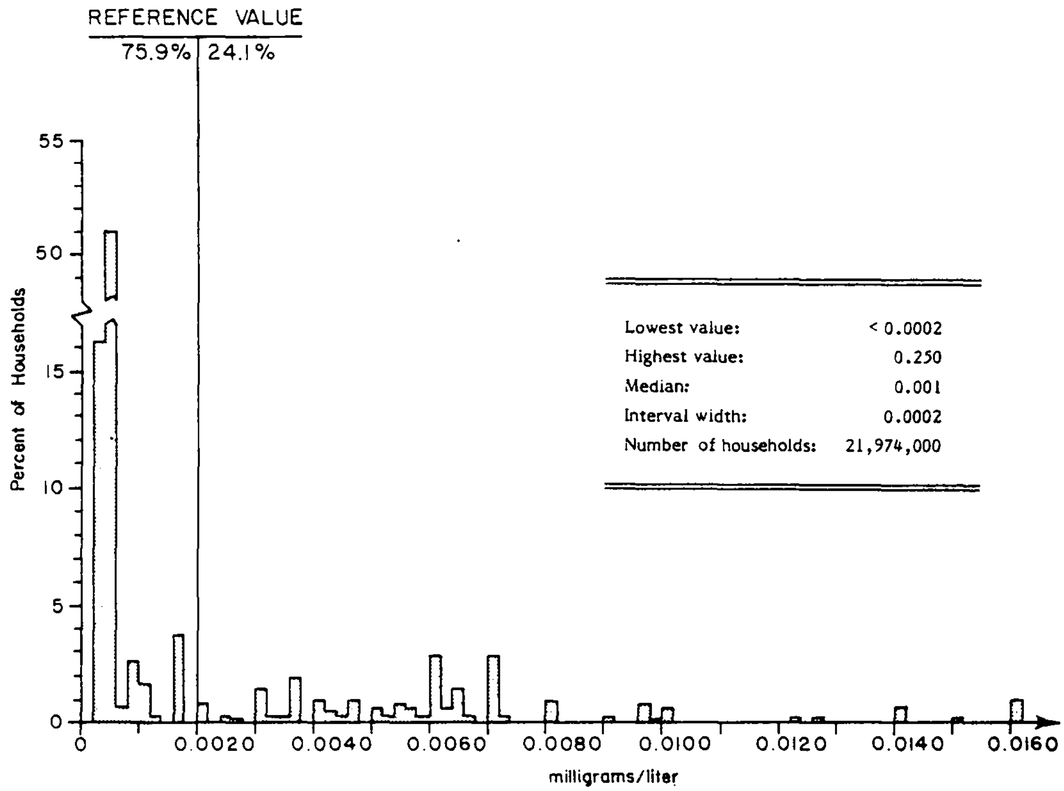
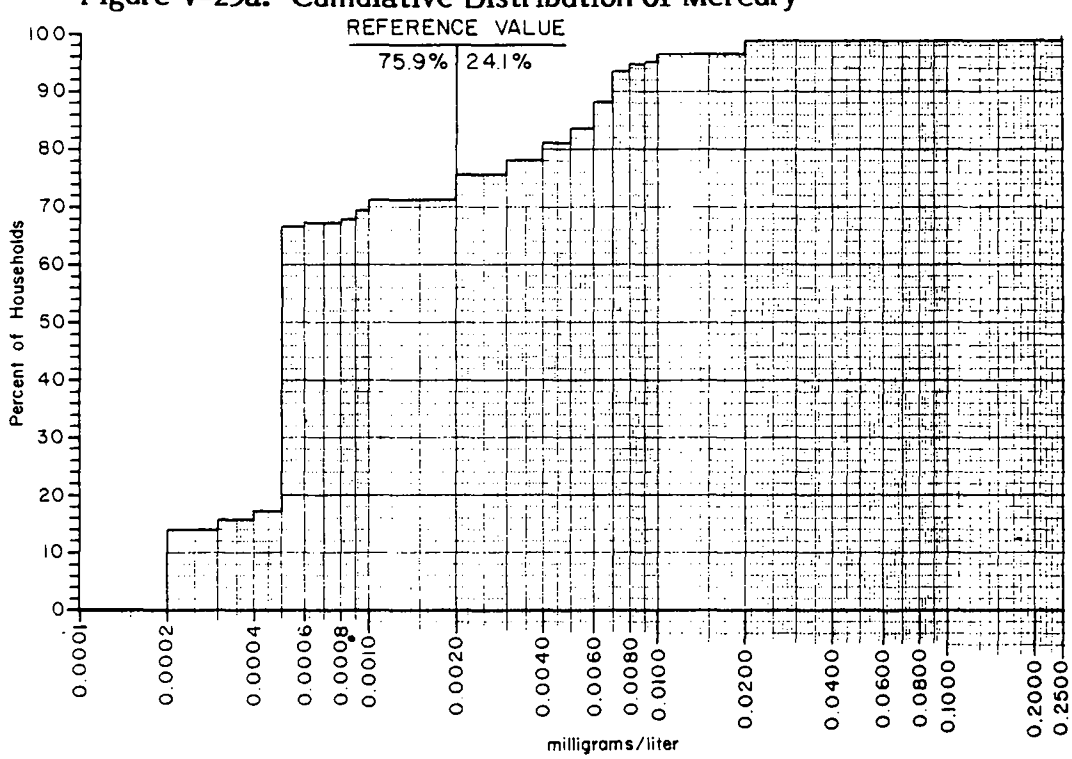


Figure V-25a. Cumulative Distribution of Mercury



NOTE: Cumulative distribution is plotted on semilog paper. Base: 21,974,000 households.

Regional Variation in Mercury in US Rural Household Supplies

Figure V-25b. Northeast

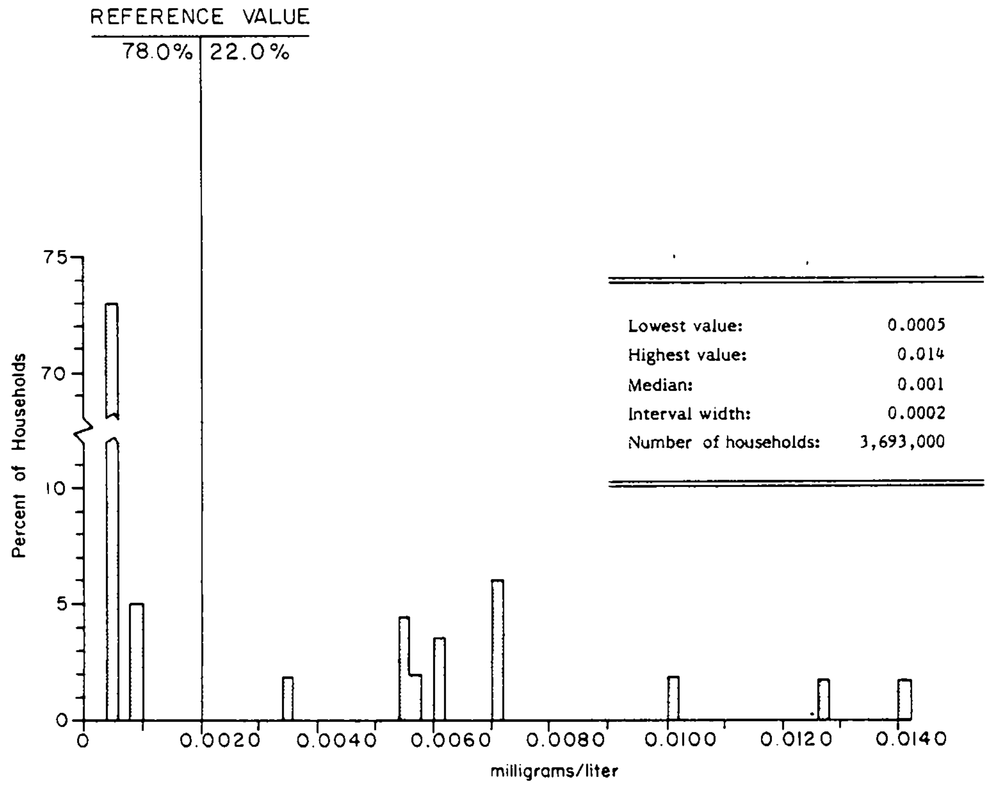
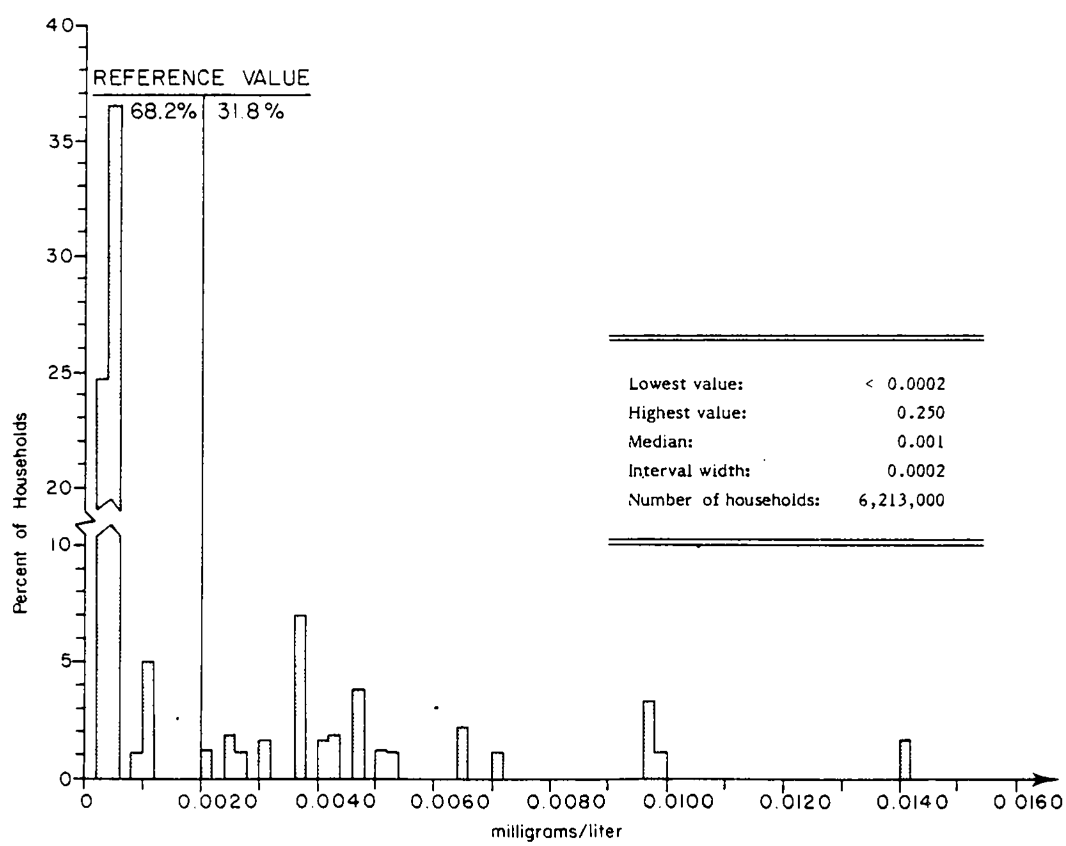


Figure V-25c. North Central



Regional Variation in Mercury (continued)

Figure V-25d. South

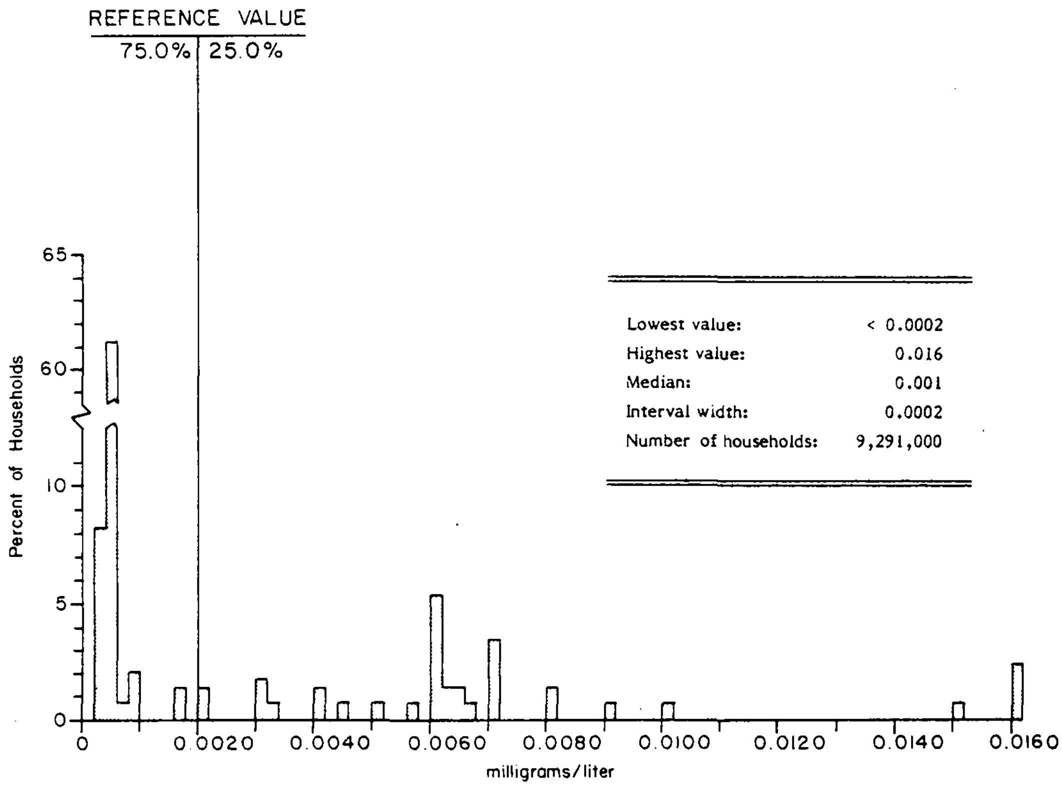
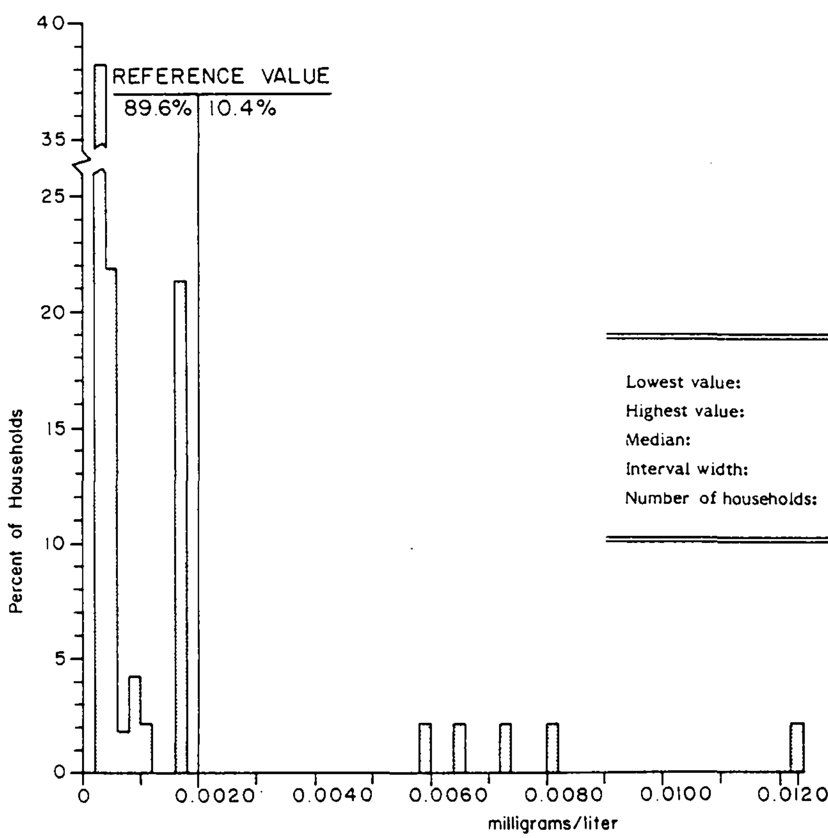


Figure V-25e. West



mercury were 22.0 percent in the Northeast, 31.8 percent in the North Central, 25.0 percent in the South, and 10.4 percent in the West.

As to patterns among the other NSA groupings, about one-fourth of households surpassed the NSA reference value both inside and outside SMSAs, in each size-of-place category, and regardless of the size of the supply system. Exceptions were a lower rate in large-community households (16.2 percent) and a higher rate in intermediate-system households (36.0 percent).

The health implications of the NSA findings are cause for concern. As noted above, the main threat from mercury is from the methylmercuric (organic) form. Mercury content was determined in NSA samples by flameless (cold vapor) atomic absorption spectrophotometry. The method is based on the specific light-absorbing characteristics of the metal being studied (in this case, mercury), and it does not determine the original chemical form of the metal. Thus, the NSA results tell us only that mercury was present in certain amounts in many US supplies. The results do not tell us whether the metal was in the highly toxic methylmercuric form, or whether it was in less dangerous inorganic forms. In this regard, EPA authorities have assumed that less than 0.1 percent of the mercury in water is in the toxic organic form.[86] On the other hand, researchers have pointed out that natural mechanisms exist in the environment which convert inorganic mercurial compounds into organic ones, so that the presence of mercury in whatever form must be taken seriously.[87]

According to Swedish authorities cited by the NRC, clinical manifestations of mercurial poisoning may occur in some persons who consume 0.3 milligrams of methylmercury per day.[88] In the NSA, 0.5 percent of all rural households had levels of 0.25 milligrams of mercury per liter of water. Since people are assumed by the EPA to drink an average of two liters of water per day,[89] persons in those 93,000 households faced potential direct health consequences if methylmercury were present, especially if they also ate food, such as fish, containing methyl-mercury.

As to the sources of the contamination, the NSA findings did not provide clear indications for further investigation. Mercury contamination was pervasive regardless of household location with respect to SMSAs or size of place, and regardless of the size of the water system. Mercury is a particularly difficult element to maintain in water specimens from the time of collection until assay in the laboratory. The difficulty usually results in inaccurately low readings. It is not known whether such a bias exists in the NSA mercury data, but the possibility indicates even more strongly the need for reinvestigation.

Chromium

Only trace amounts of this metal are found in US waters because chromium compounds are not particularly soluble. The main source of the substance is industrial wastewater. Small amounts of chromium are essential to glucose metabolism in human beings. Excessive levels of chromium are poisonous, but the toxicity depends on the chemical form of the compound. Sufficient amounts of hexavalent chromium produce gastrointestinal bleeding, and inhaled industrial chromate may cause cancer of the respiratory tract. Trivalent chromium, on the other hand, is relatively nontoxic and is the form essential in the human diet.

These complexities make it difficult for public health authorities to establish meaningful limits for chromium in drinking water. The European standards of the World Health Organization, as well as the Japanese standards, set the acceptable limit at 0.05 milligrams of chromium per liter of water. The standard is specifically for hexavalent chromium rather than for total chromium, however. The EPA, on the other hand, has set a national interim primary standard of 0.05 milligrams of total chromium per liter. The NSA assays, in water specimens in the Group II subsample, were for total chromium content as determined by atomic absorption spectrophotometry, with atomization of the specimen in a flame.

The NRC observes: "The present interim drinking water standard of 0.05 milligrams per liter is less than the no-observed-adverse-health-effect level. Consideration should be given to setting the chromium limit in terms of the hexavalent form. Extensive work is urgently needed to establish the role of dietary chromium with regard to atherosclerosis and glucose metabolism as well as its possible carcinogenic effects at low levels in lifetime feeding studies."[90]

It was decided to utilize the MCL value of 0.05 milligrams per liter as the NSA reference value.

— Chromium levels in rural supplies

Only trace amounts of chromium were present in rural supplies. The highest value was 0.012 milligrams per liter of water—only one-fourth of the MCL-based reference value of 0.05 milligrams per liter. The mean and median in rural US supplies both were recorded at the minimum level of detection, less than 0.005 milligrams of chromium per liter of water.

The means and medians did not vary from region to region or in any other NSA grouping. In view of this and the very low concentrations of chromium encountered in rural supplies, graphic plots of the distributions have been omitted from this report. On the basis of the NSA findings, chromium did not represent a health problem in rural water supplies.

Barium

An alkaline earth metal, barium occurs in trace amounts in most surface waters. Barium usually is in the form of dissolved barium sulfate in natural waters, however, and because of the low solubility of that compound, concentrations of barium ions are typically low. In sufficient amounts (0.8 to 0.9 grams), barium chloride can be a deadly poison because it overstimulates the muscles, especially the heart muscles. However, the EPA reports that: "No study appears to have been made of the amounts of barium that may be tolerated in drinking water or of effects from prolonged feeding of barium salts from which an acceptable water guideline may be set."[91]

The national interim primary MCL of one milligram of barium per liter of water is based on extrapolation from effects of industrial exposure to dusts of soluble barium salts. The NSA reference value also was one milligram of barium per liter of water.

— Barium levels in rural supplies

Trace amounts of barium compounds are frequent in water, and small amounts of the metal were found in most rural supplies. Despite the prevalence of the substance, concentrations exceeded the reference value in only 0.3 percent of all households (Figure V-26). The level in those households was 1.35 milligrams of barium per liter—35 percent greater than the reference value.

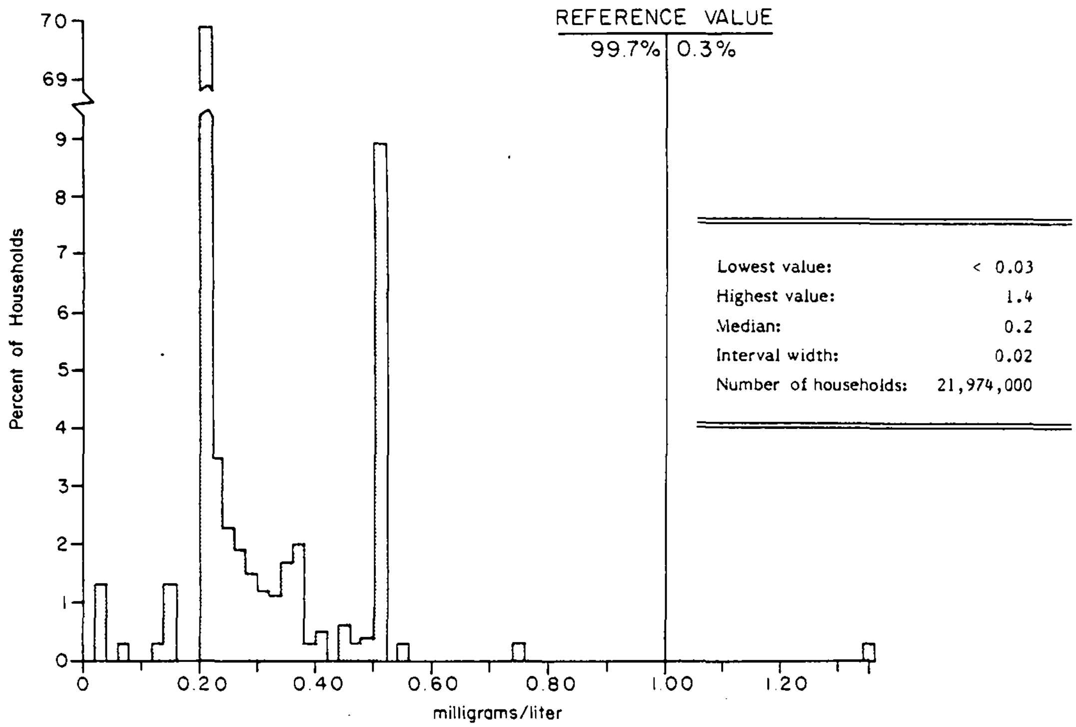
The few household supplies which exceeded the reference value occurred in the South (Figures V-26a through V-26d). Because the number of households exceeding the NSA reference value was small, and since the households all were in the South, analysis by other than regional groupings was not reliable.

Although values in excess of the reference value require attention, those for barium in the NSA did not appear to be large enough to pose a health risk.[92]

Silver

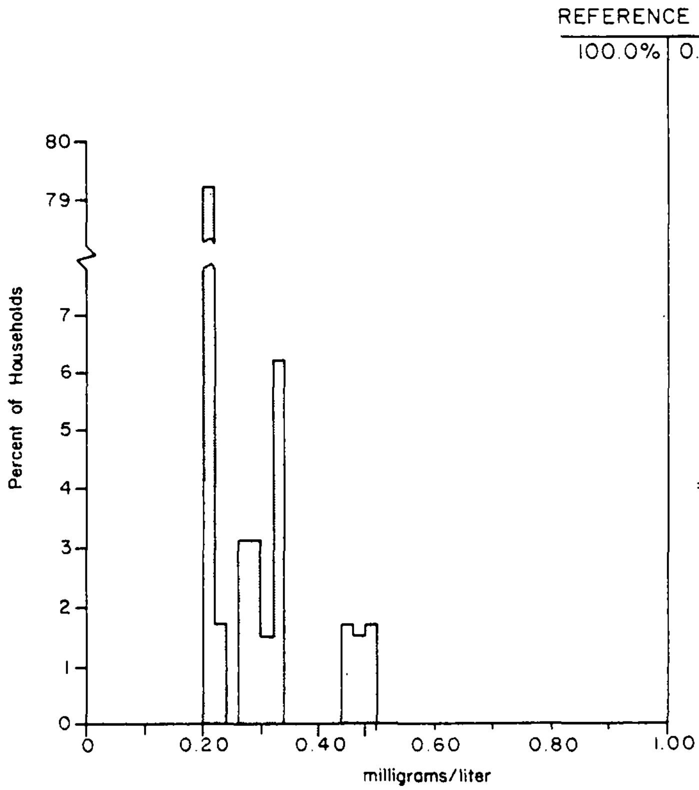
Large amounts of colloidal silver can be fatal, but only very small amounts of any silver compounds are found in US waters. Trace amounts in drinking water may come from natural or industrial sources. The NRC advises that: "Since silver ion has not been detected in water supplies in concentrations greater than half the

Figure V-26
Barium in US Rural Household Supplies



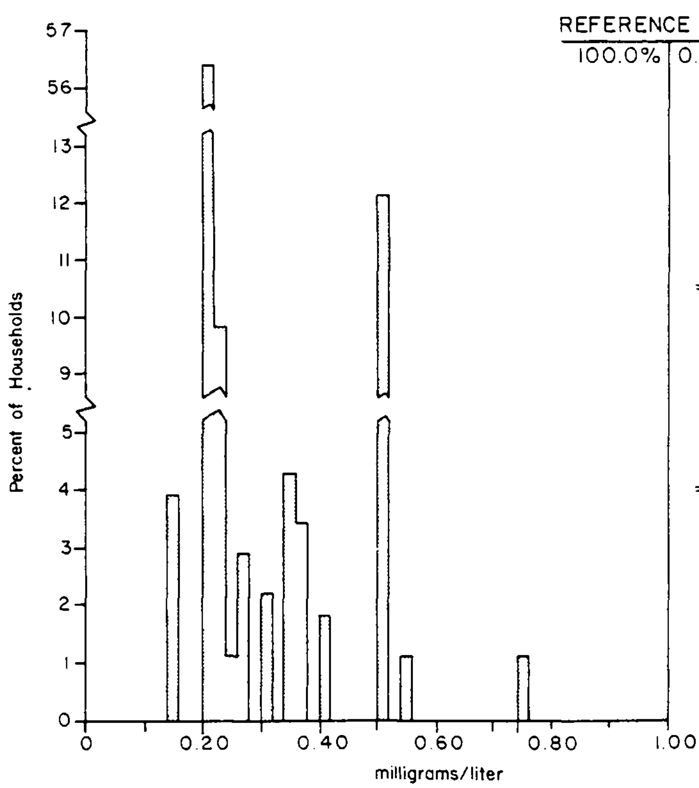
Regional Variation in Barium in US Rural Household Supplies

Figure V-26a. Northeast



Lowest value:	0.2
Highest value:	0.5
Median:	0.2
Interval width:	0.02
Number of households:	3,693,000

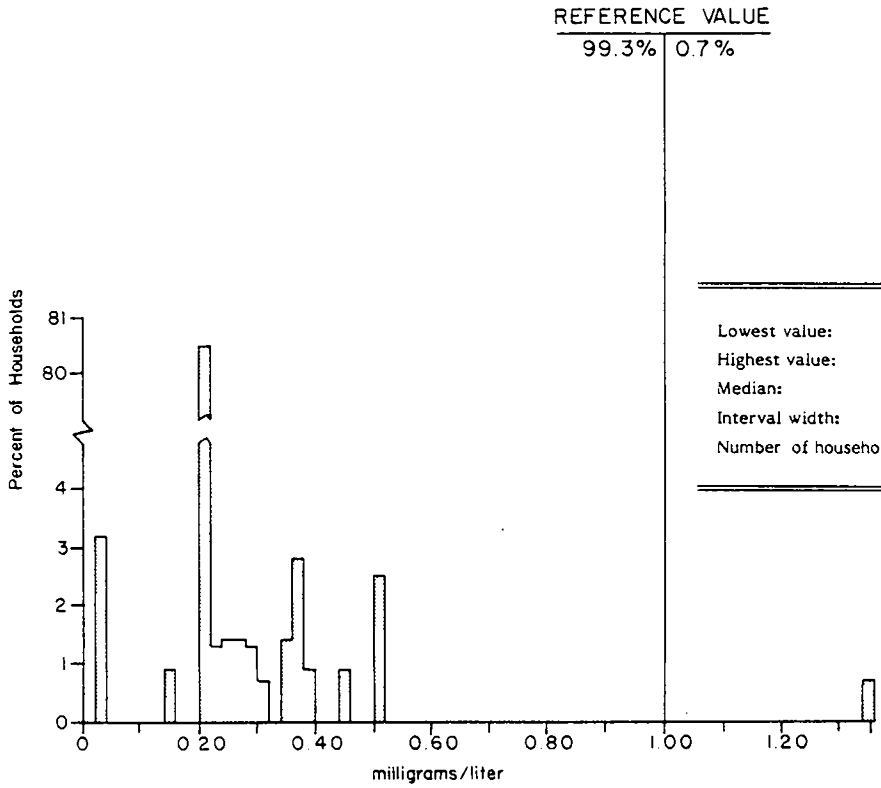
Figure V-26b. North Central



Lowest value:	0.1
Highest value:	0.7
Median:	0.2
Interval width:	0.02
Number of households:	6,213,000

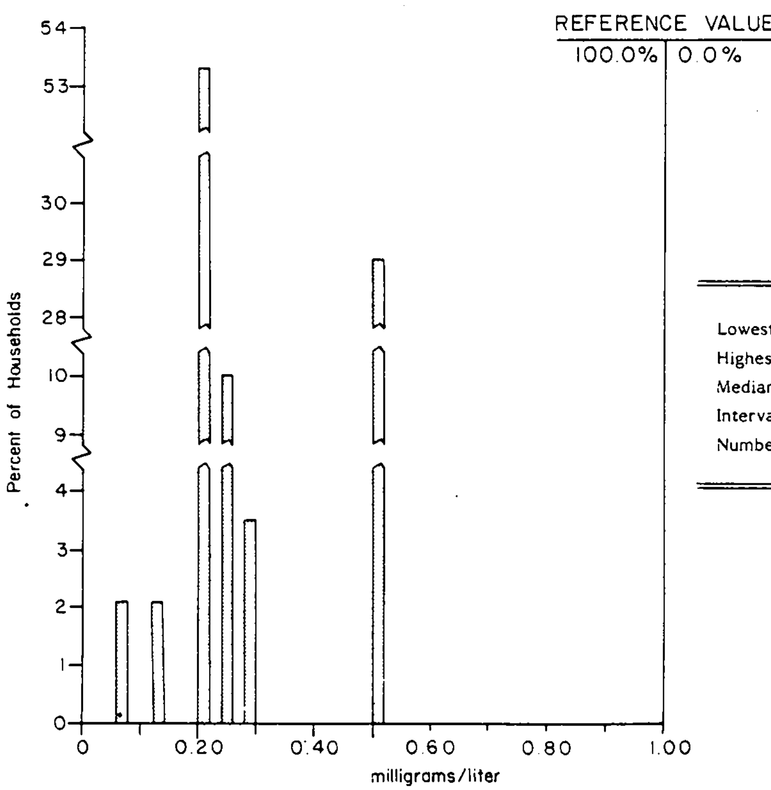
Regional Variation in Barium (continued)

Figure V-26c. South



Lowest value:	<0.03
Highest value:	1.4
Median:	0.2
Interval width:	0.02
Number of households:	9,291,000

Figure V-26d. West



Lowest value:	0.1
Highest value:	0.5
Median:	0.2
Interval width:	0.02
Number of households:	2,777,000

no-observed-adverse-health-effect level, regulation of its concentration as a primary standard would appear to be unnecessary."[93]

Silver compounds can be used as disinfectants in water, however. The EPA thus has set a national interim primary MCL of 0.05 milligrams of silver per liter of water. That MCL was the reference value used in the NSA.

— Silver levels in rural supplies

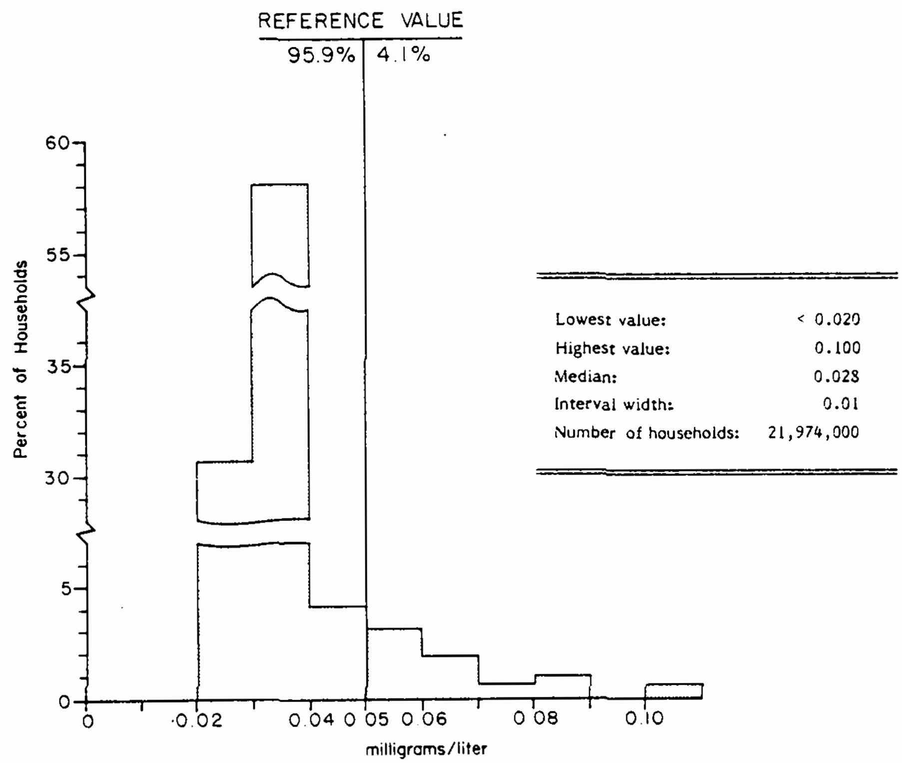
Silver was more prevalent than anticipated on the basis of findings in other surveys.[94] In addition, the proportion of larger values was greater than anticipated. That is, 4.1 percent of US rural households surpassed the reference value, which was a considerably larger proportion than was found in several studies of public water supplies.[95] The largest NSA concentration was 0.1 milligrams per liter—twice the NSA reference value (Figure V-27).

Median concentrations of the metal in all regions of the US were close to the national median of 0.028 milligrams per liter, indicating that silver was found in similar quantities in household supplies regardless of region (Figures V-27a through V-27d). One possible exception was in the West, where the median concentration was 0.021, slightly lower than in other regions. Similarly, the proportion of households above the reference value was slightly smaller in the West than in the other three regions.

Median silver concentrations and the proportions of households exceeding the reference value did not vary notably in either the SMSA/nonSMSA or size-of-place comparison. In the size-of-system grouping, however, a larger proportion of households with individual systems exceeded the reference value (7.1 percent) than did households served by either intermediate (3.4 percent) or community systems (2.1 percent).

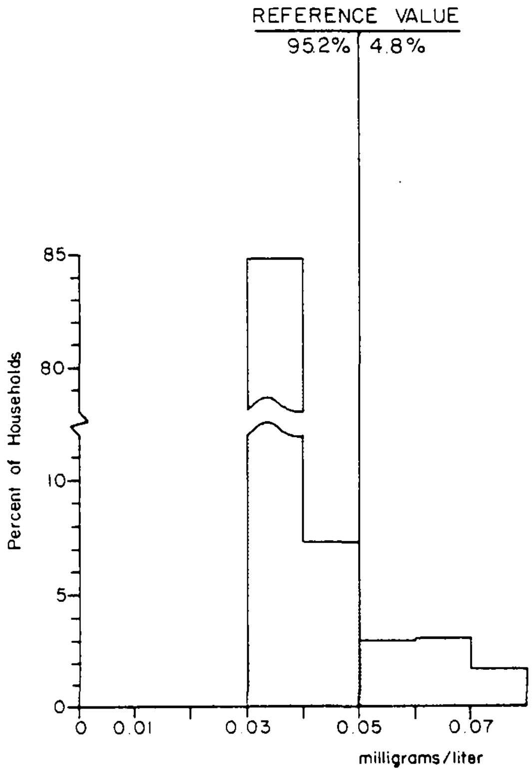
The potential health consequences of the NSA findings are difficult to assess. Even the largest concentrations in rural households are far below those

Figure V-27
Silver in US Rural Household Supplies



Regional Variation in Silver in US Rural Household Supplies

Figure V-27a. Northeast



Lowest value:	< 0.030
Highest value:	0.070
Median:	0.031
Interval width:	0.01
Number of households:	3,693,000

Figure V-27b. North Central

Lowest value:	< 0.020
Highest value:	0.080
Median:	0.026
Interval width:	0.01
Number of households:	6,213,000

Regional Variation in Silver (continued)

Figure V-27c. South

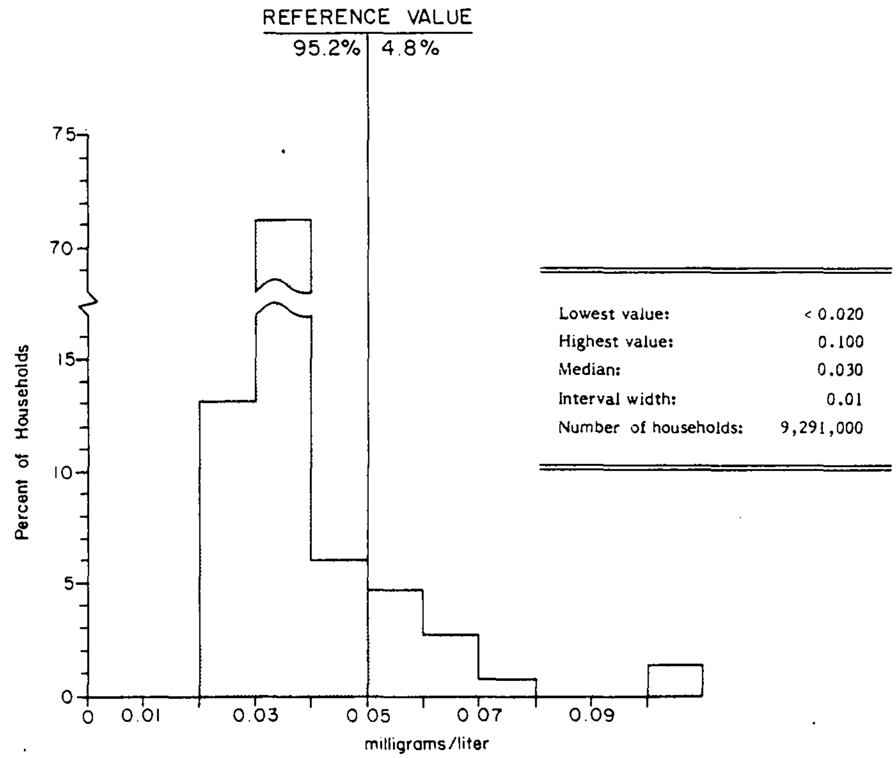
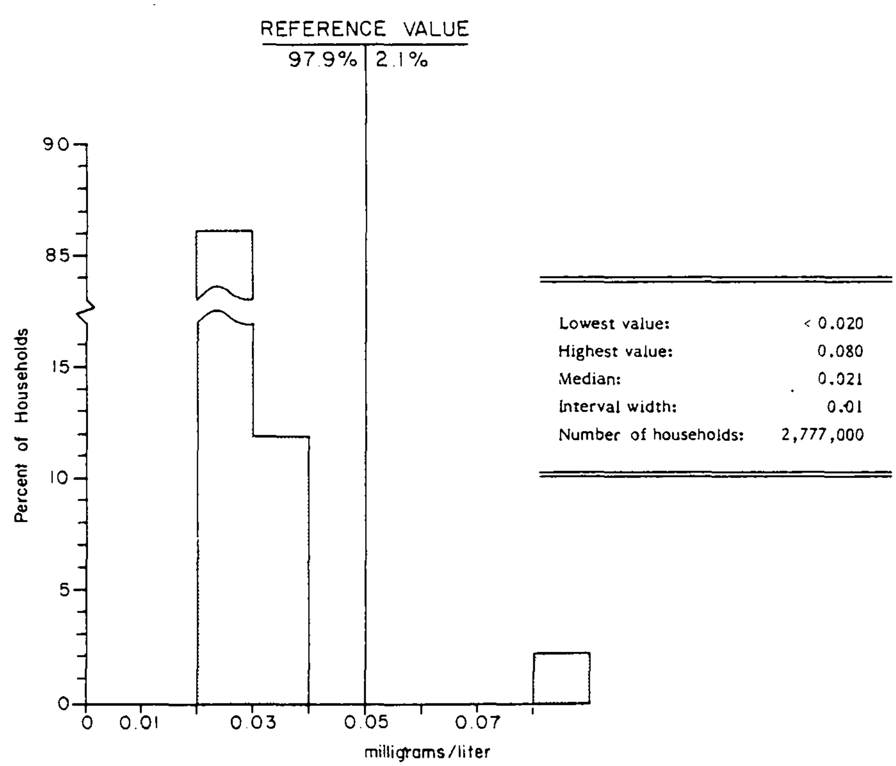


Figure V-27d. West



which are considered possibly toxic to human beings. Chronic ingestion of large amounts of silver can produce argyria, a condition which causes unsightly blue-gray discoloration of the skin. Estimates from studies of industrial exposure to silver show that the condition develops after gradual accumulation of one through five grams of silver in the human body. The NRC estimates that, based on a 50 percent retention rate for silver taken into the body, it would take 55 years for a person to consume enough silver in a supply with 0.05 milligrams per liter (the NSA reference value) to acquire argyria.[96] Thus, even at the rural households above the reference value, the consequences appeared to be limited to possible but uncertain long-term effects.

<u>Summary of inorganic constituent findings</u>

Inorganic substances studied in NSA specimens ranged from those largely with aesthetic effects, such as manganese, to those predominately with health effects, such as lead. Certain of the constituents have received particular attention from investigators in the past, and it was anticipated that they might be associated with significant findings in the NSA. Among those constituents were calcium and magnesium, key elements in water hardness; nitrates, substances which pose a special health risk for infants; sulfates, substances which may make water distasteful and even cause diarrhea; and iron and manganese, elements which cause aesthetic and economic problems.

Calcium and magnesium were present in sufficient amounts to produce moderately hard water in rural US supplies, but the substances themselves were not implicated in any direct health effects by the NSA findings. Nitrates were not discovered in large concentrations in rural supplies—fully 97.3 percent of rural households were below the NSA reference value. Sulfates were potential problems in 4.0 percent of rural households, but more often for aesthetic rather than for serious health reasons. Iron and manganese concentrations posed aesthetic problems in a number of rural households, but about eight out of ten rural households met the NSA reference value for each metal.

Although households which exceeded the NSA reference value for any of these common constituents faced potential problems which required assessment and attention, the difficulties were not beyond the scope anticipated.

There were potentially important problems posed by several other inorganic substances. Those substances, all heavy metals, were lead, cadmium, and mercury. Lead was studied in all NSA sample households, and on the basis of the results, 16.6 percent of all rural American households (numbering 3.6 million) were above the NSA reference value for lead. Cadmium and mercury were studied in NSA subsample households, and on the basis of the results, 16.8 percent and 24.1 percent of US rural households, respectively, exceeded the NSA reference value.

The possible health implications of these findings are important. The three metals have different physiological effects, but the effects are known to be potentially serious, as is detailed in the separate reports on each of the heavy metals, above.

Study of a number of other inorganic substances in NSA subsample households showed other persistent, but less consequential, problems. Supplies at 13.7 percent of rural households surpassed the NSA reference value for selenium, and although the concentrations were not large enough to pose health threats, some were large enough to suggest the need for caution in adjusting federal selenium standards, as has been discussed by the NRC. About 4 percent of rural households had values beyond the reference value for silver, a situation which posed no immediate health threat but which involved a substantial proportion of rural households.

As to some of the other NSA constituents, amounts of arsenic, chromium, and barium in rural households generally were very small and posed few health concerns. Levels of fluoride also generally were well within the NSA reference value.

In retrospect, the NSA findings point up the need to evaluate water quality in terms of all of the components of the supply—from the source water to the tap—rather than focusing too sharply on only one component, such as the source water. For example, the high levels of cadmium in the NSA are difficult to explain without reference to possible contamination from elements within the transmission and distribution system, such as the pipes. The same is true for the high levels of lead, and it may be true for the high levels of mercury. It has been customary, of course, to assess the possible contribution of lead pipes and lead-base solder to lead contamination in drinking water. This concern with possible contamination from transmission technology should be extended to assessment of other substances as well, including cadmium, mercury, sodium, and silver. Furthermore, this assessment must include both old and new technology. For example, older metal water pipes may be suspected as possible causes of heavy-metal contamination of drinking water, but plastic pipes must be assessed as well. The possibility of cadmium leaching out into water from plastic pipes has been discussed above, but the same possibility also exists for lead and mercury, a concern put forward by the World Health Organization.[97]

ORGANIC CONSTITUENTS

Whereas public health concern about inorganic substances dates back many years in the US, fears about organic materials in drinking water are more recent. In its official statement entitled Interim Primary Drinking Water Regulations—Control of Organic Chemical Contaminants in Drinking Water, February 9, 1978, the EPA presented its view of the situation. Several passages are relevant as background information:

"More than 700 specific organic chemicals have been identified in various drinking water supplies in the United States. These compounds result from such diverse sources as industrial and municipal discharges, urban and rural runoff, and natural decomposition of vegetative and animal matter, as well as from water and sewage chlorination practices. Compositions and concentrations vary from virtually nil in protected ground water to substantial levels in many surface waters and contaminated ground waters.

"Organic chemical contaminants in drinking water can be divided into two major classes: those of natural origin and those of synthetic origin. The natural substances represent by far the greatest portion and consist primarily of undefined humus and fulvous materials and others produced by normal organic decomposition or biotic transformation and are not known to be harmful in themselves.

"The synthetic chemicals in water can be subdivided into two groups. The first group consists of those chemicals that result from water treatment practices (e.g. trihalomethanes). Recent EPA studies indicate that, except for certain cases, the trihalomethanes constitute the largest portion of the identifiable synthetic chemicals in drinking water. Unlike other synthetic chemicals, chloroform and other trihalomethanes are formed during the treatment process. They are thus found in virtually every drinking water supply that is disinfected with chlorine, and not uncommonly at concentrations of several hundred parts per billion (ppb or micrograms per liter).

"The second group of synthetic chemicals consists of those chemicals introduced as a result of point and nonpoint sources of pollution. Nationally, both surface water and to a lesser degree ground waters are contaminated with a variety of these pollution-related synthetic organic chemicals ranging generally from the lower molecular weight halogenated hydrocarbons and monocyclic aromatic compounds to higher molecular weight pesticides, polycyclic aromatic compounds, and pesticide-like compounds.

"These classes of compounds have been found in drinking water using gas chromatography or gas chromatography/mass spectroscopy. However, the large bulk of organic matter (primarily natural products but also higher molecular weight synthetics) in water is not amenable to detection by these commonly used methods. Those organic contaminants which have been identified in drinking water constitute only a small percentage of the total amount of organic matter present." 98

Generally, scientific knowledge has developed slowly in defining the sources and consequences of organic materials in drinking water and drinking water sources. As a result, the EPA's strategy has been to establish regulations at a graduated pace while trying to complete the required surveys and laboratory research needed to support the regulations.

At the time of the NSA survey, US interim primary MCLs had been established for a limited number of organic chemicals. In addition, federal guidelines suggested that permissible limits of five well-known chlorinated hydrocarbon insecticides—DDT, aldrin, dieldrin, chlordane, and heptachlor—should be established on the basis of certain specified research reports which assessed the health hazards of the materials.[99]

The organic chemicals for which MCLs had been established at the time of the NSA were four other chlorinated hydrocarbon insecticides and two chlorophenoxy herbicides. The MCLs and NSA reference values are presented below. The chlorinated hydrocarbon insecticides were endrin, lindane, methoxychlor, and toxaphene. The chlorophenoxy herbicides were 2,4-D and 2,4,5-TP. Levels of these six substances were assessed in water specimens from the Group II NSA subsample. In comparing the findings for the six organic constituents with the findings for inorganic constituents, it is necessary to note that the former are reported in micrograms per liter (parts per billion), the latter generally in milligrams per liter (parts per million).

— Chlorinated hydrocarbon insecticide levels in rural supplies

Although NSA subsample specimens were examined for four chlorinated hydrocarbon insecticides (endrin, lindane, methoxychlor, and toxaphene), only two of the chemicals—lindane and methoxychlor—were discovered in any of the specimens. Since the four insecticides were found so rarely, and since the findings for lindane and methoxychlor were so similar, the results for all four chemicals are discussed here in one section rather than being considered separately.

The NSA reference values corresponded to the interim primary MCLs. The reference values were equivalent to 0.2 micrograms of endrin per liter of water, four micrograms of lindane per liter of water, 100 micrograms of methoxychlor per liter of water, and five micrograms of toxaphene per liter of water.

Endrin and toxaphene. In the NSA laboratory work, analytic reporting procedures were designed to indicate endrin only in concentrations exceeding 0.008 micrograms per liter, and to report toxaphene only in concentrations exceeding 0.17 micrograms per liter. Neither chemical was reported above those values in any of the NSA households. It is possible, of course, that some rural supplies had minute concentrations of endrin or toxaphene which were lower than the detection levels. Even so, those levels would have been considerably less than the reference values since the detection levels were so low. On the basis of the NSA findings, then, neither endrin nor toxaphene posed a health threat in rural water supplies.

Lindane. Lindane was detected in 1.6 percent of all rural household water supplies—about 347,000—but the largest concentration reported was only 0.08 micrograms per liter, one-fiftieth of the reference value.

The largest number of lindane-contaminated supplies (192,000 households) were located in the West, at a concentration of 0.006 micrograms per liter. The other contaminated supplies were in the South, where an estimated 64,000 households had the highest concentration found in the NSA (0.08 micrograms per liter). The chemical was not discovered in North Central or Northeastern households.

All of the lindane-contaminated supplies were in nonSMSA households located in other rural areas. The largest number of households (208,000) were served by community systems. A total of 68,000 households were served by intermediate systems, and the same number by individual systems. The largest concentration of lindane (0.08 micrograms per liter) was found among households using individual systems.

Methoxychlor. Only 1.0 percent of all rural household supplies had detectable amounts of methoxychlor. Those 224,000 supplies had 0.09 micrograms of methoxychlor per liter, far less than the reference value.

All of the supplies with methoxychlor contamination were in the West. The households all were outside of SMSAs, located in other rural areas, and served by community systems.

Health considerations for lindane and methoxychlor. On the basis of the NSA findings, neither methoxychlor nor lindane posed health threats in rural water supplies. Both chemicals are poisons, however, and their presence even in small amounts clearly is undesirable. Despite the predominantly open-country aspect of the location of the households with methoxychlor contamination, all were served by community systems. In contrast, households with lindane contamination were served by individual, intermediate, or community systems.

— Chlorophenoxy herbicide levels in rural supplies

As was true for the insecticides, the two herbicides studied in the NSA presented no problem to rural supplies: neither chemical was detected in any of the NSA subsample specimens. Analytic procedures were designed to detect 2,4-D only in concentrations exceeding 0.01 micrograms per liter, and to detect 2,4,5-TP only in concentrations exceeding 0.1 micrograms per liter. Interim primary MCLs for the chemicals were equivalent to 100 micrograms per liter for 2,4-D and ten micrograms per liter for 2,4,5-TP; these levels also were the NSA reference values. Again, it was possible that household supplies had minute concentrations of the herbicides which were below the laboratory detection levels, but those amounts would have been far less than what was deemed unacceptable according to the reference values. On the basis of the NSA findings, then, neither 2,4-D nor 2,4,5-TP posed a health threat in rural water supplies.

Summary of organic constituent findings

Organic constituents studied in the NSA were limited to four chlorinated hydrocarbon insecticides and two chlorophenoxy herbicides. Of these six substances, only two were detected at all in NSA households. Those two substances were lindane—found only in small proportions of households in the West and South—and methoxychlor—found only in a small proportion of households in the West. None of the values for the substances exceeded or even closely approached the respective NSA reference values.

RADIOACTIVITY

With the nuclear age in development, there is an increased likelihood of exposure to radioactivity from various military, industrial, medical, and pharmaceutical sources. Radiation from these sources is added to that from natural sources to increase our total exposure.

The potential hazard from drinking water, except in special situations, appears to be slight, however. According to the NRC: "The radiation associated with most water supplies is such a small proportion of the normal background to which all human beings are exposed that it is difficult, if not impossible, to measure any adverse health effects with certainty. In a few water supplies, however, radium can reach concentrations that pose a higher risk of bone cancer for the people exposed."[100]

For many of the other contaminants studied in the NSA, there are levels of exposure which normally pose no health hazard. Indeed, in proper amounts, and in correct chemical composition, some constituents found in water may have health benefits. Radiation, however, has no known threshold below which health risks disappear. With small doses, however, the estimated health risks for normal individuals becomes very low.

The EPA has established maximum allowable contamination levels for two broad categories of radioactive substances: those of natural origin and those most likely created by man's activities.[101] In the former category, there are MCLs for gross alpha particle activity, for radium-226, and for radium-228. In the latter category, limits are placed on average annual exposure to beta particle and photon radioactivity from artificially created radionuclides such as tritium, strontium-90, and iodine-131.

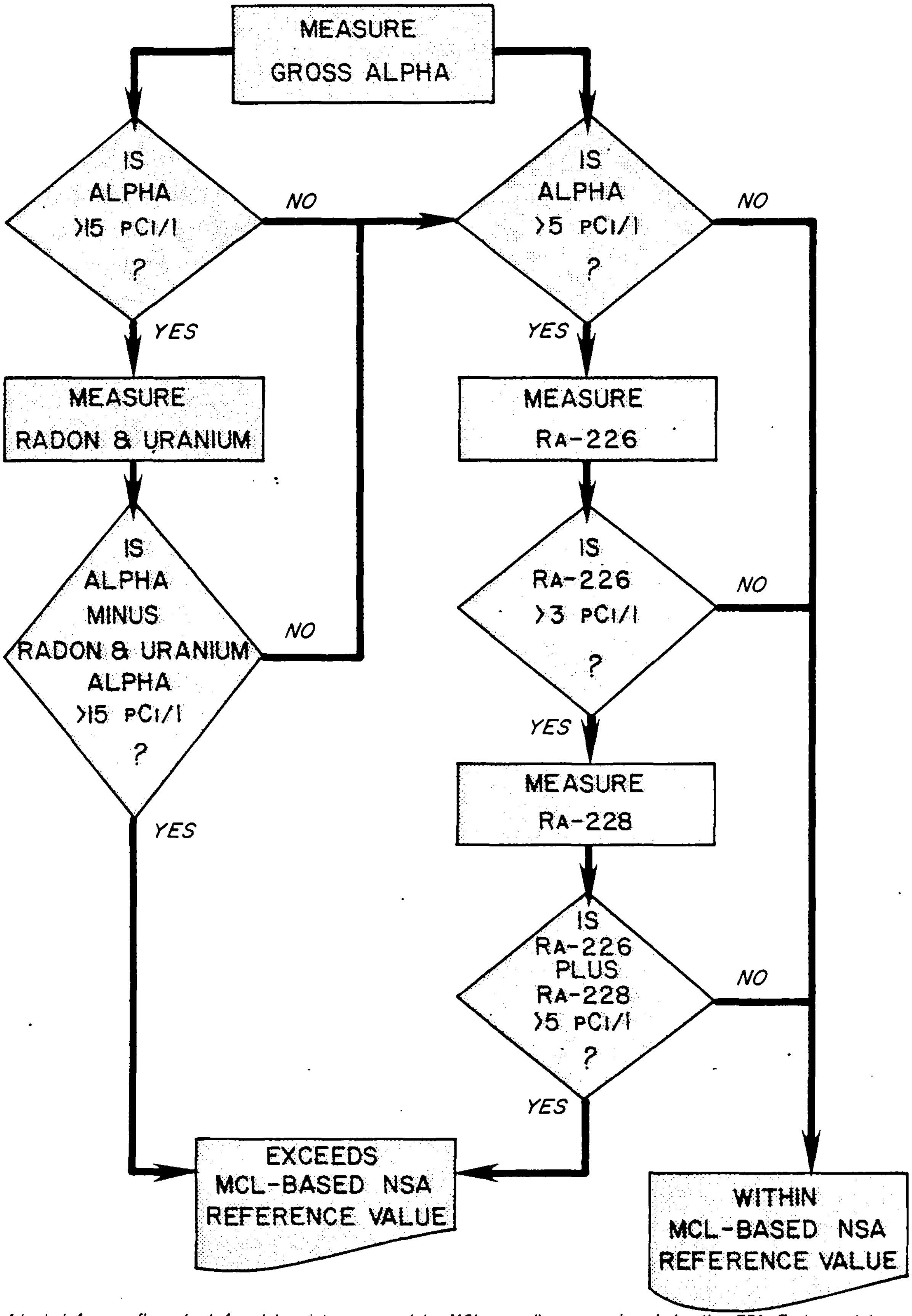
While both naturally occurring and man-made radionuclides have alpha, beta, and gamma emissions, the former are generally more important because of their alpha activity, and the latter for their beta or beta-gamma activity. Hence the MCL for groundwater, where naturally occurring radionuclides are expected to predominate, refers to alpha activity. Surface waters, on the other hand, can be affected by all types of radioactivity and are subject, under certain conditions, to both gross alpha and gross beta MCLs.

The contributors to alpha activity in groundwater are expected to be natural deposits of the uranium decay series (beginning with uranium-238) or the natural thorium decay series (beginning with thorium-232). In the United States, uranium deposits are generally more prevalent than thorium sources, especially in the South and West. As a result, more radium-226 than radium-228 is usually found in US groundwaters. Radium-228, of the thorium series, may be more prevalent in other nations, however, since thorium tends to be more common than uranium throughout the world. Furthermore, radium-228 is included in the gross alpha standard, even though it is more important as a beta emitter. The reason for including radium-228 is that its radioactive decay daughters are alpha emitters. Chemically, they are similar to calcium so, when ingested, they tend to accumulate in bone tissue.

Interpretation of the federal interim primary standard for gross alpha radiation can best be understood by referring to Figure V-28, which was prepared by the EPA Environmental Monitoring and Support Laboratory in Las Vegas. At the right of the flow chart, one sees that a specimen exceeds the MCL-based NSA reference value if gross alpha radiation is greater than fifteen picocuries per liter, providing that the radioactive contributions of uranium and radon are excluded. In

Figure V-28

Flow Chart Describing Gross Alpha Radiation Reference Values



Adapted from a flow chart for determining gross alpha MCL compliance produced by the EPA Enviromental Monitoring Systems Laboratory of Las Vegas, Nevada.

the NSA, however, specimen preparation involved evaporation. As a result, radon, a gas, escaped before its radiation could be measured. With sufficient time, radon could "grow" back as a natural result of radiation decay processes, but the analyses were not delayed and the presence of radon radiation thus was not allowed for. Nevertheless, this shortcoming was not expected to create a serious bias in the findings. Therefore, any NSA specimen which produced a reading of more than fifteen picocuries per liter, after discounting uranium radioactivity, was deemed to be above the MCL-based NSA reference value. In addition (see left portion of flow chart), if a specimen had a gross alpha reading which was less than fifteen picocuries per liter but more than five picocuries, it still exceeded the NSA reference value if the combined radiation values for radium-226 and radium-228 exceeded five picocuries per liter.

Although the NSA reference value was based on the federal interim primary MCLs, it is necessary to recall that, as explained earlier in this chapter, there is a distinction between the requirements for determining compliance with the federal regulations and the procedures followed in the NSA. In particular, compliance with the regulations must be determined on the basis of the average of several findings, not just on one as in the NSA. Specifically, compliance with radioactivity standards must be based on the analysis of an annual composite of four consecutive quarterly samples, or on the analysis of the average of results for four samples obtained at quarterly intervals.

Another qualification is that low-level radiation is difficult to measure reliably. For example, there are a variety of factors which can interfere with measurement of low-level gross alpha radiation. Most notably, large concentrations of total dissolved solids in water specimens can absorb or otherwise alter the radiation and thus influence the readings. The effect on the emission energy levels can also make it difficult to distinguish alpha from beta emission.

The standard for beta emissions generally relates to man-made radionuclides. Atmospheric nuclear-weapon testing has produced ubiquitous background radiation which will continue even though atmospheric testing has been reduced in the world. In addition, water from nuclear power plants, or from manufacturing plants using radioactive materials, occasionally contributes to the total dosage in some surface water sources. Surface water sources thus are more likely than groundwater to contain manufactured radionuclides. The federal monitoring criterion for gross beta radioactivity focuses on water sources designated as contaminated by nuclear facilities and on surface water sources which, though not designated as contaminated by effluents from nuclear facilities, serve 100,000 or more people. Each state has the right to require more stringent monitoring.

There were very few NSA specimens which were from water sources that were subject to the gross beta monitoring criterion. Therefore, an assessment of compliance was not justified and the particular radionuclides contributing to gross beta radiation were not generally measured. Nevertheless, gross beta readings were taken and will be reported in order to provide a baseline measure of the conditions in rural America.

Since much of the water tested in the NSA was from groundwater sources, the gross beta levels reported did not necessarily reflect only emissions from man-made radionuclides. For example, naturally occurring radiation from the uranium and thorium decay series in groundwater can influence beta radiation. However, the cost of determining the particular source of the beta radiation put this beyond the scope of the NSA. Hence, the reported beta emissions in the NSA were caused by an unknown mix of naturally occurring and man-made beta emitters.

Measures of radioactivity were taken only on specimens from the Group II NSA subsample; 50 picocuries per liter was the screening level used when initiating a test for gross beta MCL compliance.

— Gross alpha radiation levels in rural supplies

As expected, low levels of gross alpha radiation were found in all rural supplies, indicating the anticipated effect of ubiquitous, natural radiation sources in the environment. The levels almost always were within the reference value. In fact, only 0.5 percent of all rural households (an estimated 115,000) surpassed the reference value, all of which were in the South and located in other rural areas. Problem supplies were almost equally divided between SMSA and nonSMSA households, and equally divided between households with individual and community systems.

Additionally, 0.4 percent of all rural households (an estimated 96,000) had readings which were inconclusive but questionable. For these households, total compliance with the NSA reference value was not demonstrated.

Another 1.5 percent of all rural households (an estimated 319,000) had readings which were suspicious: readings may have exceeded the NSA reference value, but the levels of total dissolved solids in these specimens were so great that the gross alpha readings were unreliable. For these households, <u>non</u>compliance with the NSA reference value was not adequately demonstrated.

In summary, 97.5 percent of all rural households were within the gross alpha radiation reference value. Of the remaining 2.5 percent, only 0.5 percent clearly exceeded the reference value.

— Gross beta radiation levels in rural supplies

All households in the NSA had gross beta readings below the NSA reference value of 50 picocuries per liter. The highest reading was 28 picocuries per liter. The median level for rural America was only 5.36 picocuries per liter, slightly more than one-tenth of the reference value. Although the data indicated that beta emissions throughout rural America were well within the reference value, it is important to recall that about 72 percent of the major household supplies in rural

America had groundwater sources, and those sources would not generally be prone to contamination by man-made radionuclides. Furthermore, the NSA survey was designed to select representative rural households, not likely sites of contamination, so that the survey would not necessarily have detected rural supplies which used surface water containing man-made radionuclides.

Median values for gross beta radiation were quite near the national median of 5.36 picocuries per liter regardless of households' regional location, SMSA status, or size-of-place location. Median values also were at the national level regardless of the size of system serving the households.

— Other radionuclides studied in the NSA

In conjunction with the gross alpha and gross beta screening tests, certain other radionuclides were to be studied in the NSA, either when warranted by the screening test results, or as desirable on an occasional basis.

The study list included strontium-89, strontium-90, cesium-134, tritium, and iodine-131. However, the substances were assessed so infrequently that no generalizations about the results were possible.

Summary of radioactivity findings

Rural household supplies showed low levels of both gross alpha and gross beta radiation. The presence of background gross alpha radiation, in particular, was not surprising, since it is produced by natural sources commonly found in groundwater. Despite the prevalence of the radiation, levels of radioactivity were so low in the NSA that radiation in drinking water was not shown to be a national problem. These estimates do not rule out potential serious localized problems, however.

Local geological makeup is probably the best guide for indicating whether a gross alpha test is justified. Areas with known deposits of radioactive minerals should be particularly monitored. Areas downwind from weapons testing facilities, or downstream from nuclear facilities, are likely candidates for gross beta examination.

SUMMARY OF WATER QUALITY STATUS

The material in the preceding sections of Chapter V described the quality of the water conveyed by rural water supplies in terms of selected constituents. These substances, considered individually, were also the primary focus of the summaries that were prepared for each category of water quality properties (bacterial content, physical or chemical properties, inorganic constituents, organic constituents, and radioactivity). In this summary, the emphasis shifts away from the constituents as separate aspects of water quality, and toward the implications of the results for the entire set of substances.

The first part of this summary, which presents tabulations of the proportions of households exceeding each NSA reference value, provides information on the total number of constituents with reference values that were exceeded, and also the number of reference values that were exceeded by various proportions of rural households. Besides estimating the incidence of constituents that appeared in rural water supplies in concentrations over the relevant reference values for the nation, this portion of the summary also facilitates general comparisons between (1) regions of the country, (2) SMSA/nonSMSA households, (3) places of different sizes, and (4) water supply systems of different sizes. The second part of this summary, in contrast, is restricted to those substances for which primary MCLs have been established. More specifically, the second section aggregates households with supplies having constituents in concentrations greater than the level prescribed by the MCL, and compiles this information for the nation and for each analytical grouping (region, SMSA/nonSMSA, size of place, and size of system). In addition to presenting results, each component includes a brief discussion of the rationale used in selecting that particular approach to summarizing the water quality data, while the latter portion of the section addresses some limitations of these summaries.

Proportions of households exceeding NSA reference values: Approach 1

As indicated earlier in this chapter, 43 constituents were studied in the NSA (see Table V-1). Of these substances, only 28 were assigned NSA reference values (see Table V-2). (The reasons for not assigning reference values for certain constituents were detailed in the separate sections on the respective constituents in this chapter.) This portion of the summary is confined to the set of 28 constituents for which NSA reference values were defined.

While entire distributions of constituent concentrations were examined in the previous analyses, and NSA reference values were used only as descriptive tools, the focus here is exclusively on the proportions of households exceeding the NSA reference values. The reference values provide important benchmarks regarding health, aesthetic, and economic implications associated with the relevant concentrations of the constituents. Despite these different implications, there is no attempt in this first summary approach to distinguish among reference values. That is, no allowance is made for the possibility that exceeding a health-related reference value may have more serious public consequences than exceeding an aesthetic-related reference value. In the second approach, presented later, incidence rates are summarized for households exceeding only health-related reference values, in order to focus on that one aspect of water quality. Even then, however, there are various restrictions that must be established for the results to be interpreted usefully.

Incidence of households exceeding NSA reference values

One dimension of the overall national and subnational rural water quality situation is summarized in Table V-4. In that table are the percentages of rural households which exceeded the NSA reference values for the relevant constituents. All of the data were presented in the separate individual-constituent analyses in preceding sections of this chapter. However, the data previously were not displayed together as they are in Table V-4.

According to information presented in previous sections of this chapter, a total of twenty constituents were detected in concentrations that exceeded the reference values. The constituents which were never found to exceed the respective reference values at any household were chromium, all six organic pesticides, and gross beta radioactivity.

In examining Table V-4, it should be recalled that for many of the twenty constituents, results were available for only a 10 percent subsample of the NSA sample. Specifically, the following constituents (referred to as Group II constituents) were analyzed for the subsample only: arsenic, selenium, fluoride, cadmium, mercury, chromium, barium, silver, endrin, lindane, methoxychlor, toxaphene, 2,4-D, 2,4,5-TP, gross alpha radiation, and gross beta radiation. All other constituent results in Table V-4 are based on the full NSA sample.

For the nation as a whole, Table V-4 indicates that the most frequent problems were caused by bacterial contamination, iron, lead, cadmium, and mercury. The NSA reference values were exceeded for each of these constituents in 15.0 percent or more of all rural households.

It is apparent from Table V-4 that there were distinct regional differences in the results for the twenty constituents found in concentrations over the reference values. Households in the Northeast exceeded reference values for the smallest number of substances. Specifically, Northeast households exceeded the reference values for fourteen of the twenty constituents; in contrast, households in

Table V-4

Percentage of Rural US Households Exceeding NSA Reference Values

	Total Coliform (1/100 ml)	Fecal Coliform (0/100 ml)	Standard Plate Count (500/ml)	Color (15 standard color units)
NATION	28.9	12.2	19.3	2.3
REGION				
Northeast	28.3	14.0	10.2	0.5
North Central	24.4	8.0	17.1	3.4
South	31.7	13.9	22.8	2.6
West	30.6	13.6	24.8	1.6
SMSA/NonSMSA				
SMSA	18.3	6.8	13.8	1.4
NonSMSA	33.9	14.7	22.0	2.8
SIZE OF PLACE				
Large rural communities	17.7	4.9	15.0	1.5
Small rural communities	19.6	4.0	11.7	5.4
Other rural areas	31.2	13.8	20.5	2.2
SIZE OF SYSTEM				
Community	15.5	4.5	13.9	1.9
Intermediate	43.3	20.2	17.8	1.9
Individual	42.1	19.8	26.6	3.0

Table V-4 continued

	Estimated Total Dissolved Solids (500 mg/l)	Magnesium (125 mg/l)	Nitrate-N (10 mg/l)	Sulfates (250 mg/l)
NATION	14.7	0.1	2.7	4.0
REGION				
Northeast	5.0	0.0	0.3	0.5
North Central	23.9	0.1	5.8	7.4
South	10.2	0.0	1.3	0.7
West	22.2	0.5	4.0	11.7
SMSA/NonSMSA				
SMSA	15.1	0.1	1.7	2.2
NonSMSA	14.5	0.1	3.2	4.8
SIZE OF PLACE				
Large rural communities	15.8	0.0	4.2	2.6
Small rural communities	17.7	0.0	4.7	7.5
Other rural areas	14.3	0.1	2.4	3.8
SIZE OF SYSTEM				
Community	15.0	0.0	1.6	4.2
Intermediate	13.4	0.4	3.0	1.7
Individual	14.7	0.1	4.1	4.2

Table V-4 continued

	Iron (0.3 mg/l)	Manganese (0.05 mg/l)	Sodium (100 mg/l)	Lead (0.05 mg/l)	Arsenic* (0.05 mg/l)
NATION	18.7	14.2	14.3	16.6	0.8
REGION					
Northeast	16.0	16.9	6.0	9.6	0.0
North Central	28.2	19.9	19.2	10.8	1.8
South	17.0	12.3	14.1	23.1	0.0
West	7.0	4.7	15.0	16.9	2.1
SMSA/NonSMSA					
SMSA	13.8	9.9	14.9	12.9	0.0
NonSMSA	21.0	16.3	13.9	18.3	1.2
SIZE OF PLACE					
Large rural communities	9.4	11.4	15.7	15.1	0.0
Small rural communities	23.3	21.7	17.0	18.1	6.6
Other rural areas	19.5	14.0	13.8	16.6	0.4
SIZE OF SYSTEM					
Community	7.7	7.2	15.8	17.7	0.9
Intermediate	28.7	23.3	10.3	20.5	0.0
Individual	29.9	20.7	13.3	14.1	0.8

Table V-4 continued

	Selenium* (0.01 mg/l)	Fluoride* (1.4 mg/l)	Cadmium* (0.01 mg/l)	Mercury* (0.002 mg/l)	Chromium* (0.05 mg/l)
NATION	13.7	2.5	16.8	24.1	0.0
REGION					
Northeast	0.0	0.0	1.6	22.0	0.0
North Central	25.7	1.8	20.7	31.8	0.0
South	2.1	2.7	17.3	25.0	0.0
West	41.3	6.2	27.1	10.4	0.0
SMSA/NonSMSA					
SMSA	14.4	1.6	21.4	21.5	0.0
NonSMSA	13.3	2.9	14.3	25.5	0.0
SIZE OF PLACE					
Large rural communities	16.5	2.9	19.8	16.2	0.0
Small rural communities	6.6	6.6	7.3	27.6	0.0
Other rural areas	14.0	2.1	17.3	24.6	0.0
SIZE OF SYSTEM					
Community	12.5	2.9	21.2	23.3	0.0
Intermediate	21.7	6.7	26.9	36.0	0.0
Individual	13.6	0.8	7.9	22.3	0.0

Table V-4 continued

	Barium* (1.0 mg/l)	Silver* (0.05 mg/l)	Endrin* (0.0002 mg/l)	Lindane* (0.004 mg/l)	Methoxychlor* (0.1 mg/l)
NATION	0.3	4.1	0.0	0.0	0.0
REGION					
Northeast	0.0	4.8	0.0	0.0	0.0
North Central	0.0	3.7	0.0	0.0	0.0
South	0.7	4.8	0.0	0.0	0.0
West	0.0	2.1	0.0	0.0	0.0
SMSA/NonSMSA					
SMSA	0.0	5.1	0.0	0.0	0.0
NonSMSA	0.4	3.6	0.0	0.0	0.0
SIZE OF PLACE					
Large rural communities	0.0	3.3	0.0	0.0	0.0
Small rural communities	0.0	3.6	0.0	0.0	0.0
Other rural areas	0.3	4.2	0.0	0.0	0.0
SIZE OF SYSTEM					
Community	0.0	2.1	0.0	0.0	0.0
Intermediate	0.0	3.4	0.0	0.0	0.0
Individual	0.8	7.1	0.0	0.0	0.0

Table V-4 continued

	Toxaphene* (0.005 mg/l)	2,4-D* (0.1 mg/l)	2,4,5-TP* (0.01 mg/l)	Gross Alpha* (see Fig.V-28)	Gross Beta* (50 pCi/l)
NATION	0.0	0.0	0.0	0.5	0.0
REGION					
Northeast	0.0	0.0	0.0	0.0	0.0
North Central	0.0	0.0	0.0	0.0	0.0
South	0.0	0.0	0.0	1.3	0.0
West	0.0	0.0	0.0	0.0	0.0
SMSA/NonSMSA					
SMSA	0.0	0.0	0.0	0.0	0.0
NonSMSA	0.0	0.0	0.0	0.8	0.0
SIZE OF PLACE					
Large rural communities	0.0	0.0	0.0	0.0	0.0
Small rural communities	0.0	0.0	0.0	0.0	0.0
Other rural areas	0.0	0.0	0.0	0.6	0.0
SIZE OF SYSTEM					
Community	0.0	0.0	0.0	1.0	0.0
Intermediate	0.0	0.0	0.0	0.0	0.0
Individual	0.0	0.0	0.0	0.0	0.0

*Constituent analyzed for only the 10 percent NSA subsample.

each of the other three regions surpassed the reference values for eighteen of the twenty constituents.

The largest proportions of households above specific reference values occurred in the North Central. In particular, North Central households had the largest proportion of households above the reference value for seven constituents: nitrate-N, iron, manganese, sodium, color, estimated total dissolved solids, and mercury. Households in the West had the highest rates for six constituents: sulfates, magnesium, arsenic, cadmium, selenium, and fluoride. Households in the South had the largest percentages above reference values for four constituents: total coliform bacteria, lead, barium, and gross alpha radiation. Northeast households had the greatest rates for only fecal coliforms. Equal proportions of households in the South and Northeast—4.8 percent—were above the reference value for silver.

In terms of the general water quality implications of the data in Table V-4, households in the Northeast clearly were least likely to have problems. Households in the North Central generally were most likely to have potential water quality problems—whether the problems were related to health, aesthetic, or economic effects. However, potential bacteriological problems, as indicated by the findings for total coliform and fecal coliform, were most likely to occur in the South and the West. As reported previously in this chapter, the NSA findings suggested a particularly serious potential health problem involving the presence of two metals: lead and mercury. Levels of a third metal—cadmium—also caused concern. Although higher-than-reference-value concentrations of these metals were discovered in every region of the US, the rates differed substantially from one region to another. Households in the South were most likely to exceed the reference value for lead; households in the North Central were most likely to be above the reference value for mercury; households in the West were most likely to surpass the reference value for cadmium.

In terms of the magnitude of the potential for water quality problems in the rural US, the situation was most serious in the North Central and South. In these two regions combined, households had the largest percentages over the reference values for twelve out of the twenty constituents which were found in concentrations exceeding the NSA reference values. The relative magnitude of the potential problem was enhanced because such a large proportion of rural households were located in these two regions. Specifically, of all rural households in the nation, as based on the entire NSA sample, 70.1 percent were located in the North Central and South. Of all rural households in the nation, as based on the 10 percent NSA subsample, 67.3 percent were located in the North Central and South.

NonSMSA households had a higher potential for water quality problems than did SMSA households. As Table V-4 shows, more than 15.0 percent of SMSA households exceeded the reference values for total coliform bacteria, mercury, total dissolved solids, and cadmium. Among nonSMSA households, more than 15.0 percent were over NSA reference values for total coliform, mercury, iron, manganese, and lead. In all, nonSMSA households had higher percentages above the reference values for fourteen of the twenty constituents. In contrast, SMSA households had higher percentages above the reference values for only four of the twenty constituents. The situation among nonSMSA households was particularly serious because of the numbers of households involved: about two-thirds of the total US rural population lived in nonSMSA areas.

Values for total coliform bacteria, lead, and mercury exceeded the respective reference values in over 15.0 percent of the households in every size-of-place category. Iron problems tended to be more prominent in small communities and in other rural areas. Total dissolved solids and sodium problems were slightly higher in large and small rural communities than in other rural areas. Manganese problems seemed to be concentrated in small rural communities, while selenium and cadmium problems occurred most frequently in other rural areas and large rural communities.

Among all categories of system size, values for mercury and total coliform bacteria exceeded the reference values in over 15.0 percent of the households. Sodium appeared over the reference value most often among households served by community systems. Selenium was prominent among households served by intermediate systems. Five constituents were found in concentrations exceeding the reference values in more than 15.0 percent of rural households served by community water systems or by individual systems. This situation was the same for seven constituents among households served by intermediate systems. More than 15.0 percent of rural households exceeded the reference value for total coliform, regardless of the size of supply system serving the household.

<u>Summary of health-related reference values: Approach 2</u>

The second approach to analyzing the implications of the NSA laboratory findings is presented in this section. Whereas the first summary approach focused on comparisons across specific constituents, this approach assessed each household in terms of the number of constituents which exceeded MCL-based reference values. This assessment resulted in a tabulation of the number and percentage of households exceeding no reference value, one reference value, two reference values, and so forth. This second approach considered only those constituents for which the NSA reference values were based on primary MCLs. Since primary MCLs were based predominantly on health implications, this aggregation has health risk as a principal concern. However, these results are based on the 10 percent subsample of households, not the full NSA sample, since only the subsample included all the constituents for which primary MCLs were established.

In addition to the fact that these results have a reduced base, there are important limitations to the interpretability of a simple count of households exceeding a given number of reference values. Some of these limitations will be discussed after presenting the summary results; other limitations will be addressed in Chapter VI.

Number of reference values exceeded among households in the rural US

At the national level, it can be seen from Table V-5 that almost two-thirds of all rural US households (63.6 percent, or 14.0 million) exceeded one or more primary MCL-based reference values. Furthermore, almost one-third (31.7 percent) of all households were above two or more reference values and 9.9 percent exceeded three or more MCL-based reference values. Just over one-third of all households (36.4 percent) exceeded no reference value.

The results showed distinctive patterns in the different NSA groupings. As to regional differences, the rate of households above various reference values was greatest in the West, where about three-quarters of the households (75.4 percent) exceeded one or more reference values. The rates in the South (66.6 percent) and North Central (64.8 percent) also were high. Though lower than in the West, these rates were substantially higher than in the Northeast (45.2 percent). Even though the proportion of households exceeding at least one MCL-based reference value was 30 percentage points lower in the Northeast than in the West, still nearly half of the households in the Northeast exceeded at least one reference value.

The regional pattern of households above two or more MCL-based reference values was somewhat different from the overall rates. In order of magnitude, the specific rates for exceeding two or more reference values were 44.1 percent in the West, 37.8 percent in the North Central, 33.5 percent in the South, and 8.3 percent in the Northeast. In other words, although North Central households ranked third in terms of the overall regional rate for exceeding one or more reference values, those households ranked second in exceeding two or more reference values. Furthermore, the greatest number of reference values surpassed

Table V-5

Rural Households Where Major Water Supplies Had Constituent Values in Excess of Primary MCL-Based Reference Values

MCL-Based Reference Values Exceeded	Number and Percent of Households				
	Nation	Northeast	North Central	South	West
Exceeded 0	8,005,000 36.4%	2,024,000 54.8%	2,187,000 35.2%	3,105,000 33.4%	682,000 24.6%
Exceeded 1	7,007,000 31.9%	1,362,000 36.9%	1,676,000 27.0%	3,074,000 33.1%	870,000 31.3%
Exceeded 2	4,772,000 21.7%	243,000 6.6%	1,475,000 23.7%	2,601,000 28.0%	531,000 19.1%
Exceeded 3	1,613,000 7.3%	64,000 1.7%	470,000 7.6%	447,000 4.8%	578,000 20.8%
Exceeded 4	449,000 2.0%	0 0.0%	270,000 4.3%	64,000 0.7%	116,000 4.2%
Exceeded 5	128,000 0.6%	0 0.0%	136,000 2.2%	0 0.0%	0 0.0%
Total exceeding one or more reference values	13,969,000 63.6%	1,669,000 45.2%	4,026,000 64.8%	6,185,000 66.6%	2,095,000 75.4%
Total Households	21,974,000 100.0%	3,693,000 100.0%	6,213,000 100.0%	9,291,000 100.0%	2,777,000 100.0%

Table V-5 continued

MCL-Based Reference Values Exceeded	Number and Percent of Households	
	SMSA	NonSMSA
Exceeded 0	3,156,000 44.8%	4,764,000 31.9%
Exceeded 1	1,718,000 24.4%	5,365,000 35.9%
Exceeded 2	1,395,000 19.8%	3,396,000 22.7%
Exceeded 3	624,000 8.9%	974,000 6.5%
Exceeded 4	147,000 2.1%	301,000 2.0%
Exceeded 5	0 0.0%	133,000 0.9%
Total exceeding one or more reference values	3,884,000 55.2%	10,170,000 68.1%
Total Households	7,040,000 100.0%	14,934,000 100.0%

Table V-5 continued

MCL-Based Reference Values Exceeded	Number and Percent of Households: Large Rural Communities	Small Rural Communities	Other Rural Areas
Exceeded 0	1,084,000 45.7%	510,000 33.8%	6,459,000 35.7%
Exceeded 1	678,000 28.6%	636,000 42.2%	5,673,000 31.4%
Exceeded 2	608,000 25.6%	263,000 17.5%	3,922,000 21.7%
Exceeded 3	0 0.0%	99,000 6.6%	1,477,000 8.2%
Exceeded 4	0 0.0%	0 0.0%	440,000 2.4%
Exceeded 5	0 0.0%	0 0.0%	125,000 0.7%
Total exceeding one or more reference values	1,286,000 54.3%	999,000 66.2%	11,637,000 64.3%
Total Households	2,369,000 100.0%	1,509,000 100.0%	18,095,000 100.0%

Table V-5 continued

MCL-Based Reference Values Exceeded	Number and Percent of Households		
	Individual System	Intermediate System	Community System
Exceeded 0	2,734,000 31.2%	580,000 26.0%	4,589,000 41.8%
Exceeded 1	3,421,000 39.0%	693,000 31.1%	2,978,000 27.1%
Exceeded 2	1,896,000 21.6%	350,000 15.7%	2,503,000 22.8%
Exceeded 3	642,000 7.3%	285,000 12.8%	706,000 6.4%
Exceeded 4	67,000 0.8%	179,000 8.0%	205,000 1.9%
Exceeded 5	0 0.0%	141,000 6.3%	0 0.0%
Total exceeding one or more reference values	6,031,000 68.8%	1,648,000 74.0%	6,392,000 58.2%
Total Households	8,765,000 100.0%	2,228,000 100.0%	10,981,000 100.0%

Each figure in the table is rounded independently; numbers and percentages may not equal rounded totals.

per household was four in all regions except the North Central, where the maximum was five.

Among SMSA and nonSMSA households, the overall proportion of households above one or more reference values was about thirteen percentage points higher among nonSMSA households than among SMSA households (68.1 percent, compared to 55.2 percent). On the other hand, the proportion of SMSA households over two or more reference values was 30.8 percent, a proportion which was close to the comparable percentage among nonSMSA households (32.2 percent).

The size-of-place comparison showed that households in small rural communities fared poorest overall in exceeding reference values but, as seen in Table V-5, small rural communities also had the smallest proportion of households above the reference values for two or more constituents. The largest proportion of households exceeding two or more reference values occurred in other rural areas. Specifically, the rates for surpassing two or more reference values were 32.9 percent in other rural areas, 25.6 percent in large rural communities, and 24.0 percent in small rural communities.

Rates were substantially higher among households served by intermediate systems than among those served by individual or community systems. As seen in Table V-5, nearly three-quarters of all households using intermediate systems exceeded one or more reference values. This was about sixteen percentage points higher than the rate among households served by community systems. Furthermore, 42.9 percent of households served by intermediate systems exceeded two or more reference values; 6.3 percent exceeded five reference values. In contrast, 27.8 percent of individual-system households and 31.1 percent of community-system households exceeded two or more reference values, and none exceeded more than four. Overall, households served by community systems clearly fared the best in terms of this measure of water quality. Despite this, the advantage was only a relative one: 58.2 percent of households served by community systems exceeded one or more reference values. Furthermore, when rates for exceeding more than one MCL-based reference value are considered, individual systems showed lower problem rates than community systems.

Limitations of approach

This summary of counts of households exceeding MCL-based reference values needs to be qualified carefully. One complication results from an important interpretative distinction between the MCLs themselves and the MCL-based reference values used in the NSA. The primary MCLs are specific concentrations of constituents which, because they pose possible health threats, cannot be exceeded in public drinking water supplies. Thus, the analysis here does not provide information about households failing to comply with primary MCLs in the technical sense as spelled out in federal regulations. However, the analysis does provide information about households surpassing NSA reference values which are based on MCLs and which thus provide health-related measurements.

A second limitation of this approach is that each constituent is treated as though it were independent of others included in the index. That is, the summary simply adds the number of MCL-based reference values exceeded, and makes no attempt to consider their relative importance or possible interactions. The focus of the analysis so far has been on the concentrations of individual constituents in rural households. This perspective has provided insight into the relative magnitude of potential difficulties posed by different constituents. However, this analysis was not intended to provide information about the possible interrelated effects of levels of several constituents occurring simultaneously in one household.

The water-quality implications posed by multiple constituents in one supply can be assessed only in a limited fashion in the NSA. Physical and chemical interactions may occur among simultaneously present constituents, but the almost infinite combinations of constituents and concentrations cannot possibly be quantified in a general survey like the NSA.

The focus of the NSA on the individual, unique characteristics of each constituent is consistent with the current approach to water quality control, however. That is, since so many factors—ranging from the acidity of water to the presence of other compounds—can influence the effect of the constituents, it generally has been practical only to establish criteria and standards for the constituents independently. (There are, of course, exceptions such as the temperature-related MCLs for fluorides and the complex, interrelated MCLs for radioactive materials.)

A third complication of this summary approach results from the fact that some constituents with primary MCLs were studied in specimens from all NSA sample households, but some were studied only in a subsample of those households. Since all of the constituents could be assessed here only in the smaller Group II subsample, only findings referring to those 267 households are considered in this second summary approach. As a result of the smaller sample size, the confidence in the number of households estimated is lower than if the full sample had been involved. Also, subnational differences must be fairly substantial before there can be statistical confidence that the differences are real.

A final limitation of this summation of households exceeding MCL-based reference values is its inherent insensitivity. It is possible, for example, for a household to have a water supply which is relatively free from any of the measured contaminants. However, on the particular day when the water was taken for the NSA survey, a few coliform bacteria may have been in the water supply of that household. Such a household would be recorded as having exceeded one reference value. On the other hand, another household could have a water supply for which many or all of the contaminants measured in the NSA were present in concentrations very close to, but not exceeding the reference values. This household would show up as having surpassed no reference values and would therefore appear to have better water quality than the household previously described, a very dubious conclusion. This problem results from having a single threshold (the MCL-based reference value) for each constituent. While the concentration of a contaminant varies across a wide range, a count of over-reference-value cases implies that those above the reference value have poor water quality while those below have good water quality. This inherent insensitivity has other important undesirable implications: a household water supply which barely exceeds a reference value is judged equal to one which exceeds the reference value by a factor of thousands.

While these limitations must be kept in mind in evaluating the summary of rural US households exceeding MCL-based reference values, they should not be taken as a repudiation of the summary. The importance of the summary lies in showing the remarkable number of households across the US with water supplies which exceeded MCL-based reference values.

The count of over-reference-value households is a powerful summary indicating the widespread nature of water quality problems. Part of the effort in Chapter VI will be to develop summarizing indices which avoid some of the limitations outlined here. Further, Chapter VI will present indices which are more appropriate for the purposes of analyses in later chapters.

PERCEPTION OF QUALITY

So far in this chapter, water quality has been described in terms of specific substances that can be detected and measured by laboratory analysis. Another approach to portraying household water quality is to focus on people's perceptions—their subjective judgments about their water supplies. Though not necessarily as reliable as laboratory measurements, people's perceptions of the quality of their household water supply provided an important supplement to laboratory data in the NSA. First, they served as an independent source of information about household water quality; second, they reflected prevailing conditions of the household water supply, while the laboratory data reflected the particular conditions that existed the day that the NSA specimens were collected.

There was an additional reason for the NSA to assess people's subjective judgments about their household water supplies—the potential influence such judgments have on household decision-making. In that sense, NSA perceptual information may be as important as NSA laboratory data for understanding rural water conditions. People's perceptions about the quality of the household water supply probably had largely determined past household decisions about using or improving the water supply. Moreover, people's perceptions of the quality of their water supplies would have a direct bearing on any future governmental efforts to improve household water conditions.

Some simple examples illustrate the influence of perceptions of water quality on people's behavior. Most importantly, many problems of water quality cannot be discerned by drinking the water. Consequently, a person may have a firm belief that certain water is good, pure drinking water when in fact it may exceed federal MCLs for one or more constituents. In the absence of any perceptual indication of a problem in water quality, a household would continue to rely on such water instead of seeking ways to improve it.

As another example, to someone tasting it for the first time, water with a high sulfate content is usually thought to have an unpleasant odor or taste. Such water may or may not exceed federal MCLs. But since people can acquire a physiological tolerance to water with a high sulfate content,[102] people who are used to drinking it may believe that it is pleasant enough to drink and that it has no health effects of any consequence, whether or not it exceeds federal MCLs. These people would be unlikely to support governmental proposals to limit sulfates in drinking water, especially if meeting proposed regulations would entail a direct cost to their household.

In addition, people's perceptions are sometimes influenced by special circumstances. For example, if a person had a substandard dug well but none of his neighbors had adequate drilled wells, he might be content with his supply. Again, if a person were pleased with other physical characteristics of his housing, he might have a positive attitude toward a water supply which he knew had certain problems or inconveniences.

Still other factors may determine perceptions. If a person were satisfied with the operation and management of the system supplying the household water and, in addition, believed that the water was reasonably priced, he might overlook its inferior quality. Likewise, if the water were inexpensive because of an unlimited quantity being available from the supply, a person might ignore inferior quality.

Perceptions can also work the other way and influence people to make unnecessary improvements to a water supply. The opinion that some aesthetic aspect of a water supply—color, for example—is objectionable or even physically harmful could provide the impetus for expensive improvements at the household or for regulations more stringent than theoretically necessary to maintain public health.

Given the potential impact of people's perceptions of water quality on household water use and on public support for proposals that would affect household water conditions, it was important for the NSA to assess perceptions about prevailing water conditions at rural households. The inquiry included a series of questions related to perceived quality. Questions were asked about the odor, taste, clarity, color, sediment content, and temperature of the major household water supply. For each of the characteristics, respondents first were asked whether the condition was present and, if so, to what degree. Next, they were asked for a description of the condition and whether any changes occurred in it, as well as about the duration, possible reasons, seasonal variation, and agreeability of the condition.

The results, both national and subnational, are presented in sequence for each of the six perceptual characteristics related to quality (odor, taste, cloudiness, color, sediment, and temperature). At the national level, results are compiled for the intensity and duration of the perceived condition, whether or not changes occurred in it, the reported reason for the condition, and its agreeability. Subnational results are restricted to the condition's intensity and duration and any associated changes or fluctuations in it. Because they are best discussed separately, the results on seasonal variation are presented in the last part of this section. (In reading this section, it should be kept in mind that NSA perceptual data are based on the judgments of only one individual in each household—the household head or another carefully chosen adult.)

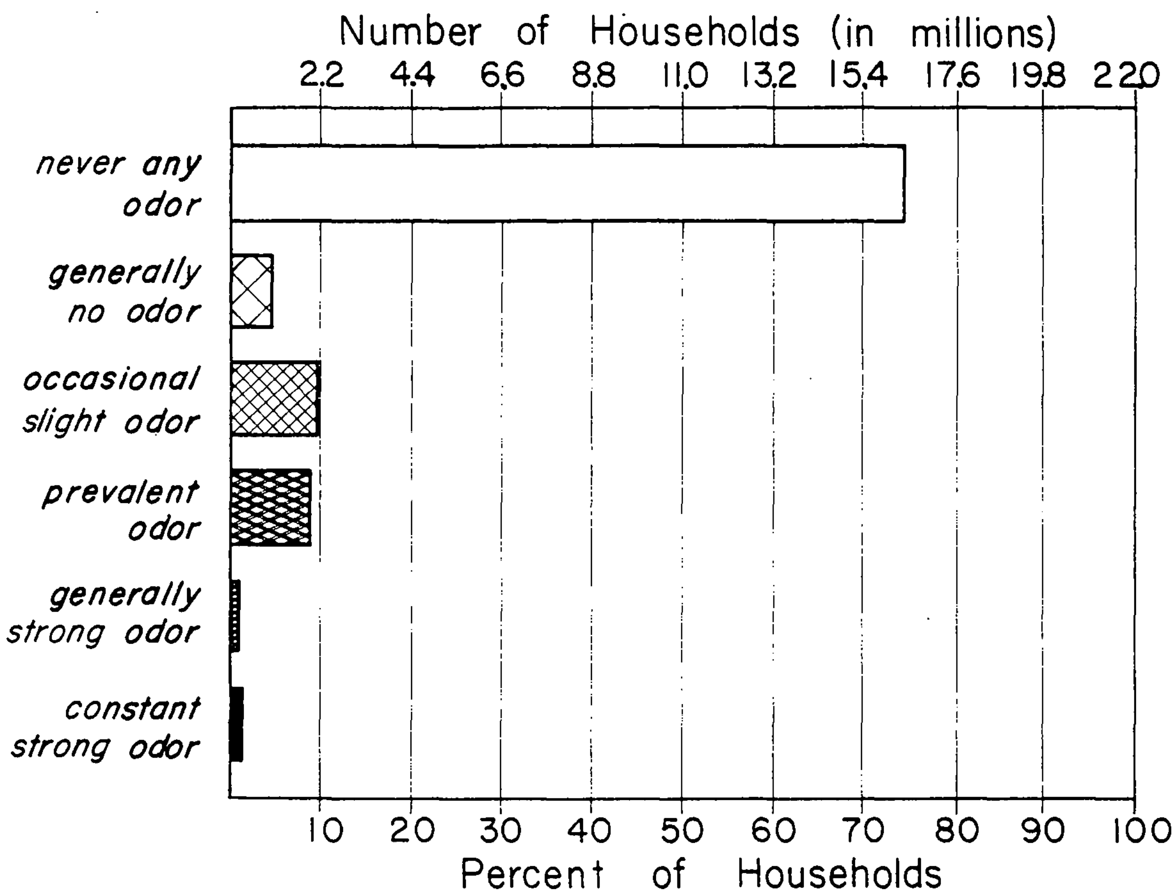
Odor

Three-quarters of all rural households (16.4 million) reported that there was never any odor present in the water supply (see Figure V-29). At another one million households, the water supply generally had no odor, while 2.2 million households reported that slight odors occurred occasionally. Another two million households reported a prevalent odor—either a slight odor that was present most or all of the time, or a strong odor that was present only some of the time. Less than 400,000 households reported that a strong odor was generally or constantly present in the water. In a related finding, though water supply conditions might be subject to fluctuations from time to time, only 17.1 percent of all households reported changes in the odor of the water supply.

Odors that were reported included some that respondents could identify as specific substances—chlorine and sulfur, for example—and others that had a less definite origin, such as "iron," and swampy or putrid odors. Although water supply

Figure V-29

Intensity and Duration of Perceived Odor in Rural Household Water Supplies



odors were expected to be described in many different ways, the most frequent responses reflected only five specific odors (see Table V-6). In particular, about 1.1 million households reported a chlorine odor, while another 0.8 million supplies were reported to smell swampy. Other frequently reported odors were sulfur (0.7 million supplies) and iron (0.3 million supplies). Some odors besides those listed individually in Table V-6 also were reported, but each was mentioned at fewer than 1 percent of the households reporting odors. These odors, which are subsumed in the "other miscellaneous" category, were detected in about 488,000 water supplies.

Reasons for water supply odor

Reasons cited for perceived water supply conditions sometimes were related to deliberate or planned activities such as chlorination and maintenance practices. Others were related to supply technology (inadequacy of physical facilities, and breakdowns of facilities), and to mismanagement of the system. The category, "inadequacy of the physical facilities," reflected the general condition of the water supply's physical components. It included responses such as (1) "the cistern does not filter out debris"; (2) "the pipes are too small"; (3) "the storage capacity is inadequate"; and (4) "the well is not deep enough." The category, "a problem within the house," on the other hand, referred to minor, short-term difficulties that were more closely associated with water supply facilities situated within the dwelling unit. Some specific responses in this category were (1) "the pipes broke," and (2) "the softening system gave out." The category, "a breakdown in the physical facilities of the water system outside the house," referred to problems such as broken pipes that occurred on the household property but outside the dwelling unit itself.

Other reasons for perceived water supply characteristics were related to natural conditions. With regard to odor, for instance, "the mineral content of the water" referred to dissolved minerals or gaseous odors. A less specific category,

Table V-6

Perceived Odors in Rural Household Water Supplies

	Nation	
Perceived Odor	Number of Households	Percent of Households
Chlorine	1,128,000	28.0
Swampy	815,000	20.2
Sulfur (rotten eggs)	692,000	17.2
Iron	334,000	8.3
Putrid (sewage odor)	264,000	6.6
Other miscellaneous	488,000	12.1
Don't know	311,000	7.7
*Total	4,032,000	100.1

*Table includes all households which reported a prevalent, generally strong, or constant strong odor, and some households that reported an occasional slight odor.

Each figure in the table is rounded independently; numbers and percentages may not equal rounded totals.

"the natural odor of the source," was used when a respondent was vague about the reasons for the water supply odor.

The categories "weather conditions" and "seasonal factors" were differentiated by their predictability. For example, if the respondent attributed a condition to spring rains, the category "seasonal factors" was used. If heavy rains were blamed for a condition, but with no mention of seasonality, the category "weather conditions" was used.

A problem attributed to a known source, but not conveniently or easily remedied, was categorized as a "situation beyond household or water system control." A case in point concerned a community experiencing odor problems attributed to a specific constituent in the water. Since the cost of removing the constituent from the water was beyond the users' ability to pay, the constituent was not removed. In another case, a disturbance of the aquifer was attributed to construction work in the area.

With regard to water supply odors (see Table V-7), by far the most prevalent reason cited for the condition was deliberate or planned activities (31.3 percent of households reporting water supply odors). Specifically, though not reflected in the table, nine out of ten households which reported a chlorine odor attributed it to deliberate or planned activities. A few of these households attributed the chlorine odor to mismanagement of the system.

Altogether, 23.8 percent of households reporting water supply odors attributed the odor to natural factors such as the mineral content of the water, the natural odor of the source, weather conditions, and seasonal factors.

Also mentioned relatively often as the cause of water supply odors were factors related to supply technology and management, such as inadequacy of physical facilities, breakdowns, and mismanagement (16.0 percent, combined).

Table V-7

Reported Reasons for Perceived Odor in Rural Household Water Supplies

Reason	Nation Number of Households	 Percent of Households
Deliberate or planned activities (additives, etc.)	1,746,000	31.3
Mineral content of the water	684,000	12.2
Inadequacy of the physical facilities of the system (pipes too small, storage capacity too small, inadequate filter, etc.	428,000	7.7
Natural odor of the source	300,000	5.4
Mismanagement of the system (ill-trained operators, inattention, etc.)	261,000	4.7
Weather conditions	256,000	4.6
A breakdown in the physical facilities of the water system outside the house	203,000	3.6
A problem within the house	201,000	3.6
Situation beyond household or water system control	139,000	2.5
Seasonal factors	90,000	1.6
Water stagnation	55,000	1.0
Other miscellaneous	126,000	2.3
Don't know	1,097,000	19.6
*Total	5,585,000	100.1

*Table includes only those households which reported an odor in their water supplies.

Each figure in the table is rounded independently; numbers and percentages may not equal rounded totals.

Agreeability of water supply odor

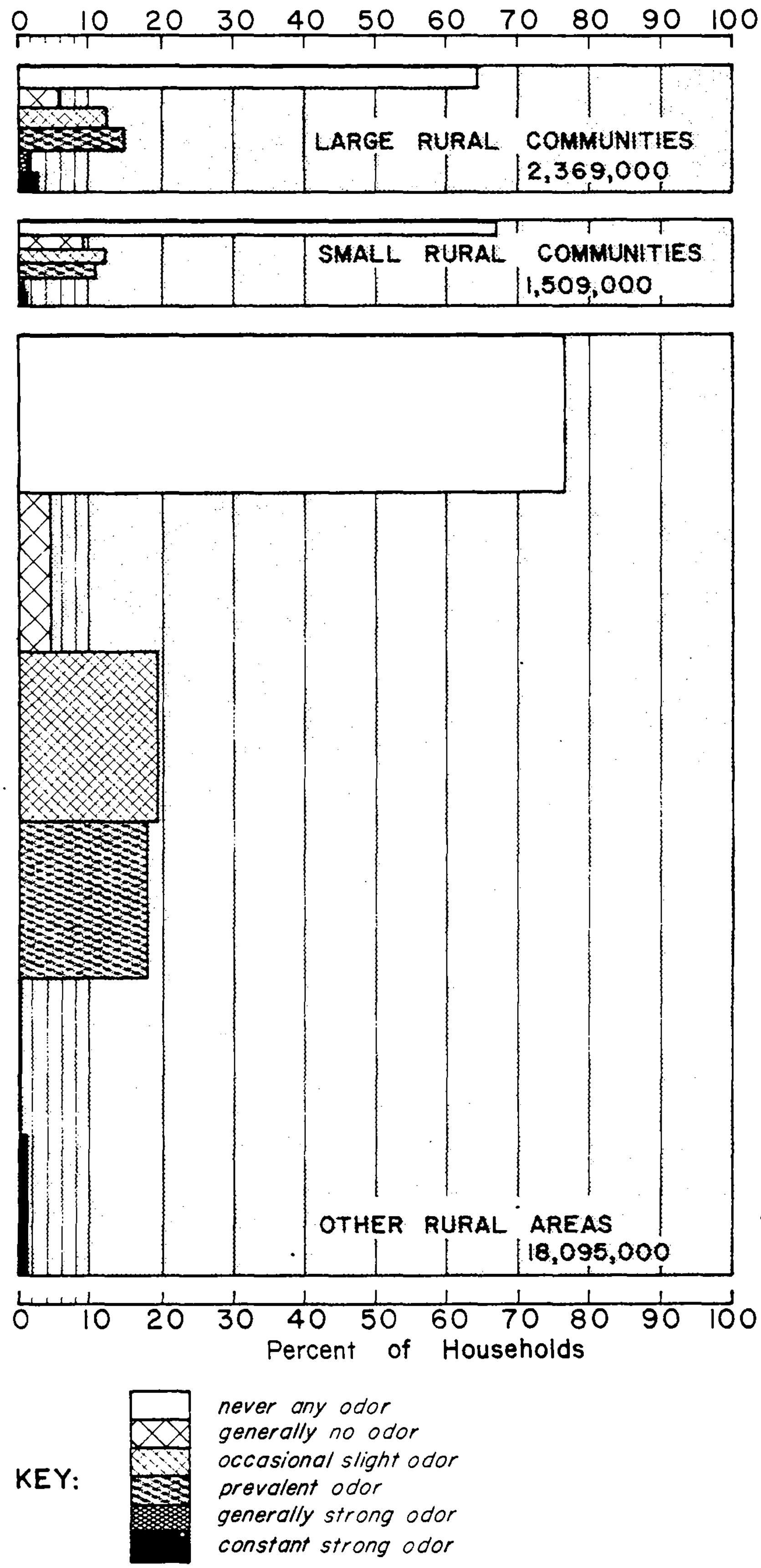
Using a five-point attitudinal scale, the NSA sought to assess how agreeable the water supply seemed in all rural households as to odor or the lack of odor. At 2.2 million households (9.5 percent), the water's odor was deemed disagreeable, while at 12.3 million households (56.1 percent), it was considered pleasant. Specifically, the water's odor was strongly disliked at 635,000 rural households (2.9 percent), moderately disliked at 1.5 million (6.6 percent), moderately liked at 8.0 million (36.3 percent), and very well liked at 4.4 million (19.8 percent). At about 7.5 million households (34.3 percent), the water was not noticed or thought about very much in regard to odor.

Major subnational patterns in water supply odor

Little variation was detected among the four regions of the United States and between SMSA and nonSMSA households in either the intensity and duration of water supply odors or in changes from the usual condition. In the size-of-place comparison, however, reported odor conditions were substantially different in other rural areas from what they were in large and small rural communities (see Figure V-29a). Specifically, more households in other rural areas reported there was never any odor in the water supply (76.5 percent, compared to 64.4 percent for large rural communities and 66.8 percent for small rural communities). Also, as place size increased, so did the prominence of water supply odors. That is, a greater proportion of households in large rural communities reported prevalent odors, generally strong odors, and constant strong odors (18.0 percent, combined) than in small rural communities (12.4 percent, combined) or other rural areas (9.7 percent, combined). Also noticed in the NSA data, though not depicted in Figure V-29a, was a stronger tendency for households in large and small rural communities to report changes in the usual condition of the water supply with regard to odor (about 27

Figure V-29a

Size-of-Place Variation in Perceived Odor in Rural Household Water Supplies



percent of households in both large and small communities, compared to about 15 percent of households in other rural areas).

A comparison of households with regard to size of supply system also showed substantial differences (see Figure V-29b). A much smaller proportion of households served by community water systems reported there was never any odor in the supply (67.7 percent, compared to 80.2 percent for intermediate systems and 81.7 percent for individual systems). Not reflected in the graph is the fact that a greater proportion of households served by community water systems reported changes in the water supply with regard to odor (24.1 percent, compared to 11.3 percent for intermediate-system households and 9.7 percent for individual-system households). This finding is consistent with changes being reported more often by households in large and small rural communities, where community water systems are more common than in other rural areas.

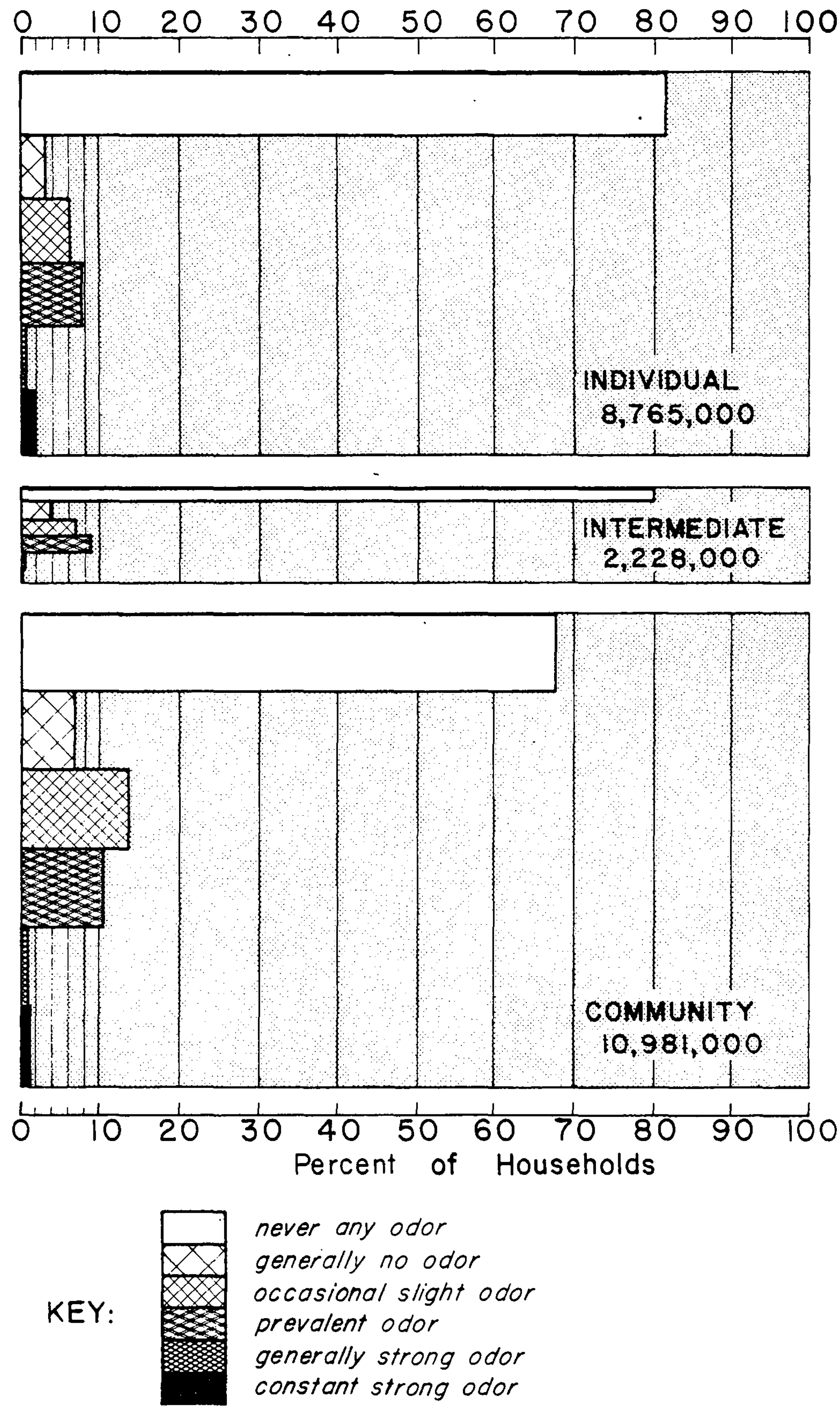
Taste

Although perceptions of odor and taste generally would be expected to occur together, water supply tastes were reported more often than were odors. In all, 5.6 million households (25.5 percent) reported water supply odors; 7.8 million households (35.5 percent) reported tastes. Some of the reported tastes were pleasant, however, in contrast to all of the reported odors. (For some respondents, the water tasted sweet, or simply "like good, clean, fresh water.")

Graphs depicting subnational variations in perceived characteristics of water supplies reflect the number of households in each subnational category. In a size-of-place comparison, for example, the size of the other-rural-areas portion of the graph reflects the fact that the bulk of the rural population lived in other rural areas.

Figure V-29b

Size-of-System Variation in Perceived Odor in Rural Household Water Supplies



At 796,000 households (3.6 percent), tastes were reported to occur infrequently; generally there was no taste (see Figure V-30). At 2.1 million households (9.7 percent), a slight taste occurred occasionally. At 4.1 million (18.6 percent), the water supply had a prevalent taste—either a slight taste that was present most or all of the time, or a strong taste that was present only some of the time. Relatively few households reported that the water supply generally had a strong taste (1.0 percent, or 218,000) or that it had a strong taste that was present constantly (2.5 percent, or 553,000).

Compared with the number of households reporting specific intensities of water supply odors, slightly fewer households reported that the water supply had generally no taste or an occasional slight taste (2.9 million versus 3.2 million, combined). Twice as many households reported prevalent tastes, generally strong tastes, and constant strong tastes (4.9 million versus 2.4 million, combined). These differences may stem from the fact that people are more aware of tastes than of odors.

Changes in taste were about as frequent as changes in odor: 15.4 percent or 3.4 million households reported changes in taste, while 17.1 percent or 3.8 million households reported changes in odor.

Strictly speaking, human beings can perceive only four tastes—sweet, sour, salty, and bitter—but these characterized only about 12 percent of the tastes noticed in household water (see Table V-8). At 1.9 million households (27.3 percent of all households where a taste was perceived), minerals were tasted in the water, while a chlorine taste was perceived at 1.1 million households. At 0.8 million households (11.0 percent), the taste was not specific enough to identify. At other households, the taste was described as "swampy" or like "good, clean, fresh water." Although it could be argued that "swampy" actually referred to a perceived odor rather than a taste, and that "good, clean, fresh water" was neither a taste nor an odor, these answers occurred frequently and were tabulated so as to preserve all

Figure V-30

Intensity and Duration of Perceived Taste in Rural Household Water Supplies

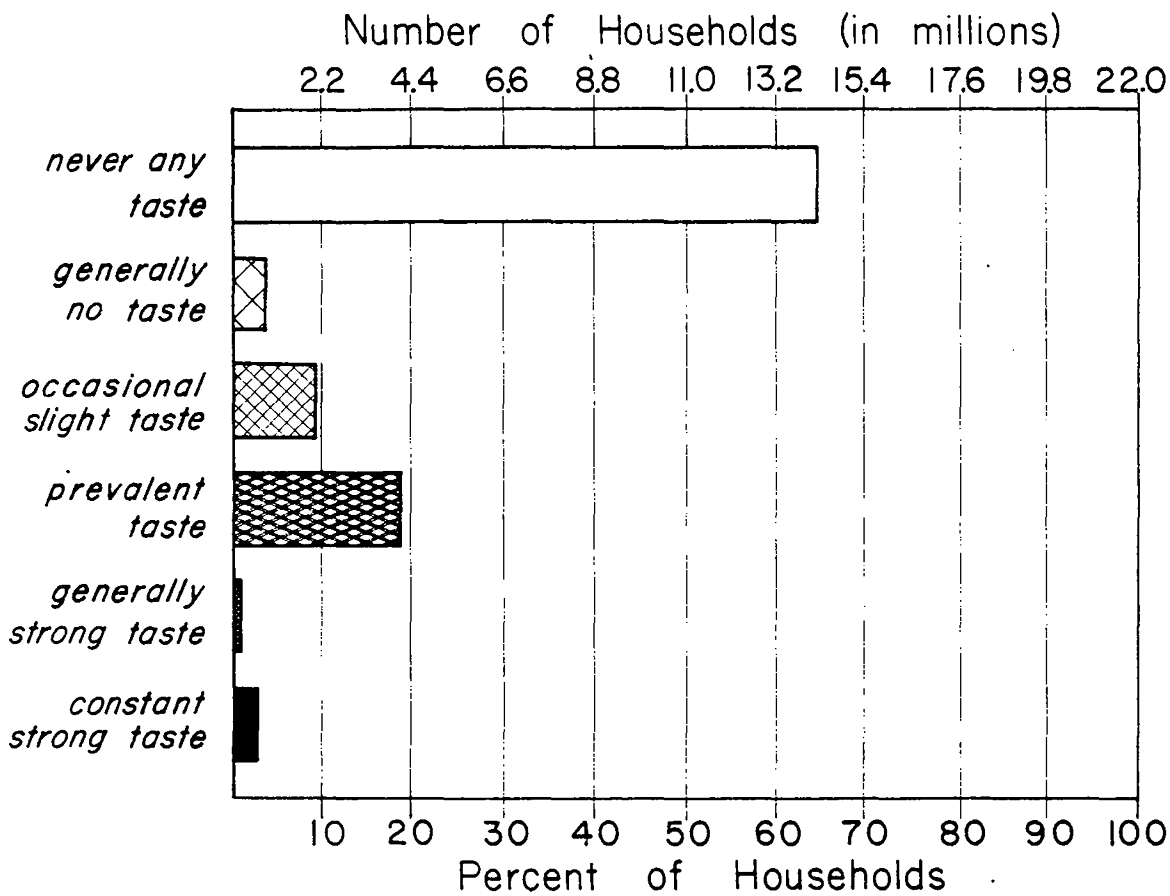


Table V-8

Perceived Tastes in Rural Household Water Supplies

	Nation	
Perceived Taste	Number of Households	Percent of Households
Mineral water	1,927,000	27.3
Chlorine	1,134,000	16.1
Taste not specific enough to identify	776,000	11.0
Swampy	590,000	8.6
Good, clean, fresh water	521,000	7.4
Sweet	377,000	5.3
Salty	258,000	3.6
Bitter	219,000	3.1
Sour	25,000	0.4
Other miscellaneous	516,000	7.3
Don't know	716,000	10.1
*Total	7,058,000	100.2

*Table includes all households which reported a prevalent, generally strong, or constant strong taste, and some households that reported an occasional slight taste.

Each figure in the table is rounded independently; numbers and percentages may not equal rounded totals.

information obtained. As shown in the table, a swampy taste was reported in about 0.6 million households, and a good, clean taste in about 0.5 million households.

Reasons for tastes

As with odors, water supply tastes were most often attributed to planned activities. This reason was cited in 2.2 million households. In close correspondence with the frequency of minerals as a perceived taste, the presence of minerals was cited as the reason for water supply tastes in 1.2 million households, while the natural condition of the source was mentioned at 0.9 million households. Tastes were attributed to supply technology (inadequacy of facilities, or breakdowns) or to system management at 13.4 percent, combined, of the households reporting tastes. Other reasons also were given, as shown in Table V-9.

Agreeability of tastes

Household water was thought to have an agreeable taste in 13.2 million, or 59.9 percent of all rural households. In addition, in 28.4 percent of all rural households (6.4 million), the water's taste was thought to be all right, or was not thought about very much. On the other hand, the taste was felt to be disagreeable in 2.4 million households—or 11.1 percent of all rural households.

Major subnational patterns in tastes

Very little regional variation was evident in the intensity and duration of water supply tastes. The largest variation—a difference of only six percentage points—occurred in the proportions of households reporting that there was never any taste in the water supply: the proportions were 60.8 percent in the Northeast, 64.6 percent in the South, 65.5 percent in the North Central, and 67.0 percent in the West. This difference was offset, however, by the proportions reporting that the water supply generally had no taste, which ranged from 7.0 percent in the

Table V-9

Reported Reasons for Perceived Taste in Rural Household Water Supplies

Reason	Nation: Number of Households	Nation: Percent of Households
Deliberate or planned activities	2,237,000	27.8
Mineral content of the water	1,190,000	14.8
Natural taste of the source	866,000	10.8
Inadequacy of the physical facilities of the system	456,000	5.7
Mismanagement of the system	373,000	4.6
A problem within the house	342,000	4.3
A breakdown in the physical facilities of the water system outside the house	247,000	3.1
Weather conditions	220,000	2.7
Seasonal factors	56,000	0.7
Other miscellaneous	337,000	4.2
Don't know	1,713,000	21.3
*Total	8,041,000	100.0

*Table includes only those households which reported a taste in their water supplies.

Each figure in the table is rounded independently; numbers and percentages may not equal rounded totals.

Northeast to 1.2 percent in the West. Otherwise, the occurrence of reported tastes held closely to the national pattern. Changes in tastes of water supplies were reported at only 11.8 percent of rural households in the North Central, compared to 16.4 percent in both the South and West and 17.9 percent in the Northeast.

No substantive differences were found between SMSA and nonSMSA households in the occurrence of tastes in the water supply, or with regard to changes in them.

Variations among the three size-of-place categories followed somewhat the same pattern as seen for water supply odors. As shown in Figure V-30a, more households in other rural areas reported that the water supply never had a taste (66.1 percent, compared to 54.6 percent of households in large rural communities and 61.2 percent in small rural communities). Further, prevalent tastes were reported in 21.3 percent of households in large rural communities, compared to 16.0 percent in small rural communities and 18.5 percent in other rural areas. However, households reported generally strong tastes and constant strong tastes in about equal proportions: 3.9 percent in large communities, 3.7 percent in small communities, and 3.4 percent in other rural areas. Changes in the taste of the water supply were reported at 25.0 percent of households in large rural communities and 23.0 percent of households in small rural communities, but at only 13.7 percent of households in other rural areas.

In a comparison of households served by supply systems of different sizes, only 57.6 percent of households served by community systems reported that the water supply never had a taste, compared to 72.2 percent of households served by individual systems and 67.9 percent of households served by intermediate systems (see Figure V-30b). Occasional slight tastes were far more frequently reported among households served by community systems, and there was little variation in the proportions of households reporting prevalent tastes, generally strong tastes, and constant strong tastes.

Figure V-30a

Size-of-Place Variation in Perceived Taste in Rural Household Water Supplies

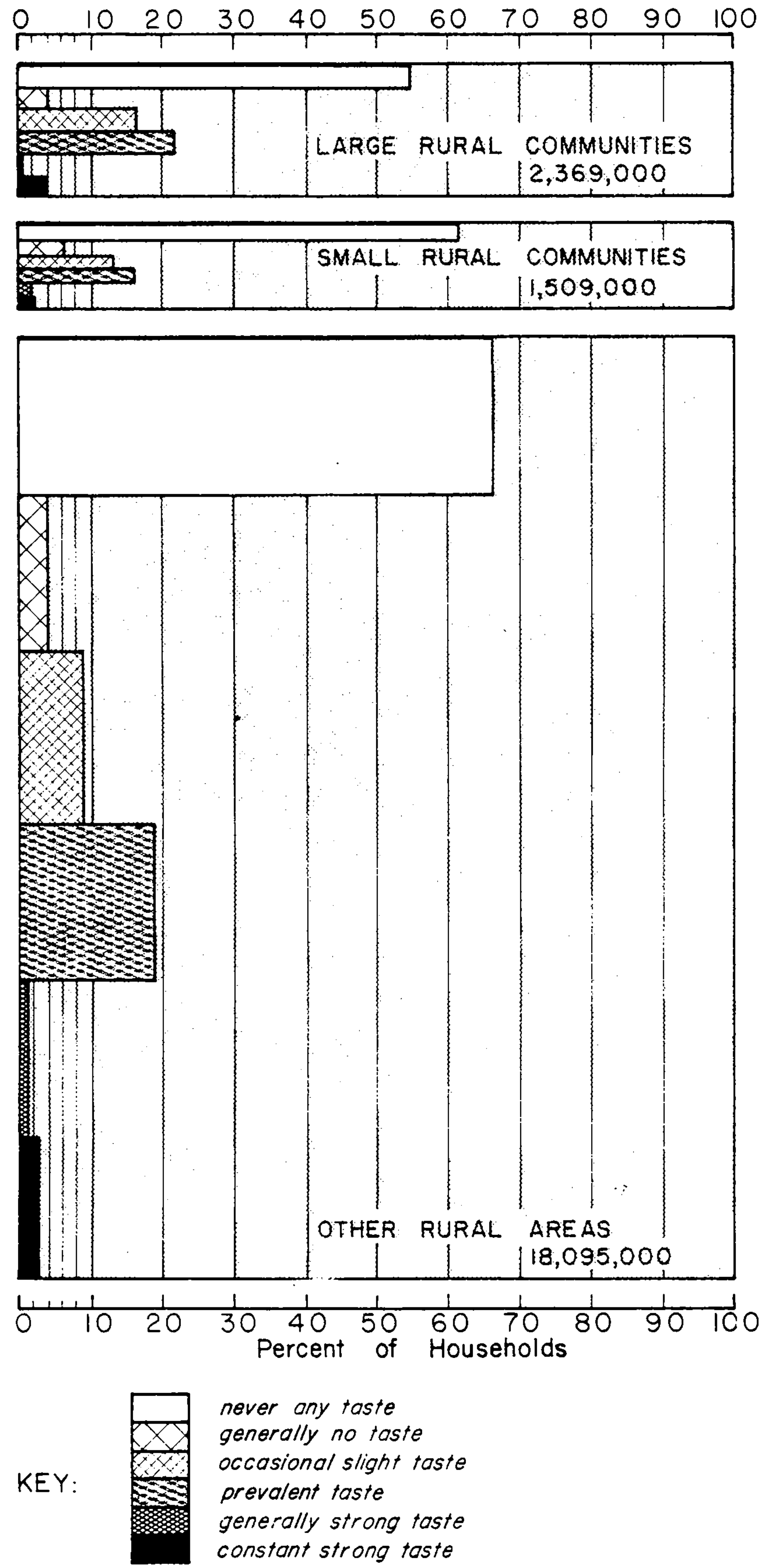
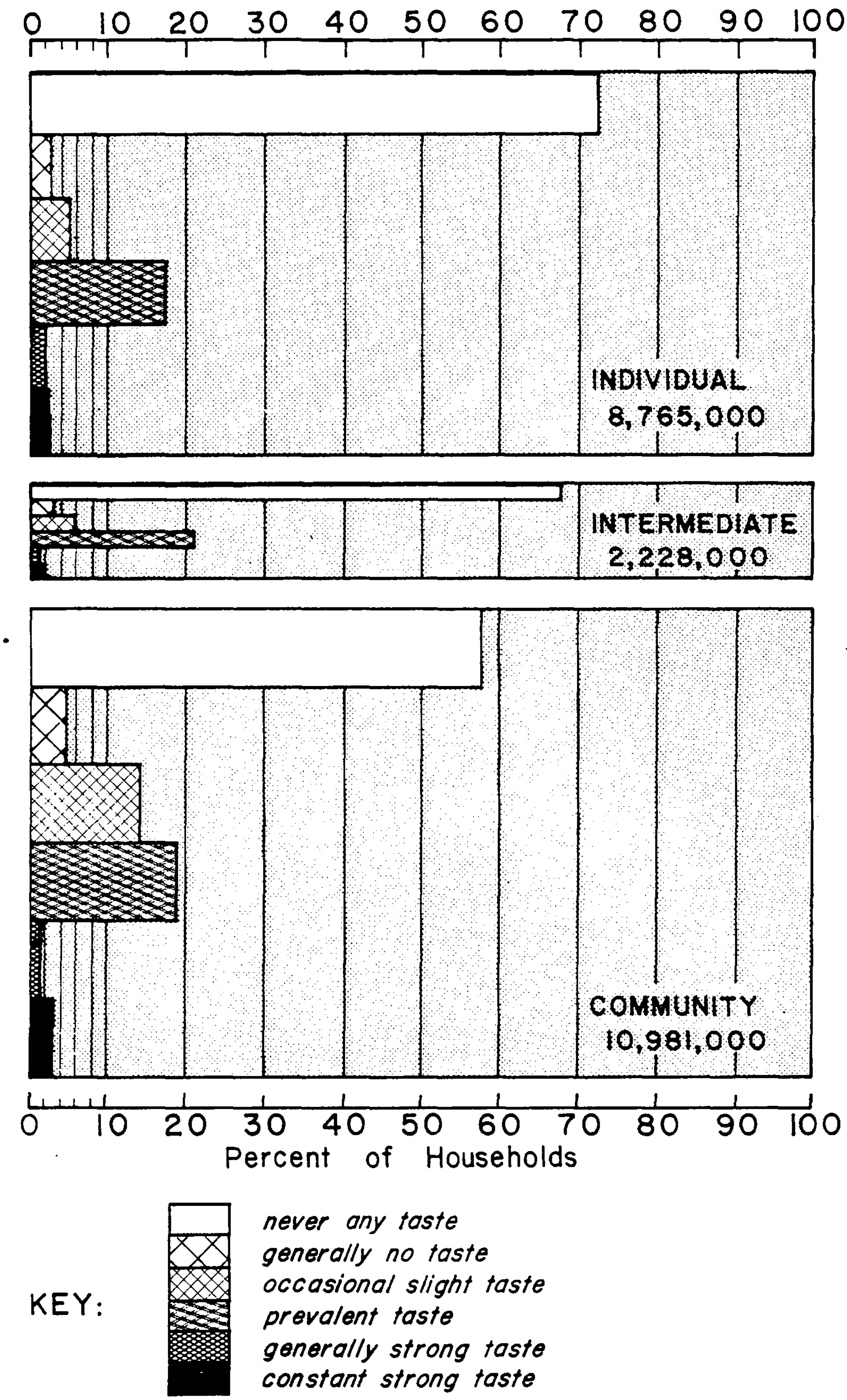


Figure V-30b

Size-of-System Variation in Perceived Taste in Rural Household Water Supplies



Changes in the taste of the water supply were noticed in approximately 9 percent of households served by individual and intermediate systems, but in about 22 percent of households served by community systems.

Cloudiness

Water's cloudiness, color, and sediment content have potential implications for water quality. These three physical attributes were included in the NSA survey because they are conditions that are easily observable and because they have been known to play a part in people's attitudes towards their water supplies.[103]

At 73.1 percent of rural households, no cloudiness was ever noticed in the water supply (see Figure V-31). At another 9.9 percent, there was generally no cloudiness present. However, 10.0 percent or 2.2 million households reported an occasional slight cloudiness, and 6.1 percent or 1.3 million households reported a prevalent cloudy condition. Less than 1 percent of rural households reported that the water supply was generally or constantly very cloudy (0.5 percent and 0.3 percent, respectively). Changes in the water supply with respect to cloudiness were reported at 23.3 percent of rural households.

Reasons for water supply cloudiness

Cloudiness was attributed to supply technology (inadequacy of facilities or breakdowns) and system management at 29.6 percent, combined, of the households reporting cloudiness. At another one million households, the condition was blamed on deliberate or planned activities. Natural forces—the weather, seasonal factors, the water's mineral content, and the "natural cloudiness of the source"—were thought to account for the condition at 23.7 percent of the households reporting cloudiness. Other reasons were also given, as shown in Table V-10. However, at a large proportion of households where cloudiness was noted in the water (19.2 percent), no reason for the condition could be cited.

Figure V-31

Intensity and Duration of Perceived Cloudiness in Rural Household Water Supplies

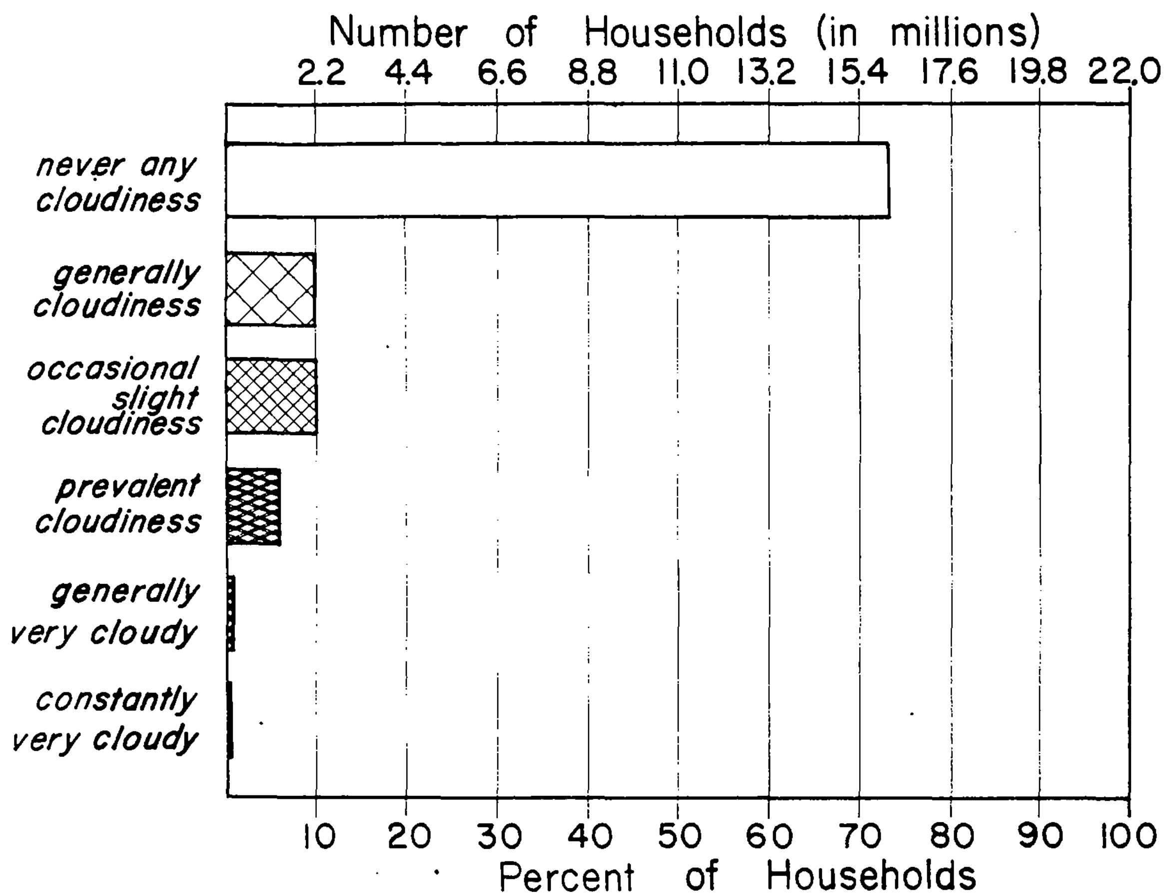


Table V-10

Reported Reasons for Perceived Cloudiness in Rural Household Water Supplies

	Nation	
Reason	Number of Households	Percent of Households
A breakdown in the physical facilities of the water system outside the house	969,000	16.2
Deliberate or planned activities	965,000	16.2
Weather conditions	703,000	11.8
Inadequacy of the physical facilities of the system	515,000	8.6
Mineral content of the water	421,000	7.0
A problem within the house	361,000	6.0
Mismanagement of the system	284,000	4.8
Natural cloudiness of the source	184,000	3.1
Seasonal factors	108,000	1.8
Water stagnation	49,000	0.8
Other miscellaneous	266,000	4.5
Don't know	1,146,000	19.2
*Total	5,971,000	100.0

*Table includes only those households which reported cloudiness in their water supplies.

Each figure in the table is rounded independently; numbers and percentages may not equal rounded totals.

Agreeability of water supply cloudiness

At fourteen million rural households (63.3 percent), the degree of clarity in the water supply was found pleasing; at 6.5 million (29.8 percent), feelings were neutral; but at 1.5 million households (6.9 percent), the condition was displeasing.

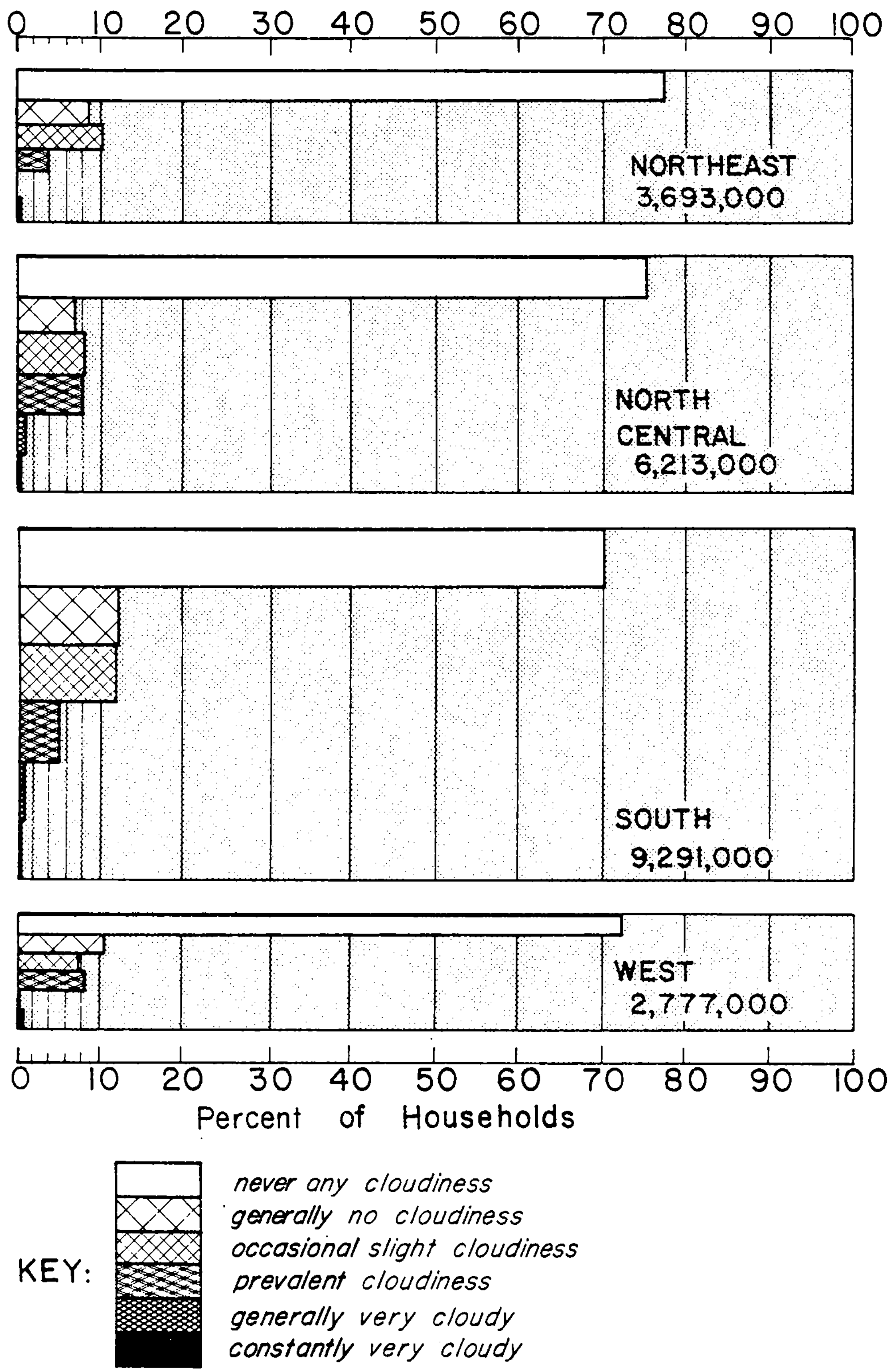
Major subnational patterns in cloudiness

Problems with cloudiness in the water supply were least often reported among households in the Northeast, where 77.4 percent of households reported there was never any cloudiness and only 4.0 percent reported cloudiness that was prevalent or worse (see Figure V-31a). Although the South had the smallest proportion of households reporting there was never any cloudiness in the water supply (70.1 percent), 24.2 percent in the South (combined) reported there was generally no cloudiness or that there was only occasional slight cloudiness. The North Central and West had the highest proportions of households where cloudiness was prevalent or worse—9.6 percent and 9.0 percent, respectively. There was also regional variation in the proportions of households reporting changes in the water supply with respect to cloudiness: changes were noticed in 26.9 percent of households in the South, 23.5 percent in the West, 21.0 percent in the North Central, and 18.1 percent in the Northeast.

The SMSA/nonSMSA comparison showed that proportionately fewer non-SMSA households reported cloudiness never being present in the water supply (71.1 percent, compared to 77.3 percent), but a higher proportion of nonSMSA households reported there was generally no cloudiness or that occasional slight cloudiness occurred (22.0 percent, compared to 15.9 percent, combined). An equal proportion of SMSA and nonSMSA households—about 7 percent—reported prevalent cloudiness or a very cloudy condition that was generally or constantly present. Changes in the usual condition were reported by 18.7 percent of SMSA households and 25.5 percent of nonSMSA households.

Figure V-31a

Regional Variation in Perceived Cloudiness in Rural Household Water Supplies



Household water supplies in other rural areas were reported free of any cloudiness more often than those in large or small rural communities (see Figure V-31b). Specifically, 74.3 percent of households in other rural areas reported there was never any cloudiness present in the water supply, compared to 69.7 percent in small communities and 65.9 percent in large communities. Also, only 6.2 percent of households in other rural areas reported a cloudy condition that was prevalent or worse, compared to 10.4 percent of households in small communities and 11.1 percent in large communities. Large rural communities had the greatest proportion of households reporting an occasional slight cloudiness—15.9 percent, compared to 9.9 percent for small rural communities and 9.3 percent for other rural areas. Changes in the water supply with respect to cloudiness were reported in 29.9 percent of households in large rural communities, 24.0 percent of households in small rural communities, and 22.4 percent of households in other rural areas.

Consistent with the variations in the size-of-place comparison, individual systems—which were most common in other rural areas—were most often free of any cloudiness. Specifically, 78.4 percent of households served by individual systems reported there was never any cloudiness in the water supply, compared to 73.3 percent of those served by intermediate systems and 68.8 percent of those served by community systems (see Figure V-31c). Water from community systems tended to be more cloudy: 9.2 percent of households served by community systems reported cloudiness that was prevalent or worse, compared to 4.4 percent of individual-system households and 5.6 percent of intermediate-system households. (The worst condition reported among intermediate-system households was prevalent cloudiness.) Changes in the water supply with respect to cloudiness were reported least frequently among households served by individual systems (18.8 percent, compared to 23.3 percent of households served by intermediate systems and 26.9 percent of households served by community systems).

Figure V-31b

Size-of-Place Variation in Perceived Cloudiness in Rural Household Water Supplies

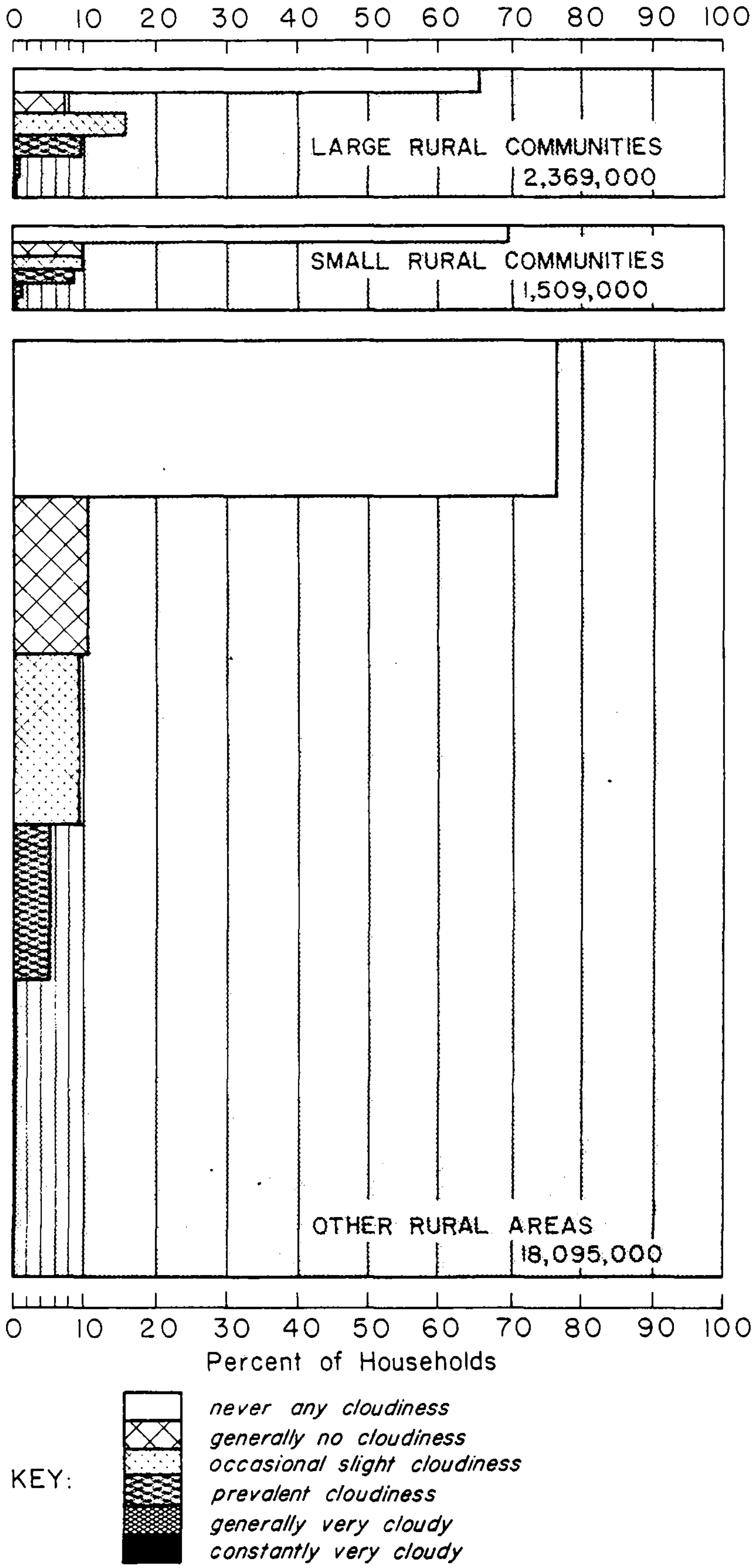
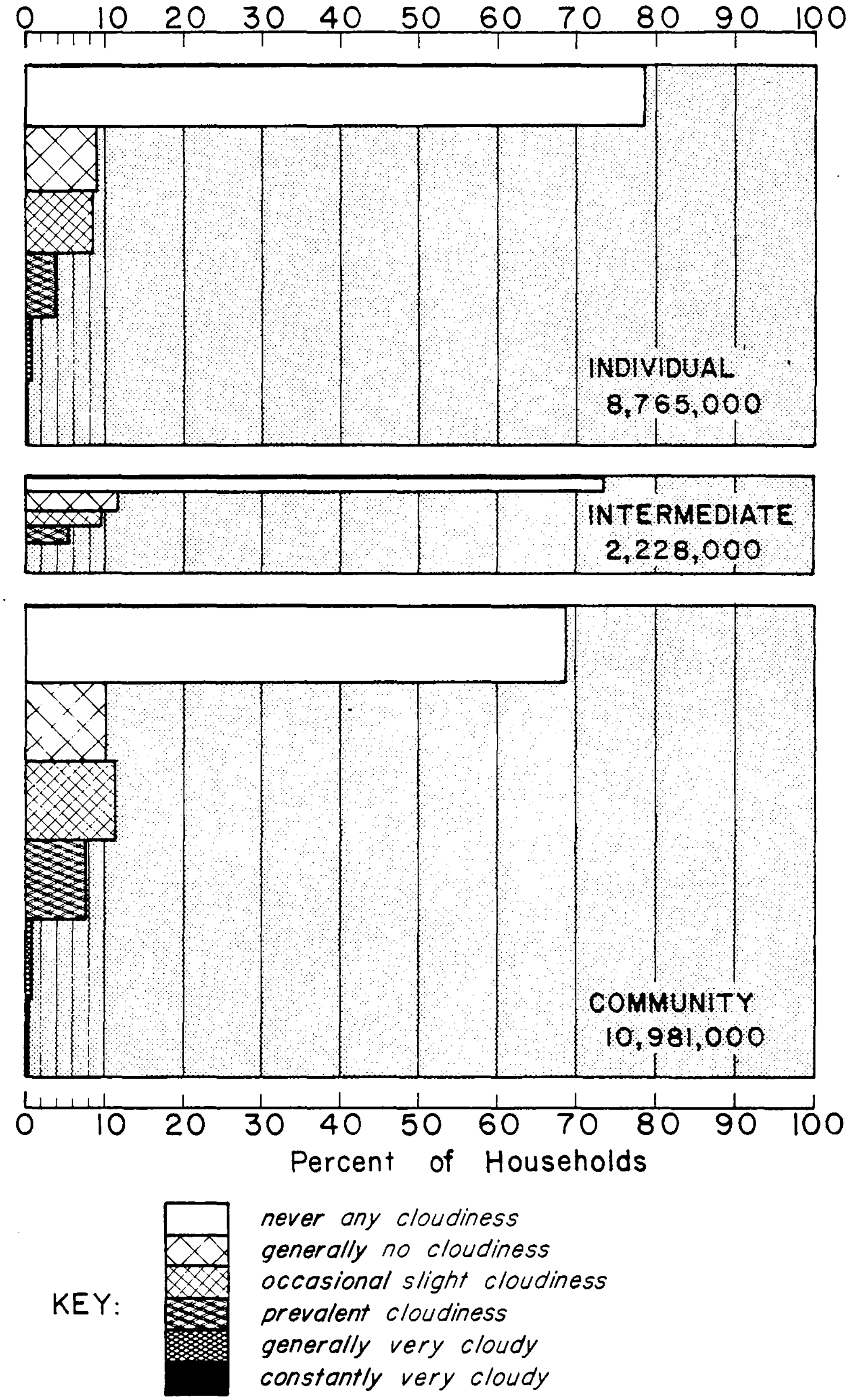


Figure V-31c

Size-of-System Variation in Perceived Cloudiness in Rural Household Water Supplies



Color

Almost 80 percent of rural households—17.5 million—reported that the water supply never had any color, while 1.3 million reported there was generally no color. An occasional slight color was noticed in 1.5 million water supplies. At another 1.4 million households, there was a prevalent color in the water supply. Worse conditions with respect to color were relatively rare: 0.9 percent or 191,000 households reported that generally the water supply was very colored, and 0.3 percent or 68,000 reported that it was very colored all the time (see Figure V-32). Changes in the water supply with respect to color were reported at 3.3 million households (14.9 percent).

The predominant colors reported were gray, yellow, white, and brown, though many others were also mentioned (see Table V-11). Gray water was reported in 0.5 million households, yellow water in 0.5 million, white water in 0.4 million, and brown water in slightly less than 0.4 million households.

Reasons for water supply color

Color was most frequently attributed to factors of supply technology (inadequacy or breakdowns of facilities) and management; such factors were blamed for the condition at 28.5 percent, combined, of households reporting a color in the water supply. At other households, color was blamed on the mineral content of the water (13.9 percent) or on deliberate or planned activities (13.4 percent). Other reasons that were reported are shown in Table V-12.

Agreeability of water supply color

Overwhelmingly—in almost 94 percent of all rural households—the water supply seemed agreeable as to color (27.7 percent of households reported neutral feelings). This finding corresponds with the fact that almost 80 percent of households reported there was never any color in the water. A mild dislike for the

Figure V-32

Intensity and Duration of Perceived Color in Rural Household Water Supplies

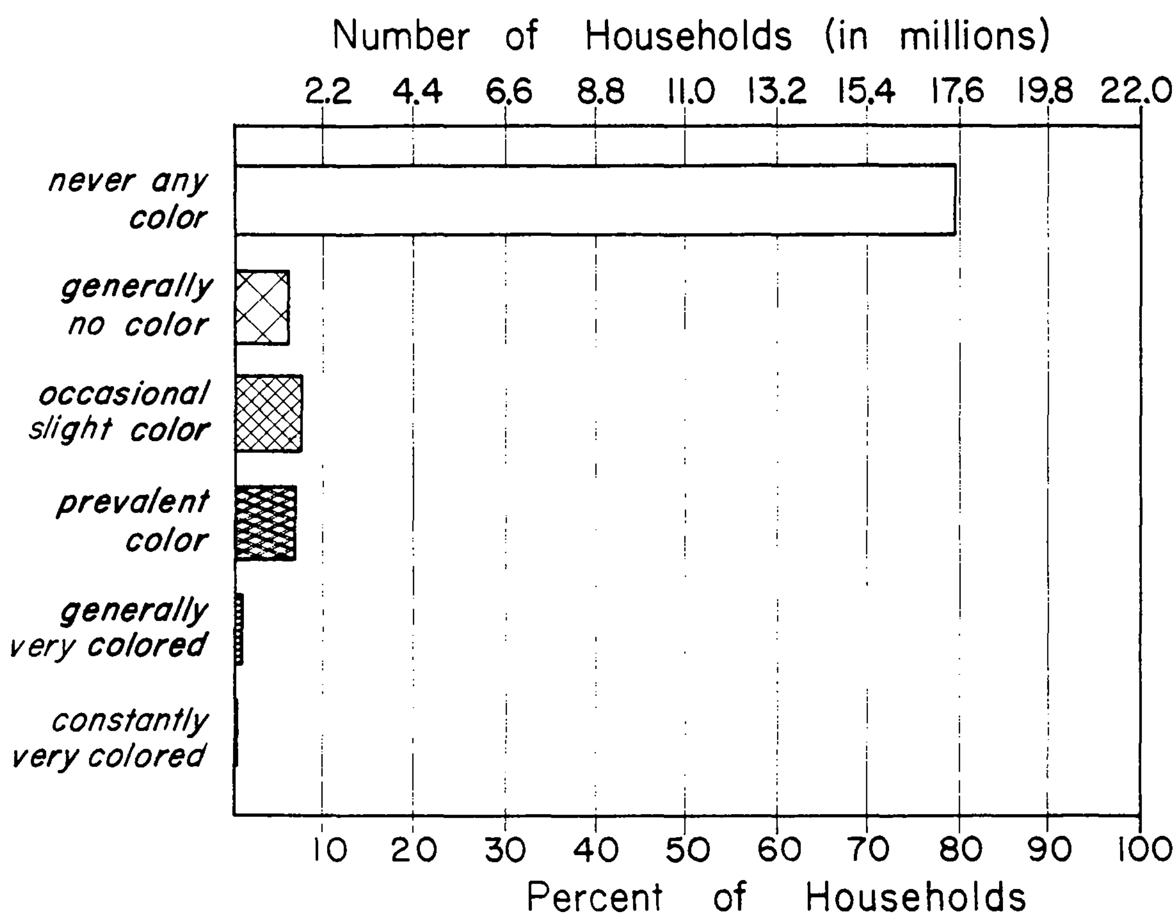


Table V-11

Perceived Colors in Rural Household Water Supplies

Colors	Nation: Number of Households	Nation: Percent of Households
Gray	462,000	19.2
Yellow	459,000	19.1
White	408,000	17.0
Brown	377,000	15.7
Red	290,000	12.1
Orange	154,000	6.4
Blue	76,000	3.1
Green	26,000	1.1
Other miscellaneous	118,000	4.9
Don't know	34,000	1.4
*Total	2,402,000	100.0

*Table includes all households which reported a prevalent color, a generally very colored condition, or a constantly very colored condition, as well as some households which reported an occasional slight color.

Each figure in the table is rounded independently; numbers and percentages may not equal rounded totals.

Table V-12

Reported Reasons for Perceived Color in Rural Household Water Supplies

Reason	Nation: Number of Households	Nation: Percent of Households
A breakdown in the physical facilities of the water system outside the house	757,000	16.8
Mineral content of the water	628,000	13.9
Deliberate or planned activities	603,000	13.4
A problem within the house	425,000	9.4
Weather conditions	380,000	8.4
Inadequacy of the physical facilities of the water system	370,000	8.2
Natural color of the source	172,000	3.8
Mismanagement of the system	158,000	3.5
Seasonal factors	69,000	1.5
Other miscellaneous	157,000	3.5
Don't know	789,000	17.5
*Total	4,508,000	99.9

*Table includes only those households which reported color in their water supplies.

Each figure in the table is rounded independently; numbers and percentages may not equal rounded totals.

color of the water was reported at 4.4 percent of rural households, while a strong dislike for it was reported at 1.9 percent, or 0.4 million households.

Major subnational patterns in color

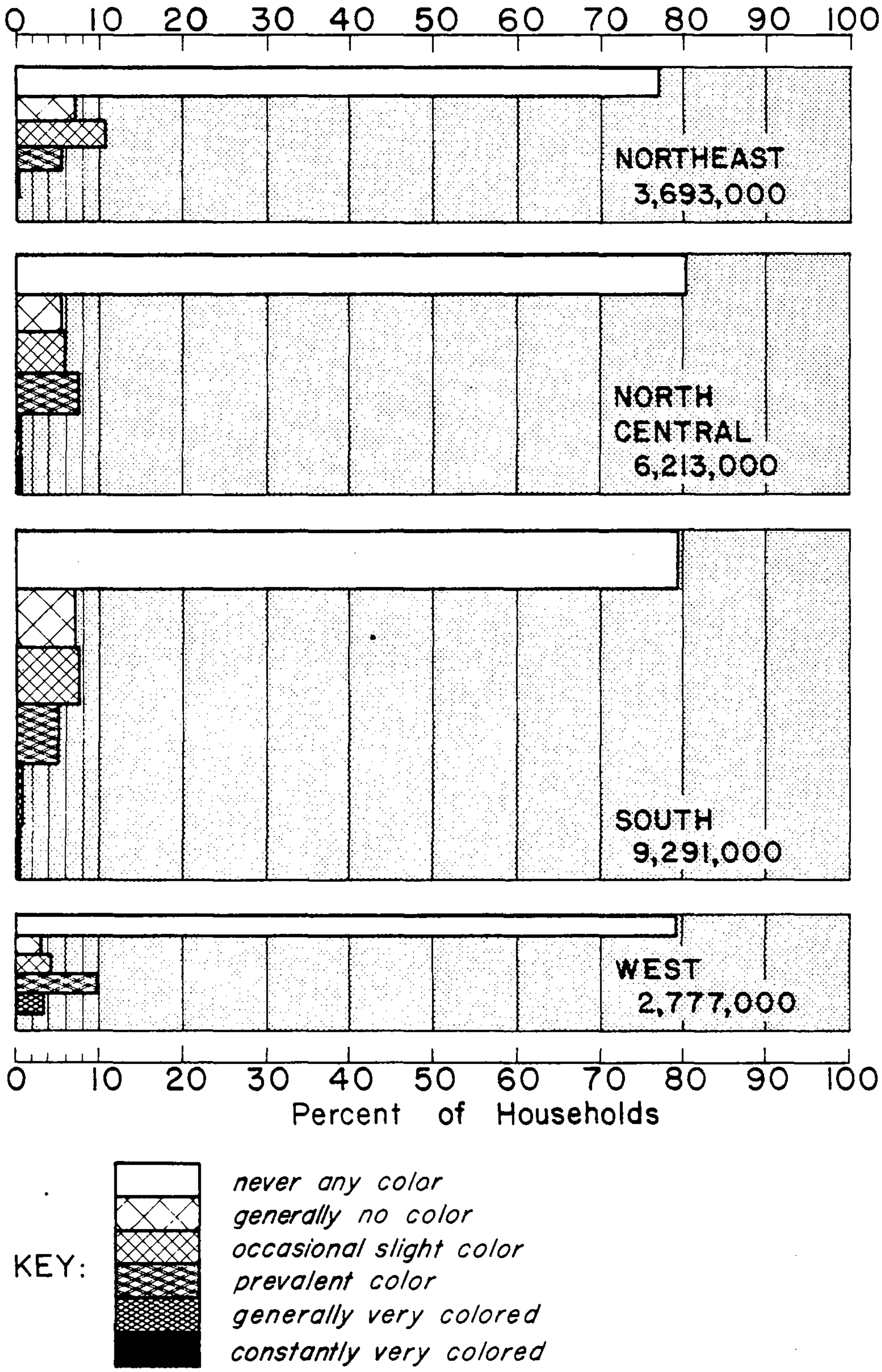
About equal proportions of households in each of the four regions reported that there was never any color present in the water supply, but some variation could be seen in the relative severity of the condition among the regions (see Figure V-32a). That is, though no households in the West reported that the water supply was always very colored, still a higher proportion of households there reported a prevalent colored condition or a generally very colored condition (12.8 percent, combined). In the North Central, 8.6 percent of households in all reported either a prevalent colored condition or a very colored condition that was present generally or constantly. By comparison, about 6 percent of households in the Northeast and South reported these conditions. (As in the West, a constantly very colored condition was never reported in the Northeast; such a condition was reported at 0.6 percent of households in the North Central and 0.4 percent in the South.)

Proportionately more households in the Northeast and South reported less severe conditions. Combining households that reported that the water supply generally had no color with those reporting that a slight color occurred occasionally, these less severe conditions were reported at 17.0 percent of households in the Northeast, 14.3 percent in the South, 11.2 percent in the North Central, and 7.3 percent in the West. The proportions of households reporting changes in the water with respect to color were 12.1 percent in the West, 13.4 percent in the North Central, 15.5 percent in the South, and 17.8 percent in the Northeast.

No substantive variation (less than four percentage points) was seen between SMSA households and nonSMSA households with respect to water supply color or changes in the water supply color.

Figure V-32a

Regional Variation in Perceived Color in Rural Household Water Supplies



Compared with large and small rural communities, a smaller proportion of households in other rural areas reported color in the household water supply (see Figure V-32b). In other rural areas, 81.4 percent of households reported that there was never any color present in the water supply, compared to 68.9 percent in large rural communities and 73.3 percent in small rural communities. The water supply exhibited a color that was prevalent or even more pervasive at 7.0 percent of households in other rural areas, 9.0 percent of households in small communities, and 10.2 percent of households in large communities.

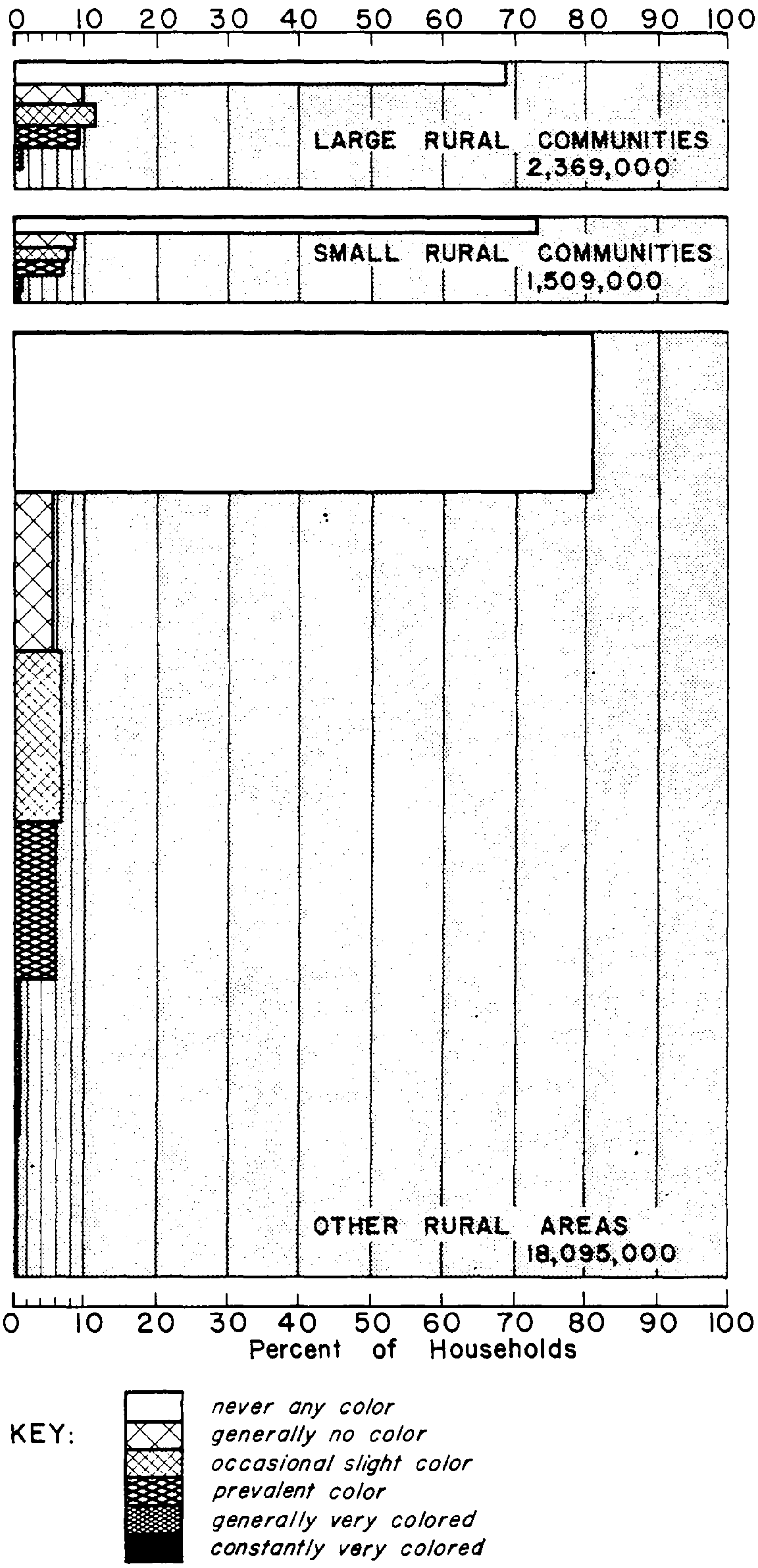
Changes in the usual condition of the water supply with respect to color were noticed by 25.0 percent of households in large communities, 21.8 percent of households in small communities, and by only 13.0 percent of households in other rural areas.

Comparing households served by water supply systems of different sizes, about equal proportions of those served by intermediate systems and community systems reported color in the household water supply: 24.4 percent for intermediate systems, and 23.4 percent for community systems. In contrast, only 16.0 percent of households served by individual systems reported water supply color. Despite this difference, which reflected the proportion of households reporting that color never occurred in the water supply, there were only slight deviations from national estimates in the proportions of households reporting various other degrees of the condition.

Consistent with the pattern seen in the size-of-place comparison, changes in the usual condition of the water supply with respect to color were reported by about 17 percent of households served either by community systems or intermediate systems, but by only 10.9 percent of households served by individual systems.

Figure V-32b

Size-of-Place Variation in Perceived Color in Rural Household Water Supplies



Sediment

While 14.7 million rural households (66.8 percent) reported there was never any sediment in the water supply, 7.3 million households (33.2 percent) experienced some degree of sedimentation (see Figure V-33). For most households reporting sediment (4.6 million, or 20.9 percent), the condition was an occasional problem, and did not involve heavy sediment. In 491,000 households (2.2 percent), the water supply generally had no sediment. A prevalent sediment condition —heavy sediment occurring some of the time or a milder condition that was present most or all of the time—was reported in two million households (9.0 percent). Heavy sediment characterized as either generally or constantly present was reported at a total of 247,000 households (1.1 percent). Changes from the usual condition of the water supply with respect to sediment were noticed at 16.8 percent of all households.

Reasons for water supply sediment

Sediment was most frequently attributed to factors of supply technology (inadequacy or breakdowns of facilities) and management; altogether, such factors were cited at 32.5 percent of rural households reporting sediment (see Table V-13). Various natural conditions—the mineral content of the water, the presence of sediment in the source, weather conditions, and seasonal factors—were cited at 25.9 percent. A large proportion of households (20.0 percent) could not give a reason for the sediment condition.

Agreeability of water supply sediment

An estimated 59.5 percent of rural households liked the water supply with respect to sediment, 14.3 percent disliked it, and 26.2 percent had neutral feelings. As would be expected, conditions of heavy sediment and no sediment both generated strong feelings. The absence of sediment was very well liked in eight

Figure V-33

Intensity and Duration of Perceived Sediment in Rural Household Water Supplies

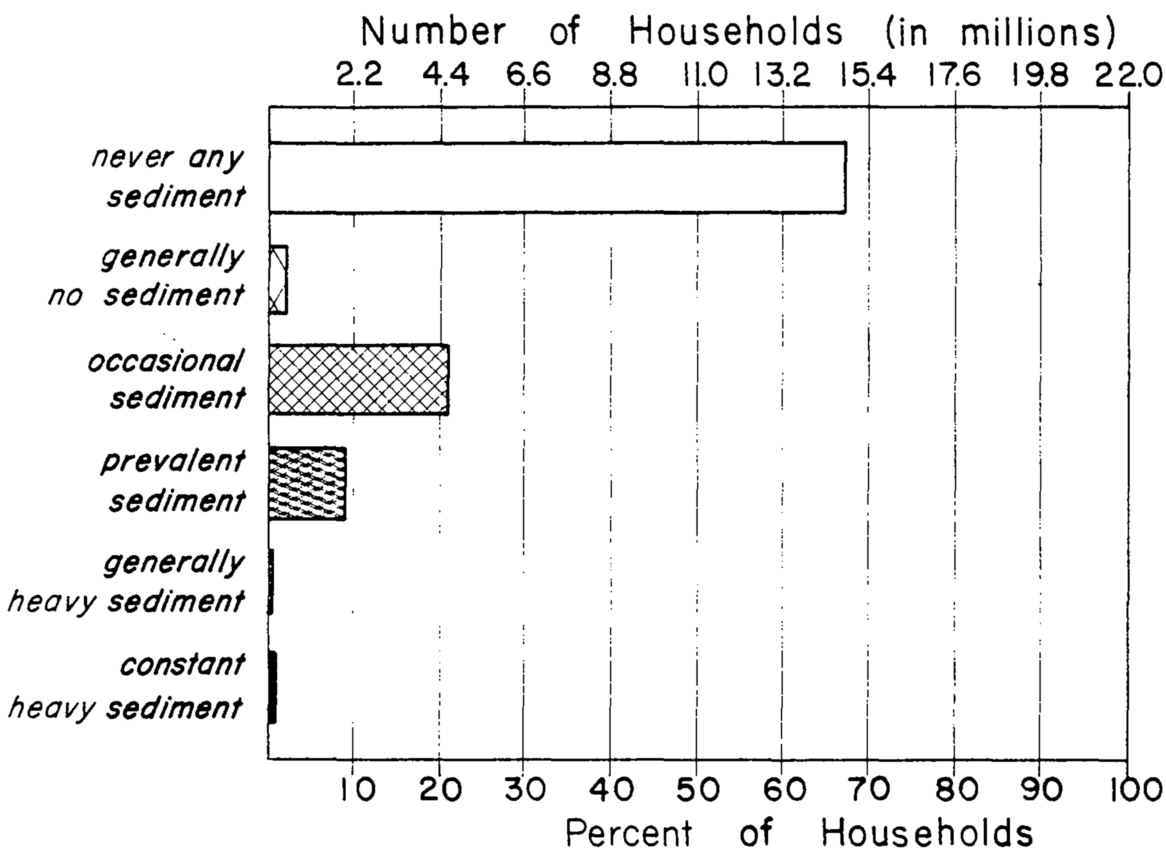


Table V-13

Reported Reasons for Perceived Sediment in Rural Household Water Supplies

	Nation	
Reason	Number of Households	Percent of Households
A breakdown in the physical facilities of the water system outside the house	1,052,000	14.4
Inadequacy of the physical facilities of the system	1,017,000	13.9
Mineral content of the water	850,000	11.6
Deliberate or planned activities	687,000	9.4
A problem within the house	634,000	8.7
Source contains sediment which does not settle out	499,000	6.8
Weather conditions	490,000	6.7
Mismanagement of the system	307,000	4.2
Seasonal factors	62,000	0.8
Other miscellaneous	260,000	3.6
Don't know	1,465,000	20.0
*Total	7,324,000	100.1

*Table includes only those households which reported sediment in their water supplies.

Each figure in the table is rounded independently; numbers and percentages may not equal rounded totals.

out of ten rural households; on the other hand, heavy sediment was strongly disliked whenever it occurred. In contrast to the strong feelings aroused by heavy sediment and a total lack of sediment, neutral feelings were expressed more frequently when the supply provided water having a moderate level of sediment.

Major subnational patterns in sediment

Except for regional differences, subnational comparisons showed no appreciable variation in the frequency and intensity of sediment conditions. The chief regional difference was the much higher proportion of households in the West that reported sediment in the water supply (see Figure V-33a). In the West, only 56.5 percent of households reported that there was never any sediment in the water, compared to 66.9 percent in the Northeast, 65.8 percent in the North Central, and 70.5 percent in the South. A small proportion in each region reported that the water supply generally had no sediment, and proportions reporting occasional sediment were about equal in the four regions. Prevalent or even more pervasive sediment conditions were reported at 16.3 percent of households in the West, combined, compared to 9.3 percent in the Northeast, 11.1 percent in the North Central, and 7.8 percent in the South. Thus, sediment was reported most frequently in the West and least frequently in the South.

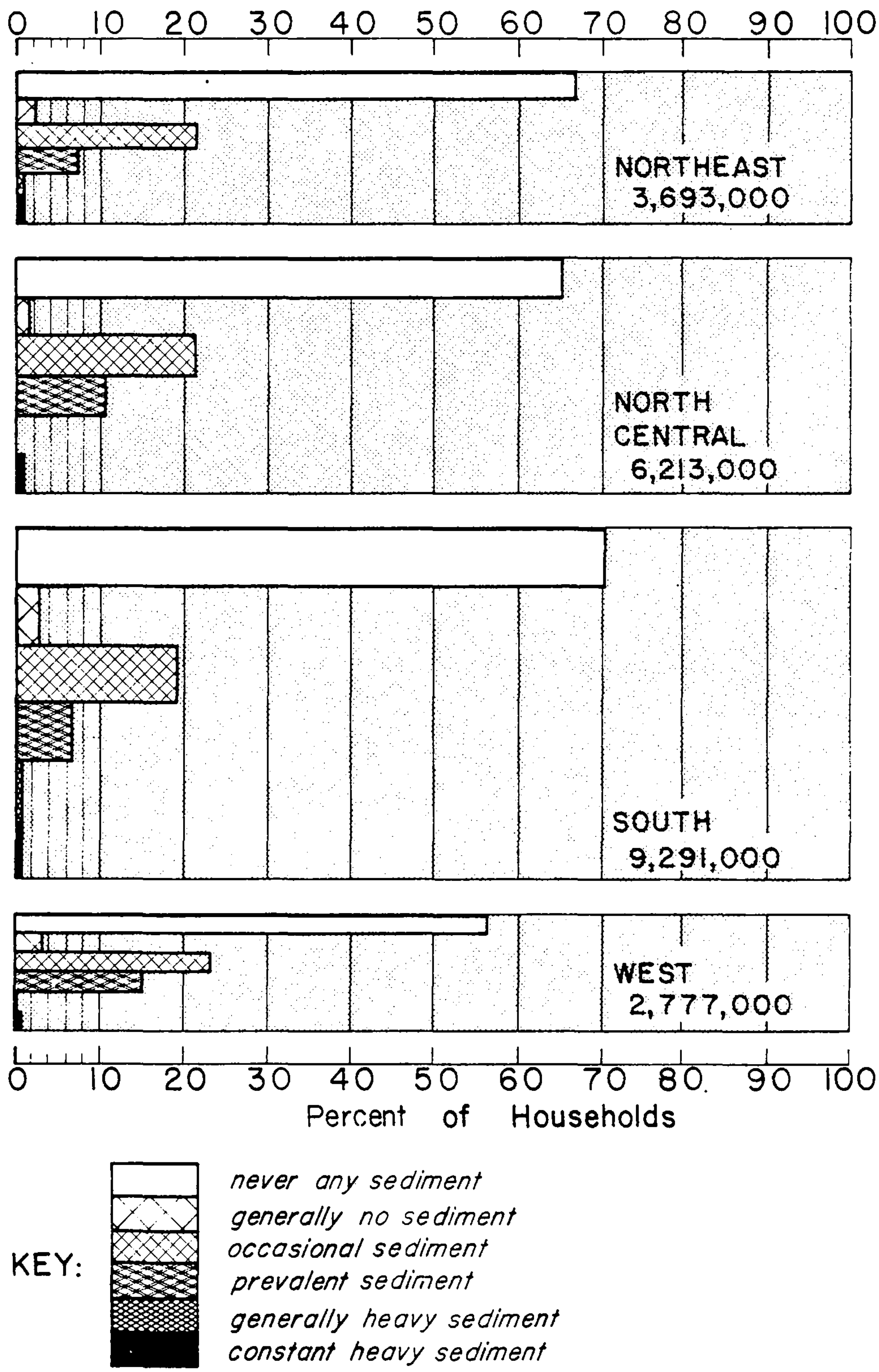
Changes from the household water supply's usual condition with respect to sediment were noticed most often in the West (20.5 percent of households, compared to 18.1 percent in the Northeast, 16.5 percent in the North Central, and 15.5 percent in the South). Other subnational comparisons showed no variation from national estimates with respect to changes from the usual sediment condition.

Temperature

At almost all rural households, the temperature of the water supply was perceived as usually cool or cold. The water was described as cool at 56.0 percent

Figure V-33a

Regional Variation in Perceived Sediment
in Rural Household Water Supplies



of rural households (12.3 million), and as cold at 37.9 percent (8.3 million). The water was depicted as warm at only 5.9 percent of rural households (1.3 million).

No changes in the usual water temperature were noticed at 75.0 percent of households, but changes were reported at 5.5 million of them. Further, for the vast majority of those 5.5 million households—92 percent—the water temperature was fairly constant; for 1.5 million, however, fluctuations in water temperature occurred all the time. Fluctuations were more common in warmer supplies than in colder ones.

Reasons for water supply temperature

At almost 61 percent of households, the temperature of the water supply was attributed to the natural temperature of the source (see Table V-14). Seasonal variation—another natural occurrence—was the next most frequently cited reason for the temperature of the water supply, but it was mentioned at only 12.5 percent of households. Other reasons, such as various possible features of the water supply system, were mentioned only infrequently. No reason could be cited at 17.7 percent of households.

The reasons given in Table V-14 for the temperature of the water supply are not distinguished by the specific usual temperature reported for the household supply. When the reasons were considered in light of the usual temperature of the water supply, some striking differences became apparent. At 92.6 percent of households where the water supply was cold, the temperature was attributed to natural conditions. In contrast, natural conditions were judged to be the cause of the water temperature at only 66.1 percent of households where the water supply was cool. Seasonal factors rarely were cited as the reason for cold temperatures (in 5.7 percent of rural households reporting cold water), but more often as the reason for cool temperatures (in 21.2 percent of households reporting cool water). In contrast to the reasons given for cold and cool water, the reasons for warm

Table V-14

Reported Reasons for Perceived Temperature of Rural Household Water Supplies

Reason	Nation: Number of Households	Nation: Percent of Households
Natural temperature of the water	13,389,000	60.9
Seasonal factors	2,754,000	12.5
Pipes are too close to the surface of the ground	835,000	3.8
Pipes pass too close to a heating device	424,000	1.9
Storage tank is in direct sunlight or otherwise heated	313,000	1.4
Other miscellaneous	367,000	1.7
Don't know	3,889,000	17.7
Total	21,974,000	99.9

Each figure in the table is rounded independently; numbers and percentages may not equal rounded totals.

water most often were related to the physical structure of the supply. That is, pipes were thought to pass too closely to heating devices in 18.9 percent of households reporting warm water, and pipes were thought to be laid too closely to the surface of the ground in 30.1 percent of those households. In further contrast, seasonal factors were cited more often at households reporting warm water temperatures (25.0 percent of these households).

Agreeability of water supply temperature

In general, the temperature of the water supply was found to be agreeable. It was described as satisfactory or better at fully 96.0 percent of rural households. A moderate dislike of the water temperature was reported at 3.0 percent of households, and a strong dislike for it was stated at only 0.9 percent.

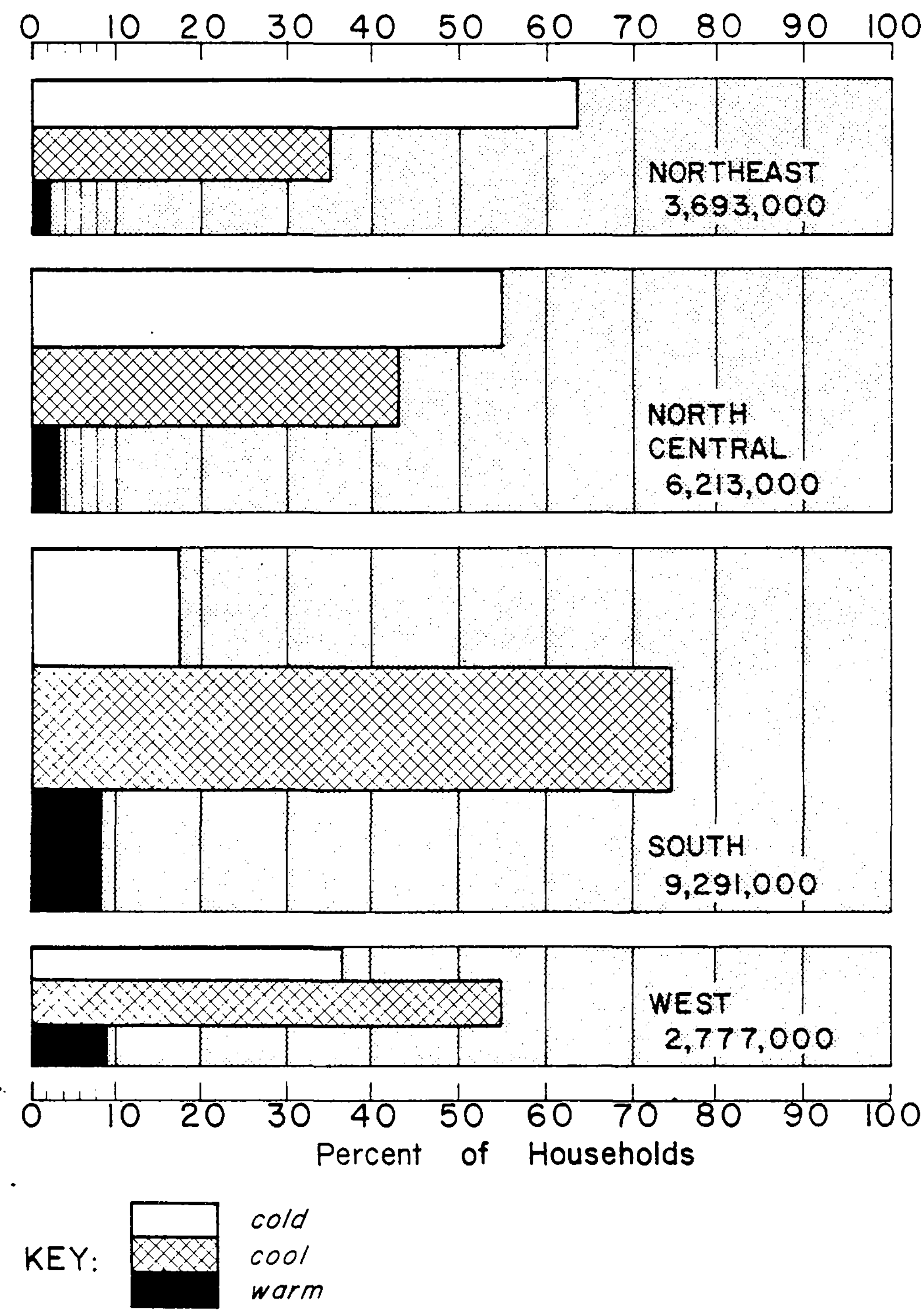
Clear preferences about water temperature were also indicated. As would be expected, a water supply that was usually cool or cold was unquestionably preferred, with cold water preferred more strongly. A moderate to strong dislike for warm water also was observed frequently.

Major subnational patterns in temperature

Regional variations in reported household water temperatures seemed to be related to climatic differences (see Figure V-34a). Water supplies in the Northeast were predominantly cold (63.3 percent of households), with only 2.2 percent reported to be warm. The North Central showed much the same pattern, though a smaller proportion of households reported that the supply was usually cold (53.8 percent). The South had the smallest proportion of households having cold supplies (17.6 percent). Overall, warm water supplies were infrequent, but they were reported by about equal proportions of households in the South and West (8.2 percent and 8.8 percent, respectively). Most households in the South and West reported cool water (74.1 percent in the South and 54.8 percent in the West).

Figure V-34a

Regional Variation in Perceived Temperature of Rural Household Water Supplies



Changes in water temperature were reported by 33.6 percent of households in the West, 28.9 percent in the South, 21.8 percent in the Northeast, and 17.1 percent in the North Central.

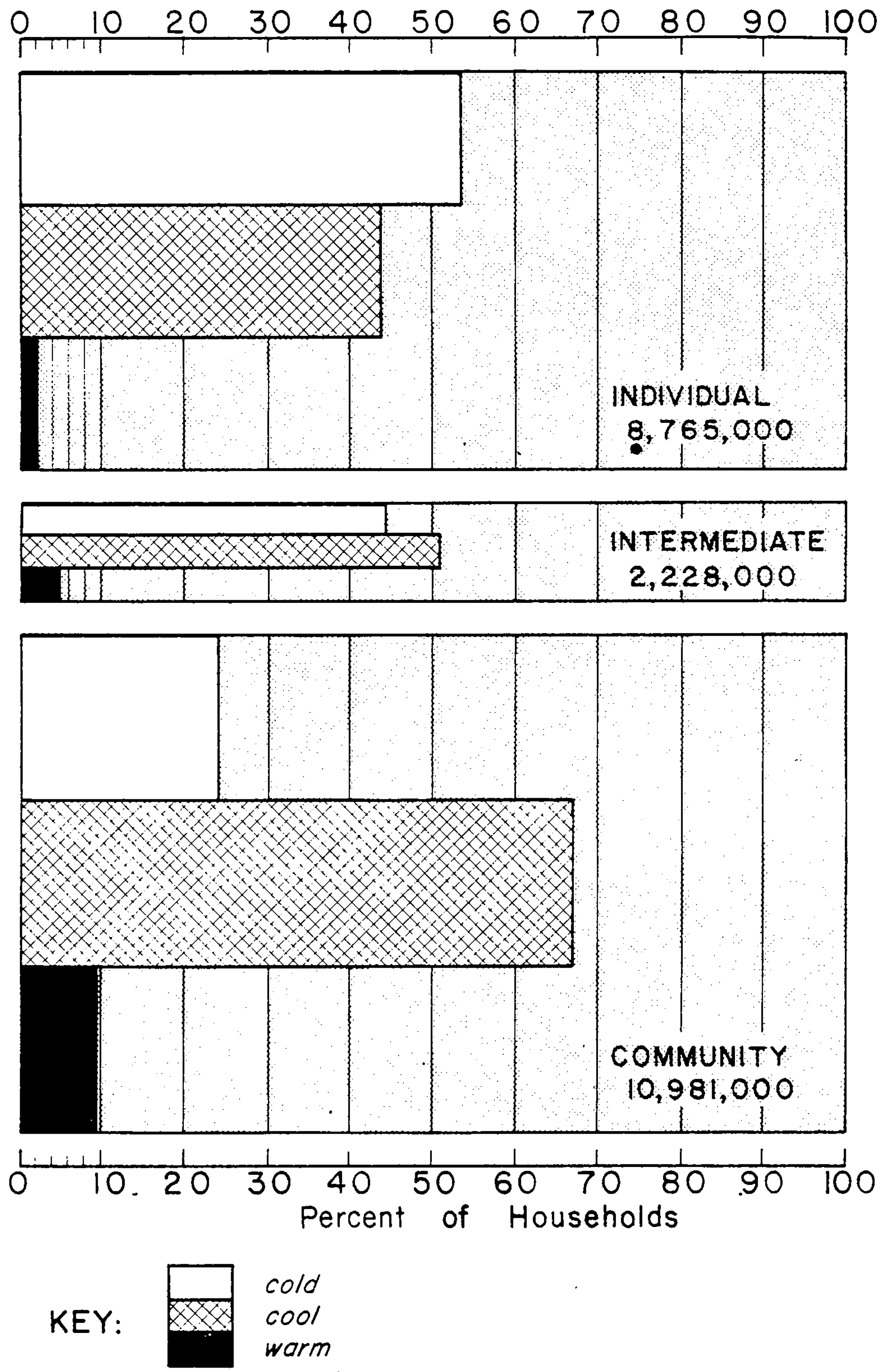
A comparison of SMSA and nonSMSA households showed a variation of three percentage points or less from national estimates of the usual temperature of rural household water supplies. Likewise, the same proportions of SMSA and nonSMSA households reported changes in the usual temperature of the supply.

Slight differences were observed when households in large rural communities, small rural communities, and other rural areas were compared. With decreasing place size, the proportion of cold supplies increased and the proportion of warm supplies decreased. For example, in large communities, 30.5 percent of household supplies were described as cold and 11.4 percent as warm. Among households in small communities, 35.4 percent were described as cold and 6.4 percent as warm. In other rural areas, 39.2 percent were described as cold and 5.2 percent as warm. Changes in the usual temperature of the water supply were more common in large rural communities, where one out of every three households reported temperature fluctuations, compared to one in four in both small rural communities and other rural areas.

Striking differences were observed in the usual temperature of the water supply among households served by systems of different sizes (see Figure V-34b). Among households served by individual systems, 53.8 percent reported cold water, 44.0 percent reported cool water, and 2.1 percent reported warm water. Among households served by intermediate systems, the proportions were 44.2 percent cold, 50.9 percent cool, and 4.9 percent warm. Households served by community systems showed a very different pattern, however: only 24.1 percent reported cold temperatures, 66.8 percent reported cool temperatures, and 9.2 percent reported warm temperatures.

Figure V-34b

Size-of-System Variation in Perceived Temperature of Rural Household Water Supplies



The proportions of households reporting changes in the usual temperature of the water supply increased as system size increased. This finding was consistent with the size-of-system differences in the usual temperature of the water supply. That is, a large proportion of households served by community systems (one out of every three) reported changes in water temperatures. On the other hand, water temperature changes were reported much less frequently among households served by individual systems (17.1 percent) and intermediate systems (19.8 percent).

Seasonal variation in perceived water quality

Household respondents were asked if they noticed seasonal variation in their water supplies with regard to odor, taste, cloudiness, color, sediment, or temperature. If any seasonal variation was identified, respondents were then asked to describe what the usual condition was during each of the four seasons. The possible responses corresponded with those characterizing respondents' initial evaluations of usual water supply conditions—for example, no taste, slight taste, or strong taste.

In general, very little seasonal variation was noticed for any of the characteristics, with the exception of temperature. As to the water's odor, taste, color, cloudiness, and sediment content, seasonal variation in each characteristic was noticed in only about one million rural households. In contrast, 7.6 million, or about one-third of all rural households, reported temperature fluctuations resulting from seasonal factors.

Strong odors occurred more frequently during the summer season, as did strong tastes. Strong odors were perceived in 0.3 million water supplies during the summer months, and strong tastes in 0.4 million. In contrast, strong odors and tastes were perceived in only about 0.1 million water supplies during the winter months. Slight odors and tastes were noticed with equal frequency during each of the four seasons.

Seasonal variations in the temperature of household water supplies were just as one would expect: cold water temperatures were reported most often in the winter months, slightly less frequently during the spring, and so forth.

Slight or heavy cloudiness was perceived most often during the winter and spring. Slight cloudiness was reported in 0.4 million rural water supplies during the winter and 0.3 million during the spring. Very cloudy conditions were reported in approximately 0.1 million water supplies during both the winter and spring.

Color was present in water supplies relatively infrequently during the winter months. A very colored condition was perceived in only 24,000 water supplies in the winter, compared to 0.2 million in the summer. Slight color was perceived in 0.2 million water supplies in winter, but in approximately 0.3 million during spring, summer, and fall.

Sediment occurred most frequently in summer and winter. In summer, 0.2 million supplies had heavy sediment and 0.4 million had moderate sediment. In winter, 38,000 supplies had heavy sediment and 0.3 million had moderate sediment.

Subnational comparisons of seasonal variation were not drawn because of the small number of households reporting seasonal variation in water conditions.

QUANTITY

Beginning with this section, the focus of Chapter V shifts away from water quality to other dimensions of household water conditions—quantity, availability, cost, affordability, and health effects. As to quantity, competing demands on water resources, diminishing underground water reserves, and occasional localized droughts have prompted new interest in the demand for water. Domestic consumption, though it constitutes only a small portion of the total demand for water, is a focus of attention because it requires water of especially high quality. In fact, the quantity of easily obtained drinking water is limited, particularly in certain geographical areas of the US. Less abundant sources in those areas can cause water supply problems for some rural households, no matter what type of water supply is used. Households which are dependent upon one supply of water for all uses (both indoor and outdoor) generally run the greatest risk of experiencing quantity problems. People who supply their own water sometimes need elaborate pumping and storage equipment to obtain a reliable supply; for these people, the equipment itself imposes mechanical limitations on water quantity.

NSA investigators focused on these considerations by exploring domestic water use, supply capacity, and users' subjective judgments about the amount of water available. Potential water use by households using individual supply systems was estimated according to the supply's pump capacity, the effective volume of pressurized storage tanks, or the capacity of other storage tanks. As to households served by community systems (fifteen or more connections), a check of the billed meter readings provided an indication of water consumption. But not all systems were metered, and for those which were, it was not always possible to obtain sufficiently detailed information about quantity from the bills. Potential water use by persons who used hauled water or purchased bottled water as their major supply was estimated by the amount of water hauled or purchased (as reported in Chapter IV). Users' judgments about the quantity of their supplies were explored in a series of direct questions (see "Perceived quantity," below).

RECORDED QUANTITY

About 4.8 million households received bills which reported the total volume of water delivered. However, since the billing periods varied, the average daily consumption at each household had to be computed, and only 4.5 million households had bills with sufficient information for this computation. This meant that fairly exact measurements of water consumption were available for roughly 20 percent of all rural households. Furthermore, for some households with more than one supply, consumption was slightly underestimated since estimates did not include the quantity of water used from supplemental supplies.

The range of average daily consumption in households served by community systems was striking. Some households averaged as little as twelve liters (three gallons) per day, others as much as 5,123 liters (1,352 gallons) per day. The mean daily consumption per household was 829 liters (219 gallons). The median was 664 liters (175 gallons) per day.

Taking into account the number of people residing in the household, daily per capita consumption ranged from a low of twelve liters (three gallons) to a high of 2,562 liters (676 gallons). (Such very high consumption figures may have been caused by the fact that many households had only one supply of water, which they used for both indoor and outdoor purposes. Some households also used the household supply for agricultural uses such as irrigation and watering livestock.) The mean consumption rate was 285 liters (75 gallons), and the median 227 liters (60 gallons), per person per day. These consumption figures were based on water bills for all four seasons, but since most of the interviews were conducted during the summer, estimates adjusted for seasonal differences would probably be lower.

The majority of rural households were not connected to metered systems, and for them, the NSA had no direct measure of water quantity. For these households, quantity could be described only in regard to devices which had a bearing on the volume of water available to the household. Capacities of pressure tanks, storage tanks, and pumps all were considered to affect both the quantity and availability of water. That is, they influenced the total volume of water a household could obtain, as well as the reliability of the supply.

There were roughly 9.8 million rural households which had on-premises water pumps for their water supplies. The average pump capacity was 41 liters (eleven gallons) per minute. The median value was 22 liters (six gallons) per minute. Most of these households (9.5 million) also had at least one pressure tank (about 1 percent had more than one pressure tank). Pressure tank capacities ranged from roughly two liters (one-half gallon) to over 10,000 liters (over 2,600 gallons). Tanks held an average (mean) of 219 liters (58 gallons); the median capacity was 114 liters (30 gallons).

An attempt also was made to measure the effective volume of pressure tanks. This involved running the water until the pump started to operate. All of the water outlets then were closed, and the pressure tank was allowed to fill. After the pump turned off, indicating the pressure tank was fully charged, one tap was opened and the water volume was measured until the pump came on again. This volume of water was taken to be the effective volume of the pressure tank. Unfortunately, the construction and layout of some systems precluded the measurement since there was no reasonable way to monitor the pump operation. Among the approximately nine million households where the effective volume of the pressure tank could be determined, the average effective volume was 51 liters (fourteen gallons) while the median was thirteen liters (three gallons). About 4 percent of these tanks were found to be completely waterlogged. That is, the cushion of compressed air in the tank which was supposed to provide the pressure was entirely dissipated. In these households, the pump went on every time a tap was opened. The largest effective volume encountered was 800 liters (211 gallons).

Auxiliary storage tanks (not pressure tanks) were relatively rare. Only 4.3 percent of all rural households had storage tanks. When they were present, they tended to be large. The average size was about 3,500 liters (925 gallons); the median was about 760 liters (200 gallons).

Pressure tanks are a more or less standard feature of many household supplies, but storage tanks are a different matter. If a household has an on-premises storage tank, it is probably because the system does not provide an adequate quantity of water on demand. Storage tanks in general represent an attempt to ensure sufficient quantities of water when needed. The fact that 4.3

percent of rural households had such devices does not mean that only 4.3 percent had a water quantity or reliability problem. However, it can be taken as an indication that those households with storage tanks could afford this fairly expensive method of supply stabilization. The sections later in this chapter on the perceptions of rural people regarding quantity and availability provide other indications of the extent of water quantity problems throughout the US.

Subnational variation in recorded quantity

There were large differences in consumption patterns from one region to another. The median daily per capita consumption among households which were metered and billed for their water was 188 liters (50 gallons) in the North Central, 212 liters (56 gallons) in the Northeast, and about 234 liters (62 gallons) in both the South and West. A comparison of means (rather than medians) showed the West with the highest average per capita daily consumption (307 liters, or 81 gallons). Average figures in other regions were 290 liters in the South, 275 liters in the Northeast, and 250 liters in the North Central. The larger average consumption figure in the West reflected the greater frequency, relative to the other regions, of households using very large quantities of water. In turn, the use of large quantities of water was related to several factors: lower levels of precipitation and coincident supplemental watering of lawns and gardens, the use of swamp coolers, and the general unavailability of supplemental supplies.

There was little difference between SMSA and nonSMSA households in daily per capita consumption, or among households in large communities, small communities, and other rural areas: median daily per capita usage was uniformly about 230 liters (61 gallons). No size-of-system comparison could be made, since only households served by community systems could provide billing information which included consumption figures.

Two-thirds of households in the West were connected to community supplies, but among those that used wells or surface supplies, the potential for greater per capita consumption still was evident—at least on the basis of pump capacity. The median pump capacity in the West was 48 liters (thirteen gallons) per minute. The other regions, by contrast, were fairly uniform at roughly twenty liters (five gallons) per minute. Pressure tanks in the West had nearly double the effective volume of that in other regions (23 liters). Storage tanks also tended to be large in the West, with a median size of 3,777 liters (997 gallons), compared to 229 liters (61 gallons) in the Northeast and 568 liters (150 gallons) in the North Central. The South, however, actually had the largest median storage tank size—3,791 liters (1,000 gallons). In the other three regions, slightly more than 5 percent of the households had storage tanks, compared to about 3 percent in the South.

There were no substantial differences between SMSA and nonSMSA households regarding pump capacity or with respect to pressure tanks and storage tanks. In the size-of-place comparison, however, it was found that households in other rural areas were more likely to have these devices. (The majority of households in other rural areas had individual wells which use such devices.) The most notable other difference was that storage tanks were used in fewer than 2 percent of households in small communities, but almost 5 percent of households in other rural areas had them. Also, in other rural areas, the median storage tank size was 758 liters (200 gallons), about twice that in small rural communities. (There were too few storage tanks in large-rural-community households to permit a comparison.)

Comparing households served by systems of different sizes, only 0.3 percent of households served by community systems had supplementary devices at the household such as pumps and storage tanks. Between households using individual systems and those using intermediate systems, the major differences pertained to the size of the devices that were used. Among households using intermediate systems, pumps had a larger median capacity (26 liters per minute, compared to twenty liters per minute), a larger median size of pressure tank (152 liters, compared to about 114 liters), and substantially larger storage tanks. About 8 percent of households using individual systems had a storage tank; the median capacity was 758 liters (200 gallons). Among households using intermediate systems, 9.4 percent had a storage tank; the median capacity was 1,895 liters (500 gallons).

PERCEIVED QUANTITY

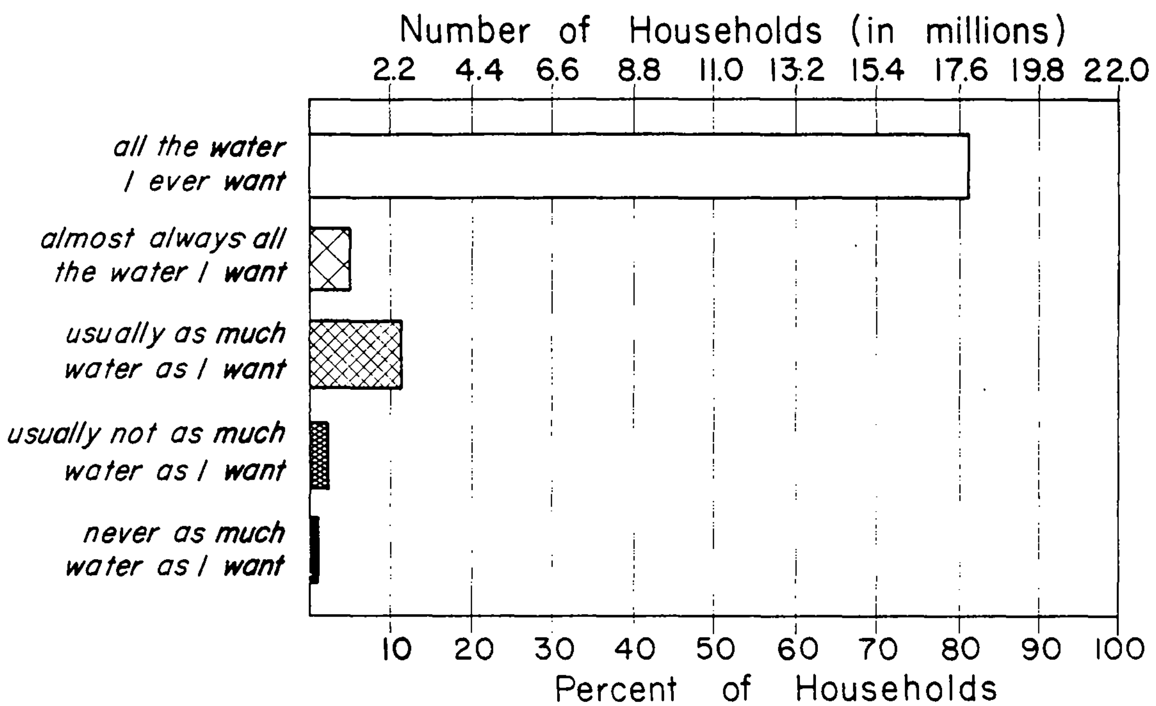
The volume of water used in a household is inextricably tied to people's beliefs about the ability of the water supply to provide enough water. Mistaken beliefs could lead the members of a household to restrict water usage unnecessarily, or to continue normal usage when the supply is actually low and requires conservation.

In the NSA, most rural households reported having ample water supplies (see Figure V-35). Of all rural households, 17.7 million (80.7 percent) reported that the major household supply completely satisfied their water requirements. In another 1.1 million households (5.0 percent), the supply almost always provided enough water. Further, almost 2.5 million households (11.3 percent) reported that the supply usually provided as much water as wanted. However, in some households, the supply usually did <u>not</u> provide as much water as people wanted (470,000 households, or 2.1 percent), and supplies at some households never provided an acceptable quantity of water (206,000, or 0.9 percent).

Little fluctuation was noticed in the amount of water readily available from household supplies. At 85.5 percent of households, no change was reported. However, some change in water quantity was noticed in 3.2 million households (14.4 percent).

Figure V-35

Perceived Quantity of Rural Household Water Supplies



<u>Reasons for insufficient quantity</u>

Of those households that reported receiving less water than they needed, or that reported changes occurring in the amount usually provided by the supply, 39.0 percent or 1.6 million households attributed the problem to inadequacy of the physical facilities of their supply. That is, the pipes, the storage tank, or some other feature of the supply was inadequate. Another 16.1 percent (680,000 households) attributed the problem to a breakdown in the system. Weather conditions reportedly caused the problem at 22.6 percent of the households, or 951,000. Interestingly, though one might expect quantity problems to be a result of an insufficient aquifer or other source, the problem was blamed on an inadequate supply at only 6.3 percent of the households (265,000). Other reported reasons for the condition are given in Table V-15.

<u>Agreeability of water supply quantity</u>

The quantity of the household water supply generally was seen as satisfactory. The amount of water obtained throughout the year was liked in 46.6 percent of all rural households (10.2 million); it was liked very much in 31.2 percent (6.9 million); and it was considered all right, or not thought about much, in 17.8 percent of rural households (3.9 million). The quantity of water available to the household was disliked in only one million rural households (4.4 percent).

<u>Major subnational patterns in perceived water quantity</u>

Although all four regions showed about equal proportions of households reporting that the water supply <u>never</u> provided enough water, the West stood out as having more frequent problems with quantity than the other three regions (see Figure V-35a). Proportionately, many fewer households in the West reported always getting enough water from the household supply (73.8 percent, compared to 83.4 percent in the Northeast, 82.9 percent in the North Central, and 80.1 percent

Table V-15

Reported Reasons for Perceived Insufficiency in Quantity of Water Provided by Rural Household Water Supplies

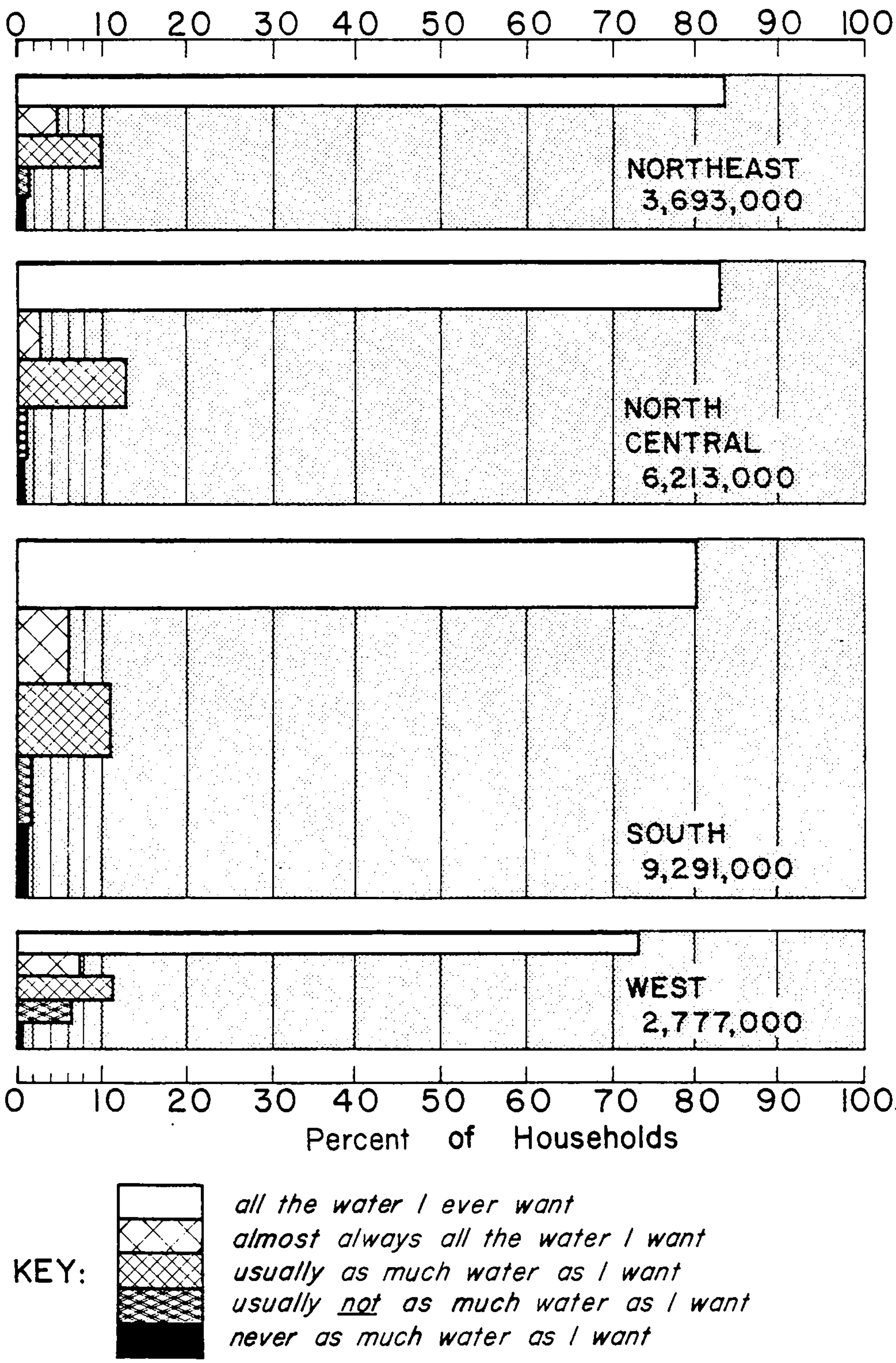
Reason	Nation: Number of Households	Nation: Percent of Households
Inadequacy of the physical facilities of the system	1,643,000	39.0
Weather conditions	951,000	22.6
A breakdown in the physical facilities of the water system outside the house	680,000	16.1
Inadequate supply	265,000	6.3
Seasonal factors	151,000	3.6
Deliberate or planned activities	145,000	3.4
A problem within the house	72,000	1.7
Mismanagement of the system	60,000	1.4
Other miscellaneous	140,000	3.3
Don't know	107,000	2.5
*Total	4,214,000	99.9

*Table includes only those households which reported that the water supply provided an insufficient quantity of water.

Each figure in the table is rounded independently; numbers and percentages may not equal rounded totals.

Figure V-35a

Regional Variation in Perceived Quantity
of Rural Household Water Supplies



in the South). The proportions reporting they almost always got enough water were bigger in the South and West (6.0 percent and 7.5 percent, respectively) than in the Northeast and North Central (4.4 percent and 2.6 percent, respectively). Supplies that usually provided enough water occurred about evenly in the four regions (from 9.8 percent in the Northeast to 12.5 percent in the North Central). In the West, 7.2 percent (200,000 households) reported either that the water supply usually did not provide enough water or that it never did, compared to 2.4 percent in the Northeast, 1.9 percent in the North Central, and 2.8 percent in the South. (The greater frequency of perceived quantity problems in the West may have been related to the greater demand for water among households in the West (see Chapter III, "Regional variation in uses of water").

Little or no variation from national estimates of perceived quantity was apparent between households located within and outside of SMSAs, or among households served by systems of different sizes. SMSA/nonSMSA variation amounted to less than two percentage points; the size-of-system comparison showed at most a difference of three percentage points in any particular category.

In the size-of-place comparison as well, there was little variation from national estimates, except that in large rural communities, a larger proportion (9.2 percent, compared to the national estimate of 5.0 percent) reported almost always getting enough water, and a smaller proportion (7.1 percent, compared to the national estimate of 11.3 percent) reported usually getting enough water from the household supply.

As to changes in the water supply with respect to quantity, a higher proportion of households in the West (20.5 percent) reported variations in the amount of water the supply provided. In the Northeast and North Central regions, changes in the quantity of water provided by the household supply were reported in roughly 11 percent of rural households. In the South, changes were noticed in 15.7 percent of all rural households.

No other subnational comparison showed substantive variations from national estimates with respect to changes in the usual quantity provided by the water supply.

Seasonal variation in perceived water quantity

Although seasonal factors rarely were cited as reasons for an insufficient water supply, seasonal variations were perceived in approximately two million rural households across the country.

It is clear from Table V-16 that quantity problems were noticed much more frequently during the summer months. Of those households where seasonal variation occurred, 36.4 percent—a total of 736,000 households—reported that during the summer, the water supply usually or never provided as much water as wanted. On the other hand, water was in abundance during the other seasons: supplies were reported to be at least usually ample in more than 89 percent of the households reporting seasonal variation.

AVAILABILITY

To completely satisfy household needs, a water supply must be capable of providing a sufficient volume of water on a continuous basis. If enough water cannot be obtained, even temporarily, the supply's availability is limited. Such limitations, whether they occur on an intermittent or protracted basis, may have significant consequences for the members of a household. Many sorts of adjustments may have to be made, such as adapting normal patterns of water use and consumption to the availability of the supply, or acquiring water from an alternate supply when the major supply is not providing enough. Thus, availability is a separate issue that must be addressed when evaluating rural water conditions, independent of water quality and distinct from the quantity of water produced by a supply.

Table V-16

Seasonal Variation in Perceived Quantity of Rural Household Water Supplies

	Percent of Households			
Quantity Provided	Spring	Summer	Fall	Winter
All the water ever wanted	54.7	10.2	49.1	66.1
Usually as much water as wanted	39.6	53.4	40.2	23.2
Usually not as much water as wanted	4.4	29.5	7.3	6.9
Never as much water as wanted	1.3	6.9	3.0	3.5
Don't know	0.0	0.0	0.3	0.3
*Total	100.0	100.0	99.9	100.0

*Table includes only those households which reported seasonal variation in the quantity of water provided by their water supplies.

Conceptually, availability has two components. First, availability may be defined in terms of reliability, a common measure of supply performance. Specific to reliability are various kinds of supply interruptions—those that are the result of intentional actions such as maintenance work, and those that result from breakdowns. The second component of availability pertains to the supply's accessibility, or the difficulty of obtaining water from the supply. Each of the two components reflects the ability of a supply to provide water whenever it is needed, which is the central concern in any definition of availability.

RELIABILITY

In the NSA, reliability was measured with reference to both intentional supply interruptions and breakdowns. An interruption was defined as any temporary loss of a supply, whether it occurred because of scheduled activities such as routine maintenance and repair operations or because of some other factor. A breakdown, on the other hand, referred to a reduction or loss of the water supply which was caused by some unanticipated event, such as equipment failure, operator error, a flood, or an earthquake. According to these definitions, interruptions and breakdowns are analogous to power outages, a concept that is employed in the electrical industry to indicate service quality. However, rather than expressing reliability as a ratio of the number of hours of unsatisfactory service to the total number of hours during a given period, as electrical outages are commonly reported, the NSA simply enumerated breakdowns and other supply interruptions which were reported at the household. The information on breakdowns was compiled for all households, while inquiries about interruptions were restricted to households at which the supply loss was serious or frequent enough to prompt the installation or use of another supply.

With respect to breakdowns, about 16.3 million households in the rural US (74.2 percent) reported that there had been no breakdowns in their water supplies during the year prior to the NSA (see Table V-17). However, approximately 5.6 million supplies, or 25.7 percent, did break down at least once. There had been a single breakdown in 15.1 percent of all rural supplies (3.3 million), while two or more occurred in 10.6 percent (2.3 million). Approximately 1.5 percent of supplies (330,000) broke down six times or more. The maximum number of breakdowns reported was 52, or an average of one per week.

When supply breakdowns occurred, they tended to be lengthy enough to be considered severe. In the NSA, a severe breakdown was defined as a loss of supply which lasted more than six consecutive hours during the previous year. More than 3.2 million households —15 percent of all rural households, or slightly more than 57 percent of those that reported supply breakdowns—indicated that one or more of the breakdowns had been severe. (For the vast majority of these households, however, only a single such incident had occurred.) Fewer than 161,000 supplies had had four or more severe breakdowns.

Generally, breakdowns did not occur within the housing structure. At about 83 percent of the 5.6 million households where supply breakdowns occurred (4.6 million), the problem arose outside of the building; at 17 percent (952,000), the problem arose inside. The pattern was the same for those 3.2 million households where severe supply breakdowns occurred: about 81 percent of these households (2.6 million) reported that the breakdowns occurred outside the structure, and 19 percent (600,000) reported they happened inside. Therefore, whether severe or not, breakdowns were substantially more often attributed to some aspect of the supply external to the household rather than to the household plumbing and treatment facilities.

Rural households reacted to water supply breakdowns in different ways, depending upon when the breakdown occurred, its duration, and other factors. The most common response was to simply wait until the supply was restored, which was what about 48 percent of the 5.6 million households (2.7 million) did. Slightly more

Table V-17

Frequency of Rural Water Supply Breakdowns During Previous Year

	Nation	
Frequency of Breakdowns	Number of Supplies	Percent of Supplies
None	16,299,000	74.2
1	3,324,000	15.1
2	1,121,000	5.1
3	520,000	2.4
4	251,000	1.1
5	106,000	0.5
6 or more	324,000	1.5
Unspecified	29,000	0.1
Total	21,974,000	100.0

Each figure in the table is rounded independently; numbers and percentages may not equal rounded totals.

than 32 percent (1.8 million) obtained water by borrowing it temporarily from friends, neighbors, or relatives, while 16.0 percent (900,000) performed the necessary repairs to restore the supply. About 5 percent of the households in which breakdowns occurred (580,000) were able to acquire water from another supply on the premises, and approximately 3 percent hauled water from an off-premise supply (168,000). The least common response to a breakdown was to purchase water from a commercial establishment; less than 2 percent of the households did this (112,000). Although most of these households had a single, characteristic reaction to a supply breakdown, certain households reported doing various things (which caused the percentages to exceed 100 percent).

Although severe breakdowns occurred at 3.2 million households, substantially fewer households had gone to the trouble and expense of installing a more reliable supply. In fact, across the nation, only about 1 percent of all households used another water supply because the major supply was frequently or chronically interrupted. While comparatively small, this proportion represented about 221,000 rural households.

To summarize, 5.6 million of the supplies from which rural households obtained their water broke down one or more times during the year before the NSA. Slightly more than 3.2 million rural households (about 15 percent) reported breakdowns that were considered severe by the NSA definition. Independent of severity, the vast majority of the 5.6 million households that reported breakdowns (about 83 percent, or 4.6 million) attributed them to problems outside of the household. When a breakdown occurred, most households (4.3 million) waited until the supply was repaired or borrowed water from relatives, friends, or neighbors.

Regional variation in reliability

According to regional compilations, there were substantial differences in the proportions of households where water supply breakdowns occurred, and in the number of breakdowns typically reported (see Table V-18). In the West, for example, 20.5 percent of all rural households experienced one or more water supply breakdowns, while in the South 29.2 percent did. Further, about 14 percent of the households in the South reported two or more breakdowns, compared to only 6.7 percent of the households in the West. In addition, household supplies in the South tended to break down more often than supplies in the other regions. This tendency was observed in spite of the fact that the supplies of a very small proportion of the households in the North Central broke down as many as 52 times, while the maximum number of supply breakdowns reported by households in the South was 25.

Compared to the number of households that noted supply breakdowns and compared to the number of rural households in each region, the number of households that reported severe breakdowns showed appreciable regional variation. Approximately 59.3 percent of the households in the North Central where breakdowns occurred reported the breakdowns to be severe, compared to 54.6 percent in the West, 51.0 percent in the South, and 49.8 percent in the Northeast. Alternatively, counting all rural households in each region, 17.1 percent of supplies in the South sustained at least one severe breakdown, while severe breakdowns were limited to 10.8 percent of the Northeast's rural households. (Severe breakdowns were experienced by 11.1 percent of households in the West and 15.0 percent in the North Central.) This finding suggests that household supplies in the South were more likely to sustain severe breakdowns than those in the Northeast, North Central, and West.

There was considerable regional variation in the point of origin of the supply breakdowns—that is, whether they arose within or outside the housing structure. Considering all rural households that reported breakdowns, whether severe or not, slightly more than 30 percent in the Northeast indicated that the breakdowns occurred within the dwelling unit, while about 70 percent reported that the breakdowns took place outside. This was in sharp contrast to the West, where

Table V-18

Regional Variation in Frequency of Rural Water Supply Breakdowns During Previous Year

Frequency of Breakdowns	Percent of Supplies: Northeast	North Central	South	West
None	78.2	74.6	70.6	79.4
1	14.6	15.4	15.6	13.8
2 or more	7.2	9.9	13.6	6.7
Unspecified	0.0	0.1	0.2	0.1
Total Percent	100.0	100.0	100.0	100.0
Total Supplies	3,693,000	6,213,000	9,291,000	2,777,000

about 2 percent reported breakdowns inside the dwelling unit and roughly 98 percent reported breakdowns outside the dwelling unit. When only severe breakdowns were considered, the same pattern emerged, except that instead of the Northeast showing the highest proportion of breakdowns inside the house, the North Central did. In the North Central, 32.5 percent of the households where breakdowns occurred reported they originated inside the house.

Finally, there were noticeable regional differences in households' reactions to supply breakdowns. About 58 percent of the households in the West that reported supply breakdowns simply waited until the water supply resumed operation, compared to 44.0 percent of the households in the Northeast. In the West, only 6.4 percent of the households that reported breakdowns repaired the supply, while 28.3 percent of those in the Northeast did. Although borrowing water was a common response in all regions, it was most prevalent in the South, where 35.7 percent of the households with inoperable supplies borrowed water temporarily. Using an alternate supply was most common in the West, where that action was taken by 9.9 percent of the households with supply breakdowns. In the Northeast, 6.2 percent of the households that reported breakdowns hauled water when their major supply was unavailable.

Only slight regional variations were detected in the proportions of rural households that had installed an alternate supply because the major supply was frequently or chronically subject to breakdowns. The proportions ranged from 0.5 percent in the South to 2.2 percent in the West.

In summary, household supplies in the South and North Central tended to be less reliable in terms of breakdowns than supplies in the other two regions. About 29 percent of the households in the South, and 25.3 percent of those in the North Central, reported supply breakdowns, compared to the national total of 25.7 percent. Severe breakdowns also tended to be more prevalent in the South and North Central, where they were reported by 17.1 percent and 15.0 percent of the households, respectively. While the majority of households in each region indicated that supply breakdowns originated outside of the structure, a much larger proportion of the households in the West (about 98 percent) attributed breakdowns to that source. Households in the West also reflected more of a tendency to either wait until the water supply was restored (approximately 58 percent) or to obtain water from an alternate supply (9.9 percent), compared to households in the other regions. For all regions, however, waiting was the most common response to a supply breakdown, and borrowing was the second most common.

SMSA/nonSMSA variation in reliability

Relative to the regional differences that were identified, the variation in SMSA and nonSMSA households with respect to supply breakdowns was insignificant. At least one supply breakdown was reported at 24.2 percent of SMSA households and at 26.4 percent of nonSMSA households. Likewise, the proportions of SMSA households that had one supply breakdown and those with two or more breakdowns (13.5 percent and 10.7 percent, respectively) were approximately the same as the proportions for nonSMSA households (15.9 percent and 10.5 percent). The largest difference between SMSA and nonSMSA households was observed in the maximum number of breakdowns reported, which was 52 for SMSA households and 25 for nonSMSA households.

Severe supply breakdowns occurred at 12.4 percent of all SMSA households and 15.7 percent of all nonSMSA households. These proportions represented 51.3 percent of the SMSA households that reported supply breakdowns and 59.6 percent of nonSMSA households that reported breakdowns. With respect to the origin of breakdowns inside or outside the house, there was a difference between SMSA households and nonSMSA households of less than three percentage points.

As for responses to breakdowns, no appreciable differences could be seen between SMSA and nonSMSA households except that a larger proportion of SMSA households waited until the water supply became available (53.5 percent, compared to 45.4 percent) and a greater proportion of nonSMSA households made repairs to the water supply (17.6 percent, compared to 11.0 percent). That is, approximately the same proportions of SMSA and nonSMSA households that reported supply breakdowns either borrowed water, purchased water, hauled water, used an alternate water supply, or obtained water by some other means.

<u>Size-of-place variation in reliability</u>

Generally, households in small rural communities reported more supply breakdowns than households in large rural communities or other rural areas (see Table V-19). Slightly less than 30 percent of households in small communities reported one or more breakdowns, compared to 22.2 percent of households in large communities. Additionally, 13.7 percent of households in small communities reported two or more breakdowns, compared to 11.5 percent in large communities and 10.2 percent in other rural areas. In large communities, the maximum number of breakdowns reported was eighteen; in small communities, it was eleven; in other rural areas, it was 52.

The data on severe breakdowns reflected roughly the same pattern of variation. Specifically, only 8.1 percent of all rural households in large communities reported severe breakdowns, compared to 16.6 percent of the households in small communities and 15.4 percent in other rural areas. These figures represented 36.4 percent of the households in large rural communities with supply malfunctions, 55.7 percent in small communities, and 59.5 percent in other rural areas. As with supply breakdowns in general, severe breakdowns occurred more frequently in small communities.

The origin of breakdowns inside or outside the house varied substantially according to the size of the place where households were situated. For example, 5.7 percent of those households in large communities where breakdowns occurred

Table V-19

Size-of-Place Variation in Frequency of Rural Water Supply Breakdowns During Previous Year

Frequency of Breakdowns	Percent of Supplies		
	Large Rural Communities	Small Rural Communities	Other Rural Areas
None	77.8	70.3	74.0
1	10.7	16.0	15.6
2 or more	11.5	13.7	10.2
Unspecified	0.0	0.0	0.2
Total Percent	100.0	100.0	100.0
Total Supplies	2,369,000	1,509,000	18,095,000

reported that the breakdowns originated inside the dwelling unit, while 94.3 percent reported that they originated outside. In small communities, 13.1 percent originated inside the dwelling and 86.9 percent originated outside. Among households in other rural areas, the comparable percentages were 19 percent inside and 81 percent outside. When only households with severe breakdowns were considered, the percentages for households in other rural areas did not change appreciably, but among households in large communities, those originating inside increased to 12.6 percent, and those originating outside decreased to 87.4 percent. Among households in small communities, the percentages changed similarly; the change amounted to six percentage points rather than seven.

Although waiting was the most frequent response to a supply breakdown among households in rural communities and in other rural areas, the proportions differed considerably. Slightly less than 72 percent of the households in large communities that reported breakdowns simply waited until the supply became available again, compared to 61.5 percent of the households in small communities and about 44 percent of the households in other rural areas. Likewise, the proportions of households in other rural areas that repaired the supply or borrowed water were significantly higher than in large or small communities. More specifically, the percentage of households that made repairs to a supply or borrowed water in response to a breakdown varied from 51.0 percent of households in other rural areas to around 35 percent of the households in small communities and 30 percent of those in large communities. No major differences besides these could be discerned in reactions to supply breakdowns at households in large communities, small communities, and other rural areas.

In summary, the supplies of households in small rural communities tended to break down more frequently than supplies providing water to households in large communities or other rural areas. About 30 percent of the households in small rural communities reported one or more supply breakdowns, compared to 26.0

percent in other rural areas and 22.2 percent in large rural communities. Consistent with this pattern, households in small rural communities also reported an appreciably higher incidence of severe supply breakdowns. Additionally, a much larger proportion of households in large rural communities simply waited until the supply was repaired, while proportionately more households in other rural areas either initiated repair operations or borrowed water.

Size-of-system variation in reliability

In relative terms, the supplies of households that obtained water from intermediate systems tended to be less reliable than the supplies of households attached to individual or community systems (see Table V-20). Approximately 33 percent of households served by intermediate systems reported at least one breakdown, compared to 26.4 percent of households served by community systems and 22.8 percent of households using individual systems. Additionally, 21.4 percent of households on intermediate systems reported severe supply breakdowns, a proportion substantially greater than the 16.0 percent of households on individual systems and the 12.3 percent of households on community systems. Consistent with these differences, the supplies of households on intermediate systems broke down more frequently in general than supplies of other households, although the maximum number of breakdowns reported—52—occurred among households on community systems. Finally, while breakdowns were least prevalent among households on individual systems, these breakdowns tended to be of longer duration. That is, breakdowns were severe 70.0 percent of the time among households served by individual systems, compared to 65.0 percent of the time among households served by intermediate systems and 46.4 percent of the time among households served by community systems.

Although breakdowns generally originated outside of the dwelling unit, the predominance of such breakdowns varied by the size of the water supply system

Table V-20

Size-of-System Variation in Frequency of Rural Water Supply Breakdowns During Previous Year

Frequency of Breakdowns	Percent of Supplies Individual System	Intermediate System	Community System
None	77.2	66.9	73.3
1	15.9	23.0	12.9
2 or more	6.9	10.1	13.5
Unspecified	0.0	0.0	0.3
Total Percent	100.0	100.0	100.0
Total Supplies	8,765,000	2,228,000	10,981,000

serving the household. Only 7.1 percent of the households on community systems that reported breakdowns said the breakdowns originated within the house, for example, while the remaining 92.9 percent noted that the breakdowns originated outside the house. Among households served by intermediate systems, the proportions were 19.3 percent inside and 80.7 percent outside; among households served by individual systems, the proportions were 30.6 percent inside and 63.4 percent outside. Similar differences were observed in the data on severe breakdowns, but they were not quite as pronounced.

Interestingly, household reactions to breakdowns differed considerably depending on the size of the system serving the household. Only about 24 percent of the households served by individual systems waited until the supply was restored, compared to 34.4 percent of the households served by intermediate systems and 67.6 percent of the households served by community systems. Conversely, 44 percent of the households served by individual systems borrowed water, compared to 36.4 percent of households served by intermediate systems and 23 percent of households served by community systems. (These are reasonable findings, since maintenance and repairs of individual systems are the responsibility of the individual household, and since breakdowns in an intermediate or community system would most often affect neighbors' supplies as well, unlike breakdowns in an individual system.) In addition, as would be expected in light of the large proportion of breakdowns originating outside of the house, only 5.0 percent of the households that were served by community systems and that reported breakdowns took action to repair the supply, while 29.2 percent of the households served by individual systems did. Finally, a much larger proportion of the households on intermediate systems—about 10 percent—hauled water when their principal supply was unavailable.

To summarize, compared with households on individual or community systems, a larger proportion of households on intermediate systems reported one or more supply breakdowns. Also, a greater proportion of households on intermediate systems reported breakdowns that were severe. While severe breakdowns were least common for households on individual systems, the duration of those breakdowns tended to be longer. Comparing responses to breakdowns, households on community systems generally waited until service was restored, while those on intermediate systems borrowed water or waited, and those on individual systems borrowed water or took action to repair the supply.

ACCESSIBILITY

The second dimension of availability is accessibility—the ease or difficulty of obtaining water from the supply. A perfectly accessible supply provides water when water is needed and does not pose an inconvenience to the user in either its location or the operation of its equipment. Further, it provides water at a pressure that accommodates the household's uses of water. Supplies that are inconvenient or which do not generate sufficient pressure to satisfy household needs are failing to some extent in providing water. Since the water flow they provide is intermittent or unpredictable, they are not unlike supplies that break down frequently. Both conditions require users to make adjustments that would be considered unusual by households that have properly designed and functioning water supplies.

In the NSA, accessibility was measured by several indicators. The concept of convenience was approached first by estimating the distance between the point at which water entered the dwelling unit and the point at which it was withdrawn from the source. Second, the number of inconvenient supplies was estimated on the basis of the number of household representatives who said they particularly disliked the water supply because of its inconvenience. (This measure may have included only extremely inconvenient supplies, however.) Another indicator of accessibility was water pressure, which was measured with a pressure gauge;

household representatives also reported on the water supply's usual pressure, any changes in pressure, and reasons for the pressure being too high or too low, fluctuating, or changing. Household representatives also reported on seasonal variation in pressure, and how much they liked or disliked the water supply's pressure.

The data on the distance between the dwelling unit and the source of the water supply applied to 10.6 million households whose water supplies consisted of wells, springs, surface water, and cisterns. (For households served by community water systems, the point of withdrawal from the source was defined as being located on the premises of the dwelling unit. Also, for hauled and purchased bottled supplies, the distance could not be determined because the source was not specified; these supplies are discussed separately in Chapter IV.) Among the 10.6 million water supplies from which data were obtained, there was a great deal of variation in supply accessibility as measured by this indicator. As shown in Table V-21, almost 52 percent of supplies (5.5 million) had the point of withdrawal either on the premises of the household (in the basement, for example), or within ten meters (33 feet) of the household structure. For another 31.9 percent (3.4 million), the point of withdrawal was eleven to 50 meters away (36 to 164 feet). Altogether, 90.2 percent of supplies (9.6 million) obtained water from a point 100 meters (328 feet) or less away from the dwelling unit. For 0.6 percent, or 63,000 supplies, however, the point of withdrawal was more than 1,000 meters away from the dwelling unit (more than half a mile). The maximum distance reported was 9,900 meters, or slightly more than six miles, and the median was nine meters (about 30 feet).

The major water supply at 2.0 percent of all rural households (442,000) was disliked specifically for its inconvenience. The NSA did not quantify the inconvenience or the magnitude of its effect on the households, but it can be assumed that for these households it was necessary to spend abnormal amounts of

Table V-21

Distance Between Rural Dwelling Unit and Point of Withdrawal from Source

Distance	Nation: Number of Supplies	Nation: Percent of Supplies
On premises	643,000	6.1
1 - 10 meters	4,818,000	45.5
11 - 50 meters	3,373,000	31.9
51 - 100 meters	711,000	6.7
101 - 1,000 meters	642,000	6.1
More than 1,000 meters	63,000	0.6
Unspecified	332,000	3.1
*Total	10,582,000	100.0

*Table excludes community water supplies, hauled supplies, and purchased bottled supplies.

Each figure in the table is rounded independently; numbers and percentages may not equal rounded totals.

time and effort in obtaining the water supply, or that whatever efforts they could expend did not result in a supply that was convenient or fully accessible.

The pressure of water supplies, as measured by a pressure gauge, ranged from a minimum of two pounds per square inch (psi) to a maximum of 190 psi. As indicated in Table V-22, about 7.5 percent of the 18.7 million supplies for which measurements were recorded (1.4 million) had a pressure of twenty psi or less; 44.5 percent (8.3 million) had a pressure of 21 through 40 psi; 31.9 percent (six million) had a pressure of 41 through 60 psi. Another 13.7 percent of supplies (2.4 million) had a pressure of 61 through 100 psi, and the remaining 2.4 percent (455,000) had a pressure higher than 100 psi. The median water pressure was approximately 39 psi. (For various reasons, the pressure measurement was not performed at all households, and 490,000 households did not have pressurized water supplies, but pressure was measured for 18.7 million households.)

The usual pressure of rural water supplies was generally felt to be satisfactory. About 83 percent of the 21.5 million rural households with pressurized supplies (17.8 million) reported that the pressure was usually about right, while 7.3 percent (1.6 million) said that it was too low and a small number of households (1 percent or 215,000) complained that the pressure was too high. Although only 8.5 percent (1.8 million) reported that fluctuating pressure was the usual condition of the supply, 22.7 percent (4.9 million) reported that the pressure changed from time to time.

Of the 6.6 million households that reported high, low, or fluctuating pressure conditions, or that reported the occurrence of pressure changes, 35.3 percent (2.3 million) indicated that the condition was fairly constant. For 64.1 percent (4.2 million), the condition was present or changed only "some of the time" or "hardly ever."

As to reasons for the water supply's pressure, 50.8 percent (3.4 million) of the 6.6 million households asked (all those where the pressure was not always

Table V-22

Rural Water Supply Pressure

Pressure (Pounds per Square Inch)	Nation: Number of Supplies	Nation: Percent of Supplies
1 - 20 psi	1,402,000	7.5
21 - 40 psi	8,301,000	44.5
41 - 60 psi	5,956,000	31.9
61 - 100 psi	2,353,000	13.7
Greater than 100 psi	455,000	2.4
*Total	18,668,000	100.0

*Pressure measurements apply to 18.7 million household supplies. Pressure could not be measured for 2.7 million households, and another 490,000 supplies were not pressurized.

Each figure in the table is rounded independently; numbers and percentages may not equal rounded totals.

"about right" or that noted changes in the water pressure) attributed the condition to a basic inadequacy of the system's physical facilities. System breakdowns outside the dwelling unit reportedly caused the pressure condition at 12.3 percent of the affected households (812,000), and another 9.7 percent of households (640,000) associated the pressure condition with problems inside the house. Of the remaining households, 6.6 percent (436,000) attributed the condition to deliberate or planned activities or to mismanagement, and 2.9 percent (191,000) related the condition to seasonal factors. Other reasons were suggested at 5.8 percent (383,000), and 11.9 percent (785,000) could not venture a reason for the pressure condition.

Almost one-fourth of the 6.6 million households where pressure was high, low, or usually fluctuating (23.2 percent, or 1.6 million) reported that they noticed seasonal variations in the water pressure. Seasonal variation most often consisted of pressure being too low or fluctuating too much in the summer (reported in 1.3 million households). In winter, by contrast, when demand for water is generally lowest, 1.3 million, or 80.9 percent, reported that the pressure was about right.

Although 30.7 percent of the 21.5 million rural households with pressurized water supplies (6.6 million) reported that the pressure was too high or too low, or that it usually fluctuated, only 7.1 percent (1.5 million) said that they disliked the pressure or that they disliked it very much. For 25.3 percent of households (5.4 million), the pressure was considered all right or was not thought about very much. On the other hand, 67.4 percent of the households (14.5 million) reported that they liked it or that they liked it very much.

As indicated by several factors, water supplies for rural households appeared generally to be accessible. About 52 percent of the supplies for which the necessary distance measurement was obtained (wells, springs, surface water supplies, and cisterns) withdrew water from a point that was within ten meters (33 feet) of the household structure. Water pressure, as determined by a pressure gauge and summarized by a median of 39 psi, was also generally sufficient. On a less positive note, however, 1.4 million households, or 7.5 percent of the households for which measurements were recorded, had supplies with a pressure of less than twenty psi. This corresponded almost exactly to the proportion of all rural households that perceived the usual water supply pressure to be too low, which was 7.3 percent. An additional 8.3 percent of the rural households with pressurized supplies reported either that the pressure was too high or that it fluctuated. Although there were other reasons, pressure difficulties were most often attributed to some unspecified inadequacy of the water supply's physical facilities. Also, since water demands are typically greater in the summer, a larger proportion of households reported seasonal pressure variations during that period in comparison to the fall, winter, or spring. Finally, while 7.1 percent of rural households with pressurized supplies expressed a moderate or strong dislike for the water pressure, 67.4 percent liked it.

Regional variation in accessibility

There was a great deal of variation from region to region in the distance between the dwelling unit and the point where the water was withdrawn from the source (see Table V-23). For the Northeast and North Central, distances were quite similar. In the Northeast, 57.7 percent of supplies had the point of withdrawal on the household premises or within ten meters of the structure, and this was true for 61 percent of supplies in the North Central. As measured by this indicator, accessibility was lower in the South and West. In the South, only 43.9 percent of supplies had the point of withdrawal on the household premises or within ten meters of the structure; in the West, the percentage was 31.0 percent. The point of withdrawal was eleven to 50 meters away from the structure for 26.0 percent of supplies in the Northeast, 27.3 percent in the North Central, 37.9 percent in the South, and 38.4 percent in the West.

Table V-23

Regional Variation in the Distance Between Rural Dwelling Unit and Point of Withdrawal from Source

	Percent of Supplies			
Distance	Northeast	North Central	South	West
On premises	4.4	9.2	4.6	2.9
1 - 10 meters	53.3	51.8	39.3	28.1
11 - 50 meters	26.0	27.3	37.9	38.4
51 - 100 meters	5.5	4.0	7.7	16.5
101 - 1,000 meters	7.1	2.6	8.2	10.4
More than 1,000 meters	0.5	0.2	0.7	2.2
Unspecified	3.2	4.9	1.7	1.6
Total Percent	100.0	100.0	100.1	100.1
*Total Supplies	2,034,000	3,825,000	3,851,000	872,000

*Table excludes community water supplies, hauled supplies, and purchased bottled supplies.

Altogether, the point of withdrawal was within 100 meters of the structure for 89.2 percent of supplies in the Northeast, 92.3 percent in the North Central, 89.5 percent in the South, and 85.9 percent in the West. The maximum distance was 3,116 meters (1.9 miles) in the Northeast; 1,840 meters (1.1 miles) in the North Central; 9,930 meters (6.2 miles) in the South; and 8,050 meters (five miles) in the West.

Relatively few households in each region reported that they disliked the water supply particularly for its inconvenience. The proportions ranged from 1 percent in the West to 2.7 percent in the South.

Water supply pressure, as measured by a pressure gauge, varied considerably from region to region (see Table V-24). Pressure between one and twenty psi was reported least often in the Northeast (4.3 percent of supplies) and most often in the North Central (10.2 percent of supplies). The bulk of household supplies in all regions had pressure readings from 21 through 60 psi. Pressure between 61 and 100 psi was found most often in the West (24.6 percent of supplies) and least often in the North Central (6.5 percent).

In all regions, the great bulk of supplies were reported to have satisfactory water pressure, according to household representatives. The proportions of households where the pressure was too high were about equal, ranging from 0.4 percent in the Northeast to 1.6 percent in the South. Pressure was reported to be too low at 8.4 percent of households in the Northeast, 6.6 percent in the North Central, 8.2 percent in the South, and 4.6 percent in the West. Fluctuating pressures were reported at 7.5 percent of households in the North Central and South, 9.6 percent in the Northeast, and 12.3 percent in the West. Changes from the usual condition of the supply with regard to pressure were reported at 30.9 percent of households in the West, compared to 23 percent in the Northeast, 20.8 percent in the North Central, and 21.3 percent in the South.

Table V-24

Regional Variation in Measured Pressure of Rural Water Supplies

	Percent of Supplies			
Pressure	Northeast	North Central	South	West
1 - 20 psi	4.3	10.2	7.2	6.5
21 - 40 psi	48.8	55.0	38.3	25.2
41 - 60 psi	33.0	28.0	38.0	42.8
61 - 100 psi	11.8	6.5	14.5	24.6
Greater than 100 psi	2.2	0.1	2.0	0.8
Total Percent	100.1	99.8	100.0	99.9
*Total Supplies	3,335,000	5,275,000	7,876,000	2,707,000

*Table includes only supplies for which pressure measurements were obtained.

Another indication that changes often occurred in pressure was that the pressure characterized as usual was reportedly present in the water supply most or all of the time at only 42.8 percent of households in the Northeast, 38.2 percent in the South, 29.4 percent in the North Central, and 28.5 percent in the West.

The proportions of households assigning various reasons to the water supply pressure also varied from region to region (see Table V-25). Of all households queried (those where the pressure was not always about right, or that reported changes in the pressure), inadequacy of the system was blamed much more often than anything else. About two-thirds of the households in the West and about half of the households in the Northeast, North Central, and South gave this as the reason for the condition. The condition was attributed to a breakdown outside the house at 20.1 percent of households in the North Central, but at only 6.5 percent in the West. Problems inside the house caused the condition at 18.4 percent of households in the Northeast, but at only 3.4 percent of households in the West.

Seasonal variation in water supply pressure occurred most often in the West, where it was reported at 14.8 percent of the households that had pressurized water supplies. By comparison, seasonal variation was reported at 7.3 percent of such households in the South, 6.4 percent in the North Central, and 4 percent in the Northeast. Seasonal variation also was most dramatic in the West, where over 90 percent of responding households reported that the pressure was about right in fall, winter, and spring, but only 9.1 percent reported it was about right in summer. In the Northeast, the pressure was about right at 69.5 percent of responding households in the fall, 79.7 percent in the winter, and 66.7 percent in the spring, but at only 12 percent in the summer. In the North Central, it was about right at 81 percent of responding households in the fall, 88.2 percent in the winter, and 79.9 percent in the spring, but at only 18.6 percent in the summer. The South showed the least dramatic pattern of seasonal differences: about 64.4 percent of responding households reported the pressure was about right in the fall, compared

Table V-25

Regional Variation in Reported Reasons for Perceived Pressure Conditions in Rural Water Supplies

Reason	Percent of Households			
	Northeast	North Central	South	West
Inadequacy of the system's physical facilities	49.3	52.0	45.1	66.1
A breakdown in the physical facilities outside the house	11.1	20.1	10.1	6.5
A problem within the house	18.4	8.5	8.9	3.4
Deliberate or planned activities	2.0	6.2	5.4	0.6
Mismanagement of the system	0.0	1.3	3.7	2.9
Seasonal factors	1.7	2.0	5.0	0.0
Other miscellaneous	5.8	2.5	8.0	5.9
Don't know	11.7	7.3	13.9	14.7
Total Percent	100.0	99.9	100.1	100.1
*Total Households	1,198,000	1,719,000	2,697,000	990,000

*Table includes only households that reported high, low, or fluctuating supply pressure, or that reported pressure changes.

to 69.1 percent in the winter, 68.5 percent in the spring, and 26.5 percent in the summer.

In the summer, pressure was too low at 35.3 percent of the households reporting seasonal variation in the Northeast, compared to 33.8 percent in the North Central, 26.4 percent in the South, and 37.9 percent in the West. It fluctuated at 48.9 percent of the responding households in the Northeast, 47.6 percent in the North Central, 40.7 percent in the South, and 51.3 percent in the West.

The agreeability of the water supply was about equal for all regions. In the West, 6.3 percent of all rural households reported they disliked the pressure, or disliked it very much; the highest proportion of households responding this way was in the South, where 7.8 percent of all rural households disliked the pressure.

SMSA/nonSMSA variation in accessibility

Distances between the dwelling unit and the point where water was withdrawn from the source tended to be greater for nonSMSA households than for households located within SMSAs. Among nonSMSA households, 49.2 percent of supplies had the point of withdrawal either on the premises or within ten meters of the dwelling unit, compared to 58.4 percent of supplies among SMSA households. The point of withdrawal was eleven to 50 meters away for 33.1 percent of nonSMSA household supplies, compared to 28.4 percent of SMSA household supplies. Distances of 51 to 100 meters occurred in about equal proportions: 7.1 percent for nonSMSA supplies and 5.7 percent for SMSA supplies. For 7.1 percent of nonSMSA supplies, the point of withdrawal was 101 to 1,000 meters away, compared to 3.0 percent of SMSA supplies. Less than 1 percent of both SMSA and nonSMSA supplies had the point of withdrawal more than 1,000 meters away from the dwelling unit.

No substantive difference was found between SMSA and nonSMSA households in the proportions that disliked the water supply particularly for its inconvenience.

Water pressure tended to be lower among nonSMSA households. Specifically, 9.0 percent of nonSMSA households had a water pressure of from one to twenty psi, compared to 4.4 percent of SMSA households. Also, a pressure of 21 to 40 psi was measured at 44.2 percent of nonSMSA households, compared to 40.3 percent of SMSA households. A pressure of 41 to 60 psi was recorded at 38.7 percent of SMSA households and 33.2 percent of nonSMSA households. Fifteen percent of SMSA supplies and 12.4 percent of nonSMSA supplies had a pressure of 61 to 100 psi. Only a few supplies—1.5 percent of SMSA supplies and 1.2 percent of nonSMSA supplies—had pressure readings above 100 psi.

Seasonal variation in water pressure was reported at 7.6 percent of SMSA households and 7.3 percent of nonSMSA households. Likewise, differences of roughly three percentage points or less were seen in the proportions of SMSA and nonSMSA households reporting various conditions of water supply pressure and in the proportions reporting that changes occurred in those conditions. However, among those households where pressure was not always about right or that reported changes in the usual condition, there was considerable variation in the reasons associated with the condition. Overwhelmingly, inadequacy of the system was blamed. (This was the reason given at 53.9 percent of SMSA households and 49.1 percent of nonSMSA households.) A problem inside the house was the cause at 11.3 percent of SMSA households and 8.8 percent of nonSMSA households. Breakdowns outside the house were blamed at 9.4 percent of SMSA households and 13.9 percent of nonSMSA households. Deliberate actions were thought to be the cause at 5.9 percent of nonSMSA households, but at only 1.3 percent of SMSA households. Several other reasons were given in about equal proportions among SMSA and nonSMSA households.

As for seasonal variation in water supply pressure, a higher proportion of nonSMSA households reported the pressure was about right in each season. The household water supply pressure in general was liked about equally at SMSA and nonSMSA households; only 6.9 percent of nonSMSA households and 7.6 percent of SMSA households reported either a moderate or strong dislike for the water supply pressure.

Size-of-place variation in accessibility

A comparison of households located in large rural communities, small rural communities, and other rural areas showed a great deal of variation in accessibility as measured by the distance between the household and the point where the water supply was withdrawn from its source. Specifically, 61.6 percent of household supplies in large rural communities had the point of withdrawal either on the premises or within ten meters of the dwelling unit, compared to 77 percent of supplies in small rural communities and only 50.8 percent in other rural areas. The point of withdrawal was eleven to 50 meters away for 24.6 percent of households in large rural communities, 14.1 percent in small communities, and 32.4 percent in other rural areas.

In other rural areas, the point of withdrawal was 51 to 100 meters away from the dwelling unit for 6.9 percent of households, and from 101 to 1,000 meters away for another 6.2 percent. Distances of more than 50 meters were reported for only 5.5 percent of supplies in large communities and 3.3 percent in small communities. Likewise, the only water supplies that withdrew water from a source over 1,000 meters away from the household were located in other rural areas (0.6 percent of the supplies in other rural areas). In small rural communities, the maximum distance reported was 75 meters (246 feet); in large rural communities, it was 200 meters (657 feet); and in other rural areas, it was 9,930 meters (6.2 miles).

Consistent with these figures was the finding that other rural areas had the greatest proportion of households reporting that the water supply was disliked particularly for its inconvenience (2.3 percent, compared to 0.5 percent of households in both large and small rural communities).

Higher pressure readings were more common in large rural communities than in small rural communities or other rural areas. In large communities, only 3.1 percent of supplies had pressure readings between one and twenty psi, compared to 5.7 percent of supplies in small rural communities and 8.2 percent of supplies in other rural areas. Similarly, 26.3 percent of supplies in large rural communities had pressure readings between 21 and 40 psi, compared to 37.7 percent in small rural communities and 45.4 percent in other rural areas. Readings between 41 and 60 psi were found in 44.4 percent of supplies in large rural communities and 41.8 percent of supplies in small rural communities, but in only 33.3 percent of supplies in other rural areas. Higher pressures were more common in large communities, where 22.4 percent of supplies had a pressure of 61 to 100 psi, and 3.7 percent had a pressure of more than 100 psi. Readings between 61 and 100 psi were found in 14.9 percent of supplies in small rural communities and 12.0 percent of supplies in other rural areas. Pressure readings higher than 100 psi were recorded for 1.1 percent of supplies in other rural areas; no supplies in small communities had pressure readings over 100 psi.

Water pressure was reported to be "about right" less often among households in large rural communities. There, 79.3 percent of households reported that the pressure was about right, compared to 82.7 percent in small rural communities and 83.8 percent in other rural areas. Otherwise, there was no substantive deviation from national estimates regarding pressure conditions, except that changes in the usual pressure were noticed more frequently at households in large communities (27.8 percent) compared to households in small rural communities (21.9 percent) and other rural areas (22.1 percent).

Reasons given for the usual condition of the water supply with respect to pressure varied considerably, however, depending on the size of place where the household was located (see Table V-26). Problems with pressure were most frequently attributed to inadequacy of the system regardless of where the household was located, but households in small rural communities in particular attributed problems to this cause (64.1 percent, compared to roughly 50 percent elsewhere). Breakdowns outside the house were seen as the cause of pressure problems most frequently in other rural areas. Deliberate actions were mentioned at 7.5 percent of households in large rural communities, compared to 1.8 percent of households in small communities and 4 percent of households in other rural areas.

Seasonal variation in water pressure was reported at 10.9 percent of households in small rural communities, 10.8 percent of households in large rural communities, and 6.6 percent of households in other rural areas. For the most part, the variation reflected difficulties during the summertime. Large rural communities showed the highest proportion of households with unsatisfactory pressure in the summer; only 15 percent of households where seasonal variation occurred said the pressure was about right in the summer, compared to 24.8 percent of households that reported seasonal variation in small communities and 18.7 percent of households that reported seasonal variation in other rural areas.

Of the households reporting that seasonal variation occurred, small rural communities had the highest proportion in every season that said the pressure was about right. In spring and fall, the lowest proportion reporting that the pressure was about right was found in other rural areas (74.7 percent in the fall and 73.5 percent in the spring).

Summertime difficulties were more often related to fluctuating water pressure than to pressure that was too low. In large and small communities both, slightly more than 50 percent reported that pressure fluctuated. This was almost twice the proportion that reported low pressure. In other rural areas, 43.4 percent

Table V-26

Size-of-Place Variation in Reported Reasons for Perceived Pressure Conditions in Rural Water Supplies

Reason	Percent of Households		
	Large Rural Communities	Small Rural Communities	Other Rural Areas
Inadequacy of the system's physical facilities	50.6	64.1	49.7
A breakdown in the physical facilities outside the house	6.4	8.5	13.6
A problem within the house	10.3	5.9	9.9
Deliberate or planned activities	7.5	1.8	4.0
Mismanagement of the system	2.4	5.0	2.0
Seasonal factors	3.9	0.0	3.0
Other miscellaneous	2.0	5.3	6.5
Don't know	17.0	9.3	11.3
Total Percent	100.1	99.9	100.0
*Total Households	8,660,000	448,000	5,296,000

*Table includes only households that reported high, low, or fluctuating supply pressure, or that reported pressure changes.

of households where seasonal variation occurred reported fluctuating pressure and 34.2 percent said the pressure was too low. The decreased pressure of summertime may have represented an improvement to some households: in large communities, 3.8 percent of households where seasonal variation occurred reported the pressure was too high for three seasons out of the year, but no households reported that the pressure was too high during the summer.

Households in large rural communities were in general less satisfied with the water pressure than households in small communities or other rural areas. Only 59 percent of households in large rural communities reported that they liked the pressure or that they liked it a great deal, compared to 69.1 percent of households in small communities and 68.5 percent of households in other rural areas. On the other hand, 10.9 percent of households in large communities expressed a moderate or strong dislike for the water supply pressure, compared to 5.6 percent of households in small communities and 6.7 percent of households in other rural areas. The other households reported that the pressure was all right, or that they didn't give it much thought.

Size-of-system variation in accessibility

Distances from the dwelling unit to the point where the water was withdrawn from its source were measured for supplies of households on individual and intermediate systems only. (By definition, the supplies of households served by community systems had the point of withdrawal on the premises.) As would be expected, supplies for households on intermediate systems showed greater distances between the point of withdrawal from the source and the dwelling unit. Among households served by individual systems, 57.8 percent of supplies had the point of withdrawal either on the premises or within ten meters of the structure, while this was true for only 27.0 percent of supplies at intermediate-system households. Distances between eleven and 50 meters were seen about equally among households on individual and intermediate systems: in 31.3 percent of individual-system households and 34 percent of intermediate-system households. Greater distances were more common for supplies of households on intermediate systems, as would be expected. Distances between 51 and 100 meters were found in 5.4 percent of households on individual systems but in 11.9 percent of households on intermediate systems. Distances between 101 and 1,000 meters were found in 3.0 percent of individual-system households but in 18.1 percent of intermediate-system households. Relatively few households had supplies which extracted water from sources more than 1,000 meters distant: 0.4 percent of households on individual systems and 1.4 percent of those on intermediate systems.

Households served by individual systems more frequently reported that the water supply was disliked particularly for its inconvenience. This situation was found at 4.3 percent of households served by individual systems (381,000 households), but at only 1.2 percent of households served by intermediate systems (27,000) and 0.3 percent of households served by community systems (34,000).

As expected, pressure readings of supplies varied quite a bit depending on the size of the water system (see Table V-27). Among supplies for households on individual and intermediate systems, pressure was virtually never over 60 psi, and for sizable proportions of supplies, the water pressure was between one and twenty psi. Only 2.2 percent of supplies among households served by community systems showed pressure readings between one and twenty psi, and almost one-quarter of these supplies had pressure readings between 61 and 100 psi. The maximum pressure was 76 psi among supplies of households on individual systems, 81 psi among those on intermediate systems, and 190 psi among those on community systems.

Surprisingly, although the pressure readings taken at rural households indicated that community systems supplied water at higher pressures than individual or intermediate systems, more households served by community systems

Table V-27

Size-of-System Variation in Measured Pressure of Rural Water Supplies

Pressure	Percent of Supplies: Individual System	Intermediate System	Community System
1 - 20 psi	11.9	17.1	2.2
21 - 40 psi	63.8	62.4	23.3
41 - 60 psi	23.6	16.9	47.1
61 - 100 psi	0.7	3.5	24.7
Greater than 100 psi	0.0	0.0	2.6
Total Percent	100.0	99.9	99.9
*Total Supplies	7,593,000	1,825,000	9,775,000

*Table includes only those supplies for which pressure measurements were obtained.

expressed dissatisfaction with the supply's water pressure. Only 80.8 percent of these households reported that the usual pressure was about right, compared to 85.2 percent of households served by individual systems and 87.9 percent served by intermediate systems. One would have expected that the lower pressures of individual and intermediate systems would prompt complaints more often than the typically higher pressures supplied by community systems.

Complaints about pressure being too high occurred infrequently, but were not restricted to households served by community systems: pressure was considered too high at 0.2 percent of households served by individual systems, 0.3 percent of households served by intermediate systems, and 1.8 percent of households served by community systems. Pressure was reportedly too low at 7.6 percent of households served by individual systems, 4.4 percent of households served by intermediate systems, and 7.7 percent of households served by community systems. Fluctuating pressure was reported at 7 percent of households served by individual systems, 7.4 percent served by intermediate systems, and 9.7 percent served by community systems.

In addition to the fact that more households served by community systems reported fluctuating water pressure, more of these households reported that changes occurred in the usual pressure—28.2 percent, compared to 15.9 percent of households served by individual systems and 20.6 percent served by intermediate systems.

Inadequacy of the system was most often seen as the cause of the various pressure conditions that were reported, regardless of the size of the system serving the household. However, the prominence of this response was most marked among households served by intermediate systems: 67.4 percent of the households where pressure was not always "about right" and which were served by intermediate systems attributed the condition to system inadequacy, compared to 52.9 percent of the households served by community systems and 42.3 percent of the households served by individual systems.

Among households served by individual systems, only two reasons besides inadequacy of the system were given by substantial proportions of responding households. These were problems inside the house (19.4 percent) and external breakdowns (18.6 percent).

Among households served by intermediate and community systems, no other reason besides inadequacy of the system was mentioned by more than 10.0 percent of responding households. External breakdowns were the next most frequently mentioned reason for the pressure condition (9.6 percent of responding households served by community systems, 8.7 percent of responding households served by intermediate systems). Problems inside the house were mentioned by 7.5 percent of households served by intermediate systems and by 5 percent of responding households served by community systems. The conditions were attributed to deliberate actions at 6.8 percent of the households served by community systems, but at none of those served by intermediate systems.

Although the actual number of households involved was small (65,000), the 2.9 percent of households which were served by intermediate systems and which reported seasonal variation in water pressure showed the most dramatic pattern. While these households had the highest proportion reporting that pressure was about right during fall, winter, and spring, they had the lowest proportion—in fact, no households at all—reporting that pressure was about right in summer. For almost two-thirds of the 65,000 households, pressure fluctuated during summer; for one-third, pressure was too low. For the other three seasons, data for these households were difficult to interpret. During the spring, 86.7 percent of the affected households said the pressure was about right and 13.3 percent said it fluctuated. During the fall, 88.8 percent said it was about right and 11.2 percent said it was too low. During the winter, 94.4 percent said the pressure was about right and 5.6 percent said it was too high.

Seasonal variation also was reported infrequently among households served by individual systems (227,000, or 2.7 percent of such households). Most seasonal pressure problems arose during summer, when only 23.1 percent of the households noticing seasonal variation said that the pressure was about right, compared to 67.5 percent in the fall, 71.7 percent in the spring, and 72 percent in the winter. During the summer, fluctuating pressure and low pressure were reported about equally (39.3 percent and 35.1 percent of the 227,000 affected households, respectively).

Surprisingly, seasonal variation was most common among households served by community systems, being reported at 1.3 million of these households, or 11.8 percent. Summer was again the season when most problems occurred, with 46.1 percent of the affected households reporting fluctuating pressure, 31.2 percent reporting low pressure, and 18.9 percent reporting pressure that was about right. In the other three seasons, roughly equal proportions reported pressure that was about right (77.5 percent in both spring and fall, and 81.8 percent in winter).

Overall, the water pressure supplied by community systems was liked least often. Of all rural households served by community systems, 63.5 percent reported that they liked the pressure conditions or liked them a great deal, compared to 70.9 percent of households served by individual systems and 74.2 percent served by intermediate systems. The supply was all right, or not thought about very much with regard to pressure, by 27.5 percent of households served by community systems, 23.3 percent served by individual systems, and 22 percent served by intermediate systems. The pressure was disliked, or disliked very much, at 8.8 percent of households served by community systems, 5.8 percent served by individual systems, and 3.9 percent served by intermediate systems.

EFFECTS OF QUALITY, QUANTITY, AND AVAILABILITY CONDITIONS

Inadequacies of water supplies in terms of quality, quantity, and availability can have a variety of consequences for households. Some of these effects are naturally more serious than others, although those that impinge upon the health and physical well-being of household residents are probably the most critical. Inconveniences associated with particular supplies, while not directly related to health, can also disrupt a household's pattern of living, sometimes seriously. The least severe water supply problems—those that interfere only minimally with the routine of the household and those that are transitory—nonetheless can become a source of irritation, frustration, or discontent if they cannot be rectified.

In the NSA interviews, residents reported a variety of problems which they associated with inadequacies of various kinds of their water supplies. In addition to being asked about general problems or inconveniences they may have experienced, residents were asked specifically whether anyone living in the household or any visitors to the household had become ill from drinking the household water. Although there are obvious problems of attribution regarding illnesses, it was important to find out the extent to which rural residents believed that their water supplies caused health problems. Also, this information was a valuable supplement to NSA laboratory data on household water quality.

Here, the issue of health effects is addressed with reference to reported illnesses. This orientation is substantially different from that in the portion of this chapter devoted to laboratory-measured water quality, where the concentrations of health-related constituents were examined specifically in regard to their potential health threat. Following the section on reported illnesses, there is a discussion of other specific problems that residents reported occurring as a consequence of perceived water supply inadequacies.

REPORTED ILLNESSES

On the basis of NSA results, illnesses among rural residents during the preceding year were thought to be associated with the water supply in 1.7 percent of all rural households (374,000 households). The possibility that household visitors had experienced water-related illnesses during the preceding year was reported in fewer households (0.9 percent or 198,000). In total, 2.3 percent of all rural households reported occasions when either residents or visitors became ill; in 0.3 percent of these households, both resident and visitor illnesses were reported.

Among those households where illnesses were attributed to the water supply, diarrhea was the most common malady, mentioned roughly one-third of the time. Abdominal pains were experienced about half as frequently as diarrhea. In the remaining households, a variety of other illnesses were reported.

Subnational variation in reported illnesses

The proportion of rural households which associated illnesses with the water supply was so small that, for the most part, it was impossible to examine the data for variations by region, SMSA/nonSMSA, size of place, or size of system. In general, however, the distribution of households reporting illnesses was relatively uniform across these subnational categories. The only significant deviation from the pattern was observed among households in large rural communities. Illnesses were reported at approximately 5.4 percent of these households, which was more than double the national rate. This finding is inconsistent with water quality measurements reported earlier in this chapter which indicated that, overall, water supplies of households in large rural communities had substantially lower concentrations of certain contaminants, including microorganisms, than household supplies in the other two size-of-place categories. One possible interpretation of this finding is that household residents in large rural communities have a greater tendency than other rural residents to attribute illnesses to the water supply.

Unfortunately, verifying this interpretation is impossible, since the NSA did not acquire data on the actual incidence of water-related diseases in rural households. Further, the total number of households involved (75,000) was not large enough to analyze in detail.

SPECIFIC SUPPLY PROBLEMS AND INCONVENIENCES

The condition of the water supply can have specific and troublesome implications for household residents besides those related to health. In the NSA, respondents were asked to identify household problems or inconveniences which were directly attributable to the water supply. In about twenty million households (91 percent), no specific problems or inconveniences were mentioned. Among the approximately two million households which noted problems or inconveniences, the water was reported to leave deposits in sinks, pipes, and on kitchenware in 659,000 households. Some households (318,000) reported that the water affected their laundry, while 132,000 households indicated that it altered the flavor or appearance of food and drink. An additional 625,000 rural households reported various combinations of the preceding problems and inconveniences, the most common of which involved the deposits and effects on laundry. Although some other individual problems were noted besides these, they were not very frequent. For example, about 79,000 households reported that the water was too costly to treat.

Subnational variation in specific supply problems and inconveniences

Some regional variation could be detected in the proportions of households reporting specific supply problems and inconveniences. Proportionally, more rural households in the Northeast were affected than in any other region (12.4 percent); problems mentioned most frequently there were that the water left deposits, affected laundry, and affected the flavor or appearance of food and drink. These effects were attributed to the high mineral content of water supplies in the Northeast. The South, on the other hand, had the smallest proportion of rural households reporting specific supply problems and inconveniences (7.3 percent).

No substantive variation could be seen in the SMSA/nonSMSA, size-of-place, and size-of-system comparisons.

COST

RECORDED COST OF HOUSEHOLD WATER, MODE OF PAYMENT, AND BILLING INTERVALS

The cost of household water is determined by a number of factors, including capital expenditures for equipment as well as ongoing costs of treatment, maintenance, and labor. Though the NSA focused on the household, there was no reliable way to collect such cost data for individual supply systems (self-suppliers). For instance, initial equipment investment—for a water pump and piping, for example—generally had been financed by a previous owner. Furthermore, it was not expected that there would be reliable records of current household costs for operating and maintaining individual supplies.

In light of these considerations, general utility bills offered the only reliable means to assess household water costs. This meant, however, that the NSA cost analysis was restricted to households served by community systems.

For the nation as a whole, 9.2 million rural households (43.7 percent) were billed regularly for their water supply. A similar number—9.1 million, or 43.2 percent—paid for water indirectly. Indirect payments were related to the operation and maintenance of self-supply equipment, and included costs of electricity, pump and pipe replacement, and storage tank maintenance, for example. In another 2.5 million households (12.0 percent), the cost of water was included in rent payments. Among the remaining 1.1 percent of rural households (approximately 236,000 households), either the cost was included in the mortgage payment or the method of payment could not be determined.

For those households which received regular water bills (9.2 million), 61.4 percent were billed monthly, 15.7 percent once every two months, 19.2 percent once every three months, and only 2.5 percent once every six months. At some households, bills were received once every four months, or even once a year (1.2 percent, combined).

Although many rural households regularly received water bills, the bills were not always available at the time of the NSA survey. In other cases, the bill was available, but it lacked major components—the amount charged or the gallons consumed. Moreover, the amount paid for water was sometimes subsumed in a total utility bill (one including sewer costs, for example). Data for households for which water costs were subsumed in a total utility bill were analyzed separately to prevent overestimation of water costs. Because of these adjustments, detailed NSA cost analysis could be projected to only 4.6 million households, essentially one-fifth of the nation's rural households.

To maintain comparability between the NSA estimates and other resources on household water cost, two approaches were used in analyzing the cost data. The first (the same approach used in the Temple, Barker, & Sloane study to be discussed shortly) involved calculating a unit cost per thousand gallons. Unfortunately, this estimate was not always reliable. This was because some bills lacked key information needed to calculate consumption. The attempt was made to obtain the most reasonable estimate, but if the daily per capita estimate seemed too high or too low (taking into account both inside and outside uses of water), the household was excluded from the cost analysis.

On the basis of the per-thousand-gallon calculation, the median water cost was $1.35 nationally. The range was from $.08 through $23.41 per thousand gallons. Because of some extremely high values, the mean was $2.55 per thousand gallons (see Table V-28).

The range for monthly household water costs was greater than that computed for costs per thousand gallons. This was expected since the per-unit cost did not take into account the monthly amount of water consumed, which varied by as much as 30,000 gallons. Water costs for the nation ranged from $1.00 to $58.00 per month. Both the mode and median were $7.00; the average monthly cost per household was $8.33.

A survey of financial characteristics of community water systems, undertaken by the consulting firm of Temple, Barker, & Sloane (TBS),[104] provides data that can be compared with NSA cost results. For the nation, NSA data showed a median cost of $1.35 per thousand gallons. In contrast, for multiple-connection systems studied in the TBS survey, average rates ranged from $.32 to $.86 per thousand gallons, depending upon the size of the population served.

The lack of correspondence between cost results for the Temple, Barker, & Sloane and NSA studies may be a result of differences in sample designs. Whereas the NSA collected cost data at the rural household, the TBS survey collected cost information from systems, which they chose from a nationwide EPA Inventory of Water Systems. Thus, NSA cost estimates were based on actual charges recorded on water bills; in the TBS study, system representatives were asked how much a typical residential customer would pay for 100,000 gallons of water, based on the system's current rate structure. Left unclear was whether the TBS estimates included costs of operation and maintenance, debt retirement, and connection charges, or whether they simply represented a unit cost for the water itself. If the cost was only for water and did not represent complete costs, the large discrepancy between the two studies would be explained, since the NSA billing amount reflected complete charges to the water user. (The only potential additional costs would have been initial, one-time-only connection fees and separately itemized

Table V-28

Regional Variation in Recorded Water Costs per Thousand Gallons (1978)

	Dollar Estimates				
Statistic	Nation	Northeast	North Central	South	West
Median	1.35	1.34	1.50	1.33	2.00
Mode	1.33	1.00	1.14	1.33	3.19
Mean	2.55	2.34	2.51	1.99	2.80
Minimum	0.08	0.46	0.33	0.26	0.08
Maximum	23.41	16.10	16.58	23.41	17.24
*Total Households	4,413,000	520,000	762,000	2,594,000	537,000

*Table includes those households where itemized utility bills were available.

service charges.) Also, part of the discrepancy can be attributed to inflation, since the TBS data were collected in the spring of 1976 and the NSA data more than two years later. Finally, probably as a result of disproportionate sampling of very large water systems in the TBS survey, average system charges were very much lower than NSA estimates.

Recorded costs at households receiving nonitemized utility bills

For the most part, charges for water were stated explicitly in water bills. Some households, however, received utility bills that included charges for water without separating them from charges for other utilities. These bills included charges for natural gas, electricity, garbage disposal, and sewage disposal in addition to water charges. Of those households receiving such nonitemized bills, about 80 percent (237,000 households) were billed for one other utility service, while roughly 20 percent (56,000 households) were billed for two other utility services in addition to water service. Sewage and garbage disposal charges were by far the most frequently included charges in these bills. Charges for electricity were least frequently included.

As would be expected, total charges shown on these nonitemized utility bills were higher than recorded costs for water at households billed specifically for water. The average household cost recorded on nonitemized bills was $15.11, compared to $8.33 per month for households being charged separately for water.

Regional variation in mode of payment, billing intervals, and recorded cost

Regional differences were observed in modes of payment for household water (see Table V-29). In most rural households, payment was made either to a designated supplier ("receive a regular billing for water"), or else to undesignated parties (i.e., an electric company, a plumbing supply company, etc.) which provided for the operation and maintenance of individual supplies. The latter situation was

Table V-29

Regional Variation in Mode of Payment for Water

	Percent of Households				
Mode of Payment	Nation	Northeast	North Central	South	West
Receive a regular billing for water	43.7	33.7	34.4	51.5	52.8
Operation and maintenance (individual systems)	43.2	50.3	57.0	35.8	26.5
Included in rent payments	12.0	14.8	7.6	11.6	19.3
Other	1.1	1.2	0.9	1.0	1.4
Total Percent	100.0	100.0	99.9	99.9	100.0
*Total Households	21,025,000	3,611,000	6,009,000	8,775,000	2,630,000

*Does not include households which associated no cost with the water supply.

most frequent in the Northeast and North Central (50.3 percent and 57.0 percent, respectively). This was consistent with the finding that the predominant type of major water supply in these regions was the individual well (see Chapter IV). Conversely, approximately 52 percent of the households in the South and West received a regular billing for water. Again, this was consistent with the finding that community water supplies were the predominant type in the South and West. Water was included in rent payments in 19.3 percent of households in the West, compared to only 7.6 percent in the North Central.

As to billing intervals, the percentage of billed households which received monthly statements varied widely from region to region. However, this difference may or may not have reflected the true condition in light of the small number of sampling points in the Northeast. Because of this uncertainty, regional variations for the billing period cannot be assessed reliably.

Mean costs per thousand gallons ranged from $1.99 in the South to $2.80 in the West (see Table V-28). Mean costs were comparable in the Northeast and North Central—$2.34 and $2.51, respectively. Similarly, the median cost was lowest in the South, $1.33 per thousand gallons, and highest in the West, with half of the households charged at least $2.00 per thousand gallons. (Again, it should be kept in mind that these cost estimates are based on information from those rural households where itemized bills were available.)

The regional variations that were detected in monthly water costs require additional discussion because factors that affect monthly water cost, such as the number of people in the household, the number and types of water-using devices, the amount of water used, and the billing month may also differ by region. Consequently, an assessment of whether cost variations are more directly influenced by geographical location or by these other variables can only be done by applying the more sophisticated analytical procedures that will be used later in this report. Specifically, for a more extensive treatment of monthly household water cost and its determinants, the reader should consult Chapter XII.

SMSA/nonSMSA variation in mode of payment, billing intervals, and recorded costs

Differences between SMSA and nonSMSA households also were observed in modes of payment for household water, but they were smaller than regional differences (see Table V-30). As shown in the table, regular billings for water predominated in SMSA households (47.4 percent of these households), whereas payment in the form of operation and maintenance of individual supplies was prevalent in nonSMSA households (46.4 percent). Water costs were included in rent payments in 15.2 percent of SMSA households and in 10.4 percent of nonSMSA households.

The billing period varied considerably between SMSA and nonSMSA households (see Table V-31). Monthly billings were twice as common for nonSMSA households (75.3 percent, compared to 36.3 percent of SMSA households). Conversely, two- and three-month billings were far more common among SMSA households. Specifically, bills were received once every two months at 27.0 percent of SMSA households and at 9.5 percent of nonSMSA households. Likewise, three-month billings appeared at 33.5 percent of households within SMSAs, compared to 11.3 percent of those outside SMSAs.

In general, households within SMSAs had lower water costs per thousand gallons. Mean rates were $1.98 for SMSA households and $2.34 for nonSMSA households. Half of the households within SMSAs were charged $1.08 or less for each thousand gallons, while half of nonSMSA households were charged a maximum of $1.62. This result was consistent with Temple, Barker, & Sloane findings.[105] In that study, residential water rates were sharply higher for multiple-connection systems associated with sparsely populated regions than for systems serving large

Table V-30

SMSA/NonSMSA Variation in Mode of Payment for Water

Mode of Payment	Percent of Households		
	Nation	SMSA	NonSMSA
Receive a regular billing for water	43.7	47.4	41.9
Operation and maintenance (individual systems)	43.2	36.7	46.4
Included in rent payments	12.0	15.2	10.4
Other	1.1	0.7	1.3
Total Percent	100.0	100.0	100.0
*Total Households	21,025,000	6,292,000	14,103,000

*Does not include households which associated no cost with the water supply.

Table V-31

SMSA/NonSMSA Variation in Billing Periods

Billing Period	Percent of Households		
	Nation	SMSA	NonSMSA
Monthly	61.4	36.3	75.3
Once every two months	15.7	27.0	9.5
Once every three months	19.2	33.5	11.3
Other	3.7	3.2	4.0
Total Percent	100.0	100.0	100.1
*Total Households	5,241,000	1,865,000	3,376,000

*Billing periods could be estimated for 5.2 million of the 9.6 million households that received regular water bills.

metropolitan areas. This trend appeared to be related to economies of size achieved in large community supply systems, a subject investigated in depth later in this report.

Size-of-place variation in mode of payment, billing intervals, and recorded costs

In addition to regional and SMSA/nonSMSA differences, substantial variation in the mode of payment for household water occurred among rural households according to whether they were located in large rural communities, small rural communities, or other rural areas (see Table V-32). For example, about four-fifths of households located in rural communities received regular water billings, whereas in other rural areas only about one-third did. The most common way of paying for water in other rural areas was through the operation and maintenance of individual water supplies (approximately 50 percent of all households). In large communities, only 6.2 percent of households paid operation and maintenance expenses. In small communities, nearly 16 percent of rural households paid for water in this fashion.

For those households that received a regular water bill, the billing periods were about the same in large and small rural communities, but were quite different in other rural areas (see Table V-33). In each category of size of place, monthly billings were the most common, but they were reported more often in large and small communities (more than 70 percent of water bills, compared to about 55 percent in other rural areas). Bimonthly billings were far more common in other rural areas (21.5 percent of water bills) than in large or small communities (about 6 percent of water bills in each).

The average cost of water per thousand gallons (the mean) was similar for households located in large and small communities ($2.52 and $2.40, respectively), but lower in other rural areas ($2.10). Median water costs were lower than the mean, and showed less variation. In large rural communities, the median cost per

Table V-32

Size-of-Place Variation in Mode of Payment for Water

Mode of Payment	Percent of Households: Large Rural Communities	Small Rural Communities	Other Rural Areas
Receive a regular billing for water	83.5	78.0	35.5
Operation and maintenance (individual systems)	6.2	15.7	50.7
Included in rent payments	10.0	5.3	12.8
Other	0.3	1.0	0.9
Total Percent	100.0	100.0	99.9
*Total Households	2,369,000	1,509,000	18,095,000

*Does not include households which associated no cost with the water supply.

Table V-33

Size-of-Place Variation in Billing Periods

	Percent of Households		
Billing period	Large rural communities	Small rural communities	Other rural areas
Monthly	72.3	70.7	55.3
Once every two months	5.4	6.0	21.5
Once every three months	17.1	17.2	20.4
Other	5.1	6.1	2.7
Total Percent	99.9	100.0	99.9
*Total Households	1,251,000	607,000	3,383,000

*Billing periods could be estimated for 5.2 million of the 9.6 million households that received regular water bills.

thousand gallons was $1.45; in small communities, it was $1.60; and in other rural areas, it was $1.33.

Size-of-system variation in mode of payment, billing intervals, and recorded costs

Almost all rural households served by individual systems paid for their water by operating and maintaining the supply (about 95 percent). However, for 2.7 percent of households with individual systems, the cost was included in rent payments (see Table V-34). A small number of households with individual systems (1.6 percent) received a regular billing for water. (These were households that purchased water on a regular basis; recall that the NSA defined purchased bottled water as an individual supply even though the distributor may have bought the water from a community system.)

For households served by intermediate systems as well, the most common way of paying for water was in the expense of operating and maintaining the system (65.0 percent of households). For 27.8 percent served by intermediate systems, the cost was subsumed in rent payments, and 4.7 percent received regular billings.

As would be expected, households served by community water systems predominantly paid for their water by a regular billing (83.0 percent). The second most common mode was to have the cost included in rent payments (16.4 percent). Interestingly, about 22,000 rural residents—probably trailer park owners—paid for household water by operating and maintaining systems of fifteen or more connections. (Another plausible explanation for this finding may have been cooperative arrangements whereby users shared in the operation and maintenance of the system.)

Although small proportions of households served by individual and intermediate systems received regular water billings, they were unable to provide

Table V-34

Size-of-System Variation in Mode of Payment for Water

Mode of Payment	Percent of Households: Individual System	Intermediate System	Community System
Receive a regular billing for water	1.6*	4.7	83.0
Operation and maintenance (individual systems)	94.7	65.0	0.2
Included in rent payments	2.7	27.8	16.4
Other	1.0	2.5	0.5
Total Percent	100.0	100.0	100.1
**Total Households	8,765,000	2,228,000	10,981,000

*These were households which purchased water on a regular basis and received a bill for it.

**Does not include households which associated no cost with the water supply.

written bills during the interview. Since billing periods and expenditures for water could not be determined for these households, no data existed for a comparison of recorded cost by size of system.

PERCEIVED COST

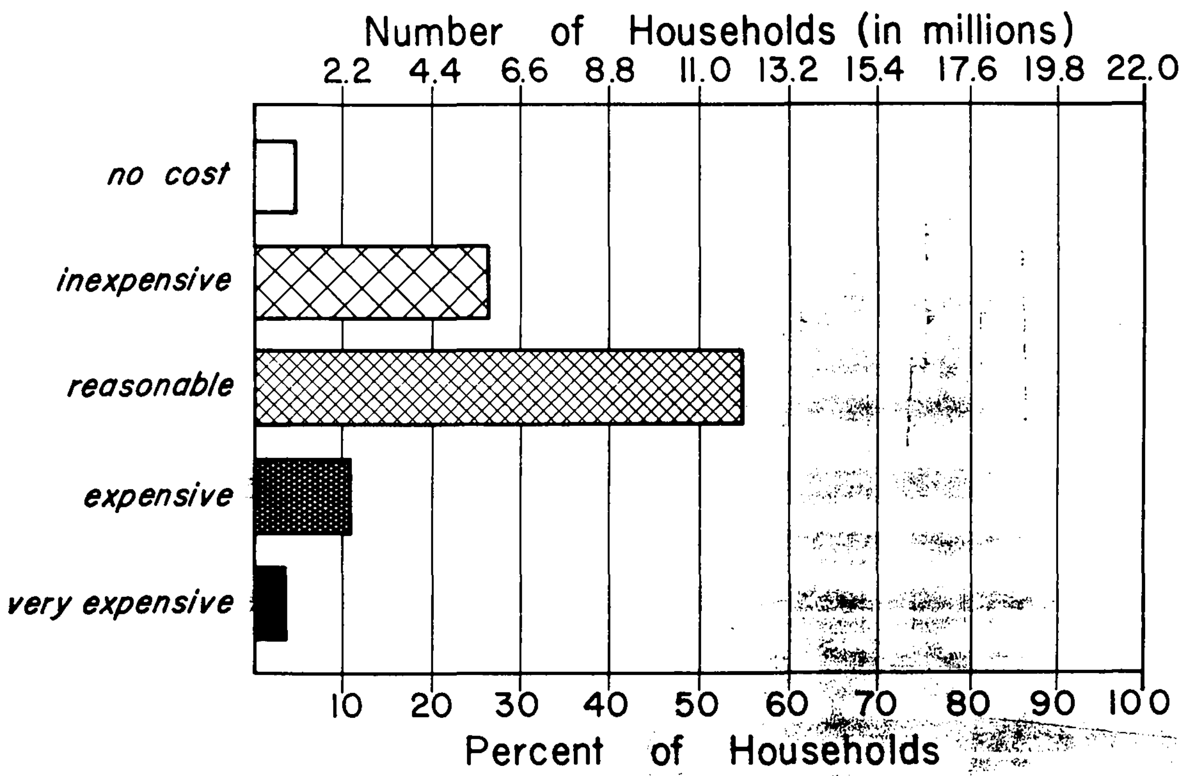
Almost all recorded NSA cost data pertained to households served by community systems because the data were compiled only from water bills available at the households. Perceived cost, on the other hand, was assessed for all rural households.

On perceived cost, respondents were first asked whether they thought the water supply was "inexpensive," "reasonable," "expensive," or "very expensive." The only other possible responses were "don't know" or that the water had "no cost." The cost of water was felt to be reasonable or inexpensive in the majority of rural households, a total of 17.3 million (see Figure V-36). Moreover, in slightly less than one million rural households, no cost was associated with the water supply. At the other end of the scale, the water was considered expensive or very expensive in 14.0 percent of all rural households, a total of about three million.

NSA interviewers also asked household representatives whether their water costs had increased, decreased, or remained the same during the past year. Water costs were judged to have remained the same in about six out of every ten rural households, a total of 12.2 million. Costs reportedly increased in 7.9 million households and decreased in only 248,000. For 631,000 households, it could not be determined if costs had changed or, if they had, in what direction. (This was often a result of respondents not living in households long enough to assess cost trends.) An additional 0.9 million households associated no cost with the water supply.

Figure V-36

Perceived Cost of Rural Household Water Supplies



<u>Subnational variation in perceived cost</u>

The cost of water was thought to be reasonable or inexpensive at the great majority of rural households in all four regions—at more than 86 percent of households in the Northeast and North Central, and at more than 75 percent of households in the South and West (see Figure V-36a). In addition, 6.6 percent of households in the West said there was no cost associated with the water supply, compared to 3.4 percent in the Northeast, 3.8 percent in the South, and 1.5 percent in the North Central. Water was reportedly expensive or very expensive for a greater proportion of households in the South and West—for 17.1 percent in the South and 18.9 percent in the West.

In a related finding, the cost of water was reported to have increased in a larger proportion of households in the West (42.6 percent, compared to about 35 percent of households in the other three regions). For many households in each region (ranging from a low of 48.2 percent in the West to a high of 63.3 percent in the Northeast), water costs appeared to have remained the same over the past year. As might be expected, cost increases were far more common than decreases. Decreases were infrequent, at best: they were reported at 3.5 percent or less of rural households in each region.

In general, perceived cost was higher in households located within SMSAs. The most noticeable differences in the SMSA/nonSMSA comparison were that only 1.8 percent of SMSA households reported that there was no cost associated with the water supply, compared to 5.7 percent of nonSMSA households, and that 19.1 percent of SMSA households reported that the water supply was expensive or very expensive, compared to 12.3 percent of nonSMSA households.

The size-of-place comparison showed that, in general, perceived water costs tended to rise with population size (see Figure V-36b). For example, in other rural areas, 5.1 percent of households reported that the water supply had no cost, compared to only 0.9 percent in large rural communities and 2.3 percent in small

Figure V-36a

Regional Variation in Perceived Cost of Rural Household Water Supplies

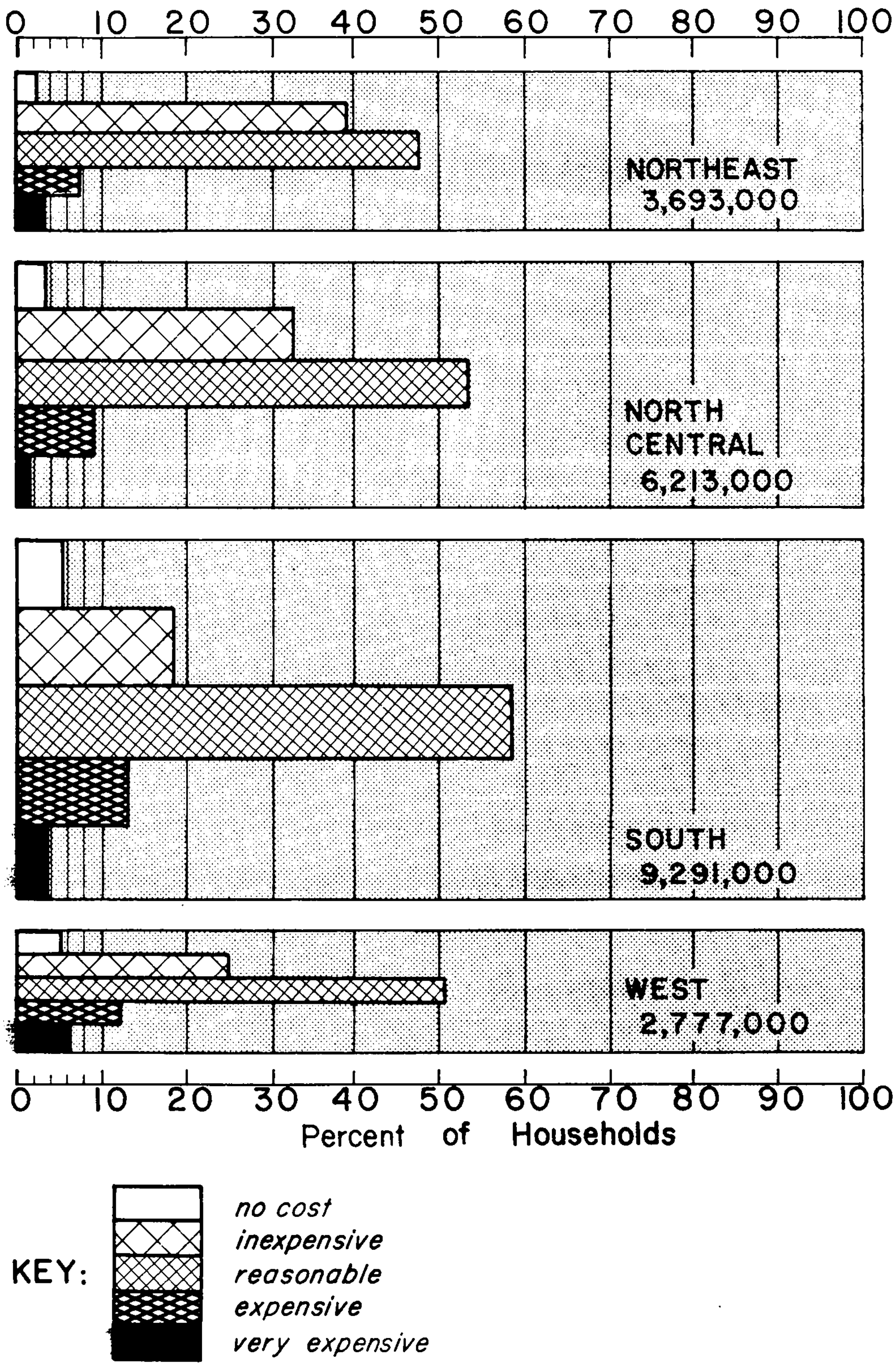
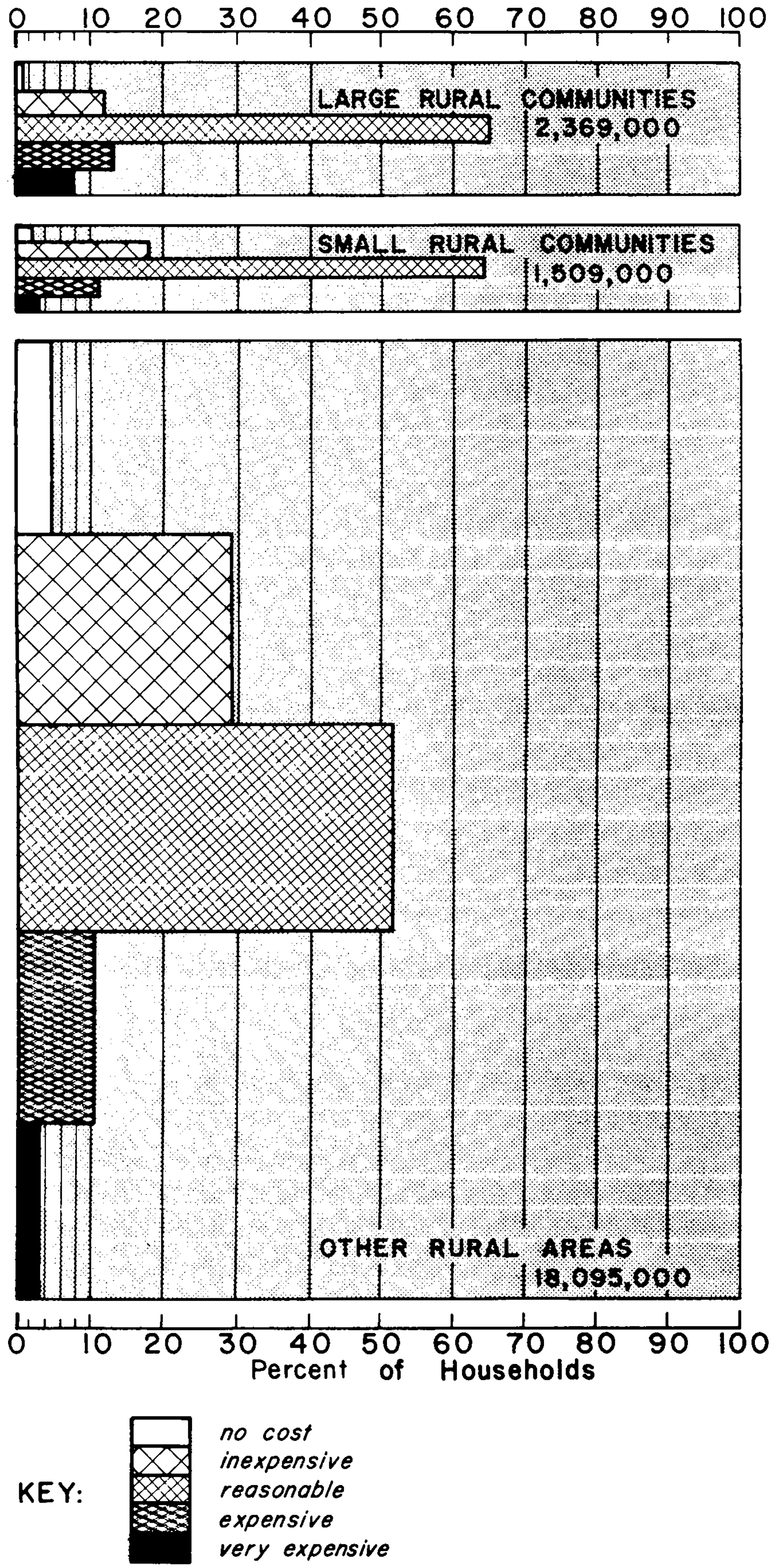


Figure V-36b

Size-of-Place Variation in Perceived Cost of Rural Household Water Supplies



rural communities. At the other extreme, about 14 percent of households in small rural communities and other rural areas reported that the water supply was expensive or very expensive, compared to 21.6 percent of households in large rural communities.

In addition, proportionately more households in large rural communities reported cost increases during the preceding year. Specifically, 44.4 percent of these households reported increases, compared to 38.7 percent in other rural areas and 31.8 percent in small rural communities. Cost decreases were equally rare in all three size-of-place categories, being reported in about 1 percent of households in each category.

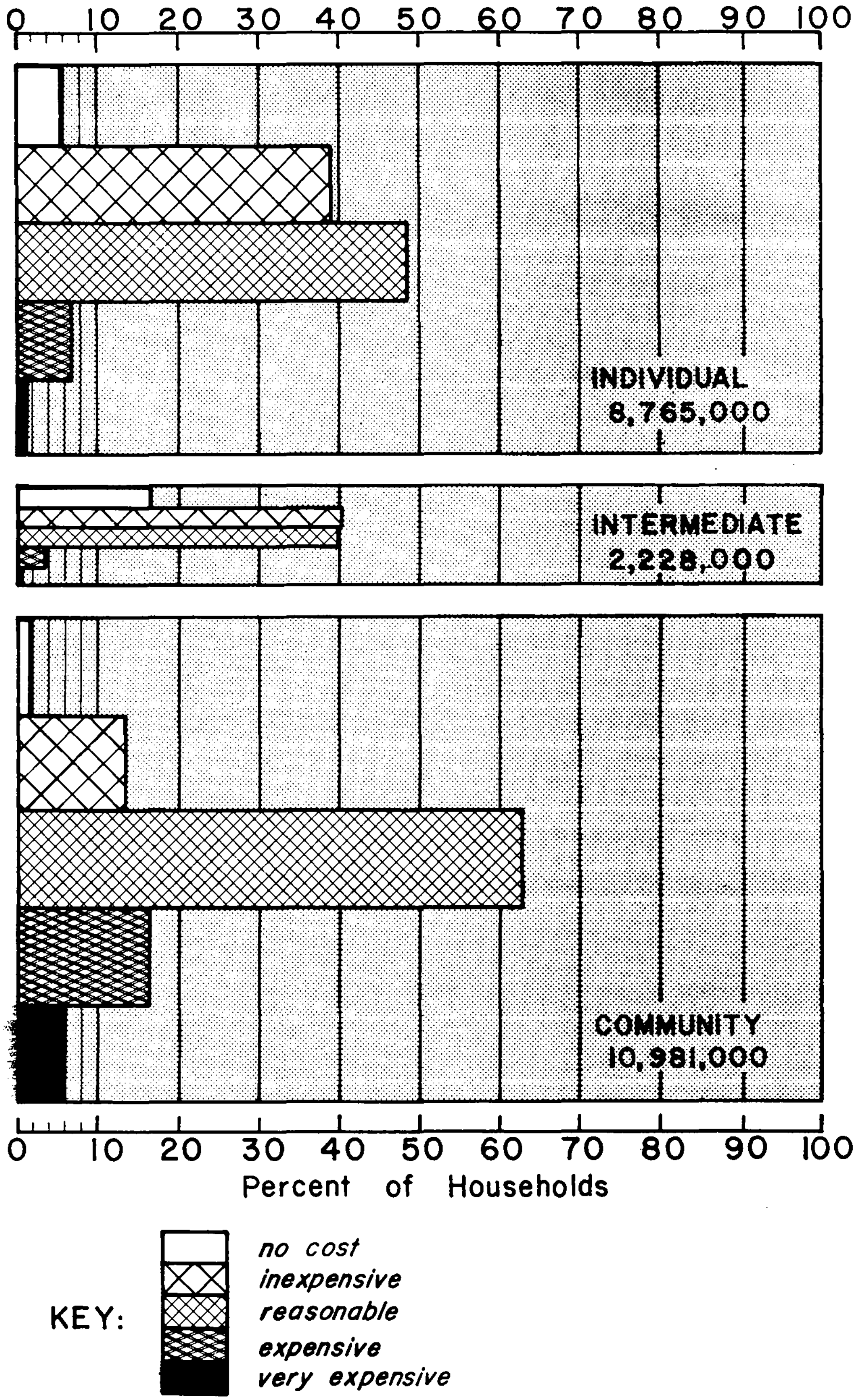
Just as perceived costs were highest at households in large rural communities, they were also highest at households served by community water systems (see Figure V-36c). This is not surprising, since 93.5 percent of households in large rural communities were served by community systems (see Chapter IV).

On the other hand, less than 2 percent of households served by community systems reported that the water supply cost nothing, compared to 5.3 percent of households served by individual systems. Surprisingly, 16.5 percent of households served by intermediate systems associated no cost with the water supply. Water supplies were felt to be expensive or very expensive at about 22 percent of households served by community systems, compared to about 7 percent of households served either by individual or intermediate systems.

Cost increases during the preceding year were reported most often by households served by individual systems (43.7 percent). However, large proportions of other households also reported cost increases—36.6 percent of households served by community systems, and 29.6 percent of households served by intermediate systems.

Figure V-36c

Size-of-System Variation in Perceived Cost of Rural Household Water Supplies



AFFORDABILITY

Obviously, the cost of water supplies is a factor in the status of rural water conditions. Cost, the availability of domestic water, and the demand for water all have widespread economic consequences. To the individual, however, the cost is a more personal, immediate concern. The individual's financial well-being, his feelings, and his motivation for acquiring water of good quality are all involved. Economic demand curves can provide accurate descriptions of the general response of users to cost and availability of water, but they do not necessarily describe that response in relation to other considerations. The curves suggest that at a certain cost level, people will tend to reduce the quantity of water they use rather than pay more money. However, the curves do not evaluate that inflection point in relation to other household expenditures. Nor do the curves tell us much about individual variability in willingness to pay more for higher quality or for larger quantities of water.

Traditionally, affordability has been defined as the ability to meet expense without detriment to one's overall financial condition. In the NSA, the concept of affordability was approached using both recorded and perceived indicators. The recorded indicator of affordability was the percentage of income used for domestic water. Perceived indicators were the reported reasonableness of the cost (see Perceived Cost section, above) and the respondent's disposition to pay more, less, or the same for a different water supply.

RECORDED INDICATORS OF AFFORDABILITY

The recorded measure of affordability which could be obtained from NSA data was the ratio of billed cost to total household income. This ratio was then multiplied by 100 to obtain a percentage of household income paid for water. Since the billed or recorded cost, as opposed to perceived cost, was available only from rural households which had sufficiently itemized water bills, the discussion of recorded indicators of affordability was limited to about 4.6 million households served by community water systems.

At these households, the proportion of household income paid for water ranged from 0.04 percent through 15.60 percent (see Figure V-37). One-quarter of the households paid 0.30 percent or less of household income for water. Half paid 0.60 percent or less. Three-quarters paid 0.99 percent or less, and one-quarter paid 1 percent or more.

The cost-to-income ratio represents one attempt to quantify affordability, but it in no way takes into account other household expenses. In other words, without additional information, there is no way to assess a particular household's ability to pay for its water supply. Implied, however, is that as the ratio increases, the probability of meeting the expense without detriment to the household's overall financial condition decreases.

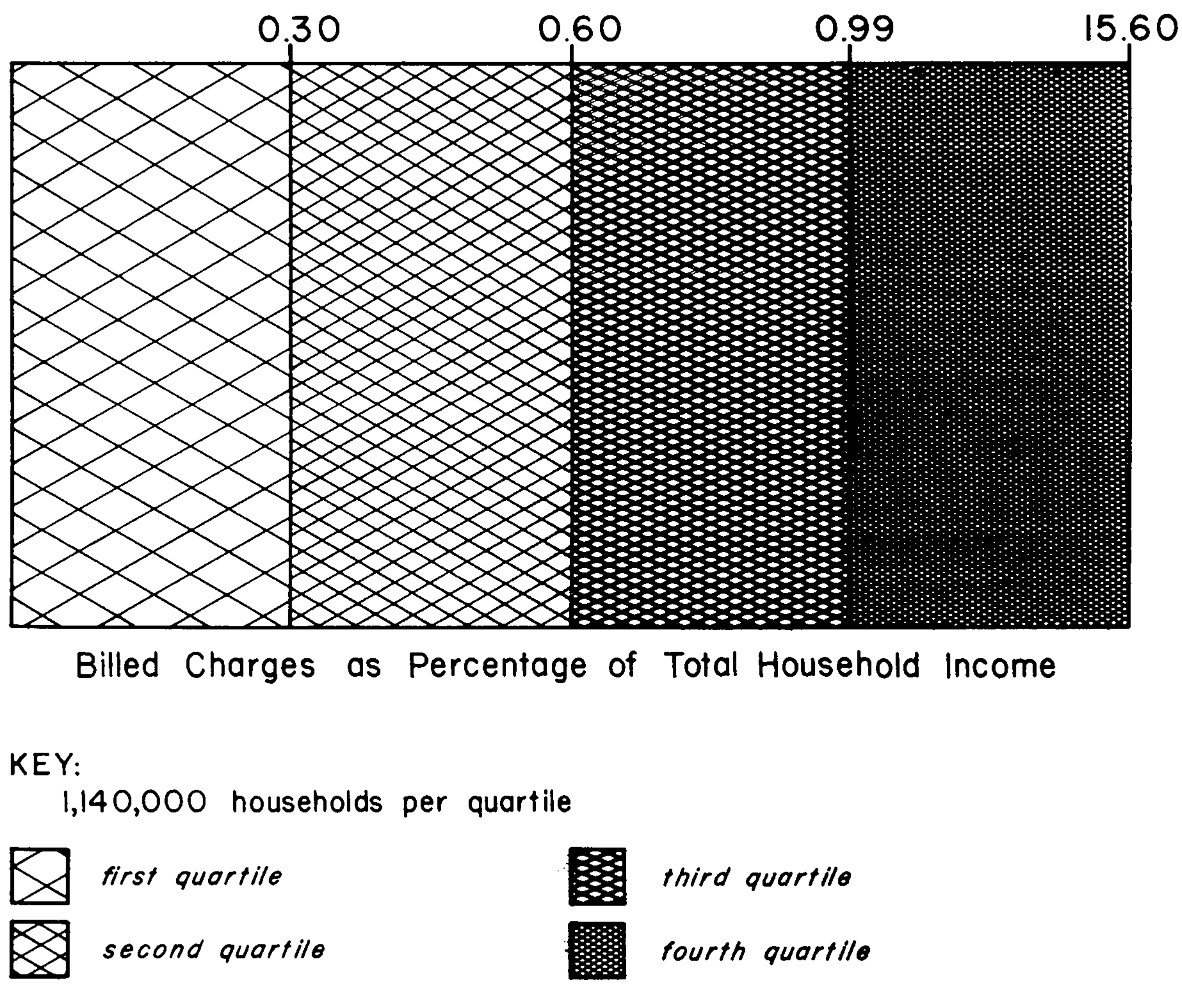
Subnational variation of recorded indicators of affordability

With respect to regional differences, households in the Northeast paid a smaller proportion of income for water than those in the South, West, or North Central (see Figure V-37a). Specifically, the median cost-to-income ratio in the Northeast was 0.38, compared to about 0.60 in the South and North Central, and 0.73 in the West. Looking at the data differently, one-fourth of the evaluated households in the South, West, and North Central paid more than 1 percent of their income for water. This amounted to 622,000 households in the South, 237,000 in the North Central, and 171,000 in the West. In contrast, only 13.0 percent of households in the Northeast (73,000 households) paid that much (not reflected in Figure V-37a).

The SMSA/nonSMSA comparison showed a more striking difference in the cost of water in relation to household income, the ratio being much higher for households located outside of SMSAs. In fact, the median ratio for nonSMSA

Figure V-37

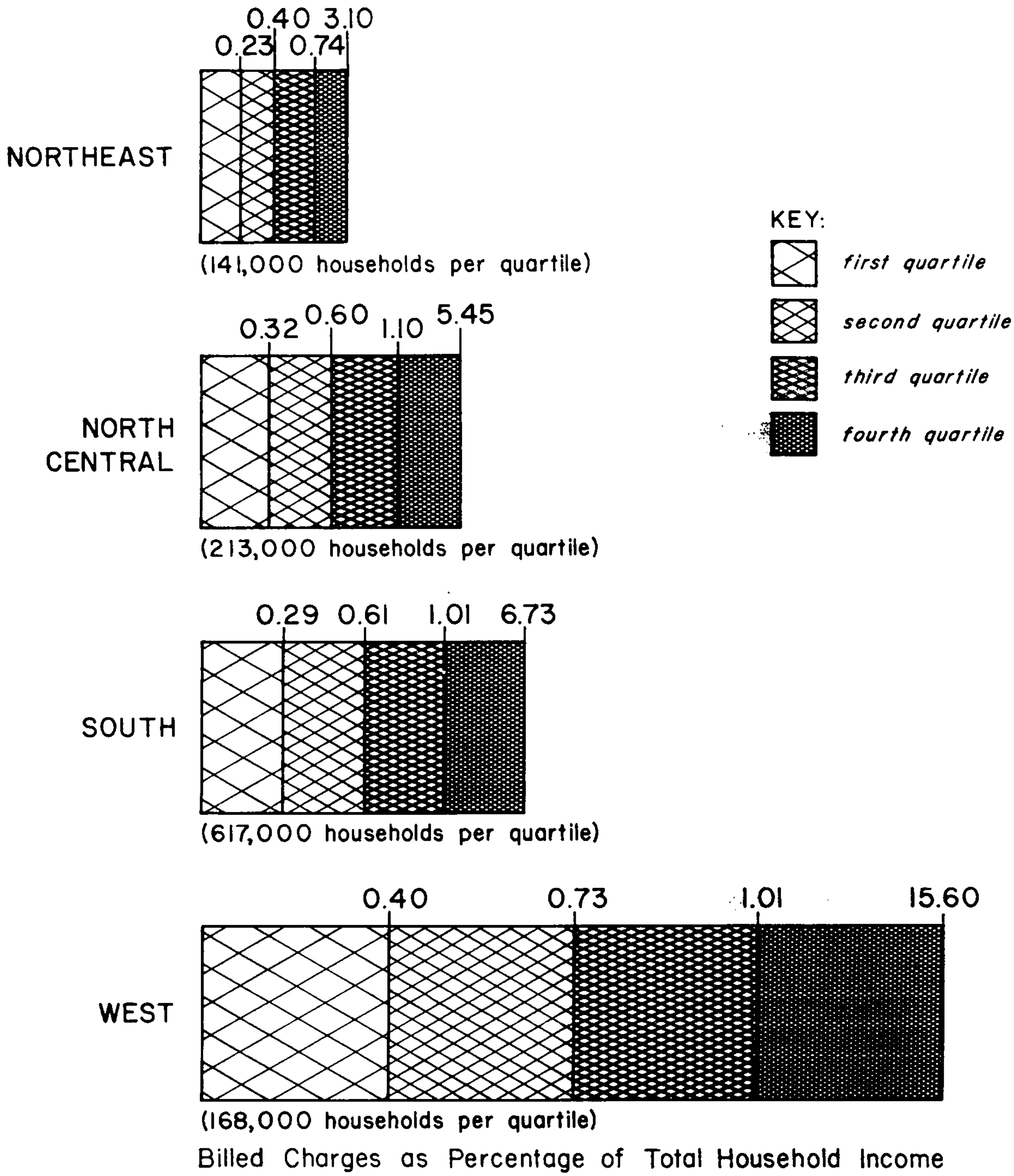
Percentage of Total Household Income Paid for Water (1978)



NOTE: Ratio could be computed only for households served by community systems.

Figure V-37a

Regional Variation in Percentage of Total Household Income Paid for Water (1978)



NOTE: Ratio could be computed only for households served by community systems.

households was twice as high as it was for households located within SMSAs (0.72 versus 0.36). As shown in Figure V-37b, three-quarters of nonSMSA households paid a maximum of 1.23 percent of their income for water, compared to three-quarters of households within SMSAs paying a maximum of 0.84 percent. Finally, the maximum cost-to-income ratio within SMSAs was 6.13, compared to 15.60 outside of SMSAs.

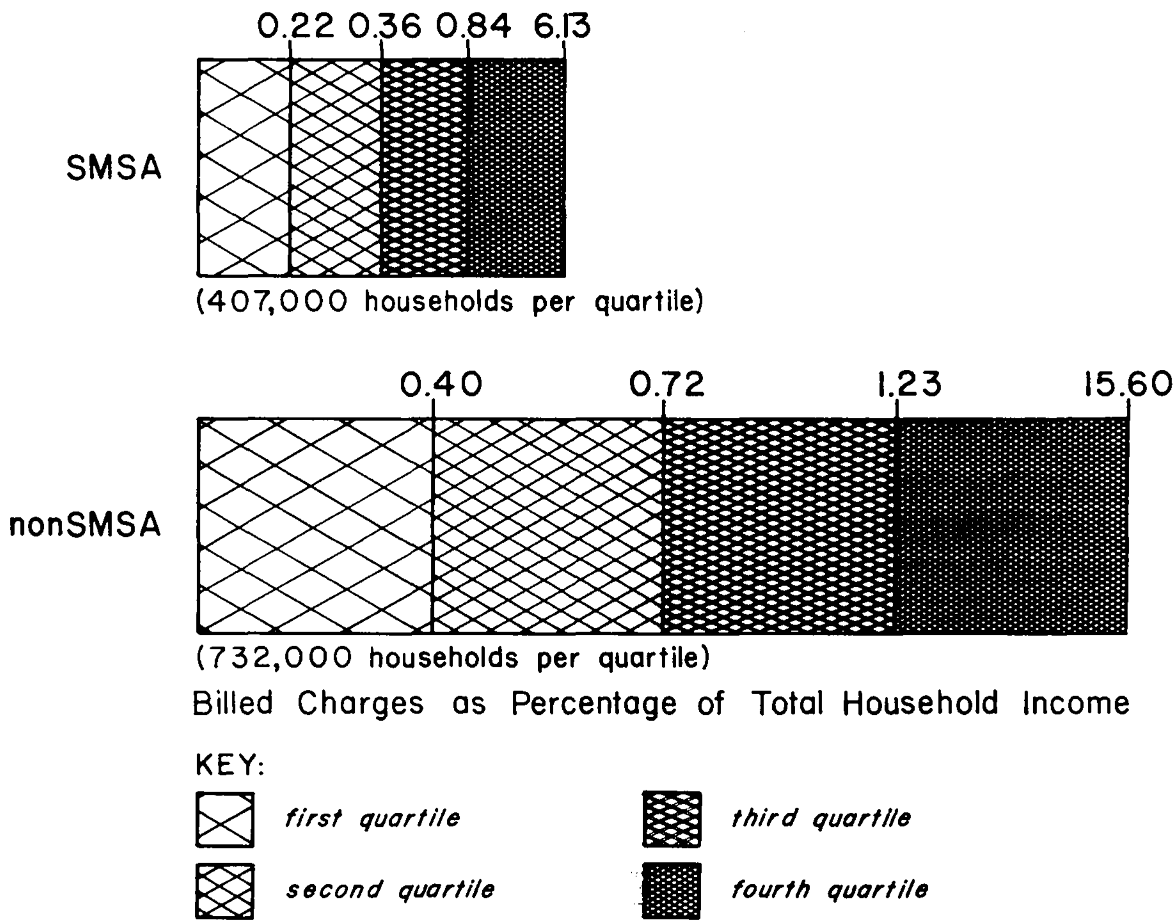
Two factors caused the large difference in cost-to-income ratios of SMSA households and nonSMSA households. First, the numerator of the ratio, the amount paid for water, was considerably higher among households located outside of SMSAs. Second, total household income (the denominator) was significantly lower outside of SMSAs. In fact, there was a difference of $6,000 between SMSA and nonSMSA median household income. With the two factors operating simultaneously, it is not surprising that the nonSMSA household ratios were so much higher than those of SMSA households.

Cost-to-income ratios also varied considerably depending on whether households were located in large rural communities, small rural communities, or other rural areas (see Figure V-37c). For three-quarters of the households in other rural areas, the highest proportion of household income spent for water was 0.86 percent, compared to 1.31 percent in small communities and 1.50 percent in large communities. Median cost-to-income ratios were about equal for large and small rural communities (0.82 and 0.76, respectively), but were much lower for other rural areas (0.52). In summary, although the very highest cost-to-income ratio occurred in other rural areas (where a single household in the NSA sample paid 15.60 percent of its income for water), costs generally were lower for households in other rural areas.

Since the available billing information pertained exclusively to households served by community water systems, affordability could not be compared by the size of the supply system serving the household.

Figure V-37b

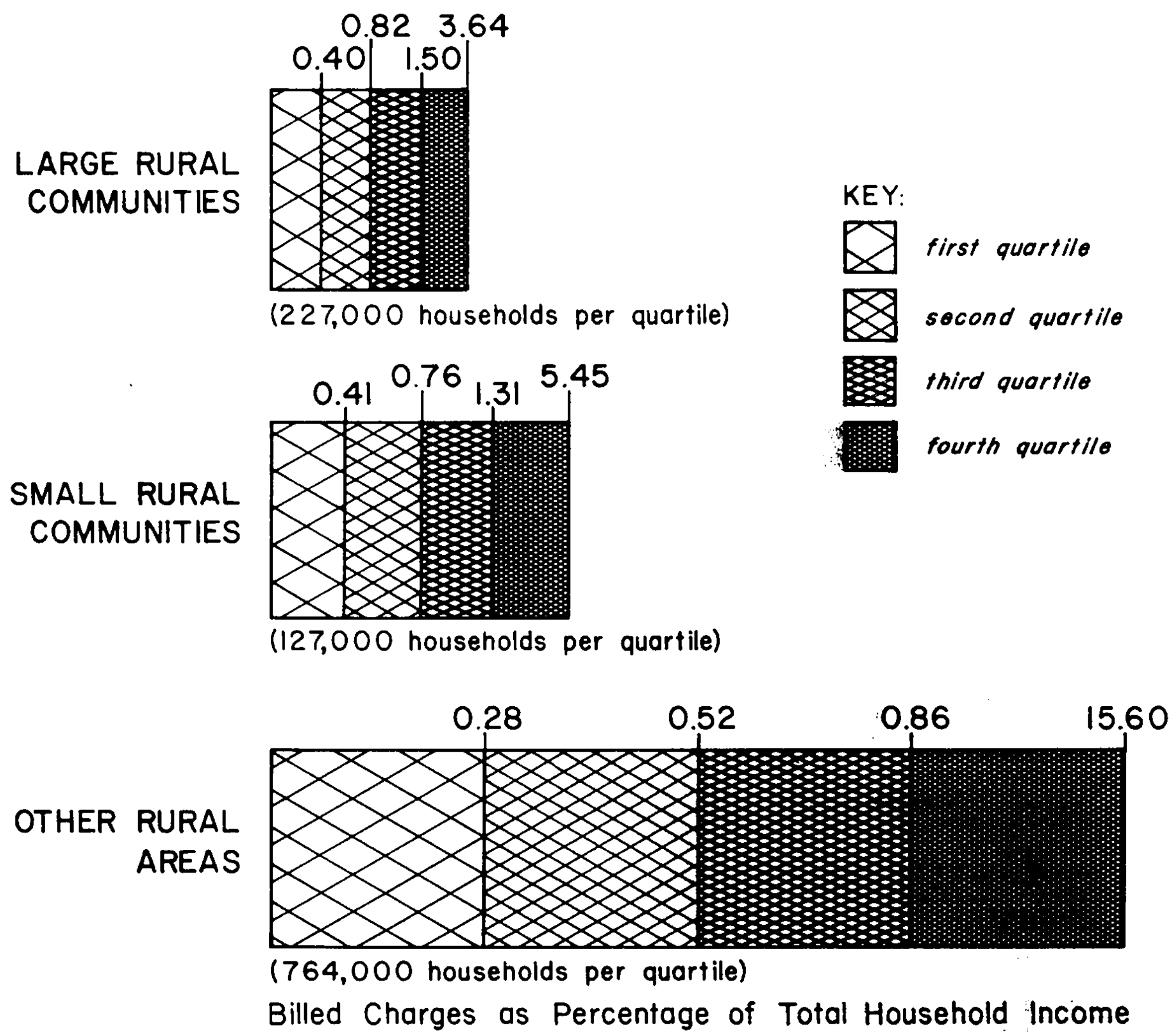
SMSA/NonSMSA Variation in Percentage of Total Household Income Paid for Water (1978)



NOTE: Ratio could be computed only for households served by community systems.

Figure V-37c

Size-of-Place Variation in Percentage of Total Household Income Paid for Water (1978)



NOTE: Ratio could be computed only for households served by community systems.

PERCEIVED AFFORDABILITY

Perceptions of cost have been discussed elsewhere in this chapter (see Figure V-36). Those same perceptions also shed some light on affordability. Recall that water was perceived to be inexpensive or absolutely without cost at 30.2 percent of all rural households (6.6 million); it was seen as reasonable at 52.6 percent of rural households (11.6 million), and either expensive or very expensive at another 14.0 percent (3.1 million households). Interestingly, a similar pattern of responses occurred when household representatives were asked if they would be willing to pay more or to pay the same amount for an "ideal" supply—one that was good to drink and provided as much water as needed. A willingness to pay more for the ideal supply was reported in 32.9 percent of all rural households (7.2 million), while 62.9 percent of household representatives (13.8 million) said they would only be willing to pay the same as they did for the current household supply. A willingness to pay less was expressed at 3.6 percent of rural households (0.8 million). Given the similarity in response patterns, one might postulate that household representatives reporting a water supply that was inexpensive or without cost were the same ones who reported they would be willing to pay more for an ideal water supply. A perception that the water was reasonably priced might be assumed to indicate a willingness to pay the same amount for a different supply, while a perception that the water supply was expensive might be equated with a desire to pay less for water. When these hypotheses were tested, however, no correlation was found between the perceived reasonableness of cost and willingness to pay for a different supply.

In summary, household water costs were considered expensive in 14.0 percent of all rural households—fully three million households. However, expensive water was not necessarily seen as unaffordable, but expensive in comparison to other costs such as electricity or sewer charges. The disposition to pay less for an ideal water supply was considered a better indicator of perceived affordability than the perceived expensiveness of the household supply, although it was a more conservative measure—that is, it included fewer households. Thus, judging by this indicator, there were less than one million rural households that had difficulty bearing the current cost of water, though four times as many households reported that the water supply was expensive or very expensive.

Subnational variation in perceived affordability

Since subnational variation in the reasonableness of perceived cost was discussed earlier (see "Subnational variation in perceived cost," above), the information will not be duplicated here with respect to the concept of affordability. The only other measure of a household's ability to bear the expense of water was the reported willingness to pay more or less than the current expenditure for an ideal water supply.

Recall that for the nation as a whole, the majority of households (62.9 percent) were willing to pay the same for the ideal water supply as they paid for their present one. As shown in Table V-35, this situation was slightly less common in the Northeast (55.9 percent of households), while a willingness to pay more for an ideal water supply was found in a higher percentage of households there (41.4 percent) than in the other three regions. In fact, a difference of eight percentage points or more was detected when comparing the Northeast with the other regions with respect to paying more for an ideal water supply. This disposition to pay more may have been related to the substantially higher median household income reported in the Northeast. Discussed in detail in Chapter III, median nonfarm income in the Northeast was about $15,500, compared to median incomes of about $12,000 in the North Central and South. The median in the West, $15,000, also was slightly less than the median reported for the Northeast. In contrast, a desire to pay less for water was expressed at 5.0 percent of households in the South and at

Table V-35

Regional Variation in Willingness to Pay for an Ideal Water Supply

Willingness to Pay	Percent of Households				
	Nation	Northeast	North Central	South	West
Willing to pay the same	62.9	55.9	64.1	64.8	63.3
Willing to pay less	3.6	1.6	2.3	5.0	4.2
Willing to pay more	32.9	41.4	33.1	29.7	31.4
Don't know	0.6	1.1	0.5	0.5	1.1
Total Percent	100.0	100.0	100.0	100.0	100.0
Total Households	21,971,000	3,693,000	6,213,000	9,290,000	2,777,000

only 1.6 percent of households in the Northeast. Again, this may have been the result of lower household income in the South.

Although less variation was observed between SMSA and nonSMSA households, proportionally more SMSA households than nonSMSA households were willing to pay more for water (35.8 percent, compared to 31.4 percent). As suggested earlier, this disposition to pay more may be a function of SMSA households having larger disposable incomes (see Chapter III).

With respect to size-of-place and size-of-system comparisons, no variation was found in willingness to pay for a different water supply.

REFERENCES

[1]General references are:

Allen, Martin J., and Geldreich, Edwin E. "Bacteriological Criteria for Ground-Water Quality." Ground Water 13 (January-February 1975).

McCabe, Leland J.; Symons, James M.; Lee, Roger D.; and Robeck, Gordon G. "Survey of Community Water Supply Systems." Journal of the American Water Works Association (November 1970): 670-687.

McCaull, Julian, and Crossland, Janice. Water Pollution. New York: Harcourt Brace Jovanovich, 1974.

National Technical Advisory Committee to the Secretary of the Interior. Water Quality Criteria. Washington, DC: US Government Printing Office, 1968.

Russell, Clifford S., editor. Safe Drinking Water: Current and Future Problems, Proceedings of a National Conference in Washington, DC, 1978.

The Safe Drinking Water Act (Serial No. 95-10). Washington, DC: US Government Printing Office, 1977.

US Environmental Protection Agency. Manual of Individual Water Supply Systems. 2nd rev. ed. Raleigh, NC: US Environmental Protection Agency, 1974.

US Environmental Protection Agency. "National Secondary Drinking Water Regulations," Federal Register 42: No. 62 (March 31, 1977): 17144-17146.

US Environmental Protection Agency. "National Interim Primary Drinking Water Regulations." Federal Register 40: No. 248 (December 24, 1975): 59566-59574.

US Environmental Protection Agency. State of the Art of Small Water Treatment Systems. Washington, DC: US Environmental Protection Agency, 1977.

[2]Board of Directors, American Water Works Association. Quality Goals for Potable Water. January 28, 1968.

[3]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations (EPA-570/0-76-003). Washington, DC: US Government Printing Office.

References continued

[4]US Environmental Protection Agency. "National Secondary Drinking Water Regulations."

[5]National Academy of Sciences. Drinking Water and Health. Washington, DC: National Academy of Sciences, 1977.

[6]Ibid.

[7]Drexel University and National Science Foundation. Water Quality and Health Significance of Bacterial Indicators of Pollution--Workshop Proceedings. Wesley O. Pipes, ed. Philadelphia: Drexel University, 1978.

[8]National Academy of Sciences, 1977, p. 72.

[9]Ibid., p. 84.

[10]Ibid, p. 83.

[11]Stevenson, Albert H. "Studies of Bathing Water Quality and Health." American Journal of Public Health 43:529-538 (May 1953).

[12]National Academy of Sciences, 1977, p. 83. First-phase assessment of Stevenson study: Cabelli, Victor J., and McCabe, Leland J. "Recreational Water Quality Criteria," News of Environmental Research in Cincinnati. Cincinnati: National Environmental Research Center, November 11, 1974.

[13]Whitsell, Wilbur J.; Hutchinson, Gary D.; and Taylor, Donald H. "Problems of Individual Supplies." The State of America's Drinking Water. Raleigh: North Carolina State University, 1975.

[14]McKee, Jack Edward, and Wolf, Harold W., eds. Water Quality Criteria, 2nd ed. Sacramento: State of California State Water Quality Control Board, 1963.

References continued

[15]Geldreich, Edwin E. "Applying Bacteriological Parameters to Recreational Water Quality." Journal of the American Water Works Association (February 1970): 113-120.

[16]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations, p. 30.

[17]National Academy of Sciences, 1977, p. 75.

[18]Geldreich, Edwin E. "Fecal Coliform and Fecal Streptococcus Density Relationships in Waste Discharges and Receiving Waters." CRC Critical Reviews in Environmental Control (October 1976):349-368.

[19]Geldreich, Edwin E. "Applying Bacteriological Parameters to Recreational Water Quality," p. 114.

[20]National Academy of Sciences, 1977, pp. 86-87.

[21]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations, p. 38.

[22]Glaze, William H.; Saleh, Farida Y.; and Kinstley, Warren. "Characterization of Nonvolatile Halogenated Compounds Formed During Water Chlorination." In Water Chlorination: Environmental Impact and Health Effects, Vol. 3, edited by Robert L. Jolley, William A. Brungs, Robert B. Cummings, and Vivian A. Jacobs, pp. 99-108. Ann Arbor: Ann Arbor Science Publishers, Inc., 1980.

[23]Levin, Morris A. "Significance of Wastewater Disinfection to Health Effects Observed in Swimmers." In Water Chlorination: Environmental Impact and Health Effects, pp. 11-25.

[24]American Public Health Association, American Water Works Association, and Water Pollution Control Federation. Standard Methods for the Examination of Water and Wastewater, 14th ed. Washington, DC: American Public Health Association, 1975, p. 132.

References continued

[25]US Environmental Protection Agency. "National Secondary Drinking Water Regulations."

[26]Drexel University, 1978, p. 98.

[27]US Environmental Protection Agency. Manual of Individual Water Supply Systems (EPA-430/9-74-007). Washington, DC: US Environmental Protection Agency, 1974, p. 7.

[28]McKee, 1963, p. 283.

[29]Hem, John D. Study and Interpretation of the Chemical Characteristics of Natural Water. Washington, DC: US Government Printing Office, 1970.

[30]McKee, 1963, p. 273.

[31]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations, pp. 122, 123.

[32]National Academy of Sciences, 1977, p. 443.

[33]National Academy of Sciences, 1977, p. 440.

[34]Hem, 1970, p. 225.

[35]American Public Health Association, p. 200.

[36]Hem, 1970.

References continued

[37]US Environmental Protection Agency. "National Secondary Drinking Water Regulations." A similar statement is available in American Heart Association. "Impact of the Environment on Cardiovascular Disease: Report of the American Heart Association Task Force on Environment and Cardiovascular System." 1980.

[38]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations, pp. 43, 45.

[39]McKee, 1963, p. 151.

[40]McKee, 1963, p. 151.

[41]World Health Organization. International Standards for Drinking-Water. Geneva: World Health Organization, 1958, p. 29.

[42]Shearer, Lois Ann; Goldsmith, John R.; Young, Clarence; Kearns, Owen A.; and Tamplin, Benjamin R. "Methemoglobin Levels in Infants in an Area with High Nitrate Water Supply." American Journal of Public Health 62 (September 1972): 1174-1180.

[43]National Academy of Sciences, 1977, p. 424.

[44]McCaull and Crossland, 1974.

[45]Ibid.

[46]National Academy of Sciences, 1977, pp. 412-414.

[47]US Environmental Protection Agency. "National Secondary Drinking Water Regulations."

References continued

[48]National Research Council, Subcommittee on Iron of the Committee on Medical and Biological Effects of Environmental Pollutants, Division of Medical Sciences Assembly of Life Sciences. Iron, p. 112. Baltimore, MD: University Park Press, 1979.

[49]McKee, 1963, p. 214.

[50]National Academy of Sciences, 1977, p. 265.

[51]National Academy of Sciences, 1977, p. 402.

[52]National Academy of Sciences, 1977, p. 410.

[53]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations, p. 124.

[54]National Academy of Sciences, 1977, pp. 400-411.

[55]Federal Register, Vol. 45, No. 168, August 27, 1980, p. 57336.

[56]National Academy of Sciences, 1977, pp. 400-411.

[57]National Academy of Sciences, 1977, pp. 310-311.

[58]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations, p. 72.

[59]Patterson, Clair C., and Settle, Dorothy M. "Lead in Albacore: Guide to Lead Pollution in Americans." Science 207 (March 14, 1980):1167-1176. AND National Academy of Sciences, 1977, pp. 255-256.

References continued

[60]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations, pp. 48-50.

[61]McKee, 1963, p. 206.

[62]Patterson, Clair C., 1980.

[63]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations, pp. 71,72,115.

[64]National Academy of Sciences, 1977, p. 420.

[65]National Academy of Sciences, 1977, p. 362.

[66]National Academy of Sciences, 1977, pp. 344-345.

[67]National Academy of Sciences, 1977, p. 369.

[68]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations, pp. 113-116.

[69]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations, pp. 48-50.

[70]National Academy of Sciences, 1977, pp. 390-399.

[71]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations, p. 66.

[72]Prasad, Ananda S. Trace Elements and Iron in Human Metabolism, pp. 55-60. New York & London: Plenum Medical Book Co., 1978.

References continued

[73]McCaull, Julian. "Building a Shorter Life." Environment 13:7 (September 1971): p. 3 ff.

[74]Ibid.

[75]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations, p. 59.

[76]McCaull, "Building a Shorter Life," 1971.

[77]McKetta, John J., and Cunningham, William A. Encyclopedia of Chemical Processing and Design, Vol. 5, pp. 406-421. New York: Marcel Dekker, Inc., 1977.

[78]Ibid.

[79]Ibid.

[80]McCaull, "Building a Shorter Life," 1971.

[81]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations, p. 61.

[82]McCaull, "Building a Shorter Life," 1971.

[83]Jonasson, I. R., and Boyle, R. W. "Geochemistry of Mercury." Special Symposium on Mercury in Man's Environment, Ottawa, Canada, February 1971.

[84]Prasad, 1978, p. 373.

[85]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations, p. 61.

References continued

[86]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations, p. 79.

[87]Grant, Neville. "Mercury in Man." Environment 13:4(May 1971):2-15, AND Wood, John M. "A Progress Report on Mercury," 14:1(January/February 1972): 33-39.

[88]National Academy of Sciences, 1977, p. 277.

[89]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations, pp. 48-50.

[90]National Academy of Sciences, 1977, p. 246.

[91]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations, p. 58.

[92]National Academy of Sciences, 1977, p. 230.

[93]National Academy of Sciences, 1977, pp. 314-315.

[94]National Academy of Sciences, 1977, pp. 289, 290.

[95]Ibid.

[96]National Academy of Sciences, 1977, p. 291.

[97]World Health Organization. European Standards for Drinking-Water. Geneva: World Health Organization, 1970, p. 33.

[98]US Environmental Protection Agency. "Interim Primary Drinking Water Regulations—Control of Organic Contaminants in Drinking Water." Federal Register 43: No.28 (February 9, 1978):5756-5780.

References continued

[99]US Environmental Protection Agency. National Interim Primary Drinking Water Regulations, p. 106.

[100]National Academy of Sciences, 1977, p. 898.

[101]US Environmental Protection Agency. "Drinking Water Regulations: Radionuclides." Federal Register 41: No. 133 (July 9, 1976):28402-28405.

[102]US Environmental Protection Agency. "National Secondary Drinking Water Regulations."

[103]Bruvold, William H. "Consumer Attitudes Toward Taste and Odor in Water." Journal of the American Water Works Association (October 1977):562-564.

[104]Temple, Barker & Sloane, Inc. Survey of Operating and Financial Characteristics of Community Water Systems. Submitted to US Environmental Protection Agency, Washington, DC. Wellesley Hills: Temple, Barker & Sloane, Inc., 1977.

[105]Temple, Barker & Sloane, Inc., 1977.

VI

Composites of US Rural Water Supply Status

In the preceding chapter, the status of US rural water supply was characterized principally in terms of quality, quantity, availability, cost, and affordability. Depending upon their complexity and the conventions for representing them empirically, these factors were originally expressed as different sets of variables, or indicators, which reflected specific properties of each status component. Quality, for example, was delineated by a large number of discrete chemicals, bacteriological contaminants, and other waterborne substances which were detected through laboratory assays. A second dimension of quality consisted of tastes, odors, colors, and other aesthetic aspects which may have been noticed by household members.

Availability, while not as conceptually elaborate as quality, was also described with respect to a set of unique measures, including indicators of accessibility and reliability. Quantity, cost, and affordability were not measured as comprehensively, however, in part because of certain practical obstacles which could not be eliminated within the constraints of the NSA. An accurate measure of water quantity, in particular, would have required continued monitoring of household water use over an extended period of time. At many households, in fact, a precise estimate of water consumption could not have been obtained without installing some type of metering device. Likewise, detailed assessments of cost and affordability could have been accomplished only through a prolonged investigation of household financial resources, income, and expenditure patterns. The data on quantity, cost, and affordability, which were restricted to one or two indicators for each factor, made it possible to explicate those status components in Chapter V. However, the information on quality and availability was much too extensive to allow a generalized interpretation. Consequently, composite measures were devised for quality and availability, and are presented in Chapter VI. Thus, although Chapter VI is actually an extension of Chapter V's description of the status of US rural water supply, it includes only two of the five factors that were used in that description.

There were a number of compelling reasons for constructing summary or composite measures for quality and availability as an alternative to employing the more specific raw data. Some reasons were peculiar to the NSA, which was designed to be an overview of rural water conditions, while others were related to dictates of the measurement process. First, although they typically did not encompass all the relevant information, the composites allowed general patterns to be established more easily than could have been done by an examination of individual parameters. Second, the emphasis on general patterns, rather than on details, was more compatible with the NSA's purpose as an overview. Third, the use of composites reduced the volume of material that could have been included in the analytical portions of this report to a manageable level. This last consideration was especially critical in the NSA because, unless the composites were formulated, separate models eventually would have had to be specified for each variable and its postulated determinants. The effort to develop the composites that are presented in this chapter was also consistent with the ultimate objective of producing any summary measure, which is to make the data more comprehensible while having a minimal effect on their original properties.

As a general procedure, the formation of composites involves synthesizing variables according to a prescribed set of principles. These principles usually differ as a function of several conditions, including the diversity of the data collected for each variable, the units in which the variables are expressed, and the substantive meaning to be conveyed by the composite, to name only a few. The present chapter was organized so as to maintain the distinctions between the principles within the context of each factor and its indicators. Since water quality is of considerable importance in determining the status of rural water supplies, and because its set of indicators was the most extensive, the composites for this factor are presented first. This section of Chapter VI is further subdivided into two parts to acknowledge the fact that quality was measured in terms of information produced by laboratories and in terms of perceptions of the rural people who used the water. The other major section of Chapter VI, which is also divided into two parts, is arranged according to the summary measures of availability.

Except for the indices that were generated from the physical constituents of water quality, which evolved from a common strategy, each composite presented in the chapter is considered independently. Specifically, the purpose of each index is established, the appropriate indicators are specified, and the composite's structure is described. Following the development of the index, its distribution of scores is compiled for the nation and for the four subnational groupings (region, SMSA/nonSMSA, size of place, and size of system).

WATER QUALITY COMPOSITES

Water quality was broadly defined in the NSA as "the adequacy of water for human use." Although the major emphasis of this definition was on water's effects on human health and well-being, its aesthetic and economic implications were also recognized. It was realized, of course, that water could be suitable for consumption in this narrow sense and still be of little use to human beings if it were not available in sufficient quantities at reasonable prices. These latter considerations were addressed separately in the NSA, however, as explained elsewhere in this report.

It was further acknowledged that domestic water quality could be judged adequate or inadequate by some particular standard based on physical and chemical measurements, yet still be considered inadequate by water users. This determination could be made on the basis of personal experiences and observations or information from other sources. Regardless of its origin, the decision that water quality is unsatisfactory could have numerous consequences—reduced consumption, use of alternative supplies, demands for additional water treatment, and pressure for regulatory change, to name some of the more significant. The user's perception of water quality as measured in the NSA was described in Chapter V. Also, the relationships between those perceptions and the measured values of water quality will be explored in a subsequent chapter. Here, however, the immediate focus is on the composite indices developed by NSA investigators to represent biological, chemical, and physical characteristics of water. Later in this chapter, judgments about tangible attributes (taste, odor, color, and so forth) will be integrated into a composite that is designed to reflect water quality strictly in terms of its perceptual aspects.

INDICES OF PHYSICAL MEASURES

The households included in the NSA could be contrasted in terms of any single physical or chemical characteristic without appreciable difficulty. Evidence for this is provided by the portion of Chapter V where such comparisons were accomplished and by innumerable other studies on the subject of water and its constituents. However, it was decidedly futile to compare households on the basis of several of the over 40 physical and chemical characteristics measured in the NSA at once. For instance, how would one evaluate the differences in water quality between two groups of households, one with supplies that had high concentrations of sulfates and manganese but with low levels of iron and turbidity, the other having supplies with an abundance of iron and turbidity but with small amounts of sulfates and manganese? Unless one employed a composite approach, any relative assessment of water quality would be restricted to making observations about each individual constituent.

The NSA indices of physical measures provided the mechanism for combining a large amount of information in a reduced, more intelligible form. The objective was a set of summary measures of water quality, based on the constituents measured in the survey, which would facilitate an understanding of overall water quality and allow comparisons among groups of rural households. These indices would also be used as analytical devices in a subsequent effort to specify factors that affect the quality of water produced by rural water supplies (see Chapter X).

In reviewing advantages and disadvantages of indexing, NSA researchers discovered that there had been a substantial professional interest in developing indices to describe water quality. The most fundamental argument in favor of indexing has been the ability of an index to characterize generally a complex situation involving a number of diverse water quality attributes. When constructed properly, an index enhances the ability to make sense of an otherwise incomprehensible assortment of facts. The major argument against an index has been that the simplification entails an unacceptable loss of specificity and an uninterpretable distortion of the original data. One particular difficulty has been that the level of precision associated with measuring any given constituent cannot be conveyed well in an index. However, this objection presumes that the units in which the data are expressed must be retained to establish differences, which is not necessarily correct. Also, as will be demonstrated in this chapter, transformations are available that preserve at least the order of the raw data, which satisfies the most critical requirement of index construction.

Background

The principles used to construct the water quality indices in the NSA were based to a large extent on precedents that emerged from other efforts to develop summary measures of water quality. Since 1965, when the first formal index appeared, there have been numerous attempts to represent gradations in water quality on a composite numerical scale.[1] Some of these indices, such as those formulated by Horton,[2] the National Sanitation Foundation,[3] Prati,[4] McDuffie,[5] and Dinius,[6] were designed to measure the quality of surface waters. In contrast, composites proposed by O'Connor,[7] Deininger,[8] Walski and Parker,[9] Stoner,[10] and Nemerow and Sumitomo,[11] were structured to reflect the different sets of uses that water can support. Another class of indices, which included composites devised by the MITRE Corporation,[12,13] Dee,[14] Inhaber,[15] Johanson and Johnson,[16] and Zoeteman,[17] was designed specifically for administrative decision-making. Finally, indices developed by Harkins,[18] and Schaeffer and Janardan,[19] were distinguished by their orientation towards established statistical approaches. These indices in particular, along with several others that have been proposed, are summarized more thoroughly by Ott.[20]

Although the water quality composites referred to in the preceding paragraph were too diverse to compare systematically, each one evolved from the same general process. This process, expressed as a series of distinct stages, involved selecting an underlying purpose for the index, designating a set of indicator constituents, determining the importance of each indicator or parameter, and specifying a method for combining the constituents into a single structure. In each case, the outcome of applying the process was a single value which was employed to differentiate bodies of water in terms of their quality.

The purpose that a composite is designed to satisfy is an important consideration in all index construction efforts. In effect, the purpose establishes the basic components and the limitations of the indices. Previous indices have been intended to reflect such varied concerns as the hygienic quality of water, the cost or effectiveness of pollution abatement activities, the aesthetic condition of water, water's suitability for specific uses, and other aspects of quality. The purpose of the NSA indices, as suggested in an earlier section of this chapter, was to measure the quality of the water provided by rural household supplies.

Indicator constituents are selected according to the information an index is designed to convey. In previous indices, constituents relevant to the substantive emphasis of the index generally were identified by literature searches or by soliciting the judgments of experts. As indicated below, the NSA used a variant of this approach to compile its set of water quality indicators.

While some indices assumed equal importance among constituents, it was more common to assign them weighting factors. Generally, this was accomplished by asking knowledgeable people to evaluate the relative significance of each indicator, given the composite's purpose. The resultant weights usually took into account the differential effect of constituents according to their potential concentrations. As noted later in the chapter, the weights for the NSA indices were based on the current water quality standards or the distributional properties of the constituents. These techniques provided the advantage of being comparatively more objective than the procedures used to produce weights for many of the other indices.

Independent of the three other stages, the last part of the index construction process is to combine the indicators into a single entity. Most often, this has been done by devising explicit mathematical functions for subindices and aggregating these into a composite. In the NSA, this approach was discarded in favor of a strategy that had a more formal statistical basis. This strategy is considered in more detail in one of the following sections, as are the indicators for the composites and the development of the weighting factors.

<u>The initial set of indicator constituents</u>

Because of a variety of unique circumstances, the NSA indices did not present some of the problems which hindered the efforts of other investigators. A major distinction was that the NSA indices were developed to reflect the quality of domestic water, while other indices were devised for water that was used as a drinking water source, for recreation, or for some other purpose. Consequently, the characteristics incorporated into the latter indices tended to be fairly general ones which indicated the broadest aspects of water quality. Constituents examined in the NSA, on the other hand, were usually of direct significance for the quality of domestic water.

The development of the NSA indices was augmented by substantial information that was refined even before the survey was undertaken. Constituents measured in the NSA originally were considered in conjunction with the effort to promulgate federal drinking water regulations. These regulations were codified as interim maximum contaminant levels (MCLs) in accordance with provisions of the Safe Drinking Water Act of 1974. The predominant underlying concern of this legislation and the MCLs was with the healthfulness of drinking water. As part of the process by which the regulations evolved, the EPA, with input from other sources, produced a preliminary list of water contaminants that posed a possible health threat.[21,22] Other considerations that influenced the decision to include a particular constituent in this list were the economic effects of properties such as water hardness and the aesthetic implications of characteristics such as color.

Also considered were the expense of controlling the concentrations of the various constituents and the expected public exposure to the constituents.

Additional deliberations by relevant federal agencies and public officials resulted in a final list of substances which were related to the broadly defined concept of water quality. Finally, interim primary MCLs were established for more than twenty contaminants deemed to be potential health threats or to indicate such threats. Public water systems with fifteen or more service connections or which served 25 or more people for more than 60 days each year were required to provide water that did not have constituent levels exceeding the MCLs.

With respect to the NSA, the MCL was selected as the principal criterion for determining which constituents should be included. A total of twenty contaminants with primary MCLs were tested for in the water specimens obtained from households in the NSA (Table VI-1). Radioactivity was measured in terms of eight specific substances and the total amount of radiation, provided that certain screening levels were exceeded. As a consequence of applying this selection principle, all of the substances for which there were official interim primary MCLs were measured directly or indirectly in the NSA survey, although those that were expected to be less prevalent were measured only in a 10 percent subsample.

A number of other constituents on the preliminary federal review list were determined to be more closely related to economic or aesthetic effects.[23] Some of these (a total of thirteen) were assigned secondary MCLs which, while not federally enforceable, were intended as guidelines for state officials. The NSA examined five of the thirteen constituents with secondary MCLs. Other substances on the preliminary list exerted effects that were so ambiguous, indeterminate, or complex that they precluded assignment of an MCL. Some of these—sodium, for example—were designated for further attention or research. Also included in this group of substances were constituents that had standards which were judged not to be

Table VI-1

Constituents Studied in NSA Survey

Constituent	Primary MCL	Secondary MCL	No MCL
Assayed in All Water Specimens:			
Total coliform	X		
Fecal coliform			X
Fecal streptococcus			X
Standard plate count			X
Nitrate-N	X		
Sulfates		X	
Calcium			X
Magnesium			X
Iron		X	
Manganese		X	
Sodium			X
Lead	X		
Turbidity	X*		
Color		X	
Specific conductance			X
Total dissolved solids		X	
Assayed in 10 Percent of the Specimens (the NSA Group II Subsample):			
Arsenic	X		
Barium	X		
Cadmium	X		
Chromium	X		
Mercury	X		
Selenium	X		
Silver	X		
Fluoride	X		
Gross Alpha	X		
Gross Beta	X*		
Endrin	X		
Lindane	X		
Methoxychlor	X		
Toxaphene	X		
2,4-D	X		
2,4,5-TP	X		
Also Measured in NSA Group II Subsample if Warranted by Screening Tests:			
Radium-226	X		
Radium-228	X		
Uranium	X		
Strontium-89	X		
Strontium-90	X		
Cesium-134	X		
Tritium	X		
Iodine-131	X		
Total MREM	X		

*Denotes constituent with primary MCL that was not applicable for the NSA.

applicable to the NSA. Gross beta radiation, for instance, had an MCL that was employed only in conjunction with monitoring of large community systems or surface water sources that were located adjacent to nuclear generating facilities. Since water for rural domestic supplies was extracted so infrequently from these latter sources, only the gross beta screening test was used. Therefore, gross beta was treated as if no MCL had been established, even though one is stipulated in the regulations. Turbidity was likewise excluded because it is not specific and can be a double count of other constituents with MCLs. By virtue of their presence on the list of substances for which the NSA compiled data, all of the preceding 41 substances were considered viable candidates for the NSA indexing effort.

The revised set of indicators

In theory, any of the substances included in Table VI-1 could have been incorporated into a water quality index. However, since several indicators were too interdependent to make a unique contribution to a composite, some constituents were eliminated. First of all, fecal coliform, fecal streptococcus, and the standard plate count were dropped from the list. Although values of those items were of considerable supplemental help in describing the implications for total coliform counts, as discussed in Chapter V, the measurements were often duplicate counts of more specific bacteria types that had already been enumerated by the total coliform test—which did have an MCL—and therefore introduced the probability of statistical redundancy (confounding). As a result, the primary indicator of bacteriological quality in the NSA was the total coliform count. This decision was consistent with the statistical requirements of the NSA, and with the professional judgment that this count was the best of the available measures of bacteriological quality (see Chapter V).

Despite this rationale, one should be aware of objections to relying exclusively on the total coliform count as the indicator of bacteriological water quality. In particular, the test seems less reliable for untreated water supplies than for those producing finished water. To illustrate this more specifically, untreated rural supplies, which typically were wells, might have certain conditions that could reduce the sensitivity of the total coliform test to coliform bacteria. The effect may be to underestimate the number of coliforms because they could not be detected or distinguished from other organisms.[24]

Although the preceding objection may be legitimate, the total coliform count has continued to receive professional support because nothing better has been discovered to replace it.[25] This was the most important reason for including it in the NSA indexing effort. Another related reason for retaining the total coliform count rather than the other indicators of biological contamination was that it was the only one of the four to have been assigned an MCL. Finally, it is important to recall that the primary purpose of the composites was to rank rural households in comparison with each other. Since the MCL was the acknowledged standard, the use of the total coliform count allowed the NSA to specify the bacterial quality of water relative to the level prescribed by federal regulations.

Besides these bacteriological constituents, specific conductance and total dissolved solids also were interdependent. In particular, specific conductance was converted to an estimate of total dissolved solids which are considered to have economic and aesthetic effects. Primarily for that reason and because total dissolved solids does have a secondary MCL in the federal regulations, specific conductance was not considered further.

Redundancy between indicators was additionally implicated in the decision to delete uranium, radium-226, and radium-228 from the list of potential index constituents. The specific reason was that the values for gross alpha radiation were included as a screening test for uranium and radium-226. It was assumed by the EPA that the test was also sufficient for detection of radium-228 since its daughters are alpha emitters even though radium-228 itself is considered a beta emitter. Radium-228, of the thorium series, is usually of geologic origin and thus more likely to be important in groundwater rather than surface water. Alpha radiation is generally of greater concern than beta radiation in groundwater. Since the gross beta standard applies to surface water, radium-228 was included under the gross alpha screen. To avoid double counting, a choice had to be made between values for either gross alpha <u>or</u> uranium, radium-226, and radium-228. Values for gross alpha were the more general measure. The gross alpha values, unlike the specific radionuclides, were measured at all subsample households (see Chapter V) and were retained for the water quality composites.

Similarly, gross beta radiation was included in the NSA index list rather than the specific beta-emitting radionuclides. Beta activity, similar to alpha activity, was monitored in all NSA subsample specimens, but the specific radionuclides were measured only when the gross beta screening value was sufficiently high, and were therefore unavailable for most households. These substances, which included strontium-89, strontium-90, cesium-134, tritium, iodine-131, and a calculation of total millirems, were omitted from the NSA set of water quality indicators along with radium-226 and radium-228.

Other constituents, although legitimate candidates for a water quality composite, were excluded from the index list because they were present only in concentrations smaller than the pre-established minimum detection levels specified by the EPA. For all of these substances, which consisted of herbicides and pesticides, the detection levels were substantially lower than their respective MCLs. Since the exact quantities of these constituents were below the detection limits, each one was assigned a value equal to the particular level of detection, which was constant for all households in the subsample. This absence of variation, which was associated with endrin, toxaphene, 2,4-D, and 2,4,5-TP, eliminated any possibility that these constituents might contribute to a composite. This was the principal reason for discarding them from the effort to develop the water quality indices.

Two other constituents, calcium and magnesium, were only of very minor significance to water quality when considered individually, but levels of the two substances together represented the degree of hardness in water (see Chapter V). Hardness is widely regarded as an important component of water quality, and was considered for inclusion in the federal regulations.[26] The characteristic was finally excluded from the regulations because of insufficient information about its significance, but it was included in the NSA as a water quality indicator with economic consequences. The list of constituents compiled for the composites included "hardness" as calculated from calcium and magnesium rather than incorporating the two elements independently.

In summary, the original collection of 41 water quality indicators was shortened to 23 constituents (Table VI-2). Those substances with primary MCLs decreased to sixteen items, while all five constituents with secondary MCLs were retained. Proportionately, the largest reduction occurred to the set of nonMCL constituents, which was diminished to two: hardness and sodium. Each of the 23 substances represented a potential component of any water quality composite developed for the NSA.

Effect of sample design

In addition to the original indicators and their properties, the sampling approach of the NSA imposed another constraint on the development of the water quality indices. The differential prevalence of constituents suggested that some substances would probably not be present in sufficient concentrations to justify laboratory assay for them in all sets of water specimens. Certain of these substances were monitored in the NSA, however, because of their inherent toxicity and the possibility that they were more widely dispersed than expected. Also,

Table VI-2

Constituents Selected for the Water Quality Composites

Constituent	Primary MCL	Secondary MCL	No MCL
Assayed in All Water Specimens:			
Total coliform	X		
Nitrate-N	X		
Sulfates		X	
Hardness			X
Iron		X	
Manganese		X	
Sodium			X
Lead	X		
Turbidity	X		
Color		X	
Total dissolved solids		X	
Assayed in 10 Percent of the Specimens (the NSA Group II Subsample):			
Arsenic	X		
Barium	X		
Cadmium	X		
Chromium	X		
Mercury	X		
Selenium	X		
Silver	X		
Fluoride	X		
Gross Alpha	X		
Gross Beta	X		
Lindane	X		
Methoxychlor	X		

measurements were compiled on these particular substances to generate a baseline with which the results of subsequent studies on water quality could be compared. Therefore, as indicated in Table VI-2, although specimens were obtained from each household selected for the survey, only eleven index constituents were assessed for all 2,654. Levels of the remaining twelve substances were determined for only 267 households, which represented about 10 percent of the entire household sample.

The decision to assay some constituents at a subsample of households had some major implications for the effort to construct the water quality composites. First, since contemporary measurement theory assumes that data are attached to common observational units, one constituent could not be combined with another unless both pertained to the same household. Obviously, this required that any prospective combinations of constituents be aligned with either of the two household groupings stipulated by the sample design (full sample or subsample). To illustrate, total coliform and nitrate could hypothetically appear in a composite which reflected some aspect of water quality for all households in the survey. Moreover, the constituents of arsenic and barium could be integrated into a separate index, but only for the 267 households in the subsample. If a composite were to be formed from these four indicators, it would be relevant only to the subsample of households. Therefore, the primary effect of the sample design was to restrict how variables could be combined. Ultimately, then, the sample design impinged upon the NSA's ability to maximize the information conveyed by the water quality indicators, since certain combinations of constituents could not be used for a particular set of households.

The sample design employed in the NSA also affected the reliability of any composites formed from the constituents. Since the statistical precision of an estimate tends to increase with the size of the sample, composites involving only constituents examined at all households in the survey would have a higher probability of being accurate than indices that included any constituent assayed at the subsample of households. While any composite could be used to make projections to all rural households or to selected subpopulations, there would be less confidence in an estimate derived from the subsample because of the smaller base (10 percent of the full sample). Therefore, a summary measure incorporating only constituents surveyed in all specimens would have maximum reliability, while one including any of the remaining substances would be considerably less reliable.

Further, this aspect of the NSA sample design meant that, beyond a point, the information contained in a composite could not be increased without precipitating a reduction in its level of precision. For example, if one assumed that there were no physical interdependencies among the 23 constituents in Table VI-2, the composite that would be maximally informative would have included all indicators in the set. However, since that index would have embodied some substances that were examined only in the subsample, it would not have been as reliable as a composite that consisted exclusively of indicators measured at the full sample of households. The effort to construct water quality indices in the NSA, therefore, explicitly recognized the necessity for making an optimum choice given these two considerations.

General development strategy

The development of the NSA water quality composites proceeded according to a general strategy that evolved from the NSA's research requirements. This strategy suggested the number of indices to be formulated, their purposes, the constituents that each index was to encompass, and a method for combining the substances. The set of decisions arrived at in the process of applying the strategy represented a compromise between the constraints imposed by the NSA's design, the revised set of indicators, and their properties.

Since water quality is a complex phenomenon consisting of several distinct but interrelated aspects, NSA researchers determined that it could not be measured effectively with a single composite. The preference that evolved was to summarize water quality in terms of two specialized indices and a single comprehensive or general measure. Each of the three indices fulfilled its principal purpose, which was to facilitate the intelligibility and interpretation of the data on the physical indicators of water quality.

The first of the specialized water quality indices was based on those constituents that had a definite and demonstrable effect on human health (see Table VI-3). Operationally, this index included only indicators that were considered important enough to have been assigned primary MCLs in the interim federal regulations, excluding three substances which were prominent enough to be analyzed separately (total coliform, nitrates, and lead), and two constituents without applicable MCLs (turbidity and gross beta). The second specialized index, which was composed of the five substances with secondary MCLs, was confined generally to constituents that had aesthetic or economic implications. Finally, the third proposed index was designed to be more comprehensive by acknowledging the entire spectrum of effects associated with the water quality indicators. This index synthesized all 23 constituents, including those that did not have an MCL. Compared to one another, the health and general indices contained more information but were less reliable than the aesthetic/economic index. (The aesthetic/economic index was based on water quality data from the full NSA sample of households, while the health and general indices were based on the subsample. As with other material presented in this report, this distinction is important because the sample size affects the statistical precision of the estimates.)

Given the disparity of constituents and the units in which they were expressed, the three indices could not be developed by directly combining their respective sets of indicators. Consequently, NSA researchers decided to formulate the indices by employing a collection of procedures which is referred to as derived scoring. The essential advantage derived scoring has over other techniques is that

Table VI-3

Components of Water Quality Indices

Index	Constituent	Effect
1 - Health Risk Index (267 households)		
	Arsenic	Health
	Barium	Health
	Cadmium	Health
	Chromium	Health
	Mercury	Health
	Selenium	Health
	Silver	Health
	Fluoride	Health
	Gross Alpha	Health
	Lindane	Health
	Methoxychlor	Health
2 - Aesthetic/Economic Index (2,654 households)		
	Sulfates	Aesthetic, health
	Iron	Aesthetic
	Manganese	Economic, aesthetic
	Color	Aesthetic
	Total dissolved solids	Economic, aesthetic
3 - General Index (267 households)		
	Total coliform	Infectious disease
	Hardness	Economic
	Nitrate-N	Health
	Sulfates	Aesthetic, health
	Iron	Aesthetic
	Manganese	Economic, aesthetic
	Sodium	Health
	Lead	Health
	Turbidity	Aesthetic, health
	Color	Aesthetic
	Total dissolved solids	Economic, aesthetic

Table VI-3 continued

Index	Constituent	Effect
3 - General Index continued:		
	Arsenic	Health
	Barium	Health
	Cadmium	Health
	Chromium	Health
	Mercury	Health
	Selenium	Health
	Silver	Health
	Fluoride	Health
	Gross Alpha	Health
	Gross Beta	Health
	Lindane	Health
	Methoxychlor	Health

it permits the researcher to establish the relative position of an observational unit or household with respect to a standardized referent. This referent can be internally generated, assuming that the sample of observations is representative, or it can be externally obtained from another sample of observations. In both cases, however, the position of the unit is determined by converting raw data into a relative measure.

Of the various methods that could be used for the conversion, NSA researchers chose to use standard scoring. This common method relies upon linear or nonlinear transformations of the raw data to produce the derived scores. These standard scores express a unit's distance from some point in a distribution, usually the mean, in terms of the standardizing criterion, typically the distribution's standard deviation. When computed with a linear transformation, the standard scores retain the exact numerical relations that were present in the original data; also, their distributional properties are identical to the properties of the original distribution. Since the properties of the two distributions correspond, any manipulation of the raw data can also be done to the standard scores without any distortion of results. Distortions become more severe with nonlinear transformations, although the order of the observational units in the distribution of standardized scores relative to the original distribution can be preserved. As will be discussed in the following segments of this chapter, each of the three water quality composites in the NSA was computed by applying a version of the standard scoring technique.

Although the methods used to construct them were substantially similar, the three indices conveyed different levels of information with varying degrees of statistical precision. When considered from this perspective, each composite was somewhat distinctive and fulfilled a function that could not be performed by the other two. This uniqueness was manifested in the structures of the composites and the patterns of variation that they were designed to disclose.

Index of health risk

The health risk index, one of the two specialized composites, consisted of the eleven water quality indicators with primary MCLs. Relative measures for the index were derived for each indicator by using its primary MCL as a standardizing device. The MCL was selected, rather than some alternative referent, because each of the constituents was directly comparable at those specific concentrations. For each substance, this comparability was established by the MCL, which implicitly equates values above the standard as unacceptable. Another reason for incorporating the MCL into the index was that the relative importance—or weighting—of the various contaminants was specified by the levels at which the MCLs were set. Consequently, the NSA researchers did not have to attempt the difficult task of assigning separate weighting factors to the substances when combining them into the index. In other words, the specific values stipulated in the regulations reflected weights that had evolved from public health experience as well as from the process of debate and review that preceded the promulgation of the standards. To illustrate, distinct criteria and widely differing safety factors were devised to designate the potential risks posed by the various substances. The built-in safety factor for cadmium, for example, was only four, while the safety factor for endrin and others of the chlorinated hydrocarbon insecticides was 500.[27]

Safety factors were set primarily in relation to the nature of the health hazard, but also in relation to the extent of scientific knowledge about the constituent, the techniques for measuring it, and the expense of controlling it. The federal government's attitude was summarized in its response to national comments on the proposed MCLs: "A question was raised about the fact that different safety factors are contained in various maximum contaminant levels. The levels are not intended to have a uniform safety factor, at least partly because the knowledge of and the nature of the health risks of the various contaminants vary widely. The levels set are the result of experience, evaluation of the available data, and professional judgement."[28] Although the use of the MCL rendered the substances for each of the specialized indices comparable for measurement purposes, it also recognized the considerable differences among them.

The primary MCLs for the eleven constituents usually consisted of a single value which could be incorporated directly into the index. In one instance, however, a value had to be selected from a range of concentrations. Specifically, the limits for fluoride ranged from 1.4 through 2.4 milligrams of fluoride per liter of water, depending on climatic temperature (under the assumption that the consumption of water, and therefore the total intake of fluoride, is greater in warmer climates). To resolve this difficulty, the lowest of the range of values was chosen for use in the composite. This decision was consistent with the underlying assumption about the weighting of constituents. That is, the MCLs were considered to be self-weighted, and NSA investigators avoided making further technical judgments about a substance's importance. The choice, then, was to assume that the lowest MCL value was more stringent, and that it should be used as the standardizing criterion.

The derivation of scores for each of the eleven constituents included in the health risk index was performed in a series of stages. First, the raw values were placed in ratio to the MCL and multiplied by an arbitrary constant, which was 10. The purpose of this procedure was to convert the original values into some relative equivalent or standard unit, which also altered their distributions by dispersing the observations. Then, if this ratio exceeded the constant, another step translated those observations with values greater than the MCL closer to the point at which the ratio and constant were equal. This was accomplished by applying a logarithmic transformation to the raw values and adding the arbitrary constant to the result. Besides normalizing the distributions, this procedure also prohibited any one constituent from artificially dominating the index. The values of the primary

MCLs for these eleven indicators are given in Table VI-4 along with other relevant information about all 23 constituents.

Expressed more formally, the scores for each indicator included in the health risk composite were derived with the following set of operations:

$$R_i = \left(\frac{X_i}{MCL}\right) 10$$

where

R_i	=	the ratio of the constituent's raw value to its MCL for the i^{th} household
X_i	=	the raw value of the constituent for the i^{th} household
MCL	=	the primary maximum contaminant level for the constituent.

Further, if $R_i \leq 10$,

$$S_i = R_i$$

where

S_i	=	the derived score for the i^{th} household
R_i	=	the ratio of the constituent's raw value to its MCL for the i^{th} household

or, if $R_i > 10$,

$$S_i = \ln(R_i) + 10$$

where

S_i	=	the derived score for the i^{th} household
ln	=	the natural logarithm
R_i	=	the ratio of the constituent's raw value to its MCL for the i^{th} household.

Table VI-4

Primary MCLs and Relevant Summary Statistics for Water Quality Indicators

Constituent	Primary MCLs Utilized	Summary Statistics[1] Mean	SD	Index Health	Aesthetic/ Economic	General
Total coliform	--	-- (14157.7)	-- (117482.5)			X
Hardness	--	-- (165.9)	-- (202.4)			X
Nitrate-N	--	-- (1.5)	-- (2.5)			X
Sulfates	--	56.4 (51.2)	108.0 (105.7)		X	X
Iron	--	0.40 (0.35)	1.30 (1.20)		X	X
Manganese	--	0.060 (0.072)	0.234 (0.201)		X	X
Sodium	--	-- (37.9)	-- (105.7)			X
Lead	--	-- (0.029)	-- (0.045)			X
Turbidity	--	-- (1.1)	-- (4.4)			X
Color	--	4.7 (4.3)	5.6 (3.9)		X	X
Total dissolved solids	--	473.2 (433.7)	482.9 (369.0)		X	X
Arsenic	0.05 mg/l	-- (0.007)	-- (0.012)	X		X
Barium	1 mg/l	-- (0.2)	-- (0.1)	X		X
Cadmium	0.01 mg/l	-- (0.006)	-- (0.007)	X		X

Table VI-4 continued

Constituent	Primary MCLs Utilized	Summary Statistics[1] Mean	Summary Statistics[1] SD	Index Health	Index Aesthetic/Economic	Index General
Chromium	0.05 mg/l[2]	-- (0.005)	-- (0.001)	X		X
Mercury	0.002 mg/l	-- (0.003)	-- (0.016)	X		X
Selenium	0.01 mg/l	-- (0.008)	-- (0.010)	X		X
Silver	0.05 mg/l	-- (0.030)	-- (0.011)	X		X
Fluoride	1.4 mg/l	-- (0.40)	-- (0.45)	X		X
Gross Alpha	15 pCi/l[3]	-- (3.3)	-- (2.6)	X		X
Gross Beta	--	-- (5.5)	-- (1.9)			X
Lindane	0.004 mg/l	-- (0.0023)	-- (0.0041)	X		X
Methoxychlor	0.1 mg/l	-- (0.02)	-- (0.01)	X		X

[1]Statistics in parentheses were computed for the subsample of households. All other entries are for the entire sample.

[2]The specified level is for total chromium.

[3]Picocuries per liter.

The application of these computational procedures generated a set of derived scores for each constituent. With this particular standardizing method, the scores were distributed around the point at which the raw value and the MCL were equal, which was in turn fixed by the arbitrary constant. The resulting distributions of derived scores were approximately symmetric and at least tended towards normality. Additionally, the order of the households was maintained, although the differences between units were no longer meaningful.

Structure of the health risk index

The health risk composite was formed by aggregating the derived scores across the eleven constituents studied in the NSA for which primary MCLs had been established. More formally, the general expression for this composite was

$$HR_i = \sum_{j=1}^{11} S_{ij}$$

where

HR_i = the value or score for the i^{th} household on the health risk index

S_{ij} = the derived score for the i^{th} household on the j^{th} constituent

$11 = J$ = the number of constituents that were incorporated into the composite.

The resultant index was self-weighting and the magnitude of any one indicator's contribution was determined by the relative stringency of its particular MCL.

The health risk composite was designed to be employed for two kinds of comparisons. One was the comparison between index values assigned to individual households or some particular subset of households. The second was the direct comparison of the household's index value to the reference level fixed by the primary MCLs (equivalent to the arbitrary constant multiplied by eleven, which was the number of constituents in the index).

The first comparison specified the position of different households relative to each other in terms of the health risk associated with their water supplies. This comparison provided a sensitive indication of the differences among households, as single entities or as elements of some aggregate (all rural households that obtained water from individual systems, for example). Consequently, it was particularly useful for determining variation among households of different types or in different geographical locations.

Consistent with the structure of the index, a household with a larger value was assumed to be exposed to more of a health risk than a household with a smaller value. However, since the magnitude of the differences among households had no interpretable meaning, no judgment could be made about the degree to which the health risk associated with one household's water supply exceeded that of another. In this sense, the index was ordinal, and simply ranked the households on the continuum it represented.

The second comparison, by contrast, examined households in relation to a fixed referent rather than in relation to other households. Specifically, the index quantified the likely health risk associated with particular households' water supplies, and allowed a comparison of these levels with acceptable levels as reflected in federal regulations. For each constituent, the referent in the composite was the point at which the concentration of the constituent was equal to the NSA reference value, which was derived from the MCL (see Chapter V). When compiled for the entire set of constituents, the combined referent or composite reference value was 110.

In interpreting any of the values for the health risk composite, it must be emphasized that the index was not designed to accommodate absolute judgments. If one household's index value is twice as large as another's, the household cannot be said to have water of half the quality. Likewise, it cannot be said that the health risk at the first household is twice as great. However, the difference in values certainly indicates that the first household's water supply is lower in quality and less healthful than the second household's. Furthermore, greater differences imply greater potential health risk, although the extent of the risk is uncertain.

National estimates of health risk

The set of values compiled for the health risk composite displayed only modest variation across all rural households, considering that it represented eleven physical constituents. For example, index scores had a maximum of 60 and a minimum of 17, compared to a theoretical maximum in excess of 120 and a minimum of 0. Figure VI-1, which presents the distribution of values on the health risk index, suggests that the scores tended to be low. Approximately 29 percent of the households had scores of 25 or less, while about 42 percent had scores of 26 through 35. None of the households had a score greater than the reference value of 110, and the average index score was 31.7. (Generally the median is presented in the tables as a measure of central tendency. The mean was used for the health risk index since the distribution was normal enough to make the mean and median almost equivalent.)

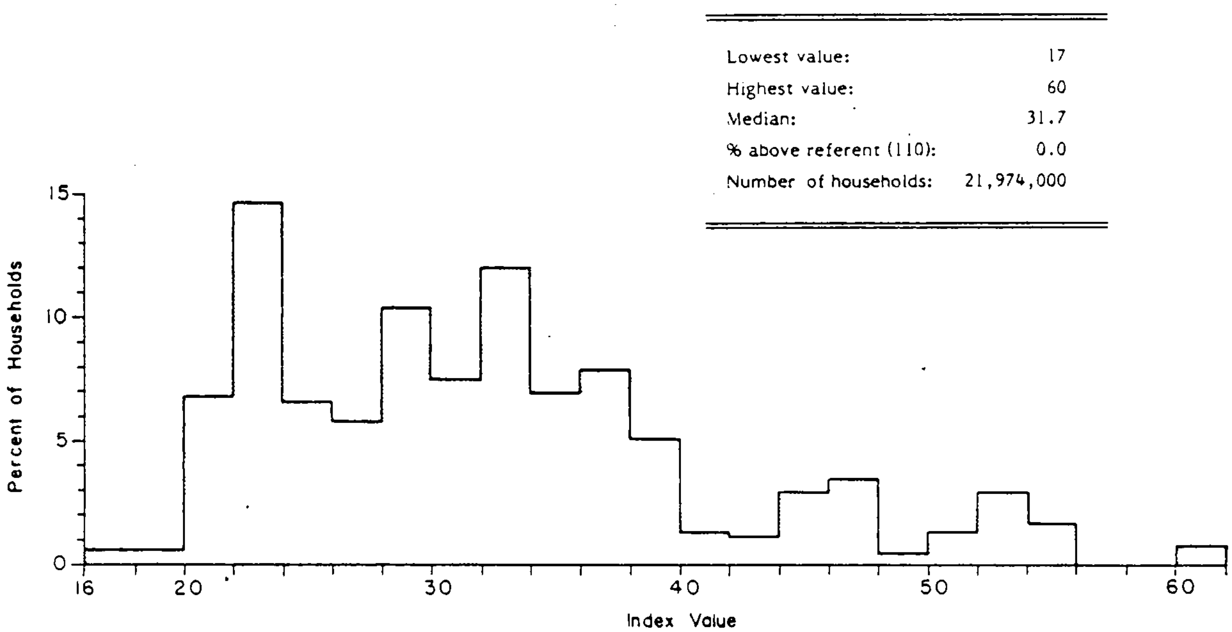
Subnational variation in health risk

— Regional variation

According to distributions compiled for households in each region, there were several distinct differences reflected by the health risk composite., Most prominent was the finding that households in the North Central and West tended to have water supplies with higher levels of potential health risk. The average score on the health risk index was 35.6 for the North Central and 35.2 for the West. By comparison, the averages for households in the South and Northeast were 30.2 and

Figure VI-1

Distribution of Values on the Health Risk Index
for Rural US Households



26.6, respectively. As Figure VI-2 suggests, these variations were generally consistent with other aspects of the distributions, including the range of scores and the proportions of households below a certain value. For example, while about 73 percent of the households in the Northeast had scores of 30 or less, only approximately 23 percent of the households in the West had comparable scores. Likewise, although the maximum index value of 60 was detected for households in the West and North Central, the respective maximums for households in the South and Northeast were 52 and 47. Combined, these results indicated that the supplies of households in the Northeast were associated with the lowest levels of health risk relative to the supplies of households in the other three regions.

— SMSA/NonSMSA variation

There were no appreciable differences between SMSA and nonSMSA households on the health risk composite. The magnitude of the variation that was observed is perhaps best summarized by the mean score obtained for each grouping, which was 32.7 for SMSA households and 31.2 for nonSMSA households.

— Size-of-place variation

Differences according to size of place were also negligible. The means varied from 33.2 for households in large communities to 31.6 for households in small communities or other rural areas.

— Size-of-system variation

Pronounced differences on the health risk composite were observed between households according to the size of system from which they obtained water. Households on intermediate systems on the average tended to be exposed to a higher level of potential health risk than households on community or individual systems. Figure VI-3, which provides the distributions of values on the health risk

Figure VI-2

Regional Distributions of Values on the Health Risk Index

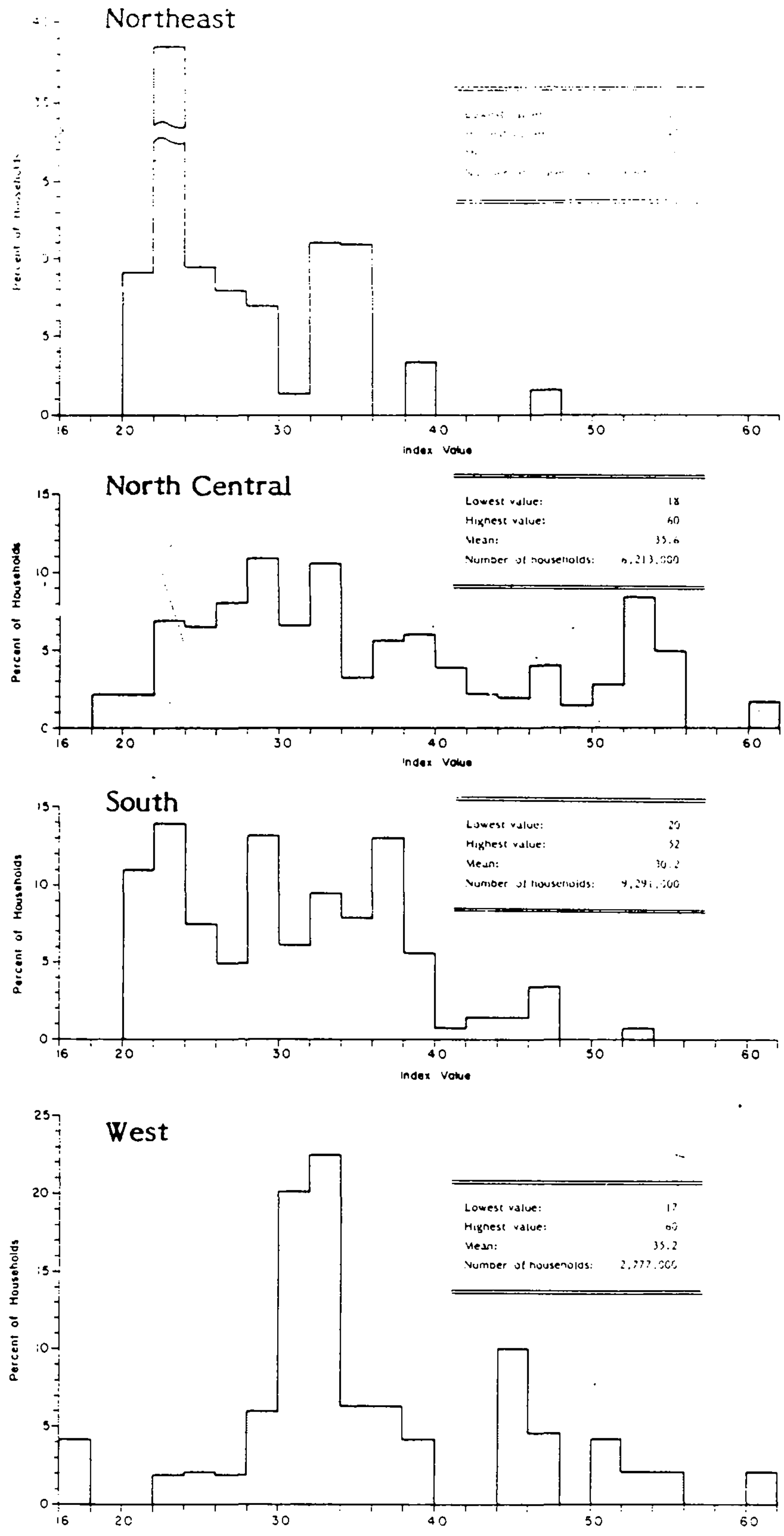
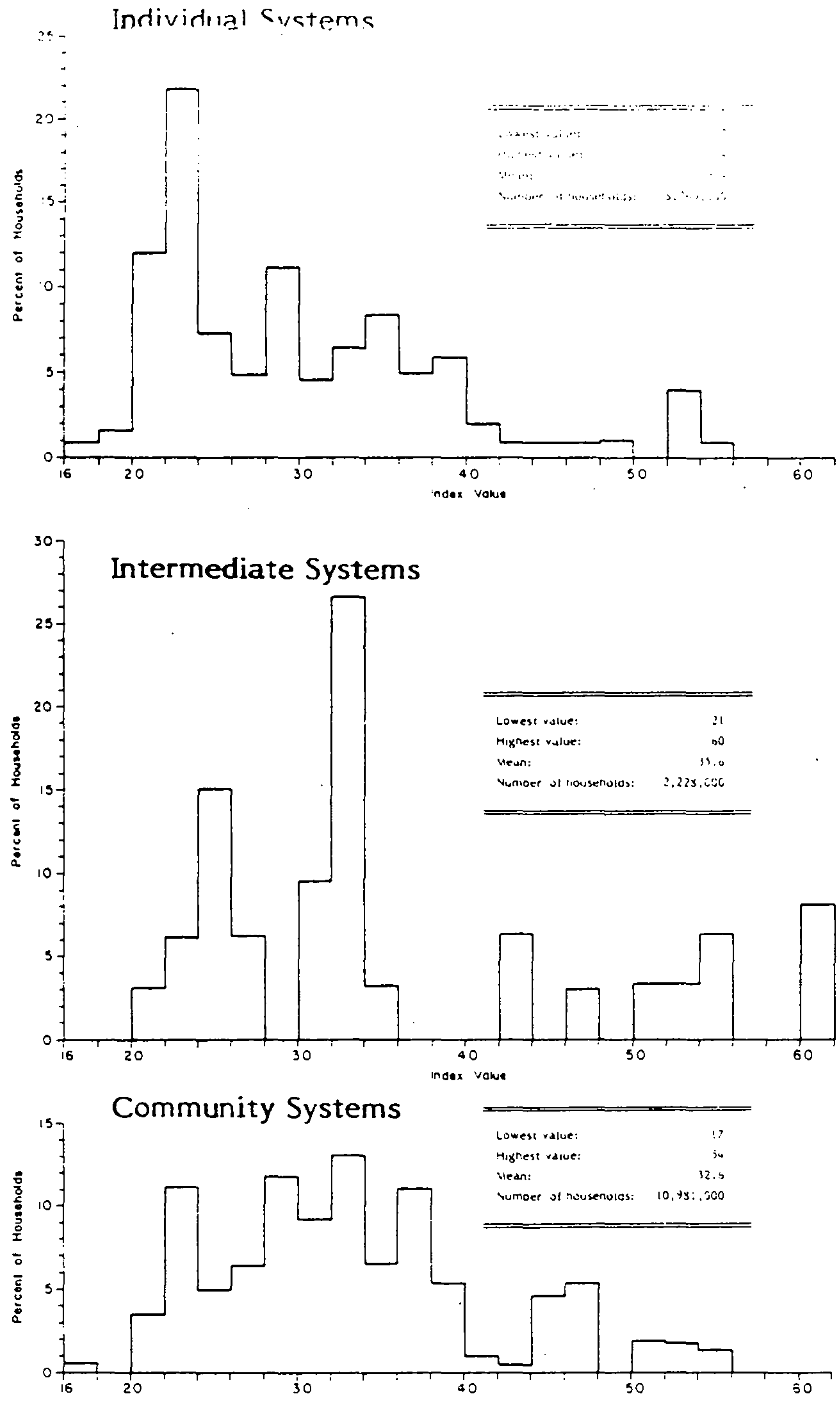


Figure VI-3

Size-of-System Distributions of Values on the Health Risk Index



index for households on community, intermediate, and individual systems, also indicates that households on individual systems generally had lower scores on the health risk composite. This pattern can be summarized by the means, which were 35.6, intermediate; 32.6, community; and 29.4, individual.

Aesthetic/economic index

The aesthetic/economic index included the five water quality indicators with secondary MCLs. Since these constituents had aesthetic or economic implications but did not affect human health, they could be distinguished qualitatively from the substances in the other specialized index. This difference was reflected in the legal status of the secondary MCLs which, unlike the primary MCLs, denoted recommended concentrations rather than levels that were legally enforceable. The unique status of the secondary MCLs was the principal reason for constructing the aesthetic/economic index with a different set of principles from those used in constructing the health risk index, although both indices were represented by linear combinations of derived scores.

In contrast to the method described previously for obtaining a set of relative measures, conventional standard scores were derived for the constituents in the aesthetic/economic index. To compute these scores, which were referred to as "z scores," the mean value of a constituent was subtracted from the raw value and the difference was divided by the distribution's standard deviation. The mean and standard deviation for each constituent are provided in Table VI-4. With this transformation, raw values that were equal to the mean received a standard score of zero, while those above the mean were positive and those below were negative. After completing this operation, a second transformation was used to convert the original scores to a more convenient form. Although others are available, the one performed on these scores involved adding a constant to each one.

The formal expression for this method of deriving standard scores was

$$Z_i = \frac{X_i - \overline{X}}{SD}$$

where

Z_i	=	the standard score for the i^{th} household
X_i	=	the value on the constituent for the i^{th} household
$\overline{X}$	=	the mean value of the constituent
SD	=	the standard deviation of the constituent.

Structure of the aesthetic/economic index

The aesthetic/economic index was constructed by additively combining the translated linearly derived or standard scores across the five constituents. This index had the general expression

$$AE_{i.} = \sum_{j=1}^{5} T_{ij}$$

where

AE_i	=	the value or score for the i^{th} household on the aesthetic/economic index
T_{ij}	=	the translated standard score for the i^{th} household on the j^{th} constituent $T_{ij} = Z_{ij}$ + constant
J	=	five, the number of constituents that were incorporated into the index.

Even though a different method was used to produce the derived scores that composed the aesthetic/economic index, its constituents were also self-weighting. In contrast to the health risk index, however, the relative contribution of the indicators was determined by their original distributional properties rather than by the stringency of their MCLs.

The aesthetic/economic index permitted the same comparisons as the other specialized composite, with one modification. Instead of comparing household water quality on the basis of a reference value derived from federal regulations, the reference value for the aesthetic/economic index was the level of water quality at the average rural household. Again, the index was ordinal and simply ranked households in terms of the aesthetic or economic effects of their water supplies. Given the direction of the composite, these effects were more pronounced at households with higher index values.

National estimates of aesthetic/economic effects

Nationally, the values on the aesthetic/economic index varied from a low of 0 to a high of 49. Despite this large range, the vast majority of rural households tended to cluster at a few specific values, as the information in Figure VI-4 suggests. For example, about 76 percent of the households had scores of 0, 1, or 2, but only approximately 2 percent had values in excess of 10. This asymmetry also was reflected in the median score which, at 1.4, was much closer to the distribution's minimum. Because the median is a preferred measure of central tendency for distributions that are excessively nonnormal, it is reported rather than the mean or average. About 24 percent of the households had index scores greater than 2, which is also the index reference value.

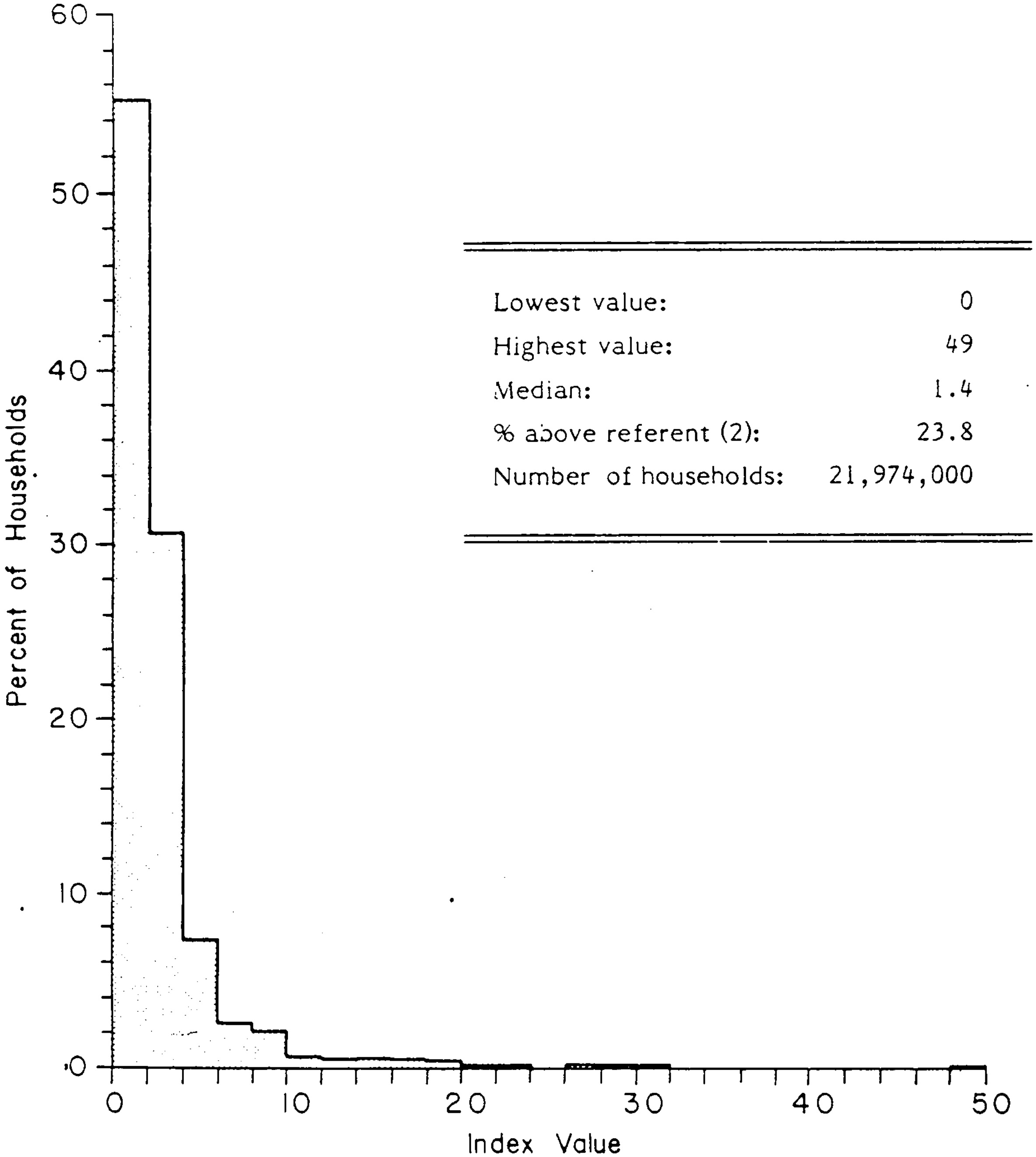
Subnational variation in aesthetic/economic effects

— Regional variation

The regional differences on the aesthetic/economic index were consistent with the pattern of regional variation on the health risk composite. More specifically, households in the North Central tended to have the highest index

Figure VI-4

Distribution of Values on the Aesthetic/Economic Index for Rural US Households



values on the average, while the lowest scores were associated with households in the Northeast. The respective medians for the four regions were 0.9 for households in the Northeast, 1.1 for households in the South, 1.8 for households in the West, and 2.2 for households in the North Central. Likewise, as Figure VI-5 indicates, the North Central also had the largest proportion of households with scores that exceeded the index reference value. These results suggested that rural households in the North Central had supplies which produced water that was least suitable from an economic or aesthetic standpoint.

— SMSA/nonSMSA variation

There were virtually no differences on the aesthetic/economic index with respect to the SMSA/nonSMSA categorization. The medians for both groupings of rural households were 1.4, and there was about a 1 percent variation in the proportions of households with scores greater than the reference value. These percentages were 23.4 for SMSA households and 24.6 for nonSMSA households.

— Size-of-place variation

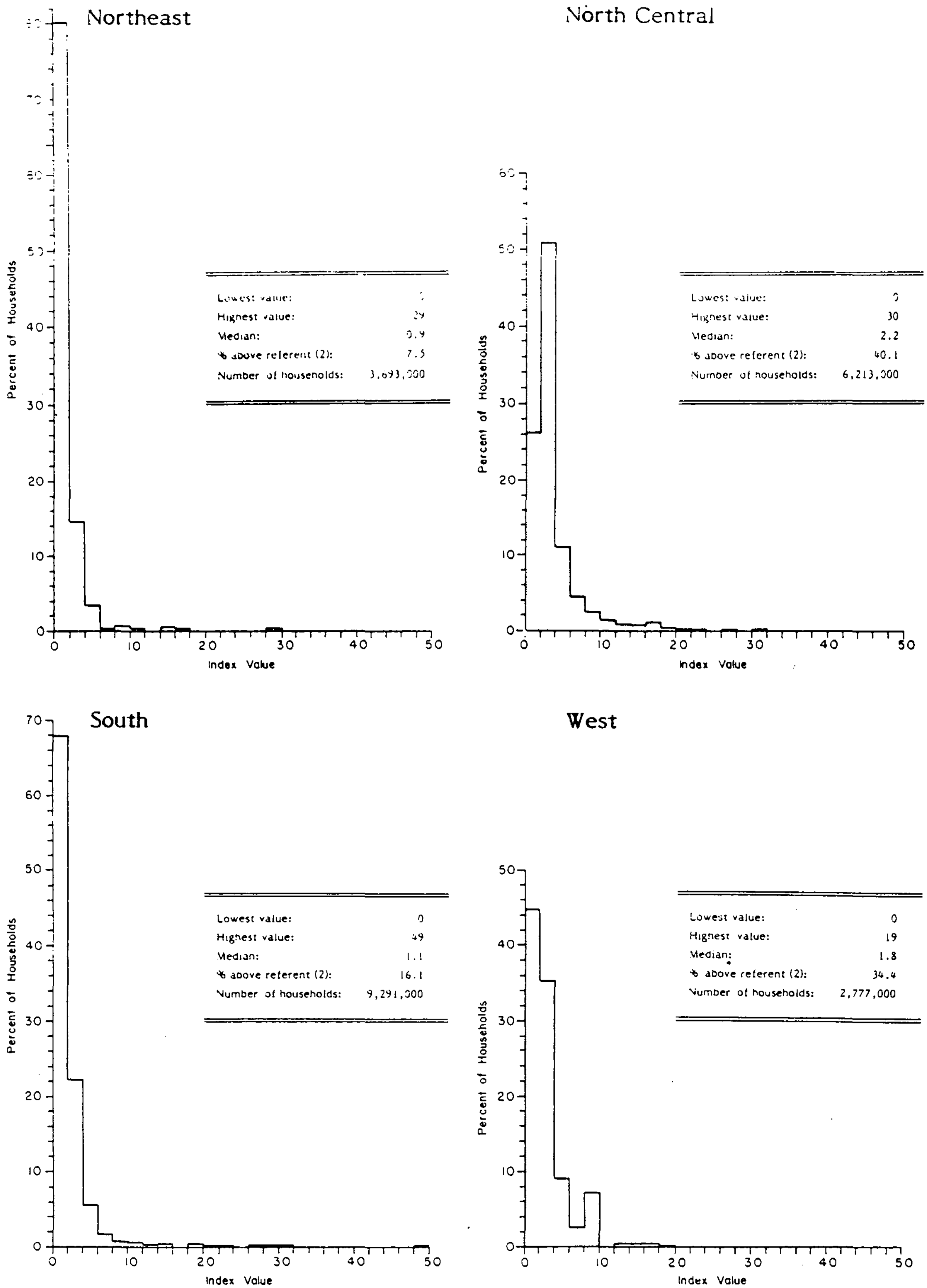
Differences on the aesthetic/economic index according to size of place were only slightly more pronounced. With a median of 1.8, households in small rural communities tended to have slightly higher values than households in large communities or other rural areas. The medians for the other two categories of households were 1.4 and 1.3, respectively. Compared to the other two categories, a larger proportion of households in small rural communities also had scores that exceeded the reference value.

— Size-of-system variation

Except for some minor inconsistencies, there were no appreciable differences between rural households on the aesthetic/economic index when grouped by

Figure VI-5

Regional Distributions of Values on the Aesthetic/Economic Index



the size of the system from which they obtained water. The medians, for example, were 1.4 for households either on individual or intermediate systems, and 1.3 for households on community systems. Similarly, the proportions of households with scores greater than the reference value varied only by about 5 percent. The respective percentages were 21.5 for households on community systems, 26.1 for households on intermediate systems, and 26.0 for households on individual systems.

General water quality index

The general water quality index developed for the NSA, which was designed to reflect health, economic, and aesthetic aspects, consisted of all 23 constituents, including those substances with no MCLs. This index, similar to the aesthetic/economic index, was formulated by adding together a set of linearly derived translated standard scores. These scores were derived for each constituent in the index using the linear transformations described previously. Again, the standard scores were relative measures that were computed from the means and standard deviations of the relevant water quality indicators.

Structure of the general water quality index

The formal equation for the general water quality composite was

$$GWQ_i = \sum_{j=1}^{23} T_{ij}$$

where

GWQ_i = the value or score for the i^{th} household on the general water quality index

T_{ij} = the translated standard score for the i^{th} household on the j^{th} constituent $T_{ij} = Z_{ij} +$ constant

J = 23, the number of constituents that were incorporated into the composite.

Since it was constructed with a similar set of principles, the general water quality index was similar in many respects to the aesthetic/economic index. In particular, the constituents were self-weighting and their relative contributions were contingent upon their distributional attributes. Also, the index was ordinal and its reference point was the level of water quality at the average rural household. Finally, the index was designed so that higher values signified lower levels of water quality.

National estimates of general water quality

For the nation, the distribution of values on the general water quality index again displayed a tendency for a disproportionately large number of households to have a limited range of values. As can be observed from Figure VI-6, which presents the distribution of values for all rural households, about 73 percent of households had scores ranging from 1 through 10. Also, about 10 percent had values in excess of 20, and fewer than 1 percent had a score of 0. While the maximum value was 36, the average score was 9, which was also the reference value. Finally, about 68 percent of the households had scores that were below the reference value, and the median score was 7.1.

Subnational variation in general water quality

— Regional variation

The distributions of values on the general water quality index in the four regions of the US reflected a pattern of variation that was similar to those observed for the other two indices. As indicated in Figure VI-7, households in the North Central had the highest median as well as the largest proportion of households with scores above the index reference value. Once again, households in the Northeast had scores that tended to be lower than the reference value; also, the Northeast had the lowest median. Additionally, households in the West had the

Figure VI-6

Distribution of Values on the General Water Quality Index
for Rural US Households

Lowest value:	0
Highest value:	36
Median:	7.1
% above referent (9):	32.2
Number of households:	21,974,000

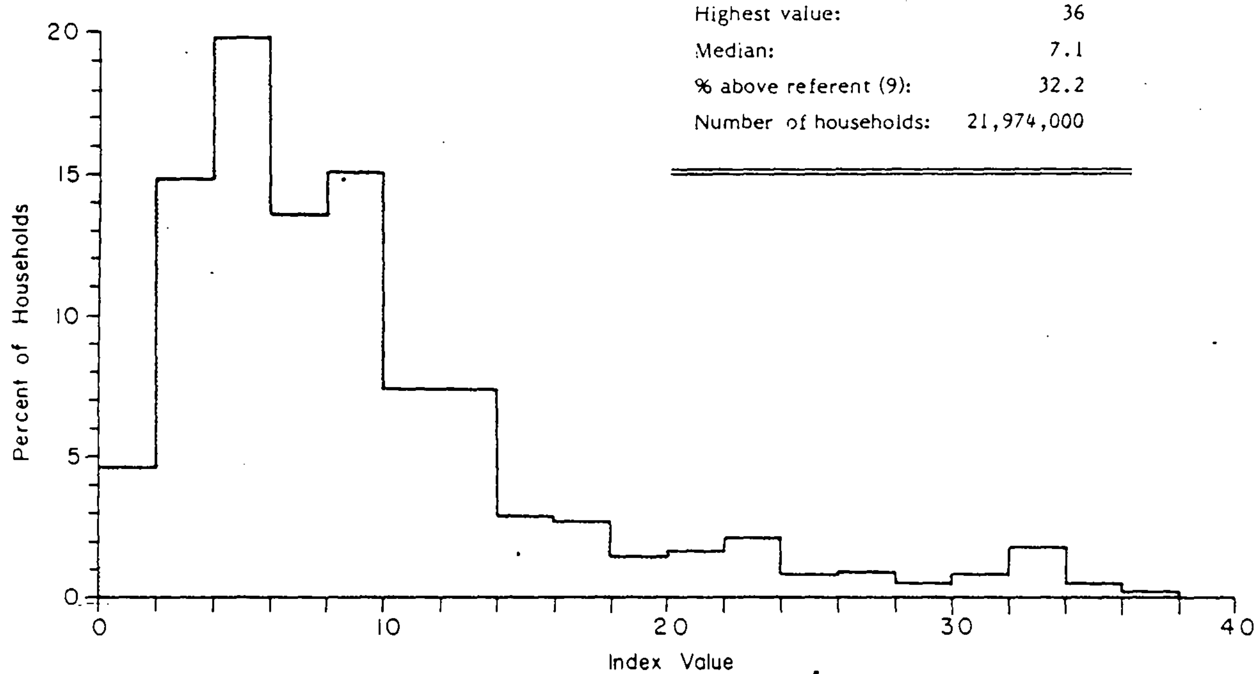
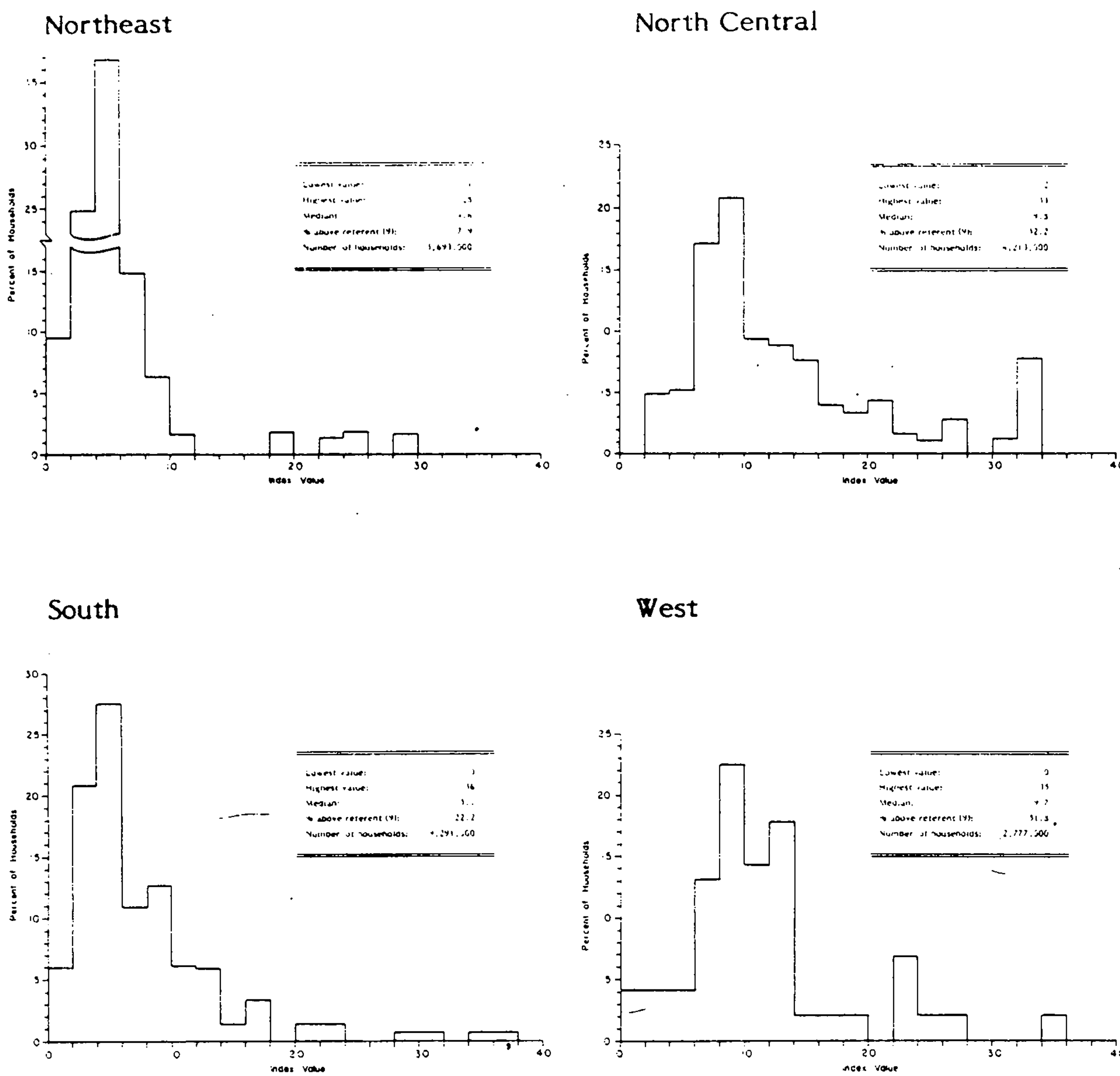


Figure VI-7

Regional Distributions of Values on the General Water Quality Index



second highest median, while households in the South had the third highest. The medians for each region were 9.8 for the North Central, 9.7 for the West, 5.1 for the South, and 4.6 for the Northeast. These results suggested that water supplies in the North Central and West produced water of lesser quality relative to the supplies of households in the other regions.

— SMSA/nonSMSA variation

SMSA/nonSMSA differences were not appreciable except for the proportions of households with scores that exceeded the index reference value. Among nonSMSA households, 35.5 percent had scores over the reference value, compared to 25.3 percent among SMSA households. By comparison, the medians for the two groupings of households were 7.0 (nonSMSA) and 7.2 (SMSA).

— Size-of-place variation

Variations in general water quality according to size of place were only slightly more pronounced. The median values were 8.1 for households in small rural communities, 7.0 for households in other rural areas, and 6.2 for households in large rural communities. In contrast to these median differences, households in large rural communities were the most likely to have scores over the index reference value of 9. The proportions of households with scores greater than the reference value were 41.2 percent in large rural communities, 33.5 percent in small rural communities, and 30.9 percent in other rural areas.

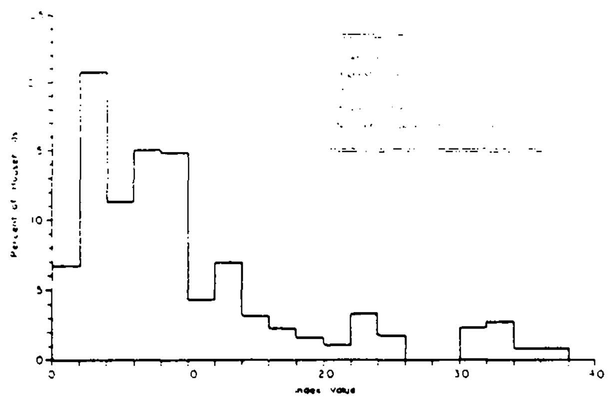
— Size-of-system variation

As suggested by the information in Figure VI-8, households on intermediate systems tended to have higher scores on the general water quality index than households on community systems or individual systems. This pattern was reflected in the medians compiled for each of the three groupings as well as in the

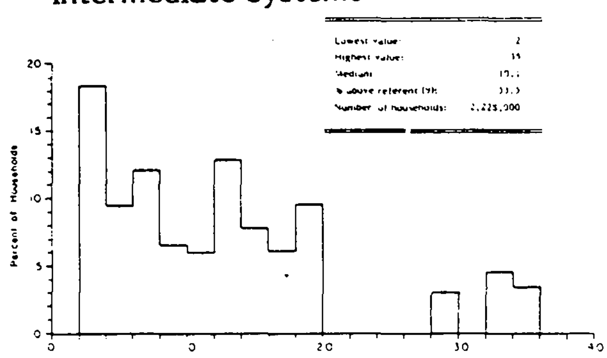
Figure VI-8

Size-of-System Distributions of Values on the General Water Quality Index

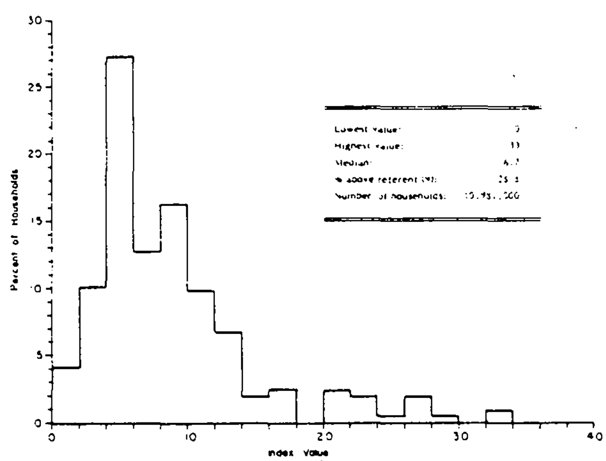
Individual Systems



Intermediate Systems



Community Systems



proportions of households with scores in excess of the reference value. Medians were 10.1 for households on intermediate systems, 7.0 for households on individual systems, and 6.7 for households on community systems. Likewise, the percentages of households with scores greater than 9 were 53.5, 31.1, and 28.8, respectively. These differences, which indicated that households on intermediate systems had supplies that produced water of lesser overall quality, were consistent with the results on the two specialized water quality indices.

Summary, indices of physical measures

In this section of Chapter VI, water quality was measured by a set of indices developed from laboratory data on 23 physical constituents. Each of the three indices encompassed information about a particular combination of substances and was structured to represent a different aspect of water quality. The first index, which consisted exclusively of constituents with primary MCLs, was designed to reflect the potential health risks to which rural households may have been exposed from their water supplies. The second index, by contrast, incorporated only substances with secondary MCLs and summarized water quality in terms of possible aesthetic and economic effects. The entire complement of substances, including those without MCLs, composed the third index, which provided a generalized expression of water quality.

Although two of the three water quality indices were mutually exclusive, all of them displayed similar patterns of differences between the household groupings. Households in the North Central were inclined to have higher values on all three indices, while households in the Northeast typically had lower scores. These results suggested that households in the North Central were more likely to be exposed to a health risk and were more subject to aesthetic and economic water quality effects than households in other regions. Another implication of these findings was that supplies of households in the North Central and West provided water that tended to be of lower overall quality than the national average. Marked variations among households also were detected on two of the three composites according to the size of system serving the household. Once again, although there were some discrepancies, the patterns were largely parallel. Households on intermediate systems had higher values on the health risk and general water quality indices, while the scores of households on individual systems or community systems were lower. This evidence strongly indicated that households on intermediate systems received water of lower quality than households served by individual or community systems. Except for differences on the general water quality index, there were only negligible variations on the indices in the SMSA/nonSMSA and size-of-place groupings. Comparisons of scores on the general water quality index indicated that households in small rural communities were receiving lower quality water than households in large rural communities or other rural areas.

INDEX OF PERCEIVED MEASURES

Another component of the NSA's effort to develop summary measures of water quality involved constructing a composite that synthesized information on rural residents' perceptions of the water provided by their major supplies. In particular, the aesthetic properties inquired about at the rural households in the NSA sample included odor, taste, clarity, color, and sediment. Information was also obtained on perceived temperature, but it did not vary enough to make any noticeable contribution to a summary index. As individual aspects of perceived water quality, the data corresponding to these indicators were presented in Chapter V. Once again, however, as with the physical constituents, it was necessary to formulate a composite from these attributes, rather than analyzing them separately. This section of Chapter VI specifies the methods and procedures that were used to incorporate these five variables into a composite index of perceived water quality.

Besides the constraint imposed by the particular combination of indicators that were selected for consideration in the NSA, the only other restriction on the indexing process was the structure of the data. For example, one index of perceived measures was proposed, as opposed to an entire set, because information was compiled for each attribute at all households in the NSA sample. In addition to this symmetry, the information on each indicator consisted of a combination of responses which reflected both magnitude and persistence. Since this was true for all five perceived indicators and because they were already expressed in ordinal units, each indicator had approximately the same form. Therefore, the principal task in developing the composite was to prescribe some technique for combining the data across the indicators.

<u>Structure of the perceived water quality index</u>

After extensive deliberations, NSA researchers determined that perceived water quality could be represented best by a simple additive measurement model. The principal motivation behind choosing this device was the lack of any indication that perceived water quality was more complex than a simple linear function of the intensity and duration of taste, odor, color, sediment, and clarity. Formally, this composite was expressed as

$$PWQ_i = T_i + O_i + C_i + S_i + Cl_i$$

where

PWQ_i = the value or score on the perceived water quality index for the i^{th} household

T_i = the value on perceived taste for the i^{th} household

O_i = the value on perceived odor for the i^{th} household

C_i = the value on perceived color for the i^{th} household

S_i = the value on perceived sediment for the i^{th} household

Cl_i = the value on perceived clarity for the i^{th} household.

Given the minimum and maximum of each of the five components—0 and 5—the preceding formula theoretically could have produced a vector of scores ranging from 0 to 25. The measure was ordinal in that it simply ranked households in relation to each other, and the magnitude of the differences had no significance. Households with higher index values were judged to have supplies that provided water of lesser perceived quality relative to households that were assigned lower values.

National estimates of perceived water quality

According to data compiled on the national level, the values on the perceived water quality index were distributed somewhat unevenly. Figure VI-9, which provides the distribution of scores on the perceived water quality index, indicates a strong tendency toward low index values. For example, about 71 percent of households had scores of 4 or less, while approximately 20 percent had scores from 5 through 9. Thus, about 91 percent of all rural households had scores of less than 10 on the perceived water quality index, compared to a theoretical maximum of 25. The median score was 2.3.

Subnational variation in perceived water quality

Regional variation

Data on regional variation in the perceived water quality index, which are presented in Figure VI-10, displayed a very uniform pattern. The distributions of index values were very similar for households in the South, Northeast, and North

Figure VI-9

Distribution of Values on the Perceived Water Quality Index for Rural US Households

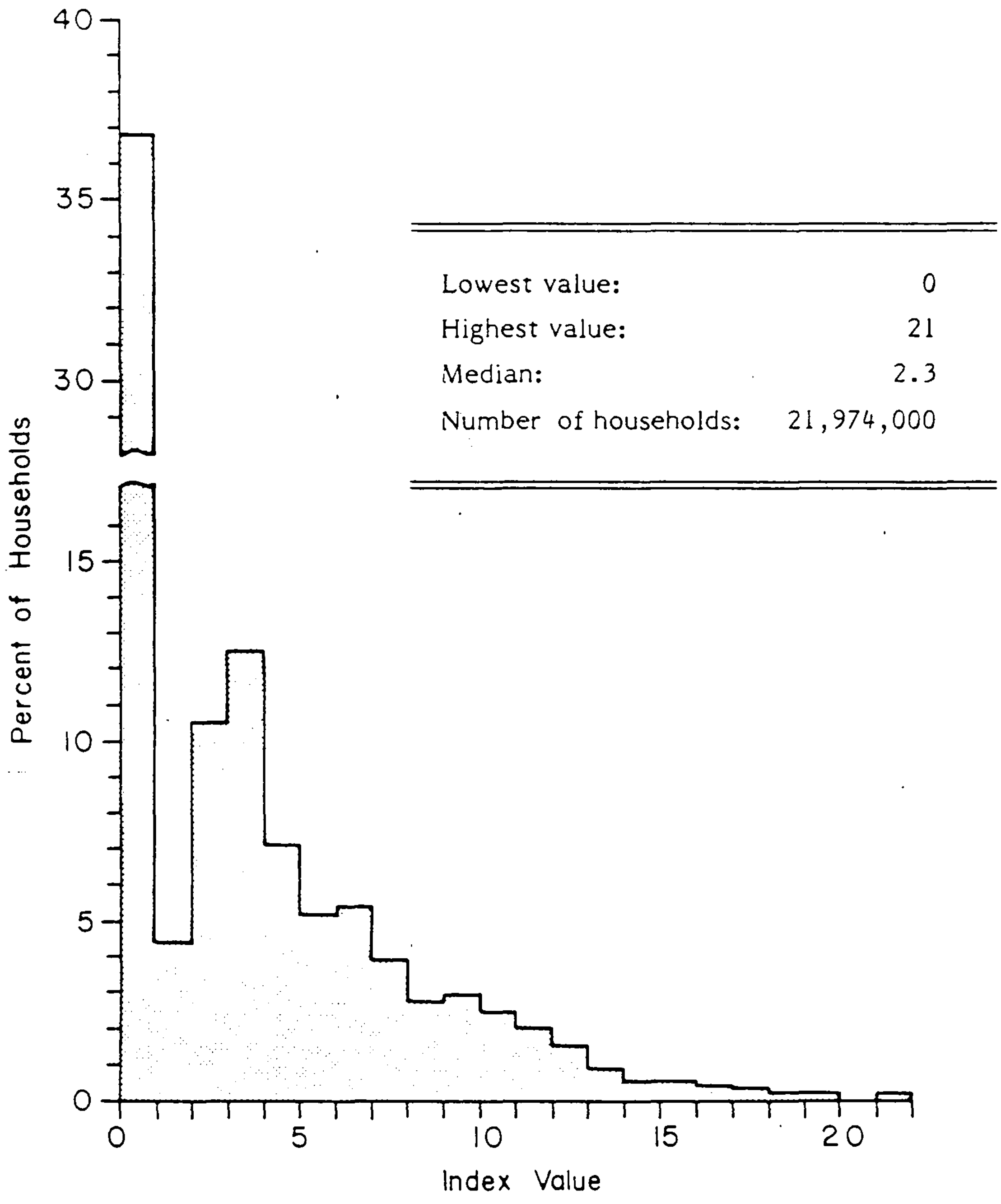
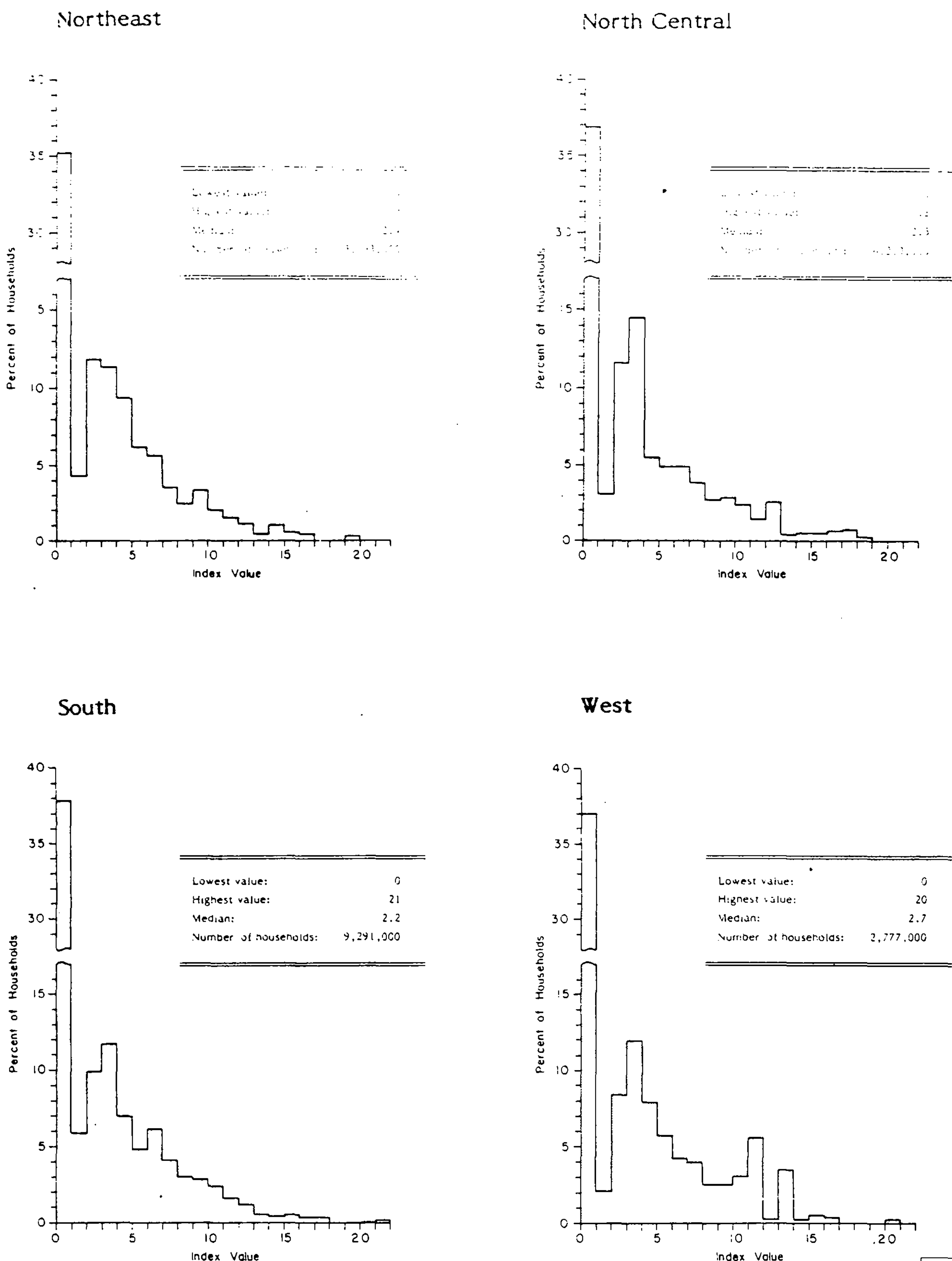


Figure VI-10

Regional Distributions of Values on the Perceived Water Quality Index



Central, while those for households in the West were somewhat different. On the average, households in the South tended to have somewhat lower scores than households in the Northeast and North Central, and households in the West tended to have higher scores. In summary, households in the South apparently perceived the quality of their water supplies to be slightly better than households in other regions did; households in the West perceived the quality of their water supplies to be lower than did households in other regions.

SMSA/nonSMSA variation

The distributions of values on the perceived water quality index were also similar for SMSA and nonSMSA households. Both SMSA and nonSMSA households had about the same proportions of households in each interval, and both had median index values which were approximately the same. According to these distributional properties, there were no appreciable differences between SMSA and nonSMSA households on the perceived water quality composite.

Size-of-place variation

In comparison to the preceding results, the size-of-place grouping showed more discernible variations. For example, households in other rural areas perceived the quality of their water supplies to be better than did households in small and large rural communities. This pattern was reflected in the entire distribution of values for each set of households as well as in the median index scores. The proportion of households in other rural areas with an index value of 4 or less was 73.0 percent, which was substantially higher than the proportion of households in either small or large communities (approximately 65 percent and 64 percent, respectively). Additionally, the medians for large and small communities were 2:6 and 2.7, both of which were significantly larger than the median for households located in other rural areas, which was 2.2.

Size-of-system variation

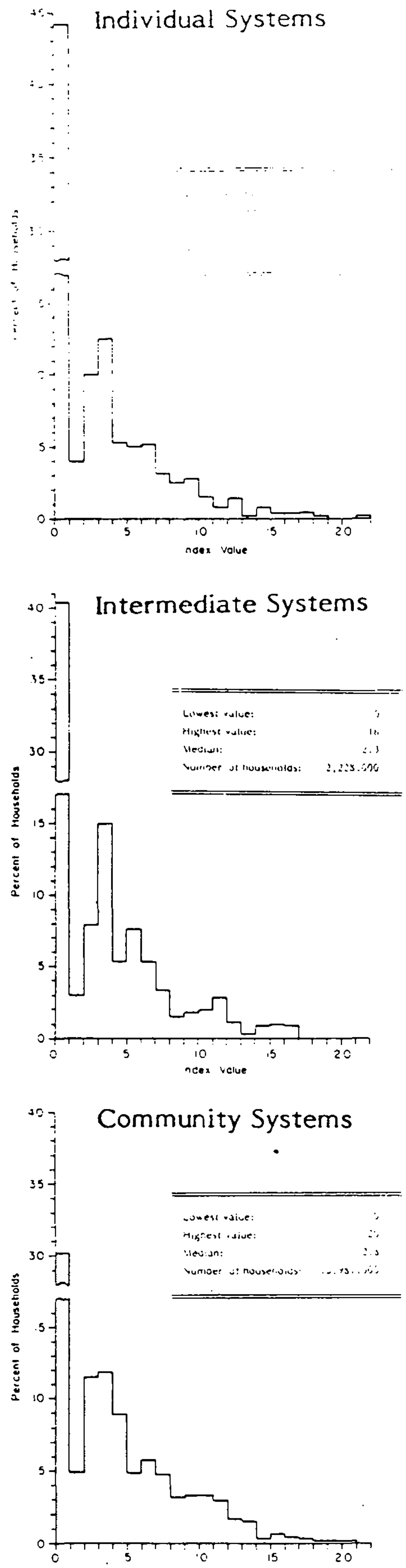
While there were at least detectable differences between rural households when they were grouped according to region, SMSA/nonSMSA, and size of place, none of these variations was as pronounced as those in the size-of-system comparison. Figure VI-11, which provides the distributions of scores on the perceived water quality index for households on individual, intermediate, and community water systems, suggests that the values for households using individual systems tended to be appreciably lower than those of households served by intermediate or community systems. Likewise, index values for households supplied by community systems were substantially higher. Only about 67 percent of the rural households on community systems had scores of 4 or less, and the median value for this household group was 2.8. In contrast, however, 76.0 percent of the households using individual systems had scores of 4 or less, while the median value for this group of rural households was only 1.6. Finally, the proportion of rural households served by intermediate systems which had an index value of 4 or less was around 72 percent, while the median score was 2.3. The direction and magnitude of these differences showed a tendency for rural households on individual systems to perceive that the quality of their water supplies was considerably better than households served by intermediate or community systems perceived their water supplies to be.

AVAILABILITY COMPOSITES

Availability in the NSA was defined as the ability of a supply to provide a sufficient quantity of water on a continuous basis. More specifically, the notion of supply availability was represented by two dimensions, reliability and accessibility. Reliability was defined with respect to supply interruptions and breakdowns, while accessibility was considered to reflect the ease with which water could be obtained from a supply. The data compiled for these indicators as individual aspects of

Figure VI-11

Size-of-System Distributions of Values on the Perceived Water Quality Index



availability are presented in Chapter V. Consequently, in this section of Chapter VI, our concern is with the principles and procedures that were employed to synthesize the information on reliability and accessibility into a corresponding set of summary measures.

INDEX OF RELIABILITY

The original data on reliability which could theoretically be incorporated into an index consisted of reported frequencies for two types of breakdowns, minor and severe. Minor breakdowns were supply malfunctions of six hours or less in duration, while severe breakdowns were those that persisted longer than six hours. Supply breakdowns were tabulated for the year prior to the NSA interview. Therefore, the reliability index was derived from these two indicators, the number of severe and minor supply breakdowns that occurred in the year before the NSA.

The index was designed to reflect both the frequency of breakdowns and their length. This was accomplished by arbitrarily weighting severe breakdowns so that they would make a greater contribution to the index than the same number of minor breakdowns. While a minor breakdown received a weight of one, all major breakdowns were weighted by a factor of two. Therefore, a household that reported three severe supply breakdowns would have received a score on the reliability index that was twice as great as the value assigned to a household that reported the same number of minor breakdowns. This weighting technique was predicated on the assumption that a single breakdown which lasted for eight hours would have approximately the same consequences for households as two breakdowns which were of four hours' duration. Without the application of some type of weighting, only the frequency of breakdowns would have been permitted to influence the index.

Structure of the reliability index

The reliability composite that was developed simply consisted of an arbitrarily weighted combination of variables that conveyed information on the incidence of minor and severe water supply breakdowns. Furthermore, these variables were synthesized by incorporating them into an additive formula. The formal expression for the reliability index was

$$R_i = M_i + 2(S_i)$$

where

R_i = the value or score on the reliability index for the i^{th} household

M_i = the frequency of minor water supply breakdowns for the i^{th} household

S_i = the frequency of severe water supply breakdowns for the i^{th} household.

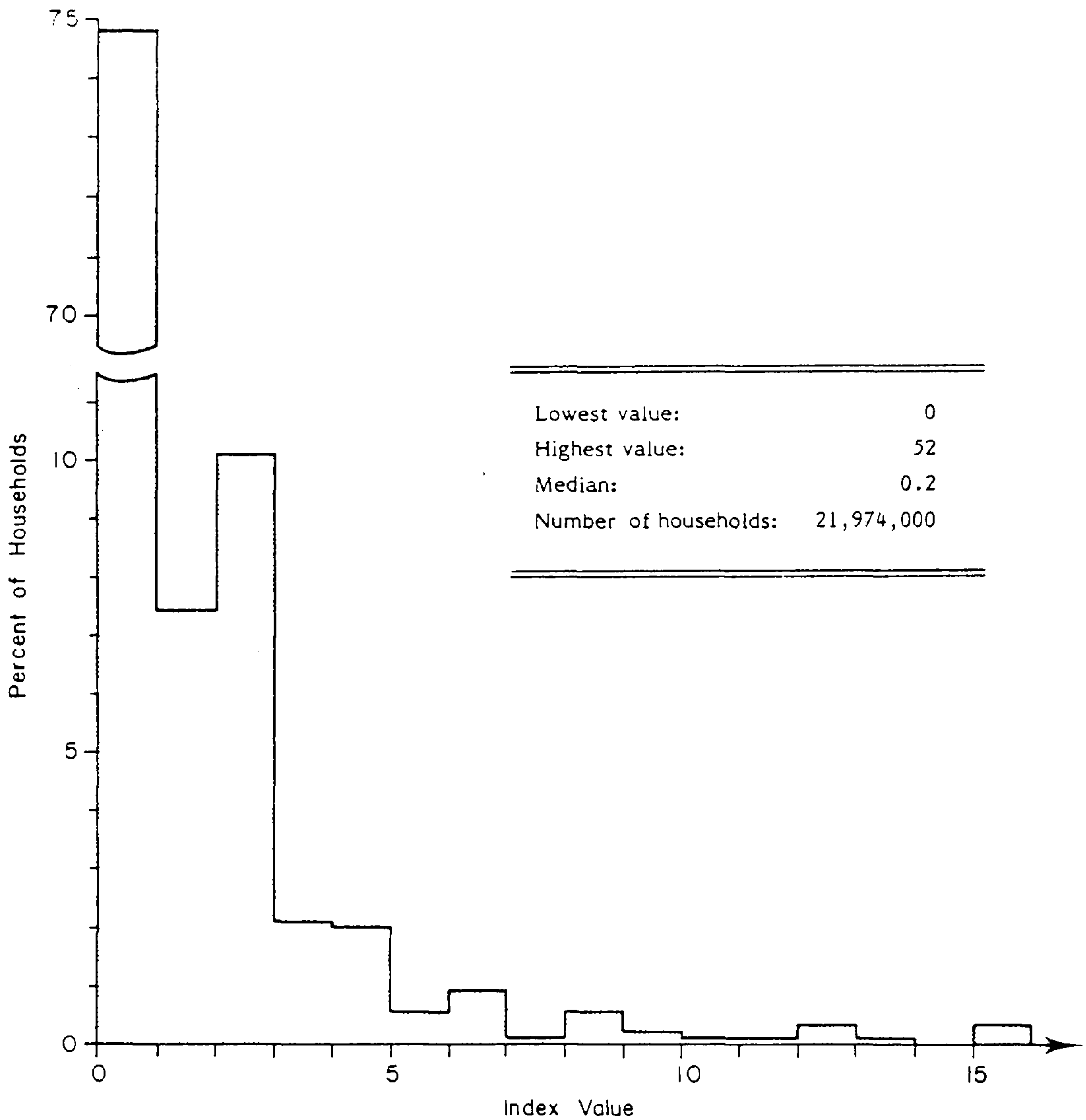
The vector of scores that was generated by applying this measurement procedure theoretically could range from 0 to a value that was constrained by the maximum number of breakdowns. Also, as with the other composites that were constructed, the reliability index had ordinal properties. Therefore, it could be employed to rank households in comparison to each other, although no particular meaning could be ascribed to the size of the differences. Households with larger values on the index were judged to have supplies that were less reliable than those that were assigned smaller values.

National estimates of reliability

According to Figure VI-12, which presents the distribution of values on the reliability index, rural water supplies tended to be very reliable. Approximately 75 percent of all rural households had a value of 0 on the reliability composite, while approximately 22 percent had scores of 1 through 4. Only about 1 percent of all

Figure VI-12

Distribution of Values on the Reliability Index
for Rural US Households



rural households across the nation had a score of 10 or greater, and the maximum value computed for the index was 52. The median value of the index was 0.2.

Subnational variation in reliability

Regional variation

However small, there was some slight variation in the reliability index according to the region in which the supply was located. Generally, as the distributions in Figure VI-13 suggest, supplies of households in the South were less reliable than supplies in other regions. Only about 71 percent of the households in the South had a reliability score of 0, compared to about 80 percent in the West, approximately 79 percent in the Northeast, and roughly 75 percent in the North Central. Likewise, the median scores ranged from a high of 0.2 for households in the South to a low of 0.1 for households in the West. Also, a much larger proportion of households in the South (5.3 percent) had index values in excess of 5.

SMSA/nonSMSA variation

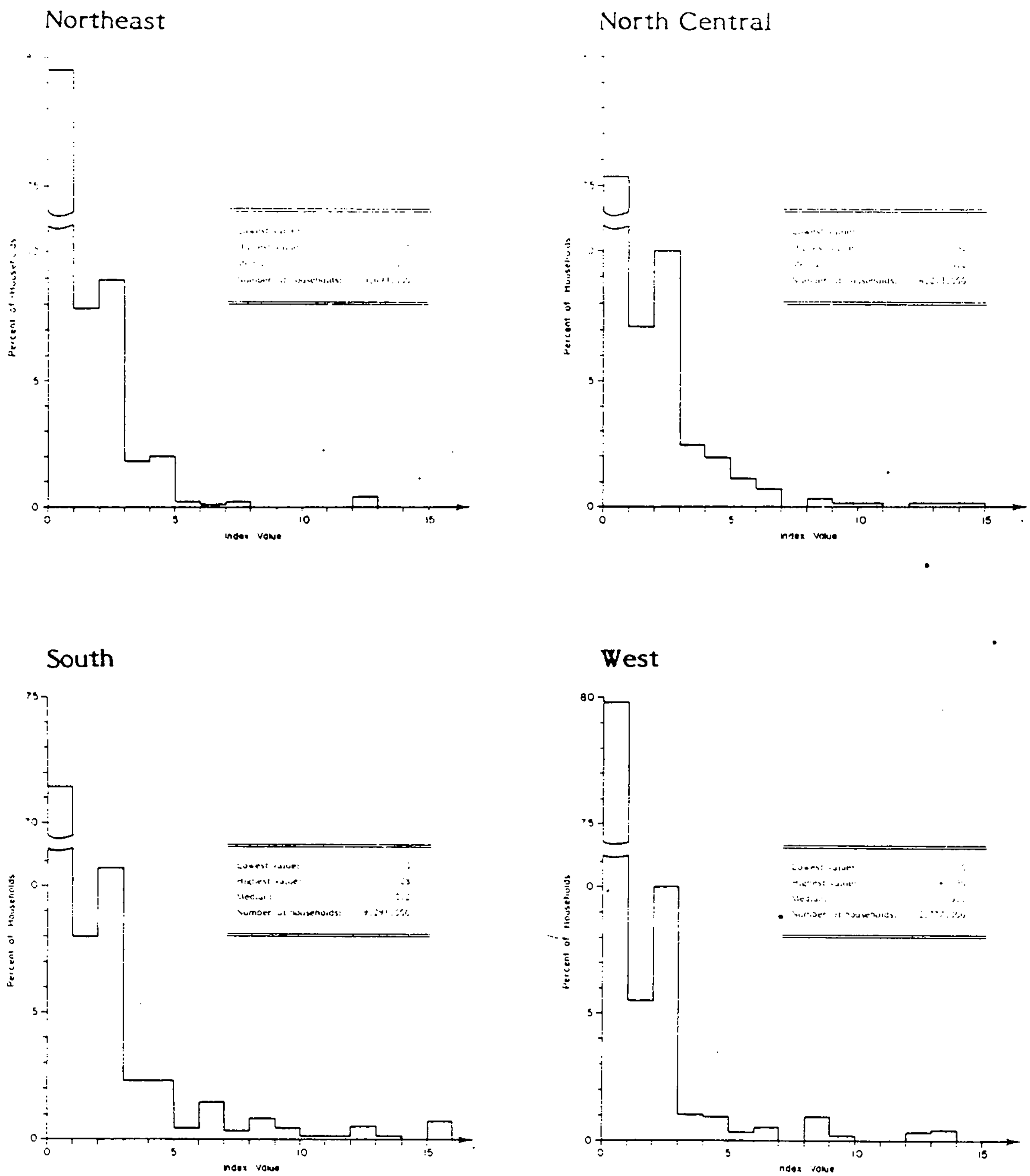
Variations in the reliability index were also small when SMSA and non-SMSA households were compared. Medians were the same, and the exact same proportions of households had values of 4 or less on the index. The major differences between SMSA and nonSMSA households on the index were in the proportions with a score of 0 (about 78 percent of SMSA households and roughly 73 percent of nonSMSA households), and in the proportions that had scores from 1 through 4 (approximately 18 percent of SMSA households and about 23 percent of nonSMSA households).

Size-of-place variation

Compared to the preceding differences, the variations according to size of place were somewhat more substantial. The largest contrasts were between

Figure VI-13

Regional Distributions of Values on the Reliability Index



households in small rural communities and those in either large rural communities or other rural areas. For example, only about 69 percent of the households in small rural communities had an index value of 0, compared to roughly 75 percent and 76.0 percent of the households in other rural areas and large rural communities, respectively. A much larger proportion of households in small rural communities, on the other hand, had an index value ranging from 1 through 4. Even though the medians were uniformly 0.2, these differences suggested that the supplies of households located in small rural communities were slightly less reliable than the supplies of households in other rural areas or large rural communities.

Size-of-system variation

A distinct pattern of variation in index scores also emerged for households using water systems of different sizes. The data indicated that the supplies of households on intermediate systems generally were not as reliable as those which provided water to individual-system or community-system households. Only about 70 percent of the households on intermediate systems received an index value of 0, while approximately 74 percent of the households on community systems and roughly 76 percent of the households on individual systems had the same composite score. However, the median score for households on intermediate systems (0.2) was the same as the medians for other households. Although households on community systems showed the same median value, a much larger proportion had a reliability index value in excess of 5. More specifically, only 2.4 percent of the households on either individual systems or intermediate systems had scores of 5 or more, while 4.9 percent of the households on community systems were assigned a value in this range.

INDEX OF ACCESSIBILITY

Data on supply accessibility, which consisted of information about recorded pressure and the distance between the extraction point and the household, were too diverse to be incorporated directly into a composite. The former indicator, for example, was measured in pounds per square inch, while the latter variable was expressed in meters. Another incompatibility between the two indicators was that they were inversely related to each other in terms of supply accessibility. In other words, supplies with higher pressure were taken to be more accessible than supplies with lower pressure, but supplies which conveyed water over greater distances were considered less accessible than those extracting water from a point close to the household. An additional constraint was imposed by the fact that households on community supplies were not even administered the question on distance because it was originally presumed that the question had relevance only for wells, springs, cisterns, and surface water supplies. Consequently, a measurement procedure had to be selected which would facilitate the resolution of these particular difficulties.

First, the pressure variable was inverted by simply subtracting each value in the vector from the maximum value. After this operation was completed, the order of the households was consistent for both pressure and distance. Next, the information on distance was expanded by assigning a value of zero meters to all households that were supplied by community systems. Implicit in this decision was an assumption that the connection to a community system was the equivalent of having a water source on the premises. Both procedures were accomplished as preliminary steps to combining the accessibility indicators, which also had to be converted into different units. To accomplish this, the derived score technique was employed to produce standard scores for both variables. These standard scores, to reiterate, were generated by subtracting a variable's mean from each of its values, and dividing the difference by the standard deviation. The final operation before actually developing the composite involved translating the standard scores by adding the appropriate constant to each one. Since the formal expressions for these procedures were presented in regard to the water quality composites, they will not be provided here.

Structure of the accessibility index

The accessibility index was composed of an additive combination of the translated standard scores that were derived from the variables for distance and pressure. Expressed more formally, the measurement model for this index was

$$A_i = TZR_i + TZD_i$$

where

A_i = the value or score on the accessibility index for the i^{th} household

TZP_i = the translated standard score on pressure for the i^{th} household

TZD_i = the translated standard score on distance for the i^{th} household.

This procedure generated a set of values that ranged from 0 to 47. The index was ordered such that households which received greater values were considered to have less accessible water supplies than households with lesser values. Also, since the composite was ordinal and simply provided a relative ranking of households in terms of supply accessibility, the magnitude of any differences had no particular significance. The only other limitation on the composite was that it did not include information on households which did not have pressurized water supplies, such as many households that obtained water by purchasing or hauling, and some households with wells. Since these supplies were perhaps the most inaccessible, the composite tended to slightly underestimate accessibility in the aggregate. Because it was distributed over the entire sample of households, this bias was judged to be negligible.

National estimates of accessibility

Figure VI-14 presents the distribution of values on the accessibility composite for all rural households except those without pressurized supplies. As seen in the figure, the scores on the index tended to cluster in a few specific intervals of the composite. About 55 percent of the households had scores of 8 or 9, and about 40 percent had scores of 6 or 7. Thus, about 95 percent of the households had scores from 6 through 9. Extreme values, both high and low, occurred very infrequently. The median score compiled for the index was 7.6, while the reference value was 7.5. Again, since the accessibility index was formulated from standard scores, the reference value simply designated the level of supply accessibility at the average rural household. However, the referent was not as useful in the context of this section's results because the proportion exceeding it could not be determined with a sufficient degree of accuracy. Therefore, the referent is not employed in the following subnational comparisons.

Subnational variation in accessibility

Regional variation

Accessibility index scores showed substantial disparities from one region to another, as shown in Figure VI-15. Most prominent among these were generally higher values for households in the North Central and Northeast, and lower values for households in the South and West. For example, around 24 percent of the households in the West had scores of 6 or less, compared to about 7 percent of North Central households. Similarly, only about 36 percent of the households in the West received accessibility scores of 8 or 9, compared to approximately 69 percent of households in the North Central. These differences were also manifested in the medians for the regions, which ranged from a maximum of 7.9 for households in the North Central to a minimum of 7.2 for households in the West. Generally, then,

Figure VI-14

Distribution of Values on the Accessibility Index
for Rural US Households

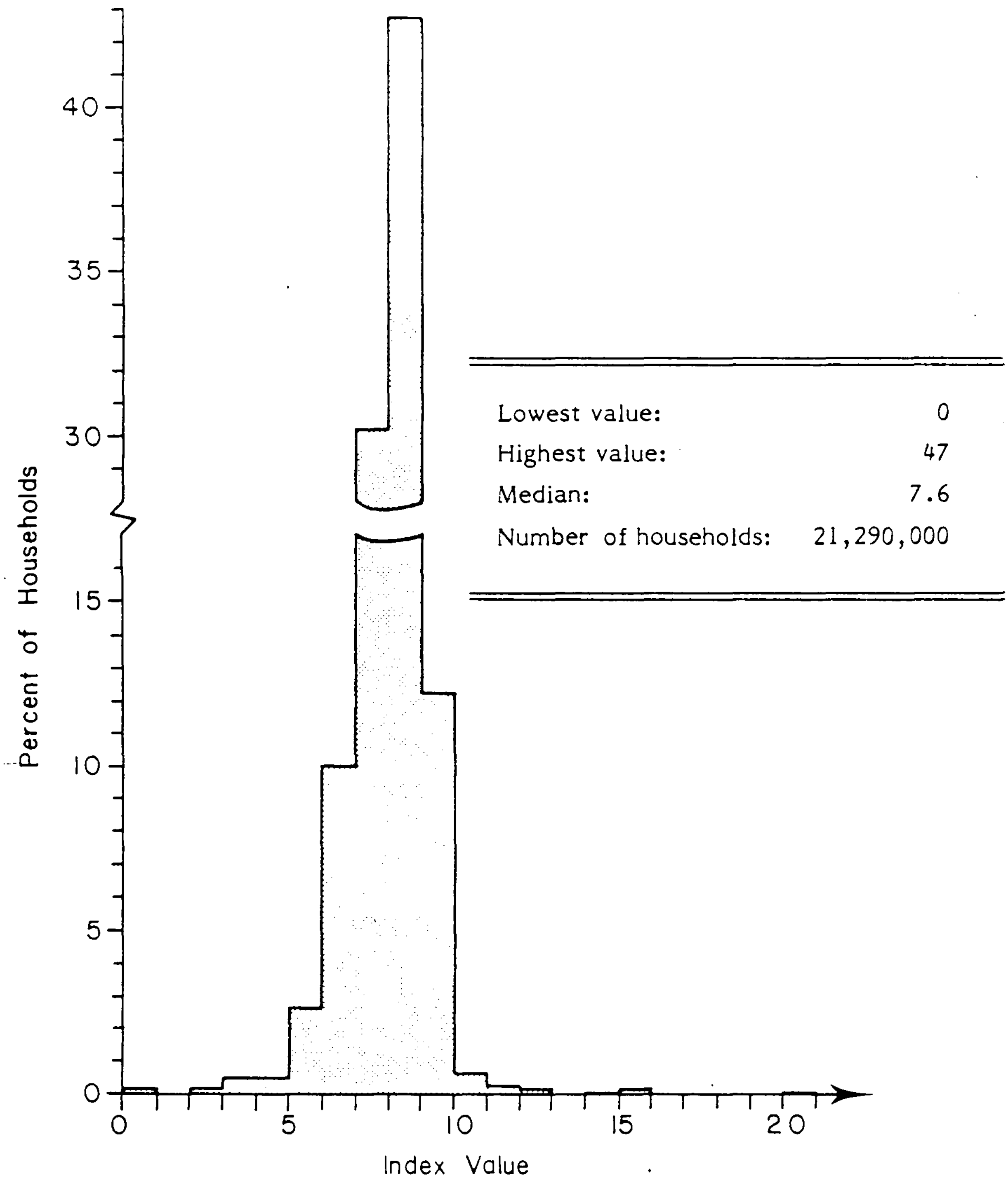
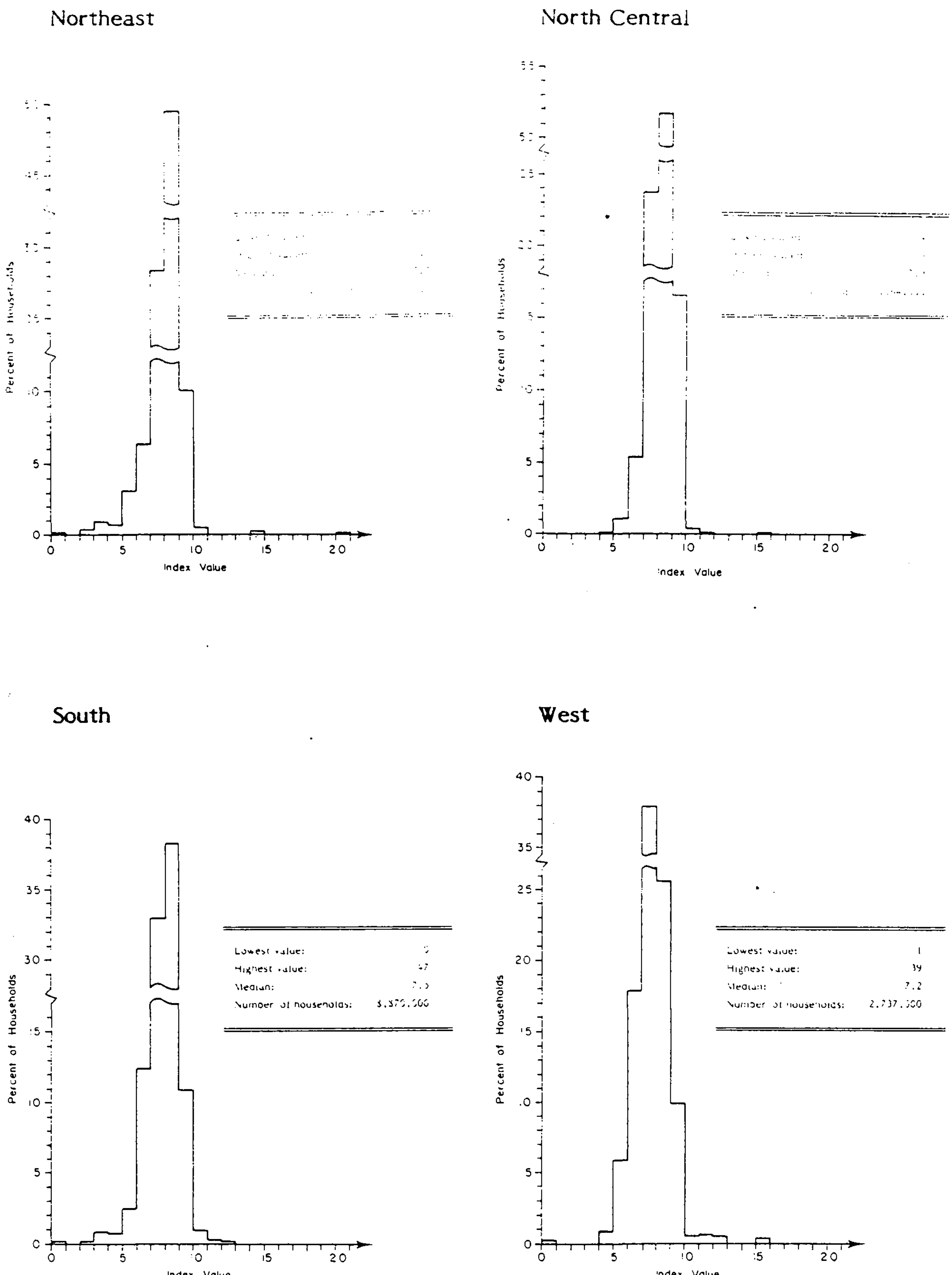


Figure VI-15

Regional Distributions of Values on the Accessibility Index



the supplies of households in the West were most accessible, and supplies in the North Central were least accessible.

SMSA/nonSMSA variation

In contrast to the preceding dissimilarities, there were only trivial variations between SMSA and nonSMSA households on the accessibility index. The distributions for the two groupings had similar configurations and the medians were approximately equal. In short, there was no conclusive evidence that the supplies of SMSA households were more or less accessible than those of nonSMSA households.

Size-of-place variation

From the information on differences in supply accessibility according to size of place, it was apparent that the supplies of households in large rural communities were more accessible than the supplies of households located in small rural communities or other rural areas. This pattern of variation was manifested in the proportions of households at various intervals of the composite as well as in the medians that were compiled. For example, about 12 percent of the households in other rural areas had an accessibility score of 6 or less, compared to about 14 percent of the households in small rural communities and approximately 23 percent of the households in large rural communities. Conversely, about 38 percent of the households in large rural communities had a score of 8 or more, which differed substantially from the roughly 47 percent of households in small rural communities and 59 percent of households in other rural areas with the same scores. Since they were sensitive to percentage fluctuations of this magnitude, the medians of 7.2 for households in large rural communities, 7.4 for households in small rural communities, and 7.7 for households in other rural areas reflected a similar progression.

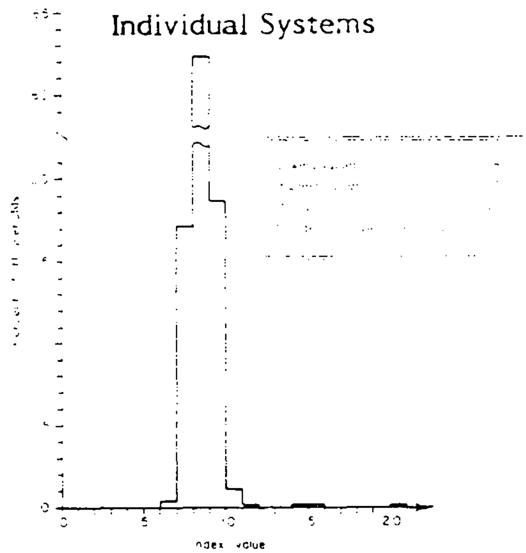
Size-of-system variation

As suggested by the information in Figure VI-16, the accessibility of supplies varied even more noticeably by the size of system which provided water to the household. Households on community systems tended to be assigned lower values on the accessibility composite, as was indicated by the large proportion (about 70 percent) of those households that received scores of 7 or less. In contrast, households on individual systems and those on intermediate systems were considerably more likely to be assigned higher values on the accessibility composite. For example, approximately 88 percent of the households on intermediate systems had a score of 8 or more, compared to about 83 percent of households on individual systems. The medians, which were 7.5 for households on community systems, 8.0 for households on individual systems, and 8.3 for households on intermediate systems, also signified that the supplies of households on intermediate systems were the least accessible. Similarly, households on community systems were substantially more accessible.

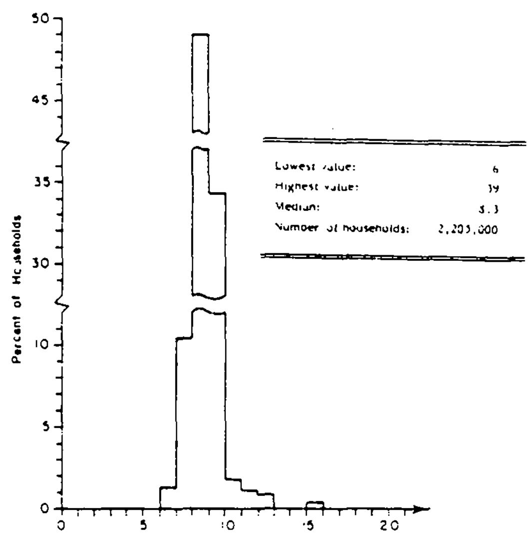
Figure VI-16

Size-of-System Distributions of Values on the Accessibility Index

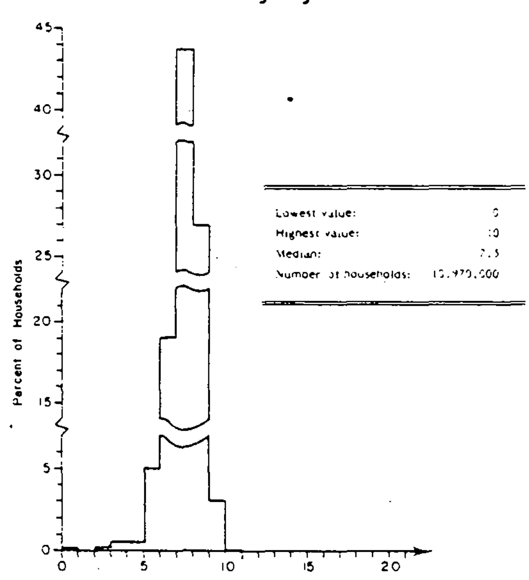
Individual Systems



Intermediate Systems



Community Systems



REFERENCES

[1] Ott, Wayne R. Environmental Indices. Ann Arbor: Ann Arbor Science, 1978.

[2] Horton, Robert K. "An Index-Number System for Rating Water Quality." Journal, Water Pollution Control Federation 37 (March 1965):300-306.

[3] Brown, Robert M.; McClelland, Nina I.; Deininger, Rolf A.; and Tozer, Ronald G. "A Water Quality Index--Do We Dare?" Water and Sewage Works 117 (October 1970):339-343.

[4] Prati, L.; Pavanello, R.; and Pesarin, F. "Assessment of Surface Water Quality by a Single Index of Pollution." Water Research 5 (1971):741-751.

[5] McDuffie, Bruce and Haney, Jonathon T. "A Proposed River Pollution Index." Paper presented at the spring 1973 meeting of the American Chemical Society, Division of Water, Air, and Waste Chemistry, New York (April 1973).

[6] Dinius, S. H. "Social Accounting System for Evaluating Water Resources." Water Resources Research 8(5)(October 1972):1159-1177.

[7] O'Connor, Michael F. "The Application of Multi-Attribute Scaling Procedures to the Development of Indices of Water Quality." Ph.D. Dissertation, University of Michigan, University Microfilms No. 72-29, 161 (1972).

[8] Deininger, Rolf A. and Landwehr, Jarate M. "A Water Quality Index for Public Water Supplies." Unpublished report, Department of Environmental and Industrial Health, School of Public Health, University of Michigan, Ann Arbor, Michigan (July 1971).

[9] Walski, Thomas M. and Parker, Frank L. "Consumers Water Quality Index." Journal of the Environmental Engineering Division ASCE (June 1974):593-611.

[10] Stoner, Jerry D. "Water Quality Indices for Specific Water Uses." US Geological Survey, Reston, Virginia, Circular No. 770 (1978).

References continued

[11] Nemerow, Nelson L. and Sumitomo, Hisashi. "Benefits of Water Quality Enhancement." Syracuse University, Syracuse, New York. Report No. 16110 DAJ, prepared for the US Environmental Protection Agency (December 1970).

[12] Truett, J. B.; Johnson, A.C.; Rowe, W. D.; Feigner, K. D.; and Manning, L. J. "Development of Water Quality Management Indices." Water Resources Bulletin 11(3)(June 1975):436-448.

[13] Greely, R. S.; Johnson, A. J.; Rowe, W. D.; and Truett, J. B. "Water Quality Indices." Report No. M72-54, MITRE Corporation, McLean, Virginia (April 1972).

[14] Dee, Norbert; Baker, Janet K.; Drobny, Neil L.; Duke, Kenneth M.; and Fahringer, David C. "Environmental Evaluation System for Water Resource Planning." Report No. PB 208 822 Battelle Columbus Laboratories, Columbus, Ohio (January 1972).

[15] Inhaber, H. "Environmental Quality: Outline for a National Index for Canada." Science 186 (November 1974):798-805.

[16] Johanson, Edward E. and Johnson, Jaret C. "Identifying and Prioritizing Locations for the Removal of In-Place Pollutants." Prepared for the US Environmental Protection Agency, Washington, DC, Contract No. 68-01-2920 (May 1976).

[17] Zoeteman, B. C. "The Potential Pollution Index as a Tool for River Quality Management." Technical Paper No. 6, Government Institute for Water Supply, World Health Organization, International Reference Centre for Community Water Supply, The Hague, The Netherlands (August 1973).

[18] Harkins, Ralph D. "An Objective Water Quality Index." Journal of the Water Pollution Control Federation 46 (March 1974): 588-591.

[19] Schaeffer, David J. and Janardan, Konanur G. "Communicating Environmental Information to the Public: A New Water Quality Index." Journal of Environmental Education 8 (Summer 1977):18-26.

References continued

[20] Ott, 1978.

[21] US Environmental Protection Agency. "National Interim Primary Drinking Water Regulations." Federal Register 40: No. 248 (December 24, 1975):59566-59574.

[22] US Environmental Protection Agency. "National Secondary Drinking Water Regulations." Federal Register 42: No. 62 (March 31, 1977):17144-17146.

[23] Calabrese, Edward J. Methodological Approaches to Deriving Environmental and Occupational Health Standards. New York: John Wiley & Sons, 1978.

[24] Allen, Martin J., and Geldreich, Edwin E.. "Bacteriological Criteria for Groundwater Quality." Ground Water 13 (1975):45-52.

[25] National Research Council. Drinking Water and Health. Washington, DC: National Academy of Sciences, 1977.

[26] US Environmental Protection Agency. "National Secondary Drinking Water Regulations."

[27] Calabrese, 1978.

[28] US Environmental Protection Agency. "National Interim Primary Drinking Water Regulations."