PUBLICATION NO. 154

R+D 85-30 ✓

DESIGN OF A DRINKING WATER QUALITY MONITORING PROGRAM

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August, 1986

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EXECUTIVE SUMMARY

The impact of acid deposition on drinking water quality has received little attention by the national acid deposition research program. Yet acid deposition may impair drinking water by depositing contaminants in surface water supplies, leaching contaminants from supply watersheds, or corroding distribution systems and, consequently, dissolving contaminants into the drinking water. A review of the existing literature on the impacts of acid deposition and the effect of acidic water on drinking water quality has revealed that the majority of surface water supplies in Massachusetts are vulnerable to acidification, that surface water supplies have experienced historical losses of acid neutralizing capacity, and that the primary potential cause of acidification-related water quality degradation of household drinking water is the corrosion of water supply distribution pipes.

A comprehensive survey of Massachusetts surface waters by the Acid Rain Monitoring Project demonstrated that: 62% of the surface waters are sufficiently low (<10 ppm) in acid neutralizing capacity to be considered vulnerable; 22% are critically sensitive with less than 2 ppm of acid neutralizing capacity; and 6% are currently acidified. An independent estimate of reservoir sensitivity by the Department of Environmental Quality Engineering found 60% to have less than 10 ppm of acid neutralizing capacity.

In an analysis of historical data from 34 Massachusetts water supplies, Taylor et al. (1985) found that although there were no significant declines in pH (i.e., increases in acidity) over the past 35-40 years, 18 sources had experienced significant losses of acid neutralizing capacity. A study by de Francesco (1986) of drinking water quality data for seven towns with vulnerable reservoirs found a significant decline in the pH in the relatively short interval since 1974 for two towns, no significant change for four others, and an increase for one. Insufficient data were available prior to 1974 to determine if any changes had occurred before that date.

Twenty-two percent of the supplies studied by Taylor et al. had pH's below 6.0, i.e. below levels recommended for prevention of serious corrosion. Although none of the raw or treated water sampled in the Taylor study exceeded U.S. EPA maximum contaminant levels for metals, the delivered water at 30% of the homes sampled exceeded the maximum contaminant level for lead; 50% exceeded the level for copper and iron. The principal source of high levels of metals and other inorganic contaminants in delivered drinking water appears to be from corrosion of the distribution system and household plumbing and not from direct deposition of atmospheric pollution or leaching from reservoir watersheds. Because pH is one of the important determinants in the corrosion process, it can be inferred that increased acidification of drinking water supplies would lead to increased corrosion of water supply lines and higher concentrations of metals in delivered tap water. In the Taylor study, typical treatment practices (filtration and chlorination) did not improve the pH of water delivered to homes, but the addition of caustic soda or other buffering material did. In those cases where the pH was raised to approximately 8.0 in the treatment process to reduce corrosion, the levels of hazardous metals were reduced

below maximum contaminant levels. Studies of Massachusetts' systems by Taylor et al. (1985), de Francesco (1986), and Karalekas et al. (1983) all indicate that pH treatment can prevent the corrosion of metals from the distribution system.

Corrosion of materials from distribution systems is a complex phenomenon. Considerable effort has been focused on devising a simple index to indicate the corrosivity or aggressiveness of water. Two indices, the Langelier Saturation Index and the Aggressiveness Index are recommended by the U.S. EPA. Many other indices have been developed. None are completely satisfactory for Massachusetts water. Nevertheless, a statewide survey of 158 Massachusetts municipal drinking waters by Zajicek (1981), using the Aggressiveness Index, found that 73% of the supplies had extremely aggressive water, 25% had moderately aggressive conditions and only 2% were not aggressive. Aggressiveness was closely correlated with pH.

Excessive metal concentrations in drinking water are not confined to public water supply systems. A major study of rural drinking water quality, the 1984 National Statistical Assessment of Rural Water Conditions, indicates that in the northeast the maximimum contaminant levels for lead are exceeded in 9.6% of rural households; cadmium in 1.6%, selenium in 2%; iron in 16%, manganese in 16.9%; and mercury in 22%. No attempt was made in the study to determine the cause of excessive contaminant levels. Nearly all rural sources in Massachusetts are supplied by private wells and are regulated by local Boards of Health. For the most part, local regulation pertains only to bacteriological levels. Few towns require additional testing, and well testing data are stored in a manner that make statewide analysis impossible. Where additional testing is required, it is often done by labs certified by the state for bacteriological testing only. Retesting of private wells is rarely required. Because the available data are limited, dispersed and of uncertain quality, it is not possible to determine if groundwater acidification has occurred in Massachusetts as it has in Sweden.

These findings suggest the need for a statistically representative survey of existing drinking water quality at the household tap in order to determine the extent of any acidification-related problems, the cause, and the portion of the population most susceptible to such water quality problems. Other surveys have attempted to describe the problem but not to delineate its cause and effect relationships or provide sufficient data to determine the population affected. To minimize collection and analytical requirements, three consecutive surveys are suggested. The first will glean supporting information from the files of the Department of Environmental Quality Engineering, U.S. Census, and town water supply files and coordinate these in compatible computerized files. The second survey will serve primarily to define the locations of different household plumbing types and add population information for a later evaluation of populations at risk. Finally, collection of tap water samples that would determine the source of any contaminants within the distribution system and collection of raw and treated water samples at the source would be done. By accumulating all available information on water quality and distribution system characteristics before collecting samples for expensive chemical analysis, the design can be made cost-efficient. Use of volunteers, as proven effective in the Acid Rain Monitoring Project, can significantly reduce data collection costs and add an important educational element.

Analysis of existing water quality and its causes would be greatly facilitated if appropriate data were available. The Commonwealth is fortunate in having historical data of excellent quality from Lawrence Experiment Station, but appropriate parameters have been monitored for only the past decade. Improvements can be made in the timing and frequency of public water supply monitoring that will facilitate long-term trend analysis in the future. Greater urgency exists for improvement in the information system for private supplies as few communities have any data, quality control is questionable and statewide access is not possible. System characteristics are insufficiently defined and the characteristics of in-house plumbing is unknown. Much of this problem can be alleviated by providing appropriate guidance to the Boards of Health regarding data collection and reporting and by establishing a centralized data management facility.

ACKNOWLEDGEMENTS

The authors wish to thank the following individuals for reviewing a draft of the manuscript and suggesting improvements: Dr. Michael E. MacDonald, the University of Minnesota Natural Resources Research Institute; Dr. Michael Frimpter, U.S. Geological Survey; Dr. Harold Hemond, Department of Civil Engineering, Massachusetts Institute of Technology; Mr. Alfred F. Ferullo, Metropolitan District Commission; Dr. William Alsop, Office of Research and Standards, Department of Environmental Quality Engineering (DEQE); Mr. Alan Van Arsdale, Division of Air Quality Control, DEQE; Messrs. Michael Pierre and William Shields, Division of Water Supply, DEQE; and Dr. John Delaney, Lawrence Experiment Station, DEQE.

Support for this project was provided by the Division of Water Pollution Control and the University of Massachusetts.

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1.0 INTRODUCTION

The impact of acid deposition on drinking water quality has received little attention by the national acid deposition research program. Acid deposition may affect the quality of water delivered to communities in one of three ways: 1) contaminants may be delivered to the catchment area -e.g., trace metals in the precipitation; 2) contaminants may be mobilized within the catchment area - e.g., low pH water dissolves metals from rock and soils; and 3) contaminants may be mobilized within the distribution system - e.g., low pH makes water more corrosive and therefore pipe material may be dissolved (Perry, 1984). In each instance, acidification per se is not a primary human health concern, but the increased concentrations of metals and other toxic substances is.

Determination of the impact of acid deposition on drinking water quality can be partitioned into three parts:

1) establish that acid deposition is the cause of acidification or increases in contaminants in the raw water supply;
2) determine the effect of raw water quality and distribution system composition on delivered drinking water quality; and
3) evaluate the human health consequences of contaminants on the human population, particularly for discrete segments of the population that may be at greater risk.

Parts one and two may be conducted independently and in any order. To be cost-effective, part three requires the characterization of delivered drinking water from part two.

Preliminary attention has been given to parts one and two by the Taylor study for public water supplies (Taylor et al., 1984a, 1984b). Historical analysis of water quality from 34 sources in Massachusetts (reviewed in detail in Section 3.2) demonstrated significant declines in buffering capacity of the majority of water sources studied. The observed declines occur during the period when acid deposition is hypothesized to have reached critical levels. Despite a strongly suggestive circumstantial case, causation has not been convincingly established. The need to rely on historical data limits the chances of demonstrating causation, although additional research could evaluate the relative likelihood of other causes of the observed trends. No previous effort has been made to evaluate historical changes in Massachusetts private water supplies.

The Taylor study also provides a preliminary examination of part two (reviewed in Section 3.2). Primary effort was focused on characterizing the water quality of raw water sources throughout the northeast. In Massachusetts, 48 sources (representing approximately 7% of all public drinking water sources) were evaluated on the basis of one or two samples each. Limited analysis of delivered drinking water quality was also done. Ten households, each in a different community in Massachusetts, were selected for sampling. Results were presented for five metals and an index of corrosion, but there was no effort to causally relate raw water quality, distribution system composition and delivered water quality. The National Statistical Assessment of Rural Water Conditions (Francis et al., 1984) provides an equally limited survey of delivered water quality for households on individual private supplies.

From the preliminary work of Taylor et al. and related surveys characterizing surface water quality, impetus arose for a more extensive analysis of the impact of acidified raw water and distribution system composition on delivered drinking water quality as a prelude to evaluation of potential health effects. The current research was initiated to compile previous findings and design a survey to adequately characterize current drinking water quality, develop predictive models of the effects of changes in acidification at the raw water source on delivered water, and suggest improvements in the existing monitoring system. Specifically the project objectives were:

I. Conduct a literature search to:
    1) determine possible effects of acid precipitation on drinking water, and
    2) identify chemical species which influence or indicate corrosivity.

II. Survey existing drinking water quality data including:
    1) compilation of the type and extent of water quality data existing in the files of state agencies, municipal water supply agencies, and boards of health, and

    2) examination of water quality data for selected Massachusetts communities to locate weaknesses in the existing data and correlate actual corrosion with chemical species.

III. Specify recommendations for:
    1) a survey of current drinking water quality as potentially impacted by acid deposition allowing development of predictive models of the relationship of raw water quality and distribution system composition with delivered drinking water quality, and
    2) improvements in the state corrosion monitoring program within the existing requirements of the National Interim Primary Drinking Water Regulations (NIPDWR) and in addition to them.

2.0 METHODS

2.1 LITERATURE REVIEW

A literature review was conducted to assess what is known about the effects of acid rain on drinking water and corrosivity. Key subjects considered in this search were acid deposition, drinking water, water distribution systems, corrosion, corrosion monitoring, and trace metals from acid rain and corrosion.

A computer-aided literature search was performed using the DIALOG Information and Retrieval Service to retrieve relevant articles and research material. Using appropriate key words, the following data bases were queried: WATERNET (1971-Present), CHEMICAL ABSTRACTS (1982-Present) and POLLUTION ABSTRACTS (1970-Present). The resulting list of articles and research materials includes the title of the articles, the author or authors, the journal or text where the articles may be found, and often times an abstract. The most relevant articles were used to search for other references which the computer search might have missed. The most pertinent references are discussed in following sections and are listed in this report's reference section.

The review also provides direction for developing a program for monitoring corrosivity. The EPA report of Taylor et al. (1984a & b) served as a basis for our assessment of water quality and corrosivity since it contained information on water supplies in Massachusetts and throughout the northeast. An article by Kirmeyer and Logsdon (1983), a manual by Environmental Science and Engineering (1984), a report by Zajicek (1981), and the Masters thesis of DeFrancesco (1986) were among the key articles used for reviewing corrosion and corrosion monitoring.

2.2 SURVEY OF EXISTING DATA

In response to the passage of the Safe Drinking Water Act, the U.S. E.P.A. established in 1977 the National Interim Primary Drinking Water Regulations (NIPDWR). These regulations include limitations on concentrations of a variety of potential drinking water contaminants. The NIPDWRs also have requirements pertaining to corrosion which 1) require a water supplier to identify the construction materials which are present in the distribution system and report them to the state and 2) to monitor for characteristics of corrosivity. The supplier must collect two samples per plant per year for analysis of corrosion characteristics for each plant using surface water sources and one sample per plant per year for each plant using groundwater sources. Determination of corrosivity characteristics must include measurement of pH, calcium, hardness, alkalinity, temperature, total dissolved solids, and calculation of either the Langelier or Aggressive Index. The Aggressive Index is used when asbestos-concrete pipe is in the distribution system.

The responsibility for regulating the drinking water quality of public supplies as prescribed by the NIPDWRs belongs to the Massachusetts Department of Environmental Quality Engineering's Division of Water Supply; private supplies are the combined responsibility of the state and local boards of health. Evaluation of the nature and extent of existing data began by contacting prominent water supply officials in the state with access to this data. Within the Department of Environmental Quality Engineering, William Shields of the Division of Water Supply and John Delaney at the Lawrence Laboratory were contacted. Floyd Taylor provided a wealth of knowledge on the existence and quality of available data based on his earlier experience (Taylor et al., 1984b). Representatives of the U.S. Geological Survey and several municipalities were also contacted directly. Since many municipalities conduct their own water quality analysis to supplement state requirements a questionnaire was sent to all water supply agencies in the state. Similarly, boards of health often require chemical analysis of private water supplies to supplement the bacteriological test required by the state. All boards of health were also sent a questionnaire to document the existence of additional data on private supplies.

Because time was not available to examine all of these data, seven municipalities were chosen for detailed evaluation. The municipalities were Amherst, Dalton, Fall River, Fitchburg, Gloucester, Hinsdale, and Springfield. They were chosen because one or more of their water supplies was identified by the Massachusetts Acid Rain Monitoring Project (A.R.M.) (Godfrey et al., 1985) as "acidified" (alkalinity $\leq$ 0.0 mg/l and pH $\leq$ 5.0) or "critical" (alkalinity $\leq$ 2.0 mg/l at any pH). This was true for all the municipalities except Springfield. Springfield was included for comparative purposes and because the water system has a good data base and is well run. It was hypothesized that this approach would not necessarily give the worst cases, but would serve as a model for assessing the problem of aggressive drinking water supplies in the Commonwealth.

Corrosion-related water quality data (i.e., copper, iron, manganese, calcium, alkalinity, pH, specific conductance, and color) were then obtained for these municipalities for the years when these parameters were concurrently measured (1973 - 1983). The Langelier, Ryznar and Aggressive indices were calculated from these data. The literature suggested that by comparing metal concentrations at the tap to those of the raw water, the extent to which corrosion is occurring could be estimated qualitatively. The pH, alkalinity, Ryznar Stability Index (RSI), and metal concentrations were examined over the study period to determine if acid rain-induced changes are affecting the drinking water supplies. The RSI was chosen over the other corrosion indices because RSI values can be compared to actual field data.

2.3 SURVEY DESIGN

The resulting information from the two sections above were used to design an appropriate survey of drinking water quality at the household tap for both public and private water supplies. Requirements of the design included geographical representativeness, appropriate consideration of private versus public supplies, surface versus groundwater, and reasonable logistics and cost. Three alternative designs are presented, varying in cost and the resolution of trends.

3.0 LITERATURE REVIEW

3.1 EFFECTS OF ACID RAIN ON DRINKING WATER

In the Northeast, the region most heavily affected by acid deposition, the pH of precipitation is considerably below the national secondary drinking water standard of 6.5 to 8.5. The pH of precipitation in the Northeast typically ranges from 4.0 to 4.5. Rainfall from certain storms may have a pH between 3.0 and 4.0. Precipitation may also fail to meet primary drinking water standards for heavy metals such as lead and copper (Sharp and Young, 1981; EPAa, 1980). Table 3.1 shows the maximum contaminant levels (MCLs) and secondary maximum contaminant levels (SMCLs) established by the NIPDWR for many contaminants related to corrosion.

Table 3.1. Maximum contaminant level (MCL) and secondary maximum contaminant level (SMCL) for selected parameters (metals in mg/l).

Contaminant	MCL	SMCL
Cadmium	0.01	****
Chromium	0.05	****
Lead	0.05	****
Silver	0.05	****
pH	****	6.5< pH <8.5
Copper	****	1.00
Iron	****	0.30
Manganese	****	0.05
Zinc	****	5.00
Asbestos	300,000 fibers/l*	

*suggested contaminant level

Sharp and Young (1981) monitored 40 roof catchment cisterns in rural Pennsylvania to evaluate direct input of heavy metals from precipitation. They found the lead content of the sediment and water mixture at the bottom of the cistern averaged 348 μg/l in systems without runoff filters. This water could be delivered to the consumer when water supplies are low or if withdrawn soon after a storm when sediments on the bottom are stirred up. Sharp and Young also found that the mean concentration of lead (134 μg/l) and cadmium (17 μg/l) in bulk snow exceeded the NIPDWR standards of 50 μg/l and 10 μg/l, respectively. All rain and snow samples failed to meet secondary standards for pH and corrosivity.

The pH dependent leachability of cadmium and lead can show a one order of magnitude difference in concentration over a shift in one pH unit, the concentration increasing exponentially with decreasing pH. The quality of water in two small streams that provide supplies to the water systems of two small Pennsylvania towns was monitored during episodes of acid runoff in 1981 by Leibfried et al. (cited in Perry, 1984). In both streams, as acid precipitation runoff increased, pH decreased and both the Ryznar Stability Index (RSI) and aluminum concentrations increased. Although there is no MCL for aluminum, it has been shown to be dangerous to kidney dialysis patients. An outbreak of dialysis encephalopathy (dialysis dementia) has been reported in Minneapolis (Berkseth and Shapiro, 1982) where aluminum content of the dialysate was 200 μg/l.

Methyl mercury and related short-chain alkyl mercurial compounds are two environmental contaminants quite dangerous to humans because they accumulate in edible fish tissue (EPA, 1980b; Clarkson, et al., 1983). Recent evidence suggests that methylation may actually decrease with decreasing pH, resulting in decreased levels in acidified waters (Campbell et al., 1984). However, Miller and Akagi (1979) have demonstrated that partitioning of methyl mercury between sediments and the water column is pH dependent. They showed that a doubling of the methyl mercury level in water occurred with a decrease of 1 pH unit (sand bottom) to 2 pH units (organic sediment bottom). Recent evidence (Bartlett and Craig, 1981; Compeau and Bartha, 1985; Craig and Moreton, 1983; Gilmour and Tuttle, 1986; Gilmour et al., 1984, 1985; Winfrey, 1985) suggests that methylation is enhanced by sulfate reduction bacteria under anoxic conditions in sediments. Based upon these studies, heavy metals may exceed drinking water standards in some acidified lakes and reservoirs.

Reed and Henningson (1984) evaluated four areas of concern regarding the effect of acid precipitation on drinking water: 1) the toxic influence of pH, 2) the increased levels of heavy metals in raw water; 3) biological imbalances in water supplies, 4) and increased corrosivity. Heavy metals in raw water may exceed existing standards in a limited number of lakes and reservoirs that have alkalinities approaching zero. Biological imbalances, notably changes in phytoplankton species dominance, due to acidification may affect taste and odor as well as treatment requirements. Of the four concerns evaluated by Reed and Henningson (1984), the most significant for water supplies was increased corrosion. Similarly, Middleton and Rhodes (1984) report that corrosivity has caused delivered water to exceed drinking water standards for toxic metals in both the United States and Sweden.

The human health concern that arises from corrosion of distribution pipes is that corroded pipe materials are transported to the tap where they may be ingested. Ingestion of lead, copper, cadmium, and zinc has been suggested as a possible cause of cardiovascular disease (EPA, 1979a). The potential relationship between ingested asbestos and cancer is being examined (Millette et al., 1980).

High levels of metals are most likely to be present in water that has remained overnight within household fixtures. As the pH of drinking water in copper piping decreases, there is an exponential increase in copper concentration in both standing and running water. Copper levels can reach concentrations greater than 8 mg/l for short periods after corrosive waters stand in pipes and taps overnight, but they decline rapidly after the first flush of running water (Berkseth and Shapiro, 1982). Lead levels, in systems which still use lead service lines, were found to be three times higher in corrosive drinking waters for first flush samples than in subsequent samples of running tap water (Moore et al., 1977). McCabe et al. (1970) found in a study of 969 water supplies that 2% of the population served was receiving lead in excess of 0.05 mg/l. Patterson (1981) found that 2.5 % of samples taken from the water supplies of 580 cities exceeded 0.05 mg/l of lead. In some sections of Boston, the widespread use of lead piping, which is characteristic of older cities, caused lead levels in tap water, prior to mid-1977, to be consistently above 0.05 mg/l in 15.4 % of the water samples, while 70% of the 383 homes surveyed had detectable lead levels (Karelekas et al., 1983). Since 1977, pH adjustment with NaOH has resulted in lower mean levels of lead (EPA, 1979a).

3.2 THE POTENTIAL FOR ACIDIFICATION OF DRINKING WATER SUPPLIES IN MASSACHUSETTS

New England waters are susceptible to the effects of acid deposition due to their generally low alkalinity or buffering capacity. Several recent surveys provide the best available picture of the vulnerability of surface waters to acid deposition. The U.S. E.P.A. Eastern Lakes Survey (ELS), Phase I (1985) characterizes all lakes over 5 hectares in the eastern U.S. Data are provided for three regions: northeast, southeast, and midwest, with further breakdowns for districts within each region (e.g. southern New England). Haines and Akielaszek (1984) surveyed 226 headwater lakes in New England. The Massachusetts Acid Rain Monitoring Project (Godfrey et al., 1985) surveyed nearly all lakes and streams in Massachusetts. Comparisons of these data on pH and alkalinity are shown in Table 3.2.

Table 3.2. Comparison of survey results for various parts of the eastern U.S., shown as cumulative percentages in each category.

		pH			Alkalinity (mg/l)		
Source	Region	<5.0	<5.5	<6.0	≤ 0	<2	<10
EPA ELS	Northeast	4%	9%	13%	5%	17%	60%
	Midwest	2%	4%	10%	2%	11%	41%
	Southeast	12%	20%	32%	22%	33%	54%
Haines & Akielaszek	New England	8%		29%		23%*	53%
EPA ELS	southern New England	6%	11%	16%	6%	19%	57%
ARM I 4/83	Massachusetts	6%		24%	5%	19%	67%
ARM I 4/84	"	8%			8%	29%	66%
ARM II 4/85	"	6%		24%	6%	22%	62%

* <1 mg/l

The comparison reveals that in the northeast, Massachusetts has a greater percentage of vulnerable surface waters than the region as a whole.

With the exception of the ARM Project, little attention has been focused on drinking water supplies by the above surveys. Although reservoir data is contained in the ARM data base, it has not yet been isolated from the rest for examination. However, the Massachusetts Department of Environmental Quality Engineering (DEQE) estimates that 60% of Massachusetts' water supply reservoirs have less than 10 mg/l of alkalinity and are, therefore, vulnerable to acid inputs. Taylor et al. (1984b) report that 69% of the reservoirs surveyed have alkalinities of less than 10 mg/l; 4% have a pH between 4.0 and 4.9 and 18% have a pH between 5.0 and 5.9. The excellent agreement between results for reservoirs and those of lakes and streams in general suggest that the two groups do not differ substantially in their vulnerability to acid deposition.

The Taylor study further demonstrated trends in the historical data for reservoirs indicating that acidification is occurring (Table 3.3). Regression analyses of 34 Massachusetts public water sources revealed that 18 sources, including Cobble Mountain Reservoir and Quabbin Reservoir had statistically significant declines in buffering capacity, 2 had significant increases, and 14 showed no significant change. For those sources with significant negative slopes, the rate of loss of alkalinity ranged from 0.05 to 0.19 mg/l per year.

Table 3.3. Alkalinity trends of raw waters in Massachusetts (modified from Table 35 in Taylor et al., 1984b).

Water Source	Community	Data Available	Statistical Significance	Slope
Crystal Lake	Gardner	1935-1980	*	- .189
Quabbin Reservoir	Boston	1944-1980	*	- .163
Roberts Meadow Brook	Northampton	1935-1980	*	- .141
Wachusett Reservoir (below surface)		1935-1981	*	- .135
Lake Pleasant Reservoir	Montague	1935-1980	*	- .133
Montgomery Reservoir	Westfield	1935-1973	*	- .123
Hatchett Brook	Southbridge	1935-1980	*	- .119
Upper Codding Brook	Lee	1935-1980	-	- .112
Egypt Brook	Dalton	1935-1980	*	- .108
Shaw Pond	Spencer	1935-1980	*	- .107
Carmody Reservoir	Holyoke	1935-1980	*	- .106
Cobble Mountain Reservoir	Springfield	1935-1980	*	- .097
Farnham Reservoir	Pittsfield	1935-1980	*	- .091
Longham Reservoir	Salem-Beverly	1935-1980	-	- .089
Pine Hill Reservoir	Worcester	1934-1979	*	- .087
Little Quittacas Pond	New Bedford	1935-1980	*	- .063
Upper Naukeag Pond	Winchendon	1935-1980	*	- .061
Great South Pond	Plymouth	1935-1980	*	- .056
Dikes Brook	Gloucester	1935-1980	*	- .051
Lovell Reservoir	Fitchburg	1935-1980	*	- .050
Belmont Reservoir	Hinsdale	1935-1980	-	- .05
Wachusett Reservoir (surface)		1935-1980	-	- .049
Fall Brook Reservoir	Leominster	1935-1980	-	- .04
Assawompsett Pond	Lakeville	1935-1980	-	- .038
Old Well	Winchendon	1935-1980	-	- .03
Upper Hoffs Reservoir	Cambridge	1935-1980	-	- .027
New Well	Winchendon	1935-1980	-	- .025
Long Pond Reservoir	Falmouth	1935-1978	-	- .022
North Watuppa Pond	Fall River	1935-1980	-	- .018
Haskell Reservoir	Gloucester	1935-1980	-	- .016
Phillipston Reservoir	Athol	1935-1981	*	+ .243
Falulah Brook	Fitchburg	1952-1980	*	+ .122
Mare Meadow	Fitchburg	1955-1980	-	+ .078
Wenham Lake	Salem-Beverly	1935-1980	-	

* significant at the 0.05 level

\- not significant at the 0.05 level

Only recently has evidence accumulated to suggest that groundwater is also at risk. Most of the research effort on groundwater impacts has occurred in Sweden, but there are no large scale surveys comparable to those for surface waters. Many individual instances of well-documented acidification of groundwater supplies exist (Grimvall et al., 1985; Forslund, 1985; Jacks and Knutson, 1981; Cole and Taylor, 1985; Henriksen and Kirkhusmo, 1985; Lang et al., 1985); and just as for surface waters, Sweden is ahead of the U.S. in the development of mitigation techniques for groundwater (Jacks and Maxe, 1984; Sverdrup, personal communication). Two recent studies shed some light on potential groundwater impacts. Veneman (unpublished, available from DEQE) estimated Massachusetts' groundwater quality sensitivity based on soil characteristics (Figure 1.1) and by mapping these soil characteristics demonstrated that acid deposition has potentially negative effects on nearly all of the state. As part of the drinking water survey conducted by Taylor et al. (1984b), a small number of municipal groundwater supplies were studied; 42% had a pH between 5.0 and 5.9 and 16% had alkalinities of less than 10 mg/l. Trend analysis was conducted on two groundwater supplies. No significant change in alkalinity was observed (Table 3.3).

The study of Taylor et al. (1984b) contains the only information on the existence and source (atmospheric, watershed, or distribution system) of contaminants in drinking water that might be caused by acid deposition. They found that metal concentrations seldom exceeded drinking water standards in raw water or finished water produced by the treatment facility (Table 3.4) indicating that, at present, atmospheric deposition of contaminants in catchments and leaching of metals from acidified catchments are not significant sources of drinking water contaminants. It is equally clear that both the raw and treated water are potentially corrosive. Taylor et al. found that the pH of finished drinking water differed little from the raw water. Twenty-two percent of the raw waters had a pH below 6.0, while 19% of the finished waters had a pH below 6.0 with an overall tendency for lower pH in the finished water. For groundwater, there was substantial improvement with 42% of the raw waters and only 20% of the finished waters below pH 6.0. It has generally been assumed that drinking water acidification would be solved by the treatment process. For the most part, it appears that treatment, as practiced in Massachusetts, has not included pH adjustment.

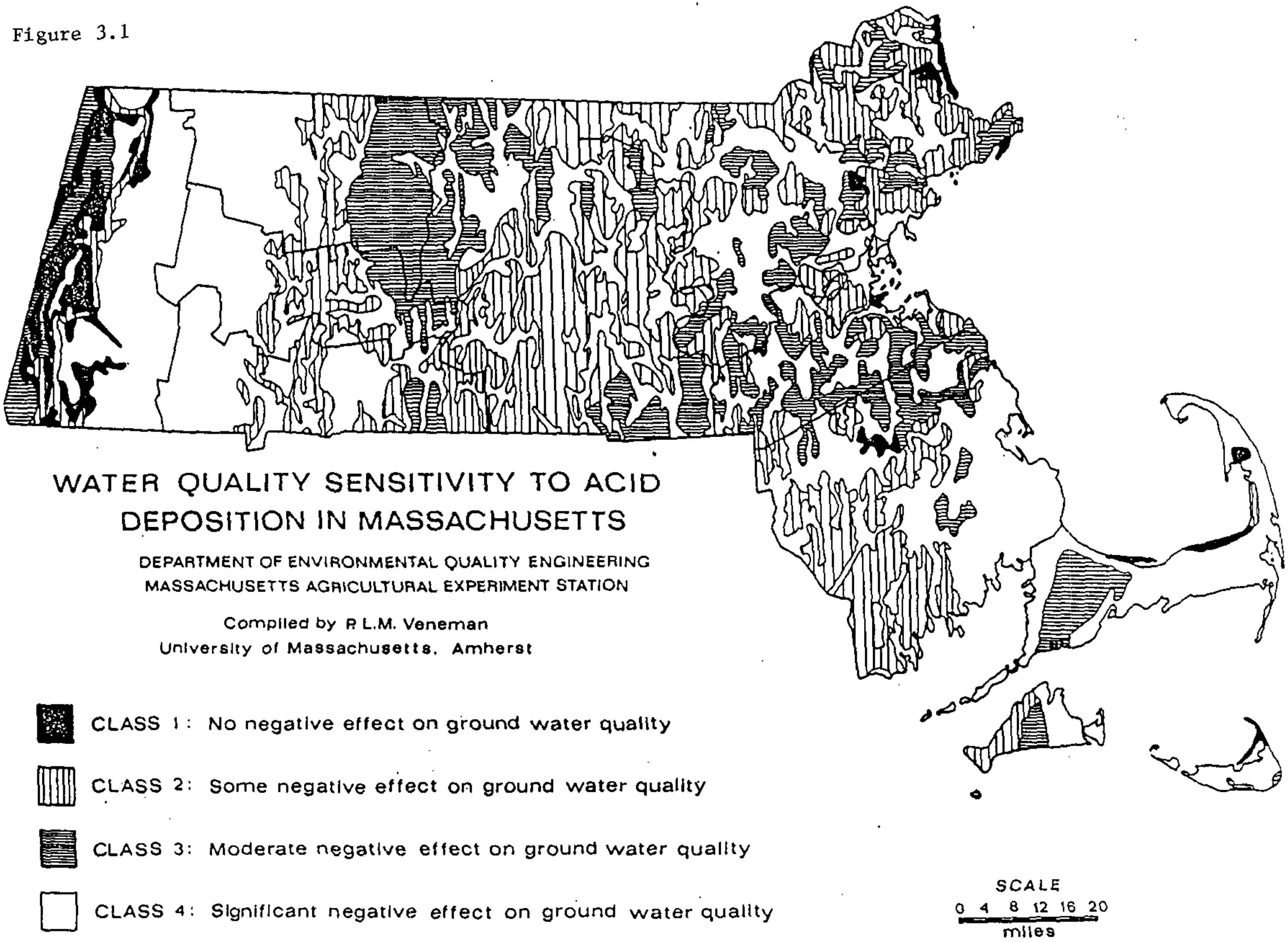
Analysis of water quality at the tap indicates that the real impact of acidified drinking water occurs through the corrosion process in the distribution system (Table 3.5).

Table 3.4. Toxic element data - surface and groundwater* (from Taylor et al., 1984b).

	Surface Water			Groundwater		
Compound or element	Number tests	No.>MCL Raw	No.>MCL Finished	Number tests	No.>MCL Raw	No.>MCL Finished
Arsenic	118	0	1	11	0	0
Barium	118	0	0	12	0	0
Cadmium	120	0	0	12	0	0
Lead	119	0	1	12	0	0
Mercury	120	1	0	12	0	0
Selenium	117	0	0	11	0	0
Aluminum	120	-	-	12	-	-
Nitrate	118	0	0	12	0	0

*Round 1 data New England and New York (Round 2 data for same area do not differ substantially).

Figure 3.1



WATER QUALITY SENSITIVITY TO ACID DEPOSITION IN MASSACHUSETTS

DEPARTMENT OF ENVIRONMENTAL QUALITY ENGINEERING
MASSACHUSETTS AGRICULTURAL EXPERIMENT STATION

Compiled by R L.M. Veneman
University of Massachusetts, Amherst

■ CLASS 1: No negative effect on ground water quality

▥ CLASS 2: Some negative effect on ground water quality

▤ CLASS 3: Moderate negative effect on ground water quality

□ CLASS 4: Significant negative effect on ground water quality

Table 3.5. Water quality of early morning tap samples (N=10) in Massachusetts (from Taylor et al., 1984b).

Compound or element	mg/l	Percent Equal to or Exceeding MCL or SMCL I	II	III	All
Lead	MCL = 0.05	30	0	0	10
Cadmium	MCL = 0.010	0	0	0	0
Copper	SMCL = 1	50	30	10	30
Iron	SMCL = 0.03	50	50	60	53
Zinc	SMCL = 5	0	0	0	0

I. Standing overnight in plumbing
II. Service line
III. Water main

While pH treatment of municipal water supplies can alleviate the impacts of more acidic water, such a policy assumes that the additional requirement for treatment will simply be added to the treatment currently in practice. This ignores the predominance and nature of small public and private water supplies in Massachusetts and throughout the northeast. Thirty-four percent of the public water supplies do not treat their water. In 1970, according to the Massachusetts Water Supply Policy Statement (Mass. Executive Office of Environmental Affairs, 1978), 5% of the Massachusetts' public living in 17% of the towns obtain their drinking water solely from private supplies. The U.S. Geological Survey estimates the Massachusetts population on private or individual water supplies at 400,000. Little is known about the water quality of private supplies, such as individual shallow wells, where more acidic shallow groundwater may increase heavy metal concentrations at the tap beyond safe drinking water standards or significantly shorten the useful life of water distribution systems and home plumbing. In the National Statistical Assessment of Rural Water Conditions (Francis et al., 1984) found that for northeastern rural households lead levels exceeded the MCL in 9.6% of households; cadmium exceeded the MCL in 1.6%; selenium, 2%; iron, 16.0%; manganese, 16.9%; sodium, 6.0%; and mercury, 22.0%. McDonald (1985) estimated that between 25,000 and 350,000 people in the northeast may be drinking water contaminated by mercury, cadmium or lead. No attempt has been made to determine how many individuals such as young children or the elderly may be exposed to high levels of contaminants.

3.3 CORROSION AND CORROSION MONITORING

3.3.1 Corrosion

All corrosion involves electrochemical processes, requiring an anode, a cathode, and an electrolyte. In drinking water systems, the electrolyte is ever present, although its nature can vary widely. Anodes and cathodes can be generated in a number of ways. A good, although somewhat old, review of the principles of corrosion has been given by Shreir (1976).

In potable water systems, the most common types of corrosion are general corrosion across the metal surface, galvanic action due to bimetallic contact, and oxygen concentration cells. Erosion corrosion, caused by fast water velocities, is possibly of less concern.

General corrosion can occur in single metal systems. When a single metal is exposed to an electrolyte, anodes and cathodes tend to form at grain boundaries. Anodes can also form at points of strain or included impurities, imposing cathodic character to points distant from the anodes. Corrosion will occur in places where dissimilar metals are in contact. Depending on the chemical composition of the anodic metal, metals that are toxic and represent a potential health hazard may be introduced into the water. Metals enter solution at the anode.

Bimetallic corrosion, due to the contact of dissimilar metals, is common in domestic plumbing systems. Perhaps the best known example is the dissolution of lead-based solders connecting copper tubing. In such a connection, the solder is anodic. The dissolving of the solder is markedly enhanced by the contact with the copper. A similar bimetallic cell can be effected by connecting galvanized iron pipe with ungalvanized iron unions or elbows. The introduction of zinc and other elements is increased as a result.

Recognition of corrosion and its by-products is usually associated with the anodic reaction. The cathodic reaction typically involves an oxidizing agent. The most common oxidizing agent found in nearly all aqueous solutions and in all potable systems is dissolved oxygen. Stronger oxidizing agents may also be present such as hypochlorous acid or hypochlorites from chlorination (Atlas et al., 1982).

While the driving force (potential) for corrosion is determined by the nature of the anodic and cathodic couples generated, the rate of the corrosion process is largely controlled by the rate at which electrical charge can be conducted through the solution, i.e., by the electrical conductivity. Low alkalinity waters having high chloride and/or sulfate concentrations could be very corrosive.

The corrosion of pipes and piping material is, thus, a complicated electrochemical process which is influenced by pH, alkalinity, dissolved oxygen, chlorine residual, dissolved solids, hardness and other factors (Kirmeyer and Logsdon, 1983; Environmental Science and Engineering, Inc., 1984; Reed and Henningson, 1984). These factors are summarized in Table 3.6.

The use of certain pipe materials in a system can affect both the rate of corrosion and the kind of contaminants or corrosion products added to the water. The type of pipe material also affects the type of corrosion control program which should be used (Environmental Science & Engineering, Inc., 1984). Table 3.7 lists the most common types of materials found in water supply systems, and briefly relates these materials to their corrosion resistance and to any potential contaminants which may be added to the water because of these materials.

Table 3.6. Chemical factors influencing corrosion.

Factors	Effects
pH	- Low pH generally accelerates corrosion; high pH may protect pipes and decrease corrosion rates
Alkalinity	- High alkalinity may help form protective coating, helps control pH changes, and reduces corrosion
Dissolved Oxygen	- Increases rate of many corrosion reactions, particularly of ferrous metals
Temperature	- High temperature increases the corrosion rate
Conductivity	- Higher values increase corrosion
Chlorine Residual	- High residual increases corrosion of ferrous metals and copper
Total Dissolved Solids	- High TDS increases conductivity and corrosion rate
Carbon Dioxide	- Particularly corrosive in copper piping
Hardness	- Higher values may help form protective coating thus reducing corrosion
Chloride, Sulfate	- High levels increase corrosion of iron, copper, and galvanized steel
Hydrogen Sulfide	- Increases corrosion rates
Silicate, Phosphates	- High levels may form protective films

Table 3.7. Corrosion properties of materials used in water distribution systems.

Distribution Material	Corrosion Resistance	Potential Contaminants
Copper	Good overall corrosion resistance; subject to corrosion from high velocities, soft water, chlorine, dissolved oxygen, and low pH	Copper and possibly iron, zinc, tin, arsenic, cadmium and lead from pipe solder
Lead	Corrodes at low pH in soft water	Lead, arsenic, and cadmium
Mild Steel	Usually corrodes uniformly; affected most by high dissolved oxygen concentrations	Iron, resulting in turbidity and red water complaints
Cast or ductile iron (unlined)	Surface erosion by aggressive waters	Iron, resulting in turbidity and red water complaints
Galvanized iron	Corrosion of zinc by aggressive waters; corrosion is accelerated by contact with copper materials and/or high temperatures	Zinc, iron, cadmium
Asbestos-cement	Good corrosion resistance; immune to electrolysis; aggressive waters can leach calcium from cement	Asbestos fibers
Plastic	Resistant to corrosion	Possible organics
Bituminous lined pipe	Resistant to corrosion	Organics

In general, the existence of a particular material in a distribution system is dependent on the time at which that part of the system was constructed. Older sections may have lead pipes. The use of lead for service lines and, in some instances, interior plumbing was widespread during the 19th century and early part of the twentieth century. Because of their durability, a considerable amount of lead pipe is still present in older sections of cities.

Another factor in the generation of toxic metals through corrosion that has received little attention relates to the common practice of electrical grounding to water pipes. The grounding of electrical equipment to water pipes, promulgated in the National Electric Code of 1897 is a practice opposed by the American Water Works Association. A policy statement opposing this practice was adopted by the AWWA Board of Directors in 1966 and revised in 1980 (AWWA, 1980). A search of WATERNET and WATERQUEST in 1984 revealed only a small number of articles which mention electrical grounding. A recent survey by the AWWA, through its April 1981 Water Research Quarterly, showed that corrosion caused by electrical grounding was of concern to many water suppliers.

Ebert (1956) discussed the dissolution of copper by stray electric currents, which demonstrates that the perception of this problem is not new. Steffan (1980) discussed the National Electric Code and the objections to it; this is a good review of the problem as perceived by water suppliers. Carlton (1974) also discussed corrosion resulting from electrical grounding to water pipes. Guerrera (1980) provided a detailed examination of Suffolk County Water Authority (NY) experience with stray electric currents in domestic water plumbing systems and the corrosion problems attendant.

Despite a general agreement that electrical grounding can result in corrosion in water pipes, there is no adequate explanation for why the corrosion occurs. This may be because of a past focus on alternating current which is not considered to cause corrosion because corrosion requires direct current with its single-directioned transfer of charge.

Two hypotheses can be suggested for how stray AC currents in water pipes can induce corrosion. The first suggests that the introduction of stray AC current into the pipe at a localized point causes the affected region to become sufficiently different from the rest of the pipe that a DC potential is induced along the pipe resulting in corrosion. The second involves a DC polarity induced in the pipe by the electrolyte. While a net migration of ionic species in the water does not occur with AC currents, the ions do attempt to migrate in the direction of opposite charge. Since the polarity reverses 60 times per second, there is no net migration of ions. However, the rate of electrophoretic transfer is different for different ions. The hydrogen ion, especially, has a migration rate many times greater than other common ions found in drinking water. This inequality of transference rates will result in localized charge separation in the electrolyte near the source of current, i.e., the pipe wall. Although this charge separation is on a microscale, it can induce the formation of anodic and cathodic regions on the metal, resulting in corrosion very similar to that occurring at grain boundaries.

Because of the variable occurrence of corrosion and highly corrodible materials, it is evident that only systematic surveys and a sampling program which utilizes monitoring techniques that include samples collected from a sufficient number of sites will be able to completely assess the magnitude of drinking water contamination from corrosion products.

Millette et al. (1980) estimated that 16.5% of the community water supplies in the U.S. are highly aggressive and 52% are moderately aggressive, i.e., corrosive. A survey of drinking water in New York City in 1970 utilizing random sampling found that 3 of 77 samples (4%) exceeded the lead MCL of 0.05 mg/l (McCabe et al., 1970). City tabulations of available records revealed that 77 of 690 samples (11%) exceeded the lead MCL (DeZuane, 1975). The discrepancy between the two sets of data could be attributed to the localized occurrence of lead in the distribution system and the choice of sampling locations (Lassovszky et al., 1980).

3.3.2 Corrosion Monitoring

The National Interim Drinking Water Regulations have requirements pertaining to corrosion which 1) require a water supplier to identify the construction materials which are present in the major distribution system and report them to the state and 2) to monitor for characteristics of corrosivity. The supplier must collect two samples per plant per year for analysis for each plant using surface water sources and one sample per plant per year for each using groundwater sources. Determination of corrosivity characteristics must include measurement of pH, calcium hardness, alkalinity, temperature, total dissolved solids, and calculation of either the Langelier or Aggressive Index. The Langelier and Aggressive indices are only indicators of the potential of a water to dissolve or precipitate calcium carbonate. The Aggressive Index is used when asbestos-cement pipe is in the distribution system. In practice, water suppliers must use other measures such as pipe inspection, coupon testing, and turbidity measurements to judge whether they have a corrosion problem. Several methods are available, but no one method provides an absolute measure of corrosivity. Several methods used together over time will indicate if corrosion is occurring and will point out any undesirable effects on the distribution system.

There are two different types of corrosion measurement: indirect and direct. The indirect methods do not measure corrosion rates. Instead the data obtained from these methods must be compared and interpreted to determine trends and changes in the system. The indirect methods described below are: 1) corrosion indices, 2) customer complaint logs, and 3) chemical analysis of water samples. The direct methods call for actual examination of corroded material and/or the measurement of corrosion rates. The direct methods discussed are: 1) examination of pipe sections and 2) rate measurements.

3.3.2.1 Indirect Methods

3.3.2.1.1 Corrosion indices

A number of indices have been developed to predict the corrosivity of a water.

The Langelier Saturation Index (LSI)(Langelier, 1936) defines the tendency of a water to form or to dissolve calcium carbonate by comparing the pH of water in contact with calcium carbonate (pHs) with the measured pH of the water. The equation used to determine the LSI is as follows:

$$\mathrm{LSI} = \mathrm{pH} - \mathrm{pHs} \qquad (1)$$

$$\mathrm{pHs} = K + \log \mathrm{Ca} + \log \mathrm{Alk} \qquad (2)$$

$$K = \log K_1/K_2 \qquad (3)$$

where pH is the measure of the water,
K_1 and K_2 are thermodynamic constants corrected for ionic strength and temperature.
Ca is in mg/l
Alk is in mg/l as $CaCO_3$

Negative values resulting from the difference between pH and pHs express the tendency of the water to be corrosive; positive values express a supersaturated condition indicating the formation of a protective scale of calcium carbonate on interior surfaces of distribution systems. At equilibrium, the LSI has a value of 0.

The Aggressive Index (AI)(AWWA, 1977) has been established as a criterion for the corrosivity of asbestos-cement pipe. It is calculated by the formula:

$$AI = pH + \log (AH) \qquad (4)$$

where pH is the measured pH of the water,
A is the total alkalinity in mg/l as $CaCO_3$,
H is the calcium hardness in mg/l as $CaCO_3$.

An AI of 12 or above indicates non-aggressive water, while values of 10 to 12 are a possible indication of moderately aggressive conditions. AI values below 10 indicate extremely aggressive conditions.

Zajicek (1981) has extensively surveyed water supplies in southern New England. Table 3.8 provides the values of the Aggressive Index value and related chemical parameters for the water supplies he surveyed. Of the 158 sites sampled in Massachusetts, 73% had AI values below 10 indicating extremely aggressive conditions, 25% were between 10 and 12 indicating moderately aggressive conditions, and 2% were above 12 indicating non-aggressive water. Furthermore, 40% of the sites did not meet the NIPDWR for pH of 6.5 or higher: 1% were between pH 5.0 and 5.5, 8% were between pH 5.5 and 6.0, and 30% were between pH 6.0 and 6.5. Sixteen percent represented tap samples that exceeded the SMCL for iron; 30.4% exceeded the manganese SMCL.

The Saturation Index (Fair, Geyer, and Okun, 1965) is very similar to the AI. For waters with pH < 8.5, they gave the equation:

$$I = pH - pH_{eq}$$

where pH = the ambient water pH

$pH_{eq} = \log K + [2.5\mu^{\frac{1}{2}}/(1 + 5.3\mu^{\frac{1}{2}} + 5.5\mu)] + pCa + pA$

$K = [Ca^{2+}][HCO_3^-]/[H^+]$, for $CaCO_3(s) + H^+ = Ca^2 + HCO_3^-$

μ = ionic strength of the water = 4H - A

H = total hardness, mol $CaCO_3$/l

pA = -log(total alkalinity, mol $CaCO_3$/l)

pCa = -log(calcium, mol/l)

The above system is in equilibrium when I = 0. If I > 0, the deposition of calcium carbonate tends to proceed; when I < 0, the dissolution of calcium carbonated is expected.

Another common corrosion index is the Ryznar Stability Index (RSI) (Ryznar, 1944). The RSI, like the LSI, is calculated from the pHs of calcium carbonate saturation. The formula for calculating the RSI is:

$$RSI = 2pHs - pH \qquad (5)$$

Table 3.8. Representative drinking water supplies in Massachusetts ordered by Aggressiveness Index (from Zajicek, 1981); a in mg/l as $CaCo_3$, b in mg metal/l, and c where AI = pH + log(alkalinity x calcium hardness.

Water Supply	pH	Alk[a]	Ca[b]	Fe[b]	Mn[b]	AI[c]
Springfield	5.6	2	2	-	-	6.4
Holyoke	5.5	2	2	-	-	6.5
Hinsdale	5.3	13	1.5	0.06	0.10	7.0
Barnstable (Craigville)	5.6	5	3.0	0.00	0.01	7.2
Southbridge	6.0	3	2	0.19	0.02	7.2
Worcester	5.8	3	3	0.10	0.02	7.2
Barnstable	5.8	7	1.7	0.26	0.07	7.3
Spencer (Shaw Pond)	6.1	5	2	0.27	0.01	7.5
Agawam	5.9	6	2.5	-	-	7.5
Fitchburg	5.8	7	3	0.76	0.04	7.5
Ashburnham	6.3	4	1.7	0.10	0.04	7.5
Brewster (GP well)	5.4	3	22	0.00	0.01	7.6
Orange	5.6	11	3.5	0.00	0.08	7.6
Gardner (tap, Main & Chestnut)	5.9	5	4.5	0.11	0.00	7.6
Harwich	6.2	7	2.4	0.08	0.10	7.8
Ashland	6.0	9	4.9	0.02	0.00	8.0
Southwick	6.3	6	3	0.05	0.00	8.0
Brewster (GP well)	6.1	7	4.8	0.00	0.00	8.0
Monroe	6.3	6	3.4	0.04	0.01	8.0
Dalton	6.2	4	6.4	0.09	0.00	8.0
Pittsfield	6.3	9	3	0.09	0.05	8.1
Marlborough	6.4	5	4.6	0.19	0.02	8.2
Grafton (South District)	6.2	6	8	0.03	0.02	8.2
Spencer (well)	6.1	9	6	0.07	0.02	8.2
Foxborough	6.3	7	6	0.05	0.01	8.3
Mashpee	6.1	14	4.7	0.42	0.05	8.3
Barre	6.0	12	6.4	0.12	0.05	8.3
Essex	6.0	22	4	4.7	0.92	8.3
Arlington	6.6	6	3.6	0.42	0.04	8.3
Provincetown	6.3	9	4.5	0.05	0.02	8.3
Maynard	6.3	12	4.6	0.08	0.07	8.4
Hudson	6.0	13	8.5	0.06	0.15	8.4
Melrose	6.5	8	3.5	0.06	0.01	8.4
Holden	6.2	10	7	0.07	0.00	8.4
Middleborough	6.1	13	6	0.00	0.07	8.4
Acton (GP well)	5.9	13	11	0.33	0.29	8.4
Leominster	6.9	4	3	0.13	0.01	8.4
Franklin	6.1	13	8	0.02	0.05	8.5
Auburn (System tap)	6.4	8	5.9	0.34	0.04	8.5
Westfield	6.6	10	3.4	0.06	0.00	8.5
Haverhill	6.1	12	8.5	0.05	0.04	8.5
Lee	6.6	8	4	0.08	0.02	8.5
Abington (filtration plant)	6.2	10	9.2	0.03	0.29	8.6
Chelmsford Center	5.8	20	12	0.04	0.04	8.6
Ludlow	6.6	9	4	0.02	0.00	8.6
Mansfield	6.1	16	8	0.03	0.02	8.6
Kingston	6.2	22	5	0.00	0.00	8.6
Millbury	5.9	16	14	0.08	0.03	8.6

Table 3.8 (cont.). Representative drinking water supplies in Massachusetts ordered by Aggressiveness Index (from Zajicek, 1981); a in mg/l as $CaCo_3$, b in mg metal/l, and c where AI = pH + log(alkalinity x calcium hardness.

Water Supply	pH	Alk[a]	Ca[b]	Fe[b]	Mn[b]	AI[c]
Manchester	6.1	23	6	0.04	0.00	8.6
Bridgewater (GP well)	6.0	16	12	0.00	0.66	8.7
Merrimac	6.1	16	9.4	0.10	0.00	8.7
Fairhaven	6.2	21	6.5	0.40	0.10	8.7
Norton	6.5	16	3.7	0.00	0.00	8.7
Chelsea	6.8	9	3.8	0.40	0.02	8.7
Marblehead	7.1	6	3.5	0.07	0.01	8.8
Billerica (Wellfield)	6.0	13	21	0.06	0.00	8.8
Greenfield (GP well)	6.0	14	17	0.03	0.03	8.8
Gardner (tap, town hall)	6.4	16	7	0.25	0.08	8.8
Lowell	6.8	9	4.4	0.03	0.03	8.8
Monson	6.2	30	7.4	0.01	0.01	8.9
Burlington (well)	5.8	22	28	0.00	0.12	9.0
Duxbury	6.5	19	6	0.10	0.02	9.0
Easton	6.3	20	10	0.00	0.00	9.0
Andover (GP Well)	6.2	17	19	0.15	0.06	9.1
Revere	7.2	9	4	0.05	0.00	9.1
Waltham	7.1	10	4	0.06	0.02	9.1
Milford	6.9	19	4.6	0.26	0.03	9.2
Framingham	7.2	10	4	0.12	0.01	9.2
Holbrook	6.7	17	7	0.13	0.15	9.2
Belchertown	6.4	16	15	0.00	0.00	9.2
Holliston	6.4	27	10	0.10	0.11	9.2
Northampton	6.7	16	7	0.10	0.00	9.2
Sturbridge	6.3	21	16	1.5	0.16	9.2
Belmont	7.2	10	3.6	0.34	0.02	9.2
Salem	6.5	15	13	0.04	0.02	9.2
Athol (GP well)	6.5	21	12	0.51	0.25	9.3
Holyoke	6.4	21	15	0.11	0.03	9.3
Palmer	6.5	26	9	-	-	9.3
Lynn	6.6	21	9.4	0.24	0.06	9.3
Concord	7.0	16	4.8	0.03	0.01	9.3
Everett	7.3	11	4	0.13	0.01	9.3
Groton	6.6	26	11	0.05	0.10	9.4
Medway	6.4	30	14	0.02	0.03	9.4
Fall River	7.6	10	2.5	0.07	0.02	9.4
Newburyport	6.5	24	12	0.13	0.02	9.4
Beverly	6.7	17	13	0.13	0.01	9.4
North Andover	7.0	14	9.5	0.07	0.03	9.5
Bedford	6.5	26	16	0.03	0.20	9.5
North Reading	6.6	27	13	0.15	0.10	9.5
Athol (Newton Reservoir)	7.0	23	5.8	0.13	0.09	9.5
Acton (GP well)	6.3	22	28	0.06	0.13	9.5
Medford	7.4	11	4.6	0.03	0.00	9.5
Barnstable	6.6	30	15	0.01	0.06	9.6
Deerfield	6.6	23	18	0.02	0.03	9.6
Lincoln	6.5	29	16	0.16	0.01	9.6

Table 3.8 (cont.). Representative drinking water supplies in Massachusetts ordered by Aggressiveness Index (from Zajicek, 1981); a in mg/l as $CaCo_3$, b in mg metal/l, and c where AI = pH + log(alkalinity x calcium hardness.

Water Supply	pH	Alk^a	Ca^b	Fe^b	Mn^b	AI^b
Burlington (Shawsheen River)	6.6	24	20	0.00	0.14	9.7
Saugus	7.9	10	2.6	0.03	0.00	9.7
Bedford	6.5	31	22	0.55	0.53	9.7
Dedham	6.4	26	29	0.69	0.70	9.7
Hingham (Treatment Plant)	6.6	24	20	0.20	0.13	9.7
Wilbraham	7.9	6	4	-	-	9.7
Amesbury	7.1	24	6.6	0.03	0.08	9.7
Lawrence (tap)	7.1	15	13	0.55	0.05	9.7
Lancaster	6.8	23	13	0.02	0.01	9.7
Templeton	6.9	21	11	0.00	0.01	9.7
Ashfield	6.8	26	15	0.41	0.21	9.8
New Bedford	7.2	23	7.4	0.00	0.01	9.8
Grafton	6.6	38	19	0.03	0.01	9.9
Needham	6.7	22	26	0.84	0.04	9.9
Sunderland	7.0	26	12	0.02	0.03	9.9
Sterling	6.9	31	13	0.02	0.01	9.9
Hanover	7.1	38	9	0.00	0.47	10.0
Bridgewater (Taunton River)	6.6	36	28	0.95	0.58	10.0
Greenfield (Surface Supply)	7.1	21	14	0.01	0.00	10.0
Methuen (Lawrence supply)	7.2	20	13	0.04	0.05	10.0
Georgetown	6.6	54	20	0.05	0.06	10.0
Attleboro	6.8	50	14	1.6	0.19	10.0
Braintree	7.2	20	14	0.00	0.09	10.0
Auburn (GP well)	6.4	52	35	2.3	0.35	10.1
Gloucester	7.2	12	26	0.09	0.01	10.1
Lawrence (reservoir)	7.3	19	15	0.08	0.08	10.2
Abington (treatment plant)	6.7	56	24	0.01	0.00	10.2
Chelmsford East	6.8	68	16	0.07	0.01	10.2
Harvard	6.9	44	25	0.04	0.01	10.3
Falmouth	6.2	9	2.5	0.08	-	10.3
Auburn (GP well)	6.5	51	46	0.02	0.01	10.3
Natick	6.9	40	28	0.00	0.01	10.4
Monterey	7.1	61	14	0.33	0.02	10.4
Hingham (tap, town hall)	7.0	48	25	0.04	0.06	10.5
North Adams	7.5	34	12	0.08	0.00	10.5
Leicester	7.1	55	22	0.00	0.00	10.6
Medfield	7.8	42	7.4	0.08	0.00	10.7
West Springfield	7.4	40	21	-	-	10.7
Cambridge	8.1	33	6.8	0.15	0.06	10.8
Great Barrington	7.3	67	21	0.45	0.05	10.8
Ayer (well)	7.0	70	37	2.8	1.7	10.8
Montague	7.6	50	19	0.01	0.03	11.0
Danvers	7.1	85	33	0.38	0.61	11.0
Andover (Haggett's Pond)	8.0	27	14	0.03	0.03	11.0
Longmeadow	7.6	56	25	0.00	0.02	11.1
Lenox	7.6	66	21	0.40	0.02	11.1
Ipswich	7.2	122	34	0.03	0.18	11.2
Brockton	9.2	6	5.9	0.01	0.02	11.2
Adams	7.7	88	19	0.00	0.00	11.3

Table 3.8 (cont.). Representative drinking water supplies in Massachusetts ordered by Aggressiveness Index (from Zajicek, 1981); a in mg/l as $CaCo_3$, b in mg metal/l, and c where AI = pH + log(alkalinity x calcium hardness.

Water Supply	pH	Alk[a]	Ca[b]	Fe[b]	Mn[b]	AI[b]
Williamstown	8.1	40	17	0.00	0.00	11.3
Hamilton	7.4	102	37	0.03	0.01	11.4
Acushnet (New Bedford Supply)	8.9	29	6.6	0.25	0.02	11.5
Hatfield	8.0	78	21	0.03	0.07	11.6
Hadley	7.8	90	35	0.00	0.33	11.7
Easthampton	8.2	67	21	0.00	0.05	11.8
Ayer (well)	8.1	77	37	0.82	0.20	12.0
Billerica (Concord River)	9.3	25	8	0.05	0.03	12.0
Reading	8.7	62	21	0.17	0.01	12.2

The RSI provides an indication of the relative scale forming or aggressive tendencies of the water. Calcium carbonate deposition increases proportionally as the index drops below 6 and corrosion increases as it rises above 6, with extremely aggressive conditions for values of 10 and above (Lassovszky et al., 1980). The RSI has been related to observations of actual corrosion using Figure 3.2

McCauley (1960) presented his Driving Force Index, which employs the solubility equilibrium of calcium carbonate using the solubility product constant:

$$DFI = [Ca^{2+}][CO_3{}^{2-}]/K_{sp} \times 10^{10}$$

In the DFI, the terms $[Ca^{2+}]$ and $[CO_3{}^{2-}]$ are the concentrations of calcium and carbonate, in mg $CaCO_3/l$, found in the water; K_{sp} is the solubility product constant for calcium carbonate which describes the saturated solution. The McCauley index would not be useful in low pH water $(pH < 8.5)$ where the carbonate ion concentration is very low and not experimentally quantifiable.

Larson (1957), concerned primarily with metallic pipe corrosion, introduced the chloride and sulfate ions as potential corroding agents into his Larson Index:

$$I_L = ([Cl^-] + [SO_4{}^{2-}])/\text{Alkalinity}$$

The index assumes that the numerator term is indicative of a corroding nature while the denominator is an inhibiting factor. Thus, the larger the quotient, the more aggressive or corrosive the water. Because there is no saturation concept used, the index is comparative. Indeed, this is the only index which does not use the calcium carbonate stability.

Feigenbaum et al. (1978) used both calcium carbonate stability and the chloride and sulfate concentrations to express a Y factor:

$$Y = AH + B([Cl^-] + [SO_4{}^{2-}])\ e^{-(1/AH)} + C$$

where H is the equilibrium constant for the calcite dissolution reaction:

$$CaCO_3(s) + CO_2 + H_2O = Ca^2 + 2HCO_3$$

$$H = [Ca^{2+}][HCO_3{}^-]^2/[CO_2]$$

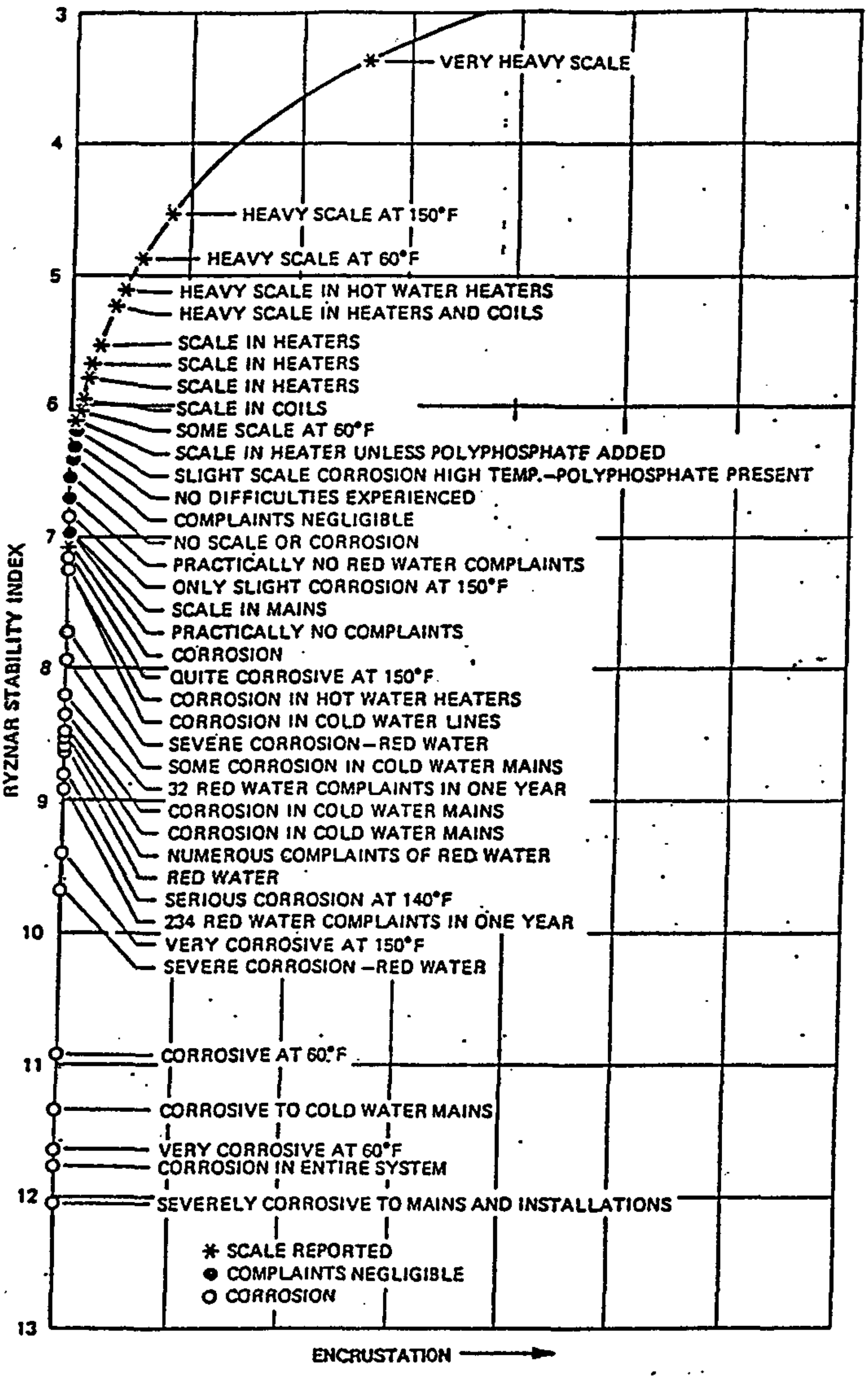
and $A = 3.5 \times 10^4$ $HCO_3{}^-$, mg $CaCO_3/l$ Cl^-, mg/l

$B = 0.34$ $SO_4{}^{2-}$, mg SO_4/l Ca^{2+}, mg/l

$C = 19.0$ CO_2, mg CO_2/l

Figure 3.2. RSI Field Observation Curve

(From Environmental Science & Technology, 1984)



This is one of the more complicated indices to have been put forth. Water having high values of Y are judged protective. It is interesting to note that these workers conclude that increased conductivity, evidenced by the higher chloride and/or sulfate, leads to a superior scale formation and protection. While this appears contradictory to the findings of Larson, it is not necessarily so. Feigenbaum and his co-workers were looking at the precipitation of calcium carbonate while Larson was concerned with the corrosion of metals. It is quite probable that certain levels of chloride and/or sulfate could lead both to increased corrosion of ferrous metals and to a uniform microcrystalline deposit of calcium carbonate.

There are other less well known indices that are, essentially, minor modifications of those already cited.

In general, indices to express the tendency of water to attack pipe materials employ the principle of calcium carbonate stability. That is, if the water is supersaturated in calcium carbonate, the formation of $CaCO_3$ on the pipe is expected to provide a protective coating against corrosion. These indices have been relied upon to predict the action of water on pipe materials, often without regard for the nature of the pipe. A water that was judged aggressive by use of an index but which did not attack pipe materials has been considered anomalous. Because of the incidence of these anomalous waters, serious doubts have been raised about the effectiveness of aggressive indices to predict water/pipe interactions. Buelow et al. (1979) commented on this by stating "... that placing absolute confidence on a single water quality standard for all water is unreasonable." Larson (1975) has written that, "Experience has shown that the greatest weakness of the saturation index occurs with water of relatively low alkalinity and calcium," yet this is the kind of water most likely to be called aggressive. Zajicek (1981) has questioned the validity of the entire saturation concept for aggressive waters as defined by the indices. He believes the concept may be of little or no use for predicting aggression except in the specific case of dissolving calcium carbonate. He offers an alternative explanation for the relationship between calcium carbonate and corrosion. It states that, with the exception of the Larson Index, all other indices are based on a calcium carbonate equilibrium, based on three suppositions:

1. if a water solution is unsaturated in calcium carbonate, more calcium carbonate can dissolve in that water,
2. if a water solution is saturated in calcium carbonate no net change will occur, and
3. if a water is supersaturated in calcium carbonate, calcium carbonate will, or should, precipitate.

These simple and logical statements would seem to support the use of indices. The formation of calcium carbonate scale from supersaturated waters is fact and the formation of a uniform, complete, and non-porous coating of calcite on a pipe would be protective. However, the nature of calcium carbonate precipitation is important in determining the adequacy of the coating. The formation of a non-porous, uniform and complete coating is favored by slow multi-nucleated precipitation leading to a uniform microcrystalline deposit. Rapid precipitation is more likely to lead to large agglomerates providing little, if any, protection. In fact, partial coverage on metallic pipes results in enhanced corrosion due to the oxygen concentration cells that can develop.

The character of the precipitated film which will form under various conditions can be predicted using the ideas set forth by von Weimarn (1914). The precipitation process can be thought to take place in two steps, nucleation and growth. To describe the rate of formation of nuclei, von Weimarn proposed the following equation:

$$W = KJ\,[(Q - L)/L]$$

where W = speed of colloidal nuclei formation
K = a constant, characteristic of the precipitation compound
J = a constant, characteristic of solution variables other than concentration
Q = concentration of precipitation compound in solution at the start of precipitation
L = solubility of coarse crystals of the precipitating compound.

The difference $Q - L$ is a measure of the extent of supersaturation, and the quotient $(Q - L)/L$ is the degree of supersaturation.

Slow nucleation, which leads to many submicroscopic nuclei, is brought about by a small value of $(Q - L)/L$. For any given substance, the solubility L is fixed so that Q controls nuclei formation. If Q is only slightly larger than L, a multi-nuclear sol is favored; if Q is much greater than L, an amorphous colloidal gel is more likely and will lead to large non-uniform crystals.

Within this framework, it is easy to see why some waters with aggressive indices well in excess of calcium carbonate saturation do not provide protection. Alternatively, waters which appear to be very aggressive in the bulk water can, for even brief intermitted periods, exceed saturation very slightly, leading to the formation of protective coatings. This conceptual approach to the precipitation process becomes more important when considering the formation of insoluble coatings of substances less soluble than calcium carbonate, such as the ferric and manganese oxides.

Recent studies of the effects of "corrosive" water as defined by various indices on asbestos-cement pipe has resulted in questions and concerns about the potential hazard of asbestos fibers ingested with water. In an U.S. E.P.A. report (Buelow et al., 1979), it was shown that in four water supplies having aggressive indices (AI) of 5.34, 5.67, 7.46, and 8.74, the water with AI = 7.46 showed no evidence of asbestos fibers and used pipe showed little or no evidence of attack by the water. Hallenbeck et al. (1978) examined 15 sections of A/C pipe from different well and surface supplies which varied from aggressive to non-aggressive and found no statistically significant release of chrysotile fibers in any supply.

3.3.2.1.2 Customer complaints

Customer complaints are often the first indication that corrosion is taking place in a distribution system. Table 3.9 indicates some typical customer complaints; however, complaints may not always be due to corrosion. For example, red water may be caused by iron in raw water that was not removed during treatment. Records of complaints about water quality should be kept in an orderly manner and should include the following: customer's name, address, date, nature of complaint, and remedial action taken. The following information should also be recorded:

1) Type of material in customer's system,
2) Whether the customer uses home treatment devices prior to consumption (softening, carbon filters),
3) Whether the complaint is related to the hot water system and, if so, what type of material is used in the hot water tank and its associated appurtenances.

Sending a questionnaire to a random sample of customers is also useful in determining the extent of corrosion.

Table 3.9. Typical Customer Complaints.

Customer complaints	Possible causes
Red water or reddish-brown staining of fixtures and/or laundry	Corrosion of iron pipe or presence of iron in water
Bluish stains on fixtures	Corrosion of copper lines
Foul taste and/or odor	By-products of microbial activity
Loss of pressure	Excessive scaling, tubercle buildup from pitting corrosion, leak in system

3.3.2.2 Direct Methods

3.3.2.2.1 Pipe examination

Physical examination of pipe sections is often the most useful inspection tool. When physical inspection is done in conjunction with pipe replacement, the cost is very low. Both macroscopic and microscopic observations of scale on the inside of a pipe are valuable tools in diagnosing the type and extent of corrosion.

Utility personnel should try to obtain pipe sections from distribution or customer plumbing systems whenever possible, such as when old lines or equipment is being replaced. If scale is not found in the pipe, an examination of the pipe wall can yield valuable information about the type and extent of corrosion.

Plumbing repair shops are a valuable resource to the utility because of their knowledge of home plumbing systems. Most shops stockpile old pipe, hot water tanks, and other equipment before disposing of them. A visit to several plumbing shops will provide a quick look at the problem areas (Kirmeyer and Logsdon, 1983).

3.3.2.2.2 Rate measurements

Common methods used to measure corrosion rates include: 1) coupon testing and 2) electrochemical methods. In coupon testing, the weight of the coupon is measured on an analytical balance before and after the placement of the coupon in a test cell with flowing water typical of the distribution system. The weight loss of the coupon is converted to a uniform corrosion rate. Coupons should be made out of the same material as found in the distribution system.

Electrochemical methods are based on the electrochemical nature of corrosion of metals in water. One type of electrochemical instrument has probes with two or three metal electrodes which can be made of the material to be studied. This type of instrument can measure corrosion rates in mils (0.001 inch) penetration per year (mpy). In another type of electrochemical instrument, the loss of material over time is detected by an increase in resistance of an electrode made of the metal of interest. Measurements over time can be used to estimate corrosion rates.

The electronic techniques give "instantaneous" corrosion rates for a particular water quality versus a 30 day or longer wait to remove a coupon and calculate its corrosion rate. As with many testing methods, interferences affect accuracy and reliability of these methods. Interferences include the velocity and direction of flow and the preparation and positioning of the probe. It is recommended that the electronic results be compared with coupon results to establish reliability of the electronic technique (Kirmeyer and Logsdon, 1983; Environmental Science and Technology, 1984).

4.0 COMPILATION OF EXISTING DATA

4.1 STATEWIDE SURVEY OF DATA AVAILABILITY

The primary reason for evaluating the state of existing data on community and individual water supplies is to provide an historical baseline against which current conditions may be compared. Without such a baseline, even crude estimates of acidification trends will be impossible. Consequently, every effort has been made to document the existence of historical data. Assembling the available data, however, is beyond the scope of this project.

The New England Water Works Association (NEWWA) in making its massive study of over 270 water supplies in the eastern United States (Taylor et al. 1984b) reviewed the existing and available drinking water data for Massachusetts. Despite the effort, only 12% of the existing water supplies were considered. The best single source of data was that of the Lawrence Experiment Station of the Department of Environmental Quality Engineering. Their files have information on community and non-community water supplies but not on industrial or private supplies. Approximately 200 surface water supplies are characterized on an annual basis in these files. Careful review of the quality control exercised over the Lawrence Experiment Station analyses indicates that these data are very likely to be highly accurate and reliable (Taylor et al. 1984b). The U.S. Geological Survey also maintains computerized records on community and individual water supplies for the period 1970-1980, but only for Cape Cod. However, their data on community water supplies is from Lawrence Experiment Station. They have data from 3000 tests on individual water supplies with approximately 20 measurements per supply.

The Lawrence Experiment Station data do not contain any information on the seasonal variability of water quality. Most of these data are collected during the months of January through May, but time of sampling has not been consistent. Many of these records extend back thirty or forty years, some even to the turn of the century. But relatively little has been computerized. Taylor et al. (1984b) computerized data for those supplies considered in their report. Unfortunately, these computer files are in non-standard computer formats. DEQE has also computerized all available data from 1977-1983. The Water Resources Research Center has obtained a copy of these files and maintains them in IBM-PC compatible form (dBase III and Lotus). In order to evaluate the potential for analysis of seasonal variation and to provide additional quality control support, we have sent a questionnaire (Table A.1) to all town water supply managers asking if they conduct any additional analyses beyond that maintained by DEQE. Of the 136 towns responding (Table A.2), forty towns conduct additional sampling and analysis. Table A.3 lists the towns, parameters measured and the year data collection was initiated for that parameter. Table A.4 lists the frequency of collection, laboratories used for analysis, collection sites, and method of filing. In nearly all cases, additional analyses have been conducted only in recent years. Many of these towns conduct their own analyses of water quality on a more frequent basis (daily, weekly, or monthly) although the parameters measured are limited. None of these records are computerized to date, although several towns are just beginning to convert to computerized record keeping. The vast majority of these additional analyses are on raw water, presumably for process control during treatment. Very few towns have an established procedure for monitoring at the tap.

Individual water supplies are not regularly monitored by the state. The responsibility for appropriate water quality rests with town boards of health. Survey questionnaires (Table A.5) were sent to the 351 local boards of health (Table A.6). One hundred and fifteen boards of health responded. Of these, 46 maintain water quality data other than bacteriological tests and these are generally relatively complete with respect to the major ions (Table A.7); 29 towns have pH data, 14 have alkalinity data, 13 have sulfate, but none have aluminum. Files are usually maintained according to house plots and not computerized. Few towns have requirements for regular monitoring of individual supplies. Four require retesting upon transfer of the property. Retesting in other towns is done only when there are major modifications to the well or septic system or reasons to believe there is contamination. Public facilities may be tested at regular intervals. Several towns in three areas, Worcester, the South Shore, and Cape Cod use a common laboratory where records may be easier to obtain.

In summary, the available data from Lawrence Experiment Station on community water supplies is accurate, extends back as far as the 19th century and is partially available in computerized form. For the most part, these data will not provide information on the seasonal variability of measurements. Seasonal variability can be addressed by augmenting the state data with data from community water suppliers where quality control procedures are adequate. The number of these is quite limited. An effort should be made to continue the computerization of all available data on water supplies available from Lawrence Experiment Station, adding the limited data available from Federal sources. Selected town files may also be computerized if they meet quality requirements and have been selected for phase II survey work.

For individual household water supplies, data are very inadequate. They are of questionable quality, represent only the initial condition of the supply, are maintained in widely distributed, non-computerized file systems that impede large scale use. The U.S. Geological Survey (U.S.G.S.) files for the Cape Cod area should be combined with existing state data in a centralized computer facility. On a case by case basis, data held by towns should be reviewed for quality and added to the centralized baseline file. The difficulties of assembling all available data coupled with the questionable nature of most of it suggest a highly selective approach to the use of data on individual water supplies. Even though some communities may have perfectly adequate historical records, it is, very likely, not possible to provide statistical representation of the historical condition of Massachusetts individual water supplies.

This is an unfortunate state of affairs. Since these data would include information on the historical condition of shallow groundwater supplies across the state, they would be, perhaps, the best indication of changes in groundwater quality resulting from acid deposition. A database of this type would also permit a full-scale assessment of the Massachusetts population at risk from this and other potential sources of contamination.

4.2 ANALYSIS OF WATER QUALITY DATA FROM SEVEN SELECTED TOWNS

Because time was not available to look at corrosion data for every community in the Commonwealth, a group of seven towns was chosen for the study. The municipalities were Amherst, Dalton, Fall River, Fitchburg, Gloucester, Hinsdale, and Springfield. The corrosion-related water quality data were obtained from Mr. Floyd B. Taylor and from the Lawrence Experiment Station (LES). Communities in the Commonwealth are required to send their raw water samples to the LES for testing once a year. Mr. Taylor's data were originally obtained from the LES. Data on the treatment process and the distribution system materials of the communities were obtained from the water superintendent of each community. These data are summarized in Tables 4.1 and 4.2.

Table 4.1. Treatment Processes Used by Communities Studied*.

Community	Supply	Treatment Processes
Amherst	Atkins Reservoir	pH adjustment with NaOH and chlorination
	Amethyst Brook Reservoir	polymer addition, direct filtration, pH adjustment with NaOH and chlorination
Dalton	Egypt Brook Reservoir	filtration and chlorination
Fall River	North Watuppa Reservoir	alum addition, flocculation, sedimentation, filtration, pH adjustment, with NaOH, and chlorination
Fitchburg	Bickford Reservoir	chlorination
Gloucester	Haskell Reservoir	prechlorination, alum addition, flocculation, sedimentation, filtration, pH adjustment with lime and chlorination
Hinsdale	Belmont Reservoir	chlorination
Springfield	Cobble Mountain Reservoir	1) slow sand filtration 2) polymer addition, direct filtration, adjustment with NaOH and chlorination

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* None of the communities uses corrosion inhibitors

Table 4.2 Piping Material Used by Communities Studied.

Community	Piping Material
Amherst	50% asbestos-cement 40% cast iron and ductile iron 10% PVC
Dalton	80% cast iron 20% asbestos-cement
Fall River	50% cast and ductile iron (lined) 45% cast iron 5% asbestos cement
Fitchburg	95% cast iron 10% unknown
Gloucester	90% cast iron 10% unknown
Hinsdale	95% cast and ductile iron 5% asbestos cement and PVC
Springfield	50% cast iron 42% cast iron (lined) 4% ductile iron (lined) 4% steel

4.2.1 Yearly Trends

4.2.1.1 pH

With few exceptions, raw and tap water pH showed no significant trends between 1973 and 1984 (Figures 4.1a - R.1g). This was true for the municipalities of Amherst, Dalton, Gloucester, and Springfield. The absence of trends could be attributed to the following possible hypotheses: 1) acid deposition is having no effect on the water supplies being studied; 2) the effect of acid deposition is small and a ten year study period is insufficient to detect any changes; and 3) samples were collected at different times of the year and seasonal variation in pH masked any trends.

The raw and tap water for the municipalities of Fitchburg and Hinsdale did show a downward trend in pH over the past ten years. The pH of the supplies for Fitchburg dropped approximately 0.8 pH units between 1974 and 1981 (Figure 4.1d), and the pH of the supply for Hinsdale dropped approximately 1.0 pH unit between 1974 and 1983 (Figure 4.1f). For the years in which tap waters were analyzed in these municipalities, the pH for the tap and raw water was about the same and decreased at about the same rate, dropping below the SMCL pH of 6.5. It is possible that acid deposition caused the downward trend in pH; however, there is no evidence to substantiate this hypothesis. Although the pH of the raw water in Fall River shows no trend, the tap water showed an increase in pH from 5.7 (below SMCL for pH) to 8.0 between 1973 and 1981 (Figure 4.1c). This increase in pH at the tap is due to recent pH adjustment with caustic soda.

4.2.1.2 Alkalinity

Alkalinity showed no trends in any of the water supplies of the seven municipalities from 1973 to 1984 (Figures 4.2a - 4.2g). Alkalinity values for the tap and raw waters in all the municipalities were low. The alkalinity for raw and tap waters ranged from 3.2 mg/l as $CaCO_3$ to 11.3 mg/l with a mean around 6.0 mg/l. The possible reasons for the absence of any trends in the alkalinity data are the same as described reasons for pH in the previous section.

4.2.1.3 Ryznar Stability Index

The RSI values indicate that all of the municipalities have corrosive water supplies and are putting corrosive water into their distribution systems (Figures 4.3a - 4.3g). An RSI value above 11.5 is considered corrosive to the entire system and any value above 12 is considered extremely corrosive to the entire system (see Figure 1). All of the supplies had average RSI values greater than 13.7 and all of the tap water samples had RSI values greater than 11.8. In general, the RSI of a particular water supply was inversely correlated with the pH of that supply, as expected from the dependence of RSI on pH.

The raw water in the reservoirs which supply water to Fitchburg and Hinsdale showed a trend of an increasing RSI, which correlates with the decrease in pH for these municipalities. This indicates increasing corrosivity in the three supplies. The Fitchburg supplies rose about 1 RSI unit from 1974 to 1983 and the Hinsdale supply rose about 3 RSI units during the same period.

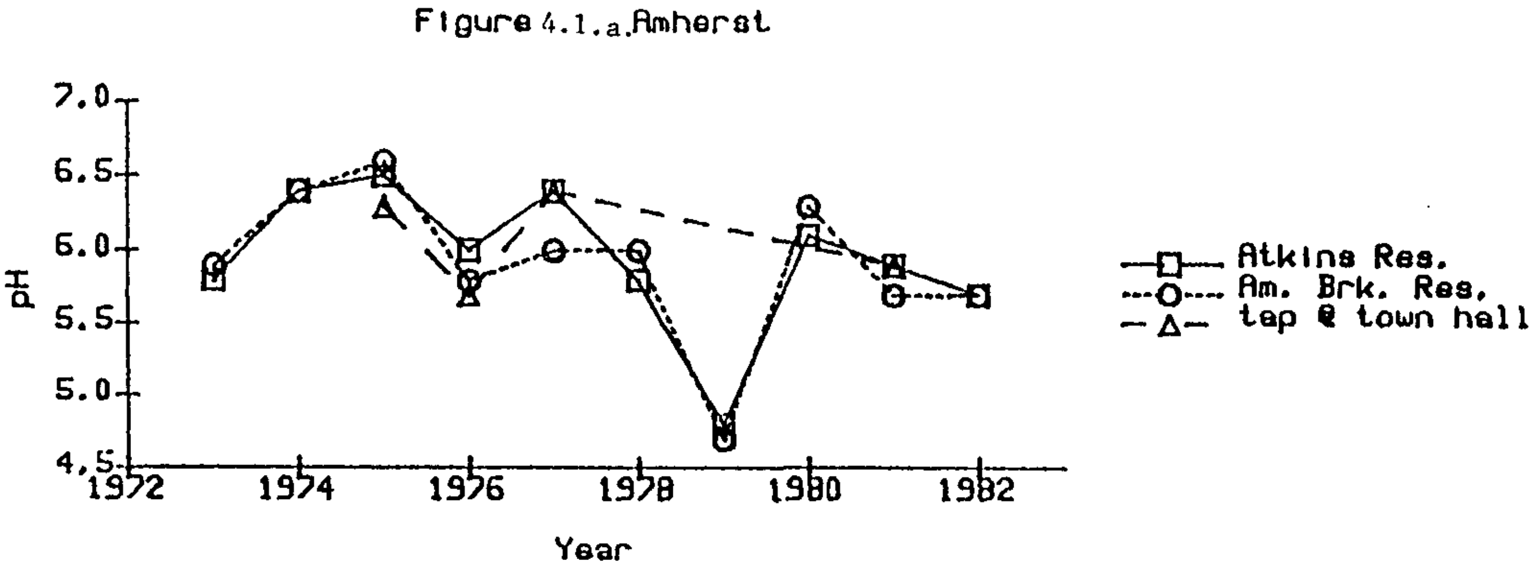


Figure 4.1. pH vs. Year for Seven Massachusetts Communities

(4.1.b-g on following 3 pages)

Figure 4.1.b.Dalton

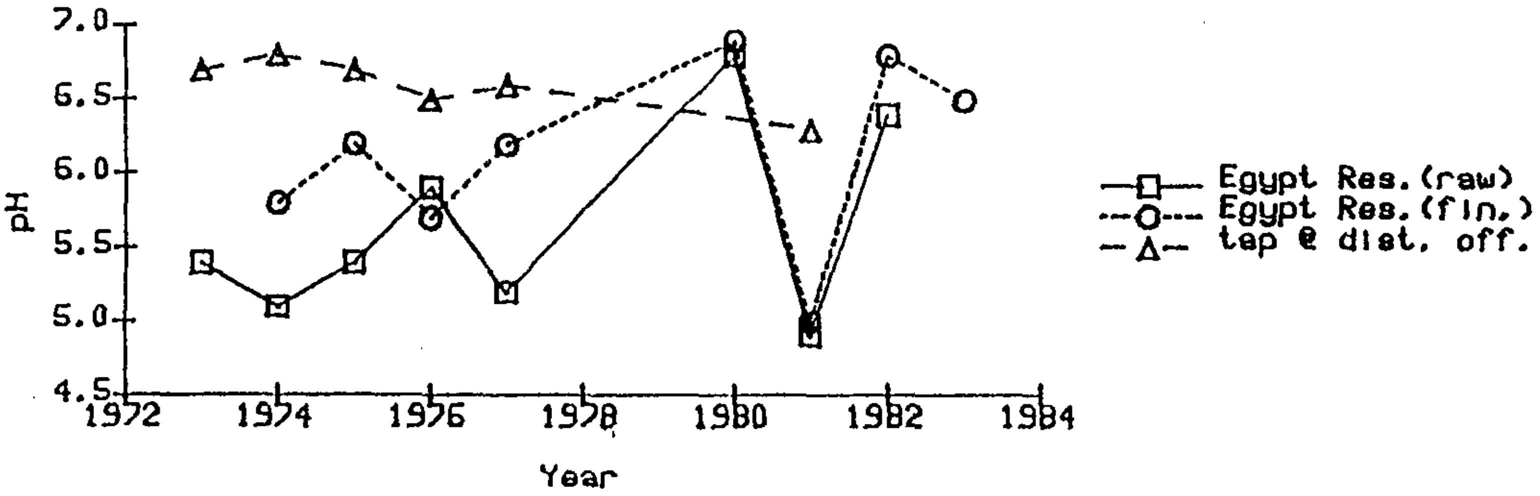


Figure 4.1.c.Fall River

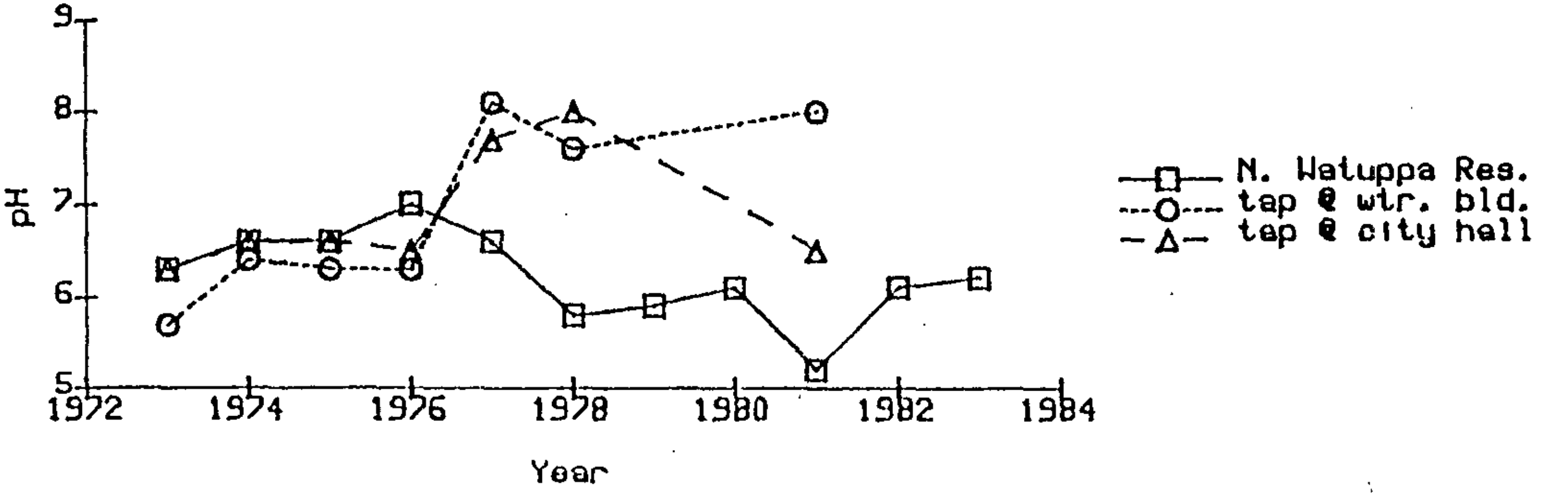


Figure 4.1.d. Fitchburg

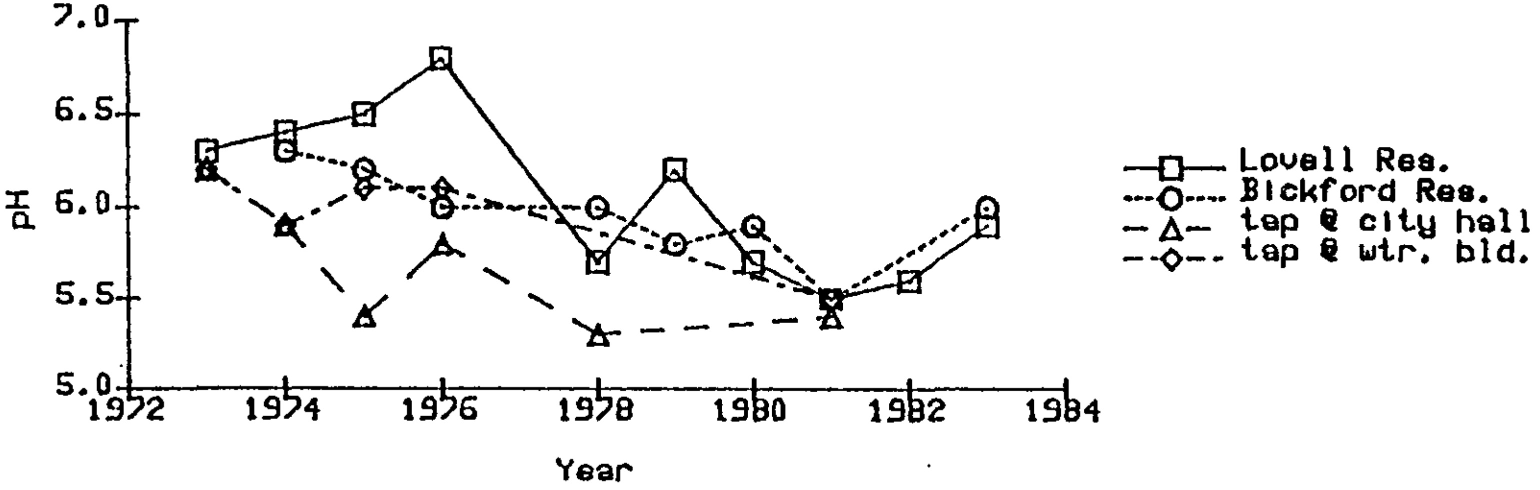


Figure 4.1.e. Gloucester

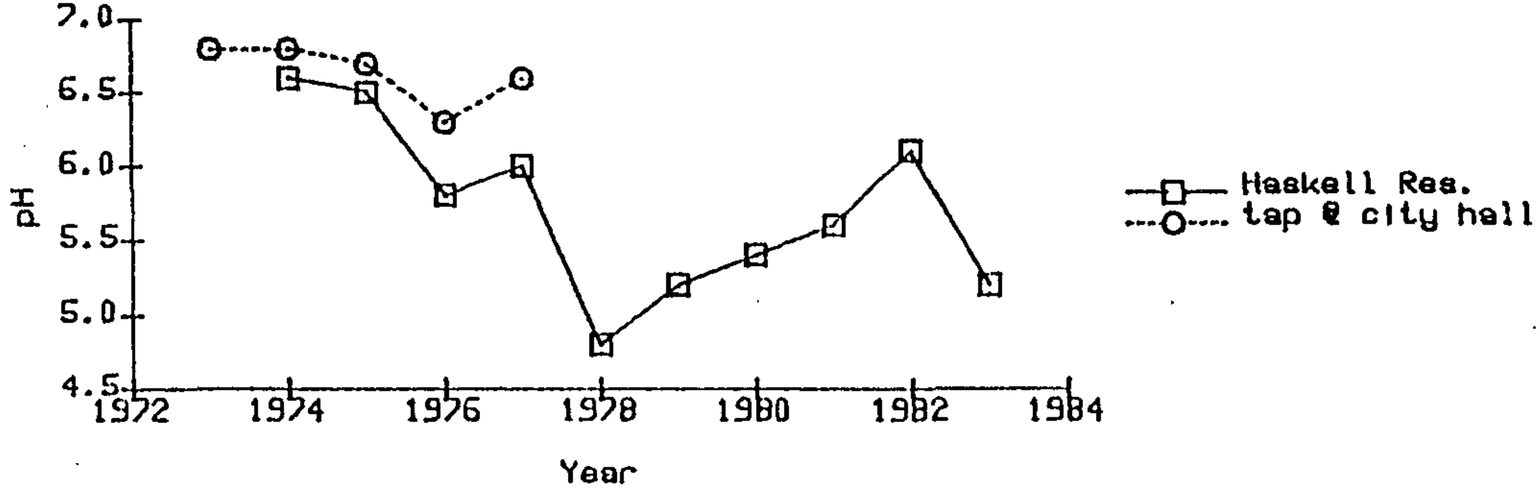


Figure 4.1.f Hinsdale

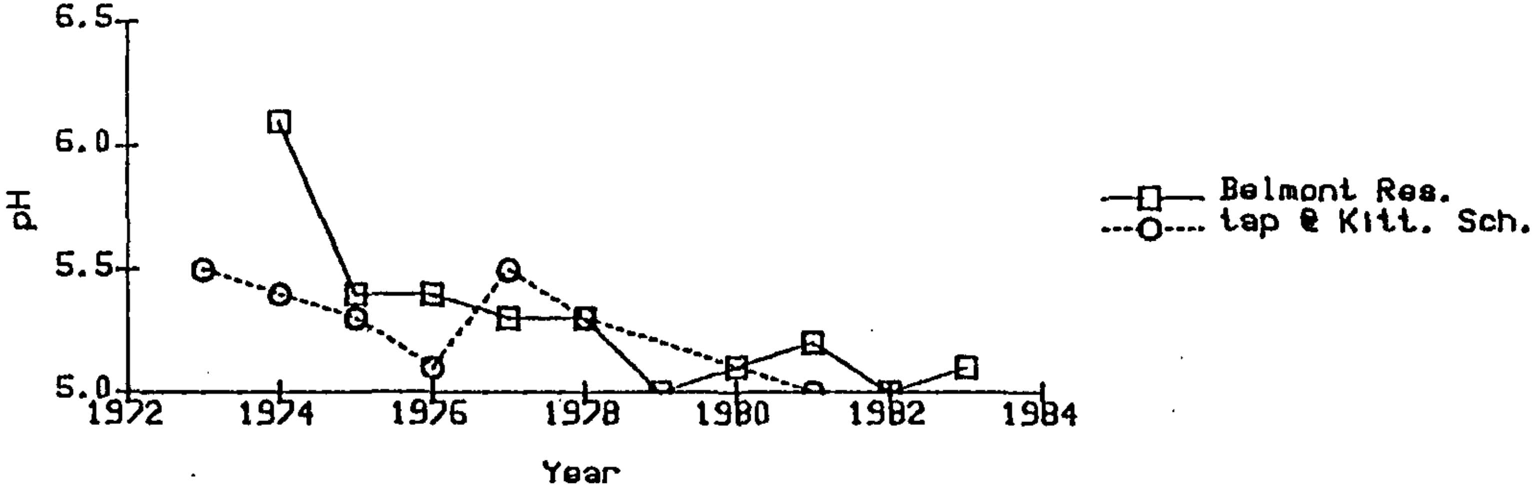


Figure 4.1.g Springfield

Figure 4.2.a Amherst

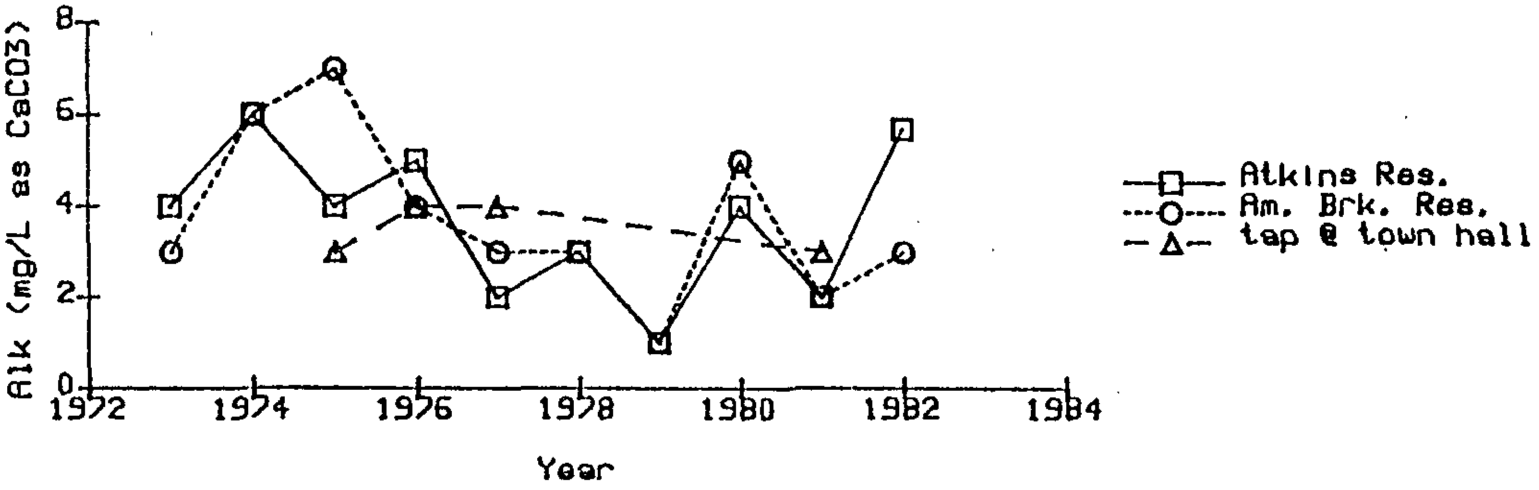


Figure 4.2. Alkalinity vs. Year for Seven Massachusetts Communities

(4.2.b-g on following 3 pages)

Figure 4.2.b.Dalton

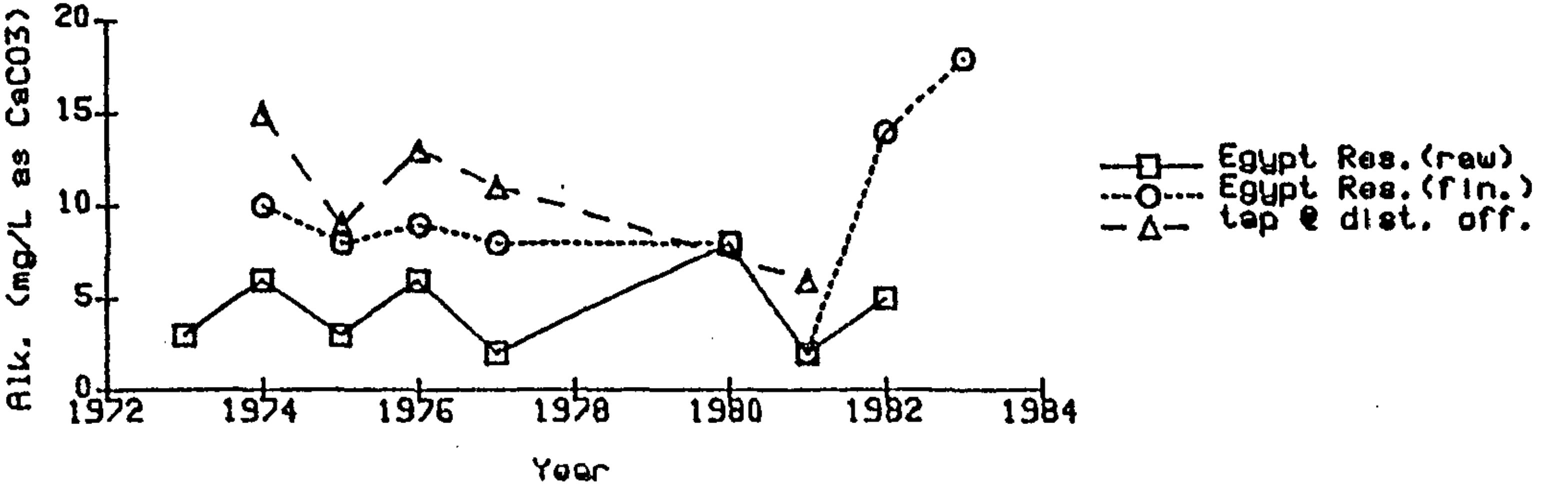


Figure 4.2.c Fall River

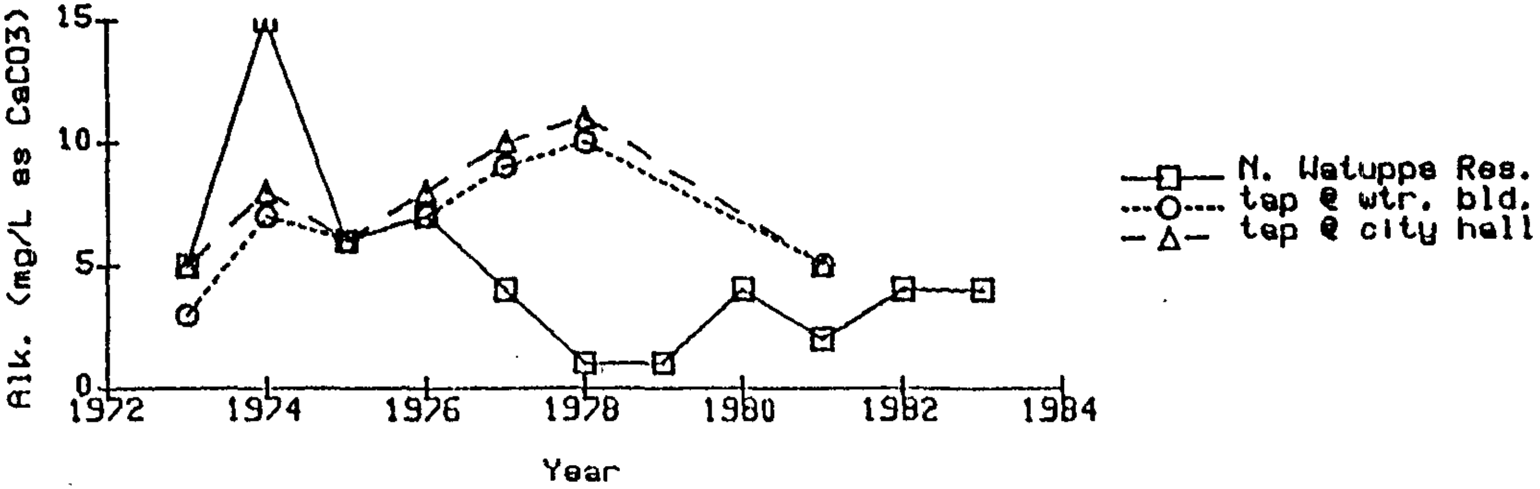


Figure 4.2.d.Fitchburg

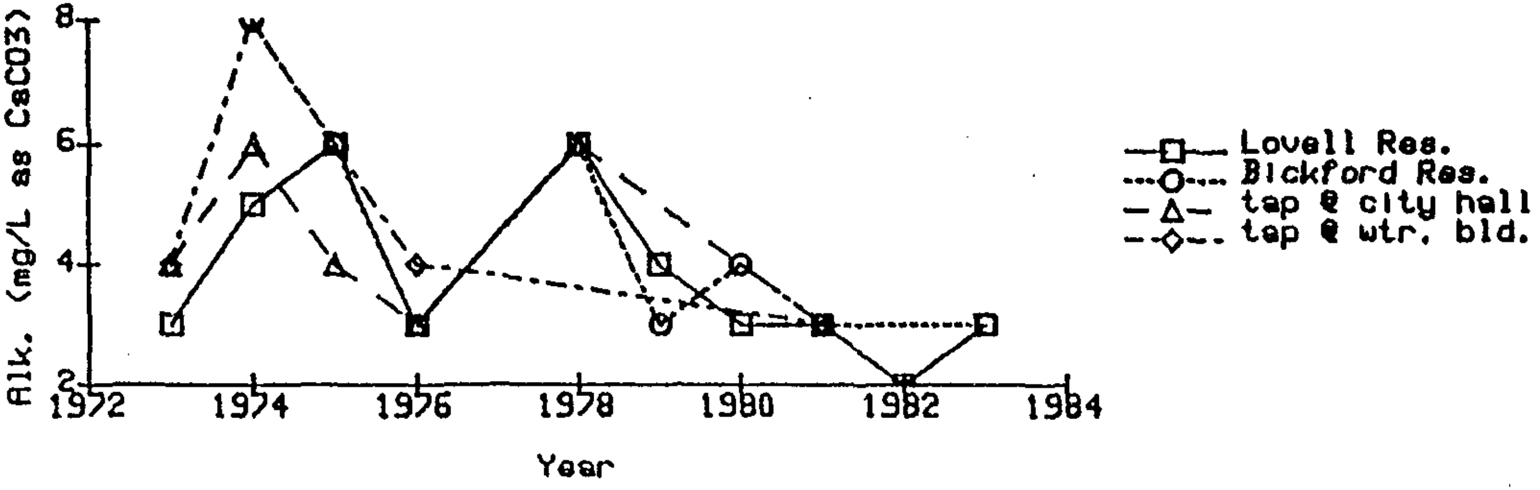


Figure4.2.e.Gloucester

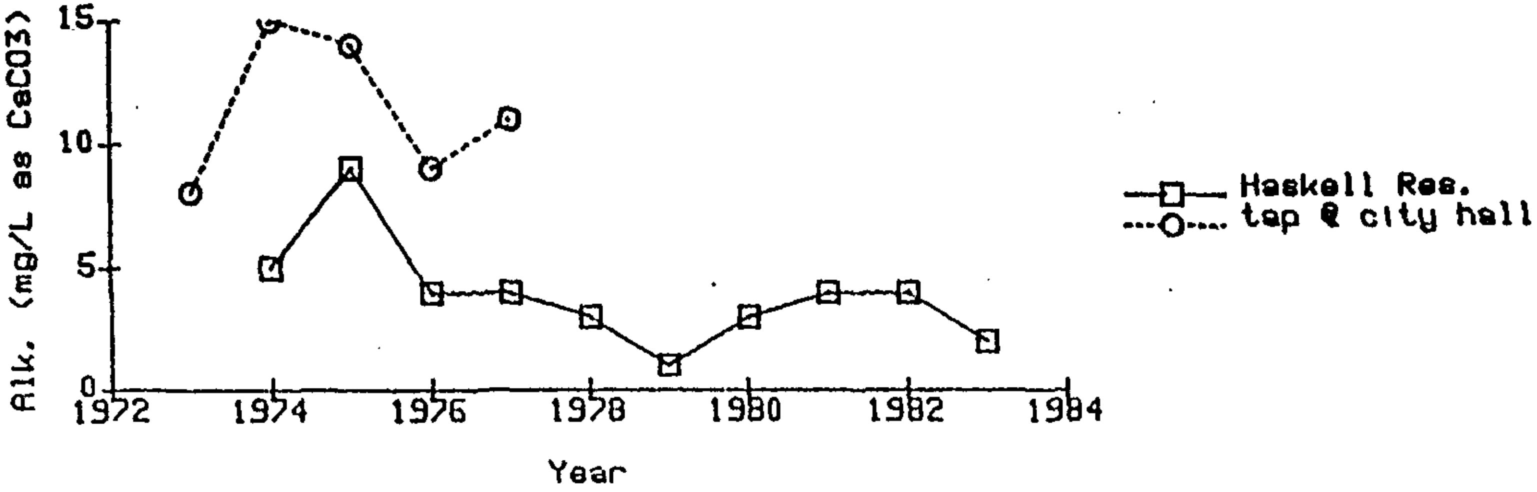


Figure 4.2.f.Hinsdale

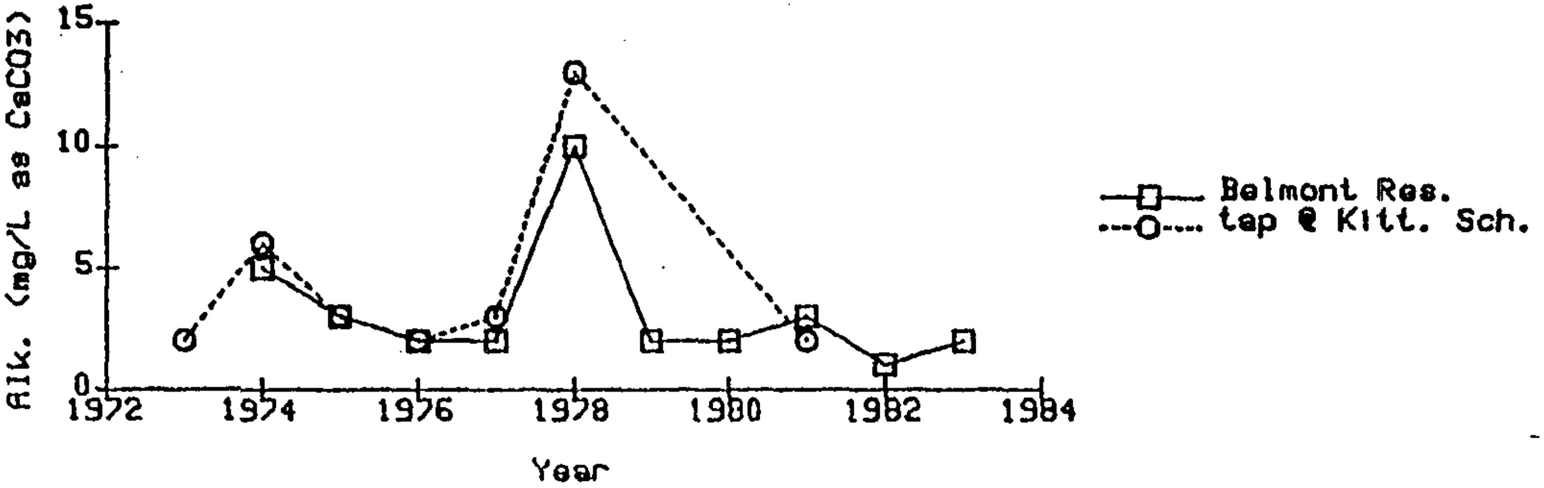


Figure 4.2.g.Springfield

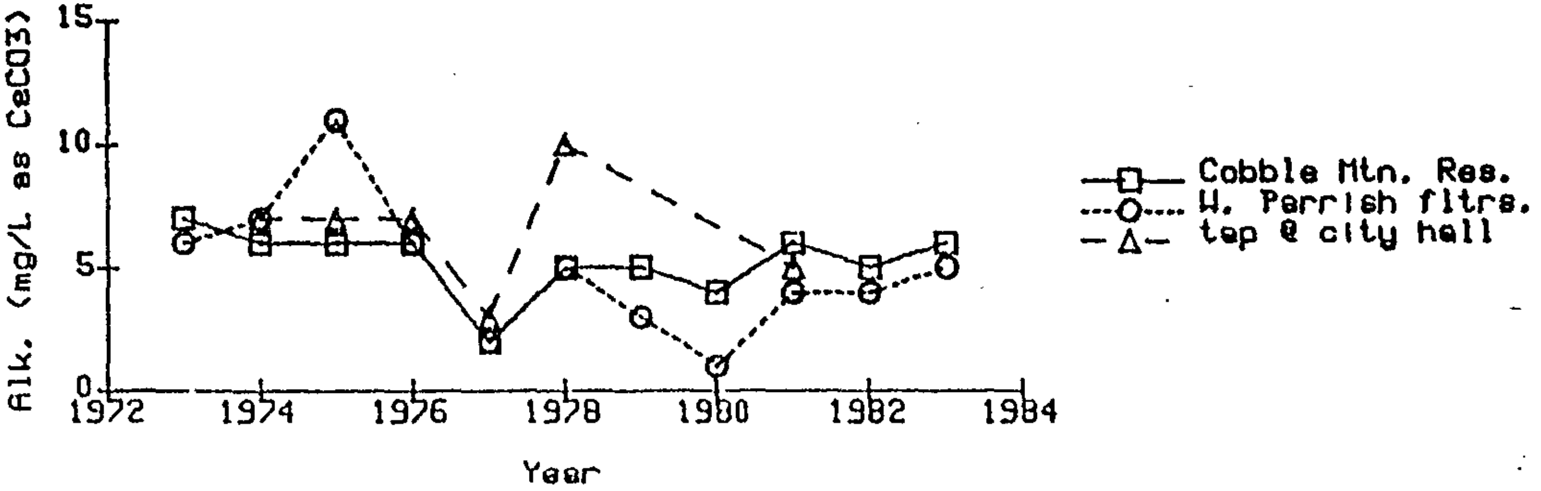


Figure 4.3a. Amherst

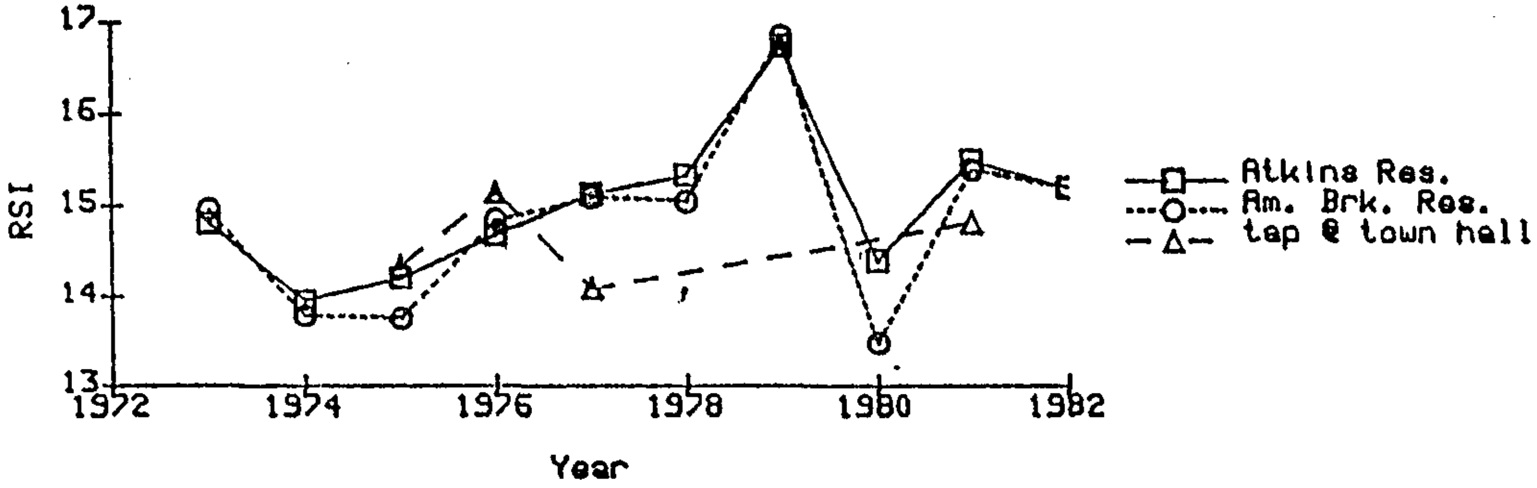


Figure 4.3. Ryznar Stability Index Values vs. Year for Seven Massachusetts Communities (4.3b-g on following 3 pages)

Figure 4.3b. Dalton

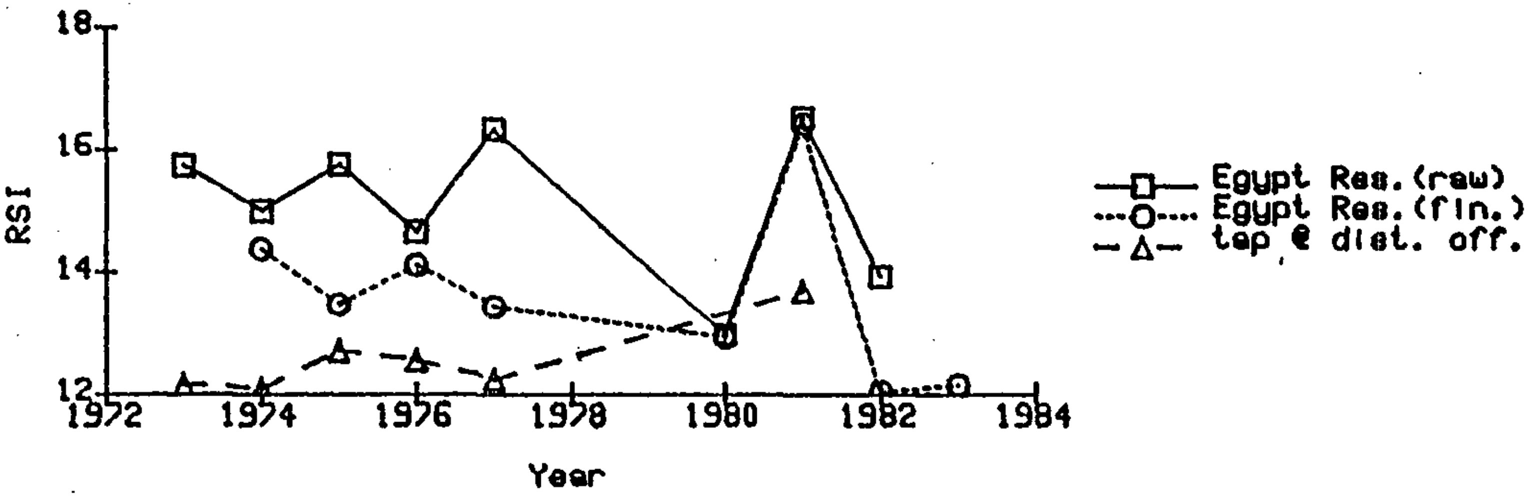


Figure 4.3c. Fall River

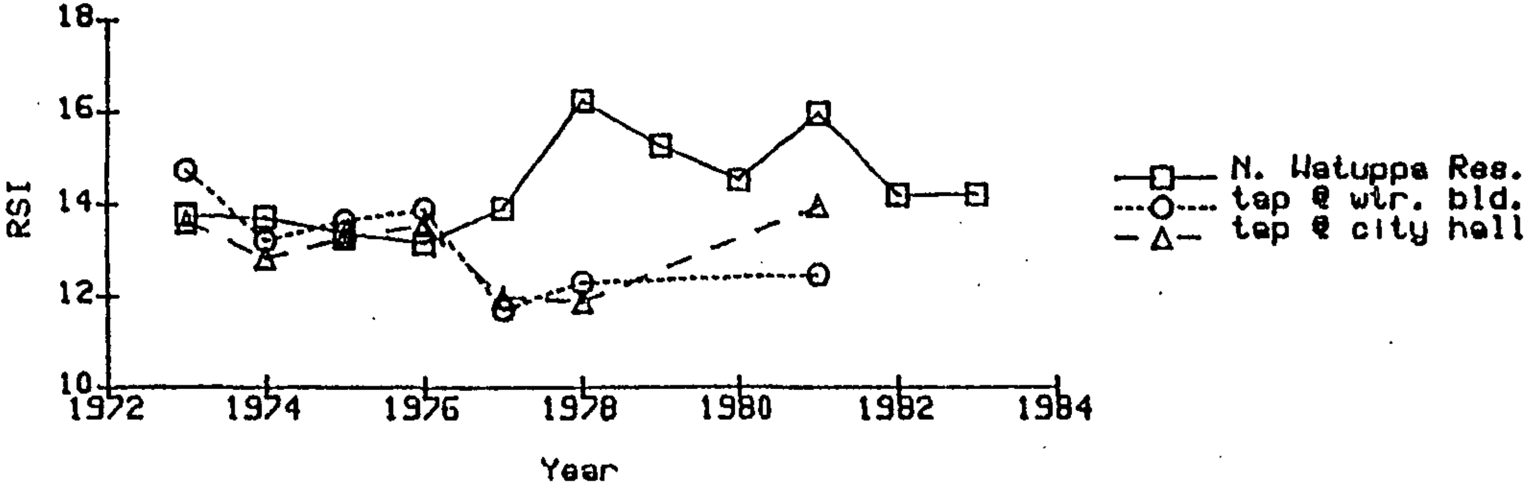


Figure 4.3d. Fitchburg

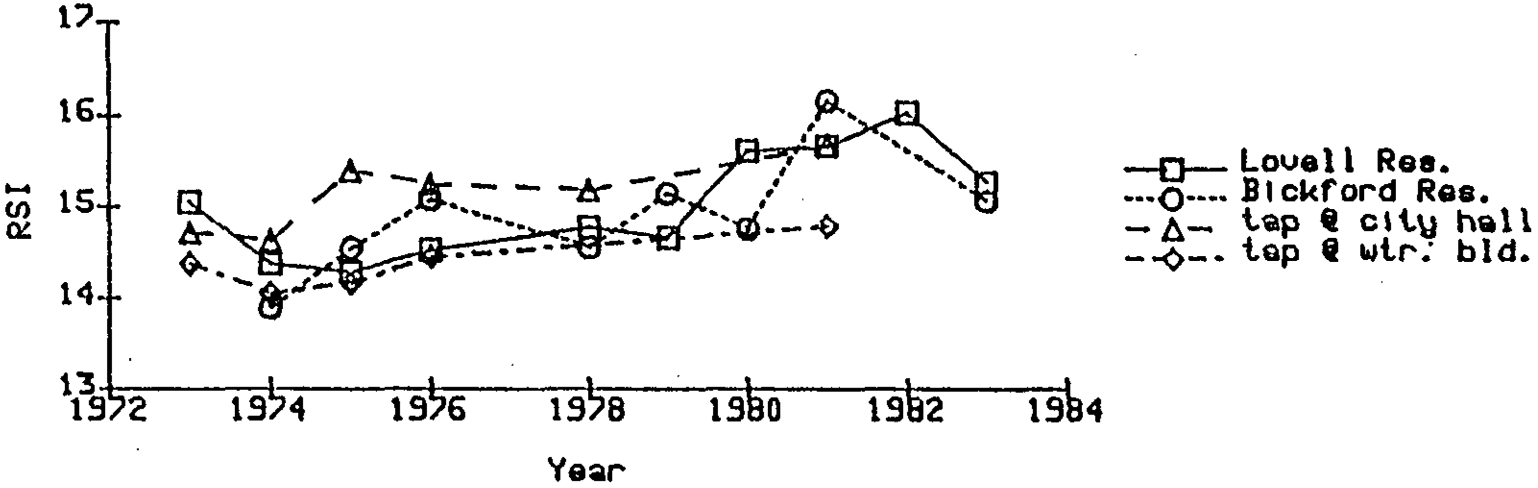


Figure 4.3e. Gloucester

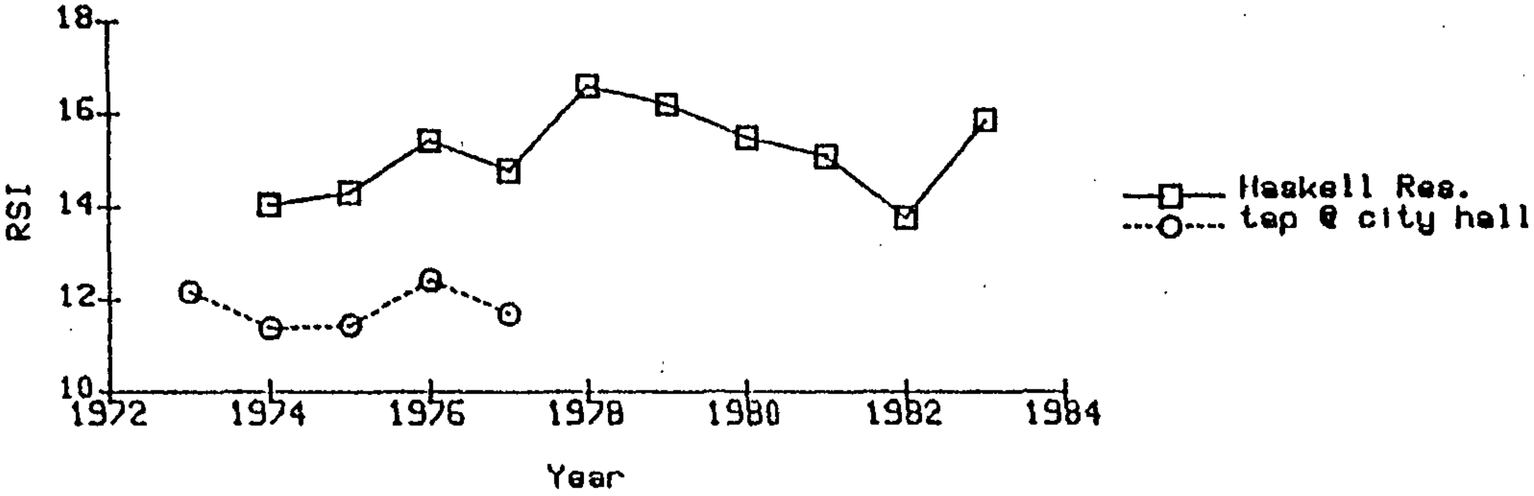


Figure 4.3f. Hinsdale

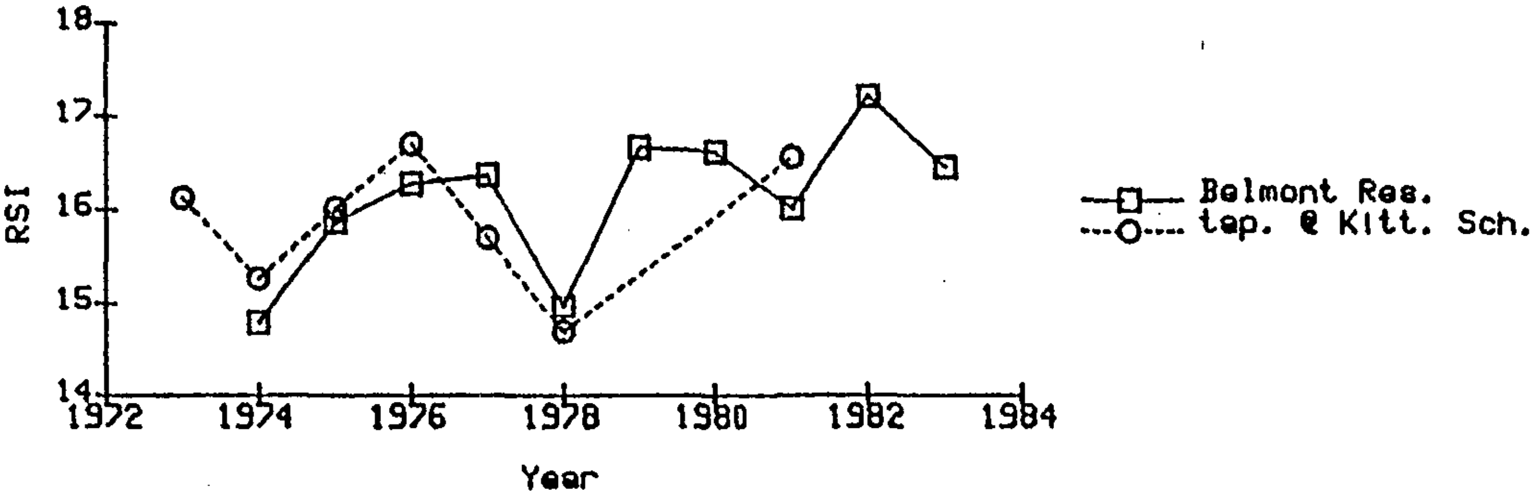
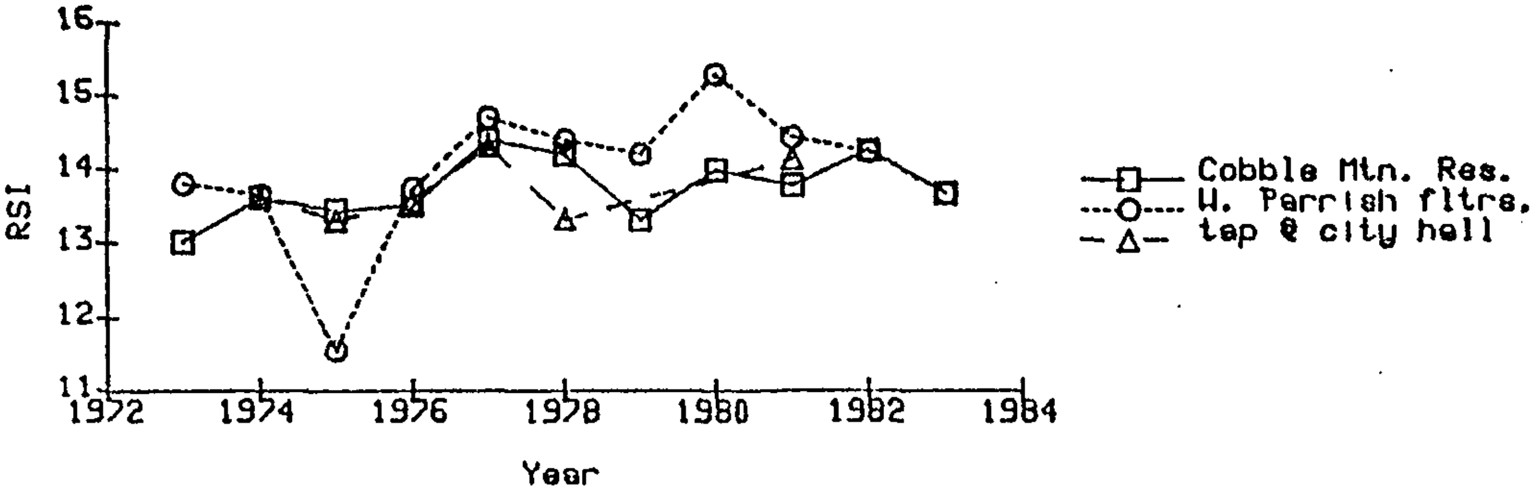


Figure 4.3g. Springfield



The tap water for both Dalton and Fitchburg increased in RSI values. The increase in RSI of the tap water in Fitchburg correlated with the increase in RSI and decrease in pH of the raw water. This is not the case for Dalton where the RSI and pH of the raw water showed no trend. Water taken from the tap in Dalton and Fitchburg increased about 1 RSI unit between 1973 and 1981. There would be added confidence in these results if more samples had been taken at the taps.

Fall River is the only municipality whose tap water appeared to be getting less corrosive which can be explained by the addition of NaOH in the mid-1970's. Water taken from the tap in Fall River decreased about 1.5 RSI units between 1973 and 1981.

RSI values for the raw and tap water in Amherst, Gloucester, and Springfield showed no upward or downward trend for the ten years of investigation.

4.2.1.4 Metals

The concentrations of copper, iron, and manganese in tap waters were compared to raw waters for the ten year period to aid identification of corrosion trends. The degree of correlation of metal concentrations with pH or RSI was also examined.

4.2.1.4.1 Copper

The average copper concentration for all raw water supplies was below 0.03 mg/l and showed little change over time (Figures 4.4a - 4.4g). This is much less than the 1.00 mg/l SMCL for copper. This low copper concentration indicates that little, if any, copper is being leached from the watershed areas.

Although all of the municipalities show some corrosion of copper, the Dalton, Fall River, and Springfield data show a decrease in copper at the tap over the ten year period. Dalton had a copper concentration at the tap of 0.46 mg/l in 1973 which dropped to 0.10 mg/l in 1981 (Figure 4.4b). Fall River went from 0.37 mg/l in 1973 to below detection in 1981 (Figure 4.4c). Springfield dropped from 0.30 mg/l in 1974 to 0.12 mg/l in 1981 (Figure 4.4g). Both Fall River and Springfield began using pH treatment with caustic soda during the ten year interval but not Dalton. No trends were seen in the remaining municipalities.

In Fall River, copper concentrations are correlated with pH and RSI - pH increases, RSI decreases, and copper decreases. In Dalton and Springfield no correlation exists. In Dalton, there is no trend in pH, increasing RSI and decreasing copper. In Springfield, there is no trend in either pH or RSI but copper decreases.

Copper concentrations in tap water were always greater than or equal to copper concentrations in the raw water, showing that corrosion was occurring to some extent in all of the building plumbing. Copper concentrations in tap water averaged approximately ten times greater than those of raw water. These results are conservative since the samples were probably not first flush, early morning samples. Further, there would be more confi-

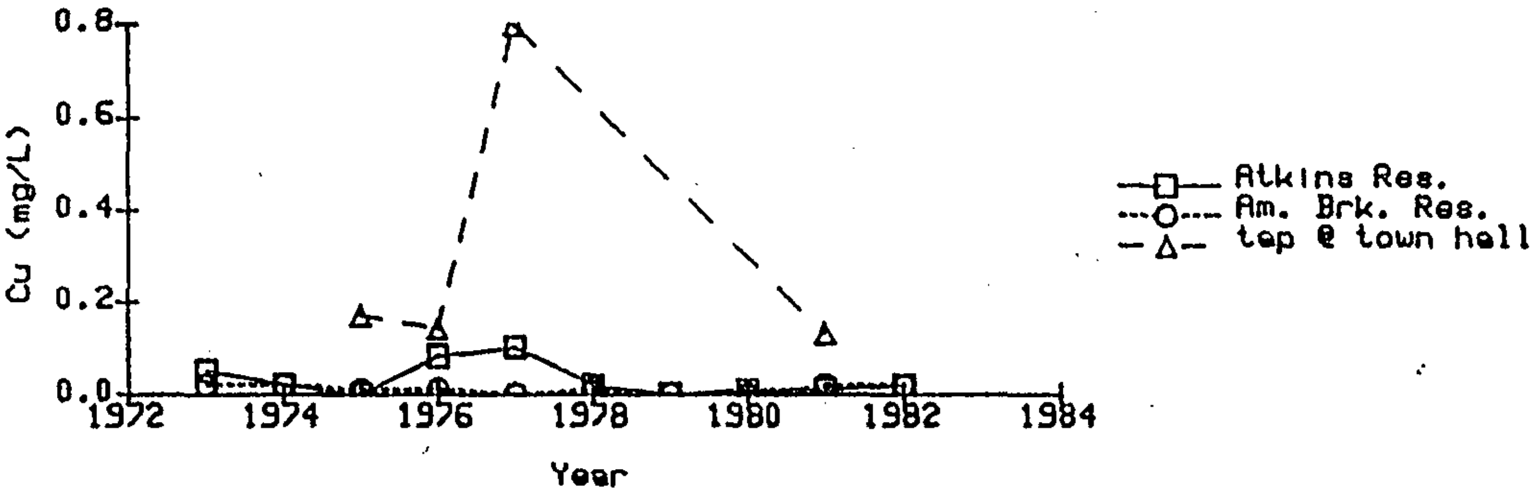


Figure 4.4a. Amherst

Figure 4.4 Copper Concentrations vs. Year for Seven Massachusetts Communities. (4.4b-g on following 3 pages)

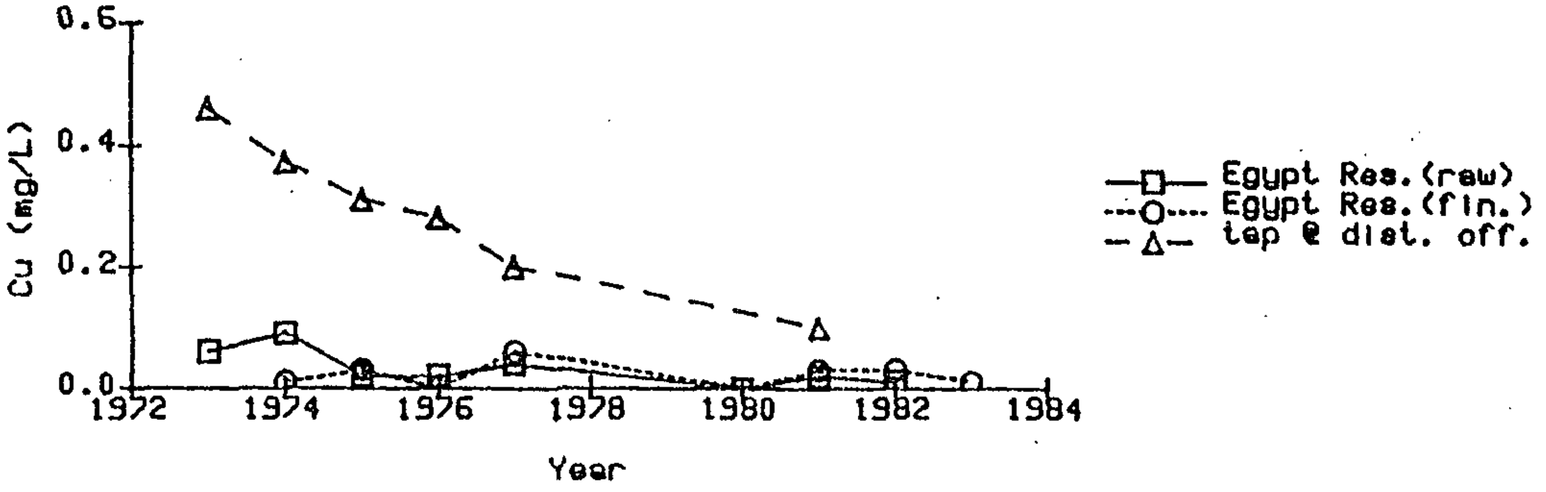


Figure 4.4b. Dalton

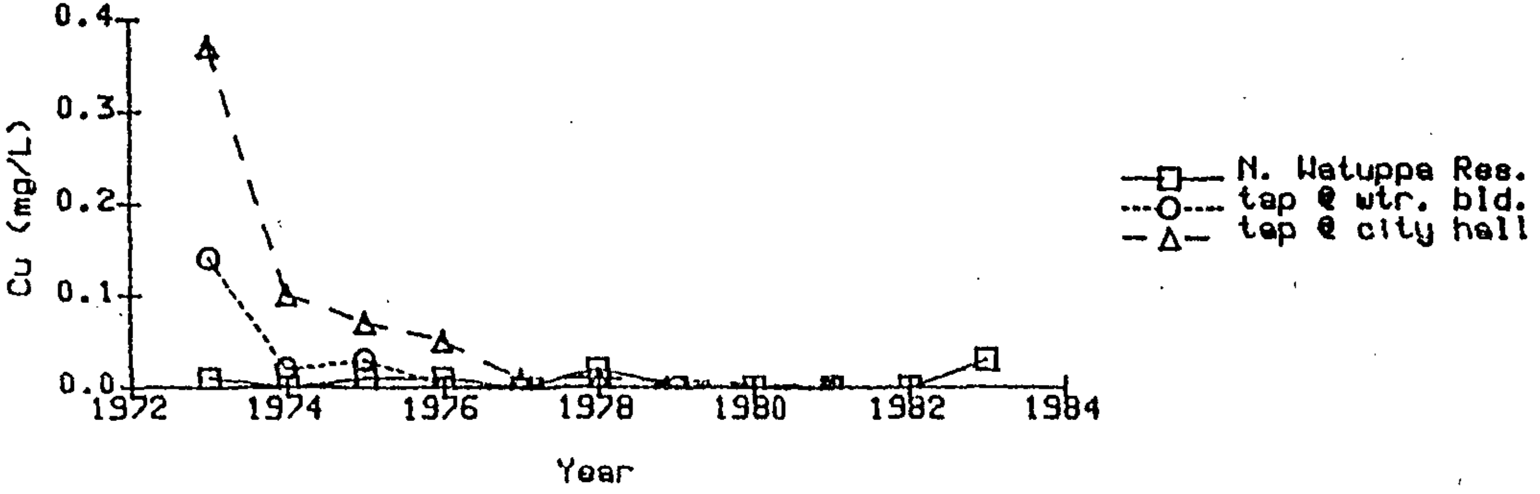


Figure 4.4c. Fall River

Figure 4.4d. Fitchburg

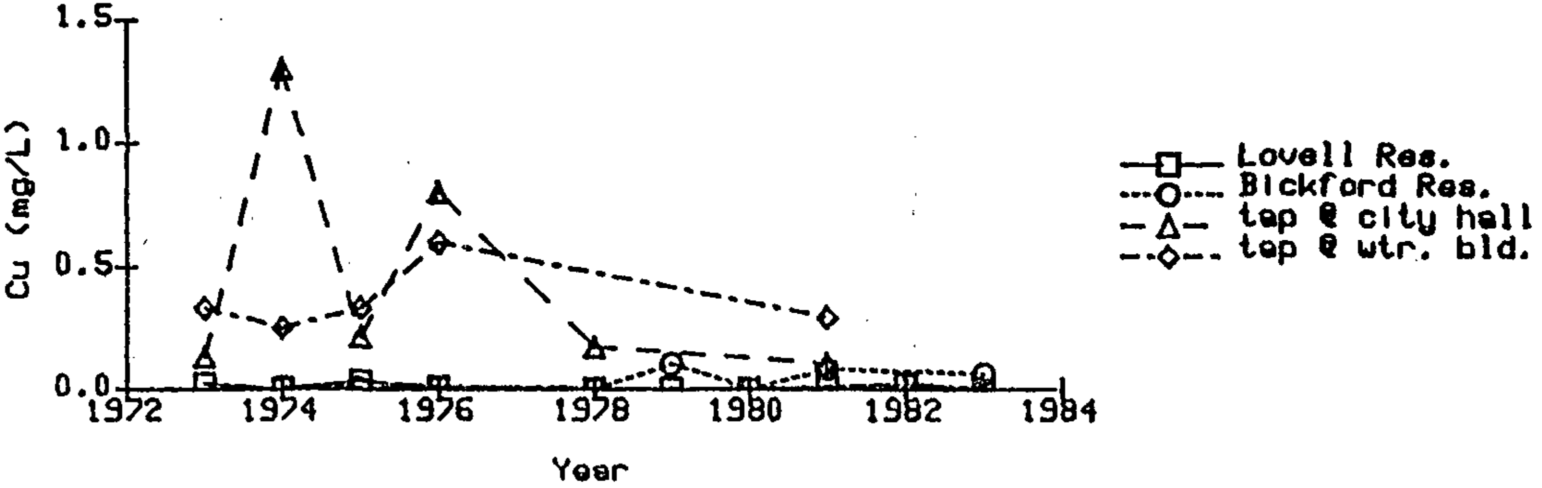


Figure 4.4e. Gloucester

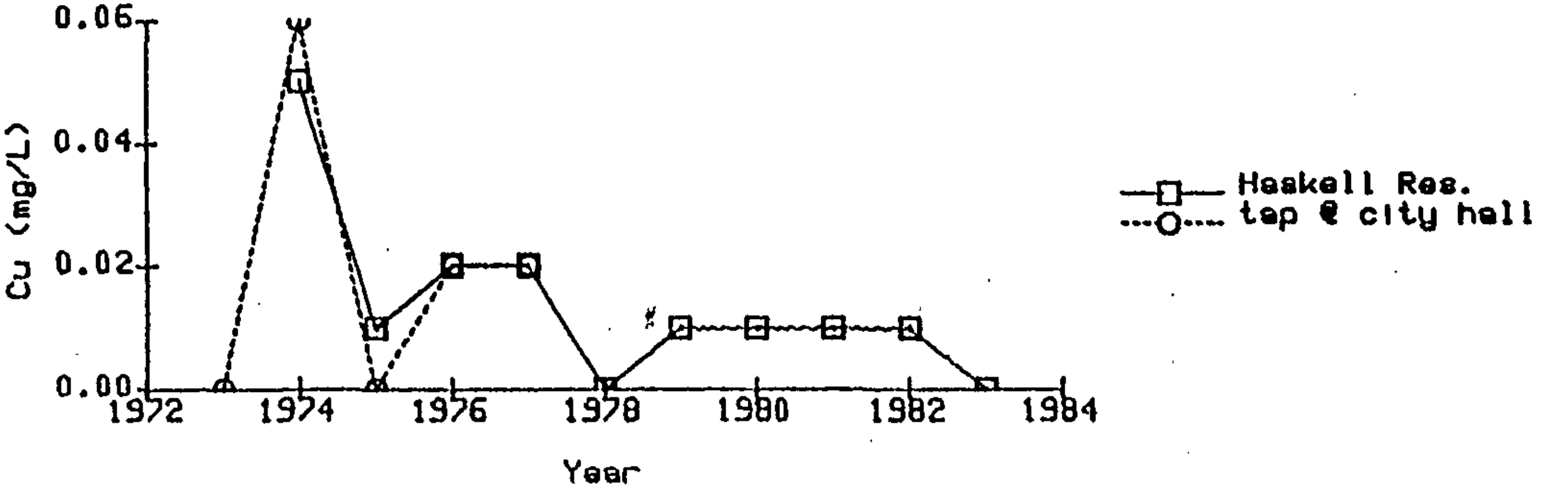


Figure 4.4f. Hinsdale

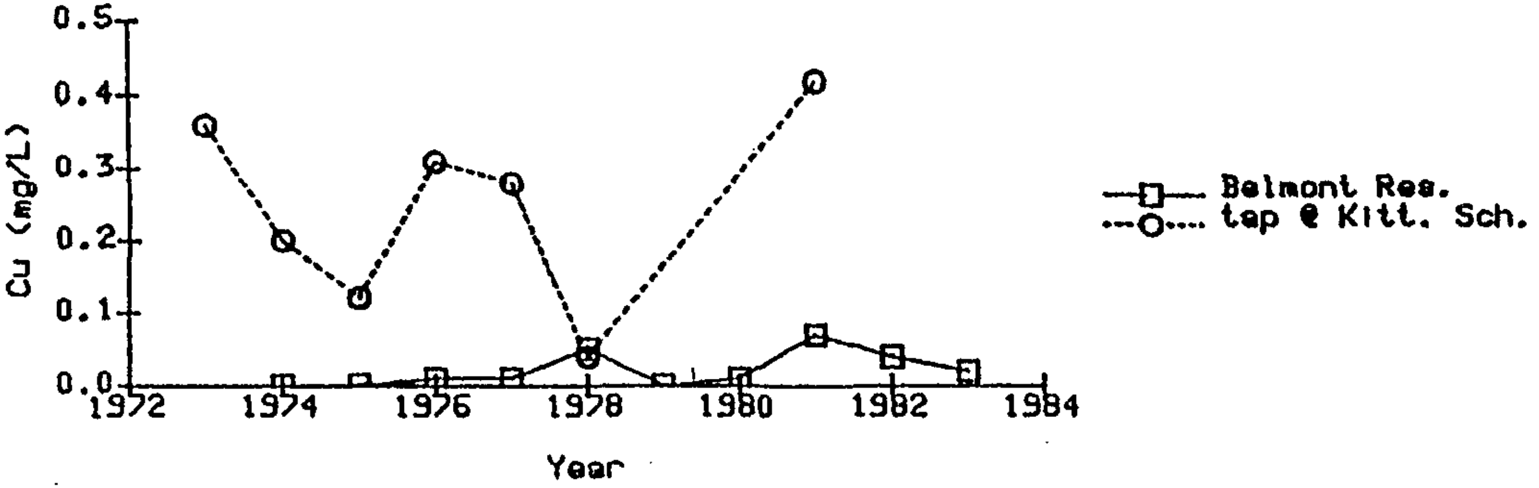
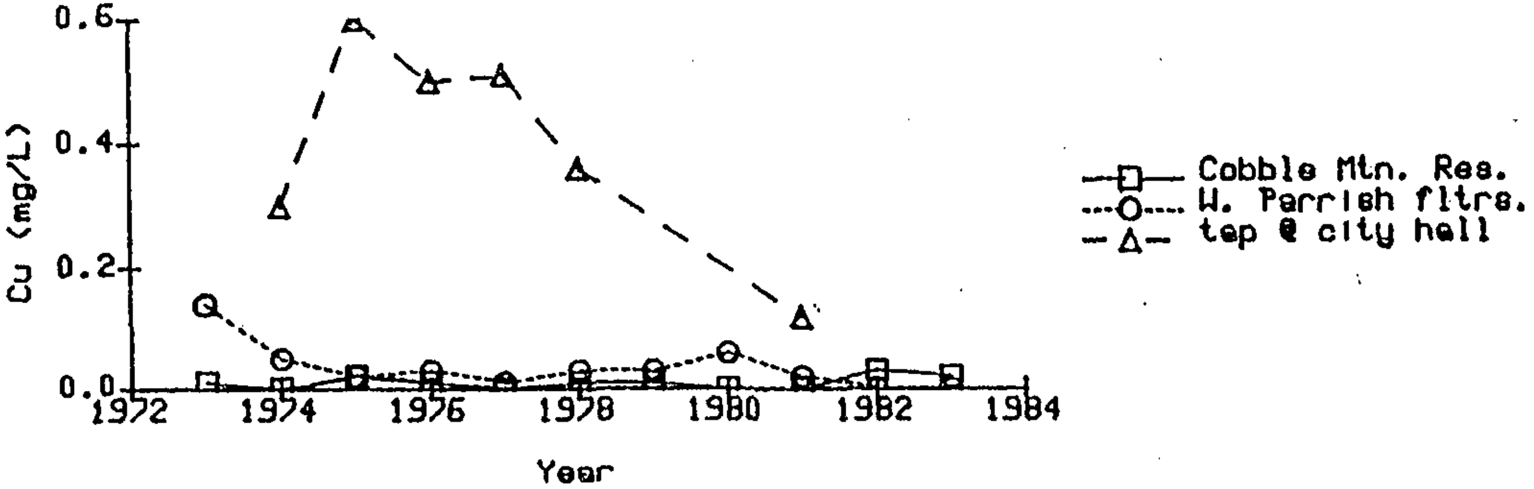


Figure 4.4g. Springfield



dence in these results if water at the tap had been analyzed every year, but nevertheless the trends are definite.

4.2.1.4.2 Iron

Amherst and Fitchburg showed higher concentrations of iron at the tap than in the raw water. Gloucester also showed higher concentrations at the tap, but tap samples were very limited. Fall River showed higher iron at the tap until 1977 after which raw water concentrations were higher. Overall, corrosion of iron is occurring in some of the distribution systems of these communities (Figures 4.5a - 4.5g). In almost every case, the iron concentration at the tap is below the SMCL of 0.30 mg/l. All of these communities have some unlined cast and ductile iron pipes. These are the likely source of iron at the tap.

Iron at the tap in Amherst showed a slight decrease over time (Figure 4.5a), although the iron concentration in raw water, pH and RSI showed no trends.

Iron decreased dramatically at the tap in Fall River between 1973 and 1981 (Figure 4.5c). In 1973, the iron concentration at the tap was about 0.30 mg/l; by 1981, it was below detection. Just as for copper, the decrease in iron correlated with an increase in pH and decrease in RSI. Along with the addition of caustic soda which started in the mid-1970's, Fall River started an on-going program of cement lining their cast and ductile iron pipes. These measures appear to be controlling corrosion of iron in the affected areas.

In Fitchburg, the iron concentration at the tap increased dramatically between 1973 and 1981 (Figure 4.5d). In 1973, the tap water at City Hall had an iron concentration of 0.28 mg/l; in 1981, it had increased to 1.20 mg/l. The increase in iron correlated with a decrease in pH and increase in the RSI. Early morning sampling performed by Taylor et al. (1984b) in Fitchburg in 1981 showed high concentrations of iron and copper in the tap water, thereby confirming our observations. At first flush, iron was 0.40 mg/l, copper was 1.45 mg/l, and lead was 0.30 mg/l. All were well in excess of drinking water standards (lead was six times the MCL).

The iron concentration at the tap in Gloucester is higher than that of raw water for 4 out of the 5 years measured, and was above the SMCL of 0.30 mg/l in 1974 (Figure 4.5e).

Dalton, Hinsdale, and Springfield had very low iron concentrations in both raw and tap waters.

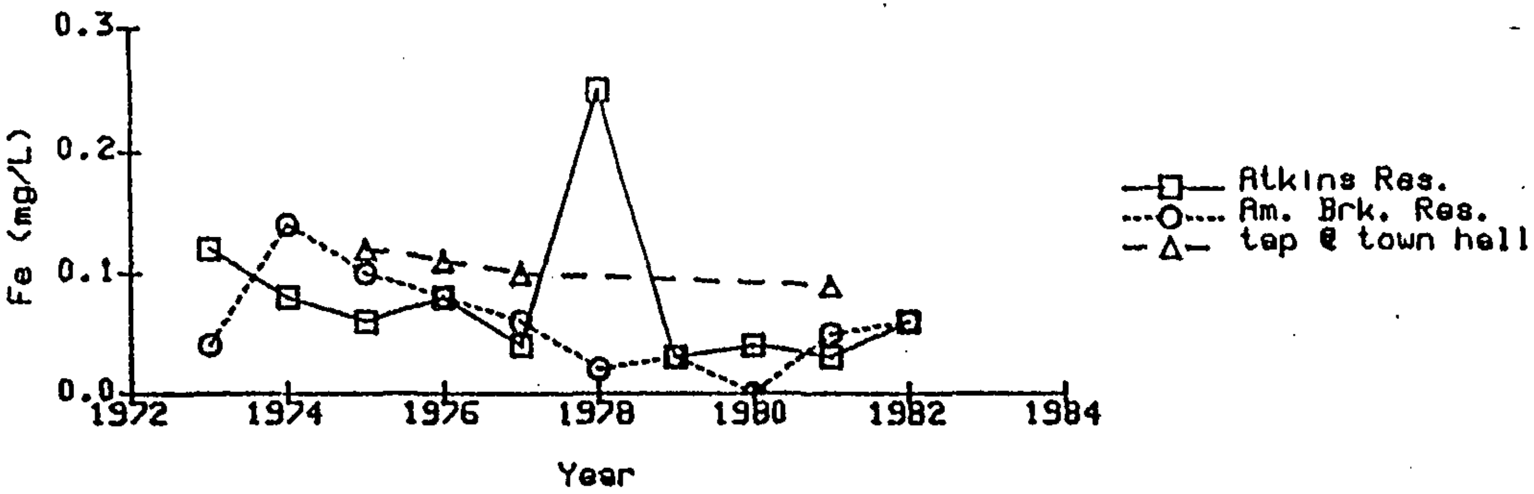


Figure 4.5a. Amherst

Figure 4.5. Iron Concentrations vs. Year for Seven Massachusetts Communities. (4.5a-g on following 3 pages)

Figure 4.5b. Dalton

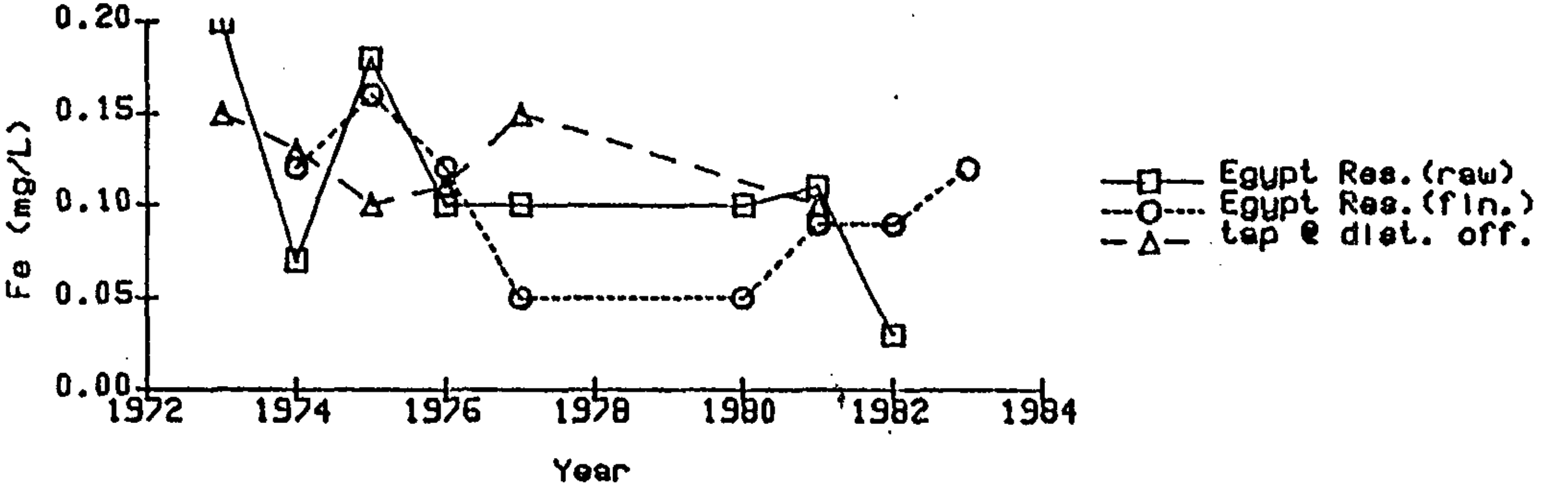


Figure 4.5c. Fall River

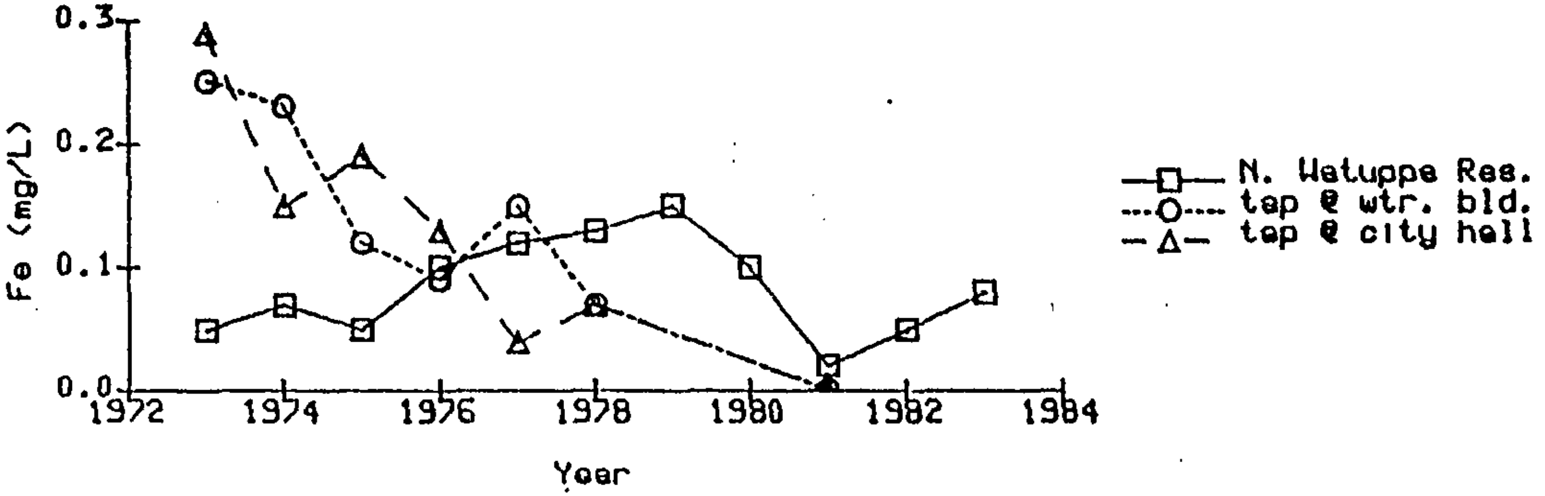


Figure 4.5d. Fitchburg

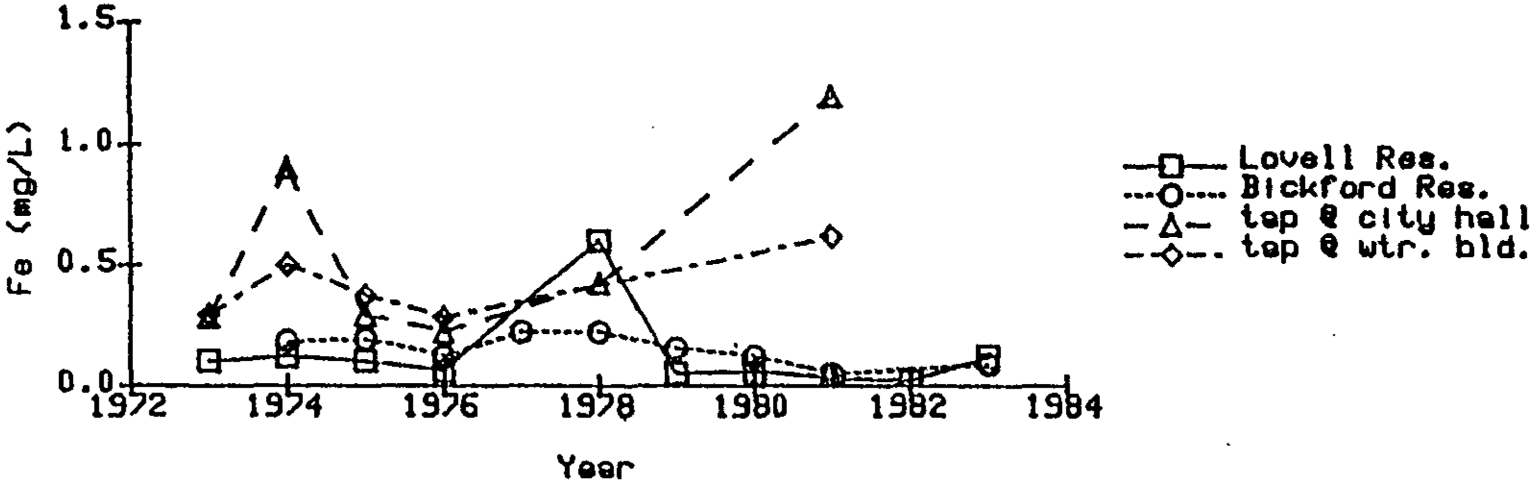


Figure 4.5e. Gloucester

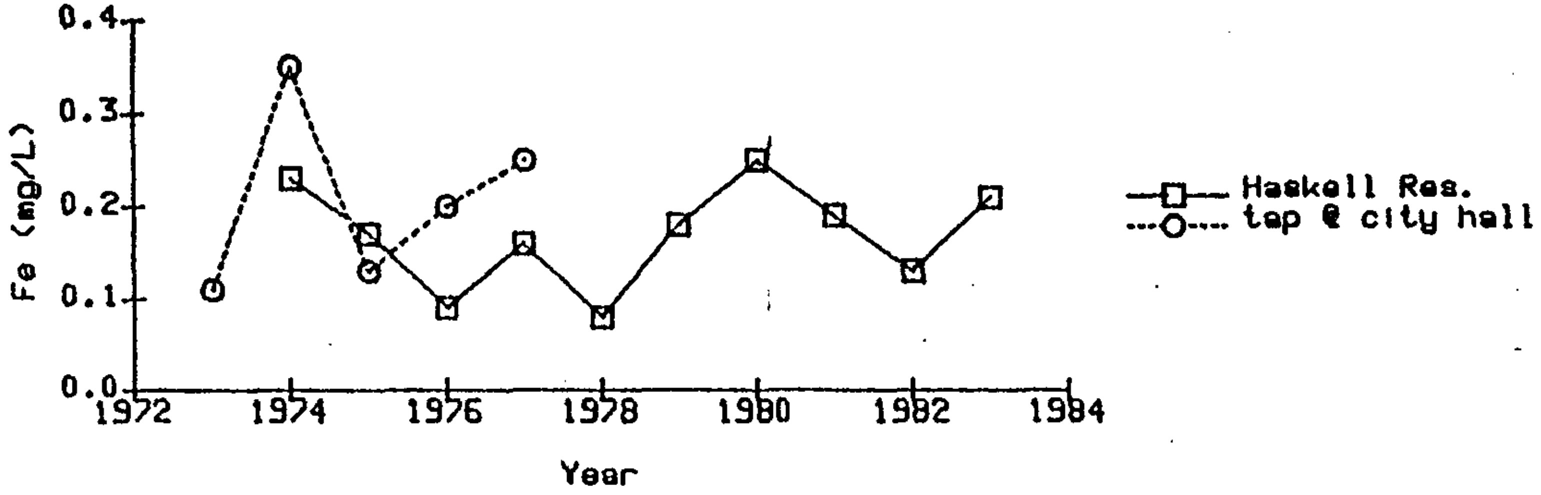


Figure 4.5f. Hinsdale

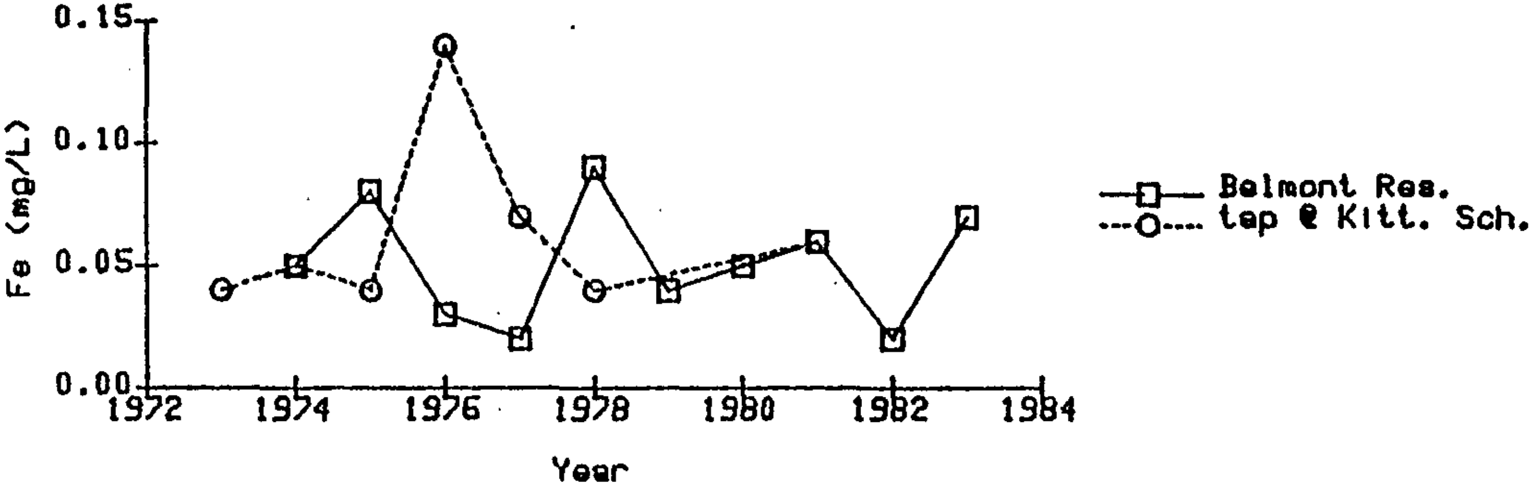
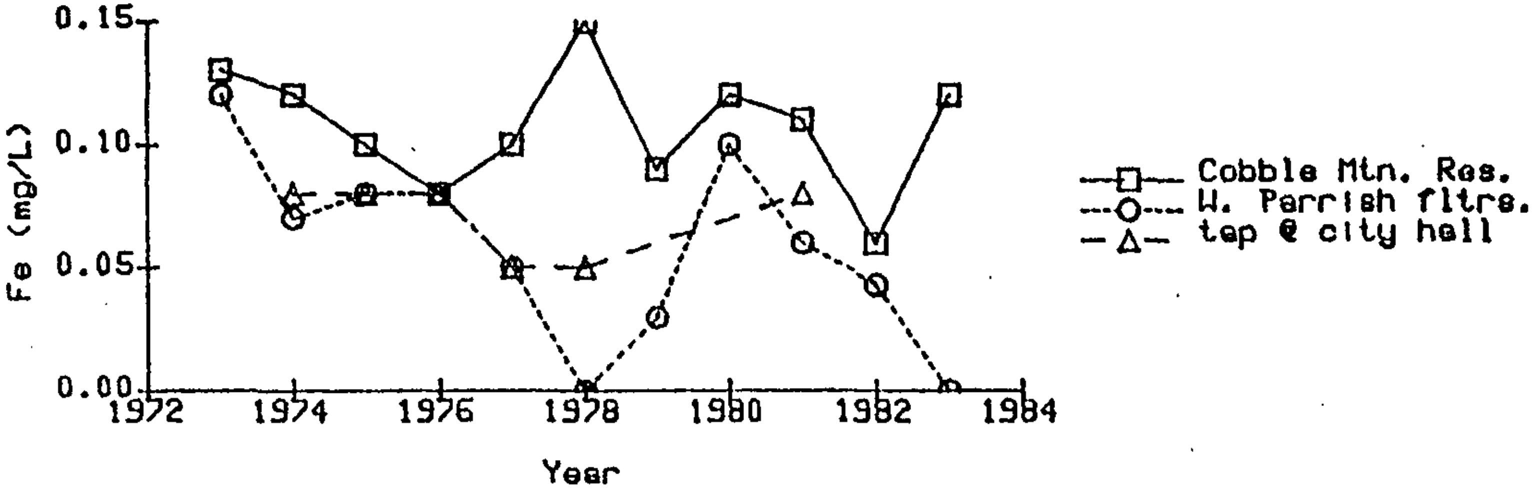


Figure 4.5g. Springfield



4.2.1.4.3 Other metals

The concentration of manganese in both the tap and raw waters were generally low for all municipalities. Only Hinsdale exceeded the SMCL of 0.05 mg/l with an average manganese concentration of 0.09 mg/l. In all cases, the manganese concentrations were higher in the raw water than the tap water, indicating that corrosion of manganese from the piping material was not occurring. Chemical species, such as lead and cadmium, were not measured until 1978. They were always below their MCL.

4.2.2 Problems with the Data

These data and their interpretation suffer from two major problems. First, only raw waters were tested every year; tap water was infrequently tested. Raw water shows strongly aggressive tendencies in most of the communities examined, but the indices alone do not provide sufficient information to determine potential corrosion or human health problems.

Second, the sampling protocol for tap samples is poorly defined, if defined at all. Typically, tap water samples are taken in midday at a municipal building. While this may characterize the water quality in the distribution system mains, it provides no information 1) on the effect of other parts of the system, particularly the building plumbing, on metal concentrations ingested during certain times of the day, 2) on the rate of corrosion in various parts of the distribution system by aggressive water, nor 3) does it indicate how representative conditions at the chosen sampling site are for the municipality as a whole. For example, the routine tap samples taken in Fitchburg in 1981 had a copper concentration of less than 0.1 mg/l at city hall and less than 0.3 mg/l at the water building (Figure 4.5d). The Taylor study found 1.45 mg/l (1.45 times the SMCL) in early morning, first flush samples. By the same token, routine tap sampling found 1.20 mg/l of iron at city hall and approximately 0.9 mg/l at the water building; Taylor found 0.40 mg/l. Lead was not tested as part of the routine monitoring, but Taylor found 0.30 mg/l in early morning, first flush samples (six times the MCL). These comparisons make it clear that Fitchburg's drinking water may have either been in substantial compliance with NIPDWR (except for iron) or vastly out of compliance. Existing monitoring programs are not adequate to determine which is true. Recommendations for improvements to the existing monitoring system are given in Section 6.0.

5.0 STUDY DESIGN

5.1 OBJECTIVES

The survey design must meet the following objectives:

1) It must provide a representative picture of the impact of acidified water on the corrosion of distribution systems and potential health impacts.

2) It must permit analysis of the individual contributions of raw water quality, treatment, distribution system type, and household plumbing type to water quality at the tap.

3) It must allow for historical comparisons that can reveal long term trends.

4) It must provide appropriate data for the development of models that relate water quality at the tap with raw water quality and composition of distribution system.

5) It must provide appropriate data to assist development of estimates of populations at risk from acid deposition-related contaminants in drinking water.

5.2 DESIGN CONSIDERATIONS

The design is constrained by available funding which will determine the number of sites that can be surveyed, the number of samples to be chemically analyzed, the method of sample collection, and the extent of development of complementary data bases needed for correlation with acid deposition. Since the funding limits are not known, wherever possible the design will provide several options varying in cost and benefit. The design further assumes that the tasks of historical analysis, corrosion modeling and assessing populations at risk will not be conducted as part of the project but as independent research efforts reliant on the data base established by this design.

Objectives 1 and 2 each establish different survey design requirements which must be compatible in order to achieve the overall survey goals. For objective 2, the survey must adequately describe the effect of acid water on various parts of the possible delivery system that result in changes in drinking water quality. Each of the factors affecting drinking water quality must be adequately surveyed regardless of its commonness or rarity in the state. Conversely, Objective 1 requires knowledge of the relative frequency of occurrence of each unique characteristic in the state.

Similar surveys often have skipped the tasks under one or the other objectives because (1) existing information provided a reasonable framework, (2) no attempt was made to establish cause and effect, or (3) area-wide representativeness was not a goal. In this case, the existing data bases will provide only a portion of the needed information, i.e., the number of households with certain combinations of supplies, distribution materials, etc. Since the establishment of cause and effect and representativeness are primary objectives, additional care in the survey design is warranted and additional sampling effort will be required.

Before describing the recommended approach, it is worthwhile describing a similar effort nationwide, the National Statistical Assessment (NSA) of Rural Water Conditions (Francis et al., 1984). That survey had the following objectives stated in the Safe Drinking Water Act of 1974:

> Sec. 3(a). The Administrator of the Environmental Protection Agency shall (after consultation with the Secretary of Agriculture and the several States) enter into arrangements with public or private entities as may be appropriate to conduct a survey of the quantity, quality and availability of rural drinking water supplies. Such survey shall include, but not be limited to, the consideration of the number of residents in each rural area --
>
> (1) presently being inadequately served by a public or private drinking water supply system, or by an individual home drinking water supply system;
>
> (2) presently having limited or otherwise inadequate access to drinking water;
>
> (3) who, due to the absence or inadequacy of a drinking water supply system, are exposed to an increased health hazard; and
>
> (4) who have experienced incidents of chronic or acute illness, which may be attributed to the absence or inadequacy of a drinking water supply system.
>
> -- P.L. 93-523
> December 16, 1974

The NSA survey was specifically designed to describe rural water supplies in terms of specific water quality constituents but not to explain why those were present in particular supplies. As the authors of the NSA report state:

> to conduct such an analysis would require geologic and hydrologic information - for instance, information from quality testing of aquifers, surface sources, and test wells situated at different depths. Also required would be information about the construction of wells, springs, cisterns, and so forth; the age and condition of household plumbing; and the presence of such things as galvanized piping from the pump to the household. Water would have to be sampled at various points along the distribution line and even at various points within a house. For the most part, this kind of information was not gathered in the NSA.

The approach used in the NSA was a stratified random design. The country was subdivided into four census regions. Using 1970 census data, 2779 census enumeration districts within 400 selected counties were chosen.

Then smaller sampling districts called "chunks" were chosen within the districts. Finally, an average of 1.2 regularly occupied households in each chunk was randomly selected. Each of the last three selections was based on use of a systematic probability sampling design proportionate to the size of the community. The total household sampling size was 2,654, chosen to represent 22 million rural dwelling units.

This task is analogous to objective 1 in the present study. Objective 2 requires the detailed information that the NSA study did not gather, and it requires a level of detail about relatively rare combinations of these supply-distribution system characteristics that can only be derived from adequate sampling of these combinations. A strictly random selection or stratified random selection process designed to find rare combinations will either be very costly or likely to miss most rare combinations.

An example will help to clarify the difference between the requirements of each objective. In order to characterize the contribution of lead versus copper pipe to the drinking water quality at the household tap for acidified source waters, a survey would need to devote approximately equal attention to documenting the changes in water quality for each plumbing type. However, knowledge of the degree of effect of lead versus copper would not permit extrapolation to specify how many households are potentially affected unless the number of households in the state with those characteristics is known. To meet objective 2, equal effort for all possible combinations of the important characteristics will provide the most efficient sampling design; to meet objective 1, a random or stratified random sampling approach is needed to give realistic "weights" to the importance of each unique combination of characteristics. Since these requirements are much more demanding than those guiding the NSA survey, special effort will have to be made to efficiently design an appropriate survey for Massachusetts of the drinking water quality and its causes.

Since objective 2 is the more specific of the two and requires the most intensive effort, that design will be focused on first with later examination of whether the results of that design can also meet the needs of objective 1. For example, first the impact of lead household plumbing on water quality (objective 2) is determined, followed by determination of how many people in the state are subject to that condition (objective 1). The latter information is readily amenable to evaluation of populations at risk because both the degree of impact (the body load per capita) and the population exposed are known. Furthermore, the design creates the necessary background information for additional studies that might address the issues of corrosion modeling and historical trends.

5.3 DESIGN OF SURVEY

Since the NSA survey found that 43.8% of the rural population in the northeast used community water systems and 46.7% used wells, only these have been considered in the study design and not the remaining 9.5% using springs, surface water, cisterns, hauled, or bottled water. The percentage using other water sources will be even smaller in the present survey because urban - suburban populations will be included and they are more likely to be using community water systems.

The literature review has revealed the major factors in the delivery of potable water from either community systems or private wells to the household tap that require investigation. They are:

1) type and nature of source (surface water or groundwater, dug and drilled well)
2) water quality at the source
3) existence of pH treatment in the system
4) distribution system materials
5) plumbing system materials

For community supplies, the first three are known or can be determined relatively easily by reference to the files of DEQE or by a quick survey of water supply managers. They are not known for private supplies. Distribution system materials are known only in a general way for each town. DEQE maintains files documenting the types of distribution materials used in each town, but this does not provide the needed resolution to determine the distribution material in the flow path to a particular household. The range of plumbing materials that might be expected is also known, but the relative occurrence of these in the Commonwealth and the specific households with each type are not known. The well depth for public groundwater supplies is known (all would be considered deep wells). Although well depth is also "known" for private supplies, it is not available in usable form (contained only in uncomputerized files of DEQE and town Boards of Health).

Although little is known about the private supplies in the Commonwealth, the task of collecting the necessary information is simplified because the systems themselves are relatively simple. Unlike public supplies, where the water to a home might come from several sources, the private supply can come only from that home's well. Describing the nature of the source water quality is, therefore, a straightforward task. By the same token, the public distribution system may contain many different piping materials in different relative proportions with varying distances from source to household, different flow rates, and different ages; the private supply has a short distribution system with a limited number of pipe materials, relatively similar flow rates, and ages that should be correlated with the age of the house. In public supplies, a variety of treatments may be used, most not intended for pH adjustment and possibly compounding the problem (e.g., chlorination lowers pH); for private supplies treatment is unlikely but easily noted.

As a starting point, the review of the literature suggested that each of the above factors should be divided into several characteristics (Table 5.1) for the purposes of insuring that each will receive appropriate attention in the survey.

Table 5.1. Table of system characteristics.

PUBLIC SUPPLIES	
Source	1. surface water
	2. groundwater
Raw water supply	1. pH < 5.0
	2. 5.0 < pH < 5.75
	3. 5.75 < pH < 6.5
	4. pH > 6.5
Treatment	1. pH adjustment
	2. no pH adjustment
Distribution system	1. unlined ferrous metals
	2. cement-lined
	3. asbestos-cement
	4. plastic-lined asbestos cement
Household system	1. copper
	2. iron
	3. plastic
	4. galvanized
	5. lead
PRIVATE SUPPLIES	
Estimated pH*	1. pH < 5.0
	2. 5.0 < pH < 5.75
	3. 5.75 < pH < 6.5
	4. pH > 6.5
Depth of well	1. shallow uncased (dug) well
	2. deep cased (drilled) well
Household system	1. copper
	2. iron
	3. plastic
	4. galvanized
	5. lead

---

* estimated from Acid Rain Monitoring Project data

PH treatment will be considered an optional aspect of this study since previous work by Karalekas et al. (1983) has shown that maintaining the pH above 8.0 will maintain levels of metals below the MCLs. However, even in treated systems, metal levels can exceed MCLs if the pH drops below pH 8.0. This survey could document the effectiveness of pH treatment on maintaining pH above 8.0 and metals below their MCLs, but sampling size would double. PH treatment and other forms of treatment (chlorination, filtration, etc.) can be evaluated, but only on a statewide basis by aggregating data from several different source-distribution system characteristics with an accompanying potential loss of resolution for any specific combination of system characteristics. It is recommended that the efficacy of different levels of pH treatment for reducing contaminants be evaluated in a separate study. Without consideration of pH treatment, the listed characteristics provide 160 unique combinations of system characteristics for public systems and 40 unique combinations for private systems.

The first task is to effectively use the available information and expertise in the design. The more that can be learned of the geographic distribution of the characteristics of interest compiled as a series of state map overlays, the more cost-effective the design can be made. The overlays will delineate actual geographic areas with common characteristics of supply and distribution.

Since the geographical location of population is important, 1980 census data provide an obvious entry. Census data provide population densities in a variety of housing types. The basic census unit is the "block," corresponding in urban areas to the city block and to the area delineated by road, river and utility rights-of-way systems in rural areas. Census data also provide information on the type of water supply: public, dug well, or drilled well. From the total census, residents of 19% of all year-round homes were asked the type of water supply: public and private water company, individual drilled well, individual dug well, or "other." These data give us a better picture of the private versus public supply situation than other sources.

This information needs to be coupled with information on the specific source of water to each block or groups of blocks and with the nature of the distribution system providing water to each block or group of blocks. This information and information on treatment types is most readily available from individual town water supply managers. Maps depicting census block data (population densities) should be used as base maps upon which the town water supply manager can circumscribe regions of similar distribution system materials and water supply sources. Experience suggests that this expertise will have to be tapped by personal interview with the water supply manager rather than by questionnaire. By using census maps as the base maps, true population densities affected by each combination of source and distribution material will be developed. An accompanying detailed questionnaire should document the specifics of treatment type, age of systems, and other characteristics important to later analyses. The questionnaire and base map approach should be initially tried on a few towns known to have a complex mix of sources and distribution materials to refine the questions and insure completeness.

It is particularly important to assure that water sources be certain for each household. In many communities, some houses may receive their water from a variety of sources during different parts of the day, depending on water demands in other parts of the community. Water in the tap may represent water from one source provided the previous evening while the water in the main is from another source provided that morning. Statistical interpretation of such confused sources would be impossible. Those areas with multiple sources may be understandable once appropriate single-source models are constructed, but at this stage they will probably doom any reasonable interpretation or yield confidence intervals that make any interpretation useless.

Further, the types of distribution system materials that can impact the water quality at the tap must be restricted. In many communities, several materials may be in the flow path to groups of households. No statistical analysis can hope to differentiate between the variable impact of unknown lengths of multiple types of materials in the water line to the house. The best and simplest analysis will focus on systems with only one type of distribution system material from source to household. Such localities will be known to the town water supply manager. Age of pipe and distance from source to household may also be important. These data should be obtained from the town manager either through the questionnaire or be implicit in the base maps. While these variables will not be used as "blocking factors" in the survey design, they will be available for later refinement of the resulting models.

Because so much of the already available data are organized by town units, it is recommended that town be the basic sampling unit. Within each town, census blocks can be compared with polygons describing areas of similar source waters and distribution systems. Areas homogeneous in these three characteristics form the basic areas of interest for further sampling. Areas of overlap, i.e. with varying degrees of homogeneity in these characteristics, will not concern us in a survey design to meet objective 2 but will cause some problems in meeting objective 1. These problems will be reviewed in a later discussion.

Using this approach of taking advantage of existing data sources and expert knowledge, there is information for public systems on the raw water quality (from DEQE files), population density for each source, treatment type (optional), and distribution system type (from the census and town water supply managers). Thus far, the picture is complete for the state without reliance on sampling theory. Only the nature of household plumbing systems and the characteristics of the water at the tap need to be determined. By focusing on relatively homogeneous systems, it may seem that major segments of the population have been selected against by this approach because their water supply system is heterogeneous. In this first effort to survey drinking water quality, it does not seem feasible to fully describe all possibilities, particularly the very complex source - distribution system relationships. This is bothersome, but there appears to be no way to adequately describe complex distribution systems at reasonable cost within the limited prior knowledge of this survey. What will be gained is a first approximation that will either allow construction of statistical models that can describe more complex systems or sufficient understanding of the important parameters to make study of complex systems economical.

For private systems, there is only the census data for guidance. They will give a sense of the distribution of private versus public supplies and dug versus drilled wells. Raw water quality and household plumbing are unknowns.

Census data, DEQE data and interviews with town water supply managers will yield base town maps with polygons delineating up to 40 different combinations (system types) of supply and distribution to households. Actually, substantially fewer system types in each town are expected. To guarantee geographic representation in the survey the state can be subdivided into four regions: northeast, southeast, central and western. County boundaries will suffice to delineate regional boundaries, yielding the following four county clusters: I -Essex, Suffolk, Middlesex, Norfolk; II -Barnstable, Dukes, Nantucket, Plymouth, Bristol; III - Worcester; IV -Franklin, Hampshire, Hampden, Berkshire.

An appropriate sampling design must be constructed to determine the household plumbing composition within these 40 system types, although it is likely that not all 40 will occur within each region. There is no appropriate information on the relative frequency of household plumbing types within geographic regions of any size nor information on the relationship between household plumbing type and any of the other variables used to form the other categories, e.g., private versus public. The sampling design must assume that such differences may exist. Post facto, categories (or even regions) can be collapsed if they are unnecessary and there will be a gain in precision as a result of greater sample size. But, initially, the worst case must be anticipated.

To estimate necessary sample sizes for the survey of plumbing types, a decision must be made about the accuracy and precision of the sample estimates and size frequencies. Some of the most interesting plumbing types for the purposes of this study (such as lead or asbestos pipe) will be relatively rare. For the sake of argument, assume that plumbing types occuring in only 5% of the households are to be detected with 95% certainty that the resulting plumbing type survey sample size estimates will vary by only ±1% of the true value. More formally:

$$\text{Probability } (|p - \hat{p}| \leq \text{precision}) = \text{accuracy}$$

The estimate of the variance of a binomial proportion can be used to solve the following equation for the desired sample size (n):

$$P = t \sqrt{\frac{(F)(1 - F)}{n}}$$

where P = precision, t = the t value of the desired level of accuracy and F = the expected frequency of occurence of a plumbing type.

By considering several possible sample sizes, expected frequencies, and levels of accuracy, the precision of estimates can be demonstrated (Table 5.2).

The choice of sample sizes is a function of statistical accuracy and precision versus cost. If a one in twenty chance of error, that is, an accuracy of 95%, is acceptable (the usual in scientific research), then a sample size of 100 will yield a precision error of not more than ±10%; 500 samples will yield an error of not more than ±5%. Relatively rare plumbing types will be detected with an error of less than ±5%. These levels would seem to be appropriate. Little improvement is gained by large increases in sample size and, by the same token, the limit of ±10% seems an appropriate lower limit to sample size. Further, this is a worst case estimate. If any system characteristics can be shown to have no effect, all samples within that characteristic can be aggregated, effectively increasing sample size by 2 to 5 fold depending on the system characteristic. For example if geographic region had no statistical effect on water quality, the 100 samples of each system type could be aggregated into a total of 400 samples, thereby reducing either the precision range to less than +5% for common plumbing types and less than +2% for rarer types or increasing the accuracy of the estimate.

Table 5.2. Precision (± %) of estimates predicted for given sample sizes at stated levels of accuracy and stated expected frequencies of plumbing types in the total population

		Accuracy					
Sample Size	Expected Frequency	0.99	0.95	0.90	0.80	0.60	0.50
75	1%	3.0	2.3	1.9	1.5	1.0	0.8
75	5%	6.5	4.9	4.1	3.2	2.1	1.7
75	10%	8.9	6.8	5.7	4.4	2.9	2.3
75	25%	12.9	9.8	8.2	6.4	4.2	3.4
75	50%	14.9	11.3	9.5	7.4	4.9	3.9
75	75%	12.9	9.8	8.2	6.4	4.2	3.4
100	1%	2.6	2.0	1.6	1.3	0.8	0.7
100	5%	5.6	4.3	3.6	2.8	1.8	1.5
100	10%	7.7	5.9	4.9	3.8	2.5	2.0
100	25%	11.2	8.5	7.1	5.5	3.6	2.9
100	50%	12.9	9.8	8.2	6.4	4.2	3.4
100	75%	11.2	8.5	7.1	5.5	3.6	2.9
150	1%	2.1	1.6	1.3	1.0	0.7	0.5
150	5%	4.6	3.5	2.9	2.3	1.5	1.2
150	10%	6.3	4.8	4.0	3.1	2.1	1.7
150	25%	9.1	6.9	5.8	4.5	3.0	2.4
150	50%	10.5	8.0	6.7	5.2	3.4	2.8
150	75%	9.1	6.9	5.8	4.5	3.0	2.4
200	1%	1.8	1.4	1.2	0.9	0.6	0.5
200	5%	4.0	3.0	2.5	2.0	1.3	1.0
200	10%	5.5	4.2	3.5	2.7	1.8	1.4
200	25%	7.9	6.0	5.0	3.9	2.6	2.1
200	50%	9.1	6.9	5.8	4.5	3.0	2.4
200	75%	7.9	6.0	5.0	3.9	2.6	2.1
500	1%	1.1	0.9	0.7	0.6	0.4	0.3
500	5%	2.5	1.9	1.6	1.2	0.8	0.7
500	10%	3.5	2.6	2.2	1.7	1.1	0.9
500	25%	5.0	3.8	3.2	2.5	1.6	1.3
500	50%	5.8	4.4	3.7	2.9	1.9	1.5
500	75%	5.0	3.8	3.2	2.5	1.6	1.3
1000	1%	0.8	0.6	0.5	0.4	0.3	0.2
1000	5%	1.8	1.4	1.1	0.9	0.6	0.5
1000	10%	2.4	1.9	1.6	1.2	0.8	0.6
1000	25%	3.5	2.7	2.3	1.8	1.2	0.9
1000	50%	4.1	3.1	2.6	2.0	1.3	1.1
1000	75%	3.5	2.7	2.3	1.8	1.2	0.9

Within each region, the above criteria translate into a need to survey 4,000 households (40 system types x 100 households/type) or 16,000 households statewide (assuming no consideration of pH treatment). This is the maximum number of surveyed households because there is no information on which to base the assumption that each region actually will have all 72 system types. These 16,000 households need to be surveyed only to determine their household plumbing characteristics, not the water quality at the tap.

Determination of household plumbing system composition would be by telephone survey. *Names should be randomly selected from the local* telephone book or town lists of residents and the street name checked to ascertain whether that household occurs within one of the polygons. If so, the head of the household would be called, the purpose of the call should be stated and he/she would be asked his/her willingness to participate in the study by responding to the telephone survey questions and potentially collecting samples from the household kitchen tap. If the response is affirmative, the head of the household would be asked a small number of questions about the household plumbing system. Before use, the survey questionnaire should be refined and tested to remove ambiguity and lengthiness and assure that it is well received by homeowners.

Responses to the 16,000 telephone surveys should be tabulated, checked for inconsistencies, and sorted into 200 unique combinations of supply-distribution-plumbing systems. The process by which an appropriate number of households is chosen for tap water chemical analysis is similar to that presented before where:

$$(\text{acceptable range})(\text{true value}) = \frac{t\ (\text{standard deviation})}{\sqrt{n}}$$

This implies that:

$$n \approx \frac{t\ (\sigma^2)}{(\text{acceptable range})^2\ (\text{true value})^2} = \frac{t\ (\text{coeff. of variation})}{(\text{acceptable range})^2}$$

Using Table A.6 of Snedecor and Cochran (1980) which specifies the appropriate range multiplier and allows us to estimate the standard deviation for various sample sizes based on the acceptable range:

$$\text{estimated } \sigma = (\text{range multiplier}^*)(\text{acceptable range})$$

$$= (\text{range multiplier}^*)(\%\ \text{range})(\text{true value})$$

$$\text{so: } n = \frac{t\ (\text{estimated } \sigma)^2(\text{true value})^2}{(\text{acceptable range})\ (\text{true value})^2}$$

Table 5.3 shows an appropriate range of households per unique system type resulting from various choices of precision and accuracy and Table 5.4 projects these values to the statewide survey.

Table 5.3. Number of households for each system type to have tap water chemical analysis for various values of accuracy and precision assuming experimental error of 20%.

Precision % of true value	Accuracy 99%	 95%	 90%	 80%
1	759	441	310	189
5	30	19	15	10
10	10	8	7	5
20	5	4	3	2
30	3	2	2	1

Table 5.4. Number of households to have tap water chemical analysis statewide (all system types) at stated values of accuracy and precision assuming experimental error of 20%.

Precision % of true value	Accuracy 99%	 95%	 90%	 80%
1	151,800	88,200	62,000	37,800
5	6,000	3,800	3,000	2,000
10	2,000	1,600	1,400	1,000
20	1,000	800	600	400
30	600	400	400	200

The selection of appropriate precision and accuracy should be determined in advance and according to the objectives of the survey. For each household, three water samples would be taken (see below) for chemical analysis. In addition, the total number of samples to be analyzed should be increased by 5 - 10% to include samples of raw and treated water at public supplies and 25% to meet QA/QC requirements. This effort will be expensive; careful attention needs to be paid to optimizing sample size. A precision of 10 -20% is consistent with the error inherent in chemical analysis and will result in reasonable sample sizes. Since increases in accuracy do not require as large an increase in sample size as increases in precision, a minimum level of 95% certainty seems appropriate.

To the number of households to be sampled to provide data for statistical analysis and modeling, an additional 10% should be added for use in testing of the resulting models. These additional households should also be representative of all system types found in the state and may be selected and sampled at the same time as other households. However, the data for households to be used for model verification purposes should be set aside and not used in model development.

The chosen number of households would be contacted to arrange for the collection of water samples. The details of procedures, analyses, data base management etc. are described in later sections.

It was mentioned earlier that the above survey design might cause some problems for achieving objective 1. The nature of these problems is now considered. The results of the telephone survey and tap water sampling will characterize the effect of household plumbing systems on tap water quality, and will, further, characterize the statewide distribution of such plumbing systems. The statewide estimates can be refined by examining the data on plumbing type and water quality for correlation with census data on age of the house or other "index" variables. Statewide data can then be adjusted for the geographic distribution of the index variable as shown by the statewide census data.

The primary difficulty occurs in statewide adjustment for effects of sources and distribution systems, because the problem of multiple water sources and multiple distribution system composition will be encountered. Data from the survey will describe the boundaries of expectation for mixed systems, but will provide little insight on how to weight the relative proportions of each distribution type or source. The problem is not with the survey results but with the lack of knowledge about the actual proportion of distribution material in a particular flow path to the household or the relative percentage of various source waters provided or the interactions. This level of resolution is simply beyond the capacity of the survey approach, and must, instead, rely on the development of detailed models based on intensive examination of a few systems. These may then be applied to the data gathered in this survey. Some information will be available as a by-product of the survey. For example, approximate pipe miles of a particular distribution material should be available from the base maps developed to describe homogeneous areas, but the interaction effects of different materials must be evaluated. Other considerations such as calculation of water supply source contribution must rest on a detailed hydrological evaluation of each supply's distribution system.

While this information would appear to be important for the evaluation of populations at risk, other uncertainties inherent in such an evaluation, such as the uncertainty surrounding prediction of the population impact (mortality, chronic effects, reduced intelligence, etc.) based on laboratory experiments or limited case histories, suggest that the limitations resulting from study of homogeneous distribution systems will be less restrictive than the limitations of the epidemiological data.

The survey approach described above will meet the data needs for the stated five objectives of the survey design. The tasks of determining the representativeness of the corrosion process and determining the key factors for water quality at the household tap are the primary focus. In accomplishing these tasks, a large part of the necessary information becomes available for further analysis of historical trends, corrosion modeling, and evaluating populations at risk from toxic materials in drinking water. As previously stated, it seems best to consider the latter three tasks as separate projects to be conducted after the initial characterization of the problem.

An initial historical analysis of acid deposition impacts on public water supply raw water quality has been conducted by Taylor et al. (1984b), although this study did not resolve all the questions surrounding this issue. Private water supplies will require extraordinary efforts to assemble the historical data and document its quality. Sufficient information appears to be available to consider short-term historical trends in a small number of towns. Those towns with potentially adequate private supply data are shown in Table 5.5.

With the data base available from the survey, corrosion modeling should make an interesting thesis problem, but it should require verification of any resulting models by coupon testing or examination of pipe sections. The prior work of Zajicek (1981) cited in this report suggests an approach that might be taken.

Table 5.5. Towns with possibly appropriate data for analysis of acidification of private water supplies on file with Board of Health.

Bedford
Bourne
Bridgewater
Carver
Essex
Fairhaven
Manchester
Rochester
Seekonk
Southborough
Tewksbury
Wareham
Westport
Whitman

Lastly, estimating populations at risk should result from the use of the proposed data base, further use of the census data, and use of the literature on human toxicity and water consumption per capita for various population groups.

In summary, three surveys are recommended to meet the stated objectives:

1. a survey of available information from the census data, DEQE files, and town water supply managers. Only the latter would involve a questionnaire and base map to delineate regions of interest.

2. a telephone survey of randomly selected households within prescribed areas of homogeneous water supply source-distribution systems.

3. a survey of individual houses selected for plumbing characteristics to collect water samples at the tap and synoptic sample collection of the raw and treated water provided to the distribution system.

In the next section, the specifics of sample collection are described.

5.4 SAMPLE COLLECTION

Raw water samples from public supplies should be collected at the intake to the distribution system. If the system has any type of treatment, an additional sample should be taken after treatment. Samples should be collected from each site once during the period March 1 - April 15, and again during the period August 1 -September 15, representing the spring run-off period and summer low flow period, respectively. These two periods have been identified by the Acid Rain Monitoring Project and related research as defining the extreme values of pH in surface waters.

Household water samples should be collected during the same periods using the protocol described by Karalekas et al. (1983) and previously used to determine tap water quality in the MDC region. Three samples are collected in early morning: a first use sample taken at the kitchen tap representing the water in the household plumbing, a second sample taken after the water at the tap has run until a temperature change is first observed representing water standing in the service line overnight, and a third sample collected after the water has been allowed to run for at least five more minutes representing the water in the town mains. Any homes with leaking fixtures would not be included in the selected sites since this would bias the early morning, first flush samples. Samples should not be collected from households which have individual household treatment systems.

In order to collect the first use, early morning sample, a member of the household must be enlisted as the sample collector. That person must be provided with a detailed description of the sample collection procedures. In addition, a sample collection data sheet should be completed for each sample, indicating location, date and time of collection, type of supply if raw water, type of piping in distribution system, plumbing type if from a tap, depth of well if from a private well supply (minimum information to be whether well is shallow (dug) or deep (drilled), age of distribution system well or plumbing, presence of holding tanks or treatment apparatus, existence of leaking faucets or fixtures, any noticeable stains on fixtures, noticeable coloration or odor of water, age of house, homeowner's length of residence, kitchen remodeling with plumbing replacement, cellar heated or not, distance of house from street or well, age and sex of family members, and any other relevant observations supplied by the operator or homeowner. It is the task of the project worker to explain the required procedure to the homeowner when sampling equipment is left at the house and to ascertain the completeness of all information when the samples are picked up for analysis. Some of this information will be available from the initial telephone survey. At least one week prior to collecting the samples the information obtained from the telephone survey should be confirmed at each site selected for sampling and any other relevant information recorded on the sample collection data sheet to minimize data collection needs on the day of water sample collection.

5.5 CHEMICAL ANALYSIS

Three alternatives are presented for chemical analysis of samples (Table 5.6). In all three scenarios, the chemical parameters listed would be analytically determined for both raw water and tap samples, to permit comparisons of raw and delivered water. This is critical for accurate assessments of corrosion or other changes which occur in the water as it passes through a distribution system and/or household plumbing.

Only the key parameters essential to an evaluation of the potential effects of acid deposition upon drinking water supplies are included in design A. The two most commonly used indicators of surface and ground water sensitivity to acidification, pH and alkalinity, depict the levels of acid and acid neutralizing capacity (ANC), respectively. Calcium is generally the major cation in natural aquatic systems and sulfate a major anion, particularly in low pH water, where it may replace bicarbonate as the predominant anion. The Langelier Saturation Index, Aggressive Index and Ryznar Stability Index can all be calculated from pH, alkalinity and calcium (assuming calcium hardness is calculated as calcium concentration for the Aggressive Index). Temperature and specific conductance are important chemical factors influencing corrosion of distribution pipes and plumbing, as are pH, alkalinity, calcium and sulfate (see Table 3.5). Copper, iron and lead are the most common metallic piping materials used in distribution systems and household plumbing, and are the most likely heavy metal contaminants arising from corrosion of pipes (see Table 3.6).

In design B, the list of chemical parameters is expanded to include all parameters listed for design A, plus additional parameters influencing corrosion (total hardness, total dissolved solids, silica), additional major cations (magnesium, sodium, potassium), additional major anions (nitrate, chloride, fluoride), additional heavy metals (cadmium, manganese, zinc), and other potentially toxic elements related to drinking water quality (aluminum, antimony, arsenic, selenium), plus color, an indication of the presence of organic material.

Design C includes all the parameters listed in design B, plus additional parameters influencing corrosion (carbon dioxide, dissolved oxygen, ammonia, free and total chlorine residual, phosphorus), additional metals (barium, chromium, mercury, silver), and asbestos, a potential corrosion product of asbestos - cement pipe. Dissolved organic carbon and total organic halides (TOX) are included as indicators of possible contamination by organic chemicals. It is possible that mobility of organic contaminants in sediments and ground water is influenced by pH. Also, work by Uden (1985) and others has indicated that chlorination of drinking water supplies may react with organic matter to create chlorinated hydrocarbons, in a process which is pH dependent. Furthermore, DOC and TOX would serve as initial indicators of possible contamination of drinking water supplies by hazardous materials which may or may not be related to atmospheric deposition of acids. Acid neutralizing capacity would be measured via the Gran Plot titration in design C.

The recommended methods to be used in analyzing each of the parameters shown in Table 5.6 are displayed in Table 5.7. ICP methods are described in the most recent revisions of the EPA manual (EPA, 1983) and ICP is listed as an alternative for analysis of certain metals in the E.P.A.'s National Lake Survey (Hillman et al., 1985). To be used in this project, the ICP must be able to reliably achieve detection limits equal to 10% of the MCL or SMCL for any metal regulated under the drinking water act, and /or meet detection limits specified in Hillman et al. (1985). For parameters for which conventional flame AA and/or ICP are considered not likely to provide adequate detection limits, graphite furnace AA is specified as an analytical method. In this way, the specification of analytical methods in Table 5.7 helps to guarantee acceptable detection limits for analytical parameters.

The holding times specified in Table 5.7 should be carefully adhered to as well, as an additional means of achieving accurate analytical results. This will require careful planning and coordination of sample collections and laboratory analyses. The laboratory supervisor should devise an analytical schedule which permits analysis of samples within the specified holding times, and all chemical analyses should be dated and recorded as a record of compliance or non-compliance with required holding times.

PH is an important analytical parameter in all three study design options. Under current EPA protocol, pH should be analyzed immediately. The large number of samples proposed by this study design will likely make field determinations of pH impractical and, perhaps, prohibitively expensive, particularly because of the constraints (both time of day and seasonal) placed upon sample collection and the cost of reliable field instrumentation. For this reason, it is recommended that samples be transported to the analytical laboratory as soon as possible after collection, where they should be analyzed immediately for pH. Temperature can be easily measured in the field by sample collectors.

If design option C is selected, chlorine residual (free and total) and dissolved oxygen would also need to be analyzed immediately. Again, it may prove impractical to measure these parameters in the field, in which case samples should be transported to the laboratory following collection and immediately analyzed. If a suitably accurate and precise field test for measurement of free and total chlorine residual can be identified and purchased within project budgetary constraints, chlorine measurements could be made in the field. As with pH, it appears unlikely that sufficient numbers of portable analytical instruments could be purchased to measure dissolved oxygen in the field using the probe method. If the probe method is used within the laboratory for dissolved oxygen, it may be possible to make some dissolved oxygen determinations in the field for comparison. If the modified Winkler method is used, 2 ml of manganous sulfate solution and 2 ml of alkaline iodide-azide solution may be added to the full B.O.D. sample bottle in the field, as described in EPA method 360.2 (EPA, 1979b). The sample may be analyzed in the laboratory within 8 hours.

Table 5.6. Chemical Parameters to be Analyzed in Each of the Three Study Design Options.

A.
- pH
- Double end point alkalinity
- Ca
- SO_4
- Cu
- Fe
- Pb
- Temperature
- Specific Conductance
- Total Dissolved Solids

B.
- pH
- Double end point alkalinity
- Hardness
- Ca
- Mg
- Na
- K
- SO_4
- NO_3
- Cl
- F
- Cd
- Cu
- Fe
- Mn
- Pb
- Zn
- Al
- As
- Sb
- Se
- Si
- Temperature
- Specific Conductance
- True Color
- Total Dissolved Solids

C.
- pH
- Gran Plot alkalinity (ANC)
- Hardness
- Ca
- Mg
- Na
- K
- SO_4
- NO_3
- Cl
- F
- Cd
- Cu
- Fe
- Mn
- Pb
- Zn
- Al
- As
- Sb
- Se
- Si
- Ag
- Ba
- Cr
- Hg
- Asbestos
- CO_2
- DOC
- TOX
- Dissolved Oxygen
- Free Chlorine Residual
- Total Chlorine Residual
- Ammonia
- Total Phosphorus
- Temperature
- Specific Conductance
- Total Diss. Solids
- True Color

Table 5.7. Analytical procedures and holding times for chemical parameters.

	Parameter	Method	Holding Time
(A)	Alkalinity, Double End Pt.	Potentiometric titration, EPA 310.1	14 Days
(C)	Alkalinity, Gran Plot	Titration with Gran Plot	14 Days
(B)	Aluminum	ICP or Furnace, EPA 202.2	6 Months
(C)	Ammonia	EPA 350.2	28 Days
(C)	Antimony	Gaseous hydride or Furnace, EPA 204.2	6 Months
(B)	Arsenic	Gaseous hydride or Furnace, EPA 206.2	6 Months
(C)	Asbestos	Electron microscopy	
(C)	Barium	ICP or Furnace, EPA 208.1	6 Months
(B)	Cadmium	Furnace, EPA 213.2	6 Months
(A)	Calcium	ICP or AA, EPA 215.1	6 Months
(C)	Carbon dioxide	Potentiometric titration, SM 406B	14 Days
(B)	Chloride	Ion chromatography	28 Days
(C)	Chlorine Residual, Free	DPD colorimetric, SM 408E	Immed.
(B)	Chlorine Residual, Total	DPD colorimetric, SM 408E	Immed.
(C)	Chromium	Furnace, EPA 218.2	6 Months
(B)	Color, true	Colorimetric, EPA 110.2	48 Hours
(A)	Copper	ICP or AA, EPA 220.1	6 Months
(C)	Dissolved Organic Carbon	Carbon analyzer, EPA 415.2	28 Days
(C)	Dissolved Oxygen	Probe or Modified Winkler (EPA 360.1 or 360.2)	Immed.
(B)	Fluoride	Ion chromatography	28 Days
(B)	Hardness	Titrimetric (EPA 130.2) or by calculation	6 Months
(A)	Iron	ICP or AA, EPA 236.1	6 Months
(A)	Lead	Furnace, EPA 239.2	6 Months
(B)	Magnesium	ICP or AA, EPA 242.1	6 Months
(B)	Manganese	Furnace, EPA 243.2	6 Months
(C)	Mercury	Cold Vapor, EPA 245.1	28 Days
(B)	Nitrate	Ion Chromatography	48 Hours
(A)	pH	Electrometric, EPA 150.1	Immed.
(B)	Potassium	ICP or AA, EPA 258.1	6 Months
(B)	Selenium	ICP, Gaseous hydride or Furnace, EPA 270.2	6 Months
(B)	Silica	ICP or Colorimetric, SM 425D	28 Days
(C)	Silver	Furnace, EPA 272.2	6 Months
(B)	Sodium	ICP or AA, EPA 273.1	6 Months
(A)	Specific Conductance	Conductivity meter, EPA 120.1	28 Days
(A)	Sulfate	Ion Chromatrography	28 Days
(A)	Temperature	Thermometer	Immed.
(B)	Total Dissolved Solids	EPA 160.1	48 Hours
(C)	Total Organic Halides	Adsorption-Pyrolysis-Titrimetric, SM 506	14 Days
(C)	Total Phosphorous	Colorimetric, persulfate digestion, SM 424F	28 Days
(B)	Zinc	ICP or AA, EPA 289.1	6 Months

Key: (A) = Design A, B, and C
(B) = Design B and C only
(C) = Design C only
SM = Standard Methods for the Examination of Water and Wastewater,
15th edition, A.P.H.A., A.W.W.A., W.P.C.F., 1980.
16th edition, A.P.H.A., A.W.W.A., W.P.C.F., 1983.
EPA = Methods for Chemical Analysis of Water and Wastes, EPA, 1983
AA = Flame atomic absorption spectroscopy
Furnace = Graphite furnace atomic absorption spectroscopy
ICP = Inductively coupled plasma atomic emission spectroscopy

5.6 SAMPLE CONTAINERS AND PRESERVATION TECHNIQUES

The required sample containers and preservation techniques for the parameters listed in Table 5.6 are shown in Table 5.8. The number and variety of sample containers and complexity of preservation techniques increases from design A through design C.

Table 5.8. Sample containers and preservation techniques for each of the three study designs.

Design	Parameters	Container	Preservation
A.	pH, alkalinity, SO_4, conductance	500 ml plastic	Cool to 4°C (F,L)
	metals (Ca,Cu,Fe,Pb)	125 ml plastic	HNO_3 to pH <2 (F)
	temperature	250 ml plastic	None (Det. in field)
B.	pH, alkalinity, silica conductance, TDS, color	500 ml plastic	Cool to 4°C (F,L)
	metals, hardness	250 ml plastic	HNO_3 to pH <2 (F)
	anions (SO_4,NO_3,Cl,F)	125 ml plastic	Cool to 4°C (F,L)
	temperature	250 ml plastic	None (Det. in field)
C.	pH, ANC (Gran), silica, conductance, TDS, color	500 ml plastic	Cool to 4°C (F,L)
	metals (except Hg), hardness	250 ml plastic	HNO_3 to pH <2 (F)
	mercury	125 ml plastic	HNO_3 pH <2 (F)
	anions	125 ml plastic	Cool to 4°C (F,L)
	asbestos		
	temperature, chlorine residual	250 ml plastic	None (Det. ASAP)
	CO_2	250 ml plastic	None (Det. ASAP)
	DOC, Ammonia, Total P	500 ml plastic	H_2SO_4 to pH <2, Cool to 4°C (F,L)
	TOX	50 ml glass with teflon septum	Cool to 4°C (F,L)
	Dissolved Oxygen	300 ml glass	(Fix on site)

Note: F = preserve in field; L = preserve in lab.

5.7 QUALITY ASSURANCE/QUALITY CONTROL

A QA/QC program should be developed for each phase of sample collection and chemical analysis. In compiling material for this section, QA/QC program designs were reviewed from related water quality surveys, including the study of drinking water quality in the eastern U.S. by Taylor et al. (1985b), the Massachusetts Acid Rain Monitoring Project (Godfrey et al., 1985), the U.S. EPA Eastern Lakes Survey (Drous et al., 1985; Hillman et al., 1985) and the U.S. Fish and Wildlife Service Acid Precipitation Mitigation Program (Saunders et al., 1985).

5.7.1 Sample Collection

All sample collectors should be trained in correct sample collection and field preservation techniques and on-site data collection methods. All sample collectors should also participate in practice runs of the field methods prior to the actual initiation of sampling. A written sample collection and preservation protocol should be printed, concisely delineating field instructions. A data collections form should be printed and used for all on-site data collection. All procedures should remain consistent throughout the sample collection phase of the project.

Sample collectors should be periodically observed in the field by the field supervisor to ensure continued compliance with the established procedures.

5.7.2 Chemical Analysis

An extensive QA/QC program should be implemented to maintain well documented accuracy and precision of analytical results for both field and laboratory analyses.

5.7.2.1 Field

A minimum of 5% of all field measurements should be replicated in the field. At a minimum of 5% of all sample locations, a full set of duplicate samples also should be collected and returned to the analytical laboratory. In addition, field blanks should be prepared at a minimum of 5% of the sampling locations, to provide an indication of the possible contamination of samples during sample collection. This would involve bringing deionized water into the field and filling sample containers for analysis following the established procedures for sample collection and preservation. Laboratory analysis of these field blanks would be compared to analysis of the deionized water which remained in the laboratory. Any significant differences between the two values would cause a review of sample collection procedures with the collector and a check of all sample collection bottle preparation procedures. Further, 1% of the samples returned to the laboratory will be double blind samples, made to appear as if they were actual field samples (see section 5.7.2.2).

5.7.2.2 Laboratory

Internal laboratory quality control should include the following measures:

- Daily preparation of standard curves for appropriate analytical instrumentation.
- Recalibration of all instrumentation not less than once every 20 samples; analysis of each standard to be followed by analysis of a blank.
- Check samples (quality control samples of known value) to be run not less than one every 20 samples; if not within 10% of expected value, machine to be recalibrated and a different check sample run. If problem persists, analyst to check for machine malfunction.
- Replicate analysis of not less than 5% of all samples brought in to lab. Results of replicates should be within 10% of each other; if not, the instrument should be checked and another set of replicates run.
- Replicate samples to be collected in the field at not less than 5% of all sample locations and analyzed in lab for all parameters.
- Daily analysis of a set of spiked field samples; recovery of spikes should be within 15% of expected value.
- Daily checking of working detection limits of instrumentation to ensure that required analytical sensitivity is maintained.
- Quality assurance samples should be brought into the field and preserved by sample collectors as regular samples, labelled and returned to the analytical laboratory as double blinds, in quantities equivalent to not less than 1% of all samples collected. These double blind samples may be derived from EPA quality assurance samples or another quality assurance program, or may be initially prepared by the analytical laboratory. In the latter case, it will be the responsibility of the field supervisor to track the double blind samples in the field and maintain adequate records so that the expected results can be compared with those obtained analytically. Prior to sending any such samples into the field, the laboratory should analyze the samples in triplicate as an internal quality control check and record the values.
- Compute charge balances for major ion data.

In addition, the laboratory should participate in external quality assurance testing via the following means:

- Participation in the U.S.E.P.A. laboratory performance evaluation programs for acid rain and drinking water analysis.
- Participation in the U.S.G.S. laboratory quality assurance program.
- A minimum of 1% of all samples should be collected in duplicate and analyzed at another respected analytical laboratory, such as the D.E.Q.E. Lawrence Experiment Station, for comparison of results.

Table 5.9 shows the percentage of additional analyses required to maintain appropriate quality control. Planning for implementation of the above QA/QC measures should begin as soon as the number of sample collection sites is known and continue through the sample site selection process to ensure that these measures are implemented evenly and consistently throughout the period of sample collection and analysis.

Table 5.9. Percent of sample analyses to be added for appropriate quality control.

Samples for QA/QC	
Field blanks	2% (1 set at 5% of households)
Double blinds	1%
Lab replicates	5%
Field replicates	5%
Inter-lab comparisons	1%
Calibration and internal checks	
Calibration	5%
Check samples	5%
Miscellaneous	1%
Calibration curves	
Analysis of spikes	
Detection limit checking	
Reruns of questionable data	
EPA/USGS QA/QC samples	
Total	25%

5.8 DATA ANALYSIS

Three stages of data analysis will be required: analysis of the initial telephone survey data, analysis of QA/QC data, and analysis of analytical results.

5.8.1 Telephone Survey

Analysis of the telephone survey data should include appropriate weighting of cells identified for randomized selection, and result in the compilation of a list of sample sites. From a statistical viewpoint, this involves estimating a multinomial proportion by "region." With existing census data for the various regions, survey results may be scaled up to statewide values with known variance. Further, in exploring the variability of the proportions, say, across a region, the well-developed contingency table techniques of log linear modeling can be used to explore questions of similarity and homogeneity between categories. Aggregation of homogeneous system types will substantially reduce estimated variances. The basic data structure would be a contingency table of home plumbing type by system type categories within regions. Cell entries would be observed frequencies from the telephone survey. Using contingency table techniques to model similarities and provide smoothed estimates of abundance could be advantageous when using this data to "weight" the chemical analysis results so as to derive statewide estimates of population at risk.

It will also be useful to explore the question of the relationship between the "age of home" and its plumbing type. If a relationship can be found, then the census data can provide us with quality, low variance data on age of home which can be used to predict plumbing type, and, consequently, further refine statewide estimates of potential problematic drinking water situations beyond that achievable strictly from the survey.

The creation and testing of models relating home age to plumbing type would use standard statistical procedures. Within the context of contingency analysis, several appropriate procedures exist. It is suggested that no one procedure be given the full responsibility for developing such models, but that for statewide and local models, generalized linear modelling techniques and, perhaps, logistic regression techniques are appropriate procedures.

5.8.2 Quality Assurance/Quality Control

Analysis of QA/QC data should be conducted on an ongoing basis throughout the period of sample collection and laboratory analysis. The laboratory analyst(s) will be responsible for proper machine calibration and recalibration, initial evaluation of check sample results, initial evaluation of replicate analyses and analyses of replicate samples, initial evaluation of analyses of spikes and checking of detection limits, all on a daily basis. This will permit essentially immediate feedback into the analytical process regarding analytical accuracy and precision. If unfavorable results are obtained on any of these measures, the laboratory analyst should be responsible for taking appropriate corrective steps, including machine recalibration, checking of equipment for malfunctions and rerunning appropriate QA/QC measures. In addition, a weekly report of all QA/QC data should be compiled for review by the statistician and/or QA/QC coordinator (see next section). Along with a weekly review of this QA/QC data, the statistician or QA/QC coordinator should, on a weekly basis, compile and evaluate available charge balance data, results of double blind sample analyses, results of analyses of EPA and U.S. Geological Survey quality assurance samples, and results of interlaboratory comparison sample analyses. The QA/QC coordinator will, at least weekly, confirm the level of laboratory performance with the laboratory personnel and identify any apparent problems or inconsistencies. Final analysis of QA/QC data should include the establishment of confidence limits around the analytical results and identification of any analytical data deemed questionable on the basis of concurrently run QA/QC data.

5.8.3 Tap Water Quality Survey

The chemical analyses of water samples provide a wealth of information on each home, within a matrix of background variables, such as plumbing type, raw water characteristics, distribution system materials, etc. The primary task is to complete a sequence of conditional analyses investigating various "types" of situations, estimating the effect of acidification both on the measured chemistry and also on their covariation. This latter interaction analysis will permit understanding of the complexity of models needed to truly mimic acidification on home water supplies in complex, heterogeneous systems.

Technically, the survey will deliver a multivariate chemistry response for each household at two time periods. The sample itself is imbedded in a design matrix of plumbing type, distribution system, raw water type, etc. The whole survey will eventually be "reweighted" to provide statewide estimates. If one desires, the analysis can be thought of in a multivariate analysis context with unique case weights. While such statistical procedures are available and their use is recommended, the best use of the data will be the development of statewide and regional maps conveying the nature of drinking water problems to the public. These maps would be supported by the statistical analyses. Statistical analyses should also provide the necessary estimates of design parameter effects, indicators of certainty, warnings about possible interactions, etc. There is no one correct way to explore and model data of the projected complexity of this survey. A robust analysis will incorporate a variety of statistical and graphical techniques ranging from purely descriptive measures through the wealth of readily available multivariate procedures allowing for simultaneous inference on many parameters at a known (or estimated) level of confidence.

Subsequent to the development of models describing the interaction of raw water quality and distribution system on the quality of delivered water, the resulting models must be tested. Using the data set reserved for model testing (see Section 5.3), raw water quality and distribution system characteristics would be used to predict tap water quality. The accuracy of prediction can then be determined by comparing predicted results with actual results from tap water analysis.

The data bases developed in parts I and II of the survey should be input and maintained using data base management systems in common use throughout the state agencies, particularly DEQE's Divisions of Water Supply and Water Pollution Control and Department of Public Health and compatible with IBM PC microcomputers. It is recommended that phase II of the Drinking Water Quality Project address the need for beginning the process of providing data acquired to a central repository in computerized format. This effort will have obvious benefits for all subsequent analyses as part of other phases of this project or other research efforts.

5.9 PROJECT ORGANIZATION AND PERSONNEL REQUIREMENTS

In this section, general recommendations for project staffing are made, recognizing that the composition of the project team assembled for the project will be dependent upon the study design options chosen and the origin and nature of the proposal accepted. The study team should include the following key personnel:

Project Manager	- responsible for overseeing, coordinating and reviewing the various aspects of the project. This person may also participate to a substantial degree in the writing and/or editing of project reports, and should organize and participate in periodic meetings of the project team, as well as meetings with state agency personnel.
Statistician	- responsible for refinement of the statistical basis of the study design, data analysis as described in the preceding section, and recommendations for any additional project deemed necessary.
Field Supervisor	- responsible for training and supervising sample collection personnel, beginning with the initial telephone survey and continuing throughout sample collection. This person

should be responsible for quality control monitoring of field activities and ensuring rapid transport of samples to the analytical laboratory.

Laboratory Supervisor - responsible for training and supervising laboratory analysts, managing the analytical laboratory, ordering analytical supplies, producing weekly QA/QC reports, and producing analytical data reports in both written (computer printouts) and electronic (IBM-PC compatible diskettes) formats.

QA/QC Coordinator - responsible for weekly evaluations of QA/QC data throughout the period of sample collection and analysis, ensuring that all field and laboratory procedures are followed, and documentation of all QA/QC measures used in the project.

Database Manager - responsible for training and supervising data entry personnel, overseeing proofreading of hand entered data, and production and maintenance of data bases for initial survey data, QA/QC data, and sample chemical analysis data.

It is not necessary that all of these roles be filled by different people; for example, the statistician and QA/QC coordinator roles could be filled by one person.

5.10 PROJECT OPTIONS

Several project options have been proposed as various aspects of the survey design have been developed. Choices are available for the number of households surveyed by telephone, the number of households for water sampling, the suite of chemical analyses, and data base management. Given the magnitude of the tasks of collecting the base line existing information, conducting the telephone survey, collecting tap water samples, and conducting the statistical analysis, three years should be the minimum time period for proposed survey, data analysis and model development.

Several strategies may be used to minimize costs without sacrificing the integrity of the survey design. Collection of data on system characteristics and collection of household water samples will be highly labor intensive. Given the successful use of volunteers for sample collection in the Acid Rain Monitoring Project, the use of volunteers for this survey should be explored. They may be used in the first survey to collect data on system characteristics and in the second survey to collect household water samples from homeowners. Spreading the effort over a large number of volunteers will reduce the time needed for each survey and minimize travel expenses and telephone expenses. Volunteers will provide benefits other than simple cost savings. The first survey to determine system characteristics and locate areas where household sampling may be conducted will benefit from an intimate knowledge of the town. Public officials may be more willing to cooperate fully with residents than with outsiders. Homeowners will also be more likely to cooperate if approached by neighbors. Further, use of volunteers will inherently create an educational aspect to the project as citizens become more knowledgeable about their drinking water quality.

Three different suites of chemical analysis are proposed. Suite A will provide the absolute minimum information needed for a gross assessment of corrosion effects; but given the overall effort required for sample collection, limiting chemical analysis to Suite A seems a false economy. Suite B will meet most needs of the project, although some factors that effect corrosion will be neglected. Suite B will also not address the question of asbestos nor provide any screening for organics. Suite C will meet all of these needs but at much greater cost. An intermediate strategy would be to employ the Suite C analyses only in circumstances where asbestos or organic chemicals are suspected based on the results of the first survey for system characteristics and data on raw water quality.

6.0 RECOMMENDATIONS FOR AN ONGOING STATE MONITORING PROGRAM

Perhaps the greatest need for a consistent, high quality monitoring program exists for private water supplies. At present, responsibility for maintaining appropriate standards and regulating existing water quality resides with the Boards of Health. However, there is little guidance for them on the appropriate parameters to measure, criteria to apply and interval for resampling. Most towns do what they think is best, given local pressures to minimize costs to the homeowner, but this is not sufficient when the potential for contamination is so pervasive and so technically complex. On the basis of the survey of existing water quality data collected by, but not necessarily readily available at, local Boards of Health, it is clear that the state needs to provide guidance to the Boards on the parameters to be measured and the frequency of resampling.

At present many Boards obtain data from labs certified only for bacteriological analysis. One element of necessary assistance to Boards of Health would be to establish appropriate quality control requirements for all parameters and to expand the existing quality control program for private laboratories to include the additional parameters. Such a program will be necessary for the following recommendation.

Data from the Boards of Health, if it is to have any utility for state policy development and the insurance of human health standards across the state must eventually reside in a central data processing facility where large-scale geographic trends may be evaluated or human health epidemiological data may be compared with drinking water quality for all segments of the population. The newly developing statewide geographic information system is a perfect location for this type of data. Boards of Health should be given guidance in how to prepare the appropriate information so that these data may meet the criteria for inclusion in the statewide database.

Public water supply sources should be sampled twice a year for surface supplies as now required, but the sampling periods should be at intervals of one month in spring and one month in summer. Groundwater supplies should be sampled at least once, preferably twice, at the same times as for surface waters.

As part of the centralized data facility, software should be developed to periodically screen all incoming data for potential problems. Consideration should be given to developing a sampling design for resampling water sources according to a prescribed statistical selection procedure.

Based on the review of critical parameters that might be affected by acidification of water supplies, the current suite of analyses should be expanded to include analysis for zinc.

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8.0 APPENDIX

TABLE A.1

DRINKING WATER QUALITY MONITORING PROJECT

Water Resources Research Center
Blaisdell House
University of Massachusetts
Amherst, MA 01003

Town: ______________________________

Water Supply Manager: ______________________________

Person filling out questionnaire: ______________________________

Position: ______________________________

1. Does the Town conduct any chemical analysis of its water supplies other than through the Department of Environmental Quality Engineering?
   Yes ______ No ______
   If No, there is no need to continue with the questionnaire but please return it to the Water Resources Research Center.

2. Does the Town maintain its own laboratory or use a private firm?
   Town lab ______ Private or other lab (specify) ____________________
   ____

3. When did the Town begin keeping records on the water quality of its supplies? ____________

4. Using the attached form, please place a check mark next to the chemical parameters that are or have been measured and indicate the approximate year these analyses were initiated (and terminated, if appropriate).

5. Does the lab maintain detailed records of the procedures used and when changes were made to newer techniques, e.g. date when colorimetric measurements of pH were dropped in favor of a pH meter or the type of indicator used in past alkalinity determinations? Yes _____ No ______

6. What water supplies are tested and when did testing begin?

   1. ______________________________
   2. ______________________________
   3. ______________________________
   4. ______________________________
   5. ______________________________
   6. ______________________________

TABLE A.1. (continued)

7. ____

8. ____

7. How frequently are samples for chemical analysis collected (indicate dates of major changes in sampling frequency)? ____________________

____

8. Are samples collected only at the intake or elsewhere (no. of sites and depths)?

____

7. How are water quality data stored by the Town? Check more than one if appropriate.

____ a. filed chronologically
____ b. filed by supply
____ c. with other water supply data
____ d. in a separate file containing only well water quality data
____ e. paper files in a filing cabinet
____ f. notebook or log book
____ g. computer   Type of computer ____________
Means of storage: 7 or 9 track tape ____
cassette tape ____
disc 8" ____
disc 5.25" ____

8. Does the Town also maintain a file on water levels in reservoirs and wells?
Yes ______   No ______

8. If so, these files are maintained in what form (choose a - g from list in question 5). ________

9. Are water quality data sent to any state agency?
____ Department of Public Health (DPH)
____ Department of Environmental Quality Engineering (DEQE)
____ Department of Environmental Management (DEM)
____ Division of Water Supply
____ Other ______________________________

10. Will the Town allow Water Resources Research Center personnel access to the water quality data during normal business hours?
Yes ______   No ______

11. Please complete this form, fold and tape so that the Water Resources Research Center Address and the stamp show on the outside and mail by August 15, 1985.

TABLE A.1 (continued)

DRINKING WATER QUALITY PROJECT
CHECKLIST OF CHEMICAL PARAMETERS TESTED ON WATER SAMPLES

Inorganic

Meas.[1]	Int.[2]	
		Alkalinity
		Aluminum
		Ammonia
		Arsenic
		Barium
		Boron
		Bromide
		Cadmium
		Calcium
		Chloride
		Chromium
		Copper
		Cyanide
		Fluoride
		Free Chlorine
		Hardness
		Iron
		Lead
		Magnesium
		Manganese
		Mercury
		Nickel
		Nitrate
		Nitrite
		Nitrogen (Organic or Kjeldahl)
		pH
		Phosphate
		Potassium
		Selenium
		Silicon
		Silver
		Sodium
		Sulfate
		Total Dissolved Solids (TDS)
		Total Suspended Solids (TSS)
		Total Solids
		Turbidity
		Zinc
		Other list:

Organic

Meas.[1]	Int.[2]	
		BOD (Biological Oxygen Demand
		COD (Chemical Oxygen Demand)
		Color
		Endrin
		Lindane
		Methorchlor
		Polychlorinatedbiphenyls (PCB's)
		Total Organic Carbon (TOC)
		Total Organic Halides (TOX)
		Toxaphene
		Trihalomethanes
		Volatile Organics (Purgeables
		2,4 D
		2,4,5 T
		Other list:

---

[1] Measured by the Town

[2] Beginning and ending year for which this parameter was measured.

Table A.2. Town and Village Water Supply Agencies responding to questionnaire and having data on water quality*.

Town	Response	Data
Acton	Y	Y
Acushnet	N	
Adams	N	
Agawam	Y	N
Amesbury	N	
Amherst	Y	N
Andover	N	
Arlington	N	
Ashburnham	N	
Ashfield	Y	N
Ashland	N	
Assonet	N	
Athol	N	
Attleboro	N	
Attleboro	Y	N
Auburn	N	
Auburn	N	
Auburn	N	
Avon	N	
Ayer	Y	N
Barnstable	Y	Y
Barre	N	
Bedford	N	
Belchertown	N	
Bellingham	Y	
Belmont	N	
Berkshire	N	
Bernardston	Y	Y
Beverly	N	
Blackstone	N	
Blanford	Y	N
Bondsville	Y	N
Boston	Y	Y
Boylston	Y	N
Braintree	N	
Brewster	N	
Bridgewater	N	
Brockton	N	
Brookfield	Y	N
Brookline	N	
Burlington	Y	Y
Buzzards Bay	Y	N
Byfield	N	
Cambridge	N	
Canton	N	
Chatham	N	
Chelmsford	N	
Chelsea	Y	N
Cheshire	N	
Cheshire	Y	N
Cheshire	Y	Y
Chester	Y	N
Chicopee	N	
Chilmark	N	
Clarksburg	N	
Clarksburg	Y	N
Clinton	N	
Cohasset	N	
Colrain	N	
Concord	N	
Cotuit	Y	N
Cummington	N	
Cuttyhunk Island	N	
Dalton	N	
Dalton	N	
Danvers	Y	Y
Dedham	N	
Dedham	N	
Deerfield	Y	Y
Dighton	N	
Dighton	Y	N
Dover	N	
Dracut	N	
Dudley	Y	N
Dunstable	N	
Duxbury	Y	N
E. Bridgewater	N	
East Brookfield	N	
East Chelmsford	Y	N
East Douglas	Y	N
East Longmeadow	Y	N
Easthampton	N	
Easthampton	Y	N
Essex	Y	Y
Everett	Y	N
Fairhaven	Y	N
Fall River	Y	Y
Falmouth	N	
Fiskdale	N	
Fitchburg	Y	Y
Foxborough	N	
Framingham	Y	N
Franklin	N	
Gardner	N	
Georgetown	Y	N
Gilbertville	N	
Gloucester	Y	N
Goshen	N	
Granby	N	
Granville	Y	N

Table A.2 (cont.). Town and Village Water Supply Agencies responding to questionnaire and having data on water quality.

Town	Response	Data
Great Barrington	N	
Great Barrington	N	
Great Barrington	Y	N
Greenfield	Y	Y
Griswoldville	Y	N
Groton	N	
Groton	Y	N
Groveland	N	
Halifax	Y	Y
Hamilton	N	
Hanover	N	
Hanson	N	
Hardwick	N	
Harvard	N	
Harwich	Y	N
Hatfield	Y	Y
Haverhill	Y	Y
Hingham	N	
Hingham	N	
Hinsdale	Y	N
Holbrook	N	
Holden	N	
Holliston	Y	N
Holyoke	N	
Holyoke	N	
Hopedale	N	
Hopkinton	Y	N
Hudson	Y	N
Huntington	Y	N
Hyannis	Y	N
Hyannis	Y	N
Ipswich	Y	N
Kingston	N	
Lancaster	Y	N
Lanesborough	N	
Lawrence	Y	Y
Lee	N	
Leicester	N	
Leicester	N	
Leicester	N	
Leicester	N	
Lenox	N	
Lenox	Y	Y
Leominster	N	
Lexington	Y	N
Lincoln	N	
Littleton	Y	Y
Longmeadow	N	
Lowell	N	
Ludlow	N	

Town	Response	Data
Lunenberg	Y	N
Lynn	N	
Lynnfield	N	
Lynnfield	N	
Malden	N	
Manchaug	N	
Manchester	N	
Manomet	N	
Mansfield	Y	Y
Marblehead	N	
Marion	N	
Marlborough	Y	Y
Marshfield	Y	N
Mattapoisett	Y	N
Maynard	Y	N
Medfield	N	
Medford	Y	N
Medway	N	
Melrose	N	
Merrimac	Y	N
Methuen	Y	Y
Middleborough	Y	N
Middleton	N	
Milford	N	
Milford	N	
Mill River	Y	Y
Millbury	N	
Millbury	N	
Millbury	Y	Y
Millbury	Y	Y
Millers Falls	N	
Millers Falls	N	
Millis	N	
Milton	N	
Minchendon	N	
Monroe Bridge	Y	N
Monson	Y	N
Montague	N	
Montague	Y	N
Monterey	N	
N. Dartmouth	N	
Nahant	N	
Nantucket	Y	N
Natick	Y	Y
Needham	Y	N
New Bedford	N	
Newburyport	N	
Newburyport	N	
Newton	Y	N
Newton Center	N	

Table A.2 (cont.). Town and Village Water Supply Agencies responding to questionnaire and having data on water quality.

Town	Response	Data
Norfolk	N	
Norfolk	Y	Y
North Adams	N	
North Andover	N	
N. Attleborough	N	
North Billerica	N	
North Brookfield	N	
North Chelmsford	N	
North Easton	Y	Y
North Reading	N	
Northampton	N	
Northampton	N	
Northborough	Y	N
Northfield	N	
Northfield	N	
Norton	N	
Norwell	N	
Norwood	N	
Oak Bluffs	N	
Onset	N	
Orange	Y	N
Orleans	N	
Osterville	Y	N
Palmer	Y	Y
Paxton	Y	N
Peabody	Y	Y
Pembroke	N	
Pepperell	N	
Pittsfield	N	
Plainville	N	
Plymouth	N	
Plymouth	Y	N
Pocasset	Y	N
Providence	N	
Provincetown	Y	Y
Quincy	N	
Randolph	N	
Raynham	N	
Raynham	Y	Y
Reading	N	
Revere	N	
Richmond	N	
Rockland	N	
Rockland	N	
Rockport	N	
Rowley	N	
Russell	N	
Rutland	Y	N
S. Deerfield	N	
Sagamore	Y	N
Sagamore Beach	N	

Town	Response	Data
Salem	N	
Salisbury	N	
Sandwich	N	
Saugus	N	
Scituate	Y	Y
Seekonk	N	
Sharon	N	
Sheffield	N	
Shelburne	N	
Shelburne Falls	Y	N
Shirley	N	
Shrewsbury	N	
Siasconset	N	
Somerset	Y	Y
Somerville	Y	N
South Chelmsford	N	
South Dennis	Y	N
South Grafton	Y	N
South Hadley	N	
South Hadley	N	
South Hadley	N	
South Royalston	N	
Southampton	Y	N
Southborough	Y	
Southbridge	N	
Southfield	N	
Southwick	Y	N
Spencer	N	
Springfield	Y	Y
Sterling	Y	N
Stockbridge	Y	N
Stockbridge	Y	N
Stoneham	Y	N
Stoughton	N	
Stow	N	
Sudbury	N	
Sunderland	N	
Swampscott	N	
Swansea	Y	Y
Taunton	N	
Taunton	N	
Templeton	Y	N
Tewksbury	Y	N
Thorndike	Y	Y
Three Rivers	Y	N
Topsfield	N	
Topsfield	N	
Topsfield	Y	N
Townsend	Y	N
Truro	N	

Table A.2 (cont.). Town and Village Water Supply Agencies responding to questionnaire and having data on water quality.

Town	Response	Data
Turners Falls	N	
Turners Falls	Y	N
Uxbridge	N	
Vineyard Haven	N	
Wakefield	Y	N
Walpole	N	
Waltham	N	
Waquoit	N	
Ware	N	
Wareham	Y	N
Warren	Y	N
Watertown	N	
Wayland	Y	Y
Webster	Y	N
Wellesley Hills	Y	Y
Wenham	Y	N
West Boylston	N	
West Bridgewater	N	
West Brookfield	Y	N
West Newbury	N	
West Springfield		
West Stockbridge		
West Upton		
West Warren	Y	N
Westborough		
Westfield		
Westford		
Westford		
Westminster		
Weston		
Westport		
Weymouth	Y	N
Whately	Y	N
Wheelwright		
Whitinsville		
Whitman	Y	N
Wilbraham		
Wilkinsonville		
Williamsburg	Y	Y
Williamstown	Y	N
Williamstown	Y	N
Wilmington	Y	Y
Winchester	Y	Y
Winthrop		
Woburn		
Worcester		
Worthington		
Wrentham		
Wrentham	Y	N
Yarmouthport	Y	Y

---

* Towns listed more than once have multiple water supply agencies.

Table A.3. Water quality data available from town water supply agencies and year of initiation.

Town	Alk	Yr	Al	Yr	NH_4	Yr	As	Yr	Ba	Yr	B	Yr	Br	Yr	Cd	Yr	Ca	Yr	Cl	Yr
Acton																				
Barnstable																				
Bernardston	m																m			
Boston	m		m		m		m		m						m		m		m	
Burlington	m																m			
Cheshire	m				m												m		m	
Danvers	m	77	m	77													m	81	m	81
Deerfield																				
Easton	m	50			m	50	m	79	m	79					m	72	m	72	m	50
Essex	m	82																		
Fall River	m	77	m	77	m	81											m	77	m	77
Fitchburg																				
Greenfield																				
Halifax	m																m		m	
Hatfield																				
Haverhill	m	80	m	80											m	82			m	80
Lawrence	m	39																		
Lenox	m	84																		
Littleton	m	82			m	82	m	82	m	82					m	82	m	82	m	82
Mansfield	m	78			m	78											m	78	m	78
Marlborough																				
Methuen	m	83																		
Millbury	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72
Mill River																				
Millbury(Oxford)	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72
Natick	m				m												m		m	
North Easton																				
Norfolk																				
Palmer																				
Peabody	m	74	m	74																
Provincetown																				
Raynham																				
Scituate			m	68															m	68
Somerset	m	68	m	68			m	79	m	79					m	79	m	76	m	68
Springfield	m		m														m		m	
Swansea																				
Thorndike																				
Wayland	m	77			m	77									m	77			m	77
Wellesley Hills			m	84			m	84	m	84					m	84				
Williamsburg	m	84					m	84	m	84					m	84	m	84	m	84
Wilmington																				
Winchester																				
Yarmouthport																				

m = measured

Table A.3 (cont.). Water quality data available from town water supply agencies and year of initiation.

Town	Cr	Yr	Cu	Yr	CN	Yr	F	Yr	FCR	Yr	Hard	Yr	Fe	Yr	Pb	Yr	Mg	Yr	Mn	Yr
Acton							m	70												
Barnstable																				
Bernardston											m		m							
Boston			m				m				m		m		m		m		m	
Burlington									m	73	m		m				m		m	
Cheshire			m								m		m				m		m	
Danvers			m	82			m	77	m	77	m	81	m	81					m	81
Deerfield																				
Easton	m	74	m	72							m	50	m	50			m	72	m	50
Essex							m	53	m	82			m	75					m	75
Fall River	m	81	m	77	m	81	m	77	m	77	m	77	m	79	m	80			m	80
Fitchburg			m	77			m	74	m	62			m	77						
Greenfield																				
Halifax			m						m		m		m				m		m	
Hatfield																				
Haverhill	m	82	m	80			m	80	m	80	m	80	m	80	m	82			m	80
Lawrence							m	83												
Lenox																				
Littleton	m	82	m	70							m	82	m	82	m	70	m	82	m	82
Mansfield			m	78							m	78	m	78			m	78	m	78
Marlborough							m	82	m	85										
Methuen													m	83					m	83
Millbury	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72
Mill River																				
Millbury(Oxford)	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72
Natick			m								m.		m				m		m	
North Easton																				
Norfolk																				
Palmer									m	77										
Peabody							m	83	m	74	m	74	m	74					m	74
Provincetown																				
Raynham									m	82			m	82					m	82
Scituate							m	54	m	68									m	68
Somerset	m	79	m	76			m	69	m	68	m	68	m	68	m	79	m	76	m	70
Springfield			m						m		m		m						m	
Swansea							m	70												
Thorndike																				
Wayland			m	77							m	77	m	77			m	77	m	77
Wellesley Hills	m	84	m	84	m	84	m	84							m	84				
Williamsburg	m	84	m	84			m	84					m	84	m	84	m	84	m	84
Wilmington													m						m	
Winchester							m		m		m	85	m	85	m	85			m	85
Yarmouthport																				

m = measured

Table A.3 (cont.). Water quality data available from town water supply agencies and year of initiation.

Town	Hg	Yr	Ni	Yr	NO_3	Yr	NO_2	Yr	N	Yr	pH	Yr	PO_4	Yr	K	Yr	Se	Yr	Si	Yr
Acton											m	83								
Barnstable																				
Bernardston					m		m		m		m				m				m	
Boston	m				m						m				m		m			
Burlington					m		m				m									
Cheshire					m		m				m				m					
Danvers											m	77	m	82						
Deerfield											m	83								
Easton	m	72			m	50	m	50	m	50	m	50	m	61	m	67				
Essex											m	82								
Fall River	m	82	m	81	m	80	m	77			m	77	m	77	m	81			m	77
Fitchburg											m	62								
Greenfield											m	85								
Halifax					m		m				m				m					
Hatfield																				
Haverhill			m	82	m	80					m	80								
Lawrence											m	39								
Lenox											m	84								
Littleton	m	82	m	82	m	82					m	70			m	82	m	82		
Mansfield					m	78	m	78	m	78	m	78			m	78				
Marlborough											m	80								
Methuen											m	83								
Millbury	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72
Mill River																				
Millbury(Oxford)	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72
Natick					m		m				m		m		m					
North Easton																				
Norfolk																				
Palmer																				
Peabody											m	74								
Provincetown																				
Raynham											m	82								
Scituate											m	67								
Somerset	m	79			m	79	m	76	m	76	m	68			m	76	m	79		
Springfield					m		m				m									
Swansea											m	83								
Thorndike																				
Wayland					m	77	m	77			m	77			m	77				
Wellesley Hills	m	84	m	84	m	84					m	84					m	84		
Williamsburg	m	84			m	84	m	84	m	84	m	84			m	84	m	84		
Wilmington											m									
Winchester											m									
Yarmouthport																				

m = measured

Table A.3 (cont.). Water quality data available from town water supply agencies and year of initiation.

Town	Ag	Yr	Na	Yr	SO_4	Yr	TDS	Yr	TSS	Yr	Tsol	Yr	Turb	Yr	Zn	Yr	BOD	Yr	COD	Yr
Acton																				
Barnstable			m	80																
Bernardston			m		m								m							
Boston	m		m		m								m		m					
Burlington			m		m								m							
Cheshire			m		m								m							
Danvers							m	81					m	77						
Deerfield																				
Easton	m	79	m	70	m	67	m	67	m	50			m	50						
Essex			m	82									m	82						
Fall River			m	82	m	77	m	82	m	82	m	80	m	77	m	79				
Fitchburg													m	77						
Greenfield													m	76						
Halifax			m		m								m							
Hatfield																				
Haverhill	m	82	m	80	m	80							m	80	m	82				
Lawrence													m	70						
Lenox													m	84						
Littleton	m	82	m	70	m	84	m	84					m	84						
Mansfield			m	78	m	78	m	78					m	78						
Marlborough													m	76						
Methuen			m	83									m	83						
Millbury	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72
Mill River																				
Millbury(Oxford)	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72
Natick			m		m								m							
North Easton																				
Norfolk																				
Palmer																				
Peabody													m	74						
Provincetown																				
Raynham																				
Scituate													m	68						
Somerset	m	79	m	76	m	76							m	75						
Springfield					m		m						m							
Swansea																				
Thorndike																				
Wayland			m	77	m	77							m	77						
Wellesley Hills	m	84													m	84				
Williamsburg	m	84	m	84	m	84														
Wilmington													m							
Winchester													m							
Yarmouthport																				

m = measured

Table A.3 (cont.). Water quality data available from town water supply agencies and year of initiation.

Town	CLR	Yr	End	Yr	Lin	Yr	Mch	Yr	PCB	Yr	TOC	Yr	TOX	Yr	TOP	Yr	TRI	Yr	VO	Yr
Acton																			m	82
Barnstable																				
Bernardston	m																			
Boston																				
Burlington			m	83	m	83	m	83											m	83
Cheshire	m																			
Danvers	m	77																		
Deerfield			m	83	m	83	m	83							m	83			m	83
Easton	m	50																	m	85
Essex	m	82																		
Fall River	m	79																		
Fitchburg																				
Greenfield																				
Halifax	m																			
Hatfield																				
Haverhill	m	80															m	82		
Lawrence	m	39																		
Lenox																				
Littleton			m	82	m	82	m	82	m	82	m	82					m	82	m	82
Mansfield	m	78																		
Marlborough	m	79																		
Methuen	m	83															m	83		
Millbury	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72
Mill River																				
Millbury(Oxford)	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72	m	72
Natick	m																			
North Easton																				
Norfolk																				
Palmer																				
Peabody	m	74																		
Provincetown																				
Raynham																				
Scituate	m	68																		
Somerset	m	68	m	82	m	82	m	82	m	80					m	82	m	82		
Springfield	m																m			
Swansea																				
Thorndike																				
Wayland	m	77																		
Wellesley Hills			m	84	m	84			m	84					m	84	m	84	m	84
Williamsburg	m	84																		
Wilmington	m																m	79	m	79
Winchester																				
Yarmouthport																				

m = measured

Table A.3 (cont.). Water quality data available from town water supply agencies and year of initiation.

Town	24D	Yr	245T	Yr	Other
Acton					
Barnstable					
Bernardston					sediment,odor
Boston					color
Burlington					
Cheshire					sediment,odor,cond.
Danvers					CCS by Fluorescence
Deerfield	m	83	m	83	several
Easton					
Essex					
Fall River					
Fitchburg					
Greenfield					
Halifax					chlorine
Hatfield					no info.
Haverhill					
Lawrence					
Lenox					
Littleton	m	82	m	82	
Mansfield					
Marlborough					
Methuen					cond.
Millbury	m	72	m	72	
Mill River					coliform
Millbury(Oxford)	m	72	m	72	
Natick					sediment,odor,cond.
North Easton					
Norfolk					
Palmer					
Peabody					
Provincetown					no info.
Raynham					
Scituate					
Somerset	m	83	m	83	
Springfield					
Swansea					
Thorndike					no info.
Wayland					sediment,silica
Wellesley Hills	m	84	m	84	
Williamsburg					
Wilmington					
Winchester					
Yarmouthport					no info.

m = measured

Table A.4. Laboratories used, frequency of sampling, collection sites, and filing procedures for town water supply agencies.

Town	Lab	Frequency	Collection	Filed
Acton	T	M,Q	R,T	P,C
Barnstable	C	M	R	L
Bernardston	P	M	R,H	P
Boston	P	W	T	?
Burlington	T,P	?	?	P
Cheshire	P	A	?	?
Danvers	T	D,S	R	P,L
Deerfield	T,P	M	R,H	P
Easton				
Essex	T	M,D	R	P
Fall River	T	D	R	P,L
Fitchburg	T	D,W	R,T	P
Greenfield	T	D	R	P
Halifax	T	A,D	R	P,L
Hatfield	P	W	R	P
Haverhill	T	M	R	P,L
Lawrence	T	D	R	P
Lenox	T,P	D	R,H	?
Littleton	T,P	M,Q	R	P
Mansfield	P	S	R,T	P
Marlborough	T	?	?	?
Methuen	T	D,W	R,T	L
Millbury				
Mill River	P	M	T	?
Millbury(Oxford)	P	M	T	P
Natick	P	Q	R	P
North Easton	P	?	?	P
Norfolk	P	A	R	?
Palmer	T,P	?	?	?
Peabody	T,P	W	R	L
Provincetown	P	Q	?	L
Raynham	T,P	D	T	P,L
Scituate	T	D	R,T	L
Somerset	T	D	R	P
Springfield	T	D,W	R	L
Swansea	T	A	R,T	?
Thorndike	P	M	R	P
Wayland	P	A	R,H	?
Wellesley Hills	P	?,W	R	P
Williamsburg	P	S	R	?
Wilmington	P	Q	R,T	P,L
Winchester	T	D,W	R	L
Yarmouthport	T,P	?	?	?

T=TOWN
C=COUNTY
P=PRIVATE

D=DAILY
W=WEEKLY
M=MONTHLY
S=SEMIANNUALLY
A=ANNUALLY

R=RAW
T=TREATED
H=TAP

P=PAPER
L=LOGBOOK
C=COMPUTER

TABLE A.5

DRINKING WATER QUALITY MONITORING PROJECT

Water Resources Research Center
Blaisdell House
University of Massachusetts
Amherst, MA 01003

Town: ____________________

Board of Health Chairperson: ____________________

Person filling out questionnaire: ____________________

Telephone number: __________

1. Has the town ever experienced well water quality problems? Define problem:
   ____
   ____

2. Has the town ever closed a well for water quality problems?
   Reason: ____________________

3. Does the town have any sources of potential contamination other than septic systems? List: ____________________
   ____

4. Does the Board of Health require analysis of well water samples other than bacteriological testing? Yes ______ No ______
   If No, there is no need to continue with the questionnaire but please return it to the Water Resources Research Center.

5. Water testing is required for:
   ______ a. all new wells
   ______ b. when property is transferred
   ______ c. other (please describe) ____________________
   ____
   ____

6. Using the form on the next page, please place a check mark next to the chemical parameters required by the Board or normally provided by water testing labs.

TABLE A.5 (continued)

7. List the names and addresses of the water testing labs most frequently providing data to the Board over the last 15-20 years, the period of their use, and the approximate frequency of use for that period.

1. ____

____

2. ____

____

3. ____

____

4. ____

____

8. How are well water quality data stored by the Board? Check more than one if appropriate.
   _____ a. by plot
   _____ b. by street address
   _____ c. with other information on the property
   _____ d. in a separate file containing only well water quality data
   _____ e. paper files in a filing cabinet
   _____ f. notebook or log book
   _____ g. computer Type of computer ____________________
   Means of storage: 7 or 9 track tape _____
   cassette tape _____
   disc 8" _____
   disc 5.25" _____

9. Does the Board also maintain a file on the depth of the wells?
   Yes ______ No ______

10. If so, these files are maintained in what form (choose a - g from list in question 5). ________

11. Are well water quality data sent to any state agency?
   _____ Department of Public Health (DPH)
   _____ Department of Environmental Quality Engineering (DEQE)
   _____ Department of Environmental Management (DEM)
   _____ Division of Water Supply
   _____ Other ______________________________

12. Will the Board allow Water Resources Research Center personnel access to the well water quality data during normal business hours?
   Yes _____ No _____

11. Please complete this form, fold and tape so that the Water Resources Research Center Address and the stamp show on the outside and mail by August 15, 1985.

TABLE A.5 (continued)

DRINKING WATER QUALITY PROJECT
CHECKLIST OF CHEMICAL PARAMETERS TESTED ON WELL WATER SAMPLES
FOR THE BOARD OF HEALTH

Inorganic

Req.[1]	Opt.[2]	
		Alkalinity
		Aluminum
		Ammonia
		Arsenic
		Barium
		Boron
		Bromide
		Cadmium
		Calcium
		Chloride
		Chromium
		Copper
		Cyanide
		Fluoride
		Free Chlorine Residual
		Hardness
		Iron
		Lead
		Magnesium
		Manganese
		Mercury
		Nickel
		Nitrate
		Nitrite
		Nitrogen (Organic or Kjeldahl)
		pH
		Phosphate
		Potassium
		Selenium
		Silicon
		Silver
		Sodium
		Sulfate
		Total Dissolved Solids (TDS)
		Total Suspended Solids (TSS)
		Total Solids
		Turbidity
		Zinc
		Other list:

Organic

Req.[1]	Opt.[2]	
		BOD (Biological Oxygen Demand
		COD (Chemical Oxygen Demand)
		Color
		Endrin
		Lindane
		Methorchlor
		Polychlorinatedbiphenyls (PCB's)
		Total Organic Carbon (TOC)
		Total Organic Halides (TOX)
		Toxaphene
		Trihalomethanes
		Volatile Organics (Purgeables
		2,4 D
		2,4,5 T
		Other

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[1] Required by the Board of Health

[2] Frequently provided by labs or requested by Board of Health

Table A.6. Boards of Health responding to questionnaire and with available data on private water supply quality.

Town	Response	Data
Abington	N	
Acton	N	
Acushnet	N	
Adams	N	
Agawam	Y	N
Alford	Y	N
Amesbury	N	
Amherst	Y	N
Andover	N	
Arlington	N	
Ashfield	Y	N
Ashland	N	
Assonet (Freetown)	N	
Athol	N	
Attleboro	N	
Auburn	N	
Avon	N	
Ayer	N	
Baldwinville	N	
Barnstable	Y	Y
Barre	N	
Becket	N	
Bedford	Y	Y
Bellingham	N	
Belmont	N	
Berkley	N	
Bernardston	N	
Beverly	Y	
Billerica	N	
Blackstone	N	
Blandford	N	
Boston	N	
Bourne	Y	Y
Boylston	N	
Braintree	Y	N
Brewster	Y	Y
Bridgewater	Y	Y
Brimfield	Y	Y
Brockton	Y	
Brookfield	N	
Brookline	N	
Buckland	N	
Burlington	N	
Cambridge	N	
Canton	N	
Carver	Y	Y
Carver	N	
Charlemont	N	
Charlton	N	
Chatham	N	
Chelmsford	N	
Chelsea	N	
Cheshire	N	
Chester	N	
Chesterfield	N	
Chicopee	Y	
Chilmark	N	
Clarksburg	Y	N
Clinton	N	
Cohasset	N	
Colrain	Y	N
Concord	Y	N
Conway	N	
Cummington	N	
Dalton	N	
Danvers	Y	N
Dartmouth	Y	Y
Dedham	N	
Deerfield	N	
Dighton	N	
Douglas	Y	N
Dover	N	
Dracut	N	
Dudley	N	
Duxbury	Y	N
East Bridgewater	N	
East Brookfield	N	
East Longmeadow	N	
Eastham	Y	Y
Easthampton	N	
Easton	N	
Edgartown	Y	Y
Egremont	N	
Erving	N	
Essex	Y	Y
Everett	Y	N
Fairhaven	Y	Y
Fall River	N	
Falmouth	Y	Y
Fitchburg	Y	N
Florida	N	
Foxborough	Y	N
Framingham	Y	Y
Franklin	Y	Y
Gardner	Y	Y
Gay Head	N	
Georgetown	N	
Gill	N	
Gloucester	Y	N
Goshen	Y	Y
Gosnold	N	
Grafton	N	
Granby	N	
Granville	N	
Great Barrington	N	
Greenfield	N	
Groveland	N	
Hadley	N	
Halifax	N	
Hamilton	N	
Hampden	N	
Hancock	N	
Hanover	Y	Y
Hanson	N	
Hardwick	N	
Harwich	N	
Hatfield	N	
Haverhill	Y	Y
Hawley	N	
Heath	Y	N
Hingham	N	
Hinsdale	N	
Holbrook	N	
Holden	Y	N
Holland	N	
Holliston	Y	Y
Holyoke	Y	N
Hopedale	N	
Hopkinton	N	
Hubbardston	N	
Hudson	N	
Hull	Y	N
Huntington	Y	N
Hyannis	N	
Ipswich	N	
Kingston	Y	Y
Lakeville	Y	Y
Lanesborough	N	
Lawrence	N	
Lee	N	
Leicester	N	
Leominster	Y	Y
Leverett	N	
Lexington	Y	N
Leyden	N	
Lincoln	N	
Longmeadow	N	
Lowell	N	
Ludlow	Y	Y
Lynn	Y	N

Table A.6 (cont.). Boards of Health responding to questionnaire and with available data on private water supply quality.

Town	Response	Data
Lynnfield	Y	
Malden	N	
Manchester	Y	Y
Mansfield	N	
Marblehead	N	
Marion	Y	Y
Marlborough	N	
Marshfield	Y	N
Mashpee	Y	Y
Mattapoiset	N	
Maynard	N	
Medfield	N	
Medford	N	
Medway	Y	N
Melrose	Y	
Mendon	N	
Merrimac	N	
Methuen	Y	N
Middleborough	Y	N
Middlefield	Y	Y
Middleton	Y	Y
Milford	N	
Millbury	Y	N
Millis	N	
Millville	N	
Milton	Y	N
Monroe	Y	N
Monson	N	
Monterey	Y	Y
Montgomery	N	
Mount Washington	Y	N
Nahant	N	
Nantucket	Y	Y
Natick	N	
New Ashford	N	
New Bedford	N	
New Braintree	N	
New Marlborough	Y	N
New Salem	N	
Newbury	Y	Y
Newburyport	N	
Norfolk	N	
North Adams	Y	N
North Andover	N	
N. Attleborough	Y	Y
North Brookfield	N	
North Reading	N	
Northampton	Y	N
Northborough	N	
Northfield	N	
Norton	N	
Norwell	Y	N
Norwood	Y	N
Oak Bluffs	N	
Oakham	N	
Orange	N	
Orange	N	
Orleans	N	
Otis	N	
Oxford	N	
Palmer	N	
Paxton	N	
Peabody	Y	N
Pelham	N	
Pembroke	N	
Pepperell	Y	N
Peru	N	
Petersham	N	
Phillipston	N	
Pittsfield	Y	
Plainfield	N	
Plainville	N	
Plymouth	N	
Plympton	N	
Princeton	N	
Provincetown	N	
Quincy	N	
Randolph	N	
Raynham	N	
Reading	N	
Rehoboth	N	
Revere	N	
Richmond	Y	N
Rochester	Y	Y
Rockland	Y	Y
Rockport	Y	N
Rowe	N	
Rowley	N	
Royalston	Y	N
Russell	N	
Rutland	Y	N
Salem	Y	N
Salisbury	N	
Sandisfield	N	
Sandwich	N	
Saugus	N	
Savoy	N	
Scituate	N	
Seekonk	Y	Y
Sharon	N	
Sheffield	N	
Shelburne	N	
Sherborn	N	
Shrewsbury	N	
Shutesbury	Y	N
Somerset	Y	N
Somerville	Y	
South Deerfield	N	
South Dennis	N	
South Hadley	Y	Y
Southborough	Y	Y
Southbridge	N	
Southhampton	N	
Southwick	N	
Spencer	N	
Springfield	Y	N
Sterling	N	
Stoneham	N	
Stoughton	N	
Stow	N	
Sturbridge	Y	N
Sudbury	Y	Y
Sunderland	N	
Sutton	N	
Swampscott	N	
Swansea	N	
Taunton	N	
Tewksbury	Y	Y
Tolland	N	
Topsfield	N	
Truro	N	
Turners Falls	N	
Tyngsborough	N	
Tyringham	N	
Upton	N	
Uxbridge	Y	N
Vineyard Haven	N	
Wakefield	Y	
Wales	Y	N
Walpole	Y	N
Waltham	Y	
Ware	N	
Wareham	Y	Y
Warren	Y	N
Washington	N	
Watertown	N	
Wayland	N	
Webster	N	
Wellesley	N	
Wellfleet	N	
Wendell	Y	N
West Boylston	N	
West Bridgewater	N	

Table A.6 (cont.). Boards of Health responding to questionnaire and with available data on private water supply quality.

Town	Response	Data
West Brookfield	Y	N
West Newbury	Y	Y
West Newton	Y	
West Springfield	N	
West Stockbridge	Y	N
West Tisbury	N	
Westborough	N	
Westfield	Y	Y
Westhampton	Y	N
Westminster	N	
Westport	Y	Y
Westwood	Y	Y
Weymouth	Y	N
Whitinsville	N	
Whitman	Y	Y
Wilbraham	N	
Williamsburg	Y	N
Williamstown	N	
Wilmington	N	
Winchendon	Y	N
Winchester	N	
Windsor	N	
Winthrop	Y	N
Woburn	N	
Worcester	Y	
Worthington	N	
Wrentham	N	
Yarmouth	N	

Table A.7. Water quality data on private water supplies available from Boards of Health.

TOWN	Alk	Al	NH_3	As	Ba	B	Br	Cd	Ca	Cl	Cr	Cu	Cn	Fl	Cl	Hard	Fe	Pb	Mg	Mn	Ni	NO_3
Barnstable																	r					r
Bedford				r	r			r	r	r				r			r					r
Bourne	r		r							r						r	r					r
Brewster																	r					
Bridgewater	r		r						r	r		r				r	r		r			r
Brimfield																						
Carver	r		r						r	r		r				r	r		r			r
Dartmouth	o		o							o		o				o	o		o			o
Eastham																	r					r
Edgartown																						
Essex				r	r			r		r	r	r		r		r	r	r	r	r		r
Fairhaven	r		r						r	r		r				r	r		r			r
Falmouth			o														r					r
Framingham	r									r							r		r			r
Franklin	r									r						r	r		r			r
Gardner																	r					r
Goshen										o												
Hanover	o								o	o						o	o		o			
Haverhill	o									o		o				o	o		o			o
Holliston										r						r	r		r			r
Kingston	o								o	o		o					o		o			o
Lakeville	o								o	r		o				r	r		r			r
Leominster	o			r												o	r		r			
Ludlow																						
Manchester	r								r	r				r		r	r		r			r
Marion																						
Mashpee												o					r					r
Middleton										r						r	r		r			r
Monterey																						
Nantucket												o					r					r
Newbury																						r
N. Attleborough										r						r	r		r			r
Rochester	r		r						r	r		r				r	r		r			r
Rockland																						
Seekonk	r								r			r				r	r		r			r
South Hadley										r		r					r		r			r
Southborough	r		r							r		r				r	r		r			r
Sudbury																r	r		r			r
Tewksbury	r		r						r	r						r	r		r			r
Wareham	r		r						r	r		r				r	r		r			r
West Newbury				o						r			o				r		r			r
Westfield																						
Westport	r								r	r		r				r	r		r			r
Westwood																						
Whitman	r								r	r		r				r	r		r			r

r = required
o = optional

Table A.7 (cont.). Water quality data on private water supplies available from Boards of Health.

TOWN	NO_2	pH	PO_4	K	Se	Si	Ag	Na	SO_4	TDS	TSS	TS	Turb	Zn	BOD	COD	Color	Other
Barnstable		r						r										conduct
Bedford		r	r	r				r	r	r	r	r	r					many organ
Bourne		r						r					r					
Brewster	r	r						r										conduct
Bridgewater		r		r				r	r				r				r	silica
Brimfield								r										
Carver		r		r				r					r				r	SiO_2,SO_4,CO_2
Dartmouth		o		o		o		o	o				o				o	
Eastham	r	r						r										
Edgartown																		pg missing
Essex		r			r		r	r	r	r			r	r			r	several,see notes
Fairhaven	r	r		r		r		r	r				r				r	odor,taste,etc.
Falmouth		r						r										conduct
Framingham	r	r						r					r				r	odor
Franklin	r	r						r					r				r	
Gardner		r																coliform
Goshen																		coliform
Hanover	o	r		o				o	o									
Haverhill		o						o					o				o	
Holliston		r											r				r	coli,color,odor
Kingston	o			o		o		o	o									add'l attached
Lakeville	o	o		o		o		r	o				o				o	
Leominster		r	r										o					
Ludlow																		no info.
Manchester		r						r	r	r							r	cond,coli,stability
Marion																		no info.
Mashpee		r						r							r			
Middleton		r						r										
Monterey																		sediment
Nantucket		r						r										
Newbury								r										
N. Attleborough		r							r								r	
Rochester		r		r				r	r				r				r	spec.cond.,odor,taste
Rockland																		no info.
Seekonk				r				r	r								r	
South Hadley	r			r				r	r				r				r	
Southborough		r						r					r				r	coli.,copper,odor
Sudbury		r						r					o				o	conduct.
Tewksbury		r							r				r					
Wareham	r	r		r		r		r	r				r				r	sediment
West Newbury		r	o					r										
Westfield																		
Westport	r	r		r				r	r				r				r	several,see notes
Westwood																		
Whitman	r	r		r		r		r	r				r				r	

r = required
o = optional

Table A.7 (cont.). Water quality data on private water supplies available from Boards of Health.

TOWN	E	L	M	P	TOC	TOX	T	THM	VO	4D	5T
Barnstable											
Bedford											
Bourne											
Brewster											
Bridgewater											
Brimfield											
Carver											
Dartmouth											
Eastham											
Edgartown											
Essex	r	r	r				r	r		r	r
Fairhaven											
Falmouth											
Framingham											
Franklin											
Gardner											
Goshen											
Hanover											
Haverhill											
Holliston									r		
Kingston											
Lakeville											
Leominster											
Ludlow											
Manchester											
Marion											
Mashpee											
Middleton											
Monterey											
Nantucket											
Newbury											
North Attleborough											
Rochester											
Rockland											
Seekonk											
South Hadley											
Southborough											
Sudbury											
Tewksbury											
Wareham											
West Newbury											
Westfield											
Westport											
Westwood											
Whitman											

r = required
o = optional

E = Endrin
L = Lindane
M = Methorchlor
PCB = PCBs
TOC = Total Organic Carbon
TOX = Total Organic Halides

T = Toxaphene
THM = Trihalomethanes
VO = Volatile Organics
4D = 2,4 D
5T = 2,4,5 T