WRRC
Bulletin 95

Water Quality Status and Trends in Minnesota—
Indices for Water Supply and Ground Water Pollution

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The work upon which this publication is based was supported in part by funds provided by the United States Department of the Interior as authorized under the Water Resources Research Act of 1964, Public Law 88-379

August, 1977
Minneapolis, Minnesota

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ACKNOWLEDGEMENTS

The assistance of the following in this project is gratefully acknowledged.

Minnesota Department of Health

Frederick F. Heisel
Paul B. Johnson
Edwin H. Ross
Gary L. Englund

Minnesota Geological Survey

Bruce M. Olson

U.S. Geological Survey, St. Paul

R.F. Norvitch and staff

University of Minnesota

Rexford D. Singer

Environmental Health Students, University of Minnesota

Milton Anderson
Jung W. Ahn
Harold Lenhart
Charlene Kannisinen
Carleen Stoskopf
Winthrop Watts

This study was conducted under the auspices of the Environmental Health Research and Training Center, University of Minnesota.

FORWORD

This bulletin is published in furtherance of the purposes of the Federal Water Resources Research Act of 1964. The purpose of the Act is to stimulate, sponsor, provide for, and supplement present programs for the conduct of research, investigations, experiments, and the training of scientists in the field of water and resources which affect water. The Act is promoting a more adequate National program of water resources research by furnishing financial assistance to non-Federal research.

The Act provides for establishment of Water Resources Research Centers at Universities throughout the Nation. On September 1, 1964, a Water Resources Research Center was established in the Graduate School as an Interdisciplinary component of the University of Minnesota. The Center has the responsibility for unifying and stimulating University water resources research through the administration of funds covered in the Act and made available by other sources; coordinating University research with water resources programs of local, State and Federal agencies and private organizations throughout the State; and assisting in training additional scientists for work in the field of water resources through research.

This Bulletin is number 9[illegible] in a series of publications designed to Present information bearing on water resources research in Minnesota and the results of some of the research sponsored by the Center. This bulletin assesses water quality status and trends in Minnesota.

This bulletin is related to the following research project:

OWRT Project No.: A-039-Minn

Annual Allotment Agreement No.: 14-31-0001-5023

Project Title: Water Quality Status and Trends in Minnesota - Indices for Water Supply and Groundwater Pollution

Principal Investigator: Conrad P. Straub, Department of Health, University of Minnesota

Project Began: July 1, 1973 Project Completed: June 30, 1976

FCST Research Category: 05-F

Publication Descriptors: Minnesota/Water Quality/Water Pollution/Groundwater Quality/Drinking Water/Public Health

Publication Abstract:

The approach taken was to examine the chemical data available on public water supplies based upon sample analyses by the Minnesota Department of Health.

Another section identified the computer program developed for subsequent retrieval of the chemical analysis data available and the physical and other data characterizing each public water supply including treatment used, etc. A final section of the report describes the techniques developed for characterizing specific organic contaminants in water.

CHARACTERIZATION OF WATER QUALITY -- MINNESOTA PUBLIC WATER SUPPLIES

All water supplies for which chemical data were reported[1,2] were used in the evaluation of water quality in community water supply systems. As stated earlier, three bases were used for comparison: 1) the Public Health Service Drinking Water Standards (1962),[3] 2) the AWWA quality goals for potable water,[4] and the EPA national interim primary drinking water regulations.[5] In 1974, the Safe Drinking Water Act[6] was published assigning responsibility for defining standards applicable to public water systems to the United State Environmental Protection Agency. Applicable primary standards for chemicals in water and related to health considerations were published in 1975[5] and for radionuclides in 1976.[7]

Criteria Used

A functionally ideal water has been definied as follows:[8]

> "Ideally, water delivered to the consumer should be clear, colorless, tasteless, and odorless. It should contain no pathogenic organisms and be free from biological forms which may be harmful to human health or aesthetically objectionable. It should not contain concentrations of chemicals which may be physiologically harmful, aesthetically objectionable, or economically damaging. The water should not be corrosive or incrusting to, or leave deposits on, water-conveying structures through which it passes, or in which it may be retained, including pipes, tanks, water heaters, and plumbing fixtures. The water should be adequately protected by natural processes, or by treatment processes, which ensure consistency in quality."

In this evaluation we shall be concerned only with the chemical parameters for which analyses were included in the 1971[1] and 1972[2] reports. The AWWA Committee on Water Quality Goals[4] believed that it should not set goals for those items primarily and principally concerned with health, but deferred to the U.S. Public Health Service (USPHS) and the medical profession regarding toxic substances. In defining standards for water used on interstate carriers, the USPHS[3] listed concentrations of chemical substances in water in two categories -- recommended levels and levels which serve as a basis for rejection of the supply. The U.S. Environmental Protection Agency (USEPA) national interim primary drinking water regulations (NIPDWR)[5] apply to all community and non-community public water supplies and differ slightly from the values reported in the USPHS Drinking Water Standards (DWS). The USPHS/DWS, the American Water Works Association (AWWA) water quality goals, and the USEPA/NIPDWR are listed in Table 1. Regarding its goals, the Committee on Water Quality Goals[4] indicated that the values they established, even though substantially more exacting than existing USPHS Drinking Water Standards with respect to aesthetic qualities, were to be generally obtainable by correct applications of known treatment processes and methods. It was also reported[4] that for all health-related constituents not included in the AWWA goals indicated in Table 1, that these goals shall require complete compliance with all recommended and

Table 1. Potable Water Quality Goals and Standards

Characteristic	AWWA Goals[4]	USPHS/DWS[3]		USEPA/NIPDWR[5,7]
	Physical Factors			
Turbidity	Less than 0.1 unit	5 units		1 unit
Nonfilterable residue	Less than 0.1 mg/l			
Macroscopic and nuisance organisms	No such organisms			
Color	Less than 3 units	15 units		
Odor	No odor	3 threshold odor number (TON)		
Taste	No objectionable taste			
	Chemical Factors (measured in mg/l)			
		Recommended Levels	Rejection Levels	
Aluminum (Al)	Less than 0.05			
Iron (Fe)	Less than 0.05	0.3		
Manganese (Mn)	Less than 0.01	0.05		
Copper (Cu)	Less than 0.02	1.0		
Zinc (Zn)	Less than 1.0	5.		
Filterable residue	Less than 200.0	500.		
Carbon-chloroform extract (CCE)	Less than 0.04	0.2		
Carbon-alcohol extract (CAE)	Less than 0.10			
Methylene blue active substances (MBAS)	Less than 0.20	0.50[a]		
Arsenic (As)		0.01	0.05	0.05
Chloride (Cl)		250.		
Cyanide (CN)		0.01	0.2	
Fluoride (F)		Variable (function of temperature)		Variable (function of temperature)

Table 1 Continued

Characteristic	AWWA Goals	USPHS/DWS Recommended Levels	USPHS/DWS Rejection Levels	USEPA/NIPDWR
Nitrate (NO_3)		45.		10.[b]
Phenols		0.001		
Sulfate (SO_4)		250.		
Barium (Ba)			1.0	1.
Cadmium (Cd)			0.01	0.010
Chromium (Cr^{+6})			0.05	0.05
Lead (Pb)			0.05	0.05
Mercury (Hg)			0.005[c]	0.002
Selenium (Se)			0.01	0.01
Silver (Ag)			0.05	0.05
	Corrosion and Scaling Factors			
Hardness (as $CaCO_3$)	80 mg/l[d]			
Alkalinity (as $CaCO_3$)	e			
Coupon tests (incrustation and loss by corrosion)	f			
	Bacteriologic Factors	**USPHS/DWS**		**USEPA/NIPDWR**
Coliform organisms (by multiple fermentation techniques)	No coliform organisms	Less than 10% of 10 ml samples show coliforms		Less than 10% of 10 ml portions in any month (Samples proportional to population) Less than three or more portions in more than one sample when less than twenty samples are examined per month Less than three or more portions in more than 5% of the samples when 20 or more samples are examined per month
		Less than 60% of 100 ml samples examined during month shall show coliforms		Less than 60% of the portions in any month. Less than five portions in more than one sample when less than five samples are examined per month. Less than five portions in more than 20% of the samples when five or more samples are examined per month.

Table 1 Continued

	Bacteriologic Factors		
Coliform organisms (by membrane filter techniques)	No coliform organisms	Arithmetic mean of all standard samples examined during month shall not exceed 1/100 ml	Less than one/100 ml as the arithmetic mean of all samples examined per month. Less than four/100 ml in more than one sample when less than 20 are examined per month. Less than four/100 ml in more than 5% of the samples when 20 or more are examined per month.
	Radiologic Factors		
Gross beta activity	Less than 100 pCi/l	Less than 1000 pCi/l in absence of ^{90}Sr and alpha emitters	Less than total dose equivalent to total body or any internal organ 4 millirem/year
^{90}Sr		10 pCi/l	8 pCi/l
^{226}Ra		3 pCi/l	5 pCi/l[g]
Gross alpha activity			15 pCi/l
^{3}H (tritium)			20,000 pCi/l.

[a]Alkyl benzene sulfonate (BAS)

[b]As nitrate nitrogen

[c]Mercury value added (see Jour. Am. Water Works Assn., 62(5):285 (1970))

[d]A balance between deposition and corrosion characteristics is necessary; a level of 80 mg/l seems best, generally, considering all quality factors: however, for some supplies a goal of 90 to 100 mg/l may be deemed desirable

[e]Change of not more than 1 mg/l (decrease of increase in distribution system, or after 12 hours at 130°F in a closed plastic bottle, followed by filtration)

[f]90-day tests (incrustation on stainless steel not to exceed 0.05 mg/cm^2; loss by corrosion of galvanized iron not to exceed 5.00 mg/cm^2

[g]$^{226}Ra + ^{228}Ra$

mandatory limits in the current USPHS/DWS. It is assumed that the same statement would be applicable to the USEPA/NIPDWR inasmuch as they do not differ materially from the USPHS/DWS mandatory limits. There are some additions to the USEPA/NIPDWR that are of interest from the chemical standpoint and these include a level for mercury, identify a nitrate-nitrogen level as a primary standard, and designate a primary standard for turbidity.

Classification of Water Quality Parameters

Based upon the levels indicated in the DWS,[3] AWWA goals,[4] and NIPDWR[5] each water supply parameter, for which information was available,[1,2] was divided into four classifications. The four ranges of values listed in Table 2 were coded from lowest level to the highest level as indicated.

In some instances, division into the four classifications was somewhat arbitrary so that the first classification (except for nitrate) generally corresponded to the AWWA goals where identified; the upper limit of classification two to the DWS values defined (except for nitrate and sodium); the upper limit of classification three was some multiple (two to ten times) of the DWS value (except for nitrate which equalled the DWS and EPA/NIPDWR limit, and for sodium where the upper limit corresponded to the permissible water intake based on a total sodium ingestion level from all sources of 1000 mg/day); and classification four exceeded the upper limits specified in classification three.

Methodology

The data used in the study were reported by the Division of Environmental Health, Minnesota Department of Health[1,2] in tabulated form and included information on the name of the supply, 1970 population, ownership (whether private or municipal), number of service connections, source of supply, well number, year well installed, well depth, pump type and capacity, treatment provided, type of storage capacity and amount of storage, date of sample collection, total hardness as $CaCO_3$, alkalinity as $CaCO_3$, calcium and $CaCO_3$, pH, pH of stability, iron, manganese, chloride, sulfate, fluoride, nitrate nitrogen, sodium, potassium, total solids, and comments. The analytical data were reported, as appropriate, in mg/liter.

If more than one well served as the source of supply, the values given for a particular parameter were averaged arithmetically. This average value was the value used for coding purposes. It would have been more appropriate to weigh the quality parameters on the basis of the actual quantities pumped into the supply system, but such data were not available. Where data were supplied on treated water quality parameters these were used for coding purposes, and the coding was represented by filling in one-half of this coding symbol. Two basic coding symbols were used: circles to designate ground water supplies, and squares to designate surface water supplies. Cities which purchased their water from another community were coded in a manner similar to the original supply. Analytical data for standby or abandoned sources were not included in the evaluation.

Table 2. Classification Scheme for Coding Parameter Levels

Parameter	Range of values, mg/l 1	2	3	4	Remarks
Hardness (as $CaCO_3$)	<80	80-100	101-250	>250	AWWA - 80-100
Iron (Fe)	<0.05	0.05-0.3	0.31-3.0	>3.0	AWWA - 0.05 PHS/DWS 0.3
Manganese (Mn)	<0.01	0.01-0.05	0.051-0.5	>0.5	AWWA - 0.01 PHS/DWS - 0.05
Chlorides (Cl)	<100	100-250	251-500	>500	PHS/DWS - 250 AWWA[a]
Sulfate (SO_4)	<100	100-250	251-500	>500	PHS/DWS - 250 AWWA[a]
Nitrates (NO_3N)	<1	1-5	5.1-10.	>10	PHS/DWS - 10 EPA/NIPDWR - 10
Sodium (Na)	<20	20-100	101-270	>270	b
Filterable residue	<200	200-500	501-1000	>1000	PHS/DWS - 500 AWWA - 200

[a]Values of <100 used and represent 1/2 of filterable residue recommended level. Reasoning analogous to that used in PHS/DWS where total dissolved solids 500; Cl - 250; SO_4-250 mg/l

[b]Tentative values proposed in the revised DWS are indicated at 20 mg/l for persons on a total sodium intake of 500 mg/day and 270 mg/l for persons on a total sodium intake of 1000 mg/day.

All sources of public water supply used in the study are shown in Figure 1. The treatment provided for each is indicated according to the legend shown.

Findings and Discussion

The sections which follow indicate the results obtained in classifying the public water supplies according to the coding scheme indicated earlier. The parameters considered included total hardness as $CaCO_3$, iron, manganese, chloride, sulfates, nitrates as nitrogen, sodium, and total dissolved solids or filterable residue.[9] Following codification of each parameter, data are presented on the number of public water systems supplying water at the various levels indicated and the actual populations served water containing the given level.[10]

The data on the chemical characteristics of the water supplies, both ground and surface, were taken from the report "State of Minnesota-Public Water Supply Data-1971". Not all the chemical data were complete for the several parameters reported, and, as a result, not all totals, neither for numbers of supplies nor for populations served, agree. One fair-sized city -- Moorhead, population 29,687 (1970) -- was not included in the evaluation since it has both a ground water and a surface supply and, from the data available, it was impossible to determine the contribution of each source to the total supply.

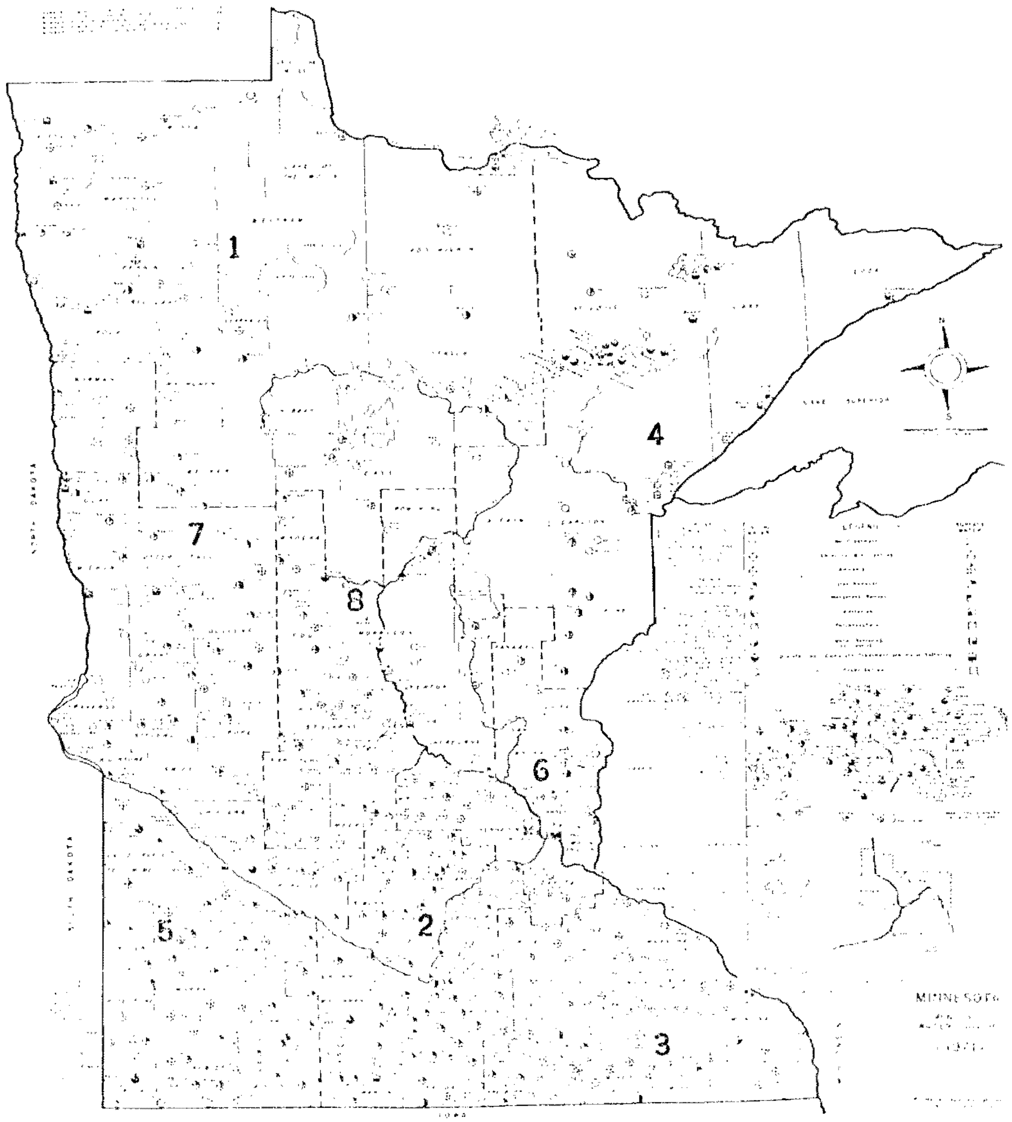
The data have been summarized in tabular and graphical form on the basis of the numbers of persons consuming waters of a given quality as indicated by the level for a particular chemical entity as well as on the basis of the numbers of systems supplying waters of the stated qualities. Data are reported for both untreated and treated ground water and for surface water supplies. Whether the results were presented for treated or untreated supplies depended on whether chemical data were provided on the finished waters. If chemical data on the finished or treated water supply were reported, these data were utilized in indicating the chemical characteristics of the water consumed. Where there were no data on treated waters, the assumption was made that the people served by that particular supply were consuming waters that had the characteristics shown for the untreated supply.

Total Hardness as $CaCO_3$

This parameter is of some interest from a public health standpoint because of the reported inverse relationship between water hardness and cardiovascular disease mortality. Although a relatively large body of literature exists purporting statistical relationships between these two parameters, there is no epidemiological evidence indicating such an association. The state of knowledge in this area may be exemplified best by the following paragraphs from Winton and McCabe.[11]

"We see several possibilities for the outcome of this water story (cardiovascular disease and water minerals). One is that the hypothesis will be proven true and the factor defined. We will then

Figure 1.



be able to adjust the composition of drinking water as a part of a heart-disease prevention program. Another is that we will find the correlation a mistake, a fault of method and data, ... the third possibility is that, although this data is telling us something, what it is saying may have very little to do with water. Water quality may only appear to influence CDV's (cardiovascular disease) because it keeps company with a presently unrecognized influential factor."

The classification applied to the total hardness data is based upon the recommendation[4] of a level of 80 to 100 mg/l of hardness expressed as $CaCO_3$ and included the following coding scheme: 1) values reported below 80 mg/l; 2) those between 80 and 100 mg/l, i.e., those falling within the limits recommended by the AWWA; 3) those in the range of 101 to 250 mg/l; and 4) those exceeding a value of 250 mg/l.

Figure 2 shows the levels of hardness observed in the ground and surface water supplies. It will be noted that there are very few supplies in the state (the exceptions being essentially surface water supplies) with hardness levels below the AWWA recommended goals of 80-100 mg/l. By far, most of the supplies exceeded concentrations of 250 mg/l. These values represent hardness of the water supplied to the consumer, but not necessarily consumed by him. In some instances individual water softening facilities may be provided. There is no indication of whether the water used for drinking purposes by-passes the softening unit.

Table 3 indicates that of a total of 532 ground water supplies for which data on raw water characteristics alone were reported, five met the criterion of less than 80 mg/l and served a total of 974 persons; four supplies were in the range of 81 to 100 mg/l and these served 3,844 persons; 138 supplies were in the range of 101 to 250 mg/l and served 341,519 persons; and 385 supplies exceeded a level of 250 mg/l and served 953,873 persons. The total number of persons served by these 532 ground water supplies was 1,300,230.

These data further indicate that only nine of the 532 supplies (≈1.7 percent) serving a total of 4,818 persons met the level for total hardness recommended by the AWWA. This represented only 0.37 percent of the persons currently served untreated* ground water supplies. In other words, 99.63 percent of the people using untreated municipal ground water were being provided waters in excess of the AWWA criterion.

Data were reported[3] on 39 treated ground water supplies serving a total of 144,947 persons. Nine of these supplies, serving 33,937 persons, showed a hardness level below 80 mg/l; three supplies serving 8,393 persons had a hardness level of 81 to 100 mg/l; 16 supplies serving 36,311 persons supplies water in the range of 101 to 250 mg/l; and 11 supplies serving 66,306 persons supplied water with a hardness level exceeding 250 mg/l.

* As defined earlier. However, they could have disinfection and fluoridation but these would have no major effect on the parameter indicated.

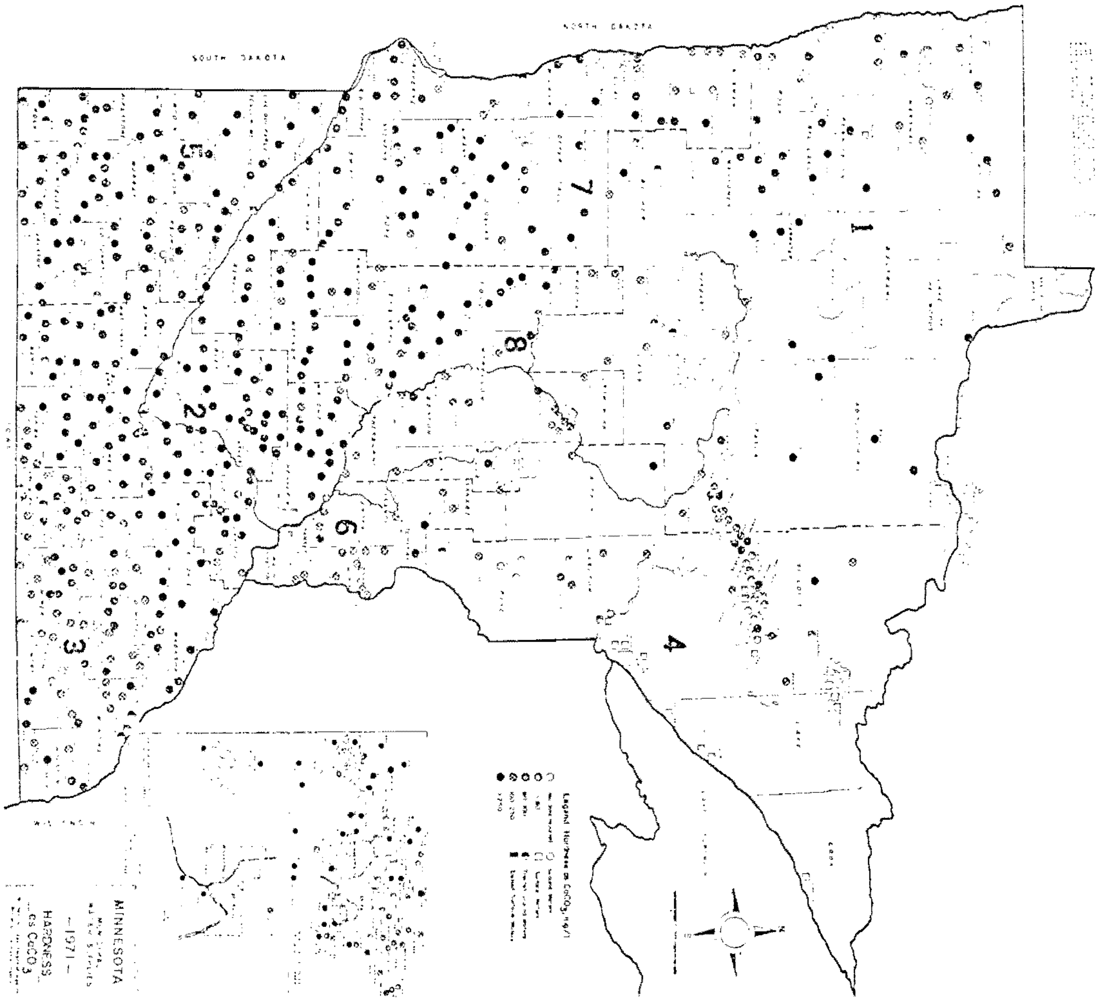


Figure 2.

Table 3. Total Hardness Data.

Concentration, mg/l as $CaCO_3$	Raw Water				Treated Water			
	Ground		Surface		Ground		Surface	
	No. Supplies	Pop. Served	No. Supplies	Pop. Served	No. Supplies	Pop. Served	No. Supplies	Pop. Served
< 80	5	974	2	9772	9	15937	23	810920
81-100	4	3844			3	8393	12	431725
101-250	138	341519			16	54311	4	13281
>250	385	953873			11	66306		
TOTALS	532	1300210	2	9772	39	144947	39	1255926

Thus, only [illegible] of the 39 (30.8 percent) treated ground water supplies serving 24,7[illegible] (1[illegible].8 percent) persons met the criterion indicated by the AWWA.

Only two supplies served untreated surface waters to 9,77[illegible] persons these waters had a hardness level below 80 mg/l. Treated surface waters were used to supply 39 communities serving 1,[illegible],926 persons for which hardness data were reported. Twenty-three supplies serving 810,920 persons, provided water with a hardness level below 80 mg/l; and 12 supplies serving [illegible],725 persons supplied water in the hardness range of 81 to 100 mg/l. Thus, of the 39 supplies serving 1,[illegible],926 persons, 35 supplies (90.[illegible] percent) serving 1,[illegible] persons (99.0 percent) met the criterion recommended by the AWWA.

Figure 3 summarizes the data given in Table A-1 (Appendix A) on hardness levels found in raw and treated ground and surface waters as a function of the number of supplies serving such waters and the number of consumers exposed to waters of the hardness concentration indicated. From these data, it is possible to identify the percentage of the population served waters of a given hardness level and the percentage of supplies serving water of that particular quality level. More detailed information on the actual levels of hardness indicated, as well as the number of supplies providing and the number of persons consuming waters of that hardness level, are shown in Table A-1.

Raw and finished water quality data for 27 plants employing some form of softening were available. These data were analyzed and the results are summarized in Table 4. These data show that average reductions in hardness level ranged from 52 to 54 percent for the lime softening processes used in 19 plants. For the seven plants employing zeolite softening the average reduction in hardness amounted to 69 percent. Hardness data reported for the finished (treated waters) could vary markedly depending upon the amount of blending, if any, taking place. Where sodium data were reported for two supplies providing lime soda ash treatment, the sodium concentrations increased approximately three-to four-fold. Where zeolite softening was used, the sodium concentrations increased approximately 1.5-to 150-fold. The median increase in sodium was 15-fold. The subject of sodium levels will be taken up in more detail in the section on sodium.

Table 4. Removal of Hardness - Public Water Supplies

Softening Treatment Process Employed	No. of Supplies	Hardness As $CaCO_3$ Removed, Average, %	Removal Range, %	Sodium Levels: No. of Supplies	Sodium Levels: Increase in Na Concentration, %
Lime softening	8	[illegible]	9-7[illegible]		
Lime soda ash	11	[illegible]	[illegible]-70	[illegible]	[illegible]07-3[illegible]
Zeolite	7	[illegible]	[illegible]	7	1[illegible]4-15,000
Other (alum + coagulant)	1	[illegible]			
Total	27				

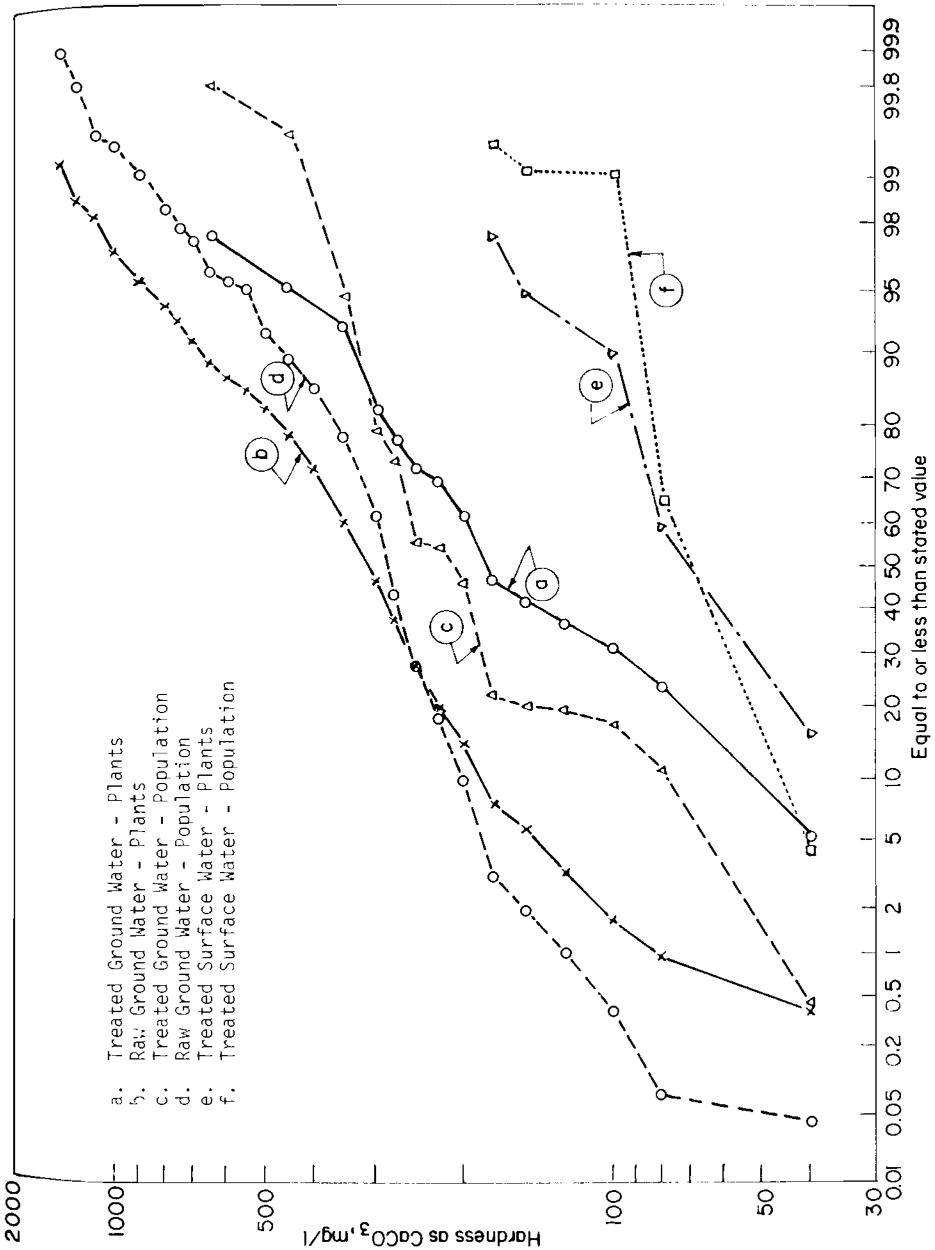


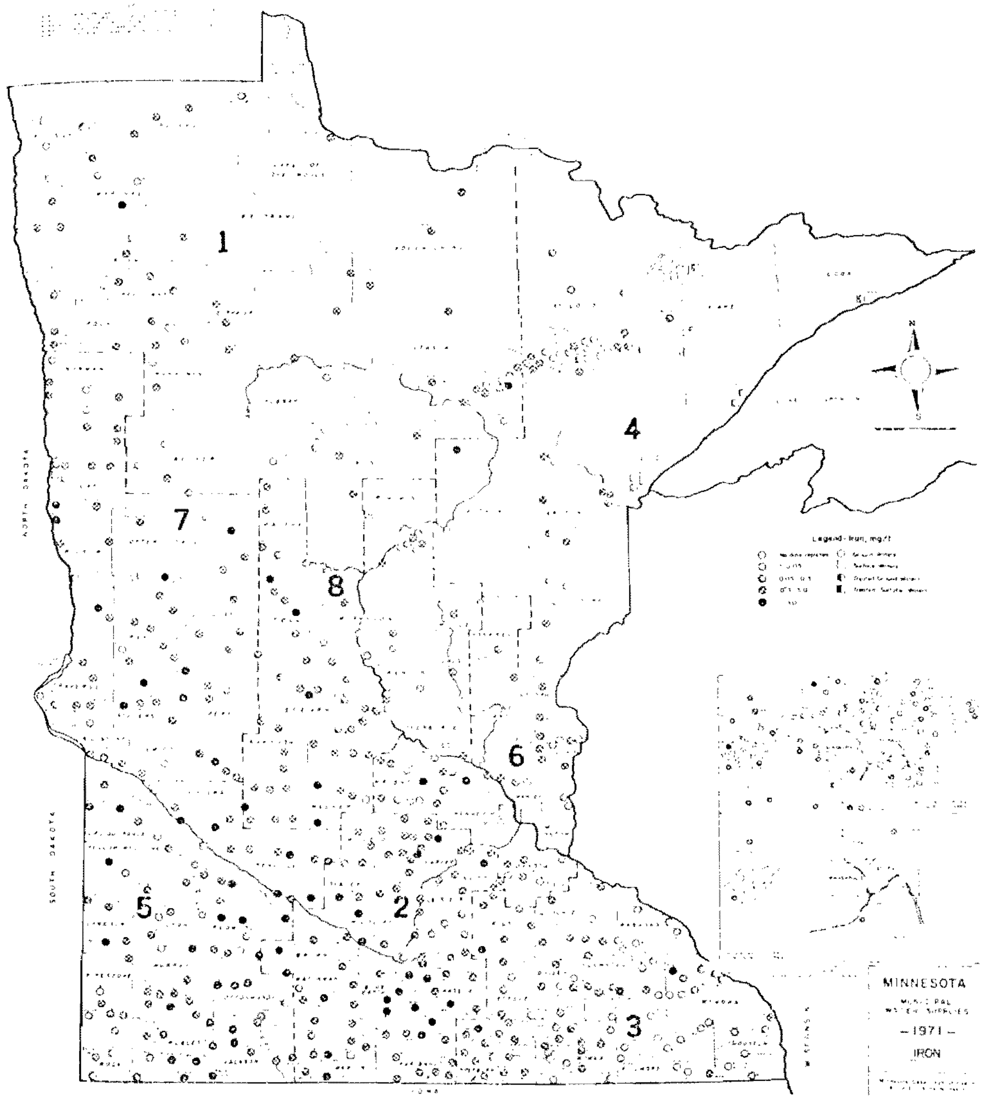
Fig. 3 Probability Plot. Hardness as $CaCO_3$. Minnesota Water Supplies. 1971.

Iron (Fe)

There is no public health problem associated with iron concentrations in the ranges found in drinking water. However, iron is objectionable in public water supplies because the taste of water may be impaired, plumbing fixtures may be stained, laundered clothes may be spotted, and deposits may accumulate in distribution systems. Taste threshold tests indicate that the form of the iron found markedly affects the ability to detect the levels of iron present.[12] The recommended concentration of 0.3 mg/l is generally acceptable in public water supplies as the characteristic red stains and deposits of hydrated ferric oxide do not show themselves.

Figure 4 shows the coded concentrations of dissolved iron in public water supplies in Minnesota. These concentrations were coded as follows:[4] 1) <0.05 mg/l which is the limit recommended by the AWWA; 2) between 0.05 and 0.3 mg/l, the range between the AWWA recommendation and that recommended in the DWS;[3] 3) between 0.31 and 3.0 mg/l, up to 10 times the value recommended in the DWS; and 4) greater than 3.0 mg/l. An examination of Fig. 4 shows that the highest concentration of iron generally occurred in those public water supplies located in south central, southwestern, and west central Minnesota north and south of the Minnesota River. Fig. 5 shows the number of plants supplying water at the various concentrations reported and the populations consuming such waters. These data are summarized in Table 5 and show that iron values were reported for 532 public ground water supplies serving 1,300,210 persons, distributed as follows: 48 supplies had reported raw water concentrations of less than 0.05 mg/l and served 84,740 persons; 102 supplies had reported concentrations in the range of 0.05 to 0.30 mg/l and served 315,127 persons; 307 supplies had reported concentrations in the range of 0.31 to 3.0 mg/l and served 799,173 persons; 74 supplies had reported concentrations of 3.1 to 10.0 mg/l and served 100,311 persons; and 1 plant serving 859 persons had a reported concentration of more than 10.0 mg/l. Two raw water surface supplies serving 9,772 persons showed concentrations in the range of 0.31 to 3.0 mg/l. There were 39 treated ground water supplies serving 144,947 persons, distributed as follows: eight supplies had reported concentrations <0.05 mg/l and served 12,587 persons; 25 supplies had reported concentrations in the range of 0.05 to 0.30 mg/l and served 124,357 persons; and 6 supplies had reported concentrations in the range of 0.31 to 3.0 mg/l and served 8,023 persons. There were also 39 treated surface water supplies serving 1,255,926 persons with reported iron concentrations as follows: 19 supplies serving 506,431 persons with concentrations <0.05 mg/l; 17 supplies serving 747,586 persons with concentrations in the range of 0.05 to 0.3 mg/l; and 3 supplies serving 1,909 persons with concentrations in the range of 0.31 to 3.0 mg/l. These data show that 5.8 percent of the supplies provided raw ground water to 5.1 percent of the population meeting the AWWA recommended value of <0.05 mg/l; 28 percent supplied raw ground water to 31 percent of the population which met the DWS level of 0.3 mg/l; approximately 57.5 percent supplied raw ground water to approximately 61.5 percent of the population which had iron concentrations in the range of 0.31 to 3.0 mg/l; approximately 14.4 percent supplied raw ground water

Figure 4



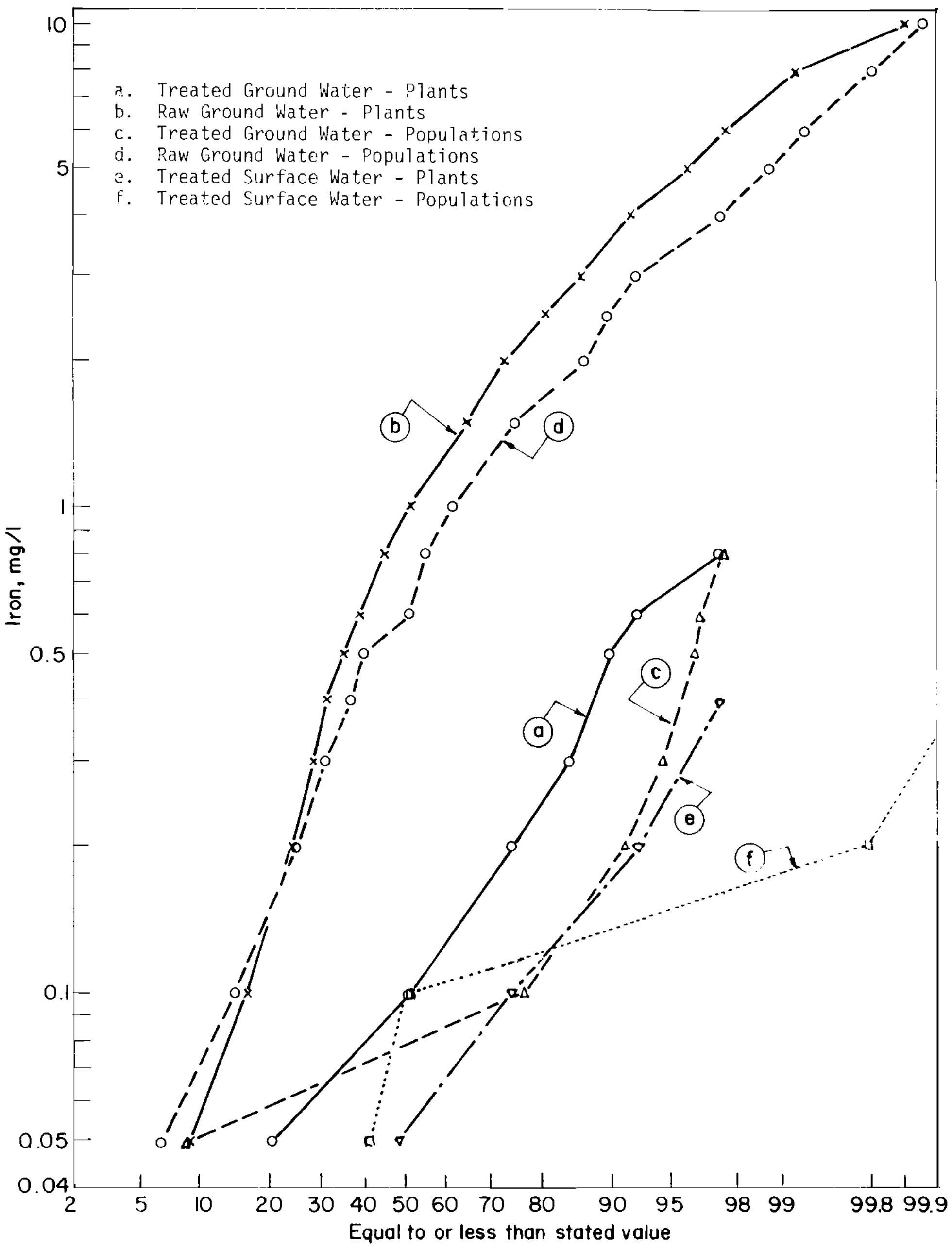


Fig. 5. Probability Plot. Iron. Minnesota Water Supplies. 1971.

Table 5. Iron.

Concentration, mg/l	Raw Water				Treated Water			
	Ground		Surface		Ground		Surface	
	No. Supplies	Pop. Served	No. Supplies	Pop. Served	No. Supplies	Pop. Served	No. Supplies	No. Served
<0.05	48	84740			8	12587	19	506431
0.05-0.30	102	315127			25	124337	17	747586
0.31-3.0	307	799173	2	9772	6	8023	3	1909
3.1-10.0	74	100311						
>10.0	1	359						
TOTALS	532	1300210	2	9772	39	144947	39	1255926

to approximately 6.4 percent of the population which had iron concentrations in the range of 3.1 to 10.0 mg/l; and approximately 0.1 percent supplied raw ground water to approximately 0.07 percent of the population which had concentrations in excess of 10.0 mg/l. Similar information on treated ground water supplies can be obtained from Fig. 5 and for both raw and treated surface and ground water supplies from Table A.2.

Iron removal data are reported for 33 plants treating ground water and for 13 plants treating surface waters. The removals reported for ground water supplies ranged from 47.8 to 99.3 percent with a median value of 92.4 and a mean value of 87.4 percent. In the case of the surface water sources removals ranged from 33.3 to 99 percent with a median value of 90.9 and a mean value of 81.6 percent.

Manganese (Mn)

At the concentrations normally found in water supplies, manganese is of little or no public health concern. However, manganese is objectionable in public water supplies because taste may be impaired,[12] plumbing fixtures stained, laundered clothes spotted, and deposits in distribution systems accumulated.

Manganese levels in public water supplies in Minnesota are shown in Fig. 6. As shown, a number of supplies, particularly in southwestern, south central, and west central Minnesota, exceeded the levels recommended by the AWWA and the DWS. The concentration values or ranges coded are as follows: 1) <0.01 mg/l recommended by the AWWA; 2) 0.01 to 0.05 mg/l, the range between that recommended by the AWWA and the DWS; 3) 0.051 to 0.5 mg/l, in the range up to 10 times the DWS recommended level; and 4) greater than 0.5 Mg/l. The results obtained are summarized in Table 6 and indicate the following: of the 529 untreated ground water supplies serving 1,298,429 persons only 2 supplies serving 3,002 persons met the recommended criterion of <0.01 mg/l Mn; an additional 226 supplies serving 631,617 persons complied with the DWS criterion of 0.05 mg/l; 272 supplies serving 625,223 persons exceeded the recommended level by as much as a factor of 10; and 29 supplies serving 38,587 persons reported a manganese level in excess of 0.50 mg/l. These data indicate only 0.38 percent of the supplies serving 0.23 percent of the population met the AWWA criterion of 0.01 mg/l of manganese. A total of 43.1 percent of the supplies serving a total of 38.9 percent of the population met the DWS criterion of 0.05 mg/l. Thus, there were 56.9 percent of the supplies serving 51.1 percent of the population that exceeded the DWS criterion of 0.05 mg/l.

In the case of treated ground water, data were available for 39 supplies serving 144,948 persons. In this category, none of the supplies met the AWWA criterion, 26 plants serving 72,881 persons met the DWS criterion of 0.05 mg/l; these values represented 66.7 percent of the supplies and 50.3 percent of the population served. Thus, there were 33.3 percent of the plants (13 supplies) that produced and 49.7 percent of the population (72,067 persons) that consumed water which exceeded the DWS criterion.

Figure 6

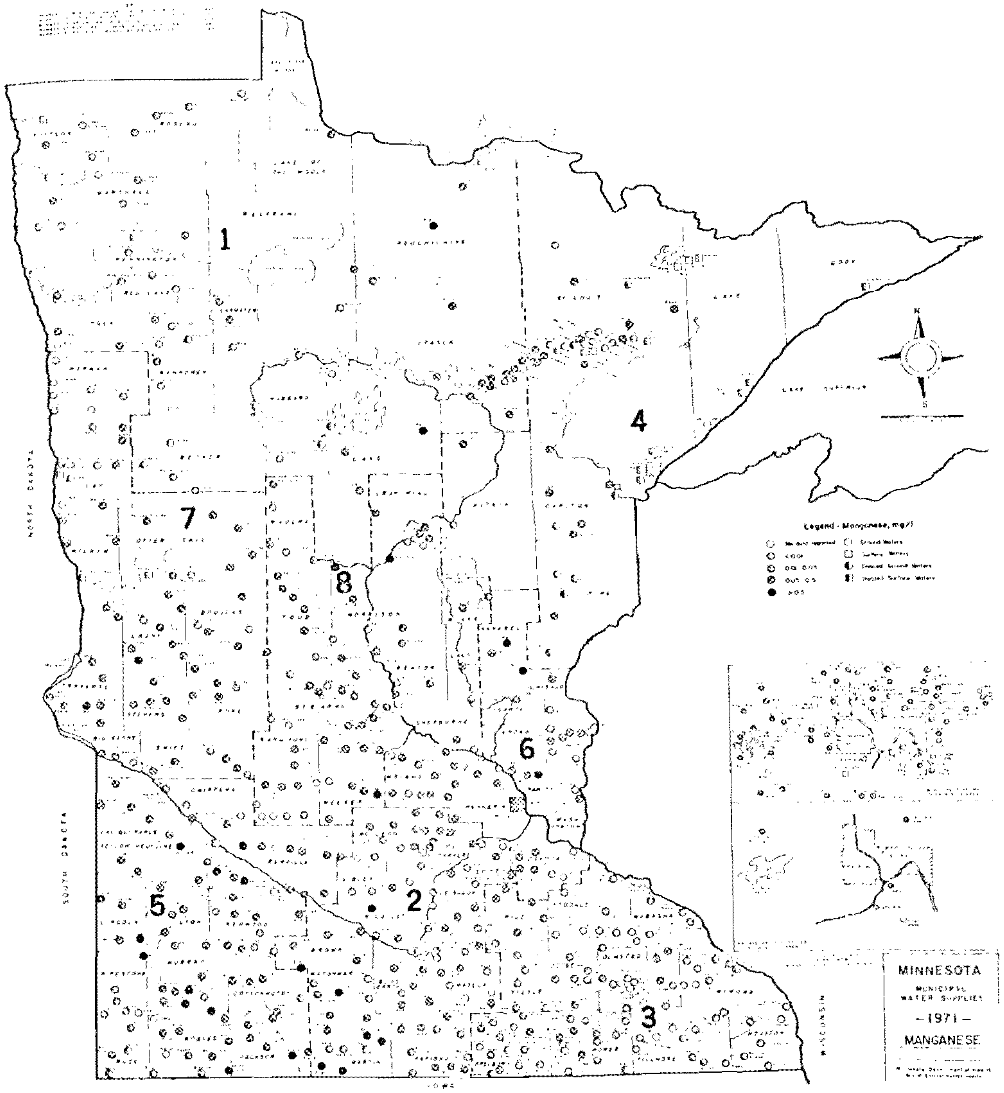


TABLE 6. Manganese.

Concentration, mg/l as Mn	Raw Water: Ground No. Supplies	Raw Water: Ground Pop. Served	Raw Water: Surface No. Supplies	Raw Water: Surface Pop. Served	Treated Water: Ground No. Supplies	Treated Water: Ground Pop. Served	Treated Water: Surface No. Supplies	Treated Water: Surface Pop. Served
<0.01	2	3002						
0.01-0.05	226	631617	2	9772	26	72881	32	637034
0.051-0.50	272	625223			11	70101		
>0.50	29	38587			2	1966		
TOTALS	529	1298429	2	9772	39	144948	32	637034

Both untreated surface water sources serving 9,772 persons and the 32 treated surface water supplies serving 637,034 persons exceeded the AWWA criterion of 0.01 mg/l but met the DWS criterion of 0.05 mg/l.

Additional information is provided in Fig. 7 and Table A.3. Figure 7 shows that 56 percent of the ground water supplies exceeded the DWS permissible concentration of 0.05 mg/l of manganese and that 51 percent of the population were supplied with ground waters in excess of this concentration. In the case of treated supplies these two percentages were 34 and 50 percent, respectively.

Manganese removal data were reported for 27 supplies -- seven surface water and 20 ground water. The removals reported for the surface waters ranged from <60.0 to <96.7 percent with a mean value of <77.8 percent and a median value of 77.8 percent. Removals for the 20 ground waters ranged from 8.3 to <99.4 percent with a mean value of <70.7 percent and a median value of <81.6 percent.

Chlorides (Cl^-)

High concentrations of chloride in water produce tastes, possibly making it objectionable for potable use. The four classifications used for chlorides were based on the AWWA[4] criterion of 100 mg/l and the level of 250 mg/l recommended by the DWS.[3] The classifications included: <100 mg/l which essentially met the AWWA criterion; a range of 100 to 250 mg/l which satisfied the DWS recommended level of 250 mg/l; a range of 251 to 500 mg/l which exceeded the DWS by a factor of 2; and a value in excess of 500 mg/l. As shown in Fig. 8, most supplies for which data were available met the lowest recommended value of 100 mg/l. There are a few supplies in northwestern Minnesota that have chloride concentrations in the range of 251 to 500 mg/l.

More specifically, the data in Table 7 show that of the 530 untreated ground water supplies, 512 (96.5 percent) met the AWWA criterion of <100 mg/l. These supplies served 1,263,259 persons (98.5 percent) of the 1,282,337 persons in this category. Fourteen additional supplies (26 percent) serving 15,924 persons (1.2 percent) met the DWS criterion of 250 mg/l. Only four supplies (0.75 percent) serving 3,154 persons (0.25 percent) did not meet the DWS criterion of 250 mg/l. The two raw water surface supplies serving 9,772 persons had chloride concentrations of <100 mg/l. The 36 treated ground water supplies serving 568,382 persons and the 40 treated surface water supplies serving 824,432 persons all showed chloride concentrations of <100 mg/l.

Additional information is presented in Fig. 9 and Table A.4.

Sulfates as $SO_4^{=}$

Sulfate ions in drinking water can have a cathartic effect on occasional users, but acclimatization is rapid. Comments in this regard in the interim drinking water regulations are of interest.[5]

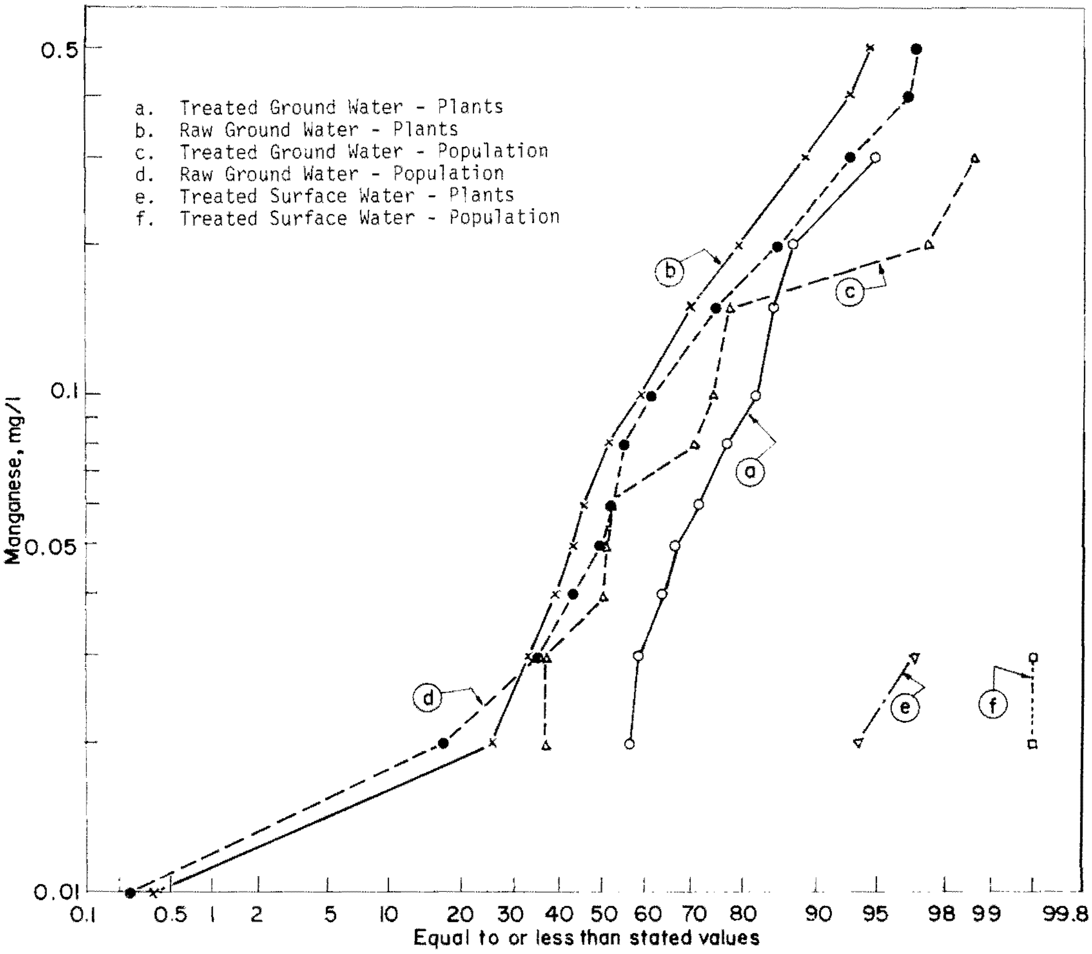


Fig. 7. Probability Plot. Manganese. Minnesota Water Supplies. 1971.

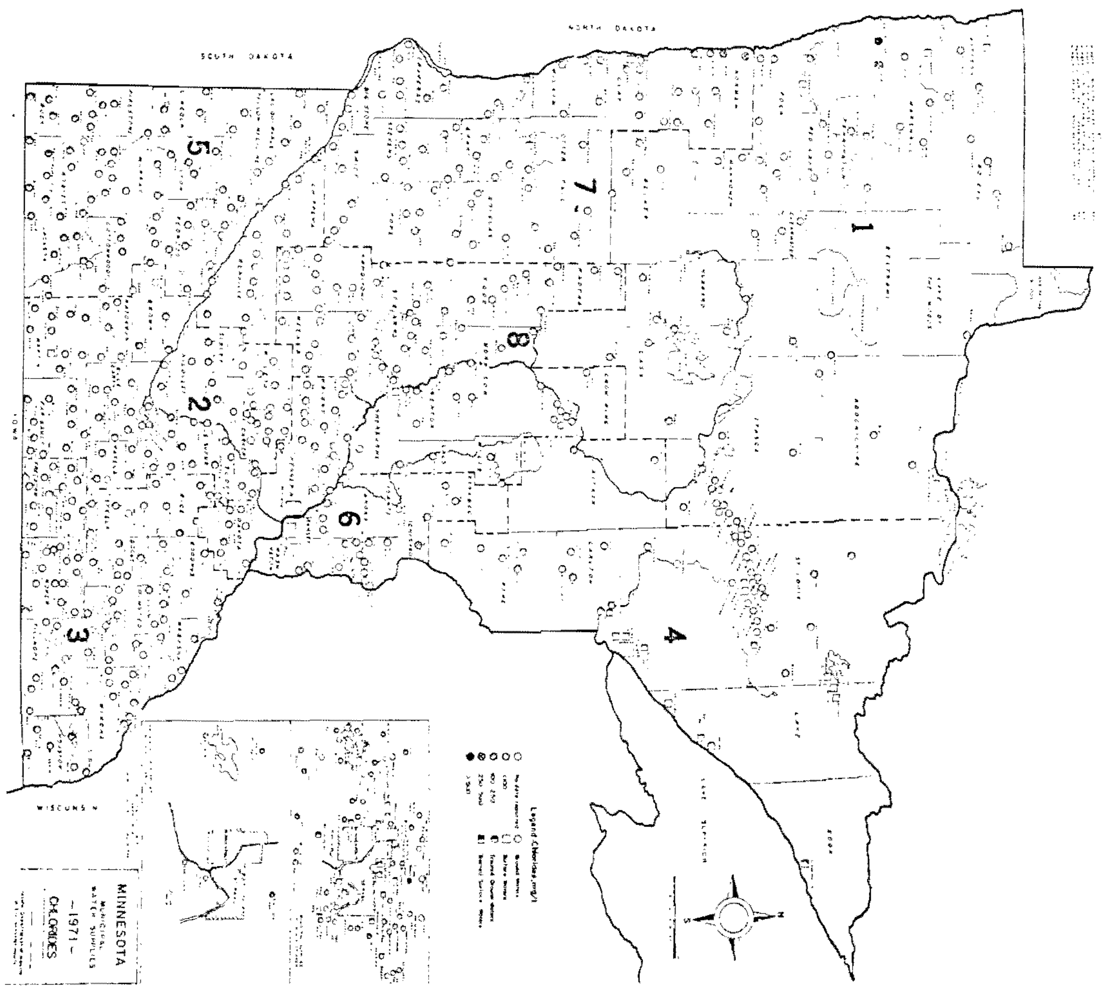


Figure 8

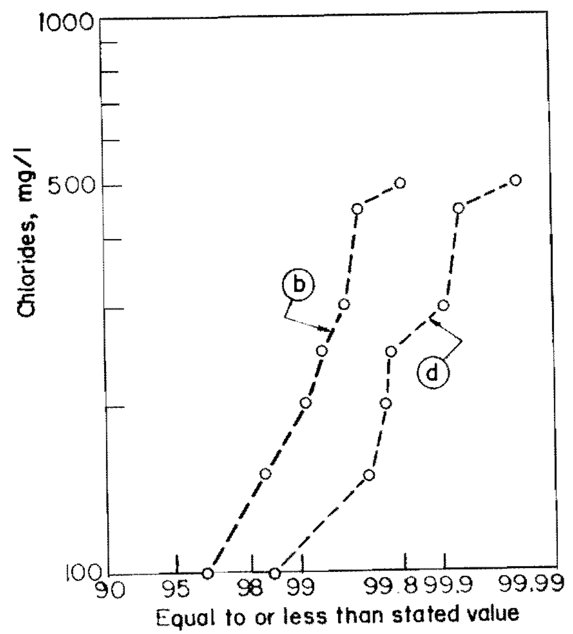


Fig. 9. Probability Plot. Chlorides. Minnesota Water Supplies. 1971. b. Raw Ground Water - Plants; and d. Raw Ground Water - Populations

Table 7. Chlorides.

Concentration, mg/l as Cl	Raw Water				Treated Water			
	Ground		Surface		Ground		Surface	
	No. Supplies	Pop. Served	No. Supplies	Pop. Served	No. Supplies	Pop. Served	No. Supplies	Pop. Served
<100	512	1263259	2	9772	36	568382	40	825433
100-250	14	15924						
251-500	3	2852						
>500	1	302						
TOTALS	530	1282337	2	9772	36	568382	40	825433

"A relatively high concentration of sulfate in drinking water has little or no known laxative effect on regular users of the water, but transients using such water sometimes experience a laxative effect. It is recommended that the State institute monitoring programs for sulfates, and that transients be notified if the sulfate content of the water is high. Such notification should include an assessment of the possible physiological effects of consumption of the water."

Additional comments are quoted from Water Quality Criteria.[13]

"Data collected by the North Dakota State Department of Health on laxative effects of mineral quality in water indicated that more than 750 mg/l sulfate had a laxative effect, and less than 600 mg/l did not.[14] If the water was high in magnesium, the effect took place at lower sulfate concentrations than if other cations were dominant. A subsequent interpretation[15] showed that laxative effects were experienced by sensitive persons not accustomed to the water when magnesium was about 200 mg/l, and the average person when magnesium was 500-1000 mg/l."

The criteria used for classifying waters of varying sulfate levels were identical to the criteria used in classifying chloride levels and are based on recommended levels of the AWWA[4] and DWS[3], i.e., 1) <100 mg/l which essentially met the AWWA criterion; 2) a range from 100 to 250 mg/l, which satisfied the DWS recommended level of 250 mg/l; 3) a range of 251 to 500 mg/l, which exceeded the DWS by a factor of two; and 4) a value greater than 500 mg/l. The actual considerations observed for the various water supplies, based on these classifications, are shown in Fig. 10.

Table 8 shows that there were 532 untreated ground water supplies serving 1,297,678 persons for which sulfate data were available. Of this number, 364 supplies serving 1,112,788 persons met the AWWA criterion of less than 100 mg/l of sulfate; an additional 71 supplies serving 66,762 persons met the DWS criterion of 250 mg/l; 49 supplies serving 74,400 persons supplies water with a sulfate content of 251-500 mg/l; and 48 supplies serving 43,728 persons supplied water with a sulfate content exceeding 500 mg/l. Thus, it will be seen that 68.4 percent of the ground water supplies serving 85.7 percent of the population satisfied the AWWA criterion of 100 mg/l sulfate; a total of 81.7 percent of the supplies and 91.1 percent of the population met the DWS criterion of 250 mg/l; and 18.3 percent of the supplies serving 8.9 percent of the population did not meet the DWS criterion. The data also point out that nine percent of the supplies serving 3.3 percent of the population exceeded a sulfate concentration of 500 mg/l. Many of these high sulfate water supplies are located in southwestern Minnesota.

There were 39 supplies serving treated ground water to 171,539 persons. Of this number, 32 supplies (82.1 percent) serving 161,594 persons (94.2 percent) met the AWWA criterion of <100 mg/l; an additional 4 supplies (total 92.3 percent) serving 8,652 persons (total 99.2 percent) met the DWS criterion of 250 mg/l; and there were three supplies serving

Figure 10

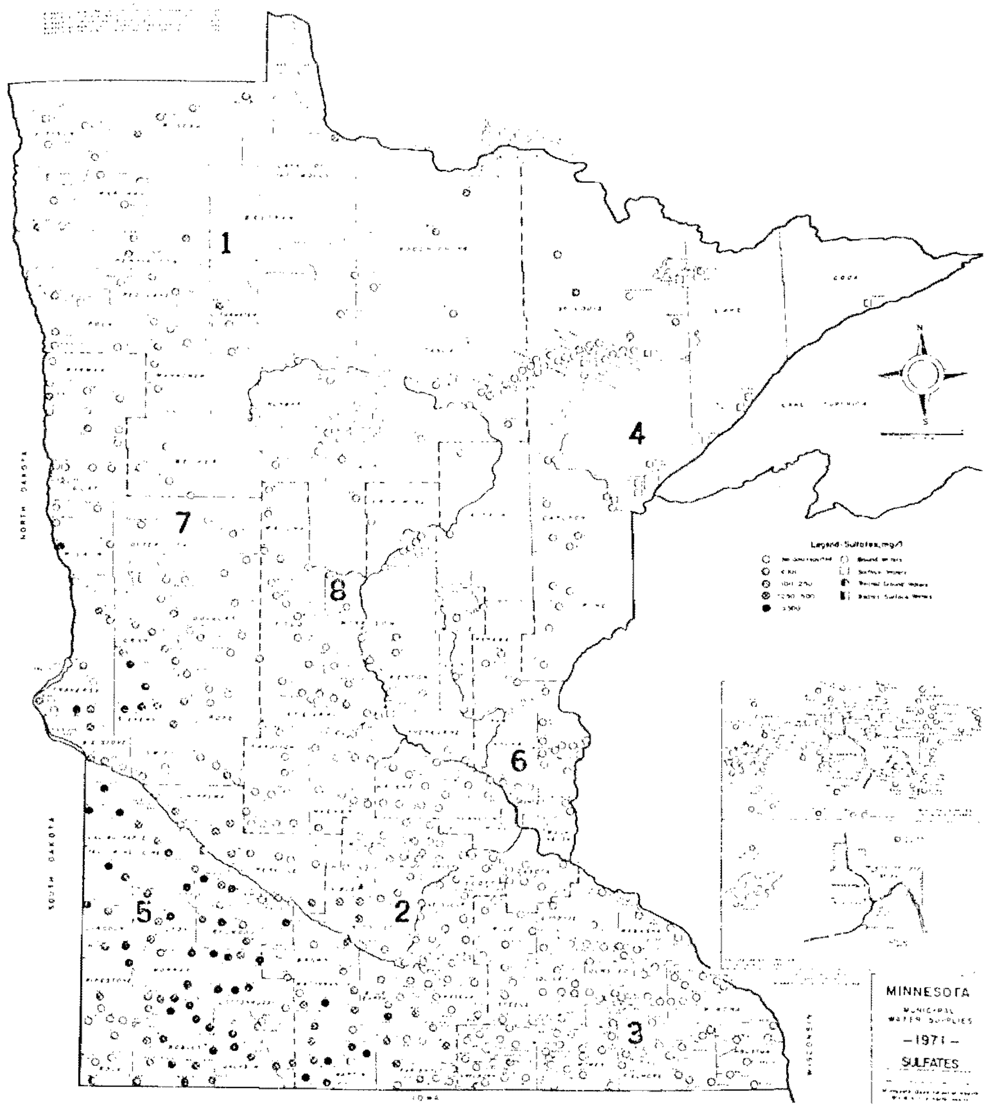


Table 8. Sulfates.

Concentration, mg/l as SO_4	Raw Water: Ground No. Supplies	Raw Water: Ground Pop. Served	Raw Water: Surface No. Supplies	Raw Water: Surface Pop. Served	Treated Water: Ground No. Supplies	Treated Water: Ground Pop. Served	Treated Water: Surface No. Supplies	Treated Water: Surface Pop. Served
<100	364	1112788	2	9772	32	161594	34	1223594
100-250	71	66762			4	8652	4	5740
251-500	49	74400			2	738		
>500	48	43728			1	555		
TOTALS	532	1297678	2	9772	39	171539	38	1229334

1,293 persons (respectively, 7.7 percent and 0.8 percent) that exceeded the DWS criterion of 250 mg/l.

As before, there were the two untreated surface supplies serving 9,722 persons that met the AWWA criterion of <100 mg/l. Of the total of 38 treated surface water supplies serving 1,229,334 persons, 34 supplies (89.5 percent) serving 1,223,594 persons (99.5 percent) met the AWWA criterion of <100 mg/l. The four remaining plants serving 5,740 persons met the DWS criterion of 250 mg/l.

Additional information will be found in Fig. 11 and in Table A.5.

Nitrates (NO_3)

High nitrate concentrations in ground water supplies in Minnesota, particularly in the case of private individual supplies, have been responsible for methemoglobinemia in infants.[16,17] Physicians have been advised to inform parents of the desirability of substituting a water supply low in nitrate in preparing infant formulas. The development of methemoglobinemia is of concern in infants under three months of age and is dependent upon the bacterial conversion of the nitrate into nitrite (NO_2^-). Hemoglobin is converted to the methemoglobin by the nitrite absorbed into the blood stream. The altered pigment can no longer transport oxygen, and the chemical manifestation of methemoglobinemia is that of oxygen deficiency or suffocation. Older children and adults generally do not seem to be affected by acute exposure. However, more recent studies in Isreal[18] indicate possibilities of chronic exposure. Another example is that of a 56-year old male who had been receiving home dialysis treatments with water containing a high nitrate concentration to produce the dialysate.[19] Extensive reviews of the problem of high nitrates in ground water supplies and methemoglobinemia have been published.[20,21,22]

The criterion used for classifying nitrate levels in water supplies was based upon the permissible concentration recommended in the DWS[3] and EPA/NIPDWR[2] of 45 mg/l of nitrate or 10 mg/l of nitrate-nitrogen. A somewhat different system was used in classifying nitrate levels in water than that used heretofor in that the first category represented water having nitrate-nitrogen concentrations below 1 mg/l; the second category included waters having a range in concentration from 1 to 5 mg/l of nitrate-nitrogen; the third category included waters having concentrations in the range of 5.1 to 10 mg/l of nitrate-nitrogen, the upper level just meeting the DWS and EPA criteria; and the fourth category included those supplies exceeding nitrate-nitrogen levels of 10 mg/l.

As noted in Fig. 12, most supplies in Minnesota met the criterion of 10 mg/l nitrate-nitrogen. Only two public ground water supplies in Pipestone County and one each in Murray, Lyon, and Stearns County exceed the recommended limit. There may be several individual wells that deliver waters higher in nitrate, but when mixed with other well waters serving the community the levels are below the recommended level of 10 mg/l nitrate-nitrogen. A few scattered samples had concentrations in the range of 5.1 to 10 mg/l of nitrate-nitrogen. Since so few samples were collected,

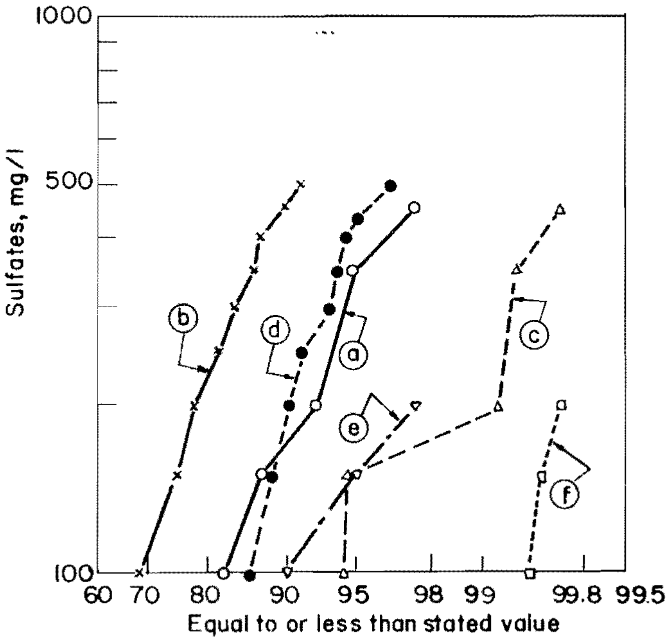
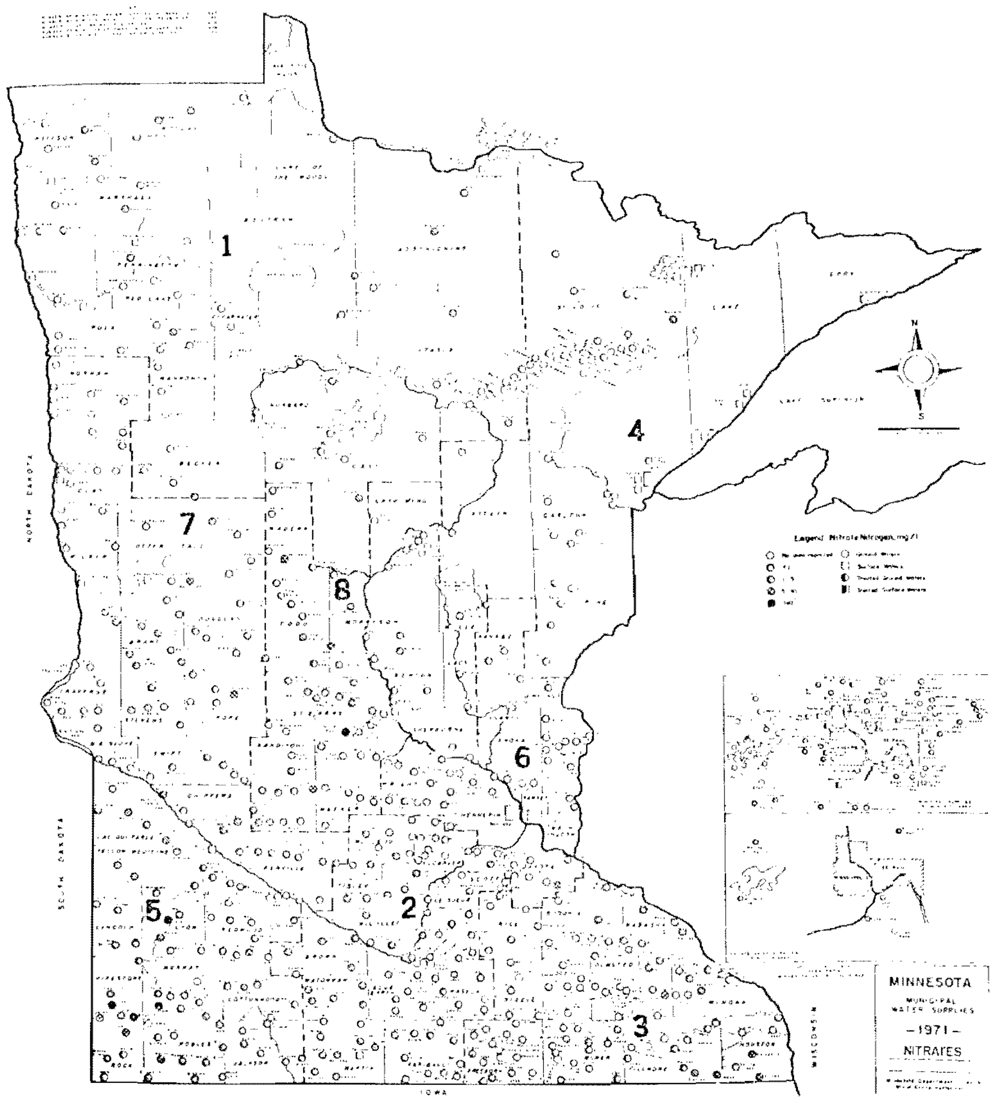


Fig. 11 Probability Plot. Sulfates. Minnesota Water Supplies. 1971. a. Treated Ground Water - Plants; b. Raw Ground Water - Plants; c. Treated Ground Water - Population; d) Treated Ground Water - Population; e. Treated Surface Water - Plants; and f. Treated Surface Water - Population.

Figure 12



seasonal variations are not known nor can they be predicted. Some data reported for a single water supply in Kansas[23] showed seasonal variations between 100 and 400 mg/l during the period April 1971 through July 1972.

With reference to Table 9, we note that values for nitrate-nitrogen were reported for 529 untreated ground water supplies serving a total population of 1,283,214. Of this number, 350 supplies serving 896,459 persons reported values of less than 1 mg/l nitrage-nitrogen; 159 supplies serving 370,974, values of 1 to 5 mg/l nitrate-nitrogen; 15 supplies serving 13,085 persons, values of 5.1 to 10 mg/l nitrate-nitrogen; and five supplies serving 2,696 persons exceeded the permissible concentration of 10 mg/l nitrate-nitrogen. Thus, one percent of the supplies serving 0.21 percent of the population exceeded permissible limits.

There were 39 treated ground water supplies serving 163,942 persons. Of this number, 30 supplies serving 140,380 persons showed concentrations of less than 1 mg/l of nitrate-nitrogen and the remaining nine supplies serving 23,562 persons had concentrations in the range of 1 to 5 mg/l nitrate-nitrogen.

The two untreated surface supplies serving 9,772 persons and 38 treated surface supplies serving 1,233,427 persons reported concentrations of nitrate-nitrogen below 1 mg/l.

Additional material will be found in Fig. 13 and Table A.6.

Conventional treatment processes are ineffective for the removal of nitrates from water. Robeck[24] reviewed the techniques for removal of nitrates in water and concluded that demineralization, distillation, and anion exchange resins may be used but that they are expensive and not too much is known concerning their operating characteristics. St. Amant and McCarty[25] described a denitrification process for reducing nitrate levels in water.

Sodium as Na^+

Restricted sodium intakes may be recommended by physicians for a significant portion of the population, including persons suffering from hypertension, edema associated with congestive cardiac failure, and women with toxemias of pregnancy. The public health implications of sodium in water have been discussed in the literature.[26,27,28] For persons on a low sodium intake regimen (500 mg/day), the recommended contribution of sodium from water would be 40 mg/day or a concentration of approximately 20 mg/l. For persons on a daily intake of sodium of 1,000 mg/day, the permissible concentration increases to 270 mg/l for a total water intake under these conditions of 540 mg/day.

Highest sodium concentrations in the state seem to be concentrated in waters along the Minnesota River Basin and the western region as shown in Fig. 14. However, it will also be noted that there were many water supplies for which no sodium values were reported. A summary of sodium and potassium contents of municipal water supplies in Minnesota was reported in 1963.[29]

Table 9. Nitrate.

Concentration, mg/l as N	Raw Water				Treated Water			
	Ground		Surface		Ground		Surface	
	No. Supplies	Pop. Served	No. Supplies	Pop. Served	No. Supplies	Pop. Served	No. Supplies	Pop. Served
<1	350	896459	2	9772	30	140380	38	1233427
1-5	159	370974			9	23562		
5.1-10	15	13085						
>10	5	2696						
TOTALS	529	1283214	2	9772	39	163942	38	1233427

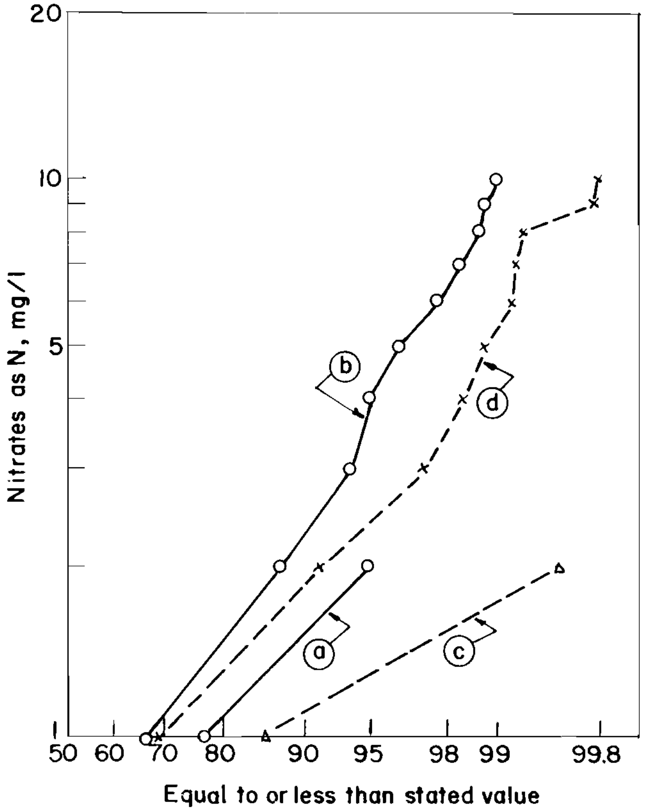
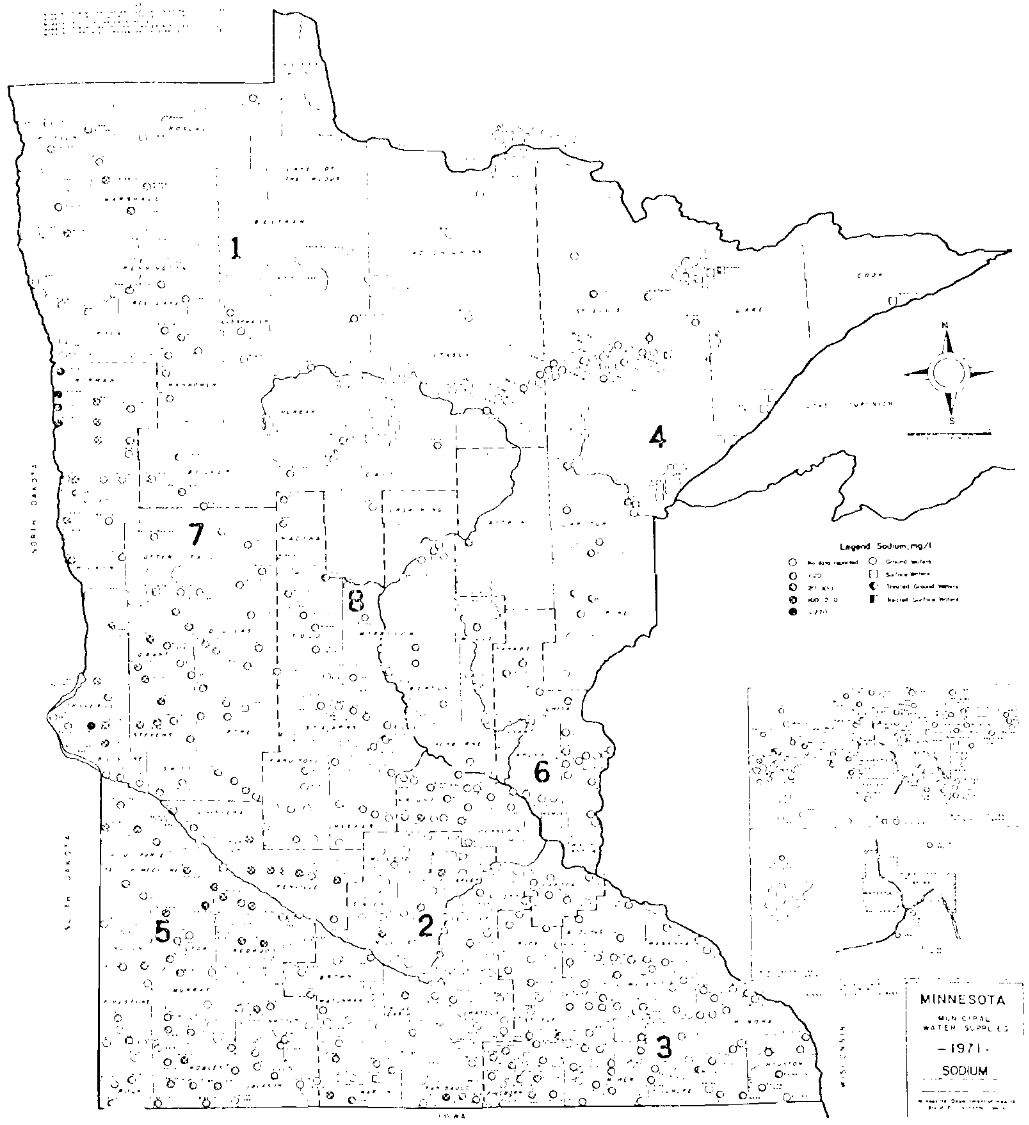


Fig. 13 Probability Plot. Nitrates as Nitrogen. Minnesota Water Supplies. 1971. a. Treated Ground Water - Plants; b. Raw Ground Water - Plants; c. Treated Ground Water - Population; and d. Raw Ground Water - Population.

Figure 14



The classification developed for categorizing sodium levels in water is based on the concern for low sodium diets recommended for a certain portion of the population. The low concentration of 20 mg/l is suggested as the mg/day. The upper level of 270 mg/l is based upon permissible increased sodium intake through the water route for persons on a diet of 1,000 mg/day of sodium. Two categories representing concentrations of 20 to 100 and 101 to 270 mg/l were selected between these two suggested levels.

Table 10 summarizes the data on sodium levels. There were 349 untreated ground water supplies serving 977,970 persons for which sodium values in water were reported. These data show that 198 supplies serving 814,198 persons could meet the criterion of 20 mg/l of sodium, 106 supplies serving 130,493 persons fell in the range of 20 to 100 mg/l; 39 supplies serving 31,126 persons were in the 101 to 270 mg/l range; and 6 supplies serving 2,153 persons exceeded a concentration level of 270 mg/l of sodium.

In the case of treated ground water supplies, 25 supplies serving 138,474 persons reported sodium levels. Eleven supplies serving 67,794 persons showed sodium levels below 20 mg/l; nine supplies serving 66,022 persons had levels ranging from 20 to 100 mg/l; and five supplies serving 4,658 persons had levels ranging from 101 to 270 mg/l.

The two untreated surface supplies serving 9,772 persons reported levels below 20 mg/l and the nine treated surface supplies serving 83,818 persons showed seven supplies serving 80,030 with sodium levels below 20 mg/l; one supply serving 3,595 persons in the range of 20 to 100 mg/l; and one supply serving 193 persons in the range of 101 to 270 mg/l.

Additional data on sodium levels are indicated in Fig. 15 and in Table A.7.

There are several municipalities in Minnesota that soften their water. Those using zeolite softening are listed in Table 11. It can be seen that the effluent sodium levels are considerably higher in some instances than are the influent values. The extent to which the sodium levels are increased would also reflect the amount of blending taking place, i.e., dilution of finished water with raw water. In the case of surface waters, the use of lime or lime soda softening will result in a reduction in the sodium levels or may represent a small increase in levels.

Table 11. Zeolite Softening Facilities - Sodium Levels, mg/l

Community	Source of Supply	Raw Water	Treated Water
Blooming Prairie	Drilled Well	5	120
Goodview	Drilled Well	43	62
Lake Park	Drilled Well	21	110
LeRoy	Drilled Well	6	80
Minnetonka Beach	Drilled Well	3	54
Preston	Drilled Well	2	150
Sabin	Drilled Well	17	260

Table 10. Sodium.

Concentration, mg/l	Raw Water				Treated Water			
	Ground		Surface		Ground		Surface	
	No. Supplies	Pop. Served	No. Supplies	Pop. Served	No. Supplies	Pop. Served	No. Supplies	Pop. Served
<20	198	814198	2	9772	11	67794	7	80030
20-100	106	130493			9	66022	1	3595
101-270	39	31126			5	4658	1	193
>270	6	2153						
Totals	349	977970	2	9772	25	138474	9	83818

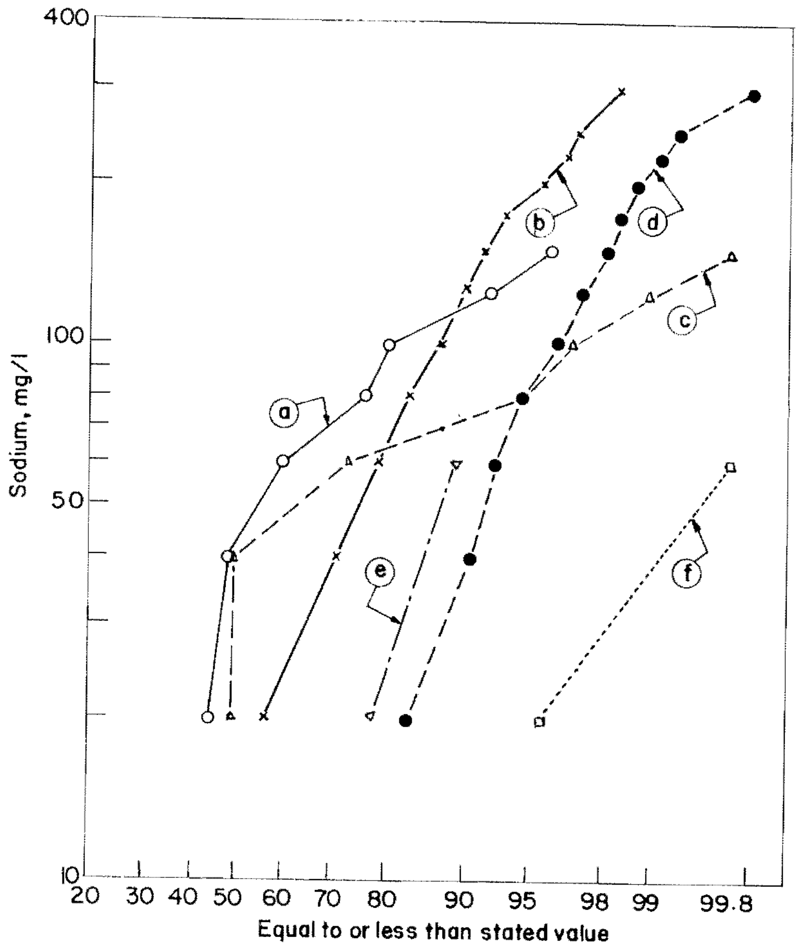


Fig. 15 Probability Plot. Sodium. Minnesota Water Supplies. 1971. a. Treated Ground Water - Plants; b. Raw Ground Water - Plants; c. Treated Ground Water - Population; d. Raw Ground Water - Population; e. Treated Surface water - Plants; and f. Treated Surface Water - Population.

Sodium levels in water supplies made available to the consumer may not be indicative of the actual sodium levels at the point of consumption. Where sodium chloride is used to regenerate individual household zeolite or cation exchange water softeners, the intake of sodium can be materially increased.

Total Solids or Filterable Residue

Although of limited health significance as a direct parameter of water quality, total solids due to minerals in water have been of some concern because of possible physiologic effects, mineral taste, and economic consequences. Studies have been carried out, notable in California,[30] to determine consumer response to taste quality[31] of mineralized waters[30] and to specific minerals found in water.[31] Waters covering a total dissolved solids range of 50 to 2,250 mg/l were included in the two studies reported[30] in which the State of California Department of Health[31] personnel participated in the sensory evaluation. In the second study[31] respondents were selected from actual consumers of the water. In this study, total dissolved solids ranged from 84 to 2,303 mg/l. As a result of these studies,[31] Bruvold and his associates suggested the following classifications for these waters: excellent ≤ 319; good 320-658; fair 659-996; poor 997-1,332; and unacceptable ≥ 1,333 mg/l. Based on the earlier study,[30] these values were ≤ 300, 301-600, 601-900, 905-1,100, and ≥ 1,101 mg/l, respectively.

The classification used here was based upon recommended levels of 200 mg/l by the AWWA,[4] and 500 mg/l by the DWS.[3] These values are derived from the recommended levels for chlorides and sulfates. The categories indicated for coding the water supplies were: 1) <200 mg/l which satisfies the AWWA criterion; 2) 200 to 500 mg/l which meets the DWS criterion; 3) 501 to 1,000 mg/l; and 4) >1,000 mg/l.

An examination of Fig. 16 shows that waters of highest total solids were found in the south central and western areas of the state. There are a fair number of supplies for which no information on total solids has been reported.

With reference to Table 12, we note that data for 345 supplies serving untreated ground water to 1,014,372 persons were reported. Of this number, five supplies serving 4,308 persons met the AWWA criterion of less than 200 mg/l total dissolved solids; 212 supplies serving 869,788 persons met the DWS criterion of 500 mg/l; 76 supplies serving 91,245 persons exceeded the DWS criterion by up to a factor of two; and 52 supplies serving 49,031 persons exceeded a level of 1,000 mg/l of total dissolved solids in their water. Thus, approximately 1.5 percent of the supplies and 0.4 percent of the population served met the AWWA criterion for total dissolved solids, 62.8 percent of the supplies serving 86.1 percent of the persons supplied met the DWS criterion, and 37.2 percent of the supplies serving 13.9 percent of the persons supplied did not meet the DWS criterion.

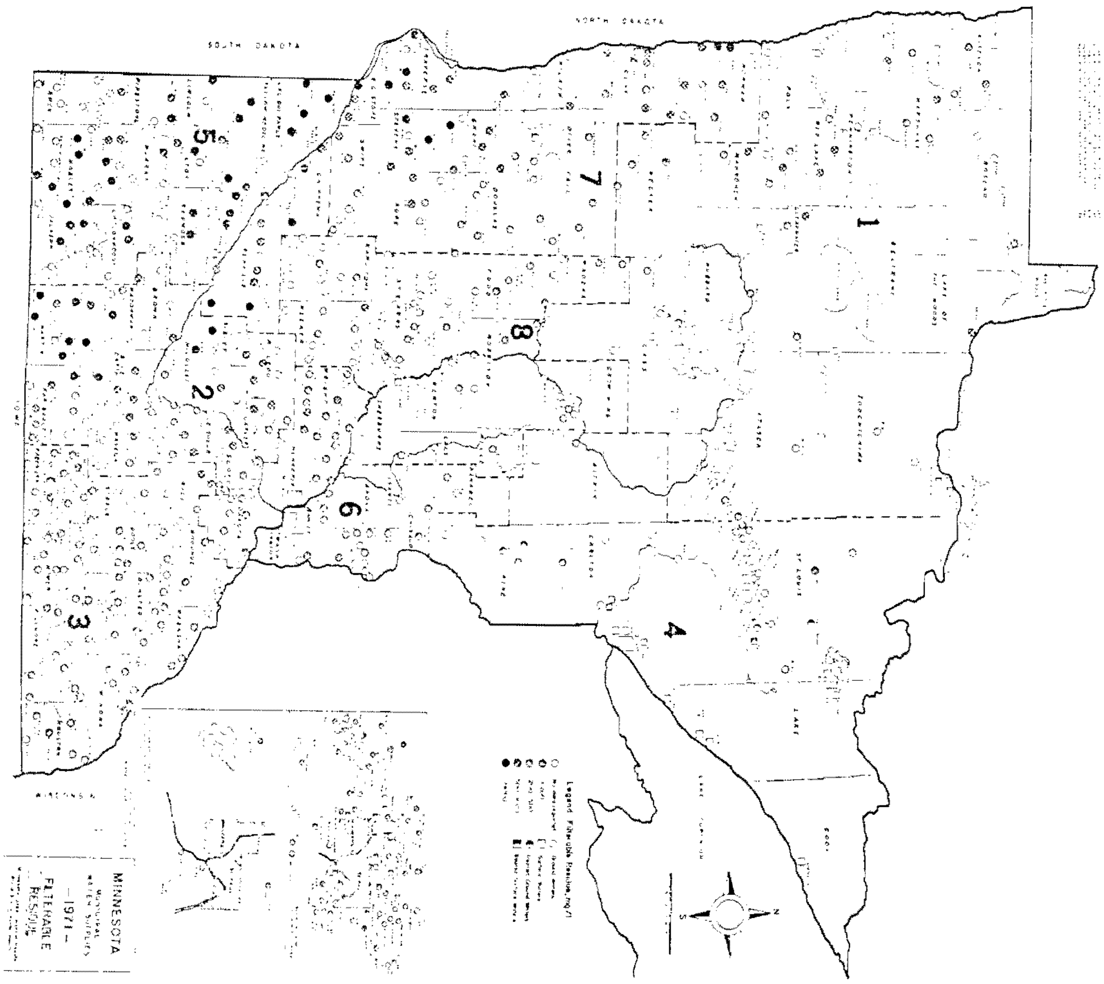


Figure 16

Table 12. Total Dissolved Solids.

Concentration, mg/l	Raw Water				Treated Water			
	Ground		Surface		Ground		Surface	
	No. Supplies	Pop. Served	No. Supplies	Pop. Served	No. Supplies	Pop. Served	No. Supplies	Pop. Served
<200	5	4308	2	9772	6	12781	21	1093250
200-500	212	869783			8	57166	2	14274
501-1000	76	91245			5	29469	1	3189
>1000	52	49031						
TOTALS	345	1014372	2	9772	19	99416	24	1110713

Data were reported for 19 treated ground water supplies serving 99,416 persons. Six supplies serving 12,781 persons met the AWWA criterion and an additional eight supplies (total 73.7 percent) serving 57,166 persons (total 70.4 percent) met the DWS criterion. Five supplies serving 29,469 persons, exceeded the DWS criterion of 500 mg/l.

The two untreated surface supplies serving 9,772 persons met the AWWA criterion. Of the 24 treated surface supplies serving 1,110,713 persons, 21 supplies (87.5 percent) serving 1,093,250 persons (98.4 percent) met the AWWA criterion, an additional two supplies (total 95.8 percent) serving 14,274 persons (total 99.7 percent) met the DWS criterion of 500 mg/l, and one supply serving 3,189 persons reported a level in the range of 500 to 1000 mg/l total dissolved solids.

Figure 17 provides more information on percent of the supplies and populations providing and consuming, respectively, waters of a given quality, and Table A.8 gives additional details concerning actual quality levels.

Treatment provided to surface waters generally reduced total dissolved solids levels as shown in Table 13. These data show reductions in the range of 26.5 to 65.3 percent. The average for the seven surface supplies listed was 44.8 percent.

Table 13. Treatment of Surface Water Supplies - Effect on Total Dissolved Solids

Community	Source of Water	Raw Water, mg/l	Treated Water, %	Reduction %
Fairmont	Budd Lake	340	250	26.5
Fergus Falls	Otter Tail River and Hoot Lake	210	120	42.8
Granite Falls	Minnesota River	1500	520	65.3
Minneapolis	Mississippi River	212	125	41.0
Moorehead	Red River	440	260	40.9
St. Cloud	Mississippi River	270	130	51.8
St. Paul	Mississippi River and Vadnais Chain of Lakes	220	120	45.5

Discussion and Summary

The chemical parameters reported for potable water supplies in the State of Minnesota have been compared with the U.S. Public Health Service Drinking Water Standards, the recommended American Water Works Association goals for specific constituents in water based on today's technology, and the USEPA National Interim Primary Drinking Water Regulations. These parameters were divided into four classifications and coded on a series of maps. The data utilized were those reported for public water supplies and do not necessarily reflect the actual waters consumed. In many instances, particularly where hard waters are encountered, individual home softening units may be used, and it would be of interest to determine to what extent this practice prevails in those areas where supplies may be somewhat marginal.

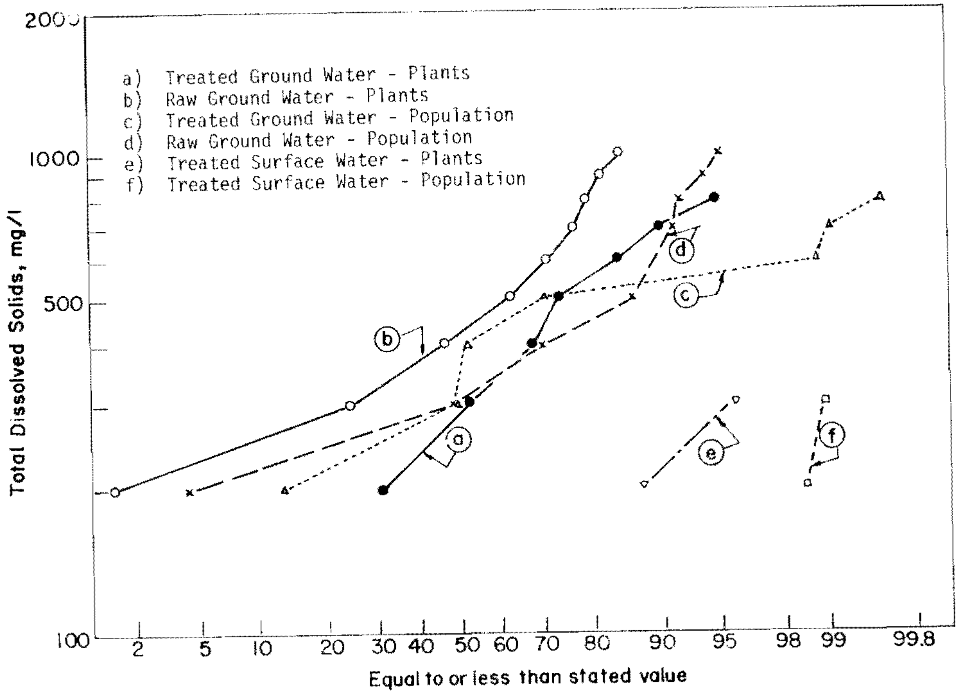


Fig. 17 Probability Plot. Total Dissolved Solids. Minnesota Water Supplies. 1971.

Of the eight parameters used in this study -- hardness, iron, manganese, chlorides, sulfates, nitrates, sodium, and filterable residue -- not all are of equal public health concern or significance. Those of public health significance would include nitrates, sodium, and possibly hardness. It is known that high nitrates in ground water supplies used in the preparation of formula can cause methemoglobinemia in infants. There are five public water supplies serving 2,696 persons which exceed the permissible nitrate concentrations. Persons on a low sodium diet, particularly those that may be restricted to a total intake of 500 mg/day may be quite concerned about the sodium concentration in public water supplies. However, should they have home softening units which are on a sodium cycle, the possibilities of higher sodium intakes must be evaluated. Considerable interest is evident in the possible inverse relationship between "hardness" in water and cardiovascular disease mortality rates. The status of this controversy has been reviewed recently by Winton and McCabe.[11] Until epidemiologic confirmation of this "finding" is elucidated, the significance of the observations reported is uncertain.

Of indirect public health concern may be the filterable residue or total dissolved solids concentration of the water in that, if the taste is unsatisfactory as a result of high mineral content, the persons supplied such waters may turn to the use of less mineralized, but possibly contaminated, sources of supply. Studies by Bruvold and associates[30,31] have indicated consumer preference for waters of lower mineral content. Since the chloride and sulfate concentrations contribute to the total dissolved solids concentration of the water, they are of interest in this regard. Chlorides pose no real hazard in Minnesota, but there are pockets of high sulfate concentration and the relation of these intakes to human health would be worthy of study. There have been indications of health effects in animals consuming high concentrations of sulfates, but none are known or reported for human exposure except in association with magnesium. Both chlorides and sulfates contribute to the non-carbonate hardness component of the water and are of economic interest.

High iron and manganese concentrations in public water supplies are of concern because such waters stain plumbing fixtures and may interfere with laundering operations. They are primarily of aesthetic or economic concern. Whether high levels of manganese have any health effect is still debatable although studies are underway to determine the effect of occupational exposures to manganese concentrations. These studies should determine potential health effects.

One element reported routinely is fluorides, but this element was not considered in this study since there is a state law requiring fluoridation of all public water supplies to a given level of concentration. There are no known sources of supply that would require defluoridation. The matter of fluoride additions, however, should be reviewed to ascertain that fluorides are being added so the public could gain from the public health benefits of this practice.

In summary, the data presented in Table 14 indicate the number of supplies exceeding the levels recommended by the AWWA, the DWS, and the NIPDWR as well as the populations served such waters. The conclusions drawn below assume that the values reported are representative of the actual waters supplied and consumed. These data are for untreated and treated ground water supplies and for untreated and treated surface supplies. An examination of these data indicates that with regard to untreated ground water supplies the major problem areas are hardness, iron, and manganese, and the same is true with regard to the populations served. The number of supplies deficient in meeting the hardness level of 250 mg/l was 72.4 percent; in meeting the iron level of 0.3 mg/l, 71.8 percent; and, in meeting the manganese level of 0.05 mg/l, 56.9 percent. The corresponding populations were 73.3, 69.2, and 51.1 percent, respectively. For treated waters, the water supplies deficient were 28.2, 15.4 and 33.3 percent, respectively, and the corresponding populations served were 45.7, 5.5, and 59.7 percent. Application of the AWWA criteria, which can be achieved on the basis of today's technology, would result in considerably higher values for the numbers of supplies as well as the populations served not meeting this criterion, as shown in Table 14.

In dealing with untreated surface waters the number of supplies total two and these meet most of the AWWA, DWS, and NIPDWR criteria cited with the exception of iron, which exceeded both the DWS and AWWA criterion, and manganese, which exceeded the AWWA criterion. The treated surface water supplies essentially satisfied the DWS recommendations with minor exceptions. However, deficiencies were indicated in meeting the manganese and iron criteria.

The data evaluated herein indicate that surface water supplies, even though subject to greater fluctuations in chemical quality from runoff, discharge of agricultural and industrial wastes, and municipal wastes, generally meet the recommended DWS as a result of treatment. However, the same cannot be said for ground water supplies in Minnesota. The constituents needing correction include hardness, iron, and manganese. There are counties in the state where some of the other constituents in water exceed levels that have been recommended. It is also obvious that not all surface supplies meet the recommended goals of the AWWA, and this condition prevails to even a greater extent in the case of ground waters used as sources of public water supply.

Acknowledgements

The writer acknowledges and appreciates most sincerely the assistance given him by the Minnesota Department of Health in making all of the data of water quality characteristics of potable supplies in the state available for this study. He also wishes to express his thanks to Mr. Jung W. Ahn for retabulating the data in a format proposed by the author and for preparing Figs. 2, 4, 6, 8, 10, 12, 14, and 16; and to Mr. Milton Anderson who initiated studies to set up a computer program for the recording and retrieval of the currently available and future data.

Table 14. Status of Water Supply Quality - Minnesota[a] - Deficiencies as Measured by AWWA Goals,[4] DWS[3] and EPA Recommendations[5]

Chemical Entity	Ground Waters															
	Untreated								Treated							
	DWS				AWWA				DWS				AWWA			
	No. Supp.	%	Pop.	%	No. Supp.	%	Pop.	%	No. Supp.	%	Pop.	%	No. Supp.	%	Pop.	%
Hardness +	335	72.4	1,183,833	73.3	523	98.31	1,296,366	99.63	11	28.2	66,306	45.7	27	69.2	120,617	83.2
Iron	362	71.8	900,343	69.2	484	90.99	1,215,470	93.48	6	15.4	8,023	5.5	31	79.5	132,3[illegible]	91.3
Manganese	301	56.9	663,810	51.1	527	99.62	1,295,427	99.77	13	33.3	72,067	49.7	39	100.0	144,943	100.0
Chlorides	4	0.7	3,154	0.23	18	3.5	19,078	1.5	--	--	--	--	--	--	--	--
Sulfates	97	18.3	118,128	8.9	168	31.6	184,890	14.3	3	7.3	1,293	0.8	7	17.9	9,335	5.8
Nitrates	5	1.0	2,696	0.21	5	1.0	2,696	0.21	--	--	--	--	--	--	--	--
Sodium*	6	1.7	2,153	0.20	151	43.3	165,772	16.8	--	--	--	--	14	56.0	70,680	51.0
Total Diss Solids	138	37.2	140,276	13.9	340	98.55	1,010,064	95.75	5	26.3	29,469	29.6	13	68.4	86,635	87.1
	Surface Waters															
Hardness	--	--	--	--	--	--	--	--	--	--	--	--	4	10.2	13,281	1.0
Iron	2	100	9,772	100	2	100	9,772	100	3	7.6	1,909	0.1	20	51.4	749,495	59.7
Manganese	--	--	--	--	2	100	9,772	100	--	--	--	--	32	100.0	637,034	100.0
Chlorides	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sulfates	--	--	--	--	--	--	--	--	--	--	--	--	1	5.2	5,740	0.5
Nitrates	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sodium*	--	--	--	--	--	--	--	--	--	--	--	--	2	22.2	3,788	4.6
Total Diss Solids	--	--	--	--	--	--	--	--	1	4.2	3,189	1.1	3	12.5	17,463	1.5

a Based on data of 1971[1]

* The separation for DWS and AWWA represent values greater than 270 and less than 20, respectively. No limits were prescribed by either the AWWA or DWS.

+ Not specified by DWS, a value of 250 mg/l hardness was used.

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WATER QUALITY INDICES

Introduction

There have been several attempts to develop an index to determine quality of waters. Among the first of these was the one developed by Horton.[1] He identified the steps in development of a water quality index as: 1) selection of quality characteristics on which the index is to be based; 2) establishment of a rating scale for each characteristic; and 3) weighting of the several characteristics. The quality characteristics and rating scales used by Horton are reproduced in Table 15.

More recently, Brown et.al.,[2] using the DELPHI process, proposed a procedure for developing a water quality index based on the following parameters: dissolved oxygen, fecal coliform density, pH, biochemical oxygen demand (5-day, 20°C), nitrates, phosphates, temperature, turbidity, and total solids. The formula for calculating a weighted mean index has the form:

$$WQI = \sum_{i=1}^{n} w_i \, q_i \qquad 1.$$

Where:

WQI = the water quality index, a number between 0 and 100

q_i = the quality of the ith parameter, number between 0 and 100

w_i = the unit weight of the ith parameter, a number between 0 and 1; and

n = number of parameters.

This type of index works best if all of the individual parameters are independent of each other.

There have been additional reports on the development of a water quality index from Brown et.al.[3,4,5,6] The authors addressed themselves to a consideration of general versus use indices[3] and they perceived a number of disadvantages with use related indices including identification of specific parameters, selection of weights and scales as a function of usage; need for more data to support the additional parameters to be measured; increased cost; and the complexity of communication processes with the public. The relative merit of use related indices versus an index of overall quality was considered to O'Connor.[7] He found that a turly crucial factor lies in identification of the critical parameters which would enter into an index determination, and that the selection of parameters was of greater importance than determining the shape of the quality curves for designated parameters. Thirteen parameters were included in the public water supply (PWS) index evaluation and included fecal coliforms, phenols, dissolved solids, fluorides, hardness, nitrates, chlorides, alkalinity, turbidity, dissolved oxygen, color, and sulfates.

Table 15. Quality Characteristics and Rating Scales for Development of Water Quality Index[1]

Sewage Treatment (% pop. served)	Rating	pH	Rating	Sp. Cond. (μmhos)	Rating
95-100	100	6-8	100	0-750	100
80-95	80	5-6; 8-9	80	750-1,500	80
70-80	60	4-5; 9-10	40	1,500-2,500	40
60-70	40	<4; >10	0	>2,500	0
50-60	20				
<50	0				

DO (% saturation)	Rating	Coliforms (MPN/100 ml)	Rating	CCE (1×10^{-3} mg/l)	Rating
>70	100	<1,000	100	0-100	100
50-70	80	1,000-5,000	80	100-200	80
30-50	60	5,000-10,000	60	200-300	60
10-30	30	10,000-20,000	30	300-400	30
<10	0	>20,000	0	>400	0

Alkalinity (mg/l)	Rating	Chloride (mg/l)	Rating	Coefficient	
20-100	100	0-100	100	Temperature (M_1)	1 or ½
5-20;100-200	80	100-175	80	Obvious pollution (M_2)	1 or ½
0-5; >200	40	175-250	40		
Acid	0	>250	0		

Weighting	
Sewage treatment	4
DO	4
pH	4
Coliforms	2
Sp. Cond.	1
CCE	1
Alkalinity	1
Chloride	1

$$QI = \left[\frac{C_1 W_1 + C_2 W_2 -- + C_n W_n}{W_1 + W_2 -- + W_n} \right] M_1 M_2$$

Deininger and Maciunas[6] extended the study of Brown et.al.[2] in developing a specific water quality index for public water supplies. They concluded:

1. "It is possible to develop a water quality index for surface waters designated for the specific use of public water supply ...
2. "The comparisons show that this index developed with a specific use-orientation does not seem to rate water quality levels in a manner markedly different from the rating made by a general, non-specific use-oriented index. Thus, it is possible to argue that water of a certain quality retains that relative quality rating regardless of the use for which it is being considered. Hence, waters of different streams can certainly be compared with regard to changes in quality levels, using one uniformly applied rating scheme.
3. "Instead of developing a number of indices for the many water uses, it appears to be more meaningful to further develop and refine a sensitive and general water quality index."

In "Validating the WQI", Brown et.al,[6] suggest other approaches to calculating the water quality index. These include consideration of the following basic models;

Multiplicative

$$WQI = \prod_{i=1}^{n} q_i^{w_i} \qquad 2.$$

Geometric

$$WQI = \prod_{i=1}^{n} q_i^{g_i \frac{1}{n}} \qquad 3.$$

Mixed Expression

$$WQI = T \sum_{i=1}^{n} w_i q_i \qquad 4.$$

Where T = a transformation expression based upon a curve which is given in the text.[6]

Water Quality Index Used in Rating Minnesota Public Water Supplies

Public water supplies in Minnesota were evaluated in accordance with the simple expression

$$\sum_{i=1}^{n} \frac{C_i}{P_i} = \text{Water Quality Index (WQI)} \qquad 5.$$

where

WQI = index value obtained

C_i = the reported concentration of the ith parameter

P_i = the recommended or regulatory permissible value for the ith parameter

n = number of parameters

This approach assumes that the parameters are independent and the total index is an additive function. A similar expression, except that the index value is set as equal to or less than one, has been used to calculate the additive radiation exposure from several different radionuclides[8] and has been applied also to assess occupational exposure from a mixture of gases.[10]

The water quality index (SWI) was calculated for those water supplies for which the following chemical parameters were reported: hardness, iron, manganese, nitrate, chloride, sulfate, sodium, and total dissolved solids or filterable residue. The water quality index was calculated for public water supplies located south of the Minnesota River and were based upon the American Water Works Association (AWWA) recommended values,[11] the U.S. Public Health Service Drinking Water Standards (USPHS/DWS),[12] and the U.S. Environmental Protection Agency National Interim Primary Drinking Water Regulations (USEPA/NIPDWR).[13] Indices were calculated for individual wells in the case of ground water supplies and for surface waters as well as for raw and treated waters where data permitted such calculations.

The index was calculated as follows:

$$\sum_{i=1}^{n} \frac{C_i}{P_i} = \frac{C_1}{P_1} + \ldots + \frac{C_8}{P_8} = \text{Water Quality Index} \qquad 6.$$

Where

C_1 = the reported hardness concentration, in mg/l as $CaCO_3$

C_2 = the reported iron concentration, in mg/l

C_3 = the manganese concentration, in mg/l

C_4 = the nitrate concentration, in mg/l as nitrate-nitrogen

C_5 = the chloride concentration, in mg/l

C_6 = the sulfate concentration, in mg/l

C_7 = the sodium concentration, in mg/l

C_8 = the total dissolved solids or filterable residue concentration, in mg/l

P_1 = the recommended hardness as $CaCO_3$ concentration, in mg/l

P_2 = the recommended iron concentration, in mg/l

P_3 = the recommended manganese concentration, in mg/l

P_4 = the recommended permissible nitrate-nitrogen concentration value, in mg/l

P_5 = the recommended chloride concentration, in mg/l

P_6 = the recommended sulfate concentration, in mg/l

P_7 = the recommended sodium concentration, in mg/l

P_8 = the recommended total dissolved solids or filterable residue, in mg/l

The equation then would appear as follows

$$+ \frac{\text{Manganese Concn.}}{\text{Recomm. Manganese Concn.}} + \frac{\text{Chloride Concn.}}{\text{Recomm. Chloride Concn.}} + \frac{\text{Sulfate concn.}}{\text{Recomm. Sulfate Concn.}}$$

$$+ \frac{\text{Nitrate-N concn.}}{\text{Recomm. Nitrate-N Concn.}} + \frac{\text{Sodium Concn.}}{\text{Recomm. Sodium Conc.}} + \frac{\text{Total Solids Concn.}}{\text{Recomm. Total Solids Concn.}} \qquad 7.$$

The calculated index values indicate the extent by which the reported quality values deviate from the recommended or permissible concentrations. In interpreting these data, it is recognized that all parameters cannot be weighted equally. Some of these are of health concern (nitrates, and possibly sodium); others are of aesthetic (total dissolved solids, iron, manganese), or economic (hardness, iron, manganese, and total dissolved solids) concern. The higher the numerical value reported, the greater the deviation from existing recommended values. These values may be useful in identifying priorities for improving given water supplies.

Ground Water Supplies - Counties in Southern Minnesota

The water quality index calculated for each municipal well supplying water to the community is listed in Tables 16 and 17. The data are listed by county and alphabetically by communities within the county. Southern Minnesota was selected for consideration because of geological and hydrogeological differences, as indicated by Winters,[14] that exist there.

> "Basement rocks, which consist primarily of Precambrian crystalline igneous rocks (granite, gabbro, and basalt) and metamorphosed igneous and sedimentary rocks, underlie the entire state. ... They must be considered [as sources of water supply] ... at scattered localities in the central and southwest parts of the State, where they are at, or relatively close to, land surface.
>
> "... In the southeast, the rocks are largely sandstone of high hydraulic conductances (permeability), limestone, and dolomite ... and consequently transmit water readily."

On this basis, the data given in Tables 16 and 17 have been reorganized as shown in Table 18, according to the two major geologic provinces indicated, and into the health districts shown in Figure 1. It will be noted that the area south of the Minnesota River to its confluence with the Mississippi River and south of the latter beyond the confluence, comprises all or portions

Table 16. Water Quality Index Values. Minnesota Public Water Supplies. Ground Waters

County	Town	Well No.	AWWA[a]	USPHS[b]
Lac Qui Parle	Bellingham	1	>112	<30
	Dawson	6	>112	<27
	Madison	1	>130	28
		2	>198	45
	Marietta	2	>144	35
Lincoln	Hendricks	1	>136	<40
		2	>83	<30
	Ivanhoe	1	>112	49
	Lake Benton	1	>211	44
Yellow Medicine	Canby	3	>239	51
		4	>185	42
		7	>68	22
	Echo	1	>94	<26
		2	>90	<24
	Hanley Falls	1	>23	<6
	Porter	1	>37	15
	Wood Lake	1	>180	43
		2	>216	<49
Lyon	Balaton	1	>27	<12
	Cottonwood	6	>121	<31
		7	>93	<21
	Lynd	1	>45	17
	Minneota	4	>86	<23
	Russell	Spring	>11	< 4
		1	>29	<14
		2	>140	<32
		3	>74	<17
Redwood	Belview	2	>289	65
		3	>228	56
	Lucan	3	>148	39
	Wabasso	1	>164	<35
		2	>130	<30
Brown	Comfrey	1	>240	<53
		2	>286	<58
	New Ulm	6	>55	<16
		15	>71	<18
		16	>60	<16
		17	>69	<18
Martin	Ceylon	1	>386	<75
		2	>88	<25
	Dunnell	2	>166	40
		3	>139	<37
	Granada	1	>939	195

Table 16. (cont'd)

County	Town	Well No.	AWWA[a]	USPHS[b]
Martin	Northrop	1	>248	56
	Trimont	3	>743	<16
Blue Earth	Amboy	1	>81	22
		2	>115	27
	Lake Crystal	1	>46	16
		2	>90	22
		3	>44	<10
	Rapidan	1	>181	<34
	St. Clair	1	>46	<12
		2	>212	<38
Faribault	Bricelyn	1	>40	<10
	Frost	1	>50	<12
	Kiester	1	>36	<9
		2	>97	<19
Freeborn	Albert Lea	2	>34	<9
		5	>43	<11
		8	>33	<9
		9	>37	<9
	Alden	2	>42	<9
		3	>67	<13
	Freeborn	2	>51	<12
	Geneva	1	>28	<7
	Glenville	2	>35	<8
	Hartland	2	>104	<22
	Hayward	2	>48	<13
	Hollandale	1	>112	<21
		2	>30	<7
	Manchester	1	>25	<7
	Myrtle	1	>22	<6
Mower	Adams	1	>11	<4
		2	>52	<11
	Dexter	1	>16	<5
	Elkton	2	>23	<7
	LeRoy	1	>22	<7
	Lyle	2	>8	<4
	Racine	1	>9	<4
	Sargeant	1	>43	<10
	Waltham	1	>13	<5
	Rose Creek	2	>22	<6
	Mapleview	1	>36	<9
Fillmore	Canton	1	>13	<5
		2	>23	<7
	Lanesboro	1	>16	<5
		2	>28	<7
	Ostrander	2	>11	<4
	Peterson	1	>16	<5

Table 16. (cont'd)

County	Town	Well No.	AWWA[a]	USPHS[b]
Fillmore	Preston	1	>8	<4
		2	>13	<5
	Spring Valley	1	>11	<4
		2	>9	<4
Houston	Caledonia	4	>17	<6
		5	>16	<6
	Hokah	1	>9	<4
	Houston	1	>16	<5
	La Crescent	2	>18	<6
		3	>15	<5
	Spring Grove	1	>12	<4
		2	>9	<3
Winona	Altura	2	>13	<5
	Goodview	1	>21	<6
	Lewiston	1	>9	<4
		2	>15	<5
	Rollingstone	1	>12	<5
		2	>16	<5
	Utica	1	>11	<4
	Winona	5	>27	<8
		6	>31	<8
		7	>20	<6
		8	>111	<23
		9	>94	<20
		10	>75	<17
		11	>106	<22
		12	>99	<22
		13	>21	<8
		14	>40	<10
		15	>33	<9
Steele	Blooming Prairie	1	>60	<12
	Ellendale	2	>50	<11
	Medford	1	>26	<8
Dodge	Claremont	1	>39	<10
	Dodge Center	1	>9	<4
		2	>9	<4
	Hayfield	1	>42	<10
	Mantorville	2	>16	<6
	Kasson	2	>76	<16
		3	>22	<7
	West Concord	1	>33	<8
Olmstead	Chatfield	1	>8	<4
	Eyota	1	>55	<12
		2	>14	<5
	Stewartville	1	>12	<4
		2	>11	<4

Table 16. (cont'd)

County	Town	Well No.	AWWA[a]	USPHS[b]
Olmstead	Rochester	8	>9	<4
		9	>13	<6
		10	>11	<5
		11	>10	<4
		12	>8	<4
		13	>9	<4
		14	>12	<4
		15	>9	<4
		16	>15	<5
		17	>10	<4
		18	>13	<5
		19	>12	<5
		20	>12	<4
		22	>10	<4
		23	>9	<4
		24	>12	<5
		25	>10	<4
Wabasha	Elgin	3	>11	<5
	Hammond	2	>10	<4
	Kellogg	2	>10	<8
	Lake City	1	>9	<4
		2	>8	<4
	Millville	1	>10	<7
	Plainview	1	>22	<6
	Wabasha	1	>12	<5
		2	>9	<4
	Zumbro Falls	3	>11	<4
Goodhue	Cannon Falls	1	>13	<5
		2	>23	<7
	Goodhue	2	>13	<5
	Kenyon	3	>21	<6
	Pine Island	1	>15	<6
		2	>12	<4
	Wanamingo	2	>23	<7
	Zumbrota	1	>17	<6
Rice	Lonsdale	1	>83	<18
		3	>69	<16
	Morristown	1	>75	<17
	Webster Township	1	>43	<11
		2	>42	<12
	Northfield	1	>29	<8
		2	>19	<6
		3	>21	<6
LeSueur	LeSueur	1	>23	<7
		2	>15	<5
	St. Peter	1	>14	<5

Table 16. (cont'd)

County	Town	Well No.	AWWA[a]	USPHS[b]
LeSueur	St. Peter	2	>15	<5
		4	>30	<9
		5	>32	<9
Scott	Elko	1	>28	<9
	Jordan	2	>45	<12
		3	>31	<9
		4	>46	<12
Dakota	Burnsville	1	>20	<6
		4	>16	<5
	Farmington	1	>18	<6
		2	>89	<18
		3	>89	<18
	Forest Hills	1	>55	<12
	Hampton	2	>7	<3
	Hastings	1	>16	<5
		2	>9	<4
		3	>11	<4
		4	>28	<4
	Lakeville	3	>23	<6
	Rosemunt	1	>44	<10
		2	>61	<14
		3	>14	<5

[a]See AWWA recommended values in Table 2.2.

[b]See USPHS and USEPA recommended and/or regulatory values (EPA values are national primary interim standards.

Table 17. Water Quality Index Values - Minnesota Public Water Supplies Ground Waters

County	Town	Well No.	AWWA[a]	USPHS[b]
Pipestone	Pipestone	1	>20	<9
		2	>21	<10
		4	>15	<6
Murray	Lake Wilson	1	>55	<15
	Chandler (dug well)	1	>44	<14
	Iona	1	>271	<57
Cottonwood	Storden	2	>308	<60
	Jeffers	1	>165	<36
		2	>285	<68
	Windom	2	>97	<22
		3	>81	<17
		4	>84	<19
		5	>67	<15
		6	>51	<13
Watonwan	Darfur	1	>11	<5
Nobles	Lismore	2	>65	<19
	Wilmont	1	>108	<40
		2	>164	<51
	Dundee	1	>164	40
	Brewster	1	>98	37
		2	>63	<29
	Worthington	14	>173	<37
		17	>97	<22
		18	>73	<20
		19	>124	<32
		24	>266	<53
		25	>95	<23
		26	>131	<30
		28	>107	<26
	Bigelow	2	>180	<47
Jackson	Heron Lake	2	>101	<29
		3	>197	<45
	Okabena	2	>203	<48
	Lakefield	1	>126	<32
		2	>98	<24

[a]See AWWA recommended values in Table 2.2.

[b]See USPHS and USEPA recommended and/or regulatory values (EPA values are national primary interim standards).

Table 18. Water Quality Indices - Counties in Districts 2, 3, 5, and 6.

District	County	Community	No. Wells	Depth Av. Ft.	Range Ft.	AWWA Criteria Av.	AWWA Criteria Range	PHS Criteria Av.	PHS Criteria Range
5	Lac Qui Parle	4	5	116	72-180	>133	>112->198	<33	<27-45
	Yellow Medicine	5	9	139	23-286	>126	>68->238	<31	<6-<51
	Lincoln	3	4	158	24-290	>136	>83->211	<41	<30-49
	Lyon	5	8	94	30-190	>77	>27->140	<21	<12-<32
	Redwood	3	5	140	83-221	>192	>130->289	<45	<30-66
	Pipestone	1	3	432	386-510	>19	>15- >21	<8	<6-<10
	Murray	3	3	119	30-240	>123	>44->271	<29	<14-<57
	Cottonwood	3	8	191	78-700	>142	>51->308	<24	<13-<68
	Nobles	6	15	109	23-360	>127	>63->266	<34	<19-<53
	Jackson	3	5	270	199-360	>145	>18->203	<36	<24-48
2	Brown	2	6	83	50-210	>130	>55->286	<30	<16-<58
	Watonwan	5	8	439	34-737	>98	>11->181	<22	<5-<38
	Martin	5	6	186	130-325	>320	>43->939	<70	<16-<195
	Scott	2	4	537	487-563	>38	>28- >46	<10	<9-<12
6	Dakota	7	15	384	195-605	>33	>7- >89	<8	<4-<18
3	Rice	4	8	436	200-760	>48	>19- >83	<12	<6-<18
	Goodhue	6	8	496	300-710	>17	>12- >23	<6	<4-<7
	Wabasha	8	10	200	50-420	>11	>8- >22	<5	<4-<8
	Steele	3	3	410	250-587	>45	>26- >60	<10	<8-<12
	Dodge	6	8	559	175-913	>31	>9- >76	<8	<4-<16
	Olmsted	4	22	657	450-1063	>13	>8- >55	<5	<4-<12
	Winona	6	18	397	144-1076	>42	>9->111	<10	<4-<23
	Freeborn	10	15	426	173-1135	>47	>22->112	<11	<6-<21
	Mower	10	11	338	186-756	>23	>8- >52	<7	<4-<11
	Fillmore	6	9	644	239-1035	>14	>8- >28	<5	<4-< 7
	Houston	5	8	461	257-630	>14	>9- >18	<5	<3-< 6

of Districts 5, 2, 3, and 6. Table 18 lists the district, the counties for which data are available within the district, the number of communities with data covering the eight parameters of interest, the number of wells with usable data, the average depth of the wells serving the area, the range of depth, and the average values and ranges of values for the water quality index based upon AWWA and PHS/EPA criteria, respectively.

The water quality indices for well supplies located in district 5 generally average about 100 (based on the AWWA recommendations) with the exception of the Pipestone supply and the supplies reported for Lyons County. There are some supplies in most of the other counties that are below 100, but in all cases all of the indices are shown for the Pipestone wells are below these values. In general, the average depths of wells in district 5 are shallower than those indicated for the other districts, and overall, the individual well depths range from 23 to 700 ft. with averages ranging from 94 to 109 ft. Fig. 18 shows the distribution of the water quality indices in districts 5, 2, and 3. This figure will be referred to in more detail subsequently.

District 2 lies intermediate of districts 5 and 3 and represents a transition zone as indicated by the range of water quality values shown. Some of the indices are high, being comparable to those of district 5, and others are low, being comparable to values shown for supplies in district 3. Data for four counties are shown and the water quality indices range from >11 to >939, with average levels of >38 to >320. Depths again vary; some being more shallow others being somewhat deeper.

Data for district 6 (Dakota County only) and district 3 are for water supplies in the south central and southeastern parts of Minnesota and represent a somewhat different geological system as stated earlier. These supplies, shown as coming from deeper wells, are of better quality. As indicated, the water quality indices vary overall from >7 to >112, with averages ranging from >11 to >48. The depths of individual wells range from 50 to 1135 ft. and the averages reported for the various counties range from 200 to 657 ft.

An examination of Fig. 18 will illustrate the differences in water quality indices for these supplies more effectively. This figure shows that the highest water quality indices overall were found for the waters in district 5 and lower values are indicated for wells located in district 3. Wells in the transition zone, district 2, have water quality indices approaching those reported for district 3 with the upper values indicated for the three sets of supplies are approximately 16 for district 3 supplies, approximately 80 for district 2 supplies, and approximately 111 for district 5 supplies.

Variations in water quality indices of individual wells serving Worthington (district 5), Rochester (district 3), and Winona (district 3) are shown in Tables 19, 20, and 21, respectively. These tables indicate the well number, the depth of the well in feet, water quality indices based on AWWA and PHS/EPA recommendations or standards, and the chemical characteristics of the eight parameters used in calculating the respective indices

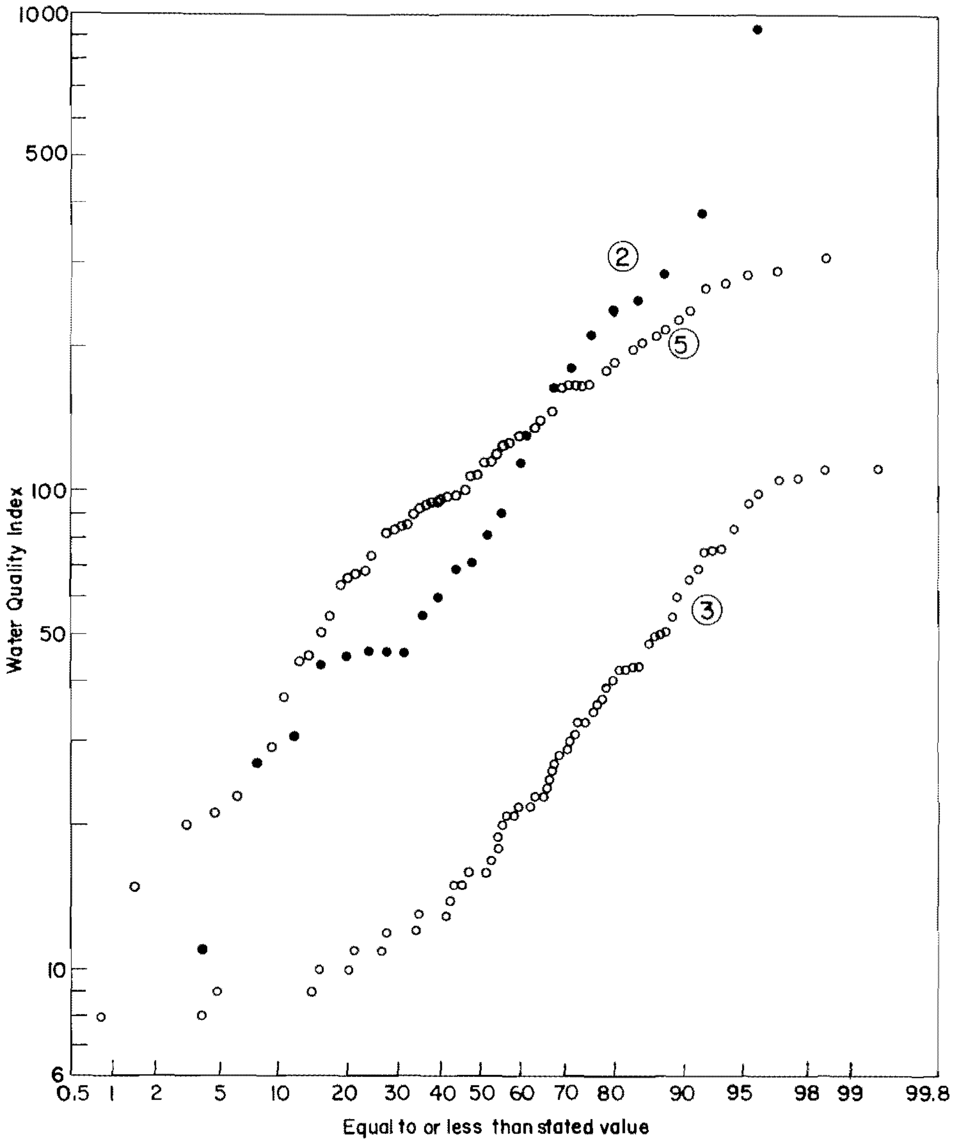


Fig. 18. Water Quality Index Based on AWWA Criteria. Water Supplies in Health Districts 2, 3, and 5.

Table 19. Water Quality Indices for Individual Wells Supplying Worthington, Minnesota District 5.

Well No.	Depth, ft.	Water Quality Indices Based on Given Criteria		mg/1						
		AWWA[a]	USPHS[b]	Hard-ness	Fe	Mn	Cl^-	$SO_4^=$	Na^+	TS
14	37	>173	<37	520	5.9	0.40	10	230	19	910
17	43	>97	<22	380	2.4	0.39	9.2	84	14	620
18	50	>73	<20	580	1.1	0.33	11	350	20	1000
25	64	>95	<23	500	2.2	0.34	8.6	370	24	1000
19	70	>124	<32	820	3.1	0.28	3.7	880	90	1900
24	70	>266	<53	650	10.	0.45	7.0	420	19	1300
28	70	>107	<26	560	2.8	0.33	16.	390	16	1000
26	76	>180	<47	560	4.1	0.30	7.2	430	20	1200

[a] See AWWA recommended values in Table 2.2.

[b] See USPHS and USEPA recommended and/or regulatory values (EPA values are national primary interim standards).

Table 20. Water Quality Indices for Individual Wells Supplying Rochester, Minnesota District 3

Well No.	Depth ft.	AWWA[a]	PHS[b]	mg/l Hard-ness	Fe	Mn	Cl⁻	SO_4	Na	TS	NO_3N
15	434	>9	<4	290	0.02	<0.02	3.0	17	3	290	<1
13	445	>9	<4	270	0.02	<0.02	<1	22	1	290	<1
8	450	>9	<4	280	0.02	<0.02	6.6	26	2	310	1.2
11	457	>10	<4	280	0.11	0.02	5.4	14	3	270	<1
14	462	>12	<4	290	0.21	0.02	2.0	15	2	270	<1
9	463	>13	<6	400	0.04	0.02	45	58	20	490	<1
10	506	>11	<5	310	0.14	0.02	3.6	25	4	260	<1
24	688	>12	<5	270	0.21	0.02	4.0	15	3	270	<1
22	730	>10	<4	270	0.09	0.02	3.3	14	4	280	<1
12	732	>8	<4	240	0.02	<0.02	6.6	14	3	260	<1
18	806	>13	<5	270	0.24	0.02	4.0	11	5	280	<1
23	809	>9	<4	240	0.09	<0.02	1.4	9.4	3	230	<1
25	848	>10	<4	260	0.11	<0.02	<1	10	1	260	<1
19	881	>12	<5	280	0.11	0.04	1.0	12	3	290	<1
17	905	>10	<4	260	0.12	0.02	1.2	16	3	250	<1
20	907	>12	<4	260	0.19	<0.02	6.3	25	3	230	<1
16	1063	>15	<5	260	0.36	<0.02	1.1	11	5	270	<1

[a]Based on AWWA criteria

[b]Based on PHS/DWS and EPA/NIPDWR criteria

Table 21. Water Quality Indices in Individual Wells Supplying Winona, Minnesota, District 3

Well No.	Depth, Ft.	Water Quality Indices Based on Given Criteria: AWWA	USPHS	mg/l Hard-ness	Fe	Mn	Cl⁻	SO_4	Na	TS
9	144	>94	<20	200	1.5	0.58	16	34	5	300
8	147	>111	<23	250	1.8	0.67	26	42	18	360
11	149	>106	<22	210	1.6	0.68	16	30	17	300
10	150	>75	<17	270	1.3	0.42	23	39	13	340
12	150	>99	<22	350	2.0	0.52	3.2	34	2	370
7	450	>20	<6	180	0.44	0.02	35	47	59	410
5	476	>27	<8	230	0.40	<0.02	140	98	160	630
6	484	>31	<8	220	0.67	0.10	31	39	28	340
13	514	>21	<8	210	0.49	<0.02	99	91	170	610
14	514	>40	<10	260	0.49	0.18	73	67	76	510
15	1056	>33	<9	310	1.0	0.06	4.0	31	2	310
Treated		>20	<7	260	0.05	0.07	78	74	75	520

Iron and manganese removal (overflow trays, cascade or other spray aerator), filter rapid sand, alkali-feed for pH adjustment, disinfection with chlorine, fluoridation with hydrofluosilicic acid.

In Tables 19 and 21 the nitrate nitrogen values are not listed because they were all reported to be less than 1. The data in Table 19 for Worthington show that the eight reported wells varied in depth from 37 to 76 feet. The water quality indices show some differences with depth with a value of >173 (based on AWWA recommendations) with somewhat lower values for the next three wells ranging in depth from 43 to 64 feet in depth (WQI were >97, >73, and >95, respectively), followed by greater variation amongst three wells reportedly of the same depth -- 70 ft. There was a difference of at least a factor of two in these values, due primarily to major differences in the iron concentrations. The final well at a depth of 76 ft showed an increased WQI value of >180. The differences in chemical characteristics of these waters are of some interest and can be seen by examining the data given in the table. For example, hardness levels varied from 380 to 820 mg/l (as $CaCO_3$), iron ranged from 1.1 to 10 mg/l, manganese ranged from 0.28 to 0.45 mg/l; chloride from 3.7 to 16 mg/l, sulfate from 84 to 880 mg/l, sodium from 14 to 90 mg/l, and total dissolved solids from 620 to 1900 mg/l. It would be of interest to identify the reasons for these differences in quality.

The data in Table 20 for Rochester are based on values reported for 17 supplies serving the area. The depth from which the supplies are drawn range from 434 to 1063 ft. Water quality indices show little variation ranging from >8 to >15 based on the AWWA criteria and from >4 to >6 based on PHS/EPA criteria. The chemical constituents reported vary within relatively narrow ranges, e.g., hardness (as $CaCO_3$) 240 to 400 mg/l, iron <0.02 to 0.36 mg/l, manganese <0.02 to 0.04 mg/l, chloride <1 to 45 mg/l, sulfates 9.4 to 58 mg/l, sodium 1 to 20 mg/l, total dissolved solids 230 to 450 mg/l, and nitrate nitrogen from <1 to 1.2 mg/l. These data and the water quality indices based on them show a very good quality water.

Table 21 for supplies serving Winona in District 3 are of some interest. Data are presented for raw water characteristics of 11 wells and also for the treated water supplied to consumers. There is some variation in quality as a function of depth; with depths covering three ranges, namely: 144 to 150 ft (5 wells), 450 to 514 ft (5 wells), and 1056 ft (one well). The WQI's show some variation with values based on AWWA criteria ranging from >75 to >111 for the shallower wells, >20 to >40 for the wells of intermediate depth, and a value of >33 for the deepest well. Major variations in composition are indicated for iron, manganese, chlorides, and sulfates, all of which affect the total dissolved solids value. The treated water has a WQI of >20 based on the AWWA criteria and shows a water of generally satisfactory overall quality except for manganese which exceeds the 0.05 mg/l recommended by the USPHS/DWS. Treatment consists of iron and manganese removal followed by rapid sand filteration, alkali pH adjustment, disinfection, and fluoridation. It is interesting to note that the WQI reported for well number 7 is equal to or lower than the WQI reported for the finished water. The chemical data show that, except for the manganese level, the specific constituents reported were all lower than those reported for the treated water.

Surface Water Supplies

Complete data for the eight parameters used to determine the WQI in surface water supplies (both raw source and treated), were available for only six supplies. The WQI's calculated for these raw and treated supplies are given in Table 22. These data show that the raw water values had WQI's (based on AWWA criteria) ranging from >7 to >138 and from <2 to <14 based on PHS/EPA criteria. Treated or finished waters showed WQI's ranging from >5 to >16 and from <1 to <5, respectively. These values, although limited in number, were generally lower than WQI's calculated for ground water supplies. In these cases the treatment processes employed appeared adequate to improve the quality of the waters as indicated by the WQI. The values shown in Table 22 are summarized in Table 23.

Discussion and Conculsions

The water quality index used in evaluating the quality of waters used for public water supplies in Minnesota is obviously simplistic, but does serve as a basis for identifying those waters that deviate to the greatest extent from recommended or required criteria indicated by the AWWA, the USPHS, and the EPA. Again, it must be further recognized that the indices reported are based on criteria associated with the eight chemical constituents reported by the Minnesota Department of Health.[15] Of the eight parameters listed only one, nitrate-nitrogen, is directly associated with health, and, except as reported in section [Nitrates (NO_3)], the population of primary concern is the infant below the age of three months. Sodium is of concern to those people who for a variety of reasons have to reduce their sodium intake. Of statistical interest, although there is no epidemiological proof of causicity, is the reported inverse relationship between hardness of the water supply and cardiovascular disease mortality. The other parameters identified in the calculation of the WQI relate to aesthetic or economic considerations.

It is obvious that if a suitable weighting scheme could be developed to identify the significance of each of the parameters included in the water quality index, its relation to the specific use to which the water supply is to be placed would be of major interest. In this regard, the water quality index suggested by Horton[1] has some merit. He stated,

> "Toxicity is not included ... [because] ... under no circumstances should streams contain substances that are injurious to humans, animals, or aquatic life."

In health-related evaluations, the assignment of weighting factors is a little more difficult because frequently we are faced with bell-shaped distributions. Thus, a deficiency of a particular substance may result in a deficiency disease, whereas an excess of the same substance may result in a toxic effect. This effect can be exemplified most easily by Figure 19 which indicates that between a deficiency disease situation and a toxic effect there must be an optimal value for the specific parameter of concern. The questions to be resolved are 1) how much of the

Table 22. Water Quality Index Values - Minnesota Public Water Supplies
Surface Water Supplies

County	Town	Source	AWWA[a]	USPHS[b]	Remarks
Yellow Medicine	Granite Falls	Minnesota River	>50	14	Raw water
			>16	<5	Treated water
Martin	Fairmont	Budd Lake	>13	<5	Raw water
			>8	<3	Treated water
Otter Tail	Fergus Falls	Otter Tail River and Hoot Lake	>8	<3	Raw water
			>6	<2	Treated water
Koochiching	International Falls	Rainey River	>7	<2	Raw water
			>5	<1	Treated water
Clay	Moorhead	Red River	>138	<26	Raw water
			>10	<3	Treated water
Sherborne	St. Cloud	Mississippi River	>11	<3	Raw water
			>5	<1	Treated water

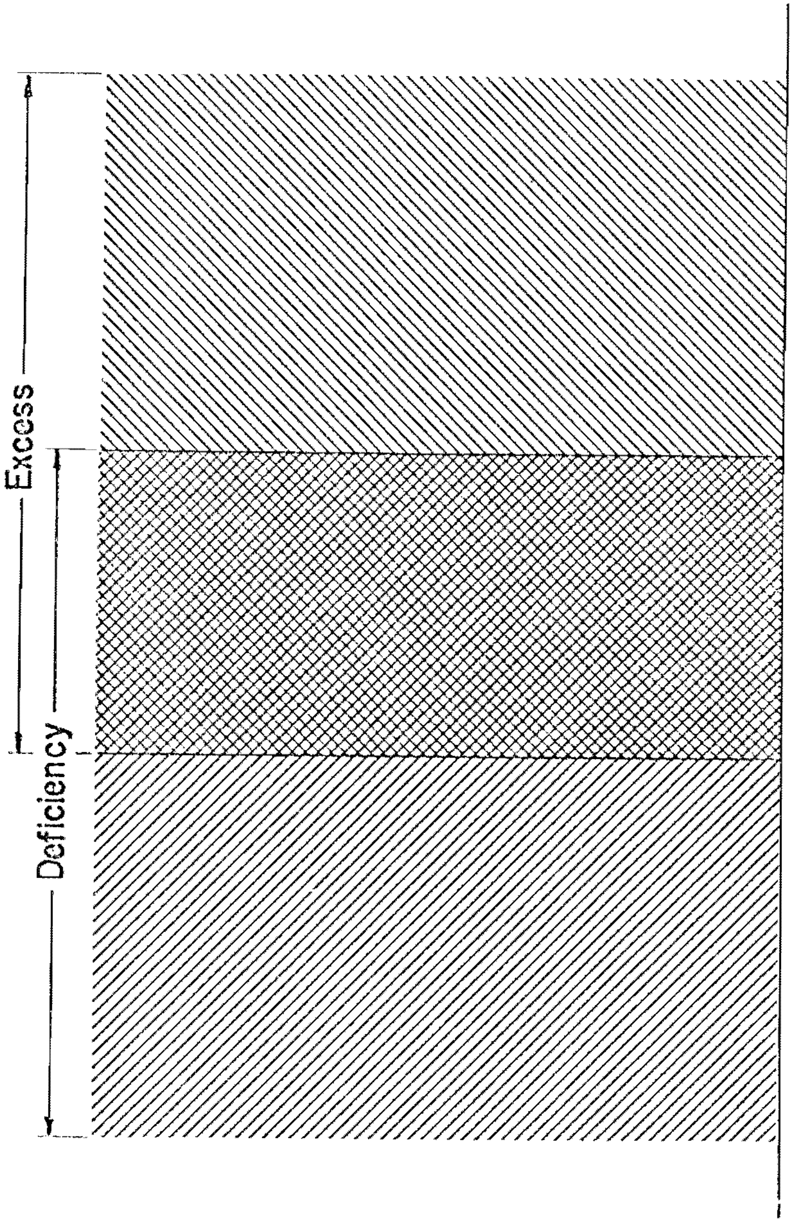
[a]Based on AWWA criteria

[b]Based on USPHS criteria

Table 23. Summary of Data Reported in Table 22.

Parameter	Based on AWWA Criteria		Based on PHS DWS & EPA criteria	
	Raw water	Treated water	Raw water	Treated water
Numbers of values	6	6	6	6
Median values	>12	>7	<4	<2.5
Mean values	>3.8	>8	<9	<2.5
Range	>7->50	>5->16	<2-<26	<1-<5

Figure 19.



Deficiency-Toxicity Relationship

given constituent is normally present in water? 2) how much of the substance is retained in the body? 3) what effect does the chemical form have on efficiency of retention? 4) how do amounts in water in relation to amounts present in other substances affect the permissible concentrations in water? The comments made with regard to deficiency diseases and the questions asked infer that there may be a necessary or a minimum value in water. In other words, complete removal may not be necessary or even desirable.

The above approach can be identified most effectively in our consideration of fluroides in water. It has been demonstrated epidemiologically with natural waters that there are relationships between fluoride levels and observed health considerations -- a deficiency in fluorides results in an increased caries incidence in children, whereas excesses have demonstrated mottling of the enamel. Furthermore, there is evidence of the toxic nature of fluorides to animals and man based on industrial and other forms of excessive exposure. The addition of fluorides to water, where needed, to provide an optimum level of this element for reducing the incidence of dental caries or the removal of fluorides from water where excess concentrations can result in mottling of the enamel are recommended and accepted public health procedures.

There is a need, therefore, to properly weight those parameters of interest in terms of the specific use to be made of the water if a meaningful water quality index is to be developed and applied. In this regard, the expression used in this analysis could be modified by applying a weighting term, w_i, to the expression given in equation 5:

$$\text{Water Quality Index} = \sum_{i=1}^{n} w_i \frac{C_i}{P_i} \qquad 8.$$

Even in its present simple form, for what it is worth, the expression given in equation 5 has some value. In the first place, the results obtained with the equation in its present form are of assistance in identifying the deviation of each constituent in the expression, and may suggest a priority for treatment. If the constituent having the highest indicated deviation, can be reduced quite easily by application of a simple economic treatment scheme, this would be of value in perhaps suggesting a priority to the kinds of treatment ot be provided. On the other hand, if the easy to remove materials do not reduce the levels to those that are recommended, it may be necessary to seek a new supply and a similar evaluation of that or other alternative sources may be helpful in determining what source represented water of desirable quality and what kind of treatment could be effectively applied to improve its quality. Second, if all values equalled the permissible concentrations recommended by the two sets of criteria applied, the water quality index would equal eight, because eight parameters were considered. If the value is less than eight, this would be indicative that the waters were of better quality with regard to the individual parameters evaluated. The addition of these terms indicates that a possible additive effect is being evaluated for the parameters considered. This observation is not valid because the criteria identified in the evaluation are not necessarily related. Some of the criteria apply to health effects, others apply to economic or aesthetic considerations, and therefore, direct comparisons cannot be made. It is like trying to add oranges and bananas, all that one can conclude is that the sum total is fruit. If one could develop meaningful weighting factors associated with specific uses of the water, and the effects were additive, than equation 5, or some reasonable modification of it, could determine the additive effects and if the total exceeded unity, than some actions would have to be taken to reduce the levels below one. On the other hand, this simple approach would not indicate in any way potentiating effects that might arise from the presence of two or more substances acting on a particular organ or even the more desirable effect of the presence of one parameter nullifying the effect of another. A third factor to take into consideration in developing appropriate standards for the ingestion of given chemical constituents in water, and this is particularly pertinent in evaluating the possible health effects, is to apply another factor to each of the terms in the expansion, namely a number associated with the efficiency of transferring the chemical agent from the intestinal tract to the site of ultimate deposition, for each deposition site in the body. This would then indicate the possible additive effects of such intake on a given tissue. For example, if we consider a substance such as iron, we might be concerned with the amount of iron ultimately deposited in a variety of soft tissues of the body, i.e., in the liver, kidney, heart, etc.

An example of the application of these thoughts to data from several supplies might be of interest. The supplies are listed in Table 24 along with the chemical data reported for each. The calculated water quality index values are indicated for each supply.

Example 1. Granada Ground Water Supply, Martin County. Applying equation 7 to the data reported results in the following terms which are to be summed:

$$WQI_{AWWA} = >9.5 + >40 + >870 + >0.020 + >6.9 + >1.8 + >4.45 + >6.0$$

$$WQI_{AWWA} = >939$$

$$WQI_{PHS} = 7.6 + 6.67 + 174 + 0.012 + 2.76 + 0.36 + 0.89 + 2.4$$

$$WQI_{PHS} = 195$$

The calculations indicate that the parameters that most greatly exceed the recommended levels are manganese and iron by values of >870 and >40, respectively. To improve the quality of these waters to where they meet recommended AWWA criteria, it would be necessary to remove iron and manganese to concentrations of <0.05 mg/l and <0.01 mg/l, respectively. Examining the components contributing to the WQI_{PHS} of 195 we note that the manganese level exceeds the recommended concentration by a factor of 174, hardness by 7.6, and iron by 6.7. It is obvious that treatment must be provided to reduce the manganese levels as well as the hardness and iron levels to markedly influence the water quality index.

Example 2. Fergus Falls surface water supply, Otter Tail County. Application of equation 7 to the data reported resulted in the following terms for summation and determination of the water quality index:

Table 24. Special Examples to Illustrate Interpretation of Water Quality Index Values

County	Supply	Well No.	Depth, ft.	Hardness as $CaCO_3$ (mg/l)	Fe (mg/l)	Mn (mg/l)	Cl (mg/l)	SO_4 (mg/l)	Nitrate Nitrogen (mg/l)	Na (mg/l)	Total Dis-solved Solids (mg/l)	Water Quality Index Based on Criteria given b: AWWA	PHS
1. Martin	Granada	1	130	760	2.0	8.7	2.9	690	1.8	89	1200	>939	195
2. Otter Tail	Fergus Falls	a	-	180	0.06	0.02	3.9	5.1	<1	13	210	>8	<3
3. Winona	Winona[b]	5-15	144-1056	245	1.06	<0.30	42.4	50	<1	110	407	>64	<14
4.		c		260	0.05	0.07	78	74	<1	75	520	>20	<7

[a] Otter Tail River and Hoot Lake

[b] Composite of all well supplies assuming equal contribution of each to total supply

[c] Treated water

$$WQI_{AWWA} = >2.25 + >1.2 + >2.0 + >0.04 + >0.05 + >1 + >0.65 + >1.05$$
$$WQI_{AWWA} = >8$$
$$WQI_{PHS} = 1.8 + 0.2 + 0.4 + 0.016 + 0.02 + 0.2 + 0.13 + 0.42$$
$$WQI_{PHS} = <3$$

The calculations indicate that the major contributor to the index term is the hardness, followed by manganese with values which are approximately double the recommended criteria for these parameters. In the case of iron, nitrate-nitrogen and total solids, the levels are approximately equal to the criteria values applied. The remaining terms, are below the recommended levels. When compared on the basis of criteria applied in calculating the WQI_{PHS} only the hardness fraction shows a value greater than 1 indicating that it exceeds the criterion applied.

Examples 3 and 4. Winona, Winona County ground water supplies raw and treated. Equation 7 was applied to a composite analysis of data represented by the 11 values reported for raw water well supplies. The terms in the WQI were as follows:

$$WQI_{AWWA} = >3.06 + >21.2 + >30. + >0.424 + >0.50 + >1 + >5.5 + >2.035$$
$$WQI_{AWWA} = >64$$
$$WQI_{PHS} = 2.45 + 3.53 + 6.0 + 0.17 + 0.2 + <0.2 + 1.1 + 0.815$$
$$WQI_{PHS} = <14$$

These data again indicate that manganese and iron are the major contributors to the WQI along with sodium. Treatment consisting of iron and manganese removal reduced the terms in the equation as follows:

$$WQI_{AWWA} = >3.25 + >1 + >7 + >0.78 + >0.74 + >1 + >3.75 + >2.6$$
$$WQI_{AWWA} = >20$$
$$WQI_{PHS} = 2.6 + 0.167 + 1.4 + 0.312 + 0.296 + <0.2 + 0.75 + 1.04$$
$$WQI_{PHS} = <7$$

These data indicate that the treated waters supplying Winona are still a little high in manganese and that this is the major term contributing to the WQI_{AWWA}. On the basis of the PHS values the major contributor to the WQI is the hardness; manganese exceeds the recommended value by 40 percent. All of the other terms show that the reported concentrations are below the criteria levels recommended.

In summary, it may be stated that the water quality index used in these analyses did have some value in identifying those water supplies which showed the greatest deviation from recommended levels and also permitted a determination of which of the parameters exceeded the limits by the greatest amount. If the effects of these parameters were all equally weighted, this would provide a basis for indicating the parameters that should be reduced first to improve the quality of the given waters.

The distribution of the EQI's calculated for the waters in the southern part of Minnesota south of the Minnesota and Mississippi Rivers are indicated in Figure 20. The distribution of these values by the various districts was indicated in Figure 18. The data shown in Figure 20 may be used to develop a classification scheme for evaluating ground water quality in southern Minnesota. As a first approach, the values suggested in Table 25 may be of interest. Those waters that showed a water quality index of less than 8 were considered to be of excellent quality; those with an index in the range of 8 to 26 as being of good quality, those with an index in the range of 26 to 80 as being of fair quality, and those with an index above 80 as being of poor quality. These values are based upon the eight parameters studied.

Table 25. Suggested Ratings for Water Supplies Based on Water Quality Index Values.

Water Quality Index	Suggested Rating	Number of Supplies Meeting the Rating Indicated			
		Based on AWWA Criteria		Based on PHS Criteria	
		Percent in group	Cumulative Percent	Percent in group	Cumulative Percent
8	Excellent	13	13	44	44
8-25	Good	29	42	36	80
26-80	Fair	33	75	17	97
80	Poor	25	100	3	100

Acknowledgement

The writer wishes to express his appreciation to Mr. Harold Lenhart for carrying out many of the calculations for water quality index in the counties in southern Minnesota.

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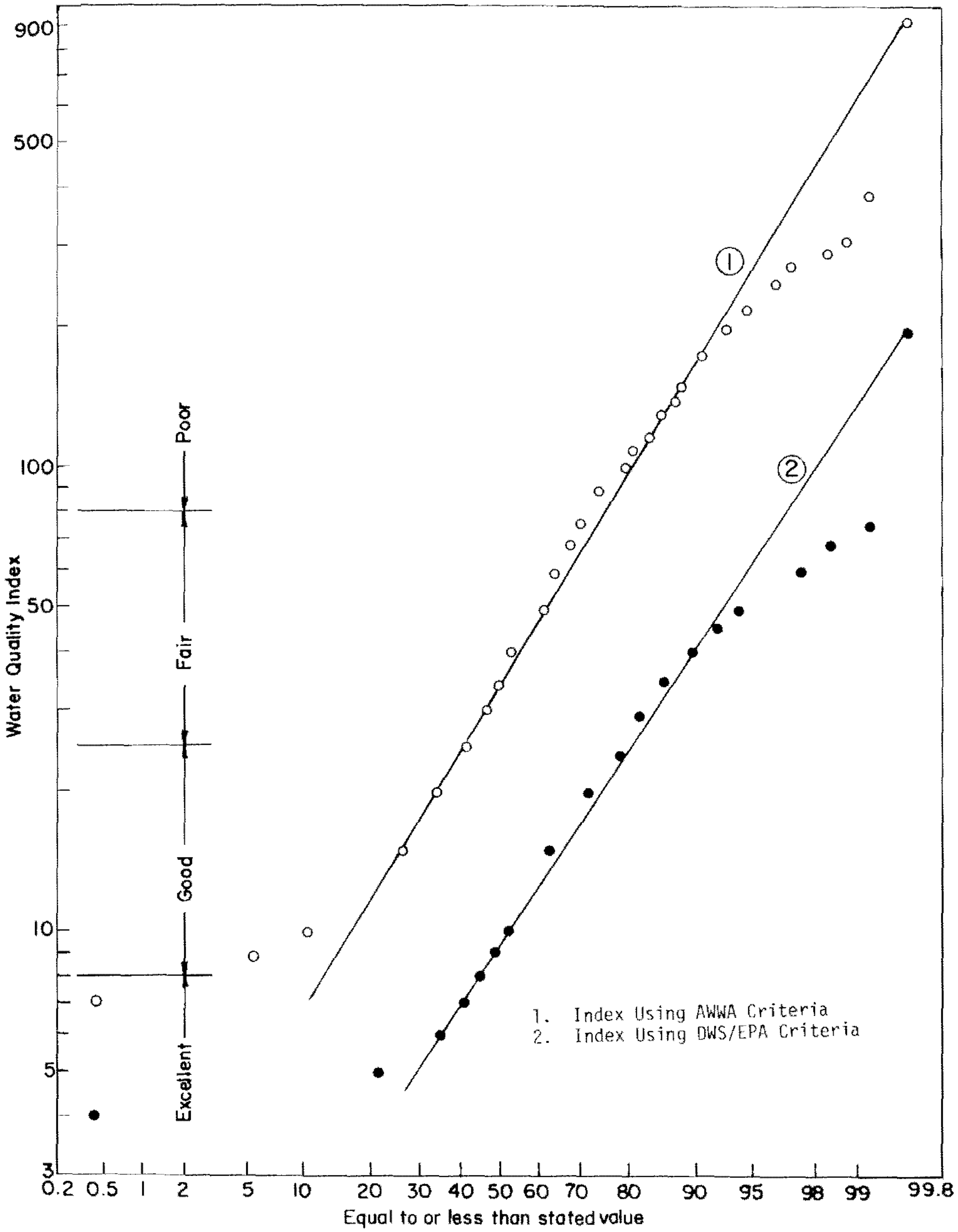

Fig. 20. Individual Well or Surface Water Sources. Minnesota Public Water Supplies South of Minnesota River. 1971 Data.

AQUIFER IDENTIFICATION - ANIONIC CONSTITUENT RATIOS

Introduction

As waters move through the ground, specific cations may be removed, adsorbed, or exchanged for other cations. Since anionic constituents are not so affected, use was made of anionic ratios as a possible basis for identifying specific aquifers. The intent was to indicate, if possible, the direction of movement of ground waters, to use this information to develop a better approach to sample collection and analysis based on a time sequence, and to better measure changes in water quality as a function of time. Ratios were used in preference to concentrations, because concentrations may change as a result of dilution, but the ratios of one anion to another will remain fairly constant. One of the earlier uses of such ratios was that indicated by Kobayashi,[1] who related the variation in deaths due to apoplexy in Japanese prefectures to the acidity of their waters. He used $CO_3:SO_4$ ratios. Since Minnesota Department of Health data[2,3] did not include information on bicarbonate or carbonate levels, but did include information on chlorides and sulfates, sulfate:chloride ratios were used in this study.

Results

The U.S. Geological Survey (USGS)[4] published chemical analyses of some Minnesota ground water supplies.[4] These included information on the bicarbonate, sulfate, and chloride levels. The $HCO_3:SO_4$ and $SO_4:Cl$ ratios were calculated from these values and are shown in Table 26. For most of the well supplies indicated, the $HCO_3:SO_4$ ratio was less than one. Only four ratios exceed one. Ratios for $SO_4:Cl$ are indicated and are quite variable. Generally, the ratios are fairly high because the chloride ratios for most Minnesota waters are quite low. It is only in northwest Minnesota that ground waters of higher chloride concentration are encountered.

As shown in Fig. 10, most of the waters containing high concentrations of sulfates are located in southwest Minnesota. It is for those supplies and supplies serving communities in other counties in southern Minnesota that ratios were determined. These $SO_4:Cl$ ratios are listed in Table 27.

The object of program NEWFILE was to establish a subfile of two existing data files which contain the information from "Division of Environmental Health, Public Water Supply Data-1971, revised 1972, State of Minn., Minn. Dept. of Health, Mpls., Minn."[2,3] The new file (TON-FILE) efficiently stores the data of interest as a string of characters according to the format indicated in Fig. 21. The nature of this file facilitates data access and manipulation with emphasis on sorting capabilities. Initial runs of this program included multiple printouts and verification techniques to ensure that proper merging of the original data files was occurring.

Table 26. Anionic Ratios - Minnesota Ground Waters[4]

	Depth*	Bicarbonate+	Sulfates+	Chlorides+	HCO_3/SO_4	SO_4/Cl
Round Lake						
101.39.24 bbd1	154	279	1750	4.0	0.16	440
101.39.93 daa1	120	544	979	4.8	0.56	200
Bigelow						
101.40.31 bdc1	86.9	532	938	0.5	0.57	1900
101.41.15 ccd1	375	480	1100	4.5	0.46	240
101.41.18 dda1	345.96	390	1680	8.8	0.23	191
101.41.23 cdc1	283.1	392	942	2.5	0.31	380
Ellsworth						
101.43.20 dbd1	19	323	60	5.8	5.4	10
102.39.7 ccc4	412	424	1350	5.0	0.31	270
102.40.7 cba1	112	392	450	8.8	0.87	51
Worthington						
102.40.25 bbb2(22)≠	58.5	388	812	15	0.48	54
102.40.27 ccd4(21)	30	328	134	8.0	1.8	23
102.40.33 ddd1(16)	40-45	390	213	6.0	1.8	35
Rushmore						
102.41.19 ddb1	375	454	1190	2.0	0.38	600
102.41.30 bad1	378	320	1610	6.5	0.20	250
Adrian						
102.43.13 add 2 (4)	39.2	311	183	24	0.17	7.6
Brewster						
103.39.25 bda1	132	418	1310	1.5	0.32	870
103.40.31 ccb3	123.9	382	703	3.0	0.54	230
Lismore						
103.42.7 aab1	26	344	307	6.5	1.1	47
Dundee						
104.39.1 bab1	80	328	1030	5.5	0.32	190
104.41.36 dcc1	514	356	924	8.0	0.39	120
Wilmont						
104.42.36 cbc1	350	346	1710	3.2	0.20	530
Fulda (Murray)	1300	405	1030	6.0	0.39	170

* In feet
\+ Concentration in mg/l
≠ Number in ( ) is well number

Table 27. SO_4:Cl Ratios - Ground Water Supplies

County	City	Well No.	Depth, ft.	$SO_4^{=}$, mg/l	Cl^- mg/l	SO_4:Cl
Lac Qui Parle						
	Marietta	1	54	940	16	59
		2	72	780	24	32
	Bellingham	1	180	670	11	61
		2	180	750	15	50
	Madison	1	110	700	9	78
		2	110	720	9.8	74
	Dawson	4	100	440	2.5	180
		6	107	390	6.0	65
		5	112	490	2.8	170
	Boyd	1	38 65	310	16	19
Yellow Medicine						
	Canby	3	100	550	6.5	85
		4	100	590	7.0	84
		7	170	670	9.0	74
	Porter	1	23	460	23	20
	Clarkfield	2	150	1200	5.6	210
	Granite Falls	Minnesota R.		260	11	24
	Hanley Falls	2	260	120	180	0.67
		1	286	120	160	0.75
	Wood Lake	1	185	580	53	11
		2	215	570	57	10
	Echo	2	67	400	10	40
		1	102	480	19	25
Lincoln						
	Hendricks	1	160	830	2.6	320
		2	160	1100	2.6	420
	Ivanhoe	2	27	200	31	6.5
		1	290	860	3.2	270
	Lake Benton	1	24	250	60	4.2
	Tyler	5	180	990	2.0	495
		6	200	940	3.0	310
		2	230	900	3.5	260
Lyon						
	Minneota	3	65	750	2.8	270
		2	120	560	7.0	80
		4	190	820	30	27

Table 27. Continued

County	City	Well No.	Depth, ft.	$SO_4^{=}$, mg/l	Cl^- mg/l	SO_4:Cl
Lyon	Russell	Spring	3	34	1.8	19
		3	35	120	2.4	50
		2	50	1000	3	330
		1	190	230	69	3.3
	Lynd	1	30	330	87	3.8
	Balaton	1	35	200	140	1.4
	Marshall	8	90	560	16	35
		10	113	590	1.8	330
		6	340	650	80	8.1
		4	426	860	30	29
		5	426	1000	80	12
		7	426	830	45	18
		1	436	850	24	35
		9	480	800	45	18
	Tracy	3	638	650	1.6	410
		2	700	600	5.0	120
	Cottonwood	6	111	950	200	4.8
		7	112	13	470	0.028
Redwood						
	Milroy	4	230	350	44	8
	Walnut Grove	1	312	710	33	22
		2	320	740	24	31
	Vesta	3	102	240	8.3	29
	Lucan	3	87	1000	3.5	290
	Revere	2	165	800	14	57
		1	198	660	22	30
	Belview	2	210	850	4.2	200
		3	221	930	5.2	180
	Wabasso	1	85	71	26	2.7
		2	99	140	3.4	41
	Wanda	1	185	330	82	4.0
	Lamberton	2	75	330	13	25
		3	87	200	18	11
	Sanborn	2	300	480	<1	>480
		1	310	560	<1	>560

Table 27. (cont'd)

County	City	Well No.	Depth, ft.	$SO_4^=$, mg/l	Cl^- mg/l	$SO_4:Cl$
Redwood						
	Morton	1	48	180	10	18
		2	48	260	13	20
	Morgan	1	148	560	<1	>560
		2	150	600	<1	>600
Pipestone						
	Jaspar	Spring	6	19	16.0	1.2
		1	8	17	6.6	2.6
		2	8	47	9.0	5.2
	Pipestone	2	386	360	26	14
		4	410	86	75	1.1
		1	500	180	58	4
		5	504	500	1	500
	Ihlen	1	408	74	5.6	13
	Trosky	1	241	87	4	22
	Edgerton	1	24	46	15	3.1
		7	26	76	13	5.8
		2	28	100	40	2.5
	Ruthton	3	100	700	1.8	390
Murray						
	Lake Wilson	2	27	210	<1	>210
		1	87	180	<1	>180
	Chandler	1	30	220	41	5.4
	Hadley	1	216	420	<1	>420
		2	216	320	<1	>320
	Iona	1	240	740	6	120
	Slayton	2	200	560	1	560
		1	209	850	<0.5	>1700
		-	-	830	1	830
	Currie	2	112	1100	<1	>1100
		1	122	1200	5.1	240
	Avoca	2	164	1300	0.84	1600
		3	167	700	0.5	1400
	Fulda	1	1300	900	5	180

Table 27. (cont'd)

County	City	Well No.	Depth, ft.	$SO_4^=$, mg/l	Cl^- mg/l	$SO_4:Cl$
Cottonwood						
	Westbrook	2	561	1700	<1	>1700
		3	602	960	27	36
	Storden	2	258	560	5	112
		1	487	600	2.5	240
	Jeffers	1	78	1300	5.5	237
		3	700	1400	<1	>1400
		2	97	2000	4	500
	Windom	3	85	95	7	14
		4	90	63	6	11
		2	97	140	6	23
		5	100	110	8.5	13
		6	120	110	10	11
	Mountain Lake	2	245	1100	4.3	256
		1	325	1100	4.3	256
Watonwan						
	Darfur	1	34	48	4.2	11
		2	160	53	3.5	15
	Butterfield	1	177	510	1.0	510
		2	512	600	2.7	220
		-	-	560	330	1.7
	St. James	4	40	520	20	26
		3	42	430	31	14
		5	47	260	16	16
		2	185	980	<1	>980
	Lewisville	1	456	340	2	170
	Madelia	3	550	190	<0.05	>3800
Rock						
	Hills	-	250	1000*	1.4*	715*
	Beaver Creek	1	505	100	1.9	53
		2	137	47	<1	>47
	Luverne	1	20	100	9	12
		6	36	80	5	16
		2	40	100	5	20
		3	40	94	6.4	15
		7	40	65	4	16

*Treated-No raw data

Table 27.(cont'd)

County	City	Well No.	Depth, ft.	$SO_4^=$, mg/l	Cl^- mg/l	SO_4:Cl
Rock						
	Luverne	12a	43	71	5.2	14
		10	44	49	15	3.3
		13	44	96	2	40
		5	45	75	12	6.2
		19	46	85	8.8	10
		20	46	67	35	1.9
		9	56	98	38	2.6
		11	66	160	5.3	30
	Hardwick	1	410	28	8.5	3.3
Nobles						
	Ellsworth	1	30	360	6.9	52
		2	23	300	<1	>300
	Adrian	3	32	230	71	3.2
		4	38	240	210	1.1
		2	43	150	52	2.9
		1	56	300	22	14
	Wilmont	1	350	1800	3.3	545
		2	360	2100	3.0	638
	Rushmore	1	372	1200	3	400
	Bigelow	1	89	1000	2	500
		2	89	770	5.2	148
	Worthington	4	35	180	12	15
		14	37	230	10	23
		16	37	400	3.5	114
		17	43	84	9.2	9.1
		15	50	250	0.84	298
		18	50	350	11	32
		25	64	370	8.6	43
		19	70	880	3.7	238
		24	70	420	7.0	60
		28	70	390	16	24
		26	76	430	7.2	60
		11	80	1000	4	250
		6	86	280	9	31
		8	100	120	16	7.5
		10	158	1400	0.8	1750
	Dundee	1	70	1000	3.3	303
	Brewster	1	124	1300	4.0	325
		2	132	1200	2.0	600

Table 27.(cont'd)

County	City	Well No.	Depth, ft.	$SO_4^=$ mg/l	Cl^- mg/l	SO_4:Cl
Nobles						
	Round Lake	2	140	1800	0.6	3000
		1	149	1750	6.8	257
Jackson						
	Heron Lake	3	275	670	1.3	520
		2	360	770	2.4	320
	Okabena	2	310	760	3.2	240
	Lakefield	2	199	290	2.1	140
		1	204	500	2.2	230
	South Windom	-	-	-	-	-
	Jackson	1	42	330	54	6.1
		2	42	180	41	4.4
	Alpha	2	98	450	<0.5	>900
	Dunnell	2	187	670	2.0	335
		3	200	630	3.0	210
	Trimont	3	140	470	2	235
	Sherburn	1	-	420	2.1	200
		2	-	430	1.6	270
	Ormsby	1	-	660	<1	>660
		2	-	120	3.8	32
		3	60	220	23	9.6
	Ceylon	1	325	500	<1	>500
		2	-	600	2.5	240
	Welcome	2	156 }	780	2.0	390
		1	263 }			
	Fairmont	Budd Lake	-	72	9.7	7.4
	Northrop	1	145	520	1.7	301
	Truman	1	102	69	1	69
		2	105	89	1	89
		3	590	520	5.2	100
	Granada	1	130	690	2.9	240

Figure 21.

ION-FILE*

DATA	CHARACTER LOCATION
Supply number from WELL-FILE	1-3
County code	4-5
Ownership code	6
1970 population	7-12
Supply number from SUPPLY-FILE	13-15
Well number	16-19
Well depth	20-23
Sample date (MMYY)	24-27
Calcium	28-31
Chlorides X 100	32-36
Sulfates X 10	38-42
Sodium X 10	43-46
Potassium X 10	48-50

*ION-FILE is 52 BCD characters long. Format conversions are handled by the subroutine to change the characters into the appropriate variable type for analysis.

The subroutine COUNTY was developed (Fig. 22) to allow analysis of the data by selected geographical locations. These locations may be specified in data cards containing county codes for the counties of interest. Up to 25 counties may be grouped together for analysis. The only limit on the number of such groups is the computer time required to perform the analysis.

This subroutine does an analysis of the ratio $SO_4^{=}/Cl^{-}$. This ratio is calculated for each well in a county of interest where both $SO_4^{=}$ and Cl^{-} data were available. A preliminary look at the distribution of this ratio was accomplished by a call to a library subroutine, FTABLE. FTABLE provides for any real variable array the minimum, maximum, mean, median, and variance. For any number of intervals up to fifty, specified in the calling program, a fequency table and histogram of relative frequencies are given for the $SO_4^{=}/Cl^{-}$ ratio. For more detailed inspection the actual ratio and its well source were listed.*

This subprogram may be easily modified to accomplish this analysis for any parameter of interest. The file is such that it may be sorted on any parameter of interest by a library sorting routine, MSSORT. Hardware and software specifications:

The programs described previously were written in MS/FORTRAN; FORTRAN language; MASTER operating system. They made use of the following Health Computer Sciences' library routines: MFPICKD, IREAD, IWRITE, MVE, and FTABLE. Documentation for these routines is available in the HCS office. (V362, VFW Cancer Research Center).

The programs were run on a CDC 3300 computer. Creation of the new file took approximately 10.5 seconds of computer time. A complete run with 19 separate counties to provide data analysis for, required approximately six and one half minutes of computer time.

The two programs are shown in Appendices B.1 and B.2 and example results are given for a single county (Appendix B.1) and for a combination of counties (Appendix B.2).

An examination of the available data show no real patterns between depths and the SO_4:Cl ratios. More detailed information is needed regarding direction and rates of flow of the specific aquifers, and much more has to be known about the respective formations and the characteristics of the water flowing through them before use can be made of this particular Parameter under present conditions of knowledge.

Acknowledgements

Appreciation is expressed to Ms. Charlene Kanniainen, Graduate Student, for preparing the computer subprogram for determining the sulfate: chloride ratios.

* Care should be taken when interpreting this information as the data base from which it was drawn was not a random sample.

Figure 22.

SUBROUTINE COUNTY

COUNTY	CODE	COUNTY	CODE
Aikin	01	Nicollet	52
Anoka	02	Nobles	53
Becker	03	Norman	54
Beltrami	04	Olmsted	55
Benton	05	Otter Tail	56
Big Stone	06	Pennington	57
Blue Earth	07	Pine	58
Brown	08	Pipestone	59
Carlton	09	Polk	60
Carver	10	Pope	61
Cass	11	Ramsey	62
Chippewa	12	Red Lake	63
Chisago	13	Redwood	64
Clay	14	Renville	65
Clearwater	15	Rice	66
Cook	16	Rock	67
Cottonwood	17	Roseau	68
Crow Wing	18	St. Louis	69
Dakota	19	Scott	70
Dodge	20	Sherburne	71
Douglas	21	Sibley	72
Faribault	22	Stearns	73
Fillmore	23	Steele	74
Freeborn	24	Stevens	75
Goodhue	25	Swift	76
Grant	26	Todd	77
Hennepin	27	Traverse	78
Houston	28	Wabasha	79
Hubbard	29	Wadena	80
Isanti	30	Waseca	81
Itasca	31	Washington	82
Jackson	32	Watonwan	83
Kanabec	33	Wilkin	84
Kandiyohi	34	Winona	85
Kittson	35	Wright	86
Koochiching	36	Yellow Medicine	87
Lac Qui Parle	37		
Lake	38		
Lake of the Woods	39		
LeSueur	40		
Lincoln	41		
Lyon	42		
McCleod	43		
Mahnomen	44		
Marshall	45		
Martin	46		
Meeker	47		
Mille Lacs	48		
Morrison	49		
Mower	50		
Murray	51		

References

1. Kobayashi, J. Geographical Relationship Between the Chemical Nature of River Water and Death-Rate from Apoplexy. Bericht des Ohara Institute für landwirtschaftliche Biologie, 11:12 (1957).

2. Minnesota Department of Health, Division of Environmental Health. State of Minnesota--Public Water Supply Data--1971.

3. Minnesota Department of Health, Division of Environmental Health, State of Minnesota--Public Water Supply Data--1972.

4. Norvitch, R.F. Geology and Ground Water Resources of Nobles County and Part of Jackson County, Minnesota. U.S. Water Supply Paper 1749, U.S. Geological Survey. Available from Superintendent of Documents, Washington, D.C. 1964.

TRANSFER OF DATA TO COMPUTERS*

Source of Data

The data contained in "State of Minnesota Public Water Supply Data, 1971, Revised 1972,"[1,2] were transferred to computer cards. Transcribing the data onto coding sheets was rejected because of the time required and the possibility of transcription errors. The layout of the "Yellow Book"[1,2] made direct keypunching feasible with a minimum of precoding of data. Since the data were listed in alphabetical order by supply name, supply numbers were assigned in numeric order. County code and health and economic district codes were added, and ownership and source codes were changed from alphabetical to numeric. Data comment codes were assigned to each sample, and decimal points were added to certain numeric fields to avoid having to add leading zeros. Pump type and capacity data and treatment data were not coded but were keyed as alphabetical fields which would acquire special computer routines to translate the alphabetical information into numeric codes. Examples of a page from the Yellow Book[1,2] before and after coding are shown in Table 28. Data pertaining to the supply were keyed on two supply data cards (1 and 2) and data pertaining to each well in the supply community are keyed on two well data cards (3 and 4). Formats of the data cards are shown in Fig. 23 and 24.

Programs Prepared

Two programs were written to edit the data cards. Program EDIT12 edits the two supply data cards (1 and 2) and creates a 136 character per record master supply data file, and program EDIT34 edits the two well data cards (3 and 4) and creates a 120 character per record master data file. Formats of the two master data files are shown in Fig. 25 and 26. The files were created so that they could be accessed interactively by teletype or Cathode ray tube (CRT) to manually correct errors found by the edit programs. The programs check for missing data, check the type, size and range of each of the data items and recode certain fields. The most complex part of the programs are the two subroutines (CKTRT in program EDIT12 and CKPUMP in program EDIT34) which check the alphabetical treatment codes and pump type and capacity codes and recode the data into numeric codes. Listings of the edit programs are shown in Appendix C as attachments C.1 and C.3 and examples of the output from each program are shown as attachments C.2 and C.4. The codes used for various data items in the master data files are shown as atachments C.5 through C.11.

References

1. Minnesota Department of Health, Division of Environmental Health, State of Minnesota -- Public Water Supply Data -- 1971.

2. Minnesota Department of Health, Division of Environmental Health, State of Minnesota -- Public Water Supply Data -- 1972.

* The work described in this section was prepared by Mr. Alain DuChene, Data Processing Technician, School of Public Health, University of Minnesota.

Table 28. Sample Entry In Data Book* Before and After Coding for Keypunching

	Name of Supply	1970 Population	Ownership	Service Connections	Average Daily Consumption (1000 gal.)	Source	Well Number	Year Installed	Well Depth	Pump Type & Capacity (GPM)	Treatment	Storage (1000 Gal.) Elevated	Ground	Pressure Tank
Before Coding	Albert Lea	19212	Mun.	5671	3000	Drilled Well	2	1923	680	VT 1800	I At Frs Dc Va	1900		
						Drilled Well	5	1958	319	VT 1500				
						Drilled Well	8	1961	300	VT 1500				
						Drilled Well	9	1965	350	VT 1500				
After Coding	Albert Lea	19212.	1	5671.	3000.	110	2	1923	680.	VT 1800	I At Frs Dc Va	1900.	-	-
	008 24 3 10					110	5	1958	319.	VT 1500				
						110	8	1961	300.	VT 1500				
						110	9	1965	350.	VT 1500				
						-	-	-	-	-				
	Supply Data: Card 1					Well Data: Card 3					Supply Data: Card 2			

	Data Comment Code	Date of Sample	Total Hardness ($CaCO_3$)	Alkalinity ($CaCO_3$)	Calcium $CaCO_3$)	pH	pH of Stability	Iron (Fe)	Manganese (Mn)	Chlorides (Cl)	Sulfates (SO_4)	Fluorides (Fl)	Nitrate Nitrogen	Sodium (Na)	Potassium (K)	Total Solids	Well Number
Before Coding		2-70	330	370	240	7.1	7.2	1.2	0.02	3.0	19	0.25	<1	13	3	360	2
		2-70	370	390	250	7.3	7.2	1.6	0.02	1.0	35	0.26	<1	17	3	420	5
		2-70	300	360	240	7.5	7.2	1.1	0.03	3.5	57	0.23	<1	14	3	390	8
		2-70	320	400	240	7.2	7.2	1.2	0.05	1.0	15	0.52	<1	15	3	390	9
		2-70	350	350	240	7.3	7.3	0.06	0.04	5.0	33	1.00	<1	17	3	420	
After Coding	01	02-70	330.	370.	240.	7.1	7.2	1.2	0.02	3.0	19.	0.25	1.	13.	3.	360.	2
	01	02-70	370.	390.	250.	7.3	7.2	1.6	0.02	1.0	35.	0.26	1.	17.	3.	420.	5
	01	02-70	300.	360.	240.	7.5	7.2	1.1	0.03	3.5	57.	0.23	1.	14.	3.	390.	8
	01	02-70	320.	400.	240.	7.2	7.2	1.2	0.05	1.0	15.	0.52	1.	15.	3.	390.	9
	02	02-70	350.	350.	240.	7.3	7.3	0.06	0.04	5.0	33.	1.00	1.	17.	3.	420.	-
		Well Data: Card 3 continued						Well Data: Card 4									

*Minnesota Department of Health, Division of Environmental Health, "Public Water Supply Data, 1971, Revised 1972."

Figure 23. Layout of Data Cards Input to Edit Programs

SUPPLY CARD RECORDS

Card 1 Column	Card 1 Data Item	Card 1 Type & Size	Card 2 Column	Card 2 Data Item	Card 2 Type & Size
1-3	Supply Number	I3	1-3	Dupl. Supply Number	I3
5-6	County Code	I2	5-54	Treatment Codes	50A1
8	Health Dist. Code	I1	56-61	Elevated Storage	F6
10-11	Economic Dist. Code	I2	63-68	Ground Storage	F6
13-44	Supply Name	8A4	70-73	Pressure Tank Storage	F4
46-52	1970 Population	F7	80	2	I1
54	Ownership Code	I1			
56-62	Service Connections	F7			
64-69	Ave. Daily Consumption	F6			
80	1	I1			

Figure 24. Layout of Data Cards Input to Edit Programs

WELL CARD RECORDS

Card 3 Column	Card 3 Data Item	Card 3 Type & Size	Card 4 Column	Card 4 Date Item	Card 4 Type & Size
1-3	Supply Number	I3	1-3	Dupl. Supply Number	I3
5-7	Source Code	I3	9-12	Dupl. Well Number	4A1
9-12	Well Number	4A1	14-18	Iron	F5
14-17	Year Installed	I4	20-24	Manganese	F5
19-23	Well Depth	F5	26-30	Chlorides	F5
25-40	Pump Type & Capacity	16A1	32-36	Sulfates	F5
44-45	Data Comment Code	I2	38-42	Fluorides	F5
47-50	Date of Sample (MMYY)	I4	44-45	Dupl. Data Comment Code	I2
52-56	Total Hardness	F5	47-50	Dupl. Date of Sample	I4
58-62	Alkalinity	F5	52-56	Nitrate Nitrogen	F5
64-68	Calcium	F5	58-62	Sodium	F5
70-73	pH	F4	64-68	Potassium	F5
75-78	pH of Stability	F4	70-74	Total Solids	F5
80	3	I1	76-79	Well Number	4A1
			80	4	I1

Figure 25. Layout of Supply Data File (136 Characters/Record)

DATA ITEM	BEGIN COLUMN	TYPE & SIZE	MISSING DATA VALUE
1. Supply Number	2	I3	0
2. County Code	5	I2	00
3. Health District Code	7	I1	0
4. Economic District Code	8	I2	00
5. Ownership Code	10	I1	0
6. 1970 Population	12	I6	-99
7. Service Connections	19	I6	-99
8. Ave. Daily Consumption (x 10)	26	I6	-99
9. Elevated Storage (x 10)	33	I6	-99
10. Ground Storage (x 10)	40	I6	-99
11. Pressure Tank Storage (x 10^2)	47	I4	-99
12. No Treatment	52	I1	9
13. Special Treatment to Certain Wells	54	I1	9
14. Purification	55	I1	9
15. Softening	56	I1	9
16. Iron and Manganese Removal	57	I1	9
17. Aeration	59	7I1	9
18. Chemicals for Coagulation or Softening	67	7I1	9
19. Disinfection	75	4I1	9
20. Filter	80	11I1	9
21. Chemical Dosage for Corrosion	92	7I1	9
22. Mixing Device or Tank	100	9I1	9
23. Ammoniation	110	4I1	9
24. Recarbonation	115	I1	9
25. Sedimentation	117	7I1	9
26. Chemical Taste or Odor Control	125	6I1	9
27. Fluoridation	132	5I1	9

Figure 26. Layout of Well Data File (120 Characters/Record)

DATA ITEM	BEGIN COLUMN	TYPE & SIZE	MISSING DATA VALUE
1. Supply Number	2	I3	0
2. Data Comment Code	6	I2	99
3. Source Code	9	I3	999
4. Purchased Supply Code	13	I3	0
5. Well Number	17	A4	9999
6. Year Installed	22	I4	9999
7. Well Depth	27	I4	-99
8. Pump Type	32	11I1	9
9. Capacity	44	I4	-99
10. Date of Sample (YYMM)	49	I4	9999
11. Total Hardness	54	I4	-99
12. Alkalinity	59	I3	-99
13. Calcium	63	I4	-99
14. pH (x 10)	68	I3	-99
15. pH of Stability (x 10)	72	I3	-99
16. Iron (x 10^2)	76	I4	-99
17. Manganese (x 10^2)	81	I4	-99
18. Chlorides (x 10^2)	86	I5	-99
19. Sulfates (x 10)	92	I5	-99
20. Fluorides (x 10^2)	98	I3	-99
21. Nitrate/Nitrogen (x 10)	102	I3	-99
22. Sodium (x 10)	106	I4	-99
23. Potassium (x 10)	111	I3	-99
24. Total Solids	115	I4	-99

ANALYTICAL STUDIES - GROUND AND SURFACE SUPPLIES*

Introduction

Public water supplies contain a variety of chemical contaminants of natural, municipal, agricultural, or industrial origin. Some of these compounds are believed to be toxic, carcinogenic, mutagenic, and/or teratogenic, and, thus, may be potentially hazardous to health. Organic chemicals as a group are of most concern. They are found in public water supplies in a wide range of concentrations, but most often in minute quantities. Existing analytical methods, which require extensive concentrations of dissolved substances in water before analyses can be made, are not feasible for the direct identification of the organic substances encountered.

Accurate, high precision, rapid, and economical methods for determining organic compounds in water are needed to separate the complex materials present into specific groups initially and subsequently into single entities within the groups. Thin-layer chromatography provides the techniques needed to separate these substances with excellent resolution, high sensitivity, great speed, and economy. For analysis, microgram quantities of material are required. In contrast to existing methods, which require concentration of up to several thousand gallons of water, the thin-layer chromatographic procedures described herein called for concentration of only three liters of sample.

Concentration techniques used, whether for large volume samples or three-liter volumes used, must be quantitative and nondestructive with regard to the physical properties and the chemical structure of the compounds. The conventional scheme of concentrating organic compounds on activated carbon with recovery by solvent extraction was used. Recognizing the inadequacies in the use of activated carbon as a sorbent and the solvents used for extraction -- variable solubilities and possible interaction of solvents -- the results of our studies are reported on a qualitative basis.

Experimental

Water samples were collected from three municipal systems using surface waters as their source of supply. Samples of the raw and treated waters were collected for examination. All three plants included coagulation and settling, lime softening, recarbonation, rapid sand filtration, and chlorine-ammonia disinfection, but neither the order of treatment processes nor the treatment chemicals used were identical.

Three-liter aliquots of each sample were filtered through a magnetic filter funnel containing 3 g (1:1000) of activated U.S.P. (powder) charcoal.** Following filtration, the charcoal adsorbent was air dried, placed in an

* The work reported herein was performed by Velta M. Goppers, Senior Scientist, Environmental Health Program, School of Public Health.

** Mallinckrodt. Cat. No. 4394.

extracting unit, and extracted for 12 hours with spectro grade chloroform* and hexane.* At the end of the extraction cycle, the extracts obtained with each solvent system were concentrated to a small volume in a rotating evaporator** at low temperature and transferred to a 3 ml volumetric flask (1:100000). Both concentrated extracts were separated into specific organic chemical groups by thin-layer chromatography.

Thin-layer chromatoplates (20 x 20 cm) were coated with 250 μm thickness of silica gel G*** by means of an adjustable applicator,**** dried in air, activated at 110 C for 30 min, and stored in a desiccator.

The concentrated chloroform and hexane extracts were chromatographed on the prepared thin-layer chromatoplates by accumulating the given extracts on predetermined spots in microliter (μl) quantities up to 3, 5, and 10 μl, and developed in specific solvent systems to separate out particular chemical compound groups from the material at the starting deposition point. The groups selectively separated were: chlorinated hydrocarbons, phosphoric acid esters, plant (vegetative) phenols and their derivatives, and detergents.

Chlorinated Hydrocarbons

The chlorinated hydrocarbons include a large group of organic compounds used widely as pesticides in agriculture. They enter surface waters with runoff and erosion of soil particulates and contaminate waters used as water supply sources. Many of the chlorinated hydrocarbon compounds are toxic and several have been restricted for use or banned. There are a number of commercially available compounds in this group including aldrin, endrin, lindane, toxaphene, and others. These substances are generally present in surface waters at nanogram per liter levels. Analyses, therefore, generally require some concentration of the compounds present. In our studies, the hydrocarbons were adsorbed on activated powdered charcoal and extracted with appropriate solvents.

Carbon-chloroform and carbon-hexane extracts were prepared and analyzed by thin-layer chromatography. Two different thin-layer chromatoplates were used: a) 250 μm thick plates prepared from silica gel G, and b) 250 μm thick plates prepared from silica gel G impregnated with fluorescein. The concentrated extracts were spotted in 1 μl quantities on predetermined areas on the prepared chromatoplates. To detect meaningful quantities of the compounds of interest, the number of microliters of extract spotted was increased.

* Eastman organic chemicals: Chlorofom.-Cat. No. 13056; Hexane-Cat. No. 13049, Eastman Kodak Co., Rochester, N.Y. 14650.

** Buchler Instruments, New York, N.Y.

*** E. Merck, Darmstadt, West Germany.

**** Desaga equipment, C., Gmbh, Heidelberg, West Germany.

The carbon-chloroform extracts, spotted on the silica gel G chromatoplates, were developed in a solvent system consisting of cyclohexane and chloroform (80:20)[1] by a one-dimensional ascending technique. The solvent was allowed to move 15 cm from the starting place (about 30 min), then removed from the solvent system, and dried in a clean air stream. The dry chromatograms were sprayed with a solution of 0.5 percent silver nitrate in ethanol followed by a solution of 0.15 percent silver nitrate in ethanol and ethyl acetate (1:). After the first and second sprayings, the plates were kept at 100°C for 5 min. Chlorinated hydrocarbons appeared as yellow spots on a blue background. The developed chromatogram (Fig. 27) showed the presence of chlorinated hydrocarbons in the raw and treated water, indicating that conventional treatment processes are ineffective for the removal of these compounds. Additional compounds appeared in the treated water, resulting from the reaction of naturally occurring substances and the chlorine added in disinfection. Similar quantities of the carbon-hexane extracts produced much weaker spots when processed in the same manner. Why this difference should occur cannot be fully explained at this time. The separation of chlorinated hydrocarbons initially present in water into single compounds was very good.

Extracts spotted on the silica gel G chromatoplates impregnated with a 0.004 percent solution of aqueous fluorescein were developed in a solvent system consisting of petroleum hydrocarbon and carbon tetrachloride (50:50)[1] by one dimensional technique. After development, the chromatoplates were air dried and inspected under ultraviolet light at 360 nm in the chromato-vue cabinet. The chlorinated hydrocarbons appeared as dark blue-violet spots on a green fluorescent background. The addition of fluorescein to the separation media increased the sensitivity of the methods. Amounts of chlorinated hydrocarbons as low as 0.002 μg could be detected by these procedures. If the chromatograms are exposed to the air after development in the solvent system, the chlorinated hydrocarbons appeared as rose-colored spots. Color intensity was a function of humidity.

Phosphoric Acid Esters

This group of compounds includes phosphoric acid and thiophosphoric acid esters. Included in the latter group are pesticides such as parathion, malathion, chlorothion, and many others.

Carbon-chloroform and carbon-hexane extracts prepared from the raw and finished waters were chromatographed on silica gel-G chromatoplates and developed for 20 min in a solvent system consisting of hexane and acetone (4:1).[2] The developed dried chromatograms were viewed under ultraviolet light at 360 nm and did not show the presence of any fluorescent compounds. The chromatograms were then sprayed with a 0.5 percent solution of palladous chloride dissolved in dilute hydrochloric acid. Separated compounds appeared in daylight as yellow spots on a light brown background. The developed chromatogram (Fig. 28) shows that phosphoric acid esters are present in both the raw and treated waters.

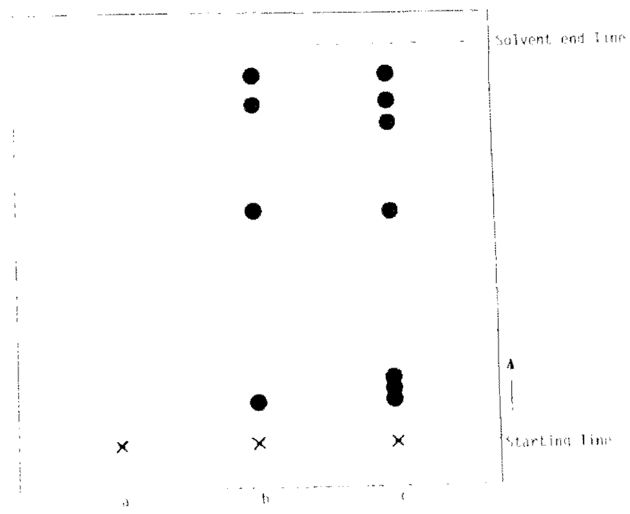

Figure 27. Thin-layer chromatogram of chlorinated hydrocarbons in: a- solvent blank; b- raw water; c- treated water. Visualized with bromophenol blue reagent.

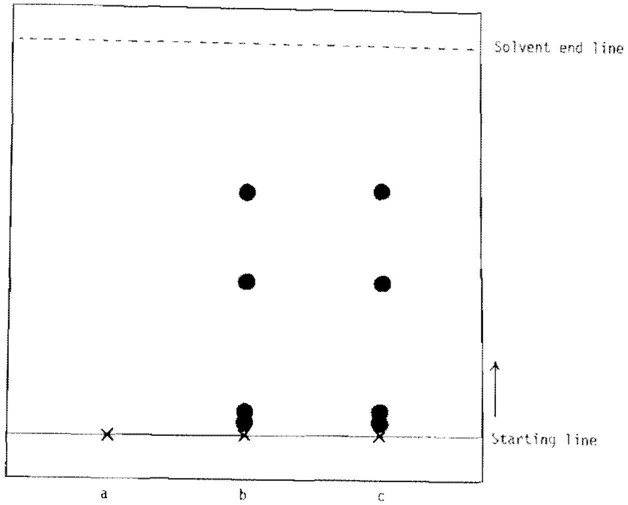

Figure 28. Thin-layer chromatogram of phosphoric acid esters in: a- solvent blank; b- raw water; c- treated water. Visualized with palladous chloride reagent.

Plant Phenols and Their Derivatives

This group of organic compounds contains hydrophilic phenolic plant compounds and their derivatives such as complex phenols and their glycosides, phenolic acids, pyrones, anthocyanins, quinone derivatives, and many other large molecular compounds. Plant phenols and their derivatives constitute a very large group of chemical compounds. To initiate chemical analysis of unknown samples, the materials must be separated systematically into closely-related chemical groups, then divided into subgroups which can be separated systematically into closely-related chemical groups, then divided into subgroups which can be separated into single substances. Chemical compounds are known to act on certain chromatographic media and certain solvent systems according to their molecular composition. Adsorption affinity is strongly affected by free phenolic groups. Phenolic ether groups, the position of the phenolic hydroxyl groups, and the presence of methyl, ethyl, or other aliphatic side chain groups strongly influence the behavior of phenolic compounds on thin-layer chromatoplates.

The carbon-chloroform and carbon-hexane extracts, which contained the organic materials concentrated from raw and finished waters, were divided into three large chromatographic groups according to their functional groups and polarity.

1. Compounds containing only one phenolic group and compounds containing no free hydroxyl group are both slightly polar and were separated from the same extracts on 250 μm thick silica gel G chromatoplates with a solvent system consisting of petroleum ether, benezene, methanol, and butanone (50:40:5:5).[3] These chromatoplates were developed, dried in a clean air stream, and inspected under ultraviolet light at 360 nm. The sensitivity of the fluorescence of the phenolic compounds in ultraviolet light was increased by adding 1 percent of the fluorescent compound "ZS Supper"*[4] to the inorganic adsorbent silica gel G. Spraying with a 1 percent solution of ferric chloride in 0.5 N hydrochloric acid made the separated phenolic compounds visible in daylight. The distribution of spots in both raw and treated waters is shown in Fig. 29.

2. Polyphenols and their derivatives with fused rings and medium polarity were separated on silica gel G chromatoplates with a solvent system consisting of toluene, chloroform, and acetone (40:25:35). The developed chromatograms were inspected under ultraviolet light at 360 nm, visualized by spraying with 0.1 N silver nitrate and 5 N ammonium hydroxide (1:5), and heated for 5 min at 105 C. Phenols appear as dark spots. The developed chromatogram is shown in Fig. 30.

3. Phenolic compounds consisting of glycosides and salt-like compounds were separated on silica gel G with a solvent system consisting of ethyl acetate, butanone, formic acid, and water (50:30:10:10).[5]

* Riedel-De-Haen AG, Seelze-Hanover, Germany.

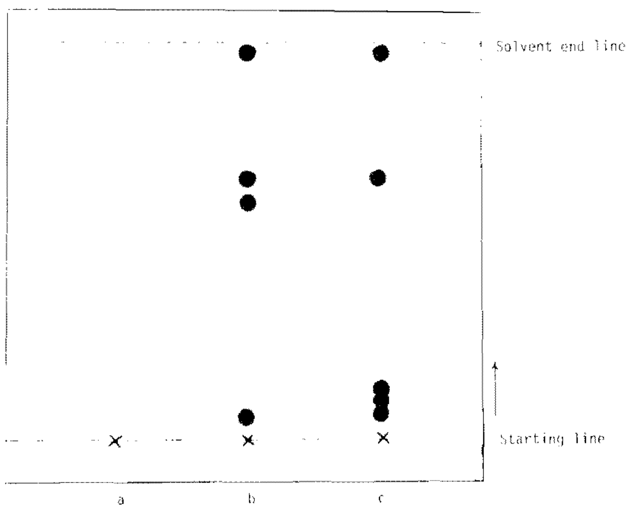

Figure 29. Thin-layer chromatogram of plant phenols and their derivatives of group No. 1 in: a- solvent blank; b- raw water; c- treated water. Visualized with ferric chloride reagent.

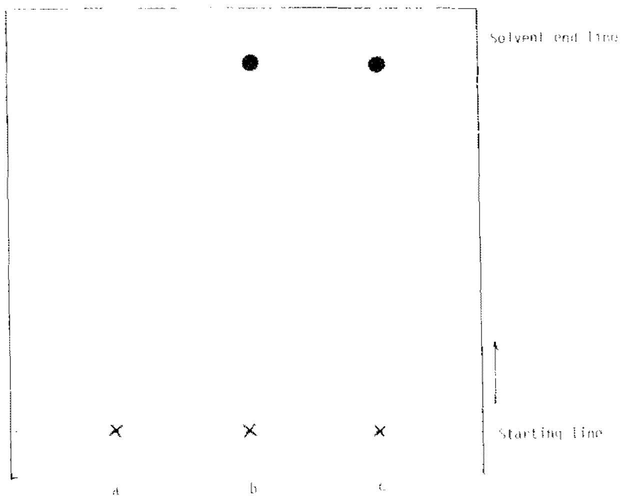

Figure 30. Thin-layer chromatogram of plant phenols and their derivatives of group No. 2 in: a- solvent blank; b- raw water; c- treated water. Visualized with silver nitrate reagent.

Developed chromatograms were inspected under ultraviolet light at 360 nm. Spraying the chromatogram with 25 percent aqueous solution of basic lead acetate[6] increased the sensitivity of the separated compounds under ultraviolet light. About 0.2 μg can be detected by this method. The developed chromatogram is shown in Fig. 31.

A small number of phenols are colored compounds, like quinone derivatives and anthocyanins, which could be detected directly on thin-layer chromatograms.

Detergents

The detergents represent a very large group of chemical compounds, and include alkyl sulfates, sulfonates, sulphonic acid derivatives, phosphates, and phosphonates. Carbon-chloroform and carbon-hexane concentrated extracts prepared from the raw and treated water samples were chromatographed on silica gel G chromatoplates containing 10 percent ammonium sulfate.[7] The chromatoplates were developed in a solvent system consisting of methanol with 5 percent 0.1 N sulfuric acid and chloroform (97:3). The unsaturated compounds were visualized on air-dried chromatograms with iodine vapors. Saturated and unsaturated compounds were detected by spraying the chromatoplates with 0.2 percent of 2',7'-dichlorofluorescein solution in ethanol, and inspected under ultraviolet light at 360 nm. The developed chromatogram is shown in Fig. 32.

Discussion

Microchemical methods using thin-layer chromatographic techniques were developed for the detection of specific groups of organic compounds in municipal water supplies. Separations (summarized in Table 29) were carried out on a silica gel G substrate on chromatoplates. Although aluminum oxide was observed to be a more reactive adsorbent than silica gel G, it was not used in the present studies because of its catalytic properties. It is known that aluminum oxide catalyzes several reactions, such as isomerization of double bonds and ester hydrolysis,[6] which might change the composition of chemical compounds in the original complicated water extract concentrate.

Standard-sized chromatoplates (20x20 cm) were used to provide a longer travel distance for better separation of the large number of components. In addition, microchromatoplates, prepared on microscope slides, were found very useful for quick production of results where the exact number of compounds was not required but just the presence or absence of a specific group. The microplates required 5-10 min for development, whereas 15-30 min was required for the standard (20x20 cm) chromatoplates depending on the nature of the solvent system used.

The results are presented on a qualitative basis because of the inadequacy in existing sample preparation techniques, particularly in the adsorption of the materials on the activated charcoal and the recovery of the adsorbed substances by the solvent extraction procedure

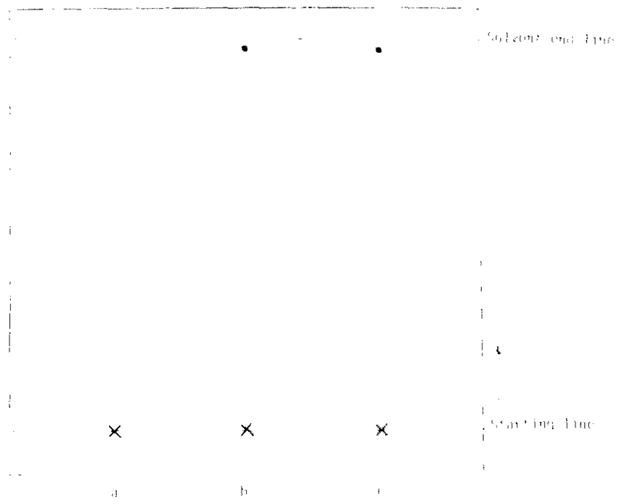

Figure 31. Thin-layer chromatogram of plant phenols and their derivatives of group No. 3 in: a- solvent blank; b- raw water; c-treated water. Compounds located in ultraviolet light at 360 nm. Intensity of fluorescence increased with lead acetate reagent.

Figure 32. Thin-layer chromatogram of detergents in: a- solvent blank; b- raw water; c- treated water. Chromatogram in ultraviolet light at 360 nm, after spraying with 0.2% 2',7'-dichlorofluorescein.

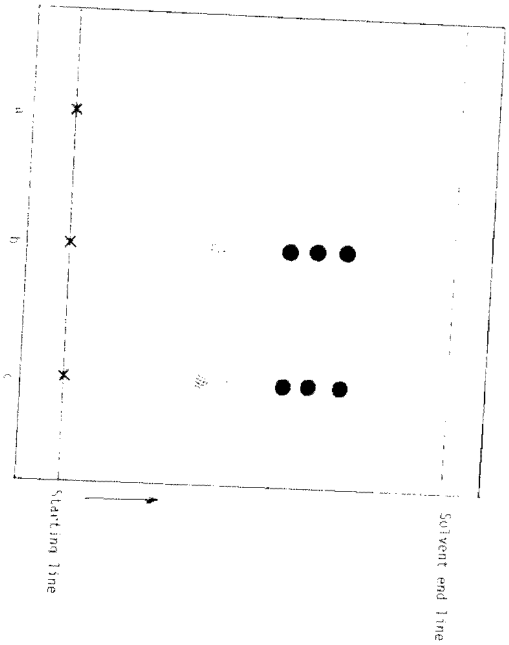

Table 29. Summary of Separation and Visualization Methods for Detection of Specific Organic Chemical Compound Groups in Municipal Water Supplies on Thin-Layer Chromatograms

Chemical Compound Group	Chromatographic Media	Developing Solvent	Compound Detecting Reagents	Fluorescence UV at 360 nm	Visible Colors in Daylight
Chlorinated Hydrocarbons	1. Silica gel G	Cyclohexane and chloroform (80:20)	a) 0.5 percent $AgNO_3$ in C_2H_5OH b) 0.2 percent bromophenol blue + 0.15 percent $AgNO_3$ in C_2H_5OH and $C_2H_5COOOCH_3$ (1:1)		Yellow spots on blue background
	2. Silica gel G impregnated with 0.004 percent of aq. sol. of fluorescein	Petroleum hydrocarbon and carbon tetrachloride (50:50)	-	Dark blue-violet spots on green fluorescent background	Rose colored spots after exposure to air
Phosphoric cid Esters	Silica gel G	Hexane and acetone (4:1)	0.5 percent $PdCl_2$ in dil. HCl	-	Yellow spots on light brown background
Plant Phenols and Their Derivatives					
1. Compd. with one phenolic group, no free -OH- group, slightly polar	Silica gel G, plus 1 percent "ZS Supper"	Petroleum ether, benzene, methanol, and butanone (50:40:5:5)	1 percent of $FeCl_3$ in 0.5 N HCl	-	Blue and greenish spots on light yellow background
2. Polyphenols and their deriv. with fused rings, medium polarity	Silica gel G	Toluene, chloroform, and acetone (40:25:35)	0.1 N $AgNO_3$ and 5 N NH_4OH (1:5)	-	Dark spots on light background
3. Glycosides and salt-like compd.	Silica gel G	Ethyl acetate, butanone, formic acid, and water (50:30:10:10)	25 percent aq. soln. of $Pb(CH_3COO)_2$	Bright fluorescent spots	-
This group contains also naturally colored compounds		Ethyl acetate, butanone, formic acid, and water (50:30:10:10)			Visible as yellow spots
Detergents	Silica gel G plus 10 percent ammonium sulfate	Methanol with 5 percent 0.1 N H_2SO_4 and chloroform (97:3)	a) Iodine vapor b) 0.2 percent soln. of 2'7'-dichlorofluorescein in C_2H_5OH	White fluorescent spots	-

used. In these studies, the conventional techniques of carbon adsorption and solvent extraction were used. Preliminary findings, with repeated adsorptions of organics on the charcoal powder indicated that subsequent passage of the effluent through a second and third carbon bed yielded approximately similar adsorptions and recoveries, thus suggesting that a quantitative result obtained by the use of the conventional adsorption and extraction methodology would be low by at least a factor of three.

Polyelectrolyte Persistence - Water Treatment

Polyelectrolyes are finding many uses in water and wastewater treatment practices. The USEPA publishes a list of polyelectrolyes for use as coagulent aids in water supply; the last of which appeared in August 1975.[9] In listing the polyelectrolytes,

> "EPA emphasizes that its findings bear only on the health aspects of the use of these products in drinking-water treatment and do not constitute endorsement or indicate effectiveness for the proposed use.
>
> "Some of the products listed may kill fish at or below maximum recommended concentrations. The review of the suitability of these products is confined to their use in drinking water treatment plants..."

EPA further states that the list includes those products that the manufacturers still wish to have listed.

The World Health Organization (WHO) International Reference Center for Community Water Supply reviewed the health aspects of the use of polyelectrolytes in water treatment.[10] They report that studies of synthetic polyelectrolyes based on polyacrylamide show the toxicity to be very low. No data are available of the possible effects of the polyelectrolyte on reproduction, teratogenicity, and mutagenicity or on the metabolism of the monomers and their combined effects with other chemicals of toxicological significance occurring in microquantities in the intake of humans from the environment. The report further states, "Because of the uncertainty of the removal of polyelectrolyes in water treatment, the best practice is to consider any toxic hazard on the basis of the applied dose of the chemicals."

Studies have shown, for example, that all of the acrylamide applied to water in a polyacrylamide coagulant aid can be found in filtered water.[11] The report also indicates

> "... synthetic polyelectrolytes may present a toxic risk. In some cases this risk is not associated with the polyelectrolyte itself but with unreacted monomer residues."

In addition to their use in water supply, polyelectrolytes are finding extensive use in wastewater treatment, in industrial waste treatment, in industry, and for increasing the discharge capacity of storm sewers. These uses are not identified in terms of permissible concentrations of poly-

electrolytes as are those products recommended for use in water treatment. If these substances are not directly biodegradable or if on degradation, they produce products that are toxic, they are of prime concern to the water-treatment field.

Procedure

Samples for analysis were collected at two water treatment plants serving the Minneapolis-St. Paul metropolitan area and included raw water, samples of water following each major processing step, the finished water, and a sample of the commercial high activity cationic liquid polyelectrolyte used as a coagulant aid.

The samples were processed as described in this section under Experimental. In addition, a standard solution of the polyelectrolytes (mg/l) was prepared by using double glass-distilled water and processed in a manner similar to that of the raw and processed-water samples.

For qualitative evaluation, the concentrated chloroform extracts were chromatographed by the ascending technique on the prepared thin-layer chromatoplates. One microliter quanities of chloroform extract totalling 10 µl were applied and accumulated on predetermined spots. Similarly, 5 µl of mercuric acetate solution in methanol (1:5) was added to each spot. The developing solvent used was that indicated by Braun and Vorendohre[12] and consisted of butanone, n-propanol, ethanol, and concentrated ammonium hydroxide (45.5:4.5:18:32). Developing time was 40 min. After development, the chromatograms were dried in a clean air stream and tested for compound location (1) by inspection under ultraviolet light at 360 nm and (2) by development with chemical reagents to make the separated compounds visible. In the latter case, the chromatograms were exposed for 5-10 min to hydrochloric acid vapors and then sprayed with 0.1 percent solution of dithizone in carbon tetrachloride. This procedure produced red and yellow spots that corresponded to the separated compounds.

Findings

As shown in Fig. 33(a) the developed thin-layer chromatogram revealed that the polyelectrolyte standard dissolved in double-distilled water contained the polymer and three monomers. The polymer remained at the initial starting place on the thin-layer chromatogram and the monomers were separated in the direction in which the solvent traveled. The chromatographic pattern obtained from the carbon chloroform extract of the raw water, Fig. 33(b), showed the presence of other organic compounds. In Fig. 33(c), which represented the organic compounds separated from the carbon chloroform extract of the finished water, the presence of the organic substances separated out in the polyelectrolyte standard were noted, i.e., the three monomers and the polymer at the starting place, those organic substances present in the raw water, and an intermediate group of compounds produced, in all probability, by reaction of the polyelectrolyte or other treatment chemicals initially present in the raw water. Based on their Rf values on the thin-layer chromatogram and

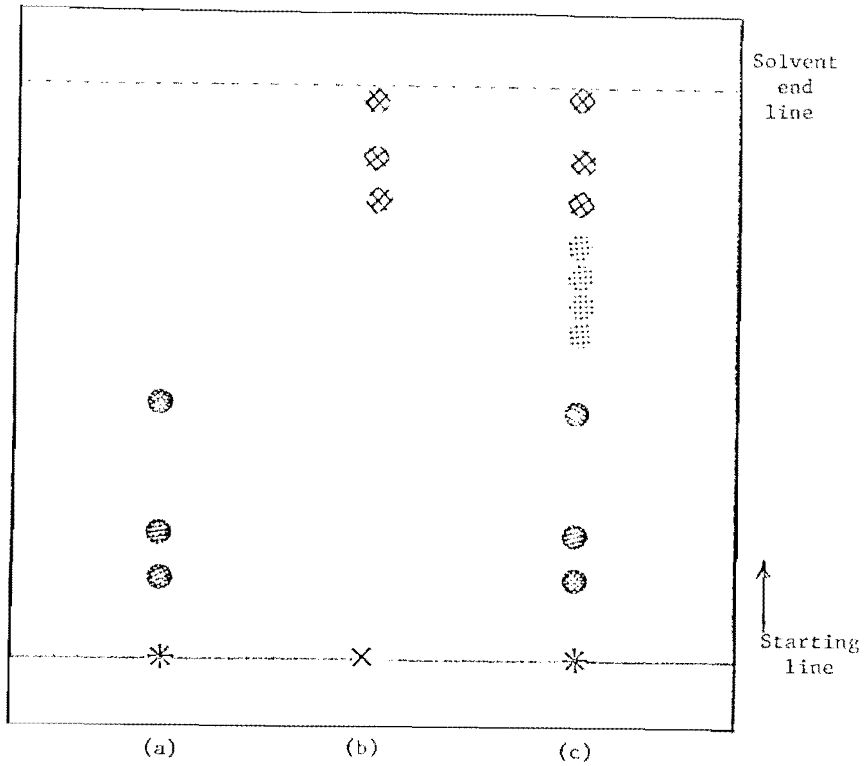

Figure 33. Thin-layer chromatogram of: (a) polyelectrolyte standard; (b) raw water; and (c) processed water (finished water).

on infrared spectra obtained, the separated compounds attributed to the addition of polyelectrolyte in water solution were identified as n-butyl methacrylate, acrylonitrile, and methyl methacrylate. The three monomers that were separated by thin-layer chromatography were eluted with carbon tetrachloride and carbon disulfide and analyzed in an infrared spectrophotometer in a 0.1-mm NaCl cell. The infrared spectra of the monomers are presented in Fig. 34, 35, 36.

The chloroform extract collected following processing of the various water samples by activated carbon adsorption was also separated on a gas chromatograph, but the compounds were not identified because of the need for reference compounds and a more specific column. These gas chromatographic scans were helpful in supporting the thin-layer chromatographic results. They too showed more compounds in the scan for finished water than in the scan for raw water. Some of these compounds could have resulted from the reaction of chlorine used as a disinfectant with the organic materials present in the water.

Discussion

The thin-layer chromatograms demonstrated that the polyelectrolyte is present in finished water, the polyelectrolyte in finished water appears as the polymer and as monomers, and the polyelectrolyte or other added chemicals (e.g., chlorine) reacted with the organic compounds in raw water forming new substances that were transferred through the various stages of water treatment to the finished water prior to discharge to the distribution system for human consumption.

The finding of the polyelectrolyte or its monomers in the finished water in itself does not necessarily constitute a health hazard. However, the presence of this material in the finished water should encourage attempts to quantify the amounts present and their distribution within the various products of water treatment, i.e., finished water, sludge, and backwash waters, and their effects on the recycling and recovery of water-treatment sludges. With such information available, it will be possible to evaluate the potential hazard of these substances on the public health of persons consuming these waters.

Organic Contaminants in Ground Water Supply

A sample of water from a well 92.4 meters in depth was analyzed by thin-layer chromatography and showed the presence of ortho- and para-cresols.

Organic Constituents in Spring Runoff Waters

Foam resulting from the aeration of runoff waters (spring floods 1975) was collected and analyzed following concentration on activated carbon and extraction with chloroform, ethanol, or petroleum ether. The extractant was analyzed by thin-layer chromatography and gas chromatography. These studies indicated the presence of hydrocarboxylic acids, gallo tannins, and some percentage of phenyl hydrocarboxylic acids (thin-layer

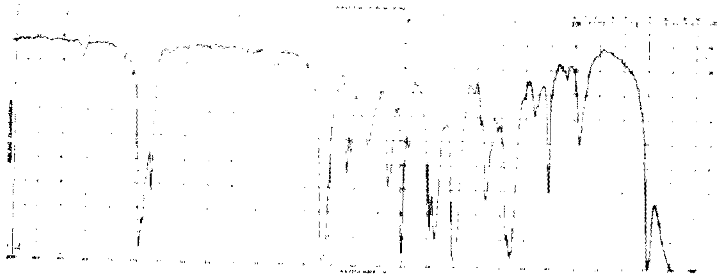

Figure 34 Reproduction of Strip Chart Showing Infrared Spectra of Compound No. 1, N-butyl Methacrylate

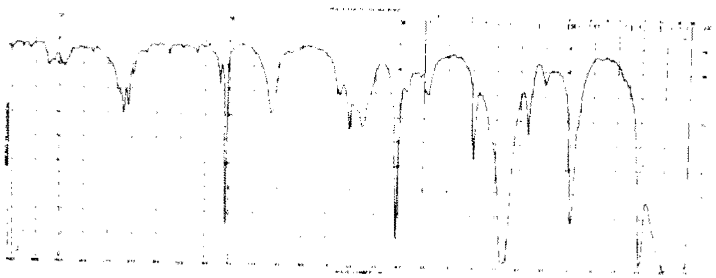

Figure 35 Reproduction of Strip Chart Showing Infrared Spectra of Compound No. 2, Acrylonitrile

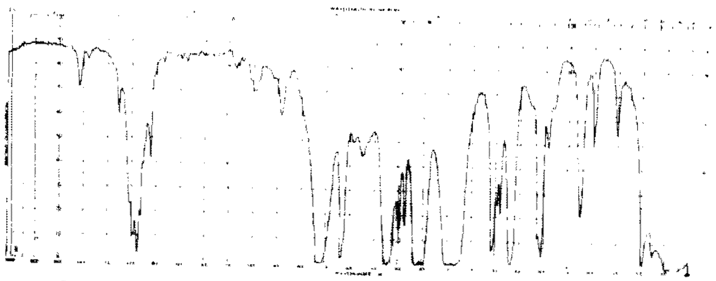

Figure 36 Reproduction of Strip Chart Showing Infrared Spectra of Compound No. 3, Methyl Methacrylate

chromatography), and partially separated hydrocarboxylic acids and humic derivatives (gas chromatograph on 5% Carbowax column). The scan obtained with the gas chromatograph is shown in Figure 37.

Inorganic Trace Substances - Sludge and Backwash Water Plant C

Lime sludges and waste backwash water samples were collected from Water Treatment Plant C and analyzed for trace inorganic heavy metals by thin-layer chromatography. The qualitative findings indicated the presence of the following cations in the sludge:

Major components: Al^{3+}, Fe^{3+}, and Ca^{2+}

Trace quantities: Ni^{2+}, Cr^{3+}, Mn^{2+}, Zn^{2+}, Mg^{2+}, Pb^{2+}, and Cd^{2+}

Minute quantities: Ba^{2+} and Ag^{+}

The backwash water contained:

Major components: Al^{3+}, Fe^{3+}, and Ca^{2+}

Trace quantities: Ni^{2+}, Cr^{3+}, Mn^{2+}, and Mg^{2+}

The raw water was analyzed for cadmium but none was found.

It would be of interest to identify the source of the substances found -- raw water or treatment chemicals used.

Summary

Ultra-micro chemical separation and detection methods based on thin-layer chromatography for minute quantities of organic and inorganic compounds in raw surface and ground waters, in treated municipal water supplies and sludges and backwash waters from water treatment plants, have been established. After development of appropriate extraction and concentration procedures, the thin-layer chromatographic methods described can be used readily to detect and measure quantitatively nanogram quantities of chlorinated hydrocarbons, phosphoric acid esters, phenols, detergents, polyelectrolytes, ortho- and para-cresols, other organics, and heavy metals. The methods have been applied successfully to the identification of these substances in a variety of waters, in backwash water, and sludges.

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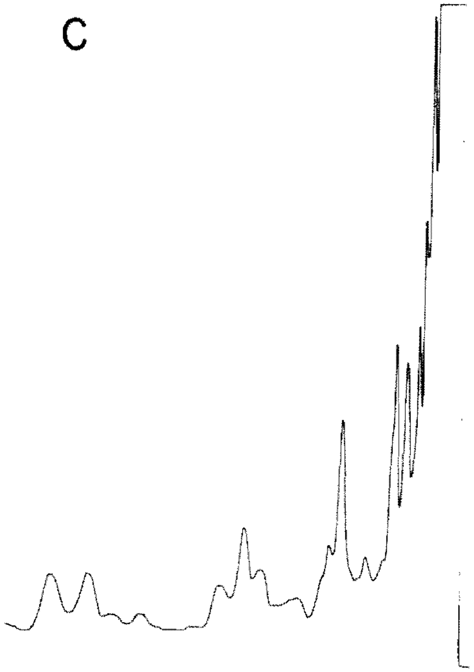

Figure 37. Gas chromatograph scan of foam collected from Mississippi River on April 25, 1975.

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APPENDIX A

APPENDIX A-1: Total Hardness

	Treated Ground						Raw Ground						Treated Surface						Raw Surface					
Total Hardness as $CaCO_3$ (mg/l)	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent
0 - 40	2	2	5.13	612	612	0.42	2	2	0.38	568	568	0.044	6	6	15.4	53392	53392	4.25						
41 - 80	7	9	23.1	15325	15937	11.0	3	5	0.94	406	974	0.075	17	23	59.0	757528	810920	64.5	2	2	100.0	9772	9772	100.0
81 - 100	3	12	30.8	8393	24330	16.8	4	9	1.69	3844	4818	0.37	12	35	89.8	431725	1242645	99.0						
101 - 125	2	14	35.9	2982	27312	18.8	8	17	3.2	8315	13133	1.01												
126 - 150	2	16	41.0	1037	28349	19.6	13	30	5.64	11118	24251	1.87	2	37	94.8	1871	1244516	99.1						
151 - 175	2	18	46.1	2850	31199	21.5	10	40	7.51	15197	39448	3.04	1	38	97.4	3189	1247705	99.3						
176 - 200	6	24	61.5	33830	65029	45.0	34	74	13.9	86406	125854	9.7												
201 - 225	3	27	69.3	13149	78178	54.0	28	102	19.2	104106	229960	17.7												
226 - 250	1	28	71.8	463	78641	54.3	45	147	27.6	116377	346337	26.7	1	39	100.0	8221	1255926	100.0						
251 - 275	2	30	77.0	26888	105529	72.9	50	197	37.0	208180	554517	42.6												
276 - 300	2	32	82.1	4823	110352	78.4	46	243	45.7	239802	794319	61.1												
301 - 350	4	36	92.3	26288	136640	94.5	75	318	59.8	211823	1006142	77.5												
351 - 400							59	377	70.9	102214	1108356	85.3												
401 - 450	1	37	95.0	7347	143987	99.5	35	412	77.5	46344	1154700	89.0												
451 - 500							26	438	82.3	35894	1190594	91.7												

APPENDIX A-1 Continued

Total Hardness as $CaCO_3$ (mg/l)	Treated Ground						Raw Ground						Treated Surface						Raw Surface					
	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent
501 - 550							13	451	84.7	32917	1223511	95.1												
551 - 600							8	459	86.3	12840	1236351	95.3												
601 - 650	1	38	97.5	405	144392	99.8	12	471	88.5	9209	1245560	96.0												
651 - 700							11	482	90.5	15924	1261484	97.3												
701 - 750							10	492	92.5	8436	1269920	97.8												
751 - 800							7	499	93.8	6113	1276033	98.3												
801 - 900							8	507	95.3	8559	1284592	99.0												
901 - 1000							8	515	96.8	5818	1290410	99.4												
1001 - 1100	1	39	100.0	555	144947		7	522	98.1	4259	1294669	99.5												
1101 - 1200							2	524	98.5	2301	1296970	99.8												
1201 - 1300							4	528	99.2	1354	1298324	99.9												
1301 - 1400																								
>1400							4	532	100.0	1886	1300210	100.0												
Totals	39			144947			532			1300210			39			1255926			2			9772		

APPENDIX A-2: Iron

Iron as Fe (mg/l)	Treated Ground						Raw Ground						Treated Surface						Raw Surface					
	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent
<0.05	8	8	20.5	12587	12587	8.7	48	48	9.01	84740	84740	6.52	19	19	48.6	506431	506431	40.3						
0.05 - 0.10	12	20	51.3	105143	117730	77.1	39	87	16.4	104444	189184	14.6	10	29	74.3	128695	635126	50.6						
0.11 - 0.20	9	29	74.4	14262	131992	91.1	41	128	24.1	138898	328082	25.3	7	36	92.4	618891	1254017	99.8						
0.21 - 0.30	4	33	84.6	4932	136924	94.5	22	150	28.2	71785	399867	30.8												
0.31 - 0.40							19	169	31.8	71419	471286	36.3	2	38	97.4	1492	1255509	99.97	2	2	100.0	9772	9772	100.0
0.41 - 0.50	2	35	89.8	2679	139603	96.3	18	187	35.2	41303	512589	39.4	1	39	100.0	417	1255926	100.0						
0.51 - 0.60	1	36	92.4	325	139928	96.6	19	206	38.8	142298	654887	50.3												
0.61 - 0.80	2	38	97.5	1269	141197	97.4	30	236	44.4	60513	715400	55.0												
0.81 - 1.00	1	39	100.0	3750	144947	100.0	37	273	51.3	85067	800467	61.9												
1.01 - 1.50							72	345	65.0	174215	974682	75.0												
1.51 - 2.00							42	387	72.8	150461	1125143	86.6												
2.01 - 2.50							40	427	80.4	39702	1164845	89.6												
2.51 - 3.00							30	457	86.0	34195	1199040	92.3												
3.01 - 4.00							31	488	91.8	67452	1266492	97.4												
4.01 - 5.00							22	510	96.0	19641	1286133	98.8												

APPENDIX A-2 Continued

Iron as Fe (mg/l)	Treated Ground: No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	Raw Ground: No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	Treated Surface: No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	Raw Surface: No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent
5.01 - 6.00							8	518	97.5	4855	1290988	99.3												
6.01 - 8.00							9	527	99.2	6886	1297874	99.8												
8.01 - 10.0							4	531	99.9	1477	1299351	99.93												
>10.0							1	532	100.0	859	1300210	100.0												
Totals	39		100.0	144947			532			1300210			39			1255926			2			9772		

APPENDIX A-3; Manganese

Manganese (mg/l)	Treated Ground: No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	Raw Ground: No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	Treated Surface: No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	Raw Surface: No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent
<0.01							2	2	0.38	3002	3002	0.23												
0.01 - 0.02	22	22	56.4	52767	52767	36.4	136	138	26.1	217425	220427	17.0	30	30	93.8	633246	633246	99.5	2	2	100.0	9772	9772	100.0
0.021 - 0.03	1	23	59.0	450	53217	36.7	35	173	32.7	230574	451001	34.7	1	31	96.9	193	633439	99.5						
0.031 - 0.04	2	25	64.1	19385	72602	50.1	32	205	38.8	103309	554310	42.7	1	32	100.0	3595	637034	100.0						
0.041 - 0.05	1	26	66.7	279	72881	50.3	23	228	43.1	80309	634619	48.9												
0.051 - 0.06	2	28	71.8	1269	74150	51.1	14	242	45.8	52282	686901	52.9												
0.061 - 0.08	2	30	77.0	28424	102574	70.8	30	272	51.4	23976	710877	54.8												
0.091 - 0.10	2	32	82.1	4800	107374	74.2	40	312	59.0	84534	795411	61.2												
0.101 - 0.15	1	33	84.7	4703	112077	77.5	58	370	70.0	179081	974492	75.0												
0.151 - 0.20	1	34	87.2	28993	141070	97.4	48	418	79.1	128781	1103273	85.0												
0.201 - 0.30	3	37	94.9	1912	142982	98.7	51	469	88.7	101030	1204303	92.9												
0.301 - 0.40							23	492	93.0	47444	1251747	96.6												
0.401 - 0.50							8	500	94.5	8095	1259842	97.0												
>0.50	2	39	100.0	1966	144948	100.0	29	529	100.0	38587	1298429	100.0												
Totals	39			144948			529			1298429			32			637034			2			9772		

APPENDIX A-4: Chlorides

Chlorides as Cl⁻ (mg/l)	Treated Ground						Raw Ground						Treated Surface						Raw Surface					
	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent
<100	36	36	100.0	568382	568382	100.0	512	512	96.5	1263259	1263259	98.5	40	40	100.0	825433	825433	100.0	2	2	100.0	9772	9772	100.0
100 - 150							9	521	98.3	14579	1277838	99.65												
151 - 200							4	525	99.1	1088	1278926	99.73												
201 - 250							1	526	99.3	257	1279183	99.75												
251 - 300							1	527	99.5	1999	1281182	99.91												
301 - 350																								
351 - 400																								
401 - 450							1	528	99.6	260	1281442	99.93												
451 - 500							1	529	99.8	593	1282035	99.976												
>500							1	530	100.0	302	1282337	100.0												
Totals	36			568382			530			1282337			40			825433			2			9772		

APPENDIX A-5: Sulfates

Sulfates as $SO_4^{=}$ (mg/l)	Treated Ground						Raw Ground						Treated Surface						Raw Surface					
	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent
<100	32	32	82.1	161594	161594	94.2	364	364	68.4	1112788	1112788	85.7	34	34	89.5	1223594	1223594	99.5	2	2	100.0	9772	9772	100.0
100 - 150	2	34	87.1	647	162241	94.6	35	399	75.0	35209	1147997	88.3	2	36	94.8	1647	1225241	99.6						
151 - 200	2	36	92.3	8005	170246	99.2	16	415	78.0	19500	1167497	89.9	1	37	97.5	904	1226145	99.7						
201 - 250							20	435	81.7	12053	1179550	91.1	1	38	100.0	3189	1229334	100.0						
251 - 300							12	447	84.0	33029	1212579	93.4												
301 - 350	1	37	94.9	333	170579	99.4	12	459	86.3	7231	1219810	93.9												
351 - 400							5	464	87.1	6525	1226335	94.4												
401 - 450	1	38	97.5	405	170984	99.7	13	477	89.6	12373	1238708	95.4												
451 - 500							7	484	91.0	15242	1253950	96.7												
>500	1	39	100.0	555	171539	100.0	48	532	100.0	43728	1297678	100.0												
Totals	39			171539			532			1297678			38			1229334			2			9772		

APPENDIX A-6: Nitrates as NO_3-N

Nitrates as NO_3-N (mg/l)	Treated Ground: No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	Raw Ground: No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	Treated Surface: No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	Raw Surface: No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent
<1	30	30	77.0	140380	140380	85.7	350	350	66.2	896459	896459	69.9	38	38	100.0	1233427	1233427	100.0	2	2	100.0	9772	9772	100.0
1 - 2	7	37	94.9	22818	163198	99.6	114	464	87.7	278665	1175124	91.6												
2.1 - 3	2	39	100.0	744	163942	100.0	32	496	93.7	73132	1248256	97.3												
3.1 - 4							6	502	95.0	13461	1261717	98.4												
4.1 - 5							7	509	96.3	5716	1267433	98.8												
5.1 - 6							8	517	97.7	7359	1274792	99.4												
6.1 - 7							3	520	98.3	1721	1276513	99.5												
7.1 - 8							2	522	98.7	1072	1277585	99.6												
8.1 - 9							1	523	98.8	2633	1280218	99.77												
9.1 - 10							1	524	99.0	300	1280518	99.79												
>10							5	529	100.0	2696	1283214	100.0												
Totals	39			163942			529			1283214			38			1233427			2			9772		

APPENDIX A-7: Sodium

Sodium as Na^+ (mg/l)	Treated Ground: No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	Raw Ground: No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	Treated Surface: No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	Raw Surface: No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent
<20	11	11	44.0	67794	67794	49.0	198	198	56.7	814198	814198	83.2	7	7	77.8	80030	80030	95.4	2	2	100.0	9772	9772	100.0
20 - 40	1	12	48.0	230	68024	49.2	50	248	71.1	72764	886962	90.5												
41 - 60	3	15	60.0	32930	100954	73.0	26	274	78.5	19660	906622	92.5	1	8	88.9	3595	83625	99.7						
61 - 80	4	19	76.0	29673	130627	94.5	16	290	83.1	18689	925311	94.4												
81 - 100	1	20	80.0	3189	133816	96.9	14	304	87.1	19380	944691	96.4												
101 - 125	3	23	92.0	2912	136728	98.9	9	313	89.7	7438	952129	97.2	1	9	100.0	193	83818	100.0						
126 - 150	1	24	96.0	1413	138141	99.7	6	319	91.5	6982	959111	98.0												
151 - 175							6	325	93.1	4373	963484	98.4												
176 - 200							8	333	95.5	3534	967018	98.7												
201 - 225							4	337	96.6	4505	971523	99.1												
226 - 250							2	339	97.1	998	972521	99.3												
251 - 270	1	25	100.0	333	138474	100.0	4	343	98.3	3296	975817	99.8												
>270							6	349	100.0	2153	977970	100.0												
Totals	25			138474			349			977970			9			83818			2			9772		

APPENDIX A-8: Total Dissolved Solids

Total Dissolved Solids (mg/l)	Treated Ground						Raw Ground					
	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent
<200	6	6	31.6	12781	12781	12.9	5	5	1.45	4308	4308	4.25
200 - 300	4	10	52.6	35533	48314	48.6	80	85	24.6	483811	488119	48.1
301 - 400	3	13	68.4	2421	50735	51.1	75	160	46.3	220659	708778	69.8
401 - 500	1	14	73.7	19212	69947	70.4	57	217	62.9	165318	874096	86.1
501 - 600	2	16	84.2	28248	98195	98.8	30	247	71.5	30466	904562	89.0
601 - 700	1	17	89.5	230	98425	99.0	18	265	76.7	20274	924836	91.1
701 - 800	1	18	94.7	658	99083	99.6	8	273	79.0	6711	931547	91.8
801 - 900	1	19	100.0	333	99416	100.0	9	282	81.6	21688	953235	93.8
901 - 1000							11	293	84.8	12106	965341	95.0
>1000							52	345	100.0	49031	1014372	100.0
Totals	19			99416			345			1014372		

Total Dissolved Solids (mg/l)	Treated Surface					
	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent
<200	21	21	87.5	1093250	1093250	98.5
200 - 300	2	23	95.8	14274	1107524	98.9
301 - 400						
401 - 500						
501 - 600	1	24	100.0	3189	1110713	100.0
601 - 700						
701 - 800						
801 - 900						
901 - 1000						
>1000						
Totals	24			1110713		

Total Dissolved Solids (mg/l)	Raw Surface					
	No. of Supplies	Cumulative	Percent	Population	Cumulative	Percent
<200	2	2	100.0	9772	9772	100.0
200 - 300						
301 - 400						
401 - 500						
501 - 600						
601 - 700						
701 - 800						
801 - 900						
901 - 1000						
>1000						
Totals	2			9772		

APPENDIX B

Appendices B and C (Computer Printout Sheets) do not appear in this bulletin as references in the text indicate. They are computer printout sheets for the ION-FILE (Appendix B.1) and the COUNTY-FILE (Appendix B.2), for the edit programs (Appendix C.1 and Appendix C.3), for the outputs of each program (Appendix C.2 and Appendix C.4), and for the master data file (Appendix C.5 through Appendix C.11). These printouts were not suitable for reproducing in printing. They are available at the offices of the Environmental Health Program, School of Public Health, University of Minnesota, Minneapolis, Minnesota.

APPENDIX C

Supply No.

Ada	001	Bertha	051	Center City	101
Adams	002	Bigelow	052	Ceylon	102
Adrian	003	Big Falls	053	Chandler	103
Aitkin	004	Bigfork	054	Chanhassen	104
Akeley	005	Big Lake	055	Chaska	105
Albany	006	Birchwood	056	Chatfield	106
Alberta	007	Bird Island	057	Chester Heights	107
Albert Lea	008	Biscay	058	Chisago City	108
Albertville	009	Biwabik	059	Chisholm	109
Alden	010	Blackduck	060	Chokio	110
Alexandria	011	Blaine	061	Cimarron	111
Alpha	012	Blomkest	062	Circle Pines	112
Altura	013	Blooming Prairie	063	Clara City	113
Alvarado	014	Bloomington	064	Claremont	114
Amboy	015	Blue Earth	064	Clarissa	115
Annandale	016	Borup	066	Clarkfield	116
Anoka	017	Bovey	067	Clarks Grove	117
Appleton	018	Boyd	068	Clearbrook	118
Apple Valley	019	Braham	069	Clements	119
Arden Hills	020	Brainerd	070	Cleveland	120
Argyle	021	Brandon	071	Climax	121
Arlington	022	Breckenridge	072	Clinton	122
Ashby	023	Brewster	073	Cloquet	123
Askov	024	Bricelyn	074	Cokato	124
Atwater	025	Brooklyn Center	075	Cold Spring	125
Aurora	026	Brooklyn Park	076	Coleraine	126
Austin	027	Brooten	077	Cologne	127
Avoca	028	Bowerville	078	Columbia Heights	128
Avon	029	Brownsdale	079	Comfrey	129
Babbitt	030	Browns Valley	080	Comstock	130
Badger	031	Brownton	081	Conger	131
Bagley	032	Buckman	082	Cook	132
Balaton	033	Buffalo	083	Cooley	133
Barnesville	034	Buffalo Lake	084	Coon Rapids	134
Barnum	035	Buhl	085	Correll	135
Barrett	036	Burnsville	086	Cosmos	136
Barry	037	Butterfield	087	Cottage Grove	137
Battle Lake	038	Byron	088	Cottonwood	138
Baudette	039	Caledonia	089	Courtland	139
Bayport	040	Callaway	090	Cromwell	140
Beardsley	041	Calumet	091	Crookston	141
Beaver Bay	042	Cambridge	092	Crosby	142
Beaver Creek	043	Campbell	093	Crystal	143
Bejou	044	Canby	094	Currie	144
Belgrade	045	Cannon Falls	095	Cuyana	145
Belle Plaine	046	Canton	096	Cyrus	146
Bellingham	047	Carlos	097	Dalton	147
Belview	048	Carlton	098	Danube	148
Bemidji	049	Cass Lake	099	Darfur	149
Benson	050	Cedar Grove	100	Darwin	150

Dassel	151	Felton	203	Halstad	252
Dawson	152	Fergus Falls	204	Hamburb	253
Deer Creek	153	Fertile	205	Hammond	254
Deer River	154	Finlayson	206	Hampton	255
Deerwood	155	Fisher	207	Hancock	256
DeGraff	156	Floodwood	208	Hanley Falls	257
Delano	157	Foley	209	Hanska	258
Delavan	158	Forest Hills Div.		Hardwick	259
Detroit Lakes	159	Dakota County	210	Harmony	260
Dexter	160	Forest Hills Su		Hartland	261
Dilworth	161	Olmsted County	211	Hastings	262
Dodge Center	162	Forest Lake	212	Hawley	263
Donnelly	163	Fosston	213	Hayfield	264
Dover	164	Fountain	214	Hayward	265
Duluth	165	Franklin (Renville)	215	Hector	266
Dumont	166	Franklin (St. Louis)	216	Henderson	267
Dundee	167	Fraser	217	Hendricks	268
Dunnell	168	Frazee	218	Hendrum	269
Eagan Township	169	Freeborn	219	Henning	270
Eagle Bend	170	Freeport	220	Herman	271
Eagle Lake	171	Fridley	221	Herman Township	272
East Grand Forks	172	Friendly Hill Addn.		Heron Lake	273
Easton	173	Dakota County	222	Hibbing	274
Echo	174	Frost	223	Hill City	275
Eden Valley	175	Fulda	224	Hills	276
Edgerton	176	Gaylord	225	Hilltop	277
Edina	177	Geneva	226	Hinckley	278
Eitzen	178	Gibbon	227	Hitterdal	279
Elba	179	Gilbert	228	Hoffman	280
Elbow Lake	180	Glencoe	229	Hokah	281
Elgin	181	Glenville	230	Holdingford	282
Elko	182	Glenwood	231	Hollandale	283
Elk River	183	Glyndon	232	Holloway	284
Elkton	184	Golden Valley	233	Hope	285
Ellendale	185	Gonvick	234	Hopkins	286
Ellsowrth	186	Goodhue	235	Houston	287
Elmshurst	187	Goodridge	236	Howard Lake	288
Elmore	188	Good Thunder	237	Hoyt Lakes	289
Elmwood Terrace	189	Goodview	238	Hugo	290
Ely	190	Graceville	239	Hutchinson	291
Elysian	191	Granada	240	Ihlen	292
Emmons	192	Grand Marais	241	International Falls	293
Erskine	193	Grand Meadow	242	Inver Grove Heights	294
Evansville	194	Grand Rapids	243	Iona	295
Eveleth	195	Granite Falls	244	Iron Junction	296
Excelsior	196	Greenbush	245	Ironton	297
Evota	197	Green Isle	246	Isle	298
Fairfax	198	Grey Eagle	247	Ivanhoe	299
Fairmont	199	Grove City	248	Jackson	300
Falcon Heights	200	Hackensack	249	Janesville	301
Faribault	201	Hadley	250	Jasper	302
Farmington	202	Hallock	251	Jeffers	303

Jordan	304
Kandiyohi	305
Karlstad	306
Kasson	307
Keewatin	308
Kelliher	309
Kellogg	310
Kelly Lake	311
Kennedy	312
Kensington	313
Kent	314
Kenyon	315
Kerkhoven	316
Kerr Location	317
Kettle River	318
Kiester	319
Kilkenny	320
Kimball	321
Kings Wood	322
Kinney	323
LaCrescent	324
Lafayette	325
Lake Benton	326
Lake Bronson	327
Lake City	328
Lake Crystal	329
Lake Elmo	330
Lakefield	331
Lake Lillian	332
Lake Park	333
Lakeville	334
Lake Wilson	335
Lamberton	336
Landfall	337
Lanesboro	338
Lauderdale	339
LeCenter	340
Leetonia	341
Lenwood Heights	342
Leonidas	343
Leota	344
LeRoy	345
Lester Prairie	346
LeSueur	347
Lewiston	348
Lewisville	349
Lexington	350
Lindstrom	351
Lismore	352
Litchfield	353
Little Falls	354
Littlefork	355
Long Lake	356
Long Prairie	357

Lonsdale	358
Loretto	359
Lowry	360
Lucan	361
Luverne	362
Lyle	363
Lynd	364
McIntosh	365
McKinley	366
Mabel	367
Madelia	368
Madison	369
Madison Lake	370
Mahnomen	371
Mahtomedi	372
Manchester	373
Mankato	374
Mantorville	375
Maple Lake	376
Maple Plain	377
Mapleton	378
Mapleview	379
Maplewood	380
Marble	381
Marietta	382
Marshall	383
Mayer	384
Maynard	385
Mazeppa	386
Meadowbrook Addn	387
Meadowlands	388
Medford	389
Medina	390
Medina-Morningside	391
Melrose	392
Menahga	393
Mendota Heights	394
Middle River	395
Milaca	396
Milan	397
Millville	398
Milroy	399
Minneapolis	400
Minneota	401
Minnesota Lake	402
Minnetonka	403
Minnetonka Beach	404
Minnestrista Wood End Shores	405
Montevideo	406
Montgomery	407
Monticello	408
Montrose	409
Moorhead	410

Moose Lake	411
Mora	412
Morgan	413
Morningside	414
Morris	415
Morristown	416
Morton	417
Motley	418
Mound	419
Mounds View	420
Mountain Iron	421
Mountain Lake	422
Murdock	423
Myrtle	424
Nashua	425
Nashwauk	426
Nerstrand	427
New Brighton	428
Newfolden	429
New Germany	430
New Hope	431
New London	432
New Market	433
New Munich	434
Newport	435
New Prague	436
New Richland	437
New Trier	438
New Ulm	439
New York Mills	440
Nicollet	441
Nielsville	442
Norcross	443
North Branch	444
Northfield	445
North Mankato	446
Northome	447
North Redwood	448
Northrup	449
North St. Paul	450
Norwood	451
Oakdale	452
Oak Park Heights	453
Odessa	454
Ogilvie	455
Okabena	456
Oklee	457
Olivia	458
Onamia	459
Ormsby	460
Orono	461
Orr	462
Ortonville	463
Osakis	464

Oslo	465
Osseo	466
Ostrander	467
Otisco	468
Owatonna	469
Parkers Prairie	470
Park Rapids	471
Parkville Location	472
Paynesville	473
Pelican Rapids	474
Pemberton	475
Pennock	476
Pequot Lakes	477
Perham	478
Perley	479
Peterson	480
Pierz	481
Pine City	482
Pine Island	483
Pine River	484
Pineville Location	485
Pipestone	486
Plainview	487
Plato	488
Plummer	489
Plymouth	490
Porter	491
Preston	492
Princeton	493
Prinsbury	494
Prior Lake	495
Proctor	496
Racine	497
Randall	498
Ranier	499
Rapidan	500
Raymond	501
Red Lake Falls	502
Red Wing	503
Redwood Falls	504
Remer	505
Renville	506
Revere	507
Rice	508
Rice Lake Township	509
Richfield	510
Richmond	511
Riverton	512
Robbinsdale	513
Rochester	514
Rockford	515
Rockville	516

Rogers	517
Rollingstone	518
Roseau	519
Rose Creek	520
Rose Harbor	521
Roseland	522
Rosemount	523
Roseville	524
Rothsay	525
Round Lake	526
Royalton	527
Rush City	528
Rushford	529
Rushmore	530
Russell	531
Ruthton	532
Sabin	533
Sacred Heart	534
St. Anthony	535
St. Bonifacius	536
St. Charles	537
St. Clair	538
St. Cloud	539
St. Hilaire	540
St. James	541
St. Joseph	542
St. Louis Park	543
St. Michael	544
St. Paul	545
St. Paul Park	546
St. Peter	547
Sanborn	548
Sandstone	549
Sargeant	550
Sartell	551
Sauk Centre	552
Sauk Rapids	553
Savage	554
Scandia (1)	555
Scandia (2)	556
Scanlon	557
Sebeka	558
Shafer	559
Shakopee	560
Shelly	561
Sherburn	562
Shoreview	563
Silver Bay	564
Silver Lake	565
Skyline	566
Slayton	567
Sleepy Eye	568

Snail Lake Park Addn.	569
South Haven	570
South International Falls	571
South St. Paul	572
Southview Heights	573
South Windom Subdiv.	574
Spicer	575
Springfield	576
Spring Grove	577
Spring Lake Park	578
Spring Park	579
Spring Valley	580
Stacy	581
Staples	582
Starbuck	583
Stephen	584
Stewart	585
Stewartville	586
Stillwater	587
Storden	588
Strandquist	589
Swanville	590
Taconite	591
Taylors Falls	592
Thief River Falls	593
Tower-Soudan	594
Tracy	595
Trimont	596
Trommald	597
Trosky	598
Truman	599
Twin Lakes	600
Twin Valley	601
Two Harbors	602
Tyler	603
Ulen	604
Underwood	605
Upsala	606
Utica	607
Verndale	608
Vernon Center	609
Vesta	610
Virginia	611
Wabasha	612
Wabasso	613
Waconia	614
Wadena	615
Waite Park	616
Waldorf	617
Walker	618

Walnut Grove	619
Walters	620
Waltham	621
Wanamingo	622
Wanda	623
Warba	624
Warren	625
Warroad	626
Waseca	627
Watertown	628
Waterville	629
Watkins	630
Watson	631
Waubun	632
Wayzata	633
Webster Township	634
Welcome	635
Wells	636
Wendell	637
Westbrook	638
West Concord	639
West St. Paul	640
West Virginia Locat	641
Wehaton	642
White Bear Lake	643
White Bear Township	644
Willernie	645
Willmar	646
Wilmont	647
Windom	648
Winger	649
Winnebago	650
Winona	651
Winsted	652
Winthrop	653
Winton	654
Wolverton	655
Woodbury	656
Wood End Shores	657
Wood Lake	658
Worthington	659
Wykoff	660
Wyoming	661
Young America	662
Zumbro Falls	663
Zumbrota	664

County Codes

Aitkin	01
Anoka	02
Becker	03
Beltrami	04
Benton	05
Big Stone	06
Blue Earth	07
Brown	08
Carlton	09
Carver	10
Cass	11
Chippewa	12
Chisago	13
Clay	14
Clearwater	15
Cook	16
Cottonwood	17
Crow Wing	18
Dakota	19
Dodge	20
Douglas	21
Faribault	22
Fillmore	23
Freeborn	24
Goodhue	25
Grant	26
Hennepin	27
Houston	28
Hubbard	29
Isanti	30
Itasca	31
Jackson	32
Kanabec	33
Kandiyohi	34
Kittson	35
Koochiching	36
Lac Qui Parle	37
Lake	38
Lake of the Woods	39
LeSueur	40
Lincoln	41
Lyon	42
McCleod	43
Mahnomen	44
Marshall	45
Martin	46
Meeker	47
Mille Lacs	48
Morrison	49
Mower	50
Murray	51
Nicollet	52
Nobles	53
Norman	54
Olmsted	55
Otter Tail	56
Pennington	57
Pine	58
Pipestone	59
Polk	60
Pope	61
Ramsey	62
Red Lake	63
Redwood	64
Renville	65
Rice	66
Rock	67
Roseau	68
St. Louis	69
Scott	70
Sherburne	71
Sibley	72
Stearns	73
Steele	74
Stevens	75
Swift	76
Todd	77
Traverse	78
Wabasha	79
Wadena	80
Waseca	81
Washington	82
Watonwan	83
Wilkin	84
Winona	85
Wright	86
Yellow Medicine	87

HEALTH DISTRICT CODES

District Office	Code
1. Bemidji	1
2. Mankato	2
3. Rochester	3
4. Duluth	4
5. Marshall	5
6. Minneapolis	6
7. Fergus Falls	7
8. Little Falls	8

ECONOMIC DISTRICT CODE

District	Code
1	1
2	2
3	3
4	4
5	5
6W	16
6E	26
7	7
8	8
9	9
10	10
11	11

OWNERSHIP CODE

0 = Data unavailable

1 = Municipal water supply

2 = Private water supply

3 = Purchased water supply

4 = Mixed ownership

WATER TREATMENT CODES

0 = absence of particular method

1 = presence of particular method

9 = missing data

METHOD	COLUMN IN SUPPLY DATA FILE
No Treatment	52
Special Treatment to Certain Wells	54
P = Purification	55
H = Softening	56
I = Iron and Manganese Removal	57
A = Aeration	59
Ac = Contact bed or trays, filled with coke or other material	60
Ak = Potassium permanganate	61
Am = Patented aerator	62
As = Spray aerator	63
At = Overflow trays, cascade or other spray aerator	64
Ao = Other type of aerator	65
C = Chemicals for Coagulation or Softening	67
Ca = with alum	68
Ci = with iron salts	69
Cl = with lime	70
Cp = with polymer aids	71
Cs = with soda ash	72
Co = with other coagulant	73
D = Disinfection	75
Dc = Chlorine gas	76
Dh = Hypochlorites	77
Do - Other means	78

F = Filtration	80
Fa = Anthrafilt	81
Fg = Gravity (slow)	82
Fh = Filter aids	83
Fm = Catalytic mineral	84
Fp = Pressure	85
Fr = Gravity (rapid)	86
Fs = Sand	87
Ft = Carbon	88
Fz = Zeolite	89
Fo = Other filtering means	90
K = Chemical Dosage for Corrosion Correction or Water Stabilization	92
Kc = By Phosphate compounds	93
Kg = By Chlorine gas	94
Kh = By Hypochlorite	95
Km = By Other means	96
Kp = By Alkali feed for pH adjustment	97
Ko = By Sodium silicate	98
M = Mixing Device or Tank	100
Ma = Air agitation	101
Mb = Baffle mixing	102
Mh = Hydraulic (standing wave flume)	103
Mi = Injection or pump suction application	104
Mp = Slow mechanical mix	105
Ms = Patented sludge mix	106
Mt = Rapid Mechanical Mix	107
Mo = Other means	108

N = Ammoniation	110
Nc = with ammonia compound	111
Ng = with ammonia gas	112
No = other means	113
R = Recarbonation	115
S = Sedimentation	117
Sb = Baffled basins	118
Sc = Covered basins	119
Sm = Mechanical sludge	120
Sv = Upward flow cylindrical tanks	121
Sz = Other means	122
So = Open basin	123
T = Chemical Taste and Odor Control	125
Tc = Activated carbon	126
Td = Chlorine dioxide	127
Tk = Potassium permanganate	128
Ts = Sulfur dioxide	129
To = Other means	130
V = Fluoridation	132
Va = with hydrofluosilicic acid	133
Vs = with sodium silicofluoride	134
Vt = with sodium fluoride	135
Vo = other means	136

DATA COMMENT CODES

00 = No Data

01 = Untreated Ground Water Sample

02 = Composite Treated Ground Water Sample

03 = Purchased Water Supply

04 = Abandoned Well

05 = Standby Well or Water Supply

06 = Disconnected Supply

07 = Creamery-owned Supply

08 = Emergency Water Supply

09 = Capped Supply

10 = Composite Untreated Ground Water Sample

11 = Untreated Surface Water Sample

12 = Treated Surface Water Sample

13 = Composite Treated Surface and Ground Water Sample

14 = Treated Ground Water Sample

15 = Well Not In Service

SOURCE CODES

SOURCE: Groundwater

100 = Unspecified Ground Water Source

110 = Drilled Well

120 = Dug Well

130 = Dug and Drilled Well

140 = Bored Well

150 = Ranney Collector Well

160 = Mine Shaft

SOURCE: SURFACE WATER

200 = Unspecified Surface Water Source

210 = Lake

- 211 = Budd Lake
- 212 = Burntside Lake
- 213 = Colby Lake
- 214 = Fall Lake
- 215 = St. Mary's Lake
- 216 = Lake Superior
- 217 = Vadnais Chain of Lakes

220 = River

- 221 = Minnesota River
- 222 = Mississippi River
- 223 = Ottertail River
- 224 = Rainy River
- 225 = Red River of the North
- 226 = Red Lake River
- 227 = South Bend Two Rivers
- 228 = Tamerack River

230 = Lake and River

- 231 = Ottertail River and Hoyt Lake

240 = Reservoir

250 = Spring

260 = Open Pit Mine

270 = Stream or Creek

PURCHASED SUPPLY CODE

Supply number of community from which water purchased.

WELL NUMBER DESIGNATION

Numeric: 1-99

Alphabetic: SCH, CRY

Alphanumeric: 5A, 5B

PUMP TYPE	COLUMN IN WELL DATA FILE
None	32
Air Lift	33
Centrifugal	34
Cylinder	35
Flowing Well	36
Jet	37
Rec	38
Submersible	39
Triple Cylinder Pump	40
Vertical Turbine	41
Unknown	42

CAPACITY

Total capacity of all pumps