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MICROBIOLOGICAL AND CHEMICAL CHANGES IN DRINKING WATER SYSTEMS CAUSED BY INCREASED TEMPERATURE DURING THE SUMMER MONTHS

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Regulatory Program Needs

As part of a continuing effort to diminish the incidence of persistent microbiological and chemical violations, the Missouri Department of Natural Resources, Division of Public Water Supplies, has enlisted the assistance of eighty-three Missouri water suppliers in a comprehensive study of chemical and microbiological problems in public drinking water systems. These studies were initiated, in part, because there are some 950 public groundwater supplies in Missouri, about 75% of the total, which do not disinfect. Most of these supplies serve small rural communities where the neighboring farm houses and stock-watering troughs increase the possibility of microbial contamination due to cross-connections and back-siphonage. In many instances, Missouri's rural areas are served by regional water systems where water is pumped from system to system to system for miles without rechlorination. The effect of long residence times on chlorine residuals and microbiological growth is of concern in such systems. Still other water systems are converting from hypochlorous acid to chloramine residuals as a means for controlling trihalomethane formation. The effect of this change on the total bacterial population in the distribution system is of special interest. Finally, Missouri has a pool of about 300 community public water supplies which tend to drift in and out of compliance with microbiological standards. Better microbiological methodologies are sought for these systems which will better identify the causes of persistent violations.

The present studies were undertaken to help the Missouri Department of Natural Resources to formulate policies for bringing these supplies into compliance.

Survey of Missouri Water Systems

Beginning in the winter of 1983-1984, fifty-three Missouri water supplies were evaluated with respect to microbiological (total and fecal coliform, fecal streptococcus, heterotrophic plate count by pour and spread plates, total bacterial direct count) and chemical (total

trihalomethanes, chlorine residuals, organic carbon) parameters. The principal results of these studies, reported in December 1984, indicated that conventional microbiological parameters overestimated the removal of bacteria by water treatment plants (1). In addition to marginal removals of bacteria, it was also evident that there was no relation between turbidity and the total number of bacteria present in the distribution system.

Finally, numerous groundwater supplies, even without treatment or disinfection, were found to have lower bacterial counts and organic carbon contents than comprehensively-treated surface waters. Based on these results, the entire effort was expanded to include eighty-three water systems and repeated in the summer of 1984. This was done to observe the effects of warm water conditions on bacterial removal efficiency, microbial growth and trihalomethane formation.

Materials and Methods

The water utilities included in the winter and summer surveys were primarily located in central and eastern Missouri. They were selected to include a comprehensive range of raw water supply and treatment (2). Source waters included both deep and shallow wells, shallow alluvial wells, and surface waters from both lake and river sources. System sizes included large municipalities, small towns, rural public water supply districts, institutional facilities, and mobile home parks. Treatment ranged from untreated, chlorination only, iron removal, to comprehensive treatment of surface waters.

For each system, raw and finished waters were collected. In addition, a sample was collected at a site representing the longest detention time in the distribution system. Intermediate sites were sampled depending on the size or complexity of the system.

Samples were collected after flame sterilizing the tap with a propane torch and running 20 liters of water to waste. Microbiological samples were collected in a sterile one liter polyethylene sample bottle containing 1 mL of a 10% sodium thiosulfate solution. The samples were stored on ice for transport and processed, generally, within 4 hours after collection. In no case were samples analyzed after 8 hours. Chlorine samples were analyzed in the field. In addition, 250 mL samples were taken for laboratory analysis. Organic carbon samples were collected in 150 mL carbon-free glass bottles with teflon-lined caps. Samples for total trihalomethane (TTHM) were collected in triplicate in 25 mL glass vials with teflon-lined caps.

The following analyses were performed in accordance with Standard Methods (3): standard plate count by pour plate incubated at 35°C for 96 hours; fecal streptococcus, total coliform, and fecal coliform by the membrane filter technique; and turbidity with a Hach 2100A turbidimeter. Total trihalomethanes were measured by the purge and trap method (4) on a Perkin-Elmer Sigma 3 gas chromatograph.

Non-standard methods included a modified standard plate count by spread plate in which 0.1 mL of sample was spread with a glass rod on the surface of dilute media (4.25 g/L M-Standard Methods Broth, BBL Microbiology Systems) and incubated at 18°C for 21 days. Organic carbon was measured using a Dohrmann-Envirotech Model DC-54 Ultra-Low-Level Total Organic Carbon Analyzer. The method used for enumerating the total number of bacteria is a slight modification of the method described by Hobbie, et.al. (5) as previously reported (6).

Counts included both the total number of cells and potential colony forming units of clumps, chains, and filaments. All counts were performed with a Leitz Ortholux microscope fitted with a Ploem vertical illuminator and 200-w mercury lamp. Micrographs were made with a Leica M1.

Coliform and Indicator Organism Colony Counts

As evident from Figure 1, the winter and summer survey data on total coliform were similar. In both seasons, Missouri water supplies, both treated and untreated, consistently met the coliform requirement. Coliform organisms were absent (< 10/L) in 96% of the winter samples and in 93% of the summer samples. Most of the positive coliform samples were obtained from unchlorinated groundwater supplies. No relationship between turbidity and coliform was evident. Instead, the greatest coliform colony count (TNTC) was observed in a chlorinated, filtered surface water having a turbidity of 0.14 NTU.

Of the total of 78 samples which showed the presence of indicator organisms (Table 1), 46 were derived from unchlorinated water supplies. Fecal coliform was observed only twice in a total of 416 samplings. However, fecal streptococcus was observed twice as frequently as total coliform. Half of the positive total coliform plates were also positive for fecal streptococcus which appeared to be the most sensitive of the indicator organisms.

Plate Count Organisms

The median value of heterotrophic plate count (HPC, pour plate) in finished and distributed water samples was 20×10^3 colonies/L in the winter and 50×10^3 colonies/L in the summer (Figure 2). The wide range of HPC values observed indicates that HPC is a sensitive indicator of the presence of planktonic distribution system organisms capable of reproducing under culture conditions. Evaluation of the data for individual systems indicates that the ratio of the HPC to the total bacterial population may serve as an index of microbial regrowth or die-away in a specific distribution system. HPC can also serve as a combined indication of both the physical removal and disinfection effectiveness of water treatment.

Direct Cell Counts

Reflecting the trend shown by the HPC, the median value of the total bacterial cell count increased from 20×10^6 cells/L in the winter to 50×10^6 cells/L in the summer (Figure 3). The log normal distribution of the data, both winter and summer, indicate the sensitivity of the direct cell count measurement. On the average, the HPC is 0.1% of the direct cell count. The relative number of microorganisms in drinking water, as enumerated by various methods, is given in Table 2.

Filtration Plant Performance

Whereas the total bacterial population was generally found to be greater in the summer, surface water filtration plants appeared to be achieving far greater removals of bacterial cells. Table 3 shows that, on the average, cell removals increased from less than one order of magnitude in the winter to two orders of magnitude in the summer.

Comparison of winter versus summer filtration plant performance is

shown graphically in Figure 4. It is evident that turbidity reductions are not paralleled by bacterial removals in the winter. Whereas turbidity reductions are consistently high, bacterial removals vary widely, from greater than 99% to less than half, averaging less than one order of magnitude. The summer data, on the other hand, occupy a domain where bacterial removals exceed turbidity removals. This may be partly a result of the greater sensitivity of the cell count measurements than turbidity in finished waters.

Seasonal comparisons of filtration plant performance with respect to the reduction in fecal streptococcus, total coliform, heterotrophic plate count, and total bacterial direct count are given in Table 4 (winter, 1983-1984) and Table 5 (summer, 1984). In both winter and summer, fecal streptococcus and total coliform indicate complete organism removal or destruction. Often, these organisms were even absent in the plant influent.

Heterotrophic plate count data, however, indicated that water treatment reduced the number of culturable organisms by up to three orders of magnitude (99.9%). Reductions were greater in the summer than in the winter.

Direct bacterial cell count data indicated that the physical removal of bacterial cells was far lower than the other microbial indicators would suggest. However, direct bacterial cell counts did confirm the improved removal of organisms during warm weather suggested by the HPC data.

The difference between the reductions indicated by the direct count and the HPC data may reflect the action of disinfectant in killing organisms or reducing their ability to reproduce. The direct count is a direct measure of the physical removal of the organisms present in the source water.

Organic Carbon

The replication of organic carbon analyses in the summer resulted in a distribution which was very similar to that obtained from the winter survey (Figure 5). Approximately two-thirds of the Missouri water supplies studied, primarily ground waters, contained less than 1 mg/L of organic carbon. Only rarely did organic carbon concentrations exceed 5 mg/L.

Surface water treatment plants were capable of reducing raw water organic carbon concentrations by 14% to 65%. Almost all of the removal took place after coagulation and sedimentation.

Trihalomethanes

While the winter and summer distribution of total trihalomethanes (TTHM) are very similar (Figure 6), the percentage of samples exceeding 100 µg/L TTHM, as might be expected, increased during warm weather. These higher concentrations were primarily found in smaller community supplies which do not come under the trihalomethane MCL regulations.

A comparison of organic carbon and trihalomethanes formed in chlorinated Missouri water supplies under winter conditions indicated that the 100 µg/L TTHM maximum contaminant level (MCL) was not exceeded in waters containing less than 3 mg/L organic carbon (Figure 7).

However, under summer conditions, when organic carbon exceeded 2 mg/L, the 100 µg/L trihalomethane MCL was occasionally exceeded (Figure 8). Figure 9, showing the combined winter and summer survey results, clearly indicates that, when organic carbon is less than 1 mg/L in Missouri waters, trihalomethane is generally below the 10 µg/L limit of detection.

Turbidity

In the summer, as well as in the winter, the turbidity of treated and distributed drinking water in Missouri was generally well below the 1 NTU maximum contaminant level (Figure 10). Where turbidities exceeded 1 NTU, the presence of iron oxides was often evident.

The lack of correlation between turbidity and total bacterial cell counts, observed during the winter (Figure 11), was again confirmed by the summer survey data (Figure 12). Verification of this result is particularly important because it conclusively demonstrates that there is no correlation between turbidity and bacteria in finished drinking waters.

Even more revealing is a comparison of finished water turbidity with subsequent turbidity measurements in the distribution systems. Did distribution system turbidities increase, decrease or remain the same? Defining an increase as a doubling of finished water turbidity (x2) and a decrease as a halving (x½), it was found that there was no change in 133 of 221 (60%) distribution system turbidity observations. There was a decrease in 59 and an increase in only 29 observations, indicating that finished water turbidities were twice as likely to decrease as to increase during distribution. Of the 29 increases, only 12 exceeded 1 NTU. Where this occurred, the presence of iron oxides was evident from the discoloration of membrane filters used to enumerate the direct count.

Does the fact that tubidity generally remains the same or decreases during distribution indicate that, similarly, microbiological parameters are static or decrease during distribution? Because HPC and total bacterial direct counts were observed to range over orders of magnitudes, an increase in each was defined as a tripling (x3) and a decrease as a reduction below one-third (x1/3). The analysis for HPC and direct count can readily distinguish such major changes which span nearly an order of magnitude (x9).

Table 6 shows that, using the parameter of change described above, the total bacterial direct count remained the same in two-thirds of the distribution system samples. However, it increased five times more frequently than it decreased.

HPC offerred an even more striking contradiction to the implications of the turbidity data. Winter and summer, HPC increased in one-half of all the distribution system samples. These trends would suggest that turbidity is negatively correlated with microbial growth in distribution systems. Besides being insensitive, turbidity remains static or declines where microbiological parameters are generally increasing.

A comparison of the changes in the distribution system indicated by the direct count and HPC is also worthy of note. The total bacterial direct counts indicate that the total number of cells found throughout the systems were very likely to remain constant (67%) or increase

(27%). In other words, the cells which are found to penetrate the distribution systems appear to remain or increase in numbers rather than lyse. HPC is far more changeable. Growth or recovery of the heterotrophic bacteria is obviously common, as is die-away. Again, it appears that the ratio of HPC to direct count will provide enormous insight into the dynamics of microbial ecology in water distribution systems. Moreover, the direct count will provide insight into the potential for regrowth once the restraining effects of disinfectant residuals are dissipated.

Summary

Overall, the summer survey yielded results which were very comparable to the winter survey results. Except for several unchlorinated groundwater supplies, coliform organisms were almost always absent in Missouri water supplies in both seasons. However, summer survey data showed that both heterotrophic plate counts and total bacterial cell counts increased by a factor of 2.5 over the winter survey data. Most important, water treatment plant performance in physically removing bacterial cells improved during warm weather. This appeared to be due to improved removal following coagulation, flocculation and sedimentation, rather than filtration.

While the distribution of organic carbon in Missouri drinking water supplies was remarkably similar, winter and summer, higher organic carbon concentrations found in some surface waters, coupled with higher temperatures and, presumably, faster chemical reaction rates, led to the formation of higher concentrations of trihalomethanes. Trihalomethane formation was clearly related to the organic carbon concentration of the chlorinated water supply, both winter and summer. No water having less than 2 mg/L organic carbon was found to form trihalomethanes in excess of the maximum contaminant level.

Except for occasional iron precipitates, Missouri drinking waters were always clear. Turbidity levels were consistently within the 1 NTU maximum contaminant level, both at the point of entry to and throughout the distribution system. Turbidity could not be correlated with any chemical or microbiological water quality parameters. Moreover, turbidity failed to indicate ineffective bacterial removal under cold weather conditions.

Finally, because microorganisms contribute little to turbidity, measurements of turbidity in the distribution system are not useful in assessing bacterial regrowth or aftergrowth.

DISCUSSION OF RESULTS

Regrowth and Aftergrowth

More and more water utility managers are becoming aware that it is important to evaluate the microbial activity in their distribution systems. Such activity may be related to corrosion and chemical changes leading to water quality deterioration. It is therefore important to both define and evaluate the microbial ecology in individual distribution systems.

Regrowth and aftergrowth, previously used as synonyms in the waterworks literature, may be thought of as two circumstances which can lead to an increase in the number of organisms recovered from the distribution system. Regrowth may be defined as the recovery of

disinfectant-injured cells which had passed into the distribution systems from the water source or treatment plant. After chlorine dissipation and time for metabolic repair, these cells may regain their ability to reproduce under culture conditions. The subsequent growth of new organisms originating from those passing the treatment processes and surviving disinfection would, similarly, be classified as regrowth.

Aftergrowth may be defined as the microbial contamination of distributed water by cells from distribution piping or external sources, such as cross-connections.

The distinction between regrowth and aftergrowth is vital to efforts to control microbial populations in distribution systems. Since regrowth involves the passage of organisms through the treatment plant, control of regrowth can be achieved by improving processes for physical removal of the cells. Since aftergrowth occurs within the distribution system, control measures would have to be directed toward modifying the microbial ecology of the organisms present in the distribution system. Such methods (scouring, main disinfection) will have no effect on regrowth because organisms are constantly being passed into the system from the treatment plant. Failure to recognize the primary source of the microbial problem will likely result in costly, misdirected and unsuccessful remedial efforts. For example, repeated efforts to disinfect mains to control coliform violations will be ineffectual where regrowth is the source of the problem.

Evaluation of the potential regrowth and aftergrowth in water distribution systems requires the systematic measurement of heterotrophic plate count and direct bacterial cell count since turbidity will not provide an index of the numbers of bacteria present.

Use of the Microscope

In the early history of water supply and treatment, the microscope was a major analytical tool. It was used extensively in the early efforts to develop treatment technology for the removal and destruction of microorganisms (7-9).

The microscope has been all but abandoned as an aid to the monitoring of drinking water quality today (3). Instead, culture techniques are used, which are highly dependent upon culture conditions and which dramatically underestimate the number of organisms actually present in water. As a result, the colony count data obtained are often unintelligible and cannot be used either for plant performance or distribution system evaluation. Unsupported by other information, this data frequently leads to erroneous assumptions or interpretations with respect to water treatment plant performance or microbial conditions in a distribution system.

In addition to enumerating the microbial population present, the microscope can also be used to evaluate the long-held assumption that most bacteria are attached to the suspended particles in the source water and are, therefore, removed along with the turbidity. Direct microscopic examination would confirm (or deny) this hypothesis.

Whereas most bacterial cells were not visible using early microscopes, present-day microscopic techniques make all cells highly visible. The acridine orange direct count (AODC) method involves staining the bacteria cells with a fluorescent dye and observing them through a microscope using ultraviolet light. Surprisingly, this

state-of-the-art technique had never before been applied in a survey of drinking waters despite being applied to numerous natural waters for nearly a decade. It has been shown to enumerate far more organisms than the plate count method.

There are many additional reasons for actually looking at the particles, including bacteria, in drinking water. Microscopic examination would help to determine the nature of turbidity in water, for example. Today, turbidity is the most measured and least understood parameter in water treatment. It is safe to say that there are almost no utilities in the nation which have identified the substances which constitute the turbidity in their finished water. Simple microscopic observation might show the post-precipitation of aluminum oxide or calcium carbonate in some systems or the formation of iron oxides due to the corrosion of mains in others. The breakthrough of clay and silt particles through filters can be observed directly. More important, the intrusion of unusually large populations of bacteria and algae into the water distribution system can be seen immediately, while there is still time to take remedial action. Finally, the actual effectiveness of water treatment with respect to the physical removal of bacteria and algae can be observed by counting the number of organisms both in the influent and the effluent.

In some instances, and at certain times, bacterial removal may parallel the removal of turbidity, as is commonly assumed. At other times, perhaps seasonally, utilities may find that the removal of microorganisms diverges markedly from the removal of turbidity. For plant operational control and evaluation of the effectiveness of water treatment, utilities should not limit measurements only to those required for regulatory purposes.

How Many Bacteria?

How many bacteria are there in raw and treated drinking waters? Informal queries (AWWA, Water Quality Technology Conference, 1984) of water utility managers and engineers have indicated that most would not even hazard a guess. Some estimated that the standard plate count is close to the total since these are the only published data they had seen. Based on the current studies, some average values have been calculated for surface and ground water supplies in Missouri.

As Figure 13 indicates, the total number counted in drinking waters may range from 10^3 to 10^{10} cells/L depending upon the water source and treatment. By contrast, coliform colony counts were absent in virtually all the treated water samples. Indeed, with the exception of the Missouri River, coliform organisms were not abundant even in raw water sources. Heterotrophic plate count organisms averaged only 0.1% of the total cell count, even including supplies where disinfection was not practiced.

What Is Turbidity?

While it may not be surprising that the total number of bacteria in drinking water is unknown to the water utilities industry, it seems very surprising that the nature of turbidity is unknown. Despite the heavy reliance on the universal, continuous monitoring of turbidity to evaluate treatment plant performance (and the microbiological quality of the treated water), the literature indicates that turbidity has never been chemically characterized, identified or fractionated.

Turbidity can be characterized and it almost certainly will be if the USEPA adopts its proposed turbidity standard of 0.2 NTU for monitoring for protection against Giardia lamblia cysts. Utilities will then try to characterize any turbidity in excess of 0.2 NTU to demonstrate that the turbidity in their particular supply is not related to wastewater contamination and the presence of disease-causing organisms.

Indeed, most turbidity-causing suspended matter has little to do with microorganisms (Figure 14). Depending upon the water, the turbidity is predominately iron oxides, calcium carbonate, aluminum oxide or a variety of silicates. The numbers of bacteria in suspension would have to be truly astronomical ($> 10^{10}$ cells/L) to contribute as little as 1 NTU to a treated water (1). No treated water in Missouri has been observed to have as many as 10^{10} cells/L. The median, 50×10^6 cells/L, would be expected to contribute 0.005 NTU to Missouri drinking waters.

While turbidity monitoring is undeniably a valuable tool for plant operational control, its absolute value alone is of no scientific significance. Moreover, the rationale for its use as a primary (microbiological) drinking water standard is indistinct and misleading.

Why Measure Organic Carbon?

Despite the fact that organic carbon is one of the most fundamental water quality parameters and despite the fact that instrumentation for its measurement at the levels found in drinking water has been available for about eight years, few water utilities monitor organic carbon and its removal. This may be due, in part, to a limited understanding of the utility and applicability of the parameter to treatment evaluation and distribution system management. Definition and quantification of the component parts of organic carbon will be useful in determining treatment technology capable of removing various fractions (Figure 15).

The distribution of the organic carbon concentrations found in Missouri water supplies is strongly related to water source (deep well, shallow well, surface water). The influence of source on water quality is clearly evident from the average organic carbon concentration observed in a survey of 98 Missouri water supplies conducted by Collins and Reach (10). Thirty six deep well waters averaged 0.23 mg/L; nineteen shallow well waters averaged 1.70 mg/L and thirty six surface waters averaged 4.3 mg/L. The present study has shown that the formation of trihalomethane following chlorination is related to the concentration of organic carbon present. In chlorinated Missouri waters, only those supplies having an organic carbon concentration greater than 2 mg/L formed trihalomethanes in excess of the 100 µg/L USEPA maximum contaminant level. Clearly, the selection of source water is the first line of defense against drinking water contamination with organic substances.

Conclusions

The principal results of this evaluation of drinking water systems have led to the conclusion that turbidity is not suitable as a primary (microbiological) drinking water standard for the following reasons.

(1) There is no correlation between turbidity and bacteria in drinking water at 1 NTU and below. Therefore, turbidity is not a reliable parameter by which to judge microbial content

or measure filtration plant efficiency with respect to the removal of microorganisms.

(2) Turbidity is not a major factor in consuming the chlorine residual. The chlorine demand in drinking water is exerted primarily by the dissolved fraction of the total organic carbon and by reducing agents on the surface of pipes.

(3) Turbidity is a qualitative measurement of light scattering and has never been chemically quantitated. Microorganisms contribute little to the measured value of turbidity. Therefore, turbidity can not be used to assess either bacterial regrowth or aftergrowth.

Acknowledgement

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Table 1. Presences of Indicator Organisms in Distribution System Samples

	Positive/Total Samples	
	Winter	Summer
Total Coliform	7/172* (3)	18/244** (14)
Fecal Coliform	0/172	2/244 (1)
Fecal Streptococcus	15/172* (6)	36/244** (22)

( ) Number of positive samples from unchlorinated water supplies

* 5 winter samples yielded both positive total coliform and fecal streptococcus

** 7 summer samples yielded both positive coliform and fecal streptococcus

Table 2: Relative Number of Microorganisms in Drinking Water as Enumerated by Various Methods

TOTAL COUNT	100,000,000/L
SPC	1,000,000/L
TOTAL COLIFORM	<10/L
FECAL COLIFORM	<1/L

Table 3: FILTRATION PLANT PERFORMANCE
COMPARISON OF WINTER AND SUMMER

Turbidity, NTU
Direct Cell Count, 10^6 Cells/L

PLANT	SAMPLE	WINTER		SUMMER	
Armstrong	Raw	43 /	4,900	6.0 /	10,400
	Finished	0.14 /	24.2	0.93 /	1,070
	Reduction	307x	200x	6x	10x
Boonville	Raw	105 /	2,600	87 /	8,910
	Finished	0.14 /	603	0.15 /	19
	Reduction	750x	4x	580x	469x
Jefferson City	Raw	140 /	2,140	17.5 /	6,170
	Finished	0.18 /	1,470	0.07 /	13
	Reduction	777x	2x	250x	475x
Fayette	Raw	7.9 /	3,180	4.3 /	4,740
	Finished	0.24 /	179	0.17 /	0.6
	Reduction	33x	18x	25x	7,900x
Glasgow	Raw	150 /	11,700	54 /	6,520
	Finished	1.2 /	957	0.07 /	5
	Reduction	125x	12x	771x	1,304x
Moberly	Raw	6.0 /	2,500	6.0 /	8,690
	Finished	0.13 /	223	0.68 /	253
	Reduction	46x	11x	9x	34x
Columbia (Well)	Raw	53 /	43	42.5 /	42
	Finished	0.73 /	7	0.40 /	4
	Reduction	73x	6x	106x	11x

Table 4 Removal of Microorganisms by Water Filtration Plants in Missouri (Winter, 1983-1984)

Plant/Sample		Direct Count, 10^6cells/L	HPC, 10^3colonies/L	Coliform, colonies/L	Fecal Strept., colonies/L
Armstrong	Raw	4900	1300	20	20
	Finished	242	1	<10	<10
Indicated Organism Reduction:		20x	>1000x	--	--
Boonville	Raw	2600	60,000	Confluent	1700
	Finished	603	12	<10	<10
	Reduction:	4x	5000x	Complete	Complete
Jefferson City	Raw	2140	1400	6600	2490
	Finished	1470	44	<10	50
	Reduction:	2x	32x	Complete	50x
Columbia	Raw*	43	2	20	<10
	Finished	7	<1	<10	<10
	Reduction:	6x	-	--	--
Fayette	Raw	3180	290	<10	20
	Finished	179	14	<10	<10
	Reduction:	18x	20x	--	--
Glasgow	Raw	11,700	87	TNTC	34,200
	Finished	957	0.2	60	1,100
	Reduction:	12x	435x	--	31x
Moberly	Raw	2500	1000	<10	<10
	Finished	223	<1	<10	<10
	Reduction:	11x	>1000x	--	--

*Shallow well water supply; all others are surface waters.

Table 6. Observed Changes in Finished Water Turbidity, Total Bacterial Direct Counts and Heterotrophic Plate Counts during Distribution

Parameter (Observations)	Increase (x2)	Unchanged	Decrease (x½)
Turbidity (221)	29 (13%)	133 (60%)	59 (27%)
	Increase (x3)	**Unchanged**	**Decrease (x1/3)**
Direct Count			
Winter (86)	22 (26%)	59 (69%)	5 (5%)
Summer (144)	40 (28%)	95 (66%)	9 (6%)
HPC			
Winter (79)	38 (48%)	30 (38%)	11 (14%)
Summer (140)	73 (52%)	42 (30%)	25 (18%)

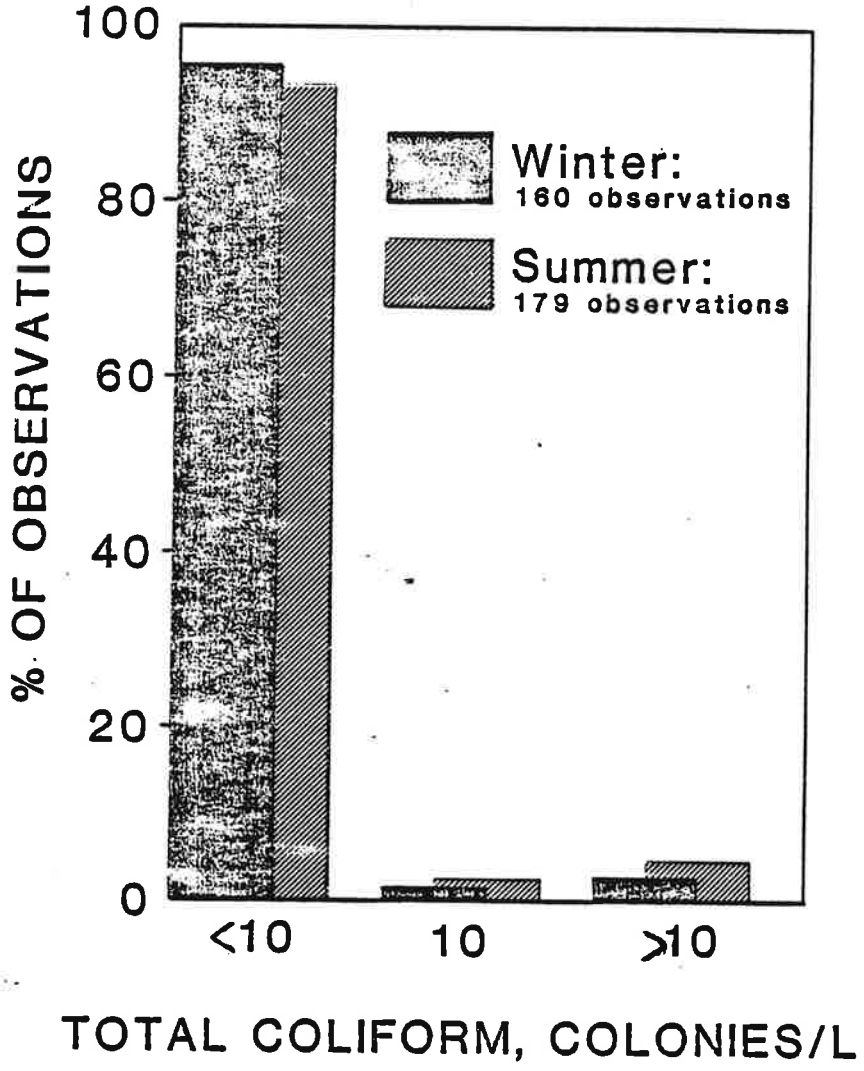


Figure 1: Distribution of Total Coliform Colony Counts in Missouri Water Supplies

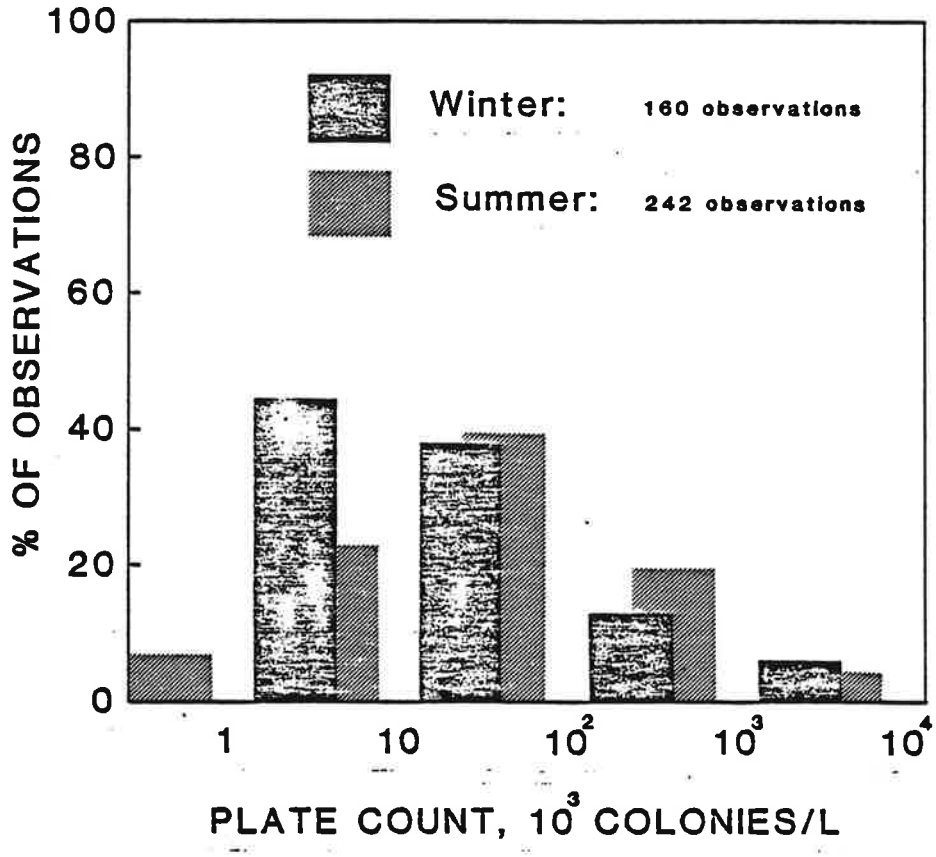


Figure 2: Distribution of Heterotrophic Plate Counts (Pour Plate) in Missouri Water Supplies

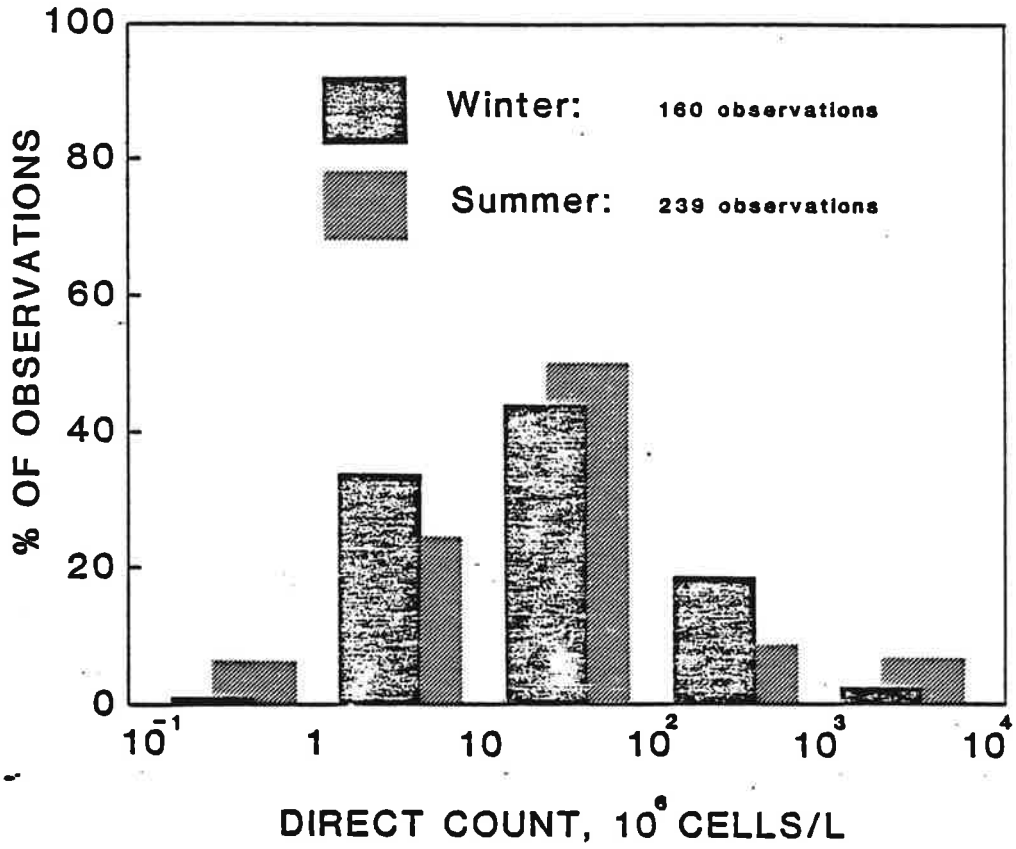


Figure 3: Distribution of Total Bacterial Direct Cell Counts in Missouri Water Supplies

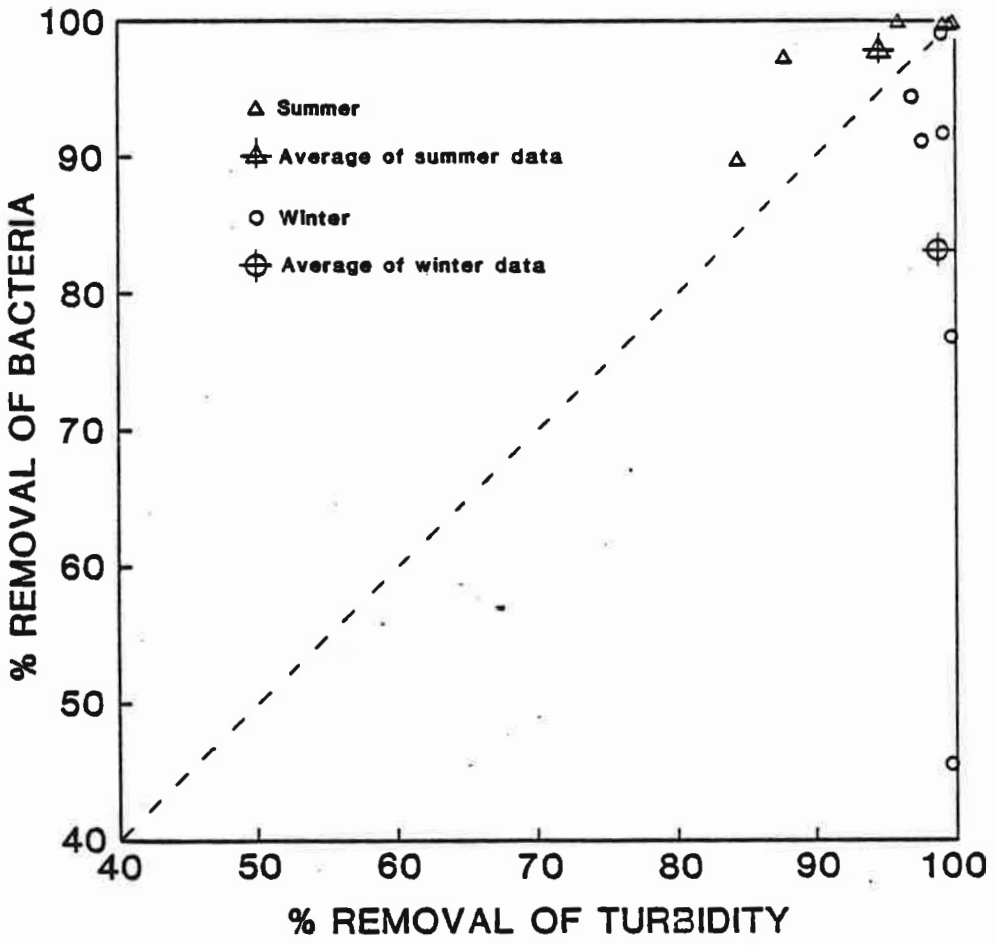


Figure 4: Comparison of Filtration Plant Effectiveness in Removing Bacterial Cells and Turbidity: Winter vs. Summer

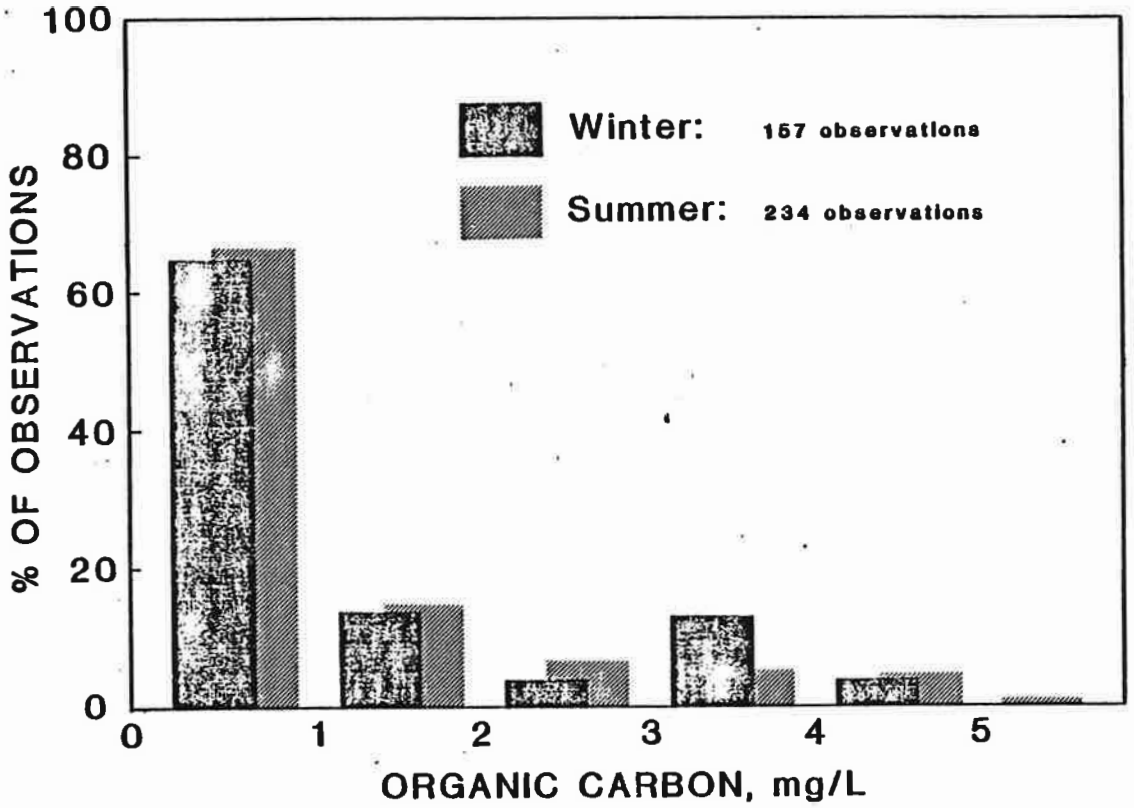


Figure 5: Distribution of Organic Carbon Concentrations in Missouri Water Supplies

Table 5: Removal of Microorganisms by Water Filtration Plants in Missouri (Summer, 1984)

Plant/Sample		Direct Count, 10^6cells/L	HPC, 10^3colonies/L	Coliform colonies/L	Fecal Strept., colonies/L
Armstrong	Raw	10,400	1510	confluent	120
	Finished	1070	.3	<10	<10
Indicated Organisms Reduction:		10x	4576x	complete	complete
Boonville	Raw	8910	1300	confluent	5600
	Finished	19	64	<10	<10
	Reduction:	471x	20x	complete	complete
Jeff City	Raw	6170	11,000	TNTC	TNTC
	Finished	13	8	<10	<10
	Reduction:	467x	1375x	complete	complete
Columbia	Raw	42	1	<10	<10
	Finished	4	0	<10	<10
	Reduction:	10x	-	--	--
Fayette	Raw	4740	403	TNTC	20
	Finished	.6	.3	<10	<10
	Reduction:	7900x	1221x	complete	--
Glasgow	Raw	6520	27,000	TNTC	30
	Finished	5	.3	<10	<10
	Reduction:	1190x	90,000x	complete	complete
Moberly	Raw	8690	4670	<10	30
	Finished	253	0	<10	<10
	Reduction:	34x	>4670	--	complete

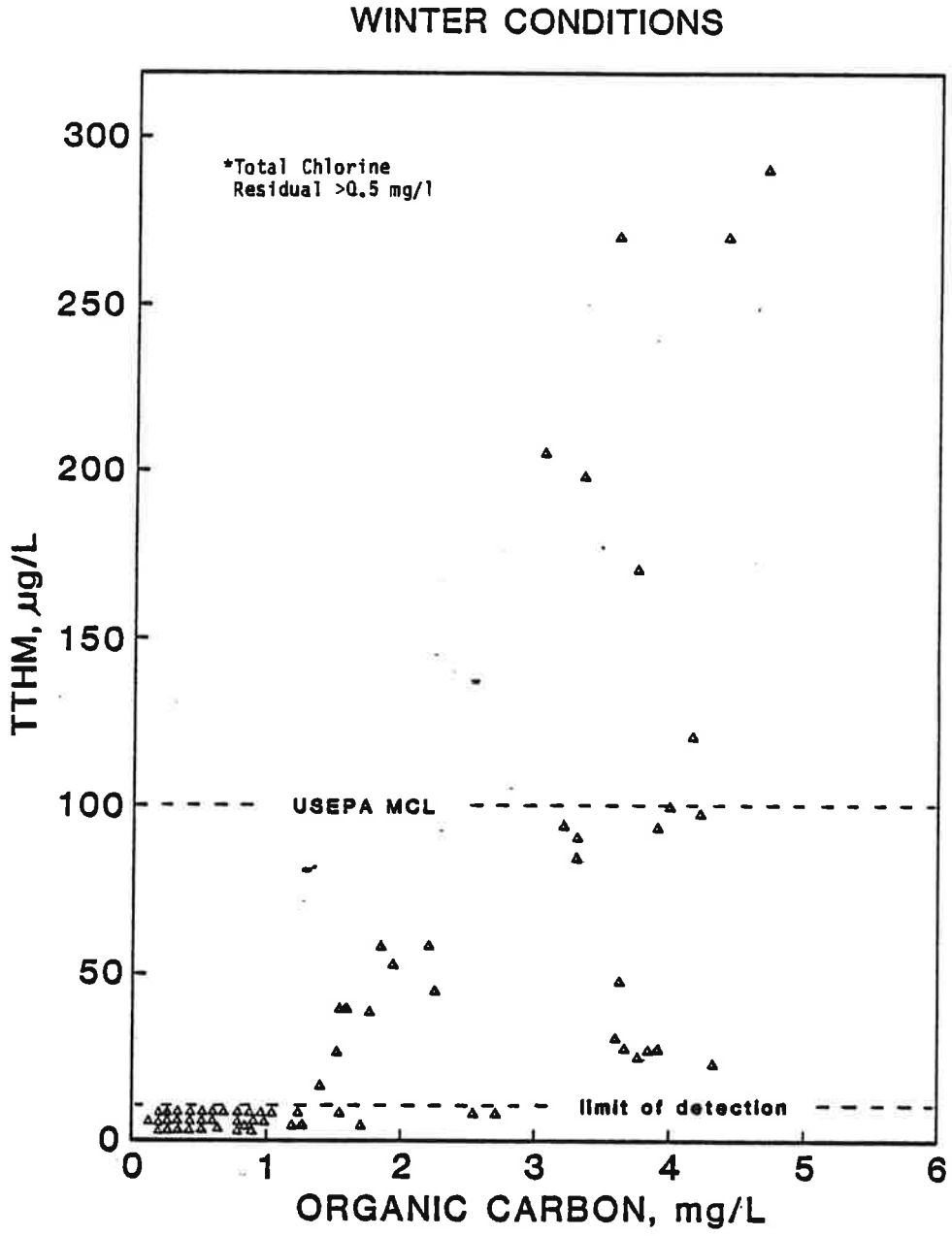


Figure 7: Total Trihalomethane in Chlorinated* Missouri Water Supplies vs. Organic Carbon

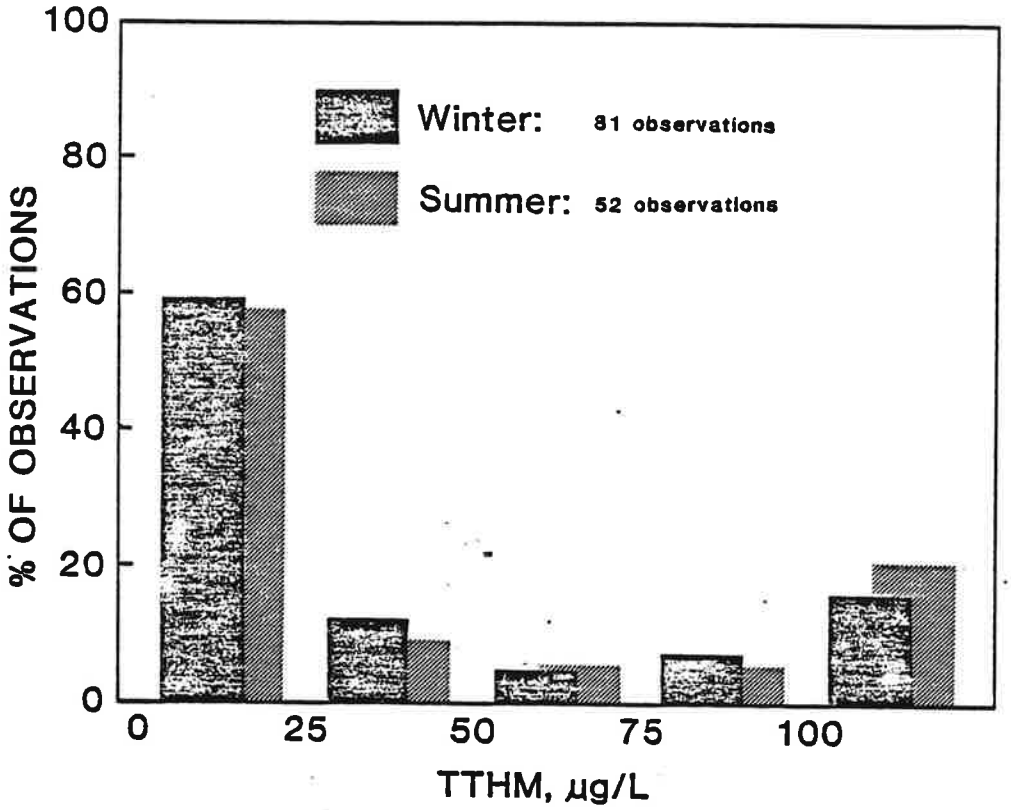


Figure 6: Distribution of Total Trihalomethane Concentration in Missouri Water Supplies

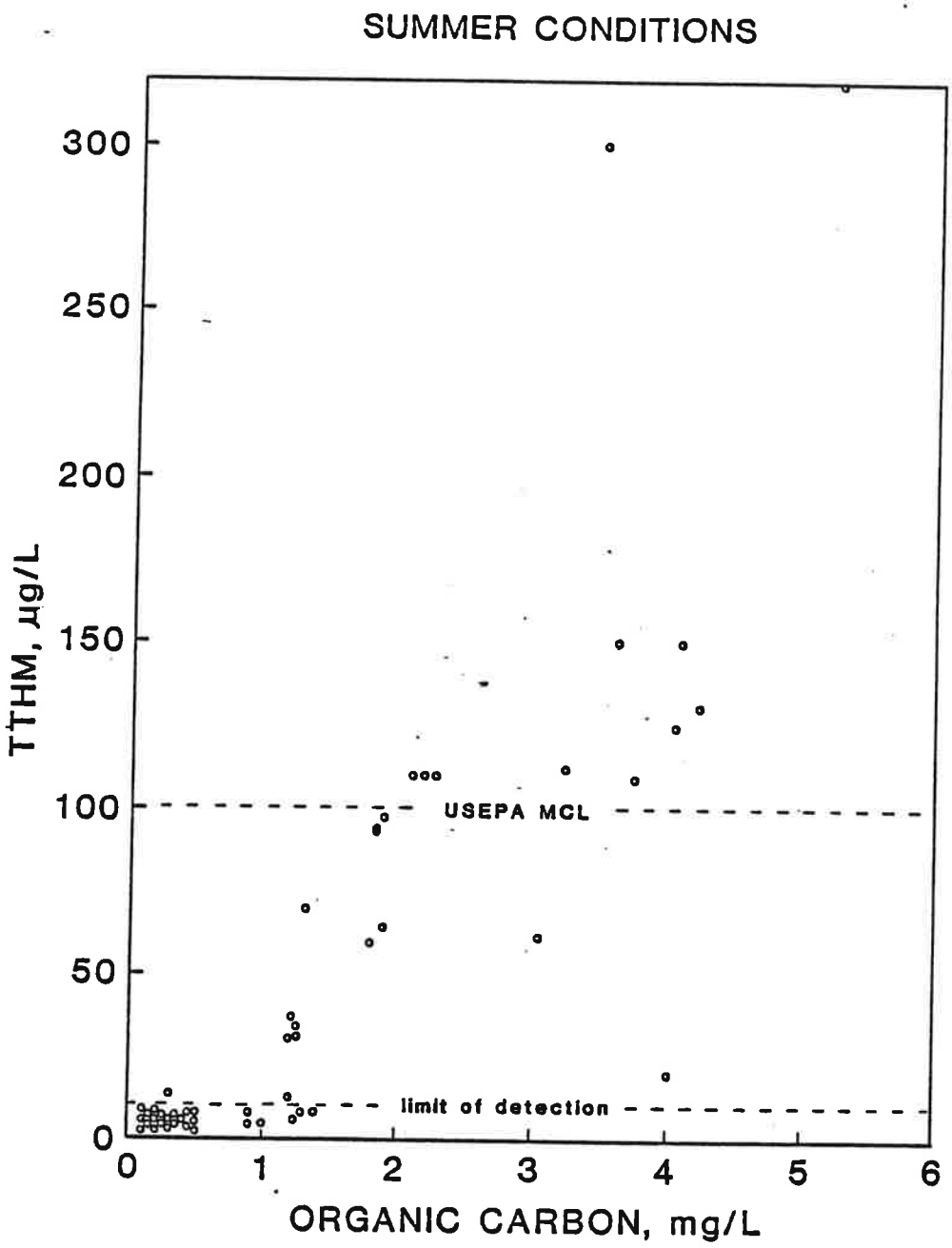


Figure 8: Total Trihalomethane in Chlorinated* Missouri Water Supplies vs. Organic Carbon

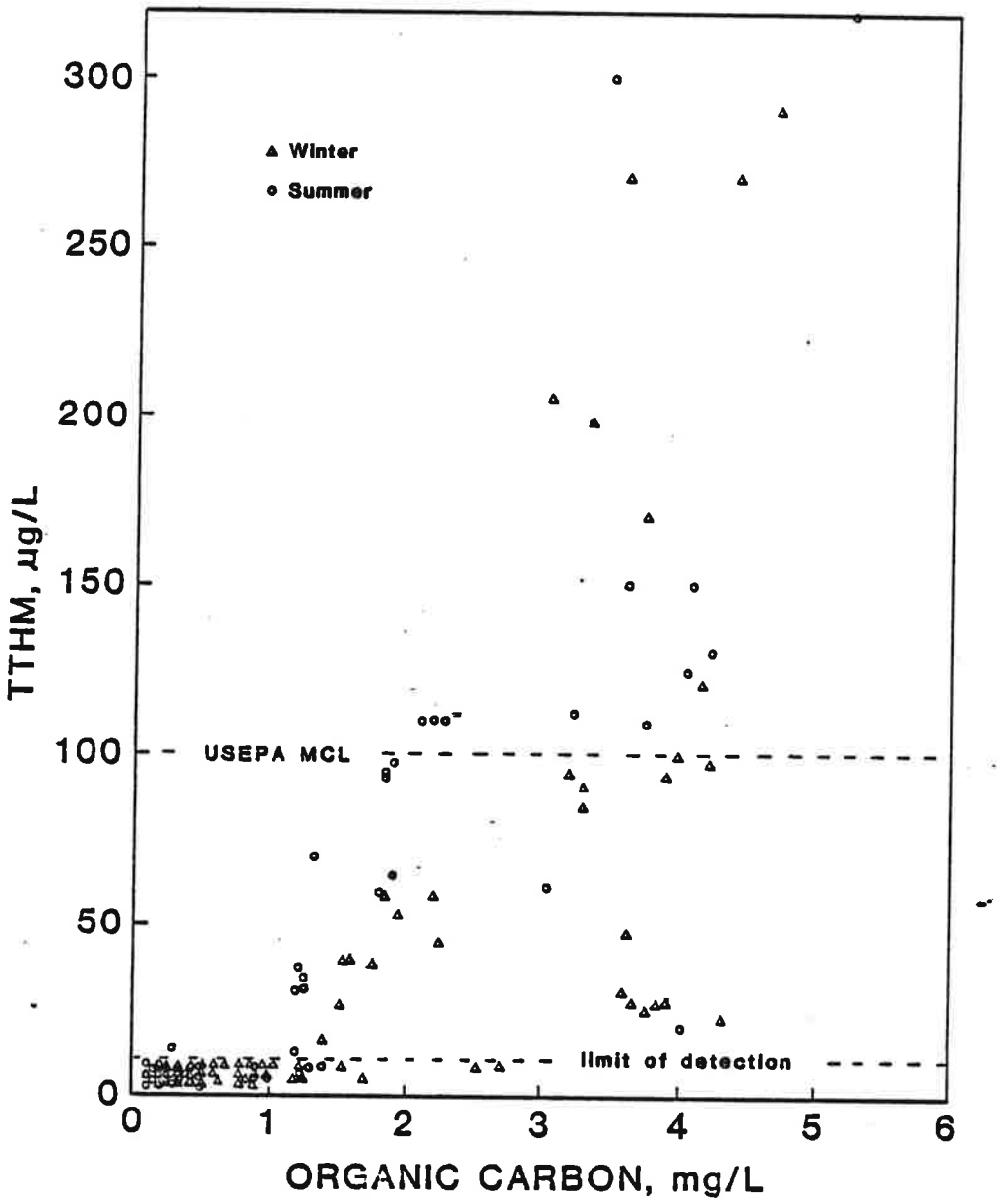


Figure 9: Total Trihalomethane in Chlorinated * Missouri Water Supplies vs. Organic Carbon

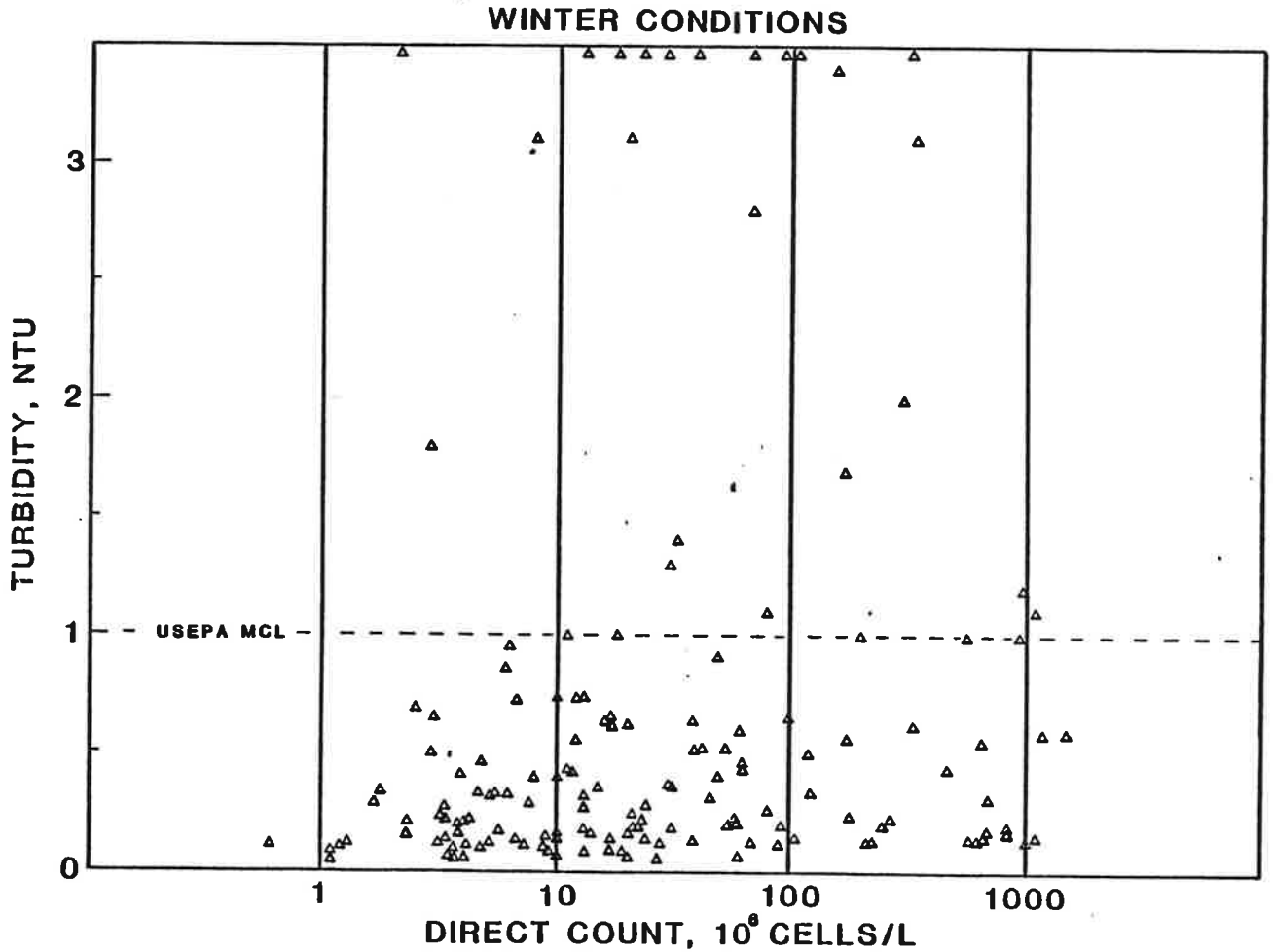


Figure 11: Turbidity vs. Direct Cell Count in Missouri Water Supplies

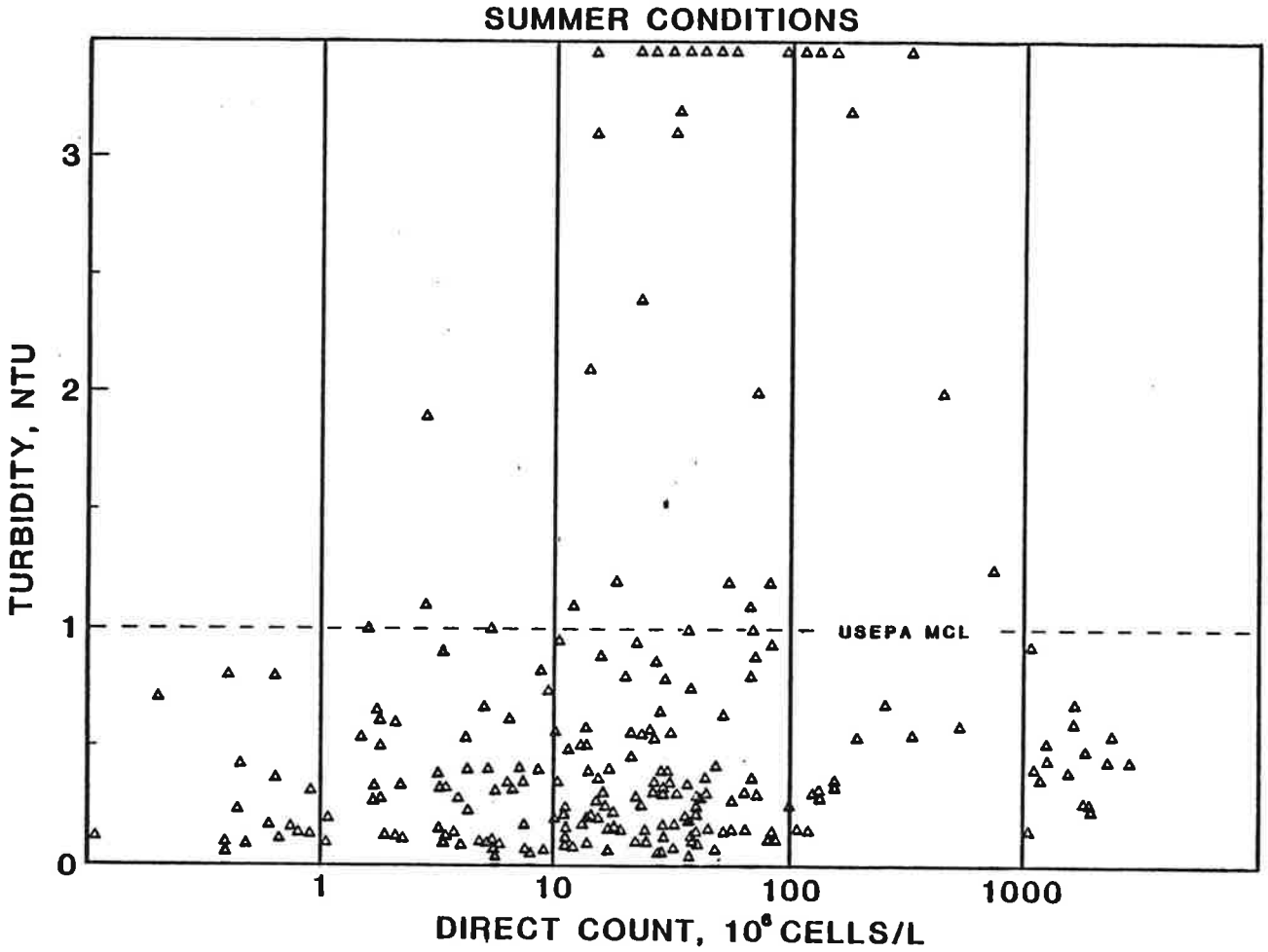


Figure 12: Turbidity vs. Direct Cell Count in Missouri Water Supplies

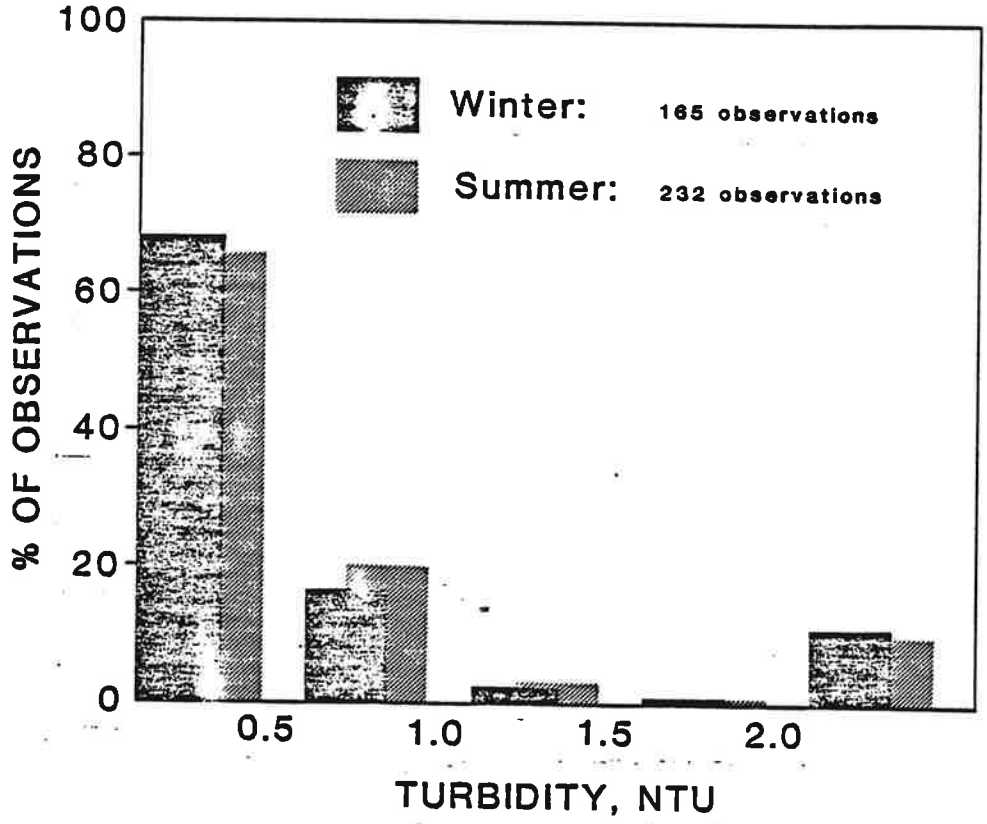
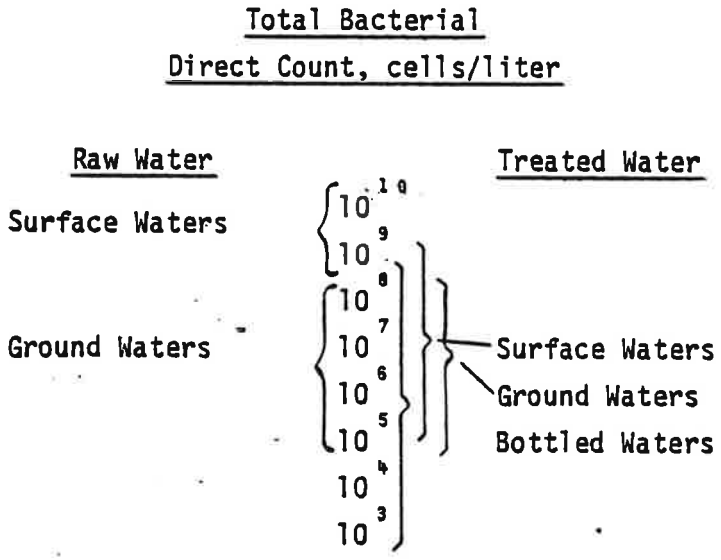


Figure 10: Distribution of Turbidity in Missouri Drinking Waters

Figure 13. Total Bacterial Direct Count in Missouri Surface, Ground and Bottled Waters



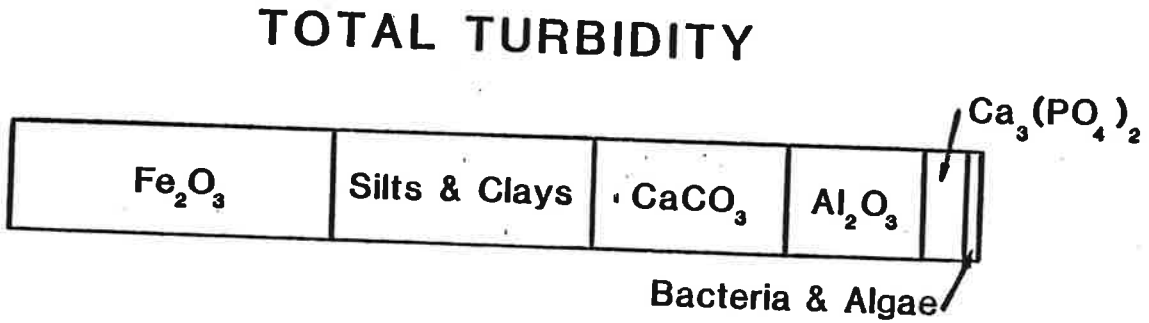


Figure 14: The Relative Composition of Turbidity