United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

Research and Development

EPA-600/S2-82-054 August 1982

EPA

Project Summary

Persistence and Detection of Coliforms in Turbid Finished Drinking Water

Ramon J. Seidler and Thomas M. Evans

The Safe Drinking Water Act requires public water systems with surface water sources to monitor turbidity, as well as coliforms, on a routine basis. The results of these two measurements provide an indication of the water quality and treatment efficiency of the system. In several regions of the country, surface waters are not filtered and precipitation carries turbidity to the consumer's tap. No experimental evidence exists to define the impact of such turbidity in systems using chlorination as the only treatment.

Models were developed to define the quantitative interrelationships between total organic carbon, disinfection efficiency, chlorine demand, and turbidity in surface waters entering a distribution system. The results illustrate that turbidity and its associated total organic carbon exert specific and predictable levels of chlorine demand. Turbidity is also associated with a decrease in disinfection efficiency, that is, turbidities in excess of 5 NTU inhibit the elimination of coliforms even when a free residual chlorine is maintained for 1 hour. Finally, at turbidities in excess of 2 NTU, a striking interference with coliform detection by membrane filtration was documented. The models will provide water treatment operators with the necessary guidelines to compensate for the undesirable effects of turbidity when they occur in the source water. The relevance of the models in different regions can be confirmed through measurement of water turbidity, chlorine demands and coliform persistence.

Other types of interference with coliform detection were found to occur in the standard most probable number (S-MPN) technique. Up to 50 percent of the coliform-contaminated drinking water samples can be missed by the S-MPN technique. Interference was not linked to turbidity but seems to be due to inadequacies in S-MPN media formulation. An abbreviated MPN technique was field tested and was found to be superior to the S-MPN in coliform detection.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The quality of finished drinking water in the United States leaves much to be desired even though it is probably better than that of most other industrialized nations. In the period between 1972 to 1976, some 27,000 individuals became ill from consumption of contaminated drinking water. In 1978 there were an additional 11,435 cases of waterborne disease. Some experts believe that as many as 90 percent of these outbreaks go unreported and that many other victims suffer, but fail to associate their illnesses with contaminated drinking water.

Epidemiological studies have shown that most of the waterborne disease outbreaks occur in semipublic water systems. These include systems serving campgrounds, parks, hotels, and restaurants that have their own water system available for use by the traveling public. These small systems also have more deficiencies in equipment design, maintenance, and monitoring than the larger municipal systems.

Many of the water supplies in the Pacific Northwest rely on the abundant surface waters as the raw water source. Many of these smaller water systems simply chlorinate the water as the only form of treatment. Fall and winter rains bring runoff into the surface streams causing them to carry considerable amounts of turbidity. Since the National Primary Drinking Water Regulations restrict the average monthly turbidity to a maximum contaminant level (MCL) of 1 nephelometric turbidity unit (1 NTU), many of these systems are not in compliance during precipitation periods. However, there is no presently available method to assess the impact of turbidity that enters distribution systems having no flocculation or filtration treatment. A study by the National Academy of Sciences concluded that, "fundamental information is needed on the interactions between viable and nonviable components of particles in drinking water and particularly on their resistance to disinfection and to other water treatment processes."

Under Section 141.13 of the Act, public water suppliers may request a turbidity MCL relaxation to 5 NTU monthly average. To qualify for such a relaxation, the supplier must show that the turbidity does not interfere with disinfection, bacteriological measurements, or with the maintenance of a satisfactory disinfectant in the distribution system. There are no guidelines available on which to base such practical decisions, and there is no scientific information to allow an assessment of how turbidity will quantitatively affect each of these parameters. The goal of the present study was to develop a quantitative assessment of the physical, chemical and bacteriological parameters associated with turbid surface waters as they relate to the regulations in Section 141.13 of the Act. The results of this cooperative agreement illustrate that turbidity has a definable effect on chlorine demand and also exerts an interference with coliform detection using the MF technique. The relationship can be expressed by mathematical models which, in the opinion of the investigators, clearly justify the MCL for turbidity in the Safe Drinking Water Act. The results expressed in the models can be used as guidelines for judging the impact of turbidity on relevant drinking water quality parameters.

Results and Discussion

Statistical Models Explaining the Impact of Turbidity

Models were developed through multiple linear regression computer analyses in order to define the relationships between turbidity, chlorine demand, total organic carbon, and disinfection efficiency ($\log_{10}$ coliform decrease). The models were based on data collected in six watersheds over a two-year period (Table 1).

In developing the models, the data obtained from each of the watersheds were not found to be significantly different. Chlorine demand (CLDMD), which is most important in predicting disinfection efficiency, was found to be a function of the turbidity and the associated total organic carbon (TOC) content of the water (Model 2). The variables, turbidity and TOC, explained 95 percent of the variation in CLDMD. Turbidity was also found to be an accurate predictor of TOC levels in the raw water (Model 1). Disinfection efficiency ($\log_{10}$ of the coliform decrease) was found to be influenced by the season, water turbidity, chlorine demand, and the initial coliform density in the raw source water (Model 3). The coefficient of multiple determination, expressed as a percentage, indicated that 66 percent of the variation in disinfection efficiency was explained by the variables in the model. The inclusion of a numerical term that describes the impact of seasonal TOC concentrations was necessary because of the rainfall patterns in the Pacific Northwest. This may not be necessary in other geographic regions. The seasonal correction factor does not have a strong numerical impact on the overall relationships. Unaccounted for variation in Model 3 may be due to such unmeasured parameters as seasonal variations in coliform populations, varying sensitivities of coliforms to chlorine, and coliform masking in turbid samples.

Impact of Turbidity on Microbiological Determinations by Membrane Filtration

Turbidity was also found to be associated with failures of the standard membrane filtration (MF) technique to detect coliforms. The MF coliform detection failures were assessed by placing filters without typical colonies (often without any visible colonies) into tubes containing lauryl tryptose broth (LTB) and processing in a manner similar to the S-MPN method. The incidence of false negative MF results (failures) was a strong function of the turbidity level of the water. Thus, at $\lesssim$ 2 NTU, only 5/36 samples were false negative. However, at 5 NTU, 15/36 samples were MF negative, but actually contained completed coliforms when the filter was placed into tubes of LTB. At turbidities in excess of 10 NTU, over 80 percent of the filters apparently free of typical colonies were found to be coliform positive by this method.

Inadequacies of the Standard MPN (S-MPN) Technique

In addition to the influence of turbidity on the MF technique, interference with coliform detection was documented in the S-MPN technique. This interference was documented by using a modified MPN (M-MPN) technique. In the M-MPN, gas negative presumptive and confirmatory tubes were processed to m-endo agar LES and examined for coliform colonies. In addition, the completed step was expanded to include two secondary broth media. Interference (or false negative results) could occur at all stages in the S-MPN technique. The M-MPN detected completed coliforms in 41 drinking water samples, while only 22 of these samples were coliform positive by the S-MPN technique. Coliform interference in the S-MPN was found to affect compliance with the Safe Drinking Water Act, especially in marginal water supply systems.

The Abbreviated MPN (A-MPN) Technique

Analysis of data from field trials using the S- and M-MPN provided possible alternatives for improving coliform recovery with less time and expense than with the M-MPN. The procedures developed for the A-MPN utilize LTB as the presumptive medium, m-endo agar LES as the confirmatory medium, and LTB as the secondary completion broth. All highly turbid but gas negative presumptive tubes were also streaked onto

Table 1. Models Derived to Predict Impact of Turbidity on Drinking Water Quality.

Model	Coefficient of Multiple Determination (R^2)	Number of Observations (N)	Mean Squared Error (MSE)	Total Squared Error (C)	Standard Error of Regression Coefficients	t Values
1) TOC[a] = 1.070	—[b]	.23	—	—	—	—
+0.153 (NTU)[c]						
2) CLDMD[d] = −0.075	0.936	17	0.0186	3.0	0.0989	−0.77
+0.029 (NTU)					0.0413	2.02
+0.405 (TOC)					0.0780	5.09
3) LFDC[e] = 1.6951	0.663	32	0.1965	4.5	0.2448	6.92
+0.0549 (Season)[f]					0.0257	2.13
−0.1676 (NTU)					0.0325	−5.15
+0.7763 (CLDMD)					0.3829	2.03
+0.0003 (TC)[g]					0.0011	2.76

[a]*Total organic carbon in mg/l.*
[b]*Multiple regression terms do not apply to linear regression involving one independent variable.*
[c]*Nephelometric turbidity units.*
[d]*Chlorine demand in mg/l.*
[e]*Log-fold decrease in coliforms.*
[f]*A numerical term (1-12, where [1] and December [12]) used to explain seasonal effects on LFDC.*
[g]*Verified total coliforms measured by MF technique.*

m-endo agar LES. Typical or atypical presumptive coliform colonies were inoculated into the secondary LTB. Based on an analysis of 155 drinking water samples, the geometric mean number of coliforms/100 ml was 1.6 for the S-MPN and 5.7 for the A-MPN. Statistical analyses confirmed that the A-MPN was superior to both the S-MPN and MF techniques for coliform recovery from drinking water.

Other Reports Based on This Research

Additional published material based on research conducted under this cooperative agreement includes:

Evans, T.M., M.W. LeChevallier, C.E. Waarvick, and R.J. Seidler. 1981. Coliform species recovered from untreated surface drinking water and drinking water by the membrane filter, standard, and modified most probable-number techniques. Appl. Environ. Microbiol. 41:657-663.

Evans, T.M., R.J. Seidler, and M.W. LeChevallier. 1981. Impact of verification media and resuscitation on accuracy of the memberane filter total coliform enumeration technique. Appl. Environ. Microbiol. 41:1144-1151.

Evans, T.M., C. Waarvick, and R.J. Seidler. 1980. Occurrence of false negative results in the most-probable-number technique used for total coliform detection in surface and drinking water supplies. Bact. Proc. p. 206.

Evans, T.M., C.E. Waarvick, R.J. Seidler, and MW. LeChevallier. 1981. Failure of the most-probable-number technique to detect coliforms in drinking water and raw water supplies. Appl. Environ. Microbiol. 41:130-138.

LeChevallier, M.W., T.M. Evans, and R.J. Seidler. 1980. Effect of turbidity on disinfection efficiency and bacterial resistance in finished drinking water. Bact. Proc. p. 200.

LeChevallier, M.W., T.M. Evans, and R.J. Seidler. 1981. Effect of turbidity on chlorination efficiency and bacterial persistence in drinking water. Appl. Environ. Microbiol. 42:159-167.

LeChevallier, M.W., R.J. Seidler, and T.M. Evans. 1980. Enumeration, and characterization of standard plate count bacteria in chlorinated and raw water supplies. Appl. Environ. Microbiol. 40:922-930.

Seidler, R.J., T.M. Evans, J.R. Kaufman, C.E. Waarvick, and M.W. LeChevallier. 1980. New directions in coliform methodology. AWWA 8th Annual Technology Conference Proceedings 161-172.

Seidler, R.J., T.M. Evans, J.R. Kaufman, C.E. Waarvick, and M.W. LeChevallier. 1981. Limitations of standard coliform enumeration techniques. J. Am. Water Works Assoc. In Press.

The full report was submitted in fulfillment of Cooperative Agreement CR-806287 by Oregon State University, Corvallis, OR, under the sponsorship of the U.S. Environmental Protection Agency.

☆ U.S. GOVERNMENT PRINTING OFFICE. 1982 -559-017/0752

R. J. Seidler and T. M. Evans are with Oregon State University, Corvallis, OR 97331.
***Harry D. Nash** is the EPA Project Officer (see below).*
The complete report, entitled "Persistence and Detection of Coliforms in Turbid Finished Drinking Water," (Order No. PB 82-227 752; Cost: $9.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Municipal Environmental Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Postage and
Fees Paid
Environmental
Protection
Agency
EPA 335

Official Business
Penalty for Private Use $300

RETURN POSTAGE GUARANTEED