Why a chlorine residual?
Facts and Uncertainties

Laith Furatian (City of Kamloops)

Water New Zealand, Hamilton NZ

September 20 2018

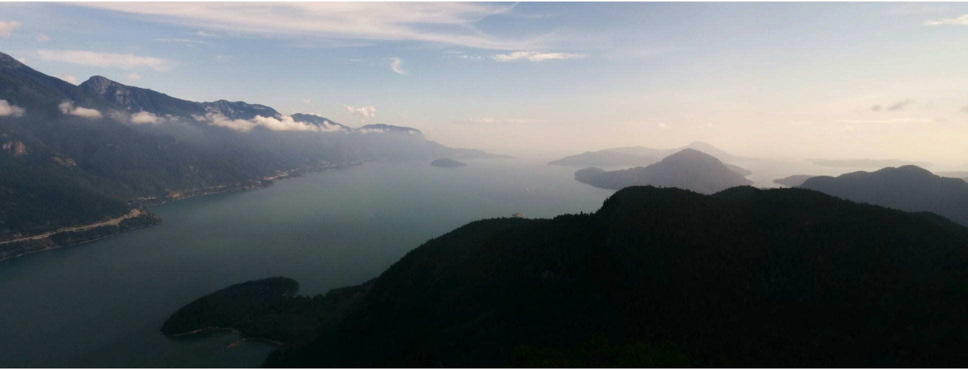
Canada's Tournament Capital

water NEW ZEALAND CONFERENCE & EXPO 19–21 September 2018, Hamilton

New Zealand and British Columbia

British Columbia, the westernmost province, is more like [New Zealand], there are a lot of untreated water supplies and it is basically rolling the dice. It is not a question of if somebody will get sick, it is a question of when and how many.

— Steve Hrudey



Durham, New Hampshire - 2008

The New England Water Works Association and the University of New Hampshire hosted personnel from a Dutch water company to present on some of their work.

“The Dutch Experience”

New England Water Works Association
a Section of the American Water Works Association

University of New Hampshire

The Dutch Drinking Water Sector

Well staffed.

Well funded.

High consumer confidence.

...and so pathogen removal is achieved by UV disinfection and several filtration steps. Thank you.

Chief Scientist

I'm sorry, does this mean you do not maintain a chlorine residual?

That is correct. We in the Netherlands provide **drinking water** to our customers, not swimming pool water.

!!!

Then how do you protect water quality in the distribution system?

We produce **biologically stable water** to avoid regrowth, maintain a **clean distribution system** and provide **positive pressure** throughout.

But during a fire you may lose positive pressure in the vicinity of a hydrant and contamination could then enter the system.

Perhaps, but then 0.2 ppm of chlorine will not give you protection from that.

A utility down south had such an incident and their engineer swears that little bit of residual chlorine saved them.

This is a **belief**. We are not here to discuss beliefs, only **facts**.

Residual Disinfectant in Distribution

In the Netherlands, and other parts of Europe, drinking water is distributed without any residual disinfectant.

In North America, maintaining a detectable level of chlorine throughout the system is either required or recommended.

What do you think?

Why maintain a residual?

Primary vs. Secondary Disinfectants

Disinfectant	Primary	Secondary
Chlorine	✔	✔
Chloramine		✔
Ultraviolet	✔	
Ozone	✔	
Chlorine Dioxide	✔	✔

Water can be considered a perishable product with a shelf life (detention time in system), packaging (pipes and storage facilities), and preservatives (free chlorine or total chlorine).

Kirmeyer et al. 1999

Chlorine vs. Chloramines

Consider for example the CT ($\min \text{mg L}^{-1}$) values stipulated for **4-log virus inactivation at pH 6 - 9**:

T °C	5	10	15
Chlorine	8.0	6.0	4.0
Chloramines	2000	1500	1000

USEPA 1989
(As cited by AWWA M20 2006)

Some untreated water is distributed in N. America

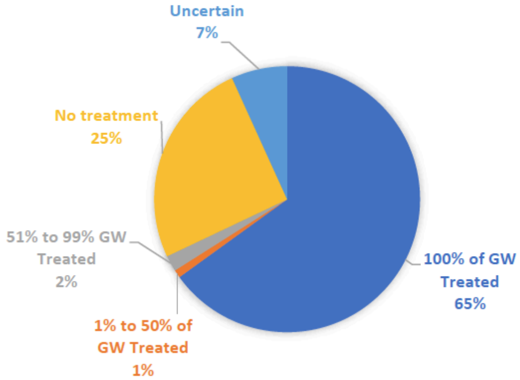


Figure 97 Extent of GW sources that are treated to achieve 4-log virus inactivation prior to the first customer (n=103)

AWWA's 2017 Disinfection Survey Results.

The benefits of chlorine persistence in the distribution system emerged over time.

Claimed benefits of maintaining a chlorine residual

Protection against contamination from source

Inhibit or control biofilm growth

Sentinel or flag for system integrity

Protection against recontamination in system

Arguments against maintaining a chlorine residual

Chlorinous taste and odour

Formation of disinfection by-products

False sense of security

We should consider the most sensitive people, not the most sensitive taste buds.

Darren Molder
Senior Environmental Health Officer
Drinking Water Officer
Vancouver Coastal Health

NAS-NRC Statement on Residual Maintenance

"Residual chlorine in the concentrations routinely employed in water utility practice will not ordinarily disinfect any sizeable amounts of contaminatory material entering the system, though this will depend on the amount of dilution at the point of contamination, on the type of residual chlorine and on the time-of-flow interval between the point of contamination and the nearest consumer. "

NAS-NRC Statement 1959

NAS-NRC Statement on Residual Maintenance

"The NAS-NRC does not consider maintenance of a residual a satisfactory substitute for good design, construction and supervision of a water distribution system, nor does it feel that the presence of a residual in the system constitutes a guarantee of water potability"

NAS-NRC Statment 1959

Distribution System Deficiencies

SURVEY OF COMMUNITY WATER SUPPLY SYSTEMS

Leland J. McCabe, James M. Symons, Roger D. Lee and Gordon G. Robeck

THE purpose of the Community Water Supply Survey (CWSS) was to determine if the American consumer's drinking water met the Drinking Water Standards.[1] To obtain nationwide coverage, the Bureau of Water Hygiene of the US Public Health Service initiated the CWSS in February of 1969 in nine areas across the country. The field work for the CWSS was conducted by the Bureau of Water Hygiene, in cooperation with the state and local health departments of the water utilities.

This survey was designed to give an assessment of drinking water quality, water supply systems, and surveillance programs in urban and suburban areas in each of the nine regions of the Department of Health, Education, and Welfare. These areas were selected to give examples of the several types of water supplies in the country. A whole Standard Metropolitan Statistical Area (SMSA) was the basis of each survey, except in Region I where the entire State of Vermont was included, with evaluations made on all public water supply systems, as defined herein, in each study area. This coverage allowed an assessment of the drinking water quality of the large central city, the suburbs, and the smaller communities located in the counties in the SMSA, and the interaction between them.

Specifically, the objectives of this survey were accomplished by determining whether or not:

1. The quality of the urban and suburban American consumer's drinking water in the selected survey areas exceeded the Constituent Limits of the Drinking Water Standards (DWS);[1]
2. The water supply systems supplying this water to the consumers had facility deficiencies that might indicate or lead to potentially unsafe drinking water;
3. The bacteriological surveillance programs over these water supply systems meet the established criteria.

SCOPE

Public water supplies in the US numbered 19,236, serving some 150,000,000 people when last inventoried in 1963.[2] The remaining 50,000,000 people had private water supplies. Most of the public water supplies were small, about 85 per cent serving 5,000 or less people. About one-half of the public was served by the 18,837 supplies that each served 100,000 or less persons, and the other one-half (77,000,000) were served by the 399 larger supplies. About 75 per cent of these public water supplies have ground water as a source, while 18 per cent use surface water. The remaining 7 per cent have a mixture of ground and surface water source.

Systems Surveyed

This survey covered 969 public water supply systems, including 885 community water supply systems (91.3 per cent of the total) and 84 special water supply systems (8.7 per cent of the total). For this survey, the following definitions of the systems were used:

Public Water Supply System. A water supply system includes the works and auxiliaries for collection, treatment, storage, and distribution of water from the sources of supply to the free-flowing outlet of the ultimate consumer. Water supply systems were included in this survey, if they had 15 or more service connections and served 25 or more consumers.

Special Water Supply Systems. Those systems serving trailer and mobile home parks, other tourist accommodations and institutions with resident populations.

Community Water Supply Systems. All other systems studied in an SMSA.

The 969 public water supply systems surveyed (5 per cent of the national total) served about 18,200,000 persons (12 per cent of the total population served by public water supplies).

For the purpose of this paper, water supply systems were divided into four types: 1) those using surface water (120 systems) or a mixture of surface and ground water as a source (46); 2) those using ground water as a source (613) [this type was further divided into: a) wells, b) springs, and c) mixture of both]; 3) those purchasing wholesale finished water as a source (106); and 4) special water supply systems (84). Table 1 shows the number of systems in each category and the population served in each region and in the entire survey.

The number of public water supply systems in various population ranges is given in Table 2. The 22 major cities included 73 per cent of the study population, while only 0.5 per cent were served by the 446 systems serving less than 500 consumers. The water treatment practices found in the survey are presented in Tables 3 and 4.

Survey Areas

Background for selection of each of the nine survey areas and the definition of Standard Metropolitan Statistical Area (SMSA) are given below.

Standard Metropolitan Statistical Area. The boundaries and titles of standard metropolitan statistical areas are established by the Bureau of the Budget with the advice of the Federal Committee on Standard Metropolitan Statistical Areas. An SMSA is a county or group of contiguous counties which contains at least one city of 50,000 inhabitants or more, or "twin cities" with a combined population of at least 50,000. In addition to the county, or counties, containing such a city or cities, contiguous counties are included in an SMSA if, according to certain criteria, they are essentially metropolitan in character and are socially and economically integrated with the central city.

Region I. State of Vermont—Vermont was included in the survey at the request of the Commissioner of Health with the concurrence of the Governor. (Replaced the initially selected SMSA in this Region.)

670

Survey in 1969

969 water supplies

Serving > 18 million

54% no ccc ordinance

90% no ccc program

(ccc = cross-connection control)

McCabe et al. 1970

Deficiencies and Waterborne Disease

Review of the Causes of Waterborne-Disease Outbreaks

Gunther F. Craun and Leland J. McCabe

Currently, about fourteen waterborne-disease outbreaks occur each year in the US and cause, on an average, 1,600 illnesses and one death per year. This is not a leading cause of the American public's illnesses, but it represents a residual that should have been eliminated in this age of sanitation.

The emphasis of this article is on deficiencies in water-supply systems and operational practices that allow disease outbreaks to occur. By reviewing these outbreaks it is hoped that some knowledge of the problem will be gained in order to prevent their recurrence. To update the record, waterborne outbreaks occurring during the 10-yr period 1961–70 were compiled and analyzed.[1]

Only outbreaks associated with water used for drinking or domestic purposes are included in this analysis. To be considered an outbreak, at least two cases of infectious disease must be reported. Except in very unique circumstances, such as one chemical poisoning for which the poison was detected in the water, a single isolated case cannot be recognized as having been caused by drinking water. With two or more cases a common source can be noted and investigated.

The investigation of outbreaks is often incomplete and conducted long after the outbreak has occurred. Consequently, relatively few outbreaks can be proved to have been caused by drinking water. The waterborne hypothesis, however, was the most logical explanation for the outbreaks reported in this article. The Riverside, Calif., outbreak in 1965 might be considered a proved waterborne outbreak because the etiological agent was isolated from the water. But even after months of investigation, the exact circumstances responsible for the outbreak could not be determined.[2-5]

Similar criteria were used to define waterborne outbreaks in two previous reviews, Weibel *et al.*[6] for the period of 1946–60, and Eliassen and Cummings[7] for the period 1938–45. These data are thus considered to be compatible with those for the period 1961–70, especially in noting trends. A criterion of five cases of illness was used by Gorman and Wolman[8] to define an outbreak in their review of waterborne disease for the period 1920–36.

Historical Trends

Waterborne disease data over the last three decades indicate that outbreaks are no longer in the decline in this country. The decline in the number of outbreaks that was noted in a previous review[6] seems to have leveled off in recent years. This trend is depicted in Fig. 1. A consistent and dramatic decrease took place from the period 1938–40 to 1951–55 when the number of waterborne outbreaks dropped from an average of 45/yr to 10/yr. Since the 1951–55 period, however, there has been no decline in the average annual number of outbreaks; rather a slight increase has occurred.

It is not known if the average of fourteen outbreaks noted during the period 1966–70 represents a real increase or is due to certain inherent factors, such as differences in reporting, and this particular point is difficult to quantify. What is significant is that no decline is apparent, and, if

A paper originally presented at the Annual Conference on Jun. 15, 1971, and subsequently updated and submitted to the JOURNAL on Jul. 5, 1972, by Gunther F. Craun, san. engr., and Leland J. McCabe; chief; both of the Criteria Development Branch, Water Supply Research Lab., Environmental Protection Agency, Cincinnati, Ohio. Both are Active Members, AWWA.

During 1946-1970, 40% of outbreaks due to distribution system deficiencies:

cross-connections and back-siphonage most common deficiency

Craun et al. 1973

Johns Hopkins Studies - lab scale intrusion tests

Water Research Vol. 14, pp. 403 to 408
Pergamon Press Ltd 1980. Printed in Great Britain

THE EFFECTIVENESS OF CHLORINE RESIDUALS IN INACTIVATION OF BACTERIA AND VIRUSES INTRODUCED BY POST-TREATMENT CONTAMINATION

M. C. Snead, V. P. Olivieri, K. Kawata and C. W. Krusé
The Johns Hopkins University, School of Hygiene and Public Health, 615 N. Wolfe Street, Baltimore, Maryland 21205, U.S.A.

(*Received September* 1979)

Abstract—The protection afforded the water consumer by the maintenance of a free or combined chlorine residual in water distribution systems was evaluated in a laboratory system provided with a simulated cross connection. Tap water, adjusted to the appropriate pH, temperature and chlorine residual, was challenged with varying levels of autoclaved sewage seeded with *Shigella sonnei*, *Salmonella typhimurium*, a coliform (IMVIC^{++--}), poliovirus 1 and f2 bacterial virus. Comparative survivals of these microorganisms were evaluated over 2 h periods. As expected, microbial inactivation was increased by lower pH, higher temperature, higher initial chlorine concentration and lower sewage concentration. An initial free chlorine residual was more effective than an equivalent initial combined chlorine residual. Generally, *S. sonnei*, *S. typhimurium* and the coliform organism were inactivated at the same rate but poliovirus 1 was more resistant and f2 was the most resistant. At pH 8, with an initial free chlorine residual of 0.7 mg l^{-1}, and added sewage levels of up to 1% by vol, 3 logs or greater bacterial inactivation was obtained within 60 min. Viral inactivation under these conditions was less than 2 logs.

INTRODUCTION

The distribution system is perhaps the most vulnerable component of a water utility. This is due in large measure to the difficulty of detecting defects in the system which has an enormous ratio of pipe surface to water volume. The introduction of infectious microorganisms into a distribution system by cross connections and back-siphonage has been implicated as a cause of numerous waterborne disease outbreaks. In municipal systems, distribution system deficiencies were involved in 11 of 22 waterborne outbreaks of infectious hepatitis during the period 1946–1974 which included the rather celebrated outbreak affecting the Holy Cross football team (Craun *et al.*, 1976). They were involved in 10 of 31 reported waterborne disease outbreaks for the period 1971–1974. The 1970 survey of community water supply systems (McCabe *et al.*, 1970) showed that about 90% of water systems had no active cross connection programs and the 54% of communities did not have cross connection control ordinances.

The maintenance of a chlorine residual, particularly a free residual, throughout a community water distribution system has been shown to be effective in meeting bacteriological standards (Buelow & Walton, 1971) and in controlling the general bacterial population within distribution lines (Geldreich *et al.*, 1972). Since the water leaving a treatment plant that practices chlorination is generally of good bacteriological quality, the superior quality of distribution system samples in those systems that maintain a chlorine residual must be due to some protection against bacterial regrowth and post-treatment contamination.

This study was designed to evaluate the effectiveness of a chlorine residual in protecting against bacterial and viral contamination. In the study autoclaved raw sewage, seeded with *Salmonella typhimurium*, *Shigella sonnei*, a recently isolated coliform organism, poliovirus 1 and f2 bacterial virus, was used as the contaminant in a series of experiments simulating contamination resulting from a cross connection.

MATERIALS AND METHODS

Bacterial and viral strains

S. typhimurium was isolated from raw sewage by the method of Olivieri *et al.* (1977) and serotyped using Difco antisera. An IMVIC^{++--} coliform organism was also isolated from raw sewage. Attempts to isolate a shigella strain from sewage were unsuccessful. A strain of *S. sonnei* maintained in the laboratory was therefore used. Bacterial cultures used in all experiments were grown overnight at 35°C in brain heart infusion (BHI) broth, washed 3 times by centrifugation and finally resuspended in a volume of saline equal to that of the original culture. The f2 bacterial virus was obtained from the American Type Culture Collection (ATCC No. 15766-B) and grown by the method given by Cramer *et al.* (1976). Poliovirus 1 (vaccine strain) was prepared in Buffalo green monkey (BGM) cells grown in roller bottles in Eagle's Minimal Essential Medium containing 5% fetal calf serum (Dahling *et al.*, 1974). Virus was harvested by freeze thawing 3 times, followed by centrifugation to remove cell debris. All experiments were performed using aliquots from a single virus preparation.

Simulated contaminant

Raw domestic sewage was sterilized by autoclaving at 121°C for 60 min. The sewage was then analyzed for the following parameters by procedures given in *Standard Methods* (1975): biochemical oxygen demand, total and suspended solids, ammonia and total nitrogen, turbidity,

United States Environmental Protection Agency
Municipal Environmental Research Laboratory
Cincinnati OH 45268
EPA-600/2-80-010
June 1980
Research and Development

Benefits of Maintaining a Chlorine Residual in Water Supply Systems

Snead et al. 1980

Johns Hopkins Studies - lab scale intrusion tests

Experimental Conditions:

- Tap water adjusted for pH, temperature, and chlorine or chloramine residual
- Autoclaved raw sewage seeded with coliform bacteria, *Salmonella*, *Shigella*, poliovirus, f2 phage
- Simulate back-siphonage and follow survival for 2 hr

Johns Hopkins Studies - lab scale intrusion tests

Key Results:

Using least favourable conditions - pH 8 and 0 °C

Chlorine ineffective when challenged by 5% sewage (v/v)

Chlorine 0.7 ppm + 1% sewage →
>3 log bacteria under 30 min and >1.5 log poliovirus in 2 h

Chlorine 0.2 ppm + 0.1% sewage →
2.5 log bacteria and 0.8 log phage in 2 h.

Chloramines 0.9 ppm + 1% sewage → 1-log bacteria after 2 h

Johns Hopkins Studies - full scale intrusion tests

Environmental Health Perspectives
Vol. 69, pp. 15-29, 1986

Stability and Effectiveness of Chlorine Disinfectants in Water Distribution Systems

by Vincent P. Olivieri,* Michael C. Snead,* Cornelius W. Krusé,*† and Kazuyoshi Kawata*

A test system for water distribution was used to evaluate the stability and effectiveness of three residual disinfectants—free chlorine, combined chlorine, and chlorine dioxide—when challenged with a sewage contaminant. The test distribution system consisted of the street main and internal plumbing for two barracks at Fort George G. Meade, MD. To the existing pipe network, 152 m (500 ft) of 13-mm (0.5 in.) copper pipe were added for sampling, and 60 m (200 ft) of 2.54-cm (1.0 in.) plastic pipe were added for circulation. The levels of residual disinfectants tested were 0.2 mg/L and 1.0 mg/L as available chlorine.

In the absence of a disinfectant residual, microorganisms in the sewage contaminant were consistently recovered at high levels. The presence of any disinfectant residual reduced the microorganism level and frequency of occurrence at the consumer's tap. Free chlorine was the most effective residual disinfectant and may serve as a marker or flag in the distribution network. Free chlorine and chlorine dioxide were the least stable in the pipe network. The loss of disinfectant in the pipe network followed first-order kinetics. The half-life determined in static tests for free chlorine, chlorine dioxide, and combined chlorine was 140, 93, and 1680 min.

Introduction

The concept of a residual disinfectant in water intended for human consumption is not new. Herodotus, the father of history, described the preparation and distribution of the water consumed by the kings of ancient Persia (*1*):

> "The Great King, when he goes to the wars, is always supplied with provisions carefully prepared at home, and with cattle of his own. Water too from the river Choaspes, which flows by Susa, is taken with him for his drink, so that is the only water which the Kings of Persia taste. Wherever he travels, he is attended by a number of four-wheeled cars drawn by mules in which Choaspes water, ready boiled for use, and stored in flagons of silver, is moved with him from place to place."

The fundamental principles for providing a safe water were practiced and noted in the earliest human records. An adequate quantity of water was taken from a known supply, treated and disinfected, and stored in flagons of silver before consumption by the king. Small quantities of silver in the water provided a disinfectant residual to protect against post-treatment contamination.

Several thousand years later, the lessons of history were slowly learned. As water treatment and distribution practices evolved and the intentional addition of biocides to the water for disinfection became the rule, the disinfectant residual was carried into the piped distribution network. However, the value of the residual disinfectant remained unclear.

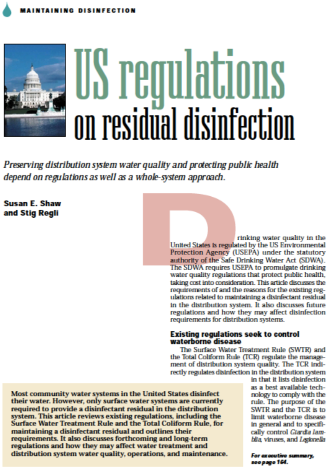
In 1958, at the request of the United States Army, the National Academy of Sciences National Research Council (NAS-NRC) prepared a statement concerning the maintenance of chlorine residuals. Portions of the report are noted below (*2*):

> "Residual chlorine in the concentrations routinely employed in water utility practice will not ordinarily disinfect any sizeable amounts of contaminatory material entering the system, though this will depend on the amount of dilution occurring at the point of contamination, on the type and concentration of residual chlorine and on the time-of-flow interval between the point of contamination and the nearest consumer. . . . It is the opinion of the NAS-NRC that the establishment of a universal standard for maintaining residual chlorine in the water in distribution system is not desirable. . . . The NAS-NRC does not consider maintainance of a residual a satisfactory substitute for good design, construction and supervision of a water distribution system, nor does it feel that the presence of a residual in the system constitutes a guarantee of water potability."

The level of pathogenic microorganisms that reach the consumer's tap during cross-connection and back-siphoning episodes is a function of dilution of the contaminating material, natural die-away, and inactivation by the residual disinfectant. The objectives of this study were to evaluate the stability and effectiveness of residual disinfectants in a test water distribution system when challenged by a sewage contaminant.

*Environmental Health Engineering, The Johns Hopkins University, Baltimore, MD 21205.
†Deceased.

Olivieri et al. 1986



MAINTAINING DISINFECTION

US regulations on residual disinfection

Preserving distribution system water quality and protecting public health depend on regulations as well as a whole-system approach.

Susan E. Shaw and Stig Regli

Drinking water quality in the United States is regulated by the US Environmental Protection Agency (USEPA) under the statutory authority of the Safe Drinking Water Act (SDWA). The SDWA requires USEPA to promulgate drinking water quality regulations that protect public health, taking cost into consideration. This article discusses the requirements of and the reasons for the existing regulations related to maintaining a disinfectant residual in the distribution system. It also discusses future regulations and how they may affect disinfection requirements for distribution systems.

Existing regulations seek to control waterborne disease

The Surface Water Treatment Rule (SWTR) and the Total Coliform Rule (TCR) regulate the management of distribution system quality. The TCR indirectly regulates disinfection in the distribution system in that it lists disinfection as a best available technology to comply with the rule. The purpose of the SWTR and the TCR is to limit waterborne disease in general and to specifically control *Giardia lamblia*, viruses, and *Legionella*

Most community water systems in the United States disinfect their water. However, only surface water systems are currently required to provide a disinfectant residual in the distribution system. This article reviews existing regulations, including the Surface Water Treatment Rule and the Total Coliform Rule, for maintaining a disinfectant residual and outlines their requirements. It also discusses forthcoming and long-term regulations and how they may affect water treatment and distribution system water quality, operations, and maintenance.

For executive summary, see page 164.

Residual requirements of the SWTR were partly based on the Johns Hopkins studies

Shaw et al. 1999

Other experimental studies of intrusion

Scale	Reference	Free Chlorine	Chloramine
Lab	Camper et al. 1998	✓	
Lab	Payment 1999	✓	
Lab/Pilot	McMath et al. 1999		✓
Lab	Baribeau et al. 2005	✓	✓
Pilot	Parents et al. 1996	✓	
Pilot	Sibille et al. 1997	✓	
Pilot	Gibbs et al. 2003	✓	

Adapted from Besner et al. 2008

Protection against intrusion by disinfectant residual

Chloramines offer negligible protection against recontamination

Major intrusion ($> 1\%$ v/v), chlorine is ineffective

Minor intrusion ($< 1\%$ v/v), chlorine effective against bacteria and viruses on timescale of minutes to hours

Experience shows cross-connection and back-siphonage events occur as a slug (i.e. major intrusion)

Recent trends in waterborne outbreaks

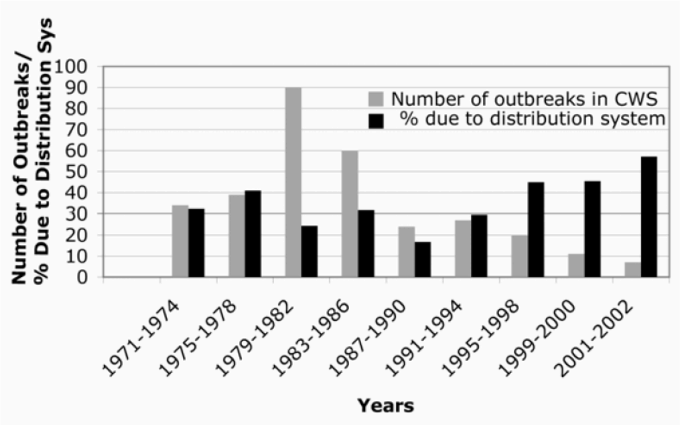
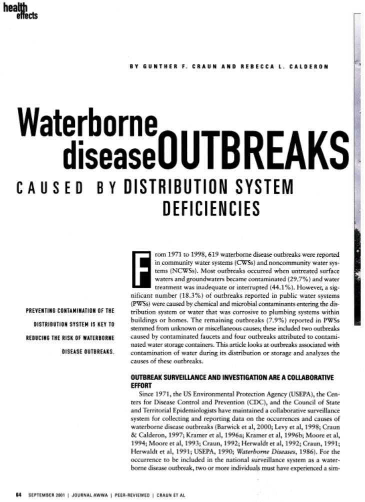


FIGURE 2 Waterborne disease outbreaks in community water systems (CWS) associated with distribution system deficiencies. Note that the majority of the reported outbreaks have been in small community systems and that the absolute numbers of outbreaks have decreased since 1982. SOURCE: Data extracted from Craun and Calderon (2001) and MMWR summary reports on waterborne disease surveillance (Lee et al., 2002 and Blackburn et al., 2004).



health effects

BY GUNTHER F. CRAUN AND REBECCA L. CALDERON

Waterborne disease OUTBREAKS CAUSED BY DISTRIBUTION SYSTEM DEFICIENCIES

PREVENTING CONTAMINATION OF THE DISTRIBUTION SYSTEM IS KEY TO REDUCING THE RISK OF WATERBORNE DISEASE OUTBREAKS.

From 1971 to 1998, 619 waterborne disease outbreaks were reported in community water systems (CWSs) and noncommunity water systems (NCWSs). Most outbreaks occurred when untreated surface waters and groundwaters became contaminated (29.7%) and water treatment was inadequate or interrupted (44.1%). However, a significant number (18.3%) of outbreaks reported in public water systems (PWSs) were caused by chemical and microbial contaminants entering the distribution system or water that was corrosive to plumbing systems within buildings or homes. The remaining outbreaks (7.9%) reported in PWSs stemmed from unknown or miscellaneous causes; these included two outbreaks caused by contaminated faucets and four outbreaks attributed to contaminated water storage containers. This article looks at outbreaks associated with contamination of water during its distribution or storage and analyzes the causes of these outbreaks.

OUTBREAK SURVEILLANCE AND INVESTIGATION ARE A COLLABORATIVE EFFORT

Since 1971, the US Environmental Protection Agency (USEPA), the Centers for Disease Control and Prevention (CDC), and the Council of State and Territorial Epidemiologists have maintained a collaborative surveillance system for collecting and reporting data on the occurrences and causes of waterborne disease outbreaks (Barwick et al, 2000; Levy et al, 1998; Craun & Calderon, 1997; Kramer et al, 1996a; Kramer et al, 1996b; Moore et al, 1994; Moore et al, 1993; Craun, 1992; Herwaldt et al, 1992; Craun, 1991; Herwaldt et al, 1991; USEPA, 1990; *Waterborne Diseases*, 1986). For the occurrence to be included in the national surveillance system as a waterborne disease outbreak, two or more individuals must have experienced a sim-

64 SEPTEMBER 2001 | JOURNAL AWWA | PEER-REVIEWED | CRAUN ET AL

1971 to 1998
cross-connection and back-siphonage (50%)

main breaks/leaks (11%)

storage contamination (10%)

main repair/install (6%)

Craun et al. 2001

Chemical contamination may be significant

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Montreal

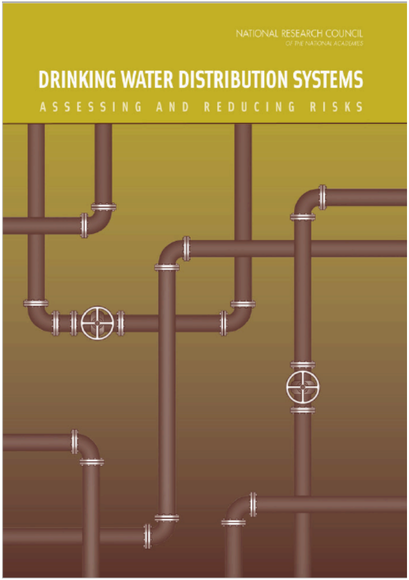
Tap water completely off-limits in sector of downtown Montreal

People within area bounded by Bleury, St-Antoine, Beaver Hall and René-Lévesque should not use water

CBC News · Posted: May 10, 2018 6:23 PM ET | Last Updated: May 11

The city says people within the affected area must not use the water at all, not even if it is boiled first. (CBC)

National Research Council - Report - 2006



A USEPA request during Total Coliform Rule revision

Distribution system integrity defined as:

1. Physical Integrity
2. Hydraulic Integrity
3. Water Quality Integrity

Reducing distribution system risks (highest priorities)

Ensure active cross-connection control and backflow prevention program in place

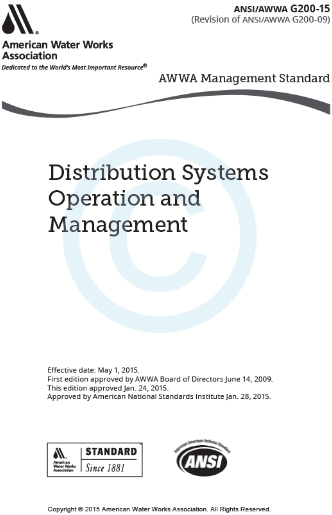
Ensure sanitary practices for main repair and construction

Monitor pressure (preferably continuously)

Adequately protect finished water

Ensure proper training of distribution system operators

G200 Standard (ANSI/AWWA)


ANSI/AWWA G200-15
(Revision of ANSI/AWWA G200-09)

American Water Works Association
Dedicated to the World's Most Important Resource®

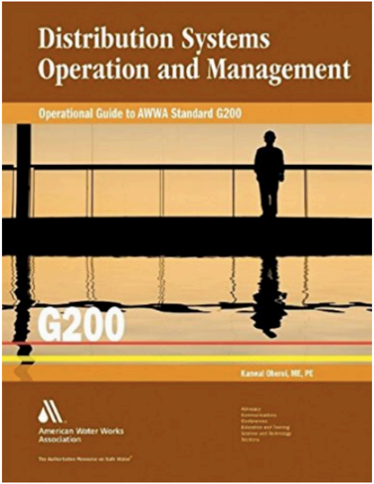
AWWA Management Standard

Distribution Systems Operation and Management

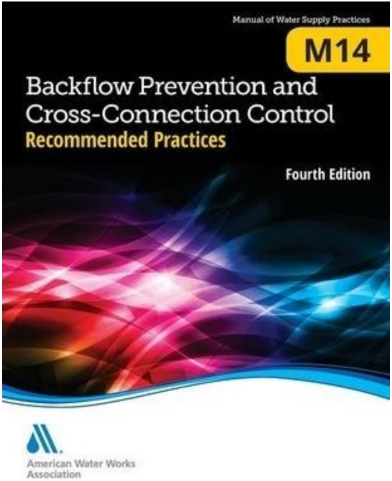
Effective date: May 1, 2015.
First edition approved by AWWA Board of Directors June 14, 2009.
This edition approved Jan. 24, 2015.
Approved by American National Standards Institute Jan. 28, 2015.

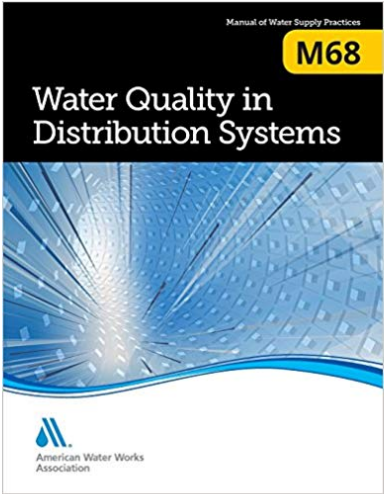
STANDARD Since 1881

ANSI



AWWA Manuals of Practice





Important Case Studies - Untreated Groundwater

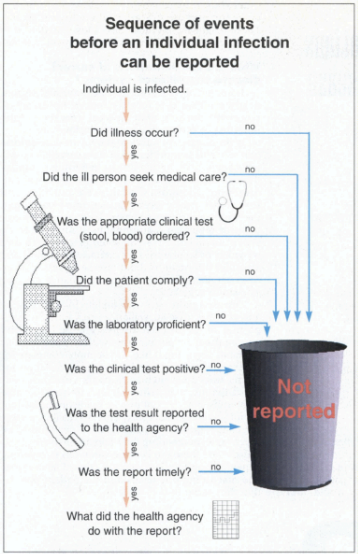
Cabool Missouri, 1989, pop. 2100
Wells (×2) 300 and 400 m deep
E. coli O157:H7 - 243 illnesses
32 hospitalizations, 4 deaths
Cold weather, main breaks, sewage contamination

Gideon Missouri, 1993, pop. 1100
Wells (×2) both 400 m deep
Salmonella typhimurium
> 650 illnesses, 7 deaths
Bird contamination of reservoir
Inappropriate flushing

NRC 2006

But that is not the end of the story.

Most waterborne outbreaks are not reported



Frost et al. 1996

Epidemic vs. Endemic Disease

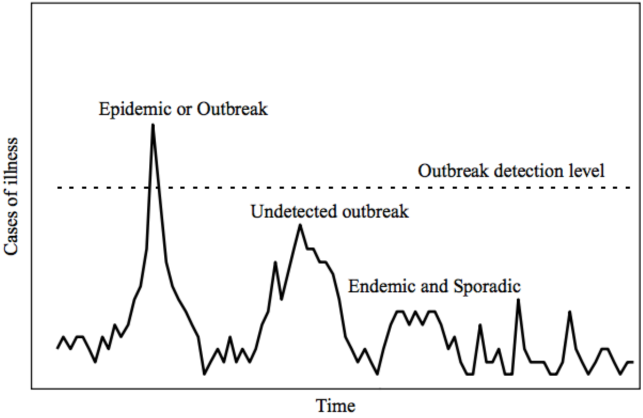


Figure 5 | Example of epidemic, endemic, and sporadic illness.

Craun et al. 2006

Analytical Epidemiology and Tap Water

Attempts to estimate risk of acute gastrointestinal disease due to exposure to tap water:

Laval 1988-1989 (Payment et al. 1991)

Laval 1993-1994 (Payment et al. 1997)

Melbourne 1997-1999 (Hellard et al. 2001)

Davenport 2000-2002 (Colford et al. 2005)

The Laval Studies

A Randomized Trial to Evaluate the Risk of Gastrointestinal Disease due to Consumption of Drinking Water Meeting Current Microbiological Standards

ABSTRACT

Background: This project directly and empirically measured the level of gastrointestinal (GI) illness related to the consumption of tapwater prepared from sewage-contaminated surface waters and meeting current water quality criteria.

Methods: A randomized intervention trial was carried out; 299 eligible households were supplied with domestic water filters (reverse-osmosis) that eliminate microbial and chemical contaminants from their water, and 307 households were left with their usual tapwater without a filter. The GI symptomatology was evaluated by means of a family health diary maintained prospectively by all study families over a 15-month period.

Results: The estimated annual incidence of GI illness was 0.76 among tapwater drinkers compared with 0.50 among filtered water drinkers ($p < 0.01$). These findings were consistently observed in all population subgroups.

Conclusion: It is estimated that 35% of the reported GI illnesses among the tapwater drinkers were water-related and preventable. Our results raise questions about the adequacy of current standards of drinking water quality to prevent waterborne endemic gastrointestinal illness. (*Am J Public Health.* 1991;81:703–708)

Pierre Payment, PhD, Lesley Richardson, MSc, Jack Siemiatycki, PhD, Ron Dewar, MSc, Michael Edwardes, PhD, and Eduardo Franco, PhD

Introduction

It has long been considered that water disinfected at 0.5 mg/L of free residual chlorine for 30 minutes at a pH less than 8, with a turbidity of less than 1 NTU would constitute minimal health risk to consumers.[1] Recently, however, increasingly sensitive analytic methods have permitted the detection of viruses[2] and parasites[3] in water meeting current water quality standards. This and several reported outbreaks of viral and parasitic diseases of waterborne origin[4] have prompted a review of the safety of current standards.[5] The suggested standards are based on the absence of fecal coliform bacteria in drinking water, fecal coliform bacteria being indicators of fecal pollution, and the ensuing risk of the presence of pathogenic microorganisms. The absence of total coliform bacteria in a majority of the samples collected is also recommended as an indicator of treatment efficiency.

While the current microbiological standards of water quality have virtually eliminated explosive outbreaks of waterborne disease,[6] there is no assurance that populations consuming drinking water prepared from sewage-contaminated wastes are free of less virulent gastrointestinal (GI) disease. While studies have addressed the health effects of recycled wastewaters[7,8] or of substandard drinking water,[9] all have relied on cases reported to the health care system to evaluate potential health effects. Other studies have addressed the health risks associated with chemicals in water or with disinfection byproducts.[10]

The present project was intended to directly and empirically answer the following question: Is there any measurable excess of GI illness related to the consumption of tap water prepared from sewage-contaminated surface waters and which meets current microbiological and physico-chemical water quality criteria?

Methods

Study Area

The study was carried out in a suburban area of Montreal comprised mainly of French Canadians with socioeconomic and education levels similar to the average of the Metropolitan Montreal area. The residents of this area are served by a single water treatment plant, which uses state-of-the-art treatment with pre-disinfection, flocculation by alum, rapid sand filtration, ozonation, and final disinfection by chlorine or chlorine dioxide. The raw water to be treated is drawn from a river which is mainly contaminated by human sewage discharges with little contamination from chemicals. The distribution system serves a population of about 40,000 people and distributes water meeting current microbiological and physico-chemical water quality standards.[5] A pilot study had shown that over 90 percent of the population drinks unmodified tap water and that the water was considered by the consumers to be of good to excellent quality.

Study Design

In order to determine the level of gastrointestinal illnesses attributable to drink-

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June 1991, Vol. 81, No. 6 American Journal of Public Health 703

Payment et al. 1991

International Journal of Environmental Health Research 7, 5–31 (1997)

A prospective epidemiological study of gastrointestinal health effects due to the consumption of drinking water

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The objective of this study was to assess if drinking water meeting currently accepted microbiological standards is the source of gastrointestinal illnesses and to attempt to identify the source(s) of these illnesses. A randomized prospective study was conducted over a period of 16 months (September 1993–December 1994) in a middle class suburban community served by a single water filtration plant. A representative sample of 1400 families were selected and randomly allocated in four groups of 350, to the following regimens: (1) tap water; (2) tap water from a continuously purged tap; (3) bottled plant water; (4) purified bottled water (tap water treated by reverse osmosis or spring water). The water treatment plant produced water that met or exceeded current North American regulations for drinking water quality. The distribution system was found to be in compliance for both coliforms and chlorine. Using the purified water group as the baseline, the excess of gastrointestinal illness associated with tap water was 14% in the tap group and 19% in the tap-valve group. Children 2–5 years old were the most affected with an excess of 17% in the tap group and 40% in the tap-valve group. Mottled plant water was not the source of any increase in the incidence of gastrointestinal illnesses, even if it contained very high levels of heterotrophic bacteria after two weeks. The data collected suggest that 14–40% of the gastrointestinal illnesses are attributable to tap water meeting current standards and that the water distribution system appears to be partly responsible for these illnesses.

Keywords: drinking water; waterborne disease; gastrointestinal illness; health effects; epidemiologic study.

Introduction

The notion that coliform-free drinking water is pathogen-free is being seriously questioned as is the value of current water quality indicators (Craun 1990). Several outbreaks of gastroenteritis and hepatitis (Wilson *et al.* 1982, Bloch *et al.* 1990, Mackenzie *et al.* 1994, Kramer *et al.* 1996), giardiasis and cryptosporidiosis (Hayes *et al.* 1989, Smith *et al.* 1989, Smith and Smith 1990) in communities with water meeting current regulations (Federal Register 1989a, Anonymous 1994), have brought to the public attention the fact that current standards may not provide complete protection (Batik *et al.* 1983, Craun 1990).

Any estimation of the waterborne fraction of disease is impaired by their low incidence in the population (Payment *et al.* 1991b) and it is only in outbreak situation that detailed analyses can

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Payment et al. 1997

Laval Study 1988-1989

Study of about 600 households in Montreal suburb drinking either tap water or point-of-use RO water over 15 month period, with self-reporting of gastrointestinal illness.

Results:

Tapwater drinkers - 0.76 episodes/person/year

RO water drinkers - 0.50 episodes/person/year

Conclusion:

Estimated 35% of GI illness among tap water drinkers due to consumption of drinking water and thus preventable.

Laval Study 1993-1994

Using same study area, 1400 families of immunocompetent adults with young children placed into four groups of 350 families and assigned to drink given water for 16 months

Groups:

1. tap water
2. tap water from continuously purged tap
3. bottled plant water
4. purified bottled water (RO or spring water)

Laval Study 1993-1994

Rate of GI illness in agreement with previous studies for tap water group (0.66 ± 0.05 episodes/person/year)

Bottled plant group $\approx$ Purified bottled water groups

Tap valve group $>$ Tap group

Conclusions:

GI illness attributable to drinking water 14 - 19% for all ages, and 17 - 40% for children 2 to 5 years

Distribution system partly responsible for portion of illnesses

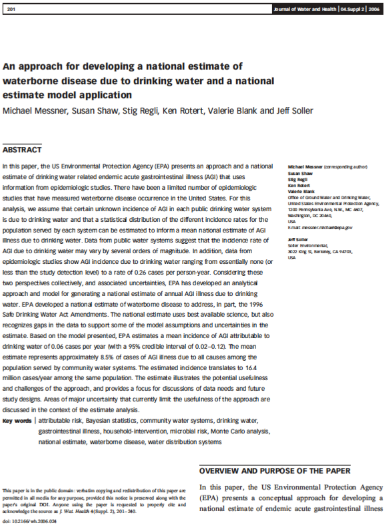
Melbourne and Davenport Studies

Melbourne, Australia Study (Hellard et al. 2001):
Double-blinded, randomized trial with 600 families with at least two children, drinking either tap or purified water over 68 week. GI illness rate in tap vs. purified: **0.79 vs. 0.82 episodes/person/year**.

Davenport, Iowa Study (Colford et al. 2005):
Randomized, controlled, triple-blinded, crossover intervention using 600 families in two groups (tap and purified). Observed over 54 weeks. GI illness rate in tap vs. purified: **2.12 vs. 2.20 episodes/person/year**.

Studies designed to detect a 15-20% and 11% effect, respectively.

1996 SDWA - Estimate of drinking water disease burden



201 Journal of Water and Health | 04.Suppl 2 | 2006

An approach for developing a national estimate of waterborne disease due to drinking water and a national estimate model application

Michael Messner, Susan Shaw, Stig Regli, Ken Rotert, Valerie Blank and Jeff Soller

ABSTRACT

In this paper, the US Environmental Protection Agency (EPA) presents an approach and a national estimate of drinking water related endemic acute gastrointestinal illness (AGI) that uses information from epidemiologic studies. There have been a limited number of epidemiologic studies that have measured waterborne disease occurrence in the United States. For this analysis, we assume that certain unknown incidence of AGI in each public drinking water system is due to drinking water and that a statistical distribution of the different incidence rates for the population served by each system can be estimated to inform a mean national estimate of AGI illness due to drinking water. Data from public water systems suggest that the incidence rate of AGI due to drinking water may vary by several orders of magnitude. In addition, data from epidemiologic studies show AGI incidence due to drinking water ranging from essentially none (or less than the study detection level) to a rate of 0.26 cases per person-year. Considering these two perspectives collectively, and associated uncertainties, EPA has developed an analytical approach and model for generating a national estimate of annual AGI illness due to drinking water. EPA developed a national estimate of waterborne disease to address, in part, the 1996 Safe Drinking Water Act Amendments. The national estimate uses best available science, but also recognizes gaps in the data to support some of the model assumptions and uncertainties in the estimate. Based on the model presented, EPA estimates a mean incidence of AGI attributable to drinking water of 0.06 cases per year (with a 95% credible interval of 0.02–0.12). The mean estimate represents approximately 8.5% of cases of AGI illness due to all causes among the population served by community water systems. The estimated incidence translates to 16.4 million cases/year among the same population. The estimate illustrates the potential usefulness and challenges of the approach, and provides a focus for discussions of data needs and future study designs. Areas of major uncertainty that currently limit the usefulness of the approach are discussed in the context of the estimate analysis.

Key words | attributable risk, Bayesian statistics, community water systems, drinking water, gastrointestinal illness, household-intervention, microbial risk, Monte Carlo analysis, national estimate, waterborne disease, water distribution systems

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doi: 10.2166/wh.2006.024

OVERVIEW AND PURPOSE OF THE PAPER

In this paper, the US Environmental Protection Agency (EPA) presents a conceptual approach for developing a national estimate of endemic acute gastrointestinal illness

Acute GI illness rate

due to drinking water

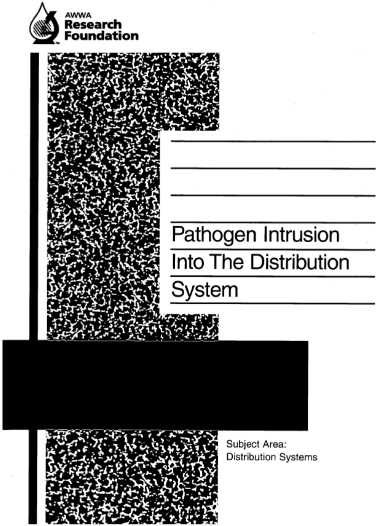
0.06 episodes/person/year

16.4 million episodes/year

(or 8.5% of total cases)

Messner al. 2006

Possible explanation for Laval Study observations

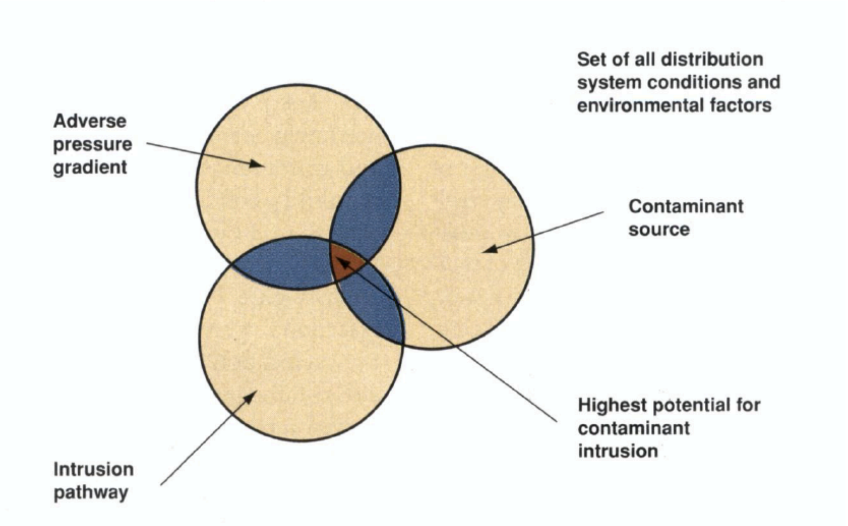


Distribution system of study area prone to low pressures and low chlorine residual.

Low level contamination entering the system suspected.

Kirmeyer et al. 2001

Risk of pathogen intrusion to distribution system



Lindley et al. 2002

Research Continued...

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EPA

Verification and Control of Pressure Transients and Intrusion in Distribution Systems

Subject Area:
Infrastructure Reliability

Friedman et al. 2004

Environ. Sci. Technol. **2010,** *44,* 269–277

Pressure Monitoring and Characterization of External Sources of Contamination at the Site of the Payment Drinking Water Epidemiological Studies

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GEORGE DI GIOVANNI,[§]
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The 1990s epidemiological studies by Payment and colleagues suggested that an increase in gastrointestinal illnesses observed in the population consuming tap water from a system meeting all water quality regulations might be associated with distribution system deficiencies. In the current study, the vulnerability of this distribution system to microbial intrusion was assessed by characterizing potential sources of contamination near pipelines and monitoring the frequency and magnitude of negative pressures. Bacterial indicators of fecal contamination were recovered more frequently in the water from flooded air-valve vaults than in the soil or water from pipe trenches. The level of fecal contamination in these various sources was more similar to levels from river water rather than wastewater. Because of its configuration, this distribution system is vulnerable to negative pressures when pressure values out of the treatment plant reach or drop below 172 kPa (25 psi), which occurred nine times during a monitoring period of 17 months. The results from this investigation suggest that this distribution system is vulnerable to contamination by intrusion. Comparison of the frequency of occurrence of negative pressure events and repair rates with data from other distribution systems suggests that the system studied by Payment and colleagues is not atypical.

system were conducted by Payment et al. (*1, 2*). The first study (*1*) compared the rate of highly credible gastrointestinal illnesses (HCGI) between a group consuming tap water (307 households) and a group consuming the tap water filtered through a reverse-osmosis (RO) unit (299 households). After a 15-month observation period, the estimated annual incidence of HCGI was 0.76 episodes per person-year among tap water drinkers compared to 0.50 among RO water drinkers, suggesting that at least 35% of the reported HCGI among the tap water drinkers were tap water-related. In the second study (*2*), data from four groups of 350 households drinking either (i) tap water, (ii) tap water from a continuously purged tap (tap-valve), (iii) bottled plant water, and (iv) purified bottled water (plant water treated by RO or spring water) were compared. After 16 months, the excess of HCGI associated with tap water was 14% in the tap group and 19% in the tap-valve group with respect to the bottled plant water groups. This excess was higher for children 2–5 years old with an excess of 17% in the tap group and 40% in the tap-valve group. Distributed water met or exceeded the water quality standards at the time and the distribution system was found to be in compliance for both coliforms and residual chlorine. Because there was no significant difference in the rate of HCGI between the bottled plant water groups, the authors suggested that distribution system contaminations could explain their observations.

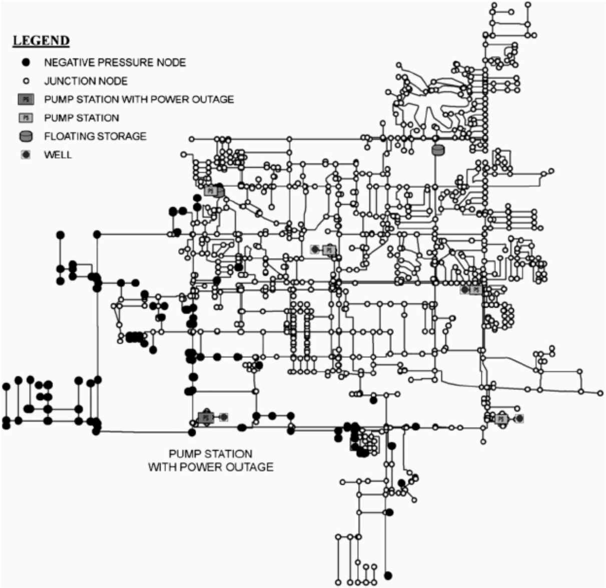
These results raised questions about the integrity of distribution systems and the likelihood of their contamination during normal operations. Two randomized, blinded intervention epidemiological studies were then conducted in Melbourne (Australia) (*3*) and Davenport (Iowa) (*4*). Results from these studies did not reveal a detectable HCGI level attributable to tap water. A case-control study conducted in England showed a strong correlation between increased risk of self-reported diarrhea and reported low pressure events at the tap (*5*). The authors concluded that up to 15% of the gastrointestinal illness may be associated with burst water mains and pressure loss events, although the study was not designed to estimate waterborne disease but sporadic cryptosporidiosis.

The Payment et al. studies provide the only epidemiological results showing a significant contribution of tap water meeting regulations to HCGI. Differences between study designs and the individual water system characteristics could explain why other studies could not confirm these findings (*6*). However, the Payment et al. estimates were used as the sole basis for the U.S. national estimate of waterborne disease due to drinking water presented by Messner et al. (*7*).

Loss of physical/hydraulic integrity can compromise water quality during distribution and may be caused by a variety of factors such as cross-connections, pipe repairs, loss of pressure, etc (*6*). The occurrence of transient negative pressures is raising public health concerns since the risk of introduction of pathogenic microorganisms exists when transient negative pressure events occur in water mains (*8*).

Besner et al. 2010

Hydraulic Modeling and QMRA



Modelling suggests chlorine (≥ 0.2 mg/L) can significantly reduce risk of infection due to virus intrusion under relevant conditions of low pressure events.

Yang et al. 2011

Unanswered (and Site Specific) Questions

What is the contribution of tap water to endemic disease?

What is the extent of pathogen intrusion from low pressure events?

Is this a significant contribution to endemic illness?

Would a chlorine residual reduce endemic illness levels?

What is the role of premise plumbing?

Knowledge Gaps

Millions drink chloraminated water.
(e.g. Toronto, Ottawa, Edmonton, Victoria)

Millions drink chlorinated water.
(e.g. Vancouver, Calgary, Winnipeg, Montreal)

Can a detectable difference in GI illness be measured between systems using the two residual types?

An analogy between a chlorine residual and seat belts

670925

A Statistical Analysis of 28,000 Accident Cases with Emphasis on Occupant Restraint Value

N. I. Bohlin
Passenger Car Engineering Dept., AB Volvo

THE VALUE AND EFFECTIVENESS of occupant restraints, especially the upper torso restraint, in car accidents have been discussed and investigated in different ways. The investigations carried out have mainly concerned experimental studies in dynamic sled runs or full-scale car barrier crashes where anthropomorphic dummies have been used. In very few cases a human cadaver has been substituted for the dummy. Further mathematical models and computer programs have been the basis for the evaluation of the restraint value. Most of the investigations, which are based on data from real accidents, are considered to have one or more of the following deficiencies of greatest importance for the conclusions derived:

1. Insufficient and nonrepresentative number of cases.
2. The "car" involved has meant the smallest European vehicle, as well as the big American one -- an uncontrolled parameter.
3. Insufficient consideration to the influence of the various systems, makes, and installations of belts or harnesses involved.

The primary purpose of this statistical analysis is to evaluate the effectiveness of the three-point upper torso shoulder restraint without the shortcomings mentioned above. It is considered to be a matter of course that findings and experiences derived from a representative and extensive number of real accident cases are superior to and more reliable than those of any experimental or theoretical study. To the best of the author's knowledge, the comprehensive investigation made is unique in regard to focusing attention on the combination of a specific car and a particular type of belt (Fig. 1). The cars involved throughout the collected material are of the same make and consist in practice of just two models (the Volvo P-12 and P-11) with about equal size and weight. The safety belt is the Volvo three-point safety harness. This harness is classified as type 2 in SAE J4c and Federal Register 11528 and has a combined lap and upper torso strap with a so-called slip-joint in conjunction with the buckle, which is attachable to the transmission tunnel without an intermediate short strap (Fig. 1). The fact that Volvo cars, which are not subjected to model or body changes

ABSTRACT

The value of the three-point safety belt has been evaluated by a statistical analysis of more than 28,000 accident cases, which concerned mainly two cars only and in which 37,511 unbelted and belted front-seat occupants were involved. The safety harness concerned is the Volvo three-point combined lap and upper torso harness with a so-called slip-joint. The average injury-reducing effect of the harness proved to vary between 0 and 90%, depending on the speed at which the accident occurred or the type of injury. Unbelted occupants sustained fatal injuries throughout the whole speed scale, whereas none of the belted occupants was fatally injured at accident speeds below 60 mph. Slight injuries only, mostly single rib cracks, bruises, etc., caused by the safety belt were reported in some cases. The three-point belt proved to be fully effective against ejection out of the car. Almost all cars involved were equipped with safety belts, of which, however, only 26% on an average were used. The frequency of use increased with the age of the occupants.

2981

Bohlin 1968

Nils Bohlin (1920 - 2002)

An analogy between a chlorine residual and seat belts

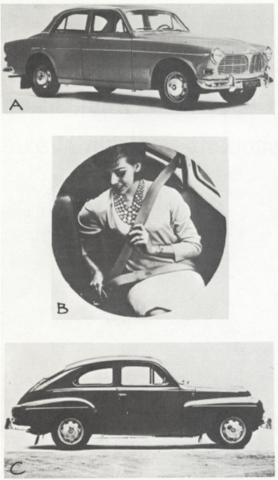


Table 2 - Number of Injuries Sustained, per 10,000
(Numbers in parentheses show actual number of cases)

	Fatal	Serious	Slight
Drivers			
Unbelted	17.2 (37)	123 (263)	388 (835)
Belted	2.9 (2)	74 (51)	255 (175)
Front-Seat Passengers			
Unbelted	18.6 (12)	249 (160)	682 (439)
Belted	3.7 (1)	82 (22)	404 (109)

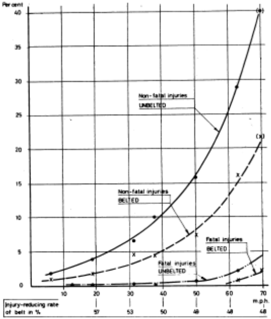
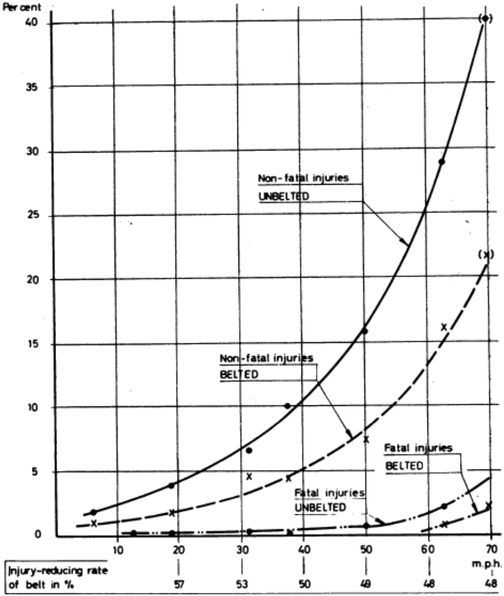


Fig. 5 - Frequency of injuries sustained by drivers in relation to accident speed

An analogy between a chlorine residual and seat belts



Chlorine Residual

Unbelted = No Chlorine

Belted = Chlorine

Contamination (e.g. sewage)

> 60 mph = > 10% v/v

Key Messages - Maintaining a chlorine residual

Regardless, proper design, operation and management is essential to protect distribution system integrity and public health. G200 compliance is a useful goal.

Chlorine provides negligible protection against protozoa, pathogens associated with major contamination, and chemical contamination.

Provides protection against contamination involving bacteria and viruses introduced via minor contamination or with significant dilution (i.e. little chlorine demand)

Unanswered questions regarding benefit of a chlorine residual may be elucidated by modelling and epidemiological studies.

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Thank You

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