# A Review of Outbreaks of Waterborne Disease Associated with Ships: Evidence for Risk Management

Roisin M. Rooney, MSc[a]
Jamie K. Bartram, PhD[a]
Elaine H. Cramer, MD, PhD[b]
Stacey Mantha, MSc[c]
Gordon Nichols, PhD[d]
Rohini Suraj, MPH[e]
Ewen C.D. Todd, PhD[f]

## SYNOPSIS

**Objective.** The organization of water supply to and on ships differs considerably from that of water supply on land. Risks of contamination can arise from source water at the port or during loading, storage, or distribution on the ship. The purpose of this article is to review documented outbreaks of waterborne diseases associated with passenger, cargo, fishing, and naval ships to identify contributing factors so that similar outbreaks can be prevented in the future.

**Methods.** The authors reviewed 21 reported outbreaks of waterborne diseases associated with ships. For each outbreak, data on pathogens/toxins, type of ship, factors contributing to outbreaks, mortality and morbidity, and remedial action are presented.

**Results.** The findings of this review show that the majority of reported outbreaks were associated with passenger ships and that more than 6,400 people were affected. Waterborne outbreaks due to Enterotoxigenic *Escherichia coli*, noroviruses, *Salmonella* spp, *Shigella* sp, *Cryptosporidium* sp, and *Giardia lamblia* occurred on ships. Enterotoxigenic *E. coli* was the pathogen most frequently associated with outbreaks. One outbreak of chemical water poisoning also occurred on a ship. Risk factors included contaminated port water, inadequate treatment, improper loading techniques, poor design and maintenance of storage tanks, ingress of contamination during repair and maintenance, cross-connections, back siphonage, and insufficient residual disinfectant.

**Conclusions.** Waterborne disease outbreaks on ships can be prevented. The factors contributing to outbreaks emphasize the need for hygienic handling of water along the supply chain from source to consumption. A comprehensive approach to water safety on ships is essential. This may be achieved by the adoption of Water Safety Plans that cover design, construction, operation, and routine inspection and maintenance.

[a]Water, Sanitation and Health Programme, Department of Protection of the Human Environment, World Health Organization, Geneva, Switzerland

[b]Vessel Sanitation Program, National Center for Environmental Health, Centers for Disease Control and Prevention, Atlanta, GA

[c]Office of Laboratory Security, Health Canada, Ottawa, Ontario, Canada

[d]Environmental Surveillance Unit, Health Protection Agency, London, U.K.

[e]U.S. Navy Environmental Health Center, Norfolk, VA

[f]National Food Safety and Toxicology Center, Michigan State University, East Lansing, MI

Address correspondence to: Roisin M. Rooney, MSc, Water, Sanitation and Health Programme, WHO, 20 Ave. Appia, Geneva 27, Switzerland 1211; tel. 41 22 791 3531; fax 41 22 791 4159; e-mail <rooneyr@who.int>.

Historically, ships have played an important role in transmitting infectious diseases around the world. Efforts to control human disease on ships can be traced back to the Middle Ages, when, in 1377, Venice and Rhodes denied access to ships carrying passengers infected with the plague and the term "quarantine" was coined.[1] Cholera pandemics in the 19th century spread mainly along trade routes, facilitated by merchant shipping.[2]

Water has been carried onboard ships since the earliest times. In pre-industrial times, water was stored in animal bladders and gourds, and on large ships in barrels.[2] Today, ships have integral water tanks and complex distribution systems. Water is also used in swimming pools and spa baths.

Safe food, water, and sanitation on vessels are crucial to the health of passengers and crew and to the shipping industry's ability to attract and retain competent employees and customers.

The purpose of this article is to provide a review of documented outbreaks of waterborne diseases associated with passenger, cargo, fishing, and naval ships. This review is designed to identify contributing factors so that similar outbreaks can be prevented in the future. This work has been carried out in the framework of the World Health Organization (WHO) project for setting guidelines for ship sanitation and is designed to provide a scientific basis for the derivation of such guidelines. This review does not cover outbreaks associated with food, which are reviewed in an accompanying article.[3] Nor does it address outbreaks of Legionnaires' disease associated with ships.

## METHODS

### Definition of waterborne diseases

Waterborne diseases result either from ingestion of contaminated water or ice, contact with water (e.g., bathing, wading, swimming, ocular exposure), or inhalation of aerosols generated from water that contains etiologic agents.[4]

Diseases acquired by ingestion are classified as:

- intoxications caused by either chemical substances or preformed toxins produced by microorganisms; these may affect the gastrointestinal tract or other organs;
- infections caused by microorganisms that produce enterotoxins (i.e., toxins that affect tissues of intestinal mucosa, usually by interfering with salt and water transport) during their growth in the intestinal tract;
- infections caused by microorganisms that invade the intestinal tract and may travel to and affect other tissues.[4]

### Study criteria

***Inclusion criteria.*** All available reports of outbreaks of waterborne disease acquired by ingestion from January 1, 1970, to June 30, 2003, and associated with a ship (i.e., passenger ship, naval ship, general cargo ship, or fishing vessel) are included. The review was not limited to any geographic area and includes reports published in peer-reviewed scientific papers, reports published on the Internet by government organizations, internal reports from government agencies, and personal communications with representatives of government agencies.

***Exclusion criteria.*** Outbreaks reported by the press or by industry, not confirmed by a public health agency, were excluded. Outbreaks reported on private sailing boats or yachts were also excluded.

### Search strategy

The search strategy for identifying studies or outbreak reports involved searching the MEDLINE, *Embase,* and *Cab Health* databases using the key words "disease outbreaks" and "ship." The bibliographies and reference list of articles identified in the electronic searches were checked for any relevant outbreak reports or studies. Government and industry websites were also searched for information on outbreaks associated with ships.

The search also included reports identified through personal communications with representatives of government institutions. Unpublished outbreaks reported to the U.S. Centers for Disease Control and Prevention (CDC) and the U.K. Communicable Disease Surveillance Centre (CDSC) were included in the database.

All reports obtained were initially examined to see if the outbreaks met the inclusion criteria. Reports were read to ensure that there was no duplication of outbreak information. In the event of duplicate information from multiple sources, the published manuscript was chosen as the reference source.

### Data extraction

For each outbreak, the information extracted included the number of people at risk as well as the numbers of those who were ill, hospitalized, and deceased; the causal agent; the type of ship; the geographic region; factors reported as contributing to outbreaks; and any remedial action taken following the outbreak.

### Categorizing levels of evidence

A method of categorizing the strength of evidence used to implicate water as a source of infection was developed for this review (adapted from Barwick et al.[5]). Waterborne disease outbreaks are classified as confirmed, probable, possible, or suspected, according to the strength of the evidence implicating water. The categories are based on the epidemiologic and water quality data provided in the outbreak report (see Figure).

## RESULTS

### Number of outbreaks and evidence implicating water as the source

Twenty-one outbreaks were included in this review. Seventeen were obtained from peer- reviewed journals, two were identified via personal communication with officials at CDC, and two were reported in non-peer-reviewed publications. Water or ice was confirmed as the source in more than half of the outbreaks (12/21; 57%). In seven outbreaks (33%), water or ice was the probable or possible source, and in two outbreaks it was the suspected source.

### Type of ship and geographic location

The majority of outbreaks were associated with passenger ships (18/21; 86%). Almost one-third of the outbreaks occurred on Caribbean cruise ships.

**Figure. Classifications for the strength of evidence implicating water as mode of transmission in ship-associated waterborne outbreaks, adapted from Barwick et al.[5]**

| *Class* | *Epidemiologic Data* | *Water-Quality Data* |
|---|---|---|
| Confirmed | Adequate:<br>(*a*) Data provided regarding exposed and unexposed persons; and (*b*) relative risk or odds ratio ≥2 or *p*-value <0.05. | Provided and adequate (historical information or laboratory data, e.g., chlorinator malfunction, no detectable free-chlorine residual, or the presence of coliforms in the water). |
| Probable | Adequate. | Not provided or inadequate. |
| Possible | Provided but limited:<br>(*a*) Epidemiologic data provided did not meet the criteria for Class I; or (*b*) the claim was made that ill persons had no exposures in common besides water, but no data were provided. | Provided and adequate. |
| Suspected | Provided but limited. | Not provided or inadequate. |

### Pathogens

Enterotoxigenic *Escherichia coli* (ETEC) was the principal pathogen and was involved in one-third of the outbreaks. Other pathogens included noroviruses (formally Norwalk-like viruses), *Salmonella* spp, *Shigella* sp, *Cryptosporidium* sp, and *Giardia* sp. One outbreak of chemical water poisoning was caused by hydroquinone. The etiologic agent was not identified in one-quarter of the outbreaks (Table 1).

### Mortality and morbidity

Information on mortality and morbidity was available in 20 outbreak reports. A total of 6,405 people were affected, with two deaths reported from two different outbreaks. The organisms associated with these deaths were *Salmonella typhi* and *Shigella flexneri* 2a.

**Table 1. Pathogens and toxins linked to outbreaks of waterborne disease associated with ships, January 1, 1970–June 30, 2003**

| *Organism/toxin* | *Number of outbreaks* | *Number of passengers and crew members affected* |
|---|---|---|
| Enterotoxigenic *Escherichia coli* | 7 | 2,917 |
| Norovirus | 3 | 788[a] |
| *Salmonella typhi* | 1 | 83 |
| *Salmonella* spp | 1 | 292 |
| *Shigella* sp | 1 | 690 |
| *Cryptosporidium* sp | 1 | 42 |
| *Giardia lamblia* | 1 | 200 |
| Unknown agent | 5 | 849 |
| Chemical water poisoning | 1 | 544 |
| Total | 21 | 6,402 |

[a]Two outbreaks

### Factors contributing to outbreaks

Contributing factors were reported in 17 outbreaks (81%) and included contaminated port water loaded onto the ship, defective storage tanks, cross-connections at loading, inadequate residual disinfection, and defective backflow preventers (Table 2). More than one factor may have contributed to each of the outbreaks reported. The main contributing factors are summarized for each pathogen in Table 3.

## DISCUSSION

This review has shown that more than 6,400 people were affected in 21 reported outbreaks that occurred from January 1, 1970, through June 30, 2003. The number of reported outbreaks of waterborne diseases associated with ships is likely to be a small fraction of the total number, as the majority of outbreaks are unlikely to be published in the scientific literature or reported to public health authorities. Even when incidents are reported to the appropriate officials, only a small percentage of outbreak reports are published in detail. Some outbreaks that affect a small percentage of passengers or crew on a given ship may go undetected.

Most of the outbreaks reported in the scientific literature were from countries that have routine infectious disease surveillance and outbreak response to such incidents. These reports are, therefore, confined to specific geographic regions.

The number of passenger days spent on ferries worldwide is likely to be at least that spent on cruise ships, and the risk factors and exposures for cruise ships and ferries are likely to be similar. The complete absence of ferries from reported outbreaks is probably due to the short duration of time on board relative to the incubation period of diseases. Thus, if an outbreak were to occur, the affected individuals would likely arrive at a destination port and disperse before symptoms develop.

Outbreaks aboard cargo vessels are likely to be underreported for different reasons. These outbreaks often involve small numbers of crew members and may not be reported because of fear of quarantine or delays at port.

**Table 2. Main factors contributing to ship-associated waterborne outbreaks, January 1, 1970–June 30, 2003**

| *Main factor contributing to outbreak* | *Bacterial* | *Viral* | *Protozoa* | *Unknown* | *Chemical* | *Total* |
|---|---|---|---|---|---|---|
| Water uplifted from unsafe source | 4 | 1 | 2 | 0 | 0 | 7 |
| Inadequate residual disinfection | 1 | 0 | 0 | 0 | 0 | 1[a] |
| Water tank contaminated by sewage or bilge | 2 | 1 | 0 | 0 | 0 | 3 |
| Inadequate treatment of source water | 1 | | | | | 1 |
| Potable water contaminated by seawater | 1 | 0 | 0 | 0 | 0 | 1 |
| Distilled water not chlorinated | 1 | | | | | 1 |
| Defective back-flow preventers | 0 | 1 | 0 | 0 | 1 | 2 |
| Cross-connection between potable and non-potable water/liquids | 0 | 0 | 0 | 1 | 0 | 1 |
| Outbreaks with no reported contributory factors | 0 | 0 | 0 | 4 | 0 | 4 |
| Total | 10 | 3 | 2 | 5 | 1 | 21 |

[a]Inadequate residual disinfection was reported as a secondary contributing factor in seven additional outbreaks.

**Evidence associating outbreaks with water**

The majority of outbreaks reviewed had considerable epidemiologic and water quality information to implicate water as the source of infection. The weight of evidence is strong in this environment because ships are self-contained, which facilitates comprehensive epidemiologic investigations. Passengers and crew members report illness to one medical facility, which helps to centralize the collection of relevant data. Case patients and contacts are generally available for interviews, and it is usually possible to collect clinical and environmental samples in a timely fashion. Sources of contamination are usually easier to trace than in community outbreaks because of the availability of documentation and records. The categorization system used showed that water was suspected as the source in only two outbreaks. Thus, this review provides much reliable information on the etiological agents and factors contributing to outbreaks. This evidence is needed to inform decisions on preventive measures.

**Water aboard ships vs. water onshore**

The organization and mechanics of water distribution from shore facilities to ships and onboard ships differ considerably from water distribution on land. Even though a port authority may receive potable water from a safe municipal supply, it usually has special arrangements for managing the water after it has entered the port. Water is delivered to ships by hoses on the dockside or transferred to ships by water boats or barges. Water boats and barges are vessels specially constructed and equipped to provide potable water aboard ships under conditions where direct shore delivery is not practicable. These craft are equipped with independent potable water tanks, water hoses, pumps, and independent pipe systems to provide potable water to ships. In contrast to shore facilities, plumbing aboard ships consists of numerous piping systems carrying potable water, seawater, sewage, and fuel, fitted into a relatively confined space. Piping systems are normally extensive and complex, making them difficult to inspect and maintain.

Water loading (i.e., transfer of water by hose from shore or water barge to ship) can offer distinct possibilities for microbial contamination. On board it may be difficult to prevent water quality deterioration in distribution due to the complex physical infrastructure of the ship. For example, loaded water may be mixed with water generated on board by reverse osmosis or distillation. Distribution may also provide greater opportunities for contamination to occur than onshore because ship movement increases the possibility of surge and back-siphonage.

The assessment of risks along the water supply chain is difficult because of insufficient epidemiologic evidence. However, from the analysis of outbreaks, there is evidence of microbial risks associated with contaminated port water, improper loading techniques, poor design and maintenance of storage tanks, ingress of contamination during repair and maintenance, cross-connections, back siphonage, inadequate treatment, and insufficient residual disinfectant.

**Hazards associated with water obtained from an unsafe source**

The International Health Regulations of 1969, which are presently in revision, stipulate that ports should supply safe potable water for ships.[6] Water suppliers, including those who operate water boats and barges, should provide water of a quality in line with the recommendations in the WHO *Guidelines for Drinking-Water Quality* (third edition).[7] However, some ports supply contaminated water to ship operators. Contaminated port water was responsible for a number of outbreaks due to ETEC, noroviruses, *Giardia lamblia,* and *Cryptosporidium* and, in the majority of these outbreaks, the source of the infection was confirmed.[8–12] In some instances, multiple ETEC serotypes were identified, indicating possible sewage contamination of source water.[8,9]

To avoid these outbreaks, the ship's master or engineer must take into account the quality and nature of source water before loading. Major cruise and ferry lines may choose to directly engage with port and local authorities to investi-

**Table 3. Pathogens/toxins with associated contributing factors for ship-associated waterborne outbreaks, January 1, 1970–June 30, 2003**

| *Pathogen/disease* | *Number of outbreaks* | *Contributing factors* |
|---|---|---|
| Enterotoxigenic *E. coli* | 7 | • Contaminated source water loaded onto the ship. (Four outbreaks: water was confirmed source in three, probable source in one.)<br>• Failures in disinfection systems. (Three outbreaks: two confirmed, one suspected.)<br>• Seepage of contaminated bilge water through inspection cover of a potable water tank. Inadequate disinfection. (Water confirmed source.)<br>• Freshly distilled water not chlorinated. (Water probable source). |
| Norovirus | 3 | • Defective backflow preventers on ice machine. (Water confirmed source.)<br>• Bilge water sometimes covered the suction line from one of the potable water storage tanks and may have been the source of the contamination. (Water confirmed source.)<br>• Contaminated loaded water. (Water confirmed source.) |
| *Salmonella typhi* | 1 | Sewage may have contaminated the drinking water tanks during drydocking and repair. Subsequent partial disinfection failed to eliminate the pathogen. (Water confirmed source.) |
| *Salmonella enteritidis* | 1 | Pathogen detected in water. Manner in which the water system became contaminated not clearly established. Circumstantial evidence suggested that the water might have been loaded directly into the potable water tanks, bypassing the disinfection system. (Water suspected source.) |
| *Shigella flexneri* | 1 | Potable water contaminated during loading process by seawater in the fire system. The water chlorination system aboard the vessel was inadequate to disinfect the contaminated water. (Water confirmed source.) |
| *Cryptosporidium* sp | 1 | Ship filled water tanks with contaminated water during a large community outbreak. Water not treated after loading. (Water confirmed source.) |
| *Giardia lamblia* | 1 | Contaminated loaded water from an unknown source. Inadequate disinfection. (Water probable source.) |
| Chemical water poisoning (hydroquinone) | 1 | A cross-connection was detected between the potable water system and a photo developer mixing tank. A previous shutdown in the water supply resulted in negative pressure in the line and facilitated the introduction of developing fluid into the potable water system. Defective backflow preventer on photocopier. (Water confirmed source.) |
| Unknown etiology | 1 | Cross-connection between potable and non-potable water storage tanks. Inadequate disinfection. (Water confirmed source.) |
| Unknown etiology | 4 | Deficiencies in water management reported during routine inspection of vessels. (Water possible source.) |
| Total | 21 | |

gate levels of safety. Vessels using irregular ports, where water treatment may be unreliable, may carry equipment for basic testing (turbidity, pH, chlorine residual, fecal indicator bacteria).

If a water source is suspected of being unsafe, extra treatment, e.g., superchlorination and/or filtration, may be needed to ensure the safety of the water. The intensity of treatment should depend on the degree of contamination of the source water. Multiple barrier treatments (e.g., chlorination, filtration, UV radiation) can give a high degree of protection and reduce the reliance on any individual treatment step.[13] However, loading water from an approved water source is always a better alternative to treating contaminated water. Ships could also generate their own water by reverse osmosis or distillation at sea, provided this water complies with the WHO *Guidelines for Drinking-Water Quality*.[7]

**Hazards associated with loading and transfer to ship**

Ingress of contaminated seawater into potable water tanks during loading was responsible for an outbreak of shigellosis that affected 690 people on a ship.[14] The potential for error was discovered during the outbreak investigation, when it was observed that potable water from a pier was routinely used to wash the decks. This potable water was connected to the ship's fire fighting system—a system normally containing seawater. Crew members, after washing the decks, could then connect a hose from a fire hydrant to an adjacent air relief vent of a potable water holding tank. In this way, any non-potable and potentially contaminated seawater remaining in the fire line could get into the tank.

This outbreak underscores the need to ensure that non-potable water, if used on a ship, is passed through a completely different piping system from potable water and that

the fittings used are incompatible with potable water fittings. Potable water hoses should be designed exclusively for the delivery of potable water and should have unique fittings. They should be handled with care to prevent contamination and should be properly labeled so that they are not used for any other purpose. It is important that crews are trained in and understand proper water handling procedures for loading and disinfecting water. Particular attention should be paid to flushing the hoses, disinfecting the loading points, and keeping the hoses clean and capped.

**Hazards associated with storage of water on ships**

A number of outbreaks were caused by contamination of potable water after it had been loaded onto a ship. Water can become contaminated onboard a ship by sewage or bilge if the water storage or waste disposal systems are not adequately designed and constructed. In one outbreak due to ETEC, bilge water could have seeped through the inspection cover of a potable water tank; this bilge water may have contained sewage.[15] Contaminated seawater could also have entered the tank whenever there was a lower pressure in the tank than in the surrounding seawater, most likely when the ship approached port. This outbreak may have been prevented if the potable water tanks were designed to be above (never immersed in) bilge water and if all covers were sanitary (protected against splash ingress) and not amenable to interference.

In one outbreak of gastroenteritis due to a norovirus, bilge water occasionally covered the suction line from one of the potable water storage tanks.[16] Ship designers and operators should pay special attention to piping installed in the bilge area, particularly the piping on the suction side of potable water pumps. It is critical that bilge water is maintained at a level below the suction lines of potable water tanks.

**Hazards due to back siphonage and cross-connections**

When potable water is delivered to non-potable systems and supplied under pressure, the system should be protected against backflow by either backflow preventers or air gaps. If backflow preventers are defective, ingress of contaminants into the distribution system cannot be prevented if negative pressure arises.

One outbreak of viral gastroenteritis was associated with contaminated ice from a machine that did not have an appropriate backflow preventer.[17] Inspection revealed that the ice machine could have been contaminated by sewage backup. Another outbreak occurred as a result of backflow of the chemical hydroquinone into the potable water system.[18] This outbreak occurred due to a cross-connection between the potable water system and a photo developer mixing tank. A previous shutdown in the water supply had resulted in negative pressure in the line and facilitated the introduction of developing fluid into the potable water system.

Proper installation of backflow preventers or other safety devices is necessary to prevent localized contamination of water or ice. These devices should be checked on a regular basis and repaired or replaced if necessary. They should be located in areas where they may be easily inspected, serviced, and maintained.

In one outbreak of gastroenteritis of unknown etiology, non-potable water could have mixed with potable water in storage tanks through a common manifold.[19] This water was supplied to the galley, bar, bakery, and ice machines. This outbreak highlights the danger of local cross-connections between potable and non-potable water during storage, and emphasizes the importance of correct design of storage tanks on a ship to ensure that potable and non-potable water do not mix.

Potable water distribution lines should not be cross-connected with the piping of any non-potable water system. In one outbreak of gastroenteritis of unknown etiology, non-potable water could have mixed with potable water in storage tanks through a common manifold. It is preferable that the piping of the potable water system is marked for easy identification. Regular checks should be carried out for cross-connections, leaks, and defective pipes.

**Hazards associated with repair and maintenance**

Regular repair and maintenance is important to ensure that water quality is not compromised. However, if repairs are not carried out correctly, they can pose their own threats. For example, an outbreak of typhoid on a ship occurred after the potable water was contaminated with excreta while the ship underwent repairs in dry dock.[20] Massive contamination of the potable water tanks with sewage was suspected. This outbreak underlines the risk of gross contamination of the potable water supply during repair and maintenance and the need for good hygienic practice and post-repair disinfection. Ship builders/rehabilitators should have documented procedures in place for physical cleaning and disinfection before commissioning/recommissioning ships as well as for dry dock repair.

**Hazards associated with insufficient residual disinfection**

Many reports of outbreaks of waterborne disease on ships identified inadequate residual disinfection as a contributing factor. This problem was cited as a contributory factor in eight outbreaks examined in this review.[8,14,15,19,20] Most of these outbreaks also had other underlying contributing factors.

Residual disinfection should not be relied on to "treat" contaminated water. It is usual to add a disinfectant residual to maintain the quality of the water in the distribution system and to kill low levels of some pathogens that may gain entry to the network. A residual disinfectant can provide a measure of ongoing safety, but it does not always eliminate infectious agents in source water or water that has been recontaminated on board a ship. Low levels of residual disinfectant are easily overcome by gross contamination.[13] For example, an outbreak due to ETEC occurred on a cruise ship in 2002. The source water was heavily contaminated with fecal material, and the pathogen survived in the distribution system despite the presence of a residual disinfectant.[9] Another outbreak of waterborn giardiasis occurred on a naval ship in 1998. Chlorine residuals were reported to have been "at least trace," and no additional treatment of

the water was carried out on board the ship.[11] Parasites such as *Cryptosporidium* spp and *Giardia lamblia* are particularly resistant to chlorine disinfection.[13] If water is suspected of being contaminated, other treatment, e.g., filtration capable of removing micron-size particles, could provide an extra barrier.[13]

Disinfectants such as chlorine should be proportionally dosed according to the water quantity loaded.[21] Automatic disinfection is usually more reliable than manual chlorination. It is essential that chlorine-dosing drums be regularly checked to ensure that they are filled with sufficient disinfectant. Loss of chlorine residual in distribution could also indicate contamination (intrusion). The chlorine levels in the water should be monitored frequently, and if they decrease, the reason for the decline or the source of the contamination should always be investigated. All crew members inspecting drums and pumps should be trained to identify faults that may occur, and all observations should be recorded. Lessons learned from outbreaks include the need to assign explicit responsibility for disinfectant residual testing.

## CONCLUSIONS AND RECOMMENDATIONS

Twenty-one waterborne outbreaks associated with ships were examined in this review. More than 6,400 people were affected during the period from January 1, 1970, through June 30, 2003. This is probably an underestimate of the true number, as many outbreaks are not reported and many reports are not published.

This review has captured diverse factors that have contributed to outbreaks. This information is useful in identifying hazards and control measures needed to prevent future outbreaks. The hazards include bacterial, viral, and protozoal agents. Current control measures do not appear to be adequate. Many of the outbreaks reviewed could have been prevented if the following measures had been taken:

- Water uplifted from safe, reliable sources at port;
- Extra treatment of water (e.g., filtration, disinfection) if water is suspected of being contaminated;
- Proper loading of water at port, with particular care to avoid cross-connections;
- Routine monitoring of residual disinfectants in distribution systems;
- Regular inspection and maintenance of potable water systems, including storage tanks, distribution pipes, and backflow preventers;
- Adequate training and supervision of crew assigned to these tasks.

Although sampling can verify that water is safe, it is not suitable for early warning or control purposes. Results may be confounded by the use of a residual disinfectant; thus sanitary inspections are necessary complementary activities. A comprehensive approach to water safety on ships is essential. This can be achieved by the adoption of Water Safety Plans (WSPs) to cover design, construction, operation, and routine inspection and maintenance.[7] WSPs build on the Hazard Analysis Critical Control Point approach, which has gained the approval of the food industry for controlling food quality.[22]

The three essential elements of WSPs are:[7]

(*1*) System assessment to determine whether the water supply chain (up to the point of consumption) as a whole can deliver potable water;

(*2*) Operational monitoring of the steps in the supply chain that are of particular importance in securing water safety;

(*3*) Management plans describing actions to be taken under normal and incident conditions, i.e., corrective action and verification.

Through identifying control measures in the water supply chain and setting operational limits, a monitoring system can be set up for each control point to ensure that correct procedures are maintained and action taken if operational limits are not achieved. Periodic sanitary surveys of the loading, storage, and distribution of water; residual chlorine tests; and checks for defective back-flow preventers and leaking pipes are an important part of any WSP. The chief advantage of a WSP is that it is proactive; it aims to prevent problems from occurring so that water safety on ships can be easily managed and outbreaks of waterborne disease prevented.

The WHO *Guide to Ship Sanitation*[23] is the official global reference on health requirements for ship construction and operation and is directly referenced in Article 14 of the1969 International Health Regulations.[6] Its purpose is to standardize the sanitary measures taken on ships, to safeguard the health of travelers, and to prevent the spread of infection from one country to another. The *Guide* was first published in 1967 and was reprinted with minor amendments in 1987. The construction, design, and size of ships have changed dramatically since the 1960s and new hazards (e.g., *Cryptosporidium*) were not foreseen when the *Guide* was first published. Therefore, WHO is updating the *Guide* in close collaboration with the shipping industry and collaborating Member States for the IHR. It has been proposed that the revised *Guide* be based on a critical review of available evidence, including the outbreaks discussed in this review.

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Any opinions, findings, conclusions and recommendations expressed in this article are those of the authors and do not necessarily reflect the official views of their institutions.

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