MAJOR ARTICLE

A Waterborne Outbreak of Gastroenteritis with Multiple Etiologies among Resort Island Visitors and Residents: Ohio, 2004

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Background. The implementation of treated municipal water systems in the 20th century led to a dramatic decrease in waterborne disease in the United States. However, communities with deficient water systems still experience waterborne outbreaks. In August 2004, we investigated an outbreak of gastroenteritis on South Bass Island, Ohio, an island of 900 residents that is visited by >500,000 persons each year.

Methods. To identify the source of illness, we conducted a case-control study and an environmental investigation. A case was defined as diarrhea in a person who traveled to the island during the period from May 1 through 30 September 2004 and became ill within 2 weeks after the visit. Healthy travel companions served as matched control subjects. We also performed an environmental assessment and extensive testing of island water sources.

Results. Among the 1450 persons reporting illness, *Campylobacter jejuni*, norovirus, *Giardia intestinalis*, and *Salmonella enterica* serotype Typhimurium were identified in 16, 9, 3, and 1 persons, respectively. We interviewed 100 case patients and 117 matched control subjects. Case patients were more likely to drink water on the island than control subjects (68% vs. 35%; matched odds ratio, 4.3; 95% confidence interval, 2.2–9.3). Sampling of ground water wells indicated contamination with multiple fecal microbes, including *Escherichia coli*, *C. jejuni*, *Salmonella* species, and *Giardia* species. Irregularities in sewage disposal practices that could have contaminated the underground aquifer were noted.

Conclusions. The combined epidemiological and environmental investigation indicated that sewage-contaminated ground water was the likely source of this large outbreak. Long-term changes to the island's water supply and sewage management infrastructure are needed.

The provision of treated drinking water has led to a dramatic decrease in waterborne disease in many regions of the world [1]. However, the availability of a safe drinking water supply and effective sewage disposal cannot be taken for granted in the United States. During 2001–2002, a total of 31 outbreaks of infection associated with drinking water were reported to the Centers for Disease Control and Prevention (CDC; Atlanta, GA) by 19 states. These outbreaks caused illness in an estimated 1020 persons, resulting in 51 hospitalizations and 7 deaths [2].

In many rural communities, groundwater from wells may be the only feasible drinking water source [3]. Many rural waterborne disease outbreaks have been associated with groundwater sources [4–8]. Ensuring the integrity of rural drinking water supplies from ground water wells requires, among other things, proper well construction, maintenance, and management and consideration of the underlying hydrogeology [9, 10]. Certain soil and geologic conditions, such as karst limestone hydrogeology, significantly increase the

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vulnerability of ground water resources to contamination.

We describe the investigation of a large waterborne outbreak of gastroenteritis that occurred on South Bass Island, a resort island on Lake Erie, Ohio. We characterize the illnesses that occurred among island visitors and residents, describe the risk factors for illness, and summarize the environmental findings.

METHODS

Epidemiologic investigation. On 18 August 2004, the Ohio Department of Health (ODH; Columbus OH) and the Ottawa County Health Department (Port Clinton, OH) invited the CDC to assist with the investigation of an outbreak of gastroenteritis associated with travel to South Bass Island, Ohio.

Case-finding was enhanced by a health alert to local health departments and hospitals; a posting on the CDC's Web-based communications network (Epi-X), CDC posting to epidemiologists in all US states (through an e-mail listserv), Canada, and Enter-net (international surveillance network); and regular press releases that encouraged persons to report illness after visiting South Bass Island via toll-free call-in lines.

All persons who reported illness were interviewed by telephone using a standard questionnaire [11], modified to include water exposure. A suspected case was defined as gastrointestinal illness in a resident of South Bass Island with onset of symptoms during the period from 30 May through 8 September 2004 or in a visitor to South Bass Island from 1 May to 30 September 2004, with onset of symptoms from 30 May to 8 September 2004 and within 2 weeks after visiting the island. A confirmed case patient was defined as a suspect case patient in whom an enteric pathogen was identified in the stool specimen.

To develop hypotheses, investigators reviewed case reports and conducted in-depth interviews by telephone. Contaminated water was strongly suspected as the vehicle of illness on the basis of size of the outbreak, the range of pathogens involved, information gathered on initial interviews with patients, and the review of recent results from water testing. To test this hypothesis, a matched case-control study was performed during the period from 30 August through 7 September 2004.

For the case-control study, a case was defined as diarrhea ($\geqslant$3 loose stools in a 24-h period) in a person who (1) traveled to South Bass Island during the period from 1 May to 30 September 2004 for a single visit of 1–7 days' duration, (2) had onset of symptoms during the period from 30 May to 8 September 2004, (3) developed symptoms within 2 weeks after visiting the island, and (4) had no contact with another person with gastrointestinal illness in the week before the onset of illness.

A control subject was defined as a person who had accompanied a case patient on a visit to South Bass Island during the period from 1 May to 30 September 2004 for a single visit of 1–7 days duration and did not develop subsequent gastrointestinal illness. One to 3 control subjects were enrolled per case patient.

For the case-control study, we attempted to enroll all visitors who had laboratory-confirmed illness and had no contact with another person with gastrointestinal illness. In addition, we generated a random selection of patients from a list of visitors to the island reporting illness to enable enrollment of 100 cases in the case-control study. Control subjects were healthy travel companions of each specific case patient with whom they had traveled to the island. The number of control subjects per case patient was dependent on how many persons who did not become ill had traveled to the island with each case.

Case patients and control subjects were interviewed by telephone and asked about drinking water exposures, recreational water exposure, and consumption specific food items. Case patients were also asked about their history of illness.

Environmental investigation. The environmental investigation involved the Ohio Environmental Protection Agency (Columbus and Bowling Green, OH), the ODH, the Ottawa County Health Department, the Ohio Department of Agriculture (Reynoldsburg, OH), and the National Center for Environmental Health at the CDC.

The village of Put-In-Bay on the island was supplied with chlorinated surface water from Lake Erie (municipal supply). Businesses in the village used auxiliary ground water wells for geothermal heating and cooling, flushing toilets, and outdoor cleaning. All other locations outside the village used water supplied by public (serving $\geqslant$25 people) or private (serving $<$25 people) ground water wells. The sewage treatment facility discharges into Lake Erie. Many residents and businesses outside the village use septic tank systems for sewage disposal. All of these water and waste systems were investigated, and auxiliary wells were inspected for cross-connections to the municipal supply.

Pre- and postchlorination ground water and municipal water, water from Lake Erie, and ice from >90 locations were tested. Samples were analyzed for total coliforms, *Escherichia coli*, *Campylobacter* species and *Salmonella* species. Processed enrichment broths from water sampling analyses were forwarded to the CDC for pathogen identification. Suspect and confirmed *Campylobacter* environmental isolates were sent to the CDC for confirmation and further characterization, such as speciation and molecular subtyping by PFGE [12, 13].

Fifty-liter water samples were also collected by the National Center for Environmental Health from randomly selected locations. Water samples were concentrated to ~200 mL using ultrafiltration membranes with a molecular weight cut-off of ~30,000 daltons [14]. Samples were sent to the National *Campylobacter* and *Helicobacter* Reference Laboratory and the Water and Environmental Projects Laboratories at the CDC for analysis. Samples were analyzed for fecal coliforms, *E. coli, Clos-*

tridium perfringens, Campylobacter species, *Salmonella* species, norovirus, enterovirus, adenovirus, coliphages, *Cryptosporidium* species, and *Giardia* species. Conventional culture methods, microscopy, and molecular methods, including PCR and PFGE, were used for detection and subtyping of microorganisms. PCR was performed to assay samples for *Salmonella* species, *G. intestinalis, Cryptosporidium* species, and adenovirus. RT-PCR was performed to test samples for enterovirus and norovirus (GI and GII).

An environmental assessment performed by the ODH included an evaluation of the ground water geology of the island, the quality of the ground water, and land use practices [15].

Laboratory investigation of patients. Stool specimens were tested for norovirus, *Salmonella* species, *Shigella* species, *Campylobacter* species, *E. coli* O157, *Giardia* species, and *Cryptosporidium* species. Specimens were examined at the ODH public health laboratory.

Three clinical specimens were tested at the CDC for enterotoxigenic *E. coli* and Shiga-toxin producing *E. coli* by PCR. The *Campylobacter* isolates were forwarded to the CDC for speciation confirmation; PFGE subtyping was completed at the ODH public health laboratory and the CDC. Three clinical *Campylobacter* isolates were tested for antimicrobial susceptibility at the National Antimicrobial Resistance Monitoring System laboratory. The Etest method (AB Biodisk) was used to determine the MICs for 8 antimicrobial agents (azithromycin, chloramphenicol, ciprofloxacin, clindamycin, erythromycin, gentamicin, nalidixic acid, and tetracycline).

Statistical analysis. Statistical analysis was performed using EpiInfo, version 6.04 (CDC), and SAS software, version 9.0 (SAS Institute). ORs, matched ORs (mORs), and 95% CIs were computed in a bivariate analysis. We used a conditional (matched) logistic regression model to examine the dose-response relationship.

RESULTS

Epidemiologic and clinical information. During the period from 30 May through 8 September 2004, a total of 1450 residents of or visitors to South Bass Island reported a gastrointestinal illness. Twenty one patients (1%) were hospitalized, and no deaths were reported (table 1). Most case patients had symptom onset during the first week of August (figure 1).

One thousand two hundred seventeen patients (84%) were Ohio residents; the remainder came from 25 additional US states, Canada, and England. Sixty-one percent were female. The median age was 40-years-old. Symptoms reported by patients included diarrhea (83%), abdominal cramps (80%), nausea (77%), vomiting (50%), fever (45%), and bloody diarrhea (5%). The median duration of illness was 4 days (range, 1–52 days) (table 1).

One hundred case patients, including 8 (8%) with confirmed infections, and 117 control subjects were enrolled in the case-control study. Several water exposures were associated with illness (table 2). Case patients were more likely than control subjects to drink tap water on the island (68 [68%] vs. 41 [35%]; mOR, 4.3; 95% CI, 2.2–9.3). The same proportion of case patients and control subjects (37%) drank commercially bottled water on the island. However, case patients were more likely to drink from a water bottle filled with tap water on the island (19 [19%] vs. 7 [6%]; mOR, 6.0; 95% CI, 1.6–30.0) (table 2).

Illness was strongly associated with consuming drinks containing ice on the island (72 [73%] vs. 62 [53%]; mOR, 7.1; 95% CI, 2.2–25.5). Fountain drinks, crushed ice drinks, and hot drinks prepared from either a well water source or from the municipal water supply were not significantly associated with illness (table 2).

Using a conditional (matched) logistic regression model, a significant dose-response effect for drinking tap water on the island was also evident. Consumption of increased amounts of tap water on the island was associated with increased odds of becoming ill (table 3). People who drank >6 cups of tap water on the island were 65 times more likely to become ill than those who did not drink any water on the island (15 [15%] vs. 2 [2%]; mOR, 64.7; 95% CI, 5.4–778.0) (table 3).

Table 1. Demographic and clinical information for 1450 patients reporting gastrointestinal illness to Ottawa County Health Department, Ohio, 30 May–8 September 2004.

Characteristic	Patients reporting gastrointestinal illness (n = 1450)
Island resident	25 (2)
Ohio resident	1217 (84)
Female sex	884 (61)
Age, median years (range)	40 (<1 to 83)[a]
Age <5 years	48 (3)[a]
Duration of illness	
Median days (range)	4 (1–52)
≤2 days	312 (27)[b]
>2 days	833 (73)[b]
Symptom	
Diarrhea	1199 (83)
Abdominal cramps	1162 (80)
Nausea	1110 (77)
Vomiting	728 (50)
Fever	650 (45)
Bloody diarrhea	66 (5)
Sought medical care	114 (8)
Hospitalization	21 (1)
Death	0 (0)

NOTE. Data are no. (%) of patients, unless otherwise indicated.

[a] For 1395 cases with age information.

[b] For 1145 cases with information on duration of illness.

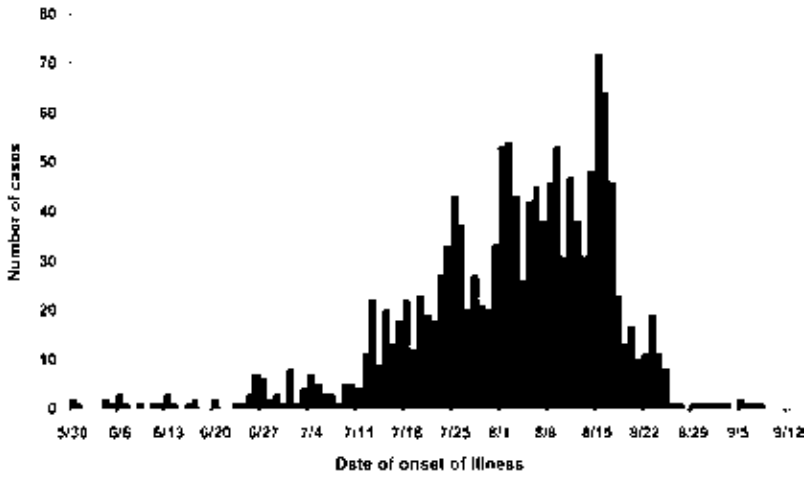

Figure 1. Cases of gastroenteritis, by date of illness onset, from 30 May through 8 September 2004, South Bass Island, Ohio ($n = 1450$)

There was no single location where all the case patients drank tap water. Water was classified at each location as either well water or municipal water, depending on the source. When stratified by water source, both well water (34 [46%] vs. 17 [19%]; mOR, 4.7; 95% CI, 1.9–17.6) and municipal water (49 [53%] vs. 24 [22%]; mOR, 8.2; 95% CI, 2.9–25.3) appeared to be associated with illness.

Contact with lake water, swimming in any pool, and the specific food items of interest were not significantly associated with illness.

Environmental investigation. The environmental investigation documented that the municipal water treatment facility on the island was functioning properly. Cross-connections from auxiliary wells to the municipal water supply were identified and eliminated by the Ohio Environmental Protection Agency.

Sixty (76%) of 79 private wells on the island tested positive for total coliforms, and 24 (30%) of 79 tested positive for *E. coli*. Seventeen (100%) of 17 businesses with noncommunity public wells had water samples that tested positive for total coliforms, and 12 businesses had samples that tested positive for *E. coli*. *Campylobacter jejuni* was cultured from 1 public water supply well. Sixteen of these 17 businesses were issued no-use orders on their wells by the Ohio Environmental Protection Agency as a consequence of sampling results. The enteric viral indicators of fecal contamination, somatic coliphages, and F-specific coliphages were detected in well-water samples, as was the spore-forming bacterial indicator of fecal contamination, *C. perfringens*. In addition to *C. jejuni,* several other human pathogens were detected in well-water samples using PCR: *Salmonella* species, *Cryptosporidium* species (and, specifically, *Cryptosporidium hominis*), adenovirus, and enterovirus. A single *Giardia intestinalis* cyst was observed in 1 well-water sample but was not confirmed by molecular analysis.

The geology of the island is such that wells receive ground water from a karst aquifer, consisting of fractured limestone, sinkholes, and underground caves (figure 2). This type of aquifer is very vulnerable to contamination. The environmental assessment demonstrated that contamination of the karst aquifer beneath the island had occurred from multiple land uses such as onsite septic systems, land application of septage, infiltration of land run-off, and, possibly, a direct hydraulic connection with Lake Erie [15].

Laboratory investigation of patients. The ODH laboratory tested 70 stool specimens for bacterial pathogens, 62 whole stool specimens for norovirus, and 67 stool specimens for parasitic agents. *C. jejuni* was identified in stool specimens obtained from 16 persons experiencing illness, norovirus in 9, *G. intestinalis* in 3, and *Salmonella enterica* serotype Typhimurium in 1. Two patients with confirmed *C. jejuni* infection were household contacts of other case patients infected with *C. jejuni*.

The clinical specimens tested for enterotoxigenic *E. coli* and Shiga-toxin producing *E. coli* were all found to be negative. The clinical isolates sent to the CDC were identified as *C. jejuni*. Five *C. jejuni* isolates were subtyped by PFGE, and the resulting PFGE tif images were uploaded to the National Molecular Subtyping Network for Foodborne Disease Surveillance (PulseNet) for comparison. Four isolates were indistinguishable by *Sma*I and *Kpn*I PFGE; 1 isolate had a different PFGE pattern. The PFGE pattern of the *C. jejuni* strain isolated from a raw well-water sample differed from those of the clinical isolates.

All 3 *C. jejuni* clinical isolates were susceptible to the 8 antimicrobial agents tested, with the exception of 1 isolate that showed intermediate resistance to erythromycin.

DISCUSSION

We describe a large outbreak of gastroenteritis with multiple etiologies among visitors to and residents of South Bass Island,

Table 2. Bivariate analysis of drinking water exposure among 100 case patients and 117 matched control subjects, South Bass Island, Ohio, 2004.

Exposure	Case patients (n = 100)	Control subjects (n = 117)	mOR (95%CI)	P
Drank tap water	68 (68)	41 (35)	4.3 (2.2–9.3)	<.001
Drank tap water from a well[a]	34 (46)	17 (19)	4.7 (1.9–17.6)	<.001
Drank municipal tap water	49 (53)	24 (22)	8.2 (2.9–25.3)	<.001
Drank commercial bottled water	37 (37)	43 (37)	1.0 (0.5–2.3)	.90
Drank water bottle filled on island	19 (19)	7 (6)	6.0 (1.6–30.0)	.005
Drank a fountain drink	37 (37)	41 (35)	1.2 (0.6–2.6)	.70
Drank a crushed ice drink	20 (20)	16 (14)	1.4 (0.6–3.3)	.50
Drank a drink with ice	72 (73)	62 (53)	7.1 (2.2–25.5)	<.001
Drank a hot drink[a]	9 (9)	10 (9)	1.1 (0.3–3.3)	.90
Drank other type of drink[a]	72 (74)	87 (76)	0.9 (0.3–2.2)	.90

NOTE. Data are no. (%) of subjects, unless otherwise indicated. mOR; matched OR.

[a] Seventy-four case patients and 90 control subjects drank water form a well, 108 control subjects drank a hot drink, and 98 case patients and 115 control subjects drank other types of drinks.

Ohio, caused by fecal contamination of the ground water aquifer. Outbreaks that affect many people and involve multiple etiologies are characteristically associated with sewage contamination of water supplies [5–8, 16–18]. The findings of the outbreak investigation indicate that contaminated drinking water was the source of illness. Drinking tap water on the island was strongly associated with illness. Furthermore, a significant dose-response effect was observed, with the association between becoming ill and drinking tap water increasing as the volume of water consumed increased. Results of the environmental investigation supported these findings, because many ground water wells were found to harbor multiple bacterial indicators of fecal contamination.

In the epidemiologic investigation, both well water and municipal water were found to be associated with illness. However, the epidemiologic study design limited our ability to differentiate the association of well water versus municipal water sources; control subjects were travel companions who usually went to the same places with their matched case patient, thus essentially matching on water source. Furthermore, there may have been misclassification of the drinking water sources, because many businesses in the village of Put-In-Bay that had auxiliary wells were found to have cross-connections to the municipal supply. These cross-connections represented a possible source of contamination of the municipal supply. Thus, the investigation could not convincingly demonstrate whether the risk was from well water, municipal water, or both. However, the results of the environmental investigation consistently showed contamination of the ground water being supplied to wells on the island. Episodic contamination of the municipal system cannot be ruled out, particularly in light of the multiple cross-connections to auxiliary wells.

The epidemiologic investigation suggests multiple ongoing points of exposure to contaminated water, and the environmental assessment found widespread contamination of the aquifer, because many wells from various locations on the island showed evidence of contamination [15, 19]. In addition, an illegal sewage disposal site on the center of the island was uncovered during the investigation, where untreated sewage from residential homes and businesses had for years been dumped into a sinkhole leading to the ground water aquifer. The sewage being disposed of at this site was licensed to be land applied and harrowed into the ground. The Board of Directors of the Ottawa County Health Department immediately revoked the hauler's license when these findings were presented to them by the outbreak investigation team. The karst aquifer geology, the unsuitability of the soil for sewage filtration, illicit sewage disposal, and infiltration of water from Lake Erie all may have contributed to widespread ground water contamination on the island.

The number of new cases of illness diminished in late August 2004. This appears to be due to several factors. The number of visitors to the island appeared to have decreased following coverage of the outbreak in the media, no-use orders were issued by the Ohio Environmental Protection Agency for public well water supplies [19], and recommendations were made during the outbreak, advising residents and visitors to consider drinking boiled or bottled water instead of tap water.

Since the outbreak, a number of short term solutions have been implemented, including the use of water hauled from the municipal treatment plant; installation of continuous disinfection devices, such as inline chlorination and ultraviolet systems; the use of bottled or boiled drinking water; extension of some of the municipal water lines; provision of recommendations for water testing and treatment of private residential systems; expansion of the water treatment plant capacity; and posted signs at the entrances to businesses to notify the public if the water supply is approved by the Ohio Environmental Protection

Table 3. Amount of tap water consumed by case patients and matched control subjects during their visits to South Bass Island, Ohio, 2004.

Amount of tap water consumed	Case patients (n = 97)	Control subjects (n = 115)	mOR (95% CI)
>6 cups	15 (15)	2 (2)	64.7 (5.4–778.0)
5–6	9 (9)	2 (2)	40.1 (2.3–687.8)
3–4	15 (15)	10 (9)	7.2 (2.1–24.7)
1–2	18 (19)	12 (10)	3.6 (1.4–9.5)
<1	8 (8)	13 (11)	1.9 (0.6–5.8)
None	32 (33)	76 (66)	…

NOTE. Data are no. (%) of subjects, unless otherwise indicated. mOR, matched OR.

Agency. The Ottawa County Health Department and the ODH have implemented more stringent construction standards for new wells designed to minimize exposure to contaminants, have improved enforcement of continuous disinfection requirements for contaminated wells, and have provided educational information to residents with recommendations for frequent bacterial testing of private wells. Further large-scale improvements to the water and waste treatment infrastructure on the island are being implemented as a consequence of the outbreak.

Water quality degradation on South Bass Island most likely occurred over a long period of time—possibly years. It would be prudent, particularly in areas with similar karst hydrogeology where ground water is a source of drinking water or where ground water is connected to surface water, to examine the available historical water-quality data trends to prevent such waterborne outbreaks of infection from occurring. Swift implementation of the Environmental Protection Agency's proposed Ground Water Rule, which specifies the appropriate use of disinfection in ground water, addresses other components of ground water systems, and establishes a targeted strategy to identify ground water systems at high risk for contamination, may have an impact on protecting public health [20].

In light of this large outbreak on South Bass Island, development of an island-wide community public water system is recommended to provide safe, sufficient, and sustainable drinking water for residents and visitors, and further investigation of the influence of sewage disposal on the underground aquifer is warranted. The benefits of adequate infrastructure to guarantee drinking water safety far outweigh its costs.

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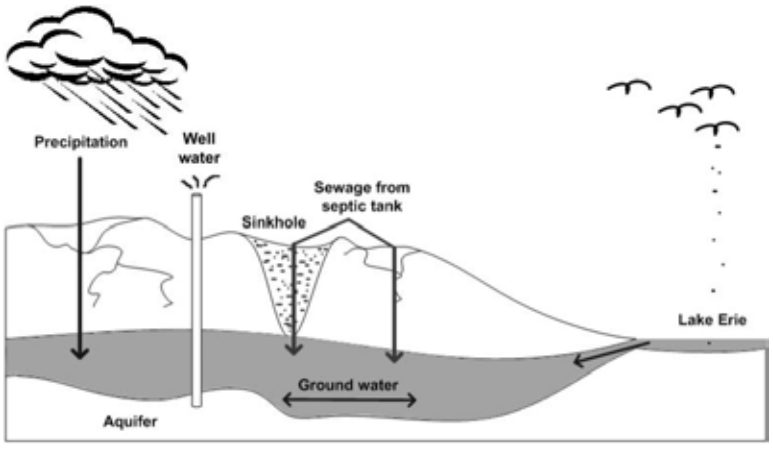

Figure 2. Representation of karst hydrogeology on South Bass Island, Ohio. From left to right of the schematic, ground water is replenished by precipitation that drains into the aquifer. This ground water can supply water to wells. Contaminants from sewage and animal reservoirs may be flushed through the fractured rock or down sinkholes into the aquifer. The karst aquifer is hydraulically connected to Lake Erie, and thus, surface water from Lake Erie may infiltrate the ground water aquifer via fractures. Soil on the island is very thin and absent in some places, providing little to no natural filtration of contaminants.

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