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# A Case of Primary Amebic Meningoencephalitis Associated with Surfing at an Artificial Surf Venue: Environmental Investigation

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## Abstract

*Naegleria fowleri* is a thermophilic ameba found in freshwater that causes primary amebic meningoencephalitis (PAM) when it enters the nose and migrates to the brain. In September 2018, a 29-year-old man died of PAM after traveling to Texas. We conducted an epidemiologic and environmental investigation to identify the water exposure associated with this PAM case. The patient's most probable water exposure occurred while surfing in an artificial surf venue. The surf venue water was not filtered or recirculated; water disinfection and water quality testing were not documented. *N. fowleri* and thermophilic amebae were detected in recreational water and sediment samples throughout the facility. Codes and standards for treated recreational water venues open to the public could be developed to address these novel venues. Clinicians and public health officials should also consider novel recreational water venues as a potential exposure for this rare amebic infection.

## Graphical Abstract

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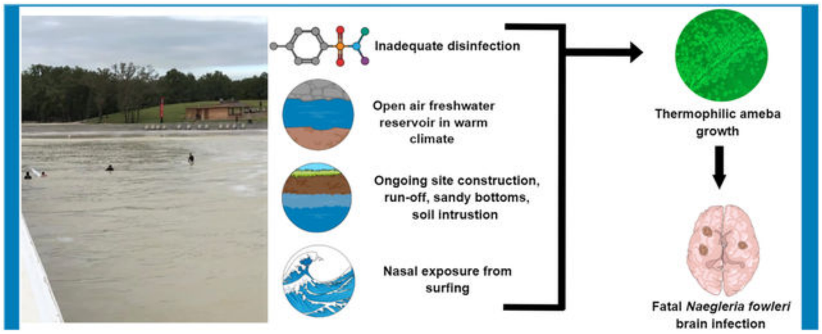


**Keywords**

*Naegleria fowleri* ; primary amebic meningoencephalitis; environmental; recreational water

## Introduction

*Naegleria fowleri*—a thermophilic, free-living ameba—thrives in warm freshwater (e.g., lakes, ponds, and hot springs) and can cause a rare and devastating brain infection called primary amebic meningoencephalitis (PAM; 0–8 infections per year most frequently in southern-tier United States) (1). In addition to warm freshwater, *N. fowleri* can also be found in treated recreational water venues (e.g., pools and splash pads) when the water is inadequately disinfected (2). *N. fowleri* is well documented in soil and, in some instances, can contaminate nearby waters through run-off (3). Free-living amebae (FLA) are also ubiquitous in biofilms, which provide a source of nutrients as well as protection from disinfectants (4, 5). Nasal exposures to the FLA, *N. fowleri*, associated with recreational water typically occur during activities that can force water containing the ameba into the nasal cavity (e.g., diving and jumping in water) and the ameba subsequently migrate to the brain. Globally, there have been less than 200 confirmed PAM cases (6). During 1962–2021, out of the 154 U.S. cases of PAM, only four survived (i.e., 97% case fatality) (1, 6, 7). Most of these confirmed cases were infected with *N. fowleri* through recreational water activities (e.g., swimming, diving, and water sports) in lakes, ponds, reservoirs, canals, and to a lesser extent inadequately disinfected pools (6, 8). Surfing had not previously been documented as a risk for exposure, even though the action of surfing frequently forces water up the surfers' nose, because until recently, surfing primarily occurred in the ocean, and *N. fowleri* has a low tolerance to saltwater (3).

Surf venues are large-format artificial (i.e., non-natural, manufactured) recreational water venues dedicated to riding on a surfboard or other wave-riding device. They generate traveling and surfable waves that mimic ocean waves. In recent decades, multiple freshwater surf venues have been built, many of them in warm-weather locations where surfing can occur year-round. Several characteristics of surf venues could affect the ability of pathogens, including *N. fowleri*, to be transmitted in these venues. Chlorination is one barrier to pathogen transmission in surf venues, but aerosolization of water (i.e., through waves) and ultraviolet light from the sun deplete the concentration of free chlorine available for disinfection. The extensive surface area of surf venues makes them especially susceptible to environmental contamination (e.g., dust and sediment), which can further deplete the free chlorine concentration and increase turbidity (9). Given the large water volume (millions of liters), it is difficult to maintain the minimum disinfectant concentration needed to prevent pathogen transmission, and surf venues are not regularly drained to assist with cleaning and scrubbing of biofilm (where *N. fowleri* can persist (10, 11)) from surfaces.

Because surf venues are relatively new, they have not been included in the Model Aquatic Health Code (MAHC) which is developed in partnership by the Council for the Model Aquatic Health Code (CMAHC) and U.S. Centers for Disease Control and Prevention (CDC). The MAHC is designed to prevent illness, injury, disability, and death associated with treated recreational water venues (e.g., pool, hot tubs, and splash pads) open to the public (12). MAHC guidance is updated regularly, in part to address novel treated recreational water venues, such as surf venues. Development of surf venue-specific public health recommendations has been limited by a lack of data. This investigation of PAM associated with a surf venue provides critical information to help inform future MAHC recommendations.

## Case Report and Epidemiologic Investigation

On September 20, 2018, CDC was notified of a possible case of PAM in a 29-year-old male New Jersey resident. The patient presented to a New Jersey hospital with fever and altered mental status and was treated presumptively for bacterial meningitis and viral encephalitis as described in the case report by Hamaty et al. (13). When his condition did not improve with broad-spectrum antimicrobial therapy, a cerebrospinal fluid (CSF) sample was examined for organisms using Giemsa Wright-stain and was concerning for amebic infection. His clinical care team consulted CDC for empiric treatment recommendations for PAM and diagnostic confirmation. CDC's Free-Living and Intestinal Ameba (FLIA) Laboratory (14) confirmed the presence of *N. fowleri* in the patient's CSF by real-time polymerase chain reaction (PCR) (15).

New Jersey Department of Health and CDC initiated the epidemiologic investigation by reviewing medical records and interviewing family and friends to identify the patient's potential exposures in the 2 weeks preceding his illness onset. The patient had traveled to Texas with friends in the week before illness onset. While there, he had surfed at an artificial inland freshwater surf venue where he repeatedly fell off the surfboard and into the water and swam at the hotel pool. His occupation involved collecting environmental water samples, but this activity was deemed unlikely to lead to nasal water exposure. Of the patient's reported nasal water exposures in the 2 weeks prior to becoming ill, the surf venue was considered the most likely exposure associated with infection and was, therefore, prioritized in the environmental investigation.

## Methods

### Environmental Investigation

Waco-McLennan County Public Health District, Texas Department of State Health Services, and CDC visited the facility on September 27, 2018. The team conducted a tour with the facility owner. Observations and inspection findings were documented on an environmental health outbreak investigation survey data collection tool. The onsite environmental assessment included interviews of the owner and staff, request to review records, evaluation of recreational water venue operation and management (including water treatment), and assessment of water sources and flow patterns.

### Environmental Sampling

Water, biofilm, and sediment samples were collected from the surf venue, other recreational water venues, and the facility water source—an open-air, ground water fed reservoir. Physical and chemical parameters, including temperature, pH, turbidity, conductivity, and total dissolved solids (TDS) were measured using a PCTSTestr™ 50 Series (Oakton Instruments, Vernon Hills, IL). Total chlorine and free chlorine concentration were measured using a Pocket Colorimeter™ II (Hach, Loveland, CO) of the water in the reservoir pools, surf venue, water slides' landing pool, lazy river, and the adult cable park pond by CDC staff on September 27, 2018 (Table 1). Water, sediment, and surface swab (biofilm) samples were collected from the reservoir pools and four recreational water venues (Figure 1). Large volume (10–50 L) water samples were collected using dead-end ultrafiltration (16), along with paired 1-L grab samples, from all water venues except the children's cable park pond. All water samples were treated with 0.1 mg/L sodium thiosulfate to neutralize any residual disinfectant in the sample. Grab samples (100-mL) were also collected in IDEXX bottles containing sodium thiosulfate for fecal indicator bacteria (total coliforms, *Escherichia coli*, and enterococci) testing. IDEXX bottles were transported overnight to CDC in Atlanta, GA on ice for processing within 24 hours of collection following standard methods (17).

The remaining samples were transported overnight to Atlanta, GA at ambient temperature to maintain *N. fowleri* viability for processing at CDC within 24 hours of collection, as previously described for environmental samples (18, 19). Briefly, ultrafilter backflush and grab water samples were concentrated by centrifugation; sediment and surface swab samples were eluted and then concentrated by centrifugation as previously described in Cope et al. (19). *N. fowleri* was tested for in environmental samples using both direct real-time PCR prior to culture and using culture followed by real-time PCR confirmation of presumptive ameba positive cultures as visualized under an epi-fluorescence microscope following methods described in Mull & Hill (18). The *N. fowleri* cultured from the environmental and case samples were genotyped based on the occurrence of three repeat sequences and characteristic single nucleotide polymorphisms (SNPs) in the internal transcribed space 1 (ITS1) and 5.8S rRNA genes as previously described (20). Only *N. fowleri* cultured from environmental samples had sufficient quantities of *N. fowleri* genomic material for genotyping.

## Results

### Observations and Interview Findings

The surf venue was part of a large recreational water facility located outside of Waco, Texas in McLennan County. Other venues at the facility included a treated landing pool with three water slides, a cement-lined, treated lazy river, a large pond with a cable park for adult waterskiing and wakeboarding, and a small pond with a cable park for teaching wakeboarding to children (Figure 1). At the time of the site visit, construction equipment was present and dirt movement was ongoing throughout the property. There were multiple portable toilets present throughout the facility and adjacent to the venues, and no public showers were noted. The owner and staff reported manually adding white chlorine granules to the water in the surf venue, water slides' landing pool, and lazy river approximately twice per week (typically on Thursdays and Sundays) in the evenings. The following morning, test strips were used to check free chlorine. No logs of free chlorine concentration or other water quality measurements (e.g., pH) were maintained.

**Reservoir—**The reservoir, comprised of two open-air polyvinyl chloride (PVC)-lined pools on top of dirt mounds, supplied water to the facility's recreational water venues. Water was pumped from an on-site ~1,000-m-deep well (sourced from the Trinity aquifer) and stored in the pools, one of which had an aerator. Water then flowed, as needed, via gravity to replenish the surf venue, water slides' landing pool, and lazy river, then ultimately drained into the cable park ponds. One of the reservoir pools had a dock, diving board, and small beach area comprised of dirt and sand at the time of the site visit. This reservoir pool was for private use only, and reportedly disinfected using chlorine but with unknown frequency and no documentation.

**Surf Venue—**The surf venue was a semicircular water body with compressed air wave-generating equipment underneath a straight concrete retaining wall. The venue was constructed with concrete, lined with PVC, covered with sand, and filled with approximately 11 million liters of water. The water depth ranged from 0 m (at the beach entry) to approximately 2.5 m (where the water met the wall). The water typically had an opaque blue appearance from an added dye, used to mitigate algal growth. On the day of the visit, the water had a murky brown appearance, and the site team noted a strong chloramine odor.

**Landing Pool for Water Slides—**The water slide venue had three, separate 18-m-high and 45-m-long "ski-jump"–style water slides that emptied into a circular landing pool filled with approximately 500,000 liters of water. The landing pool had an aerator in the center and the bottom had a PVC liner, which was partially covered by sand to create a beach on one side. The water depth ranged from 0.3 m (at the beach entry) to 5 m (at the center). Reservoir water filled the landing pool directly through a pipe. At the time of the site visit, the landing pool was not draining actively but would drain into the children's cable park pond when it overflowed such as following rain.

**Lazy River—**This approximately 0.9-km-long and 3-m-wide oval-shaped water channel loop was used by up to 1,500 patrons per day to sit in tubes and float around the surf venue. The lazy river was constructed of concrete with a water depth of 1–2.3 m and held approximately 3 million liters of water. Eight pump and filter stations located along the loop were used to generate the river current. This was the facility's only venue in which water was reported to be filtered, and the filters were reportedly backwashed three times daily. The filter media type and effective pore size were not reported. At the time of the site visit, multiple portable toilets were stationed along the loop, accessible to patrons. The lazy river also overflowed or drained into the children's cable park pond.

**Cable Park Ponds—**One natural oval pond, with an island in the middle, was outfitted with a cable-pulley system for pulling adult patrons on water skis or wakeboards and included ramps and other obstacles for performing jumps. The pond had clay soil on the bottom with grasses and cattails along the perimeter. The water had an opaque blue appearance, likely due to dye directly added to the pond or to dyed water from other recreational water venues draining into it. The adult cable park pond was not treated with chlorine or any other water treatment product. Dogs were allowed in the water and there was a conspiracy of lemurs living on the center island. There was also a smaller cable park pond with a two-lane cable system for training children to wakeboard. The pond was overgrown with cattails and drained over a sidewalk, which was covered in algae and biofilm, into the adult cable park pond. This pond was not chlorinated or treated with other water treatment product, and, at the time of the site visit, was not open to the public.

### Environmental Testing Results

Total chlorine concentration measured in the reservoir was 0.05 mg/L, and the free chlorine was 0.03 mg/L (Table 1). The reservoir temperature was 27.6 $^{O}$C and pH was 9.15. The turbidity was 2.36 nephelometric turbidity units (NTU) and the total coliforms measured 686.7 MPN/100 mL Among the facility's treated recreational water venues open to the public that were reportedly chlorinated, the total chlorine measurements ranged 0.25 mg/L in the lazy river to >2.20 mg/L in the water slides' landing pool. Free chlorine measurements ranged <0.02 mg/L in the surf venue and lazy river to 1.77 mg/L in the water slides' landing pool. Water temperatures in the venues ranged 24.7 $^{O}$C in the surf venue to 29.0 $^{O}$C in the adult cable park pond. Turbidity measurements ranged 5.31 NTU in the water slide landing pool to 558 NTU in the surf venue. Total coliforms were detected in the water slides' landing pool and lazy river (each 1 MPN/100 mL) and the adult cable park pond (1,732 MPN/100 mL). Enterococci were detected in the surf venue (2 MPN/100 mL) and adult cable park pond (101.4 MPN/100 mL).

Viable thermophilic amebae were cultured from samples collected from the surf venue and adult cable park pond and from the sediment in the reservoir, surf venue, water slides' landing pool, and adult cable park pond (Table 1). *N. fowleri* was cultured from the sediment and ultrafiltered-water samples collected at the adult cable park pond. The *N. fowleri* cultured from the environmental and case samples were identified as genotype 1.

## Discussion

In the United States, PAM is a rare infection most frequently reported in patients/persons with exposure to warm freshwater in lakes, ponds, and reservoirs in southern-tier states, primarily Florida and Texas (2). However, cases have recently been associated with exposures in states as far north as Minnesota and with new nasal water exposures—e.g., the use of tap water for nasal rinsing, backyard water slides, and rafting on an artificial whitewater river (19, 21–24). This investigation describes the environmental conditions in a novel treated recreational water venue open to the public and likely associated with a fatal

PAM case. Based on the investigation results, the most likely nasal water exposure leading to PAM was falling off the surfboard and into the surf venue, forcing water containing *N. fowleri* into the case's nasal cavity and the ameba subsequently migrated to the brain. In addition to the patients' reported activities, the surf venue exposure designation is supported by the environmental investigation that detected viable *N. fowleri* genotype 1 at the facility and noted operation and management conditions that may have contributed to ameba persistence and growth. Future work could also explore the ecology of the other FLA detected in these venues (25, 26).

*N. fowleri* was not detected in the surf venue; however, the water sampled at the time of the investigation may not have been representative of the water when the patient was exposed. Moreover, detection of viable thermophilic ameba in multiple venues at the facility indicates the potential for *N. fowleri* to be present in all venues. During the onsite visit, the team documented the following conditions that likely enabled *N. fowleri* to enter the waters and persist or amplify. The open-air surface reservoir and other recreational venues were susceptible to soil intrusion either directly from the ground water source or from run-off, dust, or person transfer, and many water venues had sand bottoms that can protect ameba from disinfection. Additionally, the water in all venues was warmed through radiant heating in the hot Texas climate, allowing the ameba to thrive. Lastly, the biofilm growth noted on surfaces where the water overflowed from one venue to another might have also contributed to growth of *N. fowleri* at this facility. While *N. fowleri* was only cultured from the cable park pond, *N. fowleri* could have potentially been present and viable in any of treated venues given these conditions.

Although rare, multiple *N. fowleri* infections have been associated with exposure to artificial freshwater venues, like the surf venue or cable park ponds (Table 2) (3, 27, 28). Disinfection or treatment of natural freshwater bodies due to *N. fowleri* is not recommended for practical and ecological reasons, but given the previous cases associated with artificial water sport venues (Table 2), venues, like the cable park, could consider signage informing patrons about the presence or risk of *N. fowleri*, particularly in seasons when the water is warmer. No PAM cases have been associated with adequately treated recreational water venues (e.g., pools and splash pads). The lazy river and water slides' landing pool are not novel venues and their design, construction, operation, and management are addressed in CDC's MAHC (12) and typically in U.S. jurisdiction codes (29). A recent review of CDC surveillance data for PAM cases documented multiple nasal water exposures in recreational water venues that had been altered or designed in ways that might have increased the risk of *N. fowleri* exposure (Table 2). In some instances, recreational water venues were constructed or maintained in ways that unintentionally facilitated the persistence or growth of *N. fowleri* (19).

Water treatment practices throughout this facility were poorly documented. At the time of the onsite visit, free chlorine concentrations were well below the recommended minimum 1 ppm needed to control transmission of pathogens, including *N. fowleri* (9, 30, 31). The pH readings in the reservoir, surf venue, water slides' landing pool, and lazy river were also well above the MAHC's recommended range (pH 7.2–7.8). pH greater than 7.8 substantially reduces the ability of the free chlorine to disinfect and could cause eye and skin irritation in patrons (30, 31). Fecal indicator bacteria (total coliforms or enterococci) were also detected in all the tested venues, indicating insufficient treatment at the facility. Multiple observed factors might have contributed to the presence of fecal indicator bacteria, including the previously noted potential for soil intrusion and a lack of showers available to patrons prior to entering the water.

At the time of the site assessment, the water in all venues had turbidity levels well above 0.5 NTU, the maximum level suggested in the MAHC annex and other pool treatment advisory groups (9, 31). High turbidity indicates high particle load, which depletes free chlorine concentration making it harder to maintain the minimum concentration needed to help prevent the transmission of pathogens. To reduce turbidity the MAHC calls for filtering water before it is disinfected (9). The lazy river was the facility's only venue with water reported to be filtered. Low turbidity is important in public recreational venues not just for mitigation of pathogens, but for swimmers' safety. Turbid water makes it difficult to see underwater distressed patrons. Several factors likely contributed to the high turbidity, including sand bottom venues (in the MAHC, sand is not an acceptable interior finish for venue basins), soil intrusion from the ongoing construction and dirt movement throughout the property, the open-air reservoir water source, and surface overflow and drainage into venues. The high turbidity may also have been due to insufficient disinfectant levels leading to microbial growth.

## Conclusion

This investigation identifies an artificial surf venue as the most likely source of exposure to *N. fowleri* for a PAM case and highlights the need for evidence-based best practices and standards to prevent the transmission of pathogens, including *N. fowleri*, in surf venues. General recommendations can be formulated based on similar venues but collecting additional data will be useful for informing future recommendations to promote healthy and safe swimming in surf venues. Waterborne pathogens, including *N. fowleri*, are inactivated by free chlorine; transmission can be prevented through venue design and construction, ensuring the recirculation, filtration, and disinfection equipment is present and meets standards, preventing water runoff from entering the venue, and having an appropriate interior finish for the venue basin (9, 31). Operation and management practices such as maintaining proper pH, at least minimum disinfectant concentration, and inspecting for and removal of biofilm from venue surfaces may also support safe swimming (32).

Surf venues represent the latest iteration of novel recreational venues that can lead to nasal water exposures and *N. fowleri* infection. Healthcare providers should consider surf venues as potential water exposures for suspected PAM cases so that appropriate treatment can be started as early as possible.

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**Synopsis:**

This investigation identifies an artificial surf venue as the most likely source of a fatal exposure to *N. fowleri* and highlights the need for new codes and standards to address these venues.

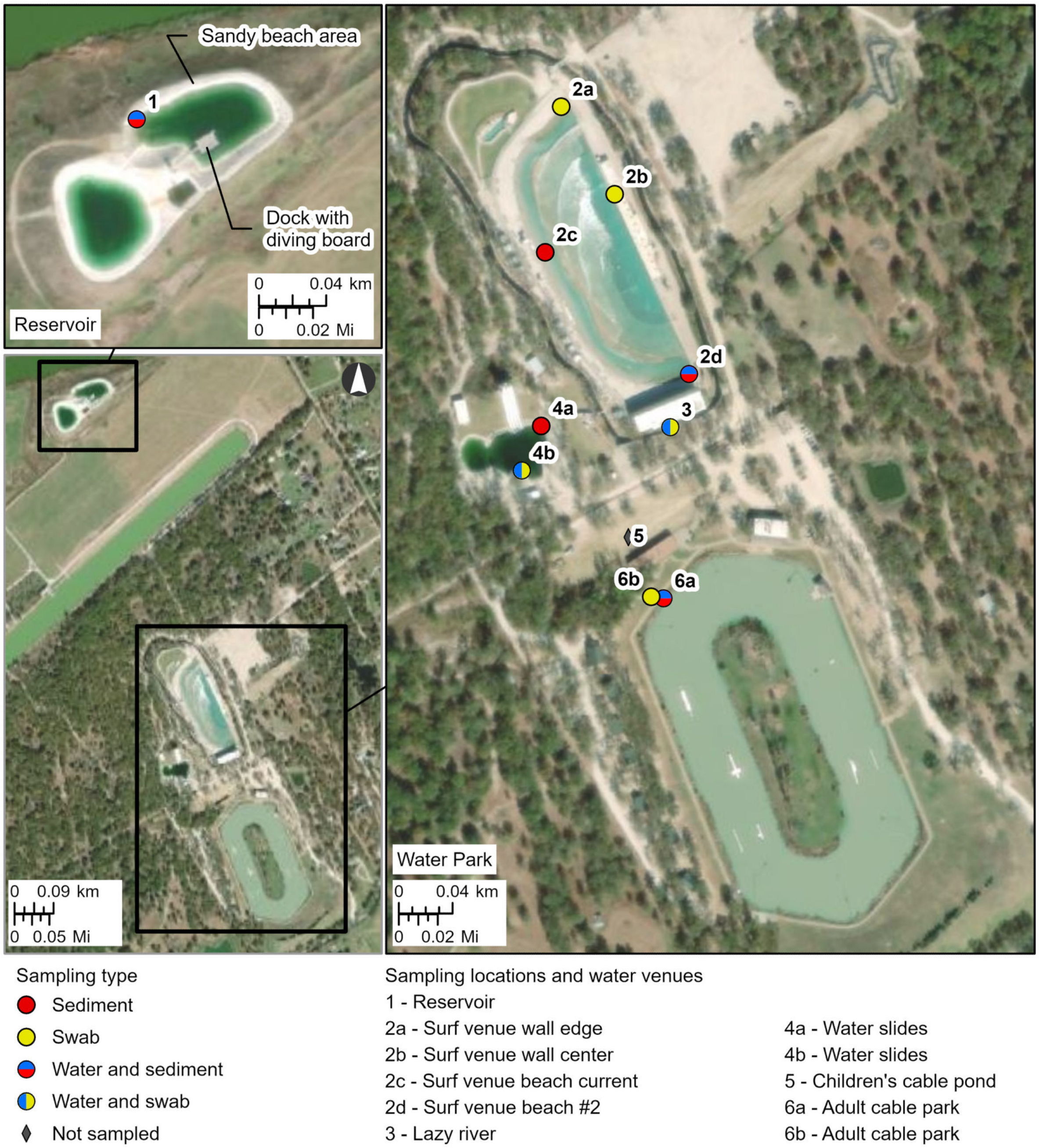


**Figure 1.**

Map* displaying sampling locations and recreational water sites at the facility

*Satellite image: GeoEye-1, Maxar, Nov. 23, 2021; Esri, Maxar, Earthstar Geographics, and the GIS User Community. Projection: Texas State Plane Central NAD 1983 (2011) Feet.

**Table 1.**

Physical and chemical water quality and microbial test results from samples collected at recreational water venues, McLennan County, Texas, Sept. 27, 2018.

| Water body | Sample types collected* | Physical water quality parameters | Total coliforms (MPN/100 mL) | *E. coli* (MPN/100 mL) | Enterococci (MPN/100 mL) | Thermophilic ameba culture** | *Naegleria fowleri* culture |
|---|---|---|---|---|---|---|---|
| Reservoir | Ultrafiltration<br>Grab<br>Sediment | Total chlorine = 0.05 mg/L<br>Free chlorine = 0.03 mg/L<br>Temperature = 27.6°C<br>pH = 9.15<br>Turbidity = 2.36 NTU<br>TDS = 868 ppm | 686.7 | <1 | 2.0 | Detected in sediment | Non-detect |
| Surf venue | Ultrafiltration<br>Grab<br>Sediment†<br>Surface swab‡ | Total chlorine = 1.03 mg/L<br>Free chlorine < 0.02 mg/L<br>Temperature = 24.7°C<br>pH = 9.31<br>Turbidity = 558 NTU<br>TDS = 1,170 ppm | <1 | <1 | 2.0 | Detected in ultrafiltered water and sediment opposite cement wall center | Non-detect |
| Water slides' landing pool | Ultrafiltration<br>Grab<br>Sediment§<br>Surface swab | Total chlorine > 2.20 mg/L<br>Free chlorine = 1.77 mg/L<br>Temperature = 25.3°C<br>pH = 8.79<br>Turbidity = 5.31 NTU<br>TDS = 1,140 ppm | 1.0 | <1 | <1 | Detected in sediment | Non-detect |
| Lazy river | Ultrafiltration<br>Grab<br>Surface swab | Total chlorine = 0.25 mg/L<br>Free chlorine < 0.02 mg/L<br>Temperature = 27.0°C<br>pH = 8.98<br>Turbidity = 20.6 NTU<br>TDS = 267 ppm | 1.0 | <1 | <1 | Non-detect | Non-detect |
| Adult cable park pond | Ultrafiltration<br>Grab<br>Sediment‖<br>Surface swab# | Total Chlorine < 0.02 mg/L<br>Free Chlorine < 0.02 mg/L<br>Temperature = 29.0°C<br>pH = 8.83<br>Turbidity = 45.0 NTU<br>TDS = 891 ppm | 1,732.9 | 1.0 | 101.4 | Detected in sediment, ultrafiltered water, and swab | Detected in sediment and ultrafiltered water |

Abbreviations: TDS: Total Dissolved Solids, PVC: polyvinyl chloride, PCR; polymerase chain reaction

* Ultrafiltration samples were 50 L volumes, except at surf venue where only 10 L filtered due to clogging.

† Sediment was collected at two sites in the surf venue: 1) beach opposite center of cement wall and 2) adjacent to south end of cement wall.

‡ Surface swabs of cement wall were collected at two sites in the surf venue: 1) center of cement wall; and 2) at intersection of sand and PVC lining on north end of cement wall.

§ Sediment was collected from sand 'beach' in the water slides' landing pool.

‖ Sediment from the adult cable park pond was collected adjacent to the children's cable pond input.

\# Surface swabs at the adult cable park collected from the pebble/cement wall drain from the children's cable park pond.

** Viable thermophilic ameba detected by culture through visual microscopy but was confirmed as not *N. fowleri* by real-time PCR.

**Table 2.**

Recreational water venues with artificial features associated with U.S. primary amebic meningoencephalitis cases, 1962–2021

| Venue | Year | County, State | Bottom composition | Water treatment | Water source | Size of water body | Other features | Number of associated PAM cases |
|---|---|---|---|---|---|---|---|---|
| Artificial lake | 2019 | Cumberland, North Carolina | Sand | Untreated | Spring | 6.5 acres, ~38 million liters | Slides, diving platforms, rope swings | 1 |
| Artificial whitewater river | 2016 | Mecklenburg, North Carolina | Concrete | 200-µm Particulate filter, ultraviolet, manual intermittent chlorination | Municipal drinking water and wells | ~44 million liters | Closed-loop, recirculated system, whitewater kayaking | 1 |
| Water park | 2013 | Pulaski, Arkansas | Sand | Chlorine, pH balanced, and chemicals | Spring and well | 3.5 acres | Slides | 2 |
| Artificial lake | 2009, 2020 | Madison, Florida | Sand | Chlorine (2009); Untreated and dyed (2020) | Well | 1.5 acres (2009); ~2.2 acres (2020) | Slide (2009); None (2020) | 2 |
| Watersports complex and cable park | 2007, 2009 | Orange, Florida | Sand | Untreated, monthly testing | Rain | — | Waterskiing and wakeboarding | 2 |
| Water park | 1979, 1980 | Orange, Florida | Sand | “Unique filtration system” | Lake | 6 acres | Slides | 2 |
| Artificial lake | 1970 | Richmond, Georgia | Sand | Untreated | — | — | Cement retaining walls | 1 |
| Lake | 1950s and 1960s | Chesterfield, Virginia | Likely sand | Unknown | Unknown | — | Slides, diving boards, fountains | 4 |

Modified from Cope et al., 2018 (19)