

Bacteriological analysis of indoor and outdoor water parks in Wisconsin

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ABSTRACT

Water parks are a rapidly growing element of the United States tourist industry. To reduce incidence of abrasion and impact injuries in such parks, designers are searching for padding materials that can withstand the harsh oxidative environments of chlorinated water. Although padded features help reduce physical injuries, they may also compromise the microbiological safety of water attractions. This study describes bacteriological testing performed on 31 different pad materials, play features and pools from 10 Wisconsin water parks. Materials and surrounding pool waters were sampled and tested quantitatively for total coliforms, *Escherichia coli*, *E. coli* 0157:H7, enterococci, staphylococci, heterotrophic bacteria, and *Pseudomonas aeruginosa*, using standard methods. Each location was sampled during three visits, and results were averaged. Pool waters were within acceptable levels of target organisms and disinfectant residuals, but target organisms were found on water features, even those submerged in chlorinated water. Bacteria were detected more frequently in pools using pad materials compared with pools without. These findings provide data that will help the public health community understand the relations between designs, materials and maintenance of water features. Additionally, the information will help state regulators and owner/operators develop guidelines to improve public health and safety at water parks.

Key words | bacterial indicators, chlorine, *E. coli*, swimming, waterborne, water parks

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INTRODUCTION

The Wisconsin tourism industry has long been a leader in outdoor water parks. Wisconsin's long winters have also led to the development of indoor water parks throughout the state. The Wisconsin Dells is a popular Midwest tourist area that hosted over 2.9 million visitors in 2004 (R. Snyder, Wisconsin Dells Tourist Bureau Director, personal communication 2005). Many of these visitors are attracted to the large water parks, which operate indoor and outdoor facilities year round. Wisconsin's pool design industry is world-renowned; more than 200 new pools are installed each year (L. Docken, Department of Commerce, personal communication 2005).

Water parks offer creative theme designs from water slides to interactive water activities. As designs for water

attractions become more creative, the possibilities of user injury and waterborne infections increase. Regulating these facilities to reduce injuries and waterborne infections is a high priority for public health officials, facility owners, park designers and operators. Wisconsin statutes provide the authority to the Department of Health and Family Services to promulgate administrative codes establishing requirements for public swimming pools ([Wisconsin Administrative Code 2002](#), Chapter HFS 172). However, this code and the code regulating the design and construction of public swimming facilities ([Wisconsin Administrative Code 2003](#), Chapter Commerce 90) have not been significantly modified since the late 1980s. Because these codes are based largely on designing and operating standard rectangular pools, they do

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not address some of the safety issues of creatively designed water parks. This paper provides new data that will facilitate a science-based reassessment not only of the Wisconsin regulations, but also of regulations nationwide.

Although swimming pool and water park recreation is generally regarded as a highly safe, sanitary and wholesome activity, associations between the use of swimming pools and disease outbreaks have been documented (Cabelli *et al.* 1982; Gustafson *et al.* 1983; Perrota *et al.* 1983; Herwaldt *et al.* 1991; Gilbert & Blake 1998; Friedman *et al.* 1999). Examples range from a non life-threatening *Pseudomonas*-related folliculitis outbreak at a Utah water park affecting 265 individuals (Perrota *et al.* 1983) to a much more serious outbreak of *Escherichia coli* O157:H7-triggered diarrhoea and/or haemolytic uraemic syndrome infecting 25 individuals at a Georgia water park (Gilbert & Blake 1998). Yoder *et al.* (2004) report that documented pool-related outbreaks have involved over 10,000 people in the past 10 years and estimate that this figure represents as little as 10% of individuals who actually suffer swimming pool-transmitted illnesses.

In Wisconsin, swimming pools are the most common source of all waterborne outbreaks (31%), followed by whirlpools (27%), beaches and private wells (15%), municipal drinking water (4%) and other sources (8%) (Wisconsin Division of Public Health 2005). During 1991–2004, 25 confirmed waterborne outbreaks associated with public swimming and whirlpools occurred. *Cryptosporidium parvum* was the most common etiological agent, and *Pseudomonas aeruginosa* was second. Bacterial agents were responsible for 56% of these outbreaks. Some of these outbreaks were attributed to improper pool operation, such as inadequate chlorination. This emphasizes the importance of proper pool maintenance and the need for regulation of swimming facilities by the public health community.

The public health responsibility for regulating the operation and design of water park facilities involves both injury prevention/reduction and control of the spread of waterborne disease. Park designers are challenged to reduce abrasion and impact injuries by cushioning surfaces at pool basins and edges with padding, and these materials may actually increase the risk for waterborne disease by harbouring and distributing bacteria. For example, foam padding in high-traffic areas may provide interstitial spaces for opportunistic bacteria to escape pool water disinfectants

and potentially infect swimmers. This study describes extensive microbiological testing of pool water, common area surfaces, play features and pad materials collected from five indoor and five outdoor Wisconsin water parks.

MATERIALS AND METHODS

Sample descriptions

The criteria for selecting samples were influenced by Chapter HFS 172 (Wisconsin Administrative Code 2002) and by the authors' appraisal of features and designs that did not necessarily exist when the code was written. Three general categories of samples were established:

- water (pool water samples);
- submerged (swabs and material samples from features below pool water surface);
- damp (swabs, material or standing water samples from features above pool water surface).

Pool water samples were further subcategorized into three types commonly found in modern water parks: activity, plunge and wading pools. Wading pools were further subcategorized as with or without a permanent poured-in-place padded surface ($N = 13$).

- Activity pools: water depth > 2 feet (61 cm); designed primarily for play activity that uses constructed features and devices ($N = 21$).
- Plunge pools: at the terminal end of waterslides that carry over 100 gpm of water down a flume; some are used with foam sled mats for riders ($N = 21$).
- Wading pools: water depth < 2 feet (61 cm); designed for infants and toddlers; may have padded, permanent poured-in-place surfaces partially or completely submerged in water ($N = 37$).

When features were duplicated both indoors and outdoors at a single park, both locations were sampled to compare effects attributed to the two environments. Most of the 15 play features sampled were categorized as damp.

Water park padded features were made of different materials. Most landing pads (or mats) were closed-cell polyethylene foam with a polyurethane base coat and a coating of hybrid polyurethane-vinyl paint. Another

commonly used landing pad was made of 92% recycled tyre material. One basin surface for an interactive play attraction/splash pad was padded with porous, permanent, poured-in-place seamless recycled rubber and a polyurethane primer and binder. Ages of installed pad materials ranged from less than 6 six months up to 4 years.

Sampling methods

Three sample collection methods were used to determine bacterial populations associated with the samples included in this study: surface swab method for permanent features (decks, rides, etc.); material removal method for replaceable temporary features (mats, fish netting, ropes, etc.); and water sample method for pool waters. Samples were collected during unannounced random visits to water park facilities and all locations were sampled at least three times. To standardize results, all bacterial counts in water were reported as colony-forming units (CFU) per 100 ml. A detailed description of each method follows.

Surface swab method

A sterile Dacron-tipped swab (Fisher Scientific, Hanover Park, Illinois) was swept across an area of approximately 100 cm². The inoculated tip was then aseptically broken off into a tube containing 10 ml sterile 0.1% pH 7.3 phosphate-buffered saline (PBS) containing a commercial preparation of sodium thiosulfate (Forest Biomedical, Salt Lake City, Utah) sufficient to neutralize 10 parts per million (ppm) residual chlorine per 100-ml sample. After transport (< 6 hours) from water park to laboratory, the collection tube was vigorously vortexed for 2 minutes to dislodge organisms from the swab. All swab results were reported as CFU per 100 cm².

Material removal method

Sterile stainless steel forceps, scalpels and/or core saws were used to remove 100 cm² portions of material, which were then transferred to sterile Whirl-Pak bags containing 100 ml PBS/thiosulfate buffer. Organisms were dislodged from sample pieces by vigorous agitation (4 minutes) using Stomacher 400 homogenization (Tekmar, Cincinnati, Ohio). All piece results were reported as CFU per 100 cm².

Water samples

Pool water samples were collected in sterile collection vessels containing sodium thiosulfate (50 mg) sufficient to neutralize 10 ppm chlorine per 100 ml. Samples were collected by removing the lid and plunging the inverted vessel into the water approximately 0.5 m below the surface, then turning the vessel upright to allow filling. Water standing on deck surfaces was collected by using a sterile pipette to transfer a 10-ml aliquot to 90 ml PBS/thiosulfate, resulting in a 100-ml sample.

Mat compression

To determine the potential for submerged mats to harbour target organisms that might be released by the pressure of a bather's body, pool water surrounding such features was sampled before and after compression. Mats were compressed by applying three consecutive 25-kg thrusts to a 20-cm² area of matting using a sterile cylinder. Water was collected in a 150-ml sterile vessel as previously described both before and after compression.

Microbiology assays

The chlorine-sensitive bacteria chosen for analysis in this study were selected either because they are microbial indicator organisms (coliforms, *E. coli*, heterotrophic bacteria) or because they have been associated with recreational water-borne disease (*Pseudomonas*, *E. coli*, enterococci, staphylococci). Enterococci and *Pseudomonas* are not included in the Wisconsin regulatory code but were included in this study because of their potential as useful indicators in creatively designed water parks. Collectively, these strains are responsible for causing folliculitis, otitis (earache), pustular dermatitis, furunculosis, conjunctivitis, pneumonia, urinary tract infections, gastroenteritis and haemolytic uraemic syndrome (Gustafson *et al.* 1983; Sosin *et al.* 1989; Murray *et al.* 1990), among others. Such illnesses, reported and unreported, undoubtedly impact economies both locally and nationally.

Total coliforms and *E. coli*

The Colilert/QuantiTray (Idexx Laboratories, Inc., Westbrook, Maine) method was used to simultaneously detect,

differentiate and enumerate total coliforms (TC) and *E. coli* (*Standard Methods* 1998). Samples (10 ml and 1 ml) were diluted with 90 or 99 ml PBS buffer, respectively, to achieve the 100-ml sample required for the QuantiTray analysis. The most-probable-number (MPN) values were then multiplied by the appropriate dilution factor and reported as number of organisms per 100 ml of sample.

The Wisconsin State Laboratory of Hygiene (WSLH) performed preliminary experiments demonstrating that *E. coli* O157:H7 is enriched in Colilert reagent at similar rates to non-O157:H7 *E. coli* (data not shown). Therefore, *E. coli* positive samples were further analysed for isolation of the serotype O157:H7. For this procedure, the *E. coli*-positive Colilert culture was streaked for isolation onto CHROMagar™ plating medium (Becton Dickinson, Franklin Lakes, New Jersey) along with a positive control. After 24 hours at 35°C, typical colonies (pink, 2–4 mm diameter) were selected for seroagglutination analysis using *E. coli* O157:H7 antiserum (Difco Laboratories, Detroit, Michigan).

Enterococci

The Enterolert/QuantiTray (Idexx Laboratories, Inc., Westbrook, Maine) method was used to detect and quantify enterococci populations using the dilution schemes described above and incubated at 41°C.

Staphylococcus aureus/epidermidis

A membrane filtration/selective media method was used to detect staphylococci and then differentiate between *S. aureus* and *S. epidermidis*. For this procedure, a 10-ml water sample was filtered through a 0.45 µm nitrocellulose filter (Millipore Corp., Bedford, Massachusetts), then placed on Baird-Parker agar (BP; Oxoid, Basingstoke, UK). The plate was incubated for 24–48 hours at 35°C, then all black colonies were presumptively identified as staphylococci. Black colonies producing a zone of clearing from lipase activity on the BP agar were presumptively identified as *S. aureus*; black, lipase-negative colonies were presumed to be *S. epidermidis*. Colonies representative of each species were streaked onto blood agar plates to confirm differentiation of *S. aureus* (beta haemolytic) from *S. epidermidis* (non-haemolytic).

Pseudomonas aeruginosa

The multiple tube method 9213 F described in *Standard Methods* (1998) was used to quantify the presence of *P. aeruginosa* in samples. The MPN was determined by creating a standard curve using Thomas's Rule (Thomas 1942).

Heterotrophic plate count

Method 9215 B was used to quantify heterotrophic bacteria (*Standard Methods* 1998). Heterotrophic plate counts (HPC) are a measure of live heterotrophic bacteria in water, reported as CFU per 100 ml. Colonies may arise from pairs, chains, clusters or single cells, all of which are included in the term 'colony-forming unit'.

Quality assurance

WSLH is certified by the United States Environmental Protection Agency (EPA) for microbiological analysis of water. All quality control and quality assurance steps required by certification, described in the *WSLH Quality Assurance Manual* (WSLH 2003), or outlined in the referenced methods, were followed.

Water chemistry analysis

All water parks in this study used sodium hypochlorite (liquid chlorine) for disinfection, and one used ozone as a supplement. Aliquots of all 150-ml water samples were tested on site for pH, free and combined chlorine using an *N, N*-diethyl-*P*-penylenediamine (DPD) ferrous ammonium sulfate (FAS) test kit, following Standard Method 4500 Cl F using a Taylor K-2006 colorimetric kit (Taylor Technologies, Sparks, Maryland) (*Standard Methods* 1998). Colour values falling between two colorimeter values were reported as half the difference of the known colour values.

RESULTS AND DISCUSSION

Pool water chemistry

Ninety-two water samples from five outdoor and five indoor water parks were collected and analysed for

compliance with water chemistry requirements set out in Chapter HFS 172 (Wisconsin Administrative Code 2002). In addition to analyses for free and combined chlorine residual, pH and temperature, bather loads in the pool at the time of sampling were also recorded as low, medium or high. Wisconsin Administrative Code requires a free chlorine residual of 1 ppm (mg l^{-1}) for plunge and activity pools and 2 ppm (mg l^{-1}) for wading pools. The required pH range is 7.2–7.8.

Eighty-eight per cent of all pool water samples were compliant with required free chlorine residuals. None contained a free chlorine residual of $<0.2 \text{ mg l}^{-1}$ (data not shown). Wading and plunge pools were below the required free chlorine residual in 12% of the samples and no activity pool samples were chlorine deficient. Wading pool free chlorine residuals ranged from 0.6 to 8.0 ppm; plunge pools ranged from 0.2 to 13.0 ppm. The required pH range was found to be in compliance in 80.5% of the water samples. The percentage of code compliance is higher than those reported by others who surveyed standard pools (Ibarluzea *et al.* 1998; Rigas *et al.* 1998). The additional design and operational features of water parks require well-trained operators to oversee multiple unique pool basins. All water parks sampled in this study were operated by personnel certified in pool operation from a national certifying organization. This could be a contributing factor to the high percentage of chemically compliant pools. Previous pool studies have not considered operator knowledge and education as a contributing factor in the microbial quality of pool water.

Pool water microbiology compliance

Chapter HFS 172 (Wisconsin Administrative Code 2002) sets a zero tolerance for TC, but allows up to 50 CFU staphylococci per 100 ml and 200 CFU heterotrophic organisms per millilitre. Using these criteria, 94.5% of the water samples were bacteriologically compliant. Of the 5.5% of samples that exceeded the code tolerance levels, staphylococci levels were the most commonly exceeded and were found in plunge and wading pools. Two samples, one from a wading pool and one from a plunge pool, detected TC in low numbers ($<20 \text{ CFU}/100 \text{ ml}$). *E. coli* was not detected in any pool water samples examined during this study (Figure 1). Heterotrophic bacteria only exceeded the

requirements once, in a wading pool with permanent poured-in-place basin materials.

Detection of target organisms in pool water

The free chlorine residual and pH range disinfection requirements in Chapter HFS 172 are intended to control microbial contaminants entering the pool water from multiple sources. Our data show this was not always the case. Figure 1 shows the occurrence of target organisms in water samples stratified by pool type and expressed as percentage positivity.

Detection of faecal indicators (*E. coli* and TC) indicates failure in the operating system and requires immediate remediation. TC were detected in two samples. However, the absence of coliforms does not guarantee the absence of other, more chlorine-resistant microorganisms such as *Pseudomonas* and *Staphylococcus* (Grabow 1991; Ibarluzea *et al.* 1998; Rigas *et al.* 1998). In this study, *Pseudomonas* and *Staphylococcus* were detected in water samples and on submerged materials with acceptable chlorine residuals $>1.0 \text{ ppm}$ and pH values between 7.2 and 7.8.

Pseudomonas was only detected in wading pools. Water pH was at least 8.0 in 50% of the *Pseudomonas*-positive samples with free chlorine residuals above 3 ppm. Values of pH greater than the ideal range (7.2 to 7.8) reduce the bactericidal impact of chlorine; samples with target organisms were found even though the pools were compliant with chlorine requirements and in and above the ideal pH range. Seyfried & Fraser (1980) showed that

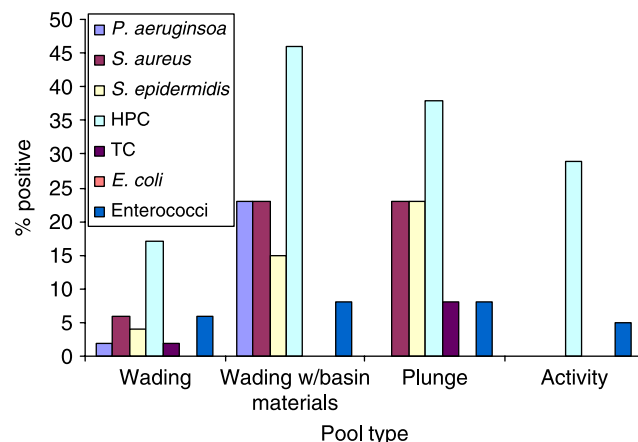


Figure 1 | Detection of target organisms in pool water categorized by function.

Pseudomonas may survive chlorine levels up to 3 ppm when pH exceeds 8.0. The sanitation quality of pool water outside proper operating levels and further compromised by flow restrictions in some features may allow survival or propagation of pseudomonads.

Enterococci were detected in every pool type (but never above 20 CFU/100 ml). Enterococci are more resistant to chlorine disinfection than are faecal coliforms (Ritter & Treece 1948; Kerin & Putnam 1968). *S. aureus* and *S. epidermidis* were found in 10% of the pool water samples; *S. aureus* was detected simultaneously with *S. epidermidis* in all but one sample. Because enterococci or staphylococci are more resistant to chlorine than coliforms and *E. coli*, Kerin & Putnam (1968) suggest that they would be more robust indicators in pool water. Cabelli *et al.* (1982) used several microbial indicators to define water quality and found that enterococci showed the best correlation to gastrointestinal symptoms. EPA recommends its use as an indicator in fresh water because it has a strong direct relation to swimming-associated illness in freshwater environments (USEPA 1994).

HPC bacteria were observed in 26% of all pool waters tested, making them the most frequently detected indicator organism. HPC bacteria are generally released from surfaces where nutrient conditions are suitable for bacterial colonization or biofilm formation. Therefore they are considered an indication of poor pool hygiene. Using multiple regression analysis, the presence of HPC bacteria was directly correlated with disinfection efficiency. Specifically, when free chlorine levels increase, HPC counts decrease ($\alpha = 0.05$, $p = 0.0005$). When pH increases, HPC counts increase ($\alpha = 0.05$, $p = 0.001$) (data not shown). Other variables (e.g. bather load, combined chlorine, and temperature) may also affect water quality, although no specific variable showed a correlation in this study.

Analyses of water attractions

Results were analysed by subdividing target organisms into faecal indicators (*E. coli*, enterococci and TC) or skin indicators (*Pseudomonas*, *S. aureus*, *S. epidermidis* and HPC). Additionally, pool categories were further separated by location of pool (indoor or outdoor) and by pools with

pad materials. Standard wading pools were compared with wading pools with permanent poured-in-place materials, and standard plunge pools were compared with those that use sled mats. Table 1 shows how the frequency of indicators detected differs when using these materials. Specifically, wading pools with basin materials triple the frequency of indicators detected in pool water regardless of pool location. Additionally, plunge pools using sled mats doubled the frequency of indicators detected. Sled mats themselves harboured both skin and faecal indicators, which seem to increase the frequency of these organisms detected in the water (data not shown).

Indoor wading pools and outdoor plunge pools had the highest percentage of skin and faecal indicators. The large amount of water that propels riders down waterslides into plunge pools dislodges residual bacterial flora from bathers. Staphylococci have been associated with bather densities in swimming pools as indicators of water quality degradation associated with bather shedding (Wade *et al.* 2003).

Comparing indoor wading and activity pools with their outdoor counterparts, slightly more indicators were detected indoors, although the difference is negligible in relation to sample size.

Table 1 | Percentage of pool water samples positive for skin (*Staphylococcus*, *Pseudomonas*, heterotrophs), faecal (enterococcus, *E. coli*, total coliforms) or all combined indicator organisms tested

Pool type	Location	Detected indicator type (%)		
		Skin	Faecal	Combined
Activity [*]	Outdoor	4.2	5.5	4.8
	Indoor	7.1	0	4.1
Wading ^{*,†}	Outdoor	7	1.3	4.6
	Indoor	8.3	4.8	6.8
Wading [‡]	Outdoor	25	0	14.3
	Indoor	29	5.5	19
Plunge [§]	Outdoor	11	0	6.3
Plunge	Outdoor	21	5	14
Wading and activity	Outdoor	6.5	2.2	4.6
Wading and activity	Indoor	7.9	2.9	5.7

^{*}Standard pools without mats used in pool.

[†]Wading pool without padded surface.

[‡]Wading pool with padded surface.

[§]Plunge pools without sled mats.

^{||}Plunge pools with sled mats.

Water samples from wading pools with permanent poured-in-place surface material are ten times more likely to contain *P. aeruginosa* than those without basin materials and three times more likely to contain *S. aureus*. In addition, water samples from plunge pools (including those with sled mats) and wading pools with permanent surfacing materials are four times more likely to contain *S. aureus* and *S. epidermidis* than samples from activity and wading pools (Figure 1).

Detection of target organisms in materials and features

Fifteen play features and 16 pad materials were evaluated and separated by location (indoor or outdoor). Damp and submerged pad materials and play features were tested. Figure 2 shows the frequency of individual target organisms detected on submerged pad materials and play features in indoor and outdoor water parks. Although *Pseudomonas*, enterococci and heterotrophic organisms were detected more often indoors, staphylococci and TC were more often detected in outdoor submerged pool features. *E. coli* was not detected in samples associated with submerged features in chlorinated pool water. Enterococci were not found in any outdoor submerged material, although they were found indoors.

Among samples categorized as damp (Figure 3), *Pseudomonas*, TC and enterococci were detected more

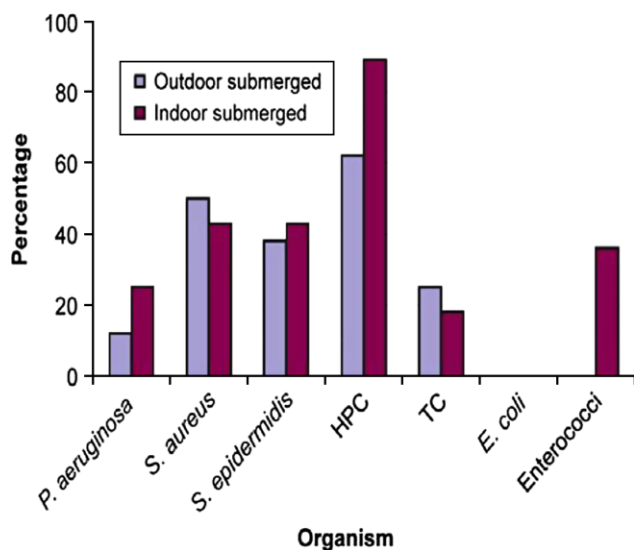


Figure 2 | Frequency of target organism detection associated with indoor or outdoor submerged features.

often indoors, whereas staphylococci, *E. coli* and heterotrophic organisms were more often detected in outdoor damp pool features.

Figure 4 compares the recovery of target organisms from play features and materials submerged in chlorinated pool water with those found in samples categorized as damp. Without exception, submersion of features and materials in chlorinated pool water reduced the frequency of target organisms. It is notable that *E. coli* were not isolated from submerged features; damp features did harbour the organism, albeit infrequently.

Target organisms were more often isolated from pad materials in the damp category compared with the submerged category. Features in the damp category were only sporadically in contact with chlorinated pool water and the highest abundance of target pathogens, including *E. coli*, occurred with such samples. The presence of enterococci, which were isolated from every feature in this category at least once, demonstrates the importance of a steady supply of chlorinated water.

Interior and exterior surfaces of some features may hinder the flow of chlorinated water and permit extended survival of bacteria compared with their more vulnerable free-floating counterparts. Also, irregular surfaces and/or interstitial areas in these features could provide a starting point for biofilm formation. Biofilms facilitate adherence of organisms to environmental surfaces and physically protect organisms from disinfectants. Biofilm-associated bacteria are up to 3,000 times more resistant to hypochlorous

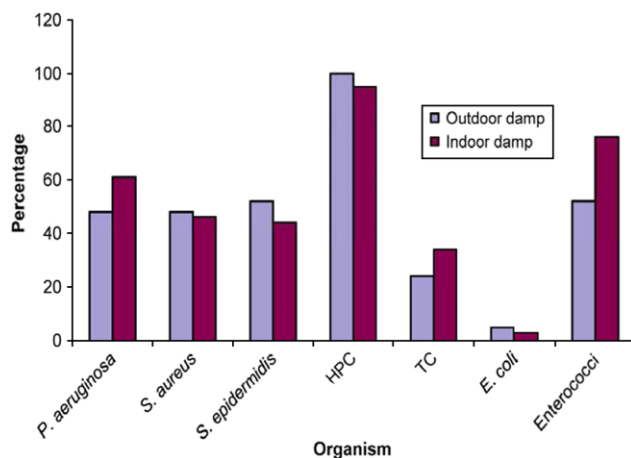


Figure 3 | Frequency of target organism detection associated with indoor or outdoor damp features.

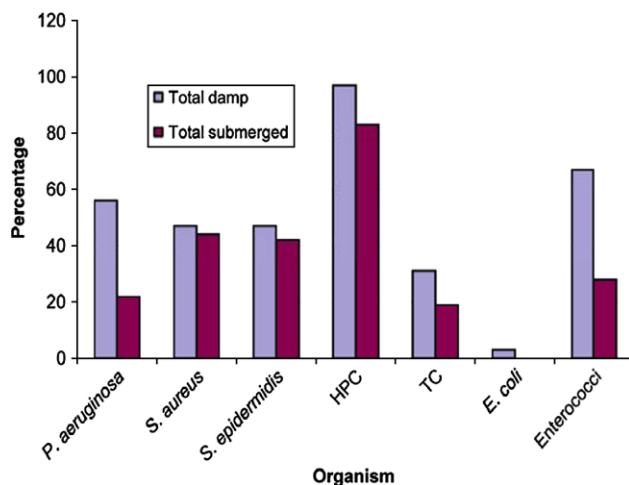


Figure 4 | Frequency of organisms detected on damp and submerged pad materials and play features.

acid compared with their free-swimming counterparts (Lechavallier *et al.* 1988). Factors such as free chlorine availability, pH, sampling method and/or biofilm presence may explain why features in continual bather contact were often positive for target organisms in spite of the ubiquitous bactericidal chlorinated water.

Play features (infant and toddler)

This study found that play features designed and used by infants and toddlers (i.e. toddler swings) harboured substantial numbers of target bacteria. Figure 5 compares the \log_{10} average amount of bacteria found on toddler play features with other play features in the park. Toddler play features averaged a substantially larger amount of bacteria than play features geared for older children and adults; in some cases, up to 1,000 times more bacteria were detected. Faecal indicators were frequently found (*E. coli* 13%, TC 53%, enterococci 87%), probably because of toddlers' incontinence. Skin indicators such as staphylococci were found in up to 80% of the samples (data not shown).

Table 2 shows average counts (\log_{10}) of target organisms detected on rubber or fabric toddler swings. Every target organism was detected more frequently and in higher numbers on fabric compared with rubber swing samples. *E. coli* and enterococci were found in concentrations as high as 1,050 CFU/100 cm² and 24,192 CFU/100 cm², respectively. *E. coli* isolated from play features were further

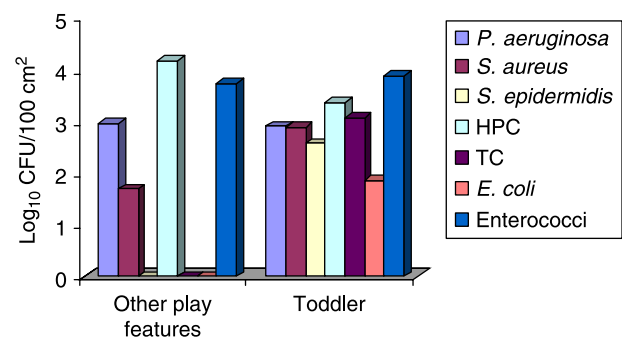


Figure 5 | Comparison of target organisms detected on play features and those designed and used by toddlers.

tested for the presence of serotype 0157:H7 and results were negative.

E. coli and TC were not detected on adult play features, although both were detected on toddler swings. Enterococci were found on both adult and toddler play features at levels as high as 5,592 CFU/100 cm² and 7,619 CFU/100 cm², respectively (Figure 5). Play features designed for young children and babies were likely vehicles for transference of gastrointestinal bacteria. The only play features with *E. coli* were those where young toddlers sit, such as baby swings. Some play features did not come with cleaning protocols, leaving pool operators to determine adequate sanitation for these materials.

Padding materials and relative risk for bacterial presence

Padding materials are defined as any impact-attenuating material designed to prevent contact injuries (e.g. abrasion,

Table 2 | Average values of target organisms detected on rubber and fabric toddler features

Organism	Log ₁₀ CFU/100 cm ²	
	Rubber	Fabric
<i>P. aeruginosa</i>	2.1	2.8
<i>S. aureus</i>	2.1	2.6
<i>S. epidermidis</i>	1.5	2.8
HPC	3.5	4.5
TC	0.4	2.7
<i>E. coli</i>	0.0	2.2
Enterococci	1.0	3.9

bruising and minor trauma). These materials undoubtedly contribute to the health and well-being of water park visitors. However, the opportunity for biofilm development (bacterial accumulation) exists because of the aquatic environment and in spite of bactericidal levels of chlorine. We looked at 16 pad materials from different parks and locations and rated them based on the quantity of bacteria found on the materials, then used the statistical relative risk determination by Griffin *et al.* (1999). Although target organisms were sub-divided into two categories of faecal indicators (*E. coli*, enterococci and TC) and skin indicators (*Pseudomonas*, *S. aureus*, *S. epidermidis* and heterotrophs), the two values were combined to determine risk rank based on the presence of bacteria. The top four risk-ranked samples were padding materials, all collected from indoor pools. Foam with coating in damp conditions, >3 years or <6 months were ranked 1 and 2, respectively, while poured-in-place rubber (damp) and foam with coating (submerged), both >3 years, were ranked 3 and 4, respectively.

Target organisms were most frequently found on plastic-coated foam pad materials, in damp and indoor locations, but least frequently found on dense rubber materials. Materials in a submerged location were generally ranked lower risk than materials in a damp location. Age of material did not impact the rankings. Permanent poured-in-place surface-attenuating materials ranked second in faecal indicators and third of sixteen in total indicators detected.

Bacterial populations were lower in samples from pad materials constructed with dense rubber compared with foam rubber. It is noteworthy that one of the foam pads was negative for TC and enterococci when sampled via swab method, but pieces of material removed from the same mat tested positive (data not shown). This comparison suggests that the method of sampling could be a factor in test results, especially when the sample consists of material with a water-permeable or porous interior. However, removing pieces of material was not acceptable for many features in this study and the swab method was the default alternative.

Target organisms released by padding compression

Although water samples from pools equipped with landing pad materials under small slides contained very low numbers

of target organisms, we further evaluated materials to determine whether compressible padding material might discharge target organisms when under the weight of a 25-kg bather. To mimic this effect, a sterile 25-kg piston was thrust against submerged padding material while pool water was simultaneously collected. Before mat compression, pool water was relatively free of target bacteria; only heterotrophic organisms were found. However, water collected during mat compression contained heterotrophic bacteria as well as *S. aureus* and *S. epidermidis*. Before compression, the average HPC count in water above the pad was 2.4 log₁₀, or 257 CFU/100 ml. *S. aureus* and *S. epidermidis* were not detected. After compression, HPC counts averaged 4.0 log₁₀, or 9,260 CFU/100 ml, and *S. aureus* and *S. epidermidis* averaged 2.4 and 2.0 log₁₀ (228 CFU/100 ml and 100 CFU/100 ml), respectively (Table 3).

The study results suggest that using landing pads on the bottom of a pool or waterslide potentially releases more bacteria into the pool recirculation system. Faecal indicators were not released from the compression studies, although this could be due to the inherent difficulty in sampling and potential errors of capturing the organisms in these methods. Mats could offer protection from residual chlorine to these organisms, but it is not known how long they could survive after release from the mats.

Evaluation of permanent poured-in-place surface-attenuating materials

This study compared wading pools with or without permanent poured-in-place surface-attenuating materials used on pool basins to cushion the impact. These materials reduce abrasions and documented injuries in playground and water park areas (data not shown). Personal interviews with park owners revealed that injury occurrences in areas

Table 3 | Target organisms detected in waters before and after compression of a landing pad under a pool slide

Organism	Log ₁₀ CFU/100 ml	
	Pre	Post
<i>S. aureus</i>	0	2.4
<i>S. epidermidis</i>	0	2.0
HPC	2.4	4.0

with these surfaces are less frequent than in those with the rough exposed aggregate surface of standard basins. The manufacturer's documentation requires free chlorine residual in the water to be below 3 ppm for use of their product. The majority of the wading pools tested in the study had residuals over 3 ppm. This may explain why neither material maintained its integrity throughout the 2 years. Both types of material were degrading; pieces were observed floating in a pool. Because pieces harbour bacteria (permanent poured-in-place surfacing material ranked third in pad materials risk), the possibility of illness from accidental ingestion of contaminated materials may be possible, albeit highly unlikely.

Water samples from wading pools with permanent poured-in-place pad materials in pool basins had the highest number (16.5%) of target organisms detected (Figure 1). All but one of the positive samples had chlorine residuals above 2.8 ppm. Water from wading pools with permanent surfacing materials is ten times more likely to contain *P. aeruginosa* than from pools without basin materials, and is three times more likely to contain *S. aureus*. In addition, when water samples from wading pools with permanent surfacing materials were compared with wading pools without the material, the frequency of indicator bacteria tripled in pools with the materials.

The American Society for Testing and Materials (ASTM) International has created a task group to develop an Interactive Play Equipment Standard that establishes guidelines for the manufacture and maintenance of play equipment. ASTM says all impact-attenuating surfaces shall be self-draining, non-slip, not retain water and not create an environment that results in the growth of algae or bacteria (Iverson 2005).

Examination of common non-pool areas

Common areas of the water parks include locker rooms or lounging decks not necessarily associated with bathing. Because bathers commonly come in contact with such areas when entering and exiting pools, some surfaces and standing puddled waters were sampled for target organisms. Although pool water samples associated with these areas were free of target organisms (data not shown), bacteria were detected on rubber mat material used on the floor of a

Table 4 | Target organism detection on wading pool decks

Organism	Log ₁₀ CFU/100 cm ²
<i>P. aeruginosa</i>	2.6
<i>S. aureus</i>	3.3
<i>S. epidermidis</i>	2.8
HPC	4.5
TC	3.8
<i>E. coli</i>	4.0
Enterococci	3.8

locker room, on the deck area itself (Table 4) and on handrails on stairs to water attractions (Table 5). Although *E. coli* were not isolated from the locker room floor samples, all other target organisms were detected 100% frequency. Additionally, enterococci, heterotrophic bacteria, *S. aureus* and *S. epidermidis* counts exceeded maximum detection limits in 30 to 100% of the trials. *E. coli* were isolated from a handrail, deck entrance to a wading pool and water collected from three deck areas not sloped to drain. One sample from a wading pool deck contained 18,420 CFU/100 ml. Standing water in deck depressions in high-traffic areas would be particularly prone to bacterial proliferation because the free chlorine titre is depleted as the water drains from bacteria-laden skin and garments (data not shown). These puddles of water may support viability for days in the absence of a thorough sanitation procedure and should be considered in inspection criteria.

None of the *E. coli* strains, which were further tested for serotype 0157:H7 characteristics, was positive. This is not surprising because Rice *et al.* (1999) found that *E. coli* 0157:H7 was reduced by approximately four orders of magnitude with 1 minute exposure time to 1.1 mg l⁻¹ free

Table 5 | Target organisms detected on handrail of water attraction

Organism	Log ₁₀ CFU/100 cm ²
<i>P. aeruginosa</i>	2.5
<i>S. aureus</i>	1.6
<i>S. epidermidis</i>	2.1
HPC	3.9
TC	4.4
<i>E. coli</i>	3.9
Enterococci	3.5

chlorine and free chlorine levels in most pool water samples were over 1.0 ppm.

Results show that common areas should be evaluated during inspection and daily maintenance. Manufacturers should provide cleaning procedures so water park staff can adequately clean and maintain the materials.

CONCLUSION

Most water samples collected for this study were within safe levels of bacteria and compliant with Wisconsin code. *E. coli* was not detected in any pool water samples. Plunge pools had the highest percentage of faecal and skin indicators detected compared with activity and wading pools. Waterslides terminate into plunge pools and can dislodge bacteria from bathers. An estimated 86.9 million persons (32.40% of the population) are colonized with *S. aureus* (Mainous *et al.* 2006). It is not surprising to find staphylococci or faecal indicators in these waters because of the velocity of water pushing bathers into the plunge pool.

Wading pools are intended for use by the youngest water park visitors: infants and toddlers. Wisconsin code requires these pools to maintain a free chlorine residual at or above 2 ppm, and many samples had even higher levels. Wading pools without permanent surfacing materials contained the least target organisms, 5.6%, perhaps because of the higher free chlorine level required and detected. These pools harbour faecal indicators on play features and both submerged and damp pad materials.

E. coli or TC were not detected on adult play features, although both were detected on toddler swings located in wading pools. Play features designed for infants and toddlers were found to be likely vehicles for transference of gastrointestinal bacteria.

Generally, our data show that pool water samples contained the smallest number of target organisms, followed by submerged samples of features and pads. The highest rate of positive samples was features and pads in the damp category. The spatial approximation to chlorinated pool water may correlate with the frequency of positive samples. The array of target organisms isolated from damp features suggests that, in the absence of exposure to chlorinated pool water, such features should be sanitized on a routine basis

using a combination of chemical and physical methods, preferably as recommended by the manufacturer. Organisms isolated from submerged features probably survive because of biofilm protection and/or hindrance to the access of chlorinated water. However, free-floating organisms, originating either from biofilms or bathers, were apparently controlled by chlorination.

The benefits of preventing impact injuries by using pad materials are appreciated and no epidemiological evidence exists linking pad materials to disease transmission. However, the frequency of bacteria detected in pools using permanent surface pad materials increased compared with pools without the materials. Study results also suggest that using landing pads on the bottom of a pool or waterslide potentially releases more bacteria into the pool recirculation system. We recommend that if pad materials and play features are used, they should be considered in inspection criteria because some offer protective environments where opportunistic pathogens such as *Pseudomonas* and *Staphylococcus aureus* can flourish. Special care and time should be dedicated for these additional features in the pool area. Manufacturers should provide cleaning and sanitizing recommendations with their products. When selecting materials used in water parks, the potential for microbial proliferation and long-term functionality should be considered. For example, toddler swings made of rubber are more easily sanitized than those made of woven fabric. This study suggests that wood may not be a suitable material for water park features because even when wood is not submerged, it retains moisture from bathers and becomes an environment for bacterial growth (data not shown).

All parks were found to be operating within proper sanitation parameters when surveyed during unannounced visits. Bacteria isolated at these water parks during this study might be typical of any public or private facility. For example, in a survey of Japanese households, Ojima *et al.* (2002) repeatedly found coliforms and *Pseudomonas* in locations such as refrigerators and dish racks, respectively, at levels of up to 10,000/100 cc². The number of reported water park-related outbreaks translates to an extremely small risk when compared with the number of bathers frequenting such facilities. Pool water is an efficient vehicle for transporting residual chlorine to bacteria, and the low incidence of positive samples reflects this.

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