This Health Hazard Evaluation (HHE) report and any recommendations made herein are for the specific facility evaluated and may not be universally applicable. Any recommendations made are not to be considered as final statements of NIOSH policy or of any agency or individual involved. Additional HHE reports are available at http://www.cdc.gov/niosh/hhe/.

CDC Workplace Safety and Health

Investigation of Employee Symptoms at an Indoor Waterpark

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DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
NIOSH *National Institute for Occupational Safety and Health*

The employer shall post a copy of this report for a period of 30 calendar days at or near the workplace(s) of affected employees. The employer shall take steps to insure that the posted determinations are not altered, defaced, or covered by other material during such period. [37 FR 23640, November 7, 1972, as amended at 45 FR 2653, January 14, 1980].

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Appendix A

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Acknowledgements

Abbreviations

ACGIH®	American Conference of Governmental Industrial Hygienists
ACH	Air changes per hour
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ANSI	American National Standards Institute
CDC	Centers for Disease Control and Prevention
CFD	Computational fluid dynamics
cfm	Cubic feet per minute
cm	Centimeter
DBP	Disinfection by-products
DIN	Deutsches Institut für Normung e.V. (German Institute for Standardization)
DPD	N,N diethyl-p-phenylene diamine
EU	Endotoxin unit
ft	Feet
g/L	Grams per liter
GWL	Great Wolf Lodge
HVAC	Heating, ventilating, and air conditioning
INRS	Institut National de Recherche et de Securite (National Institute of Research and Safety)
LAL	Limulus amoebocyte lysate
LOD	Limit of detection
LOQ	Limit of quantitation
mg/L	Milligrams per liter
mg/m^3	Milligrams per cubic meter
mL	Milliliter
mj	Millijoule
mm	Millimeter
NAICS	North American Industry Classification System
NCEH	National Center for Environmental Health
NIOSH	National Institute for Occupational Safety and Health
no.	Number
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PBZ	Personal breathing-zone
PEL	Permissible exposure limit
ppm	Parts per million
REL	Recommended exposure limit
RH	Relative humidity
RLV	Relative limit value
SQRT	Square root
STEL	Short term exposure limit
TLV®	Threshold limit value
TWA	Time-weighted average
µg	Microgram

Abbreviations (continued)

µm	Micrometer
UV	Ultraviolet
WCCHD	Warren County Combined Health District
WEEL	Workplace environmental exposure level
WHO	World Health Organization

Highlights of the NIOSH Health Hazard Evaluation

The Warren County Combined Health District asked the National Institute for Occupational Safety and Health (NIOSH) to assist in investigating the cause of symptoms reported at the Great Wolf Lodge (GWL) indoor waterpark resort in Mason, Ohio. Symptoms included cough, wheezing, shortness of breath, eye and nose irritation, and skin rashes. We conducted our investigation in March and April 2007.

What NIOSH Did

- We tested the air for trichloramine, soluble chlorine compounds, and endotoxin.
- We tested the water for fecal contamination, *Legionella*, mycobacteria, endotoxin, sulfites, and sulfates.
- We checked the water chemistry and reviewed the water system design.
- We administered questionnaires to GWL employees about their health.
- We reviewed the ventilation system design.

What NIOSH Found

- We found trichloramine concentrations similar to levels found in other indoor swimming pool studies, and some were at levels reported to cause mucous membrane irritation.
- We found air endotoxin concentrations at levels that have been associated with cough and fever.
- We did not find fecal contamination, *Legionella*, mycobacteria, sulfites, or sulfates in the pool water.
- We found that water chemistry results met Ohio state standards.
- We found that lifeguards had more work-related symptoms than employees not working inside the indoor pool area.
- We found that lifeguards had more work-related cough and eye irritation on days when the number of people using the indoor pool area was high.
- We found that the ventilation system design may not provide adequate air movement and distribution.

What Managers Can Do

- Managers should further assess the ventilation system to ensure enough air movement and proper removal of contaminants.
- Managers should consider reducing water attraction cycle times and using larger droplet discharge nozzles to reduce aerosolization of contaminants.
- Managers should consider redesigning the spray feature piping system to make sure that water used in the pools is taken directly after the filtration and treatment cycle.

- Managers should monitor and document any symptoms reported by employees and patrons.

What Employees Can Do

- Employees should report any symptoms that may be work-related to their supervisors.

In March 2007, NIOSH received a technical assistance request from the WCCHD to investigate the cause of symptoms reported by employees at the GWL indoor waterpark resort in Mason, Ohio. Reported symptoms included respiratory symptoms, eye and nose irritation, and skin rashes.

Lifeguards had significantly more work-related symptoms than employees who did not work in the indoor pool area; they had more symptoms on days when hotel occupancy was high. We found airborne chloramines and endotoxin, which may have contributed to reported symptoms. We recommend evaluating the ventilation system design to identify ways to increase air movement and reduce air contaminant levels at the pool deck level.

In March 2007, we visited the site for the first time. We met with management, WCCHD representatives, and an employee lifeguard representative; toured the facility; and interviewed workers in a private setting.

In March and April 2007, we collected area air samples for trichloramine, soluble chlorine compounds, and endotoxin. We also measured air temperature and RH, and administered questionnaires to employees regarding medical, job, and personal history; and work-related symptoms. Water chemistry tests were performed, and water samples were collected for *Legionella*, fecal coliform bacteria, mycobacteria, endotoxin, sulfites, and sulfates. A review was conducted of the water system and ventilation system designs.

The trichloramine concentrations we measured were similar to those found in other indoor swimming pool studies and some were at levels reported to cause mucous membrane irritation. Air endotoxin levels in all pool areas, except the waterfort, exceeded the ACGIH proposed RLV for endotoxin exposure (10 times the background level when symptoms consistent with endotoxin exposure are reported). Water chemistry results met Ohio state standards. No *Legionella*, mycobacteria, or fecal coliform bacteria were found in any of the water samples collected.

Lifeguards had significantly more work-related respiratory symptoms, eye and nose irritation, fever, body aches, and skin rashes in the 4 weeks prior to questionnaire completion than employees who did not work in the indoor pool area. The prevalence of work-related cough and eye irritation among the lifeguards was significantly higher on days when hotel occupancy was high.

Ventilation design concerns include the placement of air supply diffusers and return air inlets at heights of 30–80 ft above deck level. This height makes it difficult to provide adequate air movement and mixing at the pool surface and deck levels and creates the potential for short circuiting of supply air to exhaust.

This report contains recommendations for decreasing the chloramine exposures thought to cause the reported symptoms, including modification and redesign of the ventilation system to increase air movement at the pool deck level.

Keywords: NAICS 713990 (All Other Amusement and Recreation Industries), chloramines, trichloramine, nitrogen trichloride, indoor waterpark, pools, hot tubs, spas, sulfates, sulfites, endotoxin, fecal coliform, relative humidity, *Legionella***, mycobacteria, cough, respiratory symptoms, rash, eye irritation**

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Introduction

In March 2007, NIOSH received a technical assistance request from the WCCHD to investigate the cause of symptoms reported by employees at the GWL indoor waterpark resort in Mason, Ohio. Reported symptoms included cough, wheezing, shortness of breath, chest tightness, sore throat, eye and nose irritation, and skin rashes.

The WCCHD began receiving health complaints from GWL patrons in January 2007. GWL management responded by inspecting the ventilation system, water filtration system, and water chemistry. Water chemistry tests were also performed by the WCCHD, and results complied with state codes [Ohio Department of Health 2003]. GWL hired a consultant to take chlorine air samples on January 31, 2007. The nine chlorine air samples were taken over 15 minutes at various locations in the pool area and had concentrations below the NIOSH REL of 0.5 ppm and the OSHA PEL of 1 ppm. Chlorine levels were highest around the leisure river attraction at 0.4 ppm. Even though this level was below both the NIOSH REL and OSHA PEL, GWL added two supply diffusers to the air ducts above this area and one supply diffuser above the hot tub area on March 9, 2007. GWL also increased water chemistry checks from every 4 hours to every 2 hours, reduced water chlorine concentrations to the lowest concentration possible while still maintaining it above the minimum state-required level, reduced pH, lowered air temperature and humidity levels, and added more fresh water to all systems. However, WCCHD continued to receive health complaints from patrons, prompting a technical assistance request to NIOSH.

In March 2007, we visited the site for the first time. During the site visit, we met with management, WCCHD representatives, and an employee lifeguard representative; toured the indoor waterpark; and privately interviewed several lifeguards about their medical status. Most of the interviewed lifeguards reported eye and respiratory irritation at work. They also reported recurrent cough with fever. Lifeguards reported that their symptoms were worse when the bather load (number of people using the indoor pool area) was high and when outdoor air temperatures were colder. Based on those medical interviews, we determined that further investigation was warranted.

In March and April 2007, we collected area air samples for trichloramine, soluble chlorine compounds, and endotoxin. We also measured temperature and RH, and administered questionnaires to employees regarding medical, job, and personal history as well as work-related symptoms. Water chemistry tests were performed and water samples were collected for *Legionella*, fecal coliform bacteria, mycobacteria, endotoxin, sulfites, and sulfates. A review was conducted of the water system and air distribution system designs. An interim letter was provided on April 9, 2007, with the preliminary results of the air sampling performed on March 20, 2007.

Process Description

GWL is an indoor waterpark resort chain with 10 locations across the United States. The Mason, Ohio, facility opened on December 14, 2006, and includes room suites, an indoor waterpark, conference center, fitness center, restaurants, shops, and an arcade. The Ohio Department of Agriculture's Division of Amusement Ride Safety maintains jurisdiction over the aquatic amusement rides and associated pools, and the WCCHD maintains jurisdiction over the two hot tubs. The approximately 80,000-ft^2 waterpark has 11 waterslides, two activity pools, two hot tubs, a wave pool, a leisure river, a four-story interactive play system, and a variety of water features that splash, spray, and aerate large amounts of water. The total water volume at the GWL is over 400,000 gallons, the total water surface area is over 15,000 ft^2, and the depth ranges from 0 to 5 ft. The maximum occupancy for the waterpark is 3746 [Ohio Fire Code 2006], and guests can visit the pool area from 9 a.m. to 10 p.m.

GWL employs about 500 employees at the Mason facility. Of the approximately 100 lifeguards, 50%–60% are under 18 years of age. Due to employee turnover, the number of lifeguards fluctuates, but approximately 30% work full-time and 70% work part-time. Lifeguards work mainly two shifts: 8:30 a.m. to 4:30 p.m. and 4:00 p.m. to 11:00 p.m., with a few working the 11:00 a.m. to 8:00 p.m. break shift. Lifeguards patrol a defined section of the waterpark and rotate through different locations every 30 minutes.

Water Systems

The GWL has seven major water systems that circulate, disinfect, and filter water 24 hours a day. Each water system is self-contained with individual monitoring and regulating components. Water flows by gravity through the main drains and gutter systems from the pool into designated surge tanks. Water for the spray features is drawn directly from the surge tanks. However, most of the water is pumped out of the surge tank into the filtration system. The filter contains synthetic diatomaceous earth filter media which removes particles down to 1.0 micron [Zajo 2008a]. Filter beds are agitated nightly to redistribute the filter media and accumulated debris into a uniform filtering surface. Filter media is replaced approximately every 3 weeks. The filter influent and effluent pressure is checked daily to monitor the filtration efficiency.

The filtered water then passes through a UV unit, which operates at a minimum of 60 mj/cm^2 to break down combined chlorine and provide secondary disinfection. Naturally occurring levels of iron or manganese in the incoming public water supply may deposit as a residue on the UV quartz sleeves. When enough residue accumulates so that the light emitted through the quartz sleeve falls below 60 mj/cm^2, a real-time monitoring sensor in the UV unit shows a low dose reading. Additionally, technicians check the sensor readings every 2 hours. If a low dose reading is observed, the fouled sleeves are cleaned with a dilute acid solution to remove the residue.

The water then passes through an automated chemical controller system that monitors and maintains water pH and free chlorine. As needed, the controller injects sulfuric acid solution (to adjust the pH of the water) and sodium hypochlorite solution (to disinfect the water) into the recirculation pipe. After the water chemistry is adjusted, the water is heated to maintain pool temperature. The water is then sent back to the pool through floor diffusers.

In addition to the automated chemical controller system, technicians manually check water chemistry parameters including pH, alkalinity, free chlorine, and combined chlorine. Technicians take water samples from valves installed in each of the systems near the automated chemical controllers and test water chemistry. The results are recorded in a log book. Water samples are also collected poolside at elbow-length depth during park opening and closing times, and are compared with the automated chemical controller readings. GWL aims to maintain pH between 7.2 and 7.4, combined chlorine less than 0.2 ppm, and free chlorine concentrations between 1.2 and 1.6 ppm. GWL's target range for total chlorine is 1.5 to 2.0 ppm for pools and 2.5 to 3.0 ppm for the hot tubs.

Water levels are checked visually every 2 hours by technicians and continuously by automated autofill devices. An autofill device monitors the water level by using floats in the surge tanks and adds fresh water when the water level falls below a predetermined setpoint. GWL replaces all water from the family and adult hot tubs at least once a week. Technicians also perform a complete water change of the hot tubs if the combined chlorine concentrations rise above set levels.

The water for GWL's water features comes from separate well fields, one located on the east side of the Little Miami River Buried Valley Aquifer and the other at Shaker Creek Buried Valley Aquifer. Iron and manganese are removed by aeration and filtration; fluoride and chlorine are added. The supply water is not chloraminated.

Ventilation System

Eight air handling units provide heating and ventilation to the GWL indoor waterpark area. Each unit is designed to provide an air supply flow rate of 18,830 cfm to the waterpark through a 48-inch diameter main duct. The actual flow rate, however, may differ depending on the system design and installation. The units operate in different modes depending on outside environmental conditions and control set points. The units also recover heat from the exhaust air. The control set points for each air handling unit are 86°F air temperature and 83°F water temperature [Zajo 2008a]. The RH set point range is 55%–65%. Feedback from temperature and humidity sensors in the return air ducts of each individual air handling unit is used to maintain the overall temperature and humidity within the control set points.

When the outdoor air temperature is above 40°F, the air handling units provide 100% outdoor air with no air recirculation [Neuman 2007]. Below 40°F, the air handling units recirculate an increasing amount of air to a maximum of 33% (minimum 67% outdoor air supply) based on the outdoor air temperature. Two return air intakes are located at deck height along the north wall of the waterpark near the family hot tub pool and the wave pool. Each of these intakes returns approximately 19,000 cfm to the air handling units. An additional four return air intakes are located approximately 60–80 ft above the pool deck on the north wall of the middle high bay area of the waterpark. These four high bay return air ducts are 48 inches in diameter and return approximately

38,000 cfm each. According to design drawings, 70% of the return air is pulled from the high bay area, and approximately 30% is pulled from the lower return air intakes.

The air handling units have the capability to recirculate 100% of the waterpark air while in the "unoccupied mode." This mode can be set based on a timer or conditions in the facility. The units are programmed to go into the unoccupied mode one half hour after the facility closes until 2 hours before the facility opens. However, the units may remain in the "occupied mode" during these times if the humidity in the facility is greater than 40% RH.

Air is supplied to the waterpark through a series of 48-inch diameter ducts that run along the ceiling. The air supply ducts are equipped with drum-type diffusers typically 10 x 30 inches in size with a supply flow rate of approximately 1,800 cfm each. In some locations along the main duct, smaller diffusers with lower supply airflow rates are used. The main duct diameter is reduced in size as it extends further from the air handling unit to provide balancing of airflow through the outermost air supply diffusers. The air supply diffusers are located approximately between 30–80 ft above deck level depending on the location, and the return air ducts are located between 60–80 ft above deck level. The four major air supply ducts service: (1) leisure river and water slide; (2) leisure river, wave pool and south concession area; (3) activity pools and play structure; and (4) children's activity pool and hot tubs. Two air handling units supply each of these ducts, delivering a nominal flow rate of approximately 38,000 cfm.

Association of Chloramines and Symptoms in Indoor Pool Environments

Numerous case reports of eye and upper respiratory tract irritation among bathers and employees have been reported at chlorinated indoor swimming pools. Although many DBPs can be produced by the mixture of disinfectants and compounds found in pool water, chloramines, specifically trichloramine, are suspected as a primary cause of reported irritation symptoms based on exposure monitoring studies [Hery et al. 1995; Massin et al. 1998].

Chloramines are DBPs that form when chlorine combines with nitrogen-containing compounds such as sweat and urine. They include the inorganic compounds monochloramine, dichloramine, and trichloramine. Increased bather load has been significantly associated with an increase in trichloramine levels [Jacobs et al. 2007]. This is most likely due to the increase in the amount of nitrogen compounds produced; sweat contains about 1 g/L of nitrogen [WHO 2006], and the average amount of urine released into pool waters per bather is 25 to 30 mL [Gunkel and Jessen 1988]. Behavior modifications such as showering before entering and leaving the pool area, and taking bathroom breaks can decrease the amount of nitrogenous waste contaminating pool water [Dziuban et al. 2006]. Other factors affecting the chloramine concentration in indoor pool environments include water chemistry parameters (e.g., chlorine concentration, pH, temperature), aerosolization of particles caused by splashing and spraying, and air recirculation [Hery et al. 1995; Massin et al. 1998].

Trichloramine is more volatile than monochloramine and dichloramine, and is the main chloramine compound present above chlorinated water surfaces [Holzwarth et al. 1984]. It is a strong mucous membrane irritant [Barbee 1983] and has been associated with eye and upper respiratory tract irritation in swimmers and pool attendants [Massin et al. 1998]. Trichloramine poses less of a health concern in outdoor swimming pools because it dissipates into the earth's atmosphere. However, enclosed indoor swimming pools combined with inadequate ventilation and poor water chemistry control can cause airborne DBPs to accumulate.

Researchers at the INRS in France developed a sampling and analytic method for measuring chloramines in the air [Hery et al. 1998]. NIOSH investigators have developed a draft method that is a modification of the INRS method. A detailed description of the NIOSH sampling and analytical method can be found in Appendix B. These sampling and analytic methods have been used in a variety of workplaces, including indoor swimming pools, poultry facilities, and a green salad processing plant, where chloramine exposure has been linked to eye and upper respiratory irritation [Hery et al. 1995; Hery et al. 1998; NIOSH 2003; NIOSH 2006].

Additional information on OELs and health effects of chloramines can be found in Appendix C.

Water

On March 20, 2007, representatives from WCCHD, NIOSH, and NCEH toured the aquatic facility including chemical storage, disinfection monitoring and injection, recirculation and filtration systems, and the seven aquatic features. Pool water was tested for pH, free and total chlorine, and alkalinity. The NCEH investigator reviewed the construction plans to assess water system design, including water recirculation, filtration, and disinfection processes.

On March 28, 2007, environmental health staff from the WCCHD and the Ohio Department of Health completed the CDC Environmental Health Outbreak Investigation Survey to assist the overall investigation. This environmental health system assessment included a comprehensive review of the aquatic facility including a description of the water systems, water flow and treatment design, and hygiene policies and practices.

Ventilation

We interviewed maintenance managers and the ventilation design contractor to obtain information on the operation and maintenance of the air distribution systems. A visual inspection was made of the ventilation system serving the pool area, including the air handling units, and height and location of supply and return diffusers. Parameters such as pool and deck area, overall air supply flow rate, and air change rates were determined using copies of mechanical plans, blueprints, and air handling unit drawings provided by GWL and their ventilation contractor. Nominal design air supply flow rates provided on the air handling unit drawings were compared to those measured by an independent test and balance technician certified by the National Environmental Balancing Bureau in 2007. The total square footage and volume of the indoor waterpark area were calculated and used to compute outside ventilation rates per pool and deck area for comparison with building code and consensus standards. We also contacted the Mason building inspector to discuss the Ohio Building Code and inspection process.

Industrial Hygiene

We have highlighted the sampling methodology in the sections below. Additional details on sampling and analytical methods can be found in Appendix B.

Chloramine Measurements

Trichloramine and soluble chlorine compounds (monochloramine, dichloramine, hypochlorous acid, and hypochlorite) were collected using the same sampling train; therefore, unless specified, the term chloramines, refers to both trichloramine and soluble chlorine compounds.

To assess the effect of bather load on air chloramine levels, we collected area air samples for chloramines on high and low bather load days (as approximated by hotel occupancy). March 20 (1153 guests booked) and April 14 (1308 guests booked) were selected as high bather load days, and April 24 was selected as a low bather load day (70 guests booked). No PBZ samples were taken because PBZ sampling equipment attached to the lifeguards could interfere with their rescue duties and get wet. Chloramine samples were taken at eight locations approximately 3–4 ft above the deck in the pool area of the indoor waterpark, and a control sample was taken in an administrative office outside the pool area. An additional sample at the waterfort location was taken on April 14 only.

On March 20, 2007, trichloramine concentrations were measured over one 8-hour shift in 4-hour increments, and the soluble chlorine concentrations were measured in 2- and 4-hour increments. The soluble chlorine concentrations were measured over varying time periods to assess whether the humidity in the pool area would saturate the sampling media. On April 14 and April 24, both trichloramine and soluble chlorine samples were taken over two consecutive 8-hour shifts in 4-hour increments, and over a 2-hour increment before the pool opened and after it closed.

Temperature and RH were monitored alongside each chloramine sampling location. Data was recorded every minute using a Hobo® H8 Pro Series data-logger (Onset Computer Corporation, Pocasset, Massachusetts), and spot measurements were taken with a Q-Trak™ Plus monitor (TSI, Model 8554, Shoreview, Minnesota).

Endotoxin Measurements

Area air and bulk water endotoxin concentrations were measured because of lifeguard reports of recurring fever, body aches, and chest-flu (fever and cough or pneumonia) symptoms. Bulk water samples for endotoxin were taken poolside from each water filtration system and two of the surge tanks (children's pool and leisure river) on April 14, 2007. Control samples were taken from the restroom tap water. Area air samples for endotoxin concentrations were collected throughout the waterpark, and a control sample was taken in an administrative office.

Microbial Measurements

Bulk water samples for *Legionella* and mycobacteria were obtained to identify other possible causes of respiratory symptoms. Bulk water samples were taken at nine locations, with at least one sample collected poolside from each water filtration system and two of the surge tanks (children's pool and leisure river) on March 28, 2007. Water samples were taken for fecal coliform bacteria at the same locations on April 24, 2007, to check for fecal contamination.

Sulfate and Sulfite Measurements

Bulk water samples were taken poolside for sulfates and sulfites from each filtration system on March 28, 2007. These water samples were taken at the request of GWL management because of certain patrons' beliefs that their skin rash resulted from a preexisting "sulfur allergy."

Medical

Interviews

During the initial site visit, NIOSH physicians conducted confidential medical interviews with 10 lifeguards from the day shift. Management selected eight lifeguards and NIOSH selected two. Interview questions concerned personal characteristics, medical history, job duties, and work-related symptoms.

Symptom Questionnaires

Between March 20 and April 24, exposed individuals (lifeguards working inside the pool area) and unexposed individuals (employees not working inside the pool area) filled out an initial questionnaire concerning demographics, workplace information, smoking status, medical history, episodes of pneumonia or chest flu with fever and cough since working at GWL, and work-related symptoms within the prior 4 weeks. Unexposed individuals worked in Guest Services, Arcade, Bear Claw Café, Buckhorn Retail, and Starbucks. All participation was voluntary; we obtained written informed consent from the parents of all study participants under the age of 18 years.

Lifeguards completed an additional questionnaire at the end of their work shift on days that chloramine air sampling was conducted. It contained questions relating to symptoms experienced during their work shift that day.

Health outcomes of interest included work-related respiratory symptoms (cough, wheezing, shortness of breath, chest tightness), mucous membrane irritation (cough, sore throat, eye and nose irritation), systemic symptoms (fever, body aches), and skin rashes. Participants were asked not to report symptoms associated with a cold or respiratory infection. Symptoms were considered work-related if they occurred on the days or evenings that the employee worked and improved on days off work. Questions about recurrent episodes of pneumonia or chest flu with fever and cough experienced at GWL were used to identify potential cases of hypersensitivity pneumonitis.

Statistical Analysis

Statistical analysis was carried out with SAS version 9.1.3 software (SAS Institute, Cary, NC). One-way analysis of variance was used to compare the humidity and temperature arithmetic means for various locations in the pool area. A P value ≤ 0.05 was considered statistically significant. Average chloramine concentrations were calculated across location using time- weighted means. To calculate time-weighted means, sampling results that were below the LOD were assigned a value by dividing the LOD by the square root of two. Values between the LOD and LOQ were calculated from the laboratory's best estimate.

Prevalence ratios with 95% confidence intervals were calculated to compare work-related symptoms in the last 4 weeks for the exposed and unexposed employees. A prevalence ratio was considered statistically significant if the 95% confidence interval excluded the number one. Generalized linear models were used to compare respiratory symptoms for the exposure groups while controlling for smoking status (current smoker or not) and asthma status.

An employee was defined as having asthma if he or she had it currently, it was diagnosed by a health professional, and it began before starting work at GWL.

We also calculated prevalence ratios to compare work-related symptoms for lifeguards on days of high and low hotel occupancy. Generalized estimating equations were used to account for possible correlations between responses when a lifeguard filled out the additional questionnaire on more than one day. The analyses involving respiratory symptoms were adjusted for smoking status. Employees with asthma were excluded from these analyses.

RESULTS

Water

Water chemistry results are outlined in Table A1 in Appendix A. Parameters included water pH, and free and combined chlorine concentrations. Multiple measurements in each system were taken to identify potential areas of inadequate water circulation. This can be indicated by differences in water chemistry readings taken from the same water system. Most water systems had consistent measurements; however, differences were noted in some water systems. At the children's pool, water collected at the geyser spray feature had a pH of 7.8, whereas water collected on the west pool edge had a pH of 7.0. In the children's pool water system, the geyser source water is drawn from the feature's surge tank which bypasses the treatment system.

The environmental health system assessment showed that the facility design and individual aquatic features met or exceeded the state's standards. With the exception of two low pH readings (7.0 and 7.1) on March 20, disinfection parameters were acceptable. These low pH readings were not significant when averaged with other acceptable readings taken from the same water system. The water chemistry tests performed on March 20 and during the environmental health assessment on March 28 met state and local standards [Ohio Department of Health 2003]. The free and combined chlorine concentrations recorded in the GWL recordkeeping logs on the days of sampling are listed in Table A2 in Appendix A.

Ventilation

Based on the GWL blueprints, the indoor waterpark area is approximately 80,000 ft^2 and approximately 4 million ft^3 in total volume. Using the square footage, volume, and the air supply volumetric flow rates taken from the test and balance report, the calculated maximum air exchange rate (without recirculation) is approximately 2.0 ACH, and the minimum air change rate is approximately 1.3 ACH (with 33% of air recirculated). The minimum outdoor airflow rate is approximately 88,000 cfm based on the results from the test and balance report and the maximum recirculation condition of 33% during occupied operations.

Industrial Hygiene

Chloramines

Two-hundred and five area air samples were taken inside the GWL pool area. Summaries of measurements collected on high hotel occupancy days 1 and 2 (March 20 and April 14, respectively) and the low hotel occupancy day (April 24) are shown in Tables 1 and 2, with more detailed results in Tables A3, A4, and A5 in Appendix A. Tables 1 and 2 also indicate the percentage of samples that fell below the LOD (non-detectable), between the LOD and LOQ (trace), and above the LOQ (quantifiable).

Table 1. Trichloramine Air Concentrations

Hotel Occupancy	# of Samples	Range (mg/m^3)	LOD (µg/sample)	LOQ (µg/sample)	% Samples below LOD	% Samples between LOD, LOQ	% Samples above LOQ
High Occupancy Day 1	16	ND – 0.66	20	56	6	0	94
High Occupancy Day 2	45	ND – 1.06	9	170	18	62	20
Low Occupancy	38	ND – Trace	30	230	97	3	0

ND = Non detectable (below the LOD).
Trace = Values between the LOD and LOQ.

Table 2. Soluble Chlorine Air Concentrations

Hotel Occupancy	# of Samples	Range (mg/m^3)	LOD (µg/sample)	LOQ (µg/sample)	% Samples below LOD	% Samples between LOD, LOQ	% Samples above LOQ
High Occupancy Day 1	22[a]	ND – Trace	70	250	94	6	0
High Occupancy Day 2	45	0.09 – 0.25	5	16	0	20	80
Low Occupancy	39	ND – ND	20	150	100	0	0

ND = Non detectable (below the LOD).
Trace = Values between the LOD and LOQ.
[a] In some locations, two 2-hour soluble chlorine samples were collected for every 4-hour trichloramine sample.

The LOD and LOQ values varied greatly on each sampling day. The LOD is the level at which the compound of interest can be detected and distinguished from the blank response. The LOD is determined by the variability of the responses of blanks and low level standards. The LOQ is the minimum level that can be reported with confidence. The LOQ is determined either as 3.33 times the LOD or the level at which the minimum recovery for media spikes is 75%, whichever is higher. Trace values, or values between the LOD and LOQ, indicate samples where the compound was detected; however, levels were so low that they could not be quantified reliably.

On high occupancy day 1, 38 chloramine samples were taken (16 trichloramine and 22 soluble chlorine samples). On this day, the majority (94%) of trichloramine samples was quantifiable and the calculated mean was 0.44 mg/m^3. Mean concentrations were calculated at each sampling location. The highest mean trichloramine concentration by location (0.57 mg/m^3) and the overall highest trichloramine concentration collected (0.66 mg/m^3) were at the leisure river attraction, which contains water slides, spray features, and splash pools. The majority (94%) of soluble chlorine concentrations sampled on this day fell below the LOD. Therefore, we did not calculate a mean value for soluble chlorine compounds on this day. See Tables A3–A5 in Appendix A for complete chloramine results.

On high occupancy day 2, 90 chloramine samples were taken (45 trichloramine and 45 soluble chlorine samples). Of trichloramine samples collected on this day, 82% had detectable concentrations; however, only 20% of all samples were quantifiable. Although this data had many non-quantifiable concentrations, it also contained the highest trichloramine concentration found (1.06 mg/m^3) of all samples collected. This high concentration was obtained at the leisure river, which also had the highest mean concentration by location (0.80 mg/m^3). The majority (80%) of soluble chlorine concentrations on this day was quantifiable, with a maximum concentration of 0.25 mg/m^3, and a mean soluble chlorine concentration of 0.17 mg/m^3. No major differences were observed across locations for soluble chlorine.

On the low occupancy day, 77 chloramine samples were collected (38 trichloramine and 39 soluble chlorine samples). All of the soluble chlorine samples contained non-detectable concentrations. Only one trichloramine sample contained a detectable concentration, which was reported at a trace level. Therefore, means for trichloramine and soluble chlorine samples were not calculated.

Endotoxin

Air and water endotoxin levels are shown in Tables A6 and A7 in Appendix A. Air endotoxin concentrations in the pool area ranged from 18 to 84 EU/m^3 with a mean concentration of 45 EU/m^3. These air endotoxin levels were about 10 to 40 times higher than levels taken in an administrative office outside the pool area. The locations with the highest air concentrations were the wave pool (84 EU/m^3) and leisure river (67 EU/m^3). The highest water endotoxin concentrations were also found in the wave pool (61 EU/mL) and leisure river (77 EU/mL). Endotoxin levels were similar in the water systems where samples were taken from both the surge tanks and surface water. Endotoxin concentrations in water samples taken from the hot tubs were very low, and in some cases, measured lower than those found in tap water, which we sampled for comparison.

Air Temperature and Relative Humidity

Average air temperature and RH results are shown in Table A8 in Appendix A. Air temperature averages taken across locations ranged between 82°F and 89°F, with the highest temperatures located at the top of the slide tower. RH averages across locations ranged from 43% to 69%, with high observations noted at the towel rack and near the leisure river. RH and temperature taken at deck level (excludes measurements taken at the top of tower) differed significantly across locations ($P < 0.01$). The average RH varied by about 37% across locations at deck level on high occupancy day 1, and it differed by over 30% across locations at deck level on high occupancy day 2 and the low occupancy day.

Microbials

No *Legionella*, fecal coliform bacteria, or mycobacteria were found in any of the water samples.

Sulfates and Sulfites

Sulfate concentrations in water samples ranged from 940 mg/L to 1600 mg/L. No sulfites were detected. The LOD for sulfite was 0.5 mg/L.

Medical

Interviews

The 10 interviewed lifeguards all reported a cough that they associated with work and that improved on days off work. Three employees had asthma before working at GWL, and one reported that asthma symptoms had worsened since working at GWL. Two employees reported incidents of vomiting caused by excessive coughing, seven reported eye irritation, three reported nose irritation, three reported skin rash, and one employee reported two episodes of flu-like symptoms with cough and fever. One employee reported intermittent blurry and halo vision in one eye. When the visual symptoms occurred, they always started after the beginning of the shift and typically resolved within a couple hours of leaving work. The employee used one contact lens and did not experience blurry vision in the eye with the lens. In general, employees reported that their symptoms were worse when the bather load was high and when the outside temperature was colder.

Initial Questionnaire

Seventy of 103 exposed lifeguards (68%) and 74 of 99 (75%) employees working outside the indoor pool area completed the initial questionnaire within the time period March 20, 2007 – April 2, 2007. Data analysis was restricted to questionnaires received March 20, 2007 – April 2, 2007, because this time period was colder and more representative of the outdoor temperature when initial symptoms were reported. This date restriction excluded data from 12 exposed individuals.

Demographic characteristics are summarized in Table 3. Exposed individuals were younger than unexposed individuals. They were similar in terms of mean work hours per week, personal history of asthma diagnosed by a doctor or other health professional prior to employment at GWL, and personal history of hay fever or other non-drug allergies.

Table 3. Demographic Characteristics

Characteristic	Exposed (N = 69 – 70)	Unexposed (N = 74)
Age – average (range)	20 (16 – 50)	31 (15 – 61)
Male – no. (%)	37 (53%)	24 (32%)
Months in present job class – average	2.8	4.1
Work hours per week – average	31.8	32.6
Smoking, current – no. (%)	16 (23%)	12 (16%)
History of		
Asthma before GWL – no. (%)	12 (17%)	9 (12%)
Hay fever or other non-drug allergies – no. (%)	24 (34%)	29 (39%)
Eczema or atopic dermatitis – no. (%)	2 (3%)	12 (16%)

Exposed individuals were significantly more likely than unexposed individuals to report work-related respiratory symptoms, fever, body aches and eye and nose irritation during the 4 weeks prior to survey completion as shown in Table 4.

Table 4. Work-Related Symptoms[a] Between Exposure Groups

Symptom	Exposed (N = 68 – 70)	Unexposed (N = 74)	Prevalence Ratio (95% CI[b])
	no. of employees (%)		
Sore throat	22 (32%)	2 (3%)	11.80 (2.88 – 48.31)
Cough	48 (70%)	5 (7%)	10.24 (4.33 – 24.23) [c]
Wheezing	20 (29%)	2 (3%)	9.74 (2.36 – 40.19) [c]
Eye irritation	51 (73%)	6 (8%)	8.99 (4.12 – 19.61)
Fever	14 (21%)	2 (3%)	7.62 (1.80 – 32.30)
Shortness of breath	26 (38%)	4 (5%)	6.70 (2.47 – 18.20) [c]
Chest tightness	19 (28%)	3 (4%)	6.67 (2.08 – 21.35) [c]
Body aches	20 (29%)	4 (5%)	5.29 (1.90 – 14.70)
Nose irritation	33 (48%)	10 (14%)	3.54 (1.89 – 6.62)

[a] Symptoms experienced on the days or evenings that the employee worked within the prior 4 weeks, and improving on days off work; surveyed March 20, 2007 – April 2, 2007.
[b] CI denotes confidence interval.
[c] Adjusted for smoking and asthma status.

Exposed employees were also 5.8 times more likely to report an episode of chest flu (defined as fever and cough) or pneumonia since employment at GWL. Among those who reported at least one episode, the average number of episodes was 2.3.

All individuals who reported a history of asthma diagnosed by a doctor or health professional had asthma before working at the GWL. Six of the 10 exposed individuals who still had asthma reported that their asthma seemed worse when at work whereas none of the seven unexposed individuals who still had asthma reported that their asthma was worse at work.

The prevalence of reported skin rash within the prior 4 weeks was 5.0 times higher for exposed individuals than unexposed individuals ($P<0.01$). Of exposed individuals, 41% (29/70) reported having a skin rash compared to 8% (6/73) of unexposed individuals. Among the lifeguards who reported a rash, the most commonly affected areas were: leg (79%), arms (34%), and trunk (28%).

Daily Symptom Questionnaire

Fourteen of 17 exposed lifeguards completed the daily symptom questionnaire during the morning shift on high occupancy day 1, 29/43 during the morning and evening shifts on high occupancy day 2, and 27/33 during the morning and evening shifts on the low occupancy day, for a participation rate of 76%, 67% and 82%, respectively. Most lifeguards working on the high occupancy days reported work-related cough and eye irritation, as shown in Table 5. None reported blurry, foggy or halo vision on the low occupancy day. In contrast, on high occupancy day 2, 9/29 (31%) reported blurry or foggy vision.

Table 5. Daily Work-related Symptoms[a] Among Exposed Lifeguards

Symptom	High Occupancy Day 1 (N = 14)	High Occupancy Day 2 (N = 29)	Low Occupancy Day (N = 27)
	no. of employees (%)		
Cough	9 (64%)	16 (55%)	6 (22%)
Eye irritation	9 (64%)	20 (69%)	9 (33%)
Nose irritation	4 (29%)	10 (34%)	4 (15%)
Wheezing	1 (7%)	7 (24%)	2 (7%)
Shortness of breath	2 (14%)	6 (21%)	4 (15%)
Chest tightness	3 (21%)	5 (17%)	0
Sore throat	6 (43%)	2 (7%)	4 (15%)
Blurry or foggy vision	—[b]	9 (31%)	0
Blue-grey vision	—[b]	3 (10%)	1 (4%)
Halo vision	—[b]	3 (10%)	0

[a] Symptoms experienced at work, starting at beginning, middle or end of shift.
[b] This information was not collected on the initial version of the questionnaire and therefore is missing for date 3/20/07.

Data from high occupancy days 1 and 2 was combined to calculate symptom prevalence ratios comparing high versus low hotel occupancy days. Working on high hotel occupancy days was associated with a significantly increased risk of experiencing work-related cough and eye irritation, as shown in Table 6.

Table 6. Work-related Symptoms[a] Among Exposed Lifeguards On High versus Low Hotel Occupancy Days

Symptom	Prevalence Ratio (95% CI[b])
Cough	2.23 (1.10 – 4.52) [c]
Eye irritation	1.96 (1.22 – 3.17)
Wheeze	2.43 (0.50 – 11.87) [c]
Shortness of breath	1.05 (0.30 – 3.69) [c]
Nose irritation	2.16 (0.83 – 5.59)
Sore throat	1.27 (0.46 – 3.51)
Chest tightness	undefined[d]

[a] Symptoms experienced at work, starting at beginning, middle or end of shift.
[b] CI denotes confidence interval.
[c] Adjusted for smoking status; excludes lifeguards having asthma.
[d] Undefined indicates that prevalence ratios could not be calculated because no one reported symptoms on the low hotel occupancy day.

No significant association existed for blue-grey vision, and prevalence ratios could not be defined for blurry, foggy, or halo vision because no one reported those symptoms on the low occupancy day.

Discussion

The GWL indoor waterpark is a complex pool environment due to several factors: (1) the size of the contained area (about 80,000 ft^2); (2) high water volume (415,000 gallons) and water surface area; and (3) the amount of water aerosolization caused by spray features, water slides, etc. In addition, the indoor pool environment is affected by other factors including: water quality, disinfectants and their by-products, number of bathers, environmental conditions (air and water temperature, RH, etc.), and air handling unit design and function. Also, individual factors including the time spent by employees and patrons in the pool area and personal susceptibility to airborne contaminants (e.g., preexisting asthma, young children with immature respiratory systems) can affect the severity of symptoms caused by DBPs and other contaminants. Control of symptoms caused by DBPs and other contaminants requires a multidisciplinary approach, including air handling unit design, water chemistry controls, limiting aerosolizing spray features, and pool procedures and policies.

Water

Water Mixing and Circulation

The water chemistry differences in some of the water systems can be attributed to incomplete mixing of treated water or use of partially disinfected water. Investigation into the differences in the water chemistry results between the pool and spray features of the same water system showed that all the spray features draw water directly from the surge tanks. Because surge tank water is the starting point of the water filtration cycle, it could contain more contaminants than water taken at the end of the filtration cycle. Even though the spray features contribute a minute amount of water to the pool, any water contaminants present could be aerosolized.

Complete and routine water replacement in both hot tubs may have contributed to their low water endotoxin concentrations. However, this practice may not be feasible for larger bodies of water, and dilution is recommended. Dilution is a method of adding fresh water to decrease the concentration of DBPs not removed by the water treatment system. The WHO recommends a dilution rate of 30 liters of fresh water per bather to decrease the concentration of bather-generated contaminants [WHO 2006]. Adjustments of these rates need to account for evaporation rates, splash-out, elevated combined chlorine and air recirculation mode. Currently, GWL does not record the amount of water used to refresh the system, but is looking at options to measure and better control the amount of water that is removed and replaced.

Water Chemistry

Understanding, monitoring, and controlling water chemistry is an important factor that can limit the formation of DBPs and their migration from water into the air. Several outbreak investigations of respiratory and irritation symptoms at indoor swimming pools have associated symptoms with improper water chemistry control, specifically abnormal levels of pH and combined chlorine [Bowen 2007; Kaydos-Daniels 2007; Safranek 2007]. These studies showed that the combined chlorine levels in water for the majority of outbreaks were elevated on the days symptoms were reported. One Nebraska pool had a combined chlorine concentration of at least eight times the state's maximum allowable level when symptoms were reported [Safranek 2007].

About 80% (14/17) of the pool surface water samples and none of the hot tub surface water measured on March 20, 2007, exceeded the National Swimming Pool Foundation's recommended maximum combined chlorine. The highest combined chlorine levels measured 0.4 ppm, which was not exceptionally high. However, the combined chlorine value found in water does not take into account how ventilation systems and air movement affect the chloramine levels in the air. An indoor pool with normal combined chlorine levels can have high air trichloramine levels if there is insufficient intake of fresh air [Stottmeister and Voigt 2006]. Conversely, an indoor pool with relatively high combined chlorine levels can have normal air trichloramine levels if the ventilation system is highly efficient. Therefore, interpretation of combined chlorine results needs to take into account ventilation efficacy.

The state of Ohio does not have a combined chlorine standard, however, several other consensus guidelines and standards can be used to compare the combined chlorine concentrations measured at the GWL: (1) The Certified Pool-Spa Operator Handbook [Ford 2007]; (2) other state codes; and (3) the German DIN Standard 19643 [DIN 19643 1997]. The National Swimming Pool Foundation recommends a maximum combined chlorine concentration of 0.2 ppm for pools and 0.5 ppm for spas and hot tubs [Ford 2007]. The other standards mentioned have similar limits: the German DIN Standard 19643 lists a maximum combined chlorine concentration of 0.2 ppm [Simonic 2003], and several states have code regulations ranging from 0.2 ppm to 1.0 ppm.

Ventilation

The guidelines and standards discussed below were developed to provide adequate ventilation for standard still water-type pools similar to what one might encounter at a hotel or other small recreational facility. The GWL design and active aquatic features differ greatly from standard pools, therefore, the ventilation guidelines currently in place for pool facilities may not be suitable for this environment.

Comparison of Ventilation Rates with Consensus Standards and Guidelines

A number of different consensus standards and guidelines can be used to compare the ventilation rates used at the GWL indoor waterpark: (1) The ASHRAE and the ANSI publication ANSI/ASHRAE Standard 62.1-2007, *Ventilation for Acceptable Indoor Air Quality* [ASHRAE 2007a]; (2) The 2006 World Health Organization Guidelines for Safe Recreational Water Environments, Volume 2, Swimming pools and similar environments [WHO 2006]; and (3) The 2007 ASHRAE Handbook - HVAC Applications [ASHRAE 2007b]. These standards are periodically updated based on the latest scientific research. While the ventilation rates used at the GWL may meet one standard, they may not meet other guidelines or standards.

The state of Ohio incorporates the outdoor air ventilation requirements from ANSI/ASHRAE Standard 62, *Ventilation for Acceptable Indoor Air Quality*, into the Ohio Building Code and applies this standard to ventilation of indoor pool facilities. The standard recommends minimum ventilation rates for acceptable indoor air quality of enclosed spaces. According to this standard, a minimum of 2.4 liters/second per meter^2 (0.48 cfm/ft^2) of outdoor air is recommended to ventilate pool and deck areas of indoor pool facilities. For GWL, this standard corresponds to approximately 40,000 cfm of outdoor air. Based on design information, GWL exceeds this requirement by providing a minimum of 88,000 cfm during maximum recirculation operation. This ANSI/ASHRAE standard ventilation rate is based on the amount of air believed to be sufficient to dilute building and occupant generated contaminants down to an acceptable level. However, recent research on air quality in indoor pools has shown that many pools may have complaints despite meeting typical ventilation guidelines. The WHO recently updated their guidelines for indoor pool environments to recommend a minimum of 10 liters of fresh air per second per meter^2 of water surface area (2 cfm/ft^2) [WHO 2006].

The 2007 ASHRAE Handbook - HVAC Applications recommends air exchange rates between 4 and 8 ACH for indoor pool facilities depending on the use of the pool. The number of ACH is the ratio of airflow ventilation to room volume. GWL provides 1.3 to 2.0 ACH and therefore does not meet this ASHRAE guideline. The use of ACH as a performance standard for ventilation systems has been in place for many years. However, it is not always seen as a good measure of acceptable ventilation for all applications. At GWL, a large majority of the facility air volume is concentrated in a high bay area primarily comprised of unoccupied space. Therefore, the reliance on meeting a minimum number of ACH may not be applicable for this setting. However, the introduction of more outdoor air may be necessary at GWL to effectively dilute the increased contaminant load due to the large number of water spray features and high bather loads.

Air Distribution Design

The design of the air-distribution system may be more important than air exchange rate. Several criteria need to be met to ensure comfort while still maintaining acceptable air quality. For instance, while some airflow is required across the pool and deck surfaces, the amount of airflow should be minimized to prevent drafts on swimmers and to reduce evaporation [Xie and Cooper 2006]. General ASHRAE guidance recommends positioning exhaust air inlets to maximize capture effectiveness and minimize recirculation of chloramines [ASHRAE 2007b]. Chloramine compounds are heavier than air and are more likely to concentrate closer to the pool surface and deck level, and some airflow is required to move them towards an air return.

Adequate airflow rates at deck and pool surfaces are necessary to move the contaminants from the pool to the return ducts so they can be exhausted from the building. One of the major challenges with the air distribution system at GWL is the placement of supply and return air diffusers at heights of 30–80 ft above the pool deck in unoccupied areas. This may create short circuiting of airflow from the supplies to the returns in the high bay area. The height of the supply diffusers above the deck also hinders the ability of the ventilation system to provide adequate air movement at the pool deck area. Additionally, the placement of four large air return ducts approximately 60–80 ft above the pool deck makes them poorly positioned to capture and remove contaminants, such as chloramines, which concentrate at deck level, and does not promote good air movement in the areas of highest occupancy.

The use of computer-based simulations may provide some insight into the design and effect of changes to the air distribution system. CFD modeling is an analytical tool that can provide a detailed visual description of the fluid flow, heat transfer, and contaminant transport. By solving the fundamental equations of conservation of mass, momentum, and energy, a CFD model can provide information including velocity fields, temperature distribution, and chemical species concentration within a region of interest. CFD could be used to analyze existing airflow patterns and to gain insight into the effect of new distribution designs.

We are aware that GWL has changed the air distribution system to attempt to address concerns with stagnant air at deck levels. These changes included lowering three high return air vents to the deck level and installing high throw air diffusers in selected areas. The air handing units' volume of airflow was increased and ductwork changes were made to increase air movement to the front and back areas of the waterpark. GWL estimates that after these changes were made, 33% of the return air is taken from the high bay area and 67% of the air is pulled from the lower return air intakes [Zajo 2008b]. These changes were not evaluated as a part of this study. Prior to these changes, GWL's ventilation contractor performed qualitative airflow testing (using commercial fog machines) in the pool area to observe airflow patterns. NIOSH investigators were not present when the fog testing occurred and we did not review the results.

Air Temperature and Relative Humidity

Pockets of higher levels of RH were consistently seen throughout each sampling period. The variations were significant ($P < 0.01$) and may represent poor air movement at the deck level and potential build-up of contaminants. Pockets of high contaminant concentrations can occur at locations where flow is insufficient to move air to the exhaust ducts, where aerosolization from spray features occurs, or where structures may obstruct air movement.

Chloramines and Associated Symptoms

The trichloramine levels measured at the GWL were similar to levels found in other indoor swimming pool studies and some were at levels reported to cause mucous membrane irritation [Hery et al. 1995; Massin et al. 1998; Thickett et al. 2002; Jacobs et al. 2007]. The symptoms reported by GWL lifeguards are consistent with those associated with trichloramine exposure, and were higher on days when hotel occupancy was high. Hotel occupancy was used as a proxy for bather load, and increased bather load has been significantly associated with an increase in trichloramine levels [Jacobs et al. 2007]. Twenty five percent (4/16) of the trichloramine samples taken on high occupancy day 1 and 20% (9/45) taken on high occupancy day 2 exceeded a concentration of 0.5 mg/m^3, the level at which irritation symptoms have been documented [Hery et al. 1995]. In the Hery et al. study, no one reported symptoms until the chloramine concentration reached 0.5 mg/m^3, and everyone reported symptoms when the levels reached 0.7 mg/m^3. In another study involving 334 lifeguards and 63 indoor pools, the prevalence of mucous membrane irritation among lifeguards exposed to trichloramine levels above 0.5 mg/m^3 was 86% for eye irritation, 61% nose irritation, 29% throat irritation, and 42% dry cough [Massin et al. 1998]. Jacobs et al. measured trichloramine levels at six indoor swimming facilities and found an elevated prevalence of respiratory symptoms in swimming pool workers. They measured a mean trichloramine concentration of 0.56 mg/m^3, with the highest concentration reaching 1.34 mg/m^3. General respiratory symptoms were significantly higher in pool employees compared to the Dutch population sample (odds ratio ranged from 1.4 to 7.2) [Jacobs et al. 2007].

Based on concentration-response data in mice, Gagnaire et al. recommended a STEL of 1.5 mg/m^3 and a TWA of 0.5 mg/m^3 for trichloramine [Gagnaire et al. 1994]. A TWA exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Although proposed standards and past studies indicate that a comfort level for indoor pool areas would be to keep trichloramine concentrations below 0.5 mg/m^3, there have been some concerns that this level may not be low enough to prevent symptoms [Massin et al. 1998]. A study comparing the prevalence of health complaints between teenage swimmers and soccer players showed a significant increase in respiratory complaints at chloramine concentrations of 0.37 mg/m^3 or greater [Levesque et al. 2006]. The WHO recommends using an air trichloramine concentration of 0.5 mg/m^3 as a provisional value, although it states that more research is needed to investigate health effects in people who use the pool for extended periods of time and the role of trichloramine in possibly causing or exacerbating asthma [WHO 2006].

Proper air movement and distribution play a key role in reducing chloramine concentrations and health effects. In 1983, an occupational medicine physician reported a swimmer who developed coughing and wheezing only when visiting a pool equipped with an automatically controlled heat reclamation system [Penny 1983]. Symptoms were worse in the winter months when the heat reclamation system recirculated a higher amount of air to conserve energy. The patient had no respiratory symptoms when he visited an older pool with a simple air extractor. Spirometry demonstrated a 24% to 33% drop in forced expiratory volume in 1 second after swimming in the new pool, compared to a 6% drop in forced expiratory volume in 1 second after swimming in the older pool. The physician suspected that trichloramine caused the respiratory symptoms; however, no accepted method for measuring trichloramine in the air was available at that time.

Recent studies have raised questions about whether inhalation of DBPs may cause or exacerbate existing asthma. A study of two lifeguards and a swimming instructor showed that swimming pool asthma can occur in workers who are exposed to chloramines. The researchers generated trichloramines at 0.5 mg/m^3 in a challenge chamber and exposed the participants to a series of 10-minute exposures followed by spirometry. Results showed a decrease in pulmonary function [Thickett et al. 2002]. Additionally, new research indicates that there may be other volatile DBPs with potentially irritant properties in indoor pool environments [Li 2007].

Water attractions that create surface water disturbances can increase aeration of water contaminants. We found higher concentrations of trichloramine in areas around the leisure river, where there is continuous water movement and splashing. This attraction contains a high water-to-air surface area in constant motion, which can accelerate evaporation. A study conducted at an indoor swimming pool demonstrated that the operation of a water slide increased the number of respirable particles by 2.3 fold and that number increased by 5.2 fold with full water feature use [Rose et al. 1998]. Other studies have looked at chloramine concentration differences between indoor leisure pools (pools containing water-disturbing features like slides) and still water pools. In one study, mean trichloramine levels were 0.24 mg/m^3 at still water pools and 0.67 mg/m^3 at leisure pools [Massin et al. 1998]. Hery et al. also reported that air chloramine concentrations were higher in leisure pools due to the influence of slides, bubbling baths, waves, and other water activities [Hery et al. 1995].

Systemic Symptoms

Lifeguards were more likely to report work-related cough, fever, and body aches, as well as chest flu with fever and cough or pneumonia since employment at GWL. These symptoms together are consistent with hypersensitivity pneumonitis. Hypersensitivity pneumonitis is a rare condition caused by inhaling foreign substances. These substances cause the lungs to become inflamed. In indoor pool environments, this condition can be caused by inhalation of bioaerosols such as endotoxin. The air endotoxin levels measured at GWL were several times higher than background levels, and exceeded the proposed ACGIH RLV for endotoxin exposure (see Appendix C). The average air endotoxin concentration found at GWL (45 EU/m^3) was comparable to the average concentrations measured during sequential outbreaks of hypersensitivity pneumonitis at an indoor swimming pool with water spray features – 76 EU/m^3 during the first outbreak and 28 EU/m^3 during the second outbreak [Rose et al. 1998].

A prior study of lifeguards concluded that hypersensitivity pneumonitis was associated with endotoxin-containing respirable bioaerosols generated by water spray features. Full use of the water features at that pool facility resulted in a 3.5 to 8 fold increase in mean air endotoxin concentrations [Rose et al. 1998]. Water collected from the spray features at the pool grew Gram-negative bacteria, which was presumed to be the source of endotoxin. At this indoor swimming pool, eliminating bacteria found inside the spray features was key to decreasing air endotoxin levels and symptoms.

Skin Rash

GWL patrons raised questions whether allergies to sulfa medications would cause them to have allergic skin reactions when exposed to water containing sulfuric acid. Sulfuric acid can break down to sulfates. However, it is highly unlikely that the skin rash reported by the lifeguards is due to a sulfate allergy. Sulfate allergies are extremely rare, and sulfates are so common that most people have been exposed to them early in life (i.e., sulfates are contained in most personal hygiene products). Additionally, the most common “sulfur allergy” associated with medication is due to sulfonamide, which is chemically distinct from sulfates [Strom et al 2003].

We did not test for Pseudomonas bacteria because the reported skin rashes did not have the typical characteristic of folliculitis or Pseudomonas infection.

The most common areas of skin rash reported among the lifeguards involved the leg, arm, and trunk. These areas are most frequently exposed to “wet work” where the skin is in water. Possible occupational skin irritants include heat, water, and chlorine compounds. Several lifeguards reported a rash between the thighs and in the abdominal skin folds; these areas tend to remain warm and moist. Water can also be an irritant with chronic exposure, and water-induced contact dermatitis among wet workers such as hair dressers, hospital cleaners, hydrotherapists and bartenders, is well documented in the occupational dermatology literature [Tsai 1999; Lazarov 2005; Pardo 2007]. GWL lifeguards rotate through several stations, and at times stand immersed in water up to waist level to catch bathers/tubes exiting from the water slides. Oftentimes, their bathing suits remain wet throughout an entire shift. In addition to water exposure, lifeguards are exposed to chlorine compounds in the water. There have been a few case reports of contact dermatitis associated with swimming in chlorinated pool water [Neering 1977; Sasseville 1999]. However, few formal epidemiological studies exist, and the precise mechanism has not been elucidated. In a recent cross-sectional study of children swimming in either chlorinated or brominated pools, 4%–8%

of respondents developed a skin rash within 24 hours of pool use [Kelsall 2001]. These case reports and studies suggest that several environmental exposures inside the indoor pool area, including heat, water and chlorine compounds, all can contribute to the higher rate of skin rash observed among the lifeguards.

Visual Symptoms

Several lifeguards reported blurry, blue-grey and/or halo vision while at work. All reported that the visual changes were most severe during the cold winter months. While blurry vision could be a reflection of eye irritation, halo vision is much more unusual. A variety of amine compounds have been reported to cause similar visual symptoms. For example, a NIOSH investigation of blurry, halo, and blue-grey vision at a label printing facility linked the symptoms with exposure to a tertiary amine compound. In that investigation, corneal opacity was the cause of the symptoms, and appeared to be due to direct deposition of the amine compound onto the cornea [Page et al. 2003]. We offered to have the same ophthalmologist who performed the eye exams in the label printing health hazard evaluation examine lifeguards with blurry or halo vision to determine if they had corneal opacity. However, at the time the questionnaires were administered, the environmental conditions were much different from when visual symptoms reportedly peaked. As a result, we may not have captured visual symptoms during a time of peak trichloramine exposure, and no lifeguards reported the symptoms when the ophthalmologist was available. In addition, trichloramine differs from the tertiary amine in the previous health hazard evaluation because trichloramine is inorganic and insoluble in water.

Limitations

Due to concern that the sampling equipment would interfere with the lifeguards' rescue duties and get wet, we did not measure personal exposures to chloramines and endotoxin. This limited our ability to evaluate any possible association between chloramine concentrations and reported symptoms. Also, the draft NIOSH chloramine sampling and analytical method is still in development. Because of the wide differences in the LODs and LOQs for each day of sampling, we could not compare the data across all sampling days. Concentrations that were considered above the LOQ one day may have been below the LOD on another day. Therefore, observations could only be made with data from within a sampling day.

Outdoor environmental conditions significantly differed between the period of peak health complaints (January and February) and the days that NIOSH sampling occurred. The outdoor temperature averaged 35°F in January and 20°F in February. When outdoor temperatures are below 40°F, the air handling system starts recirculating indoor air. In contrast, the outdoor temperature remained above 40°F during our sampling periods in March (month average 49°F) and April (month average 52°F). Because indoor air was not recirculated during the dates of NIOSH sampling, the trichloramine and soluble chlorine levels measured in this study may not represent the concentrations present at time of initial reports of symptoms. Also, because lifeguards reported that their symptoms had improved significantly with the warmer weather, the symptom data captured during this investigation may not represent what the lifeguards might have experienced during the colder months when indoor air was recirculated.

A limitation of the ventilation assessment was the difficulty in taking airflow measurements. Standard airflow evaluation techniques such as the use of smoke visualization and tracer gas testing were difficult given the complexity and large size of the waterpark. Instead, air handling system designs were reviewed to identify ways to increase air movement at the deck level.

Environmental and procedural changes made from January to March by GWL in response to patron health concerns could have contributed to reducing air contaminant concentrations on the days we sampled compared to when the symptoms were first reported. Also, the number of bathers may have varied from when reported symptoms peaked (January/February) and our sampling days.

Around the time of survey completion, the media reported on the occurrence of respiratory and skin symptoms at GWL. Because of the heightened awareness, recall bias may have been introduced into the initial questionnaire (lifeguards may have been more inclined to recall symptoms than employees working outside the waterpark area). Also, asthmatics may be more likely to take up swimming instead of other sports because swimming is considered a sport that is less likely to cause exercise-induced asthma. Therefore, swimmers may be more likely to have asthma than people who participate in other sports. However, comparison of work-related symptoms among lifeguards on different dates should minimize this potential bias, and the completion of the daily symptom questionnaire immediately at the end of their shift should minimize recall bias.

Because only 68% of lifeguards filled out the initial questionnaire, participation bias may have occurred. In addition, because several lifeguards were reported to have quit within the study period due to work-related symptoms, our results may underestimate the prevalence of symptoms.

Conclusions

Based on our review of the ventilation system, RH, and trichloramine measurements, the ventilation system at the time of our evaluation may not be providing sufficient air movement and distribution to allow adequate capture and removal of chloramines at the pool surface and deck levels. Ventilation design concerns include the placement of air supply diffusers and return air inlets at heights of 30–80 ft above deck level, making it difficult to provide sufficient air movement at the pool surface and deck levels and creating the potential for short circuiting of supply air to the exhaust ducts. Also, recirculating air during times of high bather load may increase concentrations of contaminants in the air. The fact that the facility's overall air exchange rate is much lower than recommended by ASHRAE is also a concern.

Trichloramine concentrations measured were similar to levels found in other indoor swimming pool studies and some were at levels reported to cause irritation symptoms. Exposed individuals were significantly more likely than unexposed individuals to report work-related respiratory symptoms, eye and nose irritation, fever, body aches, and skin rashes in the 4 weeks prior to survey completion. The prevalence of work-related cough and eye irritation among the exposed individuals was significantly higher on days when hotel occupancy was high.

The water chemistry test results at GWL met Ohio state standards, and no *Legionella*, mycobacteria or fecal coliform bacteria were found in any water samples. Airborne endotoxin levels in all pool areas, except the waterfort, exceeded the proposed ACGIH RLV for endotoxin exposure, and were measured at levels that have been associated with cough and fever.

Air Distribution System

Proper ventilation design is a key component to reducing the levels of airborne DBPs, such as chloramines. To address concerns of stagnant air at deck level, GWL modified the air distribution system based in part on NIOSH recommendations made after the initial ventilation design review. While the changes to the air distribution system may help address the issues discussed in this report, including air movement and contaminant removal at the pool surface and deck level, the effect of these changes were not evaluated as a part of this study. Therefore, we recommend that GWL conduct an evaluation of the air distribution system to determine the effect of the changes made including:

1. Consider measuring deck level air velocity as well as routinely monitoring indirect measures of system performance, such as temperature and RH, at a variety of locations throughout the facility to help assess ventilation effectiveness.
2. Consider conducting ventilation testing such as air visualization tests to help identify potential stagnant areas within the facility.
3. Consider using CFD modeling to evaluate the impact of any air distribution system changes on air movement. CFD is a tool that might be useful to simulate the effect of any changes on air circulation patterns and ventilation efficiency.
4. Evaluate the facility again during cold weather to assess the air quality during times of high bather load and low outdoor temperatures (when maximum air recirculation occurs).
5. Consider increasing the air exchange rate if improvements in air distribution do not adequately reduce chloramine and endotoxin levels.

Water System

1. Keep combined chlorine levels as low as possible and continue to maintain water chemistry within recommended guidelines.
2. Increase the amount of fresh water exchange based on bather load to dilute contaminants in the water.

3. Continue to conduct water chemistry checks at poolside, and compare readings to the Chemtrol monitor to ensure accuracy and consistency.
4. Take multiple readings at various poolside locations within each water system at different times of day and at different bather loads, as often as necessary, to fully characterize the consistency of water chemistry. Also, monitor water quality collected from spray features regularly to ensure they are consistent with state standards and industry guidelines.
5. Consider redesigning the spray feature piping system to take water directly after the filtration and treatment cycle.
6. Reduce the generation of airborne respirable particles by implementing the following:
   a. Use spray nozzles that produce larger droplets, which may help reduce evaporation and aerosolization of DBPs and bioaerosols.
   b. Reduce the cycle time of water features that aerosolize water (large bucket dumps, waves, etc.).
7. Develop disinfection chemistry trends over time using the controllers' data logging features. These trends can help identify contributing factors that occur when symptoms are reported.

Procedure and Policy

1. Provide education and training to employees on recognizing the symptoms and signs of eye and respiratory irritation, skin rash, and asthma.
2. Encourage employees to report symptoms to management early; if needed, refer employees to a physician promptly.
3. Keep a log of employee symptoms related to working inside the indoor pool area, and periodically review the logs to look for trends.
4. Educate patrons on taking showers before entering and after leaving the pool area, minimizing time spent in the pool area, and encouraging children to use restroom facilities rather than urinating in the pool.

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Table A1. Water Chemistry – High Occupancy Day 1			
Feature/ Sample Location No.	pH	Chlorine (ppm) Free	Chlorine (ppm) Combined
Leisure river			
1	7.5	1.0	0.4
2	7.4	1.2	0.4
3	7.2	1.2	0.4
4	7.2	1.2	0.3
Wave			
5	7.4	1.2	0.4
6	7.2	1.2	0.3
7	7.4	1.5	0.4
Activity			
8	7.3	1.3	0.2
9	7.2	1.4	0.4
10	7.3	1.2	0.3
11	7.3	1.0	0.3
Waterfort			
12	7.6	1.0	0.2
Repeat[a]	7.4	1.0	0.3
13	7.2	1.2	0.2
Children's			
14	7.0	1.8	0.4
15	7.3	2.2	0.4
16	7.8	1.8	0.3
Adult hot tub			
17	7.6	2.0	0.2
18	7.3	3.0	0.2
Family hot tub			
19	7.1	2.5	0.4
20	7.2	3.5	0.4

[a] A repeat measurement was taken at location 12.

Table A2. Free and Combined Chlorine Concentrations in Water [a]						
Location	High Occupancy Day 1		High Occupancy Day 2		Low Occupancy Day	
	Free [b]	Combined [c]	Free [b]	Combined [c]	Free [b]	Combined [c]
Activity pool	1.4	0.1-0.3	1.6	0.2-0.4	1.8	0-0.2
Leisure river	1.0	0.1-0.5	1.2	0.3-0.7	2.6	0.05-0.3
Children's pool	2.4	0.3-0.4	1.0	0.4-0.5	1.8	0.1-0.2
Wave pool	1.4	0-0.4	2.0	0.2-0.6	1.8	0-0.2
Adult hot tub	2.0	0.2-0.4	3.0	0.2-0.3	3.6	0-0.2
Family hot tub	2.4	0.2-0.4	1.8	0.3-0.7	3.4	0-0.2
Waterfort	1.8	0.2-0.4	2.0	0.2-0.5	1.8	0-0.1

[a] All concentrations reported in ppm. Data taken from the GWL's Daily Air and Water Quality Logs.
[b] Measurements taken poolside at opening with DPD test kit.
[c] Measurements taken at valves near Chemtrol system with DPD test kit.

Table A3. Trichloramine Air Concentrations by Location and Time – High Occupancy Day 1			
Location	Trichloramine Concentration (mg/m^3)		
	9 a.m.–1 p.m.[a]	1 p.m. – 5 p.m.[a]	Mean[b]
Spirit Island food stand	0.36	ND	0.28
Lily pad pond	0.47	0.37	0.43
Leisure river, by stairs	0.64	0.49	0.57
Top of slide tower	0.46	0.35	0.41
Splash pool by turn slide [c]	0.66	0.49	0.57
Adult hot tub by exhaust	0.55	0.38	0.47
Wave pool	0.61	0.42	0.52
Towel rack	0.39	0.39	0.39
Mean[b]	0.51	0.37	0.44

ND = Non detectable (below the LOD).
[a] Approximate times.
[b] Used LOD/SQRT(2) for values below the LOD. Means were calculated by taking a time-weighted average.
[c] Pump was damaged in the field so post-calibration reading was not possible. To estimate post-calibration flow, we incorporated the average percent error measured by the rest of the pre- and post-calibrated pumps to obtain a post-calibration flow.

Table A4. Soluble Chlorine Air Concentrations by Location and Time – High Occupancy Day 2						
	Soluble Chlorine Concentration (mg/m^3)					
Location	7 a.m.-9 a.m.[a]	9 a.m.-1 p.m.[a]	1 p.m.-5 p.m.[a]	5 p.m.-9 p.m.[a]	9 p.m.-11 p.m.[a]	Mean[e]
Spirit Island food stand	**0.09**	0.17	0.18	0.20	0.20	0.18
Lily pad pond	**0.09**	0.19	0.20	0.17	0.20	0.18
Leisure river, by stairs	0.19	0.20	0.21	0.24	0.15	0.21
Top of slide tower	**0.09**[b]	0.18	0.16	**0.21**[c]	0.21	0.17
Splash pool by turn slide	0.18	0.25	0.21	0.25	0.14	0.22
Adult hot tub by exhaust	**0.09**	0.20	0.20	0.20	0.19	0.19
Wave pool	**0.09**	0.21	0.23	0.21	0.23	0.20
Towel rack	**0.09**	0.16	0.16	0.15	0.18	0.15
Waterfort	**0.09**	0.11[d]	0.13	0.11	**0.09**	0.11
Mean[e]	0.11	0.19	0.19	0.19	0.18	0.18

Values in bold are between the LOD and LOQ.
[a] Approximate times.
[b] Back portion of sample was lost.
[c] Pump failed. Sampled for 43 minutes.
[d] Small amount of sample lost in transfer.
[e] Used LOD/SQRT(2) for values below the LOD. Means were calculated by taking a time-weighted average.

Table A5. Trichloramine Air Concentrations by Location and Time – High Occupancy Day 2						
	Trichloramine Concentration (mg/m^3)					
Location	7 a.m.-9 a.m.[a]	9 a.m.-1 p.m.[a]	1 p.m.-5 p.m.[a]	5 p.m.-9 p.m.[a]	9 p.m.-11 p.m.[a]	Mean[b]
Spirit Island food stand	ND	**0.40**	**0.43**	**0.42**	**0.41**	0.38
Lily pad pond	ND	**0.78**	**0.88**	0.83	**0.60**	0.72
Leisure river, by stairs	**0.09**	0.77	0.93	1.06	**0.74**	0.80
Top of slide tower	ND	**0.39**	**0.45**	ND	**0.47**	0.36
Splash pool by turn slide	ND	0.75	0.90	0.89	**0.70**	0.73
Adult hot tub by exhaust	ND	**0.41**	**0.44**	**0.43**	**0.44**	0.38
Wave pool	ND	**0.41**	**0.85**	**0.86**	**0.54**	0.61
Towel rack	ND	**0.41**	0.77	**0.86**	**0.54**	0.59
Waterfort	**0.09**	**0.43**	**0.87**	0.81	**0.72**	0.64
Mean[b]	0.07	0.53	0.72	0.76	0.57	0.58

Values in bold are between the LOD and LOQ.
ND = Non detectable (below the LOD).
[a] Approximate times.
[b] Used LOD/SQRT(2) for values below the LOD. Means were calculated by taking a time-weighted average.

Table A6. Endotoxin Air Concentrations by Location – High Occupancy Day 2		
Location	Time (min)	Concentration (EU/m^3)
Wave pool	500	84
Leisure river, by stairs	422	67
Splash pool by turn slide	506	50
Lily pad pond	504	50
Adult hot tub by exhaust	508	46
Towel rack	509	42
Spirit Island food stand	503	25
Top of slide tower	489	25
Waterfort	507	18
Control – administrative office	510	2
Mean [a]	494	45

[a] Mean excludes control sample in administrative office.

Table A7. Endotoxin Water Concentrations by Location – High Occupancy Day 2	
Location	Concentration (EU/mL)
Surge tank – leisure river	77
Leisure river	76
Wave pool by mushroom fountain	61
Children's pool	59
Surge tank – children's pool	52
Control – women's room tap water	28
Activity pool	26
Waterfort	25
Family hot tub	19
Control – men's room tap water	15
Adult hot tub	0.54
Mean [a]	44

[a] Mean excludes control samples.

Table A8. Mean Temperature and Relative Humidity						
Location	High Occupancy Day 1		High Occupancy Day 2		Low Occupancy Day	
	(F)	(%)	(F)	(%)	(F)	(%)
Spirit Island food stand	87	43	84	46	86	44
Lily pad pond	85	62	84	58	85	50
Leisure river, by stairs	84	68	83	60	84	57
Top of slide tower	88	46	88	44	89	41
Splash pool by turn slide	85	59	83	57	85	54
Adult hot tub by exhaust	85	57	84	51	85	57
Wave pool	86	60	86	54	86	54
Towel rack	83	63	82	69	83	63
Waterfort	None[a]	None[a]	NA[b]	NA[b]	83	68
Mean	85	57	84	55	85	54

[a] No readings were taken at this location.
[b] Recording device failed at this location due to excessive water.

Chloramines

A sampling pump pulls air through a sorbent tube that traps soluble chlorine compounds onto silica gel coated with sulfamic acid. Soluble chlorine compounds include monochloramine, dichloramine, hypochlorite, and hypochlorous acid. The air then passes directly from the sorbent tube through a 37-mm polystyrene cassette loaded with two quartz fiber filters coated with sodium carbonate and diarsenic trioxide to capture trichloramine.

The air samples were collected using calibrated Aircheck™ 2000 sampling pumps (SKC, Eighty Four, Pennsylvania) at a flow rate of 1.0 liter per minute. The sampling pumps were pre- and post-calibrated with a DryCal® DC Lite primary airflow meter (Bios International Corp., Butler, New Jersey). Samples were refrigerated in the dark and analyzed within 6 days of collection.

For analysis of the sorbent tubes, the samples were desorbed by placing the impregnated silica gel from the tube into a 20 mL vial. Ten mL of a 1.0 g/L sulfamic acid solution was added to each vial, and the samples were periodically agitated for 30 minutes. The sample extracts were decanted into another vial and refrigerated until analysis. Samples were analyzed for chlorine by inductively coupled plasma – atomic emission spectroscopy at a wavelength of 134.724 nanometers. The LOD and LOQ were determined for each sample set.

During analysis of the filters, each filter was removed from the cassette and placed in a 20 mL sample vial. After 10 mL of deionized water was added, the samples were periodically agitated for 30 minutes. Samples were refrigerated and filtered prior to analysis by inductively coupled plasma – atomic emission spectroscopy at a wavelength of 134.724 nanometers. The LOD and LOQ were determined for each sample set.

Sampling collection and analysis was performed according to the NIOSH draft method, which was adapted from the INRS method [INRS 2007].

Endotoxin

Air samples were collected using an endotoxin-free 3-piece 37-mm closed-face cassette, preloaded with 0.45 µm pore-size filters. Samples were collected with AirCheck2000 personal air sampling pumps calibrated at 2 liters/minute pre- and post-shift with a DryCal DC Lite primary airflow meter. Water samples were collected with sterile screw-cap containers free of detectable endotoxin and sent to the lab for analysis. Endotoxin analysis was performed by Aerotech P&K (Cherry Hill, NJ; Phoenix, AZ). Samples were analyzed for endotoxin content with the Kinetic-QCL® instrumentation using the LAL assay [Cambrex 2005]. For these analyses, 6 EU are equivalent to one nanogram of endotoxin. The LOD was 0.005 EU per sample.

Microbials

Bulk samples were taken for *Legionella*, mycobacteria, and fecal coliform bacteria. For microbials, bulk water samples of 100 mL were poured into sterile bottles coated with sodium thiosulfate prepared by the contract lab. Samples were kept cold and in the dark until analysis. Analysis for *Legionella*, mycobacteria, and fecal coliform bacteria was performed by Microbiology Specialists Inc. (Houston, Texas). The Colilert test procedure was performed to test for total coliforms and *Escherichia coli* in water. Reagent was added to 100 mL of sample water and incubated for 24 hours. A color change indicated the presence of fecal coliform bacteria. A color change that fluoresces under a UV lamp indicated the presence of *Escherichia coli.* For mycobacteria analysis, the samples were concentrated with a centrifuge. The concentrate was then placed in a Bactech system and monitored weekly for 6 weeks. Simultaneously, the samples were plated on 7H10 agar and cultured. *Legionella* samples were centrifuged, plated on buffered charcoal yeast extract agar, and cultured for 7 to 10 days.

Sulfites and Sulfates

Water samples for sulfites and sulfates were taken in sterilized containers with no headspace. All bulk samples were placed in coolers and stored in the refrigerator, until packaged on ice and shipped to the analytical laboratory. Each sample was filtered using a 0.45 micron, 25 mm syringe filter attached to a 10 mL syringe. Sulfates and sulfites were analyzed using a Dionex DX-120 ion chromatograph. Samples were analyzed using the Environmental Protection Agency Method 300.0 [EPA 1993]. For sulfate, the LOD was 0.3 mg/L and LOQ was 0.83 mg/L; for sulfite, the LOD was 0.5 mg/L and LOQ was 1.7 mg/L.

Water Chemistry

Water testing was performed with a standard color-matching DPD test kit (Taylor Technologies Inc., Sparks, Maryland). Two solutions, DPD #1 and #2, were added to the water sample, which developed a pinkish-red color proportional to the free chlorine level. Once the free chlorine level was obtained, total chlorine was then found by adding the DPD #3 solution. Combined chlorine was calculated by subtracting free chlorine from the total chlorine [Taylor Technologies Inc. 2007].

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Appendix C: Occupational Exposure Limits and Health Effects

In evaluating the hazards posed by workplace exposures, NIOSH investigators use both mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents as a guide for making recommendations. OELs have been developed by Federal agencies and safety and health organizations to prevent the occurrence of adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. However, not all workers will be protected from adverse health effects even if their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the exposure limit. Also, some substances can be absorbed by direct contact with the skin and mucous membranes in addition to being inhaled, which contributes to the individual's overall exposure.

Most OELs are expressed as a TWA exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended STEL or ceiling values where health effects are caused by exposures over a short period. Unless otherwise noted, the STEL is a 15-minute TWA exposure that should not be exceeded at any time during a workday, and the ceiling limit is an exposure that should not be exceeded at any time.

In the U.S., OELs have been established by Federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits, while others are recommendations. The U.S. Department of Labor OSHA PELs (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits enforceable in workplaces covered under the Occupational Safety and Health Act. NIOSH RELs are recommendations based on a critical review of the scientific and technical information available on a given hazard and the adequacy of methods to identify and control the hazard. NIOSH RELs can be found in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 2005]. NIOSH also recommends different types of risk management practices (e.g., engineering controls, safe work practices, worker education/training, personal protective equipment, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects from these hazards. Other OELs that are commonly used and cited in the U.S. include the TLVs recommended by ACGIH, a professional organization, and the WEELs recommended by the American Industrial Hygiene Association, another professional organization. The TLVs and WEELs are developed by committee members of these associations from a review of the published, peer-reviewed literature. They are not consensus standards. ACGIH TLVs are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2007]. WEELs have been established for some chemicals "when no other legal or authoritative limits exist" [AIHA 2007].

Outside the U.S., OELs have been established by various agencies and organizations and include both legal and recommended limits. Since 2006, the Berufsgenossenschaftliches Institut für Arbeitsschutz (German Institute for Occupational Safety and Health) has maintained a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the U.S. [http://www.

hvbg.de/e/bia/gestis/limit_values/index.html]. The database contains international limits for over 1250 hazardous substances and is updated annually.

Employers should understand that not all hazardous chemicals have specific OSHA PELs, and for some agents the legally enforceable and recommended limits may not reflect current health-based information. However, an employer is still required by OSHA to protect its employees from hazards even in the absence of a specific OSHA PEL. OSHA requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970 (Public Law 91–596, sec. 5(a)(1))]. Thus, NIOSH investigators encourage employers to make use of other OELs when making risk assessment and risk management decisions to best protect the health of their employees. NIOSH investigators also encourage the use of the traditional hierarchy of controls approach to eliminate or minimize identified workplace hazards. This includes, in order of preference, the use of: (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation), (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection). Control banding, a qualitative risk assessment and risk management tool, is a complementary approach to protecting worker health that focuses resources on exposure controls by describing how a risk needs to be managed [http://www.cdc.gov/niosh/topics/ctrlbanding/]. This approach can be applied in situations where OELs have not been established or can be used to supplement the OELs, when available.

Chloramines

Chloramines are inorganic compounds formed by the reaction between chlorine disinfectants and nitrogenous compounds such as ammonia, amines, or organic nitrogen-containing material. The species and concentrations of chloramines are influenced by the concentration of residual chlorine, ammonia (or other nitrogen sources), pH, and temperature. In general, the lower the pH and the greater the chlorine to ammonia ratio, the higher the likelihood of producing trichloramine.

Soluble Chlorine Compounds

The term soluble chlorine designates a combination of chlorine compounds collected using the silica gel containing tube portion of the sampler used. These chlorine compounds include monochloramine, dichloramine, hypochlorous acid, and hypochlorite. No OELs have been developed for soluble chlorine or for its specific possible constituents.

Monochloramine and dichloramine are less volatile than trichloramine; monochloramine is released into the air about 300 times slower and dichloramine about three times slower than trichloramine [Holzwarth 1984]. They tend to be more abundant in water than in air. However, high air concentrations of monochloramine and dichloramine have been found in environments where water is aerosolized. In studies of chloramine exposures at poultry facilities and a green salad processing facility, eye and upper respiratory irritation symptoms were associated with soluble chlorine concentrations. In these scenarios, soluble chlorine compounds are generated from the mixing of chlorinated water with nitrogenous proteins produced by animals and plants [Hery et al. 1998; NIOSH 2003; NIOSH 2006].

Trichloramine

Trichloramine, or nitrogen trichloride, a brownish-yellow gas, has a pungent chlorine odor, is a strong irritant, and causes excessive tearing of the eyes [Barbee 1983]. Trichloramine is the most volatile and prevalent chloramine compound in the air around swimming pools [Thickett et al. 2002], has low solubility, and decomposes rapidly in sunlight. Eye and respiratory tract irritation appear to be the primary effects of exposure. Currently, no NIOSH or OSHA OELs exist for air trichloramine concentration.

Endotoxin

Endotoxin are lipopolysaccharide remnants from the outer cell wall of Gram-negative bacteria that are released when it dies [Hagmar et al. 1990; Olenchock 1997]. Gram-negative bacteria are ubiquitous in the environment. Endotoxin have a wide range of biological activities involving inflammatory, hemodynamic, and immunological responses.

In experimental studies, human volunteers exposed via inhalation to high levels of endotoxin experience airway and alveolar inflammation as well as chest tightness, fever, and malaise and have an acute reduction in lung function, as measured by forced expiratory volume in 1 second [Castellan 1995; Milton 1999]. Airborne endotoxin exposures between 45 and 400 EU/m^3 have been associated with acute airflow obstruction, mucous membrane irritation, chest tightness, cough, shortness of breath, fever, and wheezing [Castellan et al. 1987; Smid et al. 1994; Milton et al. 1996]. Chronic health effects that have been associated with airborne endotoxin exposures include chronic bronchitis, bronchial hyperreactivity, chronic airways obstruction, hypersensitivity pneumonitis, and emphysema [Castellan 1995]. A permanent decrease in pulmonary function, along with respiratory symptoms, has been reported in epidemiological studies [Milton 1999].

While a causal role for endotoxin in human health effects has become more generally accepted in recent years, no dose-response relationship has been established. One reason is that the most commonly used method of analyzing endotoxin, the LAL assay, is a comparative bioassay [Milton 1999]. In other words, changes in the LAL test procedures themselves can erroneously appear as changes in the measured endotoxin activity levels. Until problems with the LAL test are resolved, endotoxin results cannot be compared to samples collected at different times or analyzed by different laboratories. For these reasons, ACGIH has proposed that RLVs, rather than the more usual TLVs, be used as a reference for endotoxin [Milton 1999].

RLVs require that samples be collected from an area considered to represent background levels of endotoxin and be analyzed at the same time as the samples from areas of interest. The RLV is a comparison between the environment in question and background levels. ACGIH states that if health effects are consistent with endotoxin exposure, and if the endotoxin exposures exceed 10 times the simultaneously determined background levels, then the RLV action level has been exceeded, and action should be taken to reduce exposure [Milton 1999]. The proposed maximum RLV rises to 30 times the background level in an environment where no symptoms are reported [Milton 1999]. When exposures exceed the RLV action level or maximum RLV, remedial actions to control endotoxin levels are recommended. It is important to note that the nature of the relationship between the RLV and health effects has not been elucidated at this time.

Legionella

Illnesses related to *L. pneumophila* bacteria affect an estimated 8,000 to 18,000 people annually in the United States [CDC 2005]. At least 46 species and 70 serogroups have been identified in the *Legionella* genus. *L. pneumophila* is a ubiquitous aquatic organism that thrives in warm environments (32°C–45°C) and has been associated with over 90% of the legionellosis cases in the United States [CDC 2005]. The source of *Legionella* is not identified in most sporadic cases of legionellosis (cases occurring in non-outbreak settings). More cases are usually identified in the summer and early fall, but they can occur any time of year.

Environmental sampling for *Legionella* can be useful in a few very specific circumstances (such as in outbreak investigations), particularly when *Legionella* isolates are available from one or more case-patients and can therefore be typed (specifically identified) and compared with environmental isolates [CDC 2001]. Other than in these specific circumstances, environmental sampling for *Legionella* is generally not recommended because the organisms are found commonly in the environment and have been isolated from nearly every natural location where they have been sought. Reservoirs for *Legionella* bacteria are primarily aqueous (involving water) and include potable water systems, air-conditioning cooling towers, evaporative condensers, and hot-water systems [Benin et al. 2002; Fields 2002; OSHA 2005a; Sabria and Yu 2008].

Legionellosis can present in two forms. Legionnaires' disease typically includes pneumonia and can affect numerous organs of the body; illness usually occurs within 2 to 14 days after exposure to the bacteria [CDC 2005]. Treatment of Legionnaires' disease requires antibiotics. Pontiac fever, the other clinical form of legionellosis, presents as a flu-like illness that occurs within 48 to 72 hours after exposure to the bacteria [CDC 2005]. Pontiac fever is treated with symptom-based treatment rather than antibiotics. Complete recovery from Pontiac fever generally takes place within a few days. Epidemiological evidence indicates that the primary mode of transmission of *Legionella* is via the airborne route, from aerosol-producing devices [AWT 2003; OSHA 2005b]. Person-to-person transmission has not been reported.

Sulfites and Sulfates

No standard or guidelines exist for acceptable sulfite and sulfate concentrations in swimming pool water. Water samples were taken at the request of GWL management.

Mycobacteria

Mycobacteria are rod-shaped bacteria that have cell walls with a high lipid (fat) content. They are found in a great variety of natural and human-influenced aquatic environments, including in and around swimming pools, hot tubs, and spas, treated drinking water, and aerosols. They are readily aerosolized from aqueous suspension. Aerosolization is caused by the generation of airborne droplets from bubbles bursting at the water surface. Recently, reports have linked exposure to various species of mycobacteria in pools and natural waters to the development of various respiratory illnesses. These include bronchitis, hypersensitivity pneumonitis, granulomatous pneumonitis, and allergic alveolitis [Schafer et al. 2003]. For example, *Mycobacterium avium* in spa water has been linked to hypersensitivity pneumonitis and possibly pneumonia [Embil et al. 1997]. Symptoms were flu-like and included cough, fever, chills, malaise, and headaches. The illnesses followed the inhalation of heavily contaminated aerosols generated by the spa.

Due to the high lipid content of their cell wall, mycobacteria are very resistant to the disinfectants used in water treatment, including chlorine and ozone [Engelbrecht et al. 1977; Falkinham 2003]. Therefore, it is essential to maintain recommended disinfection residuals in hot tubs, spas, and pools at all times to reduce the risks of acquiring swimming pool granuloma or respiratory illness caused by mycobacteria. Thorough cleaning of surfaces and materials around pools and spas where the organism may persist is also necessary [Collins et al. 1984].

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