ORIGINAL ARTICLE

A Comprehensive Water Management Program for Multicampus Healthcare Facilities

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OBJECTIVE. Develop and implement an effective program for hazard analysis and control of waterborne pathogens at a multicampus hospital with clinics.

DESIGN. A longitudinal study. Several-year study including analysis of results from monitoring and tests of 26 building water systems.

SETTING. Outpatient and inpatient healthcare facilities network.

METHODS. The hazard analysis and critical control point (HACCP) process was used to develop a water management program (WMP) for the hospital campuses. The HACCP method systematically addressed 3 questions: (1) What are the potential waterborne hazards in the building water systems of these facilities? (2) How are the hazards being controlled? (3) How do we know that the hazards have been controlled? Microbiological and chemical tests of building water samples were used to validate the performance of the WMP; disease surveillance data further validated effective hazard control.

RESULTS. Hazard analysis showed that waterborne pathogens were generally in good control and that the water quality was good in all facilities. The hospital network has had several legionellosis cases that were identified as presumptive hospital acquired, but none was confirmed or substantiated by water testing in follow-up investigations. Building water system studies unrelated to these cases showed that pressure tanks and electronic automatic faucets required additional hazard control.

CONCLUSIONS. Application of the HACCP process for long-term building water systems management was practical and effective. The need for critical control point management of temperature, flow, and oxidant (chlorine) residual concentration was emphasized. The process resulted in discovery of water system components requiring additional hazard control.

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Disease associated with building water systems is a significant problem worldwide. Legionellosis outbreaks have now surpassed the annual number of waterborne gastrointestinal disease outbreaks; *Legionella* causes the majority of building-associated waterborne disease outbreaks in the United States.[1,2] Building-associated disease is also caused by other waterborne opportunistic pathogens including *Acinetobacter*, *Stenotrophomonas*, *Pseudomonas*, nontubercular *Mycobacterium*, *Aspergillus*, and *Fusarium*.[3-8]

The annual cost for thousands of disease cases associated with building water systems in the United States may well be in the billions of dollars. Many of these waterborne disease infections result in pneumonia, for which indirect costs (due to lost productivity, absenteeism, and disability) were estimated at $12 for every $1 of direct healthcare cost.[9]

A standard practice has been to recommend building water system management based on the principles of the hazard analysis and critical control point (HACCP) method. The method is science based and is a proven framework for evidence-based decisions in water management.[10-13] The method is based on the failure mode effect analysis process developed by the US military and then adapted for use in the food industry. It is the basis for the water safety plan advocated by the World Health Organization.[11] This process has now been applied at the Mayo Clinic facilities in Rochester, Minnesota.

In late 2010, the Mayo Clinic initiated the Potable Water Quality Program with a defined purpose "to manage the risks to our patients associated with waterborne contaminants, both biological and corrosion related, in potable water systems." This program was initially defined to include both Rochester hospitals: Rochester Methodist Hospital and St. Marys Hospital. In September 2011, Mayo Clinic outpatient buildings, where patient care is administered, were added to the scope of this project, bringing the total facility area covered to 7,500,000 ft^2 (697,600 m^2). The objectives included hazard analysis and control of potable-water uses in patient care areas, excluding dialysis water that is managed in com-

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pliance with the national Association for the Advancement of Medical Instrumentation standards and receives secondary treatment.

METHODS

HACCP Method for Building Water Risk Management

The HACCP method requires a cross functional team of individuals with knowledge of the building water systems, assigned responsibility, and is accountable for the program. The first objective for the team is to describe how water is processed and used in each facility; these descriptions are rendered into schematic process flow diagrams, with each processing step named and numbered. Next, systematic hazard analysis of each step in the process is done to (1) identify potential hazards, (2) characterize the risk as significant or not (yes or no), and (3) determine whether additional hazard control is necessary. Any process step at which hazard control is applied is designated a critical control point (CCP). At each CCP, 4 parameters regarding control of the hazard were used: (1) critical limits, (2) monitoring method(s), (3) frequency of monitoring, and (4) corrective actions to be undertaken if a critical limit is violated (note that these parameters govern the hazard control application). Lastly, evidence must be provided to show that hazards have been controlled (validation), and confirmation that the plan has been implemented (verification) must be documented.

Waterborne Pathogen Test Methods

Sample collection procedures and culture methods to detect and enumerate *Legionella*, heterotrophic aerobic bacteria, total coliforms, *Escherichia coli*, *Pseudomonas* spp., *Pseudomonas aeruginosa*, and *Mycobacterium* (nontuberculosis) were performed as previously described.[14-22] The polymerase chain reaction (PCR) for the *Legionella* genus was performed as previously described.[17,23]

Water Chemistry Tests

The sources of potable water were from the city of Rochester and from on-site wells treated to safe drinking water standards. All source water was disinfected with chlorine generally within a range of 1.0–1.2 ppm as free Cl_2. The water was slightly scale forming as indicated by positive values in the Langelier saturation index and pH ranging from 7.5 to 8.5. Water for heated uses was softened. Copper, lead, and zinc were determined according to Environmental Protection Agency method 200.7, revision 4.4. Iron was determined according to Hach method 8008 (Hach DR/890 data-logging colorimeter handbook).

Development of the Water Management Program (WMP)

The water management team (WMT) included members from Facilities Engineering, Facilities Operations, Infection Prevention and Control, and Industrial Hygiene. Process flow diagrams (PFDs) were developed to describe how water is processed in each building water system. Each processing step was named and numbered, as shown in Figure 1, for every building in order to facilitate systematic hazard analysis.

Systematic hazard analysis as described in "Methods" was then performed (data not shown) by the WMT based on the water-processing steps as defined on the PFDs. Risk characterization of areas in the facilities was identified and classified (Table 1).

Hazard Control

The output of the hazard analysis summary is the identification of what control was being applied or should be applied for each hazard (data not shown). Each location at which hazard control is applied was designated a CCP. For each CCP, 4 parameters were established: (1) the hazard control critical limit(s), (2) the monitoring method for the hazard control, (3) the frequency of monitoring hazard control, and (4) corrective actions to be undertaken if a critical limit was violated. These are compiled into the HACCP plan document (Table 2).

Flushing Potable-Water Distribution

A hazard control specification was developed for flushing cold- and hot-water distribution systems (see Table 2, col 2, rows 1, 6, flushing).

Protocol. Situations that prompt flushing: 7-day unit closure due to census, units out of service due to construction or long-term nursing closures, permanent patient room shutdowns or room change functions where the water distribution system is dormant for more than 1 year.

Execution. A minimum of 4 minutes at both hot- and cold-water fixtures; 4 minutes allows for 1 minute water transport time and 3 minutes additional flushing with chlorinated water. Wrist blades: flush both hot and cold concurrently for 4 minutes. Showers: flush hot for 4 minutes; turn off water and let shower hose hang straight to floor to dripdry; then replace shower hose to wall clip. Automatic faucets: flush for 4 minutes.

Validation and Verification

Evidence that hazards have been controlled under operating conditions (validation) and confirmation that the plan is being properly implemented (verification) are essential requirements of HACCP. Validation criteria were established for the facility based on site-specific knowledge of the systems and on current information in the literature.

Disease surveillance data and results from tests of building water samples were obtained. Using the relative risk classification described in Table 1, the WMT decided the number of water sample analyses to conduct in various facility areas. Baseline data were obtained during the initial phase of the program. The frequency of validation sampling was then

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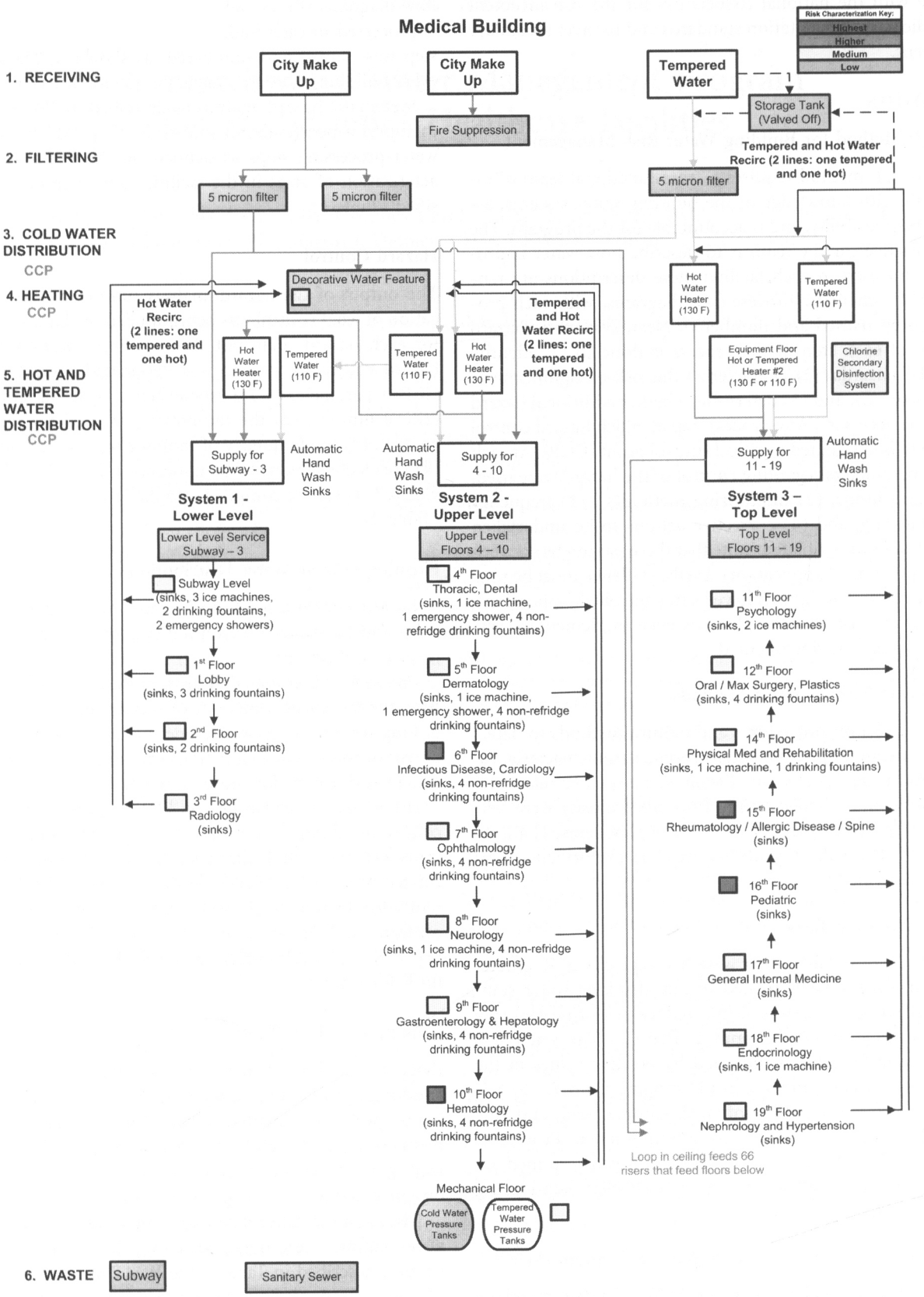


FIGURE 1. Process flow diagram for a building on the Mayo campus that described how water is processed and used in the facility. Note that each processing step is named and numbered. A color version of this figure appears online.

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TABLE 1. Risk Characterization of Areas in the Facilities

Risk classification	Rationale for risk characterization	Hospital inpatient areas (Rochester Methodist and St. Marys Hospitals)	Outpatient areas (Gonda and Mayo buildings)
Highest-risk area	Immunosuppressed hosts reside or cared for in these areas	BMT unit, solid-organ transplant, hematology, medical oncology	Hematology and medical oncology (pediatrics or adult), transplantation, chemotherapy, HIV/AIDS
Higher-risk area	Patients with multiple severe comorbidity diseases reside or procedures in areas with water usage and exposure	Nontransplant ICUs, ORs	Endoscopy, bronchoscopy, outpatient surgery
Medium-risk area	General medical/surgery patients with no or few comorbidity disease reside, general patient areas, surgical areas, public areas	General medicine and surgery	General patient areas, surgical areas, public areas
Low-risk area	Nonpatient areas	Waiting rooms, etc.	Secretarial and administrative areas

NOTE. BMT: bone marrow transplantation; HIV/AIDS: human immunodeficiency virus/acquired immunodeficiency syndrome; ICUs: intensive care units; ORs: operating rooms.

quarterly. This was a practical interval for considering any adjustments to the hazard control specifications.

RESULTS

Hazard control monitoring and critical limits (ie, quantifiable ranges applied at CCPs) were established at each of the buildings within the scope of this WMP. For example, at the distribution CCPs, free chlorine critical limits were set at 0.2–1.0 ppm as Cl_2. Monitoring locations were determined by their distal relationship from the source water as well as the risk characterization of patient care areas. A HACCP plan document was developed for each building water system in the study. For example, the HACCP plan document for the Mayo hospitals is given in Table 2. Note in this HACCP plan document that there were 7 building water-processing step locations (the 7 rows in Table 2) at which hazard control was applied and were therefore designated as CCPs.

Validation Test Results

Table 3 summarizes validation test results. Total heterotrophic aerobic bacteria testing indicated very little degradation of water quality; 94.4% of test results were equivalent to the incoming building water. About 11% of samples tested were positive for nucleic acid from *Legionella* genus (PCR results). Viable *Legionella* was detected and enumerated in 2.1% of the 1,010 building water samples analyzed by culture during the 2-year study period.[14-17] Since the PCR method cannot distinguish viable *Legionella* from nonviable *Legionella*, these results suggest that disinfection of the pathogen occurred in the system.

None of the other waterborne pathogens were detected in any of the samples, except *Pseudomonas*, which occurred sporadically at very low levels. Test results from metal analyses indicated generally low concentrations below any limit of health-related concern (data not shown).

Disease Surveillance

Mayo Clinic has an active surveillance program for legionellosis and a standardized microbiologic evaluation of pneumonia in immune-compromised hosts (ICH). The standardized protocol was bronchoalveolar lavage for ICH, which consists of smears, cultures, and PCR for bacteria, fungi, viruses, *Legionella*, and *Mycobacterium*. For *Legionella* detection, both culture and *Legionella* genus PCR were performed. In addition, urine antigen testing for *Legionella pneumophila* serogroup1 is usually performed. All positive *Legionella* cultures or positive urine antigen test results were reported to the Infection Control unit and the Department of Health. There were 2 definite nosocomial *L. pneumophila* pneumonia cases during 2011 and 2012; the cases were unrelated in time. Environment investigation revealed no matching *Legionella* species detected in the potable-water system or in the hospital rooms of patients. The 2 nosocomial legionellosis cases that were confirmed during this study period could have been the result of exposure to viable but not culturable *Legionella*; if so, methods such as coculture of water samples with amoebic hosts might have recovered the pathogen, but this was outside the scope of this study.

Validation Criteria

Before validation testing began, an arbitrary criterion was chosen of "no more than 10% percent positivity in all culture tests" based on literature reviews and because a greater than 30% positivity criterion sometimes advocated is not supported by the disease incidence and outbreak data. The data obtained during this study indicated that percent positivity

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TABLE 2. Hazard Analysis and Critical Control Point Plan Document for Hospital Building Water Systems

Processing step CCP	Critical limit for hazard control	Monitoring method	Monitoring frequency	Corrective actions	Verification records	Verification procedure
Cold-water distribution						
Sinks/showers/ sprayers	0.2–1.0 ppm free residual chlorine, continuously; flushing protocol (see "Methods"); flushing execution (see "Methods")	Samples from distal sites for DPD chlorine test, online hazard control monitoring logs	1 time per week, as performed	Facilities Operations: flush the system and test the time required to pull measurable chlorine to the outlet, add 3 min to initial flush time	Weekly log sheets, online data management system	Facilities Operations supervisor verifies each week
Drinking fountains	Maintenance per O/M manual, PM procedures and filters (when filters are used)	Follow O/M manual instructions for each respective drinking fountain model	Per manufacturer	Water management team reviews situation	Operations work logs	Facilities Operations supervisor verifies each quarter
Ice machines	Maintenance per manufacturers' O/M manual	Follow O/M manual instructions	Every 6 months	Water management team reviews situation	HVAC group work logs	Facilities Operations supervisor verifies each quarter
Emergency eyewash and showers: cold or hot	0.2–1.0 ppm free residual chlorine, continuously; flushing 1 time per week for 3 min	Samples for DPD test, online hazard control monitoring logs	Emergency showers: 1 time per month; eyewash: 1 time per week	If no measurable chlorine, flush for 7 min or until water is clear	Operations work logs	Facilities Operations supervisor verifies each month
Heating	120°–125°F at each building at hot-water heaters, 105°–120°F at distal sites for scald control	Visual thermometers at hot-water heaters or automated monitoring	3 times per week for visual thermometers at hot-water heaters or continuous for automated	If temperature is low, maintenance is dispatched to investigate/repair	Manual logs or data logger used for power plant	Facilities Operations supervisor verifies each week
Hot-water distribution	0.2–1.0 ppm free residual chlorine, continuously; flushing protocol (see "Methods"); flushing execution (see "Methods")	Samples for DPD and temperature measurements at predefined sample locations, online hazard control monitoring logs	1 time per week	Water management team reviews data regularly	Weekly log sheets and online data management system	Facilities Operations supervisor verifies each week
Decorative fountain treatment	Inside locations: 1.0–2.0 ppm free residual chlorine, continuously, pH 7.2–7.8, cyanuric acid (if used) <20 ppm; outside locations: 1.0–3.0 ppm free residual chlorine, continuously, pH 7.2–7.8, cyanuric acid 30–50 ppm; clean filters, check for cracks and leaks, clean and vacuum each week	DPD chlorine, pH, and cyanuric acid (if necessary) for grab samples, second floor pediatric unit; seventh floor meditation room, courtyard and peace garden fountains, online hazard control monitoring logs	3 times per week	If chlorine levels are low, add more product and retest; if solid product level is low in dispenser, add more product and retest; if cyanuric acid is too high, drain half the volume, refill, and retest	Weekly log sheets, test results logged and stored in Facilities Operations, TMS work orders and online data management	Facilities Operations supervisor verifies each week

NOTE. DPD: N,N-diethyl-p-phenylenediamine; HVAC: heating, ventilation, and air-conditioning; O/M: operations/maintenance; PM: preventative maintenance; TMS: total management system.

TABLE 3. Results of Quarterly Validation Testing

Type of facility	Total no. of samples analyzed	No. of samples with THAB $\geq 10^3$ (%)	No. of samples culture positive *Legionella* detected (%)	No. of samples with PCR *Legionella* genus detected (%)
Hospital	618	40 (6)	9 (2)	46 (7)
Clinics	200	11 (6)	6 (3)	37 (19)
Public area	5	0	0	0
Long-term care living	71	2 (3)	2 (3)	9 (13)
Health living center	1	0	0	0
Mental health inpatient	15	0	0	2 (13)
Research	17	2 (12)	3 (18)[a]	8 (47)[a]
Employees	83	4 (5)	1 (1)	10 (12)
All facilities	1,010	57 (5.6)	21 (2.1)	112 (11.1)

NOTE. Results are shown from quarter 2, 2011, to quarter 1, 2013.
[a] Note small sample size ($n = 17$).

in these building water systems was much lower than 10%; it was only 2.1% overall for *Legionella* detections by culture and much less for the other waterborne pathogens tested. Therefore, the hazard analysis data show evidence that the microbiological water quality and safety in these building water systems were good; the disease surveillance results further validated effective hazard control.

There were 21 building water samples taken during the study that returned detectable *Legionella* in culture tests; the WMT reviewed each result. These reviews led to further studies.

Further Studies

Of 21 samples from which *Legionella* was detected, 18 samples were from drinking fountains, pressure expansion tanks, and electronic automatic faucets. Only 3 samples taken from taps in potable-water distribution systems were positive for *Legionella* cultures during the study period. Figure 2 shows that more *Legionella* was recovered from pressure tanks (20% were positive) and electronic automatic faucets (5% were positive) compared to samples from the cold- and hot-water distribution system and all other fixtures (2% were positive).

Pressure Tank Study

A high number of *Legionella* PCR test results from pressure booster tanks yielded positive detections, especially from the tempered water system. Tepid water temperatures (110°F [43°C]) and low chlorine levels were observed. Water uses, fixtures, and volumes were similar to those of other water systems; however, many (about 26) pressure tanks with rubber diaphragms were in service throughout the facility. Analyses yielded detectable *L. pneumophila* serogroup1 from several tanks.

Studies of 26 pressure tanks included dismantling some of the tanks, removing the rubber diaphragms, and sampling biofilm deposits. *Legionella* was detected in many of these samples (data in preparation for another publication) and used to establish hazard analysis and control parameters that included regular disinfection of pressure tanks throughout all the facilities, removal of 2 tanks, and a redesign of the plumbing circuit.

Electronic Automatic Faucet Study

Several electronic automatic faucets were sampled by swabbing inside surfaces and spread plating suspensions. All surfaces sampled were heavily colonized with *Legionella* (data not shown). A new automatic faucet was installed and sampled; the hot-water supply to the tap was heavily colonized. *Legionella* was recovered in high numbers from swab analyses of the screen, the top of the fixture, the supply line, the bottom of the fixture, and the hot-water supply line, as well as after a new hot-water supply line was installed (data not shown). The flow rate was very slow through these fixtures, and the water temperature was 110°F (43°C). These results confirm findings from previous studies in which automatic faucet fixtures were highly contaminated with *Legionella*.[29,30]

Chlorine Monitoring

Monitoring at CCPs showed that chlorine residuals became depleted to levels at or below critical limits as water traveled through the system. Heat exchangers and recirculation lines were observed to be where the degradation of chlorine residuals occurred. The WMT is therefore planning to implement supplemental chlorination.

DISCUSSION

A need was identified to unite expectations of infection control standards and facility processes to clarify and improve the management of waterborne pathogens in our potable-water systems. The need to have one plan that all stakeholders could follow and understand became evident. Infection Control, Facilities Operations, Facilities Engineering, and Industrial Hygiene personnel all have key responsibilities in providing safe, potable water. A WMP was established to bring together a consistent approach to assess and monitor potable-

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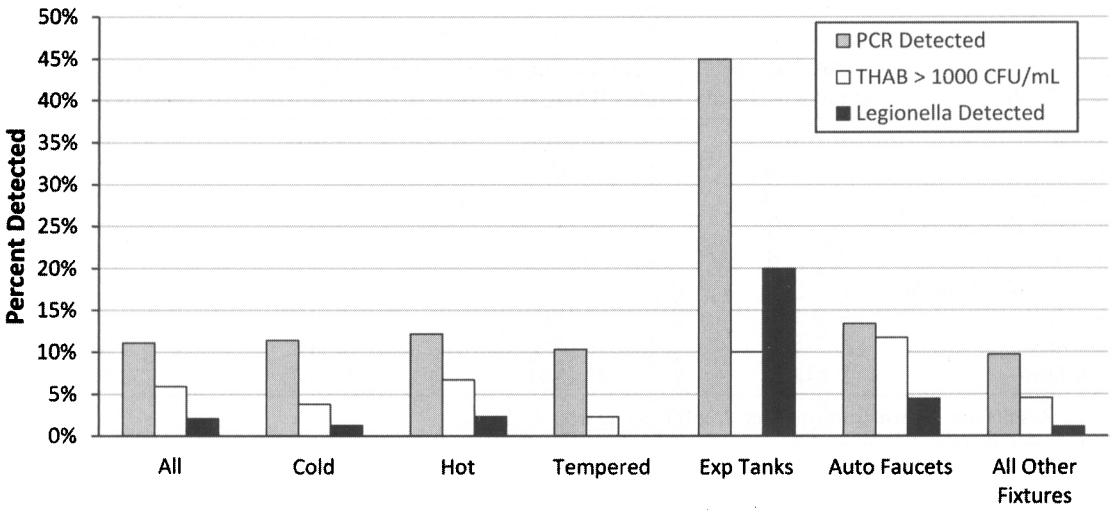


FIGURE 2. Percent of building water samples analyzed with detectable *Legionella* polymerase chain reaction (PCR), total heterotrophic aerobic bacteria (THAB; $\geq 10^3$), and *Legionella* detected by culture. Exp Tanks: pressure tanks; see "Pressure Tank Study."

water quality throughout the campus. It was agreed, after review, that the HACCP process would be used to build the WMP.

A WMT was assembled with all disciplines represented to provide oversight to the establishment of the WMP. Additionally, water management work groups were assembled for the hospitals and outpatient areas. These groups provided the staff resource to implement the HACCP process and define the WMP.

HACCP implementation identified differences in distribution, flow, and hazard control between buildings. This resulted in better descriptions of how water was being processed in the facilities and in better management of CCPs with specific corrective actions for deviations from critical limits. Streamlined, scientifically defensible, evidence-based decision making was achieved by scheduled deliberations of the WMT. Concise records were produced that document the decision-making process with defensible confirmation (verification) that the plan was actually implemented.

From studies of pressure tanks and electronic automatic faucets test results, it was decided that additional hazard control was necessary. Accordingly, the WMP was upgraded to establish CCPs at those locations in the building water systems, and further studies were undertaken (data forthcoming).

Assembling and educating the team to establish a WMP was very productive. Awareness of water quality issues was increased, and the need for individuals from Infection Control, Facilities Operations, and Facilities Engineering to work together became apparent. The lessons learned from design and operation could have come only from an effort like this because it brought issues to the forefront using a manageable process. This project started with a need to address corrosion-related potable-water issues and led to finding low chlorine levels and water distribution piping design problems. Individuals from Facilities Operations engaged individuals from Infection Prevention and Control and Industrial Hygiene to bring together combined responsibilities for the potable-water systems. This collaborative effort brought focus, education, and expectations for the management of potable-water systems in our facilities to better serve our patients going forward.

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