Report to the U.S. Environmental Protection Agency on Guidance Documents to Safely Clean, Decontaminate, and Reoccupy Flood-Damaged Houses

Terry Brennan
Gene Cole, Dr.P.H.
Brent Stephens, Ph.D.

Table of Contents

List of Figures iv
List of Tables iv
Acronyms and Abbreviations v
Executive Summary vi
1. Introduction 2
2. Hazards Presented by Floods and Flood Damage 7
  2.1 Pathogens in Flood Waters and Illnesses Associated With Floods 8
    2.1.1 Pathogens in Flood Waters 8
    2.1.2 Illnesses Associated With Floods 9
  2.2 Respiratory Problems and Moisture/Dampness 11
  2.3 Bacteria and Fungi in Indoor and Outdoor Air After Floods 11
    2.3.1 Mycotoxin Exposure 13
3. Returning Flooded Buildings to Habitable Conditions 16
  3.1 Definitions 17
  3.2 Steps to Return the House to Habitable Conditions 20
    3.2.1 Stay Safe and Healthy While Returning the House to Habitable Conditions 21
    3.2.2 Assess the Situation and Make a Plan 22
    3.2.3 Remove Water, Debris, Silt, Trash, and Items Damaged Beyond Repair 22
    3.2.4 Drying, Cleaning, and Decontaminating 23
    3.2.5 Meeting Reoccupation Criteria 37
    3.2.6 Conducting Renovations 39
4. Hazards Presented by Cleaning and Decontaminating Strategies 42
  4.1 Additional Ingestion Reports 42
  4.2 Respiratory Exposure Reports 43
    4.2.1 Asthma Studies 43
    4.2.2 Cases Reporting Exposure to Chlorine Gas or Chloramines After Mixing Products 46
  4.3 Irritancy Effects of Cleaners and Disinfectants 47
  4.4 Behavior That Leads to Exposure to Cleaners and Disinfectants 47

Appendices 54
Appendix 1: Comparison of Guidance Documents Identified in Chapter 3 54
Appendix 2: Selected References From the Literature Search in Chapter 3 70
Appendix 3: Glossary 76
Appendix 4: References 79

List of Figures

Figure 1. Frequency of flood events by U.S. county: 1996–2013 2

Figure 2. Frequency of flooding along U.S. coasts, 2010–2015 vs. 1950–1959. 3

Figure 3. Change in the frequency of river flooding in the United States, 1965–2015. 4

Figure 4. Change in the magnitude of river flooding in the United States, 1965–2015 4

Figure 5. Sodium hypochlorite (bleach) incompatibility chart 46

List of Tables

Table 1. Biological Pathogens Commonly Found in Flood Water and Residue 8

Table 2. Number and Percentage of Persons With Selected Illnesses After Hurricane Katrina, by Residency Status—New Orleans, Louisiana area, September 8–25, 2005 9

Table 3. Number and Percentage of Households With One or More Persons Reporting Illness or Injury Within 1 Week After Tropical Storm Allison, by Flood Status of Home—Houston, Texas, June 16, 2001 10

Table 4. Examples of Porous, Semiporous, and Nonporous Materials 29

Table 5. Cleaning Recommendations for Porous, Semiporous, and Nonporous Materials 30

Table 6. Types of Biocides (i.e., Disinfectants) From the *Journal of Environmental Health* 36

Table 7. Summary of Mowry et al. (2015) Table 22A: Statistics for Exposures and Outcomes by Agent 42

Table 8. How Cleaning Product Use Can Influence Inhalation Exposure to Air Pollutants 48

Table 9. Documented Inhalation Toxicity Related to Mixing of Cleaning Products 49

Table 10. Documented Associations of Asthma, Allergy, and Sick-Building Syndrome Symptoms in Relation to Cleaning Product Use 50

Acronyms and Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
ALA	American Lung Association
ANSI	American National Standards Institute
ARC	American Red Cross
CDC	Centers for Disease Control and Prevention
CI	confidence interval
cfu	colony-forming units
EPA	U.S. Environmental Protection Agency
EU/m^3	endotoxin units per cubic meter
FEMA	Federal Emergency Management Agency
HEPA	high-efficiency particulate air
HVAC	heating, ventilation, and air conditioning (systems)
ICU	intensive care unit
IICRC	Institute of Inspection Cleaning and Restoration Certification
IOM	Institute of Medicine (of the National Academies)
m^3	cubic meter
MDF	medium-density fiberboard
ml	milliliter
MRSA	methicillin-resistant *Staphylococcus aureus*
MMWR	*Morbidity and Mortality Weekly Report*
N	nitrogen
NADCA	National Air Duct Cleaners Association
NCHH	National Center for Healthy Housing
NGO	nongovernmental organization
NIOSH	National Institute for Occupational Safety and Health
OR	odds ratio
OSHA	Occupational Safety and Health Administration
PPE	personal protective equipment
QAC	quaternary ammonium compounds
RADS	reactive airways dysfunction syndrome
WHO	World Health Organization

Executive Summary

A number of state and federal government agencies and nongovernmental organizations provide critical guidance documents for safely cleaning, decontaminating, and returning to buildings following flood damage. A large record in the peer-reviewed literature describes health hazards presented by flooding events and subsequent cleanup activities. To assist the U.S. Environmental Protection Agency (EPA) in streamlining guidance for safely cleaning, decontaminating, and reoccupying homes after flood events, this document provides a review of the existing literature on the health hazards presented by floods, flood damage, and subsequent cleanup activities and summarizes several guidance documents on strategies for safely returning flooded buildings to habitable conditions.

Key findings from the review and synthesis include:

- By nature, flood waters contain a variety of hazardous substances, including potentially infectious, allergenic, and toxic soil, animal, and human-source microorganisms (often from raw sewage), as well as residues from agricultural and/or industrial chemicals, and thus can be considered grossly contaminated.
    - Microbial contaminants and their components and/or products, such as fungal spores and bacterial endotoxins, are significantly elevated in flooded buildings compared to nonflooded buildings.
    - Risks of illnesses during post-flooding cleanup of indoor spaces are elevated through a combination of dermal contact, ingestion, and/or inhalation, with respiratory health effects being the most common as a result of aerosolization or resuspension of residues on contaminated surfaces.
    - Dampness in indoor environments is an ongoing public health problem, which illustrates the need for quick and effective cleanup after a flood.
- Given the repeated findings of (1) higher fungal and endotoxin concentrations in water-damaged and damp buildings; (2) associations between adverse health effects and exposure to contaminated flood waters, building materials, and degraded indoor air quality; and (3) a variety of other physical hazards and safety issues present during floods and flood cleanup activities, a clear need exists for the general public to understand safe and effective practices for cleaning and decontaminating residences after a flooding event has occurred.
- Federal cleanup guidance documents primarily include those provided by EPA, the Centers for Disease Control and Prevention, and the Federal Emergency Management Agency. State guidance documents typically are provided by those states that have historically experienced recurring flood events. Nongovernmental organizations such as the American Red Cross, American Lung Association, National Center for Healthy Housing, and the Institute of Inspection, Cleaning, and Restoration Certification also have produced valuable and practical guidance documents geared toward assisting the public in its recovery from flooding disasters.

- Typically, as flood waters drain and recede from a home environment, residuals of ground water silt, sewage contamination, and mold will be present. Then, after the dwelling has been determined to be structurally and electrically safe to reoccupy, the primary activities involved in all flood cleanups, as evidenced from available guidance documents, include (1) removing water, sediment, and unsalvageable materials, to include porous and/or semiporous delaminating and/or mold-contaminated finishing materials (e.g., gypsum board and plywood); (2) cleaning to physically remove flood residues from remaining surfaces and materials (e.g., undamaged wood framing, metal, PVC, and painted or sealed concrete), to include inspection, cleaning, and decontamination of air-handling systems; (3) drying to reduce/eliminate all dampness, minimize associated microbial growth, and help reduce the risk of exposures and adverse health effects; and (4) meeting clearance criteria for rebuilding and reoccupation.

- The focus of cleaning and decontamination should be to maximize the physical removal of contaminants from surfaces and materials, as opposed to merely killing or inactivating microbes.

    - In the post-flooding remediation process in an indoor environment, such cleaning approaches may involve the use of shovels, buckets, wheelbarrows, hoses, wet vacuums, water extraction machines, pressure washers, warm water and detergent, biocides (i.e., sanitizers or disinfectants), and high-efficiency particulate air (HEPA) vacuuming. The cleaning and remediation of assemblies—such as floor and ceiling systems, built-in cabinets and bookcases, and heating, ventilation, and air-conditioning systems—often requires the attention of a water-damage restoration professional for proper recovery. Likewise, contents such as electronic equipment and appliances that have been directly affected by flood waters typically require the services of a qualified professional. Salvageable materials such as clothing and bedding, however, may be effectively recovered through simple laundering.

    - There are many cautions and precautions concerning the use of household bleach (sodium hypochlorite) for post-flood cleaning and decontamination. Sodium hypochlorite is a caustic, hazardous chemical that lacks detergent properties for effective cleaning, is corrosive to metals, is inactivated by organic matter (such as flood sediments), can be deadly when mixed with other chemicals such as ammonia, and is implicated in tens of thousands of visits to poison control centers each year.

    - How thoroughly a surface is cleaned using hot water, detergent, and physical agitation is directly linked to how effective a sanitizer or disinfectant will be at inactivating residual microbes. All biocides must be used with caution, according to label directions, and with appropriate personal protective equipment (PPE) that protects eyes, skin, and the respiratory system as indicated.

    - Although post-flood cleanup typically emphasizes the importance of minimizing exposures to microbial contamination, there also is risk for flood-related injuries caused by trips and falls, electrical shock, and resultant infected wounds. The use of proper PPE and adherence to a previously prepared health and safety work plan are essential.

- Clearance is the process of verifying the acceptability of the flood cleanup procedures, confirming the cleanup job is completed prior to rebuilding, and determining the suitability of the home to be reoccupied.

  - Basic clearance criteria typically include the extent of the water damage, the extent of the initial flooding contamination, and the presence of microbial growth secondary to the flood waters, such as microbial growth on wet/damp building, finishing, and/or furnishing materials. After completion of the required steps of (1) removing water and damaged/contaminated materials, (2) decontaminating remaining surfaces and materials, (3) drying the environment to maximize moisture removal and prevent additional microbial growth, and (4) cleaning the remaining surfaces/materials to reduce residual/settled contaminants that might be resuspended, the following elements of the dwelling clearance process must be determined:

    - **Is it dry?**
      - Is the indoor relative humidity acceptable? That is, is there a lack of perceived dampness?
      - Do the remaining structural building and finishing materials look and feel dry?

    - **Is it clean?**
      - Is there an absence of visible contamination, such as mold, on materials?
      - Is there a visible absence of dust (as expected from HEPA vacuuming)?

    - **Is there an odor?**
      - Is there an absence of a musty, moldy, or mildew smell?

  - Unless these three categories of questions can all be answered in the affirmative, a detailed inspection that makes use of instruments to assess dampness and microbial contamination is recommended. This is typically done by a trained professional using instrumentation and sample collection and analysis procedures and may include: (1) measurements of the moisture content of materials, (2) temperature and relative humidity measurements, (3) microscopic examination of surfaces and/or collected samples (e.g., tape lifts), and/or (4) laboratory processing of dust or swab samples for microbial culture.

  - Flood-displaced persons also may need to reoccupy their home as soon as the structure is deemed safer than alternative shelter. In that regard, basic restoration criteria require the indoor environment to be structurally sound, with functioning clean water supply, kitchen, toilets and baths, electricity, and heating and air-conditioning. In such a situation, the clearance criteria may not have been fully met but should still be addressed as soon as possible. That means that the structure and its contents have been cleaned and dried; surfaces have been determined to be free of dirt, debris, and visible mold growth; and odors and any other signs of contamination are absent.

  - In the long term, the ultimate criterion for successful reoccupation of a structure is the ability of occupants to live there without experiencing adverse health effects, as might occur from chronic exposure to residual or secondary microbial growth resulting from the flooding event.

Introduction

1

1. Introduction

Flooding in the United States accounts for three-quarters of Presidential Disaster Declarations. During the past decade, U.S. federal, state, local, and tribal governments have shown increased interest in safely cleaning up after floods. The heightened interest was at least partly in response to the loss and disruption of life, property, and services caused by large hurricanes that made landfall in highly occupied areas during the past 10 to 15 years (e.g., Hurricanes Katrina, Rita, and Sandy).

The frequency and intensity of floods varies greatly geographically, and flood frequency is greatly influenced by climatic factors. The amounts of damage to property and life from floods are particularly large when powerful storms hit major population centers. Figure 1 maps flood frequency by county in the United States between 1996 and 2013.

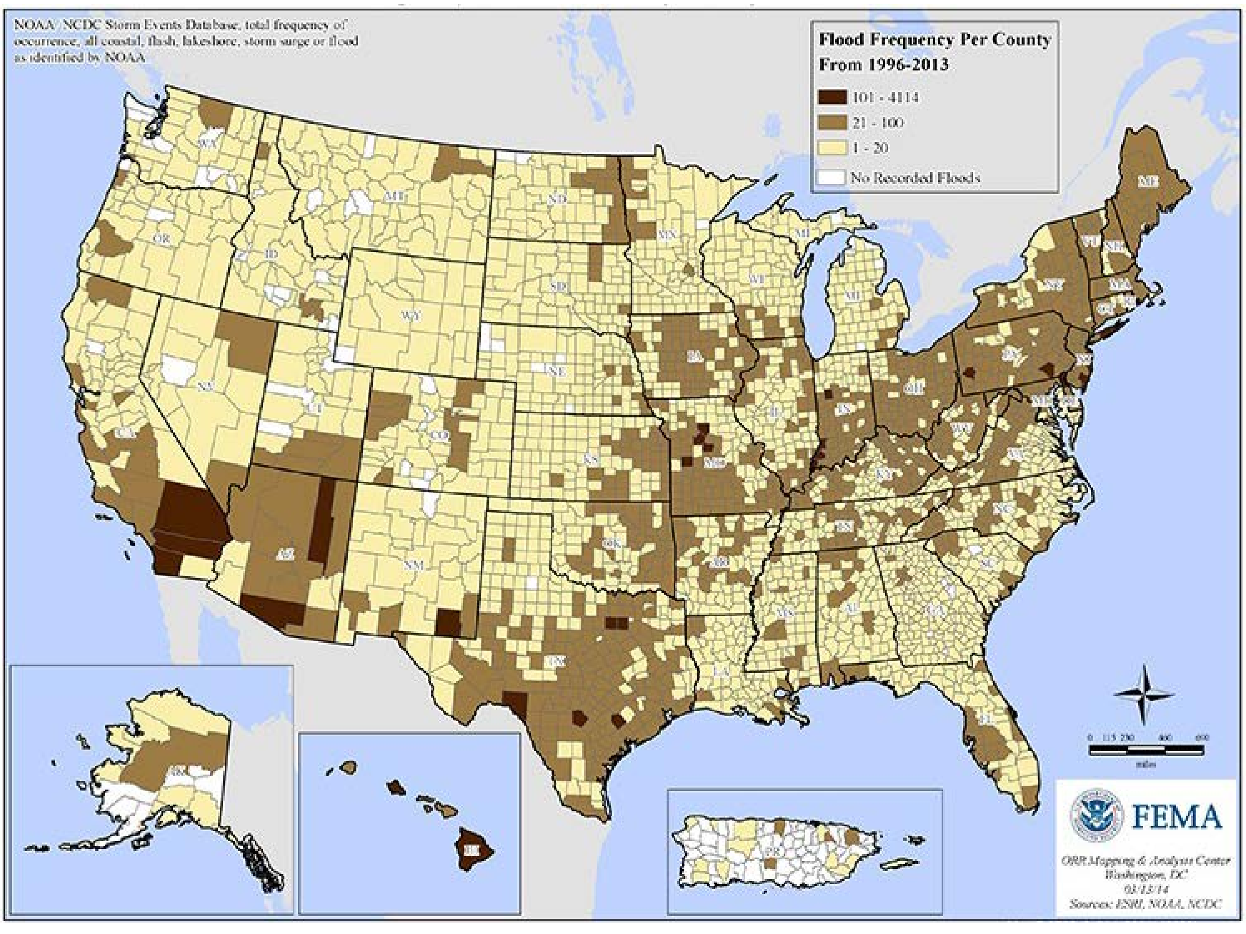


Figure 1. Frequency of flood events by U.S. county: 1996–2013.
Source: USEPA 2016.

In addition to highly damaging and visible disasters, there is increased concern because coastal cities in the United States have experienced a significant increase in the frequency of flooding events during the last 60 years (USEPA 2016), as shown in Figure 2.

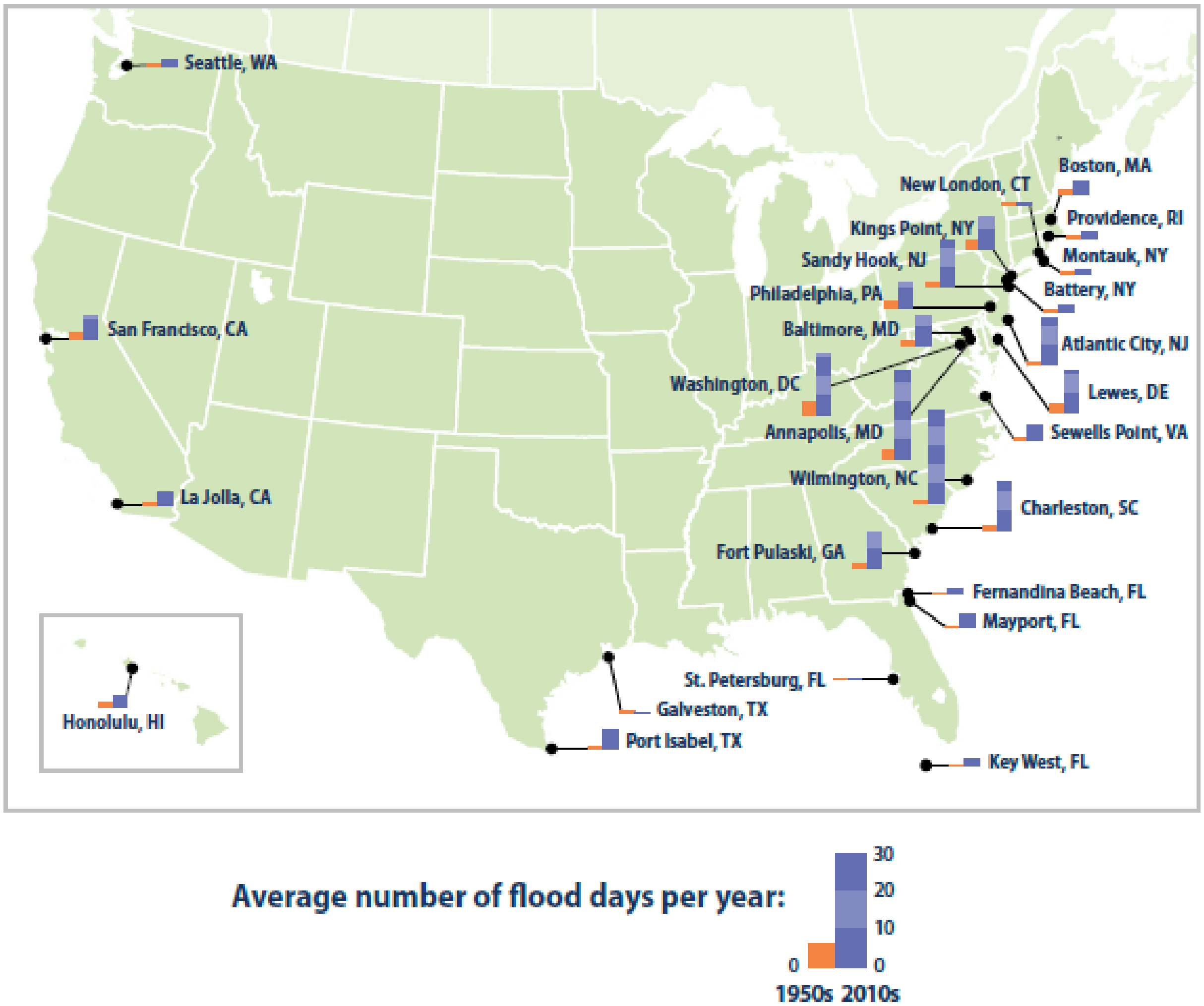


Figure 2. Frequency of flooding along U.S. coasts, 2010–2015 vs. 1950–1959. *This map shows the average number of days per year in which coastal waters rose above the local threshold for minor flooding at 27 sites along U.S. coasts. Each small bar graph compares the first decade of widespread measurements (the 1950s in orange) with the most recent decade (the 2010s in purple).*
Source: USEPA 2016.

Between 1965 and 2015, the frequency and intensity of river-related flooding increased significantly in some areas of the country and decreased in others (USEPA 2016), as shown in Figure 3 and Figure 4.

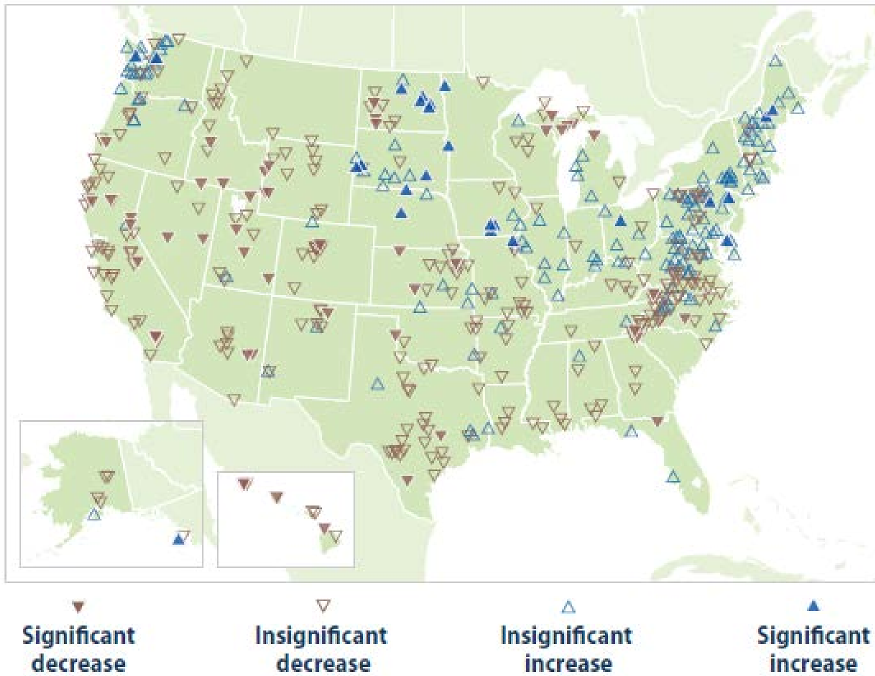


Figure 3. Change in the frequency of river flooding in the United States, 1965–2015. *The frequency of river flooding in the United States has increased in areas marked by upward-pointing blue triangles and decreased in areas marked by downward-pointing brown triangles.*
Source: USEPA 2016.

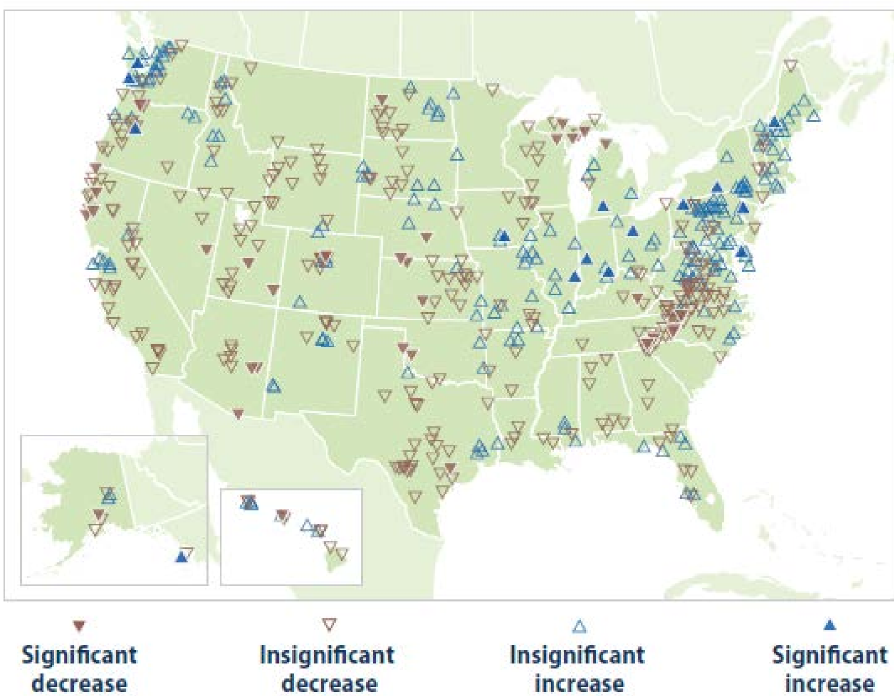


Figure 4. Change in the magnitude of river flooding in the United States, 1965–2015. *The magnitude of river flooding in the United States has increased in areas marked by upward-pointing blue triangles and decreased in areas marked by downward-pointing brown triangles.*
Source: USEPA 2016.

A number of health hazards are present in homes that have been damaged during floods, hurricanes, or other extreme weather events. Health hazards include physical trauma, electric shock, and exposures to various environmental contaminants and microorganisms. These hazards may occur during the storm or flood itself while sheltering at home or in designated shelters or while seeking safety, as well as after the storm or flood while traveling to, reentering, or cleaning up homes. A number of government agencies and nongovernmental organizations (NGOs) have developed guidance documents for safely preventing or mitigating these hazards and ultimately returning homes to habitable conditions.

To assist the U.S. Environmental Protection Agency (EPA) in streamlining guidance for safely cleaning, decontaminating, and reoccupying homes after flood events, this report reviews literature and guidance documents focused on four main activities involving flood-related cleanup: (1) assessing health hazards presented by floods, flood damage, and subsequent cleanup activities; (2) evaluating the extent of flood-related damage; (3) returning the home to a safe habitable condition; and (4) using ordinary cleaning methods appropriately and, when appropriate, biocides.

Literature reviews were conducted using PubMed, ScienceDirect, the *Morbidity and Mortality Weekly Report* (*MMWR*) search engines, and the files of the authors. Leading guidance documents that were reviewed include those published by EPA, the Centers for Disease Control and Prevention (CDC), the Federal Emergency Management Agency (FEMA), the American Red Cross (ARC), the American Lung Association (ALA), the National Center for Healthy Housing (NCHH), and the Institute of Inspection, Cleaning, and Restoration Certification (IICRC).

Results from the review are categorized and reported as follows. Chapter 2 presents a synopsis of illnesses and injuries associated with floods and related storm damage as reported by a number of government agencies and NGOs, such as the CDC, FEMA, and World Health Organization (WHO). Chapter 3 contains a discussion of government and NGO guidance documents for cleaning after floods, hurricanes, and other storm events. This section largely comprises six steps for returning a flooded home to a habitable condition; these steps were synthesized from the various guidance documents. Chapter 4 provides a review of the effectiveness of cleaning methods and selection, use, and hazards of chemical biocides and germicides for decontaminating surfaces and materials contaminated by microorganisms and their biofilms.

This publication includes a number of terms used in guidance documents. Several of these terms are commonly used to describe materials and methods that reduce, inactivate, or kill microbes or prevent their growth. Although many groups often apply their own meanings to the terms, EPA, as a regulatory body, employs standard legal definitions based primarily on the laboratory test methods required for product registration. These and other definitions that are used in guidance documents are provided in Section 3.1. Additional key terms used in this document that may not be familiar to the reader are indicated by ***bold, italicized text***, and their definitions can be found in the glossary in Appendix 3.

Hazards Presented by Floods and Flood Damage

2

2. Hazards Presented by Floods and Flood Damage

There is consistent evidence documenting that many people are injured, become ill, or die during or shortly after hurricanes and floods (CDC 1983; CDC 1992; CDC 1993a,b,c,d; CDC 1994a,b; CDC 1996a,b; CDC 2000; CDC 2005a,c,d; CDC 2006f,j; FEMA/ARC 1992; FEMA 2013; IICRC 2015; Todd 2006). Many of the deaths and injuries occur during the flood event itself. Additionally, people also suffer illness and injury while at evacuation sites or during cleanup and restoration activities (CDC 2004; CDC 2005b; CDC 2006c,k; Sullivent et al.2006; Todd 2006). Alderman et al. (2012) reviews much of the existing literature on illness, injury, and death associated with floods. Briefly, the documented adverse health effects from floods, flood damage, and subsequent cleanup activities are described below.

- Physical injury, including:
  - Drowning, physical trauma, cuts, abrasion (Alderman et al. 2012, FEMA/ARC 1992, IICRC 2015, Sullivent et al. 2006).
  - Animal bites (mammals, insects, reptiles) (CDC 2006c).

- Allergic or asthmatic episodes while occupying or cleaning damp, moldy buildings (CDC 2006a,i).

- Infection (primarily infected wounds and gastrointestinal or respiratory infections) (Alderman et al. 2012, Todd 2006), including infections obtained:
  - From contact with flood waters, which carry organisms found in sewage, soils, and animal waste (CDC 2006c).
  - During cleaning activities (from contact with or aerosolization of flood residues) (CDC 2006g).
  - From conditions in the flooded area or at evacuation locations (from contaminated water and food, strained sanitation services, and crowded conditions) (CDC 2005b, CDC 2006e, WHO 2016).

- Exposures to nonbiological contaminants (Alderman 2012), including:
  - Carbon monoxide from gas-powered equipment—such as generators, pressure washers, or water pumps—used indoors (CDC 2006c,d; WHO 2016).
  - Heavy metals (Cox et al. 2008).
  - Pesticides (Euripidou and Murray 2004).
  - Organic compounds, such as petroleum or polycyclic aromatic hydrocarbons (CDC 2006c, Euripidou and Murray 2004).

- Emotional trauma, psychological distress, and post-traumatic stress (Alderman 2012, CDC 1996a, CDC 2002, CDC 2006b, Lamond et al. 2015).

Health effects related to environmental exposures during cleanup activities fall into two major categories:

- Illnesses caused by pathogens encountered in flood waters, in conditions faced by evacuees following the flood, and in flood residue during cleaning and reoccupying buildings.

- Allergic and irritant effects (possibly related to secondary microbial growth) experienced in buildings after flood waters recede.

2.1 Pathogens in Flood Waters and Illnesses Associated With Floods

Drinking water sources that have been contaminated by flood waters are the major cause of outbreaks after flood events (WHO 2016). Flood water often is contaminated with pathogens from sewage, farm animal wastes and wild animal populations, or those that occur naturally in water bodies (Berry et al. 1994, FEMA/ARC 1992, IICRC 2015, Straub 1993). Although a complete list would be too long to present, a brief list of biological pathogens frequently reported in the literature that may be found in flood water and residue is provided in Table 1.

Table 1. Biological Pathogens Commonly Found in Flood Water and Residue

Parasites	Bacteria	Viruses
Entamoeba	*Campylobacter*	Adenovirus
Giardia	Enterococci	*Enterovirus*
	Escherichia coli	Hepatitis A
	Legionella	*Norovirus*
	Leptospira	*Parvovirus*
	Salmonella	*Rotavirus*
	Shigella	

2.1.1 Pathogens in Flood Waters

The kind and level of contamination found in flood waters varies considerably from one location to another as well as over time. The nature, size, and location of contaminant sources and the direction and volume of flood waters greatly affects flood water contamination. Further, flood waters resulting from hurricanes, tropical storms, rising rivers, or tsunamis may be significantly more contaminated than flood waters from clean sources, such as potable water or rainwater that leaks into buildings.

One water quality study illustrates the variable nature of flood water contamination. During an ongoing study of water quality in the Cape Fear watershed of North Carolina from 1996 to 2000, the area was struck by Hurricanes Fran, Bonnie, and Floyd (Mallin et al. 2002). Mallin reports that different storms had different effects on the levels of total nitrogen (N), ammonium-N, nitrate-N, total phosphorus, orthophosphate, and fecal coliform bacteria. Hurricanes Fran and Floyd had little effect on levels of coliform bacteria in the watershed area under study, whereas concentrations after Hurricane Bonnie increased from less than 100 colony-forming units (cfu) per 100 milliliters (ml) to between 131 and 16,900 cfu/100 ml. Eight of 10 samples had concentrations greater than 1,000 cfu/100 ml. Similar results were reported for samples following Hurricane Katrina (Pardue et al. 2005).

To address this issue, one of the guidance documents reviewed in this report, the *S500 Standard and Reference Guide for Professional Water Damage Restoration*, published by the IICRC (2015), is a consensus standard and reference document intended for use by water loss and restoration professionals. It categorizes water by level of contamination, from potable water (Category 1) to grossly contaminated water (Category 3). The IICRC considers all water originating from seawater, ground water, surface water, rising rivers and streams, and wind-driven rain from hurricanes and tropical storms to be Category 3.

2.1.2 Illnesses Associated With Floods

The *MMWR* search identified 22 relevant articles describing illnesses associated with floods and four articles describing only injuries. Two tables reporting injury and illness are excerpted below, one for Hurricane Katrina (Table 2) and one for Tropical Storm Allison (Table 3).

In Table 2, the reported illnesses may not be representative of a more typical flooding situation because of the extreme devastation caused by Hurricane Katrina, which resulted in poor air quality, dust, debris, fires, and other situations. Nonetheless, Hurricane Katrina is useful as a marker of an extreme natural disaster (CDC 2005c). Thousands of people became ill during and after Hurricane Katrina.

Table 2. Number and Percentage of Persons With Selected Illnesses After Hurricane Katrina, by Residency Status—New Orleans, Louisiana Area, September 8–25, 2005

	Relief workers		Residents		Unknown		Total	
Selected illnesses	No.	(%)	No.	(%)	No.	(%)	No.	(%)
Infectious-disease–related								
Skin or wound infection	101	(19.1)	192	(12.8)	347	(16.2)	**640**	**(15.4)**
Acute respiratory infection	119	(22.5)	158	(10.5)	228	(10.6)	**505**	**(12.1)**
Diarrhea	11	(2.1)	52	(3.5)	83	(3.9)	**146**	**(3.5)**
Other infectious disease	36	(6.8)	109	(7.3)	143	(6.7)	**288**	**(6.9)**
Noninfectious-disease–related								
Rash	67	(12.7)	87	(5.8)	146	(6.8)	**300**	**(7.2)**
Heat-related	34	(6.4)	80	(5.3)	93	(4.3)	**207**	**(5.0)**
Nondiarrhea gastrointestinal	23	(4.4)	77	(5.1)	108	(5.0)	**208**	**(5.0)**
Renal*	8	(1.5)	44	(2.9)	35	(1.6)	**87**	**(2.1)**
Other classifiable illness†	22	(4.2)	52	(3.5)	88	(4.1)	**162**	**(3.9)**
Other illnesses	107	(20.3)	649	(43.3)	870	(40.6)	**1,626**	**(39.0)**
Total	**528**	**(100.0)**	**1,500**	**(100.0)**	**2,141**	**(100.0)**	**4,169**	**(100.0)**

* Includes kidney stones and renal failure (i.e., chronic and acute).
† Includes diabetes, cardiovascular conditions, obstetric/gynecologic conditions, and dental problems.

Source: CDC 2005c.

Table 3 reports illnesses and injuries following Tropical Storm Allison in Texas in 2001 (CDC 2002). The significant difference in illness rates between people in flooded and nonflooded locations provides evidence for the link between flood and increased illness. Respiratory and stomach conditions are reported more frequently than other health problems, consistent with the data from Hurricane Katrina shown above. Reported illnesses that might be the result of exposure to flood residues or secondary microbial growth include:

- Gastrointestinal infection.
- Wound infection.

- Respiratory infection.
- Upper respiratory symptoms.
- Skin rash.

Table 3. Number and Percentage of Households With One or More Persons Reporting Illness or Injury Within 1 Week After Tropical Storm Allison, by Flood Status of Home—Houston, Texas, June 16, 2001

	Flooded (n=137)		Nonflooded (n=283)				
Condition	**No.**	**(%)**	**No.**	**(%)**	**OR***	**(95% CI†)**	**p value§**
Illness	35	(25.5)	19	(6.7)	4.7	(1.8– 12.0)	<0.001
Diarrhea/Stomach condition	15	(10.9)	9	(3.2)	6.2	(1.4– 28.0)	0.017
Respiratory symptoms/Cold	14	(10.2)	7	(2.5)	3.2	(0.9– 10.9)	0.046
Headache/Dizziness	10	(7.3)	4	(1.4)	4.4	(0.8– 25.6)	0.056
Anxiety/Distress	5	(3.6)	0	(0.0)	undefined	undefined	0.059
Heart attack/Heart problems	4	(2.9)	0	(0.0)	undefined	undefined	0.059
Chronic illness made worse	3	(2.2)	0	(0.0)	undefined	undefined	0.134
Undefined generalized illness	1	(0.7)	1	(0.4)	undefined	undefined	0.149
Sleep disturbance/Nightmare	12	(8.8)	2	(7.1)	3.3	(0.5– 22.3)	0.240
Rash	2	(1.5)	2	(0.7)	6.0	(0.2–149.6)	0.286
Allergies	0	(0.0)	1	(0.4)	undefined	undefined	0.527
Injury	11	(8.0)	6	(2.1)	1.9	(0.4– 8.4)	0.463
Fall	2	(1.5)	0	(0.0)	undefined	undefined	0.153
Blunt injury	1	(0.7)	0	(0.0)	undefined	undefined	0.387
Insect bite	3	(2.2)	0	(0.0)	undefined	undefined	0.394
Abrasion/Cut/Puncture	2	(1.5)	3	(1.1)	0.4	(0.0– 8.1)	0.596
Auto accident	0	(0.0)	1	(0.4)	undefined	undefined	0.683
Other undefined injury	1	(0.7)	0	(0.0)	undefined	undefined	0.683
Animal bite	2	(1.5)	2	(0.7)	1.0	(0.1– 20.0)	1.000

* Odds ratio.
† Confidence interval.
§ Analysis of odds ratio, confidence interval, and p value stratified by census tract.

Source: CDC 2002.

The information from Hurricane Katrina and Tropical Storm Allison illustrates a problem common to many of the papers reviewed for this report: They are not detailed enough for the reader to determine whether exposures came about by the ingestion of contaminated food or water, by direct contact with flood water (especially contacts involving wounds), or by exposure to flood water residue or secondary microbial growth. A number of the studies provide evidence that the illnesses were related to flood conditions or contact with flood waters (CDC 2005d, Karande et al. 2003, Kateruttanakul et al. 2005, Miettinen et al. 2001, Waring et al. 2002). Waring et al. (2002) found that persons living in flooded houses after Tropical Storm Allison had a four-fold greater illness rate than those living in nonflooded houses. A study of gastrointestinal illness that was underway when flooding occurred provides some evidence of flood-related illness that was unlikely to have been caused by contaminated drinking water (Wade et al. 2004). It found that increased gastrointestinal symptoms were observed during the flood (incidence ratio of 1.29), and there was an association between increased symptoms and contact with flood water but not with the use of tap water. An outbreak of norovirus was reported from an evacuation center (CDC 2005b), and an increase in acute respiratory illness was attributed to the close quarters experienced by a National Guard battalion (CDC 2005c).

A few studies also provide evidence that illnesses resulted from the post-event cleanup (CDC 2005c, Lee et al. 1993), and some studies contain evidence for post-occupancy exposures:

- Two weeks after Hurricane Andrew the rate of injury complaints decreased, the rate of respiratory complaints increased, and the rate of gastrointestinal complaints remained steady (Lee et al. 1993).

- Post-Hurricane Katrina data indicate that relief workers experienced significantly more skin rashes than nonworkers (CDC 2005c), providing evidence that relief workers were experiencing exposures that others were not.

- A professor at the University of Hawaii contracted leptospirosis while cleaning up after heavy rains that caused a stream to overflow and flood his laboratory. This is a single case and has none of the distracters inherent in statistics that follow major flooding events (CDC 2006g).

2.2 Respiratory Problems and Moisture/Dampness

The authors' review found numerous articles that report associations between health endpoints and buildings that are damp or contain resultant microbial growth or both. These are most relevant to exposures while occupying and restoring homes after flood waters recede. The most comprehensive document is the Institute of Medicine (IOM) of the National Academies report *Damp Indoor Spaces and Health* (IOM 2004), which concludes that there is an association between damp indoor environments and (1) upper respiratory tract symptoms, (2) asthma symptoms in sensitized persons, (3) hypersensitivity pneumonitis in susceptible persons, (4) wheezing, and (5) coughing. There also is limited or suggestive evidence of an association with lower respiratory illness in otherwise healthy children (IOM 2004, pp. 9–11). Some evidence in the literature indicates that living in flooded buildings with secondary microbial contamination is associated with symptoms consistent with those listed in the IOM report.

Upper respiratory problems were the most frequently reported symptoms among police officers and firefighters in the aftermath of Hurricane Katrina (CDC 2006b). An editorial note says that the respiratory and skin rash symptoms were similar to those reported by Hurricane Katrina relief workers (CDC 2005c), which were very similar to those reported by relief workers after Hurricane Rita (CDC 2006i). The note states, however, "The relation between floodwater exposure and reported symptoms of illness is not clear."

2.3 Bacteria and Fungi in Indoor and Outdoor Air After Floods

We live in a microbial world. Microbes, including viruses, bacteria, and fungi, exist in all environments we inhabit, on our skin, and inside our bodies (Kelley and Gilbert 2013, Konya and Scott 2014). Humans shed microbes from their bodies directly into indoor air and onto building surfaces, and individuals also acquire microbes from their surroundings (Lax et al. 2014, Lax et al. 2015). Human occupancy, building design, and building operation all influence the abundance and diversity of microbial communities in buildings—or what is collectively referred to as the ***indoor microbiome*** (Adams et al. 2013a, Adams et al. 2013b, Adams et al. 2014, Adams et al. 2015, Bhangar et al. 2016, Kembel et al. 2012, Kembel et al. 2014, Meadow et al. 2014a, Meadow et al. 2014b). Even pets introduce a greater diversity of bacterial and fungal communities into their homes (Dannemiller et al. 2016, Dunn et al. 2013).

For the most part, microbes exist in harmony with humans. Most microbes found in indoor environments appear to be inactive and likely harmless, whereas others may even be beneficial to human health (Dannemiller et al. 2014, Green 2014). It is known, however, that under certain conditions, some microbes can become metabolically active, proliferate, and lead to exposures that cause a variety of adverse health effects (Rintala et al. 2012). This is particularly true when there are major sources of liquid water or water vapor in buildings, such as when flooding occurs. Flood damage leads to wet building materials and high levels of humidity that can increase the abundance of microbes indoors (including some pathogenic microbes), even after the damage has been remedied. Evidence in the literature indicates that the following differences are found in flooded buildings compared to nonflooded buildings: airborne levels of fungal ***spores*** are higher, the rank order of some species is different indoors than the rank order outdoors, and concentrations of bacterial ***endotoxins*** and fungal metabolites (including ***mycotoxins***) are higher. In a few instances, outdoor levels are higher than ordinarily reported. Several examples are reviewed below.

- Airborne bacterial endotoxin levels measured indoors and outdoors in New Orleans between October 22 and October 28, 2005, were 23.3 ***endotoxin units per cubic meter*** (EU/m^3) and 10.5 EU/m^3, respectively. These levels, measured almost 2 months after Hurricane Katrina, were higher than in previously reported work (<1.0 EU/m^3). The post-Hurricane Katrina study consisted of indoor air samples from 20 nonrandomly selected homes that had been flooded; outdoor air samples were drawn at 11 of them. Six of the homes had been remediated (CDC 2006h).

- Another study reporting indoor and outdoor mold levels in three homes in New Orleans that had experienced flooding found that total and culturable mold spore concentrations were significantly higher indoors (100,000–100,000,000 spores/m^3) and outdoors (22,000–515,000 cfu/m^3) than are typically reported indoors even after floods (0–48,760 cfu/m^3 [mean 2,190 cfu/m^3]) (Ross et al. 2000). Chew et al. (2006) also reported bacterial endotoxin levels between 17 and 139 EU/m^3 for the same study. By comparison, a study in Boston reported a mean indoor endotoxin level of 0.64 EU/m^3 (IOM 2004).

- Within 2 months of the floods caused by Hurricane Katrina, measured levels of airborne mold ranged from 11,000 to 645,000 spores/m^3 indoors and from 21,000 to 102,000 spores/m^3 outdoors. Indoor air samples were taken at eight houses that had experienced different levels of flooding and were in various states of remediation. Two indoor endotoxin samples from flooded homes yielded mold concentrations of 4.5 and 7.3 EU/m^3. Twenty-three outdoor locations also were sampled. The mean outdoor concentration in flooded areas (66,197 spores/m^3) was double that which was found in nonflooded areas (33,179 spores/m^3). There was no significant difference between outdoor airborne endotoxin levels in flooded areas (2.2–5.6 EU/m^3) and nonflooded areas (1.5–6.9 EU/m^3 [mean of 4.1 EU/m^3]). The researchers concluded that indoor and outdoor mold levels following Hurricane Katrina posed a significant respiratory hazard (Solomon et al. 2006).

- Sampling in 100 noncompliant office buildings by EPA's Building Assessment Survey and Evaluation Study found indoor levels of fungal spores ranging from 0 to 230 cfu/m^3 and outdoor levels between 0 and 6,184 cfu/m^3 (Macher et al. 2001, Shendell et al. 2005).

- In a review of documented indoor and outdoor levels of fungal spores, Gots et al. (2003) reported a mean indoor spore level of 233 cfu/m^3 in 149 noncompliant commercial buildings and an average outdoor level of 983 cfu/m^3. Total spore counts for the buildings were 610–1,040 spores/m^3; outdoor levels ranged from 400–800,000 spores/m^3. The indoor levels for noncompliant residential buildings averaged 1,252 cfu/m^3; outdoor levels averaged 1,524 cfu/m^3 (Gots et al. 2003).

- Baxter et al. (2005) reported indoor and outdoor mold spore levels from 625 commercial and residential buildings. Outdoor levels ranged from 70– 90,000 spores/m^3 (mean of 2,000 spores/m^3). Indoor levels in clean residential buildings were found to be between 150–9,000 spores/m^3 (mean of 900 spores/m^3). Indoor levels ranged from 200–3,000,000 spores/m^3 (mean of 5,000 spores/m^3) in moldy residential buildings; 20–8,000 spores/m^3 (mean of 700 spores/m^3) in clean commercial buildings; and 200–20,000,000 spores/m^3 (mean of 5,000 spore/m^3) in moldy commercial buildings (Baxter et al. 2005).

- He et al. (2014) measured airborne concentrations of culturable fungi and bacteria in 24 flooded homes and 17 nonflooded homes at 2 and 6 months after rapid cleanup activities had been conducted following a massive flood that occurred in Brisbane, Australia, in January 2011. Indoor and outdoor measurements were conducted simultaneously. No statistically significant differences were found in fungi or bacteria levels in the flooded homes compared to the nonflooded homes, likely because a large number of volunteers were able to quickly and effectively clean the flooded houses. Among the various cleaning methods used (which included water only, water plus detergent, water plus bleach, water plus disinfectant, detergent and bleach, and water plus insecticide), the use of both detergent and bleach was the most efficient at controlling indoor bacteria, and all cleaning methods were equally effective for controlling indoor fungi (He et al. 2014).

- Emerson et al. (2015) collected passive air samples from basements in 36 flood-damaged and 14 nonflooded homes in Boulder, Colorado, 2 to 3 months after the city's historic September 2013 flooding event. Quantitative ***polymerase chain reaction*** (commonly known as PCR) was used to estimate the abundances of bacteria and fungi in the passive air samples (only indoor samples were collected; no outdoor samples were collected). Results suggested differences in bacterial and fungal community composition between flooded and nonflooded homes (i.e., *Penicillium* was the most abundant fungal taxa in flooded homes). Fungal abundances were approximately three times higher in flooded homes compared to nonflooded homes, although there were no significant differences in bacterial abundances. The authors conclude that indoor bacterial and fungal communities continue to be affected by flooding even after remediation has been conducted to remove visible evidence of flood damage and after relative humidity has returned to baseline levels, although the lack of outdoor measurements for comparison and lack of detail on remediation methods make it difficult to draw definitive conclusions from this study (Emerson et al. 2015).

2.3.1 Mycotoxin Exposure

Research during the past three decades has been limited in defining various toxic effects from molds growing on water-damaged materials in the indoor environment. Many chemical compounds or metabolites are known to be produced by a variety of fungi growing on various building or finishing materials in flooded situations—including species of *Aspergillus*, *Penicillium*, *Trichoderma*, and *Stachybotrys*—and whose mycelial fragments and/or spores are known to contain such metabolites, commonly known as mycotoxins (Miller and McMullin 2014). The potential for workers and occupants to inhale such fragments and spores, and thus incur possible resultant adverse health effects, derives from the knowledge that:

- Water-damaged buildings have a higher percentage of such spores and fungal fragments than nondamp or nonwater-damaged indoor environments (Cho et al. 2005, Foto et al. 2005, Green et al. 2011, Reponen et al. 2007).

- Exposure to metabolites from fungi commonly found in water-damaged buildings recently has been shown to cause a variety of lung inflammatory and physiological changes in lung biology in mice (Miller and McMullin 2014).

Given the repeated findings of higher fungal and endotoxin concentrations in water-damaged and damped buildings—in addition to the adverse health effects associated with exposure to contaminated flood waters, building materials, and indoor air—there is a clear need to understand and utilize safe and effective practices for cleaning and decontaminating residences after a flood event has occurred. The next chapter summarizes a number of guidance documents and evidence from the literature on means for cleaning and decontaminating after flood events to return flooded buildings to habitable conditions.

Returning Flooded Buildings to Habitable Conditions

3

3. Returning Flooded Buildings to Habitable Conditions

Floods and storm events may result in damage to homes ranging from relatively minor damage that may ruin some materials to major damage that may risk the lives of people and pets. Minor damage may include some wetting and/or contamination of: building foundations; exterior and/or interior floors, walls, and doors; equipment; furnishings; and belongings. Major damage may include: wind damage that may open the upper portions of buildings to heavy rains; flooded heating, ventilation, and air-conditioning (HVAC) equipment and backup generators; and flooding that may damage the building beyond repair (e.g., breaking foundations and walls, washing away buildings, or destroying contents and furnishings). Further, entire neighborhoods, communities, and regions may be affected. Roads and bridges may be washed out. Electric power may be lost for large regions, for a small number of buildings, or not at all. This report, however, is limited in scope to homes with minor to major damage that are assumed to be repairable.

On returning to the home after a flood event, visible damage may range from minor issues such as some wetting or contamination of materials to major issues such as full or partial standing water, overturned appliances, submerged furniture, and ruined building materials. Several guidance documents provide helpful instructions for assessing the severity of the situation.

A number of government agencies and NGOs provide guidance documents for cleaning and decontaminating buildings after flooding. The primary federal guidance comes from EPA, CDC, and FEMA. States that have historically experienced floods have produced a number of guidance documents. NGOs such as the ALA, ARC, NCHH, and IICRC have produced guidance documents. A full review of these documents is provided in Appendix 1.

The guidance documents range from a single page covering the primary steps in cleaning and drying a home to extensive technical guidance for cleaning and restoration of water-damaged buildings. None of the documents cover every aspect of safely returning a flood-damaged house to habitable condition. Although there often is overlap between documents, the documents can be divided into those that focus primarily on:

- Do-it-yourself guidance for owners, renters, and volunteers.
- More detailed, technical guidance for skilled workers, who may be professionals or skilled owners, renters, or volunteers.
- Safely getting to, entering, initially cleaning (sometimes called “mucking out”) the house, and restoring basic services such as electricity, water, sewage, heating, and cooling.
- Identifying and separating materials and items that will be salvaged and cleaned from those that will be removed and disposed of.
- Drying, cleaning, and sanitizing the house and its contents.
- Cleaning and removing mold growth as opposed to removing and cleaning flood-contaminated materials and contents.

This report focuses primarily on guidance documents from three federal agencies (EPA, CDC, and FEMA) and two documents from NGOs (NCHH and IICRC). The two NGO documents were selected because they are current, comprehensive, and widely used by community housing groups (NCHH) and professional water restoration firms (IICRC). Both documents are comprehensive, developed by practitioners and researchers in the respective fields, passed through well-established review processes, and extensively documented. The 2015 IICRC *S500 Standard and Reference Guide for Professional Water Damage Restoration* contains material that is most directly relevant and applicable to cleaning and decontaminating residences.

3.1 Definitions

All flood-damaged buildings will need to be cleaned and dried to restore them to habitable conditions. Cleaning is needed to remove contaminants deposited by flood waters. Drying prevents secondary mold growth inside the house. In some cases, structural damage will need to be repaired. Often, safe drinking and bathing water, toilets, electricity, and heating and air-conditioning systems also will need to be restored.

Ordinary cleaning equipment, methods, and products are the primary tools for removing contamination, including living organisms from environmental surfaces. When it is desirable to go beyond the effectiveness of ordinary cleaning methods, specific agents are used to kill living organisms from flood-damaged materials. Several terms are commonly used to describe materials and methods that reduce, inactivate, or kill microbes or prevent their growth. Although many groups often apply their own meanings to the terms, EPA, as a regulatory body, employs standard legal definitions based primarily on the laboratory test methods required for product registration. These and other definitions that are used in guidance documents are provided below.

Antimicrobial: EPA defines an antimicrobial substance as a substance that kills or inactivates bacteria, fungi, or viruses in the inanimate environment (excluding those on or in living organisms, food, beverages, pharmaceuticals, or cosmetics) or is used to inhibit microbial growth on materials. Antimicrobials include sterilizers, disinfectants, virucides, tuberculicides, algicides, sanitizers, bacteriostats, and fungistats. The IICRC S500 standard defines an antimicrobial as a substance that kills or controls microorganisms or inhibits their growth (IICRC 2015). The American Conference of Governmental Industrial Hygienists (ACGIH) defines an antimicrobial agent as a chemical formulation applied to or incorporated into a material to suppress or retard the growth of vegetative bacteria or fungi (ACGIH 1999). Other authorities refer to materials that specifically inhibit bacterial growth as *bacteriostats* and materials that specifically inhibit the growth of fungi as *fungistats*.

Biocide: A simple definition accepted by many groups is "any substance that kills a living organism" (ACGIH 1999, IICRC 2015). EPA uses the term "antimicrobial pesticide" to refer to the spectrum of chemical germicides, biocides, and antimicrobials.

Cleaning: According to the professional cleaning and restoration industry, cleaning may be defined as "the traditional activity of removing contaminants, pollutants and undesired substances from an environment or surface to reduce damage or harm to human health or valuable materials" (IICRC 2015). Cleaning is thus a process that may utilize one or more approaches to achieving a condition free of unwanted matter.

Clearance: Clearance is the process of verifying the acceptability of the flood cleanup procedures and confirming the job was completed prior to rebuilding and reoccupation.

Containment: Containment is a series of control measures to isolate a contaminated area (i.e., an area that is producing air contaminants) from uncontaminated areas that are outside of the contaminated area. Containment control measures include enclosing work areas within physical barriers, sealing air leakage sites in the bounding enclosure, and managing air pressure differences so air flows from uncontaminated areas into contaminated areas.

Contaminant: A contaminant is defined as any physical, chemical, biological, or radioactive substance that can have an adverse effect on air, water, or soil, or interior or exterior surfaces. Examples relevant to flood-damaged buildings include metals, asbestos, and petroleum products. Importantly, the 2015 S500 standard categorizes water by levels of contamination:

- *Category 1* water originates from a sanitary source and poses no significant risk from contact, ingestion, or inhalation.

- *Category 2* water has significant contamination and may pose a health hazard if contacted or consumed by humans. Dishwasher or washing machine overflow, toilet backup without feces, and water from aquariums are included in this category.

- *Category 3* water is heavily contaminated and can contain pathogens or toxins. Anyone who comes in contact with or consumes Category 3 water risks health impacts. Examples of Category 3 water are sewage and floods from seas, rivers, or lakes.

Decontamination: The process of reducing the amount of "contaminants" on surfaces and materials, most often referring to bacteria and fungi (which includes molds). These same contaminants also can be inactivated or suppressed using a biocide or antimicrobial, such as a sanitizer or disinfectant.

Dehumidifier: A dehumidifier is an appliance that reduces the amount of moisture in the air, and is a crucial piece of equipment in post-flood cleanups, as it aids in the drying process. Although fans may be used to move moisture into the air from wet surfaces and materials, unless that moisture is removed from the air, it will re-condense on those surfaces and materials. To restore a flooded indoor environment as quickly as possible to pre-flood conditions and reduce the risk of mold growth, dehumidification is essential.

Disinfectant: According to EPA, a disinfectant is one of three groups of antimicrobials registered by the Agency for public health uses. EPA considers an antimicrobial to be a disinfectant when it destroys or irreversibly inactivates infectious or other undesirable organisms but not necessarily their spores. EPA registers three types of disinfectant products based on submitted efficacy data: limited, general or broad spectrum, and hospital disinfectant.

Habitable condition: None of the guidance documents or the organizations that produce them provides a clear definition of habitable condition. In lieu of an explicit definition, a short discussion is included on the topic of habitability and cleaning up flood-related damage and contamination. The basic requirements for a habitable condition are structural safety, operational toilets and sewage disposal, safe drinking water, bathing and cooking water, safe electric power, operational HVAC, and physical security. These functions must be restored to flooded houses. In addition, materials, belongings, and contents must be free of contamination deposited by flood water and microbial growth that occurred after the flood. Flood-related contamination includes mold, bacteria, and wood-decaying fungi. The intent of cleaning up after a flood is to return the microbial community in the house to that of microbial communities in ordinary habitable buildings.

HEPA vacuum: A HEPA vacuum is a vacuum cleaner that has been designed with a HEPA filter as the last filtration stage. A HEPA filter is capable of capturing 0.3-micrometer particles with 99.97 percent efficiency, and thus can capture aggregates of microorganisms and microbial growth, as well as most individual fungal spores and bacteria. The vacuum cleaner must be designed so that all air drawn into the machine is expelled through the HEPA filter with none of the air leaking past it. HEPA vacuums are used to remove fine dust particles from a dry surface or material as part of a comprehensive cleaning approach and must be operated and maintained in accordance with the manufacturer's instructions. A HEPA vacuum is not a wet/dry vacuum ("shop vac") that is used to clean up water, liquid spills, or visible dust and debris.

Sanitizer: According to EPA, a sanitizer is one of three groups of antimicrobials registered by the Agency for public health uses. EPA considers an antimicrobial to be a sanitizer if it reduces but does not necessarily eliminate all microorganisms on a treated surface. For a product to be a registered sanitizer, its test results must show a reduction of at least 99.9 percent in the number of each test microorganism over the parallel control. The IICRC and ACGIH definitions of sanitizer are essentially the same as the EPA definition, but they do not include the percent reduction.

Sterilizer: According to EPA, a sterilizer is one of three groups of antimicrobials registered by the Agency for public health uses. EPA considers an antimicrobial to be a sterilizer if it destroys or eliminates all forms of bacteria, fungi and their spores, and viruses. Because spores are considered the most difficult form of microorganism to destroy, EPA considers the term "sporicide" to be synonymous with "sterilizer."

3.2 Steps to Return the House to Habitable Conditions

Six primary steps in returning a home to habitable conditions have been synthesized from the guidance documents:

1. *Stay safe and healthy while returning the house to habitable conditions*: Be prepared to stay safe at every phase of recovering from a flood.

2. *Assess the situation and make a plan*: Assess the damage and plan recovery. Reassessment may be needed as the work proceeds and new information is uncovered. Determine whether professional help is needed to return the house habitable conditions.

3. *Remove water, debris, silt, trash, and items damaged beyond repair*: The initial cleaning includes getting the bulk water out and steps to make working in the house safe from physical hazards such as slips, trips, falls, building collapse, and electric shock.

4. *Drying, cleaning, and decontaminating*: Drying facilitates restoring the house to a habitable condition and typically involves the use of fans or other "air-movers" to move moisture from surfaces and materials into the air, where it can be removed through natural ventilation, if outdoor conditions allow, or more commonly through the use of dehumidifiers. Once dry, the indoor environment can be cleaned to physically remove dust and debris prior to the use of a biocide or antimicrobial to inhibit bacterial and fungal growth in the process of decontamination.

5. *Meeting reoccupation criteria*: Clearance is the process of verifying the acceptability of the flood cleanup procedures and confirming the job was completed prior to rebuilding. It also serves to determine the suitability of the home to be reoccupied. The ultimate clearance criterion is the ability of occupants to reside in the restored dwelling in the absence of adverse health effects typically associated with water damage and microbial contamination.

6. *Conducting renovations (as needed)*: If the house is located in a ***floodplain*** and there is substantial damage (e.g., 50% or more of the market value would be required to restore the home), renovations must be made in compliance with federal and local floodplain management codes and regulations.

Each of these steps is described in more detail below.

3.2.1 Stay Safe and Healthy While Returning the House to Habitable Conditions

Those who are cleaning up a house after a flood need to be prepared to protect themselves against a number of hazards and should prepare for the following:

- *Safely get to and enter the damaged home*: In some cases, people may have sheltered in place, never leaving the home. In other cases, they may have traveled some distance to find safe haven. In either case, debris and silt that prevents access to the building must be safely removed. A number of physical hazards may wait inside the house (e.g., electric shock, poor footing, sharp edges, animals sheltering the house), as well as biological hazards in the form of sewage contamination. The 1992 FEMA/ARC document, *Repairing Your Flooded Home*, provides guidance for handling the immediate hazards. Contact the local health department for health hazard warnings such as a contaminated drinking water advisory. Contact insurance agents to determine which losses are covered and which are not.

- *Unstable portions of the structure, trips and falls, cuts and bruises*: Assess the stability of the house before entering. Bring flashlights, a battery-powered radio, and a first aid kit while working at the house.

- *Electric shock*: Make sure that the power is off at the meter before re-entering the house. Do not use equipment or electric appliances that were exposed to flood waters unless an electrical inspector has cleared them for use.

- *Exposure to contaminants, including*:
  - Deposits left by the flood.
  - Hazardous materials already in the house that have been released by flood damage.
  - Sewage contamination and/or mold or bacteria that have colonized in the house following the flood.
  - Combustion fumes from gasoline-powered tools, generators, or heaters used indoors or in attached garages.

- *Use of personal protective equipment (PPE) for protection from contaminant exposures*:
  - Wear a long-sleeve shirt, long pants, gloves, and eye protection and use an N95 respirator when engaged in cleanup.
  - Individuals with conditions that make it difficult to breathe will be unable to use a respirator and should not be present during cleanup activities. See the ARC, EPA, and FEMA guidance documents for additional guidance for do-it-yourselfers.

- *Food and drink safety*: Check with the health department for safe drinking water advisories. Bring safe drinking and wash water. Do not eat in contaminated areas.

- *Generators, grills, heaters*: Place gas-powered equipment and unvented heaters (e.g., charcoal, gasoline, kerosene space heaters) at least 15 feet from the house and never in attached garages.

- *Know when to hire a professional*: Professional cleanup and water restoration businesses are required by federal law to have a worker protection plan and protective equipment and clothing. See the S500 standard and/or the NCHH guide for extensive guidance on professional health and safety.

3.2.2 Assess the Situation and Make a Plan

The FEMA/ARC, IICRC, and NCHH documents provide extensive guidance for assessing moisture and contamination of materials, furnishings, and contents. Assessing the situation is an iterative process. Initial assessment activities include:

- Identify the potential hazards. Assess the building for structural damage, the extent of materials that were covered by flood waters, areas that are wet, and those that have secondary mold growth.
- Determine whether safe electricity, working toilets and sinks, drinkable water, and operating HVAC are present in the building.
- Determine the nature and extent of contamination and wet materials and contents. There is likely to be debris and silt deposited inside the home as well as outside. There may be standing water and mold growth. The heating and air-conditioning equipment, refrigerators, ovens, and stoves may have been flooded. Ductwork may be contaminated. **Caution**: Pumping water from below grade space too quickly may lead to collapse of foundation walls. See the FEMA/ARC guide for information.
- Divide the building into areas affected by the flood and areas that were not.

3.2.3 Remove Water, Debris, Silt, Trash, and Items Damaged Beyond Repair

The initial cleaning includes removing the bulk water and taking steps to make working in the house safe from physical hazards such as slips, trips, falls, building collapse, and electric shock. This step begins with sorting, cleaning, and drying, a process that continues in stages until things are restored to habitable conditions. Open the windows and doors and remove wet debris, silt, and standing water. If drying out the building does not begin quickly enough, the house and its contents may become contaminated by mold and bacteria or damaged by wood-decaying fungi. Removing the debris and silt opens the way for restoration. In addition to debris and trash, it is likely that there will be furniture, clothing, appliances, and other belongings that are damaged beyond repair. Deciding what is no longer worth the effort or cost of repair and what will be cleaned and saved begins the sorting process. Take out things that have become trash. Move things that will be saved to an unaffected, protected area. The least affected areas become clean work areas; the NCHH and IICRC documents provide extensive guidance on setting up and operating a clean work area. Portable, high-volume, HEPA-filtered fans can be used to pressurize the clean work area with filtered outdoor air or used in recirculation mode inside the work area to keep the air clean. The 2005 FEMA recovery advisory, *Initial Restoration for Flooded Buildings*, contains brief, direct, and useful guidance on initial drying, cleaning, and sorting (FEMA 2005). As with approaching and entering the building, staying safe is the first priority. Some building materials and equipment may have been damaged or contaminated beyond practical repair or cleaning. It is most efficient to remove these materials from the building after items that are being saved have been moved to protected areas but before final cleaning and sanitizing occur.

3.2.4 Drying, Cleaning, and Decontaminating

After the flood waters have receded and the house is structurally safe to occupy, the primary activities involved in all flood cleanups are drying, cleaning, and decontaminating. The following steps for drying, cleaning, and decontaminating a building have been synthesized from the guidance documents:

- Assessing drying, cleaning, and decontamination needs.
- Removing water and drying.
- Removing materials.
- Cleaning and decontaminating materials, surfaces, and cavities.
- Cleaning and decontaminating HVAC systems.
- Exercising caution during drying, cleaning, and decontaminating.

3.2.4.1 Assess Drying, Cleaning, and Decontamination Needs

The first set of tasks for drying, cleaning, and decontaminating involve planning. Determine the following:

- Drying needs: How much needs to be dried and how will that happen?
- Cleaning needs: What needs to be cleaned or removed and how will that happen?
- Personal protection: How will you protect your health and contain the contamination while drying and cleaning?

Then make the following plans:

Plan the drying strategy

Consider the following:

- Are there windows and doors that can be safely left open?
- What portions of the building are wet?
- How large of an area is there to dry?
- How many materials and assemblies will be difficult to dry?
- Are fans, electric heaters, or dehumidifiers needed? Is electric power available for running them?
- Identify the extent and nature of wet materials, equipment, and possessions.

Plan the cleaning and decontaminating

Identify materials, assemblies, equipment, appliances, and furnishings that are contaminated by flood waters or secondary microbial growth. The S500 standard considers all flood waters associated with weather events to be contaminated (Category 2 or 3). Anything wetted by flood water will need to be cleaned or thrown away. If an item is not worth repairing or cleaning, then remove it from the building and take it to a disposal site. Materials, contents, appliances, and equipment that have been affected by the flood are sorted into those that can be salvaged by repair, drying, and cleaning and those that are not worth saving.

Determine cleaning and decontamination procedures for the materials, belongings, furnishings, appliances, and equipment that will be salvaged and devise a plan for disposing of items that are trash. Methods for cleaning and decontamination will vary depending on the nature of the materials and objects being decontaminated. See Section 3.2.4.4 for more details.

Identify one or more areas where items that will be salvaged and cleaned can be stored, dried, and cleaned. The NCHH and IICRC documents provide extensive guidance on setting up and operating a clean work area. As mentioned above, portable, high-volume, HEPA-filtered fans can be used to pressurize the clean work area with filtered outdoor air or used in recirculation mode inside the work area to keep the air clean. The FEMA recovery advisory, *Initial Restoration for Flooded Buildings*, contains brief, direct, and useful guidance on initial drying, cleaning, and sorting.

Plan health protection and contaminant containment

Determine who will be performing the drying and cleanup. Will it be you, family, and friends? Organized volunteers? Cleanup professionals? Regardless of who it is, good health and safety practices will need to be employed. See Section 3.2.4.1 for more details on recommended health and safety practices. The NCHH contains fairly extensive discussion and illustrations on health and safety practices. The S500 standard has substantial discussion and refers to 29 CFR 1901—Occupational Safety and Health Standards and 29 CFR 1926— Safety and Health Regulations for Construction.

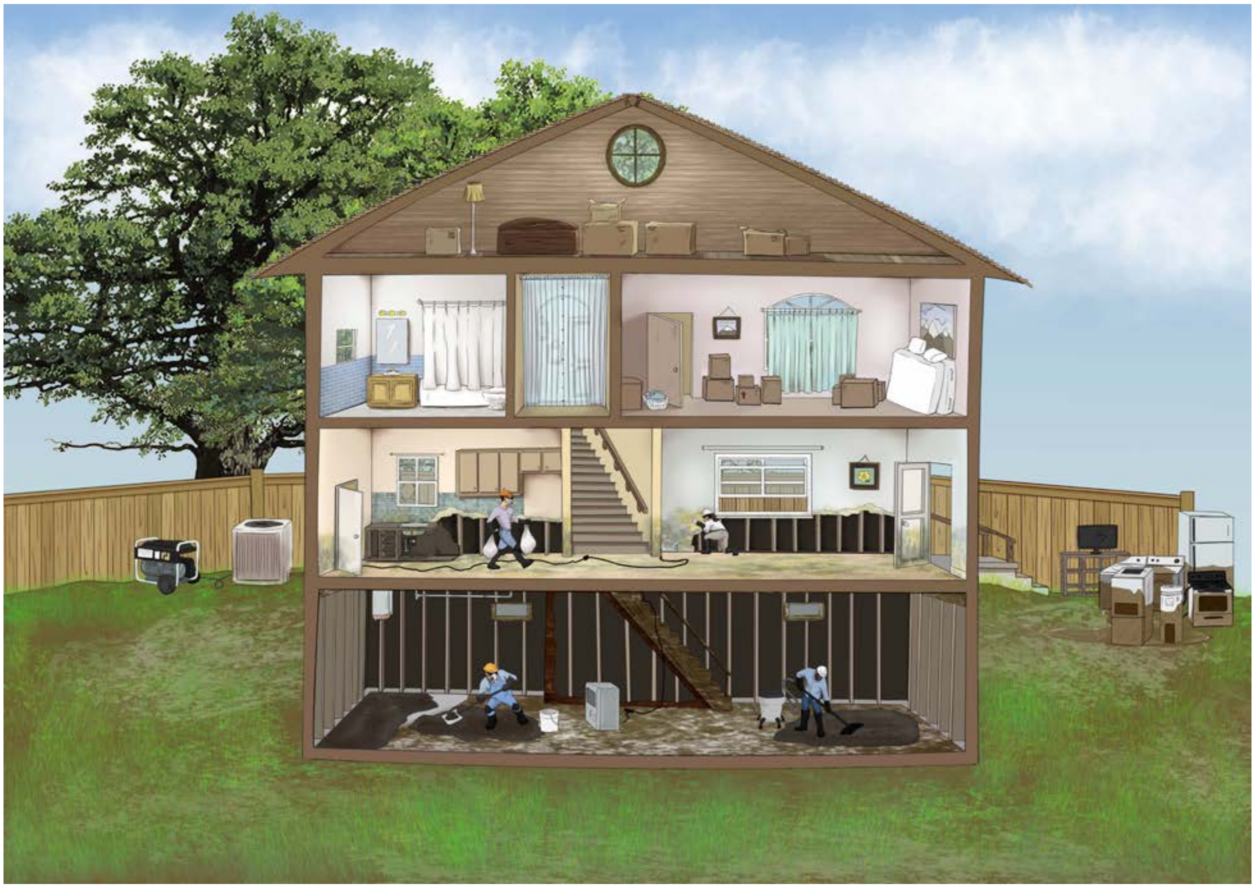
The health and safety plan should include:

- PPE and clothing required for each different activity.
- Electrical safety.
- Steps to prevent contaminants released into the air during demolition, drying, cleaning, and rebuilding from spreading to clean parts of the house. The NCHH guidance contains a good discussion of isolating work areas from clean areas.

3.2.4.2 Removing Water and Drying

Drying the building and contents may be conducted in phases. Initially, drying is intended to prevent microbial growth. Unlike soiling or a chemical contaminant deposited in a flooded building, microbial growth can quickly contaminate far more area than was initially affected by flood water. Drying damp materials prevents microbial growth and reduces the amount of cleaning that must be done. Many cleaning efforts from power washers to damp wipes are water-based. Drying must continue after water-based cleaning activities.

If it is not raining outside, opening windows and doors will provide a great deal of ventilation. How quickly things dry depends on how dry the outdoor air is compared to the indoor air. If the outdoor air is warm and dry, the building will dry quickly. For example, after extensive flooding in Brisbane, Australia, He et al. (2014) reported that the concentrations of airborne particle counts, culturable fungi, and culturable bacteria were similar in houses that were flooded and those that were not flooded because remediation was quickly carried out by thousands of volunteers who reportedly mucked them out, cleaned up, and opened the windows and doors to allow them to dry. Importantly, Brisbane has a subtropical, dry climate (less than 4 inches of rain per year).



After you have assessed the severity of the flood damage and made a plan for drying, cleaning, decontaminating, and returning the building to a habitable condition, the first step of cleanup should involve physically removing water, debris, silt, trash, and any items that are damaged beyond repair. The initial cleaning also includes taking steps to make working in the house safe from physical hazards such as slips, trips, falls, building collapse, and electric shock.

On the other hand, if flood waters remain for weeks and the climate is warm and humid, it is likely that there will be extensive mold growth unless the building can be sealed and dried using dehumidifiers, fans, and heat. As an example, after Hurricane Katrina made landfall in New Orleans on August 31, 2005, a research project was conducted to test the newly developed NCHH remediation protocol on three flooded houses. Sampling occurred over 3 months (November 2005 through January 2006). Outdoor mold concentrations remained at around 10^4 cfu/m^3 throughout the 3 months. Indoor concentrations were reported as 10^4 to 10^6 cfu/m^3 during pre-remediation, 10^5 to 10^7 cfu/m^3 during remediation, and 10^3 to 10^4 cfu/m^3 post-remediation (lower than or similar to outdoor air). Flood waters receded during the course of 3 weeks after the storm. The remediation in these houses started in November 2005 (Chew et al. 2006). The climate was hot and humid and the drying potential was very poor, however, so the materials indoors and outdoors remained wet for weeks, leading to elevated mold levels.

If the outdoor air dew point is too high, dedicated dehumidification equipment may be needed. The information collected on the extent and nature of damp materials can be used to estimate the dehumidification capacity needed and the time required to dry the hard-to-dry materials and assemblies in the house. The S500 standard has an extensive discussion on drying. The 2013 FEMA memorandum on insurance coverage for drying ("Claims Guidance—Structural Drying and Other Related Items") described in Appendix 2 also contains technical drying information and guidance on flood insurance coverage for drying activities.

How quickly things dry also depends on the nature of the materials and whether the item or assembly contains cavities, joints, cracks, or porous materials that make it difficult to air dry. Hard-surfaced, nonporous materials like glass, metal, ceramics, stone, and plastics dry quickly because the water is all at the surface where it can be mopped up and warm, dry air can be blown across it.

Once the liquid water is removed from the building and the large open surfaces are dry to the touch, problem water can still remain in cavities, cracks, and porous materials. This water cannot be removed by pumps or with buckets, as it must evaporate from the surfaces and wick to the surface from deep within damp porous materials. Air movement, dry air, and heat are needed to dry cavities, cracks, and porous materials. Some cavities such as cabinets, drawers, air handlers, and plumbing walls can be opened and aired out. Other cavities can only be accessed by removing built-in cabinets or making holes in the kick spaces, soffits, and wall or ceiling cavities. Opening these cavities greatly increases the drying rate. Cracks are hard to dry because liquid water is held between them by capillary suction in spaces that are too small to blow air through or wipe out with a rag. Examples of cracks that are difficult to dry out include the joints between floorboards, trim around windows and walls, and joints between studs and sheathings that frame a house. Materials and possessions that are hard to dry include porous materials like ***gypsum board***, wood, concrete, open cell foam, carpets, carpet pads, fabrics, and bedding. If the surfaces of porous materials are dried faster than water can wick from the interior, there will be very little new microbial growth. It is important to dry these reservoirs of water before removing drying equipment. If drying efforts stop too soon, microbial growth may begin or recur.

3.2.4.3 Removing Materials

Deciding what contents and materials will be salvaged and which will be thrown away is a balance of the economic, practical, and emotional value of each item and the difficulty and financial cost of cleaning and saving it. The greater the emotional value and the replacement cost of an item, the more likely it will be saved. A family heirloom that also is a valuable antique is something people will save. If it is an ordinary, inexpensive material with no emotional value, it is more likely to be disposed of rather than cleaned or replaced.

The guidance documents agree that removing contaminated porous materials often is warranted. There are two reasons this recommendation is common in the guidance: (1) many porous materials are hard to clean without damaging them in the process and (2) many porous materials are relatively inexpensive to replace. For example, gypsum board is difficult to clean without damaging the paper facing or gypsum core. Particleboard and ***medium-density fiberboard*** also may be damaged by flood waters or by wetting during cleaning processes. The category of water plays a conditional role in remediation. For example, gypsum board may be restorable if the water it contacts is Category 1 or 2 and the core and facing are intact, but the board must be removed if water is Category 3. By contrast, concrete is generally recoverable even when flooded by Category 3 water.

The level of detail in the guidance documents on what and how to discard the materials varies. The FEMA/ARC, NCHH, and IICRC documents contain the most extensive guidance on removing materials.

3.2.4.4 Cleaning and Decontaminating Materials, Surfaces, and Cavities

Contents to be saved and cleaned are typically first cleaned superficially and then set aside in a protected area where they can be more thoroughly cleaned and decontaminated. Walls, ceilings, and floors are dried, cleaned, and decontaminated in place.

The focus of cleaning and decontaminating should be to maximize the physical removal of contaminants, as opposed to merely killing or inactivating microbes. In the post-flooding remediation process in an indoor environment, such cleaning approaches may involve the use of:

- Shovels, buckets, wheel barrows, hoses, wet vacuum, and water extraction machines (typically this level of cleaning is conducted during the muck-out stage).
- Pressure washers and foaming detergents (FEMA 2013).
- Scrubbing, wiping, or mopping with warm water and detergent.
- HEPA vacuum.
- Sanitizers and disinfectants.

As flood waters drain and recede from a home environment, residuals of ground water silt, sewage contamination, and mold growth typically will be present. Although much of those residuals will be removed from the dwelling as part of the demolition process of water-damaged porous and semiporous materials, intact nonporous materials—such as metal, PVC, and sealed or painted concrete—along with some semiporous structural materials, such as wood framing, often can be recovered by utilizing one or more of the following cleaning approaches.

There are many ways to clean surfaces. Each has its own advantages and disadvantages. Cleaning methods can divided into wet methods and dry methods:

- Wet methods include:
    - Washing with water and a cleaner.
    - Steam cleaning.
    - Cleaning with foaming detergent.
    - Hot water extraction.
    - Low pressure flushing.
    - High pressure washing.

- Dry methods include:
  - HEPA vacuuming or vacuums that directly exhaust to outdoors.
  - Using blowers to wash air over surfaces to remove water vapor or particles.

Use a combination of wet and dry cleaning methods as appropriate. Wet cleaning methods include washing with water and a cleaner, steam cleaning, cleaning with foaming detergent, hot water extraction, low pressure flushing, and high pressure washing. Dry cleaning methods include vacuuming with HEPA vacuums or vacuums that directly exhaust to outdoors and using blowers to wash air over surfaces to remove water vapor or particles. Many nonporous or semiporous surfaces and materials may be easily cleaned by washing in warm, soapy water. Porous and some semiporous materials will need to be removed and replaced.

All of the guidance documents recommend using wet cleaning methods as the initial treatment for sound, salvageable materials. The use of detergents in wet cleaning surfaces and materials provides for the emulsification of organic residues and thus the removal of associated pathogens, allergens, and chemical pollutants. As many detergent products are formulations of quaternary ammonium compounds (QACs), they typically have a sanitizing (i.e., killing) effect on microbial contamination as well. Yet another approach is the use of microfiber cloths for the effective and nonchemical wipe down of a variety of surfaces expected to be contaminated with various microbes, including human pathogens. Also, the use of steam as a cleaning and sanitizing method has become more popular with the availability of a number of commercial equipment products.

Once wet cleaning and decontamination practices have been completed and the environment sufficiently dried, HEPA vacuuming can provide an additional measure of physical removal of any remaining residual contaminants prior to the rebuilding process.

Some surfaces and materials may be easily cleaned. For example, fabric items such as washable clothing can be cleaned by washing in warm, soapy water. Open expanses of solid, nonporous materials are easy to clean and decontaminate using warm water and mild detergent. Easily reached hard surfaced materials like wood are easy to clean. Porous materials with sealed surfaces also may be easy to clean.

The porosity of a material is important in two ways. First, porous materials absorb a great amount of water and are difficult to dry. Second, porous materials are more difficult to clean because contamination may have penetrated into the pores and because some porous materials are damaged by the cleaning process. For example, a porous material soaked with flood water carrying petroleum may become a reservoir for semivolatile contaminants that will continue to release pollutants into the air from interior pores for many years. Although scrubbing and high-pressure washing can be used to clean porous materials, they also can damage porous materials such as gypsum board.

The S500 standard divides materials into three categories based on their moisture absorption and drying nature and how sensitive they are to moisture damage:

- Porous materials: Rapidly absorb liquid water and take a long time to dry by evaporation.
- Semiporous materials: Absorb liquid water slowly and dry slowly.
- Nonporous materials: Do not absorb water at all or absorb water at a negligible rate.

Table 4 provides several examples of porous, semiporous, and nonporous materials.

Table 4. Examples of Porous, Semiporous, and Nonporous Materials

	Porous	Semiporous	Nonporous
Contents	Fabrics, textiles, furniture cushions, bedding, medium-density fiberboard (called MDF)	Unfinished wood, sandstone, plywood, expanded polystyrene	Glass, marble, granite, metals, finished wood
Interior materials	Gypsum board, ceiling tile, carpets, carpet padding	Unfinished wood, paneling, wooden flooring	Wooden products finished on all sides, ceramic or plastic tile, metal, glass
Structural materials	Oriented strand board (called OSB), gypsum sheathing	Unfinished wood, fiber-cement siding	Steel, copper, glass, ceramic tile

The guidance documents generally recommend *removing and replacing* many porous and semiporous materials and *cleaning* many nonporous materials. If the material will be physically damaged by cleaning or if the flood water is Category 3, removing and replacing is recommended, regardless of the material category. Table 5 provides recommendations from the guidance documents for cleaning or removing materials in the porous, semiporous, and nonporous categories.

Table 5. Cleaning Recommendations for Porous, Semiporous, and Nonporous Materials

Contents	
Porous	Fabrics and textiles, such as clothing, linen, and area rugs, may be washed with warm water and detergent and then dried. Furniture cushions and mattresses should be disposed of and replaced. Furniture made from porous materials such as medium-density fiberboard (MDF) may be cleaned unless it is physically decomposing or exposed to Category 2 or 3 water.
Semiporous	Unfinished wood, sandstone, plywood, and expanded polystyrene may be washed in warm water and detergent and then dried. Depending on the extent of contamination or physical damage, the item may be disposed of or more detailed remediation methods may be employed following the S500 standard.
Nonporous	Nonporous materials may be washed with warm water and detergent and then dried.
Valuables (of all kinds)	Valuables that contain moisture-sensitive materials may be restored by specialists. For example, musical instruments, paper money, paintings, sculpture, and rare or expensive books may be valuable enough to warrant restoration no matter their condition.
Interior finish materials	
Porous	Gypsum board, ceiling tile, carpets, and carpet padding/cushions should be disposed of and replaced. Items made from porous materials like MDF may be cleaned unless they are physically decomposing or exposed to Category 2 or 3 water.
Semiporous	Unfinished wood paneling may be washed with warm water and detergent and then dried. Depending on the extent of contamination or physical damage, the item may be disposed of or more detailed remediation methods may be employed following the S500 standard.
Nonporous	Wooden products finished on all sides, ceramic or plastic tile, metal, and glass may be washed with warm water and detergent and then dried.
Structural materials	
Porous	Oriented strand board (called OSB) and gypsum sheathing should be disposed of and replaced. Items made from porous materials like MDF can be cleaned unless they are physically decomposing or exposed to Category 2 or 3 water.

Semiporous	Unfinished wood, plywood sheathing, and fiber-cement siding may be washed with warm water and detergent and then dried. Depending on the extent of contamination or physical damage, the item may be disposed of or more detailed remediation methods may be employed following the S500 standard.
Nonporous	Nonporous materials like steel, copper, glass, ceramic tile, and granite may be washed with warm water and detergent and then dried.
Insulating materials	
Porous	Mineral wool, fiberglass, cellulose, and open cell spray polyurethane foam insulation should be disposed of and replaced.
Semiporous	Expanded polystyrene foam board may be washed with warm water and detergent and then dried. Depending on the extent of contamination or physical damage, the item may be disposed of or more detailed remediation methods may be employed following the S500 standard.
Nonporous	Extruded polystyrene, closed cell spray polyurethane foam, and polyisocyanurate foam board may be washed with warm water and detergent and then dried.

Although many large, exposed surfaces that are made of nonporous materials are easy to clean and dry, some assemblies are difficult to dry and may need to be taken apart to be cleaned and dried. For example, built-in cabinets and bookcases will need to be removed to expose hidden surfaces behind and beneath. Other items—such as refrigerators, stoves, electrical fixtures, equipment, and motors—should be professionally inspected and either cleaned and repaired or replaced.

The use of various cleaning methods discussed above, either individually or in combination, to remove contamination from a variety of surfaces and materials in a home environment exposed to flood conditions, appear to be feasible approaches to limiting post-flood contamination of the indoor air, as long as they are used in conjunction with the timely removal of affected materials and the rapid drying of the environment.

3.2.4.5 Cleaning and Decontaminating HVAC Systems

HVAC equipment is intended to provide comfortable conditions inside buildings regardless of how uncomfortable conditions are outdoors. To achieve this end, HVAC equipment may add or remove heat, add or remove humidity, and remove or prevent the entry of airborne contaminants. HVAC equipment must distribute the conditioned air throughout the building. There are two distinctly different approaches to providing effective distribution and collection. The first is central heating, cooling, humidification, and ventilation in which pipes and ducts provide distribution and collection. The second is the use of multiple individual heating, cooling, humidification, dehumidification, and ventilation units distributed throughout a building.

When it comes to flood damage remediation, all HVAC equipment shares a number of important characteristics:

- Nearly all of the controls they use contain electrical and electronic components that can be damaged by flood waters.
- They contain components such as ducts, air handlers, furnaces, boilers, and fans that are difficult to inspect, clean, and disinfect.
- Many of their components (e.g., ducts, pipes, air handling cabinets) are insulated inside or outside with fibrous material that gets wet easily and is difficult to clean.
- Contamination in systems that distribute air that is heated, cooled, or brought in from outdoors can be distributed throughout the building served by that system.
- In many parts of the United States, HVAC systems must be operable for a building to be occupied normally.
- Servicing, maintaining, and assessing the problems of HVAC systems are beyond the experience and training of most people.

These characteristics make it likely that flood waters will render HVAC equipment inoperable, deposited contamination will be difficult to find and clean, and contamination may be distributed through a building. Inspection and remediation are best done by professionals who are knowledgeable about the systems involved.

Four of the flood guidance documents identified in the literature search recommend cleaning or disinfecting HVAC equipment that has been flooded:

- The online EPA fact sheet, "Flood Cleanup—Avoiding Indoor Air Quality Problems," recommends cleaning and the use of disinfectants on walls, floors, closets, shelves, and contents and references the FEMA guidance for using disinfectants on HVAC equipment.
- The FEMA/ARC guide recommends hosing out ducts to clean them (if the ducts are accessible) and using a quaternary, phenolic, or pine oil-based disinfectant to sanitize them.
- The NCHH document recommends removing or replacing all of the flooded equipment but in another place recommends fungicidal coating.
- The S500 standard recommends professional inspection and cleaning according to the National Air Duct Cleaners Association (NADCA) *Standard ACR 2006: Assessment, Cleaning, and Restoration of HVAC Systems* (NADCA 2006). Any internally insulated ductwork saturated with water should be removed. When contaminated with Category 2 or 3 water, ductwork with an interior sound/insulation liner, plastic flex duct, and coated fiberboard ducting should be replaced. Use of an antimicrobial may be considered, but its use shall not be substituted for the removal of viable microbial bodies.

Five other references also address flooded HVAC equipment:

- The National Institute for Occupational Safety and Health (NIOSH) online "Recommendations for the Cleaning and Remediation of Flood Contaminated HVAC

Systems: A Guide for Building Owners and Managers*"* covers worker protection, containment, discarding materials, cleaning remaining materials, disinfecting HVAC surfaces, and resuming operations (NIOSH 2010). Regarding removal, cleaning, and disinfecting, the guide suggests:

- Relying on a professional for inspection, removal, cleaning, and disinfection.
- Removing and discarding flood-damaged insulation and filters.
- HEPA vacuuming surfaces to remove dirt and debris; cleaning with pressure washer or steam if vacuuming, depending on the level of debris.
- Disinfecting using a solution of 1 cup bleach to 1 gallon of water.
- Applying a clean water rinse.

- The NADCA *Standard ACR 2006: Assessment, Cleaning, and Restoration of HVAC Systems* is a consensus standard practice document for professionals in the field of assessing, cleaning, and remediating HVAC systems. The NADCA standard covers mold contamination in HVAC systems but not flooded systems specifically. The S500 standard and the NIOSH HVAC recommendations both refer to this standard.

- *Bioaerosols: Assessment and Control* (ACGIH 1999) contains a section on remediating microbial growth in HVAC systems. The ACGIH takes a clear position on biocide use in contaminated HVAC equipment: "Application of biocides as a substitute for removing microbial growth is not acceptable." The ACGIH reports two instances of biocide use in operating HVAC systems that resulted in the evacuation of buildings.

- EPA's webpage "Use of Disinfectants and Sanitizers in Heating, Ventilation, Air Conditioning, and Refrigeration Systems" (www.epa.gov/pesticide-labels/use-disinfectants-and-sanitizers-heating-ventilation-air-conditioning-and) includes a 2002 letter ("Letter Regarding Use of Disinfectant Products in HVAC&R Systems") that serves as an open advisory that EPA registers disinfectants and sanitizers for specific uses and that it had come to the Agency's attention that products not registered for use as disinfectants or sanitizers in HVAC systems were in fact being used in them.

- Garrison et al. (1993) compared baseline and post-remedial fungal spore levels in the supply air of experimental and control houses. The components of HVAC systems in six (winter) and five (summer) experimental houses were cleaned and sanitized, and no interventions were performed in two control houses. Eight weeks after the interventions, the experimental houses showed a 92 percent reduction (winter) and an 84 percent reduction (summer) in fungal spore levels, whereas the control houses showed no reductions.

All guidance documents recommend water and detergent as the primary cleaning and decontamination method for HVAC systems and components, but differences exist regarding the use of disinfectants. The EPA document recommends washing surfaces and provides cautions on the use of disinfectants. The CDC document *Protect Yourself from Mold* refers to EPA's *A Brief Guide to Mold, Moisture and Your Home* for guidance on disinfecting. It recommends using detergent and water or a solution of water and bleach to clean up mold and advises seeking professional help if the area of mold is more than 10 square feet. The FEMA/ARC document recommends disinfecting with QACs, phenolic, or pine-oil based products and specifies a solution of household bleach as a second choice. The NCHH guide recommends HEPA vacuuming, followed by water and detergent, followed by a solution of household bleach. The S500 standard discusses air- and water-based cleaning in detail; it cautions against the use of biocides but provides guidance for using them if circumstances warrant.

3.2.4.6 Exercising Caution During Drying, Cleaning, and Decontaminating

It is imperative to note that caution should be exercised *during each of the drying, cleaning, and decontaminating activities* described in the two previous sections.

A number of contaminants may be released while cleaning surfaces:

- Particles contaminating the surface may be resuspended when they are disturbed by cleaning tools, vacuums, rags, wipes, brushes, or mops.
- Volatile compounds may be released into the air by cleaning and sanitizing agents.

Resuspension of deposited particles and dust from surfaces (including particles of bacterial or fungal origin) can be an important source of particle exposures in the indoor environment (Boor et al. 2013, Sivasubramani et al. 2004). For deposited particles to detach from a surface and resuspend in the air, an external force such as human activity (e.g., walking, cleaning) or high airflow rates (e.g., those found in ventilation ducts) must first act on the surface-adhered particles. Given these characteristics, three particularly important sources of resuspended ***bioaerosols*** that are most relevant to flood cleanup activities include: (1) resuspension from contaminated flooring surfaces (Paton et al. 2015), (2) resuspension from contaminated ventilation ducts (Krauter and Biermann 2007), and (3) release from moldy building materials (Górny et al. 2001).

Some factors that influence the rate at which particles resuspend from surfaces include: (1) air speeds (e.g., high air speeds induce more resuspension than low air speeds), (2) surface characteristics such as surface roughness (e.g., rough surfaces tend to induce more resuspension than smooth surfaces), (3) the level of agitation produced by human activities (e.g., heavy walking tends to induce more resuspension than light walking), and (4) environmental conditions (e.g., temperature, relative humidity). For the purposes of this report, however, resuspension as a source of bioaerosol exposure primarily serves to further motivate the necessity of extensive surface cleaning after materials such as flooring surfaces, HVAC ducts, or other building materials have been contaminated. Further, homeowners, occupants, and cleaning professionals also should be aware that some cleaning activities performed to reduce microbial contamination could inadvertently (albeit temporarily) lead to elevated bioaerosol exposures. For example, high pressure sprays and scrubbers have been shown to effectively clean surfaces (Gibson et al. 1999), but the high velocities also would likely resuspend large amounts of deposited bioaerosols from any contaminated surfaces.

Therefore, the following recommendations are made to reduce resuspension rates during cleaning activities:

- Use gentle wet methods of cleaning (e.g., damp wipe with water and detergent) that collect mold spores from surfaces as the initial cleaning method. Avoid using dry methods (e.g., scraping, sanding, vacuuming) as the initial cleaning method. It takes very little disturbance to release large numbers of mold spores from a mold-covered surface.

- Clean moldy surfaces using a gentle wet method before moving furniture or other objects or before removing gypsum board, paneling, or plywood. The use of hammers, prying bars, drills, sanders, and pressure washers resuspends large numbers of spores and ***hyphae***.

- Use water and detergent, rather than water and bleach, because some objects, including many *Penicillium* and *Aspergillus* species are repelled by water. A surfactant is more effective at collecting ***hydrophobic particles***.

- Avoid high pressure washers at this stage of cleaning.

The guidance documents also recommend selecting cleaning methods that minimize exposures to cleaning and sanitizing products such as: using cleaning methods that do not create aerosols of cleaning or sanitizing products (e.g., a damp wipe with a soaked rag or microfiber wipe versus a spray application method) and using the least toxic effective sanitizing products. Specifically, the guidance documents recommend the following regarding toxic sanitizing products:

- **Exercise caution when using bleach.** Here again the guidance differs among documents. The EPA fact sheet does not specifically mention bleach, but cautions against the use of biocides and refers to the FEMA/ARC guide. CDC recommends cleaning mold with detergent and water or a solution of 1 cup bleach per gallon of water. The FEMA/ARC guide shows a preference for disinfectants other than bleach, but allows diluted household bleach as a second choice for surfaces and recommends it for suspect drinking water. The FEMA Hurricane Katrina Recovery Advisories (reviewed later with other federal documents) recommend against using bleach. The NCHH guide recommends the use of diluted household bleach on nonporous hard surfaces after thoroughly cleaning them. The S500 standard extensively discusses biocide selection and use, and it adopts the ACGIH's policy of avoiding the routine use of biocides. Regardless, household bleach (sodium hypochlorite) is a caustic and hazardous chemical even when diluted with water. Exposure can irritate the eyes, skin, nose, and lungs. It also is inactivated by organic matter and is highly corrosive to metals. See Chapter 4 for a review of the multiple hazards and reported incidents associated with bleach.

- **Do not mix bleach with ammonia.** All of the guidance documents contain this warning. Chlorine bleach reacts with a number of other compounds to produce toxic compounds. (See Figure 5 in the next chapter.)

- **Exercise caution when using disinfectants.** The S500 standard is the only guidance document that provides comprehensive guidelines on the selection and use of biocides. If the water is Category 1, the use of biocides is not warranted. If the flood waters are Category 2 or 3 or if Category 1 water has remained long enough to become Category 2 or 3, the S500 standard leaves biocide use to the professional judgment of the restorer. According to the S500 standard, biocide use (in combination with cleaning and removal) should be considered when drying will be too slow to prevent microbial growth and/or pathogenic organisms are present. The standard also notes that the use of biocides might be precluded if: (1) the sanitizers to be used (e.g., chlorine-based formulations, alcohol, peroxide, QACs) require that soiled surfaces be cleaned first and/or (2) the risk from exposure to the biocide is comparable or greater than the risk from exposure to the organism. The standard also refers to guidance from the ACGIH's *Bioaerosols: Assessment and Control*, which recommends that microbial growth be removed by cleaning or removing contaminated materials:

> *15.4 Biocide Use. Remediators must carefully consider the necessity and advisability of applying biocides when cleaning microbially contaminated surfaces (see 16.2.3). The goal of remediation programs should be the removal of all microbial growth. This generally can be accomplished by physical removal of materials supporting active growth and through cleaning of non-porous materials. Therefore, application of a biocide would serve no purpose that could not be accomplished with a detergent or cleaning agent. Prevention of future microbial contamination should be accomplished by a) avoiding the conditions that lead to past contamination, b) using materials that are not readily susceptible to biodeterioration, and c) where necessary, applying compounds designed to suppress vegetative bacterial and fungal growth or using materials treated with such compounds.*
>
> *16.2 Biocide Use and Application. Biocide use should not be considered if careful and controlled removal of contaminated material is sufficient to address a problem...b) biocide use may play an important role in the remediation of certain conditions (e.g., microbial contamination from sewage backflow into buildings).*

- **Exercise caution when using gas-phase biocides.** Both ozone and chlorine dioxide in the gas phase have technical requirements and limitations, as well as human exposure and health concerns, that realistically preclude their use for the decontamination of flood-damaged homes and other indoor environments on a routine basis. Physical removal of microbially contaminated materials, along with the implementation of effective cleaning of intact structures and materials, remains the preferred approach and has been recommended even if the contamination includes highly infectious disease agents (Cole and Lantrip 2001).

Table 6 presents information provided in the *Journal of Environmental Health* (Berry et al. 1994) to aid in selection of an appropriate biocide when applicable. Some health hazards, however, may be introduced by the use of some biocides, as reviewed in more detail in Chapter 4.

***Table 6. Types of Biocides (i.e., Disinfectants) From the* Journal of Environmental Health**

Disinfectant/Class	Use Dilution Concentration	Action	Advantages	Disadvantages
Alcohols (ethanol, isopropanol)	60%–90%	B, V, F	Nonstaining, nonirritating	Inactivated by organic matter, highly flammable
Quaternary ammonium compounds	0.4%–1.6%	B*, V*, F	Inexpensive	Inactivated by organic matter, limited efficacy
Phenolics	0.4%–5%	B,V, F, (T)	Inexpensive, residual action	Toxic, irritant, corrosive

Disinfectant/Class	Use Dilution Concentration	Action	Advantages	Disadvantages
Iodophors	75 ppm	B, V, F, S**, T**	Stable, residual action	Inactivated by organic matter, expensive
Gluteraldehyde	2.00%	B, V, F, S**, T	Unaffected by organics, noncorrosive	Irritating vapors, expensive
Hypochlorites	≥ 5,000 ppm free chlorine (mix 1:10)	B, V, F, S**, T	Inexpensive	Bleaching agent, toxic, corrosive, inactivated by organic matter[1, 2]
Hydrogen peroxide	3%	B, V, F, S**, T	Relatively stable	Corrosive, expensive [3]

Source: Berry et al. 1994.

Abbreviations:
B = Bactericidal
V = Viricidal
F = Fungicidal
T = Tuberculocidal
S = Sporicidal
* = Limited effectiveness
** = Requires prolonged contact
( ) = Not all formulations
1 = Removes color from many interior décor fabrics
2 = Dissolves protein (wool, silk)
3 = Degrades in heat or UV light

3.2.5 Meeting Reoccupation Criteria

Clearance is the process of verifying the acceptability of the flood cleanup procedures and confirming the job is completed prior to rebuilding. It also serves to determine the suitability of the home to be reoccupied. The ultimate clearance criterion is the ability of occupants to reside in the restored dwelling in the absence of adverse health effects typically associated with water damage and microbial contamination.

Basic clearance criteria typically include the scale of the water damage, the extent of the initial flooding contamination, and the presence of microbial growth secondary to the flood waters, such as microbial growth on wet/damp building, finishing, and/or furnishing materials. After completion of the required steps of: (1) removing water and damaged/contaminated materials, (2) decontaminating remaining surfaces and materials, (3) drying the environment to maximize moisture removal and prevent additional microbial growth, and (4) cleaning the remaining surfaces/materials to reduce residual/settled contaminants that might be resuspended, the following elements of the dwelling clearance process must be determined:

- **Is it dry?**
  - Is the indoor relative humidity acceptable (lack of perceived dampness)?
  - Do remaining structural building and finishing materials look and feel dry?
- **Is it clean?**
  - Is there an absence of visible contamination, such as mold, on materials?
  - Is there a visible absence of dust (as expected from HEPA vacuuming)?
- **Is there an odor?**
  - Is there an absence of a musty, moldy, or mildew smell?

After removing water and damaged/contaminated materials, decontaminating remaining surfaces and materials, drying the environment to maximize moisture removal and prevent additional microbial growth, and cleaning the remaining surfaces/materials to reduce residual/settled contaminants that might be resuspended, the following elements of the dwelling clearance process must be determined: Is it dry? Is it clean? Is there an odor? If all of these activities have been conducted and the three questions can be answered in the affirmative, the house is likely ready for safe reoccupation.

Unless these three categories of questions can all be answered in the affirmative, a detailed inspection that makes use of instruments to assess dampness and microbial contamination is recommended. This is typically done by a trained professional using instrumentation and sample collection and analysis procedures, and may include:

- Measurements of the moisture content of materials.
- Temperature and relative humidity measurements.
- Microscopic examination of surfaces and/or collected samples (e.g., tape lifts).
- Laboratory processing of dust or swab samples for microbial culture.

From a practical standpoint, people may need to reoccupy their home as soon as the structure is deemed safer than alternative shelter. In that regard, basic restoration criteria require that the indoor environment be structurally sound, with functioning clean water supply, kitchen, toilets and baths, electricity, and heating and air conditioning. In such a situation, the clearance criteria may not have been fully met, but should still be addressed as soon as possible. That means the structure and its contents have been cleaned and dried; surfaces have been determined to be free of dirt, debris, and visible mold growth; and odors and any other signs of contamination are absent. In the long term, the ultimate criterion for successful reoccupation of a structure is the ability of occupants to live there without experiencing adverse health effects, as might occur from exposure to residual or secondary microbial growth resulting from the flooding event.

3.2.6 Conducting Renovations

If the house is in a floodplain (i.e., in the 1% Annual Chance Flood Zone), federal regulations have specific flood protection requirements for houses that are being renovated after floods. The *Homeowner's Guide to Retrofitting: Six Ways to Protect Your Home from Flooding* (FEMA 2014) provides information and resources on federal flood-related regulations and techniques for making houses resistant to flood damage. The Homeowner's Guide explains how to determine whether or not a house is in a floodplain zone. If it is in a flood zone area, repair of substantially damaged buildings (e.g., 50% or more of the market value would be required to restore the home) must be made in compliance with floodplain management codes and regulations.

The six flood-resistant techniques are:

- Elevation: Raise the entire building above the regulated flood level.
- Relocation: Move the house to a site that is above the regulated flood level.
- Demolition: Tear down the flooded house and rebuild using flood-resistant methods.
- Wet floodproofing: Rebuild the foundation of the house so that the flood waters can enter and exit the foundation without breaking it.
- Dry floodproofing: Make the portion of the house below the regulated flood level water tight and strong enough to hold against the force of the flood waters.
- Barriers: Protect your house with floodwalls or levees.

In addition to federal requirements, there may be state and local codes and regulations for flood zones. The regulations may include inspection and assessment performed by the local authorities and may require retrofit measures beyond floodproofing. For example, many states in the southeastern United States require retrofits to make houses resistant to damage caused by high winds that accompany hurricane-related floods.

If a house is either not substantially damaged or not in the flood zone, then applicable state and local codes and ordinances must be followed. At a minimum:

- Rebuild the damaged area using moisture- and mold-resistant materials (see *Flood Damage-Resistant Materials Requirements Technical Bulletin 2* [FEMA 2008]).
- Do not store anything in basements that cannot tolerate being soaked in floodwater.

- Move heating and air conditioning equipment and ductwork above the flood level.

Additional resources for designing flood proofing retrofits:

- *Home Builder's Guide to Coastal Construction* (FEMA 2010).
- *Protecting Manufactured Homes from Floods and Other Hazards* (FEMA 2009).
- The Insurance Institute for Business and Home Safety's FORITIFED for Safer Living® (disastersafety.org/fortified/safer-living) is a designation program that incorporates multihazard protection requirements in new construction. The program includes protective measures and third-party inspections over and above those required in the International Residential Code.
- *Moisture Control Guidance for Building Design, Construction and Maintenance* (USEPA 2013) provides guidance for designing buildings that incorporate moisture control measures in the building enclosure and mechanical systems.

Hazards Presented by Cleaning and Decontaminating Strategies

4

4. Hazards Presented by Cleaning and Decontaminating Strategies

In this last chapter, the authors address injuries related to the use of sanitizers during cleaning and decontaminating found in the literature. A number of individual cases were found, but the most interesting finding is from the *2014 Annual Report of the American Association of Poison Control Centers Toxic Exposure Surveillance System* (Mowry et al. 2015). Table 22A of that report provides statistics for exposures and outcomes by agent. Two categories are relevant to biocides: bleaches and disinfectants. Statistics include the number of exposures, age demographics, whether intentional/unintentional, whether treated at a health care center, and outcome ranking from none to death. The relevant sections from Mowry et al.'s Table 22A are excerpted in Table 7.

Table 7. Summary of Mowry et al. (2015) Table 22A: Statistics for Exposures and Outcomes by Agent

	No. of Case Mentions	No. of Single Exposures	Uninten-tional	Inten-tional	No. Treated in Health Care Facility	Injury/Fatality				
						None	Minor	Moderate	Major	Death
Bleaches										
Borates	187	154	142	8	31	25	29	4	0	0
Hypochlorite	43,771	37,066	33,693	2,310	9,137	5,317	9,881	1,272	38	5
Nonhypochlorite	390	326	285	25	81	56	93	16	0	0
Other or unknown household	496	423	347	37	153	88	98	18	0	0
Industrial cleaner: Disinfectants	2,390	2,233	2,057	128	648	225	684	182	7	1
Chlorine gas (when household acid is mixed with hypochlorite)	2,087	1,998	1,907	90	537	206	719	264	2	0

Source: Mowry et al. 2015.

The first number that draws attention is the large number of hypochlorite exposures (43,771) listed under bleaches. Of these, 33,693 were unintentional exposures. These exposures resulted in 9,137 people receiving treatment at a health care facility. Disinfectants are listed separately under industrial cleaners. These would be exposures to more highly concentrated products than household products.

4.1 Additional Ingestion Reports

A number of cases were found in which injury or death was caused by ingestion of disinfectants; some of these cases were identified as suicides. Sodium hypochlorite was ingested more often than other disinfectants. Most of the remaining cases were the result of ingesting disinfectants that are not commonly found in household products (e.g., formaldehyde, formalin, compounds of mercury). A number of poisonings from Dettol (British proprietary disinfectants) are reported in the British literature.

- Children are frequently treated for ingesting cleaners and sanitizers (McGuigan 1999, Lamireau et al. 1997).

- In a survey of cases after Hurricane Andrew, Quinn et al. (1994) report that among the expected wounds, gastroenteritis, and skin infections, a small increase (not statistically significant) in hydrocarbon and bleach ingestion was seen.

- A review of 743 case histories involving children in Galicia (Iberian Peninsula) who ingested caustic substances found that bleach was ingested in 73 percent of the cases, and 11 percent of those cases of bleach ingestion resulted in esophageal burns. Although only 3 percent of the 743 cases involved the ingestion of dishwasher detergent, 59 percent of those cases resulted in esophageal burns (Casasnovas et al. 1997).

- The results of ingesting bleach vary from none to major injuries (Landau and Saunders 1964, Tanyel et al. 1988, Ward and Routledge 1988, Weeks and Ravitch 1969, Weeks and Ravitch 1971).

- The ingestion of water-diluted bleach is reported to be a frequent cause for visits to health care facilities but often results in minor effects (Lambert et al. 2000).

- A survey of 11 poison control centers in France found that none of them recommended hospitalization for children who ingest less than 100 ml of bleach diluted with water, but nine of them recommended hospitalization for ingesting any amount of concentrated bleach (Cardona et al. 1993).

- A number of studies reporting children ingesting bleach found no serious injury after ingestion (Harley and Collins 1997, Paredes-Osado et al. 1993, Racioppi et al. 1994). (Whether the bleach was diluted or ingested directly from the bottle often is not reported.)

- Children who ingest substances often are performing a “lick and taste” behavior and swallow small amounts (Wason 1985).

- Several papers reported more serious injuries from ingesting bleach; some of these instances are known to be suicide attempts (Babl et al. 1998, de Ferron et al. 1987, Ross and Spiller 1999, Van Rhee and Beaumont 1990).

4.2 Respiratory Exposure Reports

A number of studies reported respiratory exposures. They divide into two categories: exposures to cleaning and disinfecting products that were linked to asthma risk and exposures resulting from mixing sodium hypochlorite-based cleaners or bleach solutions with ammonia- or phosphoric acid-based cleaning products.

4.2.1 Asthma Studies

Sixteen studies were found that linked cleaning activities with increased asthma, wheezing, or ***reactive airways dysfunction syndrome*** (RADS). Of these, five studies (Medina-Ramón et al. 2003, Medina-Ramón et al. 2005, Rosenman et al. 2003, Sherriff et al. 2005, and Zock et al.

2007) found evidence of a link between sodium hypochlorite-based bleach exposures and increased risk of illness. Three linked asthma or atopy consistent with asthma to exposures to QACs. Two of these were clinical study reports that attributed exposure to QACs (benzalkonium chloride, dimethylbenzyl ammonium) to the development of four cases of asthma (Burge and Richardson 1994, Purohit et al. 2000). One was an epidemiological study of Dutch pig farmers that linked use of QACs to the development of atopic sensitization (Preller et al. 1996). Note: One additional study (Gorguner et al. 2004) linked RADS with exposure to a mixture of chlorine bleach and hydrochloric acid.

- An epidemiological study identified cleaners, construction workers, laborers, equipment cleaners, and motor vehicle operators as having a high risk of work-related wheezing (***odds ratio*** [OR] > 4.5). Persons employed in protective services occupations and as equipment cleaners were reported as having a high risk of work-related asthma (OR > 9.0) (Arif et al. 2003).

- Henneberger identified the seven most frequently reported agents for RADS as cleaning materials (15 percent), unspecified chemicals (8 percent), chlorine (7 percent), solvents (7 percent), acids-bases (6 percent), smoke (6 percent), and diesel exhaust (6 percent) (Henneberger et al. 2003).

- A case-control study of 521 cases and 932 controls found relationships between asthma and occupations. The link was strongest for men and women in the chemical, rubber, and plastic industries (OR 5.69, 2.61, and 1.72, respectively); for men only as bakers and food processors (OR 8.62), textile workers (OR 4.70), electrical and electronic workers (OR 2.83), laboratory technicians (OR 1.66), and storage workers (OR 1.57); and for women only as dental workers (4.74), wait staff (OR 3.03), and cleaners (OR 1.42) (Jaakkola et al. 2003).

- A large epidemiological study of 2,414 cleaners and 5,235 administrative workers found that the cleaners had a greater risk of adult-onset asthma compared to the administrative workers (***relative risk ratio*** 1.5) (Karjalainen et al. 2002).

- In a ***cross-sectional study*** of 4,521 women, asthma was more prevalent in a group of 593 women then employed in domestic cleaning (OR 1.46). Asthma strongly correlated to a group of 1,170 former cleaning women (OR 2.09) (Medina-Ramón et al. 2003).

- The cases of 160 domestic cleaning women who had contracted asthma, chronic bronchitis, or both were nested in a large population-based survey that included 386 nonsymptomatic women. Women who had asthma, chronic bronchitis, or both used bleach more frequently than did controls (OR 3.3 for intermediate exposures and 4.9 for high exposures). Airborne chlorine levels were measured. Asthma symptoms in domestic cleaning women were associated with exposure to bleach and possibly other irritant agents in a case-control study (Medina-Ramón et al. 2005). This study was a follow-up to an earlier study that found a link between asthma risk and cleaning professions (Medina-Ramón et al. 2003). The earlier study did not collect data that would allow insights into the agents related to asthma risk; however, the follow-up study collected data by suspected agent.

- An epidemiological study of 394 occupational asthma cases found an association between the occupation of cleaner and occupational asthma (Mendonça et al. 2003).

- A pharmacist developed occupational asthma. The reported cause was exposure to a floor cleaner containing dimethylbenzyl ammonium chloride (a QAC). Substituting a different floor cleaner resulted in significant improvement in serial peak flow measurements (Burge and Richardson 1994).

- A ***longitudinal study*** of parents and children determined the frequency with which pregnant women used 11 domestic products. A total chemical burden score was derived based on the sum of the frequency of use for the products; high total chemical burden scores correlated with persistent wheezing during early childhood (OR 2.3). The chemicals and the percentage of women using them included disinfectants (87 percent), bleach (85 percent), aerosols (72 percent), air fresheners (spray, stick, or aerosol) (68 percent), window cleaner (61 percent), carpet cleaner (36 percent), paint or varnish (33 percent), turpentine (23 percent), pesticides (21 percent), stripper (5.5 percent), and dry cleaning fluid (5 percent) (Sherriff et al. 2005).

- A case-control study to investigate the agents in cleaning activities that lead to reported asthma found that the prevalence of asthma was 1.7 times higher among cleaners than referents. The increase in asthma was associated with kitchen cleaning, furniture polishing, and the use of oven sprays and polishes (Zock et al. 2001).

- Rosenman et al. (2003) reported on 1,915 cases of adult-onset or work-related asthma. Exposure to cleaning products across a wide range of occupational settings was linked to 236 cases; the most commonly reported occupations were janitors and cleaners and housekeepers (52) and nurses and nurses' aides (37). The two most commonly reported agents were unspecified cleaning products (107 cases) and bleach (43 cases).

- Three cases of asthma symptoms were reportedly triggered by the handling of a QAC (benzakonium chloride) used as a disinfectant in hospital settings. Reference was made to a Swiss study linking QACs to contact dermatitis and to four asthma case studies associated with QACs (Purohit et al. 2000).

- RADS associated with the use of a mixture of household bleach and hydrochloric acid was reported in a retrospective case study in Turkey (Gorguner et al. 2004).

- A robust longitudinal study found a dose-response relationship between the use of household spray cleaners and asthma and wheeze events. ***Relative risk ratios*** for furniture-polish, glass-cleaning, and air-freshening sprays ranged from 1.54 to 2.0 for these products. Solvent, ammonia, and bleach cleaning products had relative risk ratios ranging from 1.12 to 2.0 (Zock et al. 2007).

- In a follow-up study to Medina-Ramón et al. (2005), 43 domestic cleaners with a recent history of asthma or chronic bronchitis kept diaries recording respiratory symptoms, peak expiratory flow, and respiratory exposures (cleaning products and tasks, smoking status). Regression models found that lower respiratory symptoms were associated with diluted bleach (OR 4.4), degreasing sprays (OR 6.9), and air fresheners (OR 7.8) (Medina-Ramón et al. 2006).

- An epidemiological study of atopic sensitization in 194 Dutch pig farmers found an association between the use of QACs and atopy (OR 6.5) (Preller et al. 1996).

4.2.2 Cases Reporting Exposure to Chlorine Gas or Chloramines After Mixing Products

Five studies and four cases were found that reported injuries occurring because bleach containing sodium hypochlorite was mixed with other compounds, releasing materials more hazardous than the hypochlorite itself. In residential and commercial buildings, the most common occurrences appear to be mixing with sodium hypochlorite with ammonia-based cleaners or drain opener. Figure 5, from the Chlorine Institute, summarizes problem mixtures. Reported symptoms range from minor acute effects to serious health hazards.

- Five episodes of temporary illness were reported among patients performing cleaning chores in a psychiatric hospital who mixed bleach with phosphoric acid cleaner. The symptoms included chest tightness, difficulty breathing, eye and throat irritation, nausea, cough, and headache (CDC 1991).
- An elderly woman with a brain tumor was reported to have died while using a mixture of chlorine bleach and ammonia to clean a bathroom (Cohle et al. 2001).
- A study of construction workers exposed to an accidental release of chlorine gas in a paper mill bleach plant found that 60 percent of 281 workers experienced flu-like symptoms; eye, nose, and throat irritation; cough; and headache. Shortness of breath not associated with age, smoking, or a history of asthma or chronic bronchitis was reported by 54 percent of the workers (Courteau et al. 1994).
- During the course of 1 year, 216 cases of exposure to chlorine or chloramine gas after mixing cleaning products at home were reported to a regional poison control center. The most frequently reported symptom was cough (180 cases); other reported symptoms were shortness of breath, throat irritation, chest pain, wheezing, dizziness, vomiting, eye irritation, and nasal irritation. Symptoms did not persist after 6 hours for 200 cases (Mrvos et al. 1993).

Figure 5. Sodium hypochlorite (bleach) incompatibility chart.

The Chlorine Institute, Inc.
1300 Wilson Boulevard
Arlington, VA 22209
Ph: 703-741-5760 // www.CL2.com

Sodium Hypochlorite Incompatibility Chart

Do NOT mix Sodium Hypochlorite (bleach) with ANY other chemical unless adequate engineering controls and personal protective equipment (PPE) are in place. Accidental mixing may cause dangerous conditions that could result in injury to personnel and/or damage to property or the environment.

Incompatible Material	Mixing May Result In
Acids, Acidic Compounds and Acid Based Cleaning Compounds such as: - Alum (Aluminum Sulfate) - Aluminum Chloride - Ferrous or Ferric Chloride - Ferrous or Ferric Sulfate - Chlorinated Solutions of Ferrous Sulfate - Hydrochloric Acid (HCl) - Sulfuric Acid - Hydrofluoric Acid - Fluorosilicic Acid - Phosphoric Acid - Brick and Concrete Cleaners	- Release of chlorine gas, may occur violently.
Chemicals and Cleaning Compounds containing ammonia such as: - Ammonium Hydroxide - Ammonium Chloride - Ammonium Silicofluoride - Ammonium Sulfate - Quaternary Ammonium Salts (Quats)	- Formation of explosive compounds. - Release of chlorine or other noxious gases.
Organic Chemicals and Chemical Compounds such as: - Solvents and Solvent Based Cleaning Compounds - Fuels and Fuel Oils - Amines - Propane - Organic Polymers - Ethylene Glycol - Insecticides - Methanol	- Formation of chlorinated organic compounds. - Formation of explosive compounds. - Release of chlorine gas, may occur violently.
Metals such as: - Copper - Nickel - Cobalt - Iron Avoid piping and material handling equipment containing stainless steel, aluminum, carbon steel or other common metals.	- Release of oxygen gas, generally does not occur violently. Could cause overpressure/rupture of a closed system.
Hydrogen Peroxide	- Release of oxygen gas, may occur violently.
Reducing agents such as: - Sodium Sulfite - Sodium Bisulfite - Sodium Hydrosulfite - Sodium Thiosulfate	- Evolution of heat, may cause splashing or boiling.

- Two episodes involving 72 soldiers who were exposed to chlorine gas from mixing bleach and ammonia during a “cleaning party” were reported to have resulted in acute respiratory symptoms (Pascuzzi and Storrow 1998).
- Three case studies of toxic pneumonitis caused by exposure to a mixture of bleach and ammonia and resulting in serious long-term injury were reported (Reisz and Gammon 1986).

- Correspondence in the *New England Journal of Medicine* reported a case of exposure to chloramine gas released by mixing household bleach with an ammonia-based cleaner; chest X-rays showed pneumonitis developed over the course of 4 hours (Tanen 1999).

4.3 Irritancy Effects of Cleaners and Disinfectants

Three sources describe irritancy effects associated with cleaners and disinfectants:

- A textbook on irritant dermatitis reports the irritant properties of cleaners and disinfectants: soaps and detergents, antiseptics and disinfectants, and acids and alkalis. Chapping, redness, scaling, and fissuring may result from exposure to soaps and detergents. (The removal of intracellular lipids is described as the mechanism.) Benzalkonium chloride (a QAC) is reported as a known cause of acute contact dermatitis. Acids are reported to denature proteins, and alkalis are reported to denature lipids (Chew and Maibach 2005).

- An overview of risk while cleaning identifies disinfectants as the most hazardous group of agents covered. Sodium hypochlorite is reported to cause allergic contact dermatitis (Wolkoff et al. 1998).

- A study of acute occupational disinfectant-related illness in adolescent workers found that hypochlorites were responsible for 45 percent of the 307 cases. Seventy-eight percent of the illnesses were mild, and there were no fatalities. Two hundred-six cases involved disinfectants whose EPA toxicity category was known; 80 percent were rated Category 1, the highest toxicity level (Brevard et al. 2003).

4.4 Behavior That Leads to Exposure to Cleaners and Disinfectants

Six references were found that provide insight into behaviors that lead to exposures. Two references link increased exposures or health endpoints to the use of sprayers.

- Exposure potential was assessed by watching subjects during cleaning activities; the strength of the warning labels was intended to be used to study the frequency and amount of use by suggested hazard, but only a tiny fraction of subjects read the labels. Thirty-nine percent of women and 15 percent of men reported using protective gloves (Kovacs et al. 1997).

- In a study of consumer behavior to provide a basis for estimating exposures to dishwashing detergents, cleaning products, and hair-styling products, bleach was included as a toilet-cleaning product. Four of 29 subjects wore gloves during toilet cleaning; diaries, observation, and videos were used to assess behaviors. Exposures occurred during mixing, checking suds, rinsing the cap, spills on the package, rinsing the cleaning cloth, wiping with the cloth, and clearing away suds. Subjects were seen to have hand-to-mouth contact during cleaning (Weegels and van Veen 2001).

- A study of dermal exposures during mixing, spraying, and wiping found that exposures for hands during the large-scale disinfection of countertops and fume hoods by wiping for 1 hour per day were more than 100 times greater than the exposures from wiping a small section of countertop for 10 to 15 minutes per day. Although there were essentially no exposures to head, arms, legs, or chest during the small-scale disinfection, there were significant exposures to these areas during the large-scale disinfection (Hughson and Aitken 2004).

- A longitudinal study of the incidence of eye symptoms, nose or throat symptoms, nose and throat symptoms, asthma, and bronchitis among 1,011 cleaners and former cleaners found that those who began using sprayers to apply cleaning products partway through the study increased the risk of eye irritation (OR 1.3), nose/throat irritation (OR 2.0), asthma (OR 2.4), and bronchitis (OR 1.9) (Nielsen and Bach 1999).

- A study of dermal and inhalation exposures to diisocyanate and oligomers found that increased inhalation and dermal exposures correlate with spraying paint. The use of gloves during spraying reduces dermal exposures (Pronk et al. 2006).

- A longitudinal study examining a hypothesized link between the use of cleaning sprays and adult asthma was conducted as a follow-up to the first phase of the European Community Respiratory Health Survey. A consistent dose-response relationship was found between the frequency of use of cleaning sprays and the relative risk of having asthma events or wheeze within the previous year. The relationship held for a wide variety of sprays as well as for individual sprays (e.g., furniture-polish, glass-cleaning, and air-freshening sprays). Liquid cleaners not used as sprays had significantly lower relative risk ratios than spray-applied products. The authors hypothesize that sprays facilitate respiratory exposures (Zock et al. 2007).

The most comprehensive review of cleaning materials and health-effects literature was found in a research report to the California Air Resources Board (Nazaroff et al. 2006). Exposure mechanisms were grouped into seven categories. Table 8, based on Table 2.2 in Nazaroff et al.'s final report, lists the seven exposure mechanisms and provides examples of each one from previous literature cited in that report.

Table 8. How Cleaning Product Use Can Influence Inhalation Exposure to Air Pollutants

Mechanism	Examples
Volatilization	Formaldehyde from wood-floor cleaning spray (Akland and Whitaker 2000; Figure 4-11); glycol ethers from hard-surface cleaners (Zhu et al. 2001; Gibson et al. 1991)
Production of airborne droplets	Aerosol or pump-spray delivery of surface cleaning products; some spray droplets remain airborne instead of depositing (Fortmann et al. 1999; Roache et al. 2000)
Suspension of powders	Fine particulate matter from carpet freshener (Steiber 1995); sodium tripolyphosphate from carpet cleaner (Lynch 2000)
Suspension of wear products	Surfactants, film formers, complexing agents, acids and bases, and disinfectants (Wolkoff et al. 1998; Vejrup and Wolkoff 2002)

Mechanism	Examples
Inappropriate mixing	Chloramines from mixing household bleach and ammonia-based cleaners; chlorine gas from mixing bleach with acid-containing cleaner (see Table 9 below)
Chemical transformations	Chloroform release from chlorine bleach chemistry in laundry applications (Shepherd et al. 1996); terpene hydrocarbons plus ozone form hydroxyl radical (Weschler and Shields 1997), hydrogen peroxide (Li et al. 2002) and secondary particulate matter (Weschler and Shields 1999; Wainman et al. 2000)
Altered surfaces	Nicotine release from walls following ammonia cleaner use in smoking environment (Webb et al. 2002); enhanced volatile organic emissions from wet linoleum (Wolkoff et al. 1995)

Source: Nazaroff et al. 2006.

Summaries of studies and case reports documenting toxic exposures from the mixing of cleaning products also are provided in Nazaroff et al. (2006). Table 9 is based on Table 2.3 of Nazaroff et al.'s final report. Table 10, which follows, is based on Table 2.4 of that report. The references are to previous literature cited in that report.

Table 9. Documented Inhalation Toxicity Related to Mixing of Cleaning Products

Nature of Study	Products Mixed	Toxic Gases	Outcomes
Case reports (two) (Faigel 1964)	Sodium hypochlorite, vinegar, bleach, and detergent; ammonia and sodium hypochlorite	Chlorine, ammonia	Acute illness with recovery in days
Case report (Dunn and Ozere 1966)	Ammonia type and hypochlorite cleaners	Ammonia	Acute illness with recovery in days
Case report (Jones 1972)	Bleach (5.25% sodium hypochlorite) and powder containing 80% sodium bisulfate	Chlorine gas	Acute illness with recovery after several days
Case report (Murphy et al. 1976)	Several products applied to clear a clogged drain [a]	Uncertain	Severe obstructive airway disease
Case report (Gapany-Gapanavicius et al. 1982a)	Ammonia with household bleach containing hypochlorite	Chloramines	Acute illness with recovery in days
Case reports (two) (Gapany-Gapanavicius et al. 1982b)	Sodium hypochlorite (5%) and hydrochloric acid (10%)	Chlorine gas	Acute illness with recovery in several days

Nature of Study	Products Mixed	Toxic Gases	Outcomes
Case reports (three) (Reisz and Gammon 1986)	Aqueous ammonia (5%–10%) with bleach (5.25% sodium hypochlorite), plus laundry detergent in two cases	Chloramines	Life-threatening toxic pneumonitis requiring prolonged hospitalization and resulting in residual symptoms
Case reports (five episodes at two state hospitals) (CDC 1991)	Bleach (sodium hypochlorite) and phosphoric acid cleaner	Chlorine	Acute poisoning symptoms that abated within hours to days; a few cases required medical treatment
Analysis of 216 cases reported to regional poison information center (Mrvos et al. 1993)	Hypochlorite-containing product with (a) ammonia (50%), (b) acid (29%), and (c) alkali (21%)	Chlorine/ chloramines	Symptom resolution for 93% of patients within 6 hours; 33% received medical care; 1 patient with a pre-existing condition required hospital admission for continued respiratory distress
Case report (Bennion and Franzblau 1997)	Sequential application of numerous cleaning products to remove a bathtub stain [b]	Hydrofluoric acid	Hemorrhagic alveolitis and adult respiratory distress syndrome; month-long hospital care; residual pulmonary deficit
Case reports (two cases each with 36 soldiers) (Pascuzzi and Storrow 1998)	Liquid bleach and ammonia mixed in bowls and buckets	Chloramine gas	Acute symptoms; two patients admitted to hospital, one required several days of intensive care observation
Case report (Tanen et al. 1999)	Liquid ammonia (3%–10% ammonia) and bleach (5% sodium hypochlorite)	Chloramine gas	Upper air compromise and pneumonitis requiring emergency tracheostomy and 7 days of hospital care
Case report (Cohle et al. 2001)	Bleach and ammonia	Cloramine gas	Death

Source: Nazaroff et al. 2006.

References: [a] Products used (selected active ingredients): Liquid Plum-R ($NaOCl$, 5%; KOH, 2%); Drano ($NaOH$, 54%; $NaNO_3$, 30%); Clorox ($NaOCl$, 5%); Sani Flush ($NaHSO_4$, 75%).

[b] Cleaning products used (active ingredient, if reported): cleanser, mildew stain remover ($NaOCl$, 25–45%), tub and tile cleaner (H_3PO_4, 18%), ammonia cleaner ($NaOH$, 2–2.5%), bleach ($NaOCl$, 5.25%), toilet cleaner (HCl, 14.5%), vinegar (CH_3COOH, 5%), rust remover (H_6F_6, 8%). Application of each product was followed by a cold-water rinse.

Table 10. Documented Associations of Asthma, Allergy, and Sick-Building Syndrome Symptoms in Relation to Cleaning Product Use

Key Finding	Reference
Dried detergent residue from carpet shampoo "caused respiratory irritation among most employees in an office building and among all staff members and most children in a day-care center."	Kreiss et al. 1982
Excessive application of carpet shampoo was associated with widespread, transient, mild respiratory illness among conference attendees.	Robinson et al. 1983
Case report of a cleaning worker's occupational asthma caused by inhalation exposure to ethanolamine from a floor-cleaning detergent.	Savonius et al. 1994
Case report of occupational asthma in a pharmacist attributed to indirect exposure to lauryl dimethyl benzyl ammonium chloride from a floor-cleaning product regularly used in his workplace.	Burge and Richardson 1994
With data from 22 offices in 12 buildings in California, researchers found a principal component vector associated with the use of cleaning products and air fresheners was useful in predicting stuffy nose (OR 1.6) and composite irritated mucous membrane symptoms (OR 1.4).	Ten-Brinke et al. 1998
Population-based study of occupational asthma revealed that "cleaners" had the fourth highest OR (1.97) for "bronchial hyper-responsiveness and asthma symptoms or medication."	Kogevinas et al. 1999
Prospective study design indicated increased risk of eye, nose, and throat symptoms; asthma and bronchitis associated with "use of sprayers" among current cleaners compared to former cleaners.	Nielsen and Bach 1999
Case report of anaphylactic shock with respiratory failure secondary to carpet cleaning in a 42-year-old female who was hospitalized for 18 days.	Lynch 2000
Case reports of female nurses who exhibited occupational asthma following exposure to surfaces cleaned with solutions containing benzalkonium chloride. Cases also were occupationally exposed to this chemical as a disinfectant.	Purohit et al. 2000
Asthma prevalence among indoor cleaners in Spain was 1.7 times the rate for office workers. Risk was associated mainly with the cleaning of private homes and "may be explained by the use of sprays and other products in kitchen cleaning and furniture polishing."	Zock et al. 2001
Population study of women in Finland revealed a relative risk ratio of asthma of 1.5 for cleaners compared to administrative workers.	Karjalainen et al. 2002
Twelve percent of confirmed cases of work-related asthma in California, Michigan, Massachusetts, and New Jersey were associated with exposure to cleaning products.	Rosenman et al. 2003
"Janitors, housekeepers, and cleaners" was the occupational group with the highest number of reported cases of occupational asthma in Sao Paulo, Brazil; "cleaning products" were the most commonly reported exposure agent.	Mendonça et al. 2003
"Cleaning materials" are the most frequently reported agents for work-related reactive airways dysfunction syndrome cases in Michigan, New Jersey, Massachusetts, and California.	Henneberger et al. 2003

Key Finding	Reference
In the National Health and Nutrition Examination Survey III survey of U.S. workers, the occupation of “cleaning” was associated with an elevated odds ratio of work-related wheezing (OR 5.4, 95% ***confidence interval*** [CI] 2.4–12.2) and work-related asthma, although not statistically significant for the latter (OR 2.4, 95% CI 0.5–10.6).	Arif et al. 2003
Population-based incident case-control study of relation between occupation and risk of developing asthma showed an association, but not a statistically significant one, for women cleaners (OR 1.42, 95% CI 0.81–2.48).	Jaakkola et al. 2003
Current or former employment as domestic cleaner was associated with a statistically significant increase in the prevalence of asthma in Barcelona, Spain. Symptoms were associated with exposure to bleach and possibly other irritant agents.	Medina-Ramón et al. 2003, 2005
The frequency with which chemical-based household products were used during the prenatal period was associated with persistent wheeze in young children. Among the 11 products in analysis were disinfectant, bleach, carpet cleaner, window cleaner, and air fresheners.	Sherriff et al. 2005

Source: Nazaroff et al. 2006.

Appendices

Appendices

Appendix 1: Comparison of Guidance Documents Identified in Chapter 3

The authors explored in more detail the assessment of the effectiveness and safety of various cleaning and decontaminating methods contained in the different guidance documents identified in the literature search. The literature search included cleanup after floods generally, as well as the use of cleaning and sanitizing methods and materials. This appendix describes guidance selected for review, categorized by agency or organization.

Multi-agency guidance:

- *Homeowner's and Renter's Guide to Mold Cleanup After Disasters*. This 4-page 2015 guide—developed jointly by the U.S. Environmental Protection Agency (EPA), Centers for Disease Control and Prevention (CDC), Federal Emergency Management Agency (FEMA), U.S. Department of Housing and Urban Development (HUD), and National Institutes of Health (NIH)—focuses on protecting individuals who return to, enter, and cleanup a home after a flood. Guidance is provided for hiring mold inspection and cleanup professionals. If a person must do the cleanup themselves, the guide recommends wearing personal protective gear and clothing, getting the liquid water out, opening windows and doors, using fans or dehumidifiers if electricity has been restored, cleaning with water and detergent, *not* mixing cleaning products or bleach and ammonia, and removing items that cannot be cleaned and dried. The guide, which also contains safety tips for using portable generators, also is available in Spanish at www.cdc.gov/mold/cleanup.htm.

FEMA guidance:

- *Repairing Your Flooded Home*. This 56-page document developed by FEMA and the American Red Cross (ARC) has been used by those responding to flooded buildings for many years and was last updated in 1992. The guidance is clear, practical, and prioritizes risks; it is the essential starting point for anyone returning to a flooded building. The guidance recommends cleaning with water and detergents. It does not seem to require the use of disinfectants, but notes that if disinfectants are used, quaternary compounds, phenolics, and pine oil disinfectants should be the first choice and bleach solutions second.

- *Initial Restoration for Flooded Buildings*. This 4-page 2015 Hurricane Katrina Advisory provides five steps for restoring buildings: air out, move out, tear out, clean out, and dry out. It cautions against using bleach on porous or dirty materials, electrical outlets, metals, soil, and materials treated for termites. The advice on cleaning and removing materials is very practical.

- *Dealing With Mold and Mildew in Your Flood Damaged Home*. This undated 7-page document discusses mold growth, health effects, cleaning and disinfecting, and mold prevention. It recommends washing hard surface materials and then disinfecting with a bleach solution. For porous materials, it suggests cleaning and using phenolic or pine oil in an effort to sanitize.

- *Mold and Mildew: Cleaning Up Your Flood Damaged Home*. This 2007 homeowner's guide, written at a simple level for areas of mold up to 25 square feet, includes health cautions, a helpful decision tree and illustrations, and removal and cleanup guidance. It also provides some recommendations for preventing further growth.

- *The ABC's of Returning to Flooded Buildings*. This 2-page fact sheet, published in 2012, is devoted to the initial phase of returning a building to habitability after a flood. It covers tools, entry, assessment, hazards, and removing items intended to be salvaged and contains a list of references for cleaning and decontaminating.

- *Cleaning Flooded Buildings: Hurricane Sandy Recovery Fact Sheet No. 1*. This 5-page fact sheet from 2013 focuses on safety while restoring flooded buildings to occupancy. Coverage of cleaning is limited to the use of foam cleaners and low pressure washing. The use of disinfectants or sanitizers appears to be assumed. A sidebar discourages the use of household bleach.

- *Claims Guidance—Structural Drying and Other Related Items*. This 2013 memorandum provides guidance on what drying activities qualify for coverage by the ***Standard Flood Insurance Policy***. It provides the technical basis and recommendations for drying structural building materials.

- *Mitigation Assessment Team Report: Hurricane Sandy in New Jersey and New York*. This 223-page report published in 2013 covers a variety of topics, including sea level rise; building codes; performance of low-rise, mid-rise, and high-rise buildings; and performance of critical facilities and assets, such as schools, historic buildings, wastewater treatment plants, transportation, and health care facilities. A valuable resource for planning agencies, code organizations, emergency preparedness agencies, and the building design and construction community.

EPA guidance:

- *Flood Cleanup: Avoiding Indoor Air Quality Problems*. This 2-page fact sheet released in 2012 by EPA's Office of Air and Radiation contains guidance on preparing for cleanup, avoiding microbial growth, removing standing water, drying, removing wet materials, avoiding problems with cleaners and disinfectants, and avoiding hazards (e.g., carbon monoxide, asbestos, lead). It has numerous links to other resources (websites). The fact sheet also recommends using household cleaners and disinfectants to clean materials and warns about safety when using disinfectants. (Note: The pdf version of this document does not display all the text found in the online document at www.epa.gov/indoor-air-quality-iaq/flood-cleanup-protect-indoor-air-quality.)

- *Flood Cleanup and the Air in Your Home*. This undated 15-page booklet released by EPA's Office of Air and Radiation contains numerous illustrations accompanied by short, simple sentences in either English or Vietnamese. It identifies reason for concern but is mostly devoted to cleanup methods and safety while cleaning.

- *Mold Remediation in Schools and Commercial Buildings*. This 45-page guide to mold remediation—released in 2001 and reprinted unchanged in 2008—includes assessment, remediation, and clearance guidance. It is not specifically written for, but is applicable to, mold growth after floods.

CDC guidance:

- *Mold Prevention Strategies and Possible Health Effects in the Aftermath of Hurricanes and Major Floods*. This 2006 27-page document appears to be written for a fairly knowledgeable audience (e.g., public health personnel, emergency responders, restoration professionals). It contains extensive discussion of health effects, worker protection, sampling, cleaning, and restoration. The document recommends cleaning materials with soap and water, then disinfecting them using a solution of bleach and water.

- *Protect Yourself From Mold*. This 2006 2-page fact sheet briefly covers mold risks, recognizing mold, preventing mold growth, and cleaning mold from materials. It recommends using detergent and water or a water and bleach solution to clean mold from materials.

- *Clean Up Safely After a Natural Disaster*. This webpage contains links to CDC guidance on cleanup after floods. It includes information about reentering flooded homes, HVAC (heating, ventilation, and air conditioning) systems, electrical hazards, chemical hazards, food and water safety, heat exposure, carbon monoxide hazards, and respiratory protection links. Many of the links are not available as pdfs.

- *Get Rid of Mold*. This undated, one-page flyer is very direct and has good illustrations. It recommends cleaning mold off materials using a solution of water and bleach. The flyer also is available in Spanish at www.cdc.gov/mold/cleanup.htm.

- *Recommendations for the Cleaning and Remediation of Flood-Contaminated HVAC Systems: A Guide for Building Owners and Managers*. This webpage provides specific guidance for cleaning and remediating HVAC equipment after floods. The guidance addresses the ducts, air handler cabinets, insulation, and fans. It does not address hydronic systems or boilers. The webpage recommends removing and discarding HVAC system components that are contaminated with flood water and cannot be effectively cleaned and disinfected, replacing them with new components.

Nongovernmental guidance:

- Institute of Inspection, Cleaning, and Restoration Certification (IICRC)
  - *S500 Standard and Reference Guide for Professional Water Damage Restoration*. The IICRC is the certification body for water restoration professionals. The 2015 S500 standard is a consensus document that forms the basis of certification by the institute. It is the most comprehensive guidance document for cleaning up buildings after a flood. The S500 industry consensus standard includes 88 pages of standard and more than 200 pages of references that explain and reference the science behind the standard. It covers water damage restoration, building physics, safety and health, administration of projects, evaluations, specialized experts, structural restoration, HVAC restoration, building contents, catastrophic events, biocides, and equipment and tools. The IICRC has

published the S500 standard for restoration after water damage since 1994. The fourth edition was published in 2015. The S500 is the only American National Standards Institute (ANSI) standard that specifically addresses cleanup after floods.

- *S520 Standard for Professional Mold Remediation*. The ANSI/IICRC S520 is a procedural standard for the remediation of mold damaged structures and contents. S520 is based on reliable remediation and restoration principles, includes research and practical experience, and attempts to combine essential academic principles with practical elements of water damage restoration for technicians facing "real-life" mold remediation challenges.

- *IICRC Storm Damage Restoration Recommendations*. The IICRC released these recommendations as a public service to those who have suffered water-related losses from storm damage. The recommendations are geared toward water-related storm damage to residential or light commercial structures only.

- National Center for Healthy Housing (NCHH)

  - *Creating a Healthy Home: A Field Guide for Cleanup of Flooded Homes*. This 18-page booklet from the NCHH, Enterprise Community Partners, Inc., and NeighborWorks® America covers the cleanup of flooded homes, health risks and worker protection, and lead, asbestos, and carbon dioxide risks. The cleanup itself is covered in eight steps: pre-work inspection, before work begins, site preparation, clean-out, gut tear-out procedure, pre-construction cleaning and treatment, selective tear out and preparation before restoration, and restore possessions. Clear, informative illustrations help with understanding each step.

- Restoration Industry Association

  - *Hurricane Cleanup Guidelines for Volunteers*. This 2006 9-page guide provides practical direction for safely returning to a flooded building, assessing the damage, and conducting removal and cleanup of flood contaminated materials.

	Homeowner's and Renter's Guide to Mold Cleanup After Disasters	***Flood Cleanup: Avoiding Indoor Air Quality Problems***	***Flood Cleanup and the Air in Your Home***
Publisher (Year)	CDC/EPA/FEMA/HUD/NIH (2015)	EPA (2003)	EPA (undated)
Target audience	Owners/renters	Owners/renters	Owners/renters
Number of pages	4	2	15
Safety returning and entering	Recommends wearing personal protective equipment (PPE) when returning to and entering a flooded home.	Recommends consulting the FEMA, ARC, CDC, and American Lung Association websites for safety information, in addition to the safety information offered in the resource itself.	Not discussed.
Call a professional?	Recommends consulting professionals affiliated with or certified by the National Environmental Health Association, American Industrial Hygiene Association, IICRC, or American Council for Accredited Certification to inspect, repair, and restore the damaged parts of the home.	Not discussed.	Recommends calling a professional in situations where the flooded home contains large amounts of mold.
Assessment	Assess the flooded home for signs or scents of mold. There should be no signs of water damage of mold growth post-remediation.	Not discussed.	Not discussed.
Remove standing water	Remove standing water as quickly as possible from the home. Use a wet vacuum to remove water from floors, carpets, and hard surfaces.	Remove standing water as quickly as possible.	Not discussed.
Drying out	Dry all items for 24–48 hours. Open all windows, doors, and cabinets of the home. Remove cabinet drawers to dry, and use fans and dehumidifiers if electricity is safely available.	References the FEMA/ARC 1992 resource *Repairing Your Flooded Home*. Advises inhabitants to be patient and make sure all materials and possessions are dry.	Advises to clean and dry all materials and possessions in the home. Features an illustration showing mopping up liquid water with rags.
Removal of contents and furnishings	Remove wet materials.	Not discussed.	Throw away anything that got wet and cannot be cleaned. Well illustrated.

	Homeowner's and Renter's Guide to Mold Cleanup After Disasters	***Flood Cleanup: Avoiding Indoor Air Quality Problems***	***Flood Cleanup and the Air in Your Home***
Removal of material and built-ins	Remove wet materials and any items that cannot be cleaned and dried within 24–48 hours. Resource includes a detailed graphic illustrating items to remove from a flooded home.	Replace wet fiberboard, insulation, and HVAC filters. References the FEMA/ARC resource *Repairing Your Flooded Home*. Provides guidance on discarding items and links readers to EPA's *Mold in Remediation in Schools and Commercial Buildings*.	Discard all wet items that cannot be sufficiently dried and cleaned. Well illustrated.
Cleaning hard surfaces	Use a wet vacuum to remove water from hard surfaces (material type not specified). Clean hard surfaces with water and detergent, and remove all visible mold.	Details the flood cleanup process and cautions occupants on the use of household cleaners and disinfectants.	Clean and dry all hard surfaces. Well illustrated.
Cleaning porous surfaces	Not discussed.	Not discussed.	Not discussed.
Cleaning cavities	Not discussed.	Not discussed.	Not discussed.
Cleaning HVAC systems and ducts	Not discussed.	Replace all flooded fiberboard, fibrous insulation, and filters in HVAC systems. Ducts should be cleaned with disinfectant or sanitizer. References the FEMA/ARC resource *Repairing Your Flooded Home*.	Not discussed.
Use of biocides	Not discussed.	Not discussed.	Not discussed.
Do not mix bleach and cleaning products	Do not mix bleach with ammonia or any other cleaning products.	Cautions mixing cleaners and disinfectants.	Do not mix cleaning products or add bleach to other chemicals. Well illustrated.
Reoccupancy criteria	No signs or scents of mold present. Ongoing health problems may be a result of hidden mold.	Not discussed.	Not discussed.
Health and safety	Recommends using an N-95 respirator and wearing goggles and gloves.	Not discussed.	Recommends using an N-95 respirator and wearing goggles, gloves, long pants, and sleeves. All illustrations include appropriate PPE.

	Homeowner's and Renter's Guide to Mold Cleanup After Disasters	***Flood Cleanup: Avoiding Indoor Air Quality Problems***	***Flood Cleanup and the Air in Your Home***
Carbon monoxide	Cautions readers about the dangers of carbon monoxide poisoning and fires. Warns against using generators or other combustion devices indoors.	Cautions readers about the dangers of carbon monoxide. Warns against using combustion devices indoors.	Provides good discussion and illustration of generator use.
Asbestos and lead	Not discussed.	Cautions readers about the adverse health effects of both asbestos and lead. Recommends the EPA Toxic Substances Control Act Assistance Information Service and the National Lead Information Center as contacts.	Not discussed.
Health effects	Health effects of mold are discussed, and protective measures are covered.	Not discussed.	Health effects of mold include asthma, allergies and breathing problems. Recommends talking to one's doctor.
Fix moisture problem	Readers are firmly advised to clean up the mold in their home and fix the moisture problem.	Not discussed.	Fix any leaking pipes and other water problems and then dry all items; otherwise, mold will grow again.
Other	Painting over mold does not solve the issue; health effects remain.	NA	NA

	Initial Restoration of Flooded Buildings	***The ABC's of Returning to Flooded Buildings***	***Cleaning Flooded Buildings: Hurricane Sandy Recovery Fact Sheet No. 1***
Publisher (Year)	FEMA (2005)	FEMA (2012)	FEMA (2013)
Target audience	Owners/workers/volunteers restoring flood damaged houses with extensive mold growth	Owners/renters	Owners/workers/volunteers restoring flood damaged houses with extensive mold growth
Number of pages	4	2	5
Safety returning and entering	References *The ABC's of Returning to Flooded Buildings*.	Contains good coverage on PPE, potential entry hazards, and details how occupants should document damage.	References *The ABC's of Returning to Flooded Buildings*. Discusses the dangers of electric shock, mold, asbestos, and lead paint.
Call a professional?	Recommends calling a professional to check the moisture content of all wood materials. This includes drywall (gypsum board) and plywood flooring. It also recommends contacting a local building inspector, structural engineer, or other appropriate professional when in doubt.	Recommends calling pest control professional for termites.	Recommends calling a remediation professional if testing confirms the presence of lead.
Assessment	Assumes that structures that have experienced long-term flooding will have extensive mold growth.	Not discussed.	Assumes mold and contamination when a flooded home has not been cleaned and dried within a few weeks of the event. Floodwaters carry a variety of contaminants, such as bacteria, oil, heavy metals, and pesticides. Safety issues in the home will have to be addressed as well.
Remove standing water	Not discussed.	Not discussed.	Recommends removing all instances of standing water, especially to clean crawlspaces.
Drying out	Air out the structure as much as possible. Advises using fans only if power is safely available. Additionally provides detailed guidance on drying wood framing, walls, floors, and gypsum board. Explains use of moisture meters. Cautions on drying long enough.	Not discussed.	Advises maintaining buildings at 50–70 degrees Fahrenheit in cold weather. Open the building as much as possible to dry if no power is safely available. Once electrical service and HVAC have been safely sanitized and restored, use fans, heaters, air conditioning and dehumidification equipment to dry the structure. Measure moisture levels and continue drying until a moisture reading of less than 15 percent is achieved.

	Initial Restoration of Flooded Buildings	*The ABC's of Returning to Flooded Buildings*	*Cleaning Flooded Buildings: Hurricane Sandy Recovery Fact Sheet No. 1*
Removal of contents and furnishings	Remove salvageable contents and throw out damaged materials that cannot be salvaged.	Extract what is salvageable and focus on high-value items that were not affected by water or that have special significance. Porous items that were not waterlogged or moldy should be second priority.	Not discussed.
Removal of material and built-ins	Tear out or move out building materials and built-ins depending on their condition.	Remove high-value, salvageable items that were not damaged or that can be easily cleaned.	Separate affected from unaffected areas.
Cleaning hard surfaces	To clean hard surfaces, use a shop vacuum with a solution of water and disinfectant in the tank to minimize the spread of dust. Use squeegees and shovels for mucking out spaces. For mold removal, advises using commercial mold removers. Wash, rinse, and pressure-wash to clean contaminated surfaces.	Clean nonporous contaminated items onsite.	Clean and sanitize all materials and contents that got wet. Clean surfaces before sanitizing. Use EPA-registered disinfectants and sanitizers. Recommends foam cleaning, brush cleaning, and pressure-washing combined with high-efficiency particulate air (HEPA) vacuums to collect the residue.
Cleaning porous surfaces	Do not scrub gypsum board until it has dried.	If porous items cannot be saved, recommends saving nonporous pieces of the items as keepsakes.	Water-damaged porous materials should be removed. Semiporous surfaces should be wiped off with disposable towels and not scrubbed.
Cleaning cavities	Remove cabinets and built-ins to access and clean hidden spaces.	Not discussed.	Crawlspaces, once opened, must have all solid contaminants removed, along with any remaining water. Cleaning foam should be used to clean all exposed sides of floor joists, foundation walls, and remaining structural elements. Potential mold growth also must be minimized.
Cleaning HVAC systems and ducts	Not discussed.	Not discussed.	Restore and sanitize electrical service and HVAC.
Use of biocides	Recommends using commercial products for sanitization and cautions against using bleach.	Not discussed.	Not discussed.
Do not mix bleach and cleaning products	Not discussed.	Not discussed.	Cautions against use of bleach. Lists both its convenience and its drawbacks.

	Initial Restoration of Flooded Buildings	***The ABC's of Returning to Flooded Buildings***	***Cleaning Flooded Buildings: Hurricane Sandy Recovery Fact Sheet No. 1***
Reoccupancy criteria	Dry things to less than 15 percent moisture content by weight.	Not discussed.	Not discussed.
Health and safety	Wear PPE.	Not discussed.	References Occupational Safety and Health Administration (OSHA) Hurricane Sandy Cleanup PPE Matrix. Recommends using a disposable N-95 respirator or a full-face respirator, along with gloves and goggles. The N-95 respirator offers the minimum lung protection needed, and the full-face respirator is recommended for mold cleaning to protect both the eyes and respiratory system.
Carbon monoxide	Not discussed.	Not discussed.	Not discussed.
Asbestos and lead	Recommends respiratory protection during the removal of flooring products, as many older pre-1970 materials contain asbestos.	Not discussed.	Both are discussed in this fact sheet. The history behind the use of the materials and the safety issues associated with them are covered. Testing by a professional and remediation are both recommended.
Health effects	Warns that if adequate drying is not achieved, inhabitants may experience health problems in the future.	Recommends inhabitants not return to their residences if they are physically or psychologically unfit and recommends they do not return alone.	Discusses flood-borne bacteria and contaminants, wet mechanical and electrical equipment, and mold growth.
Fix moisture problem	Not discussed.	Not discussed.	Not discussed.
Other	Extensively discusses cleaning crawlspaces and slabs.	Provides advice in the case of a termite infestation.	Provides detailed crawlspace cleaning guidance.

	Mold and Mildew: Cleaning Up Your Flood-Damaged Home	***Repairing Your Flooded House***	***Protect Yourself from Mold***
Publisher (Year)	FEMA (2007; update of earlier document)	FEMA/ARC (1992)	CDC (2006)
Target audience	Owners/renters	Owners/workers/volunteers restoring flood damaged houses	Owners/renters
Number of pages	12	56	2
Safety returning and entering	Recommends having an electrician inspect the home before turning on the power.	Provides extensive guidance for returning to flooded home and restoring it to operation.	Cautions inhabitants to be aware that mold may be present in the home and may be a health risk for the residents.
Call a professional?	Recommends doing it oneself if less than 25 square feet of mold is present. Recommends consulting a professional if the mold spans an area greater than 25 square feet. A professional should be consulted to check the home's HVAC and ducts that have flooded. An electrician must be called to inspect all electrical systems before switching on the power for safety purposes.	Recommends calling a professional if the reader feels any discomfort while addressing a flooded home. If the reader has no experience in construction or electrical repair, professional help is highly recommended. Government disaster programs typically provide a hotline with resources for those affected by severe natural disasters. The ARC is recommended for crisis counseling.	Not discussed.
Assessment	Mold assessment is broken down through a "decision tree" model. This resource recommends checking wall cavities to find hidden mold and to identify the source of the moisture.	Mold and fungus growth is assumed after a flooded home has been unattended for some time. Dampness promotes their growth. This is the only advice offered in this resource on flood damage assessment.	Discusses how to recognize mold growth and assess mold damage.
Remove standing water	Advises on removing standing water as soon as possible as it is a breeding ground for dangerous microorganisms.	Offers advice on removing standing water from basements.	Names standing water as a contributor to mold growth and health issues.
Drying out	Open up the house to let in air flow and dry out the home. Use fans and dehumidifiers if safe access to electricity is available. It is not recommended to use a furnace or an air conditioner if the air handlers or ductwork were flooded. Open all flooded wall cavities to clean and dry.	Provides no timeframe for drying out a flooded home. Recommends lowering the humidity in the home. Provides different options on how to lower the humidity in a flooded building.	Dry the building within 48 hours. Open all windows and use fans.

	Mold and Mildew: Cleaning Up Your Flood-Damaged Home	***Repairing Your Flooded House***	***Protect Yourself from Mold***
Removal of contents and furnishings	Remove wet items (e.g., furniture, rugs, carpeting, bedding, toys, food). If the home's content has been wet for less than 48 hours, clean and salvage the items.	Throw away flood-soaked mattresses, carpets, upholstered furniture, books, paper, fiberglass or cellulous insulation, wallboard, and food.	Remove porous materials that have been wet for more than 48 hours. All items that cannot be dried and thoroughly cleaned (carpeting, upholstery, wallpaper, gypsum board) should be removed from the home. Store salvageable items outside the house. When in doubt, take it out.
Removal of material and built-ins	Remove wet or contaminated gypsum board, ceiling tiles, and composite wood products. Remove wet insulation (foam insulation may be cleaned and salvaged).	Remove and discard flooded wallboard. Soaked wallboard presents a permanent health hazard. Different types of insulation have different reactions to floodwater. This resource explains what to do in each case.	Porous noncleanable items include drywall, floor and ceiling tiles, insulation material, and wood. Remove these items or clean if possible. When in doubt, take it out.
Cleaning hard surfaces	Wash hard surfaces with nonammonia detergent and hot water. Brush rough surfaces. Disinfect with bleach solution (1.5 cups per 1 gallon of water).	Use detergent and water to clean hard surfaces. Disinfect with quaternary, phenolic, or pine oil-based products. Use bleach only as a second choice (with care).	Clean with detergent and water or bleach solution. Refer to EPA's *A Brief Guide to Mold, Moisture and Your Home* for disinfection. Recommends professional help for areas greater than 10 square feet.
Cleaning porous surfaces	For materials that have been wet less than 48 hours, try cleaning and drying the items. When in doubt, throw it out.	Do not scrub gypsum board until it has dried.	Thoroughly clean and dry all porous materials that can be salvaged. To prevent mold growth from occurring, clean wet items with detergent and water. Remove all porous items that have been wet for more than 48 hours and cannot be thoroughly cleaned.
Cleaning cavities	Recommends checking cavities and other areas for hidden mold. Cleaning recommendations are based on the amount of mold found.	Take the backs off of furniture to let air circulate. Do not force open swollen wooden doors and drawers; wait until they have aired out and then ease them open.	Not discussed.
Cleaning HVAC systems and ducts	Flooded HVAC systems and ducts should be inspected by a professional.	Hose out ducts and wash them with disinfectant or sanitizer (quaternary, phenolic, pine oil).	Not discussed.
Use of biocides	Bleach is recommended as a disinfectant, when properly prepared.	Bleach is recommended as a disinfectant, when properly prepared.	Use detergents, soap and water, or bleach solution (1 cup bleach per 1 gallon of water).

	Mold and Mildew: Cleaning Up Your Flood-Damaged Home	***Repairing Your Flooded House***	***Protect Yourself from Mold***
Do not mix bleach and cleaning products	Cautions against mixing bleach and ammonia. Watered-down bleach can be a helpful cleaning tool.	Cautions against mixing bleach and ammonia.	Cautions against mixing bleach and ammonia.
Reoccupancy criteria	Not discussed.	Dry items to less than 15 percent moisture content by weight.	Not discussed.
Health and safety	Recommends wearing gloves and mask or respirator while cleaning or entering the home.	Recommends wearing sturdy shoes and gloves while cleaning or entering the home.	Recommends wearing an N-95 mask (if spending extended periods of time in the building or cleaning mold), gloves, and protective eyewear and practicing proper ventilation.
Carbon monoxide	Not discussed.	Readers are warned to use generators outdoors only as they give off carbon monoxide fumes.	Not discussed.
Asbestos and lead	Not discussed.	Not discussed.	Not discussed.
Health effects	Full-page discussion dedicated to the health effects associated with mold and flooding.	Not discussed.	Briefly discusses health effects.
Fix moisture problem	Identify and fix all moisture sources. Rebuild using water-resistant materials.	Identify and fix moisture source. Rebuild using water-resistant materials.	If there is mold growth in a home, inhabitants are instructed to clean up the mold and fix any water problem, such as leaks in roofs, walls, or plumbing. Controlling moisture in the home is the most critical factor for preventing mold growth.
Other	Provides extensive general advice. Defines disinfectants.	Provides extensive general advice. Defines disinfectants.	NA

	Creating a Healthy Home: A Field Guide for Clean-up of Flooded Houses	***S500 Standard and Reference Guide for Professional Water Damage Restoration***
Publisher (Year)	NCHH (2006)	IICRC (2015)
Target audience	Owners/workers/volunteers restoring flood damaged houses	Water-loss restoration professionals
Number of pages	22	333
Safety returning and entering	Conduct a pre-work inspection before returning or entering. Check for structural damage, have the electric system inspected, have all gas equipment inspected, and have the home's plumbing system inspected. Turn off gas and electricity until they are properly inspected. This resource offers tips to help identify people who should not do this work.	The S500 standard contains an extensive safety and health section directed primarily at hazards encountered while drying, cleaning, decontaminating, and restoring the building. Some of the items covered (e.g., PPE, confined space entry, heat disorders, lockout/tagout for electrical systems, safe work practices in contaminated buildings) apply to the circumstances during the initial re-entry, assessment, cleaning, and stabilization of the house.
Call a professional?	Professional inspections should be conducted for the building's electrical system, gas equipment, and plumbing. Recommends professional help for construction or restoration if the occupants are incapable of completing the tasks alone. Hire a professional if mold growth covers more than 100 square feet. Resource provides tips on how to hire a professional.	As this document is written for water-loss professionals it has no recommendations for hiring professionals.
Assessment	Inspect the home for active rain, plumbing leaks, and standing water. Divide the house into flooded and not-flooded areas. Assess which furnishings and belongings can be salvaged and saved, and make note of damage to windows, doors, and walls.	Contains extensive guidance for assessing the extent of loss, potential contaminants, appropriate work protection, the required drying capacity of dehumidification equipment, containment, and clearance.
Remove standing water	Remove any standing water. Standing water can either be pumped out or mopped out depending on the situation.	Covers pumping, extraction, and follow-up extraction.
Drying out	Open all windows, doors, and crawlspaces. Open up the attic as well.	Begin as soon as safely practical following the initial moisture intrusion. Promote evaporation of remaining water in materials. Remove vapor from air by supplying less humid air and/or dehumidification. Specific advice is provided on drying different materials (e.g., carpets, drywall) and building components (e.g., floor systems, walls).

	Creating a Healthy Home: A Field Guide for Clean-up of Flooded Houses	***S500 Standard and Reference Guide for Professional Water Damage Restoration***
Removal of contents and furnishings	Extensive guidance on salvage/removal of contents. Move salvageable items to designated safety and cleanup areas. All other materials should be placed in the trash removal area. Throw away moldy carpet, furniture, electronics, paper, books, and food in contact with flood waters. Advice is provided on wall removal and tearing out floor tiles and wood. Gut tear-out procedure described in detail. Remove or machine-wash all clothing with detergent and bleach.	Chapter 17 contains extensive guidance on evaluating the restorability of contents and materials. Throw away or clean depending on water category, object's value, and porosity of material. Cleaning, decontaminating, and drying guidance is provided for each kind of material or assembly.
Removal of material and built-ins	Remove plaster/gypsum cabinets, trim, shelves, fibrous insulation, and interior doors. Try to save plaster.	Chapter 17 contains extensive guidance on evaluating the restorability of contents and materials. Throw away or clean depending on water category, object's value, and porosity of material. Cleaning, decontaminating, and drying guidance is provided for each kind of material or assembly.
Cleaning hard surfaces	Use a HEPA vacuum to clean hard surfaces. Wash and disinfect using a bleach and nonphosphate detergent. Wood surfaces should be cleaned with nonphosphate detergent. Treat the wood surface with borate, and avoid bleach. Fungicidal coating is optional.	Contains information on air-based cleaning, such as HEPA vacuuming and air-washing, and liquid-based cleaning with detergent/water, such as ultrasonic cleaning and steam cleaning. Hard surfaced, nonporous materials are considered restorable for all categories of water.
Cleaning porous surfaces	Remove contaminated porous building materials. Save possessions and furnishings.	Chapter 17 contains extensive guidance on evaluating the restorability of contents and materials. Throw away or clean depending on water category, object's value, and porosity of material. Cleaning, decontaminating, and drying guidance is provided for each kind of material or assembly. Many porous materials are consider either not restorable or restorable based on category of water, conditions, and professional judgment.
Cleaning cavities	Wash or mist all wall cavities with a borate solution prepared to the manufacturer's directions for wood fungi.	Contains extensive drying and cleaning guidance for cavities.
Cleaning HVAC systems and ducts	Discard flooded ductwork and air handlers. Fungicidal coatings can be used to keep mold from spreading in the HVAC system.	Inspect for cleanliness and clean using the National Air Duct Cleaners Association's (2006) *Assessment, Cleaning and Restoration of HVAC Systems*. Any insulated ductwork saturated with water, regardless of category, should be removed. When contaminated with Category 2 or 3 water, ductwork with an interior sound/insulation liner, plastic flex duct, and coated fiberboard ducting should be replaced. Use of antimicrobials may be considered but use shall not be substituted for removal of viable microbial bodies.
Use of biocides	Use dilute bleach only on nonporous, hard surfaces.	Provides an extensive discussion of biocides. Refers to the American Conference of Governmental Industrial Hygienists' guidance to avoid biocides except in unusual circumstances.

	Creating a Healthy Home: A Field Guide for Clean-up of Flooded Houses	***S500 Standard and Reference Guide for Professional Water Damage Restoration***
Do not mix bleach and cleaning products	Never mix bleach and ammonia. Use a solution of 1 cup of liquid bleach to 1 gallon of water, plus nonphosphate detergent for cleaning and disinfecting.	Contains warning that chlorine bleach mixed with ammonia or acids produces chlorine gas.
Reoccupancy criteria	Not discussed.	Recommends independent post-remediation verification.
Health and safety during remediation	Resource provides two full pages of discussion on PPE. Recommends wearing a respirator, coveralls, boots, gloves, and eye and head protection. Set up a safety and cleanup area for restoration workers. Plan for dumpster or other trash removal area, and set up a clean-room containment system.	Provides extensive health and safety requirements and references.
Carbon monoxide	Do not have any unvented fuel burning devices in the home (generators mentioned).	Contains warning on the use of space heaters and back drafting atmospherically vented combustion devices (because of negative pressure in the combustion space).
Asbestos and lead	Homes built before 1978 typically have lead-based paint. Recommends using lead-safe practices when disturbing this paint. If the home contains 9 foot x 9 foot or 8 foot x 8 foot floor tiles made before 1970, assume these tiles contain asbestos. Spray these tiles with water and use caution when removing.	Refers to OSHA Standards 29 CFR 1926.62 and 1910.1025.
Health effects	Several pages are dedicated to the major health risks associated with water-damaged homes.	Contains brief descriptions of potential health effects from exposure to Category 2 and 3 water damage.
Fix moisture problem	Identify and fix moisture source. Rebuild using water-resistant materials.	No discussion of underlying moisture problems or floodproofing retrofits.
Other	Resource is comprehensive, easy to understand, and well-illustrated. Defines disinfectants. Discusses paint framing with fungicidal paint.	The book is divided into a standard of practice for responding to water loss problems and an extensive reference section that discusses the topics in detail.

Appendix 2: Selected References From the Literature Search in Chapter 3

The scientific literature search regarding cleaning and sanitizing in buildings yielded a small number of documents related directly to this issue. Highlights from some are listed below:

- Exner M, Vacata V, Hornei B, Dietlein E, Gebel J. 2004. Household cleaning and surface disinfection: New insights and strategies. *Journal of Hospital Infection* 56:S70–S75. This article demonstrates that *Staphylococcus aureus* can be transferred from one portion of a flooring surface to another by mops and found experimentally that:
    - Water and surfactants reduced concentrations by more than a factor of 100 and spread 1 in 10,000 ***colony-forming units*** (cfu) to neighboring floor sections.
    - Glycol derivatives, quaternary ammonium salts, and alkylamines reduced concentrations by more than 1,000 and spread 1 in 100,000 cfu to neighboring floor sections.
    - Aldehydes and peroxides reduced concentrations by greater than 10,000 (essentially eliminating test organism) and spread no measurable levels to neighboring floor sections.
    - Study limitation—mopping was one pass from contaminated site over three other sites and back; no scrubbing, no multiple passes, and no rinse.
- Rutala WA, Weber DJ. 2001. Surface disinfection: Should we do it? *Journal of Hospital Infection* 48(Suppl A):S64–S68. This article reports the following:
    - Cleaning floors with soap and water resulted in an 80 percent reduction in bacteria and a 99 percent reduction using phenolic disinfectant; in either case, levels were back to pre-treatment levels within a few hours (Ayliffe et al. 1966).
    - Detergents become contaminated as floors are mopped, spreading dilute contamination (Ayliffe et al. 1967).
    - ***Nosocomial infection*** rates are the same whether floors are cleaned with detergent or disinfectant (Danforth et al. 1987, Daschner et al. 1980, Dharan et al. 1999).
    - Contamination of noncritical surfaces does not seem to correlate to nosocomial infection rates or profiles (Maki et al. 1982).
    - Use of biocides might lead to organisms resistant to biocides or antibiotics (Levy 1998, McMurry et al. 1998, Moken et al. 1997).
- Wilson SC, Brasel TL, Carriker CG, Fortenberry GD, Fogle MR, Martin JM, Wu C, Andriychuk LA, Karunasena E, Straus DC. 2004. An investigation into techniques for cleaning mold-contaminated home contents. *Journal of Occupational and Environmental Hygiene* 1(7):442–447. This article reported that a combination cleaner/sanitizer was found to be effective at removing and deactivating microorganisms from environmental surfaces.

The authors' search of the literature for studies addressing cleaning or sanitization/disinfection of specific building materials revealed a dearth of citations, strongly emphasizing the need for more applied research in this area.

Although two studies present data relative to the cleaning of gypsum wallboard, it must be re-emphasized that heavily contaminated porous materials such as wallboard should be removed and replaced because fungal growth typically penetrates the material and results in regrowth at a later time. Nonsaturated, intact wallboard, however, may contain mold growth in a surface condensate layer, which then may be removed using a suitable cleaning/sanitizing/disinfecting product.

In one study, sections of unused, nonsterile gypsum board were inoculated with varying concentrations of *Stachybotrys chartarum* and incubated at high relative humidity (86 percent to 92 percent) for up to 12 weeks. Sections then were cleaned with a quaternary ammonium product, a quaternary plus chlorine dioxide, a concentrated oxygen-saline solution, or a quaternary/acrylic treatment and then reincubated. Regrowth of *S. chartarum* occurred within 5 weeks only on those sections cleaned only with the quaternary. Other fungi, mostly species of *Aspergillus, Chaetomium,* and *Penicillium*, slowly colonized (between 9 and 12 weeks) at least some areas of most cleaned/treated surfaces and most control surfaces. Surfaces cleaned/treated with the quaternary/acrylic remained visually free of colonized fungi for more than 90 days, although microscopic examination revealed fungal penetration of the coating after 3 weeks (Price and Ahearn 1999).

Another study used large sections of wallboard wet from immersion of their bottom inch in water for 8 weeks. After drying for 2 weeks, some sections were cleaned by dry brushing, some by spraying with a high-concentration hypochlorite solution and wiping, and some by spraying with a high-concentration hypochlorite solution with detergent surfactants and wiping. On continued incubation for 2 more weeks, the appearance of mold, as determined microscopically by tape-lift and by culturable swab samples, was delayed by at least 1 week on the biocide-treated sections. Other sections treated with commercially available fungicidal/fungistatic coatings remained mold free (Krause et al. 2006).

In a third study, samples of wet ***oriented strand board***, gypsum drywall, and plywood were inoculated with *Aspergillus fumigatus* spores and further incubated for 14 days, after which some were treated separately with one or the other of a high-concentration bleach solution or a commercial sodium hypochlorite/cleaner product. Subsequent sampling and testing showed kill of the *Aspergillus*, although no long-term regrowth studies were conducted. The investigators also tried to assess the capability of the tested solutions to neutralize the antigenic effects of the mold spores, but their sample was too small for meaningful interpretation and calls for further research (Martyny et al. 2005).

Although studies such as these indicate that the use of commercial biocide cleaner/treatments or fungicidal/fungistatic coatings can kill or retard the growth of water-damage molds on porous building materials for varying time periods, growth ultimately can reoccur, and hence the most cost-effective rational approach to remediation is the recommendation to replace such moisture-damaged and mold-contaminated materials, ensure adequate and complete drying of the indoor environment, and implement and maintain sustainable moisture control practices.

The use of detergents in the wet cleaning of surfaces and materials provides for the emulsification of organic residues and thus the removal of associated pathogens, allergens, and chemical pollutants. As most detergent products are formulations of quaternary ammonium compounds, they typically have a sanitizing effect in the killing of microbial contamination as well. A recent study of hospital floor cleaning methods concluded that wet scrub cleaning using detergent solution with hand-hot water was the most efficient, followed by spray cleaning, and then mopping and vacuuming (White et al. 2007). Also, a study investigating the use of detergent cleaning in livestock housing found that detergent use resulted in significant vegetative bacterial reductions on nonporous surfaces such as metal (Hancox et al. 2013), whereas another study showed that wet wiping with a detergent cleaner resulted in 1,000-fold physical reduction of *Clostridium difficile* spores from environmental surfaces (Rutala et al. 2012).

Also, the use of steam as a cleaning and sanitizing method has become more popularized with the availability of a number of commercial equipment products. A most definitive study of the capability of steam to inactivate a broad spectrum of human pathogenic bacterial challenges dried on a hard surface showed complete kill by exposure to steam vapor within 5.0 seconds (Tanner 2009). In that study, the use of bacterial challenges of methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococcus faecalis*, *Salmonella enterica*, *Pseudomonas aeruginosa*, *Escherichia coli*, and *Shigella flexneri* exposed to a steam device with its head covered with a cotton-terry material showed initial kill beginning at 0.5 seconds and continuing through 1.0 and 2.0 seconds, with complete kill of all challenges by 5.0 seconds. Such results confirmed the fact that steam begins to sanitize and kill vegetative bacteria on contact, and inactivation continues rapidly and logarithmically. The effectiveness of a steam cleaning process also was shown in a veterinary hospital where *S. aureus* and *Pseudomonas* species were reduced on stainless steel tub sinks by 94–98 percent and greater than 99 percent, respectively (Wood et al. 2014).

Once initial wet cleaning and decontamination practices have been completed and the environment sufficiently dried, then high-efficiency particulate air (HEPA) vacuuming can provide an additional measure of physical removal of any remaining residual contaminants prior to the rebuilding process. HEPA vacuuming has been recommended for the cleaning and remediation of indoor environments contaminated with bioterror and other highly infectious agents, such as *Bacillus anthracis*, as a more appropriate alternative to the use of chemical germicides (Cole and Lantrip 2001).

Yet another approach is the use of microfiber cloths for the effective and nonchemical wipe down of various surfaces expected to be contaminated with a variety of microbes, to include human pathogens. An investigation of the ability of 10 different microfiber cloths to remove microbial contamination from three common hospital surfaces (stainless steel, furniture laminate, and ceramic tile) under controlled laboratory conditions (microbial suspensions, automated cleaning device) concluded that "microfiber cloths are an effective way to reduce levels of MRSA, *E. coli*, and *C. difficile*" (Smith et al. 2011).

An interesting study has been published recently examining the effects of flooding and post-flood cleaning on airborne contamination in residential environments following the 2011 flooding of approximately 22,000 homes in Brisbane, Australia (He et al. 2014). Airborne particles, viable fungal and bacterial aerosols, and airborne dusts for elemental composition were sampled and assessed in flooded (n = 24) and nonflooded (n = 17) homes. Results showed no statistically significant differences in airborne levels for each of the contaminant groups between flooded and nonflooded houses. This was attributed to the fact that all of the flooded homes were remediated and cleaned within 1 week (some within 1 or 2 days) after flood waters had receded. Remediation included removal of flooded materials and drying, while cleaning methods were varied and included the use of water only, water plus detergent, water plus bleach, water plus disinfectant, water plus disinfectant and bleach, detergent and bleach, and water plus insecticide. Although no particular cleaning approach could be advocated, the significance of the study has shown clearly that the key to prevention of poor indoor air quality following flooding is the need to, as rapidly as possible, remove water-damaged materials, institute drying, and employ some type of cleaning method to reduce residual contamination.

In summary, the use of various cleaning methods—as they have been discussed, either individually or in combination—to remove contamination from a variety of surfaces and materials in a home environment exposed to flood conditions appears to be a feasible approach to limiting post-flood contamination of the indoor air, as long as the methods used are in conjunction with the timely removal of affected materials and the rapid drying of the environment.

Further, the literature search also uncovered a number of papers regarding cleaning and sanitizing critical medical and food preparation surfaces but not specifically related to buildings. The major points are summarized below.

- Cases of nosocomial antibiotic resistant bacteria infection correlate to hospital stays longer than 1 week before admission to an intensive care unit (ICU), treatment with vancomycin, use of quinolones before admission to the ICU, and placement in contaminated treatment rooms (which received regular ICU cleaning) (Martinez et al. 2003).

- The concentration of active ingredient in a sanitizer affects efficacy (Bremer et al. 2002).

- The specific organism's tolerance to the sanitizing agent affects efficacy (Bremer et al. 2002, Knowles and Roller 2001, Weber et al. 1999).

- The state of bacteria, planktonic organisms, free cell, or biofilm affects efficacy, with biofilm being the most difficult to inactivate (Bremer et al. 2002, Mafu et al. 1990, Peng et al. 2002).

- Chlorine is more effective at sanitizing surfaces contaminated by a biofilm of *Campylobacter jejuni* than quaternary ammonium compounds or peracetic acid sanitizers in 45-second exposures (Trachoo and Frank 2002).

- Smoother, nonporous materials (e.g., stainless steel, glass, granite) are easier to sanitize, whereas porous, rough ones (e.g., wood, mineral resin, some plastics, scratched or scored smooth surfaces) are more difficult by orders of magnitude; concrete and tile surfaces fall in between (Bremer et al. 2002, Frank and Chmielewski 1997, Mafu et al. 1990, Snyder 1997, Snyder 1999).

- The presence of contaminants on a surface or in a liquid reduces the effectiveness of the sanitizer (which may be compensated for by increased concentration, contact time, or both) (Barker et al. 2003, Barker et al. 2004, Kusumaningrum et al. 2003, Mafu et al. 1990, Peng et al. 2002, Weber et al. 1999).

- Washing with water and detergent is sometimes very effective (Peng et al. 2002, Snyder 1999), whereas other times it is not (Barker et al. 2003, Cogan et al. 1999, Scott and Bloomfield 1993).

- Combination cleaners/sanitizers are effective (Barker et al. 2003, Olson et al. 1994, Peng et al. 2002).

- Inactivating some viruses, even under good conditions, requires high concentrations and long contact time (Allwood et al. 2004, Barker et al. 2004, Jean et al. 2003, Weber et al. 1999).

- Electrolyzed water performs as an effective sanitizer (Park et al. 2002).

- Chlorine bleach must be stored at room temperature in opaque bottles (Frais et al. 2001).

- A solution of sodium hypochlorite can retain 40 to 50 percent efficacy when stored in open, clear containers for 30 days (1:50 and 1:100 solutions), 83 to 85 percent when stored in sealed, nonopaque containers for 30 days (1:5 solutions), and 97 to 100 percent efficacy when stored in dark, sealed containers for 30 days (1:50 and 1:5 solutions) (Rutala et al. 1998).

- Hypochlorite activity is reduced by the presence of heavy metal ions, biofilm, organic material, low temperature, low pH, or UV exposure. Hypochlorite has a long history of use, low toxicity at recommended use concentrations, is effective against most microbes (including viruses), and is less effective against endospore-forming bacteria (Rutala and Weber 1997).

Finally, four papers also reported cleaning or disinfecting compounds as agents that can reduce allergenicity.

- A study of mouse urinary allergen (Mus m 1) found that sodium hypochlorite reduced the allergenicity of the allergen at molar concentrations of 100:1 and fragmented the protein at higher concentrations. Dust mite (Der p 1) and cockroach (Bla g 1) allergens were tested in a mixture with Mus m 1. Much higher concentrations of sodium hypochlorite were needed to reduce the allergenicity (molar ratios of 50,000 to 500,000). It was hypothesized that the higher levels were needed with the mixture than the purified Mus m 1 because of interference by much higher protein levels (Chen and Eggleston 2001).

- A similar study of cat allergen (Fel d 1) found that although Fel d 1 could be fragmented, it required a molar ratio of 7,000. Cat-specific IgG recognition was found at a lower molar ratio of 560 (Matsui et al. 2003).

- In a study of *A. fumigatus* growth on plywood, oriented strand board, and paper-covered gypsum board, sodium hypochlorite was reported to reduce recognition of *A. fumigatus* by ***enzyme-linked immunosorbent assay*** (commonly known as ELISA) and results in a loss of skin test reactivity to the treated mold for people who are allergic to *A. fumigatus* (Martyny et al. 2005).

- In a study of allergic proteins in floor dust tested for denaturing by household cleaners, it was found that soft soap, guanidine hydrochloride, and sodium lauryl sulfate reduced antigenic and allergenic activities but none destroyed them. None of the products used to clean carpets had any effect (Dybendal et al. 1990).

Appendix 3: Glossary

bioaerosol: Short for biological aerosol; a suspension of very small airborne particles that contain living organisms or were released from living organisms.

colony-forming unit: A unit used to estimate the number of viable (able to multiply) bacterial or fungal cells in a sample.

confidence interval: A range of values calculated from observations and so defined that there is a specified probability that the value of a parameter of interest lies within it. In other words, if confidence intervals are constructed in separate experiments on the same population following the same process, the proportion of such intervals that contain the true value of the parameter will match the given confidence level.

cross-sectional study: An observational study that analyzes data collected from a population, or a representative subset, at a specific point in time.

endotoxin: Molecules found on the outer membrane of some bacteria that elicit a strong immune response in mammals. Exposure to endotoxins can lead to septic shock and death.

endotoxin units per cubic meter: A measure of an endotoxin's biological activity (potency).

enzyme-linked immunosorbent assay: Commonly known as ELISA; a biochemical technique used mainly in immunology to detect the presence of an antibody or an antigen.

floodplain: An area of land adjacent to a stream or river that stretches from the banks of its channel to the base of the enclosing valley walls and experiences flooding during periods of high discharge.

gypsum board: The generic name for a family of panel products that consist of a noncombustible core—composed primarily of gypsum—and paper surfacing on the face, back, and long edges.

hydrophobic particles: Particles that do not carry a charge and, therefore, appear to repel water.

hyphae: Long, branching filamentous structures of a fungus that can cause an allergic reaction in sensitive individuals.

indoor microbiome: The collection of microbial communities that live within human-constructed environments (buildings). These microbiomes are being studied for a variety of reasons, including how they may affect the health of human and animal residents of indoor environments.

longitudinal study: An observational study method in which data are gathered for the same subjects repeatedly over a period of time.

medium-density fiberboard: Commonly known as MDF; an engineered wood product that is formed into panels made with wood fibers combined with wax and a resin binder. When MDF is cut, sanded, or drilled, a large quantity of dust particles is released into the air; therefore, it is important that a respirator is worn and that the material is cut in a controlled and ventilated environment. Another concern is the slow release of formaldehyde over time, as MDF, particleboard, and oriented strand board have been cited as major sources of formaldehyde emissions.

mycotoxin: Toxic chemical products produced by fungi. Mycotoxins can cause weakened immune systems, allergic reactions, irritation, and death in animals and humans.

nosocomial infection: Hospital-acquired infections caused by viral, bacterial, or fungal pathogens.

odds ratio: Commonly known as OR; a measure of the association between an exposure and an outcome. The OR represents the odds that an outcome will occur given a particular exposure compared to the odds of the outcome occurring in the absence of that exposure.

oriented strand board: Commonly known as OSB; a type of engineered lumber similar to particle board, formed by adding adhesives and then compressing layers of wood strands. The resins used to create OSB have raised questions regarding the potential for OSB to emit toxic compounds, such as formaldehyde; OSB, particleboard, and medium-density fiberboard have been cited as major sources of formaldehyde emissions.

particleboard: An engineered, pressed wood product manufactured from wood chips, sawmill shavings, or even sawdust combined with a synthetic resin or other suitable binder. Safety concerns include physical (fine dust) and chemical (formaldehyde, carbon monoxide, hydrogen cyanide, phenol) exposure when cut, sanded, or drilled. Another concern is the slow release of formaldehyde over time, as particleboard, medium-density fiberboard, and oriented strand board have been cited as major sources of formaldehyde emissions.

polymerase chain reaction: Commonly known as PCR; a molecular biology technique used to amplify a single copy or a few copies of a piece of DNA. The technique is used for a variety of biological, genetic, and forensic reasons, including the identification and estimation of bacteria and fungi in samples.

reactive airways dysfunction syndrome: An asthma-like syndrome developing after a single exposure to high levels of an irritating vapor, fume, or smoke that includes coughing, wheezing, and shortness of breath.

relative risk ratio: The ratio of the probability of an event occurring (e.g., developing a disease, being injured) in an exposed group to the probability of the event occurring in a comparison, nonexposed group.

spore: A resistant structure used by bacteria, fungi, and other organisms to survive under unfavorable conditions. Mold spores can cause allergic, inflammatory, and toxic responses in sensitive individuals.

Standard Flood Insurance Policy: A policy issued to insure a building and/or its contents. The Federal Emergency Management Agency's National Flood Insurance Program offers three

Standard Flood Insurance Policy forms. These forms provide policyholders with a description of their coverage and other important coverage information.

Appendix 4: References

ACGIH (American Conference of Governmental Industrial Hygienists). 1999. *Bioaerosols: Assessment and Control*. Cincinnati, OH: ACGIH.

Adams RI, Bhangar S, Pasut W, Arens EA, Taylor JW, Lindow SE, Nazaroff WW, Bruns TD. 2015. Chamber bioaerosol study: Outdoor air and human occupants as sources of indoor airborne microbes. *PLOS ONE* 10:e0128022.

Adams RI, Miletto M, Lindow SE, Taylor JW, Bruns TD. 2014. Airborne bacterial communities in residences: Similarities and differences with fungi. *PLOS ONE* 9:e91283.

Adams RI, Miletto M, Taylor JW, Bruns TD. 2013a. The diversity and distribution of fungi on residential surfaces. *PLOS ONE* 8:e78866.

Adams RI, Miletto M, Taylor JW, Bruns TD. 2013b. Dispersal in microbes: Fungi in indoor air are dominated by outdoor air and show dispersal limitation at short distances. *The ISME Journal* 7:1262–1273.

Akland G, Whitaker DA. 2000. Characterizing the sources of human exposure to Proposition 65 substances. RTI/6830/02–03 F. Research Triangle Park, NC: Research Triangle Institute.

Alderman K, Turner LR, Tong S. 2012. Floods and human health: A systematic review. *Environment International* 47:37–47.

Allwood PB, Malik YS, Hedberg CW, Goyal SM. 2004. Effect of temperature and sanitizers on the survival of feline calicivirus, *Escherichia coli*, and F-specific coliphage MS2 on leafy salad vegetables. *Journal of Food Protection* 67(7):1451–1456.

Arif AA, Delclos GL, Whitehead LW, Tortolero SR, Lee ES. 2003. Occupational exposures associated with work-related asthma and work-related wheezing among U.S. workers. *American Journal of Industrial Medicine* 44:368–376.

Ayliffe GAJ, Collins BJ, Lowbury EJL, Babb JR, Lilly HA. 1967. Ward floors and other surfaces as reservoirs of hospital infection. *Journal of Hygiene (Cambridge)* 65: 515–536.

Ayliffe GAJ, Collins BJ, Lowbury EJL. 1966. Cleaning and disinfection of hospital floors. *British Medical Journal* 2:442–445.

Babl FE, Kharsch S, Woolf A. 1998. Airway edema following household bleach ingestion. *American Journal of Emergency Medicine* 16(5):514–516.

Barker J, Naeeni M, Bloomfield SF. 2003. The effects of cleaning and disinfection in reducing *Salmonella* contamination in a laboratory model kitchen. *Journal of Applied Microbiology* 95(6):1351–1360.

Barker J, Vipond IB, Bloomfield SF. 2004. Effects of cleaning and disinfection in reducing the spread of *Norovirus* contamination via environmental surfaces. *Journal of Hospital Infection* 58(1):42–49.

Baxter DM, Perkins JL, McGhee CR, Seltzer JM. 2005. A regional comparison of mold spore concentrations outdoors and inside “clean” and “mold contaminated” Southern California buildings. *Journal of Occupational and Environmental Hygiene* 2:8–18.

Bennion JR, Franzblau A. 1997. Chemical pneumonitis following household exposure to hydrofluoric acid. *American Journal of Industrial Medicine* 31(4):474–478.

Berry NM, Bishop J, Blackburn C, Cole E, Ewald W, Smith T, Suazo N, Swan S. 1994. Suggested guidelines for remediation of damage from sewage backflow into buildings. *Journal of Environmental Health* 57:9–15.

Bhangar S, Adams RI, Pasut W, Huffman JA, Arens EA, Taylor JW, Bruns TD, Nazaroff WW. 2016. Chamber bioaerosol study: Human emissions of size-resolved fluorescent biological aerosol particles. *Indoor Air* 26(2):193–206.

Boor BE, Siegel JA, Novoselac A. 2013. Monolayer and multilayer particle deposits on hard surfaces: Literature review and implications for particle resuspension in the indoor environment. *Aerosol Science and Technology* 47:831–847.

Bremer PJ, Monk I, Butler R. 2002. Inactivation of *Listeria monocytogenes*/*Flavobacterium* spp. biofilms using chlorine: Impact of substrate, pH, time and concentration. *Letters in Applied Microbiology* 35(4):321–325.

Brevard TA, Calvert GM, Blondell JM, Mehler LN. 2003. Acute occupational disinfectant-related illness among youth, 1993–1998. *Environmental Health Perspectives* 111(13):1654–1659.

Burge PS, Richardson MN. 1994. Occupational asthma due to indirect exposure to lauryl dimethylbenzyl ammonium chloride used in a floor cleaner. *Thorax* 49:842–843.

Cardona J, Boussemart T, Berthier M, Oriot D. 1993. Accidental bleach ingestion in children: Results of a survey in 11 anti-poison centres. Proposals for management. *Pédiatrie* 48(10):705–709.

Casasnovas AB, Martinez EE, Cives RV, Jeremias AV, Sierra RT, Cadranel S. 1997. A retrospective analysis of ingestion of caustic substances by children. Ten-year statistics in Galicia. *European Journal of Pediatrics* 156:410–414.

CDC (Centers for Disease Control and Prevention). 2006a. Mold prevention strategies and possible health effects in the aftermath of hurricanes and major floods. *Morbidity and Mortality Weekly Report (MMWR)* 55(RR-8):1–27.

CDC. 2006b. Health hazard evaluation of police officers and firefighters after Hurricane Katrina—New Orleans, Louisiana, October 17–28 and November 30–December 5, 2005. *MMWR* 55(16):456–458.

CDC. 2006c. Monitoring Poison Control Center data to detect health hazards during hurricane season—Florida, 2003–2005. *MMWR* 55(15):426–428.

CDC. 2006d. Carbon monoxide poisonings after two major hurricanes—Alabama and Texas, August–October 2005. *MMWR* 55(9):236–239.

CDC. 2006e. Illness surveillance and rapid needs assessment among Hurricane Katrina evacuees—Colorado, September 1–23, 2005. *MMWR* 55(9):244–247.

CDC. 2006f. Surveillance for illness and injury after Hurricane Katrina—three counties, Mississippi, September 5–October 11, 2005. *MMWR* 55(9):231–234.

CDC. 2006g. Brief report: Leptospirosis after flooding of a university campus—Hawaii, 2004. *MMWR* 55(5):125–127.

CDC. 2006h. Health concerns associated with mold in water-damaged homes after Hurricanes Katrina and Rita—New Orleans area, Louisiana, October 2005. *MMWR* 55(2):41–44.

CDC. 2006i. Injury and illness surveillance in hospitals and acute-care facilities after Hurricanes Katrina and Rita—New Orleans area, Louisiana, September 25–October 15, 2005. *MMWR* 55(2):35–38.

CDC. 2006j. Surveillance in hurricane evacuation centers—Louisiana, September–October 2005. *MMWR* 55(2):32–35.

CDC. 2006k. Two cases of toxigenic *Vibrio cholera* O1 infection after Hurricanes Katrina and Rita—Louisiana, October 2005. *MMWR* 55(2):31–32.

CDC. 2005a. Surveillance for illness and injury after Hurricane Katrina—New Orleans, Louisiana, September 8–25, 2005. *MMWR* 54(40):1018–1021. Erratum in: *MMWR* 54(41):1057.

CDC. 2005b. Norovirus outbreak among evacuees from Hurricane Katrina—Houston, Texas, September 2005. *MMWR* 54(40):1016–1018.

CDC. 2005c. Surveillance for illness and injury after Hurricane Katrina—New Orleans, Louisiana, September 8–25, 2005. *MMWR* 54(40):1018–1021.

CDC. 2005d. *Vibrio* illnesses after Hurricane Katrina—multiple states, August–September 2005. *MMWR* 54(37):928–931.

CDC. 2004. Brief report: Acute illness from dry ice exposure during Hurricane Ivan—Alabama, 2004. *MMWR* 53(50):1182–1183.

CDC. 2002. Tropical Storm Allison rapid needs assessment—Houston, Texas, June 2001. *MMWR* 51(17):365.

CDC. 2000. Morbidity and mortality associated with Hurricane Floyd—North Carolina, September–October 1999. *MMWR* 49(17):369–372.

CDC. 1996a. Surveillance for injuries and illnesses and rapid health-needs assessment following Hurricanes Marilyn and Opal, September–October 1995. *MMWR* 45(4):81–85.

CDC. 1996b. Deaths associated with Hurricanes Marilyn and Opal—United States, September–October 1995. *MMWR* 45(2):32–38.

CDC. 1994a. Flood-related mortality—Georgia, July 4–14, 1994. *MMWR* 43(29):526–530.

CDC. 1994b. Rapid assessment of vector-borne diseases during the Midwest flood—United States, 1993. *MMWR* 43(26):481–483.

CDC. 1993a. Flood-related mortality—Missouri, 1993. *MMWR* 42(48):941–943.

CDC. 1993b. Morbidity surveillance following the Midwest flood—Missouri, 1993. *MMWR* 42(41):797–798.

CDC. 1993c. Public health consequences of a flood disaster—Iowa, 1993. *MMWR* 42(34):653–656.

CDC. 1993d. Injuries and illnesses related to Hurricane Andrew—Louisiana, 1992. *MMWR* 42(13):242–243, 250–251.

CDC. 1992. Preliminary report: Medical examiner reports of deaths associated with Hurricane Andrew—Florida, August 1992. *MMWR* 41(35):641–644.

CDC. 1991. Chlorine gas toxicity from mixture of bleach with other cleaning products—California. *MMWR* 40(36):619–621, 627–629.

CDC. 1983. Outbreak of diarrheal illness associated with a natural disaster—Utah. *MMWR* 32(50):662–664.

Chen P, Eggleston PA. 2001. Allergenic proteins are fragmented in low concentrations of sodium hypochlorite. *Clinical and Experimental Allergy* 31(7):1086–1093.

Chew A-L, Maibach HI (eds). 2005. *Irritant Dermatitis*. Berlin, Germany: Springer-Verlag, 538 pp.

Chew GL, Wilson J, Rabito FA, Grimsley F, Iqbal S, Reponen T, Muilenberg M, Thorne P, Dearborn DG, Morley RL. 2006. Mold and endotoxin levels in the aftermath of Hurricane Katrina: A pilot project of homes in New Orleans undergoing renovation. *Environmental Health Perspectives* 114(12):1883–1889.

Cho S, Seo S, Schmechel D, Grinshpun S, Reponen T. 2005. Aerodynamic characteristics and respiratory deposition of fungal fragments. *Atmospheric Environment* 39:5454–5465.

Cogan TA, Bloomfield SF, Humphrey TJ. 1999. The effectiveness of hygiene procedures for prevention of cross-contamination from chicken carcasses in the domestic kitchen. *Letters in Applied Microbiology* 29(5):354–358.

Cohle CD, Thompson W, Eisenga BH, Cottingham SL. 2001. Unexpected death due to chloramine toxicity in a woman with a brain tumor. *Forensic Science International* 124(2–3):137–139.

Cole EC, Lantrip BM. 2001. Suggested practice for remediation of highly infectious biological agent contamination in indoor environments. *Applied Biosafety* 6(3):136–138.

Courteau JP, Cushman R, Bouchard F, Quevillon M, Chartrand A, Bherer L. 1994. Survey of construction workers repeatedly exposed to chlorine over a three to six month period in a pulpmill: I. Exposure and symptomatology. *Occupational and Environmental Medicine* 51(4):219–224.

Cox R, Amundson T, Brackin B. 2008. Evaluation of the patterns of potentially toxic exposures in Mississippi following Hurricane Katrina. *Clinical Toxicology* 46:722–727.

Danforth D, Nicolle LE, Hume K, Alfieri N, Sims H. 1987. Nosocomial infections on nursing units with floors cleaned with a disinfectant compared with detergent. *Journal of Hospital Infection* 10:229–235.

Dannemiller KC, Gent JF, Leaderer BP, Peccia J. 2016. Influence of housing characteristics on bacterial and fungal communities in homes of asthmatic children. *Indoor Air* 26(2):179–192.

Dannemiller KC, Mendell MJ, Macher JM, Kumagai K, Bradman A, Holland N, Harley K, Eskenazi B, Peccia J. 2014. Next-generation DNA sequencing reveals that low fungal diversity in house dust is associated with childhood asthma development. *Indoor Air* 24(3):236–247.

Daschner F, Rabbenstein G, Langmaack GRH. 1980. Surface decontamination in the control of hospital infections: Comparison of different methods. *Deutsche Medizinische Wochenschrift* 105(10):325–329.

de Ferron P, Gossot D, Sarfati E, Celerier M. 1987. Esogastric lesions caused by ingestion of liquid chlorine bleach in adults. *La Presse Médicale* 16(42):2110–2112.

Dharan S, Mourouga P, Copin P, Bessmer G, Tschanz B, Pittet D. 1999. Routine disinfection of patients' environmental surfaces: Myth or reality? *Journal of Hospital Infection* 42:113–117.

Dunn RR, Fierer N, Henley JB, Leff JW, Menninger HL. 2013. Home life: Factors structuring the bacterial diversity found within and between homes. *PLOS ONE* 8:e64133.

Dunn S, Ozere RL. 1966. Ammonia inhalation poisoning—household variety. *Canadian Medical Association Journal* 94(8):401.

Dybendal T, Vik H, Elsayed S. 1990. Dust from carpeted and smooth floors—III. Trials on denaturation of allergenic proteins by household cleaning solutions and chemical detergents. *Annals of Occupational Hygiene* 34(2):215–229.

Emerson JB, Keady PB, Brewer TE, Clements N, Morgan EE, Awerbuch J, Miller SL, Fierer N. 2015. Impacts of flood damage on airborne bacteria and fungi in homes after the 2013 Colorado Front Range flood. *Environmental Science & Technology* 49(5):2675–2684.

Euripidou E, Murray V. 2004. Public health impacts of floods and chemical contamination. *Journal of Public Health* 26(4):376–383.

Exner M, Vacata V, Hornei B, Dietlin E, Gebel J. 2004. Household cleaning and surface disinfection: New insights and strategies. *Journal of Hospital Infection* 56:S70–S75.

Faigel HC. 1964. Hazards to health: Mixtures of household cleaning agents. *New England Journal of Medicine* 271(12):618.

FEMA (Federal Emergency Management Agency). 2014. *Homeowner's Guide to Retrofitting: Six Ways to Protect Your Home from Flooding. Third Edition.* FEMA P-312. June. Washington, D.C.: FEMA

FEMA. 2013. *Cleaning Flooded Buildings: Hurricane Sandy Recovery Fact Sheet No. 1*. FEMA DRs-4085-NY and -4086-NJ. May. Washington, D.C.: FEMA.

FEMA. 2010. *Home Builder's Guide to Coastal Construction*. FEMA P-499. December. Washington, D.C.: FEMA.

FEMA. 2009. *Protecting Manufactured Homes From Floods and Other Hazards*. FEMA P-85. November. Washington, D.C.: FEMA.

FEMA. 2008. *Flood Damage-Resistant Materials Requirements*. Technical Bulletin 2. August. Washington, D.C.: FEMA.

FEMA. 2005. *Initial Restoration for Flooded Buildings*. Hurricane Katrina Recovery Advisory. November. Washington, D.C.: FEMA.

FEMA/American Red Cross (ARC). 1992. *Repairing Your Flooded Home*. FEMA-L198/ARC 4476. August. Washington, D.C: FEMA/ARC.

Fortmann R, Ng A, Roache N, Howard E. 1999. Gas-phase and particulate emissions during application of a water-based cleaner with a hand pump sprayer. *Indoor Air 99: Proceedings of the Eighth International Conference on Indoor Air Quality and Climate, Volume 3,* 31–36. Edinburgh, Scotland, August 8–13.

Foto M, Vrijmoed LLP, Miller JD, Ruest K, Lawton M, Dales RE. 2005. Comparison of airborne ergosterol, glucan and Air-O-Cell data in relation to physical assessments of mold damage and some other parameters. *Indoor Air* 15:256–266.

Frais S, Ng YL, Gulabivala K. 2001. Some factors affecting the concentration of available chlorine in commercial sources of sodium hypochlorite. *International Endodontic Journal* 34(3):206–215.

Frank JF, Chmielewski RA. 1997. Effectiveness of sanitation with quaternary ammonium compound or chlorine on stainless steel and other domestic food-preparation surfaces. *Journal of Food Protection* 60(1):43–47.

Gapany-Gapanavicius M, Molho M, Tirosh M. 1982a. Chloramine-induced pneumonitis from mixing household cleaning agents. *British Medical Journal* 285(6348):1086.

Gapany-Gapanavicius M, Yellin A, Almog S, Tirosh M. 1982b. Pneumomediastinum: A complication from mixing household cleaning agents. *Journal of the American Medical Association* 248:349–350.

Garrison RA, Robertson LD, Koehn RD, Wynn SR. 1993. Effect of heating-ventilation-air conditioning system sanitation on airborne fungal populations in residential environments. *Annals of Allergy, Asthma, and Immunology* 71(6):548–556.

Gibson WB, Keller PR, Foltz DJ, Harvey GJ. 1991. Diethylene glycol mono butyl ether concentrations in room air from application of cleaner formulations to hard surfaces. *Journal of Exposure Analysis and Environmental Epidemiology* 1:369–383.

Gibson H, Taylor JH, Hall KE, Holah JT. 1999. Effectiveness of cleaning techniques used in the food industry in terms of the removal of bacterial biofilms. *Journal of Applied Microbiology* 87:41–48.

Gorguner M, Aslan S, Inandi T, Cakir Z. 2004. Reactive airways dysfunction syndrome in housewives due to a bleach-hydrochloric acid mixture. *Inhalation Toxicology* 16(2):87–91.

Górny RL, Reponen T, Grinshpun SA, Willeke K. 2001. Source strength of fungal spore aerosolization from moldy building material. *Atmospheric Environment* 35:4853–4862.

Gots RE, Layton NJ, Pirages SW. 2003. Indoor health: Background levels of fungi. *AIHA Journal* 64:427–438.

Green BJ, Schmechel D, Summerbell R. 2011. Aerosolized fungal fragments. In: *Fundamentals of Mold Growth in Indoor Environments and Strategies for Healthy Living*, Adan OCG, Samson RA (eds.), pp. 211–243. The Netherlands: Academic Publishers.

Green JL. 2014. Can bioinformed design promote healthy indoor ecosystems? *Indoor Air* 24:113–115.

Hancox LR, LeBon M, Dodd CER, Mellits KH. 2013. Inclusion of detergent in a cleaning regime and effect on microbial load in livestock housing. *Veterinary Record* 173(7):167.

Harley EH, Collins MD. 1997. Liquid household bleach ingestion in children: A retrospective review. *Laryngoscope* 107(1):122–125.

He C, Salonen H, Xuan L, Crilley L, Jayasundara N, Cheung HC, Hargreaves M, Huygens F, Knibbs LD, Ayoko GA, Morawska L. 2014. The impact of flood and post-flood cleaning on airborne microbiological and particle contamination in residential houses. *Environment International* 69:9–17.

Henneberger PK, Derk SJ, Davis L, Tumpowsky C, Reilly MJ, Rosenman KD, Schill DP, Valiante D, Flattery J, Harrison R, Reinisch F, Filios, MS, Tift B. 2003. Work-related reactive airways dysfunction syndrome cases from surveillance in selected U.S. states. *Journal of Occupational and Environmental Hygiene* 45(4):360–368.

Hughson GW, Aitken RJ. 2004. Determination of dermal exposures during mixing, spraying and wiping activities. *Annals of Occupational Hygiene* 48(3):245–255.

IICRC (Institute of Inspection Cleaning and Restoration Certification). 2015. *CRC S500 Standard and Reference Guide for Professional Water Damage Restoration. Fourth Edition*. Vancouver, WA: IICRC.

IOM (Institute of Medicine of the National Academies). 2004. *Damp Indoor Spaces and Health*. IOM Committee on Damp Indoor Spaces and Board on Health Promotion and Disease Prevention. Washington, D.C.: The National Academies Press.

Jaakkola JJ, Piipari R, Jaakkola MS. 2003. Occupation and asthma: A population-based incident case-control study. *American Journal of Epidemiology* 158:981–987.

Jean J, Vachon JF, Moroni O, Darveau A, Kukavica-Ibrulj I, Fliss I. 2003. Effectiveness of commercial disinfectants for inactivating hepatitis A virus on agri-food surfaces. *Journal of Food Protection* 66(1):115–119.

Jones FL. 1972. Chlorine poisoning from mixing household cleaners. *Journal of the American Medical Association* 222(10):1312.

Karande S, Bhatt M, Kelkar A, Kulkarni M, De A, Varaiya A. 2003. An observational study to detect leptospirosis in Mumbai, India, 2000. *Archives of Disease in Childhood* 88(12):1070–1075.

Karjalainen A, Martikainen R, Karjalainen J, Klaukka T, Kurppa K. 2002. Excess incidence of asthma among Finnish cleaners employed in different industries. *European Respiratory Journal* 19:90–95.

Kateruttanakul P, Paovilai W, Kongsaengdao S, Bunnag S, Atipornwanich K, Siriwatanakul N. 2005. Respiratory complication of tsunami victims in Phuket and Phang-Nga. *Journal of the Medical Association of Thailand* 88(6):754–758.

Kelley ST, Gilbert JA. 2013. Studying the microbiology of the indoor environment. *Genome Biology* 14:202.

Kembel SW, Jones E, Kline J, Northcutt D, Stenson J, Womack AM, Bohannan BJ, Brown GZ, Green JL. 2012. Architectural design influences the diversity and structure of the built environment microbiome. *The ISME Journal* 6:1469–1479.

Kembel SW, Meadow JF, O'Connor TK, Mhuireach G, Northcutt D, Kline J, Moriyama M, Brown GZ, Bohannan BJM, Green JL. 2014. Architectural design drives the biogeography of indoor bacterial communities. *PLOS ONE* 9:e87093.

Knowles J, Roller S. 2001. Efficacy of chitosan, carvacrol, and a hydrogen peroxide-based biocide against foodborne microorganisms in suspension and adhered to stainless steel. *Journal of Food Protection* 64(10):1542–1548.

Kogevinas M, Antó JM, Sunyer J, Tobias A, Kromhout H, Burney P, European Community Respiratory Health Survey Study Group. 1999. Occupational asthma in Europe and other industrialized areas: A population-based study. *Lancet* 353:1750–1754.

Konya T, Scott JA. 2014. Recent advances in the microbiology of the built environment. *Current Sustainable/Renewable Energy Reports* 1:35–42.

Kovacs DC, Small MJ, Davidson CI, Fischoff B. 1997. Behavioral factors affecting exposure potential for household cleaning products. *Journal of Exposure Analysis and Environmental Epidemiology* 7(4):505–520.

Krause M, Geer W, Swenson, Fallah P, Robbins C. 2006. Control study of mold growth and cleaning procedure on treated and untreated wet gypsum wallboard in an indoor environment. *Journal of Occupational and Environmental Hygiene* 3:435–441.

Krauter P, Biermann A. 2007. Reaerosolization of fluidized spores in ventilation systems. *Applied and Environmental Microbiology* 73:2165–2172.

Kreiss K, Gonzalez MG, Conright KL, Scheere AR. 1982. Respiratory irritation due to carpet shampoo: Two outbreaks. *Environment International* 8:337–341.

Kusumaningrum HD, Paltinaite R, Koomen AJ, Hazeleger WC, Rombouts FM, Beumer RR. 2003. Tolerance of *Salmonella enteritidis* and *Staphylococcus aureus* to surface cleaning and household bleach. *Journal of Food Protection* 66(12):2289–2295.

Lambert H, Manuel J, Gabrion I. 2000. Poisoning by household products. *La Revue du Praticien* 50(4):365–371.

Lamireau T, Llanas B, Deprez C, el Hammar F, Vergnes P, Demarquez JL, Favarel-Garrigues JC. 1997. Severity of ingestion of caustic substances in children. *Archives de Pédiatrie* 4(6):529–534.

Lamond JE, Joseph RD, Proverbs DG. 2015. An exploration of factors affecting the long term psychological impact and deterioration of mental health in flooded households. *Environmental Research* 140:325–334.

Landau GD, Saunders WH. 1964. The effect of chlorine bleach on the esophagus. *Archives of Otolaryngology* 80:174–176.

Lax S, Nagler CR, Gilbert JA. 2015. Our interface with the built environment: Immunity and the indoor microbiota. *Trends in Immunology* 36:121–123.

Lax S, Smith DP, Hampton-Marcell J, Owens SM, Handley KM, Scott NM, Gibbons SM, Larsen P, Shogan BD, Weiss S, Metcalf JL, Ursell LK, Vazquez-Baeza Y, Van Treuren W, Hasan NA, Gibson MK, Colwell R, Dantas G, Knight R, Gilbert JA. 2014. Longitudinal analysis of microbial interaction between humans and the indoor environment. *Science* 345:1048–1052.

Lee LE, Fonseca V, Brett KM, Sanchez J, Mullen RC, Quenemoen LE, Groseclose SL, Hopkins RS. 1993. Active morbidity surveillance after Hurricane Andrew—Florida, 1992. *Journal of the American Medical Association* 270(5):591–594.

Levy SB. 1998. The challenge of antibiotic resistance. *Scientific American* March:46–53.

Li TH, Turpin BJ, Shields HC, Weschler CJ. 2002. Indoor hydrogen peroxide derived from ozone/d–limonene reactions. *Environmental Science & Technology* 36:3295–3302.

Lynch RM. 2000. Modeling of exposure to carpet-cleaning chemicals preceding irritant-induced asthma in one patient. *Environmental Health Perspectives* 108:911–913.

Macher JM, Tsaim FC, Burton LE, Liu K-S, Waldman JM. 2001. Prevalence of culturable airborne fungi in 100 U.S. office buildings in the Building Assessment Survey and Evaluation (BASE) study. 2001. *Proceedings of the American Society of Heating, Refrigerating and Air-Conditioning Engineers 2001 Indoor Air Quality Conference: Moisture, Microbes and Health Effects: Indoor Air Quality and Moisture in Buildings*, San Francisco, California, November 4–7.

Mafu AA, Roy D, Goulet J, Savoie L, Roy R. 1990. Efficiency of sanitizing agents for destroying Listeria monocytogenes on contaminated surfaces. *Journal of Dairy Science* 73(12):3428–3432.

Maki DG, Alverado CJ, Hassemer CA, Zilz MA. 1982. Relation of the inanimate hospital environment to endemic nosocomial infection. *New England Journal of Medicine* 307:1562–1566.

Mallin MA, Posey MH, McIver MR, Parsons DC, Ensign SH, Alphin TD. 2002. Impacts and recovery from multiple hurricanes in a Piedmont-coastal river system. *Bioscience* 52(11):999–1010.

Martinez JA, Ruthazer R, Hansjosten K, Barefoot L, Snydman DR. 2003. Role of environmental contamination as a risk factor for acquisition of vancomycin-resistant enterococci in patients treated in a medical intensive care unit. *Archives of Internal Medicine* 163(16):1905–1912.

Martyny JW, Jarbeck RJ, Pacheco K, Barker EA, Sills M, Silveira L, Arbuckle S, Newman L. 2005. Aerosolized sodium hypochlorite inhibits viability and allergenicity of mold on building materials. *Journal of Allergy and Clinical Immunology* 116(3):630–635.

Matsui E, Kagey-Sobotka A, Chichester K, Eggleston PA. 2003. Allergic potency of recombinant Fel d 1 is reduced by low concentrations of chlorine bleach. *Journal of Allergy and Clinical Immunology* 111(2):396–401.

McGuigan MA. Common culprits in childhood poisoning: Epidemiology, treatment and parental advice. 1999. *Paediatric Drugs* 1(4):313–324.

McMurry LM, Oethinger M, Levy SB. 1998. Overexpression of *marA, soxS, or acrAB* produces resistance to triclosan in laboratory and clinical strains of *Escherichia coli*. *FEMS Microbiology Letters* 166:305–309.

Meadow JF, Altrichter AE, Kembel SW, Kline J, Mhuireach G, Moriyama M, Northcutt D, O'Connor TK, Womack AM, Brown GZ, Green JL, Bohannan BJM. 2014a. Indoor airborne bacterial communities are influenced by ventilation, occupancy, and outdoor air source. *Indoor Air* 24(1):41–48.

Meadow JF, Altrichter AE, Kembel SW, Moriyama M, O'Connor TK, Womack AM, Brown GZ, Green JL, Bohannan BJM. 2014b. Bacterial communities on classroom surfaces vary with human contact. *Microbiome* 2(1):7.

Medina-Ramón M, Zock JP, Kogevinas, M, Sunyer J, Antó JM. 2003. Asthma symptoms in women employed in domestic cleaning: A community based study. *Thorax* 58(11):950–954.

Medina-Ramón M, Zock JP, Kogevinas M, Sunyer J, Basagaña X, Schwartz J, Burge PS, Moore V, Antó JM. 2006. Short-term respiratory effects of cleaning exposures in female domestic cleaners. *European Respiratory Journal* 27:1196–1203.

Medina-Ramón M, Zock JP, Kogevinas, M, Sunyer J, Torralba Y, Borrell A, Burgos F, Antó JM. 2005. Asthma, chronic bronchitis, and exposure to irritant agents in occupational domestic cleaning: A nested case-control study. *Occupational and Environmental Medicine* 2(9):598–606.

Mendonça EMC, Algranti E, de Freitas JBP, Rosa EA, dos Santos Freire JA, de Paula Santos U, Pinto J, Bussacos MA. 2003. Occupational asthma in the city of São Paulo, 1995–2000, with special reference to gender analysis. *American Journal of Industrial Medicine* 43(6):611–617.

Miettinen IT, Zacheus O, von Bonsdorff CH, Vartiainen T. 2001. Waterborne epidemics in Finland in 1998–1999. *Water Science and Technology* 43(12):67–71.

Miller JD, McMullin DR. 2014. Fungal secondary metabolites as harmful indoor air contaminants: 10 years on. *Applied Microbiology and Biotechnology* 98(24):9953–9966.

Moken MC, McMurry LM, Levy SB. 1997. Selection of multiple-antibiotic-resistant (*mar*) mutants of *Escherichia coli* by using disinfectant pine oil: Roles of the *mar* and *acrAB* loci. *Antimicrobial Agents and Chemotherapy* 41:2770–2772.

Mowry JB, Spyker DA, Brooks DE, McMillan N, Schauben JL. 2015. 2014 Annual Report of the American Association of Poison Control Centers' National Poison Data System (NPDS): 32nd Annual Report. *Clinical Toxicology* 53(10):962–1146.

Mrvos R, Dean BS, Krenzelok EP. 1993. Home exposures to chlorine/chloramine gas: Review of 216 cases. *Southern Medical Journal* 86(6):654–657.

Murphy DMF, Fairman RP, Lapp NL, Morgan WKC. 1976. Severe airway disease due to inhalation of fumes from cleansing agents. *Chest* 69:372–376.

NADCA (National Air Duct Cleaners Association). 2006. *Standard ACR 2006: Assessment, Cleaning, and Restoration of HVAC Systems*. Washington, D.C.: NADCA.

NIOSH (National Institute for Occupational Safety and Health). 2010. "Recommendations for the Cleaning and Remediation of Flood Contaminated HVAC Systems: A Guide for Building Owners and Managers." Last updated June 18. www.cdc.gov/niosh/topics/emres/cleaning-flood-hvac.html

Nazaroff WW, Coleman BK, Destaillats H, Hodgson AT, Liu D, Lunden MM, Singer BC, Weschler CJ. 2006. *Indoor Air Chemistry: Cleaning Agents, Ozone and Toxic Air Contaminants*. Final Report Contract 01-336. Sacramento, CA: California Air Resources Board.

Nielsen J, Bach E. 1999. Work-related eye symptoms and respiratory symptoms in female cleaners. *Occupational Medicine* 49(5):291–297.

Olson W, Vesley D, Bode M, Dubbel P, Bauer T. 1994. Hard surface cleaning performance of six alternative household cleaners under laboratory conditions. *Journal of Environmental Health* 56(6):27–31.

Pardue JH, Moe WM, McInnis D, Thibodeaux LJ, Valsaraj KT, MacIasz E, Van Heerden I, Korevec N, Yuan QZ. 2005. Chemical and microbiological parameters in New Orleans floodwater following Hurricane Katrina. *Environmental Science & Technology* 39(22):8591–8599.

Paredes-Osado JR, Gras-Albert JR, Crespo-Marco C, Mira-Navarro J. 1993. Our experience with caustic substance ingestion in children. *Acta Otorrinolaringológica Española* 44(2):101–105.

Park H, Hung YC, Kim C. 2002. Effectiveness of electrolyzed water as a sanitizer for treating different surfaces. *Journal of Food Protection* 65(8):1276–1280.

Pascuzzi TA, Storrow AB. 1998. Mass casualties from acute inhalation of chloramine gas. *Military Medicine* 163(2):102–103.

Paton S, Thompson KA, Parks SR, Bennett AM. 2015. Reaerosolization of spores from flooring surfaces to assess the risk of dissemination and transmission of infections. *Applied and Environmental Microbiology* 81:4914–4919.

Peng J, Tsai W, Chou C. 2002. Inactivation and removal of *Bacillus cereus* by sanitizer and detergent. *International Journal of Food Microbiology* 77:11–18.

Preller L, Doekes G, Heederik D, Vermeulen R, Vogelzang PF, Boleij JS. 1996. Disinfectant use as a risk factor for atopic sensitization and symptoms consistent with asthma: An epidemiological study. *European Respiratory Journal* 9:1407–1413.

Price DL, Ahearn DG. 1999. Sanitation of wallboard colonized with *Stachybotrys chartarum*. *Current Microbiology* 39(1):21–26.

Pronk A, Yu F, Vlaanderen J, Tielemans E, Preller L, Bobeldijk I, Deddens JA, Latza U, Baur X, Heederik D. 2006. Dermal, inhalation, and internal exposure to 1,6-HDI and its oligomers in car body repair shop workers and industrial spray painters. *Occupational and Environmental Medicine* 63(9):624–631.

Purohit A, Kopferschmitt-Kubler MC, Moreau C, Popin E, Blaumeiser M, Pauli G. 2000. Quaternary ammonium compounds and occupational asthma. *International Archives of Occupational and Environmental Health* 73:423–427.

Quinn B, Baker R, Pratt J. 1994. Hurricane Andrew and a pediatric emergency department. *Annals of Emergency Medicine* 23(4):737–741.

Racioppi F, Daskaleros PA, Besbelli N, Borges A, Deraemaeker C, Magalini SI, Martinez Arrieta R, Pulce C, Ruggerone ML, Vlachos P. 1994. Household bleaches based on sodium hypochlorite: Review of acute toxicology and poison control center experience. *Food and Chemical Toxicology* 32(9):845–861.

Reisz GR, Gammon RS. 1986. Toxic pneumonitis from mixing household cleaners. *Chest* 89(1):49–52.

Reponen T, Seo S, Grimsley F, Lee T, Crawford C, Grinshpun S. 2007. Fungal fragments in moldy houses: A field study in homes in New Orleans and Southern Ohio. *Atmospheric Environment* 41:8140–8149.

Rintala H, Pitkäranta M, Täubel M. 2012. Microbial communities associated with house dust. *Advances in Applied Microbiology* 78:75–120.

Roache N, Fortmann R, Ng A, Howard E. 2000. Characterization of aerosols from a water-based cleaner applied with a hand-pump sprayer. *Engineering Solutions to Indoor Air Quality Problems: Proceedings of an International Symposium*, 356–365. Research Triangle Park, NC: Air & Waste Management Association.

Robinson P, Tauxe R, Winkler W, Levy M. 1983. Respiratory illness in conference participants following exposure to rug shampoo. *Infection Control* 4:158–160.

Rosenman KD, Reilly MJ, Schill DP, Flattery J, Harrison R, Reinisch F, Pechter E, Davis L, Tumpowsky C, Filios M. 2003. Cleaning products and work-related asthma. *Journal of Occupational and Environmental Hygiene* 45(5):556–563.

Ross MA, Curtis L, Scheff PA, Hryhorczuk DO, Ramakrishnan V, Wadden RA, Persky VW. 2000. Association of asthma symptoms and severity with indoor bioaerosols. *Allergy* 55(8):705–711.

Ross MP, Spiller HA. 1999. Fatal ingestion of sodium hypochlorite bleach with associated hypernatriemia and hyperchloremic metabolic acidosis. *Veterinary and Human Toxicology* 41(2):82–86.

Rutala WA, Cole EC, Thomann CA, Weber DJ. 1998. Stability and bactericidal activity of chlorine solutions. *Infection Control and Hospital Epidemiology* 19(5):323–327.

Rutala WA, Gergen MF, Weber DJ. 2012. Efficacy of different cleaning and disinfection methods against *Clostridium difficile* spores: Importance of physical removal versus sporicidal inactivation. *Infection Control and Hospital Epidemiology* 33(12):1255–1258.

Rutala WA, Weber DJ. 2001. Surface disinfection: Should we do it? *Journal of Hospital Infection* 48(Suppl A):S64–S68.

Rutala WA, Weber DJ. 1997. Uses of inorganic hypochlorite (bleach) in health-care facilities. *Clinical Microbiology Reviews* 10(4):597–610.

Savonius B, Keskinen H, Tuppurainen M, Kanerva L. 1994. Occupational asthma caused by ethanolamines. *Allergy* 49:877–881.

Scott EA, Bloomfield SF. 1993. An in-use study of the relationship between bacterial contamination of food preparation surfaces and cleaning cloths. *Letters in Applied Microbiology* 16:173–177.

Shendell DG, Macher JM, Tsai TC, Burton L. 2005. Airborne bacteria and fungi in 100 large U.S. office buildings. In: *Proceedings of the Fifth International Conference of Bioaerosols, Fungi, Bacteria, Mycotoxins and Human Health*, 492–497. Saratoga Springs, NY: Fungal Research Group Foundation.

Shepherd JL, Corsi RL, Kemp J. 1996. Chloroform in indoor air and wastewater: The role of residential washing machines. *Journal of the Air & Waste Management Association* 46:631–642.

Sherriff A, Farrow A, Golding J, ALSPAC Study Team, Henderson J. 2005. Frequent use of chemical household products is associated with persistent wheezing in pre-school age children. *Thorax* 60:45–49.

Sivasubramani SK, Niemeier RT, Reponen T, Grinshpun SA. 2004. Assessment of the aerosolization potential for fungal spores in moldy homes. *Indoor Air* 14:405–412.

Smith DL, Gillanders S, Holah JT, Gush C. 2011. Assessing the efficacy of different microfibre cloths at removing surface micro-organisms associated with healthcare-associated infections. *Journal of Hospital Infection* 78(3):182–186.

Snyder OP Jr. 1999. *The Reduction of* E. coli *on Various Countertop Surfaces*. March 22. St. Paul, MN: Hospitality Institute of Technology and Management.

Snyder OP Jr. 1997. *The Microbiology of Cleaning and Sanitizing a Cutting Board*. St. Paul, MN: Hospitality Institute of Technology and Management.

Solomon GM, Hjelmroos-Koski M, Rotkin-Ellman M, Hammond SK. 2006. Airborne mold and endotoxin concentrations in New Orleans, Louisiana, after flooding, October through November 2005. *Environmental Health Perspectives* 114(9):1381–1386.

Steiber RS. 1995. Increases in levels of breathable fine particulates due to the application of carpet fresheners in a suburban home. *Proceedings of the Engineering Solutions to Indoor Air Quality Problems Symposium*, 29–38. Research Triangle Park, NC: Air & Waste Management Association.

Straub TM, Pepper IL, Gerba CP. 1993. Hazards from pathogenic microorganisms in land-disposed sewage sludge. *Reviews of Environmental Contamination and Toxicology* 132:55–91.

Sullivent EE 3rd, West CA, Noe RS, Thomas KE, Wallace LJ, Leeb RT. 2006. Nonfatal injuries following Hurricane Katrina—New Orleans, Louisiana, 2005. *Journal of Safety Research* 37(2):213–217.

Tanen DA. 1999. Severe lung injury after exposure to chloramine gas from household cleaners. *New England Journal of Medicine* 341(11):848–849.

Tanner BD. 2009. Reduction in infection risk through treatment of microbially contaminated surfaces with a novel, portable, saturated steam vapor disinfection system. *American Journal of Infection Control* 37(1):20–27.

Tanyel FC, Buyukpamukcu N, Hicsonmez A. 1988. Chlorine bleach ingestion in children: A review of 80 cases. *The Turkish Journal of Pediatrics* 30(2):105–108.

Ten-Brinke J, Selvin S, Hodgson AT, Fisk WJ, Mendell MJ, Koshland CP, Daisey JM. 1998. Development of new volatile organic compound (VOC) exposure metrics and their relationship to sick building syndrome symptoms. *Indoor Air* 8:140–152.

Todd B. 2006. Infection control and Hurricane Katrina. *American Journal of Nursing* 106(3):29–31.

Trachoo N, Frank JF. 2002. Effectiveness of chemical sanitizers against *Campylobacter jejuni*-containing biofilms. *Journal of Food Protection* 65(7):1117–1121.

USEPA (U.S. Environmental Protection Agency). 2016. *Climate Change Indicators in the United States, 2016. Fourth Edition*. EPA-430-R-16-004. August. Washington, D.C.: EPA.

USEPA. 2013. *Moisture Control Guidance for Building Design, Construction and Maintenance.* EPA-402-F-13-053. December. Washington, D.C.: EPA.

Van Rhee F, Beaumont DM. 1990. Gastric stricture complicating oral ingestion of bleach. *British Journal of Clinical Practice* 44(12):681–682.

Vejrup KV, Wolkoff P. 2002. Linear alkylbenzene sulfonates in indoor floor dust. *Science of the Total Environment* 300:51–58.

Wade TJ, Sandhu SK, Levy D, Lee S, LeChevallier MW, Katz L, Colford JM Jr. 2004. Did a severe flood in the Midwest cause an increase in the incidence of gastrointestinal symptoms? *American Journal of Epidemiology* 159(4):398–405.

Wainman T, Zhang JF, Weschler CJ, Lioy PJ. 2000. Ozone and limonene in indoor air: A source of submicron particle exposure. *Environmental Health Perspectives* 108(12):1139–1145.

Ward MJ, Routledge PA. 1988. Hypernatraemia and hyperchloraemic acidosis after bleach ingestion. *Human Toxicology* 7(1):37–38.

Waring SC, Reynolds KM, D’Souza G, Arafat RR. 2002. Rapid assessment of household needs in the Houston area after Tropical Storm Allison. *Disaster Management and Response* September:3–9.

Wason S. 1985. The emergency management of caustic ingestions. *Journal of Emergency Medicine* 2(3):175–182.

Webb AM, Singer BC, Nazaroff WW. 2002. Effect of gaseous ammonia on nicotine sorption. *Indoor Air 2002: Proceedings of the Ninth International Conference on Indoor Air Quality and Climate, Volume 3*, 512–517. Monterey, CA, June 30–July 5.

Weber DJ, Barbee SL, Sobsey MD, Rutala WA. 1999. The effect of blood on the antiviral activity of sodium hypochlorite, a phenolic, and a quaternary ammonium compound. *Infection Control and Hospital Epidemiology* 20(12):821–827.

Weegels MF, van Veen MP. 2001. Variation of consumer contact with household products: A preliminary investigation. *Risk Analysis* 21(3):499–511.

Weeks RS, Ravitch MM. 1971. The pathology of experimental injury to the cat esophagus by liquid chlorine bleach. *Laryngoscope* 81(9):1532–1541.

Weeks RS, Ravitch MM. 1969. Esophageal injury by liquid chlorine bleach: Experimental study. *Journal of Pediatrics* 74(6):911–916.

Weschler CJ, Shields HC. 1999. Indoor ozone/terpene reactions as a source of indoor particles. *Atmospheric Environment* 33:2301–2312.

Weschler CJ, Shields HC. 1997. Measurements of the hydroxyl radical in a manipulated but realistic indoor environment. *Environmental Science & Technology* 31(12):3719–3722.

White LF, Dancer SJ, Robertson C. 2007. A microbiological evaluation of hospital cleaning methods. *International Journal of Environmental Health Research* 17(4):285–295.

Wilson SC, Brasel TL, Carriker CG, Fortenberry GD, Fogle MR, Martin JM, Wu C, Andriychuk LA, Karunasena E, Straus DC. 2004. An investigation into techniques for cleaning mold-contaminated home contents. *Journal of Occupational and Environmental Hygiene* 1(7):442–447.

Wolkoff P, Clausen PA, Nielsen PA. 1995. Application of the field and laboratory emission cell "FLEC"—Performance study, intercomparison study, and case study of damaged linoleum in an office. *Indoor Air* 5(3):196–203.

Wolkoff P, Schneider T, Kildeso J, Degerth R, Jaroszewski M, Schunk H. 1998. Risk in cleaning: Chemical and physical exposure. *Science of the Total Environment* 215(1–2):135–156.

Wood CL, Tanner BD, Dennis JS, Luempert LG. 2014. Effectiveness of a steam cleaning unit for disinfection in a veterinary hospital. *American Journal of Veterinary Research* 75(12):1083–1088.

WHO (World Health Organization). 2016. Flooding and communicable diseases fact sheet. Last accessed December 10. www.who.int/hac/techguidance/ems/flood_cds/en/index1.html.

Zhu J, Cao XL, Beauchamp R. 2001. Determination of 2–butoxyethanol emissions from selected consumer products and its application in assessment of inhalation exposure associated with cleaning tasks. *Environment International* 26:589–597.

Zock J, Kogevinas M, Sunyer J, Almar E, Muniozguren N, Payo F, Sanchez JL, Anto JM. 2001. Asthma risk. Cleaning activities and use of specific cleaning products among Spanish indoor cleaners. *Scandinavian Journal of Work, Environment, and Health* 27(1):76–81.

Zock J, Plana E, Jarvis D, Antó JM, Kromhout H, Kennedy SM, Künzli N, Villani S, Olivieri M, Torén K, Radon K, Sunyer J, Dahlman-Hoglund A, Norbäck D, Kogevinas M. 2007. Use of household cleaning sprays and adult asthma. *American Journal of Respiratory and Critical Care Medicine* 176(8):735–741.