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

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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

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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.

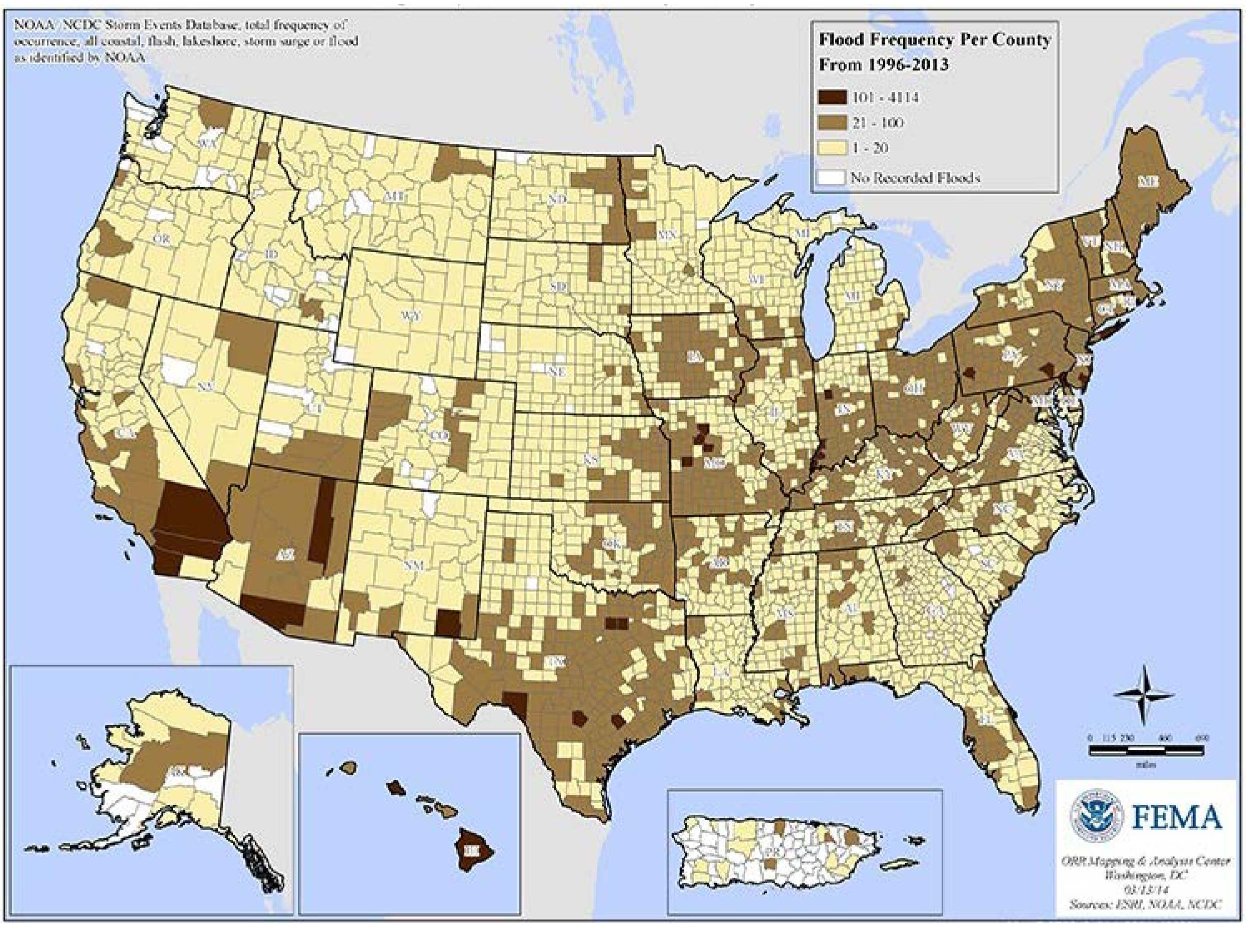

Figure 1. Frequency of flood events by U.S. county: 1996–2013.
Source: USEPA 2016.

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.

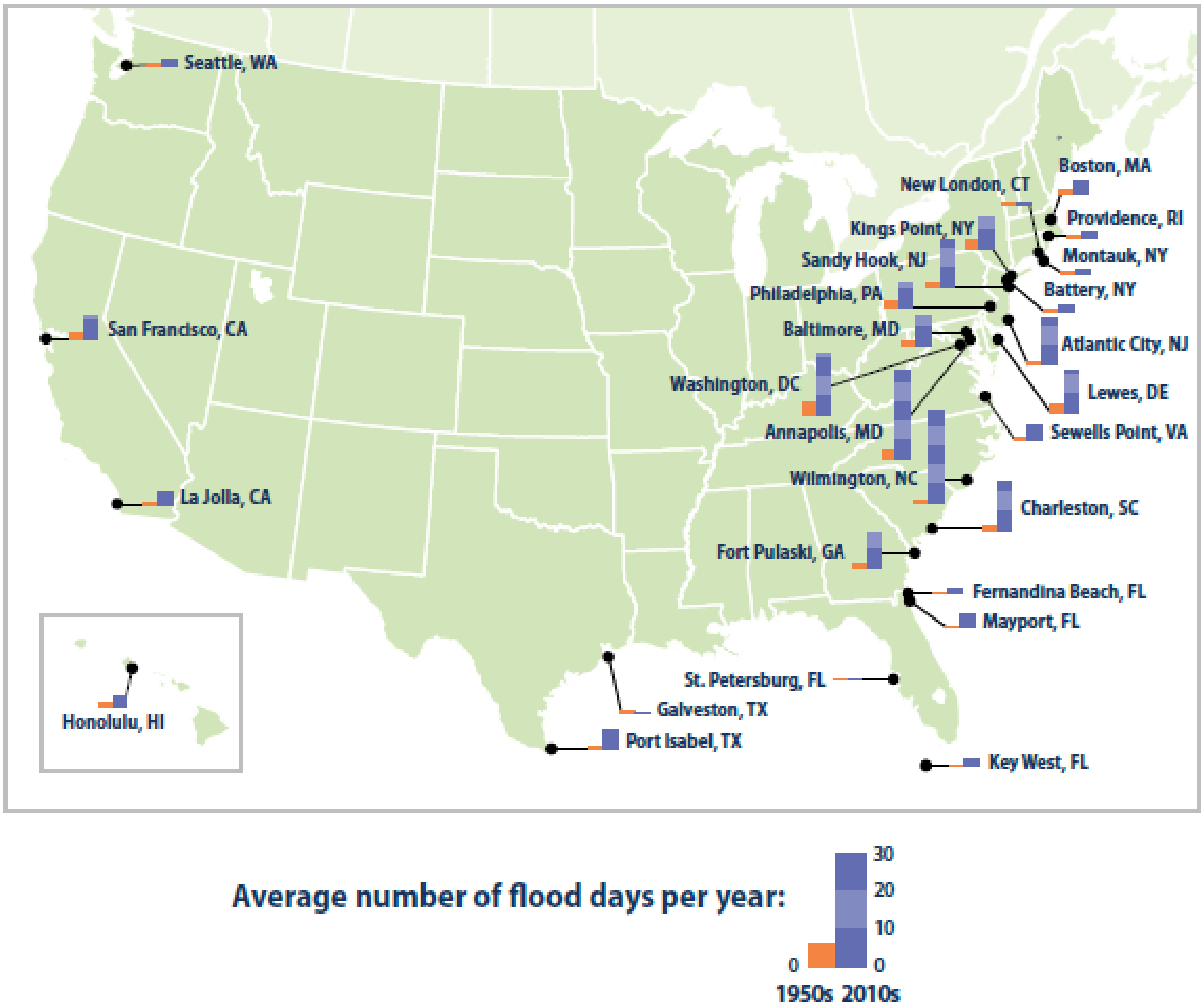

Figure 2. Frequency of flooding along U.S. coasts, 2010–2015 vs. 1950–1959. *This map shows the average number of days per year in which coastal waters rose above the local threshold for minor flooding at 27 sites along U.S. coasts. Each small bar graph compares the first decade of widespread measurements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

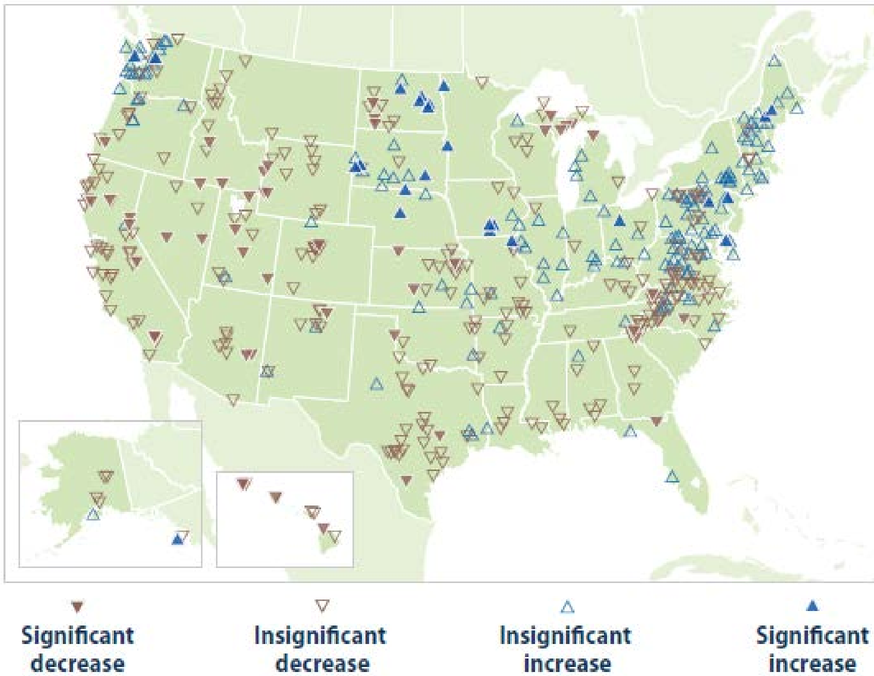

Figure 3. Change in the frequency of river flooding in the United States, 1965–2015. *The frequency of river flooding in the United States has increased in areas marked by upward-pointing blue triangles and decreased in areas marked by downward-pointing brown triangles.*
Source: USEPA 2016.

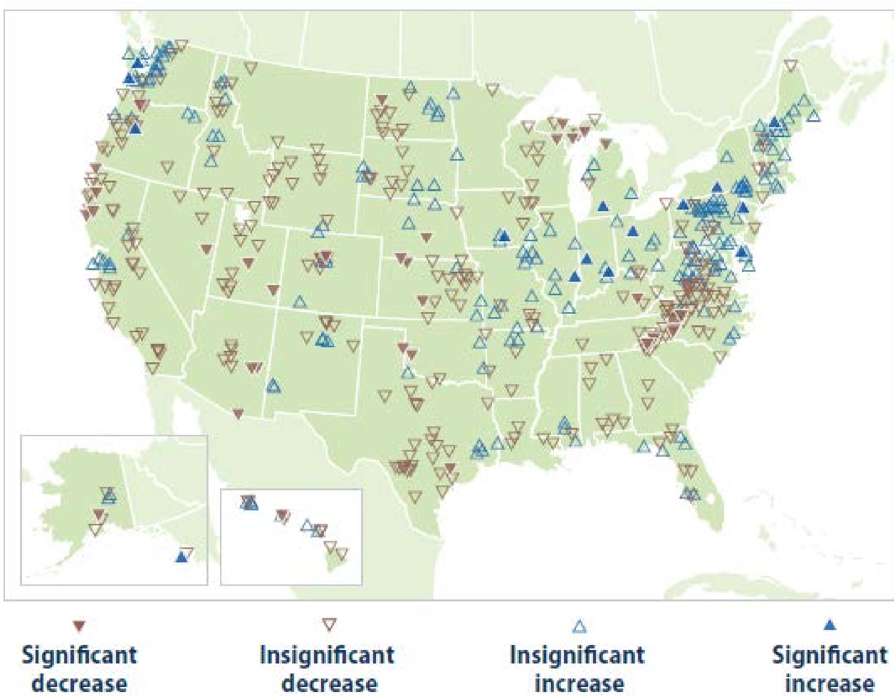

Figure 4. Change in the magnitude of river flooding in the United States, 1965–2015. *The magnitude of river flooding in the United States has increased in areas marked by upward-pointing blue triangles and decreased in areas marked by downward-pointing brown triangles.*
Source: USEPA 2016.

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

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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.

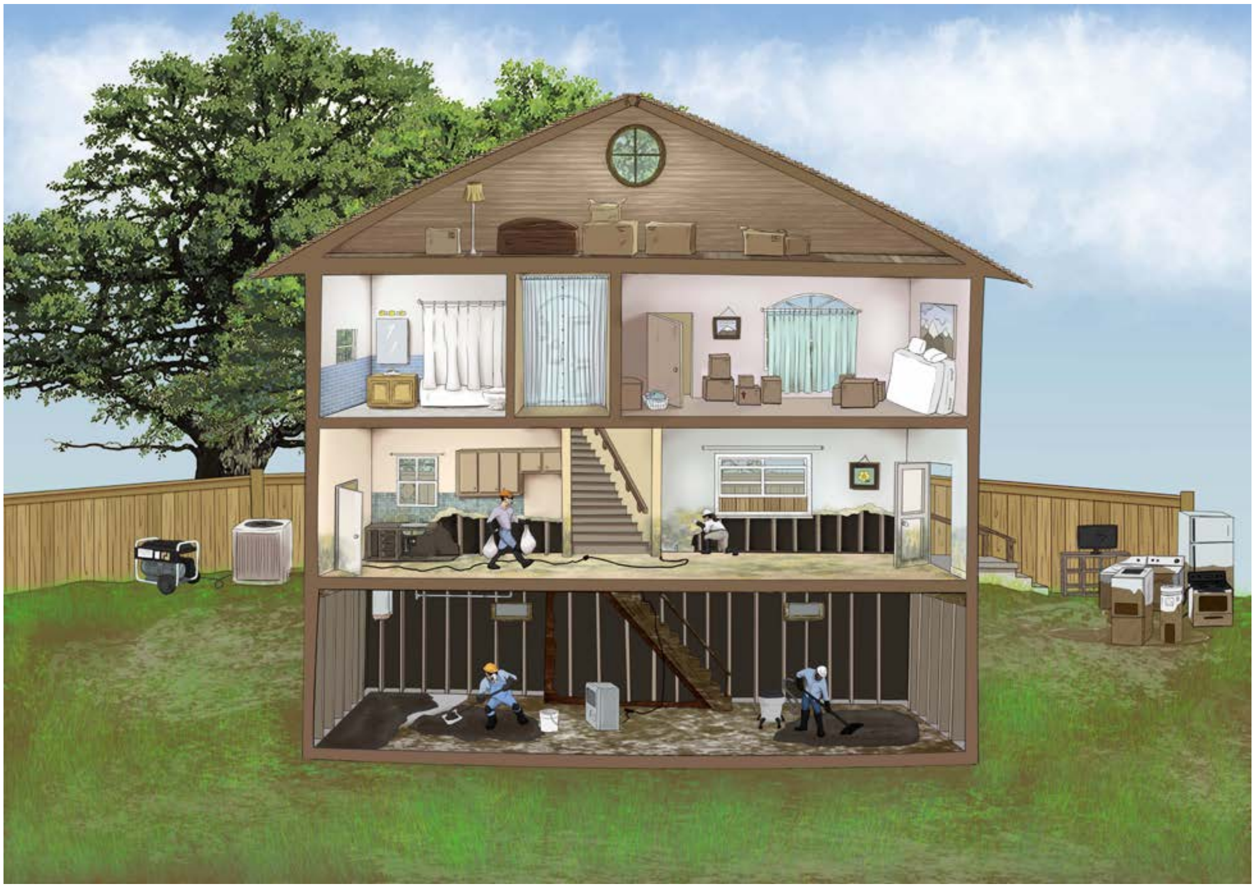
The health and safety plan should include:

- 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).



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

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.

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:
  - o HEPA vacuuming or vacuums that directly exhaust to outdoors.
  - o 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 unique code for this document is 294108

- 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.