Adverse Health Effects Associated with the Indoor Air Quality of Flood-Damaged Structures

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Kimberly A. Hoppe Parr, PhD.
GZA GeoEnvironmental, Inc.
Understanding and Communicating the Health Effects Associated with Indoor Air Quality of Flood-Damaged Structures

- **Health effects**
  - Components impacting Indoor Air Quality (IAQ) of flood-damaged buildings
  - Associated adverse health effects

- **Communication**
  - Public outreach
  - Recommendations on re-entry
Potential Hazardous Materials Associated with Flood Waters and Damaged Building Materials

- **Chemicals**
  - Businesses, industry, agriculture, storage tanks, and household
  - Cars, trucks, and other motorized vehicles

- **Sewage**

- **Debris**
  - Damaged Building Material
    - Asbestos
    - Lead

- **Carbon monoxide**
  - Unventilated equipment used during remediation (e.g. generators)

- **Bioaersols**
Bioaerosols

• Flooding is known to negatively impact indoor air quality by providing a nutrient-rich and moist habitat for microbial organisms to flourish

• Microbial Contaminants
  ❖ Bacteria
    • Endotoxin
  ❖ Fungi/ mold
    • Fungal spores
    • $(1\rightarrow 3)$-β-d-glucan
    • mycotoxins
Bacteria

- Small, single-celled organisms without a nucleus; many required for life, while many are disease-causing
  - Legionnaire’s Disease: Legionella
  - Anthrax: Bacillus anthracis

- Microbial Volatile Organic Compounds (mVOCs)
  - By-products of microbial metabolism
  - Low odor thresholds

- Endotoxin
Bacterial Toxicity: Endotoxin

- Lipopolysaccharide
- Integral component of the Gram-negative bacteria cell wall
- Shed into the environment during the growth cycle and when the bacteria die
- A recognized bacterial trigger of innate immunity and a causal agent for a variety of environmental lung diseases
  - Asthma
  - Decreased lung function
  - Chronic bronchitis
  - Organic Dust Toxic Syndrome
Fungi/Mold

• Unicellular and multicellular eukaryotic organisms

• Many species identified as causing human infections and adverse health effects.

• Need oxygen, food and water to grow and amplify

• Components
  • Life cycle: Fungal spores
  • Structural components: \((1\rightarrow 3)-\beta\)-d-glucan and chitin
  • Metabolic and defenses: mycotoxins and mVOCs
Fungi/Mold

• Require water and nutrient source to proliferate

1. Indoor Nutrient Source
   o The growing mold lives off of what it landed on, digesting the materials
   o Construction materials
     ▸ Wood
     ▸ Carpet
     ▸ Materials high in cellulose

2. Indoor Water Source:
   o Flooding
   o Humidifiers
   o Damp basements
   o Plumbing leaks
Aftermath of Hurricane Katrina

Image courtesy of P.S. Thorne
Mold – General Toxicity

Several mold species and their related components are pathogenic to humans → Inflammatory and toxic responses

1. Allergic reactions
   - Asthma
   - Allergies

2. Irritation
   - Upper Respiratory system
   - Skin
   - Mucous membranes

3. Infections
   - Aspergillosis
   - Pneumocystis pneumonia

4. Toxic responses
   - Mycotoxicosis
Mold – Mycotoxins

Toxic Mold = Toxigenic or Known to Produce Mycotoxins

<table>
<thead>
<tr>
<th>Species</th>
<th>Mycotoxin</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Aspergillus flavus</em></td>
<td>Alfatoxin</td>
</tr>
<tr>
<td><em>Penicillium crustosum</em></td>
<td>Penitrem A</td>
</tr>
<tr>
<td><em>Stachbotrys chartarum</em> (atrap)</td>
<td>Satratoxins</td>
</tr>
</tbody>
</table>

Species are associated with water-damaged and damp building materials.
Mold – Mycotoxins and mVOCs

- **Mycotoxins**
  - Associated with the potential manifestation of disease and the disease process
  - Allergen
  - Potent Cytotoxins
    - Causes cell disruption
    - Interferes with cell processes

- **Fungal mVOCs**
  - Associated with headaches, nasal irritation, fatigue
Mold – Aspergillus

- Produce the Mycotoxin Aflatoxin
  - Sinus and local infections
  - Carcinogenic
  - Causes Aspergillosis (lung disease)

- Aspergillus does not usually cause disease in healthy individuals

- Infection can be fatal in immuno-compromised individuals
Mold – *Penicillium*

- Not commonly pathogenic in healthy individuals
- Can be pathogenic in immuno-compromised and sensitive populations
  - Skin, lung and gut infections
  - Often treatable with anti-fungal remedies
Mold – Stachybotrys

- Black Mold: *Stachybotrys chartarum* (atra)

  - Indoor levels are usually low
    - Frequently grow in flood-damaged building

  - Favors building materials with high cellulose and low nitrogen content

  - Reactions can include
    - allergic rhinitis
    - skin irritation
    - sinus infection
    - pink eye
    - fatigue

Photo: https://www.epa.gov/mold/mold-remediation-schools-and-commercial-buildings-guide
Mold – Spores

- Spores (2-10 um)
- Part of the fungal life cycle
- Protective cases
  - Mold can survive in a dormant spore state during harsh conditions
- Allow the mold to spread and distribute
- Associated health effects
  - Allergies
  - Upper respiratory tract irritant

Figure: www.blackmould.me.uk/Stachybotrys
Mold – Glucan

• Fungi have rigid cell walls composed of chitin and glucans (polysaccharides)

• (1→3)β-D-glucans
  - Exposure to (1→3)β-D-glucans can result in airway inflammation and an allergic response

• Mold does not have to be alive to trigger an immune response
Mold – Pathology

- Etiology variable
- Toxicity influenced significantly by individual susceptibility
- Latency variable – acute and chronic effects
- Multiple routes of exposure
Mold – Pathology

- No standards or regulations – PEL concept
- Dose – response difficult to establish:
  - Exposure = Dosage (Dose = Concentration x Time)
  - Large variability in individual susceptibility
  - Acute v. Chronic Toxicity
  - Other
Mold – Conclusions

- Mold is ubiquitous
- Many are toxic and are associated with adverse health effects
- Water intrusion is controlling factor
- No definitive regulations
Evaluating IAQ in Flood-Damaged Structures

- Visual Inspection
- Moisture levels on building materials
- Relative humidity indoors
  - EPA recommends indoor humidity levels to be between 30-60%
- Occupant interviews
- Air Sampling
Why Evaluate IAQ after Flood? Overview

- Bacteria and mold grow optimally when moisture is present
  - Flood and storm waters entering indoor environment
  - Elevated indoor relative humidity
    - HVAC system down, damaged building envelope, etc.

- Require a nutrient source
  - Molds feed off dirt and debris left behind
  - Water logged, decaying, carbon material can be a prime habitat for mold

- High concentrations of bioaerosols have been detected inside flood-damaged homes (Chew 2006, Rao 2007, Fabian 2005, Hoppe 2012)
## IAQ: Bioaerosols in Flood-Damaged Structures

<table>
<thead>
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<tbody>
<tr>
<td></td>
<td>In-progress</td>
<td>Complete</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Culturable Bacteria (CFU/m³)</td>
<td>1300</td>
<td>790</td>
<td></td>
<td></td>
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<tr>
<td>Culturable Mold (CFU/m³)</td>
<td>420</td>
<td>180</td>
<td>22,000-515,000</td>
<td>32,700</td>
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<tr>
<td>Fungal Spores (spores/m³)</td>
<td>540</td>
<td>480</td>
<td>82,000-630,000</td>
<td>280,000</td>
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<tr>
<td>iPM (µg/m³)</td>
<td>78</td>
<td>34</td>
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<td></td>
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<tr>
<td>i Endotoxin (EU/m³)</td>
<td>1.55</td>
<td>0.3</td>
<td>17-139</td>
<td>23.3</td>
</tr>
<tr>
<td>i Glucan-linear (µg/m³)</td>
<td>0.0256</td>
<td>0.007</td>
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</tr>
<tr>
<td>i Glucan-branched (µg/m³)</td>
<td>0.0135</td>
<td>0.0034</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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1. Park et al. 2000: Massachusetts
2. Lee et al. 2000: Cincinnati
Why Evaluate IAQ after Flood?  
Health Effects

  - Inflammatory response
  - Asthma
  - Allergies
  - Develop hypersensitivities

- Organic Dust Toxic Syndrome (Schenker 1998)
  - Flu-like symptoms: malaise, headache, cough, nauseas

- Firefighters after Hurricane Katrina- ‘increased rate of developing new-onset upper respiratory symptoms’
  - sinus congestion, cough, and throat irritation (Tak 2007)

- Eye irritants
- Skin irritants
Communication & Public Outreach

• Factors contributing to increased bioaerosols
  • Duration of flood water inundation
  • High humidity - buildings cannot dry out
  • Immediacy of home owners returning and performing ‘muck and gut’
Communication & Public Outreach

• Who should/should not enter flood-damaged buildings?

Is the building structurally sound?

Disaster Recovery

After the flood: Going back home

After the floodwaters have receded, be sure it is safe to go back into your home before you set foot inside. Remember the following tips when you do go back home.

Prepare in advance

• Obey health regulations given by the Red Cross or local health department for personal and community protection. Get a tetanus shot or other vaccination if necessary.
• Call local utilities before returning to your home. They can safely turn off electricity and gas. DO NOT enter your home until these utilities have been disconnected. Otherwise, you risk electrocution or explosions. In rural areas, turn off electricity at the meter outside your home, and turn off gas at the tank.

Bring supplies with you

• Battery-powered flashlight or lantern
• Battery-powered radio
• Waterproof boots and hard-soled shoes
• Safety clothing such as goggles
• Rubber gloves
• First aid kit
• Drinking water
• Trash bags
• Cleaning supplies—water, all-purpose liquid cleaner, household bleach
• Buckets
• A camera and film to record damage
• Pen and paper to make notes for insurance claims
• A wooden stick to turn things over and to scare away snakes and small animals

Before entering your home

• Check for structural damage. Make sure your house isn’t in danger of collapsing. If you have any doubts about safety, contact a contractor before you go inside your house. If you live in town, check with the local building inspector.
• Remember that gas still may be trapped inside your home. Open windows and doors to let gas or fuel odors escape.
• To avoid causing an explosion, do not smoke, and do not use an open flame as a light source or for any other reason. Use a battery-operated flashlight or lantern.

When you’re inside your home

• List and photograph or videotape the damage to your home and possessions before you throw anything away. This will be useful for insurance claims.
• Cover broken windows and holes in the roof or walls to prevent further weather damage.
• Do not pump or drain your basement too soon. The additional pressure of saturated ground may cause basement walls to collapse. Only pump or drain about one-third of the floodwater per day.
• Do not operate gasoline-powered pumps and generators in enclosed, non-ventilated spaces. They generate poisonous fumes that can quickly overcome workers.
• Shovel out mud while it’s still moist to give walls and floors a chance to dry.

Start cleaning

• Be careful while cleaning. Mud on floors and steps is extremely slippery. Falling is a common cause of injury.
• If possible, wear rubber gloves when handling materials that have been in floodwater.

Beware of Hazards

• Check for structural damage before re-entering your home.
• Check the upper floors for flooded areas. Check for flooded basements as you go up and down stairs.
• Check for damaged furnaces. Flooded water can cause the furnace to malfunction. Even if the water is not visible in the basement, it may be present. If your furnace has been flooded, have it checked before you use it.

File your Flood Insurance Claim

• Call the insurance agent who handles your flood insurance to file a claim. Have the following information with you when you place your call:
  1. The name of your insurance company (your agent may write policies for more than one company).
  2. Your policy number.
  3. A telephone number/mark address where you can be reached.
• Take photos of any water in the house and damaged personal property. Register flood damage with the Federal Emergency Management Agency. Your insurance agent should be able to guide you through the process.
• Check with your local building department for guidelines on how to repair your home.

Clean-up

• Present mold and remove and contents immediately. Do not remove furniture, bedding, or any other items holding water in the building. Use a dehumidifier to dry affected areas.

Clean and dry your house and everything in it.

Flood Cleanup and the Air in Your Home

Use portable generators OUTSIDE and far away from the building.

Clean-up

• Present mold and remove and contents immediately. Do not remove furniture, bedding, or any other items holding water in the building. Use a dehumidifier to dry affected areas.

Flood water can make the air in your home unhealthy.

This is because when things get wet for more than 2 days they usually get moldy. There may also be germs and bugs in your home after a flood.

When cleaning wear

• Air S95 respirator (N95 or above)
• Gloves

Clean and dry hard surfaces. Throw away anything that was wet with flood water and can’t be cleaned.

EPA
For more information contact the U.S. Environmental Protection Agency (EPA) free hotline
1-800-426-4319
www.epa.gov/flood
Communication and Public Outreach

- What personal protective equipment (PPE) should be worn?

### NIOSH Interim Guidance on Personal Protective Equipment and Clothing for Flood Response Workers

The National Institute for Occupational Safety and Health (NIOSH) provides the following interim guidelines and warnings to flood cleanup workers. The hazards in flood waters are likely variable and can include sewage, household chemicals and cleaning solutions, petroleum products, hazardous industrial chemicals, pesticides, and flammable liquids. Workers must also be aware of physical hazards such as obstacles covered by flood waters (storm debris, depressions, drainage openings, ground erosion) and from displaced reptiles or other animals.

Workers and volunteers involved with flood cleanup should avoid direct skin contact with flood waters if possible and through the use of appropriate PPE and clothing. In most instances, the selection of PPE will be dependent on site-specific conditions, hazards, and tasks; the list below provides interim guidance on PPE and clothing for flood response workers responding to Hurricane Katrina:

- Electrically insulated, watertight boots with steel shank, toe, and inside. Trench shoes or sneakers should not be worn because they will transfer contamination and will prevent puncture, bite, or crush injuries. Hip waders may be appropriate to help prevent contact with flood waters;
- Heavy, waterproof, cut-resistant work gloves. Other types of protective gloves may be required if handling identified material hazards;
- Goggles, safety glasses with side shields or full face shields. Sunglasses or protective lenses may be needed in some work settings;
- Soft hat or other protective head cover. Wear an American National Standards Institute (ANSI) rated hard hat if there is any danger of falling debris or electrical hazards;
- Hearing protection when working in an environment with any noise that you must shout over to be heard;
- Comfortable, form fitting, light weight clothing including long pants and a long sleeved shirt or coveralls;
- Under some work conditions, NIOSH approved respirators may be necessary (e.g., for exposures to mold-contaminated materials/environments, or other recognized chemical, physical, or biological hazards).

Additional PPE, respiratory protection, or clothing may be required when specific exposure hazards are identified or expected at the work site. In some instances, the protective ensemble components (goggles, boots and gloves) may need to be impervious to contaminated flood or other site-specific chemical, physical, or biological hazards. Workers should be cleaned with soap and water and air-dried between uses. In all instances, workers are advised to wash their hands with soap and clean water, especially before eating or drinking. Protect any cuts or abrasions with waterproof gloves and dressings. The use of insect repellent, sunblock and lip balm may also be required for some work environments. Drink plenty of bottled water and take frequent rest breaks to avoid overheating.

### Table: Population-Specific Recommendations for Protection From Exposure to Mold in Flooded Buildings, by Specific Activity and Risk Factor

<table>
<thead>
<tr>
<th>Exposure Activity</th>
<th>None</th>
<th>Risk Factor</th>
<th>Observing from outside the demolition area (disturbs no dust)</th>
<th>Inspecting or Assessing Damage (disturbs little dust or mold)</th>
<th>Recovering moldy personal belongings (disturbs some dust or mold)</th>
<th>Sweeping, light cleaning, removing mold (disturbs much dust or mold)</th>
<th>Using power tools, cleaning, demolishing (disturbs all dust and mold)</th>
</tr>
</thead>
<tbody>
<tr>
<td>People at High Risk for Infection or Colonization</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Immunocompromiseda</td>
<td>Avoid exposure</td>
<td>Avoid exposure</td>
<td>Avoid exposure</td>
<td>Avoid exposure</td>
<td>Avoid exposure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Immunosuppressiona</td>
<td>Avoid exposure</td>
<td>Avoid exposure</td>
<td>Avoid exposure</td>
<td>Avoid exposure</td>
<td>Avoid exposure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obstructive or cavitary lung diseasea</td>
<td>Avoid exposure</td>
<td>Avoid exposure</td>
<td>Avoid exposure</td>
<td>Avoid exposure</td>
<td>Avoid exposure</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### People Who Have Diseases With Immune Sensitization

- Allergic rhinoconjunctivitis (exacerbated by moldy materials)
- Asthma (exacerbated by moldy materials)
- Hyperosensitivity pneumonitis caused by moldy materials
- Avoid exposure

### People With Unknown Risk

- Younger than 12 years | Avoid exposure | Avoid exposure | Avoid exposure | Avoid exposure | Avoid exposure |
- Pregnant | Avoid exposure | Avoid exposure | Avoid exposure | Avoid exposure | Avoid exposure |
- Older than 65 years | Avoid exposure | Avoid exposure | Avoid exposure | Avoid exposure | Avoid exposure |

Note: Everyone should avoid unnecessary exposure to mold, especially anyone at high risk for infection and anyone with a disease caused by immune sensitization to mold and mold constituents.

Important: See footnotes on next page.
Communication & Public Outreach

• Is cleaning effective?
  
  o Rapid and proper remediation is necessary to stop further mold growth
    • Mold growth can begin within 48 hours (Johanning et al. 2014)
  
  o Hoppe et al. 2012 in Cedar Rapids, Iowa
    • Homes that had Completed renovation had significantly lower concentrations of indoor bioaerosols than homes that were still under-going renovation
  
  o Study by He et al. 2014 in Brisbane, Australia
    • “This study provides quantitative evidence of the significant impact of immediate post-flood cleaning on mitigating the effects of flooding on indoor bioaerosol contamination and other pollutants.”

○ Yes, if done properly.
Practical Implications

- Water damaged building structures are associated with adverse health effects

- The number and severity of floods is on the rise and evidence-based recommendations are needed

- Proper remediation of flood-damaged homes can reduce bioaerosols to acceptable levels

- Exposures are significantly increased while remediation is in-progress leading to an increased burden of allergy and allergic rhinitis.
  - Proper PPE should be worn during renovation
  - Susceptible individuals are advised to not perform remediation
Thank you!

Kimberly A. Hoppe Parr, PhD.
Assistant Project Manager, Toxicologist
GZA GeoEnvironmental, Inc.
20900 Swenson Dr. Waukesha, WI 53186
(262)754-2584
kimberly.parr@gza.com
References

1. CDC. Mold After a Disaster. October 7, 2015 available at: http://emergency.cdc.gov/disasters/mold/