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FILTERING A NEW SOLUTION TO FEDERAL EMERGENCY MANAGEMENT THROUGH NANOTECHNOLOGY

by

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December 2019

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Providing clean, safe drinking water in the aftermath of a hurricane is critical for a community’s survival. In 2017, Hurricane Maria struck the island of Puerto Rico, leaving communities without clean, safe drinking water for days, weeks, and in some cases months. The challenges in providing long-term clean, safe drinking water echoed through official government statements and reports, as well as the news media. Recent developments in nanotechnology show great promise as a timely, cost-effective method for providing clean, safe drinking water to impacted communities. These new technologies can to supplement current water allocation programs used by the federal government by drastically reducing the amount of time and money required to provide adequate amounts of water to individuals in affected areas following a damaging hurricane. This thesis analyzes the time, money, and feasibility considerations of adopting nanotechnology-based water filtration into current emergency management. The results show nanotechnology-based water filtration can provide a timely, cost-effective method for providing clean, safe drinking water while meeting the response demands of affected communities. Nanotechnology-based water filtration can be used to drastically alter future emergency management.

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FILTERING A NEW SOLUTION TO FEDERAL EMERGENCY MANAGEMENT THROUGH NANOTECHNOLOGY

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ABSTRACT

Providing clean, safe drinking water in the aftermath of a hurricane is critical for a community's survival. In 2017, Hurricane Maria struck the island of Puerto Rico, leaving communities without clean, safe drinking water for days, weeks, and in some cases months. The challenges in providing long-term clean, safe drinking water echoed through official government statements and reports, as well as the news media. Recent developments in nanotechnology show great promise as a timely, cost-effective method for providing clean, safe drinking water to impacted communities. These new technologies can to supplement current water allocation programs used by the federal government by drastically reducing the amount of time and money required to provide adequate amounts of water to individuals in affected areas following a damaging hurricane. This thesis analyzes the time, money, and feasibility considerations of adopting nanotechnology-based water filtration into current emergency management. The results show nanotechnology-based water filtration can provide a timely, cost-effective method for providing clean, safe drinking water while meeting the response demands of affected communities. Nanotechnology-based water filtration can be used to drastically alter future emergency management.

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LIST OF ACRONYMS AND ABBREVIATIONS

AEMEAD	Puerto Rico State Agency for Emergency and Disaster Management
COTS	Commercial off-the-shelf
CSRIO	Commonwealth Scientific and Industrial Research Organization
DOE	Department of Energy
DOH	Department of Health
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
GAO	Government Accountability Office
IWGN	Interagency Working Group on Nanoscience, Engineering and Technology
NASA	National Aeronautics and Space Administration
NIST	National Institute of Standards and Technology
NNI	National Nanotechnology Initiative
NPDWR	National Primary Drinking Water Regulations
NSF	National Science Foundation
PWSS	Public Water System Supervision

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EXECUTIVE SUMMARY

Every year, the federal government must coordinate hurricane recovery and relief efforts, such as providing shelter, food, and water, to address basic human needs following a natural disaster.[1] An essential resource for human survival is water, and when a hurricane strikes, basic utilities may be destroyed, leaving individuals without water for several days. To minimize the impact on affected areas, emergency management personnel provide clean water for individuals until services are restored and proven safe for consumption. While people wait for the resumption of service, emergency managers provide water using water purification tractor trailers to provide on-site water purification and the shipment of thousands of pallets of bottled water from other areas for distribution.[2]

These methods and techniques currently in place for delivering water in emergencies have been tried and tested over many years, but breakthroughs in nanotechnology show promise for improving water filtration and hurricane response.[3] Advancements in nanotechnology could assist in addressing the innovative and cost-effective response for emergency water supplies, yet the federal government has not connected the use of nanotechnology as a beneficial resource for improving emergency management efforts.

This thesis first provides an understanding of nanotechnology-based water filtration along with its benefits and challenges. Second, the research explores the current framework for emergency management to include the statutes regulating water resources during an emergency and current water allocation techniques. Third, the Hurricane Maria case study

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[1] "Logistics Management Directorate," Federal Emergency Management Agency, April 21, 2015, https://www.fema.gov/logistics-management-directorate.

[2] American Water Works Association and CDM, *Planning for an Emergency Drinking Water Supply*, vol. EPA 600R-11/054 (Washington, DC: Environmental Protection Agency, 2011), https://www.epa.gov/sites/.../planning_for_an_emergency_drinking_water_supply.pdf.

[3] Chicgoua Noubactep, "Affordable Safe Drinking Water for Victims of Natural Disasters," in *Natural Disasters and Sustainable Development*: *Proceedings of the International Seminar on Natural Disasters and Sustainable Development*, eds. C. Katsch and H. Meliczek (Gottingen, Germany: Cuvillier Verlag, 2013), 57–75, https://www.researchgate.net/publication/256092975_Affordable_safe_drinking_water_for_victims_of_natural_disasters.

provides a real-world analysis of the current emergency management and how nanotechnology-based water filtration could reduce response time, financial burden, and improve the overall federal response. Finally, the research concludes with recommendations and ways to overcome foreseeable issues on the adoption of nanotechnology.

Currently, the scientific community recognizes the benefits of nanotechnology for improving water filtration and continues to explore new materials and methods to effectively provide clean, safe drinking water to individuals around the world. While individuals opposed to nanotechnology still believe there are some unknown environmental and personal health risks, researchers have not found any significant disadvantages, and continued research and development have led manufacturers to develop commercially viable nanotechnology-based water filtration. These new commercial products have successfully been deployed worldwide to individuals without sufficient water resources. These products provide a low-cost, long-term solution for providing clean, safe drinking water to the community. Individuals and communities in the aftermath of the hurricane find themselves in similar circumstances, and nanotechnology-based water filtration could be used to effectively mitigate emergency response issues. Such areas as emergency management are in an ideal position to benefit from the continued innovation and development of nanotechnology-based water filtration.

The current methods for providing clean, safe drinking water used by the federal government include water trucks and mobile filtration, boiling and bleaching, and prepackaged water. The difficult challenge in managing effective emergency preparedness is the inability of governments to fully anticipate the full effects of disasters on food, water, and health supplies.[4] As it stands, the statutory framework for emergency management procedures allow for the potential incorporation of nanotechnology in emergency response. However, current methods undertaken by the federal government do not rely on nanotechnology. Instead, the federal government uses methods that insufficiently meet the needs of citizens in need of water after enduring devastating hurricanes. The new

[4] Federal Emergency Management Agency, “Logistics Management Directorate.”

developments in nanotechnology-based water filtration show promise in saving both time and money.

Using available data from Hurricane Maria, an evaluation of current methods for providing emergency water supplies provides a real-world scenario to determine the effectiveness of current methods. Through a series of both foreseen and unforeseen challenges, the local government and the Federal Emergency Management Agency (FEMA) struggled to provide adequate water to the citizens in the aftermath of Hurricane Maria. Problems ranged from a lack of planning, geographic and temporal challenges, distribution failures, destroyed infrastructure, and the subsequent high costs. Even if the emergency response to Hurricane Maria had been well organized, issues with time delays and high costs would have still been enormously challenging. The lessons learned from the Hurricane Maria case study are that current methods used to distribute water in the wake of a damaging hurricane are insufficient for resolving water shortages in an efficient, timely, and effective manner.

The federal government should adopt nanotechnology-based water filtration as an innovative solution to address the need for clean water in the aftermath of a hurricane. Primarily, use of nanotechnology will save time, money, is technologically feasible, and is allowable under current federal regulations. The analysis demonstrates that nanotechnology-based water filtration will drastically reduce the amount of time and money required to provide adequate amounts of water filtration to individuals in affected areas following a damaging hurricane. Furthermore, the adoption of nanotechnology will assist the federal government in effectively and efficiently fulfilling the requirements of the Stafford Act, Safe Drinking Water Act, and the 21st Century Nanotechnology Research and Development Act. Together, FEMA, the Environmental Protection Agency (EPA), and the National Nanotechnology Initiative (NNI) should collaborate to improve federal emergency management measures and to ensure safe and clean water for all in need. Through this collaboration, the federal government can avoid another case like Hurricane Maria while saving time, money, and human lives.

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I. INTRODUCTION

Every year the federal government coordinates hurricane recovery and relief efforts, which includes providing shelter, food, and water, to address basic human survival needs following a natural disaster.[1] The most crucial of these necessities is water. When a hurricane strikes, basic utilities and supplies may be destroyed leaving individuals without water for days or longer. Therefore, it is critical that federal, state, and local governments maintain emergency management plans in order to prepare for worse case scenarios wherein a hurricane leaves citizens without access to clean and drinkable water. For the federal government, such emergency management plans are designated in current federal statutes. Certain federal government agencies are delegated the primary responsibility for administering emergency response and relief during the time of a hurricane in the United States.

Currently, emergency response personnel provide clean water for individuals until services are restored and proven safe for consumption. While people wait for the resumption of local services providing drinking water, emergency response personnel provide water using water purification tractor trailers to provide on-site water purification and the shipment of thousands of pallets of bottled water from other areas for distribution.[2] These methods and techniques currently in place for delivering water in emergencies have been tried and tested over many years, but the development of new technology—for example, nanotechnology—has portended promise for improving water filtration and hurricane response.[3] Advancements in nanotechnology could replace outdated

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[1] "Logistics Management Directorate," Federal Emergency Management Agency, April 21, 2015, https://www.fema.gov/logistics-management-directorate.

[2] American Water Works Association and CDM, *Planning for an Emergency Drinking Water Supply*, vol. EPA 600R-11/054 (Washington, DC: Environmental Protection Agency, 2011), https://www.epa.gov/sites/.../planning_for_an_emergency_drinking_water_supply.pdf.

[3] Chicgoua Noubactep, "Affordable Safe Drinking Water for Victims of Natural Disasters," in *Natural Disasters and Sustainable Development*: *Proceedings of the International Seminar on Natural Disasters and Sustainable Development*, eds. C. Katsch and H. Meliczek (Gottingen, Germany: Cuvillier Verlag, 2013), 57–75, https://www.researchgate.net/publication/256092975_Affordable_safe_drinking_water_for_victims_of_natural_disasters.

technologies and could ensure the availability of greater supplies of clean water at a cheaper cost. Although the federal government has initiated research and design of nanotechnology capabilities, the use of nanotechnology as part of emergency management plans has yet to be adopted. The federal government should consider the benefits of nanotechnology and institute use of nanotechnology for improving domestic emergency management efforts.

A. RESEARCH QUESTION

How can nanotechnology-based water filtration replace or improve current hurricane relief water allocation programs?

B. RESEARCH DESIGN

Using available data from Hurricane Maria, an analysis evaluating the time, money, and feasibility of providing water during the response to the storm and steps to improve response. Time consists of evaluating the overall time required for emergency response personnel to provide clean, safe drinking water to affected individuals. Money evaluates the overall fully burdened cost of distributed, clean, safe drinking water and budgetary requirements. Finally, the analysis of feasibility focuses on the technological and regulatory feasibility surrounding nanotechnology to determine if nanotechnology-based water is ready for acceptance within the context of emergency management. The evidence supporting these findings come from technical/after-action reports, manufactures manuals, budget requests, periodicals, and scholarly journals.

This research begins with a review of nanotechnology and the advancements in water filtration. This section discusses current water filtration systems with nanotechnology-based filtration systems. A study of current scientific research establishes the true effectiveness of nanotechnology-based filtration and reviews current commercial off-the-shelf products utilizing nanotechnology. This study will include such key factors as the cost of operation and maintenance, the efficiency of meeting Safe Drinking Water Act standards, environmental and health impacts, and current use around the world.

The thesis then shifts toward outlining and demonstrating the different types of water filtration techniques currently being used in response to disaster relief/emergency management. Using Hurricane Maria as a case study, an evaluation of current methods for providing emergency water supplies provides a real-world scenario to determine the effectiveness of current methods in terms of time, money, and feasibility.

After establishing the current and alternative states of water filtration along with the benefits and potential challenges, the research explores incorporating nanotechnology into current emergency management. The research focuses on improvements to reduce response times and overall cost of water allocation, and the feasibility of adoption in current emergency management.

Finally, once the evaluation of incorporating nanotechnology into current emergency management is completed, recommendations to provide continued funding and increase awareness of new technologies to improve future disaster relief. The goal is to assist policymakers in understanding the opportunities presented by nanotechnology in the disaster relief context and to create a well-formulated policy to improve hurricane relief.

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II. UNDERSTANDING NANOTECHNOLOGY

Nanotechnology has a wide range of applications, including improving water filtration.[4] Several researchers recognize the benefits of using nanotechnology for improving water filtration and are continuing to develop new designs for providing clean, safe drinking water to individuals around the world.[5] While individuals opposed to nanotechnology still believe there are some unknown environmental and personal health risks, researchers have not found any significant disadvantages, and continued research and development have lead manufactures to develop commercially viable nanotechnology-based water filtration.[6] These new commercial products have successfully been deployed to individuals without sufficient water resources.[7] With similar circumstances resulting from hurricanes and the need for safe and clean water, nanotechnology-based water filtration could be used to effectively mitigate emergency response issues.

A. ORIGINS, BENEFITS, AND DISADVANTAGES OF NANOTECHNOLOGY

Nanotechnology enables scientists to control the atoms and molecules of matter on a nanoscale (*i.e.*, about 1 to 100 nanometers, which equates to one billionth of a meter).[8] In December 1959, physicist Richard Feynman theorized that scientists could control the structure and organization of individual atoms of materials on a small molecular scale in order to maximize their potential.[9] Because atoms exist in everything on Earth—food, clothing, natural resources, etc.—there is significant potential for a myriad of applications

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[4] National Nanotechnology Initiative, "Benefits and Applications," 2019, https://www.nano.gov/you/nanotechnology-benefits.

[5] Mike Williams, "Nanoscale Solutions to Water Shortages," PHYS, April 1, 2016, https://phys.org/news/2016-04-nanoscale-solutions-shortages.html.

[6] Heleen van Dijk et al., "Determinants of Stakeholders' Attitudes towards a New Technology: Nanotechnology Applications for Food, Water, Energy and Medicine," *Journal of Risk Research* 20, no. 2 (February 2017): 277–98, https://doi.org/10.1080/13669877.2015.1057198.

[7] Noubactep, "Affordable Safe Drinking Water for Victims of Natural Disasters."

[8] National Nanotechnology Initiative, "What Is Nanotechnology?," accessed September 6, 2019, https://www.nano.gov/nanotech-101/what/definition.

[9] National Nanotechnology Initiative.

of nanotechnology.[10] In December 2003, the federal government established an organization to study the potential uses of nanotechnology within the United States.[11] On December 3rd, 2003, President George W. Bush signed into law the 21st Century Nanotechnology Research and Development Act within which the federal government promised over one billion dollars in funding to study nanotechnology.[12] The Act also established the National Nanotechnology Initiative (NNI), which was tasked with exploring "a future in which the ability to understand and control matter at the nanoscale leads to a revolution in technology and industry that benefits society."[13] The NNI's research has included applying nanotechnology to the medical, electronic, food, fuel industries.[14] In addition, the NNI is currently focused on using nanotechnology for its water purification benefits in order to remove pollution from groundwater.[15]

There are several important benefits to using nanotechnology for water purification. One major benefit is the ability of nanotechnology to rapidly convert otherwise undrinkable water into a product fit for human consumption in a matter of minutes at a fraction of the cost as compared to other traditional methods of water purification.[16] Nanotechnology can help clean "industrial water pollutants in groundwater" through chemical reactions.[17] Specifically, nanotechnology in the form of a filter can be used to remove sediment,

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[10] Ilka Gehrke, Andreas Geiser, and Annette Somborn-Schulz, "Innovations in Nanotechnology for Water Treatment," *Nanotechnology, Science and Applications* 8 (January 6, 2015): 1–17, https://doi.org/10.2147/NSA.S43773.

[11] "21st Century Nanotechnology Research and Development Act," Pub. L. No. 108–153 (2003), https://www.congress.gov/bill/108th-congress/senate-bill/189.

[12] Maksim Rakhlin, "Regulating Nanotechnology: A Private-Public Insurance Solution," *Duke Law & Technology Review* 7, no. 1 (2008): 1–20.

[13] National Nanotechnology Initiative, "About the NNI," 2019, https://www.nano.gov/about-nni.

[14] "Nanotechnology Applications: A Variety of Uses," UnderstandingNano, 2007, https://understandingnano.com/nanotech-applications.html.

[15] "Nanotechnology Applications: A Variety of Uses."

[16] Benedette Cuffari, "Nanotechnology and Water Purification," AZoNano, July 17, 2018, https://www.azonano.com/article.aspx?ArticleID=4918.

[17] National Nanotechnology Initiative, "Benefits and Applications."

chemical pollutants, certain particles and bacteria from water.[18] According to the NNI, nanotechnology provides inexpensive clean water through “rapid, low-cost detection and treatment of impurities in water.”[19] This is especially important when existing infrastructure is inaccessible or destroyed in the aftermath of a devastating hurricane. Subsequently, the efficiency, effectiveness, and low-cost of using nanotechnology for water purification makes this technology a strategic solution for improving emergency management.

Although there are several important benefits to using nanotechnology for water purification, there remains some unknown risk in using nanotechnology. First, while nanotechnology-based water filtration is proven to be environmentally friendly, the Environmental Protection Agency (EPA) and other government organizations continue to monitor its progress to ensure environmental safety.[20] This ongoing research will help to assess and mitigate potential environmental risks, but conclusive evidence is not fully available at this time. Second, similarly to unknown environmental risks, nanotechnology is still a relatively new technology and so, long-term risks to users of this technology are also unknown.[21] As with any developing technology, there may be disadvantages that arise in the future. Finally, there is currently no strategic plan for incorporating nanotechnology into emergency preparedness.[22] The overwhelming number of different nanotechnologies available makes it difficult for policymakers to outline a strategy for implementation and education with the public.[23] Thus, it is important that such organizations as the NNI

[18] Farida Valli, Karishma Tijoriwala, and Alpana Mahapatra, “Nanotechnology for Water Purification,” PHYS, July 29, 2010, https://phys.org/news/2010-07-nanotechnology-purification.html.

[19] National Nanotechnology Initiative, “Benefits and Applications.”

[20] Environmental Protection Agency, “Research on Nanomaterials.,” July 23, 2017, https://www.epa.gov/chemical-research/research-nanomaterials.

[21] Valli, Tijoriwala, and Mahapatra, “Nanotechnology for Water Purification.”

[22] Ilise L. Feitshans, *Nanotechnology: Balancing Benefits and Risks to Public Health and the Environment* (Strasbourg, France: Council of Europe, 2013), http://assembly.coe.int/CommitteeDocs/2013/Asocdocinf03_2013.pdf.

[23] National Nanotechnology Initiative, “Benefits and Applications.”

continue to research nanotechnology to flesh out overall benefits and disadvantages to using nanotechnology to address a growing shortage of water in the United States.[24]

B. EXAMPLES OF NANOTECHNOLOGY USES FOR WATER PURIFICATION

Nanotechnology takes many forms, especially when used for water purification. The predominant form of nanotechnology relies on what is known as a "nanofilter."[25] Nanofilters can be used to remove sediment chemical pollutants, certain particles and bacteria from water.[26] In addition, nanofilters, which are very small in size, can filter water "at a faster rate than conventional filters."[27] Given the space-saving and efficiency benefits, many companies have developed several different designs using nanofilters in order to compete against traditional water filtration systems. The three major types of nanofilters used today are: (1) the LifeSaver Bottle; (2) WaterBox; and (3) Graphene.

1. LifeSaver Bottle

The LifeSaver bottle is a portable nanotechnology-based water filtration device (*i.e.*, a water bottle) that uses nanomesh known as "ultrafiltration".[28] Nanomesh contains very small holes that are only 15 nanometers in size, but will effectively remove 99 percent of all biological and organic contaminants.[29] This ultrafiltration is proven to remove the majority of heavy metals, however, some inorganic materials, for example, dissolved salts are smaller than 15 nanometers. The total amount of water processed depends on the size of the unit.

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[24] Lavanya Madhura et al., "Nanotechnology Based Water Quality Management for Wastewater Treatment," *Environmental Chemistry Letters* 17, no. 2 (July 19, 2018): 65–121, https://doi.org/10.1007/s10311-018-0778-8.

[25] Valli, Tijoriwala, and Mahapatra, "Nanotechnology for Water Purification."

[26] Valli, Tijoriwala, and Mahapatra.

[27] Valli, Tijoriwala, and Mahapatra.

[28] LifeSaver, "Portable Water Purification Technology," LifeSaver, accessed September 6, 2019, https://iconlifesaver.com/about-us/our-technology/.

[29] LifeSaver.

Figure 1. LifeSaver 4000UF Bottle[30]

Figure 2. LifeSaver C2[31]

The LifeSaver filter and other similar water bottle types of products range from portable personal use filters to large scale filters. A smaller personal use filter can produce more than 4000 liters of water on a single filter while the large scale filters have the ability to produce 500,000 liters of water. LifeSaver bottles range from $100 USD for the small portable personal use filter to $1600 for the large scale filters.[32] The Lifesaver bottle has the ability to provide water for $0.02 per liter. A major advantage of using the LifeSaver bottle is the minimal skill required to operate the technology. Contaminated water is poured into the bottom of the bottle. Once the lid is secured, the individual uses the built-in hand pump to build pressure and force the water through the small filtration membrane. As expected, the LifeSaver bottle requires some maintenance, which includes changing filters once every three to four years or once the filter exceeds its intended design.

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[30] LifeSaver, "Water Purifier Bottles - Travel, Backpacking, Hiking, Outdoor," LifeSaver, accessed September 6, 2019, https://iconlifesaver.com/products/bottles/.

[31] LifeSaver, "LifeSaver C2.," LifeSaver, Last modified 2019, https://iconlifesaver.com/product/lifesaver-c2/.

[32] LifeSaver, "Water Purifier Bottles - Travel, Backpacking, Hiking, Outdoor."

The LifeSaver company has already developed products specifically to address emergency preparedness. Specifically, Lifesaver has developed a large scale filter, known as the "LifeSaver C2," which may filter up to 500,000 liters of water.[33] Therefore, the technology to be plugged into the emergency management area already exists.

2. WaterBox

A second formidable type of nanotechnology is the "WaterBox." The WaterBox[34] uses carbon nanotubes, designed by CB Technologies, which are the most common form of nanotechnology in water filtration. Carbon nanotubes consist of a single layer of carbon atoms that create a filtration membrane and that are rolled into a cylindrical shape. These filtration membranes are proven to remove a wide range of contaminants from water.[35] According to Alan Cummings, former CEO of Seldon Technologies states "Nanomesh can provide mobile, life-saving ground and surface water filtration in field and disaster relief environments by removal of microorganisms that cause waterborne diseases."[36] The prototypes were originally tested and proven as viable with the National Aeronautics and Space Administration (NASA).[37] The WaterBox is currently available for $8,575 USD.[38] Alternatively, the WaterStick is easy to use, requiring only a simple filter change every 15,000 liters of water filtered.[39] Although, the WaterBox is still considered to be "perfect for short-duration uses where other solutions are impractical."[40]

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33 LifeSaver, "LifeSaver C2."

34 Carbon Block Technology, "CB Tech Waterbox," Carbon Block Technology, accessed September 6, 2019, https://www.carbonblocktech.com/cb-tech-waterbox/.

35 Xitong Liu et al., "Potential of Carbon Nanotubes in Water Treatment," *Journal of Environmental Sciences* 25, no. 7 (July 1, 2013): 1263–80, https://doi.org/10.1016/S1001-0742(12)60161-2.

36 "Portable Nanomesh Creates Safer Drinking Water," accessed September 6, 2019, https://spinoff.nasa.gov/Spinoff2008/er_4.html.

37 Arun Joshi, "Advanced NASA Technology Supports Water Purification Efforts Worldwide," National Aeronautic and Space Administration, April 17, 2019, http://www.nasa.gov/mission_pages/station/research/benefits/water_purification.html.

38 Carbon Block Technology, "CB Tech Waterbox."

39 Carbon Block Technology.

40 Carbon Block Technology.

Figure 3. CB Technologies WaterBox[41]

3. Graphene

Graphene is a different type of carbon-based material that is competitive with other nanotechnology products.[42] Graphene is a one-atom-thick layer of carbon and is organized in a hexagonal pattern.[43] The difference between carbon nanotubes and graphene is the structure. Graphene is developed in single-layer sheets while carbon nanotubes may single-wall tubes or multi-walled tubes.[44] The use of the unique sheet construction found in graphene has the potential to improve current nanotechnology, specifically as it relates to water purification.[45] This technology has been adopted in two forms. The first form is the use of graphene-based membrane filter. The Commonwealth Scientific and Industrial Research Organization (CSIRO) has developed a graphene-based water filter membrane that has been proven to increase the overall effectiveness of current water filtration.[46] Researchers were able to take water from the Sydney harbor and filter it real-time removing

[41] Carbon Block Technology.

[42] Jane Bird, "Graphene Filters Change the Economics of Clean Water," *Financial Times*, January 8, 2018, https://www.ft.com/content/d768030e-d8ec-11e7-9504-59efdb70e12f.

[43] Recep Zan et al., "Atomic Structure of Graphene and H-BN Layers and Their Interactions with Metals," *Advances in Graphene Science*, July 31, 2013, https://doi.org/10.5772/56640.

[44] Zan et al.

[45] "Graphene and Water Treatment: Introduction and Market Status," Graphene, January 25, 2019, https://www.graphene-info.com/graphene-water-treatment.

[46] RMIT University, "Quick and Not-so-Dirty: A Rapid Nano-Filter for Clean Water," PHYS, September 20, 2018, https://phys.org/news/2018-09-quick-not-so-dirty-rapid-nano-filter.html.

harmful biological, organic, and inorganic compounds from the water.[47] The filter designs are not currently available for purchase on the consumer market and field tests have been limited but show great promise.[48]

The second form of graphene-based water filtration is graphene coated sand.[49] The use of graphene-coated sand is a modification of the current charcoal and sand filtration technique. Researchers at Rice University were able to take the thin layer of graphene and coat sand granules.[50] The graphene-coated sand was proven to be several times more effective than the standard sand water filter.[51] The use of graphene-coated sand can be incorporated into current technology to improve its overall effectiveness.

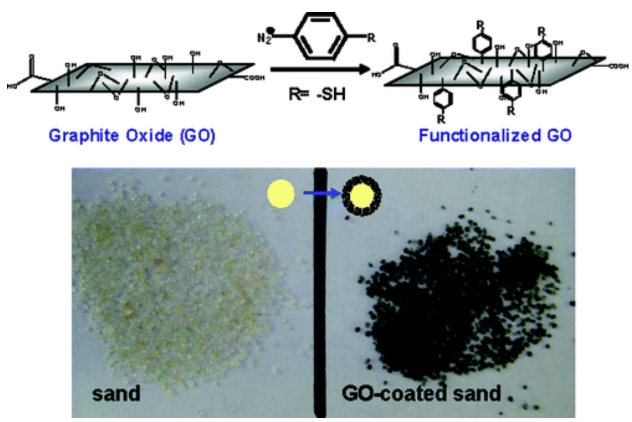

Figure 4. Graphene Coated Sand[52]

C. COMPARISON OF NANOTECHNOLOGY PRODUCTS

The below tables presents a side-by-side comparison of the various types of "commercial off the shelf" (COTS) water filtration units. The table compares the different

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47 RMIT University.

48 Graphene, "Graphene and Water Treatment: Introduction and Market Status."

49 David Ruth and Mike Williams, "'Coated Sand' Excels at Water Purification," Rice University, June 22, 2011, http://news.rice.edu/2011/06/22/coated-sand-excels-at-water-purification-2/.

50 Ruth and Williams.

51 American Chemical Society, "'Super Sand' for Better Purification of Drinking Water (Update)," PHYS, June 23, 2011, https://phys.org/news/2011-06-super-sand-purification.html.

52 American Chemical Society.

technologies by evaluating the flow rates of each system, the amount of safe drinking water produced in liters, the cost of operation, the ease of use, and power requirements. While all products have the ability to effectively filter water and therefore drastically change emergency response, the Lifesaver (nanomesh) possesses the strongest success by reducing time and money while maintaining a high level of feasibility in emergency management. The Lifesaver provides the highest quantity of clean, safe drinking water while providing low-cost, easy to use system adaptable to multiple emergency response circumstances.

Table 1. Nanotechnology-Based Water Filtration

Type of Filter	TIME		MONEY		FEASIBILITY		
	Flow Rate	Amount of Water Treated per filter	Market Value	Cost per Liter of water	Skill Level Required	Maintanance	Power Requirement
LifeSaver Bottle (Nanomesh)	1.2-12 L/min	4000-500,000 liters of water	$100-$1600	$0.02- $0.003 per liter of water	Unskilled	Filter replacement and proper storage required	Manual Pump or Gavity
WaterBox	2 L/min	15,000 liters of water	$8,575	$0.57 per liter of water	Trained	Filter replacement and replacement of some fragile components and proper storage.	Battery Power
Graphene	Flow rate varies with different applications	Currently not available for commercial use	N/A	N/A	Unskilled	Proper storage	Gravity

There are a variety of commercially available nanotechnology-based water filtration products. Yet the federal government has not yet capitalized on the many benefits of using nanotechnology for emergency management and response. Continued innovation of nanotechnology products for water purification is key for resolving the continued need for water in the wake of natural disasters. So, too, is collaboration between nanotechnology innovators and the federal government so that nanotechnology becomes the solution across the U.S.

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III. CURRENT FRAMEWORK FOR EMERGENCY MANAGEMENT

Emergency preparedness refers to the arrangements made by local, state, and federal governments as well as individual citizens in order to ensure the survival and recovery of local populations in the event of a natural disaster.[53] The difficult challenge in managing effective emergency preparedness is the inability of governments to fully anticipate the full effects of disasters on food, water, and health supplies.[54] As it stands, the statutory framework for emergency management procedures allows for the potential incorporation of nanotechnology in emergency response. However, current methods undertaken by the federal government do not presently rely on nanotechnology. Instead, the federal government uses methods that insufficiently meet the needs of citizens in need of water after enduring devastating hurricanes.

A. CURRENT STATUTORY FRAMEWORKS FOR EMERGENCY MANAGEMENT, WATER AND NANOTECHNOLOGY

There are three federal statutes that create the statutory framework governing the adoption of nanotechnology into emergency management procedures across the U.S. First, the Robert T. Stafford Disaster Relief and Emergency Assistance Act, better known as the Stafford Act, authorizes federal disaster relief procedures and activities.[55] Second, the Safe Drinking Water Act protects public drinking water with required standards for safe and clean drinking water.[56] Third, the 21st Century Nanotechnology Research and

[53] Federal Emergency Management Agency, *National Response Framework*, vol. 3rd ed. (Washington, DC: Federal Emergency Management Agency, 2016), https://www.fema.gov/media-library-data/1466014682982-9bcf8245ba4c60c120aa915abe74e15d/National_Response_Framework3rd.pdf.

[54] Federal Emergency Management Agency, "Logistics Management Directorate."

[55] "Robert T. Stafford Disaster Relief and Emergency Assistance Act," Public Law No. 93–288, *U.S. Statutes at Large* 42 (2018), codified at *U.S Code* 5121 (2018), https://www.fema.gov/media-library-data/1519395888776-af5f95a1a9237302af7e3fd5b0d07d71/StaffordAct.pdf.

[56] "Safe Drinking Water Act," Public Law No. 115–270, *U.S. Statutes at Large* 144 (2018), https://legcounsel.house.gov/Comps/Safe%20Drinking%20Water%20Act-(Title%20Xiv%20Of%20Public%20Health%20Service%20Act).pdf.

Development Act authorizes funding for nanotechnology research and development.[57] Comprehensively, each of the three statutes, as discussed below, provides the federal government's authority to mitigate the impacts of hurricanes in various locals across the U.S.

1. The Stafford Act

The Robert T. Stafford Disaster Relief and Emergency Assistance Act, better known as the Stafford Act provides an organized plan for federal assistance in the wake of a natural disaster.[58] Before the development of the Stafford Act, Congress would authorize assistance and funding on a case-by-case basis and attempt to coordinate over one hundred federal agencies to effectively address the needs of affected areas.[59] With the passage of the Stafford Act, there is now more organized coordination between federal, state, and local governments—particularly with regards to authorizations and responsibilities in the area pertaining to disaster preparedness, mitigation assistance, disaster and emergency response, and recovery. Furthermore, FEMA is the federal agency primarily responsible for coordinating federal government assistance with state and local governments under the Stafford Act.[60]

The Stafford Act provides insight into the development of disaster assistance and mitigation programs, as well as the financial contributions provided by the federal government through FEMA. The Stafford Act's significance and intent are outlined under Title 1 Sec. 101(a) and (b). Section 101(b) outlines six objectives for improving disaster relief:

1. revising and broadening the scope of existing disaster relief programs;

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[57] 21st Century Nanotechnology Research and Development Act.

[58] "Robert T. Stafford Disaster Relief and Emergency Assistance Act Fact Sheet," Association of State and Territorial Health Officials, 2019, http://www.astho.org/programs/preparedness/public-health-emergency-law/emergency-authority-and-immunity-toolkit/robert-t--stafford-disaster-relief-and-emergency-assistance-act-fact-sheet/.

[59] Robert T. Stafford Disaster Relief and Emergency Assistance Act.

[60] Association of State and Territorial Health Officials, "Robert T. Stafford Disaster Relief and Emergency Assistance Act Fact Sheet."

2. encouraging the development of comprehensive disaster preparedness and assistance plans, programs, capabilities, and organizations by the States and by local governments;
3. achieving greater coordination and responsiveness of disaster preparedness and relief programs;
4. encouraging individuals, States, and local governments to protect themselves by obtaining insurance coverage to supplement or replace governmental assistance;
5. encouraging hazard mitigation measures to reduce losses from disasters, including development of land use and construction regulations; and
6. providing Federal assistance programs for both public and private losses sustained in disasters.[61]

Since the adoption of the Stafford Act, several amendments have been signed into law, most recently the Disaster Mitigation Act of 2000, which streamlines the FEMA's mitigation planning requirements for state, local and Indian Tribal governments as part of FEMA's mitigation grant assistance.[62] Together, the amendments to the Stafford Act are intended to provide additional coverage to areas not previously covered by the Act and to assist in overall cost savings to the federal government when providing disaster mitigation assistance. Despite these amendments, the Stafford Act does not address how to incorporate new technologies nor does it require any reevaluation of established methods and/or techniques.[63] As the lead agency in disasters, FEMA plays more of a supporting and coordinating role when it comes to water-related issues and water allocation programs. Yet, the Stafford Act permits FEMA to consider nanotechnology as a method for providing water in emergencies.

2. The Safe Drinking Water Act

The Safe Drinking Water Act of 1974 was a key piece of legislation signed into law by President Gerald Ford and which established federal regulations for the compliance with

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[61] Robert T. Stafford Disaster Relief and Emergency Assistance Act.

[62] Disaster Mitigation Act of 2000, Public Law No. 106–390, *U.S. Statutes at Large* (2000), https://www.fema.gov/media-library/assets/documents/4596.

[63] Federal Emergency Management Agency, *National Response Framework*, vol. 3rd ed. (Washington, DC: Federal Emergency Management Agency, 2016), https://www.fema.gov/media-library-data/1466014682982-9bcf8245ba4c60c120aa915abe74e15d/National_Response_Framework3rd.pdf.

and enforcement of safe and clean drinking water standards across the U.S. Before the Safe Drinking Water Act, the federal government had little to no oversight on the public water utilities and wells from which most drinking water was retrieved. The lack of oversight left citizens vulnerable to a wide number of harmful parasites, chemicals, and other dissolved solids in water.[64] With an ever-growing environmental movement and growing health concerns surrounding industrial contamination and other human activities, the need for guaranteed safe drinking water has only increased. In response, the Safe Drinking Water Act delegated to the EPA the responsibility for establishing regulations and federal safety standards. Specifically, the Safe Drinking Water Act requires that the EPA "protect against both naturally-occurring and man-made contaminants that may be found in drinking water."[65]

Although the EPA is primarily responsible for water regulations under the Safe Drinking Water Act, both the federal and state governments share the responsibility for administering the established water regulations. First, the federal government provides the national standards for states to follow. Importantly, the EPA continuously updates its regulations under the Safe Drinking Water Act to account for newly discovered materials found in drinking water. The current list can be found in the National Primary Drinking Water Regulations (NPDWR).[66] Secondly, the states must ensure that the federal standards are met either with the assistance from the federal government or independently by assuming responsibility for the Public Water Supply Supervision (PWSS) Program.[67] The PWSS is a federal grant program assisting states with fundamental activities such as conducting sanitary surveys and reviewing their overall water systems to meet the Safe

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[64] Richard Weinmeyer et al., "The Safe Drinking Water Act of 1974 and Its Role in Providing Access to Safe Drinking Water in the United States," *AMA Journal of Ethics* 19, no. 10 (October 1, 2017): 1018–26, https://doi.org/10.1001/journalofethics.2017.19.10.hlaw1-1710.

[65] Environmental Protection Agency, "Understanding the Safe Drinking Water Act," June 2004, https://www.epa.gov/sites/production/files/2015-04/documents/epa816f04030.pdf.

[66] "National Primary Drinking Water Regulations," Environmental Protection Agency, modified March 22, 2018, https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations.

[67] Weinmeyer et al., "The Safe Drinking Water Act of 1974."

Drinking Water Act standards.[68] Given the importance of safe drinking water, it is critical that both the EPA and the states remain adaptable when implementing the Safe Drinking Water Act.

As it currently stands, the section 1433(b) of the Safe Drinking Water Act calls for an "Emergency Response Plan" which requires that communities develop an emergency response plan that shall include, among other things: (1) "plans and procedures that can be implemented, and *identification of equipment* that can be utilized, in the event of a malevolent act or natural hazard that threatens the ability of the community water system to deliver safe drinking water;" and "(2) actions, procedures, and *equipment* which can obviate or significantly lessen the impact of a malevolent act or natural hazard on the public health and the safety and supply of drinking water provided to communities and individuals."[69] Accordingly, it is mandatory that communities consider the type of equipment to be used to provide safe drinking water in the event of a natural disaster like a hurricane. However, the Safe Drinking Water Act does not call out any specific type of equipment.

In addition, section 1459D(a) "Review of Technologies" of the Safe Drinking Water Act requires that the Administrator of the EPA consult with federal agencies and state and local governments to review "existing and potential methods, means, equipment, and technologies (including review of cost, availability, and efficacy of such methods, means, equipment, and technologies) that." "prevent, detect, and respond to any contaminant for which a national primary drinking water regulation has been promulgated in community water systems and source water for community water systems;" and "allow for use of alternate drinking water supplies from nontraditional sources."[70] Again, none of this language calls out specific equipment and therefore, nanotechnology may be considered a viable technology for purposes of providing safe drinking water. Given this

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[68] Environmental Protection Agency, "Public Water System Supervision (PWSS) Grant Program," May 28, 2019, https://www.epa.gov/dwreginfo/public-water-system-supervision-pwss-grant-program.

[69] "Safe Drinking Water Act," Public Law No. 115–270, *U.S. Statutes at Large* 144 (2018), https://legcounsel.house.gov/Comps/Safe%20Drinking%20Water%20Act-(Title%20Xiv%20Of%20Public%20Health%20Service%20Act).pdf.

[70] Safe Drinking Water Act.

language, Congress should review nanotechnology for its potential use and benefits (*e.g.*, efficiency and low cost) in providing safe and clean drinking water so that the technology may be incorporated into future emergency response plans.

3. 21st Century Nanotechnology Research and Development Act

Prior to passing the 21st Century Nanotechnology Research and Development Act in 2003, the United States leads several research and development initiatives involving nanotechnology. In 1998, the Interagency Working Group on Nanotechnology (IWGN) was tasked to study nanoscale science, technology, and future related endeavors.[71] In 2000, President Clinton created the National Nanotechnology Initiative (NNI) to better coordinate research and development and promote competitiveness in the nanotechnology field.[72] Following all previous efforts to explore nanotechnology, President Bush signed the 21st Century Nanotechnology Research and Development Act into law.[73] The Act established a legal foundation for the National Nanotechnology Initiative (NNI), specifically-identified government agencies, and other independent agencies to explore and develop nanotechnology-related products and initiatives to address areas of national need and improved commercial and public products. The Act specifically identifies the EPA, the Department of Energy (DOE), the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and the National Institute of Standards and Technology (NIST) as those agencies that would be provided with funding to conduct the research and development of nanotechnology-based initiatives.[74]

Congress saw the benefit of allocating financial resources into the research and development of nanotechnology. Such research and development demonstrated the potential for a substantial positive impact on the U.S. economy and areas of national

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71 "Interagency Working Group on Nanoscience, Engineering, and Technology," Online Computer Library Center (OCLC) WorldCat Identities, 2019, http://worldcat.org/identities/lccn-n00002925/.

72 Neal Lane and Thomas Kalil, "The National Nanotechnology Initiative: Present at the Creation," *Issues in Science and Technology* 21, no. 4 (Summer 2005), https://issues.org/lane/.

73 21st Century Nanotechnology Research and Development Act, Public Law No. 108–153, *U.S. Statutes at Large* (2003), https://www.congress.gov/bill/108th-congress/senate-bill/189.

74 21st Century Nanotechnology Research and Development Act.

concern. The application of nanotechnology influenced a wide range of industries including manufacturing, medical, energy development, water purification, and protective equipment.[75] The U.S. continues to fund the expansion of nanotechnology, which demonstrates the U.S.'s interest in nanotechnology.[76]

While the development of the 21st Century Nanotechnology Research and Development Act provided valuable insight into the expansion and potential of nanotechnology, emerging issues and applications for nanotechnology beyond the original scope of the Act remain unaddressed. When the Act was first drafted, it was incumbent of the specific agencies to identify areas of focus research and development. Under the current programs and the structure of the Act—such areas as how nanotechnology could improve disaster recovery— have not been addressed. Therefore, the 21st Century Nanotechnology Research and Development Act could provide the appropriate research and development funding to explore the application of nanotechnology to improve hurricane recovery water allocation programs. Congress could amend the Act and would subsequently need to collaborate with relevant agencies to formulate a more comprehensive development plan for expanded uses of nanotechnology in emergency management.

Together, each of these three Acts provide language that encourages using of nanotechnology-based water filtration products to respond to needs for water in emergencies. However, it is apparent from the absence of modern methods used to provide clean and safe water that neither FEMA, EPA nor the NNI are collaborating on modern solutions to emergency management, for example, the use of nanotechnology. Still, based on the above analysis, current federal regulations would allow for use of new technologies, including nanotechnology, to provide clean and safe drinking water to individuals in need following a hurricane.

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75 Environmental Protection Agency, "Understanding the Safe Drinking Water Act."

76 National Science and Technology Council, *The National Nanotechnology Initiative: Supplement to the President's 2019 Budget* (Washington, DC: The National Nanotechnology Initiative, 2018), https://www.nano.gov/sites/default/files/NNI-FY19-Budget-Supplement.pdf.

B. CURRENT METHODS FOR PROVIDING EMERGENCY WATER SUPPLIES

Although the federal government recognizes the importance of all human necessities like food, water, and health supplies, water remains the most important resource to provide in the event of an emergency.[77] After all, humans can survive for a longer period of time with water alone, but lack of water will diminish survival no matter the amount of food available.[78] According to FEMA, "having an ample supply of clean water is a top priority in an emergency. A normally active person needs to drink at least two quarts (half-gallon) of water each day. People in hot environments, children, nursing mothers, and ill people will require even more. You will also need water for food preparation and hygiene. Individuals should store at least one gallon per person per day. In addition, consider storing at least a two-week supply of water for each member of your family. If you are unable to store this quantity, store as much as you can."[79]

The distribution and provision of clean and drinkable water are not guaranteed following a storm because the provision of clean water depends on supplies and distribution capabilities.[80] For example, infrastructure may be harmed by destructive weather, prepared water supplies may run out, natural water sources may be compromised by storm surges resulting in increased levels of bacteria, pollution, or other water-bound parasites that render water unsafe to consume.[81] Given the necessity for water for human survival, water is the resource that must be properly supplied and managed during and after an emergency.

There are several methods used by the federal government to provide clean and safe drinking water to individuals in need following a harmful natural disaster. Among the most

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[77] Federal Emergency Management Agency, "Water," May 1, 2014, https://www.ready.gov/water.

[78] Natalie Silver, "How Long Can You Live Without Water? Effects of Dehydration," *Healthline*, January 16, 2018, https://www.healthline.com/health/food-nutrition/how-long-can-you-live-without-water.

[79] Federal Emergency Management Agency, *Food and Water in an Emergency* (Washington, DC: Federal Emergency Management Agency, 2004).

[80] Federal Emergency Management Agency, "Water."

[81] Environmental Protection Agency, *Water and Wastewater Sector-Specific Plan* (Washington, DC: Department of Homeland Security, 2015), https://www.dhs.gov/sites/default/files/publications/nipp-ssp-water-2015-508.pdf.

common methods: (1) water tanker trucks and mobile filters; (2) the boil and bleaching method; and (3) bottled water.[82] All three methods are proven effective for providing clean water during an emergency. However, the federal government continues to accrue enormous costs and experience substantial delays in the distribution of water under current methods.[83] The following section will provide an overview of the current methods for providing emergency water supply and some of the successes and challenges that each of these methods create for emergency management.

1. Water Trucks and Mobile Filters

One common method of water distribution following a natural disaster is through bulk transportation and onsite production of safe drinking water. Companies are contracted through FEMA to transport water from around the country via tank trucks.[84] Tank trucks carrying water have a capacity of 500–5000 gallons of water per vehicle.[85] The safe transportation of water to various locals is overseen by the EPA and the Department of Health (DOH).[86] Specifically, water must be either treated, cleaned, or filtered and must meet local and federally established drinking water standards under the Safe Drinking Water Act.[87] Accordingly, both the federal and state governments collaborate to meet standards regulating acceptable trucks for water distribution, water sanitation, and water disinfection. For example, in the state of Washington, standards for the safe transportation of water requires transportation of 0.5 gallons of bleach for every 500 gallons of water transported.[88] This standard ensures that the water being delivered is reasonably free of

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[82] Federal Emergency Management Agency, *National Response Framework*.

[83] Federal Emergency Management Agency, *Distribution Management Plan Guide* (Washington, DC: Federal Emergency Management Agency, 2019).

[84] Federal Emergency Management Agency, "Transportation Programs," Last modified 2019, https://www.fema.gov/transportation-programs.

[85] Federal Emergency Management Agency, *Distribution Management Plan Guide*.

[86] King County, "Guidelines for Truck Transportation of Potable Water for Public Use.," 2019, https://www.kingcounty.gov/depts/health/emergency-preparedness/preparing-yourself/truck-transportation-potable-water.aspx.

[87] Environmental Protection Agency, "Understanding the Safe Drinking Water Act."

[88] King County, "Guidelines for Truck Transportation of Potable Water for Public Use."

any parasites or harmful bacteria.[89] Together, federal and state regulations ensure that the method of providing water via tank trucks is effective for emergency management purposes.

However, there are limitations to relying solely on water transported by tank truck. Tank trucks are limited to the road conditions and the ability to get effectively transport the water to individuals and are limited to the U.S. mainland.[90] Often times, major natural disasters like hurricanes cause flooding which blocks off main passageways, which results in significant delays of water deliveries. For example, Hurricane Florence initially hit North Carolina in September 2018 and either damaged and/or closed many of the main highways.[91] The damaged roads caused the North Carolina Department of Transportation to recommend "an extremely long detour."[92] The destruction and closing of the roads created a major time delay for providing such resources as water to individuals affected by Hurricane Florence.[93] Another example of the limitations of tank trucks can be found in response to Hurricane Maria, an earlier hurricane that hit in September 2017.[94] Due to the geographic challenges between the U.S. Mainland and the island of Puerto Rico, shipping in tank trucks was not a viable option for providing water to citizens.[95]

To address the shortcomings of tank trucks, the alternate method is providing onsite filtration of water and establishing local distribution locations. These mobile filtration

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[89] Environmental Protection Agency, "Water Enforcement," June 4, 2013, https://www.epa.gov/enforcement/water-enforcement.

[90] World Health Organization, *Delivering Safe Water by Tanker* (World Health Organization, 2013), https://www.unicef.org/cholera/Annexes/Supporting_Resources/Annex_9/WHO-tn12_safe_water_tanker_en.pdf.

[91] Roy Copper, *Hurricane Florence Recovery Recommendations* (Raleigh, NC: North Carolina Office of the Governor, 2018).

[92] Fox 8, "Drivers Told to Go AROUND the Carolinas as Florence Closes I-95, I-40," September 16, 2018, https://myfox8.com/2018/09/16/high-water-closes-i-95-i-40-drivers-told-to-detour-around-the-carolinas/.

[93] Copper, *Hurricane Florence Recovery Recommendations*.

[94] Federal Emergency Management Agency, *2017 Hurricane Season FEMA After-Action Report* (Washington, DC: Federal Emergency Management Agency, 2018), https://www.fema.gov/media-library/assets/documents/167249#:~:targetText=The%202017%20Hurricane%20Season%20FEMA,the%20path%20into%20the%20future.

[95] Federal Emergency Management Agency.

systems are coordinated with the U.S. Northern Command and FEMA.[96] The technology utilized in these mobile filters is reverse osmosis. Reverse osmosis has been proven to be an effective form of water purification. However, the reverse osmosis systems are powered by gasoline and are dependent on fuel of continuous operation. In the case of hurricane response, fuel is another precious and expensive commodity, and providing the necessary amount of fuel required to produce an adequate amount of drinking water may lead to substantial costs.

2. Boiling and Bleaching Water

A second common approach to clean water, as provided by the EPA, is a homemade solution to disinfect and sterilize water in case of an emergency. The first method is known as the boil method. The EPA recommends boiling water for approximately three minutes to ensure bacteria, viruses, and other harmful parasites are killed.[97] Once the water is boiled, the water should be stored in a clean, covered container.[98] The second method is to disinfect water by adding a small amount of household bleach to ensure all parasites are rendered harmless.[99] This method is good to use if an individual is unable to sterilize water following a hurricane or natural disaster. The recommended household bleach should be chlorine bleach between 6 percent and 8.25 percent of sodium hydrochloride.[100] One liter of water requires two drops of bleach. Once the bleach is added to the water, wait approximately thirty minutes before consumption.

Both methods should be reserved for emergencies and only used for a short amount of time. The EPA recommends only using such a method in case of an emergency and

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[96] United States Northern Command, "U.S. Northern Command Continues Puerto Rican Relief," October 16, 2017, http://www.northcom.mil/Newsroom/Press-Releases/Article/1344170/us-northern-command-continues-puerto-rican-relief-efforts/.

[97] Environmental Protection Agency, "Emergency Disinfection of Drinking Water," September 7, 2017, https://www.epa.gov/ground-water-and-drinking-water/emergency-disinfection-drinking-water.

[98] Environmental Protection Agency.

[99] Environmental Protection Agency.

[100] Environmental Protection Agency.

strongly advises to have an emergency supply of water for such emergencies.[101] While both methods may successfully target parasites, neither approach addresses the presence of heavy metals, viruses, and other harmful substances found in available freshwater.[102] Therefore, it is not a very effective method for acquiring clean and safe drinking water.

3. Prepackaged Water

As the third method, bottled and prepackaged water are extremely popular solutions for preparing for a lack of water in the event of an emergency.[103] Bottled water comes in a variety of sizes and is easily rationed, making it an ideal solution for individuals, families, and great communities. Such companies as the International Bottled Water Association have committed to providing bottled water to individuals and communities affected by hurricanes and natural disasters.[104] However, there are several concerns related to bottled water as a solution for emergency response management.[105]

The first concern is the associated high cost of transporting not only the water but the packaging a well. With a minimal amount of capacity per transporter, transporters may have to limit the amount of water that may be transported due to the additional weight of the packaging. While the total weight is minimal, many manufacturers reduce the total amount of plastic being used in the manufacturing of bottles to help reduce costs. The current weight of an empty plastic bottle of water is 12.7 grams, leading to an additional 1 lbs. of weight per case of water to transport.[106] Currently, bottled water costs as low as

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101 Environmental Protection Agency.

102 Environmental Protection Agency, "Potential Well Water Contaminants and Their Impacts," May 6, 2015, https://www.epa.gov/privatewells/potential-well-water-contaminants-and-their-impacts.

103 Tom Lauria, "Bottled Water Is an Important Component of Hurricane Season Preparedness," International Bottled Water Association, Last modified 2019, https://www.bottledwater.org/news/bottled-water-important-component-hurricane-season-preparedness.

104 Lauria.

105 Linda Poppenheimer, "What Is the Environmental Impact of Bottled Water?," *Green Groundswell* (blog), June 18, 2012, https://greengroundswell.com/what-is-the-environmental-impact-of-bottled-water/2012/06/18/.

106 "How Much Does Bottled Water Cost?," International Bottled Water Association, Last modified 2019, https://www.bottledwater.org/economics/real-cost-of-bottled-water.

$0.89 per gallon, compared to fractions of the cost for water from your tap.[107] During Hurricane Maria, FEMA was able to contract $0.55 a liter or $2.04 a gallon.[108] With fewer supplies being shipped at a time, it takes more shipments to provide enough bottled water to meet the needs of all individuals. Especially in long-term emergency response, providing bottled water can quickly become a costly process.[109]

The second concern is that once the water is transported to the necessary location, the water must be distributed to citizens in need. To effectively distribute a large quantity of water, multiple distribution points must be established. For example, in the case of Hurricane Katrina, bottle water was transported to the affected areas, but due to a lack of supply chain management, the bottled water in some cases was never distributed.[110] Bottled water was not distributed to citizens due to the capacity limitations of available transportation methods and a lack of coordination.[111] The lack of distribution left most individuals without water for an extended period of time.

The final concern is that for those bottles of water that are successfully distributed throughout the community, once they are used, the bottles are discarded as waste.[112] This is because bottled water is designed for one-time use.[113] Thus, once the water is fully consumed, there is no longer a need or use for the water bottle. In the event of a severe disaster, the timeframe for which bottled water is often unpredictable. Therefore, it could take a lot of bottled water to sustain local populations. Not only does this present a costly solution, but it creates a significant amount of plastic waste. Currently, there is a major

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[107] "Tap Water vs. Bottled Water," Food & Water Watch, September 16, 2015, https://www.foodandwaterwatch.org/about/live-healthy/tap-water-vs-bottled-water.

[108] Federal Emergency Management Agency, *Disaster Contracts Quarterly Report Fourth Quarter, Fiscal Year 2018.* (Washington, DC: Federal Emergency Management Agency, 2018).

[109] Philip Palin et al., *Supply Chain Resilience and the 2017 Hurricane Season* (Arlington, VA: CNA Analysis & Solutions, 2018).

[110] Zane Cope, "Water Supply When Disaster Strikes: A Look Back at Hurricane Katrina," *WaterPrepared* (blog), March 5, 2014, https://www.waterprepared.com/water-supply-disaster-strikes-look-back-hurricane-katrina/.

[111] Cope.

[112] Poppenheimer, "What Is the Environmental Impact of Bottled Water?"

[113] Poppenheimer.

trend against the use of plastic water bottles in the U.S.[114] Specifically, the trend against plastic water bottles focuses on the environmental impact and potential health concerns. In a study published in "Environmental Pollution," it was determined that water exposed to higher temperatures might transfer harmful chemicals from the plastic bottles into the water.[115] The International Bottles Water Association disputes the conclusion that plastics water bottles are harmful.[116] Continued research will determine the exact health impacts of plastic water bottles. However, the topic is now on the social radar and must be monitored to determine the long-term impact these findings may have on overall health, as this will affect whether bottled water is suitable for meeting water shortage needs from a hurricane. In conclusion, bottled water is an expensive solution that creates issues of complicated logistics and potentially harmful effects on the environment and human health.

Each of the current methods of providing clean, safe drinking water have the ability to provide an adequate amount of water for individuals. However, these current water allocation methods remain unchanged, while new technologies show promise to save both time and money. When there are other efficient, effective, and cost-effective methods, for example, nanotechnology, it would seem the federal government should adopt new methods to improve emergency responses.

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[114] Laura Parker, "How the Plastic Bottle Went from Miracle Container to Hated Garbage," *National Geographic*, August 23, 2019, https://www.nationalgeographic.com/environment/2019/08/plastic-bottles/.

[115] Ying-Ying Fan et al., "Effects of Storage Temperature and Duration on Release of Antimony and Bisphenol A from Polyethylene Terephthalate Drinking Water Bottles of China," *Environmental Pollution* 192 (September 2014): 113–20, https://doi.org/10.1016/j.envpol.2014.05.012.

[116] "Container Safety," International Bottled Water Association, 2019, https://www.bottledwater.org/health/container-safety.

IV. HURRICANE MARIA CASE STUDY

On September 20, 2017, Hurricane Maria struck the islands of St. Croix and Puerto Rico, as a category five hurricane with winds sustained over one hundred and fifty-seven miles per hour and a storm surge on the coastline approximately six to nine feet above sea level.[117] In addition to high winds and storm surge, Hurricane Maria produced as much as thirty inches of rain in some parts of the island, sparking a chain reaction of mudslides, severe flooding, and power outages. Hurricane Maria left many citizens without power or essential goods and services. Citizens were provided with a three-day notification to prepare themselves and gather the necessary resources. Local government officials were concerned with damage to critical infrastructure as this would limit the ability to provide an adequate response to individuals following the storm.[118] Without electricity, water services, and an effective means of communication to coordinate assistance, Hurricane Maria was one of the most challenging logistical emergency response operations in FEMA's history.[119] The case study shows that providing clean, safe drinking water for the island of Puerto Rico was insufficient and cost-prohibitive, thus a quicker, more efficient solution to providing clean water supplies is needed to ensure effective emergency relief.

A. BACKGROUND OF HURRICANE MARIA

The Puerto Rico State Agency for Emergency and Disaster Management (AEMEAD) was initially tasked the emergency response management under the "Commonwealth of Puerto Rico Emergency Management and Disaster Administration Agency Act" signed into law on August 2, 1999.[120] The Act provides local oversight on all emergency activities in Puerto Rico, including mitigation, preparation, recovery, and

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117 "Hurricane Maria.," Federal Emergency Management Agency, November 13, 2019, https://www.fema.gov/hurricane-maria.

118 Federal Emergency Management Agency, *2017 Hurricane Season FEMA After-Action Report*.

119 Federal Emergency Management Agency.

120 "Commonwealth of Puerto Rico Emergency Management and Disaster Administration Agency Act," Public Law No. 211, *U.S. Statutes at Large* 21 (1999), http://www.oslpr.org/download/en/1999/0211.pdf.

coordination with federal agencies to discuss the logistics of providing additional resources as needed. When Hurricane Maria was projected to strike Puerto Rico, the AEMEAD quickly realized the island was not sufficiently prepared for a hurricane of this magnitude, especially since most of the region was still recovering from a previous Hurricane Irma, which exhausted many of the local water supplies.[121] Ultimately, the AEMEAD was not prepared for the devastating loss of infrastructure and requests for assistance. These requests included a high demand for safe drinking water.

In 2017 Government Accountability Office (GAO) reported that limited local preparedness was identified as a local contributing factor to effectively undertaking the challenges of Hurricane Maria.[122] Puerto Rico officials determined that a lack of physical space available on the island meant that insufficient storage for the recommended amount of resources to address the needs of all the population.[123] The report concluded that Puerto Rico would require extensive federal assistance in the event of a major hurricane or natural disaster.[124] Based on this information, the local government could not knowingly carry out the duties as the first responders in the event of a major hurricane like Hurricane Maria. Limited preparedness was proven to be the ultimate contributing factor to the failure in emergency response. Not every state or region will be well prepared, and local governments need water options that are always prepared by default.

FEMA and other government agencies were already located in the Caribbean due to Hurricane Irma that struck several days prior.[125] However, the federal response

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[121] Rachel Roubein, "Hurricane Maria Worsens Puerto Rico's Water Woes," *TheHill*, October 4, 2017, https://thehill.com/policy/healthcare/353735-hurricane-maria-worsens-puerto-ricos-water-woes.

[122] Government Accountability Office, *2017 Hurricane and Wildfires: Initial Observations on Federal Response and Key Recovery Challenges*, GAO-18-472 (Washington, DC: Government Accountability Office, 2018).

[123] Government Accountability Office.

[124] Government Accountability Office.

[125] "Coordinated Federal Response to Hurricane Irma Continues in Caribbean," Federal Emergency Management Agency, September 10, 2017, https://www.fema.gov/news-release/2017/09/10/coordinated-federal-response-hurricane-irma-continues-caribbean.

experienced several logistical challenges in responding to Hurricane Maria that led to an overall flawed emergency response by FEMA.[126]

First, the distance between Puerto Rico and the United States presented a logistical challenge. Historically, FEMA provides emergency supplies like water within the continental United States through the U.S. highway system. However, Puerto Rico being an island away from the mainland United States, demonstrated a unique challenge for FEMA. FEMA would have to transport federally-funded emergency supplies over one thousand miles using a cargo ship and/or aircraft to affected areas.[127] Via cargo ship, a limited amount of water supplies would take greater than two days at sea to transport one ship of relief aid across the 1238 nautical miles between Florida and Puerto Rico. JAXPORT, located in Jacksonville, Florida, is the principal embarkation point for most mainland products shipped to and sold in Puerto Rico.[128] The typical transit time for good leaving JAXPORT to San Juan typically requires three to six days, depending on the vessel, course, and speed.[129] Some vessels attempted to leave for Puerto Rico before the landfall of Hurricane Maria. However, due to the storm size, cargo ships were forced to travel further east to circumvent the storm adding additional travel time.[130] Furthermore, the transportation of cargo was delayed due to the impact of Hurricane Harvey and Irma.[131] The Port at San Juan was closed from September 5, 2017, to September 7, 2017, due to Hurricane Irma.[132] As Hurricane Irma continued moving up the coast towards Florida, Jacksonville began preparing for the Hurricane Irma to hit JAXPORT. JAXPORT

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[126] Palin et al., *Supply Chain Resilience and the 2017 Hurricane Season*.

[127] Palin et al.

[128] “Puerto Rico,” Jacksonville Port Authority, February 26, 2018, https://www.jaxport.com/cargo/global-connections/caribbean/puerto-rico/.

[129] “Constraints in Optimized Networks - Evidence from the 2017 Hurricane Season,” CNA, 2017, 27, https://www.cna.org/CNA_files/PDF/IIM-2018-U-018555-Final.pdf.

[130] Robinson Meyer, “A Timeline of Hurricane Maria’s Effects on Puerto Rico,” *The Atlantic*, October 4, 2017, https://www.theatlantic.com/science/archive/2017/10/what-happened-in-puerto-rico-a-timeline-of-hurricane-maria/541956/.

[131] Federal Emergency Management Agency, *2017 Hurricane Season FEMA After-Action Report*.

[132] Federal Emergency Management Agency.

operations were stopped on September 9th, 2017, through September 13th, 2017.[133] By the time JAXPORT reopened for operations, the demand for goods was staggeringly high.[134] Requests from Texas following Hurricane Harvey and requests from South Florida, Puerto Rico, and the U.S. Virgin Islands following Hurricane Irma, created a supply chain backlog.[135] While attempting to meet the demands following Hurricane Harvey and Irma, Hurricane Maria struck Puerto Rico on September 20, 2017, adding to the backlog of requests. The capacity of JAXPORT was operating at capacity and could not meet the demand, thus adding to the time individuals had to wait for water.[136]

Via air cargo, approximately 19,090 liters of water could be transported by air from the U.S. to Puerto Rico every four hours.[137] While a quicker option, the need for drinkable water supplies is often immediate. Waiting for cargo ships and airplanes to arrive in Puerto Rico delayed the federal response during a time of increasingly dwindling resources and imminent demand.[138]

In addition, the power grid of Puerto Rico was severely damaged, adding another factor to the already challenging distribution of goods.[139] The fuel depots were connected to the power grid, and pumping fuel in the traditional sense was not possible.[140] Limited fuel forced drivers to prioritize truck routes to maximize the distribution. Without regular fueling infrastructure, the distribution of water was next to impossible. Cargo ships arriving

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133 Arelis R. Hernández and Steven Mufson, "Getting Relief Supplies to Puerto Rico Ports Is Only Half the Problem," *Washington Post*, September 28, 2018, https://www.washingtonpost.com/business/economy/getting-relief-supplies-to-puerto-rico-ports-is-only-half-the-problem/2017/09/28/9ff558a6-a460-11e7-8cfe-d5b912fabc99_story.html.

134 Federal Emergency Management Agency, *2017 Hurricane Season FEMA After-Action Report*.

135 Palin et al., *Supply Chain Resilience and the 2017 Hurricane Season*.

136 Palin et al.

137 FEMA Public Affairs, "Overview of Federal Efforts to Prepare for and Respond to Hurricane Maria," *Federal Emergency Management Agency* (blog), October 31, 2017, https://www.fema.gov/blog/2017-09-29/overview-federal-efforts-prepare-and-respond-hurricane-maria.

138 Palin et al., *Supply Chain Resilience and the 2017 Hurricane Season*.

139 Government Accountability Office, *Puerto Rico Electricity Grid Recovery: Better Information and Enhanced Coordination Is Needed to Address Challenges,* GAO-20-141 (Washington, DC: Government Accountability Office, 2019).

140 Government Accountability Office.

at the Port of San Juan carrying fuel took priority over water and food.[141] The lack of fuel distribution added to the time required to provide an adequate amount of water to the citizens.[142]

Second, the availability of water supplies was dependent on the access to infrastructure that would allow for airplanes to land and for the water supplies to be received, as well as for the water supplies to be then distributed throughout Puerto Rico.[143] Once Hurricane Maria passed, the ports were reopened, and supplies began to arrive at the Port of San Juan.

However, distribution was not timely due to access problems caused by the unpassable and often destroyed roads as well as the destruction of fueling infrastructure on the island.[144] Local roads, highways, and bridges were washed out, subjected to derbies and mudslides, and completely destroyed, rendering them unpassable.[145] A network of trucks and distribution methods had to be orchestrated to ensure citizens in other parts of the island could receive the required assistance.[146] Unlike the commercial ground transportation contracts within the United States mainland, transportation of water was left to small scale private transportation, typically a large pick-up truck or cargo van, or military transportation to include commercial-grade vehicles or helicopter.[147] Truck drivers would find themselves taking routes approximately two hours out of the way to find open roads. This unforeseen delay resulted in most of the resources being transported, outside of the immediate ports, by helicopter and again delaying the federal response.

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[141] Paul Page and Siobhan Hughes, "Puerto Rico Port Reopens but Relief Distribution Remains Slow," *Wall Street Journal*, September 26, 2017, https://www.wsj.com/articles/puerto-rico-port-reopens-but-relief-distribution-remains-slow-1506446137.

[142] Page and Hughes.

[143] Federal Emergency Management Agency, *2017 Hurricane Season FEMA After-Action Report*.

[144] Nicholas L. Green, "Humanitarian Logistics: Supply Designs for the Post Disaster Cargo Surge" (master's thesis, Air Force Institute of Technology, 2019).

[145] Kara Dapena, Daniela Hernandez, and Arian Campo-Flores, "Inside Puerto Rico's Struggle to Recover a Month after Hurricane," *Wall Street Journal*, October 20, 2017, sec. US, https://www.wsj.com/articles/inside-puerto-ricos-struggle-to-recover-a-month-after-hurricane-1508491811.

[146] Green, "Humanitarian Logistics: Supply Designs for the Post Disaster Cargo Surge."

[147] Green.

The final challenge facing FEMA in response to Hurricane Maria was the high-cost of providing water supplies to Puerto Rico. Based on a review of FEMA contracts from the fiscal year 2017 Quarter 4 through the fiscal year 2018 Quarter 2, the federal government awarded $294,835,735 in contracts to supply and transport water to Puerto Rico.[148] The majority of the cost was for bottled water.[149] According to FEMA, 74,151,954 liters of bottled water and 64,436,560 liters of potable water were shipped to Puerto Rico for $0.55 per liter.[150] The total cost for the water before delivery was $76,223,682.70. This leaves a cost of $218,612,052.30 for the transportation, storage, and distribution of water, which is $1.58 per liter. The grand total amount averaged at $2.13 per liter. Accordingly, the needs for more shipments of critical supplies resulted in more shipments overall, at a high cost to the federal government and tax-paying citizens.

B. LESSONS LEARNED

Current emergency preparedness measures undertaken by the federal government are insufficient because they are costly and take a long time, which is unacceptable in a state of emergency. The need for water is immediate following a hurricane. FEMA and EPA understand the need for clean drinking water.[151] Guidance is provided by both FEMA and EPA, echoing the importance of clean, safe drinking water during emergency situations. Although FEMA and EPA messaging regarding preparedness have increased, current preparation does not go far enough, because it takes too much time and costs too much money.

1. Time Delays

Providing water to individuals affected by a hurricane is a race against time. Emergency responders work as fast as possible to restore water services before the

[148] Federal Emergency Management Agency, *Disaster Contracts Quarterly Report Fourth Quarter, Fiscal Year 2018.*

[149] Federal Emergency Management Agency.

[150] Federal Emergency Management Agency.

[151] "EPA Signs MOU with FEMA to Support Rapid Recovery and Restoration of Water Infrastructure After Disaster Strikes," Environmental Protection Agency, June 4, 2019, https://www.epa.gov/newsreleases/epa-signs-mou-fema-support-rapid-recovery-and-restoration-water-infrastructure-after.

individuals prepared water supply runs out. As proven by the Hurricane Maria case study, such factors as geographic distance and accessible infrastructure can almost certainly delay any federal response measures.[152] After Hurricane Maria, water needed to be transported from another, often farther location, and the critical infrastructure saw extensive damage that complicated direct routes for water supply delivery. Ultimately, each of these factors presents systemic issues with timing. For example, a cargo ship can only contain a limited amount of water supplies, and if it takes several days for the finite amount of water to arrive at the area in need, then it is likely that the need for more water increased during that time. Then, as seen in Puerto Rico, crumbling infrastructure causes further delays in time. All of this adds up to days lost and an increasing need for more water supplies via cargo shipments and inaccessible roads. Time is an issue under current federal emergency management practices. Therefore, a more timely and efficient solution is needed.

2. Expensive Solutions

Water is a unique commodity in the context of emergency response. Water is often required to be distributed in large quantities. However, water has a low value to weight ratio. All these factors add to the overall cost for the federal government in responding to hurricanes. As seen in the Hurricane Maria case study, the cost of providing adequate bottled water supplies was extraordinarily high and ultimately falls on the tax-paying citizens who are left to shoulder the cost.

3. Insufficient Federal Response

The methods for providing water resources during Hurricane Maria were not effective and created a logistical challenge, which resulted in limited feasibility of the solution. Individuals were left without clean, safe drinking water for days, weeks, and in some cases months. The continuous reports from the news media and local government regarding a lack of clean, safe drinking and numerous delays in distribution clearly demonstrated the need to revise the approach to providing emergency water supplies. The

[152] Carmen Heredia Rodriguez, “Water Quality in Puerto Rico Remains Unclear Months after Hurricane Maria,” PBS, June 14, 2018, https://www.pbs.org/newshour/health/water-quality-in-puerto-rico-remains-unclear-months-after-hurricane-maria.

degree of difficulty in providing water during Hurricane Maria was exacerbated by using current methods for distributing water.

Through a series of both foreseen and unforeseen challenges, the local government and FEMA struggled to provide adequate water to the citizen in the aftermath of Hurricane Maria. Problems ranged from a lack of planning, geographic and temporal challenges, distribution failures, destroyed infrastructure, and the subsequent high costs. Even if the emergency response to Hurricane Maria had been well organized, issues with time delays and high costs would have still been enormously challenging. The lessons learned from the Hurricane Maria case study are that current methods used to distribute water in the wake of a damaging hurricane are insufficient for resolving water shortages in an efficient, timely, and effective manner. These challenges must be adequately addressed because water is a necessity.

V. NANOTECHNOLOGY AS A SOLUTION IN FEDERAL EMERGENCY MANAGEMENT

Given the advantages of using nanotechnology for water filtration, notably its efficiency and low cost, the federal government should adopt nanotechnology as the primary method for providing clean and safe water in response to water shortages resulting from hurricanes. The federal government is currently in the best position to adopt nanotechnology as a method for its emergency preparedness because current federal regulations relevant to this solution already encourage the use of new technology to ensure the effective provision of clean water to individuals in need when current systems and infrastructure are inaccessible. As previously explained, there are several advantages to using nanotechnology for water filtration purposes. Most importantly, using nanotechnology for water filtration in the context of emergency management is a timely, cost-effective, and feasible solution.

A. TIME SAVINGS

The federal government should adopt nanotechnology for water filtration in emergency contexts for its time-saving potential. Nanotechnology provides the federal government with the opportunity to produce clean drinking water on-site thus reducing the time currently required to transport water, leaving individuals to wait long periods for water. Due to the lightweight design and versatility of nanotechnology-based water filtration, large scale nanotechnology filters can be delivered, via helicopter, to rural communities quickly producing enough water for long-term sustainability.[153] The speed in which these filters can be deployed helps the federal government meet and potentially exceed DHS and EPA's proposed three-day water supply guidance without jeopardizing affected individuals. Nanotechnology-based water filtration provides the federal government with a timely and efficient solution to providing clean, safe drinking water to individuals.[154]

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[153] LifeSaver, "Portable Water Purification Technology."

[154] Bird, "Graphene Filters Change the Economics of Clean Water."

B. MONEY SAVINGS

The federal government should adopt nanotechnology due to its cost-saving potential. Both the federal and state government have an invested interest in reducing the cost of operations while improving the overall response efforts. Nanotechnology-based water filtration addresses critical components that drive the cost of water higher.[155] Water has a low value to weight ratio. Nanotechnology can decrease the initial cost of the commodity and reduce the amount of weight being transported. As seen in the Hurricane Maria case study, FEMA contracted a price of $0.55 per liter of undelivered water. Nanotechnology-based water filtration provides one liter of water for $0.02 per liter of water. If the federal government adopted nanotechnology-based water filtration over traditional methods, the cost of the water commodity would decrease from $76,223,682.70 to $2,771,770.28. The overall reduction in cost is for one event alone. The 2017 hurricane season included two additional storms, Hurricane Harvey and Hurricane Irma, adding to the overall price of water.[156] These two storms brought requests for an additional 7,460,000 liters of water.[157] The additional liters of water would add $4,103,000 in undelivered commodity cost, bringing the grand total of undelivered commodity cost of water for the 2017 hurricane season to $80,326,682.70. By using nanotechnology-based water filtration, the federal government could reduce the commodity cost of water from $80,326,682.70 to $2,920,970.28. The cost savings translates to a 97-percent reduction in commodity cost or a potential savings of $77,405,712.40 when applied to the 2017 hurricane season. The same percentage and projections could be applied to future emergency response predictions to determine the commodity cost of water.

Nanotechnology-based water filtration could provide the same quantity of water as seen in Hurricane Maria with an upfront cost of $443,200 for large scale nanotechnology-

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155 Luciana Gravotta, "Cheap Nanotech Filter Clears Hazardous Microbes and Chemicals from Drinking Water," *Scientific American*, May 7, 2013, https://www.scientificamerican.com/article/cheap-nanotech-filter-water/.

156 Federal Emergency Management Agency, *2017 Hurricane Season FEMA After-Action Report*.

157 "Federal Government Continues Response to Hurricane Harvey," Federal Emergency Management Agency, September 1, 2017, https://www.fema.gov/news-release/2017/09/01/federal-government-continues-response-hurricane-harvey.

based water filters. Additional cost comes in the form of standard maintenance and filter replacement. The current replacement cost of a 500,000 liter filter is $1600 as the current manufacturer does not sell the individual replacement filters. Additionally, to transport the same amount of water provided by one nanotechnology-based water filter, the federal government would be required to transport more than 1,100,000 pounds of water, equating to $0.72 per pound of water.

Conversely, the federal government could transport one nanotechnology-based water filter capable of filtering 500,000 liters of water, only weighing 132 pounds and source the water from any location or condition. Developing countries with limit supplies of clean drinking water are currently using nanotechnology-based water filtration to provide timely, safe drinking water whenever required at a significantly reduced operating cost.[158] The same challenges of providing clean drinking water, as seen in developing countries are similar challenges seen in emergency response. The reduction in cost would allow the federal government and tax-payers to save money in situations that continue to cost more and more.

The National Nanotechnology Initiative (NNI) is currently funded to continue the research and development to understand better the intricacies of nanotechnology and how to control matter at the nanoscale.[159] The fiscal year 2019 budget allocated $1.4 billion to the NNI to continue their research into the development and applications for nanotechnology.[160] Federal funding remains consistent with the interest of the scientific community and the potential to provide a long- term sustainable water solution. A review of previous budget requests shows minor fluctuations, leading to an overall slight decrease in funding. However, these budget decreases have not limited the NNI's ability to continue their necessary research. Such agencies as DHS and the EPA will continue to benefit from

[158] Noubactep, "Affordable Safe Drinking Water for Victims of Natural Disasters."

[159] "NNI Budget," National Nanotechnology Initiative, accessed May 5, 2019, https://www.nano.gov/about-nni/what/funding.

[160] National Science and Technology Council, *The National Nanotechnology Initiative: Supplement to the President's 2019 Budget*.

federal funding supporting the research, development, and innovative applications of nanotechnology.[161]

C. TECHNOLOGICAL AND REGULATORY FEASIBILITY

The use of nanotechnology for water filtration in response to destructive hurricanes is a highly feasible solution, both with regards to accessibility to current products and potential adoption under current federal regulations.

1. Technological Feasibility

As previously explained, there are several nanotechnology-based water filtration products already in existence, for example the LifeSaver bottle. Nanotechnology-based water filtration technology has transitioned from laboratory testing to full-fledged products available in commercial markets.[162] Most recently, individuals in the hiking and outdoor communities have used nanotechnology-based water filtration as an alternative means of carrying large, often heavy, quantities of water for backpacking and camping.[163] As seen above, such companies as LifeSaver have already developed products to meet the demands of a limited supply of drinking water in response to emergencies.[164] For example, the LifeSaver bottle has successfully been on the market since 2007 and continues to expand and develop new products.[165] Therefore, nanotechnology products can easily be plugged into emergency response contexts without having to undertake tremendous research, design, and manufacturing. Although, the federal government may choose to work with nanotechnology research companies, including the NNI, to explore further applications of nanotechnology in emergency preparedness. In conclusion, adoption of nanotechnology

[161] National Nanotechnology Initiative, "NNI Budget."

[162] MaryTheresa M. Pendergast and Eric M. V. Hoek, "A Review of Water Treatment Membrane Nanotechnologies," *Energy & Environmental Science* 4, no. 6 (June 2011): 1946–71, https://doi.org/10.1039/C0EE00541J.

[163] "How to Choose a Water Filter or Purifier," S Recreational Equipment, Inc, eptember 2019, https://www.rei.com/learn/expert-advice/water-treatment-backcountry.html.

[164] LifeSaver, "Water Purifier Bottles - Travel, Backpacking, Hiking, Outdoor."

[165] LifeSaver.

for water filtration is a feasible solution because the technology is already accessible and is commercially viable.

2. Regulatory Feasibility

Nanotechnology is a feasible solution because current federal regulations, as they are currently written, allow for use of nanotechnology as a primary method to address emergency response and water shortages. First, nanotechnology meets current clean water standards under the Safe Drinking Water Act. As addressed above, nanotechnology is proven highly effective at filtrating clean and safe drinking water. Accordingly, the use of nanotechnology for water filtration should not present any issues under the Safe Drinking Water Act. Second, FEMA's regulations under the Stafford Act permit use of new technologies in order to ensure ample supply of clean water in emergencies. Therefore, current regulations as implemented by FEMA should not bar adoption of nanotechnology to address water shortages resulting from hurricanes. Third, the NNI, consistent with the 21st Century Nanotechnology Research and Development Act, is already exploring applications for nanotechnology for water filtration purposes. As explained above, there are a multitude of nanotechnology products already in existence. Therefore, there appears to be no obstacle for requiring the NNI to focus its research primarily on exploring nanotechnology for water filtration in emergencies. In sum, existing federal regulations do not present any major obstacles to implementing nanotechnology into current emergency management procedures. The federal government can and should make nanotechnology part of its emergency response methods.

D. OVERCOMING FORESEEABLE ISSUES WITH ADOPTION OF NANOTECHNOLOGY

Although the use of nanotechnology-based water filtration products is a feasible and effective solution in response to emergency water shortages, there are foreseeable issues with implementation of this solution. First, in order to fully adopt nanotechnology as a primary method of emergency management, the federal government must coordinate with relevant parties to secure the technology via appropriate government contracts.

Second, given that nanotechnology is a relatively new product, the federal government may face some initial backlash from the public.

The first issue is with securing appropriate government contracts. While nanotechnology-based water filtration products existent in commercial markets, the federal government must collaborate with these private manufacturers to obtain ample supplies of these products at an appropriately low cost. The federal government must work on managing this solution both with regard to budget and accessibility. This will require sufficient coordination between the federal government and private manufacturers to establish the right government contracts and ensure that nanotechnology is readily available in unpredictable times of need.

The second issue is with regard to public perception.[166] Implementation of a new solution, one that many people may not be familiar with, may result in some initial mistrust in using nanotechnology in a state of emergency. However, with sufficient education and marketing by the federal government can overcome any initial mistrust in using nanotechnology long-term.

Despite these foreseeable obstacles for adopting nanotechnology into federal emergency management, nanotechnology remains a highly feasible solution, and therefore should be adopted by the federal government as part of its emergency management procedures.

[166] John T. Gourville, "Note on Innovation Diffusion: Rogers' Five Factors," *Harvard Business School*, April 17, 2006, 6.

VI. CONCLUSION

The federal government should adopt nanotechnology-based water filtration as an innovative solution to address the need for clean water in the aftermath of a hurricane. Primarily, the use of nanotechnology will save time, money, is technologically feasible, and is allowable under current federal regulations. The above analysis demonstrates that nanotechnology-based water filtration will drastically reduce the amount of time and money required to provide adequate amounts of water filtration to individuals in affected areas following a damaging hurricane. Furthermore, the adoption of nanotechnology will assist the federal government in effectively and efficiently fulfilling the requirements of the Stafford Act, Safe Drinking Water Act, and the 21st Century Nanotechnology Research and Development Act. Together, FEMA, EPA and the NNI should collaborate to improve federal emergency management measures and to ensure safe and clean water for all in need. Through this collaboration, the federal government can avoid another case like Hurricane Maria while saving time, money, and human lives.

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