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# Case Studies: Estimation of Waste and Debris Following a Large-Scale Natural Disaster

Office of Research and Development
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# Case Studies: Estimation of Waste and Debris Following a Large-Scale Natural Disaster

## December 2022

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## FOREWORD

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The Center for Environmental Solutions and Emergency Response (CESER) within the Office of Research and Development (ORD) conducts applied, stakeholder-driven research and provides responsive technical support to help solve the Nation’s environmental challenges. The Center’s research focuses on innovative approaches to address environmental challenges associated with the natural and built environment. We develop technologies and decision-support tools to help safeguard public water systems and groundwater, guide sustainable materials management, remediate sites from traditional contamination sources and emerging environmental stressors, and address potential threats from terrorism and natural disasters. CESER collaborates with both public and private sector partners to foster technologies that improve the effectiveness and reduce the cost of compliance, while anticipating emerging problems. We provide technical support to EPA regions and programs, local, states, territorial, tribal nations, and federal partners, and serve as the interagency liaison for EPA in homeland security research and technology. The Center is a leader in providing scientific solutions to protect human health and the environment.

This report contains several case studies presenting debris/waste estimates from hypothetical scenarios involving natural disasters. It is hoped that these case studies provide decision makers at the local, state, territorial, tribal, and federal levels with information that could be used to help generate pre-incident response and recovery planning documents, including disaster debris management plans, to facilitate material and waste management after a disaster.

Gregory Sayles, Director

Center for Environmental Solutions and Emergency Response

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## EXECUTIVE SUMMARY

Waste and debris management presents considerable challenges during any large-scale disaster; additional challenges will exist during a wide-area chemical, biological, radiological, or nuclear (CBRN) incident. Waste is a broad-based term that refers to all materials generated as a result of an incident that require management via reuse, recycling, recovery, treatment, and disposal. Debris is a narrower term generally referring to materials that were generated as a result of an incident but are typically commingled in a complex mixture that frequently inhibits some of the debris/waste minimization approaches that can be done with materials that are easily segregated.

The US Department of Homeland Security (DHS) has encouraged pre-incident emergency planning by states, communities, tribes, and even large facilities for a variety of disaster scenarios. EPA, in response to this general recommendation by DHS, has in turn encouraged pre-incident waste management planning by the same entities. EPA developed an online tool, the All-Hazards Waste Management Planning Tool (AHWMPT), to help these entities develop pre- and post-incident plans. An important part of pre-incident debris/waste management planning for both natural and manmade disasters is to develop a prospective inventory of debris/waste materials, including types, masses, volumes, and condition of materials, so that communities may begin planning for the management (e.g., staging, treatment, disposal) of the magnitude of prospective materials and wastes that may be generated. The types and amounts of debris that are generated by a disaster may guide many debris/waste management logsitics decisions (e.g., whether debris can be reused or recycled, whether temporary staging areas will be needed, where debris can be sent for treatment and disposal, how many trucks and other resources will be needed).

Often, emergency planners do not have sufficient time or resources to allow them to effectively plan for low-probability, high-impact incidents. The purpose of this document is to develop a set of scalable case studies of various types of scenarios that could be utilized by communities to develop an initial estimate of debris and waste quantities and types that would be suitable for use in pre-incident planning documents, including disaster debris management plans, noting that planning for natural disasters can largely be applied to planning for manmade disasters such as terrorist incidents involving contamination with chemical, biological, or radiological materials. The inventories that are presented are accompanied by Excel workbooks that can allow the user to linearly scale the estimates to better suit their planning scenarios, based on estimates of destruction, changing the size of affected areas, or by changing the number of affected populations. These case studies should facilitate development of pre-incident waste management plans by relieving emergency planners from the task of developing a hypothetical estimate of debris upon which they could base their decision-making in planning documents.

The programmatic objective of these case studies is to develop a scalable estimate of the waste and debris that would be generated by several types of hypothetical natural disasters. The natural disasters to be addressed in case study development include:

- A Category 4-5 hurricane at a coastal urban center;
- A magnitude 7-8 earthquake followed by a tsunami at an urban center; and
- An EF4 tornado at an inland, small metropolitan community.

The estimates will either be based on documentation from previous exercises, based on modeling results supplied by or acquired by the Principal Investigator (PI), or based on discussions with various Subject Matter Experts (SMEs) and manually drawn using Esri's ArcGIS software. Lists of affected infrastructure will be generally based on the Federal Emergency Management Agency's (FEMA's) Hazus infrastructure databases [1], although if a custom infrastructure data set is available for the community, then those data were used for quantifying infrastructure rather than the Hazus data.

Estimates of waste, debris, and other materials that would result from the disaster and associated response and recovery operations were developed. Estimates of destruction of the affected infrastructure will be inputted as a "fraction destroyed" user-adjustable parameter. Debris/waste estimates will be presented based on mass, volume, and type of debris/waste.

Some general observations and commonalities were made from the three scenarios described in this report. These include:

- Medical waste does not appear to be generated in significant quantities; however, significant amounts of pharmaceuticals and medical supplies may need to be managed as waste.
- Electronic equipment may constitute a significant debris stream but may be able to be managed as material.
- Animal carcasses were not included in the waste estimate but may constitute a problematic waste stream since some of the waste management practices used for disposal of animal carcasses require large sources of carbonaceous material (e.g., composting) which may not be readily available in the immediate aftermath of a disaster.
- Limitations in availability of heavy equipment may significantly impact recovery efforts for all streams.
- Segregation will likely be a significant part of cleanup to manage the different streams.

There were also some special considerations that were observed for the scenarios presented in this document:

- There is not an immediately available method to estimate the numbers of orphan tanks. It might be possible to make an estimate by compiling data of household usage of above-ground tanks and gas grills, coupled with business (particularly gas stations) usage of above ground tanks**.**
- Many communities do not have a nearby Resource Conservation and Recovery Act (RCRA) Subtitle C disposal facility to manage hazardous waste. Affected industrial facilities as well as port recovery operations may generate significant quantities of hazardous waste that would need to be transported long distances for treatment/disposal; So, communities may want to consider facilities in other areas as backups.
- Identification of the numbers and locations of radioactive sources in the affected area should be done as soon as possible. Sources would be registered with the State or the Nuclear Regulatory Commission (NRC); contact the State radiation control program to locate potential sources.
- A potential issue exists where future debris/waste management capacity may be reduced due to wastes being produced during cleanup operations, as previously damaged materials enter the debris/waste stream.
- In the event that reduced waste management capacity may impact the ability to perform recovery operations, it is suggested that other alternatives (e.g., waste-to-energy facilities) be considered.
- A significant number of transformers might be damaged and require replacement. Some of them might contain polychlorinated biphenyls (PCBs). This is a potentially important waste stream that has specific requirements associated with its management. Determine if PCB-containing electrical equipment, particularly transformers and capacitors, is located within the community so that PCB spills or other environmental releases may be planned for.

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## GLOSSARY AND LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AHWMPT | All-Hazards Waste Management Planning Tool |
| C&D | Construction and Demolition |
| CBRN | chemical, biological, radiological, or nuclear (CBRN) incident |
| CESER | Center for Environmental Solutions and Emergency Response |
| DDRT | Disaster Debris Recovery Tool |
| DHS | US Department of Homeland Security |
| DQI(s) | Data Quality Indicator(s) |
| EPA | United States Environmental Protection Agency |
| FEMA | Federal Emergency Management Agency |
| GIS | Geographical Information Services |
| HSMMD | Homeland Security Materials Management Division (EPA) |
| HSRP | Homeland Security Research Program (EPA) |
| I-WASTE | Incident Waste Decision Support Tool (iwaste.epa.gov) |
| kg | Kilogram(s) |
| $m^3$ | Cubic meter(s) |
| $mi^2$ | Square mile(s) |
| Nonstructural | The parts of the building that are joined to the structure but do not provide structural integrity to the building (e.g., wallboard) |
| NRC | Nuclear Regulatory Commission |
| OLEM | Office of Land and Emergency Management (EPA) |
| ORD | Office of Research and Development (EPA) |
| PCB | Polychlorinated biphenyl |
| PEA | Performance Evaluation Audit |
| PI | Principal Investigator |
| QA | Quality Assurance |

| | |
|---|---|
| QAPP | Quality Assurance Project Plan |
| QC | Quality Control |
| RCRA | Resource Conservation and Recovery Act |
| SF | Scaling Factor |
| SME | Subject Matter Expert |
| Structural | The parts of the building that provide structural integrity to the building |
| TSA | Technical System Audit |
| WEST | Waste Estimation Support Tool |
| WME | Waste Materials Estimator |
| $yd^3$ | Cubic yard(s) |

# 1.0 INTRODUCTION

Waste and debris management presents considerable challenges during any large-scale disaster; additional challenges will exist during a wide-area chemical, biological, radiological, or nuclear (CBRN) incident. Waste is a broad-based term that refers to all materials generated as a result of an incident that require management via reuse, recycling, recovery, treatment, and/or disposal. Debris is a narrower term generally referring to materials that were generated as a result of an incident but are typically commingled in a complex mixture that frequently inhibits some of the waste minimization approaches that can be done with materials that are easily segregated.

The US Department of Homeland Security (DHS) has encouraged pre-incident emergency planning by states, communities, tribes, and even large facilities for a variety of disaster scenarios. EPA, in response to this general recommendation by DHS, has in turn encouraged pre-incident waste management planning by the same entities [2]. EPA developed an online tool, the All-Hazards Waste Management Planning Tool (AHWMPT), to facilitate development of pre- and post-incident plans [3]. An important part of pre-incident debris/waste management planning is to develop a prospective inventory of debris/waste materials, including types, masses, and volumes, so that the management (e.g., staging, treatment, disposal) of this hypothetical debris/waste inventory can be included in the planning documents.

Many emergency planners do not have sufficient time or resources to allow them to effectively plan for low-probability high-impact incidents. The purpose of this document is to develop a set of scalable case studies of various types of scenarios that could be utilized by communities to develop an initial estimate of debris/waste quantities and types that would be suitable for use as the foundation for pre-incident planning. The inventories that are presented are accompanied by Excel workbooks that can allow the user to linearly scale the estimates to better suit their planning scenarios, based on estimates of destruction, changing the affected areas, or by changing the number of affected populations. These case studies should facilitate development of pre-incident debris/waste management plans by relieving the emergency planners from the potentially onerous task of developing a hypothetical estimate of debris/waste upon which they could base their planning documents.

## 1.1 Programmatic Objectives

The programmatic objective of these case studies is to develop a scalable estimate of the waste and debris that would be generated by several types of hypothetical natural disasters. The natural disasters to be addressed in case study development include (note – these are examples, and the severity of the incident that is used depends on availability of data to create the scenario):

- A Category 4-5 hurricane at a coastal urban center;
- A magnitude 7-8 earthquake followed by a tsunami at an urban center; and
- An EF5 tornado at a small inland metropolitan community.

## 1.2 Case Study Overview and Scope

The estimates will be based on scenarios documented from previous exercises, based on modeling results supplied by or acquired by the project team, or based on discussions with various Subject Matter Experts (SMEs). Decision support tools developed by EPA's Homeland Security Research Program (HSRP) will be used to generate waste and debris estimates based on those scenarios. Affected infrastructure will be generally based on FEMA's Hazus [1] infrastructure databases (EPA's HSRP tools make extensive use of the Hazus databases), although if a custom infrastructure data set is available for the hypothetical

community, then those data are used for quantifying infrastructure rather than the Hazus data. It must be noted that certain important key infrastructure parameters (e.g., building vulnerability) are not included in the Hazus data nor are they commonly included in the custom infrastructure data sets.

Estimates of waste, debris, and other materials will be developed that would result from response and recovery operations. Estimates of destruction of the affected infrastructure will be inputted as a "fraction destroyed" user-adjustable parameter. Debris/waste estimates will be evaluated based on mass, volume, and type of debris/waste.

# 2.0 DECISION SUPPORT TOOLS TO BE USED

Large-scale disasters have the potential to generate significant amounts of debris, waste, and materials. For example, Hurricane Katrina and the Joplin, Missouri, tornado resulted in approximately 100 million and 1.5 million cubic yards of debris/waste, respectively. Man-made chemical, biological, radiological, or nuclear (CBRN) incidents, either by way of terrorism, war, or accident, have the potential to generate as much or potentially even more debris/waste. Both natural and man-made incidents are also prone to generate some form of hazardous or contaminated waste that is more complicated to remediate or dispose of; as an example, household hazardous waste is an important waste stream from a response/recovery perspective. Recovery is significantly impacted by debris/waste management issues made by various independent decision makers (e.g., emergency managers, households, waste managers, etc.). The quantification, segregation, transportation, and storage of debris/waste can be an arduous and costly undertaking. Furthermore, these processes are intricately linked with other decisions made throughout the recovery timeline. Therefore, recovery operations, including waste management, must be holistically considered. Understanding these complex interactions can be facilitated by using models and tools that adhere to the "system-of-systems" approach.

To better understand and predict debris/waste management issues, EPA's HSRP is developing a suite of tools and resources for planning, response, and recovery purposes. These tools will be the primary sources of the debris/waste estimates and other information.

This document is primarily focused on case studies involving different natural disasters affecting different types of communities; the tools, I-WASTE and WEST, which are described below, were used to develop the debris/waste characterizations and estimates for the scenarios.

## 2.1 I-WASTE

EPA's Incident Waste Decision Support Tool (I-WASTE) (iwaste.epa.gov) [4] provides important information to support planning and response decision-making and features calculators to generate debris/waste quantity estimates, provides databases of treatment and disposal facilities, and includes a quick reference to technical information, regulations, and guidance to address the safe and efficient removal, transport, and disposal of debris/waste materials. The objective of I-WASTE is to help reduce recovery time and expense by providing quick access to information that will inform the decision-making process for incident debris/waste management. I-WASTE supports EPA's goals to strengthen resilience to disasters and complements other EPA tools such as the Disaster Debris Recovery Tool (DDRT) [5] and the All-Hazards Waste Management Planning Tool (wasteplan.epa.gov) [3]. I-WASTE has recently undergone a significant modernization effort and has been moved to cloud.gov servers to facilitate data exchange with other debris/waste management tools developed by HSRP, Office of Land and Emergency Management (OLEM), and the Regional Offices.

## 2.2 WEST

EPA's Waste Estimation Support Tool (WEST) [6-10] is a Geographical Information Services (GIS)-based decision support tool for estimating the characteristics, amounts, and residual contaminants of debris/waste generated from remediation and cleanup activities after a biological or radiological contamination incident. WEST consists of a GIS module that estimates the infrastructure and urban surfaces affected by a wide-area contaminant release and a calculator module that estimates debris/waste amounts and characteristics as a function of decontamination approaches. WEST has been released to the public and has been used in numerous national level exercises and planning scenarios and continues to be improved and refined to add additional functionality and performance. The most recent version of WEST included the ability to substitute the FEMA Hazus infrastructure databases that WEST normally uses with user-defined infrastructure databases so that communities with high resolution infrastructure databases or international partners could use WEST.

WEST was primarily designed to be used for radiological or biological release incident-generated debris/waste. However, by using the elements of WEST that reflect demolition operations and their impact on debris/waste quantities, WEST can be used to estimate the debris/waste from natural disasters. For the purposes of natural disasters, the decontamination strategies for buildings were set with no decontamination being applied. The WEST destructive decontamination technologies (e.g., excavation, removal) were included in the decontamination strategies for outdoor materials to reflect demolition of concrete and asphalt areas in outdoor areas.

# 3.0 HYPOTHETICAL SCENARIOS

In this document, three (3) hypothetical scenarios will be used to generate debris/waste estimates that could be scaled to different sized communities, different population numbers, and/or different levels of destruction that the disaster caused, using the accompanying Excel workbooks that utilize simple mathematics to apply these factors to the estimates (see Section 4). Those hypothetical scenarios include:

- A Category 4-5 hurricane at a coastal urban center (Wilmington, NC, is used as the example);
- A magnitude 7-8 earthquake followed by a tsunami at an urban center (Anchorage, AK, is used as the example); and
- An EF5 tornado at a small inland metropolitan area (Joplin, MO, is used as the example).

## 3.1 Hypothetical Scenario 1: Hurricane

### 3.1.1 Impacted Area and Infrastructure

The Waste Estimation Support Tool (WEST) [11] was used to develop debris estimates for a scenario involving a coastal urban center that experiences a category 4-5 hurricane. Wilmington, NC, was used as the example geographic study area for this type of community. WEST normally uses FEMA's Hazus-MH [1] databases to estimate affected infrastructure. However, since a "custom infrastructure" data set was available for Wilmington from New Hanover County that included the actual buildings located in the hypothetically affected area rather than the aggregated building inventory from the FEMA Hazus databases, the custom infrastructure database was used for this estimate. Destruction was included in the calculations as a percentage of the different types of infrastructure that were destroyed in the affected area. These percentages were intended to approximate the number of buildings that were completely destroyed rather than debris resulting from partial destruction. The approach taken was intended to provide the user with a simple approach for scaling the damage rather than introducing unnecessary complications that would not provide greatly improved accuracy in the estimates. The area chosen as the study area encompassed most of the populated section of Wilmington, especially the areas along the waterfront that are subject to the storm surge. Figures 1 and 2 depict the hypothetical impacted area in Wilmington, NC. In Figure 1, the blue areas represent the locations of buildings.

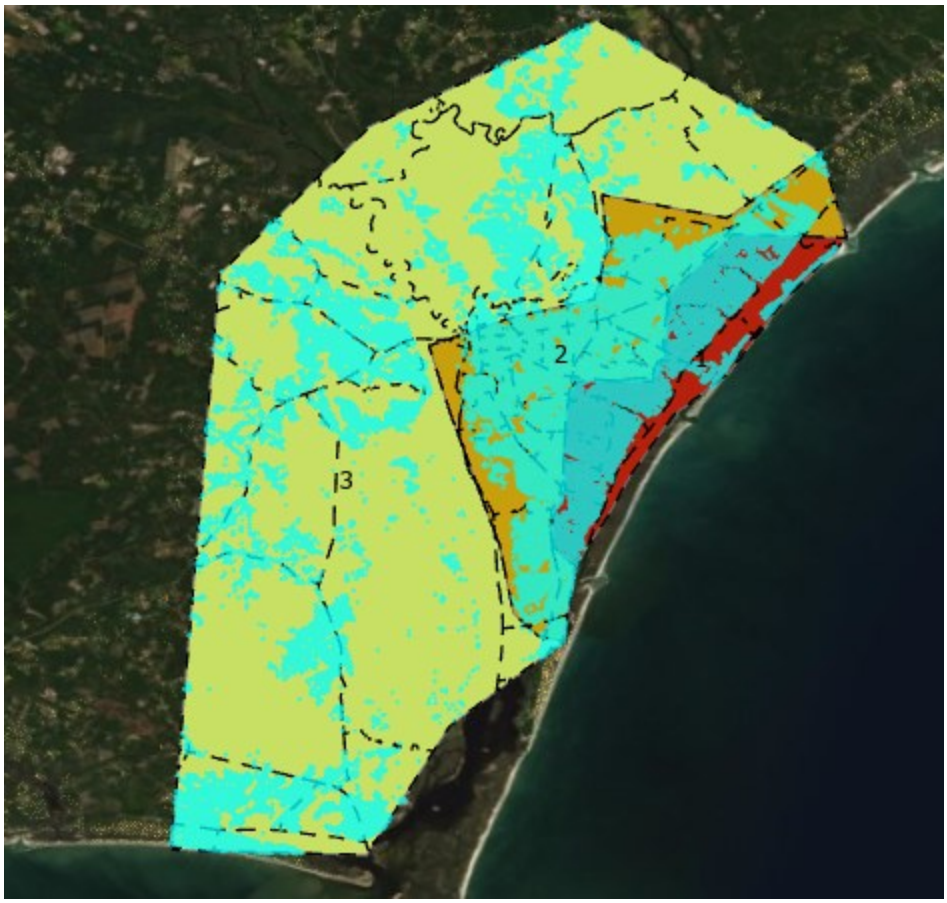


**Figure 1. Hypothetically impacted area in Wilmington, NC (numbers reflect the zone numbers and blue areas reflect locations of built infrastructure; roads and outdoor areas were included in the subsequent estimates; unique infrastructure like bridges were not included)**

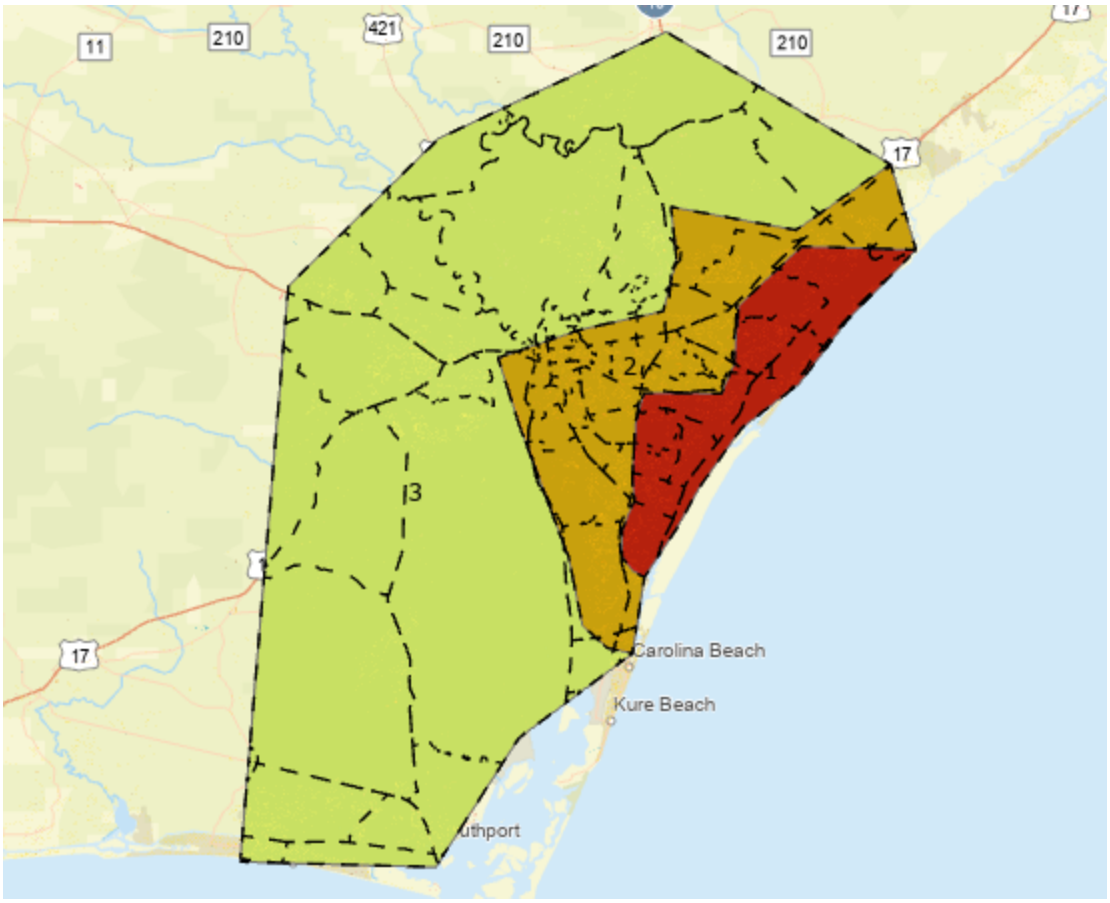


**Figure 2. Locations of geographic zones in hypothetical hurricane scenario for Wilmington, NC**

Based on the numbers of potentially damaged vertical infrastructure (i.e., buildings), I-WASTE [12] was then used to estimate the contents of the buildings that would likely be managed as debris/waste if ALL the buildings were destroyed. These estimates were then multiplied by the fraction of destroyed infrastructure from the Excel workbook to derive an estimate of debris/waste resulting from the hypothetical disaster. Note that bridges and rail systems are not included in the estimate. Roadways are included as part of the outdoor area estimation. Average building square footages were assumed based on I-WASTE default values. Table 1 lists the estimated numbers of infrastructure of different types (i.e., representing ALL the infrastructure in the study zone), using the WEST tool. Figure 3 shows a graphical representation of the potentially affected infrastructure. To convert these numbers to estimated numbers of affected infrastructure, 5% of the structures in Zone 1 would be destroyed, 2% of the structures in Zone 2 would be destroyed, and 1% of the structures in Zone 3 were estimated to be destroyed. See Section 4 to change the estimates using the included Excel workbooks. Note that the definitions of these infrastructure types is contained in the documentation for the FEMA Hazus software [1].

**Table 1. Estimate of total numbers of infrastructure in study area from hypothetical hurricane scenario***

| WEST Infrastructure Type | Zone 1 | Zone 2 | Zone 3 |
|---|---|---|---|
| Agriculture | 72 | 176 | 127 |
| Banks | 16 | 86 | 35 |
| Church/Nonprofit | 91 | 330 | 178 |
| Colleges/Universities | 2 | 14 | 4 |
| Construction | 169 | 404 | 335 |
| Emergency Response | 2 | 14 | 4 |
| Entertainment and Recreation | 181 | 538 | 243 |
| Food/Drugs/Chemicals | 5 | 39 | 48 |
| General Services | 8 | 77 | 54 |
| Grade Schools | 28 | 90 | 50 |
| Heavy | 37 | 149 | 117 |
| High Technology | 1 | 0 | 1 |
| Hospital | 1 | 30 | 2 |
| Institutional Dormitory | 16 | 133 | 34 |
| Light | 41 | 129 | 85 |
| Medical Office/Clinic | 63 | 322 | 90 |
| Metals/Minerals Processing | 6 | 13 | 7 |
| Mobile Home | 874 | 2,054 | 6462 |
| Multifamily Dwelling - 10-19 Units | 11 | 417 | 93 |
| Multifamily Dwelling - 20-49 Units | 5 | 71 | 21 |
| Multifamily Dwelling - 3-4 Units | 51 | 794 | 151 |
| Multifamily Dwelling - 50+ Units | 6 | 15 | 4 |
| Multifamily Dwelling - 5-9 Units | 20 | 743 | 163 |
| Multifamily Dwelling - Duplex | 248 | 1093 | 431 |
| Nursing Home | 11 | 36 | 11 |
| Personal and Repair Services | 122 | 562 | 294 |
| Professional/Technical Services | 266 | 776 | 442 |
| Retail Trade | 133 | 620 | 317 |
| Single Family Dwelling | 19,380 | 38,293 | 28,281 |
| Temporary Lodging | 14 | 86 | 57 |
| Theaters | 2 | 40 | 5 |
| Wholesale Trade | 95 | 371 | 224 |

*These numbers are multiplied by the estimated % destruction to estimate the numbers of destroyed infrastructure

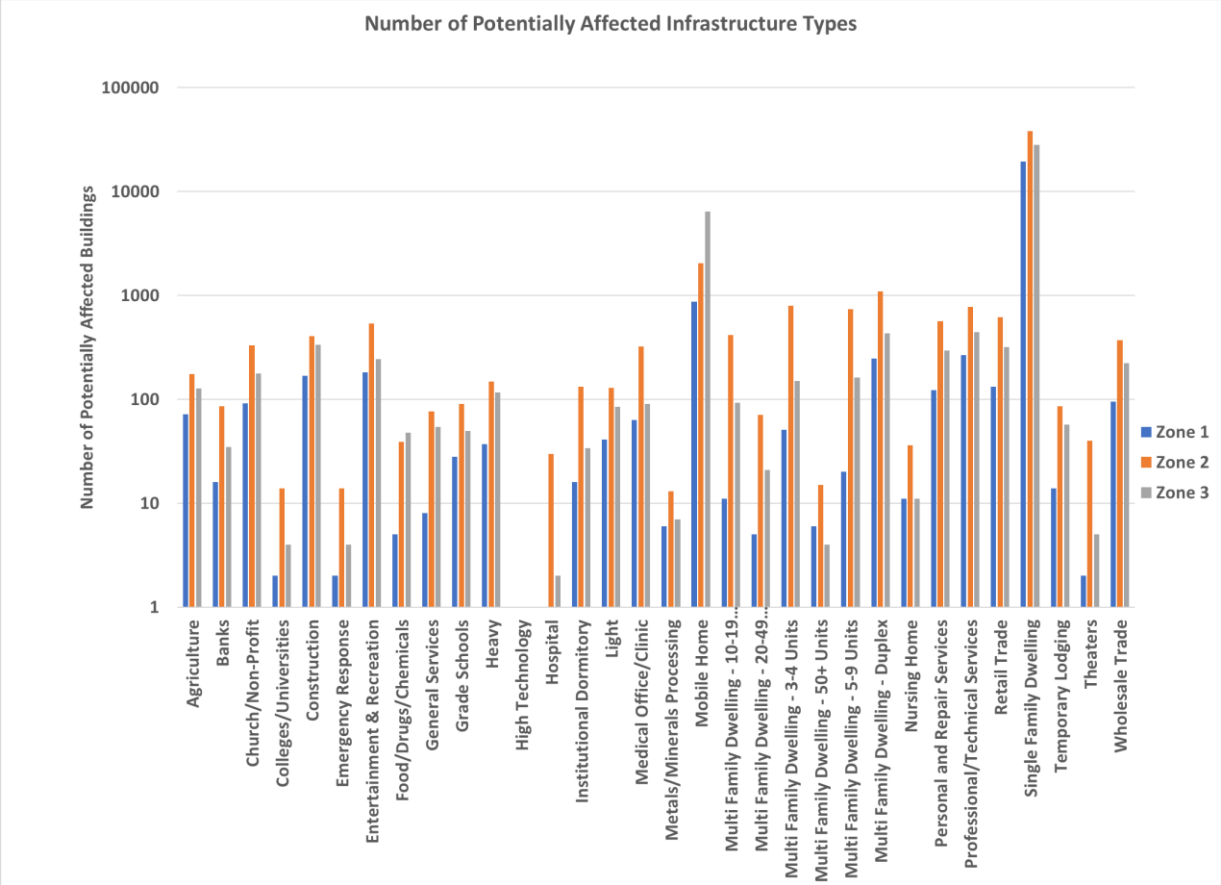


**Figure 3. Estimate of total numbers of infrastructure in hypothetical hurricane scenario**

For the purposes of estimating the potential building contents, it was necessary to cross-reference the building types from the WEST estimate to the building types within I-WASTE Waste Materials Estimator (WME). Table 2 shows the number of potentially affected structures for the purposes of calculating building contents. The last column of Table 2 shows how the building types from Table 1 were matched to those that were available in I-WASTE. Note that some building types from Table 1 did not have an obvious analog in the I-WASTE estimate that could be used to cross-reference the building types for the two tools. Those building types were not included in the estimation of building contents. Some of these building types (e.g., Agriculture) were too vaguely defined in Hazus to allow those types of buildings to be cross-referenced between WEST and I-WASTE. Those additional building types do not represent most of the building types so it is likely that their absence will not create huge errors in the debris/waste estimates. These nonincluded building types also offer an opportunity for inclusion in future versions of the tools. See Section 4 for how the buildings in WEST were cross-referenced to the buildings in I-WASTE in the development of the estimates.

**Table 2. Number of potentially affected structures for hypothetical hurricane scenario - calculation of building contents by mapping WEST building types to I-WASTE building types***

| I-WASTE WME Infrastructure Type | Zone 1 | Zone 2 | Zone 3 | Mapping of WEST Infrastructure to I-WASTE Infrastructure |
|---|---|---|---|---|
| Movie Theaters | 2 | 40 | 5 | Theaters |
| Single-Family Residences | 20004 | 47840 | 30551 | Single Family Dwelling, Multifamily Dwelling x 0.5, Mobile Home x 0.5, Institutional Dormitory*0.5 |
| Hospitals, Medium | 18 | 98 | 22 | Hospital, Medical Office/Clinic * 0.1, Nursing Home |
| Hospitals, Large | - | - | - | |
| Hotels, Small | 14 | 86 | 57 | Temporary Lodging |
| Hotels, Medium | - | - | - | |
| Hotels, Large | - | - | - | |
| Offices, Small | 341 | 1020 | 585 | Banks, Church/Nonprofit, Professional/Technical Services |
| Offices, Medium | - | - | - | |
| Offices, Large | - | - | - | |
| Schools, Elementary | 30 | 104 | 54 | Grade Schools, Colleges/Universities |
| Schools, Middle | - | - | - | |
| Schools, High | - | - | - | |
| Shopping Malls, Small | 228 | 991 | 541 | Retail Trade, Wholesale Trade |
| Shopping Malls, Medium | - | - | - | |
| Shopping Malls, Large | - | - | - | |

*These numbers are multiplied by the % destruction to estimate the numbers of destroyed infrastructure.

### 3.1.2 Debris/Waste Estimate for Hurricane Scenario

To generate the debris/waste estimates, it is necessary to assign a level of destruction to each of the 3 geographic zones used in WEST. For this scenario, Zone 1 represented the portion of the city closest to the waterfront and most likely to suffer damage due to storm surge. Zone 2 represents an intermediate level of damage, and Zone 3 is located up a hill and is less likely to suffer extensive damage. For the purposes of this debris/waste estimate, it was assumed that 5%, 2%, and 1%, respectively, of the buildings in zones 1, 2, and 3 were destroyed as a result of the storm. These percentages were intended to approximate the number of buildings that were completely destroyed rather than debris resulting from partial destruction. The approach taken was intended to provide the user with a simple approach for scaling the damage rather than introducing unnecessary complications that would not provide greatly improved accuracy in the estimates. Note that Section 4 describes how to use the accompanying Excel workbooks to change these percentages as the user sees fit. Table 3 lists the estimated mass of different structural, nonstructural, and outdoor materials. Table 4 lists the same data but in terms of volume in cubic meters. Figure 4 displays the mass estimate of those same materials.

Table 5 lists the estimated mass of building contents from the hypothetical hurricane scenario, and Figure 5 graphically illustrates these estimates. Note that analogous volumes were not displayed in these tables and figures to avoid repetition. The volumes are available in the appendices. Due to its particular interest in managing post-disaster debris/waste, household hazardous waste was put into a

separate table. Table 6 separately lists the estimated mass of household hazardous waste from the hypothetical hurricane scenario, and Figure 6 graphically illustrates these estimates.

The total amount of debris/waste generated from the hypothetical hurricane scenario using the destruction fractions that were assumed for calculation purposes and including the building contents plus the structural and nonstructural materials is estimated at 9.1E9 kg (9.1E6 tonnes) and 8.2E7 cubic meters ($m^3$). Note that the debris/waste masses are always presented in the figures and tables, but volumes are not included to avoid repetition. The volumes are still presented in the appendices.

**Table 3. Estimate of mass of nonstructural and outdoor debris/waste from hypothetical hurricane scenario (structures from Table 1)***

| | Zone 1 (kg) | Zone 2 (kg) | Zone 3 (kg) |
|---|---|---|---|
| **Outdoor Materials** | | | |
| Soil | - | - | - |
| Asphalt | 7.80E+07 | 6.45E+07 | - |
| Concrete | 3.85E+06 | 4.30E+06 | 5.61E+06 |
| **Vehicles** | | | |
| Vehicles - Cars | 1.51E+06 | 2.11E+06 | 5.18E+05 |
| Vehicles - Light Trucks | 1.35E+06 | 1.88E+06 | 4.60E+05 |
| Vehicles - Heavy Trucks | 1.70E+06 | 2.89E+06 | 8.06E+05 |
| **Vegetative Biomass** | | | |
| Vegetative Biomass - Tree Trunks | 7.29E+06 | 6.54E+06 | 2.63E+07 |
| Vegetative Biomass - Foliage/Branches | 1.53E+07 | 1.38E+07 | 5.53E+07 |
| **Nonstructural Materials** | | | |
| Drywall | 1.39E+07 | 1.55E+09 | 4.71E+08 |
| Ceiling Tiles | 1.00E+06 | 1.69E+08 | 4.58E+07 |
| Carpet | 1.03E+06 | 1.23E+08 | 3.63E+07 |
| Marble and Ceramic Tiles | 7.41E+05 | 1.29E+08 | 3.54E+07 |
| Curtains and Acoustical Material | 5.36E+02 | 4.29E+05 | 2.68E+04 |
| Wood | 8.73E+05 | 8.35E+07 | 2.67E+07 |
| Other Nonstructural Building Materials | 5.75E+06 | 6.56E+08 | 1.98E+08 |

*These calculations include the percent destruction estimate

**Table 4. Estimate of volume of nonstructural and outdoor debris/waste from hypothetical hurricane scenario (structures from Table 1)***

| | Zone 1 ($m^3$) | Zone 2 ($m^3$) | Zone 3 ($m^3$) |
|---|---|---|---|
| **Outdoor Materials** | | | |
| Soil | - | - | - |
| Asphalt | 9.52E+04 | 7.87E+04 | - |
| Concrete | 1.78E+03 | 1.99E+03 | 2.60E+03 |
| **Vehicles** | | | |
| Vehicles - Cars | 1.22E+04 | 1.70E+04 | 4.18E+03 |
| Vehicles - Light Trucks | 1.24E+04 | 1.73E+04 | 4.24E+03 |
| Vehicles - Heavy Trucks | 7.89E+03 | 1.34E+04 | 7.47E+03 |
| **Vegetative Biomass** | | | |
| Vegetative Biomass - Tree Trunks | 8.09E+03 | 7.27E+03 | 2.93E+04 |
| Vegetative Biomass - Foliage/Branches | 1.72E+04 | 1.54E+04 | 6.17E+04 |
| **Nonstructural Materials** | | | |
| Drywall | 4.34E+04 | 4.86E+06 | 1.48E+06 |
| Ceiling Tiles | 1.24E+04 | 2.09E+06 | 5.68E+05 |
| Carpet | 7.99E+03 | 9.15E+05 | 2.74E+05 |
| Marble and Ceramic Tiles | 1.38E+03 | 2.42E+05 | 6.62E+04 |
| Curtains and Acoustical Material | 1.90E+01 | 1.52E+04 | 9.50E+02 |
| Wood | 2.00E+03 | 1.91E+05 | 6.11E+04 |
| Other Nonstructural Building Materials | 8.10E+04 | 8.22E+06 | 2.58E+06 |

*These calculations include the percent destruction estimate.

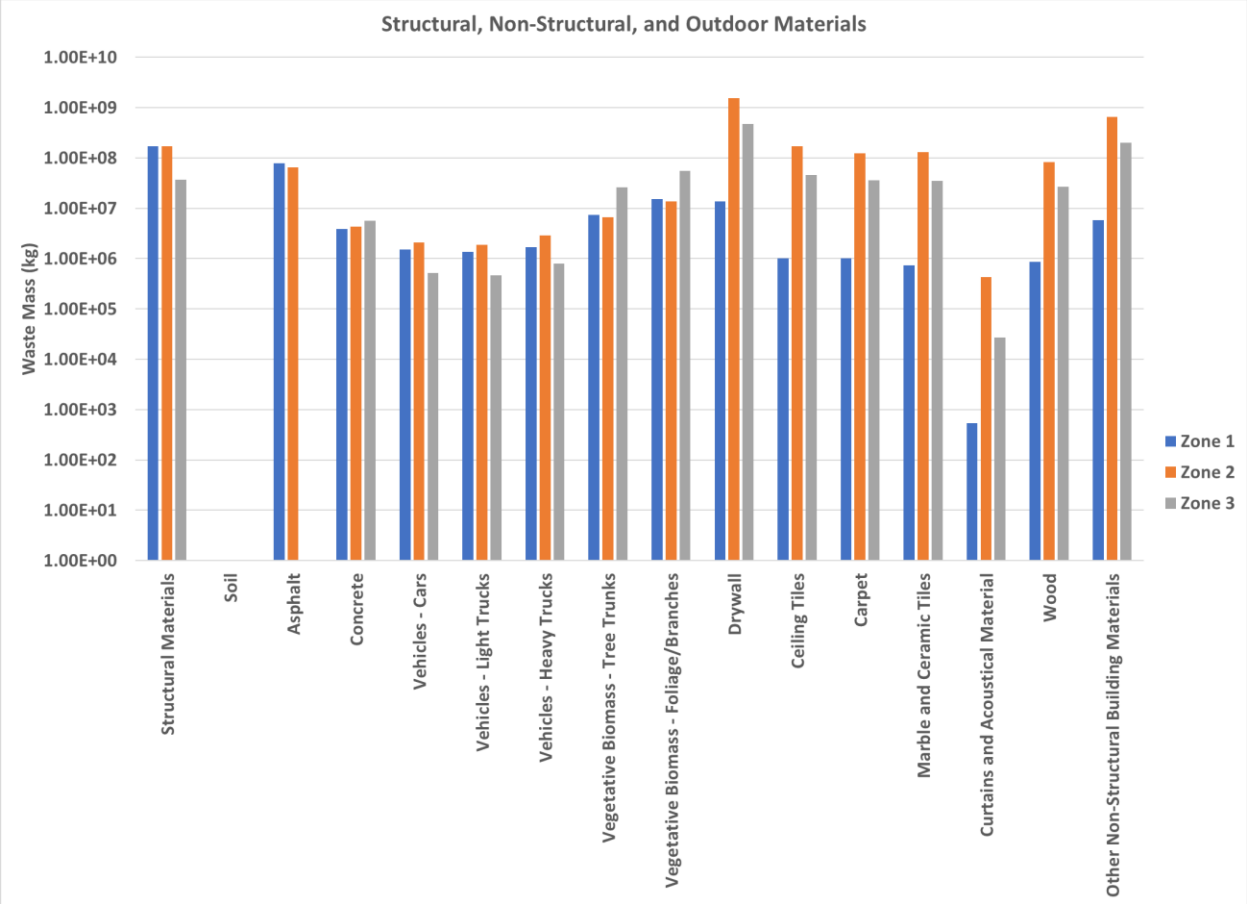


**Figure 4. Estimate of mass of structural, nonstructural, and outdoor debris/waste from hypothetical hurricane scenario**

**Table 5. Estimate of mass of building contents from hypothetical hurricane scenario***

| | Zone 1 (kg) | Zone 2 (kg) | Zone 3 (kg) |
|---|---|---|---|
| Electronic Equipment | 2.40E+06 | 3.34E+08 | 9.51E+07 |
| Industrial Electronic Equipment | 3.26E+05 | 5.69E+07 | 1.54E+07 |
| Patient Care Equipment | 5.07E+03 | 1.09E+06 | 1.22E+05 |
| Imaging Equipment | 1.08E+03 | 2.32E+05 | 2.60E+04 |
| Laboratory/Surgery Equipment | 5.24E+03 | 1.12E+06 | 1.26E+05 |
| Theater Electronic Equipment | 3.45E+02 | 2.76E+05 | 1.73E+04 |
| Concession Electronic Equipment | 5.73E+01 | 4.58E+04 | 2.86E+03 |
| Other Electronic Equipment | 9.76E+05 | 1.70E+08 | 4.62E+07 |
| Other Furniture | 1.56E+07 | 2.03E+09 | 5.78E+08 |
| Office Furniture | 2.16E+05 | 3.89E+07 | 9.57E+06 |
| Patient Care Furniture | 4.49E+03 | 9.64E+05 | 1.08E+05 |
| Retail Furniture | 3.73E+06 | 6.49E+08 | 1.77E+08 |
| Food | 8.96E+04 | 1.60E+07 | 4.31E+06 |
| Paper and Office Supplies | 1.84E+06 | 2.64E+08 | 7.35E+07 |
| Gym and Sports Equipment | 3.41E+03 | 4.73E+05 | 1.23E+05 |
| Medical Supplies | 3.58E+03 | 7.68E+05 | 8.60E+04 |
| Pharmaceuticals | 8.75E+02 | 1.39E+05 | 2.37E+04 |
| Linens | 1.97E+06 | 3.43E+08 | 9.36E+07 |
| Medical Waste | 1.83E+02 | 3.93E+04 | 4.40E+03 |
| Dishware | 1.02E+03 | 2.50E+05 | 8.29E+04 |
| Personal Effects | 1.09E+06 | 1.05E+08 | 3.34E+07 |
| Other Items and Equipment | 9.88E+05 | 1.72E+08 | 4.69E+07 |
| Art and Music Equipment | 2.45E+03 | 3.40E+05 | 8.84E+04 |
| Bathroom and Kitchen Materials | 1.36E+06 | 1.30E+08 | 4.17E+07 |

*These calculations include the percent destruction estimate

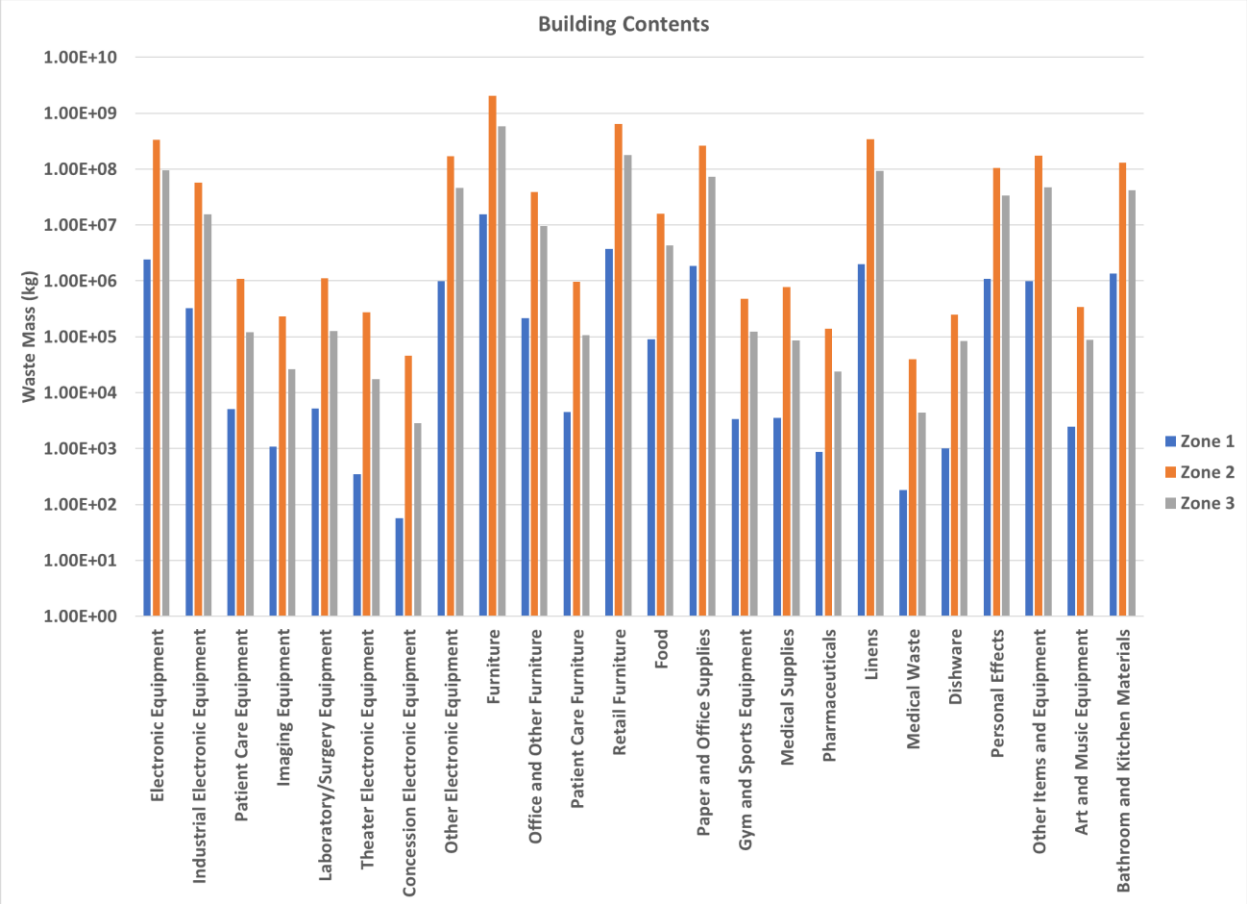


**Figure 5. Estimated mass of building contents from hypothetical hurricane scenario**

**Table 6. Estimated mass of household hazardous waste from hypothetical hurricane scenario***

| | Zone 1 (kg) | Zone 2 (kg) | Zone 3 (kg) |
|---|---|---|---|
| Oil and Latex Paint | 1.73E+04 | 1.65E+06 | 5.28E+05 |
| Used Oil | 5.18E+03 | 4.96E+05 | 1.58E+05 |
| Laboratory Packed Aerosols | 7.09E+02 | 6.78E+04 | 2.17E+04 |
| Flammable Liquids | 1.45E+03 | 1.39E+05 | 4.44E+04 |
| Bulk Fuels | 2.64E+03 | 2.52E+05 | 8.05E+04 |
| Flammable Solids | 1.73E+02 | 1.65E+04 | 5.28E+03 |
| Pesticides | 3.00E+02 | 2.87E+04 | 9.17E+03 |
| Poisons | 1.45E+03 | 1.39E+05 | 4.44E+04 |
| Antifreeze | 5.27E+02 | 5.04E+04 | 1.61E+04 |
| Batteries | 1.27E+03 | 1.22E+05 | 3.89E+04 |
| Other Corrosives | 5.00E+02 | 4.78E+04 | 1.53E+04 |
| Cleaning Supplies | 3.64E+00 | 3.48E+02 | 1.11E+02 |
| Compact Fluorescent Lights | 7.55E+02 | 7.22E+04 | 2.31E+04 |

*These calculations include the percent destruction estimate

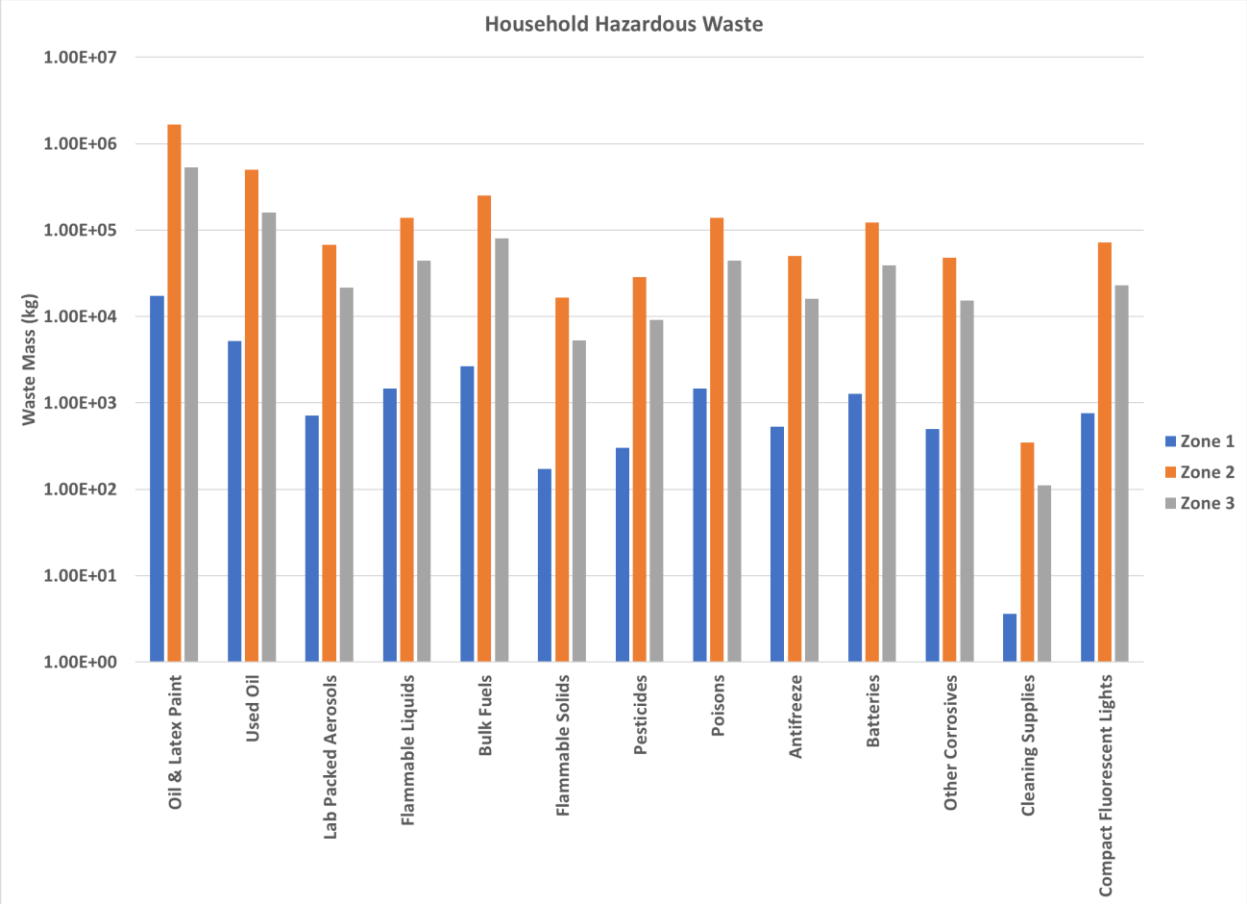


**Figure 6. Estimated mass of household hazardous waste from hypothetical hurricane scenario**

Some parts of the debris/waste stream may offer opportunities that outweigh the challenges associated with separating those materials from the vast amounts of commingled debris. Examining these estimates, the following observations are made:

- Medical waste does not appear to be generated in significant quantities; however, significant amounts of pharmaceuticals and medical supplies may need to be managed as waste.
- Electronic equipment may constitute a significant debris stream but may be able to be managed as material.
- Animal carcasses were not included in the waste estimate but may constitute a problematic waste stream since some of the waste management practices used for disposal of animal carcasses require large sources of carbonaceous material (e.g., composting) which may not be readily available in the immediate aftermath of a disaster.
- Putrescible waste (i.e., food) may be generated in quantities approaching 100 tonnes but may be able to be composted.
- Overhead satellite imagery suggests that, for this scenario, quantities of vegetative debris could approach a million tonnes. Some of the vegetative debris will likely need to be addressed; particularly the vegetative debris that is interfering with port operations and maritime navigation and road traffic and building access.
- Limitations in availability of heavy equipment may significantly impact recovery efforts for all streams.
- Segregation will likely be a significant part of cleanup to manage the different streams.

### 3.1.3 Special Considerations

There are current limitations in estimating quantities of waste and materials from some important debris streams and other special considerations:

- There is not an immediately available method to estimate the numbers of orphan tanks. It might be possible to make an estimate by compiling data of household usage of above-ground tanks and gas grills, coupled with business (particularly gas stations) usage of above ground tanks**.**
- Some materials from disaster sites may be considered "hazardous" materials, and only specialized material recovery facilities may be able to take those materials. Currently, only household hazardous waste is included in the waste estimates, but it must be considered that some other materials in the inventory may require management as hazardous materials.
- North Carolina does not have a RCRA Subtitle C disposal facility to manage hazardous waste. Affected industrial facilities as well as port recovery operations may generate significant quantities of hazardous waste that would need to be transported long distances for treatment/disposal; So, communities may want to consider facilities in other areas as backups.
- Identification of the numbers and locations of radioactive sources in the affected area should be done as soon as possible. Sources would be registered with the State or NRC; contact the State radiation control program to locate potential sources.
- A potential issue exists where future debris/waste management capacity may be reduced due to wastes being produced during cleanup operations as previously damaged materials enter the debris/waste stream.
- In the event that reduced waste management capacity may impact the ability to perform recovery operations, it is suggested that other alternatives (e.g., waste-to-energy facilities) be considered.
- A significant number of transformers might be damaged and require replacement. Some of them might contain polychlorinated biphenyls (PCBs). This is a potentially important waste stream that has specific requirements associated with its management. Determine if PCB-containing electrical equipment, particularly transformers and capacitors, is located within the community so that PCB spills or other environmental releases may be planned for.
- Identifying and managing mold-contaminated debris/waste may help to eliminate a potentially significant public health concern – currently there is not a way to estimate this debris/waste stream.

## 3.2 Hypothetical Scenario 2: Earthquake/Tsunami

This scenario is loosely based on the Capstone Exercise 2014 [13, 14] involving a hypothetical earthquake and tsunami scenario in Alaska and its effects on Anchorage. Capstone Exercise 2014 was a complex emergency preparedness exercise comprised of five distinct, but linked, component events. The Alaska Shield 2014 exercise, sponsored by the State of Alaska to commemorate the 50th anniversary of the 1964 Great Alaskan Earthquake, provided the central scenario elements: significant damage from both the quake and the tsunami it triggers affect the greater Pacific Northwest. Capstone Exercise 2014 included several preparedness activities sponsored by other departments and agencies and was designed to educate and prepare the whole community for complex, large-scale disasters and emergencies.

### 3.2.1 Impacted Area and Infrastructure

The impacted areas for Capstone Exercise 2014 included five municipalities in Alaska, including Anchorage, Homer, Seward, Kodiak, and Valdez; for this particular case study, Anchorage was selected as the community encompassing the study area. Figure 7 shows the general areas where the hypothetically affected community is.

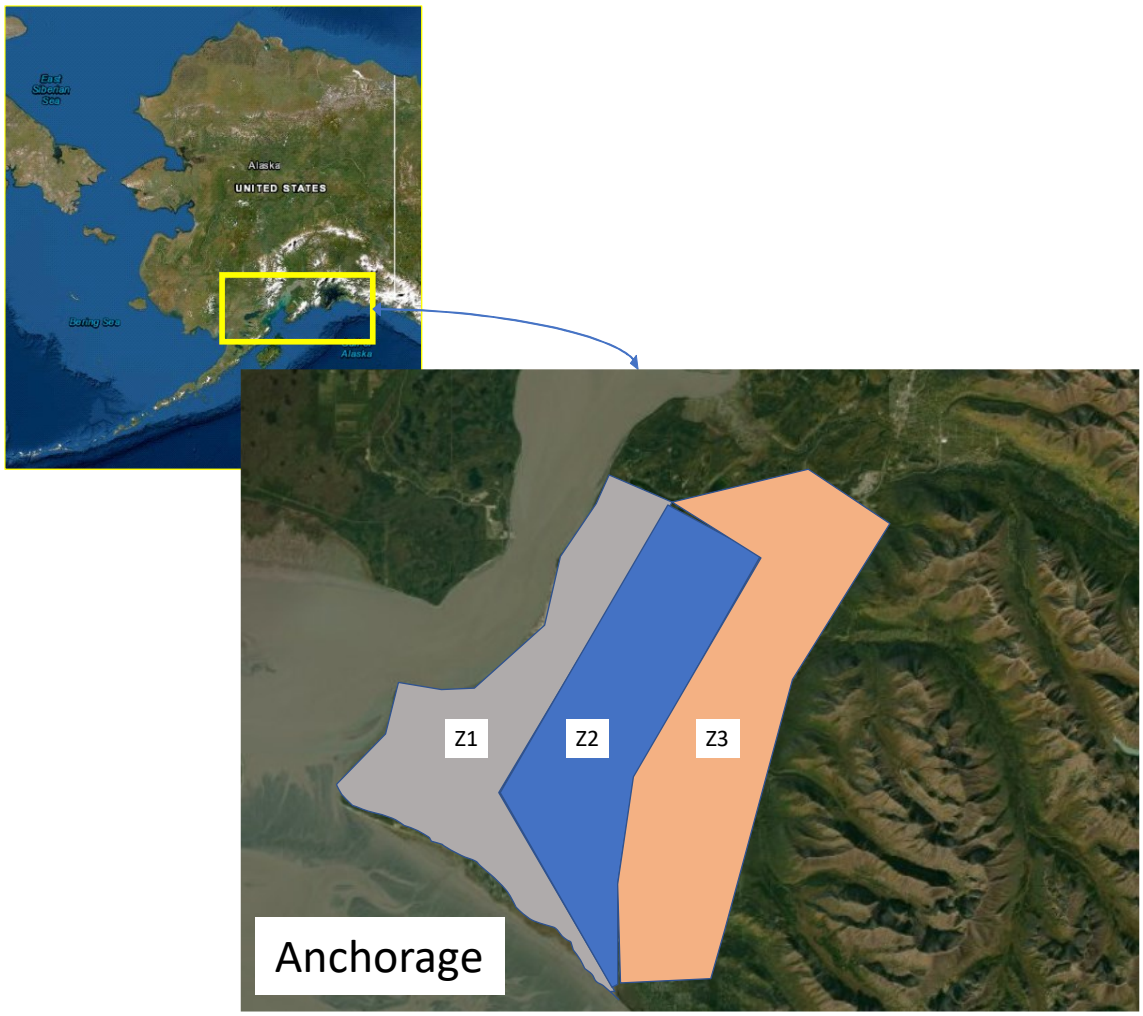


**Figure 7. The location of hypothetically-affected community in Alaska. Roads and outdoor areas were included in the subsequent estimates; unique infrastructure like bridges were not included**

The Waste Estimation Support Tool (WEST) [11] was used with the Anchorage study area. WEST uses FEMA's Hazus-MH [1] databases to estimate affected vertical infrastructure and satellite imagery to estimate roadways. The scenario of the exercise estimated that 686 single family dwellings were severely damaged or destroyed in Anchorage, which constituted roughly 1% of the single-family dwellings in the study region. Therefore, this scenario also used 1% for zones 1, 2, and 3 as the estimate of the structures that were severely damaged or destroyed by either the earthquake or tsunami. Numbers were rounded up to 1 if this estimate resulted in less than 1 damaged structure.

Figure 8 shows an overhead image of the study region for the hypothetical earthquake/tsunami scenario. This study area was used as the basis for determining the amount of affected infrastructure in the study area.

**Figure 8. Overhead satellite image of Anchorage hypothetical earthquake/tsunami study area**

Table 7 lists the estimated numbers of infrastructure of different types in the study area using the WEST tool. Note that to produce the estimate of debris/waste, the numbers in WEST (and Table 7) get multiplied by the percentage of buildings destroyed (in this case, 1%) to calculate the numbers of infrastructure that are considered destroyed for the purpose of this analysis. Based on these numbers of destroyed infrastructure, I-WASTE [12] was then used, along with an estimate of the fraction of destroyed buildings, to estimate the contents of the buildings that would likely be managed as debris/waste/materials. Average square footages were assumed based on I-WASTE default values. Details of the calculations can be found in the Appendices. Figure 9 shows a graphical representation of the potentially affected infrastructure.

For the purposes of estimating the potential building contents, it was necessary to match the building types from the WEST estimate to the building types within I-WASTE. Table 8 shows the number of potentially affected structures for the purposes of calculating building contents. The last column of Table 8 shows how the building types from Table 7 were mapped to the building types that were available in I-WASTE. Note that some building types from Table 7 did not have an obvious analog in the I-WASTE estimate that could be used; those building types were not included in the estimation of building contents.

**Table 7. Estimate of total numbers of infrastructure in study area from hypothetical earthquake/tsunami scenario***

| WEST Infrastructure Type | Zone 1 | Zone 2 | Zone 3 |
|---|---|---|---|
| Agriculture | 39 | 64 | 24 |
| Banks | 52 | 68 | 0 |
| Church/Nonprofit | 146 | 203 | 47 |
| Colleges/Universities | 6 | 2 | 1 |
| Construction | 160 | 294 | 75 |
| Emergency Response | 3 | 4 | 1 |
| Entertainment and Recreation | 283 | 328 | 58 |
| Food/Drugs/Chemicals | 26 | 24 | 3 |
| General Services | 134 | 79 | 9 |
| Grade Schools | 40 | 88 | 23 |
| Heavy | 35 | 84 | 14 |
| High Technology | 1 | 1 | 0 |
| Hospital | 2 | 20 | 0 |
| Institutional Dormitory | 81 | 154 | 61 |
| Light | 68 | 106 | 19 |
| Medical Office/Clinic | 102 | 225 | 21 |
| Metals/Minerals Processing | 21 | 38 | 4 |
| Mobile Home | 943 | 38 | 730 |
| Multifamily Dwelling - 10-19 Units | 101 | 175 | 22 |
| Multifamily Dwelling - 20-49 Units | 62 | 80 | 6 |
| Multifamily Dwelling - 3-4 Units | 917 | 1,464 | 295 |
| Multifamily Dwelling - 50+ Units | 9 | 14 | 5 |
| Multifamily Dwelling - 5-9 Units | 397 | 525 | 108 |
| Multifamily Dwelling - Duplex | 986 | 905 | 531 |
| Nursing Home | 6 | 13 | 4 |
| Personal and Repair Services | 259 | 434 | 72 |
| Professional/Technical Services | 397 | 517 | 142 |
| Retail Trade | 243 | 625 | 65 |
| Single Family Dwelling | 10,728 | 25,536 | 10,801 |
| Temporary Lodging | 113 | 71 | 16 |
| Theaters | 7 | 10 | 0 |
| Wholesale Trade | 162 | 302 | 46 |

*These numbers are multiplied by the estimated % destruction to estimate the numbers of destroyed infrastructure.

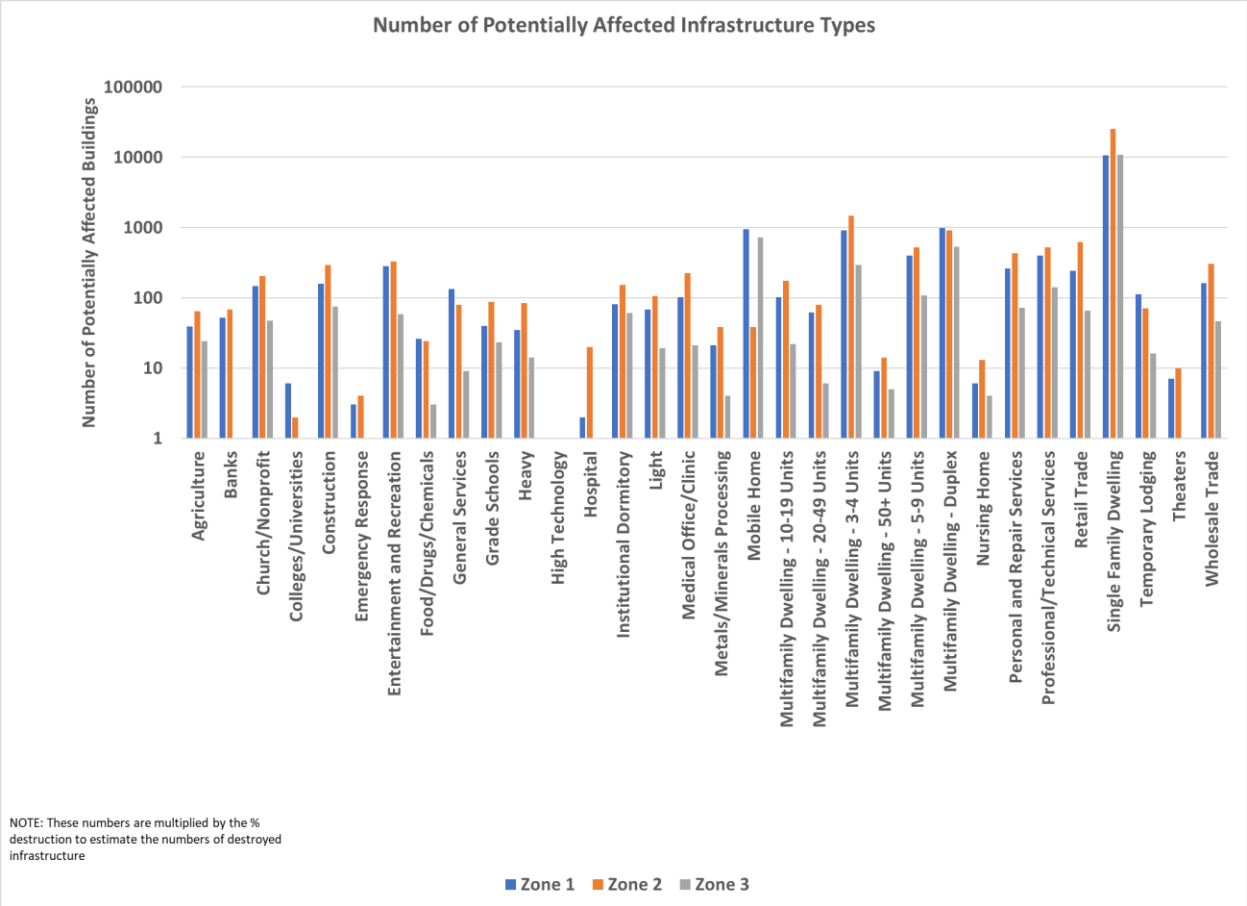


**Figure 9. Estimate of total numbers of infrastructure in study area from hypothetical earthquake/tsunami scenario**

**Table 8. Number of potentially affected structures – for calculation of building contents by mapping WEST building types to I-WASTE building types from hypothetical earthquake/tsunami scenario**

| I-WASTE WME Infrastructure Type | Zone 1 | Zone 2 | Zone 3 | Mapping of WEST Infrastructure to I-WASTE Infrastructure |
|---|---|---|---|---|
| Movie Theaters | 7 | 10 | - | Theaters |
| Single-Family Residences | 17,024 | 33,913 | 12,825 | Single Family Dwelling, Multi Family Dwelling x 0.5, Mobile Home x 0.5, Institutional Dormitory*0.5 |
| Hospitals, Medium | 18 | 56 | 6 | Hospital, Medical Office/Clinic * 0.1, Nursing Home |
| Hospitals, Large | - | - | - | |
| Hotels, Small | 113 | 71 | 16 | Temporary Lodging |
| Hotels, Medium | - | - | - | |
| Hotels, Large | - | - | - | |
| Offices, Small | 491 | 652 | 189 | Banks, Church/Non Profit, Professional/Technical Services |
| Offices, Medium | - | - | - | |
| Offices, Large | - | - | - | |
| Schools, Elementary | 46 | 90 | 24 | Grade Schools, Colleges/Universities |
| Schools, Middle | - | - | - | |
| Schools, High | - | - | - | |
| Shopping Malls, Small | 405 | 927 | 111 | Retail Trade, Wholesale Trade |
| Shopping Malls, Medium | - | - | - | |
| Shopping Malls, Large | - | - | - | |

*These numbers are multiplied by the % destruction to estimate the numbers of destroyed infrastructure.

### 3.2.2 Debris/Waste Estimate for Hypothetical Earthquake/Tsunami Scenario

Table 9 lists the estimated mass of different structural, nonstructural, and outdoor materials. Table 10 lists the same data but in terms of volume in cubic meters. Figure 10 displays the mass estimate of those same materials. Table 11 lists the estimate of the mass of building contents from the hypothetical earthquake/tsunami scenario, and Figure 11 graphically illustrates those data. Table 12 lists the estimated mass of household hazardous waste from the hypothetical earthquake/tsunami scenario, and Figure 12 graphically illustrates those data.

The total amount of debris/waste generated from the hypothetical earthquake/tsunami scenario using the destruction fraction that was assumed for calculation purposes is estimated at 4.2E9 kg (4.2E6 tonnes) and 2.8E7 $m^3$.

**Table 9. Estimate of mass of nonstructural materials and outdoor debris/waste from hypothetical earthquake/tsunami scenario (structures from Table 7)***

| | Zone 1 (kg) | Zone 2 (kg) | Zone 3 (kg) |
|---|---|---|---|
| **Outdoor Materials** | | | |
| Soil | - | - | - |
| Asphalt | 1.60E+06 | 3.56E+06 | - |
| Concrete | 3.10E+05 | 6.93E+05 | 1.90E+05 |
| **Vehicles** | | | |
| Vehicles - Cars | 3.87E+05 | 6.41E+05 | 1.84E+05 |
| Vehicles - Light Trucks | 1.83E+05 | 3.03E+05 | 8.69E+04 |
| Vehicles - Heavy Trucks | 1.80E+06 | 2.98E+06 | 8.57E+05 |
| **Vegetative Biomass** | | | |
| Vegetative Biomass - Tree Trunks | 1.23E+08 | 2.05E+08 | 7.10E+07 |
| Vegetative Biomass - Foliage/Branches | 2.58E+08 | 4.30E+08 | 1.49E+08 |
| **Non-Structural Materials** | | | |
| Drywall | 2.96E+06 | 5.99E+08 | 1.70E+08 |
| Ceiling Tiles | 3.48E+05 | 7.65E+07 | 1.00E+07 |
| Carpet | 2.48E+05 | 4.75E+07 | 1.22E+07 |
| Marble and Ceramic Tiles | 2.70E+05 | 6.04E+07 | 7.29E+06 |
| Curtains and Acoustical Material | 3.75E+02 | 5.36E+04 | - |
| Wood | 1.49E+05 | 2.96E+07 | 1.12E+07 |
| Other Nonstructural Building Materials | 1.25E+06 | 2.57E+08 | 6.99E+07 |

*These calculations include the percent destruction estimate.

**Table 10. Estimate of volume of nonstructural and outdoor debris/waste from hypothetical earthquake/tsunami scenario (structures from Table 7)*.**

| | Zone 1 ($m^3$) | Zone 2 ($m^3$) | Zone 3 ($m^3$) |
|---|---|---|---|
| **Outdoor Materials** | | | |
| Soil | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Asphalt | 1.96E+03 | 4.34E+03 | 0.00E+00 |
| Concrete | 1.44E+02 | 3.21E+02 | 8.79E+01 |
| **Vehicles** | | | |
| Vehicles - Cars | 3.12E+03 | 5.18E+03 | 1.49E+03 |
| Vehicles - Light Trucks | 1.68E+03 | 2.79E+03 | 8.01E+02 |
| Vehicles - Heavy Trucks | 8.33E+03 | 1.38E+04 | 3.97E+03 |
| **Vegetative Biomass** | | | |
| Vegetative Biomass - Tree Trunks | 1.37E+05 | 2.28E+05 | 7.91E+04 |
| Vegetative Biomass - Foliage/Branches | 2.88E+05 | 4.80E+05 | 1.67E+05 |
| **Non-Structural Materials** | | | |
| Drywall | 9.30E+03 | 1.88E+06 | 5.31E+05 |
| Ceiling Tiles | 4.32E+03 | 9.50E+05 | 1.24E+05 |
| Carpet | 1.87E+03 | 3.44E+05 | 9.65E+04 |
| Marble and Ceramic Tiles | 5.11E+02 | 1.13E+05 | 1.37E+04 |
| Curtains and Acoustical Material | 1.33E+01 | 1.90E+03 | 0.00E+00 |
| Wood | 3.40E+02 | 6.78E+04 | 2.57E+04 |
| Other Nonstructural Building Materials | 1.53E+04 | 3.01E+06 | 1.02E+06 |

*These calculations include the percent destruction estimate.

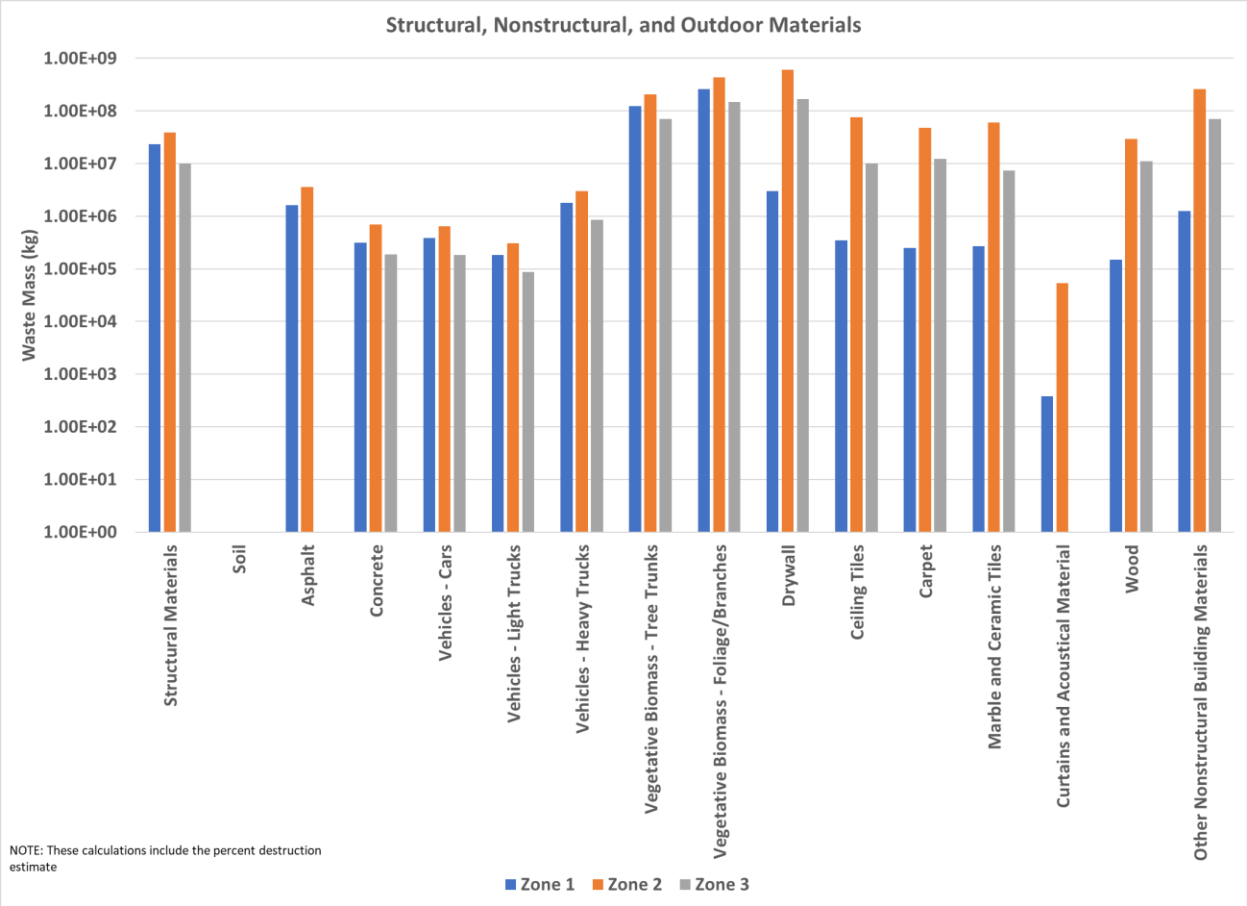


**Figure 10. Estimate of mass of structural, nonstructural, and outdoor debris/waste from hypothetical earthquake/tsunami scenario**

336 **Table 11. Estimate of mass of building contents from hypothetical earthquake/tsunami scenario***

| | Zone 1 (kg) | Zone 2 (kg) | Zone 3 (kg) |
|---|---|---|---|
| Electronic Equipment | 6.46E+03 | 1.37E+06 | 2.91E+05 |
| Industrial Electronic Equipment | 1.14E+03 | 2.51E+05 | 3.10E+04 |
| Patient Care Equipment | 1.37E+01 | 4.16E+03 | 4.58E+02 |
| Imaging Equipment | 2.55E+00 | 7.77E+02 | 8.54E+01 |
| Laboratory/Surgery Equipment | 7.46E+00 | 2.28E+03 | 2.50E+02 |
| Theater Electronic Equipment | 2.38E+00 | 3.40E+02 | 0.00E+00 |
| Concession Electronic Equipment | 4.76E-01 | 6.80E+01 | 0.00E+00 |
| Other Electronic Equipment | 2.83E+03 | 6.29E+05 | 7.73E+04 |
| Other Furniture | 2.73E+04 | 4.01E+06 | 1.27E+06 |
| Office Furniture | 1.09E+03 | 2.57E+05 | 3.05E+04 |
| Patient Care Furniture | 1.60E+01 | 4.88E+03 | 5.37E+02 |
| Retail Furniture | 3.28E+04 | 7.51E+06 | 8.99E+05 |
| Food | 2.27E+02 | 4.63E+04 | 5.76E+03 |
| Paper and Office Supplies | 2.35E+03 | 4.33E+05 | 7.97E+04 |
| Gym and Sports Equipment | 2.12E+01 | 4.14E+03 | 1.10E+03 |
| Medical Supplies | 6.92E+00 | 2.11E+03 | 2.32E+02 |
| Pharmaceuticals | 1.48E+00 | 3.84E+02 | 7.68E+01 |
| Linens | 1.05E+04 | 2.41E+06 | 2.89E+05 |
| Medical Waste | 8.92E-01 | 2.72E+02 | 2.99E+01 |
| Dishware | 1.24E+01 | 7.81E+02 | 1.76E+02 |
| Personal Effects | 2.56E+03 | 5.09E+05 | 1.92E+05 |
| Other Items and Equipment | 3.51E+03 | 8.01E+05 | 9.59E+04 |
| Art and Music Equipment | 1.06E+01 | 2.07E+03 | 5.52E+02 |
| Bathroom and Kitchen Materials | 2.55E+03 | 5.09E+05 | 1.92E+05 |

337 *These calculations include the percent destruction estimate.

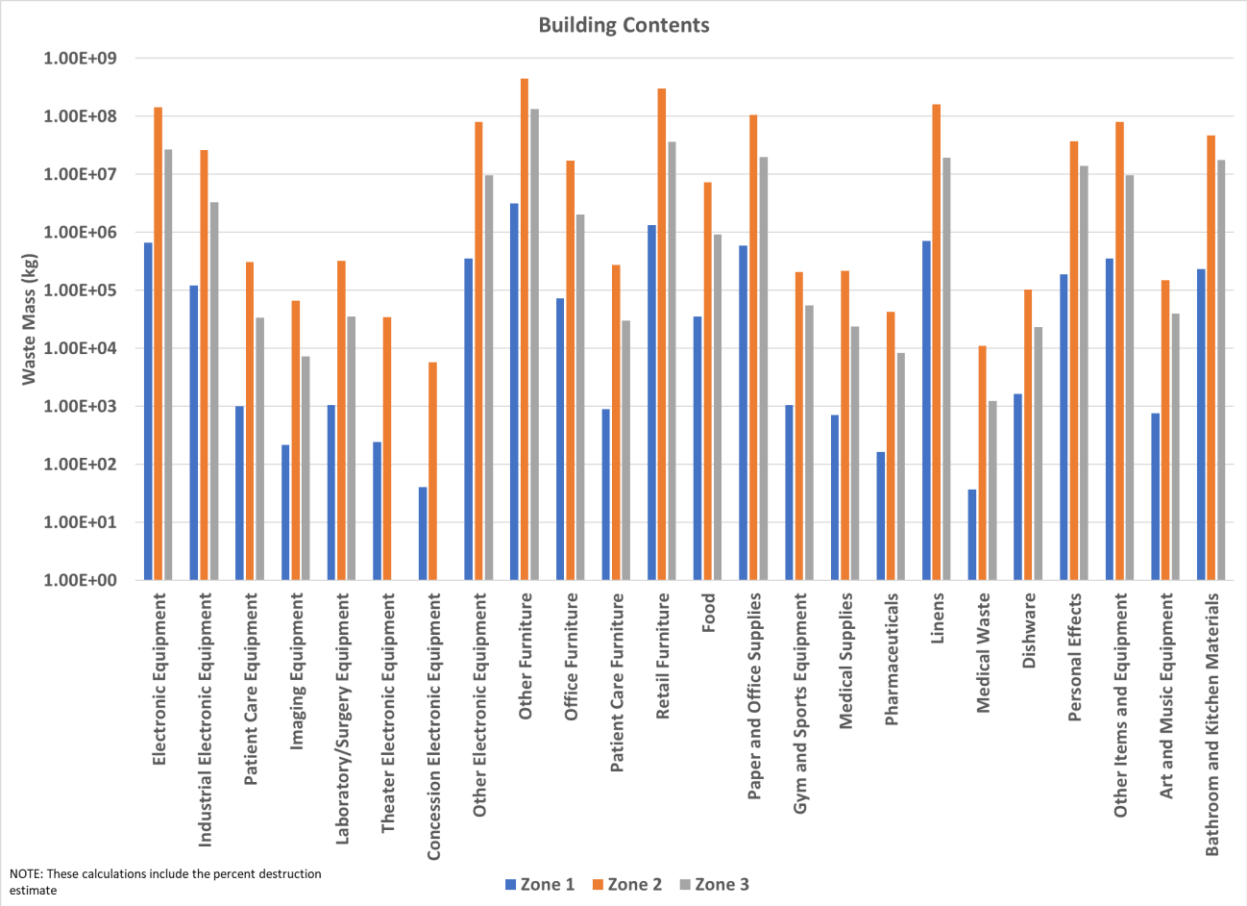


**Figure 11. Estimated mass of building contents from hypothetical earthquake/tsunami scenario**

**Table 12. Estimated mass of household hazardous waste from hypothetical earthquake/tsunami scenario***

| | Zone 1 (kg) | Zone 2 (kg) | Zone 3 (kg) |
|---|---|---|---|
| Oil & Latex Paint | 2.89E+00 | 5.77E+02 | 2.18E+02 |
| Used Oil | 1.55E+00 | 3.09E+02 | 1.17E+02 |
| Lab Packed Aerosols | 1.65E-01 | 3.29E+01 | 1.24E+01 |
| Flammable Liquids | 2.89E-01 | 5.77E+01 | 2.18E+01 |
| Bulk Fuels | 6.30E-01 | 1.25E+02 | 4.75E+01 |
| Flammable Solids | 1.12E-02 | 2.24E+00 | 8.46E-01 |
| Pesticides | 6.30E-02 | 1.25E+01 | 4.75E+00 |
| Poisons | 3.23E-01 | 6.44E+01 | 2.44E+01 |
| Antifreeze | 1.06E-01 | 2.10E+01 | 7.95E+00 |
| Batteries | 2.55E+00 | 5.09E+02 | 1.92E+02 |
| Other Corrosives | 6.47E-02 | 1.29E+01 | 4.87E+00 |
| Cleaning Supplies | 4.09E-03 | 8.14E-01 | 3.08E-01 |
| Compact Fluorescent Lights | 4.43E-01 | 8.82E+01 | 3.33E+01 |

*These calculations include the percent destruction estimate.

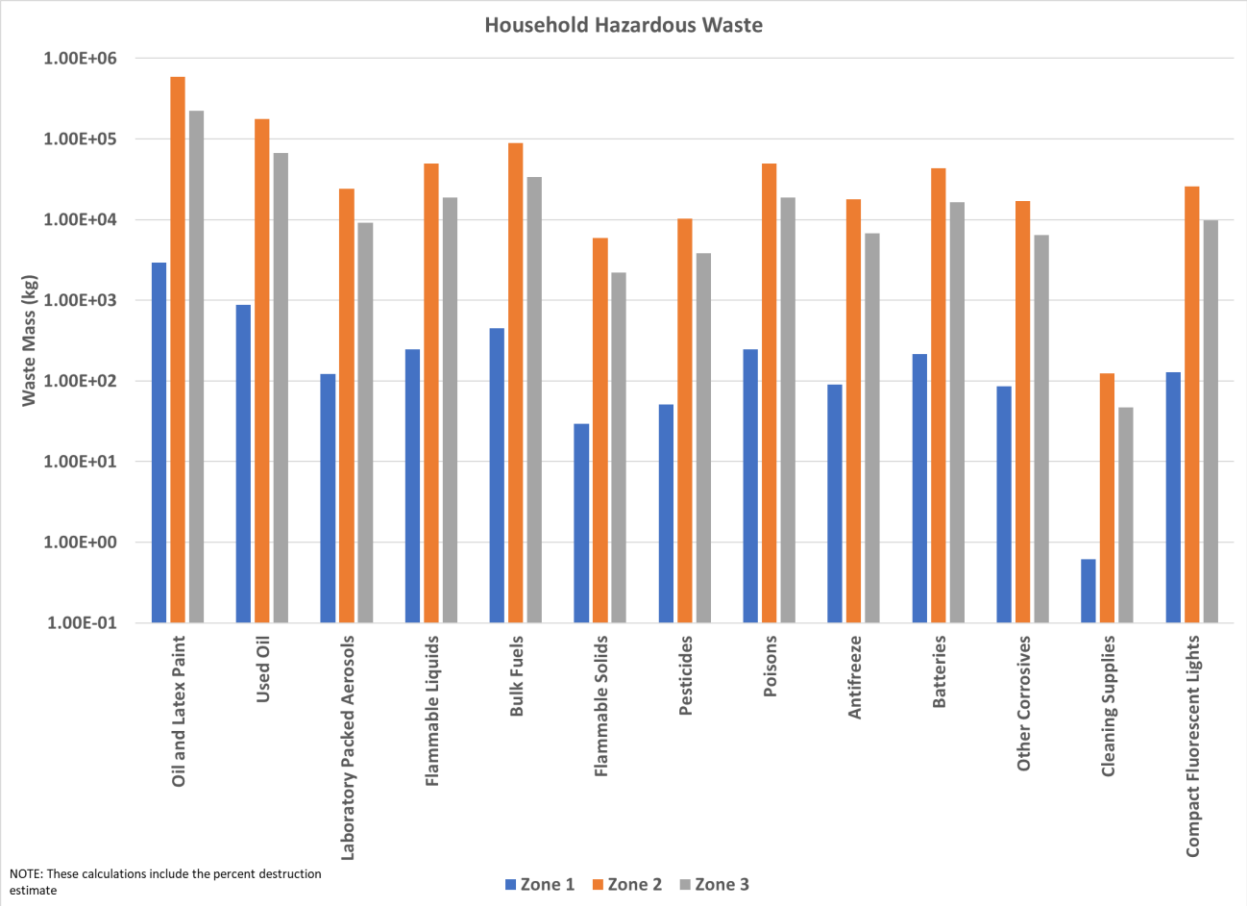


**Figure 12. Estimated mass of household hazardous waste from hypothetical earthquake/tsunami scenario**

Examining these estimates, the following observations are made:

- Medical waste does not appear to be generated in significant quantities; however, significant amounts of pharmaceuticals and medical supplies may need management as waste.
- Electronic equipment may constitute a significant waste stream but may be able to be managed as material.
- Animal carcasses were not included in the waste estimate but may constitute a problematic waste stream since some of the waste management practices used for disposal of animal carcasses require large sources of carbonaceous material (e.g., composting) which may not be readily available in the immediate aftermath of a disaster.
- Putrescible waste (e.g., food) may be generated in quantities approaching 100 tonnes.
- Overhead satellite imagery suggests that quantities of vegetative debris could be very significant, potentially on the order of 2 million tonnes. Some of the vegetative debris will likely need to be addressed; particularly the vegetative debris interfering with port operations and maritime navigation. Limitations in availability of heavy equipment may significantly impact recovery efforts.
- Limitations in availability of heavy equipment may significantly impact recovery efforts for all streams.
- Segregation will likely be a significant part of cleanup to manage the different streams.

### 3.2.3 Special Considerations

There are current limitations in estimating quantities of waste and debris from some important streams.

- There is not an immediately available method to estimate the numbers of orphan tanks. It might be possible to make an estimate by compiling data of household usage of above-ground tanks and gas grills, coupled with business (particularly gas stations) usage of above ground tanks.
- Alaska does not have a RCRA Subtitle C disposal facility to handle hazardous waste. Affected industrial facilities as well as port recovery operations may generate significant quantities of hazardous waste that would need to be transported long distances for treatment/disposal.
- Some materials from disaster sites may be considered "hazardous" materials, and only specialized material recovery facilities may be able to take those materials. Currently, only household hazardous waste is included in the waste estimates, but it must be considered that some other materials in the inventory may require management as hazardous materials.
- Identification of the numbers and potential locations of radioactive sources in the affected area should be done as soon as possible. Sources would be registered with the State or NRC; contact State radiation control program to locate potential sources.
- A significant number of transformers might be damaged and require replacement. Some of them might contain polychlorinated biphenyls (PCBs). This is a potentially important waste stream that has specific requirements associated with its management.
- Incidents such as this scenario, where oil production and transportation facilities may be affected, can result in a significant quantity of oil-soaked waste and debris. This debris may present waste management challenges, where facilities that accepted similar wastes prior to the incident may resist accepting incident-derived debris/waste. It may be possible to develop a methodology to estimate quantities of oil-soaked waste by analyzing data from previous spills and disasters.
- A significant number of transformers might be damaged and require replacement. Some of them might contain PCBs. This is a potentially important waste stream that has specific requirements associated with its management. Determine if PCB-containing electrical equipment, particularly transformers and capacitors, is located within the community so that PCB spills or other environmental releases may be planned for.
- A potential issue exists where future debris/waste management capacity may be reduced due to wastes being produced during cleanup operations as previously damaged materials enter the debris/waste stream.
- In the event that reduced waste management capacity may impact the ability to perform recovery operations, it is suggested that other alternatives (e.g., waste-to-energy facilities) be considered; in Alaska this may involve transportation of debris/waste to the lower 48 states to access such facilities.
- Transportation limitations associated with the remoteness of Alaska in general may present creative opportunities for reusing and recycling of some of the debris (potentially significant fractions) that may not be economically favorable in more populated sections of the country. Examples of such materials include machine parts, tires, wood, and other potentially reusable items.

## 3.3 Hypothetical Scenario 3: Tornado

Of the three scenarios being discussed in this report, the Tornado scenario is the only one based on an actual incident. Joplin, Missouri, was struck by a tornado on May 22, 2011 that was rated as an EF5 on the Enhanced Fujita Scale with maximum winds of 200 mph [2]. The path of the entire tornado was 22.1 miles long and was up to one mile in width. The tornado's most violent winds were observed as it traveled six miles through the central part of Joplin. The tornado displaced 14,000 people, injured

thousands of residents, and caused 162 deaths. The FEMA declared this tornado the single largest disaster ever to occur in the region. This real incident was used as the basis for the hypothetical planning incident described in this document. Although the debris/waste estimations from the decision support tools were used in a fashion similar to the other two scenarios, there are actual data from the Joplin response that can be compared to the predictions from the tools. These differences will be used to enhance future versions of the tools to enhance the accuracy of their results.

### 3.3.1 Impacted Area and Infrastructure

Some of the data from the Joplin response were used to aid the determination of some of the user-adjustable parameters in the debris/waste estimate. The tornado heavily damaged or destroyed over 8,000 structures, including the community's hospital, junior college, and eight local schools. As was mentioned earlier in the report, since the decision support tools cannot currently estimate debris from damaged structures but only demolished structures, the assumption was made that all impacted structures were destroyed. Using specific information on the types of buildings, their footprints, the number of floors from the tornado path and given the scenario parameters, an estimate was used that assumed 100% of buildings were demolished in Zone 1, 50% of buildings were demolished in Zone 2, and 15% of buildings were demolished in Zone 3.

Figure 13 shows an overhead image of the path of the tornado through the Joplin area. Figure 14 shows the 3 zones established as the study region for the hypothetical tornado scenario. This study area was used as the basis for determining the amount of affected infrastructure for this scenario. For this case study, GIS analysis of the affected area estimated that a total of 8,323 structures were impacted over an area of 8.5 square miles ($mi^2$). Zone 1 represents the most extensive building damage (100% of buildings destroyed), Zone 2 represents significant building damage (50% of buildings destroyed), and Zone 3 represents minimal damage (15% of buildings destroyed).

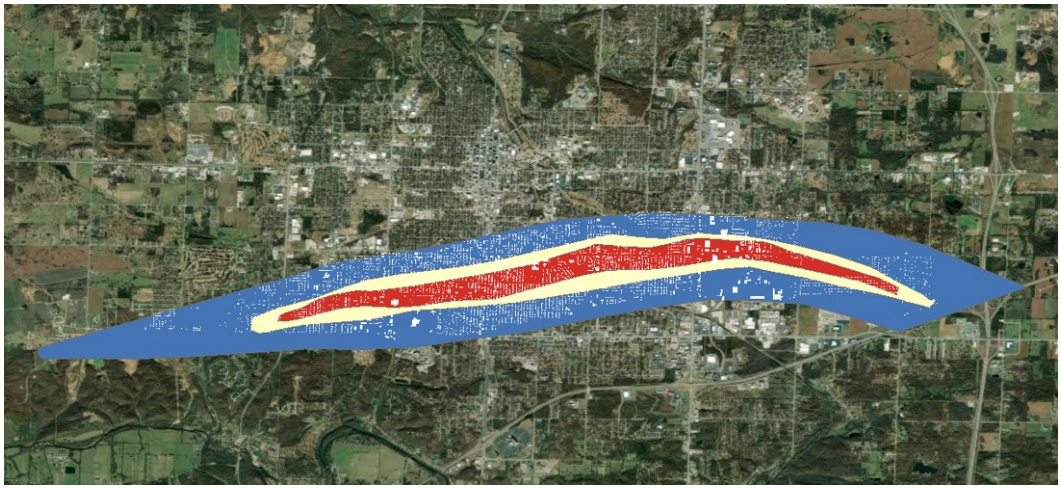

**Figure 13. Joplin tornado damage path. Roads and outdoor areas were included in the subsequent estimates; unique infrastructure like bridges were not included**

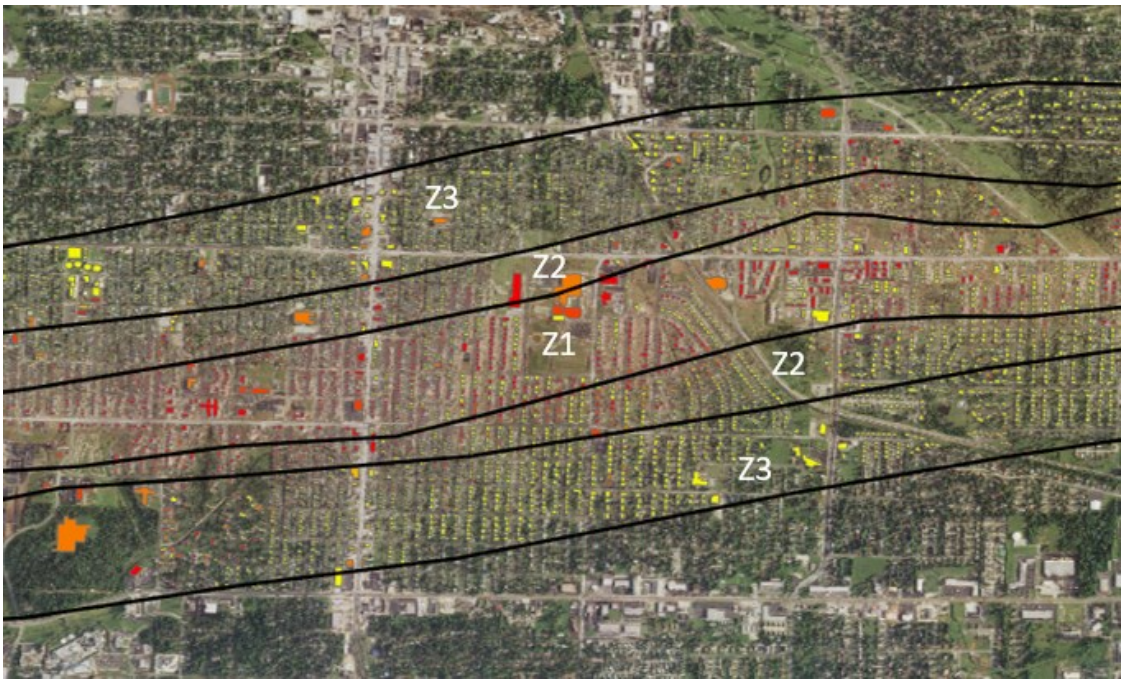


**Figure 14. Joplin tornado study area with zones comprising the damage path**

Table 13 lists the hypothetical estimated numbers of potentially damaged/destroyed infrastructure of different types using the WEST tool and the custom infrastructure data set that was available for Joplin [15]. Like the previous case studies, the numbers from WEST were multiplied by the estimated fraction of buildings destroyed in the three zones (100%, 50%, and 15% for zones 1, 2, and 3, respectively) to calculate the numbers of infrastructure that are considered destroyed for the purpose of this analysis. Figure 15 depicts the total potential infrastructure that was in the study path. The numbers in Figure 15 are multiplied by the percentage of buildings damaged by the storm to estimate the actual damaged infrastructure.

For the purposes of estimating the potential building contents, it was necessary to match the building types from the WEST estimate to the building types within I-WASTE. Table 14 shows the number of potentially affected structures for the purposes of calculating building contents. The last column of Table 14 shows how the building types from Table 13 were mapped to those that were available in I-WASTE. Note that some building types from Table 13 did not have an obvious analog in the I-WASTE estimate that could be used; those building types were not included in the estimation of building contents.

451 **Table 13. Estimate of total numbers of infrastructure in study area from hypothetical tornado scenario**

| WEST Infrastructure Type | Zone 1 | Zone 2 | Zone 3 |
|---|---|---|---|
| Agriculture | 5 | 4 | 4 |
| Banks | 4 | 5 | 6 |
| Church/Nonprofit | 14 | 12 | 24 |
| Colleges/Universities | 0 | 0 | 0 |
| Construction | 16 | 10 | 19 |
| Emergency Response | 0 | 0 | 0 |
| Entertainment and Recreation | 19 | 16 | 49 |
| Food/Drugs/Chemicals | 1 | 1 | 1 |
| General Services | 1 | 2 | 4 |
| Grade Schools | 2 | 2 | 7 |
| Heavy | 6 | 1 | 10 |
| High Technology | 0 | 0 | 0 |
| Hospital | 8 | 2 | 3 |
| Institutional Dormitory | 5 | 3 | 7 |
| Light | 6 | 2 | 12 |
| Medical Office/Clinic | 19 | 22 | 30 |
| Metals/Minerals Processing | 0 | 0 | 3 |
| Mobile Home | 62 | 39 | 95 |
| Multifamily Dwelling - 10-19 Units | 7 | 1 | 9 |
| Multifamily Dwelling - 20-49 Units | 0 | 0 | 1 |
| Multifamily Dwelling - 3-4 Units | 14 | 32 | 42 |
| Multifamily Dwelling - 50+ Units | 0 | 1 | 1 |
| Multifamily Dwelling - 5-9 Units | 24 | 14 | 38 |
| Multifamily Dwelling - Duplex | 75 | 73 | 112 |
| Nursing Home | 1 | 2 | 3 |
| Personal and Repair Services | 31 | 26 | 60 |
| Professional/Technical Services | 30 | 32 | 59 |
| Retail Trade | 39 | 24 | 52 |
| Single Family Dwelling | 1,531 | 1,755 | 3,603 |
| Temporary Lodging | 3 | 1 | 2 |
| Theaters | 1 | 0 | 0 |
| Wholesale Trade | 22 | 15 | 24 |

452 *These numbers are multiplied by the estimated % destruction to estimate the numbers of destroyed infrastructure.

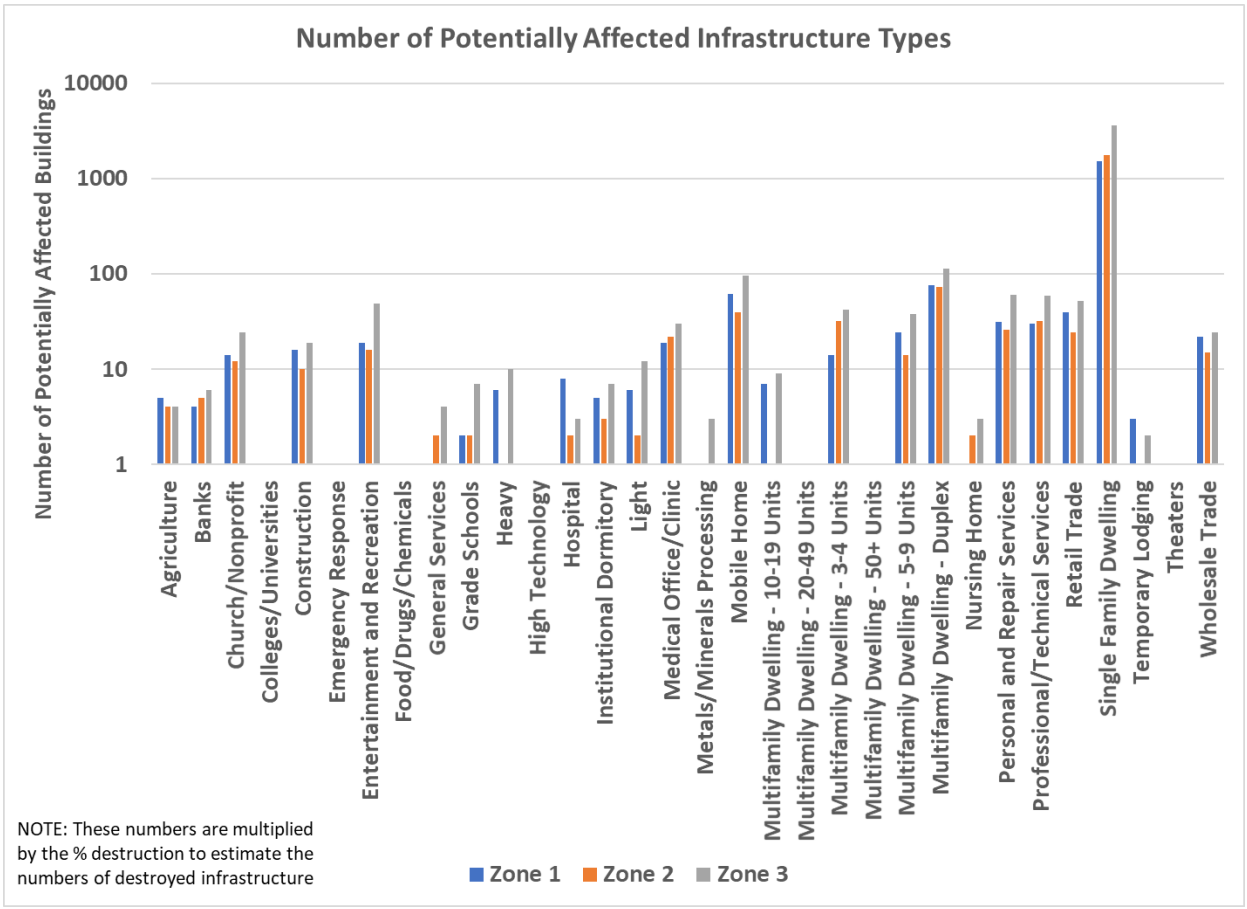


**Figure 15. Potentially affected infrastructure in hypothetical tornado scenario**

**Table 14. Number of potentially affected structures – for calculation of building contents by mapping WEST building types to I-WASTE building types from hypothetical tornado scenario**

| I-WASTE WME Infrastructure Type | Zone 1 | Zone 2 | Zone 3 | Mapping of WEST Infrastructure to I-WASTE Infrastructure |
|---|---|---|---|---|
| Movie Theaters | 1 | 0 | 0 | Theaters |
| Single-family Residences | 1,767 | 1,958 | 4,037 | Single Family Dwelling, Multifamily Dwelling x 0.5, Mobile Home x 0.5, Institutional Dormitory*0.5 |
| Hospitals, Medium | 11 | 6 | 9 | Hospital, Medical Office/Clinic * 0.1, Nursing Home |
| Hospitals, Large | 0 | 0 | 0 | |
| Hotels, Small | 3 | 1 | 2 | Temporary Lodging |
| Hotels, Medium | 0 | 0 | 0 | |
| Hotels, Large | 0 | 0 | 0 | |
| Offices, Small | 40 | 39 | 77 | Banks, Church/Nonprofit, Professional/Technical Services |
| Offices, Medium | 0 | 0 | 0 | |
| Offices, Large | 0 | 0 | 0 | |
| Schools, Elementary | 2 | 2 | 7 | Grade Schools, Colleges/Universities |
| Schools, Middle | 0 | 0 | 0 | |
| Schools, High | 0 | 0 | 0 | |
| Shopping Malls, Small | 61 | 39 | 76 | Retail Trade, Wholesale Trade |
| Shopping Malls, Medium | 0 | 0 | 0 | |
| Shopping Malls, Large | 0 | 0 | 0 | |

*These numbers are multiplied by the % destruction to estimate the numbers of destroyed infrastructure.

### 3.3.2 Debris/Waste Estimate

Based on post-incident records [2], the Joplin Tornado generated a total of 3,000,000 cubic yards ($yd^3$) of debris throughout the disaster area and resulted in $2.8 billion of damage. About 141 tonnes of e-waste and 233 tonnes of white goods were collected and recycled. Most of the vegetative debris was ground into mulch, including over 400,000 $yd^3$ of downed trees. In addition to electronic waste and hazardous waste, large amounts of construction and demolition (C&D) debris from destroyed buildings were also collected. The estimates that are going to be presented here represent calculations from models that are based on the custom infrastructure dataset and assumptions of levels of destruction that were applied equally across each of the zones in the impacted study area. Differences between the measured debris/waste quantities and the estimated debris/waste quantities will be evaluated in the future to "ground truth" the model predictions and improve those predictions.

Debris from Joplin was sent either to the Prairie View Municipal Solid Waste Landfill in Missouri or to landfills in Kansas. Roughly 1.3 million cubic yards of disaster debris were disposed of in landfills in Kansas, which constitutes more than one-third of the total debris generated by the tornado. The Kansas Department of Health and Environment offered support in distributing debris to three landfills. Due to the close proximity of the Kansas landfills to Joplin, Missouri, transportation costs were reduced.

Table 15 lists the estimated masses of different structural, nonstructural, and outdoor materials. Table 16 lists the same data but in terms of volume in cubic meters. Figure 16 displays the mass estimate of

those same materials. Table 17 lists the estimate of the mass of building contents from the hypothetical tornado scenario, and Figure 17 graphically illustrates those data. Table 18 lists the estimated mass of household hazardous waste from the hypothetical tornado scenario, and Figure 18 graphically illustrates those data.

The total amount of debris/waste generated from the hypothetical tornado scenario using the destruction fraction that was assumed for calculation purposes (100/50/15) is estimated at 1.3E10 kg (1.3E7 tonnes) and 1.0E8 $m^3$. This amount is somewhat higher than the actual amount of debris collected from the incident. The estimate also included approximately 2M tonnes of vegetative debris, approximately 2.2M $m^3$ (2.9M $yd^3$). This estimate is significantly higher than the 400,000 $yd^3$ of trees collected following the actual Joplin tornado incident; however, that 400,000 number is based on the amount of volume after grinding into mulch. Given that the estimated amount of branches/foliage has twice as much mass as tree trunks, and branches/foliage achieve much higher volume reduction when ground than do tree trunks, it is a possible explanation, at least partially, for the high estimate of vegetative biomass.

**Table 15. Estimate of mass of nonstructural and outdoor debris/waste from hypothetical tornado scenario (structures from Table 13)***

| | Zone 1 (kg) | Zone 2 (kg) | Zone 3 (kg) |
|---|---|---|---|
| **Outdoor Materials** | | | |
| Soil | - | - | - |
| Asphalt | 2.80E+06 | 9.15E+05 | 4.10E+04 |
| Concrete | 2.80E+05 | 1.04E+05 | 6.50E+03 |
| **Vehicles** | | | |
| Vehicles - Cars | 3.02E+06 | 1.44E+06 | 1.30E+06 |
| Vehicles - Light Trucks | 2.69E+06 | 1.28E+06 | 1.15E+06 |
| Vehicles - Heavy Trucks | 3.53E+06 | 1.71E+06 | 1.44E+06 |
| **Vegetative Biomass** | | | |
| Vegetative Biomass - Tree Trunks | 3.39E+08 | 1.63E+08 | 1.44E+08 |
| Vegetative Biomass - Foliage/Branches | 7.13E+08 | 3.43E+08 | 3.02E+08 |
| **Non-Structural Materials** | | | |
| Drywall | 3.45E+07 | 1.56E+09 | 9.45E+08 |
| Ceiling Tiles | 5.03E+06 | 1.65E+08 | 9.65E+07 |
| Carpet | 2.81E+06 | 1.21E+08 | 7.29E+07 |
| Marble and Ceramic Tiles | 3.96E+06 | 1.26E+08 | 7.38E+07 |
| Curtains and Acoustical Material | 5.36E+03 | 0.00E+00 | 0.00E+00 |
| Wood | 1.54E+06 | 8.54E+07 | 5.28E+07 |
| Other Nonstructural Building Materials | 1.49E+07 | 6.59E+08 | 3.99E+08 |

*These calculations include the percent destruction estimate.

**Table 16. Estimate of volume of structural, nonstructural, and outdoor debris/waste from hypothetical tornado scenario (structures from Table 13)***

| | Zone 1 ($m^3$) | Zone 2 ($m^3$) | Zone 3 ($m^3$) |
|---|---|---|---|
| **Outdoor Materials** | | | |
| Soil | - | - | - |
| Asphalt | 3.41E+03 | 1.12E+03 | 5.00E+01 |
| Concrete | 1.30E+02 | 4.81E+01 | 3.01E+00 |
| **Vehicles** | | | |
| Vehicles - Cars | 2.44E+04 | 1.16E+04 | 1.05E+04 |
| Vehicles - Light Trucks | 2.48E+04 | 1.18E+04 | 1.06E+04 |
| Vehicles - Heavy Trucks | 1.64E+04 | 7.91E+03 | 2.23E+04 |
| **Vegetative Biomass** | | | |
| Vegetative Biomass - Tree Trunks | 3.78E+05 | 1.82E+05 | 1.60E+05 |
| Vegetative Biomass - Foliage/Branches | 7.97E+05 | 3.84E+05 | 3.37E+05 |
| **Non-Structural Materials** | | | |
| Drywall | 1.08E+05 | 4.89E+06 | 2.96E+06 |
| Ceiling Tiles | 6.26E+04 | 2.05E+06 | 1.20E+06 |
| Carpet | 1.98E+04 | 9.00E+05 | 5.46E+05 |
| Marble and Ceramic Tiles | 7.39E+03 | 2.35E+05 | 1.37E+05 |
| Curtains and Acoustical Material | 1.90E+02 | - | - |
| Wood | 3.53E+03 | 1.96E+05 | 1.21E+05 |
| Other Nonstructural Building Materials | 1.63E+05 | 8.30E+06 | 5.11E+06 |

*These calculations include the percent destruction estimate.

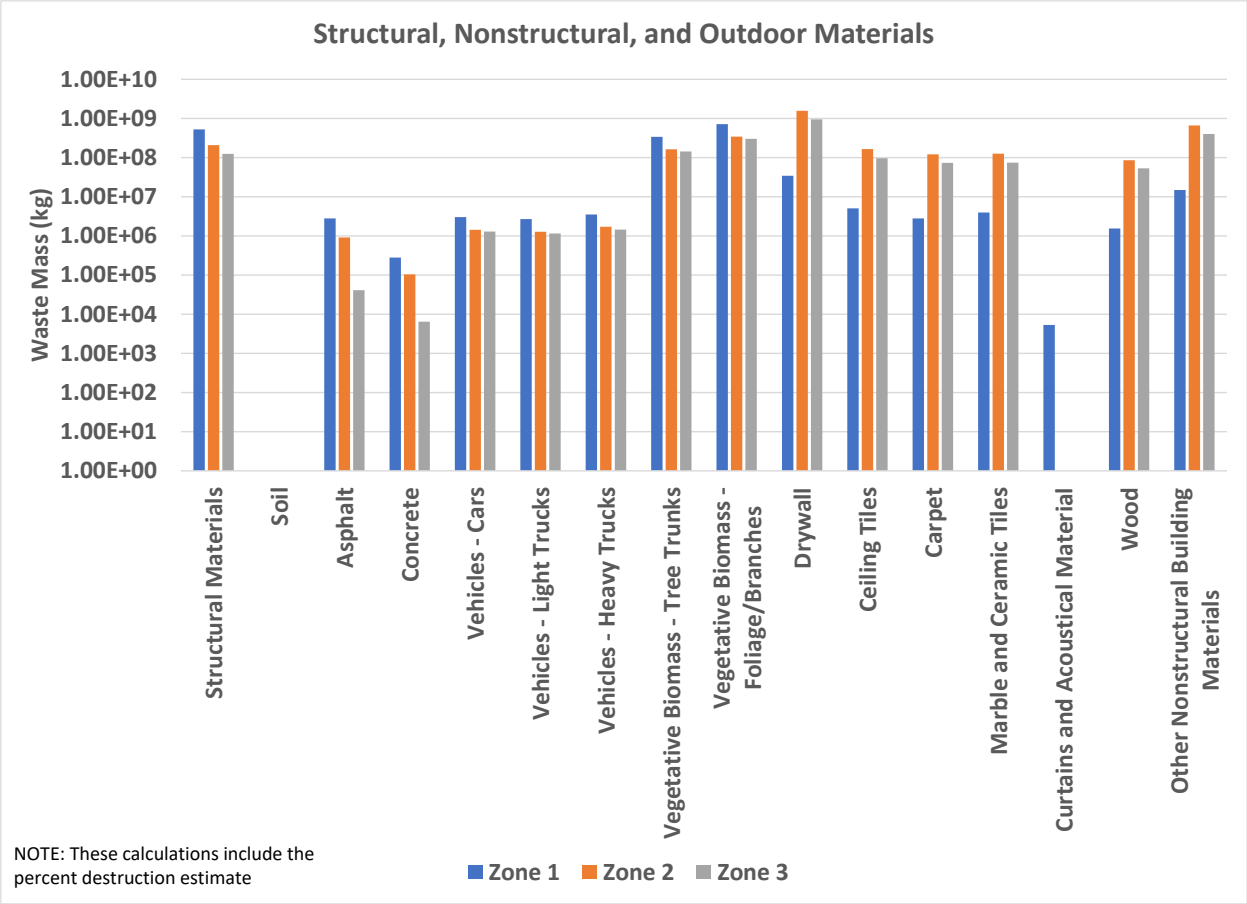


**Figure 16. Estimate of mass of structural, nonstructural, and outdoor debris/waste from hypothetical tornado scenario**

**Table 17. Estimate of mass of building contents from hypothetical tornado scenario**

| | Zone 1 (kg) | Zone 2 (kg) | Zone 3 (kg) |
|---|---|---|---|
| Electronic Equipment | 9.00E+06 | 3.32E+08 | 1.97E+08 |
| Industrial Electronic Equipment | 1.74E+06 | 5.54E+07 | 3.24E+07 |
| Patient Care Equipment | 6.04E+04 | 1.72E+06 | 7.49E+05 |
| Imaging Equipment | 1.29E+04 | 3.66E+05 | 1.60E+05 |
| Laboratory/Surgery Equipment | 6.24E+04 | 1.78E+06 | 7.73E+05 |
| Theater Electronic Equipment | 3.45E+03 | 0.00E+00 | 0.00E+00 |
| Concession Electronic Equipment | 5.73E+02 | 0.00E+00 | 0.00E+00 |
| Other Electronic Equipment | 5.22E+06 | 1.66E+08 | 9.72E+07 |
| Other Furniture | 2.62E+07 | 1.30E+09 | 7.77E+08 |
| Office Furniture | 1.35E+06 | 4.21E+07 | 2.31E+07 |
| Patient Care Furniture | 5.35E+04 | 1.52E+06 | 6.63E+05 |
| Retail Furniture | 2.00E+07 | 6.38E+08 | 3.73E+08 |
| Food | 4.92E+05 | 1.54E+07 | 8.88E+06 |
| Paper and Office Supplies | 6.62E+06 | 2.52E+08 | 1.50E+08 |
| Gym and Sports Equipment | 4.55E+03 | 2.27E+05 | 2.39E+05 |
| Medical Supplies | 4.26E+04 | 1.21E+06 | 5.28E+05 |
| Pharmaceuticals | 6.27E+03 | 1.98E+05 | 9.35E+04 |
| Linens | 1.05E+07 | 3.37E+08 | 1.97E+08 |
| Medical Waste | 2.18E+03 | 6.20E+04 | 2.70E+04 |
| Dishware | 4.36E+03 | 7.27E+04 | 4.36E+04 |
| Personal Effects | 1.93E+06 | 1.07E+08 | 6.61E+07 |
| Other Items and Equipment | 5.30E+06 | 1.69E+08 | 9.87E+07 |
| Art and Music Equipment | 3.27E+03 | 1.64E+05 | 1.72E+05 |
| Bathroom and Kitchen Materials | 2.41E+06 | 1.34E+08 | 8.26E+07 |

*These calculations include the percent destruction estimate.

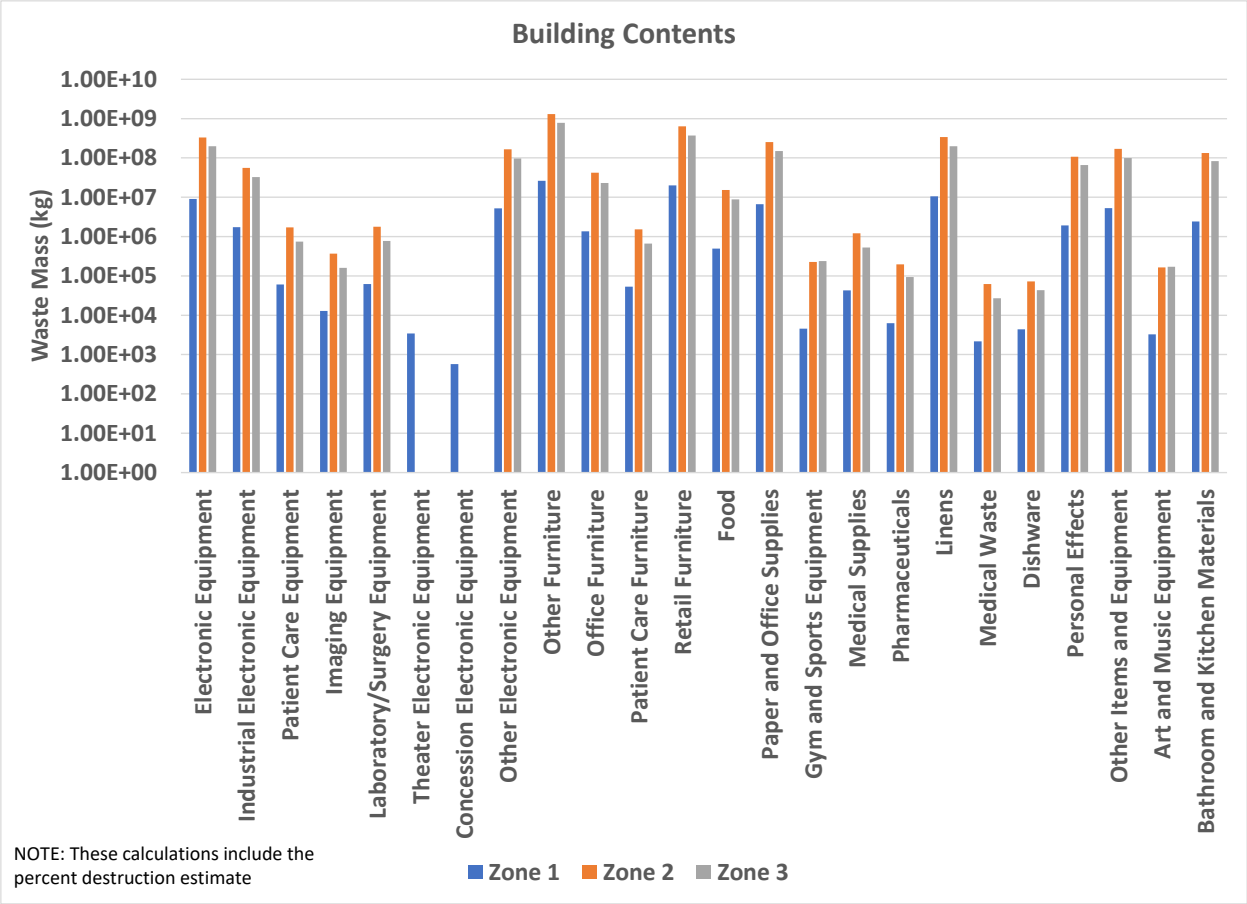


**Figure 17. Estimated mass of building contents from hypothetical tornado scenario**

**Table 18. Estimated mass of household hazardous waste from hypothetical tornado scenario**

| | Zone 1 (kg) | Zone 2 (kg) | Zone 3 (kg) |
|---|---|---|---|
| Oil and Latex Paint | 3.05E+04 | 1.69E+06 | 1.05E+06 |
| Used Oil | 9.15E+03 | 5.07E+05 | 3.14E+05 |
| Lab Packed Aerosols | 1.25E+03 | 6.94E+04 | 4.29E+04 |
| Flammable Liquids | 2.57E+03 | 1.42E+05 | 8.81E+04 |
| Bulk Fuels | 4.66E+03 | 2.58E+05 | 1.60E+05 |
| Flammable Solids | 3.05E+02 | 1.69E+04 | 1.05E+04 |
| Pesticides | 5.30E+02 | 2.94E+04 | 1.82E+04 |
| Poisons | 2.57E+03 | 1.42E+05 | 8.81E+04 |
| Antifreeze | 9.31E+02 | 5.16E+04 | 3.19E+04 |
| Batteries | 2.25E+03 | 1.25E+05 | 7.71E+04 |
| Other Corrosives | 8.83E+02 | 4.90E+04 | 3.03E+04 |
| Cleaning Supplies | 6.42E+00 | 3.56E+02 | 2.20E+02 |
| Compact Fluorescent Lights | 1.33E+03 | 7.39E+04 | 4.57E+04 |

*These calculations include the percent destruction estimate.

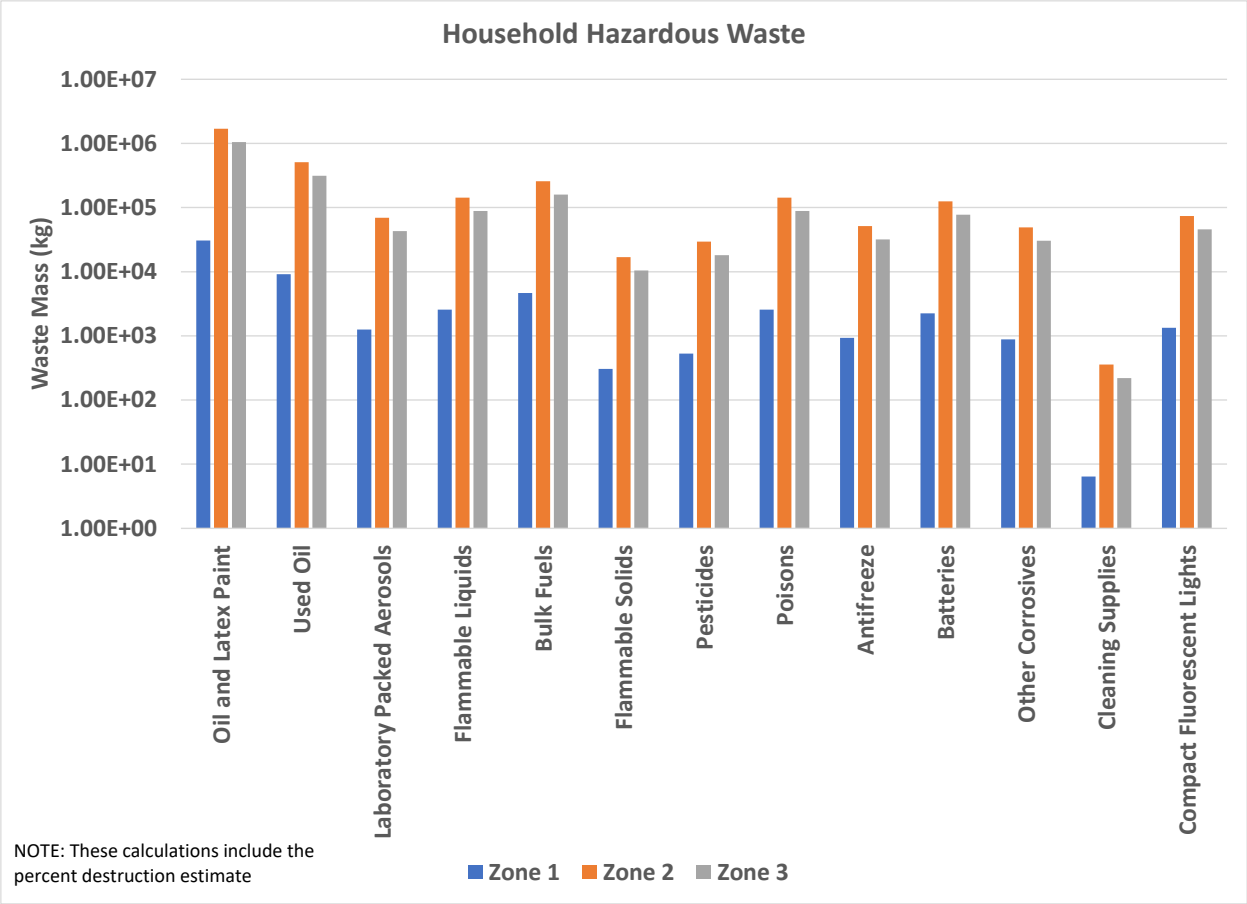


**Figure 18. Estimated mass of household hazardous waste from hypothetical tornado scenario**

Examining these estimates, the following observations are made:

- Medical waste does not appear to be generated in significant quantities; however, significant amounts of pharmaceuticals and medical supplies may need management as waste.
- Electronic equipment may constitute a significant debris/waste stream but may be able to be managed as material.
- Animal carcasses were not included in the waste estimate but may constitute a problematic waste stream since some of the waste management practices used for disposal of animal carcasses require large sources of carbonaceous material (e.g., composting) which may not be readily available in the immediate aftermath of a disaster.
- Food waste may be generated in quantities approaching 20,000 tonnes.
- Overhead satellite imagery suggests that quantities of vegetative debris could be very significant, potentially on the order of 14 million tonnes. Limitations in availability of heavy equipment may significantly impact cleanup efforts.
- Limitations in availability of heavy equipment may significantly impact recovery efforts for all streams.
- Segregation will likely be a significant part of cleanup to manage the different streams.

### 3.3.3 Special Considerations

There are current limitations in estimating quantities of debris/waste from some important debris/waste streams.

- There is not an immediately available method to estimate the numbers of orphan tanks. It might be possible to make an estimate by compiling data of household usage of above-ground tanks and gas grills, coupled with business (particularly gas stations) usage of above-ground tanks.
- Some materials from disaster sites may be considered “hazardous” materials, and only specialized material recovery facilities may be able to take those materials. Currently, only household hazardous waste is included in the waste estimates, but it must be considered that some other materials in the inventory may require management as hazardous materials.
- Missouri (in fact, all of EPA Region 7) a does not have a RCRA Subtitle C disposal facility to manage hazardous waste. Affected industrial facilities may generate significant quantities of hazardous waste that would need to be transported long distances for treatment/disposal; So, communities may want to consider facilities in other areas as backups.
- Animal carcasses (not estimated in this analysis) may constitute a significant waste stream that might require special handling and disposal operations.
- In the event that reduced waste management capacity may impact the ability to perform recovery operations, it is suggested that other alternatives (e.g., waste-to-energy facilities) be considered.
- Identification of the numbers and potential locations of radioactive sources in the affected area should be done as soon as possible. Sources would be registered with the State or NRC; contact the State radiation control program to locate potential sources.
- A significant number of transformers might be damaged and require replacement. Some of them might contain PCBs. This is a potentially important waste stream that has specific requirements associated with its management. Determine if PCB-containing electrical equipment, particularly transformers and capacitors, is located within the community so that PCB spills or other environmental releases may be planned for.
- A potential issue exists where future debris/waste management capacity may be reduced due to wastes being produced during rebuilding operations as previously damaged materials enter the debris/waste stream.

# 4.0 INSTRUCTIONS ON USING THE ACCOMPANYING EXCEL WORKBOOKS

To facilitate the potential need by emergency planners to adjust the example debris/waste inventories presented in this document, a series of Excel workbooks was prepared that took the output from the WEST- and I-WASTE-generated debris/waste inventories and allowed simple math calculations that facilitate scaling of the debris/waste estimates. It is intended that the case studies presented in this document will provide an example that could be used by planners that at least meets a "reality check" of important debris/waste streams and quantities. These examples are based on hypothetical disasters of specific communities for which, although they may provide a reasonable estimate of the characteristics and distribution of debris/waste from a disaster, there may be special considerations specific to planners' communities that require scaling the estimate to allow for larger study areas, larger populations, or different assumed levels of destruction. An example would be to plan for an EF-3 tornado instead of an EF5 tornado where the relative amount of destruction would be significantly reduced.

The Excel workbooks that accompany this report require that the light blue cells on the following Figures be filled in by copying and pasting data from WEST from the "Waste Results" page, from the .csv files that are generated by the WEST GIS App, or from other open sources of data.

Figure 19 depicts the "Scenario Info" tab from the Joplin, MO workbook (Appendix C). The light blue cells represent data that are brought in from external sources. The block of 3 cells with the "Study Area ($m^2$)" can be copied and pasted from the "plume_area.csv" file that is in the GIS Import Files that WEST uses to generate the debris/waste estimate. The "Affected Population of Example Community" was acquired from an internet search [16] and was manually inputted. The green shaded cells represent user-defined numbers that can be used to scale the overall debris/waste estimate calculations. The scaling that is performed is all linear and is based on Equation (1), allowing the user to scale the results based on their scenario having different study areas and different populations than the example. The scaling also allows the user to alter the level of destruction for the 3 geographic zones. Since the affected area and affected populations are not independent of each other (i.e., the smaller the affected areas are the fewer the people are affected), this equation somewhat oversimplifies the situation, but does allow linear scaling of the waste estimate. See the Appendices for the default areas, populations, and level of destruction used in the case studies. These estimates are based on infrastructure data from specific communities, and the results obtained by running the aforementioned tools on the user's actual communities would likely yield more accurate results3.

$$SF = \frac{User\ Comm.\ Study\ Area}{Study\ Area} X \frac{Affected\ Population\ of\ User\ Comm.}{Affected\ Population\ of\ Example\ Comm.} X\ \%\ Destruction \quad (1)$$

where SF is the Scaling Factor that is multiplied by the number of structures to adjust the number of potentially destroyed structures.

| Scenario Name: | Joplin, MO Tornado | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Example Study Area (m2) | Example Study Area (mi2) | User Community Study Area (m2) | User Community Study Area (m2) | % Destruction | Study Area Scaling Factor | Population Scaling Factor | Scaling Factor for Calculations |
| Zone 1 | 14921376 | 5.8 | 14921376 | 6 | 100 | 1.0 | 1.0 | 100 |
| Zone 2 | 3845085 | 1.5 | 3845085 | 1 | 50 | 1.0 | 1.0 | 50 |
| Zone 3 | 3558514 | 1.4 | 3558514 | 1 | 15 | 1.0 | 1.0 | 15 |

| | | |
|---|---|---|
| Affected Population of Example Community | 51762 | Inputted from External Source |
| Affected Population of User Community for Scaling Purposes | 51762 | User-Defined |
| Ratio of User's Community Size to Example Community Size | 1.00 | Calculated |

**Figure 19. Screenshot of "Scenario Info" tab**

Figure 20 shows a screenshot of the "Outdoor Surfaces" tab, where the numbers from the "ground_surface_data.csv" files are generated by WEST and placed in the GIS_ImportFiles folder. The numbers can be copied and pasted from the .csv file onto the corresponding light blue shaded areas.

| Zone Number | Media Type | Percent of Total Ground Surface |
|---|---|---|
| 1 | | |
| | Soil/Vegetation | 67 |
| | Streets - Asphalt | 8 |
| | Streets/Sidewalks - Concrete | 24 |
| 2 | | |
| | Soil/Vegetation | 78 |
| | Streets - Asphalt | 5 |
| | Streets/Sidewalks - Concrete | 17 |
| 3 | | |
| | Soil/Vegetation | 77 |
| | Streets - Asphalt | 4 |
| | Streets/Sidewalks - Concrete | 19 |

**Figure 20. Screenshot of "Outdoor Surfaces" tab**

Figure 21 shows the "Infrastructure" tab, where the numbers of potentially affected buildings can be extracted from the WEST Reporting function under "Critical/Sensitive Infrastructure." This particular report needs to be saved from WEST as a .pdf and the data copied and pasted into the worksheet in Figure 21. Figure 22 shows a screen shot of WEST with the Reports screen selecting the appropriate report with the infrastructure list.

Figure 23 shows the "Baseline Estimate" tab. The numbers for the light blue shaded area in the worksheet come from the WEST Results function under the "Grand Totals" tab (see Figure 24). For the first set of light blue cells, go to the "Grand Totals" tab in the WEST Results, select all the zones, then hit "Apply Filter" and click the "Export Data to Excel" button. For the second light blue shaded area, go to the WEST Results function under the "Ground Surfaces" tab, select all the zones, and select all the

surface types. Then hit “Apply Filter and click the “Export Data to Excel” button (see Figure 25). The numbers for that part of Figure 23 can be copied and pasted from Excel.

For the vehicles and vegetative biomass estimates, go to the Vehicles or Biomass tab, select all the zones (see Figures 26 and 27), then hit “Apply Filter” and click the “Export Data to Excel” button. Those parts of Figure 23 can be copied and pasted from Excel. Note that if a custom infrastructure database was used for the debris/waste estimate, a separate WEST run using the default infrastructure must also be run to generate the vehicles and biomass estimates – they currently are not calculated from custom infrastructure runs.

Once the light blue cells have been filled in on the four worksheets, and any changes to the user-defined parameters (green cells) have been filled in, then the tables shown on the “Debris/Waste Estimate for Graphs” worksheet and the graphs will be populated with the estimate.

| Number of Potentially Affected Structures - Calculation of Demolished Structural Materials | | | |
|---|---|---|---|
| **WEST Infrastructure Type** | **Zone 1** | **Zone 2** | **Zone 3** |
| Agriculture | 5 | 4 | 4 |
| Banks | 4 | 5 | 6 |
| Church/Non-Profit | 14 | 12 | 24 |
| Colleges/Universities | 0 | 0 | 0 |
| Construction | 16 | 10 | 19 |
| Emergency Response | 0 | 0 | 0 |
| Entertainment & Recreation | 19 | 16 | 49 |
| Food/Drugs/Chemicals | 1 | 1 | 1 |
| General Services | 1 | 2 | 4 |
| Grade Schools | 2 | 2 | 7 |
| Heavy | 6 | 1 | 10 |
| High Technology | 0 | 0 | 0 |
| Hospital | 8 | 2 | 3 |
| Institutional Dormitory | 5 | 3 | 7 |
| Light | 6 | 2 | 12 |
| Medical Office/Clinic | 19 | 22 | 30 |
| Metals/Minerals Processing | 0 | 0 | 3 |
| Mobile Home | 62 | 39 | 95 |
| Multi Family Dwelling - 10-19 Units | 7 | 1 | 9 |
| Multi Family Dwelling - 20-49 Units | 0 | 0 | 1 |
| Multi Family Dwelling - 3-4 Units | 14 | 32 | 42 |
| Multi Family Dwelling - 50+ Units | 0 | 1 | 1 |
| Multi Family Dwelling - 5-9 Units | 24 | 14 | 38 |
| Multi Family Dwelling - Duplex | 75 | 73 | 112 |
| Nursing Home | 1 | 2 | 3 |
| Personal and Repair Services | 31 | 26 | 60 |
| Professional/Technical Services | 30 | 32 | 59 |
| Retail Trade | 39 | 24 | 52 |
| Single Family Dwelling | 1,531 | 1,755 | 3,603 |
| Temporary Lodging | 3 | 1 | 2 |
| Theaters | 1 | 0 | 0 |
| Wholesale Trade | 22 | 15 | 24 |

**Figure 21. Screenshot of "Infrastructure" tab**

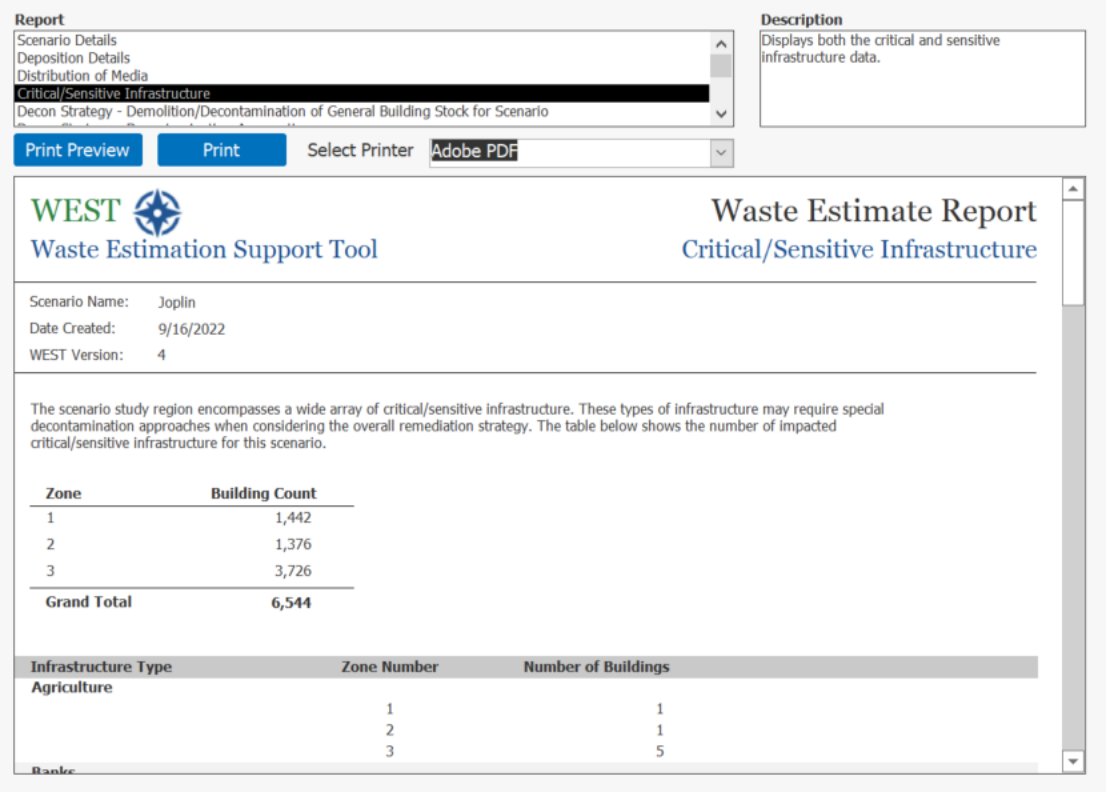


**Figure 22. Screenshot from WEST reporting function for extracting infrastructure**

| Baseline Waste Estimate | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Solid Waste from Structural Material** | **100 % Destruction** | | | | | | | | | | |
| **Zone Number** | **Solid Waste Mass (kg)** | **Solid Waste Volume (m3)** | | | | | | | | | |
| 1 | 5.27E+08 | 8.87E+05 | | | | | | | | | |
| 2 | 4.17E+08 | 7.02E+05 | | | | | | | | | |
| 3 | 8.28E+08 | 1.40E+06 | | | | | | | | | |
| **Solid Waste from Outdoor Areas** | | | | | | | | | | | |
| **Zone Number** | **Surface Type** | **Solid Waste Mass (kg)** | **Solid Waste Volume (m3)** | | | | | | | | |
| 1 | Soil | 0.00E+00 | 0.00E+00 | | | | | | | | |
| 1 | Streets - Asphalt | 2.80E+06 | 3.41E+03 | | | | | | | | |
| 1 | Streets/Sidewalks - Concrete | 2.80E+05 | 1.30E+02 | | | | | | | | |
| 2 | Soil | 0.00E+00 | 0.00E+00 | | | | | | | | |
| 2 | Streets - Asphalt | 1.83E+06 | 2.23E+03 | | | | | | | | |
| 2 | Streets/Sidewalks - Concrete | 2.08E+05 | 9.61E+01 | | | | | | | | |
| 3 | Soil | 0.00E+00 | 0.00E+00 | | | | | | | | |
| 3 | Streets - Asphalt | 2.73E+05 | 3.33E+02 | | | | | | | | |
| 3 | Streets/Sidewalks - Concrete | 4.33E+04 | 2.00E+01 | | | | | | | | |
| **Solid Waste from Vehicles** | **100% Destruction** | | | | | | | | | | |
| **Zone** | **Total Number of Vehicles** | **Cars** | **Light Trucks** | **Heavy Trucks** | **Car Mass (kg)** | **Light Truck Mass (kg)** | **Heavy Truck Mass (kg)** | **Car Volume (m3)** | **Light Truck Volume (m3)** | **Heavy Truck Volume (m3)** | |
| 1 | 3293 | 1842 | 1355 | 97 | 3.02E+06 | 2.69E+06 | 3.53E+06 | 2.44E+04 | 2.48E+04 | 1.64E+04 | |
| 2 | 3145 | 1759 | 1291 | 94 | 2.88E+06 | 2.57E+06 | 3.41E+06 | 2.33E+04 | 2.37E+04 | 1.58E+04 | |
| 3 | 9408 | 5268 | 3872 | 266 | 8.64E+06 | 7.70E+06 | 9.63E+06 | 6.97E+04 | 7.09E+04 | 4.46E+04 | |
| Note -- vehicles from Joplin default infrastructure estimate | | | | | | | | | | | |
| **Solid Waste from Vegetative Biomasss** | **100% Destruction** | | | | | | | | | | |
| **Zone** | **Tree Stems Less Than 40 ft** | **Tree Stems 40 to 60 ft** | **Tree Stems Greater Than 60 ft** | **Trunk Mass (kg)** | **Foliage/ Branches Mass (kg)** | **Total Biomass (kg)** | **Trunk Volume (m3)** | **Foliage/ Branches Volume (m3)** | **Total Biomass Volume (m3)** | | |
| 1 | 270384 | 987446 | 1052083 | 3.39E+08 | 7.13E+08 | 1.05E+09 | 3.78E+05 | 7.97E+05 | 1.18E+06 | | |
| 2 | 260303 | 950630 | 1012858 | 3.26E+08 | 6.87E+08 | 1.01E+09 | 3.64E+05 | 7.67E+05 | 1.13E+06 | | |
| 3 | 763270 | 2787474 | 2969941 | 9.57E+08 | 2.01E+09 | 2.97E+09 | 1.07E+06 | 2.25E+06 | 3.32E+06 | | |

**Figure 23. Screenshot of "Baseline Estimate" tab**

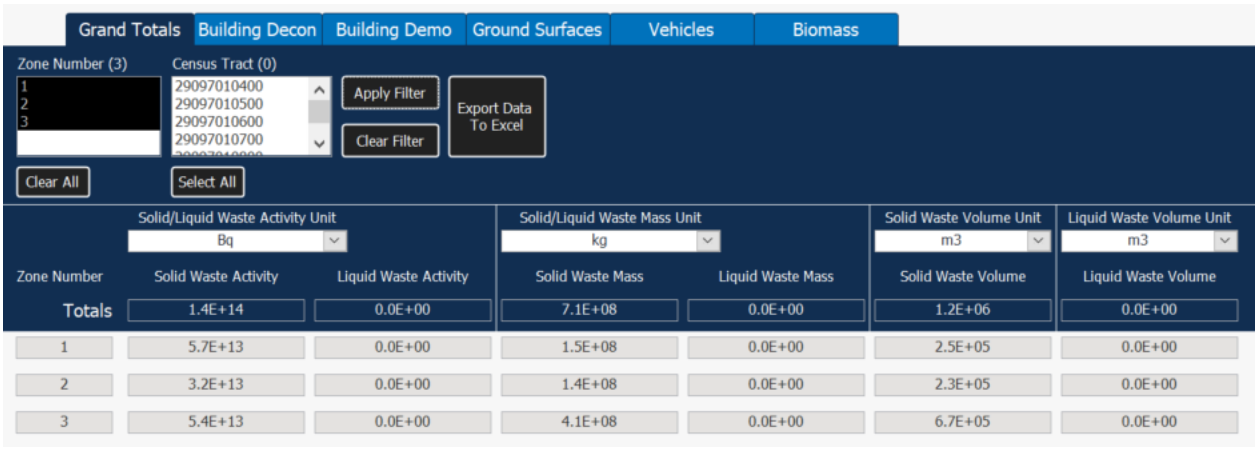


**Figure 24. Screenshot from WEST showing how to extract grand totals of debris/waste estimate.**

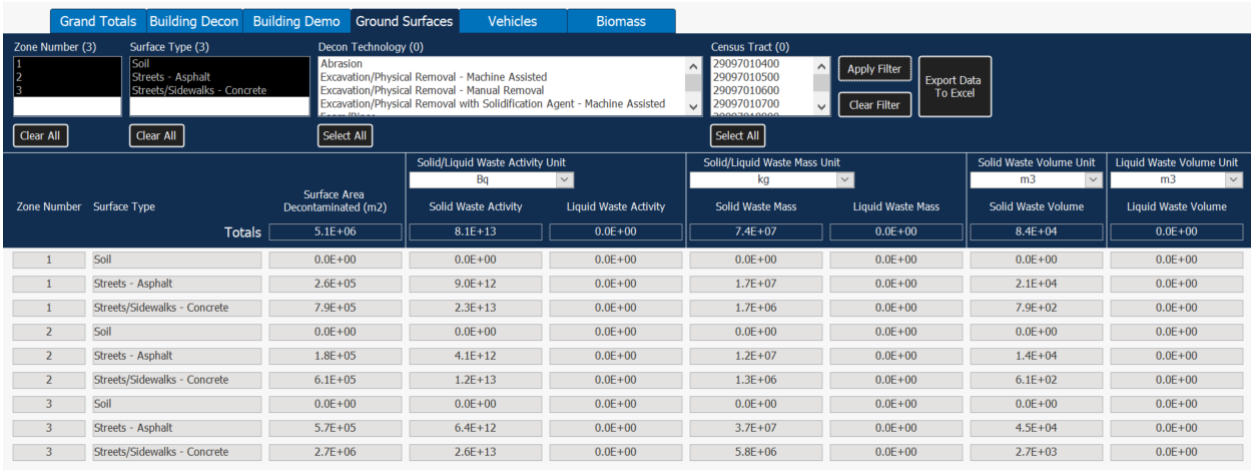


**Figure 25. Screenshot from WEST showing how to extract ground surface estimates.**

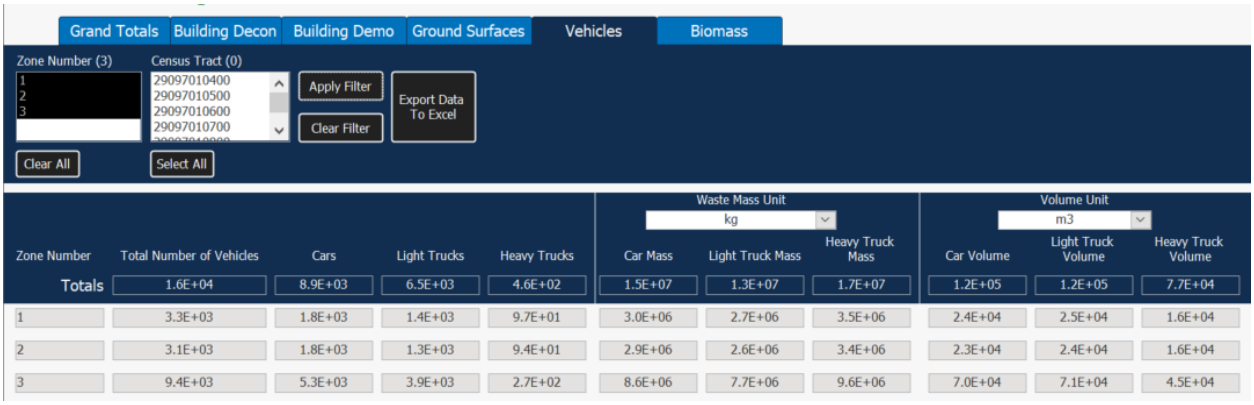


**Figure 26. Screenshot from WEST showing how to extract vehicle estimates**

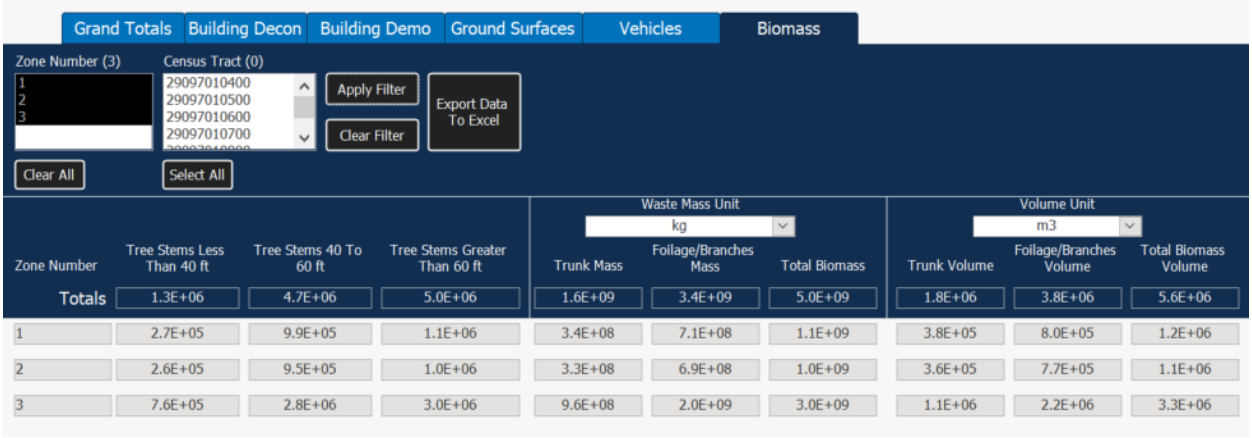


**Figure 27. Screenshot from WEST showing how to extract vegetative biomass estimates.**

# 5.0 QUALITY ASSURANCE/QUALITY CONTROL

The purpose of this effort was to utilize existing HSRP tools to generate debris/waste estimates from hypothetical natural disasters. The development of case studies was described in an approved Quality Assurance Project Plan (QAPP). There were not any experiments performed. The QAPP was adhered to with the exception that the Waste Staging and Site Selection Tool and the All-Hazards Logistics Tool were not used in the debris/waste estimates and development of the scenarios because those tools and their results are highly site-specific, and the authors believed that they would be of limited use for producing a scaleable debris/waste inventory for a wide variety of communities.

The calculations in the Excel workbooks prepared for this effort were verified for quality control purposes (QC'd) in two ways:

The bulk of the data entered into the workbooks came directly from WEST and I-WASTE and did not involve any manipulation. In fact, wherever possible, the format of the blocks of cells in the workbooks are exactly the same as the format of the corresponding blocks of cells in the outputs from the two tools to facilitate transfer of data from the tool outputs into the Excel workbooks by simply copying and pasting. The calculations in the workbooks consisted only of simple math operations (e.g., addition, multiplication) and the calculations were QC'd by substituting zero or 100% into the user-adjustable cells and verifying that the resulting calculations reflect the correct bounds of the results.

# 6.0 CONCLUSIONS

A series of debris/waste inventories was developed using existing HSRP decision support tools based on three hypothetical natural disaster scenarios. The inventories were presented based on the reporting functions that the decision support tools use. The inventories were also exported to three Excel workbooks representing each of the three disaster scenarios. The Excel workbooks allow the user to scale the reported scenarios based on geographic area, affected population, or by altering the estimates of percent destruction due to the disasters.

These debris/waste estimates should be suitable for use in developing pre-incident planning documents, including disaster debris management plans, to enhance preparedness and resiliency of communities across the United States. The estimates could be used by planners manually developing their planning documentation, but the estimates should also be in a format that makes it relatively easy to enter into the waste inventory part of the online All-Hazards Waste Management Planning Tool (wasteplan.epa.gov).

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