Integrating Decontamination Strategies into a Waste Estimation Support Tool for Radiological Incidents - 15284

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ABSTRACT

In the planning and preparedness stages for a response to a radiological incident, it is important to include waste management considerations when developing the decontamination/demolition/cleanup approach because waste management can be a driver for time and cost. An individualized type of strategy based on the occupancy of affected buildings may be an effective approach. The U.S. Environmental Protection Agency's (EPA's) Waste Estimation Support Tool (WEST) is a novel application of the Federal Emergency Management Agency (FEMA) Hazus-MH software. WEST enables users to estimate the characteristics, amount, and residual radioactivity of waste generated from remediation and cleanup activities after a radiological incident, including incidents caused by radiological dispersal devices and improvised nuclear devices, as well as nuclear power plant accidents. This paper will describe the recently released update to WEST, which includes the ability to export the waste estimate results back into ArcGIS for further visualization.

INTRODUCTION

The introduction of contaminants into the environment by means of a radiological incident has the potential to expose a significant number of people and contaminate the environment with dangerous levels of radiation [1]. The effects of a wide-area incident may last decades or longer and require significant resources to remedy. Preparedness, mitigation, and response activities are critical factors in minimizing the effects of radiological incidents [2]. Despite these efforts, recovery is largely a product of decontamination and waste management strategies, policies, timelines, available resources, and public sentiment. Such factors reiterate the need for initiating strategy and policy discussions early on in the process of planning for radiological incidents. These types of discussion are best supported by well-informed, science-based, integrated decontamination and waste management strategies. With the growing threat of terrorism and consideration of the complications arising from the Fukushima disaster in Japan, evaluating the implications of various integrated decontamination and waste management strategies both before and during a radiological incident is more important than ever.

In an effort to streamline and simplify waste estimation capabilities, EPA developed the Waste Estimation Support Tool (WEST), an application for estimating the characteristics, amounts, and residual radioactivity of waste generated from remediation and cleanup activities after a wide-area radiological incident. WEST is capable of modeling the results of an array of radiological sources, such as radiological dispersal devices, improvised nuclear devices, and nuclear power plant accidents [4]. WEST incorporates a number of novel technologies intended to facilitate decontamination and waste management associated with wide-area contamination incidents, most notably, geographic information systems (GISs), The Federal Emergency Management Agency's (FEMA's) Hazus-MH software, and satellite image classification capabilities [3,6]. By leveraging these technologies in concert with a methodology for estimating the quantity of waste (including debris) that may result from a radiological incident, users can create customized decontamination strategies. This capability enables the end-user to highlight waste quantities and characteristics and how this information plays an important role in the overall remediation strategy according to a geographical locality.

Now entering its sixth year of development, WEST has evolved into a multifaceted tool that has been used several times during radiologically themed federal exercises [5], including the Wide Area Recovery and Resiliency Program (WARRP), Liberty RadEx, and National Level Exercise 14 (2014) that addressed a hypothetical earthquake and tsunami off the coast of Alaska (WEST was used to query the Hazus infrastructure databases to identify affected infrastructure). This last example highlights the potential usefulness of WEST for all-hazards incidents. Last year, WEST introduced a new occupancy-specific option, enabling users to assign decontamination and demolition options to individual building occupancy classes (e.g., schools, residences). This capability allowed for a more detailed decontamination strategy (i.e., distribution of different decontamination technologies or demolition approaches among building types). More recent efforts have been focused on preserving the spatial context of affected infrastructure when calculating waste estimates. This feature will allow waste estimates to be imported into a GIS application such as Google Earth (from Google) or the ESRI ArcGIS platform. By doing so, end-users can graphically see the impact of their decontamination decisions on waste. Other enhancements to WEST include a streamlined user interface and the ability to generate custom reports suitable for inclusion in the documentation of exercise or response activities.

METHODS

WEST consists of three interconnected platforms: 1) a graphical user interface (GUI); 2) a geographic information system; and 3) a Visual Basic for Applications (VBA)-based Microsoft Excel® spreadsheet. The user interface comprises a scenario management system, a tool for conducting geospatial analysis, and a utility (i.e., wizard) designed to simplify the execution of the various WEST components. The GIS capability is fully automated and works in conjunction with FEMA's Hazus-MH to estimate infrastructure according to a geographic area. The VBA-based spreadsheet conducts a series of complex analyses based on a specified decontamination strategy. The methodology for creating a scenario in WEST is shown in Figure 1. The following sections will describe these platforms in greater detail.

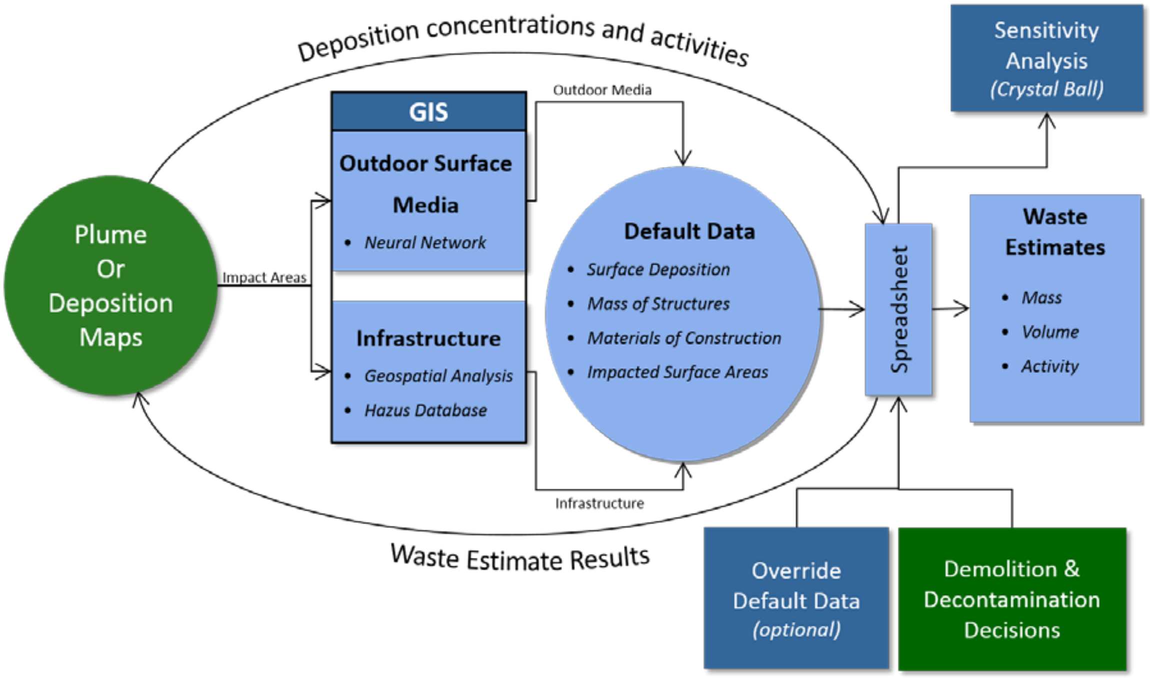

Figure 1. WEST Methodology

User Interface

The WEST GUI is comprised of a custom executable application and a Python-based ArcGIS Toolbox. The executable application provides the end-user with a point and click menu for creating and managing WEST scenarios. An example of the startup screen is shown in Figure 2. One of the unique features of the WEST GUI is its seamless interaction with Hazus-MH. By exploiting this feature, users can assign different decontamination technologies to specific infrastructure (e.g., schools, residences). This capability allows users to create a customized decontamination strategy tailored to local infrastructure.

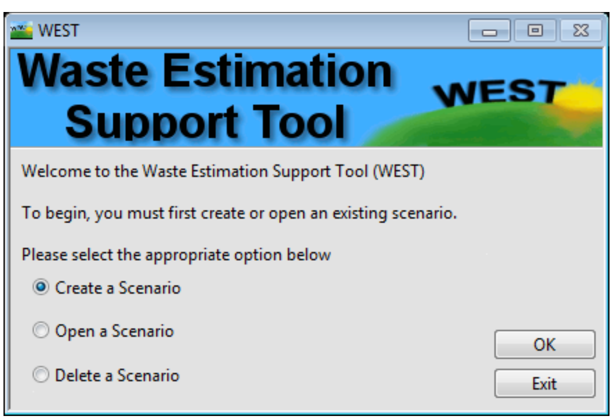

Figure 2. WEST Main Menu

Geographic Information System (GIS)

As previously mentioned, WEST works with FEMA's Hazus-MH software. Hazus-MH is a GIS-based software for predicting property loss due to an earthquake, wind, or flood event. Hazus-MH boasts a detailed census-based infrastructure database covering the continental United States (CONUS). WEST uses these infrastructure datasets to estimate the types and amounts of infrastructure that intersect a study area (i.e., contaminated area). The study area is defined by three polygons representing three varying levels of contamination. These polygons represent the contaminant plumes and are typically provided by the National Atmospheric Release Advisory Committee (NARAC); however, plume files can be created in dispersion modeling programs or even drawn manually in GIS applications. These inputs are essentially the only files needed to create a WEST scenario. Because WEST must relate a spatial context to a study area, WEST uses ESRI's ArcGIS both to interact with Hazus-MH and to obtain the necessary geospatial data. These tasks are fully automated by an ArcGIS Python-based script (i.e., Plume Tool). The Plume Tool's interface is shown in Figure 3. The Plume Tool performs the approximately 70 geospatial processes required to retrieve the necessary geospatial data as defined by the study area.

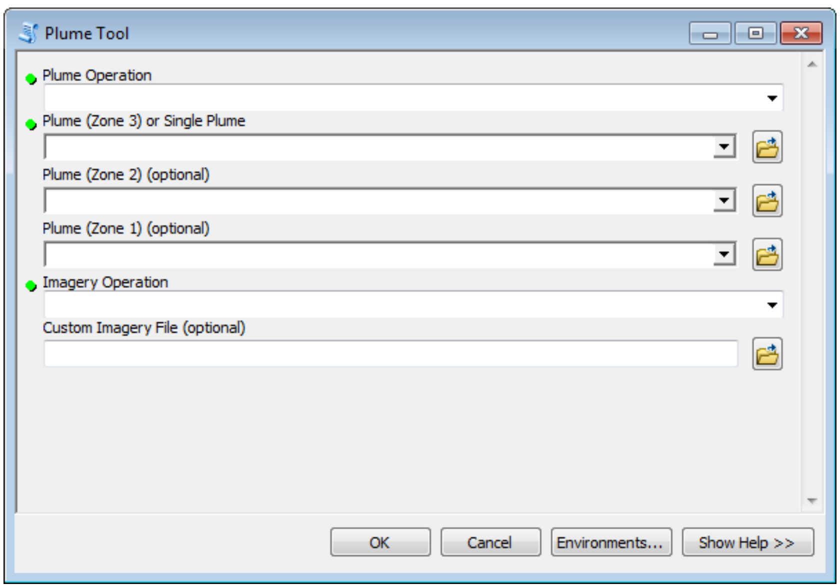

Figure 3. Plume Tool Menu

The ArcGIS-based Plume Tool conducts three basic operations: 1) verify the internal structure of the plume shapefiles and, if necessary, modify their data structure to be compatible with WEST; 2) calculate the area and distribution of census tracts within the plume; and 3) capture aerial imagery of the study area according to the boundaries of the plumes. The imagery is used later to estimate the distribution of outdoor surfaces (i.e., soil, asphalt, concrete, vegetation, and water).

Working in conjunction with the Plume Tool, the WEST User Interface hosts two discrete yet important background processes: the Database Tool and the Image Classification Tool. The Database Tool is responsible for querying the Hazus-MH database to identify which census tracts intersect the plumes. The tool retrieves the total square feet and numbers and types of infrastructure within the impacted census tracts. The tool is capable of querying regions spanning multiple states and also is compatible with customized infrastructure data that might be available from local sources at a higher resolution than in the Hazus-MH databases. The Image Classification Tool uses a feed-forward neural network to identify common outdoor surfaces (i.e., soil, asphalt, concrete, vegetation, and water) and the distribution of those surfaces within the study area. The outdoor surface media estimates that are generated coupled with the infrastructure data make up the geographical area in which decontamination technologies can be applied.

Waste Spreadsheet

WEST uses a VBA-based Microsoft Excel spreadsheet that provides an interface for users to specify various required inputs, modify default parameters, and subsequently view the results of decontamination and demolition operations on the geographic area of interest developed previously with the other WEST modules. Upon opening the spreadsheet, the user is given the option of opening an existing scenario or creating a new one. When creating a new scenario, the user must establish three sets of parameters, as detailed below:

- Geospatial Data Delineating the Area of Contamination: This input (generated from Hazus-MH and ArcGIS) represents the data generated by the WEST geospatial analysis. The geospatial data contain information on plume boundaries, infrastructure, and outdoor surfaces detected. This input cannot be modified from within the spreadsheet (i.e., the information from the geospatial analysis is automatically transferred to the spreadsheet and thereafter cannot be modified for a given scenario without returning to ArcGIS and re-running the geospatial analysis). NOTE: One of the enhancements in the newest version of WEST is to greatly simplify the operation of re-running the geospatial analysis.

- Time and Activity: Users can define the radionuclide(s) deposited at various locations (based on three deposition zone boundaries of different levels of contamination) from the incident epicenter at a given elapsed time since initial deposition. This information typically is given to a user from an external source (e.g., NARAC) and also can be updated as additional information (e.g., sampling data) becomes available.

- Decontamination Strategy: Users can specify the types of decontamination technology to be used on various indoor and outdoor surfaces for multiple user-defined building occupancy types in each deposition zone or can choose to model the demolition of a fraction of buildings in any given zone (e.g., 30 % of the residences in Zone 1 could be designated for demolition). The decontamination technologies are derived from published operational data collected by EPA through testing radioactive materials in a laboratory environment [6].

These three types of data can be used independently of each other. For example, a given Decontamination Strategy could be applied to any number of Geospatial Data sets. This design feature was implemented based on user feedback from past WEST usage, where it was common to re-run decontamination strategies on different geospatial data sets, or to re-run multiple decontamination strategies on a single geospatial data set.

Once the demolition and/or decontamination parameters have been specified, WEST then generates an estimate containing the amount and radioactivity of contaminated waste that would be generated based on the parameters defined above. The waste estimates include building materials from any demolition and/or decontamination activities, removed ground surface materials, decontamination wastes, and wastewater that might be generated during demolition or decontamination activities. These estimates can be optionally exported as a stand-alone Excel file so that results from WEST can be subjected to sensitivity analysis using Microsoft Excel add-ons such as Crystal Ball to identify impacts of decisions on such output variables as amount/activity of waste, type of waste, or remediation costs.

Mapping and Reporting

A significant enhancement to the waste spreadsheet tool that is included in the next release is the addition of functionality to allow users to create maps in Keyhole Markup Language (KML) format that identify the magnitude of decontamination and demolition waste streams by census tract in each contamination zone. The KML files quickly can be loaded into Google Earth directly from the user interface and do not require the user to have any knowledge of GIS or the KML file format.

The next release of the tool also will allow users to generate custom reports based on the details and results for each created scenario. The tool will generate a Microsoft Word document that contains generic narrative text but also will contain and document specific details, tables, and results resulting from scenario assumptions. The report is exported as a Microsoft Word file that can be further customized by the user depending on the user’s needs or the desired use of the information. The tool also will have the option for users to generate a Microsoft Excel file containing the specific information from the customized scenario and data that can be used or copied into other applications as the user’s requirements dictate.

RESULTS AND DISCUSSION

Example Scenario: Wide Area Recovery & Resiliency Program (WARRP)

The Wide Area Recovery and Resiliency Program (WARRP) was developed to exercise resiliency (the ability to recover basic services) and to re-establish social and economic systems following a catastrophic chemical, biological, or radiological (CBR) event. The collaborative program, sponsored by the Department of Homeland Security and the Denver Urban Area Security Initiative, was aimed at enhancing wide area recovery capabilities for large urban areas and critical infrastructure following a large-scale CBR incident. The WARRP radiological scenario involved a terrorist detonating a radiological dispersal device (RDD) outside the U.S. Mint in downtown Denver. The hypothetical RDD contained 2,300 curies of cesium-137 (as $^{137}CsCl$) and was dispersed over approximately 100 square kilometers via a 1,360 kilogram (kg) truck bomb. Waste estimates were derived using a polygon shapefile partitioned into three separate zones based on predicted levels of surface contamination: zone 1 = 1000 microcuries per square meter ($\mu Ci/m^2$), zone 2 = 100 $\mu Ci/m^2$, and zone 3 = 10 $\mu Ci/m^2$ as illustrated by different colors (e.g., zone 1 appears as dark orange) in Figure 4 below. The study region is described as an urbanized area consisting of a densely developed infrastructure that encompasses residential, commercial, and other nonresidential types of buildings. Figure 4 shows the boundaries (i.e., area of contamination most likely to require demolition/decontamination) used to define decontamination strategies. For illustration purposes in this example, the occupancy classes for residential structures and schools were lumped together, while all other occupancy classes were lumped together. This arbitrary division was chosen based on the likelihood of occupants either being in a susceptible population (e.g., schools) or present in potentially contaminated structures for the majority of the day (e.g., residences) versus all other structures. Figure 5 shows the distribution of infrastructure between schools/residential infrastructure and everything else. Determining the distribution of contaminated infrastructure is potentially an important consideration for determining the most effective decontamination strategy.

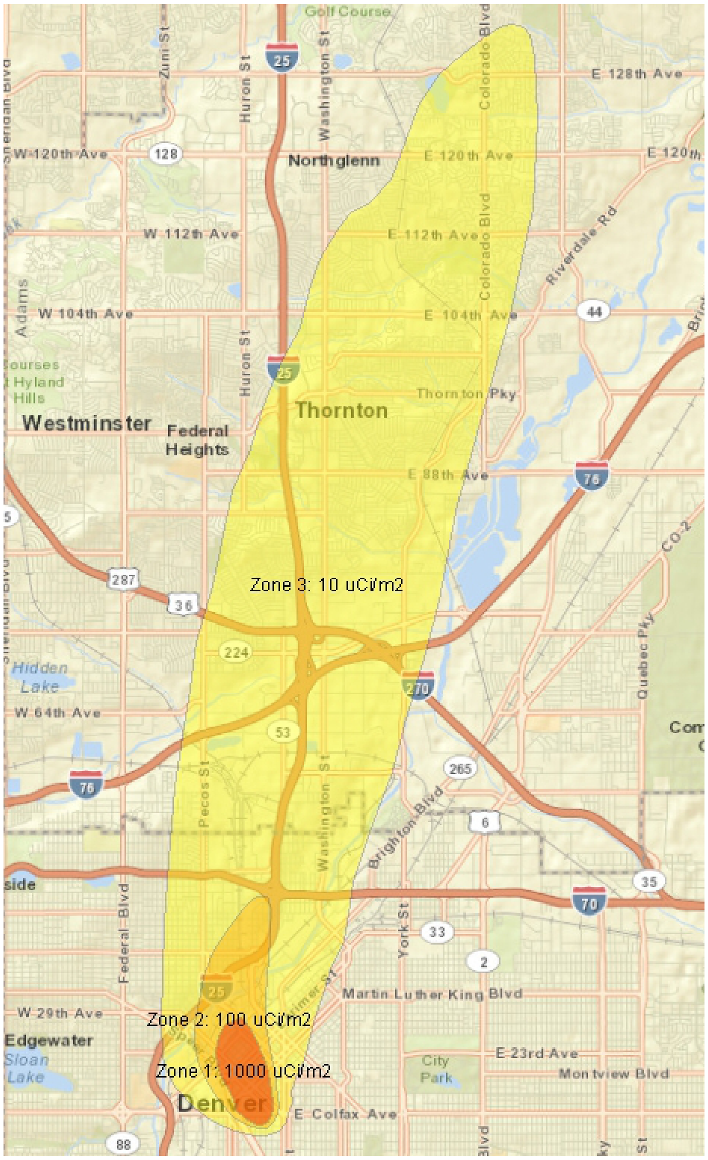

Figure 4. WARRP Plume Shapefile

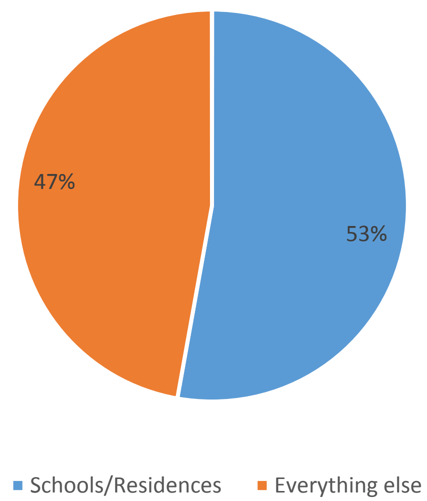

Figure 5. Estimated Distribution of Infrastructure

Decontamination Strategy

Remediation by means of decontamination or demolition following a radiological incident is an extremely complicated undertaking that often revolves around rapidly developing conditions (e.g., location and policy restrictions as well as private property ownership considerations) that may impact the overall amount of resources and time needed to produce a desired outcome. WEST accounts for these site-specific parameters by allowing the user to quickly regenerate geospatial data (i.e., plume boundaries, infrastructure, and surface media), elapsed time, contamination data, and the decontamination strategy when creating scenarios, if necessary. This capability enables dynamic parameters such as plume boundaries to be updated as better sampling data are made available.

Decontamination technologies vary greatly in application, efficacy, and amount (and activity) of waste produced. In parallel with these considerations, the decision-making process also may consider other issues such as human health risks, resource availability, and time required for application of a given decontamination technology. Based on these factors, users may apply either user-defined or pre-defined decontamination technologies that include excavation and removal, strippable coatings, washing and cleaning, and various abrasive techniques such as scabbling.

The selection of decontamination technologies will depend on the surface to which they would be applied, the desired end state, and resource availability. WEST allows decontamination technologies or demolition to be applied: 1) decontamination or demolition percentages (i.e., percentage of buildings within a certain zone or of a certain type that are decontaminated or demolished) that can be defined for specific types of infrastructure (e.g., hospitals, residences) or for buildings within a certain zone; and 2) decontamination percentages for outdoor and indoor surfaces (i.e., asphalt, concrete, soil, roofs, exterior walls, interior walls and floors). Users can choose a “no decontamination option” or “demolish infrastructure” to simulate either blast damage, deliberate demolition operations, or choose to do nothing at all. Based on the assumptions above, WEST generates estimates of waste mass, volume, and residual activity that include:

- Substrate removal (e.g., the layer of radioactive material that must be removed from structures, roads, or soil);
- Residues from the decontamination technologies (e.g., removed strippable coatings, residues from abrasive surface removal); and
- Wastewater and sludges generated by onsite decontamination efforts.

At this point WEST does not calculate waste associated with personal protective equipment (PPE) and personnel decontamination. These example decontamination strategies in the tables below are based on the WARRP scenario and reflect expert judgment but they also reflect some arbitrary decisions designed to highlight the graphing and reporting capability of WEST. The "mostly demolition" scenario, as shown in Table 1, is based on the assumption that contaminated structures, especially those with increased indoor occupancy factors (e.g., schools, residences), will retain a stigma following decontamination. Therefore, in this hypothetical scenario, school and residential infrastructure within Zone 1, and to a lesser extent Zone 2, will be demolished. As illustrated in Table 2, the "mostly decontamination" strategy will, to a greater extent, decontaminate all types of infrastructure in all zones.

Table 1. "Mostly Demolition" Approach Parameters*

Media	**Zone 1**	**Zone 2**	**Zone 3**
	Residences/education 100 % demolition 0 % decontamination	**Residences/education** 50 % demolition 50 % decontamination	**Residences/education** 0 % demolition 100 % decontamination
	Everything else 50 % demolition 50 % decontamination	**Everything else** 0 % demolition 100 % decontamination	**Everything else** 0 % demolition 100 % decontamination
Asphalt	2.5 cm removal – 70 % Wash – 30 %	2.5 cm removal – 50 % Wash – 50 %	2.5 cm removal – 30 % Wash – 70 %
Concrete	2.5 cm removal – 70 % Wash – 30 %	2.5 cm removal – 50 % Wash – 50 %	2.5 cm removal – 30 % Wash – 70 %
Soil	15 cm removal – 100 %	15 cm removal – 50 %	15 cm removal – 25 %
External Walls	Wash – 100 %	Wash – 100 %	Wash – 50 %
Roofs	Wash – 100 %	Wash – 100 %	Wash – 50 %
Interior Walls	Wash – 100 %	Grinding – 50 % Strippable Coating – 50 %	None
Floors	Mop – 100 %	Mop – 100 %	Mop – 100 %

* the percent application of a technology refers to the fraction based on the total amount of that material being decontaminated (i.e., if 50% of the buildings in a zone are being decontaminated,

and washing is being applied to 30% of the concrete, it means that washing is being applied to 30% of the 50% that is being decontaminated).

Table 2. "Mostly Decontamination" Approach Parameters*

Media	**Zone 1**	**Zone 2**	**Zone 3**
	Residences/education 10 % demolition 90 % decontamination	**Residences/education** 0 % demolition 100 % decontamination	**Residences/education** 0 % demolition 100 % decontamination
	Everything else 0 % demolition 100 % decontamination	**Everything else** 0 % demolition 100 % decontamination	**Everything else** 0 % demolition 100 % decontamination
Asphalt	2.5 cm removal – 50% Wash – 50 %	2.5 cm removal – 25 % Wash – 75 %	2.5 cm removal – 10 % Wash – 90 %
Concrete	2.5 cm removal – 50 % Wash – 50 %	2.5 cm removal – 25 % Wash – 75 %	2.5 cm removal – 10 % Wash – 90 %
Soil	15 cm removal – 100 %	15 cm removal – 50 %	15 cm removal – 25 %
External Walls	Wash – 100 %	Wash – 100 %	Wash – 100 %
Roofs	Wash – 100 %	Wash – 100 %	Wash – 100 %
Interior Walls	Wash – 100 %	Grinding – 50 % Strippable Coating – 50 %	None
Floors	Mop – 100 %	Mop – 100 %	Mop – 100 %

* the percent application of a technology refers to the fraction based on the total amount of that material being decontaminated (i.e., if 50% of the buildings in a zone are being decontaminated, and washing is being applied to 30% of the concrete, it means that washing is being applied to 30% of the 50% that is being decontaminated).

The example decontamination strategies were applied to the plumes from the original WARRP scenario. The decontamination strategies presented in this paper are solely for research purposes and by no means reflect official EPA policy. In fact, the main purpose of WEST is to evaluate the impact of decontamination assumptions on the types and amounts of waste and to improve overall recovery decision-making.

Waste Results

The WEST calculates waste from a specified decontamination strategy, estimated infrastructure, and outdoor surface media. Waste can be quantified in terms of volume, activity, and physical characteristics. The results from the "mostly decontamination" and "mostly demolition" strategies described above are shown below in Figures 6 and 7. Figures 6 and 7 show the results from the demolition and decontamination activities from the WARRP scenario, respectively. Figure 8 shows the amount of waste water produced by the decontamination and demolition activities. Note the disparity between the two decontamination scenarios in Figures 6, 7, and 8.

While demolishing schools and residences in zone 1, as prescribed by the "mostly demolition" scenario, will produce more solid waste (i.e., 3.9 million versus 7 thousand metric tons), the "mostly decontamination" strategy will produce more waste water (i.e., 3.9 versus 7.0 million gallons). Nevertheless, the overall total amount of waste estimated by the two decontamination strategies, as shown in Figure 9, is within an order of magnitude.

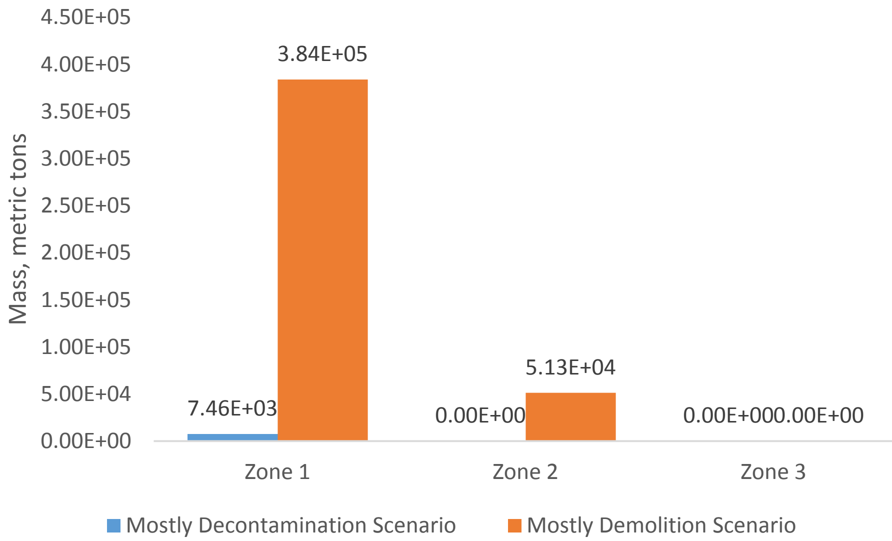

Figure 6. Example of Demolition Waste from the WARRP scenario

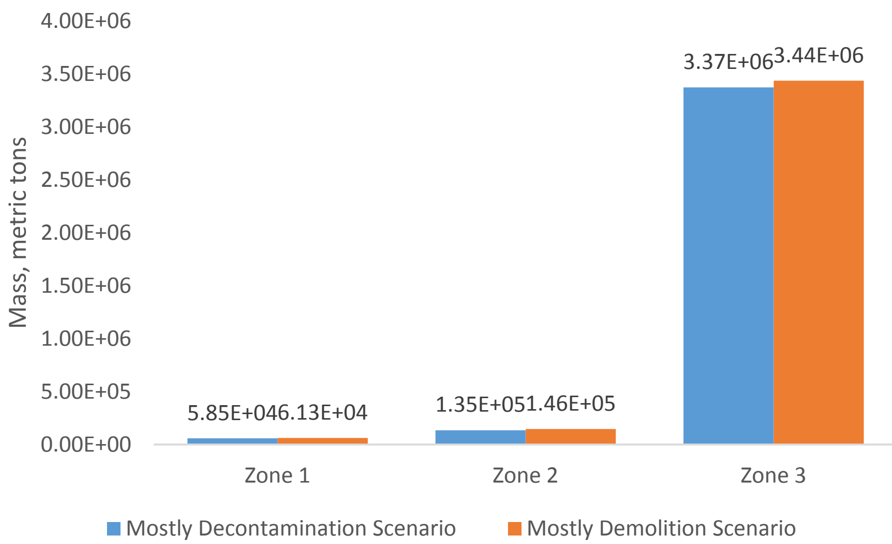

Figure 7. Example of Decontamination Waste from the WARRP scenario

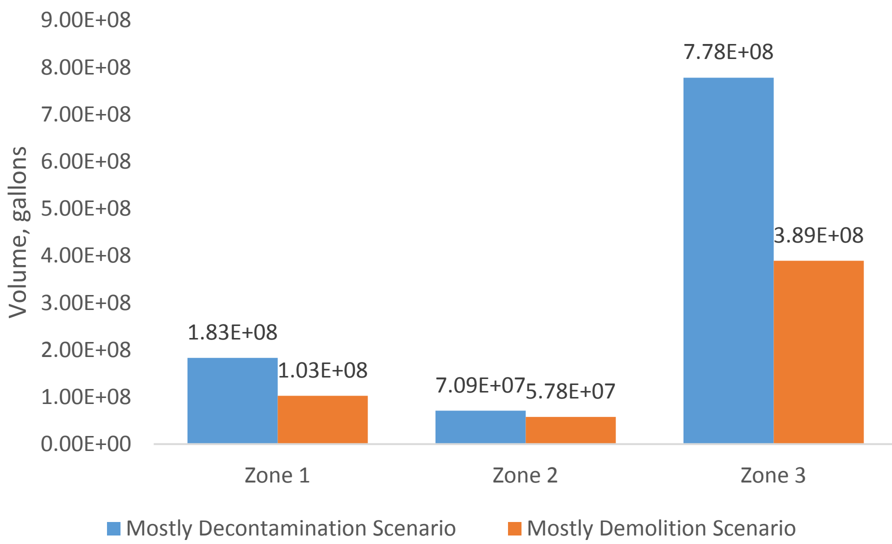

Figure 8. Example of Liquid Waste from the WARRP scenario

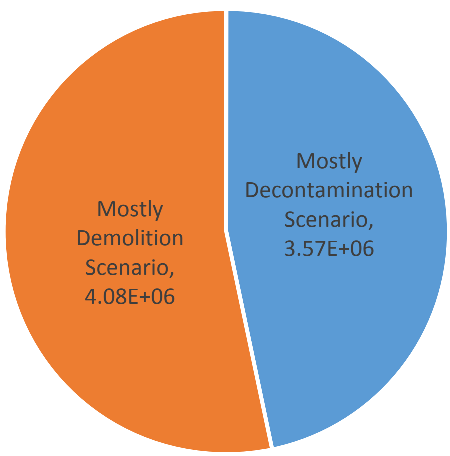

Figure 9. Distribution of Total Waste for the WARRP scenario, metric tons

Figure 10 shows the residual activity levels for both decontamination strategies between the three zones. Overall, the waste activity is estimated to be low and does not vary significantly by zone or strategy. Nonetheless, this information is important in determining the most prudent disposal pathway. For example, contaminated waste may be limited to specific disposal sites (i.e., low level radioactive waste (LLRW) sites, Resource Conservation and Recovery Act (RCRA) Subtitle C hazardous waste landfills), thus exponentially increasing waste management costs and challenging available capacities. Knowing the likely distribution of waste activity can give decision makers a starting point for where strategy and policy discussions would be most productive.

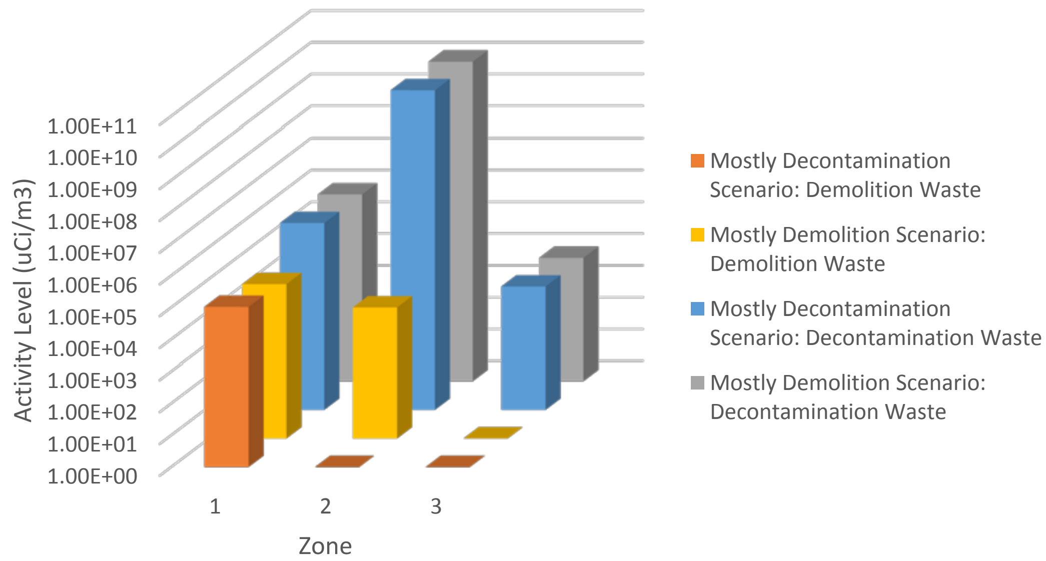

Figure 10. Estimated Residual Activity of Solid Waste by Decontamination and Demolition Strategy and Zone from the WARRP scenario

One of the recent enhancements to the WEST is the ability to plot waste results within a GIS application. This capability allows the user to view the waste implications of decontamination decisions within a spatial context, which is useful for decision-makers in crafting waste management strategies regarding transportation, locations of staging areas, and other waste-related issues. WEST maps combine the boundaries of the plume with census tracts to produce graduated color maps. The colors of the census tracts coincide with the progression of the assigned values. Two maps based on the WARRP scenario are shown below. Figure 11 shows the mass (in kg) generated by demolition activities for the mostly decontamination scenario. Figure 12 shows the same map, but for the mostly demolition scenario. The mapping capability is an excellent feature for determining the spatial distribution of waste across a study area.

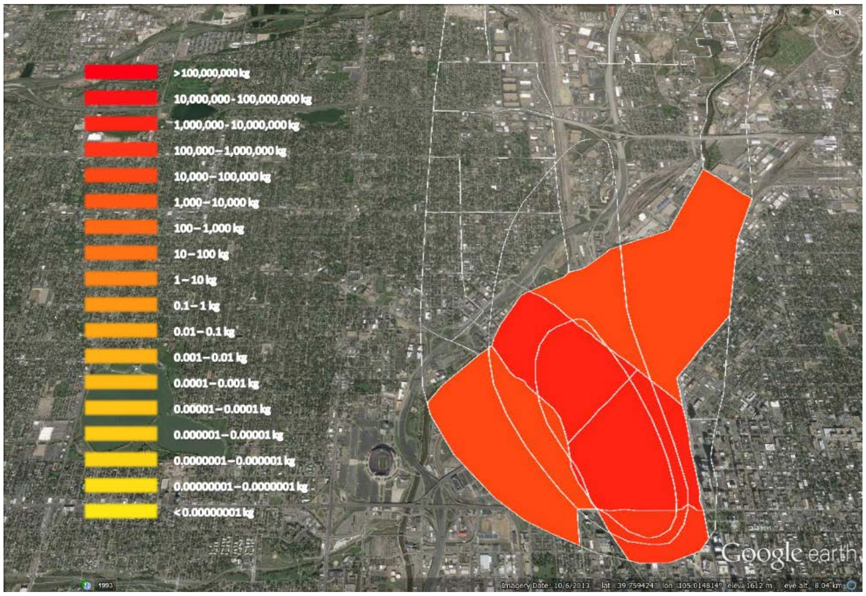

Figure 11. Mostly Decontamination Scenario: Demolition of Solid Waste (Mass in kg) Map

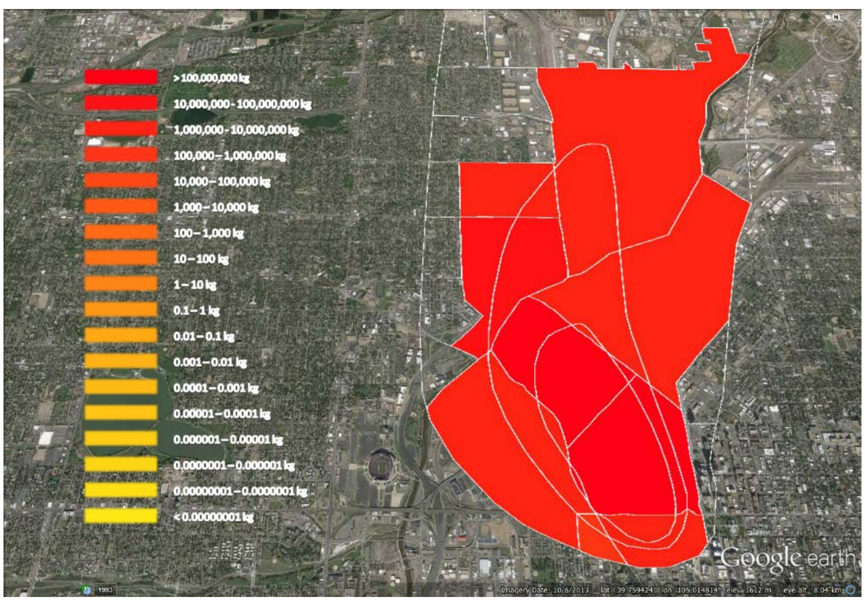

Figure 12. Mostly Demolition Scenario: Demolition Solid Waste (Mass in kg) Map

Future Enhancements

Biological Scenarios

Although not completely interchangeable, a wide-area biological incident would involve many of the same decision making processes that apply to radiological incidents. As such, many of the same benefits that WEST provides for radiological incidents could also be levied for biological incidents. The methodology, in terms of using the distribution of outdoor surface media and infrastructure, required to generate waste estimates would essentially remain the same. Only the algorithms related to fate and transport and decontamination activities would require modification. It is for this purpose that the EPA has initiated efforts to begin exploring expanding WEST to include a biological capability.

Cost and Time Factors

The addition of cost and time factors continues to be a critical enhancement for the WEST. Having the ability to estimate the cost and time factors associated with remediating a radiological incident is key to the foundation of waste management strategies. Efforts are currently underway to use information on the decontamination cost, time, and waste issues arising from the Fukushima Daiichi nuclear power plant disaster. Using these data, cost- and time-dependent algorithms based on real-world operations could be developed, allowing the end-user to better predict the implications of their decisions and to ground truth estimates.

Supplemental Waste Factors

The current version of WEST, although efficient in estimating infrastructure and outdoor surface media, is unable to predict the presence of small-scale objects (i.e., vehicles, biomass). Feature and object recognition could expand decontamination strategies to include vehicles and biomass. Current efforts are underway to implement this functionality by means of remotely sensed data.

CONCLUSIONS

WEST is an innovative GIS-based decision support tool for estimating the characteristics, amount, and residual radioactivity of waste generated from remediation and cleanup activities after a wide-area radiological incident. WEST has been applied in a number of federal exercises and continues to play a pivotal role in supporting the EPA's Homeland Security Research Program's mission. Decisions pertaining to waste management need to be made early in the recovery process. WEST facilitates these discussions by providing waste estimates within a spatial context based on user-specified decontamination strategies. Recent enhancements better convey these data by incorporating GIS capabilities and custom reporting features.

DISCLAIMER

The U.S. Environmental Protection Agency through its Office of Research and Development managed the research described here. It has been subjected to the Agency's review and has been approved for publication. Note that approval does not signify that the contents necessarily reflect the views of the Agency.

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