Geospatial Data Fusion: Training GIS for Disaster Relief Operations

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This paper will focus on the fusion of data (high-resolution imagery, multispectral imagery, raster, vector, and text data) to train geospatial analysts to support disaster relief operations. Many government and defense agencies routinely coordinate for disaster relief operations such as floods, fires, hurricanes, and earthquakes. These agencies are expected to share crucial data (sometimes available in a variety of formats) needed to make decisions in support of disaster relief operations. ArcGIS is a powerful mechanism to collect, store, analyze, and share information needed by these agencies to effectively support operations and restore disaster-affected communities in an efficient manner.

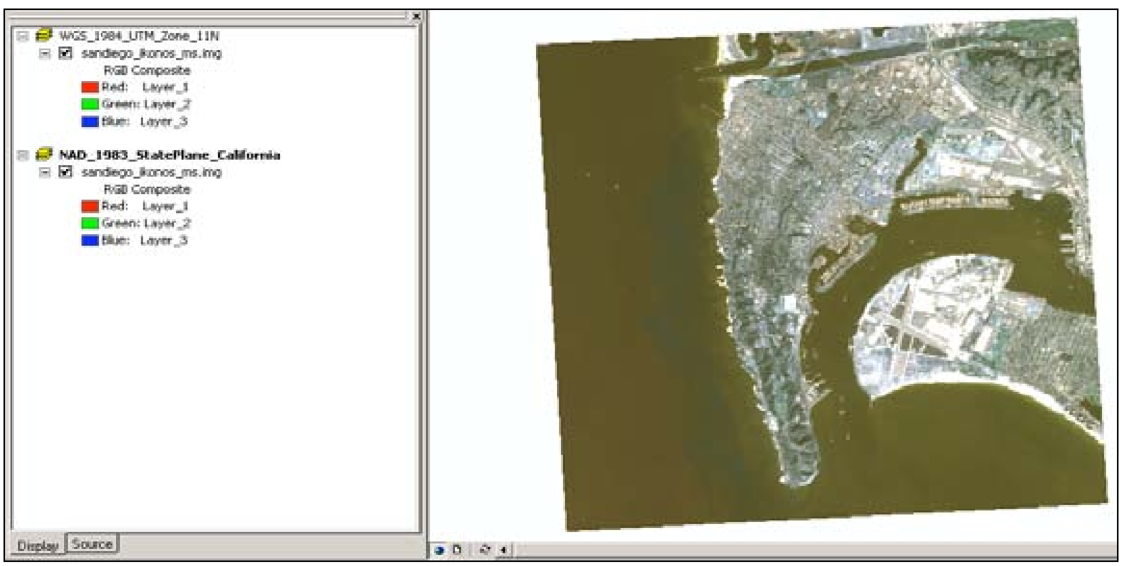
Disasters in the form of earthquakes, fires, floods, hurricanes and tornados have severe economic, financial, and social impacts on communities in the "Path of Nature's Wrath." Most disasters are characterized by short reaction/response times, overwhelming devastation to infrastructure, and a strain on the tangible and intangible resources of the affected community. Decision makers at local, state, and federal levels are expected to quickly implement plans to restore order and mitigate the aftermath of the disaster. When properly trained, emergency planners and geospatial analysts can take advantage of a geographical information system for disaster relief operations. They can use GIS to implement measures such as establish communications sites, restore electrical power, and plan traffic routes to carry emergency supplies to critical facilities. In many cases specific data sets will not be available to accommodate every possible contingency that may arise in disaster operations. For geospatial analysts, the challenge is to quickly gather data and accurately fuse it together to support emergency planners. ArcGIS is a powerful mechanism available to emergency planners to collect, store, analyze, and share geospatial information needed by agencies to effectively support operations and restore disaster-affected communities in a relatively efficient manner. This paper will address training geospatial analysts to perform data fusion using ArcGIS to create geospatial products in support of disaster relief operations.

For emergency planners, a GIS can facilitate critical decision-making before a disaster strikes an area, and also in the crucial early stages of disaster relief operations.[1] Geospatial products can provide important information such as locations of critical facilities (hospitals, water plants), transportation routes (major highways, harbor charts), and areas prone to flooding. For example, 16 counties in Oklahoma were affected by tornadoes, storms, and flooding from 3-5 May 1999. These counties were declared in a federal disaster area and almost $70 million (US) in relief funds and resources were distributed to businesses and individuals. Geospatial information can be used in every stage of a disaster relief operation, but it is important to have an existing GIS, a well-trained analyst and access to credible data sources. Fusing geospatial products such as remotely sensed imagery with a digital topographic map can be used to determine tornado destruction paths and help planners in the allocation of debris-clearing resources. Vector data can be fused to this product for network analysis to determine the best route to haul generators from a staging area to power up critical facilities. Additionally, this product can be fused later with elevation data like LIDAR to identify low-lying areas and create image-based flood maps for post-disaster insurance claims. Geospatial analysts trained for disaster relief operations can provide these types of products to emergency planners before (if possible), during, and after disasters have impacted an area.

For geospatial analysts to be able to create products and formulate analysis, a few critical tasks must be achieved. First, they must have access to a GIS and its software, preferably a powerful GIS software package with a full range of functionality like ArcGIS. Second, the analyst must have an understanding of data mining and what data best supports the particular disaster relief operation. Third, the analyst must understand the integrity of the data to include data sources, data structure/format, and spatial and/or spectral accuracy. Finally, the analyst must understand the types of products that will be need to be produced for decision-makers during various stages of the disaster relief operation. The goal is to develop timely, accurate, and relevant geospatial information that can be easily interpreted by a plethora of end-users for a wide range of disaster relief functions. Moreover, the geospatial information must be measurable quantitatively and qualitatively to assure the credibility and integrity of the products produced in support of the disaster relief effort.

ArcGIS is a powerful software package that is designed to provide a full range of functionality to disaster relief operations. Providing a common operating picture is critical to the success of any operation, and defining that picture can be problematic when federal, state, and local officials coalesce in a community stricken by a disaster. One of the major lessons learned from the 1995 bombing attack on the Alfred P. Murrah Federal Building was “a federal, state, and local cooperative partnership is essential for successful response and recovery operations following a catastrophic disaster.”[2] That successful partnership begins with a common geospatial operating picture that can be established with ArcGIS. ArcMap is the capability in ArcGIS that displays geospatial data with a common look, but can be set up via data frames in various datums, projections and coordinate systems for the creation of user-specific products. For example, local emergency planners in the United States will be accustomed to working North American Datum 1983 (NAD83) and a State Plane projection. The initial emergency electrical power responders are from the United States Army Corps of Engineer’s 249th Engineer Battalion (Prime Power), uniformed soldiers that normally work with the WGS84 Datum, the Universal Transverse Mercator projection and the Military Grid Reference System (MGRS). ArcMap has the ability to quickly establish various data frames, which can have one or many layers of geospatial information stacked for analysis within the same geographic extent.[3] This allows the geospatial analyst to conduct a wide range of GIS functions on a consistent data set, and provide customer-specific data sets in a variety of datums and projections.

Figure 1: Using Multiple Data Frames in ArcMap



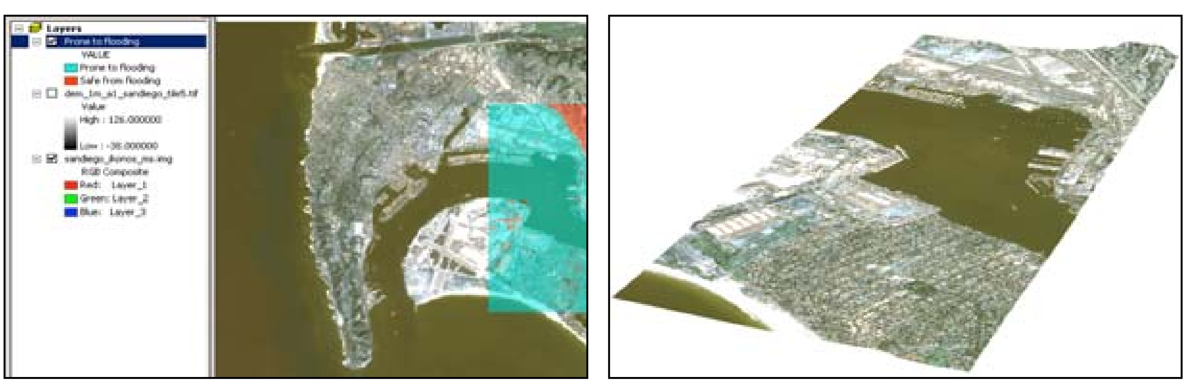
Getting the required data is one of the most crucial aspects of disaster relief GIS. Data mining is arguably the most difficult aspect of disaster relief GIS, because it has to be done quickly and the data must be able to support a myriad of geospatial products for emergency personnel and their missions. Often, very large geodatabases need to be processed for what could be just a few related facts.[4] Also, search criteria will often be changed or modified depending on the geospatial products and the stage of the disaster relief operation. With the element of time being the most important to disaster relief operations, geospatial analysts assigned to disaster relief operations should develop a checklist of data sources needed to support particular disaster relief operations. Figure 2 shows a simple example of a pre-data mining checklist for an earthquake operation and the basic geospatial products required for analysis.

Figure 2: Pre-Data Mining Checklist

Earthquake				
	Product	Source	Available	Notes
Raster	TLM 1:50,000	NIMA	Yes	
	TLM 1:24,000	USGS	Yes	
	Imagery MS	LANDSAT 30m	Yes	From 1998
	Imagery Pan	IKONOS 1m	Yes	
Vector	VMAP 1	NIMA	Yes	On CD-ROM
	VMAP 2	NIMA	No	
	DLG	USGS	Yes	
DEM	DTED1®	NIMA	Yes	
	DTED2®	NIMA	No	
	LIDAR 1m	RTV	Yes	
	RADAR	RADARSAT	Yes	
Text	GPS Locations	CF- Hospitals	Yes	Lat/Lon
	GPS Locations	CF- C2 Center	Yes	MGRS

After determining what products are and are not available, the data mining process begins. Again, the key is to determine what decision makers will need so (1) the correct data can be gathered (2) extraneous and irrelevant data is not introduced into the geospatial analysis and (3) maximum time and resources are allocated and devoted to supporting the disaster relief operation. Queries should be structured based upon the needs of the decision makers, keeping in mind the derived products will eventually be distributed to a number of end-users. One way is to narrow the initial searches to trusted Tier 1 databases, such as proprietary and government databases (municipal, state, NIMA, USGS, FEMA, etc.). The effectiveness of data mining can be simulated through geospatial data fusion and the use of ArcGIS's Raster Calculator and ArcScene. Given the directive "Find low-lying areas prone to flooding in the event of a earthquake/tsunami", multispectral imagery and LIDAR elevation data was fused, a query was developed, and a new layer of information based upon the question's criteria was created in ArcGIS from Raster Calculator. The information can be verified in three dimensions using ArcScene, and "ground truthed" with multispectral imagery as shown in Figure 3.

Figure 3: Finding Areas Prone to Flooding (Data Fusion) (c)
Copyright 2000 Space Imaging. Credit: "spaceimaging.com"



Geospatial analysts must be able to find data that best supports the disaster relief operation. The data must be in a structure and format that a host of users can access. ArcGIS can import and export raster, vector, DEMs, and text in several structures to include geodatabase, shapefiles, coverages and CAD. FEMA and USACE's CADD/GIS Technology Center are in the process of developing a disaster relief product that has two Unified Modeling Language (UML) logical data models for FEMA readiness and response. The submodels will be SDSFIE compliant and reside within a relational database. The goal is to provide a GIS model that eliminates duplication, improves data quality, and saves time in disaster response situations where critical public assistance data needs to be shared.[5] ArcGIS supports UML for the development of a geodatabase with full topological relationships, integrity rules, and behavior, as well as raster, surface, and locational representations.[6] However, it is unlikely that such a robust data model will be available over a disaster-stricken area in the near future, but the principles required to generate this data are applicable when selecting suitable data for disaster relief operations.

For example, if a requirement was to get a digital elevation model of the disaster area, then a few products could be used. NIMA DTED® Level One, RADARSAT, and LIDAR could be available, as well as contour layers derived from TINs generated from known spot heights. A geospatial analyst must be able to figure out which product will satisfy the initial product requirement, and any potential future requirements that may arise. NIMA DTED® Level One has approximately 100 meter post spacing with an absolute accuracy of ± 50 meters at 90% CE. It has an absolute vertical accuracy of ± 30 meters at 90% LE. It has a horizontal datum of WGS94 and a vertical datum at Mean Sea Level, and is stored as 16-bit data. Perhaps this product will meet the overall requirements for the operation, and satisfy any of the follow-on requirements. A comparison of the LIDAR, RADAR, and DTED® are shown in Figure 4.

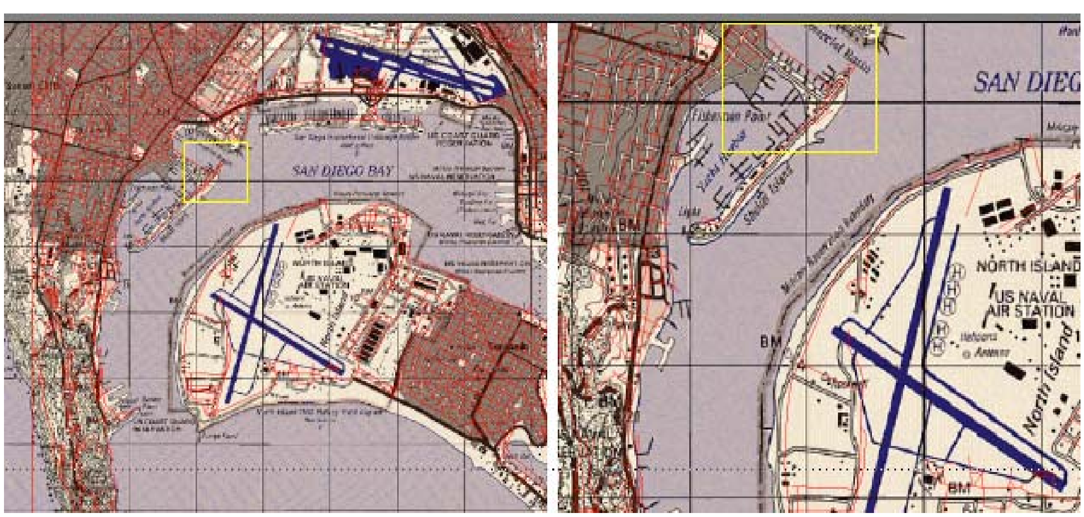
Figure 4: Comparison of digital elevation models. LIDAR data provided by Rapid Terrain Visualization, Fort Belvoir, VA. Radarsat R-Data © Copyright Canadian Space Agency 1999. All Rights Reserved © 2000 United States Government. DTED**®** is a registered trademark of the National Imagery and Mapping Agency.

There are many measurements of accuracy for geospatial data, particularly with raster data. Digital maps usually have an accuracy statement associated with them, whether on the product itself or in the metadata. Imagery will most likely have an accuracy statement associated with it, but it is always a good practice to compare the imagery against a map source. Given that the information is in the same datum, projection, and coordinate system, the geospatial analyst can determine if the data is accurate enough for disaster relief-related GIS analysis. If existing information is the only source of reference data, then a qualitative comparison of the imagery and the existing information should be performed, and the differences of the two should be analyzed.[7] A truly rigorous quantitative assessment cannot be achieved with the data set, and is probably not attainable given the time constraints of a disaster relief operation. Figure 5 displays a multispectral imagery layer displayed with a topographic line map. Qualitatively, the imagery and the digital map are both suitable products that can be used for further analysis.

Figure 5: LANDSAT 7 Multispectral Imagery and Maps: Determining Data Suitability

Another consideration is scale and how it describes geographic data. Geospatial products are created in a variety of scales, and can be displayed at different scales in software viewers. The USGS digital line graph data in Figure 6 was digitized from a 1:100,000-scale map product with its inherent accuracy statement.[8] The LANDSAT multispectral imagery in Figure 5 has a measurement scale of 30 meters that results from a pixel size of 30 meters.[9] If these data sets are displayed in ArcMap at a scale 1:100,000, then it will most likely "match up" to any other product displayed at that scale. However, if the product is viewed at a scale of 1:24,000, then it may appear that a mismatch occurs. Geospatial analysts should understand how products are developed for an intended scale and potential uses at other scales. In most cases, a product derived at a 1:100,000 scale will still be useful with products developed at a 1:50,000 scale, if displayed at a scale of 1:50,000. Figure 6 shows the products created at two different scales and displayed at two different scales.

Figure 6: Data at a 1:50,000 scale and a 1:25,000 scale

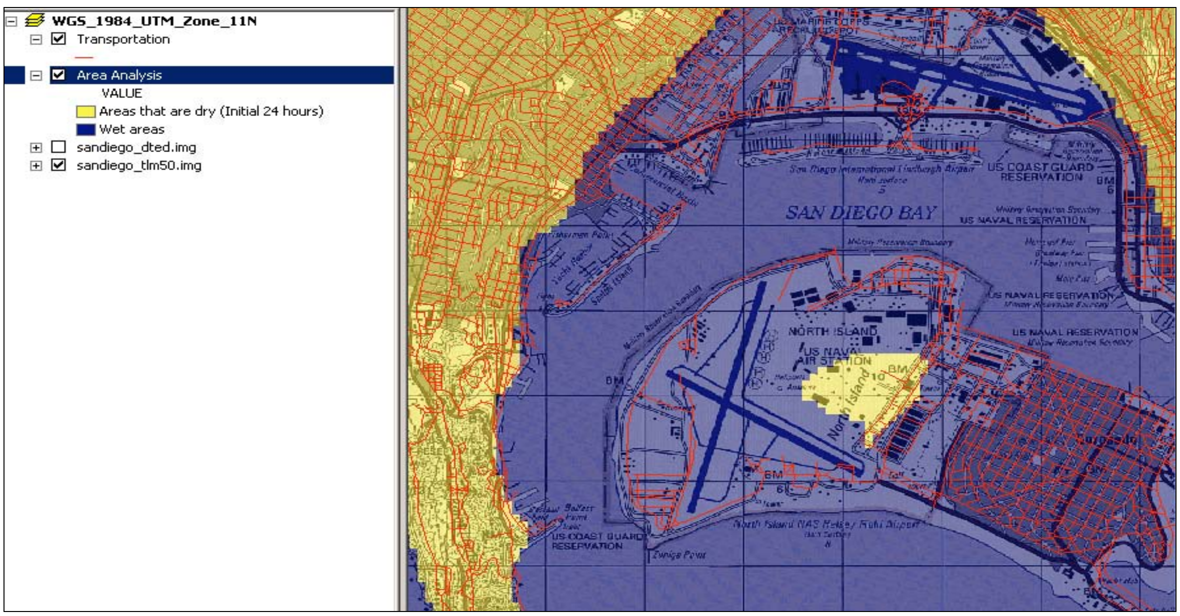


Geospatial analysts must understand the different products that may be required for various disaster relief operations. In the event of a flood, some potential products may be maps merged with elevation data and layered with transportation networks and hydrology data. Emergency planners will want to know where the dry areas are located so command/control facilities can be established. If emergency supplies are being transported to an area, then decision makers will want geospatial products that show the viable routes into the area, and potential heliport locations and marine-related information (ports, beaches, bridges, etc.). At later stages, planners may want to merge imagery with digital elevation models and vector networks to determine the extent of flooding and post-flood modeling.

For example, a quick assessment can be done using the elevation data, the transportation network, and the 1:50,000 map. The emergency operations center requested to be located on the North Island Naval Air Station. Would this be a good location? Probably not, given that most of the area will be under water up to 24 hours after a tsunami hits.

Figure 7: Finding a potential command/control location

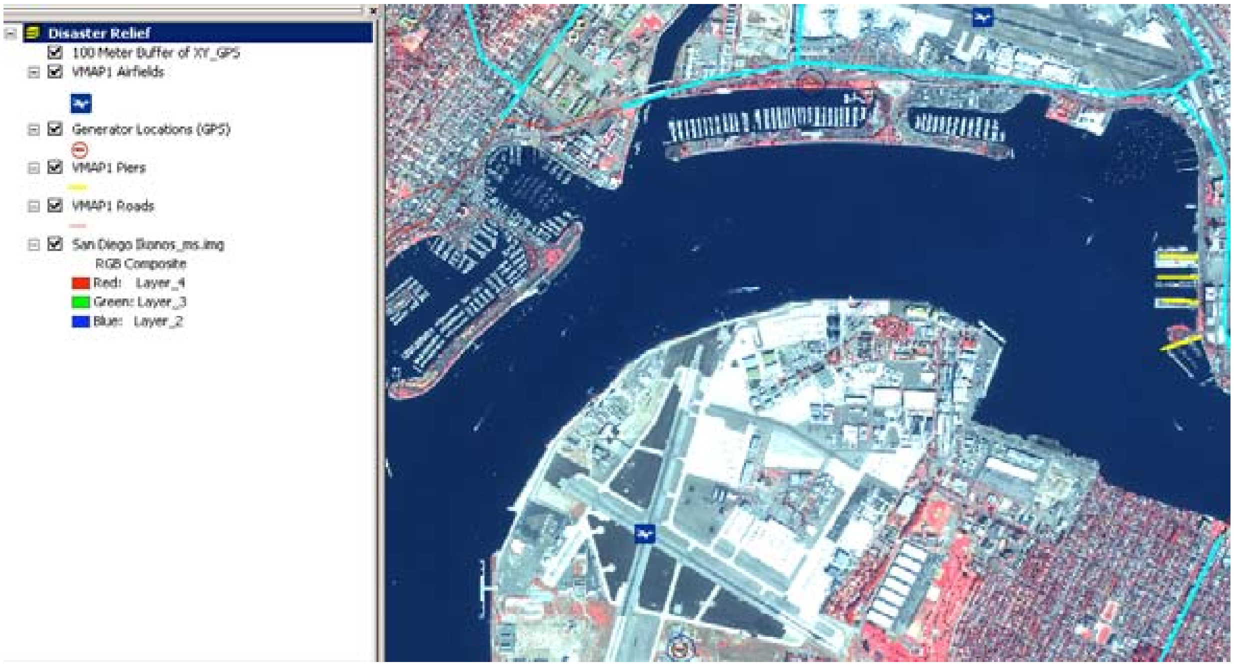
DTED® is a registered trademark of the National Imagery and Mapping Agency



Other disaster relief analysis will include the placement of emergency power generators. The GPS location of the generator is normally recorded at the site, and the coordinates are relayed to the operations center. In Figure 8, the coordinates were saved in Microsoft Excel as a .dbf file, and a Feature Class was created in ArcCatalog from an XY Event. Then, the data was saved as a personal geodatabase feature class, and symbolized using the SDSFIE 2003 symbol for an electrical generator. This process ensures that the data will be in the correct format for further analysis.

For generator placement, the criteria will be subject to transportation routes (pier to roadway), environmental constraints (noise zones, watersheds, etc.), and priority (critical facilities). The generators may be stored at a pier and transported to a site using a tractor-trailer that requires a hard, paved road upon which to travel. The generator may have a 100-meter noise buffer zone set by local zoning ordinances. Some municipalities may not allow generators to be placed within 50 meters of an existing watershed. All of this information can be brought into ArcGIS for analysis, and products can be created to provide decision makers the information they need to mitigate the effects of the disaster, as shown in Figure 8.

Figure 8: Geospatial Analysis for placing emergency power generators



Disaster relief operations provide a range of challenges for geospatial analysts, from getting data in a format that is usable to creating quantitative analysis for the distribution of relief funds. A trained geospatial analyst equipped with ArcGIS and a quality data set can provide decision makers with the information they need to restore order to a disaster stricken area. The methods and techniques outlined in this paper will provide a geospatial analyst assigned to a disaster relief operation some basic tools to develop a training plan that addresses the wide range of operations from floods to fires, and that account for the time-constrained nature of disaster response and relief.

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Endnotes:

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