Post-Event Urban Flood Mapping by Amateur Aerial Photography and Assessment of Potential Damage: Case of Fond du Lac, Wisconsin

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Abstract

Several communities are so focused on the positive benefits of a rising economy that they ignore the negative effects of the urbanization process, such as the exacerbation of flooding by increasing impermeable surfaces. Even when a flooding disaster occurs, the communities' fear of another strike decreases over time along with its preparedness. For instance, on June 12, 2008, the city of Fond du Lac, Wisconsin, was blindsided by a major flood because many never knew that their residence was located in a flood-prone area. Most city roads were reported to be underwater and in some places bridges were even submerged by the Fond du Lac River. A lot of the damage was so severe that the Federal Emergency Management Agency (FEMA) awarded Fond du Lac more than $1.2 million to assist with repairs of homes and the city. As with the case of Fond du Lac, mapping flood prone areas can prepare potential victims and enforce local floodplain management policies. To accomplish this, FEMA launched the Map Modernization project, which aims to update the nation's flood maps. However, the agency is not able to do this

alone and has decided to partner with local agencies to produce more accurate flood maps. Therefore, this project investigated the possibility of mapping urban flood areas from amateur aerial photographs and compared the resulting flood map to the most recent FEMA maps of the study area. On a broader level, the study updates the FEMA flood maps of Fond du Lac, Wisconsin, and the methodologies developed in this study can help similar cities across the nation adjust their flood maps.

Statement of the Research Purpose

Urban natural disasters are worsening because, among other reasons, an increasing portion of the world’s population lives in large cities. Thus, urban hazards, such as flooding, pose serious challenges for the future. Exposure and vulnerability are the components of hazard that are changing fastest and have the gravest implications for urban populations (Mitchell, 1999).

Flooding is the most common environmental hazard due to the established attraction of humans to river valleys and coastal areas and because these natural features are widely distributed (NC Division of Emergency Management 2004). Flash flooding in urban areas often takes residents by surprise. According to Gruntfest and Handmer (2001), the high potential for loss of life and disruption from flash flooding requires identification of the location of flooding, properties, and the people at risk. Therefore, investment should not only be applied to identifying high-risk flood areas, such as the ones near rivers and oceans, but also to the mapping of other potential urbanized flood-hazard areas. I propose to study the possibility of using a relatively simple, fast, effective and economical way of mapping flood hazards in an urban setting, which could benefit other small cities.

As evident in Chan’s (1997) study, flood events that took place as a consequence of rapid development and environmental degradation are quickly forgotten because people choose to see only the positive benefits of a rising economy while ignoring negative side effects. Flood maps could be used as a constant reminder of hazards. Flood risk management should be a part of community development and residents could play a role in managing flood risks without relying on external entities (Osti et al. 2008). The procedure and results of the proposed flood hazard mapping tasks will encourage community-based flood management and improved local use of flood maps. I plan to accomplish that goal by using the spatial analysis tools of Geographic Information Systems (GIS). That spatial technology is capable of assessing and estimating regions of hazard by creating thematic maps and overlapping them to produce a final hazard map (Mansor et al. 2004). Therefore, this study will use GIS to integrate spatial data and produce a flood risk map that is accessible and easily understood. I also plan to develop a post-flood mapping guideline to be implemented during and immediately after flood events as well as adjust existing FEMA maps and provides an assessment of potential damage.

It’s important to have accurate flood maps because the National Flood Insurance Program (NFIP), directed by FEMA, requires local governments to enact floodplain management guidelines. If these guidelines are followed, private developments in designated flood-prone areas are eligible for federally subsidized flood insurance (Dzurik 2003). FEMA has already created more than 80,000 flood insurance rate maps for roughly 20,000 communities and provides flood insurance rate map data to be used with commonly available desktop GIS and mapping programs (Whitney 1997). To bring both the information and the technology up to date, FEMA launched a Flood Map Modernization program called the Map Modernization Project. It aims to make the nation’s flood maps more accurate and to convert them to a GIS format. FEMA cannot do this sizable task alone, and has therefore utilized community programs and partnered with local agencies (Quarles et al. 2002; Engelhard 2004).

The site selected for this project is the city of Fond du Lac, Wisconsin (fig. 1). On June 12, 2008, Fond du Lac was devastated by a major flooding event (fig. 2). Since then, the city has been in the process of updating floodplain maps and regulations that haven’t changed since 1988. Updating the floodplain maps is part of a FEMA effort that uses digital technology to make the maps easier to interpret (Veremis 2008). According to Fond du Lac Community Development director, Wayne Rollin, “there are no big changes in terms of floodplain boundaries, but a big change in the usability and quality of the map.” However, many residents say that the June 2008 flood was unexpected because they never knew that they resided in a flood-prone area, thus they were not prepared to take action. For this reason, the city of Fond du Lac is an ideal site to conduct a study on ways to delineate the extent of past flood events for mapping purposes. Thus, I proposed to map the 2008 Fond du Lac flood areas using oblique amateur aerial photographs and to assess the recent FEMA floodplain map of the site. The study proposed and assessed a relatively cheap way to create, adjust or update FEMA flood maps of Fond du Lac and the methodology and lessons learned can help similar small cities across the nation adjust their flood maps.

Proposed Methodology

The use of GIS and remote sensing for mapping the flooded areas and an overlay analysis (spatial comparison) to assess the local FEMA flood map were the two major components of this project. To begin mapping the flooded area I needed to make a selection from several aerial photographs that were taken after the event. These were received courtesy of Adam Dorn, a GIS specialist serving at the Fond du Lac City/County building. Specific photographs with an optimal aerial view (covering a wide area) and an oblique vantage point were chosen. However, since the photographs were not geographically referenced to a specific location within Fond du Lac, I worked with Fond du Lac representatives to discover their locations.

After finding the photographs' locations, I fitted them to the other spatial data (map) by matching their features with corresponding features on other layers (i.e., roads) that are in a known coordinate system. This matching process is referred to as *georeferencing*, the task of aligning geographic data to a known coordinate system. I then reduced their distortions with a process called *rectification*, the process of applying a mathematical transformation to an image so that the result is a *planimetric* (having no indications of relief) image. This is done because raw digital images, such as the oblique photographs used for this project, are not aligned with any conventional geographic coordinate systems, and they commonly contain internal geometric distortions that occur during the image acquisition process (California Institute of Technology 2007). During a georeferencing task, control points must be accurately located, sufficient in number for the transformation model selected, and distributed uniformly across the image (MacroImages Inc. 2009). With the newly georeferenced/rectified aerial photographs, flooded areas can be traced/digitized and interpolated between photos. To do this, I delineated the contour of the affected areas of the June 2008 Fond du Lac flood event and created a new layer with the ArcMap software.

For the second aspect of the study, the most recent layer of FEMA flood maps of the area (a polygon layer) was compared to the layer of flood polygons resulting from the completion of the first part of the project. The two (assumed dissimilar) polygon layers were subject to a spatial overlay analysis technique, which provided coincident (common/overlapping) areas as well as non-coincident (non-overlapping) areas of each input polygon. The use of this technique is supported because we often need to overlay layers that have completely different underlying geographies in order to combine attributes from the two input layers into a third output layer (Fullerton: California State University 2009). *Union, intersect, symmetrical difference* and *identity* are the four types of overlays one could use to compare the two flood maps. However, I only wanted to produce the coincident and non-coincident sections of both maps. Therefore, I used only the intersect and the symmetrical difference overlay methods. Intersect preserves features that fall within the area extent common to the inputs while symmetrical difference preserves features that fall within the area extent that is common to only one of the inputs (Chang 2009).

Overview of Resulting Methodology

The four major components of this project were the use of GIS and remote sensing for determining the flooded areas, the application of union and overlay GIS analysis to assess the flooded areas not accounted for in the FEMA flood maps, a damage assessment of the areas, and the determination of the possible cause of the flooding (riverine vs. inadequate storm drainage).

Assessment of the Flooded Area

I first used a sample location of the flooded area that I selected from several aerial photographs taken after the event. Specific photographs with an oblique aerial view (covering a wide area) were chosen to conduct the processes of georeferencing, rectification and delineation of the flooded areas. However, because the photographs of the selected area were fewer than needed and some were severely oblique, the photos I could rectify were severely disconnected (with respect to distance) and did not cover a large enough area (fig. 3). This is because only photos of flooded areas were taken (instead of the entire city). Therefore, I could not use them alone for a manual flood delineation as originally suggested. Instead I used all available photographs (including the severely oblique ones) of the site that displayed flooded areas in the following process.

After finding the photographs’ locations, I represented the flooded extent (on the photo) by digitizing points over the corresponding ground features using a process called point digitizing. Each point was assigned a flood intensity value based on a scale of 1 to 3: "1" described minimum flooding, "2" described moderate flooding and "3" described maximum flooding (fig. 4). I *interpolated* (estimation of surface values at unsampled points based on known surface values of surrounding points) the newly digitized flood points of the area using the Ordinary Kriging[1] method (a form of interpolation). From the output of the interpolation (fig. 5), I selected the cell values that were greater than two in order to distinguish areas that were moderate to severely flooded from the areas that were barely or not flooded at all (fig. 6). I then converted the grid containing severely flooded areas from raster (representation of the world using a surface divided into a regular grid of cells) to vector (representation of the world using points, lines, and polygons) to compare them to the FEMA layer (also vector) by using a union overlay analysis process.

Comparing Flood Assessment by Photos to FEMA Map

For the second aspect of the study, I used the most recent version of the FEMA flood maps of the area. This FEMA flood map layer contains attributes that express the severity of the different flood zones. Although there are several FEMA flood zones (table 1), I only selected zones AE and AH located in the "High Risk Areas" for this project because we are only interested in the high-risk zones that are not directly related to the lake and river flooding.

I selected only the zones that were designated as "hazardous flooding areas" from the FEMA layer (using the Structured Query Language selection FLD_ZONE='AE' OR

FLD_ZONE=’AH’) and then converted that selection to a new layer (fig. 7). With the newly created layer of FEMA’s “hazardous flooding areas” flood zones and the vector layer of flooded areas derived from the photos in part A, I was able to run two sets of alternative combination of GIS operations (union-intersect and symmetrical difference overlay analysis) to select only the areas that were flooded and not accounted for by the FEMA layer. The union operation served to combine both of the layers and their attributes into a new union layer. From the union layer, I selected only the features where the FEMA flood zones and the zones I generated did not overlap. The last selection shows the areas of FEMA flood zones that I did not map and the flood zones that I generated but that FEMA did not take into account (fig. 8).

Assessment of Potential Damage

After obtaining a block population point layer (a layer that contains data on the number of houses and people in a selected area) from U.S. Census data, I clipped/removed some of the data from the population layer to fit the size of the selected Fond du Lac study area layer (fig. 9). Using the clipped block population layer and the union layer of flooded areas (generated by FEMA and by photos), I ran an intersection overlay analysis to obtain only the block population layer's point features of the flooded area (fig. 10). That operation also attached to each block point the attribute (information/description) of the corresponding flood features (from the union layer). By computing some of the attribute data attached to the previously created flood-block intersection layer, I was able to determine the number of houses in the selected damage zone, the number of occupied houses, and the number of people who live within the area that are not accounted for by FEMA. The area has a population of 821, 311 occupied households and 322 housing units (fig. 11).

Determination of the Type of Flooding

For the third aspect of the study, I created a digital elevation model to generate the *sub-watersheds* (a smaller basin within a larger drainage area where all of the surface water drains to a central point of the larger watershed) and stream networks of the selected Fond du Lac area to determine whether the flooding was due to the expansion of the rivers and lakes waters or to inadequate storm drainage in that area. This assessment assumes that flooding caused by the river will stay in the river's sub-watershed and its vicinity and that flooding caused by the lake will stay in the lake's sub-watershed and its vicinity.

After generating the sub-watershed of the entire Fond du Lac area, I selected only the sub-watersheds that are within the selected sample area to create a new layer. Overlaying the sample area's stream network layer onto the sub-watershed layer allows us to visually determine where the streams and watershed of each flooded area is connected to the river (fig. 12). The areas that contained flooding and that are not in a watershed related to a river or lake are likely to be caused from an inadequate storm drain system.

Conclusion/Future Methodology

The outcome thus far has shown that the number and distribution of photographs, as well as their obliqueness or aerial view, contributes greatly to the successful and accurate completion of this project as well as similar future projects. It also shows that the use of GIS allows for a reasonable estimate of locations that should be accounted for by FEMA. I have therefore concluded that the original approach involving georeferencing, rectification, and delineation of a flooded area based solely on aerial photos (no ground photos) is feasible (fig. 3) provided there sufficient adjacent photos. This technique is being further refined by a forthcoming study by Dr. Coulibaly and me, which will allow us to assess the efficacy of the current process as a measure of the amount of interpolated area with respect to the actual flooding mapped from aerial photographs. However, for the purpose of this study, it was necessary to supplement the aerial photos with ground photos.

Notes

1. 1. Ordinary Kriging: A kriging[2] method in which the weights of the values sum to unity. It uses an average of a subset of neighboring pairs of points to produce a particular interpolation

point.   It is the most commonly used kriging method.

2. 2. Kriging: A geostatistical interpolation technique in which the surrounding measured values are weighted to derive a predicted value for an unmeasured location.

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