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APPLICATION OF AN INTEGRATED GIS LOSS ESTIMATION METHODOLOGY TO EMERGENCY RESPONSE PREPAREDNESS

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ABSTRACT

This paper presents a hypothetical example of how a regional earthquake loss estimation study could be used by an emergency response planner to develop an emergency response plan. The loss estimation results are based on a methodology recently developed under the sponsorship of the Federal Emergency Management Agency and the National Institute of Building Sciences. The methodology is programmed to run on a desk top computer and makes use of GIS technology to enter inventory and display results. Included in the paper as examples of the types of outputs that the model can generate are maps showing casualties, expected shelter needs, expected performance of bridges, and earthquake ground motion in conjunction with the location of hazardous dams. Discussion is provided on how these maps could be used by an emergency response planner to develop emergency response plans.

KEYWORDS

Earthquake loss estimation; emergency preparedness; emergency response; GIS; geographic information system; casualties; regional loss estimation; shelter; lifelines.

INTRODUCTION

Regional earthquake loss studies have been performed for the last 20 years to help local and state governments, and emergency response planners prepare for and mitigate damage from future seismic events (FEMA, 1994). A major limitation of past regional loss studies is that they are stagnant. Inventory and geologic data were collected, one or more scenarios were evaluated and the report was written. There is, however, no mechanism to update these estimates to reflect changes in the inventory, demographics and economy of the region. Since the inventory data can not be realistically included in the final reports, updating existing studies without undertaking a major data collection effort is virtually impossible. Earthquake loss studies often include estimates of costs of repair, deaths and casualties, functional loss to lifeline systems and emergency response facilities, and regional economic impacts on a short-term and long-term basis. Reporting of results has tended to limit the effectiveness of regional loss studies. Results typically have been summarized in a report or tabular format, making it cumbersome to quickly identify those geographic areas most likely to experience significant damage.

With the development and maturity of GIS technology, many of these limitations have been overcome and dynamic loss studies that present results in a more usable format can now be performed. A recent project, sponsored by the Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS), has resulted in a powerful GIS-based software package for performing regional earthquake loss estimates (Lawson et al., 1995). The implementation of integrated GIS technology provides an approach which permits rapid evaluation of complex inventory databases under a variety of earthquake scenarios and allows users to interactively view results almost immediately. The results can be summarized in tables of loss values as well as maps of damage estimates that indicate which areas are likely to be most severely affected.

The power of GIS technology makes creating and modifying maps a simple task. For application in regional loss estimation there are a variety of useful options that are available. First, as inventory is collected and organized into databases, it can be quickly and easily displayed on a map of the region. Using various colors and symbols, different attributes can be highlighted. For example, the number and locations of seismically vulnerable structures in your region can be easily presented. Second existing maps, such as liquefaction potential maps available from the United States Geological Survey, can be digitized and displayed. These can be overlaid with maps of lifeline systems to qualitatively assess which lifeline components are subjected to increased levels of risk. Third, by mapping loss estimates thematically, localities with high losses can be quickly identified. Fourth, the performance of regional lifeline systems such as water delivery systems can be graphically displayed by mapping the system and using colors to identify those parts of the system with the highest probability of being non-functional. These are a few examples of the types of maps that can be created.

GIS technology provides emergency response planners and government officials with a very powerful tool to visualize and understand the impacts of an earthquake on a region. The hypothetical loss study in this paper highlights a few of the many possible applications of this methodology for emergency response planning.

PLANNING FOR EMERGENCY RESPONSE TO A DAMAGING EARTHQUAKE

In preparing for a disastrous earthquake the planner must quantify the impacts of the event on the community. He can then assess the type and number of personnel needed to respond to the variety of emergency situations that will arise. His plans must also include provision for the deployment of local services and the coordination of these services with those of neighboring communities and other levels of government. Several issues that will be of concern to the individuals responsible for providing emergency response after an earthquake are:

- functionality of emergency operations centers, fire stations, police stations, emergency shelters, emergency public information centers and other facilities that are needed to provide post-earthquake disaster assistance;
- functionality and capacity of hospitals and emergency rooms needed to care for the injured;
- functionality of water systems and electric power systems which affects both the shelter caseload and the type of emergency services that need to be delivered;
- functionality of highway systems, in particular with respect to the collapse of bridges or buildings which may block vital routes needed by emergency response personnel;
- functionality of other transportation facilities such as airports, railways and ferries that may be critical in delivering emergency relief in the first few days after a damaging event;
- functionality of communication systems;
- release of hazardous materials;
- the number of collapsed buildings requiring search and rescue operations;
- the number and severity of casualties which in turn affects the hospital caseload;

- the ignition and spread of fires following the earthquake which puts additional strain on the fire departments and other emergency response personnel;
- the number of damaged structures that will need to be inspected to determine whether or not they are safe for use; and
- flooding from damage to local dams or from tsunamis which would require evacuation.

In preparation for emergency response, it is likely that the planner will want to create several scenarios of different size, or at different locations within the region and occurring at different times of the year. Using the integrated-GIS loss estimation methodology, evaluating several scenarios is easy once inventory has been collected.

HYPOTHETICAL EARTHQUAKE LOSS STUDY

This particular study is for a region in San Francisco Bay Area of California. The emergency response planner is evaluating the impacts of a large but likely event (a 7.3 moment magnitude event on the San Andreas fault). This is not the maximum credible event expected for the region but is damaging enough to test emergency response services. The planner has worked with local agencies, utilities companies and several consultants to collect soils maps; liquefaction and landslide potential maps; maps of water and wastewater systems; inventories of schools, hospitals, fire stations and police stations; and inventories of electric power distribution systems. Other relevant information such as data from the 1990 census, estimates of value and structural composition of regional building stock, databases of dams, major roads and bridges, major rail lines, airports and locations of facilities storing hazardous materials are supplied with the methodology in a digital format as "default inventories". The planner has used a consultant to help augment and improve the quality of the default inventories. In particular the consultant has helped to refine the regional inventory to better reflect the structural composition of the regional building stock.

The methodology generates estimates of casualties assuming the scenario earthquake occurs at three different times of day (2 AM, 2 PM and 5 PM). At 2 AM most people will be at home, at 2 PM a significant portion of the population will be at work or in commercial complexes and at 5 PM a large number of people will be commuting. Table 1 shows a summary of the casualties resulting from this particular scenario earthquake. While it isn't shown in Table 1, the model also summarizes where the casualties are likely to occur. For example at 5 PM, 320 Level 1 casualties are likely to occur to individuals at home, 189 to those at work and 71 to those commuting.

Table 1. Summary of Casualties Assuming a Scenario Earthquake at 2 AM, 2 PM or 5 PM

Casualty Severity	Earthquake at 2 AM	Earthquake at 2 PM	Earthquake at 5 PM
Level 1 - No hospitalization required	1122*	540*	580*
Level 2 - Medical care needed but not life threatening	157*	155*	210*
Level 3 - Life threatening	66*	88*	193*
Level 4 - Fatality	47*	73*	91*
Total Level 2 and Level 3	223*	243*	403*
Total Casualties	1392*	856*	1074*
* These numbers are preliminary as the casualty model is still being calibrated.			

Having understood from Table 1 the potential load on hospitals and emergency rooms, the planner may be concerned about the location of medical facilities with respect to injured individuals. In Fig. 1 severe casualties (Levels 2 and 3) are overlaid with the locations of hospitals. The type of information displayed here may be useful in designating casualty collection points. Furthermore, the planner could use symbols on this map to indicate the size of the medical facilities (e.g. circles for hospitals with less than 50 beds, triangles facilities with 50 to 150 beds, stars facilities with more than 150 beds and squares clinics, labs and blood banks). GIS technology makes it very simple to zoom in on a particular location of the map. Thus the planner could enlarge the area in Downtown San Francisco and display more detailed information about streets, public transit systems etc. The planner also has the option to include the expected performance of the medical facilities by coloring those that are expected to be fully operational green, partially operational yellow and non-functional red. The planner may also choose to develop a database of private ambulance companies and paramedic units and identify their geographic locations on this or additional maps.

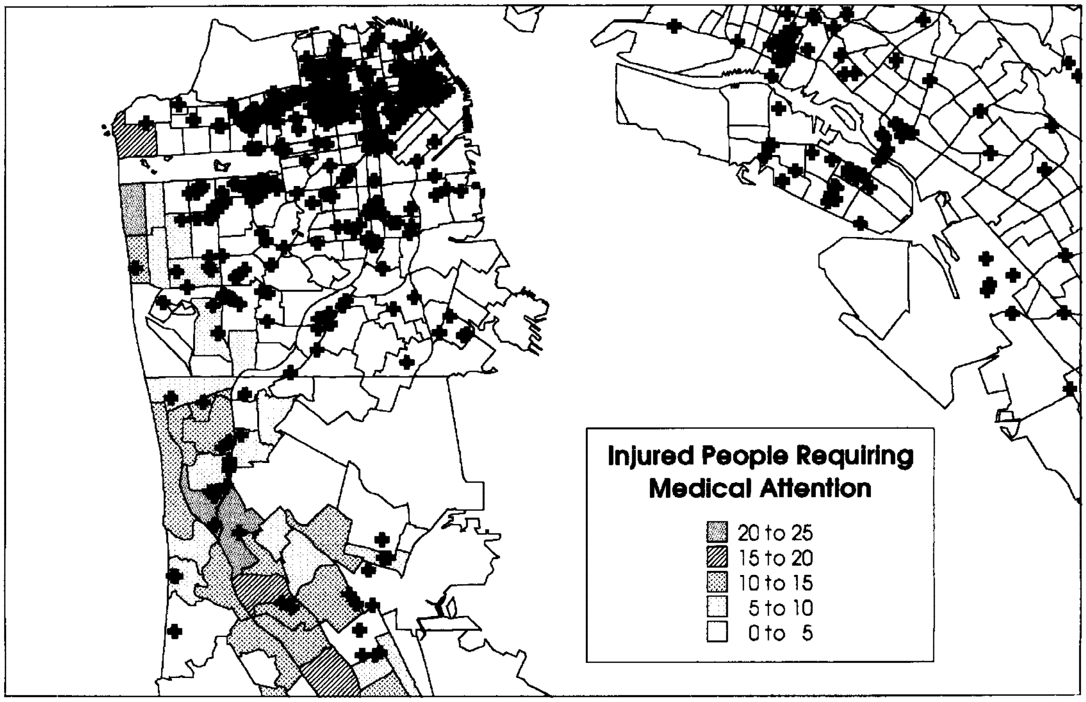

Fig. 1 Map of severe casualties at 2 AM overlaid with locations of hospitals and emergency rooms.

The number of households without power can affect a variety of emergency response functions. Individuals requiring power to operate specialized medical equipment may need to be evacuated. If the event occurs in the winter, larger numbers of people may be forced to move to shelters if power outages occur. If the power outage continues for several days, this may affect the need for food distribution. The numbers of homes without power can be mapped by census tract or summarized as shown Table 2. The model uses built in restoration relationships to give estimates of how long the system takes to return to full functionality. Planning for the distribution of water supplies can be assisted with the use of similar tables and maps of the number of households without water.

Table 2 Number of Households in Study Region Without Power.

Number of Days after Event	0 Days	1 Day	3 Days	7 Days	30 Days	90 Days
Number of Households without Power	210,000	120,000	14,000	500	0	0

There are a variety of issues that can affect the number of displaced people that will require publicly available short-term shelter after an earthquake. These include the functionality of water and power systems, the level of damage to the residential structures, ownership, income level, ethnicity, and age. The planner can interactively modify the relative importance of these factors in the model to develop a variety of scenarios related to shelter demands. One such scenario is displayed in Fig. 2. In addition the planner could use supplied census data to plot, for example, ethnicity, which would be helpful in addressing such issues as language requirements for personnel working in shelters.

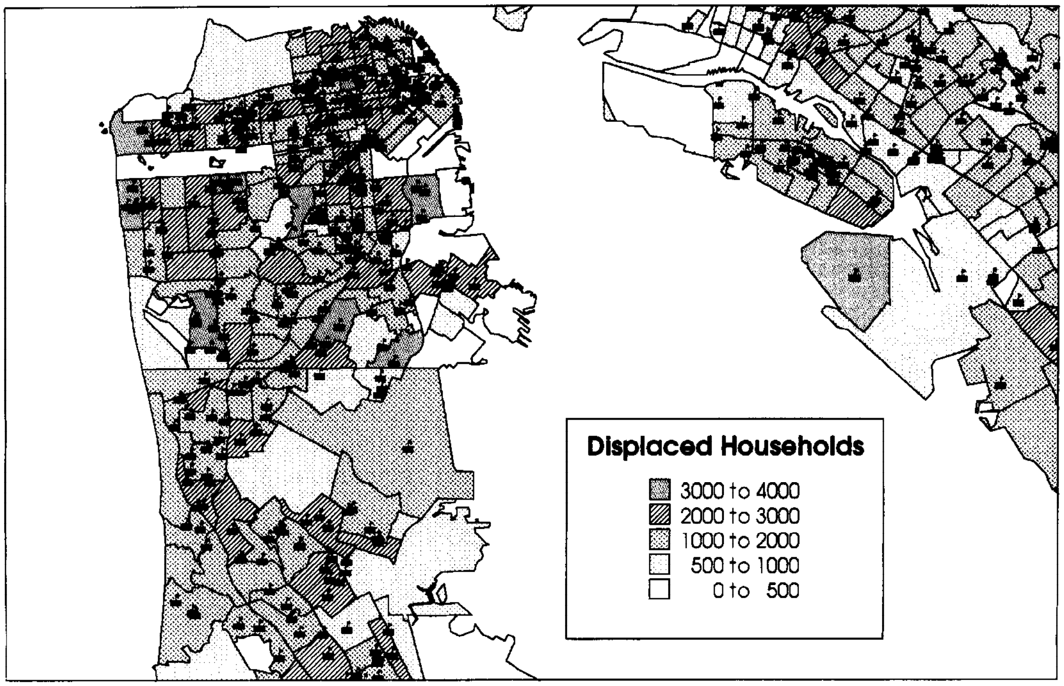

Fig. 2 Number of displaced households likely to seek shelter mapped with the locations of potential shelters.

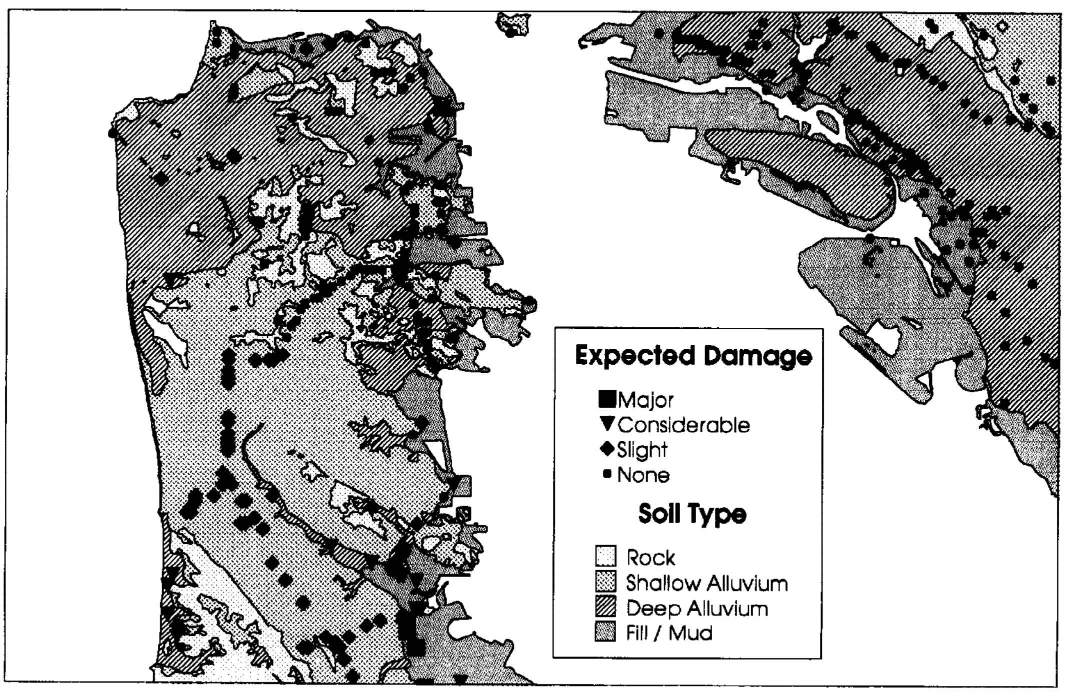

Fig. 3 Expected performance of bridges.

The functionality of transportation corridors affects the distribution of emergency supplies, the ability of fire fighters and rescue personnel to access areas, the ability to transport the injured to medical facilities, the mobilization of staff to activate emergency shelters and the ability of people to return home if the earthquake occurs during working hours. When developing earthquake preparedness exercises, the planner would like to create realistic scenarios other than the worst possible case, so that personnel can plan for operation under these circumstances. Fig. 3 shows all of the highway bridges and overpasses in the region and gives an indication of the amount of damage that they are likely to experience when subjected to the 7.3 event. The planner also can plot functionality at 0, 1, 3, 7, 30 and 90 days after the event and get some idea of how long it will take the highway system to return to full functionality. In addition to bridges, a variety of other transportation lifeline components such as roads, railroad tracks and tunnels, can be plotted and overlaid. Using a map such as Fig. 3, a planner can establish designated evacuation routes, plan for closing and posting of unsafe bridges, develop alternative routes or detours, understand what type of debris removal (from bridge damage) may be needed and quantify the public transit requirements needed to provide alternative transportation.

Evacuation of downstream inhabitants may be required if damage occurs to a dam. Figure 4 shows the dams located in the study region. The different symbols indicate whether they are classified as dams with high, medium or low hazard potential. By overlaying the dam inventory on a map of ground shaking demands, the planner can identify high hazard dams which are likely to experience significant levels of ground shaking. This type of information can provide the basis for a planner to request a detailed study of the dam's vulnerability or to prepare an inundation map which can be used for developing evacuation plans.

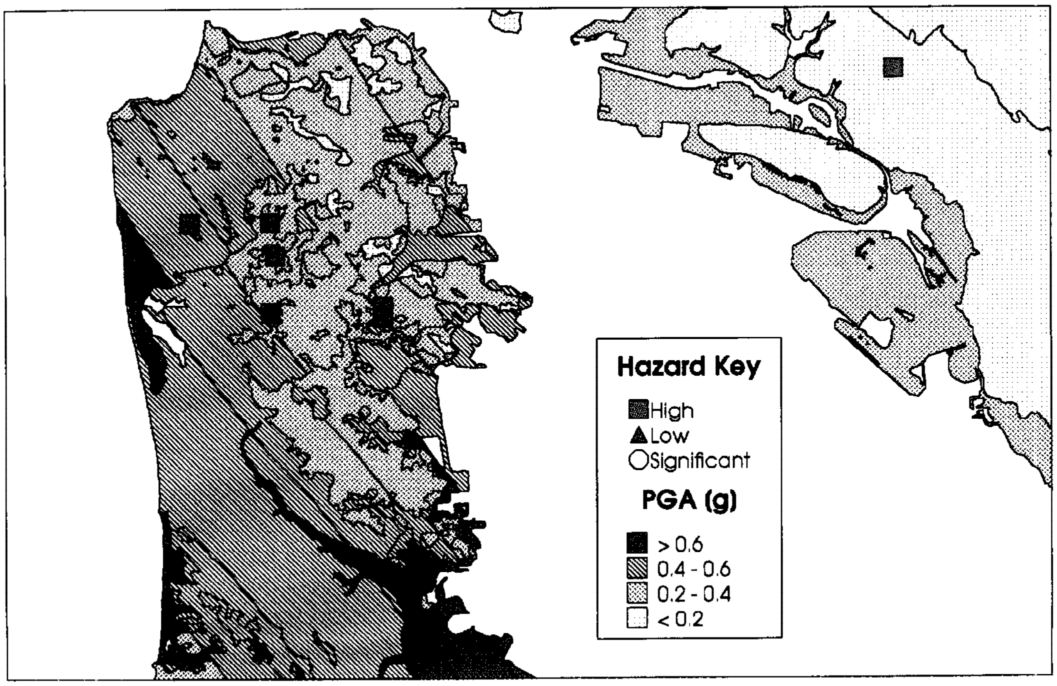

Fig. 4 Earthquake ground shaking for scenario earthquake and the locations of all dams in the region.

CONCLUSIONS

This hypothetical planning example demonstrates only a few of the ways in which results from a regional loss study can be used for emergency response preparedness. The ease with which planners can generate and modify maps and tables will make plan development and running preparedness exercises a much more manageable task. The ability to modify the model inputs and generate new results provides the planner with a powerful tool to understand the significance of his assumptions and their impact on preparedness plans. Finally, the ability to easily generate tables of numbers and graphical results will be very useful in presenting plans to cooperating agencies, government officials and interested citizens.

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