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The Role of GIS in DRR: Classifying and Improving GIS Capabilities in Small Towns and Rural Areas

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Optimizing GIS capability does not always require that the municipality obtain cutting edge professionals and resources. This paper offers a disaster risk reduction (DRR) design methodology for small towns and rural areas that employs a multi-variable classification system, enabling customization for effective DRR.

Determining appropriate GIS capacity requires that a community first be evaluated in order to identify its disaster risk reduction/disaster management (DRR/DM) requirements. These requirements are then considered in conjunction with the municipality's resources to establish the desired capability.

Qualification levels for major aspects of GIS capability with respect to DRR/DM are provided, along with descriptions of each level and suggested procedures for advancement to the next level. It should be noted that a municipality can be classified at a different level with respect to different variables. Needs vary according to the community, thus attainment of a uniform capability level may not be necessary.

The Role of GIS in DRR: Classifying and improving GIS capabilities in small towns and rural areas

The Disaster Risk Reduction (DRR) field is by its very nature, always focused on matters of life and death, and these dire concerns are often applied to large populations. Though their mandate is critical, the field's professionals are usually evident to the populations they serve only in the period immediately surrounding the disaster. Nevertheless, all stages of DRR, be they preparatory or responsive, must integrate the cutting edge of any technology that would facilitate its implementation. Thus, DRR professionals have enthusiastically welcomed Geographic Information Systems (GIS) technology upon learning of its enormous benefit to their field.

GIS (Geographic Information Systems) technology refers to hardware and software whose data, applications, and analytical methodologies are spatially based. This encompasses a variety of datasets containing geographical, geological, and social information. Satellite imagery, maps, demographic databases (censi), and weather patterns are but a few examples of such data types that can be integrated and subjected to an array of analytical techniques,

Effective DRR is critically dependant on the accurate dissemination of data, often with such speed that it must be in real-time. Since this information relates to safety issues concerning the physical environment, it usually has a strong geographical component. GIS technology provides a vehicle through which many types of information (eg. census data, weather conditions and map data) can be visually depicted. Thus, detailed information can not only be clearly represented in one view, but its presentation is not hampered by linguistic differences that present problems when communicating textually represented data. Queries can be performed on the data types that would be labor-intensive and error-prone if done manually, but are executed quickly and accurately in the GIS environment. The results can be immediately displayed in map form such that the concepts are easily comprehended by those unfamiliar with DRR or GIS.

However, GIS technology offers far more than improved data representation. GIS software has powerful computational and analytical capabilities. These capabilities can integrate multiple data types to generate analyses via sophisticated statistical and probability functions. These analytical operations tend to yield results quickly, and their variables can be altered in a user-friendly manner. This ease and flexibility of execution makes GIS software a powerful predictive modeling tool, as various potential scenarios can be envisioned, as well as the effectiveness of different responses to each situation generated in the model. The predictive abilities of GIS technology are of immeasurable value in the development of optimum procedures in all stages of DRR.

GIS Technology and Small Communities

In UN-provided models, disaster risk reduction (DRR) processes originate at the national level, from which aid "filters down" and is administered to local communities. This conceptualization of the DRR model hampers effective disaster management. While national authorities are capable of administering these procedures on large scales, the minutiae that directly affect small communities are best handled at the local level, with assistance from institutions that reach beyond the DRR system. Effective DRR cannot be implemented through a standardized procedure—it must be tailored to the needs and capabilities of each community. This paper offers a DRR design methodology for small towns and rural areas. It employs a multi-variable classification system involving the characteristics that necessitate customization for effective DRR.

Communities vary widely in their utilization of GIS in DRR contexts. However, optimizing GIS capability does not always require that the municipality obtain cutting edge professionals and resources. This is an unnecessary and unrealistic expectation in many cases. Determining appropriate GIS capacity requires that a community first be evaluated in order to identify its disaster risk reduction/disaster management (DRR/DM) requirements. These requirements are then considered in conjunction with the municipality's resources to establish the desired capability.

Qualification levels for major aspects of GIS capability with respect to DRR/DM are provided below. Descriptions of these levels are followed by suggested procedures for advancement to the next level. It should be noted that a municipality can be classified at a different level with respect to different variables. Needs vary according to the community, thus attainment of a uniform capability level may not be necessary.

Level 0:

GIS users: No GIS software users in public or private sector. However, the municipality may contain one or more individuals possessing cartography knowledge. Such expertise presupposes basic familiarity with geographical concepts and symbology. Computer access is not assumed to be available to Level 0 GIS users, but they may have indirect familiarity with GIS software and its web applications. GIS data: No imagery, map files, or access to satellite data. Descriptive Geo-data: No census or zoning data. Resource centers: No human or physical resource centers, such as universities and libraries, though some demographic information may be available via consultation with residents who are familiar with the community's residents and history. DRR/DM personnel: No DRR/DM personnel. This paper extends the definition of DRR/DM personnel beyond that of explicitly designated DRR/DM positions. This definition includes any individual whose duties result in his involvement with DRR/DM issues. Thus, emergency response personnel will be considered DRR/DM personnel.

Level 1:

The municipality contains one or more individuals whose cartography knowledge is supplemented by possessing a basic familiarity with web-based mainstream cartography and imagery GIS tools, such as Mapquest and GoogleEarth. software, but lack internet access. Alternatively, these individuals may have internet access and be familiar with popular GIS applications, such as Google Earth or Google Maps. They may

be isolated users, functioning independently of each other. GIS data: The community possesses rudimentary maps, often hand-drawn. These graphics offer a general conception of the local geography and structures, but cannot be relied upon in crisis situations where time is of the essence and those unfamiliar with the terrain must read the data. Descriptive geo-data: Social data exists in church records and in common knowledge. Local landowners and businesses keep records on tenants and employees with whom they have relationships. Resource Centers: GIS data is available, but it must be accessed by contacting local government departments. In some instances, it may be stored by private citizens who do so as a community service or whose research interests require it. The region contains conventional information repositories, such as schools and libraries, but they do not store GIS data. These institutions are well positioned to be GIS resources, as they usually have the storage capacity and can build ongoing relationships with other institutions that have access to the data. DRR/DM personnel: DRR/DM divisions (including law enforcement agencies) employ at least one individual with Level 1 GIS abilities.

Level 2:

GIS users: A small-scale, loosely connected GIS community is present. GIS users function in educational institutions, and the local media agency, or library employ individuals with basic GIS skills who are likely aware of each other, or can easily make contact if provided with contact information. GIS data: The community has immediate access to geo-referenced imagery or scaled maps. This GIS data must accurately reflect that which it depicts. For instance, the scale must be sufficiently accurate for practical use, and be of sufficiently recent collection such that it accurately reflects the structures and inhabitants it depicts. Descriptive geo-data: The municipality maintains rudimentary, but accurate demographic data. The area changes slowly, as there is minimal relocation into or out of the region. Therefore, frequent updates of demographic databases are unnecessary. The data contains location information and can be prepared for map projection. Resource Centers: Libraries and universities store maps and imagery, but the data may lack detail. The resource centers' employees have limited or non-existent GIS skills. DRR/DM personnel: Emergency agencies have GIS software on their computers and employ at least one individual with Level 2 GIS abilities.

Level 3:

Level 3 GIS users demonstrate familiarity with GIS software extensions, have the ability to create and edit files, and perform basic analytical operations on maps, such as the generation of buffer zones. (GIS buffer zones are regions whose boundaries exist at a geographical or temporal distance from a given locale. Analyses incorporating buffer zones can reveal vulnerability levels for locations within the zones.) The area has an active GIS community. Universities, libraries, and weather centers regularly exchange information, but this relationship is not as well developed with respect to DRR/DM personnel. GIS data: The region not only has access to GIS data of the quality indicated at Level 2, but also has access to multi-spectral satellite imagery that can be digitally processed. Descriptive Geo-data: The municipality maintains census data that is both detailed and current. The data offers demographic information that can facilitate land-use planning and development projects. For example, ethnicity demographics may reveal

potential language barriers that require emergency response personnel with a specific linguistic skill be deployed to that area. Resource Centers: Libraries and universities store detailed and up-to-date maps and imagery. These resources are maintained in a GIS center within the library or university. The center has at least one full time administrator with GIS skills. Resource center employees must have a working knowledge of GIS database administration, have Level 2 GIS abilities and be able to perform basic editing operations on GIS files, such as clipping. They must also be able to import the data, understand the data types and file type conversion methods. DRR/DM personnel: Agencies active during and after disasters, such as law enforcement agencies and medical responders, have full-time employees with GIS skills. These GIS specialists perform tasks that expand and refine existing DRR/DM-related databases. These improvements enable the generation of analyses that facilitate DRR/DM efforts. For example, the compilation of a shelter and evacuation site database will enhance GIS capability to respond to DRR/DM needs. The database should contain location information and descriptive information such as capacity, presence of emergency equipment, and details as to what types of disasters the structure is designed to withstand.

Level 4:

GIS users: The region's university has a GIS department with research facilities and imagery libraries. The department's instructors and researchers maintain relationships with their counterparts in the local and national DRR community. The region also maintains a DRR-certified network. These members are on permanent stand-by, but may be volunteers. Many of them are former DRR professionals with some GIS skills. These skills may be limited, but they are practical in a DRR context, such as familiarity with web-based GIS applications. GIS data: Researchers and GIS professionals in the DRR system regularly process and analyze multi-spectral imagery pertaining to the region. The maps themselves are detailed, comprehensive, and current. Descriptive Geo-data: Detailed and current descriptive data (eg. demographic data) is available. This data is geo-referenced and in a format appropriate for processing with GIS software. Resource Centers: In addition to maintaining level 3 resources, the municipality also operates its own satellite, possibly under shared ownership with another community. The satellite is likely administered by a research center with state-of-the-art capabilities. DRR/DM personnel: Agencies tasked with performing DRR/DM functions, such as those related to law enforcement and emergency medicine, have full-time employees with GIS skills. These agencies engage in inter-agency GIS coordination and communicate on a regular basis. The GIS specialists participate in multi-agency GIS conferences to facilitate this relationship, refine skills, and share information. The municipality uses web-based GIS applications to supplement its other communication capabilities. DRR/DM personnel are provided with laptops and GPS hardware to optimize their use of the web-based technology.

Methodology for Level Advancement:

Following are methodologies for advancement of one level beyond that which is currently attained.

Transition from Level 0 to Level 1:

Level 0 to Level 1 GIS Users:

Level 1 GIS users are map-literate, as the ability to understand the fundamentals of map design is not only critical in effective DRR, but also a prerequisite to working with GIS software. Level 1 users are comfortable with concepts such as scale, legend reading, coordinate systems, and map-related charts. Knowledge of these concepts should then be applied to gain basic facility with mainstream, web-based GIS tools commonly used by non-GIS specialists, such as Mapquest and GoogleEarth

Level 0 to Level 1 GIS Data:

Communities that lack maps may also suffer from inadequate remote sensing coverage. In such cases, aerial photography might provide images with detailed geological data from which professional maps can be made. If this technology is unavailable, hand drawn maps will provide a visual record of population and hazard locations.

Level 0 to Level 1 Descriptive Geo-Data:

If available, census data, zoning data, building locations, and other data expressible in a geographical framework must be converted to a GIS-friendly format. In many cases, this simply requires creating dbf files for the data or creating tables directly within the GIS software. This is an important asset for GIS-assisted DRR, as the data can be displayed in the map, thus streamlining analysis by enabling several types of data to appear in one visual context.

Level 0 to Level 1 Resource Centers (human, physical):

If libraries and universities are unavailable, local residents or government officials can step in to fill some of the gaps as GIS resource managers. Those with computers can act as limited resource centers. These individuals are responsible for storing the GIS data and regularly verifying that it is up to date. The latter can be achieved by forming relationships with others with first hand, immediate knowledge of the changes, so that the GIS resource manager will be regularly apprised of these changes.

Level 0 to Level 1 DRR/DM Personnel:

These DRR/DM personnel are not GIS specialists, but they are included in the capability requirements because their job performances would be substantially enhanced by a GIS component. They can play vital roles in maintaining effective communication networks critical in DRR contexts. Therefore, at least one individual employed in each DRR/DM agency (such as law enforcement and fire-rescue) must be selected to perform GIS functions. They should gain basic GIS and cartography skills and be among the first to receive the most current GIS data.

Transition from Level 1 to Level 2:

Level 1 to Level 2 GIS Users:

Map literacy should be followed by introductory GIS software training. Level 2 users should have the ability to open, read, and edit maps within the software. They should also be able to perform basic operations that would facilitate DRR . Thus, concepts such as measurements, map symbols, and map design techniques must be mastered.

Those with internet access should have some familiarity with online web tools such as GoogleEarth. As in the case of mapping software, these skills can be gained through accessing the online help files, third party online tutorials, and active use of the web tool. Some of these applications can be accessed free of charge. For instance, GoogleEarth can be accessed for visualization without fee. Data can be uploaded and shared as well, but these functions require payment of a fee.

Advancement to Level 2 requires computer access, but not necessarily internet access:

1. Computer access
2. Map reading software and/or online GIS tools: Examples include, but are by no means limited to ESRI ArcMap, and for online tools, GoogleEarth.
3. Potential software users: Individuals willing and able to be trained in the use of this software. This may not necessarily require access to an education facility or instructors. Individuals possessing computer skills can attain a working proficiency from many excellent hands-on tutorial textbooks in GIS.

Creating a nascent GIS community entails identifying GIS users and enquiring as to their willingness to form a network to facilitate DRR. Identifying these individuals may be a challenging task, as they may not know each other. These isolated users are sometimes employed in emergency response, media fields, and of course, weather centers. They may not hold formal GIS positions, but they are interested in GIS because this technology is so important in these fields. Other isolated users can be contacted through websites that are frequented by GIS enthusiasts who are attracted to the sites for the services they offer, such as knowledge bases, downloadable files, and forums. Many of these sites permit the placement of announcements on their forums or elsewhere on the site. Examples of such sites are gislounge.com, gisforum.com, and gisdevelopment.net.

Level 1 to Level 2 GIS data:

GIS users should have access to maps of the area, and if possible, maintain a small imagery library of both historical and contemporary maps. Contemporary maps should accurately portray the features that they depict. Therefore, any geographical changes that would compromise that portrayal must be updated to reflect those changes.

Some Level 1 municipalities will only have hand drawn maps depicting their region. Other municipalities have professionally created maps, but they may display insufficient detail, or may not be in a format readable by the GIS software. Ideally, cartographers should be commissioned to create detailed maps, or universities with GIS

or cartography departments may be of assistance. However, if these are not viable solutions, hand drawn maps can be digitized or scanned into digital form using specialized software.

Level 1 to Level 2 Descriptive Geo-Data:

Data that exists as common knowledge and in community records (such as church records) should be compiled into databases that are readable by GIS software. These records should then be refined and expanded via fieldwork. Special attention should be given to including geographical information, such as location coordinates and addresses. The geographical data must also be entered in a standardized format to ensure that the software can read and perform operations on every entry.

Level 1 to Level 2 Resource Centers:

Until recently, GIS resource centers were generally limited to large educational and research institutions. Fortunately, smaller libraries and universities now have access to resources that can assist them in building their GIS capabilities. GIS centers are especially productive in libraries, as they are already data repositories. Users can have access to vast stores of non-GIS data that can be incorporated into their GIS research, resulting in products with greater depth and accuracy due to easy access to data not readily available in GIS centers not situated in libraries. University libraries can provide the added service of acting as a reference site from which users can learn of the availability of all GIS research data throughout the university.

Resource center employees must have a working knowledge of GIS database administration, have Level 2 GIS abilities and be able to perform basic editing operations on GIS files, such as clipping. They must also be able to import the data, understand the data types and file type conversion methods.

Level 1 to Level 2 DRR/DM Personnel:

Agencies involved in emergency planning and response must provide their Level 1 GIS personnel with the resources to attain Level 2 GIS proficiency. These resources include funding for GIS courses and the installation of software and equipment necessary for them to perform Level 2 tasks.

Transition from Level 2 to Level 3:

Level 2 to Level 3 GIS users:

Level 3 users should become engaged with the GIS community, especially those elements local to their region.

Level 3 proficiency can be attained through self study if formal coursework is not a viable option. Several tutorial texts are available that provide the instruction necessary to perform the tasks described for a Level 3 user. A few of the appropriate texts appear in the reference section of this paper.

Level 2 to Level 3 GIS data:

The community must maintain its Level 2 data and gain access to multi-spectral satellite imagery. Satellite data can be obtained from governments or research

institutions that access satellites whose orbits cover the area of interest. Alternatively, they can sometimes be purchased from private companies, though this avenue may be cost-prohibitive.

Level 2 to Level 3 Descriptive geo-data:

Population databases should be enriched with descriptive data that improves DRR procedures. Examples of this data are details such as ethnicity, spoken language, and religion. If practical, DRR personnel from multiple agencies should be solicited for advice on descriptive geo-data that would facilitate their job performance. Their suggestions may include information on population density and building height. These details may not only be useful to first responders, but may also be of benefit to other DRR personnel, such as land-use planners. For instance, a risk analysis might reveal that a neighborhood bears an unacceptable risk if it exceeds a certain density, as DRR/DM resources may be insufficient for its needs.

Relatively static communities may not immediately perceive the need for detailed demographic data that provides information reflecting local common knowledge, such as ethnicity. Many small communities change little over time and may contain multiple ethnicities whose locations are consistent for generations. Local residents may dismiss the compilation of a database that includes cultural information, such as ethnicity and language as superfluous. However, if outside assistance is required in the course of disaster response, non-resident responders may be unaware of what is common knowledge to local residents. Thus, the ability to provide detailed data on population descriptions, such as the existence of ethnic enclaves will expedite response.

Level 2 to Level 3 Resource Centers:

Resource centers must develop their existing imagery and map libraries beyond what they currently possess. This should always be a goal, regardless of the capability level, but those centers storing rudimentary maps and images must focus their energies on expanding their libraries to include more sophisticated data sets. A minimum operating capability for a Level 3 resource center should contain data with which a Level 3 GIS user could generate analyses and customize maps for the municipality. This includes, but is not limited to, Level 3 GIS data and census data in GIS-readable file formats.

Level 2 to Level 3 DRR/DM Personnel:

Emergency response agencies must have at least one full-time employee with Level 3 GIS skills, or provide the resources and opportunities necessary to raise the skill level of their existing GIS specialists. The employee must also possess emergency response skills specific to that agency. This dual skill quality is important, as the GIS user will understand the needs of the agency in which he/she works, and thus can provide GIS products tailored to the agency's function. Additionally, the GIS user will be better able to communicate GIS concepts, as he/she shares the background of his/her colleagues.

Transition from Level 3 to Level 4:

Level 3 to Level 4 GIS users:

GIS-users must maintain existing relationships with their counterparts in other agencies and institutions, as well as with other GIS-users in the DRR/DM community. The information-sharing that develops out of this DRR-focused GIS community not only enhances the knowledge and skills of GIS specialists, but also lays the foundation for relationships through which critical communication will flow that will benefit each agency's DRR/DM functions.

Members of the DRR/DM community must acquire formal DRR certifications. These certifications must have an integrated GIS component and require formal, standardized training and testing. The certification programs can be identified by contacting major GIS-DRR centers for further information. Specialized GIS certifications can be found through universities with GIS academic programs. These certifications are important, as they can refine and augment critical skills for GIS users in the DRR community.

Level 3 to Level 4 GIS data:

Level 4 GIS data not only differs from level 3 qualitatively, but level 4 data will also differ depending on the requirements of each community. This level is broadly defined as GIS data that is sufficiently current and has sufficient resolution such that it meets the GIS requirements for all DRR agencies in the community. Thus, the most challenging prerequisite for achieving this level is that of funding.

Level 3 and level 4 GIS users should be sufficiently knowledgeable to be able to determine the data quality necessary to fulfill their region's needs.

Level 3 to level 4 Descriptive geo-data:

Communities with level 3 descriptive data can easily transition to level 4, if they employ level 3 GIS specialists. Level 3 GIS users should be able to geo-reference the data, and understand the file formats and conversion methods necessary to prepare the data for use by GIS software.

Level 3 to Level 4 Resource Centers:

It is highly unlikely that small communities will require level 4 resource centers in order to implement effective DRR procedures. Nevertheless, in rare cases a small community might contain a major academic or government laboratory, and its presence would qualify as a level 4 resource center.

Level 3 to Level 4 DRR/DM personnel:

Ideally, GIS training for ER professionals can be an inter-agency endeavor. GIS classes attended by representatives from multiple agencies can facilitate inter-agency functioning before, during, and after disasters. It can also encourage the development of a DRR-focused GIS community through which these specialized GIS capabilities can be further augmented and refined.

A brief comment on Level 4 Users and Centers:

GIS proficiency levels for users at Level 4 have formal GIS training at the graduate level. These professionals oversee other users who have GIS certifications with a DRR emphasis. Level 4 facilities are state of the art and provide assistance to smaller centers. They devote some resources to innovation, developing tools and techniques that advance the field.

Transitioning from one level to the next:

Some improvements may be more challenging than others in terms of time, labor, and resources. However, small communities display characteristics that place them at an advantage when compared to urban areas. For instance, the expansion and refinement of geo-data and GIS networked emergency response centers can be demanding tasks for big cities. Such endeavors would require coordinated inter-departmental efforts, and census refinements would entail specified procedures for redesigning census questions, hiring census-takers, and allocating budget requirements. Small communities can achieve these goals with greater agility by virtue of their size.

One such example is provided by the community of Freshwater in Humboldt County, California.[1] This community has employed a database system that uses GIS technology to facilitate coordination for disaster management. The application displays a user-friendly interface so that it can be easily updated by individuals who lack the technical background of a programmer or GIS specialist. The database matches resources to a variety of specialized needs, so that residents not immediately reachable by response teams can obtain assistance from those living in their vicinity. The data, which includes emergency sites, can be displayed and printed in map form. Issues of privacy and residency verification were rectified by establishing multiple access levels and password protection. These measures, combined with the user-friendly interface and the reality of previous disasters, encouraged resident participation in the project.

This database was designed by the National Science Foundation to be transferable to other communities. It is an example of the benefits reaped by municipalities that coordinate with research/academic institutions to achieve greater disaster preparedness. Thus, communities encountering difficulties when developing their GIS capabilities may receive helpful advice and/or practical assistance by consulting members of the academic and research sectors.

Furthermore, these sectors can be a valuable resource for the development of GIS skills and resource centers. The certificate programs and workshops available through many of these institutions can fulfill qualification requirements for transitioning to the next GIS user proficiency level. GIS librarians can advise communities who wish to develop their own image libraries and GIS labs. They can also serve as a link to the GIS resource network, providing access to imagery, analytical tools, and technical assistance that might otherwise be beyond the reach of a small community.

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[1] Lumbert, Jennifer and Kenyatta Perkins. 2007. Community-Based Disaster Response Design Using an Open Source GIS. *ASPRS 2007 Annual Conference*. May 7 -11. http://www.humboldt.edu/~reu-rms/reu2006-lumbert_perkins-paper.pdf.

Conclusion

This methodology is intended as a guideline for small communities wishing to incorporate GIS technology into their disaster management systems. Technological capability is separated into aspects, with each having its own set of developmental levels. The divisions have been defined with a minimum of overlap. This precision is intended to facilitate the evaluation of capabilities and requirements, as well as to clarify GIS concepts for those unfamiliar with the technology. It is understood that community needs and resources display variations reflecting those qualities that render each community unique. Thus, implementation of this methodology may entail some overlap and variation among the aspects and ability levels. While this methodological model will be refined as continued use and research require, it is hoped that this initial version will improve the manageability and implementation of GIS technology at the local level.

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