Incorporating Geoinformatics into Disaster Preparedness and Management Operations: A Caribbean Regional Approach

J. Opadeyi[1], B. Spence[2], K. Miller[3] & C. Griffith-Charles[1]

The Caribbean region is prone to a wide range of natural disasters, particularly; hurricanes, floods, volcanic eruptions and earthquakes. These occurrences cause significant distress to the people and economies of the region. The region, through the Caribbean Disaster Emergency Response Agency (CDERA) is making efforts to mitigate the socio-economic effects of these disasters and to manage the recovery process. In recent times, efforts have been made to embrace advances in geoinformatics such as, Geographic Information Systems (GIS), Global Navigation Satellite System (GNSS), and satellite Remote Sensing Systems (RSS) that provide increased efficiency in disaster management. This paper reviews trends in the use of geoinformatics for disaster management. It also reviews major challenges and issues facing the Caribbean in the effective adoption of these contemporary technologies. It concludes by advancing the need to develop implementation approaches specific to the Caribbean institutional environment.

Keywords: *Caribbean, Geoinfomatics, Geographic Information Systems, GIS, Global Navigation Satellite Systems, GNSS, Satellite Remote Sensing, SRS, Disaster Preparedness and Management*

1. Introduction

The Caribbean region is vulnerable to a wide variety of hazards. These include tropical cyclones, landslides, seismic activity, drought, flooding, and technological hazards. While the main focus has been on hurricanes, over the years, the impacts of other hazards have severely affected not only the economic, but also the social and environmental base of the region. Hurricane Gilbert of 1988 is estimated to have caused Jamaica losses equal to 65% of its GDP [1]. The economic impacts of seismic hazards have been most recently demonstrated in Montserrat, where major disruption of economic activity has resulted from volcanic activity in the Soufriere Hills [2]. In October 2001, as a result of a severe flooding event, thirteen communities in the north-eastern parishes of Jamaica were cut off from vehicular access, with the extent of damage to some roads suggesting isolation of some areas for an extensive period [3]. Similar discomfort was experienced in the flooding in Guyana in 2005.

Natural hazards have led to destruction to life and property from time immemorial. Despite technological development, their occurrences are still difficult to prevent. Their consequences however, can be mitigated through well designed and coordinated Disaster Risk Management (DRM). Through the study of the causes and effects of specific hazards, data on features that trigger the occurrences of these hazards can be collected and their behaviour monitored. Similarly, data on resources that are vulnerable to these hazards can also be collected and assessed. These two types of data, thus, provide inputs for developing mitigation plans in

[1] Department of Geomatics Engineering & Land Management, Faculty of Engineering, The University of the West Indies
Email: jacob.opadeyi@sta.uwi.edu, charisse.griffith-charles@sta.uwi.edu
[2] Department of Geography & Geology, The University of the West Indies, Mona, Jamaica
[3] Faculty of Engineering, British University of Egypt. Email: keith.miller@bue.edu.eg

respect of each hazard. Simple as it may seem, the real challenge is the quality, currency, volume, and format of the data required for such plans and the ability to integrate the data for specific applications. The data required to forecast the occurrence of hazards are grossly lacking or are dated. Mitigation plans for landslides, for example, require climatic data, topographic data, land use data, vegetation data, and socio-economic data. These data themes, if at all available, are in different government agencies, in different formats, different levels of details, and are collected for different purposes. Such disparate data are difficult to use in an integrated analysis typical of Comprehensive Disaster Management (CDM). In addition, the volume of data required to undertake meaningful analyses could be quite large for the mostly manual methods of analysis.

The need to incorporate geoinformatics into DRM was recognized during the International Decade for Natural Disaster Reduction (IDNDR), most specifically through its goals #2 and #3;

- To improve the capacity of each country to mitigate the effects of disasters
- Application of scientific and technical knowledge and promotion of hazard mapping
- Development of Early Warning Systems
- Formulation of public awareness programmes aimed at raising public awareness of disaster prevention

Within the Caribbean context, therefore, the incorporation of geoinformatics into CDM becomes a question of how it can be effectively utilized. This should be answered by an analysis of the technological tools available and their possible uses within all aspects of CDM.

2. Review of Enabling Geoinformatics Technologies for Disaster Preparedness and Management

The three geoinformatics technologies that have significant impacts in DPMO are: Remote Sensing Systems (RSS), Geographic Information Systems (GIS) and Global Navigation Satellite Systems (GNSS).

2.1 Remote Sensing Systems (RSS)

Terrestrial remote sensing is the practice of deriving information about the earth's surface by processing images acquired from an overhead perspective. Radiation is reflected or emitted in one or more frequencies or wavelengths of the electromagnetic spectrum (EMS) by all surfaces. Remote sensors operate within a subset of the EMS that ranges from the visible wavelengths through the infrared to the thermal wavelengths.

Sensors measure electromagnetic radiation and a unit of electromagnetic radiation is defined as the rate of transfer of energy recorded at a sensor, per square metre on the ground, for one steradian per unit wavelength being measured [5]. This is referred to as the spectral radiance. The spectral response of a feature varies across the EMS and is affected by the bio-physical properties of the feature. Table 1 provides the responses of bio-physical properties of natural resources to the different regions of the EMS. Table 2 illustrates the application of spectral frequency with the seven bands of Landsat7. It indicates the responsiveness of each band frequency to surface features.

TABLE 1: Bio-physical Properties and the Region of EMS Affected (Adapted from Townsend [4])

Region of EMS	Bio-physical Properties
General	Topography, azimuth and elevation of feature, atmospheric conditions
Visible / reflective infrared	Vigour, maturity, physical form and pigmentation of vegetation, moisture content of vegetation and soil, texture of features.
Thermal Infrared	Temperature, emissivity, moisture, texture, density and mineralogy of soils, atmospheric conditions, vigour, maturity, physical form, moisture content and pigmentation of vegetation.
Microwave	Micro-surface roughness, volume scattering, moisture and conductivity.

Remote sensing systems may be evaluated in terms of the type of platform, sensor type, resolution, scene size, cost, and period of operation. To provide an appreciation of the complexity involved in the selection of satellite imagery for natural hazard mapping and monitoring, a review of the sensors and resolution components of remote sensing systems is presented.

TABLE 2: An Example of Spectral Frequency Application – Landsat TM (From: Jensen [6])

Band	Frequency	Use
1	Blue	Penetration of water bodies, analysis of land use, soil and vegetation. Lower wavelength is peak transmittance of clear water, upper wavelength is limit of blue chlorophyll absorption for healthy green vegetation
2	Green	Green reflectance of healthy vegetation
3	Red	Important band for vegetation discrimination. Red chlorophyll absorption for healthy green vegetation
4	Reflective Infrared	Responsive to vegetation biomass, crop identification, land-water, soil-crop boundaries
5	Mid-infrared	Turbidity and plant water content, hydrologic research.
6	Thermal infrared	Surface temperature, vegetation classification, stress analysis and soil moisture.
7	Mid infrared	Geologic rock formations

2.1.1 Platforms

Sensors in aircraft or spacecraft acquire data and the type of platform determines the altitude of flight. Low altitude platforms are controlled by operators, are survey specific and costs are borne by the user commissioning the survey. In comparison, high altitude platforms tend to provide extensive and repetitive coverage with fixed image characteristics and economically priced data. The aircraft based platforms are Compact Airborne Spectrographic Imager (CASI) and Aerial photography, while the main satellite systems are LANDSAT, SPOT, IRS, AVHRR, RADARSAT and IKONOS.

2.1.2 Sensors

Several types of sensor systems exist and the sensor type determines the part of the EMS sensed and the format of the image. Sensors can be photographic or electro-optical in nature. Optical sensors can be imaging or non-imaging and imaging sensors consist of frame, mechanical scanners and detector arrays [7]. The most common systems are indicated below with examples.

- Photographic systems use cameras and film and record radiation in the visible and parts of the near infrared spectrum. These are used for aerial photography. Digital Aerial Photography is becoming increasingly more popular and has since replaced film-based aerial photography in many sectors. The film-based process has been seen by many as inconsistent, time-consuming and costly. Digital aerial photography on the other hand is said to have better continuous scanning and captures low-level imagery better, for more detailed mapping for damage assessment.

- Multi-spectral Imaging using Discrete Detectors and Scanning Mirrors e.g.: Landsat MSS, TM and AVHRR. The detectors utilize filters that generate the spectral bands. The mirrors oscillate through an angular displacement off-nadir and support a wide swath width. This can be used for flood monitoring of large areas.

- Multi-spectral imaging using Linear Arrays e.g. SPOT HIGH-Resolution Visible (HRV). This supports high geometric fidelity, stereoscopic imagery and topographic mapping. Sensor mirrors can be aimed to off-nadir viewing if required. This can provide for vulnerability assessment.

- Imaging spectrometry using Linear and Area Arrays: Compact Airborne Spectrographic Imager (CASI). It supports a large number of bands and detailed analysis for response planning and evacuation management.

- Synthetic Aperture Radar (SAR) e.g.: RADARSAT-1. It uses radar technology to transmit microwaves and record the waves reflected by the object. These sensors are able to pierce fog and cloud cover to be of use in hazard monitoring.

2.1.3 Resolutions

Resolution is the resolving power of a sensor [6]. The resolution of a sensor is defined in terms of its spatial, spectral, temporal and radiometric resolutions. Spatial resolution refers to the ground size of a pixel. It is a measure of the smallest separation between two objects that can be resolved by the sensor [6]. There is an inverse relationship between spatial resolution and the size of an image scene. IKONOS (0.8m panchromatic to 3.2m multispectral) and Quick Bird (0.61m panchromatic to 2.4m multispectral) have the highest resolutions currently available from commercial satellite imagery. CASI has the highest multi-spectral resolution available of airborne sensors (2-4m) and is aircraft mounted. In the Caribbean disaster context, hurricane and coastal erosion have strong human impacts and they are the two hazards which can benefit from the new capability of higher resolution images. Spatial resolution allows the delineation of surface wind convergence associated with the multiple wind and rain bands of hurricanes. In addition, rapid assessments after disastrous events in the Caribbean and a faster characterization of the damage patterns and levels are achievable according to the spatial resolution of the remotely sensed data [25].

Spectral resolution refers to the sensitivity of a sensor to the number and dimension of wavelength intervals in the EMS. Most satellite sensors are either sensitive to the visible and infrared wavelengths or to the microwave wavelengths. The spatial and spectral resolutions of a sensor are critical to feature identification. Temporal resolution indicates the frequency of coverage by the sensor. The temporal resolution of satellite sensors varies from twice per day (AVHRR) to every 26 days (SPOT). Temporal resolution is key to monitoring and change detection. It is particularly important when the feature being monitored is volatile in nature. Noteworthy also is the fact that cloud cover within the Caribbean influences the ability of the fixed temporal sensors to capture images on the surface during the daytime. Removing cloud cover thereafter from the satellite imagery may also prove to be more challenging.

Radiometric resolution defines the sensitivity of the sensor to differences in the signal strength. The radiometric resolution of a sensor directly relates to its ability to identify particular features. Most sensors have 8-bit resolutions and can support 256 grey scale mapping. In contrast, IKONOS has 11-bit resolutions and CASI supports up to 12-bit.

2.1.4 Scene Sizes

The size of a scene equates to the projected instantaneous field of view. There is an inverse relationship between scene size and spatial resolution. Scene size has implications for cost of image acquisition. It determines the number of images that must be acquired and the need for mosaicing. RADARSAT has the widest swath available and IKONOS with its high spatial resolution has a swath of 11km.

2.1.5 Costs

There are great variations in the pricing of imagery. LANDSAT is the most economical multi-spectral imagery available at a feasible spatial and spectral resolution for land cover mapping. IKONOS charges a premium price for its high-resolution product. 1m panchromatic and 4m multi-spectral at the lowest level of processing available is priced at \$29US per km^2 or \$3509US per scene. Orthorectified imagery is available for 1m panchromatic and 4m multi-spectral at \$66 US per km^2 or \$7986US per scene.

2.1.6 Period of Operations

The historical archives of a sensor are important repositories of data. The extent of these archives is a consideration in the choice of imagery. They contain evidence of change and support spatial analysis on the extent and rates of processes. The Landsat program has been collecting data since 1972.

2.2 Geographic Information System (GIS)

Improvements in information technology have provided unimaginable opportunities to support data analyses and communications in the last two decades. GIS has provided new and exciting ways of acquiring natural resource data and also providing efficient means of processing, managing and integrating this data. GIS is an organized collection of computer hardware, software, geographic data and personnel, designed to efficiently *capture, store, update, manipulate, analyze and display* all forms of geographically referenced information [8]. Geographic information plays an important role in activities such as environmental monitoring, management of land and water resources and real estate transactions. The areas of GIS applications are numerous and growing.

The increasing use of GIS in the varying professional fields has produced both tangible and intangible benefits that are enough to sustain its use into the future. The following benefits have been advanced for the use of RSS/GIS in DPMO [9] [10] [11]:

a. Provides integrated data storage and data retrieval capabilities.
b. Encourages a more systematic approach for the collection of data.
c. Leads to reduction in the overall costs of data collection and management by facilitating data sharing among users.
d. Increases comparability and compatibility of diverse data sets.
e. Makes data accessible to a wider range of decision-makers.
f. Encourages the spatial analysis of environmental impacts that are otherwise ignored because of analytical difficulties or high cost.

Over the past decade, computer hardware and software constraints to GIS development have been reduced. Data acquisition however, remains a challenge even with advances in remote sensing technology and decreasing cost of data acquisition. The removal of the intentional error in Global Navigation Satellite Systems (GNSS) readings and the availability of satellite imagery with one-metre spatial resolution have provided some relief to these constraints. The recent commercialization of the IKONOS satellite imagery with the one metre panchromatic and four-metre multi-band resolutions is revolutionizing the use of GIS for DPMO. Vulnerability or capacity assessments are an indispensable complement to risk assessment.

The use of GIS has broadened the possibilities to undertake multi-hazard assessments [21]. GIS has been used extensively to drive the multi-hazard assessment in various parts of the world such as Costa Rica, Australia and Sweden. Risk-GIS, as it has been named in the Cities Project in Australia, is a fusion of the decision support capabilities of GIS and the philosophy of risk management.

In recent years, risk assessment methodologies have increasingly incorporated the use of GIS as a means of increasing their overall utility. The Hazard United States Multi-Hazard (HAZUS-MH) methodology and software programme is one such example. HAZUS-MH, an offspring of the Hazard U.S. (HAZUS) methodology developed by the nation's Federal Emergency Managament Agency (FEMA), aims at standardizing the risk assessment and loss estimation process for flood, wind, hurricane and earthquake hazards across the U.S. [20]. One of the merits of this GIS based program is that it offers free of charge, the most extensive collections of hazard and vulnerability data [20].

The HAZUS-MH risk assessment process consists of five stages [20]:

- Identification of Hazards
- Profiling of Hazards
- Inventorizing Assets
- Estimation of Losses
- Consideration of Mitigation Options

GIS is used as a means of mapping and displaying hazard data, modelling hazard scenarios and displaying the results of loss estimates [19] [20]. Although the software's data content restricts full applicability to regions within the U.S. [19] [20], the adoption of HAZUS-MH methodology in the Caribbean territories should be made available to risk managers in the region. If used in its present state, the main challenge of the use of HAZUS-MH for Caribbean scenarios would be data acquisition.

2.2.1 Products and Services

The products and services of GIS are mainly software-based and are mostly specific to organizations which utilize its capabilities. Among the seemingly unlimited list of global GIS products and services are: standard maps, custom maps, digital data transfers, aerial photography, and subscription based web access. The cost of GIS products, services and implementation varies largely and is often based on its specific uses and level of detail required.

2.2.2 Web-Based GIS

The latest technological advances in GIS have come most notably in the form of the Internet. Access to spatial data as well as advanced mapping and spatial analysis over the Internet is becoming more common. With the advent of Java based programming, software applications for web-based GIS work are now available. Because of these advancements, many people who were not able to easily access information can now have it at their fingertips.

The following are a few examples of web-based GIS:

- ArcIMS: the Internet Map Server from ESRI enables one to create simple, "out-of-the box" map services with pan, zoom and simple query functions.
- AspMap: a web mapping component for embedding spatial data access, display and analysis capabilities in Web applications and services.
- Free Map Server Software: provides links to free map servers.
- GEO-DATA Explorer (GEODE): used to access, view, and download information from geo-spatial databases containing a broad spectrum of data produced by the USGS and other government agencies.
- Geography Network: created by ESRI and is based on ArcIMS technology, it provides an internet based forum for viewing and accessing spatial data from a variety of commercial and public domain sources.
- GeoServ.org: delivers interactive maps over the Internet and provides access to key geoscience data in the form of dynamic maps and associated databases.
- Google Earth: combines satellite imagery, geographic data and Google's search capabilities to create a virtual globe application that is downloadable.
- Google Maps: a fast and easy way to add geographic information to personal web sites.
- iMapper: Free user-friendly ArcView extension. The purpose of this extension is to allow ArcView users to display their maps and data to people over the Web in a quick and easy fashion without needing a map server.
- Map-TV: a map server that has a built in web server. This map server uses ESRI shapefile format for data display.
- Web Mapper: an online resource devoted to Internet based GIS.

Web-GIS provides the mechanism for enhancing disaster risk communications and public education.

2.3. Global Navigation Satellite Systems

GNSS is currently the primary navigation satellite service that provides real-time position to varying levels of accuracy. The drive from other sectors to implement alternative satellite systems has led to continued development and improvements to commercial delivery of GNSS. Manufacturers of receiving equipment are now providing products that will integrate GNSS with the alternative services. Integrated systems are commonly referred to as GNSS. While these services are reliable, receiver units are still limited to outdoor use with sky visibility, however improvements in receiver technology are being made in this regard, and the use of integrated satellite systems means that more satellites are available, making masking of part of the sky less critical.

In 2005, the United States made agreements with Japan and Russia separately to re-confirm their intentions to pursue common goals under a 1998 Joint Statement on GPS. The Japanese delegation briefed its U.S. counterpart on the upcoming launch of MSAS, a satellite-based augmentation system based on Japan's Multifunctional Transport Satellite (MTSAT). U.S. government representatives also expressed strong support for Japan's plans to develop the Quasi-Zenith Satellite System, a regional constellation of geosynchronous navigation satellites and ground infrastructure that will provide additional ranging signals compatible to GPS to improve the availability, accuracy, and reliability of GNSS service in Japan and neighboring countries [22]. Also, in 2005, the United States and the Russian Federation issued a joint statement on plans to increase cooperation between GPS and Russia's GLONASS system. The two sides will seek to maximize radio frequency spectrum compatibility between the two systems while continuing to provide open civil signals free of direct user fees. These major initiatives and collaboration of new GIS technologies will undoubtedly assist DPMO in regions such as the Caribbean, wherever applicable.

Similarly, new GNSS technology developments have been underway in Europe. Galileo is Europe’s satellite navigation system now under development. It is a dependent system under civilian control and interoperable with GPS and GLONASS. To reach operational status, Galileo needs a constellation of 30 satellites and an associated network of ground stations spread all around the globe. This phase has just been confirmed with the decisions taken by the European Union (EU), which has agreed on a financing package of €3.4 billion Euros and proposed to entrust the European Space Agency**2.0** (ESA) with the full deployment of Galileo by 2013. The project has been led this far by a 50-50 partnership between the European Union through the auspices of its executive branch, the European Commission (EC), and ESA. Since 2008 however, Europe’s Galileo program is seeking to accelerate receiver technology development even as the space and ground segments of the system are being implemented [23]. A group of companies have collaborated on the development of a geodetic-grade Galileo-GPS receiver: ARTUS. The Compass is another new GNSS systems developed in China. China’s Compass Navigation Satellite System (CNSS) also referred to as the Compass or Beidou 2, started operation with its first medium Earth orbit (MEO) satellite in April 2207 and since, has seen little modifications.

2.3.1 Modes of Operation

Operations that involve positioning objects where the receiver is stationary for any length of time are referred to as static positioning techniques. Standard GNSS methods can yield accuracies of better than 5mm, if the highest level of technology is employed with observation periods of several hours with multiple receivers. Operations that involve positions of objects where the receiver is in motion are referred to as kinematic positioning techniques.

2.3.2 Applications

Mr. Trimble, one of the pioneers of commercial user equipment, referred to GNSS as “*the new utility*”, and GNSS is now filling this role. The technology can be used as a rapid, relatively low-cost, field data collection tool in the creation of maps for DPMO. It can be used as a geo-referencing tool for features such as fire hydrants or landslide location. Data is stored digitally, so it can later be exported to GIS systems. The reverse procedure is also available, in that given geo-referenced data, GNSS can be used to locate objects in real time. It is in use by emergency services and commercial operators in tracking vehicles and other items. With a suitable communications link installed, this can be used for search and rescue operations.

3. Technological Responses to Disaster Preparedness and Management Operations

Disaster Preparedness and Management Operations [DPMO] are currently benefiting from improvements in technological innovations and techniques. The increasing use of these computer-assisted techniques may diminish the gap between the information produced by technical risk assessments and the understanding of risk by people. Three notable elements of DPMO that have benefited are: data acquisition, data management, and data analysis. The impacts of technological applications in these three elements are reviewed below.

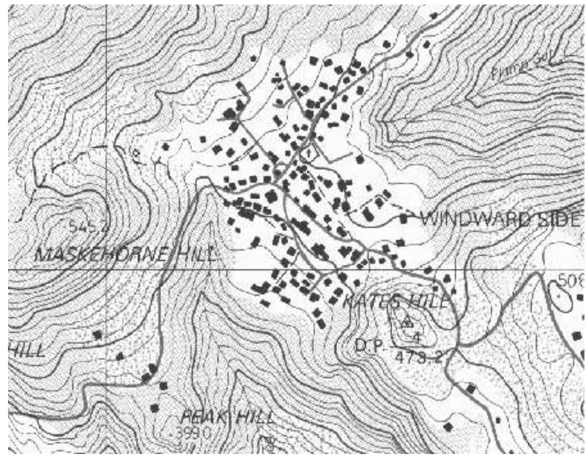
3.1 Technological Responses to Data Acquisition

Technological innovations have provided efficiency and effectiveness in the data acquisition challenges of DRM. The following are the notable technologies that have a positive impact on DPMO: high resolution commercial observational satellites; airborne video; GNSS; and telemetric data acquisition systems. These technologies have brought dramatic benefits such as: lower cost of data collection, higher data resolution and accuracy, shorter time frame with possibility for real-time data collection and higher repeatability. Data acquisition is essential in three phases of DRM. These are pre-disaster, response, and recovery phases.

3.1.1 Pre-disaster Phase

In the pre-disaster phase, an inventory of current natural and built resources is required. The knowledge of the location, magnitude, and extent of these resources should be accurate, current, detailed and complete. The traditional sources of this information are the topographic and thematic maps obtainable from the national mapping agency. These maps (especially in the Caribbean) are mostly: out-of-date, of inappropriate resolution, and are available only in hardcopy formats. These maps are thus grossly inappropriate for a modern approach to DRM. Most agencies still rely on the use of maps that are over 20 years old for DPMO, even in the face of the continuing social and economic developments of these countries.

The use of high-resolution satellite imagery such as IKONOS and Quick Bird with ground resolution of one metre or better has removed the dependency on published hardcopy maps. The fast turnaround time in the acquisition of satellite imagery, the relatively lower cost of acquisition and its immediate usability, has made it an indispensable tool for vulnerability assessment. The value of any vulnerability assessment is dependent on currency and resolution of the data input. It is therefore imperative that for any effective DRM, the acquisition of high resolution and current data on the status of the natural and built resources be considered. The use of image maps (a by-product of satellite imagery) is far superior to the use of vector maps; image maps provide the "feel and look" of the real world as opposed to polygon hatching and colour patches used in the production of vector maps as shown in Figure 1.



Topographic Map

IKONOS Image Map

FIGURE 1: Comparing Classical Topographic Map with satellite Image Map

Incorporating Modelling into GIS can add power to disaster planning in the pre-disaster phase. This will allow the relevant disaster managers to view the scope of a disaster, where the damage may be the greatest, the properties that are at highest risk, and the response required. Immediately following a large-scale event, one of the first tasks performed is locating shelters and facilitating welfare action plans. The Office of Disaster Preparedness and Emergency Management (ODPEM) in Jamaica has embarked on the development of an emergency management GIS, which is integrated across their functional business units. Spatial Innovision Ltd was contracted to implement a GIS database design to support the ODPEM. The methodology involved a mass data conversion and data acquisition from other related agencies. A master input list was created and agencies were approached in the data acquisition process. A data model, which outlined the various aspects of the ODPEM's business tasks, was created and Spatial Innovision created a customized application to address these business processes. GIS maps and tables were created using the offices' internal data that were resident in folders and hard copy maps [25].

3.1.2 Response Phase

Data acquisition at the response phase is more critical than during the pre-disaster phase. It requires real-time location of features and lives that are under threat. The improvements in the use of GNSS have provided the ability to determine the geographic position of any phenomenon with high precision at any time of the day and in any weather condition. The use of GNSS in kinematic mode also provides the ability to track the movement of any phenomena under threat. The integration of GNSS positioning with communication satellite systems has revolutionized Search and Rescue Programmes worldwide. A geostationary satellite with an altitude of about 35,000km can be used to detect and locate air-based, marine-based, or land-based distress anywhere in the world. The international Cospas-Sarsat Program and the NOAA-SARSAT are currently providing leadership in the use of these technologies to save lives [12].

The management and operations of disaster relief vehicles and the provision of real-time information to users that will lead to cost-effective and satisfied service to passengers is possible nowadays using a GPS based vehicle navigation system and communication via remote sensing. In many parts of the world GNSS and remote sensing technologies have been merged together to form an efficient disaster management system. The potential of such an integration in the Caribbean is not far-fetched. This would however require strong collaboration between the regional emergency rapid response and disaster management agencies.

Internationally, GNSS has given citizens and disasters managers alike a quantum leap forward in efficient operation of their emergency response teams. The ability to effectively identify and view the location of police, fire, rescue, and individual vehicles or boats, and how their location relates to an entire network of transportation systems in a geographic area, has become very crucial in the disaster response phase. Location information provided by GNSS, coupled with automation, reduces delay in the dispatch of emergency services. Today's widespread placement of GNSS location systems in passenger cars provides another leap in developing a comprehensive safety net. Today, many ground and maritime vehicles are equipped with autonomous crash sensors and GPS. This information, when coupled with automatic communication systems, enables a call for help even when occupants are unable to do so.

ESA/ESRIN and Eurimage started the ***Earth Watching*** project in 1993 to supply satellite data and pertinent information quickly in cases of natural disasters. The project uses satellite data to monitor various disastrous events worldwide. Radar satellite systems such as RADARSAT and ERS-1/2 satellites with their all-weather capability and ability to penetrate clouds are used for monitoring hazards like floods and oil spills. Optical satellite systems such as AVHRR, Landsat 7, SPOT and MODIS are used to monitor incidences of fires and volcanic activities. Their properties of wide-swath, high-pass repetition, and their ability to provide more precise details of already active fires and burned areas make them indispensable for DRM (http://earth.esa.int/ew/). Synthetic Aperture Radar Interferometry (INSAR) is being used for the monitoring of earthquakes and volcanoes, land subsidence, glacier dynamics, classification of different land types and construction of Digital Elevation Models (DEM's) of the Earth's surface.

3.1.3 Recovery Phase

Data acquisition, during the recovery phase of a disaster, is important for damage assessment and monitoring of post-event behaviour of the disaster itself. High-resolution satellite imagery acquired before and after the disastrous event, provides the input required for the estimation of the damage caused and the identification of safe areas for relocation and relief programmes. Using image processing techniques, it is less tedious to identify and quantify damaged resources. In the case of seismic activities, continuous data acquisition using both GNSS and satellite imagery provides effective monitoring.

In case of flooding, a comparison between the temporal images will illustrate the extent of the flood and production of a flood risk assessment plan, within the disaster context. This would help to determine remedial flood defence work to be undertaken and to prevent further damage in near real time.

3.2 Technological Response to Data Management

Comprehensive DRM required complex datasets that are available from different sources, different formats, different scales and accuracy, and with different temporal status. The use and management of these varieties of datasets in a coherent and integrated fashion present major challenges to DRM. Improvements in relational and object-oriented databases have provided the opportunity for the development and management of complex databases. Both the Japan International Cooperation Agency (JICA) and Canadian International Development Agency (CIDA) noted the need for an integrated regional approach to DRM by incorporating GIS technology in their Caribbean projects. The Inter-American Development Bank has also placed disaster mitigation and risk reduction high on its agenda and is supporting technical and technological capacity building through Geographic Information Systems (GIS) in countries such as Jamaica [24]. Notable improvements are in the areas of: data access and control, data integration, and databases.

3.2.1 Data Access and Management

Access control is required to protect information from unauthorized or accidental modification, destruction, disclosure and use. Data collection is an investment and the need for security increases as the value of information improves. This is particularly true in the present information technology environment with the need for daily virus protection. The risk management view of security evaluates access control and the need for security in terms of the following: confidentiality, integrity, availability, utility, and authenticity of information.

There are two dimensions to security: system security and data security. System security relies on technology and it is a function of software capabilities. Data security is established through data access protocol. Several security mechanisms can be employed. Username, passwords, fingerprints or voice can be used to determine authorization to a specified level of access, data or services. Access Audits should be run on a regular basis as a security measure and to monitor usage of the database.

3.2.2 Data Integration

The nature of a DRM requires that data be integrated from a number of different sources. The success of this integration affects the richness and effectiveness of the DRM. Several integration issues must be recognized and successfully managed to achieve efficient and effective integration. Existing data may have varying characteristics such as projections, datums, currency, accuracy and resolution. Metadata should be provided with all data collected to ensure that accurate information can be generated for the interpretation process.

Data of different formats can be integrated into a GIS. These include vector files, database files, text files, raster, video and scanned images, digital photographs, sound and GNSS data. The integration of multimedia datasets has served to increase the depth of DPMO. Multimedia image data include aerial and landscape photographs, infra-red images, satellite data and video based images. One limitation to widespread use of image data is the large amount of physical storage required. Improvements in data compression software are, however, alleviating this constraint.

3.2.3 Database Development

Fundamental to the successful development of GIS in support of DPMO is the development of digital natural hazard databases for the entire management area. The databases would provide support for the qualitative and quantitative analyses of queries. A conceptual data model that integrates in a distributed environment, all the basic data categories required for disaster monitoring and management can be developed. Table 3 contains a list of the basic spatial databases required for DPMO [13].

TABLE 3: Conceptual Data Model for DPMO

Band	Frequency	Use
1	Blue	Penetration of water bodies, analysis of land use, soil and vegetation. Lower wavelength is peak transmittance of clear water, upper wavelength is limit of blue chlorophyll absorption for healthy green vegetation
2	Green	Green reflectance of healthy vegetation
3	Red	Important band for vegetation discrimination. Red chlorophyll absorption for healthy green vegetation
4	Reflective Infrared	Responsive to vegetation biomass, crop identification, land-water, soil-crop boundaries
5	Mid-infrared	Turbidity and plant water content, hydrologic research.
6	Thermal infrared	Surface temperature, vegetation classification, stress analysis and soil moisture.
7	Mid infrared	Geologic rock formations

Other issues relevant in the development of data management systems for DRM are:

- Data quality assurance and quality control
- Development and maintenance of metadata
- Development and maintenance of data standard

Data sharing and exchange protocols

3.3 Technological Response to Data Analysis

Technological response to DRM is rapidly benefiting from the integrated use of Remote Sensing, GNSS and GIS technologies. Together these technologies facilitate: data integration, data sharing, data visualization, and complex data analysis. There are four categories of data analyses relevant to DPMO. These are: hazard prediction, risk assessment and quantification, response assistance and management, and discovery and recovery programmes.

GIS provides the platform for undertaking the following spatial analyses which are peculiar to DPMO. These are:

- Temporal analysis of natural hazard parameters.
- Trend analysis of the occurrence of disasters.
- Spatial analysis of the impact of disaster over a geographic region.
- Three dimensional analysis of the effect of natural hazards.
- Multivariable risk analysis.
- Natural hazard prediction and modelling.
- Simulation of response rate to vulnerable communities.
- Cause-Effect analysis.
- Analysis of impact zones or anticipated degree of severity.
- Storm runoff prediction from urban watersheds.
- Site suitability screening for hazardous waste facilities.

Hamilton [14] provided justification and examples for the use of technology for hazard and risk assessment. A range of GIS applications for solving disaster management challenges has been investigated within the region. These include: hazard mapping and vulnerability assessment – Antigua and Barbuda [15], hazardous chemical transport – Barbados [16] and the development of a hazard emergency management information system – Trinidad and Tobago [17].

4. Regional Approach for a Technology-Driven DPMO

When one considers the resource management challenges of the Caribbean, the limited human and capital capacity, and the rapidly changing information technology environment, it is imperative that a coordinated and strategic approach be developed at a regional level to take full advantage of the opportunities provided by geoinformatics.

In a CIDA-sponsored contract report prepared in 1999 by the Oceans Institute of Canada, Halifax titled "A review of remote sensing methods suitable for coastal zone management in the Caribbean", the following opportunities and constraints beg for a regional approach [18]. It was concluded that integrated use of RSS/GIS provide the appropriate tools and techniques for mapping and monitoring the following natural resources in the Caribbean [18]:

- Vegetation and land cover mapping
- Land use change detection and environmental monitoring
- Wetland identification, characterization, and monitoring of moisture conditions
- Environmental monitoring of marine habitats
- Terrain analysis and bathymetry mapping
- Shoreline change detection
- Floodplain delineation

The report however, identified the following constraints to efficient and effective utilization of RSS/GIS in the region:

- Little resident experience in the use of RSS/GIS.
- Aerial photography remained the primary source of information at local and regional level.
- Reliance on visual analysis techniques.
- Little capacity or expertise to select, acquire, analyze, or integrate remote sensing data.
- Many institutions currently not in a position to take advantage of RSS/GIS developments because of three interrelated factors: lack of knowledge, technical capability, financial resources.
- Lack of current and high-resolution maps of the natural resources.

4.1 Benefits of a Regional Approach

Taking cue from this report and evidence of several failed national efforts, a new regional approach is needed. The approach requires the establishment of a Caribbean Centre for Remote Sensing and GIS Services [CCRS-GIS]. The following activities and benefits of a regional approach are beyond the capability of individual state members:

- The establishment of a single forum for the negotiation, evaluation, and acquisition of remote sensing imageries from extra regional agencies. This would facilitate accessibility through a regular and sustained data acquisition programme in support of DPMO and natural resources management programmes in the region.

- A training institute for the training on the processing and use of satellite imageries. The high cost of setting up and maintaining modern training institutions is prohibitive to most participating states. A regional institution would be able to attract leading international trainers and researchers for high quality capacity building in the Caribbean.

- A single one-stop processing centre for the distribution of Caribbean remote sensing products. Most member states cannot afford the cost of establishing and maintaining a data processing unit of their own. It is less costly to maintain a regional processing centre than multiple local units.

- Development of regional standards in the use and classification of DPMO data and phenomena. A Caribbean standard for the identification, quantification and qualification of natural resources is imperative in the global village.

- Development of an efficient data management programme**.** The high investment in data collection may go to waste if there is no consistent data management programme. A regional data management plan would include data sharing and data dissemination protocols and cost recovery strategies among member states.

The development of a regional centre is not a new idea. The United States National Mapping Division has five Regional Mapping Centres: Earth Resources Observation Systems Data Center (EROS Data Center**)**, Mapping Applications Center, Mid-Continent Mapping Center, Rocky Mountain Mapping Center and Western Mapping Center. Several of these facilities provide direct data and information access and retrieval services via the Internet to public and private enterprise. The Canada Centre for Remote Sensing plays a similar role for Canadian enterprises. The United Nations Economic Commission for Africa (UNECA) established four sub-continent centres in Africa as part of its earth resources services group to provide training and product development services for the continent.

5. Conclusion: Towards a Caribbean Centre for Geoinformatics Services

The development of a Caribbean regional capacity for natural and built resources mapping and monitoring requires a careful and well thought out plan considering the geo-political landscape of the region, the cost, the range of users and uses and more so, the need for sustainability. The idea is for the Caribbean Community (CARICOM) to initiate the establishment of a regional centre with responsibility for the acquisition, processing, training, and distribution of remote sensing imagery for member states. The centre could be located at one of the regional agencies such as UWI/DRRC, CDERA or the Caribbean Meteorological Institute. It is envisaged that apart from the initial funding, this centre should be able to sustain itself through sales of products and services to local, regional, and international clients. Seed funding could be obtained from environmentally concerned donor agencies.

If this concept is considered favourable there would be a need to set up a mechanism to examine and recommend appropriate implementation models and plans. CARICOM has a unique opportunity not only to take the lead but also to take ownership of the foregoing benefits for its member states. There should be national and regional level buy-in to the need for incorporation of geoinformatics technologies in DPMO.

References

[1] Bisek P.A., E. B. Jones and C. Ornstein (2001) '*A Strategy and Results Framework for Comprehensive Disaster Management in the Caribbean'* Developed under the Comprehensive Approach for Disaster Management in the Caribbean Project, CDERA, USAID and UNDP.

[2] Caribbean Development Bank (CDB) (1996). *Annual Report*

[3] ODPEM Situation Report (2001): Severe Weather Event October 29, 2001

[4] Townshend, J.R.G. (1981). Terrain Analysis and Remote Sensing. London: George Allen & Unwin Ltd.

[5] United Nations Educational, Scientific and Cultural Organization (UNESCO), (1999). *Applications of Satellite and Airborne Image Data to Coastal Management*. Coastal Region and Small Island papers 4. UNESCO: Paris.

[6] Jensen, J.R. (1996). Introductory digital image processing: a remote sensing perspective. New Jersey: Prentice-Hall.

[7] Caribbean Planning for Adaptation to Global Climate Change (CPACC), (2000). Training Workshop: Feature Extraction from IKONOS Satellite Imagery. Centre for GeoSpatial Studies: St. Augustine.

[8] Opadeyi J. (1992). *Concepts, design and applications of geographic information systems for water resource management*. In Proceedings of the Caribbean workshop on water resources

management and the environment. Trinidad. 1992.

[9] Dale P F and McLaughlin J D. (1988). Land information management. New York: Oxford University Press.

[10] Aronoff S. (1989). Geographic information systems: a management perspective. Canada: WDL Publications.

[11] Star J and Estes J. (1990). Geographic information systems: an introduction. New Jersey: Prentice Hall.

[12] Barrett, E.C., Brown, K.A., and Micallef, A. (Eds) (1991) Remote Sensing for Hazard Monitoring and Disaster Assessment: Marine and Coastal Applications in the Mediterranean Region. Gordon and Breach Science Publishers, Paris.

[13] OAS, (1991) *Primer on Natural Hazard Management in Integrated Regional Development Planning*. Organization of American States (OAS), Washington, D.C.

[14] Hamilton, R. M. (2000). Science and Technology for Natural Disaster Reduction. Natural Hazards Review 1(1): 56-60.

[15] Hodgkinson-Chin, E. & Rogers, C. (2001). *'GIS as a tool in the assessment of natural hazard vulnerability, Antigua and Barbuda',* in Proceedings of the URISA Caribbean GIS Conference September, 2001.

[16] Riley, E. (2001). '*Using GIS to determine best routes for transporting hazardous chemicals in Barbados',* in Proceedings of the URISA Caribbean GIS Conference September, 2001.

[17] Ali. S. (2001). *'The Design & Development of an Automated Hazard Emergency Management Systems',* in Proceedings of the URISA Caribbean GIS Conference September, 2001

[18] Oceans Institute of Canada, (1999). *A review of remote sensing methods suitable for coastal zone management in the Caribbean*. CIDA sponsored report NRCan-98-0685/File No. 23413-9-D003.

[19] Federal Emergency Agency (1997), "HAZUS: Standard Risk Assessment (Loss Estimation) Methodology" *Multi Hazard Identification and Risk Assessment: A Cornerstone of the National Mitigation Strategy.*

[20] Federal Emergency Agency (2004), HAZUS-MH *Risk Assessment and other Group Series: Using HAZUS-MH for Risk Assessment.*

[21] United Nations International Strategy for Disaster Reduction (2004), Risk Assessment; *Chapter 2 section 3, pp 62-7.*

[22] GPS World (2005). "U.S. issues GNSS statements with Japan, Russia". FindArticles.com. Website: http://findarticles.com/p/articles/mi_m0BPW/is_1_16/ai_n9486389. Accessed: 2008-05-19

[23] Thorsten L., J. Winkel, M. Bodenbach, E. Gohler, N. Falk, A. Consoli, F. Piazza, D. Gerna, R. Granger, P. Readman, S. Simpson, H. Euler (2008), "The Art of ARTUS - *A Second-Generation Galileo/ GPS Receiver Website: http://www.insidegnss.com/auto/spring08-037-045.pdf Accessed:* 2005-05-19

[24] Caribbean Disaster Emergency Response Agency, USAID, UNDP (2001), "Comprehensive Approach For Disaster Management In The Caribbean Project: A Strategy And Results Framework for Comprehensive Disaster Management In The Caribbean"

[25] Lewis and Edwards (2004), "GIS in Emergency Management: Office of Disaster Preparedness and Emergency Management, Jamaica": *Proceedings of the Caribbean GIS Conference 2004.*

[26] Gamba, P., F. Dell'Acqua, G. Trianni (2007), "GIS and Remote Sensing for Disaster Assessment in Urban Areas" *Urban Remote Sensing Joint Event*, Paris [1-5].