Lessons Learned from Application of GIS and Remotely Sensed Imagery in the Deepwater Horizon Oil Spill Disaster Response

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Introduction

On April 20, 2010, the Deepwater Horizon oil rig leased to British Petroleum (BP) exploded in the Gulf of Mexico releasing an estimated 5000 barrels of oil daily based on National Oceanographic and Atmospheric Administration (NOAA) estimates. The Deepwater Horizon drilling platform is located approximately 50 miles southeast of the Mississippi River Delta. NOAA estimated that 700,000 gallons of #2 fuel oil or marine diesel fuel were spilled in the Gulf of Mexico. A very large oil slick reached the Louisiana shore near the Chandeleur Islands and affected miles of Louisiana coastline as well as the coasts of Mississippi and western Florida. While BP had been engaging in efforts to contain the spill, its excessive depth at nearly 5000 feet underwater made containment difficult. BP also engaged in surface methods of containment including the use of booms, chemical oil dispersants, and work with local shrimpers to visually monitor the spills extent.

A massive response from federal, state, and local officials followed to monitor the myriad environmental, economic, and social impacts of the spill. In order to assist in the environmental mitigation efforts, the Deepwater Horizon Incident Command Center in Houma, LA, near New Orleans, was put into place to help coordinate response efforts. The command center was a focal point of collaboration on response as well as GIS mapping efforts. This study reports on interviews held with agencies involved in the response with particular focus on how the use of geographic information systems (GIS) and remotely sensed imagery aided in response efforts by BP and federal, state, and local government agencies.

Prior Work

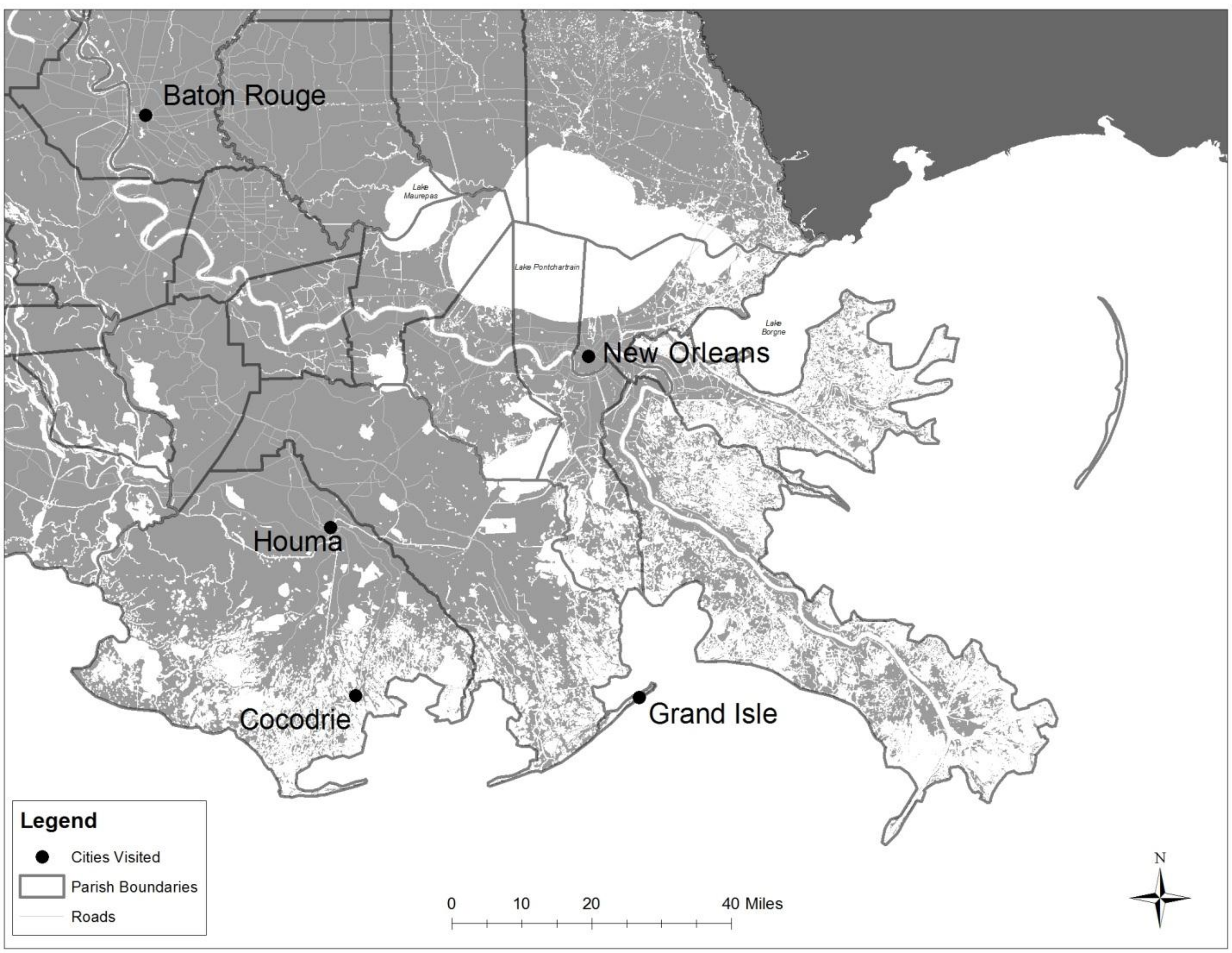
GIS technology is used in oil spill disasters primarily for monitoring the extent of the plume and for providing data to responders. For example, Ivanov *et al.* (2008) report using GIS may increase the ability to map areas with highest exposure to oil spill pollution and enhance spill mitigation efforts. Prior research has also suggested web-based GIS dissemination tools provide an effective means of exchanging information on the environmental impacts of oil spills as well as mitigation for future spills. Ambjorn (2007) describe a webGIS named Seatrack that enables users to access weather and ocean conditions as well as conduct drift simulations in the context of mitigating oil spills. Tuama and Hamre (2007) report on the DISPRO webGIS that was successfully designed for quick integration of spill data into a GIS for use in oil spill monitoring. Kulawiak *et al.* (2010) discuss the successful integration of the modeling program MARCOAST with ESRI’s webGIS application for use in visualization and simulation of extent of marine pollutants. These prior studies suggest webGIS applications can be developed with user interfaces that enable a variety of users to make use of spatial data for oil spill mitigation and emergency response efforts.

Similarly to previous work (Pine 1993, Pine 2008), the aim of this study is to provide another insightful case study on how GIS response can be best organized to coordinate effective data sharing amongst federal, state, and local responders to large scale disasters such as immense oil spills. Findings from this research build upon previous studies of how the use of GIS and web-based technologies may be best coordinated in the context of large scale environmental disasters such as very large oil spills (Pine 2006a, Pine 2006b). In particular, this study examines how geographic information technologies, including desktop and webGIS, and remote sensing data sources are used in disaster response to coastal areas using research goals and methods found in Mills *et al.* 2008, Curtis *et al.* 2006a, and Curtis *et al.* 2006b.

Research Methods

This study used the qualitative methods of observations and face-to-face interviews at the study sites in Houma and New Orleans (Creswell 2009). Since this data relied upon behavioral observation at the study sites as well as interviews, observations were likely affected to some degree by our obvious presence. As Montello and Sutton (2006) warn, full disclosure of activities and uses of data was unlikely to have been elicited from one visit to the study sites,

Figure 1. Response Agency Interview and Field Visit Sites in Louisiana.



Source: Author

Table 1. Largest Oil Spills in Oceans.

Incident	*Millions of Gallons*	*Location*	*Date Began*	*Source of Spill*
Gulf War	160-420	Persian Gulf	1/21/91	Tankers, Terminals
Deepwater Horizon	172	Gulf of Mexico	4/20/10	Platform
Ixtoc 1 Oil Well	138	Gulf of Mexico	6/3/79	Platform
Atlantic Empress-Aegean Captain	90	Trinidad and Tobago	7/19/79	Tanker
Nowruz Platform	80	Persian Gulf	2/4/83	Platform
ABT Summer	80	Angola	5/28/91	Tanker

Source: Farzaneh 2010

particularly at the BP Incident Command Center where the investigators were entering into a site with many GIS and emergency response professionals working under high stress conditions. However, the focus of this study was on how geographic information technologies were used in the response efforts and less so on the performance of individual emergency responders and managers. The study methodology was also informed by Yin's (2003) scientific approach to assessing if hypotheses are true for case studies through gathering and analysis of evidence. In this case, the two major hypotheses examined were: 1) GIS and remotely sensed imagery data significantly aided in the response and clean-up; and 2) GIS and remotely sensed data were shared among the participating agencies effectively to meet the information needs of the response team.

Interviews and field visits were conducted as part of this examination of how GIS and remotely sensed data are being used in the response to the environmental and socioeconomic impacts of the spill. The main research questions to be addressed through the interviews and site visits were: 1) what kinds of GIS data were being used to assist in the emergency response of this major environmental disaster, 2) how effectively had GIS data been exchanged amongst groups (federal, state, local, commercial) working on the response effort, and 3) what best practices can be developed for oil spills based on lessons learned from the quick response to this disaster. Interviews were held at two locations, the Incident Command Center located in downtown New

Orleans and the BP Operations Command Center in Houma, LA and field visits to oil affected sites in Cocodrie and Grand Isle, LA (see Figure 1).
The specific methods used in this rapid response research included site observations and interviews with GIS personnel and government administrators at the two major response sites in Houma and New Orleans. In addition, other government agents involved in the response were interviewed about the use of GIS to aid the response. Experts from the State of Louisiana emergency response and environmental agencies were also interviewed about the GIS needs in order to determine how well the GIS group is doing at the incident command center. In addition, similar to methods used in previous work (Jensen 2008), text analysis was performed on media coverage of the event with specific focus on GIS analysis, mapping, and data collection needs across the impact area of Louisiana, Mississippi, and Florida.

Results

Partner Agencies and Access to Remotely Sensed Data

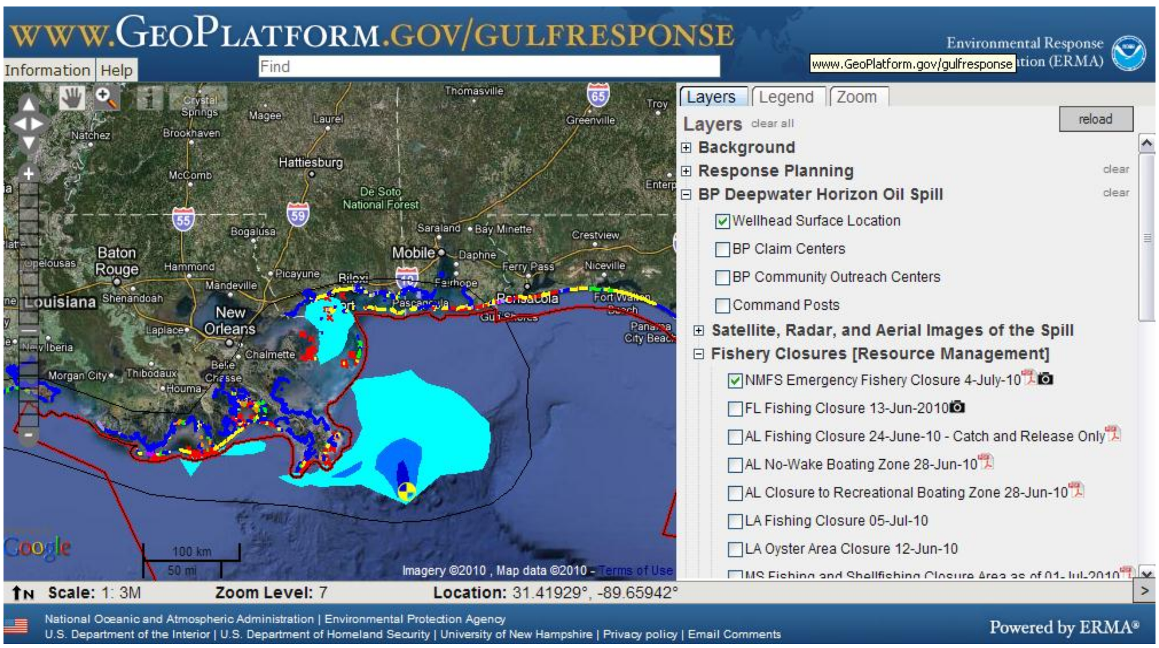
The Deepwater Horizon Incident has been compared to 1979's Ixtoc blowout in Mexico's Bay of Campeche as well as the Exxon Valdez spill of 1989 in terms of magnitude and is widely considered to be one of the worst oil spill disasters of all time (see Table 1). The Deepwater Horizon incident was declared a 'Spill of National Significance' by Department of Homeland Security Director Janet Napolitano as defined in DHS's (2008) National Response Framework and managed by the US Coast Guard. After the declaration, the USGS began receiving daily remotely sensed data from international partners who can provide remotely sensed data. The ensuing activation of the International Charter brought remotely sensed data to federal, state and local responders through a common Internet site. Under the International Charter, response agencies can use the data in response operations at no cost. Users of the remotely sensed data must comply with a set of requirements such as acknowledging the source of the data in maps or images that are released by agencies during the response. In addition, response agencies also received remotely sensed data from the US National Geospatial-Intelligence Agency (NGA) including IKONOS, Quickbird, Worldview, GeoEye, and CosmosSkymed imagery.

Two Internet sites have been established to distribute remotely sensed data including a secure site to the above data that is limited to public agencies engaged directly in support of the oil spill response. The secure site was arranged by data providers and by date of data acquisition. A second Internet site was established for public users who wanted access to mapped information about the spill. This site is a public one and is arranged by data providers such as NASA, NOAA, US Army Corp of Engineers, and USGS. The public site includes remotely sensed data such as AVIRIS, LANDSAT, MODIS, MERIS, and NESDIS data. Agencies such as NOAA, NASA, and USACE have been called on to fly photo missions along the coast in support of the spill response.

The Gulf Response GeoPlatform

NOAA (2012a) has developed the Internet mapping resource Environmental Response Management Application (ERMA) (Figure 2). This Google-based Internet mapping program was developed by staff from NOAA's Emergency Response Division within the Office of Response and Restoration and the University of New Hampshire's Coastal Response Research Center. The Internet mapping program allows public access to many layers used by public, private and non-profit organizations engaged in the oil spill response and restoration. Over 300 data layers were available to the public through the ERMA site. Many of the layers were generated by agencies involved in the response including fisheries closures, shoreline cleanup and assessment team (SCAT) results, navigation caution areas for mariners, data buoys, tides, water levels wildlife areas including refuges, management areas, marine protected areas or sanctuaries, shellfish habitats, restoration projects. In addition, federal and state agencies have provided NOAA with critical information for the Gulf of Mexico including navigational fairways and nautical charts, bathymetry contours, high resolution historical coastal imagery and LIDAR data.

Figure 2. Gulf Response GeoPlatform through NOAA's (2012) ERMA.



Source: NOAA

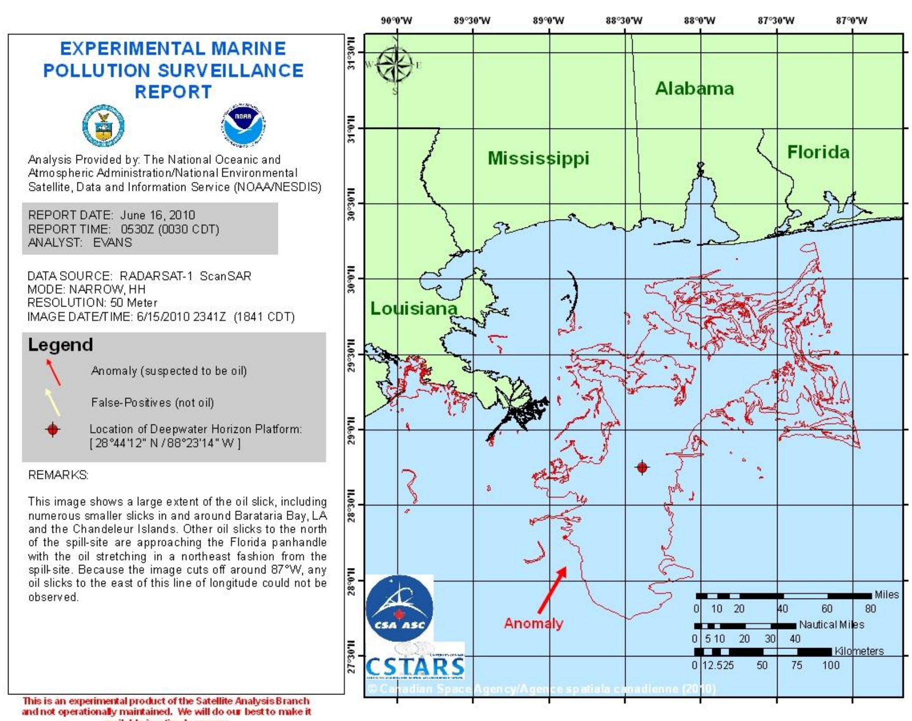
In addition to the layers developed during the response and provided by public agencies, users may open MODIS satellite images for specific dates following the spill, shoreline over flight imagery, buoy information, current wind, wave, NEXRAD radar, HF radar and NWS warnings. Response information provided on this site also include oil spill trajectories (near and off shore), satellite interpretations for potential oil foot print, fisheries closures, predicted environmental conditions (wind, wave and precipitation), navigational caution areas for mariners, and Environmental Sensitivity Index data for Texas, Louisiana, Mississippi, Alabama, and Florida. Government agency field studies that included field photos and reports on the impacts on wildlife were also included.

The ERMA mapping utility, which comes in both a public access and responder versions, provides responders with critical information that can be accessed and used to support many different response needs. Since map layers can be edited and controlled by either a response command center or a NOAA program office, the information can be kept up to date as often as new information becomes available. This Internet based mapping utility and geo-spatial library is a significant development over past attempts to obtain, store and distribute data. As part of the Hurricane Katrina response, FEMA supported the development of the Katrina and Rita Geospatial Data Clearinghouse (Mills *et al.* 2008; Curtis *et al.* 2006). The site was developed at Louisiana State University in support of the hurricane response in the Gulf of Mexico. ERMA has successfully addressed data access and distribution issues that first surfaced in the response to Hurricanes Katrina and Rita in 2005. ERMA provides access to critical geospatial data in a common format, along with metadata on the information in the site and in a timely basis.

Use of GIS and Remotely Sensed Imagery for Responders

The Incident Command Center in New Orleans is directed by the U.S. Coast Guard and provides strategic direction for federal agencies engaged in the oil spill response. Discussions with staff of NOAA's Emergency Response Division within the Office of Response and Restoration indicate many federal agencies and international partners supported the response from their regular duty stations throughout the U.S. Staff could access and use high-resolution as well as infrared MODIS images of the Gulf of Mexico for identifying current impacted areas and the projected flow of the oil along the Gulf of Mexico. Images of the Gulf of Mexico on June 19, 2010 were some of the most useful scenes since there was minimal cloud coverage in the Gulf. For example, Figure 3 is a map produced with GIS that is based on information gathered from a 50 meter resolution image taken June 15, 2010 and provided by the Canadian Space Agency

Figure 3. Characterization of the Oil Spill using RADARSAT-1 Scan Synthetic Aperture Radar



Source: NOAA (2010)

(CSTARS). The display of the extent of the spill's plume was provided by NOAA's National Environmental Satellite, Data and Information Service (NESDIS).

The National Geospatial-Intelligence Agency (NGA) used remotely sensed images to estimate boundaries for the extent of the oil spill's plume in the Gulf. When cloud conditions would not permit assessment of oil conditions along the Gulf, satellite radar data was useful in clarifying impacted areas with significant oil accumulation. Radarsat had been noted as a valuable resource for identifying oil spills in the Gulf of Mexico following Hurricane Katrina in 2005 (Pine 2006). However, remotely sensed imagery is often not effective in areas with a low density of oil accumulation.

In an interview with GIS staff of the Command Center in New Orleans, the need for a broad network of remotely sensed university labs to assist in image analysis and classification was also acknowledged. Federal agency GIS staff could coordinate the development of key data for the Command Center through conference calls or video-conferences and then work on the requested data from their normal offices. Display of the data developed for the Command Center could then be made available by way of ERMA or the responder secure Internet mapping program. Respondents also noted that the development of ERMA had grown out of both the emergency response to the Haiti earthquake and an inter-agency response drill in March of 2010.

The response to ERMA, both the secure site used by the responders and the public site, by senior response agency personnel was extremely positive. Briefings included the use of the ERMA in displaying data layers on current conditions relating to the spill. The display of different data layers using ERMA was provided in a timely manner and supported both policy and operational decisions. Emergency responders have for many years asked for timely information to deal with problems as they arise. The ERMA applications appear to be a major positive step in providing timely information for decision making.

Federal and state agency field staff operated at the BP Operations Center in Houma, LA site. Data obtained by the USGS from International Charter members was limited in its use and only available to public sector responders directly engaged in oil spill response activities. As a result, BP mapping staff did not have the extensive image library available for their use in the Houma Operations Center. BP staff did have access to the secure Internet mapping service at the Coast Guard – NOAA Incident Command Center in New Orleans. As a result, BP determined to monitor the spill in the Gulf by acquiring daily images of impacted areas. Images obtained by BP were used exclusively within the BP GIS system and not assessable by NOAA staff in New Orleans or at other locations.

In preparation of the BP GIS, extensive data sets from the Louisiana Oil Spill Coordinator's Office (LOSCO) were made available. These data sets can be obtained from LOSCO (2012) and provide an extensive base line for the potential impacts of the spill in coastal areas and included both high resolution images, LIDAR, and location information from boat launches to response resources. These data sets formed the foundation of BP's web GIS application created using ESRI's ArcServer application. This web mapping application also contained georeferenced aerial photographs of the plume's extent as well as the position and conditions of the booms used. In addition, data was collected in the field using mobile devices and uploaded directly to the spatial database.

It was noted by several GIS professionals that ESRI had donated technology and professional expertise in rapidly developing a GIS for use in the response (ESRI 2010a). GIS consultants had formed the core of the spatial database development team and ran work crews working very long hours to create the GIS for the Gulf Region within a time span of a few weeks. ESRI has also been hosting a web mapping application to serve information to the public through their ArcServer application found online (ESRI 2010b). The State of Louisiana Governor's Office of Homeland Security and Emergency Preparedness also had an effective means of disseminating information to the public using GoogleEarth's keyhole markup language (KML) files of the plume extent and trajectory found on its website (GOHSEP 2012).

Lessons Learned

Despite the challenges presented to responders by the oil spill that has continued beyond two months, GIS and remotely sensed imagery has been a great asset to both policy makers and those involved in response operations. The Internet mapping program ERMA developed by NOAA's Emergency Response Division has proven to be a valuable resource throughout the response. NOAA should be commended for this effective contribution to the response. Both the secure and public Internet mapping resources provided by NOAA are a great improvement over previous geospatial libraries and data clearinghouses in the use of technology for viewing and using the vast GIS data sets. Users of the Google mapping utility are able to select from many data layers and display data in a useful format. The program has been found to be easy to use by both policy makers and operations personnel. It is likely that similar Internet mapping technologies will be developed and deployed in future large scale disaster response.

Use of common data sets by the public and private sectors was found to be limited. Much of the remotely sensed data available to responders has significant limitations imposed by the data provider. However, some providers simply require the user give credit to the provider in images prepared in a GIS. Other data sets are limited to public sector responders and may not be accessed by private parties engaged in the response. The private sector may obtain the images, however, at a cost. Public agencies and BP contractors engaged in data collection in the Gulf Coast are using the best available global positioning systems (GPS) technology to record not only site locations, but environmental attribute characteristics. It is unclear as to the degree of data sharing by public and private parties engaged in the assessment process, but parties are at least discussing the value of data sharing.

The volume of GIS data from many sources is extensive and presents challenges to the public and private sectors for cataloging and distributing the data. Following Hurricane Katrina in 2005, public agencies identified many problems associated with using GIS and remotely sensed imagery in the response. Issues such as common formats, documentation of data sets, and access issues were examined and strategies to address them implemented. Distribution of GIS and remotely sensed data in the Oil Spill response certainly reflects the productive efforts of many organizations in addressing these issues. Support from multiple federal agencies has been extensive. For example, the USGS and Fish and Wildlife provided baseline data for the Gulf of

Mexico in anticipation of helping to understand the potential impacts of the spill in the coastal environment. The EPA's air and coastal wetlands water monitoring has been extensive. Once the spill was stopped, these agencies were able to work with NOAA and the Coast Guard on response and restoration strategies for heavily impacted wetland environments

The Deepwater Horizon Incident is very different from past natural disasters. Having the Coast Guard as the lead federal agency is not as unusual as is operating without a federal disaster declaration. The role of BP in developing and implementing a response strategy is so very different from past disasters where agencies operate under a federal disaster declaration. Federal agencies and assets have been called in as part of the response, but state and especially university resources were not as fully engaged as they could have been. States and their universities have been reluctant to engage in the spill response without being tasked by BP and to say the least, BP's attention span or focus is stretched.

Due to the nature of the oil spill and unique role of BP in the cleanup and restoration, local governments appear to be observers rather than key players in the disaster response. Louisiana along with some local government units has initiated efforts to protect the coastline or barrier islands. As a result, both state and local agencies have a need to be included in problem solving, the development of operational strategies and policy determination. Unfortunately, the current structure of the oil spill response does may not fully engage these governmental units in the response. Access to current GIS and remotely sensed data is critical in supporting state and local entities participating in the response. BP and the federal Incident Command Center may need to encourage input by state and local jurisdictions. Providing these agencies access to information concerning the oil spill will be a critical part of this engagement process.

Conclusions

Results from the evidence gathered by this study indicate that the answers to the two main research questions are that: 1) GIS and remotely sensed data played a key role in the monitoring of the spill and to a lesser degree the clean-up, and 2) GIS and remotely sensed imagery were effectively shared amongst BP's data specialists and federal and state government agencies to aid in the response. Yet, BP was able to quickly develop a GIS database and use GIS and remotely sensed data to manage the response in an exceptionally quick time period largely through the efforts of GIS consultants working extended emergency response hours. The oil spill response may have been more effective and efficient if BP had a GIS and imagery database and team prior to the event as many large oil corporations do.

Now that the immediate need for clean-up has passed, the long-term monitoring of the environmental impacts of the spill will fall to state and federal agencies. This change is also evident in the replacement of the original official website of the response, The Official Deepwater Horizon Response site, with the current Restore the Gulf (2012) site. The response to this incident has been relatively unique in the sense that a corporation has primarily lead the way in response and clean-up and it remains to be seen how the GIS and imagery collected for response can be effectively harnessed for long-term monitoring.

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