Background

Coastal sensitivity to sea level rise has become a major issue in Canada and a nation wide overview published by the Geological Survey of Canada in 1998 demonstrates that there are low, moderate, and high sensitivity regions. Some of the most severely threatened coastal areas in Canada are parts of the Atlantic coast, including most sections of southeastern New Brunswick.

Impacts of sea level rise vary from location to location and lead to many physical changes to the coastal environment. These changes, in turn, affect human uses such as settlement, tourism, fishing, agriculture, as well as wildlife uses of the coast. The most serious physical impacts of sea level rise on coastal zones are inundation and displacement of wetlands and lowlands; coastal erosion; increased vulnerability to coastal storm damage and flooding; and salinization of surface water and ground water. Accelerated sea level rise due to global warming can intensify these coastal impacts that already occur in these sensitive region.

LIDAR is the acronym for Laser Imaging and Distance Ranging. A LIDAR sensor emits a series of laser pulses and records the time difference between the light to the surface feature and return to the sensor after reflection by knowing the position of the aircraft from DGPS and orientation from an IMU (Christian and MacKinnon, 2000).

High resolution LIDAR technology can be used to produce accurate representations of the topography, with vertical accuracy of 15 to 100 cm (Hill, 2000). Although, this technology has been around for nearly fifty years (Fowler, 2003), and used in a variety of applications such as measuring atmospheric water vapors (Sapeta, 2000), it has only developed into a valuable Geomatics tool over the past few years.

A Digital Elevation Model is a representation or a visual description of the general land surface. There are many uses for digital elevation models including floodplain mapping, natural resource management, coastal zone mapping and many more applications. Traditional DEMs are typically derived from photogrammetry, and do not have the vertical accuracy or resolution suitable for floodplain mapping. The first step in flood modeling is to develop this type of surface. Floods must be simulated on a surface that best represents the actual ground elevation.

LIDAR altimetry data involves an aircraft with a high tech sensor that emits rapid laser pulses of near-infrared light in a swath towards the earth's surface and measuring the time it takes for the reflected pulses to return the sensor. The aircraft uses a high precision Global Position System (GPS) and an Inertial Measurement Unit (IMU) to determine the location and measure the attitude so that the ground location of the return pulse can be determined. The LIDAR sensor produces a series of point measurements that consists of geographic location and height of both natural and man-made features, and can be processed to produce several different products and can be integrated into a Geographic Information System (GIS).

LIDAR data for this project was collected by Terra Remote Sensing during the spring of 2003 and will conclude during the fall of 2003, as part of the Canada Climate Change Action Fund (CCAF) proposal # A591 requirements. The study area for this project is located on the Gulf Shore of New Brunswick from Kouchibouguac National Park south to Cape Jourimain consisting of ten different polygons. The resultant LIDAR data consists of files representing ground hits, and non-ground hits, both with a sixty centimeter spacing. The data was in the form of ASCII text files, all hits, non-ground and ground hits. The data will need to be imported and processed with GIS and image processing software to generate the accurate DEM products. The high accuracy and high data point density achieved by LIDAR has improved the accuracy of flood hazard mapping (Christian, 2001).

Coastal geomorphology deals with the evolution of coastal landforms (such as cliffs, rocky shores, beaches, dunes, estuaries, lagoons and deltas), the processes at work on them and the changes taking place (Bird, 2000). The New Brunswick coast is a low lying zone of irregular width, including the near shore (e.g. beach) and extending to the landward limit of penetration of marine influence (e.g. marsh). Winds, waves, currents and tides all influence the shape of the coast and the processes that mould them.

Literature Review

Although LIDAR is relatively new to the GIS world, I found that there is quite an abundance of reference material available to aid in this research project. For this review, 38 publications were chosen, including 20 journal / magazine articles, 2 books, and 16 other resources. The search for literature is still ongoing as this project progresses.

The Internet was the main source of literature but the library system was also a great source, especially the NOVANET option. I started of by searching for LIDAR, then for Sea Level Rise, Climate Change and then for combinations of the two.

Searching on the internet provided thousands of search results which had to be refined to limit the results. For example, google.ca will provide you with more then 470000 results when searching for LIDAR, and over a million sites related to sea level rise. A better approach was needed to narrow down the results, so I chose to mainly use certain databases more relevant to GIS topics such as ESRI.com, spatialnews.com, EOM, PROQUEST data base, and the NSCC Library web site.

Searching for LIDAR with the PROQUEST data research database provided about 225 articles related to LIDAR, 350 related to Sea Level Rise, and there were no results for the combination of the two, although after reading through some of the sources it was evident that several papers dealt with both topics. The quality of the literature seemed to be scientific and professional and mostly came from Governments or well known Geomatics sources.

Findings

Sea Level Rise

The Canadian coastline is one of the largest in the world and predicting where the shoreline will evolve by the year 2020 with accelerated sea level rise is difficult and depends on whether or not human intervention occurs (Shaw et al 1998). An attempt to achieve a rational view of the coast can be done by using an objective method to predict which Canadian coasts are most sensitive to sea level rise.

Sea level rise trends past, present and future were examined based on geological radiocarbon dating and recent changes from tidal records. From this study, Shaw and others have determined that in the past, sea level rise has been the rule rather then the exception. They argue that acceptance of the dynamic nature of the coast may be the first step in arriving at a conceptual framework of dealing with future changes.

A dimensionless index of sensitivity was determined for all our Canadian coasts in order to prioritize future impacts of sea level rise. Coastal sensitivity is based on susceptibility to physical changes, impacts of changes on socioeconomic and ecological systems and the capability of a region to manage or alleviate impacts (Shaw et al 1998). Some of the most sensitive regions in Canada include the majority of the Maritimes, areas in British Columbia and the Beaufort Sea Coast. Shaw and others discuss the impacts of sea level rise in four high sensitivity regions of Canada and argue that the societal responses to changes in sea level should favor retreat and accommodation strategies.

The Canadian government has funded a number of studies over the past few decades to investigate the potential impacts of an increase in mean sea level. The effects of a one meter rise in mean sea level for Charlottetown, Prince Edward Island was studied in 1984 by P.Lane and Associates Limited and another for Saint John, New Brunswick was studied in 1987 by Martec Limited. Although these two areas are geographically different, (Saint John: along a river and the Bay of Fundy vs Charlottetown: harbor on the Northumberland Strait) the results seem to be identical. An increase in coastal storm surges and extensive flooding to property and local habitat can lead to tremendous damage. These two studies perhaps led to further research and apply to this CCAF project as well.

Public education programs and long term planning are essential for managing the changes that a rise in sea level will have (Martec Ltd. 1987). There are no easy solutions to the problems that would be created. Formulation of futuristic policy and development guidelines, creation of public education programs, reconstruction of infrastructure and construction of protective mechanisms and selected research studies are all required (P. Lane and Associates, 1984).

Further research is required to determine more exactly the sea level trends and their effects on shoreline processes, flooding and groundwater / saltwater interactions. This analysis would be vital in order to produce guidelines for cost-effective development of the Municipality of Charlottetown (P. Lane and Associates, 1984). Moreover, because the science of climate change continues to evolve, the portions of the older reports that explain how much the sea will rise are somewhat obsolete, but even some older reports discuss issues that have not been analyzed enough. It seems that the concept is not a new one and that the studies continue.

The existing literature about sea level rise seems to all indicate three conclusions:

- The potential effects of climate change in the coastal zones will be considerable.
- Future risk communication, land use, development and coastal management measures can greatly reduce potential damages.
- The ongoing and complex nature of the effects will continue to make predicting the impacts highly uncertain.

Increasing concentrations of atmospheric carbon dioxide and other gases are expected to cause a global warming that could raise the sea several feet in the next century (Barth, 1984). The effects of greenhouse gases accelerate the natural rate of sea level rise, thus it is important to understand more about this issue. Global warming due to excess greenhouse gases heats up the earth's oceans that in turn melts the ice sheets and increases the volume of water. One of the direct results of global warming is an increase in sea level. This rise in sea level will have significant implications for coastal areas. A rise in sea level of even one meter during the next century could influence the outcomes of many decisions and thousands of square miles of land could be lost (Barth, 1984).

Although from greater education we can limit the amounts of pollutants that cause global warming, it is not preventable, thus we must understand the consequences. Regulatory action that would effectively limit carbon dioxide concentrations is unlikely (Barth, 1984). Although "Greenhouse Effect and Sea Level Rise – A Challenge for this Generation" refers to case studies from the United States, the principles and ideas of this book are closely related to this project. The fact that this resource was written almost two decades ago demonstrates that sea level rise is not a new problem, and will not go away.

Increasing concentrations of greenhouse gases in our atmosphere are believed to be changing our climate in unprecedented ways. Even with the intended reductions of the Kyoto Protocol, greenhouse gas concentrations will continue to rise and our climate will continue to change over the next century (McKenzie and Parlee, 2003). McKenzie and Parlee, cover the same basic theme as the one above and shows that we are still dealing with the same issues that we did twenty years ago.

The change in seal level will occur due to the thermal expansion of seawater and the melting of mountain glaciers and the polar ice caps. Global sea level has been rising since the last ice age and is expected to rise more significantly over the next century. This increase is a global estimate and sea level increases on a more regional scale will depend on a variety of factors such as the local coastline variations, changes to currents, vertical land movements, and differences in tidal patterns (McKenzie and Parlee 2003).

LIDAR and Better DEMS

Improvements in technology of Global Positioning Systems (GPS) and Inertial Measurement Units (IMU) have allowed the LIDAR industry to progress to where it currently is today. For many years lasers have been used for a variety of applications such as to measure distances between fixed points on the earth's surface. Properly designed lasers and highly accurate timing systems can result in centimeter accuracy. However, today's LIDAR applications involve mounting lasers in moving platforms. To be effective, users also must accurately know the absolute position and orientation of the laser scanning device at all times (Turner 2000). The absolute known orientation of the LIDAR sensor is important in order to process its return pulse correctly. Most systems also contain a visual component, linked to the sensor, recording images in time with the timing pulses so that the user can determine features within the LIDAR data.

Most LIDAR sensors have a scanning mirror to generate a swath of laser pulses. Ranges are determined by measuring the amount of time, a pulse takes to travel from the sensor to the ground and back to the sensor unit. A unit's precise position and attitude, instantaneous mirror angle and the collected ranges are used to calculate 3-D positions of terrain points. As many as 10,000 “positions or mass points” can be captured every second (Sapeta 2000).

New LIDAR systems can produce remarkable digital elevation model (DEM) data and are an important source of elevation information. The high density of returns provides the possibility to create rapidly and efficiently high-resolution DEM models (Turner 2000). LIDAR is also well suited for floodplain mapping, environmental analysis, urban, forestry and many other applications requiring accurate elevation data. Though LIDAR only accounts for 3-5% of all mapping applications, adoption and acceptance of the technology is clearly on the rise (Barnes, 2002).

> If a LIDAR system is sensing a forested area, for example, some pulses will reflect from leaves at the tops of the trees; some will penetrate further before reflecting from twigs, leaves or branches; and some pulses will reach and reflect from the ground. LIDAR systems have been developed to record as many as five returns from a single pulse. The "first return" represents the top of the tree canopy, while the "last return" may represent ground elevation. By interpreting such data, useful products can be produced. By evaluating "last return" data, a "bare-Earth" model can be created to represent ground elevation in the absence of vegetation (Turner 2000).

LIDAR is an appropriate complement to existing photogrammetry technologies, and it offers substantial benefits in terms of increased data collection efficiencies and accuracy levels. As LIDAR becomes more sophisticated and refined, uses for the technology will expand (Sapeta 2000).

The Prince Edward Island storm surge project in 2000 provided a new leading edge model for forecasting potential damage and flooding due to major storms. The goal of the study was to assess the physical and socio-economic impacts of climate change and sea level rise on the coast. The model developed by Environment Canada, along with an accurate DEM, can predict storm surges to within ten centimeters. Minister Goodale announced “When it comes to climate change, Canadians need accurate, up-to-date information. What we learned from this study will help us predict the local effects of climate change and plan responses well in advance.” This study was one of the first of its kind, and should serve as a basic template for our NB project.

AGRG past LIDAR Research

The applied Geomatics Research Group (AGRG) has invested thousands of dollars into the research applications of LIDAR over the past several years. Numerous different applications have been explored using the LIDAR data and the various products derived from it. Procedures, issues, results and recommendations are all discussed in several unpublished reports by both AGRG students and faculty. Thus I feel it would be hard to do a literature review relating to LIDAR without including all the past LIDAR research that has undergone at the AGRG.

Some of the many diverse past AGRG projects with LIDAR data have included various applications of the data such as wetland applications, environmental issues, urban applications, and storm surge flooding. All these papers are important to review because of the procedures and history involved with each. These papers should help to provide a solid start to this LIDAR project.

Validation for the accuracy of the LIDAR data is necessary to confirm that the data meets the quality specifications that have been provided to the vendors, and to ensure that the applications and products derived from the data would be of similar quality. Since the vertical accuracy of the LIDAR data for the AGRG must be within an average of 15cm of measured high precision GPS points, it is important to know the procedures involved with validating such data. Some previous LIDAR data flown for the AGRG have not met the required specifications, and thus had to be re-flown. Sangster (2001) has explored and documented procedures, used by the AGRG in his final report, to validate LIDAR data and its derived products.

LIDAR technology provides us with greatly improved digital elevation models (DEMs), as well as derived terrain / topographic data. The extreme accuracy and high data point density achieved by LIDAR has improved the accuracy of flood hazard mapping, which ultimately results in better flood hazard analysis (Christian 2001). This technology is increasingly becoming the alternative to the conventional methods of collecting and deriving DEMs. LIDAR data does not replace the work of the surveyor or photogrammetrist, but LIDAR is beneficial for information and accepted by clients as both economical and accurate (Spinney 2001).

The LIDAR data has a level of detail with vertical and horizontal accuracy sufficient for producing flood extents that are much more detailed than anything previously attempted in Charlottetown (Dickie, 2001). Flooding is a major issue when dealing with sea level rise, and is one of the requirements set out in the CCAF proposal, thus these previous procedures from AGRG students will play an important role in this project.

Several issues were experienced during the Charlottetown project. The derived DEM from the LIDAR data had several inaccuracies in representing vertical shoreline structures, and there was a calibration issue that resulted in the overall data being on average 0.9 meters too low (Webster 2003). Although these issues were resolved for this project, it is important to watch out for similar problems on the NBSLR project, and insure that there will be enough validation work completed.

LIDAR Data Integration

Many applications of geospatial data in coastal environments require knowledge of the near shore topography and bathymetry (Gesch & Wilson 2001). It is very rare to see both topographic and bathymetric data fused together as a seamless data model. They are often collected for different reasons and usually have different accuracy, projection, resolution and formats. Terrestrial elevation data values are referenced to mean sea level based on a geodetic datum, while bathymetry data is referenced to a chart datum, which a series of low tides from a given period of time. The U.S Geological Survey and the National Oceanic and Atmospheric Administration are on a joint trial demonstration project in Florida to try and resolve some of the major issues related to integrating these two different types of data. When available, LIDAR data was processed and merged into the model as a third source to help improve detail and accuracy.

To create a truly seamless DEM, the two data sets must be referenced to the same system, otherwise they will be disjoint (Sangster, 2001). There are many advantages to integrating topographic data and bathymetry data, thus this project discussed by Gesch & Wilson is currently being used as key baseline geospatial data sets for various studies throughout the United States. These methods would be beneficial to explore and apply to the NB SLR project.

LIDAR Limitations

Most LIDAR systems that are used for topographic mapping operate with lasers in the near-infrared portion of the spectrum. Some features such as water, new asphalt, and some roofs often absorb the laser signals. User input is important when processing the data to restore any problems such as these that may be associated with the data. Not all of the literature that I read believes that LIDAR is the greatest solution.

The current state of LIDAR technology does not provide adequate vertical precision and accuracy to replace the current method of conventional total station topographic surveying (Metz, 2000). This case was similar to the AGRG experience with Terra Remote Sensing in 2000, when the data did not meet specifications. LIDAR accuracy is usually based on the assumption that the sensor is properly calibrated as well as ideal surface terrain conditions.

Impacts & Adaptation

A recent major study in PEI has assessed the physical and socioeconomic impacts of climate change and accelerated rise in sea level. The coast of PEI was selected for this study part because it had been identified as one of the most sensitive area. The DEM for this study was derived by the AGRG using LIDAR data. Adaptations are actions taken in response to a projected or actual change in the climate or other change in the environment. The aim is to maximize positive effects and to minimize adverse impacts, thereby reducing vulnerability. Adaptation strategy needs to be adaptable and should be reassessed regularly.

Methods

The following is a brief framework for this project:

- collect ground validation field work
- get raw LIDAR data from Terra RS
- conduct basic quality control to ensure that data meets contract specifications
- process the raw LIDAR ASCII data into a DEM using ESRI software
- create 3D visualizations of the area
- get data for flood simulation models from CCAF partners
- create flooded maps
- create web-accessible GIS products (ArcIMS)

Conclusions

The complexity of the coastal zone means that we can only extrapolate change to a limited degree and must be aware of the potential for radical changes in the shape of the coast. Coastal areas are at risk and the Maritimes are among some of the most sensitive coastal areas in Canada.

Sea level rise and climate change are a global wide event and almost everybody will agree that sea level is rising and that global warming is accelerating the process, but by how much is often debated. Accelerated sea level rise will increase the coastal reorganization that already occurs in our region. People are aware there is a problem, now education and solutions need to be developed.

Accurate DEM representations are needed to properly model flooding scenarios and the results of sea level rise. LIDAR data can produce the accurate elevation data that is required for this and other coastal related problems. The literature that I have covered and the others that I am still evaluating seem to demonstrate that the requirements for this project (as outlined in the CCAF proposal #A591) are reachable goals. I do not see any real obstacles that would result in not producing the desired deliverables.

Further Research

After completing a thorough literature review for this project I found that there seemed to be a limited amount of resources that incorporated LIDAR, Sea Level Rise and Coastal Geomorphology, thus I wish to integrate all three of these subjects into this project. I feel that 3D modeling from the high resolution DEM created from the LIDAR data can provide a new insight into typical Coastal Geomorphology.

References

An Airborne Laser Topographic Mapping Study of Eastern Broward County, Florida with Applications to Hurricane Storm Surge Hazard. (n.d.) Retrieved September 19, 2003 from International Hurricane Research Center web site: http://www.ihc.fiu.edu/ihrc/research/broward/browardProject.html

Allen, J., & Birk, R. (2000, August). Flood Mapping Specifications: Technology-centric vs Application-centric. EOM: Earth Observation Magazine, 9(8). Retrieved September 18, 2003 from http://www.eomonline.com/Common/Archives/August00/birk.htm

Barnes, S. (2002). Mapping LIDAR's future. Geospatial Solutions, 12(3), 18.

Barth, B. C., & Titus, J. G. (1984). Greenhouse Effect and Sea Level Rise – A Challenge for this Generation. New York: Van Nostrand Reinhold Company.

Bird, E. (2000). Coastal Geomorphology An Introduction. Chichester: Wiley and Sons Limited.

Carter, W. E., & Shrestha, R. L. (2000). Airborne Laser Swath Mapping: Applications to Shoreline Mapping. Florida: University of Florida.

Chrstian, M. (2001). Storm surge floodplain delineation on a LiDAR DEM: A case study of coastal areas of Minas Basin, Kings County, NS. Lawrencetown, NS: Applied Geomatics Research Group, Centre of Geographic Sciences.

Chrstian, M. (2001). Urban applications and flood impact analysis with Lidar data – A case study of Bridgetown Municipality**.** Lawrencetown, NS: Applied Geomatics Research Group, Centre of Geographic Sciences.

Chrstian, M. and MacKinnon, F.(2001).LIDAR Data Processing. Lawrencetown, NS: Applied Geomatics Research Group, Centre of Geographic Sciences.

Dickie, S. (2001). Storm Surge Inundation Mapping for Charlottetown, Prince Edward Island: Analysing Flood Risk Using High-Resolution Imagery. Lawrencetown, NS: Applied Geomatics Research Group, Centre of Geographic Sciences.

Eiser, W. C., Eslinger, D. L., & Goss, H. (August, 2000). Beach Management Decision Support Using LIDAR. EOM: Earth Observation Magazine, 9(8). Retrieved September 18, 2003 from http://www.eomonline.com/Common/Archives/August00/goss.htm

Facts about Canada's coastline. (2002). Retrieved October 1, 2003 from GSC Atlantic web site: http://gsca.nrcan.gc.ca/coastweb/facts_e.php

Fowler, R. (March, 2002). The Lowdown on LIDAR. EOM: Earth Observation Magazine, 9(8). Retrieved September 18, 2003 from http://www.eomonline.com/Common/Archives/March00/fowler.htm

Gesch, D. and Wilson, R. (n.d.). Development of a Seamless Multisource Topographic / Bathymetric Elevation Model. Retrieved September 18, 2003 from http://gis.esri.com/library/userconf/proc01/professional/papers/pap480/p480.htm

Hill, J., Graham, L., Henry, R., Cotter, D., Ding, A., and Young, D. (2000). Wide-area topographic mapping and applications using airborne light detection and ranging (LIDAR) technology. Maryland:

Journal of the American Society for Photogrammetry and Remote Sensing, 66(8). Retrieved September 18, 2003 from
http://www.asprs.org/asprs/publications/pe&rs/2000journal/august/highlight.html

Kletzli, R., and Peterson, J. L. (1998). Inertial Measurement and LIDAR Meet Digital Ortho Photography: A Sensor Fusion Boon for GIS. Retrieved September 18, 2003 from
http://gis.esri.com/library/userconf/proc98/PROCEED/TO600/PAP597/P597.HTM

Lane, P., and Associates (1988). Preliminary study of the Possible Impacts of a One Metre Rise in Sea Level at Charlottetown, Prince Edward Island. Halifax: Climate Change Digest, Atmospheric Environment Service.

Lefsky, M., Cohen, W., Parker, G., Harding, D. (2002) LIDAR Remote Sensing for Ecosystem Studies. Washington: Bioscience, 52(1), 19-31.

MacKinnon, F. (2001). Wetland Application of LIDAR Data: Analysis of Vegetation and Heights in Wetlands. Lawrencetown, NS: Applied Geomatics Research Group, Centre of Geographic Sciences.

Martec Limited (1987). Effects of a One Metre Rise in Sea Level at Saint John, New Brunswick and the Lower Reaches of the Saint John River. Ottawa: Climate Change Digest, Atmospheric Environment Service.

Martin, J., Enrique, R., Kemp, G., Mashriqui, H., Day Jr., J. (2002) Landscape modeling of the Mississippi Delta. Washington: Bioscience, 52(4), 357-466.

McKenzie, K., and Parlee, K. (2003). The Road Ahead: Adapting to Climate Change in Atlantic Canada. Retrieved September 18, 2003 from http://www.elements.nb.ca/theme/climate03/cciarn/adapting.htm

Mietz, S., Davis, P., Kohl, K., Manone, M. (2002). An Evaluation of LIDAR Vertical Accuracy in Grand Canyon, Arizona. Retrieved September 14, 2003 from
http://gis.esri.com/library/userconf/proc02/pap0725/p0725.htm

Sangster, C. (2001). Validating LIDAR – Evaluating LIDAR accuracy using GPS**.** Lawrencetown, NS: Applied Geomatics Research Group, Centre of Geographic Sciences.

Sapeta, K. (2000). Have you seen the light? LIDAR technology is creating believers. Retrieved September 18, 2003 from http://www.geoplace.com/gw/2000/1000/1000lit.asp

Sea-Level Rise and Climate Change Impacts and Adaptation Needs on Prince Edward Island: Study Results. (2001). Retrieved September 19, 2003 from Environment Canada web site:
http://www.ns.ec.gc.ca/press/01-09-06c_back.html

Shaw, J. (2001). Impacts of Sea Level Rise on the Canadian Coast. Retrieved September 18, 2003 from
http://climatechange.nrcan.gc.ca/english/View.asp?x-22&oid=28

Shaw, J., Taylor, R., Solomon, S., Christian, H., and Forbes, D. (1998). Potential impacts of global sea-level rise on Canadian coasts. The Canadian Geographer, 42(4), 365-379.

Shaw, J., Taylor, R., Forbes, D., & Solomon, S. (2001). Sea level rise in Canada. Geological Survey of Canada, Bulletin 548 225-226.

Smith, B., R., (2002). Floodplain fliers: North Carolina's massive LIDAR project. Geospatial Solutions, 12(2), 28 – 34.

Spinney, J. (2001). Environmental Application of LIDAR Data: Exploring High-Resolution Watershed Delineation. Lawrencetown, NS: Applied Geomatics Research Group, Centre of Geographic Sciences.

Study leads to better understanding of Climate Change. (2001). Retrieved September 19, 2003 from Environment Canada web site: http://www.ns.ec.gc.ca/press/01-09-06c.html

Turner, A. (2001). Discover the Importance of LIDAR Technology. Retrieved September 18, 2003 from http://www.geoplace.com/gw/2001/0101/0101agf.asp

Turner, A. (2000). LIDAR provides better DEM data. Retrieved September 18, 2003 from http://www.geoplace.com/gw/2000/1100/1100agf.asp

Twilley, R.(2001). Global Warming & Sea-Level Rise in the Gulf Coast Region. Retrieved September 18, 2003 from http://www.ucsusa.org/gulf/gcsealevel.pdf

Webster, T., Dickie, S., O'Reilly, C., Forbes, D., Parkes, G., Poole, D., Quinn, R. (2003). Mapping Storm Surge Flood Risk: Using a LIDAR-Derived DEM. USA: Elevation – speacial reprint from Geospatial Solutions.

Webster, T., Dickie, S., O'Reilly, C., Forbes, Thompson, K., D., Parkes, G., (n.d.). Integration of Diverse Datasets and Knowledge to produce High Resolution Elevation Flood Risk Maps for Charlottetown, Prince Edward Island, Canada. Middleton, NS**.** Applied Geomatics Research Group.

Wildgen, J. (2002). LIDAR Imagery in Wet, Flat Places. Retrieved September 22, 2003 from http://gis.esri.com/library/userconf/proc02/pap0211/p0211.htm