A Critical Need for Water Level and Datum Information in the Northern Gulf of Mexico

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Abstract

Accurate water level information is essential for generating water level reducers for hydrographic survey soundings. The National Oceanic and Atmospheric Administration (NOAA)/National Ocean Service (NOS) operates and maintains the National Water Level Observation Network (NWLON). However, there are few NWLON stations operating within the northern Gulf of Mexico contributing to an identified gap in water level information. The tidal datums from the historical water level stations in Alabama, Mississippi, and eastern Louisiana are undermined by the enormous amount of land subsidence and resultant relative sea level rise that the area is experiencing. These datums are more than two decades old and there is a critical need for datum recoveries and updates. There are very few historical observations at all in western Louisiana. The Louisiana Spatial Reference Center funded through NOS will assist with collecting accurate land movement data that is currently another information gap for the area. Accurate geodetic information coupled with more water level information (from additional water level stations) is critical for any new hydrographic surveys in the Gulf. These survey data will assist with updating outdated nautical charts for navigation purposes as well as studies investigating increased oil spill risks from oil production and transportation infrastructure affected by coastal land loss and subsidence. Accurate water level and geodetic information will also be critical in identifying long-term sea level change as well as present shoreline and shoreline change. Hydrographic survey data will be essential for the development of new products and services, such as topographic/bathymetric and hydrodynamic modeling projects in collaboration with other agencies.

Introduction – Water Levels and Vertical Datums

The National Oceanic and Atmospheric Administration (NOAA)/National Ocean Service (NOS) operates and maintains the National Water Level Program (NWLP). The backbone of the NWLP is the National Water Level Observation Network (NWLON), which consists of 175 long-term, continuously operating water level stations throughout the United States and its island possessions and territories. Tidal datums (such as Chart Datum, which is Mean Lower Low Water (MLLW)), sea level variations and trends, and numerous high water analyses are computed from the data observations collected at NWLON and other shorter-term stations. The NOS is also responsible for providing the

[1] The authors would like to acknowledge the contributions of the following people: Howard Danley, Brian Greenawalt, Gilbert Mitchell, Capt. Nick Perugini, Joe Robinson, and Steve Soherr.

National Spatial Reference System (NSRS) throughout the U.S. In order to accomplish this, it coordinates a network of more than 600 Continuously Operating Reference Stations (CORS) that provide Global Positioning System (GPS) carrier phase and code range measurements in support of 3-dimensional positioning activities. Using GPS and leveling techniques, land elevations are related to geodetic datums, such as the North American Vertical Datum of 1988 (NAVD88). In order for tidal datums and other water level analyses to be meaningful, the land elevations (and their geodetic datums) must be understood.

There are many applications and uses of accurate water level information connected to known geodetic elevations. Some of these include assisting with and supporting hydrographic surveys for updating nautical charts, sea level rise assessments, restoration efforts, marine boundary and shoreline delineations, risk assessments, evacuation decision-making, emergency preparedness, and storm surge flood warnings. For most of these applications to be successful, it is also essential to obtain recent and accurate hydrography.

To highlight the critical needs for water level and vertical datum information within the scope of hydrography, this paper focuses on the State of Louisiana. The applications discussed for Louisiana can be expanded to other states within the Gulf of Mexico, as well as other coastal states. However, the needs in Louisiana are heightened. There are only two NWLON stations operating along the coast of Louisiana, at Grand Isle and SW Pass along the Mississippi River (Fig. 1). This deficiency is contributing to an obvious gap in water level information. The only station with a long-term sea level record is at Grand Isle where the sea level trend is estimated to be 9.85 mm/yr (http://co-ops.nos.noaa.gov/sltrends/sltrends.shtml). Figure 1 also shows a plot of the long-term variations in monthly and annual mean sea level trends for Grand Isle. However, the sea level trends in Louisiana and how they change geographically along the coast is not well understood. The historical water level information in Louisiana is, in most cases, more than two decades old, and few of those are from the western portion of the State. Aggravating matters is a similar scenario regarding geodetic information throughout the State. NOS declared in a recent “Report to Congress” (Dokka, 2003) that the State’s vertical reference system is obsolete.

Coastal Land Loss

Louisiana is suffering from huge amounts of coastal land loss, as much as 35 square miles per year, which is an equivalent of 2.55 acres per hour. Subsidence, induced by both natural and anthropogenic causes, is the main contributor to this land loss. Most of the subsidence is caused by the loading of the modern Mississippi River delta on the edge of the North American lithosphere. The accumulation of several hundred feet of sediments since the last ice age has pushed the southern edge of Northern America downward causing the Earth’s lithosphere to bend. This footprint, or load, of the delta is in southeast Louisiana; however it is causing subsidence in areas as far away as northern Louisiana, eastern Texas, Mississippi and Alabama. Compaction of delta sediments is also a major process that causes subsidence. Locally, water and oil withdrawal from shallow wells is also causing some of the subsidence. An example of local land subsidence can be seen in Figure 2.

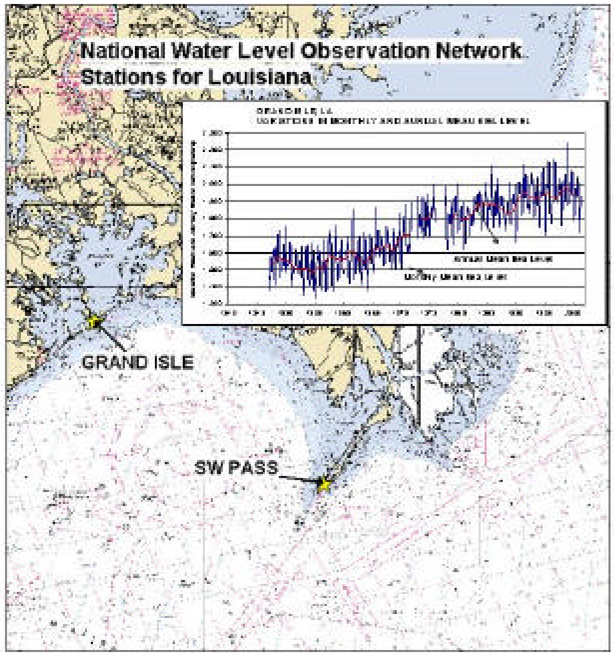
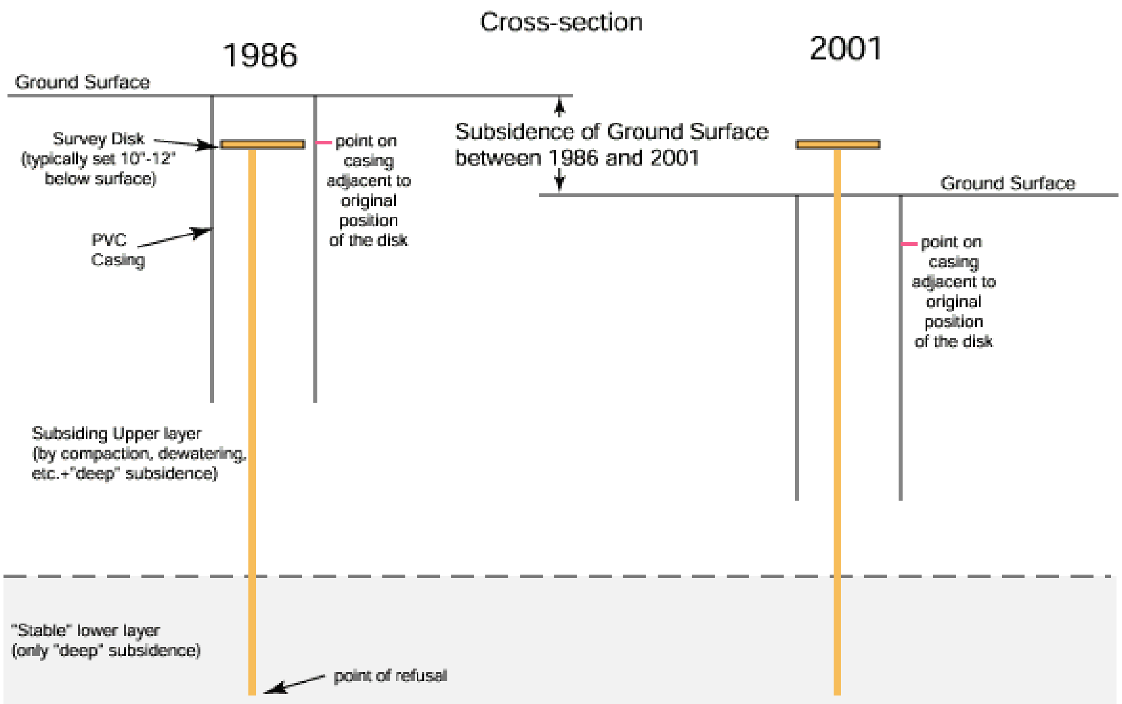


Figure 1. Location of NOAA's NWLON stations in Louisiana at Grand Isle and SW Pass. Also, long-term variations in monthly (blue curve) and annual (red curve) mean sea level plot for Grand Isle. Note the obvious upward trend.

Most of coastal Louisiana is comprised of wetlands. Since there are direct and indirect negative effects of subsidence on wetlands, coastal Louisiana is especially vulnerable to land loss. Wetlands loss from subsidence is caused directly by increased inundation from relative sea level rise. Indirectly, salt water intrusion kills salt intolerant vegetation. Barrier islands and wetlands are subjected to increased wave action and erosion from coastal storms and hurricanes. From a public safety standpoint, subsidence has also lowered evacuation roads along the coast to levels that concern citizens and emergency preparedness officials (Fig. 3).

In a study performed for the National Coastal Ecosystems Team/Division of Biological Services/Fish and Wildlife Service, Boesch, *et al.* (1983) identifies, in an effort to quantify rates of subsidence, the need for decadal sea level records from tide gauge data, as well as interpretation of long-term (centuries) sedimentary records from ^{14}C dating of organic matter and sediment thickness accumulation. They break down their subsidence studies of coastal Louisiana into two categories: long-term subsidence and short-term subsidence. The amount of long-term subsidence that coastal Louisiana is experiencing is greater than any other region within the United States. For example, subsidence rates for Louisiana since the beginning of the Cenozoic era (66.4 million years ago; Duxbury and Duxbury, 1999) are greater than 40cm/1000yr, whereas rates are only about 2cm/1000yr off of the east coast. Studies also indicate that subsidence rates have increased dramatically during the Holocene (10,000 years ago; Duxbury and Duxbury, 1999) and even more so within the last 1000 years.

a.



b.

Figure 2. Figures 2a and 2b illustrate the effects of local land subsidence in Cocodrie, Louisiana. Figure 2a is a recent photograph showing a deep driven rod mark with the bench mark disk several inches above the level of the ground and the surveying rod positioned atop the mark. Figure 2b is a schematic of the survey disk showing the original elevation of the ground surface to be approximately 10 inches above the disk in 1986 and several inches below in 2001. The ground surface surrounding the disk has subsided approximately 15 inches between 1986 and 2001 with a rate of subsidence of approximately 1 inch/year. This is not an isolated case; similar instances have been seen throughout the Louisiana coast.

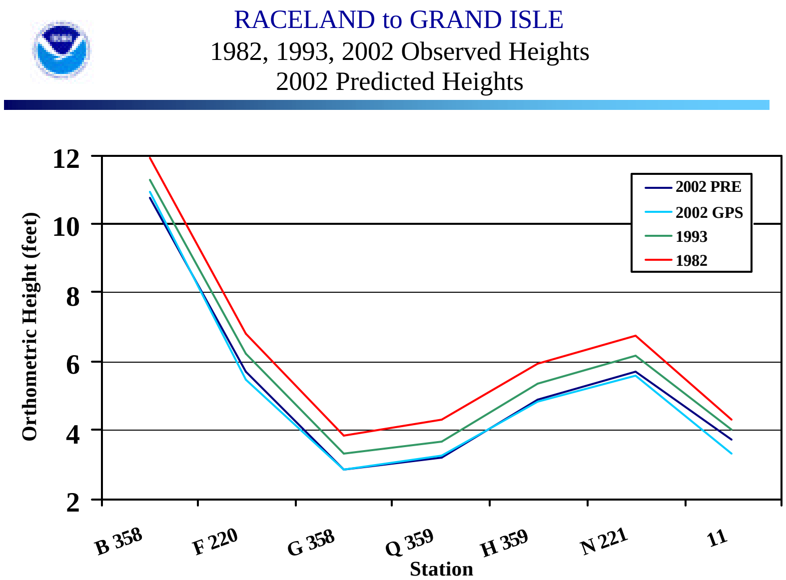


Figure 3. Evidence for approximately 1 foot of subsidence between 1982 and 2002 along Louisiana Highway 1 from Raceland to Grand Isle, LA. This road is the main evacuation route in this area. Determined by measurements of NGS. 2002 PRE is predicted road elevation based on studies by the Louisiana Spatial Reference Center.

Boesch, *et al.* (1983) note that most tide gauge data in Louisiana are inadequate to accurately assess the rate of subsidence or relative sea level rise. Subsidence and relative sea level rise, coupled with a lack of water level and geodetic information, has contributed to the undermining of accurate vertical information in Louisiana. Coastal restoration efforts require knowledge of the true land elevations and their relation to mean sea level (or tidal datums). The tidal datums from the historical water level stations in Louisiana are undermined by the enormous amount of land subsidence and relative sea level rise that the area is experiencing. These datums are more than two decades old and there is a critical need for datum recoveries and updates. Datum relationships between tide and geodetic datums are not well known. The Louisiana Spatial Reference Center (LSRC) has been created through a partnership between NGS and Louisiana State University (LSU) to address these issues and to create an accurate and long-term geodetic reference system for the State. This geodetic "height modernization" program and the ongoing program for establishing updated tidal datums will provide the required baseline vertical datum information. Establishment of a network of CORS stations throughout the state is currently in progress to support NOAA land and sea efforts (Fig. 4).

Hydrography and Nautical Charting

The NOS is responsible for producing and maintaining the suite of 1000 nautical charts that cover the coastal waters of the United States and its territories. It also provides hydrographic information for the safe navigation of maritime commerce as well as basic data for engineering, scientific and other commercial and industrial activities. Navigable waterways are a critical component of the State's economy with 155 miles of coastal navigation channels at risk from coastal erosion. According to 1998 U.S. Army Corps of Engineers statistics, the Port of Lake Charles is the 13th largest ranking port in the U.S. by tonnage. The Port handles a variety of cargo types, including petroleum coke and ore through Port-owned facilities and liquid petroleum at privately owned terminals, bagged rice and flour. It also has Liquid Natural Gas (LNG) facilities. Nautical charts in Louisiana are outdated and critically need to be updated. An example is NOAA Nautical Chart # 11351, which still depicts a shell reef that was dredged in the 1980s to acquire materials for building an excavation road (Fig. 5). The NOS is also responsible for the development of national shoreline products. The depiction of the shoreline on NOAA products is also very outdated and inaccurate due to sea level change and coastal erosion. NOAA is working to update the shoreline products in collaboration with other Federal and State agencies. Accurate geodetic information coupled with more water level information (from additional water level stations) is critical for any new hydrographic surveys in the area. Accurate water level information is essential for generating water level reducers for hydrographic survey soundings (Tronvig, 2001). Hydrographic survey data will assist with updating outdated nautical charts for navigation purposes as well as studies investigating increased oil spill risks from oil production and transportation infrastructure affected by coastal land loss and subsidence. Areas in critical need of updated hydrographic surveys in the Gulf of Mexico can be seen in Figures 6 and 7, which highlight the priority areas and the types of hydrography to be collected, respectively.

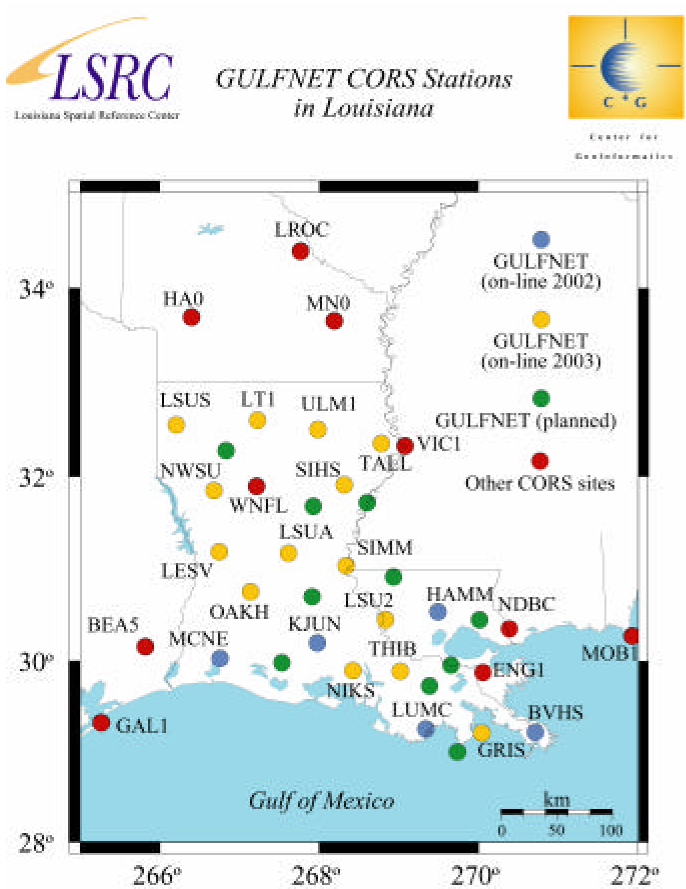


Figure 4. Continually Operating Reference Stations (CORS) in Louisiana. GULFNET is state-wide network of GPS receivers operated by Louisiana Spatial Reference Center (Dokka, 2003).

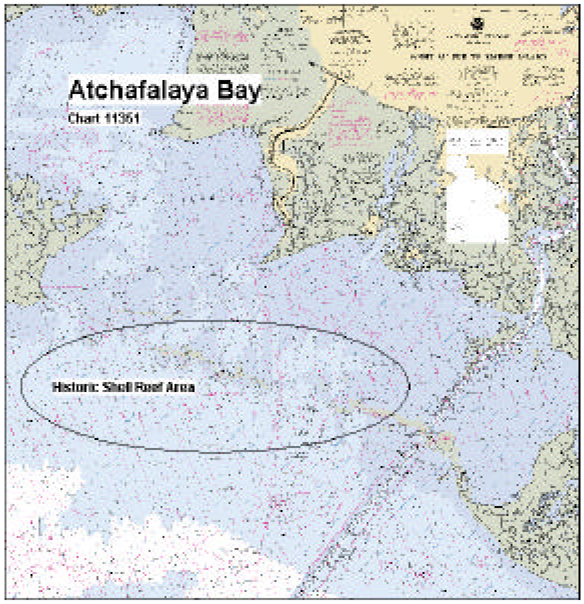


Figure 5. Many of NOAA's charts are outdated. Chart 11351 (updated May 21, 2001) still shows the existence of a shell reef, which was dredged in the 1980s for materials to help build an evacuation road.

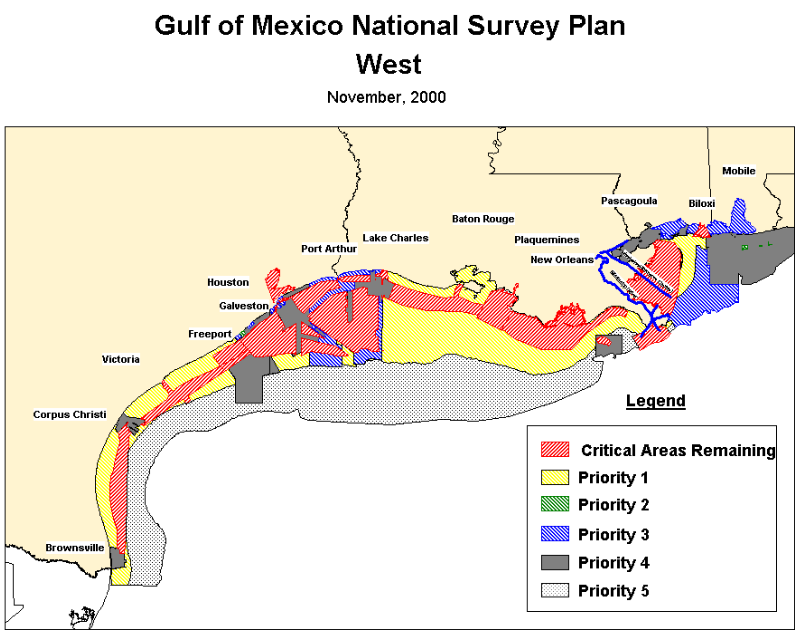


Figure 6. A snapshot of the Gulf Coast from NOAA's National Survey Plan (November, 2000) showing areas that need to be surveyed around Louisiana. The red hatched areas are considered to be critical.

Part of NOAA's charting responsibility includes the Gulf Intracoastal Waterway (GIWW), which is one of the most heavily traveled commercial waterways in the U.S. Until recently, mariners used paper nautical charts, many of which were small scale with out of date and inaccurate information, to navigate the GIWW (Fig. 8a). The first generation of electronic charts are comprised from raster chart data (Fig. 8b) and second generation electronic charts are called vector charts, which are more powerful than raster charts (Fig. 8c) because they allow features to possess certain attributes. NOAA is now working to produce a suite of vector charts called Electronic Navigational Charts (ENCs), including 25 different waterways on the GIWW between New Orleans and Galveston. In order to distribute the load of ENC data, the GIWW was separated into approximately 100-mile quarters. The first quarter is online; the second is in review; and the third is currently in process. NOAA expects all of the ENCs along the GIWW to be online between August and December 2003.

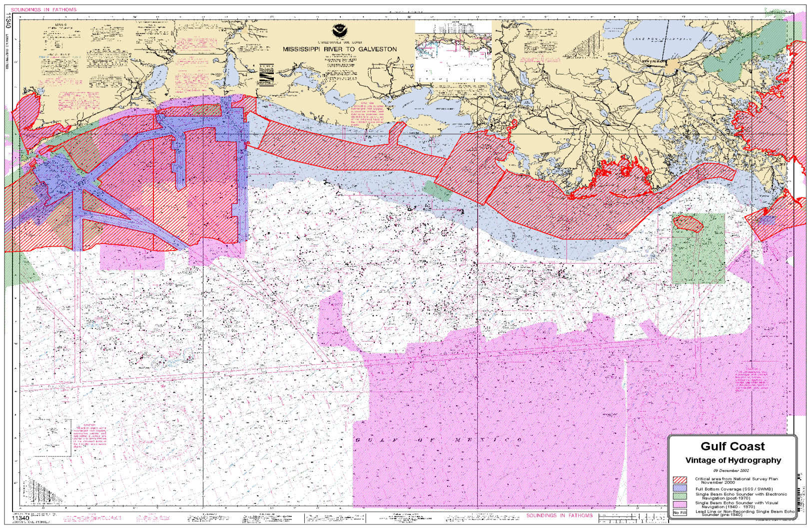


Figure 7. A snapshot of the Gulf Coast Vintage of Hydrography from NOAA's Hydrographic Survey Division showing areas around Louisiana. The red hatched areas are considered to be critical; blue areas are areas with full bottom coverage (SSS/SWMB); green areas are areas with single beam echo sounder with electronic navigation (post-1970); purple areas are where single beam echo sounder was used with visual positioning between 1940-1970; and no fill area or white areas are where leadline or non-recording single beam echo sounder was acquired (pre-1940).

One of the new Navigational Response Teams (NRT) will be working in Louisiana along the GIWW. It will perform ENC verification and collect new hydrographic data along the GIWW to support new NOAA Nautical Charts (#s 11367 and 11355). Beginning in March 2003, sounding data will be collected from New Orleans to Morgan City. This hydrographic survey work will have a focus on Port Fourchon at the request of Port Authorities due to significant amounts of oil-related equipment flowing into and out of the Port.

During this year's hydrographic surveying field season (2003), potentially as early as July, NOAA will initiate a vessel time charter to expand its hydrographic surveying capacity. The charter partner will supply operating personnel and a vessel with two launches equipped to perform multi-beam and side scan sonar surveys. Initial emphasis will be in the Gulf of Mexico as it has four of the top seven port areas: (1) New Orleans and South Louisiana, (2) Houston/Galveston, (3) Port Arthur, TX and Lake Charles, LA; and (4) Corpus Christi, TX (Note: half of these areas in the Gulf are off of Louisiana). Ships in many critical Gulf areas carry heavy commercial and passenger traffic. Commercial cargo includes oil, LNG, and other chemicals and hazardous materials.

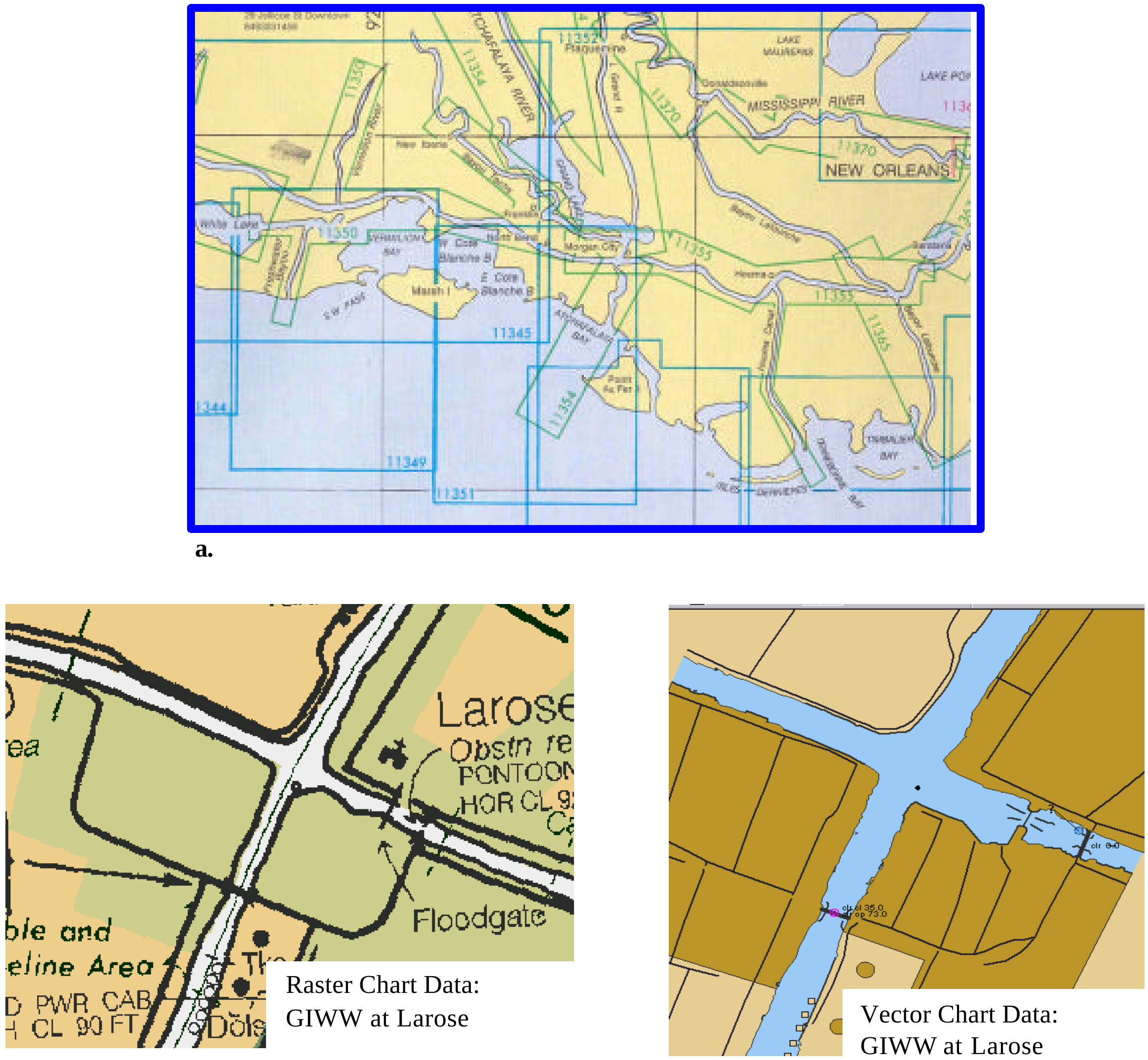


Figure 8. Figure 8a shows the existing paper chart layout for the GIWW. Figure 8b shows raster chart data of GIWW at Larose. Raster chart data are scanned images of paper charts. Figure 8c shows vector chart data of GIWW at Larose. A vector chart is a database of chart features where each feature possesses certain attributes. Note how much more powerful vector chart data are when compared to raster chart data. ENCs will be even more powerful than vector chart data.

Oil Spill and Infrastructure Risk

Coastal communities, industries and the environment are all negatively affected by the large amounts of coastal land loss in Louisiana. Eighteen percent of the Nation's oil is produced in coastal Louisiana. The loss of coastal land in Louisiana threatens 30,000 oil wells and their associated infrastructure.

The NOS is working in partnership with the Louisiana Department of Natural Resources (LDNR) to minimize the threat to oil development and transportation infrastructure due to coastal land loss. The existing above ground facilities and currently and/or previously buried pipelines are threatened by coastal erosion, storm surge flooding and land subsidence which could lead to immediate and long-term, chronic oil spills.

Through the partnership, NOS and LDNR hope to help planners and managers develop strategies for reducing economic and natural resource impacts from these risks. The objectives of the effort include: identifying hazards and vulnerability associated with oil production and transportation infrastructure; mapping zones of oil spill risk from threatened infrastructure; and developing a risk assessment framework for identifying and mitigating infrastructure at the highest risk.

The first step is to develop an oil production and transportation infrastructure vulnerability atlas for a portion of coastal Louisiana. The atlas would be a test bed for combining information that supports the project objectives. The South Lafourche Corridor is a candidate area with all of the attributes necessary for the project. Possible components of the oil production and transportation infrastructure vulnerability atlas include: high resolution and precision shoreline and bathymetry; shoreline geomorphology attributes based on NOAA Environmental Sensitivity Index (ESI) standards; biological resource and habitat information organized according to ESI standards; and location of oil wells, pipelines, and related infrastructure.

The atlas would integrate existing geospatial data so that it is consistent, works together, and is readily accessible. It will provide the foundation for an analysis and forecast component to identify infrastructure vulnerabilities and risks. NOAA oil spills models could be used to evaluate scenarios likely to occur as a result of storm-induced damage to the oil infrastructure. Physical hazard information, such as the coastal slope, rate of relative sea level rise, subsidence rates, shoreline erosion/accretion rates, tidal range and storm surge, and storm intensity and wave height combined with vulnerability will be required for a more comprehensive risk assessment. This amalgamation will enable maps of infrastructure at risk to be developed as the first step in developing mitigation strategies and techniques.

Conclusion

This paper describes several activities in which the NOS and LSRC are engaged in Louisiana. Each activity requires the knowledge of water level and vertical datum information. The applications of this information combined with the products of these activities are critical for protecting life and property in Louisiana and maintaining the economic vitality of the State and the Nation. The NOS has received several letters from a variety of constituents in Louisiana requesting assistance in setting up water level monitoring stations for a plethora of applications. In response to those letters, the NOS has met with the various parties and is currently in the process of establishing several water level stations in different regions of the State. Several projects are now underway and many more are in the discussion phase. These projects will result in significant progress toward filling the gaps in water level and datum information in Louisiana.

To address the significant rates of coastal land loss, Federal and State agencies have been working with parishes and local governments to develop a strategic coastal plan for restoring and sustaining coastal lands. In 1998, LDNR published "Coast 2050: Toward a Sustainable Coastal Louisiana." NOS' effort in producing maps of infrastructure at risk complements the goals established by "Coast 2050" whose goals are ". . .that a sustainable ecosystem will be restored in coastal Louisiana, in large part by utilizing the same natural forces that initially built the landscape."

This paper summarizes the urgency for responding to the coastal land loss and loss of coastal ecosystems in Louisiana. The ability of NOS to apply its expertise in sea level measurement, geodesy (with the LSRC), surveying and mapping, and risk assessment in an integrated fashion is being demonstrated by ongoing and new projects. Each of these projects has strong partnership components with State and local agencies ensuring that their requirements will be met.

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Coast 2050: Toward a Sustainable Coastal Louisiana
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Louisiana Spatial Reference Center
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National Geodetic Survey
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Office of Coast Survey
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