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ABSTRACT

Louisiana's coastline, especially the Mississippi River Deltaic Plain (MRDP), is experiencing some of the most extreme erosion rates in the nation and needs urgent mitigative measures to re-establish a sustainable coastal ecosystem via large-scale restoration. Sedimentological restoration is one of the strategies currently being used to achieve this goal. Sediment management plays a vital role in implementing this strategy. The Louisiana Sediment Management Plan (LASMP) facilitates sediment management for restoration by providing an inventory of potential sediment resources and tracking sediment needs, both of which are crucial to the development of regional strategies for restoration. To aid in the development of Louisiana's coastal master plan and to help fulfill the goals of the LASMP, first-order surficial sediment distribution maps for offshore and the Lower Mississippi River were developed based on existing geophysical and sedimentological data residing in the Louisiana Sand Resources Database (LASARD). LASARD was initially developed by the state of Louisiana to manage geological, geophysical, geotechnical and other related data pertaining to offshore sand searches. However, with time the scope of LASARD has expanded and it is no longer limited to data related to sand searches only. Keeping the needs of coastal restoration in mind, the sediment deposits that were mapped were broadly classified as surficial sand, surficial mixed sediment, and surficial fines and digitally archived. However, a large portion of offshore areas were classified as "unknown" due to a lack of sufficient reliable data. Based on these maps, first-order total and available (by excluding sediment impacted by oil and gas infrastructure) volume estimates were calculated for sand, mixed sediment, and fine-grained sediment. Based on the 2017 Coastal Master Plan an estimated 5,000 to 11,000 million cubic meters (MCM) of sediment is required to meet coastal Louisiana's needs. Volume estimates based on the surficial sediment maps indicate that this volume of sediment may be available but dredging all of these sediment resources is not necessarily feasible or technically sound even with sufficient resources. It is important to emphasize that these volumes are first-order estimates as these calculations are based on various geoscientific information with varying degrees of confidence. The development of such maps is a painstakingly intensive effort. These maps are living documents and are updated as new data become available. As such, the mapping is updated periodically and the volumes are updated accordingly. Ultimately the results of the mapping will be available as a digital database. These maps are basic but important tools for resource planning and play a critical role in the management of sediment resources at a regional level. Additionally, these maps are good indicators of presence as well as absence of sufficient geoscientific data. As such, they are a useful tool for conducting data gap analyses, which are typically conducted at planning stages of various investigations. These maps also form templates and/or base maps for development of comprehensive biotic and abiotic habitat maps. Most important, they play a vital role in the enforcement of federal and state regulations related to removal of decommissioned pipelines and coastal zone management. The utility of these maps is not limited to the Louisiana coastal area. Similar maps could be compiled for the entire northern Gulf of Mexico, helping not only the remaining four Gulf states but also supporting Gulf-wide efforts such as the GOMA's (Gulf of Mexico Alliance) Gulf of Mexico Master Mapping Plan (GMMMP) and RESTORE (Resources and Ecosystem Sustainability, Tourist Opportunities, and Revived Economies) Council's Coastal Monitoring and Assessment Program (CMAP).

ADDITIONAL KEYWORDS: habitat maps, Louisiana Sand Resources Database, sediment distribution, sediment management, coastal restoration

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Globally, shorelines are degrading due to an increase in the frequency and intensity of high-energy events, and relative sea level rise capped by intensive anthropogenic interventions (Zhang *et al.* 2004; Syvitski and Kettner 2011). The Mississippi River Delta Plain (MRDP) in southeast coastal Louisiana exemplifies an ecocatastrophe which was triggered by geological and geophysical processes as well as anthropogenic activities, resulting in the present degradation of the coastal landscape (Khalil *et al.* 2018). It is well documented that during the past half-century, coastal Louisiana has experienced the highest rates of land loss and erosion in the nation (Barras *et al.* 2003; Barras *et al.* 2008; Khalil *et al.* 2010). Between 1932 and 2016, Louisiana has lost approximately 4,800 km^2 (1,853 mi^2) of coastal land, much of which was lost between 1932 and 1985 (approximately 4,000 km^2 [1,544 mi^2] or 76 km^2/yr [29 mi^2/yr]). Since 1985, cumulative wetland loss has continued at a rate of approximately 25 km^2/yr (10 mi^2/yr) (Couvillion *et al.* 2017). Land loss, particularly the loss of coastal wetlands, threatens the sustainability of Louisiana's coastal ecosystem.

Given the irreversibility of usage of hard structures for coastal restoration, soft options via infusion/emplacement of sediment (sedimentological restoration) to replicate the geomorphic form have become a reliable mitigating strategy for coastal restoration amongst the coastal scientist community since late last century. One of the most important recommendations of the Second Delta Committee of The Netherlands regarding coastal defense options was to adopt a soft engineering strategy (i.e. sand nourishment of the coastal system) to mitigate long-term coastal recession (Stive *et al.* 2013). A similar strategy has been applied to mitigate the severe land loss crisis in coastal Louisiana for the last two decades (Khalil and Raynie 2015a, b).

As previously stated, the ecosystem restoration program in coastal Louisiana depends heavily on the appropriate strategies adopted for robust sedimentological restoration. This includes a comprehensive sediment management plan that integrates various sediment input mechanisms including: beneficial use of sediment dredged annually from navigational channels and harvesting sand deposits in the river and offshore (Khalil and Freeman 2014; Underwood 2012; Underwood *et al.* 2015). Thus, the success of a Louisiana coastal restoration effort depends on locating sufficient volumes of sand and mixed sediment that are suitable for placement on beaches and dunes, and for creating/nourishing wetlands. Locating potential borrow sites with suitable sediment resources that are extractable at acceptable costs is crucial to the success of restoration goals (e.g. Finkl and Khalil 2005).

The state of Louisiana undertook a major initiative to address concerns related to the future of Louisiana's coast through the development of the Coastal Master Plan. The Louisiana Coastal Protection and Restoration Authority (CPRA) developed a Coastal Master Plan to mitigate land loss and degradation of the ecosystem and reduce flood risk (CPRA 2017). The Coastal Master Plan recommends a diversity of projects to build land and reduce flood risk to balance short-term needs with long-term goals. Execution of the Coastal Master Plan will take an unprecedented effort by government, the private sector, and coastal communities to improve the sustainability of the Louisiana coast. Khalil *et al.* (2018) estimated sediment needed to offset past and future losses ranges from 5,000 to 11,000 million cubic meters (MCM), depending upon the selected Coastal Master Plan scenario.

One of the major causes of coastal land/wetland loss in Louisiana is sediment deficiency. To address this deficiency, restoration efforts must focus on the introduction of new sediment to the system. Marine sand mining on the United States continental shelf is a major activity that supplies sediment for beach and dune restoration activities. However, the muddy coasts of the Mississippi River delta plain are challenging because sand resources are scarce and their quality is variable. The potential for riverine mining of sand resources to support construction of future coastal restoration projects provides a possible solution to this problem.

Surficial sediment distribution maps for offshore coastal Louisiana and the Lower Mississippi River were initially developed using the geoscientific data archived in the Louisiana Sand Resources Database (LASARD) to assist in planning coastal restoration projects for the 2012 Coastal Master Plan. Being living documents, these maps are regularly updated when additional data are made available through LASARD. The associated volume estimates are also updated on a regular basis. The initial maps compiled in 2011 were recently updated to help guide the formulation of the 2017 Coastal Master Plan. The immediate goal of the mapping was to identify the existing and potential sediment deposits that could be further investigated for future borrow area development. These maps are integral to the Louisiana Sediment Management Plan (LASMP), which conceptualizes systematic planning and facilitates better coordination of essential components of the huge restoration and protection effort currently undertaken in Louisiana (Khalil *et al.* 2010; Khalil and Raynie 2015a). LASMP, along with its important components, LASARD and the surficial sediment distribution maps, aid the Coastal Master Plan by providing an inventory of potential sediment resources and development of appropriate regional strategies for better planning.

Such maps are a useful tool in performing gap analysis for various purposes including but not limited to sediment management, monitoring, and overall restoration approach. Valuable lessons were learned during the initial development of these maps as they aided in identifying the areas where the data density was sufficient or insufficient. Identification of data density not only helped in classifying the map elements as potential or unknown but also by providing information about availability or unavailability of data types and by quantifying the density of data. Also several types of maps can be developed in addition to sediment distribution maps, e.g. various types of habitat maps, land loss maps, vegetation maps, etc.

These maps support state regulatory efforts to enforce the Coastal Zone Management program. They also provide background data for development of federal regulations to protect sediment resources through the Bureau of Ocean Energy Management (BOEM)'s "Offshore Significant Sediment Resources Blocks," which play a critical regulatory role in decision making for removal of decommissioned pipelines. The removal of such pipelines makes available the previously inaccessible sediment resources.

In this paper, we discuss the development of surficial sediment distribution maps for the Louisiana coast and a portion of the lower Mississippi River and the role these maps play in managing coastal Louisiana's sediment resources.

REGIONALIZATION OF SEDIMENT RESOURCES

The restoration of the barrier islands and marsh habitat along Louisiana's coastline plays a major role in Louisiana's current and future Master Plans. Healthy barrier islands, which are the first line of defense, are needed to protect the mainland coastline and preserve marsh habitat. Land loss, particularly the loss of coastal wetlands, threatens the sustainability of coastal Louisiana. Multiple tropical weather systems (Hurricane Ivan in 2004; Hurricanes Dennis, Katrina, and Rita in 2005; Hurricanes Gustav and Ike in 2008) have exacerbated the degradation and erosion of barrier islands in Louisiana. To restore these eroding barrier islands and marsh habitat, sand and mixed sediment must be identified and allocated to various projects.

It is well documented that the continental shelf offshore Louisiana is typically shallow and broad with a predominantly muddy seabed with transgressive sand bodies and shallow reefs (Penland *et al.* 1988; Roberts 1997; Kjerfve 2003; Khalil *et al.* 2010). In this region, sand deposits are typically located in buried paleochannels or within bar deposits in the Lower Mississippi River (Khalil *et al.* 2010). Most of these offshore/nearshore deposits are covered by a muddy overburden consisting of mixed silt and clay. However,

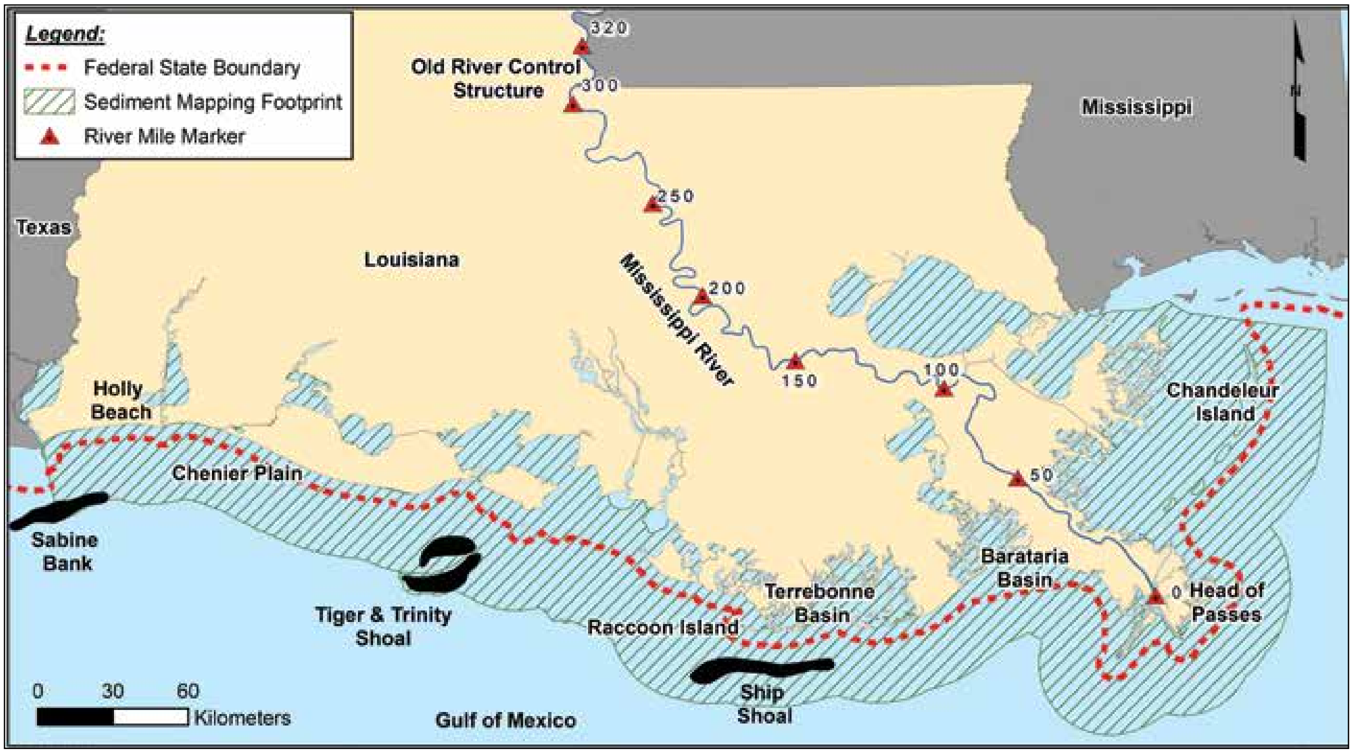

Figure 1. Location map.

large sand deposits occur as major shoals on the outer continental shelf (in federal waters) in the Sabine Bank, the Tiger and Trinity Shoal Complex, Ship Shoal, and St. Bernard Shoal (Khalil *et al.* 2010).

Maps approximating the spatial distribution of these surficial sediments are an integral part of coastal restoration planning. Louisiana has a long history of exploration for marine sediment resources. Historically large areas of the continental shelf have been surveyed and thousands of miles of seismic data and hundreds of vibracores collected. However, this is the first effort in Louisiana to compile existing data and use it on a statewide basis to develop surficial sediment distribution maps with the purpose of informing future restoration strategies via further exploration, conservation, and/or preservation of state's sediment resources.

EXISTING GEOSCIENTIFIC DATA AND LOUISIANA SAND RESOURCE DATABASE (LASARD)

The state of Louisiana initially developed the LASARD program to manage geological, geophysical, geotechnical, and other related data pertaining to offshore sand searches. It was designed to archive historical and current geoscientific data that could be queried by state, federal, and private entities for planning and executing restoration projects (Khalil *et al.* 2010). However, with time the scope of LASARD has expanded and it is no longer limited to data related to sand searches only. It now includes any geoscientific data pertaining to the exploration of sediment resources in offshore coastal Louisiana and the Lower Mississippi River as well as various data from regional monitoring programs. The objective of LASARD is broadly to centralize relevant data from various sources for better project coordination and to facilitate future planning for delineating and using sediment resources for restoration in coastal Louisiana. CPRA is using LASARD to archive pertinent data collected through its rapidly increasing monitoring, assessment, and Adaptive Management programs (e.g. Statewide Assessment & Monitoring Program [SWAMP], Coastwide Reference Monitoring System [CRMS], and Barrier Island Comprehensive Monitoring [BICM] Program). Specifically, relevant information consists predominantly of geophysical (seismic, sidescan sonar, magnetometer, and bathymetry) and geological/sedimentological data obtained by vibracore, jet probe, and grab sampler. Oil and gas infrastructure data are also incorporated, since they affect the delineation of borrow areas and subsequent dredging.

LASARD is populated with historical and current data that have been collected over several decades by private industry, universities, and federal and state agencies. Surficial sediment data made available through the usSEABED and Louisiana Sedimentary and Environmental Database (LASED) databases of the U.S. Geological Survey (USGS) were also utilized in the compilation of the offshore surficial sediment distribution map. Spatially, the majority of existing data in LASARD is concentrated within state and federal waters around the MRDP in southeast Louisiana with data becoming sparser in areas west of Raccoon Island.

Thousands of grab samples and core borings have been collected along the Louisiana coast and within the Lower Mississippi River. Of the over 280 sediment sample/grain size datasets representing over 40,000 core borings and grab samples that are currently in LASARD, over 15,000 core borings and sediment samples were incorporated into the development of the Surficial Sediment Distribution Maps. These borings and samples were collected between 1983 and 2017 by a variety of consultants and organizations. The bulk of this data is concentrated in the Terrebonne Basin, Barataria Basin, Mississippi River, and Chandeleur Islands, with the exception of the data on the Tiger and Trinity Shoal complex, part of the Chenier Plain, Holly Beach, and Sabine Bank (Figure 1). It has been indicated earlier that the geotechnical data west of Raccoon Island are comparatively sparse. Most of the avail-

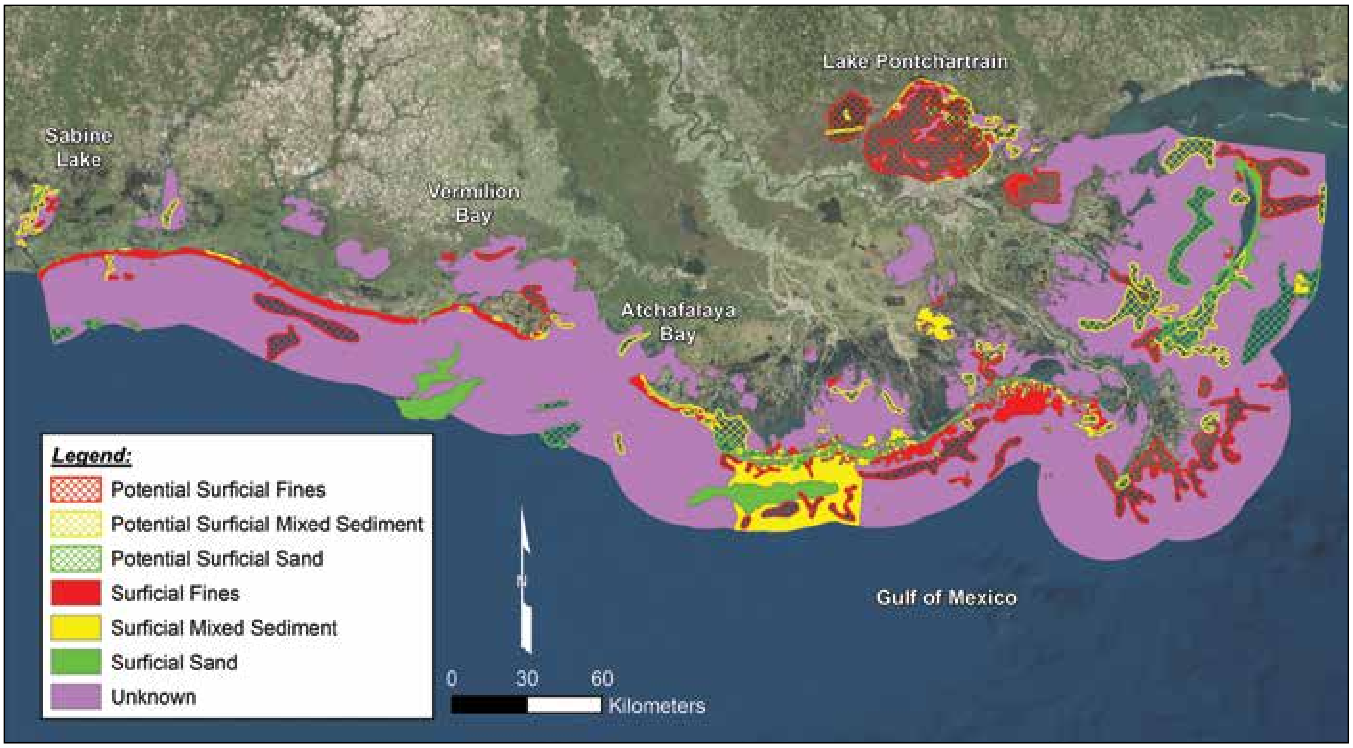

Figure 2. Offshore Louisiana surficial sediment distribution map.

able geophysical and sedimentological data were collected during exploration of sand in the Ship Shoal Complex, the Tiger and Trinity Shoal Complex, Sabine Bank, and the Chandeleur Islands (see https://cims.coastal.louisiana.gov/RecordDetail.aspx?Root=0&sid=20987).

The majority of historical seismic data collected along the Louisiana coast and within the Lower Mississippi River were collected and archived by USGS, LGS, and by private consultants on behalf of oil and gas industries. These datasets include electrodynamic "boomer" seismic data and high-resolution "chirp" subbottom data, sidescan sonar as well as bathymetric data. Data also include those collected during preliminary geophysical investigations in the Lower Mississippi River (south of New Orleans) along a 32 km (20 mi) stretch of river between River Mile 15 and River Mile 35 (Figure 1) (Finkl *et al.* 2006). Recently, during some higher-resolution surveys, data was collected in connection with the delineation of borrow areas for marsh creation (Long Distance Pipeline Dredging) and barrier island restoration. A large multibeam bathymetric dataset was made available by the U.S. Army Corps of Engineers (USACE) New Orleans District which was collected over a stretch of approximately 502 km (312 mi) from the Old River Control Structure (River Mile Marker 312) to Head of the Passes (River Mile Marker 0) under their decadal survey program (Figure 1). In order to utilize the renewable sediment resources for restoration and engineering design of major sediment diversions the frequency of bathymetric surveys and geotechnical investigations in the Lower Mississippi River have increased considerably.

During 2006, single beam bathymetric surveys were conducted along cross shore transects spaced 457 m (1,500 ft) apart under the BICM Program for the entire coast along the barrier islands and Chenier plain (see https://cims.coastal.louisiana.gov/RecordDetail.aspx?Root=0&sid=20987). During 2015, another round of surveys were repeated along the same transects. Sedimentological analyses of surficial grab samples were also undertaken and repeated (see https://cims.coastal.louisiana.gov/RecordDetail.aspx?Root=0&sid=20987). A recent addition to LASARD are the large geophysical datasets acquired during the geophysical survey in Barataria Basin conducted under SWAMP (CB&I 2016).

Data in LASARD are accessible to users through the CPRA Coastal Information Management System (CIMS) website (see https://cims.coastal.louisiana.gov/default.aspx). LASARD is of significant value to coastal planners, scientists, engineers, and others interested in coastal restoration in the northern Gulf of Mexico. Geoscientific information is easily accessible to all the stakeholders, saving both money and time and avoiding duplication of data collection efforts. While developing this database, the greatest challenges were locating available, archived datasets and bringing all of the existing datasets into a common format that could be displayed, analyzed, and used. Based on this experience, a Standard Operating Procedure (Khalil *et al.* 2015) was developed so that coastal and offshore geological, environmental, and associated data are presented uniformly in the future, thus making it easier for future datasets to be loaded into the system. In addition, for a systematic and cost-effective exploration, a protocol for sand/sediment searches in deltaic environments (also known as the Delta Sand Search Model (DSSM)) was developed in 2003. The "General Guidelines for Exploration of Sediment" have gone through several updates (Khalil 2016). Improvements to the data structure now allow users to make substantial qualitative assessments about these deposits, which will facilitate the management of Louisiana's limited sediment resources. This new information has been added to the LASARD data structure so that it can be used to assess potential sediment resources. This refined structure will allow users to determine various sediment types and deposit geometry. Queries can now be made to identify deposits that meet user defined sediment parameters, a functionality that

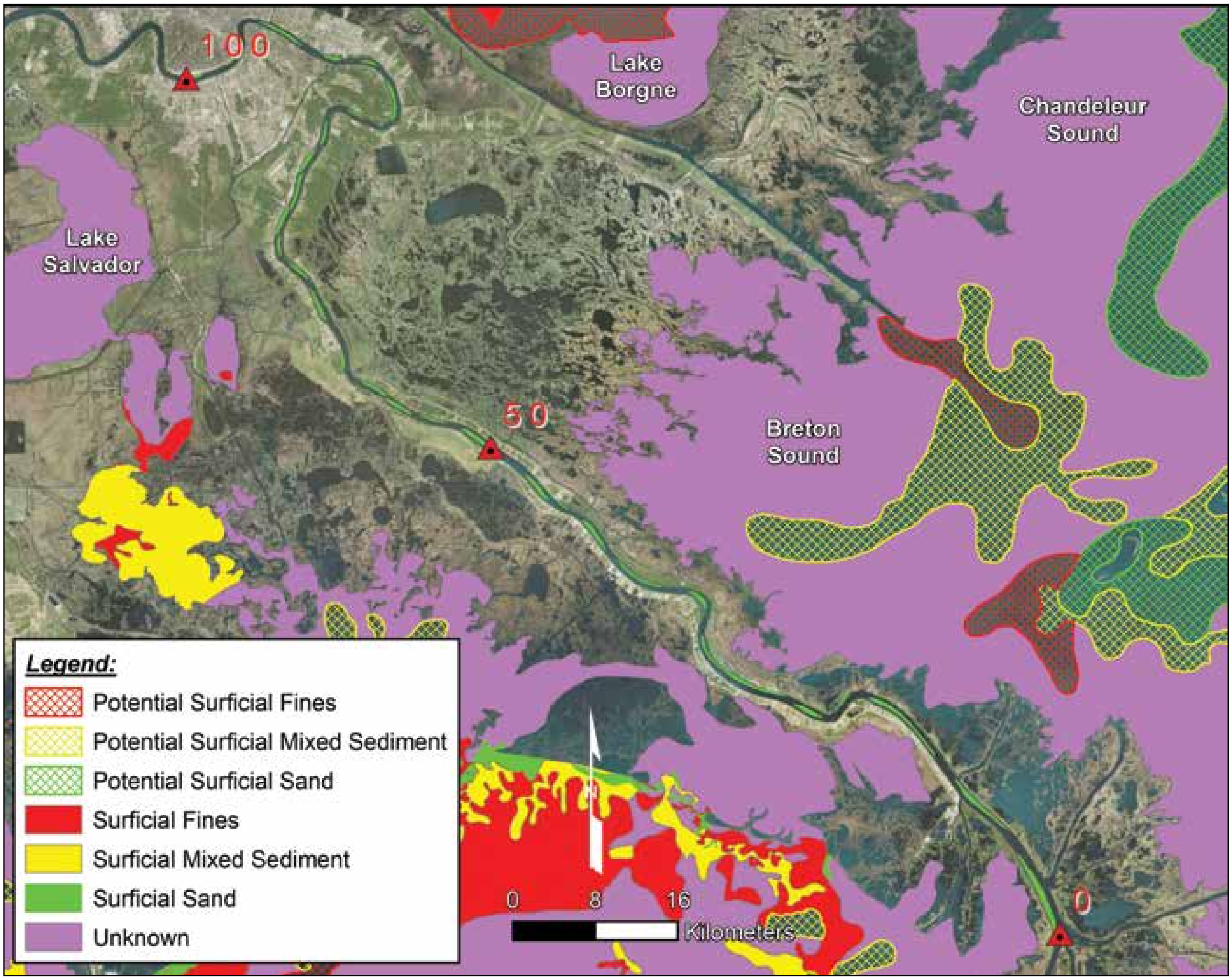

Figure 3. Map showing sand bars in Lower Mississippi River and surficial sediment distribution on both sides of the river.

assists in identifying resources that can be used to develop a sound strategy for the sediment management.

DELINEATION OF POTENTIAL SEDIMENT RESOURCES

The framework of existing data, though sparse in some areas, has been interpreted and used to identify and delineate potential sediment resources. This surficial sediment mapping effort spanned from the Texas/Louisiana border east to the Mississippi/Louisiana border and extended offshore over 27 km (17 mi) (Figure 1). The mapped area extended inland to include major inland lakes and bays. Mapping within the Mississippi River extended from Head of Passes to approximately River Mile Marker 100.

Prior to delineation of any deposits, existing core logs and sedimentological (mostly grain size) data were reviewed, classified and color coded. Per the color coding scheme green represented surficial sand, yellow represented surficial mixed sediment, red represented surficial fines and purple represented unknown (Figures 2 [offshore] and 3 [riverine]). Using this same classification system and color coding scheme, seismic data were also reviewed, classified and color coded. To map the surficial sediment deposits, the classified and color coded data were displayed in ArcGIS 10.5. Clusters of sample/seismic data with the same classification were identified. Preliminary boundaries were drawn around each cluster. If data were spaced less than 1 mi apart the cluster was designated as a surficial sediment deposit. If data were spaced more than 1 mi apart, the decreased level of confidence resulted in the cluster being designated as a "potential" deposit. Based on sediment type, the deposits were classified as surficial sand or potential surficial sand (predominantly sand with <30% silt and clay), surficial mixed sediment or potential surficial mixed sediment (sand with >30% silt and/or clay) or surficial fines or potential surficial fines (100% silt and/or clay). Areas where no data were available were labeled as "unknown." Once these initial deposits were delineated, existing bathymetric data as well as current NOAA Raster Navigational Charts (RNCs) were used to help refine the sediment deposit boundaries, particularly in situations where the clusters of data were located on a known and mapped sediment shoal (i.e. Sabine Bank, Ship Shoal, etc.).

The delineation of sediment deposit boundaries was based on several assumptions as listed below.

To ensure that mapping was only conducted in Louisiana waters, the eastern and western limits were based on the Louisiana Coastal Zone boundary as defined by the Louisiana Department of Natural Resources (LDNR) in 2012.

Table 1.
First-order estimates of sediment quantities in million cubic meters (MCM).

Location	Sediment type	Total available volume of sediment	Total dredgeable volume of sediment	Reduction in volume (%)
Lower Mississippi River	Surficial sand			
	-21 m NAVD88	120	26	78
	-27 m NAVD88	243	75	69
Offshore	Surficial sand	3,146	1,848	41
	Potential surficial sand	3,643	2,500	31
	Surficial mixed sediment	4,431	2,353	47
	Potential surficial mixed sediment	5,031	3,607	28
	Surficial fines	4,074	2,636	35
	Potential surficial fines	10,727	8,020	25

The boundaries of the delineated resource areas within the main channel of the Lower Mississippi River were based on the 229 m (750 ft) offset that the USACE typically requires from the centerline of the levees. As spatial data on the centerline of the levees was not available, it was assumed that the centerline of the levees is typically 15 m (50 ft) from the river bank. The river banks were digitized from a 2013 statewide National Agricultural Imagery Program (NAIP) image and a 229 m (750 ft) offset was applied.

Multibeam bathymetric data collected between 2012 and 2013, provided by the USACE, were gridded and used to produce 0.3 m (1 ft) isobaths and bathymetric surfaces for the sand bar deposits within the lower Mississippi River. This bathymetry was used to digitize bar formations that potentially contain sand. Where sediment samples were available, they were evaluated and used to verify the sand bar delineation.

After the entire coast had been mapped in this way, each individual deposit was reviewed to verify that the available data supported the delineation and classification. The entire coast was also reviewed to make sure that deposits had not been overlooked. Once satisfied with the delineations, geospatial topology was checked to make sure there were no gaps or overlap between adjacent deposits sharing a common boundary.

SEDIMENT VOLUME ESTIMATES

An approximate first-order estimate of available sediment for coastal Louisiana is provided in Table 1. For each surface sediment deposit within the main channel of the lower Mississippi River volumes were estimated from the bathymetry down to a cut elevation of -21 m (-70 ft) NAVD 88 and down to a cut elevation of -27 m (-90 ft) NAVD 88. The thickness of each deposit under these conditions was used to estimate volumes. For the offshore deposits the thickness of each sediment type viz. "mixed sediment," "surficial fines," and "unknown" was taken to be 3 m (10 ft). Areas delineated as surficial sand were reviewed separately. For these areas, available core borings were reviewed to determine the range of thickness of the sand in each area. This information was used to estimate an average thickness for each area, which was used to calculate the total estimated volumes.

Two volumes were calculated for each sediment deposit. The first volume estimate is based on the total available volume. The second estimate is the "useable volume," which is the volume of sediment remaining after excluding sediment within existing borrow areas and within the 305 m (1,000 ft) oil and gas infrastructure safety buffers as per existing regulations. The safety buffer in the Mississippi River was 500 feet.

It is important to note that these volumes are first-order estimates and approximation at best, based on an evaluation of existing geoscientific data. Secondly in such maps which are living documents, variability in volume estimates is commonplace as the sediment boundaries are regularly updated.

DISCUSSION

Based on this effort, 252 surficial sediment deposits were identified/delineated offshore Louisiana (Figure 2) and 30 sand bars were identified along the Lower Mississippi River (Figure 3). Areas where no data were available were labeled as "unknown." Of the 252 offshore deposits mapped, 102 contained predominantly fines, 96 contained mixed sediment, and the remaining 54 contained predominantly sand. Within the Lower Mississippi River only potential surficial sand deposits were mapped.

An estimated 120 to 243 MCM of surficial sand was mapped in the Lower Mississippi River (depending on cut depth) while a total of 31,053 MCM of sediment was estimated and mapped offshore. Of this 31,053 MCM, over half (19,402 MCM) was classified as "potential" due to a decreased level of confidence associated with data quality and data density. It is important to note that the delineation of these surficial sediment deposits is based on limited geophysical and sedimentological data, most of which were collected during reconnaissance-level surveys. Although no high resolution geophysical or geotechnical investigations were conducted as part of this study, these maps have benefitted from high resolution/engineering scale surveys undertaken for project-specific borrow area delineation which follow specific protocols for exploratory surveys (Khalil 2016) as well as for data acquisition (Khalil *et al.* 2015). The classification and boundaries of the resources mapped are tentative at best. They are, therefore, subject to change pending further investigation.

A very significant limiting factor to the actual availability of these sediment resources is the fact that offshore Louisiana is crisscrossed with numerous oil and gas pipelines (Khalil *et al.* 2010). The quantity of sediment available for restoration ("dredgeable" sediment) is drastically reduced due to safety buffer requirements by regulatory agencies for subsea oil and gas infrastructure (Figure 4). The total volume of sand available in the river is reduced from 120 to 26 MCM (assuming a -21 m NAVD 88 cut). Similarly, the total volume of sediment available offshore is reduced from 31,053 MCM to 20,964 MCM, a reduction of 32%.

The former Minerals Management Service (MMS; U.S. Department of In-

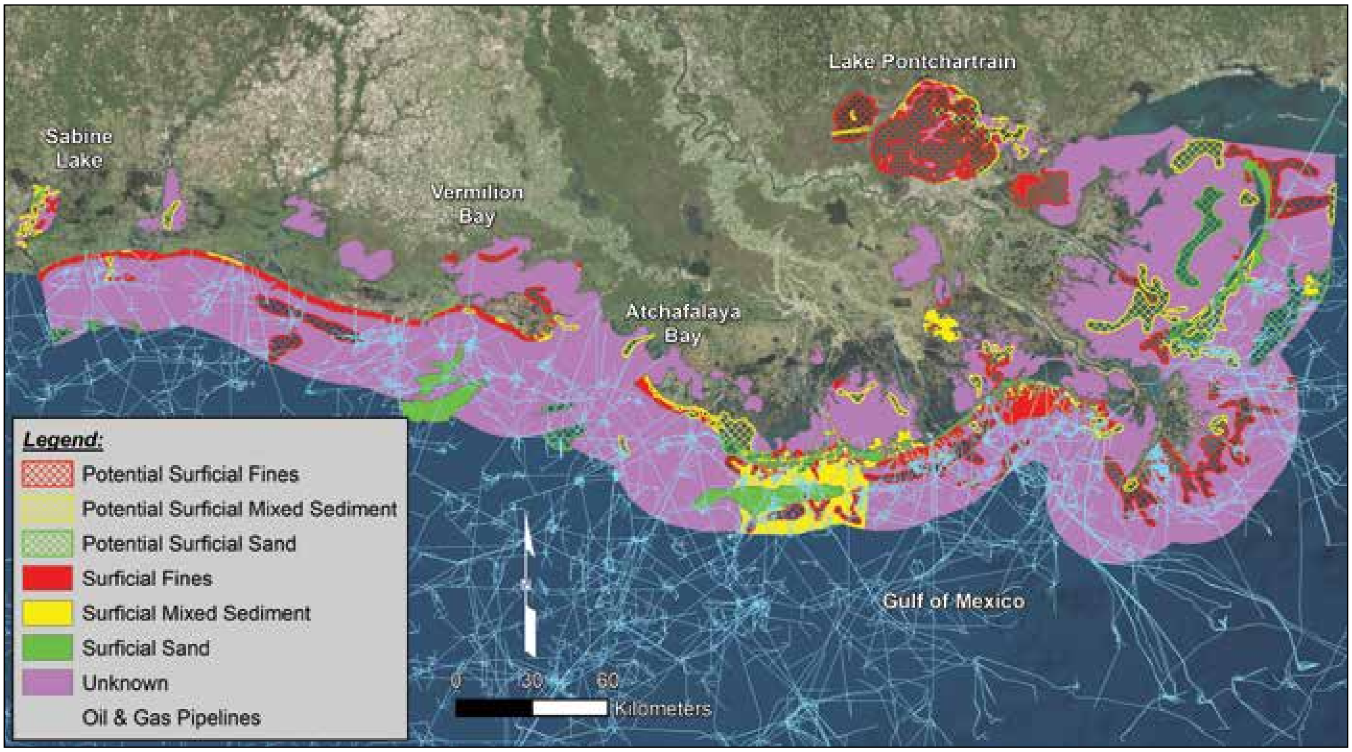

Figure 4. Map showing oil and gas pipelines/infrastructure in coastal Louisiana which often limit accessibility to available sediment resources.

terior, now the Bureau of Ocean Energy Management [BOEM]), on the basis of a study (Nairn *et al.* 2004), established a range of buffer zones (depending on sediment characteristics) around oil infrastructure and other magnetic anomalies within the Ship Shoal and other sand resource areas on the outer continental shelf (OCS) to ensure safety of the pipelines and safety of dredging operations. Thus, the presence of oil and gas infrastructure (e.g. drilling equipment, pumping platforms, and pipelines) requires buffer zones or safety corridors (often as much as 305 m [1,000 ft] wide) that automatically eliminate potential sand resources from the dredging arena (Finkl and Khalil 2005). In fact, it is estimated that a 1 km (0.6 mi) long pipeline, along with the required federal buffer offsets, will render approximately 1.8 MCM of sediment inaccessible, assuming a dredge depth of 3 m (10 ft). Looking at this from an economic perspective, the placement cost of 1 cubic meter of sand from Ship Shoal to Caminada Headland has been estimated at approximately $21 (Khalil *et al.* 2018). In the absence of per cubic meter price of sand from Ship Shoal, if we assume the placement cost as its value then, the economic value of the volume of sand rendered unavailable by a 1 km (0.6 mi) pipeline can be estimated at approximately $38 million. Considering that coastal Louisiana has tens of thousands of kilometers of pipelines, the economic impact to the coastal protection and restoration program is substantial.

Many of these aforementioned pipelines are no longer in service. The regulations to remove decommissioned pipelines are often not enforced. Recently, BOEM and the Bureau of Safety and Environmental Enforcement (BSEE), along with the state of Louisiana, have been working together to more comprehensively enforce these regulations and require the oil and gas industry to remove the decommissioned pipelines, specifically in areas identified as containing "significant sediment resources." This surficial sediment map plays an important role in these decisions by identifying areas where pipelines are overlain on potential sediment resources. In addition, it should also be noted that environmental and cultural concerns over dredging might further limit the accessibility of the surficial sediment deposits for restoration purposes. Cultural resource assessments are required as part of the permitting process and if artifacts or hazards are found, these might further reduce the size of potential borrow areas.

The surficial sediment maps developed in this effort also have an important role in gap analyses for future work. They help identify areas where data are lacking and help focus future surveys to target these areas. They also help to prioritize the need and sequence of exploration for sediment, and especially sand, for restoration. Louisiana has a very highly developed coastal program with multiple restoration projects occurring in tandem (CPRA 2012, 2017). The surficial sediment maps allow the state to take a regional approach to sediment management, which saves the state considerable dredging cost and uses the very limited sediment resources that are available for coastal restoration in the most efficient way possible. These maps aid in monitoring plans by identifying gaps where certain data types are either not sufficient or altogether absent.

These maps along with other data residing in LASARD are being used to develop the Louisiana Availability and Allocation Program (LASAAP). This is a planning tool that couples compatible sediment sources with restoration projects identified in the Coastal Master Plan. This tool will analyze dredge and construction locations along with hydrographic, geotechnical, and geophysical data in a spatial format in order to efficiently and equitably manage valuable sediment resources. The tool's primary goal is to link the sediment needs of the state's marsh, barrier island, and ridge creation/restoration projects to the various coast-wide and riverine sediment sources (Khalil and Freeman 2014; Khalil *et al.* 2018).

With the understanding that these natural systems don't follow political boundaries, GOMA's Data and Monitoring Team is spearheading GMMMP. GMMMP includes coordinating data collection and data management activities, sharing habitat mapping data and eliminating duplication of effort which will maximize the effectiveness of limited resources used to understand and manage the extent and condition of Gulf habitats. Under this focus area several actions were identified including "…identifying mapping needs and requirements to allow for informed coastal management decisions and data gap analysis…" (GOMA 2009). During this effort it came to light that geophysical, hydrographic, and sedimentological data were collected over a period of time throughout the northern Gulf of Mexico from Texas to Florida. Some of these data have already been compiled and are available in state level databases such as the Texas General Land Office's (GLO) Texas Coastal Sediments Geodatabase, and the Florida Department of Environmental Protection's (FDEP) Regional Offshore Sand Source Inventory (ROSSI). Some data are also available through NOAA or USGS databases. Based on these data, with some effort, surficial sediment distribution maps similar to those created for Louisiana could be developed for the entire northern Gulf of Mexico.

Following the Deepwater Horizon oil spill, RESTORE Council CMAP efforts were initiated to develop an inventory of monitoring and mapping data to provide consistency and provide a common platform to aggregate data across the northern Gulf of Mexico. The sediment distribution maps developed for Louisiana may provide a template for this effort in several ways, viz. development of various types of biotic and abiotic habitat maps, identifying areas with inadequate availability of various data types.

In regional northern Gulf of Mexico context, such maps could be used for several purposes. Ultimately, these maps could be used to provide first-order volume estimates for each sediment resource. These maps could play a significant role in the planning and management of sediment resources throughout the Gulf of Mexico for coastal restoration purposes. Last but not the least these maps can help identify data gaps and in focusing of additional resources.

CONCLUSIONS

This is a first attempt to compile a map showing the surficial distribution of sand, fine-grained sediment (silts, clays, etc.) and mixed sediment for the entirety of coastal Louisiana and to use these maps to estimate first-order volumes of sediment available for restoration efforts. This effort was only possible because data were available in a uniform format in LASARD. The resulting map is a living document and is updated when additional data become available. Because the density of data used to create this map is sparse, it is considered a first-order map. However, it is still valuable in several respects. These maps are being used in planning the restoration efforts in Louisiana via the Coastal Master Plan (CPRA 2012, 2017). These maps also help guide state and federal regulatory agencies in efforts to protect areas of significant sediment resources and form the basis/template for a variety of maps including various habitat maps. Moreover, due to the fact that the presence of oil and gas infrastructure can limit sediment availability, these maps can also be used to help prioritize removal of such infrastructure.

This map forms the basis of a sediment management plan for Louisiana and detailed exploration efforts for sediment/sand. As previously stated, in addition to resources planning the value of such maps are significant in regulatory enforcement. These maps play an important role in gap analyses. Finally, similar first-order surficial sediment distribution maps could be developed for the entire northern Gulf of Mexico (NGOM) if sufficient hydrographic, geophysical, geotechnical, and sedimentological data are available from federal and state agencies, academic institutions, and private industry. These maps would play a major role in the management of sediment resources throughout the NGOM by allowing each state to take a regional approach to sediment management. As indicated earlier, these maps may help regional efforts like GMMMP and CMAP in several ways especially in identification of data gaps but most importantly serve as a template to adaptively manage any such future effort either by individual states and/or GOMA or RESTORE.

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BOOK REVIEW:

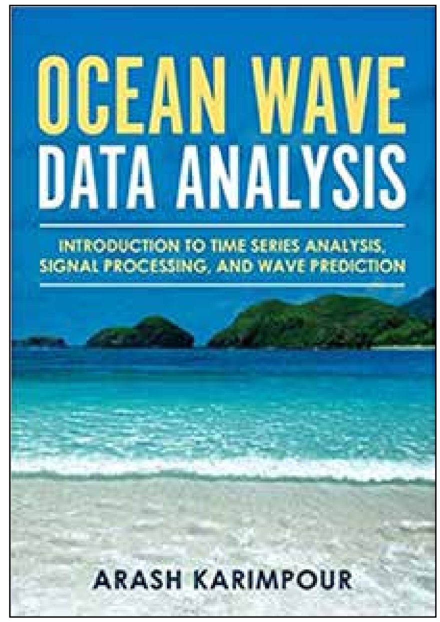
Ocean Wave Data Analysis: Introduction to Time Series Analysis, Signal Processing, and Wave Prediction

By

Arash Karimpour

May 2, 2018 ■ 304 pages, paperback ■ $41 ■ ISBN 978-0692109977

Reviewed by Atilla Bayram



Coastal field studies are performed for the purpose of scientific research, numerical model validation, or pre- and post-construction monitoring of the impact of coastal structures. Data collected from field studies often require in-depth analyses of measured quantities and distillation of large amounts of information into a few key parameters to describe the conditions observed in nature. In this book, basic concepts of data acquisition and preparation for field data collection are described in a concise and clear manner for coastal engineering and oceanography studies.

A large part of the book is devoted to an introduction to time and frequency domain data analysis, including window functions, digital filters, and data smoothing. The book is enhanced by codes written in MATLAB, GNU Octave, and Python. Step-by-step methods to calculate wave properties from pressure and velocity data in time and frequency domains are presented with practical applications in mind. Calculation of the secondary wave properties besides wave height and period is also covered and methods to separate seas and swell waves are explained.

The final section of the book concerns modeling and prediction of coastal wave properties using some of the most prominent parametric wave models, including hurricane models. The application of the widely used numerical spectral phase-averaging model, SWAN, is described using a step-by-step approach starting from input preparation (grid, model bathymetry, wind, water level data, etc.) to model execution and debugging of errors.

Professionally, I probably most benefited from reading the chapter on calculating secondary wave properties. The notation was done with care, extending for 14 pages. Though the index was extremely short, references are comprehensive and up-to-date. The book is authoritative and will be of a great value to graduate students as well professionals in the fields of coastal and ocean engineering.

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