GRAPPLING WITH FLOODING IN AN ERA OF ACCELERATING SEA-LEVEL RISE

The Final Report of
Growth and Planning Panel
At The Louisiana Universities
Marine Consortium's
DeFelice Marine Center in Cocodrie, LA

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I. Overview and Introduction

Flooding poses one of the most serious risks to the long-term viability of the Louisiana Universities Marine Consortium's (LUMCON's) Defelice Marine Center. Floods can limit personnel access to the marine center, lead to loss of power and other utilities, and corrode and degrade the physical infrastructure. When accompanied by high winds, flood events can be tremendously damaging. Floods at LUMCON's Marine Center have been increasing in frequency and depth for decades. This trend is almost certain to continue—and—accelerate in the years ahead as climate changes and global sea-levels rise, coastal Louisiana continues to subside, and as land is lost along Louisiana's coast.

Questions of how LUMCON's Marine Center should cope with flooding are particularly vexing. On one hand, the future is increasingly precarious: LUMCON employees often wonder if they will be able to get to work, resident and visiting scientists wonder whether reduced access will compromise experiments and analyses, while LUMCON administrators and maintenance staff must operate a building that faces increasingly difficult conditions (FIG 1).

Fig. 1

Satellite image of Louisiana, with the arrow pointing to the location of LUMCON's Marine Center. Image source: NASA and Louisiana State University's Earthscan Lab

And yet, these changing coastal conditions increase the need for marine research and education. Louisiana has one of the largest, most complex, and economically-important coastal systems in the country, and the state has a vested interest in understanding this coast, and educating its residents about its benefits and hazards. Meeting Louisiana's needs to understand, research, restore and sustain its coast calls for a thriving marine laboratory located on the coast. *The immersive hands-on experiences with a changing coast that a marine laboratory offers, gives students, researchers, and the public a perspective and a set of research opportunities that cannot be fully replicated on a main campus or through a virtual network*.

Furthermore, given the ongoing acceleration in global sea-level rise (IPCC 2013), the challenges faced by Louisiana today will be experienced by coastal systems across the Gulf Coast and the globe this century—creating a massive suite of research needs for physical, ecological and social scientists (NASEM 2018). **Research performed and lessons learned at LUMCON today can inform actions that are needed across the world tomorrow** (FIG 2).

Fig. 2A

When LUMCON's Marine Center floods, so do other nearby facilities. Pictured here are gas pumps at Coco Marina. Photo Credit: A. Kolker

Fig. 2B

A LUMCON researcher attempts to enter the building when the parking lot is flooded. Photo Credit: A. Kolker

To understand flood-related issues at LUMCON's Marine Center, a panel was convened to examine how LUMCON can both grow in a challenging environment, and plan for a changing future. The panel's name, "GRAPPLE," stems from the need for GRowth And PLanning, and also emphasized the need to grapple with, and address, serious site concerns. The purpose of this panel was to identify current and future hazards while presenting a strategy to move forward. The report is a comprehensive overview, one that provides directions and some specific actions. More detailed work will be needed from architects and engineers to further analyze the facility and produce plans for future adaptations. Furthermore, since this report focuses on long-term planning hurricane preparations and response should be managed through regular disaster preparedness mechanisms (FIG 3).

Fig. 3

Aerial view of LUMCON's Marine Center. Photo Credit: Taylor Jones

The panel consisted of 13 people and drew from academia, government, and the private sector (page ii). Members included university scientists who study coastal change, a representative from Louisiana's Coastal Protection and Restoration Authority, an individual from an NGO focused on coastal issues, and a local resident who runs a second generation surveying and engineering business. The statements expressed in this document represent a consensus view of the panel and the scholarly work of those listed as formal authors, and do not necessarily represent official statements of or the institutions they represent.

During the development of this report, LUMCON announced plans to move forward with a new, expansion campus in Houma in combination with several other institutions. That facility, the Houma Marine Education Campus, while largely focused on workforce development and technical activities, could provide some working environments for marine center staff during floods. Since that campus is still being designed and planned, it is impossible to fully incorporate the Houma campus into this planning document. However, this report makes clear that there are avenues for coordination and cooperation between the LUMCON campuses. The new campus offers potential strategies for resilience and an expansion of LUMCON functions—though it also comes with potential pitfalls and complications—which are also addressed here.

II. Why Do We Flood at LUMCON's Marine Center?

Floods at LUMCON's Marine Center are the result of a complex web of local, regional, and global processes, coupled with LUMCON's inherent proximity to the sea. It is important to understand all of these processes, how they have taken LUMCON to its current state of flood risk, and how this might change in the future.

A. Land Loss

Coastal Louisiana has experienced nearly 4,800 square kilometers (1,853 square miles) of land loss since 1932, during which the Terrebonne Basin has lost nearly 1302 square kilometers (504 square miles)—amounting to 29% of the total land area of the basin (Couvillion et al. 2017). This land loss results in a decreased coastal buffer that increases flood stress on Cocodrie and raises water levels more broadly across the region (LACPRA 2017).

B. Subsidence

Subsidence is the lowering of the land surface, and it is common across coastal Louisiana. In Louisiana, subsidence results from a number of factors that include the deterioration of marsh peat, the extraction of fluids including groundwater and hydrocarbons, sediment loadings on earth's crust, and potentially movements along the geological faults within the region (Yuill et al. 2009). While the scientific community often debates the exact rates of subsidence across Louisiana's coast, there are several lines of evidence that shed light on subsidence rates at LUMCON's Marine Center (FIG 4) including:

Fig. 4

Survey marker on the Marine Center grounds. When this survey marker was established, it was placed flush to the ground, and the resulting differential today is the result of shallow subsidence in the area.
Photo Credit: A. Kolker

1. Blum and Roberts (2012) examined data from long running global positioning system (GPS) stations across coastal Louisiana, including one station fixed to the roof of the main building at LUMCON's Marine Center that indicates a subsidence rate of 6 mm/yr (Blum and Roberts 2012). This value is likely to be a lower-end value because the building rests on pilings and is probably subsiding slower than other parts of the property (FIG 5).

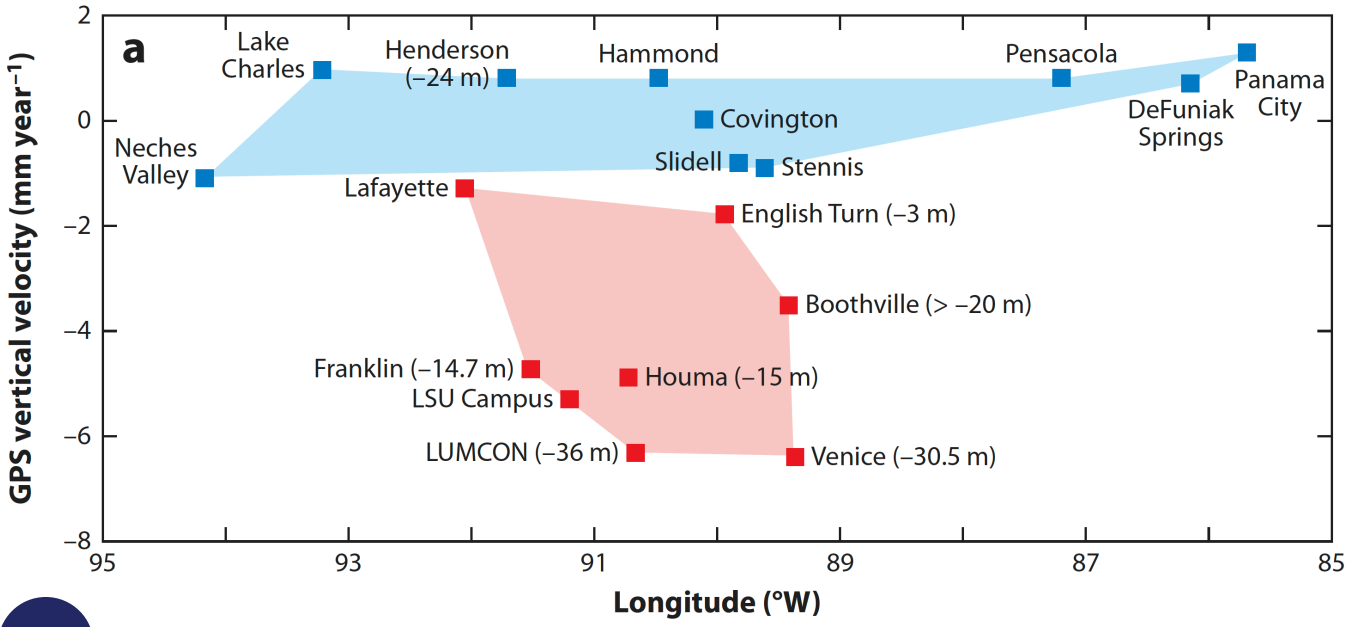

Fig. 5

Vertical velocities (mm/yr) for continuously running GPS stations along the northern Gulf of Mexico. Stations in red are in the Mississippi River Delta, whereas stations in blue are along the main continent of North America. This plot is redrafted from Blum and Roberts (2012).

2. A water level gauge operated by the US Army Corps of Engineers located on LUMCON's wooden dock records a rate of relative sea-level change of 2.02 cm/yr for the period 2011-2018 (Rivergages.com; Bayou Petit Caillou at Cocodrie 76305). This value is likely a higher-end value because the dock rests on pilings that are not anchored deeply and the dock itself may be subsiding. Additionally, weather related forcings can bias short-term water level records.

3. There are several surveying benchmarks across LUMCON. One benchmark, which was placed level with the ground when it was established in 1991 was 9 inches (22.8 cm) out of the ground in 2017. This would suggest an average rate of subsidence of 8.8 mm/yr.

4. Louisiana's coastal Master Plan uses a subsidence map that predicts the region near LUMCON experiences between 6 and 25 mm/yr of subsidence over a constant period of time. The Master Plan's low and medium scenario are based on the assumption that subsidence rates are 20% of this range, and the high scenario is based on 50% of this range, giving estimated rates of 9.8 mm/yr and 15.5 mm/yr (FIG 6).

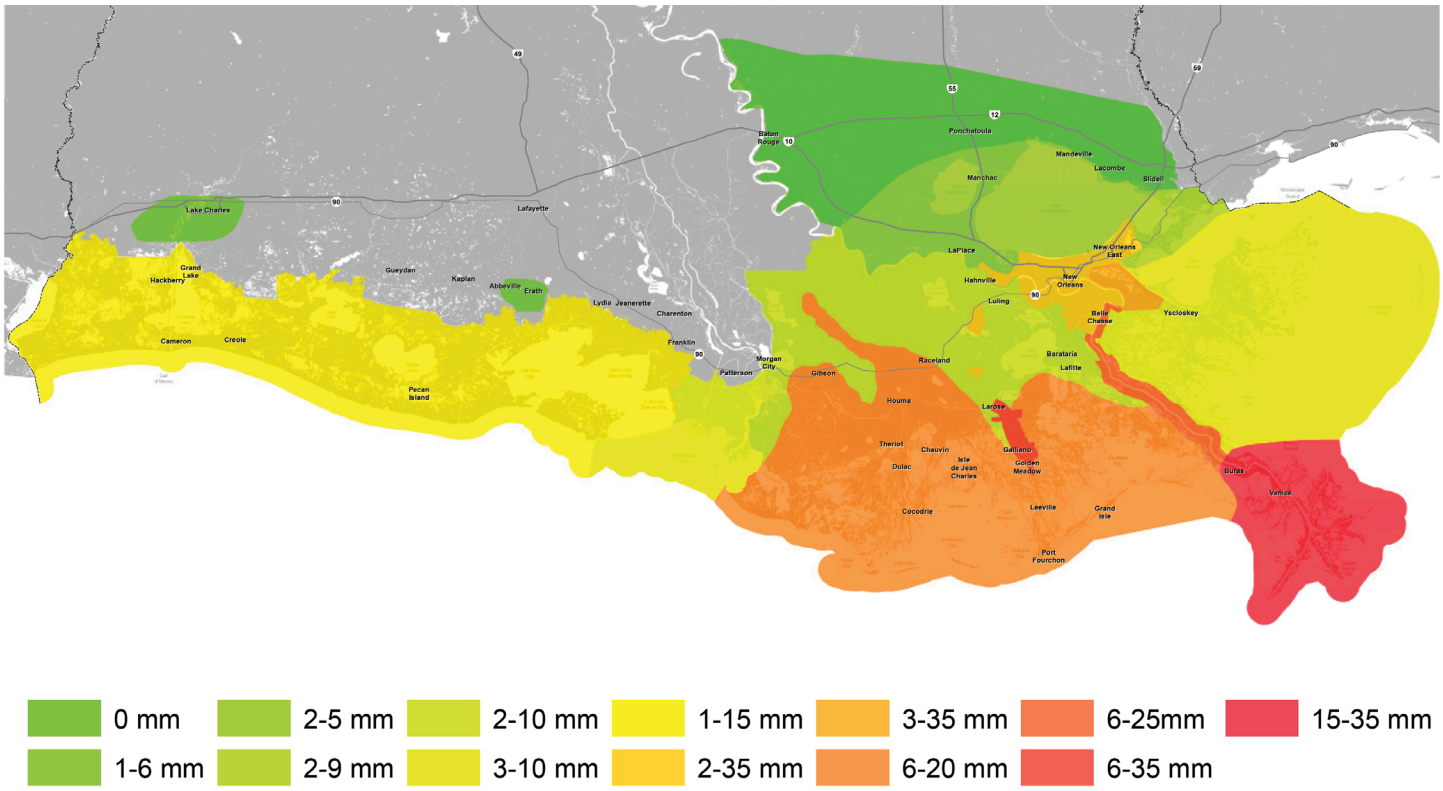

Fig. 6

Subsidence map of coastal Louisiana used in the Master Plan. Source: LAPCRA (2017)

5. An analysis of repeat surveys using Light Distance and Ranging (LIDAR) shows patterns of land surface elevation change over the period 2003-2013. Preliminary results suggest that much of the LUMCON property is subsiding at rates ranging from 3 to 5 cm/yr, with higher rates observed near the bulkhead and accretion observed along the canal that cuts across the marsh to the west of the marine center (Woock et al. 2018), though this work is still ongoing and values may need to be fully calibrated (FIG 7).

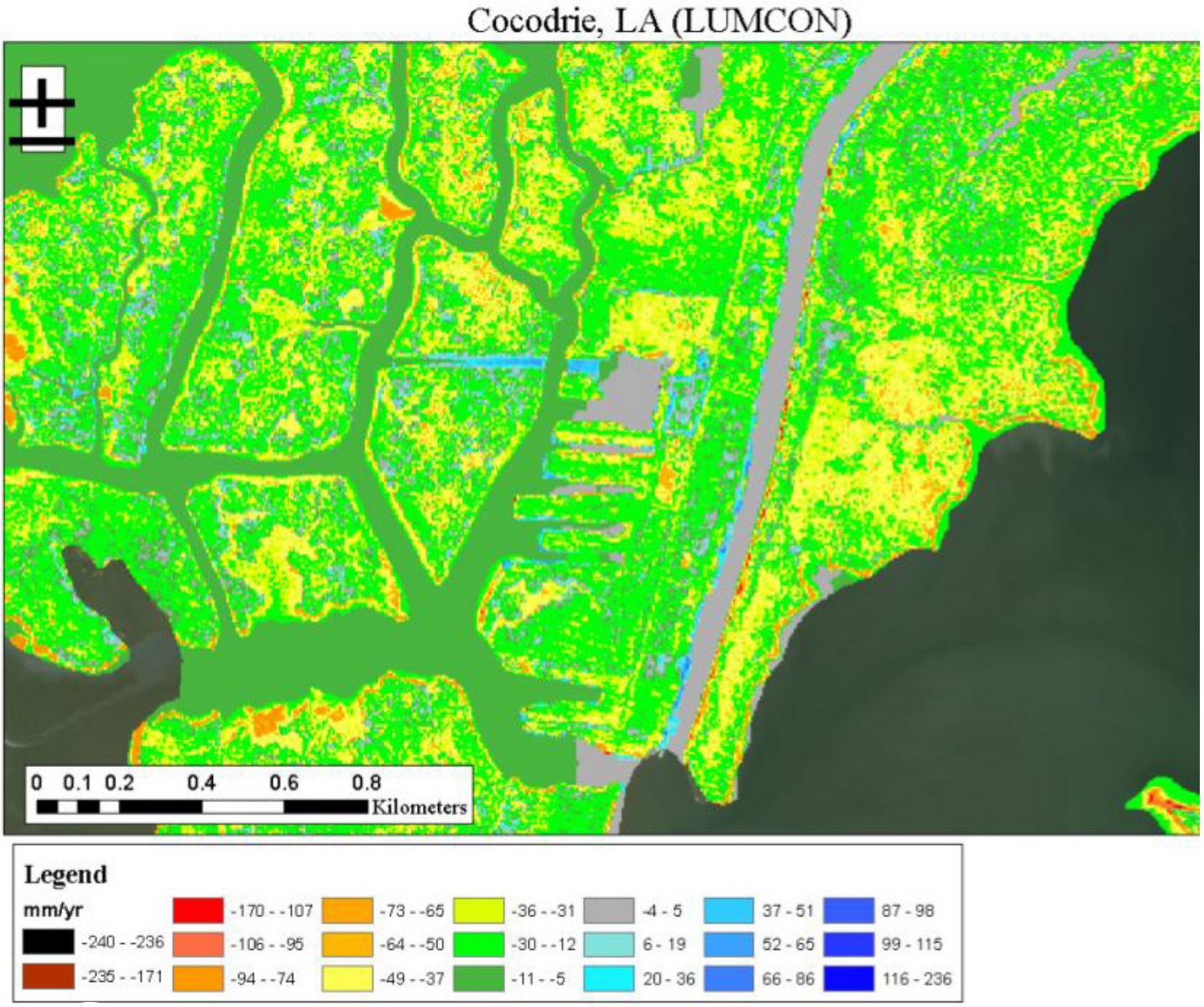

Fig. 7

The Preliminary subsidence map for areas near LUMCON's Marine Center. Image Source: Woock et al., (2018), Woock In Prep (2019)

C. Climate Change & Global Sea Level Rise

An increase in the heat content of the Earth's atmosphere and ocean, together with an increase in freshwater contributions to the global ocean from ice sheet and glacial melting, is causing ocean levels to rise globally (IPCC 2013). In the 20th century, the rate of global sea level rise was relatively modest, about 1.5 mm/ yr. Rates have accelerated since the early 1990s as a result of global warming and are now about 3.3 mm/yr (Church et al. 2013). Sea-level rise rates are likely to accelerate this century, impacting coastal systems worldwide, compounding flood risks that have been increasing in many areas for decades (Sweet et al., 2017, FIG 8).

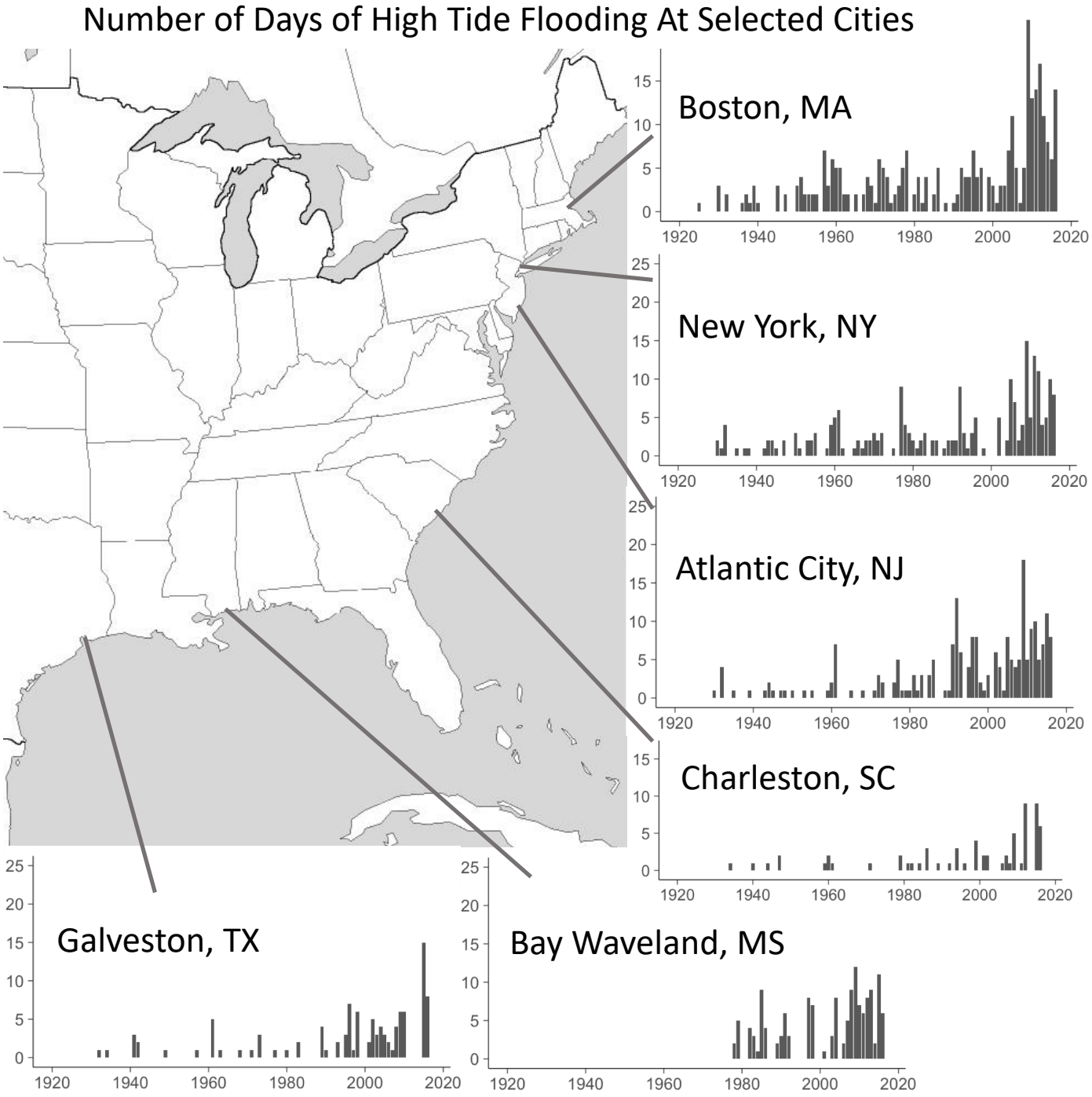

Fig. 8

Number of days of excessive high tide flooding at selected cities along the US East and Gulf Coast. Data and tidal thresholds are from Sweet et al. (2014).

D. Morganza to the Gulf

The construction of the Morganza to the Gulf (MTG) levee, a 72-mile system that cuts through much of the Terrebonne Basin, may be increasing flood levels seaward of the levee footprint. While the impacts of the MTG system on both nuisance and extreme flood levels need to be better studied, the Environmental Impact Statement associated with the MTG suggests that it could increase flooding during a 100-year event in the areas near Cocodrie by about 3 feet (USACE 2013) from deflection of surge from the levee face towards Cocodrie.

E. Hurricane and Tropical Cyclones

Hurricanes and tropical cyclones present the most dramatic form of flooding to LUMCON's Marine Center. Surges from hurricanes such as Andrew, Katrina, Rita, and Gustav raised water levels at LUMCON's Marine Center by 4-9 feet. Data developed for Louisiana's Coastal Master Plan predict that under current conditions, a storm with a 1% chance of occurring in any given year will lead to a storm surge between 3 to 4.5 meters (10 to 15 feet) in many areas near Cocodrie, with some areas experiencing over 4.8 meters (16 feet) of flooding (LACPRA 2017). As discussed below, these flood risks are expected to increase in the years ahead.

F. Southerly Winds & the Cold Front Cycle

Winds out of the southeast present one of the most common drivers of nuisance flooding at LUMCON. Often these floods are associated with approaching cold fronts, in which water is forced onshore during the approaching phase of the front and offshore during the post-frontal phase (Roberts et al. 1989; Kineke et al. 2006). Preliminary analyses of data from recent years indicate that there will be at least a small amount of water in the Marine Center's parking lot when there are onshore winds of about 9 meters per second (20 miles per hour) and a normal or spring tide.

G. Analysis of Flooding History at LUMCON's Marine Center

By almost any account, flooding at LUMCON's Marine Center is increasing and becoming more problematic. The number of times that the LUMCON parking lot floods was determined by counting the number of days that high water exceeded an elevation threshold at the long-running US Geological Survey gauge at Caillou Lake. Two thresholds were used, one at 82 cm (2.7 ft) above gauge 0 and the other at 76 cm (2.5 ft) above gauge 0, with the former being close to the level preferred by the LUMCON monitoring program, and the latter being preferred by a related project (Kolker and Sharp 2018). In either case, the trend is clear: The Marine Center's parking lot is experiencing substantially more flooding now than it did at the beginning of the century. Whereas flooding at LUMCON's parking lot used to occur several times a year, it now occurs several dozen times a year (FIG 9).

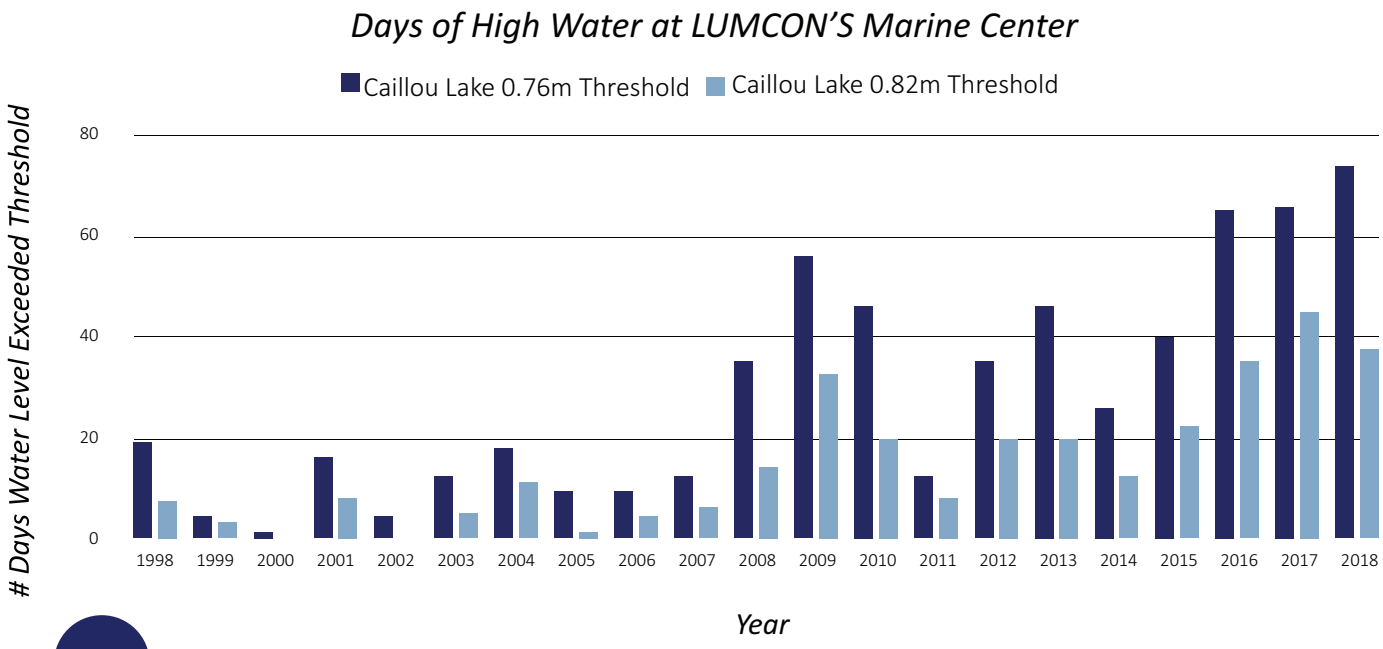

Fig. 9

Number of days of high water in south Terrebonne Parish, as determined by the long-running USGS Caillou Lake gauge.

Flooding at the Marine Center must also be viewed in light of the regional context. The lowermost part of Bayou Petit Caillou is located outside of the recently constructed Morganza to the Gulf levee. The roller gate that seals the levee at Highway 56 will close during high water. At present, closures have been limited to tropical cyclones—a result of the relatively high elevation of the road at the location of the gates. However, with continued subsidence and sea-level rise, the meteorological threshold for closure is likely to deteriorate. During the recent resilience planning exercise, the State of Louisiana dedicated funds for voluntary buy-outs to the roughly half-dozen permanent residents in Cocodrie located outside of the Morganza (lasafe.la.gov). There are several small business that exist outside the Morganza and a relatively large natural gas facility. To some extent, vehicle and utility access to LUMCON's Marine Center is linked to the viability of nearby businesses and camps.

LUMCON's Marine Center has a unique place in the community of south Terrebonne Parish. The institution is a point of pride for many local residents, many of whom are tied to Louisiana's coast through their job, diet, lifestyle, and culture. LUMCON's Marine Center is also a large, stable employer playing an important role in area's economy. LUMCON uses the services of many local business—such as hardware stores, marine supply stores, and vehicle repair shops.

Staff, students, and visiting scientists are regular guests at local restaurants. Any change to LUMCON's Marine Center could have an impact on this bayou community, its residents, and its economy.

III. Projections of Future Flood Changes at LUMCON'S Marine Center

To understand the impacts of future sea-level rise at LUMCON's Marine Center, the GRAPPLE panel examined several data sets and projections of sea level, which led to similar conclusions for future flood risks at the Marine Center. Flood maps developed as part of Louisiana's 2017 Coastal Master Plan incorporate subsidence and global sea-level rise projections provide estimates of the impacts of a storm with a 2%, 1%, and 0.2% chance of happening in any given year (i.e. a 50-year, 100-year, and 500-year storm). Maps were generated for current conditions and in the future under various master plan and sea-level rise scenarios (LACPRA 2017). All projections indicate that many areas in and near Cocodrie will experience flood waters of 4.5 meters (15 feet) or greater for a 100-year event today. In the future, the areas in south Terrebonne experiencing 4.5 meters (15 feet) or more of flooding will only expand (FIG 10).

GMSL Scenario (meters)	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2120	2150	2200
Low	0.03	0.06	0.09	0.13	0.16	0.19	0.2	0.25	0.28	0.30	0.34	0.37	0.39
Intermediate - Low	**0.04**	**0.08**	**0.13**	**0.18**	**0.24**	**0.29**	**0.35**	**0.4**	**0.45**	**0.50**	**0.60**	**0.73**	**0.95**
Intermediate	0.04	0.10	0.16	0.25	0.34	0.45	0.57	0.71	0.85	1.0	1.3	1.8	2.8
Intermediate - High	**0.05**	**0.10**	**0.19**	**0.30**	**0.44**	**0.60**	**0.79**	**1.0**	**1.2**	**1.5**	**2.0**	**3.1**	**5.1**
High	0.05	0.11	0.21	0.36	0.54	0.77	1.0	1.3	1.7	2.0	2.8	4.3	7.5
Extreme	**0.04**	**0.11**	**0.24**	**0.41**	**0.63**	**0.90**	**1.2**	**1.6**	**2.0**	**2.5**	**3.6**	**5.5**	**9.7**

Fig. 10

Global sea level predictions for the United States. Source: Sweet et al. (2017)

An alternative but complementary approach can be developed by combining predicted sea level rise from scenarios established in Sweet et al. (2017) and local subsidence scenarios based on LUMCON-specific data. This data suggests between 12 and 37.7 cm (4.7 to 14.8 inches) of local relative sea-level rise at LUMCON's Marine Center by 2030, with most projections being close to 15-23.4 cm (6 to 9 inches) (FIG 11). Furthermore, analyses conducted as part of this study, and by LUMCON's monitoring team, suggest that the difference between an inconvenient flood (one in which the parking lot has water, but does not immediately impact activities) and a problematic flood (one that shuts down most of LUMCON's daily operations) is about 15 cm (6 inches). **Projections used in this analysis suggest that within about 10-15 years, regular tidal and frontal passage-induced flooding could lead to conditions that shut down LUMCON's Marine Center several dozen times a year, if no action is taken** (FIG 12).

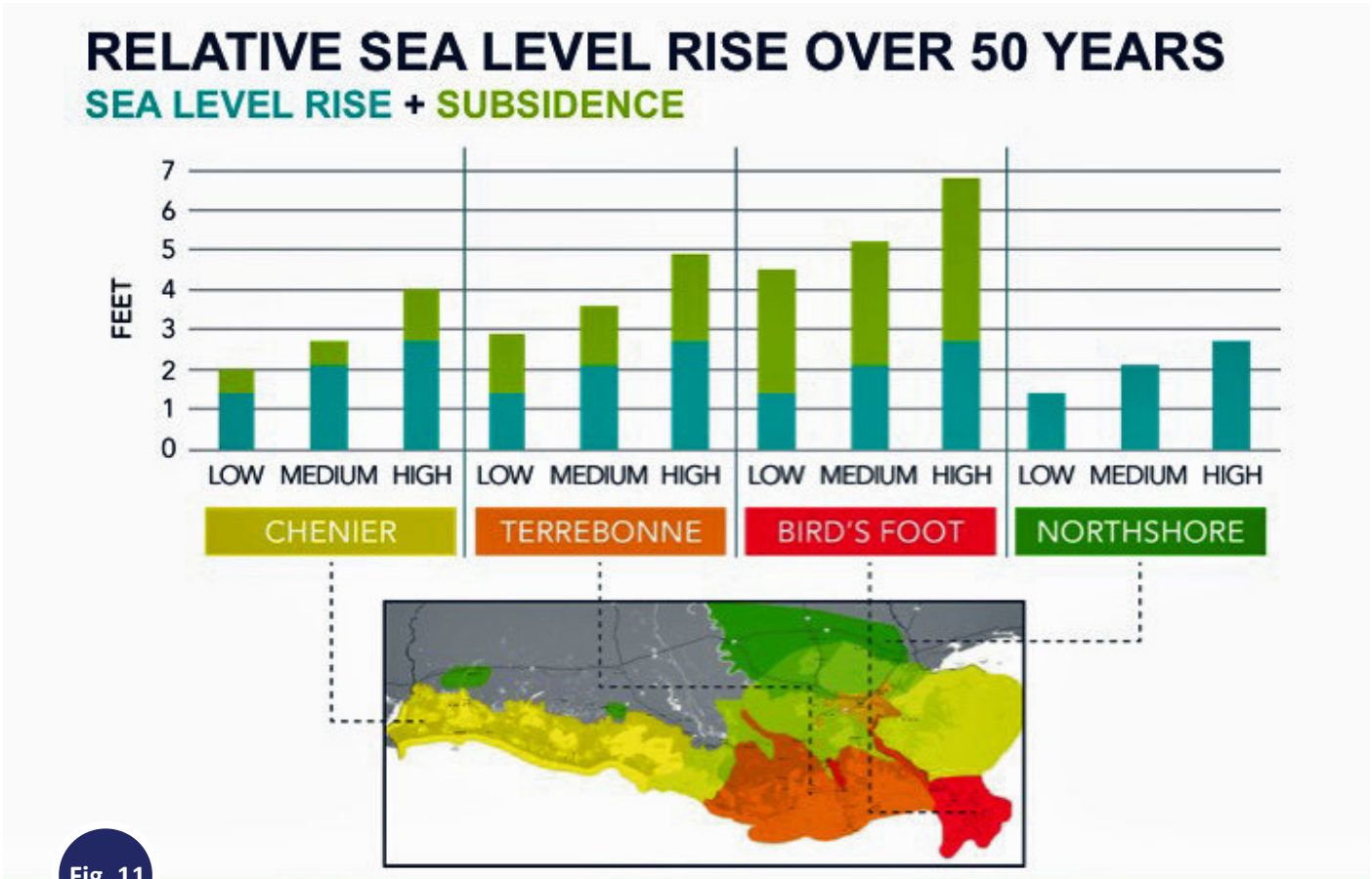

Fig. 11

Relative sea-level rise projections for coastal Louisiana for the next 50 years. Source: LACPRA (2017)

Near-Medium Term RSLR Projections for LUMCON'S Marine Center Total cm (Inches) by Date

	2020	2025	2030
Current Trends			
Low	2.8 (1.1)	7.4 (2.9)	12.0 (4.7)
Medium	3.6 (1.4)	9.6 (3.8)	15.2 (6.0)
High	6.9 (2.7)	18.4 (7.2)	29.9 (11.8)
With Accelerated SLR			
Low	4.6 (1.8)	12.2 (4.8)	19.8 (7.8)
Medium	5.4 (2.1)	14.4 (5.7)	23.4 (9.2)
High	8.7 (3.4)	23.2 (9.1)	37.7 (14.8)

Rates of accelerated sea level rise are from Sweet et al., (2017) intermediate scenario, and do not cover the full range of potential sea level scenarios.

Fig. 12

Near- to medium-term relative sea-level rise projections for LUMCON's Marine Center, as determined for this report.

IV. Analysis of Present and Future Impacts of Flooding on Operations at LUMCON's Marine Center

Key staff at LUMCON's Marine Center were asked to brief the GRAPPLE committee on how flooding impacts present day and future operations. They were asked how their department currently copes with flooding, how an increase in flood frequency and depth would impact departmental functions, what potential exists to increase resilience or allow for adaptation, and how a full or partial relocation would impact the way their department functions and fulfills its mission. LUMCON departments/areas that were included in this analysis included research, education, administration, vessel operations, and facilities and maintenance (FIG 13).

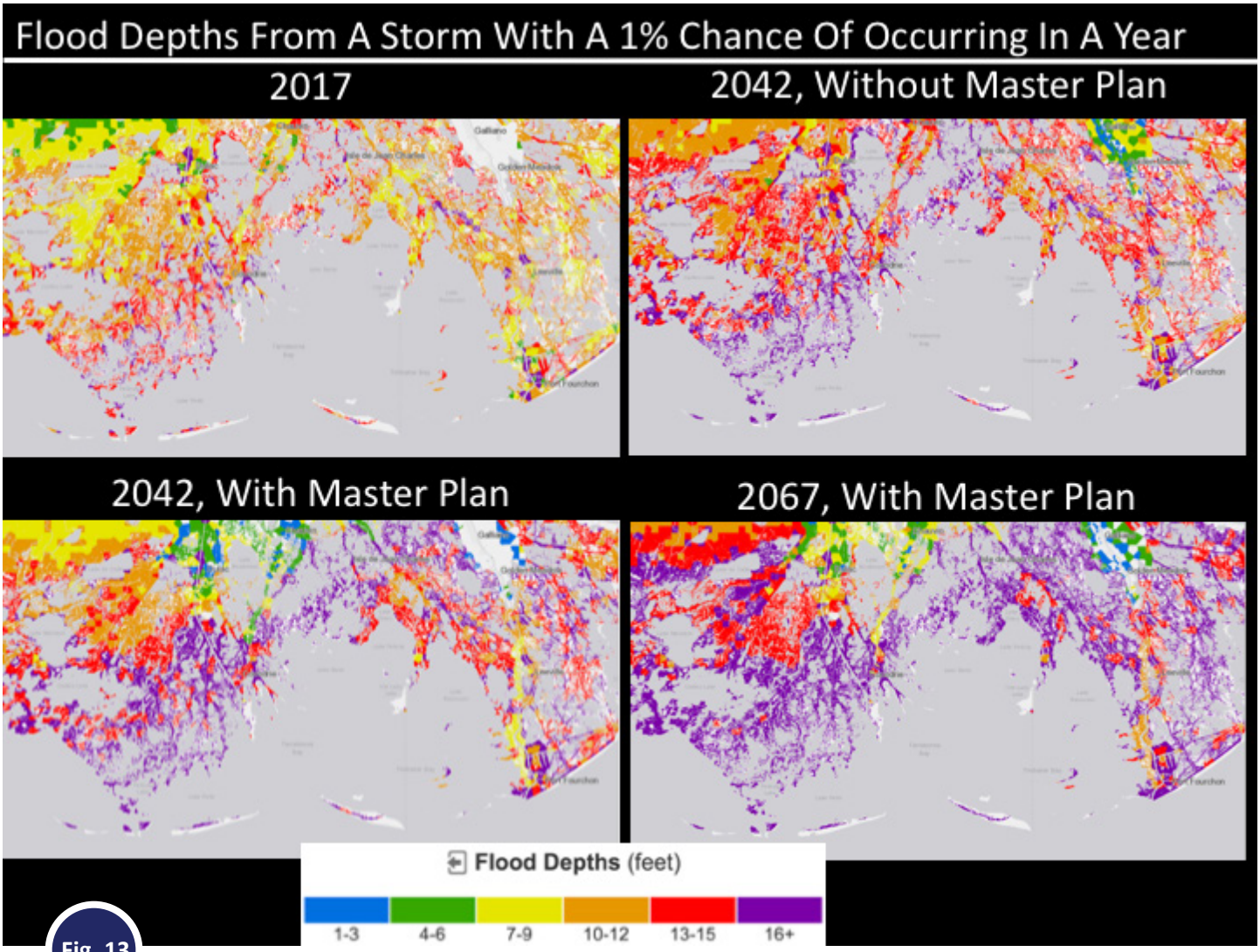

Fig. 13

Projections of flood depths near LUMCON, as determined by Louisiana's Coastal Master Plan.
Image Source: https://cims.coastal.louisiana.gov/masterplan/

A. Research

1. The Current Situation

Of all of LUMCON's functions, coping with flooding poses the greatest set of complications for LUMCON's researchers, which are the core of LUMCON activities and a major source of funds for LUMCON. Challenges include:

a. Power outages

Flooding in the parking lot has led to problems with numerous utilities, including the electrical system. These power outages, if they occur unexpectedly, can be detrimental to sensitive scientific equipment and/or experiments, even if they occur for a short time. Power outages that occur for extended time periods (> 24 hours) can be damaging to other aspects of LUMCON's research enterprise. For example, aquaculture facilities require circulating water for the survival of fish, wet lab and marsh mesocosm facilities require power to move and aerate water critical to experiments, and should cold storage warm and thaw in extended blackouts critical samples could be lost. It should be noted LUMCON has recently made advances in keeping critical circuits on generator power and improving power lines, which has improved resiliency.

b. Closures

Closure of the Marine Center is particularly challenging for researchers, even if power is maintained. For example, many laboratory procedures are conducted over an extended period of time and require regular monitoring and assessment by researchers. Furthermore, many scientific instruments must be shut down in a controlled manner and recalibrated when turned back on, which takes time. Operating scientific instruments must be coordinated with supplies and deliveries, such as the availability of analytical gas. Closures of LUMCON's Marine Center can disrupt research activities, reducing data quality, and the impacts of a closure on research can be longer than the actual time that the building is closed (FIG 14).

c. Parking lot flooding

Flooding in the parking lot leads to a set of complications that are specific to researchers. For example, a flooded parking lot could make it more difficult to arrange the logistics of receiving heavy equipment or large-sized supplies that are necessary for research. An elevator closure, which can happen during flooding, would further complicate such issues.

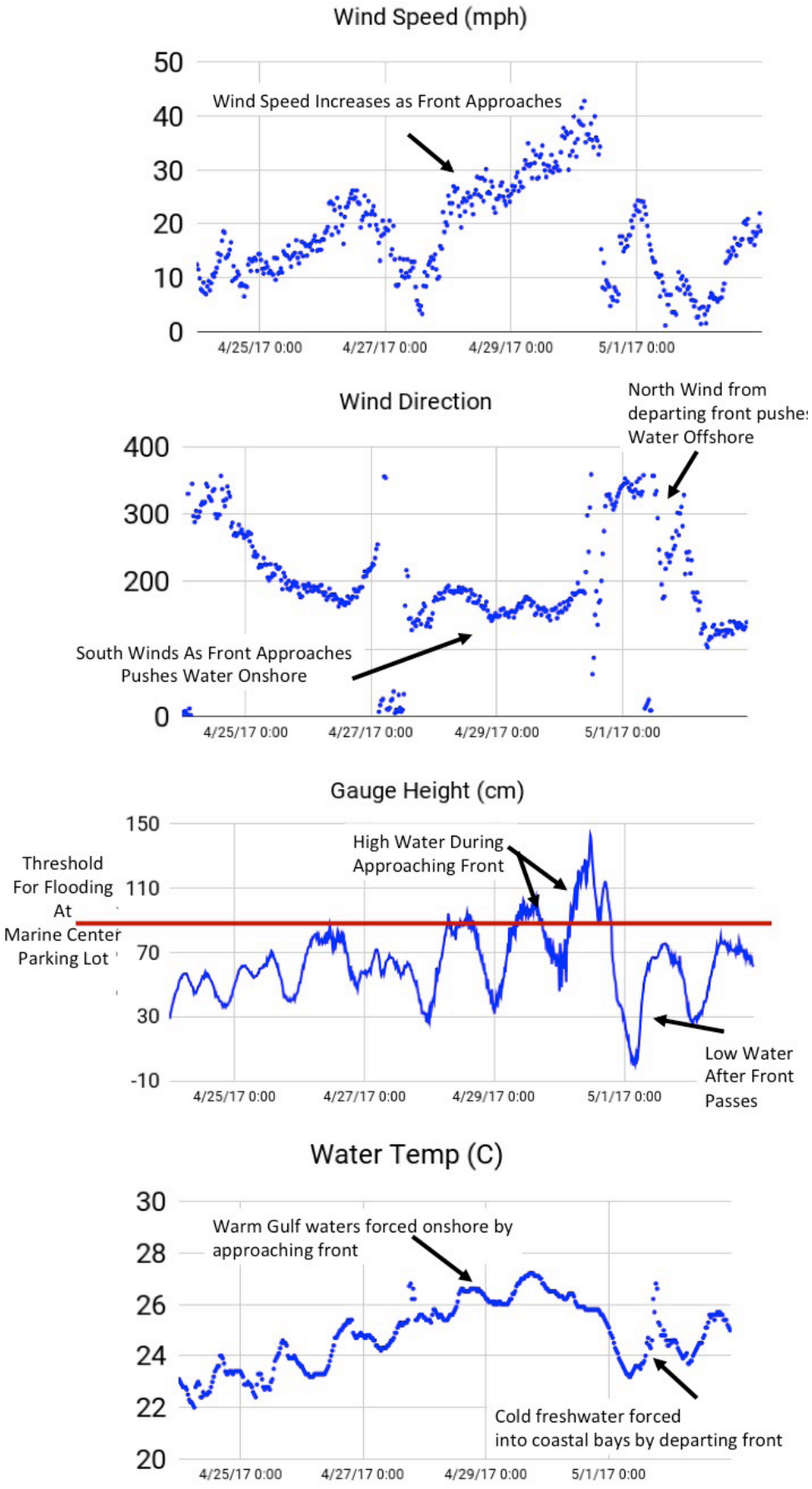

Fig. 14

Anatomy of a cold front and its impacts on water levels near LUMCON, as determined from the USGS Caillou Lake gauge.

d. Impact to field-based experiments
Flooding at LUMCON potentially poses unique complications for outdoor experiments. This is ironic as LUMCON's Marine Center offers an unparalleled opportunity to conduct field-based research and to perform manipulative experiments in ambient conditions. However, floods can also present hazards to the pipes, mounts, sensor, and wiring used in such experiments, potentially increasing costs and the logistics of conducting marine research.

e. Loss of research competitiveness
LUMCON's reputation as a world-class research institute depends on the capacity for resident faculty to maintain vigorous research programs. Closures, power outages, and impacts to outdoor scientific infrastructure can reduce that vigor, threatening research competitiveness. Pursuing a competitive research program often requires investigators to work substantially more than 40 hours a week. The need to dedicate extra time to research can be particularly critical for early career faculty who must show productivity in a specific time frame. While this committee did not define an exact number of days that a researcher can go without accessing their lab, several panel members felt more than 10 to 15 days of closures could lead to negative career impacts.

2. Opportunities for Resiliency

Despite the challenges mentioned above, there are opportunities to increase research resilience at LUMCON's Marine Center.

a. Cloud computing
Many functions of scientific work are currently conducted on a computer, even those of a field scientist, and these functions can be done remotely in a dry environment. Writing proposals and papers and analyzing data, all critical components of a scientist's career, are generally done on a computer connected to the internet. Given the preponderance of cloud-based tools, coupled with the massive amount of environmental data online, major research functions can be done remotely.

b. **Increased flooding of lower Terrebonne Bay offers an unprecedented opportunity to study sea-level rise and its impacts to coastal systems and human infrastructure; LUMCON's Marine Center can serve as a "living laboratory" of coastal change moving forward.**

3. Impacts of an Increase in Flooding

An increase in flooding could result in a substantial lack of research competitiveness for researchers at LUMCON's Marine Center. Should flooding at LUMCON's parking lot increase from nuisance flooding several dozen times a year to problematic flooding several dozen times a year, this could result in numerous problems for researchers. Laboratory-based researchers would likely find themselves separated from laboratory equipment, while researchers with field equipment at ground level could find this equipment increasingly vulnerable to floods.

4. Impacts of Moving LUMCON's Marine Center

The prospect of a complete or partial relocation presents challenges and opportunities for LUMCON's resident researchers. The GRAPPLE committee considered both a partial and a complete move inland. A partial move inland would likely lead to the development of an analytical laboratory at the emerging Houma campus. This facility would be used primarily by technical staff with the remainder of research activities occurring at LUMCON's main campus in Cocodrie. A full relocation would result in LUMCON moving all activities to a new building while (likely) dismantling the current Marine Center.

A partial move inland would result in the following benefits:

a. The ability to both protect instruments while also maintaining access to the unique environments surrounding LUMCON's Marine Center (e.g. wetlands, living marine creatures, and Louisiana's unique coastal waters).

b. Allow research lab groups a base of operations and meeting space during closures.

A full relocation could:

c. Provide a more consistent and stable environment for laboratory equipment.

d. Reduce travel logistics for visiting scientists and instrument service personnel.

e. Result in a closer proximity to the member universities, thus increasing chances for some collaborations.

A partial move inland would result in several challenges:

f. Splitting of lab personnel
A partial relocation could result in the splitting the location of personnel associated with individual research labs, with some people located in Cocodrie and others located in Houma. This could result in reduced coherence among laboratory staff and potentially reduce communication and scientific interactions.

g. Reduced presence of research staff in other elements of LUMCON's program such as education and outreach.

h. Establishing a new facility could result in the need to purchase new lab equipment, which could be duplicative with equipment at the existing facility.

A full relocation to a more protected location could result in several complications:

i. Removal from the marine environment
Moving laboratory operations from Cocodrie would reduce access to the marine environment. This may reduce real-world observations about changes in the marine environment for researchers and could also shift their focus away from field-based research. For many LUMCON faculty, the appeal of working at a marine laboratory over an inland, on-campus location is the proximity to the marine environment. A relocation to a place like the Houma campus could be unappealing for many because such locations are neither a field-based location, nor on the campus of a research university. This could result in a reduced ability to attract and retain talented researchers.

j. Time and effort associated with moving
LUMCON faculty have put considerable effort into establishing their laboratory facilities at the Marine Center. Moving these facilities will be time consuming, and the associated effort could reduce morale.

k. Reduction in utility for Louisiana researchers
The Marine Center facility and its ground serve as critical field sites and provide facilities and "launching points" for dozens of researchers throughout the broader consortium. Without a facility located in the coastal zone, research by university researchers throughout the consortium may be limited.

B. Education
1. The Current Situation: Challenges

a. Access
As is the case for other aspects of LUMCON's Marine Center, flooding in the parking lot and resulting access issues can challenge marine education programs. This can be especially vexing for some K-12 educational programs, which bring large numbers of students, parents, and chaperones who can have a wide range of mobilities and personal tolerances for flooding.

b. Scheduling
LUMCON's Marine Center serves upwards of 5,000 students per year. If one class is canceled due to flooding, rescheduling can be problematic due to other existing reservations. However, challenges vary from program to program, and the logistics of rescheduling a half-day K-12 trip could be different from those associated with rescheduling a 3-week university course.

2.The Current Situation: Opportunities

The increase in flooding at LUMCON's Marine Center creates a unique opportunity to educate students and the public about the impacts of climate change, sea-level rise, coastal change, and their impacts on coastal communities and ecosystems. **By studying at LUMCON's Marine Center, students have a unique opportunity to learn about sea-level rise, climate change, and coastal hazards first hand. LUMCON is ideally situated to prepare a new generation of scholars, leaders, and educated citizens for these Twenty-First Century challenges.**

In this context the flooding of the Marine Center's parking lot becomes an asset. Students will be faced with a navigating challenges that they will likely face at homes or work in the years ahead. The opportunity to study wetlands and other coastal ecosystems that are rapidly changing in the face of climate change and sea-level rise will help prepare students to understand the plethora of global environmental changes that will occur in their lifetimes. *The importance of this opportunity to create an immersive learning experience for students to learn about accelerated sea-level rise and coastal change and its impacts to coastal ecosystems, and the people, industries, and infrastructure that rely on them cannot be understated.*

3. Impacts of Increased Floods

As flooding increases at LUMCON's Marine Center, the potential impacts on educational activities and programs will increase. While flooding in the last decade has caused few major adverse impacts to LUMCON's educational programs (except during hurricane related shutdowns), the potential for a logistically complex shutdown and resulting course rescheduling will increase in the years ahead. Given that LUMCON's educational programs are funded largely on fees collected from school groups, the chances of a financial impact is also likely to increase in the future if no actions are taken.

4. Impacts of a Potential Relocation

The potential for a move inland poses serious challenges for LUMCON's educational programs. While some educational activities occur in classrooms, the strength and uniqueness of LUMCON's educational programs are that they are place-based, hands-on experiential learning programs that require students to be in the marine environment. A full scale relocation inland would substantially impact LUMCON's ability to provide these unique experiences, while a partial relocation would likely allow for some educational activities to be maintained on site.

C. Administration

1. Current Risks Posed By Flooding

Flooding at LUMCON's Marine Center presents a range of challenges that arise from closure and the threat of closure. Securing the building in advance of a major storm requires about two days, and reopening the facility takes about one day (assuming that there is no major damage during the storm). This diverts personnel time and resources away from regularly scheduled activities—in addition to the time lost during closure. As discussed elsewhere in this report, such closures can reduce research competitiveness and the capacity for educational staff to reach students of all ages.

a. Logistics

The logistics of getting staff to work when the facility's parking lot is flooded is problematic for LUMCON's administration, reducing the ability of LUMCON staff to get to work and perform their duties. The threat of flooding also requires a significant time commitment from senior staff to assess the risks to the facilities and operations to determine if and when the facility needs to be closed.

b. Payroll

Marine Center closures can create payroll challenges. Salaried workers may get paid for days that they do not work, potentially creating budgetary problems, particularly for grants. Hourly employees may find their hours and thus pay reduced when LUMCON is flooded, potentially creating problems for their own pocketbooks and household finances.

c. Duties

As with maintenance staff (described below), preparing for flooding can cause staff to have their work duties diverted from normal activities to flooding related duties.

2. Strategies for Coping with Flooding.

Administration has several strategies for coping with flooding. In particular, many administrative activities have been moved to online, cloud based platforms. Thus some administrative functions (e.g. finance, some human resources) can be conducted by staff remotely, provided that they have access to appropriate computing equipment such as laptops and a good internet connection.

3. If Flooding Were to Increase

Increased flooding of LUMCON's Marine Center would increasingly impact administrative activities at LUMCON. A particular concern is the ability of administrative, financial, and human resources office staff to reach the facility and interact with the scientists, researchers, and educators that are critical to LUMCON's core mission. Additional burdens come from the need to manage staff that could see either decreased workloads (if they cannot reach the Marine Center), increased workloads (if they have increased efforts to repair and adapt to flooding), or increased paperwork associated with documenting flood impacts on operations.

4. Impacts of a Relocation

A shift of LUMCON's Marine Center to a location further inland poses both opportunities and challenges for LUMCON's administrative staff.

Some of the opportunities include:

a. The potential for a larger and more diverse hiring pool, as LUMCON would be located in a more populated location.

b. Reduced need to pay salaried employees for flooding days in which no work can be done.

c. Closer proximity to Baton Rouge, which may make it easier for administrative staff to meet with key personnel in state government.

However, several significant challenges exist in any relocation scenario. In the event of a partial relocation, challenges include:

d. The separation of administrative staff and the researchers, educators, and vessel operators they support could lead to miscommunications that could impair functioning.

e. Separating researchers, administrators, and other staff could reduce LUMCON's informal but collegial workplace environment, which many LUMCON employees consider a positive element of employment.

f. The increased complexity of maintaining operations at two facilities.

In the event of a full relocation challenges include:

g. The administrative complexity of closing the existing facility.

h. The administrative complexity of opening a new facility.

D. Vessels

Vessels, by their nature, have a strong ability to cope with flooding. And yet, flooding at the Marine Center can disrupt LUMCON's vessel operations in a number of ways (FIG 15).

Fig. 15

Small boat operations during flooded conditions of the Marine Center parking lot.
Photo Credit: A. Kolker

1. Under Current Situations:

a. Flooding of the vehicles of vessel operations staff when they are out to sea
The crews of LUMCON's oceanographic vessels often stay out to sea for extended periods of time. There have been incidents in which vessel staff have had their vehicles flooded while they were out to sea, creating both financial and morale problems.

b. Parking lot flooding
Parking lot flooding creates problems for researchers who are embarking or disembarking from oceanographic cruises, which often requires moving personnel, vans, cranes, and heavy equipment across the Marine Center's parking lot. Such movements can be impaired by high water, potentially delaying trips.

c. Parking lot flooding can damage boat trailers and support vehicles
LUMCON's small boats rest on trailers which have a limited capacity, and flooding for extended periods of time can rust axles and damage electrical systems. Similar problems exist for the vans and trucks that are used to move vehicles around LUMCON's parking lots.

2. Impacts of Increased Flooding

As sea level rises, LUMCON vessels would, of course, be able to operate at sea. The inherent mobility of LUMCON's vessels also allows them to be temporarily relocated as needed. However, boat relocations can take several hours to several days, potentially resulting in operational setbacks. There is also a significant cost in personnel time associated with any of these relocation activities. As floods continue to worsen in frequency, extent, and duration at the Marine Center, the inconvenience of operating during floods will increase, impacting visiting scientists, staff, and land-based vessel operations.

3. Impacts of a Relocation

A shift away from the current Marine Center to an inland location would pose both opportunities and challenges for vessel operations.

Opportunities

a. Reduced costs of getting outside technicians/work crews to work on vessels
Many of the services that vessel operations rely on are based in or near Houma. There is often an additional expense of bringing such workers and services to Cocodrie, and this cost would be reduced by a relocation to Houma.

b. Ease of driving access for LUMCON's large boats
The drive to LUMCON's vessels for visiting scientists would be shorter if they drove to Houma rather than Cocodrie. However, this would be counterbalanced by an increase in vessel transport time to get to sea. The cost balance needs to be examined by further economic studies.

c. Ease of access to LUMCON's small boats for some activities
The relocation of some of LUMCON's small boats to Houma would increase access for researchers and educators who want to study areas outside of Terrebonne Bay, such as the Atchafalaya River, Barataria Bay, or the Birdsfoot Delta.

Challenges

d. A shift inland would require that LUMCON find space to dock and store boats, particularly a port with a deep enough draft to accommodate large oceanographic vessels. It is possible the Houma Marine Education Campus could address this concern, and more investigations into such logistics are needed.

e. As discussed above, shifting LUMCON's vessels inland would result in increased transit time to the Gulf. For a large oceanographic vessel, such as the R/V Pelican, launching from the Houma Marine Education Campus would add about 4 hours to each oceanographic cruise, increasing costs for personnel and fuel (FIG 16).

f. An inland location for small boats could position them in a less desirable area for work based in Terrebonne Bay.

E. Facilities and Maintenance

1. The Current Situation

LUMCON's facilities and maintenance experiences numerous problems during both chronic and extreme flooding. Key examples of impacts from chronic nuisance floods include:

a. Flooding of the parking lot
As discussed elsewhere, for many staff at LUMCON, the flooding of the parking lot at the Marine Center is the most noticeable flood-related issue. Parking lot flooding makes it difficult for people to get to work, poses troubles for the delivery of heavy equipment and supplies, and can rust the cars of staff and visitors. Past efforts to mitigate flooding in the parking lot have involved placing gravel on parking lot, which can be expensive.

b. Elevators
LUMCON's elevators are located at ground level and are prone to damage and corrosion. Reduced elevator capacity makes it difficult for maintenance personnel and researchers to bring heavy objects into the building. It can also reduce the accessibility of the Marine Center—particularly for people with disabilities. Elevator damage can also lead to repair costs after floods recede.

c. Underground utilities, including electrical, heating/cooling, and sewage
Many of LUMCON's utilities are linked to the main building via underground conduits from the maintenance building. This arrangement has advantages. It eliminates risks from high winds during hurricanes and makes it easy for cranes and high-clearance vehicles to operate at LUMCON's Marine Center. However, aging infrastructure is challenged during floods. There is a concern that sewage lines will backup during floods, and raw sewage will enter the flooded parking lot. Similar problems exist for the electrical system, which has led to power outages. (FIG 17).

Fig. 16

LUMCON vessel operations crews deploy a box core from the deck of the R/V *Pelican*.
Photo Credit: LUMCON vessel operations

Fig. 17

Gravel and shells in the Marine Center's parking lot make it difficult to build a levee or flood wall to keep water out. Photo Credit: A. Kolker

d. Corrosion of structural materials

Extended exposure to salt water can corrode structural materials, such as rebar, metal doors, and exposed electrical equipment. While a recent engineering survey found few structural problems with the building, long-term vigilance is recommended.

e. Requirement for generator power and other closure activities

Because LUMCON periodically shuts down due to high water events, LUMCON's facilities crew must be ready to shut down operations in advance of a storm and operate the building in a "closed" capacity. This includes shifting personnel time from other activities to closure-related activities and the need to purchase fuel for LUMCON's generator. Note that immediate activities leading up to, during, and directly after a hurricane or tropical storm should be addressed through LUMCON's hurricane preparedness program, which is separate from this report.

2. Impacts of Increased Flooding

An increase in flooding would increase the challenges that LUMCON's maintenance and facilities staff face. There would be more parking problems, more issues with utilities, and greater corrosion of building materials. This would result in an increased diversion of staff time to address flooding and a greater need to invest in generator fuel should regional power be compromised.

3. Impacts of a Relocation

Relocating from LUMCON's current location, either fully or partially, poses a suite of challenges for LUMCON's facilities and maintenance crew. In the event of a partial relocation, LUMCON's facilities and maintenance crew could find that their workload has increased, as they will have to maintain two facilities. A full relocation from Cocodrie to an inland location could eventually result in a decreased workload, but before that happens there would likely be extensive activities associated with abandoning the Cocodrie facility. Such challenges could include not only moving instruments and office equipment but also other activities associated with removing large amounts of debris and unused materials. In short, it is likely that in the near to medium term, any action regarding LUMCON's locational status would result in expanded duties for LUMCON's maintenance and facilities staff.


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V. VISION: Embracing Sea-Level Rise

While rising seas and increasing flood risks pose a myriad of threats and opportunities for LUMCON, the GRAPPLE panel believes that the best strategy is to embrace sea-level rise and coastal change. **LUMCON should use the Marine Center's unique location to study, to educate, and to inform others about the impacts of rising waters.** Coping with rising sea-levels is a global problem (IPCC 2013; Sweet et al. 2017), and LUMCON is uniquely positioned to lead research and education in this critical topic. This vision presented here is grounded in LUMCON's mission to study Louisiana's changing coastal and marine environments. It recognizes that LUMCON faculty have long excelled at studying changing coastal conditions (Reed 1989; Cahoon and Reed 1995; Rabalais et al. 1996; Rabalais et al. 2002; Sammarco and Strychar 2009; Kolker et al. 2011). Embracing sea-level rise and coastal change means incorporating it into LUMCON's core mission and activities, from research and education to maintenance, administration, and vessels. *The challenges LUMCON faces are serious and real, but they can be addressed through sufficient effort and attention.*

A. Research

While recognizing the importance of academic freedom in all research activities, LUMCON scientists should consider incorporating sea-level rise, flooding, and coastal change into their research—both from a logistical and an intellectual perspective. Intellectually, LUMCON scientists should seek to understand how sea-level rise impacts coastal ecosystems and the people who depend on them—broadly defined. Furthermore, LUMCON should seek new collaborations with researchers who study how floods and climate change affect the coastal landscape. These collaborations could include engineers who study the effects of rising waters and salt stress on concrete and metal, economists who study the influence of climate change on markets, or anthropologists, landscape architects, and planners who study coastal relocation. As LUMCON expands its faculty ranks, it should recruit candidates who can capitalize on the research opportunities presented by working in an area with one of the fastest rates of relative sea-level rise on Earth. LUMCON should also seek candidates whose research activities will be less impacted by flooding—such as prioritizing faculty who deploy rugged gear from an oceanographic vessel.

Logistically, faculty and staff need to develop tactics that incorporate the potential for flooding to limit Marine Center access. This can include infrastructure-based solutions, such as adding backup battery power, expanding and improving cold storage, and enhancing air-circulation systems in the building. Alternatively, LUMCON can seek design-based approaches that reduce the need for access to the building. This can include emphasizing field-based research over laboratory-based research and an enhanced use of data sciences and digital tools that can operate remotely on cloud-based platforms.

B. Education

To embrace sea-level rise and a changing future, LUMCON's education and outreach programs should expand their materials on sea-level rise, climate change, and flooding and their use in educational programs. At the university level, LUMCON can develop new field-based classes on sea-level rise, coastal flooding, and their impacts to ecosystems and human communities, and work with instructors of existing classes to enhance the use of such material. At the K-12 level and for teacher trainings, LUMCON's educational program should expand their use of material on climate change, sea-level rise, and coastal flooding, with care paid to the best way to reach each audience.

LUMCON's outreach activities have a unique opportunity to teach people from Louisiana and around the world about the causes and consequences of coastal flooding. New displays should be developed on why the Marine Center floods and how floods in Terrebonne Parish impact ecosystems, infrastructure, and human communities. Ideally, there should be permanent displays for the Marine Center and portable displays for community events. LUMCON should also partner with other organizations that educate the public about coastal floods, including government agencies, non-profit groups, and academic organizations (FIG 18).

Fig. 18

Displays at LUMCON's Marine Center should be expanded to incorporate flooding and sea-level rise.
Photo Credit: A. Kolker

C. Vessels

Allowing vessel operations to cope with rising flood levels largely focuses on maintaining support for shore-based logistics. LUMCON should consider acquiring high clearance vehicles that will allow for operations when the parking lot is flooded. LUMCON should also consider enhancing inland storage space for small boats and slip space inland for its larger vessels, which likely could be found at the emerging Houma Marine Education Campus.

D. Administration

Administration can cope with flooding largely by developing a more flexible work environment. Given that many administrative activities are currently done on cloud-based platforms, this is achievable. Administrators and finance/human resources staff should be allowed to work from a laptop at home or at the emerging Houma Marine Education Campus on days when LUMCON's Marine Center is flooded. However, since LUMCON's administrators will operate remotely more frequently, effort will be needed to make personal contacts, as many activities will function best if there is direct communication between administrators and the staff they support.

E. Facilities and Maintenance

Embracing sea-level rise means critical changes to how facilities are maintained and operated at LUMCON. Without their buy-in to this vision, the plan will not succeed. To ensure this, the panel suggested that there would need to be continued dialogue between this committee (or a second iteration of it) and the facilities and maintenance crew.

Overall, the vision for LUMCON must be a facility that can operate remotely, at least on a temporary basis, and for which flooding in the parking lot and adjacent areas are not a burden on activities. Critical actions needed include:

1. Rethink Parking

At present, parking under flooding conditions appears to pose a significant obstacle to normal activities. New thinking is needed.

One set of options is to create an expanded parking lot near Highway 56, which is high ground, and to expand the boardwalk network to allow people to walk to the Marine Center. Additionally, LUMCON should acquire a high clearance vehicle (or vehicles) to move people and equipment around a flooded parking lot.

As LUMCON administration rethinks parking at the Marine Center, they must also investigate whether solutions that are currently in place are sustainable for the long-term. For example, the continued resurfacing of the parking lot with gravel can be expensive and counterproductive. The gravel is readily distributed by cars, and it increases the load on underground infrastructure, potentially increasing the possibility of damage or failure. The gravel parking lot also has a permeable subsurface, which could complicate efforts to build physical barriers to flooding—such as levees, containment dikes, or coffer dams.

2. Use Water-Based Access Routes

LUMCON, of course, already has water-based access routes. The road leading to LUMCON borders Bayou Petit Caillou, and LUMCON's Marine Center harbor is a short and regularly-used boat ride from the Houma Navigation Canal. However, there are complications associated with using these routes—such as no wake zones along Bayou Petit Caillou—which could make it challenging to regularly use these as transport pathways. Investigating such challenges is a long-term need.

3. Rethink Utilities

Most of LUMCON's utilities reach the main building from an underground pathway to the Marine Center. This arrangement has value because it reduces the potential for wind damage and facilitates the use of cranes and large utility vehicles. However, the location of these systems underground makes them more vulnerable to cracking and saltwater intrusion. LUMCON needs to rethink its piping system—by putting pipes and wires in a more enclosed, saltwater-resistant casing, for example. We do note that some activities to increase the resilience of electrical utilities are currently underway.

4. Develop Energy Independence at the Marine Center Using Local Renewable Sources of Energy

The Marine Center needs to increase its ability to function when flooding or hurricanes knock out power. LUMCON also needs to prepare for the possibility that utility lines on LA56 may not be fully maintained in the future. LUMCON should examine strategies to reduce power usage and increase production of local renewable sources of energy (solar, winds, and tidal) coupled with battery-backup and generator power.

While GRAPPLE embraces sea-level rise, LUMCON will still need to look for inland areas for certain activities that will directly benefit from being located in higher, drier, and more protected environments. For example, researchers will still need to use instruments when access to the Marine Center is limited. Administrative functions, likewise, will need to continue. For laboratory equipment, LUMCON could develop an analytical laboratory at the Houma campus, while office workers could find suitable office space in this location also.

G. Complications Related To This Strategy

The strategy outlined above comes with potential complications that are yet to be resolved. These complications are by no means “deal killers” but do require serious forethought.

1. What is the Location for this Protected Environment?

The obvious location for the higher, drier space is the emerging Houma Marine Education Campus. Although Houma is more protected than Cocodrie, it is by no means flood proof. As the 2016 Baton Rouge floods showed, even seemingly safe places in Louisiana can experience damaging floods. Any changes to the location of LUMCON’s operations must acknowledge that new locations could have flood risks also.

2. Development of a Houma-Based Analytical Laboratory Could Pose Challenges for Specific Faculty About How to Manage a Laboratory from a Physical and Personnel Perspective.

An investigator with resources distributed between Cocodrie and Houma could face challenges about how to allocate resources, instruments, and personnel. Laboratory technicians, students, and administrators could have a difficult time communicating with each other, complicating functionality. Finally, dividing LUMCON personnel between locations could reduce staff cohesion, and the close working relationship between researchers and staff at LUMCON's Marine Center is often cited as one of the positive benefits of working at LUMCON.

3. Some People Would Prefer to Operate Out of Houma, Reducing Personnel at the Marine Center.

Cocodrie is a remote location; a 30-mile trip from downtown Houma that can take 45 minutes. Staff members could find that working from Houma instead of Cocodrie effectively saves several thousand dollars per year in transportation-related expenses, while providing several hundred hours per year of free time. Houma is also closer to the member universities, marine support services, and major airports for visitors. As such, some staff may prefer to work in Houma. This raises questions for supervisors about how best to allocate resources while also addressing the need to keep the Marine Center staffed and vital.

4. The Houma Campus May be Unappealing for Researchers.

While LUMCON's Marine Center is remote, it is also a highly desirable location for researchers who need to be near the nation's most complex coastal and marine systems. The Houma Marine Education Campus could prove to be undesirable for some faculty—it would offer neither the immersive marine environment of the Cocodrie Marine Center nor the analytical and personnel resources of a major research campus.

VI. Action Items to Improve Resilience at LUMCON's Marine Center

In order to achieve the vision presented in this document, many actions must occur. The list below describes many activities that will increase LUMCON's resilience while also expanding its capabilities to study coastal change. Though the list is long, it is not an exhaustive accounting of every action needed. There is still a need for more planning that includes engaging architects, engineers, and LUMCON staff. That said, this list provides actionable measures that will increase LUMCON's resilience in the years ahead. They are described on three different time scales: immediate term, near term, and long term.

IMMEDIATE TERM (less than a year)

Activities that should take place in the immediate term include:

1. Repair and fortify the Marine Center's utilities, and make them more flood resilient.

The need to fix the Marine Center's sewage system should be of the highest priority, with other utilities lagging not far behind. Suggestions for improvements include moving sewage pipes from below ground to under the building and strengthening the casing for other utilities. We note that some improvements in the Marine Center's electrical system are underway.

NEAR TERM (less that 5 years)

Activities that should take place in the near term include:

1. Rethink Parking

In the near term, LUMCON's Marine Center needs to develop solutions to the parking problem that allow people and equipment to access the Marine Center during periods of moderately high water. We suggest that LUMCON develop a parking lot on the (relative) high ground near Highway 56, while expanding the Marine Center's boardwalk network to extend from the parking lot to the Marine Center. LUMCON should also obtain a high clearance vehicle(s) to ferry people and heavy objects around the parking lot. LUMCON should also investigate developing elevated, heavy-duty causeways to allow delivery trucks to access the building. As discussed above, LUMCON should resist the temptation to repeatedly add gravel to the parking lot, which is expensive and can be counterproductive in the long term.

2. Rethink the Elevators

LUMCON's elevators are necessary to bring heavy equipment to the building and to maintain access for disabled and movement impaired persons. Progress needs to be made to rethink and redesign elevators so that they can operate while LUMCON is flooded and so that they are not damaged during floods (Fig 20).

3. Expand the Boardwalk Network

As LUMCON's Marine Center becomes flooded more frequently, it will become increasingly important to find elevated pathways around the marine center. LUMCON should expand the Marine Center's boardwalk network to allow researchers, educators, and facilities crews access to wider areas of the property, including human used areas (e.g. parking lots, buildings) as well natural areas (e.g. wetlands, creeks)(FIG 19).

Fig. 19

The elevators at the Marine Center are at ground level and must be rethought and redesigned to remain functional. Photo Credit: A. Kolker

Fig. 20

Fig 20. The boardwalk network at LUMCON's Marine Center should be expanded to allow people to access the property when it is flooded. Photo Credit: A. Kolker

4. Allow suitable areas of the property to return to marsh

LUMCON should stop mowing the lawns around the Marine Center, except in cases where clear areas are necessary for safety. Allowing these areas to revegetate will likely enhance evapotranspiration thereby removing water, while also providing a scenic coastal environment. Doing so will also provide a modest cost reduction.

5. LUMCON should recruit faculty who view the opportunity to study sea-level rise first hand as a positive career move.

This can include faculty from any discipline of marine science, as well as the social sciences. Additionally, there should be opportunities for LUMCON faculty to incorporate sea-level rise into their research—though it should be noted that many do already, and this must be done with the recognition that academic freedom is central to any research institution.

6. Increase sea-level rise research funding

LUMCON should seek out and apply for funding opportunities for researchers, educators, and their partners to study the impacts of sea-level rise on coastal ecosystems, landforms, infrastructure, and communities.

7. Enhance sea-level rise education

LUMCON's marine education programs should expand material on the causes and consequences of sea-level rise and coastal flooding into educational programs at all levels. This involves including sea-level rise into existing educational activities and developing new activities and courses that examine sea-level and coastal flooding.

8. Sea-level rise outreach

LUMCON should develop outreach products and displays that educate the public about flooding and the impacts of sea-level rise on their coast, homes, and communities.

9. Collaboration opportunities

LUMCON should develop new collaborations with faculty and researchers who want to study sea-level rise and climate change and its impact to coastal systems.

10. Foundation

While the panel knows of no immediate structural issues to the building, given the subsidence of the building and the potential for voids underneath the building, continued vigilance of LUMCON's foundation is clearly in order.

11. Enhance documentation of flooding

LUMCON's monitoring program is already documenting water levels at Cocodrie and flood events at the Marine Center, which should be continued. LUMCON needs to better monitor subsidence at the Marine Center using high precision GPS units. Overall, LUMCON should rigorously investigate relationships between global sea-level rise, Louisiana's changing coastline, and flooding at the Marine Center using hydrographic and meteorological data from publicly available sources.

12. Safe harbor and engaging the new Houma campus

Engage with the designers of the emerging Houma Marine Education Campus to develop an analytical laboratory and capacities to harbor staff during flood events at the Marine Center.

13. Accessibility

Ensure compliance with both the letter and spirit of the Americans with Disabilities Act (ADA) to ensure that the Marine Center is accessible to all.

14. Redesign LUMCON's lobby and entrances

As water levels rise, LUMCON will need to redesign its lower lobby. Since it will become exceedingly difficult to prevent water from entering the lower reaches of the building, a more practical solution will be to change the bottom floor. One likely option is to convert the lower lobby into an open air environment, making the Marine Center's primary entrance on the second floor. This is not a major change, since all Marine Center activities already occur on the second floor, and some parts of the building are already accessed through stairs that lead to the second floor.

15. Vehicular access

Work with local governmental and non-governmental organizations to enable vehicle access to Cocodrie as long as reasonably possible. Such organizations include the Department of Transportation and Development, the Cocodrie Camps Association, as well as local oil and gas interests.

LONG TERM (5-50 years)

1. Develop alternative access route

As LUMCON's Marine Center becomes increasingly isolated, it will become increasingly important to find new ways to get to the building. Of course, LUMCON has always had marine access routes at its harbor, and LUMCON should investigate using this harbor to allow employees, researchers, and visitors access the Marine Center.

2. Increase energy and utility independence

As Cocodrie becomes increasingly isolated, LUMCON will need to increase the ability of the Marine Center to operate remotely. LUMCON should look into adding renewable sources of power, such as solar and wind, while also adding battery back-up power. LUMCON should also examine obtaining a level of independence for utilities, such as composting toilets for sewage and satellite/cellular access for internet, since coastal change could impact their availability through traditional means.

3. Expand the list of activities that can be accomplished at LUMCON's Marine Center

LUMCON should broaden the portfolio of actions that can be done at its Marine Center, taking advantage of the increasing global needs to understand the impacts of accelerating sea-level rise. This includes expanding research into sea-level change, flooding, and resilience among current faculty, while also developing new partnerships with faculty who can study these new challenges. For example, LUMCON could develop collaborations with structural engineers who study salt corrosion or with anthropologists, social scientists, architects, and planners who study human migrations and response to disasters.

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