THE WATER INSTITUTE OF THE GULF®

Louisiana Coastal Neotectonics Expert Panel

WORKSHOP 3 SUMMARY

To: Carol Parsons Richards, Louisiana Coastal Protection and Restoration Authority

From:

The Water Institute of the Gulf

Mike Miner, Diana Di Leonardo, Brendan Yuill

Neotectonics Expert Panel

Elizabeth Hajek – Chair

John Anderson

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Re: Louisiana Coastal Neotectonics Workshop 3

Introduction

During the first week of June 2020, The Water Institute of the Gulf (the Institute) convened a series of three virtual presentations to take the place of the in-person workshop originally planned as part of the Louisiana Coastal Neotectonics Expert Panel Workshop series. The third workshop was held virtually to protect the health and safety of the panel and all participants during the COVID-19 pandemic. The virtual workshop information was advertised by email and on the Institute's website, as it was for the first two meetings. The objective of the workshop was to facilitate discussion of neotectonics processes in coastal Louisiana and their potential effects on coastal restoration planning. The panel members include Dr. John Anderson, Dr. Elizabeth Hajek, and Dr. David Mohrig. Three experts in the local geology, i.e. Dr. Frank Tsai, Julie Bernier, and Dr. Simone Fisaschi, presented research overviews to the panel. Workshop attendees were required to register for the virtual meeting, as a replacement for a sign-in sheet. More than thirty people attended each presentation of the workshop from government agencies, academia, nonprofit organizations, and private consulting companies.

Workshop Presentations

DR. FRANK TSAI, LOUISIANA STATE UNIVERSITY

Dr. Tsai's presentation was entitled "Understanding dynamics of groundwater flows in the Mississippi River Delta: Implications for river deltaic hydrogeology", work that was funded by the Louisiana Center of Excellence. The objectives of the project were to (1) develop a 3-D soil stratigraphy model for the area around the Mississippi River, (2) analyze spatial patterns of the constructed soil stratigraphy to identify seepage pathways for surface-groundwater interaction, and (3) develop a groundwater flow model to quantify surface-groundwater interaction and to investigate ground heave, subsidence, and erosion. An understanding of these issues is potentially important for the planning of coastal projects. High pore-water pressures during floods and hurricane storm surge can cause upward seepage of water and destabilization of sediments. Dredging in the river can also cause induced groundwater surface connections.

The study focused on the upper 50 m of stratigraphy, the approximate boundary of the Holocene and Pleistocene contact in this area. Data sets include borings, cone penetrometer tests, topo-bathy data, and river and tide stages. The stratigraphy is modeled using the Unified Soil Classification System used for geotechnical borings such as CH and CL for high plasticity clay and low plasticity clay, respectively (USDA, 2012). Boring data use these types of soil classifications. The 619 borings used to create the geostatistical stratigraphy model were not evenly distributed leading to some areas having large uncertainties. A natural neighbor interpolation method was used to model the stratigraphy. The modeled stratigraphy is described as: 47% CH, 12% CL, 11% silt, with the balance as sand and silty sand with a small amount of peat and organic matter. The surface deposits are coarse sand and silt in and around the river and river mouth. The basin areas are clay. At depths of approximately -15 m to -35 m there is a higher percentage of sand. These areas are interpreted as likely river deposits. The organic material is confined to the shallower depths. Intermittent layers of sand in the stratigraphy allow river water to be exchanged with the basins. The top 10 m are more clayey and organic rich sediment which have a greater tendency to compact.

The focus of modeling efforts in the Mississippi River Delta Plain has been on subsidence, sea level rise, and storm surge. Groundwater flow has been less well investigated. The groundwater model used for this study was USGS MODFLOW6. The MODFLOW model uses an unstructured grid with 200 m cells and 25 model layers in a domain 100 km long by 20 km wide centered on the Mississippi River channel. There is no publicly available groundwater data for the model domain, but data from river and tide gauges was used. High water levels from river floods and from simulated tropical storms and Hurricane Isaac were both simulated.

To evaluate the potential hazard, the influence of increased pore-water pressures on the factor of safety for levees was evaluated. The factor of safety is an engineering term that refers to the ratio of a structure's strength to the applied load. At values of less than 1, the structure fails. High pore-water pressures decrease the resistance of sediments to motion. Both peak floods and hurricanes cause large areas of the levees to have a high probability that the factor of safety is reduced below 1.5. Even after the peak water level, pore-water pressure remains high, prolonging the potentially hazardous time. Upward seepage of groundwater can also likely be seen in the seasonal saw tooth pattern of marsh elevation.

During the question period the panel asked about the availability of boring data and electrical logs. The boring data is collected for project specific needs, for example on the levees. The boring logs would also include some data obtained through lab analyses such as porosity, permeability, and water content, but only the soil classification was used for this research. There are no available electrical logs that Dr. Tsai is aware of. The impacts of water intrusion on vegetation were also discussed. Shallow, coarse grained aquifers create permeability for groundwater and saltwater intrusion which can have impacts on the types and amounts of vegetation that can grow in a marsh.

The panel also discussed the groundwater model. A set of wells with hydraulic head measurements would be very useful in the study area, but it does not exist. The data used for this study was primarily federal government data, but additional industry data may exist even if it isn't presently available. Only groundwater flow was simulated by the model, no channel flow. The water level time series in this study were created by the researchers. Dr. Mohrig pointed out that the model shows high variation in stage levels near the river mouth, but stage is primarily dictated by sea level at the river mouth and shouldn't vary very much; this could influence the groundwater response seen in the model. An exception to this would be storm surge which would raise the stage level. The deposits may also be more reactive to groundwater conditions that previously thought.

The panel was also interested in how much variability was contained within the CH classification since nearly 50% of the stratigraphy was classified as CH. CH represents a high plasticity clay as defined by the Unified Soil Classification System. Soil plasticity is defined through experiments, but also has field classification criteria. A sensitivity analysis could be done to determine the influence of variability in this soil class.

Audience questions:
Does the post-hurricane groundwater exchange and liquefaction risk represent a newly-recognized storm danger to communities?

- A sharp change in aquifer pressure could create momentary liquefaction, but Dr. Tsai did not study this issue.

Are there current or past CPRA projects along the river in Plaquemines Parish that have CPT-based soil behavior type (SBTs) classifications?

- While CPT data is much cheaper and easier to get than borings, this data was not used in Dr. Tsai's study. Carol Parsons Richards from CPRA will look into this question.

Have we found any evidence that the channel of the river is subsiding causing the hydraulic gradient to be reduced (flattened) above the head of passes (AHP)?

- Dr. Mohrig responded that because the lowermost channel is an alluvial channel, if it is subsiding, there is plenty of sediment to accommodate and adjust to the elevation change.

JULIE BERNIER, U.S. GEOLOGICAL SURVEY

Ms. Bernier presented on work from the U.S. Geological Survey's Gulf Coast subsidence project which took place between 2000 and 2011. Her presentation was entitled "Quantifying Wetland-Loss Trends, Processes, and Large-Scale Historical Accommodation Formation in Coastal Louisiana. Bob Morton and John Barras also worked on this project. All information on this project can be found on the USGS website (https://archive.usgs.gov/archive/sites/coastal.er.usgs.gov/gc-subsidence/). The goal was to understand the processes that cause wetlands to convert to open water, specifically focusing on the Central Delta Plain and Western Chenier Plain. The project aimed to better understand the physical processes and human influences and to better constrain wetland loss trends and volumes. Because early datasets of wetland extent and loss have coarse temporal resolution, data points from local studies and aerial imagery were also included. Wetland loss rates peaked in the mid 1960's to the mid 1970's, with rapid onset and loss seen during this period. High rates persist in some areas to the 1990's. The Chenier Plain saw the most loss between 1978 and 1990. Observations of "wet marsh" are used as an indicator that subsidence initiated wetland losses. The marsh gradually loses elevation so that it is inundated for longer and longer periods, until it is submerged.

At Grand Isle, LA the tide gauge shows variable rates of relative sea level rise, especially when compared to Pensacola tide gauges, which are thought to be geologically stable. From 1947 to 1965 the tide gauge shows a RSLR of 3.3 mm/yr. During the period from 1965 to 1993, the RSLR is 10.7 mm/yr. Finally, from 1993 to 2006 the RSLR is 4.1 mm/yr. The time period of accelerated RSLR coincides with high production of oil and gas in the area, as well as large amounts of formation water. These results are interpreted to mean that accelerated production contributed to locally high accelerated subsidence rates. Modeling results of the compaction rates of Holocene sediments (<5 mm/yr) (Meckel, 2008; Meckel et al., 2006, 2007) and production-induced reservoir compaction (Chang et al., 2014; Mallman & Zoback, 2007; Zhou & Voyiadjis, 2019) lend support to this hypothesis. If high subsidence rates are related to oil and gas production, we can expect future subsidence rates to be lower than the 1965-1993 peak rates.

Stratigraphic principles were used to help estimate the relative contributions of subsidence versus erosion at wetland loss sites. One-dimensional accommodation space was calculated as the difference in elevation between the marsh surface and the water surface. It is the combined product of subsidence and erosion of the marsh. Wetland losses in general can be attributed to long term processes (i.e. subsidence) and shorter term, event driven erosion processes (e.g. storm effects). Where the subsidence rate was greater than the erosion rate, wetland loss initiation can be attributed primarily to subsidence. Erosion in these study areas was found to not exceed subsidence. At some sites, elevation loss can be attributed almost entirely to subsidence.

The key findings from this research are: (1) rapid onset and wetland loss across coastal Louisiana is likely initiated by subsidence and (2) there is close temporal and spatial correlation between wetland loss, subsidence, and hydrocarbon production.

During the question period, the panel was interested in how the data for these studies were collected and how that affects the interpretations. It was noted that water level variations in aerial and satellite photos can affect the amount of marsh that is interpreted to be below the water level. It was acknowledged that even though there are a plethora of data in Louisiana, water levels can be hard to judge. Data that is collected over the course of a few months can help inform which changes are real and which are the result of water level variability. The stratigraphy data was collected using vibracores and consists of at least two perpendicular transects. The stratigraphic interpretations are valid for single study sites but can't be correlated between different study sites. Fluid extraction related subsidence was also recognized to be a process that occurs at a higher frequency in time as compared to compaction related subsidence.

Acceleration of wetland loss and subsidence rates are seen to be on a similar time scale as oil and gas extraction, but on a much shorter timescale compared to compaction induced subsidence. Accelerated wetland loss and subsidence rates were seen on a local scale, where the fluid extraction was occurring, not on a regional scale.

Audience Questions:
Do you account for plant death in the fresh marshes due to saltwater intrusion or produced water, which could be a major factor in increased erosion and/or loss of peat?

- This study did not look at biological processes.

Why is the process of development of accommodation space formed by faults during deposition (growth faulting) being ignored? This is a well-known process that has been working in south Louisiana for millenia. Has this process suddenly stopped happening? Wouldn't coastal planning benefit from a having a better understanding of the location and Holocene movement history across fault traces that appear to impact the surface? Fault traces can separate areas of different compaction due to persistent differences in depositional environment. Tectonic movement is not the only way a fault can impact a dynamic system like south Lousiana though it could also be important. We can't know the influence unless we study it.

- An attempt was made to map growth faults in this area, but we were unable to see conclusive evidence of deep faults propagating to the surface. In addition, growth faults probably contribute to the long term subsidence rate, but are not a dominant component of the short term loss.

What is the accuracy of the model used to support compaction induced by hydrocarbon production?

- Readers are referred to the following papers: Chang et al. (2014), Chan and Zoback (2014), and Zhou and Voyiadjis (2019).

DR. SIMONE FIASCHI, TULANE UNIVERSITY

Dr. Fiashci presented on some ongoing work that he is doing under the direction of Dr. Mead Allison at Tulane University and Dr. Cathleen Jones at NASA JPL. His presentation was entitled "Using InSAR to measure subsidence in the Mississippi River delta." This project is funded through the CPRA Lowermost Mississippi River Management Program and began in January 2020. The objective of that program is to create an efficient management strategy for the Lower Mississippi River. A better understanding of subsidence trends in the deltaic plain and the spatial distributions of subsidence trends are important to that goal. Current subsidence studies use different techniques to measure subsidence and differ by orders of magnitude. The data sets have a limited spatial distribution. This project will test a remote sensing approach to increase the availability of high-quality, large spatial extent data on land change.

InSAR (Interferometric Synthetic Aperture Radar) is a remote sensing technique using radar data collected by satellites. Imaging is possible both day and night, in all weather, has meter-scale resolution, and can cover large areas at low costs. The data and software are usually free of charge. The wavelengths used are between 3 cm and 23 cm. The wavelength is a general guide to the scale of the object that it will interact with most strongly. For example, shorter X-band radar is used to measure leaves and branches,

while longer L-band radar would be used to look at tree trunks. The radar scattering is also influenced by whether soils are dry, wet, or flooded. A flooded surface will not be 'seen' by InSAR.
InSAR relies on the coherence and phase shift of successive images to measure landscape change. Coherence is the portion of the backscatter that is maintained between two time periods, for example a building that is in the same place at time 1 and time 2. Coherence is maintained over a city for a long period of time, but over a shorter period of time in wetlands. The phase shift between images is represented by an interferogram. The repeated pattern caused by a phase shift is referred to as fringes. The number of times the fringes are repeated represents the amount of displacement. Stacked interferograms create a time series of displacement.

It is important to remember that InSAR can only measure surface movement and requires a stable reference point to measure displacement. A GPS point with a known velocity can substitute for a stable point. Examples of data that can be measured by InSAR are sediment compaction, water level change, vegetation accumulation, oxidation of organic material in soil, aquifer exploitation and recharge, tectonics, and deformation of infrastructure.

Previous studies in the Greater New Orleans area found mean subsidence rates of 6 mm/yr, and hot spot rates up to 30 mm/yr. In areas with major industry (e.g. Michoud power plant area), groundwater withdrawal is the primary subsidence driver. Compaction and oxidation were also drivers of locally high subsidence rates.

Dr. Fiaschi's planned work will use the Sentinel-1 satellite which has a revisit time of 12 days and a maximum resolution of 20 m. The current focus is wetland areas near New Orleans. The next goal is to move south along the Mississippi River wetlands, but this is a more challenging environment for InSAR. The pixel size used was 55 m by 55 m to smooth the results and maintain coherence between images. From preliminary results using 109 images from 2016 to 2020, wetland areas have many areas of low coherence. The highest subsidence rates were found in the wetlands to the east of New Orleans with subsidence rates of 35 to 40 mm/yr. The area near the Michoud powerplant shows uplift, interpreted to be related to aquifer recovery after the powerplant closure. Some wetland areas also show uplift, possibly due to water level variability or accretion. The results compare well with the velocities measured at local GPS stations; however, these preliminary results require further validation and interpretation.

The panel were all very interested in the potential for InSAR techniques in Louisiana and noted the ability of the technique to provide subsidence measurements with good spatial distribution. The strengths and limits of InSAR were discussed. Motion on faults in Lake Pontchartrain are likely within the error of InSAR, if previously calculated rates of ~1 mm/yr are correct. Differential movement along levees was discussed. The results could be related to levee height, if additional material was added to specific areas. Given the size of the pixels, it could also be related to the wetlands on either side. One of the biggest challenges of using InSAR in wetlands is the changing water levels; if an area is flooded in one image, but not another, coherence is lost. Using only winter images and a larger pixel size can improve coherence, but also increases the error. There is about 1.5 mm/yr of uncertainty from the Sentinel satellite, but in wetland areas the uncertainty increases to about 2-5 mm/yr. Corner reflectors in the wetlands would aid the effort to use InSAR there. The reflectors need to have a stable XY position at the surface.

Improved LiDAR data may help with removing the topography which is a necessary step for InSAR analysis, and interpretation of wet versus dry areas in wetlands. Dr. Krista Jankowski also informed the panel that in addition to this work, CPRA is engaged with NASA-JPL and the U.S. Geological Survey as they plan for the data that will become available when the new NASA satellite is operational in the near future. This data will include a national land level change map. CPRA is considering putting permanent InSAR reflectors in the marsh, and is considering how this data would be useful.

Audience questions:
Your data show wetlands in the southeast corner of the western lobe of Lake Borgne with subsidence rates of ca. 30 mm/yr. How can these wetlands still remain viable? Is their absolute elevation unusually high, providing them elevation capital?

- We don't know yet. These are still preliminary results.
- Mead Allison: Data from the levee board is very complicated. There are 5 different entities collecting it. They are also raising levee areas that sink as they come up.

I [Chris McLindon] am a collaborator on the Wells to Monuments Program proposal. We have recommended using deeply-anchored oil wells as monuments. These would be co-located with shallow-anchored monuments. We have recommended that this apparatus be equipped with both GPS and InSAR reflectors. What do you think of this concept?

- It would be great to have GPS data for calibration of InSAR reflectors. At least 2 years of data is needed to process any InSAR for a new location.
- Mead: Wetlands have lots of oil and gas platforms. They are a large reflector target. It would be beneficial to have GPS on them, but their foundation depths are a large unknown.

Once a mosaic of different subsidence rates are accurately mapped out over the coastal plain, what is next? In other words, we know we are sinking and have known that, is the solution on the restoration side to stack more material on these high risk areas inducing more subsidence whether through marsh creation/diversions or is the solution to build more coastal protection systems to protect us as we a situated within the subsiding land? I am curious of the views because having made the mistake of building in this land and leveeing the river, we have to find a reasonable way to remain without creating more problems.

- Krista Jankowski: As far as CPRA and the master plan goes, the goal is to incorporate the best available information which would help with the prioritization of the state's projects. That information would be used to feed the models to help prioritize coastal projects.

Next Steps

This workshop concluded the public presentation part of the Louisiana Coastal Neotectonics Panel. The Water Institute will organize a follow up meeting between CPRA and the members of the panel to discuss these presentations as well as next steps for the anticipated report/white paper. All of the presenters will be given the opportunity to contribute to a potential review paper.

References

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