Programming Adaptation: How Modeling Informs Environmental Policy in Louisiana's Coastal Master Plan

By
Eric Nost

A dissertation submitted in partial fulfillment of
the requirements for the degree of

Doctor of Philosophy
(Geography)

at the
UNIVERSITY OF WISCONSIN-MADISON
2018

Date of final oral examination: 4/19/2018
The dissertation is approved by the following members of the Final Oral Committee:
Morgan Robertson, Associate Professor, Geography
Matthew Turner, Professor, Geography
Robert Roth, Associate Professor, Geography
Erika Marín-Spiotta, Associate Professor, Geography
Kristin Eschenfelder, Professor and Director, The Information School

Acknowledgments

I've long looked forward to writing up the debts of this project, but I fear they are too deep and time is too short. I would like to thank so many people who have supported this endeavor in so many different ways. I've probably missed you; if so, let me buy you a beer sometime. I've been given an extraordinary opportunity with this project and I look forward to doing everything I can to pass on that opportunity.

Thank you first to those who read at least some of this document, especially my advisor, Morgan Robertson, who read drafts and made the usual incisive comments. Thank you also to the rest of my committee, who took time to really engage with the material: Kristin Eschenfelder, Erika Marín-Spiotta, Rob Roth, and Matt Turner. Thank you also to Daniel Grant for giving some of this a read through.

This research could not have been possible without the abundant generosity of Chris Oliver and Kelsy Yeargain, the best hosts in NOLA I could've hoped for.

I would not have made it this far (no one does) without the informal advice, support, and boosterism that often goes unrecognized in the academy. I'm especially grateful to Sarah Moore for enlisting me to help with her project, to Rebecca Lave for championing my and other junior scholars' projects, and to Eric Carter for pointing me in the right direction in the first place.

I am also thankful to department faculty and staff who guided me in their unique capacities over the years, from good vibes on a job app to helping me get paid: Keith Woodward, Kris Olds, Lisa Naughton, Sharon Kahn, and Bill Cronon.

All along the way, fellow grad students gave invaluable feedback, broke bread with me, and told me to come out of the cave. In no particular order, thank you: Niwaeli Kimambo, Kallista Bley, Carl Sack, Rafi Arefin, Ritodhi Chakraborty, Charlie Carlin, Becca Summer, Nicolle Etchart, Kramer Gillin, Nick Lally, Adam Mandelman, Mark Cooper, Will Shattuck, Colin Higgins, Heather Rosenfeld, Nathan Green, Javier Rodriguez Sandoval, Evan Applegate, Elliot Vaughn, Garrett Nelson, Rachel Boothby, Meghan Kelly, Laura Lawler, Zhe Yu Lee, Chloe Wardropper, and many others…

Beyond the hallowed halls of Science Hall, I'm forever grateful to many fellow geographers, especially Patrick Bigger, but also Jess Dempsey, Sara Knuth, Leigh Johnson, Anthony Levenda, Dillon Mahmoudi, Sophie Webber, Chris Knudson, Kelly Kay, Jim Thatcher, Taylor Shelton, Nate Millington, Jairus Rossi, David O'Sullivan, Kai Bosworth, Alex Peimer, Ritwick Ghosh, Jessa Loomis, Matt Wilson, Michael Samers, and so many others, not to mention Kate MacFarland. I learned a lot from you, and you made me feel I belong in this geography thing.

At Guelph, Jennifer Silver, Robin Roth, Noella Gray, Kirby Calvert, and John Smithers have all already made me feel welcome.

I am grateful to several Louisiana researchers for encouraging me in this research, including Brian Marks and Craig Colten, but especially Josh Lewis and Monica Barras.

I've taken on many projects that wouldn't be worth it without the solidarity. Thank you, Jenny Goldstein, Cara Steger, Toly Rinberg, Dawn Walker, Kristen Vincent, Dustin Robertson, and others.

A few other debts: the title of this dissertation, "Programming Adaptation," overlaps and resonates with Mar Hicks's (2017) new book, *Programmed Inequality.* This was unintentional on my part; go read their book. This research was conducted with the financial support of the Department of Geography, the Center for Culture, History, and Environment, the Holtz Center, and the American Association of Geographers.

To Virginia Andersen!

Table of Contents

Abstract

Environmental policy increasingly centers on deploying digital infrastructures consisting of modeling software, databases, sensor hardware, and web interfaces. While we often hear about the (potential) impacts of tech-driven policy, we hear little from behind the scenes of this infrastructure. I ask, who develops ecosystem models and how are they funded? What are the norms for learning from such models? What protocols govern how modeling is implemented in decision-making? I make a single broad claim in this dissertation: the way that governments and civil society actors manage the environment cannot be understood apart from the way they manage technology.

In particular, I examine ecosystem models designed to enable policy that is experimental, responsive, and unburdened by uncertainties – attributes commonly referred to as “adaptive management”. There are few places better than coastal Louisiana to document the opportunities and challenges of using modeling to drive adaptation. Land loss makes Louisiana the world’s fastest submerging place and threatens coastal residents, wildlife habitats, and a significant portion of the US’s energy infrastructure. Between 2012 and 2017, state agencies utilized modeling to generate and implement their latest “Master Plan” for address land loss. The plan describes which ecological restoration and flood protection projects the state will invest in over the next 30 years. Planners rely on the Integrated Compartment Model (ICM) to simulate coastal change, evaluate how projects will build or maintain land, and select projects.

I follow the ICM as planners and modelers develop, learn from, and apply it. I employed three modes of fieldwork: document analysis, semi-structured interviews, and participant observation. Through these, I triangulated what planners wrote about the ICM, what they said about it, and what they did with it. In doing so, this dissertation takes up Robbins and Moore (2015)’s call to characterize how technology produces specific social and ecological outcomes. The study demonstrates when modeling may enable transformative adaptive management. Rather than focusing on either the social dimensions of modeling (e.g. do scientists and policy-makers trust one another?) or its technical dimensions (e.g. is there enough data?), the study takes a sociotechnical approach that sees both dimensions as inseparable.

1. Introduction

1.1 Mardi Gras Pass

I make a single broad claim in this dissertation: the way that governments and civil society actors manage the *environment* cannot be understood apart from the way they manage *technology*. Environmental policy is increasingly centered on metrics that are generated through digital infrastructures made up of modeling software, databases, sensor hardware, and web interfaces. While we often hear about the impacts of tech-driven policy or even just the hype supporting it, we hear little from behind the scenes of this infrastructure. We may even take for granted that technology will inform policy, since it is supposed to embody the best available science. My claim is that this perspective does not explain how environmental policy draws on modeling in particular. It overlooks how modeling *becomes* policy-relevant. Instead, I ask, who develops ecosystem models and how are they funded? What are the norms for learning from such models? What protocols govern how modeling is implemented in decision-making?

I examine ecosystem models designed to enable policy that is experimental, responsive, and unburdened by uncertainties – attributes commonly referred to as "adaptive management" (Argyris and Schon 1978; Holling 1978; Hennessey 1994; McLain and Lee 1996; Walters 1997; Dietz et al. 2003; Steyer et al. 2003; Gunderson and Light 2006; Adger et al. 2006; Armitage et al. 2008; Armitage et al. 2009; Genskow and Wood 2011; Plummer et al. 2013; Glynn et al. 2017). Policy-makers around the world consider adaptive management a key tool in responding to climate change and its intersections with existing social and environmental issues. Model simulations are thought to provide policy-makers the capacity to decrease the vulnerability of communities and ecosystems to sea level rise, drought, and other climate impacts. Modeling may not only demonstrate possible ecosystem outcomes, but integrate these results with economic data to help experts valorize and prioritize their response.

There are few places better than coastal Louisiana to document the opportunities and challenges of using modeling to drive climate adaptation. The coast is already witness to sea level rise, which compounds ongoing coastal wetlands loss. For decades, Louisiana has lost approximately 2,000 square miles of marshlands (Couvillion et al. 2017), due to the combined effects of flood protection levees (Barry 1997; Muth 2014), navigation and pipeline canals (Scaife et al. 1983; Cahoon and Turner 1989; E. Turner 1997), oil spills (Rangoonwala et al. 2016), and geological subsidence (E. Turner 2014), in addition to sea level rise (Blum and Roberts 2009). The Mississippi River Delta is a heavily engineered landscape. Some researchers even claim the Delta is being “managed into oblivion” (Day et al. 2014). For instance, flood control levees raised along the Mississippi have prevented it from adding substrate material (mud and sand) to eroding wetlands (Kearney et al. 2011). Land loss makes Louisiana the world’s fastest submerging place and threatens coastal residents, key habitats, and a significant portion of the US’s energy infrastructure (Goldenberg 2014; Traywick 2016).

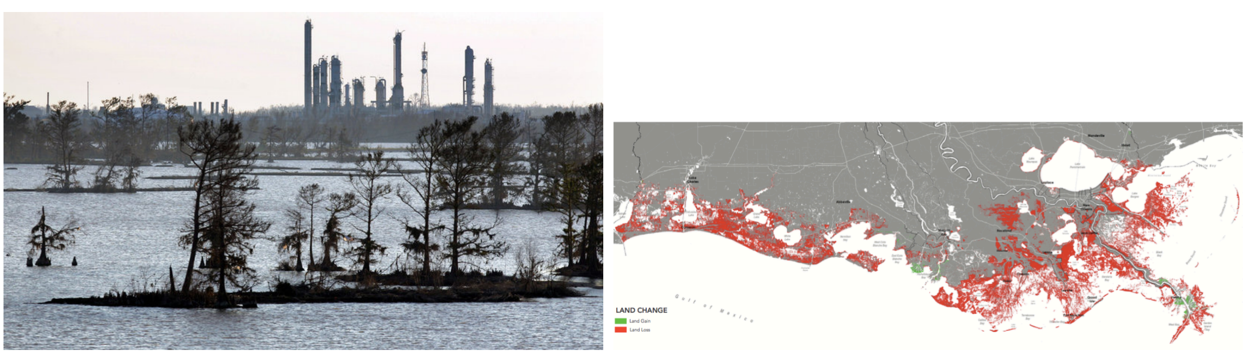


Figure 1. Two views of land loss. On the left, this cypress swamp has converted to mostly open water. The right image is a “red map” from the Master Plan showing areas expected to convert to water by 2050 without restoration. Source: NPR (2017); CPRA (2017).

In response to land loss, Louisiana planners have developed one of the most substantial ecosystem modeling efforts in the world. Between 2012 and 2017, state agencies utilized modeling to generate and implement their latest "Master Plan" for protecting the coast (CPRA 2017). The Master Plan describes which ecological restoration and flood protection projects the state will invest in over the next 30 years to stem coastal erosion. Planners rely on the Integrated Compartment Model (ICM) to simulate coastal change, evaluate how projects will build or maintain land, and select projects for the Plan. As successful as the planning has been, it faces significant technical and organizational challenges. Modeling has to account for how land loss rates and mechanisms vary across the 400-mile coast. Since land loss is not just a climate, sediment, or hydrological issue alone, the state must also draw on many different kinds of expertise. Although different modelers and state agencies are supposed to work together, one observer noted, "no one has a mandate to do collaboration" (Notes, A Community on Ecosystem Services [ACES] Conference). There are also political economic dimensions to how modelers and state planners apply coastal modeling.

The case of Mardi Gras Pass (MGP) illustrates how modeling informs adaptation policy through institutional and economic criteria, not just because it embodies the best available science. In the middle of carnival season in 2011, the Mississippi River did something it had not done in a long time in southern Louisiana: it formed a new distributary downstream of New Orleans (Figure 2). Since the 1930s, most of the river above the Bird's Foot Delta had been entirely leveed, and over time this has contributed to land loss by starving wetlands of sediment from "Big Muddy." But MGP, as the crevasse came to be known, has effectively served as a small-scale diversion of freshwater and sediment. By many accounts, it will help to restore the area's marshes and help the state adapt to storms and sea level rise. Conservationists were ecstatic. However, even though oil and gas infrastructure is at risk from wetland loss, the influential industry called for sealing the breach because it threatened some wells. Oddly, state authorities were also less than enthusiastic about MGP. As part of the Master Plan, the state intends to spend billions in coming decades to engineer similar kinds of river diversions to build land. One conservationist estimated that by building its own land, MGP is “potentially saving the state hundreds of millions of dollars." (in Masson 2017) Yet rather than embrace the free and seemingly positive change at MGP, decision-makers pointed to hydrodynamic computer models that predicted that too much sediment flowing out of MGP would make other restoration projects on the river less viable and valuable.

Figure 2. Mardi Gras Pass. Source: Lake Pontchartrain Basin Foundation.

MGP demonstrates that as an interface between science and adaptation policy, modeling is driven in part by existing economic conditions and institutional momentum. Rather than use models to adapt themselves to MGP, planners modeled to determine whether the muddy water flowing out of the crevasse would harm the area's valuable oil and gas infrastructure and undermine previous planning efforts. In popular discourse on software's place in society, digital technologies are "game-changers" and "disrupters." But, in the case of MGP, modeling software reinforced an existing set of arguably maladaptive relations between industry, government, and society. The interests of the oil and gas industry, with its boom and bust cycles and contributions to sea level rise, won out over those of conservationists, while the state lost an opportunity to build land. Some advocates see modeling and other software as fundamental to climate adaptation because digital technologies can facilitate information flows, enabling more rational and rapid responses to changing conditions. Mardi Gras Pass forces us to ask, however, when do digital technologies like modeling make for what geographer Mark Pelling (2010) calls *transformative* adaptation? For Pelling, transformative adaptation requires more than just quick fixes like sealing a crevasse or implementing programs at a larger scale (cf. Kates et al. 2012). Instead, transformation demands broader changes to the distribution of power and resources in a society.

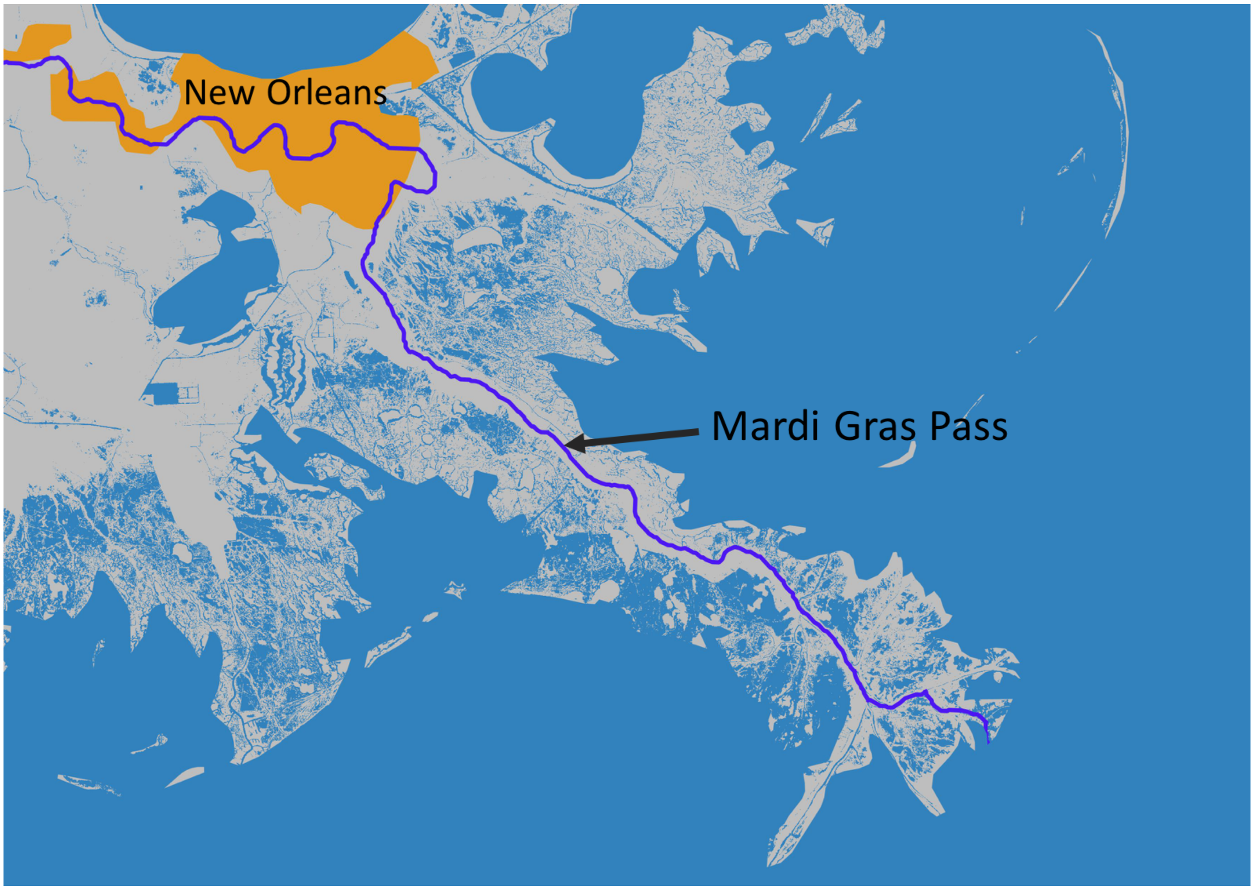


Figure 3. Location of Mardi Gras Pass in relation to New Orleans. Source: Author.

To understand whether modeling transforms or reinforces maladaptive relationships between states, civil society, and nature, we therefore start with, what are the political economic and technology-specific ways modeling actually informs environmental management? Understanding how digital technologies actually work within policy can shed light on, for instance, what kinds of technical features policy-makers find useful in models. Beyond such directly applicable impact, the question also has intellectual merit for both environmental management philosophies and critical scholarship. The question addresses a major tension between critical political ecological and conservationist perspectives. Conservationists often ask, "can technology save the planet?" (Gilpin 2014) Many answer yes; data scarcity and irregularity constrain environmental management more than political will, institutional capacity, or legitimacy (e.g. Hsu et al. 2012; Strombolis and Frank 2014). Political ecologists, however, have shown how modeling and other technologies result in harms to ecosystems, livelihoods, and democratic deliberation (e.g. Swyngedouw 2009, 2010).

In trying to reconcile conservationist and political ecological perspectives, this dissertation takes up Robbins and Moore (2015)'s call to characterize the *conditions* by which technology produces specific social and ecological outcomes, like transformative adaptation. They ask, for instance, "under what conditions, and to what extent, are GMOs a projection of unjust property relations and when, conversely, are they the tools of livelihood autonomy, farmer aspirations, or even sedition? As I see it, this line of inquiry amounts to a grand challenge in environmental governance research. As Dempsey (2016, 105) described it, "we need to understand – with some detail – the opportunities and challenges within the specific kinds of models ecosystem service advocates are creating." Simply put, when is more data and more modeling better? Answers to this question would not only advance critical political ecological scholarship. They would guide how conservationists pursue transformative socioenvironmental change – by demonstrating the inseparability of social and technical domains, and the necessity of drawing on both.

1.2 Research Questions

The overarching research question I ask is, what are the political economic and technology-specific ways modeling informs adaptation policy? This dissertation answers three specific questions to advance our understanding of digital technology as practiced within environmental governance, using the case of Louisiana's Master Plan and the role of the ICM in it.

1. *How was development of the Integrated Compartment Model constrained by the Master Plan as a governance strategy?*
2. *How is individual decision-making/learning by planners informed by the Integrated Component Model?*

3. *How does the Integrated Compartment Model enable the state to deploy coastal restoration policy?*

Or, less formally and more generally: how are models shaped by governance, and how is governance shaped by models?

Better data does not always lead to better governance. This study shows how and when modeling informs coastal policy and how it can – sometimes – enable truly adaptive management. Dominant modes of explaining why environmental governance fails or is limited point to data scarcities (Hsu et al. 2012; Strombolis and Frank 2014), institutional organizational challenges (Armitage et al. 2009; Vaughan and Dessai 2014), or how technocratic interventions like modeling foreclose "dissensus" in favor of "win-win" rhetoric (Kaika 2017). However, transformative adaptation does not just mean getting more data and better models, improving relations of trust or building "social capital" (Adger 2003; Armitage et al. 2009), or conducting "proper politics" (Swyngedouw 2010). This study finds value in these answers, but seeks to better explain how they happen and their meaning, as well as to integrate them. Rather than focusing on either the social dimensions of modeling (e.g. do scientists and policy-makers trust one another?) or its technical dimensions (e.g. is there enough data?), the study takes a different approach, a sociotechnical one. A sociotechnical approach sees something like trust as inseparable from the technologies that may enable or hinder it. Likewise, the approach sees something like data as inseparable from the political economic processes that make it available.

The dissertation proceeds in five more chapters. The background chapter further contextualizes land loss in Louisiana and the history of coastal modeling there. It pays special attention to how scientists have translated their knowledge of wetlands to policy-makers over time. Chapter three focuses on how modelers manage constraints on their work as they develop the Master Plan ICM submodels. Explaining how technology actually informs environmental governance means, in part, focusing in on specific aspects of policy-making, and the first chapter explains how it is that modeling informs coastal planners' general requirements for the Master Plan. Modelers make their work not only technically-sound but policy-relevant by managing various political and financial constraints. If modeling does foreclose transformative adaptation, it is through modelers' strategies for developing actionable models in light of these constraints. The chapter suggests that something more like transformative adaptation *is* possible through technics, but only when the right questions drive technical analysis, not more data per se.

The fourth chapter starts from the premise that planners must learn from modeling for it to inform environmental policy. I explain both how planners organize themselves to learn from the ICM and how the ICM itself shapes learning. Modeling compels the kinds of collaborative organizational structures that some scholars see as important to adaptation (Armitage et al. 2008; Armitage et al. 2009), and technical properties of the ICM also arm planners with specific kinds of insights. For instance, maps visualize simulated coastal changes. How maps visualize change – including showing the winners and losers that would result from restoration – represent technical ways modeling may enable transformative adaptation.

The fifth chapter provides a framework to understand the role of modeling in how planners implement coastal policy and restoration projects. I make a case for how the Master Plan modeling performs governance regimes, including adaptive management. The ICM and related models lend themselves to the kinds of flexible and responsive insights seen as necessary for adaptive management (Plummer et al. 2013). However, planners' application of ICM results is not straightforward and it is contested, since so much is at stake in the modeling process itself. In the sixth and concluding chapter, I synthesize an answer to the overarching research question: what are the political economic and technology-specific ways modeling informs adaptation policy?

1.3 Background to the ICM

This study focuses on the Integrated Compartment Model that is at the heart of the Master Plan, so in this section I will describe the background of the ICM and its general character. Environmental managers in Louisiana state agencies developed and rely on the ICM to determine the most cost-effective wetland restoration projects. They turned to the ICM not because it represents the most sophisticated modeling software in existence, but because it enabled them to respond to two major socio-environmental crises: the 2005 hurricane season and the 2010 BP oil spill. The 2005 hurricane season forced Louisiana resource agencies to reorganize and develop more comprehensive, pragmatic approaches to coastal restoration. Following Hurricanes Katrina and Rita, the State of Louisiana formed the Coastal Protection and Restoration Authority (CPRA) to coordinate what had previously been two separate tasks: wetland restoration and flood protection.[1] Since 2005, CPRA has released two Master Plans outlining a broad vision of restoration alongside each project the state will invest in (CPRA 2007, 2012). Planners had previously compiled several high-level model-based plans for rebuilding the coast (Coast 2050, the Louisiana Coastal Area study), but these never gained any real traction with decision-makers and funders. The 2005 hurricanes spurred planners to develop

[1] There is simply too much to say about Katrina. I can only speak to the small sliver of the storm's impact, on coastal restoration science and planning. See also Lewis et al. (2017). For more resources, see a compilation of "10 years after" stories I made here: http://atruepointofbeginning.blogspot.com/2015/08/katrina-10-roundup.html

a modeling approach that could evaluate a set of specific projects and budgets.

Planners did not perfect that modeling approach by the time the first Master Plan landed in 2007, but by the next plan in 2012, they were closer. In the intervening period, the 2010 BP spill had provided planners with a greater sense of urgency, not to mention funds to study and implement restoration. For many in the conservation world, the spill perfectly encapsulated how society inappropriately values nature. BP treated the Gulf of Mexico and onshore marshes like they were common property rather than indispensable storm surge barriers and carbon stores. The result was 11 lives lost, an estimated 1773 km of shoreline oiled (Turner and Badker 2015), and significant impacts on populations of endangered species like bottlenose dolphins. Conservationists outside of Louisiana used the spill to further promote modeling and geovisualization software that shows oil companies and governments what kinds of valuable “ecosystem services” Gulf marshes actually provide (e.g. TEEB 2010). There was a general sense that even though technological hubris was partially to blame for the spill (e.g. Klein 2010), perhaps modeling could, in its way, address some of the spill’s causes. At the time, Louisiana planners had just begun modeling to develop the 2012 Master Plan. In it, they introduced software - a “planning tool” - that helped them prioritize the projects that built the most land for $50 billion. The figure build from the $10 billion they were expecting to receive from the spill through the courts.

After 2012, CPRA had several models at their disposable, two Master Plans under their belt, and billions to actually implement restoration. Yet, planners and modelers still felt that sometimes the models were not speaking as well as they could to one another. This is what most immediately spurred development of the ICM for the 2017 plan. The ICM coordinates the six models that planners had previously run more or less separately. These six models simulate ocean wave circulation, barrier island morphology, river and basin hydraulics, wetland morphology, wetland vegetation, and fisheries. As parts of the ICM, they are linked because the output of one is used as input for another. For instance, the wave circulation model passes outputs to the barrier island model to predict barrier island morphology. Yet in the 2012 Master Plan, the wave circulation team would simulate 25 years' worth of wave conditions while the barrier island team was also simulating 25 years' worth of barrier island morphology, each based on initial conditions. After the 25 year run, the teams would share their results and run another 25 years. For the 2017 Master Plan, modeling teams and planners decided to bring all six models together under the same code and run them together, such that they inform each other at (sub)yearly timesteps. An important part of the story here is both the "technical" and "social" aspects of that change. Technically, improving the temporal resolution of the models required extensive programming changes, which limited planners' ability to use certain kinds of submodels. Socially, it necessitated collaboration amongst the separate modeling teams and, eventually, improved their ability to understand the modeling process as a whole.

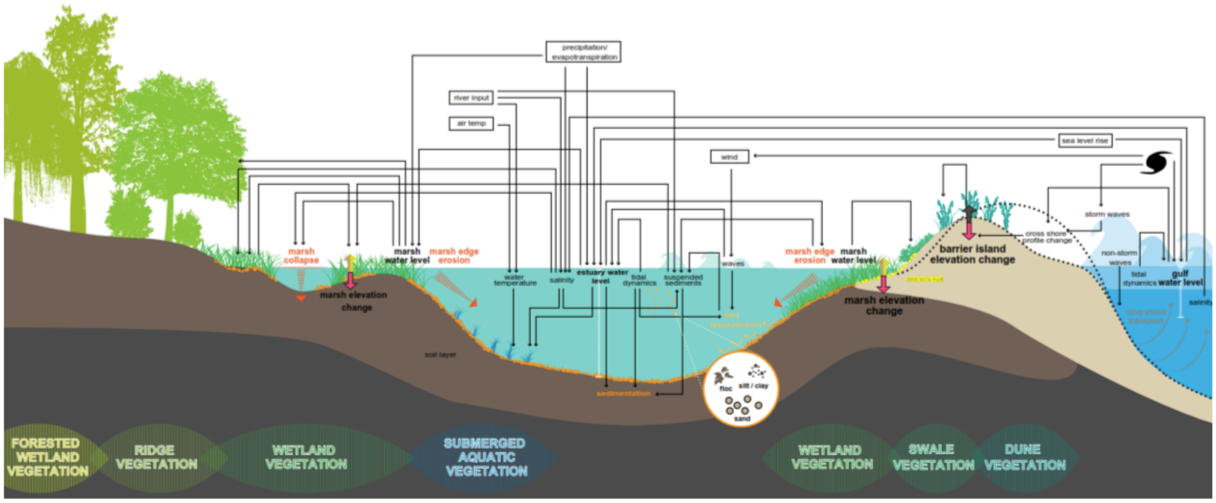


Figure 4. The biophysical processes modeled within the ICM. Source: CPRA (2017).

After getting preliminary results, planners proceeded to conduct ICM runs that assessed potential restoration projects. Then they used the "planning tool" to see how sets of projects work together and to score them using different metrics (Groves and Sharon 2013). The tool is essentially a web-based means of visualizing and interacting with model results – it is a key way planners make sense of the terabytes of data the ICM generates. The planning tool software is implemented by the RAND Corporation. CPRA staff ask Rand to produce visualizations to "filter" the amount of information they receive from the ICM. This way they can ignore model results for projects that fail to meet certain thresholds. Likewise, CPRA asks RAND to use the tool to score projects with different metrics. For instance, planners can use the planning tool to see which projects best build land around oil and gas infrastructure. In this part of the Master Plan process, CPRA also allows stakeholders on its "framework development team" to interact with a version of the planning tool and to make their own sense of the ICM results.

CPRA has called the ICM a "screen" to filter out, at a relatively high level, good projects from bad ones. Both times following the approvals of the 2012 and 2017 plans, planners began moving forward with more precise modeling of individual projects listed in the plans. Planners often enhance specific submodels of the ICM to help them understand project impacts in greater detail. Having the various ICM models in hand helps state planners because they put projects on a fast track to be approved by federal agencies. Planners also use parts of the ICM to prepare plans for adaptively managing restoration projects. By simulating a variety of operations scenarios, CPRA can develop results that allow it to operate a project flexibly, in response to changing conditions, without ever fully committing to a single plan. At the time of writing, planners and modelers have only just started envisioning the 2022 Master Plan and the role of the ICM in it.

1.4 Frameworks

I draw on three sets of scholarship as inspiration for my research questions and to contextualize my answers. The argument I make is that political ecological approaches to technology can be advanced with insights from Science and Technology Studies (STS) and with a case study focused on how it is that modeling informs environmental policy. I turn from political ecology to STS to avoid unduly dividing the technical from the social, allowing me to explain both the technology- and political economy-specific ways modeling shapes coastal governance. To date, political ecology has built bridges to STS mainly on the question of how environmental science is produced and legitimated (e.g. Lave 2012). My research extends the STS concepts of knowledge infrastructure, affordance, and performativity to the kinds of environmental governance cases political ecologists are familiar with. Finally, I synthesize this political ecology-STS approach in reference to emerging research on “digital geographies.” There are currently no digital geographies of the environment, a gap this study aims to fill.

1.4a Political ecology

Political ecology is a multidisciplinary field of research that seeks to explain past and present environmental change in terms of multiscalar political economic factors (Blaikie and Brookfield 1987, Robbins 2012 [2004]). Political ecologists were originally focused on characterizing the adaptive strategies of small-scale resource users in response to globalization and state-led conservation (Peluso 1994). There were especially interested in characterizing the “winners and losers” of environmental change and policy. Within the last 20 years, political ecologists have “studied up” to understand the relatively powerful actors – scientists, policy-makers, and conservationists – who figure largely in environmental policy itself (Robbins 2001). Along these lines, political ecologists have emphasized the role of institutional science in characterizing environmental problems and legitimating conservation efforts (Forsyth 2003; Goldman et al. 2010)

In particular, political ecologists have sought to explain what part geospatial technologies play in environmental science and policy. Researchers have investigated how GIS (Geographical Information Systems) mapping software is used in environmental science applications that may or do directly inform policy (Turner 2003; St. Martin and Hall-Arber 2008; Haussermann 2012). Political ecologists tend to critique the ways nature/society relations are represented within GIS. For instance, peasants’ land rights often cannot be represented in the kinds of discrete terms GIS software usually requires. Political ecologists propose alternative uses of GIS like countermapping (Peluso 1994; Weiner et al. 1995; St. Martin and Hall-Arber 2008) to reflect the partiality of knowledge (Robbins 2000), the geographical imaginaries of land users (Weiner et al. 1995), and in general to highlight marginal perspectives. Conventional GIS applications often involve modeling ecosystem change, but political ecologists’ research does not touch on the governance dimensions of modeling I ask after here. Some nature/society scholars directly address simulation and scenario modeling (Taylor and Buttel 1992; Johnson 2013; O'Lear 2016; Dempsey 2016). For instance, Taylor and Buttel examined the Limits to Growth model, illustrating how the assumptions it made about the state of the world, assumptions rooted in systems dynamics theory, also implied specific kinds of solutions to environmental crisis. More recently, Dempsey (2016, also 2013) argued that ecosystem services models like InVEST tend to depoliticize conservation because they fail to incorporate place- and history-specific context.

Political ecologists have bridged to STS to understand environmental science, but have not made many connections to STS via the T – technology. When political ecologists do examine the use of digital technology in environmental governance, they tend to take three different, but not exclusive, approaches. The first focuses on how GIS and remote sensing depict environmental phenomena and, in particular, the kinds of assumptions about nature and society they embed (Turner 2003, Robbins 2004). Sometimes this analysis is then extended into a second approach, which focuses more on what material and discursive effects of technologies, rather than how they represent the world. For instance, Robbins (2001) showed how his case study area was managed for the one kind of land cover remote sensing satellites could "see." In a sense, remote sensing *made* the landscape, or as he describes it, "landscapes are increasingly recreated to fit the demands of the technological optic." A third approach, the one I adopt here, sees a need to develop the "chains" or "webs" of explanation for technologies' material and discursive effects (following Robbins 2012; see Blaikie and Brookfield 1987; Rocheleau and Roth 2007; Robbins and Bishop 2008). The approach seeks to characterize what Butler (2010) calls "the felicitous conditions" or contexts by which technological objects come to act. One way to interpret these three approaches is in terms of an evolution in modes of understanding technology, from representation towards practice. I prefer to think of them in terms of different parts of the puzzle, each providing valuable insights. Here, I prioritize the third approach – "contextual performativity," described in more detail below. This dissertation is concerned with explaining whether and how modeling informs decision-making, not its inaccuracies or assumptions.

The Louisiana Master Plan case, centered on digital decision-making, offers two reflections for the field of political ecology in general. First, political ecology has always concerned itself with the nature of decision-making, even if thirty years ago this largely meant the kinds of calculations marginalized peasants made in managing their land (e.g. Stonich 1993). The nature of decision-making changes with digital technologies. On the one hand, traditional land users such as peasants have access to new kinds of tools, potentially reshaping their management strategies and generating uneven outcomes. For instance, some small-scale farmers in the developing world are gaining access to weather forecasts on cell phones, allowing them to better prepare for climate variability and potentially gain advantages vis a vis other less well-informed farmers (Vaughan and Dessai 2014). On the other hand, environmental assessment software itself is playing a more substantive and complicated role in generating metrics and management scenarios. Such software may produce its own "landscape signatures." (Lave et al. 2013) When political ecologists evaluate changing landscapes, they may, like Robbins (2001), need to explain the influence of technological "optics" or software features. This is something scholars and journalists in other fields are already seeing with, for instance, courts that rely on biased "risk assessment" algorithms during sentencing, the result reproducing a racist criminal justice system (Angwin and Larson 2016).

Second, the concept of *adaptation* has also always been central to the field of political ecology. Political ecologists are concerned not just with land managers' decision-making in the abstract, but how it achieves, or fails to achieve, adaptations to ecological and political economic dynamics. They have emphasized how communities and individuals adapt to changing climates (Bassett and Fogelman 2013), the structural constraints to adaptation (Watts 1983), and the adaptation concept as a means of governance (Nadadsy 2007; Beymer-Farris et al. 2012). The Louisiana Master Plan case, focused on digital decision-making in support of adaptive management, offers a chance to reconsider what role technology may play in adaptation. When political ecologists assess adaptation, they usually assess the relative contributions of technology and policy. Within this framing, one set of work usually rejects technical approaches for inadequately addressing social inequalities (Pelling 2010; Swyngedouw 2010). For instance, some scholars argue that modeling forecloses deliberation about how to justly solve climate problems (Hulme 2011; O'Lear 2016). A second set emphasizes the social change processes adaptation efforts do account for (Adger 2000, 2003; Lebel et al. 2006; Pelling 2010).

What political ecologies of climate adaptation need is a sociotechnical approach. Both kinds of political ecological evaluations – either rejecting technical approaches or emphasizing social change - assume some sort of divide between the technical and the social. They assume social change could be undertaken without the objects whose design shapes everyday and political life (Braun and Whatmore 2010; Meehan 2013; Meehan et al. 2013). My research starts from the assumption that social change requires technics and vice versa: planners' use of tools cannot occur without their socialization around the necessary know-how and motivation. I offer three ways of thinking about adaptation, technology, and politics:

1. Technical means of addressing adaptation, including modeling, represent terrain where adaptation is politicized. For instance, as I show in chapter three, deciding what data to include in a model requires modelers to reflect on current funding levels.
2. Planners are at the heart of "the state" that implements "top-down" adaptation. They gather the knowledge to do so in a process where they learn from and are otherwise socialized by models.
3. Specific model features make adaptive management and other adaptation governance projects possible in the first place.

1.4b Science and Technology Studies (STS)

I turn to STS to better conceptualize the boundaries between the social and the technical. I argue that three of the field's concepts - knowledge infrastructures, affordance, and performativity - can help political ecology develop "chains of explanation" for how modeling informs policy.

STS scholars show how data is as much a social artefact as a representation of reality - "[data] is always steeped in a specific way of understanding the world and constrained by given material and social conditions…." (Johnson 2015) One line of inquiry in this vein has centered on "knowledge infrastructures," or the standards, institutions, and devices that enable data production and ultimately knowledge regimes (Bowker 2000, Bowker et al. 2009; Edwards et al. 2009; see also Star and Ruhleder 1994; Star 1999). For instance, Edwards (2010) shows how modelers for the past 70 years have been building a knowledge infrastructure for understanding global climate. Standards, like those for metadata, are vital to climate science infrastructure because they create smooth connections between network parts across space and facilitate flows of information. However, for Edwards, this smoothing process is always disrupted because infrastructural systems must coordinate with one another and draw on resources outside of their control, like bespoke code, other standards, or domain experts. He calls this data friction. Such sources of friction should include political and financial factors as well (see also Bates 2017). In chapter three, I show how Louisiana modelers manage these kinds of “external” constraints to “infrastructur-ing” coastal science. Neoliberal austerity directly shapes their ability to infrastructure coastal science through, for instance, constraining how much funding they have to pursue data.

In order to understand how modeling informs policy, we need a theory about what role, if any, models themselves play as technical artefacts. For this, I draw on the STS concepts of affordance and performativity. From the early 1980s, social construction of technology (SCOT) scholars prioritized explaining how technological change happens (Mackenzie and Wajcman 1999). Although change is not what I seek to explain in this dissertation, SCOT scholars’ primary goal was to reconsider technological determinism more broadly. They confronted the idea that technological progress is inevitable, while admitting that technologies are material forces to be reckoned with. In this, they necessarily addressed the social context of technology, including how technologies are developed and how they shape social structures and forms.

Affordances and performativity represent two specific ways STS scholars have understood what technology does vis a vis its social context. First, STS scholars draw on the insights of human-computer design to argue that technologies provide “affordances” (Faraj and Azad 2011; Norman 1988). The affordance perspective on technological agency stems from work in organizational studies allied with STS. Scholars taking an affordance approach show how the design of technologies makes some kinds of collaboration, learning, and, in general, action much more intuitive and likely than others. For instance, Norman showed how the placement of door handles affords people an idea of which way the door will open (correctly or incorrectly). As such, affordance theorists aim to understand the materiality of devices like doors as well as computer models. As Leonardi (2013, 73-4) put it, “people [users] must contend with [technology’s] form in the here-and-now as though it were an objective and unrelenting force….[software] users experience a set of features that do certain things and do not do other things.” In chapter four, I draw on the “affordances” approach to describe how model features enable planners with insights that, for instance, are responsive to the relatively unique dynamics of the Louisiana coast.

However, model design makes action affordable only in the right contexts. In other words, affordance is a relational property that requires a lens on both the object itself and its users (Faraj and Azad 2011). In furthering the affordance concept, Faraj and Azad (2011) seek to split the difference between technological determinism (technology reshapes organizations) and voluntarism (organizations have full control of technology). They emphasize technological practice in context: affordances are “action possibilities and opportunities that emerge from actors engaging with a focal technology.” Technology’s materiality is not simply its physicality, but its “imbrication with the social,” making it “sociomaterial.” (see also Bakker and Bridge 2006) Affordance therefore means the “enactment of a particular set of activities that meld materiality with institutions, norms, discourses, and all other phenomena we typically define as “social.” (Faraj and Azad 2011, 74) Jarzabkowski and Pinch (2015) likewise describe sociomaterial affordance in terms of “accomplishing activity in context.” Context includes, broadly, expectations and experience. Leonardi (2013), for instance, emphasizes how user expectations shape what a technological object affords, noting that “those things that [technology] can and cannot do gain importance and are even perceivable because the people who use them have goals that they would like to use the technology to accomplish. In between the materiality of the technology and the socially formed goals of users is a perception of utility or impediment, of affordance or constraint." In other words, making sense of how models materially inform policy requires understanding their users' goals. Faraj and Azad echo the role of expectations but also emphasize the role of experience. Affordances, they explain, are not imminent to objects, but depend in part upon training: "a charcoal pencil and a piece of paper afford different affordances to an artist compared to an untrained human."

The second concept through which STS-related scholars have understood technological action is performativity. While the affordances approach usefully describes how technologies like computer models enable insights, actions, and structures within organizations, there is a need to make sense of what these affordances amount to. In chapter four, I will argue that the ICM's affordances perform adaptive management. Within the philosophy of science and STS more broadly, Langdon Winner (1980) argued that certain technologies were more or less compatible with particular modes of governance. For instance, he claimed that the risks of radioactivity may make nuclear energy production more amenable to centralized or authoritarian governance structures as opposed to democratic and decentralized control. Robbins and Moore (2015) called on political ecologists to explore similar questions within political ecology, but framed things more openly. They asked, as an example, what kind of state does a biogas digester produce?

The performativity concept helps to explain the relationship between technology and state form, treating this relationship more contextually and less determinatively. Performativity describes how technological objects like financial algorithms or modeling software encode assumptions about the world, assumptions that bring about the world the model represents when people act upon them (Mackenzie 2006; Callon 2007). Callon and Mackenzie show how economists' price-prediction models are performative because they generate the market dynamics economists say models only describe. The best example comes outside of STS. Judith Butler describes how discourses claiming the existence of two different genders actually perform their reality. She argues that there is no inherent core to gender categories, only repeated actions that name and emphasize specific bodily parts and dispositions. Such actions are as everyday and routine as proclaiming the gender of a baby at birth. In other words, these actions mediate gender. Another example is the performance of "nature's value," as mediated through ecosystem services assessment models. This value does not exist without models' calculations. With them, nature's value exists in a way shaped by the way it was measured – that is, with a necessarily limited subset of all the characteristics by which an ecosystem could be measured (Nost 2015). In chapter four, I will explain how models inform policy by performing it.

The performative agency of modeling, however, requires "felicitous conditions." Nuclear power plants do not an authoritarian state make. But they can perform such states if the conditions are right. Likewise, models do not simply construct a world in which adaptive management operates. For this to happen, models must be seen as legitimate, for instance. The dominant performativity approach from Callon and Mackenzie underemphasizes the contexts by which technology does work in the world (Butler 2010; Svetlova 2012; Muellerleile 2014; Christophers 2014; Nost 2015). I turn to feminist STS (Haraway 1991; Star 1991) to better capture the user practices, within political economic contexts, that drive performativity. Feminist studies of household technologies demonstrated how home appliances could serve as instruments of male power through their very design, but also showed how women subverted these effects (Wajcman 2004).

Building on this work, Akrich (1991) developed the notion that, through their designers, technologies "script" action for users, who may or may not end up playing the part intended for them (Svetlova 2012). In this vein, Svetlova characterized a difference between "strong" performativity (Mackenzie) and "weak" performativity, in which users mediate software's performance by modifying or dismissing it. She showed how the managers of a financial account routinely modified their price-prediction algorithms in order to get the answers they wanted. "In such cases," she writes, models become intermediaries: they "are simply channels used to transmit the financial actors' judgements into numbers" (Svetlova, 2012: 420). In short, users can appropriate or "refashion" the tools designers have made for them and technologies themselves can perform work beyond users' or designers' intentions (Suchman 1987; Woolgar 1990; Oodshourn and Pinch 2003). Akrich and Law (1996, cited in Callon 2007) provide an example where it is not just users modifying software's performance by dismissing or working around it. Instead, they demonstrated how electricity users contested the installation of meters that would have performed a neoliberal economy. In chapter four, I show how modeling affords Louisiana planners a more flexible mode of coastal governance. Yet this flexibility is exactly why some groups, like fishers, contest modeling.

What the STS concepts of knowledge infrastructures, affordance, and performativity allow me to do is develop political ecological chains of explanation for how modeling informs environmental policy. The effects of modeling are not simply "voluntarist" – the result of malicious design by state planners, patriarchs, or capitalists (cf. Winner 1980). Each of the chapters of this dissertation elaborates on the relationship between technologies, their users, and context:

1. The ways modelers rework ICM submodels to manage external constraints on their efforts.
2. The ways planners make expectations about the ICM in relation to its technical properties, making models' affordances sociomaterial.
3. Technologies like modeling mediate governance regimes, but they are contested.

1.4c Digital geographies (DG)

I find DG somewhere to locate this synthesis of PE and STS. This dissertation bridges PE and STS in order to propose some guidelines for a digital geographical approach to environmental governance. The emerging field of digital geography extends insights from cartography and other geography subfields to digital contexts: social media data, "smart cities," and so on. The field has had relatively little input from nature/society scholars (but see e.g. Gabrys 2016; Büscher et al. 2017, Hawkins and Silver 2017; Adams 2017) or political ecologists in particular. One approach would be to evaluate what differences, if any, digital technologies may have on the environment as opposed to urban space. This, however, is not my goal. Instead, I believe environmental governance represents a way to reconsider how DG explains how data and analytics are produced, practiced, and, especially, challenged.

DG stems from critical GIS and cartography discussions, human geographical approaches to technology, and critical data studies (Dalton and Thatcher 2015). Digital geographers have advanced: economic geographies of (geospatial) technology (Cockayne 2016; Thatcher et al. 2016; Alvarez León and Gleason 2017); political geographies of algorithmic governance (Amoore 2009; Crampton and Miller 2016; Lally 2016) and the meaning of citizenship in an increasingly data-driven society (Shelton forthcoming); understanding how digital technologies shape representations and experiences of place (Dodge and Kitchin 2004; Crutcher and Zook 2009; Stephens 2013), especially in cities (Leszczynski 2015); and characterizing the geospatial web – especially social media – as a mediator of power (Crampton et al. 2013; Wilson 2013).

There are a couple of key takeaways across this work.

The first key takeaway is that decision-making based on fast, opaque model algorithms fundamentally reshapes space and society. Here, I believe there is opportunity to connect digital geographies with insights from political ecology and STS, in order to better situate algorithmic decision-making. Some work in critical data studies tends to take big data advocates' claims for granted – for instance, that algorithms will soon rule our world (cf. Barnes 2013). I find that the field's greatest promise lies instead in showing how data is contested in decision-making. I believe this can be done through case studies in governance contexts where algorithms do not obviously determine decisions – such as in Louisiana's coastal Master Plan. This is because even when models are opaque and influential – as they are, for instance in how New York City allocates its budget (Powles 2017) - there will be human and institutional processes to explain (e.g. how the algorithms were authored, deployed, and evaluated). STS and especially political ecology bring grounded and empirical powers of contextualization to show how "big data," and the models that make sense of it, are produced and practiced.

Above all, contextualizing the impact of big data requires precision in defining it. The standard "3Vs" definition of big data is data-oriented, but voluminous, various, and fast data means little without the conceptual and practical apparatuses that allow it to be understood. I think about big data in three ways - first, in terms of its analytical aspects. The most important thing to understand about big data is that it does not somehow mean the end of modeling or, as Anderson (2008) famously declared, "the end of theory." Big data's promoters, like Anderson, see its use in prediction as overcoming the need for theory or modeling based on representative statistics, since big data is often supposed to encompass entire populations (n=N; Mayer-Schönberger and Cukier 2013). But this is rarely the case in many policy contexts, meaning data managers must choose algorithms and train them on relatively limited, existing data, ultimately raising questions of bias (e.g. racial bias in recidivism risk assessments – Angwin and Larson 2016; O'Neil 2016). Beyond algorithms per se, data analytics lean heavily on so-called dashboards for "seeing" trends since data "do not speak for themselves." In Louisiana, these dashboards include the planning tool Rand has come up with to help planners filter through the terabytes of ICM output (Groves and Sharon 2013). In short, I see big data as *practiced* between people and analytical tools. Explaining this practice requires bridging PE and STS to provide "chains of explanation" or "rooted networks" for analytical tools' sociomaterial affordances.

The second way I think about big data is in terms of its infrastructural aspects. Big data is marked by the use of new sensing technologies that can capture more data, more rapidly. This can mean social media sites that record users' every mouse move, or meters logging every second of water levels in a lake. In Louisiana, the Coastwide Reference Monitoring System (CRMS) consists of hundreds of ecological monitors embedded throughout the coast, gathering data on a variety of variables, in some cases at very fine temporal scales. Whatever data these sensors collect must be stored somewhere, necessitating a data infrastructure. In addition, the ICM model produces significant volumes of data itself, and modelers have encountered difficulties in sharing all that data. They have even noted that one of the main limitations of the entire modeling process is transferring data. In other words, big data practice is challenged. While it is crucial to recognize how data potentially connects different domains (e.g. finance and ecology) in novel ways, we should try not to reproduce discourse that "algorithms will rule our world" (Barnes 2013), lest we miss key challenges.

Only finally do I think about big data in terms of the characteristics of the data itself. In particular, big data is marked not just by its size, but by its disparateness (that is, how it comes from different sensors or different texts), heterogeneity (of different data types – text vs. spatial), and uncertainties (of varying quality, ambiguity, and so on). The CRMS series of coastal sensors is exemplary of this, consisting of disparate records. Modelers complain about and have to work around the fact that some data points are not comparable because which field techs gathered the more descriptive or classificatory ecological data. These characteristics constitute data's value, alongside cultural, political economic, and institutional constructs like planners' ideas about how much data is adequate for their decisions. In other words, we should see big data as *produced* rather than taking it and its value for granted. Chapter three shows how some data may not have marginal value, even to scientists.

1.5 Methodology

The methodological approach I take is to attempt the close inductive "following" that has been a hallmark of STS research, from Latour and Woolgar's (1979) study of "lab life" to Vertesi's (2013) research within the Mars rover team. At the same time, however, I am guided by political ecological approaches that recognize fieldwork as theoretically-informed. Political ecology has a strong tradition of starting with (Marxist development and peasant) theory, as infamously criticized by Vayda and Walters (1999), and working outward beyond case sites in "chains of explanation" (Blaikie and Brookfield 1987). I do not see STS and political ecological methodological approaches as necessarily opposed (but see Castree 2002), because there are a couple of frameworks – grounded theory and the extended case study method – I describe below that enable a rich twinning of inductive and deductive research.

My study is a social science project. It is not enough to validate whether models work because, after all, "it is impossible to verify the representational truth of any model of an open system" like the Louisiana coast (Oreskes et al. 1994 in O'Sullivan 2004). Instead, I am interested in observing how modeling is a process shaped by socially and politically-inflected practice.

A focus on practice – necessarily contingent - lends itself to inductive approaches. In STS, these arose out of the field's focus on the internal rather than external conditions of science (Lave 2015a). Early scholars in the field sought to characterize scientific practice as a cultural practice, and made explicit connections between their work and anthropological research, such as through "ethnomethodology." Much like conventional anthropology at the time bounded research projects to and sought depth at well-defined communities (e.g. Rappaport 1967), early science studies intensified research of and at the site of the lab. A related key set of assumptions paired to the inductive orientation of much STS research, especially that informed by Actor Network Theory, is a naiveté about the interests of actors and who these even are (see also Lave 2015b).

This aversion to entering a study without assuming certain characters drive the action and what their interests are raises a tension. While it usefully allows for fieldwork data to drive perhaps surprising results and to see structur*ing* (Holifield 2009), it is potentially oblivious to existing "external" political, economic, and social structures. It is one thing to set aside some assumptions about what scientists are interested in and motivated by, and to follow them as they become interested in specific projects, but it is another to overlook history and how such scientists have already been shaped by their disciplinary training, institutional setting, and so on.

I find that grounded theory provides a useful framework for bridging more inductive and deductive (and hence internally-focused and externally-focused) epistemologies. Grounded theory is a set of lenses which help researchers understand the subjective experience of everyday life as structured by political, economic, cultural, and social conditions (Cope 2005; Knigge and Cope 2006). As the name suggests, its practitioners aim to "ground" theory by building it up out of empirical data collection.

At the same time that my research seeks to learn from the Louisiana case in order to question political ecological assumptions about technology, it leans on a set of theoretically-oriented principles about the capitalist structuring of science and the relationship between state and society. I assume that what is happening in Louisiana is driven in part by a globalized set of discourses and relations concerning adaptive management and decision-support tools, even while what happens in Louisiana may shape this. I find support for this approach in the extended case study method (ECM) advocated by Burawoy (1998). ECM is a "crutch" for moving from the mirco to the macro. Like STS scholars, Burawoy discusses the framework in the context of formal ethnography. ECM developed in the mid twentieth century with social anthropologists who looked *outwards* from their field sites to situate them in world historical context.

These frameworks are most visible in how I coded documents and conducted participant observation. Coding allows the identification of categories and patterns (Cope 2005) through data reduction and analysis (Knigge and Cope 2006). I read documents I coded after preliminary interviews (see below), meaning I had a sense of important themes and questions already. Nevertheless, I adopted Cope's process of starting from description and moving into analysis via the iterative transition from open (what is this?) to axial (relating codes to one another) to selective (coding for a single overarching theme) coding (see Strauss).

In participant observation, I was motivated by Burawoy's ECM, which led me to attend several conferences on ecosystem services modeling. Through observation at these conferences, I was able to situate Louisiana planners' work in its proper "bigger picture" context, which is to say, how it fits in with broader discussions of adaptive management of ecosystem services through decision-support tools.

In sum, I am guided by the idea that qualitative research is a "taut rubber band" in which empirics press up on against theory, while theory also constrains empirics (Hebert 2000). While some prefer to start with theory, and "grounded" practitioners prefer to start with data and let theory emerge, I agree with Herbert (2000) that research should move between the two. Below, I provide further explanation of the methods I employed in this study.

I employed three *modes of fieldwork*: document analysis, semi-structured interviews, and participant observation. Through these, I triangulated what planners wrote about their models in official documents, what they said about them, and what they actually did with them. Each of these three moments unfurls another level of modeling practice. Following a standard approach within STS, I paid special attention to "controversies" (Jasanoff 2004) or "failures," where planners deemed models unnecessary, where models became visible in public debate (e.g. at Mardi Gras Pass), or when models were seen as the limiting factor in coastal restoration. This provided me with a way to demonstrate what factors informed model use within policy.

1.5a Document analysis

I read the modeling documentation for the 2017 Master Plan. I wanted to better understand both how modelers interpreted their results and the decisions they made about which data and submodels to include in the ICM. My main source here was the draft and final Master Plan 2017 appendices. These are where planners described the rationale behind each ICM submodel, what each could and could not do, and how they employed or dismissed model outputs. The appendices I read are publicly available online from CPRA – a full list is available in an appendix to this dissertation. My method for navigating this "archive" was to read it with an eye for practice- and results-oriented themes. My process was to allow codes to emerge from the documents. I generated around 80 unique codes, but then reduced them by eliminating duplicates and organizing (see Appendix D for a list of codes). The codes I developed included, "framing (as strategy to deal with data limitations)," "seeking other tools (to solve a problem)," or "managing uncertainty." I used these codes to structure chapter three's discussion of "making models work" and the discussion in chapter four on model affordances.

I also read the strategy documents model development teams produced in 2012 and 2013 ahead of the actual modeling effort. In these documents, modelers laid out their goals for the ICM, pointed to different models that could meet those goals, and articulated their rationales for proceeding the way they did. Related, I read the official notes from meetings of the technical advisory groups that oversaw the modeling teams. I read these documents to develop codes characterizing the ideals and imaginaries associated with modeling. The results structure the sections of chapter four on the ICM as an institution and on “good modelers.”

I conducted a document “survey” of ICM submodels in order to further understand how modelers and planners made sense of ICM outputs. In particular, I focused on the role of mapping as a way these actors communicated and understood model results. Beyond Louisiana, advocates for ES models note their potential to effectively communicate nature’s benefits in ways that decision-makers will understand and be able to act upon (e.g. Burkhard et al. 2013; Cox et al. 2013). However, much of the research in this vein has focused on the spatial analytical rather than the cartographic dimensions of ES models. Still, we know from studies of sea level rise viewers and other climate change maps that representational choices shape what policy-makers learn with maps (Neset et al. 2015; Retchless 2014; Roth et al. 2015; Fish and Calvert 2017). Based on interviews with decision-makers and the cartographic literature, I selected four factors on which to evaluate the Master Plan’s maps: scale, color, uncertainty, and difference. I wanted to understand what kinds of maps planners had access to and, decoding the features of those maps, to characterize what planners could learn from them. For each map either in the Plan, the appendices, or in two public webinars on the modeling process (n=313), I answered several questions. These included whether uncertainty was implicitly or explicitly represented, the color ramp assigned to data values, and whether and how change or differences were represented. The 313 maps accounted for more or less all publicly available Master Plan-related maps. The survey helped me explain how planners learn from models. In chapter four, I emphasize two features by which maps represented coastal data to planners: difference and scale.[2]

1.5b Interviews

I interviewed 53 key informants all along the "modeling chain," from planners to modelers to programmers, in addition to other important players in Louisiana coastal restoration, including conservationists. Documentary analysis is limited in that it reflects more or less carefully tailored statements usually intended for a public audience, rather than reflecting individual experiences, narratives, or opinions. Interviews helped me understand why planners and modelers thought about things the way they did. It also proved useful to hear people narrate processes in their own words, and to prompt people to formulate nascent ideas or opinions.

I spoke to people along the entire modeling chain: programmers, modelers, consultants, project and program managers, and members of the technical advisory committee (a full list is available in Appendix A of this dissertation). 53 interviews 'saturated' my understanding such that each additional interview yielded few new insights (Kuzel 1999). I relied in part on "gatekeepers," or well-connected and accommodating individuals within the modeling teams, to point me towards potential respondents. I always asked interviewees for additional contacts, including individuals they thought it would be worthwhile to speak with. This made for a respondent-driven sampling of informants that proved effective for accessing bureaucrats otherwise difficult to identify (Kuzel 1999). That said, I also relied on publicly available lists of model team members (CPRA 2017 C-1), as I wanted to ensure as much coverage of the teams as possible. In the end, I spoke

[2] I also looked at how the maps handled uncertainty and used color. I found that none of the maps directly represented uncertainty, though small multiples comparing high, medium, and low scenarios are arguably an indirect way of depicting uncertainty.

with the leads, and often other members too, for nearly all the ICM submodels.

In general, interviews were key to answering every research question because they were the most direct way I identified what people saw as the challenges and promises of modeling for coastal restoration, which is a way of determining the ways it informs environmental management (see Appendix B for a list of questions I asked). In particular, interviews helped me answer in chapter three how modelers workaround data limitations. These workarounds are not thoroughly documented in manuals or appendices. Manuals provided only some evidence of the tacit data strategies that interviews elicited. Interviews also shed light on how what planners saw as the utility of models in the course of decision-making. Interviews were qualitatively analyzed for recurrent themes and an iterative coding process was useful to facilitate theme extraction (Crang 1997; Crabtree and Miller 1997; Cope 2005). Among other themes, “models as heuristics”, “the value of having more data,” “uncertainty,” “difference mapping,” and “time constraints” featured. I cross-referenced these with codes from document analysis and drew out particularly illustrative quotes.

I spoke with a variety of people as part of this project, each for different reasons. Study participants can be defined in several ways. Most broadly, I spoke with people who can be labeled as conservationists, planners, and modelers. Respectively, I chose these kinds of people in order to develop insight into the broader context of coastal restoration controversies, how decisions about coastal restoration are made (through modeling), and for more insight into the process of model-making and translation. I first found conservationists and planners that were cited in major news articles on coastal restoration. From these preliminary conversations, I “snowballed” contacts to other such participants as well as to some modelers. However, most of the modelers I spoke with were selected through reference to the list of modeling team members (in the 2017 Master Plan Appendix C). I prioritized meeting with each submodel's team lead(s). I also spoke with as many members of the Science and Engineering Board and Technical Advisory Committee – both of which formally advise Master Plan modelers and planners – in order to understand how good modeling practice was characterized within the Master Plan. A full list of study participants is available in Appendix A.

Yet "conservationist" or "modeler" hardly does justice to who study participants are, if only because they are situated in particular institutional contexts. These contexts inform, but of course do not determine, their perspectives. Most of the conservationists I spoke with were employed by nonprofit non-governmental organizations like the Mississippi River Delta coalition (which is precisely why I deem them conservationists, a label that could easily apply to any study participant). The modelers I interviewed worked in a wider variety of institutions: academia, state and federal government agencies, in small and big research consultancies, and in engineering firms.

Institutional affiliation is likewise somewhat deficient in characterizing this study's participants. They also are shaped by their educational background, which is one of the questions I asked everyone in my interviews. Most interviewees expressed that they acquired a degree (or more) in natural resources or physical science disciplines. A not insignificant portion received training at LSU in Baton Rouge. Indeed, beyond institutional affiliation and educational background, place plays a role here too. Some participants grew up in the state, and shared memories of fishing, hunting, and camping as they described some of the motivations behind their career trajectory. Most participants were not actually born and raised in Louisiana (and most consultants do not even live there), but they still described to me their long-standing Louisiana connections. As one put it, the world of Louisiana coastal restoration is "a relatively small world." Even if the Master Plan draws in external experts (like those from Rand), these people likely already have been doing work on coastal issues.

1.5c Participant observation

It was not enough to talk to planners about how they used models. I took "field notes" during moments where I conducted a kind of participant observation (Cook 1997; Bogdewic 1999; Atkinson and Hammersley 2000). I asked a few modelers to show me how they work with the ICM submodels. I asked them to briefly walk me through how they code the models and I watched them explain model outputs. This was one valuable way I understood how people actually work with models, beyond what they say or write about them. It illustrated some of the technical conditions by which models inform environmental management. My observations showed me, for instance, how modelers lean on visual outputs like maps to develop narratives explaining model results.

I also observed planners present model results at public meetings, and this helped me address the broader context in which model results are used to govern. Specifically, I attended four CPRA Board meetings, a public forum in New Orleans on the draft 2017 Master Plan, and the 2016 State of the Coast conference on coastal science and policy. Likewise, I reviewed the 1,333 public comments CPRA received on the draft and final 2017 plans (see Appendix D for the documents I read and the codes I developed). I skimmed them for the term "model" or "modeling." This helped me develop a sense of how modeling's translation to policy-making was supported or contested by the public generally and by specific stakeholders. Most of the

1,333 comments were focused on related issues - specific projects, scenarios, or data – but did not explicitly mention "model*." I found 100 comments that specifically discussed the modeling. My goal was not to make any sort of quantitative claims – i.e. "most people take issue with the modeling" - because the public comment process is in a way biased towards complaints. Instead, I read the 100 model-relevant comments to develop qualitative classifications of different ways the public and stakeholders thought about modeling (e.g. "modeling has been inadequate – why wasn't x project selected?"). Their criticisms or support suggest several contextual factors for how modeling informs coastal restoration policy, as I discuss in chapter four.

1.6 "What if we were wrong?"

Those observing or active in Louisiana coastal restoration often talk about it in "win-win" terms. They see industry, government, and scientists as having finally recognized the nature of coastal erosion, with these sectors now working together hand in hand to address it (e.g. Therio 2014). In this view, land loss may represent a significant challenge, but it is one that can be addressed with the new scientific understanding and capabilities the ICM modeling represents. All while the Master Plan protects the "energy economy" *and* turns the state into a "hub" for a new water knowledge economy.

Conservationists around the world often think similarly about what modeling means for environmental management. Many imagine that data and technology could "help save the planet." (Gilpin 2014) The most prominent example of modeling applied to conservation ends - the Natural Capital Project's InVEST suite - generates land use and land cover scenarios for policy-makers. Yet, InVEST and related models have been deployed to date mostly in small-scale, narrowly-focused decision and ecological contexts (Gallagher forthcoming).

The question is, in the face of win-win gloss and hype, what does the use of ecosystem models look like in actual policy-making? When does it lead to the transformation of maladaptive relationships between the state and civil society? Mardi Gras Pass suggested to us that political and economic factors were especially relevant answers to such questions, more than how much data planners had available or how sophisticated their tools were. Modeling informed decision-making there, but in a relatively limited way – with reference to what affect the crevasse may have on oil and gas infrastructure and other restoration projects.

MGP, however, is only one part of Louisiana coastal governance. In the rest of this dissertation, I will explore other aspects the ICM and Master Plan and what they mean for how modeling informs environmental policy. The ICM/Master Plan is arguably the perfect test case for understanding the potential and limits of model-based adaptation, because in Louisiana, the political and biophysical challenges any such program will face are in sharp relief. In fact, a variety of popular media point to Louisiana as a potential model for how other parts of the US may adapt to climate change or fail to (e.g. Sack and Schwartz 2018). I proposed three research questions to understand the ICM:

1. How was development of the Integrated Compartment Model constrained by the Master Plan as a governance strategy? Modelers developed the ICM models under political and financial constraints like the availability of funding and debates about the effectiveness of this money. Modelers are building a "knowledge infrastructure" for coastal science, encountering and managing "data friction" along the way.
2. How is individual decision-making/learning by planners informed by the Integrated Component Model? In other words, what is there about the ICM itself that informs learning about coastal change? The affordance approach explains how the ICM submodels organized planners and modelers at the same time they organized themselves to learn from it.

3. How does the Integrated Component Model enable the state to deploy coastal restoration policy? CPRA's coastal policies would not look the same without the way the ICM affords, for instance, flexibility and responsiveness. Performativity explains how the ICM enabled the state to deploy policy, though not without resistance.

Before I move on to more background on land loss and coastal modeling, some caveats about what this dissertation does and does not do. I focus the research only on the models that comprise the Master Plan's ICM and the planning tool that turns ICM results into actionable information. The two are inseparable: the model outputs mean only so much without being plugged into the planning tool. I do not examine how coastal data was created. I also make no attempt to validate the ICM models, for reasons having to do with capacity, epistemology, and research objectives. It is not in the scope of this project to quantitatively validate the modeling, which would require significant time and technical resources. Given that the ICM models are predictive models, there is also a sense in which it is impossible to prove or disprove them. More generally, it is not the aim of this research to explore how the modeling may be wrong or even to question the scientific validity of the modeling effort. Instead, the research objective is to understand what modelers and planners themselves consider adequate, because this is ultimately what governs how modeling translates science into policy, not accuracy or precision per se. I prioritize how modelers acknowledge the limitations of their own work.

One research participant put it to me this way, "What if we were wrong?" Mine is a social science project that describes modelers' worry about the utility of their work in the face of an environmental crisis. Ultimately, I want to explain why it is that even though modelers acknowledge their work's limits, that it becomes policy-relevant: seen as adequate (chapter three), useful to learn with (chapter four), and objective and legitimate (chapter four).

2. Background

In this chapter, I do two things. First, I provide context for what environmental modeling is. I do so “in some detail,” as Dempsey (2016) recommends. I review both the technical aspects of modeling as well as philosophical perspectives on what it is for and what it can achieve. In providing this context, I make some reference to the history of computer modeling over the past 100 years, and climate change modeling in particular. The second thing I do in this chapter is present a comprehensive background to coastal land loss and restoration in Louisiana, weaving the evolution of coastal modeling and science into the narrative. I will focus on how scientists have sought to translate their wetlands expertise into policy, making the Louisiana coast central to the project of ecosystem services valuation as we know it today.

2.1 What is modeling?

A model is a means of reducing the world to something more manageable. As such, models are fundamentally concerned with abstraction. This immediately raises a key question about the material adequacy of model abstractions that is arguably at the heart of any modeling controversy: does the physical and social world tolerate the model? For scientists, this might mean asking, does our model of the universe fit with the data we are receiving from experiments? Does the model actually explain the data? What happens when we try to put our model into action?

Models can range from maps to document object models describing relations between “entities” on a webpage or in a GIS. For instance, a GIS user interacts with lines, points, and polygons that model the real world. As such, not all models contain algorithms per se, though they do encode rules by which reality is translated into representation. In this research, I look specifically at computer-based simulation modeling software (O’Sullivan 2004; Millington et al. 2012), which I define as statistically-informed algorithms, executed by code, that operate on data to generate predictions of future conditions under user-defined scenarios.

Because models are *made* abstractions of reality, any computer simulation model arguably "represents a theory about the world, rather than the world itself" (O'Sullivan 2004, 291) Following O'Sullivan, this suggests treating models as *narratives* that tell stories about the world that is, was, or could be. By extension, this makes modeling subject to different interpretations. The classic quip, "all models are wrong," (Box in O'Sullivan 2004) resonates with the poststructuralist point that "reality" is better described as cut by multiple truth perspectives dependent on "standpoint" (Harding 1991).

For this reason, I am not especially interested in verifying Master Plan models. While I do study what models represent and how – because this shapes what decision-makers learn with them (chapter four) – I am not interested in general questions about the adequacy of representation (but see O'Sullivan 2004). To me, the issue of adequacy is most tractable when modeling is contested. I am driven by questions about the performativity of modeling – what models do and enable.

2.1a Opening the black box

A computer model is a set of algorithms that, executed by a computer, act on data to simulate some state or process. When they think about computer modeling, many people may think of weather forecasting. Weather forecasts take a variety of data on humidity levels, temperatures, and so on and make a guess about whether it will rain tomorrow, based on how all these processes have coincided in the past. They rely on data from weather stations and are considered “forecasts” because they aim to predict the future without any knowledge of what that future will look like. Weather models predict tomorrow’s rain without knowing what tomorrow’s humidity will be - this too is simulated based on current conditions and atmospheric physics. Numerical models like this drive some of the core components of the ICM, such as the barrier island morphology or sediment distribution models.

Astute observers will recognize that models underlie many big data applications in other ways. For instance, when Wal-Mart “mines” its sales data to find patterns in when shoppers buy certain items, they are employing *statistical* models. The same is true when courts in states like Wisconsin use “repeat offender” data to forecast whether a convict is at “risk” of committing another crime upon release (Angwin and Larson 2016). These models assume a certain structure to the data and see how closely the data actually match or correlate to that structure. This is your everyday linear regression, and it drives many parts of the ICM “downstream” of the sediment or hydrology models. The fisheries and vegetation models rely heavily on this approach. In short, we can already see that computer modeling is not just one thing. Modeling has no single technical characteristic, with both mathematical and statistical models, no one application, and no one ultimate purpose (O’Sullivan 2004; Kelly et al. 2013). Over the next few paragraphs, I further open up the “black box” of modeling to specify other key differences, while noting how the ICM fits in. I lean heavily on Kelly et al. (2013)’s excellent overview of “five common modeling approaches” in ecosystem science.

Different models have different purposes. According to Kelly et al., there are five different reasons why to use a model:

1. Prediction
2. Forecasting
3. Decision-making
4. Social learning
5. System understanding

They are not mutually exclusive. First, prediction is more or less what the ICM does. For instance, you might want to know how much of the Louisiana coast will remain in 2050, given that sea level will rise three meters. Prediction requires "knowing" the future state of a variable (sea level rise) in order to calculate another (land loss). Of course, this is often not possible in ecosystem management, where future conditions are somewhat uncertain. We don't actually know how much sea level will rise. Forecasting, the second model purpose, is closely related to prediction. In forecasting, you want to know land loss but you don't know the future sea level, so you "cast" historical sea level rates forward, extrapolating from its trend. A third purpose of modeling is to inform decision-making, specifically through scenario analysis or optimization. There is "considerable overlap," Kelly et al. note, between prediction purposes and decision-making or management purposes. Most decision-making that draws on modeling involves predicting future conditions. In particular, decision-making often relies on scenario analysis, which assumes something about the future (i.e. what if sea level rise were three meters?) in order to predict some other part of the future (i.e. how much land will be lost). Fourth, models can be used for "social learning." Models, as more or less accurate representations of some part of the world, can be used to synthesize and reflect how stakeholders understand that part of the world. From this, stakeholders are thought to learn more about their own view of the world, as well as others'. Adaptive management fits in here in so far as it supposes organizations can use models to learn from previous action. Related, and fifth, models can be used to develop "system understanding." Models can "integrate" knowledge about a system's components, in order to develop insights about the system that were not possible without bringing them together. System understanding, or learning more about the nature of coastal dynamics, is somewhat of a side benefit for the ICM and Master Plan process. Kelly et al. believe that "it is not sufficient to generate accurate output behaviour but, more importantly, the model structure should be a sufficient representation of the real system under study." Sufficiently representing the real system may be a scientific ideal, but in policy-making, planners are often more concerned that the models produce reasonable and replicable outputs. Those involved in the fish modeling related that, "CPRA has indicated they are more focused on ensuring consistency in the predicted responses from the models across species than with mechanistic understanding of a particular response." ("Strategy" 2013, 5) In other words, CPRA has prioritized consistent, policy-relevant output over system understanding. To paraphrase a famous quip, "all models are wrong, but some are useful, so we're not really interested in understanding exactly why they're wrong."

The five model purposes can be summed up and furthered in terms of the question Kelly et al. pose, what are models for? Their answer is, *integration*, or the bringing together of different algorithms into one framework: integrated models "are seen as useful tools to help analyse alternatives with stakeholders, assess their outcomes, and communicate results in a transparent way." (159) For Kelly et al., integration is a process, not just an outcome. This is clearly the case for the Integrated Compartment Model, in which a primary goal is to relate and simulate forces as disparate as ocean wave frequency and vegetative propagation. There are four specific types of integration in Kelly et al.'s schema:

1. Integrated treatment of issues (i.e. bringing together social and natural dynamics). The Master Plan modeling accomplishes this especially in the flooding analysis, looking at the economic damages from the flood depths probable with future configurations of land.

2. Integration with stakeholders (i.e. social learning).
3. Integration of disciplines (i.e. geomorphology and ecology).
4. Integration of scales of analysis. This last kind of integration is especially relevant to the ICM, where some processes can be calculated at much finer spatial scales than others, even though these processes inform each other.

Pointing to the first chapter, modelers must decide how to spatially (dis)aggregate model output data when components of the ICM are passing results between each other. Kelly et al. note a set of tradeoffs modelers face between data constraints, stakeholder demands, and fidelity to the process being simulated: "In integrated modelling for policy support, scale selection is a balancing act between: i) the scales of interest for end users or stakeholders; ii) the scale at which processes occur or can be represented; iii) the linkage between model components that represent processes across different scales; and iv) practical constraints such as data or computation limitations." (160) In chapter two, we will see some contention around "the scales of interests for stakeholders," in which decision-makers do not want to calculate and visualize at the same scale as fishers do. In chapter one, we will see how ICM modelers actually engage with the practical constraints of data/computation limits, which are also financial and organizational constraints.

There are many ways to actually implement a computer model, each with its own advantages and disadvantages. Kelly et al. outline several, including systems dynamic, Bayesian, coupled component, and expert systems models. Each conceptualizes data in a different way and is more or less useful for different model purposes. Systems dynamics models aggregate and represent processes in terms of "stocks and flows." These models are rooted in a "cybernetic" understanding of the world, which I discuss below. Bayesian networks (BNs) explicitly attempt to formalize and address the uncertainties inherent to other kinds of models, in part by allowing experts to attach confidence levels to numerical relationships that they posit between processes. Kelly et al. explain: "BNs use probabilistic rather than deterministic relationships to describe the connections among system variable." Instead of saying the relationship between salinity and plant survival is simply some number, modelers can say we are only 50% sure about that. Coupled models are those models, like the ICM, that integrate separate models. Knowledge base systems, or expert systems, are a particular kind of DST that collates existing knowledge on a topic and then often relies on inference and "decision trees" to algorithmically guide users to appropriate answers.

There are many sources of uncertainty in all models. To return to the weather forecast –it does not always rain when the model says it will. In weather forecasts, a main source of uncertainty stems from the fact that even though atmospheric dynamics can be approximated by certain physical equations, they are ultimately chaotic and nonlinear. Such chaos is exacerbated by the choice of initial values for the model. A primary way meteorologists have dealt with this kind of uncertainty is through a kind of statistics called ensemble modeling. This means running the model simulation with many - each slightly different - initial conditions and then averaging the results. In ecosystem and other modeling applications, uncertainties likewise stem from initial conditions, chaos/nonlinearity, as well as other sources. Kelly et al. state that uncertainty can derive from uncertainties in system understanding (i.e. not knowing enough about how processes interact), data interpretation, inputs and measurements (i.e. the data used to initialize, calibrate, or validate the model is inaccurate or incomplete). Although modelers did not complete a formal uncertainty analysis for the ICM, because of time and computation constraints, the primary source of uncertainty in the ICM is future conditions. Will sea level rise actually be 2.2m? Experts developed scenarios as a way of mitigating this uncertainty. They said, we don't need to know exactly what sea level rise will be because we can look at several different possible rates. Related, modelers can and did run "sensitivity" analyses that showed how model outputs differed based on different values for key parameters like sea level rise. In fact, this is precisely how modelers developed the different low, medium, and high scenarios.

More broadly, there are different philosophical approaches to modeling. Modeling is not just a matter of figuring out your purpose, your model type, pressing “compute,” and then assessing uncertainties. Modelers adopt different attitudes about the object and process of their work. These attitudes vary to some extent from institution to institution and between planners, modelers themselves, and empiricists. Some modelers think about models as a kind of therapist – certainly the most unique perspective I heard in my interviews. Models are therapists, the thinking goes, because they reflect back to a modeler their unconscious understanding of the world. They reflect understanding by formalizing and objectifying it in a series of algorithms. Other modelers emphasize, instead, how models are “black boxes.” It can be difficult to interpret model outputs in light of mechanistic relationships between processes. Related to the black box metaphor, some describe modeling in terms of “sausage-making” (Voosen 2013) and quip “garbage [data] in, garbage out.” Some planners might consider models “crystal balls” for divining the future, but modelers usually try to distance themselves and others from such an interpretation, precisely because modeling of complex systems lends itself to black-boxing.

2.1b A brief history of computer modeling and decision-making

Models vary greatly and so does modeling in practice. They are not one thing, as evidenced by the history of modeling. The history of weather forecasting is well-told, especially as it spun-off into climate change modeling (e.g. by Edwards 2010). For most of the nineteenth century, weather prediction was a more clearly subjective process in which experienced analysts would make forecasts based on their own intuition or qualitative extrapolations of historical data.

Towards the turn of twentieth century, scientists began to believe it possible to forecast weather conditions using fundamental physics equations related to thermodynamics. Indeed, many scientists in the early twentieth century proved this to be the case. The challenge they ran into was that they had to make the calculations by hand. In the 1920s, Richardson was able to more or less accurately develop a numerical, eight-hour forecast. The problem was that he was late; it took him six weeks to make his calculations. He envisioned a room full of human computers making these calculations in something closer to real time and digital computers developed during World War II did promise a more rapid and extensive response. Krick famously hoped, "Give me enough time, men, and electronic computers, and I'll tell you the Newfoundland weather 200 years from now." (Lynch 2008) In the 1950s, scientists – drawing on the equations Richardson and others had previously developed – used new computers to implement the first of the global circulation models that now underpin climate change modeling (as an aside, many of these models would have been written in the Fortran programming language developed at IBM in the 1950s; Fortran still is a key language for several of the component models of the ICM). And in turn, today's climate modeling supports certain components of the Master Plan modeling process. Modelers use statistical techniques to "downscale" relatively coarse, regional precipitation, evaporation, storm frequency and intensity predictions to a Louisiana-relevant level.

The promise of digital computers to predict the weather and simulate the climate spilled over into ecology. An important connection here was John von Neumann, who had helped manage the US military's ENIAC computer for artillery guidance during World War II. He helped secure the civilian use of ENIAC for weather forecasting after the war and he argued that if computers like

ENIAC could predict weather, they could predict climate (Edwards 2010; Hickman 2018). Beyond what machine could calculate what, von Neumann began to articulate a broader modeling philosophy, one of cybernetics (Mirowski 2002). With this lens, the world becomes a system comprised of stocks and energy flows, with agents who communicate with each other to achieve a system-wide self-regulation. Information and its circulation are paramount in such regulation. Materially, computers become tools to measure, simulate, and regulate economic, social, and ecological systems. In reverse, digital computers became a metaphor for human society – social groups and human institutions could be seen to function in similar self-regulating ways.

Cyberneticians saw the world as comprised of flows of information and had a political vision to match. There are two stand-out historical examples of computer-based decision-making, both premised on cybernetics. Both, also, in their own way foreshadow the ICM and Master Plan process. First, Medina (2014) describes Project Cybersyn in Allende's Chile, where government planners consulted with leading cyberneticians to implement a planned economy. At the heart of the project was a room full of computers – not bulky machines typical of the era, but sleek interfaces, like something out of Star Trek. They were supposed to compile information from factories and help planners direct resources accordingly. The room was meant to be a relay point in building a centralized, yet distributed, coordinated economy. The basic theory was that computer calculations should be a key part of policy, potentially even distributing decision-making away from politicians in the first place. After all, if information was intertwined with regulation, its distribution could empower individuals. Before Cybersyn was actually operational, General Pinochet seized power, and computerized planning was anathema to the neoliberal policies he implemented. Like Allende's cyberneticians, the Chicago neoliberals that Pinochet consulted also believed in the self-regulation of society. However, they thought it was a product of market supply and demand dynamics, which would only be held back by computer-led coordination.

The second historical example of computer-based decision-making concerns ecosystem modeling specifically. Ecosystem modelers have long at least tried to inform environmental management. They have tried to provide either explanations for contemporary environmental conditions or predictions of future conditions. For instance, the Club of Rome's 1972 Limits to Growth report (Meadows et al.) predicted extensive environmental scarcities under continued capitalist growth. It was guided by a computer-based simulation of resource availability and population growth, and premised on the cybernetic idea that the earth represented a closed-system of feedback loops. That modeling team built upon Jay Forrester's systems dynamic model – World2 – to assess food, population, industry, resources, and pollution (Taylor and Buttel 1992). Though the model was thoroughly criticized, modelers today are still building upon it, including Boumans et al. (2002)'s GUMBO model for assessing the value of the world's ecosystem services. Costanza, a co-author of GUMBO, got his start modeling wetlands in Louisiana in the 1980s (see below).

Projects using computer simulation to inform policy, like Limits to Growth and Project Cybersyn, carried on into the 1980s and into today. Even though the cybernetic ideal of system stability has faded - to be replaced by the notion of resilience - the "man-machine-information-environment" ideal can be seen in one approach developed in the 80s: "environmental decision-support systems" (later, in the 90s, as "environmental information systems" [EIS]) (Haklay 2003; Fortun 2004a,b). Environmental decision-support systems materialized in the 1980s as industry and regulators gained greater access to computers. They implemented systems dynamics and expert systems models for the purpose of guiding institutional-level decision-making, especially in the domain of wastewater treatment. This paralled developments in other domains, like healthcare, where "decision-support tools" were seen as aids to rationality for doctors (Berg 1996). Healthcare planners believed that models like decision-trees could help systematize and formalize existing knowledge and help doctors rationalize decisions. Of course, not all doctors appreciated the imposition of an entirely new approach to or theory of medical practice, one reliant on external devices as opposed to a doctor's own best professional judgment. At the time, in the 80s, Espeland (1998) found a similar dynamic with new model-based approaches to water management in the US Southwest: two groups of Corps staff thought about modeling differently. An old guard appreciated hydraulic models but also their own best professional judgment, while new, younger planners appreciated the potential of models to rationalize decision-making (see also Stephenson and Shabman 2011).

The field of environmental information systems (EIS) formed out of this general push for rationalization and transparency in decision-making. EIS integrates technical infrastructure for collecting, analyzing, and visualizing environmental information for policy. EIS did not prioritize modeling alone, but sought to bring together databases, GIS, and other software that enable environmental management. EIS matter to how we understand the modeling-policy relation because, as Fortun (2004) put it, "they structure what people see and how they collaborate." As Haklay (2003) describes it, EIS built upon earlier environmentalist efforts that focused on the accessibility of environmental information, in the hopes that publicizing industry and government data would ensure appropriate oversight (see also Fortun 2004a,b). In the US, such efforts were rooted in legislation like the National Environmental Policy Act and the Freedom of Information Act, and ultimately, in Carson's *Silent Spring*. Globally, EIS was advanced by the UN Environmental Programme. In the late 70s, it had produced an EIS called Infoterra: "...Infoterra is thus responding to an increasing world demand for accurate, quality information on environmental planning, development ... Its achievement has been to reduce wrong decision on environmental issues made more from ignorance than ill-will." (in Haklay 2003) Infoterra, for its time, was a kind of Google or search engine for environmental data that did not host it, but would point users in the right direction.

In 1992, EIS actually became a core feature of the Rio Earth summit on sustainable development. The summit's Agenda 21 encouraged world governments to voluntarily commit to implement and track environmental planning efforts. Sections of Agenda 21, now infamously targeted by conspiracy theorists, offer a striking vision of the world, one resembling cybernetics: "In sustainable development, *everyone is a user and provider of information* considered in the broad sense." (emphasis added, quoted in Haklay 2003) EIS were meant to assemble and make sense of that information. Today, EIS find expression in sustainable development projects, but also ecosystem services markets, where tools like those of the Willamette Partnership integrate data collection, data modeling, and scenario analysis in a web platform (Nost 2015) Other EIS include Louisiana's Master Plan Data Viewer, which makes ICM data publicly available.

Today, ecosystem modeling looks a lot like Kelly et al.'s classification of it above. Many models aim for academic system understanding. But with the continued development of digital infrastructures, and conservationists' greater access to them, more and more models are focused on policy support. Models have become much more directly fused with official policy-making bodies than Meadow et al.'s Limits to Growth report for the Club of Rome. Some models do not have a life outside their use in decision-making; they serve little "basic" research purpose. Many are designed explicitly to deliver information actionable by policy-makers. Such models come in all sorts of shapes and sizes. They range from relatively simple online web maps that, for instance, help policy-makers see expected sea level rise, to sophisticated ecological models that predict changes in ecosystem services under different land use scenarios. Sometimes they computerize paper-based algorithms for calculating things like the condition of wetlands. For instance, the Oregon Rapid Wetland Assessment Protocol is a spreadsheet-based model that calculates wetlands functions, values, and ultimately "credits" for an ecosystem services market. It serves little purpose outside of its use in wetlands regulation. Then there is Louisiana's ICM, which is an assemblage of various Fortran- and Python-based models that can be run from a command line or even from a graphical interface in some cases. And beyond the ICM, there are a number of models currently in use or in development. In fact, half of all federal funding on ecosystem services goes to financing research on and development of decision-support tools (Cox et al. 2013). Perhaps two of the most prominent examples of ecosystem services modeling software are The Natural Capital Project's InVEST - a diverse set of Python tools held together with a graphical interface - and ARIES - a standalone platform for modeling services values based on Bayesian networks.

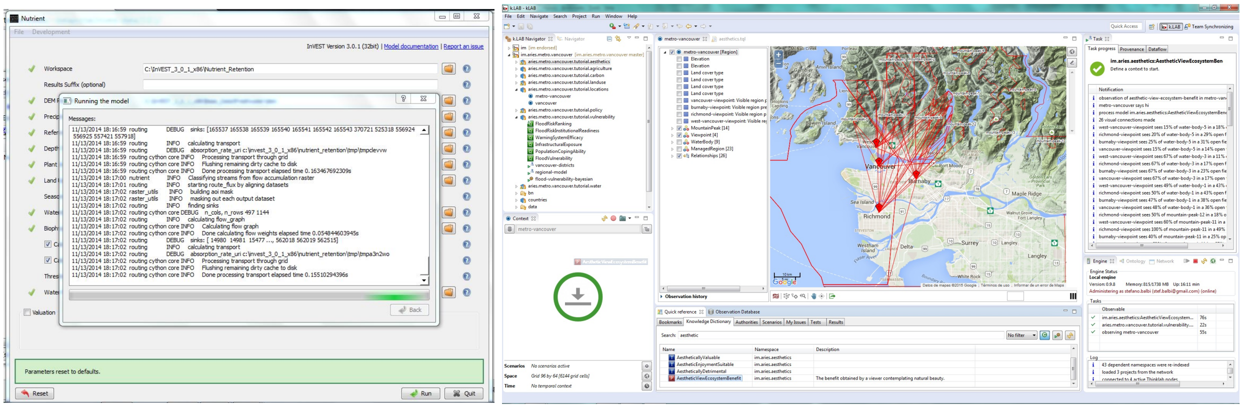


Figure 1. Views of two ecosystem services models. On the left, InVEST. Right, ARIES.

Many of these models are made by conservationist groups who either aspire to inform policy or who have established themselves as key components of environmental governance (e.g. The Nature Conservancy). Decision-makers themselves are interested in such models. Echoing Espeland (1998)'s findings, some have turned to modeling in order to move away from relying on the "best professional judgment" of experts and to increase the transparency, fairness, and legitimacy of their actions. Today, many models are designed to simulate ecological conditions in order to perform "constrained optimization" of potential land use actions. The result is a recommendation of which actions deliver the most benefits at the least cost. This allows policy-makers to operate within limited budgets and political atmospheres skeptical of wasteful spending. Models can tell policy-makers things they did not previously know and may do so in a much more rapid fashion than before.

The State of Louisiana's use of computer models to inform management decisions may constitute the single largest such effort in the US, if not the world. As I will elaborate on below, the state's Master Plan is a document the Coastal Protection and Restoration Authority of Louisiana (CPRA) produces every five years to demonstrate their predictions of land loss over the next 50 years and to outline projects that will stem it. CRPA's first plan in 2007 did not model projects, though previous efforts such as the Army Corps of Engineers's Louisiana Coastal Assessment (LCA) had. Thus, in 2012 there were already over 20 years of proposed project on the table, ready to be plugged into a new set of biophysical and ecosystem models that CPRA's team had assembled. 2012's plan was the first that took individual projects and simulated their possible effect on coastal conditions.

2.2 Drivers of land loss and what is at stake

When planners ran those models, what biophysical processes were they looking at? Coastal wetlands around the world will be affected greatly by climate change (Erban et al. 2014). Reduced or modified upstream inputs of water, ocean acidification, and so on will in turn produce social impacts through reduced fish habitat and reduction in storm surge barriers (Adger et al. 2005). Not all climate effects are outwardly negative. Changing temperatures will expand habitat ranges (of mangroves, for instance) and wetlands can keep up with sea level rise if they have the opportunity to migrate (i.e. if they have an adequate sediment supply and are not impounded by levees or other barriers; Reed 1995; Kirwan and Megonigal 2013). It is well recognized that wetlands provide crucial ecosystem services like storm surge mitigation (Engle 2011; Loomis and Paterson 2014; Caffey et al. 2014). Many services, like storm surge mitigation, are relevant to a future climate in which storms are more intense and coastal communities are already more exposed due to sea level rise.

Much is a stake with land loss, as well as with potential actions to mitigate it. Wetlands provide crucial habitat for many recreationally and commercially important species of fish. They also are key habitats for many other kinds of wildlife, most notably migratory birds that use the Mississippi River as a flyway. Louisiana's wetlands also physically provide a medium for much of the US's most crucial oil and gas infrastructure, especially pipelines. Barrier islands directly protect strategic hydrocarbon ports. When Katrina struck in 2005, the shutdown of such facilities resulted in significant increases in the price of oil and gas. Marshes and swamps are thought to slow advancing storm surges through friction. How much they slow surges is debated. An often quoted statistic, based on a USACE study from 1963, has it that every 14km of marsh will reduce a surge by 1m in height. More recent studies confirm variability (Notes, ACES conference).

The Louisiana coast loses 25,000 hectares of wetlands a year, for a variety of reasons (Stedman and Dahl 2013). Canals dredged in the middle twentieth century by the hydrocarbon industry to position drilling equipment and to lay pipelines also threaten the coast. The canals bring saltwater into formerly freshwater marshes (Scaife et al. 1983; E. Turner 1997; Theriot 2014), killing plants that cannot tolerate higher salinity levels and making the area more susceptible to tidal erosion (Ko and Day 2004). Spills from hydrocarbon extraction, like the 2010 Deepwater Horizon spill, degrade wetland habitats in a similar way (Ko and Day 2004; Silliman et al. 2012). The oil and gas industry typically placed spoils from dredging canals alongside the banks of canals. This has had two effects: it funnels storm surges through marshes and in general changes the area's hydrological regime, impounding water upgradient and drying out soils downgradient. The extraction of hydrocarbons itself has exacerbated land subsidence (E. Turner 2014; Ko and Day 2004; Morton et al. 2006). The number of barrels of onshore oil produced correlates with the rate of subsidence (Kolker et al. 2011). While the rate of land loss lessened when the industry moved drilling operations offshore, firms are still causing ecological impacts as they transport equipment (Stein 2017).

The precise extent to which the hydrocarbon industry caused land loss is debated (Olea and Coleman 2013). The industry acknowledges some responsibility, putting the figure at around 36% of land loss, while some federal researchers push it up towards 60% (Rich 2014a). Others at the USGS, say that the industry could not possibly account for such loss, and some estimates even have it lower than the industry's, at 15% (Olea and Coleman 2014). Louisiana State University researcher Eugene Turner (2014) replies with a lifetime's worth of work that the direct and indirect effects of canals and spoil banks are the most likely cause of land loss - not subsidence, levees, or sediment starvation - (Turner 1997), with estimates ranging as high as 89% (Scaife, Turner, and Costanza 1983).

Debates amongst coastal researchers about the causes of land loss are mirrored by debates about the efficacy of different restoration projects. The dynamism of the coast and the variety of social and physical factors at play generates many uncertainties. How would the delta system work in the absence of human modification? In general, deltaic rivers build natural levees as heavier sediments are deposited sooner, closer to the river, during flood events (Day et al. 2014). The backsides of these levees are lowlying wetland areas. High flooding, crevasses, and distributaries would from time to time bring mineral sediment to these wet areas. The material would build up, forming what McPhee (1989) called "mountain butter," and plants would colonize it, triggering a positive feedback loop. Plants are able to trap more sediment as it moves through the system, and organic matter itself becomes incorporated into the soil (Nyman et al. 1995; Brantley et al. 2008; Kirwan and Megonigal 201a). Indeed, most soils in the Delta are highly organic, which makes them particularly unstable and susceptible to subsidence (a spatially patchy phenomenon; Yuill et al. 2009).

Figure 2. Some of the newest land in the world outside of Buras, LA. Source: Author.

CPRA planners are proposing a variety of coastal management projects. Half of the Master Plan is actually dedicated to structural flood protection measures such as levees. In terms of ecological restoration, the state is especially interested in two courses of action. Each comes with a set of tradeoffs that planners want to model and that public debate has often centered on. First, planners intend to invest in marsh creation projects. Many marsh creation projects already exist across the coast as this has been the primary source of restoration over the past 30 years through a state-federal cost-share program called CWPPRA (described below). A marsh creation project takes material dredged from the Mississippi River or some other non-wetland source and fills in an area that has converted to open water. This raises the area's elevation and allows marsh plants to revegetate, further stabilizing the marsh. Since the dredged material must often be transported at great length from source to the restoration project, marsh creation projects are expensive, in terms of cost per acre of land created or maintained. Moreover, infamously, marsh creation projects start to "lose their value," much like a car, the minute the sediment pipeline is turned off. Sediments stabilize and begin to subside without any new addition of material (a similar dynamic is true for barrier island projects; essentially barrier island restoration is a near onshore marsh creation project). The result is that marsh creation projects are not expected to last very long. The tradeoff is that they provide habitat and ecosystem services benefits immediately, and they are a known and trusted approach to restoration.

Figure 3. A marsh creation project before and after. Source: CPRA.

The second main restoration approach planners have taken is large-scale engineered diversions of sediment, mainly from the Mississippi River. CPRA prioritizes this form of restoration. Sediment diversions are controlled crevasses in the levees that line the river. Diversions would siphon sediment-laden "Big Muddy" water and convey it into degrading basins. While the state has already constructed several large-scale diversions (Davis Pond and Caernarvon), these were designed to transfer freshwater into basins in order to restore salinity levels from an encroaching sea, rather than to transfer sediment.[3] In addition, the impacts of the Caernarvon have been hotly debated. Some scientists point to what sediment it did convey and what land it has built, others see it has having contributed to a weakening of salt marshes leading up to Hurricane Katrina (Barras 2008; E. Turner 2014). No one is really sure what impact a sediment diversion will have – there are no real world analogues. The analogies that some make, such as to the Wax Lake Delta, have enough differences as to cause debate.

Figure 4. The Davis Pond freshwater diversion. Sediment diversions will look similar, but are designed specifically to move as much sediment as possible into degrading sub-basins. Source: Corps of Engineers.

The state has not yet constructed any of the large-scale sediment diversions that would simulate

[3] Some might consider the Old River Control structure a diversion as well. McPhee (1989) describes how the structure holds the Mississippi River from changing course and flowing to the Gulf through the Atchafalaya basin. It allows only a third of the Mississippi's flow to enter the Atchafalaya. At its outlet, the Atchafalaya has built new land with "Big Muddy" sediment. It is often employed by advocates as an analogue for demonstrating what sediment diversions may accomplish, though there are significant differences.

natural delta-building processes. Planners have little idea of how to run such a diversion or exactly what effects it might have. This is why the state has invested so heavily in simulating diversions. Though their effects may be uncertain, diversions provide a much cheaper land-building alternative than marsh creation. Their upfront costs are significant, with the largest diversion is budgeted at $1 billion. But they provide continuous land-building benefits over a much longer time-span than marsh creation. However, several unique permitting requirements mean that the timeline for actually putting diversions "in on the ground" is more extended than for marsh creation. Additionally, the rate of sediment deposition via diversion may be slower than that of marsh creation, meaning that the ecosystem services and habitat benefits are not as immediate. Nonetheless, the 2012 Master Plan elaborated, "it is no longer a question of whether we will do large scale diversions but how we will do them." (CPRA 2012)

Above all else, planners want marsh creation projects and sediment diversions to build or maintain land. Building land means converting currently open water areas to marsh, while "land maintenance" refers to when a project ensures that existing marshland does not degrade in the future. But planners do have several other goals in mind. There are a variety of metrics beyond land by which planners assess restoration scenarios, including fisheries impacts, support for oil and gas infrastructure, and storm surge reductions. These metrics are purely about stakeholder interests and values. Unlike much of ecological restoration, which aspires to restore habitat to its condition at a specified historical period (e.g. pre-settlement), planners know that they cannot restore the coast of 500 years ago or even 90 years ago. While they aim to "harness [the land-building powers of] Mother Nature," planners do not ground their goals in any sort of historic reference.

2.3 State environmental management response 1960s-2005

Planners recognize that they cannot restore the coast to its condition only just 90 years ago. This is the point when land loss began, as oil and gas extraction boomed and the federal government built levees along the Mississippi. Wetlands loss did not develop out of thin air nor did coastal science and policy. Each has a long history that dates well beyond the scope of this dissertation, but I will attempt a very brief history. I will focus especially on the state's environmental management response from the 1960s and up to Hurricanes Katrina and Rita. One key thread in this story is how planners have tried to stem wetland loss by demonstrating the economic value of wetlands. During this time period, Louisiana and the rest of the Gulf Coast became a lab for policy, science, and economic investigations into valuing nature.

2.3a Early days

Viosca (1928) had already described an eroding coastal landscape by the early 1900s, placing blame on fur trappers and cypress loggers who cut into swamps and marshes. Oil and gas production along the coast quickly overtook these other extractive activities. Soon Texas oilmen were sounding the Louisiana coast's "salt domes" for oil[4]. As Theriot (2014) and Mandelman (2015) each documented, oil and gas firms' intrusion into the coast did not come easily; they had to develop technologies for navigating the squishy terrain. Eventually, they perfected barges that could dredge a canal through marsh, depositing "spoil" on the banks.

Spurred by the local New Orleans urban growth machine, the federal government also undertook canal-building efforts. This included, most notoriously, the Mississippi River Gulf Outlet (MRGO) canal between New Orleans and the Gulf. Built in the 1960s, MRGO was expected to

---

[4] See http://ericnost.github.io/sandbox/landloss/ for an interactive map showing the distribution of permitted wells over time.

provide an increase in barge traffic to the city's port, but this never materialized. Instead, it contributed to land loss by impounding hydrological flows and introducing saltier water into areas like Bayou Sauvage that were mostly freshwater swamps. MRGO funneled the Katrina storm surges that broke the levees in the Lower Ninth Ward (Lewis and Ernstson 2018). Many fishers, especially in St. Bernard Parish, contest sediment diversions because of this nearly one-hundred-year regional history in which elite urban interests have modified rural wetland landscapes in their favor (Lewis and Ernstson 2018). Fishers believe they have seen it all before.

Figure 5. The legacy of oil and gas canals is inscribed on the coastal landscape. Source: http://www.gulfmonitor.org/tag/monitoring/

The impacts of early twentieth century canals and levees were slow to develop into the crisis the state now faces (Nost and Kelly 2018). A dominant discourse suggests that at the time, no one could predict the impacts of canals and levees. Theriot's *American Energy, Imperiled Coast*, for instance, maintains that planners, ecologists, and industry officials only gradually realized the extent of land loss and the role of oil and gas operations (see Nost 2015b). However, awareness of wetlands loss is as old as wetlands loss itself, even if action to stem it is not. This awareness is represented both by coastal residents as well as state environmental officials. In fact, Louisiana state officials started permitting and regulating oil exploration as early as 1939. Landowners affected by well leaks even filed lawsuits against the industry in the early 1930s (Theriot 2014).

As Theriot tells it, following World War II, the Gulf's hydrocarbon industry grew significantly in order to meet growing demand from suburban consumers. Companies like Tennessee Gas needed to get their products from wells in Louisiana’s marshes to markets that were mainly on the rapidly urbanizing east coast. They laid hundreds of miles of pipelines in canals carved through marshland and, often, through oyster beds. At the time, in the 1950s, fishers and scientists alike could see these socioecological consequences of canals - they decreased the catch. Oil and gas companies went out of their way to provide compensation for direct damages from pipelines, partly because many working in the hydrocarbon industry were local oyster experts themselves and partly because of the influence the fisheries community was able to exert on state regulators. The industry paid what the expected catch would have fetched on the open market. These payments were ad hoc and not meant to be a systematic assessment of all of the what we would now call ecosystem services a wetland provided.

The industry’s payments inadequately accounted for canal impacts, but resource managers realized this. For instance, in 1953, debate about how Tennessee Gas’s proposed “Muskrat Line” pipeline would impact oyster beds foreshadowed today’s scientific understanding, and echoed what oystermen already knew to be true. As James McConnell, the chief of the Oyster Division of Louisiana's Wildlife and Fisheries Commission, put it, “when currents are changed by these canals and dredgings are placed along the sides of the canal, in many cases currents are stopped entirely…causing...changes in the ecology of a given area” (Theriot 2014, 54). He was particularly concerned that compensation would not account for long-term, large-scale effects:

> we feel that the long range effects resulting in permanent ecological changes are by far the most serious and the most difficult to assess damages for. Direct effects are largely a matter of obtaining ROW [right of way] and making adjustments for damages at the time of construction. The area involved is comparatively small and involves only the path of the canal and the immediate vicinity on each side. Ecological and hydrographic changes may be permanent and may affect extensive areas ten miles or more on either side of the canal. (in Theriot 2014, 58)

For the first time, conservationists were asking how to capture wetland processes the state did not see and wetland values the market would not consider. Their efforts would accelerate in the 1960s and 1970s as around the county environmental awareness percolated into planning legislation.

2.3b Valuing wetlands for planning

Into the 1960s and 70s, conservationists at state environmental agencies and at Louisiana State University (LSU) continued calling for a more formal recognition of the importance of wetlands. They were part of a growing national movement to daylight the corporate and government decision-making processes that were fouling waters and polluting the air. As the story goes, in 1969, the massive oil spill offshore of Santa Barbara, CA inspired Congress to pass the National Environmental Policy Act (NEPA), requiring all federal agencies to undertake a formal review of the costs and benefits of any action with a major effect on the environment (Clarke and Hemphill 2002). However, NEPA did not necessarily require agencies to understand or examine the kinds of long-term costs the Oyster Division chief McConnell recognized in oil and gas canals.

Conservationists around the country thus found themselves with more reason to advance techniques for wetland valuation, and their efforts were grounded in Louisiana. The field of ecological economics arose from a long-standing engagement with Louisiana's coastal marshes, as they faced the kinds of development pressure, often from the oil/gas industry, that I described above. When ecologist Eugene Odum and economist Len Shabman sparred in the 1970s over how to conceptually and empirically assess nature's value, their material was Gulf Coast marshes. A cohort of researchers at LSU published or began landmark studies on coastal change during this period. Many of them prioritized representing wetlands' value within NEPA and other planning processes described above that were beginning to be established. For instance, James Gosselink, Eugene Odum, and R.M. Pope wrote, "The Value of the Tidal Marsh" in 1974, explaining the limits of cost benefit analysis. It was a short white paper written for the LSU Center for Wetland Resources, but it nonetheless received remarkable national attention from wetland conservationists as they made their case in the 70s for increasing resource protection. Gosselink et al.'s aims were to counter development pressure on coastal ecosystems by expanding the list of things that should count as the monetary costs of development. For instance, they valued the waste assimilation capacity of wetlands by looking at what it might cost regions to fully treat their sewage if all wetlands imply vanished and were replaced with wastewater plants. Gosselink would remain highly involved with coastal planning over the next decade, leading environmental reviews of projects like the massive Louisiana Offshore Oil Port (LOOP).

Paradoxically, the LOOP project led to the state adopting a comprehensive planning regime for the entire coast. In the late 70s, as onshore oil extraction moved offshore, and as US oil imports increased, Louisiana proposed the LOOP transfer facility. It would pipe oil from foreign tankers harbored just off the coast. The pipelines for the project, as well as the platform itself, would have ecological effects. At the time, Louisiana conservationists saw no viable way to regulate the project. NEPA would only require the transfer facility itself to demonstrate expected effects, not the pipelines running onshore. But following the Santa Barbara oil platform accident in 1969, Congress had passed the Coastal Zone Management Act (CZMA). It encouraged states to develop programs for zoning and permitting coastal land uses (Theriot 2014; Houck 2015). As Theriot tells it, Louisiana decided to implement its own CZMA permitting program in exchange for the federal government giving LOOP its approval. As it came into force in the 1980s, the state's CZMA permitting program theoretically would have reduced coastal impacts. In reality, most of the ecological impacts from wells and pipelines were already entrenched. Hydrocarbon production in Louisiana wetlands plummeted in the 80s not because of CZMA but because of global restructuring. As Houck demonstrates, the state only rejected a handful of permit applications.

In the 1980s, researchers began modeling coastal wetland dynamics to formally understand the causes of land loss, wetland values, and to assess planning approaches such as the CZMA. At LSU, Bob Costanza undertook a serious of projects in the 80s to propose more effective methods of regulating the coast than CZMA (Costanza et al. 1989). In one paper in particular, 1989's "Valuation and Management of Wetland Ecosystems," Costanza and his co-authors produced another estimate of Louisiana's wetlands, a follow-up to Gosselink et al. Besides looking at the market rate of fish raised by coastal estuaries, they actually asked fishers what wetlands were worth to them. What the researchers were after was the amount each person spent on gas to get themselves to a wetland to fish. They thought this value could be considered part of a wetland's overall value and that enumerating it could force some concessions from wetland developers. . LSU in the 1980s was a hub of activity focused on valuing nature with Gosselink, Costanza, and Daly as well as Eugene Turner, another freshly-minted student of Odum, making headway on understanding the ecological effects of oil and gas canals on the coast. Though a lot of this research was never formally integrated into policy, in the 1990s, scientists would begin to directly apply their work to policy.

2.3c CWPPRA and other federal approaches to restoration

When the onshore oil industry collapsed in the 1980s, the state finally seemed ready to begin restoring the coast. With the formation of the Coalition to Restore Coastal Louisiana (CRCL) in 1987, conservationists found a rallying cry: construct diversions. Federal and state level planners proposed freshwater diversions like Caernarvon and Davis Pond as fishers began to be affected by increased salinity levels in the basins. At the time, there seemed to be a surge of awareness amongst public officials that the US as a whole had lost significant wetland habitats since settlement – from Bush's campaign promise of "no net loss" of wetlands from new development to the Swampbuster provision of the 1985 farm bill. In Louisiana, this awareness culminated in the state legislature passing Act 6 in 1989, creating a trust fund from oil and gas revenues to fund restoration. In turn, in 1990, Louisiana Senator John Breaux led federal legislation that created the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA). CWPPRA established a program within the Corps of Engineers to take federal-level recreational revenues from things like small motor taxes and direct them to wetland restoration projects across the country. Louisiana remains the primary recipient.

One of the first things the CWPPRA program was tasked with in Louisiana was developing a plan to guide which restoration projects the Corps should invest in. The first plan CWPPRA produced improved on previous ones that had little rational basis:

> Prior to that point on predictions of what the coast was going to look like were really a marker pen on the map. There was a point in the mid 90s where a bunch of folks were challenged with doing it quantitatively and actually trying to say OK the CWPPRA has been authorized. You know it has spent 20 million dollars by that point or got that many of projects in the pipeline. You know if those projects go in on the ground what difference are they gonna make? (1)[5]

Part of the CWPPRA process involved developing a certain working relationship between scientists and decision-makers. This represented a challenge, as an academic scientist who had been involved with CWPPRA at the time remarked:

> Anyway so as this plan came together a bunch of federal agencies working on it and the state folks and they were trying to write this plan and many people in the university community were going or the scientific community was saying well we kind of want to help you know. And so [we were] being kept a little bit at arms length….(1)

Only the intervention of the regional ACE office's Colonel changed the situation. He invited the scientific community in to improve the initial CWPPRA report. The Colonel wanted to move the report beyond "a collection of projects" that did not have "an overarching theme." The integration of scientists into policy was novel at the time and had lasting consequences.

> I think over that period there in the mid 90s we also saw a number of folks in the scientific community develop a one to one - a kind of trust became established. There were some key people in terms of that relationship from the agency side. But that was really helpful….That was one of a number of barriers that started to be broken about the relationship between science and decision making in coastal restoration because I think - and this is still the case in some areas - but there was a feeling that the scientists weren't

[5] In this dissertation, I have not quoted research participants by name, in order to ensure some degree of anonymity. Instead, I have referred to participants with a numerical code. However, a list of interviewees is in Appendix A.

> really interested in doing the restoration plan they really wanted to do science….And so I think that this kind of - so you actually can help with the plan. That's quite a big thing. (1)

Out of Act 6, the state established its Wetlands Restoration Program (1993), a multiagency effort that was the immediate predecessor of CPRA. With the WRP and a CWPPRA framework in hand, early attempts at restoration placed an emphasis on small-scale projects that attempted to address localized erosion concerns:

> And that is one of the big challenges with this system is it's so big and so difficult for people to get their heads around. And so there was a there was a tendency and to some extent still is a tendency to oh that shoreline is eroding. Let's fix that shoreline. And this is the bandaid on the cancer patch rather than fix anything systemic or long term. (1)

Often such bandaids entailed managing for salinity levels in a localized area. Realizing the shortcomings of this approach, the state and the Corps finally started to think big. Their first attempt at a systematic plan was Coast 2050 (1998), which compiled $14 billion worth of projects. One scientist described Coast 2050 as "a very different way of thinking about the coast. We switched from playing defense to playing offense." (1) The plan proposed many projects across the entire coast, but only at a relatively coarse level. They were "squiggly lines on maps." Experts thought a diversion would be good in some area, but had no way to precisely evaluate that claim. Ultimately, planners found no way to actually implement Coast 2050. Instead, in 2004, the Corps's Louisiana Coastal Area program completed a model, Coastal Louisiana Ecosystem Assessment and Restoration (CLEAR) that could assess projects.

> There was a check against the Coast 2050 plan but there wasn't a Coast 2050 implementation plan - because Coast 2050 is very much you know squiggly lines on maps. So then the next one was LCA - Louisiana Coastal Area…so two or three years of like nothing happen after Coast 2050 somebody again you know who was in the right place found a way in which the Corps of Engineers could actually really start looking at the system as a whole and they found the LCA authorization which was already had been passed in 1960 something. (1)

The LCA plan came about when some enterprising staff in the Corps pointed to Congressional language that allowed the agency to develop a more system-wide approach to land loss. The CLEAR model was innovative in that it linked different biophysical process. For instance, its simulations of salinity levels would directly feed into a vegetation model. In this way, CLEAR was a direct forerunner of the models used in the 2012 plan and especially of the ICM in 2017:

> The concept of linked models in Louisiana coastal planning was not new, as linked models were applied to aid restoration planning for the 2004 Louisiana Coastal Area Study (USACE, 2004) and several linked models were used to inform the 2007 Coastal Master Plan (CPRA 2017 C1, 2)

The LCA program evaluated projects with CLEAR. It evaluated them holistically by linking different biophysical processes, but it did not examine projects on an individual basis. In spite of Coast 2050's issues with "squiggly lines on maps," the best CLEAR could do was to how suites of projects would build land. Expanding on this relative disappointment, one scientist saw CLEAR as being "very quickly cobbled together." (32) The ultimate goal was not to have a list of fundable and implementable projects per se, but "to show that it [modeling to develop a plan] actually could be done." (32) As someone else working on the project put it:

> The goal of CLEAR was to link the science and the modeling to decision making - all projects, coastal projects, in the state… that was something that was lacking in the state before that time. (33)

The goal of CLEAR was not to achieve a plan for restoring the coast, but to bring scientists and decision-makers together. As a model, CLEAR may have linked different biophysical processes. It also linked different institutional process. The kind of science-policy coordination that would be necessary for the Master Plan took off in the LCA CLEAR program.

Even if CLEAR had led to a really tractable plan, it would have had little time to take root before the 2005 hurricane season upended political, economic, and ecological dynamics in the state.

CPRA would form in response to Hurricanes Katrina and Rita, and it would be tasked with developing a coastal master plan of restoration projects the state could actually implement. Even though LCA and CLEAR were “owned” by the Corps, everyone acknowledge CPRA was to be the new driver. Most of the modelers who had worked on CLEAR got wrapped up into it:

> And once CPRA was formed that was when the CLEAR program, which had been a contracted out program - we handled most of the contracts through LSU - all the modelers, well a number of them brought them under the same umbrella to support decision making. So once CPRA formed I think the need for that program dwindled and the state decided to try to do that coordination and linking of things together within their own agency or authority. (33)

2.4 Coastal management post-2005

Today, conservationists’ arguments for restoring wetland values still come from the Gulf Coast. They come from places like Mobile Bay, where coastal restoration "shows strong returns on dollars invested." It is the US Gulf Coast that has defined nature's valuation as we know it today. Louisiana in particular was proving grounds for advancing the methodologies and policy advocacy behind valuing nature. It still is. The 2010 Deepwater Horizon oil spill, for instance, reignited debates about how to place monetary values on things you can’t buy in the market: the existence of endangered brown pelicans, storm surge protection, and so on. The Gulf will continue to emplace nature’s valuation, as CPRA continues to assess land-building and storm surge reduction values in the Master Plan. Experiments in defining and applying nature’s value will therefore be shaped by the state and institutional structures putting the Master Plan together. Here, I continue the story of how CPRA was formed and how it has organized the Master Plan modeling process.

2.5a CPRA

In December of 2005, the State of Louisiana formed CPRA in a special legislative session called to respond to Hurricanes Katrina and Rita. CPRA's formation was largely a reorganization of hurricane protection functions previously housed in the Department of Transportation and wetland restoration programs housed in DNR. In other words, CPRA was not made from scratch; it involved shuffling staff in order to put storm protection efforts in conversation with efforts to create new marshlands and to "elevate to a position within state government of high visibility and action" these conversations (RS 49:214.1). Lawmakers understood that wetlands were a "first line of defense" that could reduce communities' reliance on the kinds of levees that had failed during Katrina (RS 49:214.4.1) The creation of CPRA was another move towards more system-wide analysis and governance.

The state legislature explicitly charged CPRA to put a comprehensive plan at the front and center of its work. Legislators explained that CPRA should, "develop, coordinate, make reports on, and provide oversight for a comprehensive coastal protection master plan and annual plans" while coordinating with municipal, parish, and federal officials. In turn, the legislature mandated that CPRA's Master Plans "include a comprehensive strategy addressing the protection, conservation, enhancement, and restoration of the coastal area through the construction and management of integrated coastal protection projects and programs." (RS 49:214.5.2) The law specifies that CPRA should revise its plan at least every five years (RS 49:214.5.3).

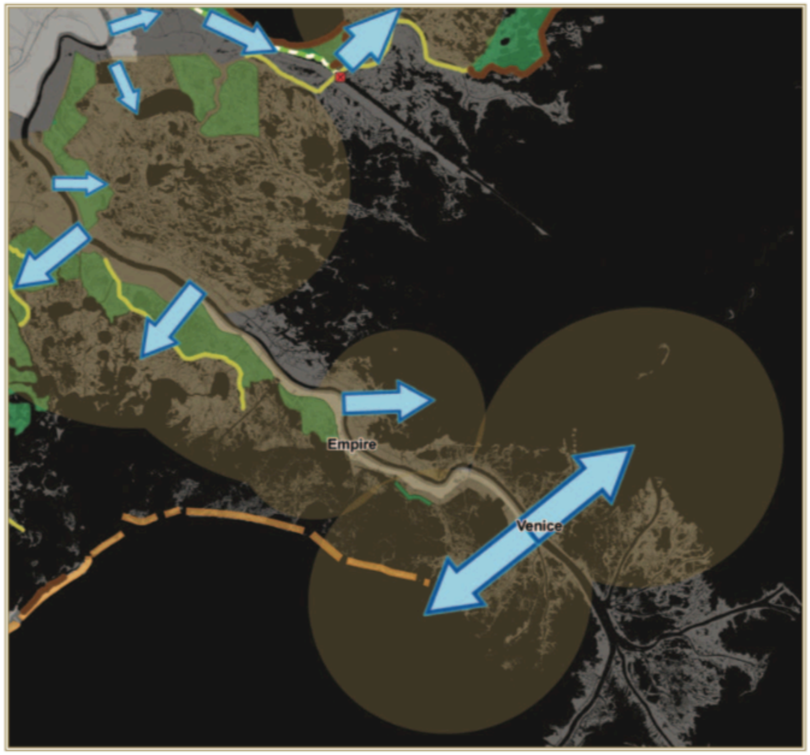


Figure 8: Mississippi River Delta Management—Concept #2, Diversions downriver.

Figure 6. “Squiggly lines” from the 2007 Master Plan. Caption [not shown] reads: “Further modeling will better describe the potential for this alternative to retain sediments within basins and increase sediment in the longshore current. Further analyses are also required to determine the potential impacts that this scenario would have on salinities and locations of commercially important species.” (CPRA 2007, 50)

The agency’s first such plan arrived less than two years after Katrina and Rita. It was seen as only a first step. In some ways, the 2007 Master Plan followed the pattern of previous coastal plans, like Coast 2050. It was a compilation of restoration projects that had previously been proposed and they were presented as “squiggly lines on maps.” There was no modeling because there was no time.

> So for the 2007 Master Plan it was just crazy. Everybody running around with their heads cut off - there were so many things going on after Katrina. It was a difficult time and we - so came up with this plan. And it's a bunch of squiggly lines. Everybody wanted to have their project and everybody's project was desperate. Nobody can say no to anybody - and nobody had any basis for saying no is another way of putting it. And so the best thing about the 2007 MP was the objectives. (1)

Where the 2007 plan advanced previous efforts like Coast 2050 was in how experts developed a set of objectives they were interested in. These goals included protecting assets from at least a 100-year flood, using natural processes like the river to build land, and supporting a working coast and its heritage. Experts were not able to model how projects met these objectives, but they were in place. The objectives took shape in 2012 when planners made their first attempt to actually prioritize their list of restoration projects – to say “no” to some proposals and yes to others. The state came to understand how intractable a “wish list” was and that it needed to make investments in coastal science.

> And so I think there's a kind of convergence of things around that kind of 2010 point. One of which is somebody in the state realizing that they actually wanted a plan, a plan that was you know it wasn't just a wish list. So there was an audience for that and importantly the state was prepared to provide money to build the tools necessary and these investments were not trivial. (1)

For the 2012 plan, the state spent these non-trivial sums of money on the tools the modeling and planning effort needed to achieve a workable plan. Experts turned the objectives into tractable metrics with the help of the RAND Corporation and its planning tool. In addition, modelers expanded how they conducted simulations. Instead of just using past trends as a guide, they incorporate what they knew about landscape dynamics: “Whereas previous modeling efforts simply projected past trends into the future, this model considered more characteristics of the landscape as predictors of change.” (CPRA 2017 C1, 3) These significant changes between 2007 and 2012 are all the more noteworthy given that planners began their work a week before the 2010 Deepwater Horizon spill.

The BP spill resulted in significant socioeconomic and environmental impacts, but it has driven a range of science in response. In 2012, Congress passed the RESTORE Act, which established a framework for transferring to the states whatever settlement the federal government reached with

BP. While there has been controversy around some states' intent to spend the money on tourism development, Louisiana passed a constitutional amendment directing all RESTORE Act funding to Master Plan projects. In addition to directly compensating states, the RESTORE Act creates a program to fund coastal science and adaptive management. It dedicates 2.5% of the BP settlement funds to new research centers across the Gulf, including one at the Water Institute of the Gulf in Baton Rouge. Those charged with implementing the RESTORE Act – funding states through competitive project proposals - want to support restoration programs that operate adaptively. One of the criteria by which they will decide to allocate funding is "Improve Science-based Decision-making Processes." For instance, the RESTORE Act calls for multi-scalar ecosystem monitoring and the coordination of monitoring programs across agencies. This requires database and expert systems to store the data, which must also be made intelligible to analysts through "improved ecosystem restoration outcome and impact measurement and reporting" efforts. With its Coastwide Reference Monitoring System and suite of Master Plan models, Louisiana sees itself well-positioned with respect to these RESTORE Act goals.

The RESTORE Act sets aside the single largest pot of money for ecological restoration in US history. Starting this year (2018), even more funds are expected to roll into state coffers from new offshore drilling royalties (Gulf of Mexico Energy Security Act [GOMESA]). Before 2006, all royalties went straight to the federal government. GOMESA returns some of that money to the states. As with the RESTORE Act funds, Louisiana has codified that all GOMESA money be directed to coastal restoration. The Coastal Protection and Restoration Fund pools GOMESA and RESTORE Act money as well as the state's own "mineral revenues." There has been significant public debate about whether monies from the Coastal Fund can be spent on projects such as upgrading highway infrastructure, or whether they must be on marshes. Either way, the statute explicitly authorizes spending money on coastal science: "Projects and programs promoting scientific, technical, and engineering advancements for the sustainability of coastal Louisiana and ensuring that the best available scientific and technical information and tools are available for the implementation of the master plan and annual plan." (RS 49:214.5.4)

2.5b Coordinating the Master Plan

By the end of 2012, CPRA had a second Master Plan in hand and a couple of sources for funding it on the horizon. The earliest payouts from BP could even support some of the projects planners had been able to deem high priorities. But no sooner had the agency finalize the plan did it turn around and launch the process for building the 2017 version. In this section, I spell out some background to the 2017 Master Plan, including who is involved in the process, how they coordinate with one another, what the models are and where they came from, and stakeholder outreach efforts.

CPRA initiates and oversees the Master Plan effort as a whole. As mentioned, CPRA consists of staff merged from DNR and DOT. It is home to experts ranging from hydraulic engineers to land title lawyers. But even with this wide swath of expertise, the agency cannot do all the work of simulating coastal change and developing a tractable plan. Instead, CPRA program managers organize and oversee modeling teams of academics, engineering firms, and others. Program managers provide teams with the instruction and guidance they need. Managers also work with outside experts to organize the modeling. Each model team is paired with an academic expert providing general guidance and is assigned a team lead who makes the final decisions about model design.

CPRA contracts with the Water Institute of the Gulf (WIG) to orchestrate the Master Plan modeling on a day to day basis. WIG is a 45-staff person nonprofit formed in late 2011 specifically to lend expertise to future Master Plan efforts and coastal restoration in general. One WIG staff person described to me what this coordination look like in practical terms:

> In the early part of the modeling, we schedule lots of - in some cases weekly phone calls with the whole team. We would have subgroup calls for people working on different components where they would get into the weeds of something that maybe the rest of the team didn't really need to spend their time listening to. We have about every few months an in-person all day sit down meeting where we would just touch base with who was doing what, are there any challenges that have come up, does someone need something from another team member, um, mostly just to keep the communication line open to prevent clusters down the line. (33)

The first key moment in the Master Plan process is when experts must determine what social and biophysical processes they want to model and what data they have or will need in order to run the models. In the fall immediately following the state legislature's approval of the 2012 plan, CPRA convened a meeting with its Predictive Models Technical Advisory Committee (PMTAC). They wanted to assess the limitations of the modeling and to chart a path forward for each model: what biophysical processes to try to incorporate and how, what new models to include, and how to revise the entire modeling framework (Model Improvement Plan, 2013) Building on this, CPRA contracted with an ecological consulting firm to write a report rationalizing different options for new ways to model fisheries. This "model strategy" phase is an important moment where modelers made explicit what data they have, what they wanted to measure and how, and what the limitations of their work would be.

Beyond fisheries, other modeling teams were also tasked with accounting for new science and technology, addressing limitations noted in the 2012 effort, and making their code or outputs compatible with the new ICM framework. By the fall of 2014, CPRA staff themselves had written reports justifying the subsidence and sea level rise values with which to initialize the ICM. CPRA called on a Scientific and Engineering Board (SEB) of outside-the-state experts to help them determine likely future scenarios. They developed low, medium, and high scenarios for several factors, including precipitation, sea level rise, and subsidence. These are assumptions about the future that the ICM models use as inputs. For instance, scientists do not know exactly how much sea levels will rise in the future, but they can pick three likely values, and plug them into the barrier island model to see how barrier islands will respond to different rates of sea level rise. Before evaluating projects, modelers first simulate "future without action" conditions. These provided a baseline by which to judge the effect of projects.

All the while, throughout 2013 and 2014, modelers at WIG were making one of the more significant changes from previous Master Plans. They were developing the ICM framework. The ICM is, simply put, a "platform" receiving the results from one model and directing them as inputs to another, linked, model. As planners describe it:

> The Integrated Compartment Model (ICM) is a computationally efficient, coast wide mass balance model that can be used for a large number of 50-year simulations in a reasonable timeframe….the ICM serves as the central modeling platform for the 2017 Coastal Master Plan to analyze the landscape performance of individual projects and alternatives (groups of projects) for a variety of future environmental scenarios for up to 50 years." (C3 1)

Though integrated simulation models are prevalent within ecology (Kelly et al. 2013), they are not as common as some would like them to be. Costanza, who developed a vegetation model still widely used in the coastal scientific community, argued that the ecosystem (services) modeling field was still too focused on models that focused on one specific ecosystem dynamic or process. Instead, he claimed that they should be tied or linked together, in much the same fashion as the Limits to Growth model (Notes, ACES 2016; indeed, Costanza has attempted a revision of the World2 model). The ICM arguably represents the most large-scale policy application of integrated simulation, at least as compared to the applications reviewed by Kelly et al. (2013).

By fall 2015, experts were already mostly done with the early stages of the modeling. Experts broadcast that "we are into calibration and validation, running scenarios, so only minor changes." (webinar) 2016 brought production runs, evaluating projects with planning tool, and stakeholder engagement. The planning tool makes sense of the ICM production runs: "it is really a means for us to organize and understand output from those predictive models and then see which projects we think might work well together, which projects might not work well together…" (CPRA 2017 G1) Its use in the Master Plan process was new to 2012, and slightly expanded upon for 2017. The motivation behind the tool was precisely experts' 30 year old concern about making coastal restoration pragmatic: "how do you go from a filing cabinet for projects to a plan? I mean that's the challenge." (1) In retrospect, it is a natural fit for planners' priorities, but it came about through very specific circumstances. One of the lead modelers had been consulting on a project in California, and met someone from RAND at a conference there. This was before Katrina, but the storm prompted them to reconnect. Katrina made the need to develop a prioritized, pragmatic plan all the more necessary. The planning tool was not ready in time to make this a reality in 2007, but it was for 2012.

CPRA uses the planning tool to pick the most rewarding projects, but also to engage stakeholders. ICM modeling largely takes place behind the scenes, beyond public scrutiny. Yet

CPRA is explicitly committed to public engagement, given the gravity of land loss and the fact that restoration will entail extensive changes to the coast. CPRA says stakeholders shape their decisions, often by serving as “ground truth.” The planners I spoke with named specific revisions they made in response to stakeholder feedback in Framework Development Team (FDT) meetings and in focus groups. For instance, the fisheries focus group played a part in the agency’s decision to dial back how many diversions it included in the 2017 plan (CPRA 2017 G4).

By late 2016, planners more or less had their plan. Even before the publication of each Master Plan, the agency releases infamous “red maps” that show the ICM’s prediction of where land will be lost along the coast in 25 and 50 years without restoration. Planners were already debuting these at the June 2016 State of the Coast conference. After CPRA released the draft of the plan, in January 2017, staff engaged in “community conversations” where they solicited input from coastal residents and revised the plan. CPRA notes how the draft MP period for 2017 led them to modify some projects, specifically around the Northshore communities and Jean Lafitte. These are places where experts’ proposed levee projects had not lived up to residents’ expectations. In April, the 2017 plan was finalized and in June it passed by the Legislature with only one dissenting vote (link).

2.6 Beyond the Master Plan

When I spoke with experts about modeling for the Master Plan, I asked them to think about the future. I asked them what they would like to be able to accomplish in the next iteration of the plan. They had a range of answers, but they all revolved around changing the modeling and planning process itself. There were three basic responses. First, many experts envisioned the 2022 five-year update focusing more on using simulation tools to adapt or alter existing projects, ones that will have been built in the intervening period. They found themselves somewhat frustrated with having to model a fresh new suite of projects each time. A second response was to say the state should spend much more time and money moving communities away from the coast rather than determining how to protect them. CPRA directly not address relocation in the 2017 plan, or in the modeling. But it did evaluate "non-structural" projects that would aid coastal residents in adapting to increased flood depths. The agency mapped parcels that would be flooded under different scenarios, but aggregated this data at a regional level. It passed the buck onto a new program called LA SAFE, a community-level approach to elevating homes and evacuating communities. It is quite possible that there will be more elevation and evacuation-type analysis in 2022 as there was already more of it in 2017 compared to 2012. Finally, a third response was to lament the political, financial, and technical constraints of the Master Plan itself. After the 2012 plan, conservationists sponsored an effort to conceptualize a future coast in ways that went beyond the Master Plan's red maps. Changing Course invited design experts from around the world to rethink rebuilding the coast, without the kinds of limits the Master Plan imposes. The winning teams prioritized large-scale diversions more than the Master Plan does, constrained as it is by political outcry from affected stakeholders. However, these diversions are sketched at a high level of abstraction as "squiggly lines on maps." Still, CPRA has said it would like to incorporate some of the Changing Course ideas into its modeling work.

Perhaps the 2022 Master Plan will incorporate some or all of these directions. Either way, it will rely on modeling. Modelers will be asked to adapt tools and practices to accommodate any new approach, just as they did for the ICM for 2017 or the planning tool in 2012. Perhaps modelers themselves will push for such changes. In the next three chapters, I follow modeling practice in the 2017 plan, expanding on the context I provided here. I start by showing how coastal experts made the ICM work in light of politics around sediment diversions, financial constraints to data collection, and limitations in their model algorithms. I then show how the coastal modeling teams organized themselves to learn from the ICM, by purchasing expertise and access to tools as well as by building an institution with norms for collaborating and interacting with ICM outputs. The ICM software itself also reorganized model teams and lent itself to specific kinds of insights. Finally, I demonstrate how modeling was used by planners to actually establish coastal policies. The kinds of models that planners have available to them inform what policies they implement. The practices and affordances I characterize in the next three chapters were crucial to the preparation of the 2017 plan, but I believe they should be true of any modeling endeavor, whether in Louisiana or not. Key context - local histories, politics, finances, and existing data infrastructures - will be different. But experts will have to make models work with and against external constraints. They will have to organize institutions to learn from modeling. And their tools will inform what they learn and how they apply it.

3. Making Models Work

Conservationists around the world advocate for "data-driven environmental governance," while saying relatively little about building the data collection, storage, and analysis infrastructures to support it. However, as the Master Plan case shows, building these infrastructures is not a straightforward technical task, but one with political economic frictions and broad implications for environmental governance and politics. In this chapter, I illustrate three strategies by which Louisiana modelers manage tradeoffs in "infrastructuring" data for the Master Plan: they work with the data; choose and build the right tools; and frame analysis. With these strategies, modelers manage political, financial, and technical constraints on their work to make ICM models computationally and institutionally adequate. I argue that these strategies are politically meaningful because modelers either accept and accommodate constraints or work around and surpass them. Although political ecologists claim that hegemonic adaptation approaches tend to be technocratic and postpolitical, I find that following modelers' tradeoffs demonstrates if and how technical practice actually forecloses transformative adaptation. I conclude that a key factor shaping the transformative potential of technical practice is what data is asked to do, not its quantity and not whether it "drives" governance per se.

3.1 Introduction

> When sitting on the beach, facing seaward, if one sees waves come from left to right, the wave direction is positive and so is the longshore transport. (pg. 70, 2017 Draft Master Plan Appendix C Chapter 3-3 - Barrier Island Model Development)

Here you are: sitting on the beach, taking in the sun and the sea, and watching the waves roll and crash left to right. Too bad it's a computer simulation. In this model of barrier island formation and change on the Louisiana coast, it's 30 years into the future, and modelers are able to say something about the basic shape of the shoreline, an average wave height for each hour, and the direction of the waves. The model calculates all these processes in order to evaluate an engineering project meant to restore part of the coast's barrier island chains. The authors' language is dry yet poetic, almost a haiku. The sentence is the only one I am aware of in which Master Plan modelers have envisioned human inhabitants of the relatively rich world generated by their models.

Predictive modeling like the barrier island component of the Master Plan's ICM opens up a plethora of futures by describing potential biophysical conditions across a range of dates yet to come. Components of the ICM have such fine spatial and temporal resolution that it is possible to imagine future vegetative conditions in a marsh south of Houma in April 2041, the length and shape of a barrier island beach that year in Chandeleur Sound, and, ultimately, the fisheries and storm surge outcomes associated with each. The whole point of the Master Plan modeling effort is to envision these kind of futures. So, why is it that for many critical scholars of environmental politics, modeling tends to be a "technocratic" exercise that "depoliticizes" and "forecloses" socio-environmental change, entrenching unjust relations between state and civil society? While also claiming themselves to be objective, modelers regularly and explicitly acknowledge the limitations of their work; it is rare to hear them declare that modeling alone should dictate policy. My argument in this chapter is that if modeling does foreclose, it is an effect of choices modelers make in developing models. By asking how modelers make the ICM and Master Plan process "work" – both technically and "institutionally" within the planning process – we can better explain if and how models limit transformative adaptation.

We can better explain if and how models limit adaptation because a tension sits at the heart of making the Master Plan models work. On the one hand, experts often want to incorporate more analysis, or perhaps even gather new data, in order to more legitimately represent the socioecological processes they and stakeholders care about. On the other hand, getting more data or doing more analysis may prove not only technically challenging, but politically infeasible if it means "studying the coast to death" while wasting limited funding. Modelers also find themselves wary of how much time they would then sift through not just "raw" data but the data the ICM itself produces as outputs.

In this chapter, I demonstrate how modelers negotiate tradeoffs between justifiable analysis and political, financial, and technical limits on data collection and analysis. I illustrate three strategies by they manage tradeoffs: they work with the data; choose and build the right tools; and frame their approach. Modelers employ these strategies in order to make ICM models computationally and institutionally adequate. I explain why modelers draw on specific strategies in terms of institutional position and individual connections. I argue that in employing these strategies, modelers both accommodate and work around constraints, with effects on the transformative potential of Louisiana's adaptation program. When scholars talk about what technology does in the world, our stories often rely on deterministic tropes – technology "locks-in" inefficiencies (see Hare forthcoming) or it totalizes knowledge systems (Scott 1999). If we instead look at how people practice technology, we can make sense of the political relevance of their actions. "Technocratic" efforts at environmental management do not necessarily entrench existing unjust state of relationships between the state and civil society. If and when modeling does entrench these relations, it is routed through modelers' practice. I conclude that a key factor shaping the transformative potential of technical practice is what modelers ask data to do, not its quantity and not whether it "drives" governance per se.

I first provide a brief review of how scholars have thought about the relationship between technology and social change, specifically with respect to climate change adaptation. I then provide some context on the political and financial environment surrounding coastal restoration in Louisiana. It is most notably marked by a dual sense that restoration is urgently needed and an intense skepticism of spending resources on modeling and assessing coastal change. This sets up the main section of this chapter, in which I describe the three ways modelers make the ICM work. In the section that follows, I explain why modelers draw on one strategy over another and what their choices mean in terms of transformative adaptation. I conclude by coming back to the simulated barrier island and spell out how modelers' strategies for implementing the barrier island submodel, and the ICM generally, both transformed the nature of adaptation in the simulation and foreclosed other possibilities.

3.2 A brief review of the scholarship

How do we understand the relationship between technology and social change? Robbins and Moore (2015) review political ecologists' perspectives on technology in terms of the violence it engenders - both literal and epistemic violence. Political ecologists tend to answer the question of how technology informs environmental governance and climate adaptation through the twin lenses of "postpolitics" and "technopolitics." (Swyngedouw 2010; Fletcher 2014; Akhter 2016; Bryant 2016; Kenis and Lievens 2016; O'Lear 2016; Thomas 2017) With the postpolitics lens, scholars see technology-based governance reducing environmental issues to a matter of numbers, consensus, and small incremental fixes, rather than retaining a focus on "proper," adversarial, and liberatory dissensus. In a similar vein, for instance, Hulme (2011) argues that in policy applications, climate modeling casts the future in terms of only a handful of biophysical variables like precipitation, rather than other more socially-relevant factors. Instead of the prediction and consensus aimed for in much model-based environmental governance, researchers see dissensus approaches as more transformative for climate adaptation and resilience (Kaika 2017). For instance, most governments have adopted climate change solutions that settle for better accounting of carbon emissions, usually through sophisticated algorithms and modeling. They have not more fundamentally aimed to change unjust carbon-dependent economies by "focusing on where, how, why, and by whom conflict and disagreement are generated." (Kaika 2017, 94) Similarly, with the technopolitics lens, scholars argue that political actors use technology to achieve political goals, which often require circumventing public debate and dissent. Researchers tend to make this out to be a deliberate action (e.g. Edwards 2010; Akhter 2016; O'Lear 2016). Hecht (1998, 15) defined technopolitics as the "strategic practice of designing or using technology to constitute, embody, or enact political goals."

An especially relevant example of the postpolitical position is how ecosystem modeling forecloses transformative social change. In this view, modeling discretizes socio-environmental phenomena that are in reality more relational or non-Cartesian (e.g. property rights); modeling obscures complexity because it cannot even include all discrete, parametric data (e.g. its use by non-locals often betrays messy local histories); modeling is regularly employed to produce consensus and shared understandings through reconciliation, rather than advancing debate and dissensus. Dempsey (2016), for instance, finds that the ecosystem services modeling tool InVEST tends to foreclose any sort of broader transformation in the contexts where it has been applied; it reinforces conventional environmental management. Foreclosure happens because the modeling entails reducing complex local conditions and histories to discrete variables. It happens in spite of the fact that the ecosystem service concept, Dempsey argues, holds some potential as an alternative way of conceptualizing the relationship between nature and society.

I take seriously the claims of postpolitical scholarship, but I find that there is a need to specify how technologies like modeling foreclose political possibility, and under what conditions (Robbins and Moore 2015; Dempsey 2016). Is it something about modeling itself, as Dempsey (2016) suggests? How it makes reductive predictions? (Hulme 2011) What about scenario modeling, which opens up a variety of futures? Is it something about how modeling is used? Even within the postpolitical frame, I think there is good reason to highlight the *unintentional* rather than intentional, technopolitical consequences of technology in governance. Yet I do want to pay attention to effects beyond those that simply entrench state power (Ferguson 1990).

One way forward is to emphasize how users work with technology. Feminist STS scholars have long shown how knowledge, data, and technologies "encode" or "embed" values and politics. This key finding echoes what postpolitical approaches say about how technologies limit social change – models may embed austerity and other conservative politics, just as many household technologies embed sexism (Wajcman 2004). However, feminist STS and history of technology scholarship on "users" also further open technological black-boxes in order to show how they are contested and countered. These scholars explain how users either accept, reject, or refashion the values and "scripts" designers embed in technology (Akrich 1991; Ooudshoorn and Pinch 2003; Svetlova 2012) Such an approach is useful to see how modelers, as users themselves, make models work, implicitly or explicitly accepting, rejecting, or refashioning the values associated with their data and tools.

Political ecologists and others have long held that technological approaches to dealing with environmental issues, perhaps climate change especially, foreclose transformative social change (Robbins and Moore 2015). I do not doubt their findings, but I am inspired to clarify when and how this is the case. While all technology may embed values and, hence, politics, I am less sure this is always a conscious, technopolitical strategy on the part of decision-makers to avoid debate and broader social change. Below, I spell out how modelers' strategies to make models work can have depoliticizing and conservative effects as well as transformative ones.

3.3 Context: How much data and analysis?

> While scientific integrity and defensibility are paramount to the process, every conservative assumption, every additional project documentation requirement, and every field monitoring component must be considered with an eye towards bottomline economics. (CPRA planners in the National Wetlands Newsletter; Zeringue et al. 2014)

In this section, I sketch out the political and financial environment in which modelers and planners operate while developing the Master Plan. In the sections that follow this one, I will argue that modelers must navigate the constraints such an environment places on their work.

Environmental managers are usually assumed to be intrinsically motivated to develop the best possible scientific understanding of an issue in policy. As policy scholars have shown, this may not always be the case, either because managers trust traditional approaches, because of their training, and/or because of how they interact on an individual basis with scientists (Lindblom 1955; Lipsky 1969; Magill 1988; Espeland 1998). Decision-makers may also be faced with external constraints like "bottomline economics" that dampen any intrinsic motivation to get behind the best available science. In Louisiana, decision-makers face tradeoffs because they operate in a context in which coastal restoration is seen as urgent and modeling is seen as expensive. There is extensive public debate in Louisiana about the relevance, necessity, and accuracy of ecological and engineering expertise in general and its application in modeling specifically.

Experts and expertise in Louisiana face a significant amount of public skepticism, a large portion of which stems directly from the failure of levees in New Orleans during Hurricane Katrina. Despite spending billions on research and construction, the Army Corps of Engineers' (Corps) levees failed. While the Corps rebuilt the levee system after Katrina, the system and the modeling behind it evoke little trust, at least from online commentators: "The Corps of Engineers had many errors in their storm surge modeling and design of the new levee system….This is the biggest waste, fraud and abuse of $14.7 billion that I have ever seen." (Marshall 2015) Frustration with the Corps is also wrapped up in Southern anti-Federal sentiment. The 2005 flooding of New Orleans is even sometimes called "the Federal flood" (Campanella in Taylor et al. 2015).

When it comes to coastal land loss, many people are worried that restoration projects – especially the sediment diversions - will be another waste of money that will not actually provide any results. The question skeptics pose is, "should we study diversions to death or build them?" (Schleifstein 2016) Worry about studying the coast to death comes in two different flavors – a populist flavor and an expert one. Reading the comments of Nola.com reveals the populist perspective, where user "Future Trends," wrote, "$122.8 Million for engineering and design? Follow the $ and find out how much $$ the engineering firms kicked back to the politicians in the form of those legal bribes called campaign contributions." (Schleifstein

2017) Similarly, at a public meeting on the draft 2017 Master Plan, a black reverend put it this way: “What's frightening me about the plan when I look at - some of these projects are not going to take place until twelve years from now, but the amount of money being spent for project design….I just think that we're being Trumped by the Master Plan. I think the Master Plan, as I've always said, is the *Master* Plan.” (CPRA 2017 G1, 202) Everyone wants restoration to be done, but they call out the money being spent to assess it.

Another flavor of worry about studying the coast to death comes from modelers and scientists themselves. They are worried about investing too much time and money into data collection and analysis. Journalist Bob Marshall (2016) summarized the dilemma they face this way:

> Any change to the science supporting Louisiana’s coastal plan is crucial because the continuously sinking coast places a deadline on action…If the state waits too long to act, most of the coast will have been swallowed by the Gulf of Mexico, resulting in the loss or relocation of the communities and vital industrial hubs it aims to save. But if it errs in selecting a strategy and projects, it might then lack the money to begin new work.

Experts know they need to get the science and “strategy” right, but they also know that they face a “deadline on action.” One modeler for the Master Plan explained to me that 2.5% of money from the BP oil spill settlement is directed towards the advancement of coastal science, including model development. But even as someone whose job involves managing the modeling effort she expressed worry about sinking money into models, “because you need on the ground restoration.” (37) Another modeler’s concern was even more trenchant: “how do we know we’re not too late?” (17) For them, the question to ask is, “what's the risk of not having data?” Some experts think, “we are at a point where we definitely cannot wait to do stuff.” (32)

Modelers and non-experts alike have their worries about studying the coast to death. The modeling process *is* extensive. One observer estimated to me that hundreds of people were involved in some degree or another in developing, implementing, and interpreting the models. Officially, the number is more like 70 (Notes, State of the Coast conference), but this figure likely does not include all the subcontracted programmers who made contributions, not to mention administrative support staff. At least three engineering, policy, and PR consulting firms - RAND, Arcadis, and Emergent Method - had staff working "day-to-day" on the plan (Notes, State of the Coast conference). Individuals and teams from over two dozen government agencies, engineering firms, consultancies, nonprofits, and academic institutions participated.

The modeling process is *expensive* as well. I was unable to determine exactly how much it cost to develop the 2017 Master Plan, as there is no single line item in CPRA's budget for it and the bid for the work was not immediately available. However, CPRA's 2015 annual budget included a $30 million line for the Water Institute of the Gulf, the nonprofit contracted to manage the modeling (CPRA 2015). Another estimate suggests that in actually implementing the Plan – building diversions, oyster reefs, and levees – 12.5% of the funds that will be spent will go into developing and applying science and engineering (Sayre 2014). As of fiscal year 2015, CPRA was planning to spend roughly $5 million every year, or about 14% of its total programmatic budget, on line items like "Model Development and Maintenance" and "Data Management." (CPRA 2016 Annual Plan)

The political climate in Louisiana right now is one skeptical about the time and money spent on assessing and modeling coastal restoration. As I show below, this informs how modelers put together the ICM – they are careful to get the science right, but also cognizant of political and financial limitations. If the modeling process were not as technically, institutionally, and financially extensive as it is, there may be more money and time for restoration, but skeptics would still probably doubt the plan, pointing out that the state had no scientific basis for its proposals. In a sense, modelers cannot win – all they can do is manage the tradeoffs that result from political, financial, and technical factors shaping their work.

3.4 Three strategies to make models work

> Proverb 1: DON'T PANIC
> …. When given a new problem to solve, there are many forces that encourage the programmer to abandon thoughtful and effective programming techniques in favor of quicker, high-pressure, unproven ones. Typically, the programmer may be loaded down with other work. Your instructor or management may be putting on the pressure by setting an unrealistic schedule or by promising a bonus for finishing early…. If you find yourself upset or ploughing ahead with a new programming assignment, 1. Stop. 2. Calm down. 3. Return to methodical programming techniques. (pg. 5, *FORTRAN with Style: Programming Proverbs*, Ledgard and Chmura 1978)
>
> Model development and analyses must not only be done in time for use in the Master Plan, but also within a defined budget and with the available expertise and staffing levels. ("Strategy" 2013, 6)

Modelers and the programmers they employ are subject to "many forces" that they must manage: a political environment skeptical of their expertise; decision-making timelines; budgets and staff; an overabundance of data, a paucity of data, the wrong data, or poor quality data. Modelers must therefore strategize about how to make the ICM submodels do what they and the planners overseeing their work would like them to do. Modelers want the models to "resolve" – that is, to run and deliver outputs. They want these outputs to make ecological and biophysical sense. But they also want the models to prove useful in a decision-making context and to be viewed as legitimate. To make the ICM work in this way, modelers lean on three strategies. The first thing modelers do is *work with the data.*

3.4a. Work with the data

In this first subsection, I show how modelers work with the data to develop and implement the ICM. Modelers emphasize how they employ the "best *available* science and technical information." (2012 Master Plan Appendix B – Plan Formulation Process, pg. 53, emphasis added). As a way of managing budget and time constraints, modelers usually draw on existing databases. However, a lot of the data that Louisiana planners use is not produced with the Master Plan models in mind, meaning modelers must make sense of what they have at hand. They work with the data deciding how much of it is really necessary to use, discarding some raw data and including others, and carefully planning how to gain new data in the future. Modelers make data "available" with three different "tactics."[6]

1. Work with the data by determining how much is necessary

Modelers often draw on existing databases, but to do so they must decide how much of that data is necessary. Modelers work with the data by determining how much they need, using statistics, risk, money, and time as criteria. Modelers are often guided by statistics in assessing what data is available and adequate for the modeling process. For instance, one of the planners at CPRA overseeing the fisheries modeling effort sees adequacy as a question of, "when do you have enough data to reliably demonstrate something?" (8) An advisor to the process recommended the principle of parsimony (9). Statistics represents a conventional, internal-to-science approach to determining data availability.

[6] In this argument, I am echoing political ecologists (Barnes 2017) and resource geographers (Bakker and Bridge 2006) who have illustrated the making of natural resources.

A fisheries modeler, however, offered a different approach focused on political economic conditions that are "external" to science per se.[7] She emphasized that modelers should think about the *risk* of not having the data:

> I think as scientists we have an affinity to want to go and collect data. I mean we like to go to the field, we want to learn and get the most up to date, precise information that we possibly can to answer that question. I think balancing, you have to ask yourself, what is the risk of not having it? What if it's not possible? You don't have the funding to hire a boat driver to take you out or you can't get landowner permission, you know. I think identifying the risk of not having it kind of might help to keep things in perspective - like how important it is that I really go and collect temperature data or can I just use the air temperature probe over there can I correlated it to this. How can we be creative and analyze the data that we already have? I'm a big proponent of that, even though I love field work as much as the next person. (17)

She argues that modelers ought to consider what data they already have at hand. Many modelers echoed that, for them, financial and institutional conditions – things like the funding to hire a boat driver - determine how much and what data is available for modeling. Put differently, they accept how budgets constrain data availability.

Money is not the only constraint modelers face; they tend to collect as much data and perform as much analysis as they can within whatever time they have. As one modeler put it, "I think we have to be really strategic especially with limited funding and limited time - the amount of time it takes to go out collect the data." For modelers, the data available is what they can acquire before hard deadlines. As a modeler based in academia, put it: "you stop when time runs out." (32) Timing is an especially consequential constraint on some of the most cutting-edge dimensions of the modeling effort. A former Louisiana DEQ director commented at a public hearing on the draft plan, explaining that the plan's sea level rise estimates were already out of

[7] I am strategically using the internal/external dichotomy as it is employed in the STS tradition, which is focused on inward-facing dimensions of scientific practice such as norms (Lave 2015).

date (CPRA 2017, G1). In its final report, the PMTAC repeated this problem: "predictions of eustatic sea level rise have changed substantially since 2014 when the 2017 Coastal Master Plan decisions on sea level rise were made" (PMTAC 6). CPRA may have the best *available*, but not the *best* science. Fall 2014 became a "stopping point" for incorporating new information (CPRA 2017 C2, 3). As one of the lead scientists on the Plan put it, "SLR is a moving target for us. We have to pick a rate when we're getting ready to do modelling - when everything's already in progress." (in modeling webinar, September 2015) Modelers and planners manage the sense of urgency around restoration by setting and accepting "stopping points" for their work. With time, but also risk, money, and statistics as criteria, they determine how much data and analysis they need to use the ICM for the Master Plan. Sometimes, in accepting time and funding constraints, this can have negative impacts - like not incorporating the most up to date climate information.

2. Work with the data by leveraging it

A follow-on tactic modelers employ is to leverage existing data sources, as a way of dealing with budget limits and institutional obstacles. CPRA itself is not a "boots on the ground" agency. As a CRPA staff member noted, "other agencies are collecting data, so how do we leverage it?" (Notes, State of the Coast conference) One of the key ways they leverage data is to organize it, giving them clearer picture of what they can use in their models. A fisheries modeler saw the problem as one of awareness: "there's quite a lot of data collection going on right now such that I think the struggle we have is making sure people are aware of it…. I think if people spend more time looking into what's out there they might find that it already exists." (17) She went on to explain to me that before she began modeling, she had to spend a lot of time just figuring out what data was available to her. She noted that the problem, at least in the case of the fisheries model, was not a lack of data, as many environmental managers in other contexts are quick to point to (e.g. Hsu et al. 2012). Nor was the problem an overabundance of data, which worries some conservationists in the “big data” era. Instead, the issue she faced was that the data she wanted was housed in many different archives. Some of it was managed by the Louisiana Department of Fish and Wildlife. Other databases were associated with the Coastwide Reference Monitoring System (CRMS). There was no synoptic view for her. This was in part driven by different agency missions, and it turned into a matter of knowing the right contacts at each agency: “they collect data to meet their legislative mandates and they have their own requirement. So the way they store it and the way you get it is very different. I know who to contact at Wildlife and Fisheries to get their data.” And so, in developing part of the fisheries model, she sat down, made her contacts, and organized a set of fisheries-relevant data. She didn’t even collect the data itself, but its metadata: “at each individual point how long they've been collecting data, what do they collect there, how often do they go, and what are the units? These types of things for every single point all across the coast - and that's an amazing amount of information.” The result was a form of curated data. This was a resource for her to know where to get the data, as well as for others: “we don't even know let people know we happen to have a database and people know that I have it. They come to me and say, hey, can I see your database? And I sit down and show them how to use it.” In creating a kind of card catalog for fisheries data, she managed cost limits on new data collection, as well as challenges stemming from how state agencies have organized coastal data into silos.

Others involved in the Master Plan modeling effort echo the need to leverage existing data, but emphasize that beyond being curated or indexed, it needs to be “mined” and “sifted.” An adviser to the Master Plan modeling process, quick to note he is an empiricist rather than a modeler, stressed the need to deal with the data already at hand by “mining” it. He felt that in most cases, there was already enough coastal restoration data available. What was necessary was statistical and analytical techniques that could make sense of it (14). Another advisor similarly noted that for him there is such a thing as too much data – “we have enough; we need to figure out how to sift through it” (29). The limitation has been, according to another modeler, the fact that “we haven't had time to or the personnel to go after information [in existing data].” (32) In this second tactic to working with the data, modelers leverage existing data sources – curating, sifting, and mining it. They draw on existing data, but not by just dumping it into their models. By leveraging data, they manage both fiscal limits to data collection and organizational challenges to incorporating data into models.

3. Work with the data by producing what you need

In the process of figuring out what data is available, modelers may find that they must actually produce the data they need. The lead on the fisheries model at the Water Institute of the Gulf described it as “targeted data collection efforts.” These efforts tend to be seen as last resorts given budget and time constraints.

When modelers do need new data, they aim to figure out how to be as efficient as possible in collecting it. Using statistical procedures, they try to determine how little data they can “get away with,” or what constitutes the minimum amount of measurement they need to do. For instance, they’ve realized that for a medium-term forecast of waves, they learn nothing new from having more than seven days’ worth of data (notes, State of the Coast conference). In preparing for how they will collect data from restoration projects - especially sediment diversions – modelers and planners are creating a monitoring program called SWAMP (System-Wide

Adaptive Management Program). At the core of SWAMP, modelers utilize the “card catalog” or inventory of existing datasets to determine where and how much data to collect. They performed a series of “power analyses,” which illustrate how much information will be necessary to make statistically significant claims (CPRA 2017 F). Power analyses are essentially statistical correlation in reverse:

> It’s all centered around, what do you want to be able to detect in that variable? Do you want to be able to say that there is a one percent change in fishery abundance from one year to the next? Or are you like, I'd rather be able to detect a 20 percent change, and maybe in this particular variable it's more important to get the finer scale changes. (17)

This modeler goes on to describe the process through which planners, in consultation with modelers, determined what they “want to be able to detect” – what questions they would like to be able to answer in the future after restoration projects are constructed:

> So [SWAMP] was all about kind of forcing us to think about what do we need to use the data for? We kind of took a step back and thought OK what are all the things we can possibly measure along our coast and can we prioritize these? We got these conceptual diagrams thinking about, what are the potential impacts along the coast and how does that connect to other things? So we had these crazy spaghetti plots and in the end ended up with a laundry list of variables through several iterations with CPRA and sitting around a table and identifying you know what's most important for the projects they're looking to build. (17)

Beyond aiding the adaptive management of restoration projects, modelers develop “targeted” means for acquiring new data that will specifically “fit” the ICM models. For instance, the model advisory committee recommended identifying the data that will specifically advance the models: “In preparation for future work, the PMTAC recommends that the modeling team closely examine the quality and quantity of data that are used to configure and calibrate the models, and identify which emerging types of data would be most useful for further improvement or testing of the models.” (PMTAC 2) They specifically identify LIDAR data and sediment transport data as key targets.

Figure 1. A monitoring station for the Coastwide Reference Monitoring System (CRMS). SWAMP aims to build upon CRMS. Source.

The effort to fit new data to the ICM models and to develop SWAMP represents a kind of coproduction of science and policy. Policy needs shape scientific data collection, which in turn informs policy when that data is used in models. It is a coproduction that requires modelers and planners make choices about *future* science and policy goals. As the authors of a report on SWAMP put it: “In order to be successful, the quality, scale, and resolution of the data must be appropriate to meet the monitoring program’s specific objectives. As a result, thorough planning of the objectives, analysis, design, and measurement choices must be conducted prior to the actual data collection” (CPRA 2017 F, 24). In this view, planners and modelers must know what the monitoring program should evaluate and achieve before they collect the data. They do not value data for data's sake; they do not want to compile all possible data to answer any possible question. Instead, the data that is to be collected is that which aligns with already existing (policy) goals. Louisiana modelers and planners manage funding constraints by producing data they need - optimizing data collection. Yet in doing so, they assume they will have similar goals for the data in the future as they do now.

3.4b. Choose or adapt the right tools

> "It's a tool to find a tool" - NOAA representative on a decision-tree "tool" to help users choose the appropriate sea level rise webmap (Notes, State of the Coast conference)

Model teams work with the data by determining how much they need, leveraging it, and, as a last resort, collecting more of it. In doing so, they manage various institutional (deadlines) and financial (austerity) constraints. However, modelers do not just seek to make available data fit into the models they already have, or even to collect new data. Instead, they work with the models themselves. Model teams are generally constrained by institutional and financial factors in building *new* tools for the ICM. As one consulting programmer put it:

> With software dev you're balancing several interests. If you had lots of time, you could develop high quality software; you could work out all the bugs. … For the Master Plan, time was not a luxury (laughs), so in deciding what to include, that was narrowed down by the time equation. But still the state was saying these are our minimum features, and we were saying, we know this is a reduced request, but this is it. So what gives? The quality of the software. So you make decisions about - do you reduce flexibility? If we know data is going to be in this or that format, we design for that and we don't make it generalizable…. We were asked to deliver tools that probably could've taken years to develop; we got just a few months. (47)

As a modeler summarized, "by this date, whatever we have done to improve the model, that's all we can do….because you can't keep tweaking." (32) Rather than building extensive new tools, modelers - and the programmers they collaborate with - tweak models and choose different models. There are three different tactics to this strategy.

1. Adapt existing models

To make the ICM credible but on-time, the first tactic modelers pursue is to adapt models to coastal conditions. The Master Plan's model teams describe needing to adapt their tools to meet the physical complexity of the coast, as their expertise and institutional expectations lead them to understand it. The Louisiana coast is a mosaic of open water, marshy, and dry, relatively stable and dynamic terrain. It is the kind of place where social scientists studying adaptive management would find themselves deeply skeptical about the abilities of abstract expertise embedded in models (e.g. Gunderson and Light 2006 on the Everglades). Many of the models used in the Master Plan, however, are actually "off-the-shelf" or "turnkey" applications meant to be applied anywhere. As one modeler put it, they would rather not "plug and chug" with such models. Instead, for instance, the engineering team leading the barrier island morphology model spent months rewriting one model's code to make it workable in the Louisiana ecological and policy context. The fisheries model had to be adapted as well: "several specific improvements to the EwE software and approach were made to accommodate the needs of the 2017 Coastal Master Plan," (CPRA 2017 C3, 30) including increasing temporal resolution to better predict within-year effects on fishers, enabling geospatial projection of the model area, and excluding certain map cells ("We needed to make some coding refinements, making sure fish aren't in the forested wetlands that the veg people were sending us" modeling webinar September 2015). The vegetation submodel represents an exception to the rule that modelers adapt tools – an exception that proves the rule. It was designed from scratch, but specifically in order to fit the coast:

> It's not really like there are you know five or six models you can take off the shelf - there really weren't any that we could take off the shelf. There's nothing out there that can do all the things that we have to. So we more or less built our own model. (32)

By designing models in-house or tweaking them, modelers manage their own and institutional expectations that their work will be specifically grounded in and applicable to the coast.

Modelers want to try to capture the complexity of coastal biophysical processes as much as possible by adapting models or even building new ones. Yet in doing so they run up against institutional time and funding constraints. As one modeler described the from-scratch vegetation submodel, "Is it the best? Probably not, but it was the best that we could do at the time within the time constraints that we had." (32) At the outset of the 2017 Master Plan effort, planners mandated modelers use already existing tools: "Available techniques and visualization tools will be utilized as necessary. To the extent possible, costly and time-consuming new development of post-processing and visualization techniques will be avoided or at least kept to a minimum" ("Model Improvement Plan" 2013, 34). Modelers make a tradeoff in following this guidance and relying on existing tools. Using them may mean accepting the limitations in those models, and ultimately spending more time modeling. Building new tools, on the other hand, may cost modelers time in the beginning but result in less time spent on QA/QC, interpretation, calibration, and so on in the long-run. While planners said modeling teams should spend limited time on developing new tools, the PMTAC disagreed for exactly this reason: "the modeling team should work to develop tools that take advantage of automated model review to expedite analysis of model runs." (PMTAC 12) One programmer with the USGS, which provides technical expertise to the Master Plan, argued to me that these kinds of automated techniques, some of which he helped to develop for the 2012 plan, allow modelers to concentrate on the core of modeling - interpretation (47). There are tensions between using existing tools and adapting them or building new ones. Building new tools may in the long-run allow better analysis and adapting tools can ensure a better fit with place-specific ecological conditions, but these tactics cost time and money.

2. Keep the model simple, at least at first

Keeping the model simple at first is the second tactic modelers pursue within the strategy of getting the right tools. While modelers employ existing or modified tools rather than developing costly, elaborate new models, “keeping it simple” often means “keeping it simple *at first*.” Much as modelers prepare for future data acquisition (e.g. SWAMP), they prepare for future analytical needs, building them into their models. In doing so, modelers manage cost and time constraints. In public presentations about the ICM models, a prominent genre of question goes something like this, “Ok, but why didn’t you include X?” For instance, about a wave model, a conference-goer asked, “What about extreme events?” (Notes, State of the Coast conference) Modelers responded that theirs was a “fair weather forecast.” They intend to start simple, get everything right, and then include hurricanes. Modelers’ “ability to use data is only as good as their ability to analyze the error,” (Notes, State of the Coast conference) so many are focused on trying to develop ways of interpreting error before introducing complexity. Modelers and planners tend to envision a future where they are able to improve the predictive capacities and analytical dimensions of their tools, just as they tend to see earlier versions as having gotten better due to increases in computing power, data availability, and improvements in the “best available science.”

Some modelers go ahead and build complexity into their code, with the idea they will have the opportunity to actually implement such analyses in the future when they have the time and/or money. The structure of modeling software’s code provides a platform for expansion. For instance, the guru behind the ICM says that he wrote code to enable analyses project managers have decided there is no time for right now, but which may be possible in the future. This was also the case for the vegetation module: “model code has been written so that the dispersal distance can be adjusted for each species if more information becomes available.” (CPRA 2017 C3-5, 6). One programmer explained how their team also built expandable code into their ICM extension, in order to make it useful beyond the Master Plan:

> We had more luxury in terms of time, so we could make it more generalized. We designed it thinking, why does it have to be specific to this region? We made choices that benefit state of Louisiana, because they could use it in the context of the Master Plan….We sort of try to build in a little extra headroom to make a tool more generalized so other people in ecological modeling community will see that benefit. (51)

Keeping models simple is a way of managing existing time and financial constraints, but modelers and programmers adopt tactical practices like building in “extra headroom” so that future model applications will have more analytical capacity. This tactic echoes how modelers approach data capacity in programs like SWAMP: they plan to get more data to address the research questions and policy goals they are currently interested in, but financially constrained from answering.

<u>3. Get other models</u>

Beyond adapting the tools they already have or building in extensions, modelers acquire other models. Modelers realize that no single model is perfect. What they try to avoid is “putting all our eggs into one model.” They seek out other tools to make up for shortcomings in the models they have and, in some cases, to manage political demands. This is most evident in the fisheries modeling effort.

To understand the possible future conditions of fisheries, in 2017 Master Plan modelers decided to run two different models. One is designed to predict habitat suitability. With this model,

model teams ask, will an area be suitable for brown shrimp in 2030 given what is already predicted about water levels and salinity, and what brown shrimp like? To answer, modelers construct statistical relations, or indices, between variables like water level and fish habitat. This habitat suitability index (HSI) approach is just one way to understand fisheries, though it is one that is readily justifiable: “they're easy to communicate, they're easy to construct, you know they've been around forever – since the 70s or 80s – and everybody uses them.” (41) HSIs are also relatively easy ways to accommodate and preempt technical challenges posed by sprawling toolsets. Discussing the 2012 plan, a modeler noted, “And this happens all the time: you set up to do something simple and people just want to hang on all kinds of bells and whistles. We built these tools for the 2012 plan based around simple hydrology and simple outputs. So we're not looking at shrimp - we're looking at shrimp habitat, which is much easier to do so.” (41)

The problem with looking at shrimp habitat is that while it is “much easier to do,” “more habitat does not mean more fish” (“Strategy” 2013, 2). Will there “actually” be brown shrimp present in an area in 2030? This is especially useful information for fishers who harvest brown shrimp and are more interested in whether the shrimp will be present and not just whether there will be suitable habitat. So for 2017, planners adopted a second model, a “food web-based model” that tracks population, nutrient, and other dynamics to forecast species presence. In fact, when planners sat down a couple of years ago to revamp their “fisheries modeling strategy,” the consultants in charge of the report originally offered a *three*-pronged modeling approach.

One way to assess planners’ dual model approach – habitat suitability and food webs - is that technological failures beget technological solutions. “The model isn’t good enough? Let’s get another one.” A better answer is that the state was responsive to high profile concerns raised by fishers. One planner couched the adoption of food web modeling in terms of the ecological dimensions of diversions: “There are lots of models to choose from, but the most appropriate is a food web model because of [diversions’] large, distributed effects” (Notes, State of the Coast conference). Yet it was arguably the controversial nature of the diversion more than the ecology per se that motivated planners. Discussing the downfalls of the HSI approach in 2012, planners wrote, “although these indices were useful in predicting changes in broad spatial patterns over time, the output of these indices provided estimates of suitability, not population dynamics, biomass, *or specific utility to people*, all of which are important characteristic of ‘ecosystem services.’” (“Model Improvement Plan” 2013, 26; emphasis added) Planners knew they had to look at how diversions affected people – for instance: “We identified specific modeling approaches that focus on oysters because of their biology (sessile shellfish), ecological and economic importance, and [because they] are *often at the center of controversy*.” (“Strategy” 2013, 41; emphasis added) The new food-web model is seemingly more suited to fishers’ interests. One modeler felt fishers approved of the approach: “I understand what they're saying. Like when you run a freeway through a little town. They're saying oh well you're going to do all this but you haven't gotten your shit together and shown us truly what you know…But they kind of liked the stuff I'm spewing because I talk about food.” Beyond just tweaking their models or holding out for better data or more money in the future, modelers seek out other models in response to political conditions.

Modelers even try to explicitly incorporate or account for these political conditions in their work by evaluating the "winners and losers" from diversions (Notes, State of the Coast conference)[8]. After completing work on the 2017 Master Plan, fisheries model teams turned their attention to analyzing one specific diversion. They again ran two models, but in this case they dropped the HSIs and used two food web models. This was to better account for uncertainty, according to one modeler:

> I would say that I think the good thing about using both approaches is it gives us a range…So when both models are telling you something that there can be a negative impact that giving you fundamentally kind of a little bit more confidence in that. (41)

The models did produce different outcomes, because in one salinity is more important (EwE) while the other (CASM) emphasizes primary production. Diversions will bring both freshwater, resulting in salinity changes, and increased nutrient levels, resulting in changes to primary production. Modelers have therefore not yet been able to say much about what *kinds* of fishers may be most affected by diversions, though they have a sense of the range of possible impacts. It is something they are spending time, expertise, and money on, responding to political skepticism of their work and of the coastal restoration program in general. As reported to the fisheries focus group, the food-web modeling did sway planners to reduce the number of diversions proposed in the 2017 Master Plan from 14 to 10 (CPRA 2017 G-4, 24).

Most political ecologists would argue that planners doubled down on modeling precisely to minimize controversy – to make it abstract, and to assess the situation and propose solutions on

[8] Planners assess and discuss restoration's "winners and losers" in other ways as well. When they use RAND's planning tool to visualize ICM output, one of their goals is "understanding the distribution of change by community." Planners do not try to sugarcoat their approach. As one journalist put it, "state coastal officials make no claim that Louisiana's 50-year, $50 billion master plan will save the entire coast; there will be winners and losers." (Sneath 2017)

their own terms. However, I argue this is not the case. Planners had already been modeling fisheries. They developed another model specifically to respond to fishers' political demands to "show us truly what you know." (41) Planners also explicitly conceptualized "winners and losers." They did not shy away from controversy; they did not turn towards "win-win" consensus-based discourse. The result was fewer diversions in the plan, though this has not minimized fishers' activism. At the very least, in this aspect of the fisheries simulation, acquiring other models opened up problems for the state as much as it foreclosed or resolved them. Planners' concern with "winners and losers" – regardless of their ultimate intent – both recognizes fishers' interests and enables further contestation.

3.4c. Frame analysis

"Data is only as good as the model" - PMTAC member, interview, February 2017

In the third strategy for making ICM models work, modelers and planners adopt standpoints from which to frame their analysis. In particular, they frame their work as pragmatic in light of political and financial constraints. Framing means developing a "model" for the data. As one adviser to the modeling teams explained to me, "data is only as good as the model." His point was that modeling is always done from somewhere, some standpoint. He pointed to a table in his office and asked, "what is the elevation of the table?" Thinking I was clever, I gave a guess based on where we were relative to sea level. His point, though, was that you can't appropriately answer the question without first explicitly answering, from where? Sea level? Sure – that's the default, but it is only a specific standpoint. What about from the floor of this room? That might be a much more pragmatic frame. Critics tend to assume that modeling, by its very nature, is received as realistic (see O'Sullivan 2004). In fact, it takes strategy – framing - to make modeling appear realistic (Edwards 2010; Nelson 2016), specifically in the face of political criticism and financial constraints.

1. Frame analysis with a question

First, modelers prioritize knowing the question they want to answer. For them, this is key to managing data overload and moving forward with analysis. As the authors of the fisheries modeling strategy laid out, narrowing the question they want to ask allows them to figure out what specific data they needed:

> The more specific and the fewer the questions that are posed for the model to answer, the easier it becomes to develop a well-suited model. A focused question reduces the possible options for representing processes (e.g., which ones and in what detail) and also focuses in on the temporal and spatial scales that are needed. (“Strategy” 2013, 3-4)

Narrowing their question is a way modelers can manage criticism that their work is inadequate; they can claim that “our work is ‘well-suited’ to this specific question.” One exception, in which modelers pursued a set of available algorithms without prioritizing their question and end goal, proves the point. As one modeler detailed:

> So the water quality equations have been in the model [ICM] since at least 2012, maybe before. And so we went down the route of trying to use them in other things without really - just because they were there. It was a lot of effort and it was a lot of time and a huge headache and really we're not even using it to answer any question. But it was there so we thought we should do it. So I think really defining - when there are so many things that are being included and you could look at its really important to know what you want to look at before you start just doing stuff. You know we're resource limited so we should kind of hone in. (51)

Master Plan modelers’ emphasis on knowing their question contrasts with proclamations from big data advocates, who predict that “unsupervised” machine learning algorithms will spell “the end of theory” (Anderson 2008). In order to manage resource constraints (time and money), modelers – not always successfully – try to “hone in” on what their goals are and direct analysis in that direction.

2. Think relatively, not precisely

The second way modelers frame analysis is to talk about model outputs in terms of relative accuracy rather than precision. Doing so helps them manage political constraints. It is easy to be impressed with tools that can paint a reasonable picture of what an acre of land in the Mississippi River Delta will look like the first week of March 2058. Of course, this claim (intentional or not, boasted or not) to precision is what leads many to be skeptical of model-based environmental management (see O'Sullivan 2004). Master Plan modelers and planners try not to make such claims. For them, precise numbers only mean so much. Planners could claim that the ICM shows exactly what the future holds - that, for instance, X quantity of brown shrimp will be present in this part of the coast in 2050 because of this project. Instead, planners talk about modeling as an exercise in comparing scenarios and projects relatively. They ask, does this project result in more or less brown shrimp than the other one? As the fisheries modelers summarized: "Model results are better interpreted in a comparative mode and for large responses and trends, rather than used for specific predictions of biomasses in certain locations and in specific years." ("Strategy" 2013, 25) While planners are not *solely* interested in relative comparisons, it does help them frame their work in terms that may be more credible.

By analyzing project performance relatively, planners are able to manage other political challenges as well. Thinking relatively, rather than precisely, means planners do not have commit themselves to a single vision of what climate and its governance will look like in the future. Planners note that in their simulations they do not have to pick the one climate scenario they think is most likely (see Groves and Lempert 2007; Adger et al. 2009). Planners find it hard to choose one probable scenario because of the biophysical complexity of coastal change and uncertain management dynamics:

> It was challenging to determine a more or less likely set of values to drive the modeling effort. Some of these environmental drivers are influenced by climate change or management decisions in the future (e.g., eustatic sea level rise [ESLR] and river nutrient concentrations, respectively), and some are based on processes that are not fully understood (e.g., subsidence, marsh collapse threshold). Such complexity made it challenging to identify values for the future scenarios to drive the models. (CPRA 2017 C2, 1)

Planners instead compare projects as they perform under each of the three scenarios they developed: "This review made no likelihood estimations of specific scenario values of future SLR to use in the 2017 Coastal Master Plan predictive models, and thus all values within the recommended range are considered equally plausible." (CPRA 2017 C2-1, 4) However, this approach poses a problem because, for various reasons, some projects will do very well under one scenario and not well at all under another scenario. For instance, a sediment diversion might be very effective at building land if sea level rise is moderate, but it may build hardly any land if seas rise at the extreme end of predictions. As one planner asked, "how do we pick projects if they depend so much on the scenario we're testing?" The answer was that there is, "no single answer, so we pick projects that do good regardless [of the scenario]." (Notes, State of the Coast conference) Planners frame their analysis of model outputs in terms of getting the best possible outcome while hedging their bets about what the future holds. For them, this is a turn towards pragmatism and a way to manage uncertainties about whether political leaders (including counterparts in state government) will attempt to mitigate climate change.

<u>3. Optimize</u>

Finally, planners frame their analysis in terms of optimization. This means that they are using data to make sure they select the projects that will build the most land with the limited resources available for coastal restoration. Planners frame the Master Plan modeling effort as about determining what kind of coast they can build and maintain with the financial resources and political capital they have on hand. The ICM modeling produced an estimated 200 terabytes worth of data through hundreds of simulations (CPRA 2017 C3, 56). For reference, this amount of data is equivalent to approximately 100,000 hours of video (Quora). So much data is meaningless without a motivating question. Using the planning tool, planners asked the data, "what kind of coast can we build?" For instance, they may assume that they will have $50 billion to implement restoration projects over 50 years. As the CPRA program manager explained, "50 billion dollars is just a way to constrain and look at projects... if you got 50 billion on day one, this is what you do." (Notes, State of the Coast conference) What $50 billion suite of projects creates the most land? Projects that are not as cost effective filter out. This cost constraint is not the only filter planners apply - though it is the most important one - and they can apply multiple ones together. Stakeholders may be interested in filtering the data to prioritize projects benefitting the oil and gas industry. Planners would then ask, what suite of projects build the most land around industry-dependent communities and infrastructure, for $50 billion?

For planners, framing analysis in terms of constraints is politically feasible and realistic. CPRA Chairman stated that the approach "represents a balancing act between what is necessary and what is possible." (Schleifstein 2017) Chief of Research Haase believes it translates into "an honest plan. It's not promising everything to everybody in an unrealistic manner." (Snell 2017) As one modeler summarized, "it's not a chicken in every pot." (1) Starting from constraints may be politically and financially realistic but the plan will still be costlier than expected and it will likely fail to result in reversing land loss. Planners acknowledge that: 1) the $50 billion in projects they have selected will increase to $92 billion with inflation and unexpected costs; 2) even this suite of projects will not be enough to begin to build land in net terms. It will only decrease the rate of land loss (Marshall 2017).

To make the point clearer - planners could have framed the modeling approach differently. Rather than framing analysis in terms of constrained optimization, they could have instead started with a specific goal in mind. For instance, they might have determined that they need to create 3,000 square miles of land over the next 50 years and asked, how do we get there? The constrained approach - figuring out how best to spend $50 billion - may not result in projects that together build 3,000 square miles of land. Starting with a land building target in mind may be politically infeasible, however. It may cost well over $50 billion. The boundaries between the two approaches are not hard and fast. Obviously planners have broad goals in mind as they experiment with various constraints. The optimization approach is a specific choice by planners to make their analysis and proposals appear pragmatic.

For the 2012 Master Plan, planners did originally frame the modeling approach in terms of targets or goals rather than constraints. The challenge they faced, however, was to take model outputs and evaluate how projects were expected to perform across a wide range of what they called "ecosystem services" – species habitat, land built, and flood reduction. In order to assess projects, planners had to make these metrics quantitatively comparable:

> RAND helped us think about how we could combine metrics which were not commensurate. So you can't …. add shrimp habitat to alligator habitat. They're just not you know they might still be in habitat units but they're not additive. And you know the whole issue of acres versus habitat was, whatever, they were non-commensurate units and [RAND] came up with a way of getting around that by having targets for the coast. A project was going to be evaluated not on how much it achieved in an absolute sense but how much progress it made towards the target and progress toward that target then became the commensurate metric. Like a percent. (1)

Instead of comparing X acres of shrimp habitat and Z acres of alligator habitat created by one project versus Y acres of shrimp habitat and A acres of alligator habitat created by another, planners turned to targets: a project might generate X% of the overall shrimp habitat goal and Y% of the alligator habitat goal for a basin. Planners had difficulty getting these targets to work, specifically because of the spatial scale at which they tried to calculate them:

> I think the thing that we had not fully – I mean we knew it but we weren't processing it….was that the land loss problem is huge while the coast is enormous. And so we were setting targets like we want a 50 percent increase in land area in this very large area. And you could never get anywhere near it because it was too big a target. You see what I mean and it was because we were focusing on the loss not on the system. (1)

Wrestling with the spatial complexity of the coast proved to be key in compelling planners and modelers to move away from the target frame:

> The challenge is where the stakeholders felt like they wanted to see species, the models were saying well that's not where they're going to be (laughs). And at that point there was a real breakthrough moment of like let's just let the model tell us where things will be and have the model that will help us build this balance of outcomes. (19)

Planners were ultimately unable to get it the target approach to work, in time, for stakeholders. In a "real breakthrough moment," they switched at the last minute to the current focus on optimizing a certain set of constraints, or decision-drivers:

> Instead we decided we don't have targets. What we have is cost constraint. And so there are - the constraints really set how much is done. So you're not trying to achieve something, you're working within a limited set of constraints - without a particular outcome in mind. (1)

At least some planners and modelers think the target approach could work and regret having to switch:

> I will maintain - as I say this regularly - that if we had another two months we could've made [the targets] work…Anyway, so we could've come back and redone it. Now I really I'm still frustrated that we didn't do that. (1)

Not without reservations, planners and modelers framed their data analysis in terms of optimization, as a way to meet time constraints and to appear financially pragmatic. In doing so, they sacrificed aspirational but specific goals for the coast.

3.5 Discussion

"We have to fight with the science we have, not the science we would like to have." – Former CPRA Chairman Garrett Graves.

3.5a Explaining modelers' strategies

In order to make models work – to deliver outputs that will be taken seriously - modelers manage political, financial, and technical forces. They lean on three strategies: they work with the data, choose the right tools, and frame their analysis. In this section, I first explain why modelers adopt the strategies they do and then I explore what consequences their strategies have. Modelers do not practice them in a voluntaristic way. That is, they are not free to frame the data in any way they want and they do not simply choose the right tools. The strategies modelers adopt to manage political, financial, and technical constraints are shaped by institutional culture and trajectories – where they work, who they know, and existing investments in software.

Institutional culture informs which strategies and tactics modelers adopt to make models work. Some institutions are more conservative than others. For instance, the Engineering with Nature program at the Corp's experimental research center ERDC did a survey that found out that the biggest barrier to the Corps trying new approaches to water management was Corps culture itself. In contrast, CPRA Chairman Bradberry has talked about engendering a culture of "continuous improvement" and Executive Director Michael Ellis prioritizes "urgency, accountability, and reputation" (Notes, CPRA board meeting March 2017). The attitude that something urgently needs to be done manifests in how planners and modelers manage technical constraints. Master Plan program leaders told me, “we’ll make the tradeoff, sacrificing more data for taking action now.” Other institutions have built reputations around certain approaches to policy analysis, so it is not surprising that in the Master Plan their modelers they employ follow suit. For instance, the RAND Institute helps CPRA optimize project selection within pre-determined financial constraints. RAND’s lifeblood and reason for existence is providing expertise governments do not think they have, and demonstrating policy options that are actually actionable for agencies. If RAND proposed something like extensive data collection, cash-strapped governments probably would not hire them. Engineering firms tend to pursue the goals of their (sub)contracts in a timely manner but they also have an incentive to advocate for more data collection since more studies mean more billable hours. One person associated with the Master Plan process speculated there would be problems when the state tries to contract with a firm to do the EISs for the diversions, since the firm will want to conduct more research than the state sees as necessary. Academics tend to be in a position where it is easier to call for more data and time, and they do, but this is tempered by personal commitments to moving forward with projects. The vegetation model lead is an academic, but is clear about what she sees as a need to move forward with projects and to do more with less data and funding. In short, modelers’ choice of tactics - framing as optimization, using existing data as opposed to generating new data, etc. - is tied in part to institutional position.

Personal connections and financial commitments to software and other modelers have shaped how model teams “choose or build the right tools.” One modeler explained that it is a relatively small community of modelers that he works with, so it was somewhat natural CPRA turned to him for the 2012 and 2017 plans. The contract with RAND and, consequently, the planning tool approach, occurred via a personal connection WIG staff made at a conference. Modeling teams choose, if they can, specific models because of their experience with them and even with other people closely associated with them. This was the case with the food-web fisheries model - "… the modeling team has experience in developing the [EwE fisheries] models and in working with the original authors of the models" (PMTAC 26) - as well as the barrier island model: "The BIMODE Team decided to use the SWAN nearshore wave transformation model due to the familiarity with the model and previous use of SWAN..." (CPRA 2017 C3-4, 12) In addition to institutional factors, existing investments shape what strategies and tactics modelers adopt and in what particular ways they adopt them.

3.5b What it means for modelers to accommodate and work around constraints

In this sub-section, I explain how model teams' strategies - regardless of why they draw on them - have the effect of either accommodating or working around political, financial, and technical constraints. Modelers and planners accommodate such constraints when they frame modeling in terms of determining how much land they can build for $50 billion, or when they design programs like SWAMP to collect only as much data as they can afford. Modelers and planners work around limits when they spend the time and resources to develop new approaches to fisheries modeling.

Accommodating and working around constraints are important effects of modeling practice. As actions modelers take in relation to existing political, financial, and technical conditions, they may entrench or transform state and civil society relationships. Accommodating constraints sounds conservative, just as working around constraints sounds transformative. Yet this is a limited mapping. Instead, we should ask, under what conditions do these approaches entrench or transform? When might acquiring more data – working around financial and technical constraints - actually entrench relations between state, capital, and society? Under what conditions might it transform such relations?

More data without a transformative question entrenches. When modelers and planners optimize, they are asking, “what kind of coast can we have?” In contrast to the planning approach called “backcasting,” (Robinson 2003) Louisiana planners frame their analysis as constrained by political or financial limits. Planners compute what projects will give them the most land within a “reasonable” $50 billion budget. Adding more biophysical or demographic data into their calculations would arguably only reproduce certain kinds of vulnerability. Some vulnerability-reducing restoration projects would still not make the cut. The new data might point towards more efficient or even more beneficial projects, but if there is still a funding cap rather than a target, there is no guarantee that the result will be a sustainable coast.

Modelers and planners are clearly interested in supporting communities' livelihoods. But the way they have framed the Master Plan – in terms of constraints instead of targets – arguably limits support for communities. The choice to frame data analysis in this way means that modelers are entrenching austerity conditions and the vulnerability that results, rather than challenging them. This one way modeling forecloses, by circumscribing future socioecological conditions to the boundaries of political and financial status quos. A similar dynamic is evident in planning for the SWAMP data collection program: modelers accommodate funding constraints by optimizing data collection. In doing so, they have to assume modelers in the future will have similar research and policy goals for the data as they do now. Building data infrastructural capacity around current research needs and existing austerity arguably limits data's utility to socioecological justice.

More data when the question is, "what coast do we want?," may prove transformative in several ways. Rather than calling for the optimization of existing resources, such a question demands planners find the necessary resources. It centers the goal of sustaining livelihoods. It is also the kind of question that is still amenable to technical analysis. Asking the right question of more data proved transformative in the fisheries modeling case. Fishers pressed the state to gather more data and conduct more analysis, but with *their* questions in mind: will fish be present in this location in the future? Who will win and lose? The result is an approach to coastal adaptation that is at least somewhat more amenable to the continuation of fishers' livelihoods and respectful of their voice. Fishers gained a certain power vis a vis planners. Transformation does not mean liberation; fishers are still concerned about diversions. As a representative of one fisherman's group articulated: "Fishing expertise should be included in the plan...How will they mitigate the impacts?" This perspective seems to prove the rule – modeling winners and losers was not about securing "win-win" consensus. Instead, it reproduced forms of dissensus.

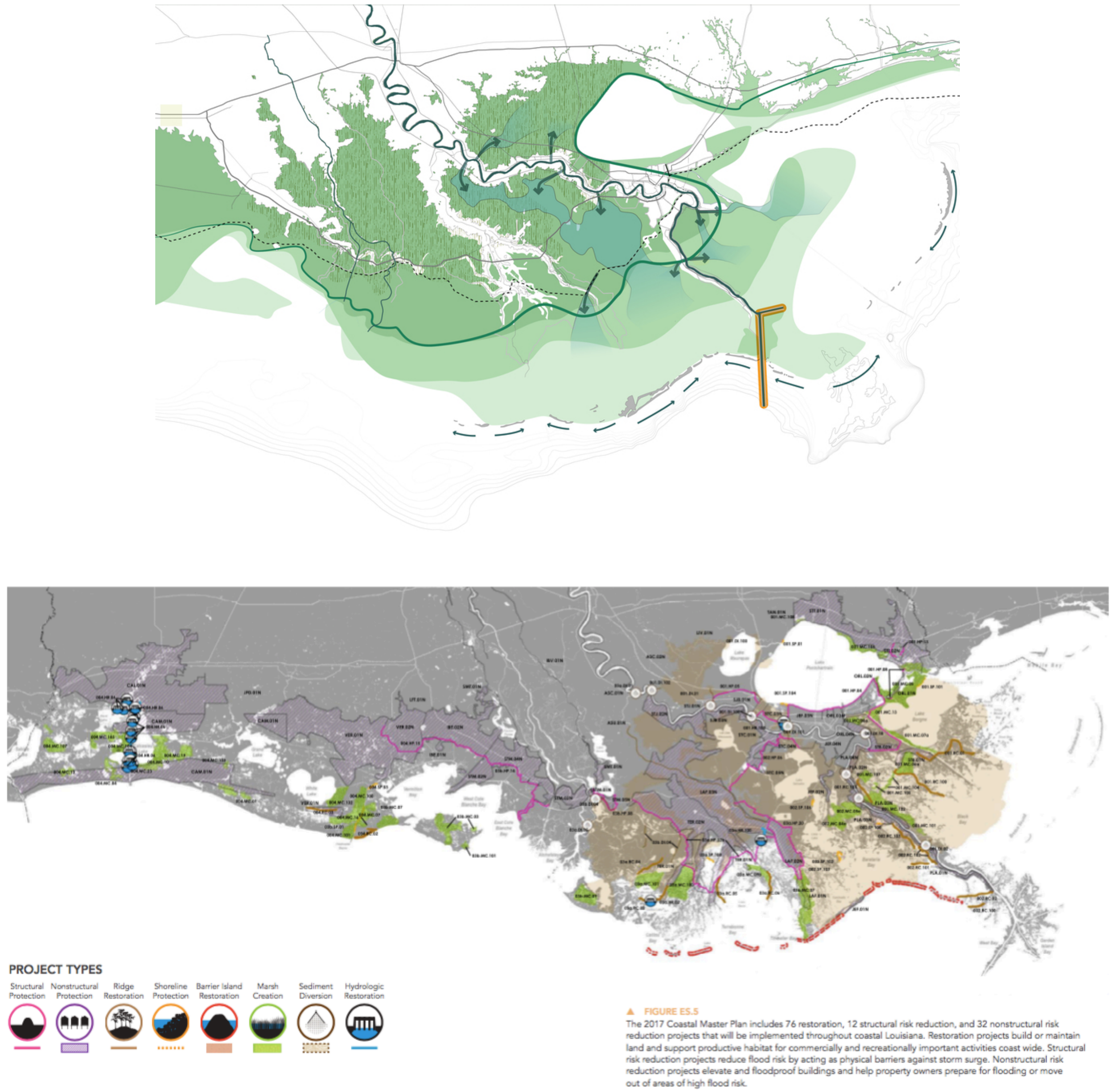


Figure 2. “Squiggly lines” redux. The top image is an entry in the Changing Course design challenge and represents a high-level, but relatively dramatic proposal for coastal restoration. The bottom image is a map depicting the suite of projects planners selected to include in the draft 2017 Master Plan.

Even *less* data may be transformative depending on what question modelers and planners put to it. In between the 2012 and 2017 Master Plans, CPRA, the Corps, and a coalition of nonprofits organized the Changing Course design challenge (Marshall 2015). It was an international effort that asked academics and consulting firms to sketch out a re-engineered coast. They relied on essentially two pieces of data: topo/bathrymetry and the amount of sediment available in the

Mississippi River watershed. This data was paired with a potentially transformative question: how can we build the most land possible, setting aside the financial, technical, and political constraints the Master Plan imposes? Design challenge participants were released from many of the political and financial limits Master Plan modelers had to confront: "[teams] were given a 100-year time frame instead of 50, and they were unencumbered by the budget realities, public-review processes and political approval required by state actions." (Marshall 2015) As a result, the CC teams did not shy away from some controversial political issues. For instance, their plans would disrupt existing, deeply entrenched navigation interests. Yet their work still had at least some impact on the Master Plan effort. The (now former) CPRA executive director noted that the agency is "investigating some of the specific land-building ideas and computer models that came out of the competition." (Marshall 2015) CC still represented a very technocratic exercise. Its driving question is, how much land can we build, rather than, more directly, how can we sustain people and livelihoods? What is redeeming about it relative to the Master Plan's optimization framing is how Changing Course participants "backcast," or as one conservationist put it, "This is where we want to be in the future, and this is how we're going to get there." (Marshall 2015) Changing Course is potentially transformative in so far as it actually aspires to land-ful coast and imagines a different relationship between the state and capital.

3.6 Conclusions

Let's return to that virtual barrier island beach, watching the waves in 2040. Our vacation represents something remarkable – a relatively robust vision of a future world. We're here at this particular configuration of sand and water because of the way modelers organized their effort – how they made their models work in the face of technical, financial, and political contexts. They *worked with the data* – making it available through curation, time and money-saving practices, and generating new data; they *chose and built appropriate tools*; they *framed* their work. Although I did not have the space to elaborate these specific examples in this chapter, the barrier island model team itself generated new data through a form of "input reduction" and rewrote model code to make it better fit the specific dynamics at play on the Louisiana coast.

We could make the stakes clearer. The "actual" barrier island beach in 2040 may not look like the virtual one, for whatever reason: climate scenarios turned out to be beyond any value planners considered, other model parameters were too coarse, or because of any other coincidence of political and ecological factors. Whether or not the barrier island is there, we can attempt an explanation linking the island to the shape of the modeling process, including computational limits and how modelers responded to them as well as their choice to optimize within financial constraints. Within the $50 billion constraint on funding, perhaps the beach restoration was just not as worthy as other projects and was not actually restored. That would likely put it under water by now (2040). The $50 billion went to other restoration and protection projects that may be sustaining land and livelihoods elsewhere on the coast, but these projects are likely not even reversing land loss on the whole. They may not even maintain some 2015-level flood depths.[9] This beach and the storm surge reduction it represented were not as big a bang for planners' buck, but the island would probably have contributed to a more sustainable coast.

The decisions of modelers and planners may seem like purely technical choices about how to deploy and analyze data. They are in fact choices about accommodating or overcoming status

[9] I have begun a GIS analysis of Master Plan data, showing that many areas of the coast are still expected to flood as much as or even more than they currently do. In some cases, the plan simply does not touch specific communities or projects do not keep up with subsidence and sea level rise. In extreme cases, the plan makes places *worse off* in 50 years than they would be without restoration.

quos: existing funding sources, data availability, commitments to specific software, deadlines, and so on. As comments on the existing state of things, planners' technical choices are, intentionally or not, imbued with social meaning. Rather than being devoid of politics, model technics are one place where adaptation politics plays out. What often limits the translation of science into policy, via modeling, is not so much the unwieldiness of "big data" or the scarcity of data. It is the availability of "shovel-ready" data that has less "friction" with political or financial constraints. To better understand the science-policy interface, we need to understand modelers' practice, not just how much data is available to them.

Conservationists and technology advocates often claim that, "many analysis problems are really data integration problems – before you can take action, you need all your facts in one place." (Strombolis and Frank 2014; see also Hsu et al. 2012) While I think it is important to look at how modelers put "all their facts in one place," I disagree that analysis or its challenges are reducible to it. I think scholars should pay attention to what modelers and planners ask data to do, rather than how much data do they have or whether data drives decision-making per se. What modelers and planners ask data to do depends on institutional position as well as politics. Fishers built a movement against diversions and the result was modeling that prioritized showing how diversions affect fisheries - not just fish habitat - and what winners and losers diversions generate. Here, I am not as quick as postpolitics scholars to dismiss a role for technology in transformative socioecological change - it enables or can be harnessed for such change (by showing winners and losers). Undoubtedly, modelers *are* often explicitly interested in using models to *ease* conflict (Dietz et al. 2003; Kelly et al. 2013) Just as often, however, models are generative of it (i.e. they repoliticize) (Espeland 1998). And they can be used to further dissensus.[10]

Paying attention to how modelers make their tools work illustrates that modeling does not necessarily foreclose transformative socioecological change. Modeling is just one place where the stuff of politics - demands, interests, deliberation, and distribution - are all routed, for better or worse. At every step of the Master Plan modeling process, modelers make decisions with respect to status quo funding levels, dataset availability, and so on. These choices – intentional or not – are where civil society groups can engage modelers about making different decisions. If modeling does foreclose transformative adaptation – by conscribing future research and policy needs, by starting from conservative assumptions instead of final goals, etc. – it does so only through modelers' strategies. In this chapter, I aimed to open up the hidden abode of modeling.

[10] Another way to think about this is that even though fishers' concerns were met on quantitative terms (more numbers, but about food webs), they achieved something qualitative (a shift in status and power). This has some analogies to Mann (2008), who detailed the case of Los Angeles unions who struck for only a penny raise: a small quantitative change, but a significant qualitative one. By winning, the unions forced an acknowledgment of their rights and position.

4. Learning with models

If (more, better) data is to "drive" conservation and transform adaptation, then it must be learned from. This chapter explains how Louisiana modelers and planners learn from the ICM. Planners declare, "the tools did not make decisions for us… they just show us the numbers." This is a common refrain in environmental governance. However, for three reasons, it does not do justice to how the ICM did inform Louisiana planners' efforts and their insights. First, a substantial amount of organizational work is required for the ICM to "just show the numbers." Second, since the tools are not actually making any decisions – modelers and planners interpret the ICM output – the Master Plan effort needed "good modelers." Finally, while the ICM submodels did not make decisions, they did not just show the numbers either - they visualized and otherwise formatted the numbers in ways that afforded specific kinds of learning and action. In short, learning with models is both a social and technical process. The takeaway is that the state does not just deploy tools. As with its use of science more broadly, the state must *translate* expertise. It must engage with modeling through political economy, institution- and subject-building, and models' technical features. In turn, state planning structures themselves are shaped by modeling.

> "Do not fall in love with your model (it will not love you back)." (cited in "Strategy" 2013, 9; from Wainwright and Mulligan 2004)

4.1 Introduction

I am walking above southern Louisiana. At the new Water Campus in Baton Rouge, CPRA and LSU are putting the final touches on a redeveloped physical model of the lower Mississippi River. My guide and I are on rafters 20 feet above the 10,000 square feet model, which is several times larger than the old model built in 2004 (Hardy 2017). This new model will be pieced together in 216 different half-ton sections of dense foam, each of which can take up to 30 hours to cut. The scale is impressive at a mile a foot, horizontally, meaning the model itself needs to be cut to one-quarter millimeter precision. It covers from just below Baton Rouge to Southwest

Pass. Researchers and planners alike hope to use the model not only to learn more about how the river transports sediments, but to experiment with different diversion scenarios and what effect they will have on the entire river system. The cost of the LCD projectors that will dynamically paint the panels alone comes to about $1.5 million. Given all the money that planners have sunk into computational models, also investing serious money in a physical model seems odd. That planners are interested in both kinds of models suggests that each have unique properties that enable decision-making in different ways.

Figure 1. The new Water Campus in Baton Rouge is home to a physical model of the lower Mississippi River. On the left, a view of the model as it is being assembled. On the right, a view of a single panel of the model. The straight lines that are visible are oil and gas canals, and their spoil banks. Source: Author.

In this chapter, I explore what exactly it is that *computer models* do for decision-makers. The previous chapter examined the strategies modelers employed to build data infrastructures in the face of political and financial constraints. I argued that these strategies are important moments in which adaptation is politicized. This chapter looks more closely at how the ICM produces outputs. Modelers and planners' goal is to use model outputs to make decisions about what parts of the coast to protect and restore. The models themselves bear an imprint on this decision-making process. CPRA cannot possibly determine everything it wants to know with pen and paper, or even a large-scale physical model. Computer models help planners learn about (predicted) coastal conditions at a greater scale, pace, and resolution than ever before.

The ICM submodels are so powerful that planners find themselves repeating that the modeling "tools" were only one factor in their calculus. In the 2012 Master Plan, CPRA wrote, "the tools did not make decisions for us." (CPRA 2012) At the 2016 State of the Coast conference, one planner echoed that "models, forecasts do not make decisions, but inform it. They do not make decisions for us" (Notes, State of the Coast conference). This is true in the sense that there is no model that delivers an answer that planners are bound to. Planners feel that the "tools just show us the numbers." Such attitudes towards the role of technology in environmental management are not limited to Louisiana. Around the world, environmental planners who draw on modeling to accomplish and justify their work feel much the same way. As a participant in a workshop on ecosystem services policy described one model, "the tool does a lot - it enables you to do other things. In this case, the tool gives you the info and you run with it - exactly the info you need for that question, but it doesn't answer it for you." (Notes, ACES conference)

Implied in the mantra, "tools don't answer our questions, they just give us the info," is a learning process. Models show "the" numbers, then planners think about them, and, in the end, they make reasoned decisions. The sentiment is that models are not a particularly important part of the process. They don't do the important work of deciding; they just show the numbers, as if they were just waiting there. This imaginary looks something like a group of planners ("us") who come up to a computer, press a key, and get screens full of integers they digest and deliberate on. But does this actually describe how coastal restoration decision-making takes place?

I argue that the perspective that "tools do not make decisions for us…they just show us the numbers" does not do justice to how modeling actually informs environmental planning. This is for three reasons. First, the ICM does not simply show "the" numbers. Instead, a substantial amount of organizational work brings together the expertise and tools to produce those numbers. Second, since the ICM is not actually making decisions – modelers and planners interpret the ICM output – the Master Plan effort needed "good modelers." Finally, while the ICM submodels did not make decisions, they did not just show the numbers either - they visualized and otherwise delivered the numbers in ways that afforded specific kinds of learning and action.

The argument proceeds in three sections. In the first section, I position actors in the chains of expertise that comprise model development and use. CPRA must engage this chain of expertise and its political economy in order to learn from the ICM. Second, I look at what it means to interact with model results. Here, I note how different actors in the modeling chain – from programmers to modelers to models themselves – must translate their expertise. In the final section, I illustrate the kinds of organization and learning models themselves afford. I conclude that coastal learning is simultaneously both a social and technical process, whereas many perspectives would emphasize one or the other.

Through a sociotechnical approach, we can learn three things about the role of technology in transformative adaptation. First, transformative adaptation is not about getting the tools right, since these have their social dimensions. For instance, in order to learn from and adapt with the ICM, planners rely on the making of "good modelers," translations between different kinds of expertise, and political economic investments. Second, at the same time, transformative adaptation is not just a matter of adjusting social relations in the right way. Building adaptive capacity, increasing stakeholder representation, or in general improving what Adger calls the “social infrastructure” for adaptation all have technical dimensions. For instance, below I show how models like the ICM and other software themselves structure social organization and learning. Third, and ultimately, the state planning apparatus does not just deploy models as its tools. More accurately, the state strives to enable the conditions by which tools afford specific kinds of insights. It must engage models through political economy, institution- and subject-building, and their technical properties. In turn, the state is shaped by its tools. The popular imaginary that “tools don’t make decisions for us, they just provide exactly the numbers we need,” inadequately explains how modeling informs adaptation policy.

4.2 A brief review of the scholarship

We need to know more about *who* produces *what* kind of knowledge for the state and *how*. For instance, as I show below, the state planning apparatus reorganizes itself around the ICM. This finding is at odds with how critical political ecologists often think about state-led science. For Scott (1999), the modern state executes well-laid plans. Utopian “technocrats” comprising the state devise plans that are far-removed from the socioecological systems they concern (cf. Robbins 2000, 2006). These technocrats then impose their abstractions on actual communities and ecosystems, with often violent outcomes. However, as many scholars of the state have shown, although the “state” may overlook reality in models and other forms of expertise, the state is not even a single unitary thing to begin with (Mitchell 1999). Instead, the line dividing the state from civil society is more an effect of attempts to make the state *seem* like a unified, coherent thing. This perspective suggests we need to emphasize the role civil society actors play in doing work we normally see as the state's. In Louisiana's Master Plan, these actors include nonprofit staff, academics, and engineers at consulting firms.

Scott and the political ecology tradition that follows is mostly interested in the impacts of state management on communities and ecosystems, for good reasons. Yet, STS scholars have long explained that modeling is just as much about coordinating people as calculating x y or z (Jasanoff 2004; Medina 2014; Vertesi 2015; Millo and Mackenzie 2009). That is, an important effect of modeling is how the process itself reshapes the state, not just what the state uses model results to do. The literature on adaptive management elaborates on the importance of collaboration, trust, and learning within the state (Armitage et al. 2008; Armitage et al. 2009). This scholarship argues that in order to implement model-based adaptive management, the state itself must change. Change involves on the one hand political economics - new ways to purchase expertise - and on the other hand an institution-building project requiring new modeling-interpreting subjects. Indeed, adapting environmental management to involve learning from models entails changing what it means to be a planner (see Magill 1988; Espeland 1998). Planners are supposed to absorb information from model outputs, learn something from it, and help the institution learn something as well, without being overwhelmed by the amount of information directed their way or by the uncertainties explicitly or implicitly attached to it (Levine et al. 2015). For instance, below I show how modelers are trained to interpret uncertainty for planners.

Modeling is just as much about coordinating people as calculating "the numbers," but calculation itself *affords* specific kinds of insights and actions. By "afford," I mean modeling "shows the numbers" in ways that enable and constrain what planners learn and do. The affordances concept explains technological action in a way that addresses both users' attributes (their expertise and motivation) and the features of the technology itself. While scholars like Winner (1980) advance a *technology*-oriented, practice-independent explanation for how design shapes action, and Norman (1988) focused more on users' *perception* of "action possibilities," Faraj and Azad (2011) insist on what they call "sociomateriality." For them, affordances represent "a relational construct linking" *both* technology and user perception - "the capabilities afforded by technology artifacts [and] the actors' purposes." The authors demonstrate how software design matters using the example of ribbons in word processors. Originally a feature of typewriters, the "ribbon" was integrated into word processing software in different ways over time. In Office 2007, a major revision of the ribbon to make it "simpler" spurred protests from users. Even though the new ribbon theoretically offered easier word processing, it did not afford this, since users were accustomed to the old design, did not necessarily need "easier" features. Affordance, as a sociomaterial process, means examining what kinds of knowledge and action software enables for planners, while also seeing how software enables this only in relation to planners' expectations and expertise. In the third section of this chapter, I show how ICM models afford planners a kind of *coordination* and *flexibility* they previously did not have (cf. McLain and Lee 1996; Plummer et al. 2013). Planners find themselves much more capable of collaboratively addressing new research or policy questions as they arise. The planning tool allows decision-makers to *easily* work with information in ways they previously were unable to. Maps from ICM submodels are useful, planners note, for *visualizing* model output and, in some cases, sharing results with the public. This chapter emphasizes these characteristics of model-based learning and organization, while the next chapter demonstrates how planners apply model outputs in policy.

4.3 Organizing the ICM, Coordinating the Master Plan

When CPRA wrote, "tools did not make decisions for us…they just showed us the numbers," who were they talking about? People work to author, run, and evaluate number-crunching models. In this section, I show how that labor was organized. In the first sub-section, I explain how coordinating model labor is a political economic project, meaning it requires buying expertise, accessing tools, and managing people. In the second sub-section, "Build an institution," I explain how coordinating modeling labor is an institution-building project, meaning it requires the making of norms, habits, and, ultimately, subjects – model users.

Before moving to the first sub-section, I briefly recap the modeling chain of expertise. Because of the scope of land loss and the technical features they want to implement, planners must bring together lots of different expertise: programmers and developers, modelers, consultants, project and program managers, the Framework Development Team (FDT), the Science and Engineering Board (SEB), and the Predictive Models Technical Advisory Committee (PMTAC). All are meant to draw upon each other's work and collaborate. Programmers write the code that governs models. They usually work right alongside the modelers. Developers are also programmers, but are tasked with actually tweaking models and designing ancillary applications, not just implementing code. Modelers conceptualize, direct programmers, interpret results, and write reports for planners. They are often housed in private engineering firms, but might be at the Water Institute of the Gulf (WIG) or in academia, and work as contractors or subcontractors. Planners themselves are either project or program managers. Project managers coordinate the work of specific model teams by directing their analyses and writing up results. To this point in the modeling chain, most of the work occurs "behind the scenes." Program managers translate model results for more public arenas: they take questions and answers to stakeholders, respond to the media, and present at conferences or public hearings. The FDT, consisting largely of stakeholder groups, guides program managers in formulating what kinds of questions to examine in the Master Plan generally. The SEB and the PMTAC review modelers' progress and make suggestions on how to organize the effort. One of the WIG staff members suggested that all in all, "at one point we would have had 50 people either directly involved or involved peripherally." (33)

4.3a Pay for expertise - people and models

How does the state access the expertise – the people and the tools – that show it the numbers? Coordinating labor across the modeling chain is a political economic project, meaning it requires buying expertise, accessing tools, and managing people. The modeling chain comes together and shows decision-makers "the numbers" through this political economy, though not without challenges. Subcontracting with experts represents the first part of the political economy of coastal modeling. CPRA has made WIG responsible for subcontracting with experts to form the different model teams. WIG releases RFPs and contracts, which structure how modeling work is performed. For instance, a major sticking point in the 2012 modeling effort was naming conventions, so in an RFP/contract for 2017, WIG required that "Model Subtask Teams will be contractually required to adhere to the data management structure and framework." ("Coordination with the Planning Tool" 17) Subcontracting expertise is common even for smaller organizations that develop their own models - even the nonprofit conservationist group LPBF has contracted out modeling work.

When WIG subcontracts with experts they are sometimes paying for experience with specific software. Many of the Master Plan subcontracts are won by consultancies that operate either out of engineering firms or nonprofits. Consultancies often specialize in particular software applications. This is for many reasons, but especially the availability of funding, personal connections, and competition. If a state agency or WIG hires a consulting firm, that group's model specializations come with it. Or more commonly, if a funder wants a certain model, they hire the group that specializes in it. This was more or less one modelers' experience: "it was weird – they [their firm] called because they were trying to break into hydrodynamic, water, like the Master Plan. So some people said you should tap into [this modeler] because they the ecological modeling. So, here I am six years later." (41) Since the firm wanted to go after Master Plan contracts, they sought out this modeler and their expertise in the kinds of modeling CPRA and WIG was interested in. Before planners even get the numbers, they have thought who can provide them with specific kinds of numbers. Planners either have to know who has this kind of expertise or find a group like WIG who does.

Modelers find that competition for limited funding is fierce. One modeler working for a national firm took a broad view of the situation: "times are tough down here [in Louisiana] because you know we're 10 years behind the national curve. Right now we're in a state budget crisis so we are all bustin' to write proposals." (41) Modelers have to think about what their competitors are doing and what they can offer: "Consulting, contracting - I don't like how fast it is….If you say you can't do it or it can't be done, somebody else will." (41) This was their experience with a recent project that ran parallel with the Master Plan, more closely evaluating diversions' impacts:

"…. especially this last Delta management project - we're not doing sea turtles and I worried about that because others said you know we can do that - and ultimately it turned out OK but if you say you can't do it or it's going to take longer - somebody is always willing to come in and people don't know the difference." When the state contracts for modeling expertise, it creates and engages with competition between firms.

Beyond paying for expertise per se, WIG and CPRA must access the ICM submodels themselves, which are either proprietary or open. Planners are especially interested in open access software for two reasons, beyond the fact that it can be cheaper. They want to get behind the code to have "complete control" and to draw on shared resources for debugging and visualization. First, open source provides an opportunity to open up the modeling black box and prevent tools from making the decisions: "It is necessary that CPRA has access to―and works with―the source code of any selected models…Source code is the only way to have complete control over all aspects of the model, including the inner workings and how outputs are reported." ("Strategy" 2013, 6) Fish modelers note that although documentation can shed light on what a model is doing, documentation is still just another layer on top of the code: "while documentation is helpful, often the only true way to see exactly how a model represents a process is by looking at the computer code itself." ("Strategy" 2013, 93) For one fish modeler, this meant preferring CASM, "because I can get the code and I don't trust Windows based applications. I want to be able to manipulate, know what's going on." (41) Open source applications facilitate getting the numbers and making sure they are right; they help modelers ensure proper understanding of model equations.

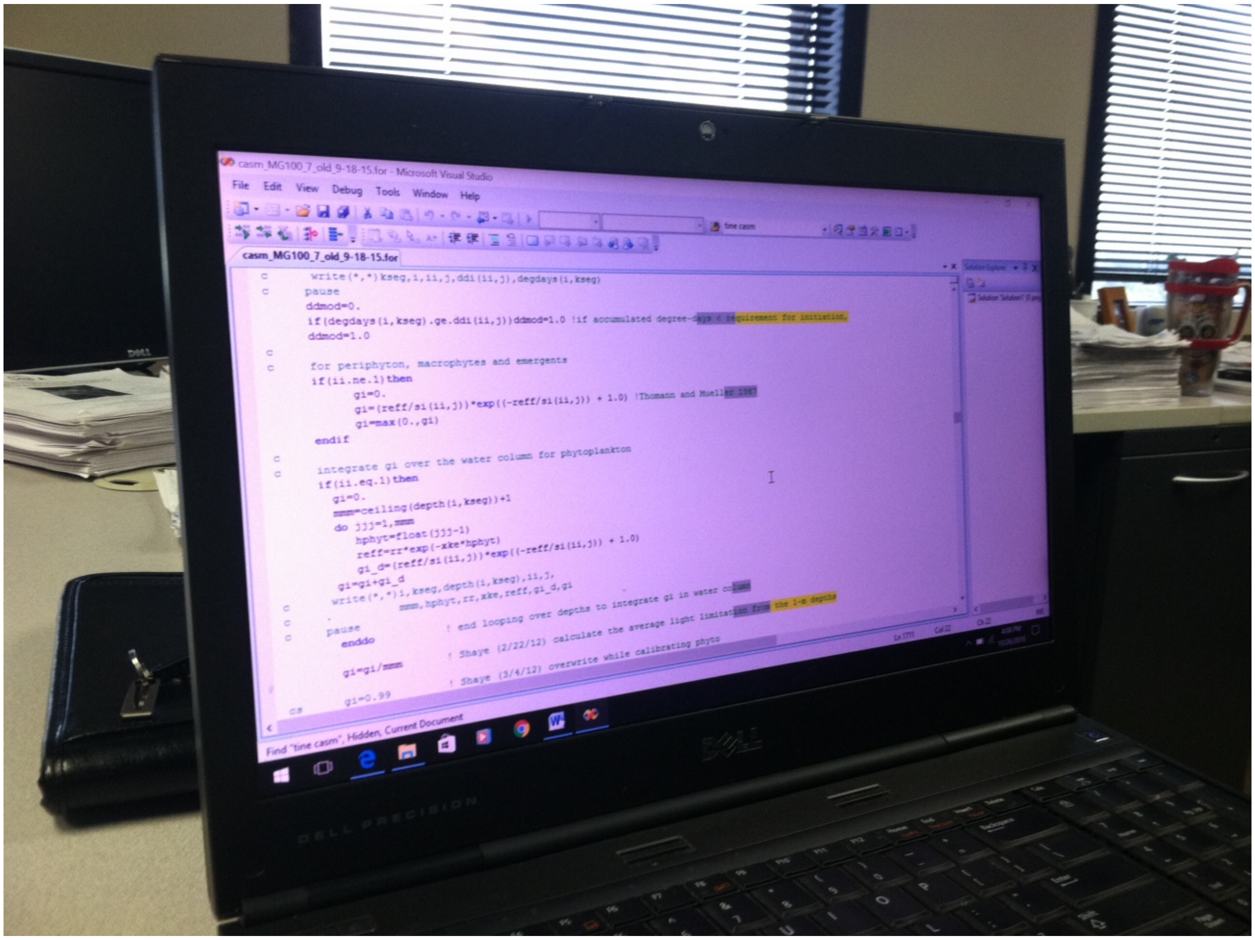


Figure 2. Modelers often want to “get behind the code” of a model in order to understand how it works. Open source tools make this easier. Source: Author.

Second, open source also provides modelers with more tools to choose from: “aligning the ICM with these [open] research community standards would have benefits, including using community tools for model visualization, analysis, and debugging.” (PMTAC 12) Modelers have noted, in particular, a couple of problems with proprietary software from the geospatial analysis company Esri. The morphology submodel team drew on the industry-standard Arc software suite (“libraries”) to perform their geospatial calculations, but they “would like to remove the Esri libraries and recode all the morphology components with something else… then we can push it onto supercomputers.” (51) For one modeler, the most important improvement that could be made for the 2022 effort is dealing with a spatial resolution problem caused by the limits of

Esri’s tool: “[it’s] been a huge headache that we didn't anticipate - the way that Esri handles [recalculating raster resolution] made it a little difficult at times.” (51) Open source geospatial tools could get around this difficulty and allow the ICM to be put on a supercomputer, speeding up modeling, getting the numbers more quickly.

CPRA and WIG’s reliance on contractors and open software generates three challenges that belie the idea that ICM submodels “just” show the numbers. The sustainability of the Master Plan modeling process is challenged by how it is currently organized through contractors and open tools. First, funding streams are subject to fluctuations and uncertainties. Open source model development tends to happen on a piecemeal basis if at all. Several consultants described how they have to write basic model extension and development work into their contracts. RESTORE Act money may have an impact here, though the increasing availability of funding will not address model sustainability in itself. Programmers expressed a worry that more funding would be paired with “hype” around certain kinds of model features (e.g. “dashboards”). The tools might just get fancier without strategic thinking about long-term needs, while one-off funding sources like RESTORE would dry up eventually anyway.

Second, like modeling, data collection is based on a contractor system. Difficulties with the data collection program are suggestive of limits to contract-based modeling, and also pose direct problems for modelers. For instance, data reliability issues from contracting challenged the vegetation model team:

> On the ground, it's hard to relate some of the flooding parameters to [plant] species because some of the ways that the data collection was passed out - elevation measurements were not done in a consistent basis. The first round when the CRMS stations were established everything was contracted out to different groups and so

> different surveying companies, depending on which environment they were in, you know there wasn't a set kind of way of measuring marsh elevation at the sites….So there are some limitations in those data that you have to be aware of. (32)

Contract data collection has proven a challenge because different contractors, in different parts of the coast, relied on different standards. This causes modelers to doubt the data and jeopardizes its long-term viability.

Finally, although WIG has proven a successful coordinator of modeling expertise, its role in the Master Plan process - and even its existence - are contested. Some academics wonder why WIG was chosen over LSU to manage the Master Plan contracts. Contracts for modeling have been routed through LSU in the past - for the LCA effort in particular. Several modelers noted to me that there are certain constraints on reimbursing academics. Moreover, who gets contracted with modelers over time has become a personnel problem:

> A lack of acknowledgment for some people, seeing that in the next go round maybe you find a new person to do task x y or z for the plan and you pull them onto the team because they can actually do it better, but the first person has been involved for 10 years in this effort and then all of sudden they feel marginalized. (33)

When planners explain that "the tools simply show us the numbers" they overlook the political economic work of paying for data, models, expertise, and even, as the above quote suggests, modeler management. These all inform how planners get numbers in the first place. A substantial amount of organizational work – purchasing expertise, accessing tools, and managing people - is required for models to simply do anything. Coordinating expertise is in part a political economic project involving the buying and selling of expertise. Coordinating expertise is also about building an institution for learning about the coast, which I turn to now.

4.3b Build an institution

Coordinating expertise is first a political economic project and second an institution-building project. Building an institution is about aligning norms, knowledge, and expectations along the modeling chain. I examine this alignment as it happens through different kinds of translation: managing expectations, making sense of uncertainties, etc. Without this translation, planners do not get any numbers, much less “the” numbers they want.

First, at the very back-end of the modeling chain, software developers build extensions for the model teams, but they must manage planners’ expectations about what kinds of features are possible. Such extensions include software for visualizing model outputs. Developers say they let the process of creating these kinds of tools be client-driven - it’s not on them to make decisions about what is and is not important. But there is a back and forth translation between planners and developers. As one developer put it:

> The way we work with all of our partners, it is an iterative process, and it is driven by the partner. We say, what do you want?, what do you hope to find?, or how do you want to analyze this particular data? And we work from there. Specifically, with [a tool for comparing scenarios], we would not have thought to develop it on our own. Maybe eventually. It was driven by CPRA saying, we got all these scenarios and we need to be able to tell the differences between them. When you have a partner driving what they want to see – that greatly simplifies what features get thrown in and what doesn’t. (47)

This developer details how they make their expertise available to others along the modeling chain. They describe an iterative, yet partner-driven translation process, in this case to develop a tool for learning about coastal change. Another developer explained how his outfit puts on a road show every year where they go to policy-makers and explain what kinds of software features are and are not possible. For instance, developers had to explain that while “with the web visualization - that was what they wanted at the time [to map model outputs on the web]… it was not technically feasible, with the type of browser libraries that existed at the time, to do 3D visualization." (47) Planners themselves tell the story differently, reflecting on how, "programmers can do anything, but do we really need that?" (4) Planners feel like they are already taking a measured approach to what model features they want. Before planners get any numbers, they negotiate about what is possible to show.

Expectation management works in reverse as well, with developers becoming more familiar with what it means to be a policy-maker. As part of this, one developer described becoming more familiar with the domain (ecology) of the model-extension tools he builds. Developers also undergo a discovery process: they are often figuring out what is actually technically possible for them to accomplish *as* they write the software. In short, programmers see themselves as facilitators to coordinating expertise: "we are not the modeling team, we are data integration. We are sitting in a role helping to provide glue between the teams." (47)

Managing expectations is a way of aligning work across different organizations and across programmers, modelers, and planners. When expectation management works, it can produce a sense of shared success amongst these actors. Some modelers noted that their expectations were low for the newly integrated model, the ICM. One of the modelers behind the ICM reflected that, "I think that there's other people like at CPRA where we've been starting to use the ICM on some other non-Master Plan questions…[they have been] quite pleasantly surprised at the questions that we can answer. Yeah the expectations I think were probably always lower than what the model could do, which is a better position to be in." (51) Decision-makers did not expect much of the ICM, and they have been pleasantly surprised. This is a "better position to be in" partly because it builds trust that the ICM can answer the questions authorities want it to. If expectations were high and the ICM failed to meet them, modelers and planners might blame one another.

Programmers interface with modelers too, not just planners. Even though many modelers know code, the often employ or collaborate with programmers who code for them. There are technical and cultural differences to be translated between programmers and modelers. One of the vegetation modelers noted that modern model-coding skills were “one of the things that I don't have, but one of the people on my team is actually trained in computer programming….So in the old days I did actually write programs. But I'm not really trained (the languages have changed).” (32) Finding the right programmer expertise is a constraint to the submodels that are selected for the ICM: “someone needs to know the programming language and invest some time in learning the specific model code.” (“Strategy” 2013, 6) Even when modelers are experts in specific models and their code, they can still end up overseeing modeling work rather than implementing code. One of the fisheries modelers noted, “I did a lot of like technical support advising... The two [programmers] that work with me most of the time - I'm kind of just overseeing and guiding. They’re in their whatever, late 20s, early 30s, so they're all much better programmers.” (41) There are cultural, generational, and domain differences between modelers and programmers that must be negotiated (see also Nijhuis 2017).

In particular, modelers must find a way to translate model conceptualization into the actual programming. Modelers explain their expectations about how fisheries or vegetation processes should be coded in the submodels. This is not always easy. Modelers often find that some processes are still not coded properly or to their liking, a consequence of mistranslating expectations. Another of the fisheries modelers explained how she and her programmer negotiate to implement the model:

> I don't do a lot of the code - I conceptualize it or I analyze it and then we have someone who's doing a lot of coding. And absolutely I mean communication here is so key. You know you write in as much detail as you can in the report. And I give it to the person who can code it in the model and then I review it and we talk about it together and we look at the output and we're like that output is not making sense at all. And we go back and say oh that's because the way you pull in wetland data - I wanted you know fresh wetlands and salines and you put in forested, but I didn't want forest - but for him that's what's a wetland is [a swamp]. So you know communication - we talk. And that's why we have meetings - well you know I'd walk in the hallway and kind of put my head in: everything going OK? You need me to look at the code? He sends it to me, I look at it, I send it back. (17)

This modeler describes a thorough in-person way of managing expectations for how to code submodels. You thought wetlands meant swamps? No, I wanted marshes. Some level of mistranslation between modelers and coders may be unavoidable. A vegetation modeler noted that even with a programmer on her team, “there are some things that you know aren't programmed right in my mind.” (32) Other modelers saw problems with submodels inheriting bugs or the visions of one person. (35) Expectations are not always met.

One of the principal translation points in the modeling chain occurs between the modeling teams and CPRA planners. This translation is mediated formally, through prescription and oversight, and informally, through norms. While CPRA contracts the Master Plan modeling effort out to WIG and beyond that to subcontractors, planners clearly want oversight. For some specific model inputs and outputs, CPRA has ideas of what they want, and they seek the modeling teams who will abide. Modelers report how CPRA specifies certain parameter values for their work, based on what project managers want to be measured. This was evident in the storm modeling: “Data [for storms] were provided at CPRA-specified locations per event to be stitched in the 50-

year records…" (CPRA 2017 C3-2, 2) CPRA's mandating of model parameters is most evident, however, in two of the most political and uncertain ones: subsidence and ESLR. CPRA determines these values itself ahead of the main modeling effort and asks subcontractors to use them. As the barrier island team reported, "Subsidence and ESLR are incorporated into the BIMODE model through manual adjustments following guidance documents prepared by CPRA." (CPRA 2017 C3-4, v). To get the numbers they want, planners make their expectations to modelers clear. Their expectations may be spelled out formally in guidance documents, or informally through norms. As the PMTAC advised, it is CPRA's job to delineate, to "explicitly lay out how the experts interpret the output and how it can be used for decision making." In the other direction, "It is up to the modeling team experts to interpret the outcomes and to understand and communicate the model limitations." (PMTAC 31) This is where "good modelers" are necessary to interpret numbers, since models do not make decisions.

4.4 "Good modelers"

In this section, I describe what modelers think it means to be a good modeler. Their interpretation and communication of outcomes and limits, especially with respect to uncertainties, is a key element of how knowledge, expectations, and norms are translated across the modeling chain. Because tools are *not* making decisions for planners, planners rely on good modelers to help them learn what the numbers mean. The ICM may show numbers, but someone has to make sense of them. Good modelers do this in several ways.

Above all else, modelers tell stories. One modeler described this expectation and how unusual it was given his previous training:

> So I think it's a little weird coming from an engineering background to think of it this way but it makes sense and like there really is a story for each project that we model. And

> so that's like what we're told to do when we do analysis - like what's the storyline here? And you can step through it….And there's really no way to step people through [the data] other than to like one of us on the modeling team has to identify what's the anomaly that needs some - it's some non-intuitive thing that needs to be explained. And you really just have to there's no other way than to step through it and figure out why it's happening. (51)

Planners and the Master Plan advisory teams actually encourage and expect modelers to discuss model outputs, and especially aberrant outputs, narratively.

If modelers are supposed to tell stories about (anomalous) numbers, they have audiences. As one modeler described the then-novel project prioritization approach for the 2012 plan: "we had an audience (that was ready for a prioritized plan)." (1) Modelers and their advisers propose some general and specific guidelines for interacting with their audiences. One is knowing the difference between academic and applied audiences and the rigor required for each. Contracting, for instance, involves different standards from academic modeling: "Before when I was a grad student and postdoc - it's an academic exercise. And when I got into this and [my advisor] told me: if you're going to use this stuff for application, you really have to show that the model is working and you can simulate." (41)

Related, a good modeler knows how to communicate uncertainty differently to different audiences. Some planners are concerned about showing model uncertainties to the public. In fact, there are no explicit representations of uncertainty in the Master Plan document itself. Yet the PMTAC expects a good modeler to be able to communicate uncertainty to the public: "remember, this is modeling, and although this is the best we can do right now, the team needs to make sure the public and end users know that outcomes are not 100% certain..." (PMTAC, 22) But some audience members are better than others at understanding uncertainty. The PMTAC continued: “when reporting uncertainty, the level of understanding of the audience is an important consideration to avoid misinterpretation. Some users, for example, may conflate common statistical tests with reported model uncertainty” (PMTAC, 15) It is important, modelers say, to be clear about the numerical bounds of uncertainty:

> our conclusion was a lot of stuff was like plus or minus 10 percent. And after we were done with this everybody was going, what is that [result]? And I was like that's 7 percent. We have a 35 species food web that's linked to all of the environmental variables - ignore that [small, 7 percent number]. Think of it as the minimum threshold. Just ignore it and then they're like who said that? I don't know, just do it. (41)

This modeler decided that a 10 percent change was the minimum threshold for a “real” change as opposed to a statistical artefact. Good modelers devise their own guidelines for communicating model results in the light of uncertainties.

Model uncertainties often stem from predictive simulation and good modelers advise planners to be clear about whether the model can actually predict the future (it can’t). As the PMTAC advised, “take outcomes of future scenarios with a grain of salt; we do not have a crystal ball.” (PMTAC, 25) Fish modelers echoed this sentiment, noting that their models do not provide forecasts (a formal definition of which involves knowledge of the independent variables’ future values; Kelly et al. 2013):

> It is also important to emphasize that the fish models are not forecasting tools. None of the models will generate abundances and biomasses expected in the future for specific years and locations. Model predictions for 10 years into the simulations are not what is expected to be measured in the year 2023 at that location. This is not achievable and in fact, is not how model predictions for fisheries stock assessment to set quotas are interpreted. (“Strategy” 2013, 93)

In particular, modelers feel the need sometimes to remind planners of the difference between the model and reality. When interpreting model results, planners sometimes fall back to explanations based on what they know about, say, fish biology. Yet, “when we present stuff they're [CPRA] like, oh well the fish are doing that and that because that's what fish do - no, the model fish are doing that because [of x y z reason related to the model's code]" Modelers remind CPRA, you're looking at model fish not real fish. Model fish only do what they do because of the processes modelers code.

A good modeler *does* know what real fish can do though; they are experienced in the field. The PMTAC felt the need to comment on generational, cultural, and institutional constraints in this vein: "It is important for modelers to have some first-hand contact with the modeled system. … Such experience is particularly valuable to junior modeling team members." (PMTAC, 16). Likewise, one modeler felt data and new software could only inform model interpretation so much: "you still need people who have lived breathed and work here their entire life who know that piece of marsh better than anybody else. And no technology will replace that" (17)

A good modeler is transparent about their reasoning. The fish modelers themselves lamented some of the opaque ways in which other models appear to have been selected, and the lack of methodological transparency in these other models:

> Often the way ecological and fish model analyses are presented can create the appearance that the model was selected arbitrarily or in an ad hoc manner. Usually, only the structure and results of the final model are presented. The analysis is then viewed in isolation, without the benefit of knowing how and why the particular model, from the many possible models, was utilized. Models used by experienced modelers are never arbitrarily selected. ("Strategy" 2013, 2)

As part of being reasonable and transparent, a good modeler is conservative in aims and interpretations. The PMTAC advised program managers to "encourage CLARA team to be more conservative." (PMTAC, 25) One modeler described the work of a modeler as one of "yea, but" – as in, "yes you can make that interpretation, but that's not the whole story." She said, "and that is what always happens with modelers. We're kind of this, Yes but. And nobody wants to hear that.” (41)

That “nobody wants to hear” how complicated modeling is suggests how good modeling is not always possible. As modelers themselves see it, this is for a variety of reasons: poor coordination with clients, a lack of incentives, and incoherent terminology (as expressed in “Strategy” 2013, 20). In spite of some mistranslations, the Master Plan team has built workable norms around how to learn from the ICM. For planners to see the numbers they deliberate with, they need good modelers who are expected to translate results, uncertainties, and assumptions.

4.5 Tools don’t make decisions, but they afford learning and organization

In this section, I describe five ways in which the ICM submodels themselves afforded planners insights and organization. Specifically, they afforded coordination, visualization, ease, flexibility, and fit. Showing the numbers is not just about good modelers, building an institution, and buying expertise. In tandem/relation to these factors/processes, ICM submodels afford visualizing specific kinds of numbers. Models may not have made planners’ decisions for them, but they did shape those decisions, as they enabled specific kinds of learning and action.

4.5a Coordination

This subsection bridges the previous discussion, which demonstrated how coordinating the Master Plan modeling is a political economic project consisting of purchasing expertise, building institutional norms, and crafting good modelers. Coordination also involves the ICM models themselves; they afford it.

In the PMTAC's final external review of the 2012 modeling effort, "coordination and communication" gets more space than any other single section. There were two main problems with coordinating the 2012 modeling process: some data had to be transferred manually and teams were isolated from one another. Modelers I spoke with told horror stories of having to drive hard drives to Lafayette to have data manually loaded onto the USGS server that hosted model output. Teams were also isolated from one another physically and in terms of workflow. In 2012, the individual models were run separately – there was no ICM. Each model was run for 25 simulated years and only then were results passed between them. Then they were run again for another 25 simulated years. As a result, each team felt their work was isolated from that other teams:

> So when they were individual models [in 2012], feedback had to be done but it was only done once across the model simulation. The first 25 years of the planning simulations were all on the existing landscape. And then so they ran hydro for 25 years, gave the veg team 25 years of salinity. Veg then did a 25 year simulation and then they gave those 25 years of veg and salinity and water levels to morph….that handing off of the data. It was really time consuming because you have to upload it to the FTP. They have to wait, then uploads fail because the connection fails. You know there's a lot of error and just hiccups inherent to that system including just like labeling, having the wrong label because we're all doing all these different simulations and different scenarios different projects. (51)

It was hard for modeling teams to understand what other models – even those that were passing them output - were doing and why. The lack of coordination resulted in individual modelers being unable to "see," describe, or intuit in any detail the overall results.

Most everyone agreed that this lack of coordination was untenable. For 2017, the ICM code coordinated the work of modeling teams by increasing temporal resolution and compelling teams to talk. The six main Master Plan models (eco-hydrology, barrier island morphology, wetland morphology, vegetation, fisheries, and storm surge/waves) are now run together in the ICM. It consists of 2000 lines of Python code that allow the different models to "speak" with one another, passing outputs from one submodel to another. For instance, when the hydrology model is done computing a simulated day, it will pass results through the ICM to the vegetation model, which will determine what kinds of wetland plants exist given salinity conditions. Because the entire suite of models now runs simultaneously, everything must be in place before modelers click "run." They must be ready to receive inputs from and send outputs to other teams. The new model code structure means each team must become more familiar with the other models, resulting in, many modelers say, a greater feel for the entire effort.

The ICM coordinates teams not just because of how it structures simulation, but because it compelled other teams to rewrite code in their own submodels. Since the ICM was written in the Python programming language, model teams had to ensure their outputs were also in Python. For the vegetation model:

> A substantial effort has been undertaken to implement the model in Python. The previous version of LAVegMod used a combination of R and C++ code. Translation of the model into Python reduced the size (i.e., number of lines) of the code base, simplified many of the algorithms, made the subroutine easier to integrate with the overall ICM, and simplified the communication of information back and forth between ICM subroutines. (CPRA 2017 C3, 13)

The veg team made a code change that had nothing to do with better understanding coastal vegetation processes per se but was instead about "coordination and communication." Code reorganized teams and afforded a sense of better communication amongst them.

The ICM coordinated teams, but not without challenges. The ICM integration meant resetting some code and hiring a Fortran coder.[11] WIG hired staff specifically to put the models in conversation with one another. The individual that was hired to implement the integration found himself at the center of the entire modeling effort, at least for a while. By channelizing all model outputs through 2000 lines of Python, integration actually temporarily centralized expertise in the one person who was writing the framework code. Rather than compel coordination, integration at first afforded model teams a dependence on the ICM coder. As such, one modeler, not part of the Master Plan effort but familiar with it, observed that the modeling teams seemed fragmented and unable to see the bigger picture. Another observer made connections to a classic problem in software development, the "bus factor": "the challenge [with integrating the models in the ICM] is that you then end up with one person who knows everything about the model…if this person gets hit by a bus, then what?" (33) Over time, as Master Plan modelers themselves describe it, they were better able to understand what other models were doing, their assumptions, and how all the pieces fit together: "There was a lot of stuff that wasn't explained satisfactorily just because no one had everything available and maybe even didn't know how everything worked together. But now all of the people that are modeling this - it's not just us but there's other teams that are running these models too. They all can look at everything - I think it's improved things greatly." (51)

The ICM code eventually coordinated teams, but logistical and emotional labor provided by WIG staff was also pivotal. Programmers see themselves as the "glue" binding the team together, but so too do the technical coordinators who host weekly and monthly check-ins between WIG,

[11] To help translate between Fortran, the language of many submodels, and the new Python language. Some think that programmers who know Fortran, a 50-year-old language, are relatively rare.

CPRA, and the model teams: "[we have] sort of a good enough understanding of all of the pieces and parts to be able to kind of help be the glue." (33) For the ICM to afford coordination, there needed to be a kind of "social" glue, not just a "technical" one. This is because, as staff put it, "to make something like this work you have to include people that have not only the expertise but the time available to do it, and a personality that just doesn't keep throwing wrenches into the process." Being the "social" glue means being an "emotional coach" and practicing, according to one coordinator:

> … translation in terms of keeping everyone's feathers from getting ruffled. In that if one group thinks another group is pushing too hard or this group has something come up and it's taking too long and now this other group is compressed with their timelines, I'm the buffer and typically have taken on this role of, oh, well, do you really need to say it that way? We're all stressed out, this is a team effort. (33)

Political economy, institution-building, and code all brought experts together for the 2017 Master Plan modeling effort. In this subsection, I demonstrated how the sociomaterialty of code - an objective/technical artefact produced by modelers/programmers – afforded coordination between previously compartmentalized model teams. The ICM did not just show planners numbers.

4.5b Visualization

The ICM submodels afford learning through visualization. When modelers say that the tools just show them the numbers, they are in a way right: models do *show* numbers. But these numbers are presented in visual forms that lend themselves to specific kinds of learning and communication. The ICM itself lacks visual outputs since planners want to avoid costly, proprietary GUIs that black box the biophysical processes encoded in model algorithms. But in the post-2012 Model Improvement Plan, planners wrote, "It [the Model Decision Team] will emphasize to the modeling teams that preparing easy-to-understand graphics and animations is essential and critical for planners and decision makers." ("Model Improvement Plan" 2013, 34)

Visualizing model outputs is a priority for decision-makers, in part because they are "easy-to-understand."

Visualizing model outputs, especially through maps, is a priority for several other reasons. Mapping helps modelers debug and hence better intuit model results. One modeler described his interactions with planners around interpreting model results:

> From a decision making standpoint…. it's really just that number. But a lot of times they'll be like, why is that? And then you need to look at the map and you need to see where the land is changing. For instance, it might be in Upper Pontchartrain because we put a seawall up at Lake Pontchartrain outlet and under the high scenario, sea level rises and it's shut almost all the time because the water is high - so it keeps things in there…The maps are particularly helpful. (51)

Although planners sometimes do just want to see "that number," they often want more intuition. This modeler found that because maps distill and spatialize model output, they can more readily alert their users to unexpected results, like a model run that generates a surprising amount of land loss. The first question it occurs to modelers to ask is *where* is this loss occurring, and modelers use place as a guide to explain the mechanisms behind it. Visual debugging is not an insight mapping affords, but it contributes to model-based learning. Mapping affords two specific kinds of insights: 1) coastal changes; 2) trends.

<u>1. Coastal changes</u>

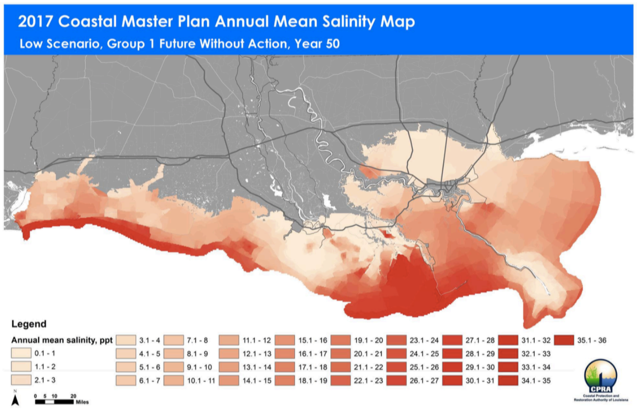
There are four cartographic strategies modelers and planners rely on in learning about coastal change:

1) small multiples of scenarios, of changes over time, and of *both* time and scenario changes (n=78) (see Figure 3);
2) changes directly valued on univariate maps (n=72) (see Figure 4);
3) side by side maps comparing one time or scenario to another (n=17) (see Figure 5);
4) animated maps (I did not directly survey these, but a suite of animated maps is included in the Master Plan appendices).

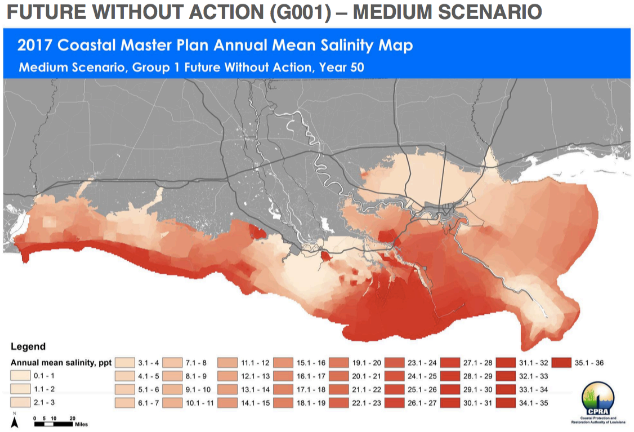
167, or 53%, of all maps I examined were intended to display differences in either scenarios, time, or some other condition (see Figure 3). One modeler explained why small multiples were especially useful for comparing scenarios (e.g. future with and without action) and illustrating differences:

> So we always make three sets of maps. So there's going to be the future without action map…. And then the difference map with the projects or without the projects. And so those two can pretty much tell you the whole story. But then we also will have the future with action as well. You can always compare again to whichever direction you want to go. (51)

The small multiple approach to scenarios was adopted for 25 (8%) of all maps, and most of these were presented through PowerPoint slide decks. Other modelers explained how small multiples aid them in observing expected changes over time rather than differences between scenarios: "...It [mapping] helps a lot. We use maps a lot especially when you're linking these models like the Master Plan and it's just kind of figuring out again what time frame are you trying to capture." Temporal comparison was in fact the most frequent (30) use of small multiples (representing 9.5% of all maps; additionally, 24 maps aimed to capture both temporal and scenario differences). Small multiples can afford a broad overview of coastal change while also preserving information about absolute values. But they may not afford seeing the winners and losers of simulated changes if those changes are not strong or the data is incorrectly classified.



FUTURE WITHOUT ACTION (G001) – MEDIUM SCENARIO



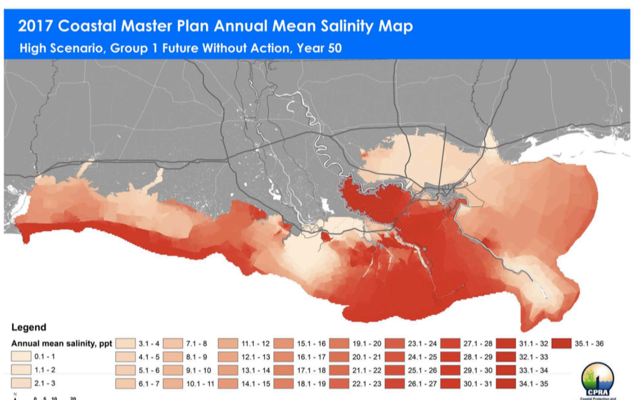


Figure 3. Types of maps used in the Master Plan modeling process. A small multiple set of maps showing salinity levels under different scenarios. They were presented sequentially in a PowerPoint presentation. Source: Modeling update webinar. https://vimeo.com/184690425 and https://vimeo.com/140946351

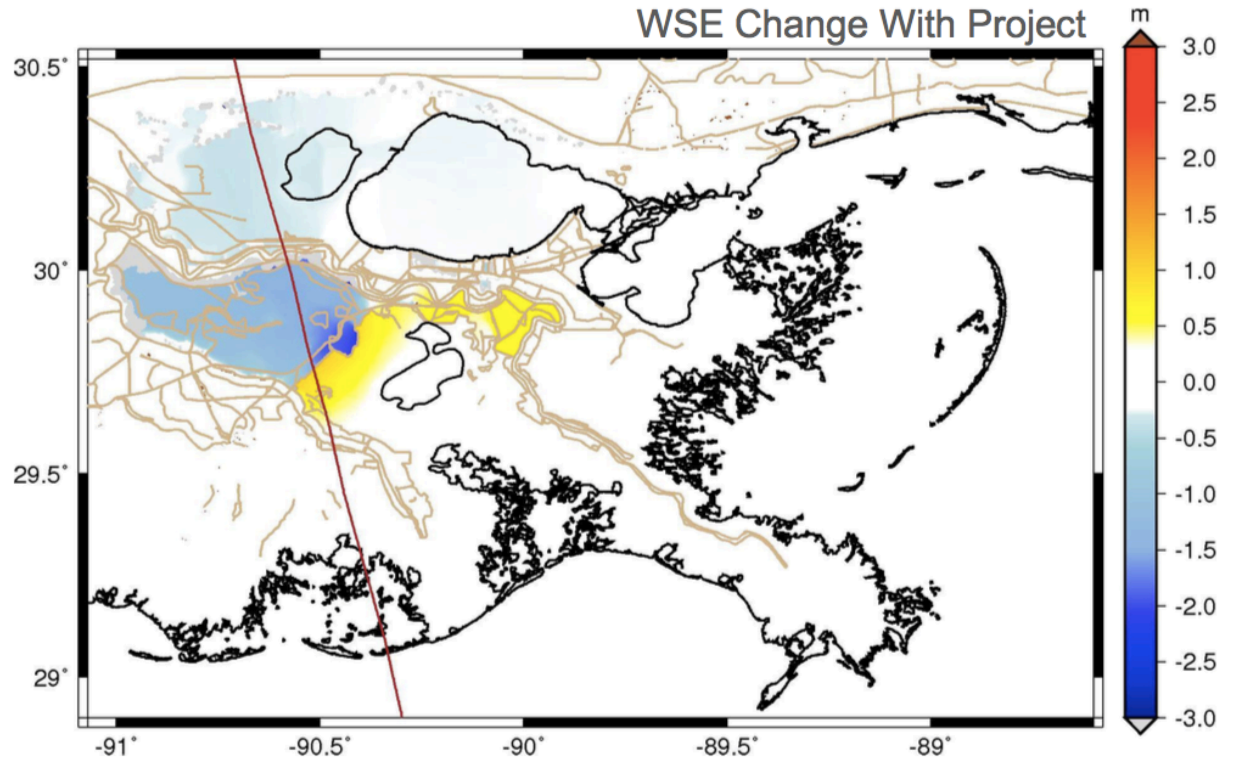


Figure 4. Types of maps used in the Master Plan modeling process. A map representing changes in flood depths that would be caused by one restoration project. Source: Modeling update webinar. https://vimeo.com/184690425 and https://vimeo.com/140946351

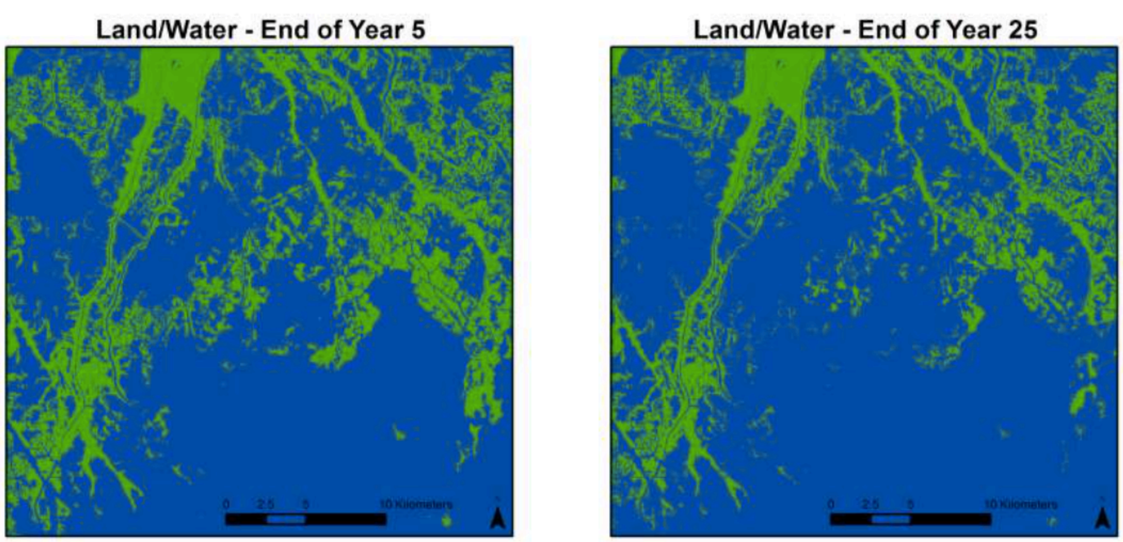


Figure 5. Types of maps used in the Master Plan modeling process. A side by side comparison of land over time. Source: Modeling update webinar. https://vimeo.com/184690425 and https://vimeo.com/140946351

To more directly represent scenario or temporal changes, modelers produced what they called "difference maps," which visualize change as a variable (see Figure 4). These were a common kind of map that planners drew up on (n=72; 23% of all maps). One modeler described the value of a difference map in this way:

> A difference map is useful. So if we look at the diversion runs - if you have a starting water level in Breton Sound and you turn on mid-Breton diversion and - your impact on stages, you know it's really big, like over a meter near the outfall, less further way down. But that difference map - the magnitudes decrease over time. So as sea levels rise you have a smaller impact on the stage just because its [already] higher so it doesn't make as much of a difference. So I think things like that are really cool to see. (51)

Instead of just showing the absolute value of a variable (water level), difference maps indicate the change (a relatively small change in water levels). A single map directly encodes change, affording insight into the impact of restoration (minimal compared to sea level rise). It is a "cool" finding, but in other cases, difference mapping can clearly demonstrate potential "losers" from restoration projects. For instance, in Figure 4, planners produced a difference map illustrating the change in flooding depths from a diversion. Because diversions will move water along with sediment, they increase flooding risks for some upstream communities.

Modelers and planners also relied on animated maps to understand coastal change over time. The Master Plan appendices include animations of simulated habitat and food web changes over time. According to the Master Plan effort's advisers, these animations afford debugging: "animate things as much as possible. Our eyes are very good at quickly picking out data anomalies." (PMTAC 32) Animated and even interactive maps are also thought to efficiently illustrate actual, rather than anomalous, differences. As one developer put it:

> Before they [planners] went very computing centric, they had these physical maps of different scenarios that would come out. It was decision makers in the room, saying hey there's a scenario, there's another one, what do we do? It's very static. The way that visualization in a computing context helps with that is things can be very dynamic….You might have this dataset that covers the coast, but at that scale you're not able to see say in Calcasieu Lake or something, what is the particular effect of black bass, for instance. With viz tools, you can zoom in, create animations - oh man, scientists, ecologists, decision-makers: they *love* animations. Because it's dynamic, it shows change. That's what they're after. Where is the change, what is the change, how is it changing? You can answer those questions with visualization. It's hard to see otherwise. (47)

In a very practical way, seeing change is at the heart of environmental planning. A planner evaluates the merits of some development or intervention, guided by information about what effect that project will have. Louisiana planners are interested in answering questions about coastal change and restoration's impacts, something which visualization affords more than other methods, like physical maps.

Visualization may afford planners insights into coastal changes, but change is not necessarily what fishers or other stakeholders are interested in. When change is the valued variable, difference mapping affords seeing increases or decreases in one place, but it does not say much about absolute values. It indicates the relative magnitude of a change, but it does not say whether it is a small or big number that is changing. Acknowledging fishers' concerns in this respect, one planner put it like this: "you want to see where the fish are, not what the change is." A place may experience a 50% decrease in the shrimp population, but if there were not many shrimp there to begin with, the 50% change is relatively meaningless information. As they evaluate restoration projects, visualization affords planners different kinds of information on possible coastal changes. In their evaluation, they expect small multiples and other mapping strategies will show them the numbers. As fishers evaluate restoration projects, however, difference maps afford them nothing because they do not expect to see changes. Instead, they expect maps to show them absolute values.

2. Trends

Planners are ultimately looking for trends when they visualize changes over time or differences between scenarios. They expect to learn about coastal change at specific spatial scales, and certain kinds of mapping afford this. For instance, to learn about very local conditions and specific projects, modelers could map an entire database of point data or large cartographic scale thematic data. But to see trends, modelers might have to aggregate these data into various areal units at different scales.

Louisiana planners stress that in learning about future coastal conditions they are “focused on the ‘big-picture’, not scores within individual grid cells.” (Notes from webinar, September 2015) This is especially true in how they learn from the fisheries model. As one fisheries modeler put it, “we're not so much interested in an individual 500m^2 cell. We're interested in a larger scale (ecoregion)…What is our average suitability in this area when we implement these projects relative to if we didn't do anything?” (41) Predicting fish populations and even habitat suitability is notoriously fraught with uncertainties, leading modelers to prioritize trends rather than individual data points. Planners envision a similar strategy in using ICM models for future adaptive management programs: “it is important to recognize the models are not forecasting models and do not necessarily represent exact time points into the future. Instead, they should provide, in a general sense, the direction and magnitude of change and the potential variability that may be experienced in the system over time.” (CPRA 2017 F, 27) Although big data discourse emphasizes it, planners make no expectations about achieving absolute precision.

Instead, they expect to see the “direction and magnitude” of change. For “good” modelers, mapping affords seeing model outputs in terms of heuristics and trends rather than precision.

Master Plan maps afford *multi-scalar* analysis, however. This is a case where software properties afford multiple and unintended uses. Cartographers have long noted how maps afford readings in terms of precision as much as they afford insights into trends. Good modelers worry that some stakeholders, such as fishers, falsely view model outputs as precise rather than relative:

> You know when we show maps it's very scary sometimes because you know people think that because you predict something at this point - I mean our models aren't that good that we can say this is what happens….People will look at their own backyard and say you know this is what the model says, it's going to happen. So maps are very deceiving in that way sometimes. (32)

To avoid these kinds of misinterpretations, modelers could aggregate data. In my survey of the Master Plan maps, I found this rarely happened. Data tend to be visualized at the spatial resolution they are calculated at in the submodels. For instance, land loss data are calculated and visualized at the $30m^2$ resolution. Aggregating this data into census tracts or different basin levels might better afford conservative insights into trends. Stakeholders like fishers and landowners, however, prefer precision over trends, because they expect to see how restoration will affect the places they fish or hunt. Landowners hate “amoebas on the map,” or the generalized representations of coastal change and proposed projects (2). Amoebas afford these stakeholders nothing, but they afford state-level planner an understanding of coastal trends.

Planners’ tools clearly do not just “show” numbers, they visualize them. In visualizing coastal change and trends, modeling informs planners such that it is hard to say that tools absolutely do not make decisions. Maps afford planners insights into how scenarios differ from one another (e.g. future with and without action) and how coastal conditions are expected to change, within each scenario, over time.

4.5c Ease

Modeling also affords easy decision-making. The Master Plan modeling process involves putting differences and trends in comparison with another, and ultimately, optimizing tradeoffs. Sometimes comparison and optimization is made easy through visualization, and in that way, easy decision-making is an extension of visual-based learning. When planners claim that "tools didn't make decisions for us," they belie how the "planning tool" they rely on was designed to make decisions easier.

Programmers claim planners want "easy button" types of software, such as "dashboards" ("they all want dashboards" another programmer echoed.) A dashboard is software for visualizing multiple data streams in a way that is supposed to ease holistic, coordinated learning. One programmer recounted how a representative from the Governor's office made a request: "someone told me I wanted a dashboard." The programmer explained, well a dashboard is ok, but you have to know exactly what data, visuals, and analytics you want. Programmers can develop tools that tell planners all sorts of different things, he notes, but they can't make the decision for planners. If tools do not make decisions for planners, neither do programmers.

In part, easy means transparent. Programmers cannot design easy buttons that make decisions for planners because there are too many factors by planners might make those decisions - land, money, habitat, etc. What is the appropriate weight that should be placed on each of these metrics? This was the question motivating the development of the "planning tool" that Rand analysts put together for the 2012 and 2017 Master Plans (Groves and Sharon 2013). The Corps had conducted multi-criteria decision-making post-Katrina. But it tried to account for too many factors and it was unclear why certain factors were weighted in the analysis the way they were. In response, the planning tool is designed to let planners interactively weight different factors. If they value supporting oil and gas communities more than, say, preserving alligator habitat, what suite of projects should they select? The tool's developer explained:

> And so what we wanted to do was rather than trying to develop you know this black box bunch of weights that just spit out an answer, let's instead build something where we can help the state look at … differences across different objectives, and be more transparent about what would happen if you did xyz. (19)

The planning tool was meant to avoid "black boxing" the criteria by which planners assessed coastal changes. They wanted to make their assessment more transparent while also easing how they compared different objectives.

The planning tool affords easy learning through optimization and visual filters. As its developer describes it, the tool has a math component – the optimization – and then visualization of the results. One scientist put it this way:

> This tool that they use to show the data you know is really easy. So there's a huge database underlying all this right. And there's just an interface into that database. All these project runs we do for every scenario for every output. And you can see a graph of land for one scenario and say well there's this change in the other scenario, sea level rise, and the graph moves. It's just a really elegant way of looking at a very large amount of data. (1)

As this scientist explains, the visualization "elegantly" filters extraneous data. Rand analysts use the planning tool to filter information for CPRA, making learning from the terabytes of ICM scenario data easier.

Planners and their aides at Rand intended to avoid building a black box, but they may have done just that. The planning tool does not automatically afford easy learning. Observing the modeling teams' work, the PMTAC reported that "the Planning Tool (PT) seems to be very powerful, but it's also complex. It could be a challenge to narrow down so much complexity into making decisions. Clearly state how the PT will be used, what factors will be considered, etc., so that it is not viewed as a black box." (PMTAC 38) Planners do not expect decision-making to be too easy anyway, since they do not want to sacrifice a values-based deliberation of what simulation results mean. Justifying their use of the planning tool, a lead planner explained that there really is no easy button: "there's no button in the planning tool - as far as I can tell - that says here's the best solution." (Notes, State of the Coast conference). The tool's lead said, "we use it iteratively. So it's not like we've been building a big tool and we'll press a button and we'll get all this analysis." (19) Modelers and planners expect ease, but not too much. This "easy but not too easy" perspective is applied throughout the modeling chain, first with the ICM submodels themselves: "A model is not selected primarily because it has been used before or is easy to explain." ("Strategy" 2013, 3) Easiness can be deceptive, as the fish modelers explained: "Simply because a model has a salinity knob does not mean it can just be changed to simulate the effects of the restoration action on growth." ("Strategy" 2013, 93) A fisheries model may seem to afford easy simulation with a knob (as on a dashboard), but modelers are dubious.

Planners organize their use of the planning tool to avoid overly easy learning and decision-making. The tool itself does not make any decisions, nor does any single CPRA staff member. In fact, "the tool is not designed for the CPRA analysis team – they certainly could do that but it's technical…" (19) Instead, CPRA planners ask Rand to show them specific results, like what if oil and gas communities are our objective? With the planning tool, Rand generates the appropriate charts and sends them back to CPRA. Planners then show the results to the FDT. The idea behind the tool was “the state would be able to have important conversations with stakeholders about what to do.” (19) This form of stakeholder consultation represents a change in coastal governance that occurred slowly over time. It was punctuated and advanced by different kinds of technologies. Previously, as one coastal scientist involved in policy observed:

> projects were picked out using a set of kind of decision trees that were just a bunch of people sitting around in a room kind of deciding. So I think the big advance has been that we've gone from a bunch of people sitting around in a room deciding to something that is more where they can still sit around and decide but they have information to help them. (1)

As a member of an external advisory committee put it, the goal is to “slow down to go fast.” (44)

Louisiana planners expect to learn about the coast and proposed restoration projects with ease. Dashboards like the planning tool, with mathematical optimization, visual filtering, and “knobs” for experimentation, afford efficient comparative analysis. Yet, much like some maps are “double-edge swords” affording misinterpretation, software may make learning and decision-making too easy. User expectations and expertise shape technological action, not just the technical properties of maps or software. Planners have adopted procedures for “slowing down” learning by turning over results to stakeholders. The fact that CPRA itself does not have the expertise to use the planning tool further slows learning down. When planners say “tools did not make decisions for us…they just show us the numbers,” they really should say, “tools did not make decisions for us but afforded our ability to learn without being overwhelmed by all the data, showing us the numbers in a digestible, but also preformatted way that we could share with our stakeholders.”

4.5d Flexibility

Models afford planners flexibility through speed and responsiveness. Models do not just show planners numbers, but show them numbers relatively quickly and in response to what questions they ask the data. The current set of submodels in the ICM are numerical, “desktop” models that have processing power than even just a decade or two ago. One modeler explained the switch to relatively powerful yet quick and simple desktop models:

> This is 15 years ago. It wasn't something that you needed a mainframe computer or a supercomputer. You know it was something that you could do … on your desktop or something that was accessible and understandable not overly complex. (1)

Desktop models may not be as quick as spreadsheet models but they are usually more comprehensive, while also not being so sophisticated that they need to be run on a supercomputer.

The speed of modeling affords more rapid turnaround compared to earlier intensive “supercomputer” or quick but general “spreadsheet” methods. One conservationist anticipated “drive-by salinities” (42), in which automated sensors would in real-time feed into models that could alert decision-makers to recent changes in salinity levels. This would allow planners to better “fit” the operation of diversions to dynamic coastal conditions. A fisheries modeler emphasized “things like water level, salinities – absolutely, make instantaneous. If they [decision-makers] realize that there is a you know a huge spike or a drop….I think that's an example of where that information comes in handy or right before a major event happens.” Such data might have proven useful in a crisis situation like the BP oil spill: “You know I think what they realized that BP is there was this frantic need to hurry. OK. So what data do we have? Where is it?” (17)

The hypothetical example of the BP spill response demonstrates that planners' and modelers' tools afford them flexibility through *quicker* access to information, as well as through *responsive* access to information. With the planning tool, users conduct "experiments" to respond to stakeholder concerns. From the perspective of one modeler:

> You can also do experiments…. it's basically adding an additional constraint. To see what difference it makes - there's an awful lot of what ifs. And so the diversions thing is very high profile in 2012, so these kinds of experiments went on you know we analyzed a whole bunch of diversions - small diversions medium diversions and big diversions. (1)

The planning tool enabled CPRA and Rand to run "experiments" on what projects would be selected under different funding scenarios, or whether smaller-scale sediment diversion projects could still produce similar land-building outcomes. In this sub-section, I described how the planning tool affords planners not just ease in learning about the future coast. It affords them a kind of dynamic adaptability or responsiveness through data exploration and experimentation.

4.5e Fit

Modeling affords information that is actionable in the biophysical context of Louisiana's coast. One of the explicit goals of the 2017 Master Plan was "fit." As stated in the post-2012 Model Improvement Plan: "Louisiana's geographically dynamic coast requires flexible and dynamic modeling tools. Just as the coast differs from one region to another, the modeling tools that are applied to this area will need to vary to ensure they most efficiently reflect the system complexity and produce the desired outputs." ("Model Improvement Plan" 2013) In this sub-section, I show how place-based learning is afforded by processing power and model adaptations, but only in relation to what modelers expect their tools can reasonably say about the complex coast. The ICM submodels do not just show the numbers – they show the numbers modelers have made sure "reflect" the coast.

Modelers expect their tools to meet coastal conditions. One fisheries modeler wondered whether applying “off-the-shelf” generic models would suffice. They called these “plug and chugs”:

> Can you predict with a plug and chug? So can you predict like biomass results that match what your data say - you know, kind of match….So we set up the CASM (food web fisheries model) to be basin specific. And then we initialize each basin. Basically you're putting in initial biomasses things like that based off of the basins for decision making. We do it by basin. It's hard. (41)

Modelers want to match the models they have with the “on-the-ground” conditions their field experience tells them exist. In this case, they adapted a generic fisheries food web model (CASM) to compute basin by basin rather than across the entire coast. Other ICM submodels operate in this fashion, including the core hydrodynamic submodel. These make the same calculations in each basin, but they are initialized separately, basin by basin, in order to generate results that “fit” and are more contextually appropriate.

Computational limits have prevented modelers from fitting their tools to the Louisiana coast. Processing power previously afforded generalized calculations. One modeler who has been working on coastal restoration policy for over two decades described how:

> the thing that confounded us in LCA was the hydrology of the estuaries - getting the water right in the estuaries. The salinities and the water level pans getting those to look right and be responsive. That was pretty difficult… because it's physics right. You have to solve a lot of physics equations. I mean you know we're talking 15 years ago computational. I’ve got more power in my pocket now than I had in my office then. So that was difficult. (1)

Modelers’ computing capabilities now, compared to 15 years ago, afford them better fit. Yet at an even more basic level, the Louisiana coast is so dynamic that modelers find it challenge to understand until they model it and think through how and why the results surprise them:

> The hydrodynamics in coastal Louisiana are extremely complex. And so it's very difficult to really imagine you know what a certain change in the landscape will actually do until you model it…Before we ran the models I actually wrote down my expectations for each

> project. And so then I compare the model outputs to what I was expecting. When it didn't match up I didn't say the model was wrong I just said you know why is the model doing this and then looking at why it was doing it I could see that the model was actually correct. (32)

Models afford fit through geographically-specific adaptations and increased processing power, as well as through the ways modelers manage their expectations. Modelers prepare themselves to interpret oftentimes unexpected results. The ICM models do not just show planners "the numbers," but afford them place-specific numbers for learning with.

4.6 Conclusions

Planners claim "the tools did not make decisions for us… they just show us the numbers." This does not do justice to how tools did inform their insights and efforts. One way to highlight what computer modeling affords in the Master Plan is to compare it with physical modeling. Back at the Water Campus, I was left wondering how the new physical model fit into the overall picture of coastal restoration given that a computer model, the ICM, is central to the Master Plan. Physical models may afford even greater visual intuition than mapped computer model outputs, leading to greater public engagement. Physical modeling does not afford relatively quick experimentation and flexibility like (desktop) computer modeling does. [12] Physical modelers actually can conduct a 50 year run in a couple of days: "you don't have to wait for the computer or do field studies, and you can bring people together to watch it rather than sit around the computer screen." (Notes, State of the Coast conference) In fact, the couple of days it takes to run the physical model is less than the eight to ten days it takes a computer to simulate 50 years. However, a single computer can do up to six 50 year simulations at once. Computer models additionally afford a kind of place-based learning or fit with coastal dynamics. There are

[12] To be clear, there is no hard and fast line between physical and numerical modeling, since the quantitative interpretation of physical model runs requires computation and these results are often fed back into numerical model algorithms.

uncertainties with computer modeling that modelers note are in the 10% range, but as a lead physical modeler noted, the new Water Campus installation is not designed to pick up very sensitive "2% changes [or even 10% changes] but doubling kinds of changes (on an order of magnitude)." (0) Physical modeling does not have the same *kind* of fit as computer models do. As the physical model's project manager (quoted by Hardy 2017) noted, "physical models are good at investigating…how a particular diversion will affect the whole system." Computer modeling, in short, affords flexibility and fit through visualization and ease. The ICM submodels do not just show planners the numbers; they show the numbers in specific ways.

After exploring the process by which planners actually learned about coastal changes, we can reconsider their decision-making imaginary. Instead of something like a group of CPRA planners who come up to computer, press a key, and getting screens full of integers they digest and deliberate with, we see something else: program managers who hire "good modelers" as contractors and who access models that help coordinate everyone, models that ultimately show numbers on maps and charts for easy, responsive, place-based learning. Instead of "tools didn't make decisions for us, they just showed us the numbers," planners might say, "tools did not spit out binding answers, but they afforded specific insights and structured us, based in part on how we organized around them."

The typical way to think about modeling in environmental governance is that "the state" uses models to achieve its goals. This approach black boxes the most important parts of the process – who comprises the state, how models are used, and what kinds of knowledge those models enable. In the Louisiana Master Plan, a variety of civil society actors are brought together to learn with the ICM. Their expectations for these models, and the technical properties of the software itself, afford forms of learning that are much more specific than “abstract.” Modeling affords flexible, responsive, place-based, and scalar insights. Transformative adaptation therefore requires both social and technical approaches. Transforming bureaucracies to be better learners and more responsive to context is something facilitated by models themselves. It is not just a “social” achievement. Likewise, getting models to work in the first place requires proper funding, expertise, and expectations.

5. Governing with models

The previous chapter described the kinds of institutions and insights into coastal conditions that the ICM affords. Modeling enables planners to learn collaboratively, experiment with scenarios, and develop responsive, place-based knowledge about coastal conditions. To what end? In this chapter, I take a further step to show that models mediate state governance regimes. In particular, I demonstrate how modeling enables the state to govern flexibly in the face of an uncertain future, while still supporting specific restoration projects and stakeholders. The argument proceeds in three parts. First, planners have relied on modeling to implement restoration projects, in a way that allows them to manage uncertainties in future biophysical conditions. Second, aided by the planning tool, planners make sense of ICM outputs through metrics. These metrics help them select restoration projects benefitting relatively powerful stakeholders like the oil and gas industry. Third, planners invest in specific models and modeling endeavors, with the intended and unintended effect of increasing the coastal restoration program's legitimacy. The achievement of these benefits – managing uncertainties, supporting special interests, and legitimating policy – does not come easy. Modeling may mediate adaptive management, but it displaces uncertainties about project outcomes onto fishers, many of whom in turn contest the state's approach. Some oil and gas interests do not think the modeling goes far enough to protect their infrastructure. Finally, modeling often generates frictions even though it is supposed to smooth relationships between the state government and other governmental entities. I argue for a vocabulary of performance to describe models and other technical objects' work within governance; they are not tools the state simply deploys to achieve its will. In both substantive and procedural terms, the state's modeling produces winners and losers, and, as a result, dispute, countering, and other challenges or limits. While we often think about technology's use in governance as a roll-out, I show how the state cannot just deploy models since modeling is conflict-prone.

5.1 Introduction

In the introduction to this dissertation, we visited Mardi Gras Pass (MGP). MGP is a crevasse the Mississippi River formed at an old spillway during the 2012 flood season, and it has been at the center of controversy ever since. Some conservationists laud the fact that it will build new land and serve as a living experiment for future diversions, at virtually no cost to the state. An oil and gas firm, on the other hand, is concerned about ensuring access to its wells, while CPRA is worried that MGP will make engineered sediment diversions – the ones it has been planning for nearly a decade now – less valuable. As part of implementing its planned Mid-Breton Sound diversion, the state modeled what it would mean to keep MGP open and flowing as is or even to develop it into a larger, controlled sediment diversion. Hydrodynamic models enabled planners to respond relatively quickly, using localized data to simulate system-wide sediment fluxes, land-building, and water flow. Planners pointed at these model results to justify their decision to not proceed with a diversion at MGP and to close it. This decision represents an adaptive response to a changing coast, but it also reinforced the primacy of both the oil and gas industry and the state's existing plans. It did so at the expense of a more transformative adaptation in which relationships of power between the state, fossil fuel firms, and fishers could be reconsidered.

This led me to the question I ask in this chapter: what exactly is the role of modeling in producing such effects, entrenching rather than transforming dominant power structures in coastal governance? The larger research question in this dissertation is how modeling informs transformative adaptation policy, making it necessary to consider what role, if any, model properties themselves play as instruments or mediators of power. In the previous chapter, I emphasized how ICM features informed governance in as much as they afforded both numbers and institutional structures for learning about coastal change. This chapter concerns the decisions made and policies set with modeling. At MGP, modeling appeared to afford planners' decisions, through fit and flexibility: planners pointed to locally-tuned models to highlight the rigor of their work and simulation allowed them to test the crevasse/potential diversion's impacts. I argue that in such ways models mediate decision-making and thus perform relationships between state, market, and civil society. I show in particular that coastal modeling performs both adaptive management and petrostate governance regimes, in addition to legitimating these. Nevertheless, model results – and the modeling process itself – are contested because they produce winners and losers.

The argument unfolds in three sections. First, planners have relied on modeling to implement and adaptively manage restoration projects, such that the state can manage uncertainties in future biophysical conditions. Modeling performs a governance regime of adaptive management, but in a way that leads fishers to contest it. Second, aided by the planning tool, planners make sense of model outputs through metrics that lead them to select restoration projects benefitting already powerful stakeholders like the oil and gas industry. Modeling perpetuates Louisiana as a petrostate, though some oil and gas interests do not think the modeling goes far enough to protect their infrastructure. Third, planners invest in specific models and modeling endeavors in the hopes of legitimating the coastal restoration program. While planners hope modeling can smooth relationships between the state and other governmental entities, it often generates frictions instead.

This chapter expands on research illustrating how state power is in part comprised and undermined by technical objects. I believe a vocabulary of performance can describe such objects' work within governance. Modeling performs adaptive and petrostate governance regimes and plays both an intentional and unintentional part in legitimating state plans. However, in defending its work, the state walks a fine line between modeling objectively and modeling in response to stakeholder interests, generating contestation along the way. Models do not represent tools the state simply deploys to achieve its will. While we often think about the use of technology in governance in terms of a roll-out, I show how the state's use of technology is conflict-prone.

First, I show why I think "mediate" and "perform" are the right concepts to talk about the governance effects modeling achieves. Then I discuss, in turn, the effects I have seen in the Louisiana coastal restoration case: adaptive management, petrostate, and legitimacy. Before proceeding, I make a brief note about the parts of the Master Plan process I discuss in this chapter. After listing projects within the Master Plan, planners move forward in different endeavors to develop policy and specs for building and operating projects. It is this moment that I detail in the first section of this chapter, on adaptive management, and the third, on the legitimacy of the coastal restoration program. The second section, on how modeling advances special interests, is mostly concerned with the ICM modeling that takes place during the main Master Plan development phase.

5.2 A brief review of the scholarship

I am led to better understand the role of modeling in producing governance outcomes for two reasons. The first reason is because at the end of the most recent Master Plan process, the coastal restoration program will, on the whole, arguably prove adaptive – responsive to changes in future biophysical conditions – but not socially transformative. Instead, the Master Plan seems to reinforce many maladaptive relationships between state, market, and civil society. The second reason is because controversy surrounds coastal restoration. Whether in the wake of Mardi Gras Pass, in online news story comments decrying how much money is spent on modeling, or at mundane meetings of bureaucratic committees (see below), coastal restoration, and the role of modeling in it, are not taken for granted. How do we explain the role of modeling in generating these results: an adaptive but contested governance? Below, I will spell out why I think performance and mediation represent the right way to answer the question. What is at stake is showing that models are not tools the state simply deploys to achieve its will; they are objects with affordances and limits that the state must confront.

Performativity is just one way of conceptualizing if and how technological forms, like simulation modeling, translate into political forms like adaptive management. From a different angle, we might instead reduce the Master Plan's conservative effects to their social and economic context. We might claim that maladaptive outcomes were the result of planners implementing already hegemonic adaptive management ideals; model properties and capacities were purely incidental. One could even write an entire dissertation on Louisiana coastal governance without engaging the modeling process, instead explaining uneven outcomes in terms of the many political and economic forces invested in land loss and restoration. Indeed, within political ecology, scholars tend to pursue this approach, treating models or modeling processes as more or less incidental to more important and interesting socioecological relations of power and marginalization. This is certainly a better perspective than its reverse: seeing new and more capable models as somehow inexorably leading towards an adaptive state. But what it leaves unexplained is why planners choose to model at all and how the modeling process itself might also generate marginalization.

Some political ecologists are beginning to reconsider the field's treatment of technological objects in environmental governance. A long line of thinking within STS, and only just emerging within political ecology, more closely examines the relationship between materiality and political form. Winner (1980), for instance, made two claims: that material artifacts could either by design or unintentionally enable systems of social control, and that some technologies required specific governance structures. Other scholars have continued to make similar links between technological features and political forms (Mitchell 2010) I find such explanations for how materiality shapes governance lacking in as much as they prioritize intentionality (malicious design), determinism (technologies requiring something), or, in some cases, crude description (i.e. Mitchell's [2002] "chemicals contributed to the course of events.") I find them valuable in as much as they emphasize practice, use, and context.

With a recent "materialist return", political ecologists are drawing on STS approaches and seeking to address how technological objects are part and parcel of conventional political ecological concerns around, for instance, conservation and control (see the addition of an "objects" chapter in Robbins' 2012 [2004] introductory text). But their answers have limitations. Robbins and Moore (2015) called on political ecologists to ask, following Winner, "what kind of state do certain technologies give us?" I believe another need is some way to explain how technologies "give" states. Meehan et al. (2013) provide one answer. They articulate a view that places objects at the center of policing – there are no "social" relations per se, only objects like wiretaps, surveillance cameras, and standardized tests that create a disciplinary state (see also Sundberg 2011). The challenge with this perspective is that while it usefully centers objects as important components of control, it does not also ask who put those objects to work in the first place and why (Leonardi 2013). We need to center both dimensions: objects and contexts.

I have argued alongside others for "sociomaterial" approaches that can avoid social determinisms, technological determinisms, and crude description in explaining the relationship between technological objects and social relations (Leonardi 2013, Jarzabkowski and Pinch 2013; Nost 2015). Performativity represents one such sociomaterial approach. It usefully describes, for instance, how gender discourse produces gendered subjects (Butler). Gender is largely not something someone intentionally performs (i.e. drag). It is socially structured and mediated through routine, repeated, and institutionalized acts like pointing to body features and declaring a newborn's gender. Scholars often use the term "mediate" to describe how physical objects perform social relations like gender or class. For instance, Latour (2005) argues that the physical differences between silk and nylon became sociomaterial differences mediating class when silk became associated with upper class uses and nylon, others; class receives its expression in part through these differences. The sociomateriality of modeling is the computational affordances of ease, flexibility, and fit, alongside planners' expertise in and expectations for these in a given use context. Modeling mediates adaptive management precisely because it enables planners to respond to coastal conditions in ways they would not otherwise. Without hydrodynamic simulation, planners' intervention would look different; modeling affords planners flexibility, fit, and legitimacy in their intervention, "giving us," or performing, the adaptive state.

In Louisiana, models perform something called adaptive management, they perform the petrostate when they lessen anxiety about the industry's assets and investments, and they tend to legitimate the state's coastal restoration program. Without modeling there is arguably no such thing as adaptive management or the petrostate, and planners' actions are not by default legitimate. All these things must be brought into being, with modelers and planners repeatedly pointing to model results and claiming that diversions will be best managed adaptively, that the Master Plan works for oil and gas, and that it is equitable, trustworthy, and effective. Modeling brings such policies into being in specific ways, though not easily, as if modeling simply "gave us" an adaptive petrostate. Following Butler (2010) and others, I place an emphasis on the contexts that allow something to be performative. In Louisiana, model performances are disputed, countered, and have limits – fishers claim the modeling is illegitimate, oil and gas firms note the models do not do enough for them, and smoothing relationships between state entities can backfire. To the extent that model performances do succeed, it is arguably because of both their intentional and surprising legitimacy effects. What I demonstrate in this chapter is that models are more than just passive instruments of state power.

5.3 Who gets to be certain?

"I had a plan for everything except if there was no master plan." – Leslie Knope, *Parks and Recreation*, "Master Plan"

5.3a "Dial or switch": Modeling performs adaptive governance

Here I explain the first way governance is performed by models. I show how model affordances of fit and flexibility mediate how the state implements adaptive management. Briefly, environmental management can be thought of through a technological analogy – as either a dial or a light switch. A dial has more "freedom" than a switch has at least three states, while a switch only has two. In adaptive management of sediment diversions, Louisiana planners aim to move beyond existing “switch” approaches that rely on hard and fast numeric, on/off-type thresholds. They aim to move towards a more conditional and responsive dial approach. The flexibility affordances of modeling enable such a dial, but precisely for this reason fishers contest planners’ adaptive management process.

I will develop the argument in this section through reference to a meeting of the Governor’s Sediment Diversion Committee. In October 2016, experts presented the analysis they were developing on how to operate the Mid-Barataria diversion. The diversion was approved in the 2012 plan, but only given a green light to proceed to an engineering-level design process in 2015. Since then, modelers have been working to understand exactly how the diversion will impact its outflow catchment. At the committee meeting, modelers presented new information suggesting that marsh creation projects and diversions could work together symbiotically; new marshes might slow down diverted sediment and build even more new land. I discuss this specific analysis, and its broader significance to the legitimacy of the state’s work in the third section. For now, what is important is how the committee responded to modelers’ presentation. Excited, committee members asked, “can we use this information at existing [freshwater] diversions like Carnarvon or Davis Pond in order to build more land there?” Planners mumbled a non-response. In fact, the state cannot actually use this modeling to inform the operation of existing freshwater diversions. CPRA is legally limited in how it can adapt its plans for managing existing freshwater diversions.

This is a sore spot for the state. Previous experiences with the troubled Carnarvon freshwater diversion - where the state was locked into opening and closing the diversion when salinity levels hit certain numeric thresholds - have left planners deeply skeptical of concretizing operational plans. One conservationist nonprofit even developed a webapp for visualizing salinity levels in Breton Sound. Their intent was to help the state manage Carnarvon as responsively as possible, but its use has not amounted to much. At existing freshwater diversions like Carnarvon, the state is locked into management goals no one likes. Planners are interested in using modeling to inform a different approach for the new sediment diversions.

Figure 1. Charter boat captain George Ricks has contested how state planners have begun implementing diversions. Here, he is standing in front of the troubled Carnarvon diversion. Source: Al-Jazeera.

In order to develop management guidelines for sediment diversions, the state has turned to modeling that is more in-depth and attuned to delta-specific dynamics than even the ICM. Currently, the most significant challenge planners face is determining when to open and close diversions. They want to be able to move the most sediment with the least amount of cold freshwater, to which many fish species are sensitive. CPRA sees modeling as helping to address this challenge in three ways. First, in general, planners believe that simulating different river conditions and operations scenarios can provide a basic knowledge base that will inform future decisions about closing and opening the gates. Second, with modeling, CPRA can supersede the need for one permanent metric. Instead of being bound to a single threshold like, "open the diversion when the Mississippi River is flowing at 500,000 cubic feet per second (cfs)," CPRA is aiming for something that can be adjusted annually. Planners intend to model every year of operation, drawing on short-term weather forecasts and changing landscape conditions to determine the parameters for when to open and close a diversion. One year – or in one season – the threshold may be at 500,000 cfs; the next year or next season it may be at some other level. Third, even on a daily basis, CPRA planners intend to use real-time data to monitor conditions and outcomes and to tweak operations. In short, simulation gives planners flexibility and model resolution enables a kind of fit to specific diversion locations and operations timeframes. By simulating a variety of operations scenarios, planners gain insights that allow them to operate a project flexibly, simulating possibilities in direct response to changing conditions, without ever committing long-term to a single plan of action.

To the extent that planners practice this adaptive management philosophy, they stand in contrast to many other places where bureaucracies constrain adaptive management approaches. Conventional environmental management approaches tend to be more like "switches" then the "dial" planners are putting into place with their diversions modeling (Notes, ACES conference; Plummer et al. 2013). That is, environmental management mostly relies on static numeric thresholds. The Carnarvon diversion, for instance, is operated in a light switch way. It is either turned on or off based on a measure of salinity and river levels. Policy scholars envision adaptive management as a cyclical process in which management goals and outcomes evolve – something a hard and fast "switch" does not afford. Planners would prefer a dial they can play with - a more complex algorithm for managing new diversions. The challenge is that current environmental law itself envisions management in linear, "switch" terms, in part due to public participation and judicial review standards. According to these due process principles, the public has a right to deliberate on specific actions. Responsive, adaptive management would be slowed down by continuous review, and it would be hard to find a plan that works for everyone. Planners face structural barriers in implementing adaptive management –there are few incentives for them to do so, in light of these legal challenges. Administrative agencies "have not often been rewarded for flexibility, openness and any willingness to experiment, monitor, and adapt."

Planners nationally and in Louisiana believe that modeling and other "decision-support" software can be a fix to some of these barriers. They see modeling as providing a legitimate basis for "playing with the dial" because some outcomes can be forecasted – experiments can be simulated before they are implemented. Planners also feel modeling can inform rigid public participation/due process standards by demonstrating the possible effects of management. Modeling could even account for stakeholder interests ahead of time. Yet planners' approach is different from first determining an operation plan, checking its possible effects, and debating with stakeholders to refine it. That the state will have no set-in-stone operational plan for diversions is something that leaves fishers deeply uncertain.

5.3b How fishers contest adaptive modeling

One of the main reasons diversions are controversial is precisely because of how planners have used - and intend to use - modeling as part of their adaptive management. The process puts fishers in limbo. At the same sediment diversion committee meeting in October 2016, where modelers presented on how marsh creation and sediment diversions could work together, George Ricks, a charter boat captain, got up and delivered a public comment. His comment did not concern what the models predicted nor even the merit of sediment diversions. Instead, he critiqued the modeling process. Ricks talked about what he called “spaghetti models.” Spaghetti models are those tropical storm forecasts in which meteorologists map out an ensemble of possible tracks. Ricks made the point that you couldn’t *really* track a storm – and prepare for it or not - until it had an eye. He was making an extended analogy to the diversions. Until you planners determine the operations regime, he said, you can’t predict their effects on socioeconomics and fisheries, and we fishers can’t respond. Captain Ricks repeated his comments against the adaptive management plan at the biennial State of the Coast conference, focusing on how fishers and other stakeholders should be able to inform the process.

Dozens of public comments on the Master Plan echo Ricks’s concerns about sediment diversions and several speak specifically to the modeling effort, rather than any particular project. Intensifying fishers’ activism is a nearly one-hundred-year regional history in which elite urban interests have modified rural wetland landscapes in their favor, without any real serious input from fishers and other local residents (Lewis and Ernstson 2018). Fishers, especially in St. Bernard Parish, believe they have seen it all before. Before most of them were alive, in 1927, a cabal of New Orleans city bankers and leaders chose to dynamite the Mississippi River levees at Carnarvon to flood St. Bernard Parish and relieve pressures on the city’s own levees (Barry

1997; Lewis and Ernstson 2018). In the 60s and 70s, city, state and federal leaders decided to press forward with constructing the ill-fated the Mississippi River Gulf Outlet (MRGO) canal through the heart of the parish. 30 years ago, the state and Corps planned and build the Carnarvon freshwater diversion on the site where city leaders had blown up the levee. Both Carnarvon and MRGO have been linked to exacerbating hurricane damage, changing hydrological regimes, and altering fish populations. These marsh modifications – and the technocratic or sometimes even illegal process of implementing them - have led to winners and losers, and fishers fear they will be the latter with new diversions (Sneath 2017). Over 100 fishers, mostly Vietnamese fishers from St. Bernard, signed and submitted form letters commenting on the draft 2017 Master Plan, describing how much income they believe would lose under the plan. These letters constituted the single largest grouping of comments. Many fishers advocate against diversions, against the Master Plan modeling process, and for other forms of restoration, like marsh creation.

Figure 2. Many fishers contest sediment diversions and call for marsh creation projects instead. Source: Nola.com.

The diversions modeling process exacerbates fishers' historical and material concerns. Beyond the basic question of, will there be enough easily accessible fish?, fishers ask, will I be able to adequately plan adaptations to any changes? While simulations will enable the state to respond flexibly to uncertainties in project performance, future sea level rise, and so on, the very lack of any concrete, long-term operations agenda disables fishers. With modeling, the state gets to plan, but not fishers. Environmental managers the world over are increasingly accounting for uncertain futures, in part through (stochastic) modeling. Challenges to these efforts are not necessarily rooted in who wins and loses from management actions, but who gets to manage uncertainty. Louisiana planners would prefer a situation in which their actions and future conditions were entirely predictable, but the flexible modeling process at least allows them to manage uncertainties, especially vis a vis fishers. Even though sediment diversions are empirically untested, the state points to modeling in order to justify moving forward (Sneath 2017). The state is in essence saying, if there are uncertainties, they are not necessarily on us, as we can account for them and respond. Reporter Mark Schleifstein summarizes, "The problem that fishers face is uncertainty. The state is basing its master plan projects on computer modeling that predicts things like salinity before, during and after diversions are operated. The fishers contend there's no guarantee the models are accurate… and to adjust them to address fishing issues [based on] the way the diversions [will actually be] operated."

Fishers contest the modeling in several ways (Marshall 2015). First, they speak about "spaghetti models" at public hearings or highlight the limits to planners' analysis. Captain Ricks himself notes that CPRA only considered two scenarios in the ICM– a future with diversions or a future with no restoration projects at all. What about a future without diversions, but with marsh creation and other projects? Second, fishers also directly contest the necessity of modeling in the first place, instead pointing to historical and empirical data, as well as their own observations. Ricks has said, "I think instead of looking at all sorts of [model-based] studies, they should just look at the results of the Caernarvon diversions." (Alexander-Bloch 2015) One scientist even argues that when CPRA models to determine diversions operations, they should incorporate fishers' "traditional ecological knowledge": "modeling being done to determine the effects of freshwater on fisheries as part of the master plan program should include their understanding of what fish will be available when the diversions are operated." This would be one step forward in helping fishers plan adaptations. Finally, with the notable exception of Ricks, while *recreational* fishers tend to actually support diversions, this does not mean they accept the modeling. Captain Ryan Lambert – like Ricks, a charter boat captain - supports diversions and argues against other fishers' claims that diversions will not work. He has even implemented his own small-scale diversion projects. But he is skeptical of the modeling because he sees there being lots of money to be made from it (by consultants), and because the modeling just confirms what he already knows from his own experience with restoration (i.e. the finding presented at the sediment diversions committee that marsh creation and diversions can work together.)

In this section, we saw that place- and time-specific fit and flexible simulation were model affordances for planners. They enable CPRA to operate diversions adaptively, as a "dial," and to overcome limits to conventional environmental management based on "switches". Modeling performs a form of the adaptive state – one that is still exposed to the effects of sea level rise, more intense hurricanes, or even diversion outcomes themselves, but equipped with experimental capacities that can inform a project-specific and timely response (cf. Braun 2014). Yet this kind of adaptive state is contested, because the modeling process itself generates winners – the state planning apparatus – and losers - fishers.

5.4 Shoring up investments

5.4a Modeling affords maladaptive adaptive management

In this section, I show how modeling enables the state to support stakeholders' interests, especially those of CPRA itself and the oil and gas industry. Increasingly, governments around the world are aiming for more than objectivity in their analyses (cf. Porter 1995), but stakeholder engagement (Lemos 2003). They want to at least appear responsive to the interests of stakeholders. In this first sub-section, "Modeling affords maladaptive adaptive management," I show how the state's approach to adaptive modeling not only redistributes uncertainty towards fishers (see above), it entrenches the interests of the state planning apparatus itself. Modeling leads planners to adapt to meet their goals instead of questioning whether to change the goals themselves.

I will make the case by returning once again to Mardi Gras Pass. Hydrodynamic modeling of the crevasse enabled planners to see if it would fit within their plans, rather than forcing planners to adapt themselves to it. In many ways, the state has a lot on the line with MGP. MGP diverts freshwater and sediment, much like the diversions the state wants to engineer. But MGP's existence is possibly a detriment to those structures. When MGP formed in 2012, then-CPRA Chairman Garrett Graves claimed, "If we can benefit the coast for 'free,' we would like to do that. The challenge is making sure that we are making decisions with our eyes open." (Marshall 2013b) To help them "open their eyes" and assess whether to seal the crevasse or develop it into a regulated diversion, state planners conducted a computer modeling exercise that was guided by site-based data collection. Modelers adjusted ICM submodels for an application more finegrained than the Master Plan project selection process. Before CPRA's decision on MGP, Graves reflected, "If the engineers and scientists say that Bohemia [Spillway, the location of MGP] is the best place to get sediment out of the river, I'd go out there with a shovel today." (Marshall 2013b) Ultimately, CPRA's engineers and scientists found that MGP would not be the most efficient place to develop a larger diversion to draw sediment from the river into Breton Sound. They decided it should be sealed.

The modeling around MGP was not just an engineering and science exercise, however. It was framed with the interests of the state itself in mind, a frame which model properties afforded. The decision about whether to leave MGP open or not was constrained by CPRA's existing planning investments. CPRA was worried that if they kept MGP open - even if just for a little while - it would become costlier to close if they ultimately chose to: "we would be spending tens of millions of dollars filling the growing hole created by the uncontrolled diversion." (Marshall 2013a) While they could have reaped the benefits of a free small-scale diversion at MGP, planners pointed to models showing that an uncontrolled diversion at MGP would diminish the efficacy of other projects. As Graves put it, "our efforts will be focused on investing our 'water capital' to ensure the largest return on that investment or the biggest 'bang for our buck.'" (Marshall 2013a)

Planners asked a specific question of the models: can this new information about the crevasse help us meet our existing restoration goals? They did not ask: can this information possibly mean changing the goals themselves? In public discourse around the transformative potential of new digital technologies, software "apps" are seen as game-changers and disrupters. But, in the case of MGP, modeling software reinforced an existing state agenda (and as we will see below in the next sub-section, an existing set of relationships between state and capital). Rather than use modeling to adapt the coastal restoration program to MGP, planners modeled to see if MGP would fit into their already completed work.

Modeling actually affords this kind of conservative analysis, rather than a more transformative analysis. It is relatively easier to model discretely (what is the effect on our goals?) than to model dynamically (how can we change our goals?). Planners and modelers asked, which of the three potential sites for a Mid-Breton diversion will provide more land, individually as well as in consideration of all the other projects we have planned? Each potential project site, including MGP, was examined relatively discretely, one at a time. Modelers asked, for instance, if 2,000 cfs flowed through MGP, how much land would it build? How much land would other planned projects end up building as a result? In other words, modelers considered impacts on other already-planned restoration projects in a static, unidirectional way. This is the kind of approach planners had taken in the Master Plan modeling process all along. They did not conduct a dynamic evaluation of how other projects might need to change to accommodate sediment and water flowing out of MGP.

Modeling dynamically is a social and material challenge. Asking what it would mean to let MGP flow free is a more difficult question to code, especially in the context of planners' intent to optimize project operations. It would entail measuring many things together, all at once – land outcomes, fisheries impacts, and so on at all diversions – with computation costs increasing with each site under analysis. The question planners and modelers would ask in this scenario is less constrained and more agnostic: considering all projects on the river, including MGP, what is the flow rate for each that will build the most land? Yet this is the kind of question that would accommodate the existence of MGP and force planners to adjust their goals to it. It is possible that the discrete kind of modeling could have shown MGP was a more optimal way to build land than the already planned projects. But the only way to ensure MGP remained in the landscape would have been the more computationally-challenging dynamic approach.

For many ecosystem scientists who want to see adaptive management become mainstream in environmental governance, “true” or “transformative” adaptive management involves potentially changing goals themselves. Some restorationists and modelers involved in the Master Plan expressed this philosophy to me, even if it has not been the state’s approach so far. One modeler focused on changing goals, posing a hypothetical scenario: “What if our problem is well we've lost land and there's nothing we can do about it anymore?...And now we have this huge, all our fisheries stocks have crashed. So now we're suddenly developing a plan to tackle that. You know I think revisiting your problem is part of it part of the step.” (17) This modeler went on to say that revisiting the management problem would involve readjusting the goals themselves to be more realistic. While there are divergent orientations towards adaptive management within the coastal restoration program, MGP shows that there are real technical and institutional constraints to implementing more transformative versions of it. Modeling done in reaction to MGP afforded planners an opportunity to confirm their already existing plans.

Before proceeding to the next sub-section on how modeling enables the state to support stakeholder interests, it is worth reflecting on what the previous two sections have told us about adaptive management. They have demonstrated how, in drawing on modeling to manage diversions, it is the state planning apparatus that wins. In the “Dial or Switch” section, we saw how CPRA can free itself from metrics it has found overly restrictive in earlier diversion projects. The agency can manage an uncertain future drawing on the dial-like fit and flexibility modeling affords. However, the result is that fishers find themselves in limbo, unsure about what their future holds. Their complaints are not over model results per se as much as the modeling process.

In this sub-section, “Modeling maladaptive adaptive management,” we saw how with modeling, planners are afforded adapting to meet their original goals rather than changing the goals themselves. The effect is to benefit the state planning apparatus, and as we will see in the next section, other stakeholder interests.

With modeling, planners open themselves up to a wide range of plausible futures, and respond to them. There is nothing about modeling per se that necessarily forecloses potential futures, just sociomaterial affordances in this direction. In the last section’s case of planning diversions operations, modeling, computationally, afforded a range of future scenarios, but these met an overly flexible planning process to foreclose adaptive transformation. In this sub-section, planners’ expectations around computation costs and concern for their existing investments reinforced how modeling affords discrete rather than dynamic optimization. What has generated controversy is precisely the fact that planners have not drawn on modeling to advance any *particular* future, and that when they have, in the case of MGP, it has been a future that benefits the state's own existing investments. In drawing on modeling, planners have been shaped by specific modeling properties that mediate an adaptive benefactor of special interests.

5.4b The petrostate

A "petrostate" is a government materially and ideologically captured by oil companies who direct its planning apparatus to their own ends (Watts 2004, 2012; Mitchell 2009, 2011; Mufson 2010). In as much as Louisiana is a petrostate, its own mandates are advanced when the interests of the oil and gas industry are also advanced. Modeling, I argue, performs an important role in advancing these interests. The oil and gas industries have special interests in seeing restoration projects rebuild the marshland that buffers their infrastructure and employees' homes from storm surges. The ICM modeling process directly enables planners to select such projects.

In this section, I will first make the case for how Louisiana, especially in its coastal restoration program, is wedded to the hydrocarbon industry. Then I will show how specific components of the Master Plan modeling afford decisions that favor fossil fuel interests. Modeling performs the state not just as a flexible manager of its own investments, but as a guarantor of capital. Finally, I highlight a couple of ways modeling for oil and gas is contested; it is sometimes counter-modeled and sometimes seen as not going far enough to support the industry.

Fossil fuels and coastal restoration are intertwined biophysically and institutionally. Biophysically, the oil and gas industry built an extensive network of pipelines through the coast, and it was relying on wetlands to hold this infrastructure in place (Theriot 2014). Firms like Chevron are now undertaking restoration projects of their own, while hoping the state can come up with a more systemic land-building solution (Traywick 2016).

Institutionally, the state funds itself in several ways through the oil and gas industries. The Louisiana Mid-Continental Oil and Gas Association (LMOGA), the trade group for Louisiana-based oil and gas companies, boasts that 13 percent of the state government's revenue comes from the industry. However, this figure varies due to boom and bust cycles, the relative aggressiveness of different administrations towards the industry, and by specific state government allocation. For instance, although in fiscal year 2015 oil and gas taxes accounted for 12-13% of state revenues, the figure dropped to 8% in 2016. It had been as high as 40% in the 80s and early 90s, a rate comparable to Norway or Alberta. Recent oil prices, which have been at record lows, mean that the state receives less than a million dollars a year in offshore oil drilling royalties directly (Traywick 2016). While the state will gain around $7 billion for coastal restoration from the 2010 Deepwater Horizon spill, it lost $1 billion from severance taxes at the same time (2011-2014), due to exemptions and loopholes (Rhoden 2015).

Such drops in revenue or missed opportunities are consequential for coastal restoration. Although the 2007 Gulf of Mexico Security Act (GOMESA) promised to dedicate a larger share of federal royalties to Gulf Coast states starting in 2018, both Presidents Obama and Trump have suggested reneging on the deal. Louisiana has enacted constitutional provisions requiring those monies (and BP oil spill fines) be spent on restoration (Schleifstein 2016). CPRA predicts that the second largest dependable source of funding for coastal restoration (besides BP) will be these offshore oil royalties (Marshall 2017) Yet, because of low oil prices, the state's first share of GOMESA royalties in 2018 is half of what CPRA planners had hoped. Unfortunately, GOMESA represents the only recurring federal source of funding for coastal restoration. Likewise, the state’s own oil and gas taxes – the State Mineral Revenues – are the only state-level recurring source of funding for coastal restoration. Yet this fund is also at half of its usual levels because of lower fuel prices, meaning CPRA has had to make cuts over the past two years. Even with GOMESA money and BP spill fines in hand, the state will not have enough money for restoration (Tulane Water Institute 2015), and, in the face of a $2 billion budget deficit, these monies are at threat of being redirected.

In short, the Louisiana state government shares many characteristics with petrostates in so far as it experiences a kind of dependency on the cash flows it can secure from hydrocarbon extraction. In Louisiana, this dependency has a number of significant implications for the scale and scope of coastal restoration. It is indicative of the supportive rather than antagonistic relationship the state tends to take with the oil and gas industry. Although one could suppose that modeling sea level rise and other climate impacts might lead to a confrontation with fossil fuel interests, in the next section I show how modeling enables planners to support them.

5.4c How modeling performs the petrostate

The Master Plan modeling process benefits oil and gas by assessing impacts to its infrastructure. Several spatial analytical dimensions of the ICM afford this, and it occurs in two separate moments: first, in metrics that evaluate how restoration projects would benefit industry infrastructure; second, through localized analysis of potential sites like MGP.

Fossil fuel industries are represented in the ICM through metrics that enumerate how well restoration projects support infrastructure and communities in which industry employment is high.[13] Part of the Master Plan modeling process involves making quantitative interpretations of key model outputs like land built or maintained and expected flood damages. Planners want to build land and reduce flooding, but they know that not all land is created equally and they want to determine if restoration projects' benefits will help specific interests, compared to a future without action and alternative sets of projects. Modelers created a series of "metrics," including support for navigation, protection of historic properties, and support for oil and gas communities. This last metric is evaluated for 25 communities across the coast. These communities are in "close proximity to one another and are associated with similar oil and gas facilities." (CPRA 2017 C4-11, 22) Communities receive higher scores on the metric when there are projects minimizing flood damages and maximizing the amount of land built. Expected flood damages are calculated for commercial and industrial as well as residential assets. The results are aggregated to six ecoregions and uploaded to the planning tool, where planners compare whether oil and gas communities in these areas are better off (i.e. have more land and less flood damages) with Master Plan projects or without them. In the 2017 Master Plan, planners found that the metric values were mostly positive, meaning that compared to a future without action, diversions and other restoration projects would sustain more land and reduce flood risk for oil and gas communities (CPRA 2017 C4-11, 27).

[13] The storm surge modeling does take into account the existence of oil and gas canals, though model documentation does not explain where these canals came from. Oil and gas extraction and the resulting land loss have also increased open areas in bays, allowing tides to move further onshore and affecting sediment supply for barrier islands: "over time the area of the interior bays has increased as a result of natural and anthropogenic factors (e.g., subsidence, oil and gas exploration) leading to increases in tidal prism. Increases in the tidal prism jet sediment further offshore, which increases the ebb shoal capacity and reduces sediment bypassing at inlets." (CPRA C3-4, 5) As far as I know, this parenthetical represents the only mention of oil and gas impacts in any of the Master Plan modeling appendices.

Modeling in support of oil and gas communities was not something new to the 2017 plan, but incorporating some of its infrastructure like refineries was. Planners reflected that "the 2012 Coastal Master Plan analysis did not include data on some key classes of coastal assets, such as power plants, refineries, ports, or other types of critical infrastructure." (CPRA 2017 C3, 44) As planners elaborated at the State of the Coast conference, oil and gas stakeholders had told CPRA that they built their pipeline infrastructure based on the wetland landscape of 60 years ago, the bare bones of which remain (Schleifstein 2015). The industry was therefore less concerned about the amount of wetlands in the landscape, and more concerned about their spatial configuration. Firms do not want wetlands to move (Notes, State of the Coast conference). This priority was more or less directly encoded into the planning tool metric. Modelers report that the "highest values [for the metric] are attained by retaining the current configuration of land-water (based on the grid cells) assuming that oil and gas facilities have been constructed taking the current landscape into [consideration]….." (CPRA 2017 C4-11, 25) The spatial analytic dimensions of ICM models, in this case acting much like GIS, afford such a calculation. Modelers can overlay infrastructural and landscape data and then create buffers around pipelines, refineries, and other assets to calculate the amount of nearby land.

The oil and gas industry asked the state to evaluate its restoration efforts in a specific way, and the state did. Planners used the results in deliberating between alternative sets of projects, trying to ensure that the draft plan would maximize the metric. In this way, the ICM modeling will drive a landscape spatially configured for the needs of the oil and gas industry. In fact, some of the projects that have been modeled in the Master Plan over the past ten years are now coming online and they explicitly benefit oil and gas. The Caminada Headlands barrier island improvement is the largest restoration project CPRA has ever completed. Its main purpose is to protect Port Fourchon, through which most US oil imports are routed. Modeling, through spatial analytical affordances, therefore mediates a petrostate; it represents a critical means by which the Louisiana government serves the interests of fossil fuel industries.

The more localized, in-depth modeling of potential sites, like what is being done to manage diversions, represents another way modeling mediates the petrostate. Once more we'll revisit Mardi Gras Pass. As described earlier, the state modeled to see if the crevasse would align with its already existing plans for sediment diversions along the river. They also modeled what effect the crevasse would have on oil/gas infrastructure in the area. Conservation nonprofits were ecstatic when the breach first occurred, with one stating, "If this is blocked up, we'd better give up the coast and move away." (Schleifstein 2013) Yet the oil and gas industry called for the breach to be blocked up. A firm from Dallas, TX called Sundown Energy was operating in the nearby Potash Field and a road to their oil wells had been cut out by the crevasse. LPBF's director replied that the company could use its dock to move oil, as it had done in the past, but the firm noted that roads are cheaper, to the tune of $12,000 a month. It proposed rebuilding the road but installing a culvert to allow a limited amount of water to remain flowing. (Marshall 2013a) One online commentator observed the tension between coastal wetland restoration and the profit margins of Sundown by asking, "what will win, the interests of an oil company or the needs of southeast Louisiana?" (in Schleifstein 2013).

Figure 3. How Mardi Gras Pass has cutoff a road to an oil field. Source.

As noted above in the “maladaptive adaptive management” section, planners asked modelers whether to seal the crevasse and to evaluate what it would mean to transform MGP into a full-scale sediment diversion. Modelers predicted that a diversion at MGP would cost $3 million less but create 500 fewer acres of new land compared to a project elsewhere on the river (Diversion Panel presentation, slide 22). When CPRA presented the results of the modeling analysis at a board meeting in January 2015, they repeated these equivocal figures, but emphasized how they found that a diversion at MGP would threaten to Sundown’s infrastructure. The board chose to proceed with a diversion at a different location, in no small part because of the direct impacts to oil and gas infrastructure at the MGP site. The spatial resolution of the models – increased after the Master Plan in order to evaluate specific projects – afforded this kind of more site-specific finding rather than community or ecoregion-level finding like for the ICM-based metrics. Being able to see infrastructure around MGP and overlay it with predicted hydrodynamics was key to planners' analysis and justification. In this second way, modeling mediates the petrostate.

5.4d How modeling for oil and gas is countered and limited

So far we have seen how modeling enabled planners to prioritize oil and gas concerns. However, modeling is not simply a tool through which oil and gas interests are always, seamlessly, advanced. In some contexts, modeling affords analyses that counter the industry's proposals. The state's first large sediment diversion will be in Mid-Barataria. However, CPRA and other state agencies have allowed a coal terminal to be built in right in the intended path of that diversion's spillway (the canal directing flows to the larger basin). The agency had the authority to vocalize any concerns to the other state entities that were permitting the terminal, but planners provided no comment. However, staff at WIG actually conducted modeling to *counter* the decision when conservationists took the case to court. WIG's analysis showed that the ships that would dock at the terminal would alter hydrodynamics on that portion of the river, to the detriment of the diversion's operation. In court, model results helped persuade the judge to rescind the permit (cite).

Some oil and gas firms, and private landowners more generally, do not embrace the state's modeling. In public comments, many firms noted work they themselves are doing, with one commenter looking at the future without action red map and noting that it failed to account for the restoration his group was conducting around Port Fourchon. Firms like Chevron suggest that the state draw on their subsidence data to improve the modeling. A letter from X, disappointed to not see a particular project, threatened that, "if the HNC (Houma Navigational Canal) is not maintained, the Oil and Gas Industry it supports will leave (i.e. McDermott International) and the

State of LA stands to lose a lot of revenue which will be needed to complete the construction of a lot of the projects in the Master Plan." (CPRA 2017 G2) Although such comments dispute how well the Master Plan modeling supports the oil and gas industry, they fit squarely within a paradigm in which the state is supposed to do more for capitalized private interests.

Does modeling future land loss provoke a confrontation between the state and the oil and gas industry, obscure their close relation, or something else? We might expect to see controversy when planners set out to model the future of a coast the industry was significantly responsible for damaging. However, the spatial analytical dimensions of modeling - overlays, buffers, and a relatively fine resolution for evaluating specific sites - afford state agencies the ability to literally shore up the value of fossil fuel industries. In evaluating impacts to their infrastructure and their workers' residences – rather than impacts such industries themselves cause - modeling entrenches Louisiana as a petrostate.

5.5 Lagniappe legitimation

"Hope for the best. Plan for the worst." Introduction, 2017 Master Plan.

Given the controversial nature of coastal restoration - either in the terms expressed by fishers or in terms of the Master Plan's costs and uncertainties - the state is interested in defending its proposals. Planners consider modeling important in this respect. As one modeler noted, the difference that computer modeling allows is: "model outputs [are brought in] to actually drive their decision. In the beginning it was, what do you think, do you think this thing will last for a while? (laughs)." Modeling mediates the legitimacy of the state's coastal restoration program, in three specific ways: scenario analysis boosts the apparent effectiveness of projects; model results quell dissent; modeling and models smooth intergovernmental relationships. Modeling mediates such effects in both intentional and unintentional ways. For instance, planners purposefully draw on modeling to achieve some of these effects. Model design unintentionally produces other legitimating results. Such surprises are “lagniappe” – Louisiana Creole for “an unexpected bonus.” Modeling brings together disparate information in ways paper and pen cannot and, in conjunction with the expectations modelers and planners arrange for themselves (see chapter 2), it affords surprising results that perform the state’s coastal restoration program as legitimate.

5.5a Scenario modeling saves face

How planners manage their expectations is especially relevant for the first way in which modeling mediates legitimacy. Scenario modeling enables the state to save face. The ability to feasibly calculate three alternative futures (best, middle, and worst-case scenarios) affords planners a range of ways to portray and evaluate their work. If they were only able to calculate one scenario – perhaps because of computational limits – planners would be much more constrained in how they defended the plan, both before and after its implementation. If that single scenario did not come true, coastal residents would likely claim CPRA was wrong and, as a result, underprepared. Instead, CPRA has taken on a “no regrets” approach that is facilitated by scenario modeling. With the help of experts at the Rand Corporation who have developed various analytical methods for dealing with uncertainty (e.g. Groves and Lempert 2007), CPRA formulates a plan that relies on “planning for the worst, but hoping for the best.” Planners evaluate projects in comparison primarily to the worst case scenario, but then they make sure projects will also work in the medium and low scenarios. According to CPRA Chief of Research Haase, "If we plan for that high scenario but we actually get a medium or a low, what does that mean? You do lose a little bit of efficiency….but you're way better than if you plan for a low and end up with a high." (Schleifstein 2017) In the Master Plan document itself, CPRA illustrates the plan's benefits only by showing land built or maintained by restoration projects under the high scenario (CPRA 2017, 100). Some of the scientists I spoke with, reflecting on this, made the somewhat cynical interpretation that in its no regrets approach, CPRA is aiming low so that restoration projects will almost certainly seem successful. The only way the state can lose is if the future turns out worse than even the worst case scenario imagines. What mediates the state "winning," or being successful with restoration projects, is modeling's capacity to calculate these multiple scenarios.

5.5b Modeling quells dissent

The second way modeling mediates the Master Plan as legitimate is by enabling the state to quell dissent on sediment diversions. Planners conducted modeling specifically to experiment with how diversions and marsh creation projects might work together and even enhance each other. Given their experiences with Carnarvon, fishers like Captain Ricks are skeptical of whether sediment diversions will build land and instead argue for marsh creation projects that rely on dredging sediment from the river, transporting it by pipeline, and depositing it in basins. CPRA believes that modeling can diffuse tensions around diversions, potentially leading to a "ceasefire" between the state and fishers (Marshall 2016). The state points to the modeling it has done around how to operate the first diversion at Mid-Barataria. Planners actually presented the preliminary results of this analysis at the October 2016 diversions committee meeting where Ricks delivered his "spaghetti model" address. They found that diversions could enhance created marshes with extra nutrients and sediment, and slow down diverted freshwater, ultimately mitigating impacts on salt-sensitive shrimp and oysters. Planners were not expecting that marsh creation projects at diversions could actually prove beneficial for fisheries. As one planner put it, "it was lagniappe" (Marshall 2016). Ricks later reflected that he was "happy to see them paying attention to the impacts of diversions on the fisheries" - a boost for the acceptability of CPRA's efforts to build diversions, even though assessing fisheries impacts was not CPRA's initial goal. Intentionally or not, what mediates the legitimacy of diversions in the Master Plan is how modeling affords experimentation.

5.5c Modeling smooths intergovernmental relationships

The third and most substantial way modeling mediates legitimacy is by smoothing relationships between state government and other governmental entities. There are two such intergovernmental relations, the first being between state and parish governments. All coastal communities want their restoration project, and modeling – sometimes surprisingly – enables the state to more or less appease everyone. There is a long history of patronage politics in Louisiana that cannot be covered here. It suffices to say that parish and state leaders, as "political bosses," have long tried to dole out construction projects to constituencies in order to curry their favor (e.g. the Perez family in Plaquemines Parish and former Governor Huey Long). This history resonates today, with the majority of public comments on the draft plan involving parishes fighting for local projects. Many comments, especially from the parishes, involve requesting that an already underway or proposed project be incorporated into the plan. The modeling process itself, as currently socially and technically organized, is conducive to this clientelistic or pork-barrel politics. Any individual or organization can put forward a project, and it is then screened through the ICM modeling and planning tool analysis to determine whether it is viable.

Theoretically, the project assessment and selection process could be done differently. Other conservationists working in the Gulf have taken a different approach, where they model the coast in order to determine where the best restoration sites would be (Natural Capital Project), rather than modeling to determine if a specific project will be successful. The former could be considered a more inductive approach to optimization; the latter – the actual ICM approach - more deductive.[14] Inductively determining the best locations for diversions, marsh creation, and so on might circumvent any special interests in project proposals, but it also overlooks the vast resource of proposals that have been on the table for years, sometimes even decades. It is also more computationally expensive, because the optimization is less constrained than, what will the effects of this project be? Moreover, as some modelers noted to me, inductive modeling would work only if coastal land loss and restoration were not also "social issues" (35). If all planners cared about were the ecological variables they could parameterize, they could more or less easily model to determine the best restoration sites. Instead, planners want to engage with the social dimensions of restoration, though the approach opens the door to localized, special interests.

Modeling therefore enables the state to mollify local parish concerns, though the success of this is not always intentional. It is sometimes lagniappe, but it is nevertheless an important effect. The state has found luck in previous years' modeling when the final set of projects it has chosen – the projects that will build the most land at the cheapest cost – have been equally distributed amongst parish stakeholders. As one modeler put it, the modeling put "a chicken in every pot" (echoing former Governor Long's famous campaign slogan):

> I think the state fell on its feet in 2012. They did not have to make many difficult decisions because the analysis that we did and the planning tool came up with a mix of projects that were spread across the coast. A really bad answer for the state's perspective I think would've been if they were all one kind of project and they were all grouped in one area….I mean it was just like there's a mix of stuff and something in here for everybody - not everybody got what they wanted, but they got something.

---

[14] This distinction – modeling the effects of a project vs. modeling to find the best sites for a project - mirrors the discrete vs. dynamic modeling approaches described in the "Maladaptive adaptive management" section.

The way the Master Plan process is set up, institutionally and technically, it is possible to include a wide range of possible projects, model them all, and ensure every parish gets a seemingly equitable portion of the significant investment the projects represent. This has the effect of defending the state's effort vis a vis coastal parishes that might otherwise feel marginalized.

Parishes and other governmental entities tend to like big earth-moving projects, because they demonstrate to constituencies that they are taking action. It turns out that the ICM affords selecting these kinds of projects, further ensuring parish and other governmental buy-in. As they are currently designed, the ICM submodels afford the evaluation of large projects rather than smaller ones. This is in part because of the vegetation submodel, which has one of the coarser spatial resolutions of the ICM submodels:

> Well, that's one of things - we cannot evaluate very small projects. You know they're within the error of the model. So you know if some project has an effect of less than a kilometer square area, which is four cells in our model, we don't pay attention to that. Because that's within the error of the modeling. (32)

According to CPRA Chief of Research Haase, the models can only evaluate restoration projects that will have impacts that are more than 500 acres in size (Lux 2017). Only large projects with substantial footprints can be simulated. Mediated by models, the plan therefore prioritizes and justifies large-scale projects, benefitting a state that is more interested in massive construction projects than small-scale or social change-oriented efforts anyway.

The second intergovernmental relation that modeling is supposed to smooth is the relationship between the state and federal government. As one modeler put it to me, “you can't mess with the Mississippi River [by creating a diversion] without the Corps.” (41) To make its analysis appear legitimate and, ultimately, to speed the process of getting approval to "mess" with the river, the state has chosen to use specific models and has engaged in collaborative modeling efforts. For instance, the state decided to use the Adcirc model to predict flood depths, in part because it is widely used by the Corps and other federal agencies like FEMA to do the same. These agencies know and trust the model, meaning they have one less reason to doubt CPRA's results. Parallel to the Master Plan, CPRA has also started a collaborative modeling effort with the Corps to develop the knowledge infrastructure for modeling diversion impacts in a more precise way. The intent is similar to why the state chose Adcirc – to build trustworthy models. Ultimately, CPRA wants to have the tools that will enable its contractors to write a defensible and successful environmental impact statement for the diversions' permits, which the Corps will issue. In developing a modeling approach alongside the Corps, some suggest that CPRA is hoping that the legitimacy of the analysis will be taken for granted. As part of this, for instance, the agencies are already modeling to see how operating Mid-Barataria diversion would affect key habitats (Schleifstein 2016) At the same time, the state has modeled in order to encourage the Corps to see how coastal restoration would benefit the agency's own mission. Some modeling indicated that diversions could result in less of a need for the Corps to dredge the Mississippi's navigation channel, a typically costly effort (Schleifstein 2015). Selecting or building trustworthy models mediates the legitimacy of the state's coastal restoration program as its first projects face federal scrutiny.

5.5d Limits in modeling to make legitimate

So far we have seen how modeling tends to perform the state's efforts as legitimate, because modeling afforded planners a no-regrets approach, experimentation with stakeholder concerns, and results that were equitable and credible to other government entities. Modeling is supposed to quell public dissent and smooth relationships between planners and stakeholders, but that does not always work. For instance, some members of the public still see conflicts of interests in modeling. One of the comments on the draft plan reads, "These computer numbers about yearly reduction in damage are fudged numbers created by the very commissions whose jobs depend on getting additional funding from tax payers for their pet projects." This observer feels like the modeling is intentionally manipulated by planners in order to justify projects.

Modeling is also supposed to smooth relationships between the state and parishes, but some parishes still feel left out and think modeling is not even all that necessary. Southwestern Louisiana tends to feel marginalized from the New Orleans area and Bird's Foot portions of the coast. Southwestern parishes are developing their own coastal plans, in part to try and force the state to include those projects in the Master Plan and fund them. The CPRA board representative from this area commented, "[The parish] also recommend[s] that the State view the local coastal plans in Calcasieu, Cameron, and Vermilion, as viable products that are consistent with the master plan with the understanding that the projects are not fully modeled or yet vetted... we'll get that to you as soon as we have it." As one southwestern resident put it, "So what if our plan isn't modeled?" (CPRA 2017 G2a, 122) The state has both organized modeling to help defend its plan vis a vis the parishes and lucked out in this. But for some Louisianans, there is nothing about the modeling itself that makes for a legitimate plan.

Modeling is supposed to smooth relationships between the state and the Corps, but it has generated frictions as well. Because of politics and epistemological differences, the collaborative modeling effort between the agencies ended up developing two models instead of one, resulting in what one observer called “a mess.” For instance, the agencies split in part because of different modeling philosophies, with the Corps aiming for a first principles rather than an empirics-based approach (53). Ultimately, the state has expressed its impatience with these limits to how modeling justifies its work . The new executive director of WIG leaned on modeling itself as a justification: "We've done the modeling. We have done the science. We know that this will work....We are going to turn it [the Mid-Barataria diversion] on sooner [than 2022, which is when the Colonel said would be the earliest the diversion could be approved]." (in Schleifstein 2017). Meanwhile, the Corps itself is modeling to show the state that certain aspects of land loss and restoration are not as bad as the state makes them out to be. In a context where the state is struggling to get the Corps to recognize its own efforts, the Corps’s modeling amounts to a kind of counter-modeling. CPRA loves to hate the Corps’s small engineered crevasse at West Bay, in the Bird’s Foot, because it was a costly experiment with, at least at first, unexpected effects. But modelers at the Corps's research center in Vicksburg are doing some calculations showing that the long-term consequences have not been as bad as previously thought (Snell n.d.).

Modeling mediates the legitimacy of the state’s coastal restoration program, but not in any straightforward way. Scenario modeling affords the state the ability to “plan for the worst and hope for the best,” increasing the likelihood that its projects will be successful. Modeling’s experimentation affordances enable planners to defend their work by evaluating stakeholder concerns, even if positive results are a given. Specific models, by virtue of how they are embedded in the right institutions, are trustworthy. All this relies in part on surprise and is also contested. The state gets lucky with certain results, but intentionally or not, modeling mediates the effect of legitimacy. As such, modeling is also terrain where the state's efforts in general can be thwarted, by members of the public questioning its purpose, necessity, or accuracy.

5.6 Conclusions

As we saw in chapter 2, one of planners' key claims is that "tools [models] did not make decisions for us....they just showed us the numbers." In chapter 2, we evaluate this claim in terms of who was actually responsible for the Master Plan – models or planners. Here in this chapter, which has emphasized the role of modeling in legitimating state action, we should also read the quote in a different light. We should assess what it means that planners are making such a claim - or, the function of its rhetoric. Planners emphasize how they accounted for subjective interests or values in their decisions, while also justifying those decisions in disinterested and rigorous objectivity ("the numbers"). The decision-making imaginary at work here has a planner sitting at their desk waiting to get raw, unfiltered numbers so that they can share and make sense of those numbers at the next stakeholders meeting. Subjectivity comes after, and is rooted in, objectivity. Such an imaginary may not be far from practice – planners and focus group representatives do use a limited access version of Rand's planning tool to see the ICM's numbers and then to deliberate about what the numbers mean. Models spit out numbers that are rigorous and in many ways disinterested and, ultimately, objective. In reality, those numbers themselves – not just the deliberation – are "subjective." They are often purposefully "interested" (i.e. the oil and gas metrics), the models are selected for specific reasons (i.e. because federal counterparts trust them), and the modeling process is oriented around the concerns of state planners (i.e. how to manage diversions).

In this chapter, I explored how the dual, subjective yet objective defense plays out in modeling practice and what it means. Planners around the world have long justified their actions with reference to abstract expertise embedded in charts, models, etc. As Porter (1995) famously argued, planners do not refer to models out of a commitment to nature or science so much as a need to bolster their own power and legitimacy. Many scholars have noted how modeling authorizes itself in so far as its black-box nature gives it an air of objectivity (e.g. Hulme 2011) Louisiana planners claim their work is objective and good *precisely because* it involves modeling and the "best available numbers." But planners also *disavow* models when they say "tools didn't make decisions for us" since they want to acknowledge and incorporate stakeholder preferences. They believe they can do so through modeling since environmental management scholars argue that models can build common sense and consensus amongst stakeholders in resource allocation issues (Dietz et al. 2003). As Kelly et al. (2013, 176; emphasis added) summarized, "model[s] can capture a shared understanding of system processes and *can help people to manage disagreements*. With the aid of a model, for example, *conflict over management options can often be reduced* to more easily resolvable conflicts concerning underlying system assumptions."

Planners walk a fine line when it comes to using models, however – the line being seen as too subjective and not subjective enough. I saw that when the state walks this line, it opens itself up to contestation. Critical sociologists have shown that just as often as models build consensus, they generate conflict (Espeland 1998). In Louisiana, these conflicts are not always about the underlying system assumptions in the ICM or other models, and the winners and losers of modeling do not stem just from what happens when decision-makers act on model results. Instead, the challenges to modeling concern what and how it mediates. Fishers contest how

CPRA and the state planning apparatus are trying to be responsive to their own priorities by developing flexible metrics (too subjective). Oil and gas firms lament that the Master Plan is not more supportive of their industry (not subjective enough).

In short, I showed how the state's use of technology is conflict-prone. This is a different way of thinking about tools beyond "instruments of the state," one that illustrates potential fractures in technology-driven environmental governance. While we often think about technology's use in governance as a mere roll-out, models are not tools the state simply deploys to achieve its will.

In the same vein, I also showed how the state cannot just deploy models, but must confront their technical affordances. In other words, modeling "gives us" adaptive and petrostate kinds of governance, but in a performative way. Scholars have successfully demonstrated how the state is not a thing, but is comprised of different (human) actors (Mitchell 2009). This chapter expanded on other work illustrating how the state is comprised by technical objects. It provided a vocabulary of performance and mediation to better describe these objects' work within governance. Rather than seeing objects in themselves as the most important explanatory factor, I tested a sociomaterial approach combining model features with user expectations and experiences. I sought a way to account for what modeling seemed to do at MGP - planners pointed at it to reinforce their plans – but which also could account for what I saw at the Sediment Diversions Committee, where Captain Ricks contested the state's modeling process.

Performativity acknowledges the important role of objects in mediating governance approaches, while also witnessing contestation. In Louisiana, modeling has performed an adaptive management and petrostate coastal restoration regime. This may not be unexpected precisely because of the technical properties of modeling: it both simulates (allowing adaptation) and tends to perpetuate biases present in the data and algorithms which comprise it (Angwin and Larson 2016). At the same time, simulation evokes a range of potential futures and modeling surprises. So which is it? Performance - more than “deployment,” “instrumentalization,” or other such terms - suggests both a stability to what modeling does in governance *and* a sense of tenuousness and non-determinism. As long as the models keep operating as they have, and planners expect the same things from them, they will mediate an adaptive petrostate. But contests make the future of modeling itself uncertain – models could be performed differently, mediating different coastal governance regimes.

6. Conclusions

I start concluding this dissertation with a review of three main chapters (three, four, and five). I then make some reflections on my approach to understanding the ways modeling informs environmental policy. I synthesize the study's three main conclusions, offer some thoughts on what these mean for coastal policy more broadly, and finish with a call for three lines of future research.

6.1 Review

Chapter three described how modelers manage political and financial constraints in building an infrastructure for coastal science and policy. In environmental policy circles, the "best available science" is often presumed to drive governance. However, the case of the Louisiana Master Plan illustrates that modelers realize they cannot always get the science or data they want. Modelers are subject to a political environment skeptical of their expertise, decision-making timelines, budget and staffing limits, and an overabundance of data, a paucity of data, the wrong data, or poor quality data. Modelers must therefore strategize about how to make the ICM do what they and planners would like it to do. Modelers want the ICM to "resolve" – that is, to run and deliver outputs. They want these outputs to make ecological and biophysical sense. But they also want the ICM to prove useful in a decision-making context and to be viewed as legitimate. To make ICM submodels work in this way, modelers lean on three strategies: 1) They "work with the data," 2) they "choose or adapt the right tools," and 3) they "frame" their analysis. In choosing between these strategies, modelers' choices are shaped by institutional factors like where they work and existing investments in software. Modelers' and planners' decisions may seem like purely technical decisions about how to use models and data. In fact, they are choices to accept or work around existing funding sources, data availability, and commitments to specific models.

I found that following these tradeoffs demonstrated if and how technical practice actually forecloses transformative adaptation.

Chapter four explained how if (more, better) data is to "drive" conservation and transform adaptation, then it must be learned from. Planners are adamant "the tools did not make decisions for us… they just show us the numbers" - a common refrain in environmental governance. But it is a position that does not do justice to how models did inform planners' efforts and insights. First, a substantial amount of organizational work was required for the ICM to "just show the numbers," including determining how to pay for expertise and access models. The ICM itself had a part to play in coordinating experts along what I described as the "modeling chain." Second, because the tools were in fact not actually making the decisions – modelers and planners interpreted the numbers tools showed – the Master Plan effort needed "good modelers." "Good modelers" account for model uncertainty and tell stories about ICM outputs. Finally, while models did not make decisions, their technical features "afforded" specific kinds of insights by visualizing difference and trends, ease, flexibility, and fit. In other words, this chapter found that the boundaries between the social and the technical in environmental governance are not as clear-cut as planners claim. Planners sometimes see a world in which they can press a button, get information, and then deliberate with stakeholders about what that information means. But this imaginary assumes a social dimension "over there" with stakeholders and a technical one "over here" with models. It overlooks the social dimensions of organizing *for* modeling, and the technical dimensions of being organized *by* modeling.

In chapter five, I argued that model affordances also mediate how the state governs in the face of uncertainties and in support of specific restoration projects and stakeholders. In other words, the state does not just will itself into existence as a legitimate, adaptive benefactor of coastal special interests; it must develop as well as rely on the affordances and unintentional effects of modeling. In making this argument, I reviewed the final step of the Master Plan process, where planners govern with ICM outputs. First, planners rely on modeling to implement and adaptively manage specific restoration projects, but in a way that allows the state to manage uncertainties in future biophysical conditions. Second, aided by the planning tool, planners make sense of model outputs in ways that lead them to select restoration projects benefitting stakeholders like the oil and gas industry. Third, planners invest in specific models and modeling endeavors that have the effect of increasing the legitimacy of the coastal restoration program. However, various stakeholders contest the restoration projects and policies enabled by models, and, crucially, the modeling itself. Modeling may mediate adaptive management, but it displaced uncertainties about project outcomes onto fishers and many resist the state's flexible approach to modeling diversions. Some oil and gas interests do not think the modeling goes far enough to protect their infrastructure. Finally, modeling often contributes to frictions even though it is meant to smooth relationships between the state government and other governmental entities. I ended the chapter by evaluating planners' claim that "the tools [models] did not make decisions for us…they just showed us the numbers" in a different light from chapter four. Planners claimed their policies are objective and good precisely because they involve "just the numbers," modeling, and the "best available science and technology." But planners also disavowed modeling when they said "tools didn't make decisions for us," since they want to acknowledge and incorporate the preferences of stakeholders like the oil and gas industry. As one consultant put it in describing the genesis of the planning tool:

> …really the starting point was hey we need to come up with a plan [the Master Plan], and it has to be objective, because for too long it's been more of a collection of pet projects, programs with different goals….. we would use the same set of models to evaluate all different project types and then build a tool, which is essentially a way to look at all this information that was coming out of the models ["the numbers"], to compare the impacts of different projects on different metrics. Recognizing that CPRA you know values different things in different ways in different places along the coast. [We wanted a tool not for making decisions itself but] so the state would be able to have important conversations with stakeholders about what to do. (19)

I suggested that such an approach means planners walked a fine line in using the ICM and the planning tool – the line being seen as too subjective and not subjective enough. This is a different way of thinking about tools beyond "instruments of the state," one that illustrates the challenges with model-based environmental governance and how it must be constantly performed.

6.2 Reflecting on Mardi Gras Pass

This dissertation sought to explain how modeling software for ecosystem valuation is used in particular contexts, and whether its use achieves what Pelling (2010) called "transformative" adaptation. I took up Dempsey's (2016) call to understand "in some detail" what these models do. In the same vein, I took up Robbins and Moore's twin calls to political ecologists to rethink their "Hobbit-like," distrustful stance towards technology and to consider what kinds of governance regimes different technologies are amenable to and generative of. I looked to Louisiana's coastal Master Plan to answer these questions because it represents one of the world's most substantive, large-scale, and long-term attempts to use modeling for policy. Many commentators see Louisiana as a test case for how the rest of the US, if not other parts of the world, will pursue climate adaptation. Yet the coastal restoration program is still in its infancy. Only a handful of projects that were modeled have actually been constructed. Without much in the way of ecological outcomes, how can we talk about what makes for transformative adaptation? I think there are two ways.

First, we can adopt a conservative stance, taking modeled outcomes at face value. If what the ICM predicts does come true, we can expect the reproduction of many kinds of vulnerability. For instance, as we saw in chapter three, even if planners are able to implement their current $50 billion plan for protecting the coast, some communities will still face increased flooding. Some areas will even see more flooding *with* the plan than without it. Such uneven outcomes do not represent a transformative form of adaptation. We also saw in both chapter three and three that some aspects of the modeling leave intact the clientelistic relationship between the state and the oil/gas industry. This industry contributes on both ends – subsidence and rising seas – to land loss and is subject to boom and bust cycles. The result is that some communities will maintain a degree of socioeconomic vulnerability.

The second way to talk about outcomes is to talk about process. Even if we set aside what the ICM predicts, the process of model-based governance itself generates important adaptation outcomes. Researchers note the importance of "social infrastructure" to facilitating adaptation both at the community level and within governance networks more broadly (e.g. Dietz et al. 2003) As we saw in chapter four, the ICM itself compelled a transformation in the state's collaborative learning "infrastructure," in ways that align with what adaptive management researchers see as necessary for adaptive policy.

In addition, critical political ecologists show how procedural justice concerns around the recognition and authority of marginalized actors are key to transformative adaptation (Eriksen et al. 2015; Nightingale 2017). In chapter five, fishers contested modeling precisely because planners are modeling in a way that leaves fishers uncertain about what diversions operations will look like. This dissertation cannot report on sediment diversions' actual biophysical impacts. It can claim this: the main way in which planners assess diversion operations has the effect of re-marginalizing resource groups. Their approach leaves fishers unsure what diversion operations will be, *concretely*, while planners become more equipped over the long-term to manage future changes. At the same time, we saw in chapter three how coastal experts sought more data and modeling to understand, *broadly*, how diversions may impact fishers. This came after fishers' groups struggled against the inclusion of diversions in the plan. Again, this dissertation cannot assess proposed diversions' impacts, but it can say that calculating the winners and losers from diversions represents a kind of procedural transformation important to adaptation (Eriksen et al. 2015; Nightingale 2017). Those calculations take seriously and elevate fishers' concerns, recognizing their status as marginal resource users. Though this kind of modeling may be on the state's terms (cf. Nightingale 2017), fishers' voices have seen greater consideration.

There is one ecological outcome that we should make sense of. This dissertation began at Mardi Gras Pass. There, we saw how an unexpected crevasse diverted the Mississippi River into degrading marshes around Breton Sound. Given the site's history as a spillway constructed to mitigate flooding, the crevasse was hardly a "natural" event. Nevertheless, its appearance caused tremendous debate amongst conservationists, planners, and industry. Planners assessed it with modeling tailored to site conditions. As we saw in chapter five, this modeling stated that other restoration projects planners have invested time and money in would be worth less. Oil/gas infrastructure would also be threatened by keeping the crevasse open. What the state concluded from the analysis was two things: first, that it would not move forward with expanding MGP into a regulated sediment diversion and second, that the crevasse should be closed. In terms of the state's first conclusion - that it should not develop MGP into a diversion - we can reiterate everything we concluded above: institutional and financial investments shaped model-based decision-making, entrenching an existing state of affairs between state and special interests. Modeling expressed and reinforced this vulnerability-producing relationship.

In terms of the state's second conclusion - to close MGP – it turns out that the crevasse has not actually been filled yet. Modeling enabled a recommendation to close it, but modeling cannot act alone in the world. While MGP therefore currently operates freely, the Lake Ponchartrain Basin Foundation (LPBF) has conducted scientific studies of its impact, finding that it has distributed sediment to at least 15,000 acres of degrading marsh (Masson 2017). How do we explain the role of modeling in this kind of environmental change? Explaining the ongoing change at MGP would require understanding how model statements about MGP – what effect it would have on other diversions and oil and gas infrastructure - *failed* to result in quick action to seal the crevasse. We would also consider the role of conservationists like LPBF in countermodeling to demonstrate the land-building capacities of MGP. And we would highlight the significant legal challenges to sealing the breach, including permit requirements.

However, I did not explain the current ecological outcomes at MGP in this study. Instead, I focused on the closing of MGP, for three reasons. First, both of planners' conclusions about the site reflect how modeling informs policy, if not reality, conservatively rather than disruptively. Second, and related, modeling results can become important political statements in the world. The modeling done on MGP may not have led to it being shut down yet, but it has revealed to conservationists, fishers, and others that the state will sacrifice cheap new land in order to protect its planning investments and oil/gas interests.

The third and final reason I have focused on MGP's closure is that it is widely expected that the crevasse will eventually be closed or more strictly regulated. When it is, we will need to explain how and why the state turned down a free chance to build new coastal marshland, its stated goal. One approach would emphasize how clientelistic state/capital relations generated a landscape deprived of MGP's land-building benefits. This approach would situate environmental managers' decisions within a petro-state governance framework. In other words, it explains the closure of MGP and resulting landscape changes in terms of how states are supposed to facilitate the reproduction of petro-capital. However, my argument has been that viewing ecosystem management only through the lens of petro-capitalism is incomplete. It overlooks how modeling is a mediating moment in reproducing the relationship between state and capital. When planners model to measure how restoration will affect the oil and gas industry, they reproduce petro-capital. Moreover, this reproduction is tenuous. As chapter five showed, it is reliant on model affordances, unintentional effects, and it is contested. I have argued here that we can attempt *sociotechnical* explanation for the kinds of modeling-mediated environmental changes that MGP represents. Such an explanation follows a chain from real or simulated landscapes to modeling practice - decisions about what data to include and how modeling was organized (chapters three and four) - and situating model affordances in relation to state austerity politics and discourse (chapter five).

To finalize the MGP arc: political economic and technical factors explain how modeling informed planners' decisions. As shown in chapter five, these factors include the state's existing investments, oil/gas and navigational interests, and how modeling afforded a static assessment of MGP's impact on other diversions. The outcome already is a foreclosing and forsaking of diversion-built, vulnerability-reducing land. At the same time, legal issues and conservationists' countermodeling have mitigated this, leaving the crevasse open to build some new land. In short, I have oriented much discussion in this dissertation around MGP because it shows that a) political and financial, in addition to technical factors, shape how models are used in policy; b) modeling can generate both policy and ecological outcomes.

In a way, I have again landed more or less where many political ecologists find themselves: states use technology to foreclose transformative socioecological change. However, my approach was different, for two reasons. First, I added modeling software itself to the "chain" or "webs" of factors explaining how modeling foreclosed transformative change at MGP. Second, my study is not limited to the case of MGP. There are other facets of coastal restoration where I have found technology to be more transformative. MGP is just one flash point in coastal restoration. If the general story over the course of this dissertation seems at times contradictory (e.g. sometimes modeling advances just adaptation for fishers, sometimes modeling elides it), that is a reflection of the fact that governance, even with sophisticated technology, is not straightforward. It may also be a reflection of how scholars sometimes treat governance abstractly. Instead, specific governance processes are profoundly shaped by ever-changing context.

In closing this dissertation,-I do three things. First, I connect these findings to the research questions and frameworks that motivated this research. I then present my conclusions: a) financial, political, technical conditions are behind how modeling informs adaptation policy; b) transformative adaptation has to do with modelers' practices and models' affordances; c) transformative adaptation is sociotechnical. Second, I further describe some of the policy stakes from these conclusions. Finally, I suggest where this work might lead. I outline three areas of future research on digital environments: infrastructure, practice, and praxis.

6.3 Synthesis

In this section, I directly answer the main overarching questions that motivated this research – how does modeling inform policy in actual contexts and how does modeling foreclose or lead to transformative adaptation policy? In synthesizing my answers across all three substantive chapters, I develop three conclusions. I begin by saying a bit more about why I think it is important to ask how modeling informs policy in specific geographic contexts.

As described in the introduction to this dissertation, conservationists are optimistic about the ability of ecosystem services modeling software to inform better environmental management. This optimism tends to make few references to on-the-ground realities. It sets apart ecosystem models from their social and political contexts. The implicit promise is that science will lead to better conservation by holistically describing ecosystems with better algorithms. So, asking how modeling informs policy in specific contexts is an antidote to optimistic assumptions that modeling or any other kind of conservation technology will by default inform policy.

Political ecologists already claim that conservation management ignores concrete local conditions. But political ecologists also tend to see technology as an expression of capitalism or state logics. Their pessimism makes modeling overdetermined by its broader social context. It overlooks how modeling is practiced. I believe that political ecologists should rethink their pessimism about technology, by further exploring how technology informs environmental management. Another way of thinking about this is that capitalism and the state engage technology only in specific geographic contexts. Robertson (2006) illustrated how the production of scientific metrics for states/markets is a process requiring individual actors' translations. Likewise, we should see the role of modeling practice in translating science into state planning.

6.3a How modeling informs adaptation policy

Now I will revisit the research questions and synthesize three answers. The broad research question was, does modeling even inform policy? I found three factors by which modeling informed policy:

- Political - e.g. model results enter into policy within the context of public outcry over how much money is spent on the Master Plan and how modelers manage this.
- Financial - e.g. model results enter into policy in the context of how much funding is available for modeling and available for restoration in general.
- Technical - e.g. model results enter into policy by affording different insights.

I found that these factors explain how modeling informs policy better than how technically advanced, objective, or representative of the "best available science" modeling is.

6.3b Transformative adaptation: modelers' practices and models' affordances

But my venture was that it also pays to more specifically ask, when does modeling indicate *transformative adaptation* – a transformation of state, capital, and civil society relationships that furthers adaptation to climate change vulnerabilities? When does modeling foreclose such a transformation?

These are worthy questions because a prominent postpolitics argument says that technology forecloses transformative climate change action. The argument claims modeling discretizes complex phenomenon, obscures issues by reducing them to a few variables, ignores local historical factors, and generally aims for consensus rather than dissensus, especially in the face of urgent climate crises. I do not completely disagree with this argument, but I believe it is worth taking two steps to advance it: first, how exactly does modeling foreclose? Is it something about modeling itself? Second, asking, is it always true that modeling forecloses transformative change?

I found political, financial, and technical factors indicate whether modeling transforms how state and civil society adapt. These structure and are managed by modelers' practices and models' affordances. First, modelers' practices include managing political, financial, and technical constraints to make their tools viable for the Master Plan. It is precisely the ways they do so that indicate foreclosure or transformation. This can be rephrased or summarized as, what do modelers and planners ask data and models to do? Sometimes the question they ask is foreclosing, sometimes it is transformative. Examples of foreclosing questions include experts asking:

- How can we fit MGP into existing plans and oil/gas infrastructure? (Rather than, how to adapt these to MGP?)

- How much land can we build with $50 billion? (Rather than, how much land do we need to ensure sustainable livelihoods?)
- What is the least amount of data we can collect to answer the questions we expect to ask of restoration projects? (Rather than, how much data do we need to collect to ask a wide range of questions, given that the future is uncertain?)

In other words, the *amount* of data itself is not an important factor. This actually suggests that modeling data is not inherently foreclosing. Examples of *transformative* questions experts ask: who will win and lose from diversions? How can we get the data to show this? These questions are transformative because they afford fishers and other marginalized groups recognition of their role in governance. They also allow fishers to plan for and contest diversions. In other words, these questions are potentially generative of "dissensus," even though they are routed through modeling. Technology, therefore, is a mediator of social change. Modeling enables change while intervening and shaping social it.

Beyond how *modelers'* practices foreclose or transform adaptation, *models'* "practices" inform it. The affordances of modeling reflect its transformative possibilities. Models afford the kinds of insights and organizational styles that many see as important to enabling the state to perform adaptive governance. Specifically, for instance, models can compel a reorganization of how experts collaborate (as we saw with the ICM in chapter four). However, models also mediate governance, and how they do so can exacerbate vulnerabilities. For instance, fishers are left in limbo with the simulations that prepare planners to flexibly operate diversions. This forecloses transformative adaptation by actually creating a new kind of vulnerability for fishers (chapter five).

6.3c Transformative adaptation is sociotechnical

Louisiana's restoration program blurs the lines between what we typically think of separately as "social" and "technical" environmental management practices. Researchers cannot just focus on the social dimensions of environmental governance, as if they existed apart from the technical aspects. Expert knowledge and organizational structure is enabled, constrained, and translated by ICM models, as technical artefacts (chapter four). At the same time, they afford insight and structure, they do so on their own – planners' expectations and expertise are conditions enabling models to act. The way modelers manage constraints is not just "technical" either (chapter three). Their decisions about how to deal with time and budget constraints represent important ways adaptation is politicized. We are limited in lamenting austerity if we fail to consider how it is expressed through modeling practice. Many of the "social" struggles around adaptation in Louisiana – like funding home elevations for poor residents - have roots, flare up, and are given material character in modeling (Gulf Restoration Network, n.d.). Related, we cannot just lament modeling as technocratic – a conscious or unconscious way state actors subvert politics. That is because modeling practice itself, and in reference to the world it simulates, always engages with questions of who gets what and who matters. It is easy to treat modeling as eliding politics because it represents the world in overly discrete, reductive, or ignorant ways. But if we look at modeling as practice, we can witness the contested and contestable processes that explain why it does.

6.4 Policy implications

Adaptation is a sociotechnical process. This insight has two kinds of implications for environmental management. First, experts cannot just focus on getting the data right. Some tech advocates argue that data infrastructur-ing limits them more than figure out how to analyze the data (Strombolis and Frank 2014). This may be technically true, but getting the question right is more important for producing transformative social changes, as is the cultivation of expert subjects, translation between kinds of expertise, and political economic factors. The second implication, however, is that building capacity, increasing stakeholder representation, or in general improving “social infrastructure” (Armitage et al. 2008; Armitage et al. 2009), will not cut it either because these have technical dimensions. Transformation is not just a matter of changing social relations in the right way because models and other technologies enable social organization and learning.

I have characterized some of what these conclusions mean for the Master Plan case:

Targets first, optimize second – Planners claim that optimizing the projects they select is an important part of developing a realistic and objective Master Plan. Realistic because it accommodates the general lack of funding for restoration, objective because optimization relies on numeric ICM output. But optimization means decision-makers have to pass on some projects that will reduce vulnerabilities. Planners already emphasize their process is also subjective because it incorporates stakeholder feedback and preferences. I suggest this opens up an opportunity to ask different questions in the Plan. Planners and modelers could return to the original, targets-based approach for analyzing ICM output (see chapter three). Instead of selecting the projects that will build the most land for $50 billion, they could model to determine how much land would be necessary to reduce flooding for everyone, or to maintain fisheries, and what set of projects would be needed to do so. After all, flood reduction and a working coast are already two of CPRA’s goals; the agency should demonstrate what resources it would take to achieve them.

Map winners and losers – If CPRA sticks with the optimization approach, there will be obvious winners and losers. The agency has already admitted that their current plan will not reverse land loss – it will simply slow it. While the winners and losers may be apparent to the planners interacting with ICM outputs, there is more CPRA could do to make clear who Master Plan proposals will benefit and who they will harm. Leaders do already examine ICM outputs by region to get a feel for which communities will benefit and by how much. They also model food webs to estimate the effects of diversions on different fishers. There can be much more of this kind of analysis, especially in the agency's public-facing maps and reports. For instance, its Resilience Viewer enables users to see whether they will be flooded with or without the plan, but the webmap does not really afford this kind of insight. It is difficult to assess change with the tool since, for instance, it maps absolute flood height values, not differences in flood heights between scenarios.

Go basic – identify a broad, ambitious program for collecting data about the coast, rather than one based on current expectations of future data needs. This will ensure that coastal experts have the informational resources in the future to respond to unforeseen events and research questions.

Make investments in technology – when I spoke with coastal restoration experts, they often talked about how modeling software has gotten better over time. Sometimes they described this as almost a natural process. In fact, it happened through specific investments modelers pushed for and planners made. I also asked experts what tools they would like in the future. For these to come about, the state will need to make strategic decisions about funding model development. Many improvements may be reliant on the open source community or industry trends. Most, like reworking the ICM's spatial analysis code in order to move away from proprietary software and towards cloud computing, will not occur on their own. In the spirit of "going basic," such investments may be targeted towards specific changes, but should also ensure flexibility based on unanticipated future needs.

Manage expectations – within the community of coastal experts, I found some differences of perspective on whether "tools make decisions." Some believe a way to "ease" decision-making is what planners are looking for. On the other hand, some consultants acknowledge "it's not like we've been building a big tool and we'll press a button and we'll get all this analysis," and planners argue that the "tools didn't make decisions for us." From my perspective, "building an institution" for coastal science and policy is dependent on shared expectations, but those do not seem to be in place on this specific issue.

Understand and improve process – When experts run simulations to flexibly manage diversions, they hope to be able to optimize land-building outcomes in light of changing sea levels and river conditions. This flexibility makes life less certain for fishers. There is opportunity for experts to improve the diversions planning process by defining concrete plans and assessing their impacts on fishers.

6.5 Future directions

Where does this work lead? My own long-term research interest centers on valuation – how do unvalued parts of our socioecological world come to have value within a capitalist economic system? I have examined how "alternative" tourism in underdeveloped places can paradoxically commodify those places (Nost 2013), how "community"-oriented agriculture can also paradoxically rely on commodification (Nost 2014), how ecosystem assessment models calculate "nature's value" for new markets in environmental restoration (Nost 2015), and how hazardous waste re-enters commodity circuits (Moore et al. in review). This dissertation addressed the role of technology in valuation by asking, how does modeling play a part in state planning efforts that value underappreciated wetland ecosystem services? In this "future directions" section, I detail three research paths that I see as important beyond the Louisiana coastal Master Plan and that I hope digital geographers and political ecologists will take up: digital infrastructures, practice, and praxis.

6.5a Digital infrastructures

In this research stream, I ask, what are the platforms that enable environmental governance? How are these designed, applied, and contested, and what consequences do they have for conservationists, "environmental publics" (Eden 2016), and governments? By infrastructures, I am drawing on Edwards's and others' work on infrastructure as the institutional standards and technical devices that facilitate networks, smooth "data friction," and enable knowledge regimes. For instance, climate modelers have developed an extensive infrastructure comprising of climate models and standards for making technically-sound predictions - an infrastructure that has informed, most notably, the development of international climate governance bodies like the IPCCC. The internet itself is structured by open "protocols" that allow computers around the world to speak to one another. But by "platforms," I am specifically referring to the more "surficial" infrastructures consisting of the *triad* of *models/algorithms, websites,* and *databases* (rather than the "deep" infrastructure of TCP/IP protocols or what Johnson [2018] article author calls "Internet 1.0"). Airbnb, for instance, is a platform for short-term rentals, consisting of an incredibly detailed database of "home hotels" and a public-facing website that allows users to interact with the database. The Airbnb platform has enabled a re-intensification of housing markets, arguably deepening the subsumption of the home to capital and significantly impacting housing affordability and availability around the world (Fields; Wachsmuth) As a result, governments around the world – including, most notably, the City of New Orleans – have sought to regulate the conditions by which homeowners, renters, and landlords can participate in the platform. New Orleans in particular has done so in part by requiring Airbnb to regularly turn over its database to officials for cross-verification with the city's own short-term rental licensing database.

Airbnb provides an example where digital infrastructures are front and center in urban governance. I would like to see digital infrastructures more squarely situated as an object of concern within political ecological approaches to environmental governance. We should not just focus on the downstream conflicts around knowledge, land, and markets that data have a part in. Instead, we should also pay attention to the contested and consequential governance of infrastructures for this data. This call builds on chapter three and the broader point that environmental governance is inseparable from technology governance. Data infrastructures like government environmental databases and websites are important sites of contestation themselves. Although there is probably no real Airbnb analogy in the environmental realm, we can think of something like The Natural Capital Project's suite of modeling tools or The Nature Conservancy's (TNC) Coastal Resilience web portal as platforms for environmental governance. One Airbnb-like environmental governance platform is the case of "precision conservation" in California's rice fields (an analogy made explicit in an argument by Jayachandran [2017]).

There, Cornell University researchers and TNC have developed models that use crowdsource presence data on migrating birds in order to predict these birds' flight plans and recommend which rice farmers TNC should pay to temporarily keep their fields flooded as "pop-up habitat."

I see data infrastructural research as happening within, between, and beyond the state. Within the state, this might mean land titling databases. In many contexts where land has not been formally titled, it would be key to ask, what does it mean to represent land titles in a computer database? In what way is land represented? Who is doing this work and what "strategies" are they using to make the database work? How is the database contested? Actions taken by the Harper government in Canada and the Trump administration in the US (Rinberg et al. 2018) also raise pressing questions about how states produce, maintain, and distribute environmental databases.

There is also fruitful research to be done on how platforms mediate interactions *between* the state and civil society. The relationship between citizens and bureaucracy is a long-explored one (i.e. e-government; Eschenfelder 2004; Eschenfelder and Miller 2007; Feldpausch-Parker and Peterson 2015; Hart et al. 2015). Increasingly, the way the public interacts with the state is through social media and agency websites. This does not necessarily imply a greater depth of engagement, but digital interaction is potentially different than previous modes and potentially "transformative" of the citizen-state relationship (Eschenfelder 2004). How can we understand the changing relationship between state and society, by researching its web presence? The "rogue" Twitter accounts that formed at the beginning of the Trump administration, or the Obama EPA's contested use of social media around the Clean Water Rule, represent potential case studies furthering "Nature 2.0" research on "digital environmental politics" (e.g. Büscher et al. 2017; Hawkins and Silver 2017). Additionally, the Environmental Data and Governance Initiative has tracked how federal agencies are altering the presentation of climate change on their websites, by removing pages and links and by altering language (Rinberg et al. 2018). In so far as climate change communication is a terrain for contemporary environmental politics, highlighting federal agencies' modifications to their web platforms can be a starting point for a line of Nature 2.0 research beyond the conservation realm per se.

Finally, there is important work that could be done on digital infrastructures beyond the state. This dissertation focused solely on infrastructures developed and used by actors within or closely aligned to the state, and ultimately, *for* the state as it plans coastal restoration. But conservationist groups have long been adopting many state environmental planning functions - and the digital infrastructures that go with these functions. The "pop-up habitat" example above provides one illustration. How is conservation practice changed as conservationists become data managers? As one conservationist organization in Maryland described their water quality management tool, "this is really big data. 900 times the resolution, meaning 900 times more data. It puts a strain on our local infrastructure. Older computers don't have the power to even bring it up. We're working to enable our partners with web tools instead." (Notes, webinar September 2016) Conservationists' models comprise an infrastructure that is buttressed by a variety of proprietary and open source devices, embodied knowledge, and social institutions. But developing and maintaining this infrastructure reworks or requires new conservation subjectivities, if only because conservationists consequently spend less time in the field.

6.5b Digital practice

The focus on "conservationist subjectivities" around data infrastructure leads into the second of three future research streams, concerning digital practice. I build on chapter four of this dissertation to ask, who are the *users* of models, maps, social media and in general the digital infrastructure of environmental governance? In particular, what can these users learn and do with their tools - what are they afforded?

In this research trajectory, I focus mostly on users *beyond* the state. In this dissertation, I explained how planners within state agencies are afforded insights on, for instance, trends in coastal change. In other words, the case has focused largely on how *states* and their affiliates practice digital technologies like computer models. Political ecology, however, has long focused on the decision-making frameworks and contexts of peasant land managers (e.g. Blaikie). A very relevant question is how individual *non-state actors* practice decision-support software. A case study in "smart farming" would draw on and extend classic political ecology approaches. Smart farming describes a suite of technologies – remote sensing, precision application tractors, and "dashboards" – that are meant to aid farmers in increasing yields, reducing nutrient applications, and achieving other conservation benefits. There is an explosion of public interest in smart farming given concerns farmers have about the privacy of data collected by tractor sensors and the propriety nature of hardware and software in new farm equipment (article). Academic research has sought to conceptualize these data concerns (e.g. Fraser 2018). I think another important line of inquiry has to do with practice: comparing the discourses imagining how farmers *should* use these tools and what they will accomplish with them, and how farmers actually do use them.

I also intended to expand the survey of Master Plan maps that I conducted in chapter four. Beyond the Master Plan, I believe we need to understand what ecosystem services models enable their expert users to see. Conservationists hope these models can mediate between science and environmental policy, so it is important to understand how they translate that science. Advocates for ecosystem services-oriented policy say that the ecosystem services concept itself makes communicating environmental protection and restoration to decision-makers easier. There are good reasons to be skeptical of this claim. Unfortunately, much of the geographical research on ecosystem services models has essentially focused on their algorithms for spatial analysis. How they represent and communicate the spatial dimensions of ecosystem services matters. I am especially interested in how ecosystem services models depict the winners and losers of managing for ecosystem services. At ecosystem services policy conferences, I have heard model-makers talk about depicting "winners and losers," but a preliminary survey I conducted suggests few tools enable their users to clearly see winners and losers (see here). For instance, CPRA's "Data Viewer" for the Master Plan allows users to view projected flood depths in their neighborhoods under different scenarios, but the webmap does not afford showing who will face increased flood depths with and without the actions proposed in the plan.

6.5c Digital praxis and pedagogy

Building from the observation that few if any ecosystem services models enable their users to understand winners and losers, in this final research stream, I ask, can we make decision-support models and webmaps differently? More broadly, how can data serve progressive ends in and beyond the classroom? Answering these questions requires splitting the difference between critiques of data as disciplining (e.g. Shapiro et al. 2017) and the emphasis in both environmental justice work as well as critical GIS that we ignore data only at our own risk (e.g. Fortun 2016;

Moore et al. 2017). Data can be strategically mobilized to transformative ends. Some are beginning to articulate principles for what conditions enable such strategic data mobilization, emphasizing: community self-determination around data representation and easy access to tools for data analysis (i.e. what Walker et al. (in review) call environmental data justice.)

In terms of more concrete applications of environmental data justice principles, I am interested in how political ecologists might use big data to visualize and analyze environmental change, conflict, and control (Nost et al. 2017; Moore et al. 2017; McCarthy and Thatcher 2017; Foo forthcoming). To follow-up on the question of how ecosystem services models represent winners and losers, I see a need to build an "alternative" ecosystem services decision-support tool that would enable users to see "winners and losers" and which could facilitate experiments with different approaches to representing nature within policy. I will be building from the previously mentioned preliminary survey of ecosystem services models and from CPRA's Master Plan Data Viewer in particular, to implement an example of such a tool, in advance of Louisiana's State of the Coast conference in 2020.

References

Adams, W. M. 2017. Geographies of conservation II: Technology, surveillance and conservation by algorithm. *Progress in Human Geography* :030913251774022.

Adger, W. N. 2003. Social capital, collective action, and adaptation to climate change. *Economic geography* 79 (4):387–404.

Adger, W. N. 2005. Social-Ecological Resilience to Coastal Disasters. *Science* 309 (5737):1036–1039.

Adger, W. N. 2006. Vulnerability. *Global Environmental Change* 16 (3):268–281.

Adger, W. N., S. Huq, K. Brown, D. Conway, and M. Hulme. 2003. Adaptation to climate change in the developing world. *Progress in Development Studies* 3 (3):179–195.

Akrich, M. 1992. The de-scription of technical objects. Shaping technology/building society 205– 224.

Akhter, M. 2016. Desiring the data state in the Indus Basin. *Transactions of the Institute of British Geographers*. http://doi.wiley.com/10.1111/tran.12169 (last accessed 9 April 2017).

Alexander-Bloch, B. 2015. St. Bernard council adopts resolution opposing proposed sediment diversions. *NOLA.com*. http://www.nola.com/politics/index.ssf/2015/04/proposed_sediment_diversions_o.html (last accessed 2 March 2018).

Alvarez León, L. F., and C. J. Gleason. 2017. Production, Property, and the Construction of Remotely Sensed Data. *Annals of the American Association of Geographers* :1–15.

Amoore, L. 2016. Cloud geographies: Computing, data, sovereignty. *Progress in Human Geography* :030913251666214.

Anderson, C. 2008. The End of Theory: The Data Deluge Makes the Scientific Method Obsolete. *WIRED*. https://www.wired.com/2008/06/pb-theory/ (last accessed 2 March 2018).

Angwin, J., and L. Larson. 2016. Machine Bias. *ProPublica*. https://www.propublica.org/article/machine-bias-risk-assessments-in-criminal-sentencing (last accessed 2 March 2018).

Argyris, C., & Schon, D. (1978) *Organisational learning: A theory of action perspective*. Reading, Mass: Addison Wesley.

Armitage, D., M. Marschke, and R. Plummer. 2008. Adaptive co-management and the paradox of learning. *Global Environmental Change* 18 (1):86–98.

Armitage, D. R., R. Plummer, F. Berkes, R. I. Arthur, A. T. Charles, I. J. Davidson-Hunt, A. P. Diduck, N. C. Doubleday, D. S. Johnson, M. Marschke, P. McConney, E. W. Pinkerton, and E. K. Wollenberg. 2009. Adaptive co-management for social–ecological complexity. *Frontiers in Ecology and the Environment* 7 (2):95–102.

Atkinson, P., and M. Hammersley. 2000. Ethnography and participant observation. *Handbook of Qualitative Research*.

Bakker, K., and G. Bridge. 2006. Material worlds? Resource geographies and the `matter of nature’. *Progress in Human Geography* 30 (1):5–27.

Barnes, J. 2017. States of maintenance: Power, politics, and Egypt’s irrigation infrastructure. *Environment and Planning D: Society and Space* 35 (1):146–164.

Barnes, T. J. 2013. Big data, little history. *Dialogues in Human Geography* 3 (3):297–302.

Barras, J. A. 2005. Land area changes in coastal Louisiana after Hurricanes Katrina and Rita. *Science and the storms: the USGS response to the hurricanes of* :98–113.

Barry, John M. 1997. Rising tide: the great Mississippi flood of 1927 and how it changed America. New York: Simon & Schuster.

Bassett, T. J., and C. Fogelman. 2013. Déjà vu or something new? The adaptation concept in the climate change literature. *Geoforum* 48:42–53.

Bates, J. 2017. The politics of data friction. *Journal of Documentation*. http://www.emeraldinsight.com/doi/10.1108/JD-05-2017-0080 (last accessed 22 December 2017).

Berg. 1997. *Rationalizing Medical Work*. MIT Press. https://mitpress.mit.edu/books/rationalizing-medical-work (last accessed 2 March 2018).

Beymer-Farris, B. A., T. J. Bassett, and I. Bryceson. 2012. Promises and pitfalls of adaptive management in resilience thinking: the lens of political ecology. In *Resilience and the Cultural Landscape*, eds. T. Plieninger and C. Bieling, 283–300. Cambridge: Cambridge University Press http://ebooks.cambridge.org/ref/id/CBO9781139107778A026 (last accessed 2 March 2018).

Blaikie, P. 1985. Chapters 5-7. pages 79-88, 107-137 In The Political Economy of Soil Erosion in Developing Countries. London and New York: Longman.

Blaikie, P., and H. Brookfield. 1987. Land Degradation and Society. Routledge Kegan & Paul.

Blum M D and Roberts H H 2009 Drowning of the Mississippi delta due to insufficient sediment supply and global sea-level rise Nat. Geosci. 2 488–91

Bogdewic, S. P. 1999. Participant Observation. In Doing qualitative research, eds. B. F. Crabtree and W. L. Miller. SAGE Publications Ltd.

Boumans, R., R. Costanza, J. Farley, M. A. Wilson, R. Portela, J. Rotmans, F. Villa, and M. Grasso. 2002. Modeling the dynamics of the integrated earth system and the value of global ecosystem services using the GUMBO model. *Ecological economics* 41 (3):529–560.

Bowker, G. C. 2000. Biodiversity Datadiversity. *Social Studies of Science* 30 (5):643–683.

Bowker, G. C., K. Baker, F. Millerand, and D. Ribes. 2009. Toward Information Infrastructure Studies: Ways of Knowing in a Networked Environment. In *International Handbook of Internet Research*, eds. J. Hunsinger, L. Klastrup, and M. Allen, 97–117. Dordrecht: Springer Netherlands http://link.springer.com/10.1007/978-1-4020-9789-8_5 (last accessed 11 April 2017).

Bracking, S. 2015. The Anti-Politics of Climate Finance: The Creation and Performativity of the Green Climate Fund. *Antipode* 47 (2):281–302.

Brantley, C. G., J. W. Day, R. R. Lane, E. Hyfield, J. N. Day, and J.-Y. Ko. 2008. Primary production, nutrient dynamics, and accretion of a coastal freshwater forested wetland assimilation system in Louisiana. *Ecological Engineering* 34 (1):7–22.

Braun, B. P. 2014. A new urban dispositif? Governing life in an age of climate change. *Environment and Planning D: Society and Space* 32 (1):49–64.

Braun, Bruce and Sarah Whatmore, eds. 2010. Political Matter: Technoscience, Democracy and Public Life. Minneapolis: University of Minnesota Press, 319pp.

Brown, K. 2014. Global environmental change I: A social turn for resilience? *Progress in Human Geography* 38 (1):107–117.

Bryant, G. 2016. The Politics of Carbon Market Design: Rethinking the Techno-politics and Post-politics of Climate Change: The Politics of Carbon Market Design. *Antipode* 48 (4):877–898.

Burawoy, M. 1998. The Extended Case Method. *SOCIOLOGICAL THEORY*.

Burkhard, B., N. Crossman, S. Nedkov, K. Petz, and R. Alkemade. 2013. Mapping and modelling ecosystem services for science, policy and practice. *Ecosystem Services* 4:1–3.

Büscher, B., S. Koot, and I. L. Nelson. 2017. Introduction. Nature 2.0: New media, online activism and the cyberpolitics of environmental conservation. *Geoforum* 79:111–113.

Butler J. 1990. Gender Trouble: Feminism and the Subversion of Identity (Routledge, London)

———. 2010. PERFORMATIVE AGENCY. *Journal of Cultural Economy* 3 (2):147–161.

Caffey, R. H., H. Wang, and D. R. Petrolia. 2014. Trajectory economics: Assessing the flow of ecosystem services from coastal restoration. *Ecological Economics* 100:74–84.

Cahoon, D. R., and G. R. Guntenspergen. 2010. Climate change, sea-level rise, and coastal wetlands. *National Wetlands Newsletter* 32 (1):8–12.

Cahoon, D. R., and R. E. Turner. 1989. Accretion and Canal Impacts in a Rapidly Subsiding Wetland II. Feldspar Marker Horizon Technique. *Estuaries* 12 (4):260.

Callon, M. 2007. What does it mean to say that economics is performative. *Do economists make markets* :311–357.

Castree, N. 2002. False Antitheses? Marxism, Nature and Actor-Networks. *Antipode* 34 (1):111–146.

Christophers, B. 2014. From Marx to market and back again: Performing the economy. *Geoforum* 57:12–20.

Clarke, K. C. and Jeffrey J. Hemphill (2002)The Santa Barbabra Oil Spill, A Retrospective. Yearbook of the Association of Pacific Coast Geographers, Editor Darrick Danta, University of Hawai'i Press, vol. 64, pp. 157-162.

Cockayne, D. G. 2016. Affect and value in critical examinations of the production and 'prosumption of Big Data. *Big Data & Society* 3 (2). http://bds.sagepub.com/lookup/doi/10.1177/2053951716640566 (last accessed 11 April 2017).

Costanza, R., S. C. Farber, and J. Maxwell. 1989. Valuation and management of wetland ecosystems. *Ecological economics* 1 (4):335–361.

Coastal Protection and Restoration Authority. 2017. Louisiana's comprehensive master plan for a sustainable coast. http://coastal.la.gov/our-plan/2017-coastal-master-plan/. Coastal Protection and Restoration Authority, State of Louisiana. (accessed 17 October 2017).

CPRA. 2012. Louisiana's comprehensive master plan for a sustainable coast. http://www.coastalmasterplan.louisiana.gov/2012-master-plan/final-master-plan/. Coastal Protection and Restoration Authority, State of Louisiana. (accessed 30 November 2014).

Cook, I. 1997. Participant Observation. In Methods in human geography, eds. Flowerdew and Martin.

Cope, M. 2005. Coding Qualitative Data. In Iain Hay (ed.) *Qualitative Methodologies for Human Geographers*, 2nd edition Oxford University Press, pp. 310-324.

Couvillion, B. R., H. Beck, D. Schoolmaster, and M. Fischer. 2017. *Land area change in coastal Louisiana (1932 to 2016)*. Reston, VA: U.S. Geological Survey. http://pubs.er.usgs.gov/publication/sim3381 (last accessed 2 March 2018).

Cox, L. M., A. L. Almeter, and K. A. Saterson. 2013. Protecting our life support systems: An inventory of U.S. federal research on ecosystem services. *Ecosystem Services* 5:163–169.

Crampton, J. W., M. Graham, A. Poorthuis, T. Shelton, M. Stephens, M. W. Wilson, and M. Zook. 2013. Beyond the geotag: situating 'big data' and leveraging the potential of the geoweb. *Cartography and Geographic Information Science* 40 (2):130–139.

Crampton, J. and A. Miller. 2016. Intervention Symposium – Algorithmic Governance. *Antipode*.

Crang, M. 1997. Analyzing qualitative materials. In Methods in human geography, eds. Flowerdew and Martin.

Crutcher, M., and M. Zook. 2009. Placemarks and waterlines: Racialized cyberscapes in post-Katrina Google Earth. *Geoforum* 40 (4):523–534.

Dalton, C. M., and J. Thatcher. 2015. Inflated granularity: Spatial "Big Data" and geodemographics. *Big Data & Society* 2 (2):205395171560114.

Day J, G. P. Kemp, A.M. Freeman, and D. Muth, eds., Perspectives on the Restoration of the Mississippi Delta: The Once and Future Delta. New York, Springer.

Dempsey, J. 2013. Biodiversity loss as material risk: Tracking the changing meanings and materialities of biodiversity conservation. *Geoforum* 45:41–51.

———. 2016. *Enterprising Nature: Economics, Markets, and Finance in Global Biodiversity Politics*. John Wiley & Sons.

Dempsey, J., and M. M. Robertson. 2012. Ecosystem services: Tensions, impurities, and points of engagement within neoliberalism. *Progress in Human Geography* 36 (6):758–779.

Dietz, T., E. Ostrom, and P. Stern. 2003. The Struggle to Govern the Commons. *Science* 302 (5648):1171–1171.

Dodge, M., and R. Kitchin. 2004. Flying through Code/Space: The Real Virtuality of Air Travel. *Environment and Planning A* 36 (2):195–211.

Easterling, K. 2016. *Extrastatecraft: The Power of Infrastructure Space* Reprint edition. London: Verso.

Edwards, P. N. 2010. *A vast machine: computer models, climate data, and the politics of global warming*. Cambridge, Mass: MIT Press.

Edwards, P. N., G. C. Bowker, S. J. Jackson, and R. Williams. 2009. Introduction: an agenda for infrastructure studies. *Journal of the Association for Information Systems* 10 (5):6.

Engle, V. D. 2011. Estimating the Provision of Ecosystem Services by Gulf of Mexico Coastal Wetlands. *Wetlands* 31 (1):179–193.

Erban, L. E., S. M. Gorelick, and H. A. Zebker. 2014. Groundwater extraction, land subsidence, and sea-level rise in the Mekong Delta, Vietnam. *Environmental Research Letters* 9 (8):084010.

Eriksen, S. H., A. J. Nightingale, and H. Eakin. 2015. Reframing adaptation: The political nature of climate change adaptation. *Global Environmental Change* 35:523–533.

Eschenfelder, K. R. 2004. Behind the Web site: An inside look at the production of Web-based textual government information. *Government Information Quarterly* 21 (3):337–358.

Eschenfelder, K. R., and C. A. Miller. 2007. Examining the role of Web site information in facilitating different citizen–government relationships: A case study of state Chronic Wasting Disease Web sites. *Government Information Quarterly* 24 (1):64–88.

Espeland, W.N., 1998. *The Struggle for Water: Politics, Rationality, and Identity in the American Southwest*. University of Chicago Press, Chicago.

Etherington, D., and M. Jones. 2018. Re-stating the post-political: Depoliticization, social inequalities, and city-region growth. *Environment and Planning A: Economy and Space* 50 (1):51–72.

Faraj S, Azad B, 2011, "The materiality of technology: an affordance perspective", in Materiality and Organizing: Social Interaction in a Technological World Eds Lonardi PM, Nardi BA, Kallinikos J (Oxford University Press) pp 237–258

Feldpausch-Parker, A. M., and T. R. Peterson. 2015. Communicating the Science behind Carbon Sequestration: A Case Study of US Department of Energy and Regional Partnership Websites. *Environmental Communication* 9 (3):326–345.

Ferguson, J. 1994. *The Anti-Politics Machine*. https://www.upress.umn.edu/book-division/books/the-anti-politics-machine (last accessed 2 March 2018).

Fish, C. S., and K. Calvert. 2017. An Analysis of Interactive Solar Energy Web Maps for Urban Energy Sustainability. *Cartographic Perspectives* 0 (85):5–22.

Fletcher, R. 2014. Orchestrating Consent: Post-politics and Intensification of Nature ™ Inc. at the 2012 World Conservation Congress. *Conservation and Society* 12 (3):329.

Forsyth, T. 2003. Critical political ecology: The politics of environmental science. London: Routledge.

Fortun, K. 2004a. Environmental information systems as appropriate technology. *Design Issues* 20 (3):54–65.

———. 2004b. From Bhopal to the informating of environmentalism: Risk communication in historical perspective. *Osiris* 19:283–296.

Fortun, K., L. Poirier, A. Morgan, B. Costelloe-Kuehn, and M. Fortun. 2016. Pushback: Critical data designers and pollution politics. *Big Data & Society* 3 (2). http://bds.sagepub.com/lookup/doi/10.1177/2053951716668903 (last accessed 19 July 2017).

Fraser, A. 2018. Land grab/data grab: precision agriculture and its new horizons. *The Journal of Peasant Studies* :1–20.

Gabrys, J. 2016. Practicing, materialising and contesting environmental data. *Big Data & Society* 3 (2). http://bds.sagepub.com/lookup/doi/10.1177/2053951716673391 (last accessed 19 July 2017).

Garnett, E. 2016. Developing a feeling for error: Practices of monitoring and modelling air pollution data. *Big Data & Society* 3 (2):205395171665806.

Genskow, K. D., and D. M. Wood. 2011. Improving Voluntary Environmental Management Programs: Facilitating Learning and Adaptation. *Environmental Management* 47 (5):907–916.

Gilpin, L. 2014. 10 big data projects that could help save the planet. *TechRepublic*. https://www.techrepublic.com/article/10-big-data-projects-that-could-help-save-the-planet/ (last accessed 2 March 2018).

Glynn, P. D., A. A. Voinov, C. D. Shapiro, and P. A. White. 2017. From data to decisions: Processing information, biases, and beliefs for improved management of natural resources and environments: FROM DATA TO DECISIONS. *Earth's Future* 5 (4):356–378.

Goldenberg, S. 2014. "Lost Louisiana: the race to reclaim vanished land back from the sea." The Guardian. http://www.theguardian.com/environment/2014/oct/14/lost-louisiana-the-race-to-reclaim-vanished-land-back-from-the-sea (accessed 30 November 2014)

Goldman, M., P. Nadasdy, and M. Turner. 2010. *Knowing Nature*. University of Chicago Press. http://www.press.uchicago.edu/ucp/books/book/chicago/K/bo10348588.html (last accessed 23 October 2017).

Groves, D. G., and R. J. Lempert. 2007. A new analytic method for finding policy-relevant scenarios. *Global Environmental Change* 17 (1):73–85.

Groves, D. G., and C. Sharon. 2013. Planning Tool to Support Planning the Future of Coastal Louisiana. *Journal of Coastal Research* 67:147–161.

Gunderson, L., and S. S. Light. 2006. Adaptive management and adaptive governance in the everglades ecosystem. *Policy Sciences* 39 (4):323–334.

Haraway D, *1991 Simians, Cyborgs and Women: The Reinvention of Nature* (Routledge, New York)

Harding, S. 1991. *Whose Science/ Whose Knowledge?* Milton Keynes: Open University Press.

Hardy, S. 2017. Water Campus' plans for impressive model of Mississippi River. *The Advocate*. http://www.theadvocate.com/baton_rouge/news/environment/article_fd3c2114-9e36-11e7-9d06-fb7b6748cece.html (last accessed 2 March 2018).

Hart, N., E. Ulmer, and L. White. 2015. Social Media: Changing the Landscape of Rulemaking. *Natural Resources & Environment* 30 (1):27.

Hausermann, H. 2012. From polygons to politics: Everyday practice and environmental governance in Veracruz, Mexico. *Geoforum* 43 (5):1002–1013.

Hawkins, R., and J. J. Silver. 2017. From selfie to #sealfie: Nature 2.0 and the digital cultural politics of an internationally contested resource. *Geoforum* 79:114–123.

Hecht G. 1998. *The Radiance of France: Nuclear Power and National Identity after World War II*. Cambridge, MA,. MIT Press.

Hennessey, T. 1994. Governance and adaptive management for estuarine ecosystems: the case of Chesapeake Bay. *Coastal Management* 22: 119-145.

Herbert, S. 2000. For Ethnography. *Progress in Human Geography* 24(4): 550-568.

Hickman, L. 2018. Timeline: The history of climate modelling. *Carbon Brief*. https://www.carbonbrief.org/timeline-history-climate-modelling (last accessed 2 March 2018).

Hicks, M. 2017. *Programmed Inequality: How Britain Discarded Women Technologists and Lost Its Edge in Computing*. MIT Press.

Holifield, R. 2009. Actor-Network Theory as a Critical Approach to Environmental Justice: A Case against Synthesis with Urban Political Ecology. *Antipode* 41 (4):637–658.

Holling CS. 1978. *Adaptive Environmental Assessment and Management*. John Wiley & Sons

Houck, O. A. 2015. The reckoning: oil and gas development in the Louisiana coastal zone. *Tulane Environmental Law Journal* :185–296.

Hsu, A., A. de Sherbinin, and H. Shi. 2012. Seeking truth from facts: The challenge of environmental indicator development in China. *Environmental Development* 3:39–51.

Hull, M. S. 2012. Documents and Bureaucracy. *Annual Review of Anthropology* 41 (1):251–267.

Hulme, M. 2011. Reducing the future to climate: a story of climate determinism and reductionism. *Osiris* 26 (1):245–266.

Jarzabkowski, P., and T. Pinch. 2013. Sociomateriality is 'the New Black': accomplishing repurposing, reinscripting and repairing in context. *M@n@gement* 16 (5):579.

Jasanoff, S.D., 2004. States of Knowledge. The Co-production of Science and Social Order. Routledge, International Library of Sociology, Oxon and New York.

JAYACHANDRAN, S. 2017. Using the Airbnb Model to Protect the Environment - The New York Times. *The New York Times* 29 December. https://www.nytimes.com/2017/12/29/business/economy/airbnb-protect-environment.html (last accessed 2 March 2018).

Johnson, J. A. 2015. How data does political things: The processes of encoding and decoding data are never neutral. *Impact of Social Sciences Blog*. http://eprints.lse.ac.uk/70890/ (last accessed 7 September 2017).

Johnson, L. 2013. Catastrophe bonds and financial risk: Securing capital and rule through contingency. *Geoforum* 45:30–40.

Johnson, S. 2018. Beyond the Bitcoin Bubble. *The New York Times* 16 January. https://www.nytimes.com/2018/01/16/magazine/beyond-the-bitcoin-bubble.html (last accessed 2 March 2018).

Kaika, M. 2017. 'Don't call me resilient again!': the New Urban Agenda as immunology… or… what happens when communities refuse to be vaccinated with 'smart cities' and indicators. *Environment and Urbanization* 29 (1):89–102.

Kangas, D. J. 2007. *Kierkegaard's instant: On beginnings*. Indiana University Press.

Kates, R. W., W. R. Travis, and T. J. Wilbanks. 2012. Transformational adaptation when incremental adaptations to climate change are insufficient. *Proceedings of the National Academy of Sciences* 109 (19):7156–7161.

Kearney, M. S., J. C. A. Riter, and R. E. Turner. 2011. Freshwater river diversions for marsh restoration in Louisiana: Twenty-six years of changing vegetative cover and marsh area: TWENTY-SIX YEARS AT THREE DIVERSIONS. *Geophysical Research Letters* 38 (16):n/a-n/a.

Kelly (Letcher), R. A., A. J. Jakeman, O. Barreteau, M. E. Borsuk, S. ElSawah, S. H. Hamilton, H. J. Henriksen, S. Kuikka, H. R. Maier, A. E. Rizzoli, H. van Delden, and A. A. Voinov. 2013. Selecting among five common modelling approaches for integrated environmental assessment and management. *Environmental Modelling & Software* 47:159–181.

Kenis, A., and M. Lievens. 2016. Imagining the carbon neutral city: The (post)politics of time and space. *Environment and Planning A*. http://epn.sagepub.com/lookup/doi/10.1177/0308518X16680617 (last accessed 10 April 2017).

Kirwan, M. L., and J. P. Megonigal. 2013. Tidal wetland stability in the face of human impacts and sea-level rise. *Nature* 504 (7478):53–60.

Klein, N. 2010. Gulf oil spill - A hole in the world | Naomi Klein. *The Guardian*. http://www.theguardian.com/theguardian/2010/jun/19/naomi-klein-gulf-oil-spill (last accessed 3 March 2018).

Knigge, L., and M. Cope. 2006. Grounded Visualization: Integrating the Analysis of Qualitative and Quantitative Data through Grounded Theory and Visualization. *Environment and Planning A* 38 (11):2021–2037.

Ko, J.Y. and Day, J.W., 2004. A review of ecological impacts of oil and gas developments on coastal ecosystems in the Mississippi Delta. Ocean & Coastal Management, 47(11–12), 597–623.

Kolker, A. S., M. A. Allison, and S. Hameed. 2011. An evaluation of subsidence rates and sea-level variability in the northern Gulf of Mexico: SUBSIDENCE AND SEA LEVEL VARIABILITY. *Geophysical Research Letters* 38 (21):n/a-n/a.

Kull, C. A., X. Arnauld de Sartre, and M. Castro-Larrañaga. 2015. The political ecology of ecosystem services. *Geoforum* 61:122–134.

Kuzel, A. J. 1992. Sampling in qualitative inquiry. Doing qualitative research :31–44.

Kvale, S. 1996. Thematizing and Designing an Interview Study. In Interviews: An Introduction. SAGE Publications Ltd.

Lally, N. 2017. Crowdsourced surveillance and networked data. *Security Dialogue* 48 (1):63–77.
Latour, B. and S. Woolgar. 1979. *Laboratory Life: The Construction of Scientific Facts*. Sage.
Latour, B. 2005. *Reassembling the social: an introduction to actor-network-theory*. Oxford ; New York: Oxford University Press.
Lave, R., M. W. Wilson, E. S. Barron, C. Biermann, M. A. Carey, C. S. Duvall, L. Johnson, K. M. Lane, N. McClintock, D. Munroe, R. Pain, J. Proctor, B. L. Rhoads, M. M. Robertson, J. Rossi, N. F. Sayre, G. Simon, M. Tadaki, and C. Van Dyke. 2014. Intervention: Critical physical geography: Critical physical geography. *The Canadian Geographer / Le Géographe canadien* 58 (1):1–10.
Lave, R. 2012. Bridging Political Ecology and STS: A Field Analysis of the Rosgen Wars. *Annals of the Association of American Geographers* 102 (2):366–382.
———. 2015a. “Reassembling the structural: political ecology and actor-network theory”, in *Handbook of Political Ecology* Eds T Perreault, G Bridge, J McCarthy (Routledge, New York) pp 213–223
———. 2015b. Discussant: “Why STS cannot handle neoliberalism.” Society for Social Studies of Science, Denver, CO.
Lebel, L., J. Anderies, B. Campbell, C. Folke, S. Hatfield-Dodds, T. Hughes, and J. Wilson. 2006. Governance and the capacity to manage resilience in regional social-ecological systems. *Ecology and Society* 11 (1).
Lemos, M. C. 2003. A tale of two policies: The politics of climate forecas drought relief in Ceara, Brazil. *Policy Sciences* 36:101–123.
Leonardi, P. M. 2013. Theoretical foundations for the study of sociomateriality. *Information and Organization* 23 (2):59–76.
Leszczynski, A. 2016. Speculative futures: Cities, data, and governance beyond smart urbanism. *Environment and Planning A* 48 (9):1691–1708.
Levine, J., K. M. A. Chan, and T. Satterfield. 2015. From rational actor to efficient complexity manager: Exorcising the ghost of Homo economicus with a unified synthesis of cognition research. *Ecological Economics* 114:22–32.
Lewis, J. 2015. *Deltaic Dilemmas: Ecologies of Infrastructure in New Orleans*. Doctoral Thesis, Stockholm University.
Lewis, J. A., W. C. Zipperer, H. Ernstson, B. Bernik, R. Hazen, T. Elmqvist, and M. J. Blum. 2017. Socioecological disparities in New Orleans following Hurricane Katrina. *Ecosphere* 8 (9):e01922.
Lewis, J. and H. Ernstson. 2018. Contesting the Coast: Ecosystems as Infrastructure in the Mississippi River Delta. Progress in Planning.
Lindblom, C. E. 1959. The Science of “Muddling Through.” *Public Administration Review* 19 (2):79.
Lipsky, M. 1969. TOWARD A THEORY OF STREET-LEVEL BUREAUCRACY. *Institute for Research on Poverty - Discussion Papers*.
Loomis, D. K., and S. K. Paterson. 2014. The human dimensions of coastal ecosystem services: Managing for social values. *Ecological Indicators* 44:6–10.
Lux, T. 2017. If Canals Contributed To Loss, Why Not Just Fill Them Back In? *WWNO*. http://wwno.org/post/if-canals-contributed-loss-why-not-just-fill-them-back (last accessed 2 March 2018).
Lynch, P. 2008. The origins of computer weather prediction and climate modeling. *Journal of Computational Physics* 227 (7):3431–3444.

MacKenzie, D. A., and J. Wajcman eds. 1999. *The social shaping of technology* 2nd ed. Buckingham [Eng.] ; Philadelphia: Open University Press.

MacKenzie D, 2006. An Engine Not a Camera: How Financial Models Shape Markets. MIT Press, Cambridge, MA.

Magill, A. W. *1988*. Natural *resource professionals*: The reluctant public servants. *Environmental Professional*, 10, 295-30

Mann G 2007 *Our daily bread: wages, workers and the political economy of the American West* UNC Press, Chapel Hill NC

Marshall, B. 2013a. "Natural river diversion at Mardi Gras Pass gains support from political, commercial interests." The Lens. http://thelensnola.org/2013/03/27/natural-river-diversion-at-mardi-gras-pass-gains-support-from-political-commercial-interests/ (accessed 30 November 2014).

———. 2013b. "Two-year-old breach in Mississippi River could be formally named 'Mardi Gras Pass'" The Lens. http://thelensnola.org/2014/07/11/two-year-old-breach-in-mississippi-river-could-be-formally-named-mardi-gras-pass/

———. 2015a. Experts: Talk now about drastic changes, or deal with coastal crisis later. *The Lens*. https://thelensnola.org/2015/09/15/coastal-planners-talk-now-about-drastic-changes-or-deal-with-crisis-later/ (last accessed 2 March 2018).

———. 2015b. State coastal authority OKs two diversions, but construction unlikely for three years. *The Lens*. https://thelensnola.org/2015/10/21/state-coastal-authority-oks-two-diversions-but-construction-unlikely-for-3-years/ (last accessed 2 March 2018).

———. 2016a. Increasing estimates for sea-level rise bring questions on coastal plan. *The Lens*. https://thelensnola.org/2016/03/01/sharply-increasing-estimates-for-sea-level-rise-raise-questions-about-coastal-plan/ (last accessed 2 March 2018).

———. 2016b. Should we use diversions or pipelines to rebuild the coast? Maybe we don't have to choose. *The Lens*. https://thelensnola.org/2016/10/11/should-we-use-diversions-or-pipelines-to-rebuild-the-coast-maybe-we-dont-have-to-choose/ (last accessed 2 March 2018).

———. 2017. Coastal flooding may force thousands of homes in Louisiana to be elevated or bought out. *The Lens*. https://thelensnola.org/2017/01/03/latest-coastal-restoration-plan-says-thousands-of-homes-may-have-to-be-elevated-or-bought-out/ (last accessed 2 March 2018).

Masson, T. 2017. Oyster harvesters funding study to close Mardi Gras Pass. *NOLA.com*. http://www.nola.com/outdoors/index.ssf/2017/07/oyster_harvesters_funding_stud.html (last accessed 2 March 2018).

Mayer-Schönberger V, Cukier K, 2013, Big Data: A Revolution That Will Transform How We Live,

McAfee, J. 1989. The Control of Nature. Farrar, Straus, and Giroux.

McCarthy, J., and J. Thatcher. 2017. Visualizing new political ecologies: A critical data studies analysis of the World Bank's renewable energy resource mapping initiative. *Geoforum*. http://linkinghub.elsevier.com/retrieve/pii/S0016718517300726 (last accessed 19 January 2018).

McLain, R. J., and R. G. Lee. 1996. Adaptive management: promises and pitfalls. *Environmental management* 20 (4):437–448.

Medina, E. 2014. Cybernetic Revolutionaries: Technology and Politics in Allende's Chile. MIT Press.

Meehan, K. 2013. Disciplining de facto development: water theft and hydrosocial order in Tijuana. *Environment and Planning D: Society and Space* 31 (2):319–336.
Meehan, K., I. G. R. Shaw, and S. A. Marston. 2013. Political geographies of the object. *Political Geography* 33:1–10.
Millington, J. D. A., D. O'Sullivan, and G. L. W. Perry. 2012. Model histories: Narrative explanation in generative simulation modelling. *Geoforum* 43 (6):1025–1034.
Millo, Y., and D. MacKenzie. 2009. The usefulness of inaccurate models: Towards an understanding of the emergence of financial risk management. *Accounting, Organizations and Society* 34 (5):638–653.
Mirowski, P. 2002. *Machine dreams: economics becomes a cyborg science*. Cambridge ; New York: Cambridge University Press.
Mitchell T, 1999, "Society, economy and the state effect" in *State/Culture: State Formation After the Cultural Turn* Ed G Steinmetz (Cornell University Press) pp 76–97
Mitchell, T. 2009. Carbon democracy. *Economy and Society* 38 (3):399–432.
———. 2011. *Carbon democracy: political power in the age of oil*. London ; New York: Verso.
Moore, S. A., R. E. Roth, H. Rosenfeld, E. Nost, K. Vincent, M. Rafi Arefin, and T. M. A. Buckingham. 2017. Undisciplining environmental justice research with visual storytelling. *Geoforum*. http://linkinghub.elsevier.com/retrieve/pii/S0016718517300520 (last accessed 10 April 2017).
Morton, R. A., J. C. Bernier, and J. A. Barras. 2006. Evidence of regional subsidence and associated interior wetland loss induced by hydrocarbon production, Gulf Coast region, USA. *Environmental Geology* 50 (2):261–274.
Muellerleile, C. 2013. Turning Financial Markets inside Out: Polanyi, Performativity and Disembeddedness. *Environment and Planning A* 45 (7):1625–1642.
Mufson, S. 2010. Oil spills. Poverty. Corruption. Why Louisiana is America's petro-state. *Washington Post* 18 July. http://www.washingtonpost.com/wp-dyn/content/article/2010/07/16/AR2010071602721.html (last accessed 2 March 2018).
McAfee, J. 1989. *The Control of Nature*. Farrar, Straus, and Giroux.
Muth, D. 2014. The Once and Future Delta. In Perspectives on the Restoration of the Mississippi Delta, eds. J. W. Day, G. P. Kemp, A. M. Freeman, and D. P. Muth, 9–28. Springer.
Nadasdy, P. 2007. Adaptive co-management and the gospel of resilience. *Adaptive co-management: collaboration, learning and multi-level governance* :208–227.
Nelson, N. 2016. Model homes for model organisms: Intersections of animal welfare and behavioral neuroscience around the environment of the laboratory mouse. *BioSocieties* 11 (1):46–66.
Neset, T.-S., T. Opach, P. Lion, A. Lilja, and J. Johansson. 2016. Map-Based Web Tools Supporting Climate Change Adaptation. *The Professional Geographer* 68 (1):103–114.
Nightingale, A. J. 2017. Power and politics in climate change adaptation efforts: Struggles over authority and recognition in the context of political instability. *Geoforum* 84:11–20.
Nijhuis, M. 2017. The Common Language of Conservation. http://www.lastwordonnothing.com/2017/05/24/the-common-language-of-conservation/ (last accessed 2 March 2018).
Norman, D. A. *The design of everyday things*. Basic Books, New York, NY, 1988.
Nost, E. 2013. The Power of Place: Tourism Development in Costa Rica. *Tourism Geographies* 15 (1):88–106.

———. 2014. Scaling-up local foods: Commodity practice in community supported agriculture (CSA). *Journal of rural studies* 34:152–160.

———. 2015a. Performing nature's value: software and the making of Oregon's ecosystem services markets. *Environment and Planning A* 47 (12):2573–2590.

———. 2015b. "American Coast, Imperiled Energy. A review of Jason P. Theriot's American Energy, Imperiled Coast" *Southern Spaces*.

Nost, E., H. Rosenfeld, K. Vincent, S. A. Moore, and R. E. Roth. 2017. HazMatMapper: an online and interactive geographic visualization tool for exploring transnational flows of hazardous waste and environmental justice. *Journal of Maps* 13 (1):14–23.

Nost, E. and M. Kelly. 2018. "Land Loss and Restoration in Coastal Louisiana: 1932-2009" in *Water: An Atlas*. Guerrilla Cartography.

Nyman, J. A., R. D. DeLaune, S. R. Pezeshki, and W. H. Patrick. 1995. Organic Matter Fluxes and Marsh Stability in a Rapidly Submerging Estuarine Marsh. *Estuaries* 18 (1):207.

Olea, R. A., and J. L. Coleman. 2014. A Synoptic Examination of Causes of Land Loss in Southern Louisiana as Related to the Exploitation of Subsurface Geologic Resources. *Journal of Coastal Research* 297:1025–1044.

O'Lear, S. 2016. Climate science and slow violence: A view from political geography and STS on mobilizing technoscientific ontologies of climate change. *Political Geography* 52:4–13.

O'Neil, C. *Weapons of Math Destruction: How Big Data Increases Inequality and Threatens Democracy*. Crown.

Ooudshoorn, N., and T. Pinch. 2005. *How Users Matter*. MIT Press. https://mitpress.mit.edu/books/how-users-matter (last accessed 2 March 2018).

O'Sullivan, D. 2004. Complexity science and human geography. *Transactions of the Institute of British Geographers* 29 (3):282–295.

Ottinger, G. 2010. Constructing empowerment through interpretations of environmental surveillance data. *Surveillance & Society* 8 (2):221–234.

Pelling, M. 2010. Adaptation to climate change: from resilience to transformation. Routledge.

Peluso, N. 1994. *Rich Forests, Poor People*. https://www.ucpress.edu/book.php?isbn=9780520089310 (last accessed 2 March 2018).

Peyronnin, N., R. Caffey, J. Cowan, D. Justic, A. Kolker, S. Laska, A. McCorquodale, E. Melancon, J. Nyman, R. Twilley, J. Visser, J. White, and J. Wilkins. 2017. Optimizing Sediment Diversion Operations: Working Group Recommendations for Integrating Complex Ecological and Social Landscape Interactions. *Water* 9 (6):368.

Plummer, R., D. R. Armitage, and R. C. de Loë. 2013. Adaptive Comanagement and Its Relationship to Environmental Governance. *Ecology and Society* 18 (1).

Porter, T. M. 1995. *Trust in numbers: the pursuit of objectivity in science and public life*. Princeton, N.J: Princeton University Press.

Powles, J. 2017. New York City's Bold, Flawed Attempt to Make Algorithms Accountable. *The New Yorker*. https://www.newyorker.com/tech/elements/new-york-citys-bold-flawed-attempt-to-make-algorithms-accountable (last accessed 2 March 2018).

Rangoonwala, A., C. E. Jones, and E. Ramsey. 2016. Wetland shoreline recession in the Mississippi River Delta from petroleum oiling and cyclonic storms: MRD SHORELINE RECESSION. *Geophysical Research Letters* 43 (22):11,652-11,660.

Rappaport, R.A., 1967. *Pigs for the Ancestors: Ritual in the Ecology of a New Guinea People*. Yale University Press, New Haven.

Reducing Flood Risk. *Gulf Restoration Network*. https://healthygulf.org/our-work/sustaining-coastal-communities/reducing-flood-risk (last accessed 2 March 2018).
Reed, D. J. 1995. The response of coastal marshes to sea-level rise: Survival or submergence? *Earth Surface Processes and Landforms* 20 (1):39–48.
Retchless, D. P. 2014. Sea Level Rise Maps: How Individual Differences Complicate the Cartographic Communication of an Uncertain Climate Change Hazard. *Cartographic Perspectives* 0 (77):17–32.
Rhoden, R. 2015. La. lost $1.1 billion from 2010-2014 because of severance tax exemption on horizontal drilling, audit says. *NOLA.com*. http://www.nola.com/politics/index.ssf/2015/10/la_lost_11_billion_due_to_seve.html (last accessed 2 March 2018).
Richter, A., and S. Fitzpatrick. 2017. Situated responses to the post-political city: an introduction. *Area*. http://doi.wiley.com/10.1111/area.12406 (last accessed 6 December 2017).
Robbins, P. 2000. The practical politics of knowing: state environmental knowledge and local political economy. *Economic Geography* 76 (2):126–144.
———. 2001. Fixed categories in a portable landscape: the causes and consequences of land-cover categorization. Environment and Planning A 33 (1):161–179.
———. 2003. Beyond ground truth: GIS and the environmental knowledge of herders, professional foresters, and other traditional communities. Human Ecology 31 (2).
———. 2006. The politics of barstool biology: Environmental knowledge and power in greater Northern Yellowstone. *Geoforum* 37 (2):185–199.
———. 2012 [2004]. Political Ecology: A Critical Introduction. Second Edition. Wiley-Blackwell.
Robbins, P., and K. Monroe Bishop. 2008. There and back again: Epiphany, disillusionment, and rediscovery in political ecology. *Geoforum* 39 (2):747–755.
Robbins, P., and S. Moore. 2015. Love your symptoms: A sympathetic diagnosis of the Ecomodernist Manifesto. *ENTITLE blog - a collaborative writing project on Political Ecology*. https://entitleblog.org/2015/06/19/love-your-symptoms-a-sympathetic-diagnosis-of-the-ecomodernist-manifesto/ (last accessed 2 March 2018).
Robertson, M. M. 2006. The nature that capital can see: science, state, and market in the commodification of ecosystem services. Environment and Planning D: Society and Space 24 (3):367–387.
Robinson, J. 2003. Future subjunctive: backcasting as social learning. *Futures* 35 (8):839–856.
Rocheleau, D., and R. Roth. 2007. Rooted networks, relational webs and powers of connection: Rethinking human and political ecologies. *Geoforum* 38 (3):433–437.
Roth, R. E., C. Quinn, and D. Hart. 2015. The Competitive Analysis Method for Evaluating Water Level Visualization Tools. Modern Trends in Cartography, Lecture Notes in Geoinformation and Cartography Chapter 19: 241–256.
Sack, K., and J. Schwartz. 2018. Left to Louisiana's Tides, a Village Fights for Time. *The New York Times* 24 February. https://www.nytimes.com/interactive/2018/02/24/us/jean-lafitte-floodwaters.html, https://www.nytimes.com/interactive/2018/02/24/us/jean-lafitte-floodwaters.html (last accessed 2 March 2018).
Sayre, K. 2014. Louisiana $50 billion coastal restoration plan would inject billions more into economy every year, study finds. *NOLA.com*.

http://www.nola.com/business/index.ssf/2014/03/louisiana_50_billion_coastal_r.html (last accessed 2 March 2018).
Scaife, W.B., R.E. Turner, R. Costanza. 1983. Recent land loss and canal impacts in coastal Louisiana. Environmental Management 7:433-442.
Schleifstein, M. 2013. New Mardi Gras Pass could be restricted if oil facility gets OK to rebuild road. Nola.com. http://www.nola.com/environment/index.ssf/2013/01/new_mardi_gras_pass_could_be_r.html
———. 2015a. Historic vote moves 2 Mississippi River sediment diversions toward construction. *NOLA.com*. http://www.nola.com/environment/index.ssf/2015/10/historic_vote_moves_two_missis.html (last accessed 2 March 2018).
———. 2015b. Louisiana coastal restoration: State studying diversions' effects on economy, fishing. *NOLA.com*. http://www.nola.com/environment/index.ssf/2015/02/state_has_embarked_on_comprehe.html (last accessed 2 March 2018).
———. 2016a. Louisiana to pay Corps $1.5 million to speed sediment diversion permit review. *NOLA.com*. http://www.nola.com/environment/index.ssf/2016/04/louisiana_to_pay_corps_15_mill.html (last accessed 2 March 2018).
———. 2016b. State's coastal czar: Finalize clear path forward on diversions. *NOLA.com*. http://www.nola.com/environment/index.ssf/2016/02/states_coastal_goal_finalize_c.html#incart_river_index_topics (last accessed 2 March 2018).
———. 2017a. $663 million proposed for coastal restoration, levees in FY 2018. *NOLA.com*. http://www.nola.com/environment/index.ssf/2017/01/663_million_proposed_for_coast.html (last accessed 2 March 2018).
———. 2017b. Aboard tall-mast ship, Dutch scientist's pep talk lauds Louisiana coastal initiative. *NOLA.com*. https://www.nola.com/environment/index.ssf/2017/03/water_institute_celebrates_5_y.html (last accessed 2 March 2018).
———. 2017c. As one legislator tears up, Senate committee OKs Louisiana coastal master plan. *NOLA.com'*. http://www.nola.com/environment/index.ssf/2017/05/coast_master_plan_budget_appro.html (last accessed 2 March 2018).
———. 2017d. Storm surge damage falls $8.3 billion a year in Louisiana's new coastal plan. *NOLA.com*. https://www.nola.com/environment/index.ssf/2017/01/2017_master_plan_surge_damage.html (last accessed 2 March 2018).
Scott, J. 1998. *Seeing Like a State*. New Haven; Yale University Press.
Shapiro, N., J. Roberts, and N. Zakariya. 2017. A Wary Alliance: From Enumerating the Environment to Inviting Apprehension. *Engaging Science, Technology, and Society* 3:575.
Silliman, B. R., J. van de Koppel, M. W. McCoy, J. Diller, G. N. Kasozi, K. Earl, P. N. Adams, and A. R. Zimmerman. 2012. Degradation and resilience in Louisiana salt marshes after the BP-Deepwater Horizon oil spill. *Proceedings of the National Academy of Sciences* 109 (28):11234–11239.

Sneath, S. 2017a. In St. Bernard Parish, fishers wary of Louisiana's plan to save coast. *NOLA.com*. http://www.nola.com/environment/index.ssf/2017/03/st_bernard_coastal_master_plan.html (last accessed 2 March 2018).

———. 2017b. Most Louisianians worry about coastal land loss, but don't blame climate change: poll. *NOLA.com*. http://www.nola.com/environment/index.ssf/2017/03/st_bernard_coastal_master_plan.html (last accessed 2 March 2018).

Snell, J. 2017. Louisiana's master plan represents a strategic retreat... *FOX 8*. http://www.fox8live.com/story/34575132/louisianas-master-plan-represents-a-strategic-retreat-from-vulnerable-areas (last accessed 2 March 2018).

———. No date. Task Force rescues coastal project slated for closure - FOX 8, WVUE, fox8live.com, weather, app, news, saints. *FOX 8*. http://www.fox8live.com/story/19800157/task-force-rescues-coastal-project-slated-for-closing (last accessed 2 March 2018).

St. Martin, K., and M. Hall-Arber. 2008. The missing layer: Geo-technologies, communities, and implications for marine spatial planning. *Marine Policy* 32 (5):779–786.

Star, S. L., and K. Ruhleder. 1994. Steps towards an ecology of infrastructure: complex problems in design and access for large-scale collaborative systems. In *Proceedings of the 1994 ACM conference on Computer supported cooperative work*, 253–264. ACM.

Star, S. L.1991. Power, technology and the phenomenology of conventions: on being allergic to onions.

———. 1999. The Ethnography of Infrastructure. *American Behavioral Scientist* 43 (3):377–391.

Stein, M. I. 2017. Hilcorp seeks dredging permit a year after dragging drilling barge through shallow water. *The Lens*. https://thelensnola.org/2017/03/18/hilcorp-energy-seeks-dredging-permit-a-year-after-dragging-drilling-barge-through-shallow-water/ (last accessed 2 March 2018).

Stephens, M. 2013. Gender and the GeoWeb: divisions in the production of user-generated cartographic information. *GeoJournal* 78 (6):981–996.

Stephenson, S. K., and L. Shabman. 2011. Executing CADRe: Integration of Models with Negotiation Processes. *Converging Waters*.

Steyer, G. D., C. E. Sasser, J. M. Visser, E. M. Swenson, J. a. Nyman, and R. C. Raynie. 2003. A proposed coast-wide reference monitoring system for evaluating Wetland restoration trajectories in Louisiana. Environmental Monitoring and Assessment 81 (January 2001):107–117.

Stonich, S. 1993. *"I Am Destroying the Land!": The Political Ecology of Poverty and Environmental Destruction in Honduras*. Boulder: Westview Press;

Strombolis, J., and A. Frank. 2014. Can Big Data Save Lives? *100 Resilient Cities*. http://www.100resilientcities.org/can-big-data-save-lives/ (last accessed 2 March 2018).

Suchman, L. A. 1987. *Plans and situated actions: the problem of human-machine communication*. Cambridge ; New York: Cambridge University Press.

Sundberg, J. 2011. Diabolic *Caminos* in the Desert and Cat Fights on the Río: A Posthumanist Political Ecology of Boundary Enforcement in the United States–Mexico Borderlands. *Annals of the Association of American Geographers* 101 (2):318–336.

Svetlova, E. 2012. On the performative power of financial models. *Economy and Society* 41 (3):418–434.
Swyngedouw, E. 2009. The Antinomies of the Postpolitical City: In Search of a Democratic Politics of Environmental Production. International Journal of Urban and Regional Research 33 (3):601–620.
Swyngedouw, E. 2010. Apocalypse Forever? *Theory, Culture & Society* 27 (2–3):213–232.
———. 2013. The non-political politics of climate change. *ACME: An International Journal for Critical Geographies* 12 (1):1–8.
Taylor, P. and F. Buttel. 1992. How do we know we have global environmental problems? Science and the globalization of environmental discourse. Geoforum 23(3): 405 416.
Taylor, W. M., M. P. Levine, O. Rooksby, and J.-K. Sobott. 2015. *The "Katrina Effect": On the Nature of Catastrophe*. Bloomsbury Publishing.
TEEB. 2010. The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB.
Thatcher, J., D. O'Sullivan, and D. Mahmoudi. 2016. Data colonialism through accumulation by dispossession: New metaphors for daily data. *Environment and Planning D: Society and Space* 34 (6):990–1006.
Theriot, J. P. 2014. American Energy, Imperiled Coast: Oil and Gas Development in Louisiana's Wetlands. Baton Rouge, LA: Louisiana State University Press.
Thomas, A. C. 2017. Everyday experiences of post-politicising processes in rural freshwater management. *Environment and Planning A* :0308518X1769197.
Traywick, C. 2016. Louisiana's Sinking Coast Is a $100 Billion Nightmare for Big Oil. *Bloomberg.com* 17 August. https://www.bloomberg.com/news/features/2016-08-17/louisiana-s-sinking-coast-is-a-100-billion-nightmare-for-big-oil (last accessed 2 March 2018).
Turner, R. E. 1997. Wetland Loss in the Northern Gulf of Mexico: Multiple Working Hypotheses. *Estuaries* 20 (1):1.
Turner, R. E. 2014. Discussion of: Olea, R.A. and Coleman, J.L., Jr., 2014. A Synoptic Examination of Causes of Land Loss in Southern Louisiana as Related to the Exploitation of Subsurface Geological Resources. *Journal of Coastal Research* , 30(5), 1025–1044. *Journal of Coastal Research* 298:1330–1334.
Turner, R. E., and J. E. Bodker. 2016. The effects of N, P and crude oil on the decomposition of Spartina alterniflora belowground biomass. *Wetlands Ecology and Management* 24 (3):373–380.
Turner, M. D. 2003. Methodological Reflections on the Use of Remote Human Ecological Research. *Human Ecology* 31 (2):255–279.
Valentine, G. 1997. Tell me about...: using interviews as a research methodology. In *Methods in human geography*, 110–128.
Vayda, A. and B. Walters. 1999. Against Political Ecology. *Human Ecology* 27(1): 167-179.
Vaughan, C., and S. Dessai. 2014. Climate services for society: origins, institutional arrangements, and design elements for an evaluation framework: Climate services for society. *Wiley Interdisciplinary Reviews: Climate Change* 5 (5):587–603.
Vertesi J (2012) Seeing like a rover: Visualization, embodiment, and interaction on the Mars Exploration Rover Mission. *Social Studies of Science* 42(3): 393–414.

Voosen, P. 2013. Who Is Conservation For? *The Chronicle of Higher Education*. https://www.chronicle.com/article/Who-Is-Conservation-For-/142853 (last accessed 2 March 2018).
Wajcman, J. 2004. *Technofeminism*. University of Cambridge. http://www.uoc.edu/uocpapers/5/dt/eng/wajcman.html (last accessed 2 March 2018).
Walters, C. J., and R. Hilborn. 1978. Ecological optimization and adaptive management. *Annual review of Ecology and Systematics* 9 (1):157–188.
Watts, M. 1983. On the poverty of theory: natural hazards research in context. *Interpretation of Calamity: From the Viewpoint of Human Ecology*. Allen & Unwinn, Boston :231–262.
Watts, M. 2012. A tale of two gulfs: life, death, and dispossession along two oil frontiers. *American Quarterly* 64 (3):437–467.
Watts, M. J. 2004. Oil as money: The devil's excrement and the spectacle of black gold. *Reading economic geography* :205–219.
Weiner, D., TA Warner, TM Harris, and RM Levin. 1995. "Apartheid representations in a digital landscape: GIS, remote sensing and local knowledge in Kiepersol, South Africa." *Cartography and Geographic Information Systems* 22(1): 30-44.
Wilson, M. W. 2015. Morgan Freeman is dead and other big data stories. *cultural geographies* 22 (2):345–349.
Winner, L. 1980. Do artifacts have politics? *Daedalus* :121–136.
———. 2001. *Autonomous technology: technics-out-of-control as a theme in political thought* 9. printing. Cambridge, Mass.: MIT Press.
Woolgar, S. 1990. Configuring the user: the case of usability trials. *The Sociological Review* 38 (1_suppl):58–99.
Yuill, B., D. Lavoie, and D. J. Reed. 2009. Understanding Subsidence Processes in Coastal Louisiana. *Journal of Coastal Research* 10054:23–36.
Zeringue, J. R. Raynie, C. Killebrew, B. Perez, G. Holm, and D. Huxley. 2014. The Blue Carbon Bottom Line: Considerations for Project Viability. *National Wetlands Newsletter* 36(1).

Appendices

A: Interviews

Alaina Owens Grace	Administrative coordinator, WIG
Alex McCorquodale	Model lead, UNO
Alisha Renfro	Coastal scientist for nonprofit
Angelina Freeman	Model team lead, CPRA
Ann Hijuelos	Modeler, WIG
Brad Inman	CWPPRA lead, Corps of Engineers
Brady Couvillion	Modeler, USGS
Bren Haase	Coastal Resources Administrator, CPRA
Buddy Clairain	Model lead, Moffat and Nichol
Clinton Wilson	Modeler, LSU
Craig Conzelmann	USGS programmer
Dan Childers	SEB, ASU
David Groves	RAND
David Lindquist	Model team lead, CPRA
David Muth	Coastal scientist for nonprofit
Denise Reed	Science chief, WIG
Ed Haywood	Data manager, CPRA
Ehab Meselhe	Model lead, WIG
Eric White	Modeler, WIG
Eugene Turner	Academic ecologist
Gary Brown	Hydrodynamics modeling, Corps
Gordon Thomson	Model team lead, CB&I
Greg Ceccine	Director, RAND Gulf States
Greg Steyer	USGS adaptive management lead
Hugh Roberts	Model team lead, Arcadis
James McKelvey	USGS programmer
Jenneke Visser	Coastal scientist, model lead
John Calloway	PMTAC, USF
John Day	Academic ecologist
John Lopez	Lake Ponchartrain Basin Foundation
Jordan Fischbach	RAND
Karen Westphal	Audubon Society
Karim Belhadjali	Master Plan program manager, CPRA

Kenneth Bagstad	Modeler, USGS
Kenny Ribeck	Department of Fish and Wildlife
Kim de Mutsert	Model team lead, UVA
Mandy Green	Model decision team, CPRA
Mark Wingate	Restoration director, Corps of Engineers
Mead Allison	Modeler, WIG and Tulane
Melanie Saucier	Model decision team, CPRA
Michael Poff	Model team lead, Coastal Engineering Consultants
Mike Orbach	SEB, Duke
Mike Waldon	PMTACT
Morgan Crutcher	Coalition to Restore Coastal Louisiana
Natalie Peyronnin	Lead modeler from 2012
Nick Spreyer	Outreach lead, Emergent Method/WIG
Paul Frey	Framework development team, landowner
Randy Mortello	Landowner, FDT
Richard Raynie	Adaptive management lead, CPRA
Robert B Naim	Baird and associates
Ryan Lambert	Charter boat captain
Sandra Knight	SEB, WaterWorks
Scott Eustis	Gulf Restoration Network
Scott Hagen	PMTAC, LSU
Scott Hemmerling	Vulnerability and metrics lead, WIG
Shaye Sable	Fish model development team, Dynamic Solutions
Wim Kimmerer	Technical Advisory Committee, SFSU

B: Semi-structured interview questions

Background

- What is your educational background?
- What led you to the position you're in now?
- What experience do you have with models? What kinds of formal training and informal experience? How closely do you work with them?

Model design and history

General:

- Tell me about how the ICM came about? What was the inspiration? What were the drawbacks of previous models?
- Why build a model specifically for the MP rather than take one "off the shelf"?
- What other models do you draw on?
- What do you see as the biggest limits to the modeling effort right now?
- What would you do differently if you could do it again?

Who models?

- Can you describe the chain of modeling here? How does one go from X to model output? I imagine you start with an idea of what you want to predict. What next?
- Why are there all these different actors at the table? In your view, is there something unique that your firm/agency/institution brings to the table that others can't?
- Tell me about the coordination among the modeling/technical team. Tell me about a time things really gelled, and a time things broke down.
- Tell me about your interactions w/ developers/programmers/decision-makers? What's hard to explain, what do they want, etc.
- In what ways do you feel responsive to project/program managers/decision-makers/stakeholders? How do their mandates, interests, or what you do?

What data and how much?

- Tell me about the process of deciding what data, processes, or components to include/exclude in the model. Who was at the table? Was there a table?
- In many ways you're modeling a no-analogue scenario. How do you handle that? What kinds of data do you draw on or seek to collect? What are your workarounds for data limitations?
- What was not included in the ICM/PT that you would have like to have included?
- In your view, is there such a thing as too much data or too much analysis?
- One could imagine taking a different approach to the modeling where instead of starting with projects and figuring out their impact, you start with coastal conditions, and figure out where the best places to do projects would be. Why the former approach, and not the other?

Models and decision-making

- What kind of maps, in particular, work for you as decision-maker, modeler, etc.
- Tell me about a time you interpreted model results

- Tell me about a time you confronted uncertainty in the model.
- What do the models help you do that you couldn't before? What can't they do, in your opinion?
- What do you see as the proper role of the models? Another way of asking that is, how do you understand and interpret model results? Are models heuristics or photographs?
- Tell me about a time you were frustrated with the model, and a time the model surprised you.
- Tell me about a time you said, "I don't like what this is telling me/letting me do, I'm going to do something else."
- What do you expect of your model?
- Do you have to know your question going into modeling? Or just model and see what happens?
- What models would you like to have?

Outputs and broader political context

- What do you see as the biggest uncertainties in coastal restoration? In the models specifically?
- What do you do once you have a model output? What's the process of getting a model result and, ultimately, it ending up in the Master Plan? (and beyond, informing project design?)
- What does adaptive management mean to you?
- How do you see models informing adaptive management? Do they help achieve goals based on new information, or do you change goals based on new information?
- Describe your interaction(s) with the TAC and/or FDT and/or stakeholder focus groups: tell me about a time when they pushed back on what you were doing…a time when they really supported you…a time when they told you something you hadn't thought about.
- Tell me about how the models inform deliberation. Give me an example.

C: Document analysis

- Master Plan
    - Appendix C: Modeling
        - Chapter 1 – Introduction, May 2016
        - Chapter 2 - Future Scenarios, May 2016
            - Attachment C2-1: Eustatic Sea Level Rise
            - Attachment C2-2: Subsidence
            - Attachment C2-5: Options for Sensitivity Analyses
        - Chapter 3 - Modeling Components and Overview
            - Attachment C3-1.1: Sediment Distribution Supporting Information
            - Attachment C3-2: Marsh Edge Erosion
            - Attachment C3-3: Storms in the ICM Boundary Conditions
            - Attachment C3-4: Barrier Island Model Development (BIMODE)
            - Attachment C3-5: Vegetation
            - Attachment C3-12: Eastern Oyster, Crassostrea virginica, Habitat Suitability Index Model
            - Attachment C3-13: Brown Shrimp, Farfantepenaeus aztecus, Habitat Suitability Index Model
        - Chapter 4 – Model Outcomes and Interpretations, November 2016
            - Attachment C4-11: Metrics
        - Attachment C5-1: Predictive Models Technical Advisory Committee (PM-TAC) Report
    - Appendix D: Planning Tool Report
    - Appendix F: Adaptive Management Plan
    - Attachment G3: Framework Development Team
    - Attachment G4: Focus Groups
- 2017 Coastal Master Plan Model Improvement Plan, August 2013
- Strategy for Selecting Fish Modeling Approaches, October 2013
- Modeling update webinar September 2015
- Modeling update webinar September 2016

D: Document codes

<u>Public comments</u>
Attachment G1: Public Hearing Transcripts
Attachment G2-A: Public Comments
Attachment G2-B: Public Comments
Attachment G2-C: Public Comments

- Transparency and engagement
    - More transparency about modeling is needed
    - Modeling is already transparent
    - Public involvement in modeling has been extensive

- Model distrust
    - The models will be better next time
    - There's a difference between real science and modeling
    - The Master Plan modeling has been inadequate
        - It fails to understand fisheries
        - You can't model culture
        - It fails to see what's wrong
        - It doesn't show who wins/loses
        - Traditional ecological knowledge needs to be incorporated
        - It could impact local industry
        - Other models are better
        - Why wasn't x project selected?
    - We don't need a model…we know from experience
        - Our parish is doing good work without modeling

- What modeling does
    - The tool is just something to organize our thoughts
    - What models allow us to ask
    - What models show
        - Who wins/loses

- Other
    - There are better models than last time
    - Models are hard to use
    - We only have models to tell us about the coast

Document analysis

1. Context
    a. Respond to tech changes
    b. Urgency
        i. We have to do something
        ii. But we can't do everything
    c. Collaboration
        i. What an agency wants
        ii. In-person meetings
        iii. Programmers
    d. Costs
    e. Experience, training, and credentials
    f. Legacies of previous efforts (pre-2012)
    g. Place-based ecology and coastal uniqueness
2. Putting data to work
    a. Existing data
        i. Too much data
        ii. Translate between data formats
        iii. Collate sources
        iv. Get the most important data, not everything
        v. Aggregate
        vi. Synthesize missing data
    b. New data
        i. Determine which data you need/and of what quality
        ii. Justify data collection
        iii. Targeted research to collect new data
    c. Data management
3. Modeling philosophies or approaches
    a. Likelihood vs. risk
    b. Mechanistic vs. empirical
    c. Explicit vs. implicit representation
    d. First or widely accepted principles
4. Picking a model
    a. Buyer beware
    b. Know model requirements
    c. Know the code
    d. Criteria
        i. Feasibility
        ii. Appropriateness
    e. Off the shelf models
5. Making models
    a. Input matters (garbage in, garbage out)
    b. Best available vs most accessible (complexity is a choice)
    c. Integrate or link models
    d. Compare to other models
    e. Use multiple models

   f. Know what you want to find
      i. Set expectations and goals
      ii. Schematization
      iii. Find the relationships you know exist
   g. Care and effort
6. Reporting model results
   a. Story making
   b. Quantify uncertainty
   c. Ground truthing and feedback
   d. Differences (or not) between model and real life
   e. Know and make visible constraints
   f. Trust and credibility in interpretation
   g. Audience and users
7. What models do
   a. Test what we know and don't know
   b. Forecast
   c. Tradeoff
   d. Visualize
   e. Interface
   f. Screen
   g. Generate data
   h. Future models should…
8. What can go wrong
   a. Overfitting
   b. Black boxing
   c. Model instability
   d. Storms are tough
9. Other
   a. Scale
   b. Differences between MP modeling and modeling specific restoration projects
   c. Sensitivity

E: Map survey

File name and image location
Venue
- Master Plan itself
- Appendix

Type
- Reference
- Thematic

Source
- Made by modeling team
- Referenced from another study

Format
- More or less direct model output
- Significantly modified for presentation

Purpose
- To show differences or changes
- To show absolute values

How difference was represented
- Side by side maps
- Small multiples
- Animation
- Directly valued
- Not applicable

Difference type
- Over time
- Between scenarios
- Both time and scenarios
- Between observations and simulations
- Between model versions
- Not applicable

Resolution
Scale
- Coastwide
- Part of the coast
- Sub-basin level

Color scale
Representation of uncertainty
- Yes [type]
- No
- Not applicable

F: Frequently used acronyms

ACE/ACOE/Corps	US Army Corps of Engineers
ACES	A Community on Ecosystem Services
CLEAR	Coastal Louisiana Ecosystem Assessment and Restoration
CPRA	Coastal Protection and Restoration Authority
CRMS	Coastwide Reference Monitoring System
FDT	Framework Development Team
GOMESA	Gulf of Mexico Energy Security Act
ICM	Integrated Compartment Model
LPBF	Lake Pontchartrain Basin Foundation
LSU	Louisiana State University
MGP	Mardi Gras Pass
MP	Master Plan
MRHDMS	Mississippi River Hydro-Delta Management Study
PMTAC	Predictive Models Technical Advisory Committee
PT	Planning Tool
SEB	Science and Engineering Board
SWAMP	System-wide Assessment and Monitoring Program
WIG	Water Institute of the Gulf