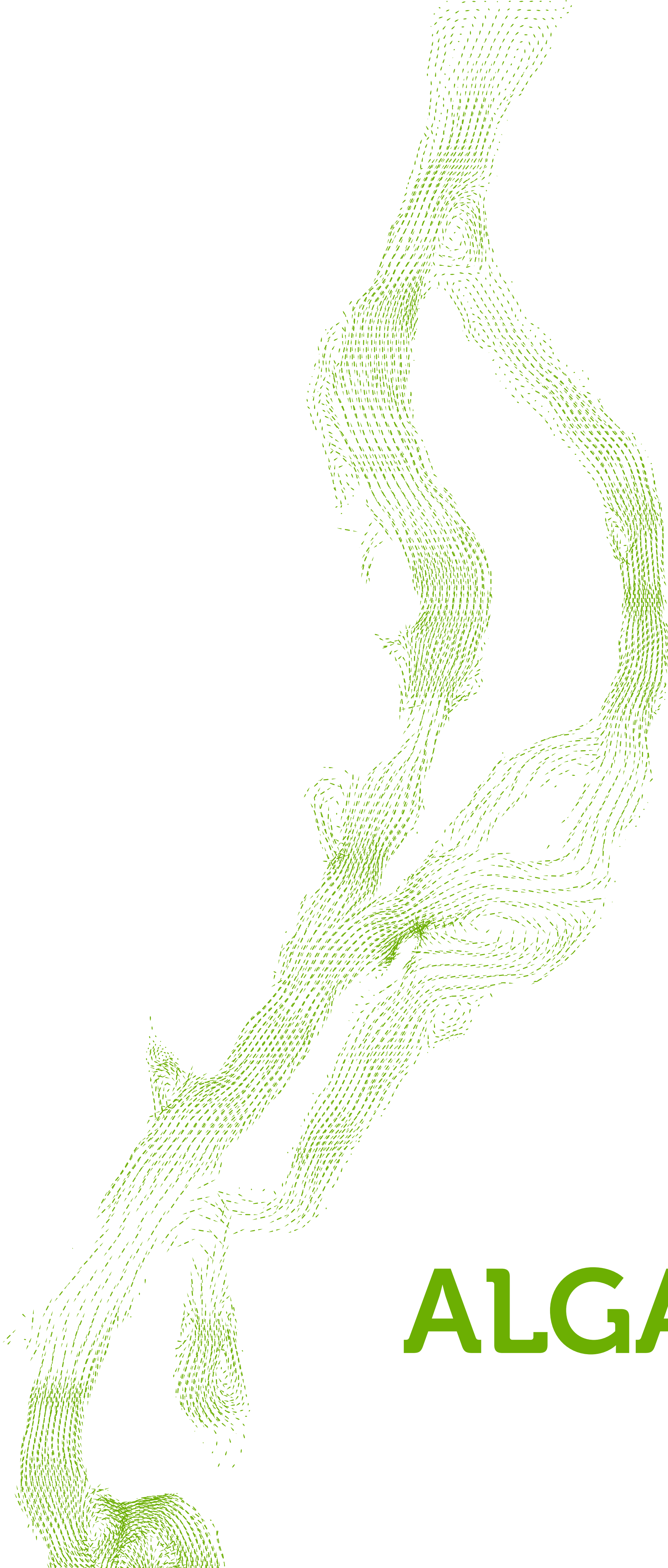
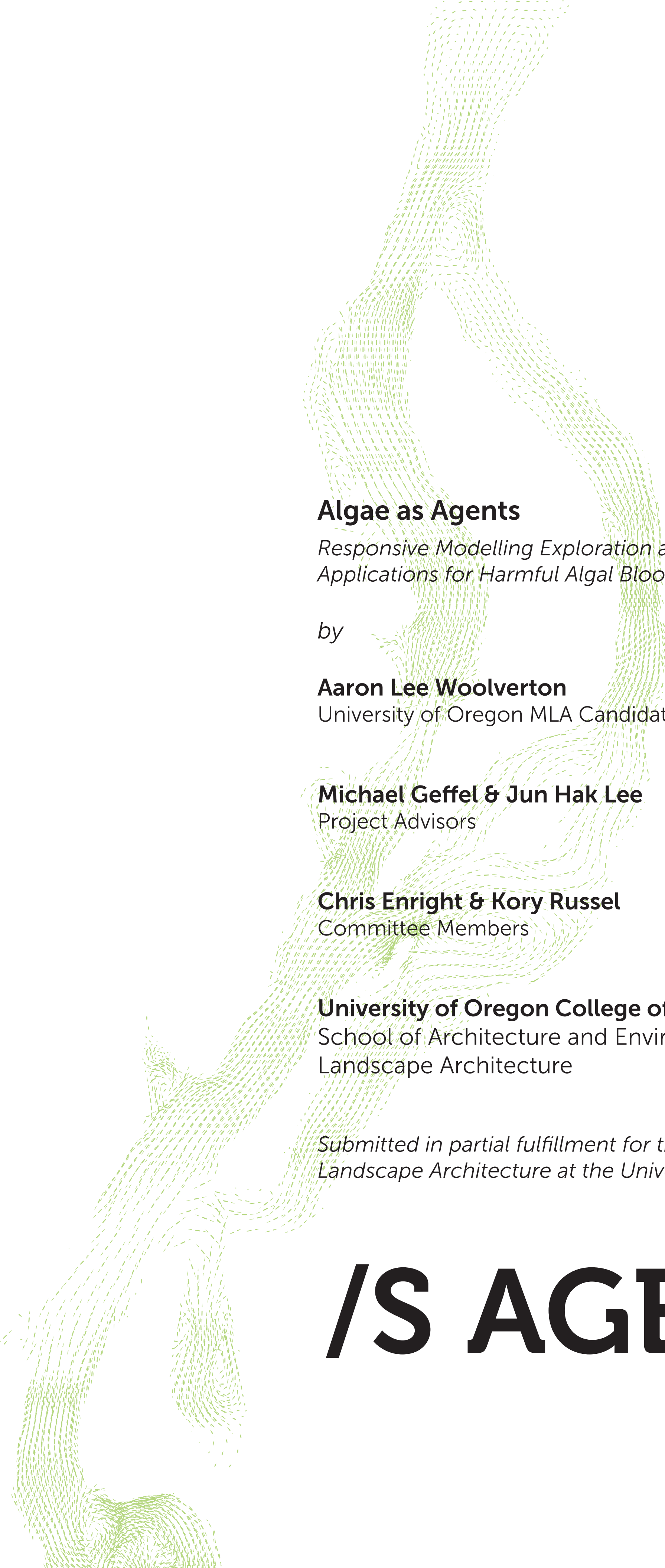


ALGAE A/



Algae as Agents

Responsive Modelling Exploration and Projective Design Applications for Harmful Algal Blooms

by

Aaron Lee Woolverton
University of Oregon MLA Candidate, 2021

Michael Geffel & Jun Hak Lee
Project Advisors

Chris Enright & Kory Russel
Committee Members

University of Oregon College of Design
School of Architecture and Environment
Landscape Architecture

Submitted in partial fulfillment for the Master's of Landscape Architecture at the University of Oregon

/S AGENTS

Acknowledgments

I would like to thank my advisers Michael Geffel and Jun Hak Lee for their patience, guidance, and inspiration surrounding *Algae as Agents.* Both Michael and Jun are incredibly dedicated professors and have supported my approach towards landscape architectural design as well as the many methods discovered throughout this project. Their vision and ideas resonate with me as a designer and I feel grateful to have worked with them on this project. Chris Enright and Ignacio Lopez Buson have also been incredibly helpful and formative through their guidance and thoughts surrounding *Algae as Agents*. With this, I'd like to thank the greater University of Oregon Landscape Faculty for their tireless guidance throughout the past 3 years. Of course, a big thank you to my cohort, who have provided friendship and a social foundation that has gotten me through the past 3 years. As my peers, I am so grateful to have gotten to meet you and grow together throughout this process. Thank you to Heather Tietz for her many ideas, company, and willingness to provide feedback on the fly. To my family, thank you so much for all your boundless support and love - I'm so grateful to have you and appreciate your willingness to be there for me in an instant.

Contents

List of Figures

Abstract

As a means of understanding landscape phenomenon, responsive modeling establishes a place to concurrently hinge between generating and testing hypotheses while incorporating the expanding agency of computational modeling and live data streams. Inspired by the ideas of process discourse and research through design, this project will investigate the harmful recurrence of algae blooms in South Florida waterways through the means of responsive modeling. *Algae as Agents* aims to define the responsive model as a research method via case study investigation and analysis; subsequently, responsive modeling practices and concepts has the potential to be translated from these case studies into the context of South Florida via projective design methodologies.

The overall goal of the project is to establish an iterative design approach as the platform to understand the complexities of algae mitigation while simultaneously providing the researcher a place to test design outcomes experimentally. Following these design translations is a reflective meta-analysis revealing both the limitations and knowledge garnered throughout the design process. This discussion expands the meaning of the responsive model while providing it more definition within the realm of landscape architecture research strategies. By projecting responsive modeling concepts into this context, we have an opportunity to speculate upon this issue, illuminate algae's nature through an apolitical lens, and expand our growing list of research design methodologies.

1.
Introduction


projected agents
01
02
03
03 floating aerators

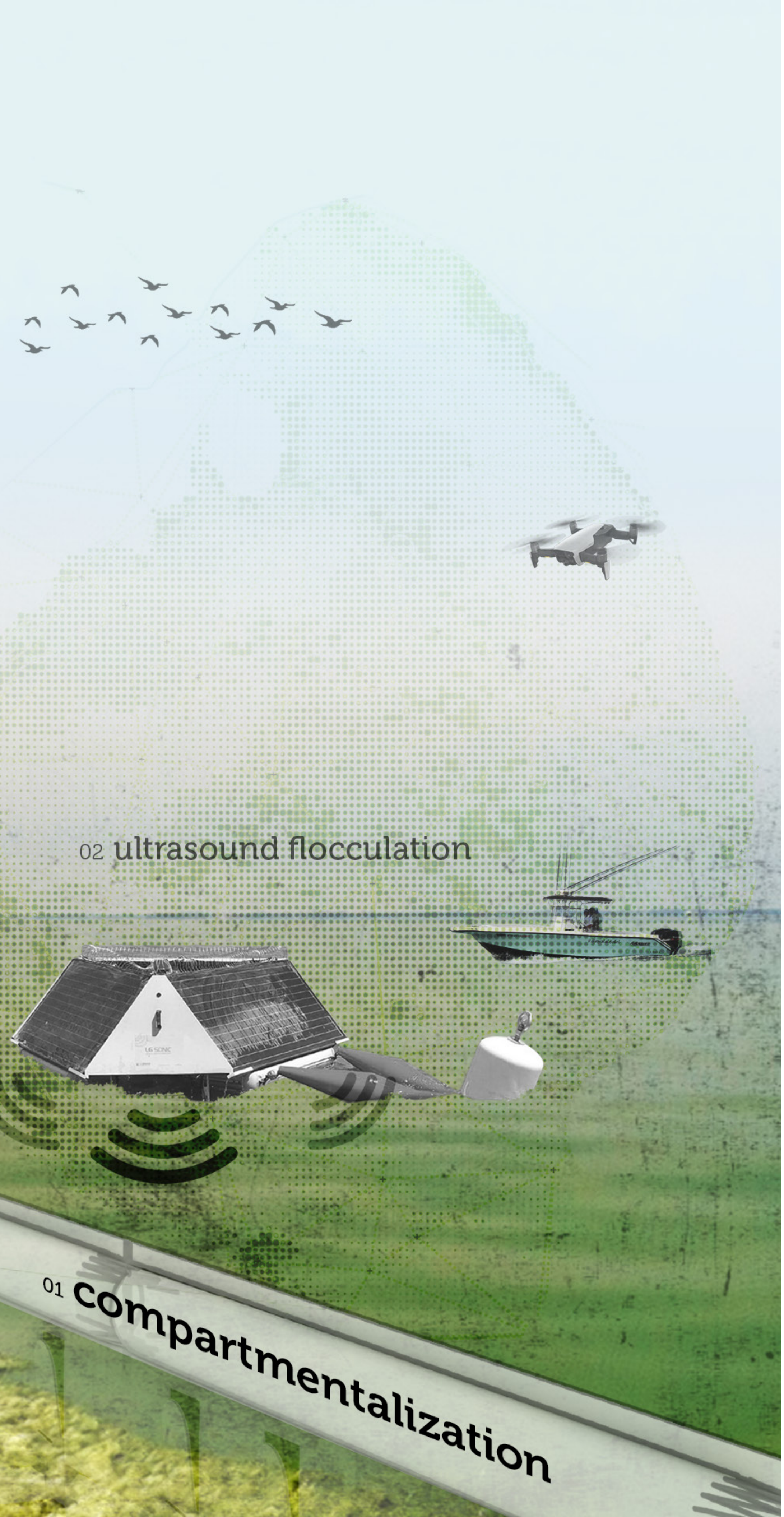


Figure 1.1 / Lake Okeechobee Applied Tactics

Lake Okeechobee is where algae enters the system; algae develops here due to high Nitrogen and Phosphorous entering the system and relatively low turbulence across the waterbody. Controlling nitrogen and phosphorous input into the lake is highly complicated because the watershed is incredibly vast and is downstream from the Kissimmee River, which meanders through thousands of acres of farmland. However, the one advantage here is that water leaving the system is highly controlled by the USACE and provides an opportunity to monitor actively, sense, and mitigate algae blooms before it heads downstream.

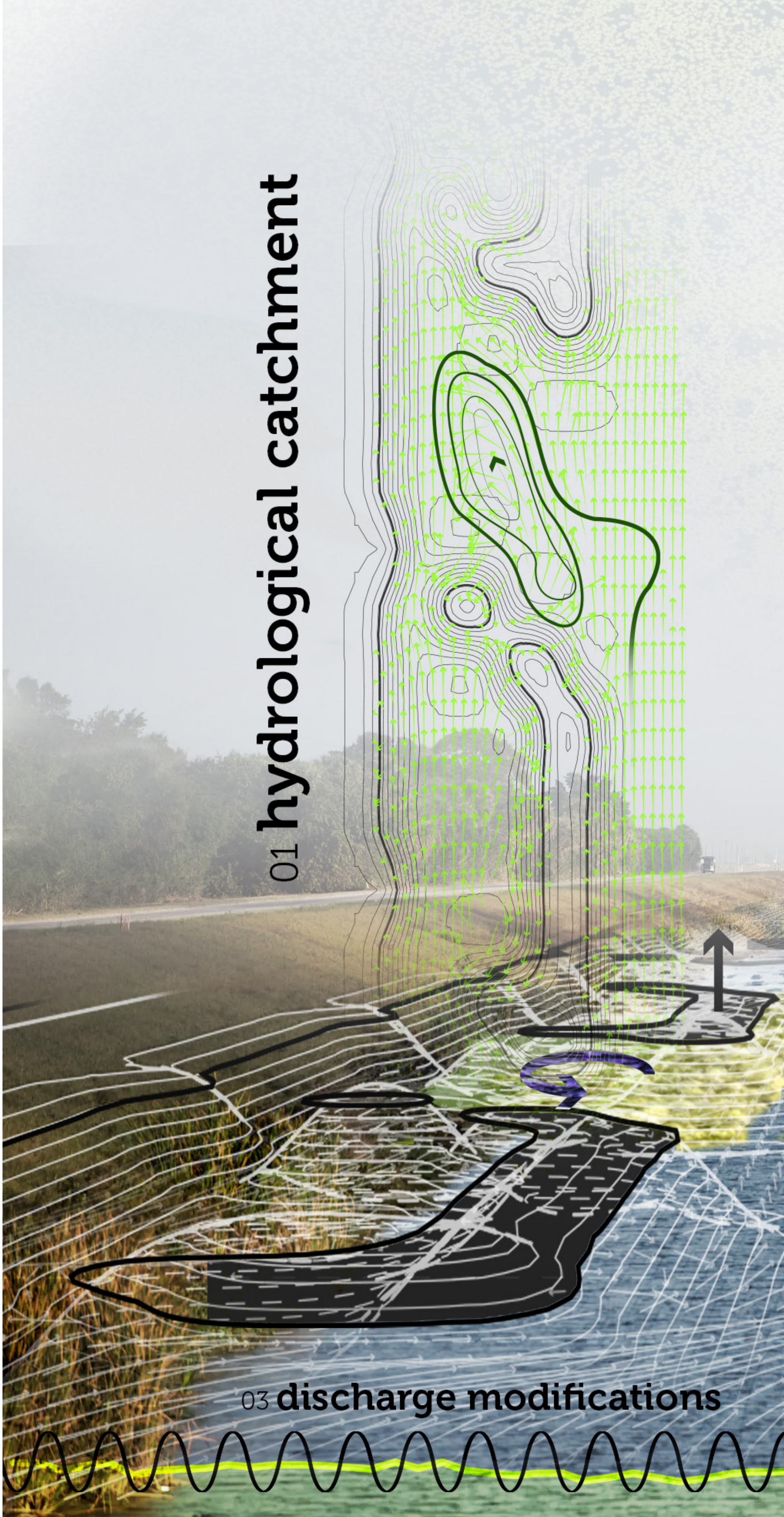
This rendering reveals several ideas about the mitigation of algae blooms throughout the Lake Okeechobee waterbody. As seen here, several robotic agents may aide in the compartmentalization, flocculation, and aeration of algae cells. Compartmentalization reduces the algae's capacity to reproduce. Ultrasound flocculation has been proven to destroy the gas vesicles found within algae and, therefore, its ability to stay buoyant. As the algae sinks, it loses access to sufficient light levels. Finally, aerators may be moved around by drones to increase surface water turbulence and reoxygenate waters.

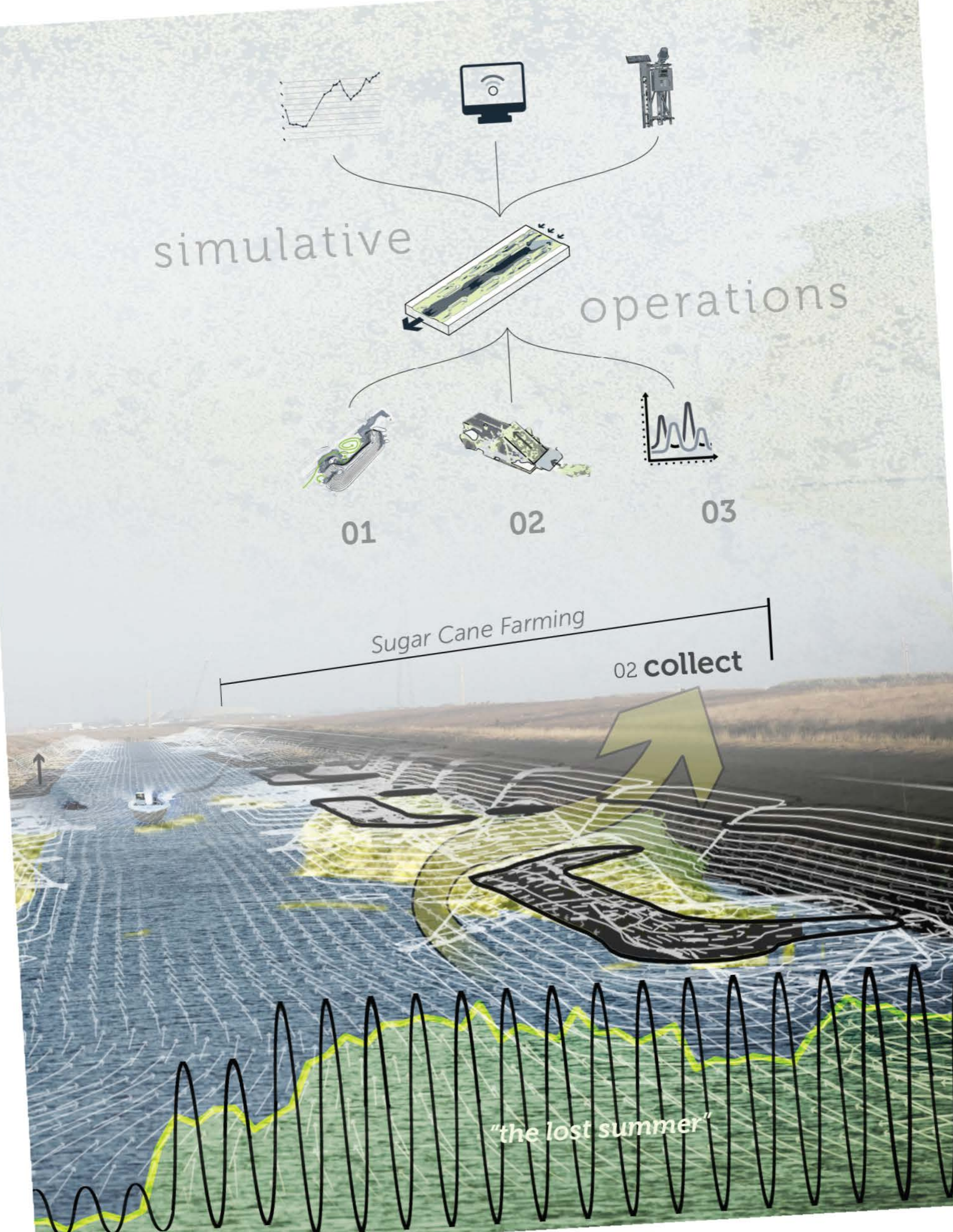
Figure 1.2 / C-44 Applied Tactics

Similar to the previous rendering, this image showcases several landscape tactics for mitigating harmful algae blooms throughout the St. Lucie Canal. While most algae inoculate in the Lake Okeechobee basin, C-44 acts as the conduit in which algae may float downstream into the St. Lucie Estuary. Like Lake Okeechobee, the advantage here is that algae is limited by certain boundaries and will move downstream.

Here we see the use of landscape infrastructure that modifies the way water moves and mixes, resulting in resuspended sediments that may flocculate algae. Other tactics include the collection of algae down the canal as it gets caught in eddies. Finally, experimentation may be further explored through observing pulsated discharges from the Port Mayaca Lock & Spillway (S-80). This kind of responsive landscape may be best explored by simulating specific discharge rates with a mutable shoreline. Shoreline topographic structures may inform where and how algae may move downstream.

Represented as “Simulative Operations”, this model environment may be explored through the testing of different discharge rates.




simulative
operations
01
02
03
Sugar Cane Farming
02 collect
"the lost summer"

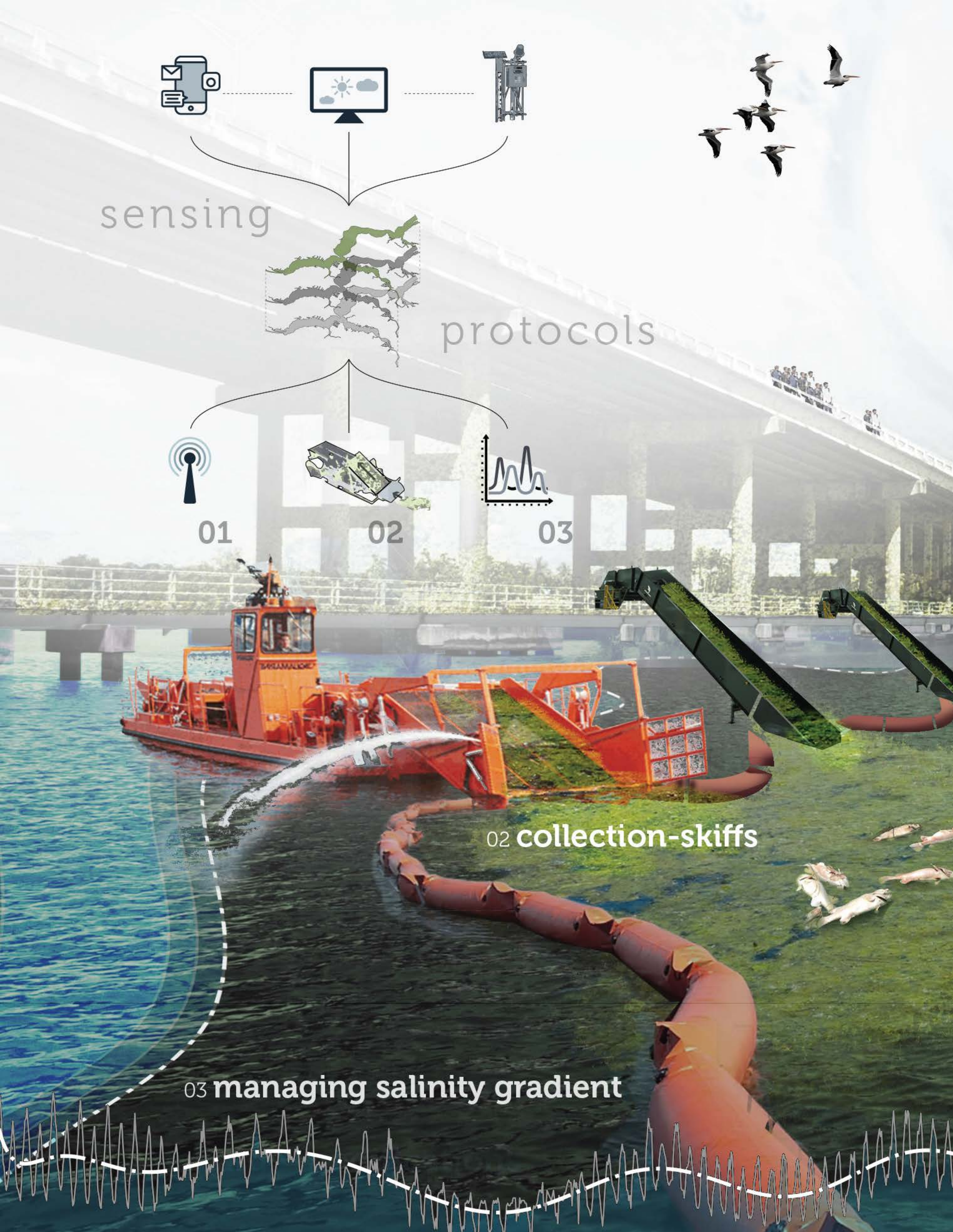

sensing
protocols
01
02
03
02 collection-skiffs
03 managing salinity gradient

Figure 1.3 / St. Lucie Estuary Applied Tactics

As the algae blooms move into the St. Lucie Estuary downstream, the sensing environment will need to be expanded upon through drone flybys, real-time water quality monitoring, and live feeds from local community members and estuary enthusiasts. The model may also tap into forecasted weather systems and tidal charts to inform the upstream St. Lucie Lock & Spillway when to release freshwater and maintain a more natural salinity gradient.

The estuary may become a landscape-scale responsive model, in which salinity levels throughout the estuary may be maintained to match historical levels. Through this process, local ecologies may thrive, and the potential for algae blooms may be controlled through the automated responses of the spillway if algae forms in these waters due to general poor water quality, skiff collectors and algae cleanup conveyors may be installed along with existing infrastructure and move around to blooming scums.

Project Aim and Scope

The realm of landscape architecture has focused on incorporating complex information and data processing through the means of modeling and representational translations. There is a long history of tools, instruments, and representational approaches to realizing and grappling with the complexities of the natural systems around us.[1] Today, with increased access to computational tools, such as algorithmic aided modeling and artificial intelligences, the field of landscape architecture sees increased opportunities to weave environmental modeling tools and live data streams into the design process via dynamic modeling.[2] The primary objective behind this project is to both define dynamic (responsive) modeling and develop a computational modeling process for interfacing the complexity of harmful algae blooms.

When considering modeling frameworks from our recent past, Carl Steinitz developed a robust approach towards Geodesign and Alternative Futures throughout his career. Steinitz's iterative framework towards modeling, although applicable to many landscape problems, operates outside of the realm of abduction and experimental design.[3] Over the past decade, a list of responsive modeling projects has been explored and seeks to redefine our discipline and close the gaps identified in Steinitz's framework. Among current academics, like Bradley Cantrell and Justine Holzman, or collaborations between the Dredge Research Collective and SCAPE, the responsive model continually redefines the practice of landscape architecture by pushing the boundaries of our discipline. Responsive modeling is innately speculative for it concurrently hinges between generating and testing hypotheses while incorporating the expanding agency of machine learning.[4] Through this comparative analysis, the definition of the Responsive Model may be made more clear and provide the designer a basis for projective design methodologies to explore within the infrastructural issues of South Florida.

1 See Anderson and Ortega (2016), especially their foreword section illuminating Innovations in Landscape Architecture.

2 Cantrell et al. explores "Deep-learning" methods which consider the incorporation of machine-learning and autonomous intelligence in the management of degrading ecosystems.

3 See Steinitz (2012), Part II of his book on Geodesign (Chapters 3 through 6). Also refer to Deming and Swaffield's text on Landscape Architecture Research: inquiry, strategy, design (2011)

4 See Cantrell and Holzman's text Responsive Landscapes: Strategies for Responsive Technologies in Landscape Architecture. (2016)

Scope

Due to the massive scale of this algae issue and the impacts it has on coastal infrastructures, the descriptive analysis and study will encompass a large area within the South Florida Water Management District. Looking at regional-scale flows, nutrient loading, and hydrological flows, the regional-scale model will inform how the entire system operates as a whole. Ideally, these investigations will lead to a better understanding of land-use impacts within the watershed as well as local management. Agencies such as the South Florida Water Management District (SFWMD) and the Army Corp of Engineers (USACE) have a long list of infrastructural projects intended to recover the ongoing environmental impacts of harmful algae blooms. Informed by the Comprehensive Everglades Recovery Plan,[5] these agencies will be working for a very long time, slowly implementing large infrastructural projects that provide very little green infrastructure and may, subsequently, cause more long-term damage to local ecologies and natural resources. It's arguable that these top-down oriented master plans, or "decision" models in reference to Steinitz, have a tendency to turn into politico-economic constructs.

Ultimately, through studying and accumulating responsive modeling case studies and applications, this project will synthesize responsive modeling as a design approach and attempt to transpose responsive methods onto the context of South Florida. Ideally, the responsive model may be seen as a new form of research method, and the knowledge collected during this projective design methodology may be valuable for landscape researchers and designers dealing with parallel questions and infrastructural problems.

5 The Comprehensive Everglades Recovery Plan (CERP) is headed by the Army Corp of Engineers and entails a long list of large-scale infrastructural projects aimed at mitigating the algae issues. These projects, though in theory should help the algae issues, take a very long time to construct and monitor. The measures taken here are aimed at preventing algae blooms; how may we begin to use tactics and responsive systems as a means to control algae blooms through the infrastructure itself?

Defining the Problem

Water has the power to infiltrate our society through physical, cultural, and spiritual means; however, it has been viewed and represented as both a victim and culprit of environmental disaster. In places like the Everglades, where historical ecosystems and hydrological processes have become severed,[6] we see how land use, habitat fragmentation, development, and coastal modification result in ecological devastation. Meanwhile, human settlement has become increasingly more detached from what is considered the nation's largest sub-tropical river through large-scale water management systems. All of these forces upon the land may only be visible through the growing advent of toxic, harmful algae blooms that proliferate through major waterways and recreational areas.[7]

These massively scaled algal blooms have become an epidemic throughout the waters of South Florida. For the past 20 years, very little has been done to manage this issue directly. After a recent 2016 algae bloom, the state's governor put more resources into dealing with the patterns of these catastrophes; however, due to the scope and gaps in knowledge, especially in regards to managing algae spatially, these issues haven't seen much, if any, resolution. Through research and academic journals, it's clear that the future of our waterways and their health will become more uncertain due to changing climates and political atmospheres. Perpetuating this phenomenon is the disconnection we may experience from our local environments, where our landscapes' intrinsically beautiful features can become toxic, algal nightmares. In South Florida, water has become both the victim and the culprit representing a complicated relationship that seems to have no clear answer.

South Florida: A Highly Productive Landscape

Coastal ecosystems are among the world's most productive systems for they provide more services to human well-being than most other systems on the planet.[8] According to the UN and Zhai et

6 (Homestead & Us, 2018)

7 See Babbitt (2005), page 19

8 Refer to the Carpenter & Millennium Ecosystem Assessment Program (2005) al., coastal zones provide fundamental interactions between land and water, providing rich ecological diversity, cultural connections, and food supplies that entice tourists and travelers alike.[9] In 2006, 40% of the world's population lived within 60 miles of a coastline while 28% were situated within coastal zones.[10] This is an ecosystem typology that accounts for approximately 5% of the planet's surface and a major actor in bridging habitats and life cycles together.[11]

In South Florida, coastal environments are perhaps the region's most economically rich resources and provide an array of ecosystem services to locals.[12] The Indian River Lagoon is considered the "cradle of the ocean." It provides about half of the fish caught along the state's eastern side, generating around 30 million USD annually.[13] According to John et al. and their studies of South Florida ecosystems, services such as recreational access, food supply, property protection, and ornamental beauty bring approximately 19 billion USD annually to the southeastern coast, between Miami and Port St. Lucie.[14] Beyond measurable dollar values, the Indian River Lagoon is a massive node along the Atlantic Flyway, an international corridor for migrating birds. Its ecological health determines the health of so many other habitats.[14]

With a growing world-wide population, these coastal systems will see rapid urbanization and subsequent anthropogenic impacts; which include ecosystem degradation, over-extraction, and nitrogen loading from various land-uses.[15] As an example of ecosystem degradation, the UN has determined that 80% of all fisheries are overexploited and, in 2017, aquaculture and fishery resources equated to over 100 billion USD globally.[16] In O'neil et al.'s research poorly managed aquaculture and overfishing results in modified food webs, enabling cyanobacteria to dominate algal communities. Although many factors determine the health of coastal ecosystems, the UN expresses its concern that, as coastlines become more developed, anthropogenic pressures and demands will most likely result in habitat loss and degradation through massive increases in nutrient-loaded waters by 2050.[17]

Ultimately, there still seems to be a list of unknowns regarding how CyanoHABs will respond to climate change within and around the Indian River Lagoon. For instance, most cyanobacterial strains

9 Refer to both the United Nations Environment (2006) & Zhai et al. (2019)

10 Refer to the United Nations Environment Report on Marine and Coastal Ecosystems and Human Well-being (2006)

11 Refer to the Carpenter & Millennium Ecosystem Assessment Program (2005)

12 John et al. provides insight on the economic importance of South Florida's Coastal Ecosystems which extend beyond the resources of the coast themselves. We must ask ourselves - is there a value we can put on the novel ecosystems around us?

13 The St. Johns River Water Management District contracted an economic analysis of the Indian RIver Lagoon. Though this report was developed in 2007, the economic value of the lagoon is critically important to consider when assessing the impacts of the algae blooms, whcih are starting to occur on an annual basis.

14 See St. Johns River Water Management District assessment. It's important to consider ecological dynamics that extend far beyond local ecologies.

15 Refer to both the United Nations Environment (2006) & Zhai et al. (2019)

16 See O'Neil et al.'s (2012) Section 6, Synthesis and future directions.

17 Refer to the United Nations Environment Report on Marine and Coastal Ecosystems and Human Well-being (2006) do not have tolerances for changes in water salinity.[18] The Indian River Lagoon is considered an estuary with several natural "mixing" processes which predicate the health of the water body and its salinity levels.[19] Therefore, it is essential to process climatic changes within this lagoon, such as rain events and sea-level rise, to paint a clear picture between future uncertainties and increased nutrient loads. In the meantime, Chapra et al. admit that their studies on cyanobacteria did not consider increases in salinity due to sea-level rise.[20]

A Disconnected Place

Arguably, land use planning should be connected to preserving the natural resources and cultural values of a place. Babbitt's Cities in the Wilderness explores the discordant relationship we experience between the ways land may be used about its historical socio-ecological resources. His first chapter, "Everglades Forever," focuses on the politically charged nature within and around the condition of the Florida Everglades. Once an ancient river of tall prairie grasses and wetlands,[21] this pristine ecosystem has been divided, drained, and developed into a broken place.[22] Early settlement in South Florida consisted of fears against flooding waters, monsoons, and hurricane seasons. These fears grew into pleas with the federal government after devastating storms destroyed thousands of homes in the 1920s.[23]

The Everglades, also known as the Ancient River of Grass, is a massive mono-functionally engineered landscape in the center of the southern section of Florida. As seen in Figure 1.4, the landscape has experienced drastic change due to early Euro-American colonization and the demands for development and sugar cane farming. All of these rapid changes have resulted in a "land of algae blooms." The series of historical maps reveals a long history of slow environmental violence placed upon the Florida Everglades; there's over a century-long process of draining the ancient river of grass to monetize lands and convert the swamp into mono-cultural farming practices.[24] It would almost be too simple to say that water management practices throughout South Florida are complicated. There is an incredibly long history of "draining the swamp" and parceling the land for ownership in the late 19th to early 20th century. According to Marjory Stoneman Douglas, one of the leading environmentalists supporting the restoration of

18 See O'Neil et al.'s (2012) Section 2.3.3 concerning Salinity.

19 See St. Johns River Water Management District assessment.(2007)

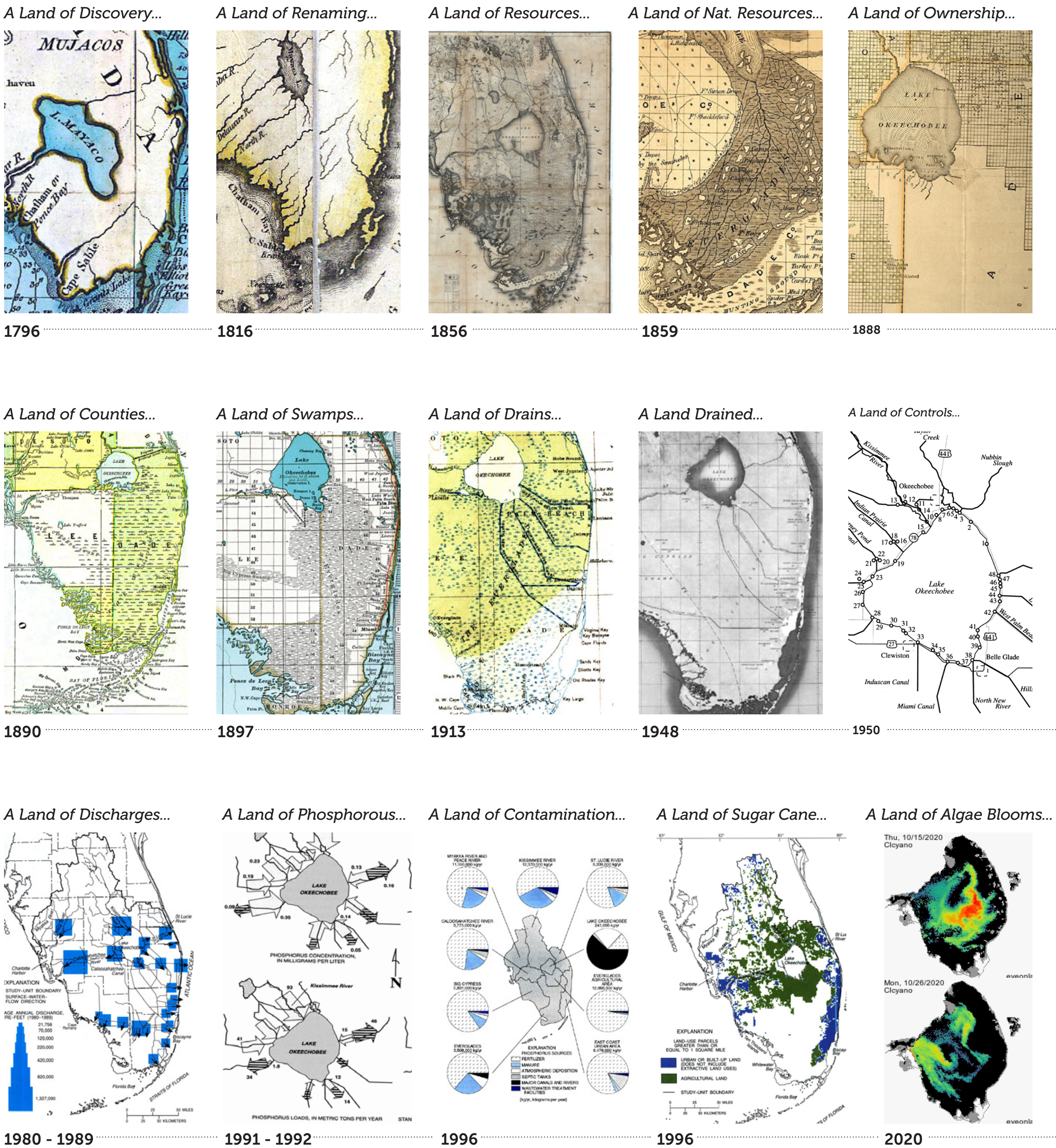
20 See Chapra et al.'s Results and Discussion of Harmful Algae Blooms (2017)

21 See Douglas's River of Ancient Grass (1997)

22 (Babbitt, 2005)

23 See Douglas's River of Ancient Grass (1997)

24 Babbit's CIties in the WIlderness and Douglas' Ancient River of Grass provide an in-depth narrative of the tragedies and environmental injustices taken place within and around the Florida Everglades.



Data Resources

Courtesy of the Geography and Map Division of the Library of Congress Courtesy the U.S. National Oceanic and Atmospheric Administration

Courtesy the University of South Florida Library

Courtesy of the Special Collections Department, University of South Florida

Courtesy of EyeOnLakeO

Figure 1.4 / Historical Mapping Exercise

A Timeline of Cartographic Impressions and Foci of the Everglades.

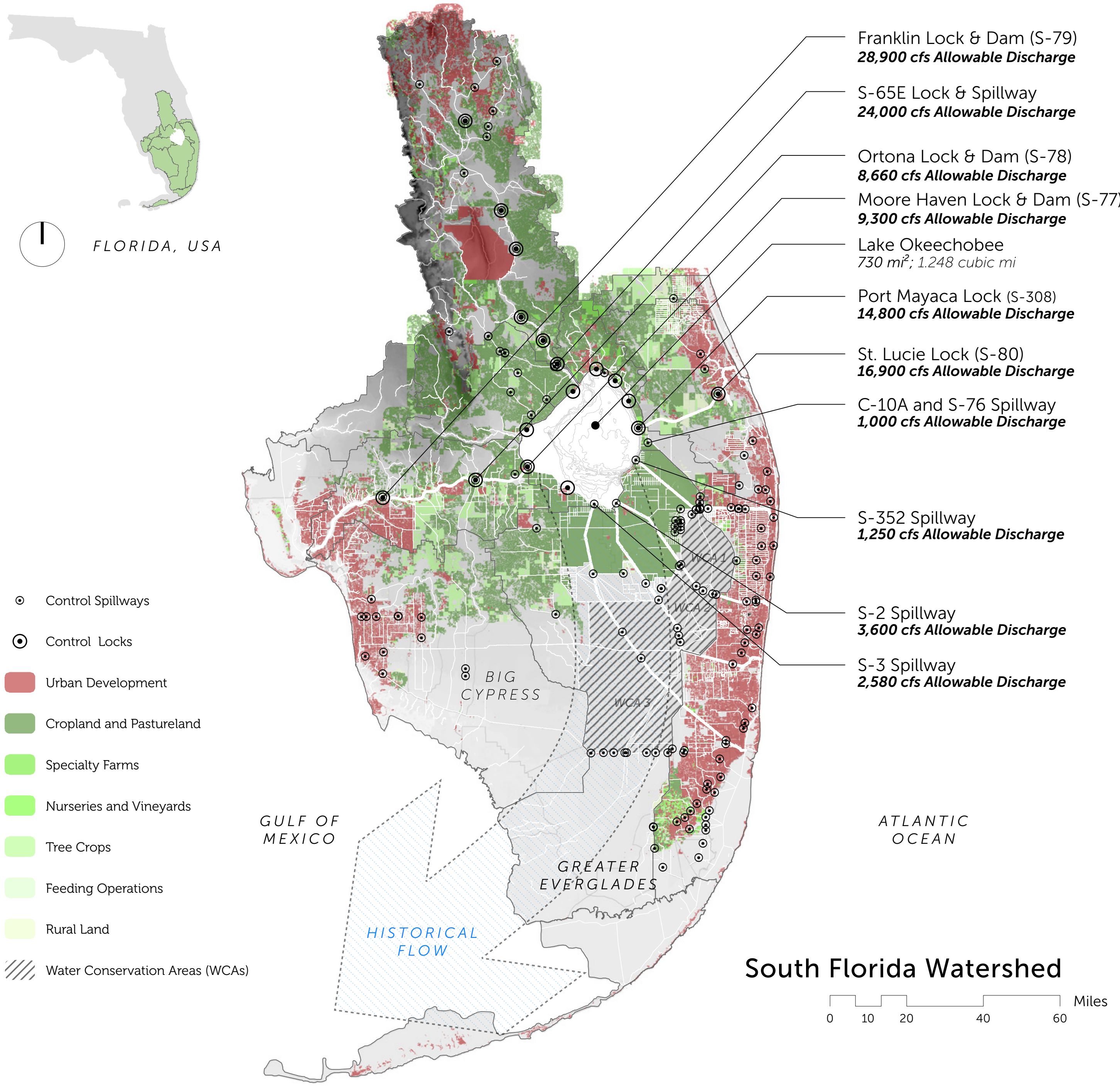


Figure 1.5 / Analysis of Existing Infrastructure at Lake Okeechobee

Breakdown of Waterflow (CFS) Capacity per Lock Structure

Data Resources

U.S. Geological Survey, 2017, 1/3rd arc-second Digital Elevation Models (DEMs) - USGS National Map 3DEP Downloadable Data Collection: U.S. Geological Survey.

Data provided by South Florida Water Management District, https://geo-sfwmd.hub.arcgis.com/

USACE Lake Okeechobee Regulatory Schedule (LORS) and Lake Okeechobee System Operating Manual (LOSOM)

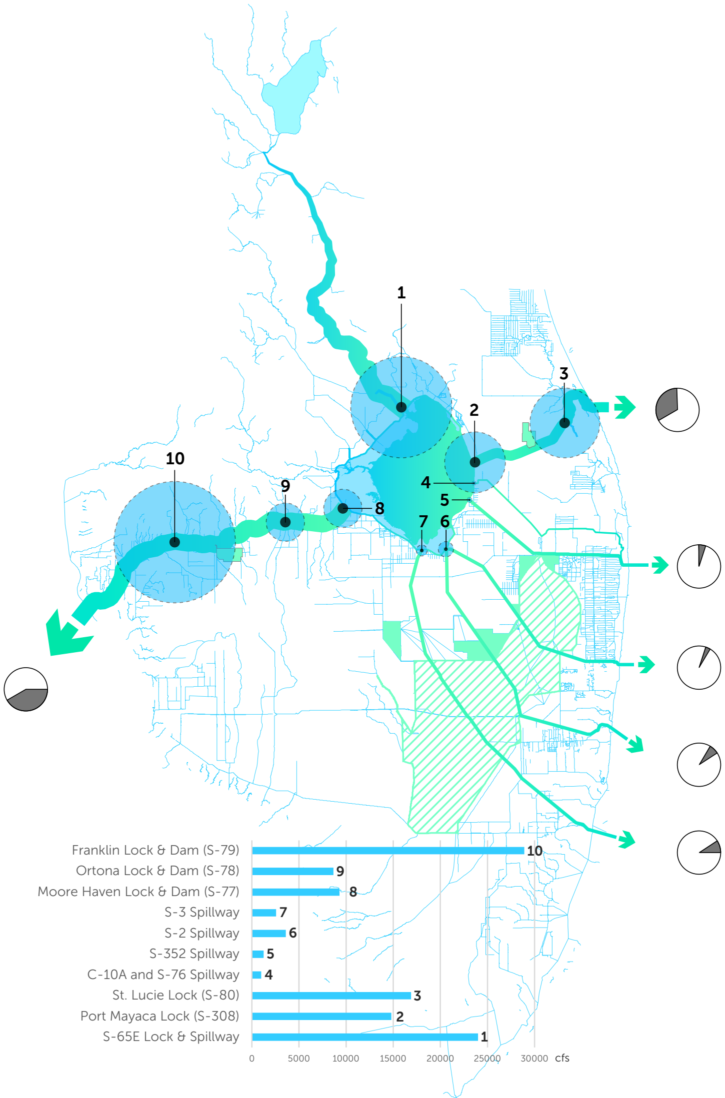


Figure 1.6 / Lake Okeechobee Water Flow System Analysis

Water Flow Discharge allowances, in Cubic Ft per Sec (CFS), at major Spillway Infrastructures throughout the Lake Okeechobee water management area. Major discharges occur along the East-to-West canal structures (C-43 Caloosahatchee River, and C-44 St. Lucie River). Smaller allowances of water are allowed southward down towards 3 large Water Conservation Areas (WCAs) through what was once an imperative historical hydrological flow. This change in the system has resulted in large-scale consequences throughout the Greater Everglades and enabled settlers to develop throughout certain swamp-lands.

the Everglades, the relationship between Euro-American settlers and the river of ancient grass is a rather brutal history where natural resources were exploited birds for feathers and alligators for shoes. The entire hydrological system is separated into three; one third for Sugar, another third for water storage, and, lastly, a third preserved for nature.[25]

Throughout the next 60 years, the Army Corp of Engineers was contracted to construct a massive system of earthen dikes around Lake Okeechobee and sections of the Everglades.[26] As these geoengineered basins filled up, the Corp dredged a system of canals, channels, and storm water treatment areas (See Figures 1.5 & 1.6) to divert water from the state's center towards southern reservoirs, the eastern Indian River Lagoon (IRL), and western Caloosahatchee River.[27] We may think of these channels as mono-functional release valves; a mechanism on the landscape that controls water levels within Lake Okeechobee. Although this mechanism ensures relative safe water levels for locals,[28]

25 See Babbit's *Cities in the Wilderness* (1994), page 24.

26 See Babbitt (2005), page 25

27 See Douglas's River of Ancient Grass (1997)

28 See Babbitt (2005), pages 13 to 54 it inadvertently creates a concentrated release of toxic algae into the easterly IRL, which is considered the most biologically diverse estuary within the United States of America.[29]

This process of systematic bifurcation resulted in a massive decline of ecological integrity.[30] Although the downfall of the Everglades started happening before the draining of swamps, the bifurcated ecological system resulted in broken management practices for a poorly designed system from the inception of this infrastructural landscape. Douglas also reveals that although the USACE had pure intentions in assisting the recovery of the Everglades through their control measures, the "greatest decline" in ecosystem functioning occurred soon after the construction of the levees:

> *The greatest documented decline has come since the early 1960s, when the levees around the Everglades were completed, the natural flows blocked. Yet new evidence suggests that the decline was going on more slowly for many years. With technology borrowed from Australia, the park has studied core samples from the corals of Florida Bay to track the history of upstream damage. The layers in the coral, as readable as tree rings, show a clear drop in the nourishing inflows of fresh water to the coral around 1910 - about the earliest attempts to drain the Everglades.*[31]

Today, these control structures support one of the largest sugar cane farming industries in the country; not surprisingly, the control of water stage heights throughout the lake are inherently political and predominantly revolve around the needs of sugarcane production. The USACE operates under the Flood Control Act of 1948,[32] which is also known as the Central and Southern Florida (C&SF) Project, where priorities are set as follows:[33]

1. Flood and storm risk management
2. Navigation
3. Water supply
4. Enhancement of fish and wildlife
5. Recreation

Environmental groups, like BullSugar, conclude that the USACE's priority for Water Supply is somewhat politically skewed, and suggest that stage heights revolve around this need of water for the production of sugar cane.[34]

29 See St. Johns River Water Management District (2007), Home to the Indian River Lagoon National Estuary Program

30 See Douglas's River of Ancient Grass (1997), pages 412 to 413.

31 See Douglas's River of Ancient Grass (1997), page 398.

32 See Babbit's *Cities in the Wilderness* (1994), page 30, and refer to BullSugar.org/operations/ for more information.

33 See BullSugar.org/operations/ for more information regarding USACE operations and other infrastructural issues concerning South Florida Water Management.

34 See Bullsugar's Mission at https://bullsugar.org/about-us/

The Army Corp of Engineers Operating Manual

The priorities mentioned previously led to the creation of what is known as the Lake Okeechobee System Operating Manual (LOSOM); a manual that sets prescribed water stage heights throughout the 12 months of the year (See Figure 1.7). According to BullSugar.Org, these priorities were established in 1948, when the population in South Florida was approximately 2.5 Million people. In 2019, the population of South Florida reached 9.1 Million.[35] It's arguable that the needs and priorities of Lake Okeechobee management has fallen short of serving the majority of its people. The LOSOM was most recently updated in 2008 and has been put through a reviewing process in the past several years.[36]

35 See Census County Populations of South Florida at www.census.gov.

36 Refer to Martin County's update on LOSOM status: https://www.martin.fl.us/LOSOM

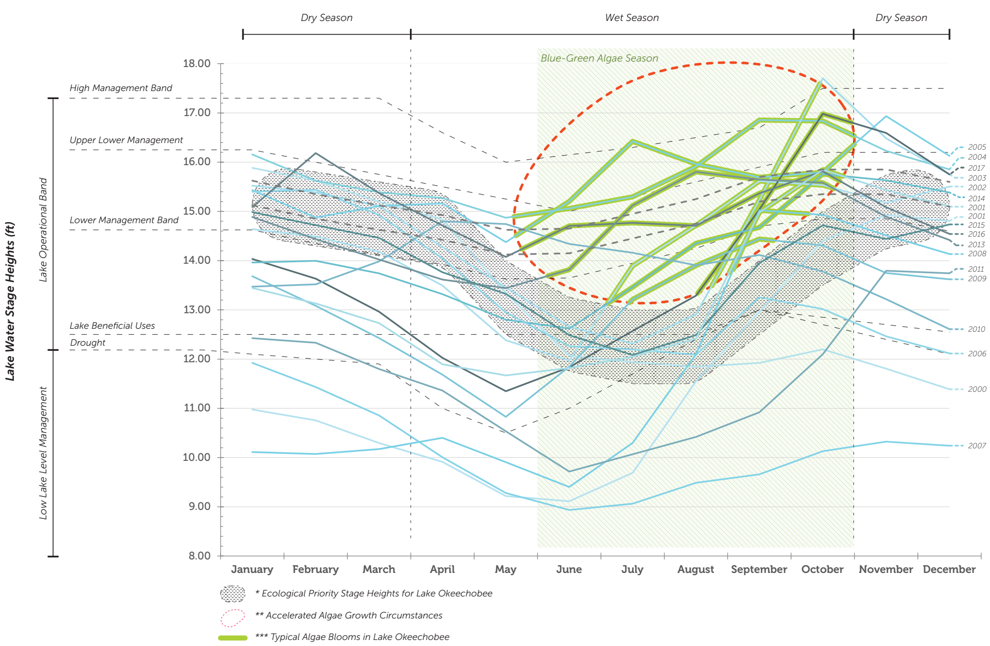


Figure 1.7 / USACE LOSOM, Historical Water Heights, and Algae Blooms

This is a composite graph mapping USACE Lake Okeechobee System Operating Manual (LOSOM) operational bands. Each operational band suggests the water stage heights suggested for the lake during different seasons of the year. It's important to highlight the green tone in which algae proliferates throughout the system. The red outline calls-out stage-heights that typically see algae blooms. It's arguable, especially in reference to the Audubon Florida's review, that algae will dominate in a lake with higher water stage-heights.

The LOSOM establishes a guideline for water stage heights throughout the entire lake in response to climatic events throughout the year. It's clear through historical outflow measurements that the USACE was focused on discharging and pumping water from the lake into adjacent canal outflows with safety concerns. In the past, especially before the 1970s, the USACE would regularly release large amounts of water to the eastern and western estuaries known as the Indian River Lagoon and Caloosahatchee River, respectively.[37] However, research over the past couple of decades suggests outflows of the lake should ideally match historical flows and avoid large releases into estuaries. As a result, current LOSOM (2008) discharge operations occur in "pulses".[38]

37 Data gathered by the SFWMD DBHydro Network. Refer to the discharge graphs seen in the following URL: http://eyeonlakeo.com/Historical/index.html

38 See the USACE 2008 LOSOM Documentation.

In many ways, the balancing of water discharge is complicated and must be met with more detailed research and analysis, especially regarding the ecological health of surrounding estuaries and water conservation areas. Lake Okeechobee was, historically, a shallower body of water, and due to an increase in its water stage height, environmentalists have seen a change in ecological health. After constructing several levees and dams, the USACE started holding the water above a 15-foot stage height.[39] Deep waters result in the following:

1. Sediment stirs at the bottom and kills off aquatic plants.[40]
2. Light availability reductions kill off aquatic plants and other macroinvertibrates impacting overall ecological health and filtration of nutrients.[41]
3. More water means more phosphorous storage capacity.[42]

According to the Audubon Florida, healthy lake levels shall never exceed 16 feet or fall below 11 feet - this is mainly due to the surrounding marshes of the lake. When water stage heights are too high, the plants throughout the marshes die from incoming wave action and loss of light access.[43] Meanwhile, when lake levels fall below 11 feet or stay there too long, marshes may dry out. Therefore, an ideal lake level resides between 6 inches of 12.5 feet at the end of the dry season and within 6 inches of 15.5 feet at the end of the wet season.[44]

With all of this information in mind, we can assume that algae blooms in the lake typically occur when water stage heights are too high during the wet season; however, recent algae blooms, including the 2016 outbreak, occurred when water levels were maintained well within the USACE management band. This realization provides us a reason to question the current management practices concerning lake level management. How may we begin to manage stage heights more accurately and efficiently? How may we mitigate these algae issues through a more adaptive, exploratory method?

Today, these issues result in massive infrastructural projects that work through the lens of preventative measures and stormwater treatment reservoirs. The Army Corp of Engineers explores mitigation through the Everglades And South Florida Restoration Plan (E & E&SF, or SFER).[45] The SFER is a component of a much larger restoration framework, known as the

39 See Audubon Florida's A Brief History of Lake Okeechobee Ecosystem Responses To Water Level Management (2017)

40 Audubon Florida's Everglades and Audubon Florida's High Water Levels in Lake Okeechobee: The Threat of Disaster (n.d.)

41 Inofrmation from Paul Gray, Science Coordinator from Audubon Florida's Everglades and Audubon Florida's A Brief History of Lake Okeechobee Ecosystem Responses To Water Level Management (2017)

42 Audubon Florida's Everglades and Audubon Florida's High Water Levels in Lake Okeechobee: The Threat of disaster (n.d.)

43 See Audubon FLorida's The Lake Okeechobee Ecosystem: A Delicate Balance of Water

44 See Figure A-1 "Stage Envelopes" in the Audubon Florida's The Lake Okeechobee Ecosystem: A Delicate Balance of Water or Figure 1.4 Below which illustrates the ecological priority stage envelopes via the gray area.

45 See the USACE's Everglades & South Florida Ecosystem Restoration Critical Restoration Projects (Overview)

Comprehensive Everglades Restoration Plan (CERP), developed back in the later decades of the 20th Century and authorized by Congress in 2000.[46]

Although the landscape modifications found in the SFER may help treat water and benefit ecosystems downstream, its approach may be considered inherently bureaucratic, mono-functional, and costly.[47] Overall funding for the E&SF lands at $249 million while the USACE website "Status" section reads: "Cost estimates for the projects have increased over time due to inflation, unexpected site conditions, design modifications necessary to meet the project goals, and construction bids higher than those originally estimated."[48] Meanwhile, one report developed by the James Madison Institute provides critical facts and figures related to the actual amount of money spent on restoring the Everglades ecosystem. According to this report, over $1.8 billion was spent by the State of Florida and $938 million was spent by the federal government on restoration, totaling over 2.7 billion dollars on the issues related to ecosystem restoration and water quality. The report also illuminates that, technically, the government owns approximately 5.5 million acres of South Florida, which is half of its landmass.[49]

For example, one recently completed project, the C-44 Reservoir, is designed to treat water flowing down the C-44 Canal, known as the St. Lucie Canal. The Reservoir is an additional piece of the already existing and growing infrastructure - converting about 10,000 Acres of land into a mono-functional, one-stop attempt of a solution priced at around 197 million dollars in construction costs.[50] The entire design includes a 3,400-acre reservoir & 6,300 acres of stormwater treatment areas (STAs) that may store up to 60,500 acre-feet of Lake Okeechobee water. With this, an extensive pumping system, capable of pumping 1,100 cubic feet per second, will be installed at the end of a large canal diverting water down the C-44 Canal into the newly fabricated basin. The topographic adjustments needed to control hydrological flows throughout this system include a 9.2-mile long, 30-foot-high earthen embankment that encircles the entire C-44 reservoir to ensure the catchment of water.[51]

As seen in Figure 1.8, the entire system hinges on a 20,000 linear-foot "intake canal" (IC) that diverts 60% of the water discharged into the C-44 Canal [52] from lake Okeechobee into a series of stages, or cells. These cells act as water retention basins in which algae may be mitigated and

46 See the South Florida Ecosystem Restoration Program at https://www.

47 See James Madison Institute's "Solving the Everglades Riddle: Addressing Water Quality and Quantity to Restore a Florida Legacy", page 8, "Complexities of Everglades Restoration" Section describing the rugulatory process as a "Rbrik's Cube".

48 See Sections 2 and 4 in South Florida Ecosystem Restoration Program

49 See James Madison Institute's "Solving the Everglades Riddle: Addressing Water Quality and Quantity to Restore a Florida Legacy", page 7 & 8.

50 See the USACE's Everglades & South Florida Ecosystem Restoration Critical Restoration Projects (Overview)

51 See Bergeron Land Development's C-44 Reservoir Project page at https://www.bergeronlanddev.com/c-44-reservoir/

52 See the USACE's Everglades & South Florida Ecosystem Restoration Critical Restoration Projects (Overview) treated. According to the USACE's Review Plan for the C-44 Project, the water will circulate throughout the system and will be introduced to sedimentation and the "natural transformation of nutrients" within the various cells. The review clearly notes how this system is not authorized or intended to be used for flood control; it's sole purpose is to provide environmental reclamation.[53]

Although the state argues this infrastructure will assist in providing increased water quality health and a reduction in CyanoHAB outbreaks, this kind of Reservoir has been used in other parts of the everglades as a means to manage discharge rates and flood control. As previously mentioned and seen in Figure 1.5, several large water conservation areas (WCAs) are on the fringes of significant urban and suburban developments. These WCAs were established right after the Flood Control act of 1948 in The Central and Southern Florida Project for Flood Control and Other Purposes in 1950.[54] The WCAs were designed to mitigate floods through large-scale levees while buffering water discharged from Lake Okeechobee. Meanwhile, the sitting water may recharge drinking water into the Biscayne Aquifer while simultaneously decelerating salt-water intrusion.[55]

According to a recent 2016 Environmental Report, the WCAs become incredibly complicated to operate from the view of the ecosystem and the considerable population of flora and fauna that call it home. As a synopsis, due to the rapid changes seen in the WCAs brought on by water management decisions and meteorological fluctuations, disruptive flooding events followed by quick droughts can exhaust many ecological resources.[56] Although the Florida Fish and Wildlife service (FWC) proclaim the C-44 Reservoir to be safe enough to operate in terms of existing ecology, they fail to see past the potential ecology developed on this site during toxic algae off-seasons. If we were to create a parallel to the southern WCAs, the C-44 STAs may become a very large ecological trap for sensitive species. The FWC does admit that the STAs "may affect, but is not likely to adversely affect," [57] the rapidly depleting wood stork; however, these newly imposed STAs will become the toxic-foraging grounds for an already threatened, Florida-native wading bird.[58] Perhaps the State is weighing the ecological health of the IRL above the existing landscape where the C-44 Reservoir is situated, in which case does make logical sense. However, this massively engineered landscape provides only *one singular solution* and fails to consider the past, present, and numerous future variables at play

53 See the USACE's Review Plan for C-44 Reservoir/Stormwater Treatment (STA) Project (2012)

54 See Janine Lemaire and Bénédicte Sisto review of the Everglades and its historic destruction in The Everglades Ecosystem: Under Protection or Under Threat? (2012)

55 See section 1.3.5 "Water Conservation Areas" of the USACE's Central And Southern Florida Project Comprehensive Review Study: Final Integrated Feasibility Report And Programmatic Environmental Impact Statement (1999)

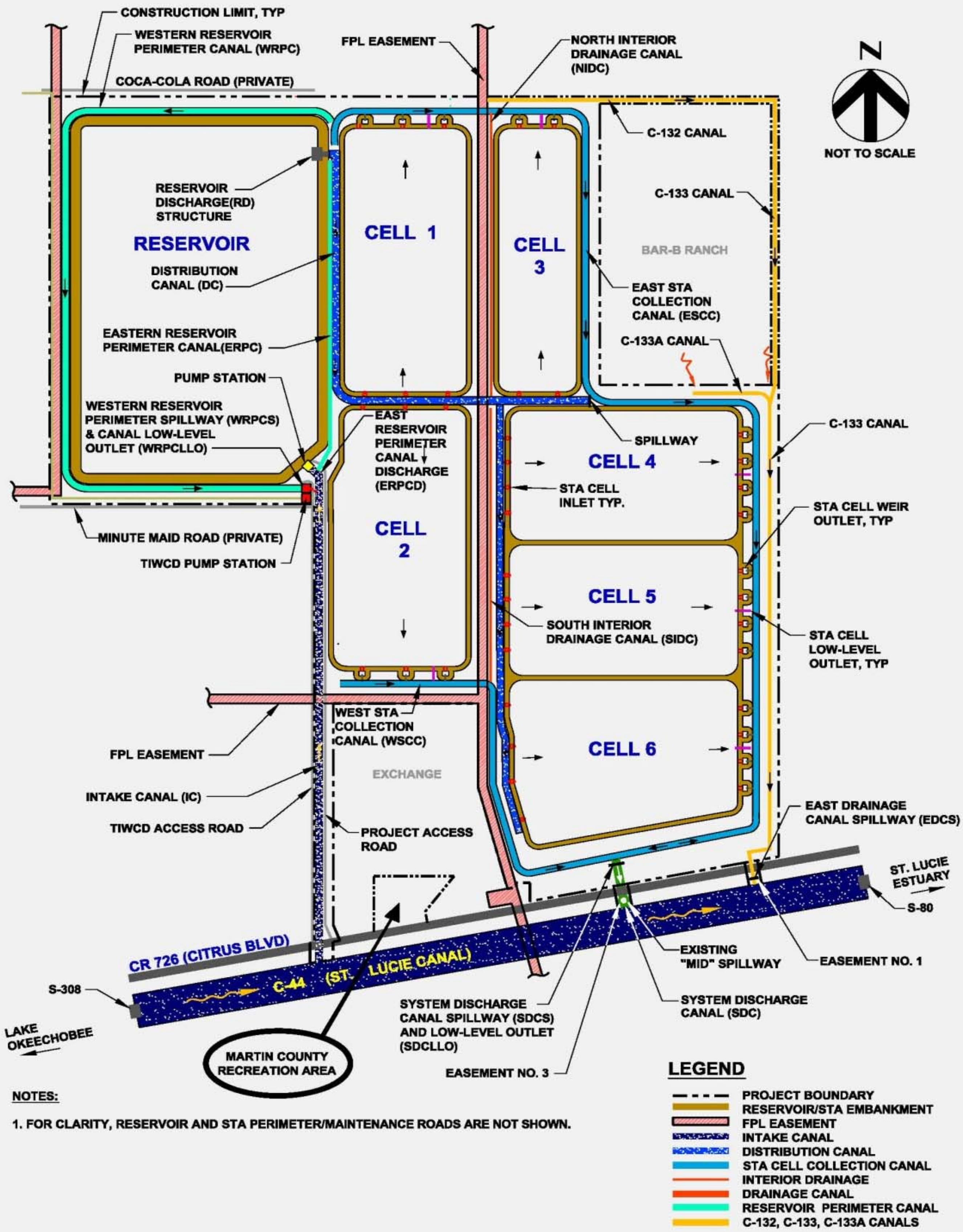
56 See Dreschel and Sklar's 2016 South Florida Environmental Report Chapter 6: Everglades Research and Evaluation (2016)

57 See the Florida Fish and Wildlife Commission's 2006 Report to the Army Corp of Engineers.

58 See the Florida Audubon's info on the Wood Stork at https://fl.audubon.org/birds/wood-stork

Figure 1.8 / The C-44 Reservoir Plan courtesy USACE

C-44 Reservoir and STA plan as well as the various landscape infrastructure needed to effectively accomplish the engineer's goals.



CONSTRUCTION LIMIT, TYP
WESTERN RESERVOIR PERIMETER CANAL (WRPC)
COCA-COLA ROAD (PRIVATE)
FPL EASEMENT
NORTH INTERIOR DRAINAGE CANAL (NIDC)
N
NOT TO SCALE
C-132 CANAL
C-133 CANAL
RESERVOIR DISCHARGE(RD) STRUCTURE
RESERVOIR
CELL 1
CELL 3
BAR-B RANCH
DISTRIBUTION CANAL (DC)
EAST STA COLLECTION CANAL (ESCC)
EASTERN RESERVOIR PERIMETER CANAL(ERPC)
C-133A CANAL
PUMP STATION
WESTERN RESERVOIR PERIMETER SPILLWAY (WRPCS) & CANAL LOW-LEVEL OUTLET (WRPCLLO)
EAST RESERVOIR PERIMETER CANAL DISCHARGE (ERPCD)
SPILLWAY
C-133 CANAL
CELL 4
STA CELL INLET TYP.
MINUTE MAID ROAD (PRIVATE)
TIWCD PUMP STATION
CELL 2
STA CELL WEIR OUTLET, TYP
CELL 5
SOUTH INTERIOR DRAINAGE CANAL (SIDC)
STA CELL LOW-LEVEL OUTLET, TYP
WEST STA COLLECTION CANAL (WSCC)
FPL EASEMENT
CELL 6
EXCHANGE
INTAKE CANAL (IC)
TIWCD ACCESS ROAD
PROJECT ACCESS ROAD
EAST DRAINAGE CANAL SPILLWAY (EDCS)
ST. LUCIE ESTUARY
S-80
CR 726 (CITRUS BLVD)
C-44 (ST. LUCIE CANAL)
EXISTING "MID" SPILLWAY
EASEMENT NO. 1
S-308
LAKE OKEECHOBEE
SYSTEM DISCHARGE CANAL SPILLWAY (SDCS) AND LOW-LEVEL OUTLET (SDCLLO)
SYSTEM DISCHARGE CANAL (SDC)
MARTIN COUNTY RECREATION AREA
EASEMENT NO. 3
LEGEND
PROJECT BOUNDARY
RESERVOIR/STA EMBANKMENT
FPL EASEMENT
INTAKE CANAL
DISTRIBUTION CANAL
STA CELL COLLECTION CANAL
INTERIOR DRAINAGE
DRAINAGE CANAL
RESERVOIR PERIMETER CANAL
C-132, C-133, C-133A CANALS
NOTES:
1. FOR CLARITY, RESERVOIR AND STA PERIMETER/MAINTENANCE ROADS ARE NOT SHOWN.

while also failing to exploring various landscape tactics for managing algae in new, innovative ways.

The resulting synthetic ecologies of the WCAs are tied to the decisions made by South Florida Water Managers as well as the Lake Okeechobee's capacity to hold, redirect, and treat water. The ecological system itself becomes a responsive indicator of these decisions. This information leads to an important question: How may we modify existing infrastructure to alleviate growing water quality concerns and tell the story of cyanobacterial algae blooms?

The "Lost Summer" of 2016

Local newspapers and publications have coined the expressions "The Lost Summer" and the "Summer of Slime" to describe the recurring events of algae blooms throughout Lake Okeechobee. Interestingly, this nomenclature has been used throughout the 2000s via articles and press releases and seems to represent the recursive nature of this seasonal phenomenon. There has been a "lost summer" of 2013, a "lost summer" of 2016, and a more recent "lost summer" of 2018.[59] Ed Killer, a journalist and writer for TCPalm, coined the term "Lost Decade" in a more recent op-ed explaining the 2018 algae blooms.[60]

59 Explore TCPalms and Miami Heralds archives for articles revealing the status of Lake Okeechobee waters.

60 Find Ed Killer's op-ed on the Lake Okeechobee crisis of 2018 and his insight into the issue.

Figure 1.9 / The 2018 "Lost Decade" Summer Algae Blooms

These photos, courtesy of Leah Voss from TCPalm, show changes in the Algae Bloom biomass over July 25th, 2018 (left) to August 15th, 2018 (right). Leah took these images at the same spot in the "Sportsmen" Canal of Stuart, FL. These images help explain the temporality of the problem while also showing how algae blooms leave a mark upon the physical structures built throughout the St. Lucie Estuary. We can only imagine the impacts this has on the ecological system at play here.

The Summer of 2016 in South Florida saw the largest recorded cyanobacterial outbreak in history. Although, there has been other record breaking years of massive cyanoHAB outbreaks, seen in 2005 and 2013, the year of 2016 presented some unique challenges to water managers and resulted in a state of emergency declared by governor Rick Scott.[61] Lake Okeechobee saw high rainfall activity during the 2015 to 2016 winter season and warmer temperatures brought on by the concurrent El Niño event.[62] According to NASA, in early May of 2016, 85 km^2, or 33 mi^2, of the surface area of the lake was completely covered in algae scum.[63] This loading of nutrient-rich waters in the lake warranted a more extended period of discharges through the primary spillways, resulting in the release of billions of gallons of freshwater, which changed the salinity levels of the estuary to favor freshwater cyanobacterial species, like Microsystis aeruginosa.[64] This project explores algae phenomenon and design through the timeline of the "Lost Summer" of 2016. Although the data during this time is somewhat limited, the simulations and models will utilize what's available from monitoring stations, hydrographs from approved discharge data by the Army Corp of Engineers and USGS, and any remote sensed visuals and images from satellites and fly-bys.

The resulting work of the Army Corp is an assembly of broken ecological systems, barricaded by earthworks, wholly disconnected from historical Everglades hydrological flows. This disconnection translated well beyond historical ecological systems by imposing a physical and metaphysical boundary between local users and their landscapes. As Babbitt puts it, the early twentieth century demands for establishing federally regulated and managed watersheds created a rift that has lasted into today; culturally, we are both unaware and disinterested in managing our waters.[65]

I would concur with Babbitt's take on Florida's significant disconnection to its Everglades. Having grown up right outside the Everglades in a suburban town known as Weston, a journey out into its wonder takes a considerable amount of time due to these large-scale levees. Most Floridians can only see into this landscape when they gain elevation driving over interstate highway ramps or mounting the levees themselves. Although this dissociation prevails, the increasing rates of algal outbreaks and its proliferation in the Indian River Lagoon have posed new questions and inspired others to act.[66]

61 See the introduction to Oehrle et. al's "Toxin composition of the 2016 Microcystis aeruginosa bloom in the St. Lucie Estuary, Florida".

62 See Kramer et al's "Nitrogen limitation, toxin synthesis potential, and toxicity of cyanobacterial populations in Lake Okeechobee and the St. Lucie River Estuary, Florida, during the 2016 state of emergency event" and their

63 See NASA's Earth Observation which includes imagery from NASA's Landsat 8 Satellite.

64 See Kramer et al and Oehrle et al's papers on the Microsystis algal outbreak during the summer of 2016.

65 See Babbitt (2005), page 26

66 Organizations like the Friends of the Everglades and Bull Sugar have put pressure on law-makers concerning the algal outbreaks.

The Blue-Green Algae Epidemic

The type of algae impacting the waters of Lake Okeechobee and the Indian River Lagoon are know as "Blue-Green" algae.[67] Interestingly, this biomass is not even considered a true species of algae, in fact, it is a form of bacteria that behaves like eukaryotic algae.[68] It is known to most researchers as cyanobacteria harmful algal blooms, or CyanoHABs, an ancient phytoplankton,[69] that has been credited for the oxygenation of our prehistoric atmosphere.[70] These CyanoHABs feature a long list of toxins that impact the lives of humans, animals, and plants alike. Recent studies have linked these toxins to the amyotrophic lateral sclerosis parkinsonism–dementia complex (ALS-PDC) – which are debilitating, neurological diseases.[71] Not surprisingly, these toxins have lasting impacts on ecosystem health as well: reducing water clarity through particulate matter, suppressing plant growth and macroinvertebrate activity while suffocating most fauna of healthy oxygen levels.[72] In the context of South Florida, this algae has made lasting impacts ranging between the depletion and suppression of seagrasses, the drowning of manatees, and the killing of household pets.

67 St. Johns River Water Management District (2007), Home to the Indian River Lagoon National Estuary

68 See O'Neil et al.'s introduction of Harmful Algae Blooms (2012)

69 Chapra et al. (2017) provides an acronym for Cyanobacterial Harmful Algae Blooms, which is easier to refer to it by.

70 See O'Neil et al.'s introduction of Harmful Algae Blooms (2012)

71 See O'Neil et al.'s (2012) Section 2.1 concerning CyanoHAB toxins.

72 See Chapra et al.'s introduction of Harmful Algae Blooms (2017)

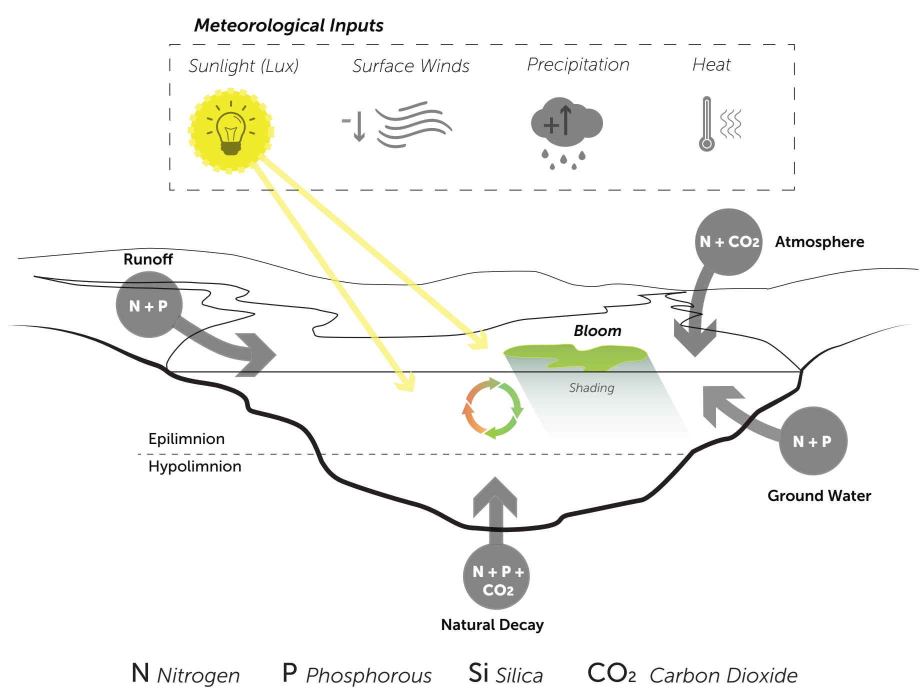


Figure 1.10 / The CyanoHAB Cycle & Input Drivers

This diagram maps out the primary drivers surrounding cyanobacterial blooms. It's important to note that, although phosphorous and nitrogen inputs are the main drivers behind the Lake Okeechobee algae blooms, meteorological factors do influence algae proliferation.

Many drivers are influencing the growth of these CyanoHABs (See Figure 1.9). The primary driver is nutrient-loaded waters from agricultural land-uses, urban development, and leaking septic tanks. Hydrological modification, such as water channelization, leads to lower ecosystem function, which typically occurs throughout urbanization, development, and agricultural land uses.[73] Elosegi and Sabater research the implications of these man-made adjustments on the ecological well-being of waterways. They emphasize the importance of understanding hydrological function when reviewing ecosystem health.[74] Beyond land-use and water movement, it has been proven that CyanoHAB outbreaks occur more frequently in warmer, acidic waters due to variables brought on by global climate change.[75]

Changing Climates

As we begin to see changes in our climatic events, we will also see an undeniable increase in harmful algal blooms.[76] According to the Intergovernmental Panel on Climate Change's latest report on our global climate crisis, the world is to reach an average warming of 1.5° Celsius between the years 2030 and 2052,[77] while other models suggest an increase between 1 to 3.5° Celsius by the year 2100.[78] With this projection comes the expectation that there will be an increase in extreme weather events, with a steep rise in seasonal temperatures and, consequently, sea-levels.[79] In fact, the IPCC designates lower-lying coastal regions as areas of greater risks and impacts with the forthcoming pressures of climate change.[80] In relation to algae blooms, current trends in climate change will see an increase in toxic taxa due to specific drivers that go beyond increases in atmospheric temperatures.[81]

The IPCC weighs nutrient loading as the primary driver of water quality degradation,[82] while, likewise, O'neil et al. suggests this process of eutrophication as the primary driver behind cyanobacteria outbreaks.[83] More specific drivers influencing the proliferation of harmful algae include changes in precipitation and drought seasons, water PH balances and salinization.[84] Although nutrient loading from land-use may be understood as the kindle for harmful algae, researchers believe that changes in climatic events and hydrological chemistry will act as the fuel.[85] For example, as rain events become more extreme during specific seasons, and droughts last longer, collected storm-water

73 See Elosegi & Sabater (2013)

74 See Elosegi & Sabater (2013)

75 See Chapra et al.'s Results and Discussion of Harmful Algae Blooms (2017)

76 See Chapra et al.'s Results and Discussion of Harmful Algae Blooms (2017)

77 See page 6 of the Intergovernmental Panel on Climate Change's Report (2018)

78 Refer to Steven P. Hamburg et al.'s online resource provided by the US Global Change Information center. (1997)

79 See page 7 of the Intergovernmental Panel on Climate Change's Report (2018)

80 See page 10 of the Intergovernmental Panel on Climate Change's Report (2018)

81 See Chapra et al.'s Results and Discussion of Harmful Algae Blooms (2017)

82 Intergovernmental Panel on Climate Change Report (2018)

83 See O'Neil et al.'s (2012) Section 6, Synthesis and future directions.

84 See Chapra et al.'s Results and Discussion of Harmful Algae Blooms (2017)

85 See O'Neil et al.'s (2012) Section 6, Synthesis and future directions.

runoff within lakes and reservoirs will have a higher chance of hosting cyanobacterial blooms.[86] Unfortunately, in places like South Florida, these infected waters move downstream and typically dump out into the ocean impacting coastal ecosystems and reef habitats. Although CyanoHABS only occur in freshwaters due to the bacteria's inability to fix Nitrogen in waters with higher salinity levels, with massive discharges down the Saint Lucie River (C-44), CyanoHABS have been seen to make it out into near-shore waters, especially during the Lost Summer of 2016. Unfortunately, in places like South Florida, these infected waters move downstream and typically dump out into the ocean impacting coastal ecosystems and reef habitats. According to Stuart Oehrle et al., over 154 billion gallons of Lake Okeechobee water passed through the St. Lucie Estuary, significantly reducing salinity levels of the entire estuary. Waters inside of the St. Lucie Inlet, which separates the Estuary Lagoon to the Atlantic Ocean, saw half as many salts in their solution than typical.[87]

Moving Forward...

Merriam-Webster defines *agent* as "something that produces or is capable of producing an effect: "an active or efficient cause" and "a means or instrument by which a guiding intelligence achieves a result." Algae has been an agent and ecosystem indicator throughout the Earth's history; researchers have used paleoecological surveys of lake sediment to understand algae in the context of today's changing climates.[88] How else may we use properties of algae and the principles explored in this paper to inform complex decision making and sustainable ecological design?

Jan Stevenson, author of Ecological Assessments with "Algae: A Review and Synthesis", provides keen insights on the importance of water management and the need for additional research in order to influence future environmental policies:

> *Water resources are among the most valuable and most widely threatened. Sound science is needed to wisely manage these resources with appropriate balance between over protection and under protection. The importance of trade-offs among ecosystem services in watershed management is sufficiently great that research is needed for highly refined quantitative relationships that address ecological complexity of CHANS (coupled human and natural systems), and environmental policy.*[89]

86 See Chapra et al.'s Results and Discussion of Harmful Algae Blooms (2017)

87 See Stuart Oehrle et al.'s report and study on the Toxin composition of the 2016 Microcystis aeruginosa bloom in the St. Lucie Estuary, Florida

88 Jan Stevenson (2014) argues, as a researcher, that our understanding of environmental management may include algae as a kind of assessor. He admits that much more research is required in the realm of algae,; however, our advancement in modeling and simulation is promising.

89 See Stevenson (2014), page 455.

With Stevenson's point in mind, the growing changes in our ecological systems brought on by climate change provide even more complexity to managing our watersheds. However, I would argue that the context of this issue requires more than objective exploration and engineered approaches seen in the USACE's CERP approach. CyanoHABs impact many people and haven't been adequately researched through a design lens. It's time to paint a more complete picture of its effects and consider transdisciplinary methods that appeal to abductive reasoning.

In respect to South Florida, modeling and simulating these stressors may generate new ideas and concepts around this issue, moreover, realizing these complexities and communicating them to the masses will become increasingly important. Following the ideas of process discourse and research through design,[90] this project aims at realizing the complexity of this algal landscape through the responsive modeling tactics. In many ways, the models and simulations produced throughout the journey will become landscapes and artifacts within themselves; appealing stakeholders to envision a new approach to water management, ecological sensitivity, and restorative landscape architecture.

The following section will continue research in the context of the "landscape as model", revealing the importance of understanding complex phenomena through visualization and responsive modeling feedback. The section afterward will discuss the responsive model and its place as a research-through-design methodology. Finally, the report will explore the findings and explorations of this landscape via responsive modeling typologies, establishing a responsive research through design framework in and of itself through the lens of landscape as model.

90 The design process has been heavily influenced by Raxworthy's ideas concerning process discourse (2017), Lenzholzer et al.'s discussion on research through design (2013), and Nijhuis' thoughts on design-related landscape architecture design (2012).

2.

Models as Manifesto

The Nature of Modeling

We find a rich history in which our relationship with technology and its capacity for our designs are intertwined. This history, an ever-changing organism, is constantly redefining our praxis and re-shaping how we think and engage the world altogether. Over the past century, design disciplines have become increasingly more systems-oriented.[1] Underpinning this phenomenon is the realization that humans are innately pattern-based. In many pieces of literature about design and computation, such as Architectural Intelligence, Innovations in Landscape Architecture, and Dynamic Patterns: Visualizing Landscapes in a Digital Age, we see a common thread: patterns. According to Keith VanDerSys and Karen McCloskey, pattern-finding and pattern-forming become a landscape architect's tool for understanding the infinite interactions that surround us.[2] This perspective argues that the only way to grapple with this engagement of interacting agents is through modeling, observation, and computation. As we see an increased focus on the symbiosis between the natural world and our built infrastructure, we will see an increased emphasis on understanding patterns via systems-oriented design, and therefore, computational modeling.

From Christopher Alexander's *A Pattern Language*[3] to the works of Lawrence Halprin,[4] we see how pattern-languages and cybernetics inform our notion of landscape and landscape practice. In fact, so much of the science of ecology is directly informed by the principles of cybernetics and patterns. In many ways, it's hard to fully define and comprehend the history of modeling within the practice of Landscape Architecture. In reference to Halprin's work, a piece of landscape modeling could be considered a choreographic score, diagramming the inputs and outputs of participants. Regarding Howard Fisher, landscape modeling may be viewed as a computer-based cartographic system to aid in analyzing different places. These technologies center the designer as the "architect," the mastermind defining the process through a series of decisions and projections - however, other approaches towards a systems-based design land the study material in line with the designers themselves. This abductive approach may

1 See Keith VanDerSys and Karen M'Closkey's Introduction to Dynamic Patterns: Visualizing Landscapes in a Digital Age.

2 See Keith VanDerSys and Karen McCloskey's Afterword in Dynamic Patterns: Visualizing Landscapes in a Digital Age.

3 A Pattern Language provides a series of patterns, or codes, that provide designers and planners a language or kit of parts to logically abide by. The book prescribes the development of certain landscapes and environments based off of a network of recommendations. It's truly a manifesto written as hypertext, in which readers may follow an index to certain patterns they may be dealing with.

4 VanDerSys and M'Closkey review Halprin's work and argue how the sciences of Cybernetics informed his design approach in their Introduction: "Systems and Ecology in Landscape Architecture".

be seen through the process of responsive modeling, in which the designer actively monitors, simulates, and experiments with the study material.

Ultimately, this section will reveal how computation and contemporary innovations in landscape architecture modeling have defined our practice. In doing this, we may begin to consider the model as both a declaration upon the landscape, or manifesto, and a discovery-oriented process, or heuristic. But, more importantly, is the distinction between models as manifesto and models as heuristics. Although both approaches towards design provide sufficient information to make decisions, manifestos imply a solutions-based, deductive-dominated structure while heuristic suggests a more abductive, recursive process.[5] Regarding this project's context, the Comprehensive Everglades Restoration Plan (CERP) will be understood as a series of models as manifesto, illuminating the politico-economic regime set in place by the Army Corp of Engineers. Through this acknowledgment, the responsive model will become more clearly defined within the realm of landscape architectural research methods.

A Brief History of Modeling in Landscape Architecture

Within the realm of design, there have been those who practice design and those who design for the practice of designing. In other words, there are practicing architects who design for the built environment, and there are information architects who design the programs used by the practicing architects.[6] Molly Wright Steenson explores the many relationships shared between the histories of architectural design and the practice of computational programming in her book Architectural Intelligence. As Steenson puts it, while traveling into and exploring the space between design and programming, the two disciplines start to converge at certain points.

Throughout her text, Steenson calls out many moments in which the two realms are working synchronously and providing essential feedback to one another. Architectural designers and urban planners have utilized computational programming for the growing complexity of their projects and design intentions during the mid-20th century. Douglas Engelbart, the pioneer of computational interfaces and the

5 See CM Steenbergen's Introduction: Design research, research by Design (2002).

6 See Molly Wright Steenson's section titled Architect. Anti-Architect, and Architecting in her book Architectural Intelligence.

Augmented Research Center (ARC) founder at Stanford, approached computational programming with, specifically, the architect in mind. Engelbart used the architect and their object-oriented problem solving to render scale and depth to the capacity of the computer. According to Nicholas Negroponte, some of Engelbarts' writings describe the computer in the 1950s through architect and architectural design practice.[7] Steenson points out that this overlapping most likely exists due to the architect's capacity to solve complex problems within the spatial realm; design problems are multidimensional, programmatic, and need computer-aided assistance during the mid-20th century.

Of course, the need for computation extends well beyond the practice of architectural design. For example, during the mid-20th century, many landscape architects and planners were interested in computational-aided landscape analysis and cartographic projections. Nick Chrisman's Charting the Unknown provides helpful insight into the history of computational cartographic modeling. According to Chrisman, the earliest known geographic information systems technology dates back to the mid-1960s. Howard Fisher and William Warntz developed SYMAP, or Synagraphic Mapping System, in Harvard's Laboratory for Computer Graphics and Spatial Analysis.[8] As another example of the entanglement between architectural design and computational practice, Fisher was a Harvard Graduate from the College of Design and Architecture. His interest in computer programming and mapping resulted in a whole generation of environmental designers and landscape architects focusing on the concurrent ecological movement of the late 1960s. Fisher sought feedback and inspiration from practicing designers like Phillip Lewis and Ian McHarg, who furthered the development of GIS software through their overlaying techniques for landscape suitability analysis.[9] Fisher will also be an inspiration for the incoming generation of landscape architects and environmental planners. Perhaps the most notable for this project, Carl Steinitz, worked very closely with Fisher and will develop a framework that many planners and environmental projects still follow today. Refer to Figure 2.1 for more information related to the development of GIS. Notice how there's a very long list of computational programs that overlap one another, illuminating the iterative, multi-faceted relationship between software and design tool development.

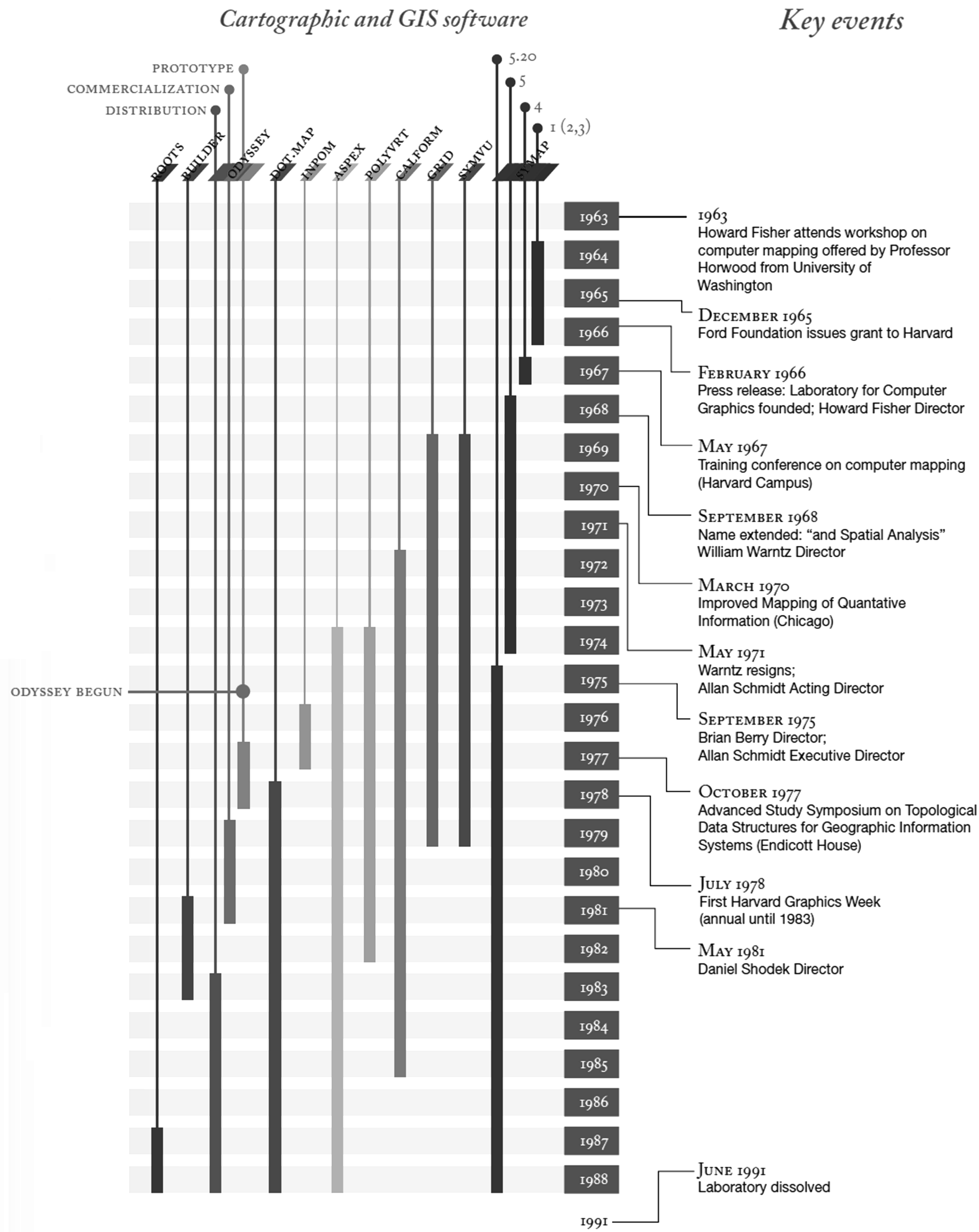
7 Nicholas Negroponte's Book The Architecture Machine, reveals his work on the URBAN2 and URBAN5 Urban Design softwares during his time at MIT. This piece includes an excerpt explaining the relationship between Englebart's ideas on computation and architectural practice.

8 See Chrisman's introduction, page 1, of Charting the Unknown, 2006.

9 See Chrisman's introduction, page 4, of Charting the Unknown, 2006 .

Figure 2.1 / Chrisman's Timeline of Cartographic Modeling Software and GIS Softwares

Borrowed from Chrisman's *Charting the Unknown,* this timeline charts out the development of GIS softwares during Harvard's Laboratory for Computer Graphics and Spatial Analysis era. Seen here, the Laboratory lasted for almost 30 years and influenced the thought of many prominent designers in the realm of landscape architecture. What's interesting is the parallel softwares that were in development during this time, and how SYMAP stood the test of time.


Cartographic and GIS software
Key events
PROTOTYPE
COMMERCIALIZATION
DISTRIBUTION
5.20
5
4
1 (2,3)
ROOTS
BUILDER
ODYSSEY
DOT.MAP
INPOM
ASPEX
POLYVRT
CALFORM
GRID
SYMVU
SYMAP
ODYSSEY BEGUN
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1991
1963
Howard Fisher attends workshop on computer mapping offered by Professor Horwood from University of Washington
December 1965
Ford Foundation issues grant to Harvard
February 1966
Press release: Laboratory for Computer Graphics founded; Howard Fisher Director
May 1967
Training conference on computer mapping (Harvard Campus)
September 1968
Name extended: “and Spatial Analysis” William Warntz Director
March 1970
Improved Mapping of Quantative Information (Chicago)
May 1971
Warntz resigns;
Allan Schmidt Acting Director
September 1975
Brian Berry Director;
Allan Schmidt Executive Director
October 1977
Advanced Study Symposium on Topological Data Structures for Geographic Information Systems (Endicott House)
July 1978
First Harvard Graphics Week (annual until 1983)
May 1981
Daniel Shodek Director
June 1991
Laboratory dissolved

Geodesign and The CERP

Steinitz's Framework for Geodesign and Alternative futures was attributed mainly to his experiences at Harvard's Laboratory for Computer Graphics and Spatial Analysis. Working as a research assistant for Howard Fisher, focusing on landscape architectural mapping and regional planning, Steinitz was engaging in large-scale planning projects with complex geophysical issues. As Steinitz recalls, his first major teaching assignment included leading a multidisciplinary studio focused on the regional development of the Delmarva Peninsula from 1966 to 1967.[10] According to Steinitz, this was the first time SYMAP was adequately applied to any project,[11] and featured an array of vector data, overlain map imagery, and resulting suitability analysis in McHargian fashion.[12] Soon after the Delmarva Project, Steinitz and Peter Rogers collaborated on another studio focusing on modeling the conflicts between the environmental vulnerability of regional-scale landscapes and development projects in Southwestern Boston. Steinitz considers this to be the beginning of his Geodesign Framework, introducing "decision" and "impact" models for assessing risk and implications based on a series of decisions. Although Steinitz will go on to redefine and practice with his framework or Geodesign, as seen in Figure 2.2, in the following decades, the 1967 Boston studio initiated his thinking for organized plans of action, especially as it relates to "large-scale, significant" design problems.[13]

Geodesign as Manifesto

The Geodesign framework is primarily considered a bridge between design professionals and the geographic sciences. Steinitz references the need for collaborative efforts to design change for large-scale landscape systems adequately. Steinitz also stresses the importance of models throughout the entirety of his framework. His framework revolves around an iterative decision-making process informed by models that represent, process, evaluate, change, predict, and answer questions of a specific problem. The design logic represented in Steinitz's framework may be represented in various landscape interventions seen throughout South Florida, which is especially true when we consider the CERP.

10 See Steinitz Introduction in his 2012 A Framework for Geodesign, or Steinitz Introduction to ESRI's Geodesign: Past, Present, and Future where Steinitz explains his role and overall importance of Harvard's Lab for Spatial Analysis.

11 See Page 6 of Steinitz Introduction to Geodesign: Past, Present, and Future.

12 See Chrisman's section on the Delmarva Project, pages 4 to 5, in Charting the Unknown.

13 See Steinitz Introduction in his 2012 A Framework for Geodesign,Page 3.

The CERP master plan is host to a series of regional-scale & long-term construction projects that speak to the ideals of models as manifestos. Although these projects aim to solve specific issues, they are structured around top-down-oriented decisions that over-simplify problems and seek to serve some political agenda and/or cause. Furthermore, the CERP expresses Steinitz approach towards landscape architecture modeling through its very own process, which includes models similar to Steinitz's framework for geodesign:

1. Representation Models
2. Process Models
3. Evaluation Models
4. Change Models
5. Impact Models
6. Decision Models

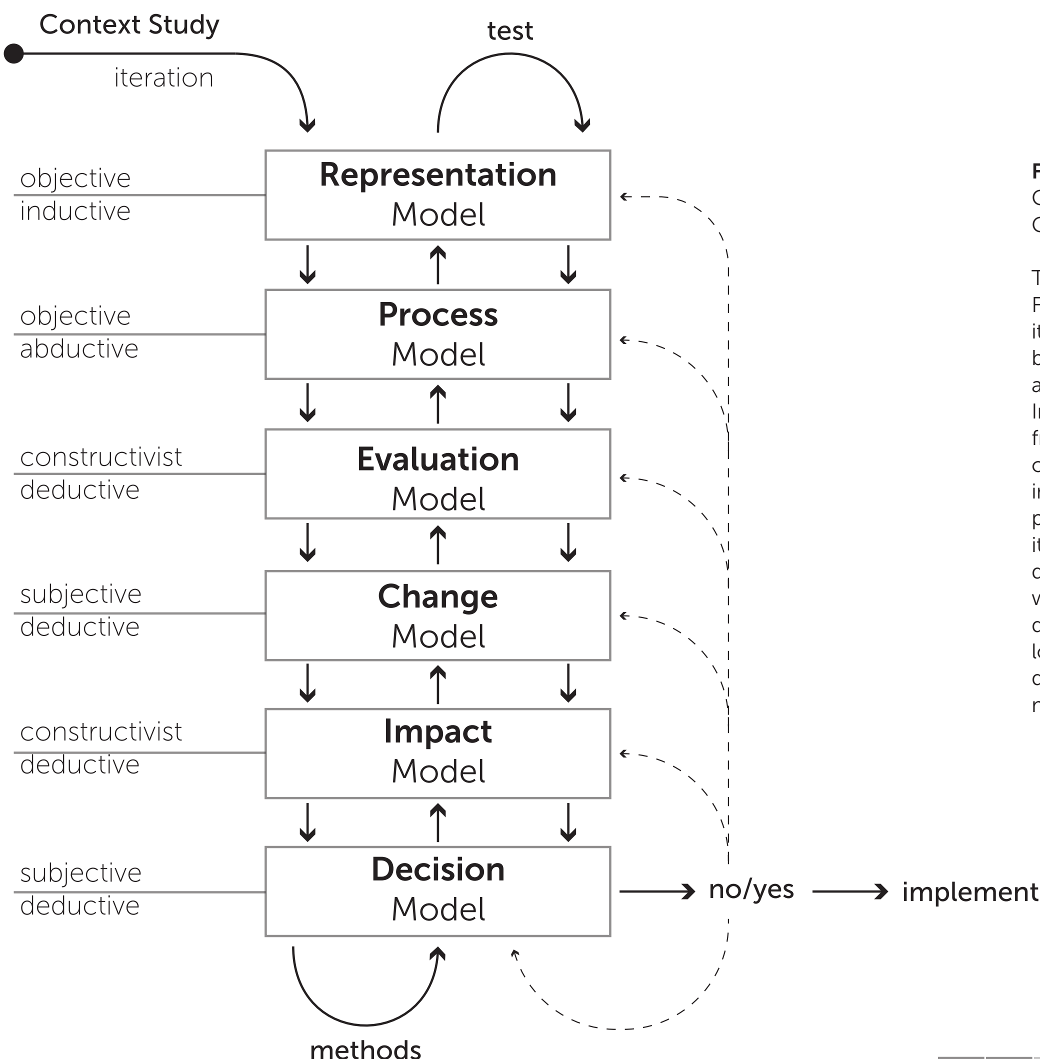


Figure 2.2 / Adaptation of Carl Steinitz Framework of Geodesign "Process Structure"

This adaptation of Steinitz's Framework explores the iterative process of going between "Methods", "Tests", and "implementation."
Initially published in 1995, this framework has been adapted over Steinitz's career. It's important to note that this process is designed to be iterative, and it mostly hinges on deductive reasoning. In other words, most of these models deduce or conclude top-down logical structures with the designer/policymakers making most of the decisions.

It's important to note here that, although the framework is discussed in a linear fashion, Steinitz suggests that the process may become non-linear.[14] This section will explore the Steinitz Framework and how it fits into Deming and Swaffield's Design Research Methodologies. Specifically, the Framework for Geodesign will be defined within a design research methodology. By doing this, the Geodesign Framework is understood as a design research method that is mainly objectivist-oriented while following a deductive, top-down decision-making process. However, it differs from research through design in that it fails to work in a fully abductive, recursive manner.

Deming and Swaffield's Landscape Architectural Research: Inquiry, Strategy, Design provides designers a categorical map of research methodologies to use as strategies for dealing with design problems. One of the foundations of their framework, similar to Steinitz, stresses the interdisciplinary nature of Landscape Architecture. As a result, they provide a wide range of methods and a matrix (See Figure 2.3) that defines specific research strategies along an x-axis, including inductive to deductive reasoning and a y-axis, which places the strategies within an objective to subjective lens.[15]

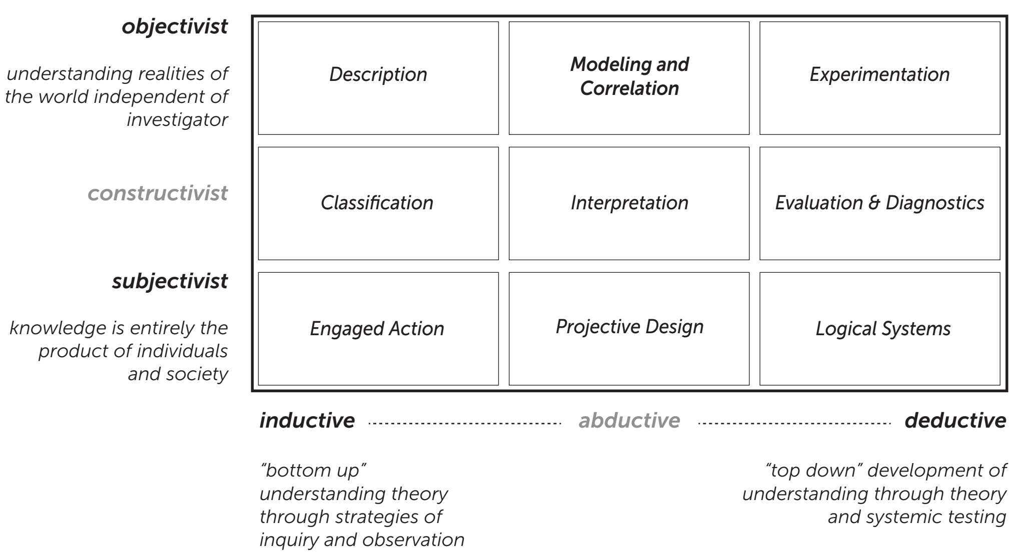


Figure 2.3 / Adaptation of Deming and Swaffield's Framework of Research Strategies

This matrix showcases the 9 dominant research strategies within Deming and Swaffield's *Landscape Architectural Research : Inquiry, Strategy, Design.* The chart is structured around the understanding of theory and seperate philosophical points of view.

The purpose of analyzing the Steinitz framework and translating it into Deming and Swaffield's matrix is to understand Geodesign within the context of design research strategies. As for another reason for this transferral, Deming and Swaffield define landscape modeling within a particular section of their framework. Arguably, landscape modeling has

14 See Chapter 3 of Steinitz Introduction in his 2012 A Framework for Geodesign. Steinitz walks through each one of the models of the framework and clearly defines them through examples and questions.

15 See the Introduction, Page 7, to Deming and Swaffield's Landscape Architectural Research : Inquiry, Strategy, Design extended itself well beyond the confines of a singular methodology. This comparative analysis will, indeed, prove that landscape modeling is both trans-disciplinary and multi-dimensional with respect to research methods.

To walk-through Steinitz's Framework linearly, in reference to Figure 2.2, "Process Structure", Representational Models deal with reality. They aim to accurately represent a place. This includes the representation of the overall scale, context, space, and time within a study area.[16] The primary question the geodesigner should ask them-self is: "How should the study area be designed?" Through this process emerges a representation, or objectively reproduced, abstraction of a place. When considering Deming and Swaffield's Matrix of Design Methods and in reference to Figure 2.4, Representational Models are most aptly placed within the Descriptive Strategies. Deming and Swaffield explain these strategies as rooted in empiricism and are typically seen as the first stage in any research project.[17] Although Representational Models may be considered a descriptive model, seen in their Chapter 6 "Modeling and Correlation Strategies", representation is more Descriptive for it deals with static data, and doesn't put the landscape through any abductive test.

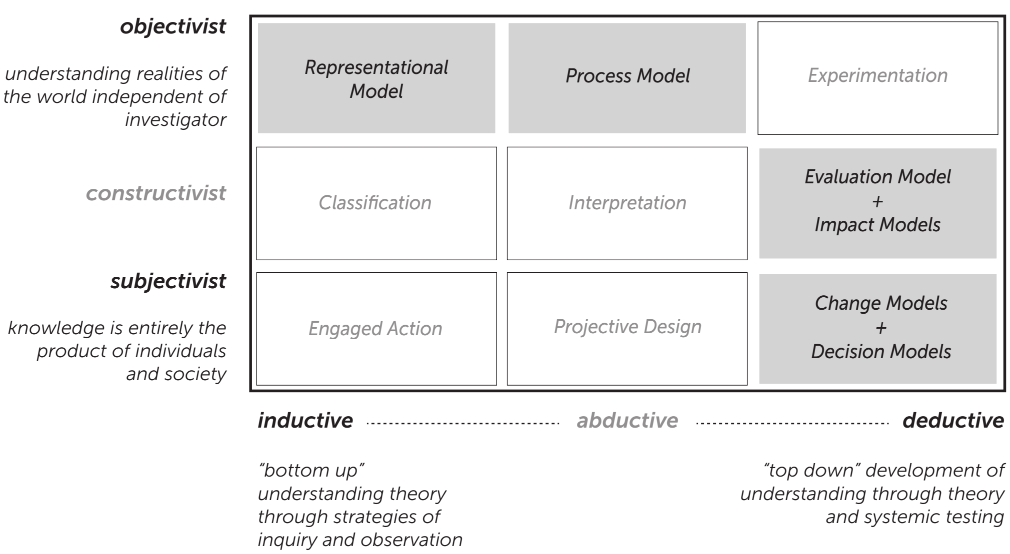


Figure 2.4 / Synthetic Logic between Deming and Swaffield's Matrix and Steinitz Framework

This matrix showcases the nine dominant research strategies within Deming and Swaffield's Landscape Architectural Research: Inquiry, Strategy, Design & its synthetic relationship to Steinitz Framework. As seen here, Steinitz Framework spans between both axes. Take note of how most of the models fall within the deductive approach of design methodologies.

The next set of models include Process Models, which are mainly concerned with how a study area operates; this encompasses the relevant processes and functions occurring in one place and they are considered transferable between different places. Steinitz poses these questions: "What are the areas major physical, ecological, and human

16 See Steinitz A Framework for Geodesign, Chapter 4, page 37, for more information on Representational Models.

17 See the "Descriptive Strategies" in Deming and Swaffields Chapter 5, Pages 65 to 85.

geographical processes? How does the study area operate?"[18] Deming and Swaffield's 6th Chapter, Modeling and Correlation, aims at defining the model within this chapter. Although models are, in fact, an abductive design method, the model may exist outside of objectivity. Deming and Swaffield admit that:

> *"The process of model building may be bottom-up, working from small units to build a representation of larger reality, or top-down, starting with aggregated data and breaking it into parts... Modeling can be used for a range of research-related purposes, from synthesizing descriptive information to predicting and communicating the way systems operate to the exploration of possible new relationships. This range of roles prefigures how modeling techniques can be used in different ways within a number of different research strategies and designs."* [19]

The process model reflects Modeling and Correctional Strategies for it is relational and aims to render the relationship between a place and its functions; an accurate model of systems. The theory is generated and tested simultaneously, in which theoretical implications weave into the model itself and vice versa.[20] This idea fits neatly into abduction, and may be defined as an analytical, descriptive, or predictive model in Deming and Swaffield's list of Modeling Strategies.

Next up is Steinitz's Evaluation model. Evaluation models address the spatial and social concerns of a localized area including the perceptions and overall performance of landscapes. In doing this, the landscape may be assessed in terms of past, present, and future. Steinitz asks the following questions: "Is the current study area working well?"[21] In order to make these evaluations, it's important to develop a meaningful set of criteria for evaluation.[22] This kind of assessment can be found in Deming and Swaffield's chapter 10, "Evaluation and Diagnosis", and is considered to be the most widely used set of strategies within the field of environmental design.[23] Both Diagnostics and Landscape Assessment describe the evaluation model for they both deal with the subjective creation of criteria and the constructivist assessment of landscape spaces. There's a very long list of Evaluative models within the field of Landscape Architecture. Deming and Swaffield reference Ian McHarg's overlaying technique,[24] while many of Steinitz's geodesign projects work within the realm of landscape assessment.

After pursuing constructivist explorations through the Evaluation Model and defining criterion, Steinitz has us return to more subjectivity

18 See Steinitz A Framework for Geodesign, Chapter 4, page 37, for more information on Process Models.

19 See Page 88, the "Modeling and Correlation Strategies" section in Deming and Swaffield's Landscape Architectural Research : Inquiry, Strategy, Design

20 See Steinitz A Framework for Geodesign, Chapter 5, page 83, for more information on Representational Models.

21 See Steinitz A Framework for Geodesign, Chapter 4, page 38.
22 See Steinitz A Framework for Geodesign, Chapter 5, pages 60 to 62, for more information on Evaluation models.

23 See Page 174, the introduction to "Evaluation and Diagnostics" section in Deming and Swaffield's Landscape Architectural Research : Inquiry, Strategy, Design.

24 Deming and Swaffield provide a variety of examples in each one of their sections. See Pages 182 to 186 for more information about Diagnostics and Landscape Assessment.

in the Change Model. These models represent scenarios or future outcomes of specific data and information processed over time. Key components during this stage of the Geodesign Framework include proposing and simulating changes within the landscape and representing those scenarios. Steinitz stresses this question: "How might the study area be altered?"[25] Akin to Deming and Swaffield's Predictive Modeling section of their Modeling and Correlation strategies, this model is more appropriately placed in the Logical Systems Strategies of their matrix. The argument here is that change models are inherently rules-based, deduce phenomenon and typically see more subjectivity through their creation. An example of a Change Model includes anticipatory modeling, in which, according to Steinitz's text, designers will use their own experience and understanding of landscape planning and deduce future scenarios. Another model, rule-based modeling, frees the geodesign team to develop rules and directives for creating the design; Steinitz compares this model to algorithms. In reference to Deming and Swaffield's Matrix, Logical Systems attempt to make sense of complex phenomenon via order and systematic reasoning.[26] It is considered to be the methodology that incorporates the most systems-oriented thought and translates well into sister disciplines.[27]

After developing an "axiomatic" language, the designer moves on to the Impact Model. Impact models are used to establish metrics for assessing the costs and benefits of all potential changes from the preceding models.[28] Steinitz asks the following questions when considering an impact model: "What difference might the changes cause? In which ways are foreseen changes seen as beneficial or harmful?"[29] According to Steinitz, an impact model can be an Environmental Impact Statement, a regulatory step in environmental design that results in a map that shows the difference between prior states of the design area and the proposed changes.[30] This modeling approach is more constructivist-oriented, considering social parameters and norms such as laws and standards. Meanwhile, Impact Models are still largely deductive, and decisions are made in a top-down, hierarchical way. Therefore, Impact Models are placed alongside Evaluation Models within Deming and Swaffield's Evaluation and Diagnosis Strategies. As previously mentioned, Evaluation and Diagnostics deal with the reality of landscape while comparing and contrasting alternatives. Though it may seem like pure classification, this discernment aims to compare real-world phenomenon or practices

25 See Steinitz A Framework for Geodesign, Chapter 4, page 38.

26 See Page 223, the introduction to "Logical Systems (Axioms, Rules, and Argumentation)" section in Deming and Swaffield's Landscape Architectural Research : Inquiry, Strategy, Design.

27 See Page 235, the summary to "Logical Systems (Axioms, Rules, and Argumentation)" section in Deming and Swaffield's Landscape Architectural Research : Inquiry, Strategy, Design

28 See Steinitz A Framework for Geodesign, Chapter 5, pages 48 to 49, for more information on Impact Models.

29 See Steinitz A Framework for Geodesign, Chapter 4, page 39.

30 See Steinitz A Framework for Geodesign, Chapter 5, pages 49, for more information on Impact Models.

with an abstract measurement predetermined by socio-political norms, understandings, and expectations.[31]

The final model in Steinitz Framework includes the Decision Model. As Steinitz puts it, "Decision Models are based upon the personal, cultural, and institutional knowledge of decision makers, and these people are highly influential in any project".[32] To fully understand a decision model, one must understand the project goals and objectives while being able to quantify those goals and objectives as a gradient between highest to lowest priorities. Steinitz asks "How should the study area be changed? Who are the major stakeholders?"[33] Decision Models are placed alongside Change Models in Deming and Swaffield's Logical Systems strategies through this understanding. Decision models are highly subjective and result in more top-down-oriented reasoning. Interestingly, Deming and Swaffield utilize Carl Steinitz Framework for Geodesign in this chapter, referencing the Decision Model as an example of axiomatic, rule-making logic within the tactic of Logical Relationships. They describe this research method as an approach towards ordering and synthesizing strategies and sequences akin to coding, programming, mathematics, virtual realities, and decision models. This realization brings us back to Steinitz's history with Harvard's Laboratory for Computer Graphics and Spatial Analysis, in which computational programming and design thinking converged to formulate both the software for geospatial analysis and the geospatial design process.

The Central and Southern Florida Project; a Manifesto

As mentioned in the introduction, the Comprehensive Everglades Restoration Plan, or CERP, is an extensive restoration framework passed by Congress through the Water Resources Development Act (WRDA) of 2000. Although this is an integral piece of legislation related to the management of the Everglades, there's a very long history of projects concerned with water management, ecosystem recovery, and restoration. The Central and Southern Florida Project (CSF) was originally mandated in 1948, which enabled the US Army Corp of Engineers to "drain the swamp" and develop the infrastructure we see today to manage water supply and control flooding. Following the 1948 mandate was a series of Flood Control Acts that lasted for the next 20 years and included constructing the primary infrastructure within the study area of this project.[34] The CSF

31 See Page 174, the introduction to "Evaluation and Diagnostics" section in Deming and Swaffield's Landscape Architectural Research : Inquiry, Strategy, Design.

32 See Steinitz A Framework for Geodesign, Chapter 5, pages 46 to 47, for more information on Change Models.

33 See Steinitz A Framework for Geodesign, Chapter 4, page 39.

34 See the introduction of the Central And Southern Florida Project Comprehensive Review Study's Final Integrated Feasibility Report And Programmatic Environmental Impact Statement

Project Comprehensive Review was initiated in the Water Resources Development Act (WRDA) of 1992 and was officially authorized in the WRDA of 2000.[35] Today, the CSF has many other implications. Ironically, it involves restoration projects to improve the 1000 miles of canals and levees, 150 water control structures, and 16 major pump stations built during the mid 20th century. The project approach and process surrounding the "Restudy" of the modern CSF includes an incredibly comprehensive investigation informed by the works of multiple federal and state agencies. The resulting plan follows a logic similar to Steinitz's Geodesign framework, following a deductive design approach with models that consider past, present, future conditions, models that assess environmental impacts, and finally, decision models that recommend specific action plans (See Figure 2.5). The projects that arose from the CERP feature frameworks speak to models as manifestos. The principal objective revolves around top-down-oriented decision trees and the evaluation of suggested alternatives.[36]

35 See Page 3 of the 10th Year Report to Congress of The Comprehensive Everglades Restoration Plan: Central and Southern Florida Project.

36 See Section 7 of Plan Formulation and Evaluation of the Central And Southern Florida Project Comprehensive Review Study's Final Integrated Feasibility Report And Programmatic Environmental Impact Statement

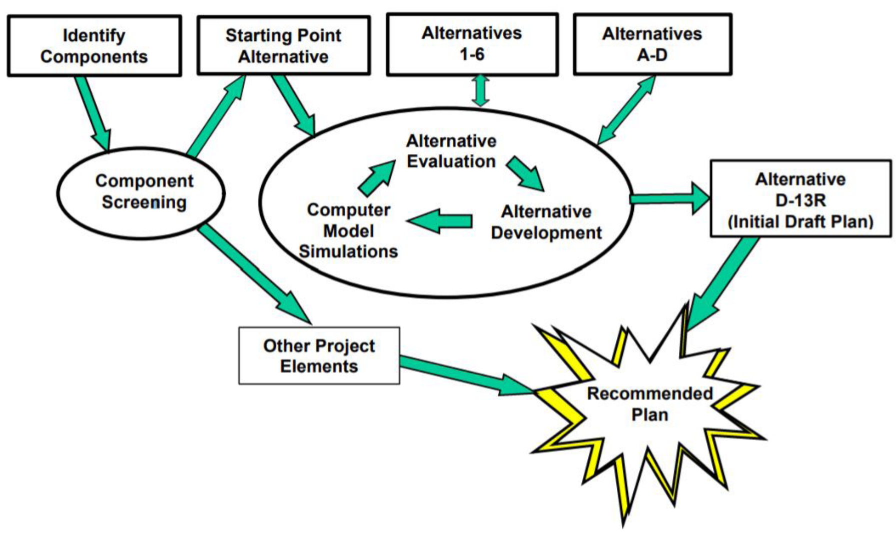


Figure 2.5 / Formulation and Evaluation Model Process

This conceptual model explains the primary approach to the CFS and utilizes very similar models seen in Steinitz's Geodesign Framework. It's clear through this conceptual model that the output of this process results in a singular, solution-based alternative. However, it's important to note that although there is an abductive, circular approach seen in the oval of this diagram, the sequence of events asks the designers to start from a predetermined "Starting Point," which suggests its inherently hierarchical structure. This diagram is borrowed from Section 7 of the Final Integrated Feasibility Report And Programmatic Environmental Impact Statement, page 7-2.

Although the CSF Project Comprehensive Review is incredibly robust and provides an extensive historical, ecological, socio-cultural, and economical account for the South Florida landscape, it's results aren't clearly captured in the 5-year reviews set forth by the Army Corp of Engineers. Many things look great on paper, especially when modeled conceptually, however, implementation is typically more convoluted and politically charged than we can imagine. With this, the CSF, SFER, CEPP, and CERP is managed by both federal and state agencies, issues have arisen in regards to jurisdiction, scope, and monetary responsibilities. Although the CSF came forth with an implementation plan, the Army Corp of Engineers held very little accountability of the process at the beginning of authorization from congress. According to Michael Grunwald and the Washington Post, many of the projects pursued throughout the Everglades hasn't directly benefited ecosystem restoration at all. In his article, Grunwald interviewed over 200 scientists involved in the CERP, and many have come forward with similar concerns regarding the massive infrastructural projects taken place throughout the Ecosystem. Grunwald writes:

> *"The restoration leaders have already bought enough land to cover four Manhattans, and hundreds of scientists and engineers are at work on everything from surveys mapping the bumps and dips of the Everglades to equations modeling how sea grasses synthesize nitrogen. But many scientists believe the 4,000-page plan (CERP) reflects an engineer's bias for fancy engineering, clinging to man's control of nature instead of removing man-made structures and letting nature heal itself. Many environmentalists are increasingly skeptical that the highly political agencies that nearly killed the Everglades can save it now"* [37]

Interfacing these issues is perhaps the most perplexing within the context of the Everglades and its existing management system. Although many Floridians and Everglades enthusiasts support the CERP, the question isn't whether the CERP is a good plan. With the growing epidemic of algae infecting and proliferating our waterways, the question should be: how else may we engage this issue? I would argue that there is no answer to these problems. The world will most certainly see a rise in temperature at its current rates, water will become more acidic, and coastlines will continue to develop. However, there is room to generate an adaptive set of methods to mitigate these harmful algae blooms through responsive model inquiry. Perhaps, due to the complexity of this issue, there is room for exploratory landscape architectural methods that are not inherently solutions-based but experimental. According to Julian Raxworthy, process-driven strategies often shift the architect from finding purity in form and structure to experimenting with new methods.[38] Though there is a lot of ongoing research in response to these issues in the Everglades, there's room to explore how experimental design methods and analysis through design may illuminate new strategies.

37 See Grunwald's Implementing the Comprehensive Everglades Restoration Plan (CERP) (2012), Pages 5 through 13.

38 Julian Raxworthy's article critically reviews the books and works of 21st century landscape designers. His text formulates the analogies between site to model, environment to simulations, and feedback to responses.

Responsive Modeling

The conception of "process discourse" during the late 20th and early 21st centuries has largely shifted landscape architect's focus from form to process; this paradigm shift pays attention to both landscape design process and the design's workflow as process.[39] Meanwhile, designers are tasked with answering long-term environmental challenges through quick decisions. David Salomon introduces the idea of monitors and sensing the environment as a way in avoiding environmental disaster through surveillance.[40] Other Landscape architects, like Bradley Cantrell, introduce responsive methods for analyzing and understanding complex ecological processes.

Much of his work supports the idea that if we are to understand how ecological processes work thoroughly, we must include the use of sensing technology, environmental simulations, and responsive technologies to help facilitate the complex, multifaceted relationships often seen in ecology. Responsive modeling is a contemporary landscape design approach that embraces the dialogical nature of landscape material, process, and computation. Central components to the responsive model include sensors (sensing), computation (feedbacks), and automated decision-making (machine learning) so that the model may eventually embody a form of artificial sentience. In many ways, the responsive model becomes a form of synthetic ecology itself. [41]

Although scientists have been mapping algal outbreaks since the late 1900s through satellite imagery, there still exists gaps in knowledge between species identification, toxic bacterial relationships, and pigment colors.[42] With this, there also seems to be gaps in knowledge between accurate remote sensing and simulation modeling with future uncertain conditions and overall planning implementation. One study suggests the uncertainties and increased need for monitoring these cyanobacterial blooms due to climate change,[43] while another expresses the need for more holistic approaches towards establishing relationships between pigment color and water quality. More specifically, according to Richard Stumpf, there are challenges in remote sensing algal blooms and their

39 See Julian Raxworthy (2017)

40 See David Salomon's piece "Warning Signals" in LA+ (2015).

41 See Bradley Cantrell and Justine Holzman's "Responsive Landscapes" (2016)

42 See Klemas' review of current limitations surrounding remote sensing algal outbreaks (2012), page 38.

43 See O'Neil et al.'s (2012) Section 6, Synthesis and future directions.

associated toxins through satellite imagery; ultimately requiring field studies with advancing technologies to establish more direct relationships between aerial imagery and sampled water.[44] There are many gaps in knowledge between understanding how to accurately map and model the impacts of harmful algae blooms. The next section will reveal why utilizing heuristic oriented modeling techniques will both realize the possibilities with mapping and modeling algae as well as learning from the modeled algae for informed design decisions.

Responsive Models as Heuristics

To fully understand and utilize the responsive model as a design methodology, it's essential to know how it stands within existing research methodological frameworks. This section will juxtapose Bradley Cantrell and Justine Holzman's Responsive Landscapes: Strategies for Responsive Technologies in Landscape Architecture to Carl Steinitz's Geodesign framework. Through this act of "Synthetic Logic," or comparative analysis, we may develop associations and relationships between two or more disparate ideologies or conceptual frameworks.[45] Ultimately, this process identifies the responsive model as a proper research design approach by landing its core methodologies along with Deming and Swaffield's matrix of abductive design strategies. In doing this, both frameworks are better understood through similarities and differences. This study will realize the complexity of modeling as a design methodology by extending it beyond a singular set of techniques; meanwhile, the differences between the model as manifesto versus model as heuristic will become more evident.

There are several concurrences that subsist between Steinitz and the Cantrell-Holzman Framework that are worth pointing out. The first significant coincidence is the fact that these designers are all Harvard Graduates and developed their ideas and theories related to modeling during their time at Harvard's Graduate School of Design,[46] and in the case of Cantrell, continuing his explorations as a professor at Louisiana State University. Interestingly, both frameworks were explored and developed simultaneously; that is, both frameworks evolved and became more defined as they were tested through the instruction of studios, installations, and real-world projects in their respective places.[47] As for another parallel, they are both structured around six significant concepts that feature different kinds of models. Although the model typologies

44 Similar to Klemas, Stumpf et al.'s 2016 article reviews the limitations of remote sensing satellite imagery - especially the spectral limitations of current cameras. Hopefully, with increased hyper-spectral imagery cameras, we may more accurately geotag certain chlorophyl pigments that suggest cyanobacteria.

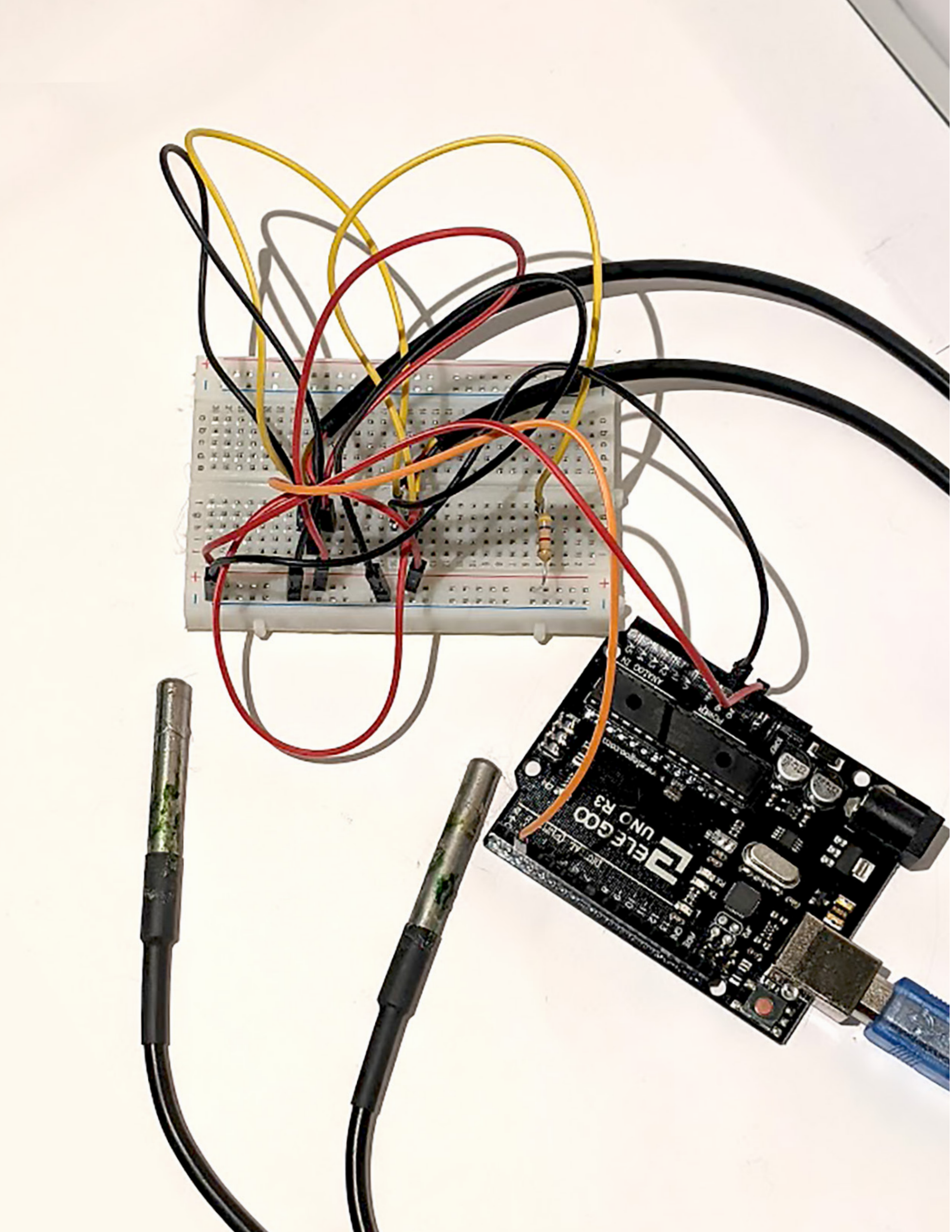
45 See Page 227, the Synthetic Logic section to "Logical Systems (Axioms, Rules, and Argumentation)" strategies in Deming and Swaffield's Landscape Architectural Research : Inquiry, Strategy, Design (2010)

46 See Steinitz A Framework for Geodesign, Chapter 1, pages 12 to 13 and Modelo's "An Interview with a Landscape Architect" for more information on how these landscape architectural approaches were developed.

47 See Steinitz A Framework for Geodesign, Chapter 1, pages 12 to 13 and Modelo's "An Interview with a Landscape Architect" for more information on how these landscape architectural approaches were developed.

Figure 2.6 / Arduino Sensor with Water Temperature Set-up

This is an image of one of the design responses explored in this project utilizing Arduino to record water temperatures. The Arduino interface is often incorporated in the Responsive Modeling process as a means of sensing specific outcomes or variables and extending our knowledge in an inductive way.


ELEGOO
UNO R3

between the frameworks aren't fully translatable, they feature similarities and could be subjectively conformed to fit into another to establish novel, meaningful connections. The images shown in Figure 2.4 reveal how synthetic logic was used to understand the methodological placement of the Cantrell-Holzman framework. Each box highlights an element of the Cantrell-Holzman Framework. At the same time, the diagrams below show where they would land on the Steinitz framework, which may then be translated to the Deming-Swaffield matrix of design research strategies.

Cantrell and Holzman's *Responsive Landscapes: Strategies for Responsive Technologies in Landscape Architecture* may be broken up into 6 major chapters. These chapters represent alternate approaches to responsive landscape design and modeling and they are as follows:

1. Elucidate
2. Compress
3. Displace
4. Connect
5. Ambient
6. Modify

All of these verbs refer to a kind of response. These responses, or interactions, fulfill a cycle where phenomenon is sensed, represented, and actuated. According to their text, an *actuation* refers to the process of converting sensed data into a physical or virtual action.[48] As a result, the responsive model becomes a landscape in which forces, senses, materials, interactions, and moments become altered in some way.

The first two responsive landscape typologies in the Cantrell-Holzman framework include *elucidate* and *compress*. To *elucidate* is to bring into focus the often invisible information that enters our periphery, or escapes us entirely, through visualization and actuation.[49] Meanwhile, to *compress* is to establish a mutable continuum that allows us to explore temporal relationships and processes.[50] Upon further review, these two responsive modeling approaches relate most to Steinitz Representational and Process Models. These models are rooted in objectivity and operate within Deming and Swaffield's Modeling and Correlation Strategies. Although these models have algorithms and logical systems that help them perform, making the model a Logical System, the decision-making

48 See Cantrell and Holzman's "Responsive Landscapes" (2016), page 23, for more information.

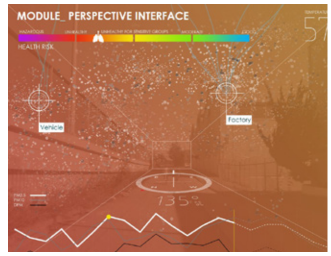
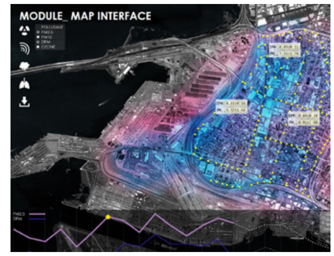
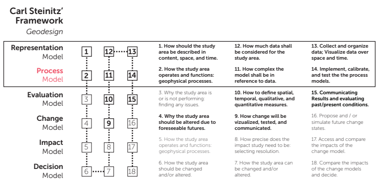
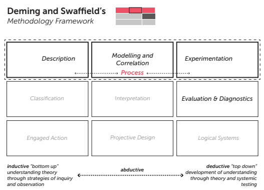
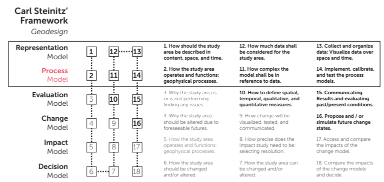
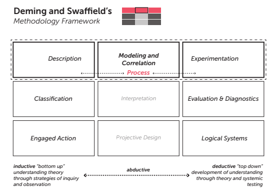
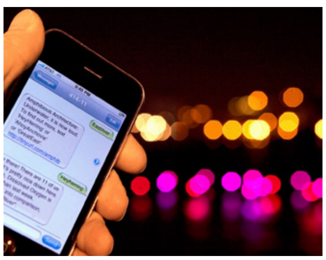
49 See Cantrell and Holzman's "Responsive Landscapes" (2016), page 64, for more information.

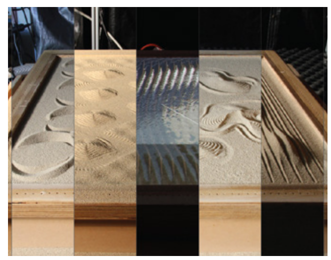
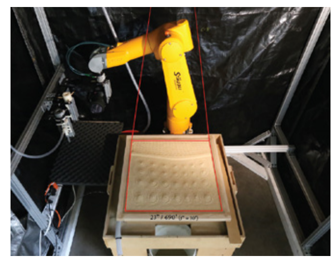
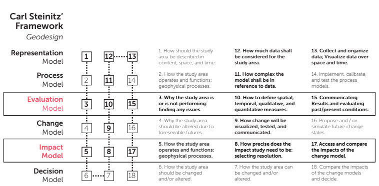
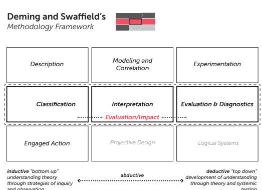
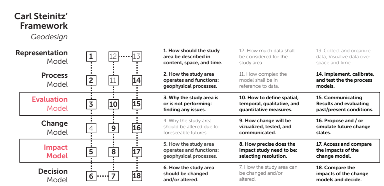
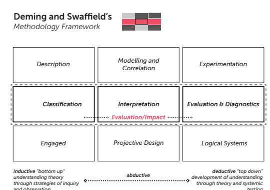
50 See Cantrell and Holzman's "Responsive Landscapes" (2016), pages 90-91, for more information.

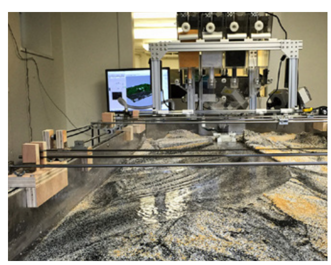
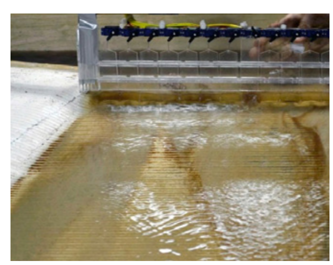
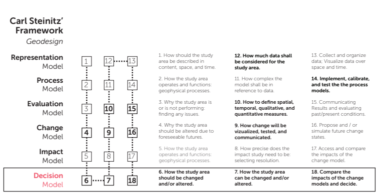
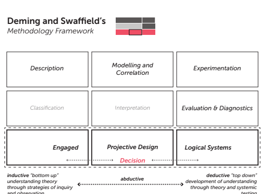
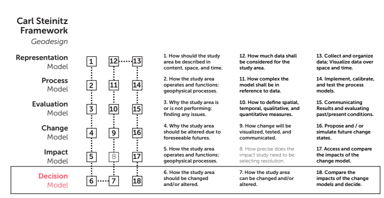
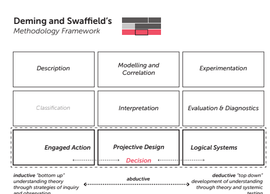
Figure 2.7 / Process Identifying Responsive Modeling within the Deming and Swaffield Matrix

These diagrams show how synthetic logic was used to compare and contrast the Cantell-Holzman Responsive Model to Carl Steinitz's Geodesign Framework. The major findings include how modeling moves between subjective, constructive, and objective design strategies. Although Steinitz Geodesign Framework is inherently more of a deductive approach, the Cantrell-Holzman Responsive Model is more abductive by its nature.




MODULE_ PERSPECTIVE INTERFACE
HEALTH RISK
Vehicle
Factory

MODULE_ MAP INTERFACE

Carl Steinitz' Framework
Geodesign
Representation Model
Process Model
Evaluation Model
Change Model
Impact Model
Decision Model

Deming and Swaffield's
Methodology Framework
Description
Modeling and Correlation
Experimentation
Process
Classification
Interpretation
Evaluation & Diagnostics
Engaged Action
Projective Design
Logical Systems
abductive

Carl Steinitz' Framework
Geodesign
Representation Model
Process Model
Evaluation Model
Change Model
Impact Model
Decision Model

Deming and Swaffield's
Methodology Framework
Description
Modelling and Correlation
Experimentation
Process
Classification
Interpretation
Evaluation & Diagnostics
Engaged Action
Projective Design
Logical Systems
abductive





Carl Steinitz' Framework
Geodesign
Representation Model
Process Model
Evaluation Model
Change Model
Impact Model
Decision Model

Deming and Swaffield's
Methodology Framework
Description
Modeling and Correlation
Experimentation
Classification
Interpretation
Evaluation/Impact
Evaluation & Diagnostics
Engaged Action
Projective Design
Logical Systems
abductive

Carl Steinitz' Framework
Geodesign
Representation Model
Process Model
Evaluation Model
Change Model
Impact Model
Decision Model

Deming and Swaffield's
Methodology Framework
Description
Modelling and Correlation
Experimentation
Classification
Interpretation
Evaluation/Impact
Evaluation & Diagnostics
Engaged
Projective Design
Logical Systems
abductive





Carl Steinitz' Framework
Geodesign
Representation Model
Process Model
Evaluation Model
Change Model
Impact Model
Decision Model

Deming and Swaffield's
Methodology Framework
Description
Modelling and Correlation
Experimentation
Classification
Interpretation
Evaluation & Diagnostics
Engaged
Projective Design
Decision
Logical Systems
abductive

Carl Steinitz Framework
Geodesign
Representation Model
Process Model
Evaluation Model
Change Model
Impact Model
Decision Model

Deming and Swaffield's
Methodology Framework
Description
Modelling and Correlation
Experimentation
Classification
Interpretation
Evaluation & Diagnostics
Engaged Action
Projective Design
Decision
Logical Systems
abductive

processes are not the model's primary purpose. Models that elucidate are dealing with induction, for they aim to understand landscape phenomena from the bottom-up. They seek to understand landscape circumstances and realize how phenomena work overtime.

If we take the Cantrell and Holzman's *compress* case study, "Datascapes", we see an intent to reveal "hidden" data, in real-time. The project aims to create a virtual landscape that connects community members to local environmental quality within West Oakland, California through an interactive map. This virtual model becomes a place to understand air quality in West Oakland and how it may change during certain times. This project approaches pollution through utilizing data from air quality monitoring stations within and surrounding West Oakland.[51] By accessing this data, the team was able to weave together air quality hazards, thermal comfort, and climatic data into a geospatial map. With this base data, the interface converges these factors and suggests commuting routes, ensuring maximum health and safety, as well as working with timetables and projections for future conditions. At its core, "Datascapes" represents a simulative operation, compressing various types of forces while simulating and representing them across a landscape over time.

The following two responsive landscape typologies in the Cantrell-Holzman framework include displacing and connect. These two modeling typologies work on opposite ends to one another. Cantrell and Holzman describe displacement as an evaluative step that allows us to reconfigure physical phenomenon with temporal timelines. Through the process of re-contextualizing, we may understand new relationships while stripping out any and all barriers. As a result, tools and conventions may be used in new ways to generate connections.[52] To *connect* is to establish a one-to-one relationship between user inputs and landscape outputs in real-time. This connection allows users to understand the system and place them as a part of it.[53] Both connect and displace represent Steinitz's Impact and Evaluation models most closely because they deal with landscape assessment and societal norms. It's arguable that connect opposes displace, for it places the users into a deeper understanding of landscape context. In contrast, displace obscures any contextual insights to make complex phenomena more readily understandable. As a result, these two models act primarily within a constructivist lens, for they center the model around the landscape participant. Although connect realizes and highlights through an inductive

51 See Cantrell and Holzman's "Responsive Landscapes" (2016). pages 114 - 117 or see "Datascapes" at http://

52 See Cantrell and Holzman's "Responsive Landscapes" (2016), pages 122 - 123, for more information.

53 See Cantrell and Holzman's "Responsive Landscapes" (2016), pages 170 - 173, for more information.

Figure 2.8 / "Datascapes" by Yitian Wang, Yi Liu, and Matty A. Williams; Louissiana State University

This image shows the mapping interface to "Datascapes" in which airborne pollution is tracked through meteorological data and speculated upon based off of algorithms. The model suggests specific routes for locals to reduce their contact with airborne pollutants.

DPM 0.89±0.11
PM2.5 7.16±1.74
DPM 0.81±0.16
PM2.5 6.92±1.68
DPM 0.84±0.10
PM2.5 6.91±1.68
RANGE
Daily
Monthly
Yearly
DATE
Curren
11
12
13
14
15
16
17
18
19
20
21
22
23

process, displacement approaches modeling through a more deductive lens, developing subjective criteria for pursuing a disconnection for time and place.

If we examine the project "Amphibious Architecture and Pier 35 "Ecopark" as an example, we will see a responsive landscape that fulfills Cantrell and Holzman's connect modeling typology. Commissioned by the New York City Economic Development Corporation in collaboration with a long list of artists and designers led by Natalie Jeremijenko, Pier 35 Ecopark includes a mussel habitat and a series of signals that connect urban dwellers to the interactions of underwater creatures.[54] This project seeks to captivate passerbys through immersing them into the complexities of aquatic ecosystems and connecting them to underwater life via a text messaging interface.[55] Through utilizing digital sensors, this project indicates several environmental factors at play near Pier 35 in the Bronx and East River. The lights behave as a sort of water quality indicator, where blue represents healthy waters and pink represents poor water quality.[56] Additional LEDs blink when a fish comes into contact with the beacons. The computational system reads fish behavior and may identify a species based on these interactions. Amphibious Architecture responds by relaying this information to passerbys through SMS text messages - establishing a live feed between invisible ecological dynamics and the public realm with an innovative form of environmental education.[57] "Amphibious Architecture" represents a responsive model that engages the collective in innovative ways and connects people to the ecological resources that surround them.

The final two models in Cantrell and Holzman's book include ambient and modify. To successfully ambient, one must distribute actions throughout an environment to perform tasks and learn from their impacts. Through ambient signals and conditional associations, people may learn more about their environment. This type of model, similar to elucidate, aims at making information more readily available; however, the processing of this data is much more abstract.[58] Responsive models that modify provide a series of specific procedures and decisions linked to a form of logic that results in altering interactive relationships. Modification is perhaps the most hybridized system of models, featuring a recursive process that iterates upon itself; with this in mind, modify is closest to a form of ecological, autonomous intelligence.[59] Whereas ambient features a model

54 See "Ecoempathy in the East RIver: Amphibious Architecture" at https://ecoempathyproject.wordpress.com/page/3/

55 See Cantrell and Holzman's "Responsive Landscapes" (2016), pages 194 - 197, for more information.

56 See Pier 35 Ecopark at http://www.thelivingnewyork.com/

57 See Cantrell and Holzman's "Responsive Landscapes" (2016), page 196, for more information.

58 See Cantrell and Holzman's "Responsive Landscapes" (2016), pages 216 - 218, for more information.

59 See Cantrell and Holzman's "Responsive Landscapes" (2016), pages 250 - 256, for more information.

Figure 2.9 / Amphibious Architecture Buoys and Sensors

These are the buoys that indicate water quality, fish interaction, and catch the attention of passerbys. Blue lights suggest better water quality while pink indicates poor water quality. The blinking lights suggest fish interaction with the sensors beneath the surface.

that adapts and signals to the inputs of certain variables, modify actively responds to those inputs as a means of generative design. When referring to Steinitz's Geodesign Framework, these models represent Change and Decision models most closely. As such, ambient model's adaptation and change revolve around the subjective meaning and abstraction of induced environmental sensing while modification is purely programmed around subjective, deductive, top-down logic that tend to favor ecological dynamics.

The project "Synthetic Mudscapes" is an example of Cantrell and Holzman's modify chapter. Located off the shorelines of New Orleans, this project was a studio led by both Jeff Carney and Bradley Cantrell at Louisiana State University in the Louisiana Coastal Sustainability Studio.[60] Through the use of responsive technologies and dynamic monitoring, Synthetic Mudscapes intends to strategically work with deltaic forces of land building for a multi-layered defense against climate change through the use of responsive technologies and dynamic monitoring. The project looks at several scales and study areas to determine the best approach for a synthetically built ecological infrastructure. This project approaches land building by intensifying an existing coast-wide monitoring system and real-time data monitoring network through rendering a virtual mesh of simulated fluids and environmental processes. This mesh becomes the framework of the design process, allowing for recursive design and decision-making processes. The designers incorporated computational fluid modeling methods in tandem with an agent-based land-building infrastructure, such as the robotic spillway,[61] to suggest multi-variate design strategies for decision making. This kind of responsive approach forms a computational symbiosis between decision making and ecological health and well-being; forming an evolutionary infrastructure that adapts to the needs of ecologies on local levels and regional-wide impacts.[62] These systems-based models represent a kind of projected agent upon the landscape, in which certain materials, processes, and ecological dynamics take precedent over others. Although these models are still considered abductive, this project resulted in a much more top-down, deductive approach in which algorithms and machine learning were applied to make logical decisions. Although computed by machines, these decisions are subjective creations of the humans who write the codes and are therefor considered Logical Systems when we consider Deming and Swaffield's matrix of research strategies.

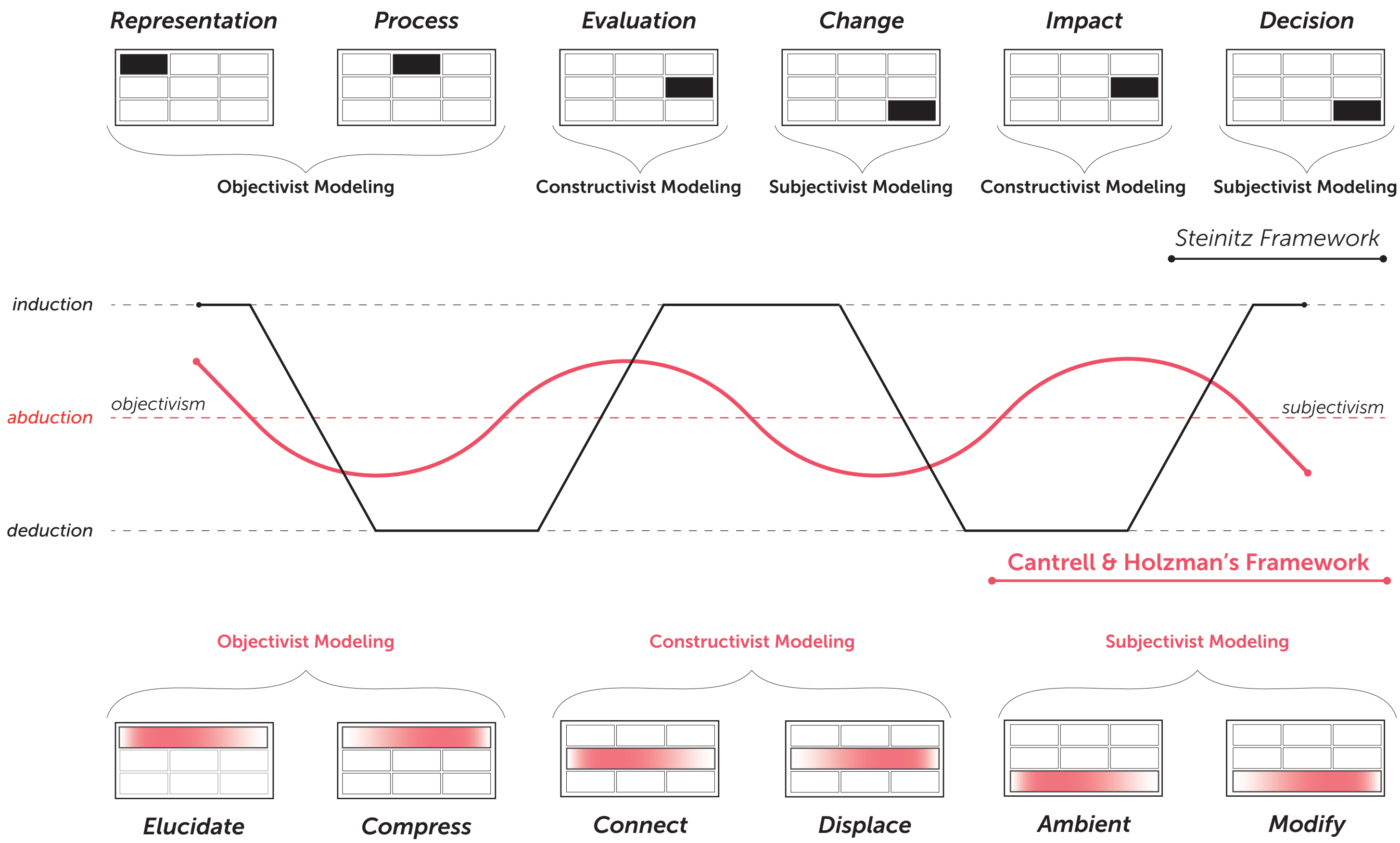
60 See Elizabeth Anne William et al's Synthetic Mudscapes : Human Interventions in Deltaic Land Building.

61 See Cantrell's Responses in an interview at https://blog.ted.com/ted-fellow-bradley-contrell-on-computational-landscape-architecture/

62 See Cantrell and Holzman's "Responsive Landscapes" (2016), page 282, for more information.

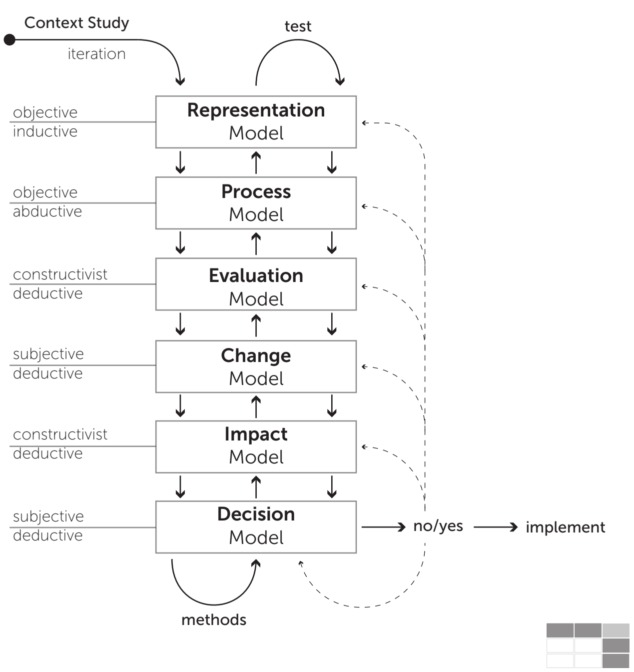
Figure 2.10 / The Fluid Modeling Table

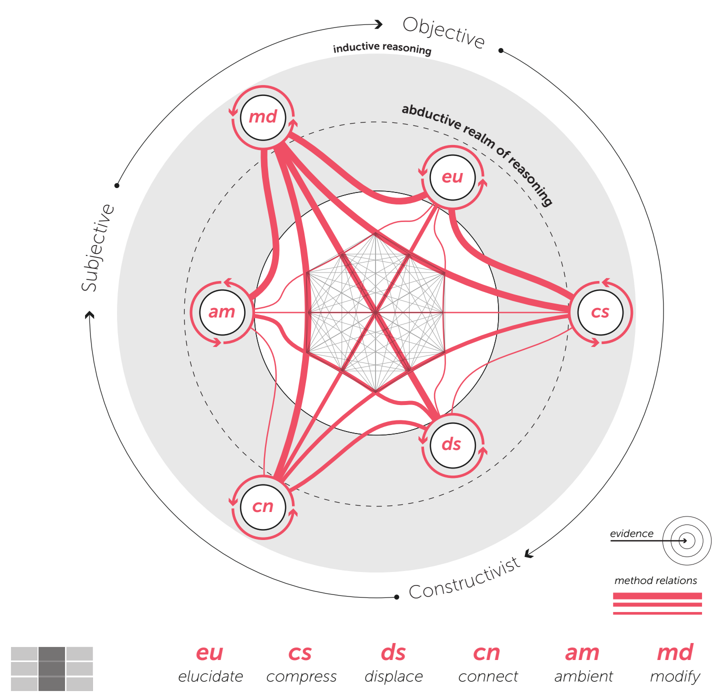
This image shows a collaborative model developed by Cantrell and students from Harvard's GSD that explores sediment dynamics through water flow. The model provides real-time feedback, connected to a virtual modeling interface, supplying point cloud data from the resulting fluvial changes within the model through sensors.



Steinitz Framework for Geodesign & Alternative Futures

Cantrell & Holzman's Responsive Landscapes Framework





After developing an understanding of the Cantrell-Holzman Responsive Model, especially as it translates to Carl Steinitz's Geodesign Framework, we see an alternative approach to landscape modeling altogether. Although each modeling approach has its advantages, the responsive model could be thought of as a singular place where most, if not all, of Steinitz's ideas, questions, and theories may be recursively tested through abductive reasoning. The diagrams on the opposite page reveal the significant differences between the two frameworks. The Steinitz model rarely considers abductive reasoning, as it asks geodesigners to inductively understand site, abductively process site phenomenon, and focuses on making deductive evaluations, changes, cost-benefit analyses, and, ultimately, decisions. Arguably, the significant differences of these frameworks are due to both the technological advances available to designers and Cantrell-Holzman's departure from modeling within the constraints of geographical information models. As a result, responsive models become the bridge in which disparate software, phenomenon, and hypotheses converge to inform landscape processes.

All in all, the Steinitz model is a framework developed around the making of decisions to solve complex problems. The Cantrell-Holzman responsive model hinges on both inductive and deductive reasoning. In reference to Deming and Swaffield's matrix, the responsive model may borrow from any of the nine research strategies in their text; with this said, responsive models are inherently abductive and centered along their abductive axis. The six responsive model typologies fit into the three abductive research strategies as follows:

- *Elucidate* and *Compress* fit into Modeling and Correlation
- *Connect* and *Displace* tie into Design Interpretation
- *Ambient* and *Modify* align most with Projective Design

These methods branch out into adjacent research strategies. While elucidate, connect, and ambient feature more induction as responsive models, compress, displace, and modify exemplify more deductive reasoning. Tension is why the responsive modeling framework lands so central to Deming and Swaffield's matrix; although they have been presented in a typified manner, the responsive model blurs the entire Deming and Swaffield matrix. It becomes a landscape that draws deep connections between various ways of thinking and research strategies.

Figure 2.11 / Juxtaposing the Major Modeling Frameworks

The images on the opposite page reveal the process of synthetic logic, in which frameworks have been translated and transposed onto one another to form a new meaning and understanding of modeling as a landscape architectural research method. Although Deming and Swaffield define modeling as, primarily, both an abductive-objective strategy, this process shows how Geodesign and Responsive models break out of that confined definition. Responsive models have the capacity to work along the objective, constructivist, and subjective axis.

Applications for Algae

Along with landscape architectural models, there exists a history of modeling applications for understanding Cyanobacterial Harmful algae blooms, or CyanoHABs, in the oceanographic and ecological sciences. These models have been proven to be instrumental in the research of CyanoHABs and provide researchers a place to both generate and test hypotheses. According to Peter Franks, a professor, and researcher at the University of California San Diego, applications for modeling algae are inherently heuristic. In this way, the algae model is often considered a heuristic tool for the abduction of algal-phytoplankton dynamics and, more specifically, how algae may engage the system.[63] In his 1997 text exploring modeling applications of algae, he concludes how the modeling of algae is, indeed, used to simultaneously test and generate new knowledge through interpolation. He admits that when applying the theoretical modeling against gathered field-data, limitations of the data become more perceptible, and subsequently, the model has a series of constraints that must be foregrounded in any study.[64] Ecological consequences of harmful algae blooms are difficult to simulate and, as a result, the modeling process becomes more fine-tuned throughout the study itself. Similar to many of the models developed by the Dredge Research Collective and their questions surrounding sediment management,[65] algae is another landscape material that is both difficult to model and lacks appropriate management.

Although these limitations may always persist in the pursuit of modeling algae, there has been advances in both the algae modeling and model applications through several organizations. The Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB) Program aims at fostering international cooperation in the pursuit of HAB research which, primarily, includes the predictive modeling of harmful algae blooms.[66] This program led to the development of a variety of modeling workshops that connected algae researchers with environmental modelers. This engagement resulted in the development of predictive algae modeling based on the ecological and hydrological mechanisms underlying the organism's population dynamics.[67] Inspired by the various

63 See Franks Discussion in Models of Harmful Algal Blooms (1997) in order to understand the heuristic nature of algae modeling.

64 See Franks Introduction to Models of Harmful Algal Blooms (1997) for a historical walk-through of modeling applications for algae. In short, Franks typifies early models as the following: aggregated, multi-species, models with simple physics, and models with detailed physics.

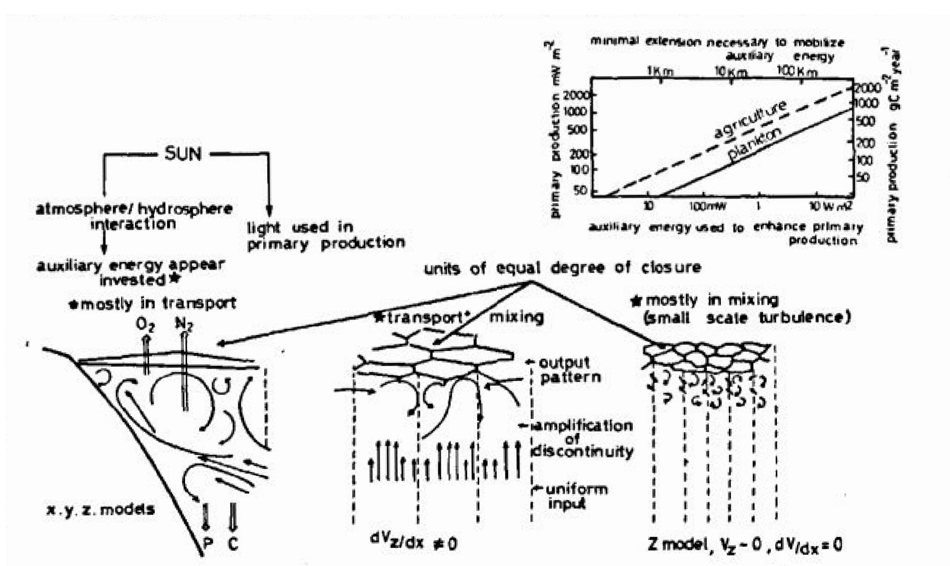
65 See the works of the Dredge Research Collective at https://

66 Refer to GEOHAB modeling: Linking Observations to Predictions: A Workshop Report (2011)

67 See Franks Introduction to Recent Advances in Modeling of Harmful Algal Blooms (2018) models generated by GEOHAB, Franks moved on to explore more recent modeling applications and covers modeling through the periods of 1997-2012 [68] and 2012-2016.[69] His most recent text in 2018 provides a more elaborate discussion on modeling types and he reviews these models through the lens of the modeler. Similar to Steinitz and Cantrell-Holzman's frameworks, Franks develops six categories of algae modeling applications that could very well be translated onto Steinitz's Geodesign framework in a fashion similar to the preceding chapter. These models include: [70]

1. Conceptual
2. Empirical-statistical
3. Process
4. Diagnostic
5. Predictive-simulation
6. Management

The first two models are inherently static in that they synthesize and abstract the system into more comprehensible measures and processes. Conceptual models often resemble diagrams of the many variables impacting algae proliferation while empirical-statistical models aim to quantify relationships among observations through statistics. They do not utilize mathematical equations to solve the growth of algae within a given system over time (See Figure 2.12).[71]



68 See Franks's "Modeling of harmful algal blooms: advances in the last decade" (2014) In: Rossini's Toxins and biologically active compound from microalgae, Biological effects and risk management, vol 2.

69 See Franks Introduction to Recent Advances in Modeling of Harmful Algal Blooms (2018)

70 See section 19.2 of Franks Recent Advances in Modeling of Harmful Algal Blooms (2018) for more information regarding modeling algae.

71 See sections 19.2.1 and 19.2.2 of Franks Recent Advances in Modeling of Harmful Algal Blooms (2018) for more information regarding conceptual and statistical models

Figure 2.12 / Margalef's Mandala (1978)

This is an example of Frank's conceptual model borrowed from Ramon Margalef's 1978 text *Life-forms of phytoplankton as survival alternatives in an unstable environment.* It's one of the earliest forms of concept models exploring the various types of phytoplankton and marine microorganisms that may arise due to specific environmental conditions. This model has been iterated upon over the past several decades.

The following process, diagnostic, predictive-simulation, and decision models all utilize mathematics to solve algae as it changes over time through dynamic interpolation. Process models often consider *state variables*, such as nitrate, phosphorous, or cell concentration, along with *transfer functions,* which include the algae cell nutrient uptake rate or impact by suspended sediments - to name a few.[72] Process models are considered the most heuristic in that they test how algae may perform in a system with certain state variables. Franks admits that process models are particularly good at exploring system performance and how specific mechanisms may impact algal growth.[73]

As seen in Figure 2.13, There are several studies that explore how parameterizing state variables and specific control measures impact harmful algae growth in an ecosystem, especially as it relates to the eutrophication process. These projects reveal the complexities of modeling algae and how imperative process models become in abductively engaging the organism.[74] Although all of the models discussed in Franks text are worth exploring for this project, the original questions lean more towards testing through an abductive lens and, therefore, investigating algae within the existing infrastructure through process modeling.

72 See section 19.2.3 of Franks Recent Advances in Modeling of Harmful Algal Blooms (2018) for more information regarding process models. See Alves-de-Souza et al. (2015) for an example of abductively investigating plankton community in reference to various state variables.

73 See section 19.2.3 of Franks Recent Advances in Modeling of Harmful Algal Blooms (2018) for more information regarding process models.

74 See Sunda and Shertzer (2014), Yamaguchi and Sai (2015), and Alves-de-Souza et al. (2015) for examples of algae models that explore top-down and/or bottom-up controls on HABS, while combining laboratory and field data to parameterize, drive, and test their models.

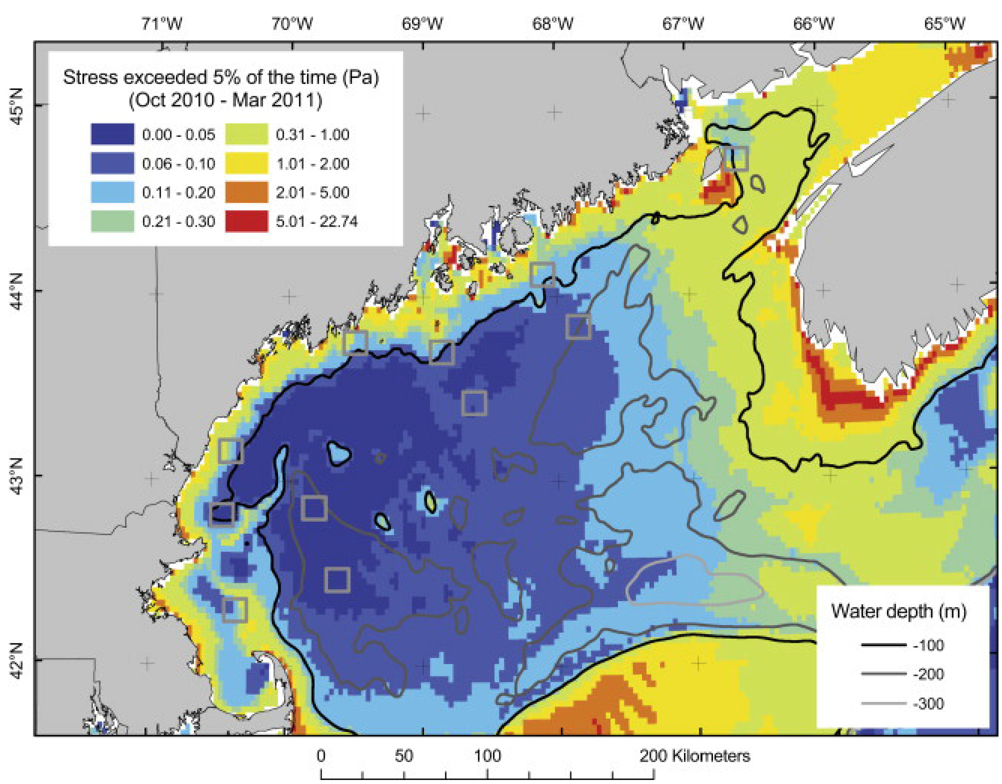


Figure 2.13 / Sediment Resuspension and Alexandrium fundyense population dynamics in the Gulf of Maine

The images on the opposite page show a study in the Gulf of Maine examining the relationship of sediment resuspension, currents, and algae proliferation by coupling physical and biological models together. The model was able to help the researchers understand the relationship between physical stresses, shoreline erodibility, and subsequent mobilization of the *Alexandrium fundyense* throughout the water column. As an example of an algae process model posed by Franks, this model may be iterated upon to predict and forecast algae population dynamics.

Algae Management and Tactics for Mitigation

Over the past decade, research has been developed to provide water managers a coherent set of tactics for the mitigation of harmful algae blooms. These tactics are typically structured around two types of mitigation: preventative measures and control measures (See Figure 2.14).[75] Preventative measures form a kind of landscape resilience through the preemptive implementation of systems that typically reduce the amount of nutrients loading the system. Examples of these measures may be the implementation and upgrade of sewage management, runoff catchment, the construction of retention wetlands, floating islands, or the planting of aquatic plant structures.[76] While preventative measures aim to prevent algae proliferation before nutrient-loading, control measures aim to control the nutrient-loaded algae in the interim. It's suggested that this kind of action occurs in already existing infrastructures that face algae scums while, simultaneously, provide rapid, positive results.[77] The Environmental Protection Agency (EPA) labels this as "physical" controls in that it physically engages harmful algae scum and includes the following examples: dredging, surface water mixing (horizontal), booms for compartmentalization, and flow manipulation.[78] Ultimately, the application of these measures should be guided by certain assessments

75 See the Lake Ecological and Cyanobacterial Diagnosis and Measures Knowledge base in Stroom and Kardinaal's How to combat cyanobacterial blooms: strategy toward preventive lake restoration and reactive control measures (2016)

76 See the Report: Solutions for managing cyanobacterial blooms: A scientific summary for policy makers published by IOC/UNESCO (2019) & The EPA's Summary of Waterbody Management Measures for Cyanobacterial Blooms

77 See page 564, "Selecting Measures" Section of Stroom and Kardinaal (2016).

78 See the Report: Solutions for managing cyanobacterial blooms: A scientific summary for policy makers published by IOC/UNESCO (2019) & The EPA's Summary of Waterbody Management Measures for Cyanobacterial Blooms

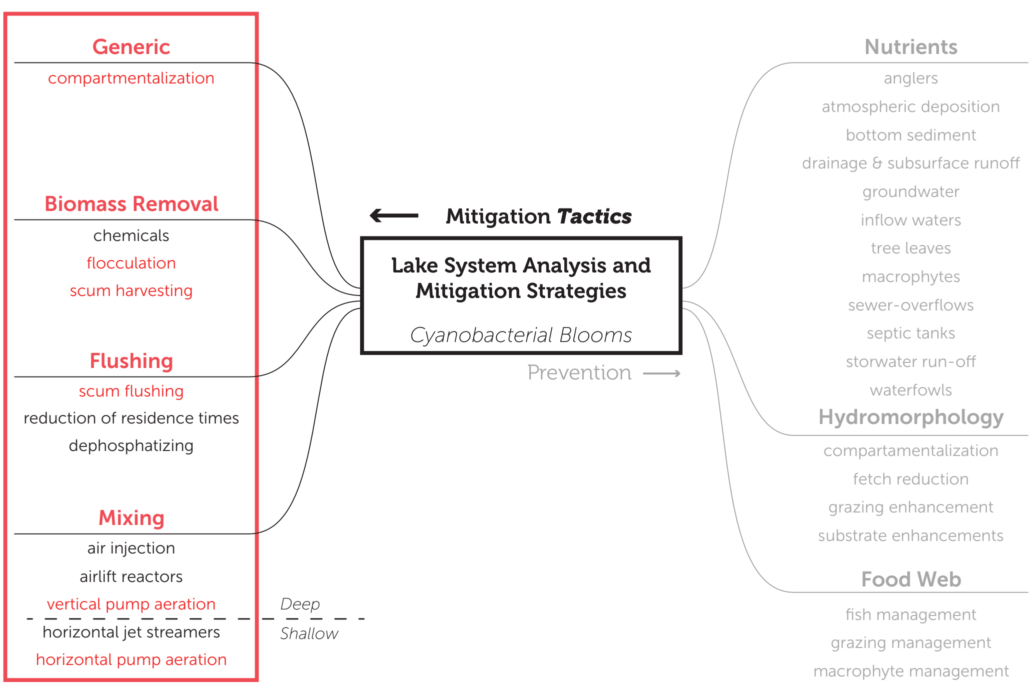


Figure 2.14 / The Lake Ecological and Cyanobacterial Diagnosis and Measures Control and Preventative Tactics as adapted by Stroom and Kardinaal (2015)

This diagram lists out the primary preventative and control measure utilized to manage harmful algae blooms. As seen in the list, preventive measures include more complex biophysical processes employed by existing USACE management projects. These kinds of tactics take time to analyze and are being explored in LILA studies. Control measures include functions that are more readily understandable via accessible virtual modeling software.

and decisions to meet functional requirements.[79] Although both preventative and control tactics are well-suited for the Lake Okeechobee system, this project considers how physical controls may modify and enhance existing infrastructure examined in the introduction. This kind of mitigation tactic is more easily understood through existing, and available, algae modeling softwares and may provide the designer more innovative, speculative designs that bridge together analysis and design actuation.

In response to the annual incidence of CyanoHAB outbreaks, the State of Florida, and it's Governor Ron Desantis, established a Blue-Green Algae Task force in an executive order dated in January of 2019. The order is broken up into three sections that focus on:

1. Water quality, quantity, and supply
2. Restructuring to focus on environmental accountability and transparency
3. Ensuring Florida's valuable and vulnerable coastlines are protected

One of the major outputs from this order was the development of an online information database and mapping interface that aims to provide key water quality data communicated to the public, as seen in Figure 2.15.[80] Current algae mitigation and management practices within the Lake Okeechobee System span across many federal and statewide agencies and include a long list of projects that focus more on both preventative and control tactics, such as water treatment reservoirs seen at the C-44 Basin Storage Reservoir and updated Lake Management water release discharges that work more like "pulses" versus large flushes.[81] Along with these previously mentioned projects, the state's Department of Environmental Protection has invested over $10 million in the adoption of "innovative" algae mitigation technologies. One of the primary "innovative", technological solutions to this issue involves a chemical algaecide, or in this case, a cyanocide.[82]

This algaecide, produced by the company BlueGreen Water Technologies, is a sodium percarbonate based compound that turns into hydrogen peroxide when it is introduced to water. The converted hydrogen peroxide then reduces the photosynthesizing ability of the cyanobacterial species.[83] Although the product is highly effective against

79 See page 565, "Synthesis" section, of Stroom and Kardinaal (2016).

80 See more information about the Blue Green Algae Task force at https://

81 See the US Army Corp of Engineer's Report to Congress – Comprehensive Everglades Restoration Plan at https://issuu.com/usace_saj/docs/final_2020_report_to_congress_on_cerp_progress_hig.

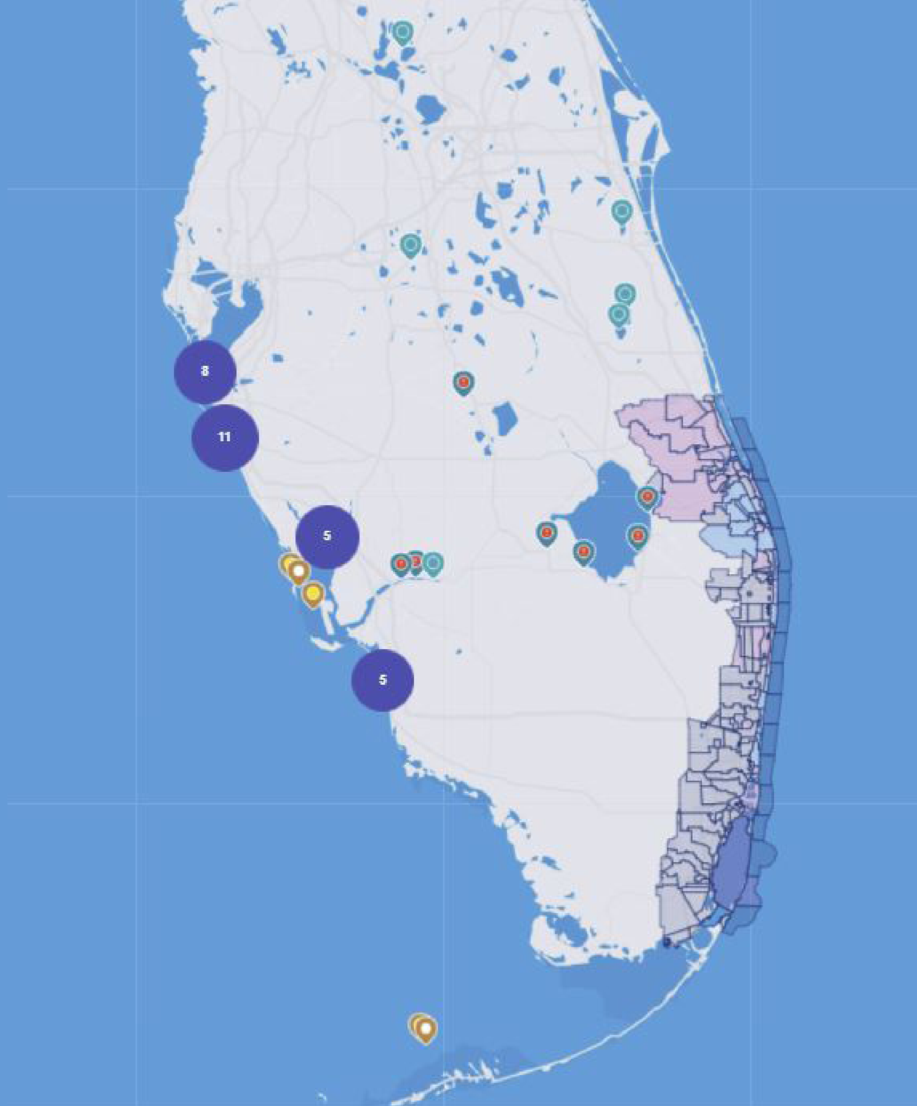
82 See Restoration Initiatives at https://

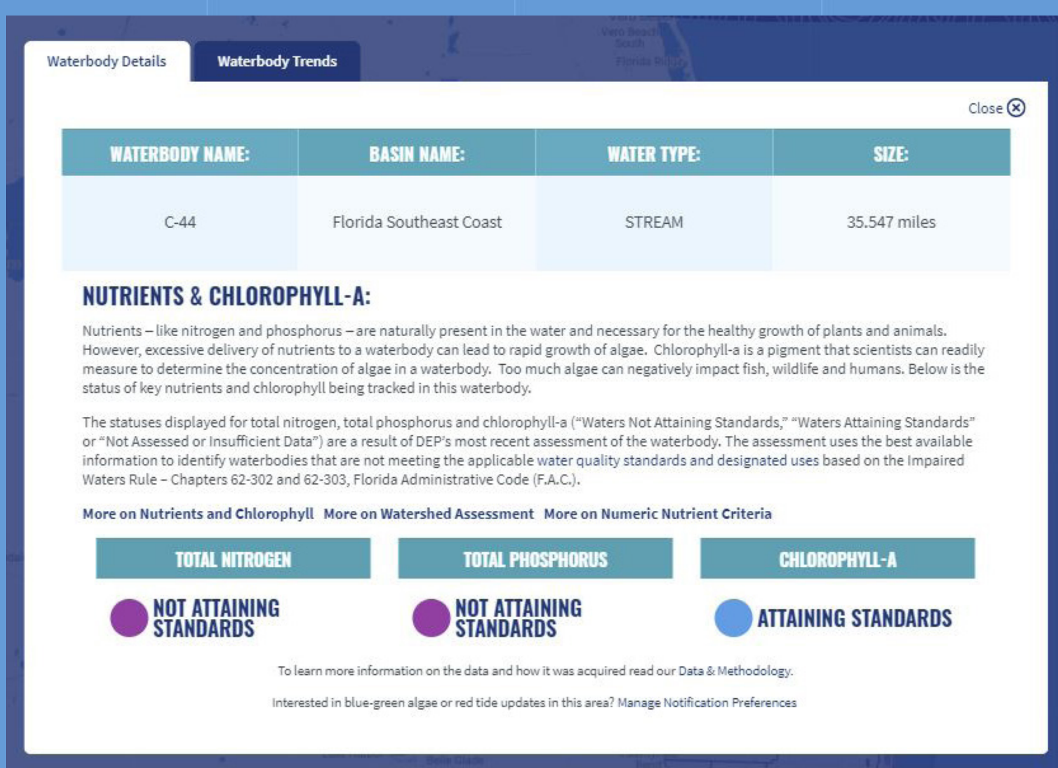
83 See the introduction of Mathjuis et al.'s Selective suppression of harmful cyanobacteria in an entire lake with hydrogen peroxide (2012)

Figure 2.15 / Algae Task Force Mapping and Educational Platform

These images show the output of Florida's Algae Task Force Water Quality Map service. The map primarily colors watersheds with a color to denote whether the health of the waterway is attaining certain standards. Previous versions showcased specific quantities of chemical levels, however, a newer version simplifies the total nitrogen and phosphorous category into three levels or standards. This is a subtle example of Models as Manifestos, in which evaluation may be subjectively simplified to suppress certain knowledge and objective information. This is a critique upon the use of models to represent landscape phenomenon. Either way, the St. Lucie waterbodies are not currently "attaining standards".

Map provided by *https://protectingfloridatogether.gov/water-quality-status-dashboard*





Waterbody Details | Waterbody Trends

Close ⊗

WATERBODY NAME:	BASIN NAME:	WATER TYPE:	SIZE:
C-44	Florida Southeast Coast	STREAM	35.547 miles

NUTRIENTS & CHLOROPHYLL-A:

Nutrients – like nitrogen and phosphorus – are naturally present in the water and necessary for the healthy growth of plants and animals. However, excessive delivery of nutrients to a waterbody can lead to rapid growth of algae. Chlorophyll-a is a pigment that scientists can readily measure to determine the concentration of algae in a waterbody. Too much algae can negatively impact fish, wildlife and humans. Below is the status of key nutrients and chlorophyll being tracked in this waterbody.

The statuses displayed for total nitrogen, total phosphorus and chlorophyll-a ("Waters Not Attaining Standards," "Waters Attaining Standards" or "Not Assessed or Insufficient Data") are a result of DEP's most recent assessment of the waterbody. The assessment uses the best available information to identify waterbodies that are not meeting the applicable water quality standards and designated uses based on the Impaired Waters Rule – Chapters 62-302 and 62-303, Florida Administrative Code (F.A.C.).

More on Nutrients and Chlorophyll More on Watershed Assessment More on Numeric Nutrient Criteria

TOTAL NITROGEN	TOTAL PHOSPHORUS	CHLOROPHYLL-A
NOT ATTAINING STANDARDS	NOT ATTAINING STANDARDS	ATTAINING STANDARDS

To learn more information on the data and how it was acquired read our Data & Methodology.

Interested in blue-green algae or red tide updates in this area? Manage Notification Preferences

algae,[84] it's a kind of biocide that impacts the livelihoods of many species.[85] The product's safety specification outlines the following warning: "This pesticide is toxic to birds. This product is highly toxic to bees and other beneficial insects exposed to direct contact on blooming crops or weeds".[86] Several studies have been conducted to observe and investigate the adverse impacts hydrogen peroxide may have on mesocosmic and microcosmic communities within an ecosystem. According to Lizhou et al., higher levels of hydrogen peroxide may lead to "water disinfection" in which both phytoplankton and bacterioplankton species may be removed from the community structures of sensitive aquatic ecosystems. Even though the Florida's Department of Environmental Protection plans on providing data via experiments in Lake Minneola, this resulting mitigation tactic will hopefully come last in extreme events to ensure ecosystem longevity.[87] BlueGreen Technologies is looking at several methods for the application of this algaecide on-top of algae blooms. This includes manual application where algae-managers may toss Lake Guard Oxy powder along shorelines. Meanwhile, other applications include more surgical administration through drone technology and less precise methods by using crop, or in this case algae, dusters as seen in Figure 2.16.[88]

The use of algaecides throughout waterways should be a concern to everyone for it threatens the future of our ecosystems. Although hydrogen peroxide based algaecides dissolve within waterways relatively quickly,[89] they may lead to various unfavorable outcomes such as the depletion of microcosmic ecosystems that support a variety of species through the food chain. It's incredibly ironic that the state of Florida is exploring chemical solutions to chemical problems. While the Department of Environmental Protection is exploring this potential "solution", South Florida features a multi-disciplinary, landscape-scaled eco-hydrological research facility exploring the many anthropogenic impacts placed upon the Everglades known as The Loxahatchee Impoundment Landscape Assessment (LILA) .

Managed by the South Florida Water Management District in conjunction with Florida Atlantic University and Florida International University, scientists and landscape managers utilize LILA by evaluating changes in the ecosystem, such as nitrogen and phosphorous fluctuations, in a responsive manner.[90] Similar to the 200-acre hydrological model of

84 See the Hydrogen Peroxide Section of Mathjuis et al.'s Selective suppression of harmful cyanobacteria in an entire lake with hydrogen peroxide (2012).

85 See Glaeser et al. (2014)

86 See BlueGreen Water Technology's Lake Guard Oxy Product Sheet https://bgtechs.com/?page_id=16

87 See the Lake Mineeola tab at the following https://www.sjrwmd.com/projects/

88 See BlueGreen Water Technologies Facebook page at https://www.facebook.com/

89 See the Hydrogen Peroxide Section of Mathjuis et al.'s Selective suppression of harmful cyanobacteria in an entire lake with hydrogen peroxide (2012).

90 See Dreschel et. al's The Loxahatchee Impoundment Landscape Assessment (LILA) Facility: Supporting Everglades Restoration Research for More Than a Decade (2013)

Figure 2.16 / BlueGreen Water Technologies Application of Lake Algaecides

These photos show BlueGreen Water Technologies application process found on their website and Facebook page. The company is currently exploring how the algaecide may be applied to lakes and waterways experience algae blooms. These methods include dumping the algaecide powder directly onto surface waters using drone technology to "surgically" apply the sodium percarbonate onto algae scum (above), and using "algaecide dusters", similar to crop dusters, in which aircraft apply the material on larger scums (below).

the Mississippi River Basin that influenced the works of Brad Cantrell, LILA shows how testing ecological phenomenon in a physical place informs decision-making, adaptive management, and abductive hypothesis.[91] LILA is a 17-hectare facility featuring several environmental cells exploring various habitat typologies throughout the greater everglades. It's located within the Everglades itself and is funded by the CERP. Some of the many experiments occurring in LILA include studying the impacts waterflows and hydroperiods (length of time in which the wetland is inundated with water) may have on the local ecologies of wading birds and fish.[92] The images seen in Figure 2.17 show some of the experimental structures and plots set up for environmental monitoring and analysis of certain phenomenon and conveys the overall landscape-scale experiments occurring throughout LILA.

The following Sections will explore how responsive models may be transposed into the South Florida context to understand algae mitigation through the various control measures mentioned previously. In what ways may responsive technologies help us compartmentalize algae scums, increase flocculation by sediment mixing, and collect algae biomass to be converted into fertilizers and biofuels?[93] Ideally, the following design process will establish a coherent set of tactics informed by previous research and realize those tactics through responsive models rendering algae dynamics, mapping, and simulation.

91 See Kristi Cheramie' s The Scale of Nature: Modeling the Mississippi River

92 See Bradley Cantrell and Adam Mekies Codify: Parametric and Computational Design in Landscape Architecture (2018) for more information related to LILA.

93 See AECOM's Toxic Algae Removal Projects which includes a focus project in South Florida: https://aecom.com/uk/projects/toxic-algae-removal/

Figure 2.17 / LILA Experimental Stations

Along with analyzing phosphorous and nitrogen, these experiments aim at understanding the ecological responses of specific environmental processes that occur throughout the greater Everglades. The top image is a mesocosm flume experiment that doses small sections of wetlands. The bottom photo is a series of plots that are testing algal growth in response to fertilization with nitrogen and phosphorous.

The photos are courtesy Curtis J. Richardson and information credit should go to Cantrell and Mekies in their *Codify: Parametric and Computational Design in Landscape Architecture (2018)*

3.

Methodology

Methods Introduction

Abductive design methodologies may be thought of as a recursive and exploratory process. According to Steffen Nijhuis and Jeroen de Vries, Research through Design (RTD) is an abductive approach that hinges between both generating and testing hypotheses simultaneously. Therefore, effective solutions emerge by weighing the abductions, or discovered hypotheses, and adjusting them to the observations seen throughout the research through design process.[1] In this way, the RTD process approaches design via "strategies", or achieving goals to address research questions in a hueristic lens.[2] Nijhuis and Vries explain the RTD process as a series of strategies through the use of a solution space, goal space, and systematic path. In many ways, the process governing this project's methodology can be expressed through Figure 3.1, in which the responsive model is the solution space and the goal space is the accumulation of basic knowledge pertaining to both algae mitigation and responsive modeling as a design process.

1 See CM Steenbergen's Introduction: Design research, research by Design (2002) and Deming and Swaffields work Landscape architecture research: Inquiry, strategy, design (2011)

2 See Nijhuis and Vries' Design as Research in Landscape Architecture (2020), page 91

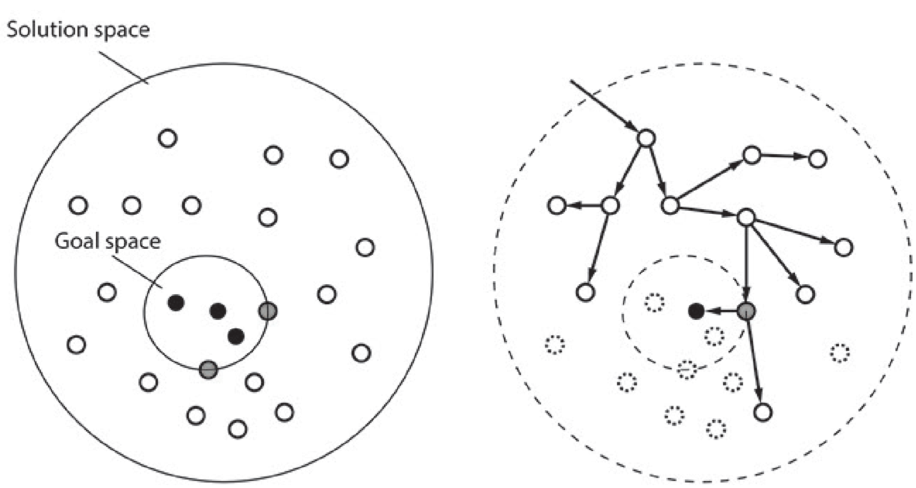


Figure 3.1 / Research through Design

RTD processes do not consist of design exclusively. This diagram represents the RTD investigation space, in which both problems and objectives may be refined and changed through a systematic path. Through this representation, we see how RTD is a purely abductive logic, in which new knowledge may guide us towards a specific goal state.

Diagram courtesy Nijhuis & De Vries (2020)

In its most simplest form, research through design, or RTD, is a research method in which spatial design and investigation becomes the leading driver of the research-design process. The foundation to this concept, according to Dr. Steffen Nijhuis, suggests design is a form of research with embedded cultural thought, meaning, and practice. In this way, the RTD process quickly becomes metalogical; in which the critical examination of design processes may both inform the methods used within an RTD project and lead designers to produce new knowledge within the realm of design.[3] As discussed in the previous section, this project aims at defining the responsive model as an RTD method through case study analysis and experimental design studies.

To fully understand responsive models as a design methodology and application to the South Florida algae crisis, Algae as Agents utilizes a constructivist methodology to uncover knowledge from previous responsive modeling applications. According to Lenzholzer et al., a constructivist approach leads to a flexible design process, generating new, innovative knowledge within the realm of design while building off of previously developed works.[4] This meta-logical approach to the design problem will extend the questions investigated in this thesis in two parts: (1) developing a responsive modeling framework through case study investigation while projecting these strategies within the context of South Florida infrastructural issues & (2) developing a responsive approach in designing for algae mitigation.

This section will briefly explore a design through research methodology created by Steffen Nijhuis. This process includes researching design case studies and projectively testing the knowledge learned from those cases into the context of the study area through design translation. In doing this translation, the designer may begin to abductively investigate how previous responsive models may engage with this crisis in the context of South Florida. Altogether, this design methodology may be considered basic research. New knowledge, techniques, and abductive "strategies" may be further developed within Landscape Architecture, extended into our understanding of algae management and mitigation, and applied to the development of responsive models. Ultimately, this design approach and strategy will extend our knowledge within the realm of RTD and designing for large-scale infrastructural algae issues.

3 See Nijhuis and Vries' Design as Research in Landscape Architecture (2020)

4 See section 3.2, "Constructivist 'research through designing'" of Sanda Lenzholzer et al.'s Research through designing' in landscape architecture (2013)

Research Through Design (RTD)

According to Deming & Swaffield, design as research is a highly debated topic within the realm of design disciplines. There's a long list of research theorists who have grappled with the concept in a 2007 Journal of Architectural Education, or JAE, publication themed at understanding design as research.[5] This notable JAE publication, and the published works of these design researchers, resulted in two primary stances surrounding RTD. The group that advocates for RTD recognize design as a completely valid source of research for several reasons: [6]

1. Design must be informed by empirical evidence and is built up by a variety of observations
2. Design cases embody knowledge within themselves
3. Design work is innately experimental in its own right
4. Design is inherently reflexive, interpretive, and reflective

5 See Deming and Swaffield's Landscape Architectural Research : Inquiry, Strategy, Design (2010), section 3.5 discussing Research and Scholarship.

6 See page 38 of Deming and Swaffield's Landscape Architectural Research : Inquiry, Strategy, Design (2010)

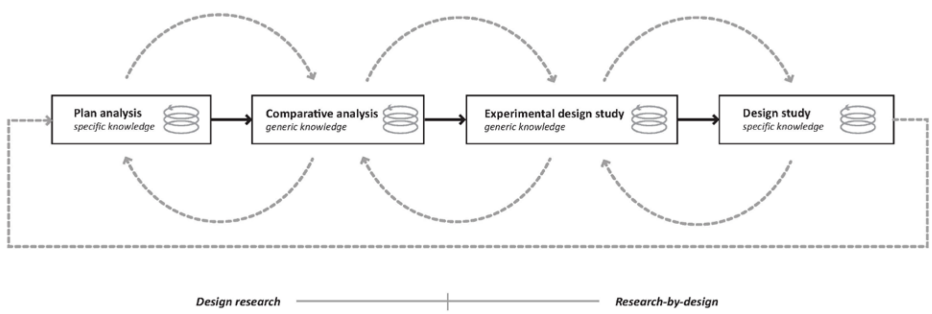


Figure 3.2 / RTD as an Iterative Design Framework

As seen in this diagram, Nijhuis and Bobbink's RTD approach is highly iterative and features a semi-linear process that engages both design research and research-by-design domains. Thus, we establish a connection between the knowledge garnered in a more conventional research process and push that knowledge forward through experimental designs.

Diagram courtesy Nijhuis & Bobbink (2012)

Following Deming and Swaffield's text on popular research strategies, Nijhuis and Bobbink created an RTD framework in 2012 that encompasses, and addresses, all of the principles listed above. As seen in Figure 3.2, their framework is structured with 4 primary modes of research that may be broken up between two research domains: "design research" and "research as design". In accordance to Nijhuis' methodology, designed landscapes embody an immense amount of knowledge pertaining to architectonics, material culture, and spatial information that may be accessed within the domain of design research. This research domain may be approached through both plan analysis and comparative analysis.

Plan Analysis. This mode of research employs research strategies relevant to understanding the multitude of layers expressed in a composition of landscape architecture. Through this process, the design researcher will achieve specific knowledge evident in a designed object within a determined context. Nijhuis and Bobbink suggest four layers, or forms, in which design researchers may start to distinguish landscape design elements. These forms represent a systematic, descriptive-oriented[7] approach towards understanding designed landscapes and establish important relationships between one another: [8]

1. *Basic Form* is a flattened analysis of designed interventions upon the context and is typically conceptual or diagrammatic.
2. *Spatial Form* analyzes the three-dimensional qualities of a designed landscape, focusing on the experiential moments represented.
3. *Metaphorical Form* is a bit more subjective in that the researcher extracts the symbolism, or meaning, behind the work.
4. *Programmatic Form* analyzes the overall functional structure of the place and how it may relate to circulation.

Comparative Analysis. After forming coherent understandings of a series of case studies through *Plan Analysis*, Nijhuis and Bobbink move into a more comparative realm, in which case studies are typified in a general fashion and synthetically translated [9] upon one another in order to establish patterns, potential solutions, and a landscape architectural "toolbox", or kit of parts.[10] Once several patterns and associations are established through this process, a series of design principles, compositions and frameworks may be identified and advanced in the following research by design process.[11]

Between analyzing landscape case studies and developing a comparative framework to understand patterns and formal languages, design by research reveals knowledge specific to particular issues or design problems in a typified manner. From here, we may progress into the research-by-design domain, in which the knowledge discovered in the design research process may be tested or studied through the design process. The overall goal of the research-through-design process includes utilizing the insight garnered in the previous phase and translating it into a new context to explore or solve a specific problem related to landscape design.[12] Nijhuis and Bobbink structure this domain around the final two modes of design exploration, including experimental design studies and design studies.

7 See chapter 5 of Deming and Swaffield's Landscape Architectural Research : Inquiry, Strategy, Design (2010)

8 See section 3.1.1 of Nijhuis and Bobbink's Design-related Research in Landscape Architecture (2012)

9 See the Synthetic Logic section to "Logical Systems (Axioms, Rules, and Argumentation)" strategies in Deming and Swaffield's Landscape Architectural Research : Inquiry, Strategy, Design (2010)

10 See page 248 of Nijhuis and Bobbink's *Design-related Research in Landscape Architecture* (2012)

11 See section 3.1.2 of Nijhuis and Bobbink's Design-related Research in Landscape Architecture (2012)

12 See section 3.2 of Nijhuis and Bobbink's Design-related Research in Landscape Architecture (2012)

Experimental Design Study. Nijhuis and Bobbink refer to this mode of the research-by-design domain as a translation, or the moment in which the discovered knowledge gained in the previous process may be placed into a new context.[13] Deming and Swaffield label this research method as the "metaphor of experimentation", and they suggest that it is an abductive way of exploring design principles in which hypotheses and design strategies may be actively tested. They go on to explain how this kind of research strategy is metalogical:

> A second line of development of the metaphor of experimentation seeks to create stronger connections between landscape architecture research and the science disciplines that also focus upon the land, by framing landscape planning research as a meta-experiment. The term "meta" is typically used to describe a higher-level analysis that compares and synthesizes the results of many other more detailed studies.[14]

Altogether, this translation, or metaphor, becomes process-oriented. As a result, the compositions identified in the design research stage may be further developed and put under pressure by the issues relevant in the site under investigation.[15]

Design Studies. After the experimental design study, the following mode of research includes design studies, in which new knowledge is generated post-experimentation. The design study looks more like a final design, though it does not have to be. Whereas experimental design studies represent the process of translating components of case studies into the context, the design study is a visualized realization of those translations. Nijhuis and Bobbink refer to this outcome as a model, and they conclude that this mode of research is heuristic.[16] Deming and Swaffield would label this process as a form of projective design, which lands itself central to their matrix of research strategies.[17] In reference to De Landa and Ellingsen's "Possibility Spaces", through the pursuit of investigating what might be, we find a place to abductively engage the possibilities of spaces: "The modeler is informed by the processes through which the metaphor physically acquired its formal characteristics and from those processes extracts rule sets".[18] As such, the model, or design study, becomes an analytical device, closing the loop between design research and research-by-design.

13 See section 3.2 of Nijhuis and Bobbink's Design-related Research in Landscape Architecture (2012)

14 See page 124 of Deming and Swaffield's Landscape Architectural Research : Inquiry, Strategy, Design (2010)

15 See section 3.2.1 of Nijhuis and Bobbink's Design-related Research in Landscape Architecture (2012)

16 See section 3.2.2 of Nijhuis and Bobbink's Design-related Research in Landscape Architecture (2012)

17 See page 209 of Deming and Swaffield's Landscape Architectural Research : Inquiry, Strategy, Design (2010)

18 See page 218 of Models (2007)

The Responsive Research Domain

The methodology used throughout Algae as Agents is very similar to Nijhuis and Bobbink's RTD methodology. The overall format and structure of this project's process remained largely the same; however, the major departure revolves around the content researched throughout both research domains. Whereas their strategy revolves around plan analysis and the diagrammatic interpretation of landscape case studies, this project aims at finding a series of responsive models to further extend our knowledge on this relatively new approach to landscape modeling. Specifically, the design research domain in Algae as Agents is pursued to develop a deeper understanding of responsive models as a research through design method. Figure 3.3 shows the significant departures of the design research domain or the "Responsive Model Research" domain of the project. This domain features several research methods, including site investigation, literature reviews, responsive model interpretations, and the development of a responsive model framework.

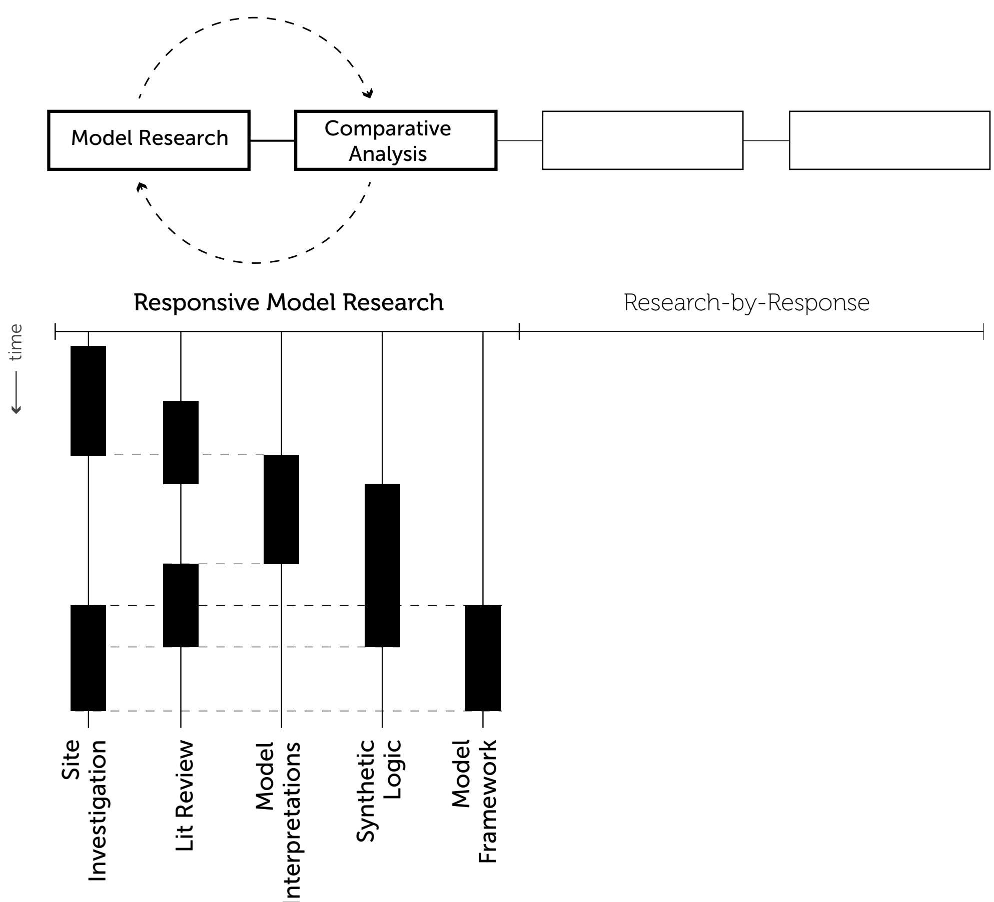


Figure 3.3 / Responsive Model Research

This adaptation of Nijhuis and Bobbink's RTD process shows the design research domain where responsive model case studies were investigated. Below the overall framework, a bar-plot graph shows how this project's research domain was conducted via five primary research outputs. These include Site Investigation, Literature Review, Model Interpretations, Synthetic Logic, and developing a Responsive Model Framework.

Model Research. As previously reviewed in the Models as Manifesto section of this report, two standard landscape modeling methods were selected and synthetically compared to one another. This transposing of modeling frameworks led to the discovery of various case studies and literature relating to responsive models. The selection of these responsive models came through the literature review of several texts and websites that explore modern technology and its relationship to landscape design processes. The responsive modeling case studies chosen were limited to the texts reviewed; however, these texts are relatively modern and feature a wide variety of landscape modeling techniques and applications. The selected texts and sources are as follow:

1. Bradley Cantrell and Justine Holzman's *Responsive Landscapes: Strategies for Responsive Technologies in Landscape Architecture (2016)*
2. Karen M'Closkey and Keith VanDerSys *Dynamic Patterns: Visualizing Landscapes In A Digital Age (2017)*
3. Bradley Cantrell and Adam Mekies *Codify: Parametric and Computational Design in Landscape Architecture (2018)*
4. Bradley Cantrell and Justine Holzman's Responsive Landscapes Website at *http://responsivelandscapes.com/book-framework/*
5. Aiman Tabony and Enriqueta Llabres-Valls Relational Urbanism Lab at *http://llabrestabonyarchitects.com/practice*
6. Jana VanderGoot and Michael Ezban's Studio at https://vandergootezbanstudio.com/About

Comparative Analysis. After the review of these resources for responsive modeling inspiration, specific models were selected based on their suitability to translate into the given issues and context surrounding algal blooms. These decisions were made after a descriptive case study analysis,[19] in which the purpose, approach, and implications of the model were written and deduced. Most of the limitations surrounding these translations, which will be discussed later on, have revolved around access to certain data and remote sensing instruments. With this, a greater focus was put onto the use of computational fluid dynamic modeling since the context of this problem revolves around the movement of water and the ensuing algae blooms.

19 See section 5.6, "Descriptive Case Studies" in Deming and Swaffield's Landscape Architectural Research : Inquiry, Strategy, Design (2010)

The Research-by-Response Domain

While more conventional approaches to research-by-design include translating typified landscape compositions into a new landscape context, Algae as Agents approaches research-by-design as a series of responses. Responsive model queries translate into the process of analyzing and understanding algae. The knowledge gained through these processes is noted and further developed down the line of experimental design studies. Algae as Agents features five experimental models that explore algae and the many environmental variables that interface this issue. The frameworks investigated in the Models as Manifesto section represent the methods utilized in this domain of research-by-design (hence research-by-response). These methods relate to 5 of the responsive modeling approaches found in Cantrell-Holzman's framework and may be seen in Figure 3.4 in reference to time and usage. Take note of the relationship between the responsive modeling approaches.

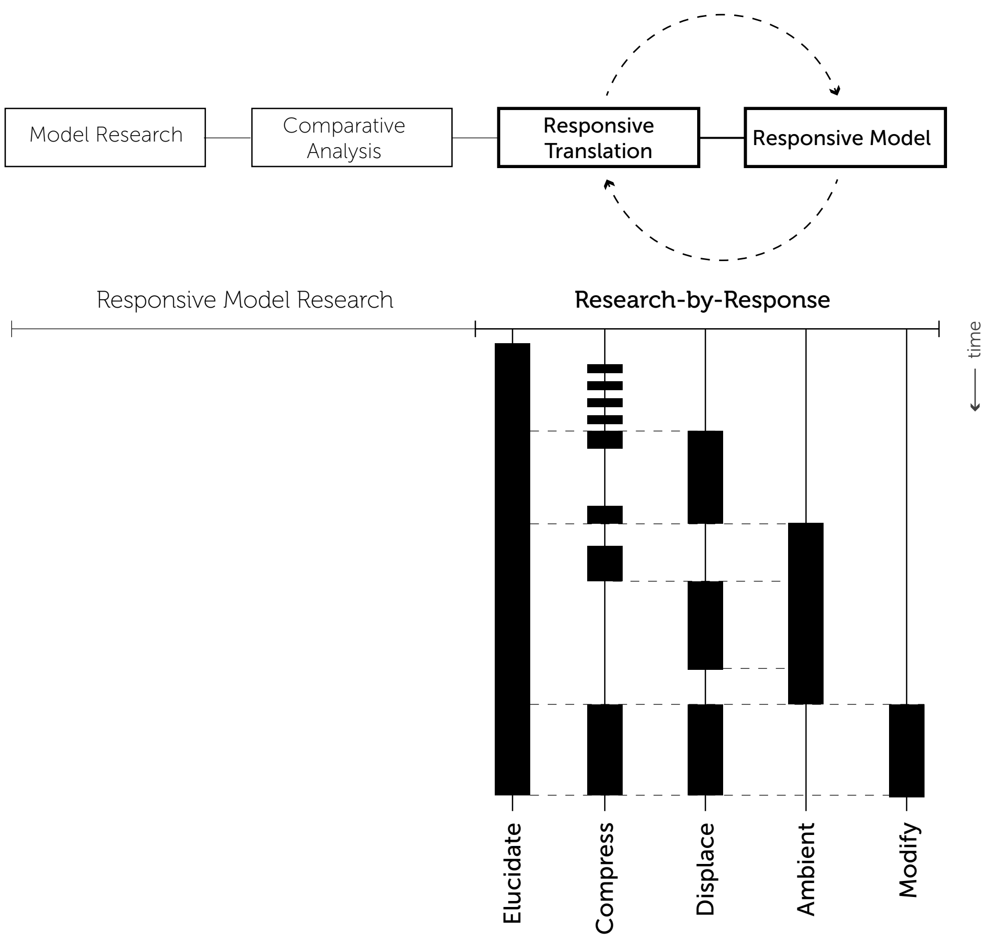


Figure 3.4 / Research-by-Response

Once enough information and data is established in the preceding design research domain, experimental translations may be explored as a heuristic, iterative process. Once responsive model methods and processes are translated into the context of South Florida, the final stage mode of design may include a responsive landscape model of the site and the discovered ideas relevant to this problem.

Responsive Translation. As seen in the previous figure, several patterns emerged from using the Cantrell-Holzman framework in this context. The principle Elucidate was used throughout the entire process, while principles like Compress were utilized piecemeal to hypothesize certain phenomena while testing others. The Ambient process was highly independent of the other sections of the framework; meanwhile, Modify required almost all other design methods to establish a more operable, holistic model. Although more discussion will come further in this report, the most important takeaway is that modeling requires the use of many research-design methods and is not limited to one way of knowing or doing. In terms of methodology for this mode of research, you may refer to the Models as Manifesto section of this report or the following sub-section "Methods Overview", which utilizes the Deming and Swaffield Matrix and research strategies as a place to summarize parts of the following process:

1. Exploring sensed data and modeling environments found in the previous research domain and considering them in the context of South Florida; will it make sense overall?
2. Gathering relevant real-time data inspired by the previous step.
3. Developing a modeling environment to represent, or *Elucidate/ Displace*, the sensed data or landscape material.
4. Constructing interoperability between modeling environments so that simulation may be conducted, or *Compressed.*
5. Working back and forth between modeling environment and simulation environment to abductively engage the sensed data and simulated phenomenon.

Responsive Model. After reviewing previously researched models through interpretation, considering available data and sensing instruments, setting up a modeling environment, and connecting to other environmental softwares, the previous mode naturally leads us into a Responsive Model. The Responsive Model represents a designed landscape structured by the processes and approaches inspired previously. Through utilizing design reflection,[20] the responsive model may be evaluated, assessed, and generate new questions for the project overall. With this, future models may be further synthesized to reflect pieces of the process that works best as well as represent the most relevant environmental processes as it relates to algae blooms.

20 See section 12.4 "Design Reflections" in Deming and Swaffield's Landscape Architectural Research : Inquiry, Strategy, Design (2010)

Testing Responses...

Finally, to complete the loop to this adaptation of Nijhuis et al.'s framework, the process is iterative. It formulates a successive, incremental strategy of design explorations that actively engage one another. In other words, each responsive model developed through this design process started in the responsive research domain and moved into the research-by-response domain; this established reflective inquiry between these domains of knowledge, and therefore, an abductive approach towards responsive model development. Figure 3.5 realizes this moment of reflexive inquiry located towards the center of the methodology framework. This moment, or bridge between domains, is where most of the knowledge experienced through this heuristic process may be identified as a meta-analysis. The following section will discuss this bridge between domains to extend our expertise into the realm of responsive models.

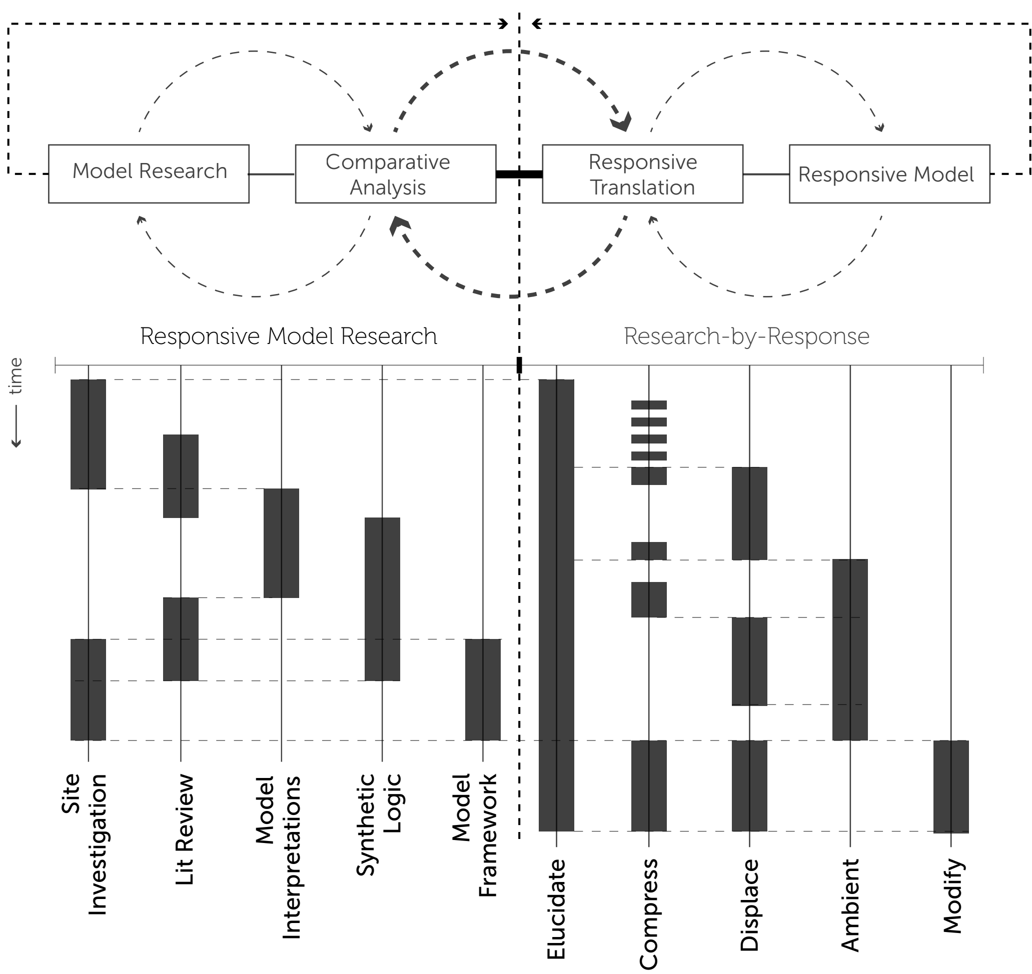
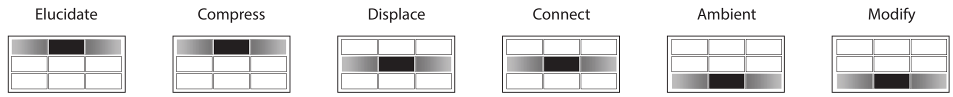
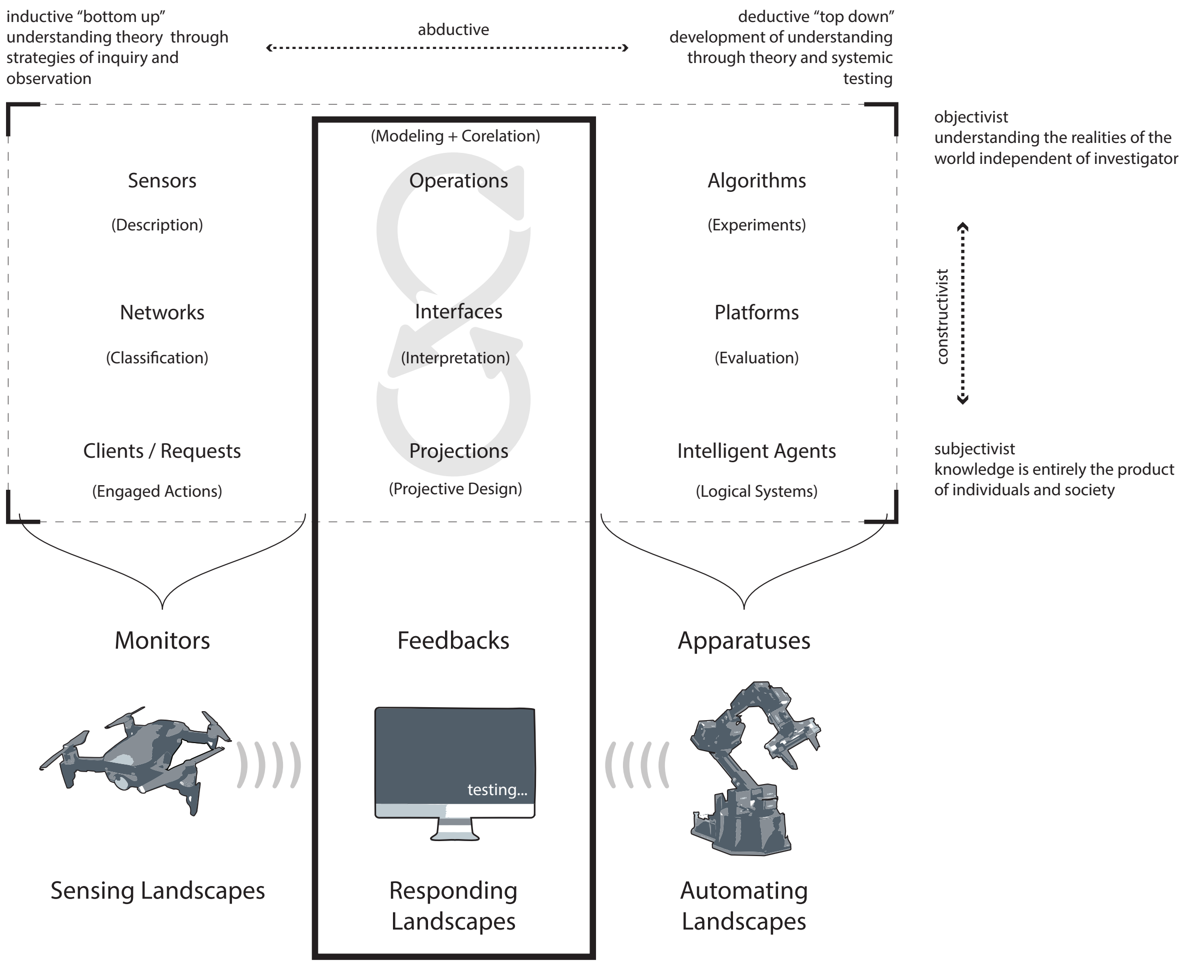
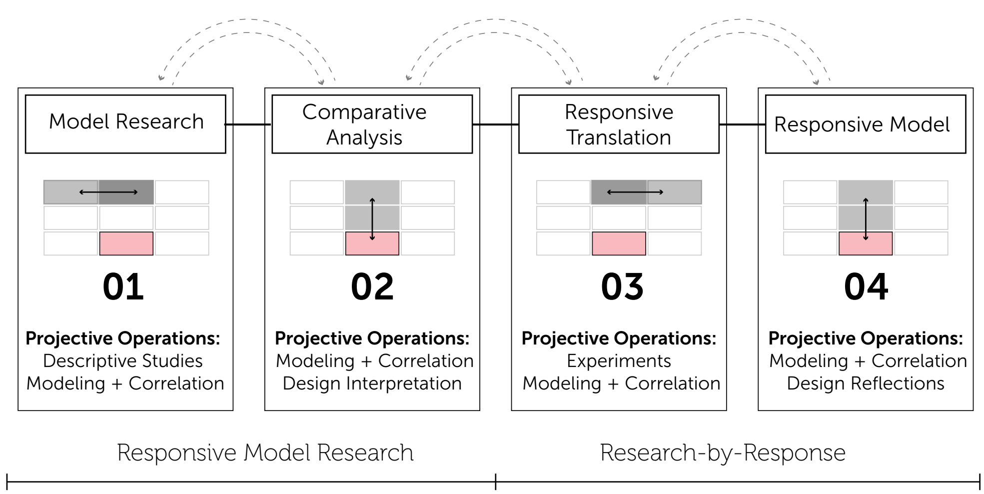


Figure 3.5 / The Iterative Process and Bridging Between Domains

This diagram shows the major point, or fold, in this design process in which new knowledge may be established through design and research. This occurs between the bridging of research domains, in which typological discoveries related to responsive models may be translated into South Florida.


Elucidate
Compress
Displace
Connect
Ambient
Modify


inductive "bottom up" understanding theory through strategies of inquiry and observation
abductive
deductive "top down" development of understanding through theory and systemic testing
objectivist
understanding the realities of the world independent of investigator
constructivist
subjectivist
knowledge is entirely the product of individuals and society
(Modeling + Corelation)
Sensors
(Description)
Operations
Algorithms
(Experiments)
Networks
(Classification)
Interfaces
(Interpretation)
Platforms
(Evaluation)
Clients / Requests
(Engaged Actions)
Projections
(Projective Design)
Intelligent Agents
(Logical Systems)
Monitors
Feedbacks
Apparatuses
testing...
Sensing Landscapes
Responding Landscapes
Automating Landscapes


Model Research
Comparative Analysis
Responsive Translation
Responsive Model
01
Projective Operations:
Descriptive Studies
Modeling + Correlation
02
Projective Operations:
Modeling + Correlation
Design Interpretation
03
Projective Operations:
Experiments
Modeling + Correlation
04
Projective Operations:
Modeling + Correlation
Design Reflections
Responsive Model Research
Research-by-Response

Methods Overview

As a means to synthesize and recall the concepts discussed in the previous *Models as Manifesto* section, the following list will synthesize the methods utilized while Figure 3.6 illustrates how it fulfills an abductive design approach. Although the research methods used in this process are listed in order, the process was highly reflexive and may not have approached the design explorations linearly as follows:

01.1.1: Descriptive Observations of Watershed and Management
01.1.2: Analytical/Synthetic Modeling of Knowledge Learned

01.2.1: Design Interpretations of Descriptive Knowledge

02.1.1: Case Study Research
02.1.2: Case Study Design Analysis via Typology

02.2.1: Design Interpretation of Case Study Analysis

03.1.1: Metaphor of Experimentation
03.1.2: Dynamic Modeling of Translations

03.2.1: Experimental Design Reflections

04.1.1: Develop Responsive Model
04.1.2: Testing Responsive Model

04.2.1: Design Reflections & Meta-Analysis

To sum up the methodological process, a series of interpretations from the design research domain and reflections in the research-by-design domain become constructive moments throughout this heuristic modeling process. As seen in the list, design interpretation and reflection allow the designer to maneuver and learn from a sequence of research strategies. This is a standard method used and may be considered a form of projective operation.[21]

Figure 3.6 / Adapted Methodological Frameworks in One Place

The diagrams on the following page reveal the lessons learned in the Modeling as Manifesto section and the sequence of methods or strategies utilized throughout the research project. The list on this page may be compared to the lower diagram on the following page. All in all, this figure aims at painting the Responsive Model as an abductive tool and this process as an abductive research strategy.

21 See Chapter 12 "Projective Design" in Deming and Swaffield's Landscape Architectural Research : Inquiry, Strategy, Design (2010)

4.
Design Responses

Design Findings & Responses

This section will discuss the case studies that were investigated for responsive modeling applications and research and the exploration of responsive models developed for the context of harmful algal blooms throughout South Florida. Although its preceding case study primarily informs each modeling approach, each responsive model exploration takes insight from the case studies throughout this entire section.

01 Case Study */ Nuage Vert, HeHe*

Located in Helsinki Finland, the Nuage Vert, or the "Green Cloud", actively measures the physical output of the Salmisaari power plant and projects it back onto the power plant's smokestack.[1] The designers, Helen Evans & Heiko Hansen, were able to actively map the cloud through thermal imaging and project regional energy consumption data onto the cloud as a green outline. As residents unplugged and scaled back on energy consumption, the plume grows larger and the outline thinner - this inverse relationship is due to the plant's need to emit more vapor due to limited storage capacity.[2] Nuage Vert is a case study explored in the Cantrell-Holzman text and represents an *Elucidate* model for it expands our sensory range by exposing us to peripheral information.[3]

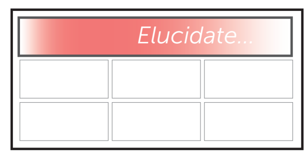
As a result, the green cloud becomes a sort of amorphous construct, materializing within the public realm as a sort of collective conscious (See Figure 4.2). Overall, the project comments on the ineffectiveness of conventional measurements to adequately convey energy consumption and simultaneously communicate measurements to energy users. As written by Evans and Hansen on their website, "It shifts the discourse about climate change and carbon emissions from abstract immaterial models based on the individual, to the tangible reality of urban life."[4] As a result, this responsive system lands in Cantrell and Holzman's Elucidate Chapter; bringing into focus what enters our periphery or escapes our senses entirely.[5] The primary tools and approach towards this kind of installation included thermal imaging cameras, a thermo-graphic processing script, and high-grade lasers for projection.

1 See page 75 of Cantrell and Holzman's Responsive Landscapes.

2 See page 79 of Cantrell and Holzman's Responsive Landscapes.

3 See page 54 of Cantrell and Holzman's Responsive Landscapes (2016) & review Modeling as Manifesto Section of this report.

4 Visit http://hehe.org.free.fr/hehe/texte/nv/ for more information related to the Nuage Vert and other work by the collaboration of Helen Evans and Heiko Hansen.



5 See page 79 of Cantrell and Holzman's Responsive Landscapes (2016) and review Modeling as Manifesto Section of this report.

Figure 4.1 / The Nuage Vert

This image shows the Nuage Vert in action, beaming laser beams upon the Salmisaari power plant's plume of billowing smoke. As seen here, local residents and office workers may examine the plume as it changes in size. This example reveals how minor plumage equates to higher energy consumption based on the outline's thickness.

Image courtesy of Helen Evans and Heiko Hansen.

In response to the Nuage Vert and the consistent outbreak of harmful algae blooms in South Florida, the Lake Okeechobee Model, seen in Figure 4.3, takes data collected by the processed hyper-spectral imagery from the European Space Agency's (ESA) Copernicus Sentinel-3a satellite. The Sentinel-3a satellite is one of two satellites (with Sentinel-3b) and includes several on-board instruments that measure sea-surface topography, sea and land-surface temperatures, ocean and land color with high-end accuracy and resolution.[6] The overall goal of the mission includes the forecasting of ocean systems and supports overall environmental and climate monitoring.[7] With respect to Lake Okeechobee, the Sentinel provides daily hyper-spectral image output to the National Center for Coastal Ocean Sciences (NCCOS) and their team analyzing Harmful algae blooms. The current mission is actively mapping major bodies of water impacted by anthropogenic changes throughout the country, including sites like the Gulf of Maine, Lake Pontchartrain, and, of course Lake Okeechobee.[8]

Purpose. The overall purpose of this model aims to analyze and document the movement of algal biomass throughout Lake Okeechobee. In doing this, we may establish a dynamic pattern or relationship between time and biomass movement. The model helps us elucidate the algae biomass that proliferates throughout certain times of the year as well as provides the designer a platform to analyze algae scums both spatially and temporally. The model has an algorithm that defines a spatial boundary around algae flotsam which may suggest areas of higher priority within the Lake Okeechobee boundaries.

Approach. Utilizing image sampling components and python through the Grasshopper Environment, Sentinel-3a hyperspectral output was imported into the Rhino Scene. The Sentinel-3a rasterset utilizes a warmer-to-cooler color map, similar to a heatmap, as a means to describe higher algae biomasses. Each RGB raster color was then analyzed and extracted; warmer RGB values were prescribed a higher value while cooler colors are set at a lower value (0). The script then goes on to recreate a mesh-raster, in which the mesh may then be represented with a customized color map. In many ways, the Lake Okeechobee Model is simply reinterpreting the maps generated from NCCOS, however,

6 Learn more about the Sentine-3a at https://sentinel.esa.int/web/sentinel/missions/sentinel-3

7 See more information at the Copernicus's https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Overview6

8 See https://coastalscience.noaa.gov/research/stressor-impacts-mitigation/hab-monitoring-system/ for more infomation regarding NCCOS and their mission.

Figure 4.2 / Lake Okeechobee Algae Projections

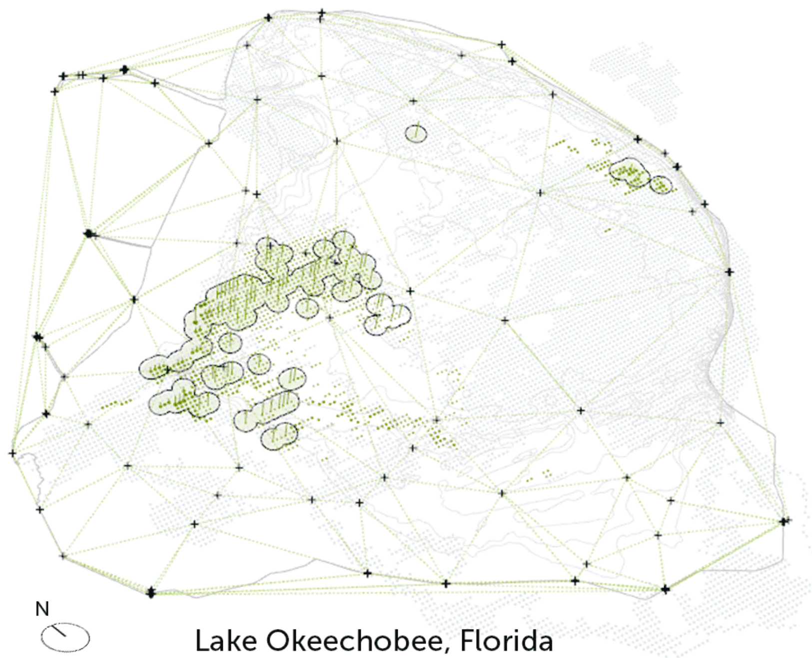
As we can see, algae is an incredibly dynamic piece of biota within the Lake Okeechobee system. It lives on a particularly short time-scale in which blooms may come and go within a given day. This series of imagery was taken during July of 2020, which was a relatively good year for algae biomass control and management.

Date: 05/31/2020

% 5.91

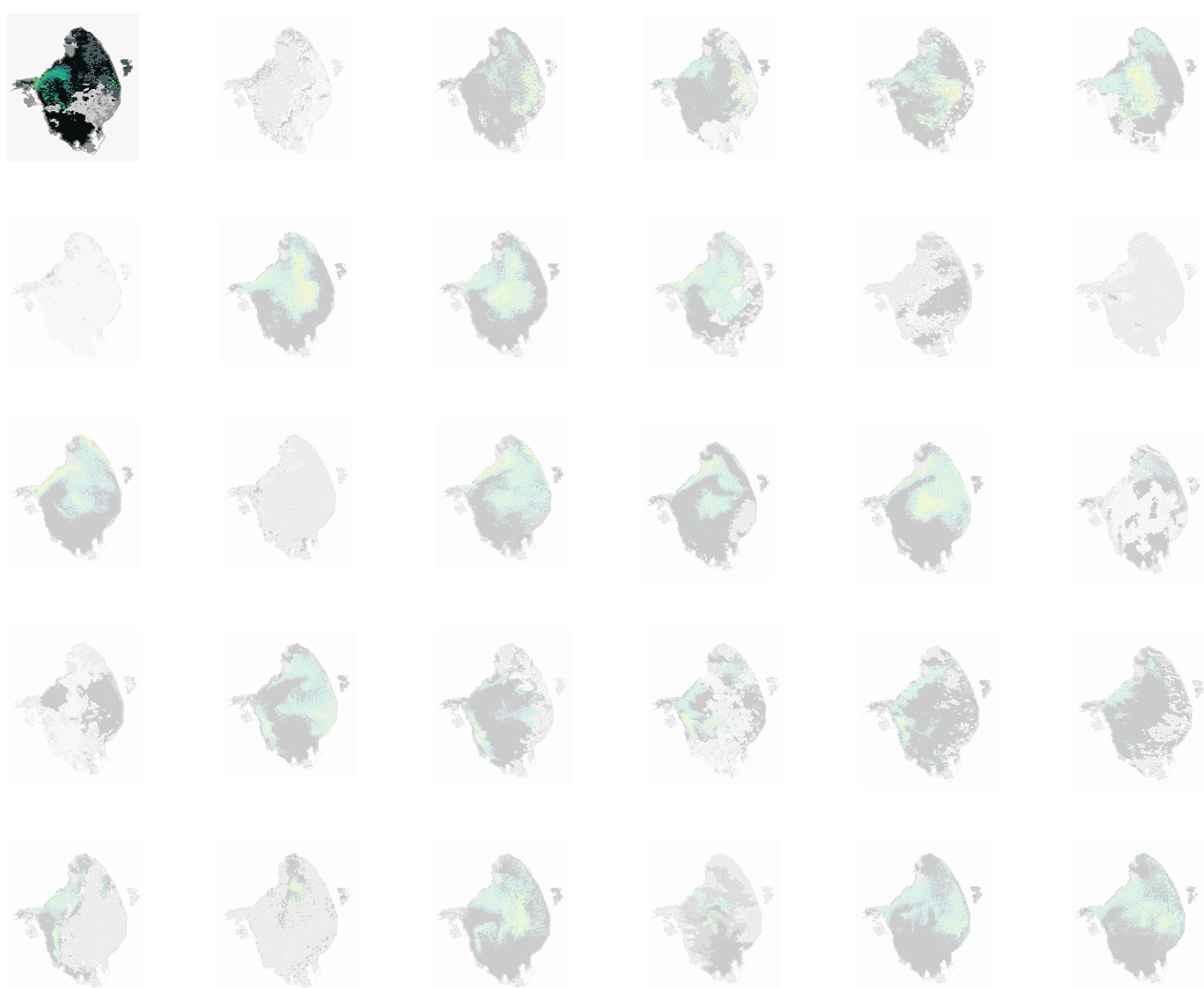
43.12 mi² of Water Discoloration

Cyanobacteria Density & Variation



Lake Okeechobee, Florida

Hyperspectral Imagery from copernicus sentinel-3 mission as it records daily algae blooms in the lake's waterbody.



through the process of raster-data extraction, the hyperspectral data may then be subjectively altered and redisplayed . This subjective alteration is an important step towards he effective communication of real-time sensed data; it's an integral part of developing a responsive modeling environment.

Implications. Aerial imagery is often viewed in a static way, in which the viewer considers the landscape during a singular reference of time. The NCCOS system has been limited by this convention of analysis and doesn't explore time-lapse imagery to explain algae movement. Through this modeling process, an environment was created in which aerial photography may be analyzed in both a spatial and temporal lens. This invites the design-researcher to capture data and reinterpret landscape phenomenon in a variety of ways while also providing diagrams and graphic charts that further explain the issue. Through this process, the scale and occurrence of cyanobacterial outbreaks may be more effectively communicated through algorithmic processing. The Okeechobee model's connection to the Sentinel-3 implies the escalating phenomenon we are facing and the novel technologies we will need to further elucidate this issue.

Limitations. Although more dynamic than NCCOS's representation of algae in Lake Okeechobee, the model can only reproduce daily imagery of Lake Okeechobee due to the Satellite's orbital period. This means the model is limited in terms of temporal scale. With this, the data sensed by the Sentinel-3 is limited in terms of what is visible to the Satellite's camera. As seen in Figure 4.4, there is a series of outputs that remain gray which indicates that there was too much cloud coverage in the sky and resulted in null values. Overall, the model lacks the integration of various meteorological inputs, such as wind, rain, and sun, as well as the use of hydrodynamic modeling. It's important to note that all of these additional inputs may be incorporated within this model through the Grasshopper and Rhino environment. If these considerations were to be pursued, the resulting model may help establish relationships between what is sensed by the satellite and what may be sensed on the ground through weather stations and water quality monitors. Establishing an association between remotely sensed hyperspectral data and real-time monitors will only extend our capacity to understand the relationship between what is visible and what is not.

Figure 4.3 / Lake Okeechobee Algae Projections (Detail)

This detail view of the Lake Okeechobee model reveals how cloud coverage is a mjor limitation to this model's viability. The light-blue triangles represents null, or empty, values due to cloud coverage. On this day, there were some large algae blooms that were seen in between the overcast.

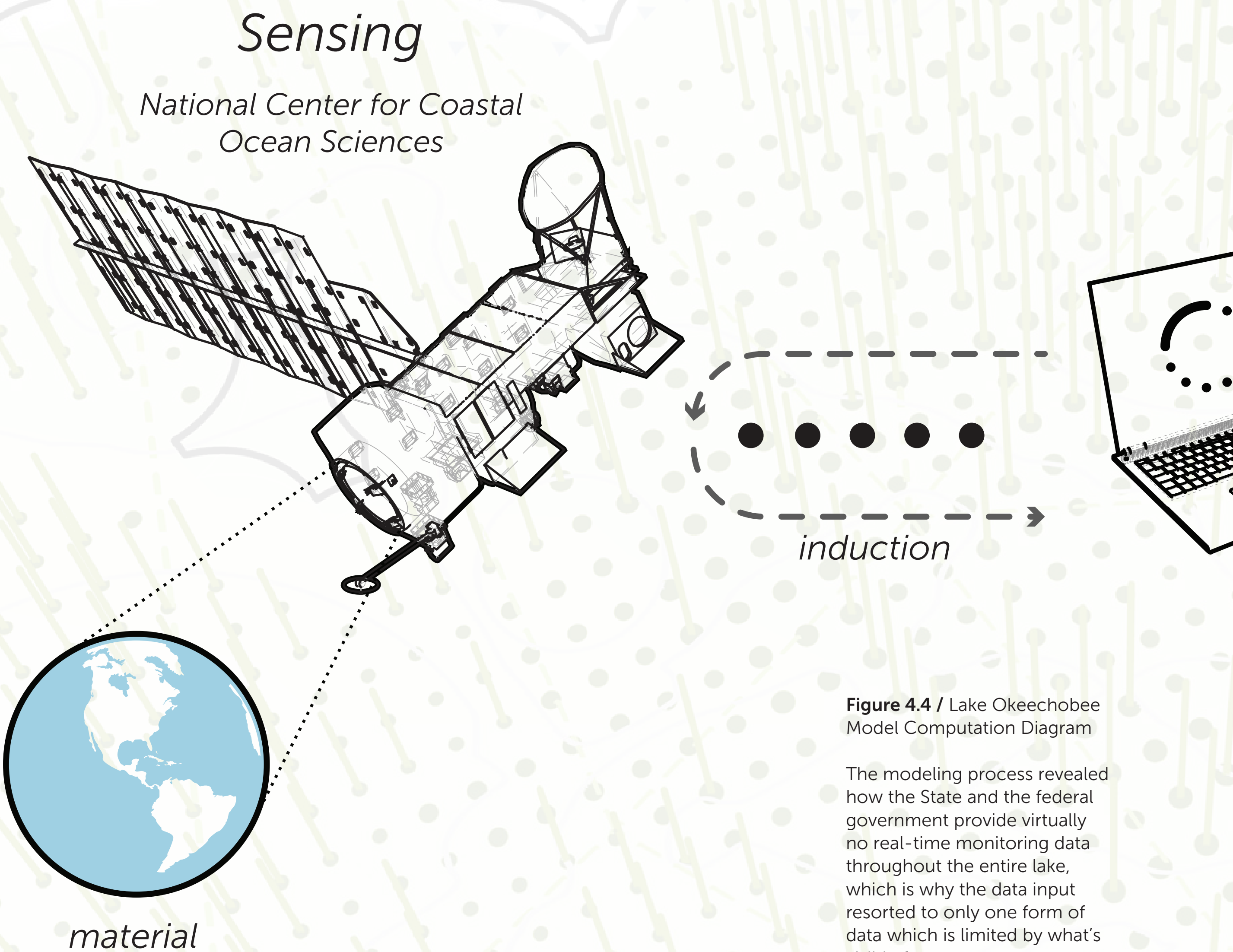


Figure 4.4 / Lake Okeechobee Model Computation Diagram

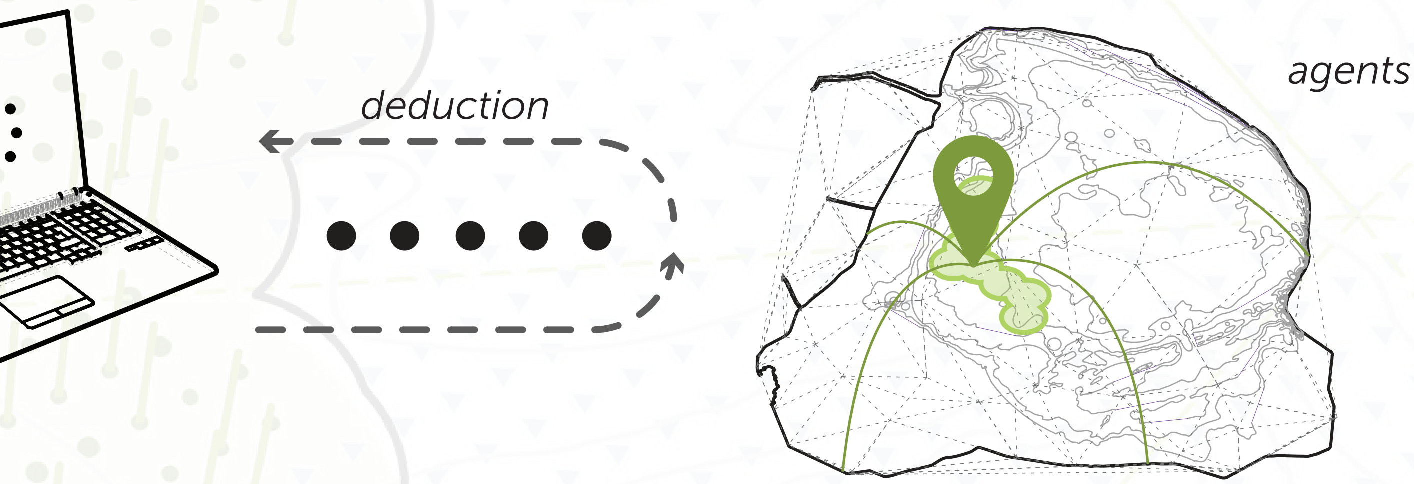
The modeling process revealed how the State and the federal government provide virtually no real-time monitoring data throughout the entire lake, which is why the data input resorted to only one form of data which is limited by what's visible from space.

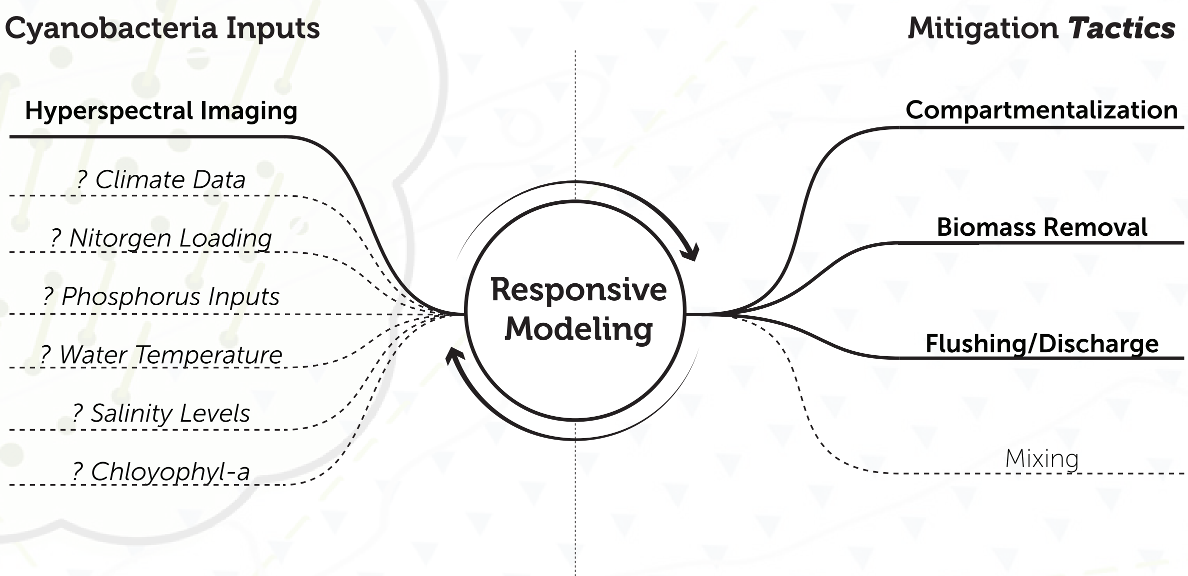
There's a considerable gap in providing sensed water quality information here. Water managers should be mandated to develop more monitoring systems to understand Lake Okeechobee's water quality and health.

Ideally, South Florida infrastructure may be updated to actively communicate the data output from this satellite towards mitigating algae blooms and exploring methods for managing lake water stage heights.

Responsive Landscape

Speculative Interface





The Mississippi River Delta, located along the shorelines of New Orleans, is a series of deltaic wetland ecologies that, historically, provided habitat for countless species and protected the shoreline from erosion. As the delta has seen a disappearance of its land mass due to the management of the Mississippi and Atchafalaya, New Orleans and its inhabitants are at risk of flooding and storm surge intrusion. Cantrell's Synthetic Mudscapes explores this project through a speculative "mesh" of interacting monitors and responsive systems.[9] Attuning Sediment Transfer, an exploration in the Cyborg Coasts at Harvard's GSD, could be considered a piece of this system-wide infrastructure.[10]

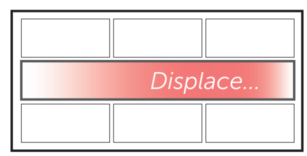
Utilizing an experimental and speculative methodology, Attuning Sediment Transfer explores how the kinetic force of sound may influence sediment movement and accumulation through resuspension. Designer Ricardo Jnani Gonzalez hypothesizes that, through using vibrations, riverbed sediment may be suspended up-river to strategically build barrier islands and wetland habitat off shore, slowing the creeping land loss seen along the New Orleans Shoreline.[11] The experiment included the use of speakers, fine red sediment, and camera sensors that show the visual patterns and hydrodynamic movements of specific frequencies. Through this interaction, a series of responsive, robotic mechanisms may be deployed into the Mississippi and Atchafalaya Rivers to encourage sediment movement into the Gulf of Mexico. This phase of the project represents the *Displace*[12] modeling typology, for it reconfigures landscape phenomenon by sensing outside of any true context.

By simply recording the interactions between sediment and frequency levels, Gonzalez illustrated the dynamic patterns that emerge from sediment resuspension. A certain frequency results in an appropriate amount of resuspension and sediment movement. As a result, the design included robotic prototypes that may engage the suspension of sediment from the riverbed, encouraging responsive changes to the landscape in the pursuit of off-shore deltaic land-building. Gonzalez also considered how this robotic riverbed network may influence river current through modularity and variability in pattern, resulting in a parametric system that responds to the needs of the river's conditions which was abductively understood through their experimental design process.

9 See page 279 in Cantrell and Holzman's Responsive Landscapes for more information on Synthetic Mudscapes.

10 The Studio Cyborg Coasts: Responsive Hydrologies incorporated an array of responsive modeling techniques as a studio course at the GSD in 2015. The course focused on its primary method of inquiry, sensing, and looping feedback into the design process.

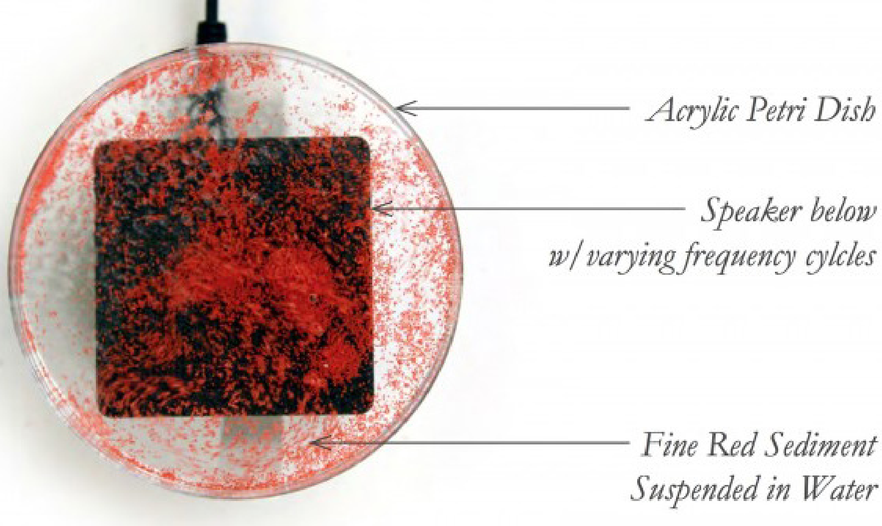
11 Visit Responsive Landscapes online platform at http://

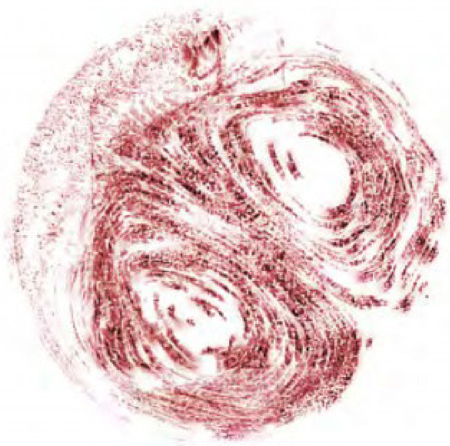


12 See Displace on page 122 of Cantrell and Holzman's Responsive Landscapes (2016) and review Modeling as Manifesto Section of this report.

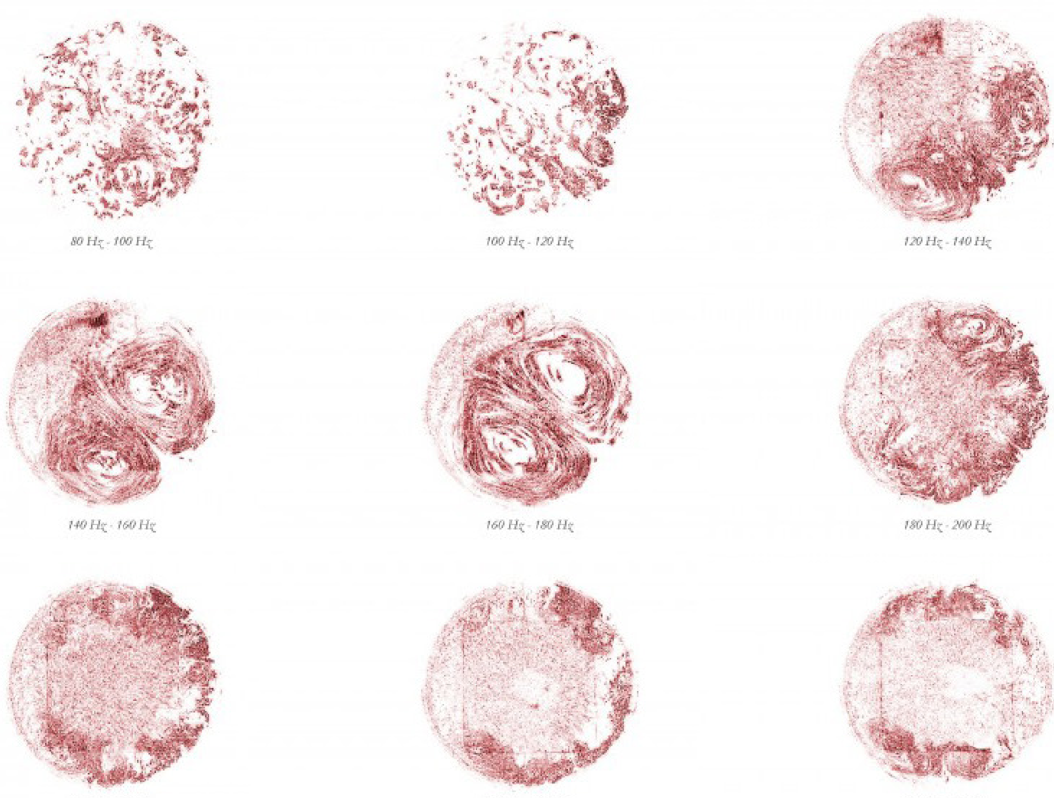
Figure 4.5 / Attuning Sediment Transfer Experimental Study

These images show the experimental setup surrounding re-suspending red clay sediment in water. The overall concept is relatively simple and yields an interesting array of distortion and order to the interactions of sound and sediment materials. Gonzalez provides a frequency reading, in hertz, to show how the kinetic force of sound renders a pattern in sediment.





Motion Isolation
– Highilights suspended sediment's movement pattern at the various frequency range



Learning from Attuning Sediment Transfer, this experiment aims at understanding algae through a series of tests while measuring certain outcomes. Seen in Figure 4.6, the algae is growing while water temperature values are being recorded to suggest the differences in cultured and non-cultured water mediums. As seen in the timelapse, the cultured water medium allowed for the *Anabaena variabilis* to become buoyant and float towards the water surface. Overall water temperature sensing show slightly warming temperatures in the cultured solution.

Purpose. Overall, this was an empirically study to learn from and reveal certain patterns in algae as a material and showcase the patterns produced by its growth cycle. In doing this experimental observation, the general nature of algae may be better understood and provide inspirational feedback for future studies. The data collected throughout this experiment is used later on in the rapid prototyping model exploration and confirmed many of the characteristics learned about algae in the earlier chapters.

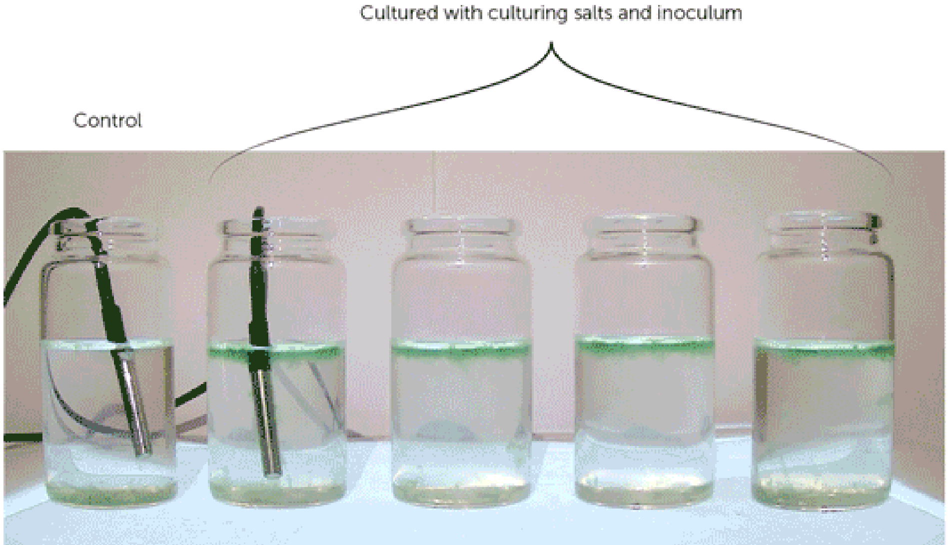
Approach. With the use of several simple sensing instruments, such as a webcam and an Arduino microcontroller, images and water temperatures were measured simultaneously to one another. The Arduino was connected to a DS18B20 waterproof temperature sensor. The Arduino sketch allowed for the use of two of these sensors, and with serial communication to the Putty software, data was actively recorded in a text file format. Python was used to parse the output from python and to generate the water temperature line graph through the Matplotlib module seen in Figure 4.6.

Implications. This responsive modeling experiment records the difference between cultured and non-cultured mediums as it relates to algae scum. As seen in this model, algae struggles to stay buoyant in water that has less nutrients and this water remains slightly cooler.

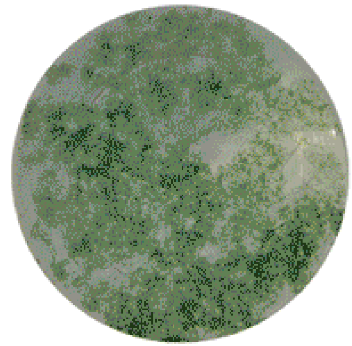
Limitations. The modeling environment is highly controlled and lacks pertinent site specific materials; which includes the exact cyanobacterial species and sediment found in the St. Lucie Estuary. With this in mind, it doesn't fully represent the site and its context.

Figure 4.6 / Experimenting with Algae

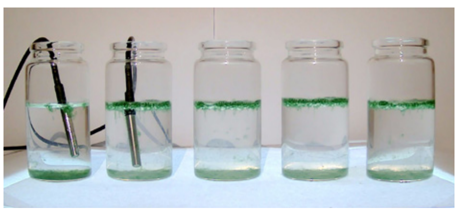
Image output of the experiment may be seen to the right; revealing the growth process while temperature is being sensed every second. The result of this process of the experiment illuminates the relationship between temperature and algae growth as well as the differences between non-cultured and cultured mediums for algae cultivation.



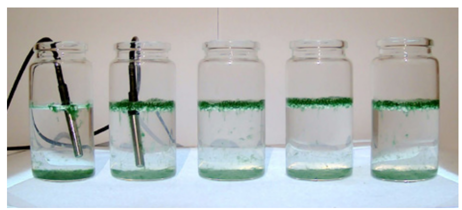
Anabaena variabilis is a species within the family of filamentous cyanobacteria. Similar to the microcystins that infect the water's of South Florida, anabaena forms a thick layer of bouyant scum that fixes nitrogen.



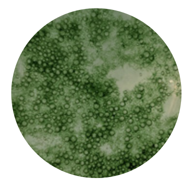
Day 1



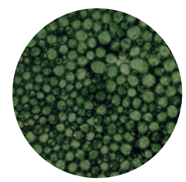
Day 2



Day 3



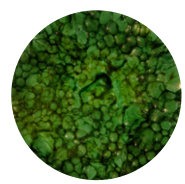
Day 2



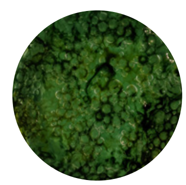
Day 3

Day 10

Day 11

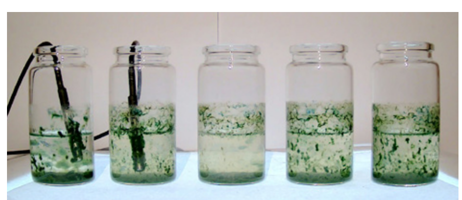


Day 10

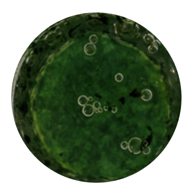


Day 11

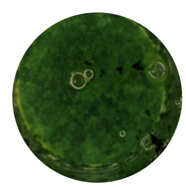
Day 17



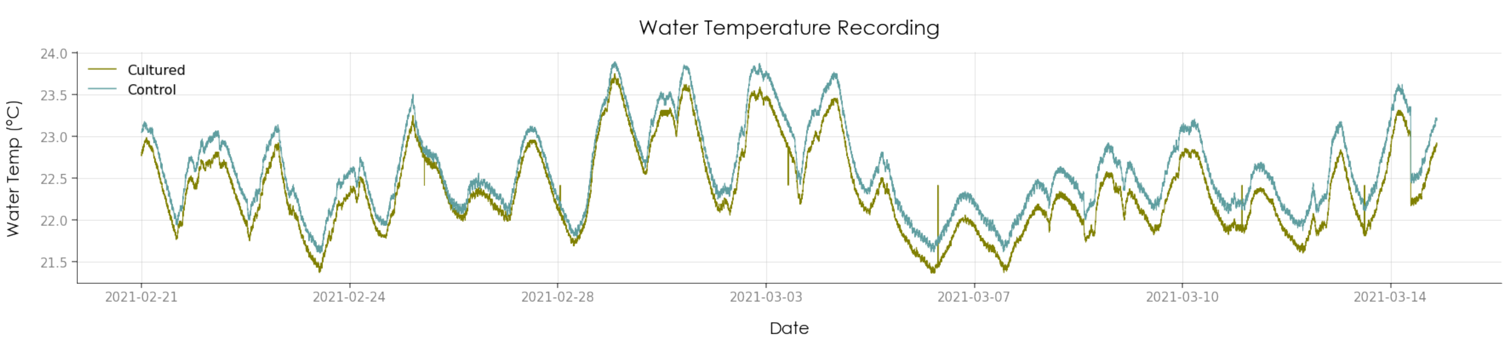
Day 18



Day 17

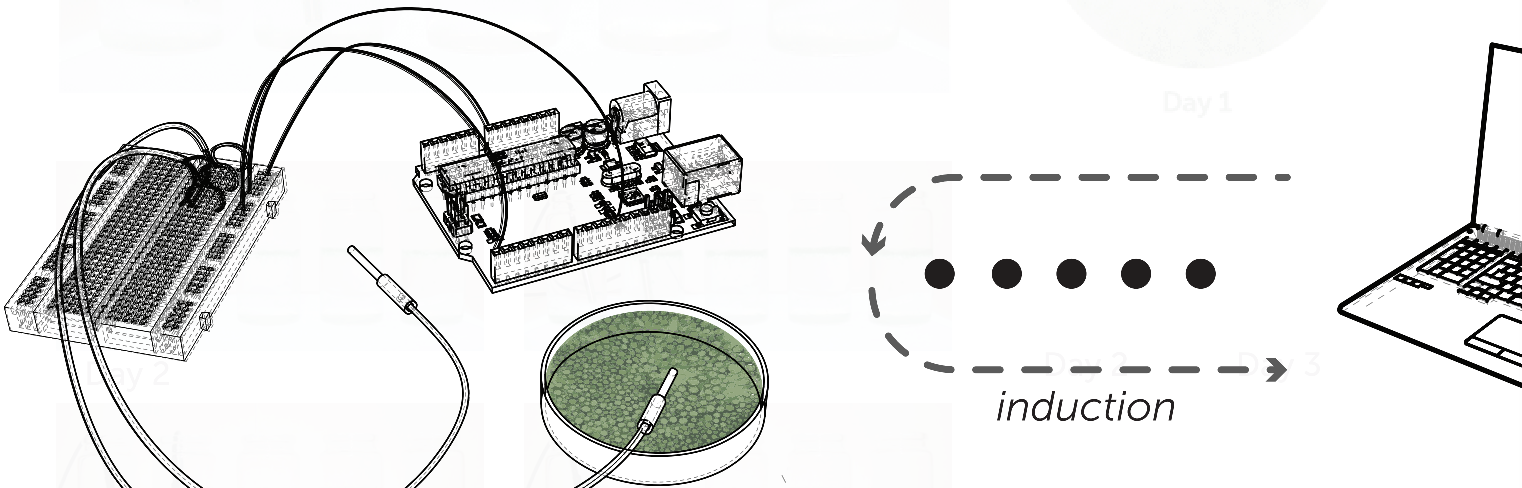


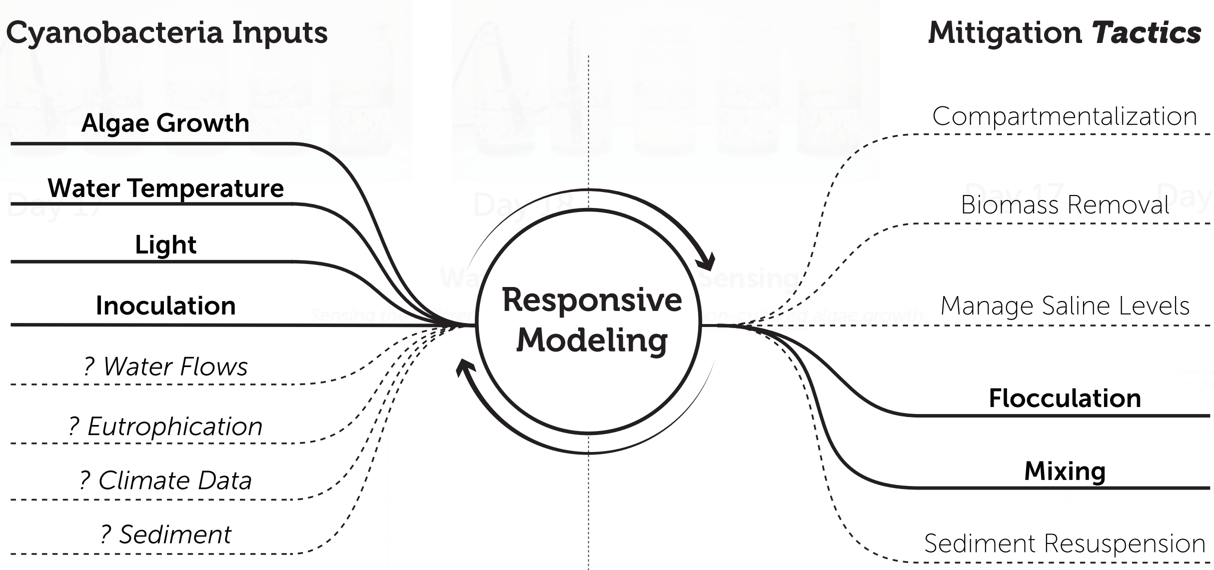
Day 18



Sensing

Arduino Sketch w/ DS18b20 Water Temperature Sensors





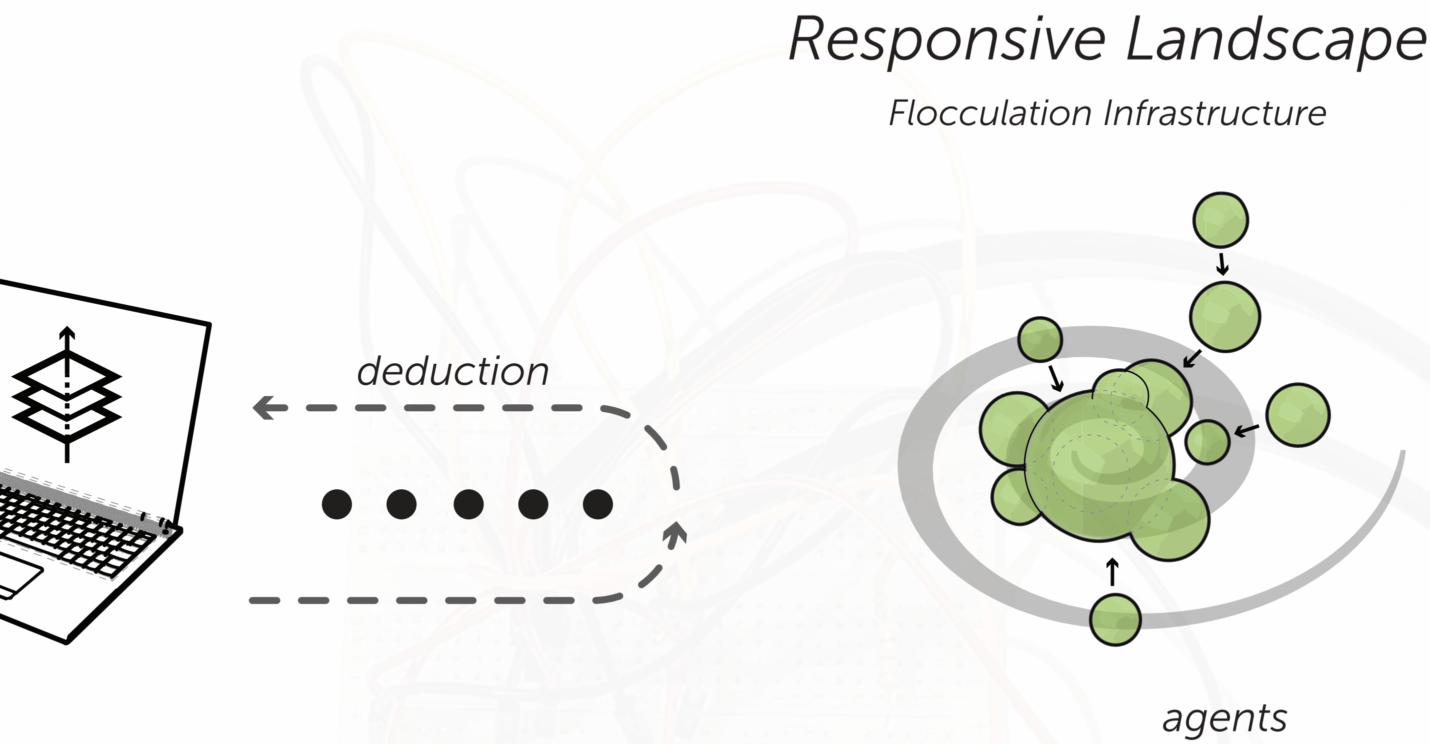


Figure 4.7 / Algae Experiment Computation Process

There are several advantages to learning and using coding languages such as Python as a tool for landscape investigation. It allows us to bridge between a variety of software, and above all, a place to parse, manage, modify, and visualize data.

The major limitation here includes the fact that this modeling environment is incredibly small and features a small list of variables.

Next steps would include experimenting with other variables and understanding how the movement of water impacts algae growth in the real world.

Testing the Waters, located along the Delaware River in Philadelphia, explores the suitability of wetland ecologies throughout a post-industrial landscape. Through the city's "Green City, Clean Waters", Master Plan for the Central Delaware, and Estuary Restoration Act, the project aims at understanding both recreational and ecological potential by investigating the relationship between hydrological dynamics, water stage elevations (WSEs), and discharge rates. Through incorporating these dynamics, a better understanding of littoral and shoreline ecology may be more holistically designed.[13]

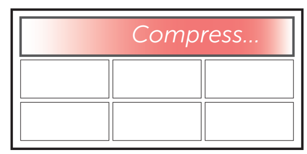
Karen M'Closkey and Keith VanDerSys explore these kinds of dynamics through computational modeling software and interoperability into the Grasshopper/Rhino environment.[14] In doing this, the process of analysis and design become inherently unified; a recursive and responsive feedback is established between real-time data, simulation, and decision-making. They consider this kind of modeling approach to be expressing "accretive patterns", in which data may be visualized and understood through point (place), line (vector), and time.[15] This approach in landscape analysis results in gradients, or transitions, in which pattern is perceived via changes placed upon the environment and may be adequately described as a *Compress* model when referring to responsive modeling.[16]

The challenges surrounding *Testing the Waters* and its process include both software interoperability and access to reliable data. M'Closkey and VanDerSys developed methods between importing output from a computational fluid dynamics model (Aquaveo SRH-2D) into Rhino via Grasshopper scripting. This process enables the designer to actively engage the data inside a design platform and make decisions based on simulative outcomes. With this, the design team had to generate their own bathymetry data of the Delaware due to the lack of open-source data. The process behind this project reveal the gaps in interdisciplinary analysis and our capacity to leverage environmental modeling tools in contemporary ways within the field of landscape architecture. I was fortunate enough to receive a demo from Keith VanDerSys, explaining the process of setting up a hydrological dynamic model through Aquaveo and importing it back into the Rhino Environment.

13 VIsit https://peg-ola.com/research/testing-the-waters/ for more information surrounding Testing the Waters

14 See page 65 in M'Closkey and VanDerSys' Dynamic Patterns: Visualizing Landscape in a Digital Age

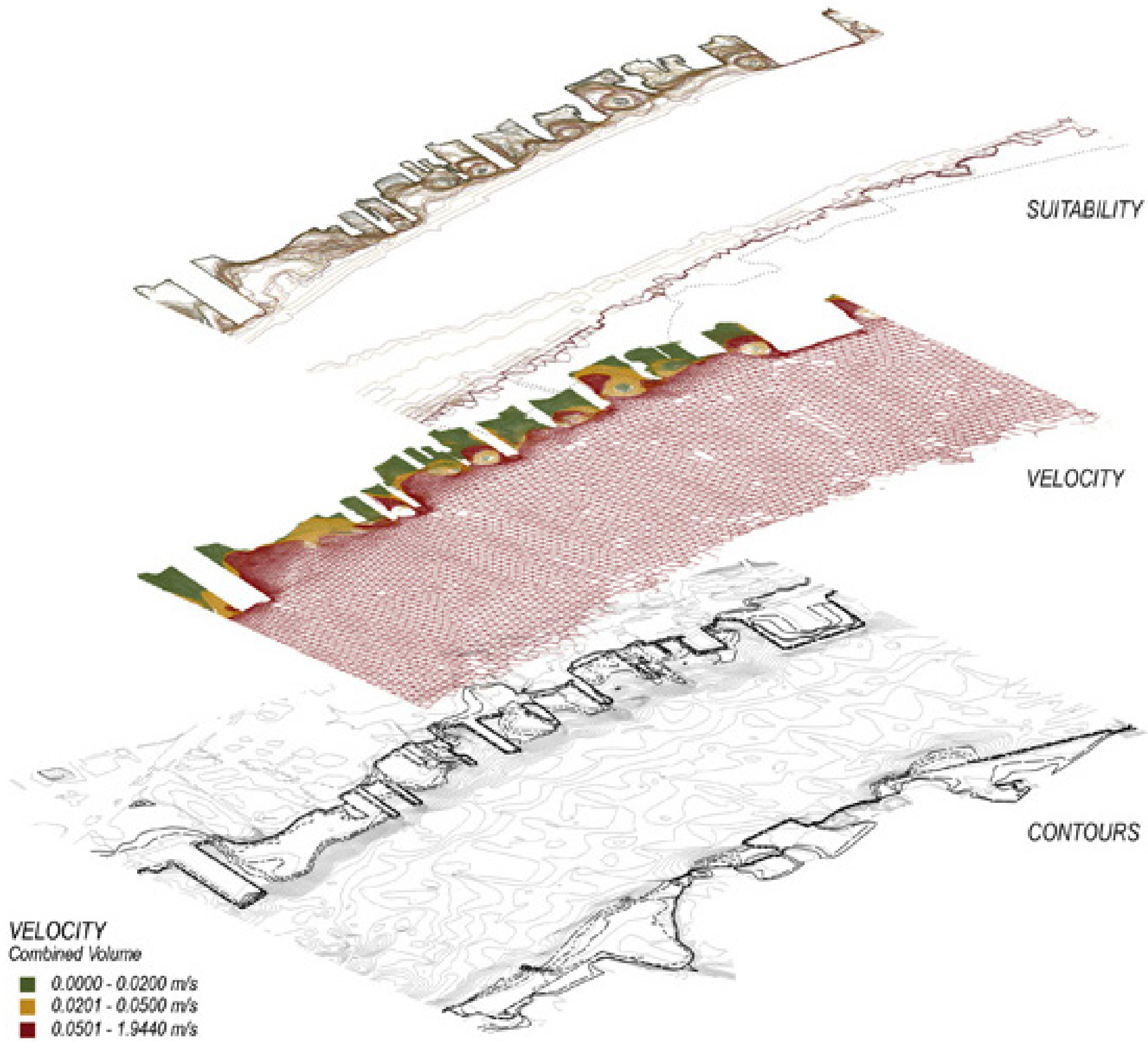
15 VIsit https://peg-ola.com/research/testing-the-waters/ for more examples of imagery and output from the Aquaveo into Rhino for visualization and design analysis.



16 See Compress on page 90 of Cantrell and Holzman's Responsive Landscapes (2016) and review Modeling as Manifesto Section of this report.

Figure 4.8 / Testing the Waters at the Delaware River, Philadelphia

Analytical suitability analysis of the Delaware River and East Philadelphia waterfront modeled dynamically through the Aquaveo CFD model and represented within the Rhino environment. Interoperability is achieved through Grasshopper and allows data to be studied through timestep output and parameter type. For example, velocity direction and magnitude are highlighted in the upper diagram. At the same time, water stage elevation data is reinterpreted in the lower diagrams - image courtesy of the office of PEG landscape architects.



SUITABILITY
VELOCITY
CONTOURS
VELOCITY
Combined Volume
0.0000 - 0.0200 m/s
0.0201 - 0.0500 m/s
0.0501 - 1.9440 m/s

ELEVATION
Subtidal Zone
Intertidal Zone
Transgression Zone
1.0 m - 10 y. high
0.1 m - 2 y. high
-0.1 m - MHW
-2.0 m - MLW
-3.0 m
-4.0 m
-5.0 m
Dredging
Subtidal Zones
Intertidal Zones
Transgression Zones

Taking insight from PEG and their approach towards hydrodynamic modeling and interoperability, this design study investigates the impacts of shoreline modification options along a segment of the St. Lucie Canal (C-44). One of the key components behind this modeling study was the use of a 2D computational fluid dynamic model developed by the National Center for Computational Hydroscience and Engineering. This model, known as CCHE2D, provides users several modules for the analysis and modeling of water flow, sediment analysis, and the eutrophication (algae growth) process.[17] There's a handful of environmental studies that were accomplished with this modeling software,[18] and it provides researchers a process-oriented model aimed at establishing relationships between environmental conditions and algae growth.

Purpose. The overall intent of this model includes developing interoperability between the Rhino and CCHE2D interface to provide the designer a place to investigate how channel hydromorphology may impact the travel, and livelihood, of algae scum. With this, the model establishes correlation between suspended sediments and its impacts on algae. As sediment becomes resuspended into the water column, algae may be negatively impacted and, therefore, reduce in density (mg/l). Ideally, these studies may lead to discussions that consider how existing pieces of infrastructure may be modified and how these modifications support various algae mitigation tactics, such as collection and flocculation. As expressed in Figure 4.8, modifying the existing channel results in a hydrological design that radically alters the movement and presence of algae when compared to the existing C-44 Canal.

Approach. There's several layers to this model's process, which include the use of Python modules for data collection, Grasshopper scripting, and connecting to the CCHE2D Model. These steps include:

1. Utilizing the USGS Hydro-networks module to collect hydrograph data, or water discharge rates, to incorporate into the simulation.
2. Developing a parametric channel model in Rhino via Grasshopper
3. Converting the Rhino mesh into an ASCII file for CCHE2D Import
4. Using the CCHE2D interface for simulation of flows and algae
5. Exporting CCHE2D data and parsing the data through Python

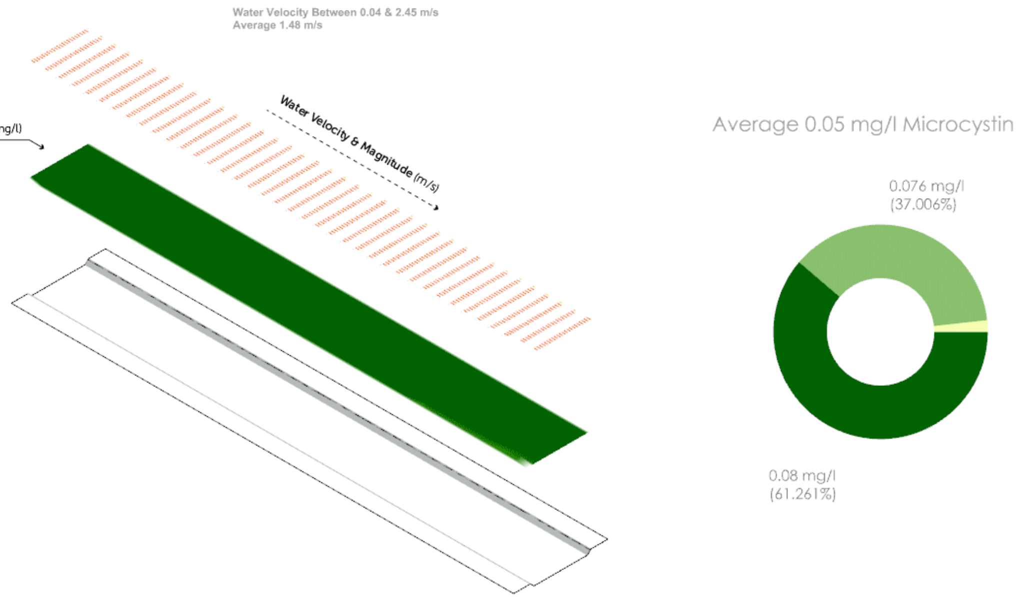
17 See the National Center for Computational Hydroscience and Engineering's CCHE2D model at https://www.ncche.olemiss.edu/cche2d-flw-model/

18 See the publication authored by Chao, X., Jia, Y. and Hossain, A. K. M. A. (2016) and National Center for Computational Hydroscience and Engineering's research publication page: https://www.ncche.olemiss.edu/journal-publications/

Figure 4.9 / Experimenting with C-44 Channel Modifications

These axons showcase the output of the CCHE2D hydrodynamic flow model. Along with showcasing hydrological flows at the top layer, the layer below shows how algae scum and microcystin move and respond to the hydromorphology of the new canal. Options A & B reveal how modifications along the shoreline result in algae accumulation due to the formation of eddies.

Seen through this lens, the existing canal can be thought of as sterile, in which its full potential is being overlooked when considering modifying existing infrastructure.

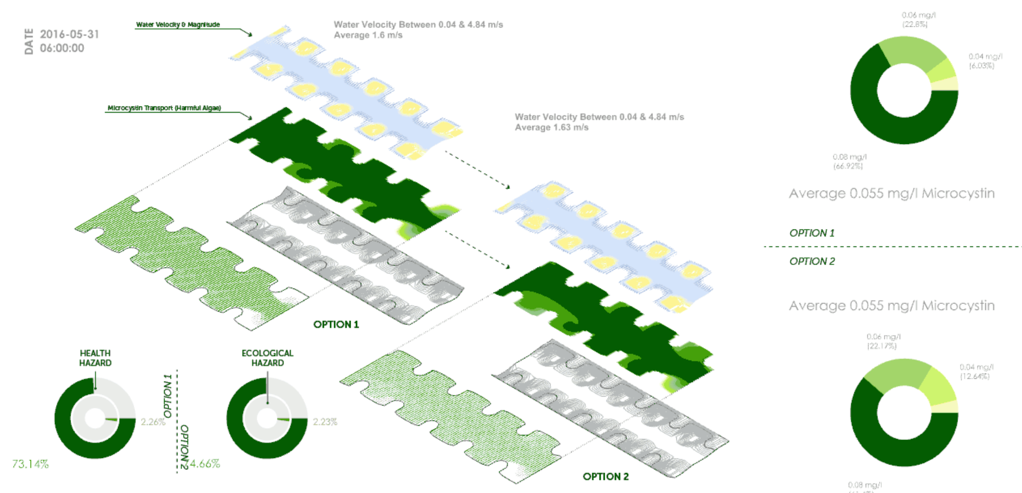


Existing C-44 Channel

The existing C-44 Canal acts as a conduit for harmful algae to move between Lake Okeechobee and the St. Lucie Estuary. This experimental design study explores how modifications on the canal may impact algae proliferation and movement for biomass reduction and collection.

Channel Option A "Eddies"

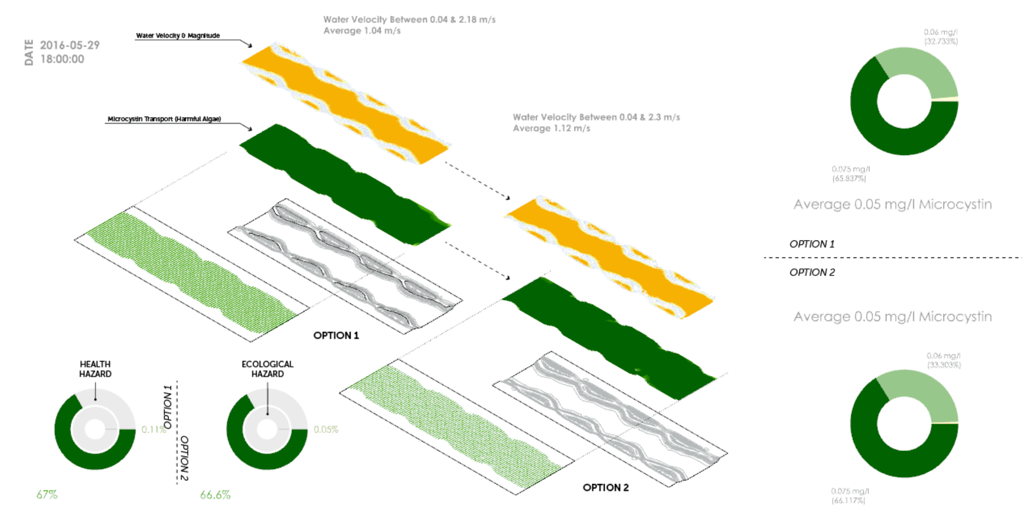
This option encourages the swirling of waters through recessions near the shoreline. This swirling motion results in eddies that change in viscosity due to the discharging waters from the Port Mayaca Lock. Option A1 creates recessions opposite to one another down the stretch of the canal while Option A2 alternates the recession. It's clear that Option A captures the most algae as seen in the composite line graph.



Channel Option B "Sine"

Option B is similar in concept to Option A, however it encourages mixing more evenly throughout the entire width of the channel. Unlike Option A, this option does a better job at reducing algae throughout the entire channel and is very responsive when discharges slow down over longer periods of time, as seen in the line graph around 06/09/2016.

.



6. Importing parsed data and visualizing through Grasshopper
7. Making changes to the parametric channel design in response to Simulation Outputs
8. Re-running the changes made in the parametric model through the CCHE2D interface and iterate upon the process

The results may be compared to one another, especially through environmental data visualization, as seen in Figure 4.9. The line graph above overlays discharge rates (left-side y-axis) and average microcsytin levels (right-side y-axis) in relation to the 4 options designed throughout this responsive modeling study. The gray dashed line expresses the existing channel. Here we may see how certain C-44 redesigns result in increased algal biomass or a reduction in microcystin levels due to sediment resuspension. It's important to note that a reduction in algae biomass may not necessarily be favorable; it depends on the intention behind the modification throughout the C-44 canal. If we'd like to capture algal biomass, Option A clearly does a better job at slowing and capturing algae in pockets of eddys whereas Option D encourages more mixing and, therefore, algae cell flocculation.

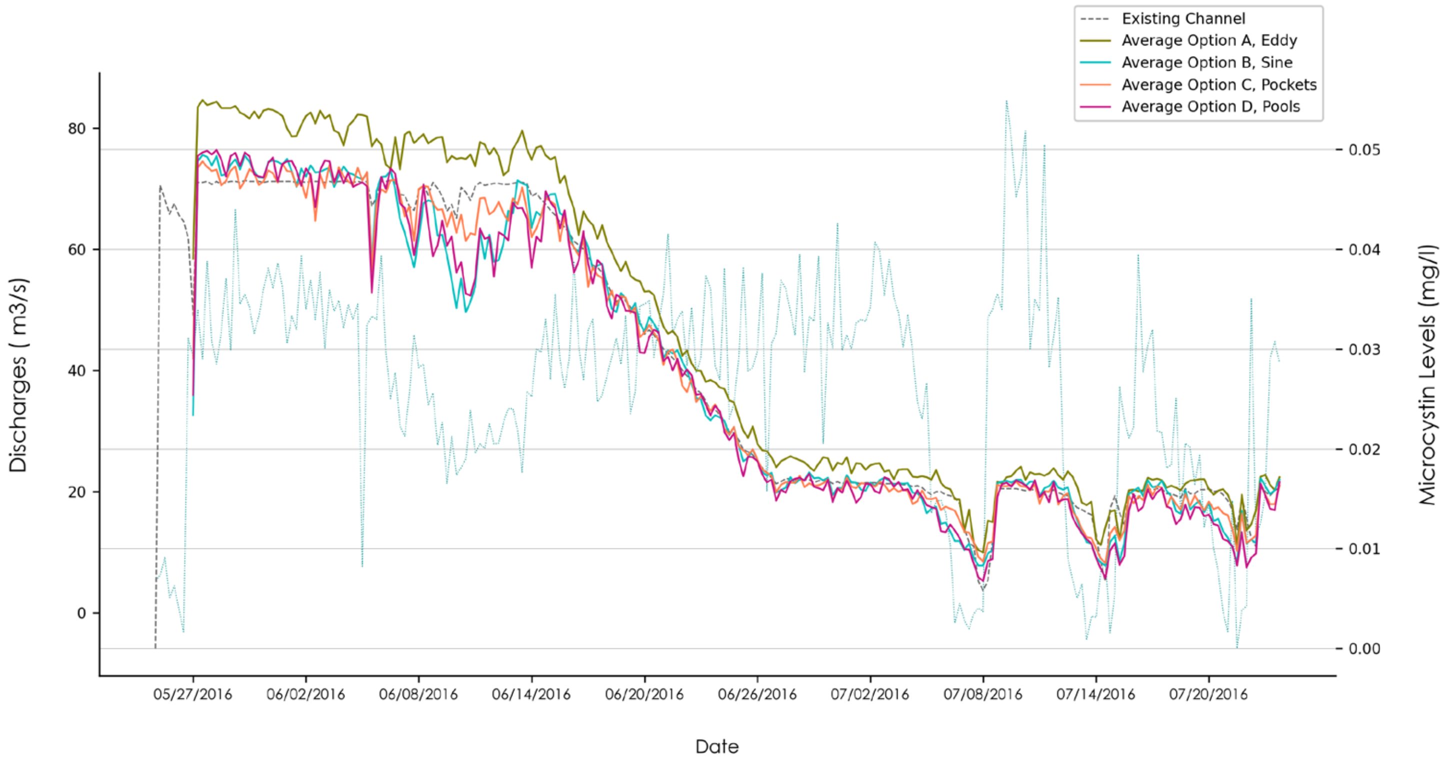
Implications. Algae mitigation may be positively impacted by the informed design of hydrological channels, which are an already existing piece of infrastructure in this landscape. Through a modified lens, we can develop a set of principles or desired outcomes in which our models may aim to achieve. Through this approach, we are open-endedly exploring the impacts of certain decisions and the various tactics that will arise from such decisions. This is key to the abductive nature of responsive models: the C-44 canal model represents how the designer may deduce, or presuppose, the outcome of a certain decision along the channel while actively observing, and inducing, those decisions through visualization concurrently.

Limitations. The simulation environment only accounts for certain parameters. Although an appropriate approach in terms of algae residence times, this model considers algae as a chemical and therefore only computes the decay rate of algae in relation to suspended sediments and doesn't consider algal growth-rates as it passes through the channel. All in all, the model can be developed further, especially in the scripting process, so that design and analysis may happen in more simultaneity.

Figure 4.10 / Experimenting with C-44 Channel Modifications and Synthesis (Line Graph)

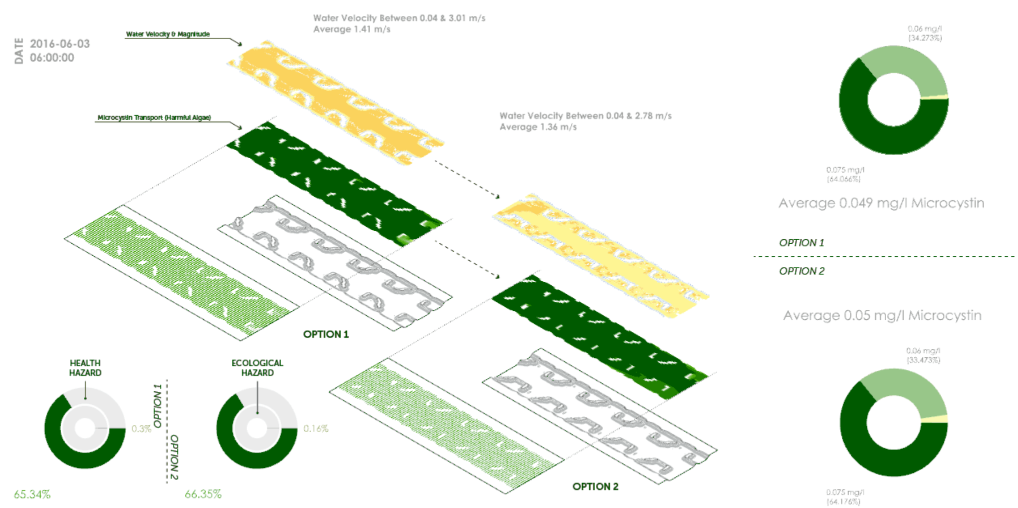
Options C and D explore how modifications within the channel modify algae dynamics and result in tactics relating less to collection and more towards resuspended sediment action and algae flocculation.

The line graph above synthesizes all of the options through finding an average of each option (the mean between the two sub-options). This chart illustrates how each channel is performing.



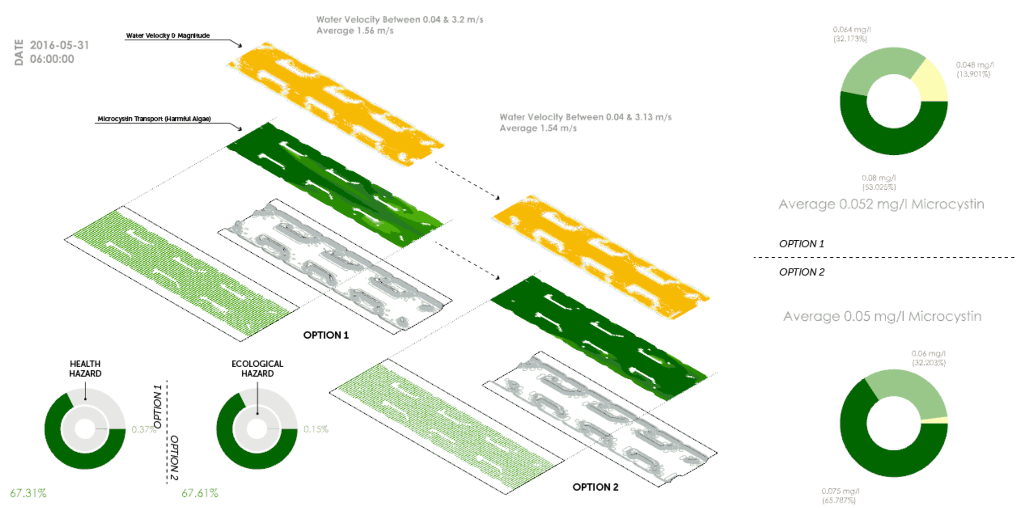
Channel Option C "Pockets"

This option features a series of "pockets" which have topographic forms creating both 90 degree edges and 45 degree angles. This system allows for space to collect algae in eddies created by the pockets and create mixing throughout the entirety of the channel. As seen in the line graph above, this option captures more algae overall when compared to Options B & D.



Channel Option D "Pools"

Similar to chevrons, this option features more angles to encourage mixing throughout the C-44 Canal. Akin to Option C, these pools were designed to slow water movement towards the shoreline while encourage more movement near the center of the channel. This option mitigates the most amount of algae due to higher levels of resuspended sediment that gets pushed upwards towards the water's surface.



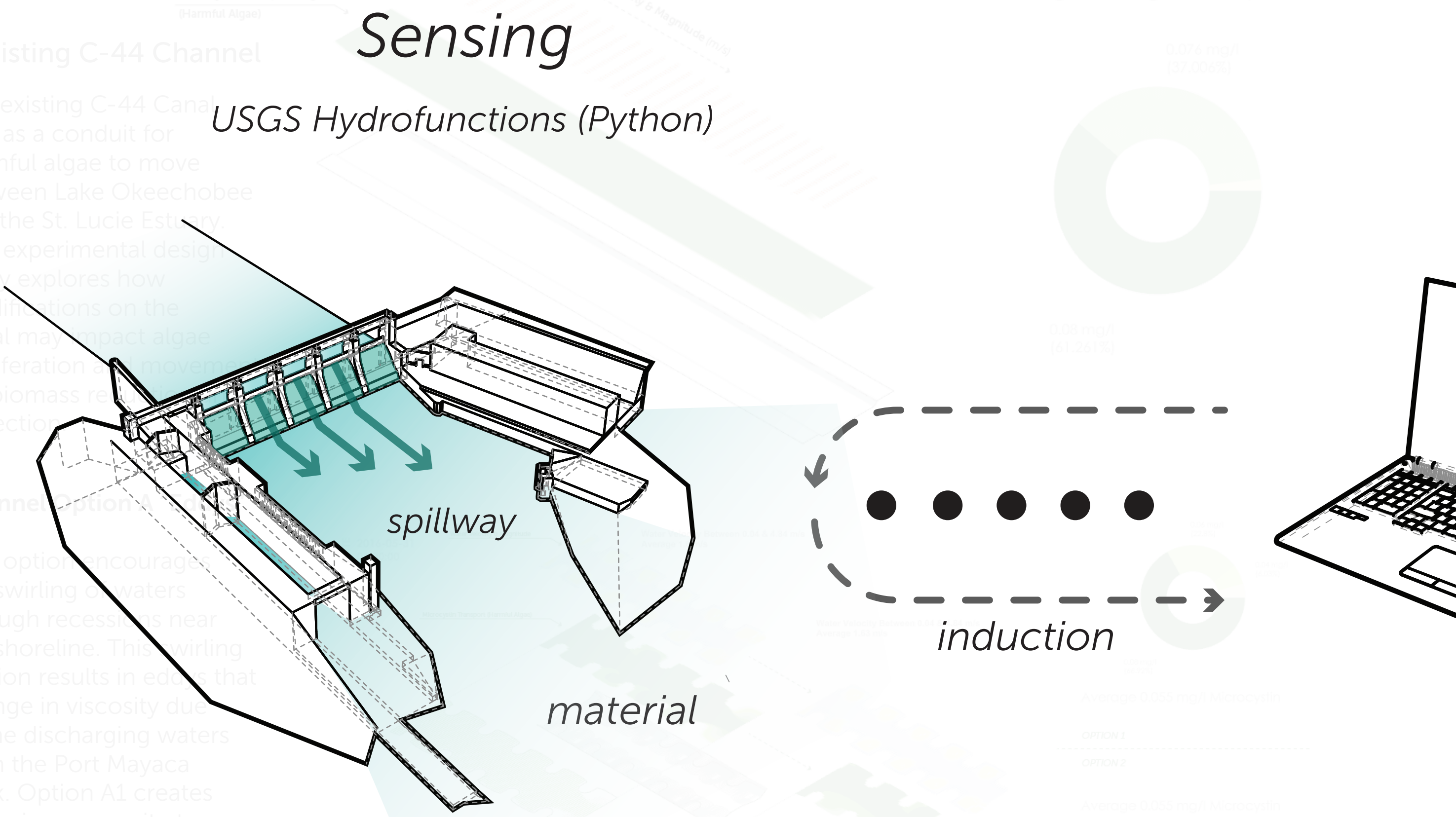
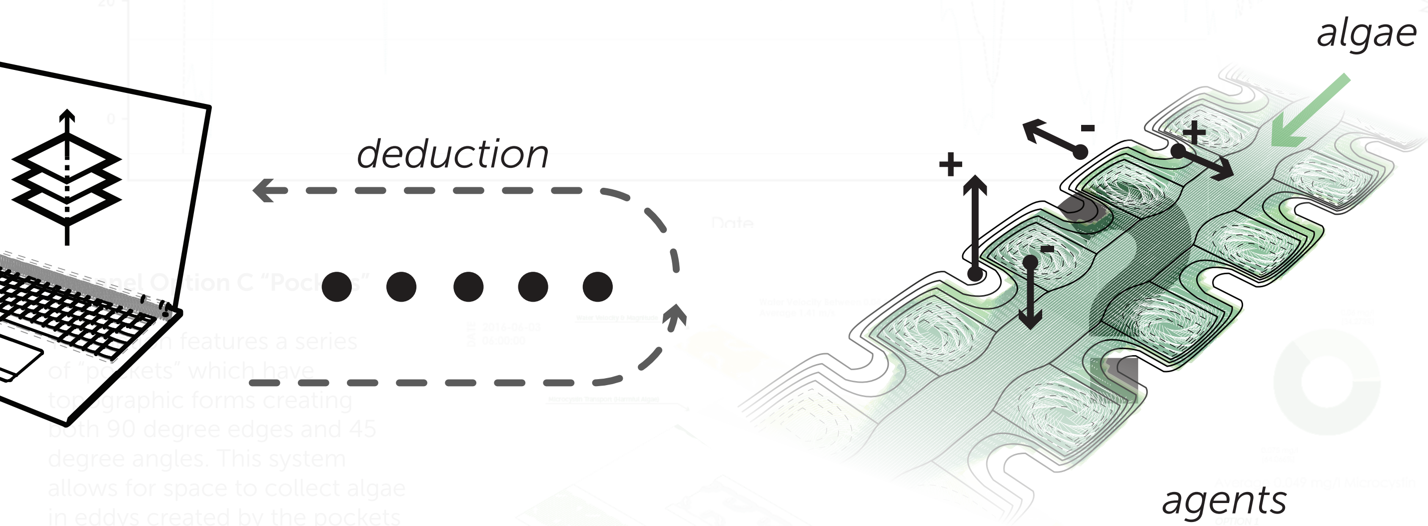


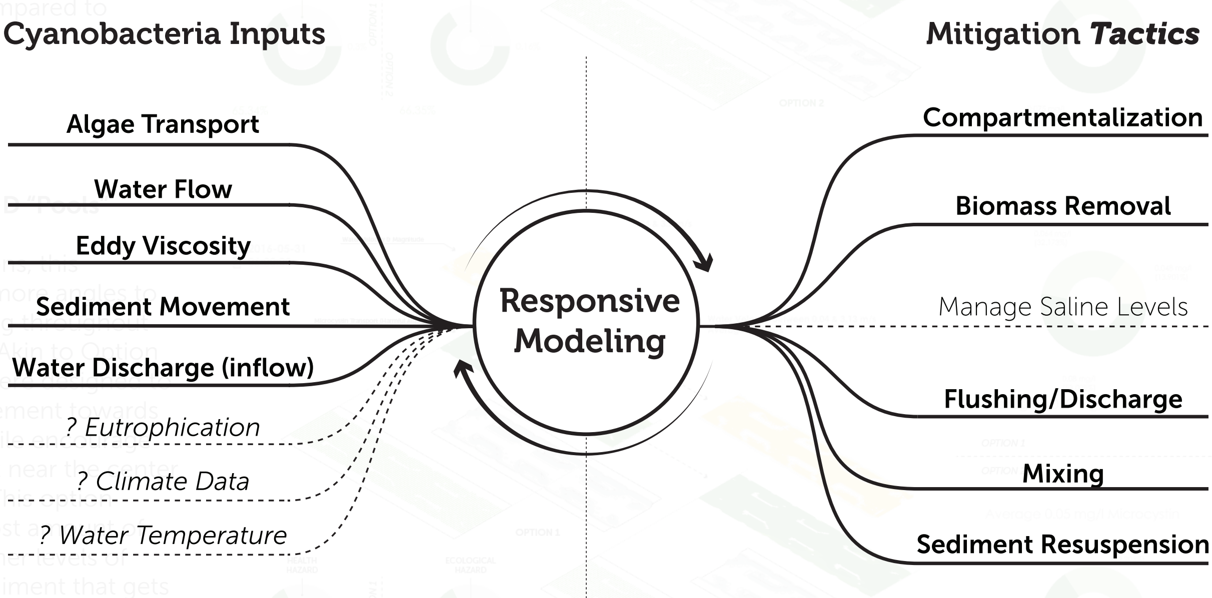
Figure 4.11 / St. Lucie Canal Computation Process

The approach to this model includes using python and the USGS hydrofunctions module, which allows us to tap into real-time spillway discharge and water quality data from an online databaseThe output of that simulation may be brought back into the Rhino design environment for further investigation, and changes to the design may keep evolving. This model may be helpful in the context of this problem because water managers and environmental engineers keep building new infrastructure - seen here is the modification of existing infrastructure and how it may be used to more effectively collect, remove, and retain algae before it enters the estuary environment.

Responsive Landscape

Parametric Modeling as per Designer





04 Case Study */ Saturation Scenarios, VanderGoot Ezban Studio*

Owens Lake, California, is a place where responsive models have been explored, tried and tested. According to Cantrell and Holzman, the "former" lake has been drained by the water-demanding Los Angeles, resulting in a dried out lake-bed producing extremely hazardous dust-storms.[19] The winds that come through this area pick-up carcinogenic dust particulates, causing respiratory illness and higher cancer rates among local communities.[20]

Ironically, the method for dealing with this kind of environmental issue involves the use of a Dust Control Measure, which features infrastructure known as "bubblers". This watering system, similar to a sprinkler, actively spreads misted waters into the atmosphere, equating to approximately 35 Sq Miles of synthetically modified lake-bed. Through this process, dangerous dust particulate is drawn down to the ground, while, inadvertently, estuarine and slat-marsh habitat is created.[21] According to Michael Ezban, Saturation Scenarios aims at both projecting and indexing the effects of water saturation variability, flooding, and habitat creation throughout the Owens Lake Dust Control Management system. The model computes registered saturation events in two uniform processes: (1) sequence and intensity of water saturation is expressed over temporal timelines while (2) linear logs, represented as multi-colored bars on the X and Y axis, convey the overlapping of saturation throughout the entire mapping sequence (See Figure 4.10).[22] Ezban utilized data from Los Angeles' Power and Water department, tapping into an existing network of information, to illustrate how the conveyance of water will, overtime, create new emerging ecologies.

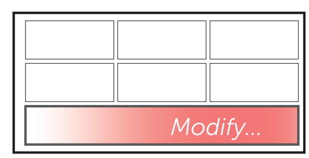
This responsive modeling approach becomes agent-based when considering water and how it may affectively alter landscape conditions with the decisions made within the Dust Management System. M'Closkey and VanDerSys suggest that Saturation Scenarios may be developed further in an interface that illuminates the complexities of site, hydrology, weather, and habitat creation. Saturation Scenarios exemplifies the Modify model for it realizes the impacts brought on by the consequences of technological interventions.[23] In this case, Owens Lake ecological restoration doesn't come from what has been, rather, it honors current ecological interactions with pre-existing infrastructure.

19 See page 79 of Cantrell and Holzman's Responsive Landscapes.

20 See page 65 in M'Closkey and VanDerSys' Dynamic Patterns: Visualizing Landscape in a Digital Age

21 See Owens Lake Habitat Plan, prepared by the Los Angeles Department of Water and Power, which details the Dust Control Measure in detail.

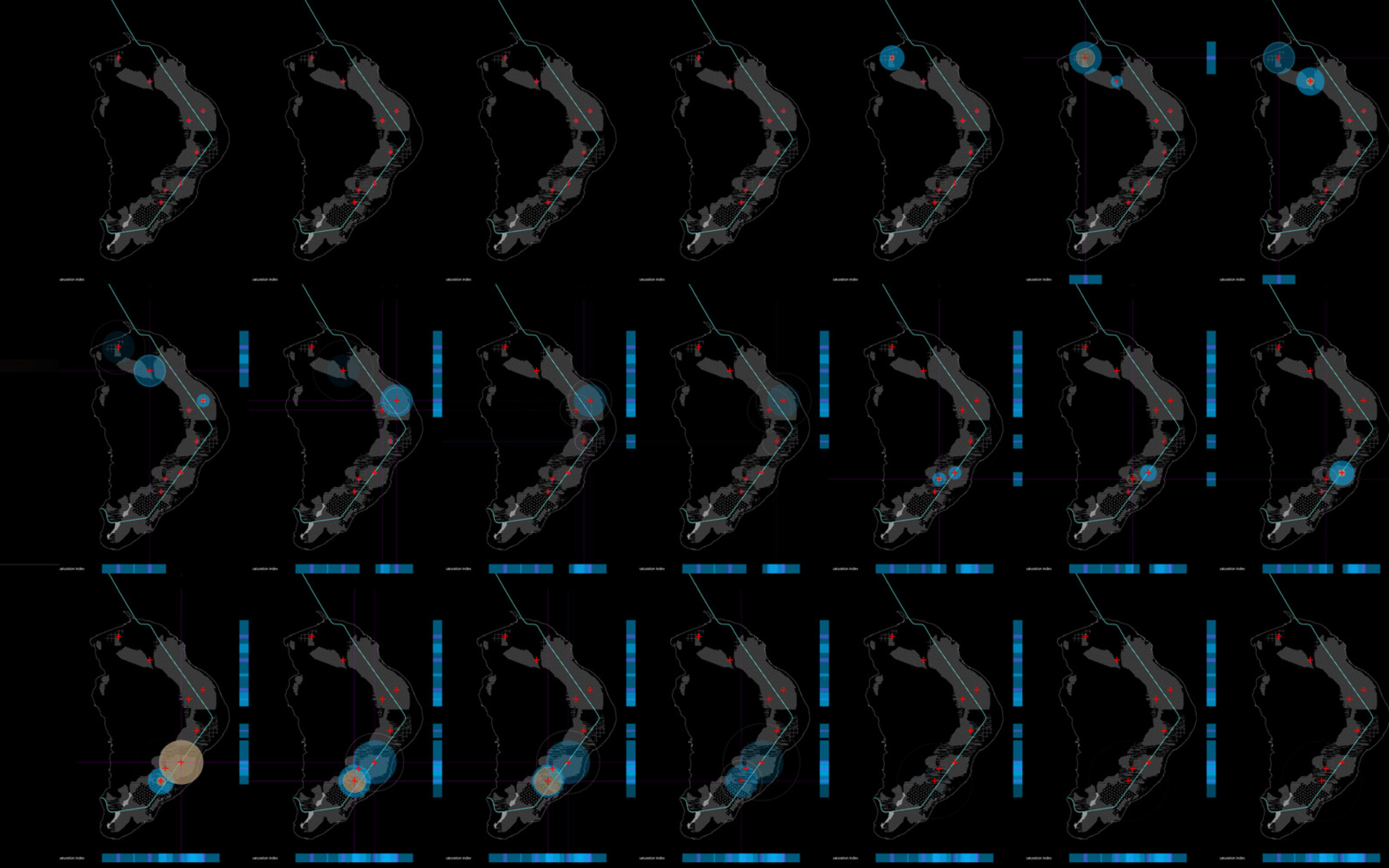
22 Visit VanderGoot Ezban Studio's website at https://www.

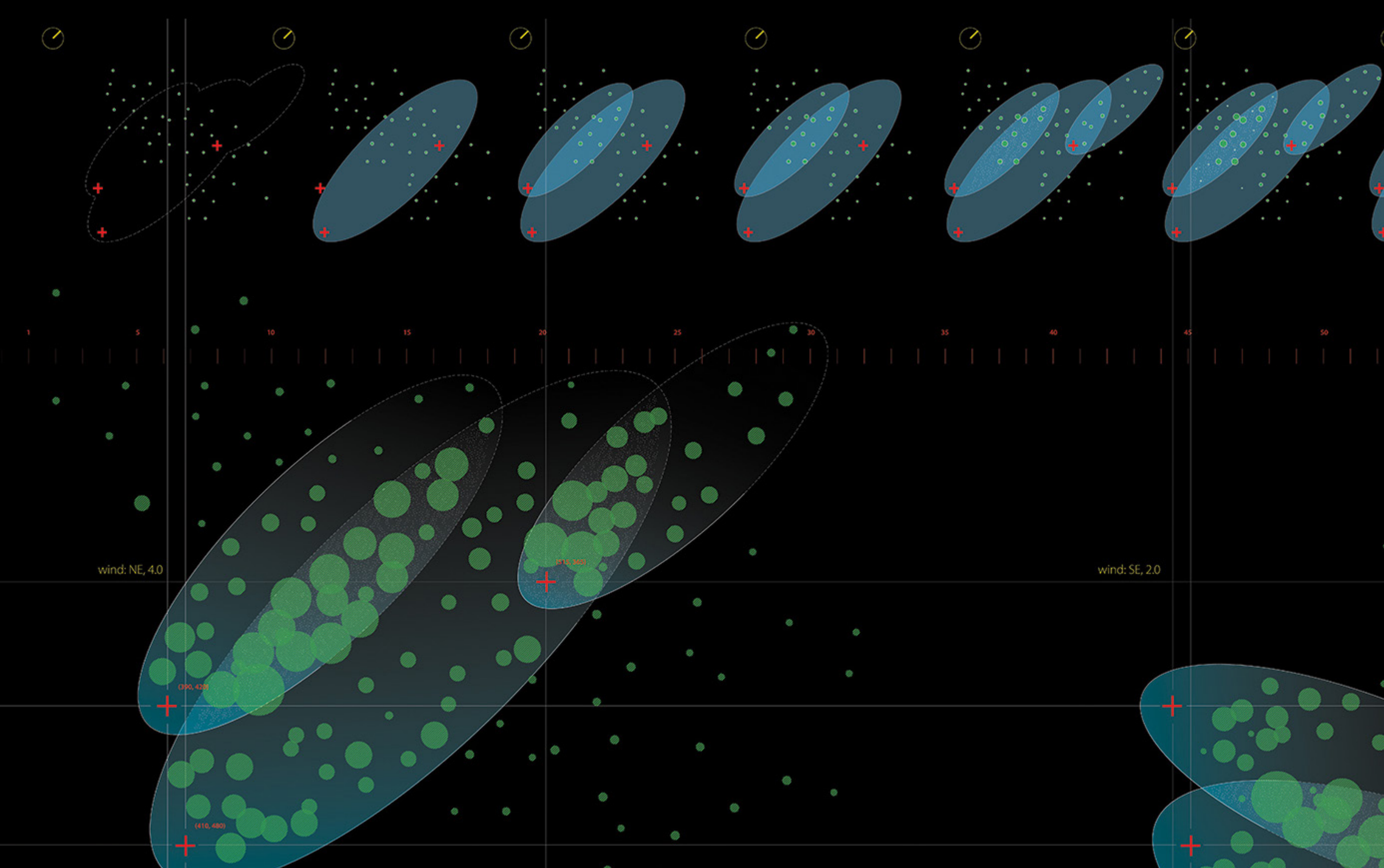


23 See Modify on page 250 of Cantrell and Holzman's Responsive Landscapes (2016) and review Modeling as Manifesto Section of this report.

Figure 4.12 / Experimenting with Channel Modifications

These axons showcase the output of the CCHE-2D hydrodynamic flow model. The next step of the process will include algae decay rates in relation to suspended sediment. The sediment experiences resuspension due to horizontal and vertical mixing in the water column. Hydrological options with more complexity provide more mixing potential and should, theoretically, hinder and limit algae growth throughout the discharge flushing process.


saturation index


1
5
10
15
20
25
30
35
40
45
50
wind: NE, 4.0
(515, 365)
(390, 420)
(410, 480)
wind: SE, 2.0

Having the ability to access a variety of monitors measuring real-time water quality, the estuary model realizes the immense impacts water management infrastructure has on this ecosystem. With the help of Python, the CCHE2D model, Grasshopper, and the Rhino Environment, the St. Lucie Estuary may establish various connections between sediment dynamics, estuarine bathymetry, water temperature and salinity levels; all of which are tied to the discharges set forth at the St. Lucie Lock and Spillway (S-80). Water managers should understand, more holistically, the implications sending water downstream into the Estuary has on these various parameters. This model may, ideally, provide a place to optimize disharge patters.

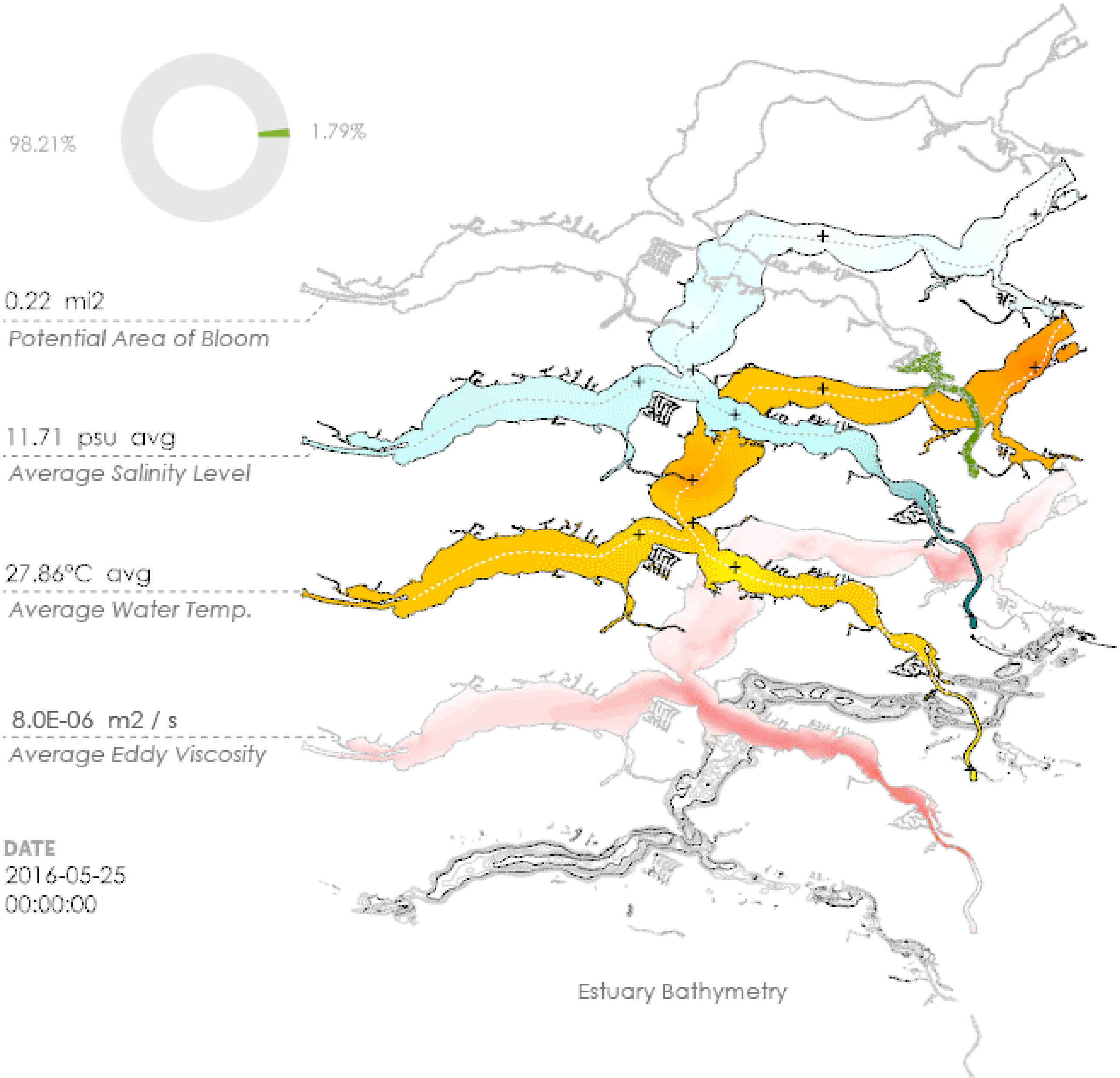
Purpose. Beyond developing an environment conveying the many parameters impacting algae growth and succession, this model allows us to understand how the decisions made upstream impact local ecologies. Whereas Ezban analyzes the synthetic ecologies brought on by the use of bubblers for dust management, this translation attempts to show how the 2016 discharge of water upstream impacted salinity levels and water temperatures downstream throughout the St. Lucie Estuary. These parameters are immensely important as they provide an environment suitable for the proliferation of algae scum. Departing from Ezban's attempt at realizing how ecology may be generated through the model, Figure 4.10 shows us areas where damaging algae may be wreaking havoc upon the existing ecology due to the mapping and analysis of environmental data. With this visualization is the assumption that estuarine habitat will succeed in places where water quality parameters see less rapid change.

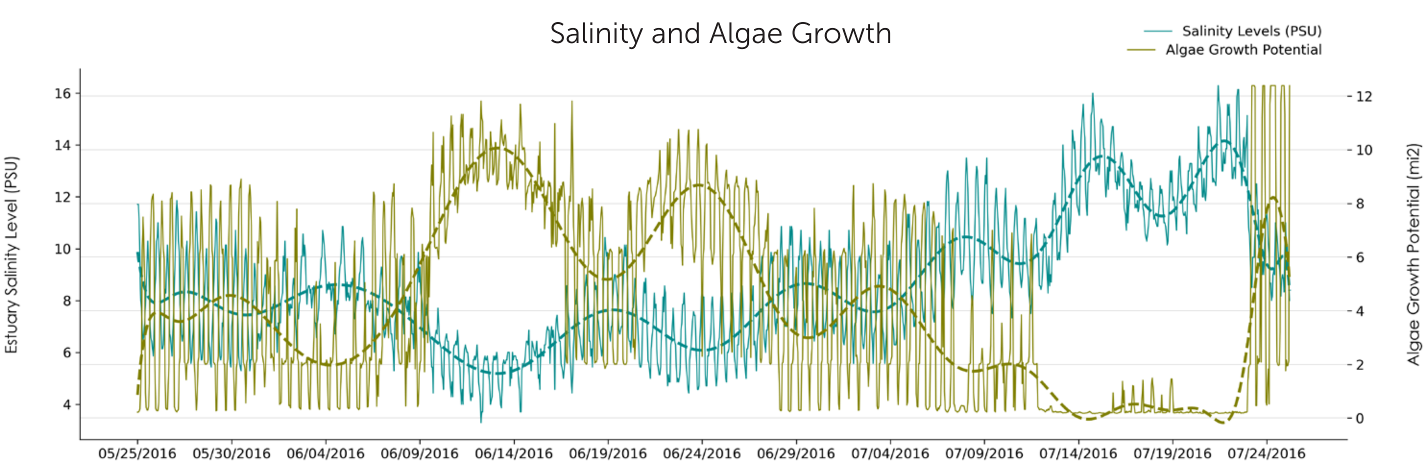
Approach. This is a multi-faceted landscape model in which several modules, plugins and softwares are utilized to simulate and visualize relevant data and phenomenon. Beginning with bathymetry data collected by NOAA and Martin County as a raster dataset, the elevation model was constructed inside the Rhino environment via Bison. Parallel to this, python was utilized to query API servers with data specific to discharge rates (USGS Hydronetworks) and water quality data from the LOBO network set-up by Florida Atlantic University, or FAU. From here, we may use the discharge hydrographs queried from the USGS hydronetwork and plug that into a CCHE2D simulation case. The water quality data from

Figure 4.13 / Understanding The Salinity Gradient

This model aims to establish relationships between sediment drop-off and water salinity levels to communicate where algae typically proliferates. Cyanobacteria is a harmful, *freshwater* species of bacteria that is negatively impacted by sediment, therefore, it may be mitigated in areas where salinity fluctuates and deposition may occur due to suspended sediment drop-out.

As seen in the line graph at the bottom of the page, there is an inverse relationship between algae growth potential and estuary salinity levels.


98.21%
1.79%
0.22 mi2
Potential Area of Bloom
11.71 psu avg
Average Salinity Level
27.86°C avg
Average Water Temp.
8.0E-06 m2 / s
Average Eddy Viscosity
DATE
2016-05-25
00:00:00
Estuary Bathymetry


Salinity and Algae Growth
Salinity Levels (PSU)
Algae Growth Potential
Estuary Salinity Level (PSU)
Algae Growth Potential (mi2)
05/25/2016
05/30/2016
06/04/2016
06/09/2016
06/14/2016
06/19/2016
06/24/2016
06/29/2016
07/04/2016
07/09/2016
07/14/2016
07/19/2016
07/24/2016

the FAU LOBO network was imported directly into the Rhino environment and was rendered as a raster-mesh to show how certain parametric levels change over hourly records. After the CCHE2D simulation is complete, the sediment and hydrological flow results may be imported into the Rhino environment similar to the C-44 channel modification model. So with all of this data in one place, we may test how certain discharge rates impact this ecosystem in ways that are not perceptible to everyday instruments. As seen in Figure 4.11, the model creates a series of moments in which insightful patterns emerge.

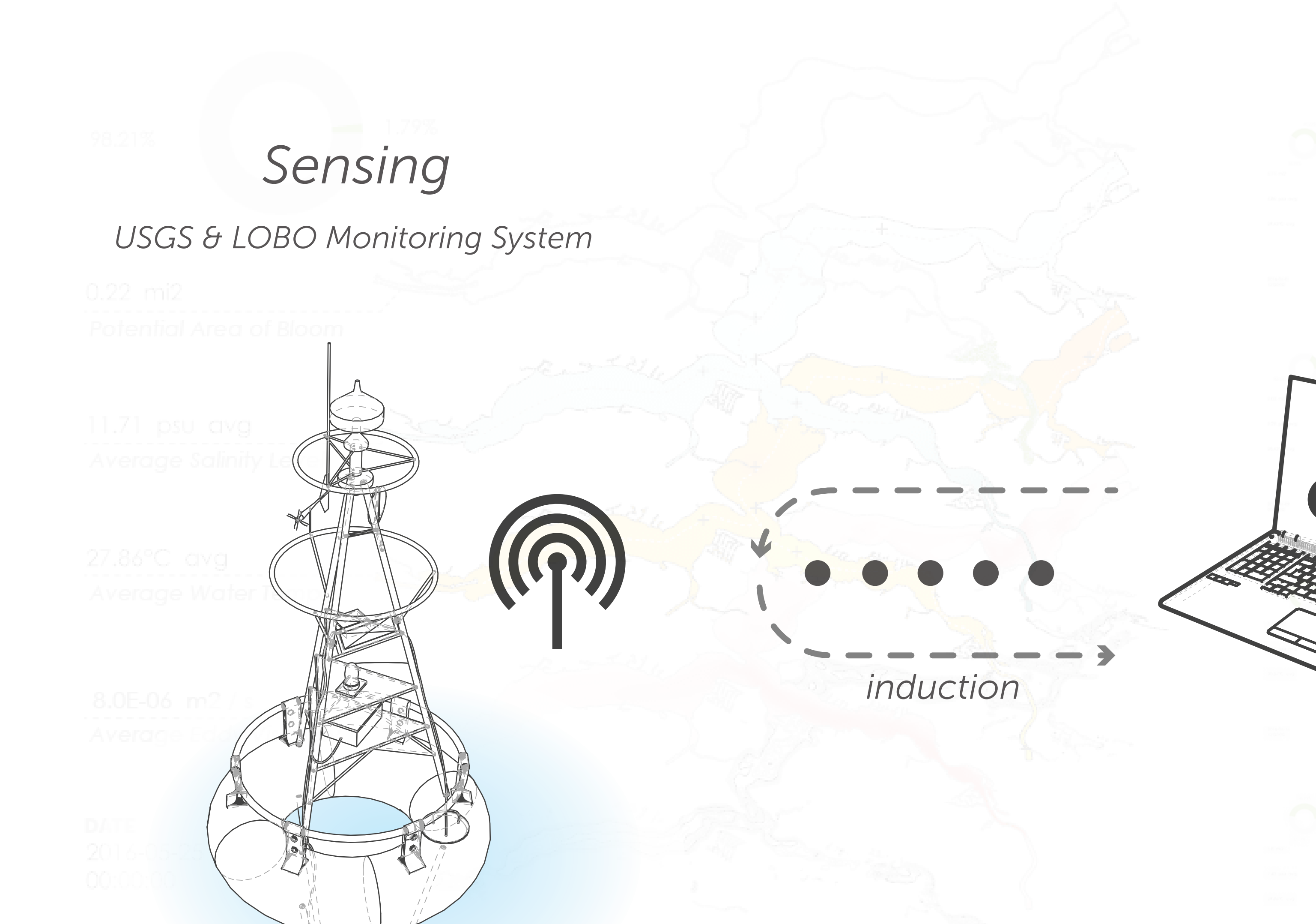
Implications. In addition to representing the spatial variation of salinity levels, water temperature, and sedimentation throughout this estuary, the St. Lucie Estuary Model shows us how, through real-time monitoring, USACE operations may utilize sensors as a way to inform their management practice. Although the major drivers behind USACE operations revolve around flood-risk management upstream, rapid landscape assessment can aide ecologies downstream by informing freshwater discharge rates to encourage more ecologically viable salinity levels. This reveals that we may close the gap between actively inducing knowledge while deducing synchronized outcomes through decisions.

Limitations. Half of this model is the recording of real-time data while the other half is the output of a simulation. Although, theoretically, it's an interesting junction, the simulation is only the calculation of flow events and sediment dynamics and cannot live up to the accuracy of sensed phenomenon. There is a lot of information missing with respect to sediment modeling throughout this estuary. Assumptions were made due to the lack of information regarding the estuary-bed, especially as it relates to bed roughness, which is the friction water experiences against the bottom of the waterway. More data may be incorporated into this model to make it more artificially intelligent and relevant in regards to computational landscape; this includes historical salinity levels in the estuary, current and forecasted meteorological events as well as tidal charts. In an ideal scenario, the St. Lucie Spillway may recreate historical freshwater outflows as a means to promote more balance within the system. Meanwhile, monitoring systems downstream can keep this system in check by relaying to the spillway to either release or hold water (depending on oceanic tides and rainfall events). This model only considers past and current trends and lacks predictive modeling.

Figure 4.14 / Responsive Models as Catalogs

Over time, the Estuary model catalogs specific moments and reveals a series of patterns and relationship between sensed phenomenon and potential outcomes. Though this process, managers may begin to understand the massive impacts freshwater discharge rates can have on the estuary. Over time, an AI algorithm may begin to learn from these scenarios and suggest how we may be more efficient with discharge rates in response to ecosystem health.

.



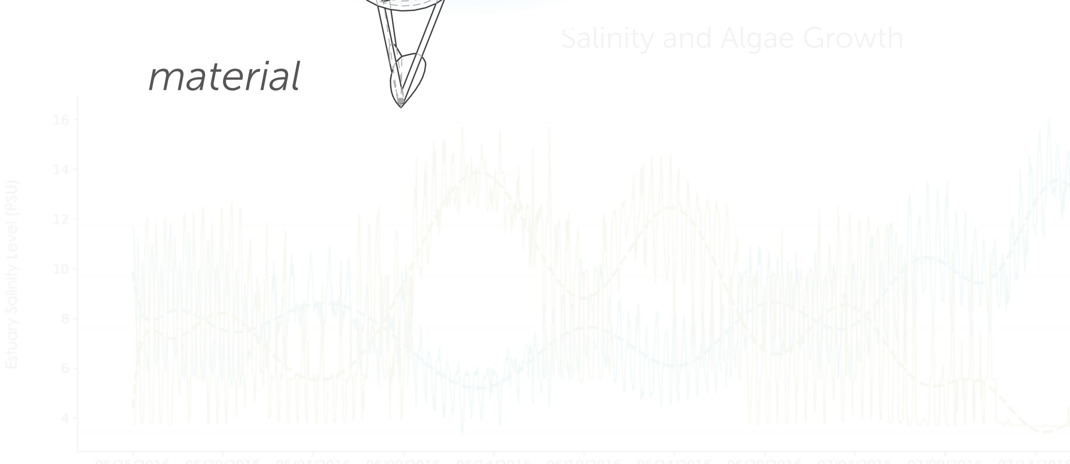
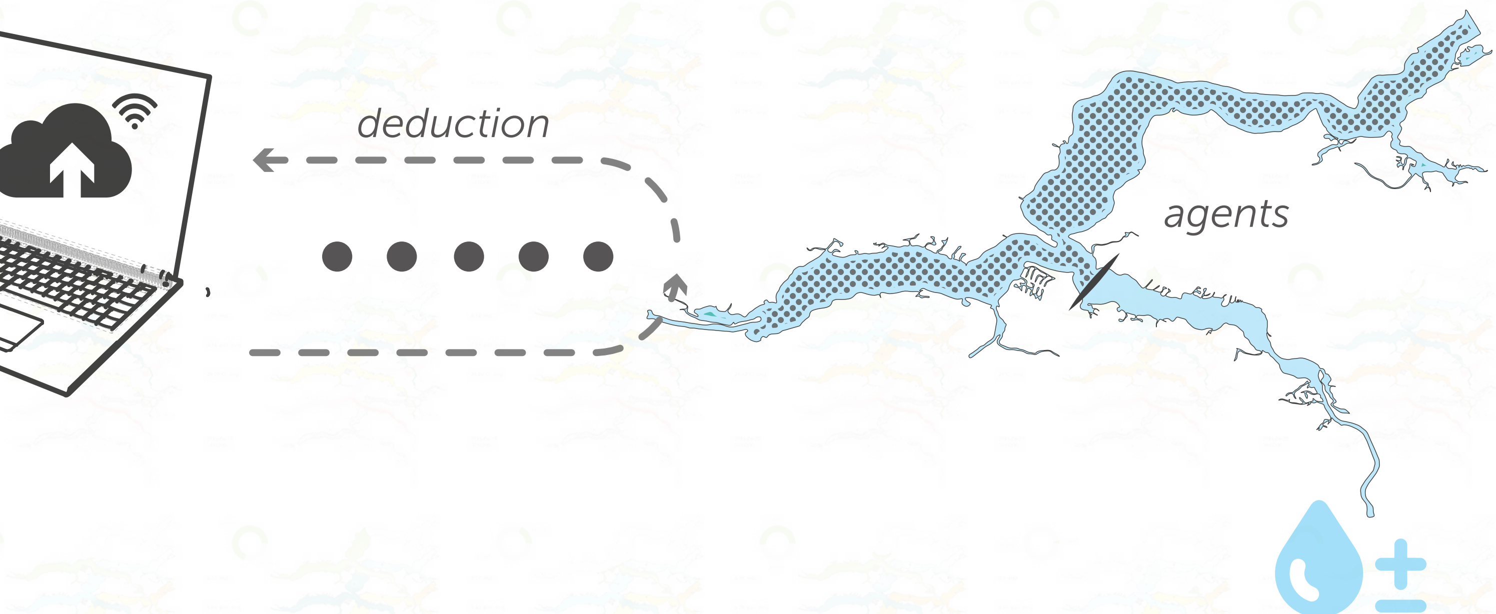


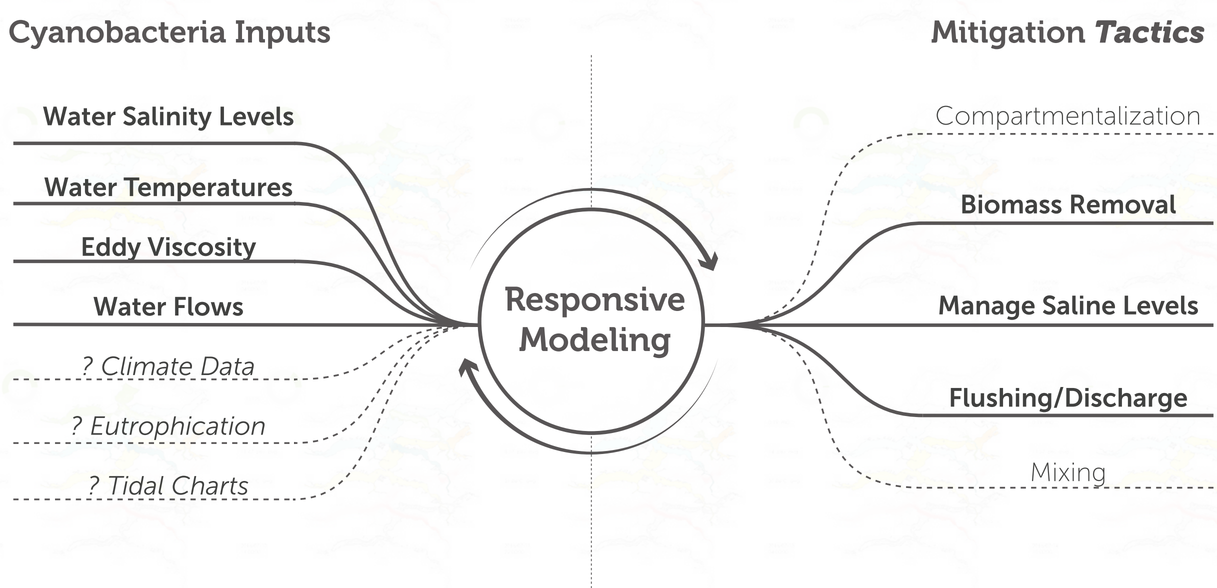
Figure 4.15 / St. Lucie Estuary Computation Process

Utilizing Python and accessing online databases, I relocated a series of sensed data in one place within the Rhino environment. The data is sourced by the USGS and the Florida Atlantic U's St. Lucie Estuary monitoring system. Overall, we can analyze and suggest how current water quality trends provide an environment suitable for algae growth while tapping into several real-time monitoring systems to understand the relationship between a long list of variables in one place. Mapping out the Salinity Gradient could be one tactic employed by water managers so that algae may be trapped inside the estuary at a certain point and collected before it goes even further.

Responsive Landscape

Speculative Interface

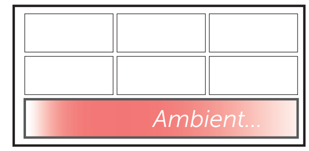




With a discrete focus on exploring machine landscapes, *Autonomous Ecology* deals with the realities of urban life and was designed by Aiman Tabony and Enriqueta Llabres-Valls through their Relational Urbanism LAB, in collaboration with the Bartlett School of Architecture. Located near the Canary Wharf on the Thames in London, UK, *Autonomous Ecologies* proposes an infrastructure that mines the plastic waste that flushes down the Thames and into the North Sea and Adjacent English Channel. Through the process of naturally collecting trash via hydrological flows, the landscape may begin to grow and expand itself by autonomously and continually appending to itself through the process of recycling and large scale 3D printing.

The design included a series of experiments exploring the relationship between form and hydrological flows. Employing the RhinoCFD plugin for Rhino 3D as a computational fluid dynamic model, the results highlight how deposition and turbulence engage with one another; this correlation lead to the strategic redirection of waste and sediment throughout this landscape (See Figure 4.13). The designers also tested methods for using their materials through rapid 3D printing typologies. Overall, the virtual modeling process, engagement with material exploration, and the design's engagement with site can be considered responsive and demonstrates an Ambient model for the spatial structure grows overtime in relationship to plastic collection.[24]

Autonomous Ecologies grapples and engages with the impacts of globalization. Perhaps an interesting take on urban ecologies,[25] the project strategically places a mechanistic landscape infrastructure tasked with cleaning up our consumptive nature outside of London's major financial district. In this way, the project reflects our capital-minded tendencies back at us while simultaneously creating public space. Designer Enriqueta Llabres concludes that this piece challenges our very conceptions of urban places: "The project aims to challenge the meaning of public space, iconicity and centrality. Its hyper realistic aesthetic reflects on the material processes involving machine landscapes; opening a scenario where automation and digital fabrication reformulates future ecologies."[26]



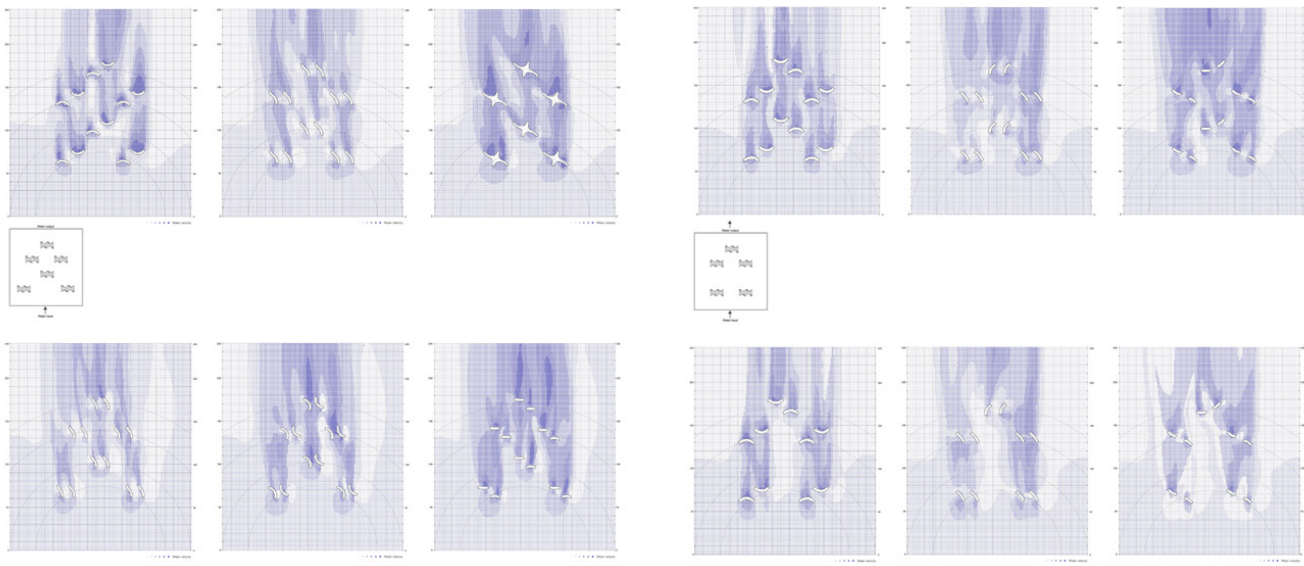
24 See Ambient on page 216 of Cantrell and Holzman's Responsive Landscapes (2016) and review Modeling as Manifesto Section of this report.

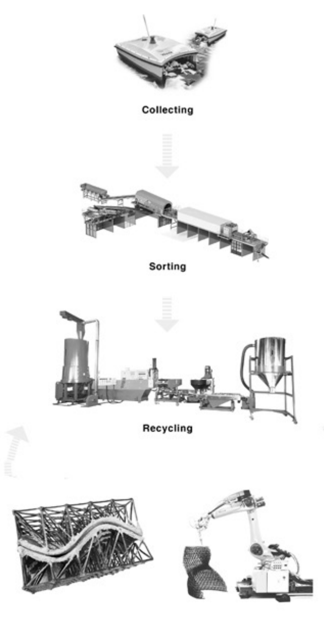
25 In reference to Charles Waldheim's Landscape as Urbanism, which outlines the theory explaining how landscape, more than buildings, have changed how our cities urbanize throughout the 21st century.

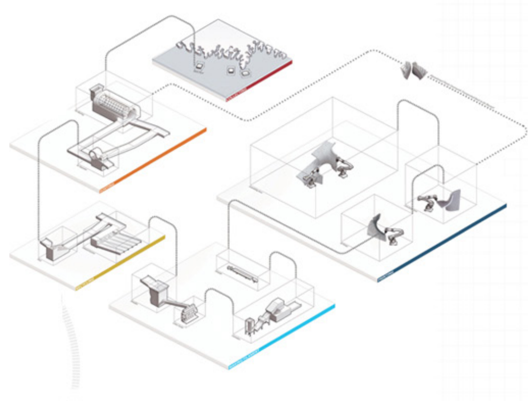
26 See the description of Autonomous Ecologies at the Relational Urbanism LAB at http://relationalurbanism.com/rulab/autonomous-ecology/

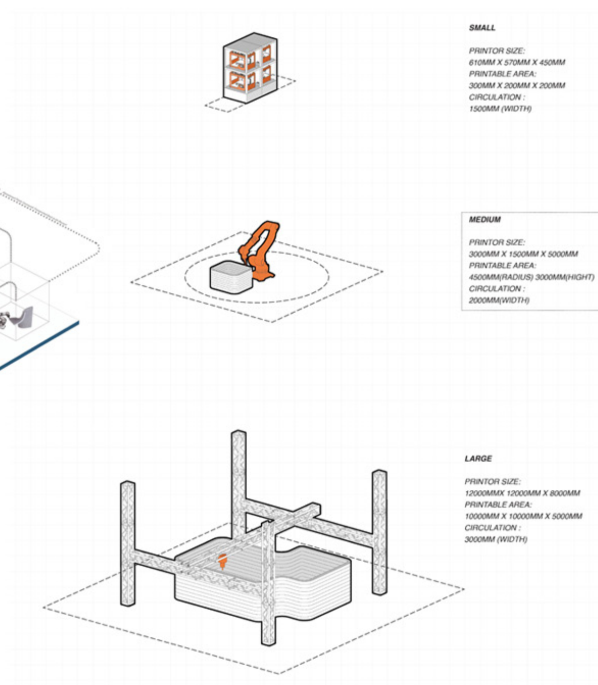
Figure 4.16 / Autonomous Ecologies and Up-cycling

These images of Autonomous Ecologies show Enriqueta Llabres-Valls' abstract approach towards dealing with waste and up-cycling plastics through the use of 3D printing public space right near the Canary Wharf. The studies at the top of the right-hand page explore the relationship between form and water flow through the RhinoCFD plugin. The central diagram, renders the overall design and suggests how, over time, may grow and expand based on the needs of the public. The diagram at the bottom reveals the intent to use collected plastics as a means to build the physical structures along the site.




Collecting
Sorting
Recycling
Concrete Formwork
3D Printing




SMALL
PRINTOR SIZE:
610MM X 570MM X 450MM
PRINTABLE AREA:
300MM X 200MM X 200MM
CIRCULATION :
1500MM (WIDTH)
MEDIUM
PRINTOR SIZE:
3000MM X 1500MM X 5000MM
PRINTABLE AREA:
4500MM(RADIUS) 3000MM(HIGHT)
CIRCULATION :
2000MM(WIDTH)
LARGE
PRINTOR SIZE:
12000MMX 12000MM X 8000MM
PRINTABLE AREA:
10000MM X 10000MM X 5000MM
CIRCULATION :
3000MM (WIDTH)

05 Response / *Algae Mitigation Tiles*

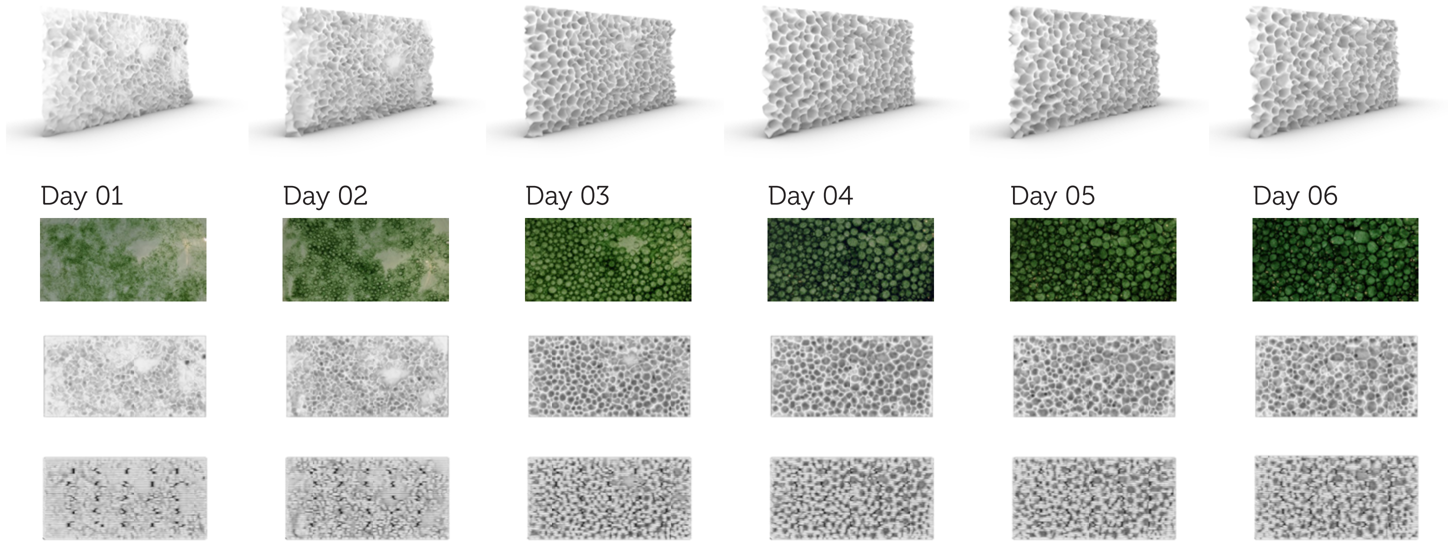
Considering the concepts and ideas explored in Autonomous Ecologies, this project explores how objects may be designed, rapidly prototyped, and simulated to understand how algae, similar to plastic recycling, may be captured and up-cycled. The project utilized computational fluid dynamics as a means of testing how the tile may entrap algae as it flows over its surface. Although Autonomous Ecologies explores landform and larger-scale infrastructure, this translation considers a smaller scale, as a building block that may be used along existing infrastructures.

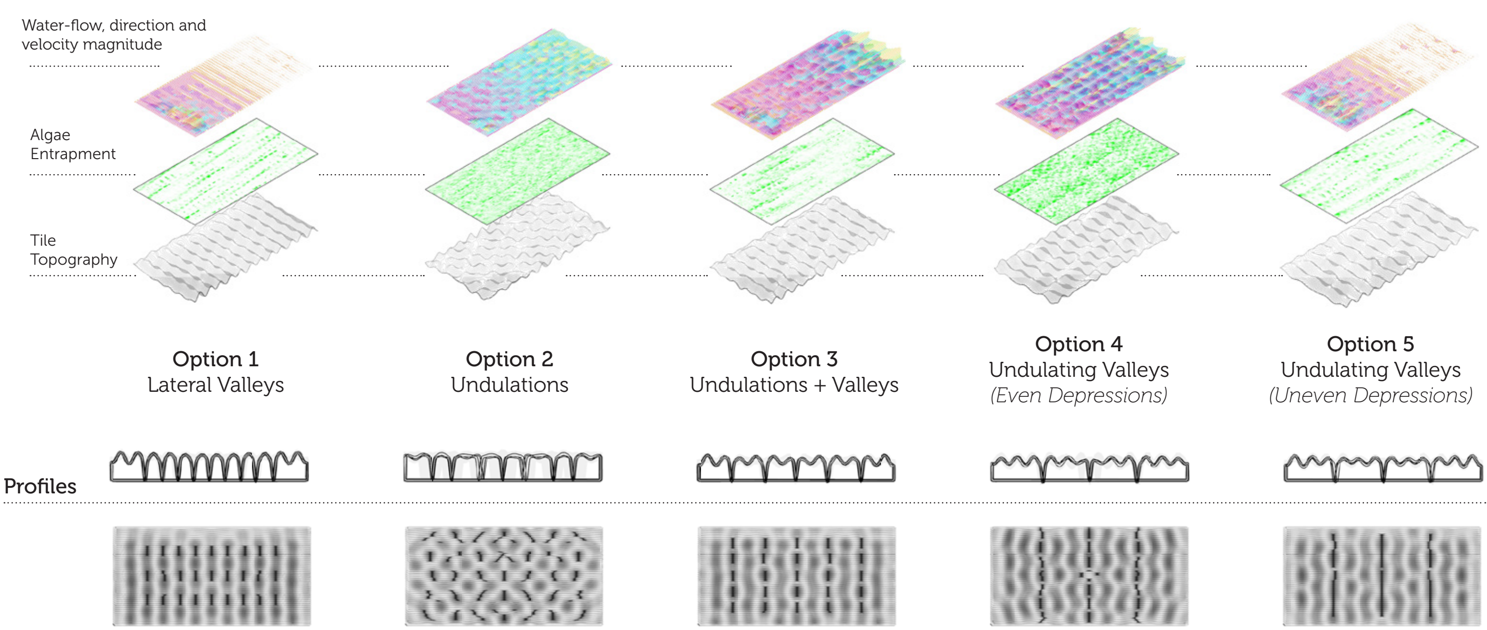
Purpose. This model's objective was to understand how the advances in additive manufacturing may be procured to alleviate algae issues throughout South Florida. This design process included the daily image output from the algae experiment and understanding how pattern may be abstracted and applied to a 3D printed surface. The result included a parameterized pattern of surface geometry and a computational fluid simulation of those surfaces. Each tile has it's own advantages; however, as each form was prototyped and developed further, certain design parameters led to a more effective algae-catching tile design. The result of this study led to the concept of installing these tiles upon existing check-dams, spillways, and seawalls. Over time, algae may accumulate onto the surface of these objects to reveal the failing water quality of the St. Lucie Estuary.

Approach. The primary approach to this model included the rapid prototyping of tile designs within the Grasshopper environment in conjunction with simulating water movement over tile surfaces. Tile prototypes were tested against gravity as they were printed out of a Cartesian-style 3D potter bot. Adjustments had to be made to account for sagging in the clay form and this was accomplished through the methodical bridging between the front and back walls of the tile. This may be seen in the profiles shown in Figure 4.13 and Figure 4.14 on the following page. As the simulations were developed between Rhino and CCHE2D, certain patterns and bridging locations resulted in more or less eddy viscosity values - which is referred to as algae entrapment in Figure 4.14 and shown in the diagrammatic axons towards the bottom of the page. As tile designs were altered to become more structurally

Figure 4.17 / 3D Printed Algae Collection Tiles

This study explored how rapid prototyping and simulations may inform one another to effectively capture algae as it runs over a tile's surface. Several computational processes were incorporated through the Grasshopper Environment, which includes deriving pattern from images of algae samples from the previous model exploration. These patterns were parameterized and further tested through computational fluid dynamics. Rapid prototyping allowed for certain adjustments to be made in response to gravity.


Day 01
Day 02
Day 03
Day 04
Day 05
Day 06


Water-flow, direction and velocity magnitude
Algae Entrapment
Tile Topography
Option 1
Lateral Valleys
Option 2
Undulations
Option 3
Undulations + Valleys
Option 4
Undulating Valleys
(Even Depressions)
Option 5
Undulating Valleys
(Uneven Depressions)
Profiles

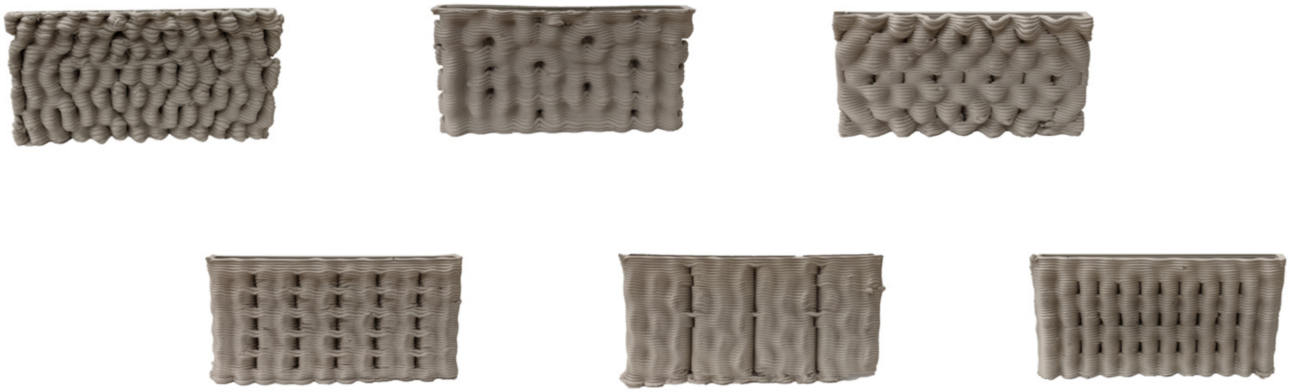
stable, simulations provided another inductive layer to the process. The parameterized script was a model responding to the effectiveness of certain patterns via simulation and the need for the tile to stand up appropriately.

Implications. The mitigation of algae may be informed through smaller-scaled infrastructure aimed at both collecting and exposing algae in waterways. With this, the collection of algae may be advantageous in terms of reusing it's rich oils for bio-fuels, fertilizers, and alginate in clay and ceramic products. More specific to Autonomous Ecologies and the principles of Ambient, these tiles form a landscape infrastructure that may become a part of the material stream all-together if algae were to be used within the clay bodies. This model could suggest how algae may become a part of the collection system itself, while also exposing algae as it gets collected throughout the watershed. The design process examined an interesting relationship between structural integrity and hydrodynamics that were concurrently tested in both physical and virtual platforms. This process allowed both a deeper understanding of the mutualism that exists between clay and algae.

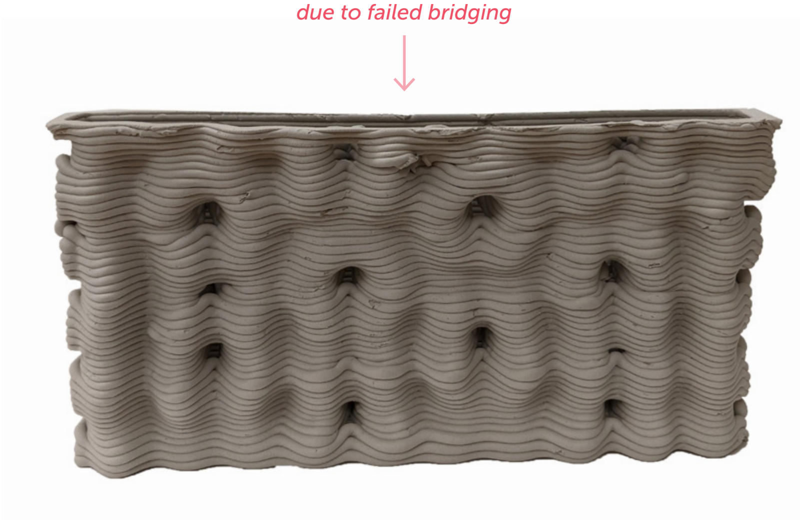
Limitations. Most prevalent in this modeling study is the disconnection between data visualized through virtual analysis and the impacts gravity had on the physical outputs. In other words, the model loses most of its responsive capacity due to the fact that these two processes were not communicating to one another; sensors were not provided to formulate a feedback loop into the virtual modeling process. Many of the decisions made in the virtual model were based on the observations seen and recorded from the 3D printer and the goal to capture algae through the simulation. Along with this, the model is limited by scale, material, and equipment. I was fortunate enough to have access to a 3D potter bot during this phase of the project. I was able to learn both the constraints in dimensions with this 3D printer (24" h x 14" diameter) and its storage capacity limits of clay. Due to physical size constraints, this model's resolution is very limited and is apt at exploring product-sized, modular interventions. As seen in Figure 4.14, clay has its own limits as well, and the outcome of this process is limited to the structural integrity of soft clay as it prints out of a moving nozzle.

Figure 4.18 / 3D Printed Algae Collection Tiles

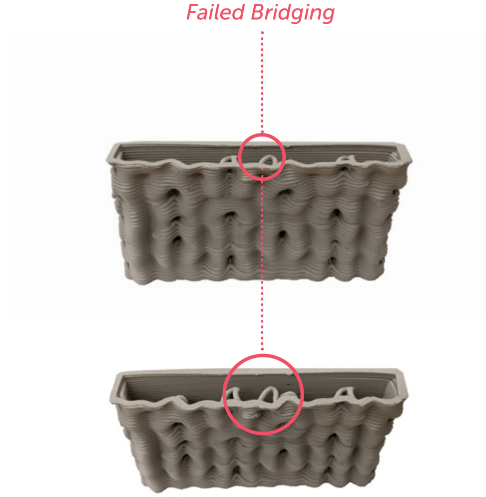
These are images of the printed prototypes from the 3D potter bot. Up above is a series of options that show the variability and flexibility written into the Grasshopper code. The images below show how controlled bridging needed to be satisfied to create a more structurally stable algae tile.

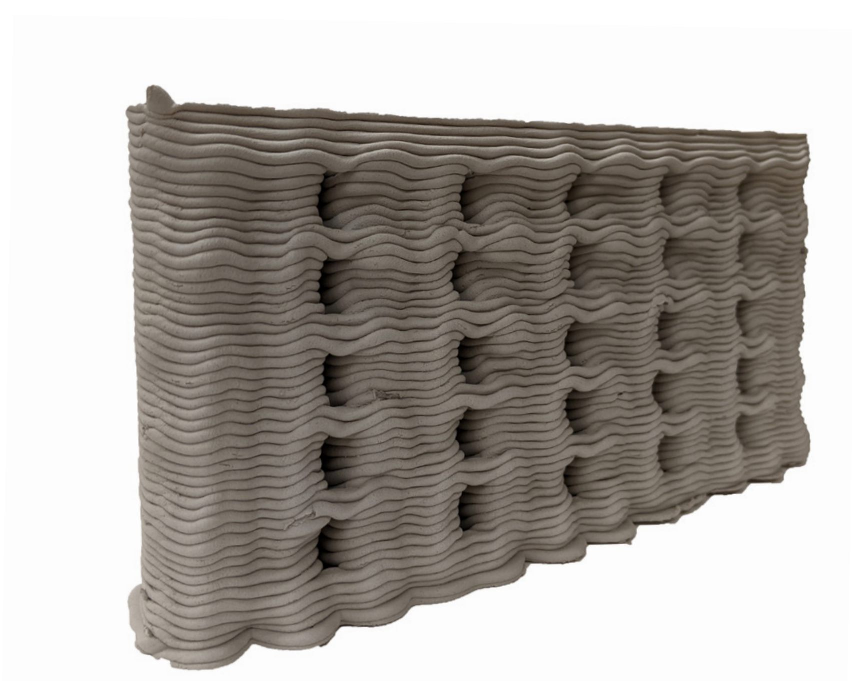


Sagging in the Form due to failed bridging

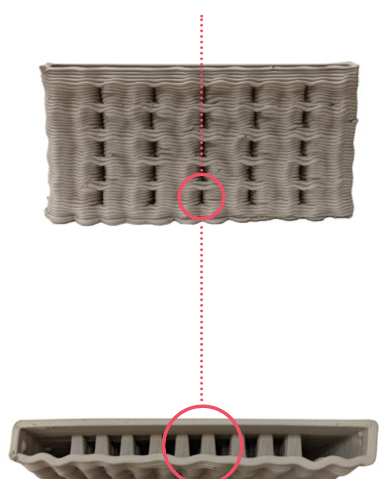


Failed Bridging





Controlled Bridging
Holes provide another layer for hydrodynamics and may help aerate water as it flows over the tiles.

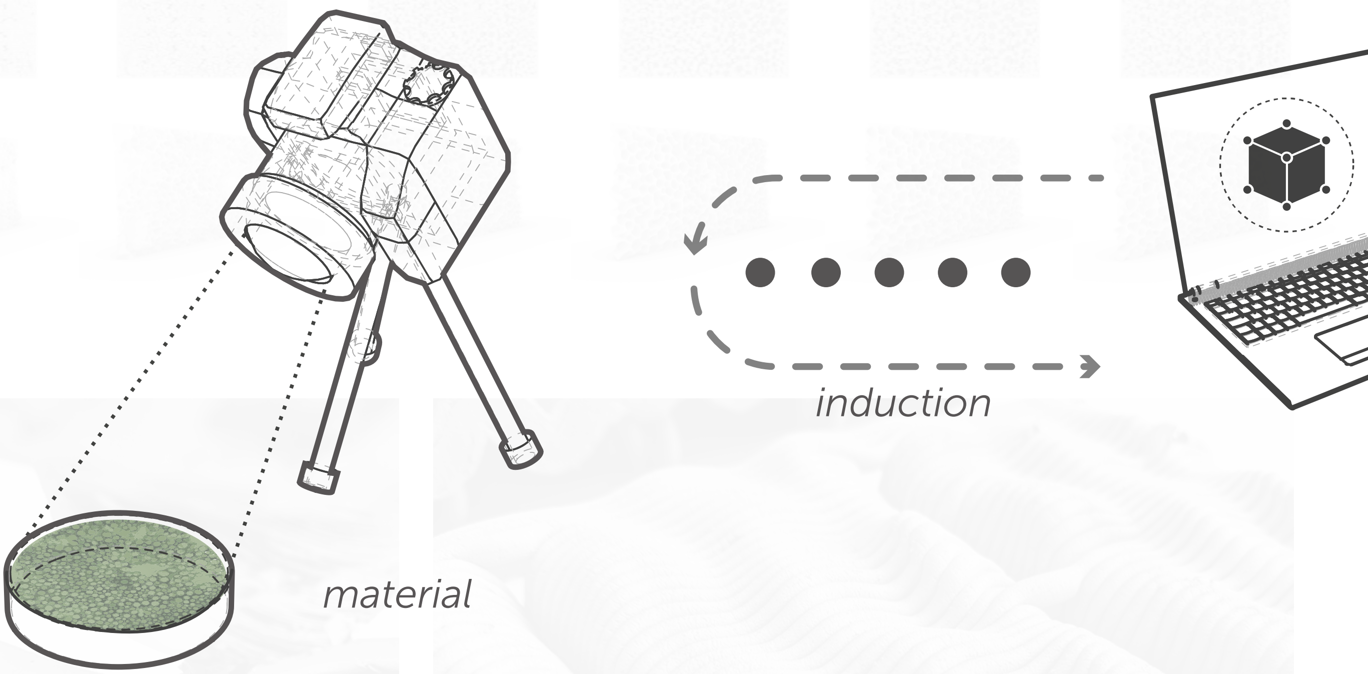


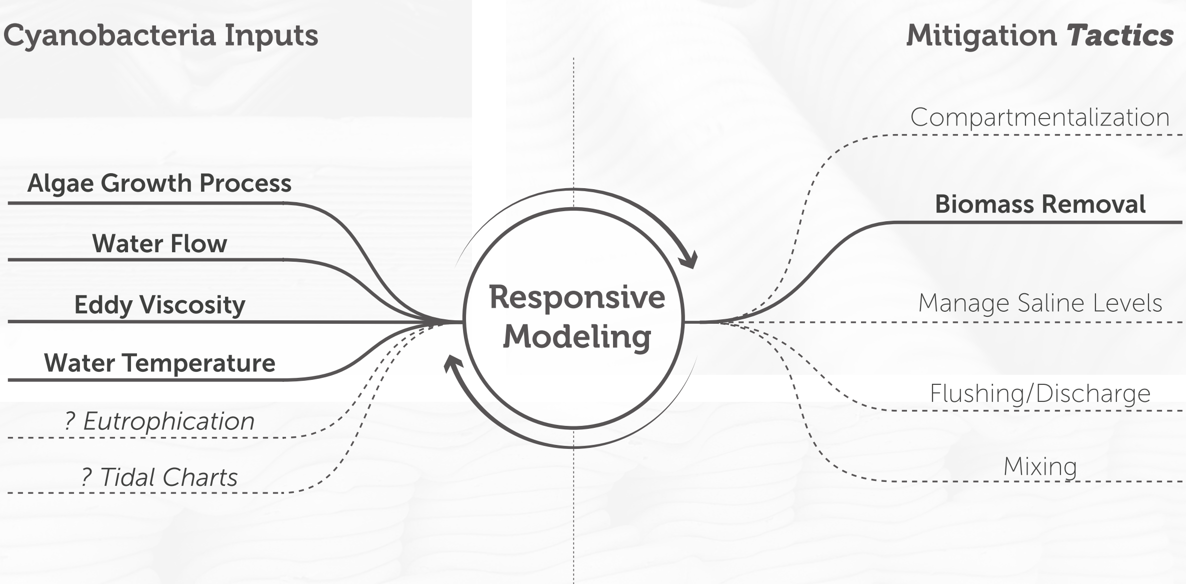
Sensing

Webcam & Algae Experiment

Respon

Rhino + Gras





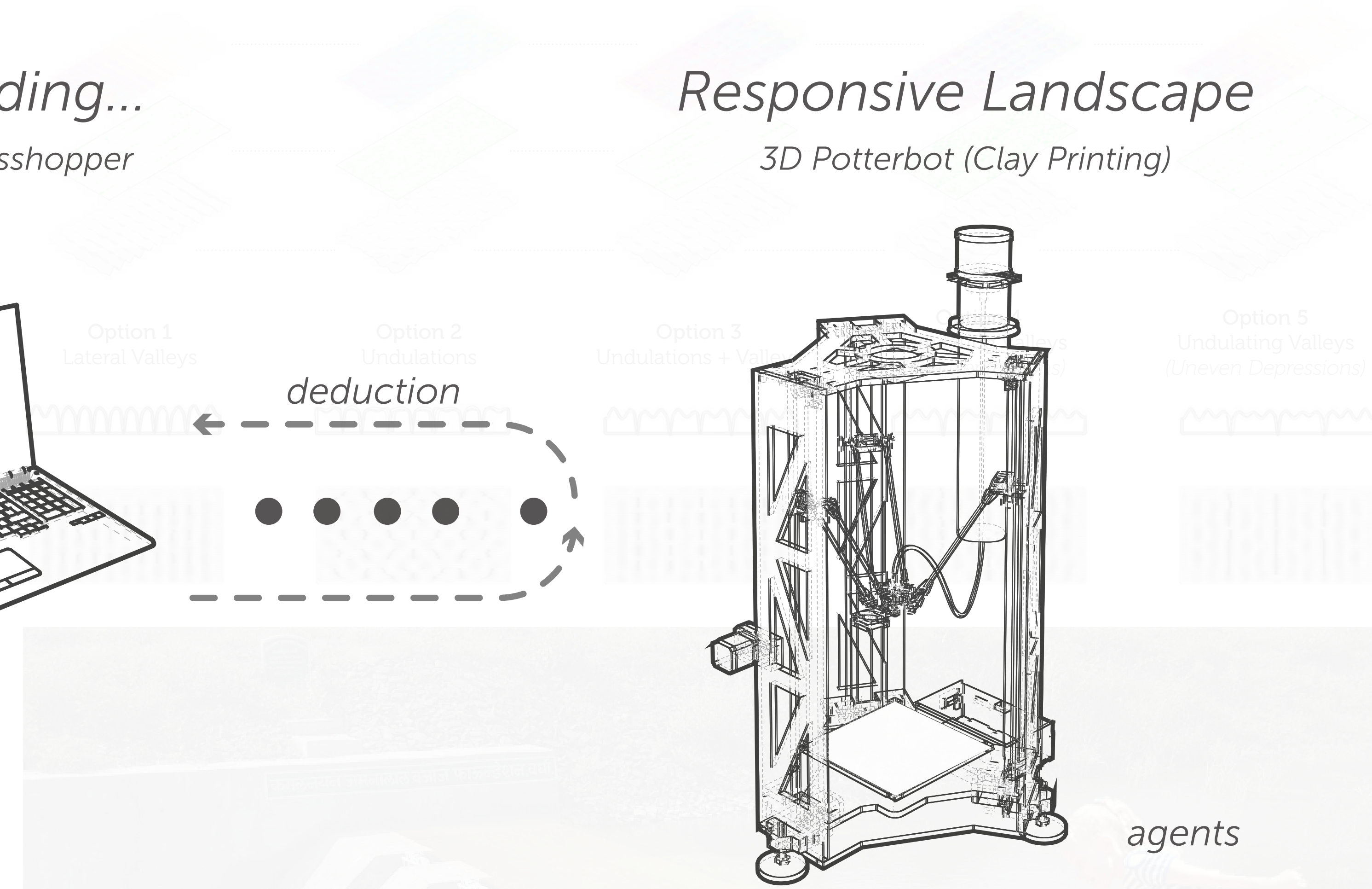


Figure 4.19 / Algae Mitigation Tile Computation Process

This modeling environment creates new associations between landscape material and landscape interventions by exploring algae patterns in the form of 3d printing clay. Images were pushed through a computational algorithm that generated patterned tiles. Tiles were then analyzed through computational fluid modeling to maximize their capacity to capture algae.

The major limitations surrounding this responsive model approach include the dimensional constraints of the 3D Potterbot printer and the lack of real-world prototyping and testing.

.

Meta-analysis of Models

Moving on from purely translating responsive model inspirations, we may now begin to compare and contrast the experimental design results as a means of design reflection. Similar to the preceding sub-section, the following will reveal the overall purpose, approach, implications, and limitations of the design process in its entirety. To satisfy the Nijhuis and Bobbink methodology, this meta-analysis will lead to a deeper understanding of the responsive model and the principles governing its composition. With this, the analysis will show us where there is room for further developing the responsive model as a design method, especially related to algae management.

Purpose. The responsive modeling case studies generated new processes and means of exploring algae blooms through computational operations and responsive modeling. In addition, all of the responsive modeling examples introduce innovative means in highlighting, mapping, and realizing the impacts landscape infrastructure may have on the environment. In response to these inspirations, Algae as Agents has discovered several means in communicating algae dynamics through computation, which resulted in a variety of graphics, media, and artifacts related to the regional-scale problems experienced in the greater South Florida Watershed.

While every model developed throughout this design process aims to visualize algae somehow, the focus of each model varies greatly, as does the process of building those responsive models. The technology and data resources used for each and every model is very different, and their purpose remains specific to what information they are taking in and communicating. The Lake Okeechobee model, inspired by Cantrell-Holzman's elucidate chapter, reprocesses and projects hyperspectral data into the rhino scene for further spatial investigation. The Algae Experiment displaces algae from its context and allows us to better understand how it grows and responds to certain temperature parameters. The C-44 Channel model allows us to respond to modifications designed within the St.

Lucie Canal actively and represent algae dynamics via simulation. The St. Lucie Estuary model compresses various data, water quality parameters, and space to understand the relationship between salinity levels, water temperatures, and algae growth potential over time. Finally, the Algae Mitigation tiles show us how rapid prototyping and small-scale landscape interventions may lead us towards understanding the algae phenomenon in new ambient ways.

The case studies also reveal how landscape infrastructure may lead to synthetic ecologies along with encouraging novel methods in algae dynamic visualization and alteration. Specific protocols and management regimes lead to manipulated landscape ecosystems. Every model extends our understanding of how landscape architects may begin to engage with this issue. Following the Cantrell-Holzman framework, does so through a variety of design methods and intentions. The models show us that we do have agency and the capacity to work on examining more holistic solutions through the modern technology we have.

Approach. Programming languages were the foundation for every model explored throughout this research. In order to collect, manage, and manipulate specific data, the process required some knowledge in the Grasshopper interface, Python programming, and Gcode languages. Along with understanding these languages, the following Grasshopper Plugins and Python Modules were utilized to complete the models explored in the preceding section:

1. The Grasshopper Interface:
    - 1.1 Grasshopper Python*; running custom code*
    - 1.2 Proving Ground; *data visualization in Rhino scene*
    - 1.3 Bison; *importing LiDAR and creating meshes*
    - 1.4 Groundhog; *hydro channel analysis*
    - 1.5 Human; *customizing preview and graphics*

2. Python Modules:
    - 1.1 import OS*; working with the operating system*
    - 1.2 import IO*; working with various file types*
    - 1.3 import Pandas; *data analysis tool*

1.4 import Matplotlib; *data visualization library*
1.5 import Matplotlib.animations; *data animations library*
1.6 import Hydrofunctions; *USGS waterway data*
1.7 import Math; *variety of math related functions*
1.8 import Numpy; *more math functions and arrays*
1.9 import Datetime; *working with dates and times*
1.10 import itertools; *iterative tools for looping*

To clearly define the approach of each model, the Lake Okeechobee Model utilizes Sentinel-3 hyperspectral imagery which is processed through Grasshopper Python and built using image sampling techniques in the Grasshopper environment. The Algae Experiment employed an Ardunio microcontroller for temperature sensing and a webcam for image output. Both the sensed temperature and imagery were processed through Python for visualization and GIF creation. The C-44 Channel Model is, perhaps, the most complex, in which Grasshopper and Rhino is used to build the canal bathymetry, python and the USGS Hydrofunctions module provides discharge rates and other sediment parameters, and the CCHE2D model simulates water flow and algae dynamics. Altogether, through the concept of interoperability, these processes return to the Rhino/Grasshopper interface so that informed decision may be made. The St. Lucie Estuary Model also applies Python and Grasshopper so that real-time sensed data may be visualized in the Rhino environment. The resulting visualization renders where algae blooms may potentially occur. The final Algae Mitigation Tiles utilize a similar image sampling technique in the Lake Okeechobee model. The tile pattern, informed by algae growth, is built inside of the Grasshopper environment, while Gcode scripting allows the tile to be sent to a 3D Clay Potterbot for rapid prototyping.

With all of this in mind, it’s important to note that responsive modeling may be approached through the Arduino interface. Although Arduino is incredibly important in regards to sensing the phenomenon produced in physical models, Grasshopper and Python become the bridge between sensed phenomenon and importing that sensed data into the digital realm. Although many Responsive modeling case studies explore the Arduino suite, Python and Grasshopper are essential in transcribing the sensed and simulated data into the design platform.

Figure 4.20 / Exhibit of Work

On May 20th, 2021, I held a collaborative exhibition with Heather Tietz, showcasing our Masters's Projects. As seen in this photo, the work was displayed in a variety of ways. I managed animations of all the models onto a screen, the physical algae mitigation tiles, and the algae experiment. This exhibition provided an opportunity to publicly show this work, inviting instructors and fellow cohort members to host a discussion about the impacts of globalization, the use of modeling with respect to Landscape Architecture, and further understanding the models in a dialogical setting.
.

Implications. Through various sensing instruments and tools, we can understand the growing algae crisis in new and innovative ways. Like sediment and dredge management practices, algae is a landscape material that may be charted, collected, and repurposed in various ways. These tactics may now be explored more specifically through the responsive model. If landscape managers in this region continue to push for abductive methods in engaging this issue, more ecological knowledge will be garnered, and this knowledge is compelling. The results of these models may keep us more informed of the damage we may have on sensitive ecosystems, provide warning signals and alerts for local community members while providing a collaborative network in managing the issue. Issues related to landscape infrastructure can become highly political and managed beyond most stakeholders' control; upstream decisions lead to downstream consequences. Ideally, the responsive knowledge and its abductive implications have the potential to reverse this decision-making process.

Limitations. As a design method, responsive modeling features a variety of limitations. The most prevalent restriction is the fact that a responsive model is a particular set of operations. With this, a lot of knowledge is needed to understand the necessary data and landscape dynamics relevant to any investigation. In addition, once a responsive model is built to deal with certain data inputs, it is incredibly cumbersome to manipulate its process and capacity for dealing with alternative data. As a result, the responsive model design is extremely iterative; once more information is discovered through the modeling process, a new iteration of the model may be developed. As a result, it takes quite a bit of time to develop a responsive modeling process, and only so much information may be deduced through a single process.

Each modeling application has its limitations, and it is generally related to the model's approach and purpose. The Lake Okeechobee Model is limited by what is visible from space; elucidating may only occur if sensing data is possible and accessible. The Algae experiment is limited by scale and the controls of the displaced growing environment. The C-44 Channel Model is limited by data processing and the amount of information we can simulate. The amount of computational processing limits the St. Lucie Estuary model; in fact, both the C-44 Channel and St. Lucie Estuary are cumbersome models to run. It takes a while to visualize and render the data fully. These two models are entirely digital, and this digitization is partitioned by what can be processed and processing times. To modify and compress is to use a lot of computational processing. The models may become complex very quickly due to the variety of plugins, sensors, and algorithms required for their success. At last, the Algae Mitigation Tiles are limited by the dimensions of the 3D clay printer and the structural integrity of clay as a printing material.

The responsive model is both data and material-driven. As a result, the model is only as good as the data given and the information we have about the material. Limitations occur concerning both computational processing capabilities and the sensing instruments provided for understanding material dynamics. Scale becomes the following limitation, for only so much data can be understood in small-scale modeling environments. The larger the physical modeling environment, the more we may begin to understand sensed phenomena accurately. Of course, larger-scaled physical models are more costly and harder to maintain. Meanwhile, large-scale digital models require way too much processing power depending on the resolution and data input. Finding a balance between all of these responsive modeling limitations is a challenge and requires a lot of investigation.

Closing the Loop

The advantage in borrowing Nijhuis and Bobbink's RTD methodology for this project opens up a series of discussions relating to what the responsive model is and how it may assist in the mitigation of algae in South Florida. To recall the methodology section *Testing Responses*, this is where we close the loop between research domains. As the reflection to the preceding experimental design translations, additional insight, knowledge, and critique may be contemplated.

The asserted limitations provide us a coherent understanding of what the responsive model could be; therefore, limits provide us a framework, or series of principles, to better understand the responsive model and the elements we should consider when designing and constructing a responsive model. From an overall point of view, these limitations revolved, mostly, around data accessibility, remote sensing instruments, and processing power. However, there were patterns discovered relating to foundational processes governing computational modeling, such as scale or the communication between programs. The use of software, like Grasshopper, and programming languages, such as Python, was beneficial in that it opened many doors between programs and data processing.

In the same vein, the implications reveal to us the potential of the responsive model when analyzing and evaluating the South Florida algae crisis. As a result, we may surmise a series of suggestions and future steps for the issues surrounding algae mitigation. All in all, the implications become visionary heuristics; they may empower the water managers to make more holistic, informed decisions while keeping stakeholders, such as community members, more involved in the process. Through this, the responsive model, indeed, becomes a landscape of sharing knowledge and decisions across boundaries. The concluding section will examine and reflect upon these limitations and implications, providing a detailed discussion on responsive modeling principles and will synthesize the project overall as a final reflection.

5.

Conclusion

Principles of Responsive Modeling

The following principles are derived from the limitations discussed in the Design Findings and Responses section. These are the results from both of the design research domains as adapted from the Nijhuis and Bobbink RTD methodology, which investigated responsive model case studies and resulted in the translation of responsive model processes into the South Florida context.

1. Acquisition, *or data collection.* Where is the data located? This principle has us explore the various databases and resources relevant to the investigation and has us request necessary tokens for API requests.

Acquisition consists of two primary pathways. If the responsive modeler has access to sensing instruments, this principle becomes relatively straightforward; next steps include understanding what needs to be sensed and why. After developing an understanding of sensing needs, several sensing platforms may be explored, such as Arduino or Raspberry Pi, in which sensors and sensing codes, or *sketches*, may be tailored to the model. If the scale of the project is more regional, the model may have to tap into Statewide, or even Federal, databases and monitoring systems. If this is the case, the modeler will have to search for available monitoring systems, look for tokens or keys for data access, and review how to query certain data through API requests. Too much data is typically better than too little; therefore, it's important to consider resources with several sensing outputs.

2. Resolution, *or scale.* What is the scale to be investigated? This principle considers study area size, context to include, and data resolution, or information stored in a unit of measurement.

This principle, though it may sound general and obvious, is incredibly important when dealing with data and visualization. Many of the challenges endured throughout Algae as Agents included the parsing of either too much or too little data. If responsive modelers understand this principle, it means that there's a balance between data and space; therefore reducing the overall processing weight with respect to adequately visualizing data. Figure 5.1 reveals how data resolution is an act of balance. As seen from left to right, too little resolution results in missing details while too much resolution may break certain parts of the model. The responsive model is a sensitive composition; specific knowledge is required before defining model bounds and intended detail for clarity sake.

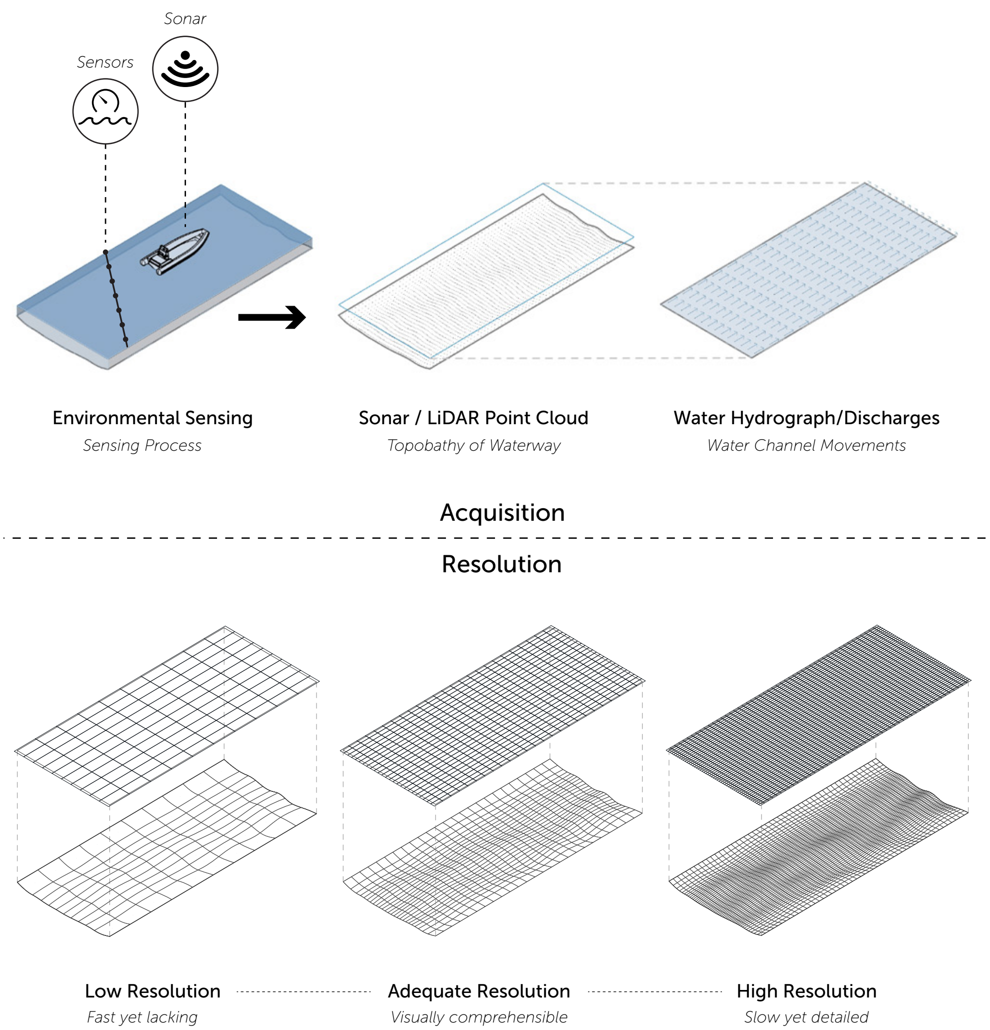


Figure 5.1 / The Principles of Acquisition and Resolution

This diagram reveals the process of collecting data and finding an appropriate way of representing the data. By sensing the environment to represent it digitally, the responsive model must balance necessary data and appropriately represent it. Although more information is better than less, this isn't necessarily true when defining the model's scale, domains, and detail. If too low, the model lacks detail. If too high, the model will become impossible to manage,
.

3. Conjugation, ***or exchange.*** What modeling environments do we need to satisfy the study goal? Through this process, developing interoperability, or connections, to alternative software may be necessary for the responsive model

Interoperability is the process of working between programs and typically includes the transference of data outputs. This exchange of sensed, simulated, or predicted data is necessary when constructing a responsive model because most design softwares lack the capacity to simulate complex bio-physical processes. In the case of Algae as Agents, hydrodynamics was a major focus, and therefore required the use of a hydrodynamic computational model (CCHE2D). Utilizing programming languages, like Python and Grasshopper, enabled conjugation between the Rhino modeling environment and external processing softwares. Figure 5.2 represents the process between converting rhino topography into an ASCII file for CCHE2D mesh import. An ASCII is a type of raw text file that denotes the XYZ coordinates of the Rhino mesh and makes it easy to translate topographic explorations in a variety of GIS softwares and simulation based programs.

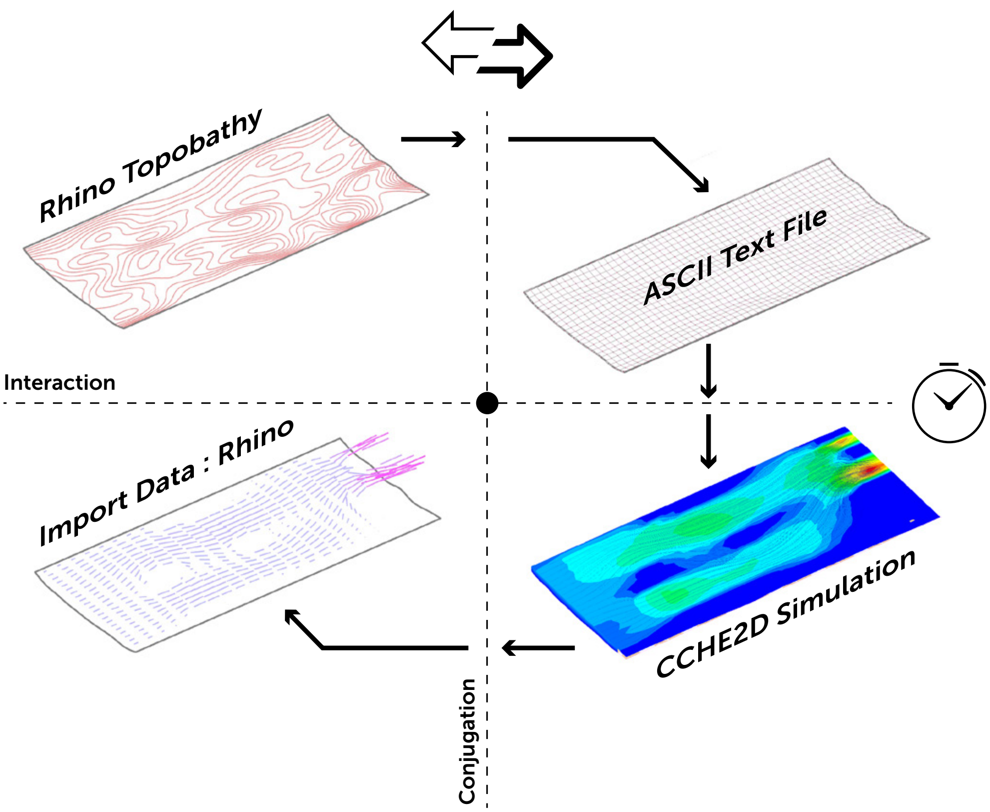


Figure 5.2 / The Principles of Conjugation & Interaction

This diagram maps out the relationship between Conjugating, connecting to outside software, interacting or bringing the output from the external software back into the design platform. In this case, a method was created to export Rhino mesh geometry into an ASCII file for CCHE2D import. After the simulation is complete from CCHE2D, the output text file is parsed and reinterpreted through the Grasshopper Environment.

4. Interaction, ***or latency.*** How long does it take to move between processing platforms? Higher-performing responsive models may move seamlessly between sensing, computation, and response.

While conjugation steers us towards bridging multiple platforms, interaction suggests the need for minimal delay between platforms. In order to accomplish an interactive model, the delay between sensing, or simulation, and informed responses shall be as minimal as possible. If we develop a responsive model with poorly constructed interaction, we may become completely disconnected between inductive analysis and deductive responses; the model loses its place as an abductive platform, in which hypothesis is generated and tested. Without adequate interaction, the following principles will become increasingly more challenging to fulfill.

5. Mutation, *or parameterization.* Is the system under investigation changeable? In order to react, or respond, to the inputs of a study, the model must be dynamic and morphable.

Mutation is an evolutionary process. In order for the responsive model to evolve, it must have the capacity to mutate and take its own form. The advantage of utilizing the Grasshopper interface includes the ability to parametrically adjust, or respond, to the insights gained through the previous principles. Mutation may also work through the use of a physical model with the appropriate sensing instruments. Once the model receives necessary information from sensors, monitors, or simulation, it may be manually adjusted or take on an autonomous nature altogether. As seen in Figure 5.3, a mutable model allows us to explore change and how that change may work within a simulative environment. In this case, a topobathy grasshopper script provided the modeler a place to investigate specific landscape form; as a result, we may elucidate and learn from the changes made within the mutable model. It's through mutation that we may begin to experimentally, and abductively, explore how landscape intervention may respond to one another. As seen below, there's an association between shallow waterbodies and velocity.

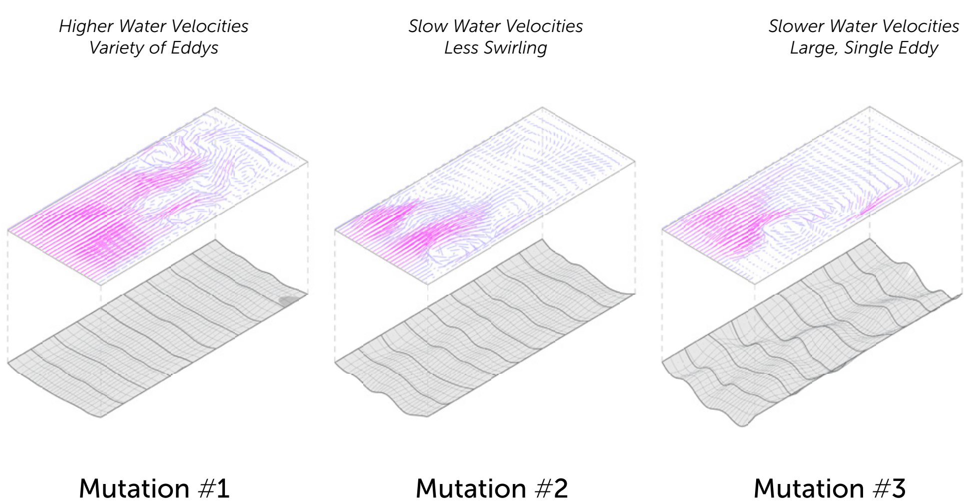


Figure 5.3 / The Principle of Mutation

This is a representation of a Grasshopper script that is entirely mutable. The topobathy is a loft from a series of curve profiles. The curve profiles may be manually adjusted to create forms for further investigation. In the case of this script, the algorithm adjusting the topobathy curve profiles is randomly adjusted. The height is defined by a range that may also be adjusted. The results from the CCHE2D simulation show an association between channel depth and water speeds.

6. Actuation, *or operation.* Does the model have the capacity to act or make decisions? The most challenging principle to achieve in which the model develops a form of sentience and an ability to make decisions.

Actuation elevates the model from purely visualizing phenomenon and decisions made by the modeler to making its own cognizant responses. This is known as autonomous intelligence, and it may be built into the responsive modeling environment. Bradley Cantrell & Justine Holzman refer to actuation as the embedment of intelligence into the model, in which machine learning algorithms may help solve novel issues defined by the modeler.[1] Once actuation is developed, the model's intelligence may become a form of synthetic ecology, in which computational landscape management creates new forms of landscape intervention and subsequent ecosystem dynamics.[2] The experimental design studies in the previous section did not reached this level of responsive modeling development, however a handful of models explored as inspiration for this project reveal this principle and it typically takes specific AI scripting knowledge. Figure 5.4 shows how solvers, such as Grasshopper's very own Galapagos, may be scripted to solve certain problems. In this case, the model was introduced to an algorithm that would find the highest velocities through Phillip Belesky's Groundhog plugin. The best solution, average solution, and worst solution was then simulated in the CCHE2D environment.

Ultimately, these principles may help guide inquisitive designers towards the development of a responsive model. In many ways, these principles act as a sequence of actions in which one may lead into the following in an organic manner. From understanding the model's *resolution*, we may move into the *acquisition* of data. Once we have usable data and establish *conjugation* between necessary platforms, we may simultaneously actualize an appropriate *interaction*. Finally, the scripting of a dynamic, mutable model will naturally lead to a system that may learn from those *mutations* and *actuate* a predetermined outcome.

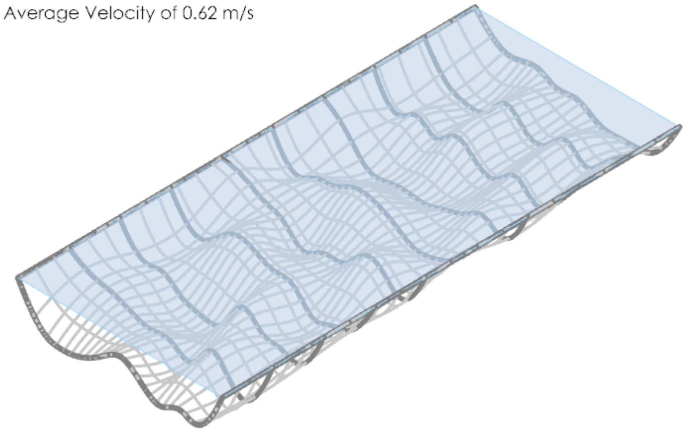
1 See Cantrell and Holzman's "Responsive Landscapes" (2016), page 64, for more information.

2 See Cantrell and Holzman's Synthetic Ecologies: protocols, simulation, and manipulation for indeterminate landscapes (2014)

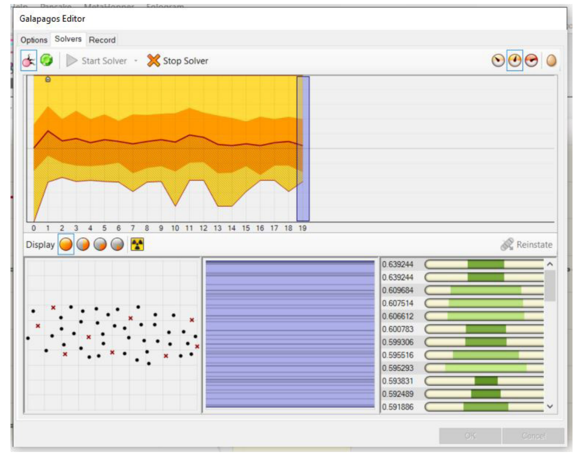
Figure 5.4 / The Principle of Actuation

This diagram shows how the computer may be used to find certain solutions to a predefined question automatically. In this case, the algorithm asked Grasshopper and Galapagos to find a variation of channel profiles that result in the highest velocities. As seen in the top-left, grasshopper searches through these mutations, iterating through all of the possible variations, and starts to find "solutions" or modifications that are closest to the goal of higher velocity. This is actively mapped out in the Galapagos solver, seen in the upper-right. The bottom shows the solver's results, in which the best, worst, and average solutions were chosen to run through the CCHE2D simulator. The result verifies Phillip Belesky's Groundhog component for channel hydrology.

Average Velocity of 0.62 m/s



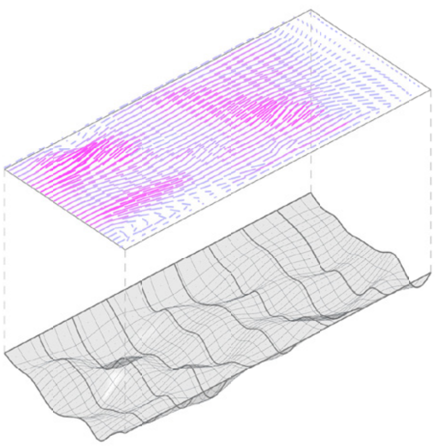
Galapagos Solver

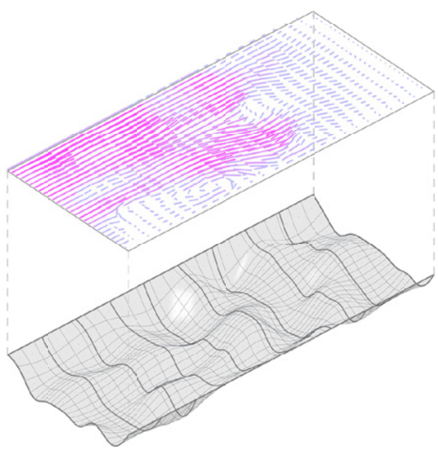


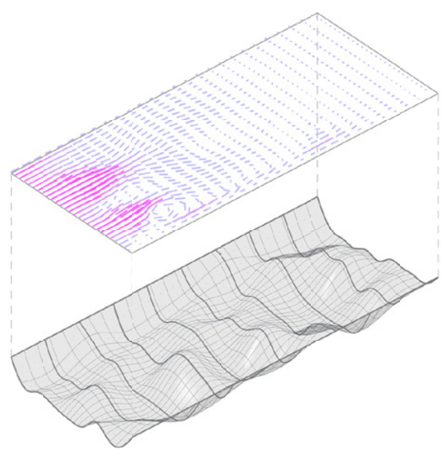
Highest Water Velocities
Produce Higher Turbulence and Eddy Viscosity

Moderate Water Velocities
Even Spread of Velocity

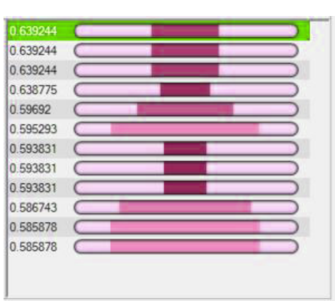
Slow Water Velocities
Low Viscosity and Deposition



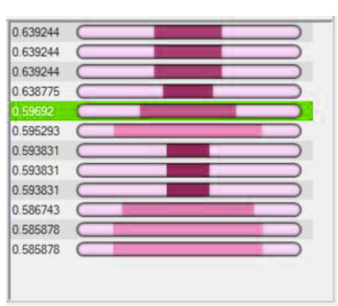




Most Fit Mutation



Moderate Mutation



Least Fit Mutation

Looking Back & Forwards

Guided by design research and research-by-design, Algae as Agents realizes how the responsive model is a research methodology that employs a variety of abductive processes and design strategies. Of course, the development of such a model takes time to understand the various material properties and methods that may occur throughout the system. Therefore, substantial analysis and review of literature, management practices, and research pertaining to algae was conducted well before the development of any model seen in the Design Responses section. This is an important note because it reminds us that our understanding shall inform models of specific patterns and insights of ecological processes and landscape management.

The additional research written on understanding the historical context of geospatial modeling related to Steinitz shows us how the computational landscape model is a continually maturing approach towards understanding the world around us. Bradley Cantrell's approach towards responsive modeling is inherently tied to the histories of geospatial modeling systems. Although Cantrell introduces sensors and mechanical instruments into the modeling process, much of the science and philosophies surrounding the geospatial sciences may be seen in the responsive model; this is apparent in the structure of logical operations, data, and the ways we visualize, map, and communicate data. To summarize the significant differences between these computational modeling frameworks:

The technological advancements & access to sensing instruments seen in Cantrell's Responsive Model were not available to Carl Steinitz in the late 20th Century. Geodesign is structured around an iterative framework designed for decision-makers while the Responsive Model learns from itself to benefit subjectively prescribed algorithms. Both models meander between induction and deduction, however, the Responsive model works more abductively due to its capacity for parallel computing.

With a more coherent understanding of these two modeling approaches, case studies were examined further to develop insight into what has been previously advanced through responsive modeling. Some of the principles explored in the meta-analysis in the Design Findings & Responses section were informed by the knowledge gained in these case studies. With this, the process of translating the information and methods discovered in the design research domain led to a series of limitations and implications that further informed the principles relevant to constructing a responsive model. We may achieve multi-faceted results through this layered approach, extending well beyond the principles of responsive modeling into suggestions for water managers engaged with cyanobacterial blooms in South Florida. Many of these suggestions remain highly speculative and may be developed further in future research and experimental model studies. Algae as Agents shows us how the application of responsive modeling can engage the biophysical complexities of algae and water management systems.

In continuing this research, more focus should be put towards developing a model that engages the actuation principle. If actuation were achieved, the model would actively solve problems autonomously, welcoming new insight into these dynamics' complexities as it performs. In other words, machine learning may help guide us toward a more profound understanding between meeting water manager protocols and managing algae proliferation. One example to illustrate this level of responsive modeling would be testing the relationship between Lake Okeechobee water stage heights concerning remotely sensed algae blooms. If water stage heights are relatively high and algae blooms are starting to spread, spillways and outfalls may be opened to keep water levels on track and potentially increase overall ecological dynamics throughout the lake (lower lake levels result in healthier ecological dynamics).

Designing a model capable of machine learning could become an incredibly collaborative experience, in which the Army Corp of Engineers, ecologists, programmers, community members, and landscape architects may have a place to collectively meet, either virtually or in-person, and gain new knowledge surrounding this issue.

6.

Bibliography

Abruzzo, Emily, et al. Models: 306090 11. Princeton Architectural Press, 2007.

Alexander, Christopher, et al. A Pattern Language: Towns, Buildings, Construction. OUP USA, 1977.

Alves-de-Souza, Catharina, et al. "Significance of Plankton Community Structure and Nutrient Availability for the Control of Dinoflagellate Blooms by Parasites: A Modeling Approach." PLOS ONE, vol. 10, no. 6, Public Library of Science, June 2015, p. e0127623. PLoS Journals, doi:10.1371/journal.pone.0127623.

"An Interview with Landscape Architect Bradley Cantrell." Modelo Blog, https://modelo.io/blog/index.php/design-manifestos-bradley-cantrell/. Accessed 12 Mar. 2021.

Anderson, Jonathon R., and Daniel H. Ortega. Innovations in Landscape Architecture. Routledge, 2016.

Army Corp of Engineers: Jacksonville DIstrict. "2015-2020 MOMENTUM: Report to Congress – Comprehensive Everglades Restoration Plan." Issuu, https://issuu.com/usace_saj/docs/final_2020_report_to_congress_on_cerp_progress_hig. Accessed 5 Mar. 2021.

Army Corp of Engineers: Jacksonville District. Central and Southern Florida Project: Water Control Plan for Lake Okeechobee and Everglades Agricultural Area. Mar. 2008, https://www.saj.usace.army.mil/Portals/44/docs/h2omgmt/LORSdocs/2008_LORS_WCP_mar2008.pdf.

Army Corp of Engineers: Jacksonville DIstrict. Lake Okeechobee System Operating Manual (LOSOM). https://www.saj.usace.army.mil/LOSOM/. Accessed 24 Oct. 2020.

Audubon_fl_high_water_levels_in_lake_okeechobee_-_the_threat_of_diaster.Pdf. https://fl.audubon.org/sites/default/files/static_pages/attachments/audubon_fl_high_water_levels_in_lake_okeechobee_-_the_threat_of_diaster.pdf. Accessed 8 Jan. 2021.

Babbitt, Bruce E. Cities in the Wilderness: A New Vision of Land Use in America. Island Press, 2005. ProQuest Ebook Central, http://ebookcentral.proquest.com/lib/uoregon/detail.action?docID=3317378.

Bélanger, Pierre. Landscape as Infrastructure : A Base Primer. Abingdon, Oxon, 2016.

Belesky, Philip. "Testing Terrain: Exploring the Computational Design of Natural Systems in Landscape Architecture." Testing Terrain: Exploring the Computational Design of Natural Systems in Landscape Architecture, 2018.

Bloom in Lake Okeechobee. NASA Earth Observatory, 6 July 2016, https://earthobservatory.nasa.gov/images/88311/bloom-in-lake-okeechobee.

Butman, Bradford, et al. "Investigating the Importance of Sediment Resuspension in Alexandrium Fundyense Cyst Population Dynamics in the Gulf of Maine." Deep Sea Research Part II: Topical Studies in Oceanography, vol. 103, May 2014, pp. 79–95. ScienceDirect, doi:10.1016/j.dsr2.2013.10.011.

Cantrell, Bradley. "Adaptation." LA+; Interdisciplinary Journal of Landscape Architecture, vol. 01, no. 04, 04, 2015, pp. 69–75.

---. "Designing Autonomy: Opportunities for New Wildness in the Anthropocene." Trends in Ecology & Evolution, vol. 32, no. 3, Elsevier, Mar. 2017, pp. 156–66. www.cell.com, doi:10.1016/j.tree.2016.12.004.

Cantrell, Bradley; Holzman. "Synthetic Ecologies: Protocols, Simulation, and Manipulation for Indeterminate Landscapes." ACADIA 14: Design Agency [Proceedings of the 34th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA) ISBN 9781926724478]Los Angeles 23-25 October, 2014), Pp. 709-718, CUMINCAD, 2014. papers.cumincad.org, http://papers.cumincad.org/cgi-bin/works/paper/acadia14_709.

Cantrell, Bradley, and Justine Holzman. Responsive Landscapes: Strategies for Responsive Technologies in Landscape Architecture. First edition, Routledge, 2016.

Cantrell, Bradley, and Adam Mekies. Codify: Parametric and Computational Design in Landscape Architecture. Routledge, 2018.

Carey, Cayelan C., et al. "Eco-Physiological Adaptations That Favour Freshwater Cyanobacteria in a Changing Climate." Water Research, vol. 46, no. 5, 5, Apr. 2012, pp. 1394–407. ScienceDirect, doi:10.1016/j.watres.2011.12.016.

Carpenter, Stephen R. and Millennium Ecosystem Assessment (Program), editors. Ecosystems and Human Well-Being: Scenarios: Findings of the Scenarios Working Group, Millennium Ecosystem Assessment. Island Press, 2005.

Chao, Xiaobo, et al. "Numerical Modeling of Sediment Transport and Its Effect on Algal Biomass Distribution in Lake Pontchartrain Due to Flood Release from Bonnet Carré Spillway." Journal of Geoscience and Environment Protection, vol. 04, Jan. 2016, pp. 64–79. ResearchGate, doi:10.4236/gep.2016.49006.

Chapra, Steven C., et al. "Climate Change Impacts on Harmful Algal Blooms in U.S. Freshwaters: A Screening-Level Assessment." Environmental Science & Technology, vol. 51, no. 16, 16, Aug. 2017, pp. 8933–43. ACS Publications, doi:10.1021/acs.est.7b01498.

Cheramie, Kristi. "The Scale of Nature: Modeling the Mississippi River." Places Journal, Mar. 2011. placesjournal.org, doi:10.22269/110321.

Comprehensive Everglades Restoration Plan, ... Report to Congress. https://ufdc.ufl.edu/AA00064951/00002. Accessed 5 Mar. 2021.

Cyano_mitigation_GlobalHAB2019.Pdf. http://www.globalhab.info/files/Cyano_mitigation_GlobalHAB2019.pdf. Accessed 6 Jan. 2021.

Deleuze, Gilles. Difference and Repetition. Columbia University Press, 1994.

Deming, Elen M. Landscape Architecture Research : Inquiry, Strategy, Design. Chichester : John Wiley & Sons, 2011.

Dillon, P. J. “The Phosphorus Budget of Cameron Lake, Ontario: The Importance of Flushing Rate to the Degree of Eutrophy of Lakes1.” Limnology and Oceanography, vol. 20, no. 1, 1975, pp. 28–39. Wiley Online Library, doi:https://doi.org/10.4319/lo.1975.20.1.0028.

Douglas, Marjory Stoneman. The Everglades: River of Grass. Pineapple Press Inc, 1997.

Dredge Research Collaborative. https://dredgeresearchcollaborative.org/. Accessed 24 Oct. 2020.

Dreschel, Thomas, et al. The Loxahatchee Impoundment Landscape Assessment (LILA) Facility: Supporting Everglades Restoration Research for More Than a Decade. 2013.

Dreschel, Thomas, and Fred Sklar. 2016 South Florida Environmental Report Chapter 6: Everglades Research and Evaluation. 2016. ResearchGate, doi:10.13140/RG.2.1.2117.0961.

Ed Killer. We’re in Recovery Mode. 26 May 2018, https://www.tcpalm.com/story/sports/2018/05/26/were-recovery-mode/642945002/.

Elosegi, Arturo, and Sergi Sabater. “Effects of Hydromorphological Impacts on River Ecosystem Functioning: A Review and Suggestions for Assessing Ecological Impacts.” Hydrobiologia, vol. 712, no. 1, 1, July 2013, pp. 129–43. Gale Academic OneFile.

Everglades & South Florida Ecosystem Restoration Critical Restoration Projects (Overview) (C). https://www.saj.usace.army.mil/About/Congressional-Fact-Sheets-2020/Everglades-South-Florida-Ecosystem-Restoration-Critical-Restoration-Projects-Overview-C/. Accessed 27 Jan. 2021.

Everglades Restoration Initiatives. https://www.evergladesrestoration.gov/sferp/. Accessed 27 Jan. 2021.

Foster, Kelleann. “Geodesign Parsed: Placing It within the Rubric of

Recognized Design Theories." Landscape and Urban Planning, vol. 156, Dec. 2016, pp. 92–100. ScienceDirect, doi:10.1016/j.landurbplan.2016.06.017.

Franks, Peter J. S. "Models of Harmful Algal Blooms." Limnology and Oceanography, vol. 42, no. 5, 1997, pp. 1273–82.
---. "Recent Advances in Modelling of Harmful Algal Blooms." Global Ecology and Oceanography of Harmful Algal Blooms, edited by Patricia M. Glibert et al., Springer International Publishing, 2018, pp. 359–77. Springer Link, doi:10.1007/978-3-319-70069-4_19.

Girot, Christophe. "Simulation As Model." LA+; Interdisciplinary Journal of Landscape Architecture, vol. 01, no. 04, 04, 2015, pp. 50–57.

Glaeser, Stefanie P., et al. "Contrasting Effects of Singlet Oxygen and Hydrogen Peroxide on Bacterial Community Composition in a Humic Lake." PLOS ONE, vol. 9, no. 3, Public Library of Science, Mar. 2014, p. e92518. PLoS Journals, doi:10.1371/journal.pone.0092518.

Gray, Paul N. A Brief History of Lake Okeechobee Ecosystem Responses To Water Level Management. p. 9.

How High, How Low Should Lake O Go to Prevent Algae Blooms? https://www.tcpalm.com/story/news/local/indian-river-lagoon/health/2018/08/14/how-high-how-low-should-lake-o-go-prevent-algae-blooms/866967002/. Accessed 8 Jan. 2021.

Howarth, Robert W., and Roxanne Marino. "Nitrogen as the Limiting Nutrient for Eutrophication in Coastal Marine Ecosystems: Evolving Views over Three Decades." Limnology and Oceanography, vol. 51, no. 1part2, 2006, pp. 364–76. Wiley Online Library, doi:https://doi.org/10.4319/lo.2006.51.1_part_2.0364.

Implementing the Comprehensive Everglades Restoration Plan (CERP) :Hearing before the Committee on Environment and Public Works, United States Senate, One Hundred Seventh Congress, Second Session, on Oversight of the Restoration of the Everglades, September 13, 2002. Washington :, 2004, http://hdl.handle.net/2027/uc1.b5139076.

Indian River Lagoon - South. https://www.saj.usace.army.mil/Missions/Environmental/Ecosystem-Restoration/Indian-River-Lagoon-South/www.sfwmdgov/c44cam/. Accessed 27 Jan. 2021.

Institute, The James Madison. "Solving the Everglades Riddle: Addressing Water Quality and Quantity to Restore a Florida Legacy." James Madison Institute, 6 June 2017, https://www.jamesmadison.org/solving-the-everglades-riddle-addressing-water-quality-and-quantity-to-restore-a-florida-legacy/.

Intergovernmental Panel on Climate Change. Global Warming of 1.5°C. 2018. Open WorldCat, http://www.ipcc.ch/report/sr15/.

Johns, Grace, et al. "Developing Economic Indices to Assess the Human Dimensions of the South Florida Coastal Marine Ecosystem Services." Ecological Indicators, vol. 44, Sept. 2014, pp. 69–80. DOI.org (Crossref), doi:10.1016/j.ecolind.2014.04.014.

Klemas, Victor. "Remote Sensing of Algal Blooms: An Overview with Case Studies." Journal of Coastal Research, vol. 28, no. 1A, 1A, 2012, pp. 34–43. JSTOR.

Kramer, Benjamin J., et al. "Nitrogen Limitation, Toxin Synthesis Potential, and Toxicity of Cyanobacterial Populations in Lake Okeechobee and the St. Lucie River Estuary, Florida, during the 2016 State of Emergency Event." PLOS ONE, edited by Todd Miller, vol. 13, no. 5, 5, May 2018, p. e0196278. DOI.org (Crossref), doi:10.1371/journal.pone.0196278.

Lemaire, Janine, and Bénédicte Sisto. "The Everglades Ecosystem: Under Protection or Under Threat?" Miranda. Revue Pluridisciplinaire Du Monde Anglophone / Multidisciplinary Peer-Reviewed Journal on the English-Speaking World, no. 6, 6, Université Toulouse 2 - Le Mirail, June 2012. journals.openedition.org, doi:10.4000/miranda.2881.

Lenzholzer, Sanda, et al. "'Research through Designing' in Landscape Architecture." Landscape and Urban Planning, vol. 113, May 2013, pp. 120–27, doi:10.1016/j.landurbplan.2013.02.003.

Lin, Lizhou, et al. "The Ecological Risks of Hydrogen Peroxide as a Cyanocide: Its Effect on the Community Structure of Bacterioplankton." Journal of Oceanology and Limnology, vol. 36, no. 6, Nov. 2018, pp. 2231–42. Springer Link, doi:10.1007/s00343-018-7233-3.

Lister, Nina-Marie. "Resilience: Designing the New Sustainability." Topos: The International Review of Landscape Architecture & Urban Design, no. 90, 90, 2015, pp. 14–21. bvh.

Margalef, R. "Life-Forms of Phytoplankton as Survival Alternatives in an Unstable Environment." Undefined, 1978. www.semanticscholar.org, /paper/Life-forms-of-phytoplankton-as-survival-in-an-Margalef/1aa7aba56b3efc96f62c6d8278a5e171a44aa18e.

Marjory Stoneman Douglas - Division of Cultural Affairs - Florida Department of State. https://dos.myflorida.com/cultural/programs/florida-artists-hall-of-fame/marjory-stoneman-douglas/. Accessed 8 Jan. 2021.

Matthijs, Hans C. P., Daniel Jančula, et al. "Existing and Emerging Cyanocidal Compounds: New Perspectives for Cyanobacterial Bloom Mitigation." Aquatic Ecology, vol. 50, no. 3, Sept. 2016, pp. 443–60. Springer Link, doi:10.1007/s10452-016-9577-0.

Matthijs, Hans C. P., Petra M. Visser, et al. "Selective Suppression of Harmful Cyanobacteria in an Entire Lake with Hydrogen Peroxide." Water Research, vol. 46, no. 5, Apr. 2012, pp. 1460–72. ScienceDirect, doi:10.1016/j.watres.2011.11.016.

McGillicuddy Jr., Dennis J., et al. GEOHAB Modelling: Linking Observations to Predictions: A Workshop Report. International Council of Scientific Unions. Scientific Committee on Oceanic Research, Jan. 2011. digital.csic.es, https://digital.csic.es/handle/10261/53192.

M'Closkey, Karen, and Keith VanDerSys. Dynamic Patterns: Visualizing Landscapes In A Digital Age. Routledge, Taylor & Francis Group, 2017.

Nijhuis, Inge Bobbink Steffen. "Design-Related Research in Landscape Architecture.(Report)(Author Abstract)." Journal of Design Research, vol. 10, no. 4, 4, 2012, p. 239.

Nijhuis, Steffen, and Jeroen de Vries. "Design as Research in Landscape Architecture." Landscape Journal: Design, Planning, and Management of the Land, vol. 38, no. 1, University of Wisconsin Press, 2019, pp. 87–103.

Oehrle, Stuart, et al. "Toxin Composition of the 2016 Microcystis Aeruginosa Bloom in the St. Lucie Estuary, Florida." Toxicon, vol. 138, Nov. 2017, pp. 169–72. ScienceDirect, doi:10.1016/j.toxicon.2017.09.005.

O'Neil, J. M., et al. "The Rise of Harmful Cyanobacteria Blooms: The Potential Roles of Eutrophication and Climate Change." Harmful Algae, vol. 14, Feb. 2012, pp. 313–34. DOI.org (Crossref), doi:10.1016/j.hal.2011.10.027.

Peterson - Solving the Everglades Riddle.Pdf. https://www.jamesmadison.org/wp-content/uploads/2018/06/Everglades-Backgrounder-v08.pdf. Accessed 27 Jan. 2021.

Ralston, David K., and Stephanie K. Moore. "Modeling Harmful Algal Blooms in a Changing Climate." Harmful Algae, vol. 91, Jan. 2020, p. 101729. ScienceDirect, doi:10.1016/j.hal.2019.101729.

Raxworthy, J. "Responsive Landscapes: Strategies for Responsive Technologies in Landscape Architecture." Journal Of Landscape Architecture, vol. 12, no. 2, 2, 2017, pp. 90–91.

Research.Pdf. https://mospace.umsystem.edu/xmlui/bitstream/handle/10355/46477/research.pdf. Accessed 1 Feb. 2021.

Rossini, Gian Paolo. Toxins and Biologically Active Compounds from Microalgae, Volume 2: Biological Effects and Risk Management. CRC Press, 2014.

Salomon, David. “Warning Signals.” LA+; Interdisciplinary Journal of Landscape Architecture, vol. 01, no. 09, 09, 2015, pp. 32–39.

Smith, Bob. S.2797 - 106th Congress (1999-2000): Restoring the Everglades, an American Legacy Act. 27 July 2000, https://www.congress.gov/bill/106th-congress/senate-bill/2797. 1999/2000.

Srwe1-Chap8.Pdf. https://www.who.int/water_sanitation_health/bathing/srwe1-chap8.pdf. Accessed 6 Feb. 2021.

St. Johns River Water Management District. Indian River Lagoon National Estuary Program. 2007, https://www.sjrwmd.com/waterways/indian-river-lagoon/.

Steenbergen, Clemens M., and Technische Universiteit Delft, editors. Architectural Design and Composition. THOTH Publishers ; Faculty of Architecture, TU Delft, 2002.

Steenson, Molly Wright. Architectural Intelligence: How Designers and Architects Created the Digital Landscape. MIT Press, 2017.

Steinitz, Carl. A Framework for Geodesign: Changing Geography by Design ; [the People of the Place, Design Professions, Geographic Sciences, Information Technologies]. 1. ed, Esri Press, 2012.

Steinitz, Carl. Geodesign: Past, Present, and Future. p. 54. 1. ed, Esri Press, 2013.

Steven P. Hamburg, et al. “Common Questions about Climate Change.” Global Change Research Information Office, 1997, http://www.gcrio.org/ipcc/qa/index.html.

Stevenson, Jan. “Ecological Assessments with Algae: A Review and Synthesis.” Journal of Phycology, vol. 50, no. 3, 3, 2014, pp. 437–61. Wiley Online Library, doi:10.1111/jpy.12189.

Stroom, Jasper M., and W. Edwin A. Kardinaal. “How to Combat Cyanobacterial Blooms: Strategy toward Preventive Lake Restoration and Reactive Control Measures.” Aquatic Ecology, vol. 50, no. 3, 3, Sept. 2016, pp. 541–76. Springer Link, doi:10.1007/s10452-016-9593-0.

Sunda, William G., and Kyle W. Shertzer. “Positive Feedbacks between Bottom-up and Top-down Controls Promote the Formation and Toxicity of Ecosystem Disruptive Algal Blooms: A Modeling Study.” Harmful Algae, vol. 39, Oct. 2014, pp. 342–56. ScienceDirect, doi:10.1016/j.hal.2014.09.005.

“Synthetic Mudscapes: Human Interventions in Deltaic Land Building.” LSU Coastal Sustainability Studio, https://css.lsu.edu/project/synthetic-mudscapes-human-interventions-in-deltaic-land-building/. Accessed 18 Mar. 2021.

“The Mississippi River Basin Model.” Atlas Obscura, http://www.atlasobscura.com/places/the-mississippi-river-basin-model. Accessed 5 Apr. 2021.

Tonk, Linda, et al. “Salt Tolerance of the Harmful Cyanobacterium Microcystis Aeruginosa.” Aquatic Microbial Ecology, vol. 46, no. 2, Feb. 2007, pp. 117–23. www.int-res.com, doi:10.3354/ame046117.

Toxic Algae Threatens FL Coasts with Another Lost Summer | Miami Herald. https://www.miamiherald.com/news/local/environment/article213849429.html. Accessed 15 Feb. 2021.

United Nations Environment. Marine and Coastal Ecosystems and Human Well-Being: A Synthesis Report Based on the Findings of the Millennium Ecosystems Assessment. UNEP, 2006. wedocs.unep.org, https://wedocs.unep.org/handle/20.500.11822/9461.

US Army Corp of Engineers, Jacksonville District. Central And Southern Florida Project Comprehensive Review Study: Final Integrated Feasibility Report And Programmatic Environmental Impact Statement. Apr. 1999.

---. Review Plan for C-44 Reservoir/Stormwater Treatment (STA) Project. Dec. 2012.

US EPA, OW. “Control Measures for Cyanobacterial HABs in Surface Water.” US EPA, 20 Aug. 2018, https://www.epa.gov/cyanohabs/control-measures-cyanobacterial-habs-surface-water.

Williams, Elizabeth Anne. “Synthetic Mudscapes: Human Interventions in Deltaic Land Building.” International Symposium for Next Generation Infrastructure Conference Proceedings, ISNGI, 2015. DOI.org (Crossref), doi:10.14324/000.cp.1469406.

Winsberg, Eric. “Simulated Experiments: Methodology for a Virtual World.” Philosophy of Science, vol. 70, no. 1, The University of Chicago Press, Jan. 2003, pp. 105–25. journals.uchicago.edu (Atypon), doi:10.1086/367872.

Yamaguchi, Haruo, and Koji Sai. “Simulating the Vertical Dynamics of Phosphate and Their Effects on the Growth of Harmful Algae.” Estuarine, Coastal and Shelf Science, vol. 164, Oct. 2015, pp. 425–32. ScienceDirect, doi:10.1016/j.ecss.2015.07.043.