UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

SEA LEVEL RISE IN EGYPT'S NILE RIVER DELTA: POLICY RECOMMENDATIONS TO ADDRESS AGRICULTURAL DECLINE AND INFRASTRUCTURAL DAMAGE

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

Degree of

MASTER OF ARTS IN INTERNATIONAL STUDIES

By

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Norman, Oklahoma
2020

SEA LEVEL RISE IN EGYPT'S NILE RIVER DELTA: POLICY RECOMMENDATIONS TO ADDRESS AGRICULTURAL DECLINE AND INFRASTRUCTURAL DAMAGE

A THESIS APPROVED FOR THE
COLLEGE OF INTERNATIONAL STUDIES

BY THE COMMITTEE CONSISTING OF

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Acknowledgements

First and foremost, I express immeasurable gratitude to my committee of powerful women.

Dr. Natalie Letsa, thank you for your generosity in time, energy, and mentorship. You are an exquisite human being, and I have been so fortunate to have your guidance during this program and my thesis writing process. Thank you for fostering my love for political economy in your class last fall, for helping me to analyze research from a macro perspective, for always keeping your office door open, and for fielding all of my random questions! You are amazing, and I am beyond grateful to know you. Thank you for everything.

Dr. Michelle Morais de Sá e Silva, thank you for your kindness, support, and intuitive perspective during my writing process. Since taking your international development class as an undergraduate student, I have admired your depth of understanding in all things aid and development. You are passionate, intelligent, and kind. It has been an honor to know you and have you on my team for so many years.

Dr. Emma Colven, thank you for your deep intellect, kindness, and generosity. Your meticulous and highly analytical feedback on my various drafts has been invaluable in helping me to craft a thesis of which I can be proud. You are sharp as a tack and exactly the expert that I wanted to provide mentorship as I researched water politics in the Nile Delta. You are incredible, adventurous, infinitely knowledgeable, and kind. Thank you.

Thank you to my fiancé, **Jacob**, for encouraging me always, with promises of adventure and burgers as rewards for writing! Thank you to my mom, **Marsha**, for all the love, kindness, and camaraderie throughout my life, and especially as I delved into this graduate program. Despite the excessive quarantining caused by the 2020 coronavirus, we navigated and enjoyed life together, with lots of fruit smoothies, burgers, broccoli, fried chicken, tree trimming, gardening, long walks, and TV marathons of *Naked and Afraid*, *Killing Eve*, *Ozark*, *Tiger King*, *Schitt's Creek*, and *Brooklyn Nine-Nine*. You are my best friend, and I love you forever.

Thank you to my darling **Cecilia**, my partner in crime since the beginning of this program. Our mutual support, Starbucks study nights, venting sessions, and laughter pushed me through the most demanding days of this program and life itself. I am so grateful for you and so proud of you.

Thank you to **Kelly**, my best friend since 9th grade. Though our academic and professional paths diverged, we have remained close, always able to spark a conversation or gobble up pad Thai on a moment's notice. You have been with me for nearly a decade, always loving and supportive and steadfast throughout our academic journeys. I am so proud of you, and I love you.

Finally, thank you to my **entire graduate cohort** and the University of Oklahoma's **Department of International and Area Studies**. I tackled six years in IAS and am finishing with a whole world ahead of me, thanks to the love and generosity of this program. I am so excited for the future and so grateful to every single person who raised me up to reach my goals.

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Abbreviations

AoA – Agreement on Agriculture

CLIMB – Climate-Induced Changes on the Hydrology of Mediterranean Basins

CWP – Crop Water Productivity

DRM – Disaster Risk Management

GDP – Gross Domestic Product

GFDRR – Global Facility for Disaster Reduction and Recovery

GIS – Geographic Information System

GMSL – Global Mean Sea Level

IDP – Internally Displaced Persons

IDSC – Information and Decision Support Center

IMF – International Monetary Fund

INGO – International Non-Governmental Organization

IPCC – Intergovernmental Panel on Climate Change

LSS – Linear Systematic Sampling

MENA – Middle East and North Africa

NGO – Non-Governmental Organization

SLR – Sea Level Rise

UN – United Nations

UNFCCC – United Nations Framework Convention on Climate Change

UNHCR – United Nations High Commissioner for Refugees

USAID – United States Agency for International Development

USD – United States Dollar

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Abstract

In this thesis, I evaluate the effects of sea level rise on agriculture and infrastructure in Egypt's Nile River Delta. In response to these effects, I propose policy recommendations to adapt to sea level rise and ultimately mitigate agricultural decline and infrastructural damage. Sea levels have steadily risen over the last 100 years, resulting in excess seawater and salt in the lower and middle regions of the delta. Because more than half of Egypt's population lives and works in the Nile Delta, sea level rise is a growing and impending catastrophe for Egypt. Farmers in the delta are already battling excess salt, which kills their crops, stunts growth, and exacerbates food insecurity and vulnerability. Climate scientists predict that these effects will worsen substantially if policymakers do not take aggressive action. Infrastructure along the delta's coast has already experienced ruin from floodwater, causing people to lose their homes, their livelihoods, and their stability. After examining these issues from various angles, I have proposed five policy recommendations, meant to be implemented in a hierarchical manner, from least to most difficult. Three feasible recommendations to address agricultural decline include 1) more efficient systems of water use, 2) government subsidies for shallow-root, water-efficient crop seeds, and 3) regulation of groundwater extraction. Two recommendations to address damaged infrastructure and the resulting displaced populations include 1) steel storm surge barriers, and 2) a mass, voluntary retreat. The mass voluntary retreat is a last resort, as it has historically been complex and has raised issues of ethicality.

Chapter 1: Introduction and Policy Outline

Sea level rise (SLR) due to global climate change has reduced agricultural productivity and destabilized infrastructure in Egypt's Nile River Delta region. Roughly 50% of Egypt's population lives and works along the delta, earning their living through farming and fishing.[1] With unemployment at 29% for youth, 36% for educated males, and 57% for educated females, agriculture is one of the primary economic sectors in Egypt, comprising 29% of total jobs.[2] The delta, then, is critical to local economic development and the stability of Egypt at large. Increased salinity and inundation from sea level rise have resulted in lower crop yield due to lack of freshwater, higher demand for freshwater, flooded homes and buildings due to inundation, and crumbling infrastructure due to sinkholes and softened ground.[3] Sea level rise and its repercussions, then, are pressing threats for local Egyptian economies along the Nile Delta. Thus, policy recommendations to adapt to these effects are of critical importance.

This thesis will examine peer-reviewed research and data to assess the effects of sea level rise on the agricultural productivity and infrastructure of communities living along Egypt's Nile River Delta. The policy recommendations provided will attempt to provide short-term adaptations for predicted decreases in agricultural output and damage to infrastructure caused by salinity and flooding. I define "infrastructure" in this paper as material structures such as houses and buildings.

This focus on short-term adaptations instead of long-term mitigation stems from the much more complex issue of absolute authority of states. Wealthy, industrialized states produce

[1] "Egypt." World Population Review, 2020, http://worldpopulationreview.com/countries/egypt-population/.
[2] Donovan, Dan. "Egypt's Coming Climate Calamity." *U.S. News & World Report*, 2015.
[3] El-Raey, Mohamed. "Vulnerability assessment of the coastal zone of the Nile delta of Egypt, to the impacts of sea level rise." *Ocean and Coastal Management*, 37(1), 1997, pp. 29-40.

the majority of greenhouse gas emissions, and simultaneously these states possess the wealth and resources to mitigate the resulting climate effects.[4] However, climate change is a globally scaled process, best addressed through global cooperation. International venues such as the United Nations are one of the most effective forums for cooperation and action toward these issues because of their strong, established unions among states. However, the UN's acknowledgment of absolute state authority limits its ability to demand or otherwise initiate total cooperation.[5]

As a result, addressing the true source of sea level rise and its effects on the Nile Delta is far more complex than could be addressed in a single paper. Thus, this thesis will assess current research and data and provide short-term recommendations for reducing the impacts of SLR on the delta. In doing so, it will simultaneously represent a call to action on the part of states, encouraging stronger global cooperation in the battle against climate change.

Recommendations for increased agricultural output will include three strategies: 1) the cultivation of specific water-efficient and shallow-root crops, which require the least amount of fresh water yet produce handsome yields, 2) efficient water use systems and subsidized crop teepees, which ensure that minimal water is lost to spillage or evaporation, and 3) government control of aquifer withdrawals, such that lack of regulation does not continue leading to excess withdrawal, spillage, and general waste. Policy recommendations for addressing and reducing the impacts of infrastructural damage hinge upon infrastructural development beyond the edges of the Nile River Delta and its valleys. Ultimately, vulnerable populations will be moved further away from potentially inundated areas. Recommendations for addressing and mitigating infrastructural damage include two plans: 1) steel storm surge barriers on the Nile River's two

[4] Jones, Reece. Violent Borders: Refugees and the Right To Move, 2016, p. 143.
[5] Ibid.

main branches (Damietta and Rosetta), which operate via computer and close according to sea level gauges and climate predictions and 2) a voluntary, mass retreat in which funding and support from various NGOs and intergovernmental organizations assist Egypt's most vulnerable to successfully move away from the coast to safer ground.

This thesis will move in specific sequence, with sections providing background information on the Nile Delta, current data on sea level rise, scholarly examinations of the predicted effects of sea level rise on Nile Delta agriculture and infrastructure, and my policy recommendations to address these effects. The Methods section will discuss my research and writing process. Chapter 2 will cover the Nile Delta's geology, history, economy, and politics. Chapter 3 will outline current research and data on the predicted repercussions of sea level rise on agricultural productivity in the Nile Delta, followed by policy recommendations to enhance agricultural productivity. Chapter 4 will outline current research and data on infrastructural damage and population displacement caused by sea level rise, followed by policy recommendations to address these problems.

1.1 Methods

The data, research, and recommendations used to inform this thesis originated from accredited, peer-reviewed journals from disciplines including international relations, geology, political science, horticulture, economics, history, and environmental science. Supplemented with government documents and articles from reputable news sources including *Reuters*, *Foreign Policy*, and *Cairo Press*, the information in this document has been compiled and presented to accurately reflect Egypt's Nile River Delta and the effects of sea level rise on its economic development, with specific focus on agricultural productivity and infrastructural damage.

I elected to focus my research on these symptoms of sea level rise because they are two of the most critical in terms of human capital. Framing these problems as issues of human rights or public health may not encourage government involvement as effectively, as Egyptian leadership has implicitly and explicitly expressed disenchantment in aiding its poor and vulnerable populations.[6] I therefore use an economic framework in order to spur attention and action on the part of Egypt's national, regional, and local governments. Losing a critical food source and revenue stream through agricultural hindrance will directly harm local populations, by risking their lives, homes, and economies. From an economic perspective, this poses a financial risk to Egypt's total economy via the value supplied by local populations.

In synthesizing academic articles with news sources, I found congruence between both types of sources, as they largely agreed that sea level rise is a threat to agriculture and infrastructure in the Nile Delta. This evidence provides a critical foundation for my policy recommendations for increasing agricultural productivity and addressing the need for population

[6] Hearst, David. "Curtains for Sisi? How Mohamed Ali upstaged Egypt's greatest showman." *Middle East Eye*, 2019.

resettlement. Limitations to these policy recommendations include a lack of primary sources, such as first-person observations in the delta. I therefore rely on the research and data collection of others. This presents potential issues concerning the reliability of sources. In order to ensure the reliability and validity of my sources, I draw only on data from peer-reviewed research produced by accredited institutions and their respective actors.

Chapter 2: History, Economy, Geology, and Politics of the Nile River Delta

This section of the paper will provide geological, historical, economic, and political background on the Nile Delta, in order to provide readers with the foundation necessary to understand the policy recommendations. Formed over thousands of years, Egypt's Nile River Delta is an arcuate (arc-shaped) buildup of rich sediment, carried from the rushing Nile River to the slow-moving Mediterranean Sea. Stretching from Alexandria to Port Said, the Nile Delta borders nearly 150 miles of Mediterranean coastline, making it one of the largest river deltas in the world. Ancient scholars long pondered the delta's origins, postulating that it was either carved through Egypt naturally or man-made in response to dry climate and famine.

Despite being nestled within Egypt's hot desert landscape, the Nile River Delta maintains fertile moisture, with average winter temperatures of 53.6°F and summer temperatures of 87.8°F.[7] Animal and plant life along the Nile have long been incorporated in Egyptian religion and art, emphasizing the centrality of the Nile and its life-giving nature in Egypt.[8] Animal and plant populations along the delta include thousands of migrating birds, especially whiskered terns, grey herons, and egrets. Turtles, frogs, and fish are the primary animal life, as crocodiles and hippopotamus no longer exist there in abundance. Figure 1 displays a satellite image of the delta in 2003, its fertile sediment and plant life depicted by the intense green color.

For at least five thousand years, Egyptians have lived and farmed in the Nile Delta, as historical construction of dams helped to manipulate flooding and facilitate irrigation. In its early days, the delta had seven main branches wherein smaller flows of river water created streams leading into the Mediterranean Sea. These branches were called the Pelusiac, Tanitic,

[7] "Nile Delta Facts." *Sciencing*, 2017.
[8] Janick, Jules. "Ancient Egyptian Agriculture and the Origins of Horticulture." *Acta Horticulturae*, 2002, p. 24.

Mendesian, Phatnitic, Sebennytic, Bolbitine, and Canopic.[9] To control flooding, however, ancient Egyptians dammed these original seven branches (scholars estimate around AD 24-79) and created two new ones that now actively flood, named the Damietta and the Rosetta.[10] These two modern branches flow toward the east and west, respectively. As a result of its size, location,

Fig. 1: Satellite imagery of the Nile River Delta (visible in green), 2003. Source: NASA

and geography, the delta has become a lush economic hub for Egypt. Presently, some 40 million people live along the Nile Delta, with Alexandria, one of Egypt's major cities, serving as home

[9] Cooper, John. *The Medieval Nile: Route, Navigation, and Landscape in Islamic Egypt*. The American University in Cairo Press, 2014, p. 76.
[10] Ibid, p. 76.

to nearly 5 million. Other key cities within the delta include Zagazig, Mansura, Port Said, Kheima, and Tanta, all of which depend largely on the health of the Nile Delta for their prosperity.

2.1 Geology

The Nile Delta began its formation in the Late Pliocene, with the progradation of coastal sands and accumulation of turbidities.[11] Its structural and depositional landscape have resulted from a long history of plate-tectonic movement. Resting on the external area of the African Plate, the delta resulted partially from plate movements that subsequently opened the Red Sea and Arabian Peninsula.[12] Surrounded by subtropical desert landscapes, the delta's sediment is composed of some 25% medium silt and 75% fine silt and clay.[13] Atmospheric circulation around the Mediterranean Sea leads to fluctuating winds and waves along the delta, with varying degrees of power, as the delta rests roughly 18 meters above sea level when measured in Cairo, Egypt's capital, which is 150 kilometers south of the coastline.

The delta's primary geological provinces include 1) the upper delta, characterized by strong fluviatile deposition, 2) the lower delta, comprising a lagoon belt and transitional environments, 3) the delta front and beach-dunes, formed by coastal drift, 4) the inner continental shelf, with a 50m depth and characterized by the muddy Damietta and Rosetta branches, 5) the middle and outer continental shelf, filled with relict sediment and eroded surfaces, and 6) the "muddy prodelta of the continental slope and rise (Nile Cone)."[14] Stanley (1996) argued that coastal erosion along the Nile Cone was a result of a decreasing supply of

[11] Sestini, G. "Nile Delta: a review of depositional environments and geological history." *Geological Society*, 1989, p. 99.
[12] Ibid.
[13] Ibid., p. 101.
[14] Ibid., p. 104.

sediment reaching the sea, caused by man-made waterways and wetlands.[15] The six geological provinces of the delta all harbor agriculture and infrastructure, as seen below in Figure 2.

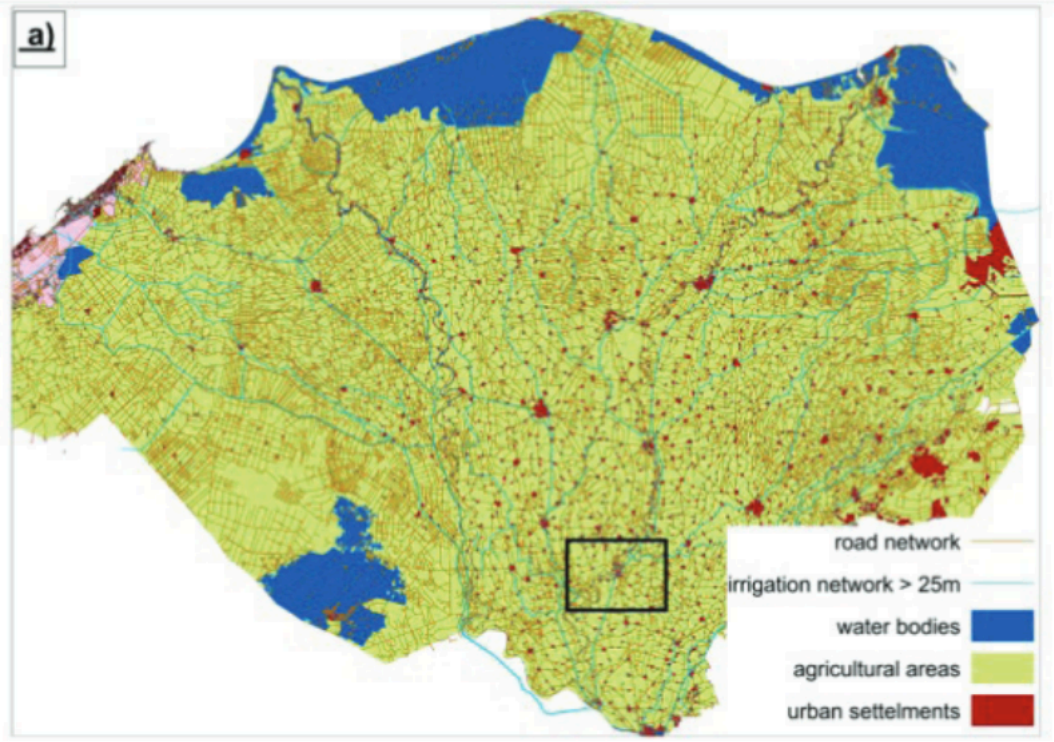

Fig. 2: Geographical visualization of water, agriculture, and urban settlements in the Nile Delta. Source: Alfiky, et al. (2012)

2.2 Economic Development in Ancient Egypt

This section of the paper will provide a deeper historical background of the Nile River Delta in order to orient readers and explain the importance of the delta. Its longstanding centrality in Egyptian life helps to explain why the Nile is still crucial to Egypt's economy and the lives of half its population. Historically, ancient Egyptians relied on the Nile River and its seasonal flooding to bolster their agricultural economy. Fertile soil from rich sediment deposits meant that long-term crop growth was plentiful. In fact, Egypt is credited with being one of the first

[15] Stanley, Daniel Jean. "Nile delta: extreme case of sediment entrapment on a delta plain and consequent coastal land loss." *Marine Geology*, 129(3), 1996.

civilizations to practice large scale agriculture.[16] Its basin irrigation systems were an early development that spurred large-scale agriculture and the Egyptian economy at large. By carving out deep embankments around and through crop fields, farmers were able to trap irrigated water around the crops, guaranteeing long-term hydration for the growing plants. This led to stable crop production, specifically of barley, flax, and papyrus.[17]

Seasonally, the Nile Delta would flood in August and September, submerging the surrounding plains with nearly two meters of nutrient-rich water, a process called inundation. In October, when the floodwaters typically retreated, the residual soils would be left rich and plentiful with nutrients, ideal for planting enormous fields of crops. Farmers intervened minimally with the growing season, as the soil was moist enough to be somewhat self-sufficient, especially after the implementation of improved irrigation methods as described above.[18] Crops were ready for harvest around March and May nearly every year. This cyclical agriculture depended entirely on the Nile Delta and its predictable flooding.

To optimize the delta's behaviors and flooding patterns, ancient Egyptians perfected infrastructural types of irrigation too, wherein they diverted floodwater away from vulnerable regions, such as large cities, and sent them to other farmlands. The importance of irrigation and agriculture in ancient Egyptian society cannot be overstated, as it formed the backbone of the country's economic growth through surpluses in food production, labor, and in its consolidation of Egyptian peoples along the delta, making taxation and state-building more efficient.[19] The

[16] Allen, Robert C. "Agriculture and the Origins of the State in Ancient Egypt." *Explorations in Economic History*, vol. 34, 1997, pp. 135-154.
[17] Janick, Jules. "Ancient Egyptian Agriculture and the Origins of Horticulture." *Acta Horticulturae*, 2002, p. 23.
[18] Ibid.
[19] Allen, Robert C. "Agriculture and the Origins of the State in Ancient Egypt." *Explorations in Economic History*, vol. 34, 1997, pp. 135-154.

foraging economy of Egypt's past made way for this burgeoning agricultural economy, fully supported by the Nile River Delta.

Egyptian archaeology depicts pharaohs and kings providing water and crops to their people, a connection that reinforced the cruciality of the Nile Delta. Egyptians cultivated orchards and gardens, too, most often used to grow vegetables, fruit, and vines. Staple crops included barley, cereals, beans, onions, radishes, parsley, and lettuce.[20] Growing fruit required more sophisticated methodology, including propagation and stronger irrigation systems. Sorghum, palm dates, grapes, watermelon, figs, carobs, olives, pomegranates, and peaches were some of the primary staples.[21] After meeting their own needs, Egyptian farmers could then sell these mass-produced plants at local, regional, and international markets, creating strong trading relationships with adjacent territories and some overseas.

2.3 Egypt's Modern Nile Delta Economy

Sea level rise and its detrimental effects on agricultural productivity and infrastructure are especially dangerous because of Egypt's meager social safety nets. After Egypt's recent financial crisis, an inevitable outcome of the global recession in 2007, foreign investment in the country skyrocketed, as investors purchased over 20% of local debt. Because of this, the Egyptian government had to severely cut civil spending to pay off the interest on its debts, leaving over 60% of the Egyptian population in a poor or vulnerable state.[22] With installments and loans added into the equation, about 58% of Egypt's government spending goes straight to debt repayment.[23] As a result, the local economies along the Nile Delta are especially vulnerable to

[20] Ibid.
[21] Janick, Jules. "The Origins of Fruits, Fruit Growing and Fruit Breeding." *Plant Breeding Reviews*, no. 25, 2005 pp. 255-320.
[22] Hamed, Yehia. "Egypt's Economy Isn't Booming. It's Collapsing. *Foreign Policy*, 2019.
[23] Ibid.

the intense effects of sea level rise, because national safety nets are basically nonexistent. Debt repayment holds the government's fiscal attention.

The IMF has exacerbated instability by exaggerating the country's economic health in yearly reports, including borrowed money in calculations of Egypt's foreign currency reserves.[24] In simple terms, Egypt appears prosperous to outsiders because it has borrowed beyond its means and boasts a strong stash of reserve currency. However, this growing debt promises to crumble the country. Further destabilizing the economy, the terms of the IMF's loans to Egypt have pressed the country to reduce its economic deficit, either by cutting government salaries or public spending.[25] Current Egyptian President Abdel Fattah el-Sisi has adopted the latter, stating in a 2019 address that "the Egyptian people can endure more."[26] With no social safety nets, many of Egypt's poor are sinking deeper into poverty. The IMF's terms strive to maximize growth and minimize the economic deficit, no matter the short-term cost to Egypt's people. Internal debt in Egypt sits at roughly $236bn, which comprises 85% of GDP; yet, President Sisi's plans have consistently involved Gulf aid and general foreign aid as opposed to economic reform within the country.[27]

2.4 Sea Level Rise in the Delta

Sea levels have steadily risen over the last 100 years.[28] Using tide gauge observation and radar altimeters in satellites, climate scientists have monitored sea level in nearly 200 countries with

[24] Ibid.
[25] Ibid.
[26] Hearst, David. "Curtains for Sisi? How Mohamed Ali upstaged Egypt's greatest showman." *Middle East Eye*, 2019.
[27] "Egypt: Battered Economy." Africa Research Bulletin: Economic, Financial, and Technical Series, 51(5), 2014, p. 20410.
[28] Horikawa, Kiyoshi. "Sea-level rise caused by climate change and its implications for society." *Proceedings of the Japan Academy in Physical and Biological Sciences*, 89(7), 2013, p. 283.

1900 gauges.[29] From 1860 to 2009, global mean sea level (GMSL) has increased 21cm, and the current rate of increase doubled between 1993 and 2009, averaging 3.2mm per year.[30] This has been a result of global warming, which causes significant melting of ice, which then runs into the world's oceans and causes them to rise.

Climate scientists and economic researchers generally agree that agricultural productivity will significantly decline along the delta and that sea level rise will be a major contributor to this decline. Figure 3 illustrates a traditional tide gauge, used to measure sea level. Aboukhaled, et al.'s widely-cited 1975 soil survey found that the percentages of salt-affected soils relative to

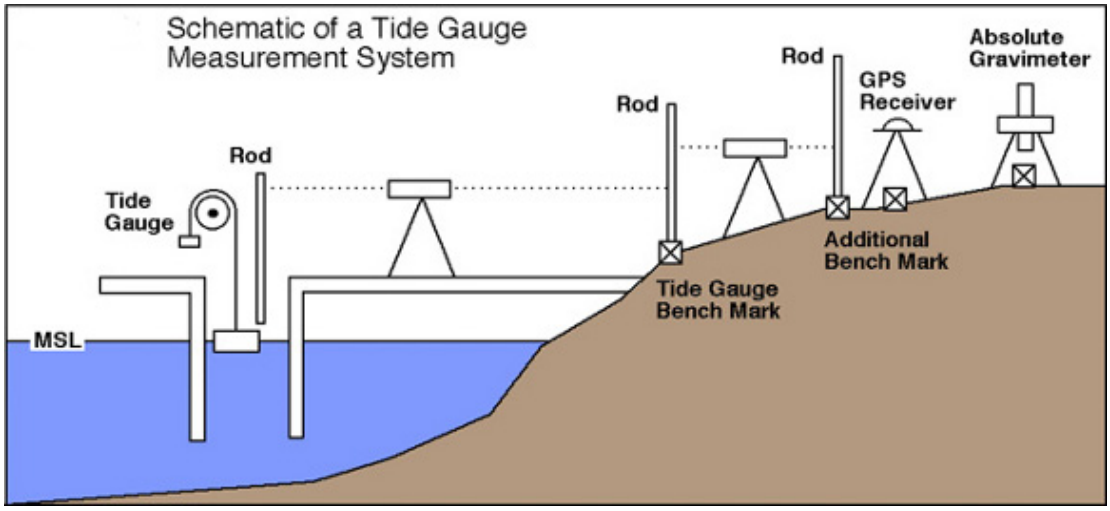

Figure 3: A traditional tide gauge. These tide gauges "commonly used tide gauge measurement system, a float operating in a stilling well. Surveys of the tide gauge site are performed regularly to account for any settling of the site. Tide gauges may also move vertically with the region as a result of post-glacial rebound, tectonic uplift or crustal subsidence."[1] Source: University of Colorado Sea Level Research Group, 2011.

total cultivated lands in the Nile Delta was 60% in the Lower Delta, 25% in the Middle Delta, 20% in the Upper Delta.[31] Hammad and Mohamed's recent, widely-cited 2018 soil survey found

[29] Ibid., p. 284.
[30] Ibid., p. 286.
[31] Aboukhaled, et al. "Research on crop water use, salt affected soils and drainage in the Arab Republic of Egypt." *Food and Agriculture Organization of the United Nations, Near East Regional Office, Cairo, Egypt*., 1975, p. 62-79.

that 100% of the Lower Delta and Middle Delta are now affected, with about 50% of the Upper Delta affected.[32] Both reports cited sea level rise and the inundation of saltwater as the primary culprits.

Pioneering climate scientists of the 1980s and 90s pursued some of the first in-depth investigations of sea level rise in the Nile River Delta, concluding that sea level rise was a major threat to agriculture and the Egyptian economy at large. Broadus, et al. (1986), El-Raey (1990), Frihy (1992), and Stanley and Warne (1993) all argued that sea level rise would cause severe flooding, erosion, and salinity in the northern regions of the Nile River Delta. Their research found that this loss of land would negatively affect agricultural output in the country. Examining economic and demographic data, Broadus, et al. (1986) emphasized the vulnerability of Egypt to sea level rise, as some 15% of GDP originated from agriculture in the delta in the mid-1980s.[33] El-Raey (1990) calculated that about $35 billion in GDP would be lost to flooding by 2100, as agricultural output would be severely stunted.[34]

Researchers in the 90s found that coastal erosion, too, would worsen. Frihy (1992) argued that sea level rise coupled with river damming along the Nile would accelerate coastal erosion and increase the salinity of aquifers, limiting available freshwater and hindering Egypt's agricultural sector and placing Nile Delta residents in danger of water scarcity.[35] Further emphasizing land loss, Stanley and Warne (1993) found that erosion and salinization had led to

[32] Hamman and Mohamed. "Mapping soil salinity in the East Nile Delta using several methodological approaches of salinity assessment." *The Egyptian Journal of Remote Sensing and Space Sciences*, 2018, p. 4.
[33] Broadus, et al. Rising Sea Levels and Damming of Rivers: Possible Effects in Egypt and Bangladesh, 1986, p. 171.
[34] El-Raey, Mohamed. "Vulnerability assessment of the coastal zone of the Nile delta of Egypt, to the impacts of sea level rise." *Ocean and Coastal Management*, 37(1), 1997, pp. 29-40.
[35] Frihy, Omran E. "Sea-level rise and shoreline retreat of the Nile Delta promontories, Egypt." *Natural Hazards*, vol. 5, 1992.

"a marked decline in agricultural productivity and loss of land and coastal lagoons."[36] These early predictions and arguments continue today, as more recent research continues to pinpoint sea level rise as a major threat to agriculture and the economy of Egypt's Nile River Delta.

Among more recent climate scientists studying sea level rise in the delta, a vast majority believe that rising sea levels pose a strong threat to agriculture. Yates and Strzepek (1998), Sušnik, et al. (2015), and McCarl, et al. (2015) all agree that 1) sea level is steadily rising in the delta, 2) this rise will stunt agricultural growth, and 3) this rise is a pending economic catastrophe for Egypt. These scientists conclusively find that sea levels are rising faster now than they did in the early 1900s. In her evaluation of the issue, Sušnik (2015) gauged sea level rise in the Nile River Delta and the effects of salt-water intrusion on infrastructure in Alexandria.[37] Called CLIMB (Climate-Induced changes on the hydrology of Mediterranean Basins), Sušnik's project utilized field measurements, multi-parametric remote sensing, and comparison of changing water levels from 1971-2000 to a projection period of 2041-2070.[38] Her team's findings included a rising risk of drought in Alexandria, shifts in rainfall patterns, higher temperatures in all seasons, and increased soil and groundwater salinization.

Researchers largely find that Egypt's growing population coupled with this growing seawater intrusion expedite the degradation of agricultural land within the delta. In addition to predictions of stronger drought, the report predicted a growing deficit in freshwater volume, leading to increased stress on agriculture and the Nile Delta economy through water scarcity.[39]

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[36] Stanley, DJ, and AG Warne. "Nile delta: recent geological evolution and human impact." *Science*, 260(5108), 1993, p. 628.
[37] Sušnik, Janez, et al. "Interdisciplinary Assessment of Sea-Level Rise and Climate Change Impacts on the Lower Nile Delta, Egypt." *Science of the Total Environment*, vol. 503-504, 2015, pp. 279–288.
[38] Ibid.
[39] Ibid.

Most of the salt-affected areas of the delta are in the northern-central area and the eastern and western areas. Some 900,000 hectares or 60% of irrigated lands suffer from excess salt due to SLR.[40] Egypt's crop production is expected to worsen, and because it is a key part of the local economy, economic development could stagnate or reverse. Sušnik (2015)'s findings are important because of their breadth and implications. She echoes what so many other scholars have been pointing to over the decades: Egypt is at severe risk from sea level rise.

In Rosetta, Egypt, literature on Nile Delta agriculture finds that declining yields and economic slowdown are already happening and will continue to see major hindrances. Sušnik (2015) analyzed crop yields and revenues, focusing on the effects of SLR and increased salinity. Each month, her team calculated water sources, demands, balance, food production, agricultural revenue, and land loss caused by SLR.[41] Using a regression relationship, her team found that freshwater is an overexploited resource in Rosetta, too, especially due to sea level rise and salinity which pollutes drinkable water.[42] Additionally, crop yield has decreased due to freshwater scarcity, resulting in declines in local food yields and economic output in the region. Overall, the study implicated sea level rise as being a serious threat, with "implications for food security, economic development, and the ability to engage in international trade."[43] Figure 2 shows the current land use in the upper delta as of 2013. The vast majority of land within the Nile Delta has been cultivated for agriculture, irrigation, and industry, emphasizing the delta's cruciality in Egypt's local economy.

[40] Ibid.
[41] Ibid.
[42] Ibid.
[43] Ibid., p. 283.

The economic impacts of agricultural decline are far-reaching, and the vast majority of researchers on the subject have found strong evidence of this. Yates and Strzepek (1988) used a quadratic programming sector model to determine the impacts of sea level rise on Egypt's agricultural economy, citing a strong vulnerability in Egypt as climate change and the impacts of sea level rise cause excessive salinity in agricultural land. McCarl, et al. (2015) express strong concern about the economic repercussions of sea level rise on Egypt's agricultural sectors. McCarl, et al. (2015) assert that Nile Delta agriculture is especially vulnerable to the impacts of sea level rise, and they argue that the economic damages of sea level rise are increasing to cause more devastating effects on GDP and costs to local Egyptian consumers.[44] Specifically, the authors analyze crop yields, non-agricultural water use, water supply, and land loss due to sea level rise from 2030 to 2060, arguing that Egypt will experience up to a 260% increase in food prices for local consumers.[45] Thus, in addition to a lower production to sell, farmers in the delta may not be able to feed themselves and their own families. Populations close to and far from the Mediterranean coastline will experience these effects, though groups closer to the coastline will experience stronger repercussions of flooding and land subsidence.[46]

Waterlogging, a result of flooding, has been a major research topic among climate scientists studying the Nile Delta, as they argue that saltwater has penetrated aquifers and groundwater far beyond the Nile Delta's lower arc. Mohamedin, et al. (2010) take the analysis of sea level rise and decreased agricultural productivity and evaluate waterlogging of crop fields. Similar to El-Marsafawy et al.'s findings, Mohamedin, et al. analyzed the effects of soil salinity

[44] McCarl, et al. "Climate change vulnerability and adaptation strategies in Egypt's agricultural sector." *Mitigation and Adaptation Strategies for Global Change*, 20(7), 2015.
[45] Ibid., p. 1107.
[46] Hereher, Mohamed E. "Vulnerability of the Nile Delta to sea level rise: an assessment using remote sensing." *Geomatics, Natural Hazards & Risk*, 1(4), 2010, p. 318.

and waterlogging on crop productivity within the northeastern Nile Delta region, finding that these phenomena had degraded soil resources and would require amelioration to "satisfy the increasing requirements of foods, industrial raw materials, and ultimately the enhancement of the agricultural sector income."[47] Just like El-Marsafawy, Sušnik, Yates, Strzepek, and McCarl, Mohamedin, et al. argues that sea level rise and the resulting salinity and inundation are negatively affecting agriculture.

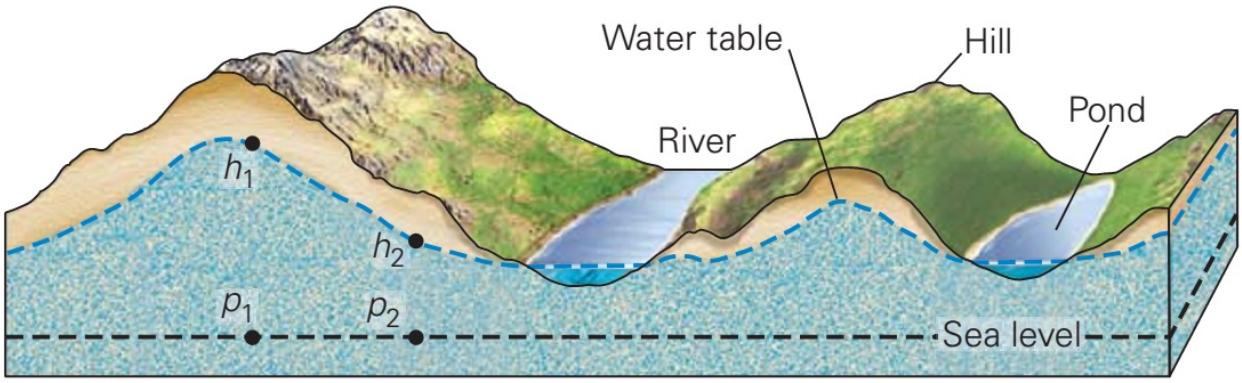

Fig. 4: Illustration of a water table, which is the surface above the zone of saturation. Water tables separate groundwater zones from aerated zones above them. Points h_1 and h_2 represent a hydraulic gradient, or the slope of the water table. P_1 and p_2. Source: Learning Geology, 2020.

Using Linear Systematic Sampling (LSS), Mohamedin, et al. documented water table depths and salinity levels in 26 pilot areas with Egypt's Nile Delta.[48] Water table depths less than 1m were categorized as waterlogged, 1-1.5m were semi-waterlogged, and >1.5m were categorized as normal or semi-drained.[49] Figure 4 depicts a typical water table, also known as the ground zone between the groundwater zone and aerated zone. Essentially, rising sea levels are creating increased pressure from saltwater, pushing this saltwater into porous coastal soil below ground. As this saltwater seeps into underground freshwater aquifers, the force and pressure push

[47] Mohamedin, et al. "The Negative Role of Soil Salinity and Waterlogging on Crop Productivity in the eastern Region of the Nile Delta, Egypt." *Journal of Agriculture and Biological Sciences*, 6(4), 2010, p. 379.
[48] Ibid.
[49] Ibid.

freshwater higher and higher until water tables are dangerously thin or non-existent, and a pond or lake emerges.

In addressing a clear and impending decline in agricultural productivity, water scientists suggest crop adaptations to circumvent dwindling freshwater volumes due to inundation and salinity. El-Marsafawy (2018) evaluated Nile Delta crops and their water usage to determine which crops produced the highest yield using the least amount of water. His team's measure, called *crop water productivity* (CWP), combined crop yield and divided it by water consumption (evapotranspiration) for each crop. The objective was to inform decision-making processes within Egypt's agricultural sector, helping to identify the ideal crops in the region and their CWP trends over time. Evaluating CWP over a period of three decades, El-Marsafawy found that all crops showed a 41% increase in CWP between decades 1 and 2, and a 22% increase in CWP between decades 2 and 3.[50] He attributes this consistent increase to the use of high-yield cultivars (selectively bred plant varieties) and improved agronomic (plant genetics/soil management) practices.

Along with the increases in crop water productivity (CWP), crop water consumption (ET_C) declined over the three decades. He argues that this must be the result of changing climatic conditions, of which his team could not specifically pinpoint.[51] The crops that showed the *highest increase in CWP* over the three decades were the winter tomato (210% increase in CWP), the mango (154% increase in CWP), the summer tomato (145% increase), winter onion (132% increase), nili tomato (128% increase), grapes (122% increase), and flax (114% increase).[52] Overall, however, the crops with the highest CWP values in general were sugar beets

[50] Ibid., p. 9.
[51] Ibid.
[52] Ibid., p. 11.

(13.79 $kg \cdot m^{-3}$), winter potatoes (10.69 $kg \cdot m^{-3}$), winter tomatoes (10.58 $kg \cdot m^{-3}$), winter eggplants (10.05 $kg \cdot m^{-3}$), and cucumbers (9.91 $kg \cdot m^{-3}$). Emphasized in this study was the effectiveness of current irrigation and agronomic practices. Nile Delta irrigation techniques and technology have consistently improved, as have soil management strategies, selective crop breeding, and crop rotation. The limiting factor in Egypt's agricultural productivity, then, is often freshwater. Thus, El-Marsafawy's findings could lend themselves to adaptive strategies for agriculture in the delta.

Suggested remedies for these impending dangers are largely short-term plans of adaptation. McCarl, et al. suggest adaptation strategies, such as "changing crop mix . . . improving water supply efficiency, increasing agricultural technical process . . . and reducing population related demand growth."[53] Elaborating on these ideas, the authors advocate for an elimination of sugarcane production, reduction in rice, cotton, and wheat, as these crops require significantly more freshwater than others. They advocate for repairs to network leakages and other inefficiencies in water supply, and slowing population growth. They do not provide suggestions for slowing population growth, however. Their suggestions on crop mixing and water efficiency have merit, but slowing population growth may be more difficult.

Other climate experts advocate for shallow-rooted crops to combat waterlogging and inundation. Lemonick (2012) supports Mohamedin's findings, as he argues that agricultural productivity depends on a certain depth of water tables, around 1.5m at the least.[54] Water tables significantly thinner result in excess water around crops (waterlogging) which kills or stunts crop growth.[55] Unsurprisingly, Lemonick (2012) also found that deeper water tables (thicker layers of ground) facilitated better crop yields. Cotton showed consistent increases in yield as water table

[53] Ibid., p. 110.
[54] Lemonick, Michael D. "Rising Sea Level May Trigger Groundwater Floods." *Climate Central*, 2012.
[55] Ibid.

depths increased from 1m to 1.5m.[56] Cotton, wheat, and sunflower strains yielded the lowest values at shallow water tables of <1m. Generally, however, shallow-rooted crops were able to withstand shallower water tables, as their short roots did not penetrate deeply enough to absorb excessive amounts of saltwater. Shallow-root crops regularly grown in the Nile Delta include cabbage, onions, corn, and flowering annuals. Coupled with El-Marsafawy and Mohamedin, Lemonick provides useful insight into how Egyptian farmers might be able to adapt their agricultural strategies to adapt and survive sea level rise. Productive crops with shallow roots may be a viable, short-term adaptation to supply enough food to Egypt's growing population.

During the last 500 years, as Nile River discharge was confined to the Damietta and Rosetta distributaries, coastal progradation began in those areas. However, since the construction of the Aswan Dam in the 1960s, natural flows of sediment have been halted, their movement reliant on the stop and release of the dam itself. As a result, the arc of the delta has eroded substantially, as the river's consistently flowing sediment is no longer able to balance subsidence and prevent heavy recession of the beach-lagoon system along the coast.[57] Construction of the Aswan Dam intended to create predictable flow of the Nile River into Lake Nasser in Egypt, where the stored water could be controlled for agriculture, drinking, and other necessary uses.[58] After the World Bank withdrew funding for the project, the Soviet Union provided assistance, as the Suez Canal (bordered by Egypt) became geopolitically coveted in the midst of the Cold War.[59]

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[56] Ibid., p. 381.
[57] Summerhayes, et al. "Nile Delta: Nature and Evolution of Continental Shelf Sediments." *Marine Geology*, vol. 27, 1978.
[58] Strzepek, et al. "The value of the high Aswan Dam to the Egyptian economy." *Ecological Economics*, 66(1), 2008, p. 117.
[59] Ibid.

Compounding the issue of erosion caused by the damming of sediment, sea level rise has led to higher, more frequent lapping waves that wear away the delta's arcuate coastline, causing further recession, salinity, and inundation of the land.[60] Climate literature generally agrees that modern sea level rise (defined as a departure from the long-term background levels) began in the early 1900s.[61] Historically, sea level rise had been observed as relatively stable for 3,000 years, measuring about 120m when averaged around fluctuations.[62] However, during the early 1900s, average sea level rise rose to 1.7mm per year, and as of 2013, the rate is 3.1mm per year.[63] Figure 5 demonstrates sea level rise measurements from coastal gauges and satellite altimeters from 1860 to 2010, showing a steady increase.

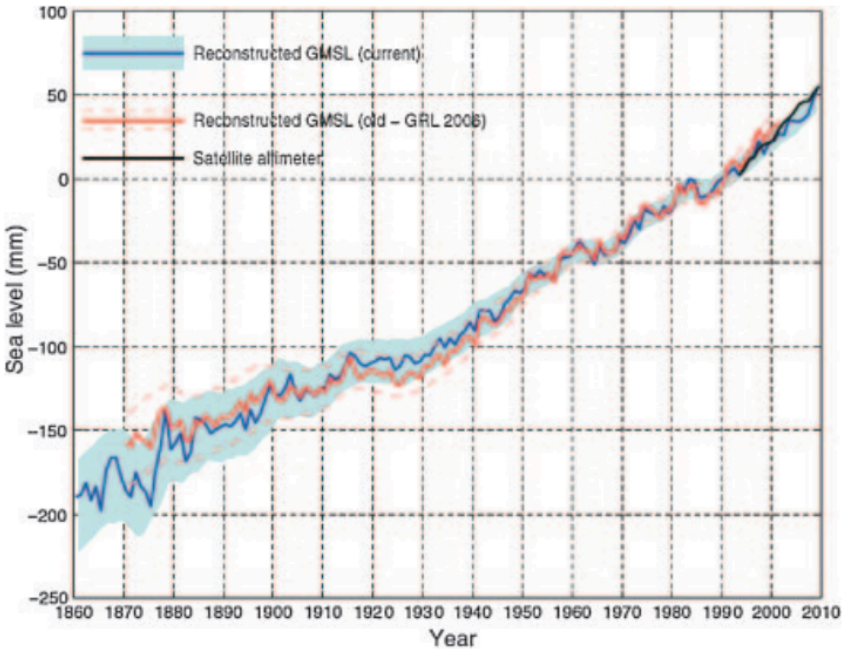

Fig. 5: Global mean sea level from 1860 to 2010. The blue line represents coastal sea level data, the red is an estimate by Church and White (2006), and the black is satellite altimeter data starting in 1993. Source: Mimura 2013.

[60] El-Asmar, H.M., and M.E. Hereher. "Change detection of the coastal zone east of the Nile Delta using remote sensing." *Environmental Earth Science*, 2009.
[61] Gehrels and Woodworth. "When did modern rates of sea-level rise start?" *Global and Planetary Change*, vol. 100, 2013, p. 263.
[62] Mimura, Nobuo. "Sea-level rise caused by climate change and its implications for society." *Proceedings of the Japan Academy, Series B Physical and Biological Sciences*, 89(7), 2013, p. 282.
[63] Williams, S. J. "Sea-Level Rise Implications for Coastal Regions." *Journal of Coastal Research*, vol. 63, 2013, p. 184.

In their 1997 report, the Intergovernmental Panel on Climate Change found that coastal regions of the African continent were particularly vulnerable to sea level rise because of their low-lying geography, widespread poverty, and dependence on freshwater for agriculture.[64] In Egypt's case, particularly within the Nile River Delta, poverty and dependence on agriculture exacerbate its vulnerabilities to sea level rise. The IPCC report, overall, found that low-latitude, coastal regions worldwide were vulnerable to climate change, especially sea level rise.[65]

2.5 Political Beliefs Among Egyptian Farmers, Leadership, and Global Actors

Because it provides the majority of Egypt's water and is the central population and economic hub of Egypt, the Nile River and its delta have become central in international and Egyptian politics. Egypt is one of the poorest states in terms of freshwater availability per capita, with about 660 cubic meters of water for each resident per year.[66] Despite this irrefutable fact, there are competing scientific and political explanations of this water scarcity in Egypt. Barnes (2015) argues that despite an obvious correlation of climate change with dwindling water supply in Egypt, not all actors (farmers in the delta, Egyptian leadership, global climate scientists) view climate change as the most significant factor affecting water resources.[67] Rather, these three groups of actors have very specific and differing perspectives, outlined in the subsequent paragraph.

The three major competing perspectives are as follows: 1) From the perspective of the international community, water scarcity in the Nile Delta is viewed as a result of climate change

[64] Watson, et al. "The Regional Impacts of Climate Change: An Assessment of Vulnerability." Intergovernmental Panel on Climate Change, 1997, p. 6.
[65] Ibid., p. 16.
[66] Conniff, Richard. "The Vanishing Nile: A Great River Faces a Multitude of Threats." *Yale Environment*, 2015.
[67] Barnes, Jessica. "Scale and Agency: Climate Change and the Future of Egypt's Water" in *Climate Cultures: Anthropological Perspectives on Climate Change*, 2015, p. 129.

and sea level rise.[68] 2) Local governments and politicians, meanwhile, tend to assess water scarcity in relation to dam building by competing countries in the basin, such as Sudan and Ethiopia. 3) Lastly, farmers, fisherman, local engineers, and local populations along the delta tend to view water scarcity as being affected by government structures of water control, specifically the operators of the dams.[69] International workshops, panels, and initiatives to address climate change impacts on the Nile River Delta basin have spurred water specialists and climate advocates to push for government-level action in Egypt; yet, social and political disconnections between the Egyptian government and the people who actually live along the Nile River Delta have hindered such action.[70]

Specifically, the disparity in opinions on *what is causing* water scarcity leads the Egyptian government to focus on political discussions with Ethiopia and Sudan, while the Egyptian delta farmers focus on adaptation of their crop planting, water usage, and compliance to government regulations. Essentially, these stark differences in perspective have, understandably, prevented unity in the battle against sea level rise and its symptoms in Egypt. As a result of these three key perspectives, policymaking to address agriculture and infrastructural damage becomes more complex and intersectional. Policies must consider the way in which each type of actor perceives water scarcity, ultimately addressing sea level rise through various nuanced recommendations.

Degefu and He (2016) address the increasing political demands on Nile Delta water through the term *water bankruptcy*, arguing that this phenomenon is inevitable and that delta riparian countries (Egypt, Sudan, and Ethiopia) would benefit from incorporating this pending

[68] Ibid.
[69] Ibid.
[70] Ibid.

inevitability into their contingency plans.[71] Vella (2016) agrees that both environmental and political factors threaten the water supply in Egypt's Nile River Delta, arguing that the country must increase local food production by adopting technologies that optimize crop yields and through land reclamation projects.[72]

The politics of Egypt's Nile River Delta are complex and far-reaching as they encompass many levels and regions of actors. As the Nile River supplies water and food to several riparian countries in Africa, policy recommendations must take into account the various forms of agency and political agendas within each circle of actors.

Chapter 3. Policy Problem #1: Decreased Agricultural Productivity

Sea level rise (SLR) has caused excessive volumes of saltwater to penetrate soil and underground aquifers in the Nile Delta, polluting large volumes of freshwater.[73] As a result, agricultural productivity has been stunted.[74] Coupled with Egypt's growing population and resulting water demands, policies to effectively improve agricultural productivity are crucial to the survival of peoples along the delta. Another critical symptom of SLR, inundation has resulted in immense flooding, sinkholes, and destabilization of physical infrastructure (specifically homes and buildings) along the delta and adjacent regions. Some 50% of Egypt's population is vulnerable as sea level rise threatens to stunt their agricultural production and flood their homes.[75] For instance, rice paddy fields in the delta, staples in agriculture, are often empty due to a decline in fresh water.[76] Nile farmers have had to irrigate their crop fields with untreated drainage water

[71] Degefu, Dagmawi Mulugeta, and Weijun He. "Water bankruptcy in the mighty Nile river basin." *Sustainable Water Resources Management*, 2(1), 2016.
[72] Vella, Jay. "The Future of Good and Water Security in New Egypt." *Future Directions International*, 2016.
[73] Horikawa, Kiyoshi. "Sea-level rise caused by climate change and its implications for society." *Proceedings of the Japan Academy in Physical and Biological Sciences*, 89(7), 2013, p. 283.
[74] Saleh, Heba. "Egyptian farmers hit as Nile Delta comes under threat." *Financial Times*, 2018.
[75] "Egypt." World Population Review, 2020, http://worldpopulationreview.com/countries/egypt-population/.
[76] Lemonick, Michael D. "Rising Sea Level May Trigger Groundwater Floods." *Climate Central*, 2012.

from fish farms, potentially causing health problems from pollution.[77] As a result, harvests are much less plentiful and inadequate to feed the growing delta populations.

3.1 Current Research and Data

Agriculture in Egypt supports the country's food needs, provides raw materials to domestic industry, and accounts for roughly 11% of the country's GDP.[78] In the 1980s, agriculture accounted for 20% of GDP, and in 2000, it accounted for 16%; yet, despite this substantial decrease in GDP contribution, the number of laborers in Egypt's agricultural sector has *remained the same*, comprising about 29% of the country's total population.[79] Farmers, wholesalers, processors, transporters, and exporters rely on the stability of Egypt's agricultural sector for their incomes. However, some 50% of food in the country comes from imports, possibly a result of diminished agricultural output and underdeveloped economic policy.

As a result, Egypt is highly vulnerable to fluctuations in international food prices.[80] For reference, Yemen is the only MENA (Middle East and North Africa) country that imports more food than Egypt, measured as a percent of total export revenues. In other words, Egypt spends more on food imports than it earns on food exports, and it is in a steep trade deficit. Salinity and waterlogging from sea level rise have only exacerbated Egypt's agricultural health, and these effects are far-reaching, causing strife for the country at large, but especially in the fragile Nile River Delta. Egypt's current policies, largely focused on increasing output of wheat and maize, do not directly address the effects of sea level rise and the harm it will cause to agriculture.

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[77] Ibid.
[78] Tellioglu and Konandreas. "Agricultural Policies, Trade and Sustainable Development in Egypt." *Food and Agriculture Organization of the United Nations*, 2017, p. 2.
[79] Ibid.
[80] Ibid.

3.2 Current Policy

Bolstering agricultural productivity has long been a goal of Egypt's government, especially as half of its population lives along the Nile Delta, dependent upon the very farming and agriculture that is in danger from sea level rise. Despite this reliance on agriculture, however, Egypt has been dependent on food imports since the 1970s, largely because of the incompatibility of its rapid population growth and inadequate agricultural production.[81] Since the 1970s, Egyptian policymakers have fought against the country's dependency on food imports, and their battle continues as the country strives to improve total output. Despite existing climate research, policymakers in Egypt have generally not addressed the effects of sea level rise directly. This has likely been caused by the disparate perspectives on the issue of water scarcity.

In Egypt's 2012-2017 strategic development plan, the officials attempted to bolster wheat production to a level of self-sufficiency, measured at 74% of total domestically-produced wheat (thus, 26% was imported).[82] In the government's 2013-2015 plan, it increased targets to 81%, having reached the initial 74% goal. Additionally, Egypt vowed to increase maize production to 92% in 2030. In order to do this, the government has encouraged the use of optimized seed varieties and has expanded available land for cultivation.[83] Marsafawy (2018), McCarl, et al. (2015), and Lemonick (2012) all suggested the use of optimized seeds (shallow root, water efficient) to improve output. Further, Egyptian leadership outlined efforts to improve food security and rural livelihoods through sustainable, resource-efficient agricultural practices.[84] Specifically, the plans outline 1) repair to leaking or inefficient irrigation systems, 2) expansion

[81] USAID, "Agriculture and Food Security in Egypt." 2020.
[82] Tellioglu and Konandreas. "Agricultural Policies, Trade, and Sustainable Development in Egypt." *Food and Agriculture Organization of the United Nations*, 2017, p. 7.
[83] Ibid., p. 7.
[84] Ibid., p. 8.

to reclaimed lands, 3) better water harvesting techniques, and 4) soil surveys to manage land degradation.[85] Though promising in theory, many of the government's plans have not come to fruition, as the volatility of the global economy hinders Egypt's growth.

In response to global economic volatility, Egypt's food subsidy policies involve strong government involvement in the country's wheat value chain. The government "purchases almost all of the domestically-produced wheat from farmers, at or above the global market prices for cost, insurance, freight, with the aim of promoting domestic wheat production."[86] In addition to selling this wheat at a loss to domestic bakeries, the Egyptian government subsidizes bread for domestic consumers below a certain income threshold. However, these policies have suffered from inefficiency, revenue loss, and corruption, especially as a burgeoning population, weakening currency, and growing global prices have left the Egyptian government paying more and more to buy the wheat.[87] The country is suffering from economic instability in a turbulent global economy. Coupled with substantial government subsidies in agricultural and thus a lack of total income, the economy struggles to grow, and in fact may regress as sea level rise thwarts agriculture further.

Wichelns (2000) addresses these concerns and outlines policy initiatives by the Egyptian government and its Ministry of Public Works and Water Resources, indicting the government's elimination of subsidies and the Ministry's reuse of saline drainage water as problems for agricultural productivity.[88] Government policy reforms in Egypt in 1986 ended long-standing restrictions on cropping patterns, which had previously required farmers to sell their production

[85] Ibid.
[86] Ibid.
[87] Ibid.
[88] Wichelns, Dennis. "Policy Recommendations to Maintain and Enhance Agricultural Productivity in the Nile River Delta." *International Journal of Water Resources Development*, 16(4), 2000.

at a low cost to the government. As a result, farmers began increasing their planting areas to meet population growth demands, which in turn has increased demands of water. Despite ending initial cropping restrictions, the Egyptian government tightened controls on cotton farming and prices, which pushed Nile Delta farmers toward rice cultivation, which had fewer restrictions and stipulations. Rice, compared to cotton, requires significantly more water and generates even more drainage.[89] In the late 1990s, the Egyptian government responded to the shift to rice by placing production restrictions on it, too, but farmers have generally ignored the restrictions, as they are desperate to feed their families and meet demand.

Ultimately, Nile Delta farmers have historically adapted to government price controls, which determine the crops that will produce the highest net monetary yield. Government policies that require fair fees for irrigation water and drainage might encourage farmers to use their water resources more sparingly. Instead of hard price controls on the produced goods, the Egyptian government could implement stronger controls on water costs. Along with focusing on water prices instead of crop prices, the Egyptian government could release its holds on cotton prices and allow farmers to earn true market prices.[90]

3.3 Policy Recommendations to Increase Agricultural Productivity

In order to bolster agricultural productivity in Egypt's Nile River Delta, I outline below three policy recommendations: 1) developing more efficient systems of water use; 2) the use of government subsidies for shallow-root, water efficient crop seeds; and 3) regulation of groundwater extraction.

Recommendation #1: Development of efficient water use systems

[89] Ibid., p. 667.
[90] Ibid., p. 673.

In developing more efficient systems of water use, I recommend a government initiative to repair waterline leakages and provide subsidized water teepees for crops (these ensure that most or all water goes straight to the crop and is not wasted). I expect this investment to provide strong returns when water is used more effectively, with minimal spillage and waste caused by leakage and indirect watering procedures. To ensure that this policy incorporates international, national, and local farmer interests, the Ministry of Agriculture and Land Reclamation of Egypt will provide initiative information to international parties and local Egyptian farmers. The information will provide details and intended outcomes of the water system initiative, so that Nile Delta farmers understand the benefits, may ask questions, voice concerns, and feel that their government acknowledges them. Internationally, climate change experts, who tend to address water scarcity in scientific terms, will approve of the attempts to utilize water efficiently and with minimal waste, as teepees prevent excess evaporation, and waterline repairs optimize total available water volumes.

Estimating the cost of this water efficiency initiative is difficult. The website and document archive for Egypt's Ministry of Water Resources and Irrigation is "under construction" in many areas, making irrigation and pipeline information hard to gather. Further, because the Nile River Delta irrigation systems comprise locally-made and developed systems, there is not one hub of information to consolidate all of them. Thus, I recommend that local authorities, and farmers outline estimates for their respective regions to submit to the Ministry of Agriculture, the Ministry of Water Resources, and the Ministry of Public Works. These outlines will estimate will land area, planted area, average crop production, expected revenue, labor costs, and any other pertinent variables and costs. The goal here will be to provide accurate cost estimates for this project. Of course, all involved parties will have to check and balance one another to limit

corruption, so involvement of a third party, perhaps the UN, may be necessary. To fund this project, I recommend requesting assistance from WaterAid. WaterAid is a leading international NGO helping to provide clean water and sanitation resources to global communities in need. Its 2019 revenue was just over 14 million USD, so it has only modest resources.[91] However, WaterAid has country programs in Niger and Ethiopia, so it may be willing to extend its reach to Egypt.

Potential pitfalls of this project, of course, include extreme costs, unwillingness of the ministries to acknowledge and move forward with the recommendations, corruption that leads to revenue siphoning, and the fact that salinity and flooding will continue to worsen freshwater resources in Egypt. Creating strong political avenues between the ministries and local farmers will be key to avoid corruption. Showing the ministries the potential revenue increases may improve their willingness to move forward with the project.

I make this recommendation above others because it is one of the most direct methods of increasing freshwater availability in Egypt. As a developing country with struggling taxation policies, Egypt may experience hindrances in repairing waterlines and subsidizing crop teepees solely for lack of funding.[92] However, I would recommend that the Egyptian Ministry of Water Resources requests funding from USAID, under USAID's Water and Development Program. Egypt has historically been one of the United States' primary beneficiaries through USAID.

Recommendation #2: Government subsidies on cash and staple crops in addition to water-efficient seed cultivars

[91] WaterAid, "Annual 2019 Report." 2019.
[92] IMF. "Arab Republic of Egypt – Tax Revenue Mobilization," 2017, p. 28.

I recommend a second government initiative to purchase and distribute seeds for Egypt's main cash and staple crops (cotton and wheat) alongside efficient seed cultivars: winter tomatoes, mangos, and winter onions, which have been proven to produce very high yields with less water than other crops.[93] Subsidies for the water-efficient cultivars will be slightly higher, to encourage their purchase and planting. However, because Egypt relies heavily on wheat and cotton for national revenue and food supply, wheat and cotton will continue to be subsidized to offset production loss from flooded crop fields.

Additionally, I recommend government seed subsidies for shallow-root crops like cabbage and corn, which are better able to grow despite increased waterlogging and thinning water tables in the delta.[94] All of the aforementioned crops can be utilized as farmers need them, especially for feeding themselves, their families, and their communities. Ultimately, however, these water-efficient crops are not likely to provide enough yield for revenue beyond sustenance. Therefore, continuing to bolster Egypt's production of wheat and cotton will be key to this policy proposal. The water-efficient cultivars are meant to be supplementary sustenance, while cotton and wheat will continue to provide major revenue streams for the country.

I envision this project starting small, wherein the Egyptian government forms agreements with large farms in the delta, asking the respective farmers to allocate some 10% of planting land to the water-productive and shallow-root crops. This way, the repercussions of failure are minimal, and farmers most able to implement the changes can do so.

The primary goal in this recommendation is to help farmers supplement their food needs and the food needs of their local communities. Mangos, tomatoes, onions, and cabbage will

[93] El-Marsafawy, et al. "Evolution of Crop Water Productivity in the Nile Delta over Three Decades (1985-2015)." *Water*, 2018, 10(9), p. 2.
[94] Lemonick, Michael D. "Rising Sea Level May Trigger Groundwater Floods." *Climate Central*, 2012.

never be staple crops, and they do not generate substantial revenue. However, they may be able to decrease food scarcity and food vulnerability to a significant extent. If the government provides these subsidies and can encourage a few large farms to plant these crops, the benefits could be immense.

Similar to the water efficiency initiative, this initiative will require close contact between Nile Delta farmers and local authorities, and the Egyptian government at large. Providing thorough and accurate price breakdowns for average crop production, land area, and potential revenue will help the Egyptian government to properly allocate seeds. Again, in this scenario, like the water efficiency initiative, corruption will inhibit some aspects of this project. However, emphasizing the total improvement in Egypt's GDP and employment will help to convince leadership all around.

As of 2019, the Egyptian government pays its farmers roughly 670 Egyptian pounds ($42.50 USD) per ardeb (bushel) of wheat, depending on quality.[95] The cost to plant one acre of field with wheat costs approximately 3,000 Egyptian pounds ($190.50 USD), and each acre of wheat field will produce roughly 24 ardeb (3,600 kg) of wheat, assuming favorable circumstances. That calculates to roughly $1,020 USD of revenue per acre, without considering equipment and labor costs. Global demand for wheat is high, while demand for onions, mangos, and tomatoes is not, which is why this policy recommendation seeks to highly subsidize onion, mango, and tomato seeds to encourage farmers to plant them in tandem with their cash crops.[96] The ultimate goal here is to help farmers better adapt to increased salinity and flooding in their crop fields while still encouraging growth of staple and cash crops.

[95] Xinhua. "Egyptian farmers harvest wheat crops amid government plans for promoting self-sufficiency." *Xinhua News*, 2019.
[96] USDA. "Grain – World Markets and Trade." 2020.

Clear pitfalls of this recommendation include immense pushback from farmers who do not wish to have their crop production micromanaged by the Egyptian government. The disparities in political perspectives, mentioned earlier in this thesis, will be obvious obstacles during the implementation of this recommendation. From a governmental angle, Egyptian leadership may be hesitant to provide the subsidized crop seeds. Even more, the water-efficient and shallow-rooted crops may not create significant increases in agricultural production. Predictions of these outcomes are just that – predictions. However, emphasizing the potential of this initiative to farmers, including increased resilience of crops, decreased food scarcity, and improved job security, may help to convince them to try it. Heavily subsidizing these crops while also bolstering the country's emphasis on wheat and cotton may create a favorable middle ground, in which the country continues to meet revenue demands while simultaneously reducing food scarcity and job insecurity. Nile Delta farmers will certainly be hesitant and may refuse these provisions. I expect that but am hopeful that enough farmers will try the recommendation to find out if it has any merit.

Emphasizing the potential to the Egyptian government and Ministry of Agriculture, such as helping Nile Delta populations and preventing uprisings, may convince them of the need for these subsidies. If this recommendation fails for any of the aforementioned reasons, Egypt may need substantially more food aid in the coming decades. However, my recommendations to address infrastructural damage include steel storm surge barriers, which may double as a way to prevent excess salinity and floodwater in crop fields.

Recommendation #3: Government control of aquifer withdrawals

Controls on aquifer withdrawals refer to the regulated use of groundwater to irrigate reclaimed farmland. In order to avoid overuse of these finite aquifers, I recommend that the Egyptian

government forms multilateral aquifer withdrawal treaties with regional and local farmers in Egypt. In these treaties, farmers would agree to a certain volume of extraction per month, in exchange for the promised seed subsidies and water teepees. Current levels of groundwater (aquifer) extraction in Egypt are roughly 12 x 10^9 m^3 / year (3.1 trillion gallons per year), and this number is expected to increase with population growth.[97] The total available volume of aquifers is roughly 4050 x 10^9 m^3, which means that, at this withdrawal rate, Egypt would have enough groundwater to sustain its water needs for approximately 337.5 years more, depending on future trends. This longevity could increase with stronger control on aquifer withdrawals and the use of water efficient crops, as outlined in the previous two policy recommendations.

However, because of the informal nature of some Nile Delta agriculture, such regulation may be difficult. Pitfalls of this recommendation include unwillingness from all parties to participate and enforce these regulations, especially because of the constant oversight required. Further, the incompatible political intersections between Egyptian leadership and local Nile Delta farmers may result in immense pushback and unwillingness to cooperate. Thus, this recommendation serves as potential. Starting small and forming regulatory treaties with *some* farmers and local authorities would be a start, such that the project can gain experience. However, my intent is that government-subsidized seeds and water teepees would provide incentive for farmers and local authorities in the Nile Delta to agree and comply with regulations, so long as they are fair. Much negotiation would be required to form any sort of guidelines for this project, but the potential is there.

[97] Mabrouk, et al. "Impacts of sea level rise and groundwater extraction scenarios on fresh groundwater resources in the Nile Delta governorates, Egypt." *Water*, 10(11), 2018, p. 6.

Chapter 4. Policy Problem #2: Damaged Infrastructure

4.1 Current Research and Data

Flood damage of infrastructure, specifically homes and buildings, has been a documented problem in the northern delta since the mid-1980s.[98] Predictions have increased among climate scientists and coastal researchers, with stronger emphasis on the repercussions of flooding and land subsidence on Nile Delta populations living closest to the Mediterranean coastline.[99] Researchers argue that populations will be displaced, so policy recommendations must consider infrastructural rebuilding in tandem with population resettlement.

Climate scientists evaluating this problem have predicted immense damage to populations in Egypt's Nile Delta, especially those close to the coastline. In his report on sea level rise in the delta, El-Raey (1997) used geographic information system mapping (GIS), ground-based surveys, and remote-sensing techniques to explain the economic vulnerabilities in Alexandria, Rosetta, and Port-Said, which were that two million people would have to leave their homes, close to 250,000 jobs would no longer exist, and $35 billion in Egypt's economic revenue would be lost due to property flooding, stagnation in tourism, and land subsidence.[100] Sušnik (2015) found that sea water intrusion into Egypt's coastal aquifers has polluted clayey alluvial soils, worsening land subsidence and causing topographic deformities including sinkholes and cavities.[101]

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[98] Smith and Abdel-Kader. "Coastal erosion along the Egyptian delta." *Journal of Coastal Research*, 4(2), 1988.
[99] Stanley, Daniel Jean. "Subsidence in the Northeastern Nile Delta: Rapid Rates, Possible Causes, and Consequences." *Science*, 240(4851), 1988, pp. 497-500.
[100] El-Raey, Mohamed. "Vulnerability assessment of the coastal zone of the Nile delta of Egypt, to the impacts of sea level rise." *Ocean and Coastal Management*, 37(1), 1997, pp. 29-40.
[101] Sušnik, Janez, et al. "Interdisciplinary Assessment of Sea-Level Rise and Climate Change Impacts on the Lower Nile Delta, Egypt." *Science of the Total Environment*, vol. 503-504, 2015, pp. 279–288.

In turn, buildings and homes within the delta are vulnerable, and some have degraded and collapsed already in Alexandria. Various buildings have been abandoned, as they are presently unsteady due to being closest to the Mediterranean coastline. CLIMB used Differential Synthetic Aperture Radar, Interferometric Point Target Analysis, and ASAR imagery to identify critical land subsidence in Alexandria. Additionally, Sušnik (2015) predicted that local residents in Rosetta may have to relocate and forfeit their properties as loss of income prevents their staying.

Going further, Sušnik identified some 35% of Alexandria's population to be residing below sea-level. The implications of SLR for these groups would potentially mean resettlement plans, to which the population may not be receptive. In taking a household survey, Sušnik found that most of the population had limited ability to migrate, and 20% claimed that they would refuse a government-mandated migration program.[102] As such, Alexandria would face huge numbers of displaced peoples, resulting in conflict and deprivation. SLR of just 0.5 meters could lead to a loss of 13% agricultural land and a reduction on freshwater resources. Vermeer and Rahmstorf (2009) bolster Sušnik and El-Raey's arguments, as they believe that a 20cm to 2m rise could arise by 2100.[103]

Historical rates of land subsidence have not been as intense as they are today, proving that infrastructure and populations along the Nile Delta are especially at risk. Willis and Church (2012) concur with Sušnik, El-Raey, and Vermeer and Rahmstorf. Willis and Church argue that even a 0.5m rise could potentially displace 3.8 million people living along the Nile Delta due to

[102] Ibid., p. 284.
[103] Vermeer, Martin, and Stefan Rahmstorf. "Global sea level linked to global temperature." National Academy of Sciences, 106(51), 2009, p. 21528.

flooding.[104] With a focus on subsidence issues, Stanley (1988) provides historical rates of subsidence along the northern arc of the Nile Delta, outlining the same predictions of the aforementioned authors: sea level rise is causing exacerbated land subsidence along the Nile Delta coastline.[105] For the last 7500 years, the delta has subsided up to 0.5cm per year, but rapidly rising sea levels mean that this rate could increase to as much as 1m by 2100, with potentially devastating effects to the land and infrastructure along the delta.[106]

Using the PSI technique to assess land deformation, Gebremichael, et al. (2018) supports the arguments by Sušnik and Stanley, asserting that land deformation along the Nile Delta has been caused by both natural and human elements, including natural compaction of Holocene sediment and man-made fluid extraction apparatuses.[107] Further, Gebremichael's team found that by 2100, approximately 2,660 km^2 of the northern Nile Delta would be inundated by sea level rise, affecting over 5.7 million people via displacement and flooded homes.[108]

To address infrastructural threats of sea level rise, Koslov (2016) makes the argument for the term *retreat,* defined as "removing hard coastal defenses to create space for the coastline to move, for water to come in, and for intertidal habitats such as wetlands and salt marshes to flourish."[109] In other words, Koslov suggests that adapting to sea level rise may be more feasible than *preventing* it. Retreat involves moving populations to higher ground and allowing retreating coastlines to develop into natural buffers. Governments would offer compensation and assistance to populations in return for their relocation.

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[104] Willis, Josh K., and John A. Church. "Regional Sea-Level Projection." *Science*, 336(6081), 2012, pp. 550–551.
[105] Stanley, Daniel Jean. "Subsidence in the Northeastern Nile Delta: Rapid Rates, Possible Causes, and Consequences." *Science*, 240(4851), 1988, pp. 497-500.
[106] Ibid.
[107] Gebremichael, et al. "Assessing Land Deformation and Sea Encroachment in the Nile Delta: A Radar Interferometric and Inundation Modeling Approach." *Journal of Geophysical Research*, 123(4), 2018, p. 3220.
[108] Ibid.
[109] Koslov, Liz. "The Case for Retreat." *Public Culture*, 28(2), 2016, p. 362.

The complexity of population resettlement is far-reaching, however. A contentious issue for political and economic reasons, managed retreat has been feared by governments and political leadership because of the costs of "unbuilding" the receding coastline landscape and losing income from it.[110] Socially, too, "managed" retreat bears unfavorable connotations, as it alludes to surrender or defeat and has historically been a euphemism in devastating, forced population movements. Koslov argues that these connotations, coupled with political and economic fears, have hindered the potential for retreat. Instead, she views it as a powerful and evocative movement, focused on "grassroots efforts to democratize and transform space and place."[111] In the case of Nile River Delta populations, ensuring a bottom-up approach to retreat will be important to ensure that vulnerable populations have agency and feel secure in the process.

4.2. Current Policy

Because most of Egypt's infrastructure and peoples are concentrated along the Nile Delta, inundation and land subsidence have demanded the attention of policymakers for the last 20 years. In 2000, Egyptian leadership implemented a disaster risk management (DRM) initiative, including a governmental department dedicated to the cause. Titled the Information and Decision Support Center (IDSC), the department produced its first 2011 strategy for adaptation to climate change, including risk reduction, adaptation, and mitigation plans.[112] Tenets of the strategy included technological innovations for addressing water scarcity, insurance plans, enhanced early warning systems, and bolstering the IDSC's financial and resource reserves. However, this

[110] Ibid., p. 363.
[111] Ibid., p. 381.
[112] Global Facility for Disaster Reduction and Recovery. "Egypt." 2019.

department does not focus solely on climate-related issues; thus, in the years since its inception, efforts to combat salinity and inundation have not been sufficiently widespread.

At the international level, the Global Facility for Disaster Reduction and Recovery (GFDRR) has provided substantial risk training and monetary grants to Egypt's IDSC and Egyptian leaders at the national, regional, and local levels.[113] The GFDRR categorizes Egypt's major disaster threats as coastal flooding, river flooding, and water scarcity, primary symptoms of sea level rise.[114] Over the last two decades, Egypt submitted two national reports to the United Nations Framework Convention on Climate Change (UNFCCC), detailing Egypt's climate action plan. With regard to infrastructure and displaced populations, Egypt's 2015 plan sought to improve living standards of citizens and provide protection to the poor; however, their execution plans were extremely vague.[115] The government intended to implement changes in land use, stronger coastal zone management, and enhanced national-regional partnerships for managing crises.

Egypt has several ministries and agencies that are responsible for various aspects of its coastal protection policies. The Ministry of Water Resources and Irrigation develops shore protection programs and carries out research projects for the same purpose. The Environmental Affairs Agency develops coastal zone guidelines, and The Ministry of Housing and the Urban Planning Authority both develop guidelines for infrastructural planning along the coastline. However, their websites do not provide significant information on their initiatives, and they do not seem to aggressively address sea level rise and its direct effects on infrastructure and population displacement. I believe that this is because sea level rise is a recent phenomenon and

[113] Ibid.
[114] Ibid.
[115] Arab Republic of Egypt, "Egyptian Intended Nationally Determined Contribution." *UNFCCC*, 2015, p. 4.

because Egypt is a developing nation with institutions and resources that are preoccupied with issues that they deem more pressing.

4.3 Policy Recommendations to Address Damaged Infrastructure

In order to address and mitigate damaged infrastructure and the resulting displaced populations, I outline below two recommendations: 1) steel storm surge barriers, and 2) a mass, voluntary retreat of peoples along the delta coastline.

Recommendation #1: Steel Storm Surge Barriers on the Damietta and Rosetta Branches

Two steel, maneuverable (like gates) storm surge barriers would serve to stop excessive sea intrusion, and they would simultaneously be able to reopen for import/export, moving freight,

Fig. 6: Maeslantkering barrier in South Holland, Netherlands. Source: *Rijnmond*, 2018.

and other essential functions. I envision these storm surge barriers to resemble the Maeslantkering in the Netherlands. With a sill plate as its foundation, the Maeslantkering is made of steel, is 22-meters-high on both gates, and is 210 meters long. Figure 6 displays its two large gates, controlled by a computer as they swing open or closed, depending on sea level gauge

readings and climate predictions. In Egypt, this barrier would be placed at Egypt's two main Nile River branches, the Damietta and Rosetta, in order to control flooding when sea levels are highest.

The cost to build Maeslantkering in 1997 was $488 million. After calculating a 60% inflation of the USD from 1997 to 2020, I calculate that constructing two of these storm surge barriers for Egypt would cost around $1.57 billion.[116] Given that Egypt has not caused sea level rise on its own, Egypt will not pay for these barriers. Rather, this project will ideally be spearheaded by the Environmental Defense Fund and World Bank, with financial support from the United States, a strong and longstanding ally to Egypt. Given the United States' long history of aid to Egypt and the U.S.' heavy interests in the Middle East, including access to the Gulf of Suez, Persian Gulf, and Israel, I have no doubt that Egyptian leaders and policymakers can make the case for funding. Additionally, I would request substantial grants from the Environmental Defense Fund and World Bank, given that Egypt is especially vulnerable to sea level rise despite being a minor contributor to it.

Potential downfalls of this policy recommendation include failure to gather support and funding, farmer discontent with government control over water, and failure to guard Rosetta, Alexandria, and Port Said from flooding. The Netherlands has had immense success at protecting its city of Rotterdam from sea intrusion using its storm surge barrier, so I would recommend that policymakers cite its success when proposing the project.[117] Funding-wise, the Environmental Defense Fund, the United States, and the World Bank combined could be convinced of the necessity of this barrier. In the U.S.' case, the potential of losing Egypt as a geopolitical ally

[116] Bureau of Labor Statistics, "Consumer Price Index – March 2020." 2020.
[117] Kimmelman, Michael. "The Dutch Have Solutions To Rising Seas. The World Is Watching." *The New York Times*, 2017.

(including the revenue that brings) would likely be enough to elicit a strong monetary response. Bartering with its political ties to the United States is not meant as antagonism from Egypt; rather, it is a call to action from a longtime ally who needs help. The World Bank may be willing to negotiate a loan/grant deal with Egypt, too, if the United States is on board. Egypt's Department of Public Works would spearhead the construction of the barrier, with input and advice from the Ministry of Water Resources.

This recommendation comes from a strong need to protect Egypt's vulnerable populations immediately. In order to avoid major flooding, infrastructural damage, and death, erecting this storm surge barrier will create an immediate safeguard for the most vulnerable populations, and it will buy significantly more time for Egypt to conduct a major retreat of its people. Further, placing the storm surge barrier on the Rosetta and Damietta branches of the Nile means that the Nile's major flood lines will be better controlled at the source (Mediterranean Sea). Egyptian leadership tends to be supportive of large-scale infrastructural measures of development, so this project will likely be well-received, especially with support from various INGOs.[118] With outside funding and involvement, and perhaps blueprints from the Dutch engineers of Maeslantkering, I am confident that Egypt can erect these necessary barriers and protect itself and its peoples from continued sea level rise.

Last Resort: Recommendation #2: Mass Voluntary Retreat Program

A highly complex and difficult recommendation, this voluntary retreat program is a last resort plan and would entail helping peoples in the Nile Delta to move further away from the Mediterranean coastline. In order to avoid overwhelm, the program will begin by offering retreat

[118] Vio, E. "Can Sisi turn around Egypt's economy with mega projects?" *TRT World*, 2018.

facilitation to peoples closest to the Mediterranean coastline, who are most vulnerable. The program will move in steps.

Step 1

Incremental movement and establishment of major government buildings and local resources in designated retreat location. Establishment of homes and key infrastructure.

Step 2

Slow relocation of willing peoples to retreat location. A recent survey of vulnerable peoples in Alexandria, Egypt, found that those most willing to relocate would do so only if the retreat program were transparent in its goals, provided financial compensation, and provided job security.[119] Those with strong communal ties in urban areas are least likely to participate in voluntary retreat. In this proposed program, those willing to retreat will receive compensation in the form of free housing and land, commensurate with the value and size of their previous housing and land. In addition, they will receive relocation stipends and government assistance until they are able to acquire jobs.

Step 3

Management of the program will involve significant technical input from the UNHCR and the Egyptian Ministry of Housing, Utilities, and Urban Development. This program will request assistance and funding from USAID, the United Nations High Commissioner for Refugees, the Environmental Defense Fund, and the International Organization for Migration. The UNHCR does not allocate significant funds to internally displaced peoples, so they may only provide

[119] Kloos & Baumert. "Preventative resettlement in anticipation of sea level rise: a choice experiment from Alexandria, Egypt." *Natural Hazards*, vol. 76, p. 99.

technical support. Ideally, every single ministry within Egypt's government (some 32 total) will be involved in various capacities, as the project will require expertise in nearly every area.

I envision Egypt's Ministry of Housing, Utilities, and Urban Development to command the project, such that Egypt itself maintains agency and leadership within its own borders. Working alongside the housing ministry would be the Ministry of Climate Change and Environmental Science and the Ministry of Health and Population. Trained refugee workers from the United Nations would help to create international ties and support between Egypt and its global allies. Funding from USAID and the Environmental Defense Fund would go towards food, supplies, shelter, healthcare, transportation, construction, and startup income for vulnerable Nile Delta peoples who voluntarily agree to retreat.

The UNHCR's 2020 budget includes a total of $2.6 billion, with $763 million allocated under its Pillar 4 initiative for internally displaced persons (IDP).[120] Its efforts in Egypt have largely consisted of asylum seekers from other nations, including Eritrea, Ethiopia, and Iraq. In fact, based on recent reports, climate refugees within Egypt itself have not been a major part of initiatives. However, the UNHCR's 2018 Global Compact on Refugees outlines its commitment to climate refugees.[121] Therefore, having the UNHCR as a major player in this mass retreat will be key to its success and completion. Logistically, I envision the Egyptian government releasing a major public address in which it outlines the plans for the voluntary retreat, encouraging regional and local leaders to also release addresses, such that word spreads, and anyone in need will be aware of the help provided. Egypt's Ministries of Housing, Health and Population, and

[120] UNHCR. "Financials – Global Focus," http://reporting.unhcr.org/financial#tabs-financial-budget, 2020.
[121] UNHCR. "2018 Global compact on refugees," https://www.unhcr.org/gcr/GCR_English.pdf, 2018.

Climate Change will serve in a more omniscient role, such that they have oversight of the project.

With funding from USAID, the Green Climate Fund, the Green Economy Financing Facilities, and the Environmental Defense Fund, aid workers will bring in food, clothing, basic medicines, and other supplies to support retreats. A major part of this retreat program, however, will be the widespread construction projects of houses and buildings. As voluntary retreats occur, displaced peoples will need new homes and communities. Headed by Egypt's Ministry of Housing and Urban Planning Authority, the government will begin construction. In the most vulnerable Nile Delta regions, coastal land subsidence is predicted to happen at up to 90 meters per year.[122] Therefore, I recommend moving all voluntary retreaters at least 4,500 meters back from the Nile and Mediterranean shores, to give them roughly least 50 years of safety from land subsidence and flooding. This measure is, of course, dependent on rates of sea level rise and land erosion.

The ethics of voluntary retreat are complicated. Though retreat scholarship is highly polarized, most experts agree that any retreat should focus heavily on the needs and desires of the local communities in question.[123] Specifically, those orchestrating voluntary retreats must place immense emphasis on cultural preservation and human dignity, among other things.[124] This initiative will be the most difficult of all the proposals. Helping people to move to new territory will deeply disrupt their lives, incomes, and health. I recommend that the program moves slowly and lasts as long as it needs to (i.e. forever), such that voluntary retreaters can prepare and

[122] Hereher, Mohamed E. "Vulnerability of the Nile Delta to sea level rise: an assessment using remote sensing." *Geomatics, Natural Hazards & Risk*, 1(4), 2010, p. 316.
[123] Farbotko, C. "No retreat: Climate change and voluntary immobility in the Pacific Islands." Migration Policy Institute, 2018.
[124] Ibid.

acclimate to their new environments at their own paces. As mentioned prior, all voluntary retreaters will receive compensation in the form of housing and land, as well as a stipend according to their prior incomes.

I draw lessons and information for Egypt's voluntary retreat program from U.S. home buyout programs and a small, unsuccessful case study of managed retreat in Matatā, New Zealand. Many home buyout programs in the U.S., meant to move residents away from inundated or damaged property, have lacked transparency.[125] Vague contract language and stipulations have meant that residents are sometimes unsure about the agendas of their local governments, who typically carry out these programs. This has resulted in a lack of trust. In utilizing this research to inform my recommendation on retreat in Egypt, I emphasize strong adherence to transparency and cultivation of trust among all parties.

Logistically, retreat can be difficult because of uncertainty amongst the various players involved. A failed example of managed retreat comes from Matatā, New Zealand. Matatā is small coastal community along the Bay of Plenty on one of New Zealand's northernmost islands. In 2005, a heavy storm flooded Matatā's Awatarariki stream and resulted in significant land subsidence, flooding, and severe water damage to 87 properties.[126] In assessing the damages and predicting future problems, local authorities and experts initiated plans for risk management, ultimately agreeing on the idea of a managed retreat.[127] The overarching theme of the Matatā retreat effort was uncertainty, especially as it affected the multiple, intersecting interests of this project. Interests of local government, funding avenues, social/political/economic concerns, and

[125] Tucker, D. "Stanford research finds transparency may improve U.S. home buyout programs." *Stanford News*, 2018.
[126] Hanna, et al. "The uncertainty contagion: Revealing the interrelated, cascading uncertainties of managed retreat." *Sustainability*, 2020, p. 3.
[127] Ibid.

community interests all compounded and resulted in **inaction**. To this day, no retreat has happened for the vulnerable communities near Matatā's Awatarariki stream.

Egypt's Nile River Delta is much larger than the small community of Matatā, emphasizing the strong possibility of similar failure in achieving the goals of this retreat program. Not only will Egypt's program incorporate local and national governments, local communities, and the various social/political/economic concerns as did Matatā, but it will also incorporate international players. My hope is that the incorporation of international third parties (UNHCR and Environmental Defense Fund) will actually help this project to find some success. These organizations, especially the UNHCR, are trained in migratory efforts, whereas the parties in Matatā were not. Further, in Egypt's case, the consequences of delaying this kind of retreat will be severe, as discussed throughout this thesis. The magnitude of impending danger for Egypt coupled with significant international support, may help this project to succeed, slowly and deliberately. It will depend upon a momentous and combined effort from many players.

Conclusion

Summary

This thesis has evaluated the effects of sea level rise on agricultural productivity and infrastructural damage in Egypt's Nile River Delta. Because sea level rise is caused by the cumulative, global production of greenhouse gases, remedying it is complex. Egypt's Nile River Delta is coastal and low-lying, making it particularly vulnerable to rising sea levels. With over half of Egypt's population living and working in the delta, the impending crisis could be catastrophic. These delta communities are already battling excess flooding and salt, and this problem is expected to worsen without substantial efforts to stop it. Climate scientists and economists predict disastrous health, social, and political consequences in the Nile Delta if increasing sea levels are not addressed aggressively.

In my evaluation of the problem, I identified two areas – agriculture and infrastructure – where policy implementation is most critical. Agriculture is a major sector of employment and GDP in Egypt, and most infrastructure is concentrated in the delta. Thus, these two areas will continue to be the most extensively affected by sea level rise. To address agricultural decline, I proposed 1) more efficient systems of water use, which include repair of waterlines and crop teepees, 2) government subsidies for shallow-root, water-efficient crop seeds, which are best able to handle excess water and salt, and 3) regulation of groundwater extraction, such that extraction is less wasteful and more targeted towards necessity. To address infrastructural damage, I proposed 1) steel storm surge barriers, which will stop excess seawater from infiltrating the main branches of the delta, and 2) a mass, voluntary retreat, such that vulnerable peoples in the delta have the support and resources to move away from flooded areas of the delta, should they wish to do so.

While potentially promising, these policy proposals are not bulletproof. As a developing economy, Egypt may struggle to subsidize a nationwide water-system repair initiative. The Ministry of Water Resources in Egypt does not have documentation of all irrigation systems, because not all have been constructed by the government itself. Facilitating a delta-wide estimate of waterlines, repair costs, and general need will be a huge undertaking, and it is not immune to corruption, greed, or inefficiency. However, attempting this project is key, and I foresee the benefits outweighing the pitfalls.

Government subsidies of certain crop species, specifically those that can handle excess salt and floodwater, may also cause problems, as farmers become upset that their crop practices are being controlled. However, with transparency on the government's part, I foresee delta farmers acclimating to incorporate new seed species, especially when they witness the improved growth rates and harvest potential. Controlling aquifer withdrawals, too, will be difficult, largely due to the political strife between Egyptian leadership and delta communities. This proposal may be the most difficult to implement, but with regional and national cooperation, I expect more efficient use of groundwater, such that agriculture and consumption are top priority.

Also not immune to difficulty are the recommendations for storm surge barriers and a mass retreat. Expensive as they are, the steel storm surge barriers could be lifechanging for communities closest to the Mediterranean coastline. Their ability to close during especially high sea levels and storms will shelter communities that are most susceptible to such events. With aid from the United States and meticulous planning, I have confidence that storm surge barriers on the Damietta and Rosetta will provide immense benefit and protection to communities in the Nile Delta. The mass retreat will be, by far, the most difficult endeavor, but it is the most critical of all. With cooperation from the Egyptian government, the UNHCR, USAID, the Green Climate

Fund, the Green Economy Financing Facilities, and the Environmental Defense Fund, supporting Nile Delta communities in voluntary retreat can be successful. Key in this proposal is the *voluntary* aspect of the plan. No one will be forced to move. Rather, plentiful support will be provided by the aforementioned organizations, such that retreat is as smooth as possible for those interested.

Avenues for Further Research

Sea level rise is a constantly-evolving problem, and for this reason, it will require constant research and attention for amelioration. In Egypt's Nile River Delta, specifically, surveys and data on public opinions of the problem are lacking. Extensive interviews with Nile Delta farmers, fisherman, and communities is scarce, and it would provide important insight into what is happening on the ground. My research has shown an obvious disconnection between Egyptian leadership and the millions of peoples living and working along the Nile River Delta. Any policy that aids in strengthening the communication and relationships between these two entities will help to bolster Egypt as a whole and tackle the effects of sea level rise head on.

Additionally, more analysis is needed on the logistics of a voluntary retreat in the delta. The Nile Delta is a very special case because of its long-standing centrality in Egyptian life. Over 50 million people live in the delta and depend upon it, since Egypt's vast desert landscape is largely inhospitable. Helping people to retreat from this crucial area is an overwhelmingly intersectional, complex idea. It will require substantial cooperation and discussion from various entities.

Ultimately, I am hopeful for the continued attention paid to Egypt and its historic Nile River Delta. Sea level rise is an impending threat that can be remedied with significant global cooperation. I am confident that continued interest and grassroots efforts will ultimately push

governments and NGOs to action, little by little, such that vulnerable regions like the Nile Delta are saved. To preserve its life-giving existence in Egypt is critical, such that its communities can grow and thrive for centuries to come.

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