Climate-Change Impact on Florida’s Water Resources

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Emerging changes in water availability in the U.S. state of Florida have been recognized as a combined result of human perturbations, natural variability, and climate change. Florida is particularly susceptible to the impacts of the sea level rise due to its extensive coastline, low elevation, and lack of topographic relief to promote drainage. Owing to the porous nature of the state’s aquifer systems, saltwater intrusion into coastal areas is an evolving threat. Additionally, anthropogenic intervention has increased the contribution of nutrients and sediments to many lakes, reservoirs, and rivers, subsequently causing eutrophication and sedimentation problems.

climate change water resources saltwater intrusion

1. Groundwater Resources of Florida

In Florida, groundwater is the primary source of urban potable water [1]. The principal aquifers in Florida include the Floridan Aquifer System, the Sand-and-Gravel Aquifer, the Surficial and Intermediate Aquifers, and the Biscayne Aquifer. The Floridan Aquifer System extends across the entire state and supplies freshwater to cities such as Tallahassee, Jacksonville, Gainesville, Orlando, Daytona Beach, Tampa, and St. Petersburg [1]. Based on permeability, the Floridan Aquifer was divided into the Upper Floridan Aquifer and Lower Floridan Aquifer [2]. During the last glacial period, the whole aquifer system was recharged through infiltrating atmospheric precipitation [3]. Additionally, the rise in sea level caused an increase in hydraulic head, which subsequently lowered the rate of groundwater movement, and its confined freshwater within the Upper Floridan Aquifer and allowed salt water to mobilize into the Lower Floridan Aquifer [4]. In South Florida, the Floridan is too saline to use for drinking or agricultural water sources [1].

Florida’s surficial or shallow aquifer system is separated from the Floridan Aquifer System by a confining bed of clay [5]. The surficial Sand-and-Gravel Aquifer in the western panhandle and the unconfined surficial Biscayne Aquifer (carbonate) in the southeast are used for drinking water [1]. The highly productive Biscayne Aquifer is recharged primarily from rainfall events and, during dry periods, from canals connected to Lake Okeechobee [6]. An extensive system of canals and other control systems and pumping stations manage the Biscayne Aquifer and other freshwater resources in South Florida [7]. The Surficial Aquifer System and the Intermediate Aquifer System typically produce lesser amounts of freshwater and supply water to smaller public water supplies in SWFWMD [8].

In South Florida and the eastern portion of Peninsular Florida, one or more aquifers exist between the local surficial aquifer and the underlying Floridan Aquifer System; these aquifers are referred to as Intermediate Aquifers [8][9]. The sediments which comprise the Intermediate Aquifers exist over most parts of the state; however, in certain areas, the sediments are relatively impermeable and do not yield water to supply wells. As a result, the Intermediate Aquifers are not widely used, and, hence, the aquifers are not well-characterized [10]. The Intermediate Aquifers are predominantly used for supplying water to the southwest part of the state [11].

1.1. Florida’s Aquifers

The International Panel on Climate Change (IPCC) considered saltwater intrusion into coastal aquifers to be a major future impact of sea level rise, particularly under a worst-case scenario. Saltwater intrusion is a natural process which can occur through various pathways, including lateral and upward intrusion from coastal waters, downward infiltration from brackish surface water, and vertical transport of saltwater near discharging wells [12][13]. Saltwater intrusion has already occurred to some extent in numerous North American coastal aquifers, which are currently under pressure due to over-abstraction [12]. Numerous researchers have found that the extent of saltwater encroachment is variable, site-specific, and closely linked to the hydrogeological setting of the coastal aquifer [12][14]. Much of Florida’s coastline is particularly at risk due to a combination of changes in precipitation and temperature, overdraft of groundwater, and sea level rise [15].

Over the last few decades, unsustainable withdrawal of groundwater by public-supply wells and irrigation wells has become an increasingly concerning issue in Florida [16][17]. Groundwater over extraction is also the predominant cause of saltwater intrusion in Florida’s coastal regions; however, lowering water-table heights through drainage canals have caused further saltwater intrusion in the southeastern portion of the state [12]. The mixing of saltwater with fresh groundwater impacts the overall quality and availability of groundwater. The USEPA standards for Total Dissolved Solids (TDS) and chlorides are 500 mg·L^{-1} and 250 mg·L^{-1}, respectively. In comparison, the concentrations of TDS and chlorides in seawater are 35,700 mg·L^{-1} and 19,400 mg·L^{-1}, respectively. As a result, saltwater intrusion and water-quality deterioration have become the main constraints in the groundwater management issues of many coastal aquifers [12]. The effects of the changing climate are expected to exacerbate these problems in many areas of Florida due to the increasing average surface temperature, decreasing rainfall, and increasing evapotranspiration, which, in turn, will reduce renewable groundwater supplies and cause groundwater levels to decline further [18][19][20].

The Floridan Aquifer

For most cities in Central and Northern Florida, the Floridan Aquifer serves as their main source of drinking water. Locally, the Floridan Aquifer is intensively pumped to support urban development and increased agricultural activities [1]. Precipitation and leakage from canals, lakes, and streams replenish the aquifer [21]. Over-pumping of the aquifer has resulted in the lowering of the potentiometric surface, consequently increasing the likelihood for saltwater movement from the deeper saline zones into freshwater zones [7][21][22]. Saltwater encroachment into the Upper Floridan Aquifer occurs due to the upward leakage of connate water from the Lower Floridan Aquifer and lateral intrusion of the freshwater/seawater boundary that occurs at varying distances from the Northeast Florida Coast in SJRWMD [23]. Saltwater contamination of the aquifer poses a threat to groundwater quality in the coastal areas of Duval, Nassau, and St. Johns Counties [22]. This phenomenon will likely be aggravated by a possible reduction in precipitation in the future due to global climate change. As a result, due to the increased use of groundwater in Florida's coastal region, there is mounting concern regarding the influence of the changing climate on groundwater quantity and quality [21][22]. Additionally, any change in the rate of recharge and groundwater withdrawal from the state's aquifers due to the changing climate can impact the hydrologic budgets of various regions in Florida [21].

The Biscayne Aquifer

In South Florida, declining groundwater levels have allowed higher-gradient seawater to encroach into groundwater supply systems, making the water unusable without additional processing [17][24]. Over the past century, the saltwater interface in the shallow karstic Biscayne Aquifer has progressively moved further inland. Saltwater intrusion into parts of the aquifer is a serious concern for the 6 million residents of Miami, Fort Lauderdale, the Florida Keys, and Palm Beach who heavily rely on the aquifer for their source of potable water [18][25]. Initially, saltwater encroached into the Biscayne Aquifer as the Everglades were drained to expand the dry land for urban development and agriculture [25]. The draining caused the water levels to decline and, in combination with intermittent droughts, allowed saltwater to migrate inland through the base of the aquifer and to leak into the freshwater aquifer from the canals [25]. The freshwater Everglades recharge the Biscayne Aquifer, and as rising seawater levels submerge low-lying portions of the Everglades, portions of the aquifer become saline [26]. As of 2011, roughly 1200 km^2 of the mainland part of the aquifer was encroached by saltwater [25].

The Surficial Aquifer System

During the 19th century, much of the Everglades was drained for agriculture and urban development, and, currently, the water levels and water flow are mostly controlled by an elaborate system of levees and canals [27]. The lowering of the water table across the Everglades allowed for urban development along the coastal region, but in Southeast Florida, this reduced the quantity of water available for recharging the aquifer [28]. Additionally, the over-pumping of groundwater has resulted in saline intrusion in the surficial aquifers along the northeastern coastal areas of the state [23]. Most estimates of the associated sea level rise range from 0.45 m to 1.37 m for the increase in sea level by the end of this century [28][29][30]. This will complicate matters further when the rise in sea level increases the groundwater table of the Surficial Aquifer System in the future [28][30].

2. Interaction of Climate Change and Eutrophication

The FDEP lists over 1400 water bodies of Florida, including rivers, springs, wetlands, and estuaries, as impaired by pollutants. Many of these waterbodies are impaired due to nutrient overloading (nitrogen (N) and/or phosphorus (P)) from anthropogenic sources [30][31]. For example, increased nutrient loading from anthropogenic activities has resulted in ecological changes in many water bodies in Florida (e.g., Lake Okeechobee, Lake George, Lake Seminole, Lake Kissimmee, Lake Apopka, Lake Istokpoga, East and West Lake Tohopekaliga, Crescent Lake and Orange Lake, Indian River lagoon, and Florida Bay), and these aquatic systems have been classified either as eutrophic or hypereutrophic [32][33][34][35][36][37]. However, some lakes of Florida are naturally eutrophic due to the release of macronutrients from the region's soils and bedrock [31].

Harmful algal and cyanobacteria blooms (HACBs) proliferate in warm water with high nutrient loads [38][39]. There are many kinds of HACBs, which are caused by diverse organisms, including toxic phytoplankton and cyanobacteria (blue-green algae). Harmful algal blooms consisting of a variety of algae have been observed in Biscayne Bay, the Indian River Lagoon, the St. Lucie Estuary, Lake Okeechobee, the Florida Keys, and the Caloosahatchee Estuary [40][41][42][43][44]. For example, Phlips et al. [45] investigated the scales of spatiotemporal variability in harmful algal species dispersal in the Indian River Lagoon and observed five potential toxin-producing algal species at bloom level, namely the diatom *Pseudo-nitzschia calliantha* and the dinoflagellates *Pyrodinium bahamense* var. *bahamense*, *Prorocentrum rathymum*, *Cochlodinium polykrikoides*, and *Karlodinium veneficum*. Several studies have found that, in the nearshore water of Florida's western coast, red tides are frequently caused by *Karenia brevis* [45][46][47]. Furthermore, according to the National Ocean and Atmospheric Administration [48], a remarkably persistent red tide impacted part of the state's coastal region between 2017 and 2018, dissipating in the winter of 2018–2019. The red tide persisted on the southwestern coastal area beginning in October of 2017 and spread to the Panhandle and the eastern coast of the state. Researchers have found that Florida's risk of HACBs will increase due to warming caused by changing climatic conditions [43][49]. For instance, the toxin-producing *Microcystis* grows faster than other non-harmful algae when water temperatures are above 25 °C [50]. The potential future effects of climate change also include an increase in extreme weather events, including the occurrence of intense storms and extreme precipitation, followed by longer periods of drought [50]. Researchers have already found that the intensity of harmful algal bloom in Florida's lakes is impacted by summer drought; particularly in Lake Apopka and in shallow lakes nearby Orlando, the abundance of cyanobacteria can be fivefold intense in drought years compared to that of wet years [37][51]. As such, it is possible that, in the future, climate-induced droughts may aggravate harmful algal blooms in Florida's lakes and reservoirs.

Although there is a general recognition that climate change and global warming play a major role in the expansion and persistence HACBs in Florida's water bodies, uncertainty remains regarding the exact extent to which future climatic conditions will increase the frequency, intensity, and distribution of several HACBs in these waters [52][53][54][55]. For certain HACB species (e.g., *Dinophysis*), it is possible to predict local and regional patterns at a seasonal level. In the U.S.; the Integrated Ocean Observing System continually collects coastal and marine data for the rapid detection and timely prediction of environmental changes that encourage HACBs and their subsequent mobilization to coastal water [56].

State and local governmental agencies play a key role in monitoring HACBs, researching treatment alternatives, and informing the public about HACBs' impact on human health, whereas federal governmental agencies are primarily responsible for developing management plans to prevent, control, and mitigate HACBs Currently, various Florida state agencies regularly monitor over 75 species of marine, coastal, estuarine, and freshwater HACBs [55]. Furthermore, in order to mitigate the public health and environmental implications of HACBs, the USEPA has emphasized the significance of minimizing nutrient pollution from all sources. Growing environmental concerns about the negative environmental effects of increased nutrient discharges to coastal waters have resulted in mandatory reductions in the number of ocean discharges in Florida [56].

Currently, HACB climate-change research efforts are primarily focused on forecasting HACB occurrences and preventing their adverse effects on the environment [57]. The complexities of the HACB problem, its causes, prevalence, distribution, and consequences are becoming well characterized; nevertheless, there appears to be a knowledge gap regarding the links between each degree Celsius rise and the likelihood/rise risk of HACBs.

2.1. Lake Okeechobee

Currently, climate change and eutrophication are both critical environmental issues for Lake Okeechobee, which is the central feature of the interconnected Kissimmee River–Lake Okeechobee–Everglades ecosystems of Florida [58]. Lake Okeechobee is a shallow lake (2.7 m) in South Florida, which supplies water to the Everglades and Florida Bay [30][59][60]. The lake supplies water, flood control, and recreational opportunities to a population of 3.5 million people [30][60]. For several decades, the lake has experienced accelerated eutrophication owing to excessive nutrient loads from an agriculturally dominated drainage basin [61]. The lake is most susceptible to having massive blooms of the cyanobacteria *Microcystis aeruginosa* that are persistent during almost the whole year due to the conducive climatic condition [62][63].

To prevent failure of the Herbert Hoover Dike, which encircles Lake Okeechobee, the U.S. Army Corps of Engineers control the release of water from the lake into the St. Lucie and Caloosahatchee estuaries. During the flood-control releases and heavy precipitation events, large quantities of water with high levels of nutrients (mostly N and P), as well as HACBs, are carried off downstream to the Indian River Lagoon and the St. Lucie Estuary, resulting in HACBs in these waters [30][43][49][64][65]. In 2018, harmful algal bloom occurrence caused by lake water discharges from the Army Corps of Engineers prompted a State of Emergency declaration in South Florida (Glades, Hendry, Lee, Martin, Okeechobee, Palm Beach, and St. Lucie counties; [66]. It is noteworthy that restoration and conservation efforts to prevent Lake Okeechobee from being overwhelmed by nutrients and subsequent algal blooms have not been achieved due to sediment accumulation and resuspension of legacy phosphorus, which accumulated within the drainage basin from past inputs of fertilizers and manures [30][61][67][68].

Goly and Teegavarapu [69] investigated the impacts of Atlantic Multidecadal Oscillation (AMO) and El Niño–Southern Oscillation (ENSO) on regional precipitation extremes and characteristics in Florida. These researchers indicate that AMO influences vary in the peninsula, as well as in parts of Continental Florida, and the warm (cool) phase of AMO causes increased rainfall extremes throughout the wet (dry) season. Furthermore, most of the extremes in the southern and eastern parts of Florida occur in June and September, during the warm phase, which could be due to the increased number of hurricane landfalls. Approximately 20% (30%) of the annual extremes occur in the dry season during the AMO warm (cool) phase, and more than half of the extremes are observed during the El Niño. The impacts of ENSO and AMO on rainfall extremes and characteristics are spatially uniform and non-uniform across the state, respectively. An evaluation of ENSO impacts on dry-season precipitation suggested that the effects of ENSO are confined to the dry season with El Niño–related extremes and total precipitation increase (decrease) during the negative (positive) phases of the AMO. In addition, water inputs to Lake Okeechobee varied by 40% between the warm and cool phases of AMO. Therefore, it is imperative that both FDEP and FWMDs consider including the influences of climate change in the Lake Okeechobee restoration projects to achieve the intended outcomes.

2.2. Indian River Lagoon System

The Indian River Lagoon system, which extends 240 km along Florida’s east central coast, is a group of three connected lagoons: the Mosquito Lagoon, the Banana River, and the Indian River [70][71]. The Indian River Lagoon is a poorly drained shallow estuarine system in the central coast of Eastern Florida. In recent years, anthropogenic activities have increased the pollution level in the Indian River Lagoon due to accelerated population growth, urban development, discharge of untreated or minimally treated stormwater and wastewater, widespread application of nutrient enriched fertilizers, causeway construction to obstruct water flow, and freshwater diversion from the St. Johns River into the estuarine system [72]. The Indian River Lagoon system is able to absorb some of the pollutants, but, when overburdened, the estuarine system suffers [56].

The National Oceanic and Atmospheric Agency’s [73] estuarine eutrophication survey of the South Atlantic region indicates that the Indian River Lagoon was hypereutrophic with respect to excessive carbon fixation. During the following years, the estuarine system experienced changes in water quality and clarity due to anthropogenic nutrient loading, produced more HACBs, and experienced fish kill episodes [56][74][75][76]. Phlips et al. [71] monitored the water quality of the Indian River Lagoon for a decade and found that the more frequent bloom formers were the potentially toxic dinoflagellate *Pyrodinium bahamense* var. *bahamense* and two centric diatoms, *Dactyliosolen fragilissimus* and *Cerataulina pelagica*. The average phytoplankton bio-volumes were considerably higher in the sampling locations in the northern parts of the Indian River Lagoon in comparison to that of the central lagoon. Researchers found that the differences in the dynamics of phytoplankton populations in the northern and central lagoon suggest connections between hydrology and drainage basin characteristics in describing the response of phytoplankton communities of coastal ecosystems to changing nutrient load and climate conditions.

Between 2012 and 2013, ‘brown tides’ caused *Aureoumbra lagunensis* to occur in the Mosquito Lagoon and Northern Indian River Lagoon along Florida’s eastern coast, and this was the first documented case of the algae in Florida’s waters [74][77][78]. The detrimental effects of these events included the deterioration of the overall water quality, along with shellfish and fish kills as a result of oxygen deficiency [77][78]. It is likely that the increasing temperatures linked to the changing climate will stimulate further occurrences of HACBs in the Indian River Lagoon. The sustainable management of eutrophic water bodies is a complex issue and requires the united efforts of citizens, scientists, resource managers, and government decision makers. Given the interconnected nature of Florida’s water bodies, management strategies to improve the Indian River Lagoon’s water quality requires a holistic approach aimed at a reduction in the pollutants released from all sources, the development of efficient and cost-effective techniques for nutrient recovery from wastewater and recycling techniques, and the active management of the entire ecosystem through monitoring and control [67]. The SJRWMD [79], along with various federal and state agencies, local governments, and academic institutions, is working solely and collaboratively to improve the Indian River Lagoon’s water quality by removing and/or minimizing legacy nutrient and sediment loads.

3. Impacts of Changing Climate on the Florida Everglades

The Florida Everglades is an extensive wetland, which stretches roughly 160 km from the Kissimmee River basin through Lake Okeechobee to Florida Bay in Southeastern Florida [80][81]. During the twentieth century, much of the Everglades was drained for agriculture and urban development, and now it has been reduced to half of its original size [27]. Levees and canals have changed the area’s hydrological system and also disturbed the natural north-to-south flow pattern [82]. Due to decades of residential and agricultural growth, increased nutrient pollution from upstream activities degraded the water quality in the Everglades [83][84][85][86]. The extent of nutrient loading in the Florida Everglades is mainly found in adjacent water inflow points or canals; therefore, the peripheral area is nutrient effected, whereas interior parts of the wetland are less impacted [87]. In 2000, the Comprehensive Everglades Restoration Program, with a 35+-year timeline, was enacted to re-establish pre-drainage flows and preserve the Everglade ecosystem [88][89]. The early results of the restoration efforts have been positive, with substantial drops in pollution levels and a reversal in the trend of several negative indicators [90]. The SFWMD reports that, over the past two decades, Florida has invested USD 1.8 billion in phosphorus control programs, which have substantially improved the water quality of the Everglades. Furthermore, scientific monitoring suggests that ≥90% of the Everglades currently meets ultra-clean water quality standards of 10 ppb or less for phosphorus. However, considerable future efforts are still essential to reach a sustainable balance in this human-dominated watershed ecosystem and wetland [90]. Note that sea level rise and projected changes in temperature, precipitation, and evapotranspiration were not considered in the development of the Comprehensive Everglades Restoration Program [91][92]. The water level in the Everglades fluctuates with varying precipitation and freshwater flow patterns, along with tidal effects [91][93]. Additionally, over the last five decades, investigators have found an increase in the water level at some inland freshwater sites within the Everglades National Park, which is comparable to the observed increase in regional sea level https://www.nps.gov/ever/learn/nature/climate-change-references.htm, accessed on 25 June 2023 [93]. It is important that fresh-to-marine head differences are included in water governance decisions to lessen the negative impacts of sea level rise across the Everglades landscape [91].

An important part of the Everglades hydrologic budget is evapotranspiration. Many scientists have extensively studied the evapotranspiration of the Everglades, e.g., [94][95][96]. Rainfall and evapotranspiration are the key components in the hydrology of the area. Due to global warming, future increases in air temperature will increase the evapotranspiration rate; hence, irrigated agricultural land will require more water. According to the USEPA [97], over the next five decades, the total demand for water in the area will likely increase by more than 25%. It should be noted that the total quantity of available water, however, is not likely to increase, and it is also possible that the amount of available water may decline. Additionally, increased evapotranspiration rates, coupled with reduced rainfall, will significantly reduce the tributary inflows and result in a substantial drop in the water levels of Lake Okeechobee [94]. Moreover, with the rising sea level, saltwater will encroach into the interior of the Everglades and threaten cypress swamps, along with other saltwater-intolerant species [97]. Furthermore, increasing salinity may threaten the Biscayne Aquifer, which is recharged by surface water in the Everglades [97].

4. Climate-Change Influences on Runoff and Sediment Loads to Apalachicola River

The Apalachicola River and Bay drainage basin is the southern extent of the Apalachicola–Chattahoochee–Flint Rivers Basin that covers roughly 51,800 km^2 of the U.S. states of Georgia, Alabama, and Florida [98]. The Apalachicola River has the largest discharge of all the rivers in Florida, accounting for roughly one-third of freshwater runoff on the west coast of Florida [99]. The Apalachicola River begins at The Jim Woodruff Lock and Dam, flows towards the south, and eventually discharges to the shallow estuarine Apalachicola Bay, where it is the primary source of freshwater [100][101]. The Apalachicola River has a wide floodplain and is subject to variable seasonal flow [102][103]. As the up-gradient river, Apalachicola River has a direct influence on the Apalachicola Bay; the sediment and pollutant loads of the river considerably impact the water quality of the Bay [104]. The river receives substantial amounts of pollutants, including nutrients, microbial pathogens, sediment, petroleum products, metals, pesticides, and a variety of contaminants, from nonpoint sources of pollution [98]. Between 1978 and 2012, the average annual discharge of the Apalachicola River was 680 $cm^3 \cdot s^{-1}$ [103].

Hovenga et al. [102] used a Soil and Water Assessment Tool (SWAT) model to study the effects of climate and land-use changes on water quantity and quality in the Apalachicola River Basin under historical conditions. The findings suggest that climate change may induce seasonal changes that could prolong or entirely change periods of high and low runoff and sediment loading, and larger sediment loading was associated with the expansion of agriculture and urban areas, as well as deforestation in the region. Chen et al. [104] investigated possible climate-change effects on runoff and sediment load in the Apalachicola River Basin by using a SWAT model and assessed the impact of the changing climate during a 24-h extreme precipitation event (2 March 1991) with a 25-year return period. These investigators found that climate change is expected to influence surface runoff and sediment load in the river basin more severely during extreme rainfall events. The study also found that the peak streamflow and peak sediment load may rise by 50% and 89%, respectively, due to more intense and less frequent rainfall events. This is of concern because urban development and stormwater runoff both influence the productivity of the Apalachicola system [99]. The FDEP reports that, out of 312 waterbody segments in the Apalachicola River and Bay watershed, 7 segments are already impaired for nutrients and 41 segments for mercury [98]. The intensity of the heaviest extreme precipitation events is known to increase with global warming and may increase flood magnitudes and result in increased sediment and pollutant loadings to the Apalachicola Bay, particularly due to sea level rise [102][104][105].

5. Influences of Ocean Acidification on Florida’s Coastal Water

Ocean acidification can adversely impact aquatic life, specifically calcium-carbonate-shell/skeleton-building organisms, due to decreased carbonate availability and increased acidity [106][107]. The acidic seawater causes organisms’ shell or skeleton to dissolve, and increased acidity also results in the reduced calcification rates of these organisms [107]. Impacts of ocean acidification are well documented in Florida [18][108][109]. Most of Florida is susceptible to the formation of sinkholes due to the underlying thick carbonate deposits, which can be dissolved by circulating groundwater [110]. Groundwater passes into and out of storage in the carbonate-rock aquifers, and in many areas, groundwater mixes with seawater where water flows from land to sea through the limestone (calcium carbonate) foundation [111][112]. It is not fully understood how the interaction between freshwater acidification and ocean acidification, along with the changes in coastal ocean carbon chemistry, will influence the limestone foundation or Florida’s coastal aquifers [113].

Eutrophication can contribute large amounts of CO_2 to coastal water, and it can result in stronger changes in seawater carbonate chemistry than that associated with ocean-acidification processes [114]. Once the algae die, their cells are degraded by heterotrophic bacteria, oxygen is consumed, and CO_2 is released. In shallow coastal shelf systems, eutrophication can eventually lower pH seawater to levels which typically occur at advanced stages of ocean acidification [113]. Agricultural runoff from South Florida to Florida Bay (Lapointe et al., 2008) and periodic discharge of groundwater contaminated with septic tank effluent in shallow nearshore waters of Florida Keys have resulted in coastal eutrophication [40][115]. Rising surface ocean temperatures, nutrient loading, and atmospheric CO_2 are expected to further aggravate the acidification process [116].

During the next century, along with extreme temperature fluctuations from a changing climate, ocean acidification may also impact coral reefs in the Florida Keys as atmospheric CO_2 concentrations continue to rise. Muehllehner et al. [108] collected water samples along the 200 km stretch of the Florida Reef Tract north of Biscayne National Park to the Looe Key National Marine Sanctuary and found that the limestone, which primarily forms the foundation of coral reefs along the Florida Reef Tract, is dissolving during the fall and winter months. In particular, the Upper Florida Keys were the most affected by the annual loss of limestone surpassing the quantity the corals are capable of producing. Coral reefs in the Florida Keys are threatened by a multi-year outbreak of stony coral tissue loss disease, which began during the summer of 2014. The disease adversely affected nearly 50% of the coral species (e.g., *Colpophyllia natans*, *Dendrogyra cylindrus*, *Diploria labyrinthiformis*, *Meandrina meandrites*, *Montastraea cavernosa*, *Orbicella faveolata*, *Pseudodiploria strigosa*, and *Siderastrea siderea*) on the Florida Reef Tract [117][118][119]. Thermal stress, in combination with other environmental stressors, lowers the tolerance of corals to pathogens and contributes to persistent or recurring outbreaks [117][120] The adverse impacts of human-induced climate change will likely hinder the recovery of Florida’s coral reefs in the foreseeable future [121][122][123].

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