

Climate change and water supply: governance and adaptation planning in Florida

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Abstract

Florida has been described as ‘ground zero’ for climate change in the United States with coastal communities vulnerable to sea-level rise and water supplies under threat from saline-water intrusion, changes in precipitation amounts and patterns, and temperature-driven increases in demands. Water utilities and regional suppliers are responsible for their own water supply plans and adaptation strategies, which are developed largely by a relatively small group of technical specialists (internal and contracted). Water supply planning is prescribed by the state water governance system and local community planning processes. The degree of engagement of large coastal communities and water utilities and regional water suppliers in Florida with climate change research is generally high. Climate change-induced impacts to water supplies and demands over the common 20-year planning horizon are likely to be small relative to increases in demand caused by projected on-going population growth and normal climatic variation. Water utilities in Florida have been incidentally moving toward more climate-resilient supplies (e.g., brackish groundwater desalination) due to the unavailability of additional permittable, inexpensive fresh groundwater rather than climate change concerns. Climate change will narrow the alternatives for future water-supply development.

Keywords: Adaptation; Climate change; Florida; Groundwater; Resilience; Water

Highlights

- Addresses adaptation of water supply to climate change in Florida, a state with a high vulnerability to climate change.
- Addresses how regulatory frameworks impact the adaptation process.

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- Discusses how adaptation of water supplies to increased demands from population growth results in increased resilience to climate change.
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Introduction

There is now little doubt in the scientific community that the global climate is changing as a result of human activities at a rapid (by historical human experience) and accelerating rate (IPCC, 2014, 2019). In addition to the direct impacts of higher temperatures, secondary impacts will increasingly continue to occur, particularly rising sea levels and increases in evaporation and precipitation rates (i.e., an acceleration of the hydrologic cycle). Climate change will impact water resources through spatial changes in the amount, seasonality, intensity and form of precipitation, melting of glaciers, temperature-induced changes in water demands, and salinization of coastal aquifers caused by rising sea levels (Vörösmarty et al., 2000; Bates et al., 2008; Kundzewicz et al., 2008).

Responses to climate change are mitigation and adaptation. Mitigation is defined by the Intergovernmental Panel on Climate Change (IPCC, n.d.) as ‘a human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs)’. Adaptation was defined by the IPCC (n.d.) as ‘the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate harm or exploit beneficial opportunities’. Adger et al. (2007) observed that ‘adaptation to climate change takes place through adjustments to reduce vulnerability or enhance resilience in response to observed or expected changes in climate and associated extreme weather events’.

Adaptation includes both anticipatory (proactive) and reactive actions (Adger et al., 2007). Anticipatory adaptation involves acting before actually confronting a problem, whereas reactive adaptation is triggered by past or current events. Anticipatory adaptation can allow for a less disruptive transition to new climatic conditions. Reactive adaptations may be forced in the absence of sufficient anticipatory actions. For example, if climate change causes wells to run dry, then communities have no choice but to adapt in some manner by either finding alternative water sources, dramatically decreasing water use, or migrating to another location where water is more plentiful.

Adaptation was downplayed in the early climate change literature because of the perception that if there were satisfactory options to cope with climate change, then there would be less incentive to curb GHG emissions (Pielke et al., 2007). By the time of the Fourth Assessment Report of the IPCC (2007), a great number of papers, reports, and books had been published on all aspects of adaptation to climate change (Adger et al., 2007). It was recognized by the IPCC that mitigation will be insufficient to avoid climate change and that adaptation will have to occur in response to climate change. It was also recognized that a number of limits and barriers exist to the implementation of adaptation, including physical and ecological limits, financial barriers, informational and cognitive barriers, and social and cultural barriers (Adger et al., 2007; Klein et al., 2014).

The climate change adaptation literature now addresses virtually all sectors of society. Multiple studies investigated the adaptation needs of the water industry and recommended procedures for assessing vulnerability and identifying strategies to increase resilience (e.g., IWA Specialist Group on Climate Change, 2009; Danilenko et al., 2010; Yates & Miller, 2011; Bloetscher et al., 2014; USEPA, 2015). Within the adaptation literature, an idealized narrative has evolved in which adaptation involves close

collaboration between climate change researchers and decision makers, active involvement of all stakeholders, and consideration of diverse issues including environmental impacts and social equity. A common theme is the need for greater communication (i.e., to bridge the gap) between the suppliers and users of climate information (Feldman & Ingram, 2009; Hewitt *et al.*, 2017). Several key practical issues that have received relatively little attention are who actually makes adaptation decisions, how such decisions are made, and the time frames that are used for planning and capital investment.

Florida has been called ‘ground zero’ for climate change in the United States because of its low-lying topography and long coastline and thus susceptibility to sea-level rise and increased storm activity (e.g., UCS & REF, 2019). The impacts of climate change are superimposed on a rapidly growing population. Coastal county and city governments in Florida that are most at risk have been active in evaluating their vulnerability to climate change and assessing and implementing strategies to increase their resilience to climate change. For example, the City of Miami Beach has been raising the level of its main streets by 0.6–0.9 m (2–3 ft) to combat rising sea levels.

Approximately 63% of the total water supply and 85% of the public water supply in Florida are obtained from groundwater (Marella & Dixon, 2018). Despite a high annual state-wide average rainfall of 136.4 cm (53.7 in; NOAA, n.d.), exploitation of fresh groundwater is believed to be close to sustainable limits under current climate conditions in much of Florida due to environmental constraints. Water utilities are already straining to find additional water supplies to meet increases in demand anticipated under current climate conditions as a result of the projected population growth.

This paper examines water supply planning and project implementation in Florida and how it may facilitate or impede adaptation to climate change. An overview is provided of projected climate changes in Florida, followed by a summary of the roles of various levels of government and private sector entities (i.e., water users) in water supply planning and how they inform or implement climate change adaptation, and then an examination of the extent and manner in which information from the climate change research community is being incorporated into the adaptation decision-making process.

Florida climate change projections

Climate modeling predictions are subject to what has been referred to as a ‘cascade of uncertainties’, which flows from uncertainties in GHG emissions scenarios, to uncertainties in the general circulation models (GCMs; also referred to as global climate models), and then to the downscaling of GCM data to the regional and local scales (e.g., Foley, 2010; Falloon *et al.*, 2014). Additional uncertainties occur in simulations of the effects of predicted local climate changes on surface water flows and aquifer recharge and water levels. Hence, projections of future climate have considerable overall uncertainty.

The latest IPCC (2019) projections are that the global mean sea-level (GMSL) rise under the low emissions RCP2.6 scenario will be 0.39 m (0.26–0.53 m, likely range) for the period 2081–2100 and 0.43 m (0.29–0.59 m, likely range) in 2100 with respect to 1986–2005. For the higher emissions RCP8.5 scenario, the corresponding projected GMSL rise is 0.71 m (0.51–0.92 m, likely range) for 2081–2100 and 0.84 m (0.61–1.10 m, likely range) in 2100 (IPCC, 2019). The IPCC (2019) noted that ‘Extreme sea level events that are historically rare (once per century in the recent past) are projected to occur frequently (at least once per year) at many locations by 2050 in all RCP scenarios, especially in tropical regions (high confidence)’. Some scientists believe that the sea-level rise in southern Florida may be higher than the IPCC estimates (Wanless, 2017; Sealey *et al.*, 2018).

Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group (Compact) unified sea level project projected that in the short term, the local (relative) sea-level rise will be 15.2–25.4 cm (6–10 in) by 2030 and 35.6–66 cm (14–26 in) by 2060 above the 1992 mean sea level (Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group, 2015). The Compact projected a sea-level rise of 78.7–154.9 cm (31–61 in) by 2100. A sea-level rise of 1 m or more would have catastrophic human and environmental impacts. Low-lying communities and much of Everglades National Park would be inundated.

The latest coarse-scale model results published by the IPCC (2014) project changes in average precipitation in Florida being in the -10 to $+10\%$ range for 2081–2100 relative to 1986–2005 under the RCP2.6 and RCP8.5 scenarios. A 10% change in annual precipitation is well within the range of natural variation (Figure 1). The Third National Climate Assessment projects a -5 to $+3.6\%$ change in water availability in Florida for 2010–2060 with the greatest decrease projected in the western panhandle and the greatest increase in the central and upper east coast of the state (Carter et al., 2014). The Fourth National Climate Assessment emphasized the likely occurrence of more extreme weather events (droughts and floods) in the region (Carter et al., 2018).

Governmental and private sector involvement in Florida water planning and climate

Change adaptation

Federal government. Water use in the United States is governed on the state level, so the federal government plays a minimal direct role in water supply planning and climate change adaptation in Florida. Federal agencies, such as the National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), and U.S. Geological Survey (USGS), collect and

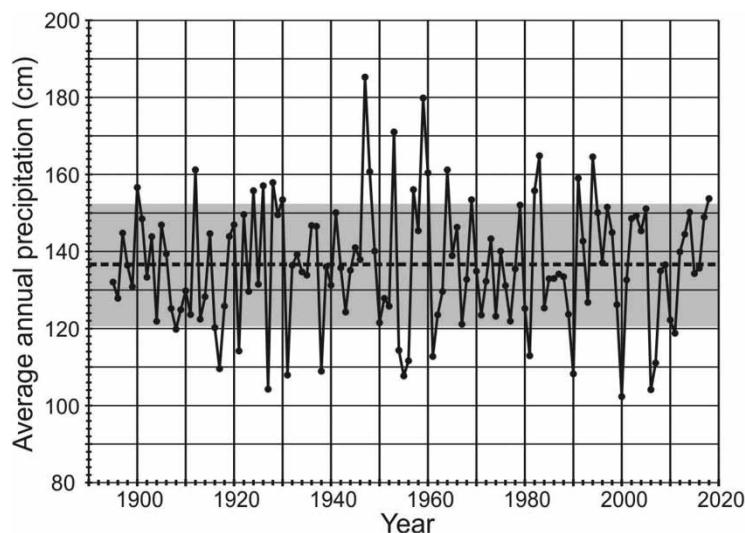


Fig. 1. Florida annual average precipitation with mean (dashed line) and one standard deviation (shaded). Data source: NOAA (n.d.).

disseminate climate and water monitoring data. The USGS performs climate change research. For example, the USGS conducted a groundwater modeling investigation of the impacts of sea-level rise on groundwater resources in southeastern Florida (Hughes et al., 2016).

The U.S. Global Change Research Program (USGCRP) coordinates federal research and investments on climate change and their impacts on society (USGCRP, n.d.). The USGCRP prepares national climate assessment reports that summarize potential regional climate changes, and impacts, risks, and adaptation options (USGCRP, 2017, 2018). These reports provide coarse-scale guidance on potential climate changes in Florida. The U.S. Environmental Protection Agency (USEPA) provides information on adaptation strategies to assist water utilities and communities plan for climate change (USEPA, n.d.-a). The National Research Council (NRC), which is the working arm of the United States National Academies, has published reports prepared by expert teams on various aspects of climate change.

Florida water management districts: water use permitting. The State of Florida holds the use of water in trust for the benefit of all entities including people and the environment. Water use in Florida is governed under the reasonable use doctrine, which allows landowners beneficial use of water so as long as the use does not harm other water users, the aquifer or surface water systems, or the environment. The Florida Water Resources Act of 1972 (Chapter 373, Florida Statutes) established five water management districts (Districts; Figure 2) that have the regulatory responsibility of addressing such issues as water supply, drainage/flood protection, water quality, and protection of natural resources (Davis et al., 2018). The Districts also perform technical investigations, surface water and groundwater monitoring, and acquire and manage lands for water management purposes.

A consumptive use permit (CUP, also referred to as a water use permit) is required in Florida for the use of groundwater and surface water with the exceptions of domestic uses, home irrigation, and water

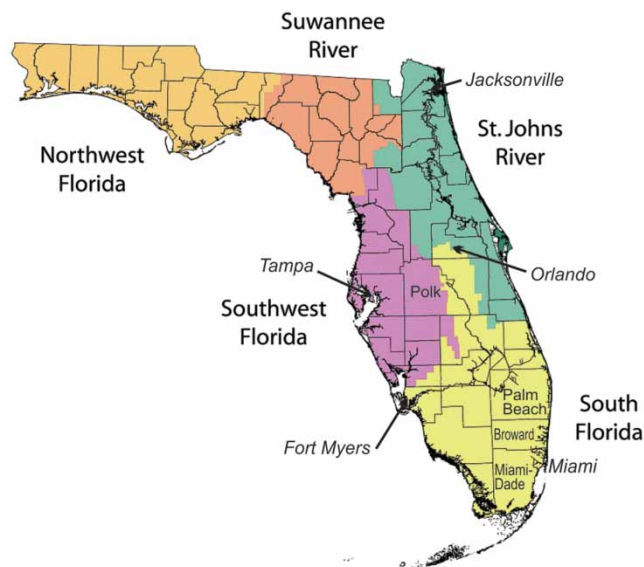


Fig. 2. Map of the five Florida water management districts. Modified map from the Florida Department of Environmental Protection.

used for firefighting. To obtain a permit, the applicant must demonstrate that the proposed use of water is reasonable and beneficial, will not interfere with any presently existing legal use of water, and is consistent with the public interest (Florida Statutes 373.223).

Permit applicants must demonstrate a need for the requested water and provide reasonable assurance that the proposed use will not impact existing, earlier-permitted users, the water source, or the environment. Impacts to the water source include saline-water intrusion into aquifers. Reasonable assurance can be provided through applicable historic monitoring data or modeling. Groundwater modeling is normally required to assess the individual impacts of proposed withdrawals and the cumulative impacts from the proposed withdrawals by the applicant and those of existing legal users and other pending applications for a CUP. In the SFWMD, the modeling scenario is a 1-in-10-year drought event. Accepted modeling procedures and adverse impact criteria are specified in applicants' handbooks (e.g., SFWMD, 2015). Permits are issued if cumulative modeled drawdowns do not exceed thresholds for what are considered unacceptable impacts, which might be maximum drawdowns in wetlands or causing specified minimum flows and levels in surface water bodies to not be met. If cumulative drawdowns reach or exceed an unacceptable level, then no additional withdrawals may be permitted or existing allocations may even be decreased. Third-party interests that would be substantially affected by the issuance of a requested permit have the opportunity to request an administrative hearing prior to the issuance of the permit.

A CUP allocation is not 'owned' by the applicant. Permits have a finite duration and there is not an inherent right to a renewal. The duration of a CUP is 20 years if the applicant demonstrates reasonable assurance that the proposed use meets the conditions for issuance for the requested duration. Permits may be issued for a shorter duration for temporary uses or for just the time period for which such reasonable assurances can be provided. Long duration permits may be obtained for AWS projects (e.g., desalination systems).

Climate change is not a direct consideration in the water use permitting process in Florida. Permits commonly have limiting conditions that require monitoring plans to be developed and implemented and state that mitigation measures, including reductions in withdrawals, may be required if water use is demonstrated to be causing adverse conditions. The Districts can impose water use restrictions during times of water shortage, which usually involve limits on outdoor water use (e.g., lawn watering, car washing). Florida does not recognize priority in that junior permit holders cannot be forced to preferentially stop or reduce water use during times of water shortages. There is, however, preference given in extreme droughts to critical uses, such as public water supply. If Florida's climate shifts to drier conditions, then the Districts have the authority to force demand reductions (i.e., conservation) and development of alternative, less-climate sensitive supplies through water use restrictions and reductions in allocations.

Florida water management districts: regional water supply planning. Under Florida law (Florida Statutes 373.709), the governing board of each District is required to conduct regional planning to determine whether 'existing sources of water are not adequate to supply water for all existing and future reasonable-beneficial uses and to sustain the water resources and related natural systems for the planning period'. Each regional water supply plan (RWSP) must be based on at least a 20-year planning period and be reviewed every 5 years. Regional water supply planning is required to be conducted 'in an open public process, in coordination and cooperation with local governments, regional water supply authorities, government-owned and privately owned water and wastewater utilities,

multijurisdictional water supply entities, self-suppliers, reuse utilities, the Department of Environmental Protection, the Department of Agriculture and Consumer Services, and other affected and interested parties' (Florida Statutes 373.709).

RWSPs are required to quantify water supply needs for all existing and future reasonable-beneficial uses within the planning horizon and include a 'list of water supply development project options, including traditional and alternative water supply (AWS) project options that are technically and financially feasible, from which local government, government-owned and privately owned utilities, regional water supply authorities, multijurisdictional water supply entities, self-suppliers, and others may choose for water supply development' (Florida Statutes 373.709).

Recent RWSPs by the different Districts address climate change with varying degree of specificity. The Southwest Florida Water Management District (SWFWMD) RWSP for the Tampa Bay Region (SWFWMD, 2015) addressed climate change with a relatively high degree of detail. Reported climate change-related actions by the SWFWMD (2015) include:

- participation in local, state, and national discussions on these issues in order to accommodate timely and effective responses to climate changes as they become evident;
- an extensive monitoring program;
- use and modification of existing groundwater models to predict density and water-level driven changes to aquifers utilized for water supply;
- through cooperative funding, assisting water utilities and regional water supply authorities with well-field evaluations for improving withdrawal operations and planning for brackish treatment upgrades;
- encouraging maximized use of diverse water supply sources and establishing system redundancies to ensure a resilient water supply; and
- promoting water conservation across all use sectors, including agricultural and industrial uses, which not only saves supplies for the future but also reduces chemical and energy use.

Nevertheless, it is recognized that local governments and private users are principally responsible for developing and communicating appropriate risk assessment and adaptation strategies for their own water uses. The Districts have provided support in the planning and implementation of adaptation strategies and some Districts provide partial funding for AWS projects.

Local Government Comprehensive Planning. The Local Government Comprehensive Planning Act of 1975 recognized the traditional role of local government in land-use control and was intended to guide local land-use decisions through the development and implementation of comprehensive plans (Carriker, 2006). The key elements of the 1975 Act are that local governments were to prepare and adopt local comprehensive plans and that future development must conform to the adopted plans (Carriker, 2006). Florida Statutes Section 163.3177 requires that local government comprehensive plans provide the policy foundation for local planning and land-use decisions involving capital improvements, conservation, intergovernmental coordination, recreation, open space, future land use, housing, transportation, coastal management (where applicable), and public facilities.

The water supply element of comprehensive plan elements must be updated to incorporate the AWS project or projects selected by the local government from those identified in the District RWSPs or proposed by the local government within 18 months after the local District governing board approves an updated RWSP (Florida Statutes 163.3177(6)(c)3). The water supply elements of comprehensive

plans are required to evaluate current and projected industrial, agricultural, and potable water needs and sources for at least a 10-year period.

Comprehensive plans are also required to contain a capital improvements element designed to consider the need for and the location of public facilities (Florida Statutes 163.3177(3)(a)). Capital improvement plans (CIPs) are required to cover at least a 5-year period and include a schedule of when the improvements are needed and their estimated costs and funding options. CIPs are updated annually.

Climate change is not specifically required to be incorporated into comprehensive plans. The effects of climate change will likely be small over a 10-year comprehensive plan horizon. Nevertheless, internet searches of coastal counties and municipalities in Florida, which have a relatively high vulnerability to climate change through sea-level rise, reveal that most have taken at least some steps to plan for increasing the resiliency of their communities. Regional planning councils are also actively considering the potential impacts of climate change.

The greatest local planning and implementation efforts for climate change have been made in counties and communities that are highly vulnerable to sea-level rise. Monroe County, whose population resides mostly on the low-lying Florida Keys, has been a leader in climate change preparedness. For example, Monroe County established a Climate Change Advisory Committee that is charged with making recommendations to the Board of County Commissioners regarding appropriate mitigation and adaptation policies required to address climate change issues. Miami-Dade County and the City of Miami Beach have also been particularly active in preparing their communities for climate change.

Public water utilities, regional wholesale water suppliers, and private groundwater users. Water suppliers and users in Florida are ultimately responsible for identifying and permitting water supplies required to meet their own and the needs of their customers. Water utilities in Florida are typically run by directors or heads who are appointed by elected officials, such as county commissions and city or town councils. Regional water supply authorities (e.g., Tampa Bay Water, Peace River Manasota Regional Water Supply Authority) are governed by a board of directors consisting of representatives who are elected officials (e.g., County Commissioners, City Council persons) appointed by the member governments. Water supply planning is performed directly by water utility, supplier, or user staff or in conjunction with contracted external engineering, hydrogeology, and hydrology consultants. The primary decision makers for water supply and climate change adaptation plans are normally technical staff, who must justify their plans to higher levels of organization management and government that are responsible for approving plans and expenditures. For a city water supply plan, for example, utility technical staff and their consultants develop the plans, which are subject to the approval of the utility director or manager. Expenditures for implementing the plans require city council approval.

Water supply and climate change decision-making Florida

Decision-making process

Although climate change will have society-wide impacts, adaptation decisions with respect to municipal water supplies are actually made by a small number of people; utility and wholesale supplier managers and their in-house technical staff and supporting consultants. Elected officials enter the

process largely through the approval of capital investments. Water supply planning is largely a technical issue with limited opportunities for general public input. The general public can influence state-wide and local water policy through the electoral process. There have been extreme cases outside of Florida where public opinion exerted sufficient pressure to impact water supply decisions with a notable example being the effective opposition in the early 1990s to proposed San Diego potable reuse plans (toilet-to-tap campaign). Tucson, Arizona, was able to gain support for potable reuse through active stakeholder engagement (Megdal & Forrest, 2015). Stakeholder involvement has been identified by utility managers as a critical issue for demand management, particularly successful implementation of conservation plans (White, 2014).

From the authors' first-hand experiences, the water use planning for water utilities in Florida (and elsewhere) starts with projections of future demands based largely on population projections, usually obtained from the Florida Bureau of Economic and Business Research (BEBR) or internally derived. Projected future water use rates are obtained from the projected future populations and historic per capita water use rate data and estimates of future commercial/industrial demand. Irrigation demands for agricultural, recreational (e.g., golf course), and landscaping uses are based on the irrigation area and per acre irrigation water requirements obtained, for example, using the Blaney-Criddle method or a modification thereof.

The next step is an evaluation of water supplies physically available and permissible from existing sources. Modeling is usually performed to estimate drawdowns from proposed groundwater sources, which are evaluated with respect to District permitting criteria. For surface water withdrawals, historical flow data are evaluated to determine the seasonal availability of water that is potentially extractable while meeting minimum flow requirements.

Professionals involved in the development of water supply plans are aware of regulatory (District) impact thresholds and water supply options are screened based on whether they would meet permitting criteria. If a deficit in available, conventional freshwater supplies is identified during a planning horizon, then AWS and/or demand reduction options are evaluated. The water-supply decision-making process tends to be siloed as the key issues are of a technical nature and evaluated by technical staff. Water utility directors and their staff are typically thoroughly familiar with current water use and temporal trends in their service areas and the sources of supplies available to meet demands.

Typically, some form of multi-criteria decision making (MCDM) is employed, and a cost-benefit analysis is performed to identify the preferred water supply option. Reliability of supplies is a consideration along with cost in the planning process. There is great variation in the effort and technical sophistication of the planning processes employed by utilities which is in general correlated with the size and the complexity of their supply system. Sophisticated integrated water resources management (IWRM) decision support systems are available that can evaluate a wide variety of hydrologic factors, managerial options, and climate-driven changes demand (Yates & Miller, 2011), but are overkill for many utilities and users where the water supply choices are apparent.

Decision-making horizon

In Florida, the formal utility and regulatory time frame for water supply planning is usually no more than 20 years. However, it should not be presumed that longer time frames are not given due to consideration where appropriate. New infrastructure would not be constructed in areas subject to

inundation from sea-level rise during their operational lives or they would be constructed so as to not be vulnerable to sea level (e.g., constructed on elevated pads).

The model-predicted range of climate change-driven changes in precipitation is within the range of historical variation for 20-year planning horizons. In general, the greatest focus of climate change investigation in Florida has been on the risk of inundation caused by increases in mean sea level and extreme high-water events.

The limited investigations of climate change impacts on local water supplies suggest minimal impacts on water resources over the 20-year planning period. For example, the USGS modeling of saline-water intrusion in Miami-Dade County indicates that the combination of high-rate sea level rising and ground-water pumping at the 2025 permitted rate would not result in significant movement of the saline-water interface over 30 years (MDWASD, 2014).

Engagement of decision makers with climate change research

Climate change issues are frequently the subject of newspaper articles and television news stories and are addressed in annual local and state-wide water conferences, so general awareness of climate change in Florida is high. Climate change had been politicized in Florida (and elsewhere in the United States) with the former governor Rick Scott even reportedly banning the use of the words ‘climate change’ and ‘global warming’ in governmental correspondence (Korten, 2015). Sea-level rise was to be referred to as ‘nuisance flooding’ (Korten, 2015). Despite a paucity at times of past executive-level leadership in Florida, local communities most vulnerable to climate change are actively engaged in assessing their vulnerabilities to climate change and at least investigating options to increase their resilience. In a marked change in attitude, Florida lawmakers under the new governor Ron DeSantis created a state-wide Office of Resiliency and established a task force to investigate how best to protect the state’s 2,173 km (1,350 miles) of coastline from rising sea levels.

Surveys and interview studies have shown that water utility professionals in general are aware of general climate change issues but may be unsure how to best interact with climate change scientists and incorporate climate change into their planning process (e.g., White *et al.*, 2008; Danilenko *et al.*, 2010; Economist Intelligence Unit, 2012; Mosher & Ekstrom, 2012; Baker *et al.*, 2018; Kay *et al.*, 2018; Raucher *et al.*, 2018). The degree of engagement with the climate change research community also depends upon perceived vulnerability to sea-level rise and the size of the utility with larger utilities having greater technical and financial resources.

Major water suppliers and communities in Florida are involved in collaborative efforts with the climate change research community, so there is a flow of information between the two communities. For example, in January 2010, Broward, Miami-Dade, Monroe, and Palm Beach Counties joined to form the Southeast Florida Regional Climate Change Compact as a way to coordinate mitigation and adaptation activities across county lines (SEFRCCC, n.d.). The Florida Water and Climate Alliance (FloridaWCA), which is facilitated by the University of Florida Water Institute, is a ‘stakeholder-scientist partnership committed to increasing the relevance of climate science data and tools at relevant time and space scales to support decision-making in water resource management, planning and supply operations in Florida’ (FloridaWCA, 2020). The FloridaWCA collaborators include six major public water supply utilities, three water management districts in Florida, local government representatives, and several academic organizations including the UF Water Institute, Florida State University Center for

Ocean-Atmospheric Studies (COAPS), the Florida Climate Institute (FCI), and UF/IFAS Center for Public Issues Education (FloridaWCA, 2020).

Tampa Bay Water (TBW) is a regional wholesale water supplier that supplies water to more than 2.5 million people through the governments it serves. TBW is a member of the Water Utility Climate Alliance (WUCA), an organization composed of 12 of the nation's largest water providers, 'that is dedicated to enhancing climate change research and improving water management decision-making to ensure that water utilities will be positioned to respond to climate change and protect our water supplies' (WUCA, 2020). TBW staff and the University of Florida Water Institute researchers have been collaborating on the incorporation of climate predictions from GCMs and statistically downscaled data into the agency's hydrologic and demand forecast models (Gregg, 2020). TBW's has a diversified water supply including fresh groundwater, surface water, and seawater desalination, which reduces its climate risk (USEPA, n.d.-b). The SWFWMD is currently having a density-dependent solute-transport model for the Tampa Bay region updated to be used to evaluate the impacts of sea-level rise on coastal aquifers.

The impacts of saline-water intrusion on coastal aquifers have been investigated through solute-transport modeling studies performed by the USGS, water management districts, and contracted consultants and university staff. Miami-Dade County is addressing climate change and sea-level rise through a multi-faceted approach of mitigation and adaptation, as well as through its participation in the 100 Resilient Cities network. Both Miami-Dade and neighboring Broward counties in southeastern Florida in collaboration with the USGS have been developing models to predict saline-water intrusion into the Biscayne Aquifer (the primary water source in the region) and the potential for increased inundation (Hughes & White, 2016; Hughes et al., 2016; Decker et al., 2019).

The Palm Beach County Water Utilities Department (PBCWUD) participated in an investigation with the Water Research Foundation and the University Corporation for Atmospheric Research to develop a decision support system for alternatives analysis and ranking of water supply and capital planning options (Yates & Miller, 2011). Scenario-based planning methods were used to select alternatives under different combinations of climate, future population, and demand projections (Yates & Miller, 2011).

Discussion: preparedness of Florida's water supply for climate change

Although awareness of climate change appears to be high among water supply decision makers in Florida and larger coastal utilities and water suppliers have at least some engagement with the climate change research community, there is little evidence that climate change is a now significant factor in water supply planning. Coastal communities are considering the general impacts of the sea-level rise on all their infrastructure. For example, the Miami-Dade County (2010) comprehensive Climate Change Action Plan calls for the examination of the implications of sea-level rise on vulnerable facilities (i.e., solid waste facilities and water and wastewater utilities).

Population growth induced increases in water demand will likely pose a much greater challenge to water providers than projected climate changes. Florida's population is projected to increase from an estimated 20.84 million in 2018 to about 26.37 million in 2040 (Rayer & Wang, 2019), a 26.5% increase. According to the Florida Department of Environmental Protection (FDEP) 2018 Regional Water Supply Planning Report, the population in Florida is expected to grow by 27% to 25.2 million people between 2015 and 2035, while water demands are expected to grow by 18% to 28.4 million m³/d (7.5×10^9 gallons per day; FDEP, 2019).

Climate change may also increase water demands with greater use occurring with higher temperature and lesser precipitation conditions. Methods are available to estimate the potential climate change impacts on water demand (e.g., Keifer *et al.*, 2013). Keifer *et al.* (2013) applied their methodology to TBW and projected increases in average demand across all climate scenarios from 7,578 m³/d (2 million gallons per day, MGD) (+1.2%) for the 2055 cool/wet scenario to 83,333 m³/d (22 MGD) (+9.9%) for the 2090 hot/dry scenario. A key source of uncertainty is the societal responses to climate change impacts on water use, such as the implementation of conservation measures (Keifer *et al.*, 2013). Under more extreme conditions, the permanent inundation and abandonment of some coastal areas would significantly decrease local water demands.

The greatest impact of climate change to water resources may be related to sea-level rise and associated saline-water intrusion, which would have the greatest impact on near-coastal wellfields, particularly if the most extreme SLR scenarios come to pass. Saline-water intrusion is monitored, and the historical response has been to abandon wells closest to the coast and move production inland. This option is now constrained in many areas by inland environmental impacts (e.g., drawdowns in wetlands).

Even though climate change is currently not a significant driver in water planning in Florida, water providers out of necessity have been moving toward alternative water sources because of regulatory limits on further fresh groundwater production. Florida is a leader in wastewater recycling and larger utilities have been increasingly implementing brackish groundwater desalination, aquifer storage and recovery, wastewater reuse, and aquifer recharge projects. Indirect and direct potable reuse projects are now also being investigated, which would have been unthinkable several decades ago. Where the development of alternative water supplies is beyond the financial capability of smaller water utilities, such projects can be developed cooperatively by multiple utilities in a region. For example, the Polk Regional Water Cooperative in central Florida, whose 16 member governments consist of 15 cities and Polk County, is in the design and permitting phase for two brackish groundwater desalination plants and aquifer recharge projects using seasonally available excess surface water, which are intended to allow the members to meet projected demands through the year 2070. Similarly, the Water Cooperative of Central Florida, consisting of the Toho Water Authority, Orange County Utilities, Polk County Utilities, the City of St. Cloud, and the Reedy Creek Improvement District (which supplies Disney World), are collectively developing the Cypress Lake Wellfield Project, which will be a 30 MGD brackish groundwater desalination system. Cooperatives allow individual utilities to take advantage of the economies of scale of large projects.

Adger *et al.* (2007) observed that adaptation measures are seldom undertaken in response to climate change alone, which has been the case in Florida with respect to water supply. It is now widely recognized in the climate change literature that adaptation in general should employ ‘no regrets’ options that are robust against a wide range of plausible climate and societal change futures (Lempert & Schlesinger, 2000; Heltberg *et al.*, 2009; Yates & Miller, 2011; Klein *et al.*, 2014). Florida has been moving toward more resilient water supply systems that incorporate multiple sources because of current regulatory limitations on additional fresh groundwater withdrawals. Water planning is dominated largely by concerns (and associated regulatory restrictions) over environmental issues such as maintaining wetland hydroperiods and minimum flows and levels in lakes, rivers, and springs, rather than climate change.

The move toward alternative water supplies in Florida has had the incidental benefit of making water supply systems more resilient to climate change. However, significant vulnerabilities remain if climate change turns out to be more extreme and rapid than current projections. Long-term planning to climate change (beyond the commonly used 20-year horizon) in general involves broader and more difficult societal considerations. For example, how much capital investment should be allocated to areas

(communities) that are projected to be inundated by 2100. An extreme example in Florida is the Comprehensive Everglades Restoration Plan (CERP). A sea-level rise of 1 m (3 ft) by 2100 has been projected in some simulations, which would inundate much of the Everglades (including the national park). Therefore, the question arises as to whether the multi-billion dollars CERP plan designed to save the Everglades needs to be substantially altered to reflect more recent climate and sea-level rise projections (Nuttle, 2019).

Rising sea levels could eventually cause some highly populated low-lying coastal areas to become uninhabitable, forcing the migration of local populations. Greater sea-level rises have been described as eventually turning the City of Miami from ‘the nation’s urban fantasyland into an American Atlantis’ (Goodell, 2013). Inland communities could face great water supply (and other socioeconomic) challenges from the resettlement of displaced coastal populations (Hauer et al., 2016; Hauer, 2017). The U.S. Corps of Engineers has initiated studies of options to protect parts of the city of Miami from extreme sea-level rise (Harris, 2020), but preparedness for the most severe potential impacts of climate change in Florida is poor (as is the case for most of the world).

Conclusions

The Florida experience with adaptation to climate change has some atypical aspects, such as a high dependency on groundwater for public supply and a relatively high exposure to sea-level rise. Although climate change has become a high visibility issue, little adaptive planning specific to climate change is being undertaken in the water sector. The planning horizon for water suppliers and water management districts in their regional water supply plans is commonly a 20-year time frame over which the predicted potential hydrologic impacts of climate change will likely not extend outside the natural climatic variability and will be less of a challenge than increases in demand associated with population growth. There is uncertainty over whether precipitation will either increase or decrease in the state. The greatest attention continues to be paid to the potential impacts of sea-level rise on coastal aquifers, which modeling results suggest will not be significant over the next 20 years. Water supply planning tends to be siloed with the decision makers being small groups of technical experts (engineers and hydrogeologists) rather than being made by an idealized broad societal consensus. Although climate change is not driving water planning in Florida, water supply systems are incidentally becoming more resilient to climate change through the increasing adoption of alternative, less climate-sensitive, water sources (e.g., brackish groundwater and seawater desalination and wastewater reuse), which is being driven largely by regulatory limitations on additional fresh groundwater withdrawals.

Data availability statement

All relevant data are included in the paper or its Supplementary Information.

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