IMPLICATIONS OF ALTERED FRESHWATER FLOWS ON ESTUARINE FISH AND SHELLFISH: A CASE STUDY OF THE LOWER SUWANNEE RIVER

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Photo: Steven W. Hinton

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Executive Summary

Estuarine environments provide habitat for a wide array of recreationally- and commercially-important fisheries. Estuarine and estuarine-dependent fisheries rely on freshwater inputs to maintain the ecological integrity of the estuaries they inhabit, but mounting anthropogenic pressures on inland water supplies threaten to starve downstream estuaries of their freshwater lifeblood. Additionally, sea levels are rising, and the rate of sea level rise is expected to accelerate in the future. If rising seas are unmatched by increasing freshwater flows, estuaries will disappear from the coast as they are squeezed upriver. The estuary formed where the Suwannee River, one of the last remaining undammed and un-diverted rivers in the U.S., discharges into the Gulf of Mexico provides an interesting setting in which to evaluate how changing freshwater flows and sea level will impact coastal systems and communities.

Relationships between estuarine resources and the economic and social benefits they provide to numerous stakeholders must not be overlooked when deciding how to manage freshwater flows and withdrawals. These benefits include livelihoods provisions in the form of sales, income, and jobs; contributions to sustenance; property destruction prevention; and cultural significance. Stakeholder involvement strategies such as participatory research and stakeholder analysis can be employed to gain a greater understanding of different users, their particular interests in the resource, and what ecosystem services they may risk if the resource is not managed in their favor.

Extensive legal and regulatory frameworks have been created to achieve equitable allocation of freshwater resources for human demand and environmental function. However, increased scarcity and changing environments pose significant challenges to these systems, which for the most part have not seriously addressed water allocation between competing public interests. The Lower Suwannee River will hopefully benefit from being in Florida, a state with a comprehensive and forward-looking water resource law. Florida law restricts water use that causes the flows and levels of waterbodies to fall below the acceptable standards adopted to protect natural ecosystems. However, ensuring that these minimum flow and level standards account for issues like increasing sea level rise, and that water management authorities can effectively enforce these protections will be critical to the subsequent impact on estuarine fish and shellfish of the lower Suwanee River.

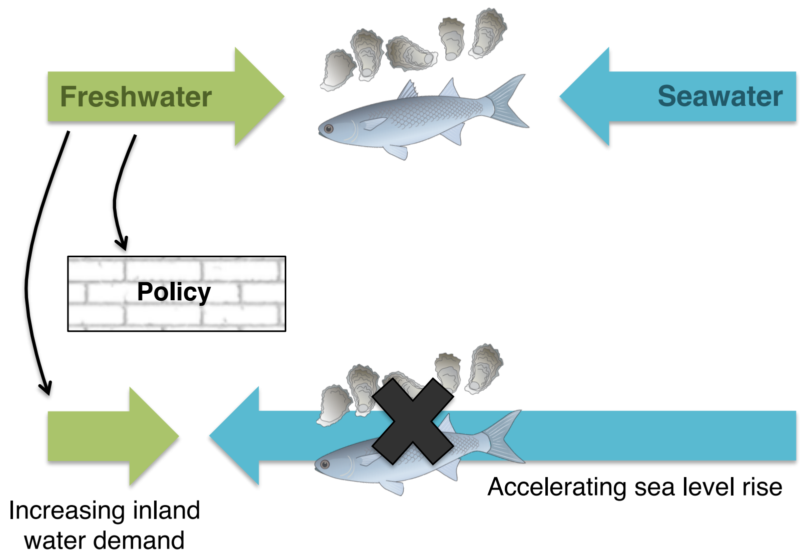

Figure 1. Implications of altered freshwater flows on estuarine fish and shellfish. Changes in estuarine environments as a result of diminishing freshwater flows and increasing sea level threaten to harm estuarine and estuarine-dependent fish and shellfish. However, existing policy levers offer protections to these systems such that ecological harm may be avoided. Credit: fish and oyster images created by the Integration and Application Network.

Introduction

Estuarine environments are found where rivers flow into the sea. These interfacial zones are highly dynamic and characterized by brackish salinities, which can fluctuate in the range of approximately 0.5-30 parts per thousand (ppt) as a function of mixing seawater (salinity of approximately 35 ppt) and riverine outflows (salinity of less than 0.5 ppt).[1] Estuarine salinities often vary wildly due to inter- and intra-annual variation in the magnitude and timing of freshwater inputs; freshwater variability is primarily explained by the balance of rainfall and evapotranspiration, the rates of which vary seasonally. The morphology of an estuarine basin can also influence its salinity regime depending on the extent to which surrounding landforms entrain freshwater.[1]

Though estuarine systems are primarily defined by their brackish salinities, the constant exchange of fresh and saline waters creates conditions that support a diverse suite of habitats and organisms.[1,2] Moreover, freshwater flows deliver nutrients and organic matter to the coast, and consequently fuel high rates of primary productivity and the transfer of energy to higher trophic levels.[3] This utilization and transformation of nutrients and organic matter also results in estuaries being important biogeochemical hotspots along the fresh-marine continuum.[3] As with salinity, large inter- and intra-annual variability is observed in the productivity of estuarine systems,[4] which further exemplifies how these systems are constantly in flux.

Estuaries' downstream positions in the landscape make them integrators of upstream disturbance.[5] As coastal basins are among the most populated in the world, estuarine systems and the services they provide are increasingly threatened by anthropogenic activity.[2,6] In particular, there is mounting concern that ever-increasing human consumption of freshwater will starve downstream estuaries of their riverine inputs,[7–9] especially since estuaries are the last to "drink" from the rivers that supply them.

Sea level rise further compounds the impacts associated with reduced freshwater flows to estuarine systems (Figure 1). With the rate of sea level rise expected to accelerate in the future as a result of unremitting greenhouse gas emissions,[10] seawater will drown out estuarine environments unless our rising seas are met with increased riverine flows;[1] when riverine discharge is insufficient to counter sea level rise, estuarine zones will drift upriver and, thus, possibly decrease in areal extent. The combined effect of decreased freshwater flow and accelerated sea level rise is expected to fundamentally shift estuarine water chemistry, and detrimentally impact the fish and shellfish communities that rely on these brackish environments.[1]

With these growing pressures being placed on estuarine environments, policymakers must make innovative reforms to the regulation of water resources to ensure that all stakeholders within a watershed are adequately served. More often, these decisions must be made between different governing institutions who share these expansive resources. Therefore, implementation of water laws across different jurisdictions that reflect the interconnectivity of hydrological system serve as a prerequisite to any meaningful management. Once adequate laws are in place, there is still the challenge of coordination between agencies, which involves balancing the interests of each and developing joints strategies to address the issue of water allocation. Critical to these strategies is the creation of a water use permitting system which monitors location and amount of water withdrawals and an environment protection component which creates a minimum threshold of acceptable impacts to waterbodies, particularly those that support productive ecosystems.

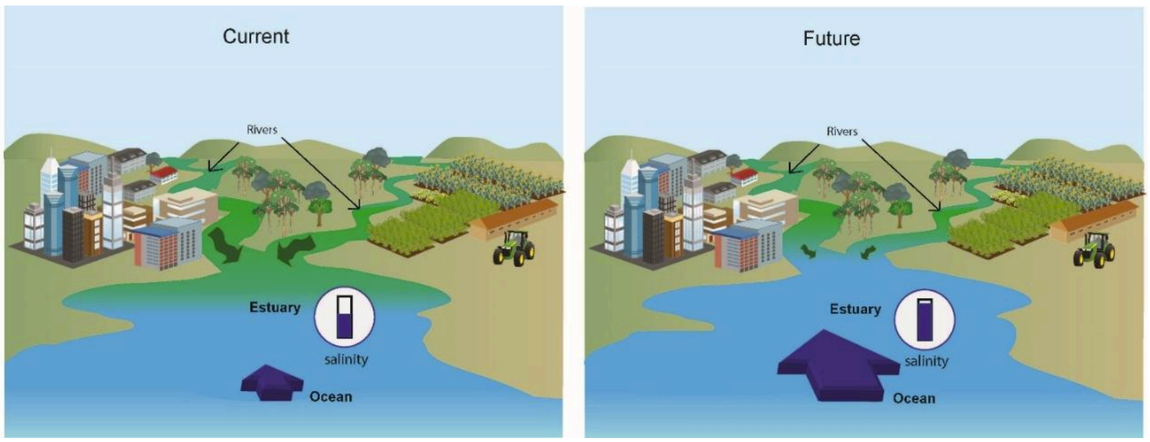

Figure 2. Shifting estuarine distributions as a function of sea level rise and reduced freshwater flow. In minimally-impacted coastal basins, freshwater flows counterbalance marine waters to create estuarine systems characterized by brackish salinities (left panel). However, many coastal basins are expected to experience (1) decreased riverine flow due *to increased human consumption associated with expanding coastal development, and (2) increased inland saltwater encroachment due to the effects of sea level rise. Therefore, in the future, many estuaries may become more saline due to the compounding effects of decreased riverine discharge and increased sea level (right panel). Credit: Florida Sea Grant.*[1]

The following figure was adapted from an article specific to the management of shellfish aquaculture and illustrates the relationships between coastal marine ecosystems and the coastal economy, both of which influence and are influenced by the presence and health of fisheries. Additionally, it demonstrates how knowledge of the coastal ecosystem and coastal economy can lead to predictions that influence decision-making in terms of the management process and thus the success and viability of the ecosystems and economy (Figure 3).

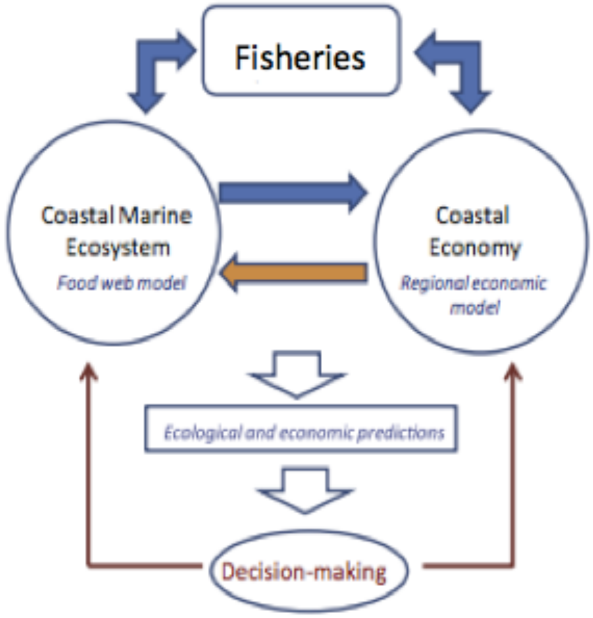

Figure 3: **Holistic Framework for Fisheries Management** (Byron et al. 2015, 16)

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SCIENTIFIC BACKGROUND (NATALIE NELSON)

Linkages between freshwater flow and estuarine fish and shellfish

Several studies have concluded that estuarine and estuarine-dependent fisheries' abundances correlate with freshwater flow, but the underlying relationships by which individual fish species depend on freshwater discharges are not always clearly understood. This is due, in part, to the variability observed across estuarine and estuarine-dependent fish species' responses to freshwater,[8,9,11] and inseparability of various driving mechanisms linking freshwater discharges to fishery production in estuarine systems.[9] Despite the challenges associated with isolating its specific effect on estuarine fishery production, freshwater flow has been implicated as an important driver of fish dynamics in estuarine systems through several interacting mechanisms. Specifically, riverine discharges are believed to:

- Deliver nutrient and organic matter pulses that enhance rates of primary and secondary productivity, thus increasing fish growth and survival.[11]
- Connect estuaries to their fringing wetlands, which provide structurally complex refugia for juvenile species.[12]
- Drive variability in estuarine salinity, sediment load, and water temperature, thereby altering habitat quality on inter- and intra-annual timescales.[9] These shifts in habitat suitability create a wider array of ecological niches that can support diverse species, and may also reduce harvesting pressure on estuarine fish species since fishermen have to adapt their fishing strategies accordingly.[9]
- Create turbid conditions that impact habitat availability for certain fish species,[9] and may also assist vulnerable juvenile fish to avoid predation.[12]
- Trigger migration patterns (e.g., migration for spawning purposes, larval migration) through thermal and chemical cues. [9,11,13]

This mélange of processes results in freshwater flow predominantly producing a positive net effect on estuarine and estuarine-dependent fisheries,[8,9] but studies on this subject often uncover nuanced findings. For example, spotted seatrout and red drum abundances were evaluated over a 13-year study in Tampa Bay and its adjoining freshwater sources (i.e., the Manatee, Little Manatee, and Alafia Rivers), and freshwater flows were found to positively influence large and small juvenile red drum, and small, but not large, juvenile spotted seatrout.[12] This discrepancy between the seatrout size classes was attributed to larger juvenile seatrout having a preference for benthic, as opposed to planktonic, prey; since planktonic organisms are more readily influenced by freshwater flow, this difference in dietary preference may result in the larger juveniles being less sensitive to changes in freshwater. Additionally, in the Suwannee River estuary, age-0 sand seatrout, spotted seatrout, and red drum were all found to positively correlate to freshwater discharge over a 9-year period, while pinfish displayed a negative relationship with the estuary's freshwater inputs.[11] In this case, the inverse relationship between pinfish and flow was hypothesized to precipitate from the spawning behavior of pinfish, whose spawning activities take place offshore in late winter when Suwannee River discharge is at its peak. In summary, the relationships between freshwater flow and estuarine fishery production are complex and their interpretation requires strong understanding of fish ecology and biology, but observations from the outlined studies[11,12] and others[e.g.,13,14] provide compelling evidence of the existing linkages between freshwater flow and estuarine fishes.

Whereas the effects of freshwater flow on fish populations are convoluted and difficult to untangle, the relationships between freshwater flow and sessile estuarine shellfish (e.g., hard clams and oysters) are relatively straightforward due to their immobility and documented optimal salinity ranges. The upper and lower thresholds that define these optimal salinity ranges result in there being both positive and negative relationships between shellfish and freshwater flow since salinities can quickly drift above or below the ideal ranges when riverine discharge is low or high, respectively.[8,9]

Hard clams thrive in a salinity range of 20-30 ppt, and will begin to display signs of stress (e.g., failure to bury, gaping, irregular mantle edges) once salinities exceed this range.[15] Though hard clams are relatively resilient and can endure salinity stress, they cannot survive when salinities persist below 20 ppt or above 30 ppt for prolonged periods of time. Marine salinities are typically about 35 ppt, and, thus, outside of the optimal range for hard clam growth. Therefore, the brackish salinities associated with estuarine environments are well-suited to support hard clam populations, and contingent on the regular influence of freshwater flows.

Oysters (specifically, the Eastern oyster, *Crassostrea virginica*) prosper when salinities are in the range of approximately 14-28 ppt.[16] Although the physiology of the Eastern oyster permits its growth and survival at salinities outside of this range, other detrimental effects become pronounced at suboptimal salinities. These detrimental effects include increased rates of predation and parasitism, as well as changes in trophic productivity.[7,8,17] Additionally, at particularly low salinities, oyster spawning and recruitment are negatively impacted.[18] Although oysters can endure periods of unsuitable salinity, the frequency with which they are exposed to these conditions is believed to decrease their resiliency to future stressors.[7] Therefore, oyster productivity is less likely to rebound when salinities frequently fall out of oyster-optimal ranges. The salinity sensitivity of oysters led Bergquist et al. (2006)[19] to conclude that "*…oysters provide a useful index of the effect of changing river flow and salinity on estuaries in general.*" and *"Monitoring oyster reef state in the lower intertidal will provide biological indicators more responsive to the salinity conditions of the estuary."*

Additionally, scientists have recently proposed that the reef structures created by oysters produce a damming effect on riverine discharge.[20] By providing a physical barrier counter to the direction of the riverine outflow, these reefs help to detain freshwater within the estuary. This detention effect not only helps to maintain brackish salinities within the estuary, but also allows for oysters to support their own growth and survival, particularly in systems that may at times be freshwater-limited.

CASE STUDY: SUWANNEE RIVER ESTUARY (NATALIE NELSON)

"Way down upon de Swanee ribber…"

In July 1977, National Geographic published an article in its magazine on the Suwannee River, in which the authors characterize the Suwannee as *"one of the most celebrated rivers in America"* due to the popularity of Stephen Foster's 1851 ballad "Way Down Upon the Suwannee River."[21] Today, the Suwannee remains one of the most special rivers in the U.S. for its ecological and recreational value. The Suwannee River is one of the country's last riverine waterbodies to remain hydrologically "intact" and without dams or flow diversions, and The Nature Conservancy has described the Suwannee River Basin as a "critical watershed to protect freshwater biodiversity."[22] Moreover, the state of Florida has designated the Suwannee as one of the state's few Outstanding Florida Waters due to its exceptional natural features.[22]

The Suwannee River flows for over 390 km from its headwaters in the Okefenokee Swamp of southern Georgia to Florida's Big Bend, where it discharges into the Gulf of Mexico.[23] In the reach just downstream of its swampy headwaters, the Suwannee's waters are low in mineral content and stained a dark brown, resulting in the river being described as a "blackwater" system.[22,24] As the Suwannee approaches the coast, its waters become less dark due to the influence of spring discharge.[22,23] An estimated nine first magnitude springs and 63 second magnitude springs flow into the lower basin of the Suwannee River, and, in total, provide an estimated 30-50% of the Suwannee's annual average flow.[23]

The freshwater flows of the Suwannee create an expansive estuary that stretches approximately from Horseshoe Point (Horseshoe Beach) to Rattlesnake Key (Cedar Key).[19] This estuary is the largest in the Big Bend and delivers about 60% of the freshwater to the entire Big Bend coast. This estuary supports a rich community of fish and shellfish, including, but not limited to, tarpon, spotted seatrout, sheepshead, and Eastern oysters. The presence of extensive wild Eastern oyster reefs is among the most unique features of the estuary as oyster reefs are considered to be one of the most endangered marine habitats in the world (> 85% loss globally).[25] In fact, the oyster reefs in the Gulf of Mexico have fared considerably well relative to the other ecoregions in the world where oysters are found, leading the authors of a recent study on global oyster reef trends to conclude that *"oyster fisheries in the Gulf of Mexico are probably the last remaining opportunity to achieve both large-scale oyster reef conservation and sustainable fisheries."*[25]

Additionally, the Suwannee estuary supports a thriving Northern hard clam (*Mercenaria mercenaria*) aquaculture industry in Cedar Key (nicknamed "Clamelot") consisting of over 300 aquaculture operations across 950 acres of leased submerged lands.[26] In this region, Suwannee River discharges maintain brackish salinities that sustain the hard clams; the influence of the Suwannee River can be seen in salinity monitoring data collected at one of the submerged clam lease sites (Figure 2).

The Suwannee River Basin is minimally populated relative to the rest of Florida; compared to the statewide average of 239 people per square mile, the Suwannee River Basin only houses an average of 30 people per square mile.[22] Moreover, the coastal zone of the Suwannee River Basin consists of the least developed coastline in the state.[27] The low population density and lack of extensive development helps to protect the Suwannee River and the Suwannee River Estuary from many human activities that commonly impact riverine and coastal systems, such as cultural eutrophication and dredging.[28]

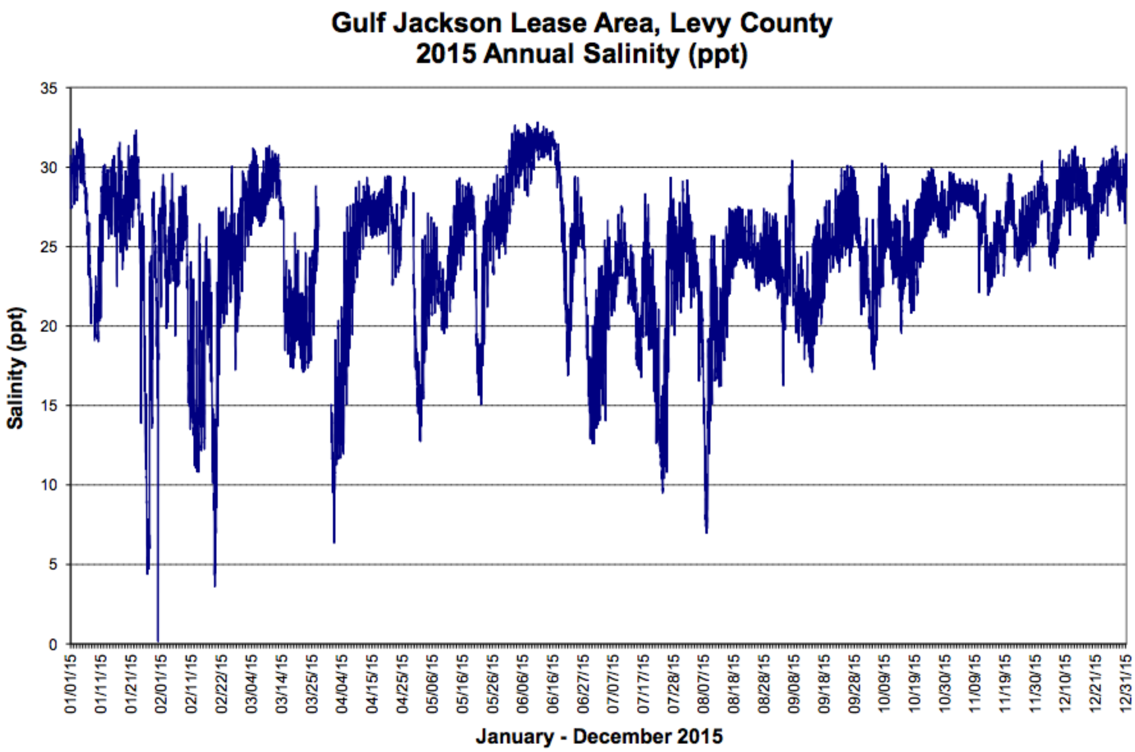

Figure 4. Salinity in the Gulf Jackson Lease Area, 2015. Salinity in parts per thousand (ppt) collected throughout 2015 at the Gulf Jackson Lease Area, which is located northwest of Cedar Key. Note that these salinity values remain below that of marine waters (35 ppt), thus highlighting the influence of freshwater in maintaining shellfish-favorable ambient water quality in this region. Source: UF/IFAS.

Threats to the Suwannee River Estuary

As with many estuaries across the world, the Suwannee Estuary face two primary threats moving forward: (1) increased demand for freshwater within the Suwannee River Basin, thus potentially resulting in decreased freshwater flows to the Suwannee Estuary, and (2) sea level rise and the ensuing inland movement of marine waters.

The Suwannee River Water Management District expects a 28% increase in water demand from 2015 – 2035, which corresponds to an increase in consumption of 66 million gallons of water per day. Mounting pressure on the public water supply is attributed to projected increases in agricultural irrigation and industrial water use.[29] Additionally, groundwater stores that had historically supplied springs and waterways of the Suwannee River Basin are in decline due to excessive pumping from within the basin, the St. Johns River Water Management District, and south Georgia.[30] This pumping has actually shifted the groundwater divide westward such that the Suwannee River Basin has lost a portion of its aquifer to the St. Johns River Basin (Figure 3).[30] In summary, less freshwater is expected to arrive to the Suwannee River estuary as a result of projected increases in freshwater usage upstream, and groundwater levels are expected to continue changing in the Suwannee's disfavor.

This expected reduction in freshwater delivery to the Suwannee Estuary and Big Bend will be further exacerbated by rising seas. For the southeastern U.S., sea level is projected to rise by 32-40 inches by 2100,[10] which would result in the estuary migrating upriver. Furthermore, the inland movement of seawater would negatively impact groundwater dynamics and spring flows,[22] thus creating another mechanism by which freshwater flows to the Suwannee would be reduced.

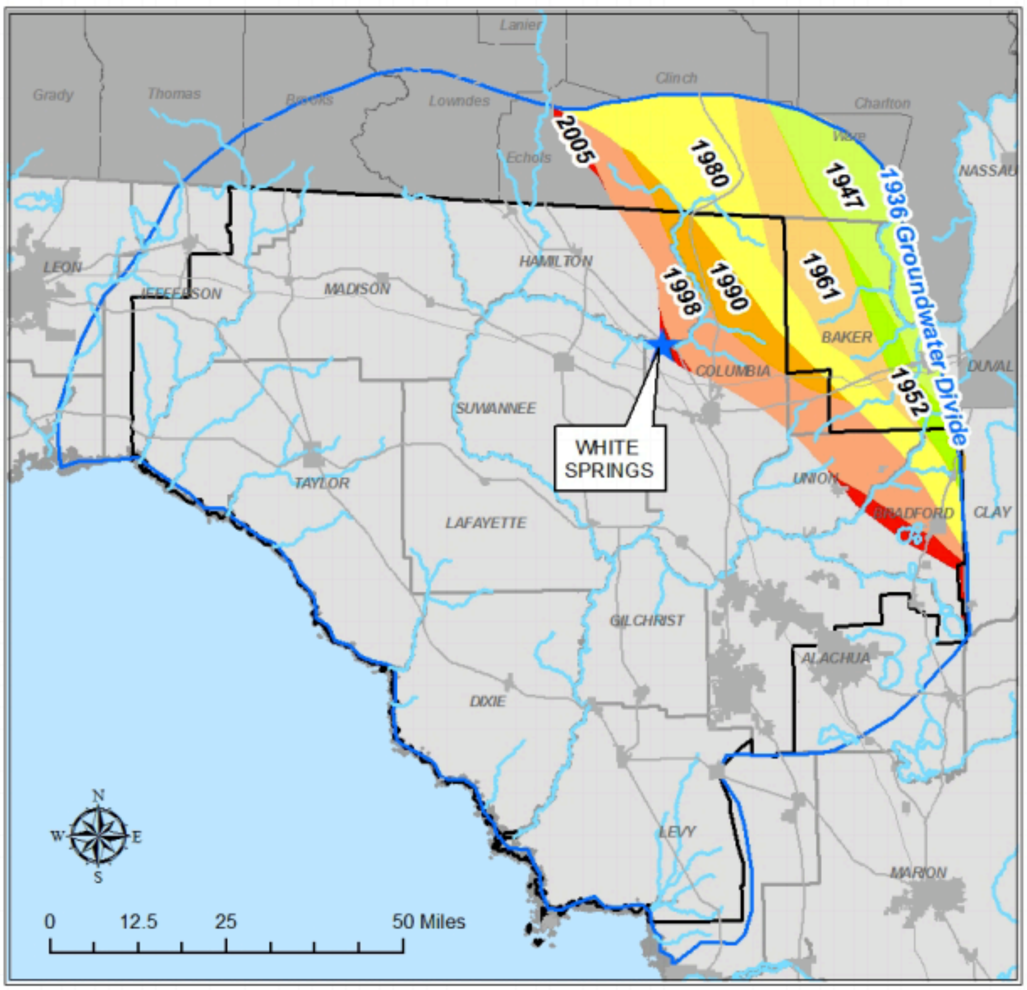

Figure 5. Migration of the groundwater divide in the Suwannee River Water Management District from 1936-2005. Pumping from the Suwannee River Basin, St. Johns River Basin, and south Georgia has driven a westward shift in the boundary of the Suwannee's ground-watershed. Source: SRWMD 2010 Water Supply Assessment.

Lens into a water-starved future: oyster reef loss
Between 1982 and 2011, oyster reefs in the Suwannee Estuary and Big Bend area declined by 66%, with the greatest losses occurring among offshore reefs (loss of 88%) and lowest among inshore reefs (50%).[28] Sea level rise and reductions in the Suwannee River's flows are attributed to driving this loss. In recent years, there have been more and more unusually low flow events (where a low flow event is defined as being less than one standard deviation below the monthly mean flow calculated from data collected over 1942 to 2009), and, compared to historical records, less flow has emerged from the Suwannee per drop of rainfall (Figure 4). This decrease in freshwater flows results in salinities increasing in the estuary, which ultimately fuels oyster loss.

The fact that these losses in oyster reef are already happening today suggests that wild oysters will fare poorly in a future where freshwater is increasingly limited.

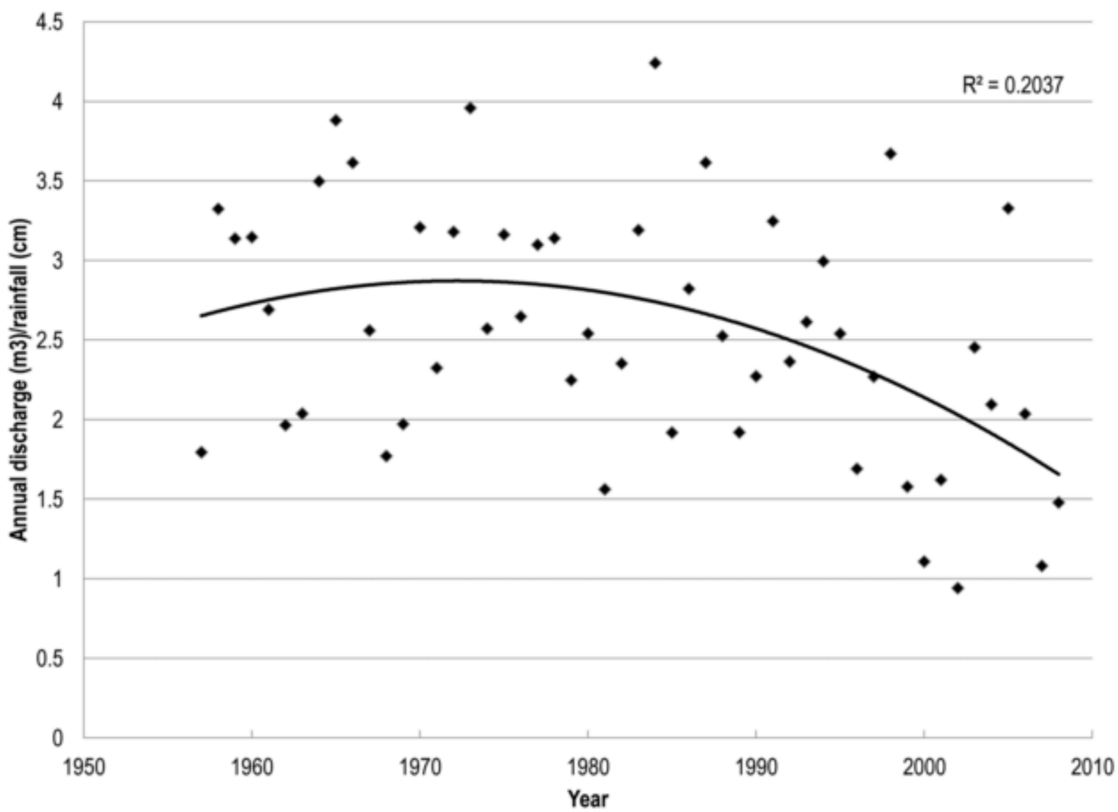

Figure 6. Observations of flow-per-rainfall from the Suwannee River. The trend in these observations demonstrates that the river's flows are declining relative to rainfall. This suggests that decreases in the Suwannee River's flows may result as a function of increased water use in the basin rather than climatic forcing (Seavey et al. 2011).

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Ecosystem Services from Estuaries (Sarah Ward)

Estuaries containing sustainable fisheries resources provide numerous ecosystem services, or "direct or indirect contributions that ecosystems make to the well-being of human populations" (Barbier et al. 2011, 170). Healthy estuaries, and in this case estuaries with particular levels of salinity and freshwater inputs allowing for the presence of aquatic species, provide additional ecosystem services that have environmental, economic, and social components. For the purposes of this report I will be addressing the following economic and social ecosystem services:

- Economic provisions by way of fisheries through sales, income, and jobs, both commercially and recreationally
- Contributions to food security and sustenance
- Shoreline stabilization and prevention of property destruction
- Cultural significance

As previously discussed, there are several species of fish within Florida's Gulf of Mexico estuarine systems that have positive relationships with freshwater flows related to salinity, the delivery of organic matter, and turbidity, among other factors. Up to 90% of recreational fish and 75% of commercial fish rely on estuaries at some point in their life cycle, whether that be for spawning, feeding, or habitat, and thus maintaining freshwater flow levels has an impact on the productivity of recreational and commercial fisheries in estuaries ("What's at Stake: The Economic Value" 2010, 3). Estuarine and coastal fisheries supply the global economy with approximately $230 billion USD per year, as well as produce 80 metric tons of food annually (Barange et al. 2014, 211). Commercial fisheries in Florida in the Gulf of Mexico were valued at over $5.5 billion USD in sales, $3 billion USD in income, and provided over 100,000 jobs in 2008, thus contributing greatly to the local economy and providing livelihoods for a multitude of people (1). These commercial fisheries also contribute to food security and sustenance in local communities as well as in markets through which the fish can be transported for sale and consumption.

One of the most crucial commercial species in the region is the eastern oyster, which had a total landed value of over $5 million USD commercially on the west coast of Florida in 2008 ("What's at Stake: The Economic Value" 2010, 2). As of 2012, aquaculture of clams, oysters, and fish species together contributed to over $68 million USD in sales ("Florida Seafood and Aquaculture" 2017). Oysters rely on a particular salinity range in order to be healthy and resilient and thus a change in freshwater flows could alter the recruitment and harvest, and subsequently the value of the species as well as that of other common commercially harvested species.

The presence of oyster reefs within an estuary not only provides economic benefits to a coastal community, but also helps to protect coastal properties from damage related to shoreline destabilization and storm surges by working to reduce wave energy as it reaches the shore (Blair et al. 2014, 4). Oyster reefs in the Gulf of Mexico have been found to contribute to a "51-90% reduction in wave height and 76-99% reduction in wave energy", lessening the impact of waves on coastal erosion and destruction of property (Kroeger 2012, vi). These impacts can be valuated primarily in terms of the value of the property that was protected by the reefs and the amount of money that was saved through the prevention of property destruction. It has been estimated that a five meter wide oyster reef could be valued at up to $1.5 million USD per hectare in terms of its stabilization and property destruction prevention capabilities (Grabowski et al. 2012, 905).

Recreational fisheries also make a significant contribution to the economies of counties bordering the estuary, with the industry being valued at $5.65 billion USD in sales while providing over 54,000 jobs in 2008 ("What's at Stake: The Economic Value" 2010, 1). These contributions were made by likely over 16 million recreational fishing trips on the west coast of Florida based on 2006 data ("Gulf of Mexico Summary" n.d., 116). The absence of species reliant on freshwater flows could decrease the number of recreational trips made and have a negative effect on the local economy. Overall, it is apparent that fishing communities with sustainable yields enable local fishermen and others involved in the industry to be empowered and be able to provide for their families (Lynch et al. 2016, 117). Without the presence of these fish, fishermen are less likely to have power over their economic situation (Nayak et al. 2014, 7). A study on fisheries-dependent communities in India and Brazil found that "economic or income poverty is directly linked to the loss of fish productivity" and that environmental fluctuations contribute to the extent of this poverty (7).

While it is possible to quantify the economic value of several components of fisheries in the region, it is critical to note that the specific valuation of the ecosystem services that would be *lost* due to a reduction of freshwater flows combined with saltwater intrusion has not yet been quantified. That being said, if species were to collapse due to reduced freshwater flows, many people in coastal communities who are reliant on fisheries resources would be out of a job and without prior planning and management, there may not be many opportunities available for quick reemployment and individual livelihoods would subsequently suffer.

There are also numerous ecosystem services provided by fisheries in coastal and estuarine communities that are much more difficult, if not impossible, to valuate. These services include societal ties to fisheries such as cultural significance, spiritual or religious connections, individual identities, and aesthetic or inspirational values (Lynch et al. 2016, 118). Coastal communities are likely to identify with the fishing industry and maintain historical and cultural ties to the prosperity of its commercial and recreational benefits. This was evident through discussion with stakeholders and local residents in Cedar Key. While these values may not be able to be quantified as easily as economic and food security impacts, they cannot be ignored when creating management strategies for estuarine resources that deeply affect peoples' livelihoods and culture. The following figure illustrates the connections between ecosystems and their valued services, as well as how human actions feed back into this system (Figure 7).

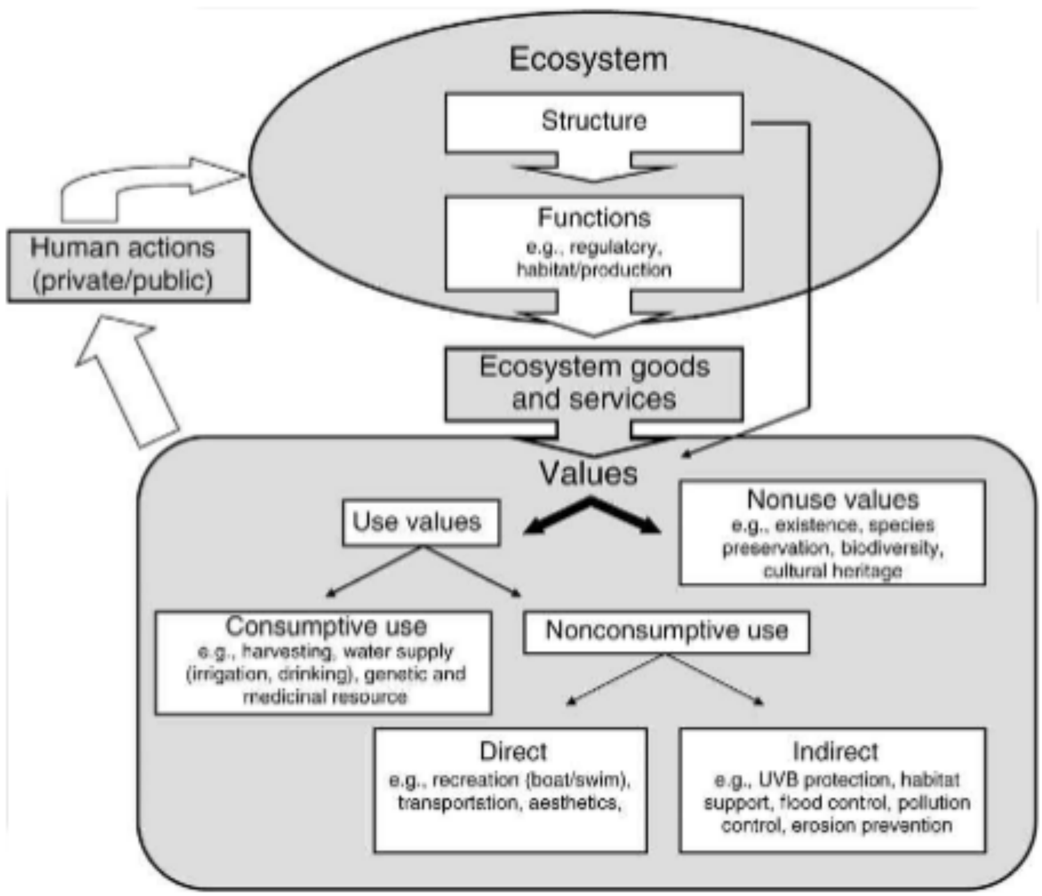

Figure 7: Valuation of Ecosystem Goods and Services (Barbier et al. 2011, 174)

STAKEHOLDER ENGAGEMENT IN FRESHWATER FLOW MANAGEMENT (SARAH WARD)

Florida is considered one of the most water-rich states in the country due to its high level of rainfall and aquifer resources (Borisova and Rogers 2014, 4). Because of this, there are a variety of uses of Florida's freshwater and thus different stakeholders involved in its management. For the purpose of this report, a stakeholder is an individual or group that has a "stake in a particular issue or system" (Grimble and Wellard 1997, 175). The various uses of freshwater in Florida include agriculture, commercial-industrial-mining, domestic, public supply, power generation, recreational-landscape irrigation, and fisheries (2). It is critical to note that the largest withdrawals of freshwater come from agriculture with 40% usage and public supply with 35% usage and thus these industries contain critical stakeholders when it comes to management decisions. That being said, stakeholders with smaller usage percentages are still critical to management discussions because they are still considered a stakeholder regarding the use of the water. It is crucial for the communication between stakeholders to include discussion regarding the ecosystem services provided to all stakeholders, whether that be fishermen or agriculturalists, and to keep in mind the geographic range between stakeholders in order to make sure all of those involved understand deeply the positions and interests of all potential users of the freshwater (Richter 2009, 1056).

In the case of estuarine fisheries like those in the Suwannee River Basin, stakeholders include "fisherman and their representative organizations", as well as the broader coastal community, those who buy, sell, and transport fish, and environmental groups (Mackinson 2011, 18). Agriculture has similar stakeholders, including farmers, their special interest groups, members of their broader community, and those who buy, sell, and transport agricultural products. Public supply stakeholders include municipalities, citizens who benefit from the use of the water, and those who benefit from municipal water employment opportunities. This is not an exhaustive list, but rather it aims to identify key stakeholders who may be involved in management conversations. This report will primarily focus on the inclusion of fisheries stakeholders and coastal community members into decision-making regarding freshwater usage. Additionally, the involved stakeholders do not all lie within the same geographic region. Florida's Suwannee River Management District spans over 7,640 square miles and inland agricultural operations and municipalities that have a stake in the use of the water could be upwards of 100 miles from the mouth of the Suwannee, where a majority of the fisheries industry stakeholders reside ("About the District" 2017).

It is critical to incorporate the local community and fisheries industry members into stakeholder discussions and decision-making regarding freshwater flow because they are likely to have local knowledge that can contribute to "expert" knowledge and they are likely to know historically what has and hasn't worked in the past in terms of solutions and what is likely to work in their particular communities in the future (Spalding et al. 2014, 54). Additionally, as previously discussed, there are significant economic and social ties between freshwater flows and estuarine communities and industries and thus these impacts will be directly affecting these communities and the stakeholders that rely on them. This likely makes those individuals and groups more interested in the management decisions due to the high risk of losing livelihoods or cultural value if the resource is mismanaged. Based on discussions during the stakeholder panel in Cedar Key and other fieldwork experiences, it seems that the local community feels underrepresented and underutilized in the overall management of estuarine resources.

One method that could be employed to engage stakeholders is participatory research, which is characterized as "both scientists and stakeholders being involved in all stages of the research planning and delivery", which in this case would be when determining how freshwater is used, by whom, and to what extent (Mackinson et al. 2011, 18). Pilot projects that employ participatory research through stakeholder engagement are likely to encourage further stakeholder involvement in other future natural resource management discussions. Participatory research should be unbiased, void of political influence and self-interests, and purely scientific (Mackinson et al. 2011, 19. Stakeholders should contribute the best science possible to the research in order to later inform decision-making that will balance the different self-interests of the stakeholders, which are likely to be influenced by politics and economics. It is suggested that when stakeholders are involved in the research component of management they should be compensated, however payment should not be made for involvement in public workshops and opportunities within the decision-making process.

Stakeholder analysis is another method that could be executed in concurrence with stakeholder input in order to be more aware of the different components of a management issue and who the introduced policies may impact (Grimble and Wellard 1997, 175). Stakeholder analysis is specifically used to improve policies regarding the management of crosscutting resources as well as to better understand the impacts of policies that are put in place (177). This method looks at the management of resources that have diverse stakeholders and uses, as well as wide-ranging concerns and underrepresented groups (179). Stakeholder analysis identifies conflicting interests and the trade-offs that must be made by each stakeholder in order to come to a conclusion as to how to manage the resource in question (180). This method could be used in the case of freshwater withdrawals in the Suwannee River Basin if conducted by an independent organization or committee in order to compare and contrast what is at stake for each group of actors and what they would be willing to trade off in order to maintain some control over access and use of the freshwater flows. This would be most effective if stakeholders were directly consulted to receive information for the analysis rather than having the committee do independent research on the stakeholders without a consultation.

It is crucial to have effective communication between stakeholders and those directly in control of the management decisions because without this, tensions between groups and individuals could heighten if one feels that they are not being listed to, respected, or valued (Kaplan and McCay 2004, 257). By allowing stakeholders to engage in participatory science and research, a sense of trust is more likely to be developed among the different actors due to recognition of entities other than those in direct control or traditionally appointed scientists as having valid knowledge and expertise (258). Allowing different stakeholders to be involved in research and management processes also educates other stakeholders and the traditional managers or regulators on the effects that their decisions have on each of the groups that rely on the use of the freshwater in the Suwanee River Basin, which has historically not been common when looking at natural resource management (Kaplan and McCay 2004, 258). This solidifies both the scientific backing behind management decisions as well as recognizes the vast importance of freshwater resources to the social and economic integrity of different communities, as these factors are among the largest contributing ecosystem services provided by freshwater sources and estuarine ecosystems.

Arguably the most prominent recent example of distrust and animosity over the management of freshwater flows and lack of stakeholder involvement is the water war between Alabama, Georgia, and Florida. For decades, these three states have battled and gone to court over the withdrawal of freshwater from the Apalachicola-Chattahoochee-Flint River Basin by Georgia for agricultural and municipal uses. The state of Florida has contested that the withdrawals were taking more than their fair share of the water and that they were negatively affecting Florida's coastal economy and potentially contributed to the collapse of the eastern oyster in the Apalachicola Bay ("Water War History" 2011). This has created hostility between states, industries, and communities all vying over the use of the same resource. A conflict of this proportion in the Suwannee River Basin could be catastrophic for the sustainability of the coastal ecosystem as well as the livelihoods of fisherman and local residents.

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Water Management Regimes and Policies (Daniel Ward)

Background of Water Allocation Law

One of the most critical challenges to come from population growth and climate change could be the allocation of freshwater supplies, including apportionment to maintain natural flows and levels of waterbodies. As a common yet indispensable resource for life, the availability of water looms great as its limits are realized. Legal frameworks have developed over time to manage, divert, and use water under different hydrological conditions; however, these prove ineffective for equitable distribution with increasing scarcity.

In the United States, water rights have generally progressed in two distinct approaches, riparian doctrine in the East and prior appropriation doctrine in the West.[1] Under riparian doctrine, water rights belong to landowners whose land adjoins a water body or has access to groundwater. Generally, the only limitation to common law riparian rights was the reasonable use rule, which granted landowners rights to surface water if their use did not unreasonably interfere with the flow or quality of water to another user.[2] Groundwater use, before a reliable means to measure the adverse impacts on neighboring landowners, could be extracted essentially without restriction.[3] Riparian law evolved out of court cases that settled disputes between riparian property owners.[4] However, without conflict between landowners there was little consideration about the impact of diminished freshwater flow to environment itself. Historically, this system of law was sufficient in the Eastern states that received ample rainfall to meet the needs of its human populations.

The doctrine of prior appropriation, which developed in the drier Western states, offers no such benefit to riparian landowners. Rather, water is allocated by the "first in time, first in right" principle.[2] Specifically, the specific amount of water is appropriated by permit so that prior water users have priority over users who receive later permits. As water resources decline, later permitted users lose their water rights first.

Realizing water shortages, many Eastern states have incorporated facets of the prior appropriation doctrine into their common law riparian rights, namely the allocation of water by quantity and duration through an administrative permit process.[2] Florida has been a leading model for such reforms, enacting a comprehensive statutory scheme known as the Florida Water Resources Act (FWRA). Under the current version of the FWRA, water allocations are specified by location, nature, quantity of permitted water use, and are subject to monitoring and reporting requirements.[5] Additionally, it provides for the establishment of minimum flows and levels of specific water bodies.[6]

Florida Water Law

Under a two-tiered appropriation system, Florida manages its water resources with the Florida Department of Environmental Protection who overseas water resources at the state-wide level and five regional Water Management Districts (WMDs) that implement many core aspects of the regulatory framework, including water use via consumptive use permits and environmental protection standards such as minimum flows and levels of water bodies.[7] The jurisdiction of these regulatory and planning agencies were created based on watersheds rather than political boundaries.[8] The purpose for using hydrological boundaries in lieu of political ensures that each WMD can properly manage all surface water related issues within its respective watershed. At the same time, this limits undue influence that individual counties or municipalities have in the decision-making process. While hydrological boundaries account for groundwater (aquifer) recharge potential in each watershed, impacts from groundwater withdrawals are not similarly confined.

In Florida, ground waters and surface waters are publicly owned, and water use permits are required depending on type of use and withdrawal amounts.[9] Each water management district must create a regional district water management plan with a 20-year projection to be updated no less than every five years.[10] As part of this plan, the district must make provisions for minimum flows and levels, provide a reasoned methodology for their adoption, and make a water supply assessment to examine current and future water use needs and conservation strategies. The plan must comply with statutory law by considering the reasonable-beneficial use of the water resources in authorizing its consumptive use permits.

Environmental Implications

FWRA provides authorization to the state's WMDs to adopt their own regulations for consumptive use permits to ensure that water use is "is not harmful to the water resources of the area."[11] The statutory standard for authorizing consumptive use of water considers three factors. "The proposed use of water: (a) Is a reasonable-beneficial use … (b)Will not interfere with any presently existing legal use of water; and (c) Is consistent with the public interest."[12] Furthermore, to provide reasonable assurances that the consumptive use is reasonable-beneficial, an applicant shall demonstrate that the consumptive use meets several criteria set forth in the applicable water management district rules.[13] Currently these criteria include stipulations that water uses "will not cause armful water impacts," "will not cause harmful saltwater intrusion," and "are in accordance with minimum flows and levels"[14]

Presumably, the public interest consideration should also provide a legal basis for denying permits that cause environmental harm; however, both the FWRA and district rules lack clarification as to the precise meaning of "public interest." Currently, Florida's water law does not make any distinction regarding allocation preference between competing uses that both serve a public interest. Beyond mentioning public interest throughout the statutory language, it makes no effort to discuss whether a direct public interest in the form of environmental protection is preferential to a public interest derived from individual water users who provide important services, such as agricultural producers.

The FWRA does provide some guidance regarding circumstances where two or more water use applicants are competing for the same limited water supply. This guidance provides WMDs the right to approve the application that "best serves the public interest," and utilizes the prior appropriation doctrine standard that gives preference to renewal applications over new applications, and uses that are closer to the water source.[15]

Ultimately, the criteria as set forth by the WMD's implementation rules provides the most definitive standard for water use's impact on environmental resources. Of these, the establishment of minimum flows and levels is the most discernable benchmark to measure the impact of consumptive use permits.

Minimum Flows and Levels (MFLs)

Florida's five water management districts are responsible for establishing minimum flows and levels for all waters, surface and ground, within their watersheds.[16] Minimum flows and levels are "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area."[17] Furthermore, minimum flows and levels "shall be calculated . . . using the best information available" and "may … reflect seasonal variations."[18] By having MFLs, water management districts are required to "consider . . . the protection of nonconsumptive uses," such as estuary function, and can protect those uses at their discretion.[19]

Determination of MFL is made by considering the amount of water withdrawals that would be "significantly harmful" to the water resource values as provided in the Water Resource Implementation Rule.[20] Unfortunately, this rule provides no further guidance as to what constitutes significant harm. While it could be argued that significant harm should weigh the importance of human and ecological values, water management districts have focused their consideration on resources that are most sensitive to reduced water quantity in determining MFLs. These efforts by water management districts, via MFL establishment technical reports, are purely scientific based decisions that evaluate freshwater flow impact on ecological and other water resource functions. Short of amending the law to clarify the significant harm language, a sound legal interpretation might be to apply the non-degradation standard set for water quality to water quantity. This interpretation is bolstered by the fact that among the list of water resources values protected by MFLs is water quality. This is particularly important in the context of freshwater flow to prevent saltwater intrusions into aquifers and estuary ecosystems.

However, as water resource scarcity increases and avoidance of significant harm becomes impossible, the purely scientific approach to establish MFLs will certainly have to incorporate economic and social considerations to a greater degree. At that point, ecological resources, such as national wild refuges, outstanding Florida waterways, aquatic preserves, and marine sanctuaries, may become important designations to establishing a lower threshold for significant harm. Within the water management district regulatory framework, certain designations, in the form of priority lists, have already been created to guide the maintenance and protection of significant water resources.

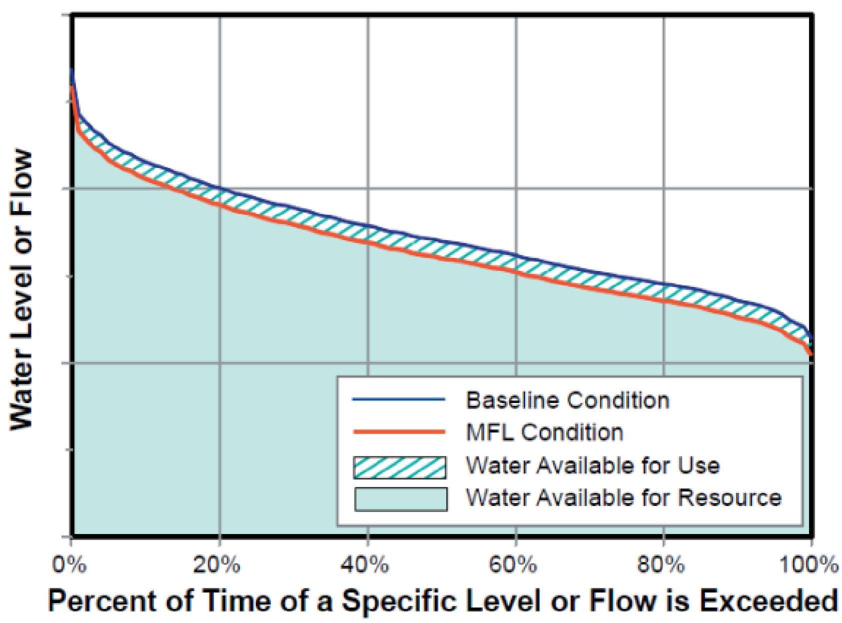

Figure 8. Minimum Flows and Levels. The two curves show the percentage of time each water level or flow is equaled or exceeded; this is called a water level or flow duration curve. The blue shaded area below the MFL curve represents the water available for protection of fish and wildlife or public health and safety. If use of water resources

shifts the water flow and/or levels below that defined by the MFLs, significant harm is expected to occur. Source: Suwannee River Water Management District,

Priority Lists
The water management districts are required to create a priority list of waters for the establishment of MFLs.[21] The statutes further require that water management districts "include those waters which are experiencing or may reasonably be expected to experience adverse impacts," which in effect limits lawsuits to force the adoption of MFLs for imperiled bodies of water.[22] This limitation does not preclude substantially affected persons from requiring independent scientific peer review of "all scientific or technical data, methodologies, and models, including all scientific and technical assumptions employed in each model . . . ."[23] Therefore, to the extent any water management district has not fully accounted for the potential adverse effects of water use, those affected have a forum to challenge the district's conclusions. In the event of an MFL violation or violation within the water management district's twenty-year projection, the district must develop and implement prevention or recovery plans provided in its Regional Water Supply Plans.[24]

Legal and Regulatory Limitations
Despite Florida's robust water laws, specifically its consumptive use permitting program and MFL criteria, Florida's rivers, lakes, and springs have still suffered from degradation due to reduced flows and levels. This is in part attributable to periodic droughts and a continually growing population that relies on Florida's once seemingly endless water resources; however, water management districts have also struggled to effectively implement water use monitoring programs and many MFLs remain either unestablished or unmet. For instance, the Suwannee River Water Management District reported that 60% of agricultural wells of 8" diameter or greater are monitored and 32.14% of water bodies ae meeting their adopted MFLs.[25] While there are some ambiguities in the statutory language that may present future courts with the challenge of determining priority of competing uses, the more pressing issue may be increasing the application of science in informing the law, and public engagement in enforcing the law.

APPLICATION OF LAW: LOWER SUWANNEE RIVER (DANIEL WARD)

As discussed earlier, the Suwannee River and its estuary are facing challenges associated with reduced freshwater discharge and sea level rise. The statutorily required reasonable-beneficial use of water permits in the Suwannee River Water Management District (SRWMD) is elucidated through its implementation rules, which include preventing environmental harm, requiring water conservation, and use of treated water when possible.[26] These rules require that the water use, except for direct human consumption, must be the lowest quality source available for the intended use, and that the use must not cause saltwater intrusion, [27] Additionally, the rules have specific criteria to protect water needed for ecological functions. These rules prohibit consumptive uses of water that would result in water flows or levels less than MFLs established for a specified waterbody in the priority list.[28]

The Lower Suwannee River, which encompasses its estuary ecosystem and several springs, is on the SRWMD's MFL priority list, and was among the first waterbodies in the district to have an established MFL. This MFL, established in 2005, received justification through a technical report produced by the district.[29] In applying the water resource values from the water resource implementation rule, the district concluded that fish and wildlife habitats and the passage of fish, estuarine resources, and water quality were the resources most sensitive to flow reduction, with the primary source of harm being saltwater intrusion caused by diminished flow.

Arguably, enough of the scientific data used in this report has changed since it was published to warrant an updated report. For instance, sea level trends now demonstrate a rate of increase greater than the historic trends assumed in the report. The decline of offshore oyster reefs may also be indicative of an MFL threshold below that necessary to maintain all estuarine resources. However, the report indicated that oyster habitat loss would occur regardless of the proposed MFL; and therefore, protection may not have been feasible.[58] Regardless, sea level rise at an increasing rate will require increased freshwater flow to maintain the resources which the adopted MFLs were established to protect, such as submerged aquatic vegetation and other estuarine species vulnerable to further saltwater intrusion.

In 2017, MFLs for the Lower Suwannee River were placed under evaluation by the district to determine the potential effect of water withdrawals outside the district's jurisdiction, specifically within the St Johns River Water Management District.[30] This reevaluation of MFLs was partly in response to the North Florida Regional Water Supply Partnership. This is an interagency agreement between the Suwannee and St. Johns River Water Management Districts to develop and implement joint MFL prevention and recovery strategies to address the problem of water withdrawals in one district impacting water resources in the other district. These strategies, which include development of one consistent MFL process, development of one consistent definition of "harm," and, development of other environment constraints in the absence of an MFL, are to be included in this evolving partnership agreement.[31] Also pursuant to these terms, SRWMD is adopting MFLs for springs and other water sources that feed the Suwannee River within the next few years.[32]

MFL Schedule

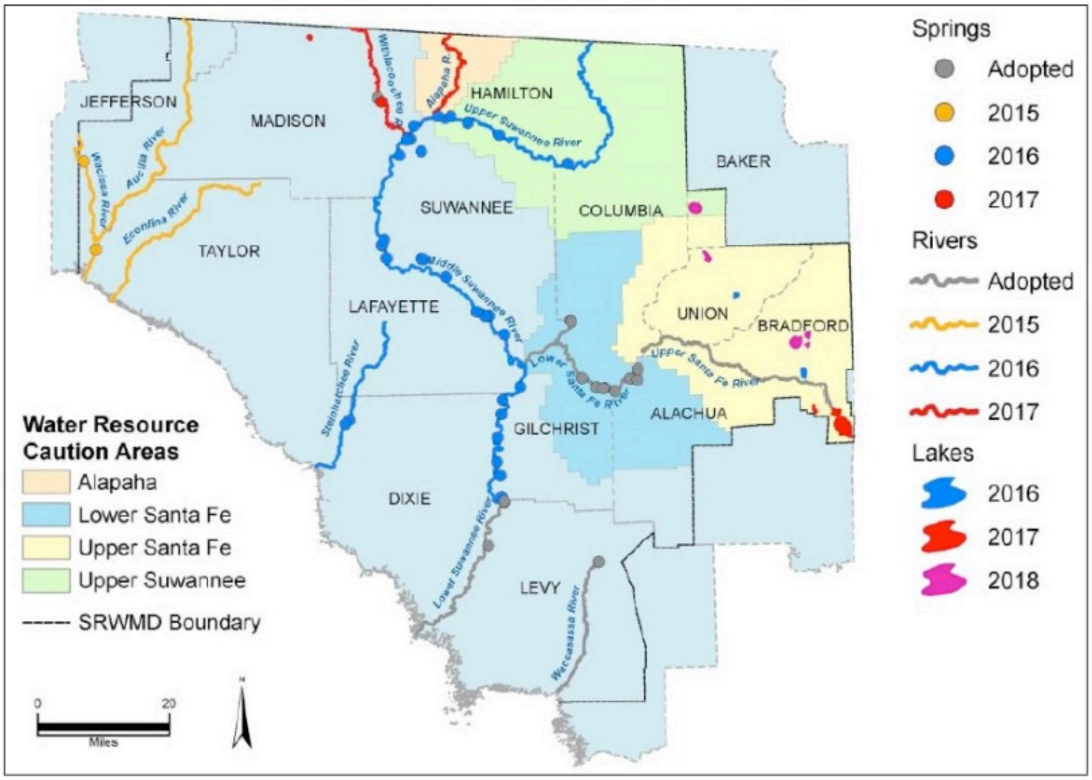

Figure 9. Schedule for adoption of minimum flows and levels of priority listed water bodies. Source: Suwannee River Water Management District Strategic Plan 2017-2021, February 29, 2016,

The SRWMD has reported that only about 32% of waterbodies with adopted MFLs were meeting those MFLs.[25] If the flow from remaining 68% of waterbodies can be restored, as well as the waterbodies that may not meet their scheduled MFLs, flow to the lower Suwannee basin and estuary will likely improve. At the crux of this issue is a clearer understanding of how specific withdrawals affect the MFLs of specific waterbodies. Setting MFLs alone would be an insufficient solution if the SRWMD could not also determine which users were contributing to the reduction of flow below the MFL. Detailed water monitoring of consumptive use permits is an integral component to ensure that water resources are properly distributed to human and environmental needs.

See end notes for references.

Results and Discussion

The Suwannee River Estuary is threatened by the combined effects of (1) reductions in freshwater flows due to inland water consumption, and (2) sea level rise. Though sparsely populated, several coastal communities in this area depend on the Suwannee River to create an estuarine environment along Florida's Big Bend. In particular, this region is known for its aquaculture of Northern hard clams and harvesting of wild Eastern oysters, and both of these species require brackish salinities to thrive. Moreover, many recreationally-important fish species caught in this area rely on estuarine settings during some, or all, parts of their life cycles. Thus, the influence of freshwater flow is of critical importance for the ecology and economy of this area, and maintaining adequate freshwater flow in the context of accelerating rates of sea level rise will be necessary to avoid significant harm to the Suwannee River Estuary and its coastal communities.

To accomplish adequate freshwater flow to the Lower Suwannee River, the SRWMD district and its respective stakeholders must continually monitor its priority list of waters and MFLs schedule to account for emerging scientific studies and changing environments. Although MFLs were adopted for the Lower Suwannee in 2005, updated predictions regarding sea level rise as well as impacts from water withdrawals in other water management jurisdictions have demonstrated the need to update and implement new MFLs. Such changes also underscore the need to support continued data collection and monitoring of important environmental criteria (e.g., groundwater levels, spring discharge, salinity in the estuary, fishery populations, etc.) in order to inform effective decision- and policy-making.

Stakeholders impacted by the district's recommendations must exercise their legal rights to ensure that MFLs and other relevant criteria are informed by the latest scientific methods and data. As the importance of aquaculture continues to grow in the Suwannee river estuary, so does the importance of adequate freshwater flow. Those depending on these industries for their livelihoods need to be involved in the decision-making process as MFLs are updated and adopted by the district. Public engagement is necessary through workshops to ascertain the various public interests to determine what course of action best serves the public interest. MFLs and other adaptive strategies need to have forward looking considerations such as the increasing rate of sea level rise, and have contingency plans for best and worst case scenarios.

Finally, the creation of interagency, and possibly interstate, agreements may become more necessary for long-term management as sustainable water supplies reach their carrying capacity for populations and ecosystems. The creation of the North Florida Regional Water Supply Partnership is an example of how collaboration in water monitoring and environmental protection strategies has become an essential method to manage this public resource.

Conclusions and Recommendations

- Support long-term monitoring of water quality, fishery populations, and habitat quality in the Suwannee River Estuary
- Priority list of waterbodies, i.e. those imperiled by reduced flows, developed and updated annually
- Methods, flows or levels updated and peer-reviewed to incorporate accelerating sea level rise models.
- Workshops held for public input, to include aquaculture interests to address impact of lost offshore oyster reef habitat.

- Recovery or prevention strategies developed for waterbodies that do not meet minimum flows and levels.
- Water management district adopts/updates minimum flows and levels by accounting for cross-boundary water withdrawal impacts.
- Necessary recovery strategies included in North Florida Regional Water Supply Plan Partnership, which could include novel water use constraints beyond minimum flows and levels.

Endnotes:

[1] Smolen, M.D., Mittelstet, A., and B. Harjo. 2012. *Whose Water Is It Anyway? Comparing the Water*
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[3] *Id*.
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[5] FLA. STAT. ANN. § 373.229
[6] FLA STAT. ANN. § 373.042
[7] Borisova, T. and R. Carriker. 2009. Public Policy and Water in Florida. EDIS #799. UF/IFAS Extension, Gainesville, FL. Published May 2009, revised December 2013.
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[10] FLA. STAT. ANN. § 373.036(2)
[11] FLA. STAT. ANN. § 373.219(1)
[12] FLA. STAT. ANN. § 373.223(1
[13] FLA. ADMIN. CODE ANN. r 40A, B, C, D, or E-2.301. (2014)
[14] *Id*.
[15] FLA. STAT. ANN. § 373.233
[16] FLA STAT. ANN. § 373.042
[17] FLA STAT. ANN. § 373.042(1)(a), (b))
[18] FLA STAT. ANN. § 373.042(1)(b)
[19] *Id*.
[20] *Id*.
[21] FLA STAT. ANN. § 373.042(6)
[22] FLA STAT. ANN. § 373.042(3)
[23] FLA. STAT ANN. § 373.042(6)(a)
[24] FLA. STAT ANN. § 373.0421(2)
[25] Suwannee River Water Management District Strategic Plan 2017-2021, February 29, 2016, http://www.srwmd.state.fl.us/DocumentCenter/View/11389
[26] FLA. ADMIN. CODE ANN. r 40B-2.301 (2014)
[27] .*Id*.
[28] *Id*.
[29] TECHNICAL REPORT, MFL ESTABLISHMENT FOR THE LOWER SUWANNEE RIVER & ESTUARY, LITTLE FANNING, FANNING, & MANATEE SPRINGS, Suwannee River Water Management District, OCTOBER 2005

[30] SRWMD. 2017. Website. http://www.srwmd.state.fl.us/DocumentCenter/View/11553

[31] North Florida Regional Water Supply Partnership Water Supply Plan. 2017. Website. http://northfloridawater.com/watersupplyplan/document.html

[32] *Id*.