No. 142, Original

In The
Supreme Court of the United States

STATE OF FLORIDA,

Plaintiff,

v.

STATE OF GEORGIA,

Defendant.

DIRECT TESTIMONY OF WILLIAM MCANALLY, Ph.D.

October 26, 2016

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INTRODUCTION AND OVERVIEW

1. I, William H. McAnally, Ph.D., offer the following as my Direct Testimony.

2. I am a water resources engineer with specialized expertise in coastal and estuarine physical processes and their modeling.

3. The State of Georgia retained me to evaluate the effect of past, projected, and hypothetical scenarios of Apalachicola River flows on average salinity and water quality in Apalachicola Bay. I was also asked to review the expert reports and testimony of Drs. Marcia Greenblatt and Scott Douglass.

SUMMARY OF OPINIONS

4. The different scenarios of Georgia's consumptive use that Dr. Philip Bedient provided resulted in small differences in salinity values in Apalachicola Bay. I analyzed four scenarios representing Georgia's consumptive use in 1992 (Scenario 1992), 2011 (Baseline), projected 2040 (Scenario 2040), and Conservation Scenario (Baseline plus 1000 cubic feet per second (cfs) in the dry season) with constant mean sea level. The discharge variations among these scenarios cause both positive and negative salinity differences ranging from 0.1 to 0.7 (±15%) practical salinity units[1] (psu) in average dry season and monthly salinity.

5. These differences are small when considered in the context of salinity levels in the central Bay which can range from near zero to 39 psu. They are also small in comparison with fluctuations of ±14 psu (2 standard deviations) in observed average daily salinity and with calculated uncertainty bounds.

6. My models and analyses indicate that between 2002 and 2014 sea level rise increased salinity in central Apalachicola Bay by a relative small 0.6 psu (±30%). By 2040 sea-level rise-induced salinity increases will be between +0.3 psu and +4 psu (±30%). I consider the high end of that range more likely than the low end due in part to recent higher estimates of glacial melting.

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[1] Salinity is sometimes expressed as practical salinity units (psu) and sometimes as parts per thousand, or ppt. The units are equivalent for practical purposes.

7. My model results show that flow variations among the scenarios will not significantly affect dissolved oxygen in Apalachicola Bay.

8. Findings by Florida's expert, Dr. Greenblatt[2], are qualitatively consistent with mine to the extent that salinity differences between her two flow scenarios, called "Remedy" and "Future Withdrawals," are relatively small. Her findings reinforce my findings concerning the minimal effect of various flow scenarios on salinity in the Bay.

9. Florida's expert, Dr. Douglass, hypothesized[3] that narrowing of barrier island passes might mitigate the impact of sea level rise on salinity. My modeling shows that even if the passes change as predicted by Dr. Douglass, sea level rise will still cause increased salinity in Apalachicola Bay.

BACKGROUND AND PROFESSIONAL QUALIFICATIONS

10. I have 47 years of water resources engineering experience and have worked extensively in estuarine hydrodynamics, sediment transport, and modeling. I hold Ph.D. and M.S. degrees in Coastal and Oceanographic Engineering from the University of Florida and a B.S.E. in Civil Engineering from Arizona State University. I am a Registered Professional Engineer in my home state of Mississippi (#6275) and am board certified as a Diplomate in Coastal Engineering by the Academy of Coastal, Port, Ocean, and Navigation Engineers.

11. I was employed by the United States Army Corps of Engineers from 1969 to 2002, including as Chief of the Estuaries Division from 1985 through 1998 and as the Technical Director, Navigation, of the U.S. Army Engineer R&D Center (Waterways Experiment Station) from 1999 to 2002.

12. Beginning in 2002, I was employed with Mississippi State University for 12 years, teaching in the Department of Civil and Environmental Engineering and serving terms as the Co-Director of the NOAA-affiliated Northern Gulf Institute and Associate Director of the Geosystems Research Institute. I currently serve as Research Professor Emeritus at Mississippi State University, advising graduate students and participating in research projects as needed.

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[2] Direct Testimony of M. Greenblatt (Oct. 14, 2016).

[3] Direct Testimony of S. Douglass (Oct. 14, 2016).

13. Since 2005 I have worked in association with Dynamic Solutions, LLC, providing consulting services in river, lake, estuary, and coastal hydrodynamics, sedimentation, and water quality topic areas.

14. I have studied many estuarine systems in U.S. Atlantic, Pacific and Gulf of Mexico coastal zones using field investigations, laboratory tests, model experiments, and desk analyses. My experience in the Southeast includes investigations of tides, currents, salinity, sedimentation, and ecosystems in the Carolinas, Georgia, Florida, Alabama, Mississippi, Louisiana, and Texas.

15. I have studied sea level issues in the Gulf of Mexico and elsewhere for about 30 years, including an in-depth analysis of, and publications on, apparent sea level rise and its effects on coastal morphology in Louisiana.

16. Specifically, I have experience modeling and analyzing salinity changes in oyster-producing areas of Texas, Louisiana, and Mississippi caused by regulating freshwater discharge and other projects. Many of these studies are represented in my list of publications listed in my curriculum vitae[4], which includes about 150 papers, engineering manuals, and technical reports. I have taught graduate and undergraduate university courses in tidal hydraulics, sedimentation, data collection and analysis methods, and other subjects, and presently teach professional development courses on these and related topics.

IMPACT OF APALACHICOLA RIVER DISCHARGE ON BAY SALINITY

17. As in all estuaries, Apalachicola Bay salinity can be envisioned as a balance between two competing forces – sea water pushing inward from the Gulf and fresh water pushing out from the river. Other processes, such as rise and fall of the tides and winds, affect salinity but sea water and fresh water are the primary drivers, particularly for monthly average salinities. If all else is equal, reducing freshwater flow increases average salinity and adding freshwater flow decreases average salinity. If all else is equal, rising sea level increases average salinity and falling sea level decreases it. If both freshwater flow and sea level are changing,

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[4] Expert Report of Dr. William H. McAnally, State of Florida v. State of Georgia, No. 142 Original, May 20, 2016. ("My report") (GX0871).

average salinities may increase or decrease, depending on location and the changes' relative magnitude.

18. Salinity is a measure of the quantity of mineral salts dissolved in water. Gulf of Mexico water has a salinity of about 36 psu and river water typically has a salinity on the order of 0.1 psu. Salinity within Apalachicola Bay varies temporally and spatially across this range in response to a number of forcing processes, including river discharge, winds, tides and sea level. Evaporation in dry periods can increase salinity locally in the Bay to values greater than 36 psu. Daily average salinities at central Bay stations fluctuate on the order of ±14 psu.

19. Apalachicola River discharge into Apalachicola Bay is affected by precipitation runoff, evapotranspiration, upstream consumptive uses, groundwater exchanges, and regulation by dams. I did not independently analyze those effects on river discharge but used river discharge (or flows) as measured by the U.S. Geological Survey and as modeled by Dr. Phillip Bedient as inputs to my analyses.[5]

20. Some of the documents in this case refer to freshwater flow being the "dominant" driver of salinity in Apalachicola Bay. Such statements mischaracterize the processes that affect salinity. As noted above, salinity at a given location and time represents a balance between the forces of Gulf salt water and river fresh water. Without river flow, the Bay waters would be at Gulf salinity. Without the Gulf waters, the Bay would be fresh water. Neither can be considered dominant overall.

21. I analyzed the impact of both Apalachicola River flow differences and sea level rise on salinity in the Bay using two very different methods—statistical analyses of observed data at key locations (East Bay, Cat Point, and Dry Bar) and a standard physics-based numerical model of Apalachicola Bay and the surrounding Gulf area. These two methods provided consistent results, and their agreement convinces me that the results and my interpretation are scientifically sound and defensible.

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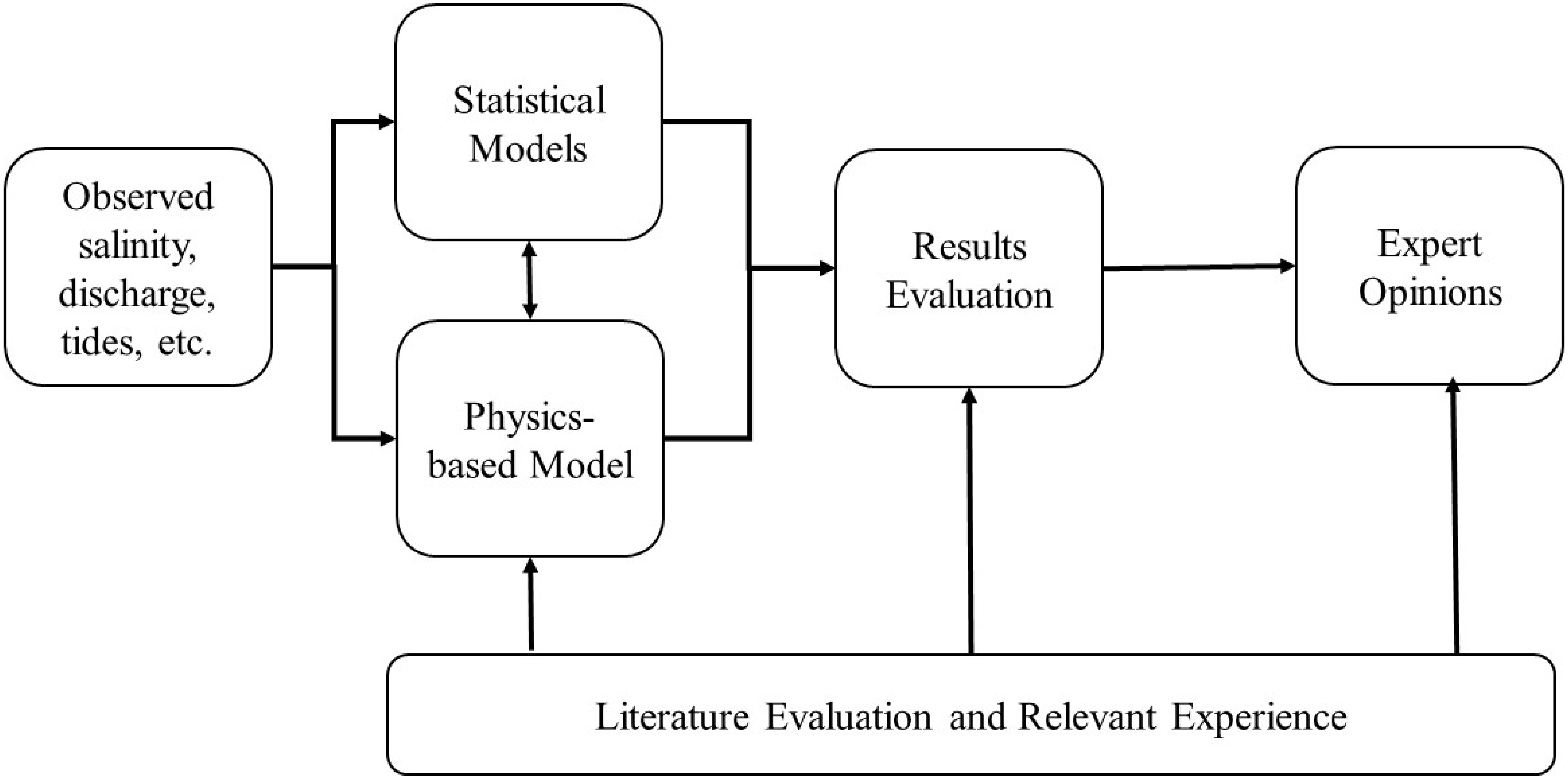
[5] JX-128 refers to information obtained from the USGS. Such data are typically relied upon by experts in my field, and I relied upon them to inform my opinions.

23. McAnally Dem. 1 illustrates my dual, parallel methods approach.



McAnally Dem. 1. Illustration of the Dual Methods Approach Used in My Analyses.

I. Flow Scenarios

24. The tested scenarios of freshwater flow used in my analysis are river discharge time series for the period 1992 through 2011 generated by Dr. Philip Bedient's HEC-ResSim model which provided simulated river flow at the Sumatra Gage (reflecting inflows from the Apalachicola River to Apalachicola Bay).[6] The scenarios simulated flows from1992 through 2011, but with different levels of water consumption by Georgia. The flow scenarios I used in my analysis include:

- **Scenario 2011 (Baseline):** Georgia's upstream consumptive use quantities were set equal to those of 2011;
- **Scenario 2040:** Georgia's upstream consumptive use quantities were specified to be the State of Georgia's projected basin-wide water demand in 2040;
- **Scenario 1992:** Georgia's upstream consumptive use quantities were reduced to those occurring in 1992; and
- **Conservation Scenario:** Baseline, except that streamflows in the Flint River were increased by 1000 cfs (28.3 cms) during the low-flow season. I am informed that this scenario was based on a remedy proposed by Dr. Sunding.

A. Overview of EFDC Model

25. I used the physics-based Environmental Fluid Dynamics Code ("EFDC") model to analyze the impact of flow scenarios and sea level on salinity in the Apalachicola Bay. This model is endorsed by the U.S. Environmental Protection Agency, and my company, Dynamic Solutions, has significant and broad experience applying it to estuarine and coastal systems. It is described in detail in Appendix D of my expert report.

26. Good modeling practice requires that the numerical models that are used to evaluate the effect of projected and hypothetical scenarios on salinity and water quality be physics-based, three-dimensional (3-D), and time-varying. They should be non-proprietary and in the public domain, with source code available—unless no other good numerical model option is available. Model software should be based on sound, scientific principles and should have

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[6] GX-1031 is a true and accurate copy of model outputs that I received from Dr. Bedient. GX-0911 is a true and accurate copy of outputs I received from Dr. Bedient related to Conservation Scenario.

been accepted as technically defensible through a peer review process.[7] The EFDC model satisfies all of these criteria.

27. For a model to provide valid results, it is important to test the sensitivity of the model domain (area covered by the model), model grid (the 3-D cells that make up the model), and bathymetry (the floor of the bay and gulf).[8] This ensures that results from the model are not inappropriately influenced by some aspect of the model setup. I also validated my model parameters to achieve maximum agreement between model simulations and observed measurements. Appendix D of my expert report (GX-0871) provides substantial detail on my EFDC modeling setup and validation.

B. Results of EFDC Modeling

28. Good modeling practice requires controlled experiments or simulations keep all variables constant except for the tested variable. In this case, the testing variable was flow rate from the Apalachicola River. In order to keep all other variables constant, I used simulated flows for these scenarios rather than comparing simulated flows with observed values at the Sumatra gage. (For sea level rise simulations I used observed flows.) GX-1039 is a true and accurate copy of outputs from my model results.

29. Results from my EFDC model simulations for the four scenarios and two time periods (1993 and 2010-2011) are as follows (scenario results are compared with results from Baseline (2011)):

- **Scenario 1992**: The difference in salinity between 2011 consumption (Baseline 2011 Scenario) and 1992 consumption (1992 scenario) was a decreased annual and dry season (July-September) average salinity by up to 0.5 psu ± 0.05 psu.
- **Scenario 2040**: The difference in salinity between 2011 consumption (Baseline 2011) and projected future use in 2040 (2040 Scenario) was negligible, less than 0.1 psu ± 0.05 psu, on annual and dry season (July-September) average salinities.

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[7] These principles are discussed in depth by EPA 2009. Guidance on the Development, Evaluation, and Application of Environmental Models. EPA/100/K-09/003, Office of the Science Advisor, Council for Regulatory Environmental Modeling, U.S. Environmental Protection Agency, Washington, DC.

[8] I relied on a variety of sources for my model setup, including GX-0787, GX-0788, and GX-1003 (as further described in list of exhibits cited).

- **Conservation Scenario:** The difference between 2011 consumption (Baseline 2011) and the Conservation scenario were decreased annual and dry season (July-September) average salinity of up to -0.7 psu ± 0.05 psu compared with Baseline results

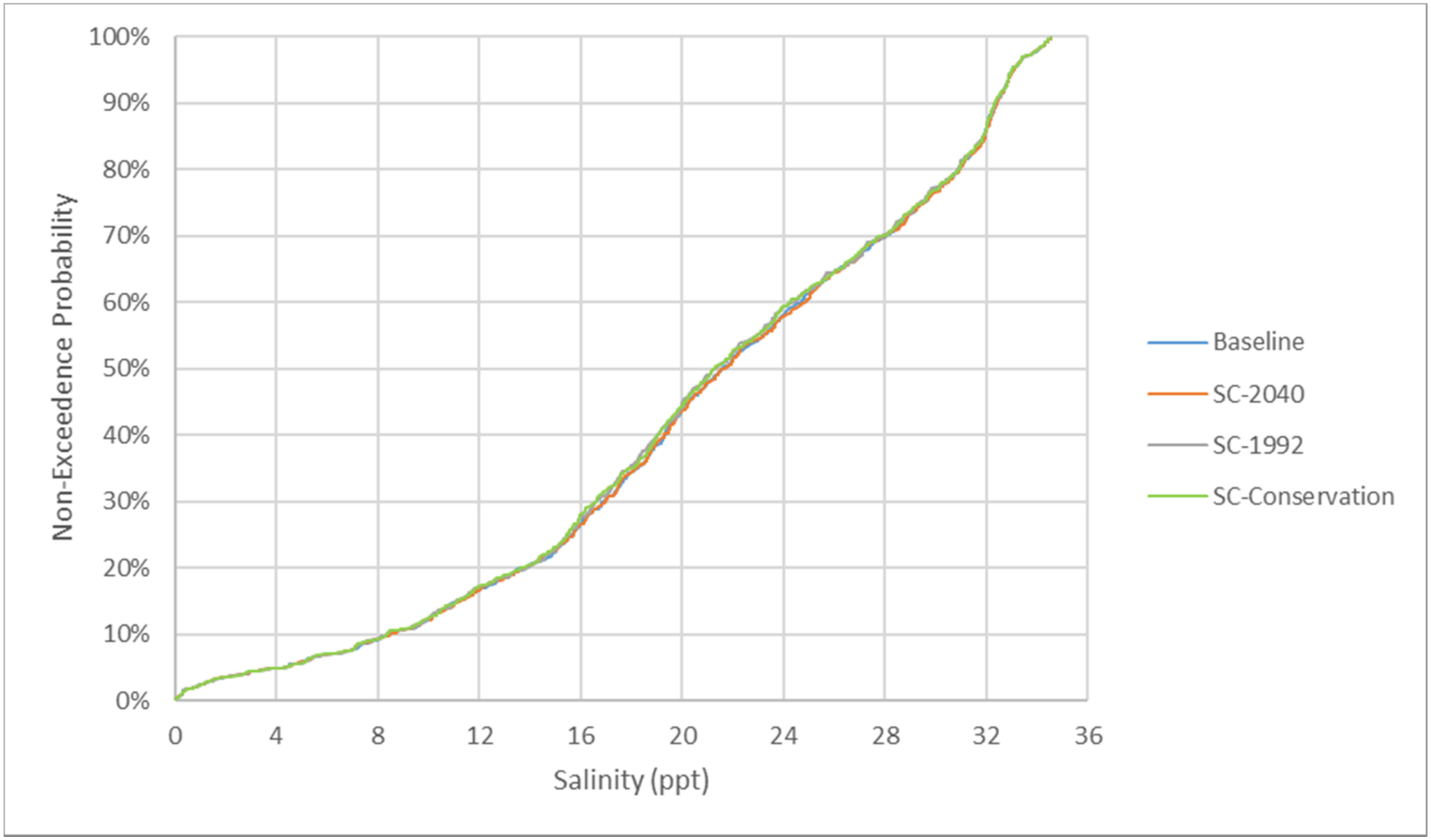
30. A graphical portrayal of salinity differences between the Baseline Scenario and Scenarios 1992, 2040, and Conservation is shown in McAnally Dem. 2, a cumulative percent non-exceedance plot for bottom salinity at Cat Point for the years 2010 and 2011. This is a standard hydrologic analysis graphic which provides an efficient summary of the frequency in which salinities occur at a given location.

31. McAnally Dem. 2 shows that salinity for all three scenarios was 16 psu (or lower) 27% of the time and 32 psu (or lower) 84% of the time. The curves for the three scenarios are virtually indistinguishable, which indicates that the scenarios produced similar salinity values over a wide range of conditions.

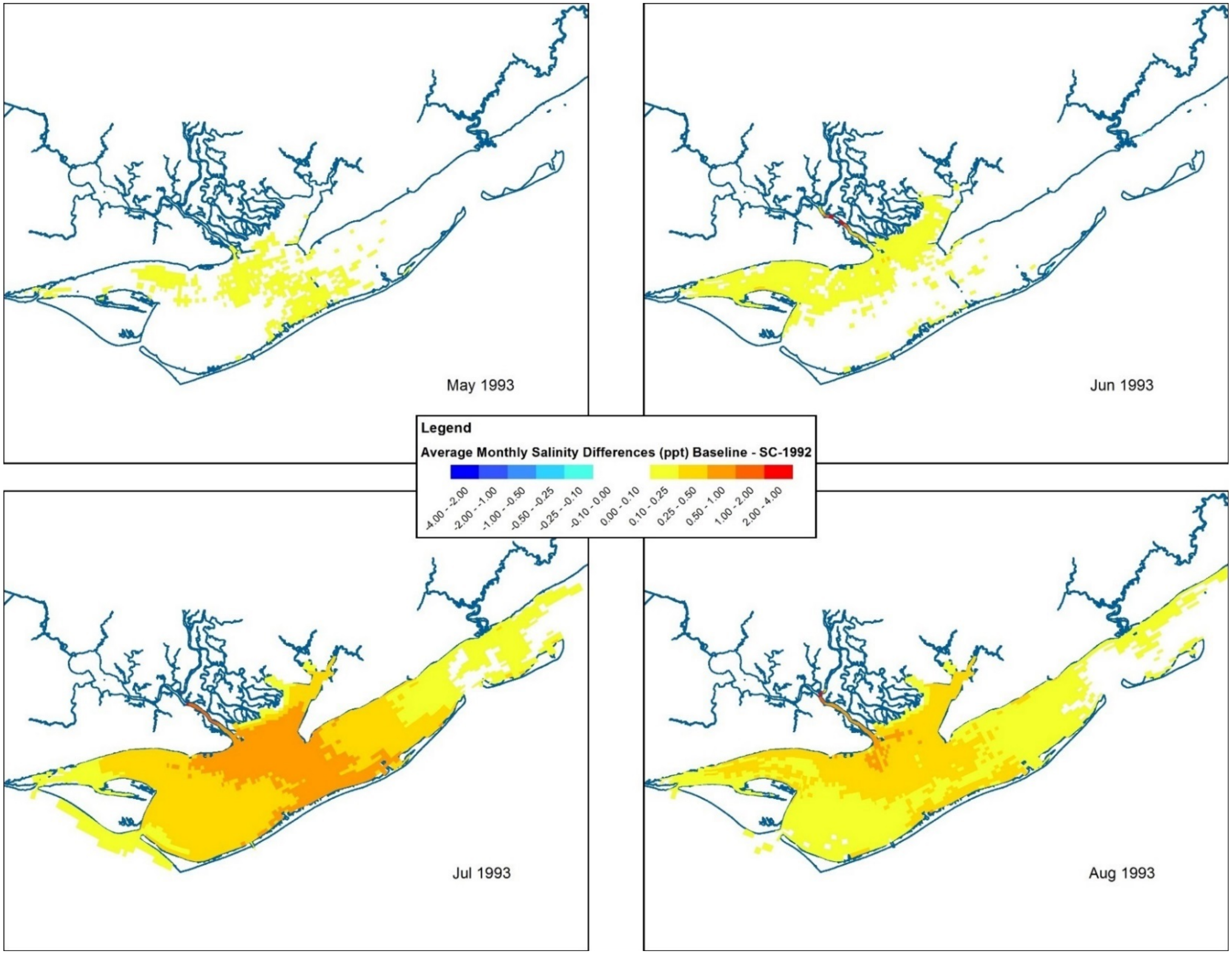
32. Salinities at other locations in the Bay showed similar small differences, proportional to their distance from the Apalachicola River mouth and subject to the upper limit of Gulf salinity plus evaporation effects.

33. Another way to compare the scenarios is to use a map that shows the differences between different scenarios. McAnally Dem. 3 displays color contours representing monthly average salinity differences between the 2011 Baseline Scenario and Scenario 1992 for four months in 1993. The largest differences occur in July and August with a maximum difference of less than 1 psu.

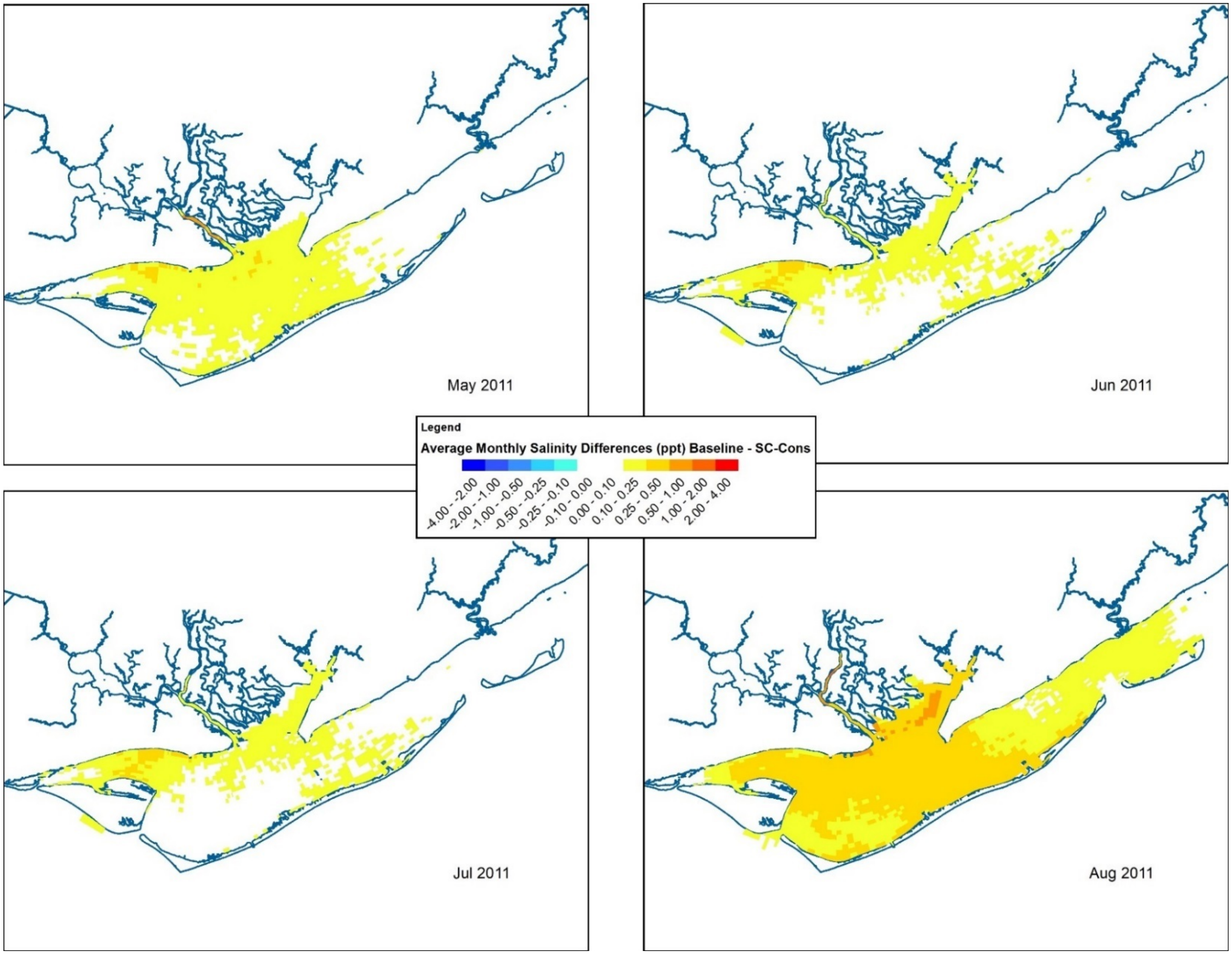
34. If upstream conservation measures increase Apalachicola River peak summer stream flows by 1,000 cfs (Conservation Scenario), the impact on salinity compared with Baseline will be less than 1 psu. For example, McAnally Dem. 4 shows the difference between salinity values for the 2011 scenario and those for the Conservation Scenario for four months in drought year 2011.



McAnally Dem. 2: Cumulative frequency distribution of salinity near the bottom of the water column at Cat Point for freshwater flow scenarios applied to 2010 – 2011. (Expert Report of Dr. William H. McAnally, Fig. 2)



McAnally Dem. 3: Example Salinity Differences Between Baseline (2011 Consumption) and 1992 Consumption (Expert Report of Dr. William H. McAnally, Fig. 149 in Appendix D)



McAnally Dem. 4: Comparison Between Baseline (2011 Consumption) with Proposed 1,000 cfs Remedy (Expert Report of Dr. William H. McAnally, Fig. 175 in Appendix D.)

35. In August increasing summer stream flows by 1,000 cfs decreases Bay salinity by less than about 1 psu. Some localized differences among the Scenarios are greater than the representative results shown here but they do not constitute a pattern of substantial effects.

II. Statistical Model Analysis

36. The results of my alternate method—a statistical model—produced salinity difference projections similar (within ±1 percent) to the physics-based numerical model results. The fact that the statistical model results are so close to my physic-based modeling results provides support for the validity of both since they were generated by different methods.

A. Calculating Statistical Relationships

37. The statistical model relies on observed data from various variables in the Apalachicola Bay area and employs mathematics to analyze the relationship between those variables. The methods I used – multiple regression and spectral analyses – are standard methods in coastal engineering and other fields. I have published reports on their application, including their use in analyzing estuarine salinities.

38. For this analysis, the observed variables included Apalachicola River discharge as measured at the Sumatra Gage, wind as measured at East Bay, tide as measured at the NOAA Apalachicola station, and salinity as measured at East Bay, Dry Bar, and Cat Point, shown in McAnally Dem. 5.[9]

B. Basic Statistics

39. McAnally Dem. 6 shows basic statistical measures for the data sets over the period 2002-2014, which was the common period available for all of the data in the table. Six-minute interval tidal data were converted to diurnal tide range – the distance between daily high waterand low water – and mid-tide level (MTL) – the average of daily high and low waters – before analysis. MTL is a daily time series; therefore, it is not an exact surrogate for mean sea

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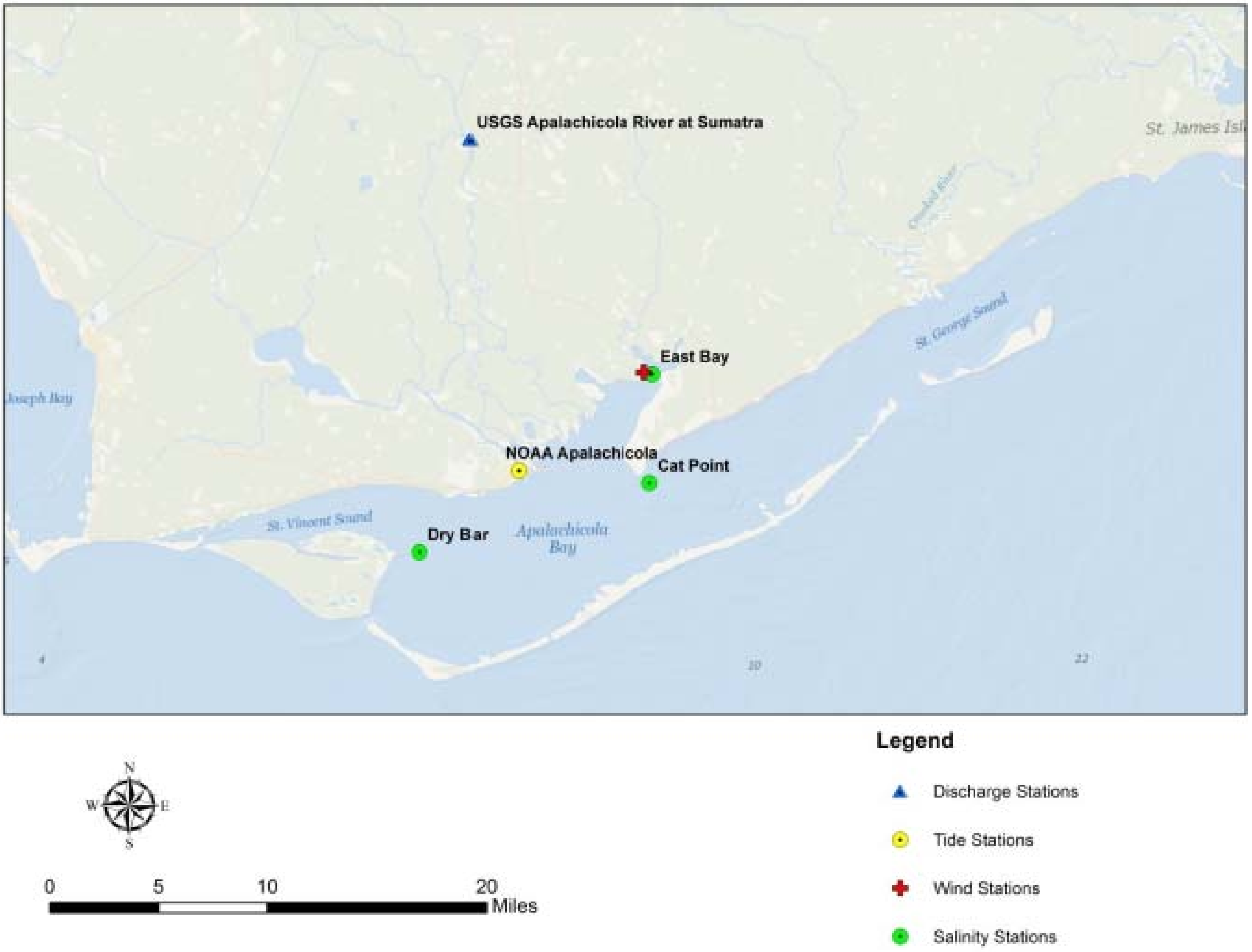
[9] Source data includes: GX1003 (Central Data Management Office, National Estuarine Research Reserve Program, 2015); JX127 (NOAA data found at http://tidesandcurrents.noaa.gov/); and JX-128 (USGS surface water discharge).

level; however, its trend follows mean sea level and is employed below as representing the rate of change in Gulf of Mexico levels.



McAnally Dem. 5: Map of Apalachicola Bay and Data Stations (Expert Report of William McAnally, Fig. 4 in Appendix C.

Parameter	Units	Number of Points	Missing Data		Statistical Measure on Daily Values			
			Number	Percent	Average Value	Maximum Value	Minimum Value	Standard Deviation
River Discharge	cfs	8401	0	0	20,106	166,000	4,400	16,600
Wind Magnitude	m/sec	449,515	13,597	3%	2.8	22.2	0	1.7
Wind Direction	deg N	449,515	13,597	3%	169	360	0	115
Tide Range	m	4746	0	0%	0.52	1.89	0	0.13
Mid-Tide Level	m	4746	0	0%	0.05	1.30	-0.54	0.15
Salinity Dry Bar	psu	389,871	16,969	4%	21.5	39	0.1	7.5
Salinity Cat Point	psu	369,089	12,285	3%	21.6	38	0.1	7.5
Salinity East Bay Surface	psu	369,049	12,851	4%	9.8	34.4	0	7.4
Salinity East Bay Bottom*	psu	345,471	74,969	22%	--	--	--	--
Temperature Dry Bar	deg C	372,992	16,879	4%	22.3	34.5	2.8	6.4
Temperature Cat Point	deg C	376,204	13,562	4%	22.4	34.2	5.8	6.5
Temperature East Bay Surface	deg C	373,911	15,960	4%	22.7	34.9	-1.2	6.4
Temperature East Bay Bottom	deg C	370,603	19,268	5%	23.0	34.4	3.7	6.4
DO Dry Bar	mg/l	365,066	24,805	7%	7.4	20.5	0.1	1.8
DO Cat Point	mg/l	348,218	41,563	12%	7.1	15.2	0.1	1.7
DO East Bay Surface	mg/l	352,740	37,131	10%	6.7	41.5	0	2.9
DO East Bay Bottom*	mg/l	318,263	71,608	22%	--	--	--	--

McAnally Dem. 6: Basic Statistics for Data Stations
(Expert Report of William McAnally, Table 5 in Appendix C.)

C. Spectral Analysis

40. Spectral analysis is a mathematical technique used to examine time series data, such as Apalachicola Bay daily average salinities over several years, by transforming them into the frequency domain (cycles per day) for analysis. Auto- and cross-covariances and their frequency spectra were calculated between each assumed independent process – river discharge, wind (north-south and east-west components), tide range, and mid-tide level (MTL) – paired with dependent salinity at each station – Dry Bar, Cat Point, and East Bay (surface). These statistical methods are mathematically sophisticated, yet standard tools in coastal engineering. I have found them useful in previous studies to better understand the relationships between the observed variables such as freshwater discharge, sea level, and salinity. I did not use the spectral analysis results directly; rather, I used them to inform the statistical analyses used in the Daily Value Model, described below.

D. Daily Value Model

41. I used the results of the spectral analyses to design a statistical model of daily average salinity at the representative locations of East Bay, Cat Point, and Dry Bar. Using multiple linear and non-linear regressions the model estimates salinity at each of those stations from specified inputs of Apalachicola River discharge, mid-tide-level, and wind speed and direction. The statistical model displayed a high degree of correlation with 10 to 20 years of observed data, and I consider it to be a good estimator of future salinities when used in combination with the physics-based EFDC model. Detailed results from my statistical analysis are given in Appendix C of my expert report (GX-0871).

E. Results of Statistical Model Analysis

42. Flow-specific projections were calculated for the 1992 through 2011 period using the daily value model for three scenarios, all based on Dr. Phillip Bedient's HEC ResSim simulation of Apalachicola River discharge at Sumatra. The three scenarios consisted of: (1) a Baseline, in which consumptive use quantities were set equal to those of 2011, (2) Scenario 2040, in which consumptive use quantities were specified to be a projected 2040 condition, and (3) Scenario 1992, which consumptive use quantities were reduced to those occurring in 1992.

43. McAnally Dem. 7 shows estimated change statistics using the daily values model. For the 20-year period average daily salinity changes ranged from 0 to -0.6 psu with a two-standard-deviation scatter of ±0.4 to ±1.2 psu.

F. Comparison with Physics-Based Model

44. I compared the salinity changes calculated by the daily values model for the three flow scenarios with those from the EFDC model. Results are shown in McAnally Dem. 8 for 2010-2011. They demonstrate that the individual daily value model average absolute results differ from the more rigorous EFDC numerical model results by as much as 22% because the daily value model simulations neglected wind and tidal effects. But when I isolate the impact of flow on salinity by comparing each scenario to the 2011 baseline (Base-to Plan) those relative results are within ±1% for this period and these locations, falling well within expected uncertainty bounds.

IMPACT OF SEA LEVEL RISE ON SALINITY OF APALACHICOLA BAY

I. Estimated Sea Level Rise

45. Sea level change research lies at the intersection of climatology and coastal/oceanographic engineering. Sea level rise is a topic of interest to coastal engineers, because sea level changes affect most coastal projects, particularly those for flood damage reduction and coastal protection. My graduate coursework included evaluation of sea level changes and their effects on coastal systems. I performed sea level change analyses for the Corps of Engineers, particularly in coastal Louisiana, and taught them to my students at Mississippi State University. I consider myself qualified to read, evaluate, and apply the scientific literature on the subject.

46. Climate change-induced sea level rise consists principally of two components – thermal expansion of sea water and melting/launching of land-based glaciers. As modeling of glacial melting has improved, it has taken on a larger role in projected sea level rise, with the latest International Panel on Climate Change report (IPCC 2013[10]) increasing previous sea level

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[10] Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor,

rise rate predictions because of greater Greenland ice sheet melting than previously estimated. Still more recent research reported in the literature (e.g. DeConto and Pollard 2016[11]) suggests that the IPCC has also underestimated the contribution of the West Antarctic ice sheet. I believe that the next updating of the IPCC estimates of sea level rise will be higher than the 2013 report.

S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp. (FLEX 339)

[11] Robert M. DeConto and David Pollard, 2016. Contribution of Antarctica to past and future sea-level rise, NATURE, VOL 531, April, 591-597. (GX0861)

Location	1992-2011		Jul-Sep 1992-2011		Parameter
	Scenario 2040	Scenario 1992	Scenario 2040	Scenario 1992	
Dry Bar	0.0	-0.3	0.0	-0.4	Average
	4.2	3.1	1.2	0.0	Maximum
	-1.2	-3.5	-0.4	-1.7	Minimum
	0.3	0.4	0.1	0.3	Standard Deviation
Cat Point	0.0	-0.3	0.0	-0.5	Average
	4.9	3.7	1.4	0.0	Maximum
	-1.4	-4.0	-0.5	-2.1	Minimum
	0.3	0.4	0.2	0.3	Standard Deviation
East Bay	0.0	-0.3	0.0	-0.6	Average
	6.3	4.7	1.6	0.0	Maximum
	-1.7	-4.8	-0.7	-3.2	Minimum
	0.4	0.6	0.2	0.4	Standard Deviation

* NOTE: Positive values indicate that the Scenario salinity is higher than Baseline

McAnally Dem. 7: Statistical Model Results for Scenario Salinity Changes from Baseline. (Expert Report of William McAnally, Table 7 in Appendix C.)

Location	Salinity, psu					
	SC Baseline		SC 2040		SC 1992	
	EFDC	DVM Q	EFDC	DVM Q	EFDC	DVM Q
Cat Point	19.9	22.2	19.9	22.2	19.8	21.9
Dry Bar	19.8	24.1	19.8	24.2	19.7	24.0
East Bay	9.8	11.4	9.9	11.5	9.7	11.2

	Differences Between Models, %				
	Absolute Models Difference	Absolute Models Difference	Base-to-Plan Change	Absolute Models Difference	Base-to-Plan Change
Cat Point	-12%	-12%	0%	-11%	-1%
Dry Bar	-22%	-22%	1%	-22%	-1%
East Bay	-16%	-16%	1%	-15%	-1%

McAnally Dem. 8: Comparison of Statistical Model with Physics-Based Model Scenario Results. (Expert Report of William McAnally, Table 8 in Appendix C.)

47. Sea level rise has increased salinities in Apalachicola Bay since at least 2002. It will have an increasing effect on future Bay salinities. I project sea level rise-induced salinity increases of 0.3 to 4 psu (±30%) by 2040 at central Bay locations if river flows are unchanged. An accelerated rate of sea level rise is possible, with a correspondingly greater increase in salinity.

48. Both NOAA and the Corps of Engineers recommend that a range of sea level scenarios be used in coastal planning and design and their tools provide low, medium, and high projections for Apalachicola Bay. McAnally Dem. 9 shows the highest and lowest of those projections, which are based on those agencies' analyses of historical data at Apalachicola Bay.[12] My assessment of the literature indicates that the actual rise is more likely to be closer to the High Projection than the Low Projection and may be even higher than the High Projection, due in part to rising estimates of glacial melting. NOAA is a reliable source for sea level rise projections because it is the United States agency responsible for official climate and sea level projections. (JX-061) The Corps of Engineers is a reliable source for sea level rise projections because it is the United States government lead on coastal engineering, including sea level rise, and they have worked closely with NOAA to develop these tools. NOAA and the Corps analyzed historical sea level data at Apalachicola and applied procedures developed by the National Academy of Sciences to project those data into the future. I consider them to be the authoritative source for official U.S. government projections of future sea level.

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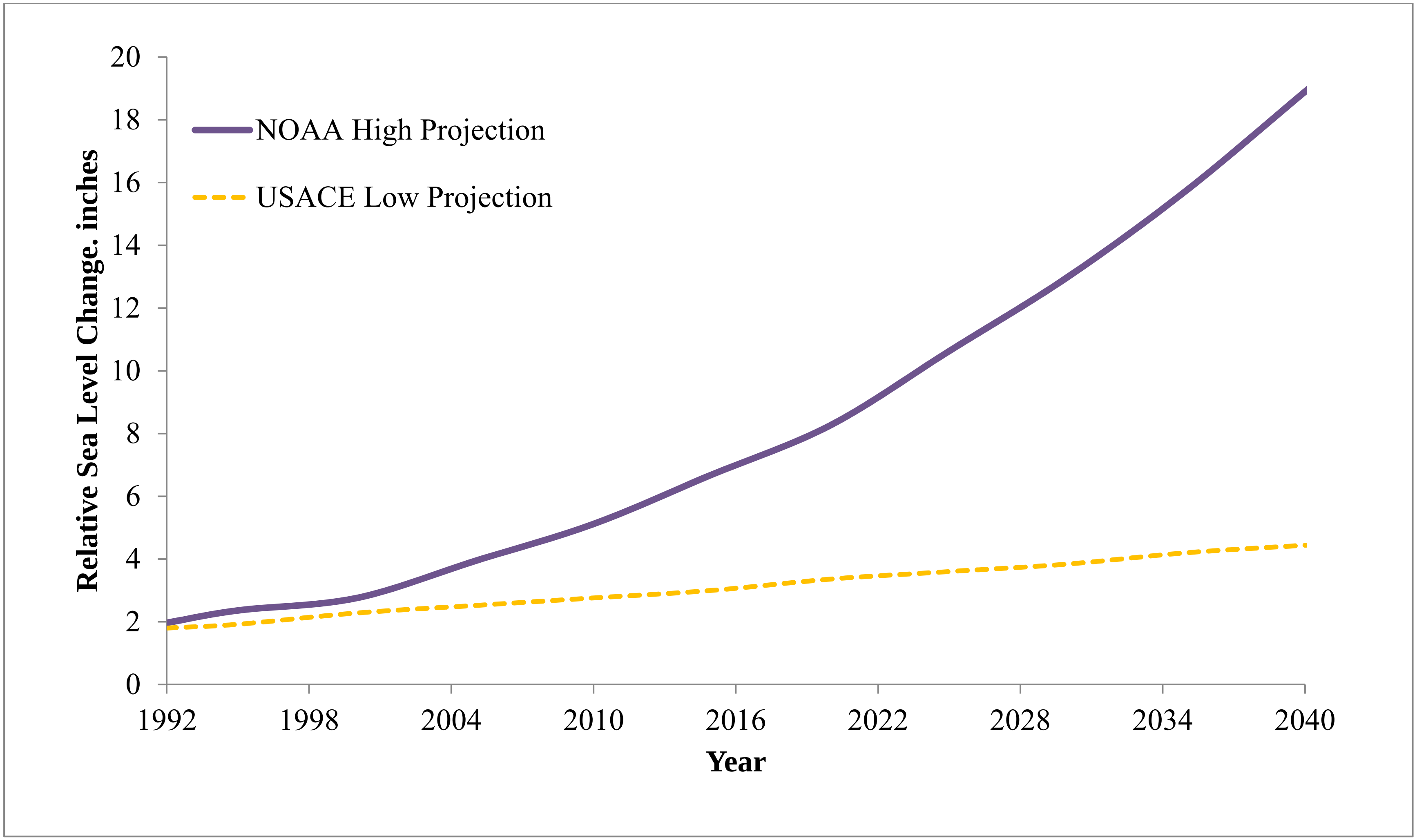
[12] These projections are based on a tool maintained by the Army Corps for location-specific sea level rise projections. (JX116).



McAnally Dem. 9: NOAA and Corps of Engineers Sea Level Projections. (Expert Report of William McAnally, Figure 3.)

II. Impact on Apalachicola Bay

49. The statistical analyses of observed data (using the most nearly complete salinity data set of 2002 – 2014 and other data) show that sea level rose about 3 inches from 2002 – 2014 and positively correlated with salinity increases. My physics-based modeling shows that there is a cause-and-effect relationship between sea level and salinity. Both methods show that sea level rise has already caused a salinity increase of about 0.6 psu (±0.2 psu) in Apalachicola Bay during that same period.

50. My interpretation of these results, the EFDC tests described below, and the literature indicate that salinity will continue to increase with rising future sea level. McAnally Dem. 10 illustrates how the sea level in McAnally Dem. 9 is projected to change salinity according to the daily value statistics-based model described above.

51. Dr. Douglass has opined that geomorphic changes such as narrowing of passes into the Bay may negate the impact of sea level rise (SLR) on salinity. In order to quantify the effects of sea level rise with a hypothetical narrowing of pass size, three test cases were run in the EFDC model for 2010 – 2011 observed river flows and tides:

a. BASE – no sea level rise (SLR) and no pass (inlet cross-sections) size reduction

b. SLR, no pass size reduction

c. SLR, with pass size reduction

52. To simulate the geomorphic changes of the passes for case c, I used assumptions taken from the report submitted by Dr. Douglass[13] which states:

> The effect of SLR on the size of the tidal inlets of Indian Pass, West Pass, and Sikes Cut will likely be minimal… East Pass has been closing down throughout the history of good shoreline surveying (the past 160 years). As mentioned above, it has narrowed about 8,000 feet (1.5 miles) since 1856… continue to gradually close down East Pass during the next century even as sea levels rise. Also, the NE end of Dog Island has been growing to

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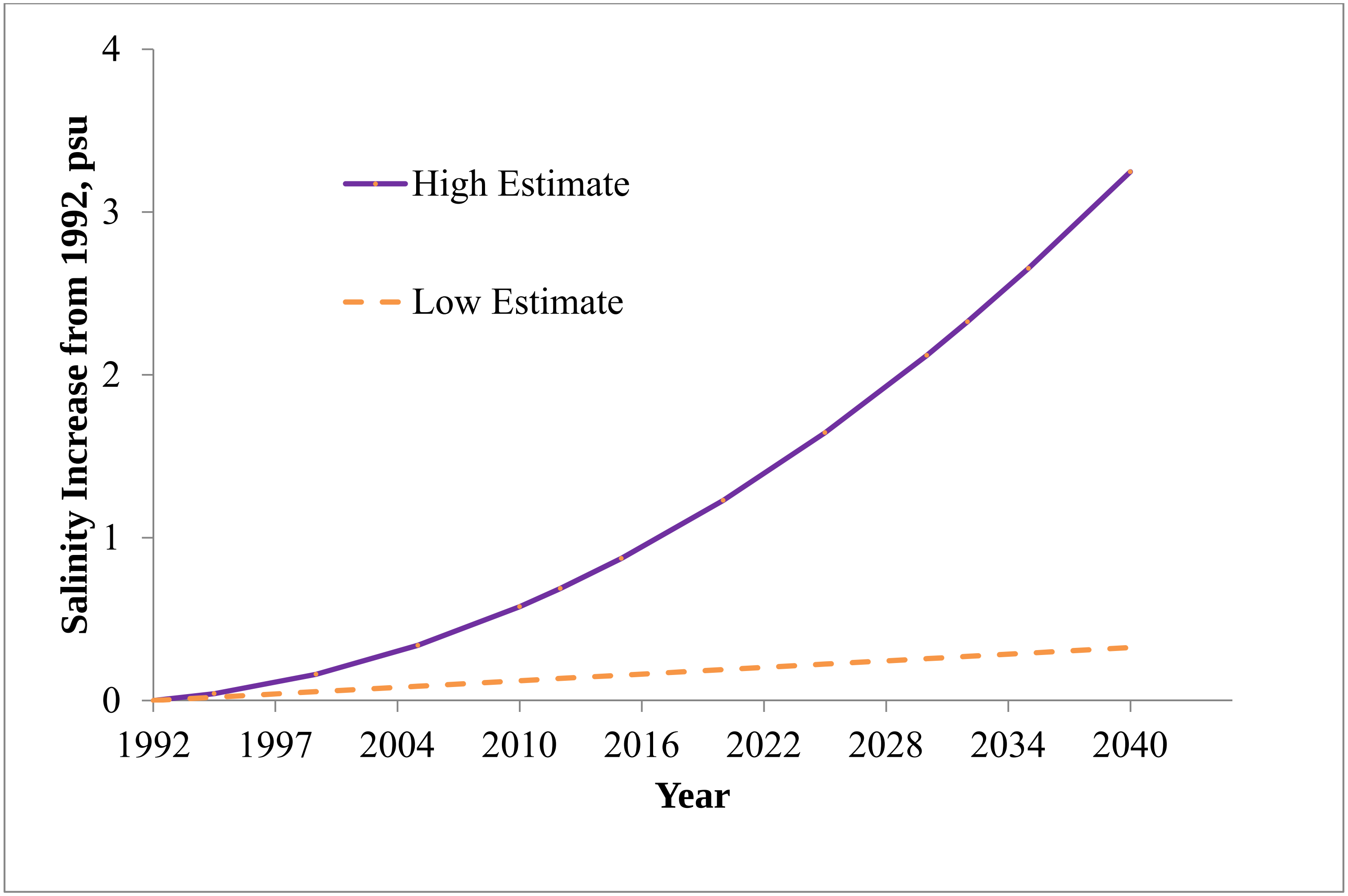
[13] FX-788

the NE for the last 160 years and this northern migration will likely continue as described…”



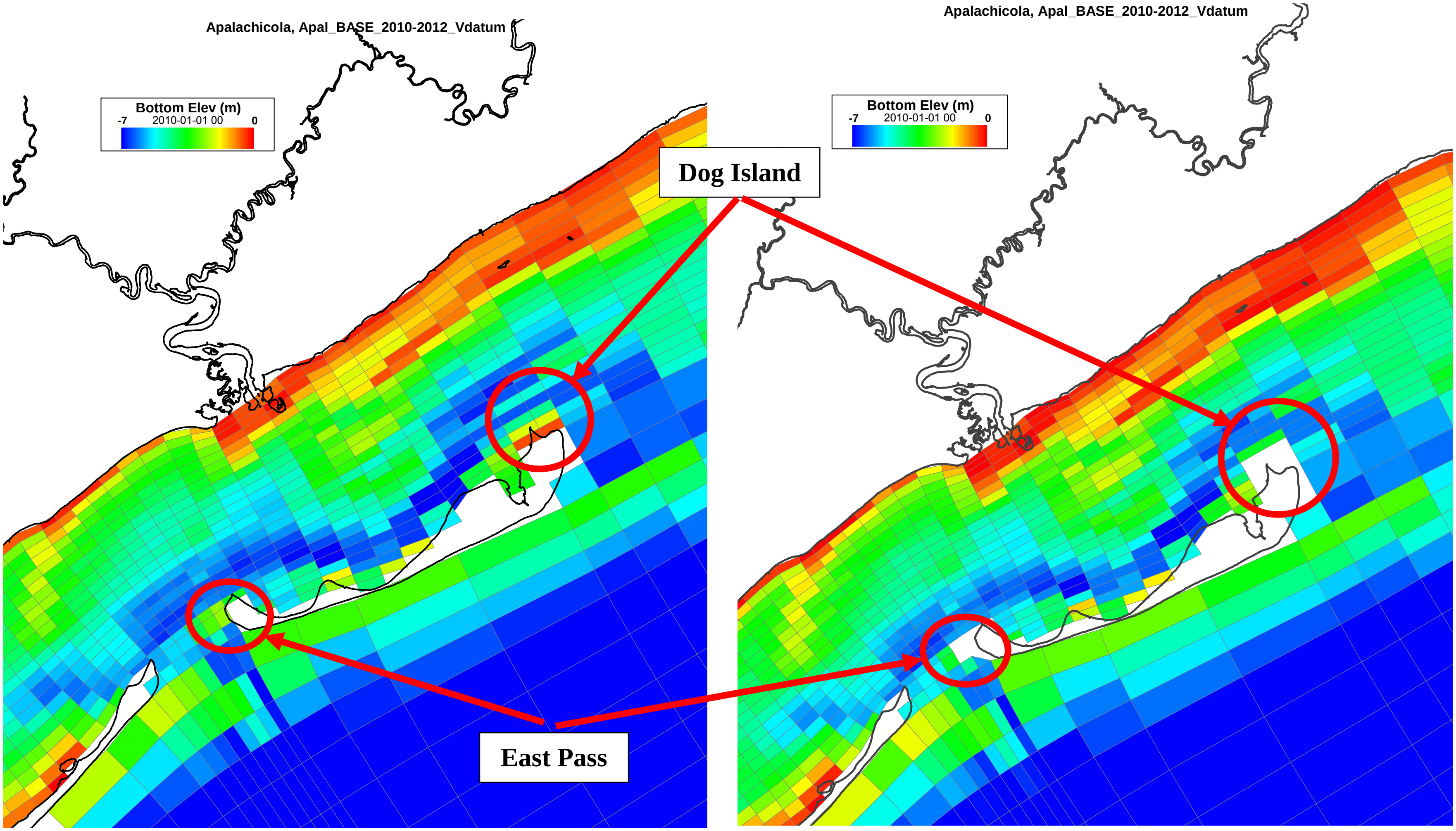
McAnally Dem. 10: Statistical Model Projections of Salinity Increase from Sea Level Rise Projections by Federal Agencies. (Expert Report of William McAnally, Figure 4.)

53. The rate of narrowing of East Pass and Dog Island can be calculated from Dr. Douglass' findings to be approximately 15.2 m/year, which would result in these passes being approximately 760 meters narrower in 50 years' time. I modified East Pass and Dog Island in the EFDC model to represent that cross-sectional area decrease as detailed in McAnally Dem. 11. Douglass states that changes to Indian Pass, West Pass, and Sikes cut would be minimal, so those passes were not altered in the model.

54. The model was run with 0.26 meters (10 in) of sea level rise, which approximately corresponds to an intermediate rate for year 2040 on McAnally Dem. 9. Sea level rise will also push Bay mainland shorelines inland and increase salinities in Apalachicola Bay, but that effect could not be modeled without extensive grid modifications and associated sensitivity testing, so it was omitted. McAnally Dem. 12 shows annual average salinity as calculated by EFDC at seven points in the Bay for the three test cases. Case b (SLR, no geomorphic changes) produced significant changes in salinity in the Bay with annual average salinity differences ranging from 0.8 to 2.3 psu (±30%).

55. For case c (SLR, with pass narrowing), salinities were essentially the same as case b, where I modeled sea level rise alone. The maximum difference was 0.1 psu. This indicates that the width of East and Dog Island passes is not a controlling factor for salinity transport into the Bay under the range of conditions tested. In other words, even if the passes narrow as predicted by Dr. Douglass, it will not mitigate the impact of SLR on salinity.

56. My findings indicate that SLR will have a significant impact on Apalachicola Bay salinity by 2040. I believe that the SLR-induced increase will be closer to 4 psu than to 1 psu. Given that my results comparing 2040 Scenario with 2011 Baseline show a difference of less than 0.1 psu, I expect that the impact of SLR will overwhelm the impact from consumptive use reflected in the scenarios.



a) No Pass Change

b) With Pass Changes

McAnally Dem. 11: Locations of Morphologic Changes Projected by Dr. Douglass and Modeled with the EFDC Physics-Based Model. (Expert Report of William McAnally, Fig. 183 in Appendix D.)

ID	BASE	SLR, No Geomorphic Change	SLR, With Pass Narrowing
Cat Point	20.0	21.4	21.4
Dry Bar	19.8	20.9	20.9
East Bay	10.0	12.3	12.3
Mid-Bay	19.9	21.4	21.3
Sikes Cut	24.8	25.6	25.6
St. Vincent Sound	19.0	19.8	19.8
St. George Sound	24.6	25.5	25.4

McAnally Dem. 12: Effects of Pass Cross-Sectional Area Decreases on Sea Level Rise.
(Expert Report of William McAnally, Table 32 in Appendix D.)

IMPACT OF APALACHICOLA RIVER FLOWS ON DISSOLVED OXYGEN

57. I also analyzed the impact of fresh water flows on dissolved oxygen. The flow variations among the four analyzed scenarios do not significantly affect dissolved oxygen in Apalachicola Bay.

58. Dissolved oxygen concentrations in water serve as a useful water quality marker in that they are a consequence of interactions among nutrient supply, biological activity, organic material, temperature, and circulation, among other factors. Some of these constituents in Apalachicola Bay are delivered by upstream flows and also by local drainage, particularly from Tates Hell swamp and the community of East Point, Florida. Biological activity and chemical reactions within the Bay then both produce and consume dissolved oxygen. Thus dissolved oxygen concentrations in the Bay are potentially affected by all the processes that contribute to salinity plus many more.

59. The EFDC physics-based model showed that Scenarios 1992, 2040, and Conservation flows do not have a significant effect on dissolved oxygen compared with the Baseline (Scenario 2011). The numerical model indicates a trivial difference (less than 0.01 mg/l ±24%) in average annual dissolved oxygen among tested scenarios. Similarly, the statistical analysis showed that observed dissolved oxygen at the measurement locations of East Bay, Cat Point, and Dry Bar did not correlate with river discharge, confirming the model results.

UNCERTAINTY AND ERROR CONSIDERATIONS

I. Uncertainty

60. The U.S. National Academy of Sciences recommends uncertainty quantification for all environmental studies. Uncertainty does not represent a flaw in science and engineering. It is a quantification of accuracy and precision which informs decision-making by placing confidence limits, or uncertainty bounds, on results. The U.S. National Academy of Sciences recommends uncertainty quantification for all environmental studies.

61. Factors contributing to uncertainty in model results include errors and random variation in observed data and model error. All observed data contain measurement error. I have assumed a uniform measurement error of ±10 percent in observed data based on my education

and experience. Errors can be larger than that because of instrument drift and fouling plus sample mishandling, but 10% is a reasonable approximation for data collected by capable experts. Manufacturer's stated sensor sensitivity should never be used as an objective error measure as it is based on ideal laboratory conditions, not real-life deployments and environments.

62. Models incur errors through assumptions, numerical approximations and round-off, among others. The best method to define uncertainty bounds in models is to use model validation goodness-of-fit metrics, such as root-mean-square differences between model results and observed data which I have used in my report and here.

63. The combined uncertainty of model and measurement errors are determined by standard joint probability statistical methods.

64. The Base-to-Plan model comparison principle used here declares that relative changes between base and plan results are more accurate than absolute changes. To the extent that uncertainties in both are introduced by the same mechanisms, are comparable in size, and are perhaps self-compensating, as Base and Plan errors tend to cancel each other out. A rule of thumb is that the uncertainty bounds can be estimated for Base-to-Plan comparisons as one-half of the overall uncertainty bounds estimated from model and measurement uncertainty. My models used here are expected to exhibit uncertainty bounds of ±30% in absolute magnitudes and ±15% in Base-to-Plan differences. These values are typical of model uncertainty bounds for salinity predictions that I have encountered.

II. Accounting for possible errors

65. I understand that questions have been raised about possible errors in the U.S. Geological Survey's discharge data at Sumatra and the potential for such errors to affect Dr. Bedient's flow modeling and my Bay modeling. If any errors in measured discharge or Dr. Bedient's discharge results are within ±10 percent, then my existing uncertainty bounds have already accounted for them and my results will not be affected. If errors larger than that are demonstrated, I can recalculate my uncertainty bounds and determine if any conclusions should be revised.

CRITIQUES OF FLORIDA'S EXPERT ANALYSES

I. Criticisms of Dr. Greenblatt's Analysis

66. Dr. Greenblatt's two flow scenario findings are qualitatively consistent with mine to the extent that salinity differences between her two flow scenarios, called "Remedy" and "Future Withdrawals," are relatively small.

67. Dr. Greenblatt misrepresents my critique of her modeling by saying that I questioned the validity of her model. I did not. I said that her model testing was incomplete because she skipped standard and customary steps, including providing uncertainty bounds on results.

68. Dr. Greenblatt's report lacks the standard and customary disclosure of an explicit statement of the model's uncertainty bounds. I am surprised that she stated in her Direct Testimony (¶ 37), "Such a study is rarely performed in practice in my field." Uncertainty bounds analyses are common in hydraulic studies such as this one and have been labeled as necessary elements since at least 2009 by the National Academy of Sciences[14] and Environmental Protection Agency.[15] They represent good modeling practice, and their omission is a serious deficiency in Dr. Greenblatt's report and testimony.

69. Dr. Greenblatt is mistaken in stating that, "sea level rise will not have a discernable effect on salinity in Apalachicola Bay." Direct Testimony of M. Greenblatt, ¶ 33. I used two different methods to establish that sea level has a significant effect on salinity in Apalachicola Bay and will further increase it in the future. She did not run any model simulations of sea level rise, therefore her statement is speculative and not an evidence-based conclusion.

70. Dr. Greenblatt makes several mistakes in her Direct Testimony, ¶ 38-41, specifically:

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[14] NAS, 2012. Assessing the Reliability of Complex Models. U.S. National Academy of Science, National Academies Press, Washington DC.

[15] Op cit.

71. She erroneously states that I did not offer a correlation coefficient to demonstrate the strength of the mathematical relationship in my statistical model. Table 6 in Appendix C of my report provides correlation coefficients for the statistical model. I also provided data files containing all the subsidiary calculations, including correlation coefficients.

72. She states that my analyses show correlation but she erroneously claims that it fails to show cause-and-effect. My dual approach to the question proves both correlation (the statistical model) and cause-and-effect (the physics-based EFDC model.)

73. She says that my report "admits" that the flow-only version of my statistical model is a reasonable approximation of salinity but fails to include the rest of the pertinent sentence – "… provided due caution is exercised." (Page C-24 of my report.) One of those due cautions is holding sea level constant, which the flow-only statistical model does.

74. Dr. Greenblatt is partly correct when she says my physics-based model simulations do not include <u>all</u> the complex responses of the Bay to sea level rise. She cites sedimentation and pass depth changes but fails to mention landward migration of the shoreline and breaching of the barrier islands, both of which have been observed elsewhere and would certainly cause increased central Apalachicola Bay salinity. I simulated one of those responses – migration of barrier islands, the one most likely to offset salinity – with the physics-based EFDC model and found that Dr. Douglass' projected island migration did not offset sea-level induced salinity increases.

II. Criticisms of Dr. Douglass' Analysis

75. Dr. Douglass' morphological analyses appear to be sound for the relatively low rate of sea level rise that he assumes; however, he then goes beyond those analyses to speculate about salinity effects without any modeling and without any calculations. In contrast, I performed both modeling and statistical analyses to generate quantitative results showing salinity increases. I produced an evidence-based conclusion that sea level rise has already caused salinity increases in Apalachicola Bay and will continue to do so in the next few decades.

76. Dr. Douglass' report (FX-788) and testimony showed that he is aware of other, higher estimated sea level rise rates than the single value he used in his analyses; however, his

estimates of morphological change were based on a world-wide sea level rise projected by the IPCC[16], not one specific to Apalachicola Bay. He did not follow U.S. Army Corps of Engineers and National Oceanic and Atmospheric Administration guidelines, which specify that a range of sea level rise rates should be used in all important analyses, nor did he use their readily available specific estimates of projected Apalachicola sea level rise. (JX116)

77. Dr. Douglass' Direct Testimony (¶ 19) falsely states, "Based on tide gage measurements, the rate of sea-level rise in the Bay does not appear to be accelerating. The tide gage at Apalachicola has measured an average rate of rise of 1.96 mm/year over the past 40 years." McAnally Dem. 13 (from the NOAA web site he cites) clearly shows that sea level rise at Apalachicola accelerated from 1.38 mm/yr prior to 2006 to 1.96 mm/yr in 2015.

78. Dr. Douglass testified that barrier island sedimentation processes and historical data indicate that St. George and Dog islands will migrate shoreward in the future. He further testified that tidal exchange between the Gulf and Apalachicola Bay will "likely" be reduced over the next century by reduction of East Pass and Dog Island Pass cross-sectional areas. Dr. Douglass made no calculations to test how his hypothetical narrowing of passes would impact salinity; whereas, I tested his projection by modeling the impact of such changes on salinity. I found that even if the passes' cross-sectional areas decrease as predicted by Dr. Douglass, tides and salinity in central areas of the Bay will be largely unaffected and sea level rise will still increase average salinity in the central Bay.

79. Dr. Douglass faults my modeling for not changing the depths in East Pass and Dog Island Pass. Yet, tidal hydraulics experts know that "form" energy losses (caused by eddies swirling behind the barrier islands) are much larger than the frictional energy losses (caused by the bed's drag on water flowing through the pass throat) that Dr. Douglass cites. Thus, my reduction of the passes' cross-section is a more stringent constraint on tides than are the depth changes Dr. Douglass now suggests.

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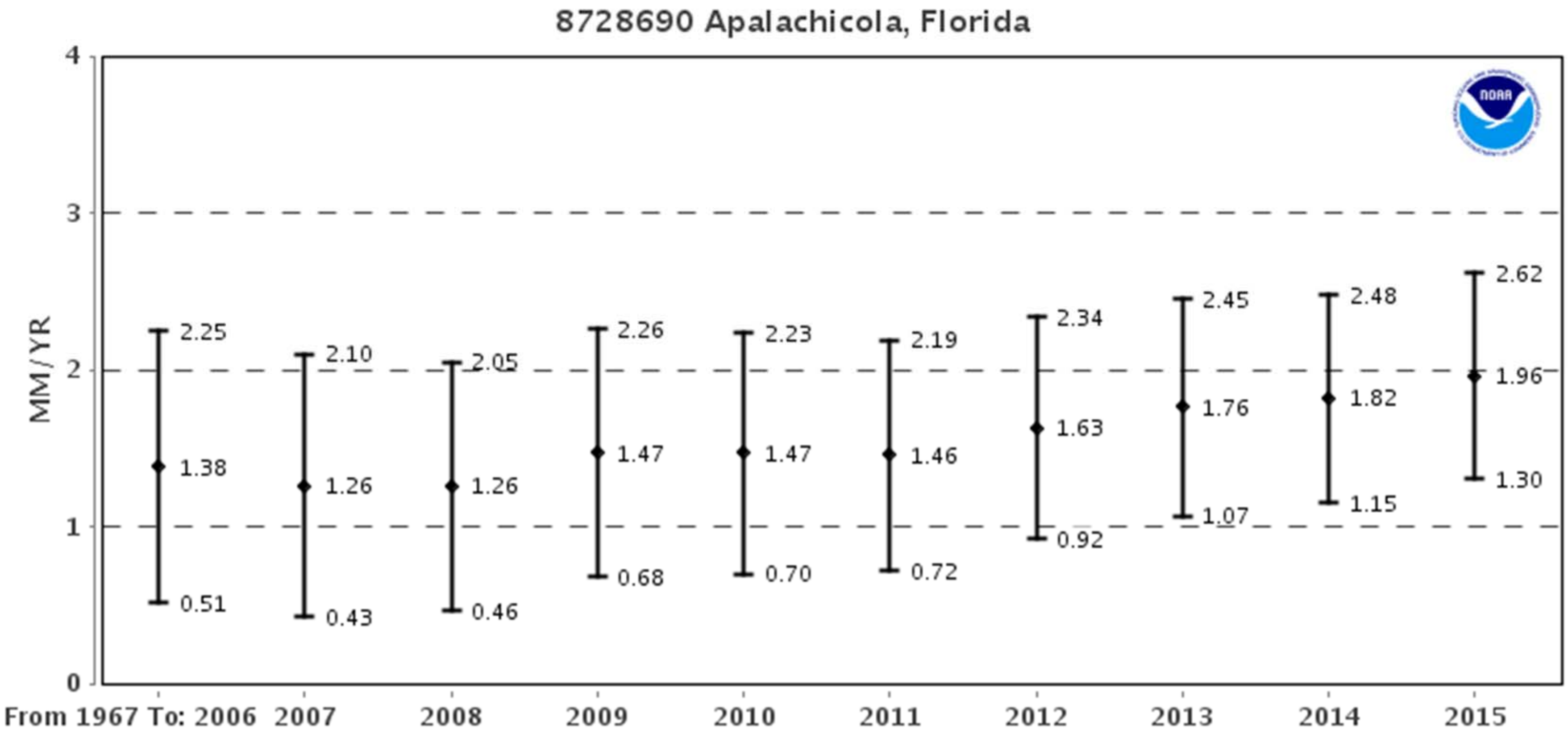
[16] Op cit.



McAnally Dem. 13: Accelerating Rates of Sea Level Rise at Apalachicola Bay according to NOAA[17]

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[17] Copied from "Previous Mean Sea Level Trends, Apalachicola, Florida." National Oceanic and Atmospheric Administration, http://tidesandcurrents.noaa.gov/sltrends/sltrends_update.htm?stnid=8728690. Accessed 22 October 2016. (JX-127)

80. Dr. Douglass provides no quantitative analysis to support his opinion that sedimentation may partially offset the impact of sea level rise on salinity in the Bay. He has not conducted analyses on the likely future rate of sedimentation or the extent to which that might actually offset the impact of sea level rise. My experience in similar Gulf of Mexico estuaries indicates that even if sedimentation rates in the Bay continued at or near historical rates, the sedimentation will occur primarily near the mouth of the Apalachicola River and will not offset central Bay salinity increases from sea level rise.

81. Of the major hydrodynamic and morphological responses to sea level rise – certain landward migration of the shoreline, possible barrier island breaching, probable morphologic migration of the barrier islands, and probable Bay sedimentation – the first two would cause central Bay salinity to increase, the third I have shown to have inconsequential salinity effects, and the fourth has been shown by my statistical analyses to be non-offsetting. For these reasons, it is evident that sea level rise will most certainly cause central Apalachicola Bay salinities to increase and that arguments to the contrary by Drs. Douglass and Greenblatt are contrived and specious.

82. Dr. Douglass' direct testimony makes a number of disparaging comments about my modeling. His comments indicate a lack of understanding of salinity modeling in general and my analyses in particular. I modeled one of the several possible morphological effects of sea level rise – the one most likely to mitigate a salinity increase – and found that it did not have the effect Dr. Douglass thought "likely." While it would be satisfying to model all the processes, my analyses provide ample quantitative evidence, which, in combination with my extensive experience in modeling and analyses of estuarine salinity, supports a firm conclusion that sea level rise has caused, and will continue to cause salinity increases in Apalachicola Bay.

CONCLUSIONS

83. Based on my application of generally accepted methodologies, my review of the data and literature, my experience in similar Gulf of Mexico estuaries, and the evidence from two separate methods of engineering calculations, I have a high degree of scientific certainty in three general conclusions:

84. Apalachicola Bay average dry season salinity will experience very small differences, less than ±1 psu, under the four river discharge scenarios that I examined.

a. Apalachicola Bay dissolved oxygen levels will experience no significant differences caused by the four river discharge scenarios that I examined.

b. In the next few decades, sea level rise will cause Apalachicola Bay average salinity to increase at least as much as, and probably much more than, differences in Apalachicola Bay freshwater flows caused by the four flow scenarios.

LIST OF EXHIBITS CITED

- JX-061: NOAA. Global Sea Level Rise Scenarios for the United States. In: NOAA Technical Report OAR CPO-1, National Climate Assessment, Climate Program Office (CPO), Silver Spring, Maryland.

- JX-116: This is a tool created by National Oceanic and Atmospheric Administration (NOAA) and the United States Army Corps to estimate location-specific sea level rise projection. Experts in my field recognize that NOAA and the United States Army Corps are a reliable source for this type of information. This tool is frequently relied upon by other experts in my field, and I relied on it to inform my opinions.

- JX-127: This exhibit is a true and accurate copy of information collected by NOAA. Experts in my field recognize that NOAA is a reliable source for this type of information. I relied on this data to support a number of opinions in this case. Experts in my field rely on this type of data and I relied upon it to inform my opinions in this case.

- JX-128: This exhibit is an online database maintained by the USGS. I utilized data obtained from this database. Experts in my field recognize the USGS as a reliable source for this type of information. Such data is typically relied upon by experts in my field, and I relied upon them to inform my opinions.

- GX-0787: This is a true and accurate copy of NOAA. National Geophysical Data Center, U.S. Coastal Relief Model, (http://www.ngdc.noaa.gov/mgg/coastal/crm.html). Experts in my field recognize that NOAA is a reliable source for this type of information. I utilized data obtained from this source. Such data is typically relied upon by experts in my field, and I relied upon them to inform my opinions.

- GX-0788: This is a true and accurate copy of NOAA. Shoreline Data Explorer, NOAA, NGS (http://www.ngs.noaa.gov/RSD/shore_data/NGS_Shoreline_Products.htm). Experts in my field recognize that NOAA is a reliable source for this type of information. Such data is typically relied upon by experts in my field, and I relied upon them to inform my opinions.

- GX-0861: This is a true and accurate copy of Robert M. DeConto and David Pollard, 2016. Contribution of Antarctica to past and future sea-level rise, NATURE, VOL 531, April, 591-597. Experts in my field typically rely on such reports, and I relied upon in to inform my opinions.

- GX-0871: This is a true and accurate copy of the expert report that I submitted in this case.

- GX-0911: This is a true and accurate copy of outputs I received from Dr. Bedient related to Conservation Scenario.

- GX-1003: This is a true and accurate copy of Central Data Management Office, National Estuarine Research Reserve Program, 2015 (http://cdmo.baruch.sc.edu/mobile/). Such data is typically relied upon by experts in my field, and I relied upon them to inform my opinions.

- GX-1031: This is a true and accurate copy of model outputs that I received from Dr. Bedient related to Baseline (2011), 1992, and 2040 scenarios.

- FX 339: This exhibit is a true and accurate copy of Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.