Historical Freshwater Inflow Alteration and its Potential Effect on Estuarine Biota in Gulf of Mexico Estuaries

Workshop Summary

Pensacola Beach , Florida
March 14-16, 1995

Workshop Staff

National Oceanic and Atmospheric Administration
National Ocean Service
Office of Ocean Resources Conservation and Assessment
Strategic Environmental Assessments Division

1305 East-West Highway SSMC4, 9th Floor
Silver Spring, MD 20910
(301) 713-3000

C. John Klein
Mark Monaco
S. Paul Orlando
Miranda Harris
Susan Holliday
Russell Ives

Gulf of Mexico Program Freshwater Inflow Committee Co-Chairs

Bruce Moulton
Texas Natural Resources Conservation Commission
12100 Park 35 Circle, Building F
Austin, TX 78711-3087
(512) 239-4809

Susan Rees
U.S. Army Corps of Engineers, Planning Division
109 St. Joseph Street
Mobile, AL 36602
(205) 694-4141

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Background

In cooperation with the Freshwater Inflow Committee of the U.S. Environmental Protection Agency's Gulf of Mexico Program (GOMP), NOAA's Strategic Environmental Assessments (SEA) Division convened a workshop from March 14-16, 1995 to identify estuaries to examine important relationships among freshwater inflow alteration, estuarine habitat, and biological resources using information derived from the National Estuarine Inventory (NEI). Twenty-three Gulf scientists and estuarine resource managers participated in the workshop in Pensacola Beach, Florida. The primary goal was to identify and prioritize a subset of Gulf estuaries where freshwater inflow may potentially be managed to restore and/or enhance estuarine resources and habitat. Through a sequenced, consensus-building workshop process, five estuaries were selected that represent high-priority, freshwater-related habitat and resource issues across all Gulf estuaries. Plans are to conduct detailed, site-specific analyses for the five systems through the Freshwater Inflow Committee. This report summarizes the discussions and recommendations of the workshop participants, and provides a point of reference for the continuing evolution of the GOMP Freshwater Inflow Committee's long-term program.

EPA's Gulf of Mexico Program

The Gulf of Mexico Program is a cooperative partnership among Federal, State, and local government agencies, as well as people who use the Gulf. During the early stages of program development, eight priority environmental problems were identified, and the following Issue Committees established to address them: Marine Debris; Public Health; Habitat Degradation; Coastal and Shoreline Erosion; Nutrient Enrichment; Toxic Substances and Pesticides; Freshwater Inflow (FWI); and Living Aquatic Resources. There are important linkages among these issue committees, and the GOMP works to coordinate and integrate their activities accordingly.

The Freshwater Inflow Committee is charged with characterizing the problems associated with alterations to freshwater inflow into the Gulf and identifying appropriate ways to protect living marine resources. In support of this goal, the committee funded NOAA's SEA Division to conduct a workshop to provide a basis for integrating various activities with the other issue committees.

Gulf of Mexico Estuaries

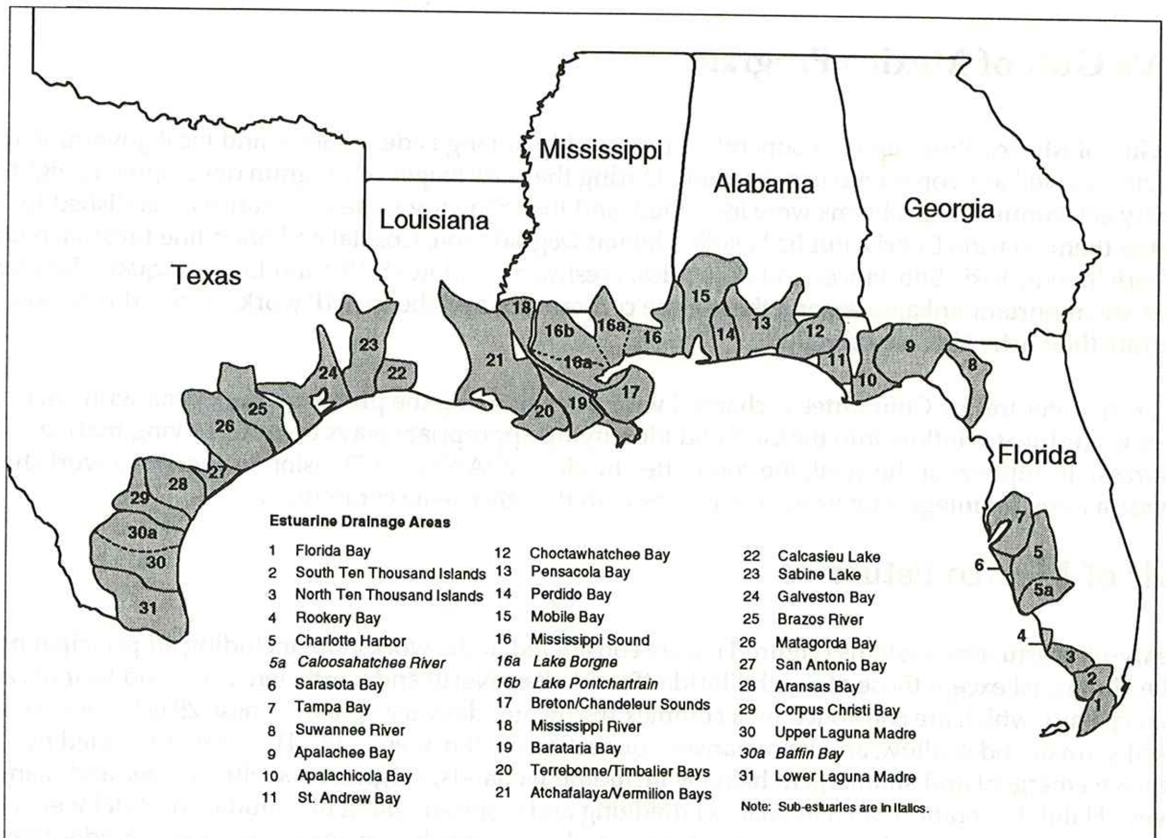
Twenty-nine estuarine systems (Figure 1) were considered at the workshop, including all principal bays of the Gulf coast except those of South Florida (Florida Bay, North and South Ten Thousand Islands, and Rookery Bay), which are controlled by a complex freshwater delivery system. These 29 estuaries are typically small and shallow, and have narrow connections to the open Gulf. They are dominated by extensive emergent and submergent habitats including wetlands, seagrasses, shellfish reefs, and mangroves. Habitat alteration, such as channel dredging and disposal, filling of subtidal and tidal wetlands, inlet stabilization, and freshwater impoundments and diversions has increased in recent decades to meet growing municipal, agricultural, and industrial demands.

Within the region, freshwater inflow volumes range two to three orders of magnitude, from the arid segments of the south Texas coast to the water-rich Mississippi delta. Equally significant is the timing of freshwater delivery to these estuaries, which ranges from seasonal dominance within the central Gulf to isolated, short-duration, high-intensity pulses in central Florida and south Texas. The timing and fluctuation of river flow are further modified by reservoirs, located on most major rivers flowing to Gulf estuaries. The importance of freshwater inflow to salinity and nutrient distributions, habitat, water circulation, and pollutant transport is directly affected by both the volume and timing of freshwater inputs. Therefore, its influence varies both between estuaries and within any given estuary.

At the extreme ends of the Gulf are the shallow, high-salinity estuaries of the southwest Florida peninsula and south Texas, which receive minimal freshwater input. Physical characteristics of theses systems sharply contrast with those of the broad, water-rich, low-salinity embayments located between Mobile Bay and the Atchafalaya River delta. Intermediate conditions exist from Suwannee River to Perdido Bay and from Calcasieu Lake to Matagorda Bay. In these areas estuaries are relatively deep, receive moderate freshwater inflow, and have intermediate salinity concentrations.

Freshwater also conveys important nutrients, sediments, pollutants, and pathogens to Gulf estuaries that may be sensitive to past or future alteration of freshwater delivery. These issues, however, were not directly addressed at this workshop.

Figure 1. *Gulf of Mexico estuaries*



SEA's National Estuarine Inventory Program

Since the late 1980s, SEA has been conducting strategic assessments of Gulf of Mexico estuaries, watersheds, and their resources. Existing data sets that consistently describe physical environments, biological resources, water quality, pollution sources, and human activities in the Gulf region are components of a nationwide program to assess the health and use of estuarine environments. Such information is vital for an objective, unbiased approach to define estuarine issues (or problems) consistently, and to compare the relative priority of these issues across all Gulf estuaries. The temporal and spatial resolution of this information is sufficient for making meaningful first-order (or screening-level) comparisons and rankings. The Gulf-wide perspective offered by these data sets provided a unique opportunity for workshop participants to evaluate the severity and representativeness of conditions in their estuaries within a larger context. Each participant was provided with a notebook of data summaries describing freshwater inflow trends, salinity variability, and biota for each estuary in the region.

Nearly all the information presented at the workshop was derived from two programs within SEA's National Estuarine Inventory (NEI): the Estuarine Living Marine Resources (ELMR) Program and the Estuarine Salinity Characterization Project. Both programs represent long-term synthesis and assessment activities jointly conducted with numerous Gulf institutions and experts. Databases from these programs were restructured to facilitate the development of the ranking factors in Part 1 of the workshop.

In contrast, analyses of historic freshwater inflow trends and the "Biosalinity Index (BSI)" were specifically developed for this workshop. Both data sets were designed to ensure consistency and comparability with the existing NEI spatial framework. The BSI is based on data available through the ELMR Program and Salinity Characterization project. The freshwater analyses were developed by SEA, and refined through a technical review process involving 15 Gulf hydrologists and scientists prior to the workshop.

An expanded description of how this information was used in the workshop is provided in Appendices 1-3.

Workshop Participants

Twenty-three persons attended the workshop, all from the Gulf of Mexico region (Appendix 4). Attendees were selected to ensure adequate technical expertise, geographic representation across the Gulf states, and institutional diversity. There were six Federal participants, 10 from State and local agencies, and seven from nongovernment organizations and universities. To keep the workshop manageable, invitations could not be extended to all interested persons. However, this document will be distributed to people beyond the workshop participants, and their comments solicited.

Overview of the Approach and Key Results

Approach

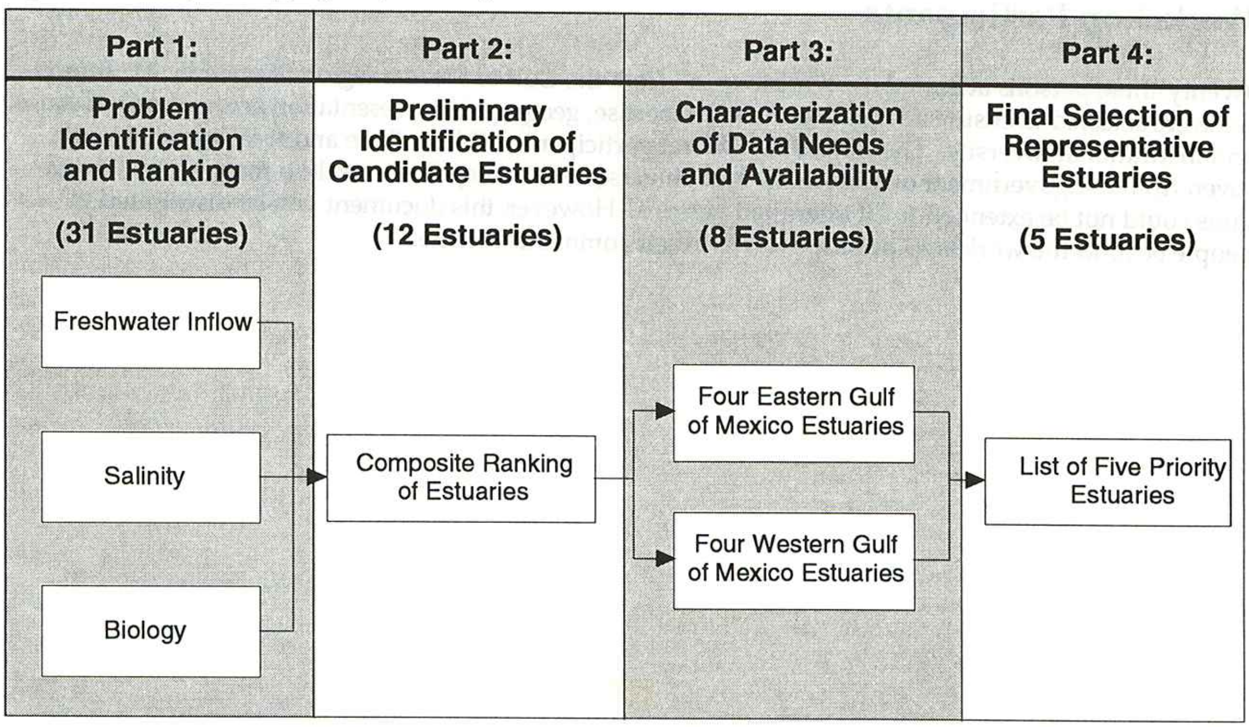
The workshop was divided into four facilitated work sessions through which participants could interactively reach consensus on session objectives. As noted below, the four-part process (Figure 2) included both plenary and independent work sessions to evaluate important relationships among freshwater inflow alteration, estuarine habitat (represented by estuarine salinity), and potentially salinity-sensitive biological resources for 29 Gulf of Mexico estuaries:

Part 1: Problem Identification and Rankings (three simultaneous work sessions); The NEI data provided by SEA was used in each group to develop ranking factors that quantify the extent of the problem.

Part 2: Preliminary Identification of Candidate Estuaries (plenary); A composite score was developed for each estuary by combining the rankings from each work session in Part 1. Estuaries with the highest rankings were identified, and the representativeness of that subset was determined in relation to the freshwater-salinity-biology issues across other Gulf estuaries.

Part 3: Information Needs and Data Availability for Representative Estuaries (two simultaneous work sessions); In order to conduct the site-specific analysis, sufficient data is required. This work session was used to determine if such data are available to further explore freshwater-salinity-biology relationship.

Figure 2. *Process for identifying and prioritizing estuaries*



Part 4: Final Selection of Representative Estuaries (plenary). The final list of five estuaries was verified.

The workshop format provided a systematic approach for encoding the participants' preferences and recommendations. A series of worksheets was developed to guide discussions and provide a consistent format for organizing results.

Part 1: Problem Identification and Rankings

Participants were assigned to one of three work groups focusing on a specific component of the freshwater-salinity-biology relationship. As an initial step, each work group received a background set of data generated by the SEA Division (see Appendices 1-3) to provide a basis for the development of factors for inter-estuarine comparisons. The work group then used these factors to rank estuaries as high, medium, or low to compare and contrast the relative importance of each estuary for that discipline. An estuary received a high ranking if it met the criteria outlined in Table 1.

Table 1. *Definition of high-ranking estuary for each work group*

Group	Focus	A "high-ranking" estuary is:
Freshwater Inflow	Historic freshwater inflow trends and associated watershed characteristics	Statistically significant trends in historical freshwater delivered to the estuary, potentially due to anthropogenic activities in the watershed
Salinity	Salinity variability associated with freshwater inflow	Large changes in seasonal salinity concentrations, primarily due to freshwater inflow changes
Biology	Biological resources potentially sensitive to changes in estuarine salinity	High number of potentially salinity-sensitive species and/or limited area of preferred salinity zone available in estuary

Freshwater Inflow (Appendix 1). Nine ranking factors were developed to address aspects of estuarine freshwater inflow. Information was derived primarily from U.S. Geological Survey data sets adapted to SEA's NEI framework. Four ranking factors were developed to prioritize estuaries based on increases or decreases in historical seasonal inflows. For each estuary, seasonal freshwater trends were determined from 15-year moving averages of USGS gaged streamflow data for three-month high- and low-flow seasons. Five other ranking factors, describing watershed activities that affect freshwater inflow, were based on combinations of population trends, reservoir characteristics, and proposed management actions. At the end of the work session, a scoring system was developed to combine the nine ranking factors for each estuary to determine the overall influence of historical freshwater inflow alteration in each system.

Salinity Variability (Appendix 2). Six ranking factors were developed to describe the temporal and spatial variability of salinity and the extent to which variability is associated with freshwater inflow. Information was adapted from the SEA report, *Salinity Characteristics of Gulf of Mexico Estuaries* (Orlando, et. al, 1993). In this report, surface- and bottom-salinity distributions were defined at 5 ppt intervals for two three-month periods reflecting typical and present-day high- and low-salinity conditions for each estuary. Prior to the workshop, SEA digitized the seasonal salinity distributions for each estuary and developed estimates of estuarine surface area represented by each salinity zone. This information was captured in electronic spreadsheet format and used to develop ranking factors during this work session. At the end of the work session, a scoring system was developed to combine the six ranking factors for each estuary and determine the overall influence of freshwater inflow on salinity variability in each system.

Salinity-Sensitive Biota (Appendix 3). The Biosalinity index (BSI) was developed to assess biological sensitivity of GOM resources to changes in salinity regimes. The BSI integrates SEA's ELMR biological data with its Gulf salinity characterization information. Data is integrated on the temporal and spatial distribution and relative abundance of 44 important fishes and macro-invertebrates found in Gulf estuaries and their use of five biologically based salinity zones. It was used to develop five ranking factors for selected individual species and a composite indicator for all 44 species in each estuary. Two other ranking factors were developed that characterized submerged aquatic vegetation and ecological resiliency. At the end of the work session, a scoring system was developed to combine the seven ranking factors for each estuary and determine the overall influence of salinity on biota in each system.

Part 2: Preliminary Identification of Candidate Estuaries

Through a facilitated plenary session, participants developed a scoring system to integrate the results of Part 1. The goal was to identify those estuaries receiving the highest rankings across all three disciplines (Table 2). Participants then reviewed the subset of priority estuaries receiving the highest rankings to determine if they should be considered for refined analyses of the freshwater-salinity-biology relationship

Table 2. *Overall Ranking by estuary based on composite of ranking factors used in each working session*

Estuary Code	Estuary Name	FWI Score	Salinity Score	Biology Score	Total Score	Bin Rank
G050	**Charlotte Harbor**	5	5	5	15	H
G051	**Caloosahatchee River**	5	5	5	15	H
G162	**Lake Pontchartrain**	5	5	5	15	H
G120	**Choctawhatchee Bay**	5	5	3	13	H
G161	**Lake Borgne**	5	5	3	13	H
G240	**Galveston Bay**	5	5	3	13	H
G290	**Corpus Christi Bay**	5	3	5	13	H
G190	**Barataria Bay**	5	3	5	13	H
G070	**Tampa Bay**	5	5	1	11	H
G170	**Breton/Chandeleur Sounds**	5	3	3	11	H
G140	**Perdido Bay**	3	3	5	11	H
G210	**Atchafalaya/Vermilion Bays**	3	3	5	11	H
G230	Sabine Lake	5	1	3	9	M
G060	Sarasota Bay	5	3	1	9	M
G280	Aransas Bay	3	1	5	9	M
G310	Lower Laguna Madre	3	1	5	9	M
G130	Pensacola Bay	3	3	3	9	M
G180	Mississippi River	3	3	3	9	M
G200	Terrebonne/Timbalier Bays	3	3	3	9	M
G260	Matagorda Bay	3	5	1	9	M
G100	Apalachicola Bay	1	5	3	9	M
G300	Upper Laguna Madre	3	1	3	7	M
G080	Suwannee River	3	3	1	7	M
G040	Rookery Bay	1	1	5	7	M
G220	Calcasieu Lake	1	1	5	7	M
G250	Brazos River	1	1	5	7	M
G150	Mobile Bay	1	5	1	7	M
G090	Apalachee Bay	1	3	1	5	L
G110	St. Andrew Bay	1	3	1	5	L
G160	Mississippi Sound	1	3	1	5	L
G270	San Antonio Bay	3	1	1	5	L

required for habitat suitability analysis. An estuary was removed from this list if it did not meet the following criteria:

- The estuary has clearly experienced long-term freshwater inflow changes that are likely to impact important salinity-sensitive biota; or
- The estuary represents high-priority environmental conditions (with respect to the freshwater-salinity-biology relationship) in other Gulf estuaries; and
- The estuary offers reasonable management opportunities.

Both Breton and Chandeleur Sounds estuary and Barataria Bay did not meet either criteria because of either recently completed or proposed diversions from the Mississippi River. In addition, Charlotte Harbor and Caloosahatchee River were combined into one estuary, separate from lakes Pontchartrain and Borgne. Ultimately, eight estuaries were selected: Charlotte Harbor and Caloosahatchee River; Tampa Bay; Choctawhatchee Bay; Perdido Bay; Lakes Pontchartrain and Borgne; Atchafalaya and Vermilion Bays; Galveston Bay; and Corpus Christi Bay.

Part 3: Information Needs and Data Availability for Representative Estuaries

This session was conducted to determine information needs and data availability for site-specific analyses of the freshwater-salinity-biology relationship for the eight estuaries identified in Part 2. Participants were separated into two facilitated work groups, representing the eastern and western Gulf of Mexico regions, and instructed to examine four estuaries each. Participants first identified other morphologic, habitat, and water-quality parameters beyond salinity and freshwater inflow believed to be required for site-specific analysis, then qualitatively assessed data availability for each of these parameters. Data availability was judged to be either high (readily available), medium (difficult to obtain), or low (unavailable).

Part 4: Final Selection of Representative Estuaries

Participants reviewed the results of Part 3 in plenary to confirm the appropriateness of the subset of estuaries meeting the criteria identified in Part 2. Choctawhatchee Bay and Lakes Pontchartrain and Borgne were determined to have too little data and information available for future site-specific analyses, and were therefore removed from the list. In addition, Tampa Bay was excluded due to its geographic proximity to Charlotte Harbor, and because Charlotte Harbor represents a potential freshwater use and estuarine resource conflict typical of other Gulf estuaries. In all, five estuaries were identified as representative: Charlotte Harbor and Caloosahatchee River; Perdido Bay; Atchafalaya and Vermilion Bays; Galveston Bay; and Corpus Christi Bay.

How Well Did the Process Work?

Comments received from GOMP officials and a post-workshop survey of participants indicated favorable responses to both the approach and screening-level data sets used. Constructive comments were also provided to refine aspects of the workshop process.

Data. The data and information SEA provided to participants was perhaps the factor that generated the most commentary. It was agreed that the information both stimulated and maintained discussions focused on work session objectives. Further, the consistency of the information and its level of detail was considered suitable for making high-order assessments and inter-estuarine comparisons. Thus, the data was acknowledged to be critically important given the range of issues, workshop objectives, and time constraints. Some respondents, however, felt that the physical and hydrologic information might have been better used if participants could have reviewed it before the workshop.

Pre-Workshop Technical Review. Before the workshop, 15 participants were asked to provide technical guidance on analytical methods and presentation formats for the freshwater inflow components. This effort refined the value and accuracy of the information used at the workshop, and it was suggested that a similar effort, although labor- and time-intensive, could have been beneficial for the salinity and biology components as well.

Minor Inconsistencies. While every attempt was made to maintain an objective, unbiased approach, it was suggested that the criteria to evaluate both the relative priority of estuaries and relative abundance of existing information be more explicit. This could be expanded to include follow-up activities to inventory data and information availability, and to identify other freshwater inflow-related issues beyond salinity and potentially biologically sensitive species.

Next Steps

After reviewing this workshop summary and the recommended list of estuaries, a final list of candidate estuaries for further detailed analyses will be developed. These estuaries will become the focus for habitat suitability modeling as outlined in the Freshwater Inflow Issue Committee's Action Item Agenda. Work on this element of the program is anticipated to begin in this fiscal year.

Appendix 1: Freshwater Inflow

Preliminary Assessments

A procedure was devised to determine long-term trends in freshwater inflow. The daily discharge record from a select combination of stream flow gages was used in the calculations. These figures were added together and subsequently scaled up by the ungaged area for that collection of gages only during those periods for which data existed for contributing stations. This daily record was then aggregated to monthly averages of the daily flow for each year over the entire period of record (POR). The 12 long-term monthly means based on the adjusted discharge record were also determined, and the minimum monthly mean was used to establish the beginning month of the water year for that system. The data was subdivided into three-month high- and low-flow periods determined uniquely for each water year, based on the highest or lowest three-month average. The three monthly values of each high and low period were then averaged to get a seasonal freshwater inflow value for that year.

The resulting seasonal time series was normalized to express flow in unitless terms that could be compared between seasons and systems. This was accomplished by determining the POR maximum and minimum values of the annual high- and low-flow period means respectively, to assess the range of the data for each system and season, then normalizing through the following calculation:

$$\text{Normalized Data} = \frac{\text{Yearly Seasonal Mean Value} - \text{Seasonal POR Minimum}}{\text{Seasonal POR Maximum} - \text{Seasonal POR Minimum}}$$

The data are then expressed in terms of a percentage of the known range in flows for a wet or dry hydroperiod, thereby providing a common scale with which to interpret trends.

Seven-, 15-, and 25-year boxcar moving average filters were applied to these normalized values for the high and low periods. These time periods were chosen based on the results of a Fast Fourier Transform (FFT) periodgram analysis that indicated these were significant periodicities in the time series. Applying a moving boxcar filter effectively smoothed out most data fluctuations. The 15-year filter showed a reasonable compromise between loss of data at the 25-year period and excessive noise at the seven-year period filter length. Overall trends were comparable among all three smoothing lengths, and consistent irrespective of the averaging window used.

A linear regression was applied to these data for both low and high freshwater inflow periods, and a significance test conducted for each estuary, as reflected in Tables 3 and 4, respectively. Trends were considered significantly different from zero if the absolute value of the T test statistic was greater than 2.02 ($\alpha = 0.05$, 40 df). Negative and positive slopes indicated decreasing and increasing trends, respectively.

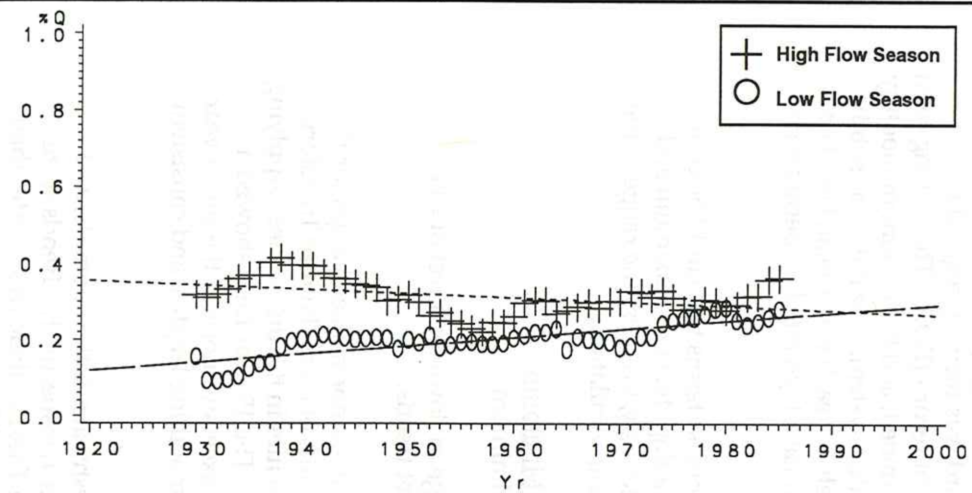
In addition to freshwater trend analysis, other factors potentially affecting either the timing or volume of freshwater inputs were characterized, including: trends in population; number of reservoirs; and water use. Figure 3 depicts how the information is organized for Galveston Bay. All information on both trends and factors was available in digital spreadsheets for use by workshop attendees.

Factor Development

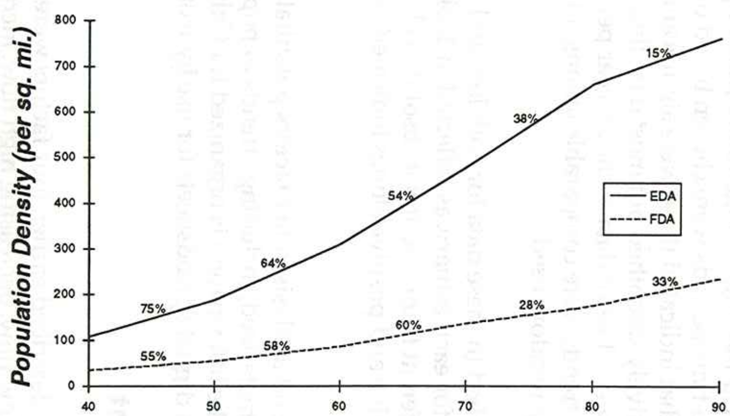
Based on the trend analysis described earlier, four factors were developed characterizing the following flow scenarios: decreasing low flow, decreasing high flow, increasing low flow, and increasing high flow.

Figure 3. *Freshwater inflow trends analysis and related data for Galveston Bay, Texas*

Freshwater Trends

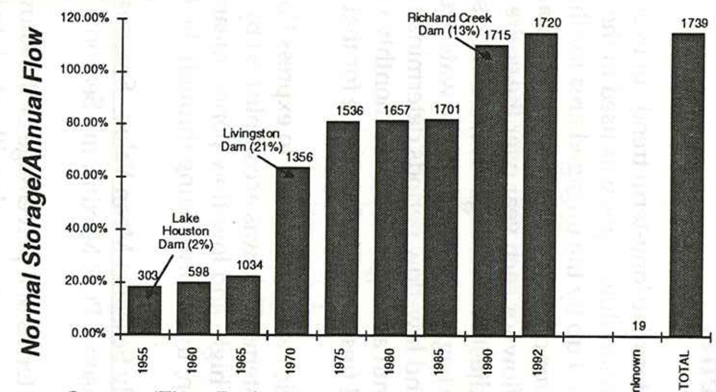


Population Trends



- EDA Total Population (1990) – **2,951,307**
- FDA Total Population (1990) – **4,680,280**
- EDA Population Density (1990) – **761 per sq. mile**
- FDA Population Density (1990) – **234 per sq. mile**
- EDA Total Population Percent Change (1940 - 1990) – **+605%**
- FDA Total Population Percent Change (1940 - 1990) – **+566%**

Reservoirs



- Storage/Flow Ratio (1992) – **114.90%**
- Storage/Flow Ratio Percent Change (1940 - 1990) – **+530%**

Water Use

Type of Use	Percentage of Consumptive Use	Percentage of Return Flow
Domestic/Commercial	0	0
Industrial/Mining	24	4
Thermoelectric Power	21	95
Agricultural	54	1

- Percent of Average Annual Adjusted Mean Flow that is Consumptive Use = **3.5%**
- Percent of Average Annual Adjusted Mean Flow that is Return Flow = **29.0%**

Galveston Bay (G240)

An estuary was characterized as exhibiting one of the above flow scenarios if the trend was considered significant (see prior explanation) and had an adjusted $R^2 > 0.5$. A ranking for each estuary was then developed by weighting the score of an individual factor and summing across all factors. Weighting factors were assigned as follows: decreasing low flow = 4; decreasing high flow = 3; increasing low flow = 2; and increasing high flow = 1. These weights were based on what characteristic the group felt had the greatest to least impact on estuarine resources. These results are summarized in Table 5. Note that although Breton/Chandeleur Sounds scored a 0, it was ranked as high because a recently completed freshwater diversion has significantly altered flows to this system.

A second group of factors was developed to characterize anthropogenic activities that could potentially affect changes in the volume or delivery rate of freshwater inflow. They consisted of the following five factors: 1) a ratio of total reservoir capacity for all reservoirs within the drainage basin of an estuary to the average annual freshwater inflow volume; 2) total population change from 1940 to 1990; 3) 1990 population density within the estuarine drainage area; 4) proposed management actions that could affect fresh-

Table 3. *Freshwater inflow statistics for three-month low-flow period*

Estuary Code	Estuary	Slope	R sq	P value	Std Err	T = HO	Upper 95%	Lower 95%
G071	Tampa Bay (Manatee River)	-0.00745	0.608	5.43E-05	0.00168	-4.431	-0.0041	-0.0108
G051	Caloosahatchee River *	-0.00359	0.582	3.12E-09	0.00050	-7.243	-0.0026	-0.0046
G120	Choctawhatchee Bay	-0.00321	0.646	2.40E-12	0.00034	-9.322	-0.0025	-0.0039
G300	Upper Laguna Madre	-0.00295	0.105	1.59E-01	0.00206	-1.432	0.0012	-0.0071
G310	Lower Laguna Madre	-0.00295	0.105	1.59E-01	0.00206	-1.432	0.0012	-0.0071
G131	Pensacola Bay (Escambia River)	-0.00234	0.154	4.68E-03	0.00079	-2.967	-0.0008	-0.0039
G261	Colorado River	-0.00223	0.355	9.70E-05	0.00052	-4.253	-0.0012	-0.0033
G130	Pensacola Bay (all sources)	-0.00171	0.115	1.35E-02	0.00067	-2.564	-0.0004	-0.0031
G070	Tampa Bay (all sources)	-0.00166	0.084	2.69E-02	0.00073	-2.283	-0.0002	-0.0031
G110	St. Andrew Bay	-0.00156	0.155	4.84E-03	0.00053	-2.954	-0.0005	-0.0026
G080	Suwannee River	-0.00148	0.092	3.43E-02	0.00068	-2.179	-0.0001	-0.0029
G132	Pensacola Bay (Yellow & Black Rivers)	-0.00145	0.220	1.00E-03	0.00041	-3.504	-0.0006	-0.0023
G220	Calcasieu Lake	-0.00140	0.266	2.65E-04	0.00035	-3.938	-0.0007	-0.0021
G072	Tampa Bay (Alafia & Hillsborough R.)	-0.00129	0.051	6.93E-02	0.00069	-1.858	0.0001	-0.0027
G140	Perdido Bay	-0.00102	0.011	2.40E-01	0.00086	-1.189	0.0007	-0.0028
G052	Charlotte Harbor (Peace River)	-0.00085	0.034	1.07E-01	0.00052	-1.643	0.0002	-0.0019
G050	Charlotte Harbor (all sources)	-0.00063	0.000	3.25E-01	0.00063	-0.995	0.0006	-0.0019
G053	Charlotte Harbor (Myakka River)	0.00008	-0.024	8.70E-01	0.00050	0.164	0.0011	-0.0009
G251	Brazos River	0.00015	0.004	2.75E-01	0.00013	1.105	0.0004	-0.0001
G100	Apalachicola Bay	0.00020	-0.012	5.54E-01	0.00034	0.596	0.0009	-0.0005
G250	Brazos & San Bernard Rivers	0.00044	0.110	1.06E-02	0.00017	2.661	0.0008	0.0001
G162	Lake Pontchartrain	0.00065	0.053	7.90E-02	0.00036	1.795	0.0014	-0.0001
G160	Mississippi Sound	0.00074	0.134	6.49E-03	0.00026	2.846	0.0013	0.0002
G090	Apalachee Bay	0.00121	0.232	1.62E-04	0.00030	4.093	0.0018	0.0006
G280	Aransas Bay	0.00145	0.576	1.56E-09	0.00019	7.440	0.0018	0.0011
G260	Matagorda Bay	0.00170	0.393	3.47E-06	0.00032	5.246	0.0023	0.0010
G073	Tampa Bay (Little Manatee Rivers)	0.00216	0.183	2.78E-03	0.00069	3.154	0.0035	0.0008
G240	Galveston Bay	0.00219	0.631	5.64E-13	0.00022	9.756	0.0026	0.0017
G040	Rookery Bay	0.00231	-0.313	8.31E-01	0.01079	0.215	0.0240	-0.0194
G270	San Antonio Bay	0.00287	0.477	5.92E-08	0.00045	6.410	0.0038	0.0020
G290	Corpus Christi Bay	0.00449	0.781	7.84E-16	0.00038	11.829	0.0053	0.0037
G150	Mobile Bay	0.00498	0.320	3.43E-03	0.00162	3.079	0.0082	0.0017
G180	Mississippi River	0.00562	0.833	1.34E-19	0.00038	14.874	0.0064	0.0049
G230	Sabine Lake	0.00566	0.625	6.46E-13	0.00058	9.716	0.0068	0.0045
G161	Lake Borgne	0.00567	0.722	1.70E-13	0.00056	10.122	0.0068	0.0045
G252	San Bernard River	0.00599	0.447	3.08E-05	0.00130	4.602	0.0086	0.0034
G210	Atchafalaya/Vermlion Bay	0.00843	0.388	5.10E-03	0.00287	2.935	0.0142	0.0027
G054	Caloosahatchee River	0.00907	0.673	1.52E-06	0.00237	5.484	0.0178	0.0082

* Flow at G051 represents from Lake Okeechobee
** Flow at G054 represents total flow minus releases from Lake Okeechobee

water inflow (e.g., diversion or reservoirs); and 5) potential population growth. All factors were weighted equally, and factors 1, 2, and 3 assigned a value of one if the estuary fell within the top 10 for those attributes. For factors 4 and 5, a value of one was assigned only if the group felt there was relatively strong potential for the activity to occur. These results are summarized in Table 6. For purposes of comparison between the two sets of factors (i.e., trends versus anthropogenic activities), the latter was ranked according to the following criteria: five, four, and three were considered high; two medium; and one low.

The purpose of the second set of factors was to modify the overall rating as determined by the set of trend factors, if the ranking based on anthropogenic activities would result in a higher overall ranking. In cases where this occurred, the overall ranking was assigned according to the anthropogenic factors analysis. As a result, the ranking of Lake Pontchartrain and Galveston and Corpus Christi Bays was changed to high (H). In addition, overall rankings for Sarasota, Barataria and Terrebonne/Timbalier Bays were based solely on the anthropogenic factors analysis, as gaged freshwater inflow records were not available.

Table 4. *Freshwater inflow statistics for three-month high-flow period*

Estuary Code	Estuary	Slope	R sq	P value	Std Err	T = HO	Upper 95%	Lower 95%
G310	Lower Laguna Madre	-0.00966	0.711	1.51E-05	0.00201	-4.814	-0.0056	-0.0137
G300	Upper Laguna Madre	-0.00966	0.711	1.51E-05	0.00201	-4.814	-0.0056	-0.0137
G073	Tampa Bay (Little Manatee River)	-0.00745	0.913	2.12E-25	0.00036	-20.515	-0.0067	-0.0082
G070	Tampa Bay (all sources)	-0.00574	0.802	3.36E-18	0.00042	-13.694	-0.0049	-0.0066
G050	Charlotte Harbor (all sources)	-0.00539	0.687	9.14E-14	0.00052	-10.313	-0.0043	-0.0064
G053	Charlotte Harbor (Myakka River)	-0.00537	0.813	4.76E-18	0.00040	-13.571	-0.0046	-0.0062
G052	Charlotte Harbor(Peace River)	-0.00487	0.674	2.40E-13	0.00049	-10.017	-0.0039	-0.0058
G072	Tampa Bay (Alafia & Hillsborough R.)	-0.00467	0.768	1.56E-16	0.00038	-12.366	-0.0039	-0.0054
G230	Sabine Lake	-0.00380	0.591	6.10E-12	0.00042	-9.044	-0.0030	-0.0046
G051	Caloosahatchee River *	-0.00380	0.605	9.06E-10	0.00050	-7.595	-0.0028	-0.0048
G150	Mobile Bay	-0.00217	0.079	1.17E-01	0.00136	-1.595	0.0006	-0.0049
G071	Tampa Bay (Manatee River)	-0.00173	-0.008	3.48E-01	0.00182	-0.949	0.0019	-0.0054
G240	Galveston Bay	-0.00109	0.138	2.95E-03	0.00035	-3.133	-0.0004	-0.0018
G180	Mississippi River	-0.00100	0.028	1.39E-01	0.00066	-1.505	0.0003	-0.0023
G251	Brazos River	-0.00056	0.075	2.30E-02	0.00024	-2.349	-0.0001	-0.0010
G250	Brazos & San Bernard Rivers	-0.00011	-0.018	7.17E-01	0.00030	-0.365	0.0005	-0.0007
G290	Corpus Christi Bay	0.00023	-0.023	7.47E-01	0.00071	0.324	0.0017	-0.0012
G252	San Bernard River	0.00062	-0.021	4.87E-01	0.00089	0.701	0.0024	-0.0012
G120	Choctawhatchee Bay	0.00074	0.008	2.50E-01	0.00064	1.165	0.0020	-0.0005
G100	Apalachicola Bay	0.00081	0.148	1.98E-03	0.00025	3.272	0.0013	0.0003
G090	Apalachee Bay	0.00083	0.108	9.53E-03	0.00031	2.701	0.0014	0.0002
G261	Colorado River	0.00097	0.203	4.47E-03	0.00032	2.983	0.0016	0.0003
G110	St. Andrew Bay	0.00132	0.091	2.67E-02	0.00058	2.286	0.0025	0.0002
G220	Calcasieu Lake	0.00151	0.043	1.02E-01	0.00091	1.666	0.0033	-0.0003
G160	Mississippi Sound	0.00216	0.281	6.81E-05	0.00049	4.361	0.0032	0.0012
G210	Atchafalaya/Vermilion Bay	0.00247	0.032	2.43E-01	0.00209	1.183	0.0067	-0.0017
G280	Aransas Bay	0.00272	0.286	1.44E-04	0.00066	4.130	0.0041	0.0014
G080	Suwanee River	0.00333	0.694	3.55E-12	0.00036	9.205	0.0041	0.0026
G130	Pensacola Bay (all sources)	0.00395	0.431	5.15E-07	0.00068	5.795	0.0053	0.0026
G132	Pensacola Bay (Yellow & Black Rivers)	0.00397	0.552	5.31E-09	0.00056	7.092	0.0051	0.0028
G131	Pensacola Bay (Escambia River)	0.00402	0.432	4.97E-07	0.00069	5.805	0.0054	0.0026
G162	Lake Pontchartrain	0.00405	0.523	2.16E-08	0.00060	6.694	0.0053	0.0028
G260	Matagorda Bay	0.00434	0.567	1.82E-09	0.00059	7.397	0.0055	0.0032
G270	San Antonio Bay	0.00438	0.672	1.15E-12	0.00046	9.543	0.0053	0.0035
G140	Perdido Bay	0.00475	0.565	7.12E-09	0.00068	7.009	0.0061	0.0034
G161	Lake Borgne	0.00494	0.536	1.54E-08	0.00073	6.791	0.0064	0.0035
G040	Rookery Bay	0.00611	-0.041	3.64E-01	0.00667	0.917	0.0195	-0.0073
G054	Caloosahatchee River **	0.01183	0.703	3.74E-05	0.00260	4.544	0.0171	0.0066

* Flow at G051 represents releases from Lake Okeechobee

** Flow at G054 represents total flow minus releases from Lake Okeechobee

Table 5. *Freshwater inflow rankings based on flow trends*

Estuary Code	Estuary	Factor 1	Factor 2	Factor 3	Factor 4	Total Score	Bin Rank
G070	Tampa Bay	4	3			7	H
G230	Sabine Lake		3	2		5	H
G120	Choctawhatchee Bay	4				4	H
G050	Charlotte Harbor		3			3	H
G051	Caloosahatchee River [1]			2	1	3	H
G162	Lake Borgne			2	1	3	H
G170	Breton/Chandeleur Sounds [2]					0	H
G300	Upper Laguna Madre [3]		3			3	M
G310	Lower Laguna Madre [3]		3			3	M
G210	Atchafalaya/Vermilion Bays			2		2	M
G240	Galveston Bay			2		2	M
G280	Aransas Bay			2		2	M
G290	Corpus Christi Bay			2		2	M
G180	Mississippi River			2		2	M
G130	Pensacola Bay				1	1	M
G140	Perdido Bay				1	1	M
G161	Lake Pontchartrain				1	1	M
G260	Matagorda Bay				1	1	M
G270	San Antonio Bay				1	1	M
G080	Suwannee River				1	1	M
G060	Sarasota Bay [4]						M
G040	Rookery Bay					0	L
G090	Apalachee Bay					0	L
G100	Apalachicola Bay					0	L
G110	St. Andrew Bay					0	L
G150	Mobile Bay					0	L
G160	Mississippi Sound					0	L
G190	Barataria Bay [4]						L
G200	Terrebonne/Timbalier Bays [4]						L
G220	Calcasieu Lake					0	L
G250	Brazos River					0	L

Factor 1: Decreasing Low Flow
Factor 2: Decreasing High Flow
Factor 3: Increasing Low Flow
Factor 4: Increasing High Flow

Key: H = 3-7
M = 1-2
L = 0

NOTES:
1. Based on G054.
2. Breton/Chandeleur Sound has been ranked as a H because there was not enough data available to justify it being ranked as a M or L.
3. Upper and Lower Laguna Madre has been ranked as M because the percent of the gaged flow is small, therefore it is misleading to rank them as H.
4. Gaged freshwater inflow records not available.

Table 6. *Freshwater inflow rankings based on anthropogenic effects*

Estuary Code	Estuary	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Total Score	Bin Rank
G070	Tampa Bay	1	1	1	1	1	5	H
G050	Charlotte Harbor	1		1	1	1	4	H
G240	Galveston Bay	1	1	1		1	4	H
G051	Caloosahatchee River	1	1	1			3	H
G060	Sarasota Bay		1	1		1	3	H
G161	Lake Pontchartrain		1	1	1		3	H
G190	Barataria Bay		1	1	1		3	H
G290	Corpus Christi Bay	1		1		1	3	H
G080	Suwannee River	1			1		2	M
G162	Lake Borgne	1		1			2	M
G200	Terrebonne/Timbalier Bays		1			1	2	M
G260	Matagorda Bay	1			1		2	M
G040	Rookery Bay			1			1	L
G090	Apalachee Bay		1				1	L
G110	St. Andrew Bay		1				1	L
G120	Choctawhatchee Bay					1	1	L
G130	Pensacola Bay					1	1	L
G140	Perdido Bay		1				1	L
G150	Mobile Bay					1	1	L
G170	Breton/Chandeleur Sounds				1		1	L
G180	Mississippi River	1					1	L
G210	Atchafalaya/Vermillion Bays				1		1	L
G230	Sabine Lake	1					1	L
G270	San Antonio Bay				1		1	L
G280	Aransas Bay	1					1	L
G100	Apalachicola Bay							L
G160	Mississippi Sound							L
G220	Calcasieu Lake							L
G250	Brazos River							L
G300	Upper Laguna Madre							L
G310	Lower Laguna Madre							L

Factor 1: Normal Storage Volume/Average Freshwater Inflow Volume
Factor 2: Total Population Change from 1940 - 1990
Factor 3: 1990 Population Density (EDA only)
Factor 4: Proposed Management Actions (diversions, etc.)
Factor 5: Potential Population Growth

Key: H = 3-5
M = 2
L = <2

Appendix 2: Salinity

Preliminary Assessments

Information used in the salinity work session was adapted from SEA's report *Salinity Characteristics of Gulf of Mexico Estuaries* (Orlando et. al, 1993). This report emphasized two aspects of salinity: its spatial structure and its variability. Structure refers to the horizontal and vertical distribution of salinity, defined at 5 ppt intervals for both the surface and bottom layers of the water column during two three-month periods reflecting "typical" or "present-day" high- and low-salinity conditions. "Typical" refers to salinity measured under a range of freshwater inflow conditions consistent with long-term averages for each three-month period. The intent was to exclude extreme, episodic events, such as tropical storms and severe droughts, that offer little management opportunity. "Present-day" conditions are used when the salinity distributions postdate all major modifications of the estuary and its watershed.

"Variability" refers to the spatial and temporal changes associated with the salinity structure. The frequency and magnitude of salinity variability differ across estuaries and within any given estuary, depending on the relative influence of the operable forcing mechanisms. Within most estuaries, the primary forcing mechanisms include freshwater inflow, tides, wind, and coastal shelf processes. In some estuaries, salinity variability may also depend on other mechanisms, such as brine discharges (e.g., Brazos River), evaporation (e.g., Corpus Christi Bay), density currents (e.g., Galveston Bay), interestuary exchanges (e.g., San Antonio Bay), and river plumes from adjacent estuaries (e.g., Barataria Bay). Variability time scales range from hours to decades. SEA's report uses a matrix format to consistently summarize the magnitude of salinity variability at each time scale, identify the dominant forcing mechanisms responsible for the variability, and indicate the region of the estuary most likely to experience variability at that time scale. Data and information for the variability matrices were derived from SEA's historical salinity data sets, professional literature, and expert consultation.

SEA also provided work session participants with digital estimates of estuarine area by 5 ppt salinity increments for both the surface and bottom layers of the water column. This information was available in spreadsheet format, and provided the basis for developing factors during the work session. Participants also received historical salinity summaries that described long-term average monthly and average seasonal salinity concentrations for each estuary. An example of these summaries is given in Figure 4 for Galveston Bay.

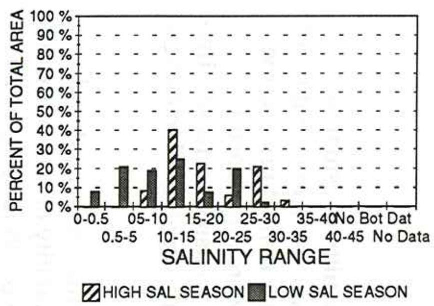
Factor Development

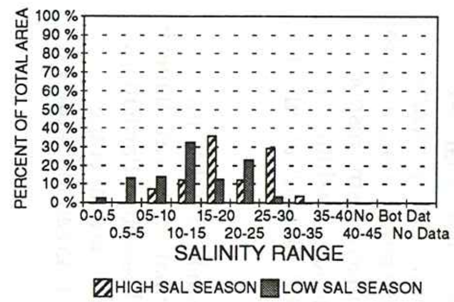
The objective of the salinity session was to examine the temporal and spatial variability of estuarine salinity and the extent to which it is associated with freshwater inflow. This session was somewhat more difficult than the others, in that SEA did not develop indices (e.g., BSI or freshwater trends) prior to the workshop to aid in factor development. In the work session, six ranking factors were developed to describe salinity: three addressing salinity variability (i.e., Factors 1-3); and three focusing on its sensitivity to freshwater inflow (i.e., Factors 4-6). Ultimately, only Factors 4-6 were directly considered in assigning an overall salinity rating to each estuary.

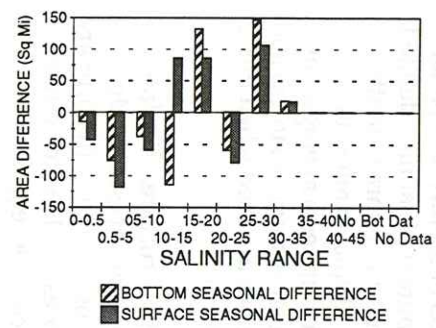
Factors 1-3: Salinity Variability. To facilitate the linkage between salinity and estuarine habitat and biota, the salinity work session focused on developing factors to describe the variability of four of the five biologically significant salinity zones. These zones were identified through pre-workshop analysis by SEA's ELMR Program, which documents the limited ways in which biological organisms align themselves to salinity. These zones are: 0-5 ppt, 5-15 ppt, 15-25 ppt, and >25 ppt. The variability of the 0.0-0.5 tidal fresh zone was not characterized, due to data availability limitations.

Figure 4. *Salinity analysis and related data for Galveston Bay, Texas*

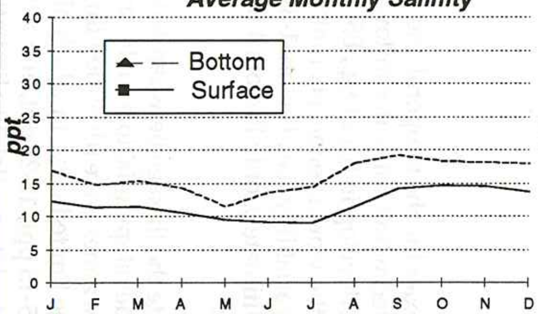
Representative Seasonal Salinity

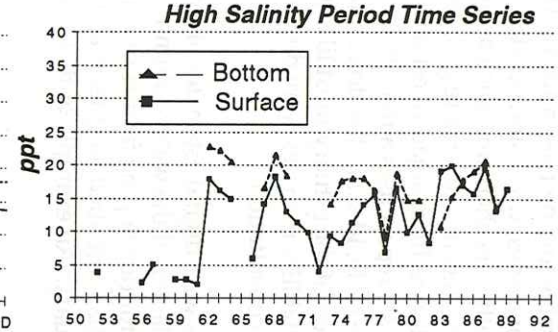


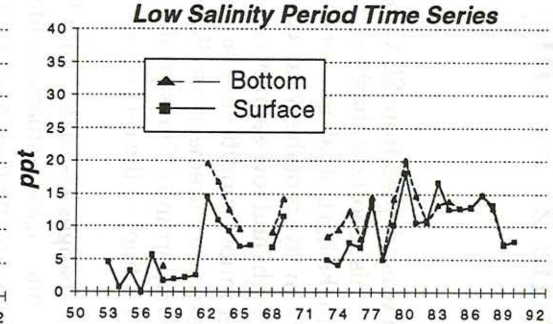




Long-Term Salinity (1970 - 1990)

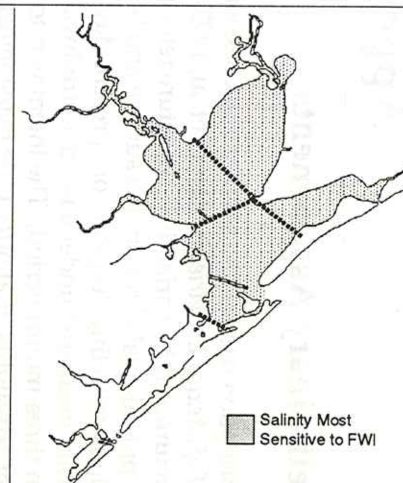






Salinity Variability and Freshwater Inflow

Estuary Type:	Four
Seasonal Variability:	Medium
Days-Weeks Variability:	Low
Greatest Salinity Response to FW:	Trinity Bay, but substantial influence in Upper & Lower Galveston Bays and East Bay
Least Salinity Response to FW:	West Bay - but responds to local basin runoff
Vertical Stratification:	• MS throughout most of estuary during high flow • MS-HS in HSC during low flow
Other Factors:	• Occasional releases from Lake Houston Reservoir (San Jacinto River) • Circulation restricted by Redfish, Hanna, & Karankaway Reefs and disposal areas • Houston Ship Channel (13 m) • 80% tidal prism volume through Bolivar Roads • Low flow salt extrusion releases at Lake Livingston (Trinity River) since 1970



Salinity Sensitivity

Galveston Bay (G240)

Work session participants used the digital estimates of estuarine surface area by 5 ppt salinity zone to quantify surface area lost or gained by each of the four zones between the high- and low-salinity seasons. For example, a particular estuary may have 50 square miles of the 0-5 ppt zone during the low-salinity season, but only 10 during the high-salinity season. The difference between these areas represented the areal change between seasons. Since this absolute difference was thought to give preferentially higher weighting to larger estuaries, it was normalized by the total surface area of the estuary to indicate the percentage represented by the seasonal change in this zone. This value was computed for all estuaries, then used to rank them according to the highest percentages. Factor 1 described this change for the 0-5 ppt zone, while Factors 2 and 3 described the 5-15 ppt and 15-25 ppt zones, respectively. The >25 ppt salinity zone was thought to be minimally impacted by freshwater-inflow changes.

Factors 4-6: Salinity Variability and Freshwater. These factors were developed to describe the influence of seasonal freshwater in the estuary. Factors 4 and 5 loosely quantified the relative change in seasonal salinity per unit change in seasonal freshwater inflow. Factor 4 considered the influence of freshwater over the entire estuary as the ratio of: the difference in average estuary-wide seasonal salinity concentrations (normalized by the average estuary-wide high-salinity seasonal concentration) to the difference in average seasonal freshwater inflow (normalized by average seasonal inflow during the low-salinity season), or:

$$\frac{\Delta\, S‰ \text{ conc (high - low } S‰ \text{ season) / (high } S‰ \text{ season)}}{\Delta\, \text{FWI (low - high } S‰ \text{ season) / FWI (low } S‰ \text{ season)}}$$

Factor 5 described the influence of seasonal freshwater on the two salinity zones located immediately adjacent to the freshwater source (i.e., 0-5 ppt and 5-15 ppt). The change in salinity zones was expressed as the surface area lost or gained by these zones between the low- and high-salinity seasons (i.e., Factor 1 + Factor 2, above):

$$\frac{\Delta S‰ \text{ zone 1 (hi-low } S‰ \text{ season)/(hi } S‰ \text{ season)} + \Delta S‰ \text{ zone 2 (hi-low } S‰ \text{ season)/(hi } S‰ \text{ season)}}{\Delta\, \text{FWI (low-hi } S‰ \text{ season) / FWI (low } S‰ \text{ season)}}$$

Factors 4 and 5 were again thought to give preferentially higher weighting to larger estuaries or estuaries with large seasonal shifts in freshwater inflow.

In contrast, Factor 6 was developed to highlight estuaries with minimal freshwater inflows that have an important influence on salinity in localized regions of the estuary. This factor quantified the ratio of estuarine volume to freshwater inflow during the high-salinity period. A high value suggested that the spatial extent of freshwater influence was likely confined to tributaries, rather than the open estuary (e.g., Tampa Bay and Charlotte Harbor).

During the work session, estuaries were ranked as high, medium, or low with respect to each of the factors defined above. At the end of the session, a scoring process was developed to combine these rankings into a single value per estuary. In this process, only Factors 4 to 6 were used, as the essence of Factors 1 to 3 was thought to be captured by Factors 4 and 5. For each estuary, a value of five was assigned for each high rank, three for medium, and one for low. These values were summed for each estuary, and a final score assigned in the following manner:

Score	Final Ranking
11	High
9	Medium
≤7	Low

Table 7 summarizes individual factor scores and combined ranking. The following estuaries received the highest combined ranking for salinity: Charlotte Harbor, Tampa Bay, Apalachicola Bay, Choctawhatchee Bay, Mobile Bay, Galveston Bay, and Matagorda Bay.

Table 7. *Salinity rankings*

Estuary Code	Estuary	Factor 4	Factor 5	Factor 6	Total Rank	Bin Rank
G050	Charlotte Harbor	3	3	5	11	H
G070	Tampa Bay	3	3	5	11	H
G100	Apalachicola Bay	5	5	1	11	H
G120	Choctawhatchee Bay	5	5	1	11	H
G150	Mobile Bay	5	5	1	11	H
G240	Galveston Bay	3	5	3	11	H
G160	Matagorda Bay	3	3	5	11	H
G051	Caloosahatchee River	1	3	5	9	M
G080	Suwannee River	3	5	1	9	M
G090	Apalachee Bay	3	3	3	9	M
G110	St. Andrew Bay	3	3	3	9	M
G130	Pensacola Bay	5	3	1	9	M
G160	Mississippi Sound	3	3	3	9	M
G162	Lake Pontchartrain	1	5	3	9	M
G161	Lake Borgne	1	5	3	9	M
G140	Perdido Bay	3	1	3	7	L
G210	Atchafalaya/Vermilion Bays	1	5	1	7	L
G220	Calcasieu Lake	3	3	1	7	L
G230	Sabine Lake	3	3	1	7	L
G290	Corpus Christi Bay	3	1	3	7	L
G170	Breton/Chandeleur Sounds	1	1	3	5	L
G190	Barataria Bay	1	1	3	5	L
G270	San Antonio Bay	3	1	1	5	L
G040	Rookery Bay	1	1	1	3	L
G060	Sarasota Bay	1	1	1	3	L
G180	Mississippi River	1	1	1	3	L
G200	Terrebonne/Timbalier Bays	1	1	1	3	L
G250	Brazos River	1	1	1	3	L
G280	Aransas Bay	1	1	1	3	L
G300	Upper Laguna Madre	1	1	1	3	L
G310	Lower Laguna Madre	1	1	1	3	L

Factor 4: (change in salinity between high and low periods/high period) / (change in flow between high and low periods/high period)

***Factor 5:** % change in salinity zone surface area between high and low periods / % change in freshwater inflow volume between high and low flow periods

Factor 6: estuary volume/average low freshwater inflow volume

Key: H = 11
M = 9
L = ≤7

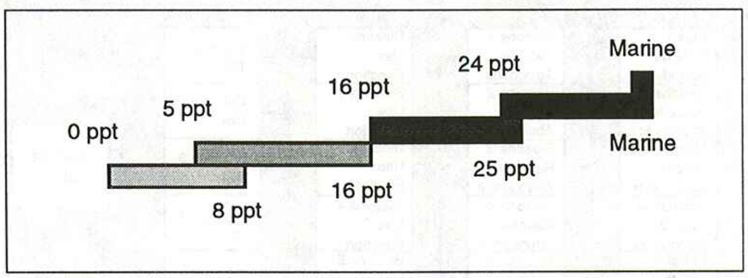
**this factor was only for low salinity zones (0-5 ppt & 5-15 ppt)*

Appendix 3: Biology

Preliminary Assessments

Biologically Based Salinity Zone Data. The methods of Bulger et al., 1993, were used to develop biologically based salinity zones for estuaries of the Gulf of Mexico (Tampa Bay, FL to the Laguna Madre, TX). Zone boundaries were defined based on a multivariate statistical technique: principal component analysis (PCA). This analysis was conducted with field salinity data and salinity range co-occurrences of 161 fish species found in Mississippi Sound, Mobile Bay, and Weeks Bay. Data used to compile the species salinity co-occurrence matrix were obtained from: 1) the Alabama Coastal Area Board's (ACAB) baseline survey of Mobile Bay and Mississippi Sound trawl survey, 1982-1981; 2) the Gulf Coast Research Laboratory's (GCRL) Mississippi trawl survey data, 1982-1994; and 3) the Weeks Bay National Estuarine Research Reserve's seine survey data, 1988-1989. Field collections were cross-referenced with station salinity data to provide a measure of habitat (salinity) association. Application of PCA to the data matrix identified five principal components, each corresponding to an individual biologically based salinity zone (Figure 5).

Figure 5. *Biologically based overlapping salinity zones for central Gulf of Mexico estuaries*



ELMR Data. Species salinity range/tolerance data compiled by the SEA Division's ELMR Program were used to assign 44 Gulf fishes and invertebrates to the biologically based salinity zones. The ELMR habitat association data describe species salinity ranges relative to NEI salinity zones [tidal fresh zone (0-0.5 ppt), mixing (0.5-25 ppt), and seawater zone (>25ppt)], and Venice system salinity zones [limnetic (0-0.5 ppt), oligohaline (0.5-5 ppt), mesohaline (5-18 ppt), polyhaline (18-30 ppt) and euhaline (>30 ppt)]. This information is available in Patillo et al, in prep. These eight zones overlap and, in most cases, align with the PCA-derived zones, making it possible to realign ELMR species' relative abundance data to the five biologically based salinity zones. ELMR relative abundance estimates are available in Nelson ed., 1992.

The NEI tidal fresh zone was considered equivalent to that of the biologically based zones. Similarly, the 24-marine zone and the NEI seawater zone (>25 ppt) were considered equivalent. Thus, ELMR relative abundance data were directly transferred to the fresh and marine biologically based zones.

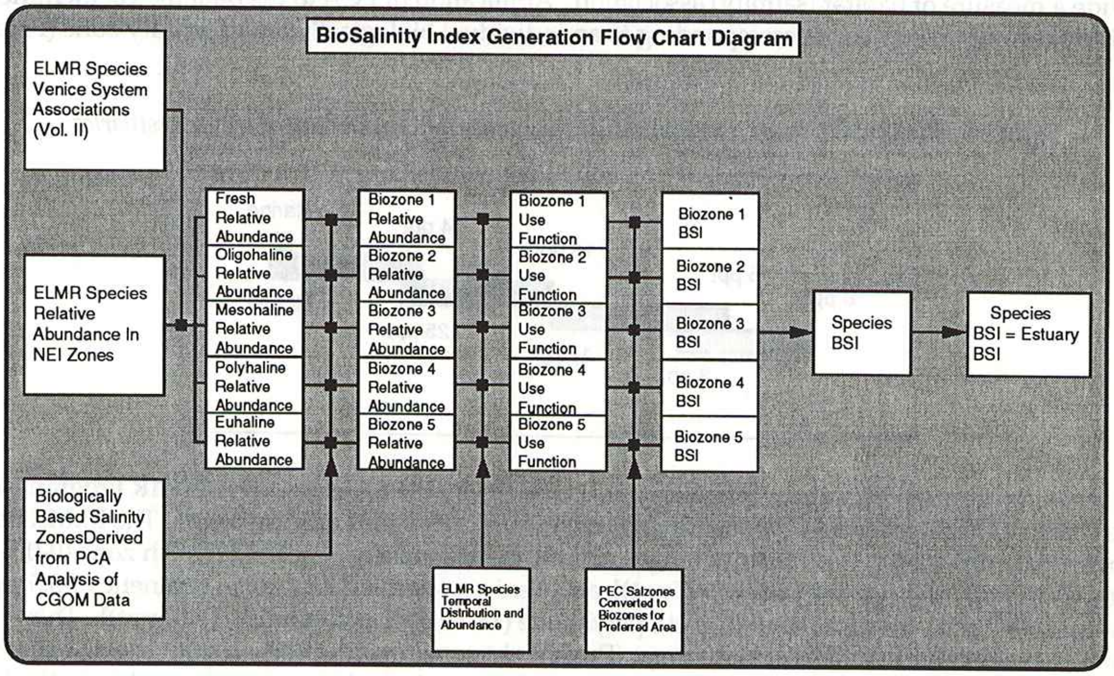
The NEI mixing zone encompasses three biologically based salinity zones (0-8 ppt, 5-18 ppt, and 16-25 ppt). Realigning ELMR relative abundance data to the remaining bio-based zones was accomplished by transferring the NEI mixing zone ELMR relative abundance estimates to the biological zones based on species habitat associations with the oligohaline, mesohaline and/or polyhaline zones of the Venice system. Thus, the three original NEI/ELMR salinity zones were expanded into five bio-based zones.

ELMR-Salinity Zone Coupling. The Biosalinity Index (BSI) includes both spatial and temporal distributions within its mathematical expression. The ELMR spatial, temporal, and relative abundance data provided the information necessary to define the species-use patterns across Gulf of Mexico estuaries.

The salinity characterization project provided the spatial component by calculating relative salinity zone surface areas (for 5 ppt isohalines) in Gulf estuaries during low-salinity periods. The overall BSI process is shown in Figure 6. Calculated isohaline surface areas were then realigned to fit the biologically based salinity zones for an estimate of bio-based zone areas. The following alignments were made: 1) <0.5 ppt (corresponding to the fresh zone); 2) >0.5-8 ppt (corresponding to 0-8 ppt zone); 3) 5-15 ppt (corresponding to 5-16 ppt zone); 4) 15-25 ppt (corresponding to 16-25 ppt zone); and 5) 25-35 ppt (corresponding to 25-marine zone). The >0.5-8 ppt zone area was calculated by multiplying the NEI 5-10 ppt zone area by 0.6 (3 of 5 ppt's from the 5-10 ppt zone) and adding it to the >0.5-5 ppt zone area to achieve an estimated area proportionate to a >0.5-8 ppt zone. Thus, the adjusted isohalines/bio-based zone areas could be determined.

The steps described above provide both the spatial and temporal components needed to calculate an index of biosensitivity to salinity fluxes in Gulf estuaries. The BSI incorporates salinity zone size (km^2

Figure 6. *Biosalinity index generation procedure*



surface area) and monthly relative abundance data for each bio-zone in an estuary. If a species exclusively uses the two lower salinity zones within an estuary, its population may exhibit a sharp decline in relative abundance if those zones decrease in size. Likewise, a population may experience a period of growth associated with an increase in the size of its optimum or preferred salinity zone(s). BSI values for a given species can be compared across Gulf estuaries. Similarly, BSI values for all species in a given system may be summed and compared to other estuaries. The summed BSIs provide a measure of relative assemblage of an estuary and its salinity sensitivity. Individual salinity zone BSI values were calculated and summed to achieve an estuary-specific species BSI value (Figure 6). The temporal component of the Biosalinity Index, termed the Use Function (U_f), is expressed as:

$$U_f = (\text{months observed . yr}^{-1})(\text{estuary specific salinity zone maximum abundance rank}).$$

Salinity Zone Use (Sz), the preferred salinity zone area divided by the total system area, provides the spatial component to the Biosalinity Index, resulting in the following formula:

$$BSI = (U_f/U_{fmax})(Sz).$$

Including U_{fmax} in the equation causes the product to fall between 0 and 1, which fits the conventional protocol for most biological indices. BSI values for a given species can be compared across Gulf estuaries, and may prove to be a useful tool for population management. Similarly, BSI values for the total system nekton community may be summed and compared to other estuaries' ΣBSI's to provide a measure of relative assemblage zone use and salinity sensitivity.

It is important to note that disparities in BSI values across estuaries may not always translate into different salinity sensitivities. Differences may be attributed to variations in species' abundances and/or distributions within the bio-based salinity zones. As an example, Table 8 summarizes the BSI for ELMR species in Galveston Bay.

Factor Development

Consensus was reached on the use of seven factors that characterize the bio-sensitivity of Gulf of Mexico estuaries to changes in salinity. Five of these factors were species-specific BSI values and two were added by the breakout group. The five species of concern were: *brown*, *white*, and *pink shrimp*, along with *spotted seatrout* and the *American oyster*. The two supplemental factors were the abundance of *submerged aquatic vegetation* (SAV), and the *ecological resiliency* (natural and man-made capacity to handle changes in freshwater inflow) of an estuary.

The species-based BSI values were calculated prior to the workshop and presented to the biological breakout group as an overall BSI ranking for each of the 25 estuaries with both living resource and salinity data available. The BSI characterizes two components of estuary biosensitivity: 1) a use function, based on a species' temporal occurrence and relative abundance in an estuary; and 2) a habitat function, based on the use of biologically derived salinity zones and a species salinity range, or affinity, across each zone.

Species. The biological breakout group decided to drop the ranking of estuaries by the overall BSI index and use the BSI for individual species values in each bay. The "indicator" species were selected based on geographic representation across the Gulf of Mexico (except South Florida) and variation in salinity preferences. Table 9 shows the BSI index for biosensitivity for each species as translated to high, moderate, or low sensitivity to changes in salinity. The individual "indicator" species ranking was almost identical to the summed overall estuary BSI ranking.

Submerged Aquatic Vegetation. The group proposed ranking estuaries based on the relative abundance of SAV. The assumption was that SAV is important habitat that is sensitive to changes in freshwater inflow. Based on their expertise and knowledge, the group assigned high, moderate, and low relative abundance rankings of SAV for each estuary, as shown in Table 9.

Ecological Resiliency. This factor was based on the group's knowledge of the potential response of Gulf of Mexico estuarine ecosystems to changes in salinity. This factor had two components: 1) an estuary's natural ability to mitigate/respond to changes in salinity based on species community composition; and 2) the infrastructure available to regulated freshwater inflow.

The BSI was not available for estuaries south of Tampa Bay; however, consensus was that the southwest Florida estuaries are highly sensitive to potential changes in salinity regimes, and that therefore received a combined ranking of high.

Table 8. *Biosalinity index for Galveston Bay, Texas*

SUMMARY DATA

SPECIES	Total Area	(P.A) Preferred Area	Total Zones = 4 Zones Used	BSI
Bay scallop	587	454	V	0.12
American oyster	587	587	II,III,IV,V	0.79
Atlantic rangia	587	404	II,III,IV	0.41
Quahogs	587	563	III,IV,V	0.45
Bay squid	587	563	III,IV,V	0.48
Brown shrimp	587	587	II,III,IV,V	0.35
Pink shrimp	587	587	II,III,IV,V	0.16
White shrimp	587	587	II,III,IV,V	0.70
Daggerblade grass shrimp	587	587	II,III,IV,V	0.94
Spiny lobster	587	0	none	0.00
Blue crab	587	587	II,III,IV,V	0.80
Gulf stone crab	587	563	III,IV,V	0.45
Stone crab	587	0	none	0.00
Bull shark	587	587	II,III,IV,V	0.23
Tarpon	587	587	II,III,IV,V	0.20
Alabama shad	587	0	none	0.00
Gulf menhaden	587	587	II,III,IV,V	0.45
Yellowfin menhaden	587	0	none	0.00
Gizzard shad	587	587	II,III,IV,V	0.30
Bay anchovy	587	587	II,III,IV,V	0.94
Hardhead catfish	587	587	II,III,IV,V	0.57
Sheepshead minnow	587	587	II,III,IV,V	0.80
Gulf killifish	587	587	II,III,IV,V	0.80
Silversides	587	587	II,III,IV,V	0.74
Snook	587	454	IV,V	0.23
Bluefish	587	587	II,III,IV,V	0.06
Blue runner	587	454	IV,V	0.31
Crevalle jack	587	587	II,III,IV,V	0.45
Florida pompano	587	454	IV,V	0.04
Gray snapper	587	454	IV,V	0.05
Sheepshead	587	587	II,III,IV,V	0.60
Pinfish	587	587	II,III,IV,V	0.40
Silver perch	587	587	II,III,IV,V	0.60
Sand seatrout	587	587	II,III,IV,V	0.68
Spotted seatrout	587	587	II,III,IV,V	0.59
Spot	587	587	II,III,IV,V	0.65
Atlantic croaker	587	587	II,III,IV,V	0.87
Black drum	587	587	II,III,IV,V	0.60
Red drum	587	587	II,III,IV,V	0.60
Striped mullet	587	587	II,III,IV,V	0.80
Code goby	587	454	IV,V	0.31
Spanish mackerel	587	587	II,III,IV,V	0.13
Gulf flounder	587	454	IV,V	0.13
Southern flounder	587	587	II,III,IV,V	0.59

Biologically based Salinity Zones

Salinity Zone	Range (ppt.)
I	0.0-0.5
II	0.5-8.0
III	5.0-16.0
IV	16.0-25.0
V	>25.0

Table 9. *Biology group rankings*

Estuary Code	Estuary Name	Brown Shrimp BSI	White Shrimp BSI	Pink Shrimp BSI	Spotted Seatrout BSI	Oyster BSI	SAV Abundance	Ecological Resiliency	Total	Rank	Bin Rank
	Southwest Florida Ecosystems										H
G210	Atchafalaya/Vermilion Bays	5	3	5	5	5	3	5	31	1	H
G140	Perdido Bay	5	5	1	3	5	5	5	29	2	H
G290	Corpus Christi Bay	5	5	3	3	5	3	5	29	3	H
G162	Lake Pontchartrain	1	1	5	5	5	5	5	27	4	H
G250	Brazos River	3	3	5	5	5	5	1	27	5	H
G280	Aransas Bay	5	5	3	5	3	3	3	27	6	H
G190	Barataria Bay	3	3	5	5	1	5	3	25	7	H
G220	Calcasieu Lake	5	3		3	3	5	5	24	8	H
G310	Lower Laguna Madre	3	5	3	3	5	1	3	23	9	H
G100	Apalachicola Bay	5	1	1	5	1	5	3	21	10	M
G130	Pensacola Bay	3	3	3	3	5	3	1	21	11	M
G170	Breton/Chandeleur Sounds	5	5	3	1	1	3	3	21	12	M
G200	Terrebonne/Timbalier Bays	3	3	5	1	1	5	3	21	13	M
G240	Galveston Bay	1	5	5	3	1	5	1	21	14	M
G300	Upper Laguna Madre	3	5	3	3	5	1	1	21	15	M
G230	Sabine Lake	3	1		5	3	5	3	20	16	M
G120	Choctawhatchee Bay	5	3	1	1	3	3	3	19	17	M
G161	Lake Borgne	1	1	5	1	3	5	3	19	18	M
G080	Suwannee River		5	3	1	1	3	3	16	19	L
G110	St. Andrew Bay	1	5	1	1	5	1	1	15	20	L
G150	Mobile Bay	3	1	3	1	3	3	1	15	21	L
G160	Mississippi Sound	1	1	1	1	3	5	3	15	22	L
G260	Matagorda Bay	1	1	3	5	1	3	1	15	23	L
G270	San Antonio Bay	1	1	5	3	1	3	1	15	24	L
G070	Tampa Bay			1	3	3	3	1	11	25	L
G090	Apalachee Bay		1	3	3	1	1	1	10	26	L

Key: H = High Biosensitivity = 5; M = Moderate Biosensitivity = 3; L = Low Biosensitivity = 1

Appendix 4: List of Participants

Tom Ballou Jr.
Sherwin Alumina Plant - Reynolds Metal Co.
P.O. Box 9911
Corpus Christi, TX 78469
(512) 777-2352 FAX (512) 777-2218

Clyde Brown
10808 Pecan Road
Pascagoula, MS 39581
(601) 475-2382 FAX (601) 475-5555

George Crozier
Dauphin Island Sea Laboratory
P.O. Box 369
Dauphin Island, AL 36528
(334) 861-2882 FAX (334) 861-4646

Fred Deegan
Mississippi Department of Marine Resources
2620 Beach Boulevard
Biloxi, MS 39531
(601) 385-5880 FAX (601) 385-5864

Mike Durako
Florida Department of Environmental Protection
Florida Marine Research Institute
100 8th Ave. SE
St. Petersburg, FL 33701
(813) 896-8626 FAX (813) 823-0166

Ernie Estevez
Mote Marine Laboratory
1600 Thompson Parkway
Sarasota, FL 34236
(813) 388-4441 FAX (813) 388-4312

Sid Flannery
Southwest Florida Water Management District
2379 Broad Street
Brooksville, FL 34609
(904) 796-7211 FAX (904) 754-6885

John Good
Suwannee River Water Management District
Route 3, Box 64
Live Oak, FL 32060
(904) 362-1001 FAX (904) 362-1056

Jay Grymes
Louisiana State University Office of State Climatology
254 Howe-Russel Complex
Baton Rouge, LA 70803-4105
(504) 388-5021 FAX (504) 388-2912

Tom Herrington
U.S. Food and Drug Administration
c/o USEPA Gulf of Mexico Program Office
Building 1103
Stennis Space Center, MS 39529-6000
(601) 688-3726 FAX (601) 688-2709

Charles Hunsicker
Manatee County Public Services
P.O. Box 25010
Bradenton, FL 32406
(813) 792-8811 FAX (813) 795-3490

Ken Jones
Northwest Florida Water Management District
Route 1, Box 3100
Havana, FL 32333
(904) 539-5999 FAX (904) 539-4380

Graham Lewis
Northwest Florida Water Management District
Route 1, Box 3100
Havana, FL 32333
(904) 539-5999 FAX (904) 539-4380

Robert Mattson
Suwannee River Water Management District
Route 3, Box 64
Live Oak, FL 32060
(904) 362-1001 FAX (904) 362-1056

Teresa McTigue
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
411 East St. Mary Blvd., Room 453
Lafayette, LA 70503
(318) 482-5915 FAX (318) 482-6630

Bruce Moulton
Texas Natural Resources Conservation Commission
12100 Park 35 Circle, Building F
Austin, TX 78711-3087
(512) 239-4809 FAX (512) 239-4808

Gary Powell
Texas Water Development Board
1700 North Congress, Suite 455
Austin, TX 78711-2321
(512) 936-0823 FAX (512) 936-1488

Drew Puffer
Gulf of Mexico Program Office
U.S. Environmental Protection Agency
Building 1103, Room 202
Stennis Space Center, MS 39529-6000
(601) 688-3913 FAX (601) 688-2709

Susan Rees
U.S. Army Corps of Engineers, Planning Division
109 St. Joseph Street
Mobile, AL 36602
(205) 694-4141 FAX (205) 690-2424

Yvonne Stoker
U.S. Geological Survey
4710 Eisenhower Blvd (B-5)
Tampa, FL 33634
(813) 243-5800 FAX (813) 243-5806

Erick Swenson
Coastal Ecology Institute
Center for Wetlands Research
Louisiana State University
Baton Rouge, LA 70803
(504) 388-6454 FAX (504) 388-6326

George Ward
Center for Research in Water Resources
PRC, Building 119
University of Texas
Austin, TX 78758
(512) 471-0114 FAX (512) 471-0072

John Weber
U.S. Army Corps of Engineers, CELMN-PD-R
Foot of Prytania Street
New Orleans, LA 70118
(504) 862-2516 FAX (504) 862-2572

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