FRESHWATER INFLOWS TO TEXAS BAYS AND ESTUARIES: A REGIONAL-SCALE REVIEW, SYNTHESIS, AND RECOMMENDATIONS

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Outline

- How I got started
- Regulatory environment
- What we have learned over 30+ years
- New Book
  - Synthesis Efforts
  - Management solutions
  - Engagement (StoryMap)

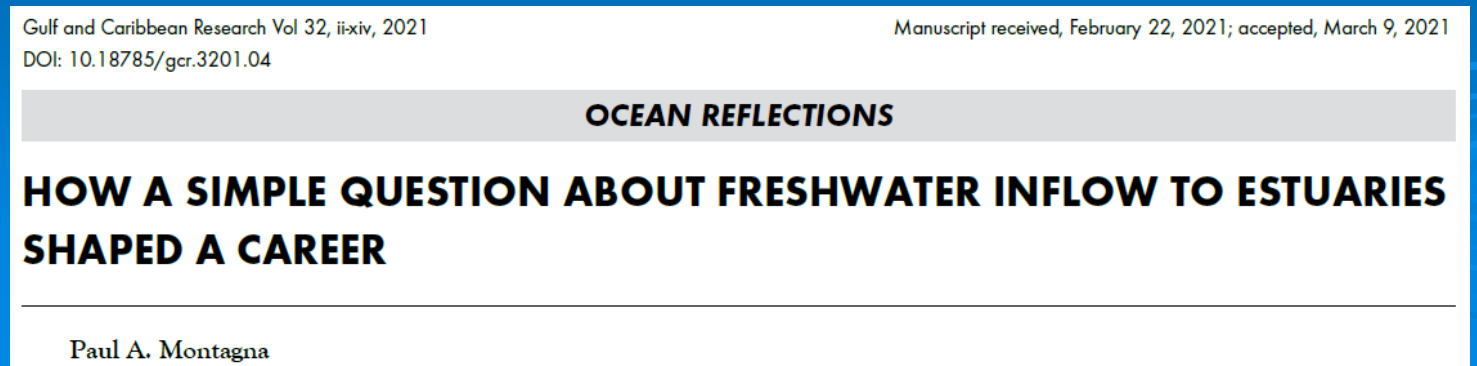
Wesley Seale Dam,
Lake Corpus Christi

A Simple Question by Gary Powell Started it all

Died 2MAR2013

- Summer of 1986, Gary (with Bob Jones) convened a group of new UTMSI scientists (Ed Buskey, Ken Dunton, Paul Montagna, Terry Whitledge), and existing staff (Tony Amos, Scott Holt, Rick Kalke, Peter Thomas)
- He asked a simple question:

  How much freshwater must flow into San Antonio Bay to maintain estuary health?



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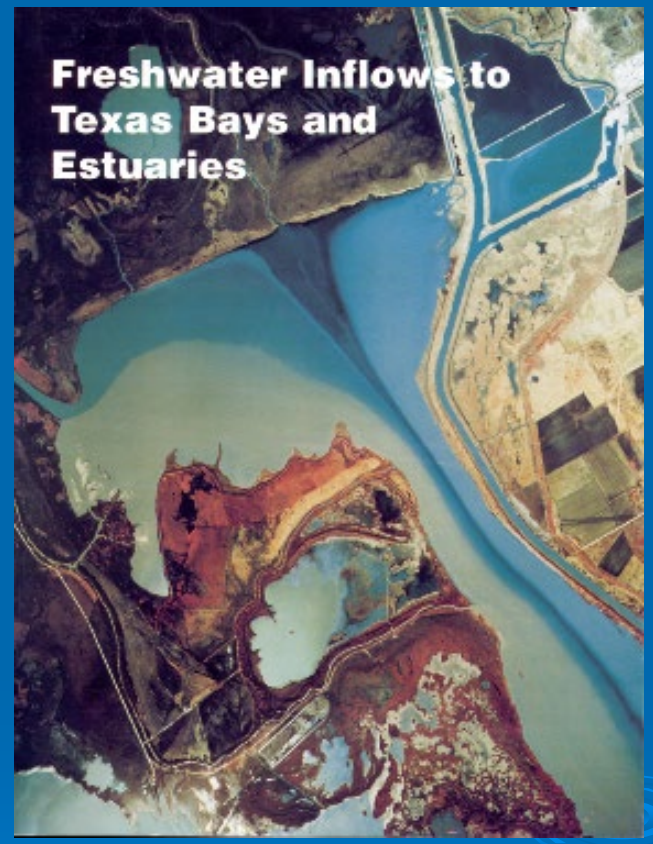
OCEAN REFLECTIONS

HOW A SIMPLE QUESTION ABOUT FRESHWATER INFLOW TO ESTUARIES SHAPED A CAREER

Paul A. Montagna

Culminated In a Synthesis

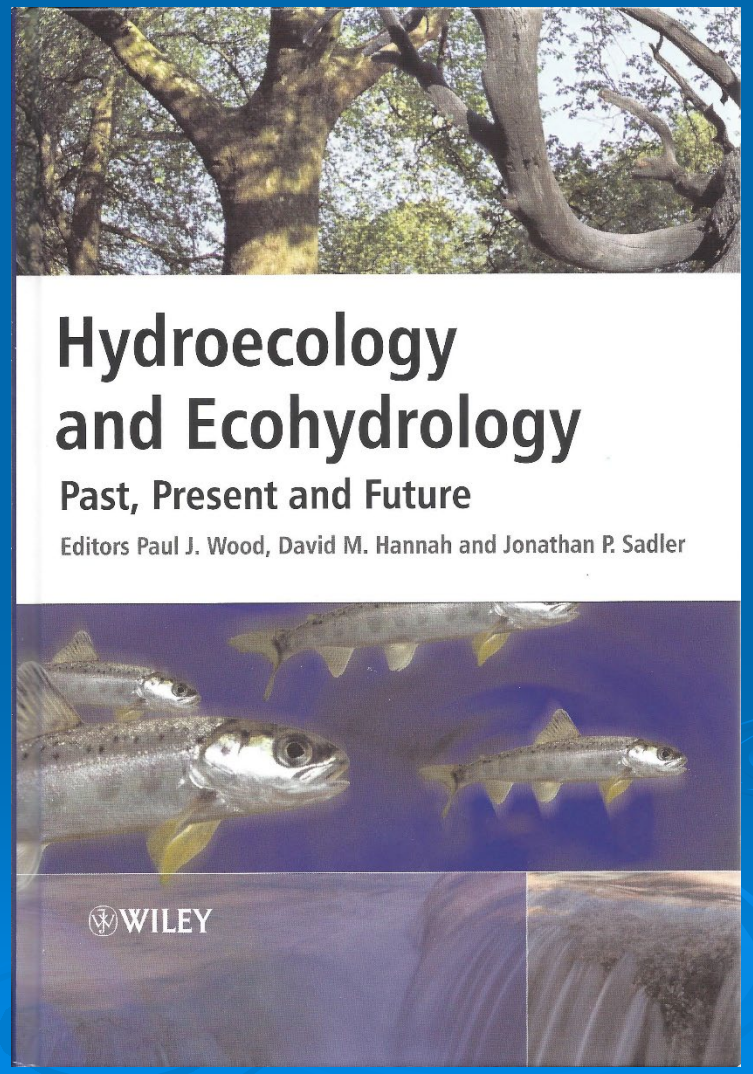
- *Freshwater Inflow to Texas Bays and Estuaries*
  - *Ecological Relationships and Methods for Determinations of Needs*
- William Longley (TWDB), Editor, 1994
- Jointly with TPWD
- Hydrology, Salinity, and TXBLEND everywhere in State
- Nutrient and sediment loading most places
- Detailed ecological process studies and TEXEMPT on San Antonio Bay only



A New Scientific Discipline is Born

- What I didn't realize, was that a whole new subdiscipline of ecology was being created
- An integrative science that provides a foundation for sustainable management of water resources
- Textbook in 2007
- Journal *Ecohydrology* established in 2008

2008

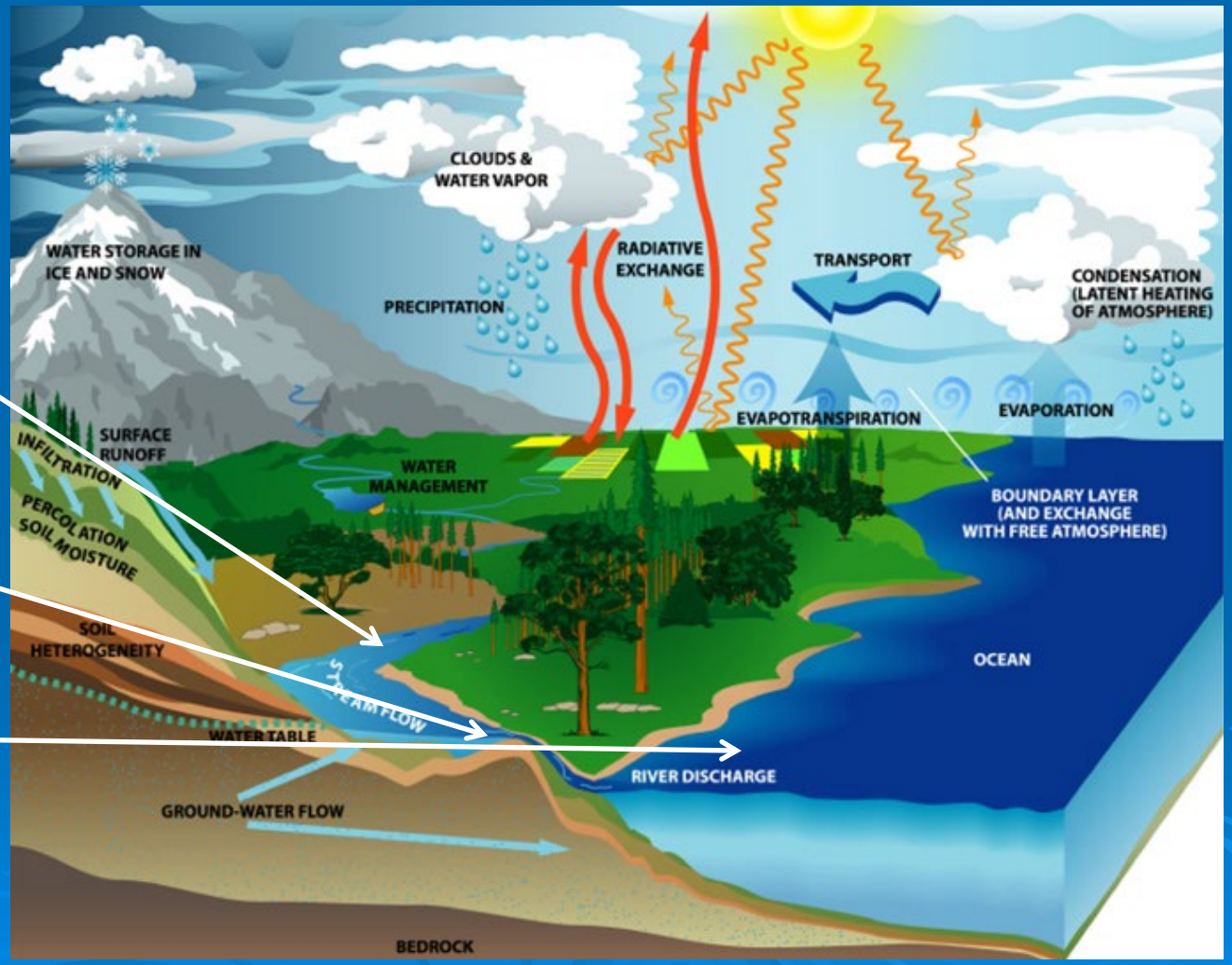


2007

Defining Environmental Flow

Definitions

- Instream: flow within streams and rivers
- Inflow: from rivers to estuaries
- Outflow: from estuaries to the coastal ocean



Difference in Instream vs. Inflow Approaches

- Freshwater systems: Flow defines habitat

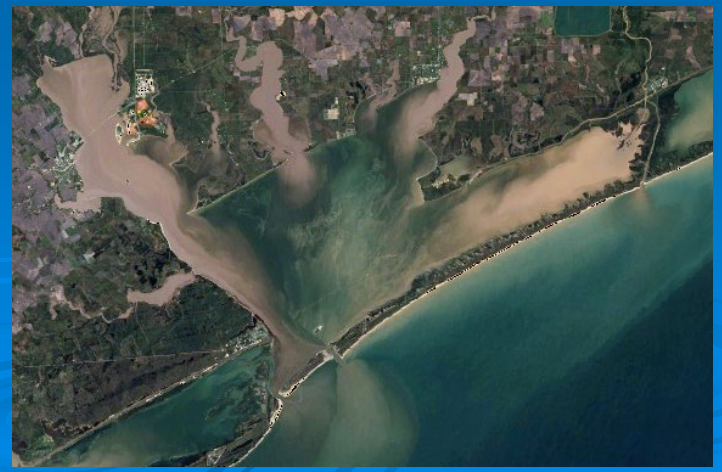

Rapid


Riffle


Run

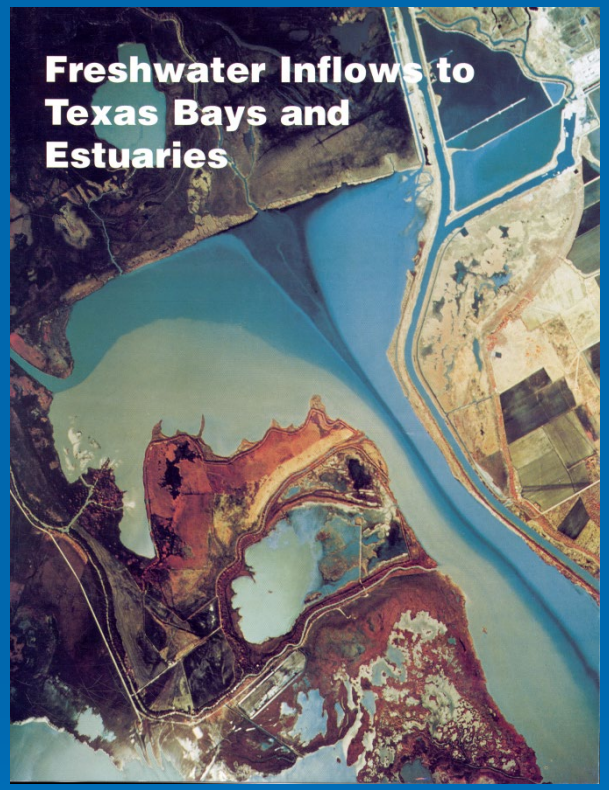

Pool

- Coastal waters: Flow defines conditions and conditions create estuary habitat

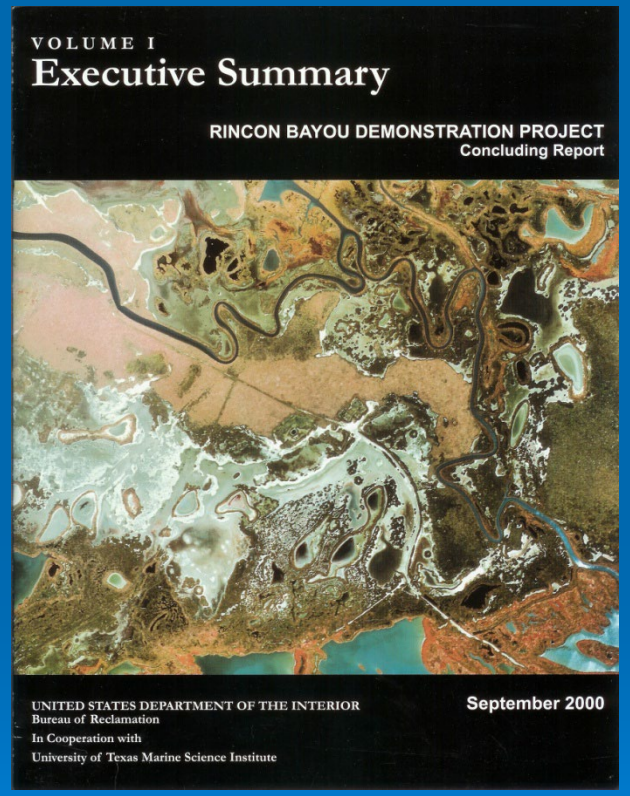


Turbidity plumes in Lavaca and Matagorda Bays after a flood

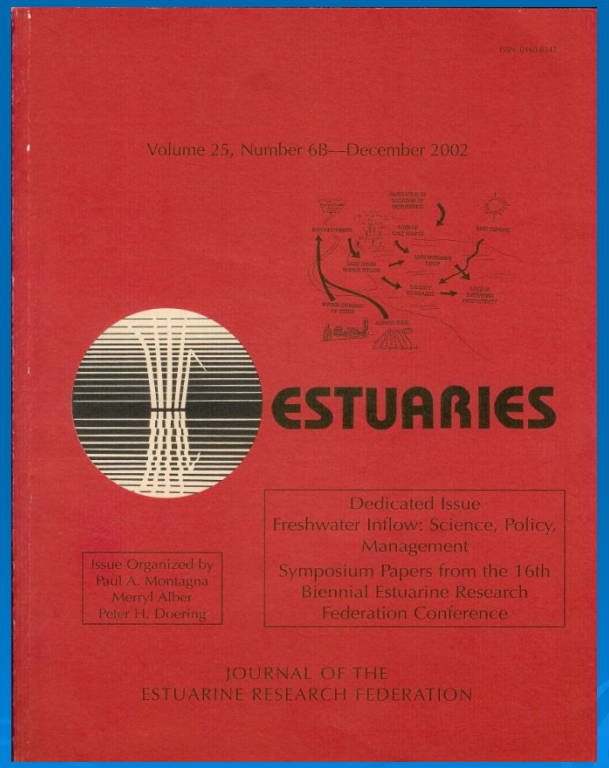
Previous Synthesis Efforts



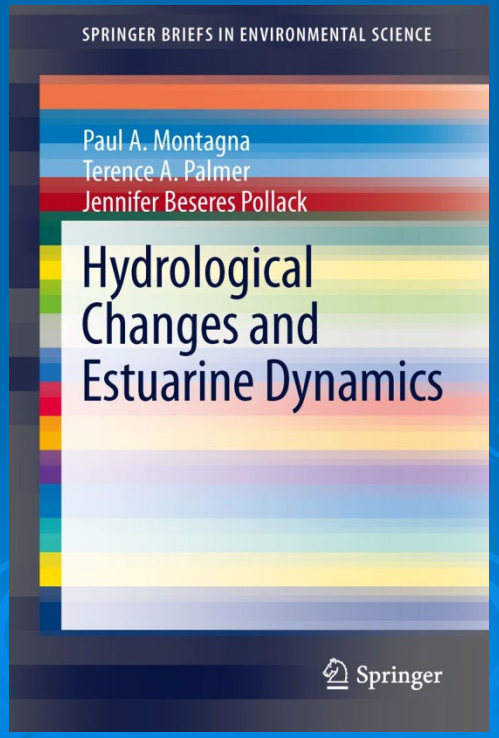
1995



2000



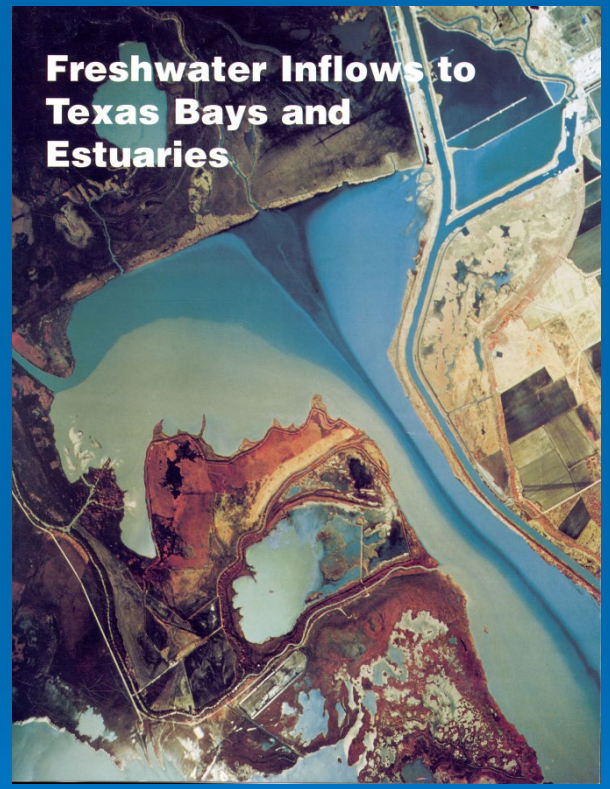
2002



2013

Need For a New Synthesis

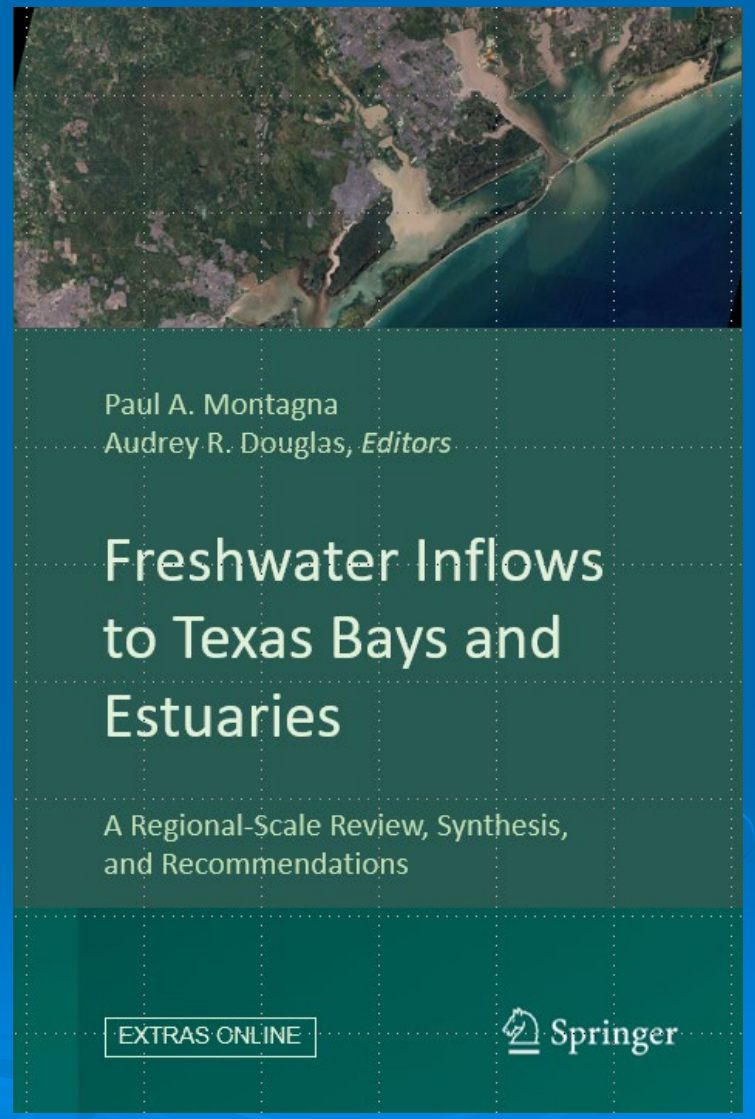
- Although published in 1995, latest data was from 1989
  - Lots of new data since 1989
- BBEST and BBASC reports since 2009
  - For every system
- Adaptive Management Studies since 2014



- It was time to put it all together!

Next Steps – Updated Synthesis

- Publish a new edition of “Freshwater Inflow to Texas Bays and Estuaries”
  - Legal framework is SB3, not HB2
  - Management goal now different
  - Methodology now different
  - 30 years of new data
  - Support adaptive management
  - Common, easily accessible historical data
  - Products that span beginners to experts
- Started April 2021, submitted Jan 2024



Cover Mock-up

Freshwater Inflow to Texas Bays & Estuaries

- 17+ chapters & 34 authors/co-authors:

Preface/Foreword/Acknowledgements. P.A. Montagna

1. Introduction - History of Inflow Studies in Texas. P. A. Montagna, W.L. Longley, E.A. Gomaa & J.C. Brown
2. Historical Perspective and Context of Freshwater Inflow Policy and Law in Texas. Myron J. Hess
3. Climate Effects on Inflows. J. Nielsen-Gammon & A.A. Tarter
4. Hydrology, Circulation, and Salinity. D. Opdyke, J. Hoffmann, P.A. Montagna & J.F. Trungale
5. Groundwater-Surface Water Interactions in the Coastal Zone. A.R. Douglas & D. Murgulet
6. Influence of Inflows on Estuary Sediments. A.R. Douglas, P.A. Montagna & T. Dellapenna
7. Nutrient-Phytoplankton Dynamics in Texas Estuaries. M.S. Wetz, L. Beecraft, M. McBride, J.L. Steichen & A. Quigg
8. Physical and Biogeochemical Conditions and Trends in Texas Estuaries. X. Hu & H. Yin
9. Coastal Wetland Habitats in Texas. J.C. Gibeaut, P.A. Montagna, J. Magolan & P. Huang
10. Submerged Aquatic Vegetation, Marshes, and Mangroves. K.A. Capistrant-Fossa, B.E. Batterton and K.H. Dunton

Freshwater Inflow to Texas Bays & Estuaries

- 17+ chapters & 34 authors/co-authors:

10. Submerged Aquatic Vegetation, Marshes, and Mangroves. K.A. Capistrant-Fossa, B.E. Batterton and K.H. Dunton
11. Effect of Freshwater Inflow on Benthic Infauna. P.A. Montagna, R.D. Kalke & L.J. Hyde
12. Effects of Climate-Driven Salinity Regimes on Oyster Disease Dynamics at Local and Regional Scales. K.B. Savage, T.A. Palmer, P.A. Montagna & J. Beseres Pollack
13. Plankton Dynamics in Texas Estuaries. A. Quigg, J.L. Steichen, L. Beecraft & M.S. Wetz
14. Nekton and Mobile Epibenthos. D.M. Coffey, G.W. Stunz & P.A. Montagna
15. Nitrogen and Phosphorous Budgets for Texas Estuaries. D.A. Marshall & P.A. Montagna
16. Social and Economic Values of Environmental Flows to the Coast. D.W. Yoskowitz
17. Summary of Recommendations for the Future. P.A. Montagna & A.R. Douglas

- Extras: Online supplements, data, documents, and oral histories
- StoryMap

Chapter 2:History of Inflow Legislation in Texas

- 1985: House Bill 2
  - Established data collection programs necessary to “support a sound ecological environment”
    - Protected 7 species: White shrimp, brown shrimp, blue crab, oyster, red drum, spotted seatrout, black drum
  - 1994: *Freshwater Inflow to Texas Bays and Estuaries*

- 2007: Senate Bill 3
  - Required environmental flow regime standards for geographic segments state-wide
  - Standard must be “adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats . . .”
  - Standards adopted between 2011 - 2014

Current Texas Law: Senate Bill 3 (2007)

- Basin-specific Standards
- Science-based Environmental Flow Objectives
- Local Stakeholder Process to Balance Water Needs

- Certainty for Water Rights Permit Applicants
- Follow-up Adaptive Management on 10-year cycles

SB3 Standards are Complex

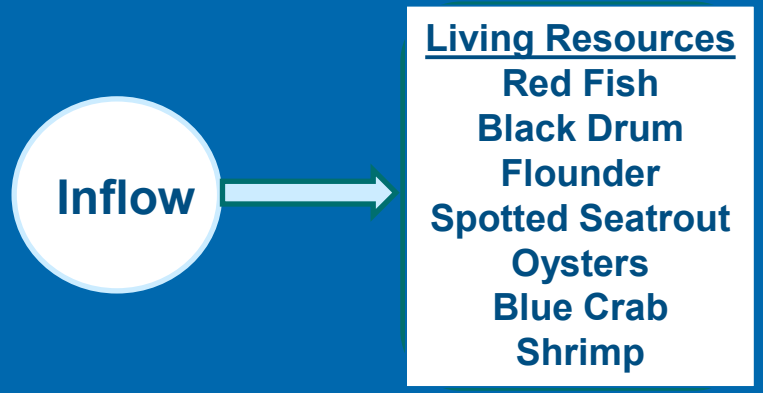
TCEQ - Chapter 298g - Environmental Flow Standards for Brazos River and its associated Bay and Estuary System. USGS Gage 08116650, Brazos River near Rosharon

Season	Subsistence	Hydrologic Condition	Base	Dry Condition Seasonal Pulse	Average Condition Seasonal Pulse	Wet Condition Seasonal Pulse
Winter	430 cfs	Dry	1,140 cfs	1 per season Trigger: 9,090 cfs Volume: 94,700 af Duration: 12 days	3 per season Trigger: 9,090 cfs Volume: 94,700 af Duration: 12 days	2 per season Trigger: 13,600 cfs Volume: 168,000 af Duration: 16 days
		Average	2,090 cfs			
		Wet	4,700 cfs			
Spring	430 cfs	Dry	1,250 cfs	1 per season Trigger: 6,580 cfs Volume: 58,500 af Duration: 10 days	3 per season Trigger: 6,580 cfs Volume: 58,500 af Duration: 10 days	2 per season Trigger: 14,200 cfs Volume: 184,000 af Duration: 18 days
		Average	2,570 cfs			
		Wet	4,740 cfs			
Summer	430 cfs	Dry	930 cfs	1 per season Trigger: 2,490 cfs Volume: 14,900 af Duration: 6 days	3 per season Trigger: 2,490 cfs Volume: 14,900 af Duration: 6 days	2 per season Trigger: 4,980 cfs Volume: 39,100 af Duration: 9 days
		Average	1,420 cfs			
		Wet	2,630 cfs			

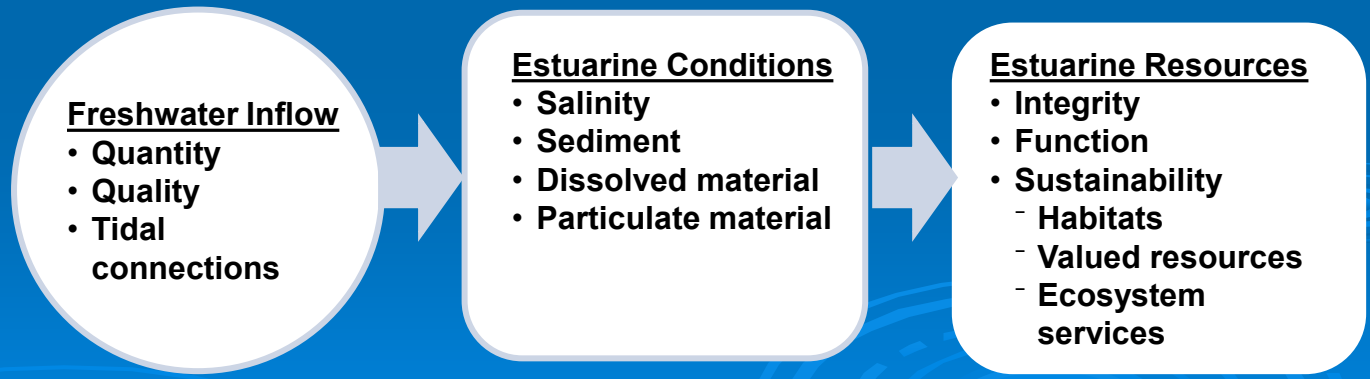
- 3-Dimensions:
  1. Climatic condition (dry, average, and wetaa0
  2. Season
  3. Hydrologic condition (subsistence, base, and pulse flows)
- Based on statistical analysis of past flows
- Geography is the 4th dimension

Chapter 1: History of Inflow Science in Texas

- Reflects two major eras:
  - 1985 HB2
    - Influenced by riverine studies
    - Species-based approach

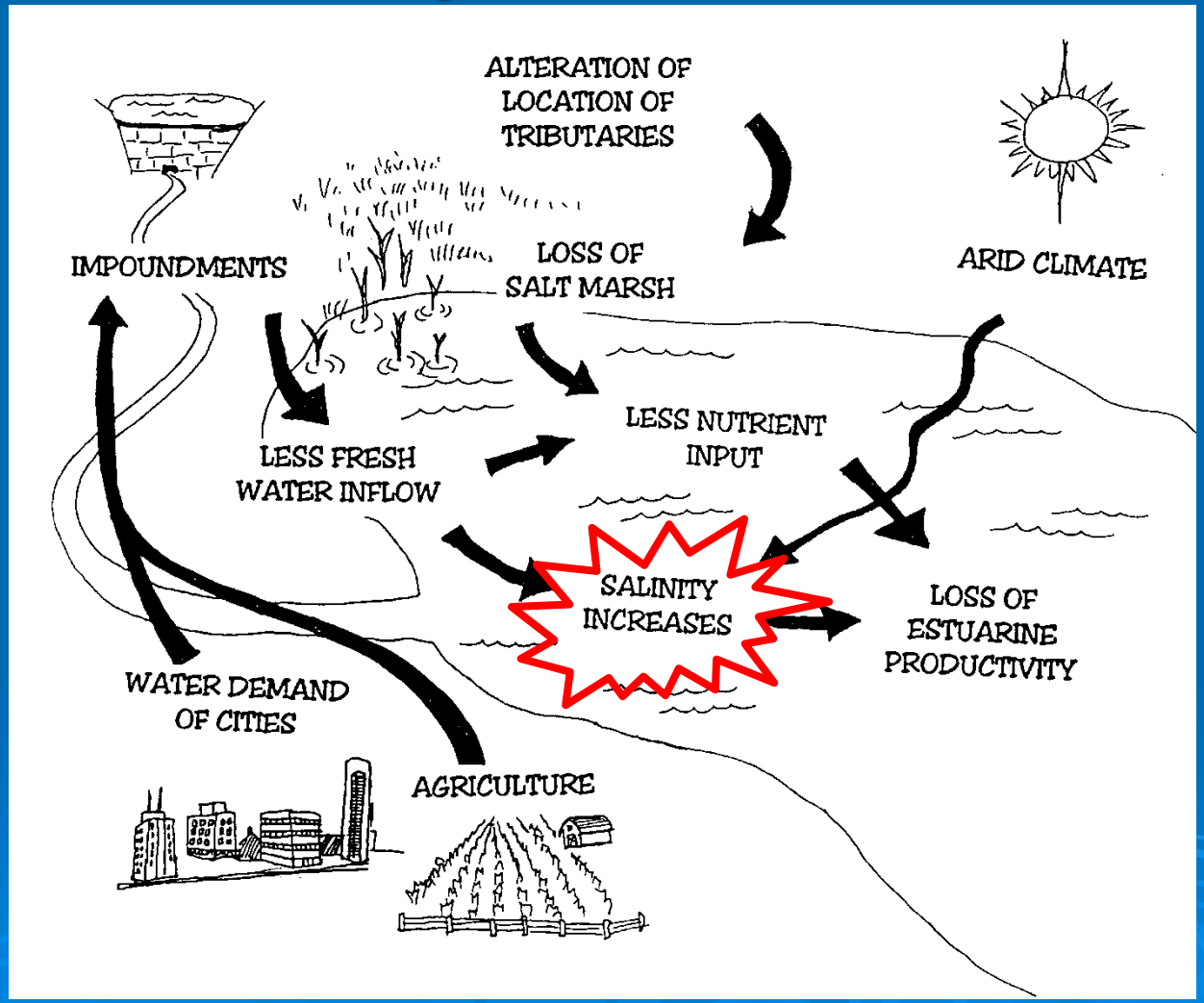


  - 2007 SB3
    - Evolving estuary science
    - Ecosystem-based approach



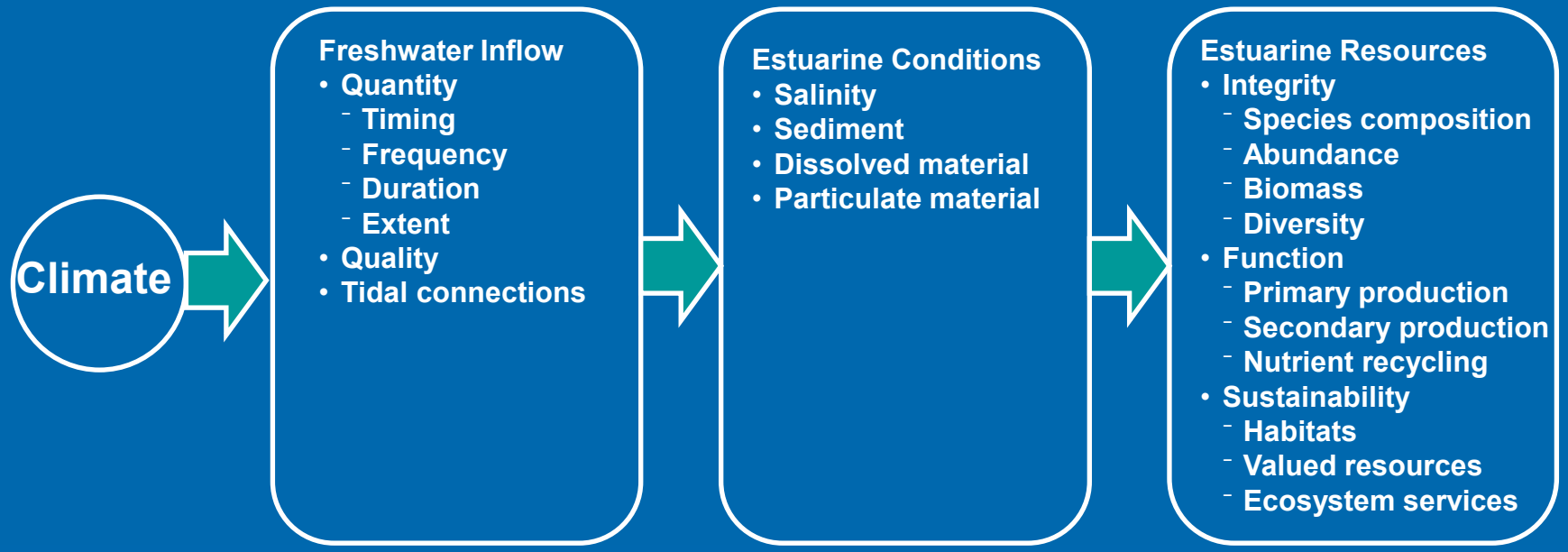
Chapter 1: Altered Freshwater Inflow Changes Coastal Bays & Estuaries

- Changes:
  - Hydrology
  - Nutrients
  - Sediments
  - Salinity
- Loses:
  - Habitat
  - Biodiversity
  - Productivity
  - Ecosystem Services



Source: Montagna et al. 1996, CCBNEP #8
http://cbbep.org/publications/virtuallibrary/ccbnep08.pdf

Chapter 1: Inflow Has Indirect Effects on Biological Resources: "Domino Theory"



Evolution of the idea:

- Alber (2002) *Estuaries* 25:1246-1261 https://doi.org/10.1007/BF02692222
- Science Advisory Committee (2009) Methodologies for Establishing a Freshwater Inflow Regime https://hdl.handle.net/1969.6/94344
- Palmer et al. (2011) *Hydrobiologia* 667:49-67 https://doi.org/10.1007/s10750-011-0637-0
- Montagna et al. (2013) *Hydrological Change and Estuarine Dynamics* https://doi.org/10.1007/978-1-4614-5833-3
- Montagna (2021) *Gulf and Caribbean Research* 32:14 pp. https://doi.org/10.18785/gcr.3201.04

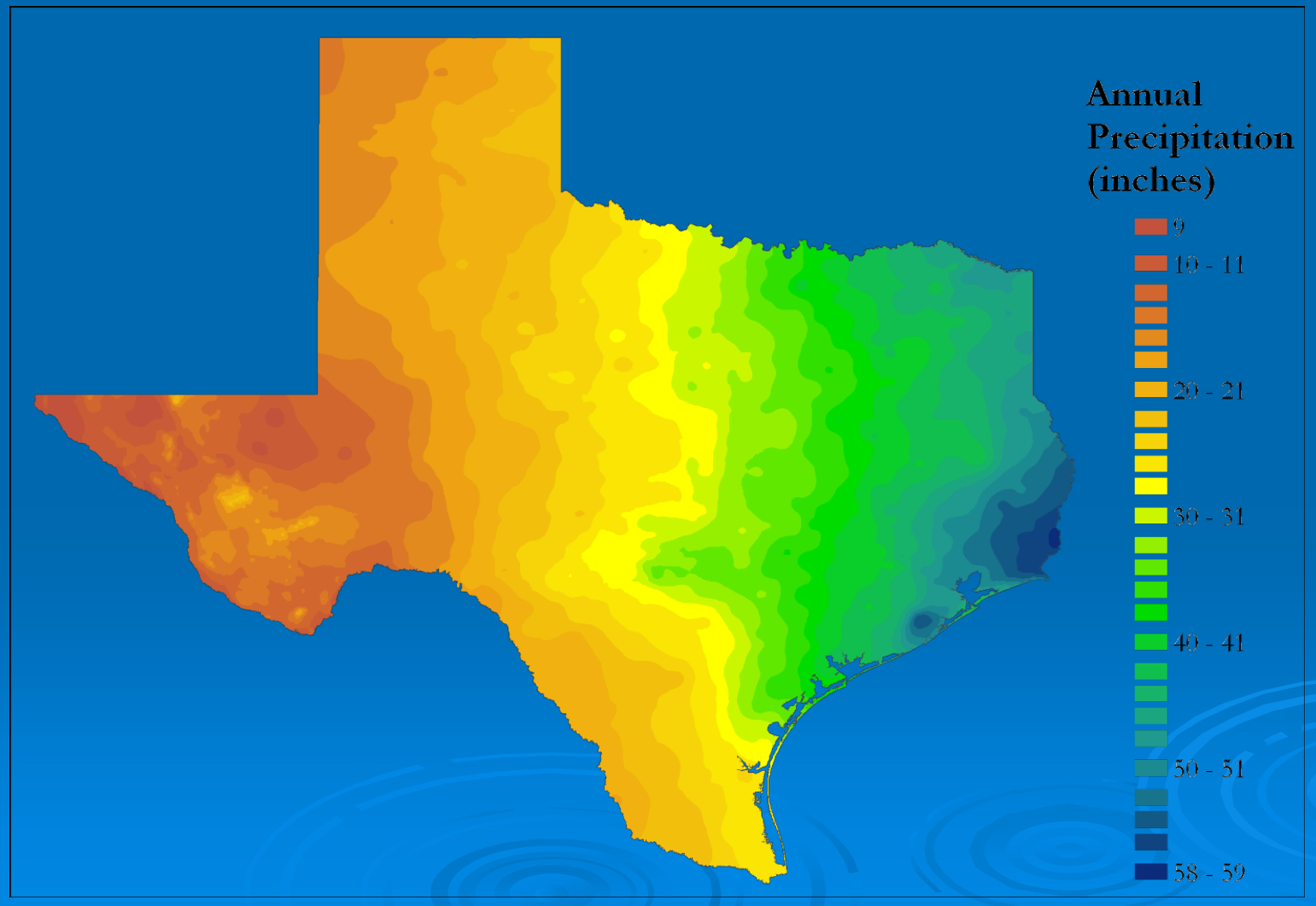
Chapter 1: Texas Estuary Science
What Have We Learned in 30+ Years?

- Approach has evolved:
  - From direct to indirect effects on consumers
  - From species to ecosystem-based management
  - From system-focused to estuary comparisons
- There are now many quantitative tools:
  - Max-bin regression
  - Percent of flow approach
  - Productivity model
  - Community structure/salinity habitat model
  - Water quality models
  - Water quality coupled to flow models

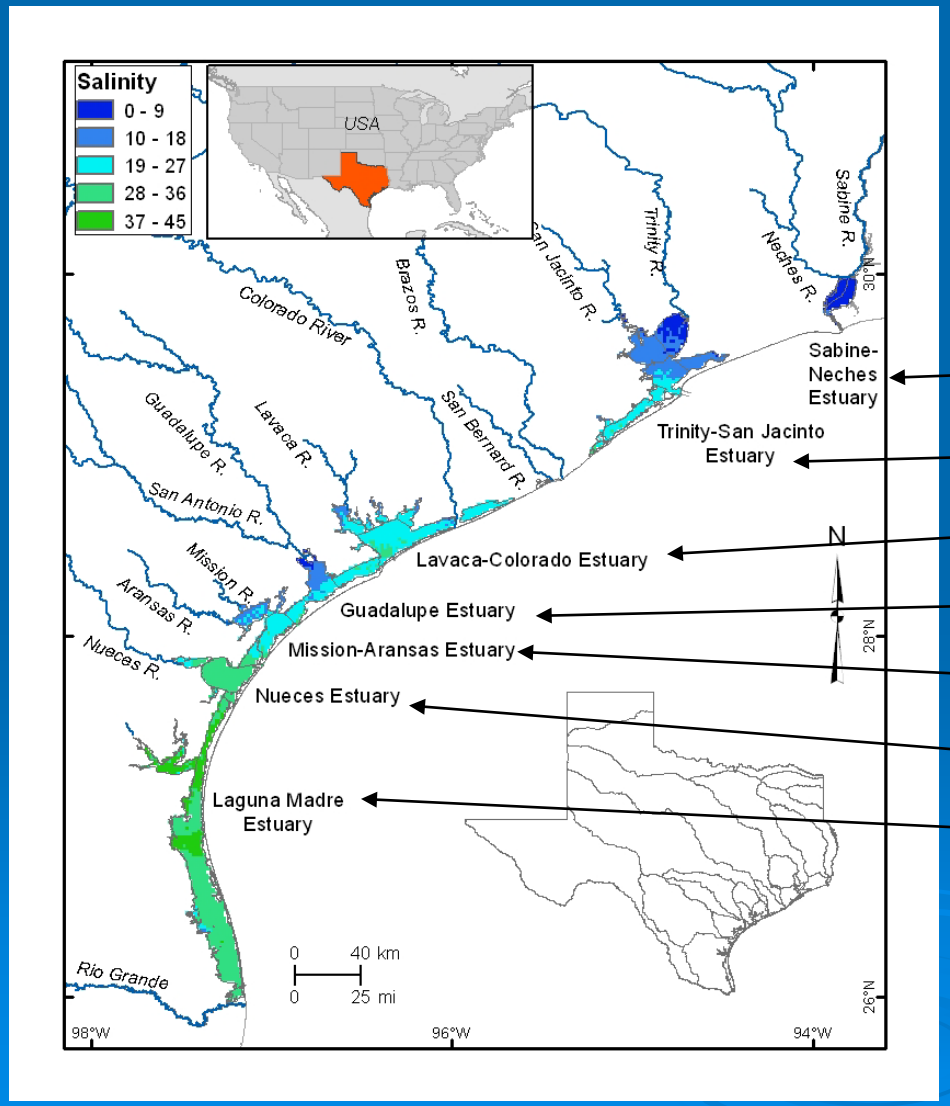
Chapter 1: Texas Estuary Science
What Have We Learned in 30+ Years?

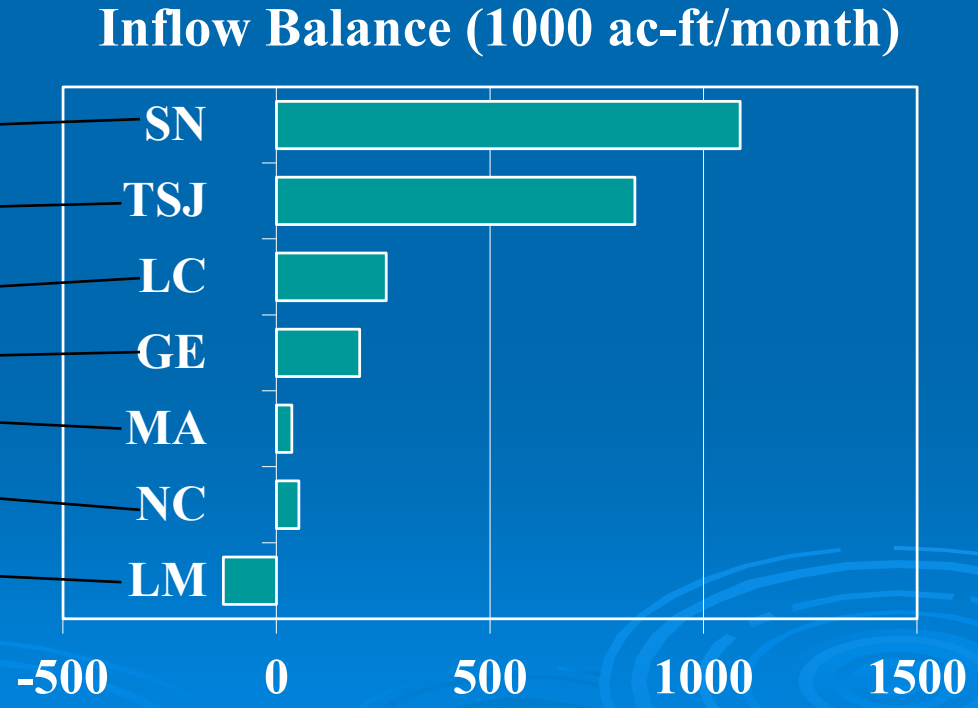
- Inflow controls community structure and productivity
  - Salinity zones define estuary habitat
  - More flow means more community and functional diversity
  - Freshwater residence time drives process rates
- Management implications
  - Have developed quite a few products and tools
  - Community structure and functional groups change dramatic
  - Restoration works
  - Manage for refuges in upper parts of estuaries during droughts, i.e., small volumes matter

Chapter 1: Introduction
Rainfall Gradient From East to West in Texas



Chapter 1: Texas Coast-Wide Inflow Gradient Provides a Perfect Natural Experiment

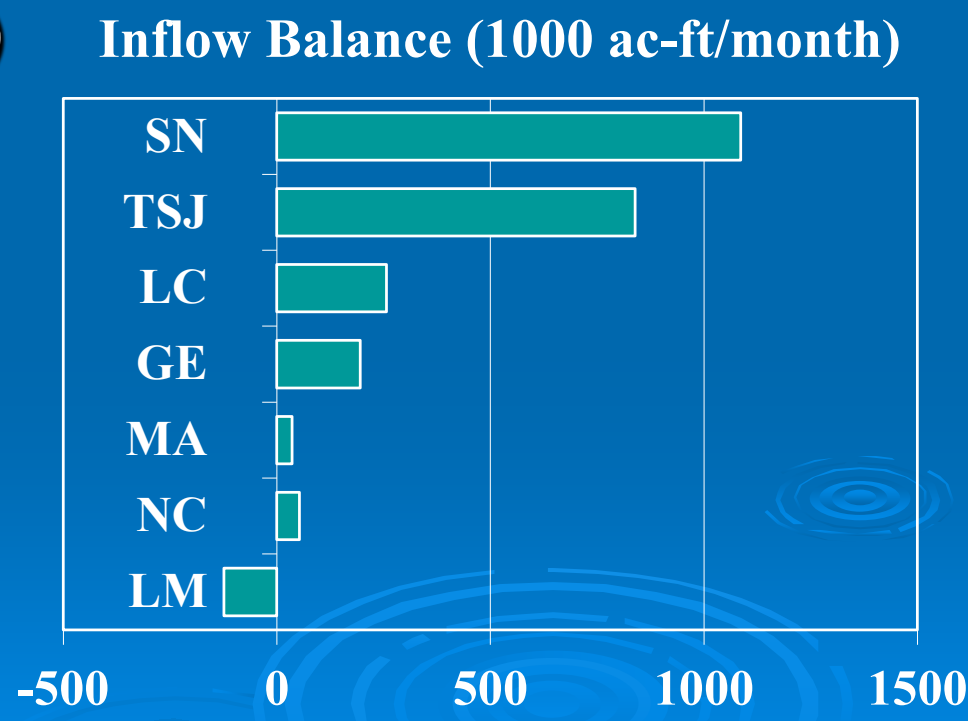




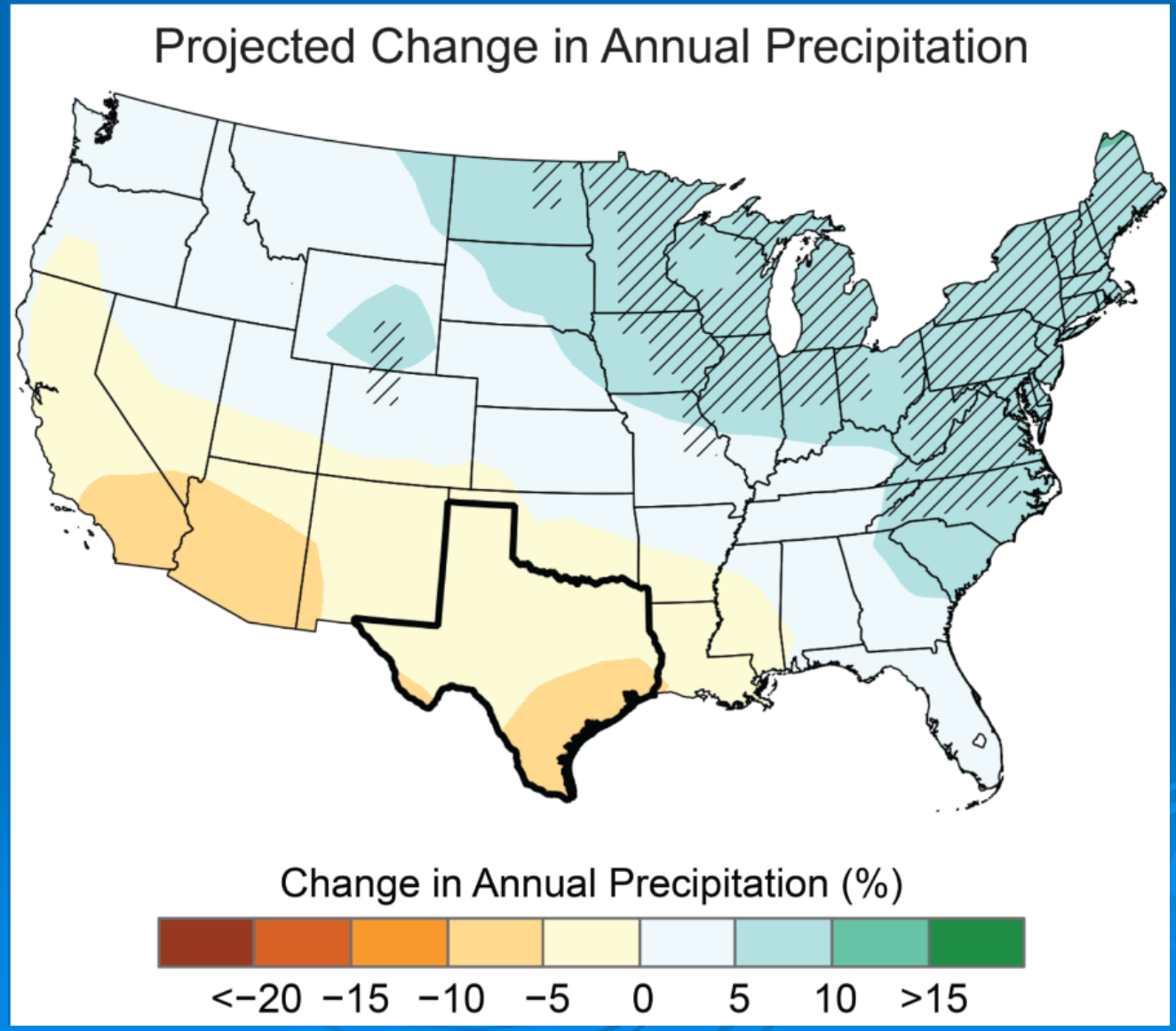
Inflow (TWDB): 1941-2009
Salinity (TPWD): 1977-2015

Chapter 1: Texas Estuary Comparisons

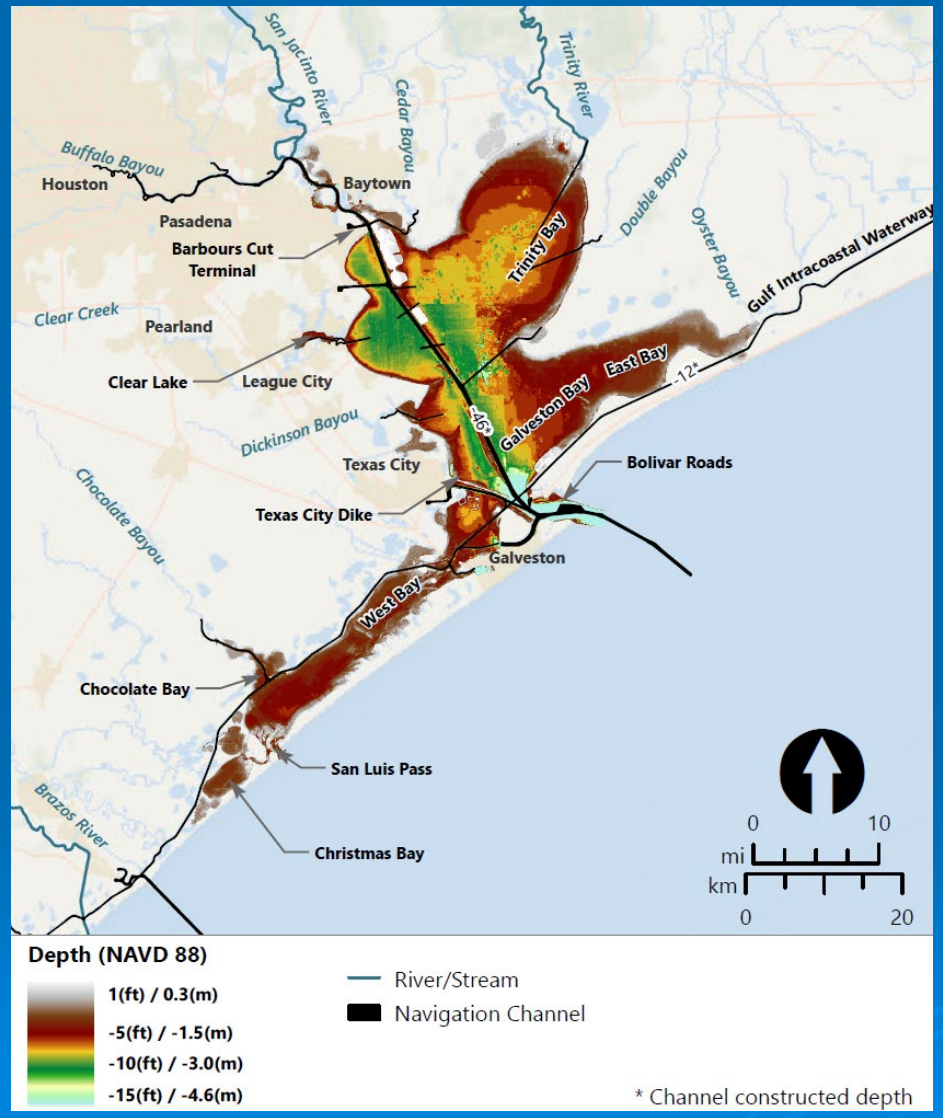
- The climatic gradient provides a perfect natural experiment replicated at the treatment level
  - 2 highly positive estuaries (SN and TSJ)
  - 2 positive estuaries (LC and GE)
  - 2 neutral estuaries (MA and NC)
  - 2 negative estuaries (UL and LL)



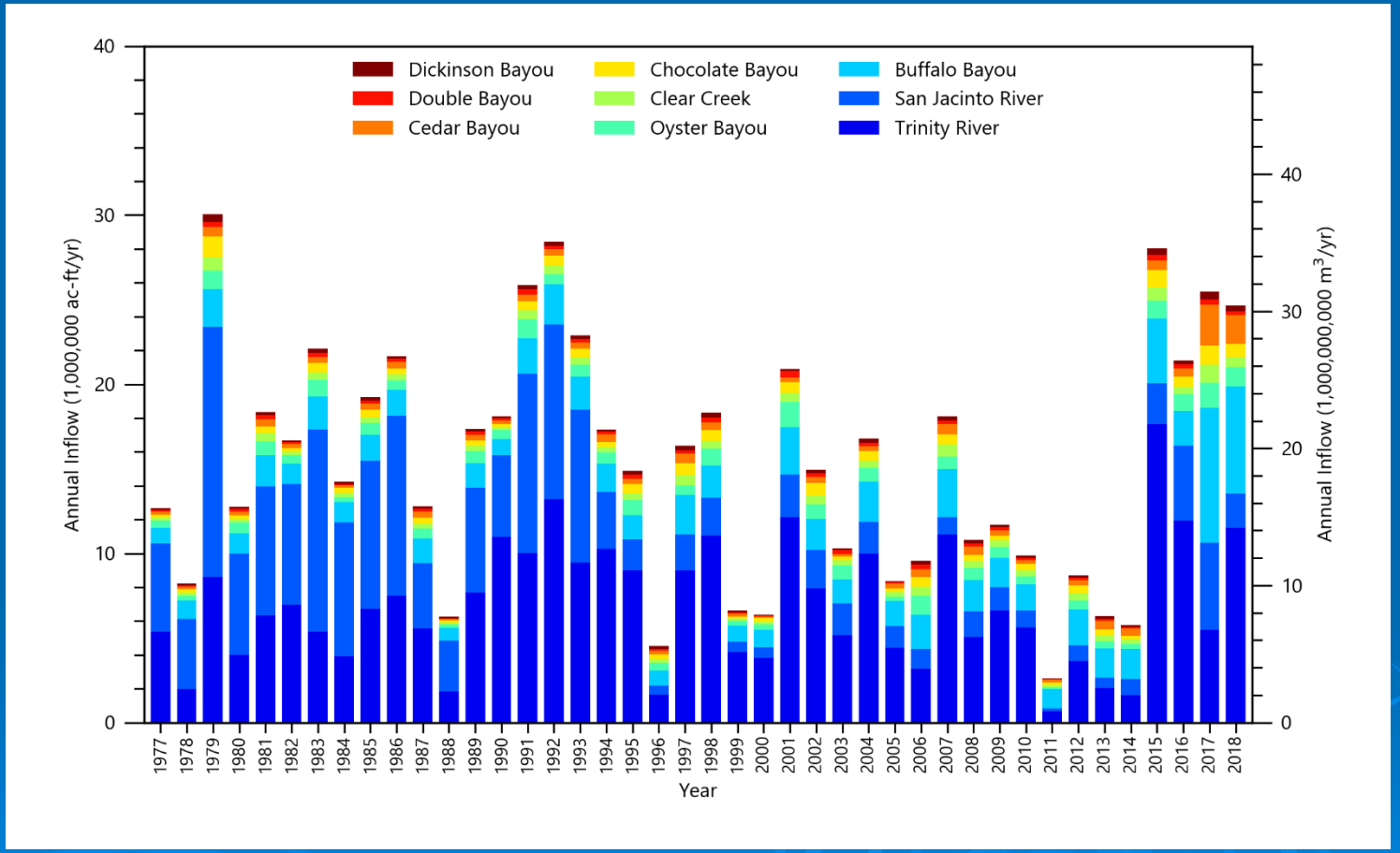
Chapter 3: Climate



Chapter 4: Hydrology, Circulation, Salinity

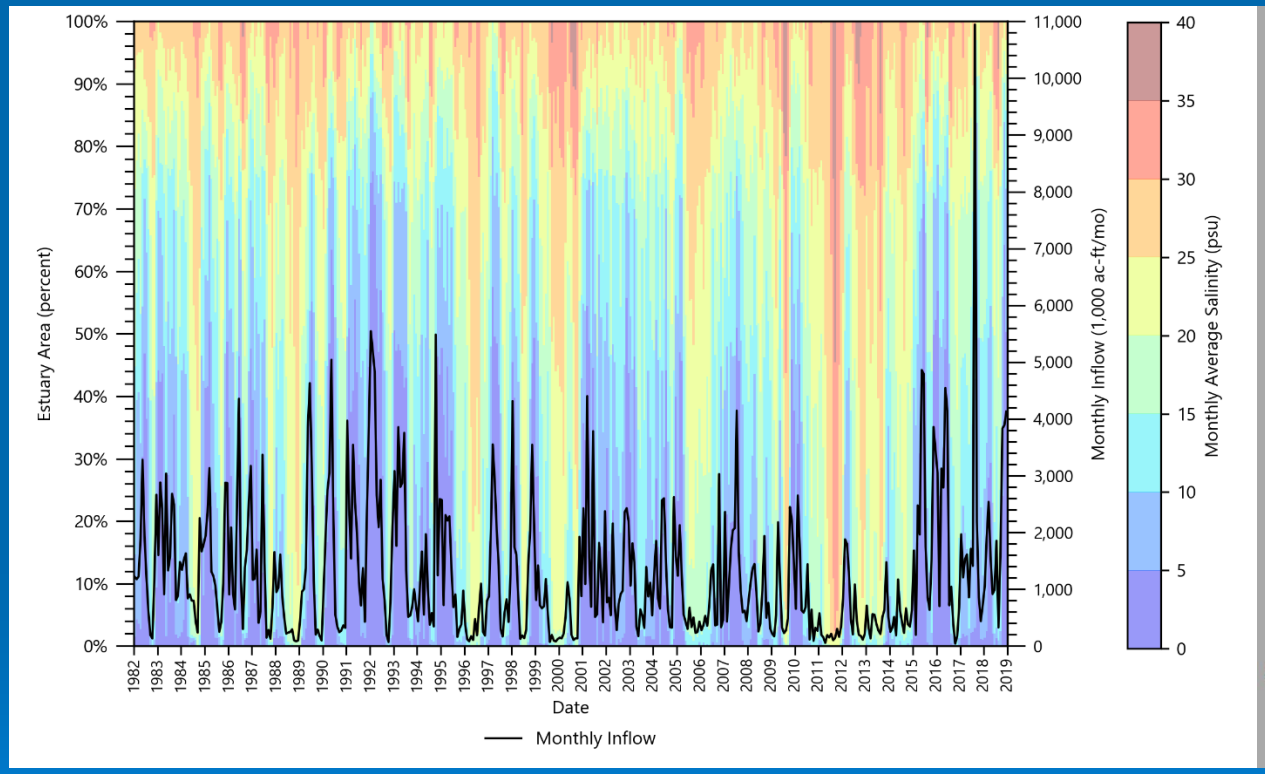


High resolution bathymetry

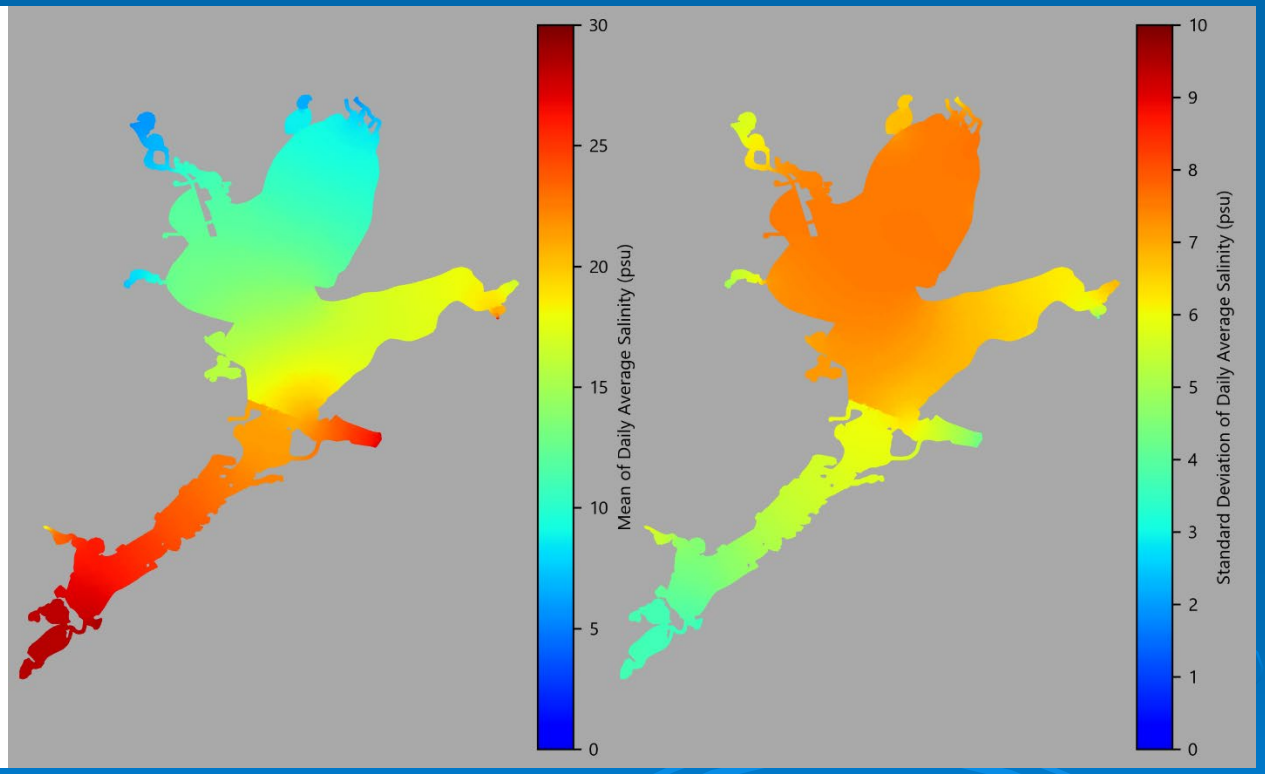


Inflow from all sources

Chapter 4: Hydrology, Circulation, Salinity



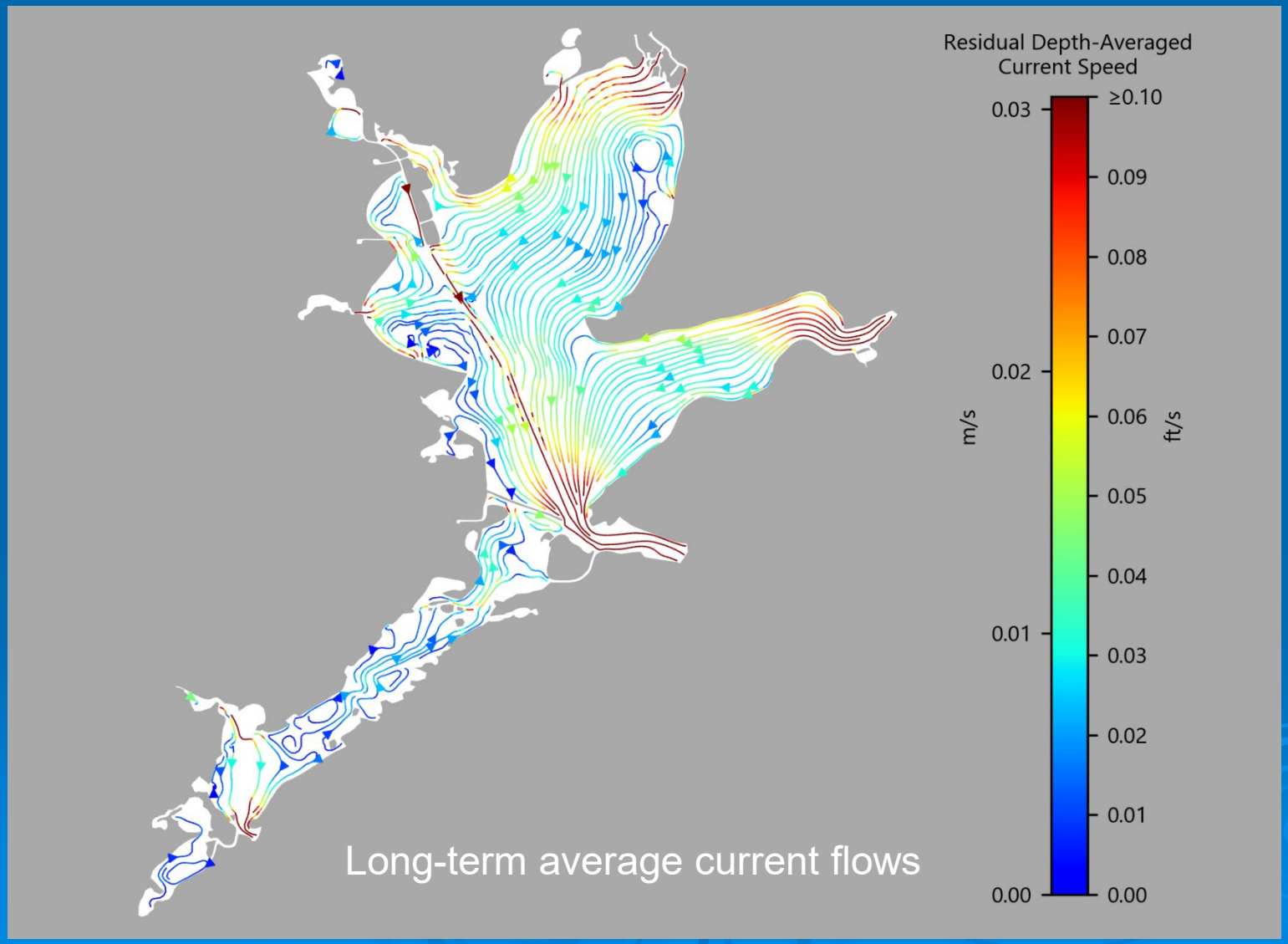
Percent area of salinity zone over time



Overall salinity mean

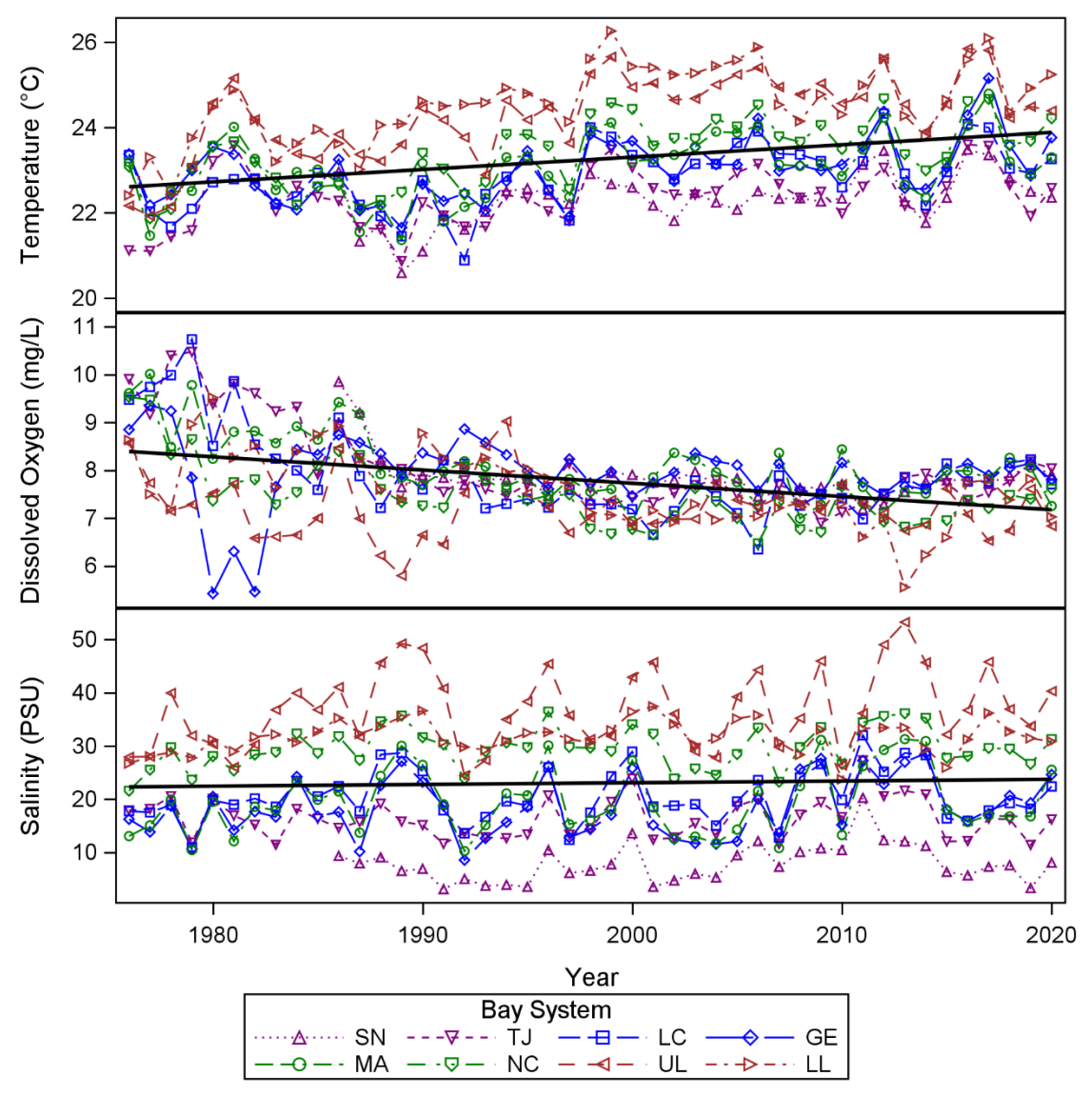
Overall salinity variance

Chapter 4: Hydrology, Circulation, Salinity



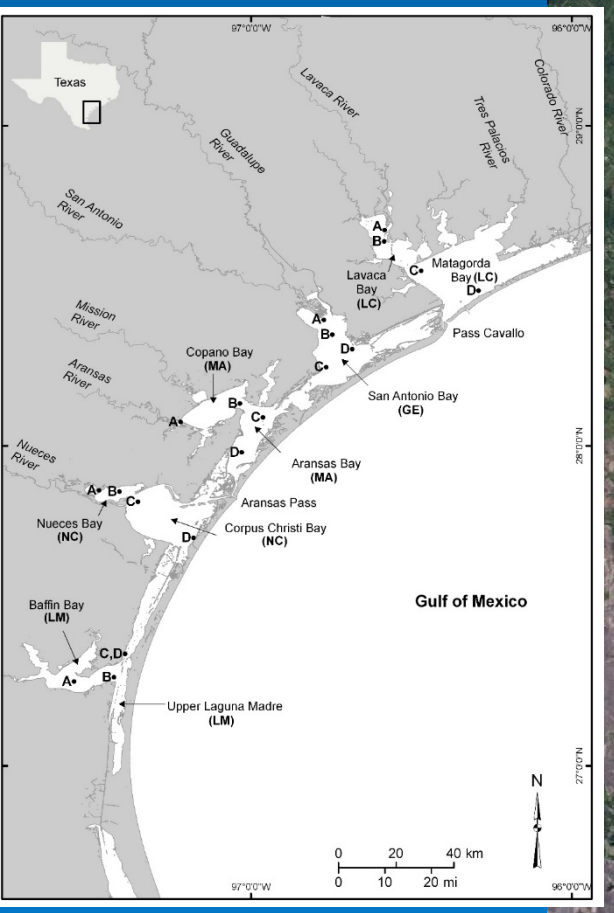
Long-term average current flows

Chapter 4: Hydrology, Circulation, Salinity



- Temperature increased 3% over 40+ years (P <0.0001)
- Dissolved Oxygen decreased 3% over 40+ years (P <0.0001)
- Salinity increased 3% 3% over 40+ years, but not significant (P = 0.44)
- HABITAT CHANGE!

Chapter 11: HRI Long-Term Studies



Gradient in turbidity during a flooding event indicates inflow differences

Lavaca-Colorado

Guadalupe

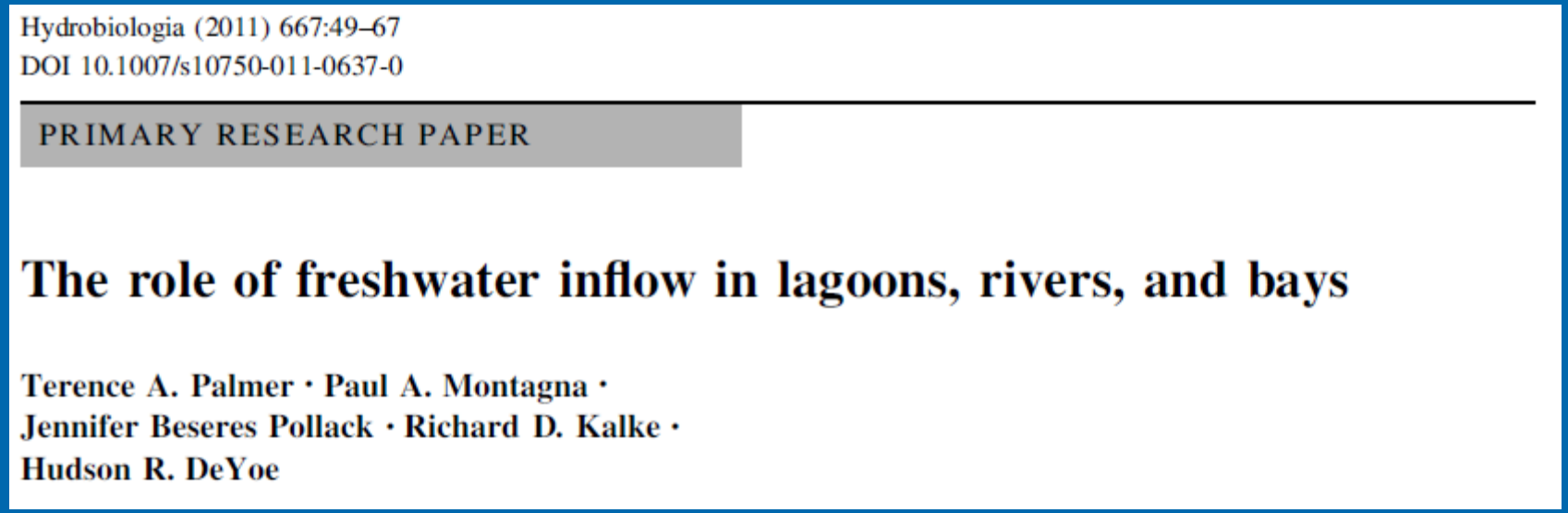
Mission-Aransas

Nueces

Measured water and sediment quality from 1987 to 2019 (32 years)

11.6.2002

Brazos River Monitoring (2001-2005)



Hydrobiologia (2011) 667:49–67
DOI 10.1007/s10750-011-0637-0

PRIMARY RESEARCH PAPER

The role of freshwater inflow in lagoons, rivers, and bays

Terence A. Palmer · Paul A. Montagna ·
Jennifer Beseres Pollack · Richard D. Kalke ·
Hudson R. DeYoe

- Compared 5 systems:
  - 3 River estuaries: Rio Grande, San Bernard River, and Brazos River
  - 4 Lagoon estuaries: Christmas Bay, Cedar Lakes, East Matagorda Bay, and South Bay Coastal Preserve
  - 2 major bays: Lavaca and Matagorda Bays

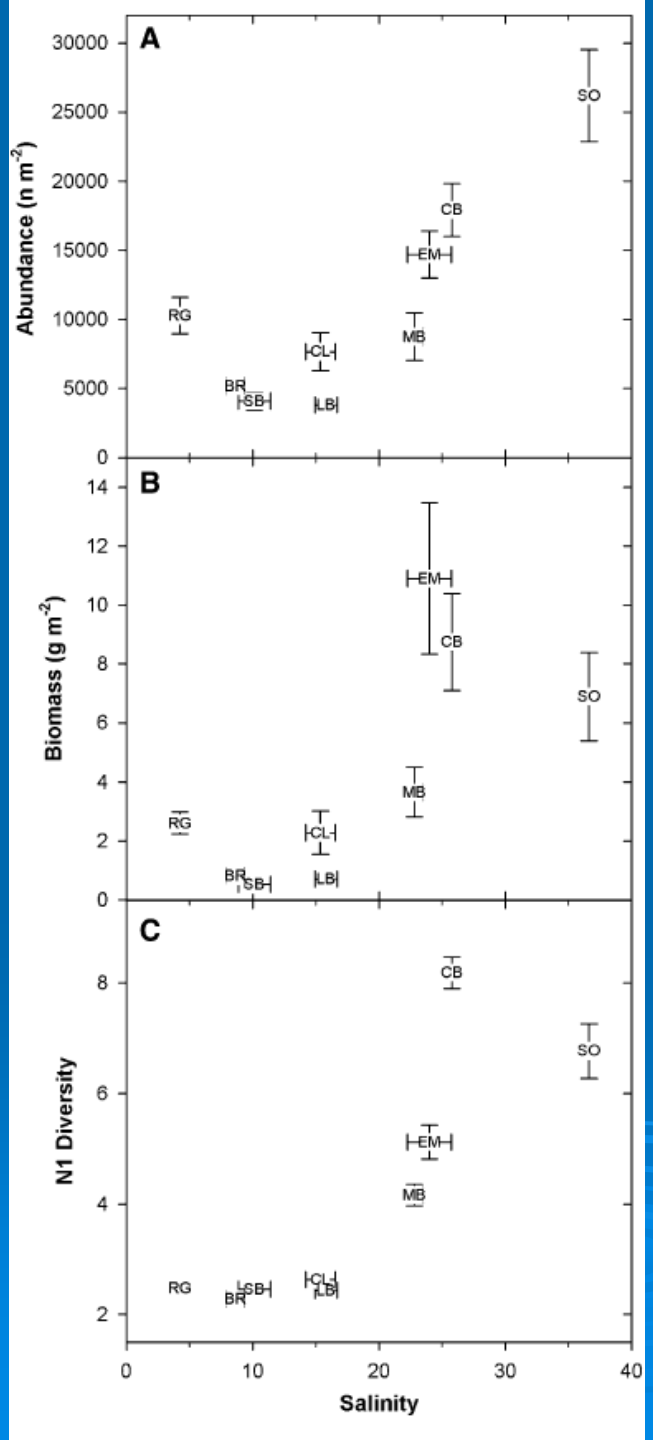
Rivers Have Highest Nutrients

System	Temperature (°C)	Salinity (psu)	DO (mg/L)	NH_4 (µM)	NO_{2+3} (µM)	PO_4 (µM)	Chl-a (µg/L)
Rio Grande	25.1	4.2	7.4	5.8	26.5	5.7	20.8
Brazos River	23.3	8.6	6.7	7.6	40.4	2.3	9.2
San Bernard River	23.0	10.1	7.2	6.3	16.8	2.7	6.5
Cedar Lakes	23.5	15.4	8.8	4.8	5.9	1.5	5.0
Lavaca Bay	21.9	15.8	7.3	1.4	3.6	1.3	8.8
Matagorda Bay	23.5	22.8	6.7	1.0	2.3	1.0	8.5
East Matagorda Bay	22.7	24.0	7.0	1.5	4.9	1.2	11.1
Christmas Bay	21.2	25.8	7.3	1.1	1.2	0.4	5.6
South Bay	25.0	36.6	6.9	5.1	0.8	0.2	2.7

- Nutrients correlated with low salinity
- Brazos River only system with high N:P ratio (18)
- Chlorophyll correlated with low salinity and high nutrients

Macrofauna

- Macrofauna abundance, biomass, and diversity is correlated with salinity
- Brazos relatively low in macrofauna because of low average salinity
- Flex point at about 20 psu

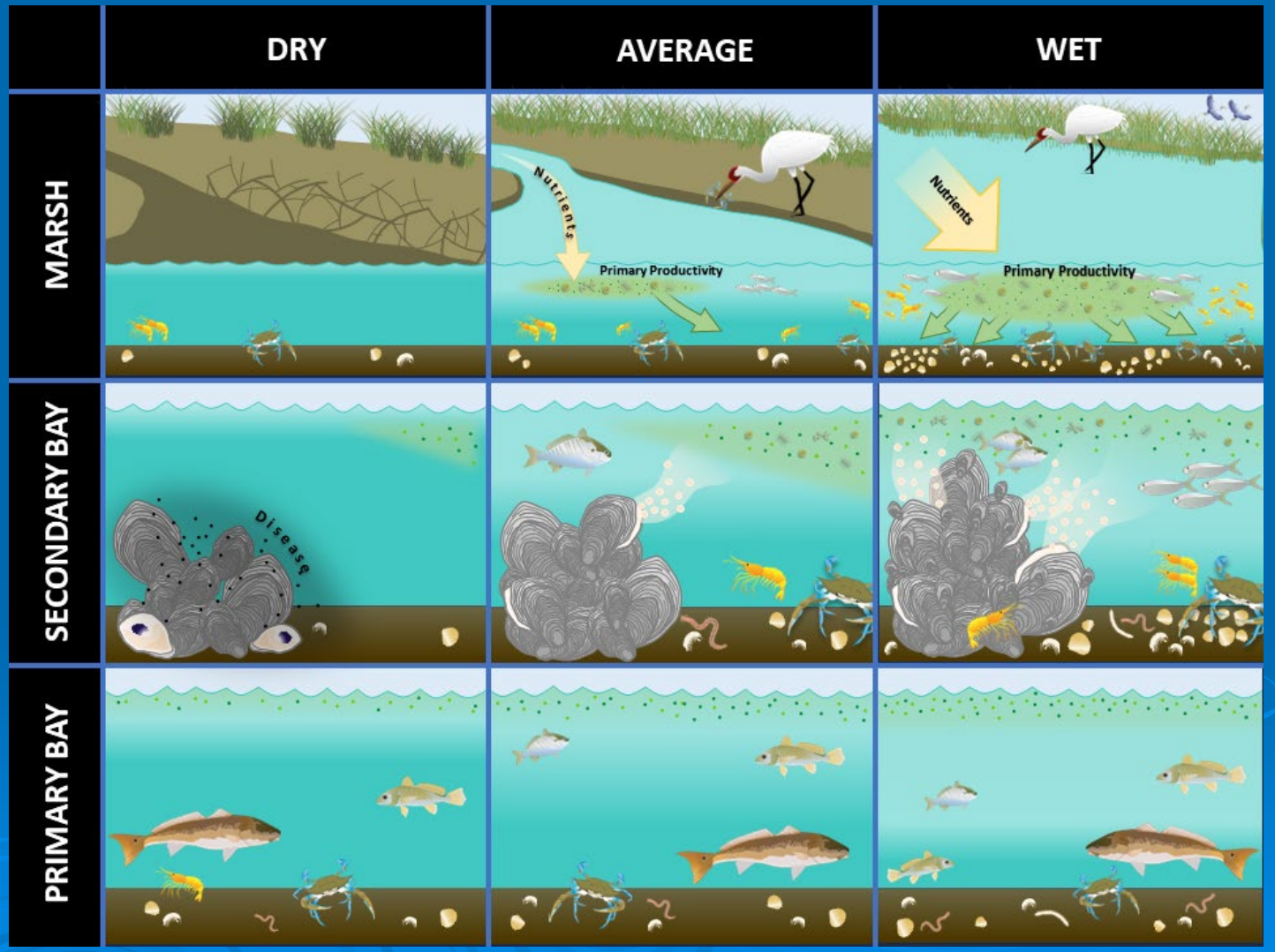


Chapter 16: Conclusion and Recommendations

- There is a lot of data, but little is focused to define estuary responses to inflow that connects physical characteristics and biological responses
  - State-wide monitoring approach is needed
- 3-D physics-based models of circulation needed
  - Updated bathymetry, shoreline locations, and salinity monitoring to calibrate and validate the models
- Mechanistic studies needed to link biological response to physical dynamics
- Because of the semi-arid climate, there may never be enough water to dilute salinity in all bay systems, especially in central and south Texas, so focused flows protect key nursery habitats during droughts is needed
- Some FWI standards are complex, using complex hydrology tables
  - A simpler, standard, approach is needed
  - Should be linked to biological outcomes, not just hydrology

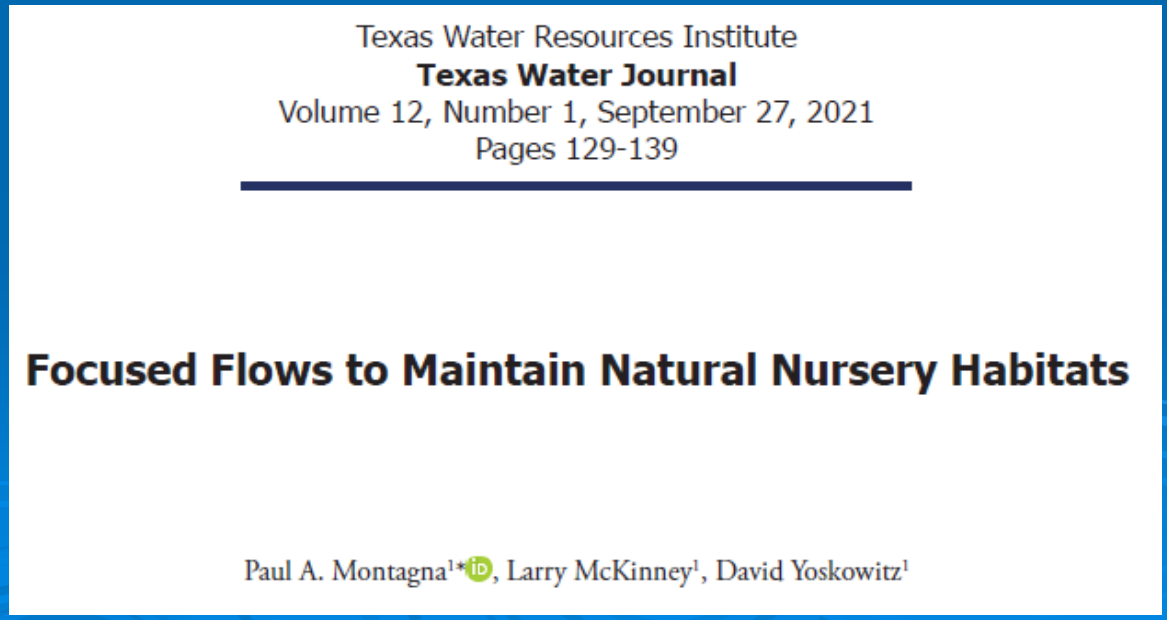
Chapter 16: Conclusion and Recommendations

- Everything is fine during average and wet periods, droughts are the problem



Chapter 16: Better Outcomes Are Possible

- Focused flows to sustain natural nurseries during droughts
  - If the nursery function is protected, the bay will repopulate when it rains again
  - Smaller volumes of the bays need protection, so lower volumes of environmental water is needed



https://doi.org/10.21423/twj.v12i1.7123

ArcGIS StoryMap

- Web-based application to share maps in the context of narrative text and other multimedia content
- Under development, will be asking folks to review it soon
  - https://storymaps.arcgis.com/collections/88ebe5b53085412e8a2d385e34e98ab9
  - Maps, tables, figures, oral histories
  - Authors: Michelle Culver, Dan Opdyke, Audrey Douglas, Paul Montagna, and Elani Morgan.

Collection

Freshwater Inflows to Texas Bays and Estuaries

A Regional-Scale Review, Synthesis, and Recommendations

Editors: Paul A. Montagna • Audrey R. Douglas

Get started

This Story Map presents an overview of the content from the book Freshwater Inflows to Texas Bays and Estuaries, A Regional-Scale Review, Synthesis, and Recommendations. Story Map authors: Michelle Culver, Dan Opdyke, Audrey Douglas, Paul Montagna, and Elani Morgan.

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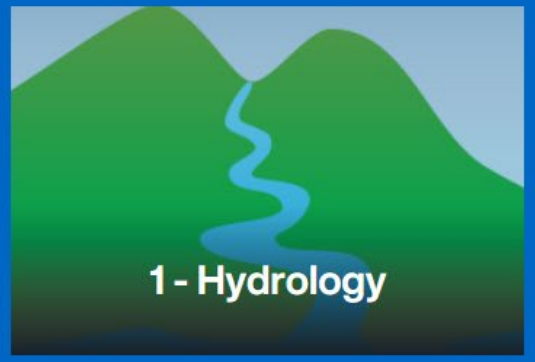

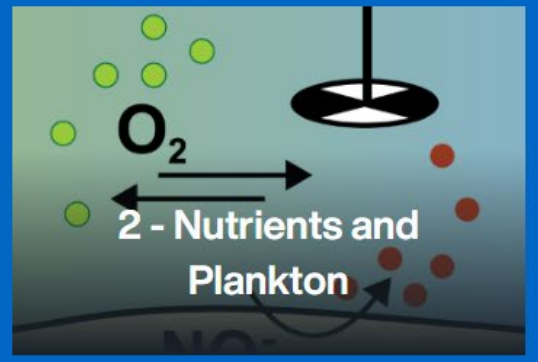

With Help From Many (over many years)

- Sponsors (past and present)
  - Local
    - City of Corpus Christi
    - Coastal Bend Bays & Estuaries Program
    - Lower Colorado River Authority
    - Matagorda Bay Mitigation Trust (Today)
  - State
    - TX Water Development Board (Today)
    - TX General Land Office (Today)
    - TX Sea Grant
  - Federal
    - National Aeronautics and Space Administration
    - National Oceanic Atmospheric Administration (Today)
    - National Science Foundation
    - US Army Corps of Engineers
    - US Bureau of Reclamation
  - Foundations
    - Harte RF, CF
    - Tinker
    - Hershey
    - Mitchell
    - National Fish and Wildlife Foundation

- Staff
  - Rick Kalke
  - Larry Hyde
  - +16 others
- 44 Students
- 15 Postdocs


Questions?
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