Nutrients Dynamics in Galveston Bay and Potential Cycling within the Ecosystem as Identified by Recent Stable Isotope Studies

GOMA Nutrient Criteria Research Framework
March 2009

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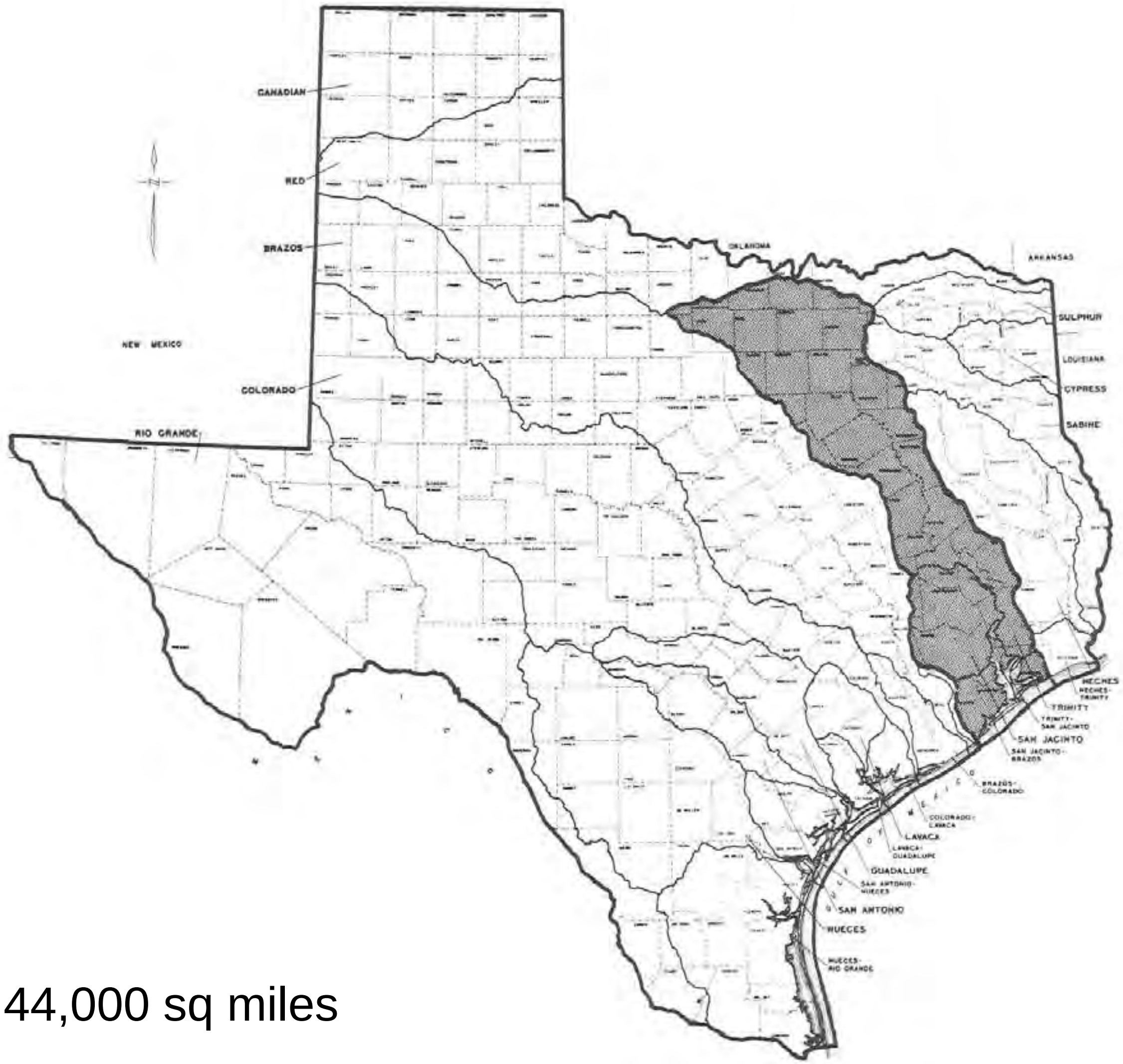
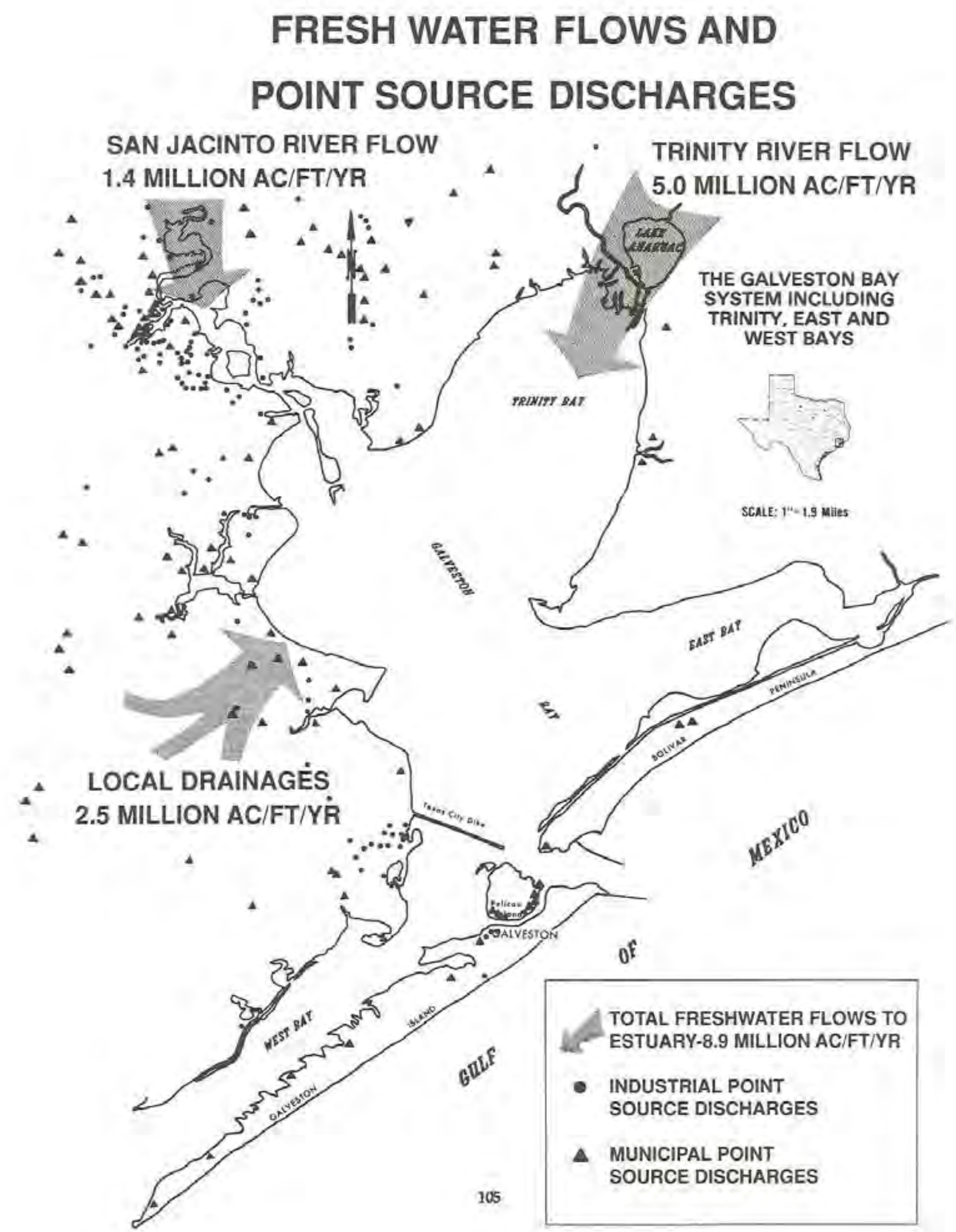
San Jacinto River
Trinity River
Buffalo Bayou
Cedar Bayou
Houston Ship Channel
Trinity Bay
Armand Bayou
Oyster Bayou
Upper & Lower
Galveston Bay
Clear Creek & Lake
East Bay
Dickinson Bayou & Bay
East Intracoastal Waterway
Texas City Channel
Galveston Channel
West Bay
Chocolate Bayou & Bay
Bastrop Bayou
Christmas Bay

GALVESTON BAY SYSTEM WATERSHED



44,000 sq miles

Trinity and San Jac
Provide more than
80% of fw. inflow



NOAA 1988

Circulation Patterns

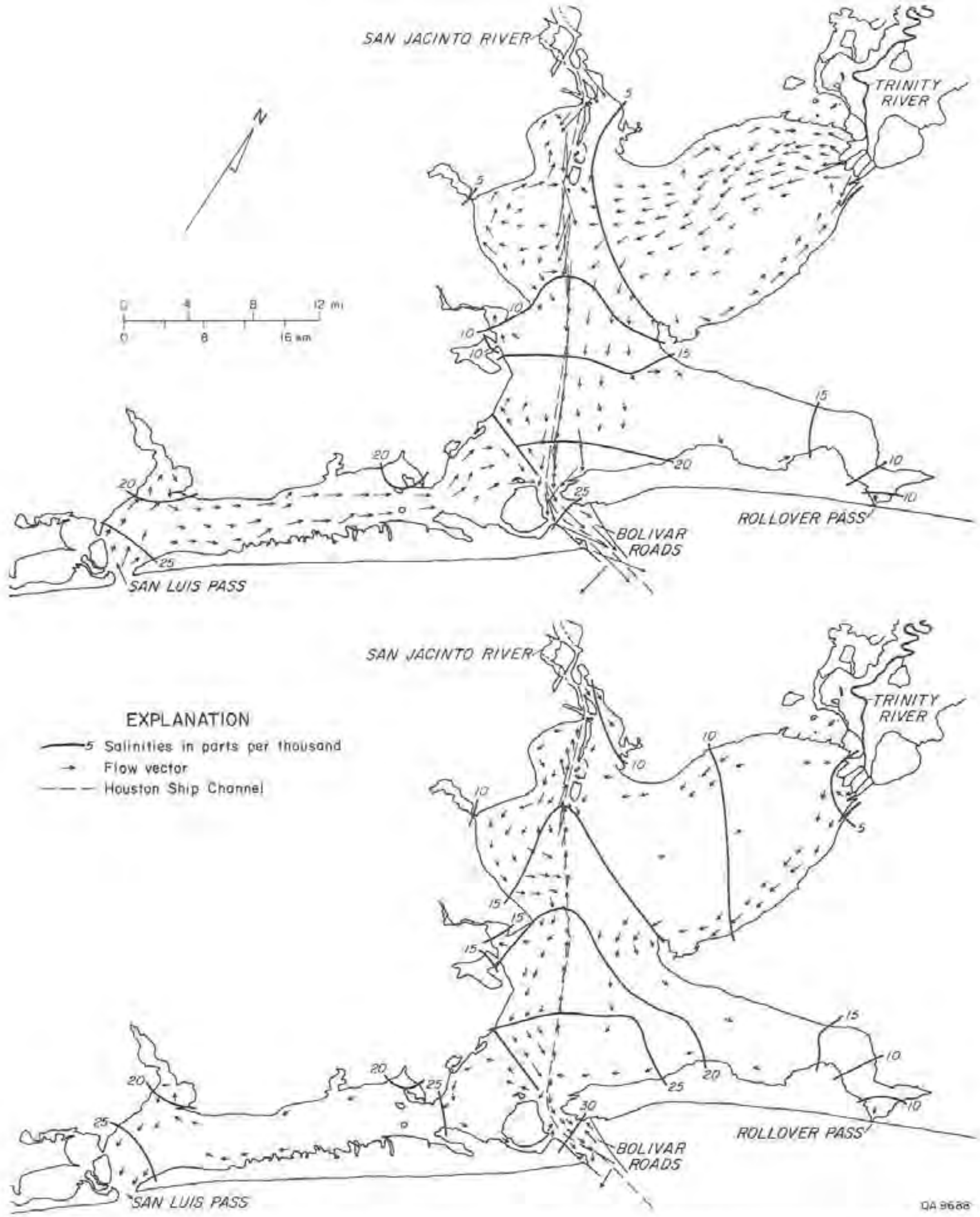
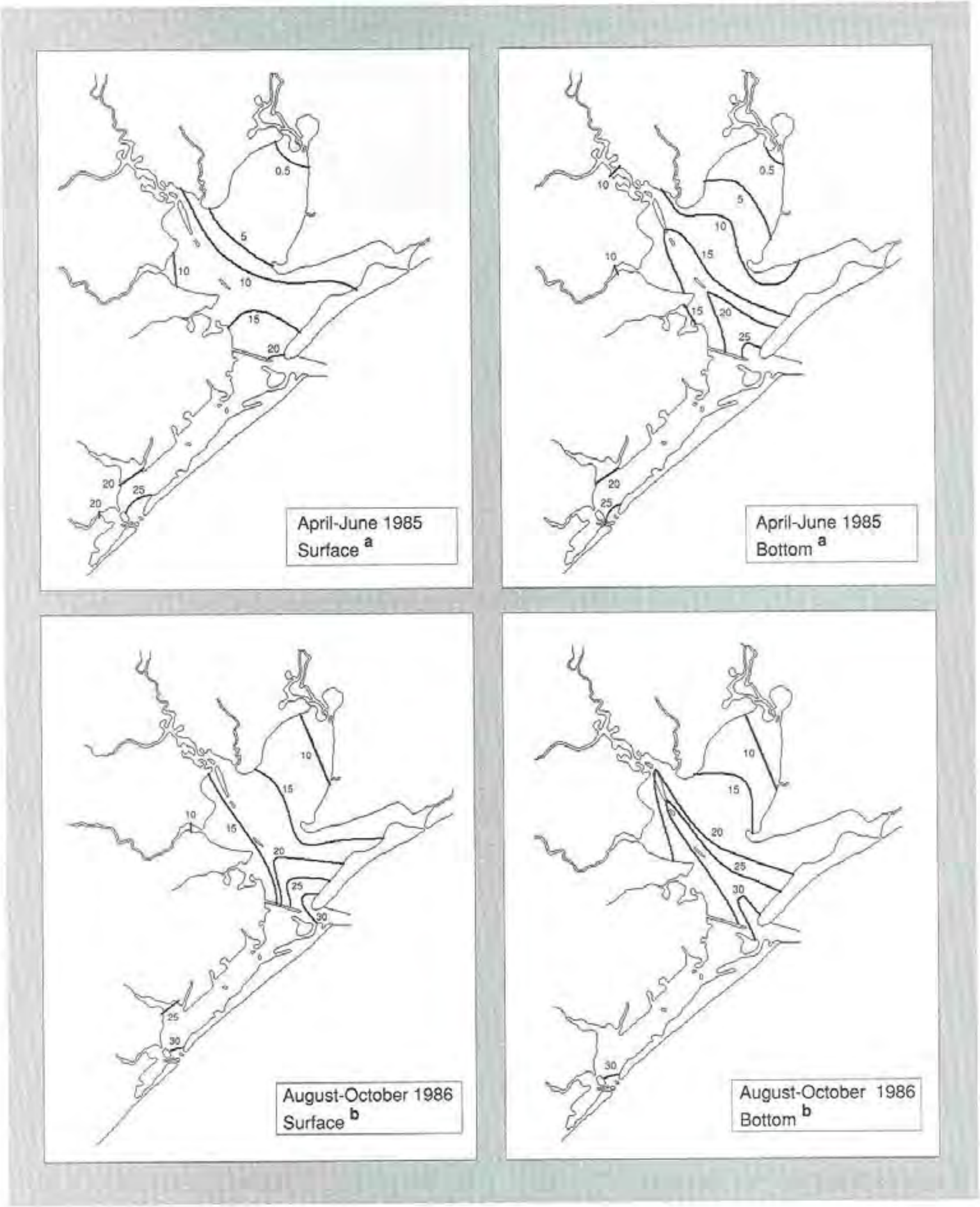


Figure 1.8. Simulated salinities in the Galveston Bay System, 1941-1976, under the influence of freshwater inflows for May (freshest) and August (most saline), and average monthly circulation patterns for same months, after Texas Water Development Board, 1982 (16). Top diagram is May; lower diagram is August.

TWDB 1982

Figure 131. *Surface and bottom salinities during low- and high-salinity periods*



a. Data Sources: TSDH, 1991; TWC, 1991; TWDB, 1991a; TPWD, 1991
b. Data Sources: TSDH, 1991; TWC, 1991; TWDB, 1991a

Influence of HSC on tidal transport & salinity

NOAA 1993

Facts and Figures

- 44,000 sq. miles estuarine drainage area
- 600 sq miles – surface area
- 20-25% of drainage area urbanized (local higher)
- High density population and growing
- Projected to add many more people in next 25 years
- Concerns about freshwater supplies
- Bacteria, dissolved oxygen and nutrient issues

Facts and Figures

- 10 to 12 feet maximum (except for channels)
- Mean summer high temp – 80s (F)
- Mean winter low mid 40s
- Mean annual rainfall 50 inches
- Southerly winds, frequent storms
- Diurnal cycle, 14 day, maximum tide 2 ft
- Water levels > 15ft hurricane, norther < 2ft
- Wind driven, positive estuary most years.

Facts and Figures

- Clay soils
- Native Prairie (west) and piney woods north and east.
- Low slope
- Rapid urbanization has led to flashy urban streams, increase sedimentation and turbidity
- Many waterbodies on 303d list for dissolved oxygen, bacteria and some nutrients

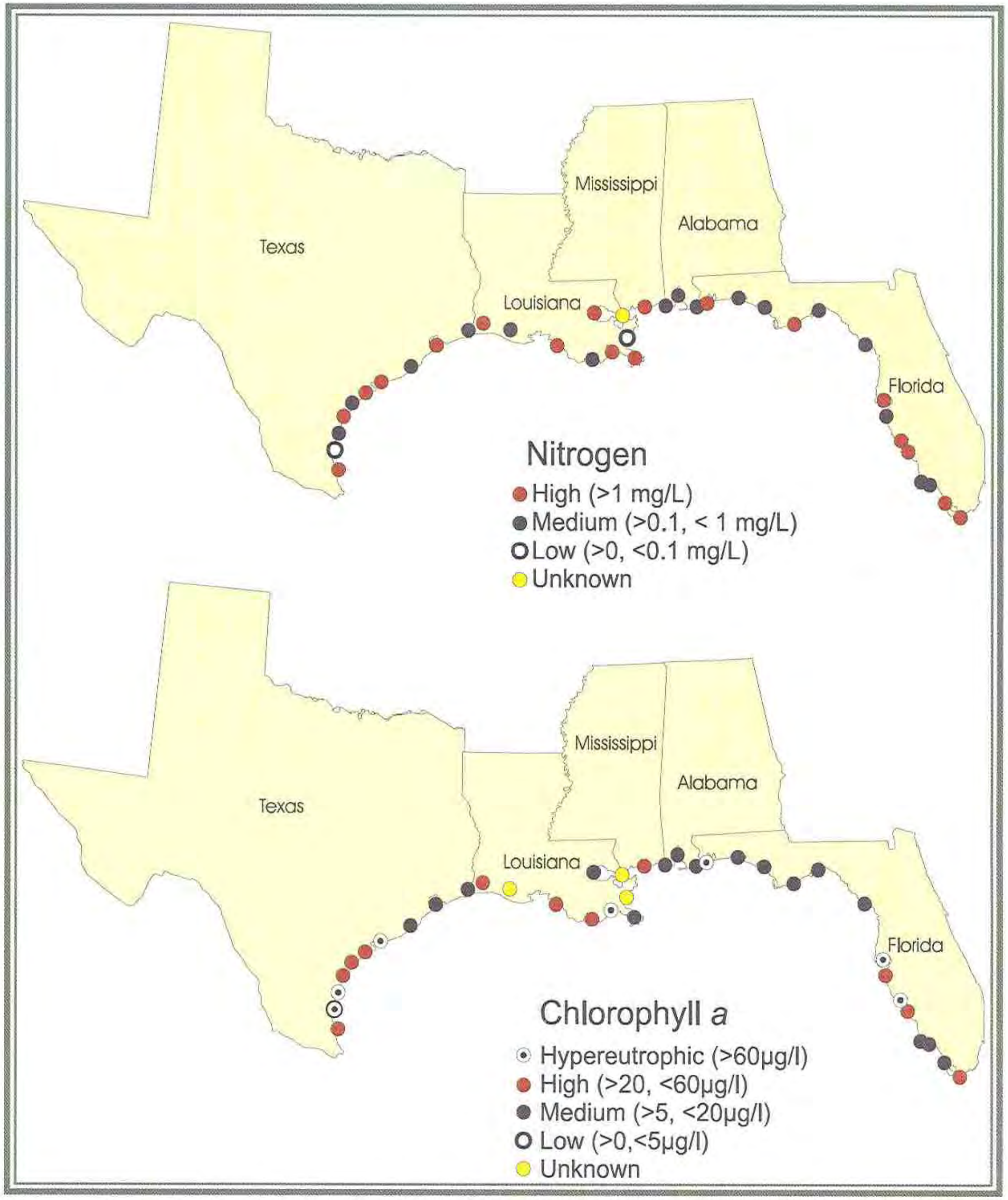
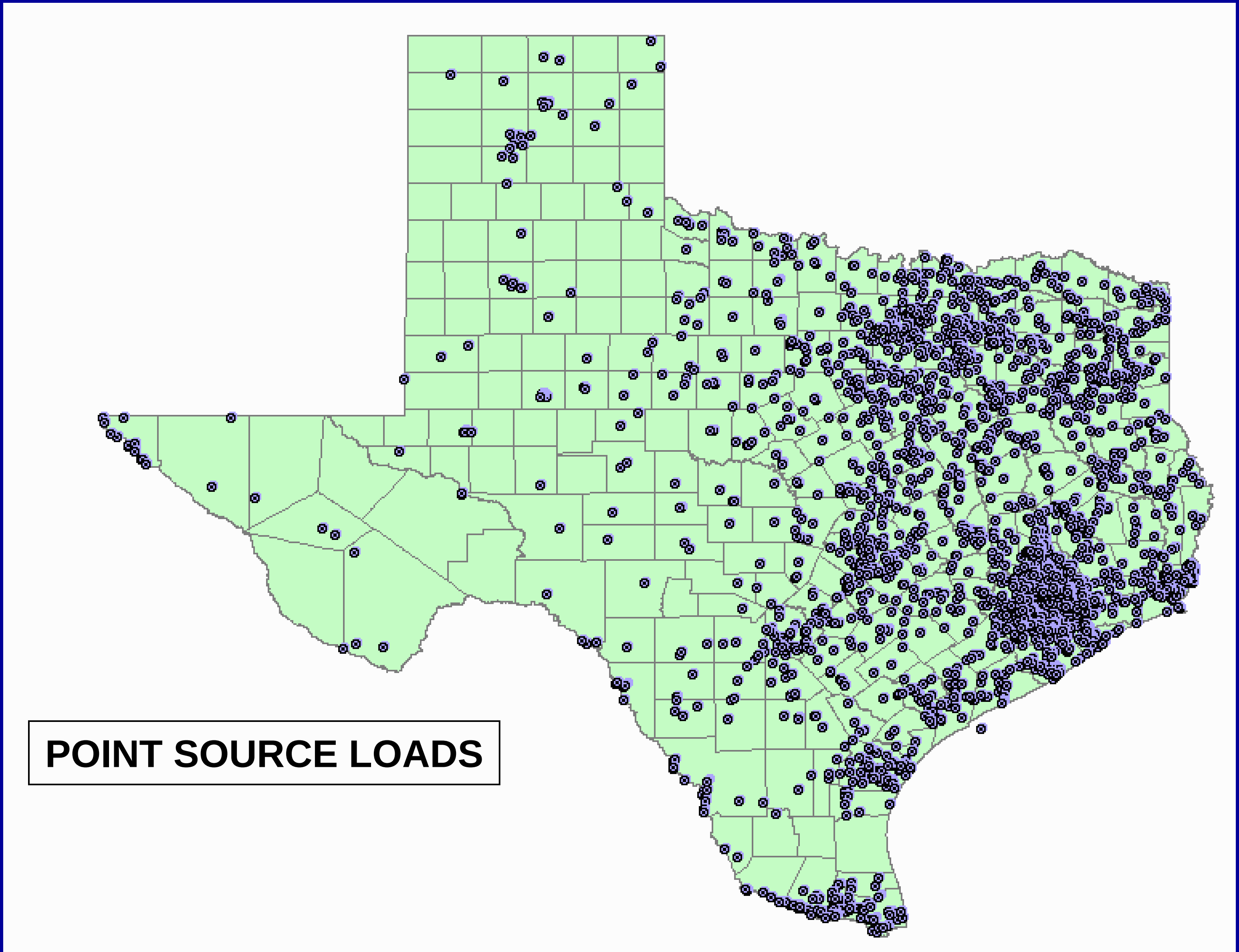


Fig. 13. Concentrations of nitrogen (mg/l) and chlorophyll *a* (µg/l) observed in estuaries of the Gulf of Mexico based on the Estuarine Eutrophication Survey (NOAA, 1997).

Point Sources



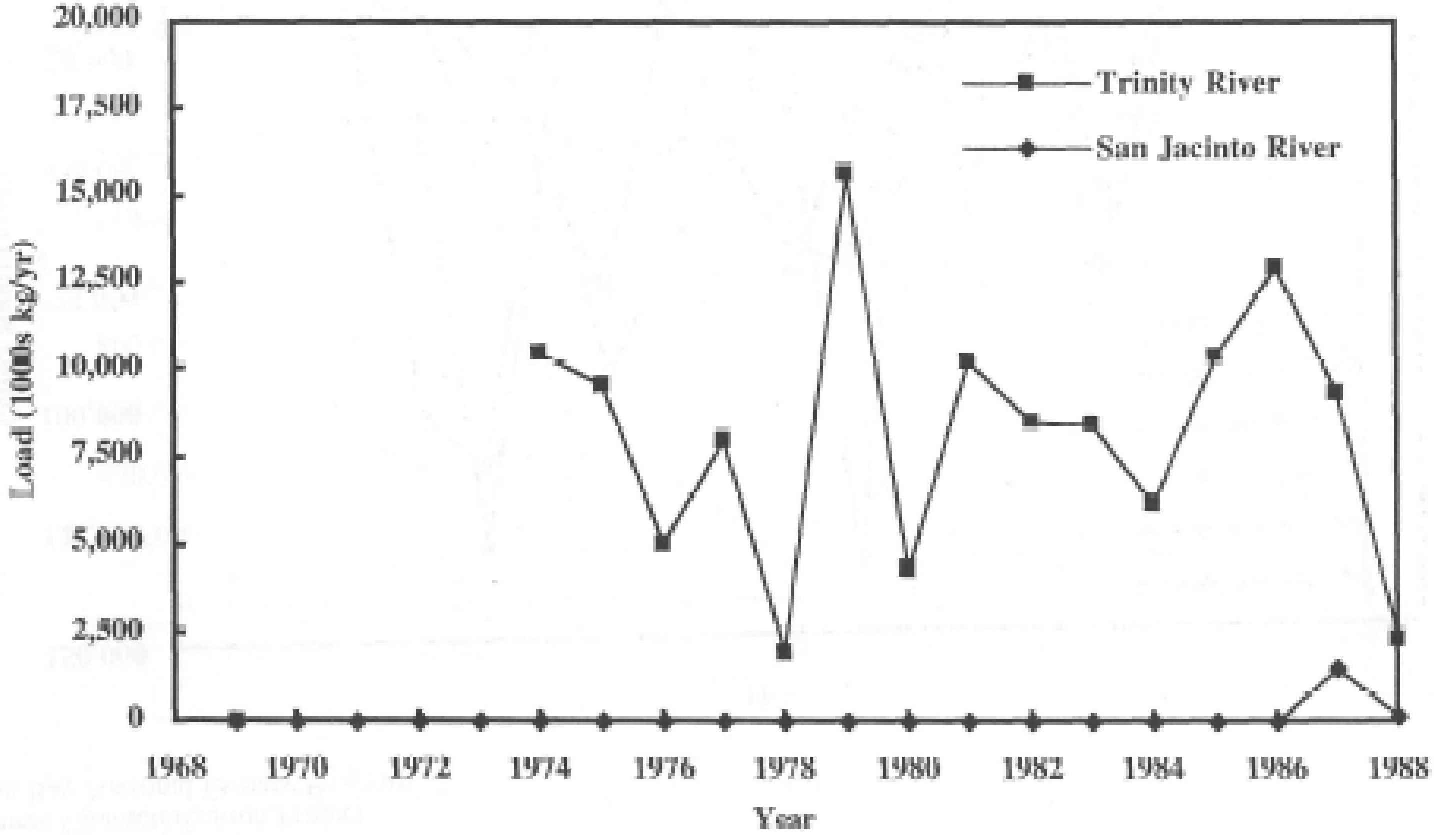
Point Source Loads

- Galveston Bay contains 747 industrial point sources, the largest concentration of in any estuarine area nationwide
- Total number of permitees – 1,932 in watershed (1,151 below Lake Livingston and Houston dam)
- Largest number of permitted outfalls in state
- Numerous small package plants, few regional plants. Maintenance an issue in past
- Septic tanks in rural areas (poor soils, much runoff)

NOAA 1990. Estuaries of the United States

Figure 4.5 - Estimated Loads of Total Nitrogen into Galveston Bay from the Trinity River at Romayor and the San Jacinto River from 1969 through 1988

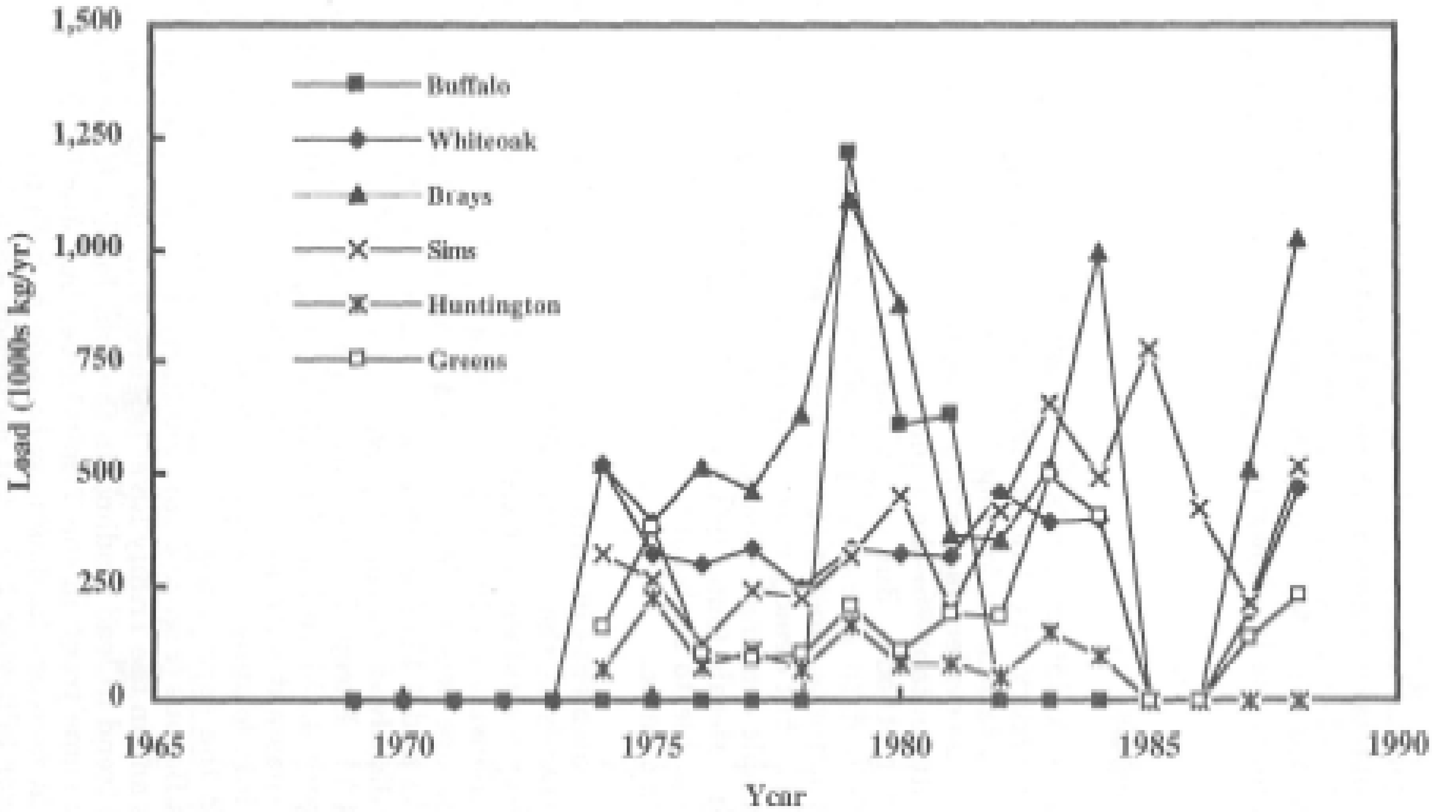
Point Source Characterization Project
Galveston Bay National Estuary Program



1993 Armstrong and Ward

Figure 4.6 - Estimated Loads of Total Nitrogen into Galveston Bay from Tributaries in the Houston Area from 1969 through 1988

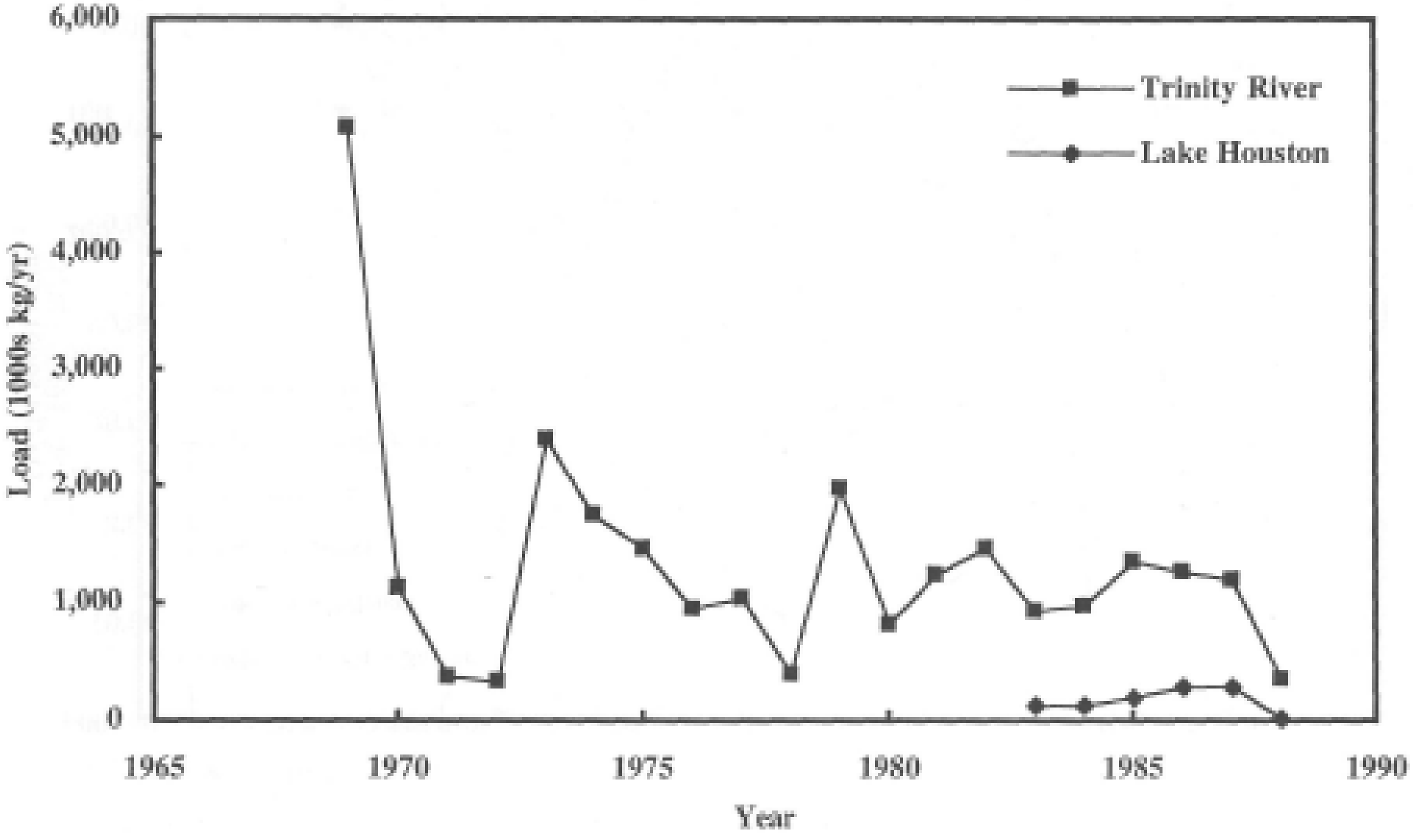
Point Source Characterization Project
Galveston Bay National Estuary Program



1993 Armstrong and Ward

Figure 4.7 - Estimated Loads of Total Phosphorus into Galveston Bay from the Trinity River at Romayor and the San Jacinto River from 1969 through 1988

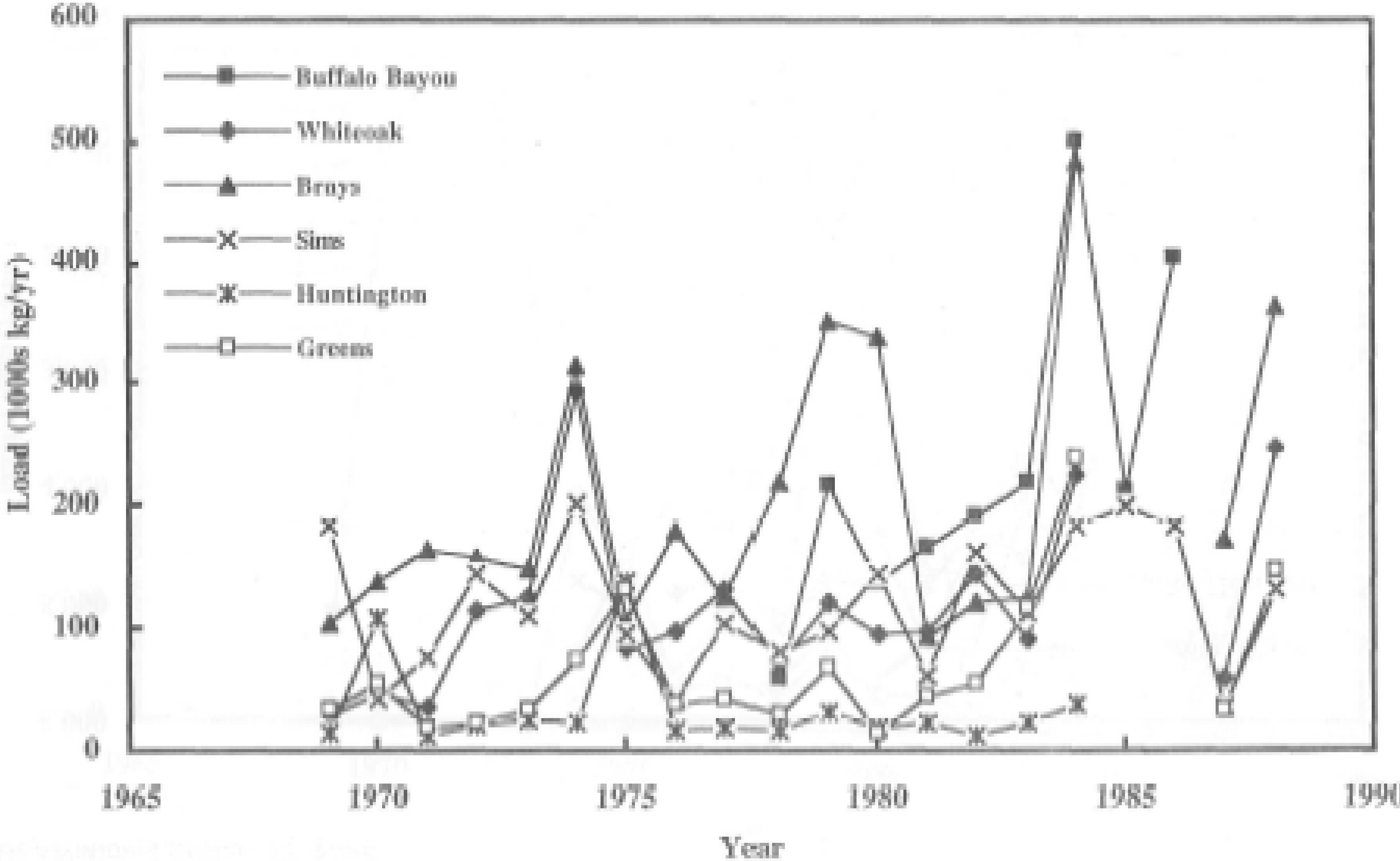
Point Source Characterization Project
Galveston Bay National Estuary Program



1993 Armstrong and Ward

Figure 4.8 - Estimated Loads of Total Phosphorus into Galveston Bay from Tributaries in the Houston Area from 1969 through 1988

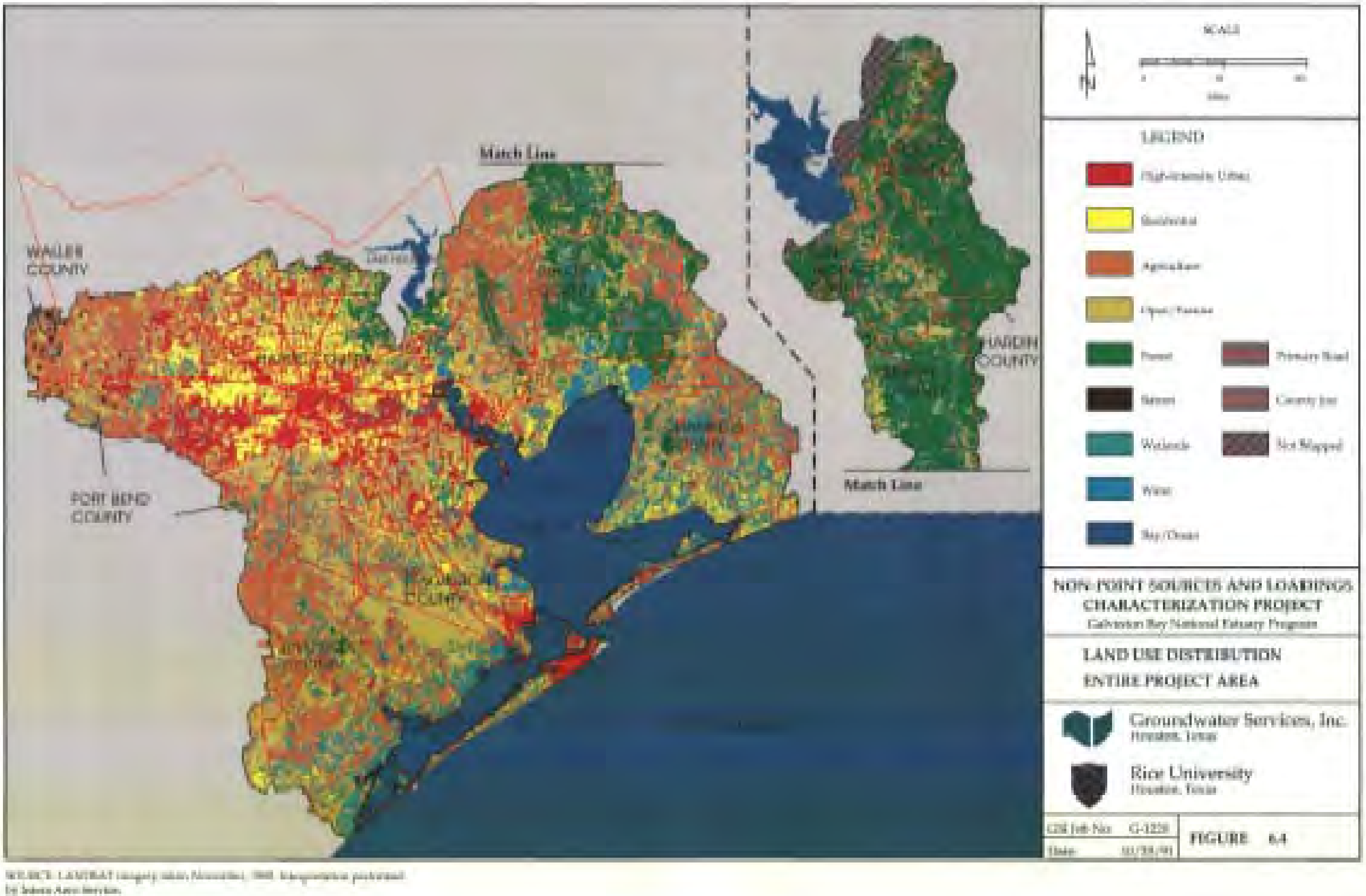
Point Source Characterization Project
Galveston Bay National Estuary Program



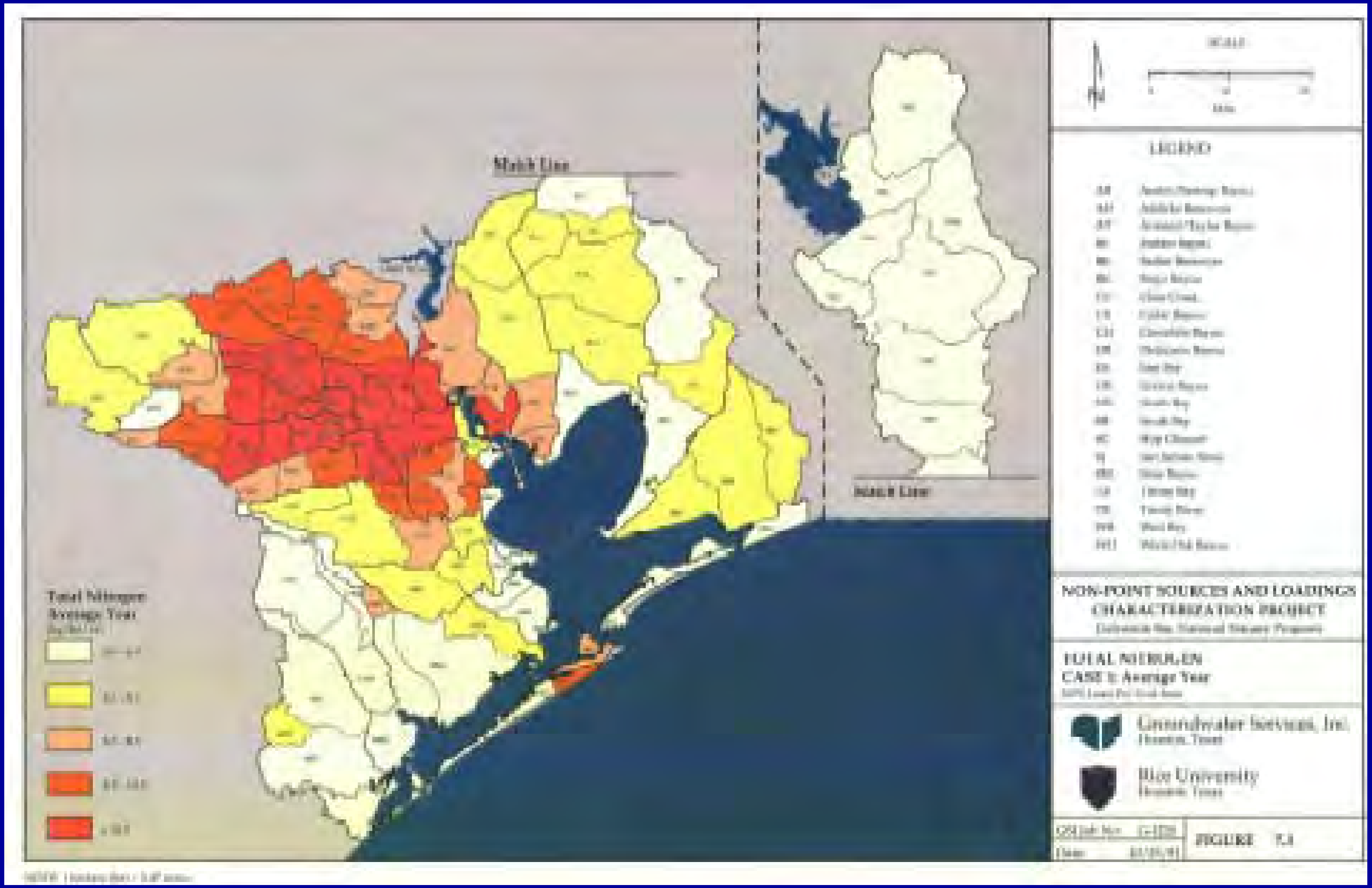
1993 Armstrong and Ward

Non-Point Source Load Estimates

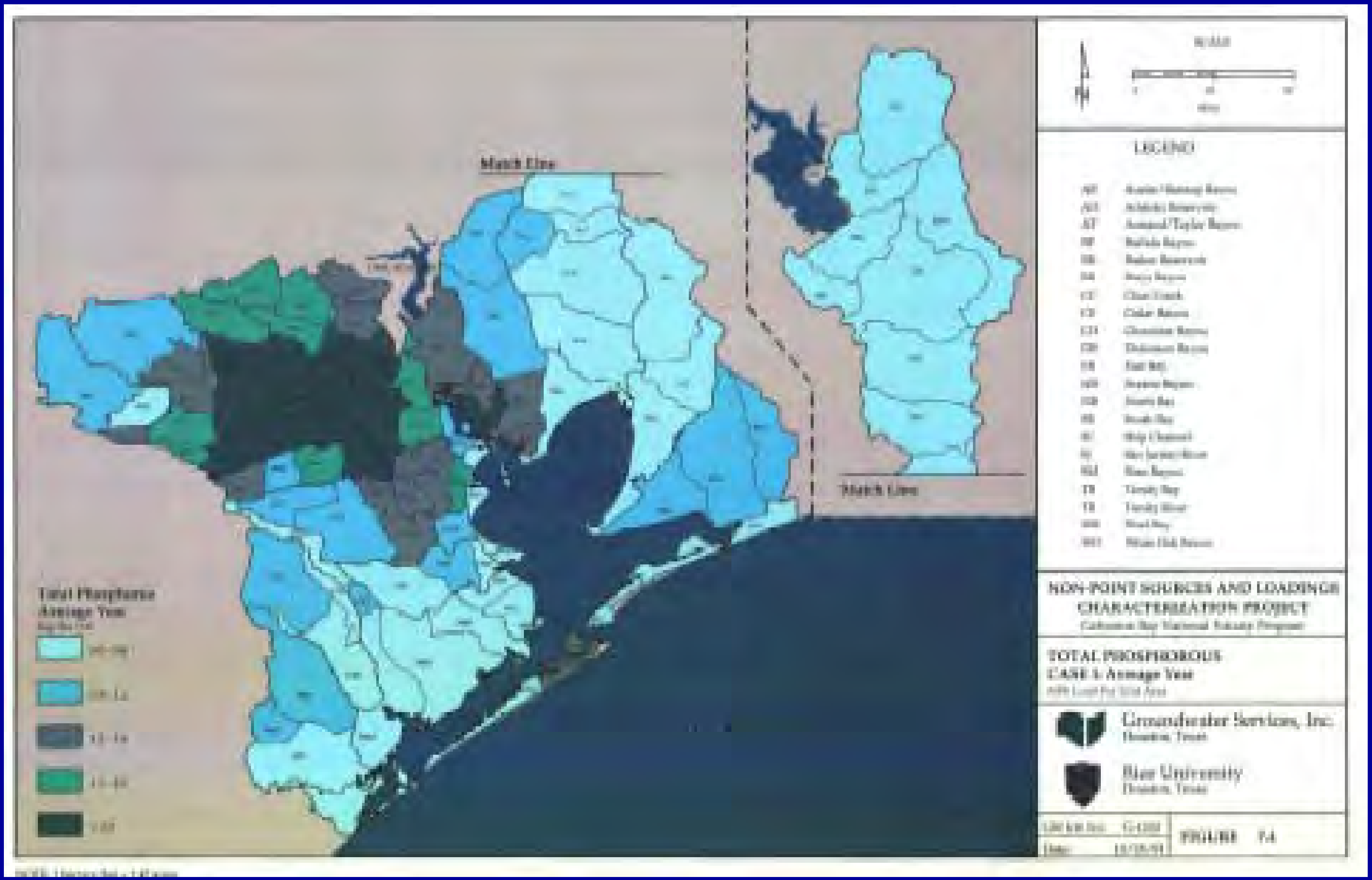
Newell et al. 1992; TCB 2001, Jensen 2009



Newell et al. 1992. (red = urbanized)



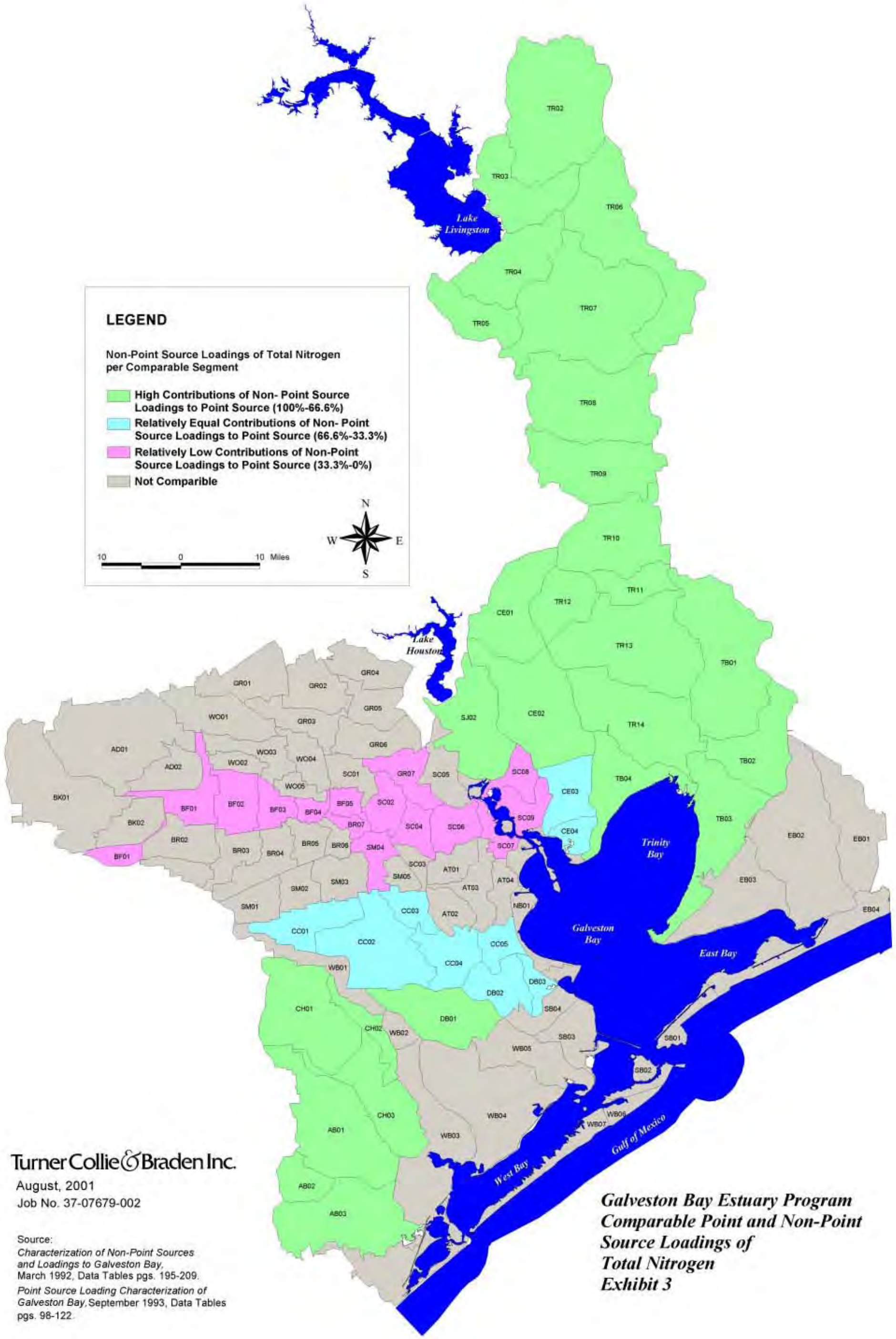
Newell et al. 1992. (red = highest non-point source loads of N average year)



Newell et al. 1992. (dark blue = highest non-point source loads of P average year)

Point vs. Non-point Sources TCB 2001

1. In most cases the non-point contribution to N and P dominates point source contributions.
2. There are, however, some cases in which the point source clearly contributed more loadings. Namely, in the San Jacinto River basin, Total P and Total N are controlled by point source contributions.
3. In the Clear Creek segment of the San Jacinto-Brazos Coastal basin, point source loadings of Total P and Total N were also high.



Turner Collie & Braden Inc.

August, 2001

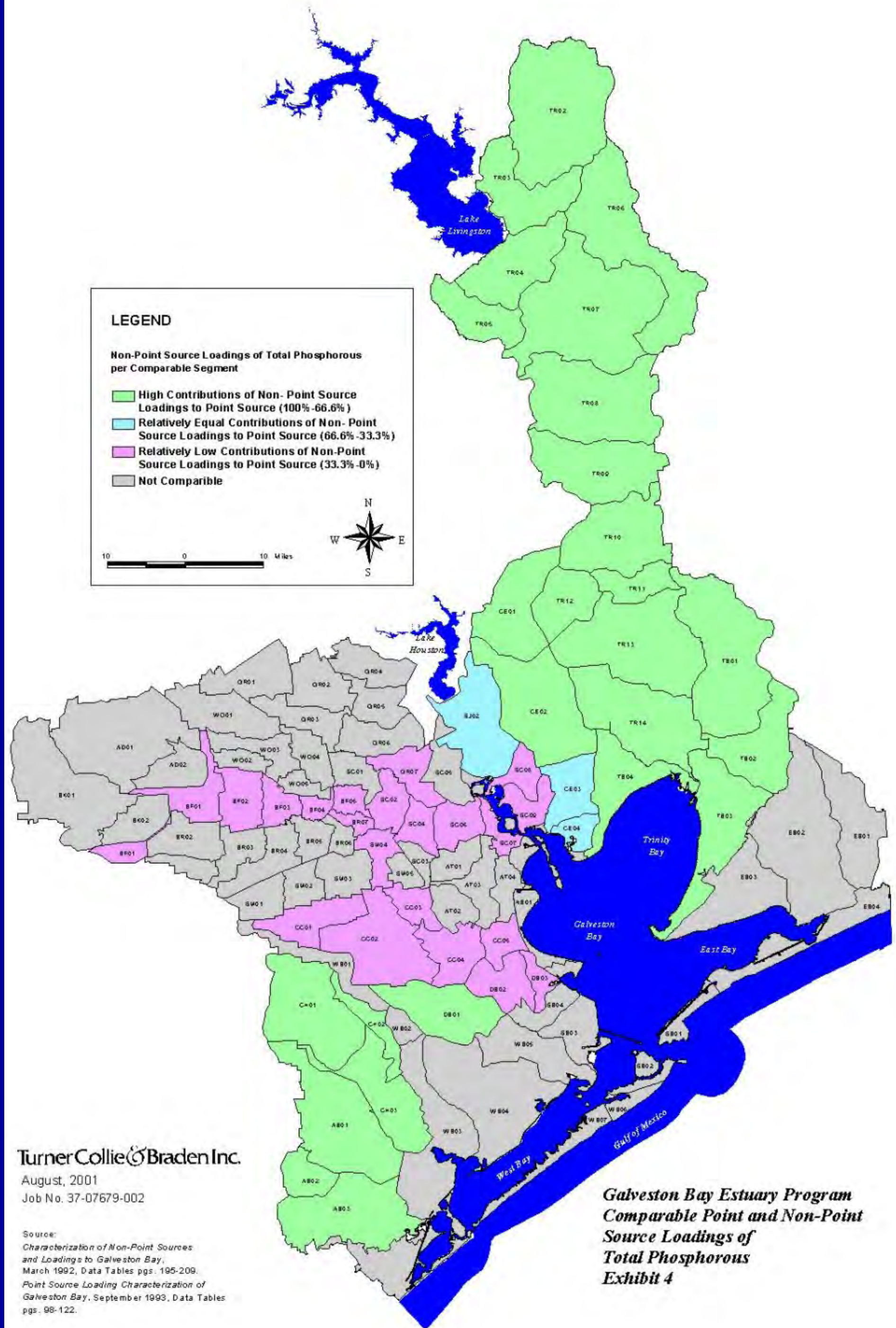
Job No. 37-07679-002

Source:

Characterization of Non-Point Sources and Loadings to Galveston Bay, March 1992, Data Tables pgs. 195-209.

Point Source Loading Characterization of Galveston Bay, September 1993, Data Tables pgs. 98-122.

Galveston Bay Estuary Program Comparable Point and Non-Point Source Loadings of Total Nitrogen Exhibit 3


LEGEND
Non-Point Source Loadings of Total Phosphorous per Comparable Segment
High Contributions of Non- Point Source Loadings to Point Source (100% -66.6%)
Relatively Equal Contributions of Non- Point Source Loadings to Point Source (66.6% -33.3%)
Relatively Low Contributions of Non-Point Source Loadings to Point Source (33.3% -0%)
Not Comparible
N
W
E
S
10
0
10 Miles
Lake Livingston
Lake Houston
Trinity Bay
Galveston Bay
East Bay
West Bay
Gulf of Mexico
Turner Collie & Braden Inc.
August, 2001
Job No. 37-07679-002
Source:
Characterization of Non-Point Sources and Loadings to Galveston Bay, March 1992, Data Tables pgs. 195-209.
Point Source Loading Characterization of Galveston Bay, September 1993, Data Tables pgs. 98-122.
Galveston Bay Estuary Program
Comparable Point and Non-Point
Source Loadings of
Total Phosphorous
Exhibit 4

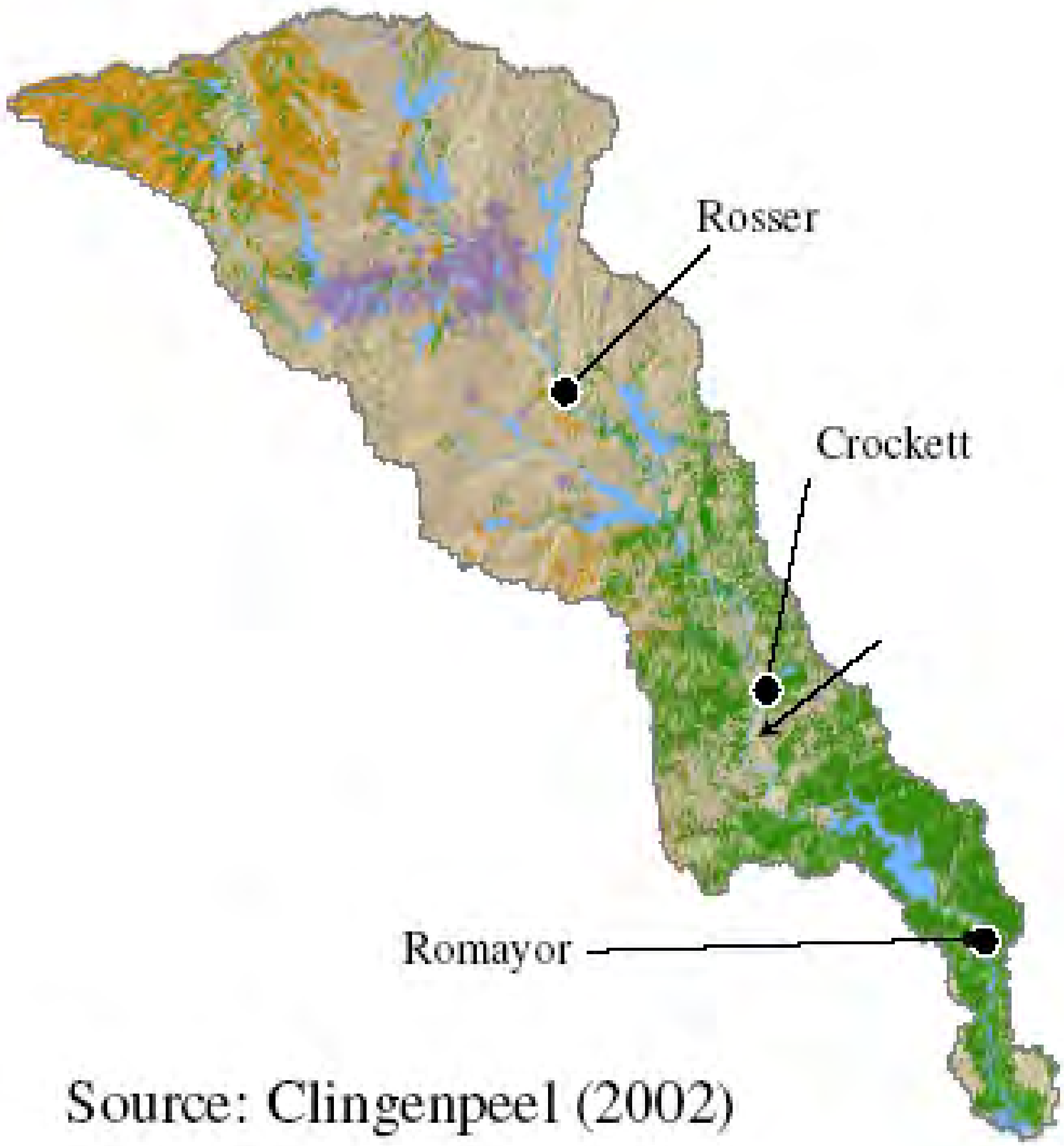
Summary Findings

Point source loads to Galveston Bay were investigated by Armstrong and Ward (1993). Their study found total N loads from point sources to be 8,425 Metric Tons per year (MT/yr), reasonably close to our 1991 estimate of 9,200 MT/yr. Nonpoint source loads were estimated for the NEP by Newell, et. al. (1992). They estimated the average nonpoint source total N load for the entire watershed to be 23,128 MT/yr, somewhat larger than the 1991 paper estimate of approximately 12,400 MT/yr.

Jensen et al. 2009. NUTRIENT INPUTS TO GALVESTON BAY AND UPCOMING CRITERIA CONSIDERATIONS

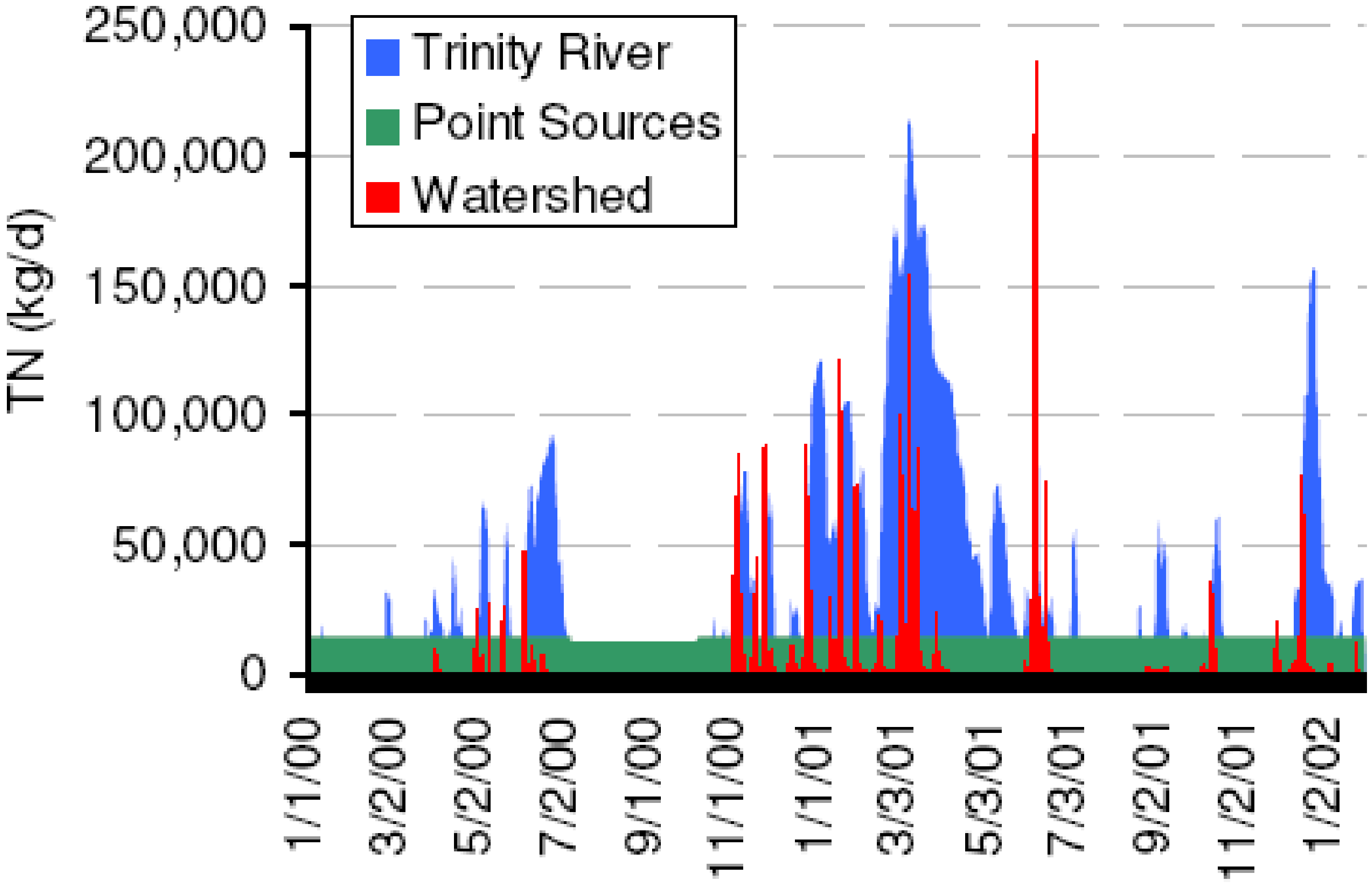
Effect of Lake Livingston Reservoir

Figure 2 – Station Locations



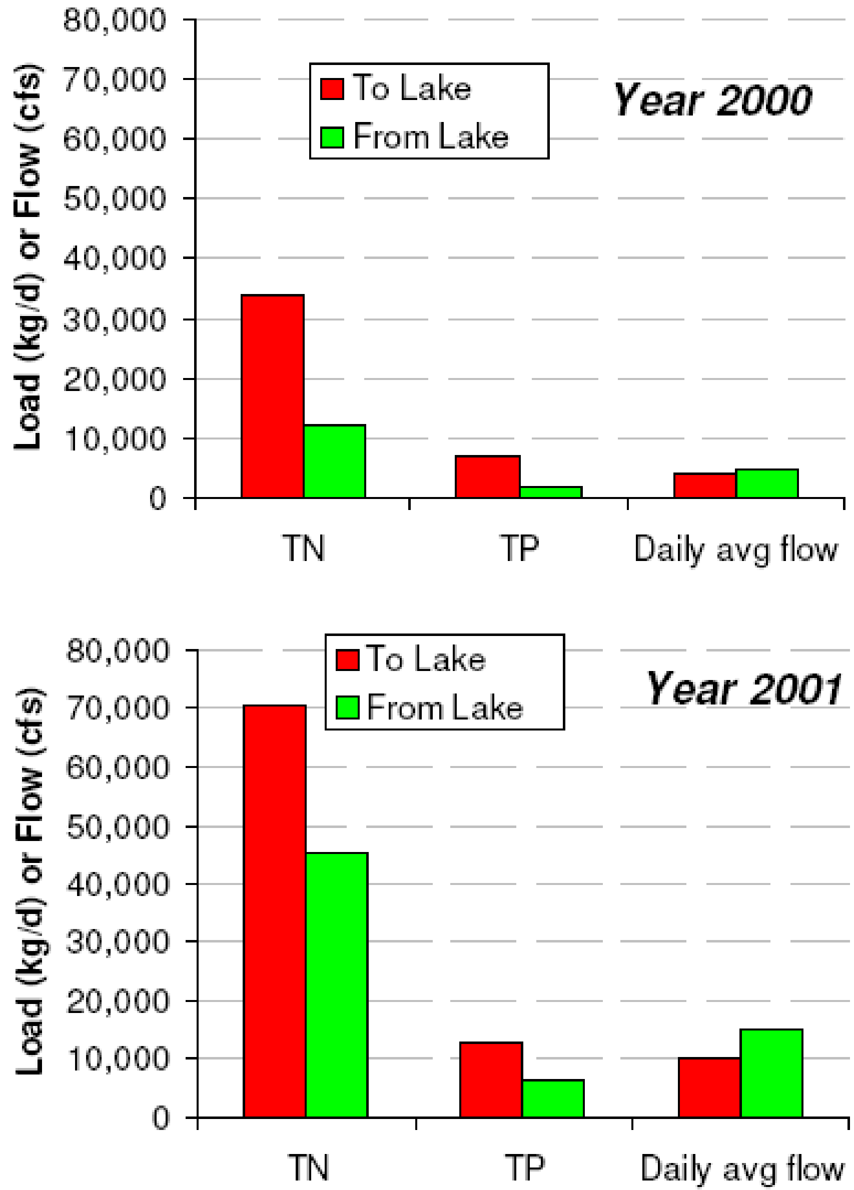
Source: Clingenpeel (2002)

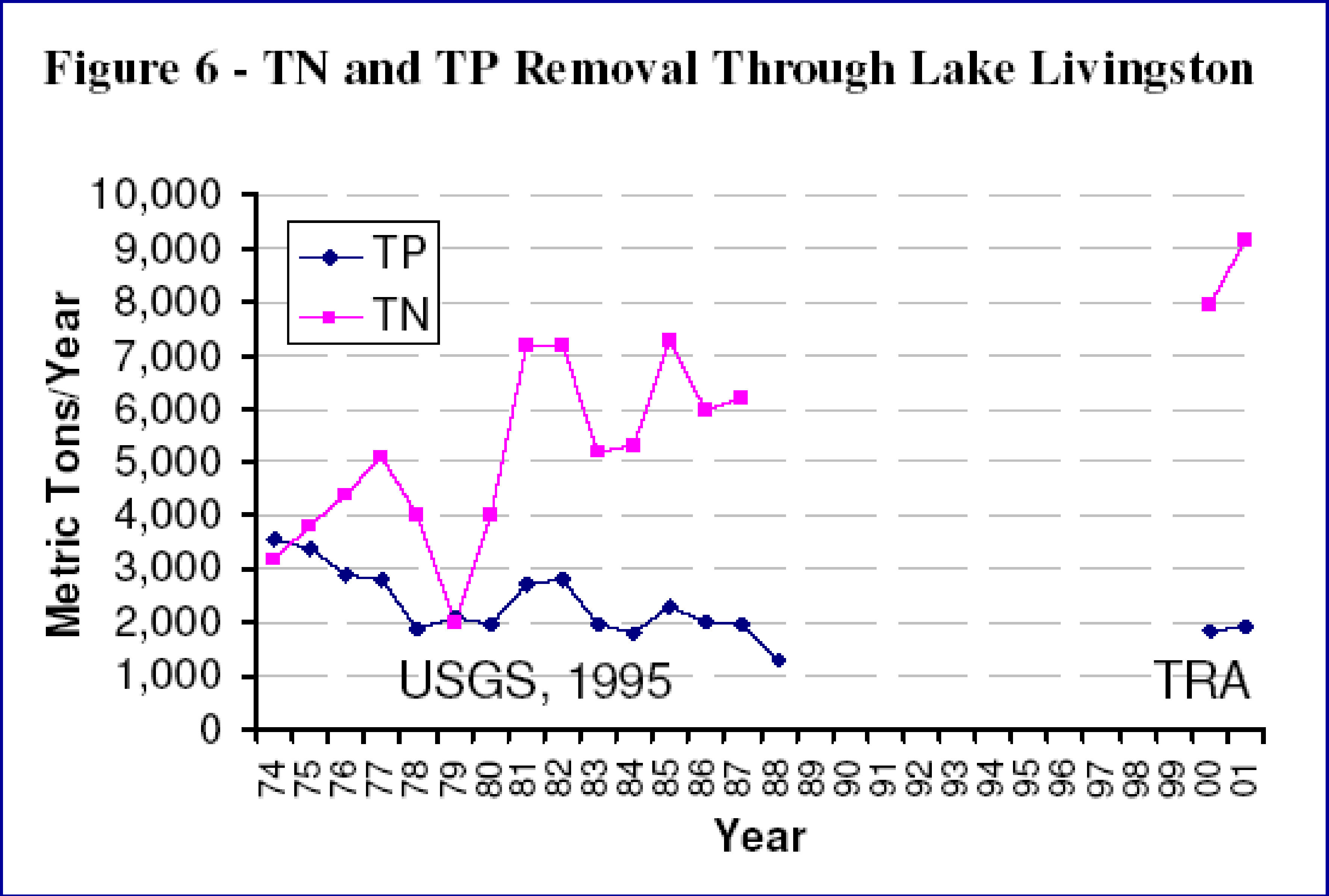
Figure 3 - Total Estimated TN Loadings to Lake Livingston



Source: Clingenpeel (2002)

Figure 4 - Average Daily Loads of TN and TP to and from Lake Livingston





Jensen et al. 2009

Overall Budget - N

TN INPUTS	AMOUNTS (MT/YR)
Median Inflows	30,386
Wastewater	7,300
Direct Rain	700
Nitrogen Fixation	560
Entrainment from Gulf	1,749
TOTAL INPUTS	40,695

TN OUTPUTS	AMOUNTS (MT/YR)
Advection to Gulf	9,752
Entrainment to Gulf	24,460
Transfer to Fisheries	1,065
Sediment Accumulatio	2,251
Denitrification	3,167
TOTAL OUTPUTS	40,695

Brock 1996 TWDB. 1988 – 1990 Data

Atmospheric Loading

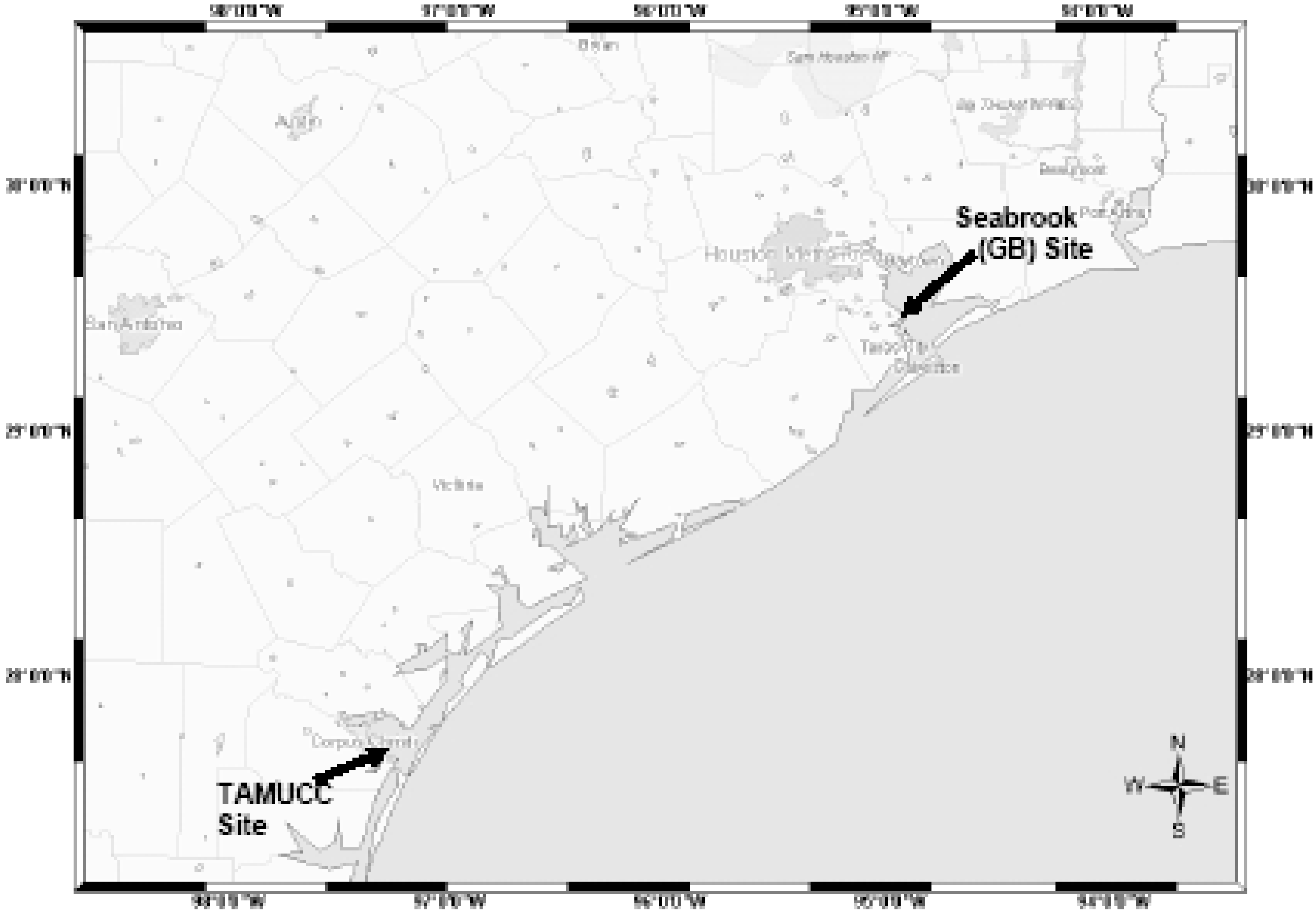


Figure 1. Atmospheric sampling station locations in coastal Texas.

Wade 2002. Galveston State of the Bay 8.

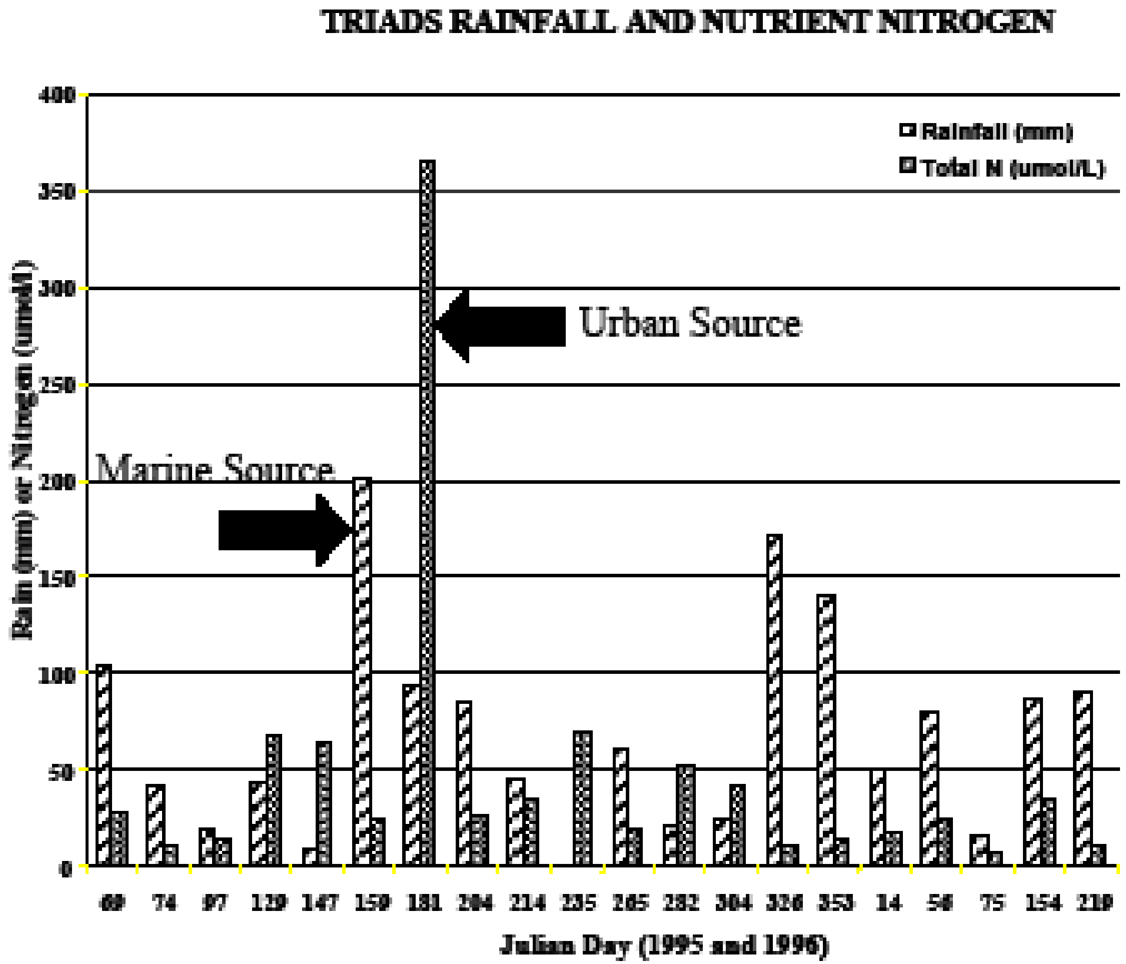


Figure 2. Rainfall and total nutrient nitrogen for Seabrook, TX station during operation in 1995 through 1996. Note the large difference between marine and urban sourced nitrogen concentration.

Wade 2002. Galveston State of the Bay 8.

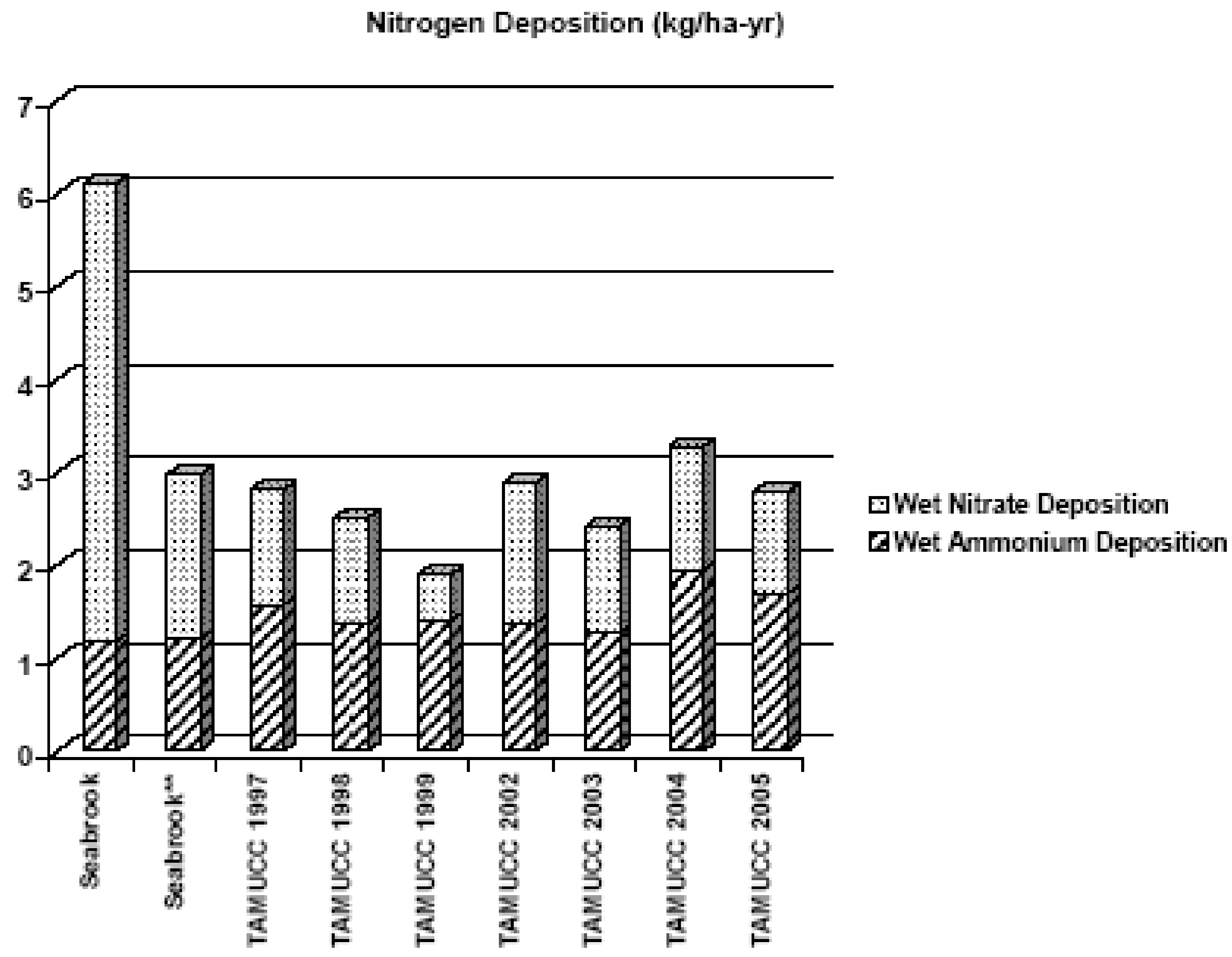


Figure 3. Nitrogen deposition to Galveston (Seabrook) and Corpus Christi (TAMUCC) Bays.
** indicates one rain event omitted from Seabrook total.

Wade 2002, Galveston State of the Bay 8.

Atmospheric Loading

The total input from atmospheric deposition of nutrient nitrogen directly to the Bay is estimated as 1.76x106 Kg/year or 8.6% of the total nutrient nitrogen input to Galveston Bay with another 2.8% from atmospheric input to the watershed.

Therefore, atmospheric inputs supplies about 10% of the nutrient nitrogen to Galveston Bay in 1996.

Wade 2002. Galveston State of the Bay 8.

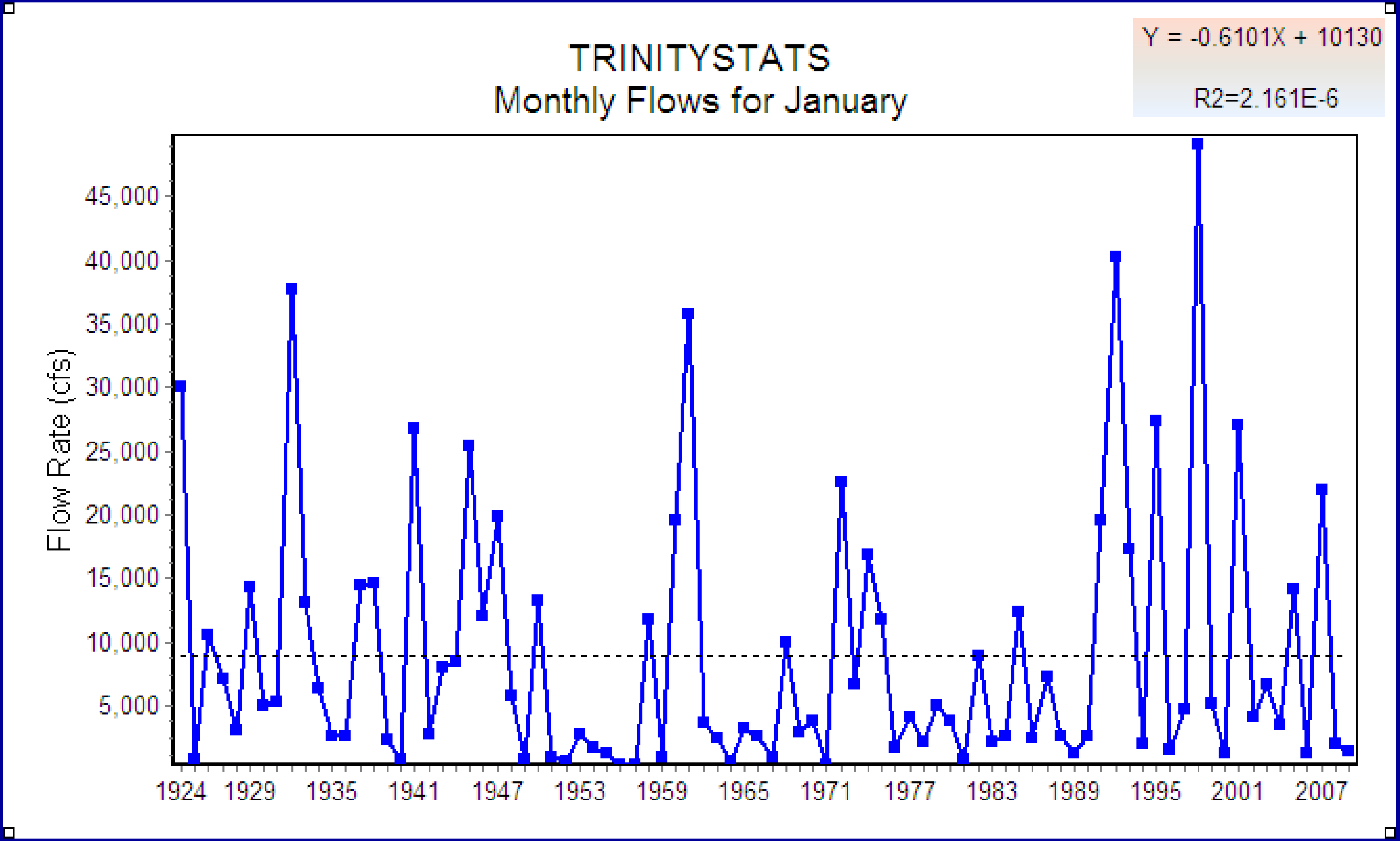
Atmospheric Loading: Comparison to Other Studies

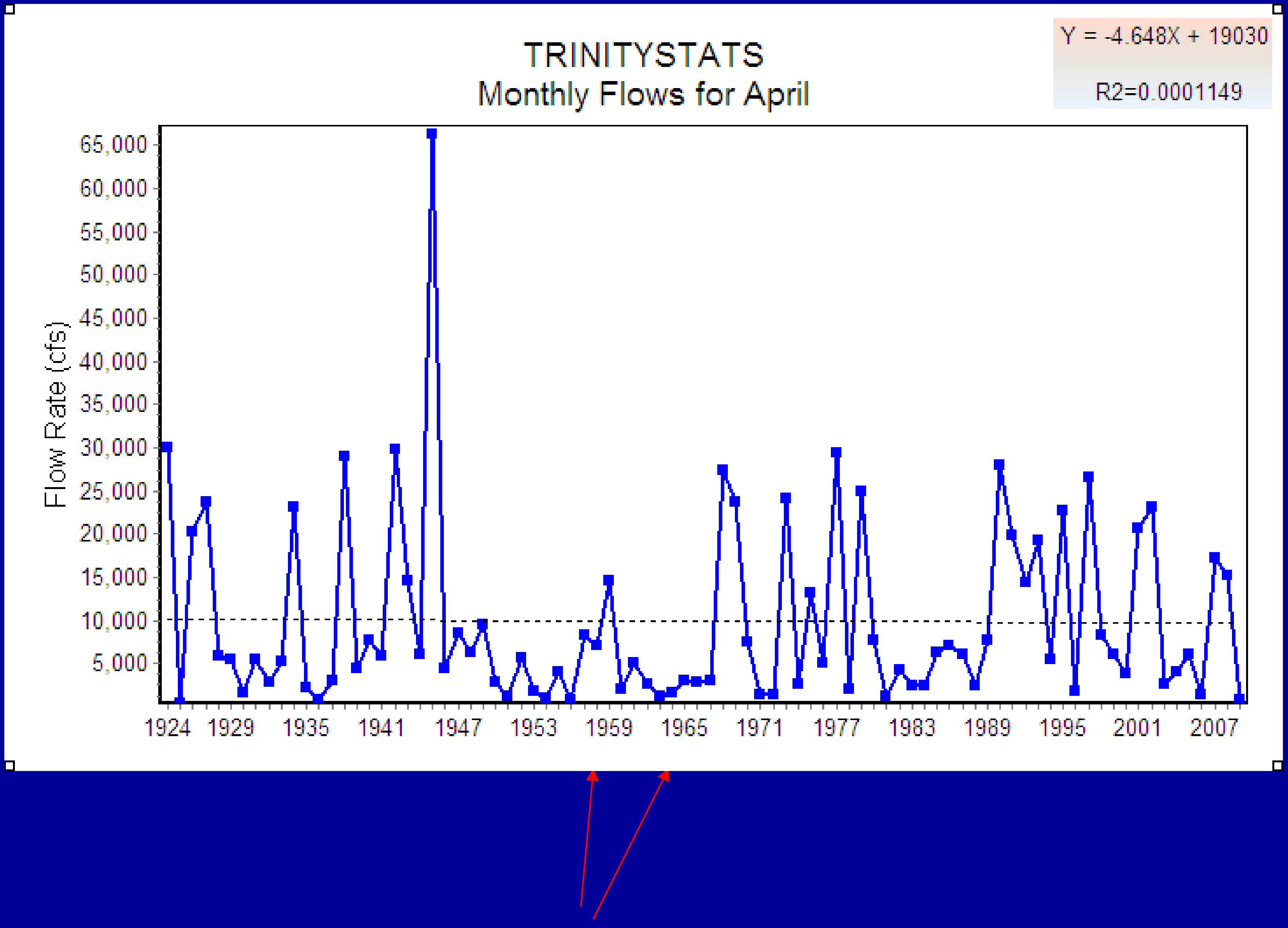
Table 1. Comparison of nutrient nitrogen deposition.

	Total Nitrogen Deposition	Dry/Wet Ratio	Wet Deposition	Directly Deposition to Bay
	(kg-N/ha-yr)		(kg-N/ha-yr)	(kg-N/yr)
Coastal Bend Bays	7.1 to 7.5	1.3 to 2.0	2.5 to 3.1	$1.05 x 10^6$
Tampa Bay	7.3	0.78	3.2	$0.76 x 10^6$
Galveston Bay	12.3 (2 x Wet)	1.0 (Est)	6.16	$1.76 x 10^6$

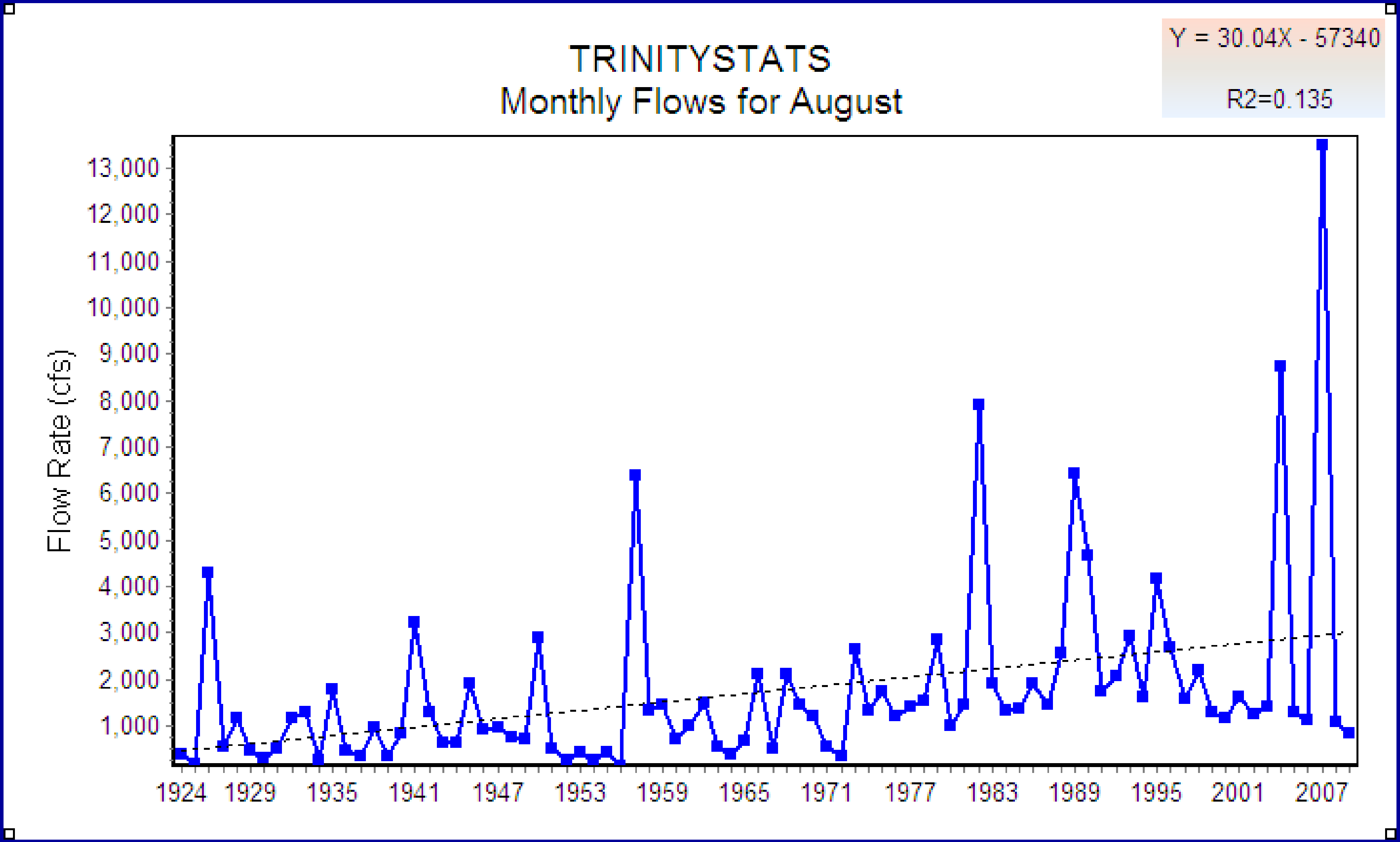
Wade 2002. Galveston State of the Bay 8.

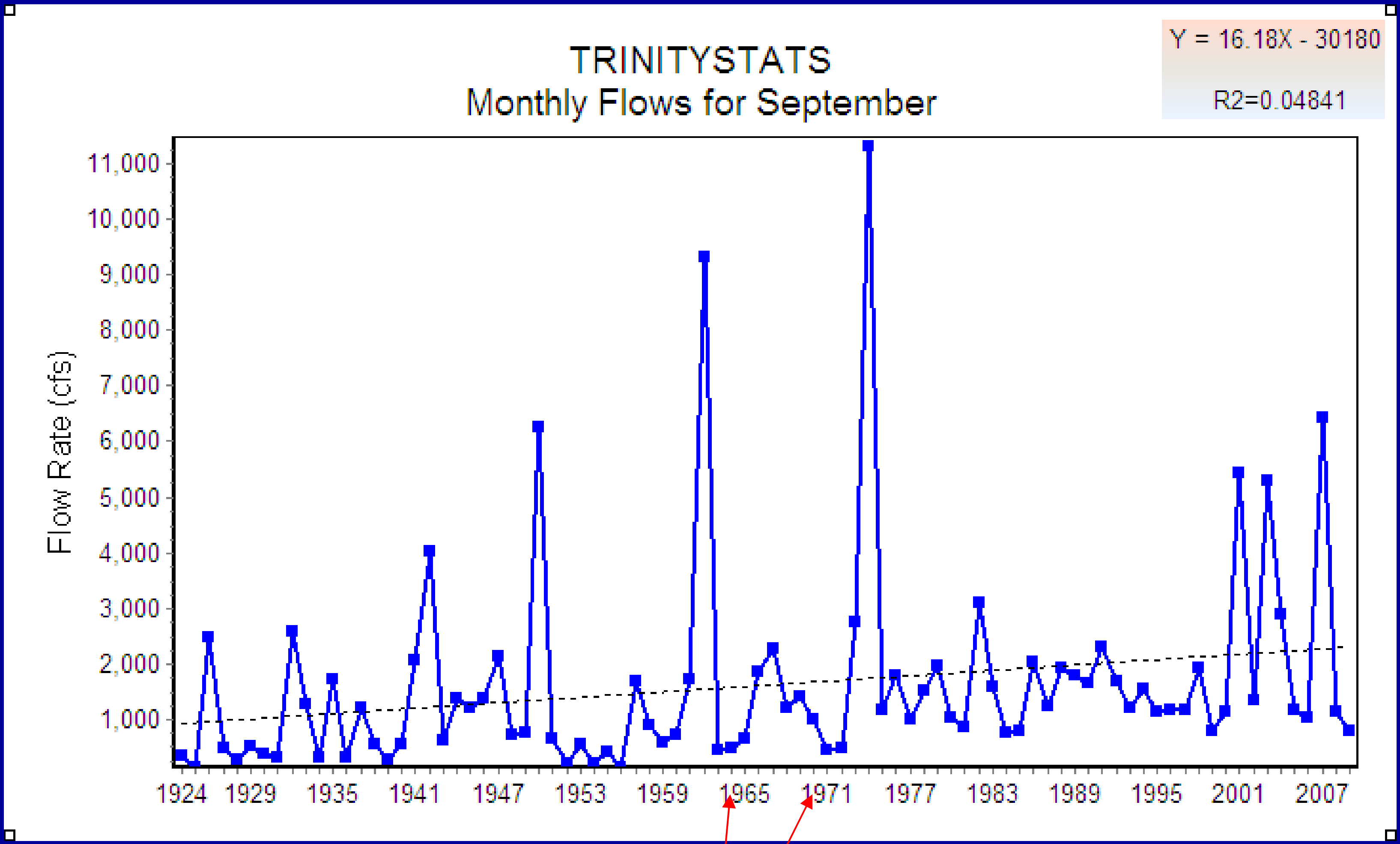
Spatial and Temporal Trends


TRINITYSTATS
Monthly Flows for January
Y = -0.6101X + 10130
R2=2.161E-6
Flow Rate (cfs)
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
1924
1929
1935
1941
1947
1953
1959
1965
1971
1977
1983
1989
1995
2001
2007

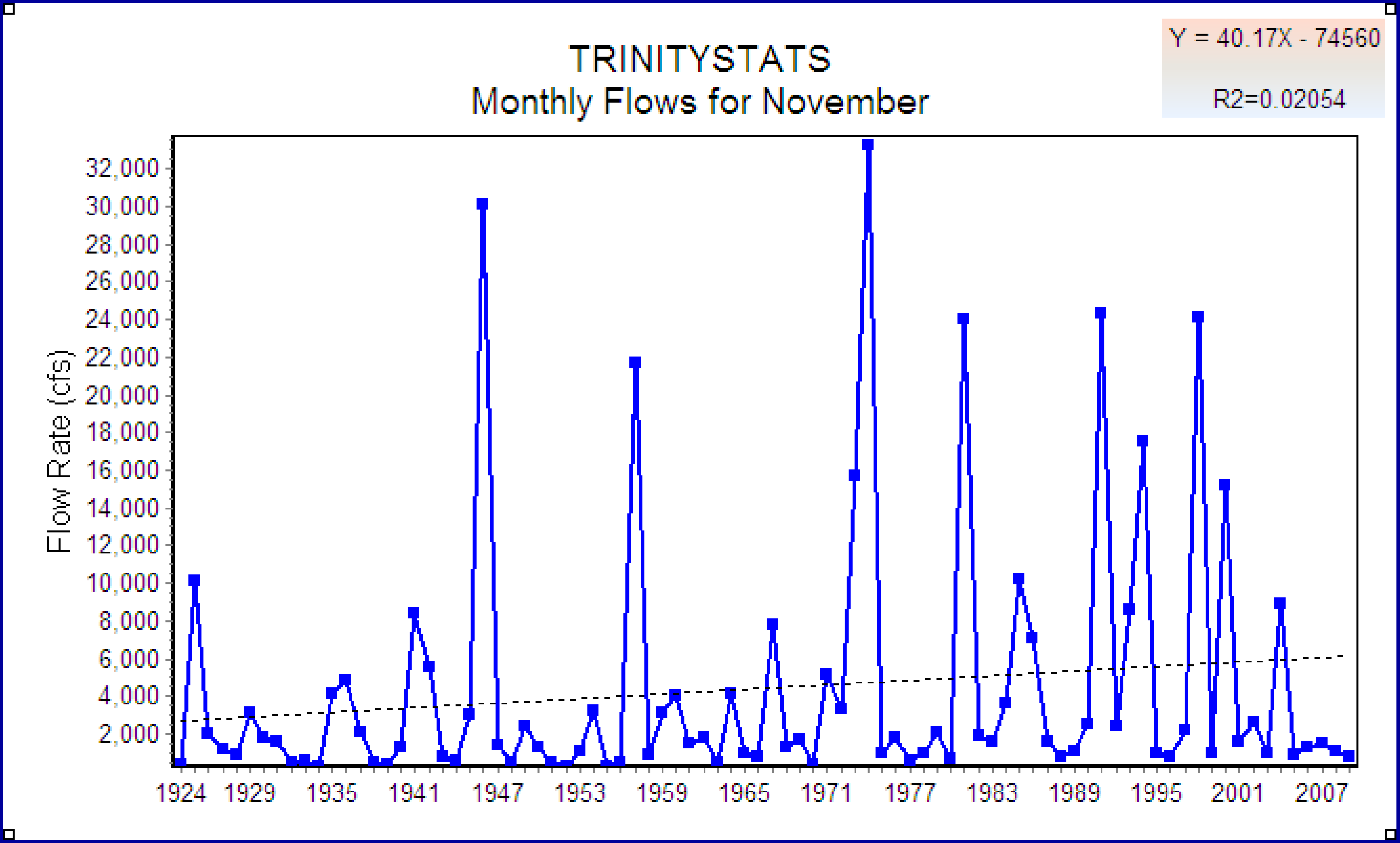


Trinity River Dam (Lake Livingston Built)

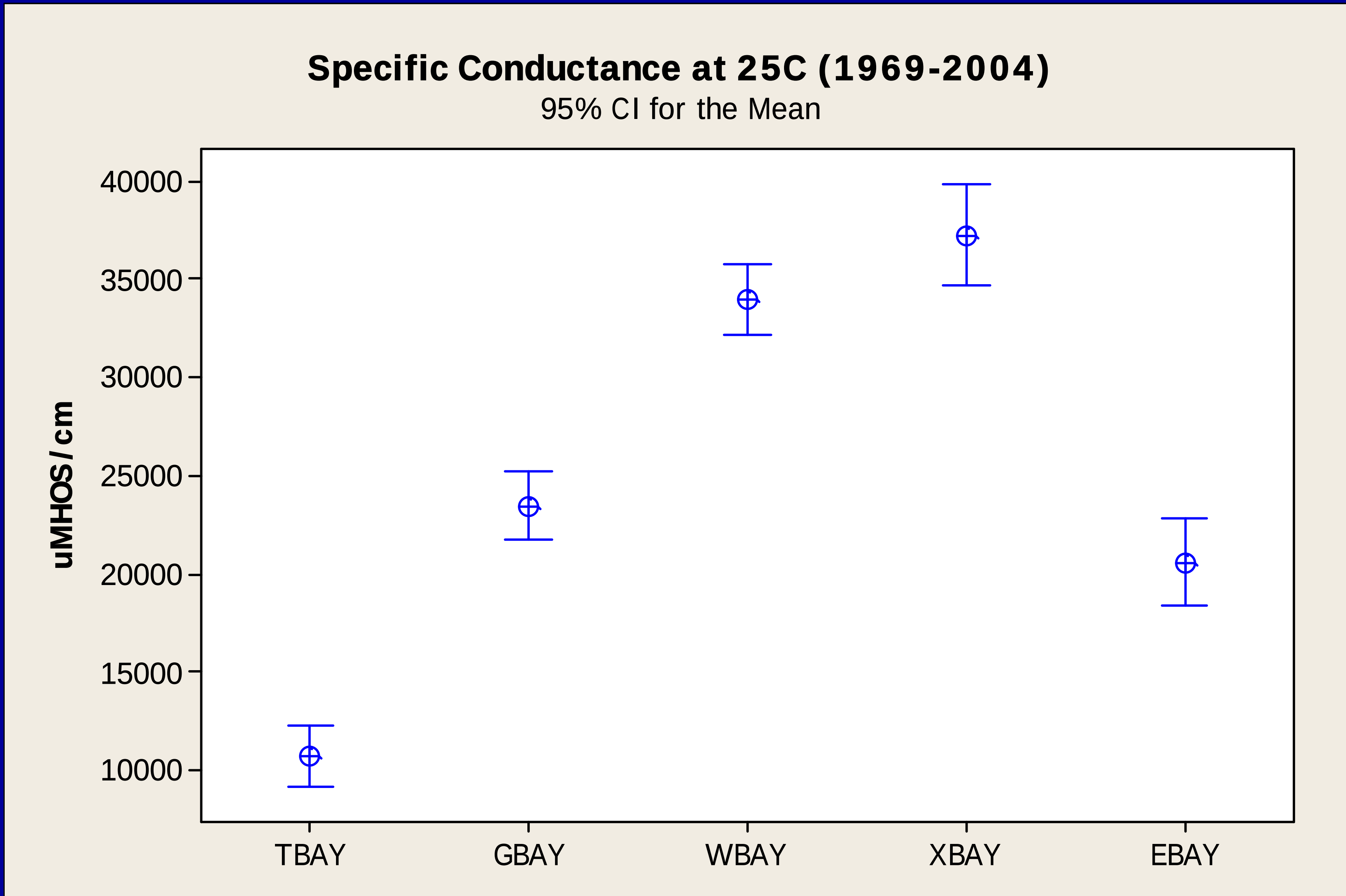

TRINITYSTATS
Monthly Flows for August
Y = 30.04X - 57340
R2=0.135
Flow Rate (cfs)
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
1924
1929
1935
1941
1947
1953
1959
1965
1971
1977
1983
1989
1995
2001
2007



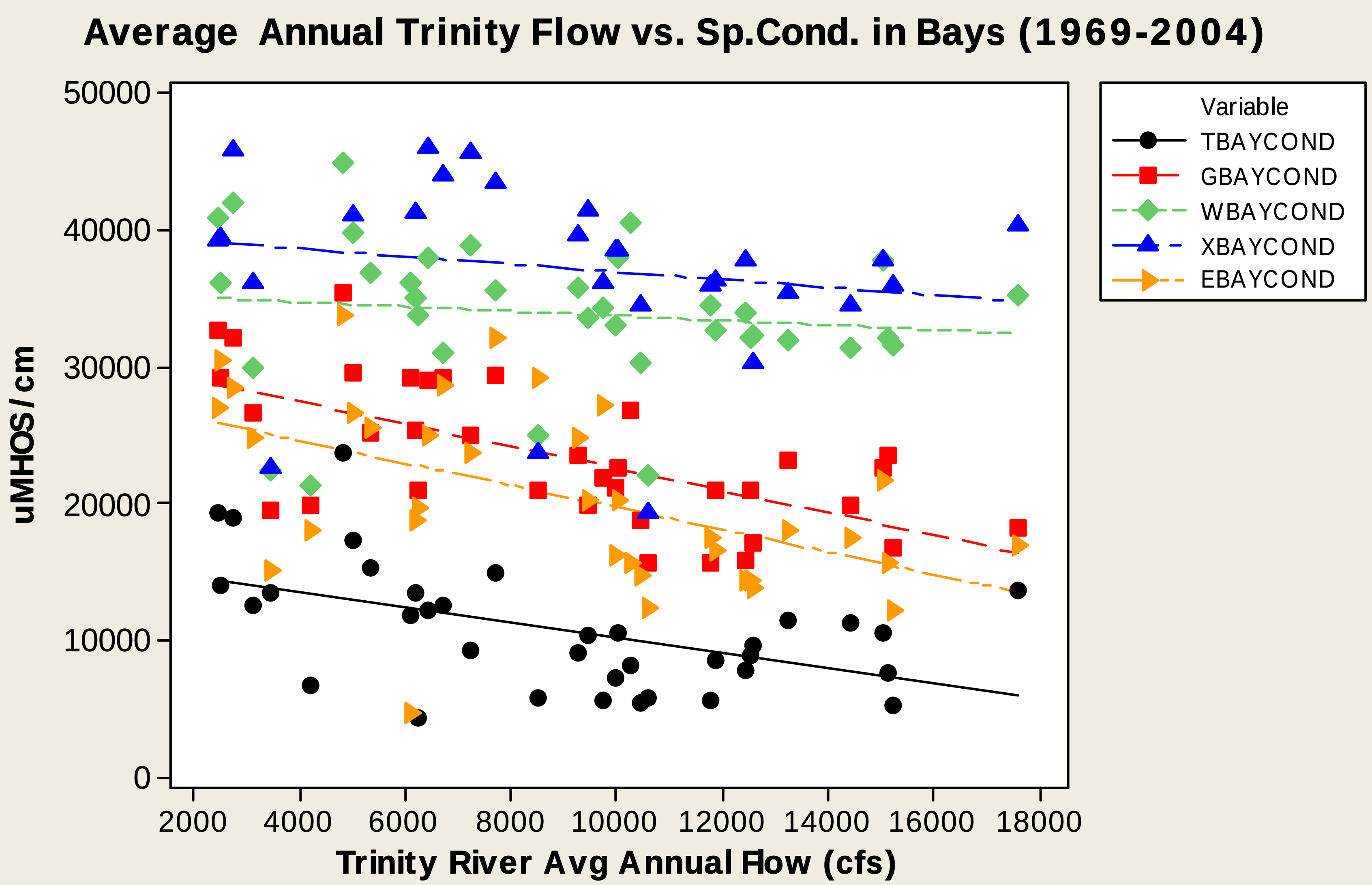
Trinity River Dam (Lake Livingston Built)



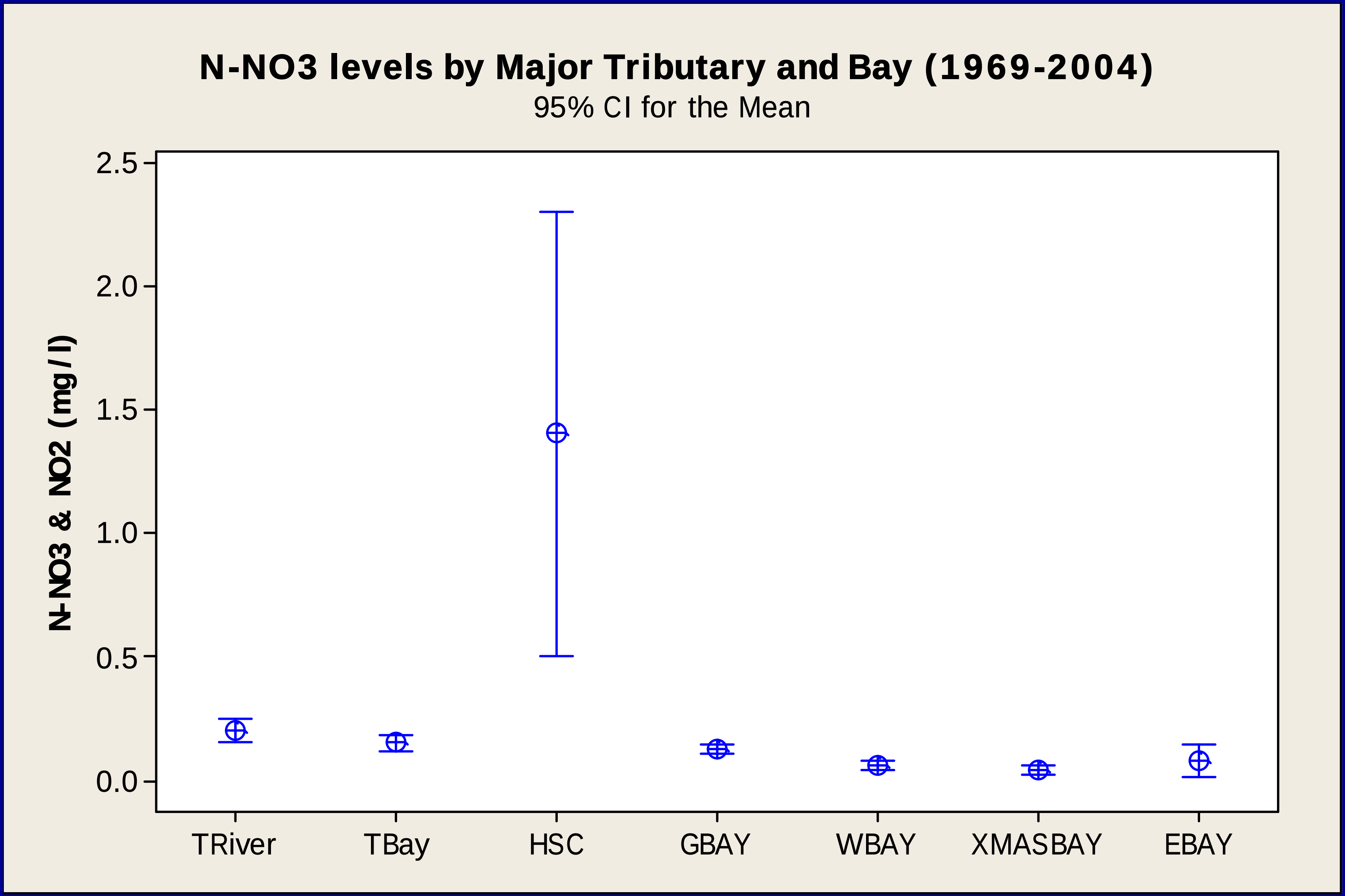
TRINITYSTATS
Monthly Flows for November
Y = 40.17X - 74560
R2=0.02054
Flow Rate (cfs)
32,000
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
1924
1929
1935
1941
1947
1953
1959
1965
1971
1977
1983
1989
1995
2001
2007



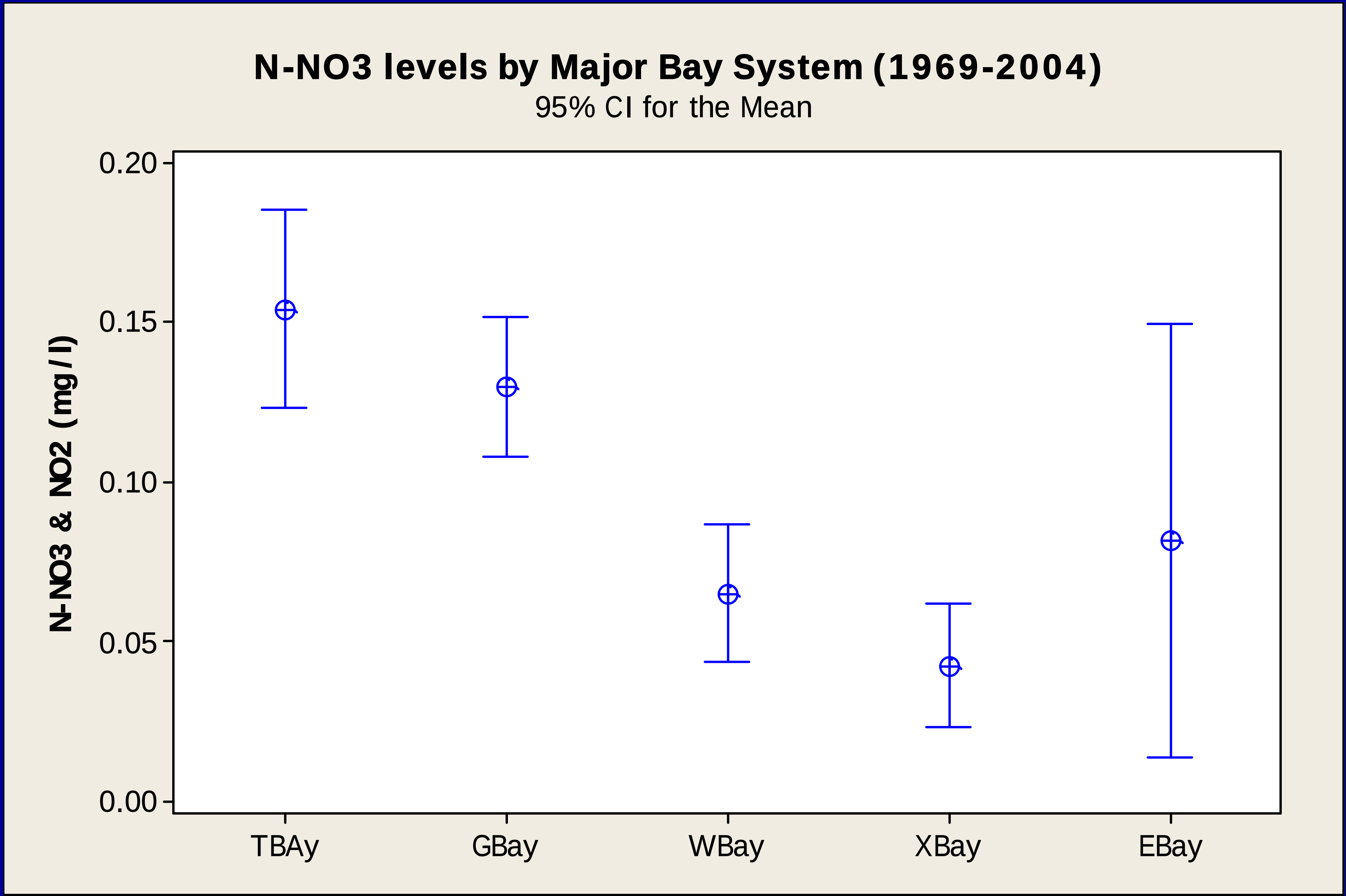
Specific Conductance at 25C (1969-2004)
95% CI for the Mean
uMHOS / cm
40000
35000
30000
25000
20000
15000
10000
TBAY
GBAY
WBAY
XBAY
EBAY



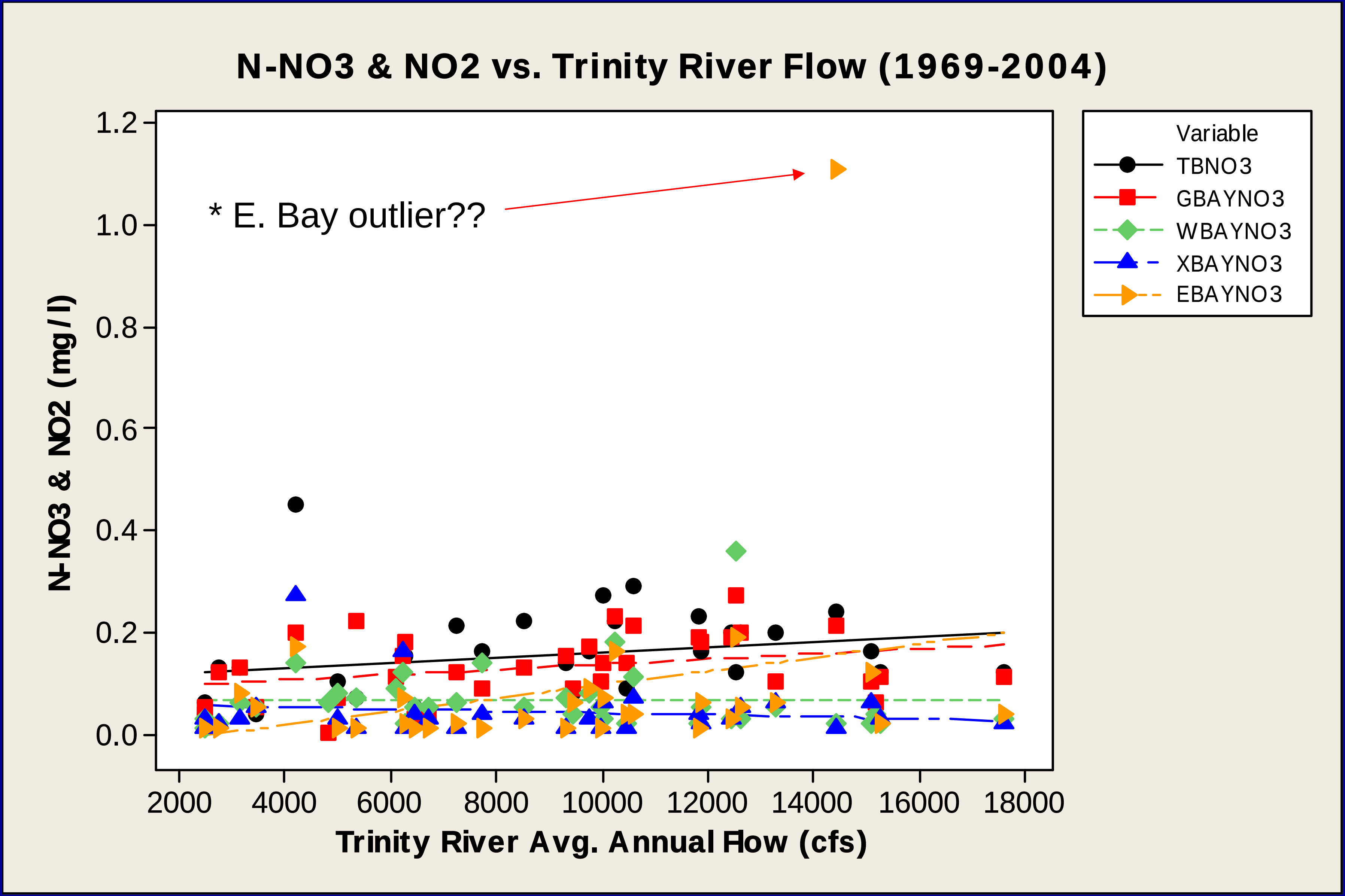
Average Annual Trinity Flow vs. Sp.Cond. in Bays (1969-2004)
uMHOS/cm
50000
40000
30000
20000
10000
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Trinity River Avg Annual Flow (cfs)
Variable
TBAYCOND
GBAYCOND
WBAYCOND
XBAYCOND
EBAYCOND



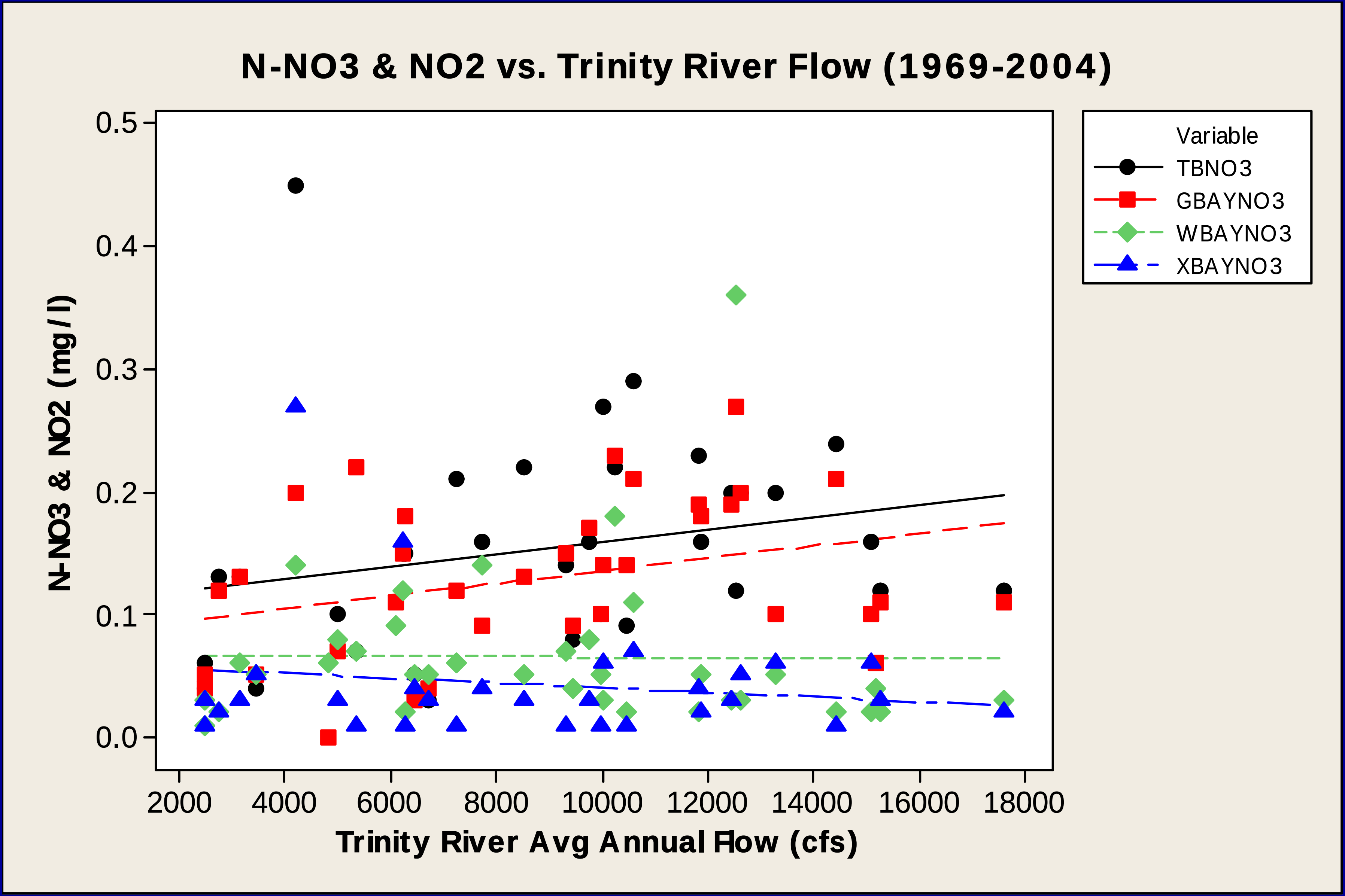
Extremely high N levels in the urbanized end of the San Jacinto Basin – HSC!!



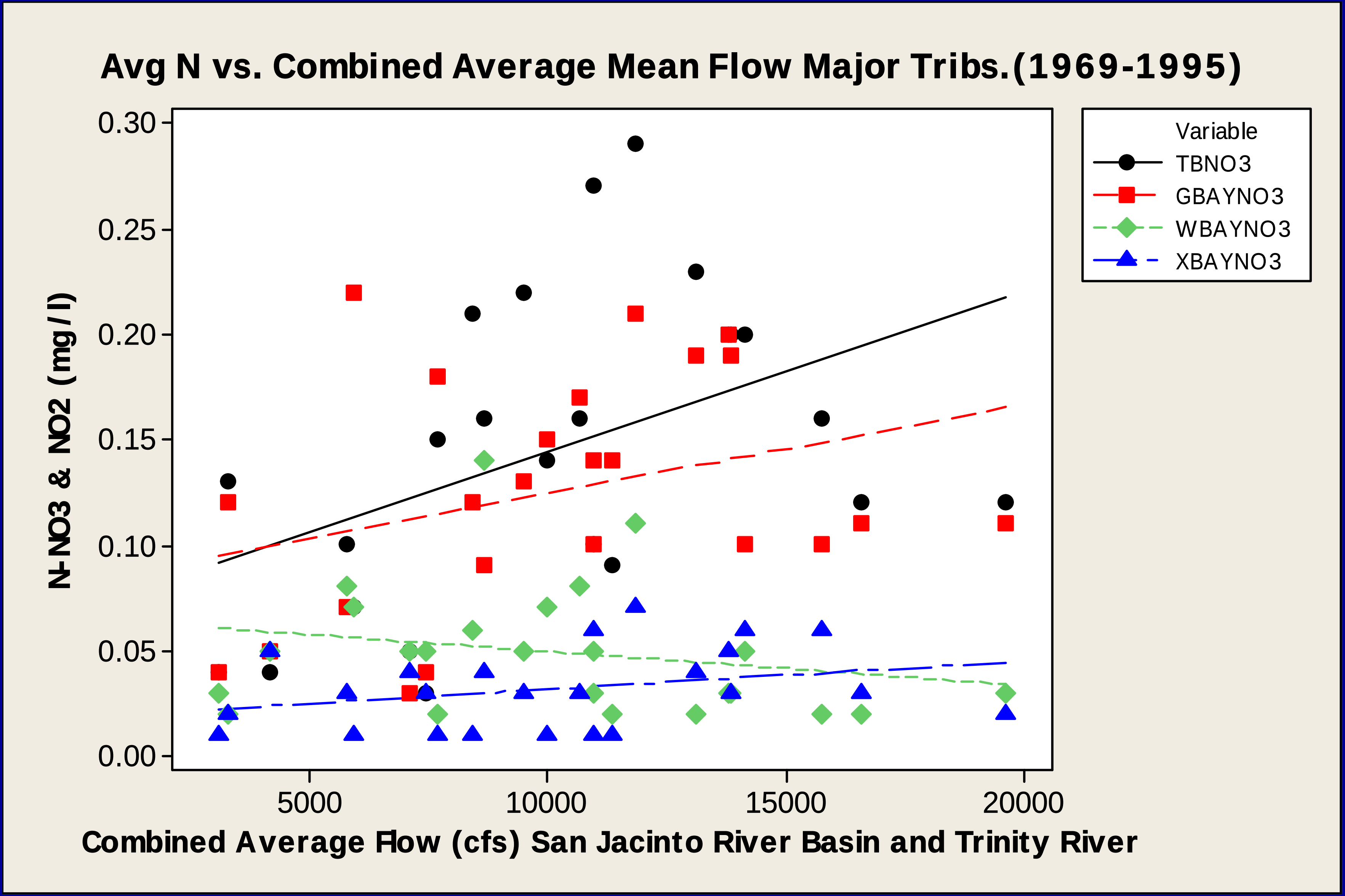
Major Differences Between XBay and West Bay vs. Rest of Bay System



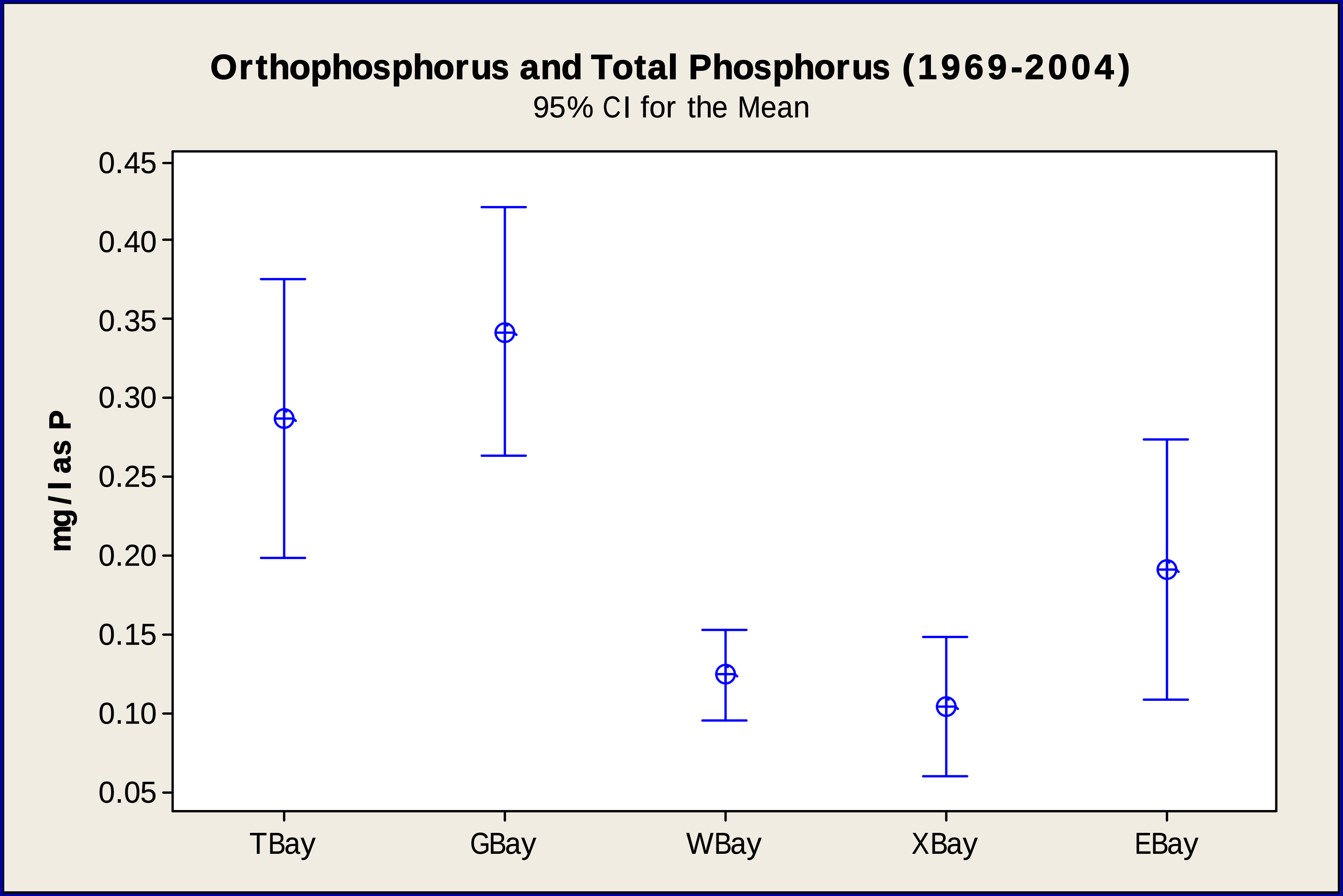
NOTE: West and XMAS Bay do not seem to respond to Trinity River Flows

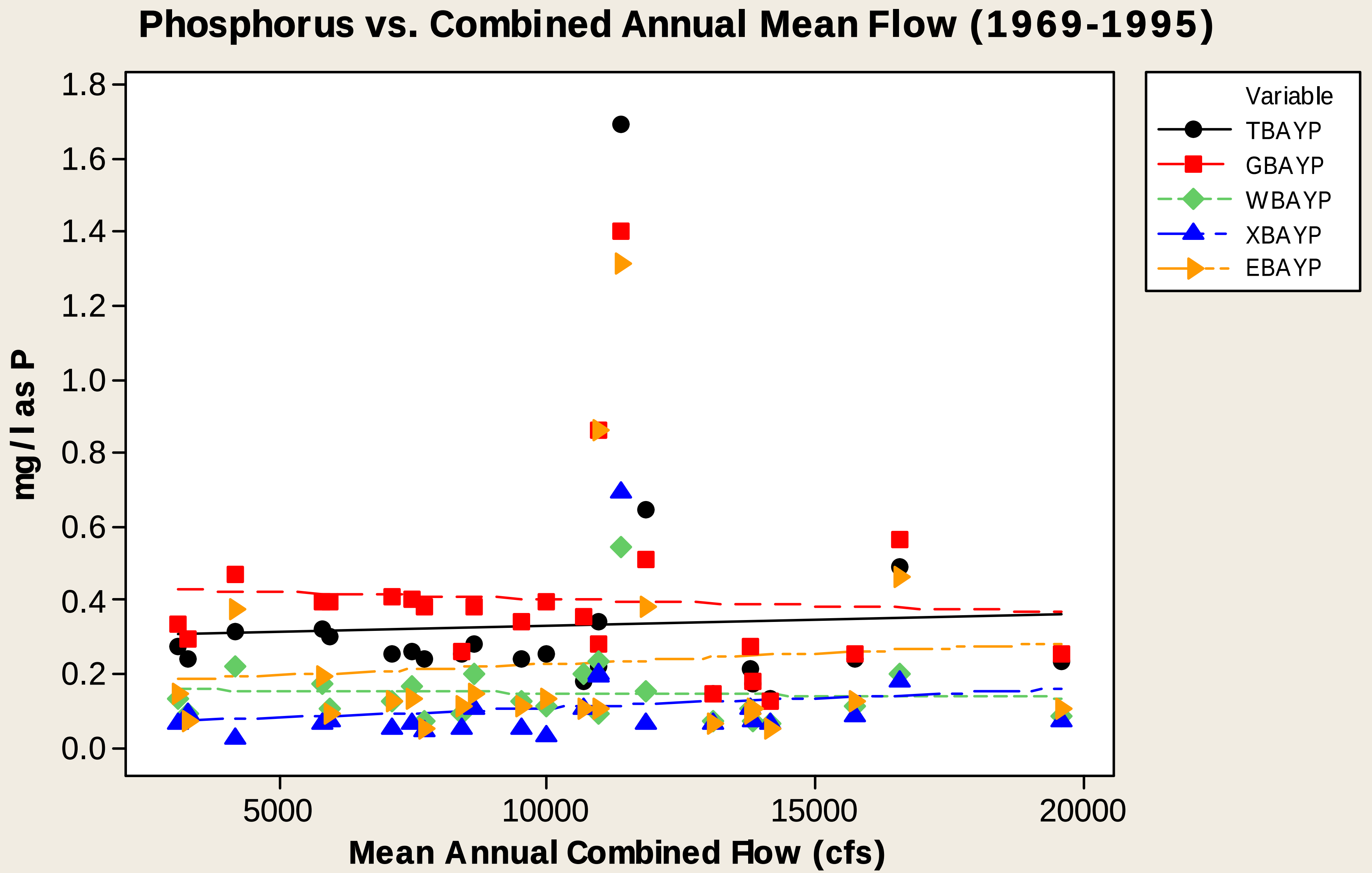


NOTE: West and XMAS Bay do not seem to respond to Trinity River Flows

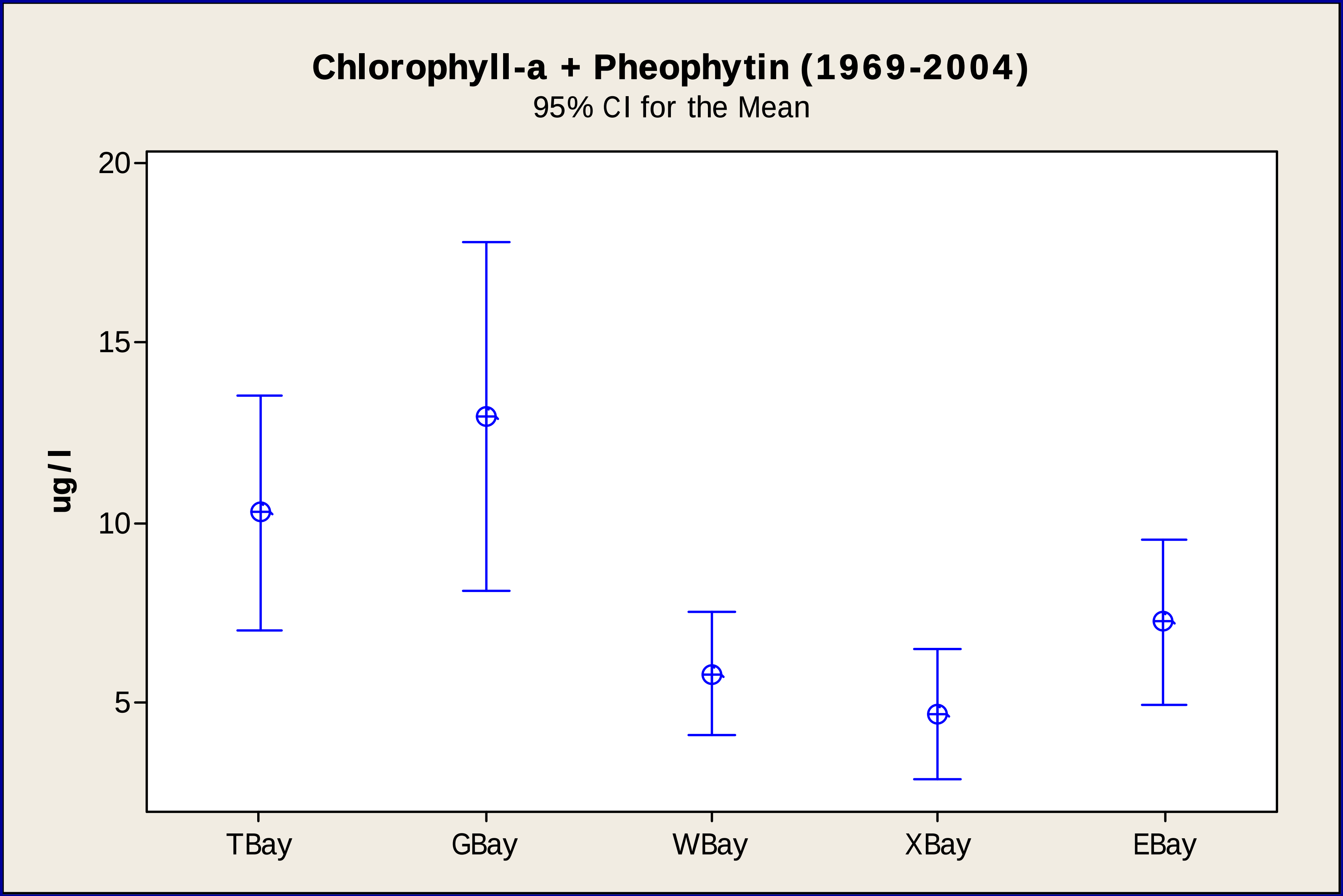


NOTE: West and XMAS Bay do not seem to respond to Combined Upper Bay Flows

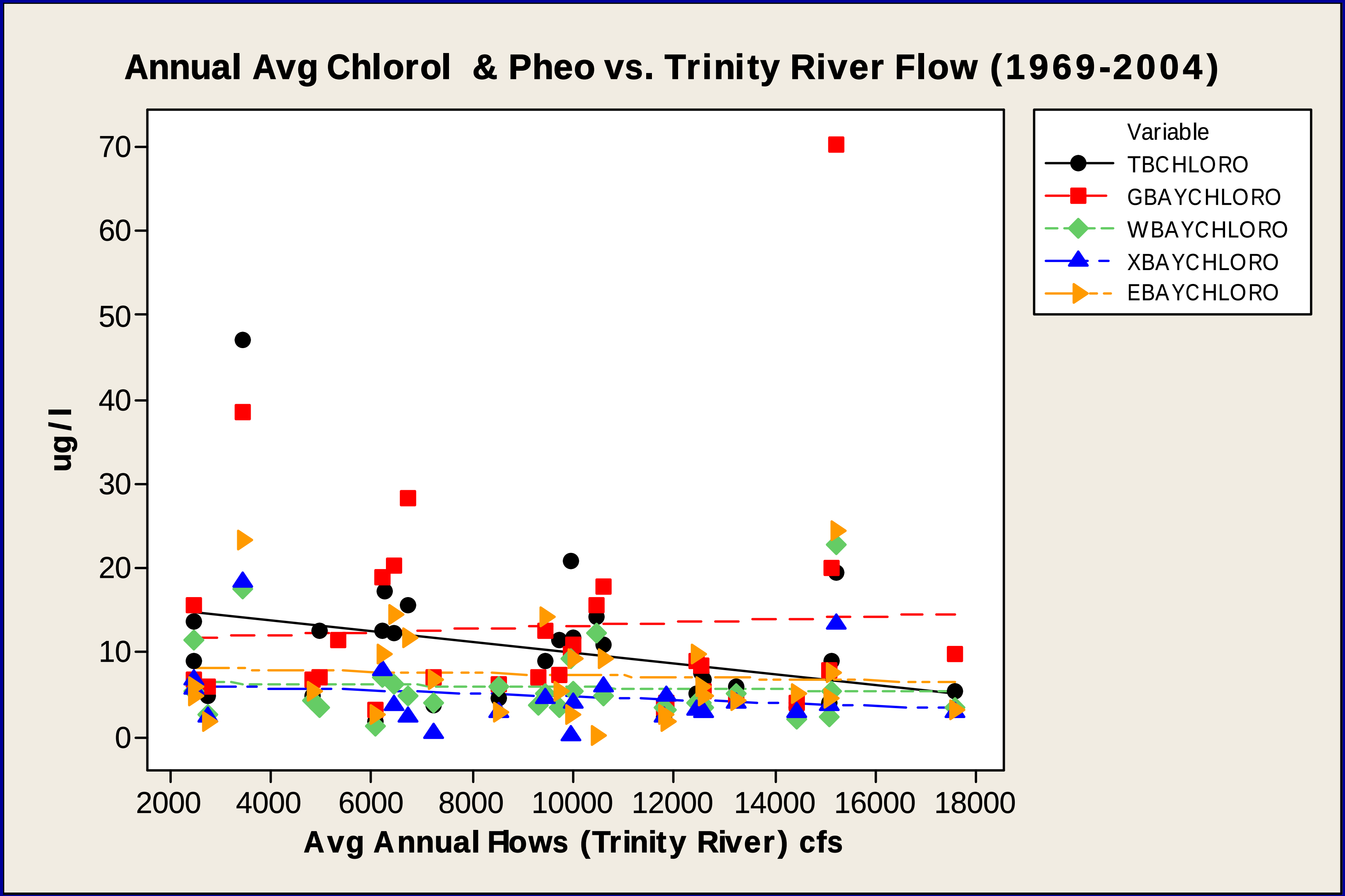

Orthophosphorus and Total Phosphorus (1969-2004)
95% CI for the Mean
mg/l as P
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
TBay
GBay
WBay
XBay
EBay



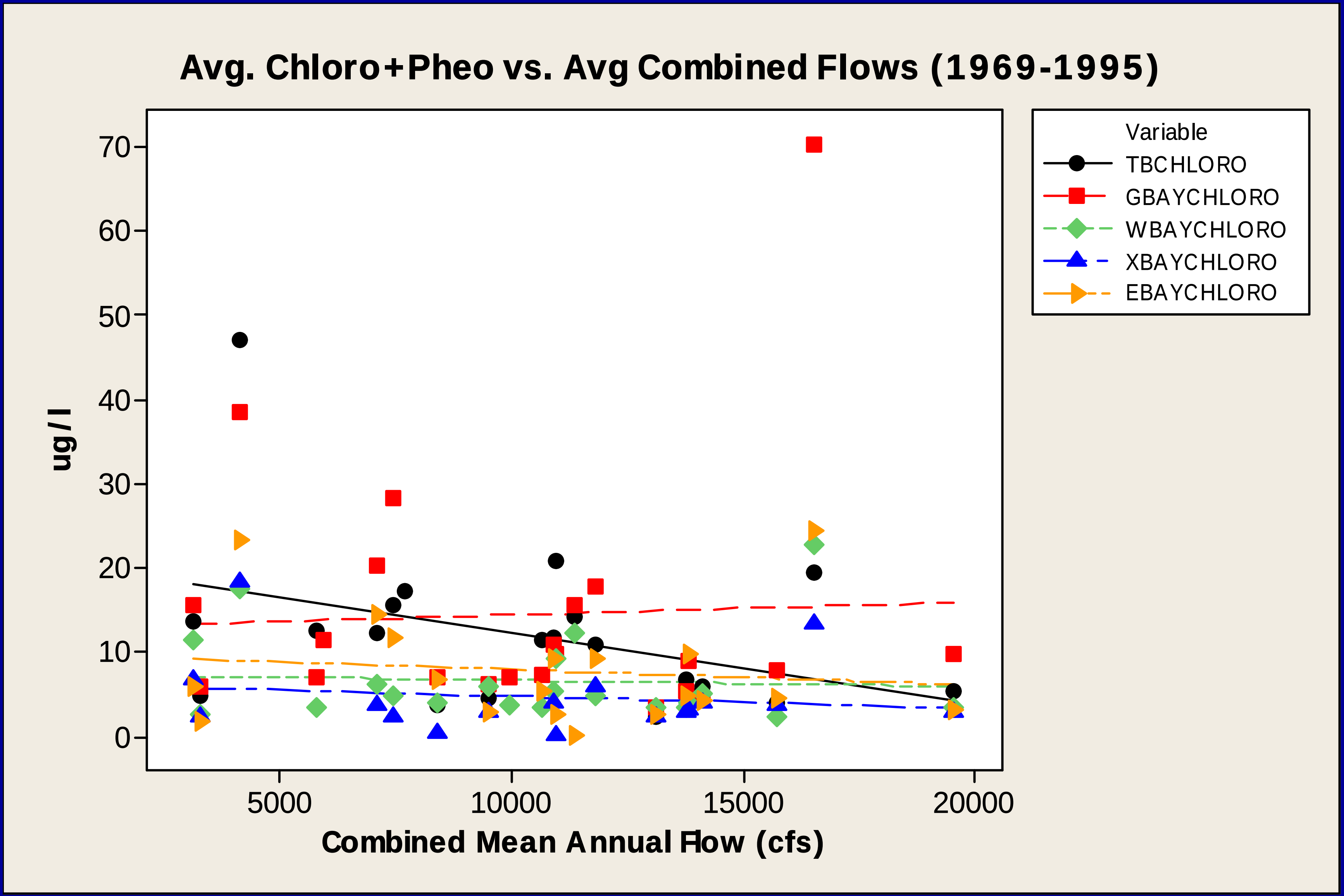
Not much of a trend, despite inter-bay differences. Spatially separated despite flows!! SAME TREND WITH Trinity River flows only analysis.



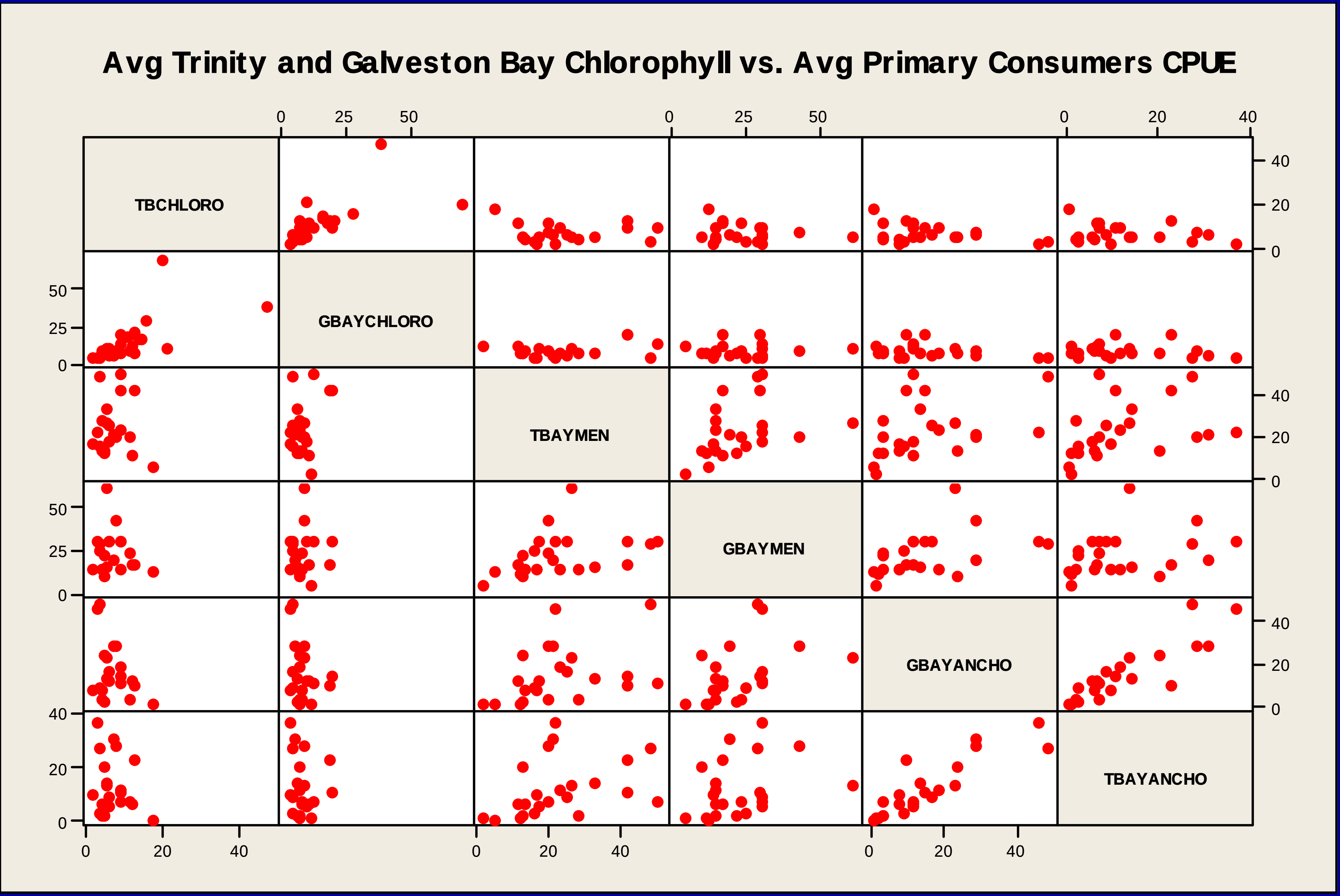
NOTE: Galveston Bay has slightly higher levels of phytoplankton.



Not much of a trend, despite inter-bay differences. Spatially separated despite flows!!
T. Bay goes down with flow, G. Bay goes up slightly.

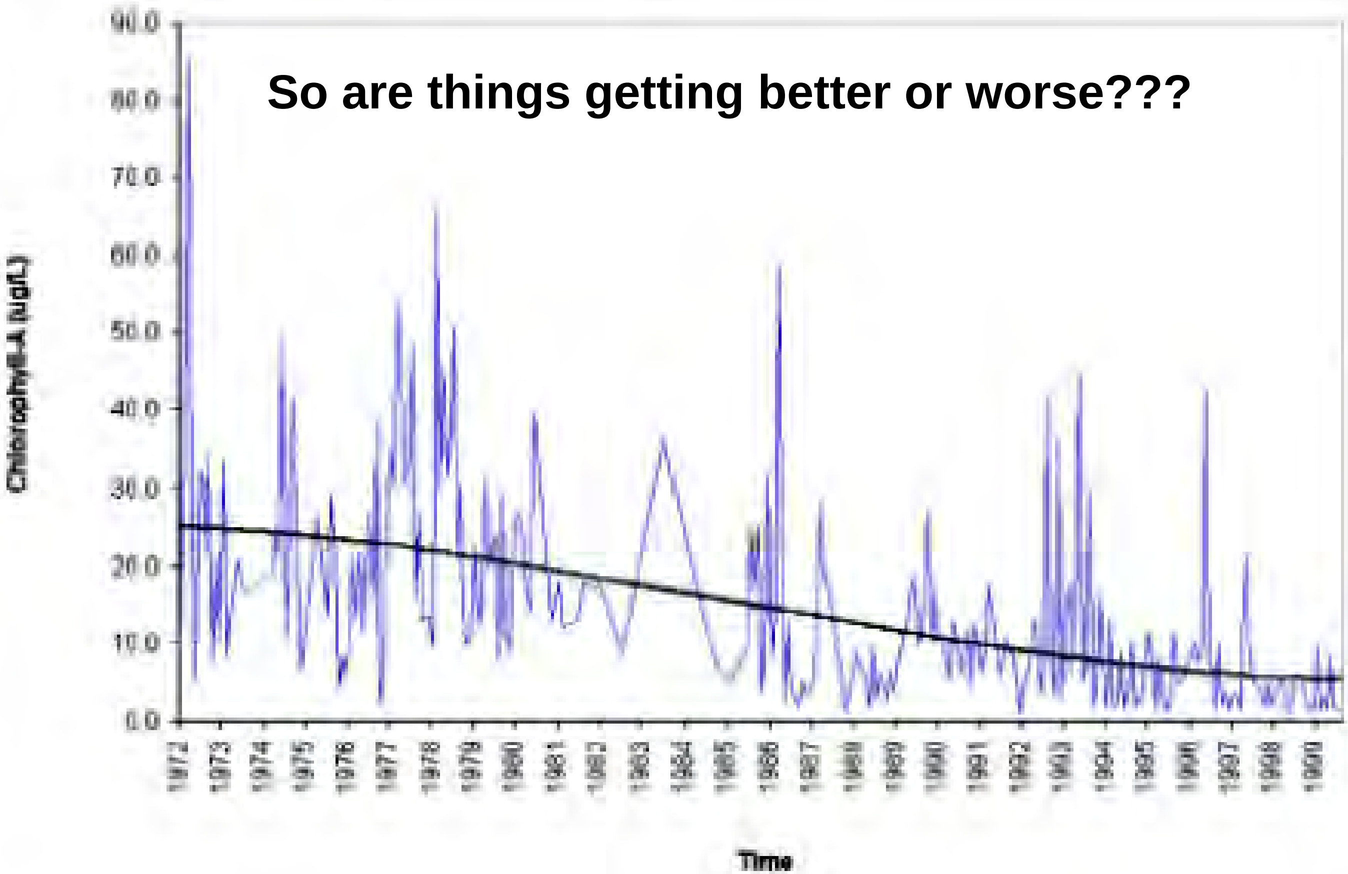


DITTO: Combined Flows. Spatially separated despite flows!! Where is N coming from? G. Bay goes up with flow, T. Bay goes down?

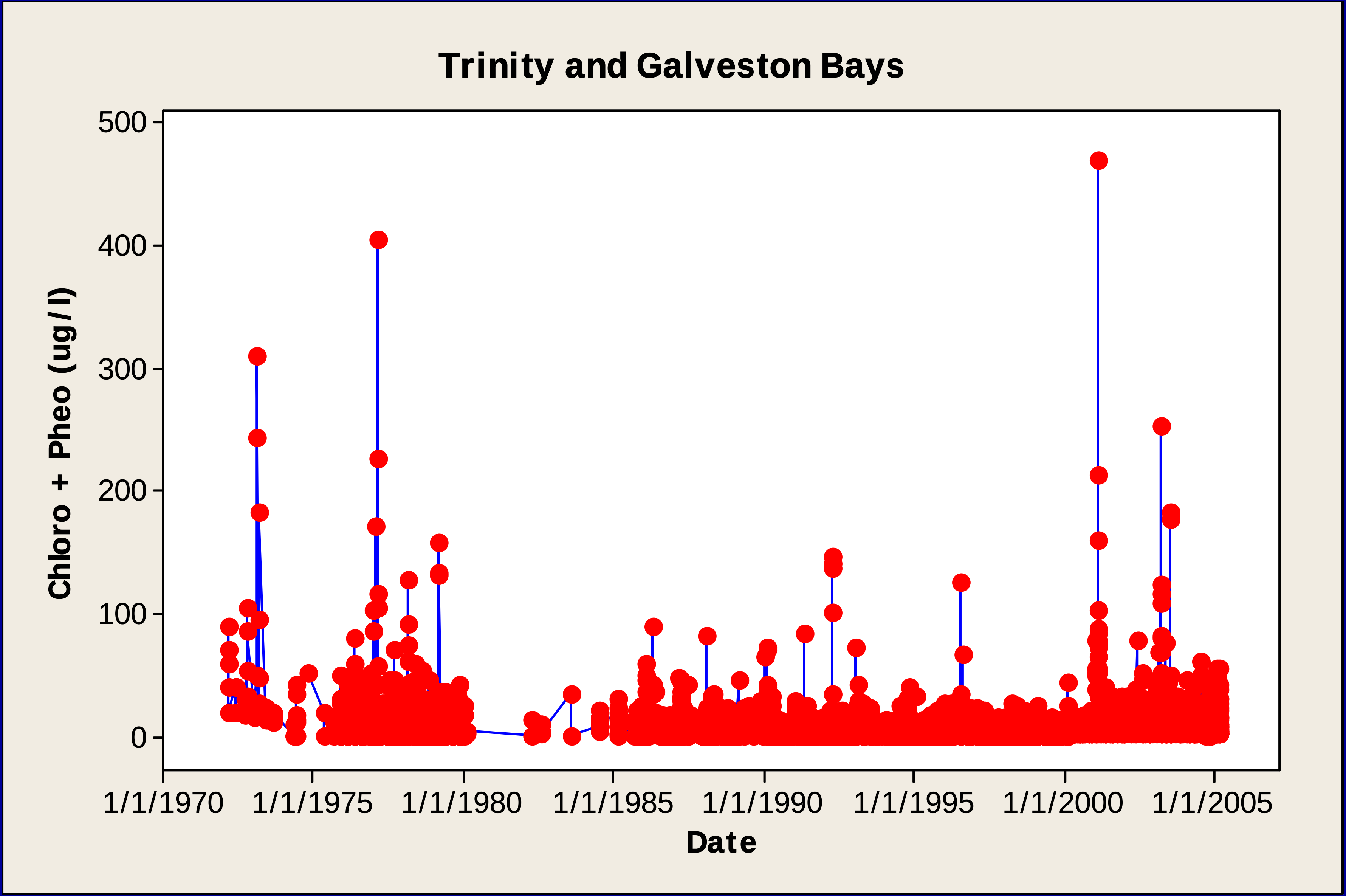


No strong correlations between chlorophyll and Menhaden and Bay Anchovy

Figure 7 – Monthly Average Chlorophyll *a* Concentrations in Galveston Bay

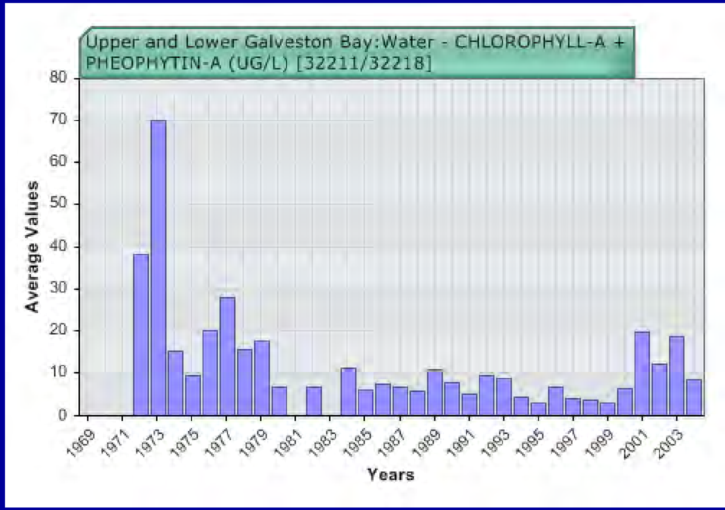


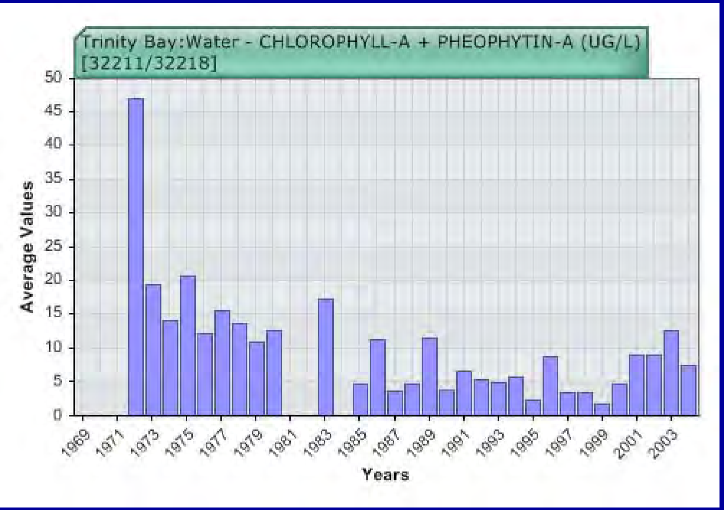
Source: Lester and Gonzales (2002), citing from Criner and Johnican (2001)

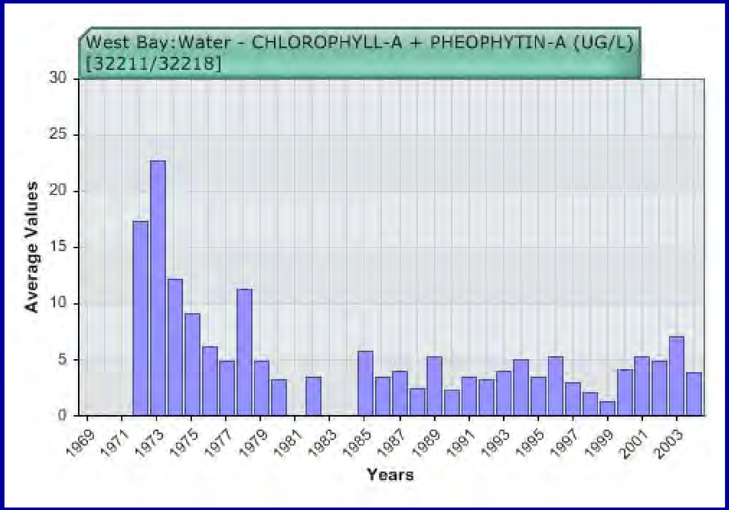


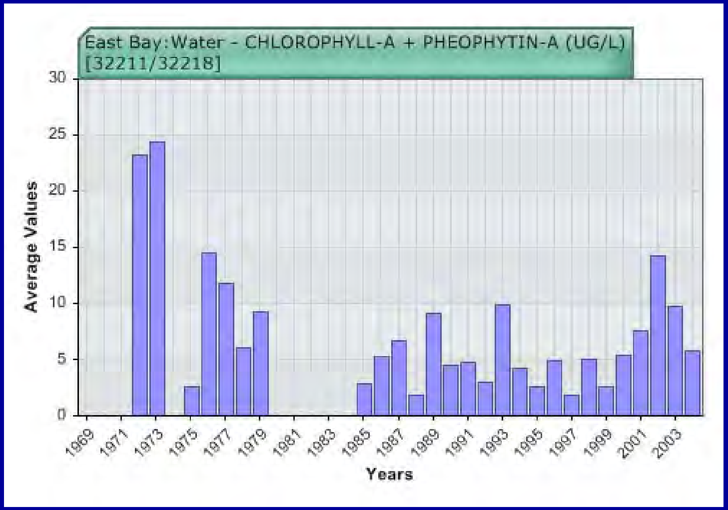
Trinity and Galveston Bays
Chloro + Pheo (ug/l)
500
400
300
200
100
0
1/1/1970
1/1/1975
1/1/1980
1/1/1985
1/1/1990
1/1/1995
1/1/2000
1/1/2005
Date

Chloro/Pheo trends





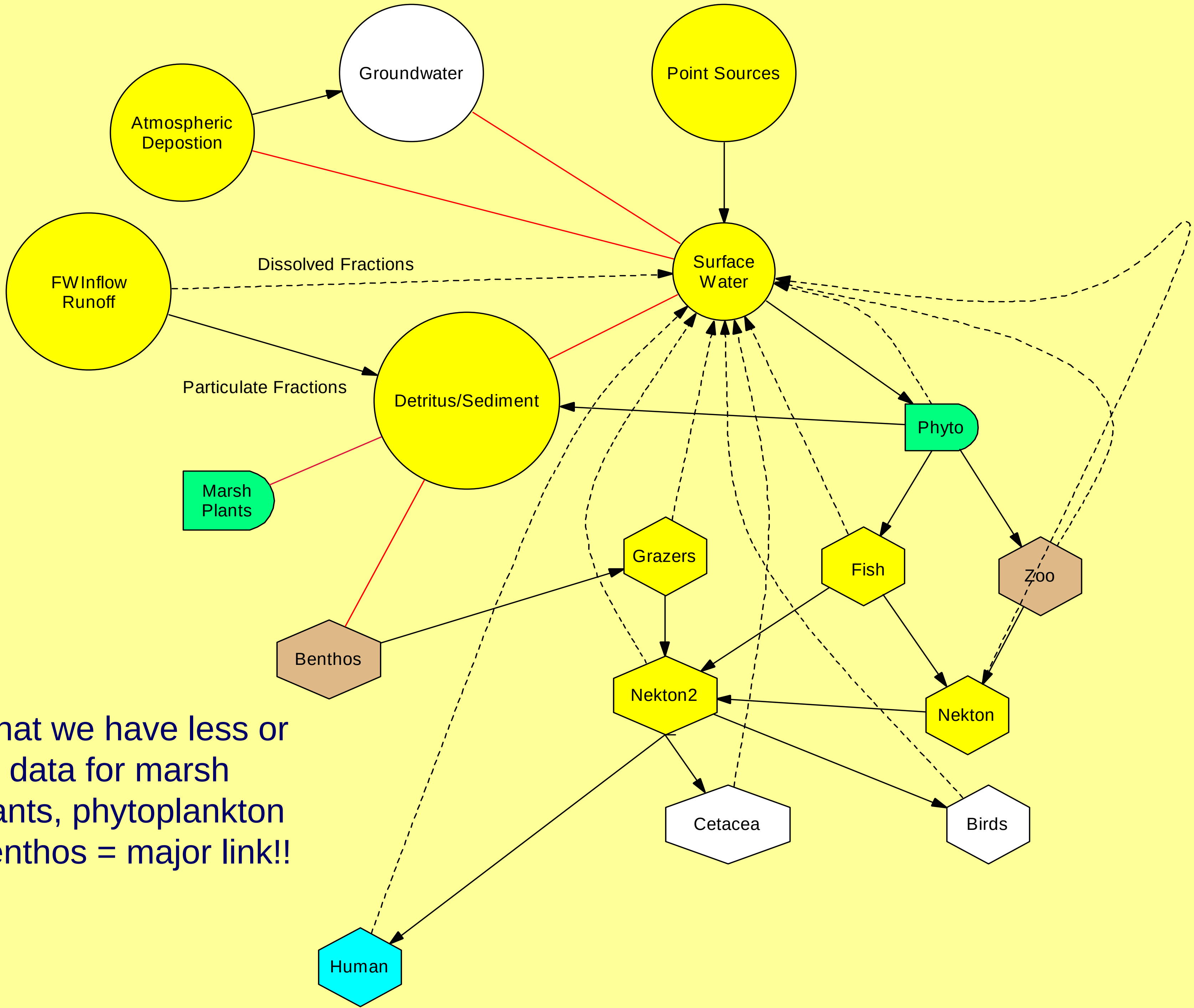




Stable Isotopes as Tools

Constructing Food Web - tools

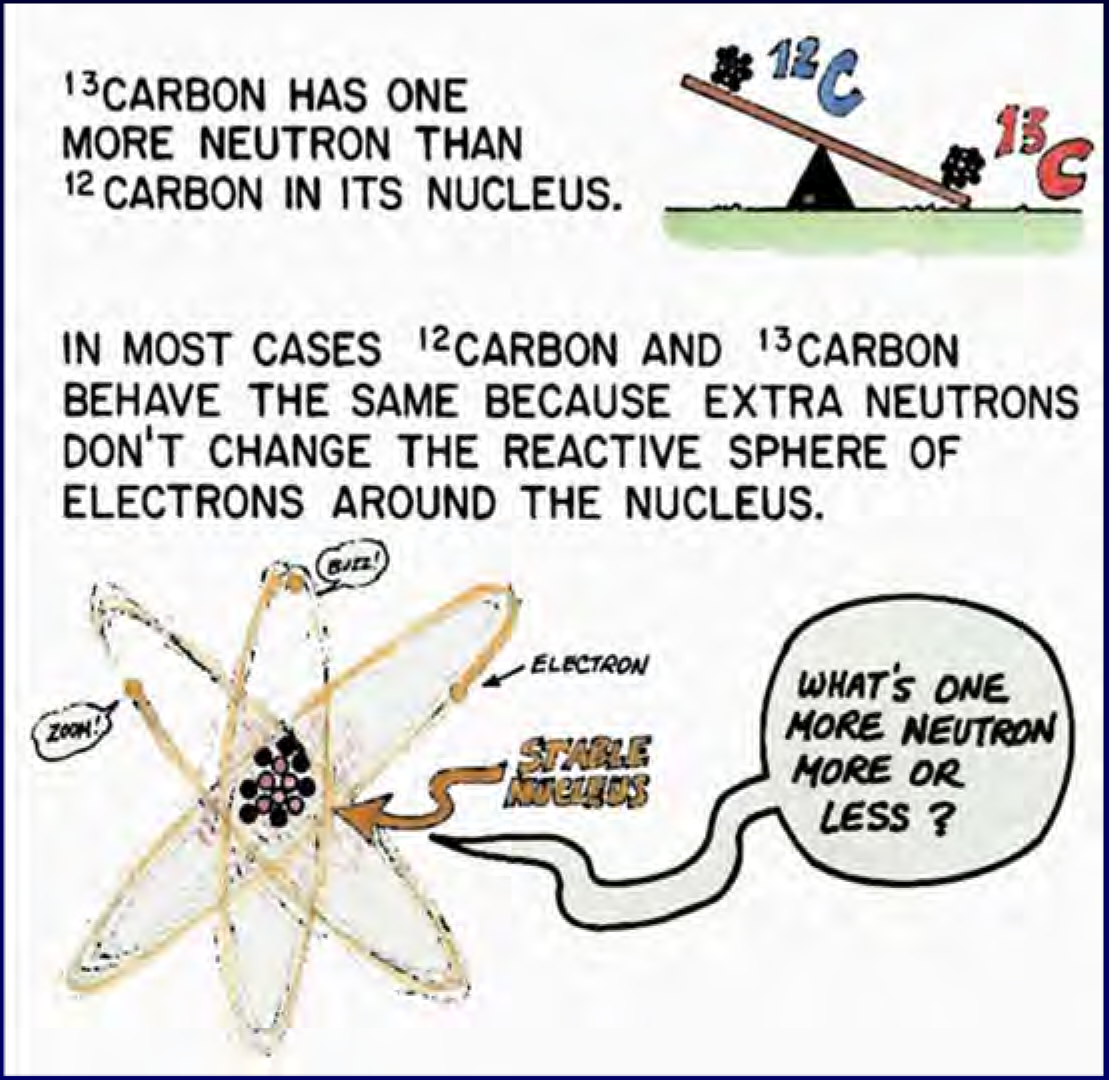
- Stomach Analysis
- Stable Isotope Analysis
  - Long-term patterns and information on food items and trophic position possible
  - Little or no taxonomic detail



What we have less or no data for marsh plants, phytoplankton
Benthos = major link!!

Isotopes

- Isotopes – atoms w/ different # of neutrons
- Different atomic weights
  - Termed heavy & light
  - React differently in kinetic reactions



(Fry 2006)

Stable Isotopes

^{13}C

- Determines primary source of nutrition
  - C_3 & C_4 photosynthesis (terrestrial plants & marsh grasses)
  - Minimally enriched with trophic level ($<1^0/_{00}$)

^{15}N

- Identifies trophic position
  - Enriched as trophic level increases (3 to $4^0/_{00}$)
  - Excretion of the lighter isotopes through metabolic processes

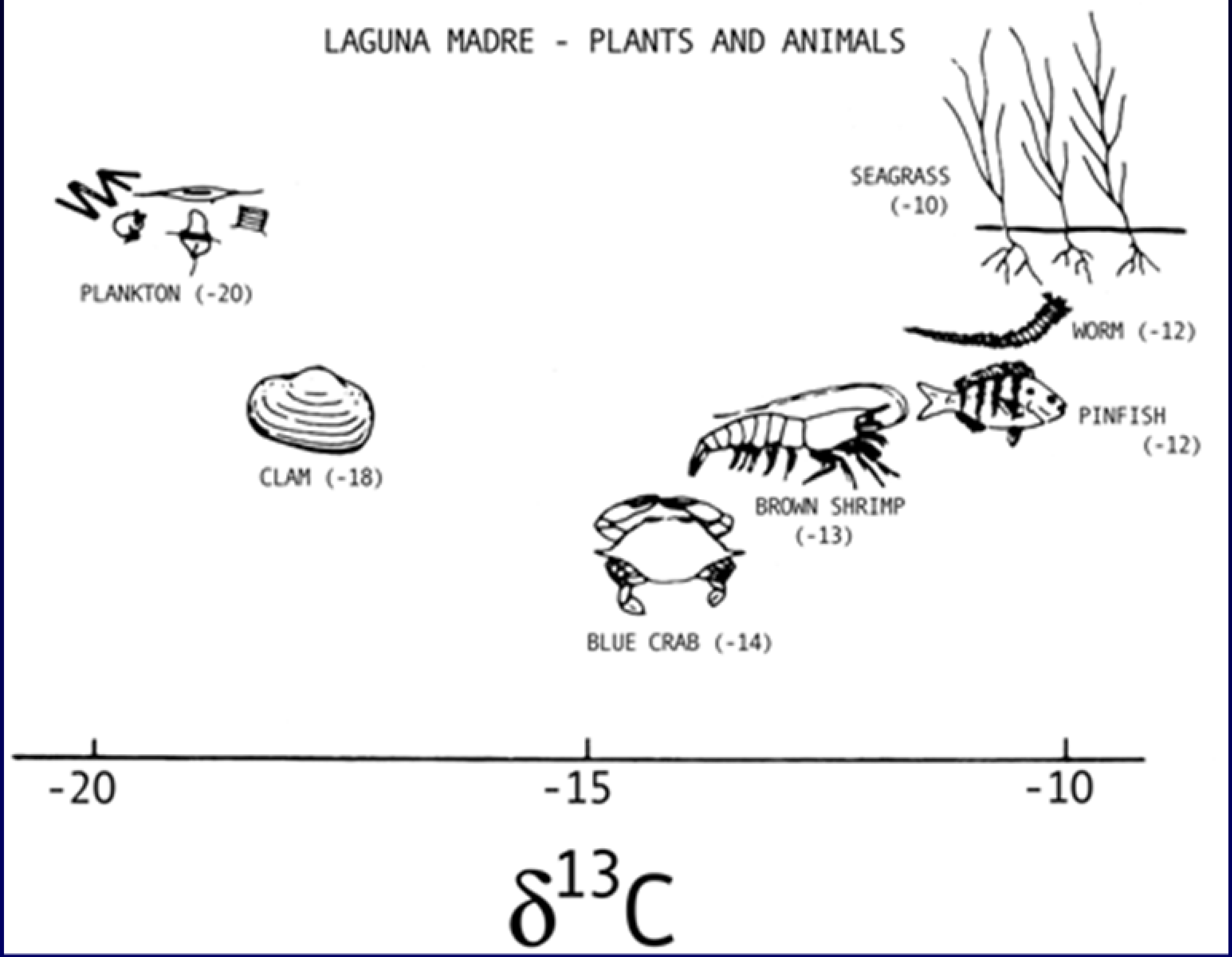
Stable Isotope Analysis

$$\delta^{15}N‰ \text{ vs. } [std] = \left(\frac{R_{sample} - R_{std}}{R_{std}} \right) (1000\,\delta\,‰)$$

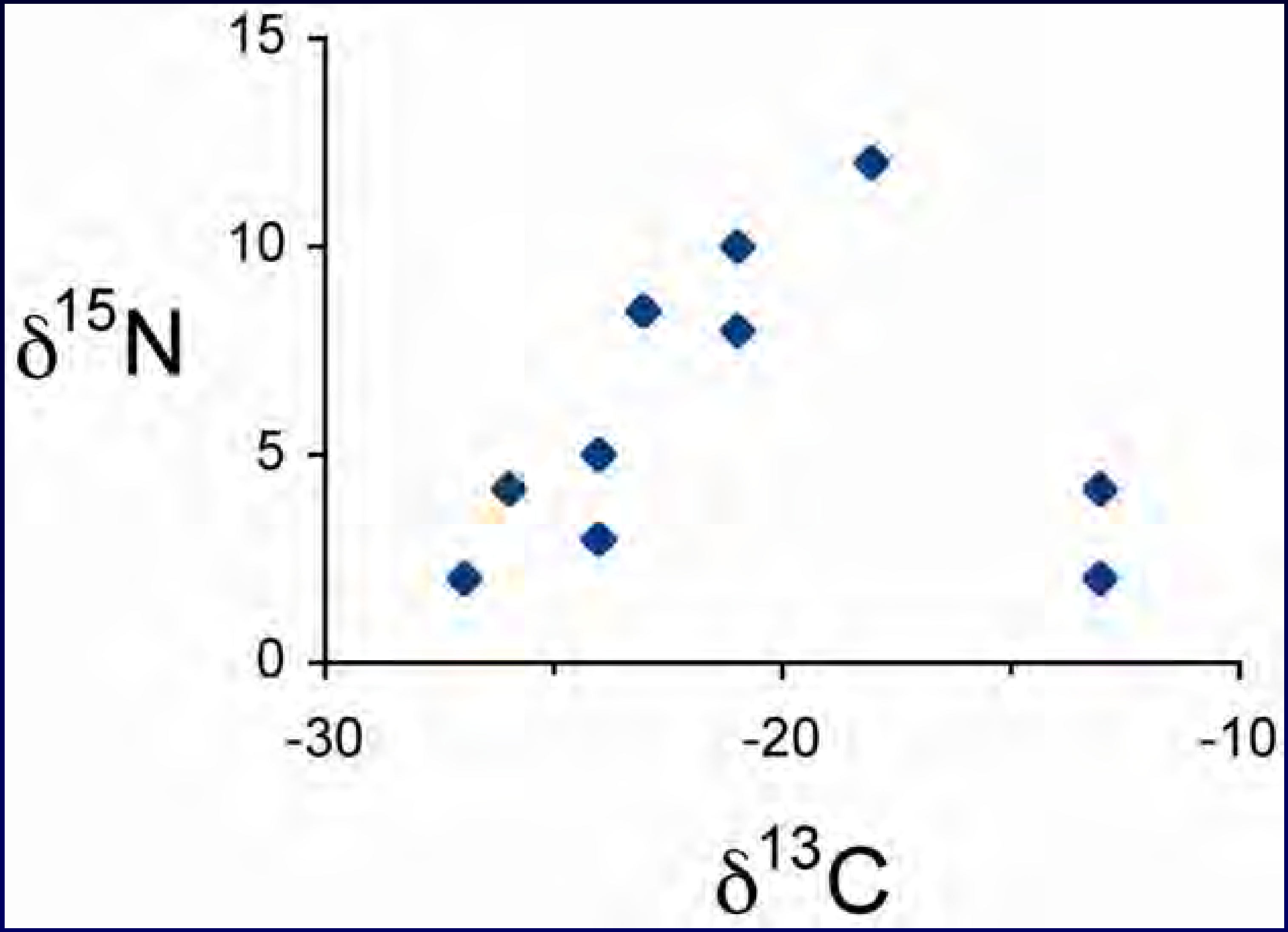
Where

$$R = \left(\frac{At\%^{15}N}{At\%^{14}N} \right)$$

Stable isotopes are chemical isotopes that are not radioactive. About 2/3rds of elements have more than one stable isotope. Different stable isotopes of the same element have the same chemical characteristics and therefore behave almost identically. **The mass differences, due to a difference in the number of neutrons, result in partial separation of the light isotopes from the heavy isotopes** during chemical reactions (isotope fractionation



From Fry 2006. Fig. 5.4. Conceptual model of carbon flow in the Texas seagrass meadows, with only two carbon sources present, seagrass and phytoplankton (P.L. Parker, personal communication, ca. 1976).

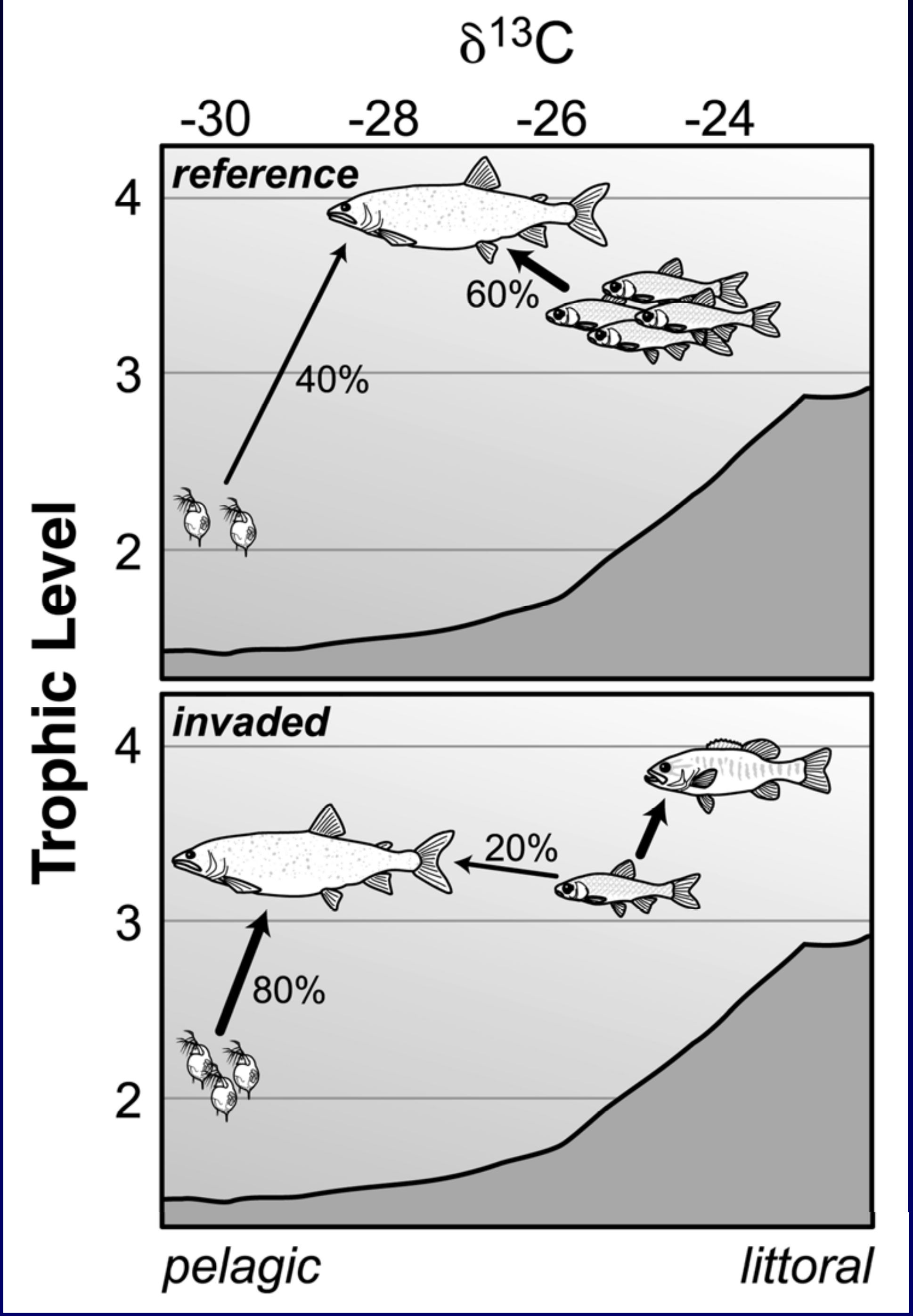


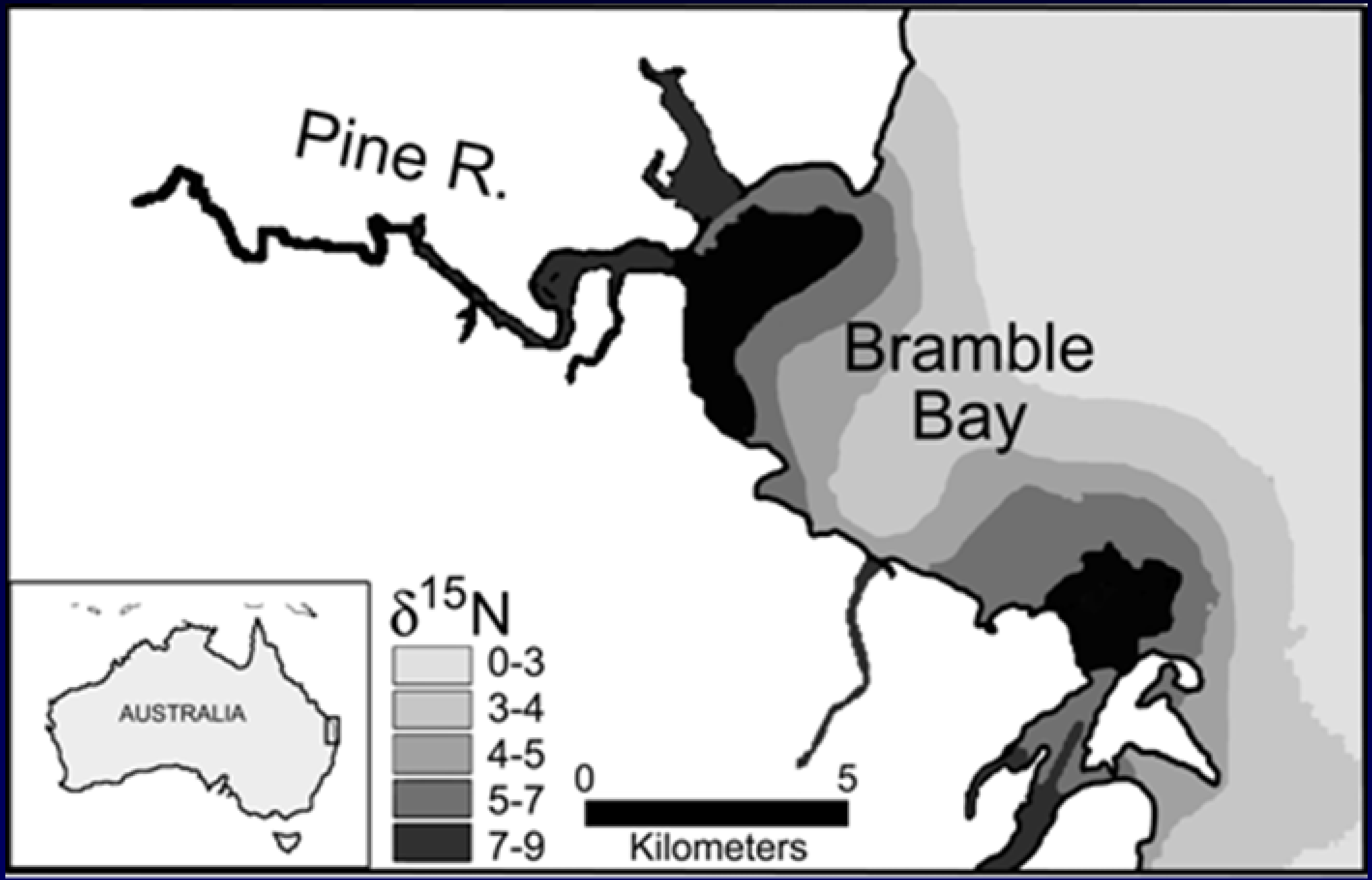
Fry 2006. Chapter 5. Fig. E. As previous figure, but with added data from the second round of sampling.

(Fry 2006). Fig. 3.8. Effects of species introductions measured in lake ecosystems. Introduction of nearshore bass species forces the native top predator, lake trout, offshore.

Reflecting this spatial displacement, lake trout diets shift towards feeding in a more pelagic food web (as measured by lower $\delta^{13}C$) and at a lower trophic level (as measured by lower $\delta^{15}N$; with $\delta^{15}N$ translated into the y-axis "trophic level" in this figure).

* d15N becomes enriched about 2.2 to 3.4 per mil per trophic level.
Can use to estimate trophic level.

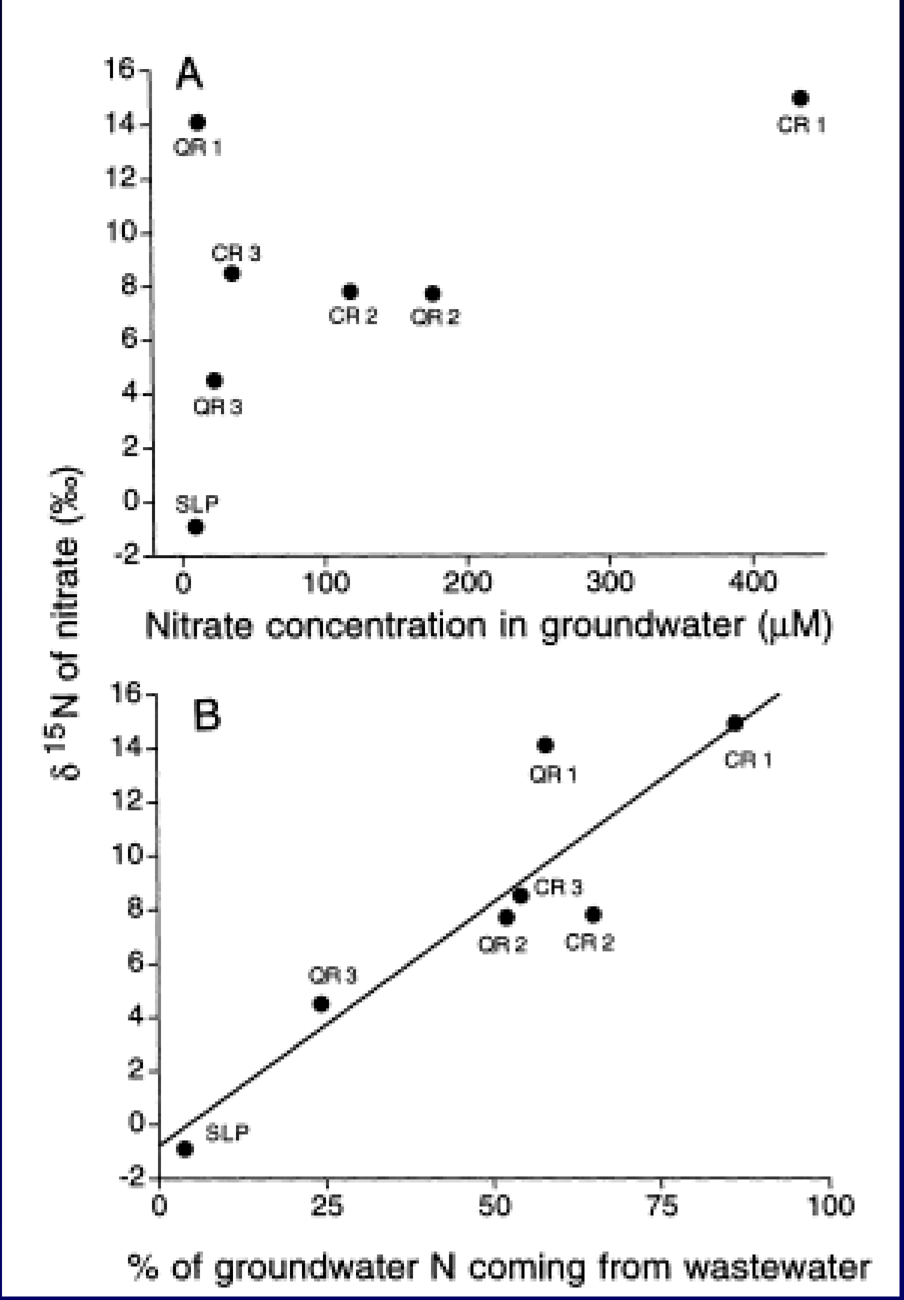




Fry (2006). Fig. 3.6. $\delta^{15}N$ values of algae in Moreton Bay, Australia where the city of Brisbane occupies the western shore. High $\delta^{15}N$ values along the western shore indicate N pollution inputs from watershed rivers and local sewage treatment facilities.

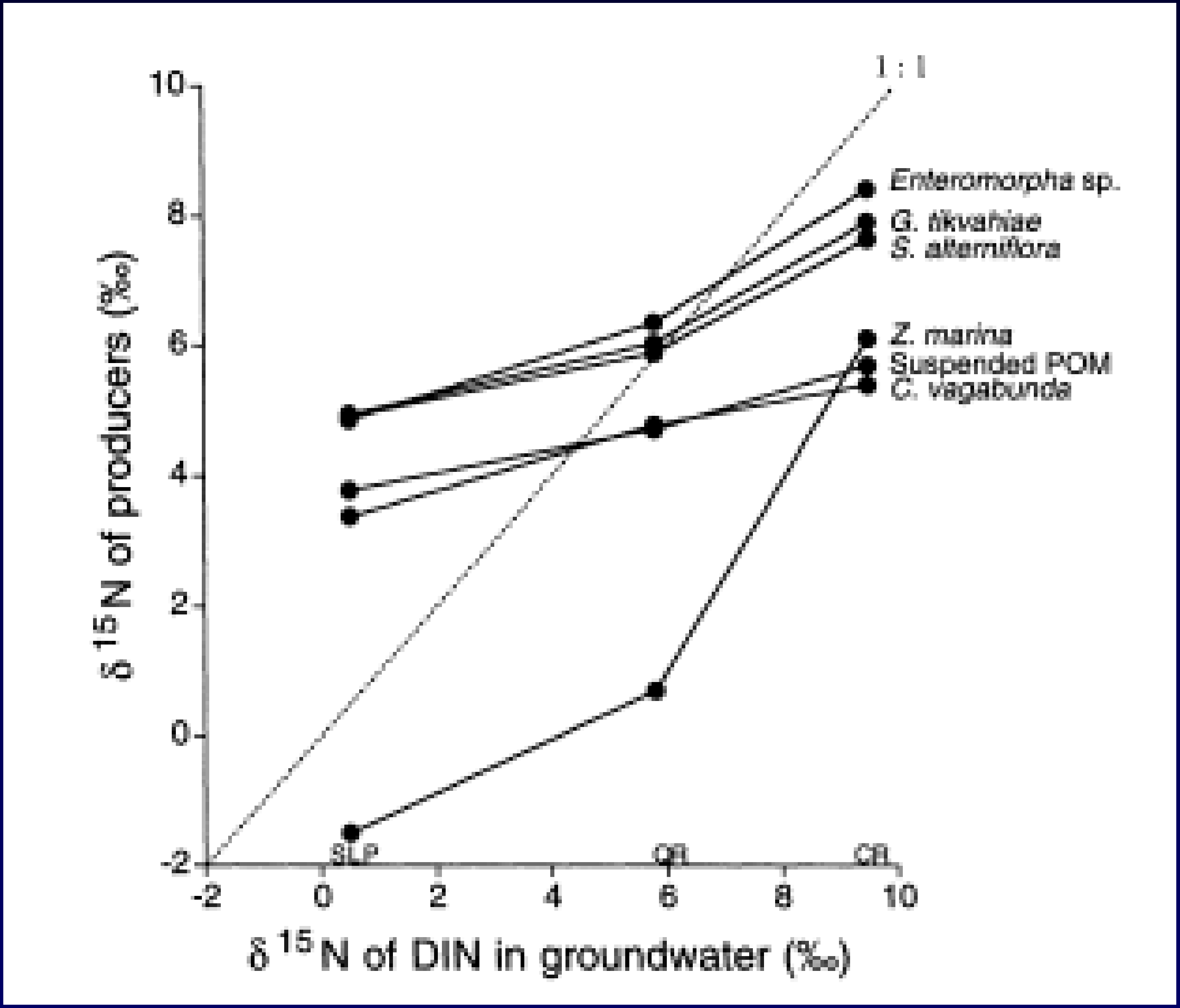
Mechanism

- Volatilization of ammonia and denitrification of wastewater N sources removes ^{14}N at a faster rate than ^{15}N
- Remaining nitrate from wastewater that enters an aquifer or waterbody typically has *d* ^{15}N values between +10 and +20 per mil vs. natural background levels of +2 and +8 per mil.



Mass. Study – Groundwater

McClelland and Valiela 1998



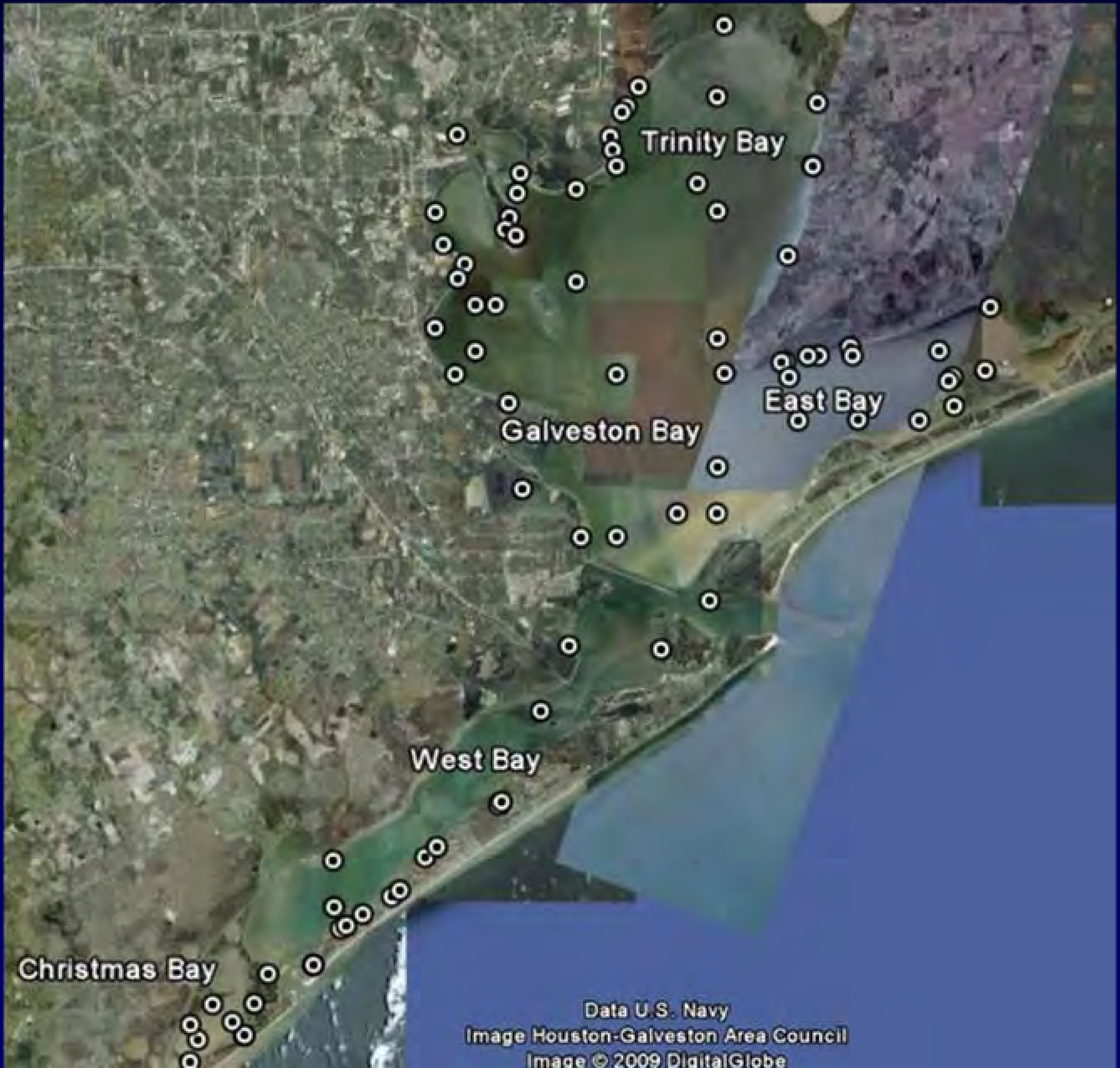
McClelland and Valiela 1998

Mass. Study – Groundwater

Significance

- No comprehensive stable isotope research from Galveston Bay
  - Holt and Ingall (2000)
    - Spotted seatrout
  - Gleason (1986) & Fry (2008)
    - Brown shrimp
- Ecosystem approach to estuarine management
  - Data needed on dietary habits
  - Use of models
    - Ecopath with Ecosim (EwE)

Study Location



Study Populations

Fish species

- *P. cromis* (≤ 198) - Pcs
- *P. cromis* (199-318) - Pcm
- *P. cromis* (≥ 319) – Pcl

- *M. undulatus* (≤ 136) - Mus
- *M. undulatus* (137-226) - Mum
- *M. undulatus* (≥ 227) - Mul

- *C. nebulosus* (≤ 216) - Cns
- *C. nebulosus* (217-380) -Cnm
- *C. nebulosus* (≥ 381) - Cnl

- *C. arenarius* (≤ 99) - Cas
- *C. arenarius* (100-198) - Cam
- *C. arenarius* (≥ 199) - Cal

Fish species cont.

- *S. ocellatus* (≤ 276) - Sos
- *S. ocellatus*(277-518) - Som
- *S. ocellatus* (≥ 519) - Sol

- *L. xanthurus* (≤ 136) - Lxs
- *L. xanthurus* (> 136) – Lxl

Primary productivity

- *Spartina alterniflora*
- *Halodule wrightii*
- Benthic algae
- Particulate matter (PM)
- Vegetative detritus (*S. alterniflora*)
- *S. alterniflora* epiphytes

(Martinez-Andrade et al. 2005)

Field Methods

- Sampling methods
  - Bay trawl
  - Bag seine
  - Gill net
  - Chlorophyll filter
  - Plant removal
  - Algae scraping

- Water quality parameters
  - D.O.
  - Temp.
  - Turbidity
  - Salinity

Identifying and measuring catch to TL (mm)

Storage Methods

Cryogenic vials

- Samples stored in cryogenic vials
  - Fish – sampled mid dorsal region
  - Plankton – used chlorophyll filter, collected on glass fiber filter
- Storage
  - In field, – portable liquid N_2 vats
  - In lab – Stored in - 80˚C freezer in lab

Lab Methods

- Freeze-dried
- Ground w/ SPEX CertiPrep 8000D Mixer/Mill
- Processed at The Stable Isotope Lab at the Univ. of Georgia w/ a Carlo Erba CHN Elemental Analyzer and a Finnigan Delta C mass spectrometer

LABCONCO FreeZone freeze-drier

Data Analysis

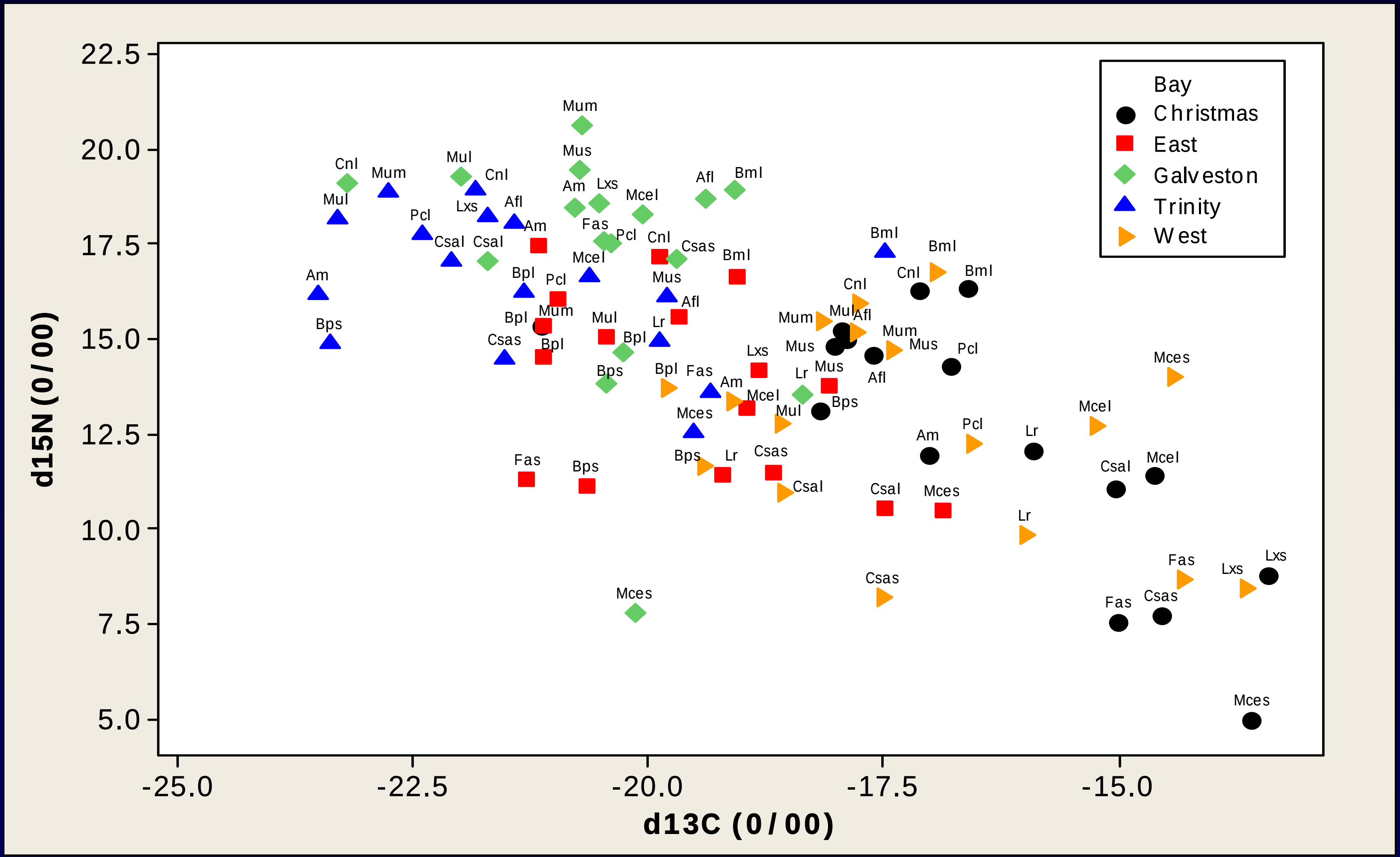
Stable Isotope Analysis

- $\delta X = [(R_{sample} / R_{standard}) - 1] \times 1000$
  - R = ratio of heavy to light isotope
  - Ex: $^{13}C/^{12}C$ or $^{15}N/^{14}N$
  - Standards = PeeDee Belemnite and N_2
- Mean of isotopic values
- Scatterplot of isotopic values

Results

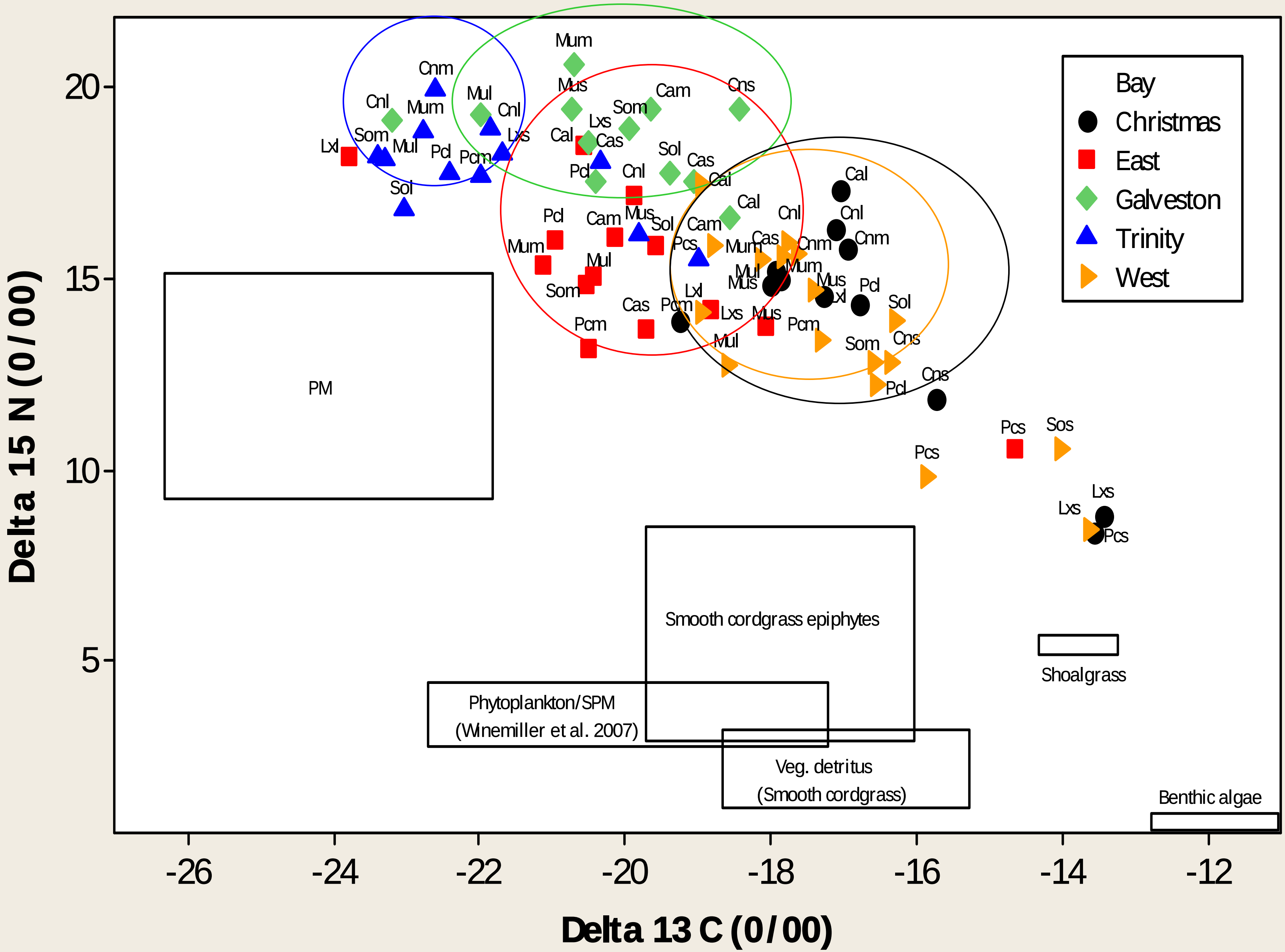
Bay	Number of Samples
Christmas	46
East	42
Galveston	42
Trinity	33
West	56
Total	**219**

Preliminary Data: (Crossen et al. 2009 State of the Bay) - poster



δ15N and δ13C values for 17 different species taken from the Galveston Bay estuary, TX. Fas: *F. aztecus* (≤ 75 mm); Csas: *C. sapidus* (≤ 109 mm); Csal: *C. sapidus* (> 109 mm); Bps: *B. patronus* (≤ 152 mm); Bpl: *B. patronus* (>152 mm); Am: *A. mitchilli*; Afl: *A. felis* (> 155 mm); Bml: *B. marinus* (> 339 mm), Mces: *M. cephalus* (≤ 233 mm); Mcel: *M. cephalus* (> 233 mm); Lr: *L. rhomboides*; Pcl: *P. cromis* (≥ 319 mm); Mus: *M. undulatus* (≤ 136 mm); Mum: *M. undulatus* (137 – 226 mm); Mul: *M. undulatus* (≥ 227 mm); Cnl: *C. nebulosus* (≥ 381 mm); Lxs: *L. xanthurus* (≤ 136 mm)

Sciaenid Isotopic Data from 5 bays in Galveston Bay



C & N Isotopes

- Christmas Bay and West Bay in addition to having lower average N-NO3 & NO2 appear to have different sources (in-situ??) of nitrogen vs. Galveston Bay nad Trinity Bay and E. Bay
- *d* ^{15}N: G.Bay > T. Bay > E. Bay > W. Bay > XMas
- Food webs driven by different sources of N. in different parts of the bay!
- Trinity Bay and Galveston Bay – anthropogenic sources (point source and non-point sources??)
- Note: West Bay and Xmas Bay hydrologically isolated.

Utility of Stable Isotope Studies

- Methods to identify eutrophication caused by increased anthropogenic N loading would help managers preserve critical habitats
- Use of stable N isotope ratios can be used to track wastewater N (& other anthropogenic sources) and therefore provide one such method
- Direct detection of wastewater N in estuarine biota should provide a means to i.d. potential human sources and manage them.