AN OVERVIEW OF

# ESTUARIES

# ESTUARY

- coastal waterbody
- semi-enclosed
- free connection to open sea
- influx of sea water
- freshwater influx
- small to intermediate scale

# ESTUARY CHARACTERISTICS

TRANSITIONAL BETWEEN FRESHWATER & MARINE

INFLUENCED BY MANY FACTORS

DYNAMIC, HIGHLY VARIABLE

## TERRESTRIAL

FRESHWATER

FLOODS & DROUGHTS

SEDIMENT

NUTRIENTS

EFFLUENTS

## ESTUARINE / COASTAL

SALINITY INTRUSION

SEA/LAND BREEZE

LONGSHORE CURRENTS

LITTORAL SAND

## OCEANIC

SALTWATER

TIDES

METEOROLOGY-DRIVEN SEA-LEVEL VARIATIONS

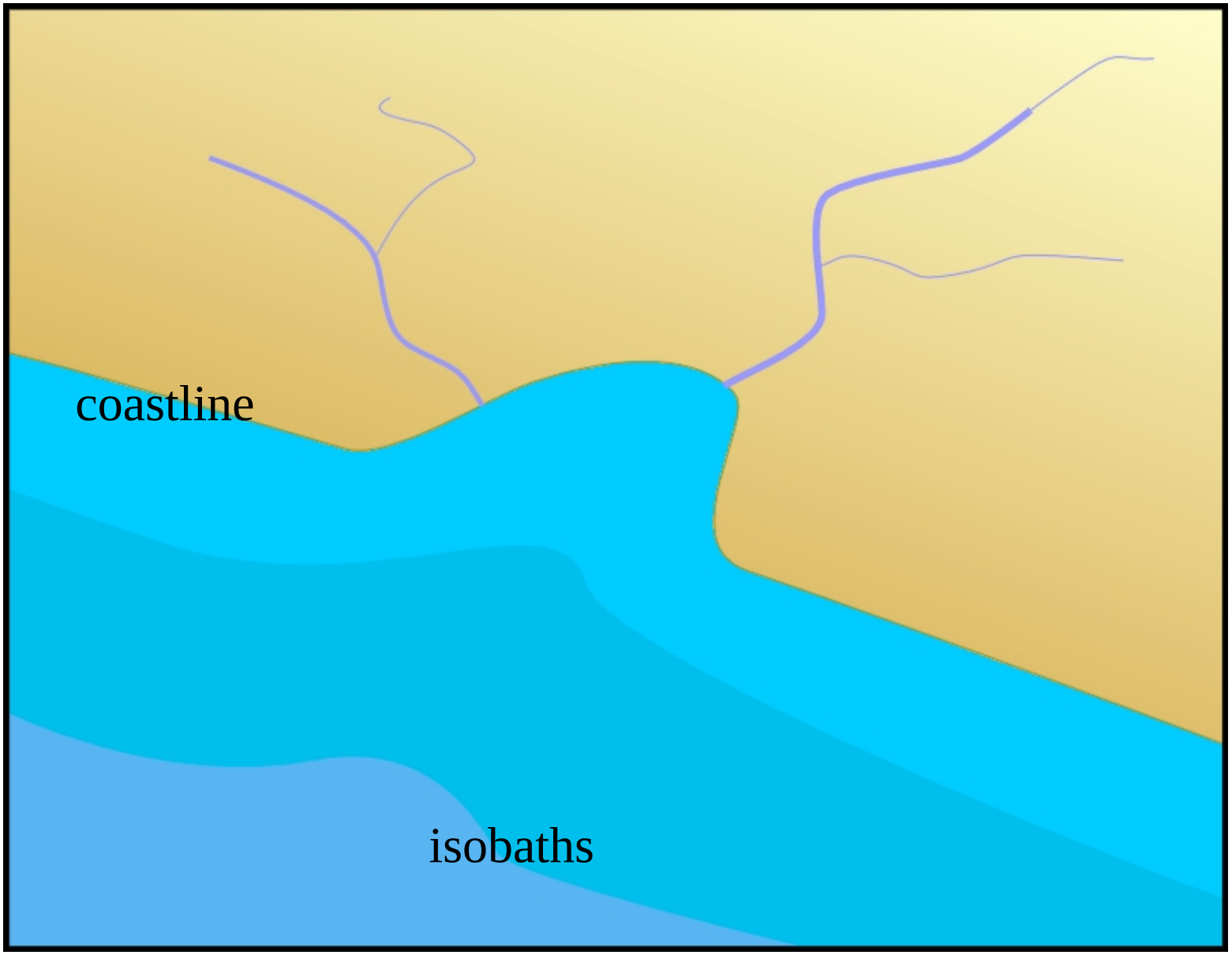
WAVES

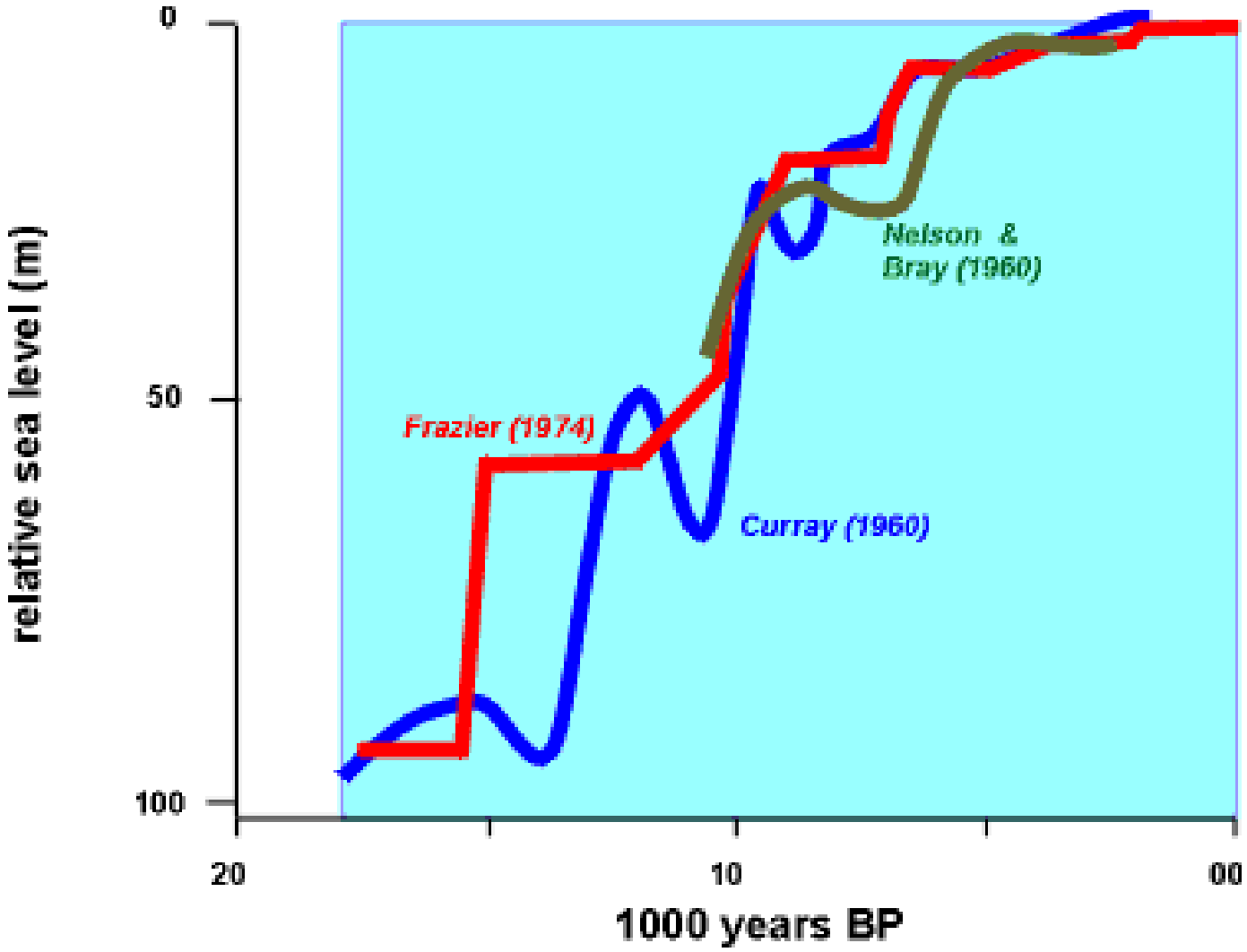
MARINE STORMS & SURGES

# ESTUARY HYDROGRAPHY
# (a.k.a. circulation)

## PRIMARY FORCING FACTORS

- MORPHOLOGY & BATHYMETRY
- TIDES
- HYDROLOGY (FRESHWATER INFLOW)
- METEOROLOGY
- SALINITY INTRUSION (DENSITY CURRENTS)


coastline
isobaths


0
50
100
relative sea level (m)
20
10
00
1000 years BP
Nelson &
Bray (1960)
Frazier (1974)
Curray (1960)

# GEOMORPHIC ESTUARY TYPES

- **CHANNEL ESTUARY (river channel estuary)**
- **COASTAL PLAIN ESTUARY (drowned river valley)**
- **FJORD**
- **LAGOON (bar-built estuary)**
- **TECTONOBAY**

# ESTUARY HYDROGRAPHY
# (a.k.a. circulation)

## PRIMARY FORCING FACTORS

MORPHOLOGY & BATHYMETRY

**TIDES**

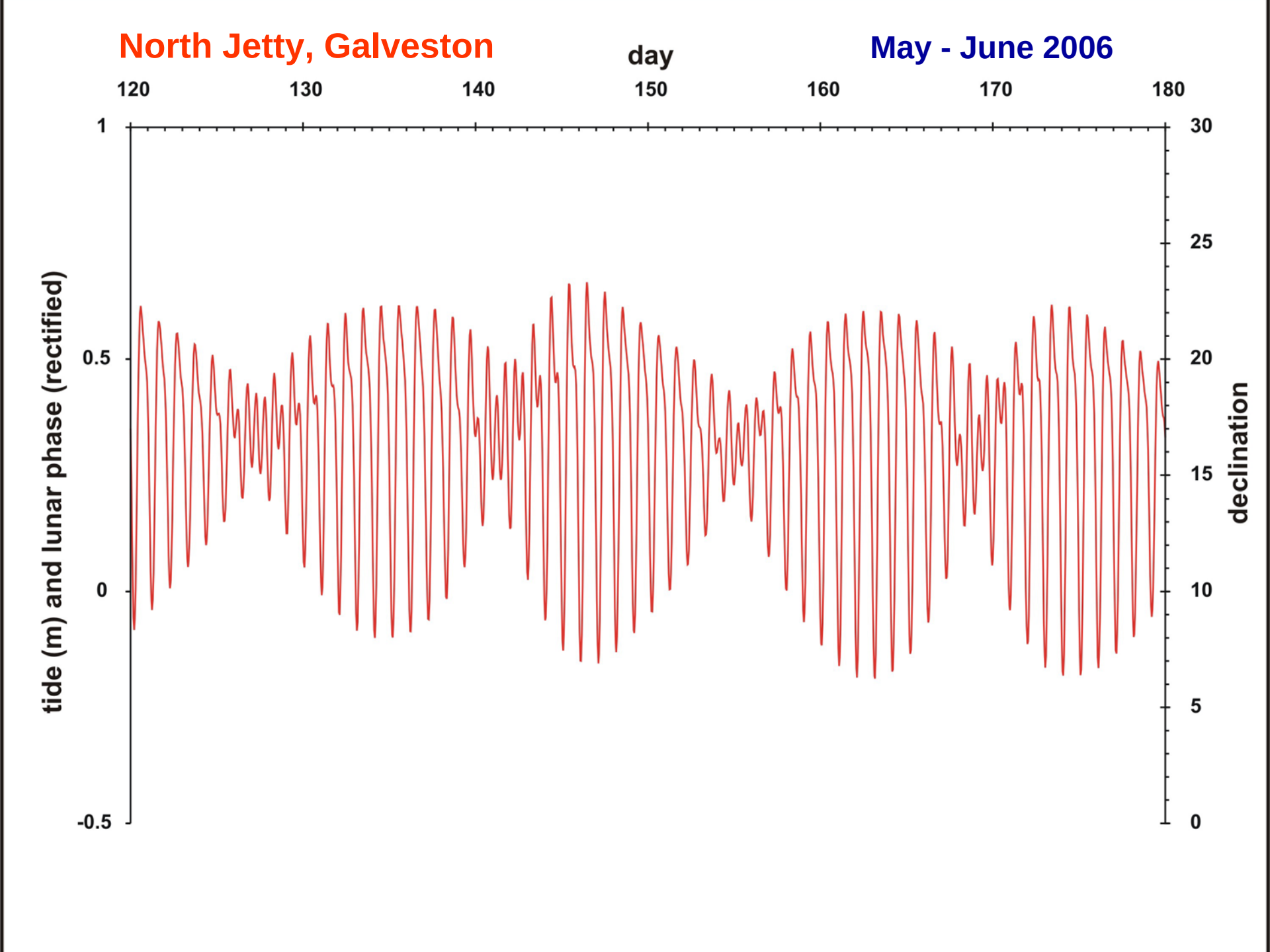
HYDROLOGY (FRESHWATER INFLOW)

METEOROLOGY

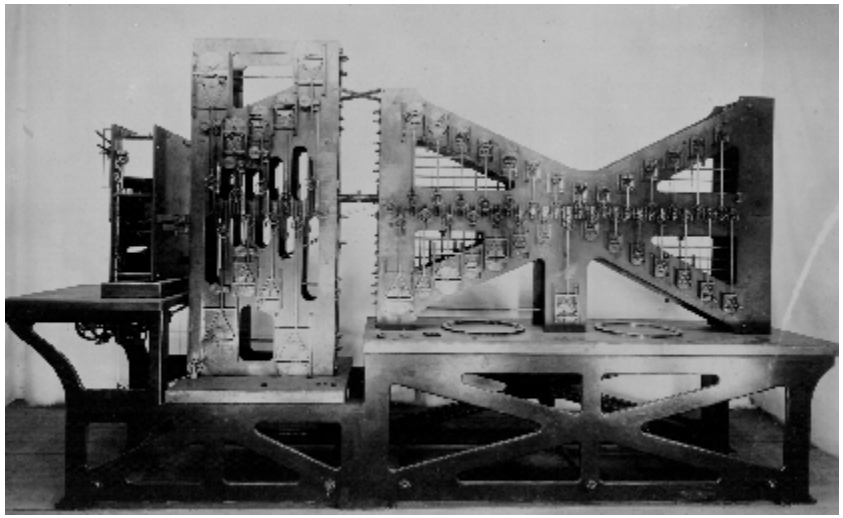
SALINITY INTRUSION
(DENSITY CURRENTS)

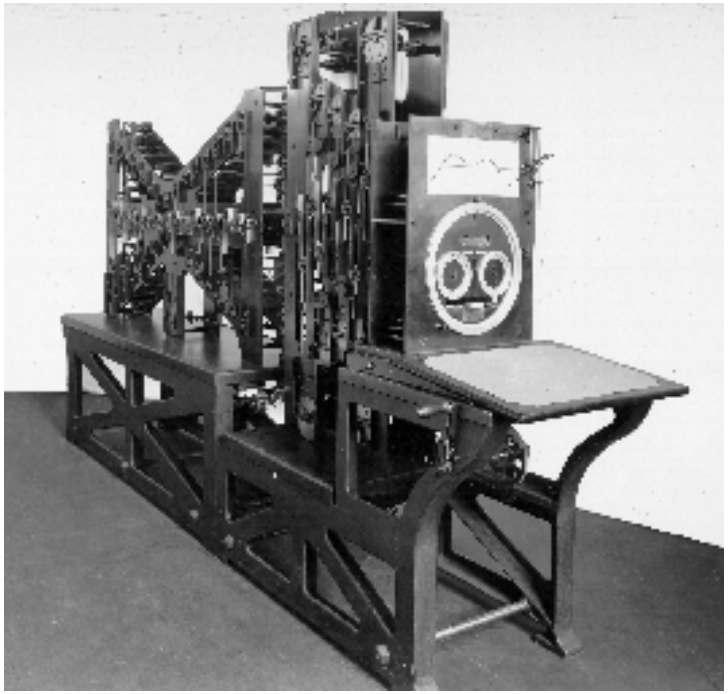
# Predominant “tidal” harmonics on Texas coast

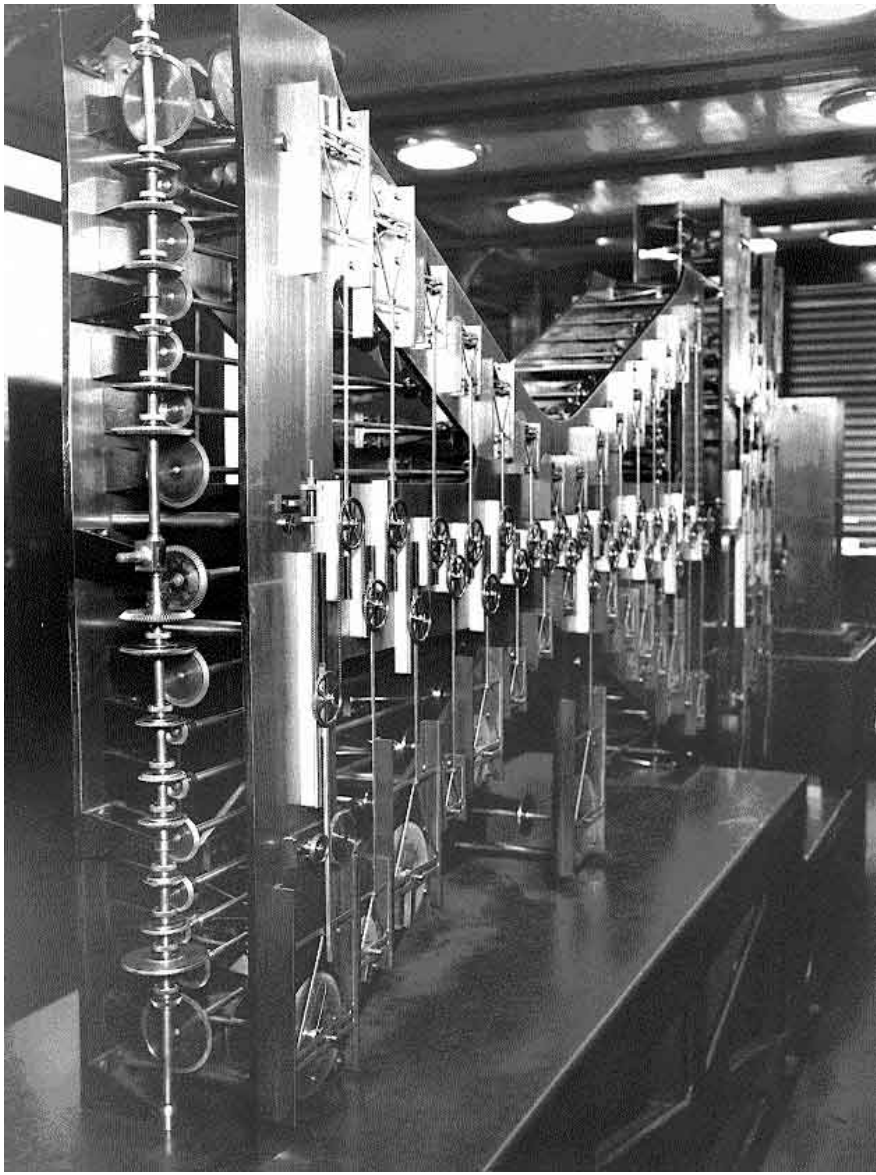
| | | |
|---|---|---|
| **SEMIDIURNAL** | **12.4 hr** | **LUNAR-SOLAR** |
| **DIURNAL** | **24.8 hr** | **LUNAR-SOLAR** |
| **FORTNIGHTLY** | **13.6 da** | **LUNAR DECLINATION** |
| **SEMIANNUAL** | **6 mos** | **SECULAR** |
| **DECLINATION** | **18.6 yr** | **TIDAL EPOCH** |


North Jetty, Galveston
May - June 2006
day
120
130
140
150
160
170
180
1
0.5
0
-0.5
tide (m) and lunar phase (rectified)
30
25
20
15
10
5
0
declination

# USC&GS Tide Machine No. 2 ca. 1910





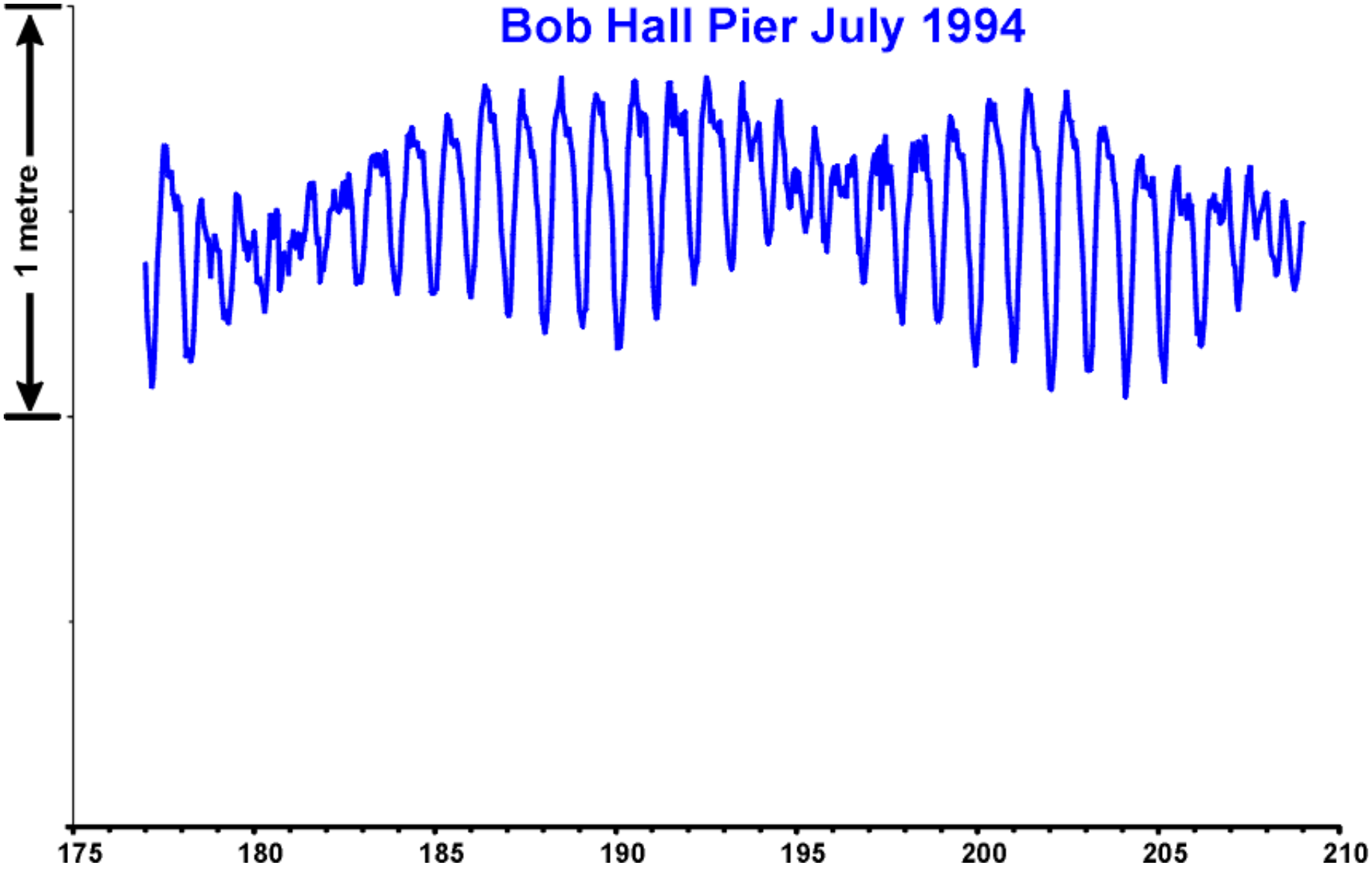


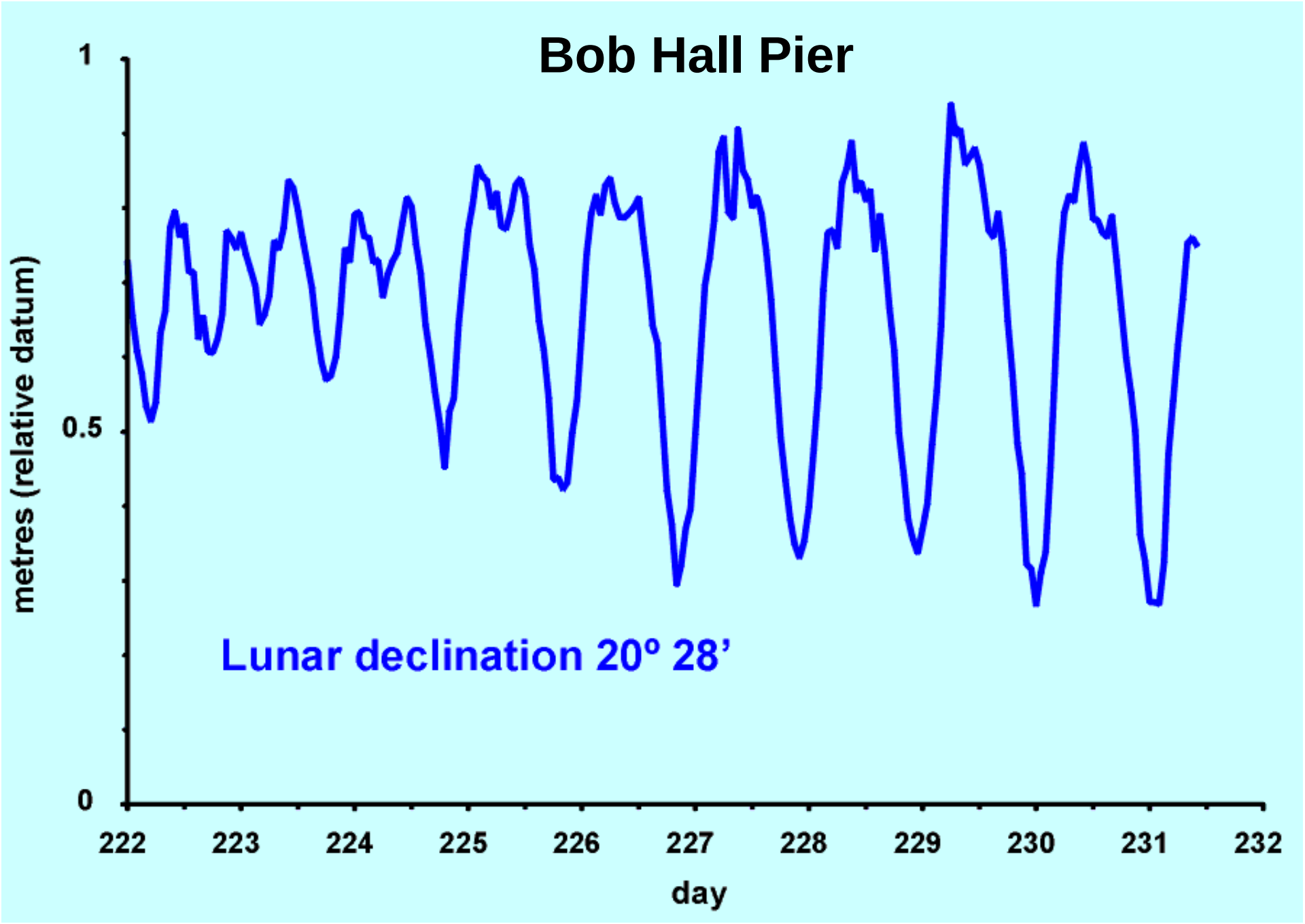
# THREE FACTOIDS
# ABOUT TIDES ON THE TEXAS COAST

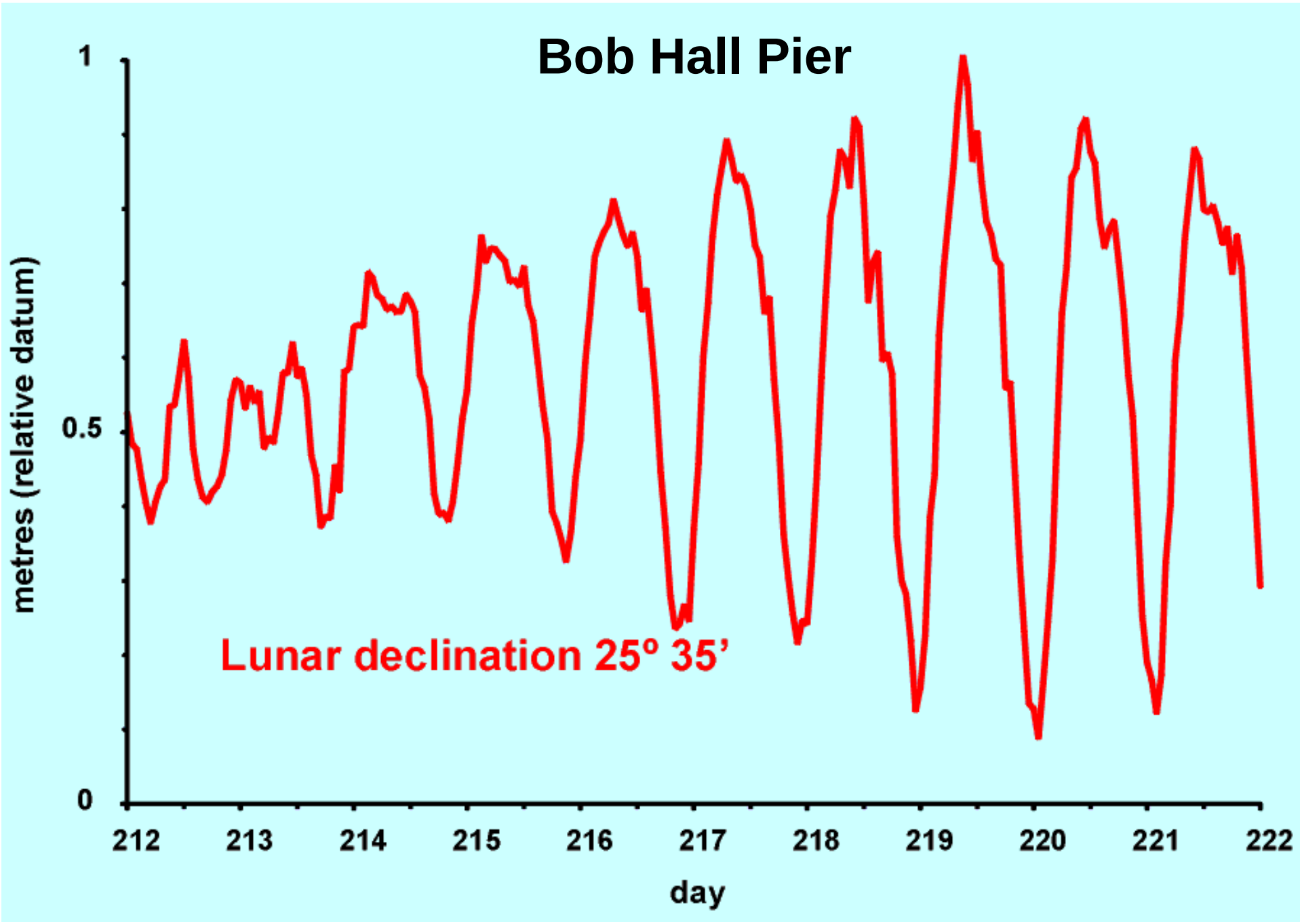
**“Microtidal” - Offshore tidal range around a meter**

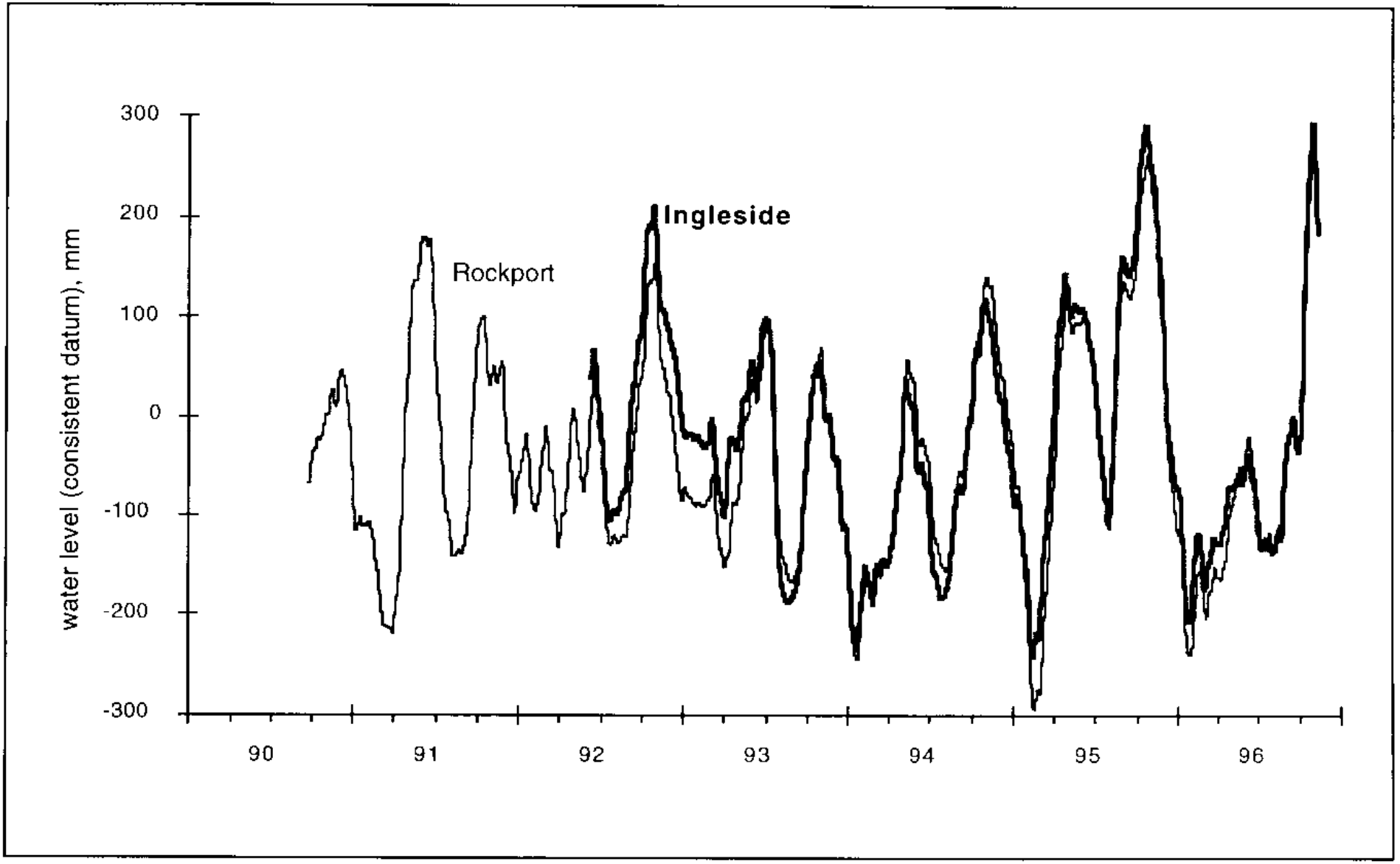
**Tide range larger on the Gulf shore, smaller inside the bays**

**Dominated by 4 – 5 principal frequencies**

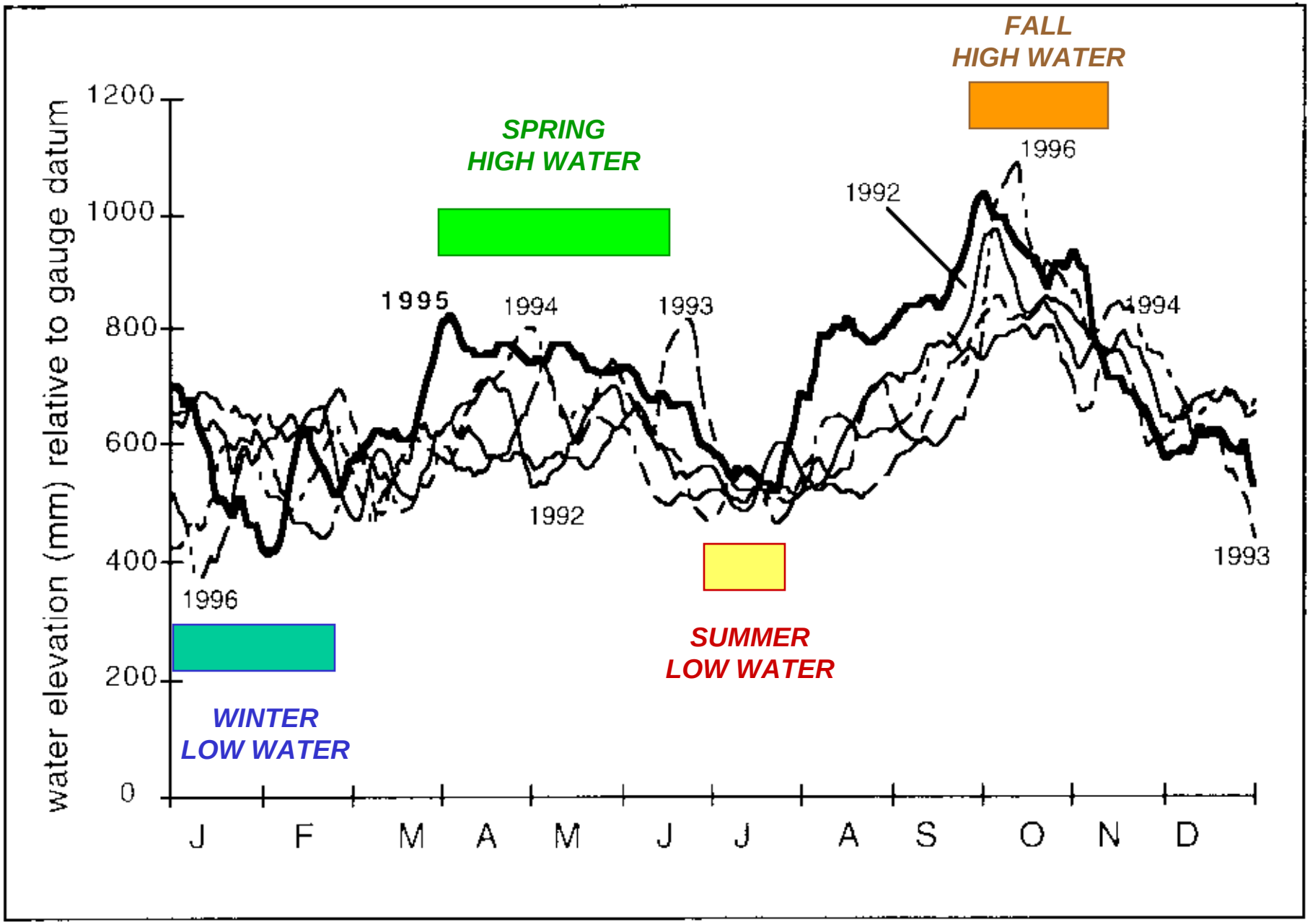

Bob Hall Pier July 1994
1 metre
175
180
185
190
195
200
205
210


Bob Hall Pier
1
0.5
0
metres (relative datum)
Lunar declination 20º 28’
222
223
224
225
226
227
228
229
230
231
232
day


Bob Hall Pier
1
0.5
0
metres (relative datum)
Lunar declination 25° 35’
212
213
214
215
216
217
218
219
220
221
222
day




**27-day sliding mean of water level at two stations in Coastal Bend bays**




**Tidal-averaged water level variation at Bob Hall Pier, 1992-96**

# ESTUARY HYDROGRAPHY
# (a.k.a. circulation)

## PRIMARY FORCING FACTORS

MORPHOLOGY & BATHYMETRY

TIDES

**HYDROLOGY (FRESHWATER INFLOW)**

METEOROLOGY

SALINITY INTRUSION
(DENSITY CURRENTS)

# SIX (6) FACTOIDS ABOUT TEXAS SURFACE WATER

**RAINFALL IS PRODUCED ALMOST ENTIRELY FROM DEEP CONVECTION**

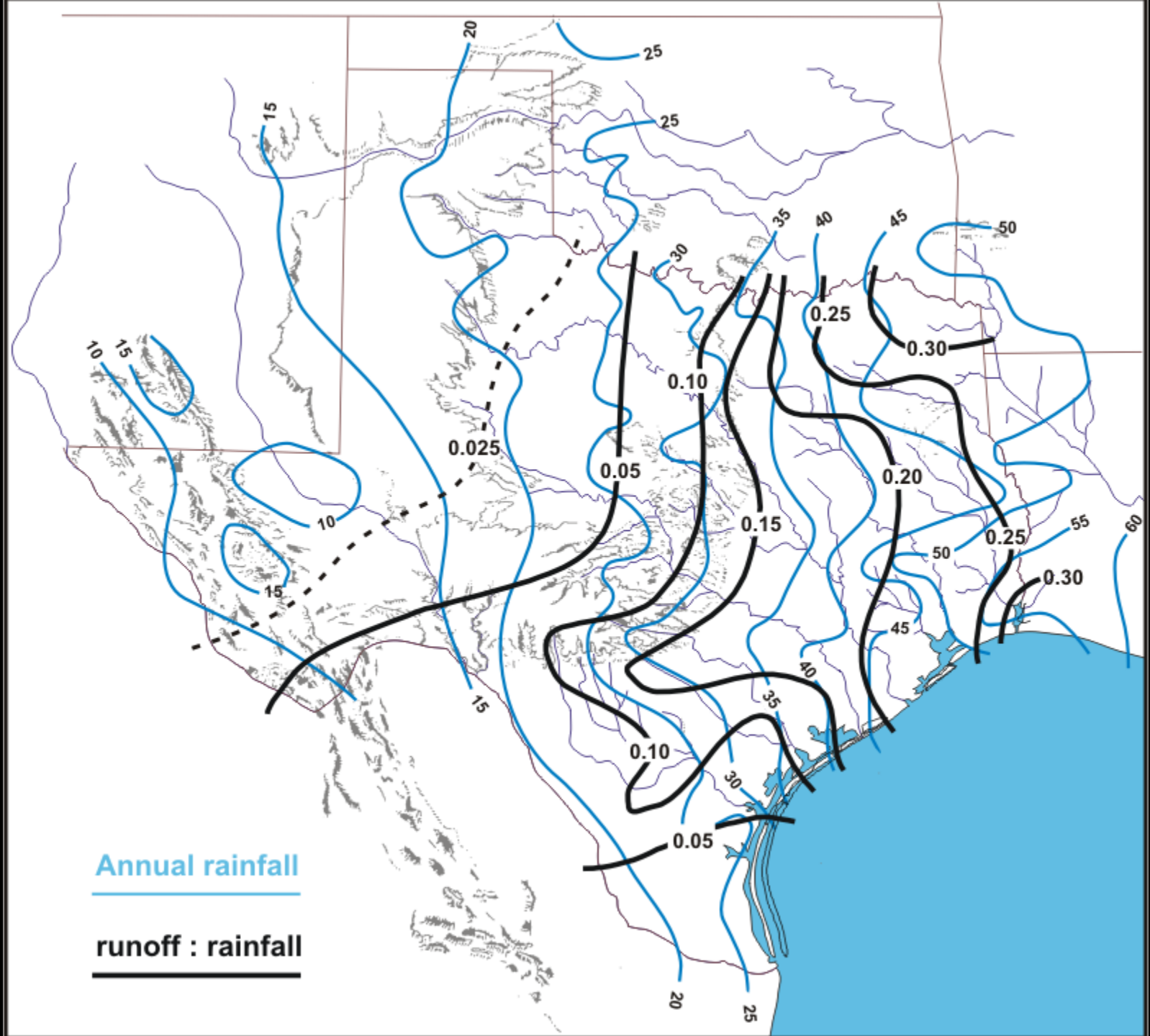
**RAINFALL DECLINES PRECIPITOUSLY FROM EAST TO WEST**

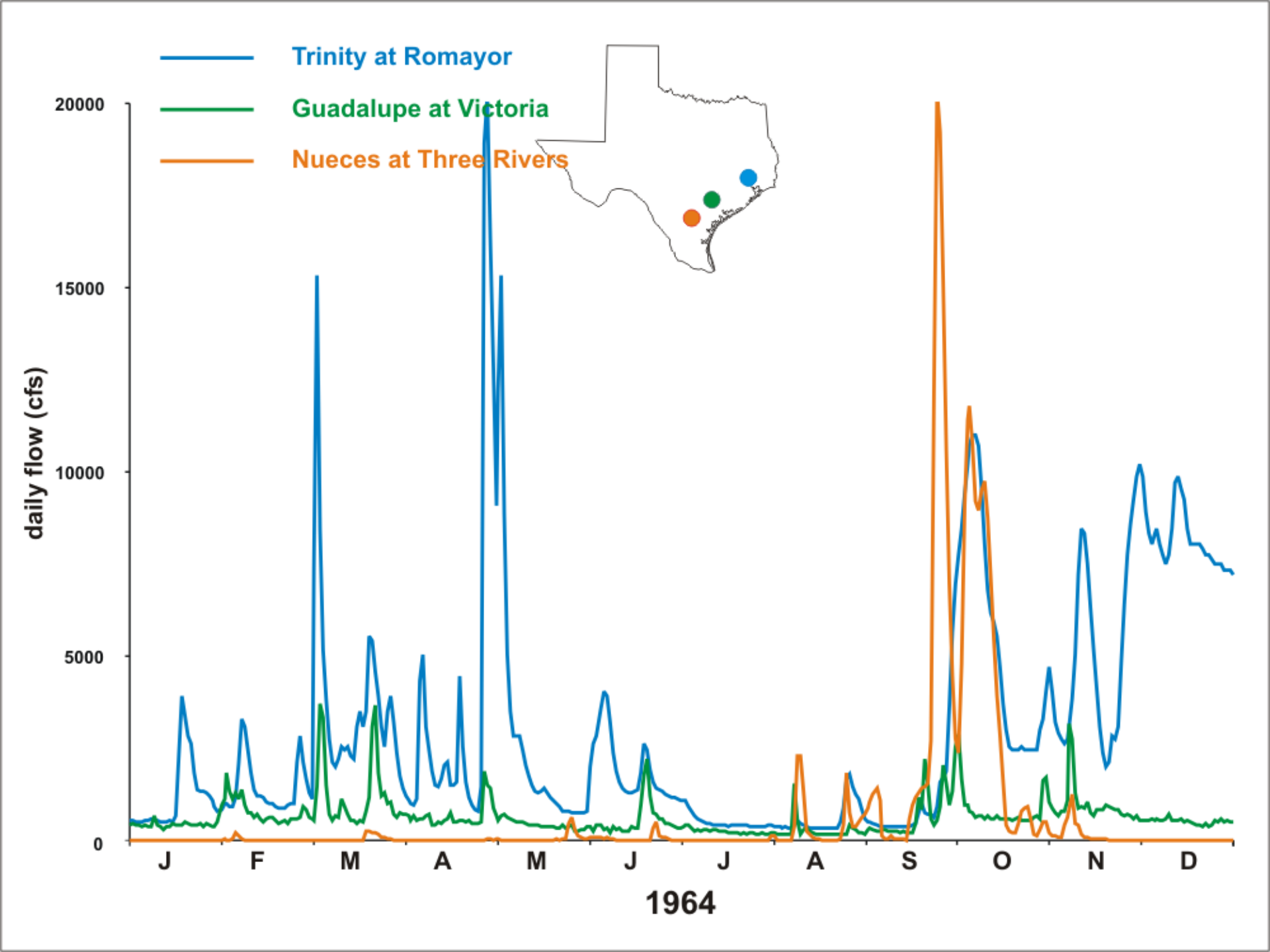
**RUNOFF IS SMALL AS A PROPORTION OF RAINFALL**

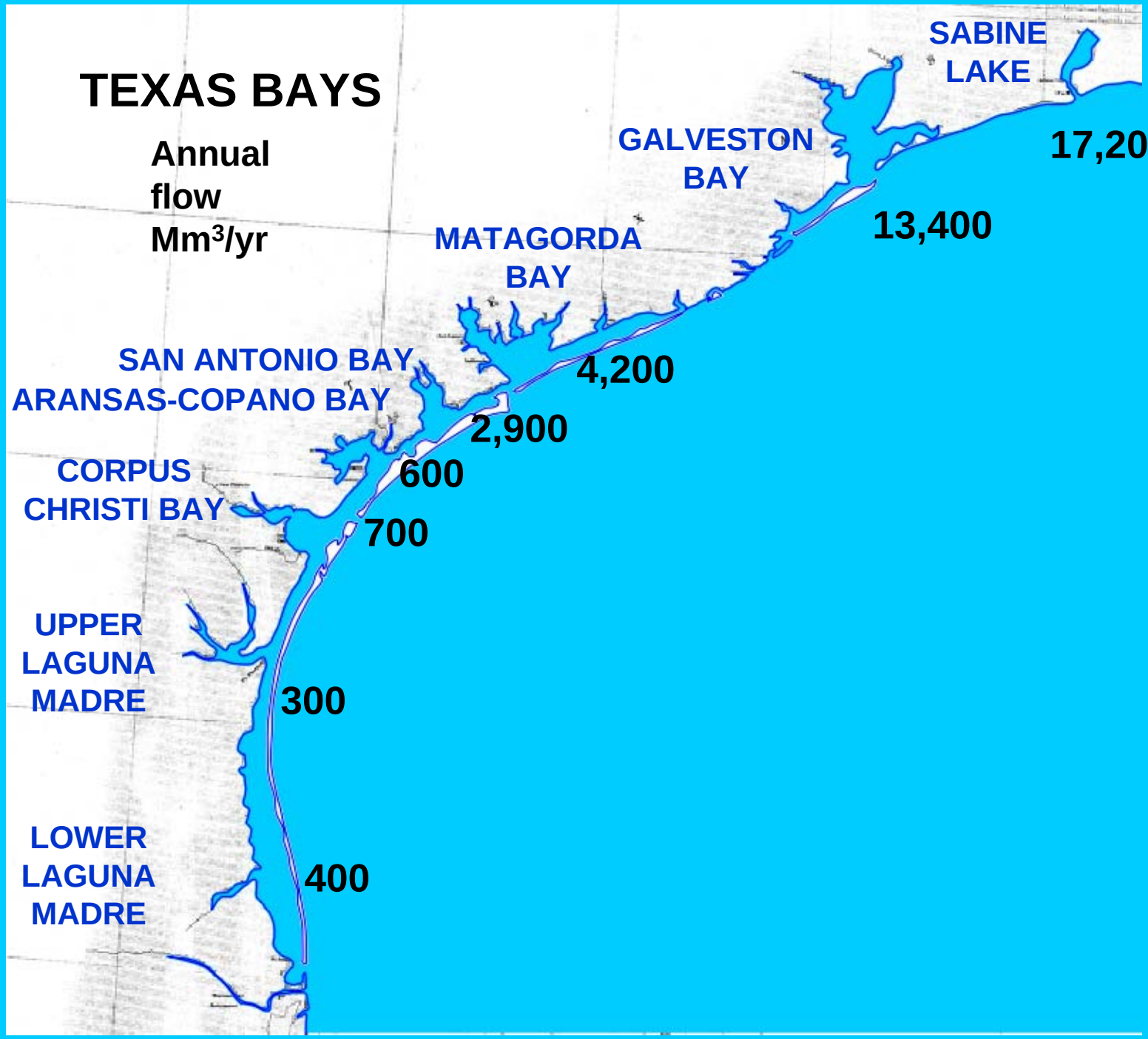
**RUNOFF DECLINES EVEN MORE PRECIPITOUSLY FROM EAST TO WEST**

**STREAMFLOW IS FLASHY**

**STREAMFLOW EXHIBITS LARGE VACILLATIONS ON TIME SCALES OF MONTHS TO YEARS**


Annual rainfall
runoff : rainfall
10
15
20
25
30
35
40
45
50
55
60
0.025
0.05
0.10
0.15
0.20
0.25
0.30

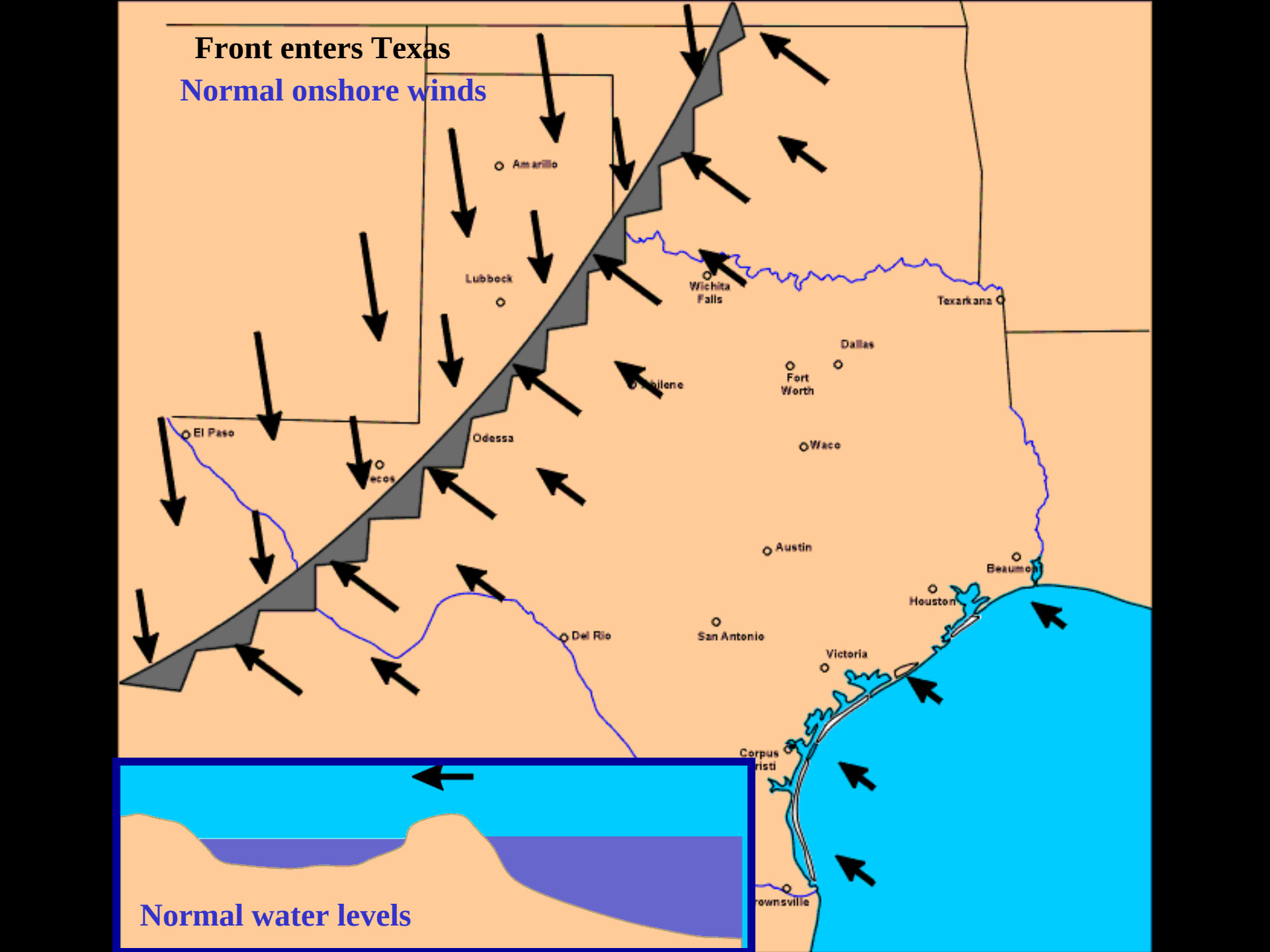

Trinity at Romayor
Guadalupe at Victoria
Nueces at Three Rivers
20000
15000
10000
5000
0
daily flow (cfs)
J
F
M
A
M
J
J
A
S
O
N
D
1964

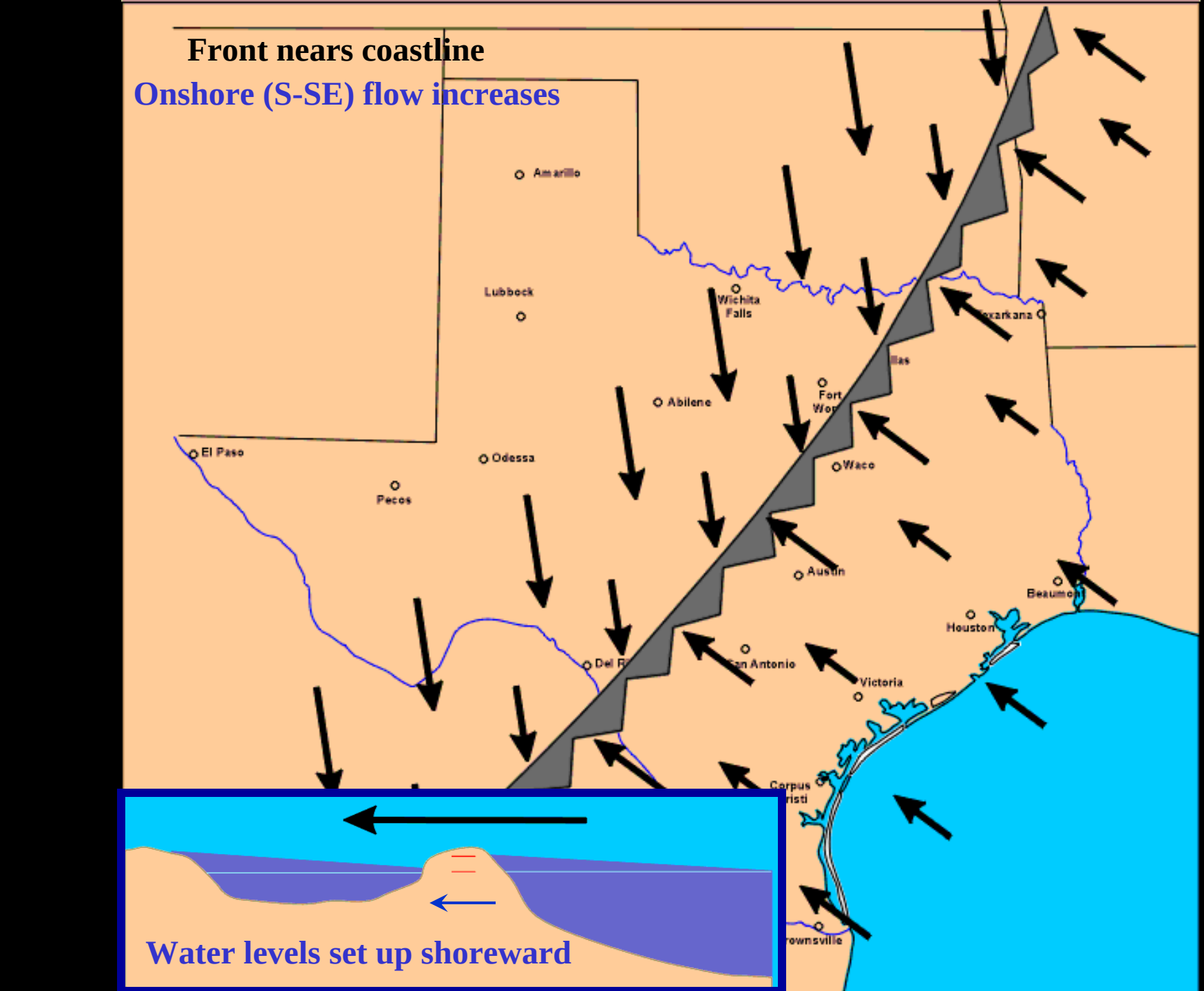

TEXAS BAYS
Annual flow Mm³/yr
SABINE LAKE
17,200
GALVESTON BAY
13,400
MATAGORDA BAY
4,200
SAN ANTONIO BAY
ARANSAS-COPANO BAY
2,900
600
CORPUS CHRISTI BAY
700
UPPER LAGUNA MADRE
300
LOWER LAGUNA MADRE
400

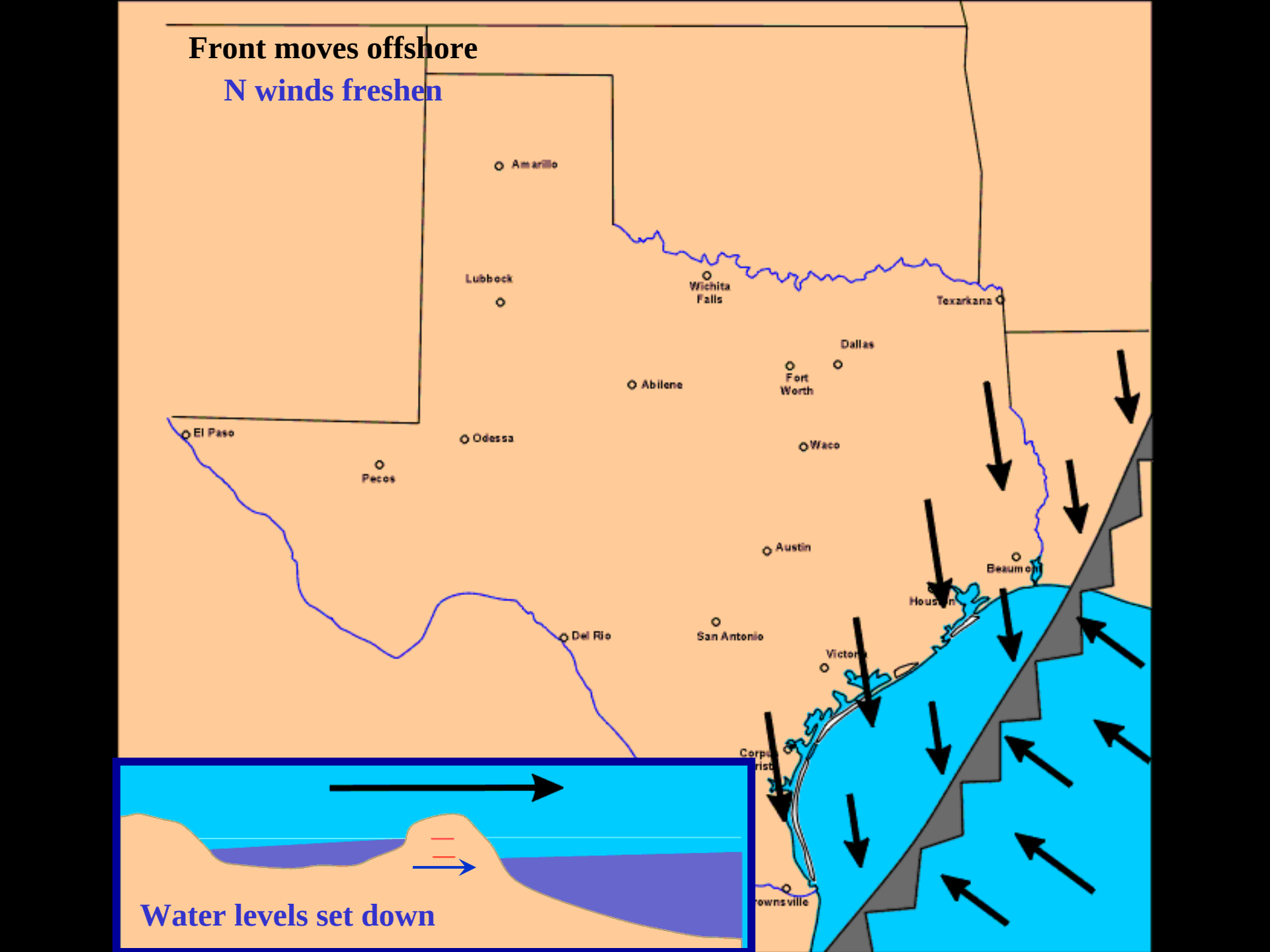
# ESTUARY HYDROGRAPHY
# (a.k.a. circulation)

## PRIMARY FORCING FACTORS

- MORPHOLOGY & BATHYMETRY
- TIDES
- HYDROLOGY (FRESHWATER INFLOW)
- **METEOROLOGY**
- SALINITY INTRUSION (DENSITY CURRENTS)


Front enters Texas
Normal onshore winds
Amarillo
Lubbock
Wichita Falls
Texarkana
Dallas
Fort Worth
Abilene
El Paso
Odessa
Waco
Austin
Beaumont
Houston
Del Rio
San Antonio
Victoria
Corpus Christi
Brownsville
Normal water levels


Front nears coastline
Onshore (S-SE) flow increases
Amarillo
Lubbock
Wichita Falls
Abilene
Fort Worth
Waco
El Paso
Odessa
Pecos
Austin
Houston
Beaumont
Victoria
Corpus Christi
Water levels set up shoreward


Front moves offshore
N winds freshen
Amarillo
Lubbock
Wichita Falls
Texarkana
Dallas
Fort Worth
Abilene
El Paso
Odessa
Waco
Pecos
Austin
Beaumont
Houston
Del Rio
San Antonio
Victoria
Brownsville
Water levels set down

# ESTUARY HYDROGRAPHY
# (a.k.a. circulation)

## PRIMARY FORCING FACTORS

MORPHOLOGY & BATHYMETRY

TIDES

HYDROLOGY (FRESHWATER INFLOW)

METEOROLOGY

**SALINITY INTRUSION**
**(DENSITY CURRENTS)**

# SALINITY

PROPORTION OF DISSOLVED SOLIDS IN WATER

IN SEAWATER, PREDOMINANTLY SALTS

MEASURED IN PARTS PER THOUSAND

ABBREVIATION: ppt or ‰

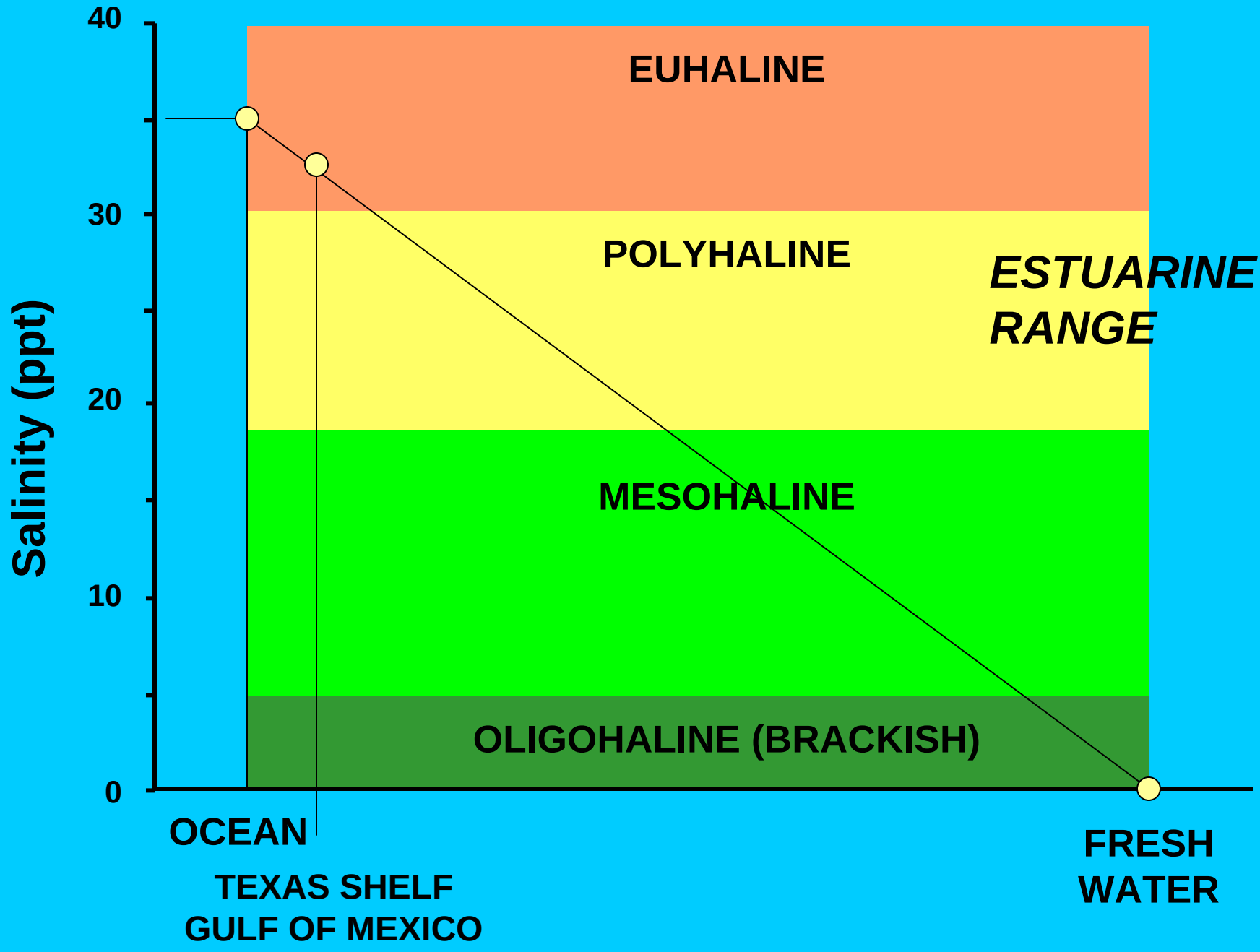
Also GRAMS PER KILOGRAM: g/kg

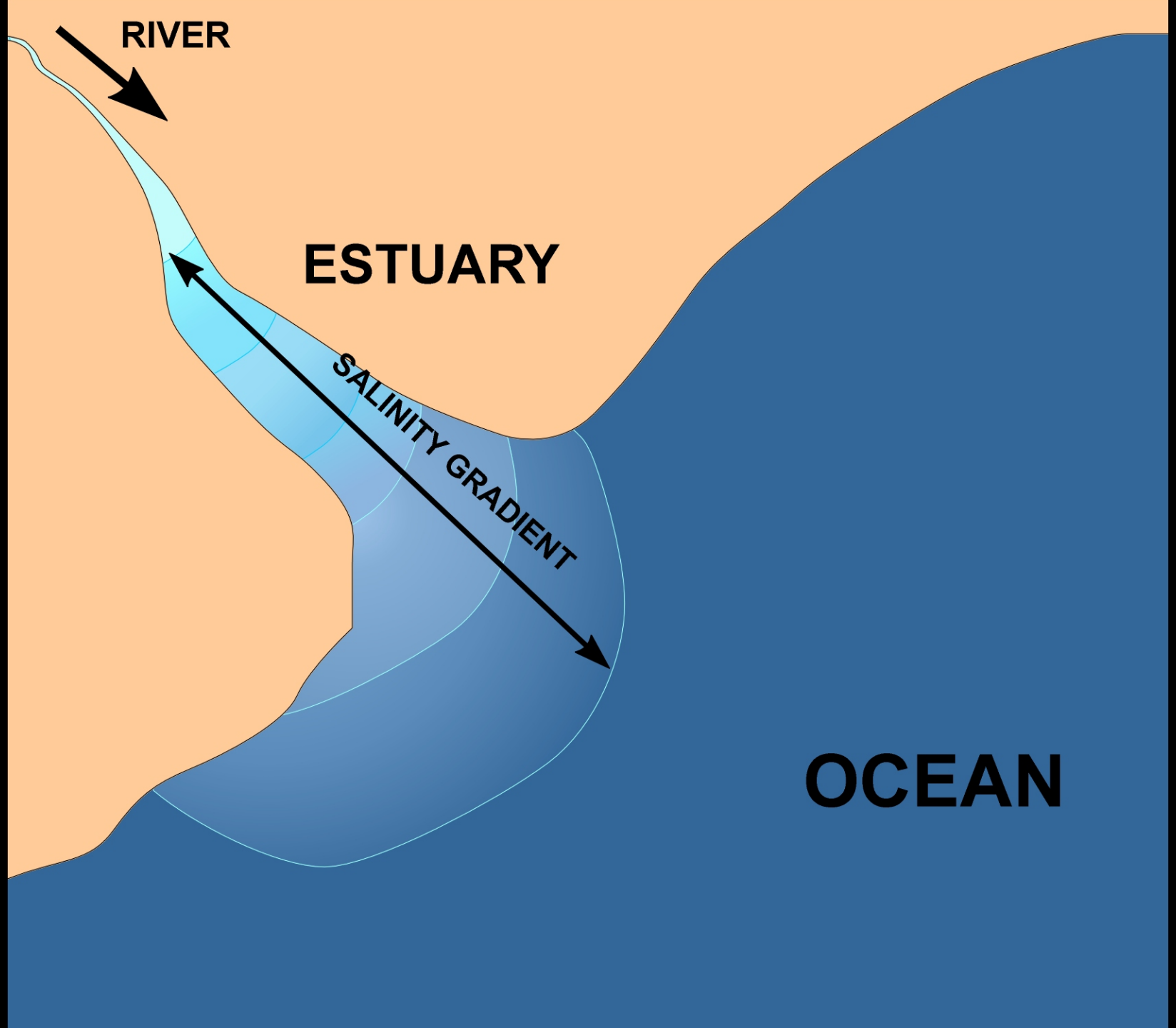
YOU MAY ALSO ENCOUNTER UNITS:

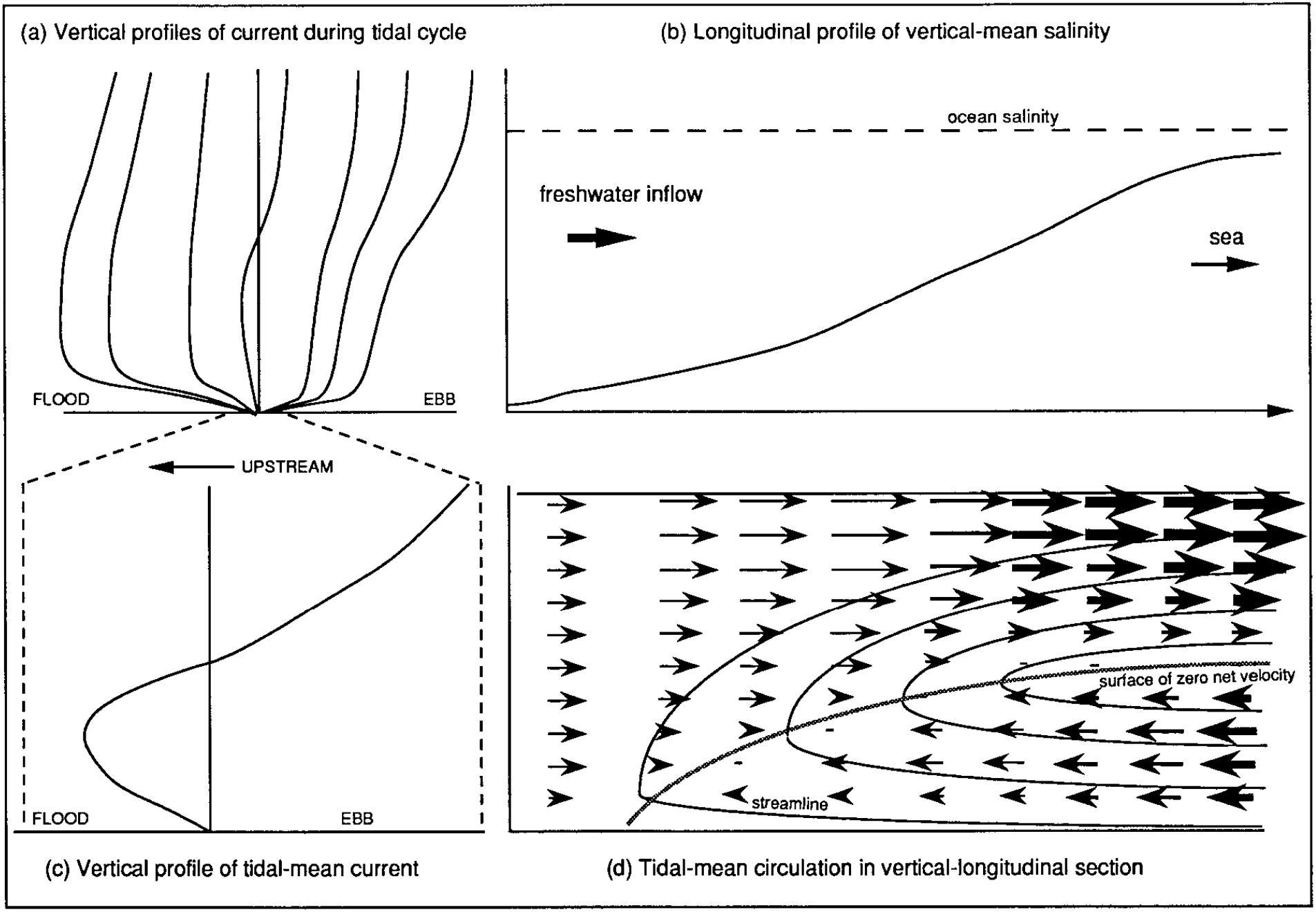
GRAMS PER LITER: g/L

PRACTICAL SALINITY UNITS: psu

IN ESTUARIES, CONSIDER THESE EQUIVALENT


40
30
20
10
0
Salinity (ppt)
EUHALINE
POLYHALINE
MESOHALINE
OLIGOHALINE (BRACKISH)
ESTUARINE RANGE
OCEAN
TEXAS SHELF
GULF OF MEXICO
FRESH WATER


RIVER
ESTUARY
SALINITY GRADIENT
OCEAN


(a) Vertical profiles of current during tidal cycle
FLOOD
EBB
(b) Longitudinal profile of vertical-mean salinity
ocean salinity
freshwater inflow
sea
UPSTREAM
FLOOD
EBB
surface of zero net velocity
streamline
(c) Vertical profile of tidal-mean current
(d) Tidal-mean circulation in vertical-longitudinal section

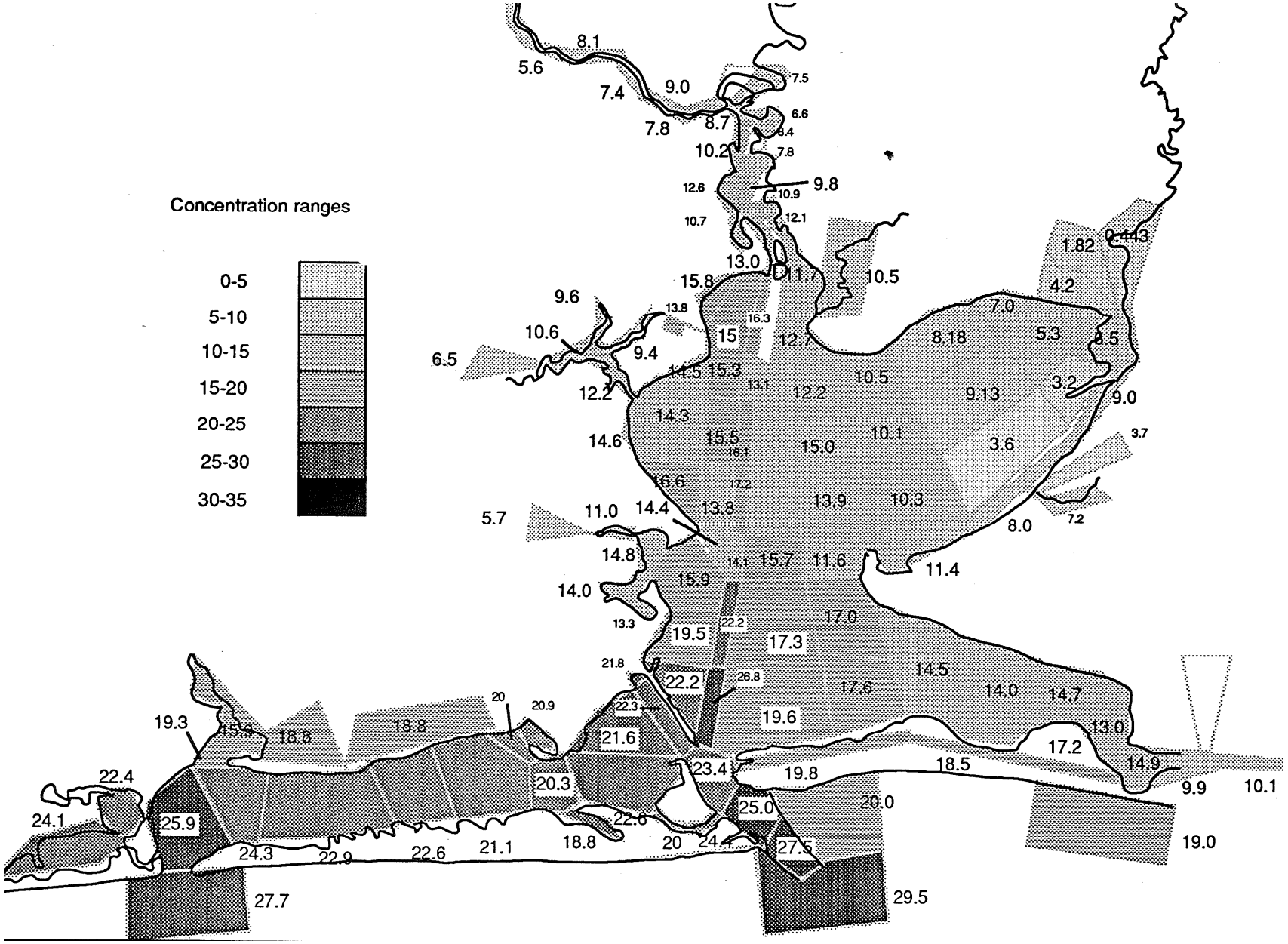
## THREE (3) FACTOIDS ABOUT

# DENSITY CURRENTS

**FORCED BY THE HORIZONTAL GRADIENT IN SALINITY**

**FLOW ABOUT AN ORDER OF MAGNITUDE GREATER THAN INFLOW**

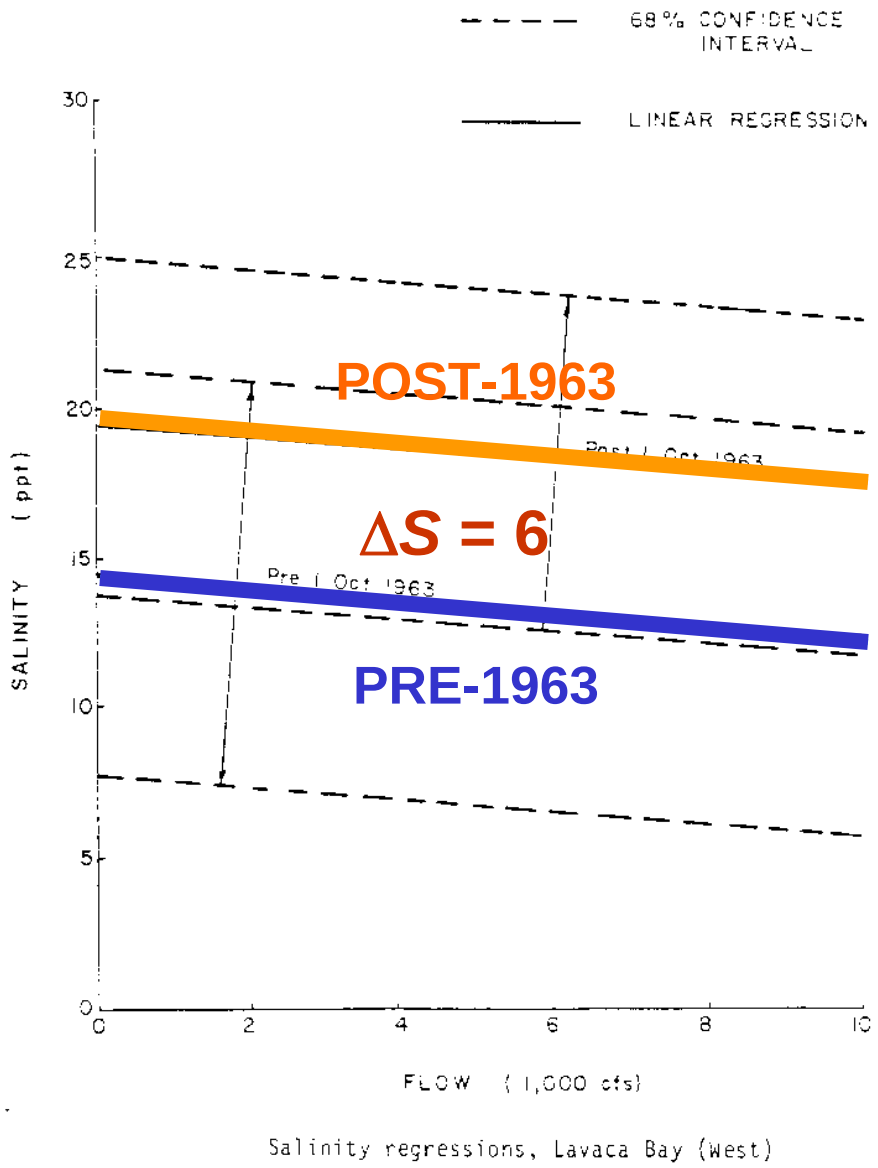
**INCREASES AS THE CUBE OF DEPTH**




# SALINITIES IN GALVESTON BAY, PERIOD OF RECORD AVERAGE

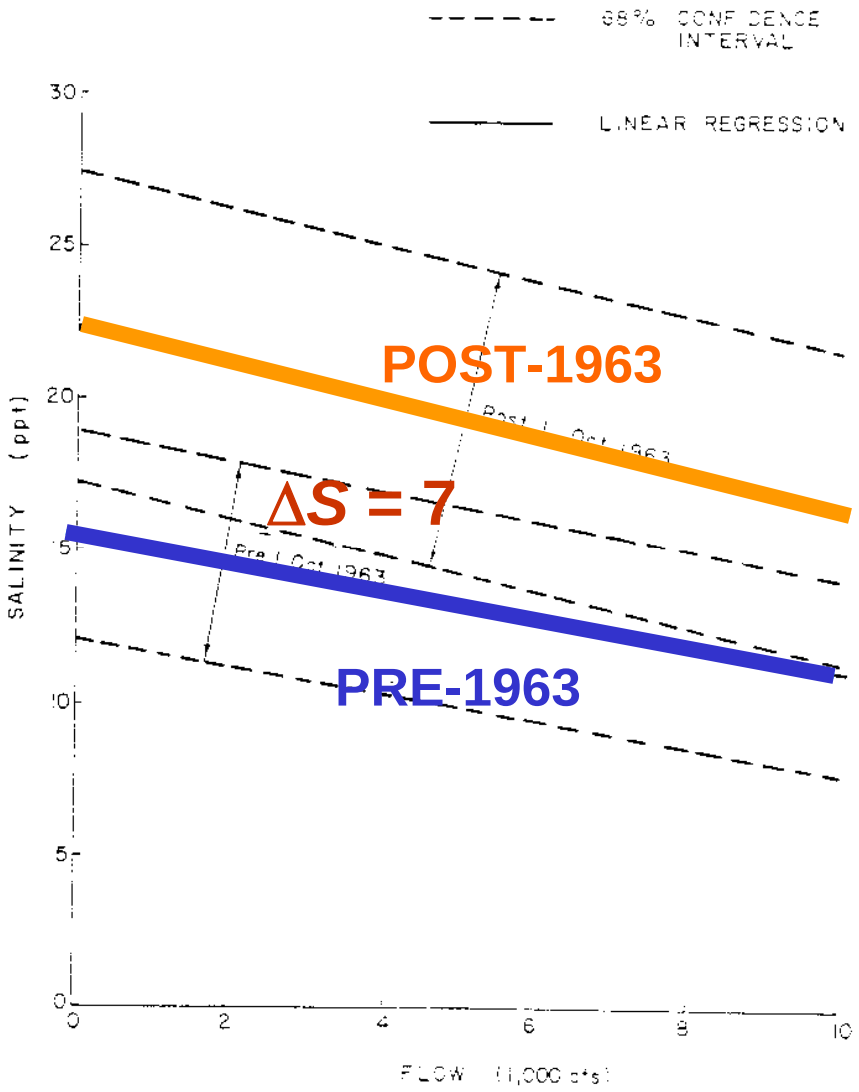

Lavaca & Navidad Rivers
Point Comfort
SH 35
Port Lavaca
Lavaca Bay
Cox Bay
Keller Bay
Karankaway Bay
Palacios
Tres Palacios Bay
Matagorda Bay
Colorado River
Matagorda
East Matagorda Bay
"East Arm"
Gulf of Mexico
Pass Cavallo
0 5 10
kilometers

# LAVACA BAY

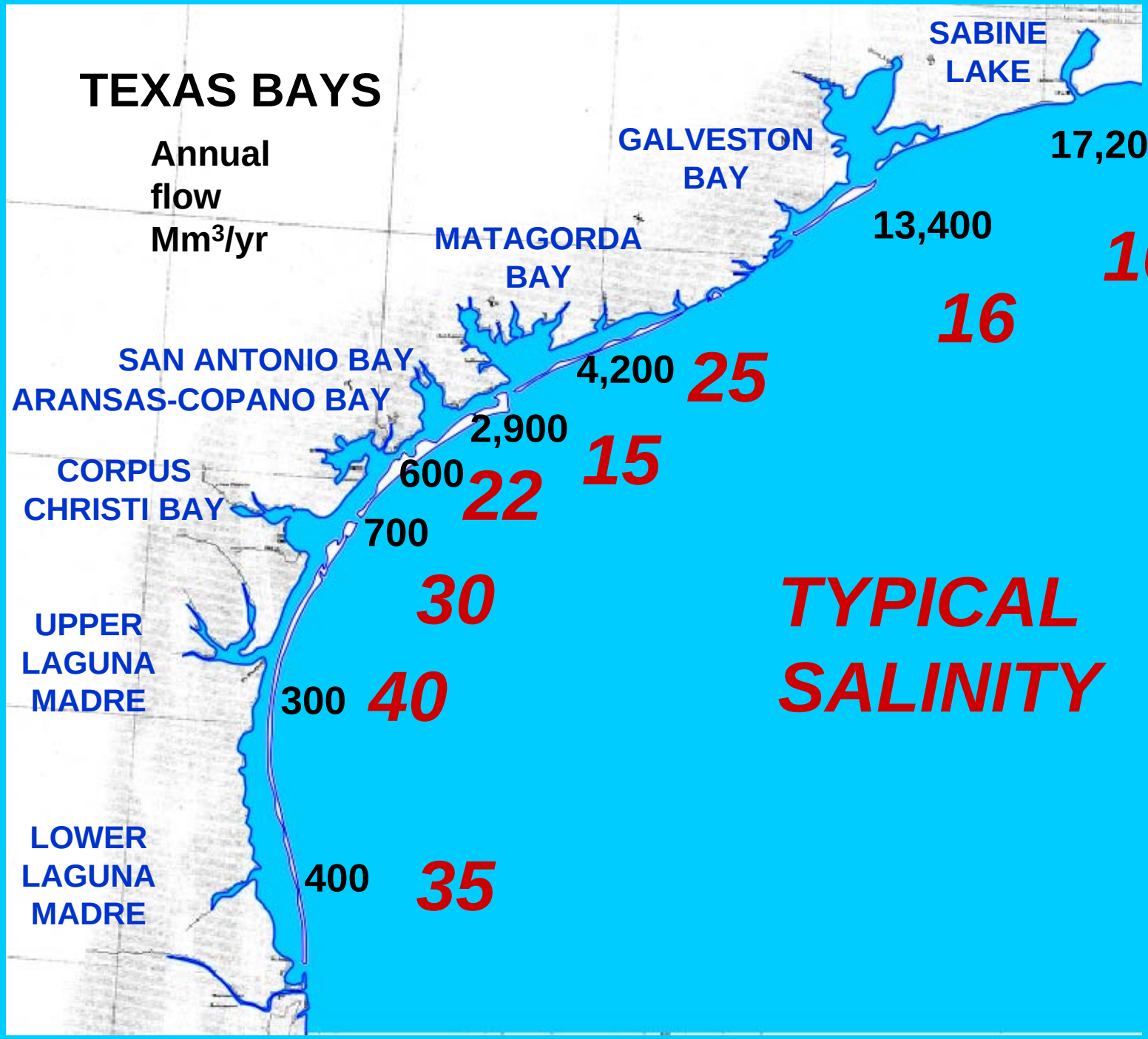



Salinity regressions, Lavaca Bay (West)

# UPPER MATAGORDA BAY

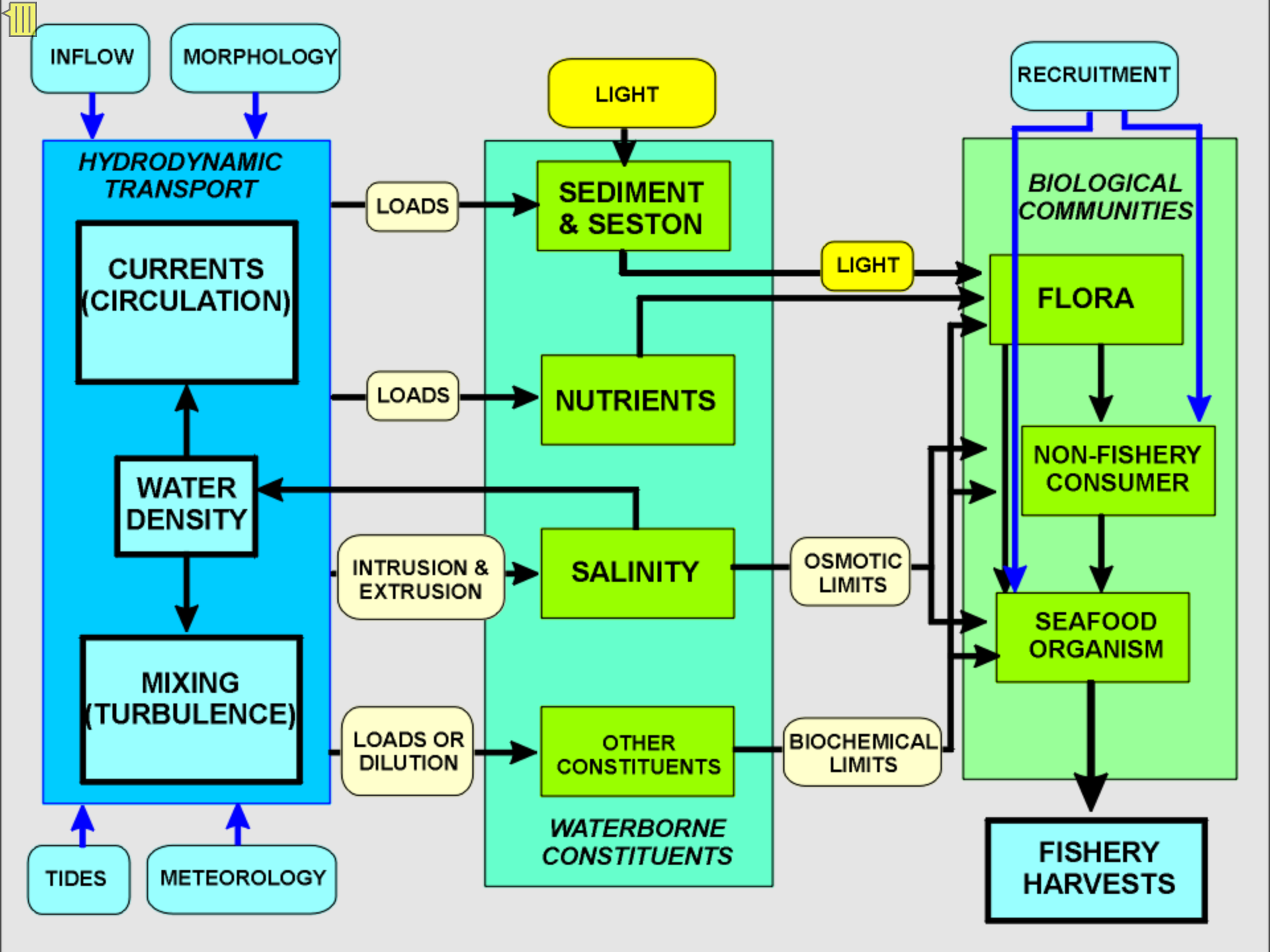



Salinity regressions, Upper Matagorda Bay (West)


TEXAS BAYS
Annual flow Mm³/yr
SABINE LAKE
GALVESTON BAY
17,200
MATAGORDA BAY
13,400
10
16
SAN ANTONIO BAY
ARANSAS-COPANO BAY
4,200
25
2,900
15
CORPUS CHRISTI BAY
600
22
700
30
TYPICAL SALINITY
UPPER LAGUNA MADRE
300
40
LOWER LAGUNA MADRE
400
35

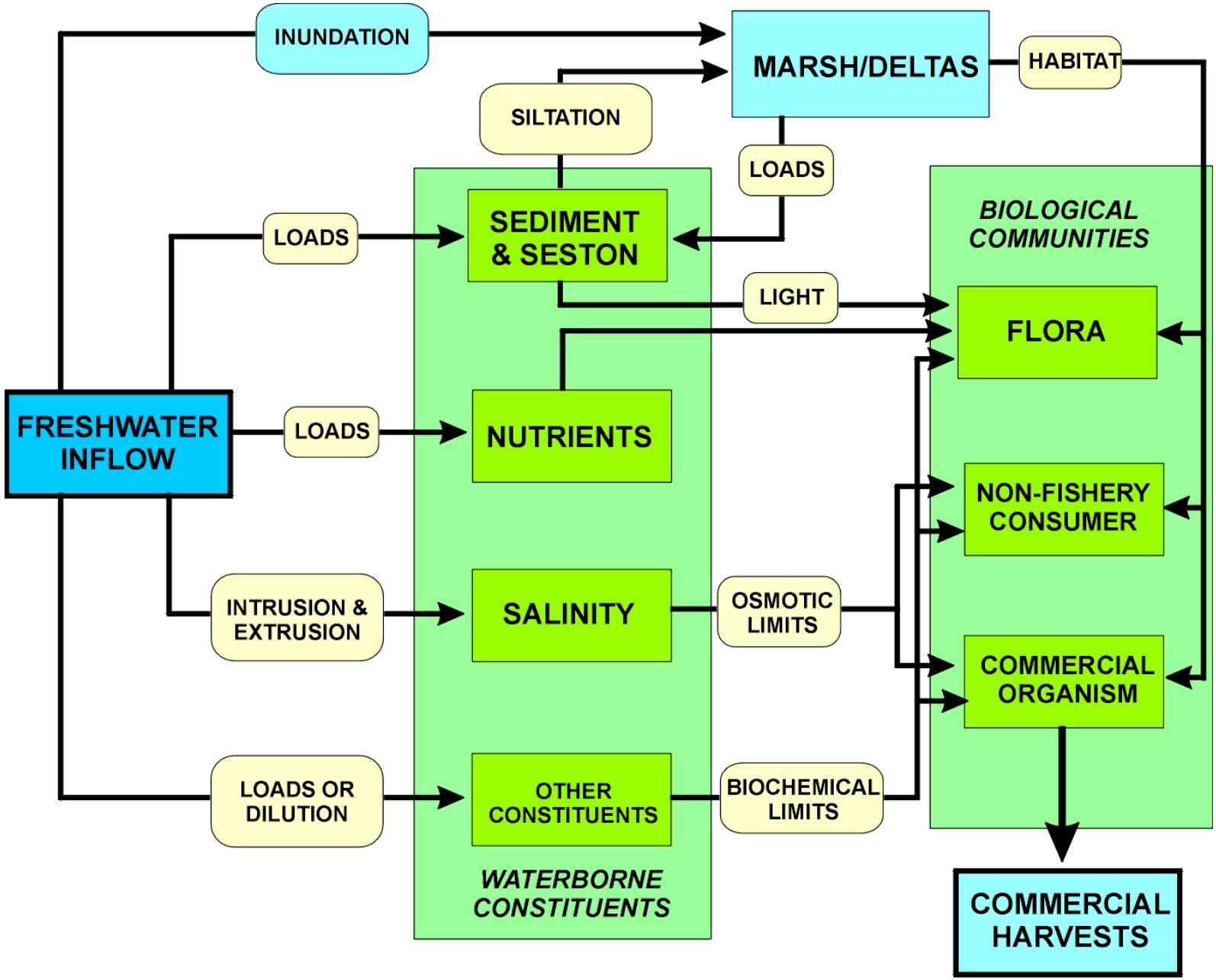
# ESTUARY CHARACTERISTICS

- TRANSITIONAL BETWEEN FRESHWATER & MARINE
- INFLUENCED BY MANY FACTORS
- DYNAMIC, HIGHLY VARIABLE
- PRODUCTIVE, BUT WITH SPECIALIZED ORGANISMS
- WIDE RANGE IN HABITATS SPANNING THE ESTUARINE ZONE
- MAJORITY OF THE LARGER ANIMALS IN ESTUARY ONLY TEMPORARILY FOR SPECIFIC BIOLOGICAL PURPOSES


INFLOW
MORPHOLOGY
LIGHT
RECRUITMENT
HYDRODYNAMIC TRANSPORT
LOADS
SEDIMENT & SESTON
BIOLOGICAL COMMUNITIES
CURRENTS (CIRCULATION)
LIGHT
FLORA
LOADS
NUTRIENTS
NON-FISHERY CONSUMER
WATER DENSITY
INTRUSION & EXTRUSION
SALINITY
OSMOTIC LIMITS
SEAFOOD ORGANISM
MIXING (TURBULENCE)
LOADS OR DILUTION
OTHER CONSTITUENTS
BIOCHEMICAL LIMITS
WATERBORNE CONSTITUENTS
TIDES
METEOROLOGY
FISHERY HARVESTS

## Potential freshwater inflow effects on estuary

- dilutes seawater
- carries nutrients, trace constituents, and terrestrial sediments into estuary
- contributes to gradient of water properties across estuary
- produces inundation and flushing of important zones, due to short-term flooding
- variability over time creates fluctuation in estuarine properties, important to ecosystem function
- source of renewal water

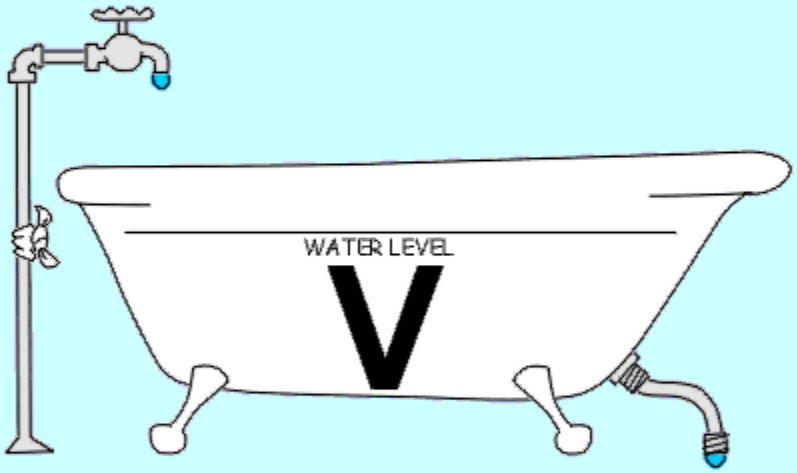



SCHEMATIC OF CAUSAL LINKS BETWEEN INFLOW AND ELEMENTS OF ESTUARY ECOSYSTEM

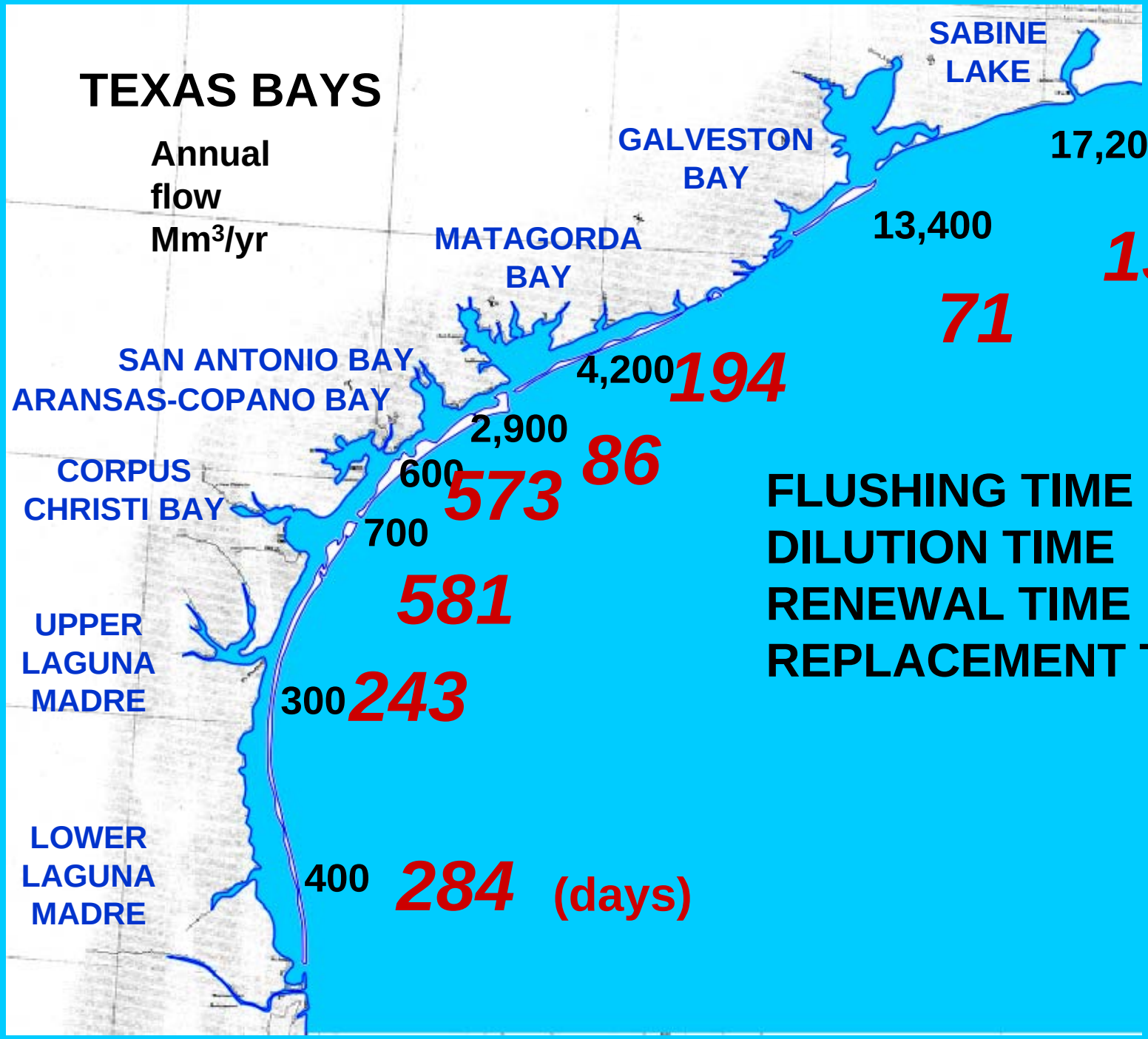
# WHOLE-VOLUME WATER BUDGET OF BAY

FRESHWATER
INFLOW

Q




$$T = V/Q$$

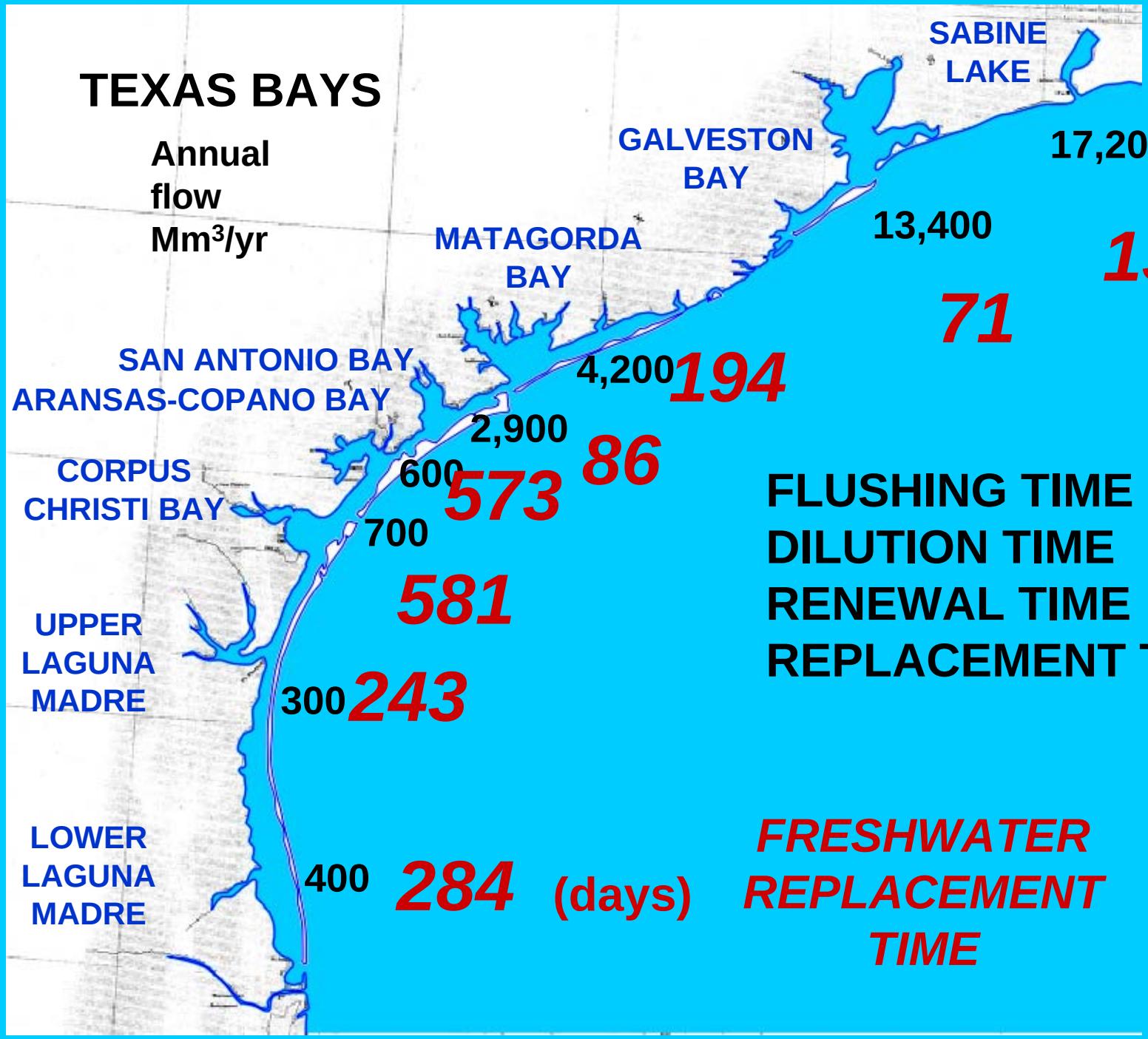

TEXAS BAYS
Annual flow Mm³/yr
SABINE LAKE
GALVESTON BAY
17,200
13,400
13
71
MATAGORDA BAY
SAN ANTONIO BAY
ARANSAS-COPANO BAY
4,200
194
2,900
86
CORPUS CHRISTI BAY
600
573
700
581
UPPER LAGUNA MADRE
300
243
LOWER LAGUNA MADRE
400
284
(days)
FLUSHING TIME
DILUTION TIME
RENEWAL TIME
REPLACEMENT TIME

FRESHWATER INFLOW

DISCHARGES

DENSITY (SALINITY) CURRENT

TIDES


TEXAS BAYS
Annual flow Mm³/yr
SABINE LAKE
GALVESTON BAY
17,200
13,400
13
71
MATAGORDA BAY
SAN ANTONIO BAY
ARANSAS-COPANO BAY
4,200
194
2,900
86
CORPUS CHRISTI BAY
600
573
700
581
UPPER LAGUNA MADRE
300
243
LOWER LAGUNA MADRE
400
284
(days)
FLUSHING TIME
DILUTION TIME
RENEWAL TIME
REPLACEMENT TIME
FRESHWATER REPLACEMENT TIME

# COMPONENTS OF EXCHANGE

**UNI-DIRECTIONAL (a.k.a. throughflow)**

**Inflow, diversions, discharges, density current**

**BI-DIRECTIONAL (a.k.a. sloshing)**

**Tides, meteorological exchanges,**

**secular exchanges**

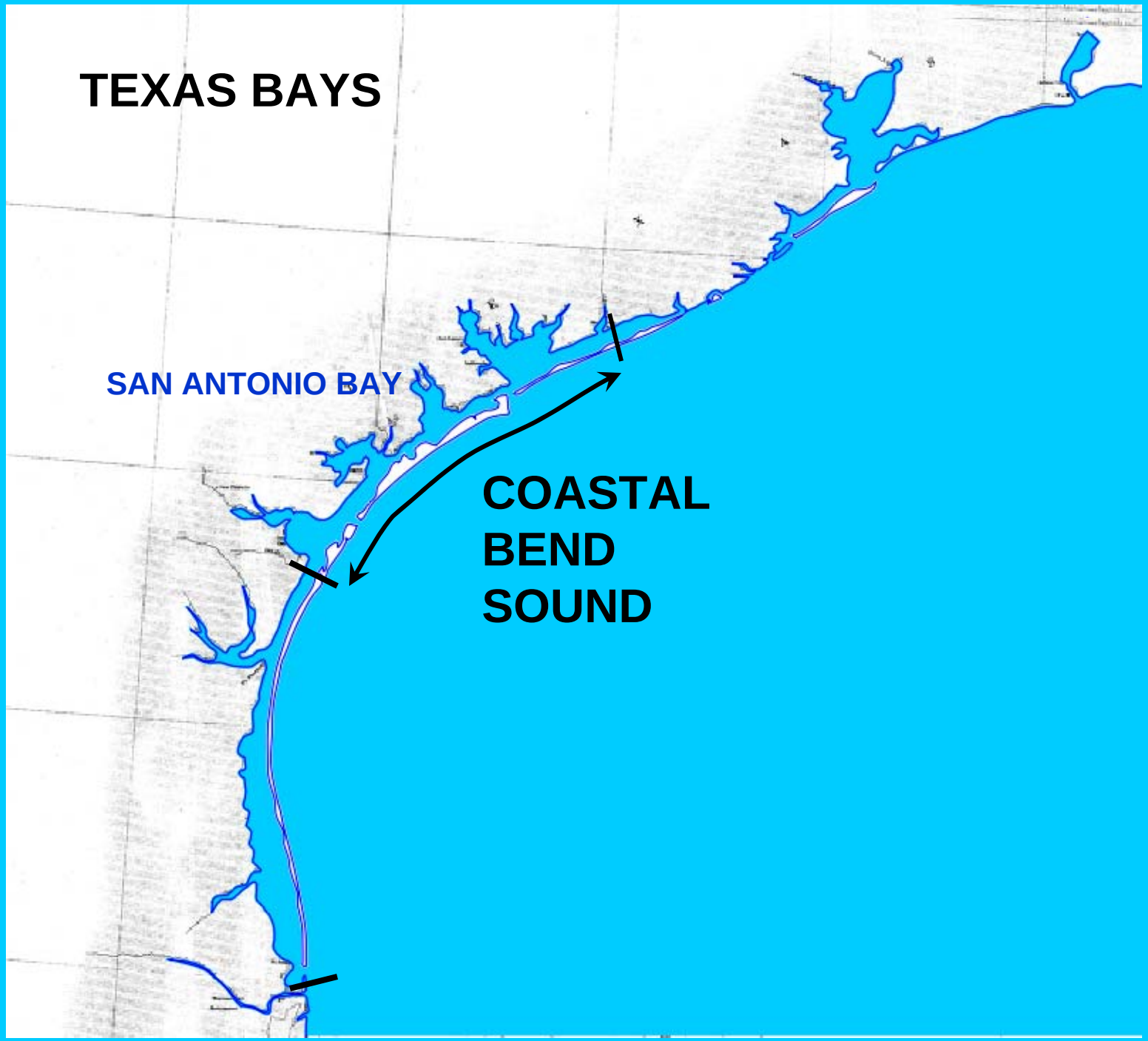

San Antonio Bay

# FEATURES OF SAN ANTONIO BAY

INFLOWS PREDOMINANTLY ENTER ESTUARY IN ONE POINT

LIES ON A CLIMATOLOGICAL GRADIENT BETWEEN HUMID, HIGH-INFLOW UPPER COAST, AND ARID, LOW-INFLOW LOWER COAST

PART OF LARGER ESTUARY SYSTEM


TEXAS BAYS
SAN ANTONIO BAY
COASTAL
BEND
SOUND


Lavaca/Navidad
Colorado
Guadalupe
Aransas/Mission/Copano
Nueces

# FEATURES OF SAN ANTONIO BAY

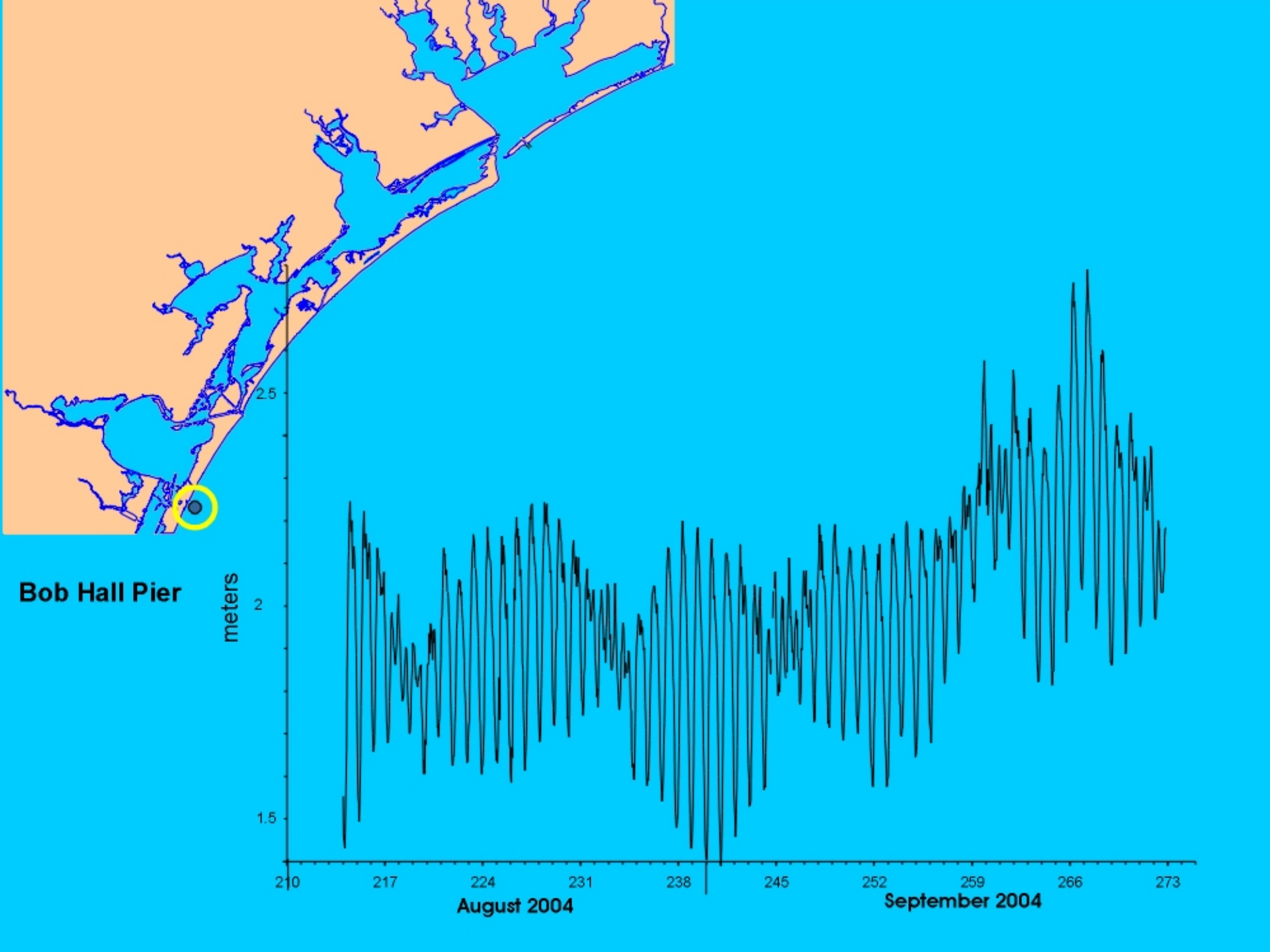
INFLOWS PREDOMINANTLY ENTER ESTUARY IN ONE POINT

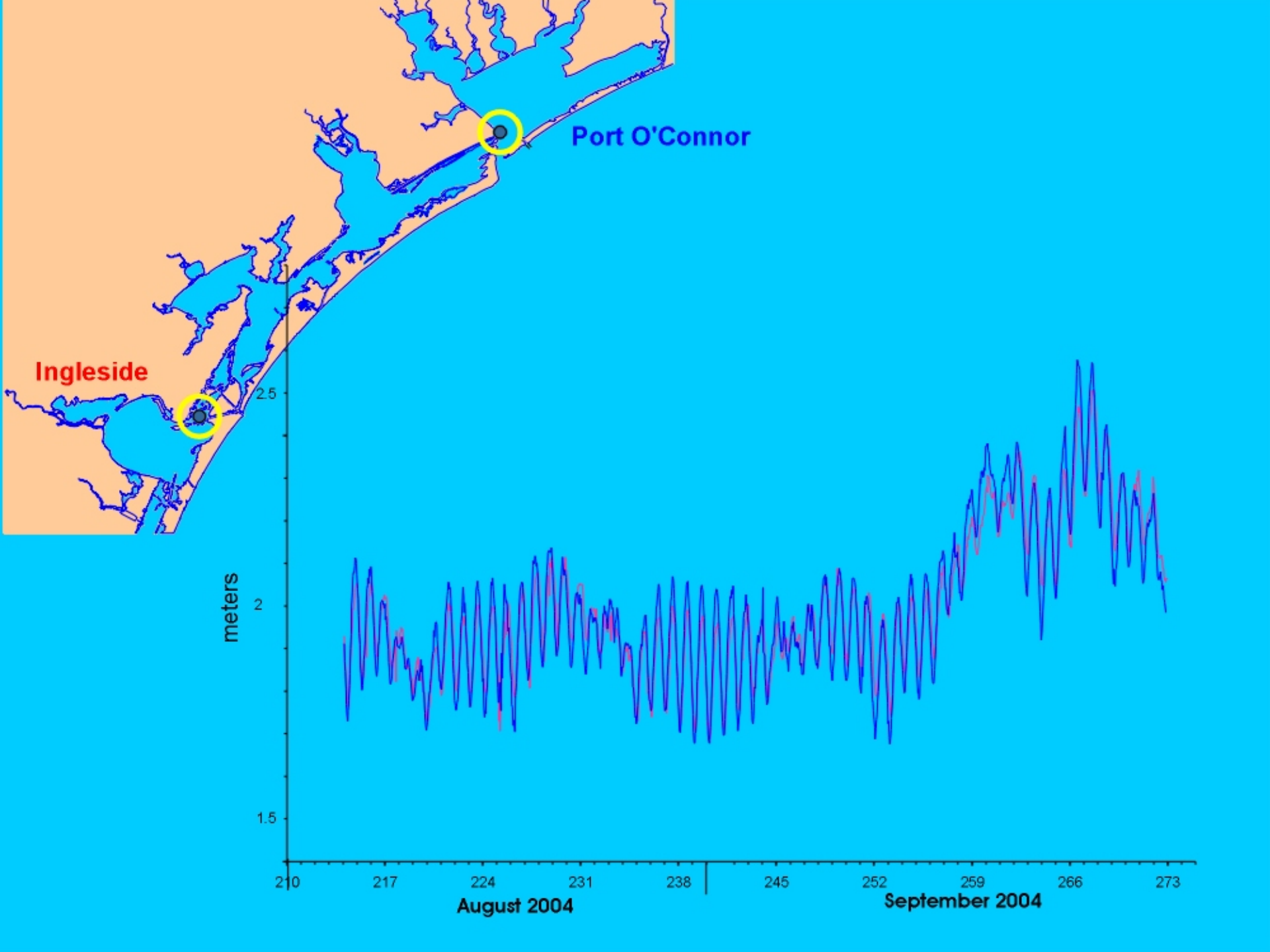
LIES ON A CLIMATOLOGICAL GRADIENT BETWEEN HUMID, HIGH-INFLOW UPPER COAST, AND ARID, LOW-INFLOW LOWER COAST

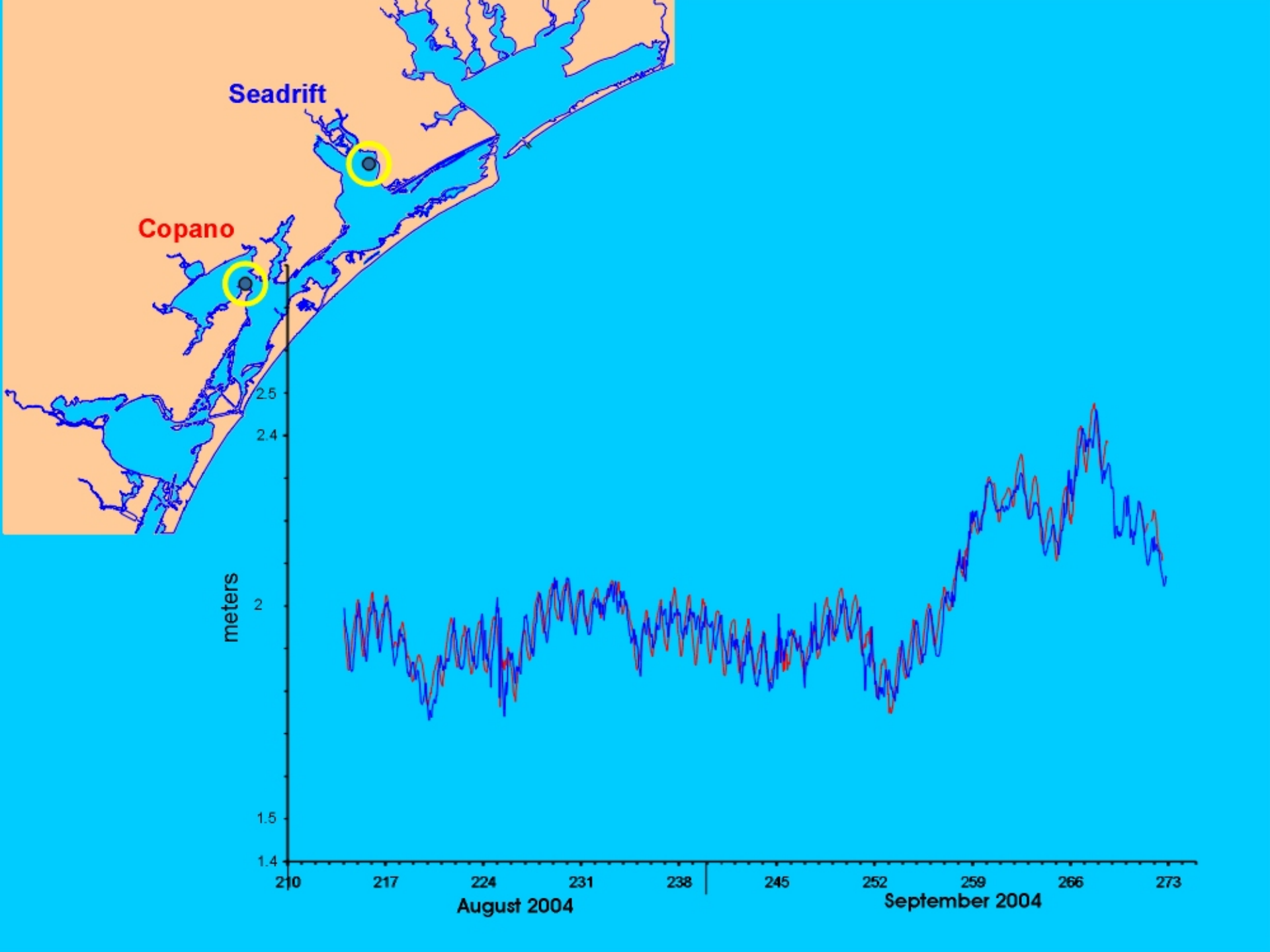
PART OF LARGER ESTUARY SYSTEM

NO DIRECT TIDAL INLET

(CEDAR BAYOU, WHEN OPEN, HAS MINIMAL TIDAL PRISM)


Bob Hall Pier
meters
2.5
2
1.5
210
217
224
231
238
245
252
259
266
273
August 2004
September 2004


Port O'Connor
Ingleside
meters
2.5
2
1.5
210
217
224
231
238
245
252
259
266
273
August 2004
September 2004


Seadrift
Copano
meters
2.5
2.4
2
1.5
1.4
210
217
224
231
238
245
252
259
266
273
August 2004
September 2004

# FEATURES OF SAN ANTONIO BAY

INFLOWS PREDOMINANTLY ENTER ESTUARY IN ONE POINT

LIES ON A CLIMATOLOGICAL GRADIENT BETWEEN HUMID, HIGH-INFLOW UPPER COAST, AND ARID, LOW-INFLOW LOWER COAST

PART OF LARGER ESTUARY SYSTEM

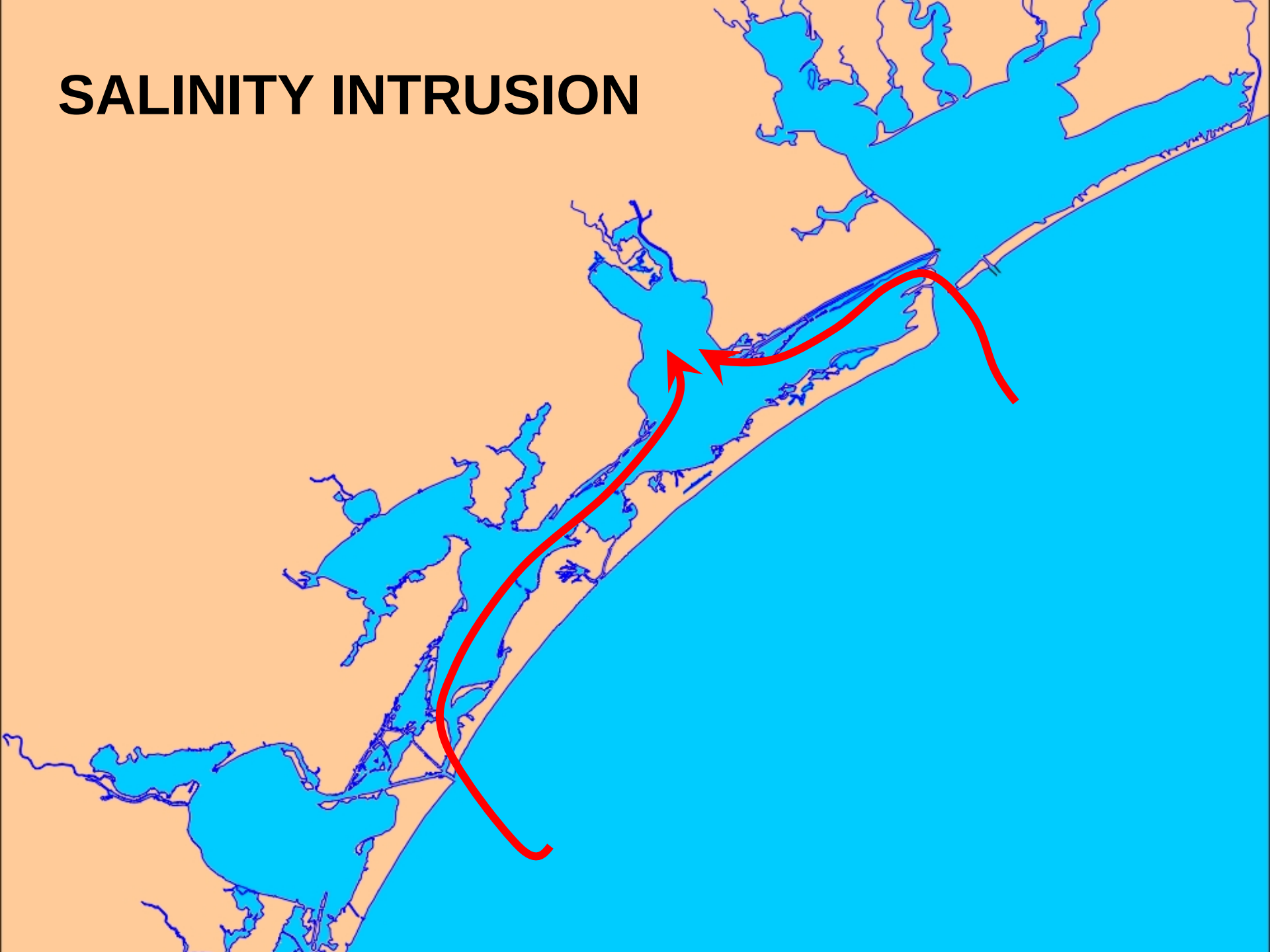
NO DIRECT TIDAL INLET

(CEDAR BAYOU, WHEN OPEN, HAS MINIMAL TIDAL PRISM)

NO DEEP-DRAFT SHIP CHANNEL

SALINITY INTRUSION OCCURS FROM ARANSAS PASS & MATAGORDA ENTRANCE/PASS CAVALLO

# SALINITY INTRUSION



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ACTS AS AN INTEGRATOR OF INFLOW: HAS SLUGGISH RESPONSE TO FLUCTUATIONS OF FLOOD & DROUGHT