Nueces River and Corpus Christi and Baffin Bays
Basin and Bay Expert Science Team (Nueces BBEST)

Environmental Flows Recommendations Report

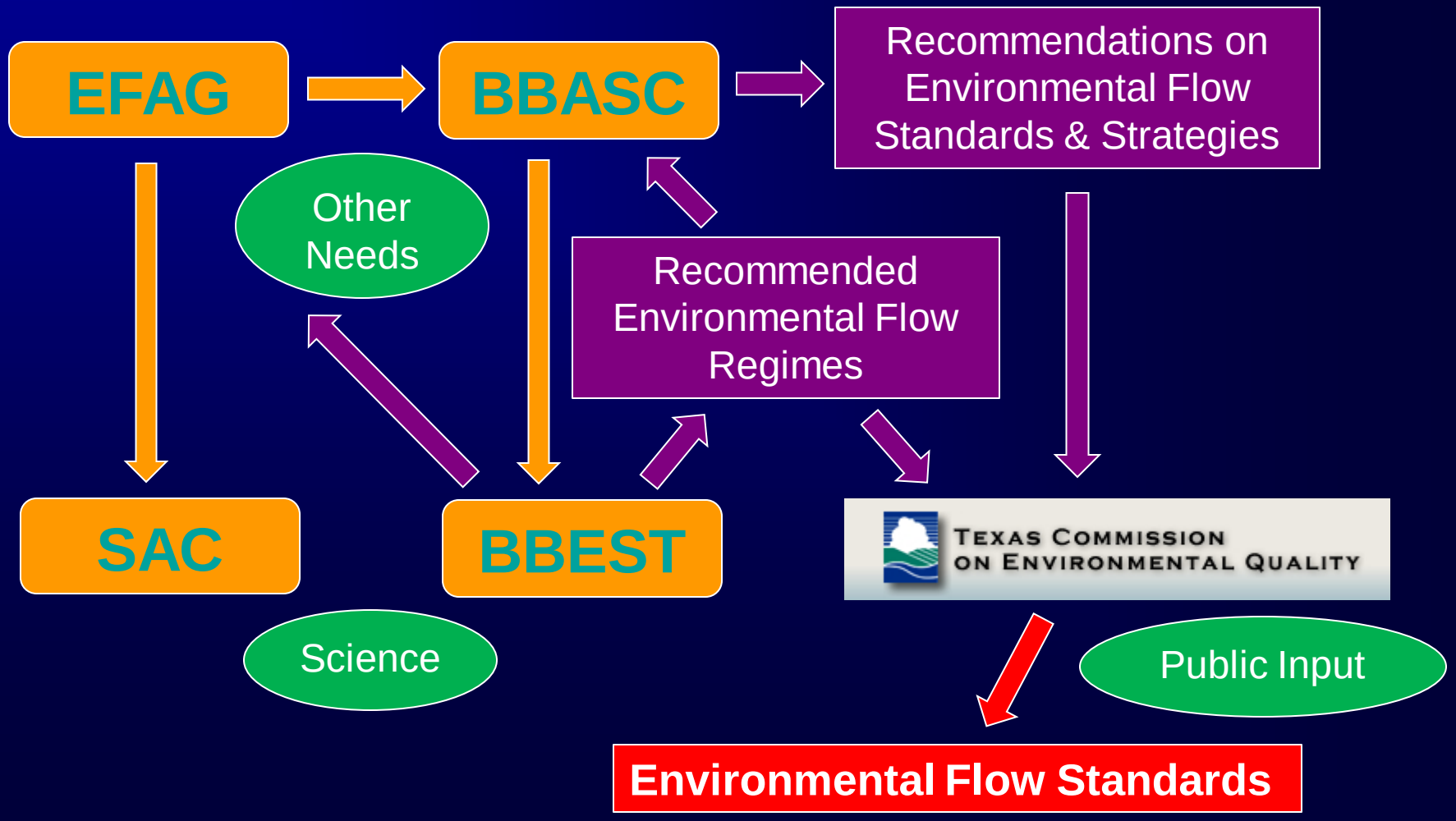
Sam Vaugh, PE
Dave Buzan
Greg Stunz, PhD

October 19, 2011

Topics of Discussion

1) SB3 Environmental Flows Process
2) Nueces BBEST Charge & Membership
3) Environmental Flow Regime Recommendations
4) Environmental Flow Analyses:
   a) Hydrology
   b) Instream
   c) Estuary
5) Application of Recommendations

SB3 Environmental Flows Process



Basin & Bay Expert Science Team (BBEST)

1) **Comprised of technical experts with knowledge of the river basin and bay system and/or development of environmental flow regimes.**
2) **Charged to develop environmental flow analyses and recommended environmental flow regimes based on best available science through a consensus process.**
3) **Provide environmental flow regime recommendations by March 1, 2012.**
4) **Provide technical support to the Nueces BBASC in its development of recommendations on environmental flow standards & strategies (by September 1, 2012) and a work plan (thereafter).**

Basin & Bay Expert Science Team (BBEST)

Member	Hydrology	Instream	Estuary
Sam Vaugh, Chair	★		
Rocky Freund, Vice Chair	✓	✓	
Dave Buzan		★	✓
Greg Stunz			★
Tom Arsuffi		✓	
Ken Dunton			✓
Ben Hodges	✓		✓
David Hoeinghaus	✓	✓	
Ryan Smith	✓	✓	
Lonnie Stewart	✓	✓	
Jace Tunnell			✓
Lance Williams		✓	

Nueces BBEST Recommendations Report

1) Preamble – Sound Ecological Environment
2) Overview of Watersheds & Bays
3) Instream Flow Analyses
4) Freshwater Inflow Analyses
5) Integration of Instream Flow & Estuary Inflow Regimes
6) Environmental Flow Regime Recommendations
7) Adaptive Management
8) References

Science Advisory Committee (SAC)

Technical Guidance:

a) Geographic Scope
b) Use of Hydrologic Data
c) Fluvial Sediment Transport (Geomorphology)
d) Freshwater Inflow Regime for Estuaries
e) Biological Overlays
f) Nutrient & Water Quality Overlay
g) Flow Regimes to Environmental Flow Standards
h) Lessons Learned
i) Work Plans for Adaptive Management
j) Flow Regimes & Water Supply Projects
k) Attainment Frequencies & Hydrologic Conditions

Environmental Flow Regime Recommendations

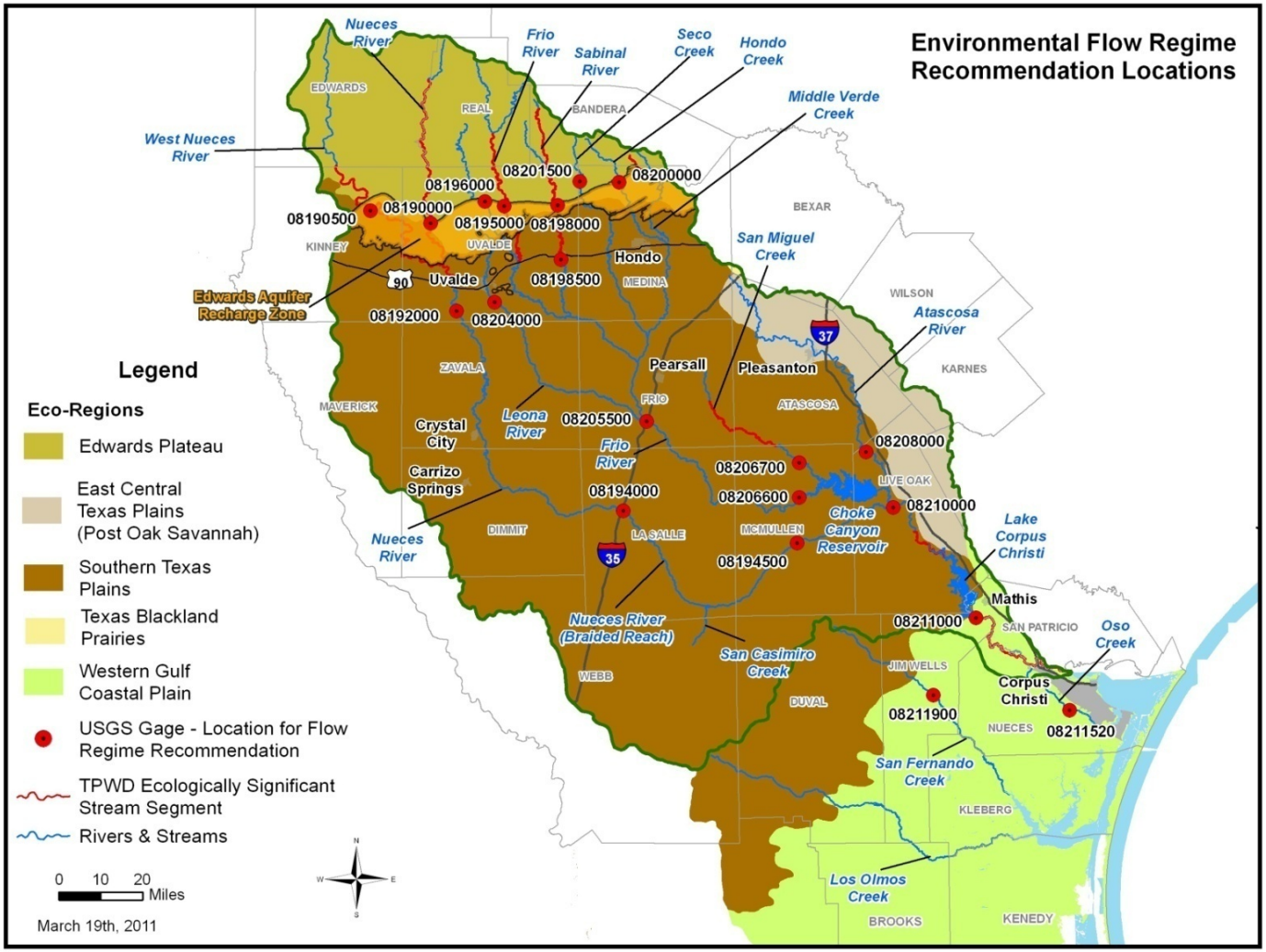
1) Instream Flows
   a) Hydrology-based Environmental Flow Regime (HEFR) Methodology
   b) Biology, Water Quality, Geomorphology, and Riparian Biological Overlays
2) Freshwater Inflows to Bays & Estuaries
   a) Salinity Zone Methodology Applied to Focal Species
   b) Nutrient, Sediment, and Other Overlays

Hydrology Analyses

1) Geographic Scope (Section 3.1)
2) Hydrology-Based Environmental Flow Regime (HEFR) Analyses (Section 3.2)
3) Freshwater Inflows to Estuaries (Section 4)

Hydrology – Geographic Scope

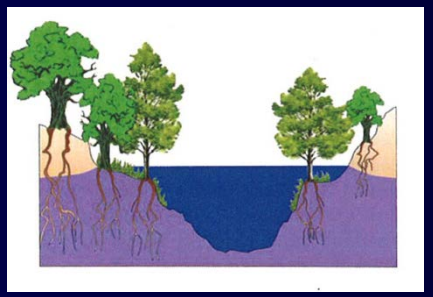
Hydrology – Geographic Scope

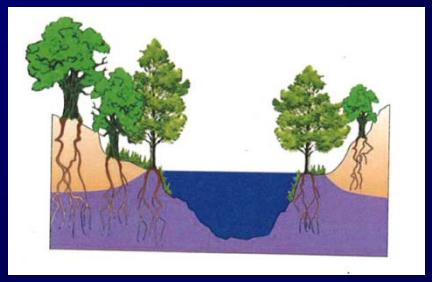


Hydrology – Flow Regime Components and HEFR

1) IHA Hydrographic Separation
2) Season Selections
3) Perennial & Intermittent Streams
4) HEFR Results
5) Consideration of Streamflow Trends

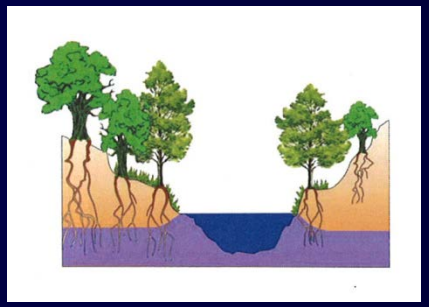
Overbank

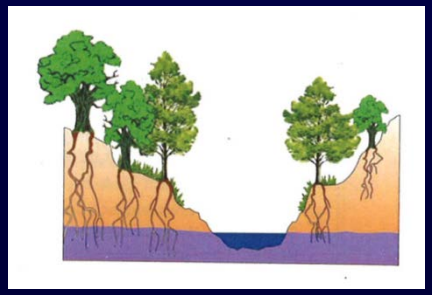




High Pulse

Base





Subsistence

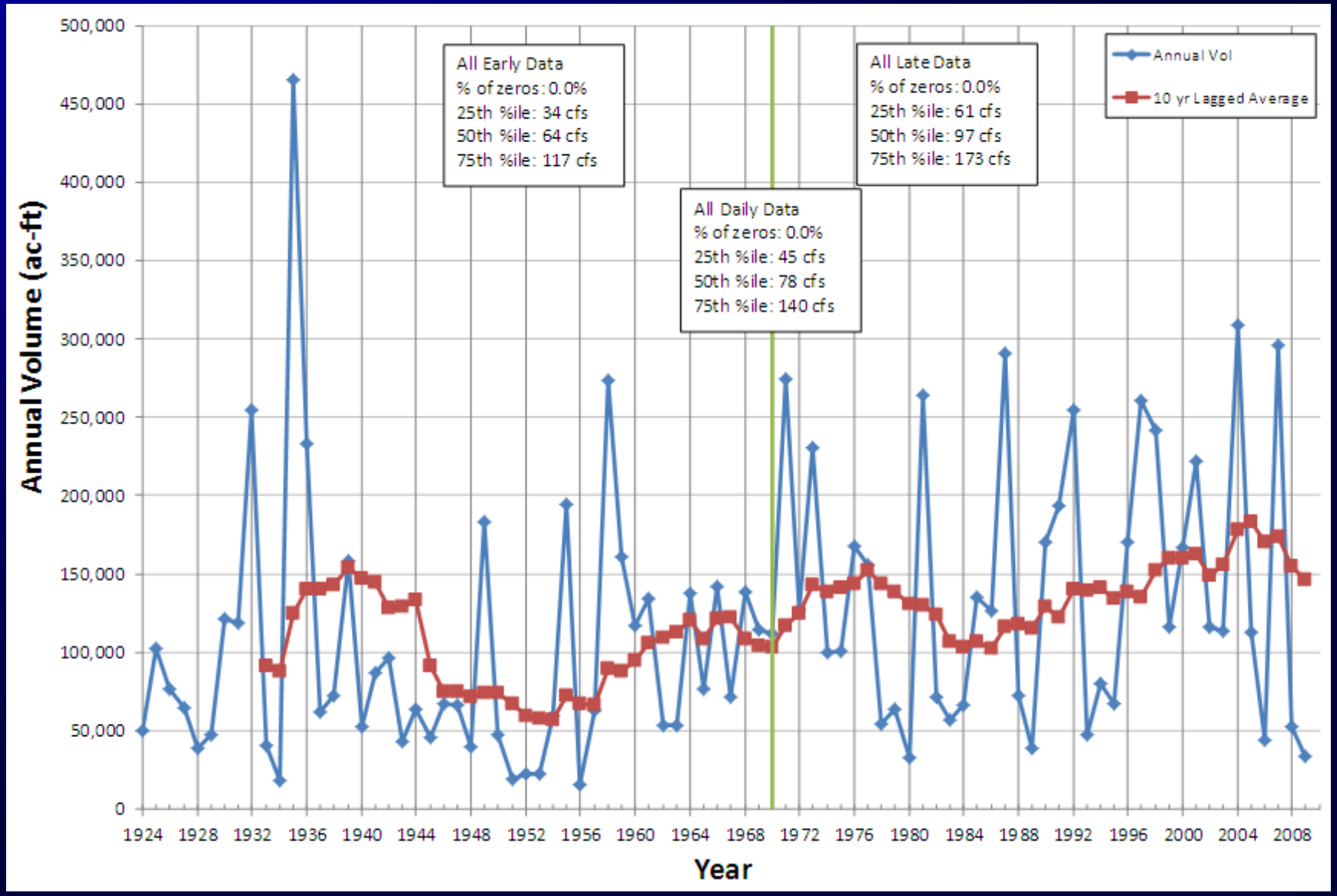
Hydrology-based Environmental Flow Regime (HEFR) Methodology

HEFR is used to provide an initial characterization of environmental systems with readily available data in the absence of definitive data relating flow alteration to ecological response.

Advantages:

1) **Hydrology is a key variable for instream, and a good indicator for estuarine, environmental flows.**
2) **Consistent with TIFP and SAC guidance.**
3) **Lengthy records at multiple streamflow gage locations.**

Hydrology - Nueces River @ Laguna



Instream Flow Regime Recommendation

Overbank Events	Qp: 15,600 cfs with Average Frequency 1 per 5 years Regressed Volume is 124,000 Duration Bound is 107			
High Flow Pulses	Qp: 4,750 cfs with Average Frequency 1 per 2 years Regressed Volume is 38,600 Duration Bound is 64			
	Qp: 2,220 cfs with Average Frequency 1 per year Regressed Volume is 18,400 Duration Bound is 46			
	Qp: 590 cfs with Average Frequency 2 per year Volume Bound is 11,300 Duration Bound is 26			
	Qp: 48 cfs with Average Frequency 1 per season Volume Bound is 1,000 Duration Bound is 7	Qp: 390 cfs with Average Frequency 1 per season Volume Bound is 6,070 Duration Bound is 17	Qp: 170 cfs with Average Frequency 1 per season Volume Bound is 3,100 Duration Bound is 14	Qp: 50 cfs with Average Frequency 1 per season Volume Bound is 800 Duration Bound is 5
		Qp: 99 cfs with Average Frequency 2 per season Volume Bound is 1,560 Duration Bound is 9		
Base Flows (cfs)	92		76	92
	65		48	65
	51	44	32	41
Subsistence Flows (cfs)	14	18	16	14
	Dec, Jan, Feb, Mar	Apr, May, Jun	Jul, Aug, Sep	Oct, Nov
	Winter	Spring	Summer	Fall

Wet

Avg

Dry

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Pulse volumes are in units of acre-feet and durations are in days.
Period of Record used : 1/1/1924 to 12/31/2009.

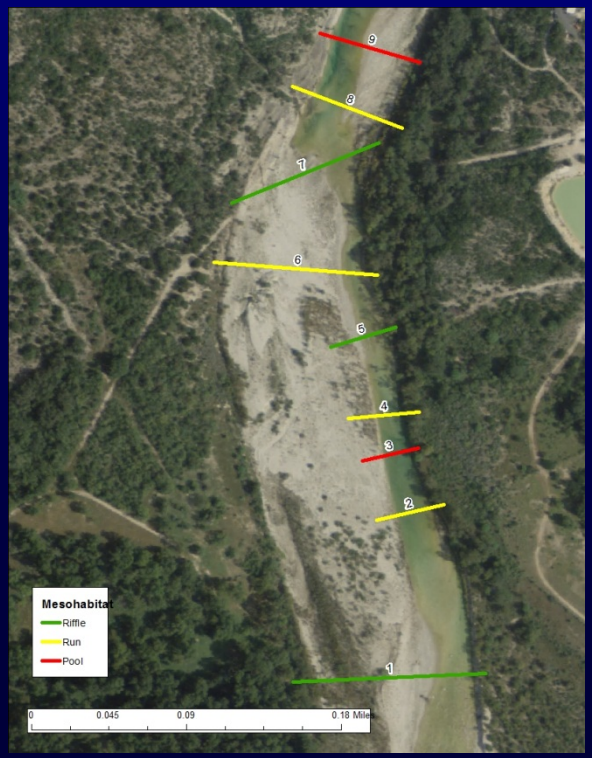
Nueces River @ Laguna (NRL)

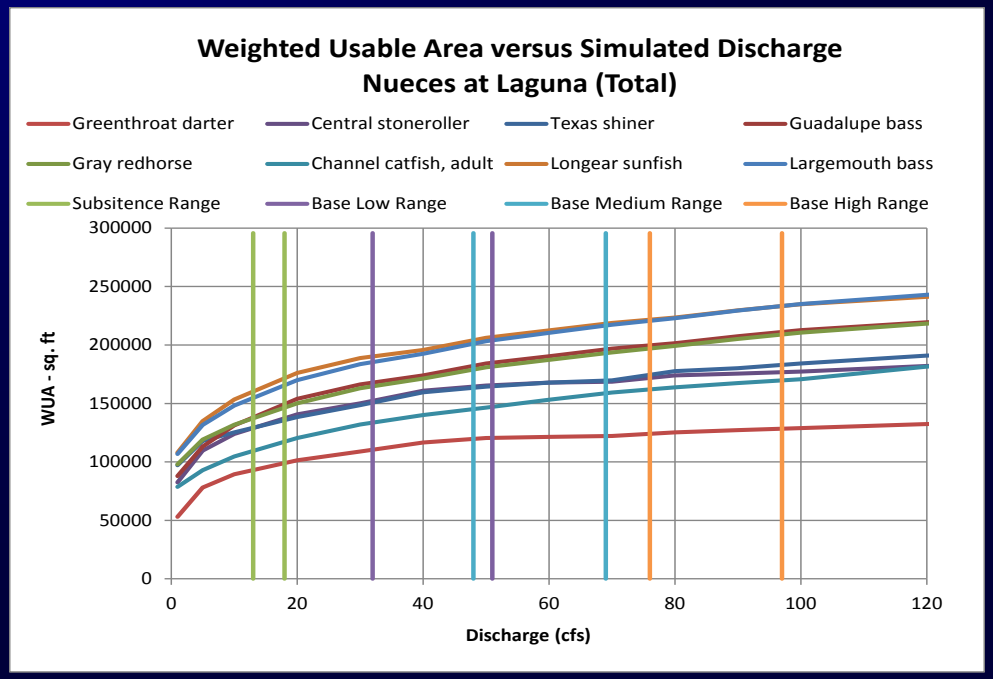
Instream Flow Analyses

1) Biology Overlay (Section 3.3)
2) Water Quality Overlay (Section 3.4)
3) Geomorphology Overlay (Section 3.5)
4) Riparian Overlay (Section 3.6)

Instream – Biology Overlay

1) Contracted for Development of Instream Flow-Habitat Relationships with TWDB & TPWD technical support.
2) Sites selected include Nueces River @ Laguna; Frio River @ Concan; and Nueces River @ Three Rivers.

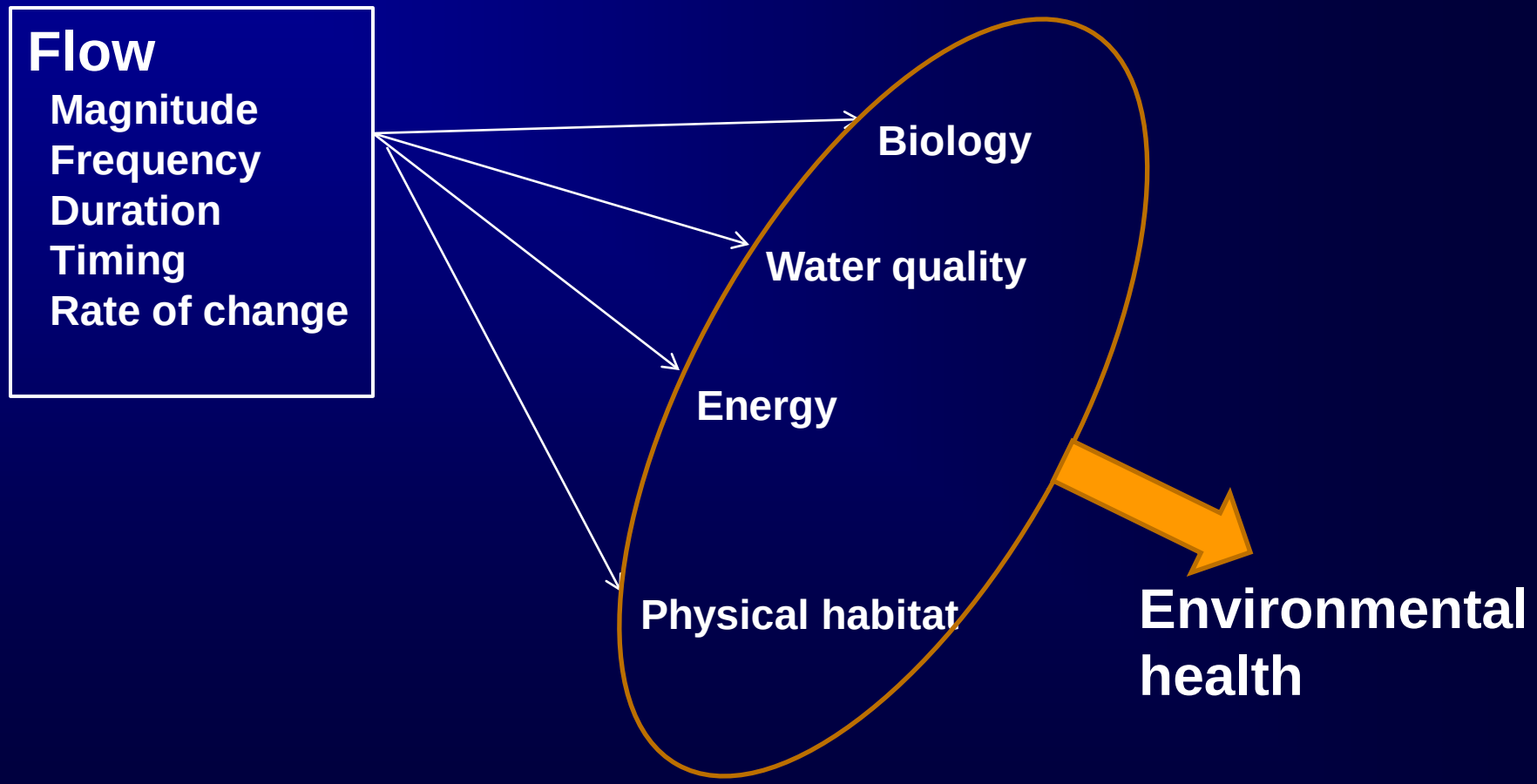




Instream – Additional Overlays

1) **Water Quality – Analyzed TCEQ/USGS data focusing on relationships between flow, dissolved oxygen, temperature, and nutrients.**
2) **Geomorphology – TWDB evaluated sediment transport using hydrologic time series at three sites (Nueces River @ Uvalde, Cotulla, and Three Rivers).**
3) **Riparian – Maps developed using TPWD Texas Ecological System Classification illustrations of riparian and floodplain vegetative communities.**

Natural Flow Paradigm
(adapted from Poff et al., 1997)



Aquatic Animals

- 89 fish species
  - 5 habitats (riffles, runs, pools)
  - State fish of Texas
- 11 freshwater clam (mussel) species
  - 1 state-threatened species
- Variety of aquatic insects and river shrimp

Channel catfish

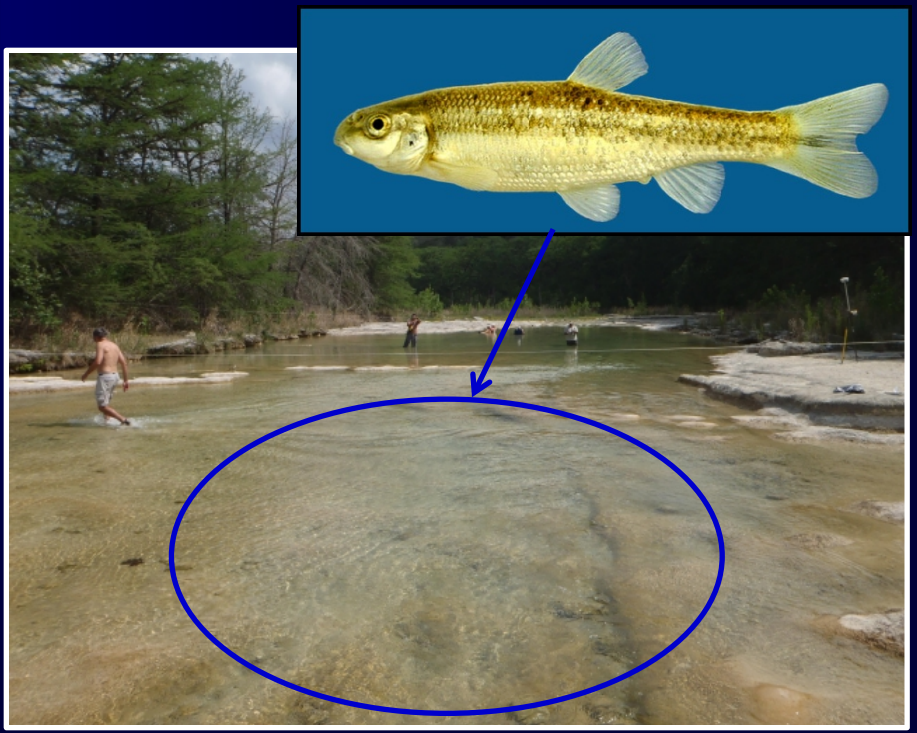
Deep, slow pools

Shallow, rapid riffles

Habitat Choices

spotted gar – pools at night, spawn on plants

stoneroller – shallow, flowing, bedrock

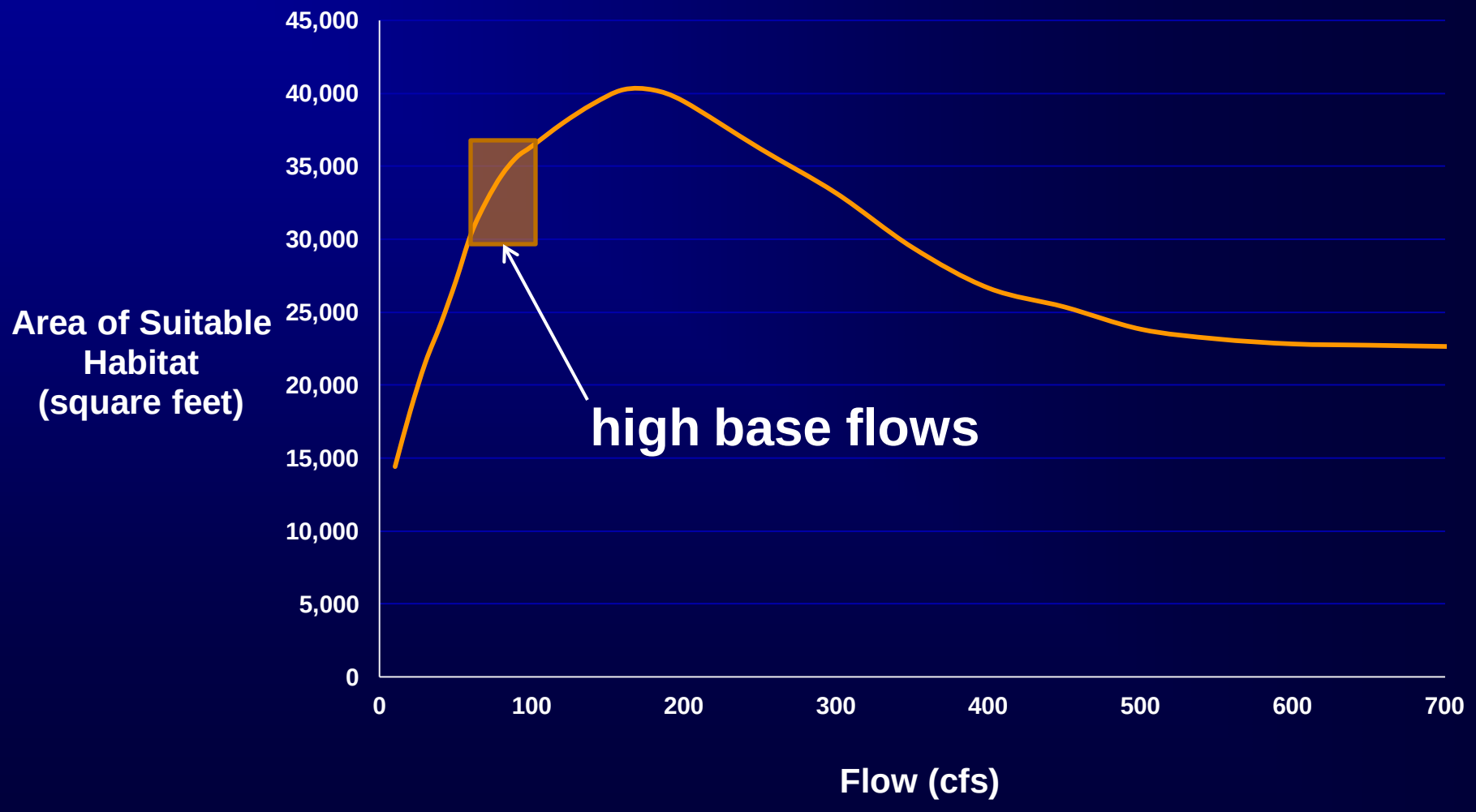


Mussels

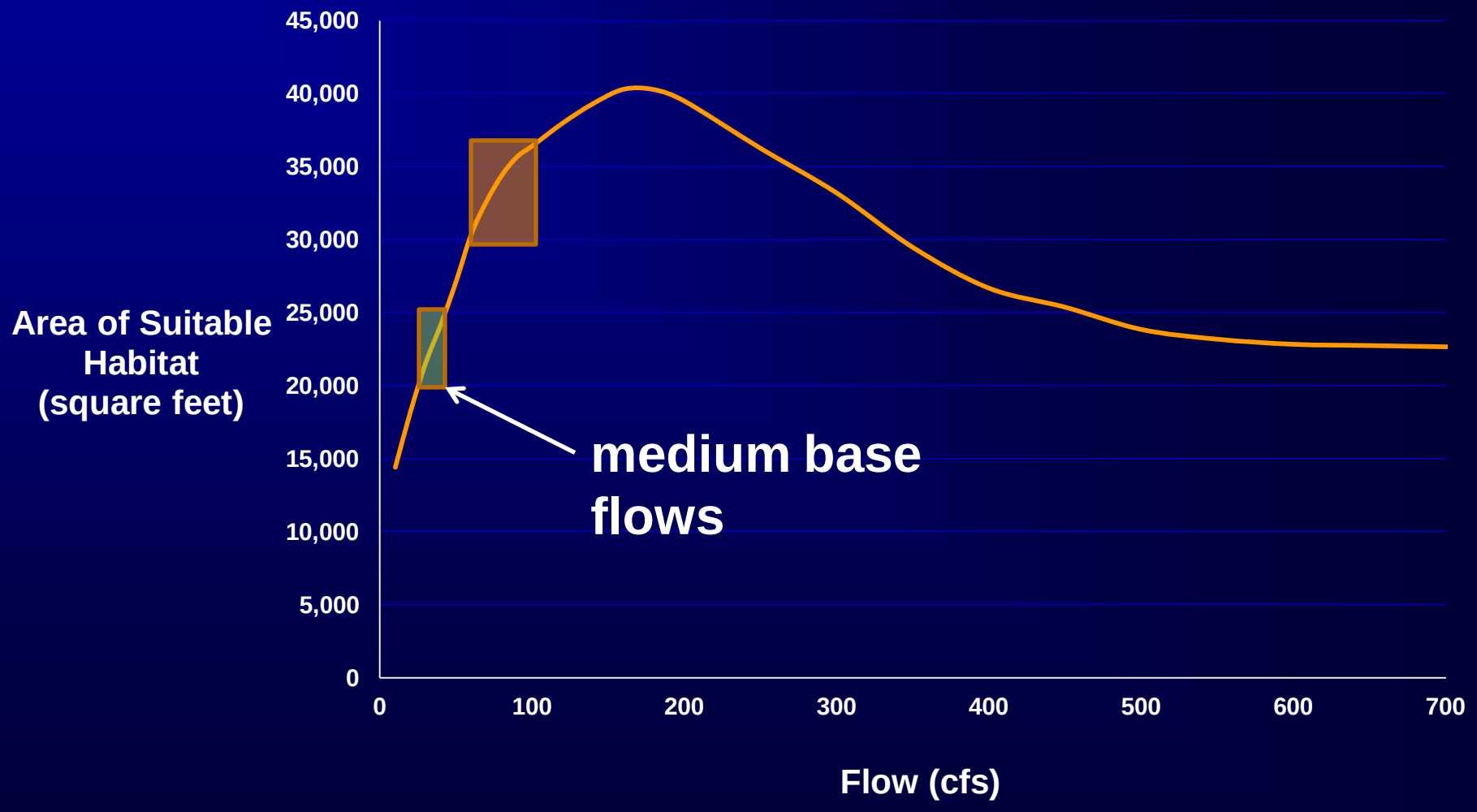
Source: http://unionid.missouristate.edu

Mussels - Live

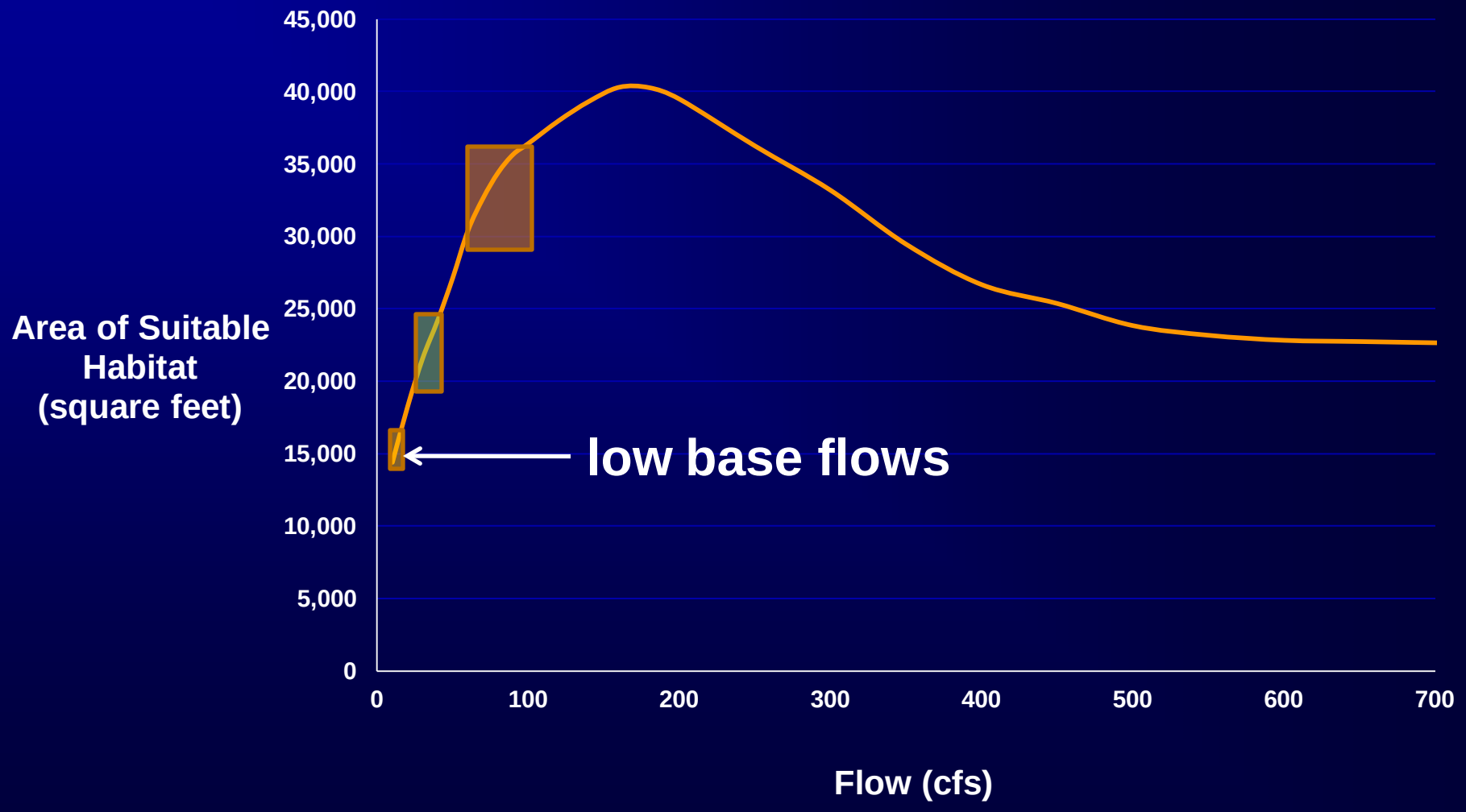
Blue Catfish: Habitat Area and Flow



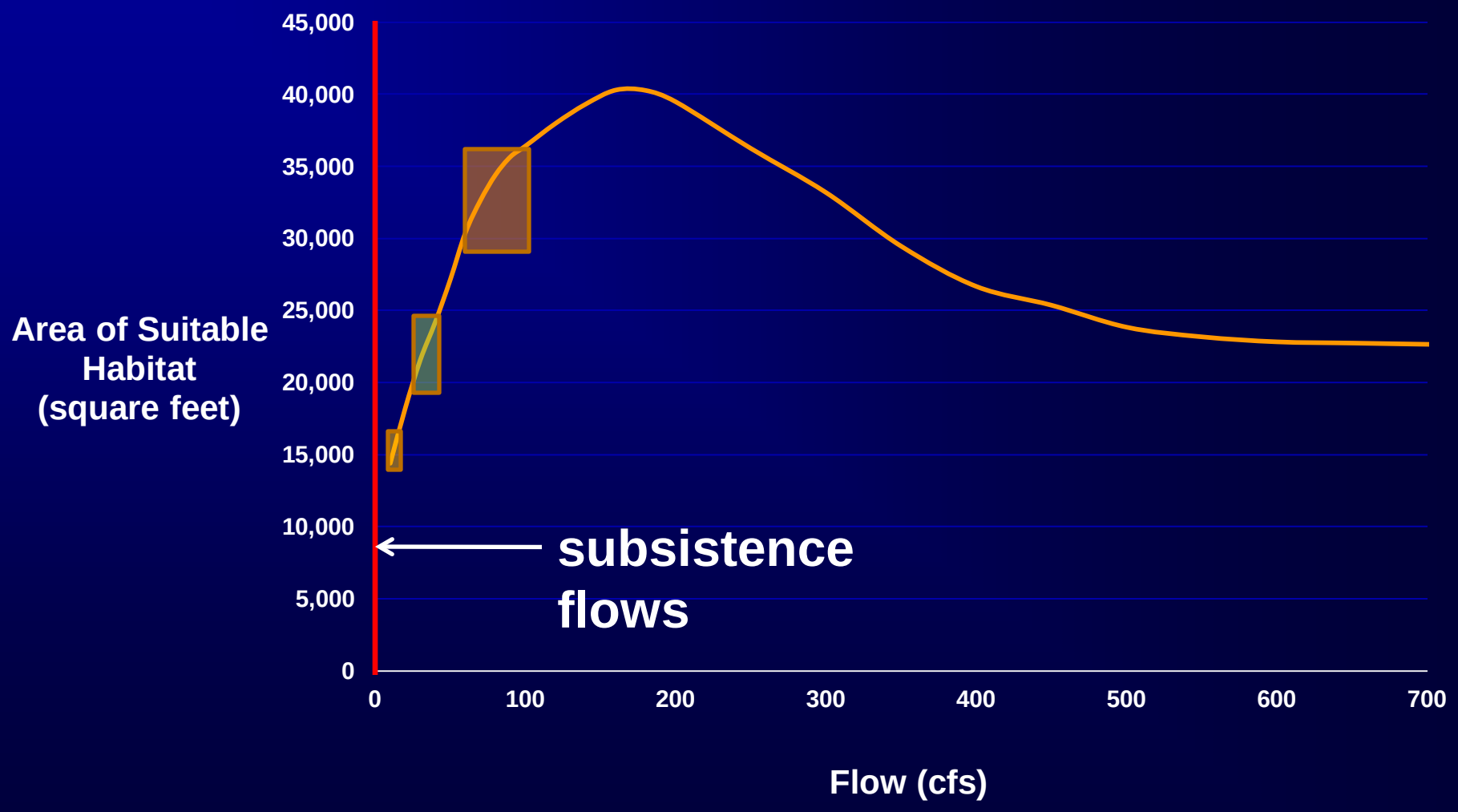
Blue Catfish: Habitat Area and Flow



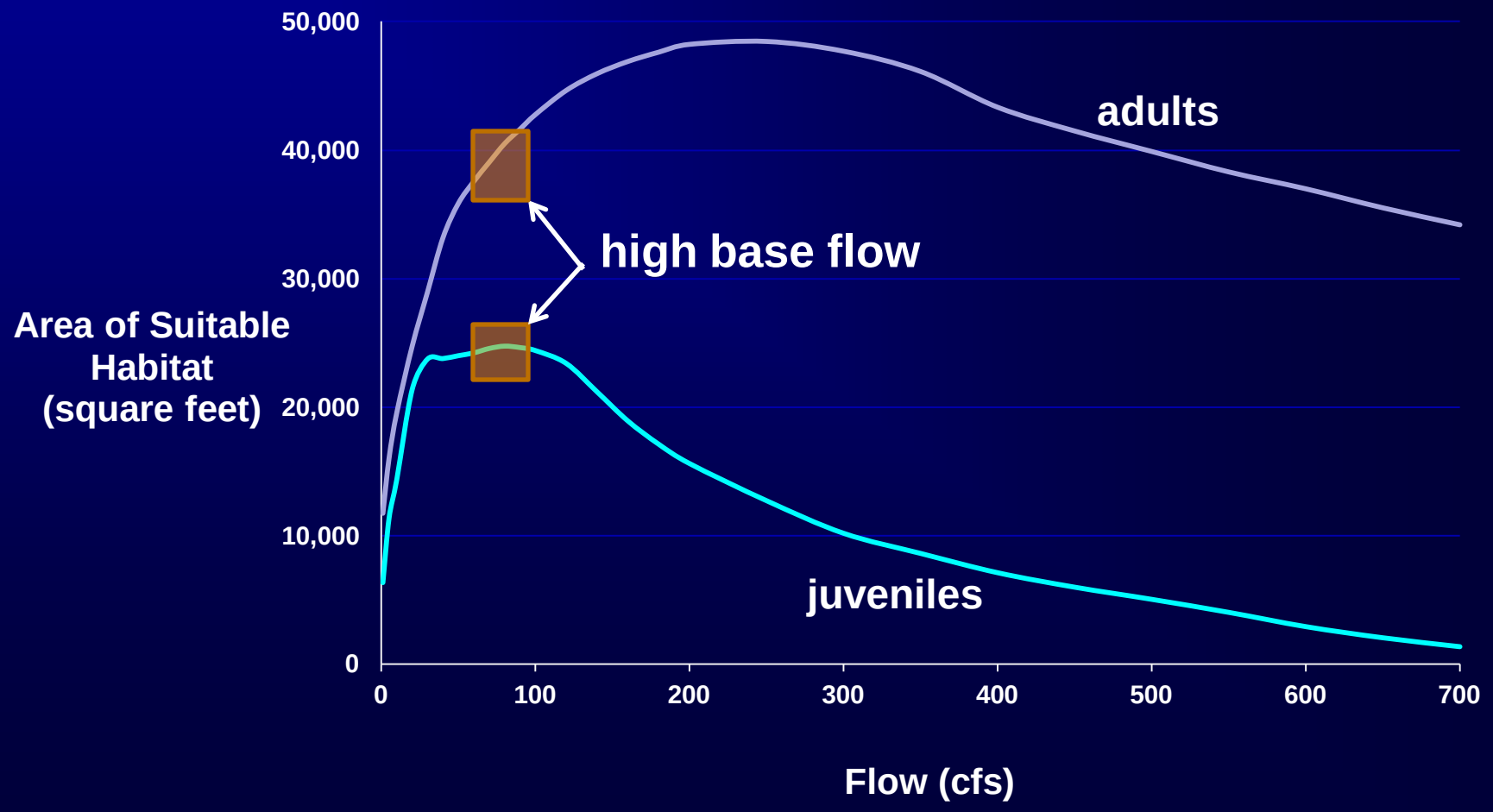
Blue Catfish: Habitat Area and Flow



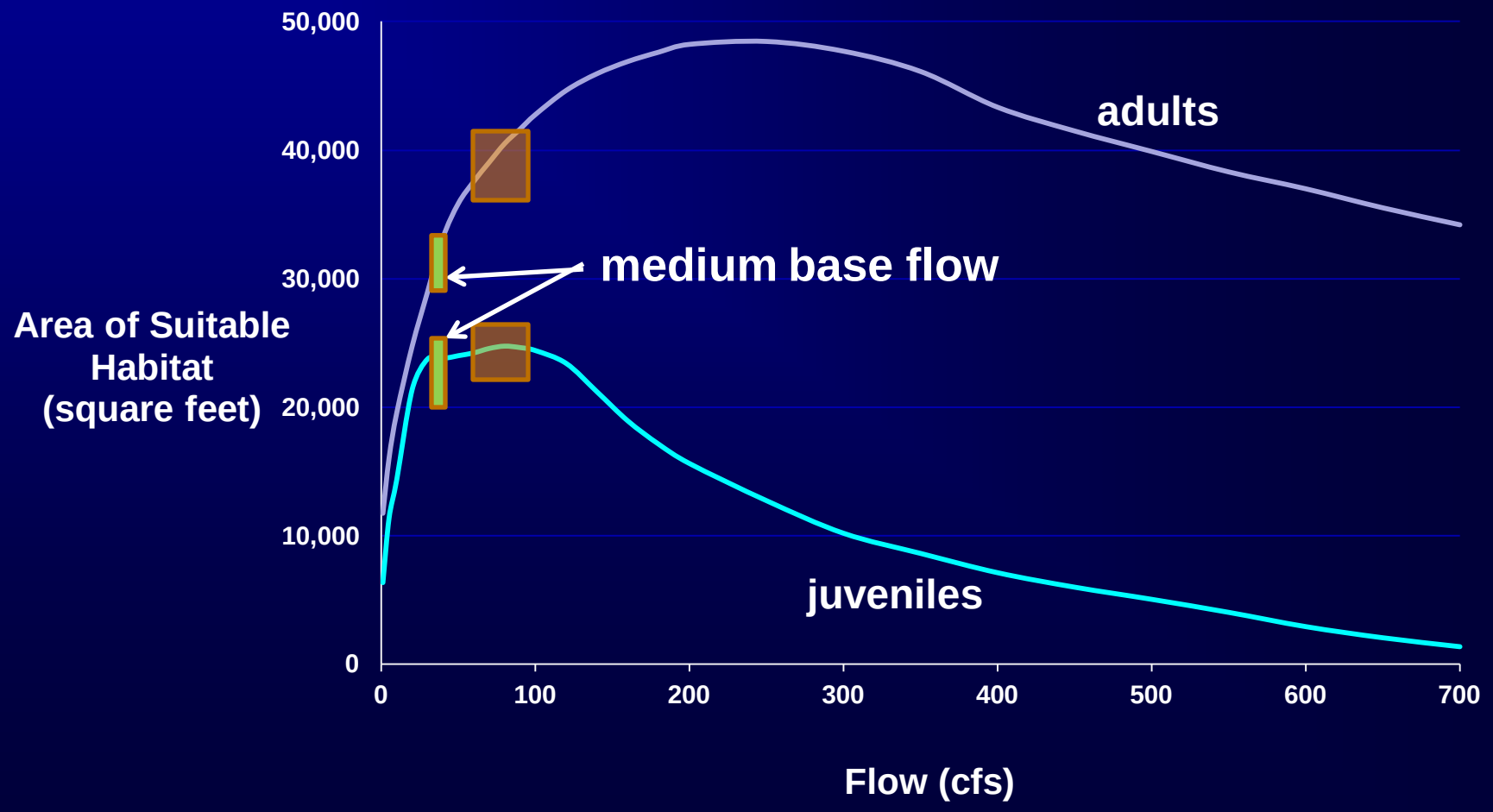
Blue Catfish: Habitat Area and Flow



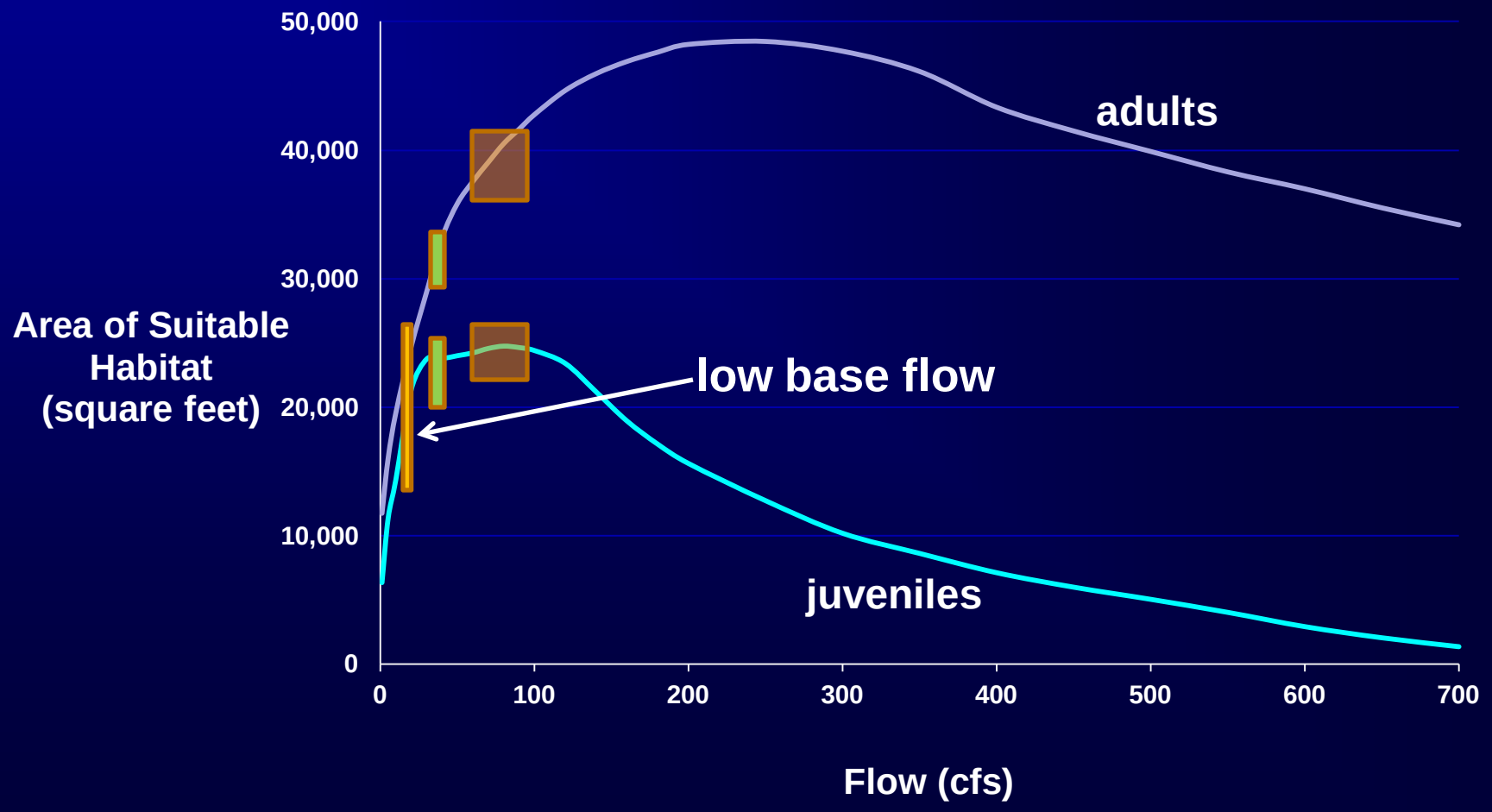
Channel Catfish: Habitat Area and Flow



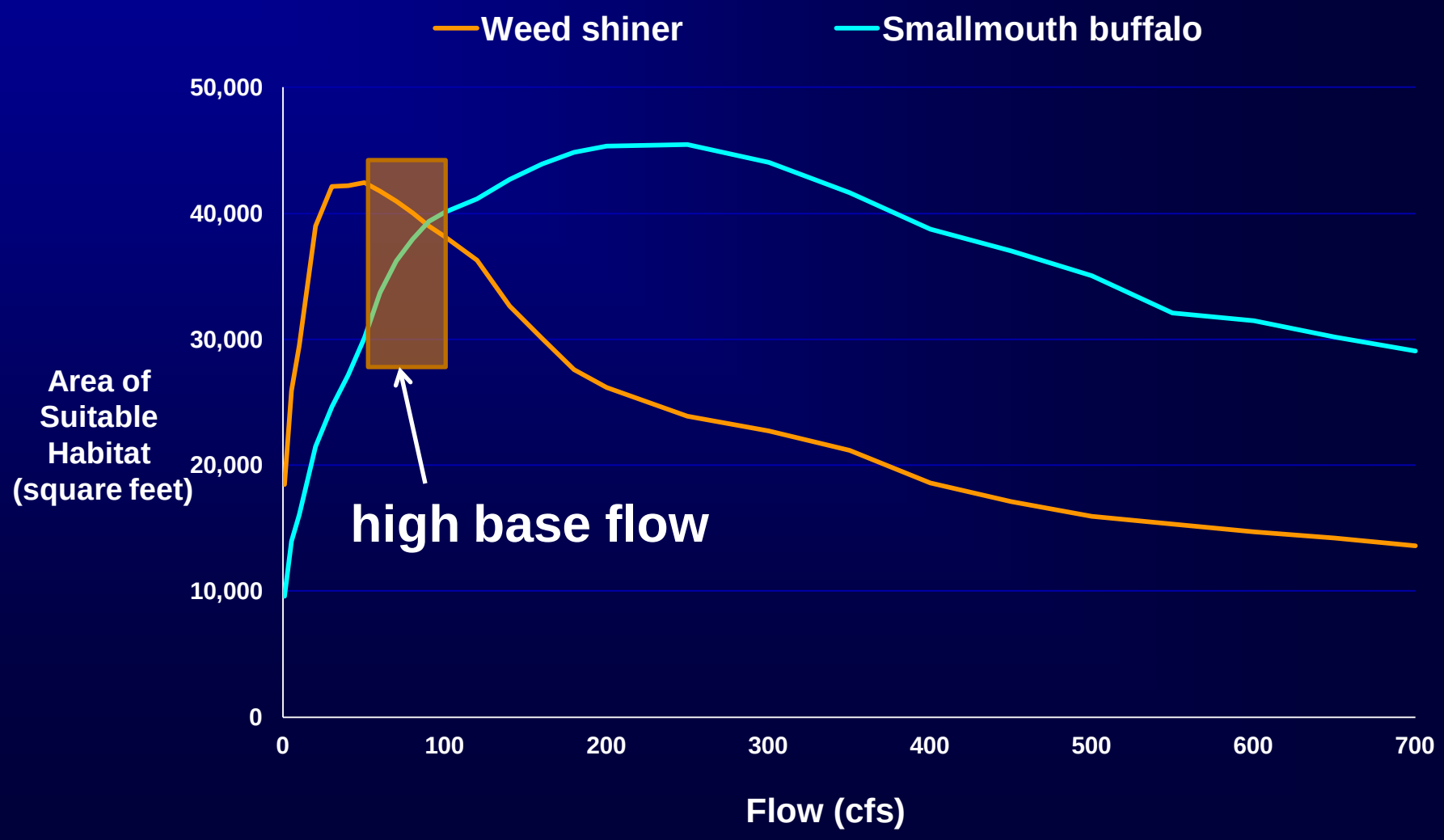
Channel Catfish: Habitat Area and Flow



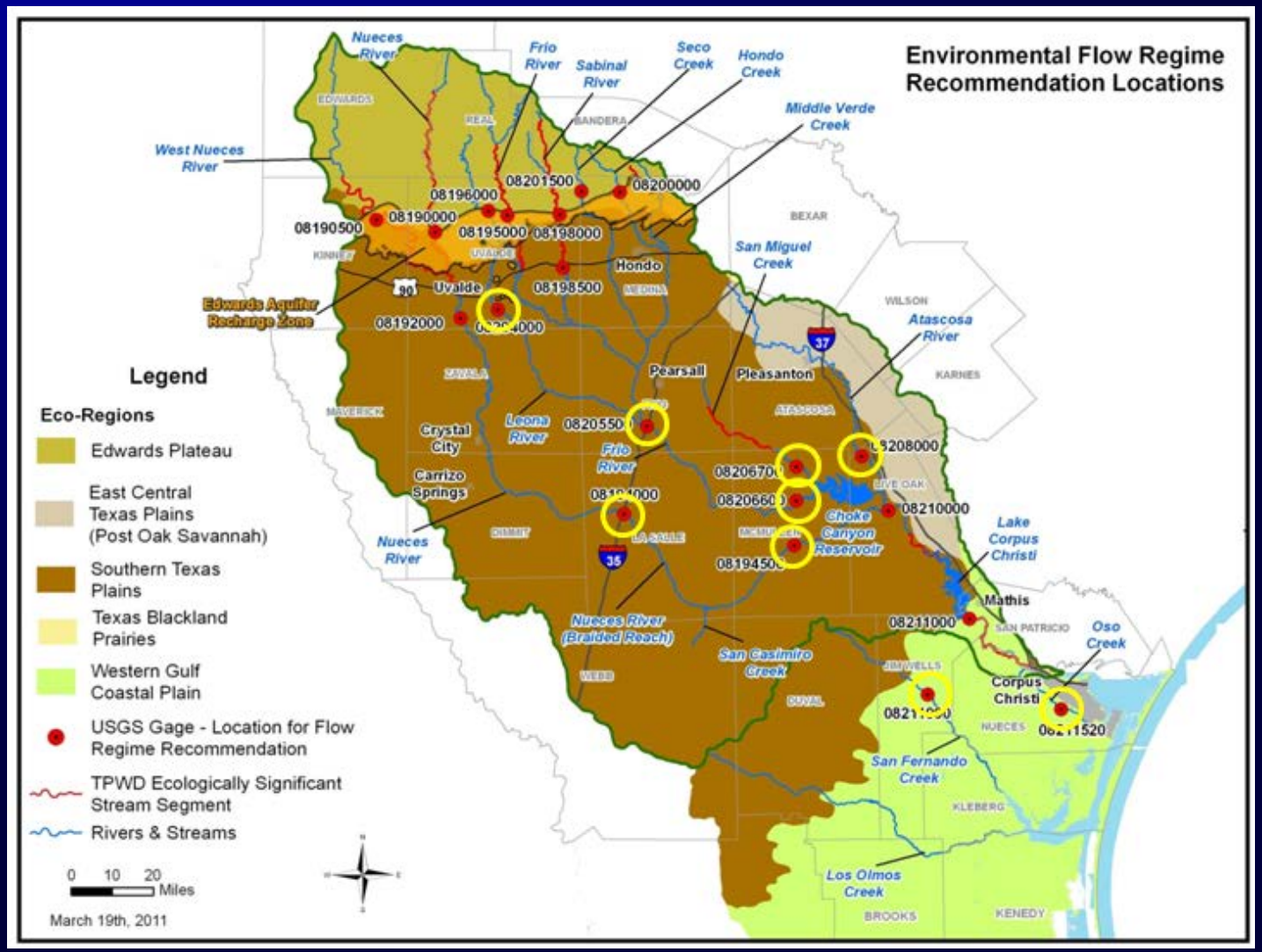
Channel Catfish: Habitat Area and Flow



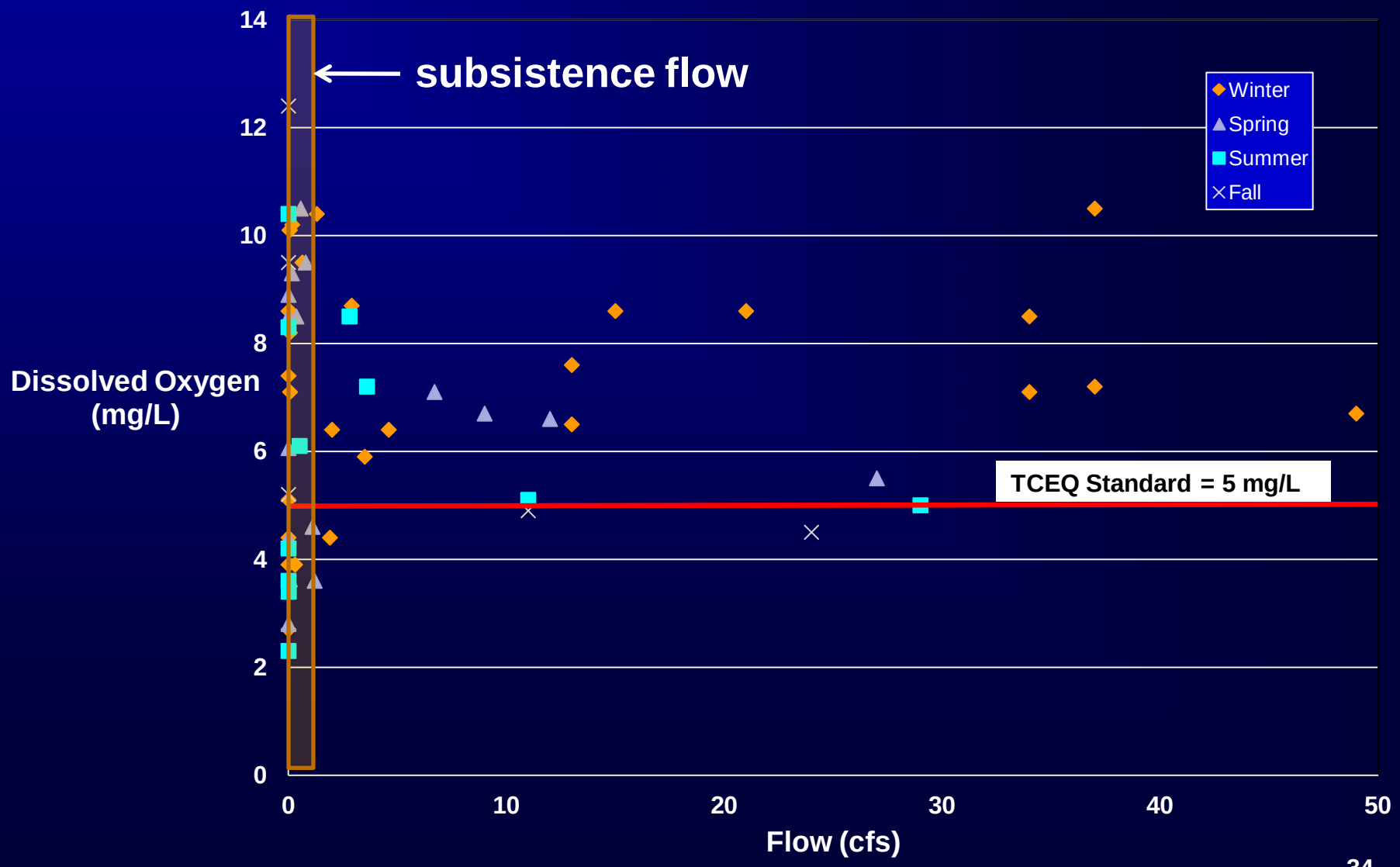
Weed Shiner and Smallmouth Buffalo



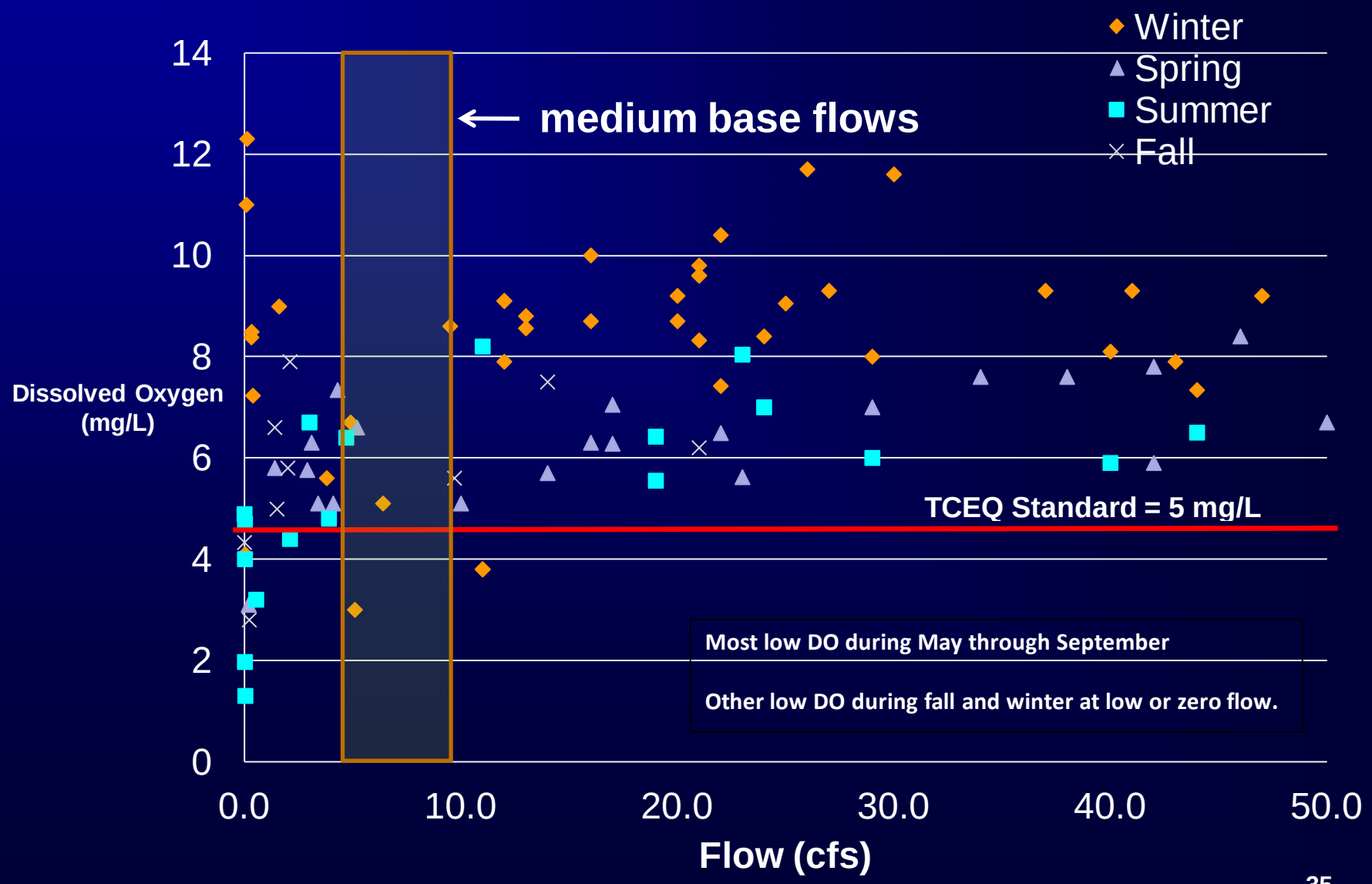
Water Quality: Sites with Low Dissolved Oxygen Data



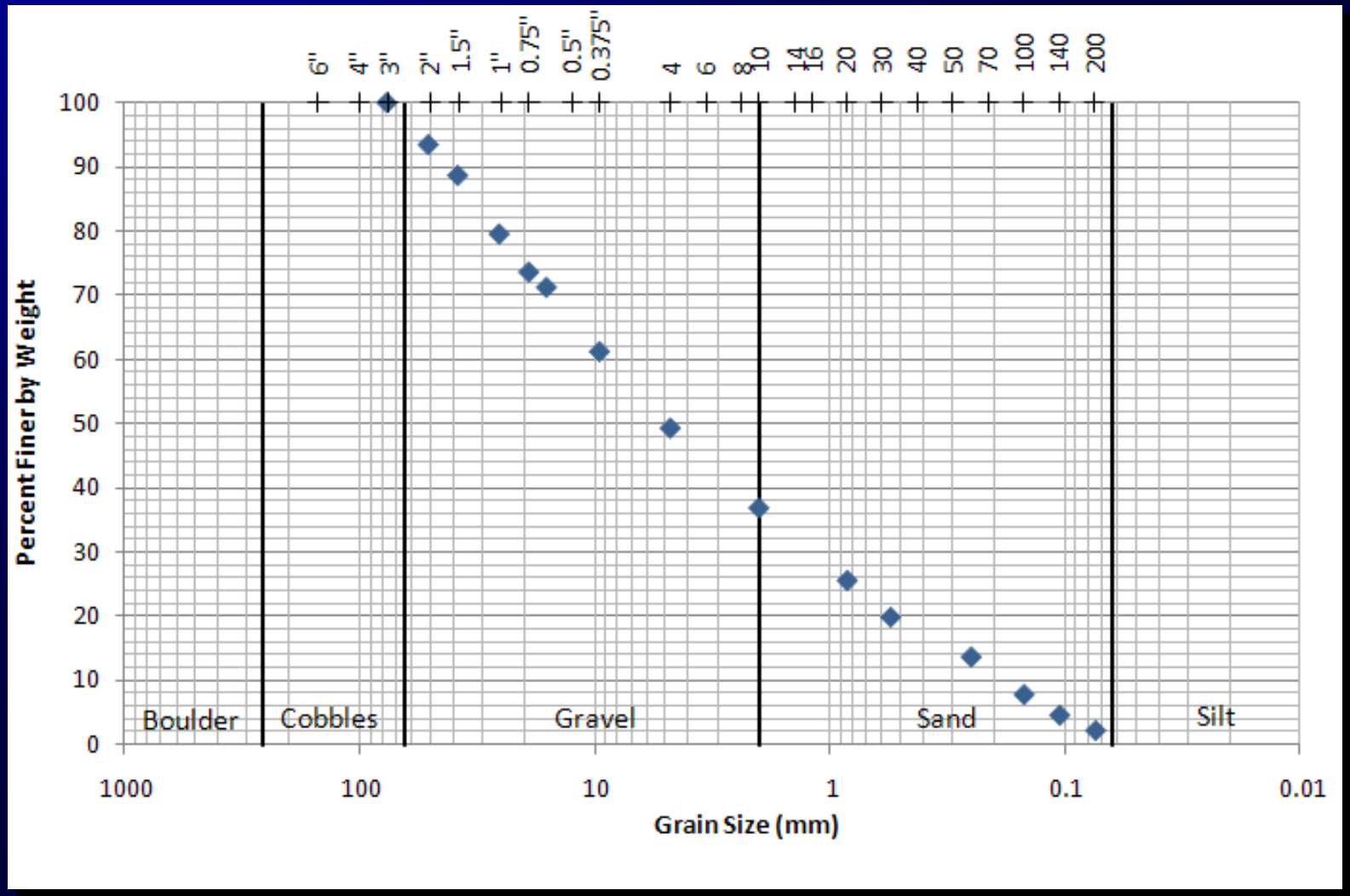
Nueces at Cotulla: Oxygen



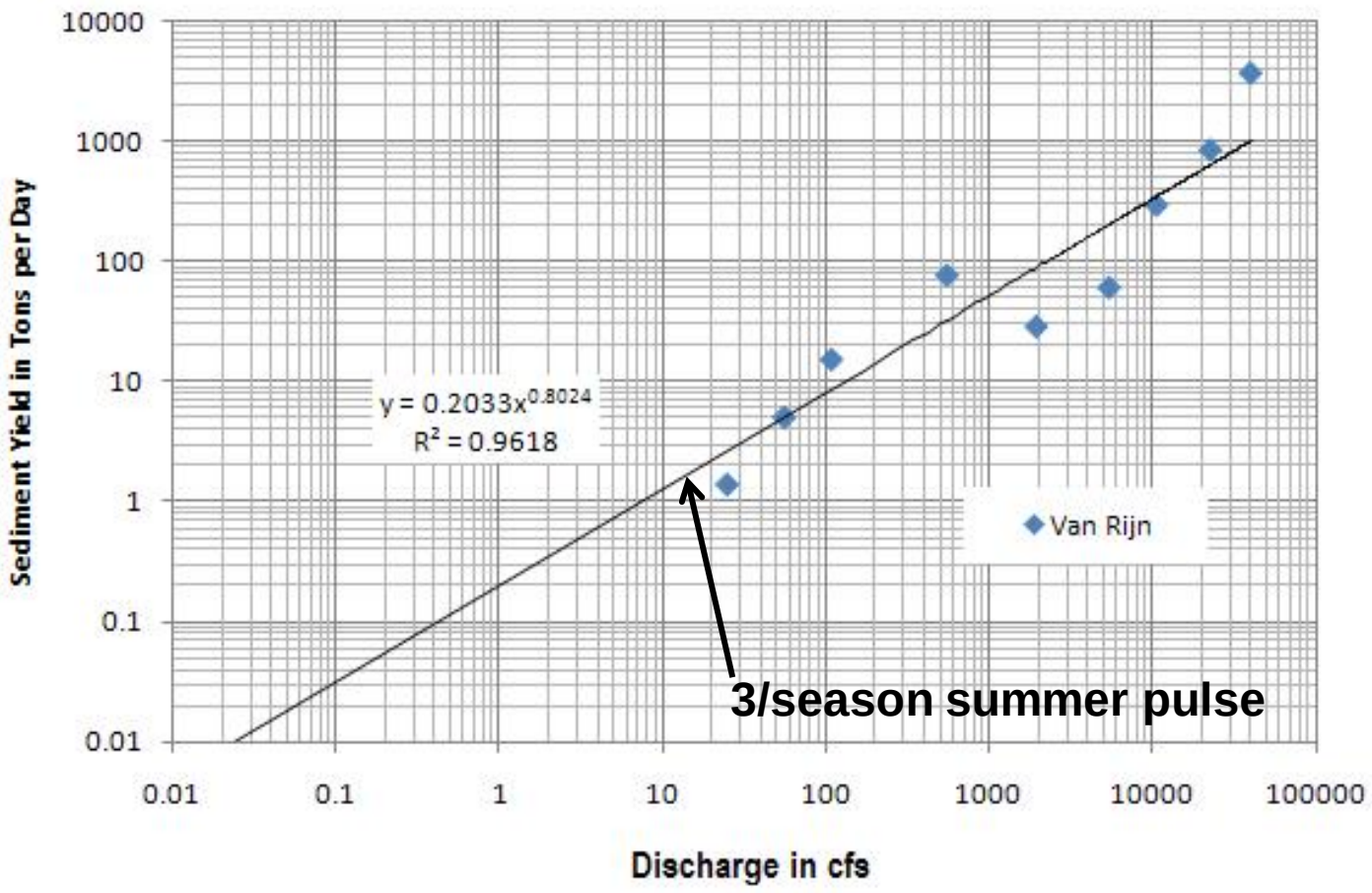
Frio at Derby: Oxygen



Geomorphology
Nueces at Cotulla: Sediment Size



Nueces at Cotulla: Sediment Movement



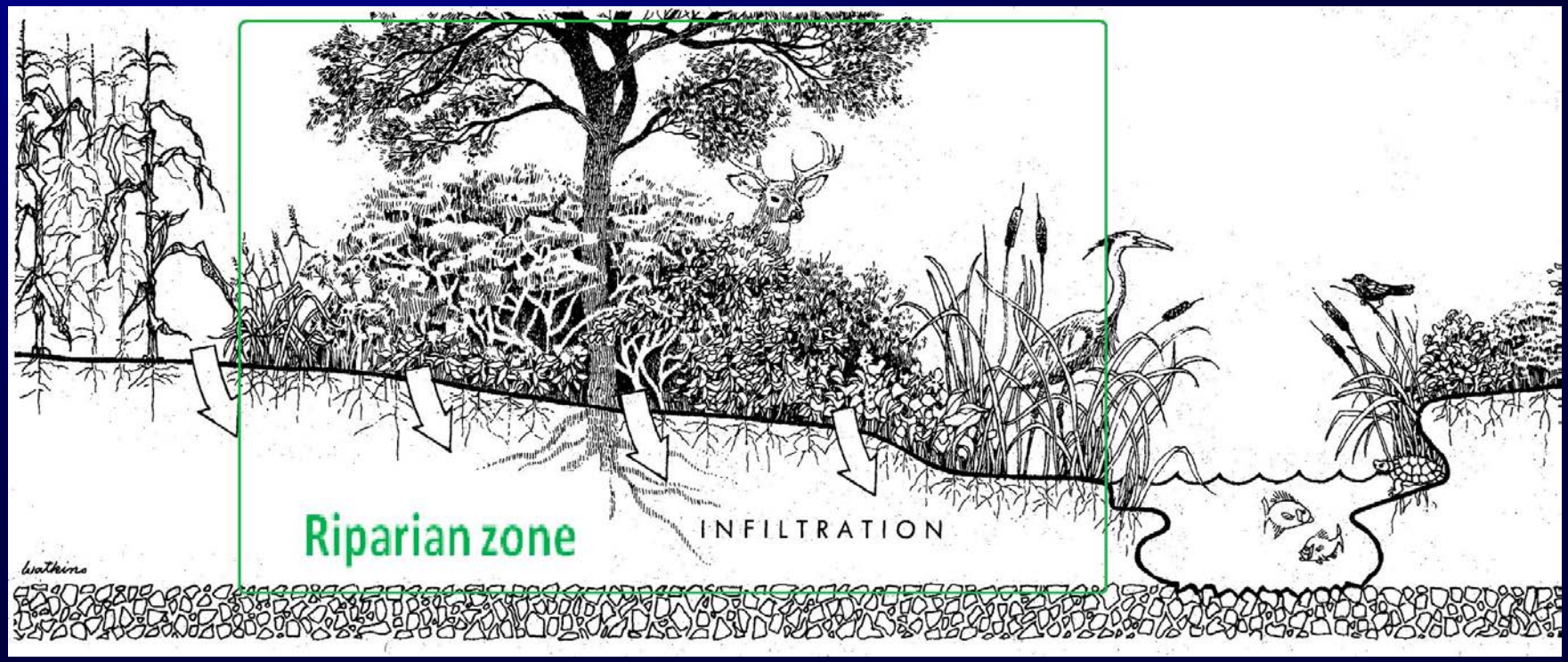
Sediment Movement:
Nueces at Cotulla: Period of Record Effect

	Average Annual Water (acre-feet)	Average Annual Sediment Moved (Tons)
1936 – 1996 (Baseline) (regulated flows)	**181,000 (100%)**	**4,050 (100%)**
1924 – 1969	194,000 (**108%**)	4,130 (**102%**)
1970 – 2009	172,000 (**95%**)	4,170 (**103%**)
1924 – 2009	184,000 (**102%**)	4,150 (**102%**)

Sediment Movement:
Nueces at Cotulla: Pulse Effect

	Average Annual Water (acre-feet)	Average Annual Sediment Moved (Tons)
1936 – 1996 (Baseline) (regulated flows)	**181,000 (100%)**	**4,050 (100%)**
Upper bounds - pulse volumes and durations	30,800 **(17%)**	1,660 **(41%)**
Central tendency - pulse volumes and durations	21,800 **(12%)**	1,230 **(30%)**
Seasonal pulses only	8,010 **(4%)**	640 **(16%)**

Riparian Zone



Riparian Zone: San Miguel Creek

Freshwater Inflow Analyses

1) Hydrology, Salinity, and Inflow Characterization Methodology (Section 4.1)
2) Salinity Gradient Methodology (Section 4.2)
3) Focal Species and Indicators of Estuarine Health (Section 4.3)
4) Drought Criteria Methodology (Section 4.4)
5) Freshwater Inflow Needs (Section 4.5)

Sound Ecological Environment

Sound Ecological Environment

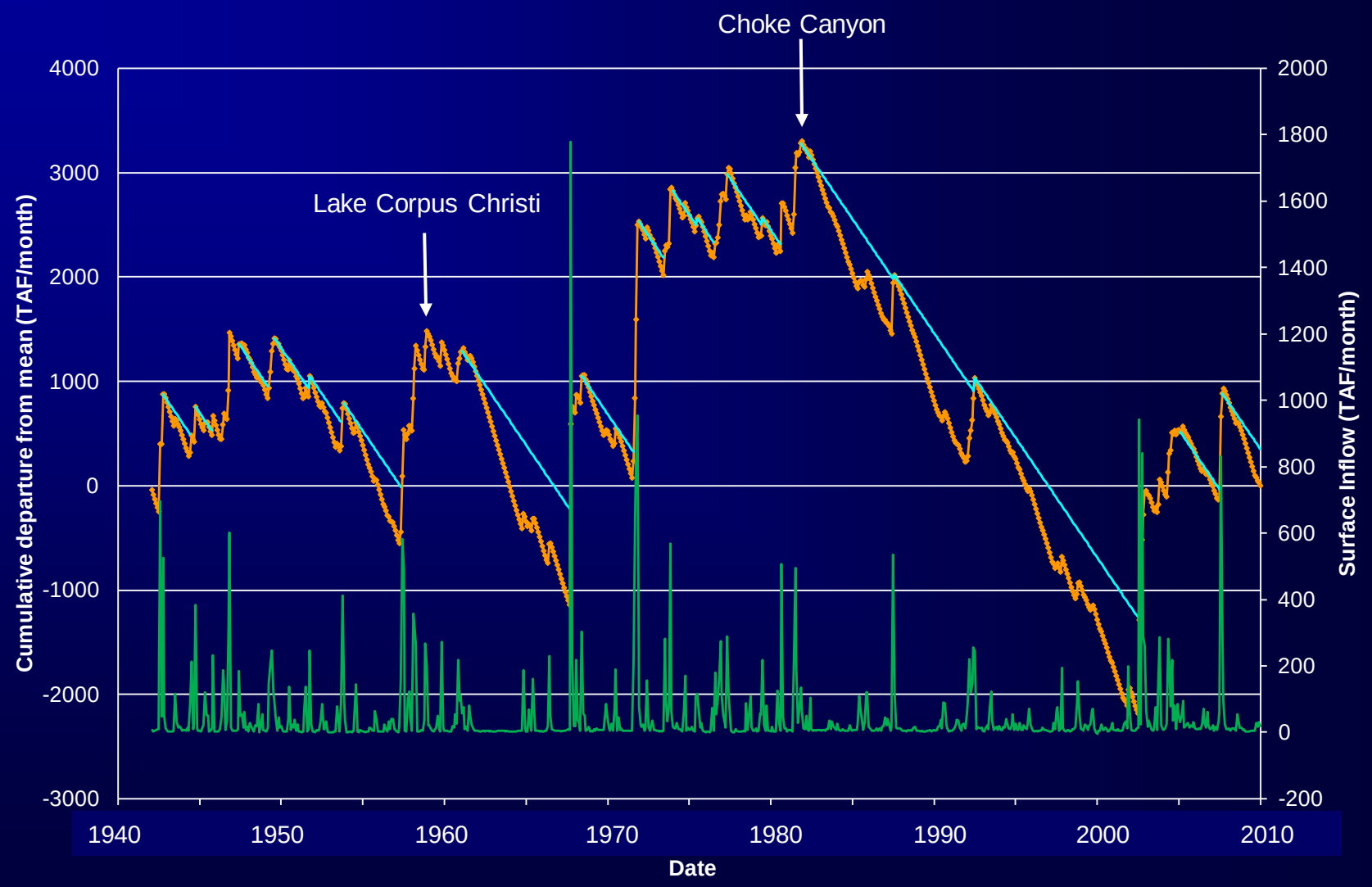
"A schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies."

According to SAC guidance (SAC 2009a), a sound ecological environment is one that:

- **sustains the full complement of native species in perpetuity,**
- **sustains key habitat features required by these species,**
- **retains key features of the natural flow regime required by these species to complete their life cycles, and**
- **sustains key ecosystem processes and services, such as elemental cycling and the productivity of important plant and animal populations.**

- 1.2M cu yd from Nueces Bay ’58 alone (probably an underestimate)
- 30’s oyster harvest ended → shell harvest → considered totally fished out (live and substrate) by 1967
- 300’ rule but dredgers took advantage of “live” reefs during drought years of ‘50 and 60 ‘s

Rangia cuneata


Choke Canyon
Lake Corpus Christi
Cumulative departure from mean (TAF/month)
Surface Inflow (TAF/month)
Date
4000
3000
2000
1000
0
-1000
-2000
-3000
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-200
1940
1950
1960
1970
1980
1990
2000
2010

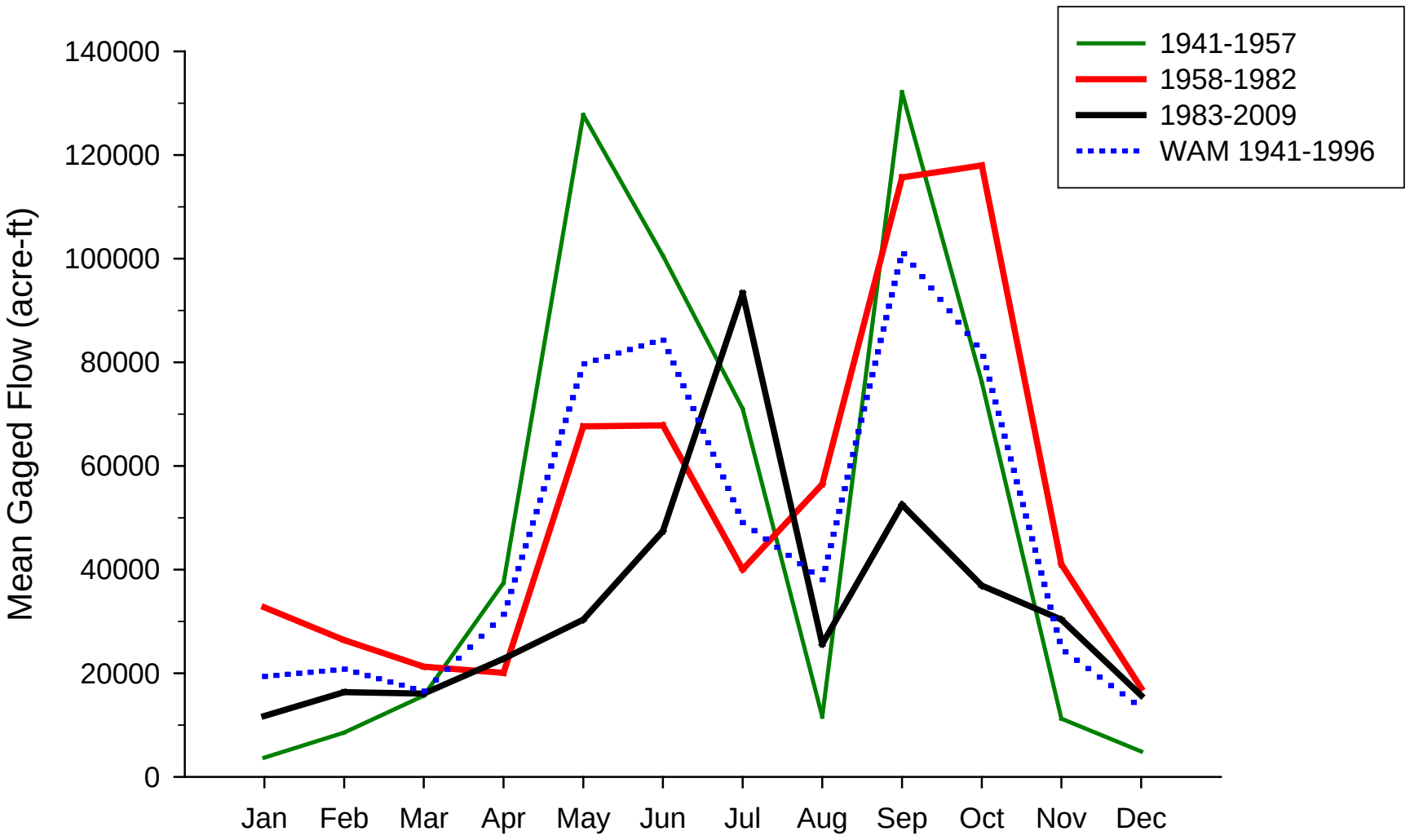

1941-1957
1958-1982
1983-2009
WAM 1941-1996
Mean Gaged Flow (acre-ft)
140000
120000
100000
80000
60000
40000
20000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Table 2-1: Summary of mean annual flow of the Nueces River into the Nueces Estuary (1940 to 1996)[1] and upper Nueces Delta (1940 to 1999)[2]. Time periods in both studies were based upon the construction dates of large reservoirs in the watershed.

Time Period	Mean annual river flow into Nueces Estuary (acre-ft)	Percent change from Period I	Mean annual river flow into upper Nueces Delta (acre-ft)	Percent change from Period I
1940-1957	619,000	—	127,997	—
1958-1982	614,000	-0.8%	77,989	-39.1%
1983-1996(9)	279,000	-54.9%	537	-99.6%

[1] Source: Asquith *et al.* 1997.
[2] Source: Irlbeck and Ward 2000.

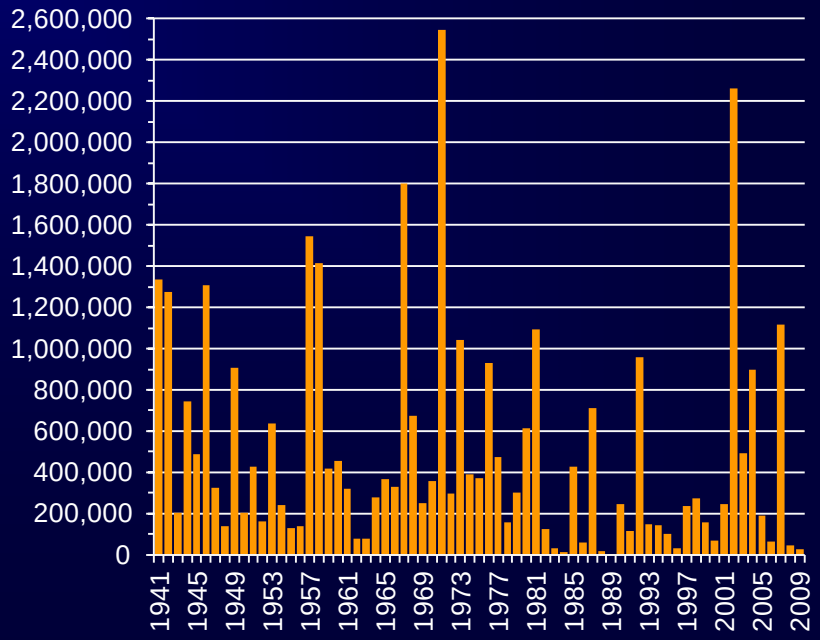
Note: 1 acre-ft = 1.2336 10^3 m^3

- **1958 – Lake Corpus Christi → 1 Overbanking per year**
- **1982 – Lake Choke Canyon → 1 Overbanking every 3 years**
- **Major modifications and channelization of river preventing overbanking**

Unsound because…

- **Loss/alteration of key habitat features and natural flow regimes required by indicator species**
- **Nutrient elemental cycling and sediment loading are compromised**
- **<u>KEY POINT</u>: A modification of flow regime is required to rebuild these species and processes to sound levels**

Freshwater Inflow Analyses



Steps:

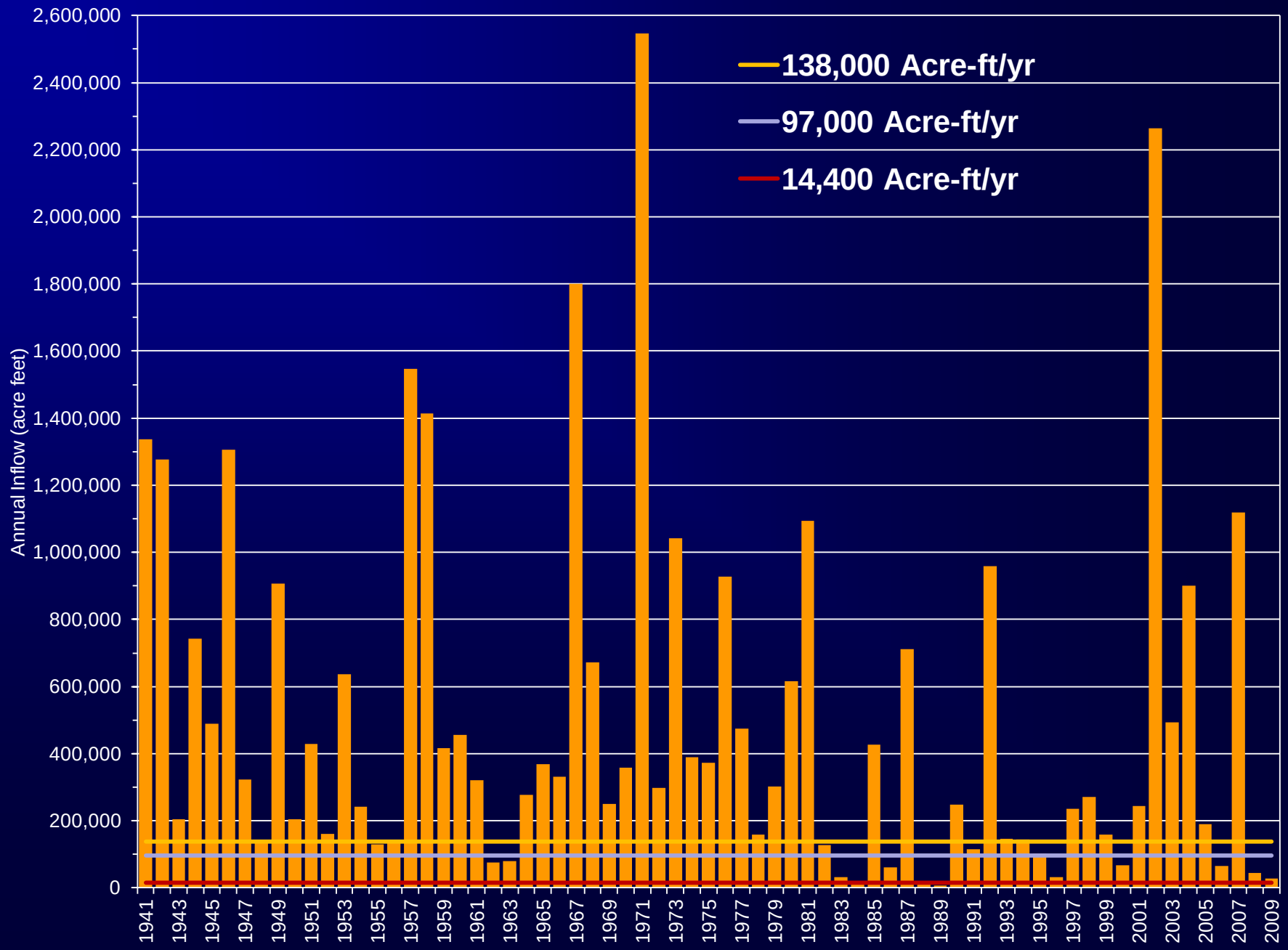
1. Characterize historical water availability patterns

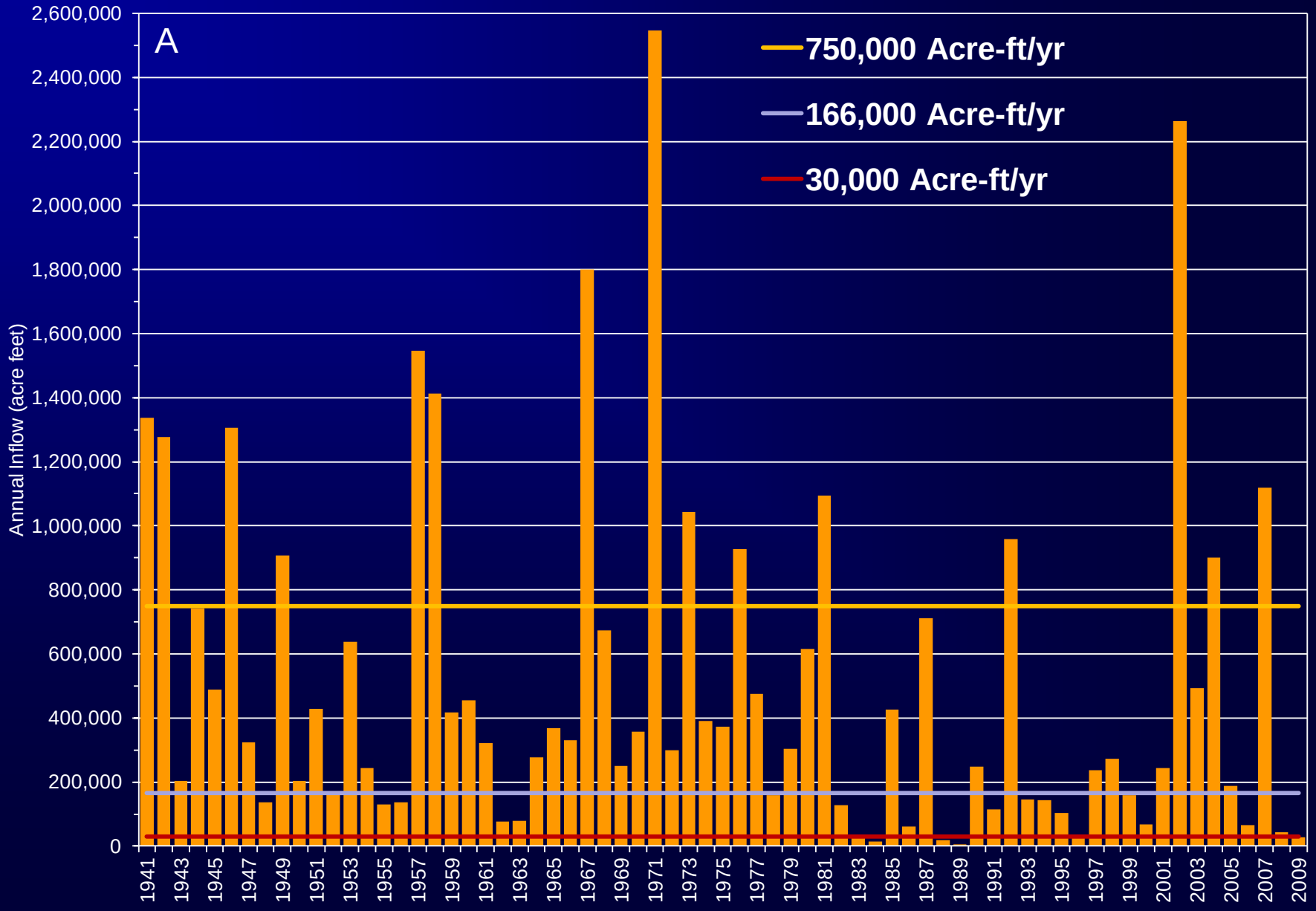
2. Examine flow and salinity relationships

3. Indentify focal species (Canaries)

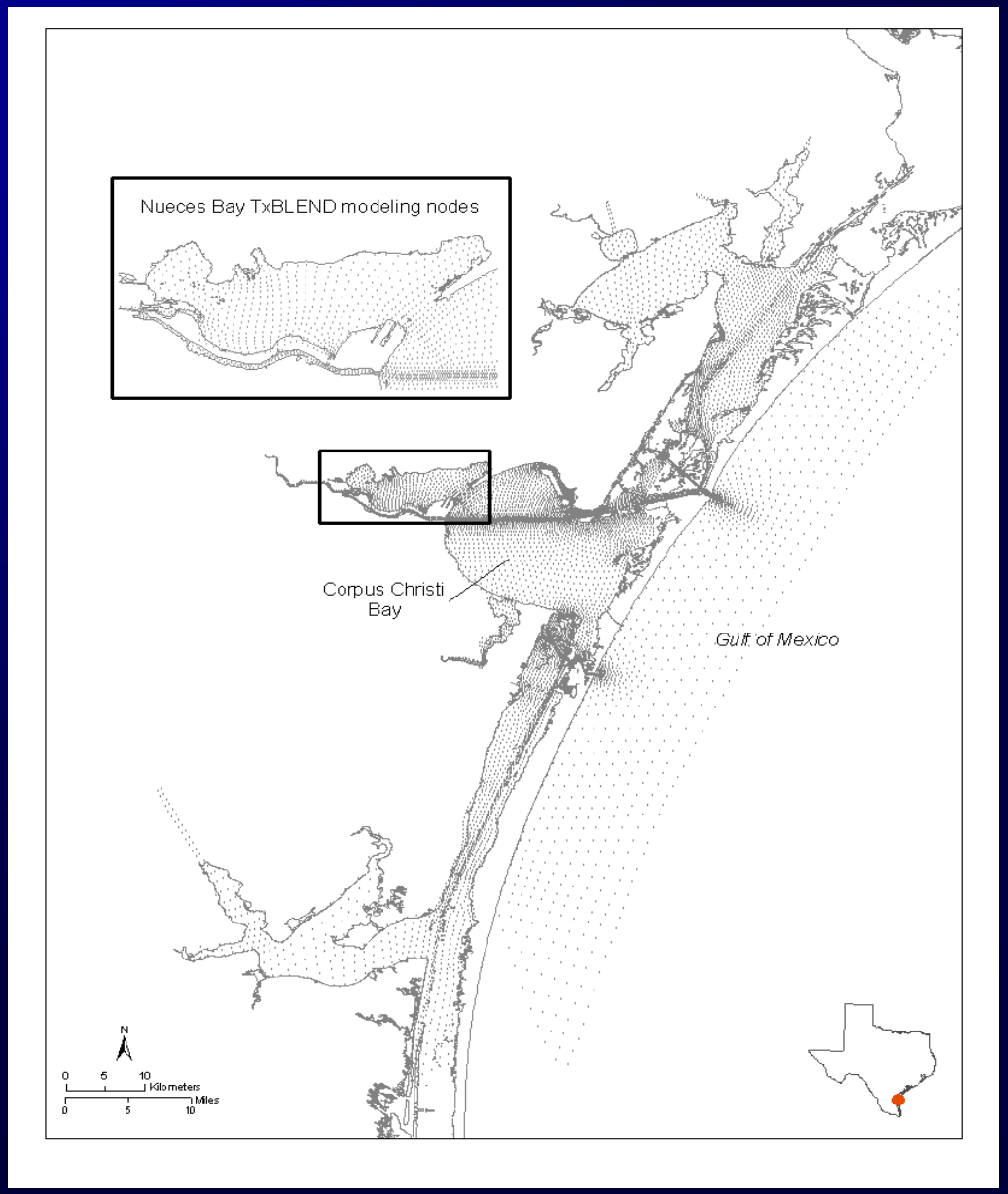
4. Recommend flow that will create a sound environment

Nueces Bay Inflow – Agreed Order

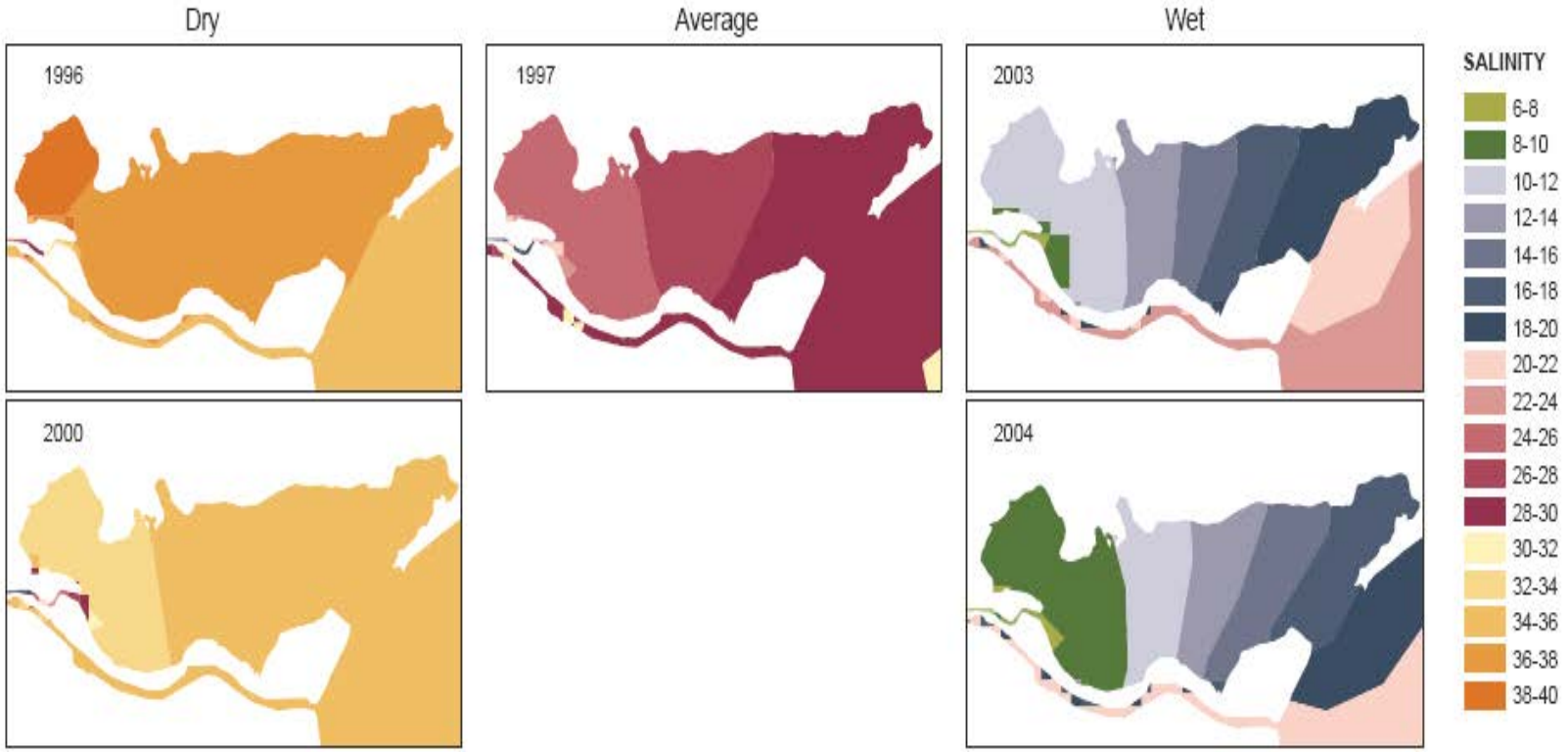


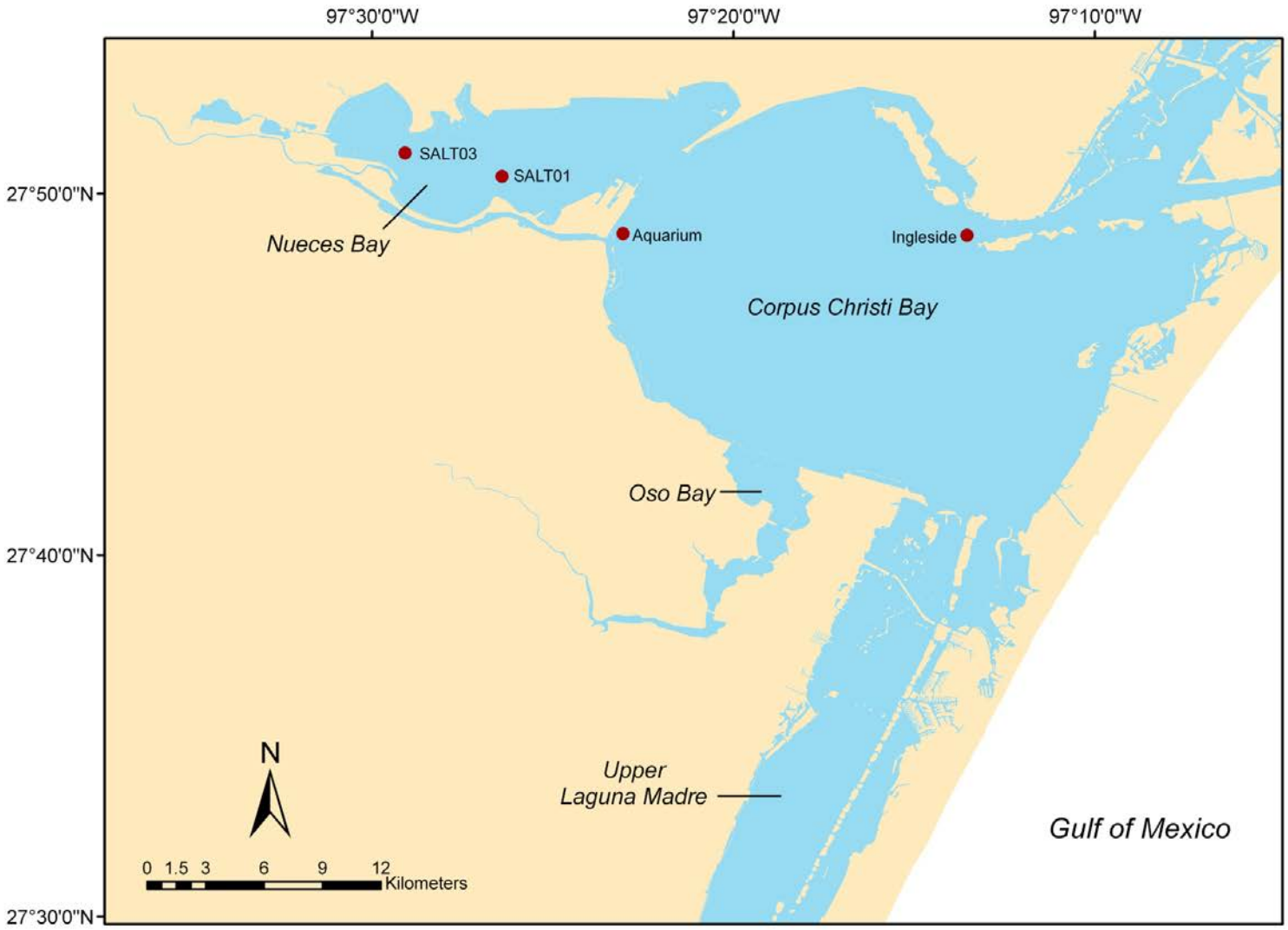

A
750,000 Acre-ft/yr
166,000 Acre-ft/yr
30,000 Acre-ft/yr
Annual Inflow (acre feet)
2,600,000
2,400,000
2,200,000
2,000,000
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1941
1943
1945
1947
1949
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009

How does the bay respond to inflow?



TxBLEND modeled salinity, August 2011 TWDB J. Matsumoto, GIS post processing TPWD L. Hamlin


Dry
Average
Wet
1996
1997
2003
2000
2004
SALINITY
6-8
8-10
10-12
12-14
14-16
16-18
18-20
20-22
22-24
24-26
26-28
28-30
30-32
32-34
34-36
36-38
38-40


97°30'0"W
97°20'0"W
97°10'0"W
27°50'0"N
27°40'0"N
27°30'0"N
SALT03
SALT01
Aquarium
Ingleside
Nueces Bay
Corpus Christi Bay
Oso Bay
Upper
Laguna Madre
Gulf of Mexico
N
0 1.5 3 6 9 12
Kilometers

Steps:

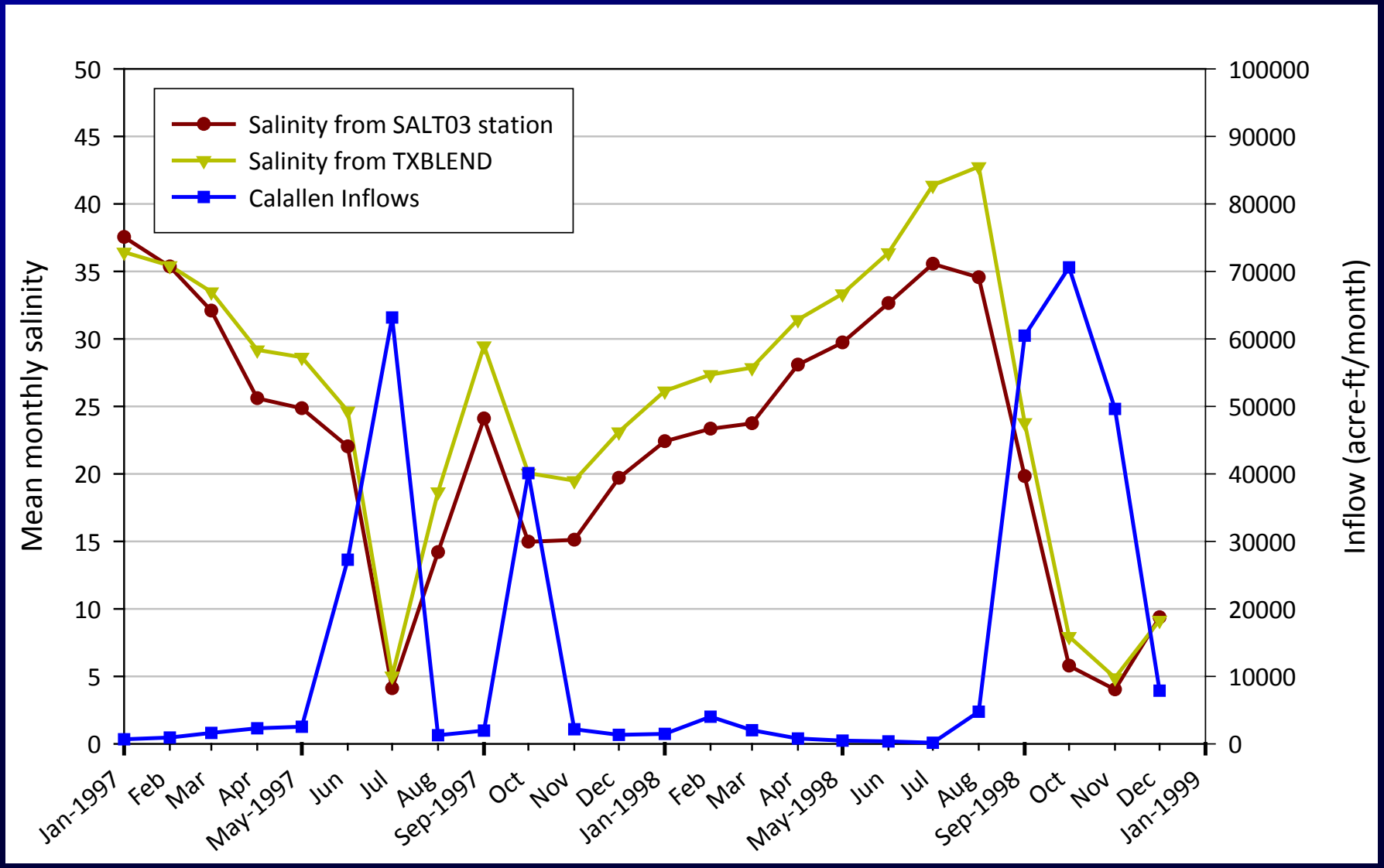
1. Characterize historical water availability patterns

2. <u>Examine flow and salinity relationships</u>

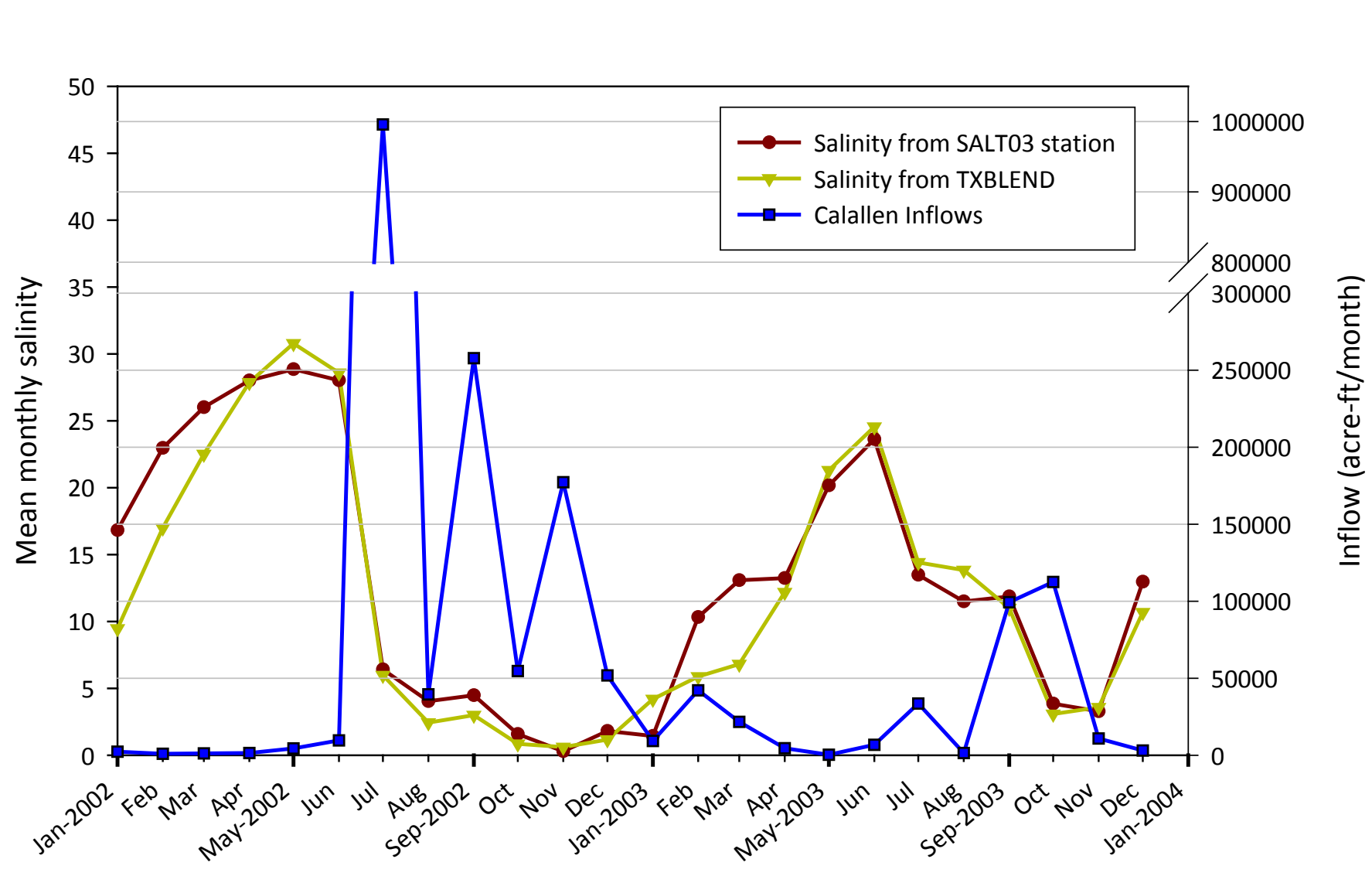
3. Indentify focal species (Canaries)

4. Recommend flow that will create a sound environment

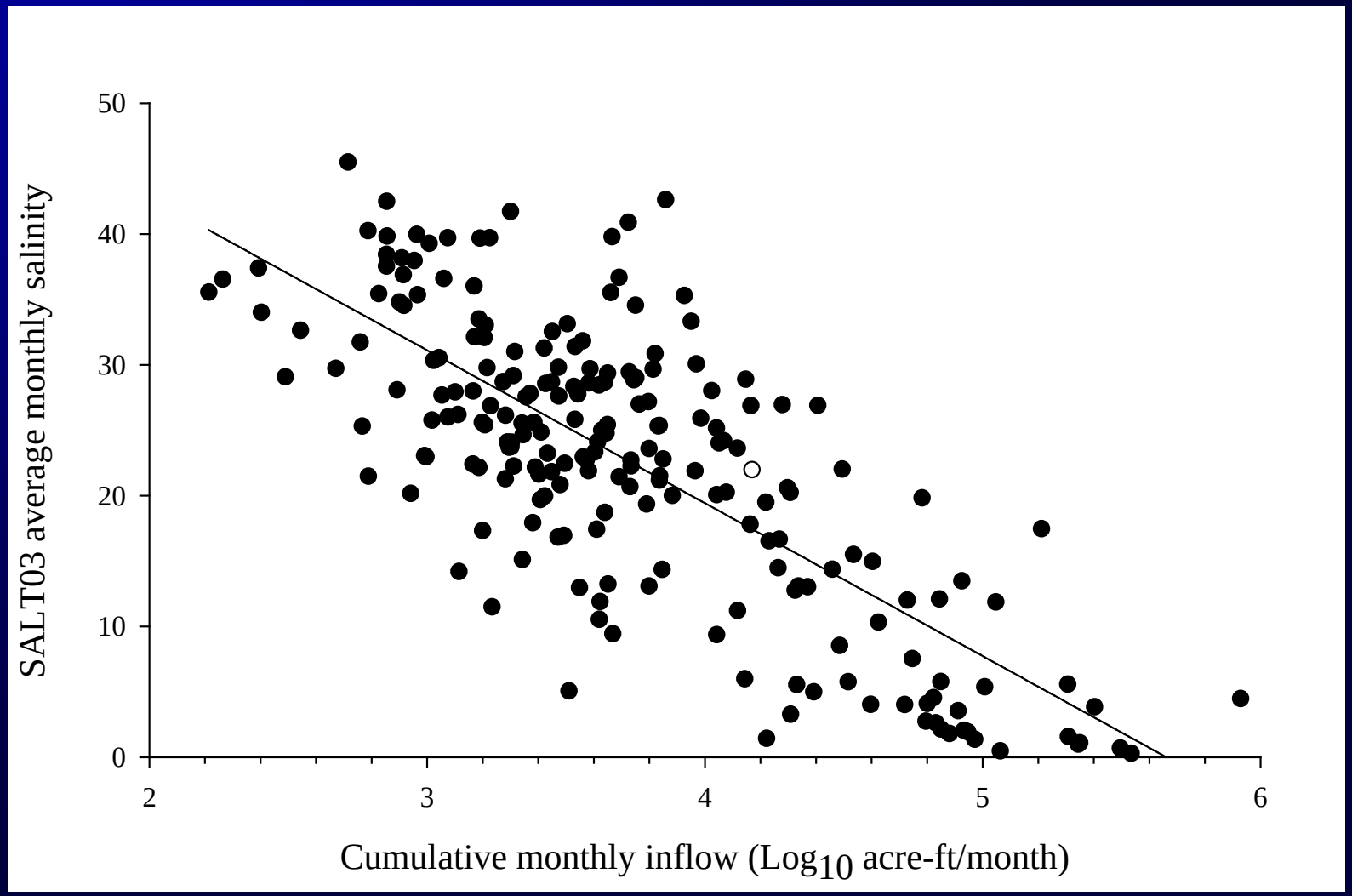
Average Years: 1997-1998



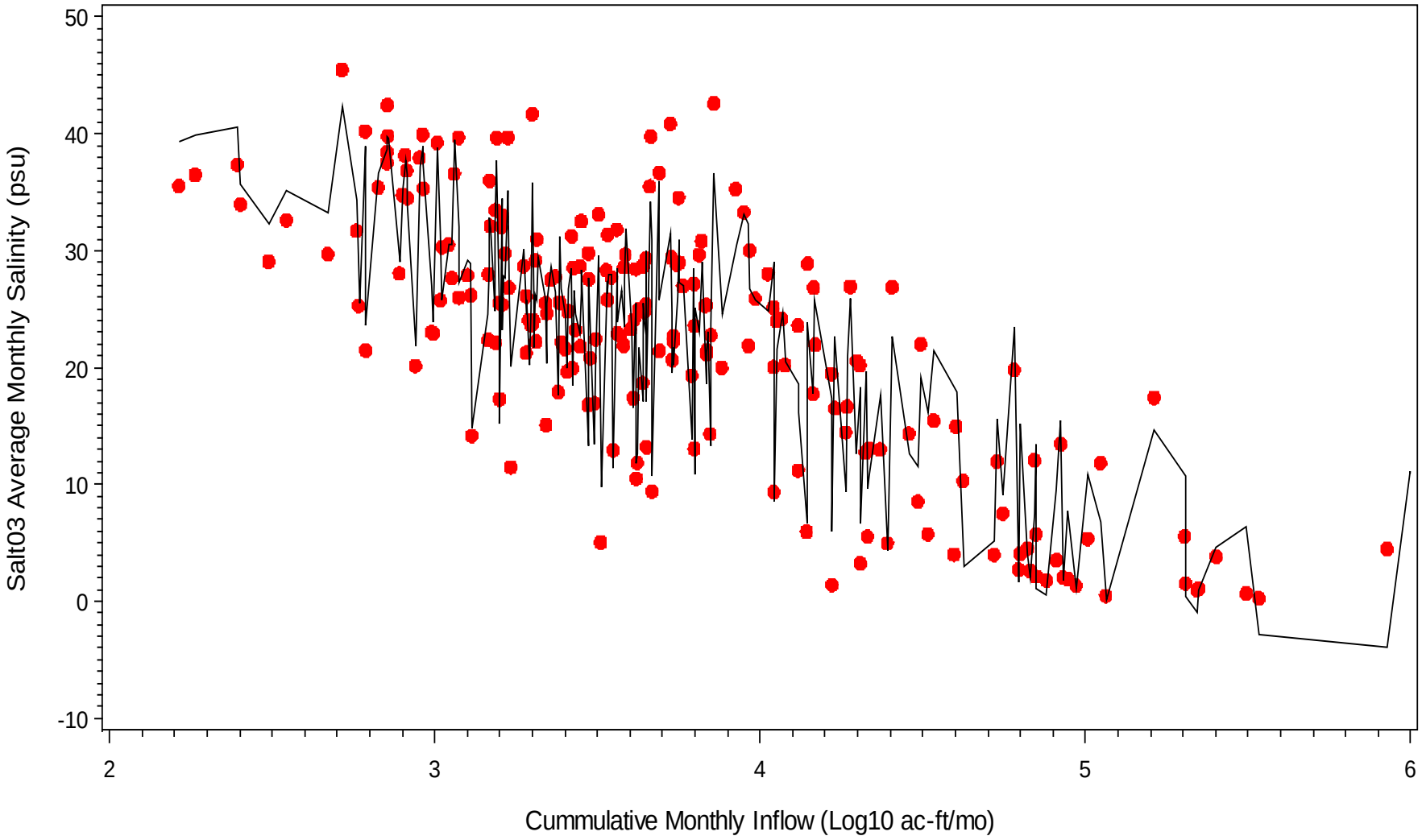
Wet Years: 2002-2003



A flow-salinity "key"…



Salinity = 66.183 – (11.690 x $\log_{10}$(inflow)); R^2 = 0.58.



Salinity = 32.85 - (6.648 * Log10(Inflow)) + 0.6480*PrevSal, R^2=0.90

Steps:

1. Characterize historical water availability patterns

2. Examine flow and salinity relationships

3. <u>Indentify focal species (Canaries)</u>

4. Recommend flow that will create a sound environment

Species

Spartina alterniflora

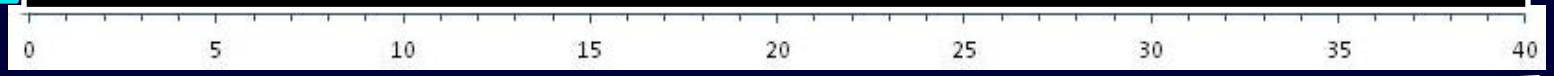
Benthic Infauna

Crassostrea virginica

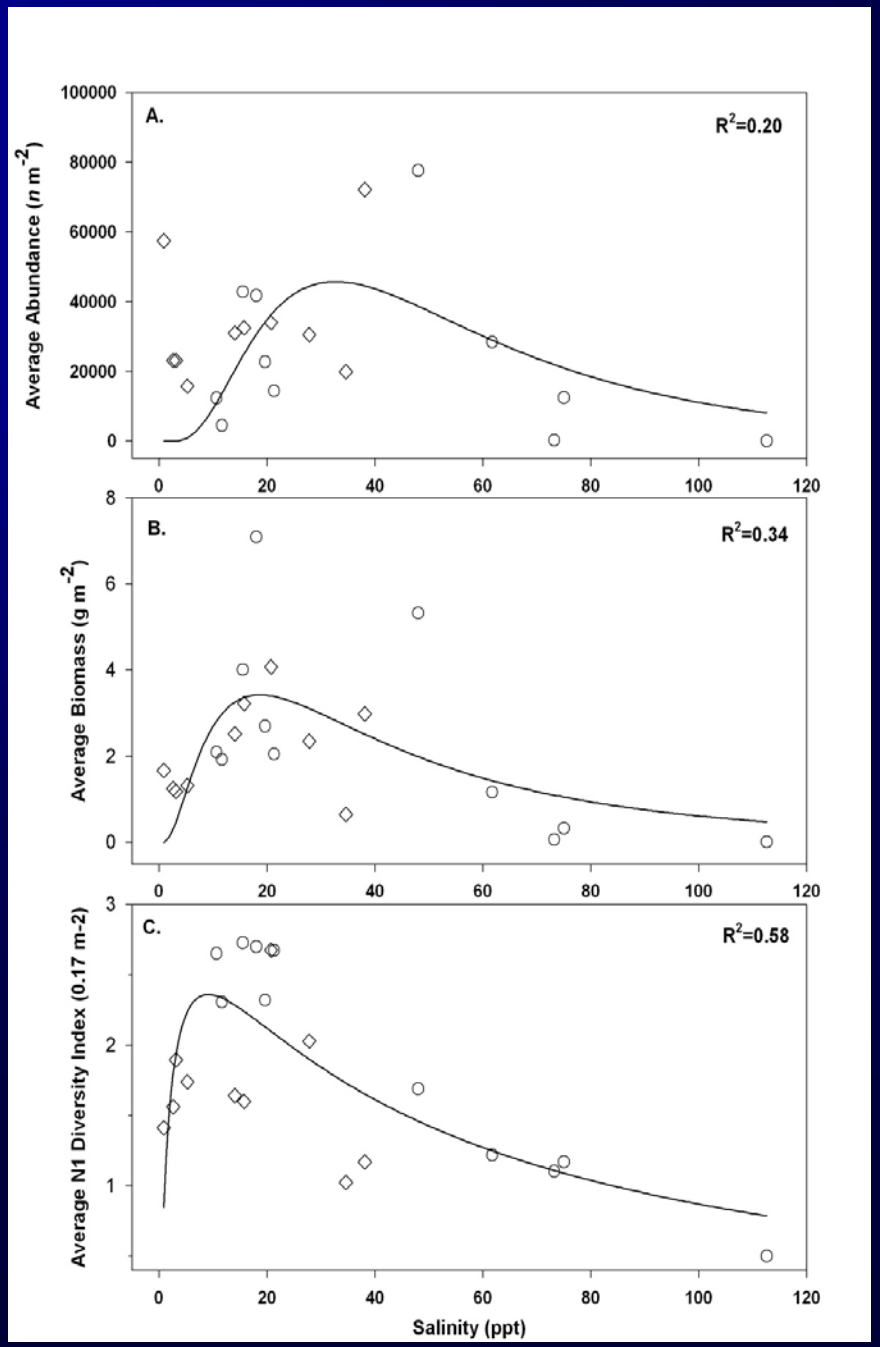
Callinectes sapidus

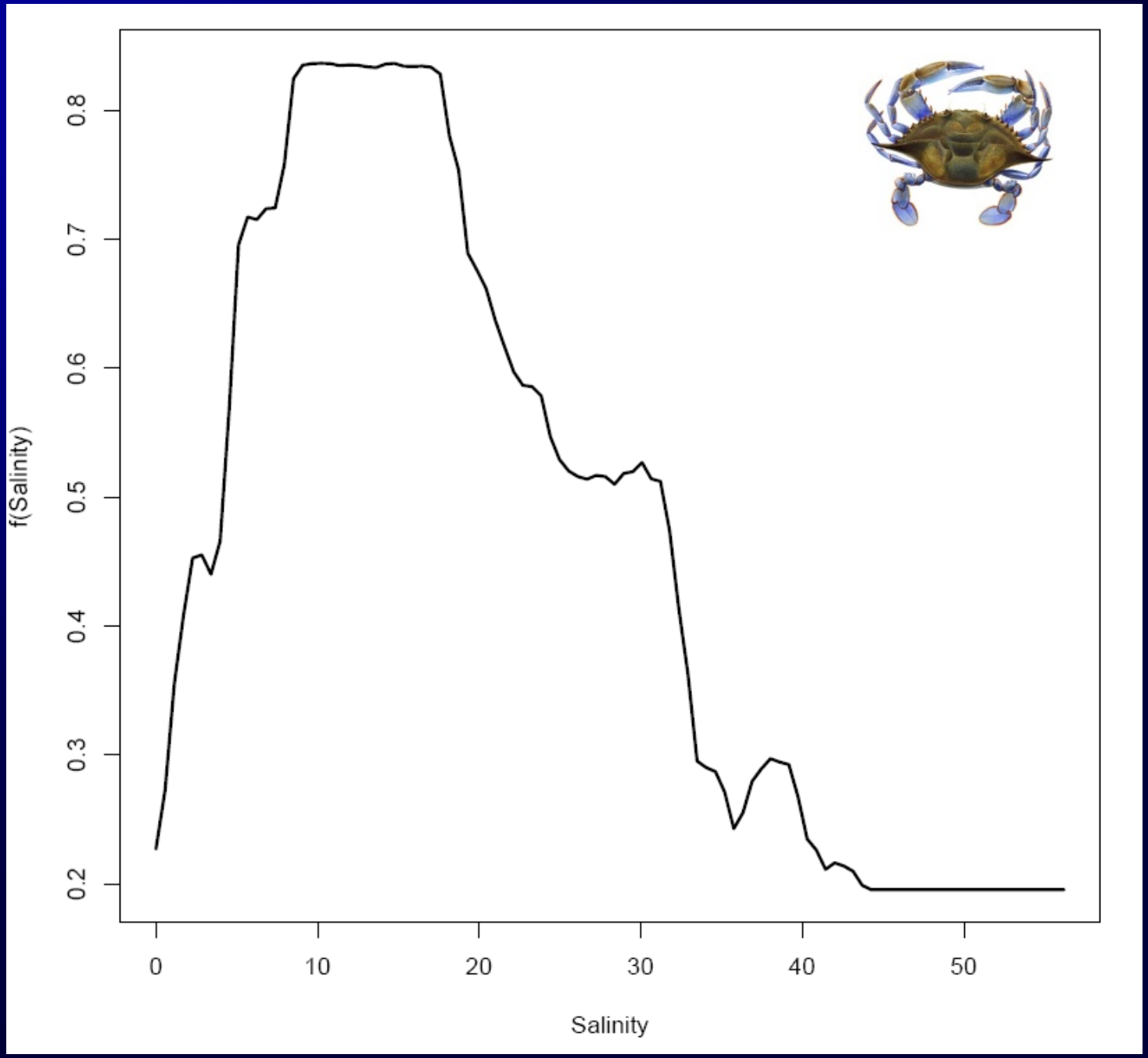
Micropogonias undulatus

Key Indicator Species



Salinity


A.
R^2=0.20
Average Abundance (n m^{-2})
100000
80000
60000
40000
20000
0
B.
R^2=0.34
Average Biomass (g m^{-2})
8
6
4
2
0
C.
R^2=0.58
Average N1 Diversity Index (0.17 m-2)
3
2
1
0
20
40
60
80
100
120
Salinity (ppt)


f(Salinity)
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
10
20
30
40
50
Salinity

Indicator Species Profiles

Species

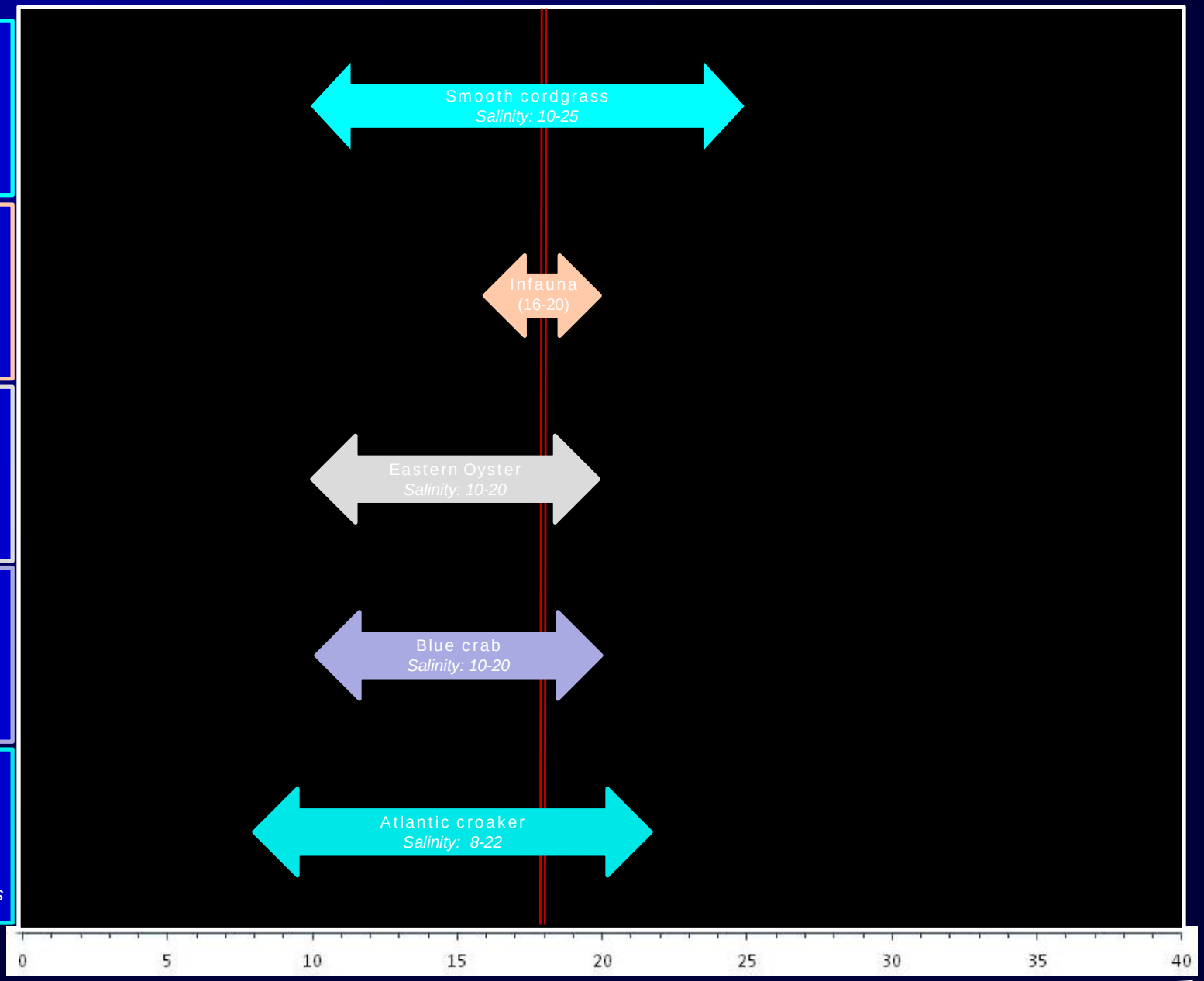
Spartina alterniflora

Benthic Infauna

Crassostrea virginica

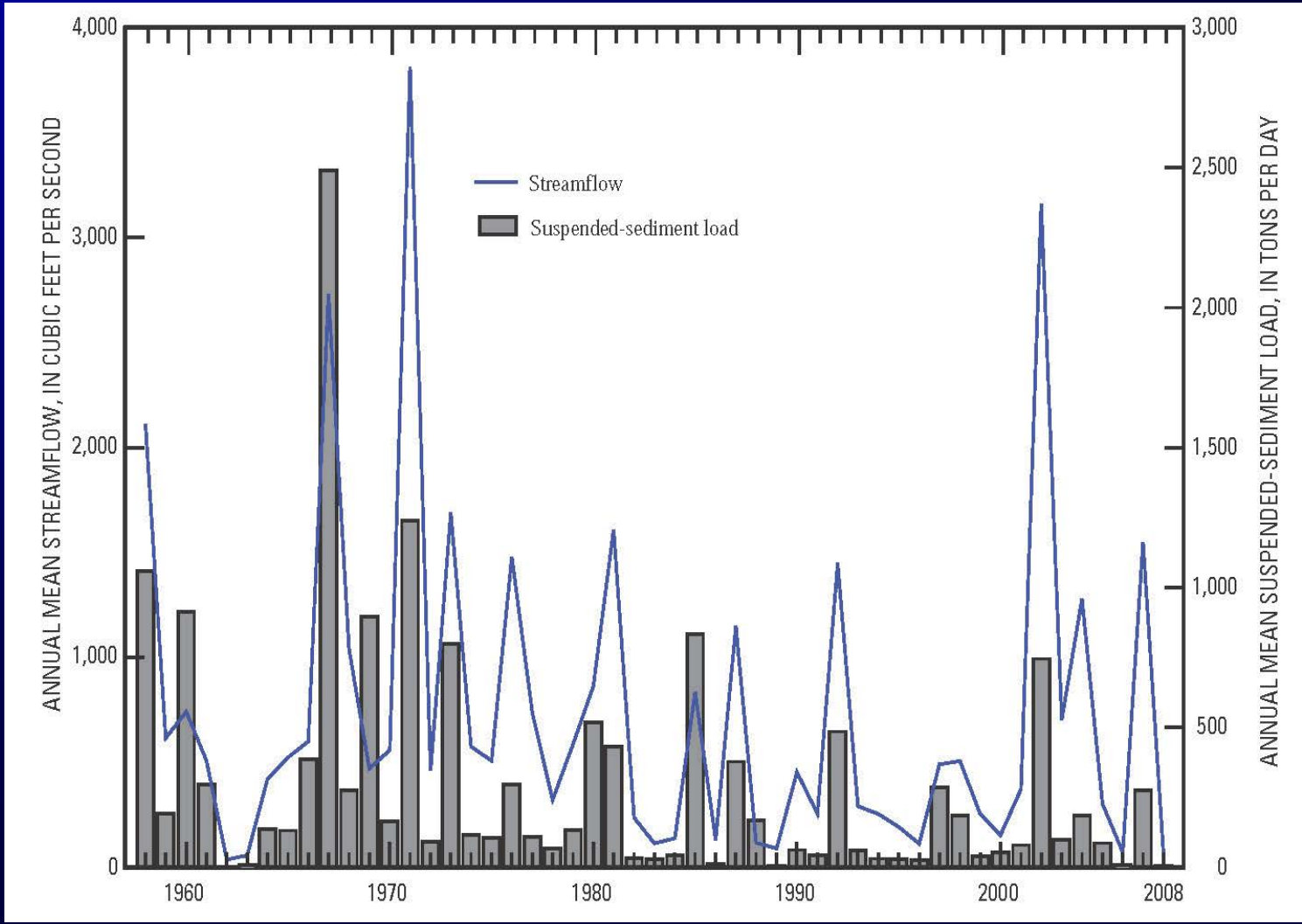
Callinectes sapidus

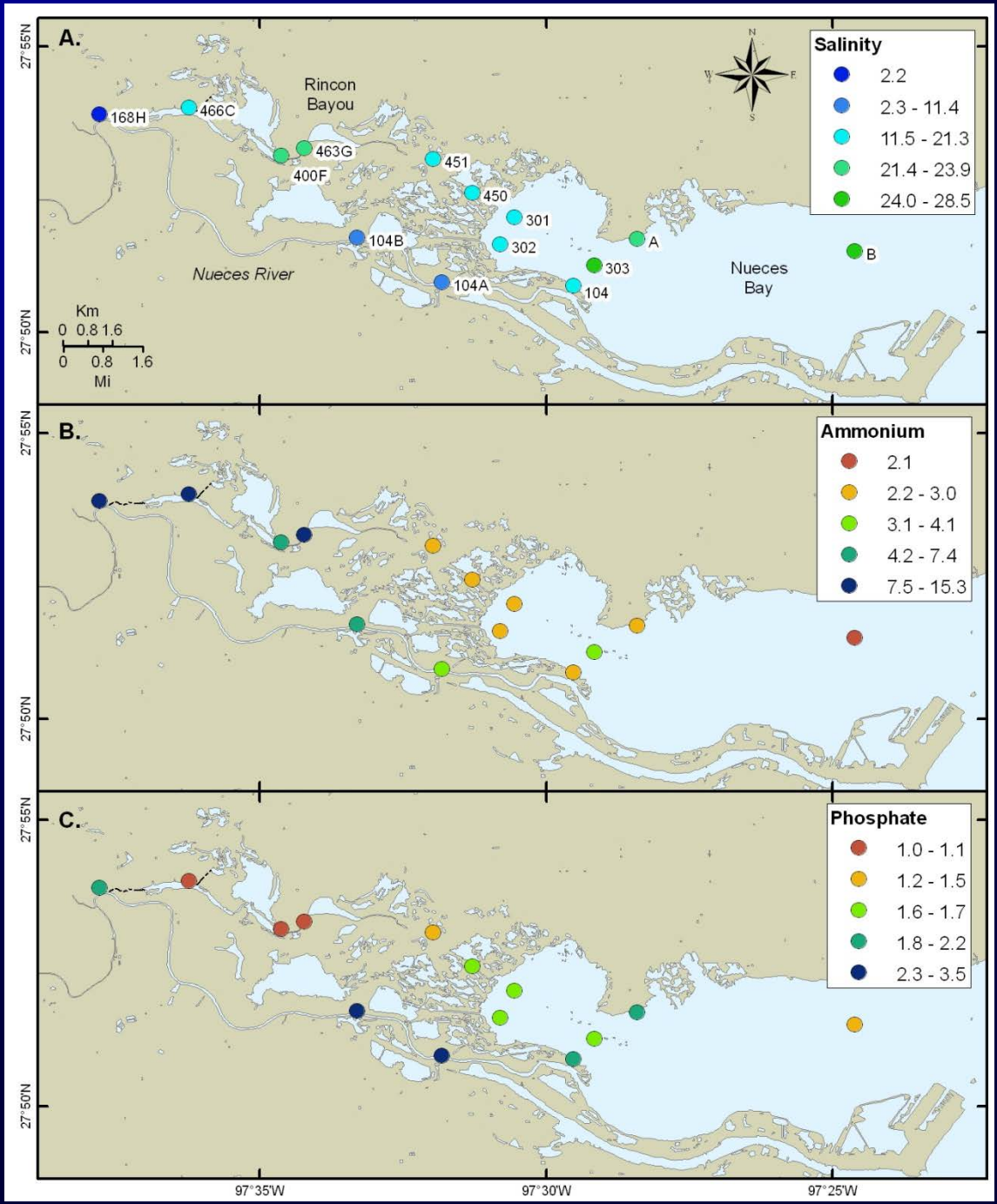
Micropogonias undulatus



Salinity

Sediment and Nutrient Considerations




A.
Salinity
2.2
2.3 - 11.4
11.5 - 21.3
21.4 - 23.9
24.0 - 28.5
Rincon Bayou
168H
466C
463G
400F
451
450
301
302
303
104
104A
104B
A
B
Nueces River
Nueces Bay
Km
0 0.8 1.6
0 0.8 1.6
Mi
B.
Ammonium
2.1
2.2 - 3.0
3.1 - 4.1
4.2 - 7.4
7.5 - 15.3
C.
Phosphate
1.0 - 1.1
1.2 - 1.5
1.6 - 1.7
1.8 - 2.2
2.3 - 3.5
27°55'N
27°50'N
97°35'W
97°30'W
97°25'W

Steps:

1. Characterize historical water availability patterns

2. Examine flow and salinity relationships

3. Indentify focal species (Canaries)

4. <u>Recommend flow that will create a sound environment</u>

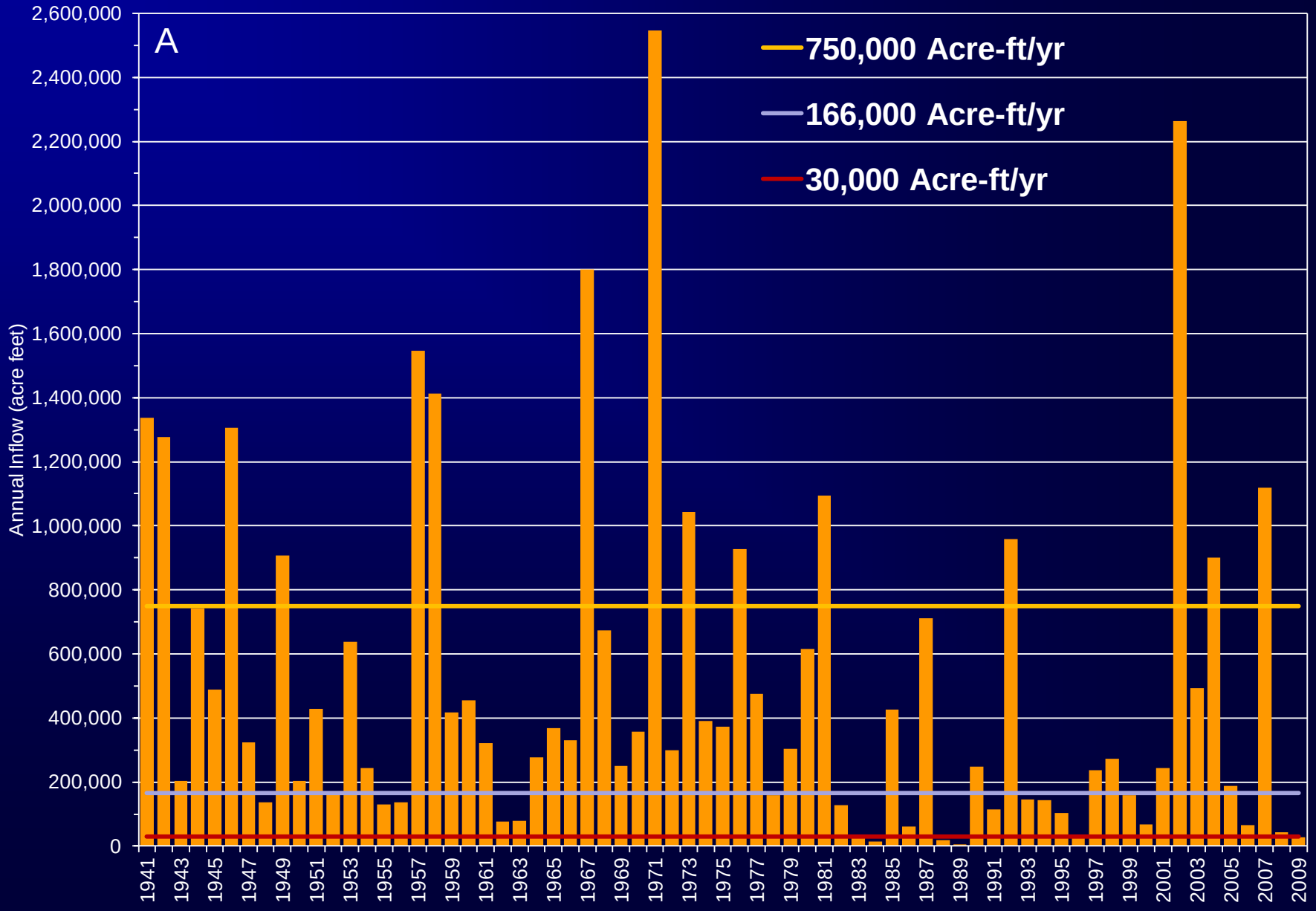
Condition (Target Salinity)	Nueces Bay Freshwater Inflow Regime (Attainment)			Recommendations		Historical Attainment		
	1 overbanking event per year of 39,000 acre-ft; maximum discharge of 3600 cfs			Annual Total	Attainment	1941-2009	1941-1982	1983-2009
High (10)	125,000 Acre-ft (20%)	250,000 Acre-ft (25%)	375,000 Acre-ft (20%)	750,000	25%	22%	26%	15%
Base (18)	22,000 Acre-ft (60%)	88,000 Acre-ft (60%)	56,000 Acre-ft (75%)	166,000	80%	67%	81%	44%
Subsistence (34)	5,000 Acre-ft (95%)	10,000 Acre-ft (95%)	15,000 Acre-ft (95%)	30,000	95%	94%	100%	85%
	Nov Dec Jan Feb	Mar Apr May Jun	Jul Aug Sep Oct					
	Winter	Spring	Summer Fall					

	Nueces River Flow (Acre-ft)			
Nueces Delta Porewater Target Salinity	22,000 (244/day)	88,000 (978/day)	38,000 (422/day)	18,000 (200/day)
25	**Winter**	**Spring**	**Summer**	**Fall**

- We set target salinities based on indicator species' salinity requirements for base condition. We then used TxBLEND model outputs to generate target salinities that correspond with high and subsistence conditions.
- We used the below regression from Nueces Bay inflow and SALT03 station to calculate freshwater inflow that would generate target salinities. However, based on marsh plant salinity requirements in the delta there needs to be an annual inflow of 166,000 acre-ft. Therefore, the bay-calculated inflow of 160,000 acre-ft was increased by an additional 6,000 acre-ft to meet base conditions for marsh plants. We also examined historical inflow regimes and determined what the inflow was 95% of the time during the full period of record (1941-2009). We used that inflow as the basis for the annual recommendation for subsistence conditions.

$$\text{Salinity} = 66.183 - (11.690 \times \text{Log}_{10}(\text{Inflow}))$$

- The allocation for seasonal inflow requirements were based on meeting the biological needs of all indicator species, while accounting for historical patterns of water availability.
- Attainment recommendations were based on historical inflow patterns and how often these conditions were met taking into consideration flow regime changes pre- and post-dam flows.


A
750,000 Acre-ft/yr
166,000 Acre-ft/yr
30,000 Acre-ft/yr
Annual Inflow (acre feet)
2,600,000
2,400,000
2,200,000
2,000,000
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1941
1943
1945
1947
1949
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009

Example Application of Environmental Flow Regime Recommendations

1) **Run-of-River Diversion (up to 400 cfs) from the Nueces River near Laguna with and Off-Channel Storage Reservoir (44,000 acft).**
2) **This is a theoretical project for illustrative purposes only. No such project is recommended in any current regional or state water plan.**

Instream Flow Regime Recommendation

Overbank Events	Qp: 15,600 cfs with Average Frequency 1 per 5 years Regressed Volume is 124,000 Duration Bound is 107			
High Flow Pulses	Qp: 4,750 cfs with Average Frequency 1 per 2 years Regressed Volume is 38,600 Duration Bound is 64			
	Qp: 2,220 cfs with Average Frequency 1 per year Regressed Volume is 18,400 Duration Bound is 46			
	Qp: 590 cfs with Average Frequency 2 per year Volume Bound is 11,300 Duration Bound is 26			
	Qp: 48 cfs with Average Frequency 1 per season Volume Bound is 1,000 Duration Bound is 7	Qp: 390 cfs with Average Frequency 1 per season Volume Bound is 6,070 Duration Bound is 17	Qp: 170 cfs with Average Frequency 1 per season Volume Bound is 3,100 Duration Bound is 14	Qp: 50 cfs with Average Frequency 1 per season Volume Bound is 800 Duration Bound is 5
		Qp: 99 cfs with Average Frequency 2 per season Volume Bound is 1,560 Duration Bound is 9		
Base Flows (cfs)	92		76	92
	65		48	65
	51	44	32	41
Subsistence Flows (cfs)	14	18	16	14
	Dec, Jan, Feb, Mar	Apr, May, Jun	Jul, Aug, Sep	Oct, Nov
	Winter	Spring	Summer	Fall

Wet

Avg

Dry

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Pulse volumes are in units of acre-feet and durations are in days.
Period of Record used : 1/1/1924 to 12/31/2009.

Nueces River @ Laguna (NRL)

Hydrologic Conditions

1) Use cumulative streamflow volumes for the preceding 12 months to define hydrologic conditions for the following season. Set trigger volumes such that Dry, Average, and Wet conditions will apply 25%, 50%, and 25% of the time, respectively.
2) Subsistence hydrologic conditions are a sub-category of Dry hydrologic conditions with trigger volumes set such that Subsistence conditions apply 10% of the time.
3) Hydrologic conditions apply to base flows and determine when passage of only Subsistence flows may be allowable.

Instream Flow Regime Recommendation Application Example

Flow Regime → **Permit Conditions**

<u>Nomenclature</u>

Q = Inflow (varies daily)

S = Subsistence Flow (varies w/ season)

B = Base Flow (varies w/ season & hydrologic condition)

P_i = Pulse Flow (varies w/ season & applicable tier)*

* Up to six tiers of pulses (2/season, 1/season, 2/year, 1/year, 1/2–years, and/or 1/5–years) are potentially applicable at Laguna in a season. Up to eight tiers (4/season, 3/season, and those listed above) are potentially applicable at some other sites.

Subsistence Hydrologic Condition Base Flow Application Example

Situation

a) $Q < S$

b) $B > Q > S$

c) $P_i > Q > B$

d) $Q > P_i$

Inflow Pass-Through

a) Q (inflow)

b) S (subsistence flow)

c) B (base flow)

d) Min (P_i or Q) until volume or duration has passed

Dry Hydrologic Condition
Base Flow Application Example

Situation

a) $Q < S$

b) $B > Q > S$

c) $P_i > Q > B$

d) $Q > P_i$

Inflow Pass-Through

a) Q (inflow)

b) Q (inflow)

c) B (base flow)

d) Min (P_i or Q) until volume or duration has passed

Average or Wet Hydrologic Conditions Base Flow Application Example

Situation

a) $Q < B$

b) $P_i > Q > B$

c) $Q > P_i$

Inflow Pass-Through

a) Q

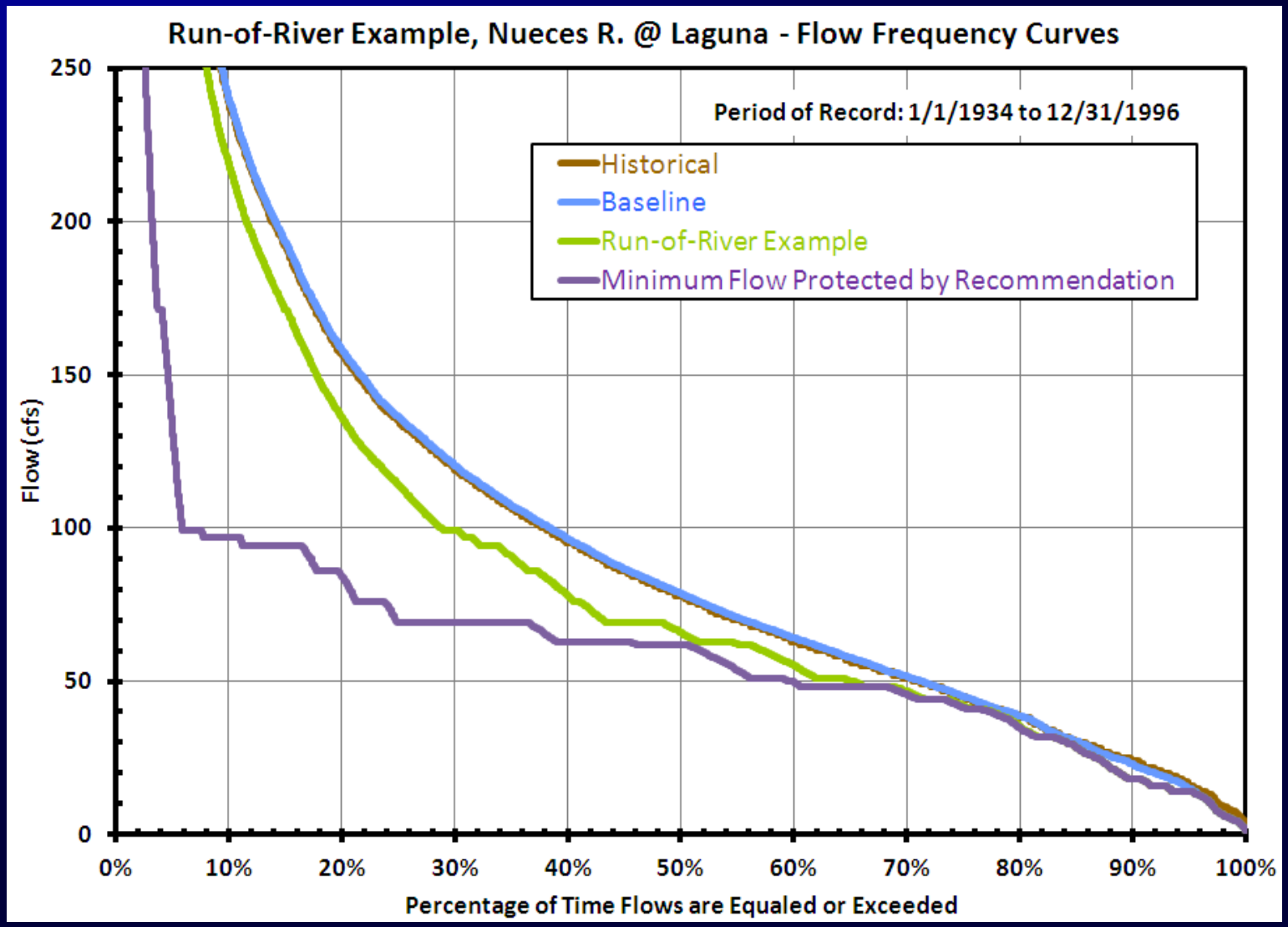
b) B

c) Min (P_i or Q) until volume or duration pass

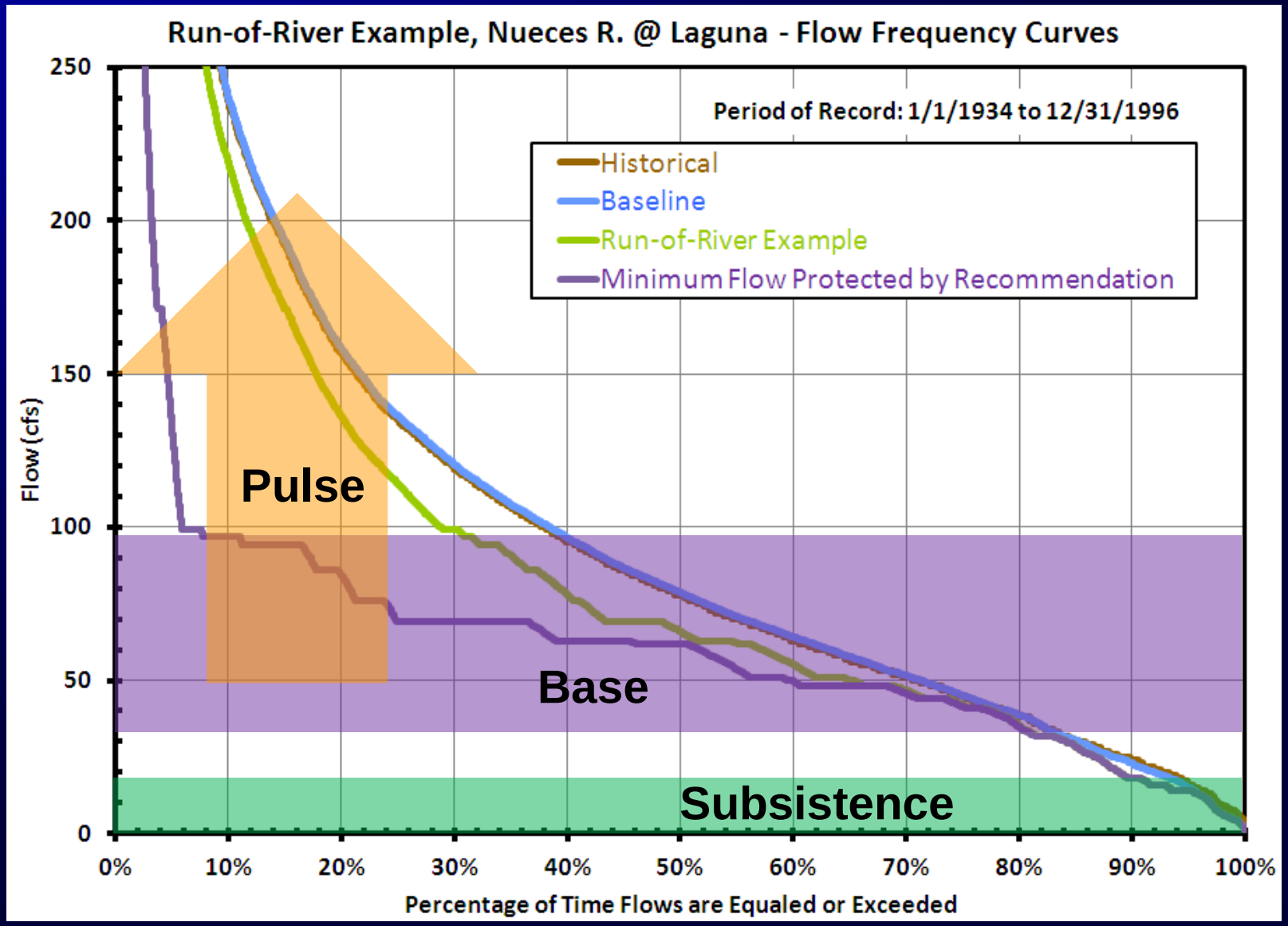
The Flow Regime Application Tool (FRAT) May be Used to Perform Example Applications of Potential Instream Flow Regime Recommendations

The BBEST Considers Resulting Flows to Assess Adequacy to Support a Sound Ecological Environment

Example Application of Instream Flow Regime Recommendations

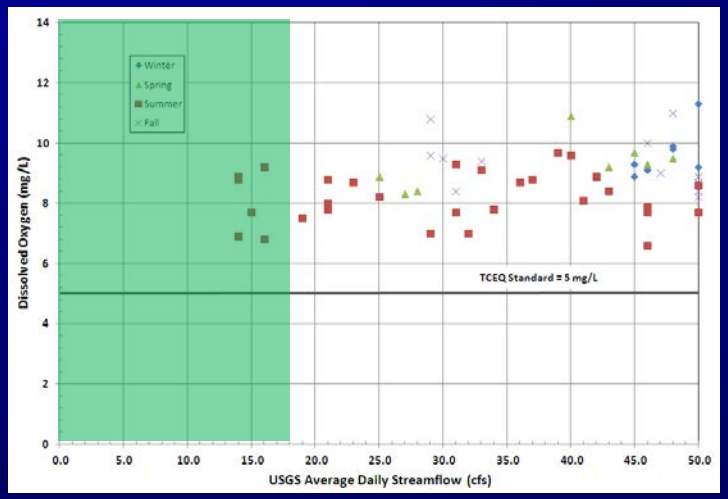


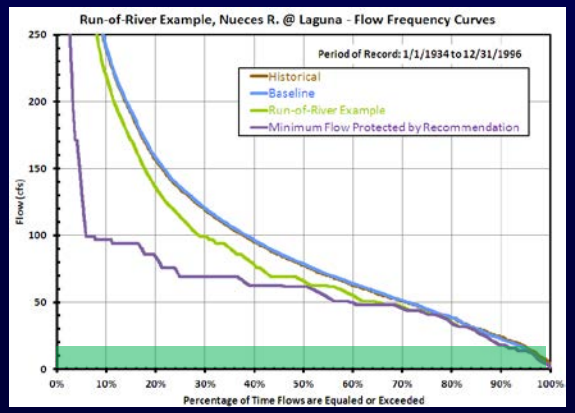
Flow Regime Components



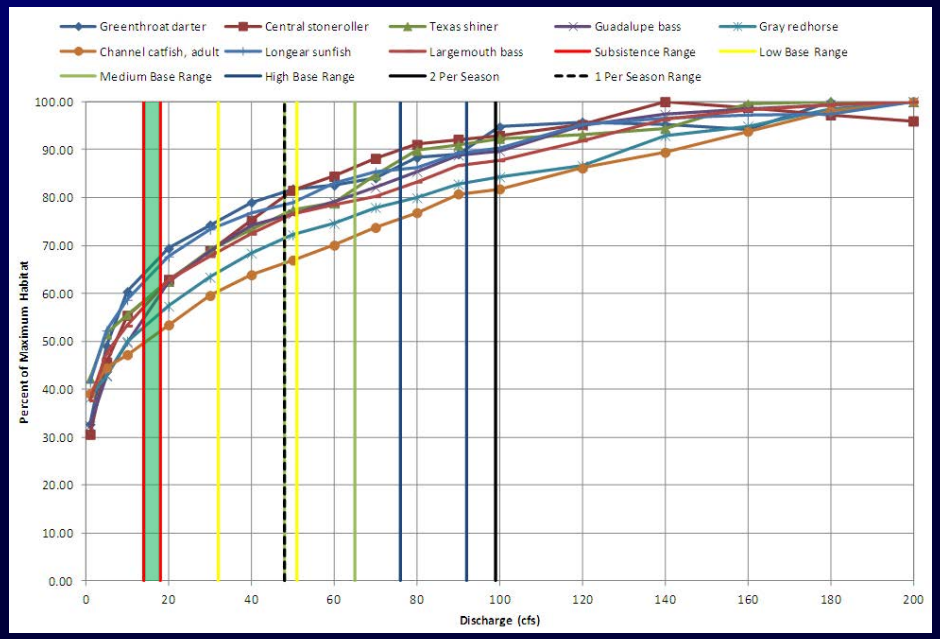
Ecological Significance - Subsistence

Water Quality



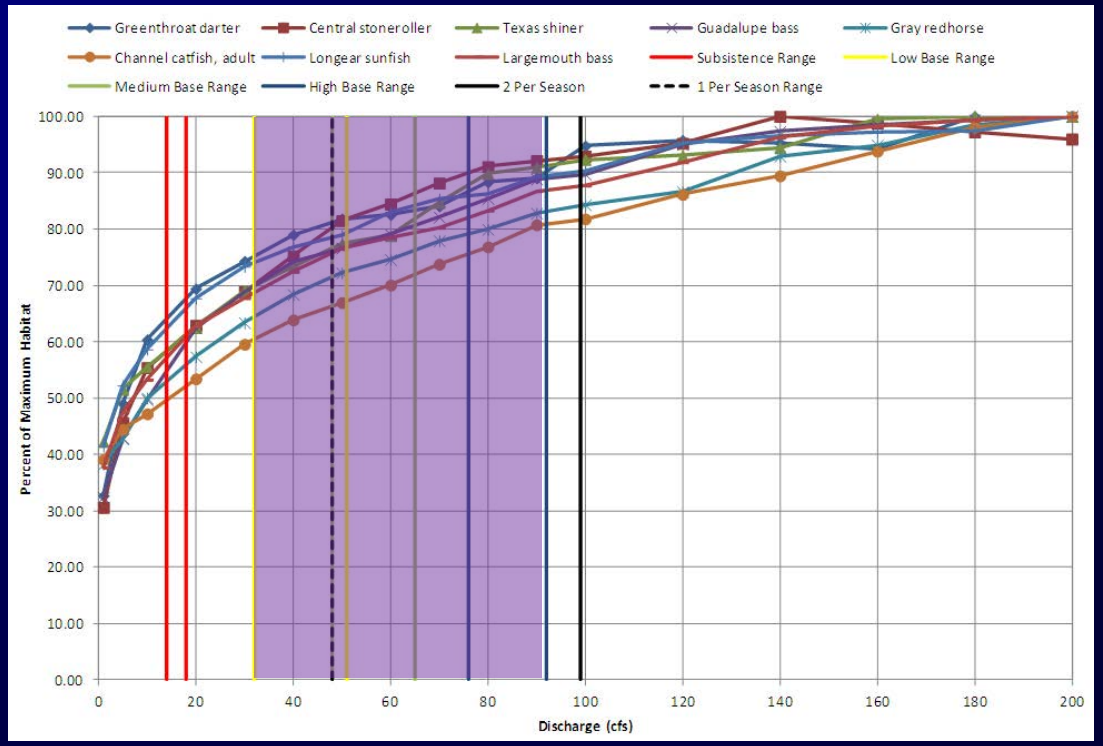


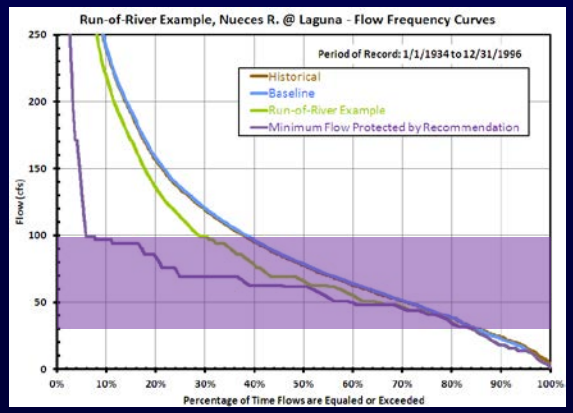
Aquatic Habitat



Ecological Significance - Base

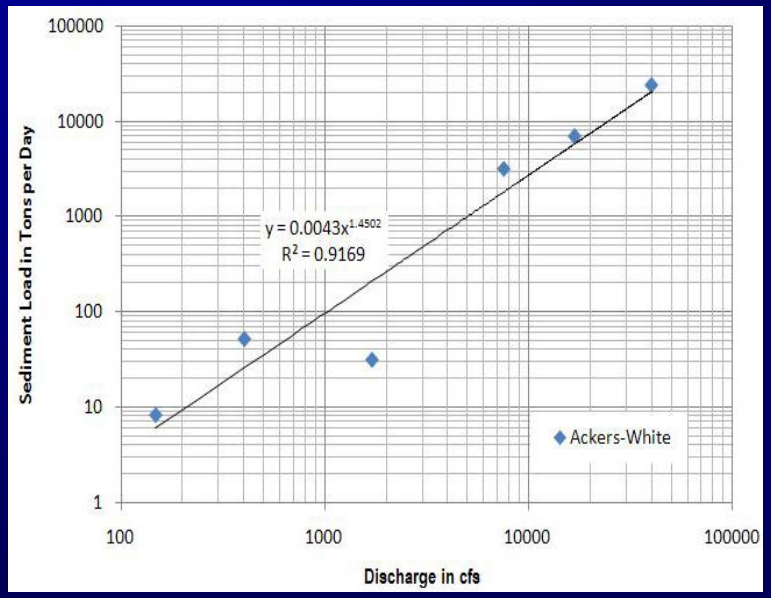
Aquatic Habitat

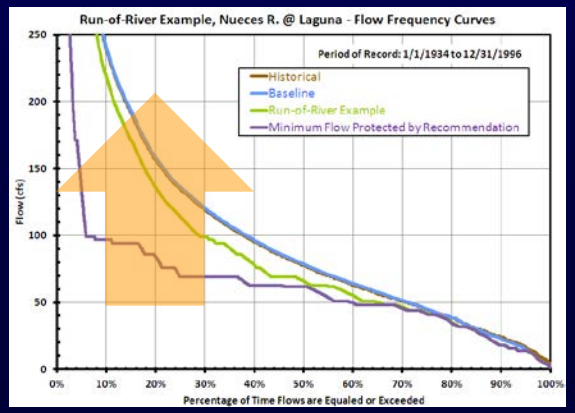




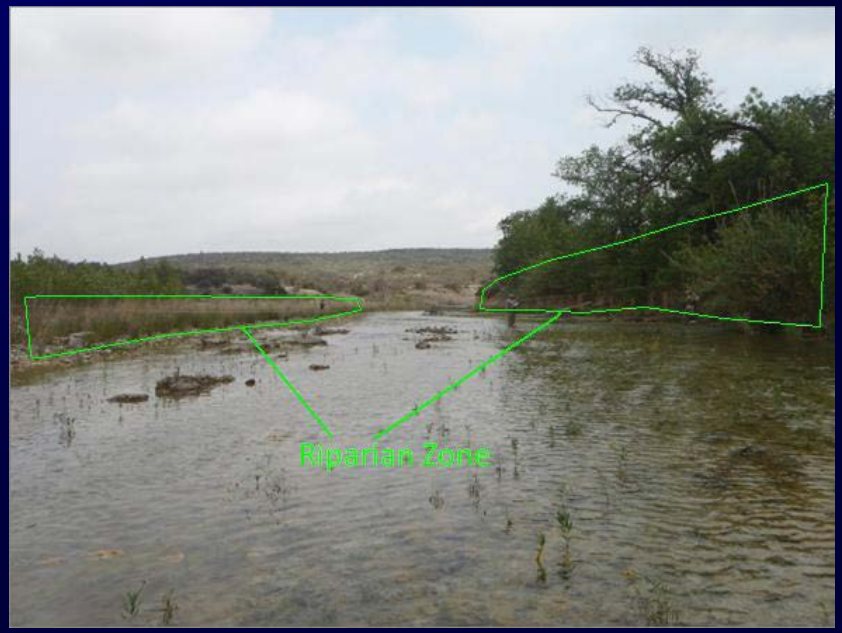
Ecological Significance - Pulses

Geomorphology

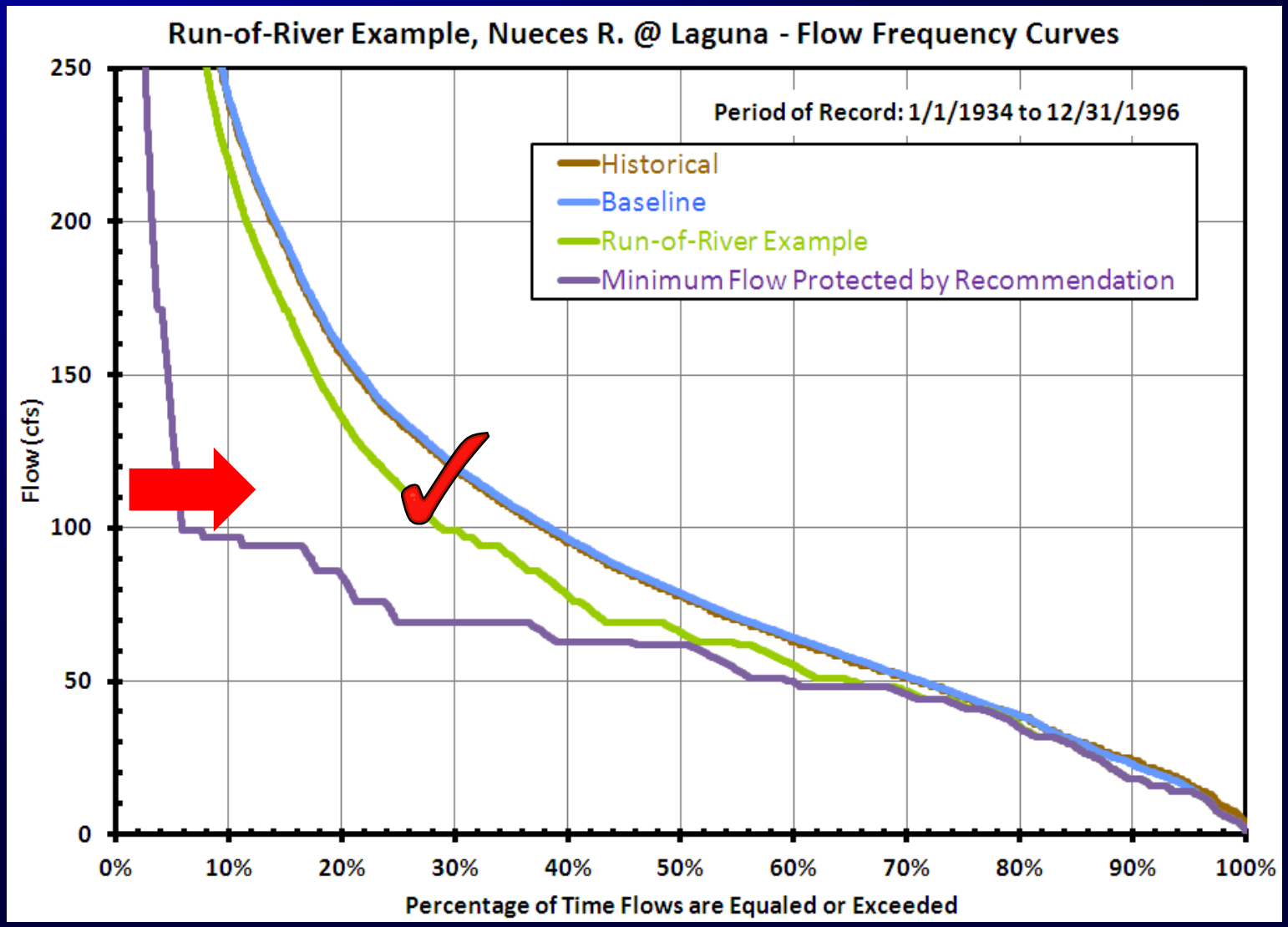




Riparian Ecology



Example Application of Instream Flow Regime Recommendations



Questions, Comments, & Discussion