Pre-Delta-Tour NAS Briefing
Tides and Transport Processes

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8/13/2024

ACKNOWLEDGEMENTS

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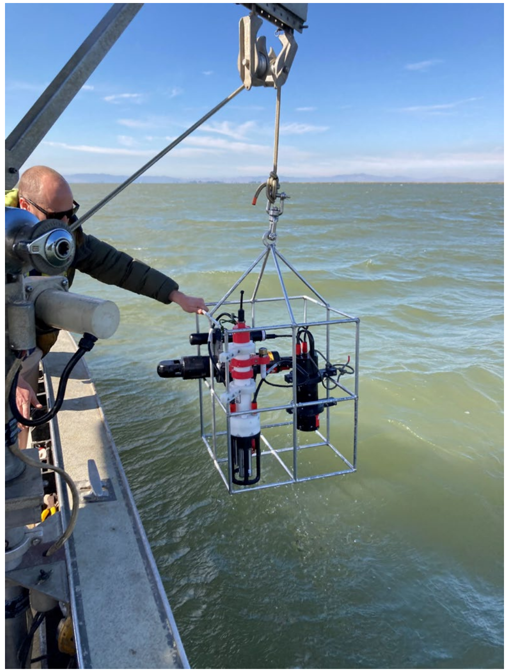


Purpose: Provide context/basic background. There is a lot to see/understand in a short period of time

Agenda

The San Francisco Estuary (SFE) is a food limited system

Making the connection between places that produce food and those the accumulate it

Background on low frequency variations in the tides and implications

Transport – what is it, why is it important and how is it achieved

California WaterBlog February 13, 2018

Advice on Voluntary Settlements for California's Bay-Delta Water Quality Control Plan Part 1: Addressing a Manageable Suite of Ecosystem Problems

by Jeffrey Mount, PPIC Water Policy Center and others (see below)

Advice focused on three fundamental ecological problems:

•***The Delta has become a low-productivity estuary***.

•*Ecosystem conditions favor non-native plants and animals over many native species.*

•*Water quality is declining*.

Three Tools were suggested to Address These Problems

Managing freshwater flows.

Managing tides.

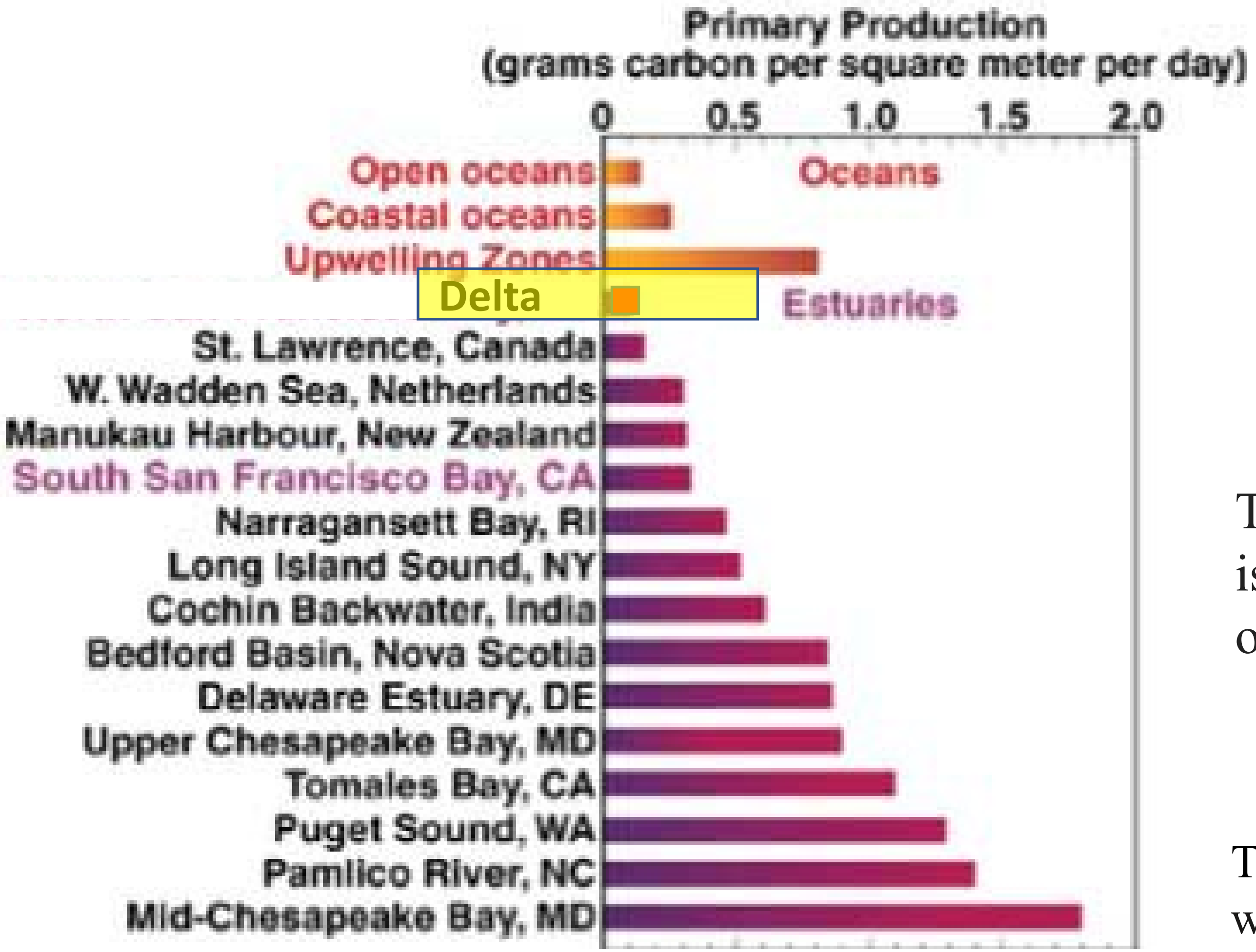
Managing landscapes.

These three tools **must be applied in concert**.. Applying any one of these tools without the others substantially reduces the likelihood of success.

Group included (in alphabetical order): Jon Burau (US Geological Survey [USGS]), Jim Cloern (USGS), John Durand (UC Davis), Greg Gartrell (consulting engineer), Brian Gray (PPIC), Ellen Hanak (PPIC), Carson Jeffres (UC Davis), Wim Kimmerer (SFSU), Jay Lund (UC Davis), Jeffrey Mount (PPIC), and Peter Moyle (UC Davis).

Food (organic carbon) is limiting native fish populations

Northern San Francisco Bay and the Delta are low productivity systems



From Cloern et al. 1994

Why is the Delta Starving?

PPIC blog posted Aug. 9 2021 (Bardeen interview of Cloern, 2021)

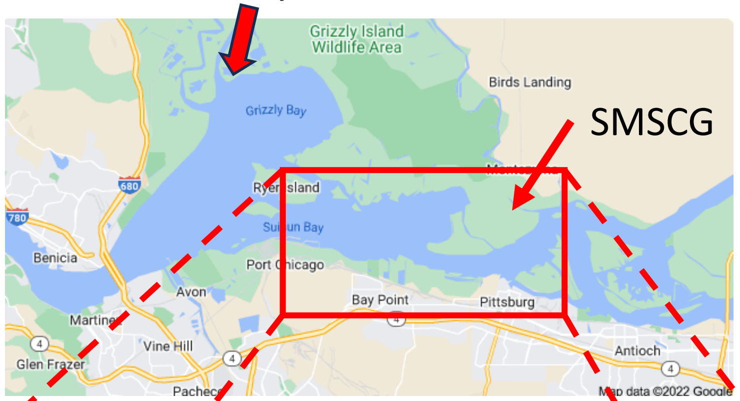
The vast majority of aquatic "habitat" in the Delta is poor, mostly comprised of low-productivity open-water conveyance canals and flooded "Islands".

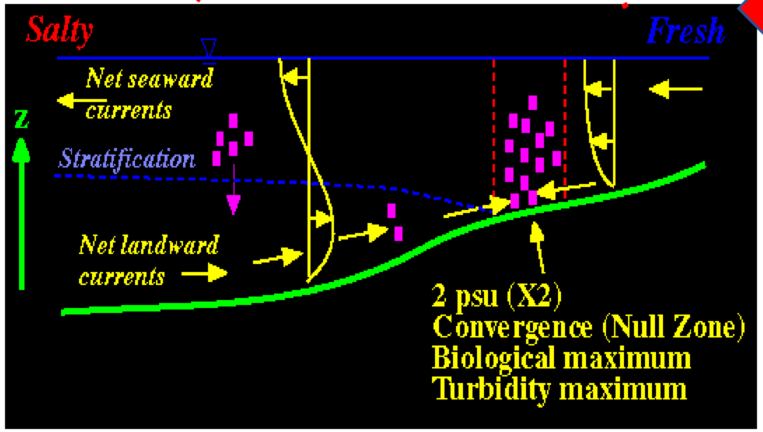
The Delta has "lost virtually all of its high-productivity marshes while lower-productivity open-water habitats have increased" PPIC blog posted Aug 2, 2021. Bardeen and Cloern, 2021: "Why is the Delta Starving?" .

Connecting “Magical Places” that produce food and accumulate it

Low Salinity Zone (ETM, LSZ, X2)

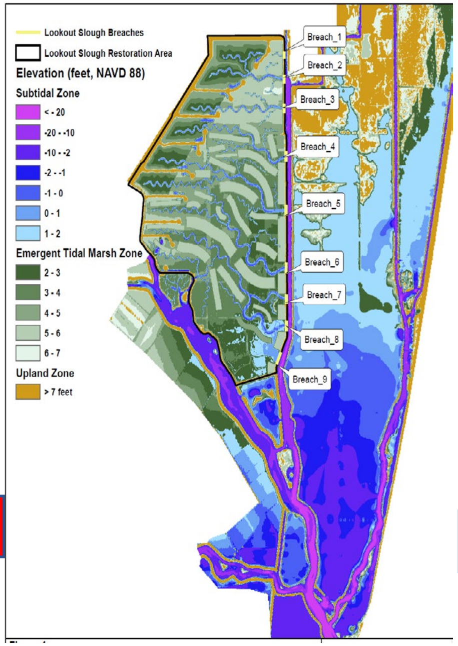
Productivity from Suisun Marsh





Gravitational circulation accumulates detritus
Creates stratification that can initiate phytoplankton blooms

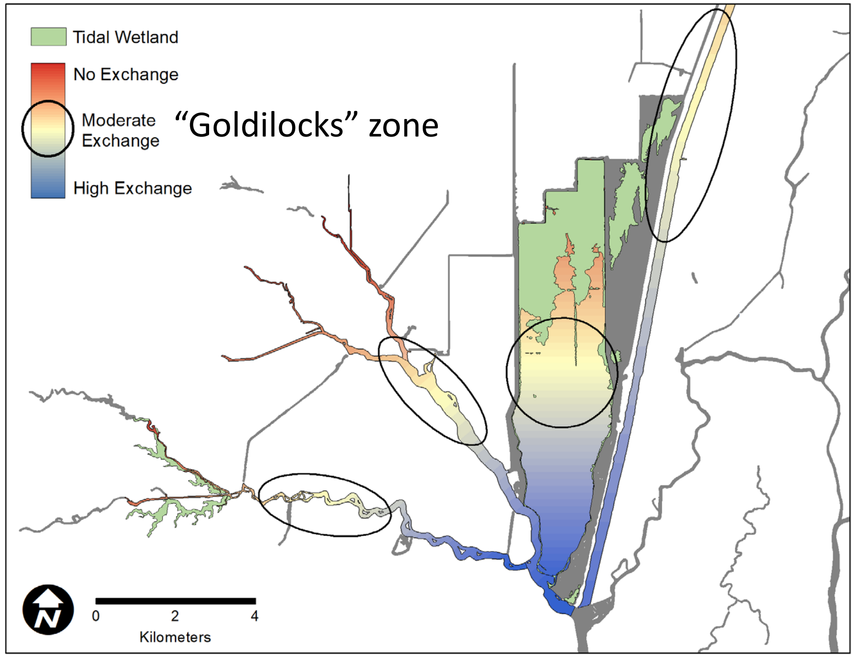
Detritus phytoplankton



Wetlands
Food production
(**Organic Carbon**)
and
Local export

Detritus phytoplankton

Terminal Basins/Channels



Pelagic hot spots based on the Lagrangian to Eulerian Ratio.

(1) “Goldilocks” residence time zone

(2) Standing wave behavior creates Turbidity Maxima Zone (TMZ) and accumulates **detritus**

“Wetlands are **magical places** where land and water meet.”

PPIC blog posted Aug 2, 2021 Bardeen and Cloern, 2021: “Why is the Delta Starving?” .

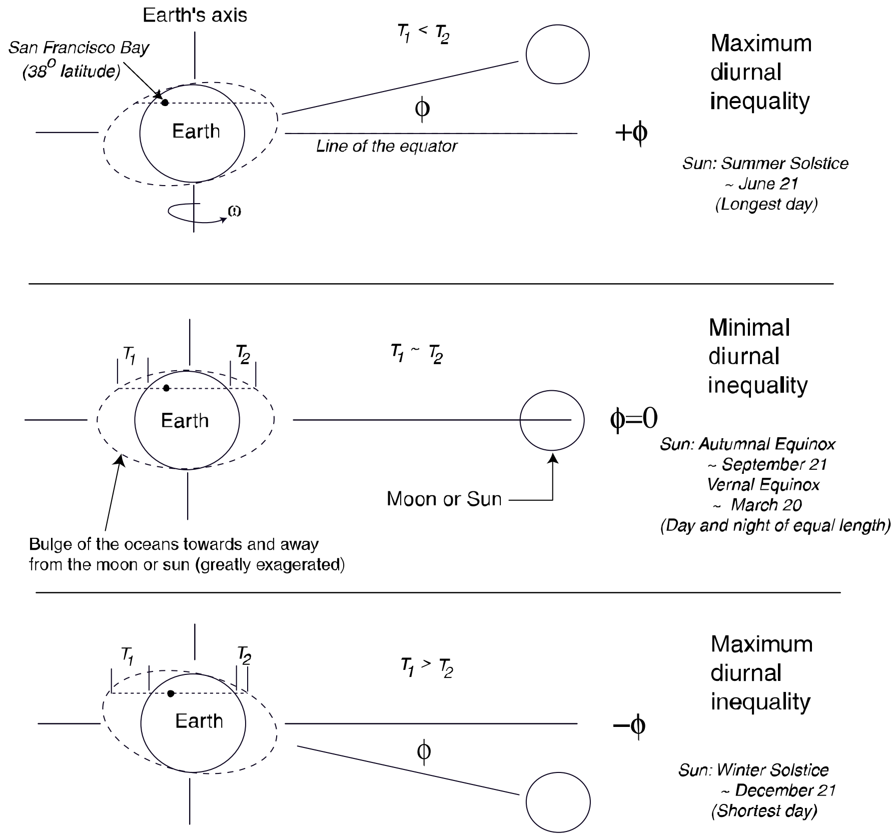
Manage the Tides?   What?

We can’t change the astronomical relationships between earth, sun and moon, but…

The Astronomical Origins of the Tides, in the SFE, unlike east coast estuaries, has a strong declinational aspect

Declinational

Tropic/Equatorial cycle – Diurnal Inequality



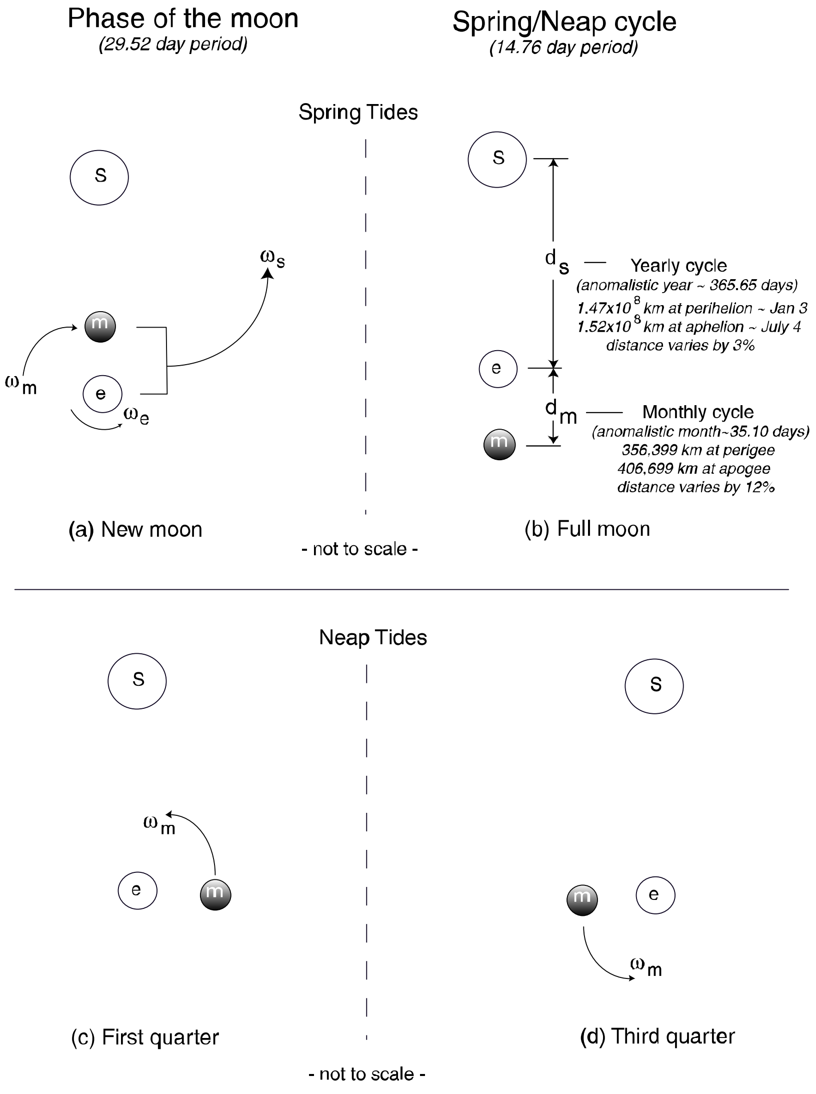
	ϕ^o	Period of oscillation
Moon	21.0[1]	27.33 days[2]
Sun	23.5	365.2 days

[1] The moons maximum declination varies from 28.5° to 18.5° over a 18.6 year cycle. The value shown applies to January 1, 2000 and is increasing at this time.

[2] Tropical month

Gravitational Alignment of earth, moon and Sun

Spring/Neap



We can "manage the tides" to improve ecosystem services and water supply reliability in two ways:

(1) Modify transport processes within landscapes that are controlled by the tides (On Tour - Franks Tract?)
(Focus of this talk)

(2) **Synchronize management actions with low frequency (>24hrs) variability in the tides.**
Low frequency variability: fortnightly (14 day), monthly, seasonal, 18.6-year timescales. (Focus of this talk)

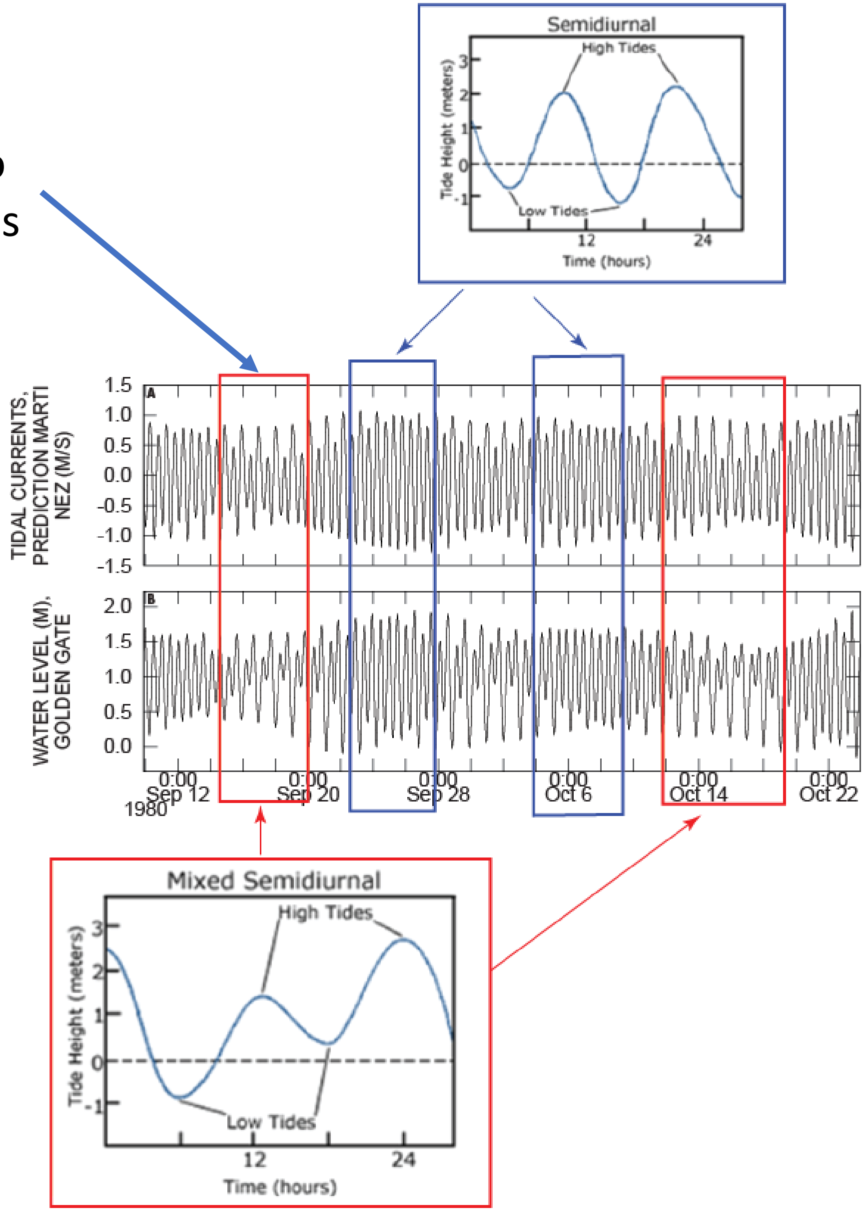
This is a big deal because we are finding ecosystem services fundamentally operates at all these timescales

Which gives us management actions at a wider variety timescales that can target
specific ecosystem services

Spoiler alert: the spring/neap (14-day) cycle does not dominate SFE tides, nor is it the only show in town.

The Tides in the SFE cycle between semidiurnal and mixed tides at fortnightly, monthly, seasonal and 18.6 year cycles

Diurnal inequality due to Declinational partial tides

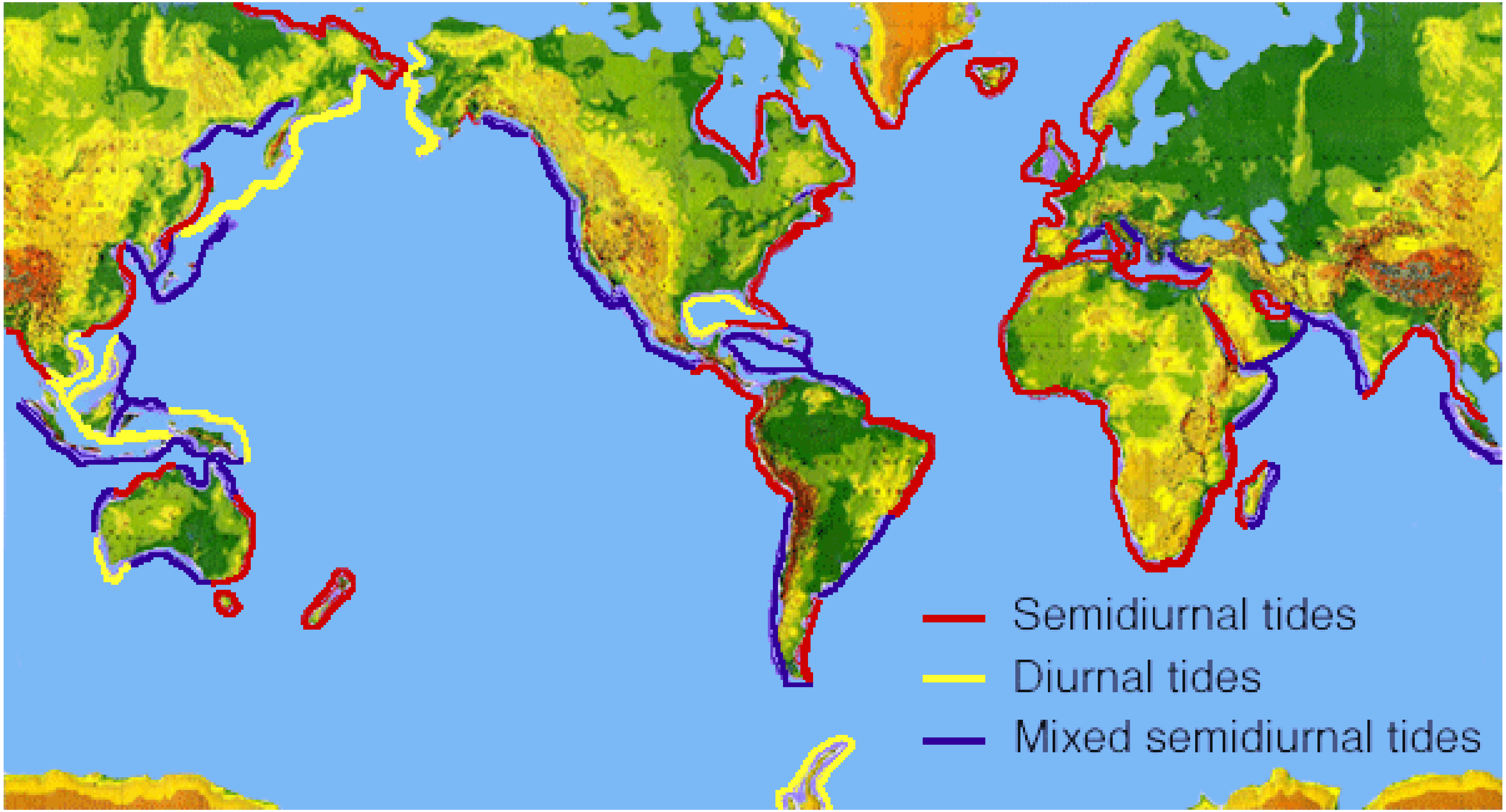


How did we not know the spring/neap cycle wasn't dominating low frequency variability SFE tides?

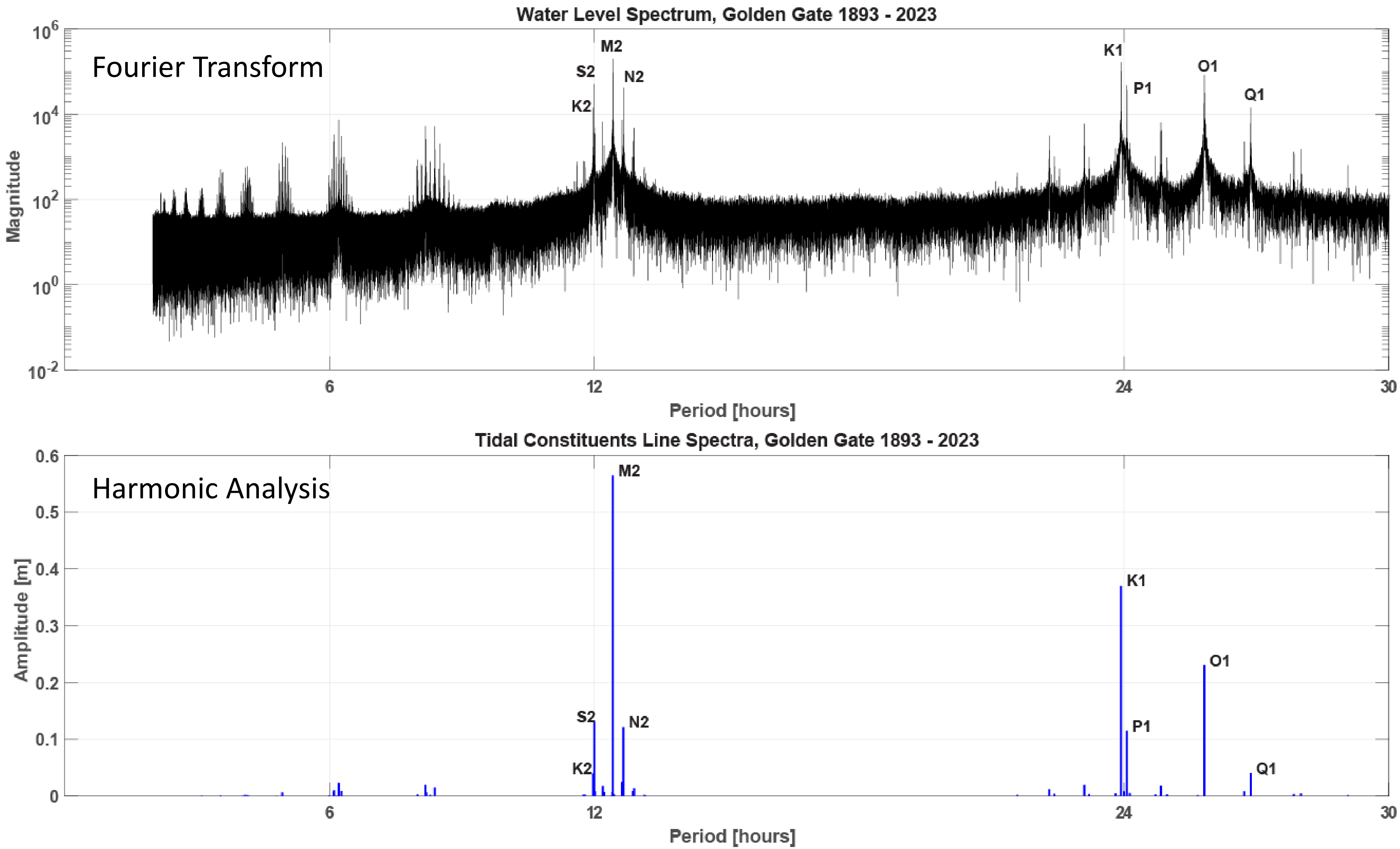
(1) Our forefathers apparently adopted it from work done in east coast estuaries

(2) Traditional tidal analysis methods alone didn't reveal it (Fourier and Harmonic Analysis).

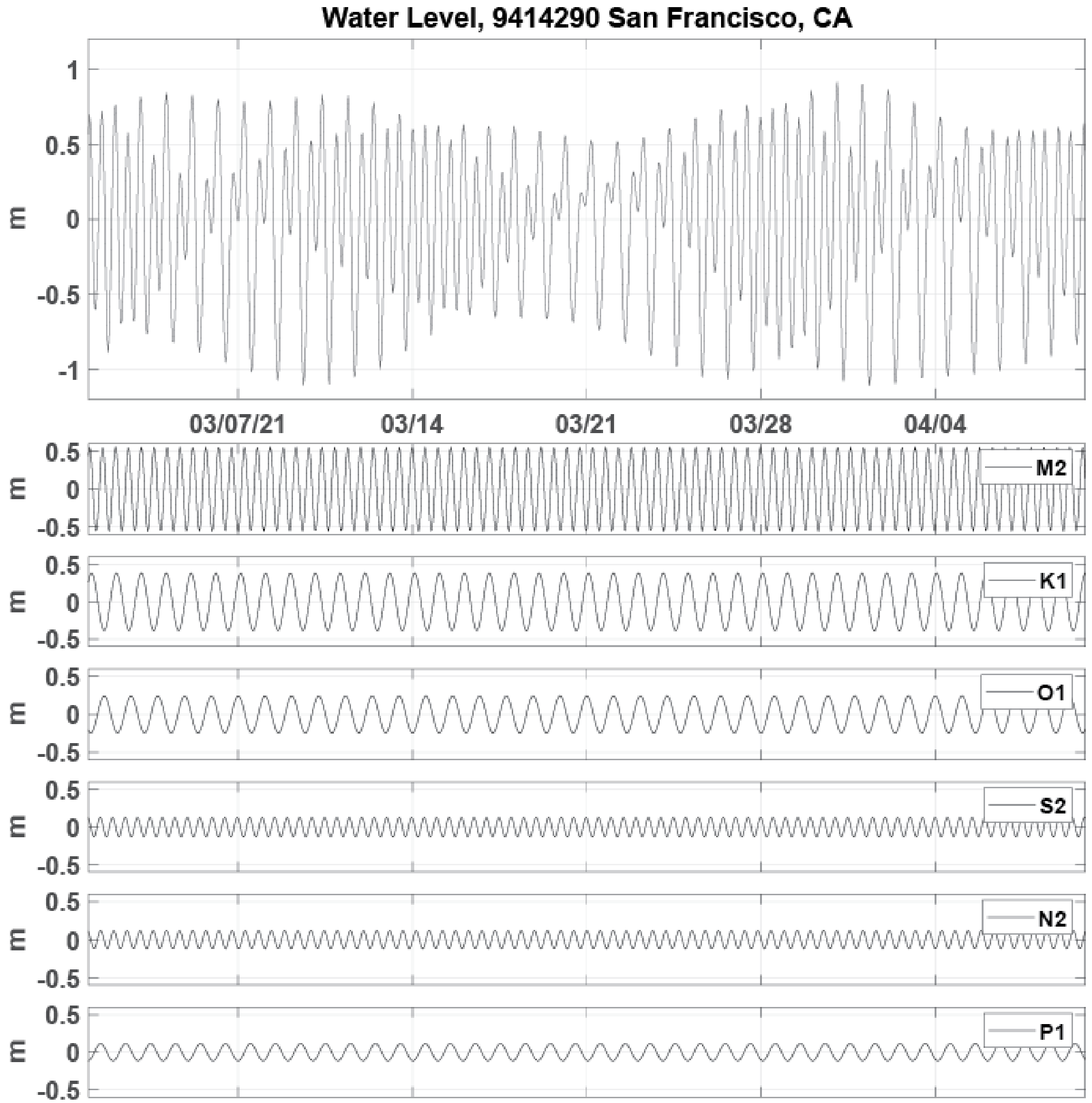
World Map of the tides



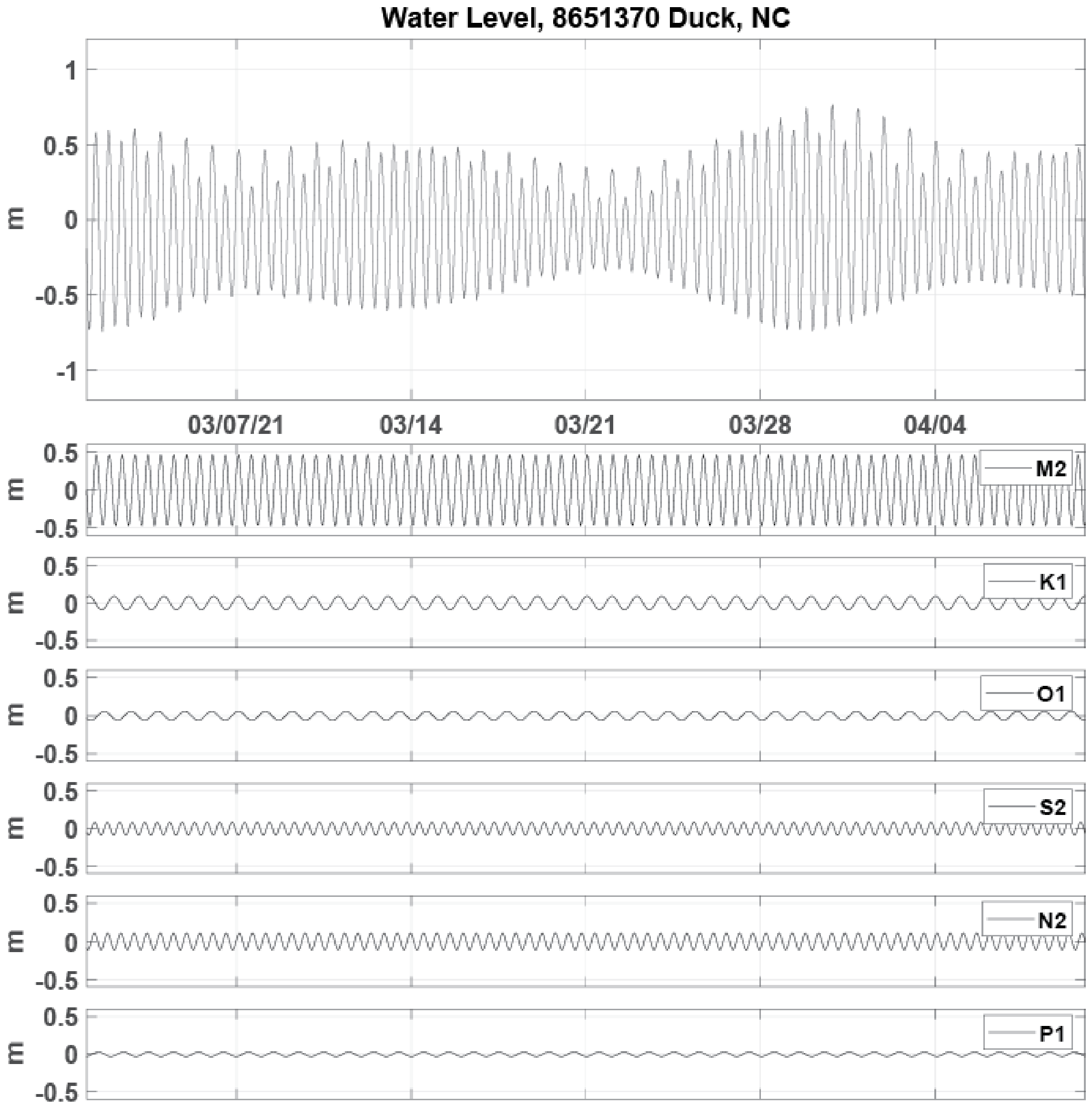
Traditional Methods for determining the spectral content of the Tides



Examples of Harmonic Analysis Results for West and East Coast Estuaries



East Coast Estuaries



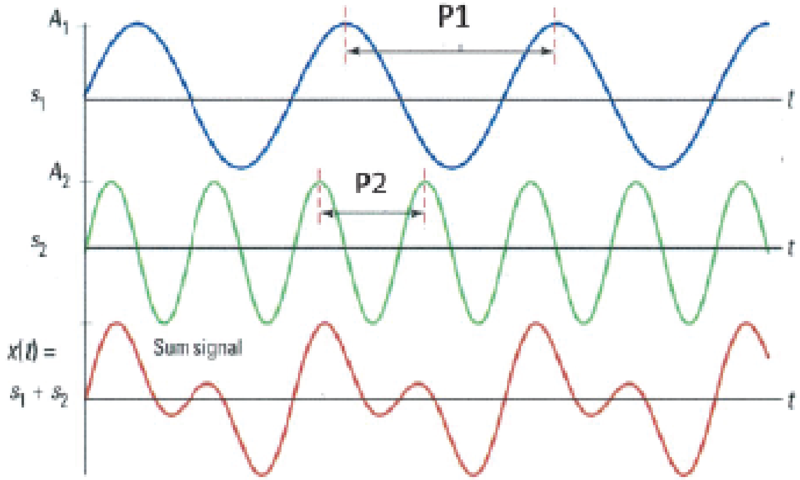
Modulation frequency and amplitude

Sum of two sinusoids creates the tidal envelopes

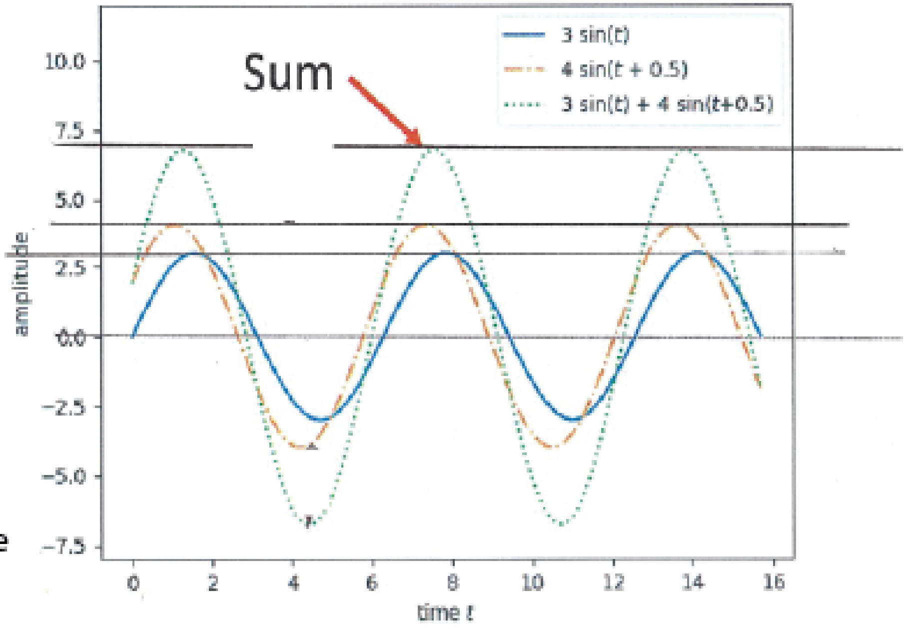
Constructive and destructive interference

With different periods

With similar periods

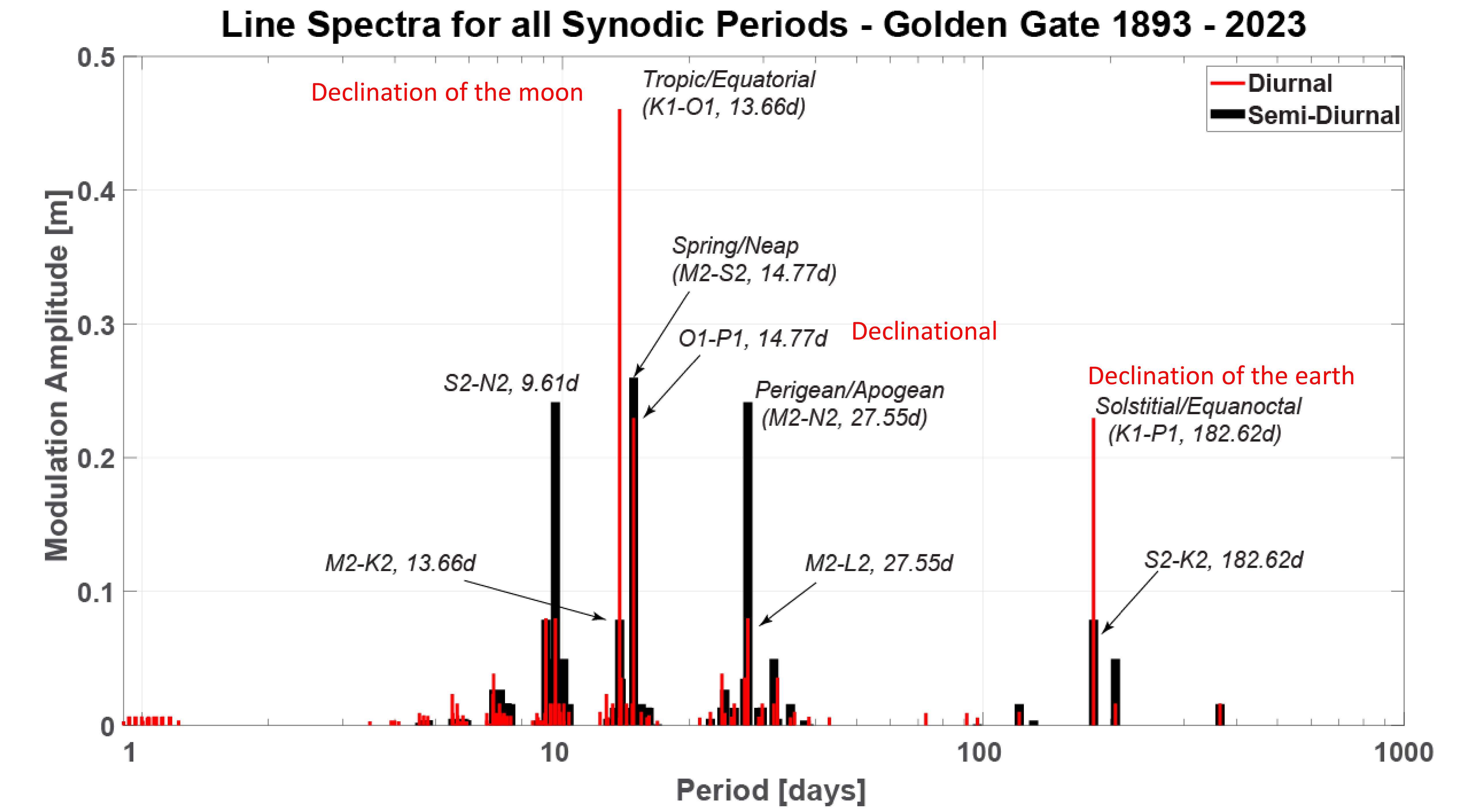


High Frequency constructive and destructive interference

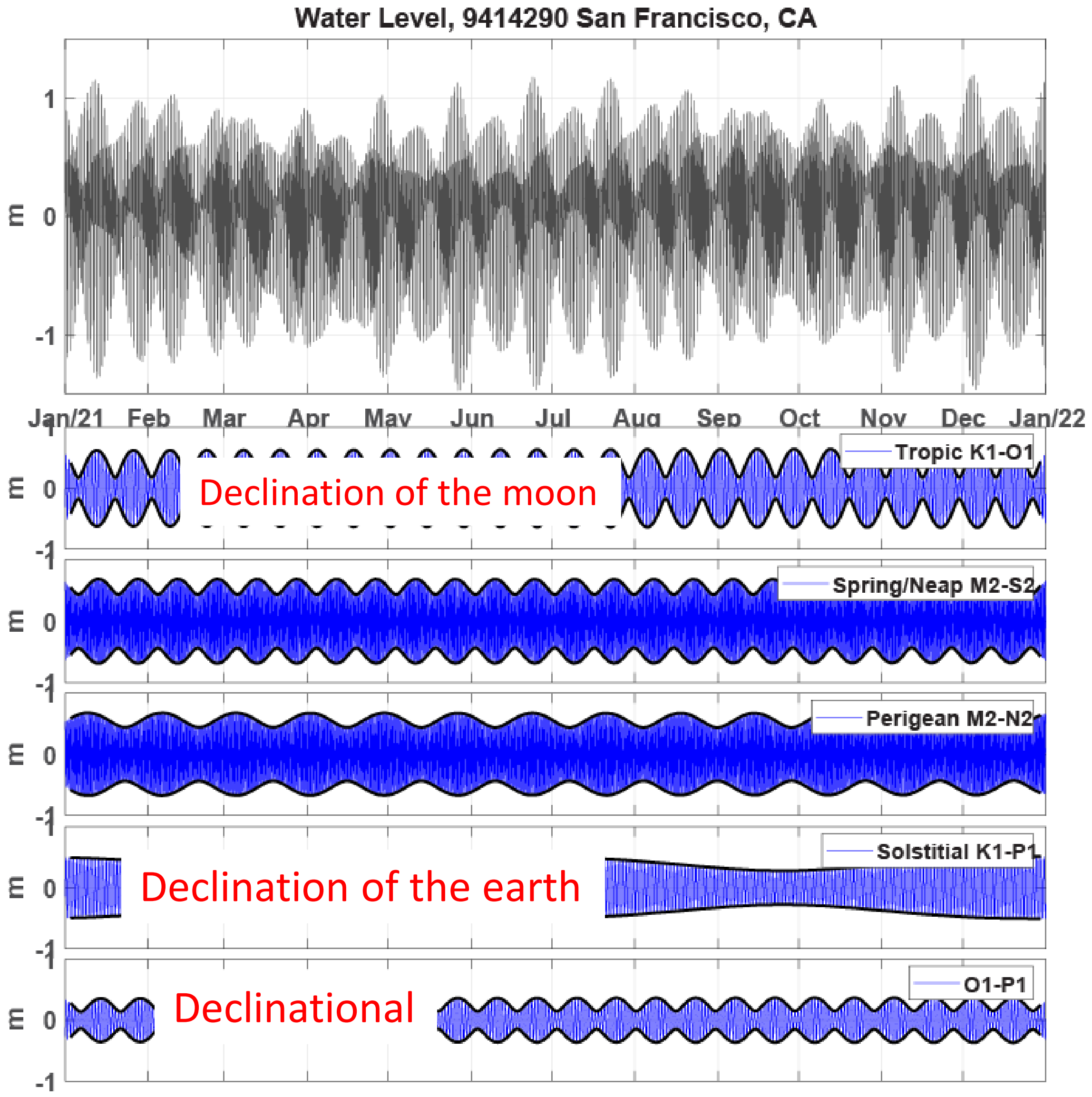


Modulation difference in the frequencies between sine waves

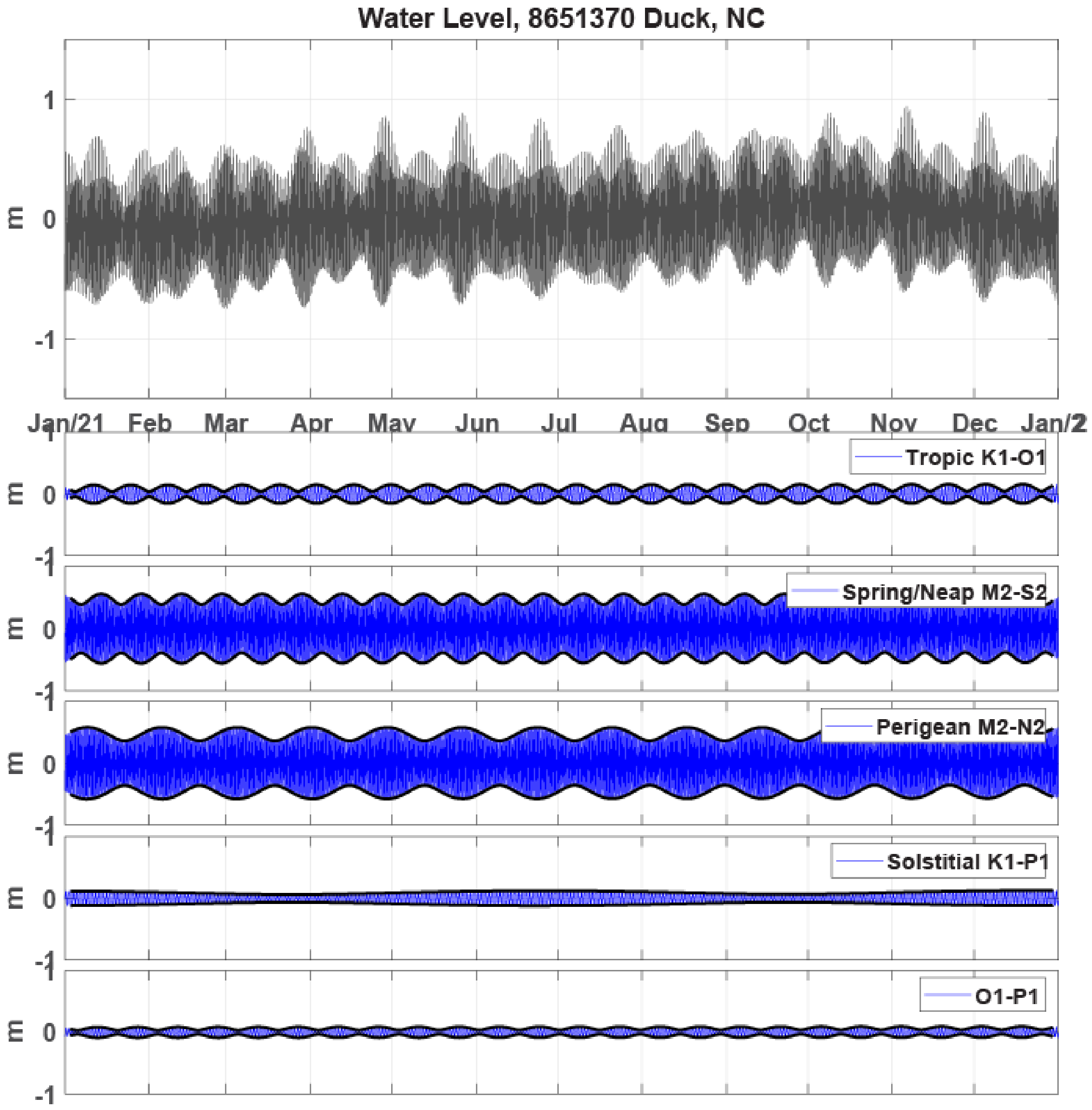
Modulation amplitude = 2*[H1, H2]$_{min}$


Line Spectra for all Synodic Periods - Golden Gate 1893 - 2023
Diurnal
Semi-Diurnal
Declination of the moon
Tropic/Equatorial
(K1-O1, 13.66d)
Spring/Neap
(M2-S2, 14.77d)
O1-P1, 14.77d
Declinational
S2-N2, 9.61d
Perigean/Apogean
(M2-N2, 27.55d)
Declination of the earth
Solstitial/Equanoctal
(K1-P1, 182.62d)
M2-K2, 13.66d
M2-L2, 27.55d
S2-K2, 182.62d
Modulation Amplitude [m]
0
0.1
0.2
0.3
0.4
0.5
1
10
100
1000
Period [days]

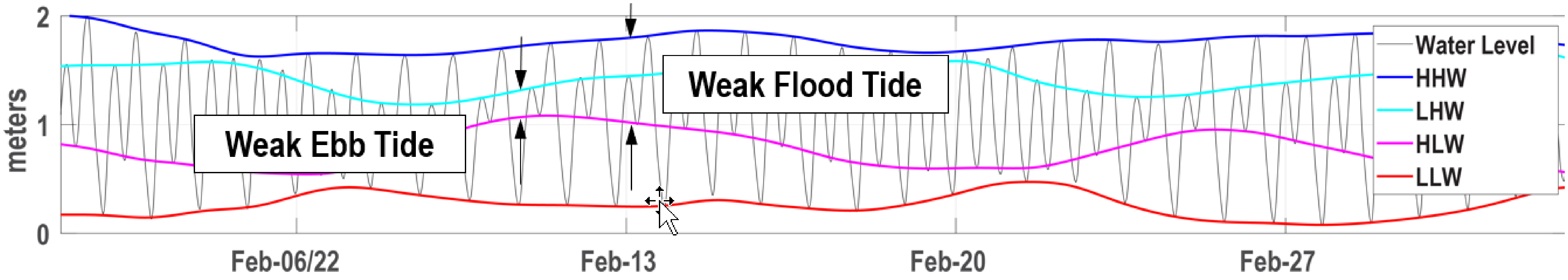
Modulation frequencies (synodic periods) and amplitudes



East Coast Estuaries



We discovered this when started to investigate the importance of the tidal envelopes (modulation frequencies) as a driver of transport processes and ecosystem services



Spring/neap (fortnightly, 14 day) (old) conceptual model of low frequency variability

(1**) Fortnightly period variability** was (nearly) the only low frequency mode considered

(2) Neap tides - Gravitational Circulation, which drives stratification and accumulation of detritus occurs during **neap tides** (weaker vertical mixing), phytoplankton

(3) Spring tides - Horizontal Dispersion, which drives salinity intrusion, shallow-water exchange, horizontal transports between habitats, etc.

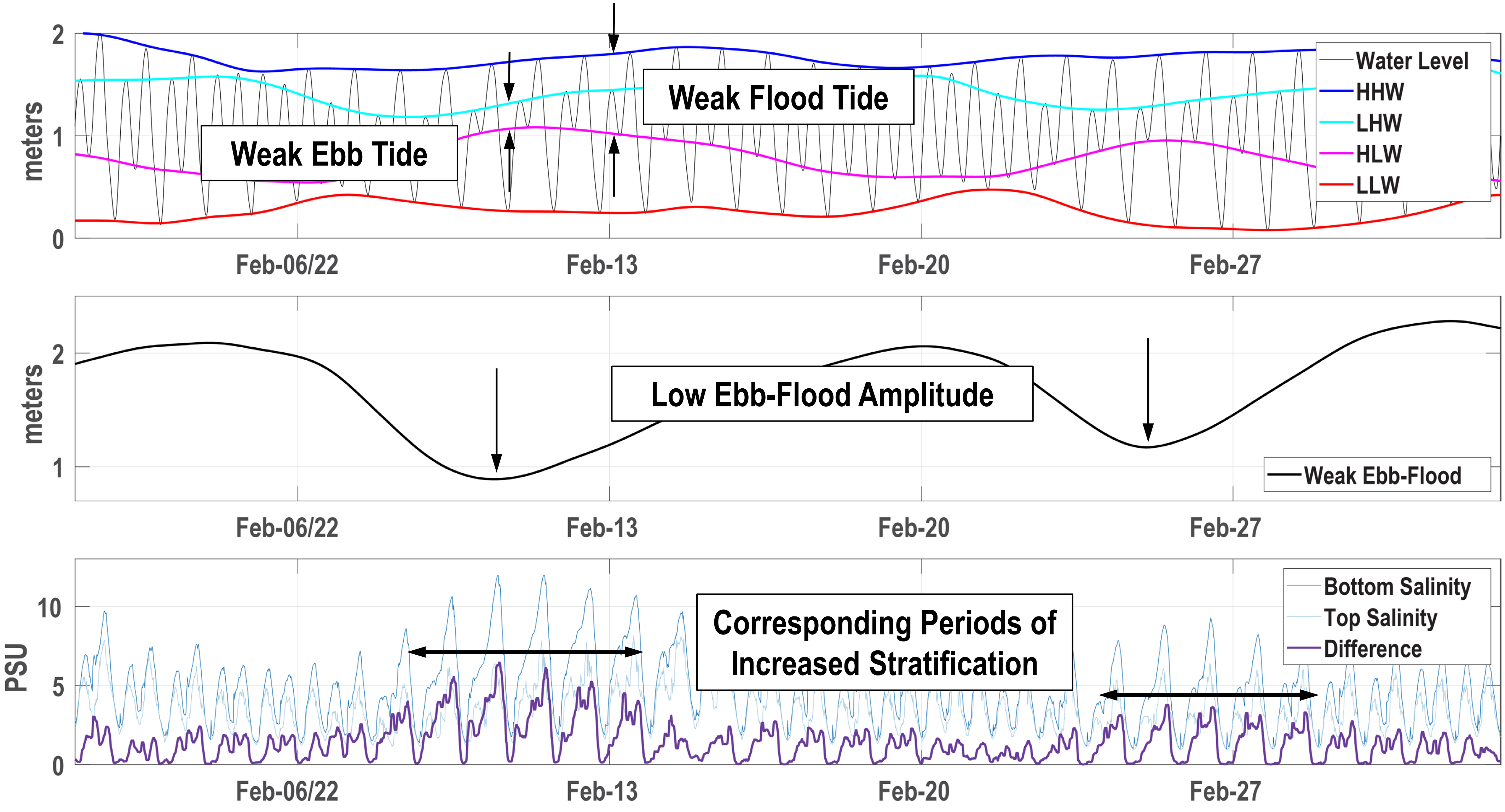
Mixed tide (diurnal inequality) model of low frequency variability

(1) Multiple periods of low frequency variability
(Fortnightly, monthly, seasonal, 18.y year cycle)

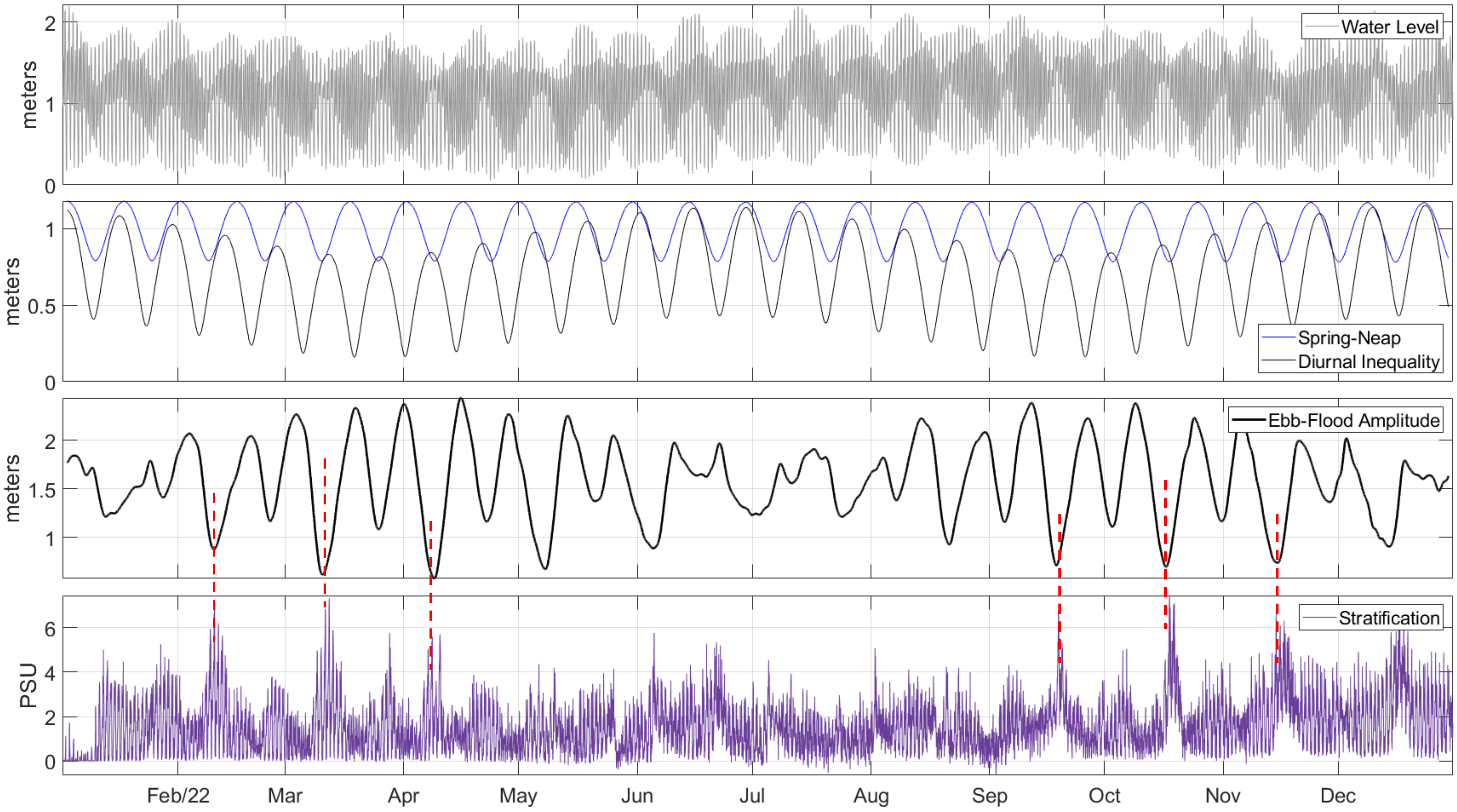
(2**) Mixed Tides - Gravitational Circulation**, which drives stratification and accumulation of detritus occurs during **neap tides** (weaker vertical mixing), phytoplankton

(3) **Semidiurnal Tides - Horizontal Dispersion**, which drives salinity intrusion, shallow-water exchange, horizontal transports between habitats, etc.

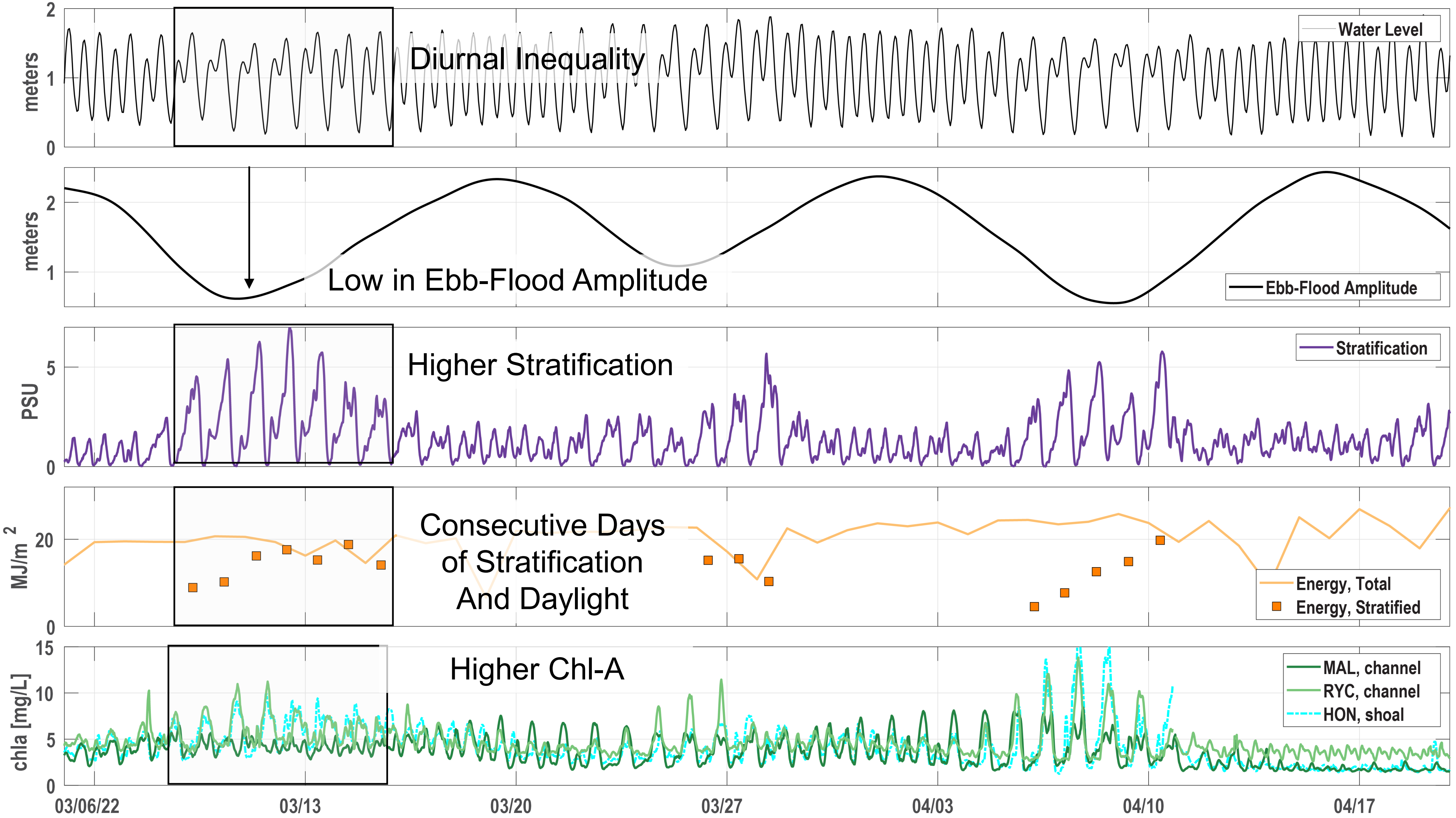
EBB-FLOOD AMPLITUDE METRIC



Weak ebb-flood set (amplitude) – 1 year timeseries



WEAK TIDES, STRATIFICATION, DAYLIGHT AND INCREASED CHL-A

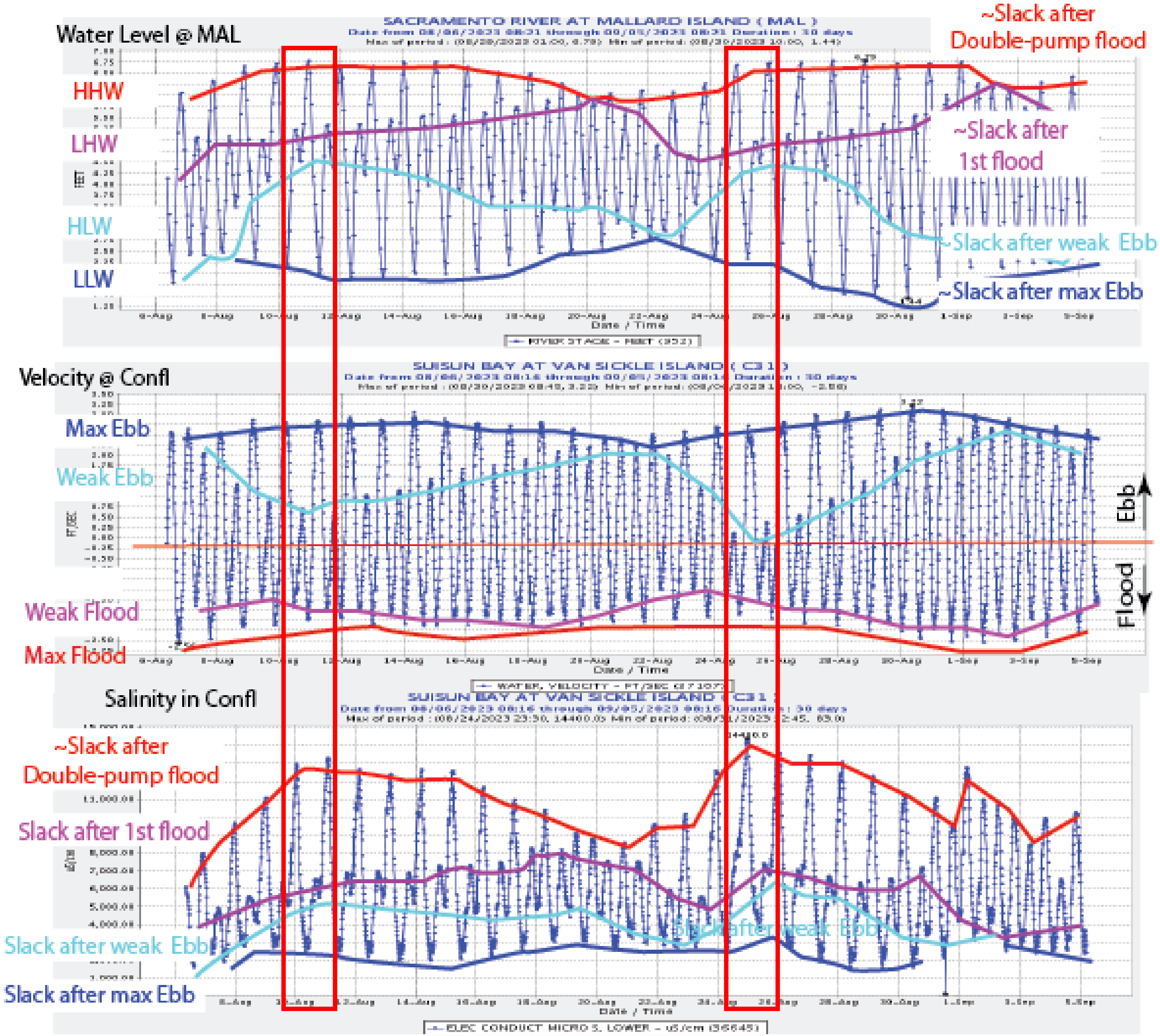


The diurnal inequality is a sequence of:

Moderate flood
Weak ebb
Moderate flood
Big Ebb

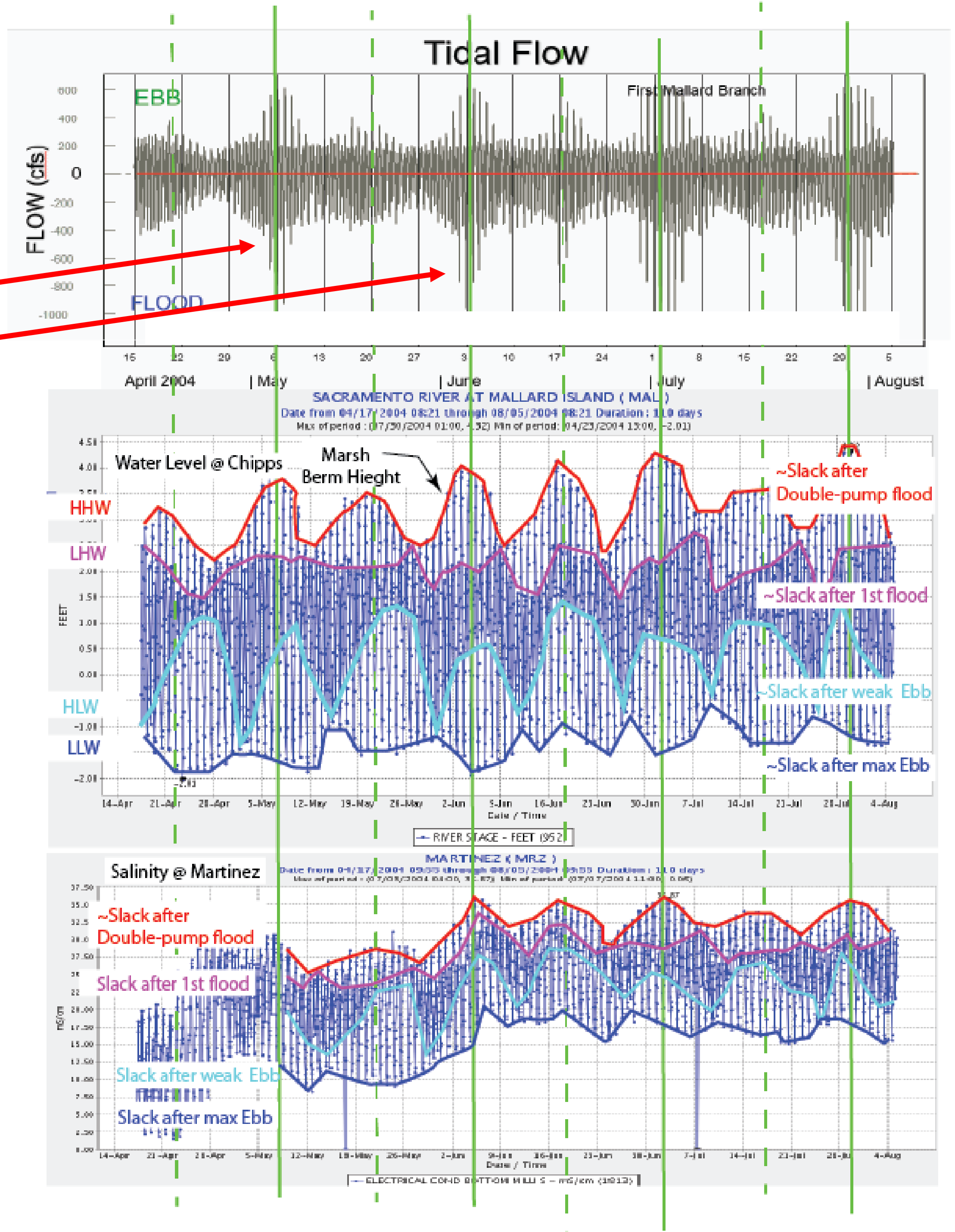
Period of weak vertical mixing:
Gravitational circulation
Stratification
Phytoplankton bloom?
Increased detrital accumulation

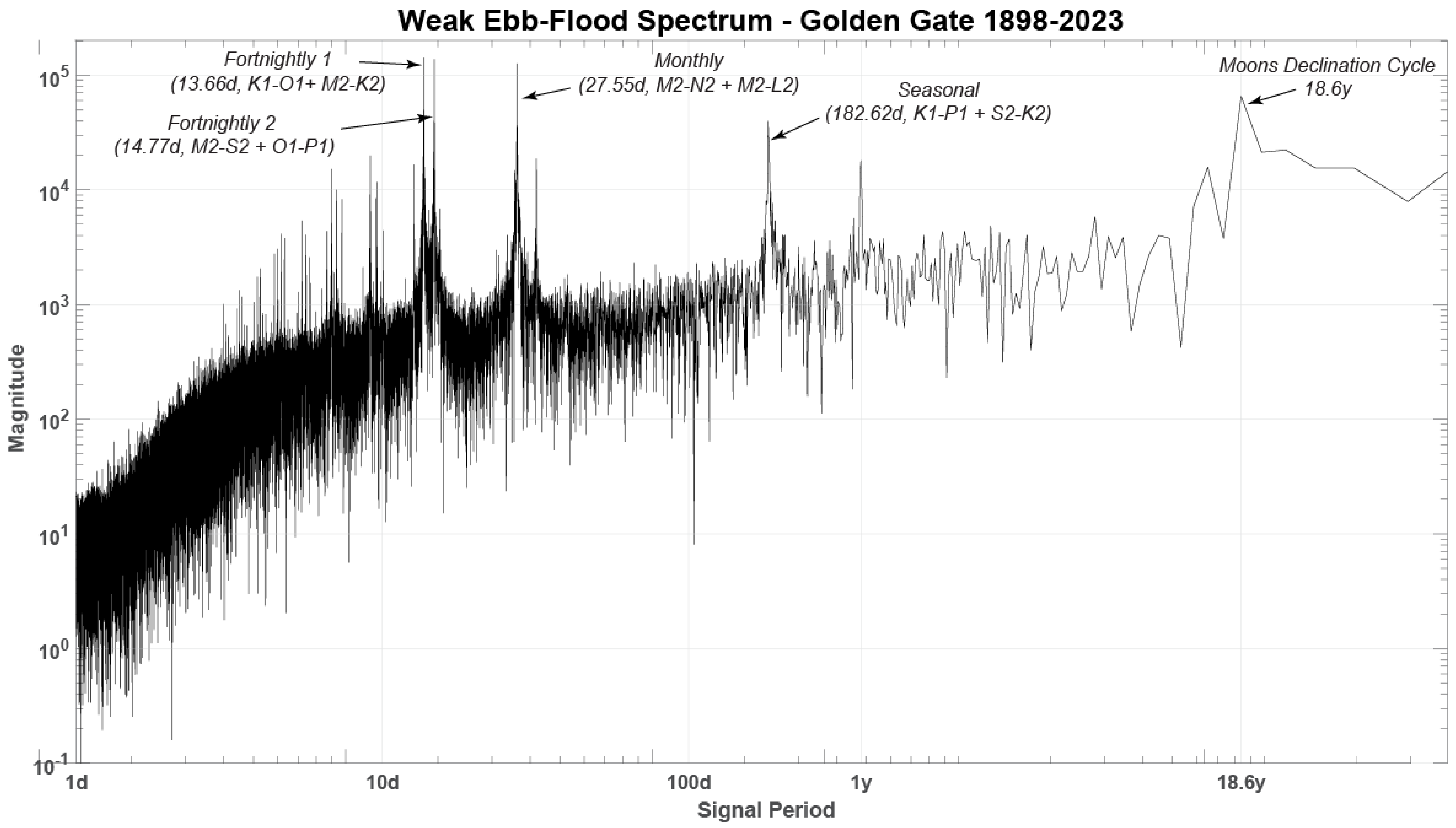
Period of maximal tidal exchange
Horizontal Dispersion



Tidal Marshes also dump all their phytoplankton and detrital biomass during the diurnal Inequality

That is locally maximally tidally exchanged and dispersively mixed in adjacent channels





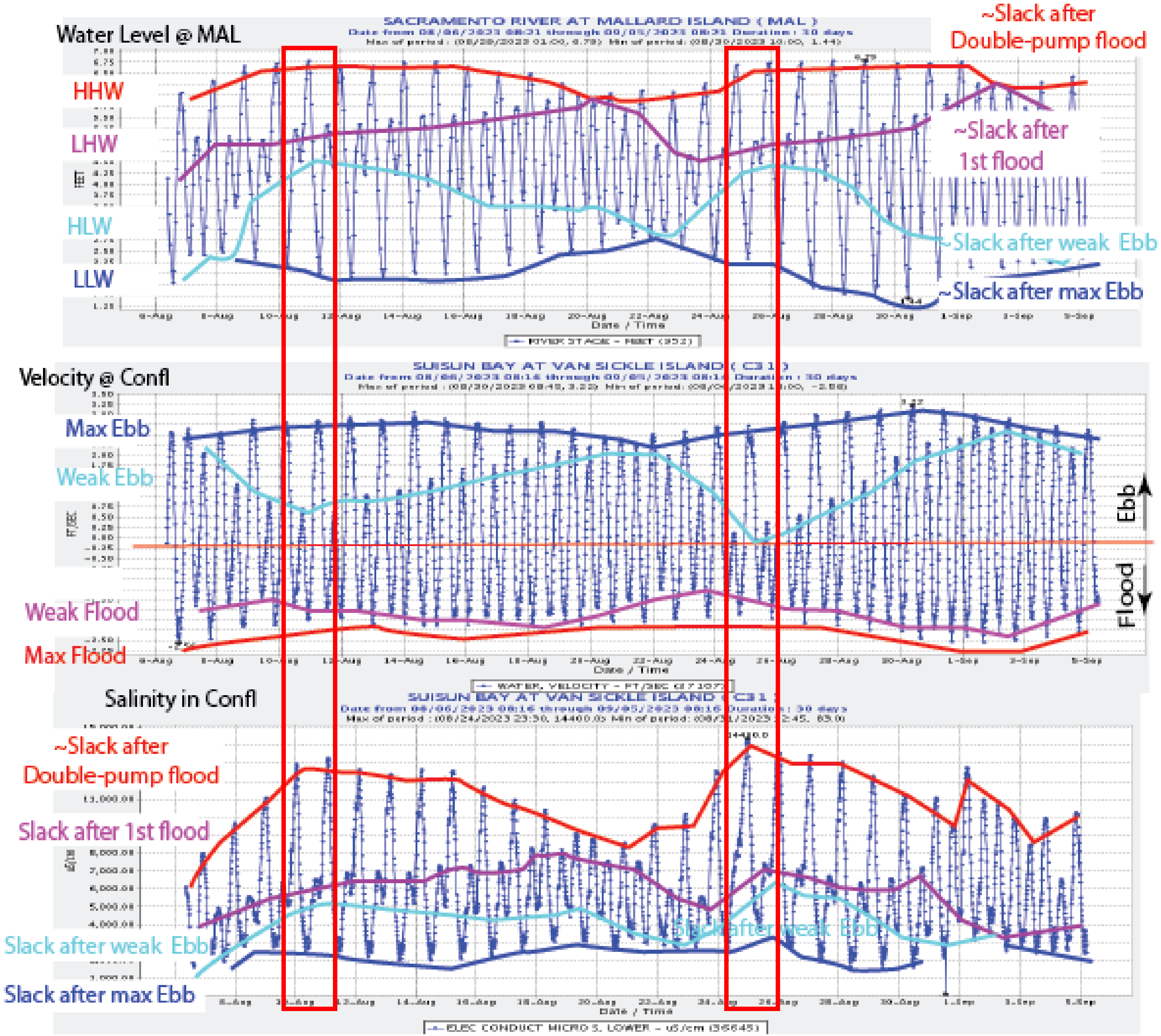
Weak Ebb-Flood Spectrum - Golden Gate 1898-2023
Fortnightly 1
(13.66d, K1-O1+ M2-K2)
Fortnightly 2
(14.77d, M2-S2 + O1-P1)
Monthly
(27.55d, M2-N2 + M2-L2)
Seasonal
(182.62d, K1-P1 + S2-K2)
Moons Declination Cycle
18.6y
Magnitude
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
1d
10d
100d
1y
18.6y
Signal Period

The diurnal inequality is a sequence of:

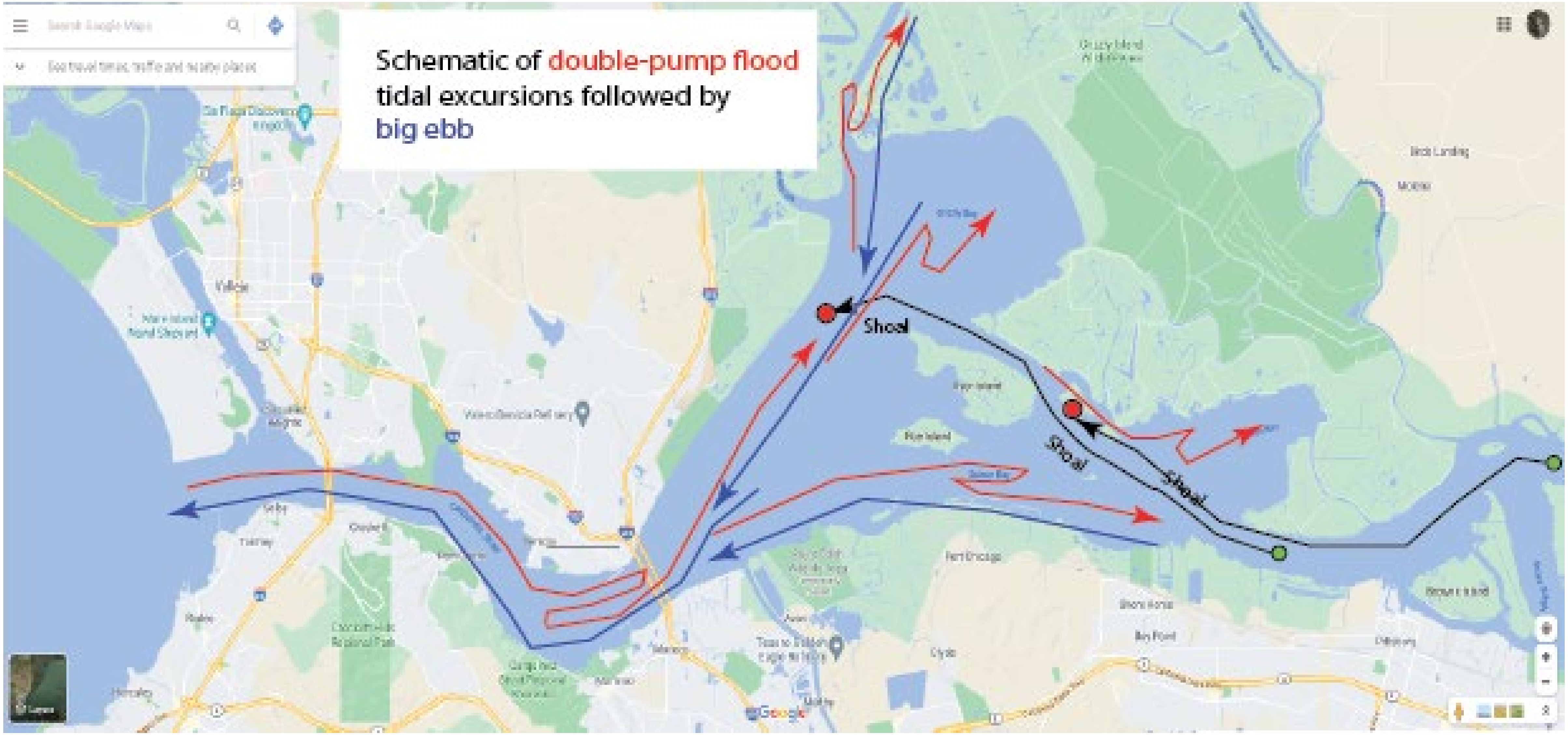
Moderate flood
Weak ebb
Moderate flood
Big Ebb

Period of weak vertical mixing
Gravitational circulation
Stratification
Phytoplankton bloom?
Increased detrital accumulation

Period of maximal tidal exchange
Horizontal Dispersion

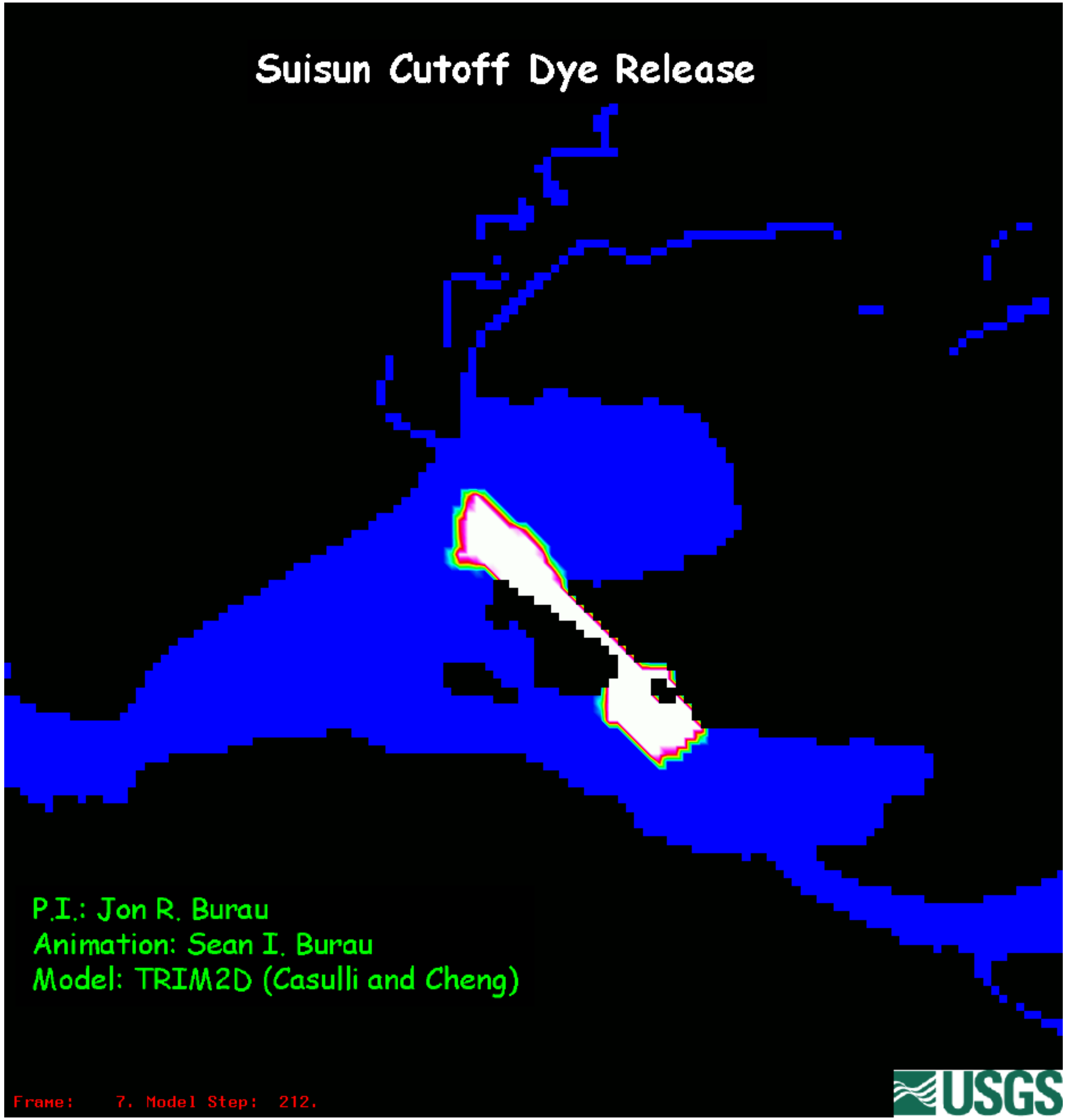


Schematic of double pump floods, big ebb tidal excursions increases dispersive transports



Reminder:

GC is transporting
detritus and organisms
from San Pablo Bay
With the up-estuary
bottom current while
tidal exchange in happening
In this animation


Suisun Cutoff Dye Release
P.I.: Jon R. Burau
Animation: Sean I. Burau
Model: TRIM2D (Casulli and Cheng)
Frame: 7. Model Step: 212.
USGS

Peaks in the diurnal inequality are also periods of maximal salinity intrusion

Because both of the salinity intrusion mechanisms
Peak during the diurnal inequality

(1)Gravitational circulation (likely the weaker mechanism)
(2)Landward dispersive mixing during the double pump floods

The tides (including the low-frequency modes) can be accurately hindcast and forecast

We can use these predictions to guide retrospective analysis and the timing of
(1) monitoring,
(2) research and
(3) WATER PROJECT OPERATIONS

Transport Processes

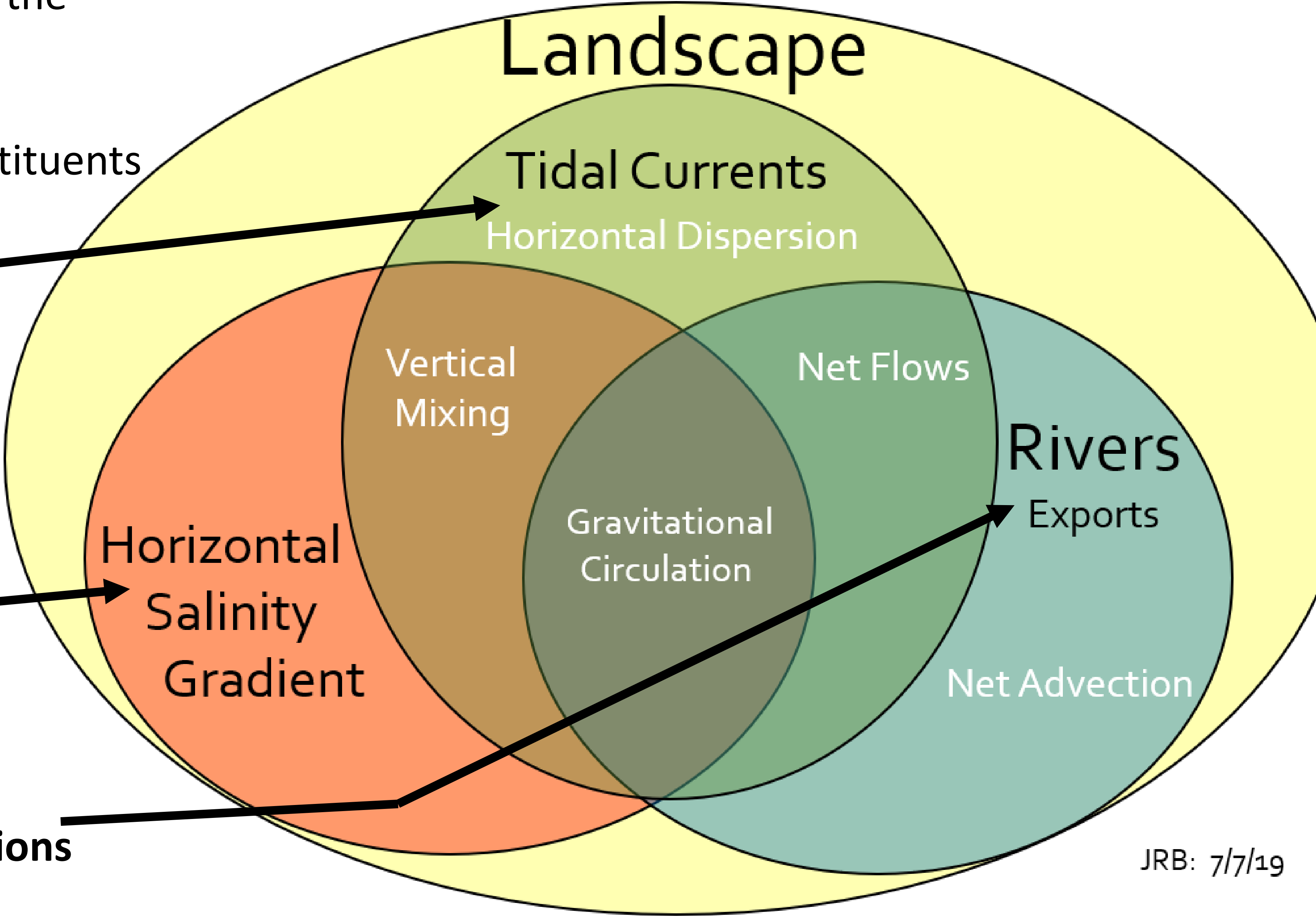
Understanding Transport Processes

Can be our guide to modifying landscapes
to enhance ecosystem services
and water supply reliability

Transport =
The movement of **stuff** in the water from place to place

Stuff = water quality constituents
= organisms

Transport in the Delta

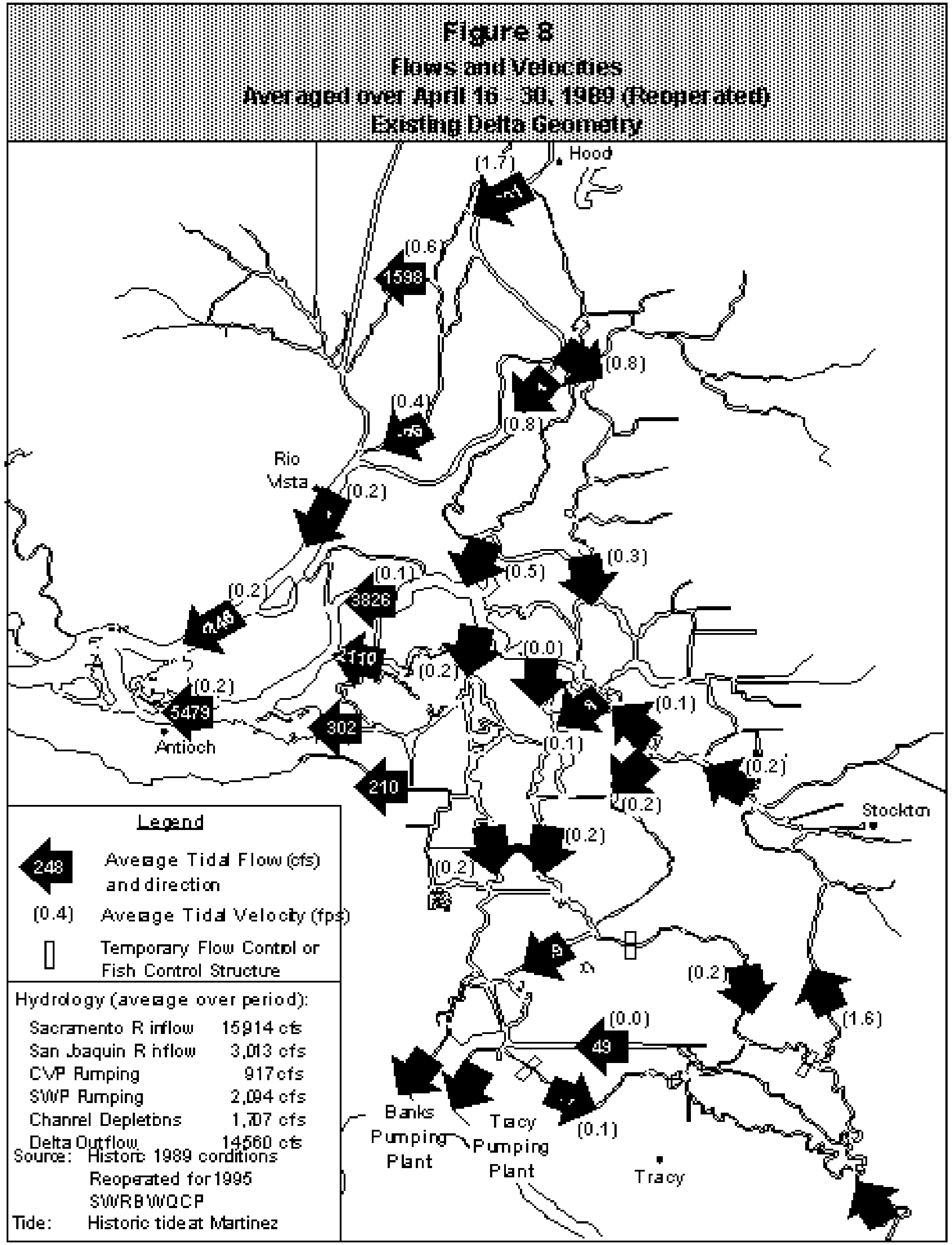


The key is..

Modifying these two **Transport mechanisms**
And
Through synchronization
With water **project operations**

JRB: 7/7/19

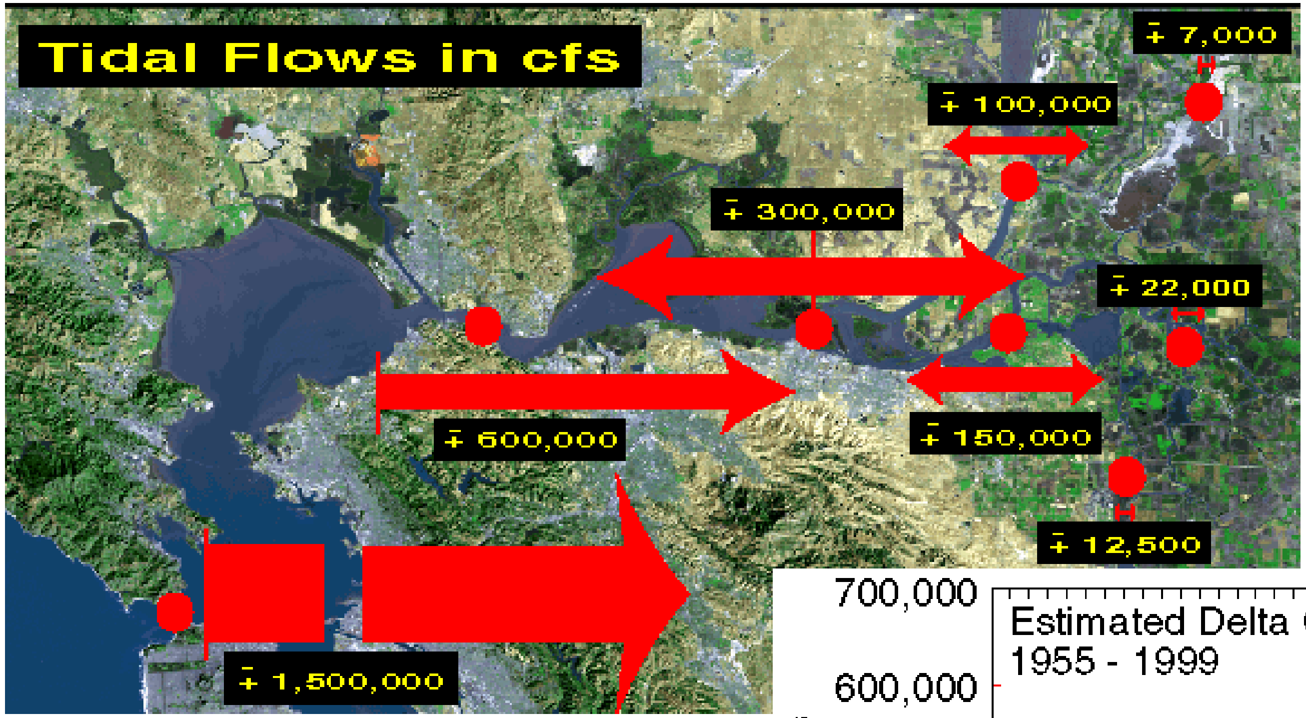
Conceptual Model I: River Model of the Delta (Net Flow Picture)

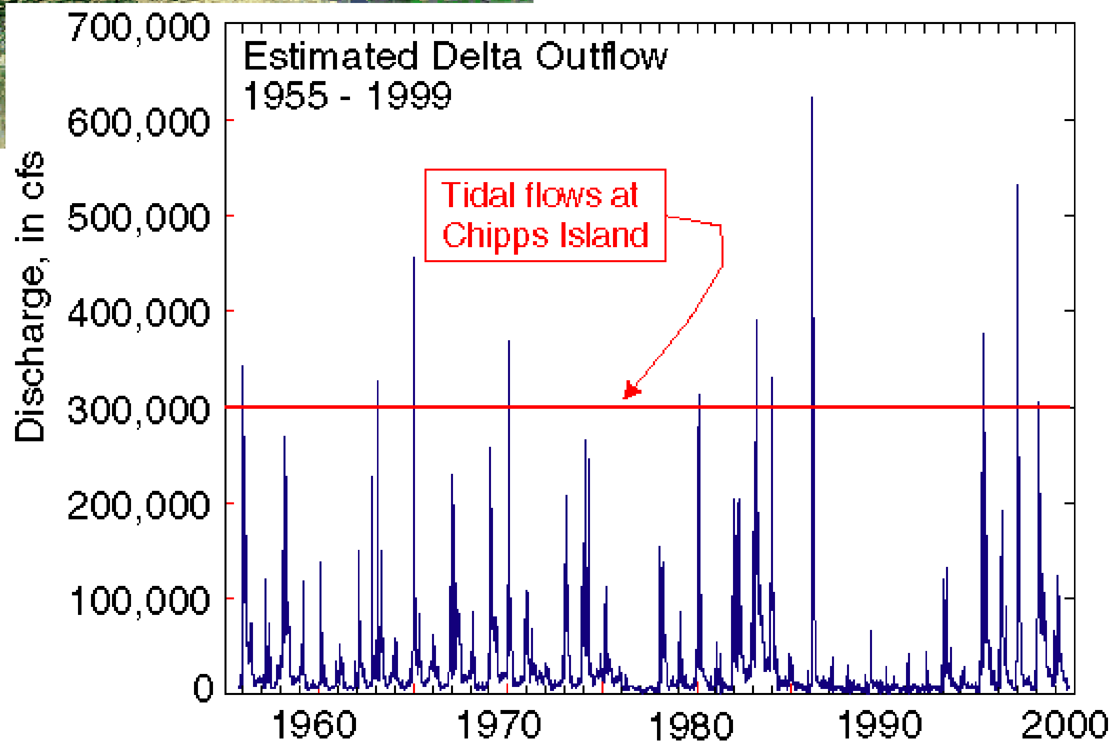


Courtesy of the DWR Modeling Section web page

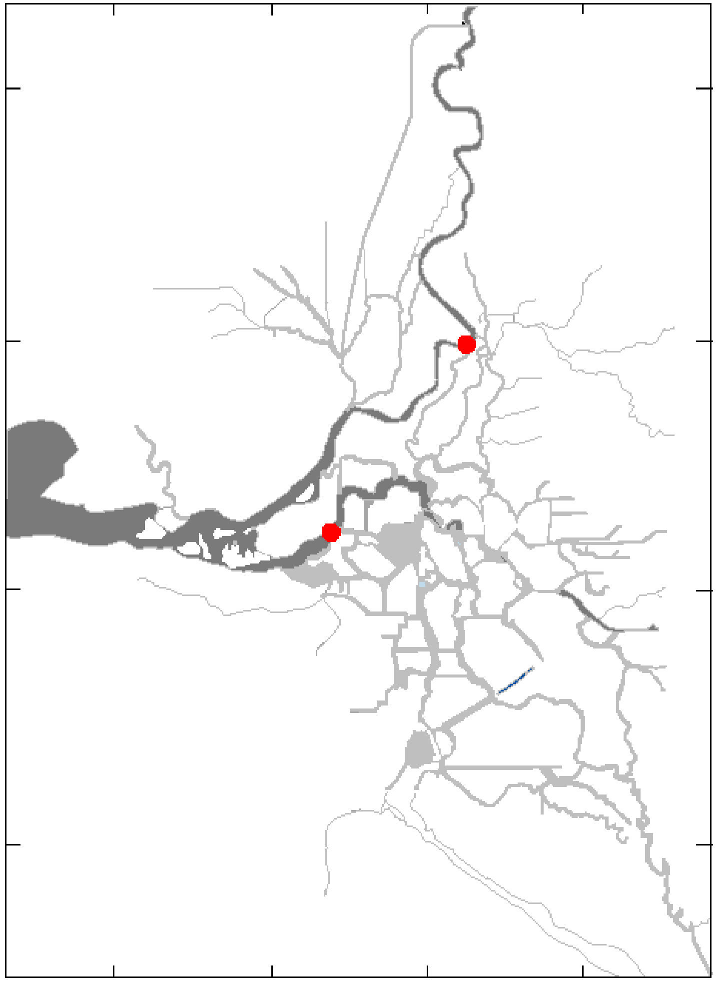
JRB

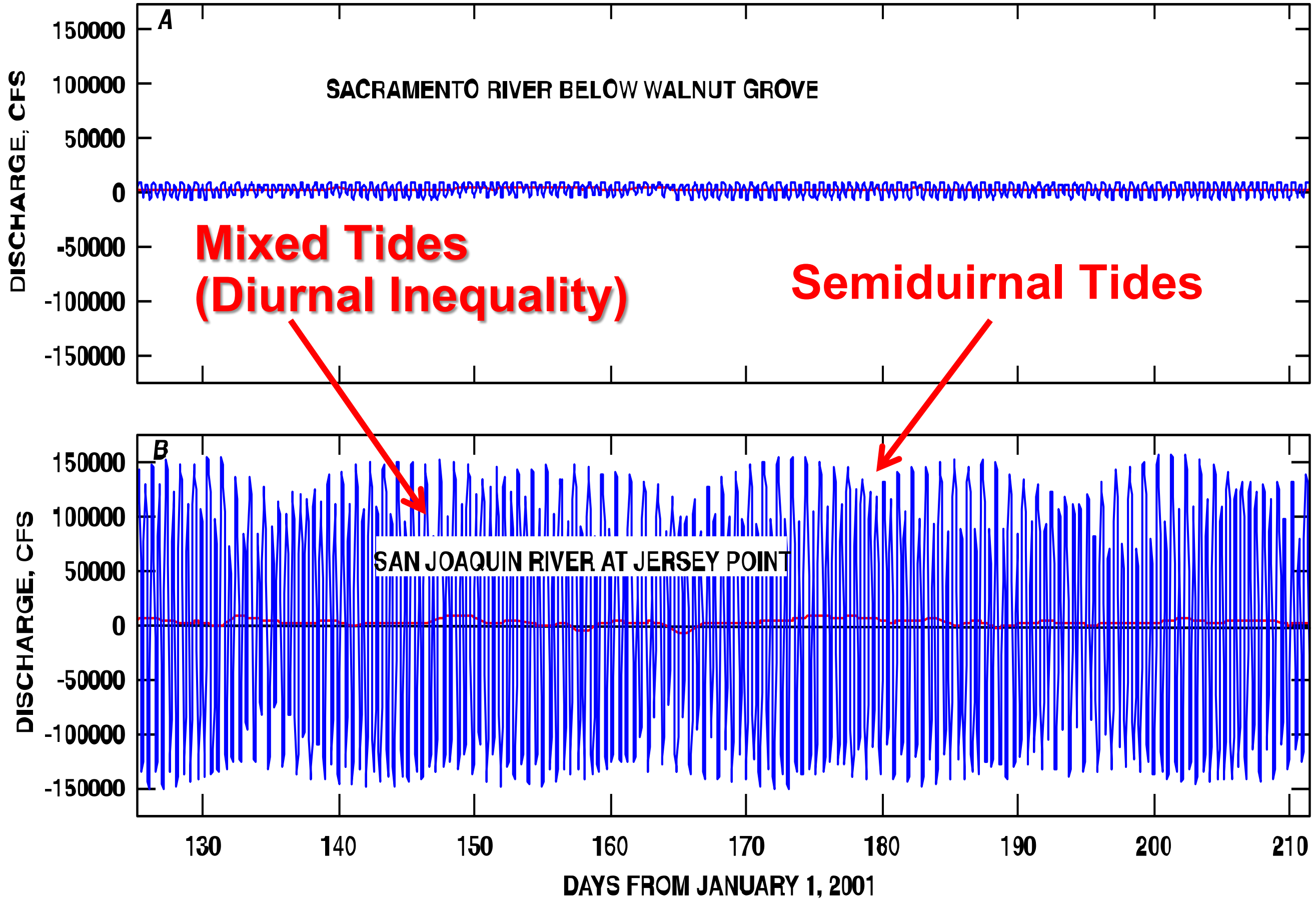
Conceptual Model II: Delta as a Tidal Lagoon





We **now know** the tides vary between a strongly mixed tide to semidiurnal tides over fortnightly (14 day), monthly, seasonal and 18.6 year cycles





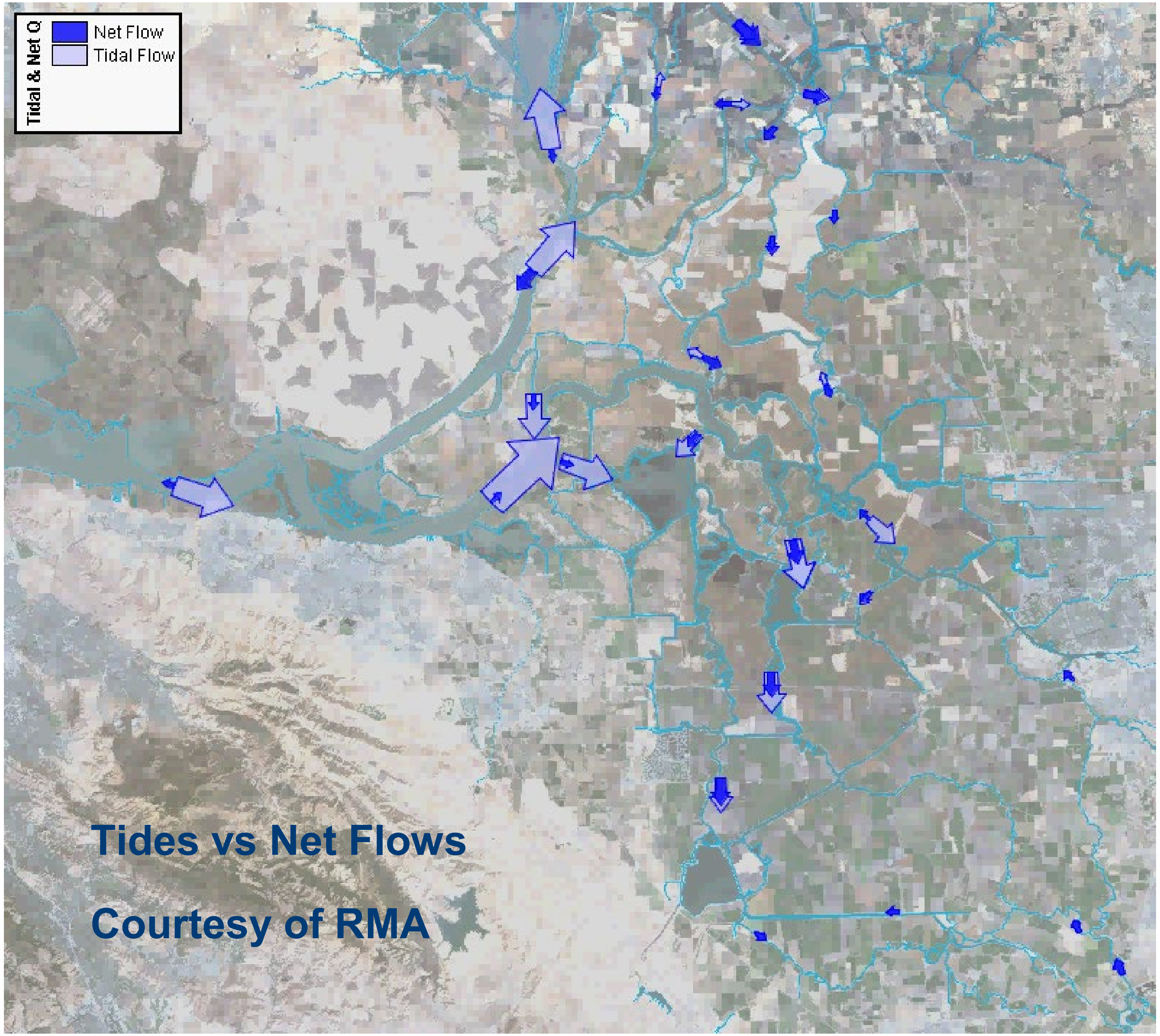
The **spring/neap cycle** does not dominate tides in the SFE

The **Tidal currents** (discharges) **dominate over the Net currents** (discharges) throughout the Delta, most of the time

JRB: Insert Delta Regions here

The Hydrodynamics in the delta are complex

The delta is
Strongly tidally
forced



Courtesy of RMA

Because the tidal currents are strong, the delta is incredibly dynamic - water, constituents, and organisms are almost always in motion

AND…

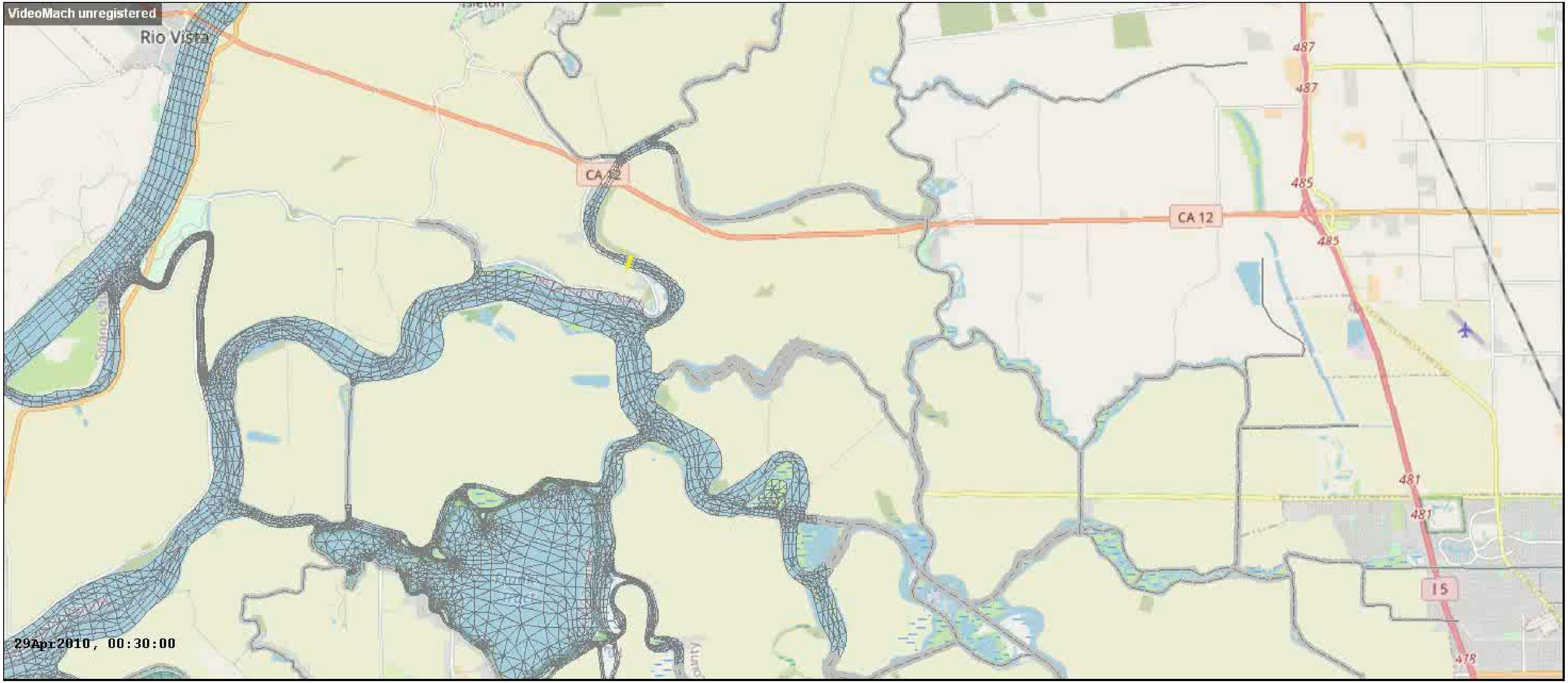
They move long distances..

Relative to the Scale of the landscape

Courtesy of RMA

Radio-Tagged Salmon Released in Georgiana Slough @ Ryde Hotel

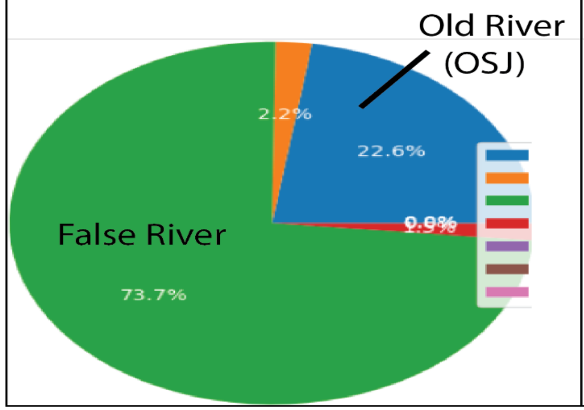
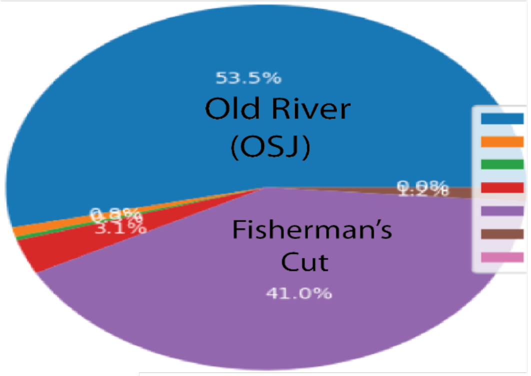
Release of Particles in Mokelumne River (2D Numerical Model)

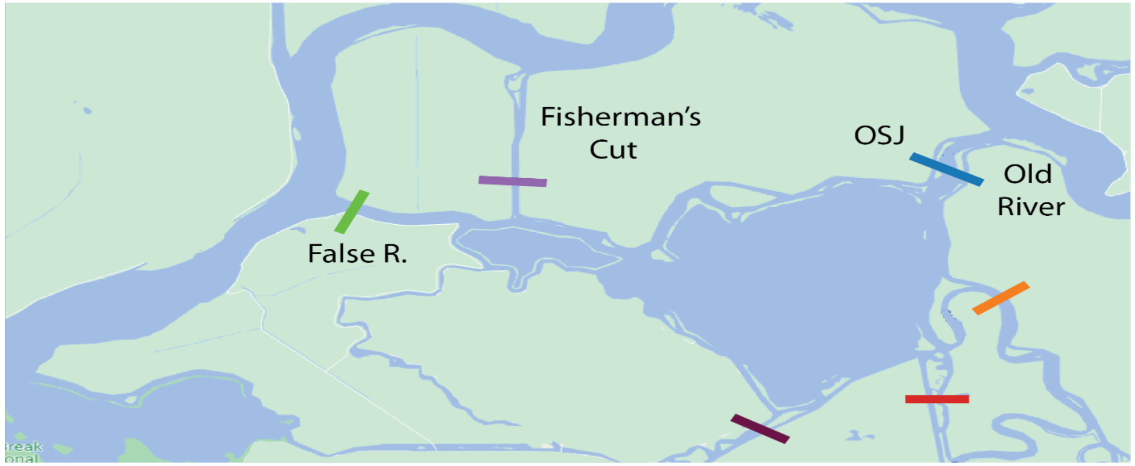


Courtesy of Steve Andrews, RMA

Particle entrainment in Franks using 2D hydrodynamic model

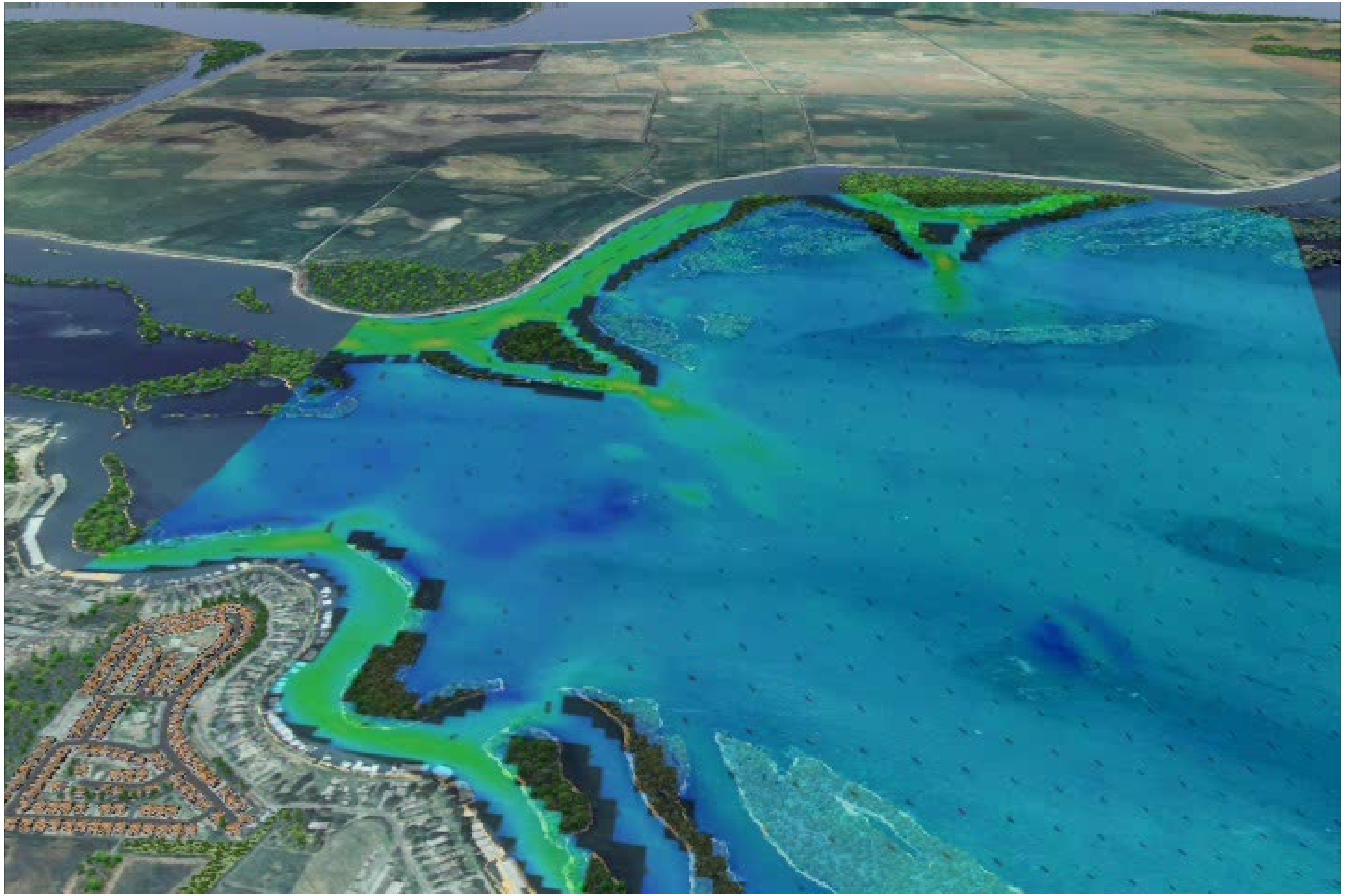
A 3D model with particles with behavior (IBM) would likely have:
(1) Greater entrainment in Franks with No Barrier
(2) Less entrainment in Old River (OSJ) with Barrier In

No Barrier 38% Enter Franks	Barrier In 25% Enter Franks
	

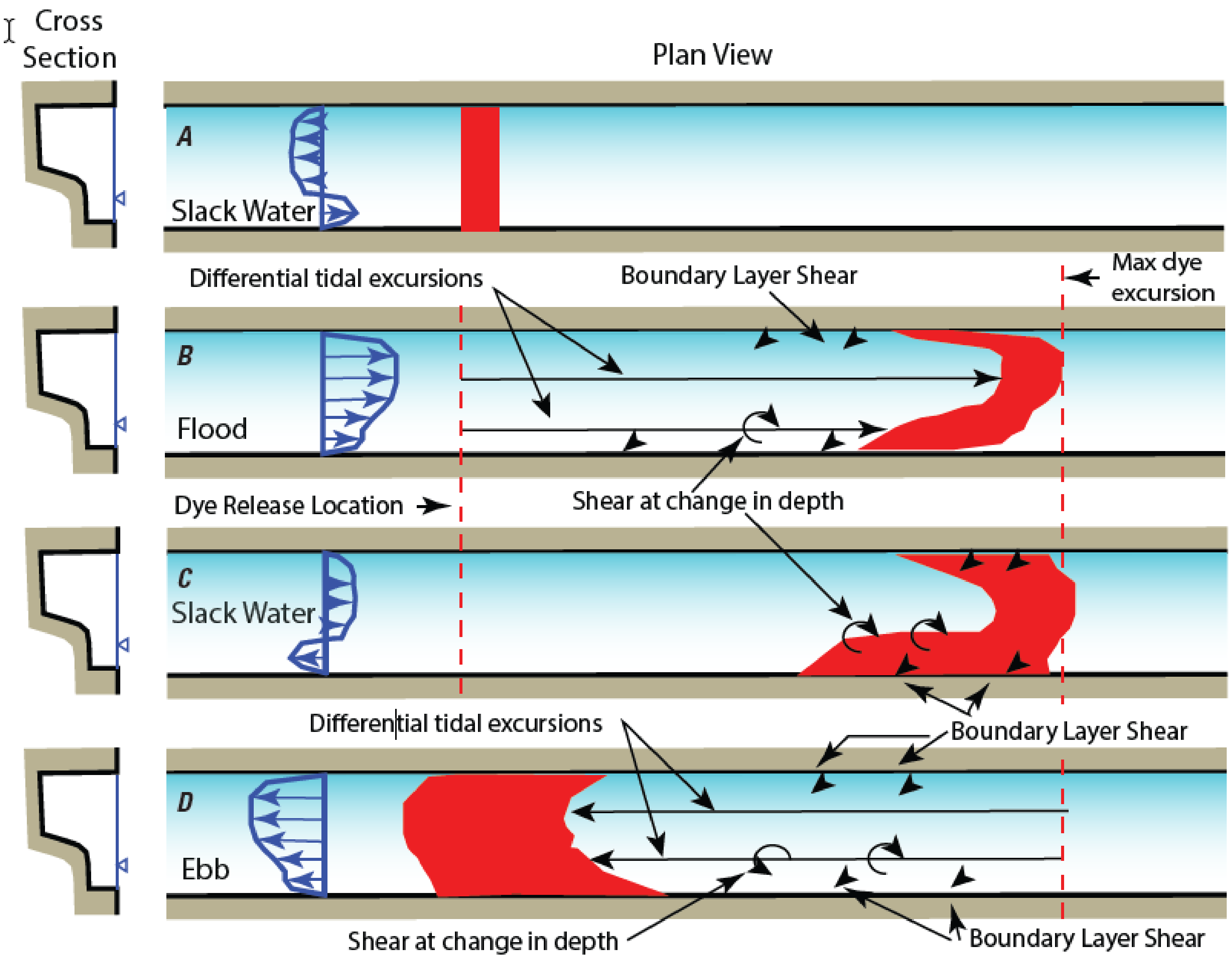


Franks Tract – Massive dispersive mixing

Franks Tract Nozzle – Flood/Ebb asymmetry adds to dispersion
Jet in potential flow out



Shear flow dispersion (weak) and tidal straining (strong in wide channels)



Thanks for your attention!

Bring layers!
Go light on the coffee – minimal access to bathrooms

See ya tomorrow on the water!