Flow, Sediment, and Water Quality Monitoring in the Delta: A case for a high-frequency flux-based monitoring program

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USGS

JRB

Outline

Jon: Basic concepts, flow monitoring

Dave: Examples from
suspended sediment concentration time series

Brian: Examples from
organic carbon and nutrient time series

What do we mean by:

a high-frequency flux-based monitoring program ?

We discuss the need for
high frequency sampling first.

In most cases, management questions center on how things change quarterly, seasonally and between years…

what we refer to as the…

“management timescales”.

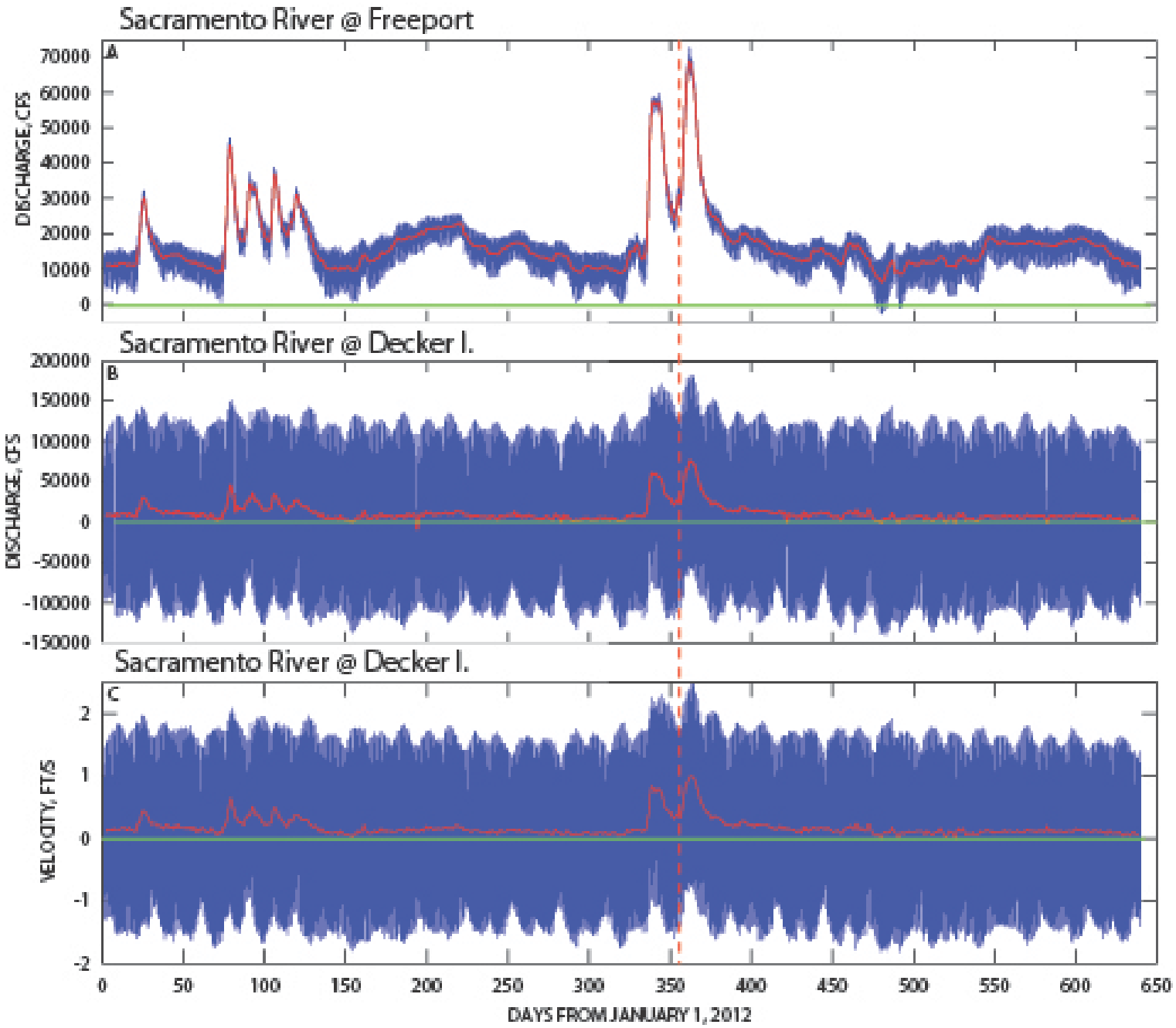
Collecting unbiased, unaliased data at "management timescales" in the delta is actually VERY challenging

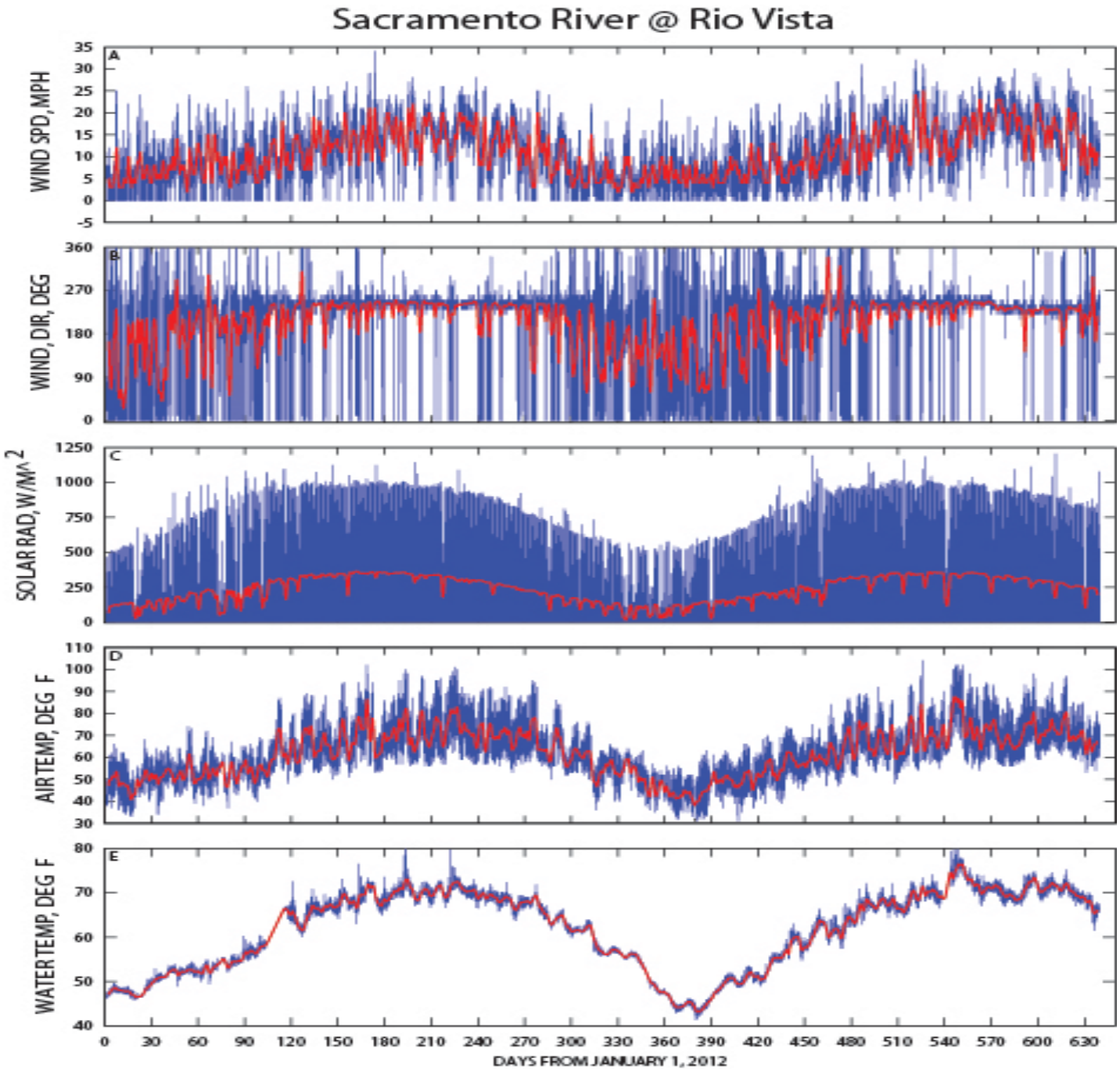
Invariably high frequency variability (tides, etc.) gets "in the way"

Temporal variability is strongly influenced by the following physical forcing mechanisms (from high freq to low):

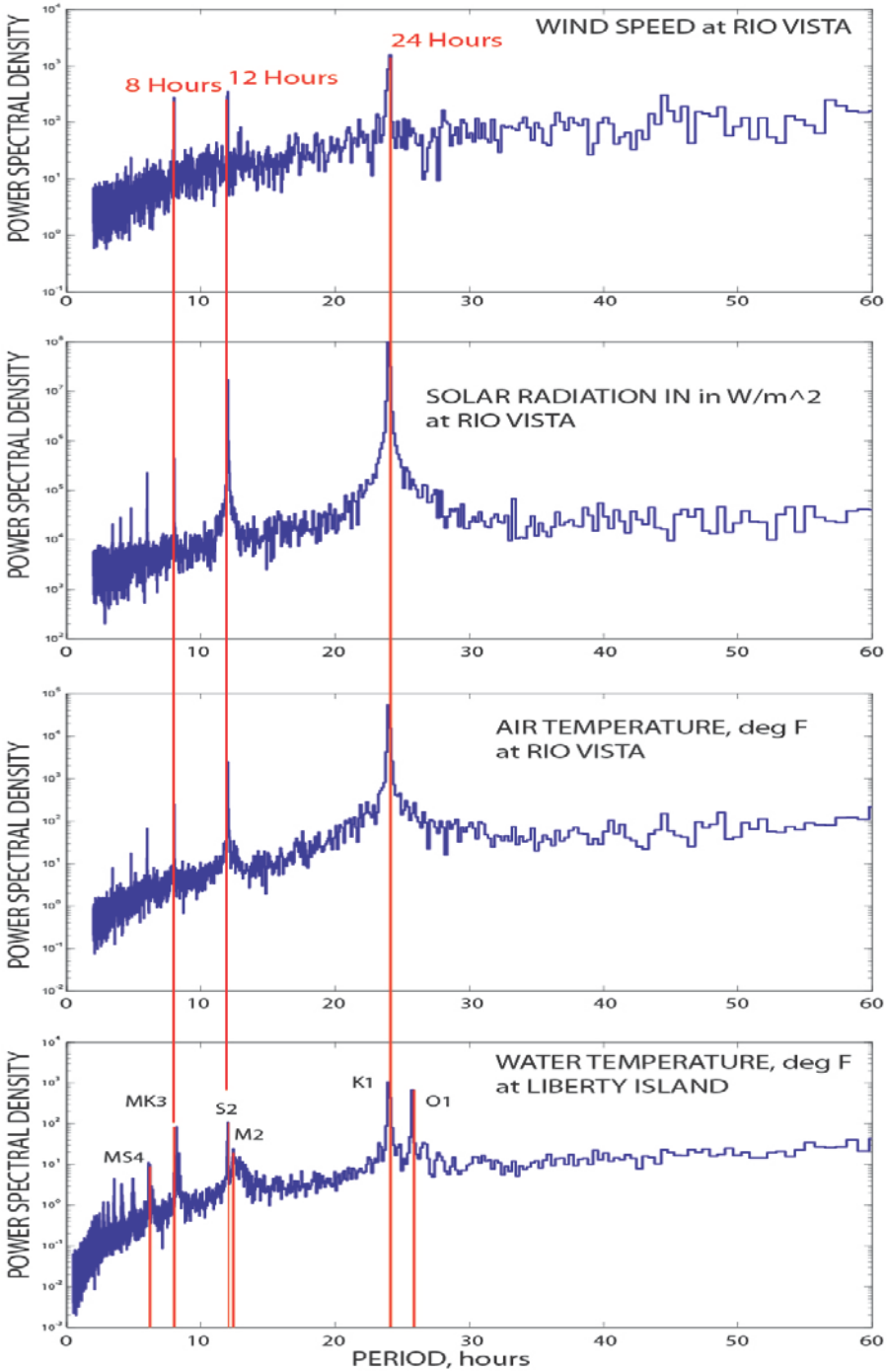
(1) Tidal Currents
(2) Wind Speed
(**2**) Solar Radiation (day/night)
(3) Air Temperature,
which together control
(4) Water Temperatures
(5) Hydrology (river inputs and pumping).

Use data from Sacramento River at Decker Island as an example..


Sacramento River @ Freeport
A
DISCHARGE, CFS
70000
60000
50000
40000
30000
20000
10000
0
Sacramento River @ Decker I.
B
DISCHARGE, CFS
200000
150000
100000
50000
0
-50000
-100000
-150000
Sacramento River @ Decker I.
C
VELOCITY, FT/S
2
1
0
-1
-2
0
50
100
150
200
250
300
350
400
450
500
550
600
650
DAYS FROM JANUARY 1, 2012

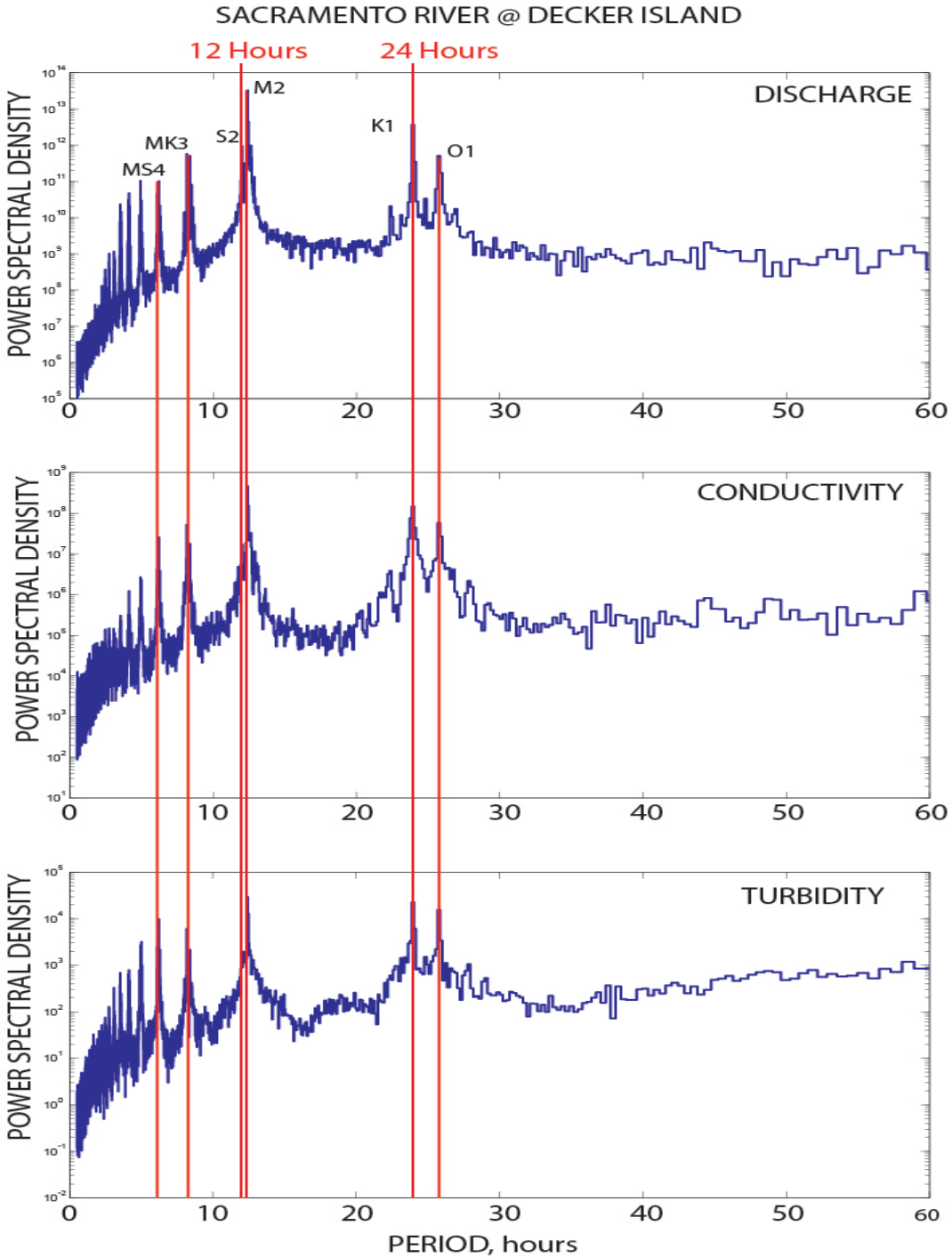

Sacramento River @ Rio Vista
A
WIND SPD, MPH
35
30
25
20
15
10
5
0
-5
B
WIND, DIR, DEG
360
270
180
90
0
C
SOLAR RAD, W/M^2
1250
1000
750
500
250
0
D
AIRTEMP, DEG F
110
100
90
80
70
60
50
40
30
E
WATERTEMP, DEG F
80
70
60
50
40
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630
DAYS FROM JANUARY 1, 2012

Together, these principal physical drivers create temporal variability at primarily 12 hour, 24 hour, 14 day (fortnightly) and seasonal timescales.



Meteorological Variables
(Diurnal)

Diurnal+Tidal

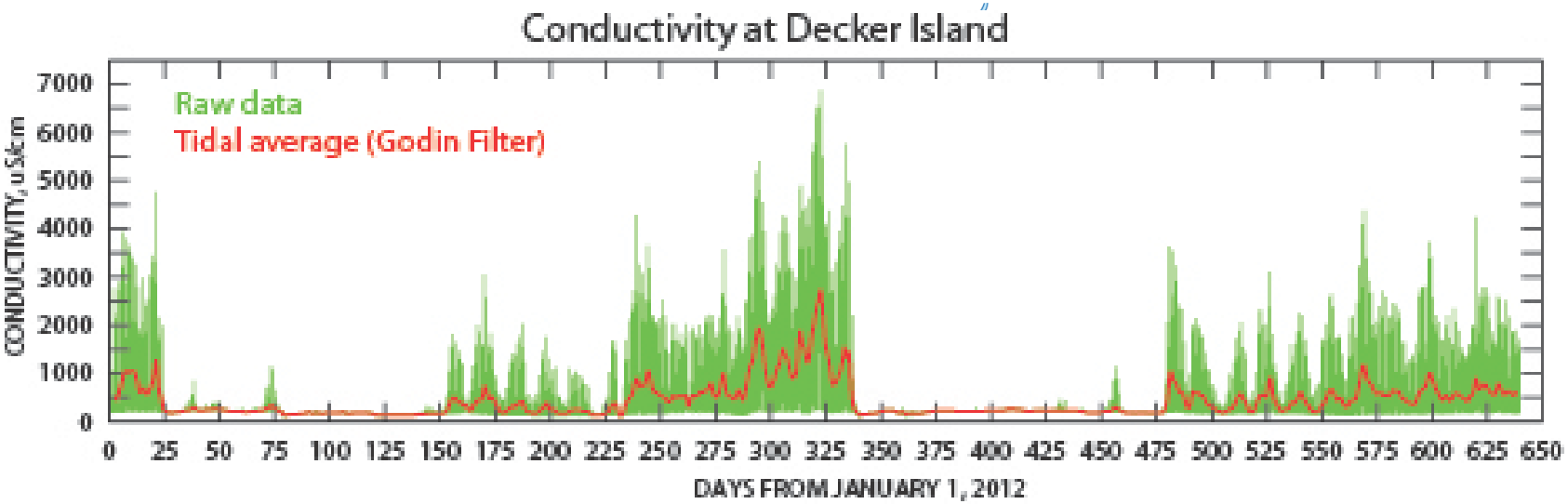


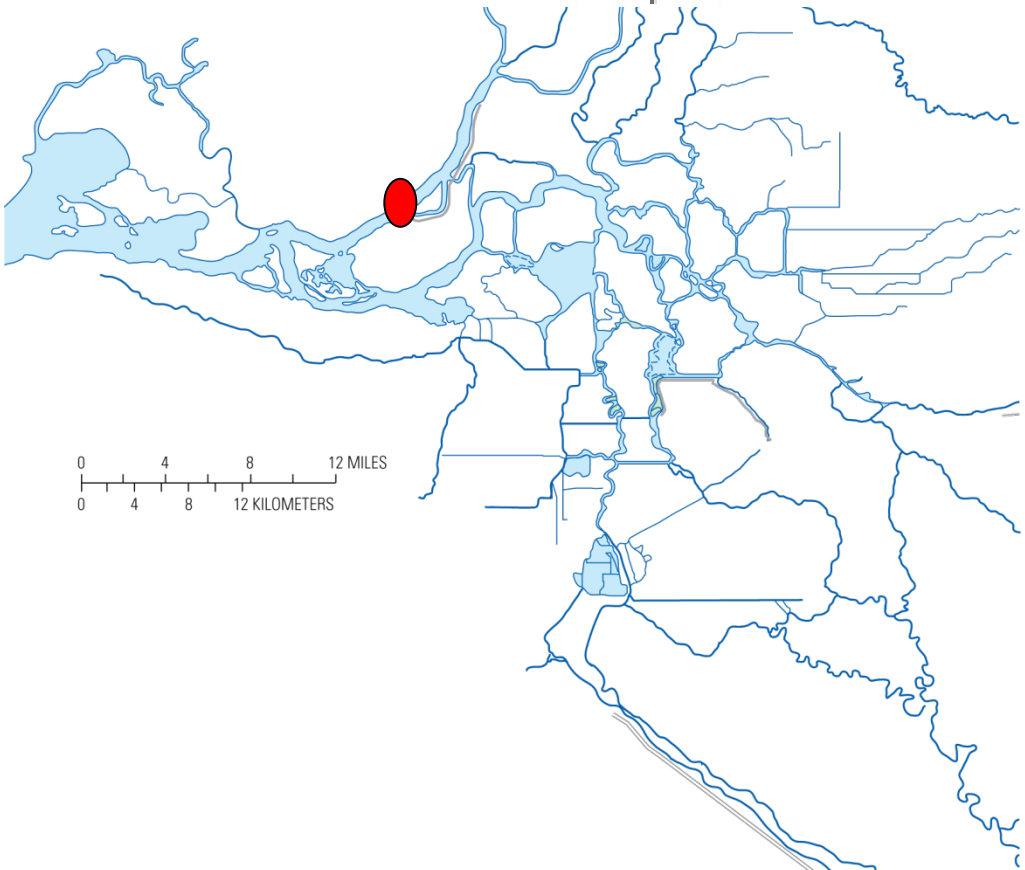
Water Constituents

Aliasing (sampling too slowly) Example

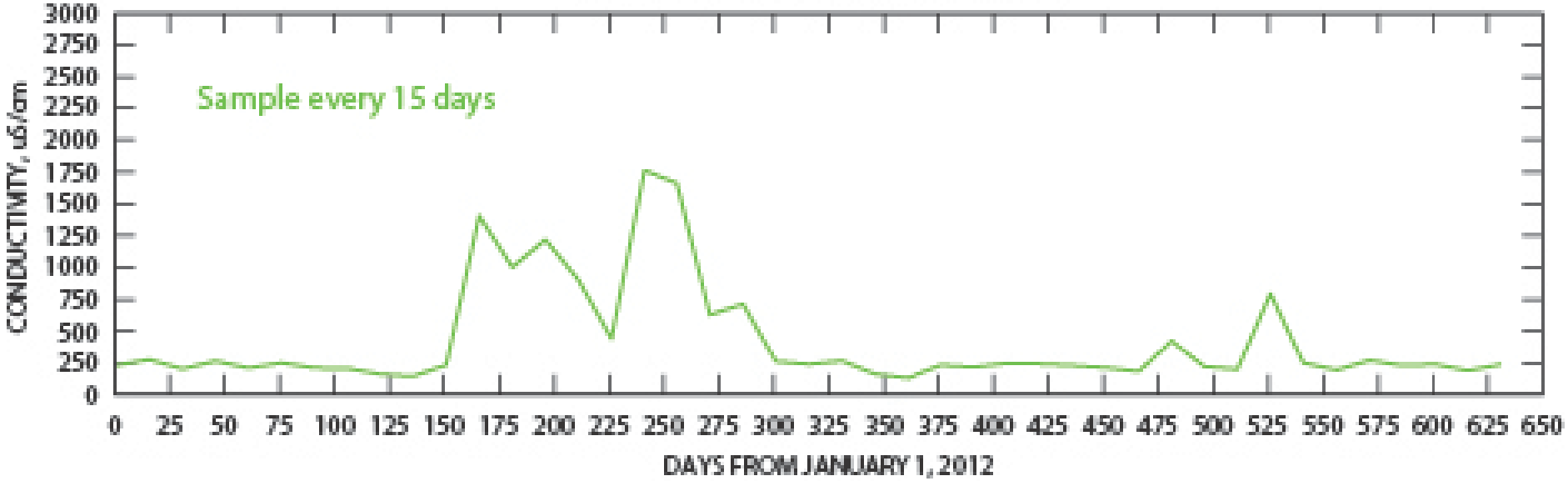
Plots of Electrical Conductivity at Decker Island

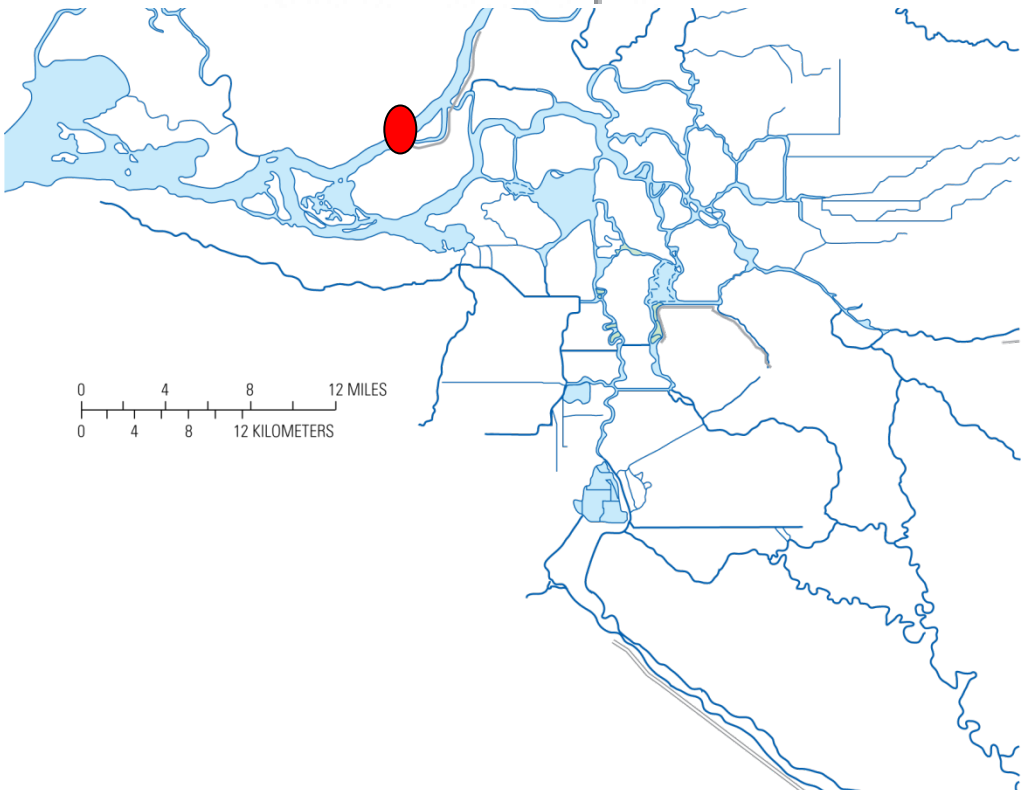
Sample using different strategies

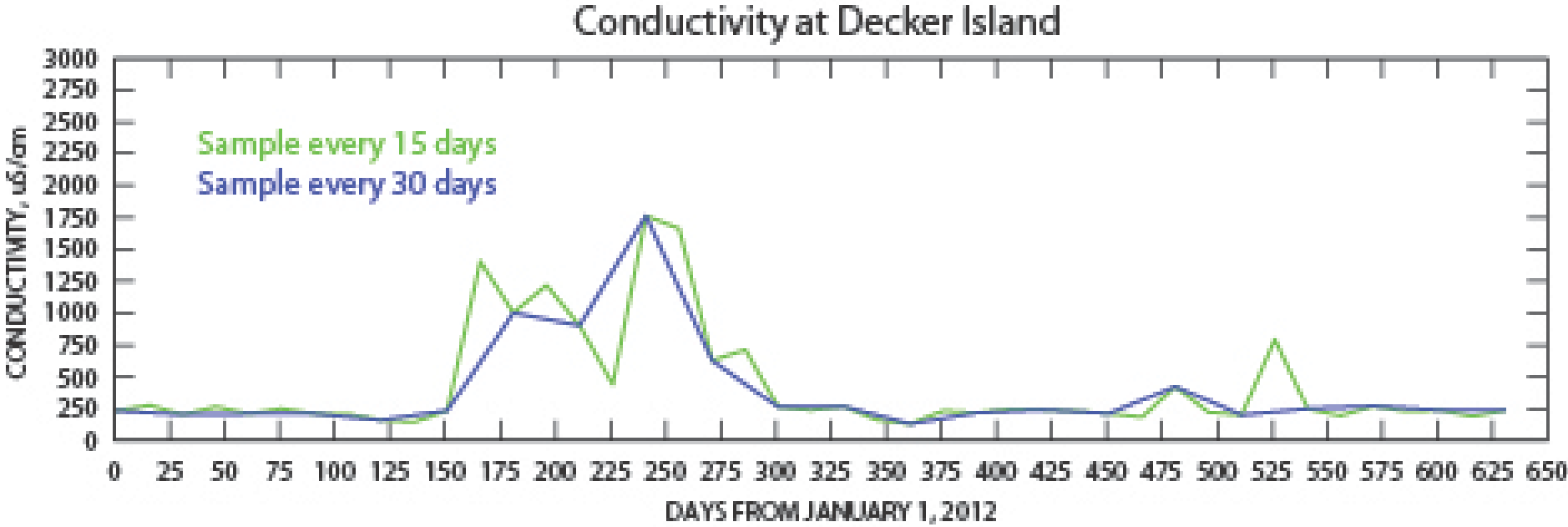

Conductivity at Decker Island
Raw data
Tidal average (Godin Filter)
CONDUCTIVITY, uS/cm
7000
6000
5000
4000
3000
2000
1000
0
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500 525 550 575 600 625 650
DAYS FROM JANUARY 1, 2012

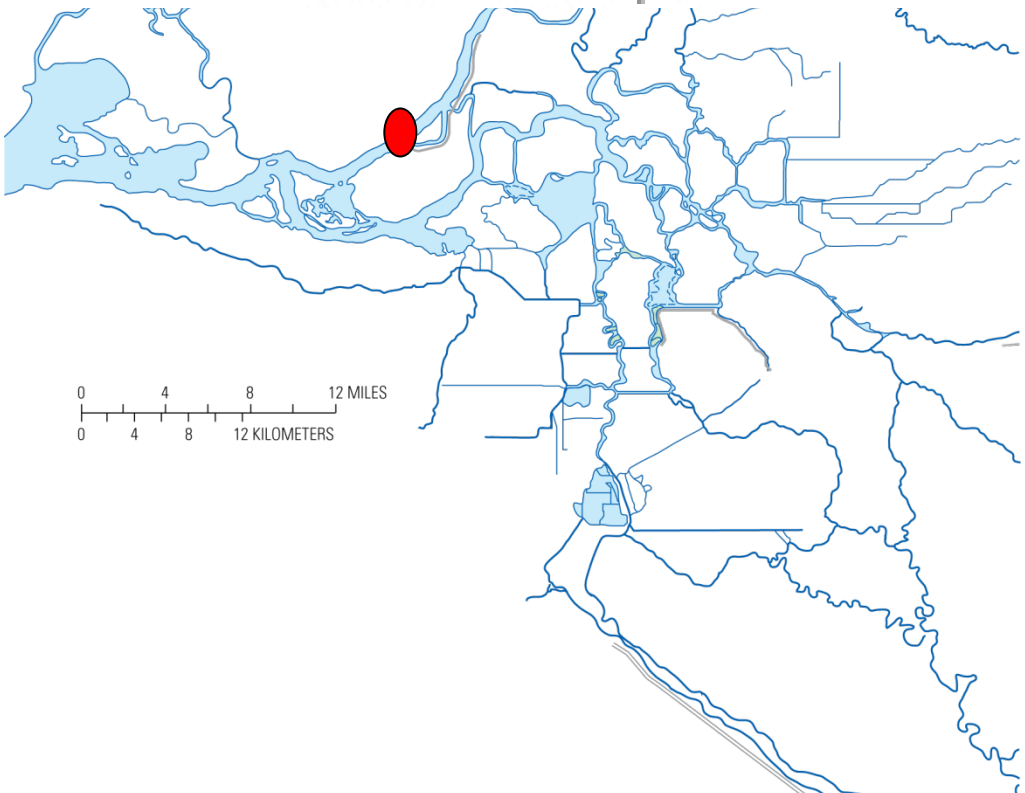

0 4 8 12 MILES
0 4 8 12 KILOMETERS

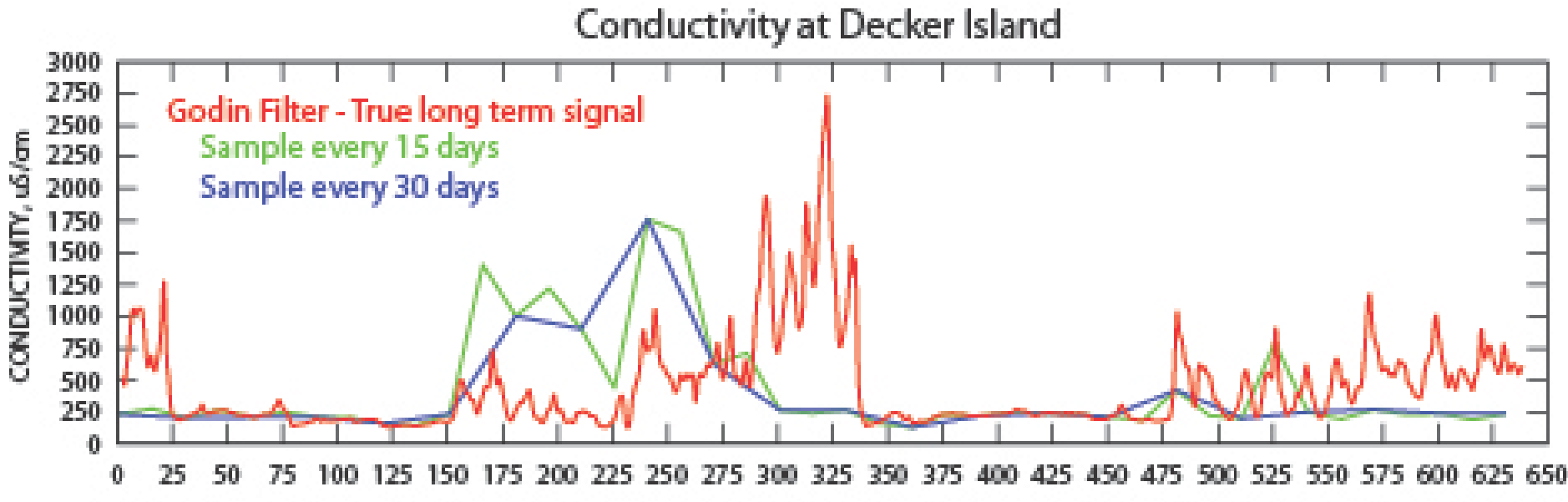
Conductivity at Decker Island

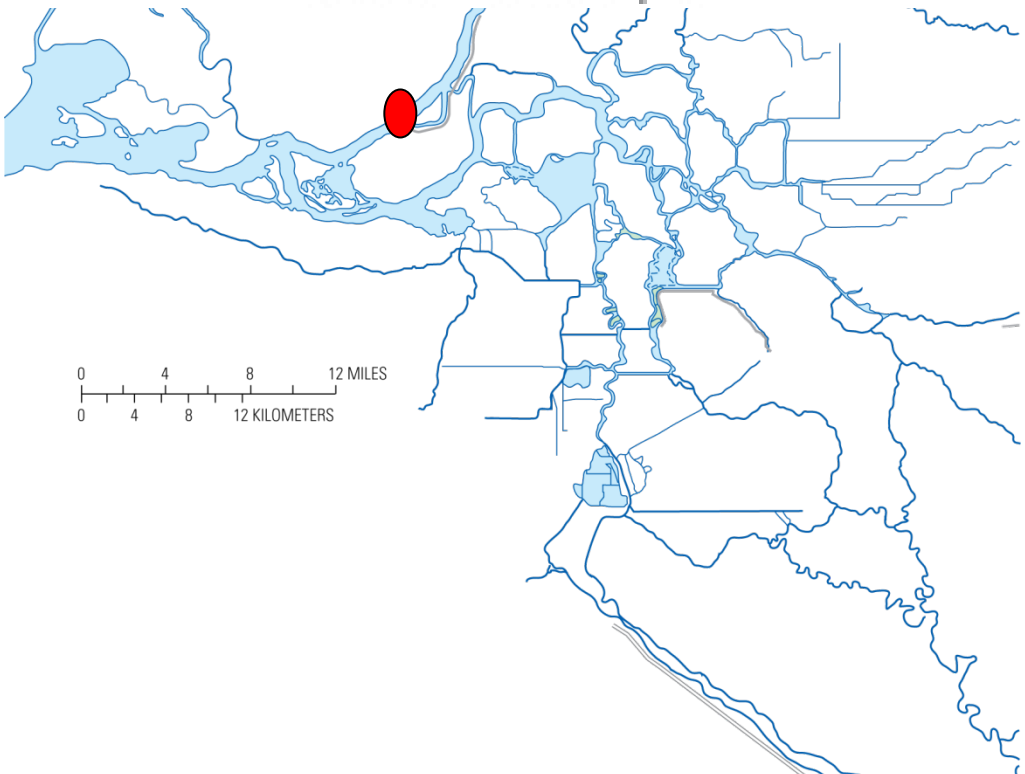


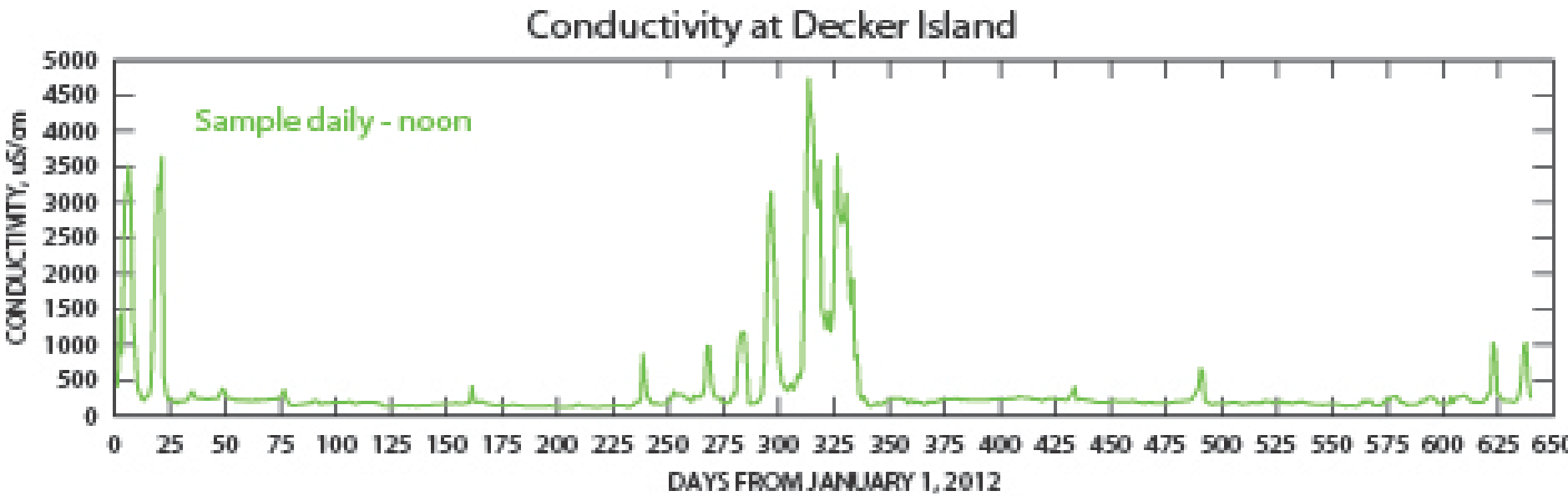


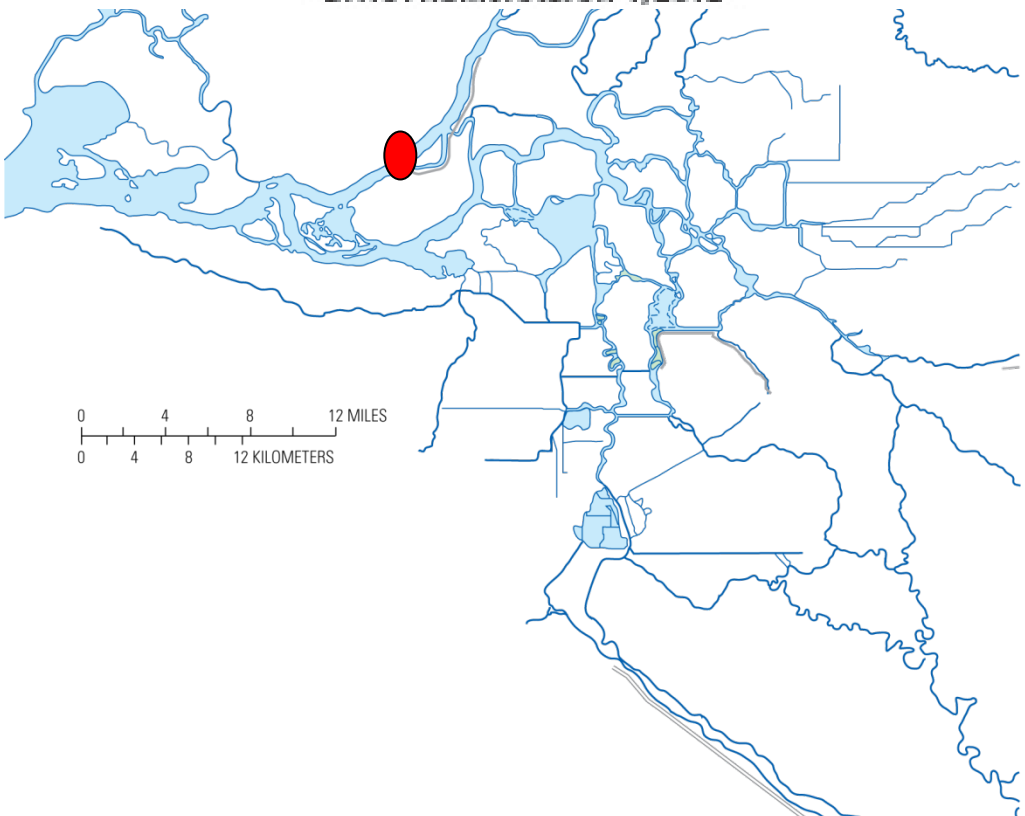

Conductivity at Decker Island
Sample every 15 days
Sample every 30 days
CONDUCTIVITY, uS/cm
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500 525 550 575 600 625 650
DAYS FROM JANUARY 1, 2012

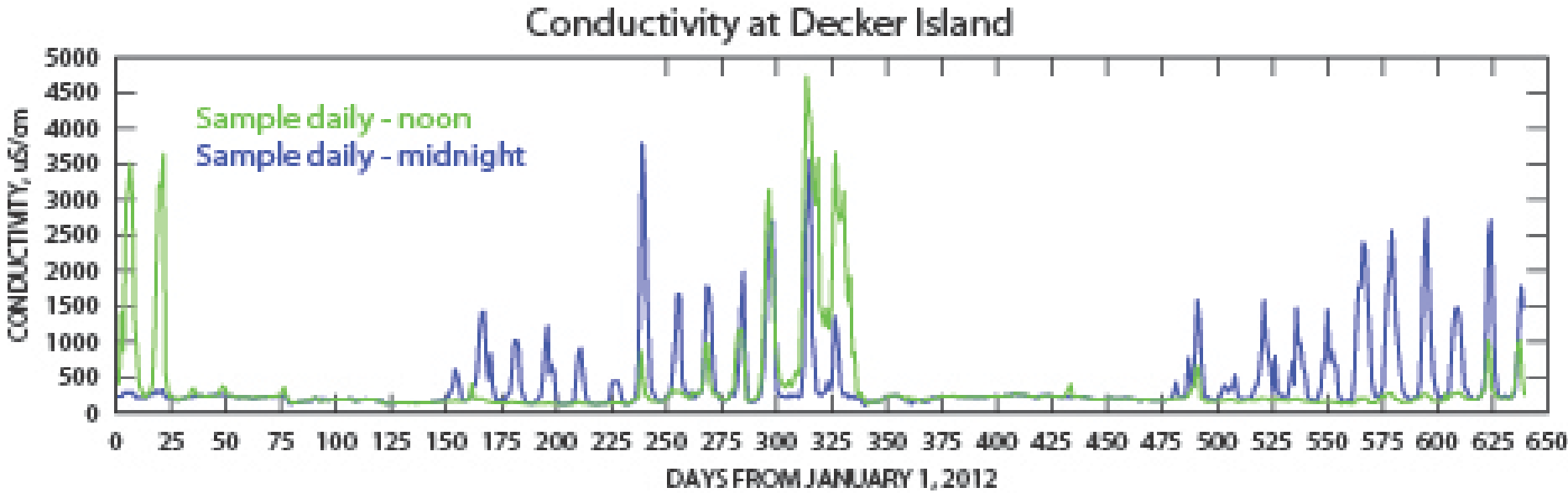

0 4 8 12 MILES
0 4 8 12 KILOMETERS

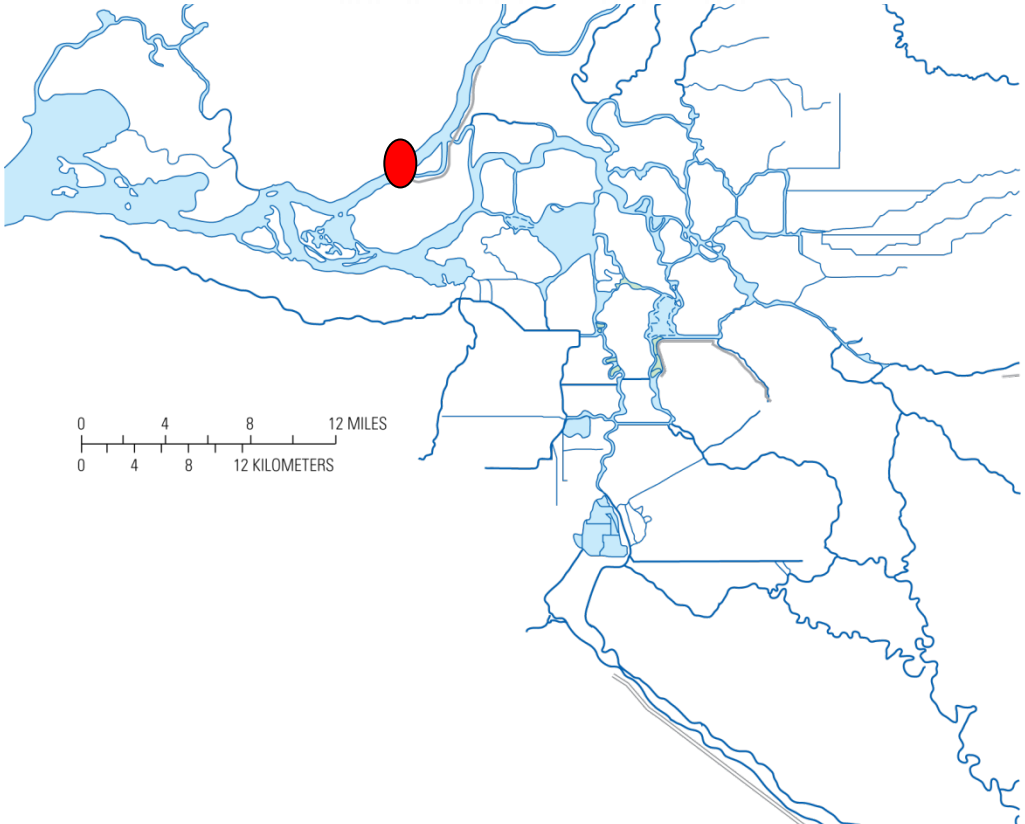

Conductivity at Decker Island
Godin Filter - True long term signal
Sample every 15 days
Sample every 30 days
CONDUCTIVITY, uS/cm
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500 525 550 575 600 625 650
DAYS FROM JANUARY 1, 2012


0 4 8 12 MILES
0 4 8 12 KILOMETERS

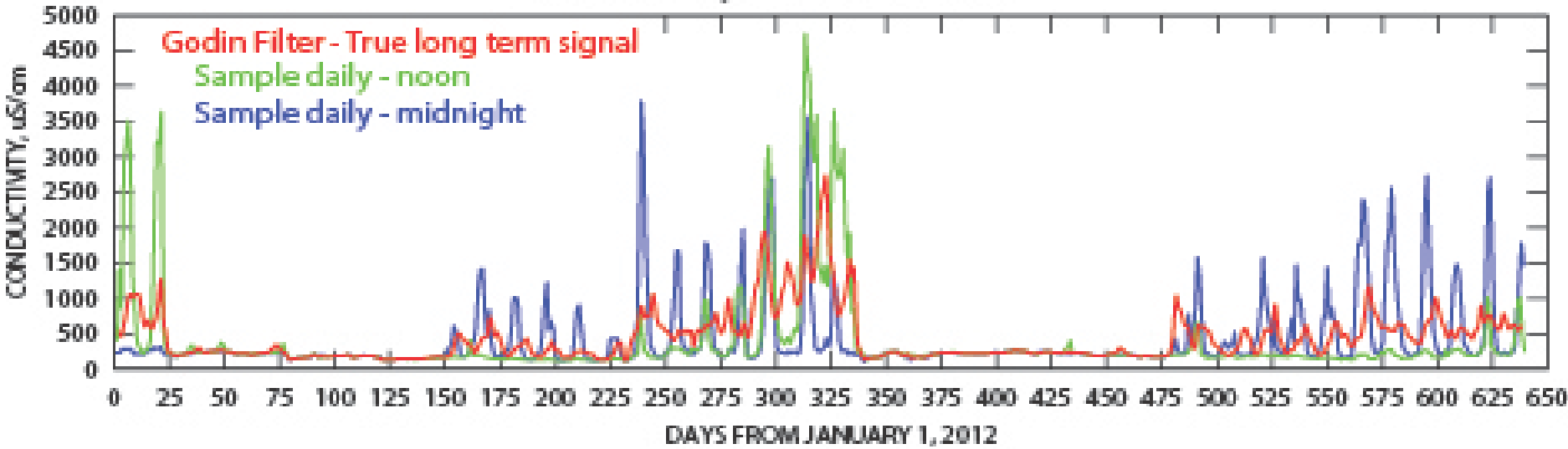

Conductivity at Decker Island
Sample daily - noon
CONDUCTIVITY, uS/cm
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500 525 550 575 600 625 650
DAYS FROM JANUARY 1, 2012

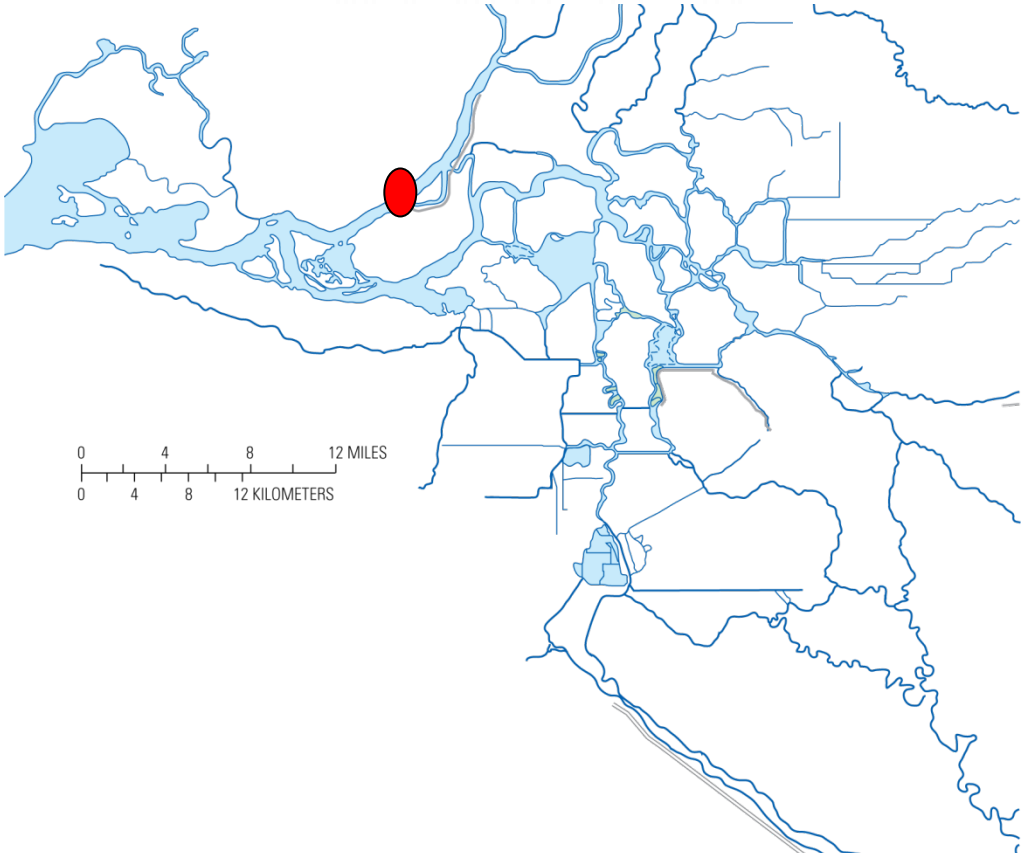

0 4 8 12 MILES
0 4 8 12 KILOMETERS


Conductivity at Decker Island
Sample daily - noon
Sample daily - midnight
CONDUCTIVITY, uS/cm
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500 525 550 575 600 625 650
DAYS FROM JANUARY 1, 2012


0 4 8 12 MILES
0 4 8 12 KILOMETERS

Conductivity at Decker Island



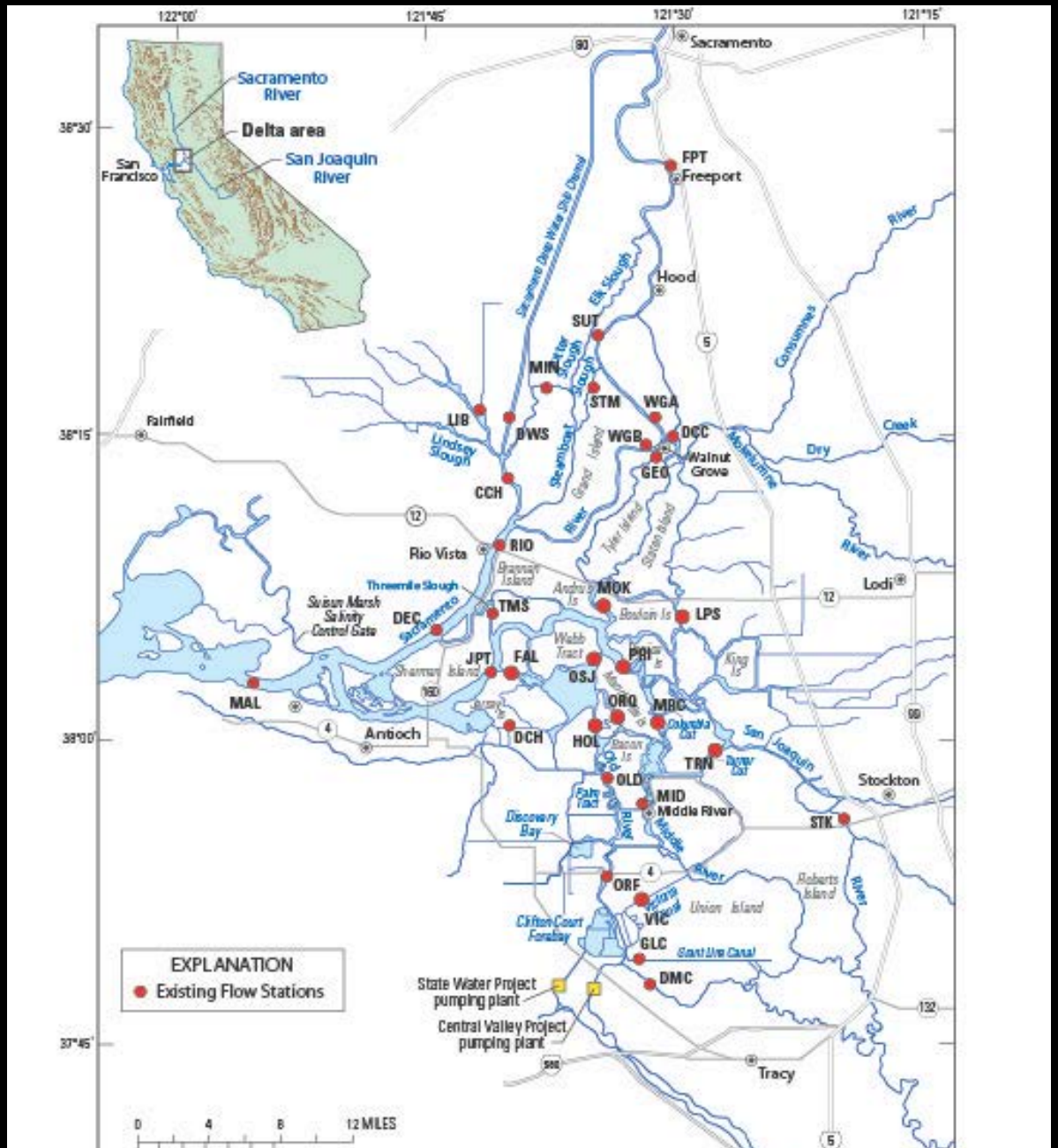


Flux-based monitoring program?

Measure EVERYTHING adjacent to flow stations
(EC, Temp, Chl-a, Turb, OC, FISH!)

Flux = (Discharge)*stuff

Flow Station Network (circa Nov 2013)

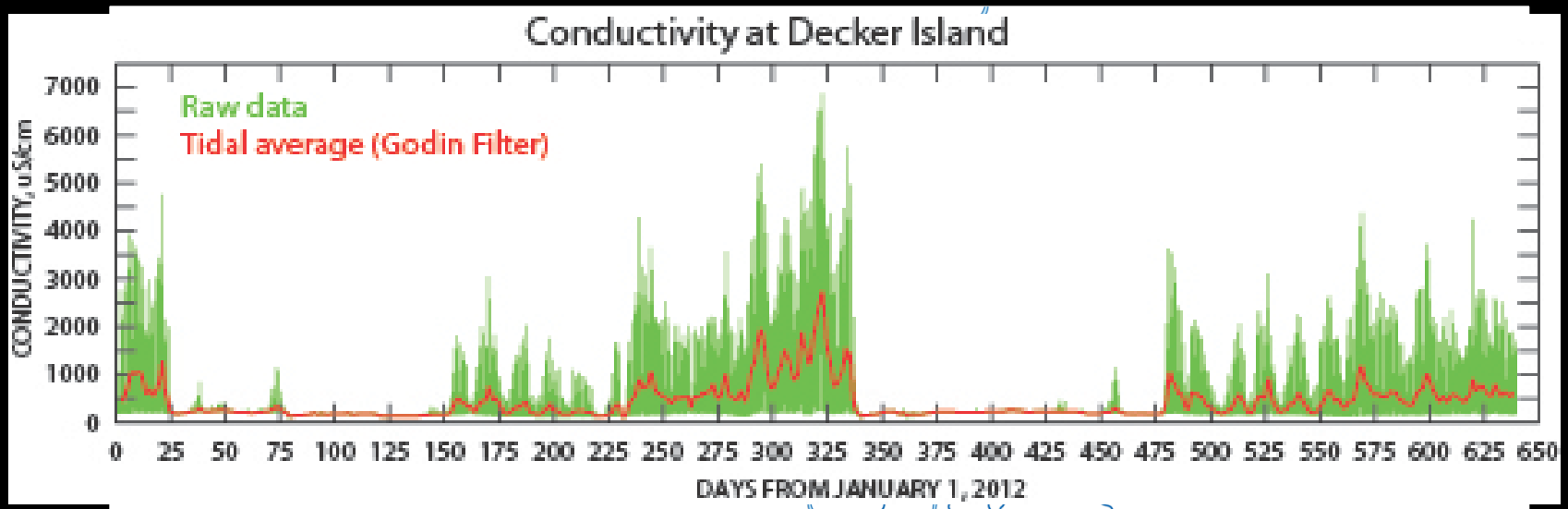


Typical Station – Cache Slough

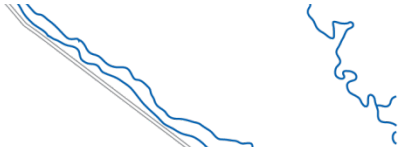
Flux-based monitoring program?

By measuring adjacent to flow (V, Q)
we can not only tell how a parameter varies in time..

We can deduce its
Spatial structure (within a tidal excursion)
and tell where its been and where its going



So what controls variability in salinity at Decker?

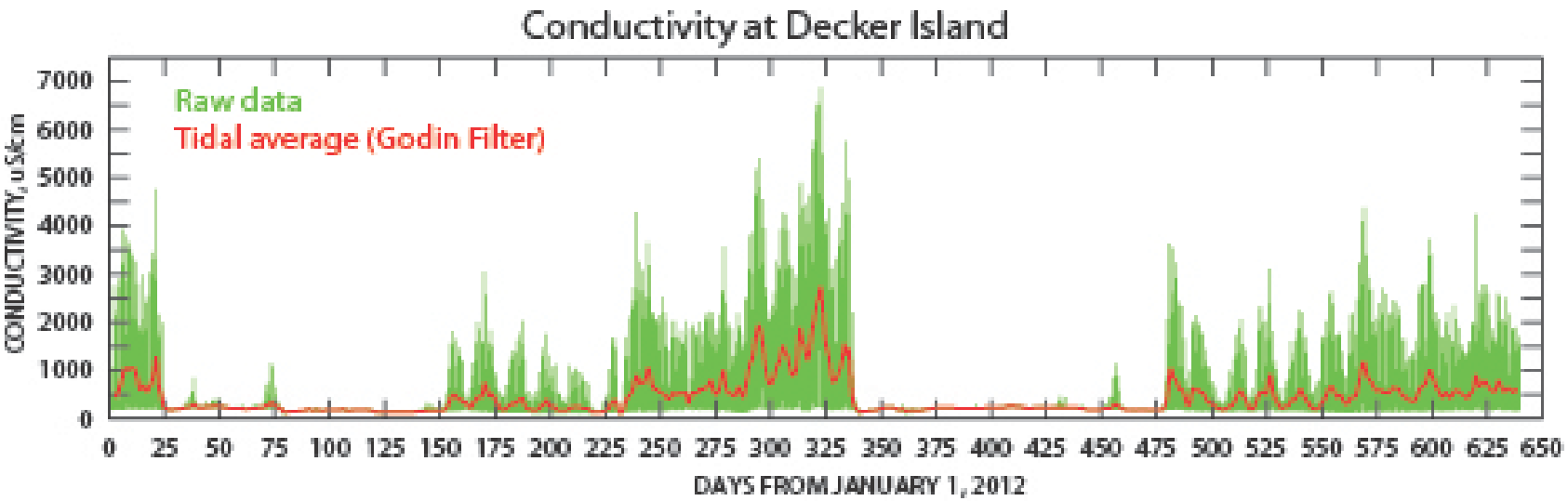


Animation of particle tracks

Drifter tracks during solstice spring tide

Animation of salt field

File: salt.field.DSC.avi



$$\frac{\partial C}{\partial t} = -U\frac{\partial C}{\partial x} + D\frac{\partial^2 C}{\partial^2 x} + S$$

In General…

$$\frac{\partial C'}{\partial t} = -U'\frac{\partial C}{\partial x}$$

Tidal timescale

$$\frac{\partial <C>}{\partial t} = -<U>\frac{\partial C}{\partial x} + <D\frac{\partial^2 C}{\partial^2 x}> + <S>$$

Residual timescale

$$X = X' + <X>$$

$$<X> = Tidal\ average\ \ X' = tidal\ timescale, X = measured$$

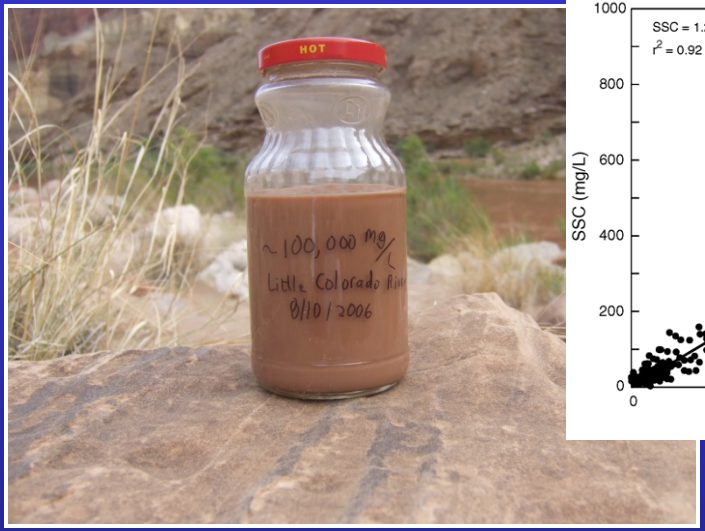
Why do we study turbidity AND sediment?

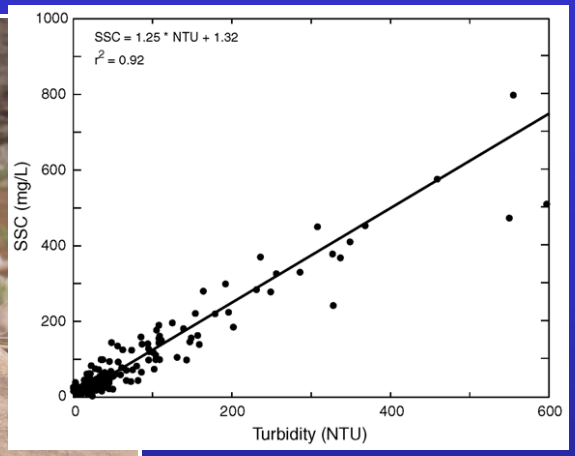
- Suspended sediment is the primary cause of turbidity in the Delta
- Turbidity is an optical property of water that's great for monitoring but not for understanding rates of movement (flux) or physical processes
- The principle of conservation of (sediment) mass allows physics-based numerical modeling and calculation of sediment budgets
- Sediment transport and geomorphology affects wetland sustainability, navigation/dredging, levee stability, contaminant transport, aquatic vegetation, and phytoplankton, in addition to fish habitat

USGS

Concentration and flux

- Suspended-sediment concentration = Mass/Volume (milligrams per liter). Primary cause of turbidity in the Estuary.





Ganju et al. 2007

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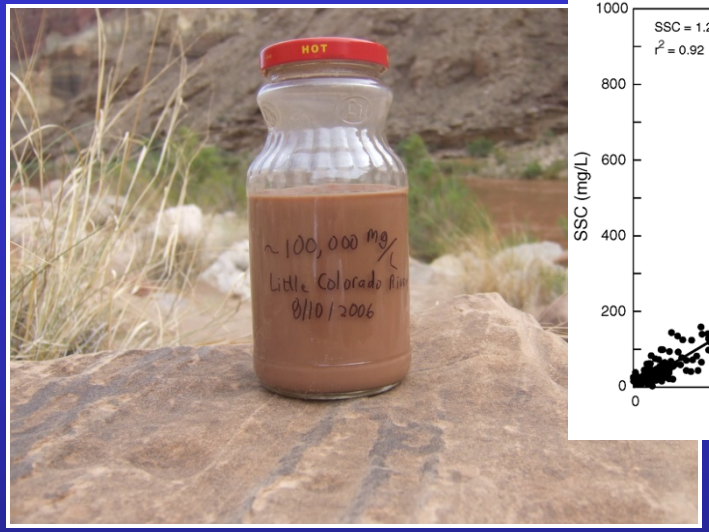
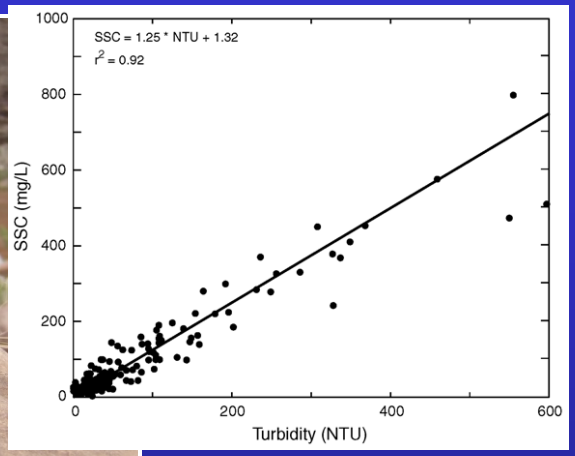




Ganju et al. 2007

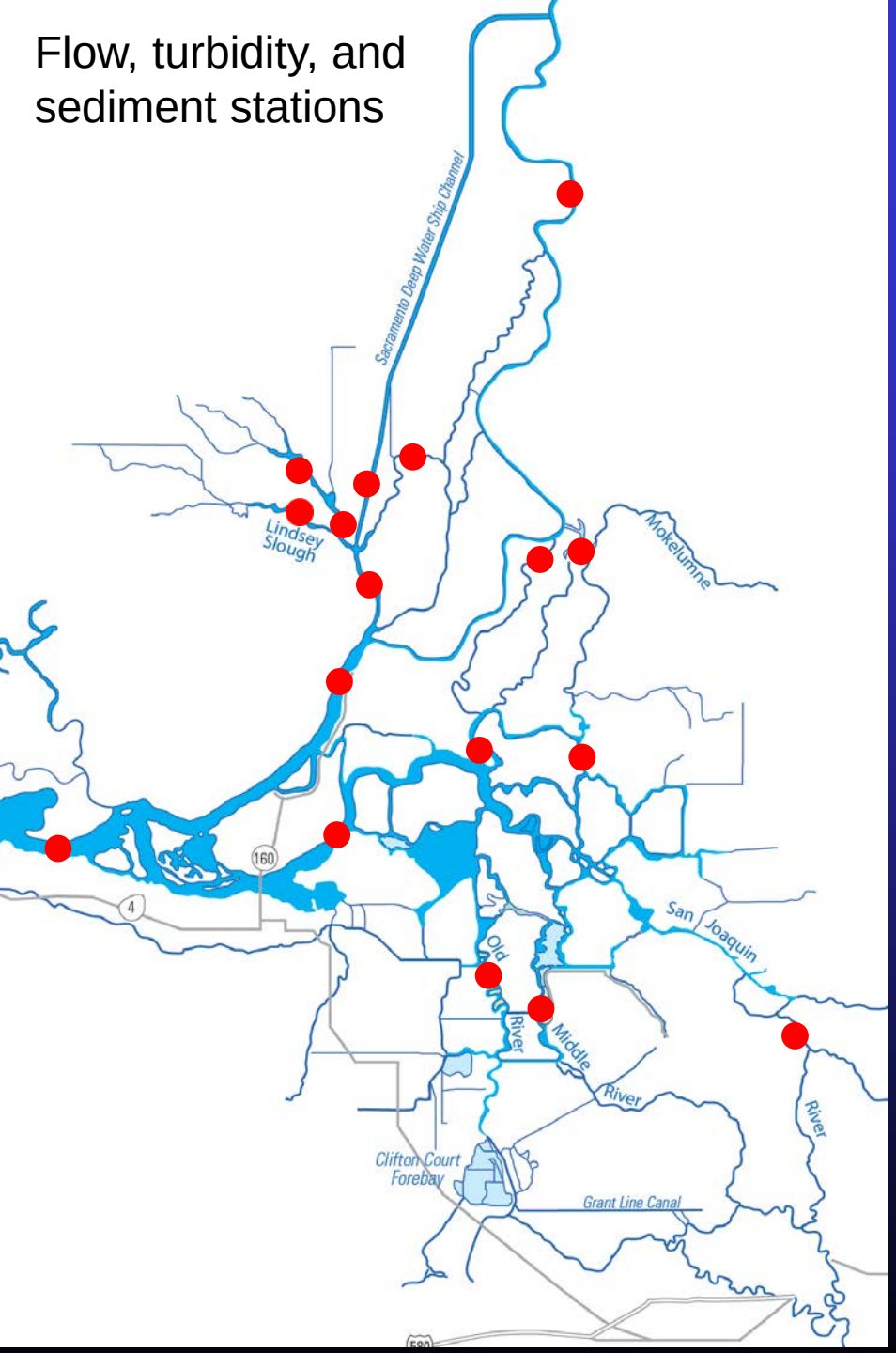
- Flux = Mass moving through a cross section over a known time (kilograms per second). Quantifies movement of sediment. More useful, we measure both.

Little Colorado River, 2-year flood

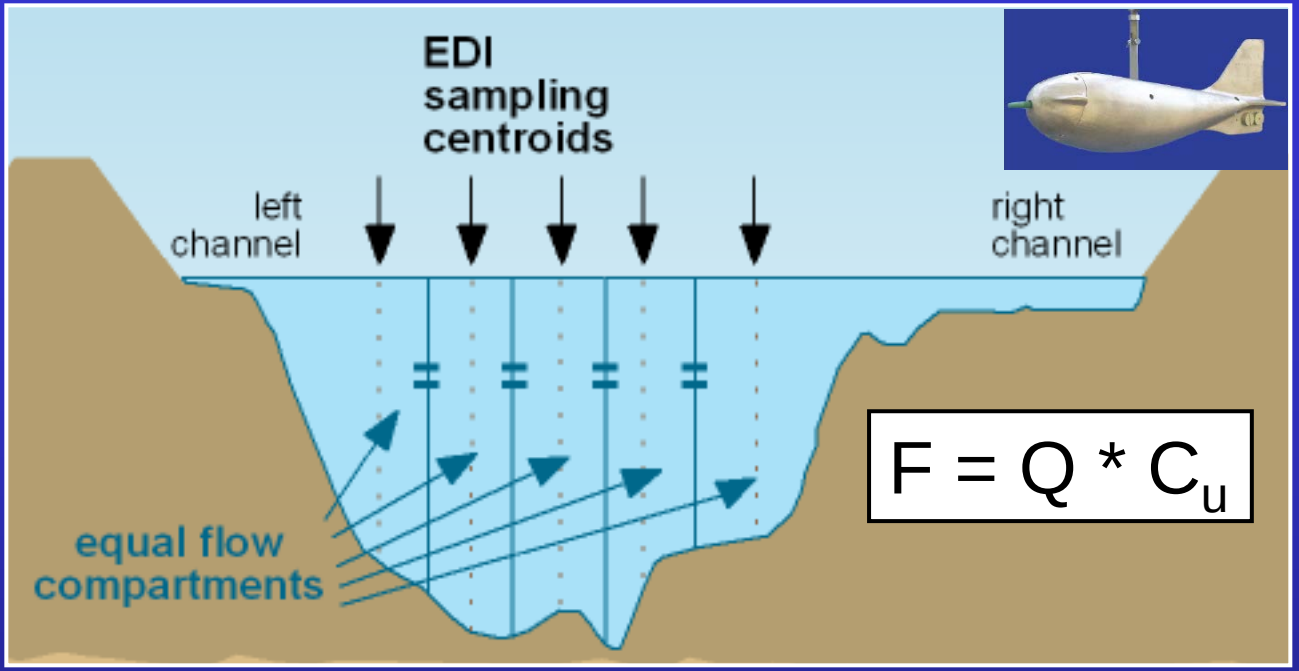
USGS

Monitoring network

Flow, turbidity, and sediment stations



Measuring sediment flux

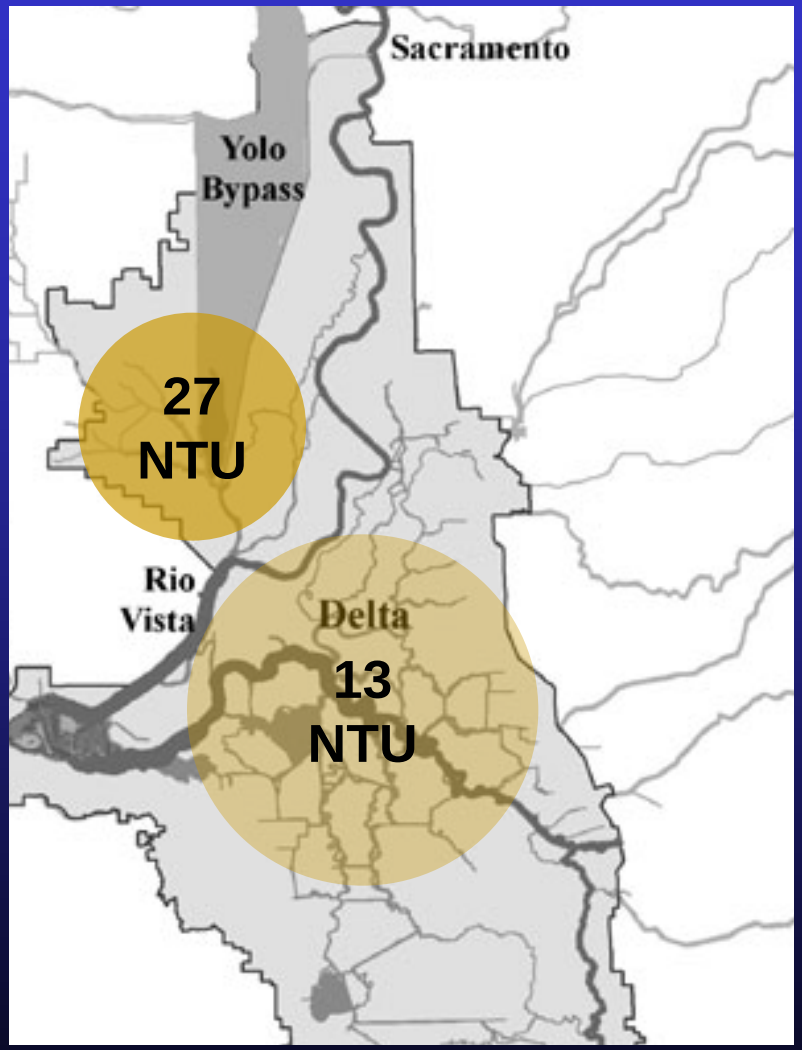


USGS

Constituent	Method	Frequency
1) Water elevation (Jon+)	Pressure transducer	15 minutes
2) Index velocity (Jon+)	Sideward looking ADCP	
3) Point turbidity (Jon+)	Optical sensor	
4) Discharge (Jon+)	Downward ADCP transect	Multiple boat measurements during site visits
5) Velocity-weighted cross sectional average suspended-sediment concentration	Equal discharge increment (EDI)	
6) Discharge (Jon+)	Index velocity method (calibrate 1 and 2 to 4)	15 minutes
7) Velocity-weighted cross sectional average suspended-sediment concentration	Calibrate 3 to 5	
8) Suspended-sediment flux (kg/s)	Product of 6 and 7	

USGS

Cache Slough: the Delta's most turbid waters
(and favorable delta smelt habitat)

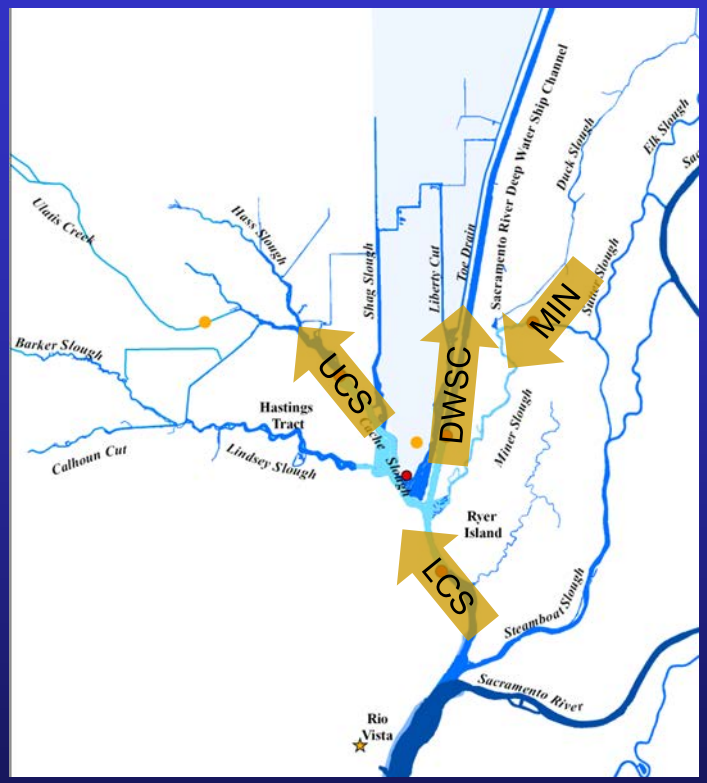


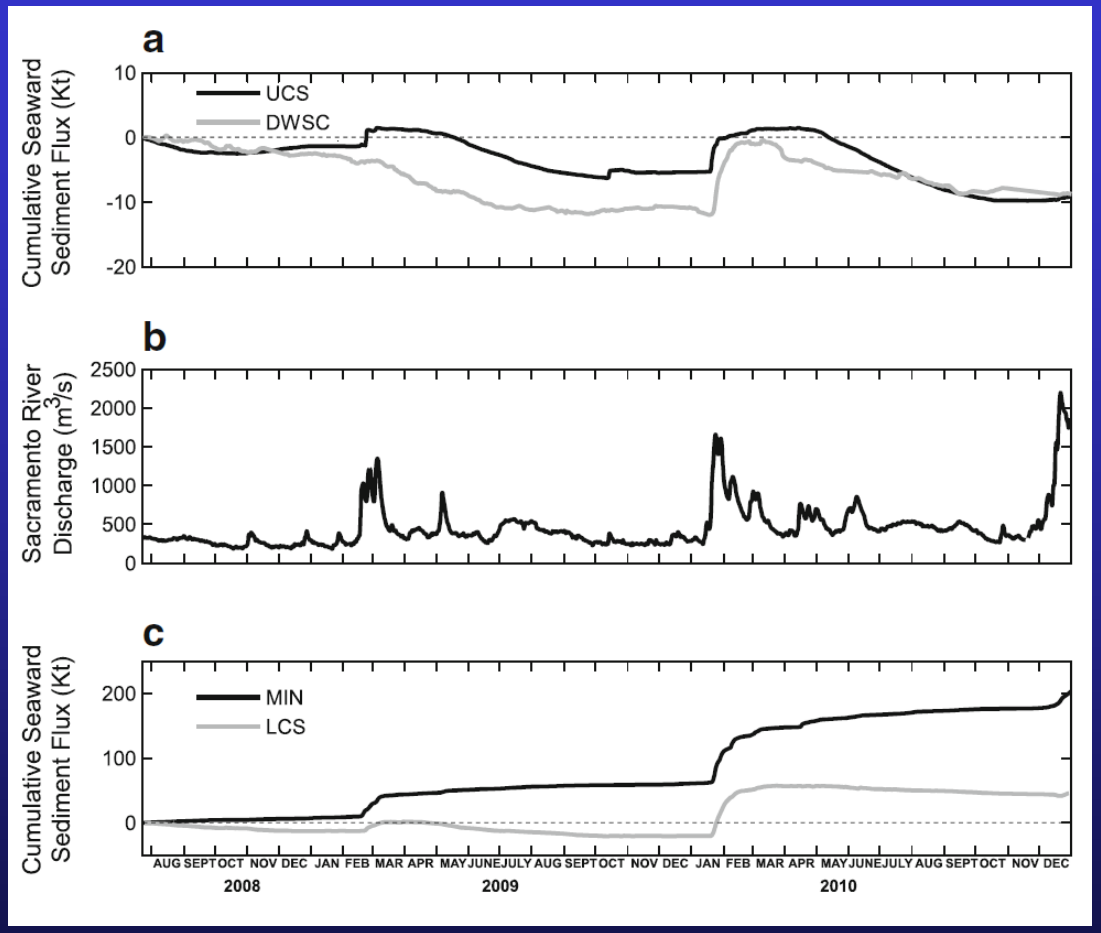
Average turbidity
WY 2009 & 2010

Morgan-King and Schoellhamer 2013, Sommer et al 2011

USGS

Sediment fluxes



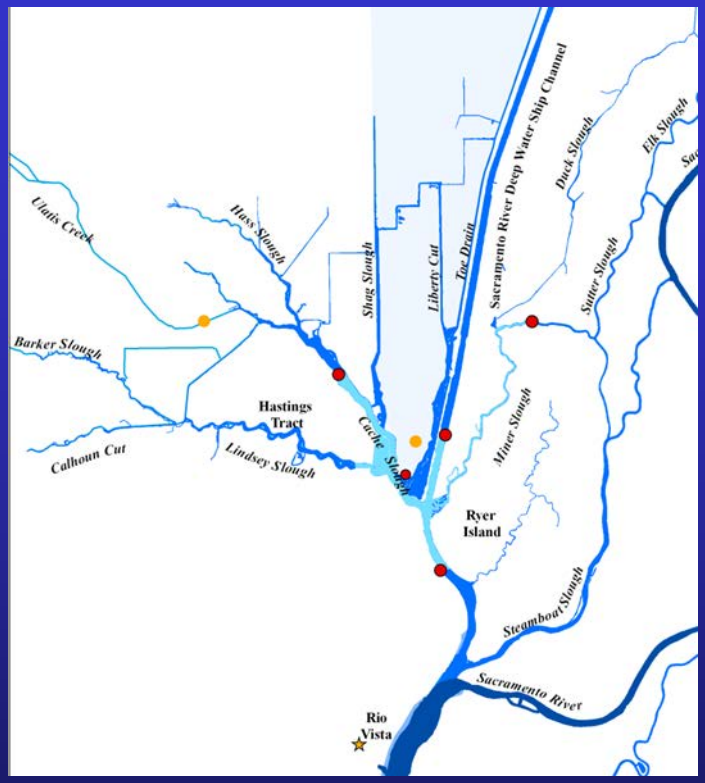


Morgan-King and Schoellhamer 2013

Sediment Trapping

1) Mechanisms:
   - Dead-end channels and low freshwater flow
   - Tidal asymmetry (flood dominant velocities)
   - Limited tidal excursion

2) Trapped sediment mass undergoes a repeated cycle of tidal and wind-wave resuspension

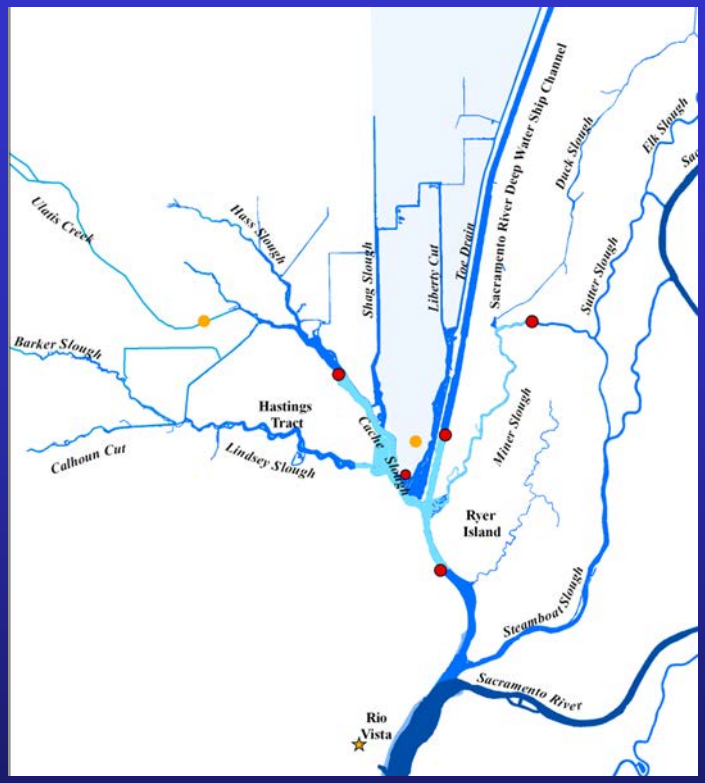


Morgan-King and Schoellhamer 2013

USGS

Isolated dead-end sloughs

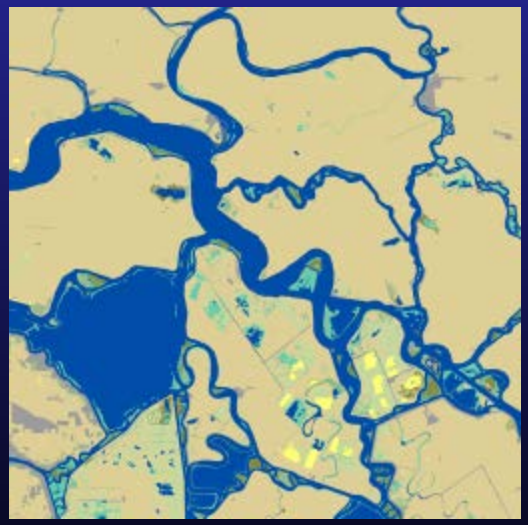
- Create desirable habitat
- Were once a prominent feature of the Delta
- Except for Cache Slough, the Delta is now connected waterways with little isolation



Morgan-King and Schoellhamer 2013

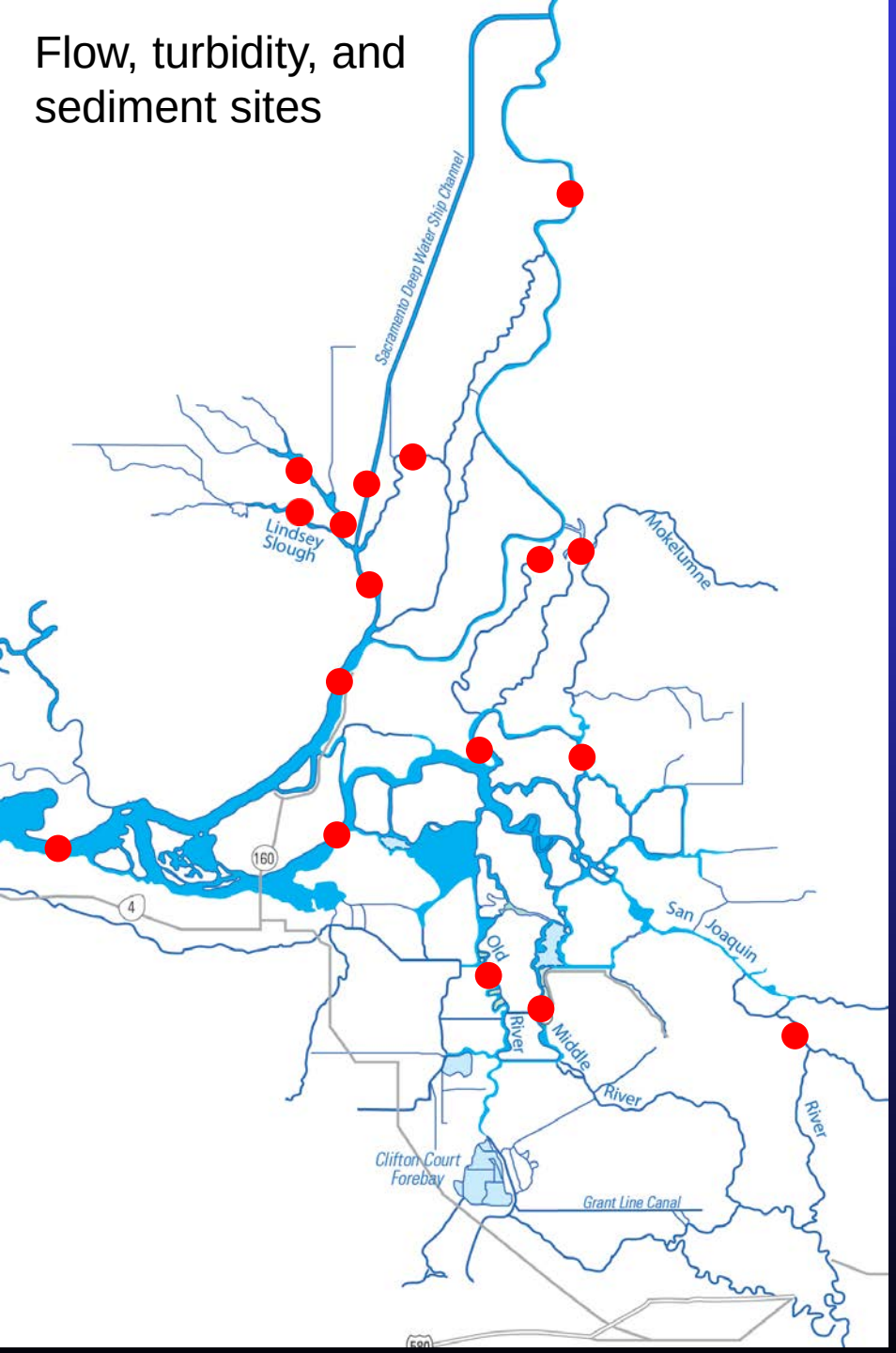
Early 1800s

Early 2000s



Whipple et al. 2012

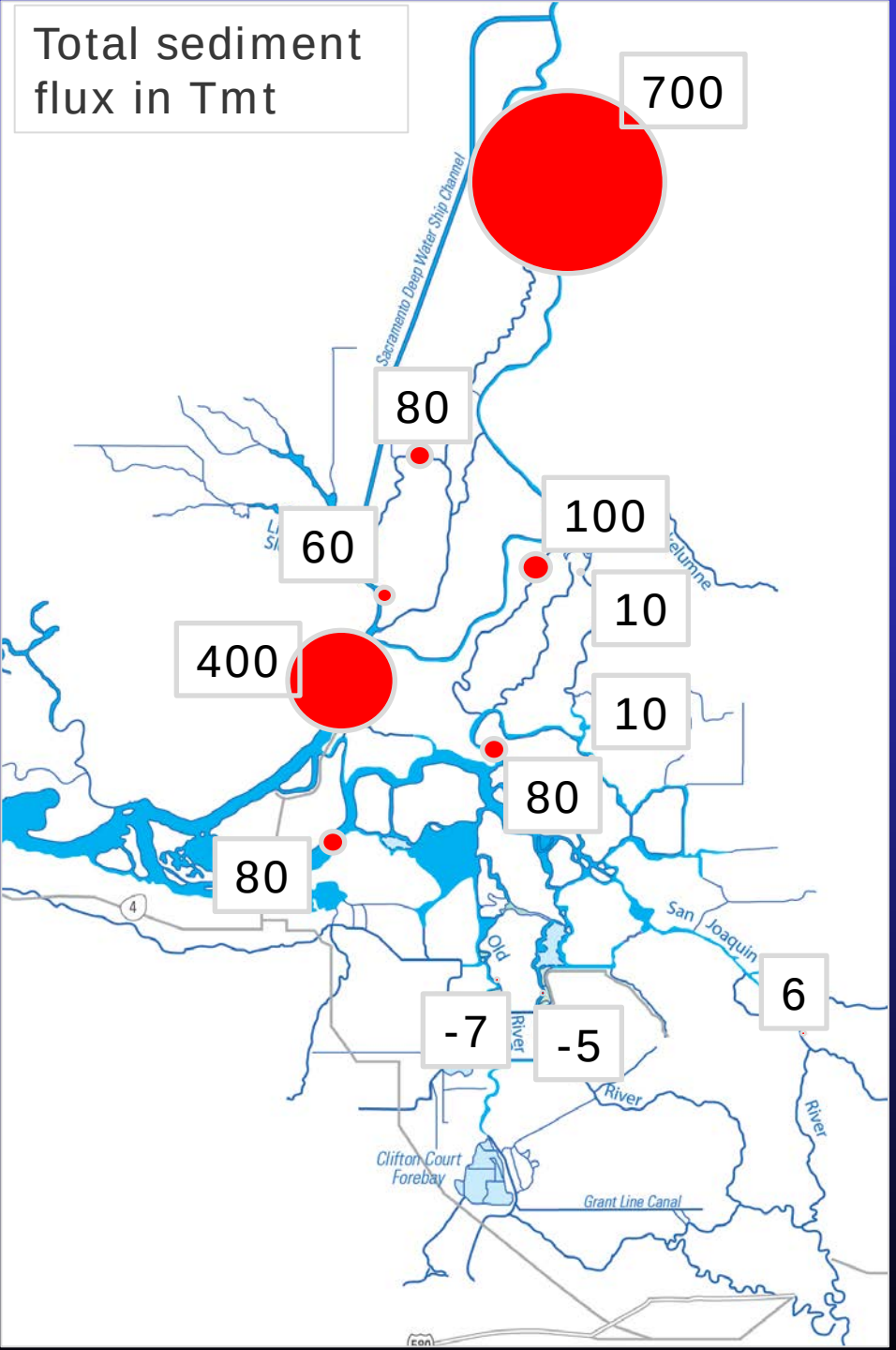
Flow, turbidity, and sediment sites



First flush 2012/2013

Where did the sediment coming down the Sacramento River go in the Delta?

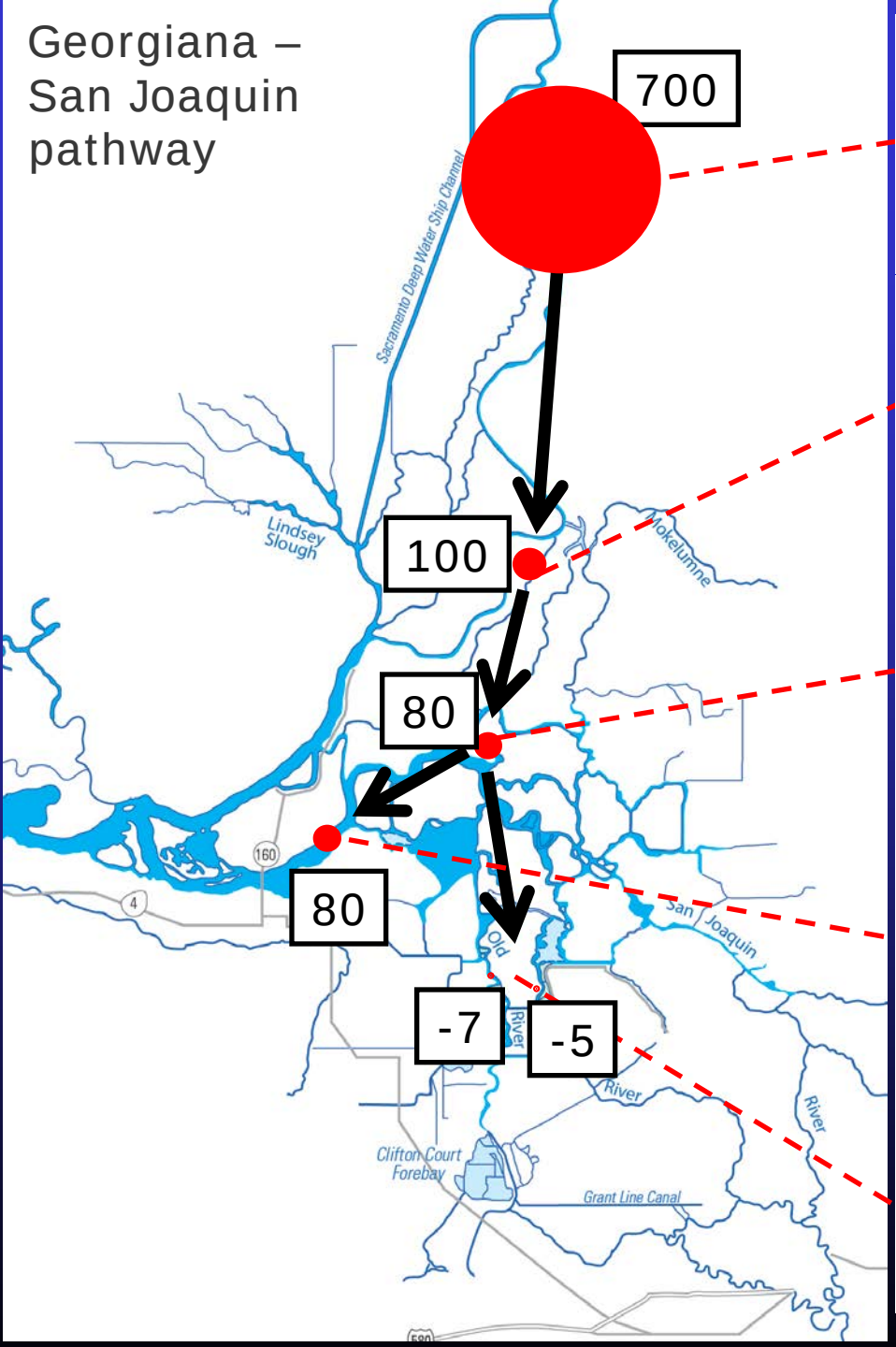
USGS

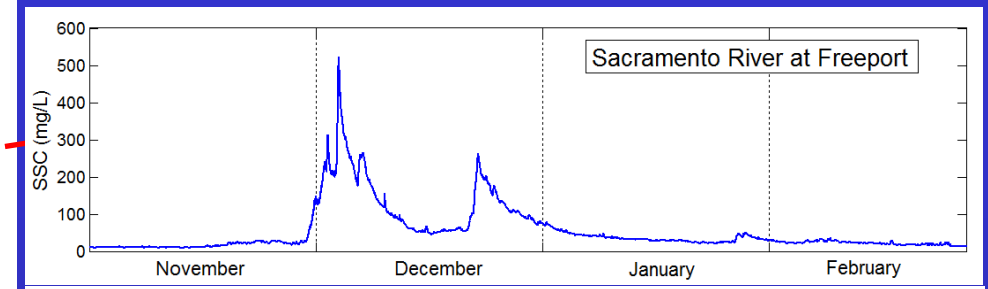


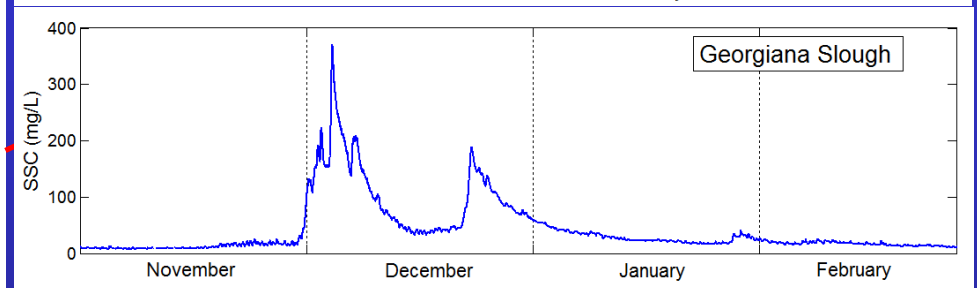
- Sediment dispersed through Sacramento River distributary channels (Miner, Sutter, Steamboat, Georgiana)
- Miner-Cache Slough pathway (10-15%)
- Georgiana-lower Mokelumne-San Joaquin pathway (15-20%)

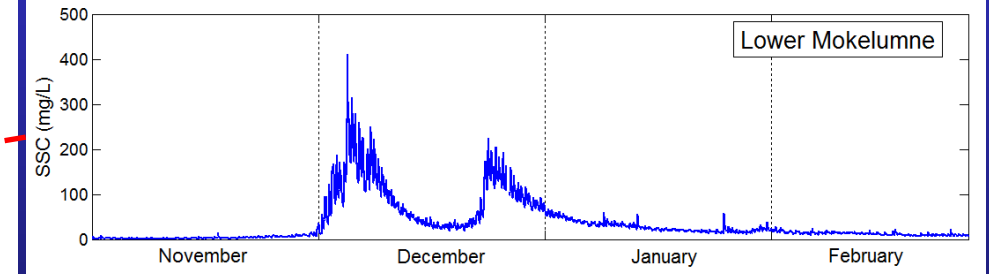
USGS

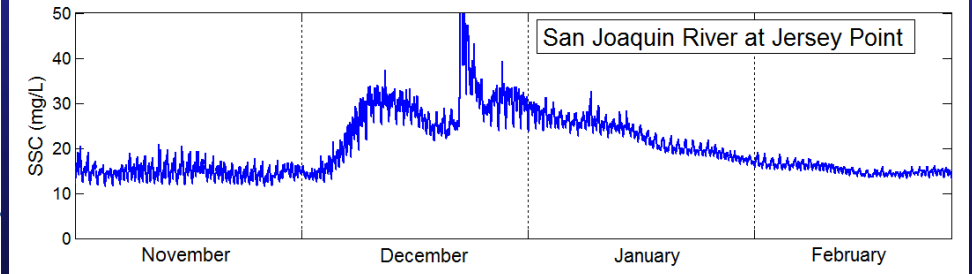
Georgiana – San Joaquin pathway

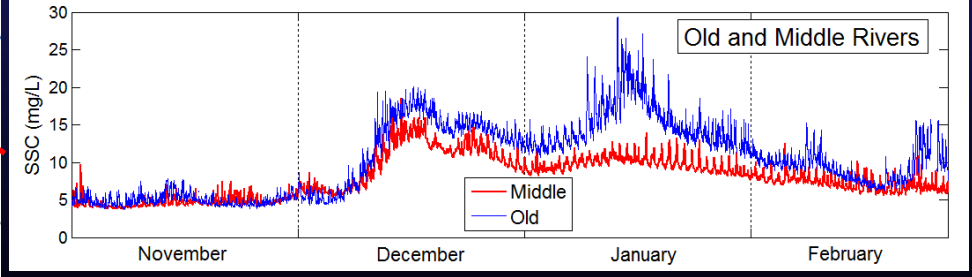


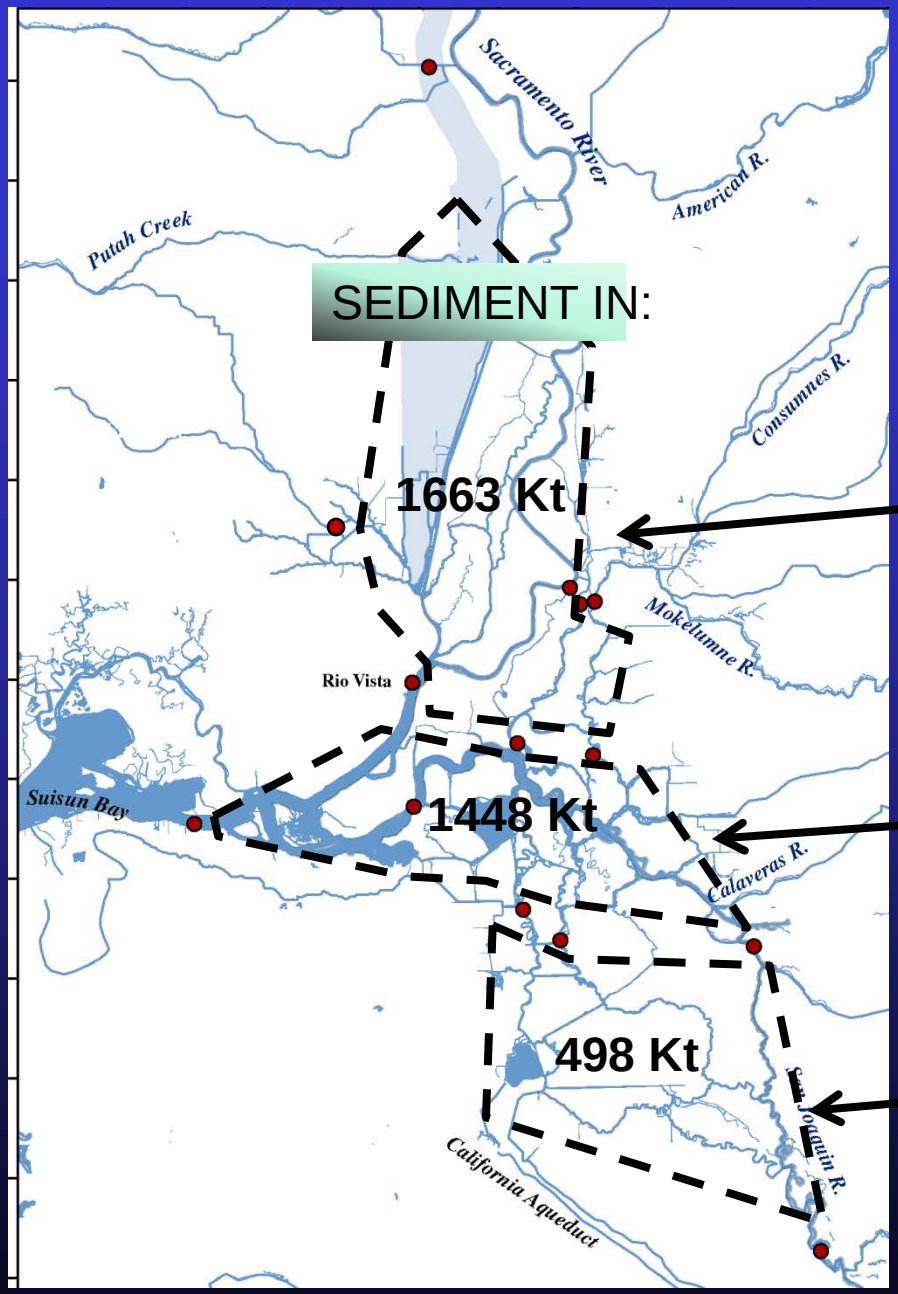












WY2011

Preliminary data subject to revision

Deposition = Mass in – Mass out

NORTH DELTA

Trap Efficiency: 23%
Deposition:380 Kt

CENTRAL DELTA

Trap Efficiency: 55%
Deposition:796 Kt

SOUTH DELTA

Trap Efficiency: 67%
Deposition: 332 Kt

USGS

Summary: sediment monitoring provides

- Spatial and temporal variation of suspended sediment concentration and flux
- Knowledge of controlling processes
- Sediment transport pathways
- Sediment budgets
- Data for developing numerical models

Thanks to USGS Delta sediment project colleagues Paul Buchanan, Doug Dean, Joan Lopez, Tara Morgan-King, Matt Marineau, Amber Powell, Chris Silva, Travis von Dessonneck, Kurt Weidich, and Scott Wright

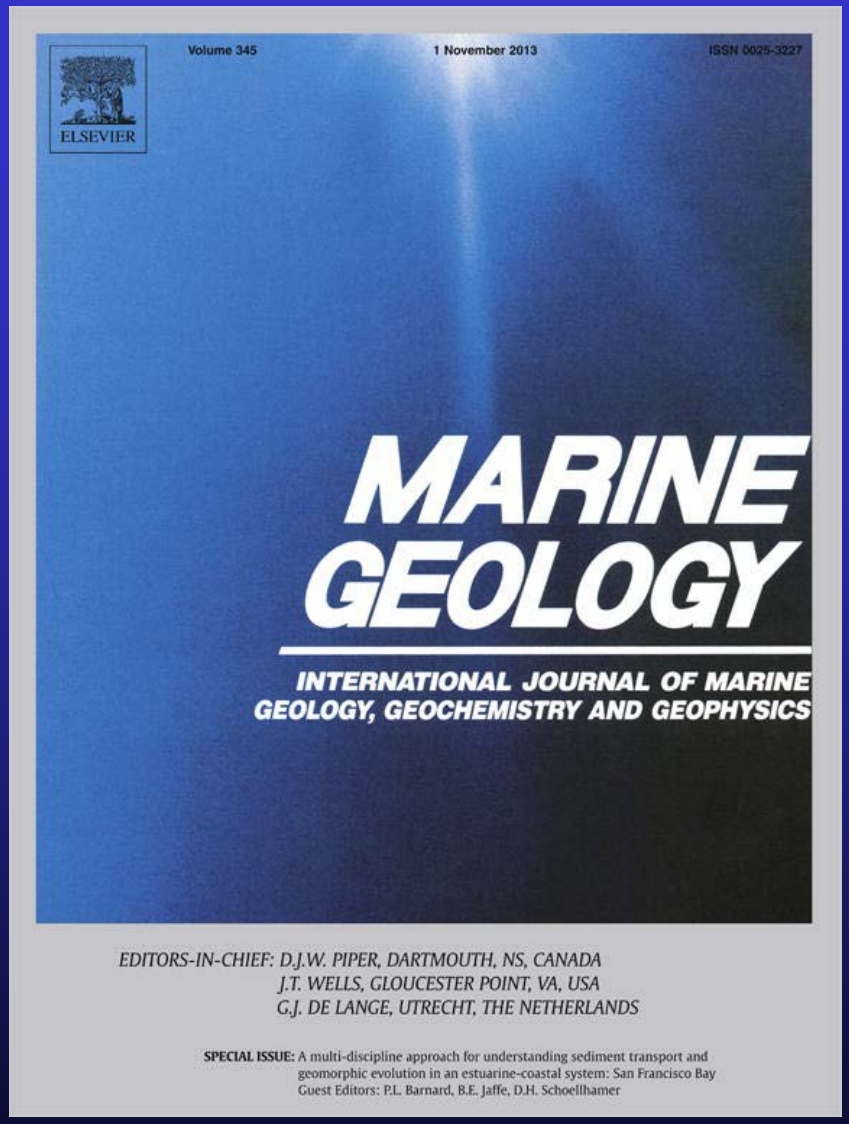
Supported by the US Bureau of Reclamation and the Interagency Ecological Program

USGS

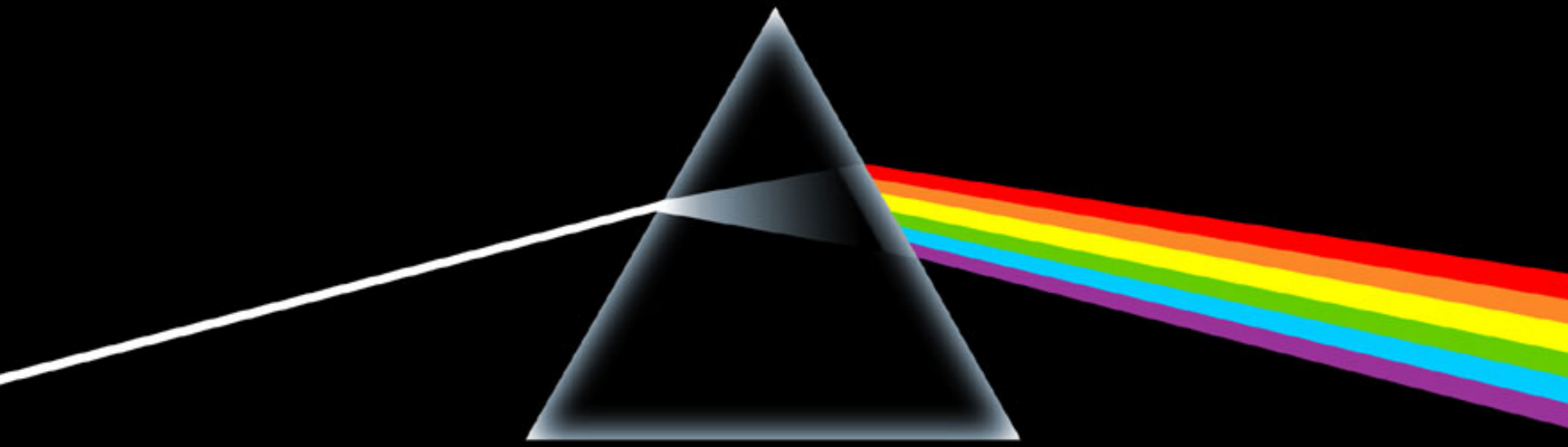
Marine Geology Special Issue

A multi-discipline approach for understanding sediment transport and geomorphic evolution in an estuarine-coastal system: San Francisco Bay

- 21 papers available on line and just published in *Marine Geology* volume 345
- Includes sand, mud, coast, watersheds, Delta, data, models, and more!
- Editors: Patrick Barnard, Bruce Jaffe, and David Schoellhamer



USGS



How continuous, co-located, high-frequency, optical[a] measurements (AKA Monitoring) can illuminate processes affecting water and habitat quality across the Delta and Estuary

Brian Bergamaschi, Bryan Downing, Brian Pellerin, Jacob Fleck, JohnFranco Saraceno, Tamara Kraus, George Aiken, Emmanuel Boss, and many others in and not in the USGS CAWSC aquatic biogeochemistry group

[a]mostly

Why continuous high-frequency monitoring?

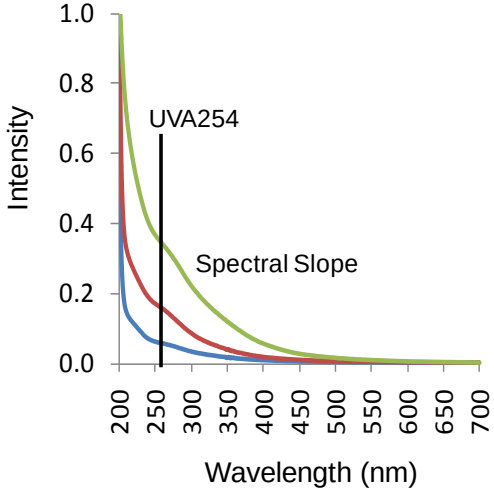
A revolution in monitoring

Commercially-available sensors for:

- Dissolved organic matter (amount, type)
- Sediments / turbidity (amount, size, type)
- Nutrients (nitrate, ammonium, phosphate)
- Proxy measurements (mercury, pathogens)
- Bromide, bisulfide
- Phytoplankton taxonomy

Cost: $1,000 - $20,000+ USD for sensors *plus* cost of operation

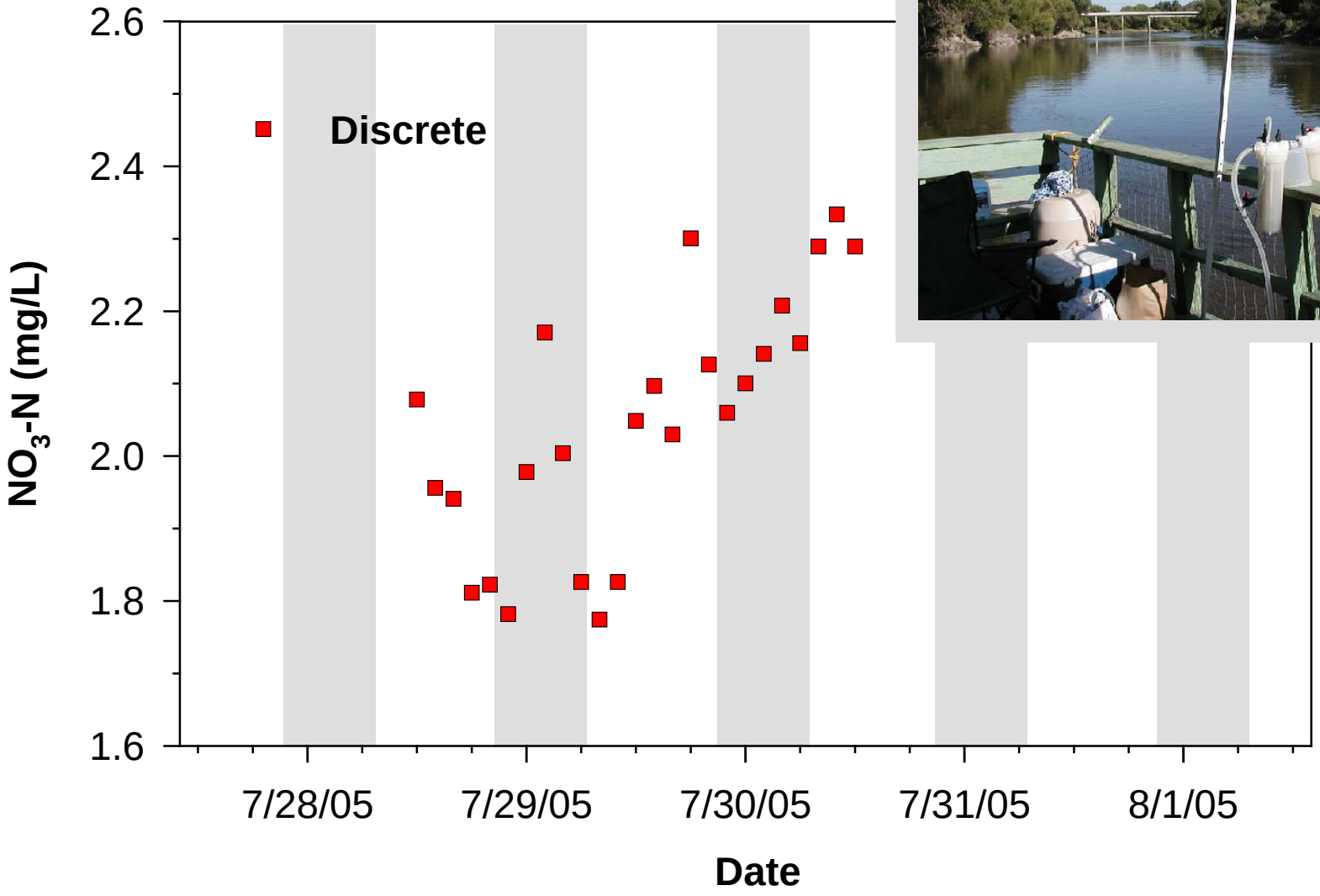
From benchtop…

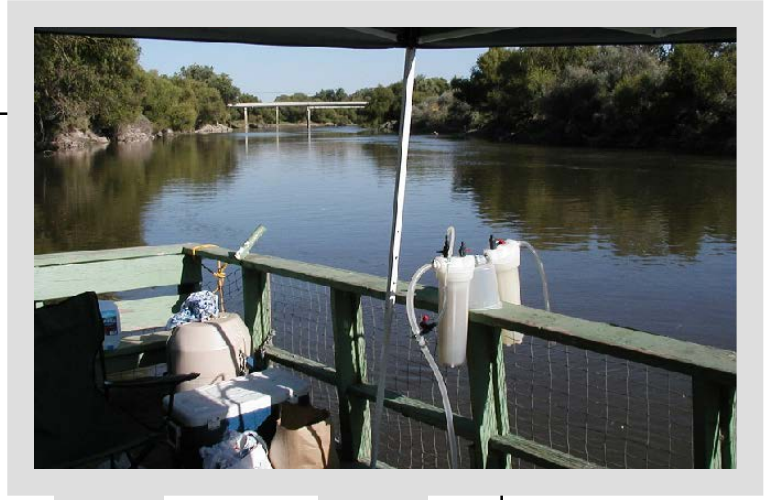


…to field instrument

Nitrate Variability – San Joaquin River

Assessing nitrate variability in the San Joaquin River, Crows Landing, CA
(Satlantic ISUS nitrate analyzer)

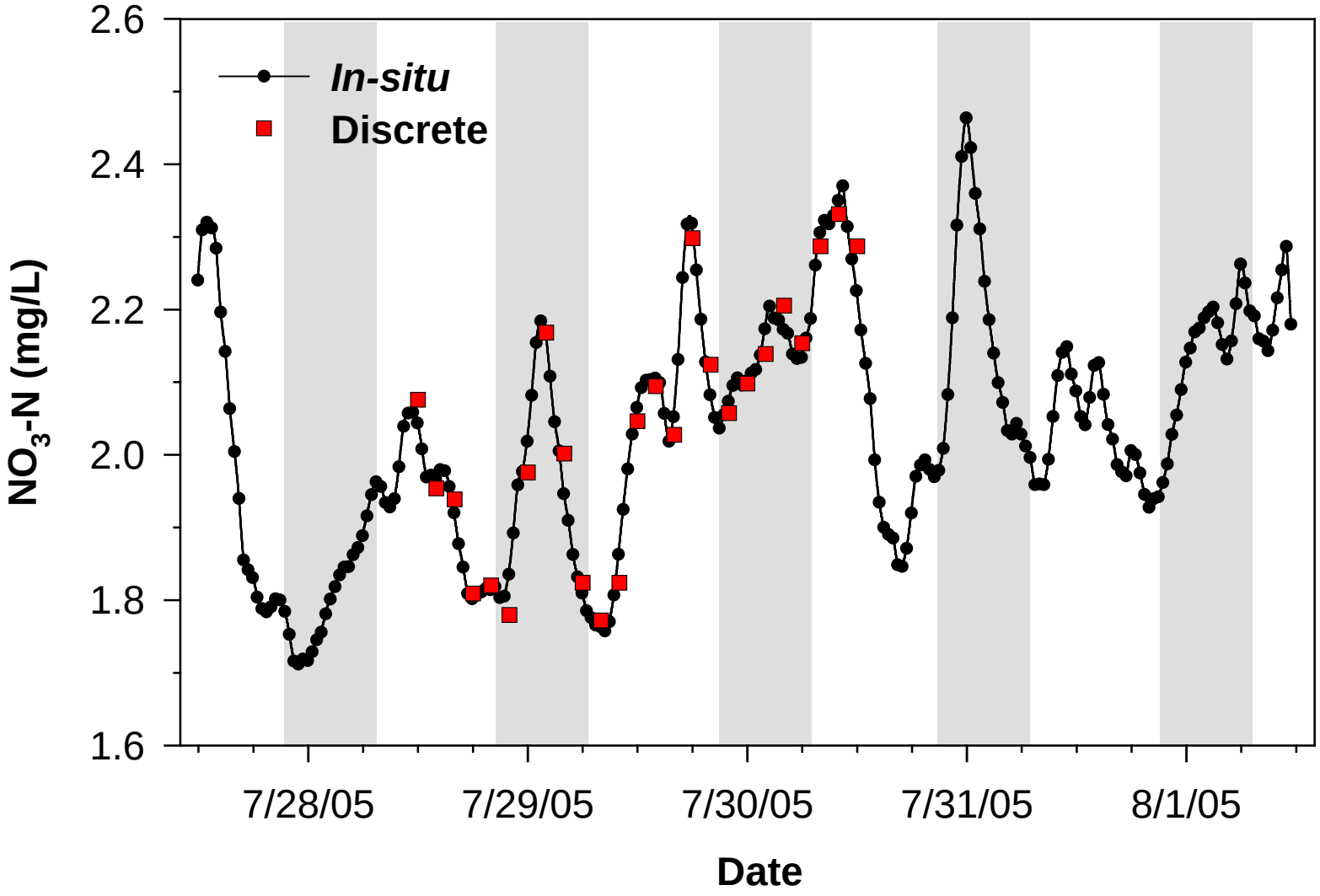




Pellerin et al., 2009

Nitrate Variability – San Joaquin River

Assessing diurnal nitrate variability in the San Joaquin River, Crows Landing, CA (Satlantic ISUS nitrate analyzer)

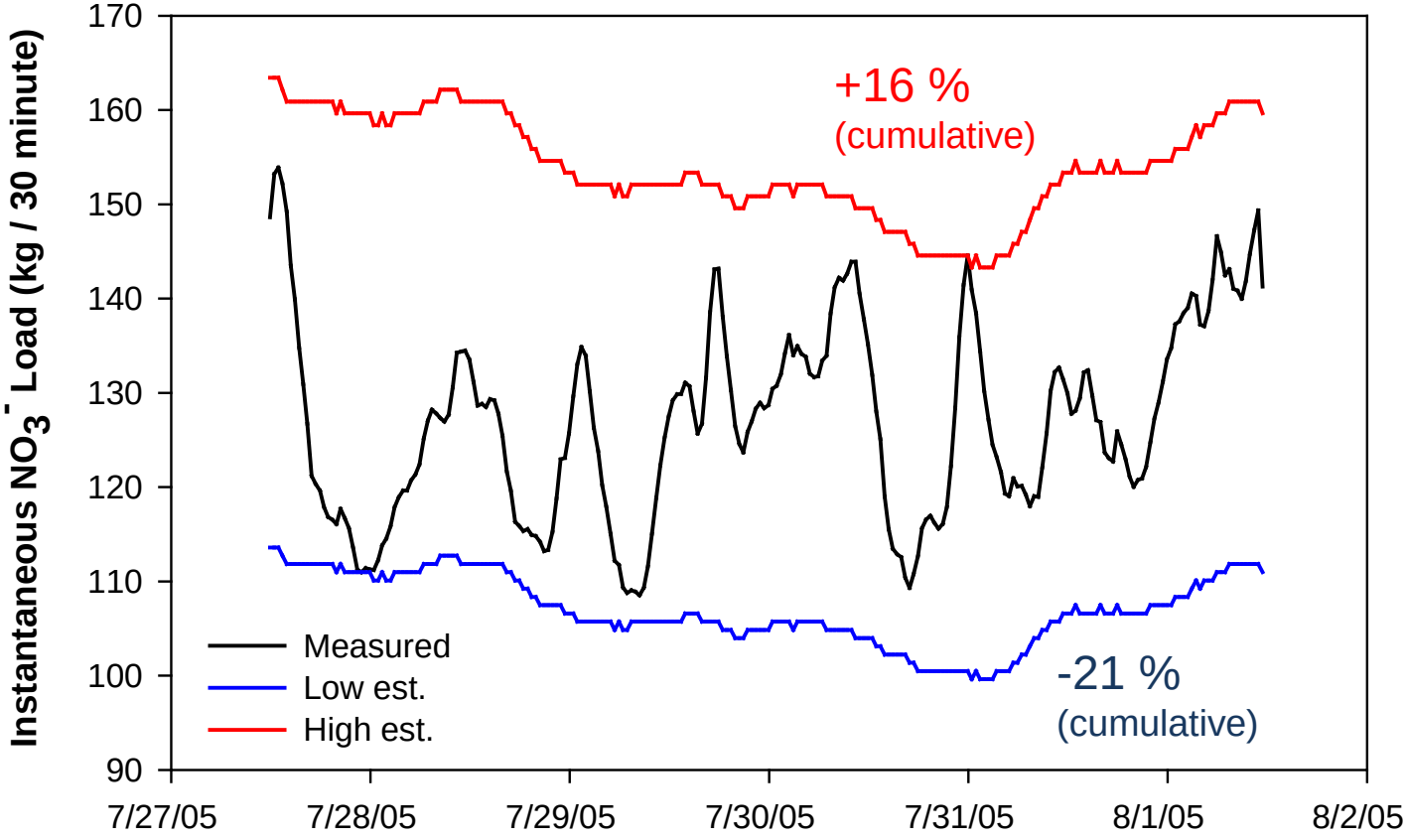


Pellerin et al., 2009

Nitrate Loads – San Joaquin River

Difference in instantaneous and cumulative nitrate load at Crows Landing during the study period. **Daily loads were -23 to +30 % relative to measured load** using continuous data.

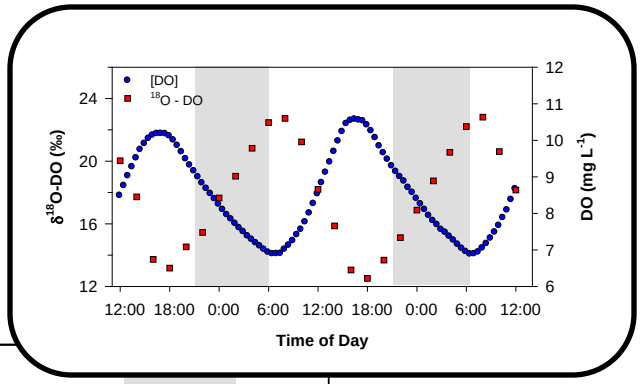
	Daily Load (kg nitrate / day)			% Difference	
	Measured	Low est.	High est.	Low est.	High est.
28-Jul	5875	5305	7631	-10	30
29-Jul	6563	5064	7284	-23	11
30-Jul	6160	4956	7130	-20	16
31-Jul	6047	5024	7228	-17	20

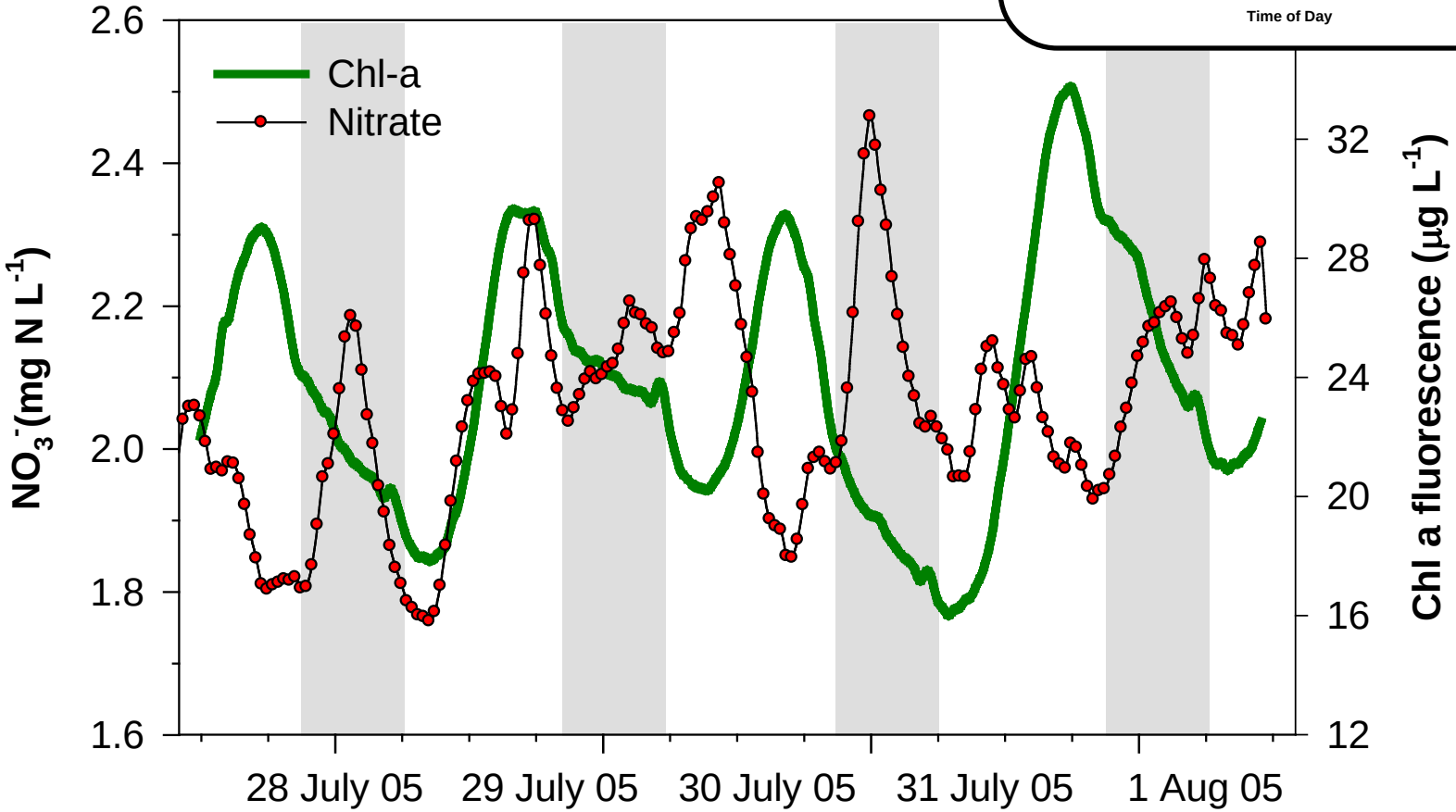


Pellerin et al., 2009

Drivers of nitrate variability - SJR

Combination of discrete and in situ data show high biological activity in the SJR (*right*), but no evidence for direct link between NO_3^- concentrations and chlorophyll not apparent.





Pellerin et al., 2009

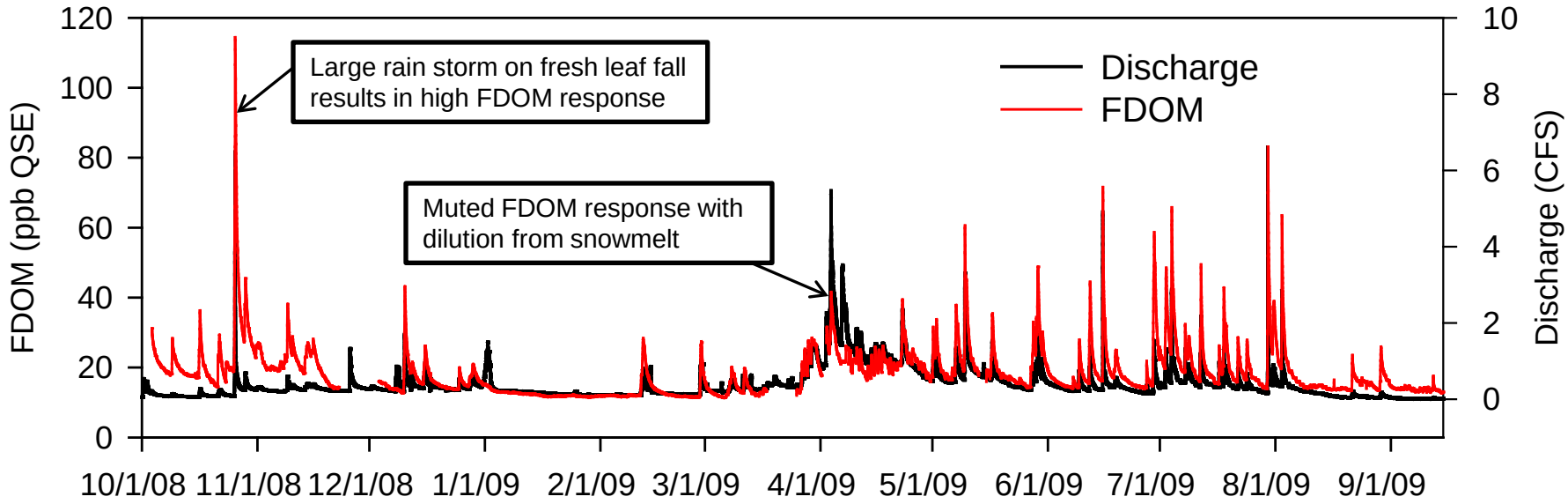
Why continuous HF monitoring in the Delta?

MANY DIFFERENT TIME SCALES

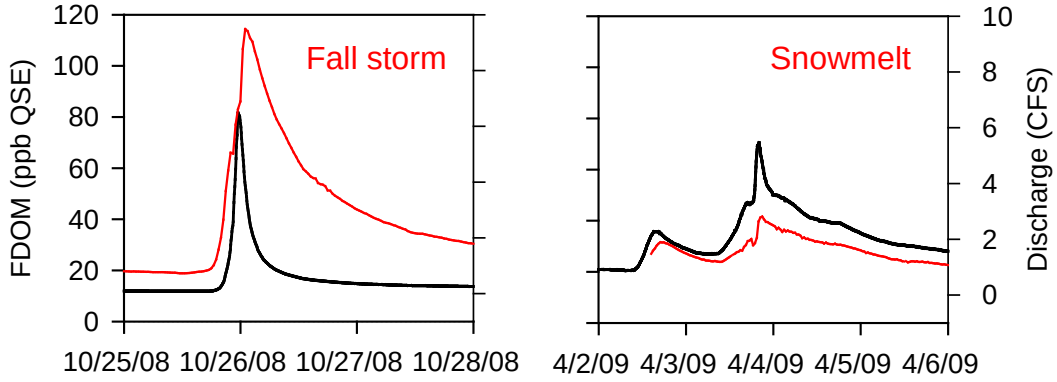
- Variability in concentrations and loads related to:
  - Variability of inputs
    - River concentrations and flows
    - Upstream processes
  - Tidal action
    - Varies by season, wind, etc.
  - Biology and whole-ecosystem processes
    - Photosynthesis
    - Food webs dynamics (e.g. uptake)
    - Physical processes (e.g. light penetration)
  - Climate and weather
    - Episodic events (rainfall, snowmelt)
    - Catastrophic events (arkstorms, floods)
    - CLIMATE CHANGE
  - Land use / management (point and non-point)
    - Agricultural runoff (irrigation)
    - Urban runoff (storm water, waste water)
    - Intentional or unintentional contaminant discharge

STORMS: DOC Time Series at Sleepers River, VT

What does FDOM response to hydrology tell us about organic carbon (and mercury) dynamics in watersheds?



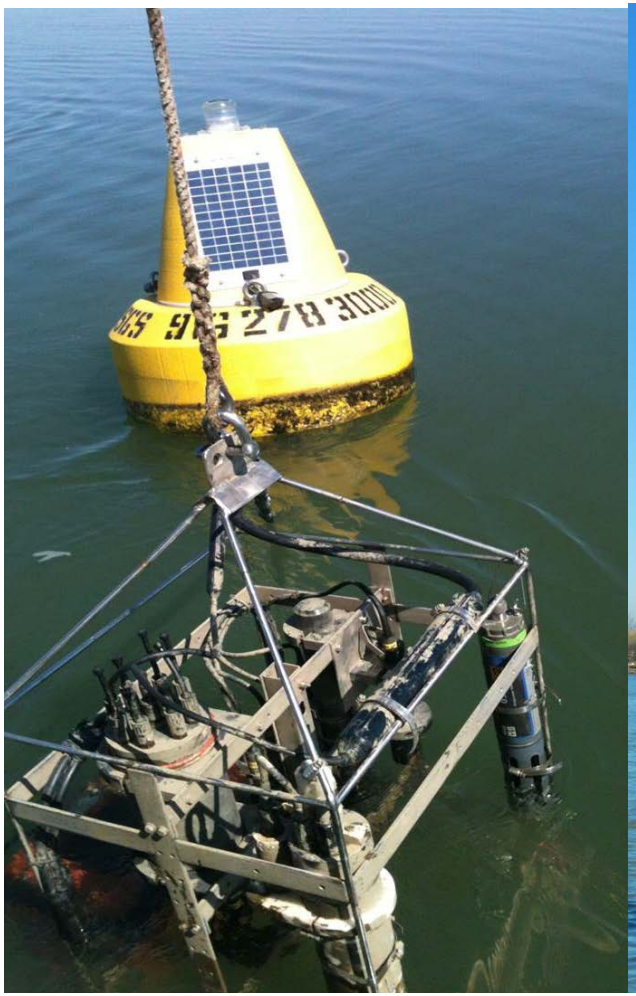
DOC-discharge response during seasonal events with similar peak discharge



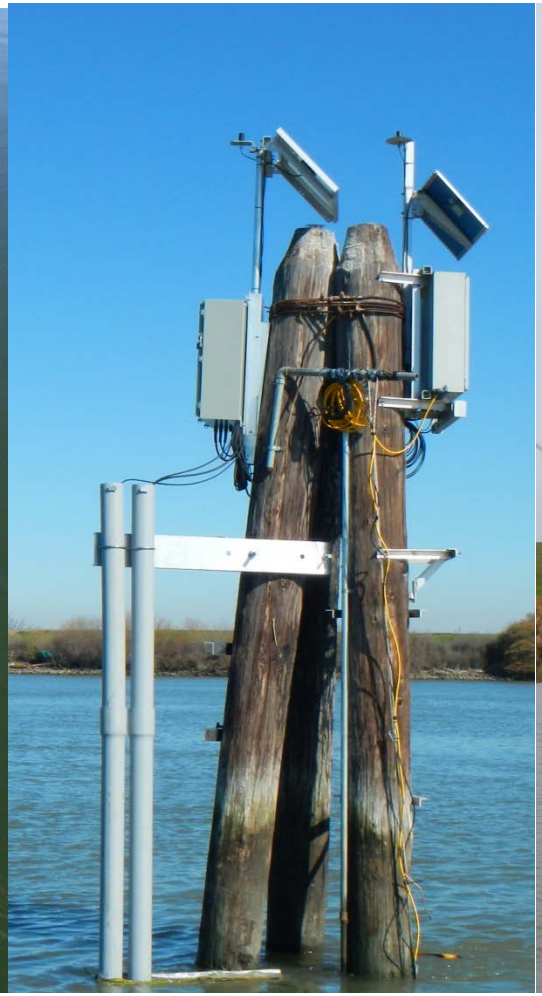
(B. Pellerin, J. Shanley, J. Saraceno, G. Aiken, S. Sebestyen, B. Bergamaschi , 2012)

Delta monitoring network

Liberty Island

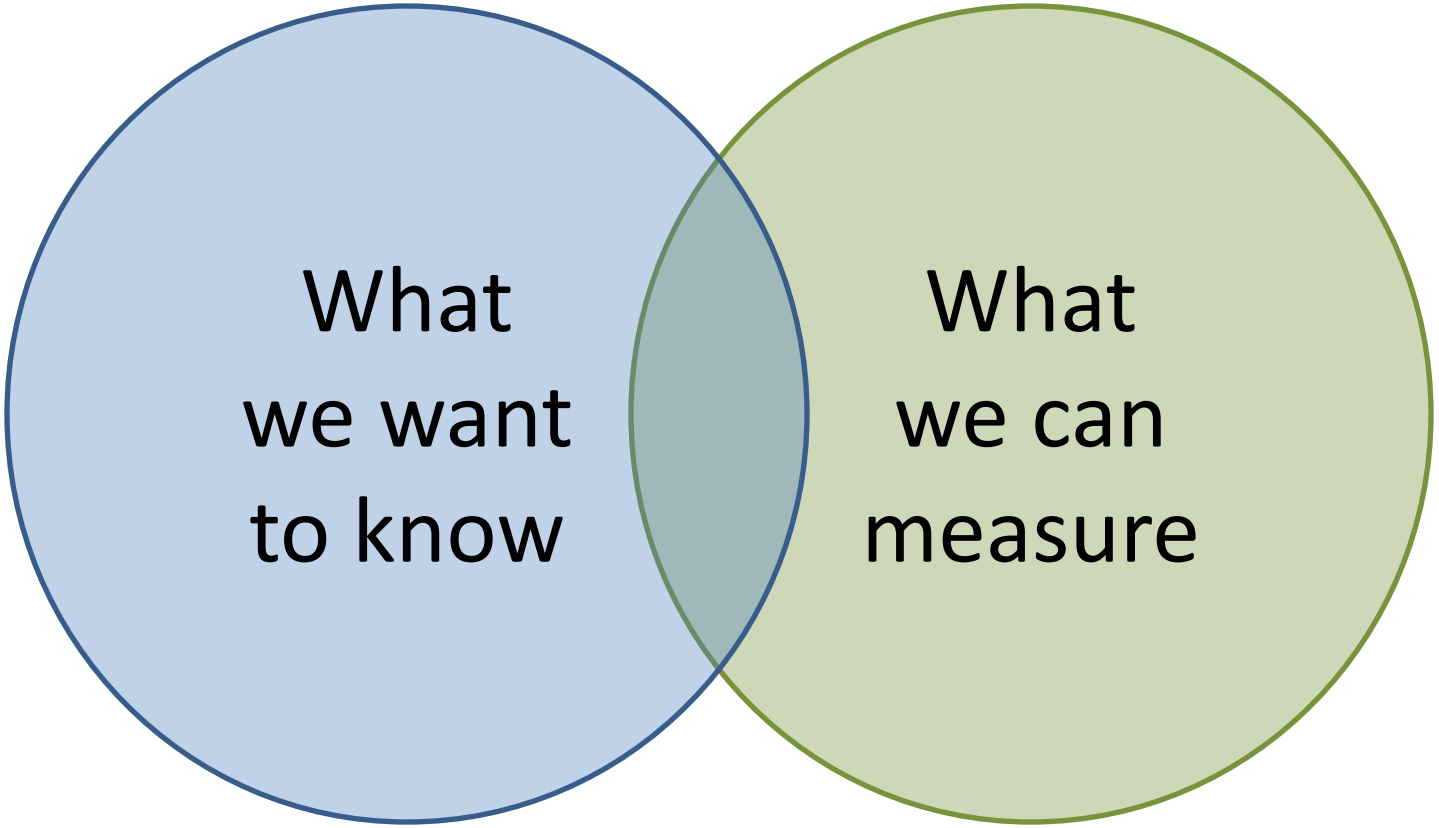


Cache Slough

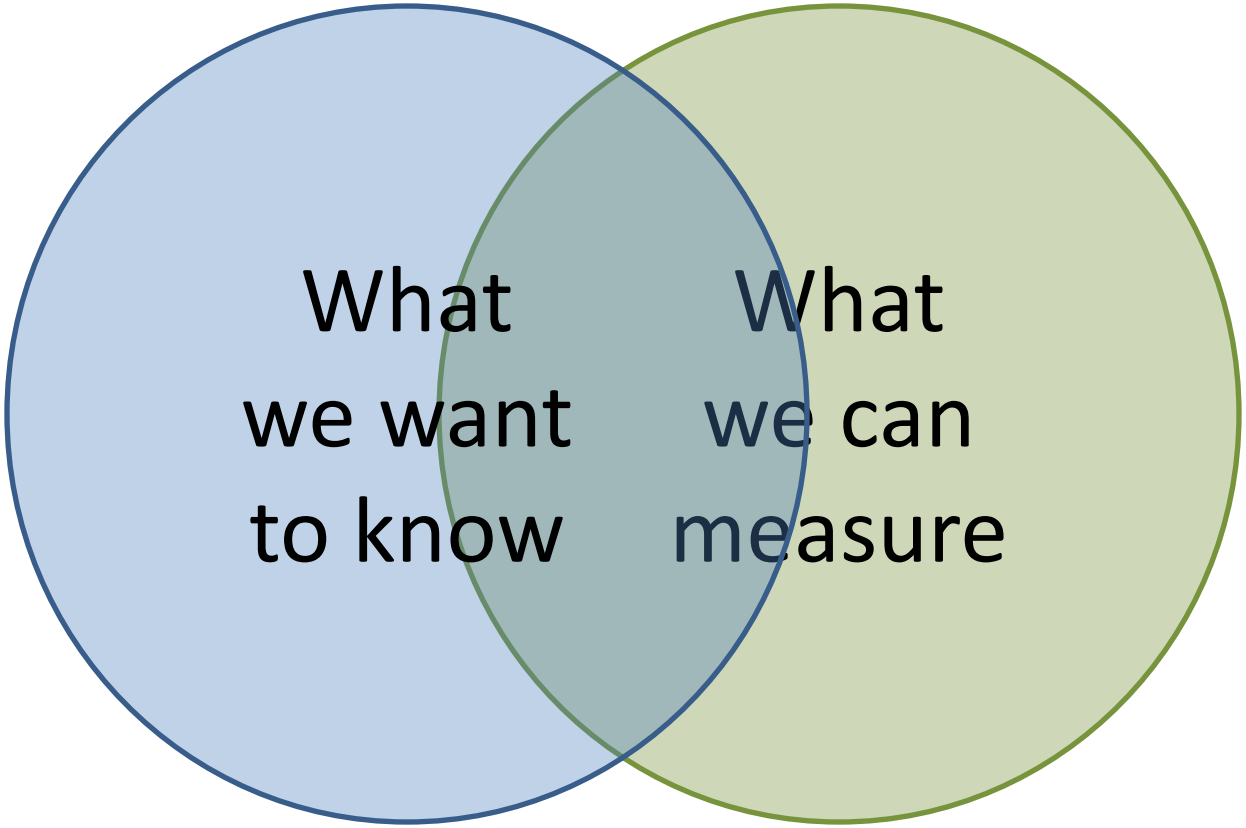


Decker Island

Monitoring versus science?

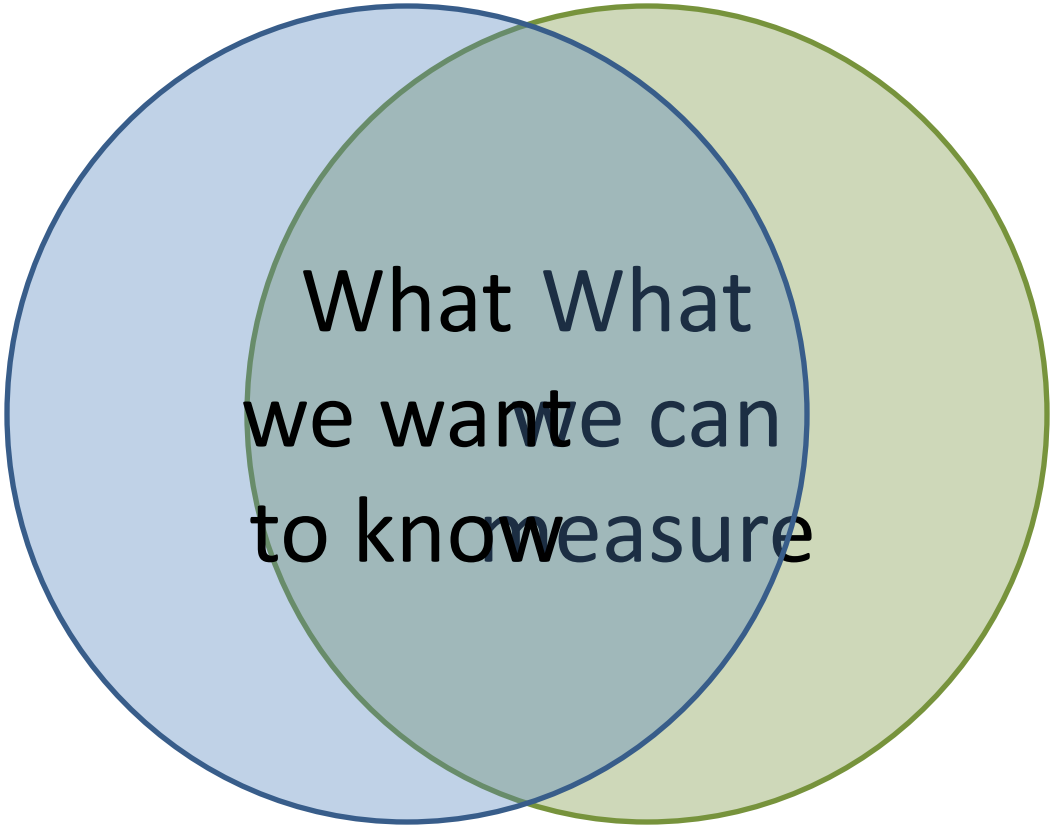


Monitoring versus science?



NEW INSTRUMENTATION

Monitoring versus science?

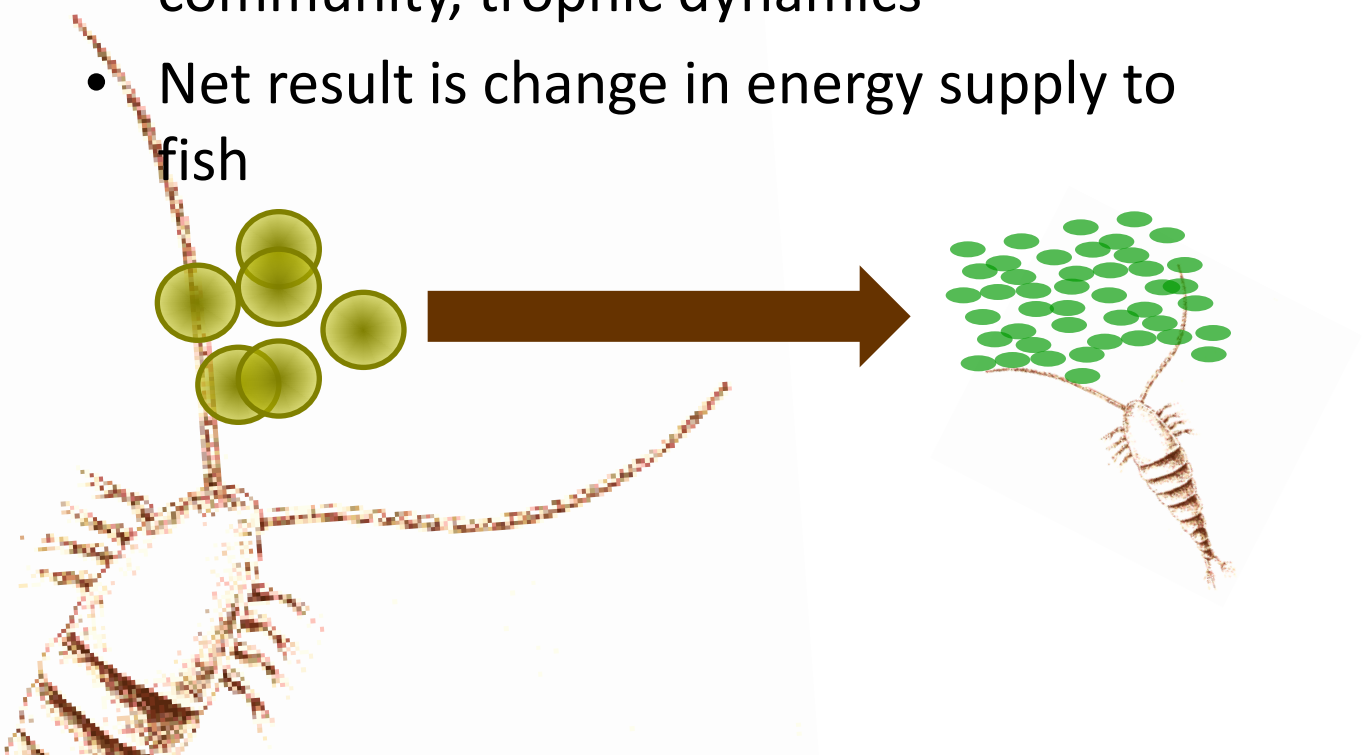


NEW INSTRUMENTATION + NEW METHODS AND MODELS

WHAT WE WANT TO KNOW:

Phytoplankton and the food web

- Changes in N and P supply, Nitrogen forms, and N:P ratios cause changes in phytoplankton community
- This in turn causes changes in zooplankton community, trophic dynamics
- Net result is change in energy supply to fish



What we can measure

Nutrients

NO_3

PO_4

NH_4^+

Light

Seed stocks

PP production

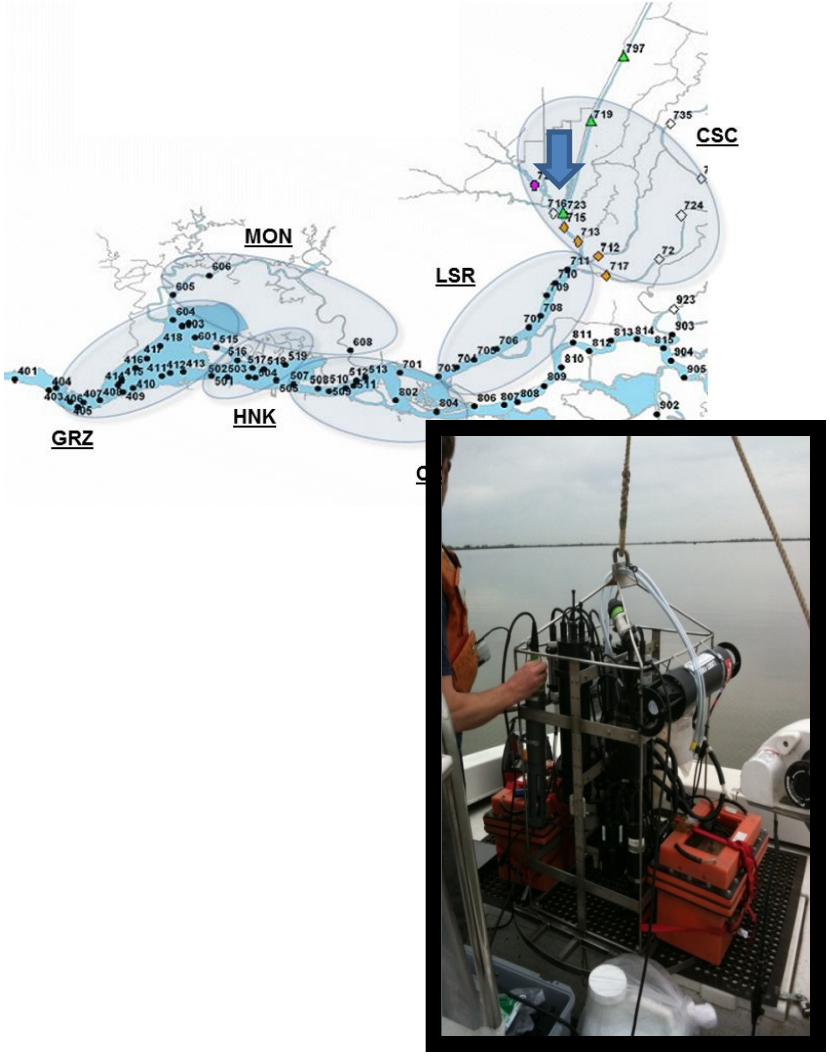
PP Taxonomy

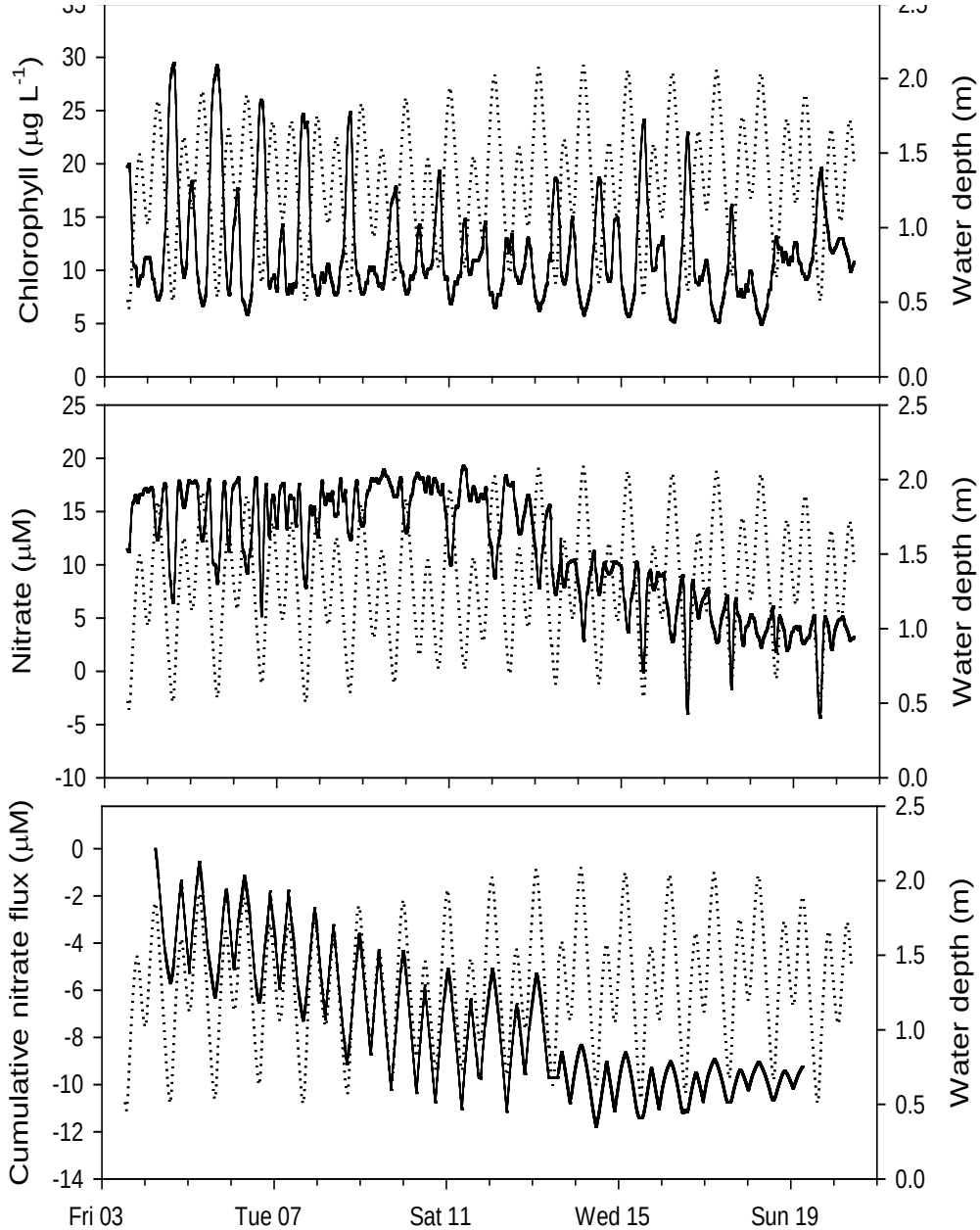
PP location

PP timing

WHAT WE WANT TO KNOW:

-Nutrient uptake



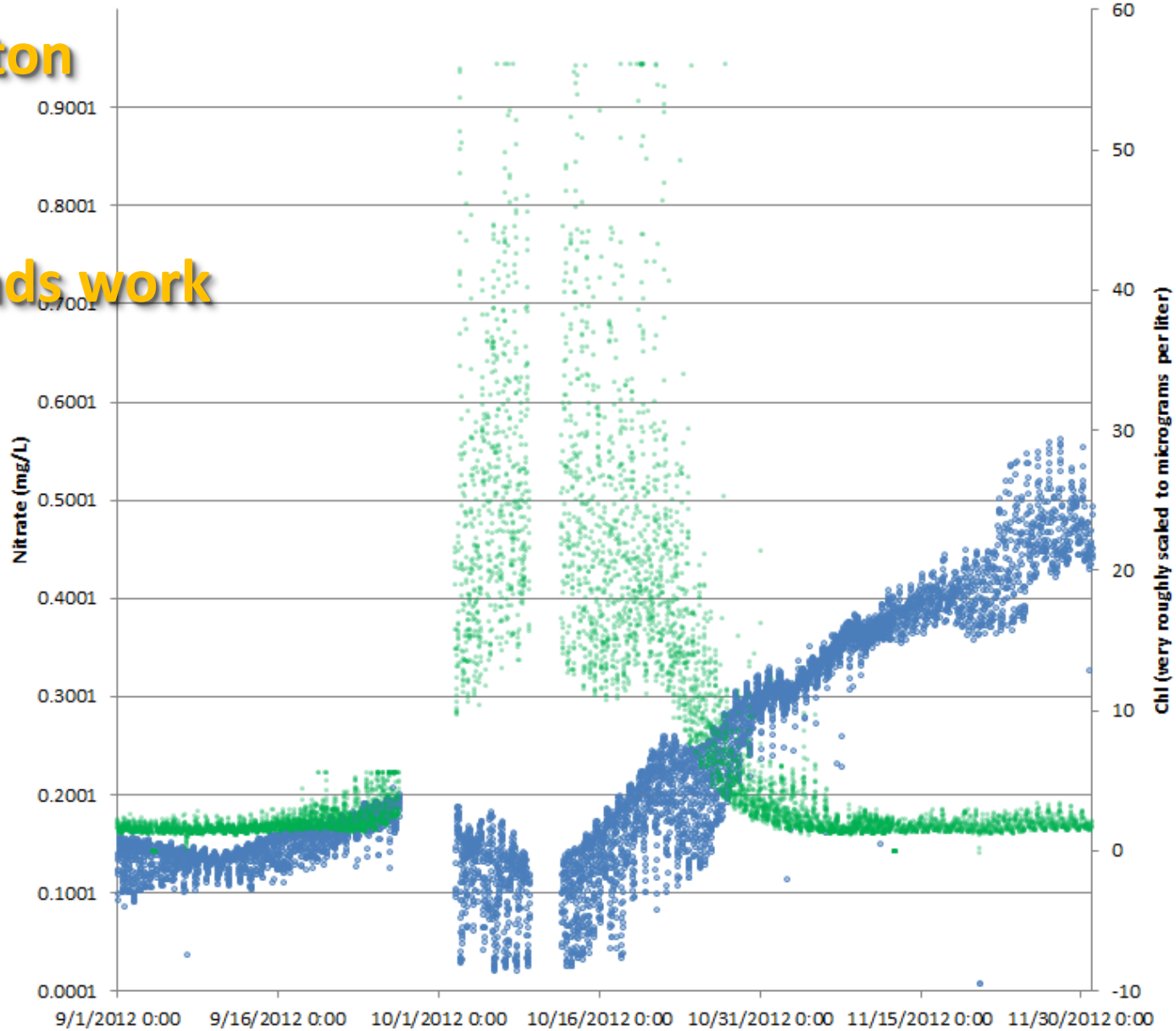


Liberty Island

WHAT WE WANT TO KNOW:

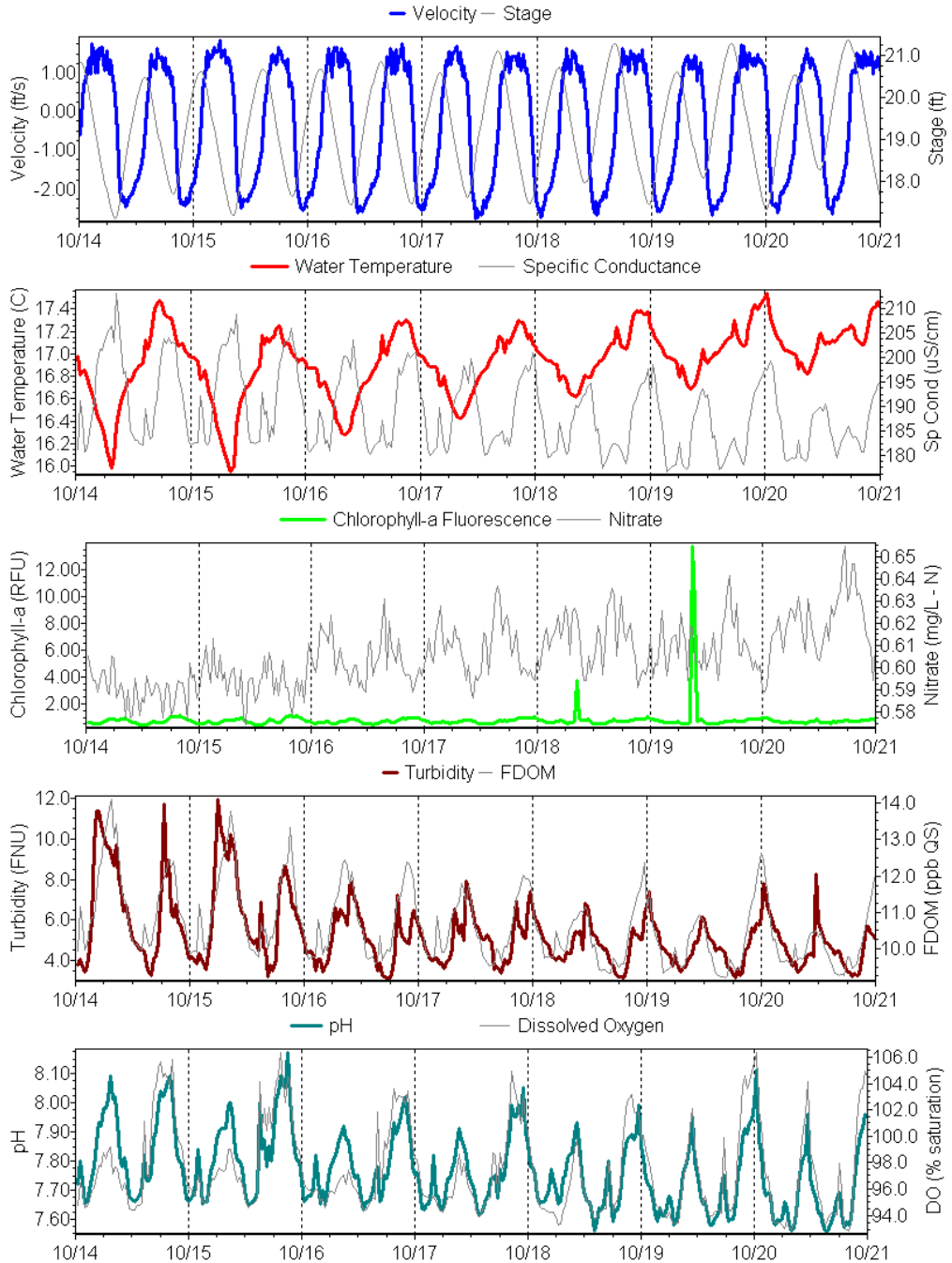
Phytoplankton Production

How wetlands work



Liberty Island

USGS 381443121405701, LIBERTY ISLAND AT HASTINGS TRACT

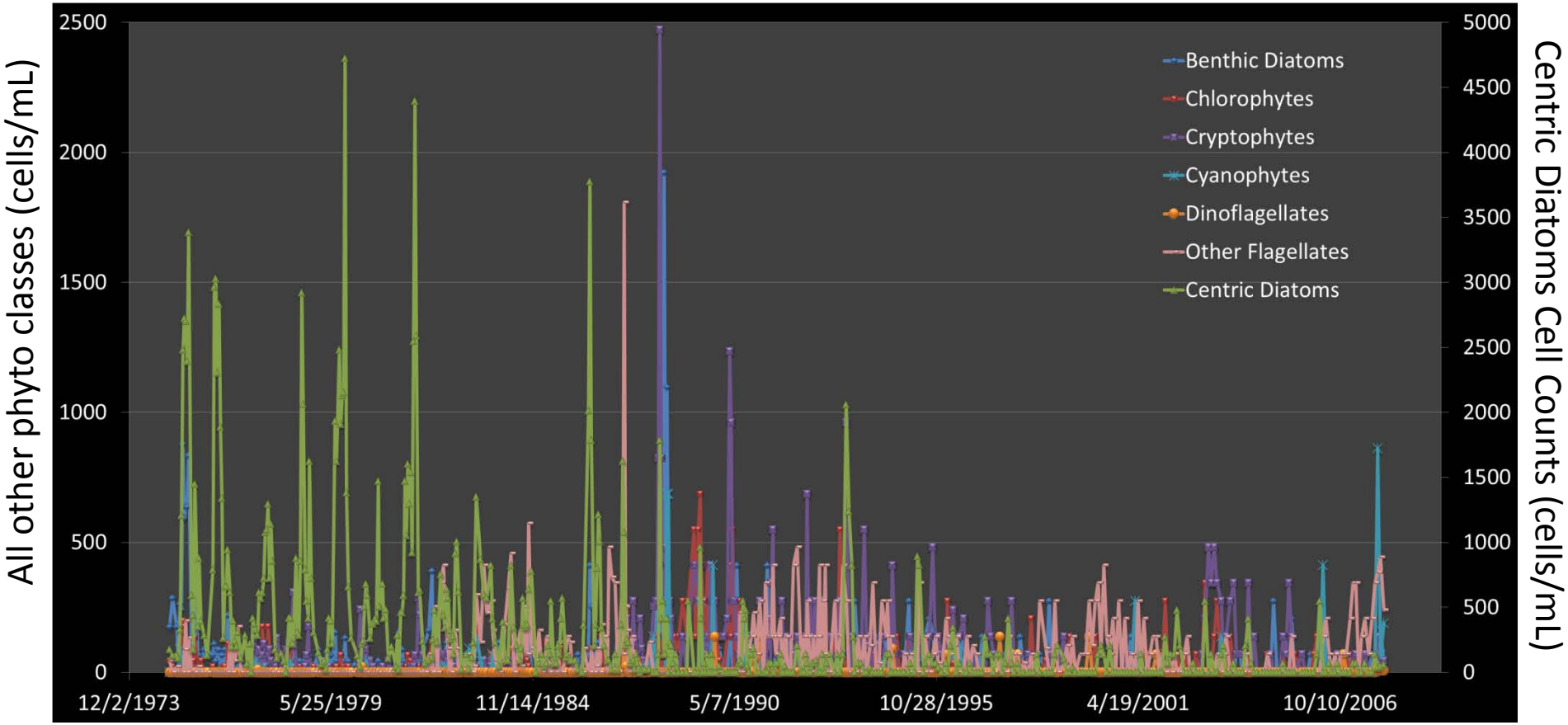


WHAT WE WANT TO KNOW:

Phytoplankton taxonomy

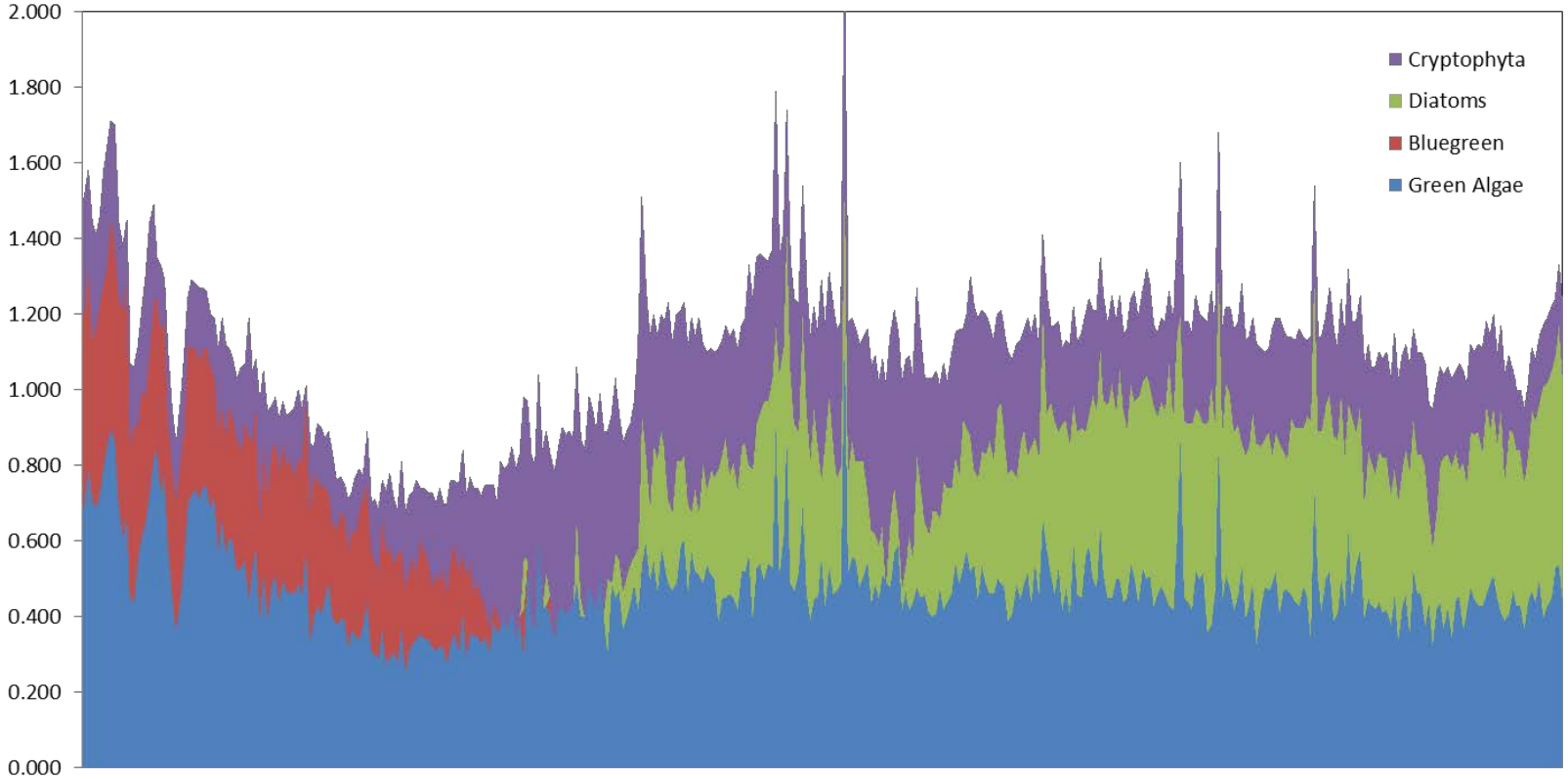
Monthly Phytoplankton Cell Counts in the Lower Sacramento/northern SFE 1973-2006

Diatoms → Mixed → Crypto + other flagellates →



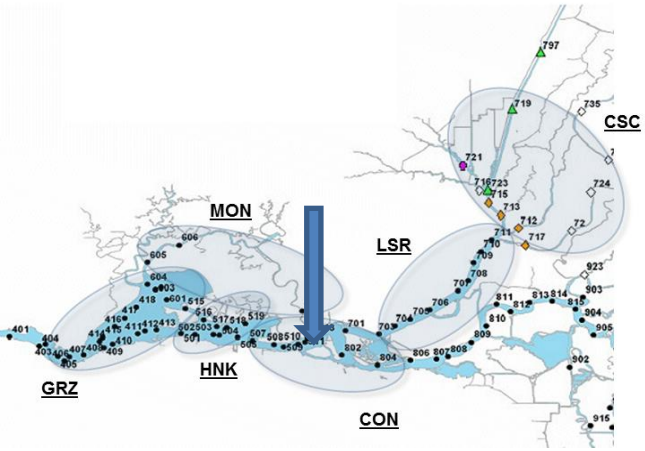
WHAT WE WANT TO KNOW:

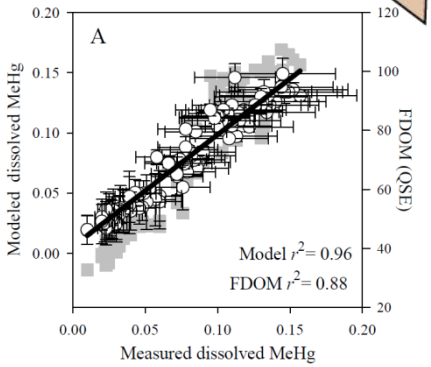
Phytoplankton taxonomy

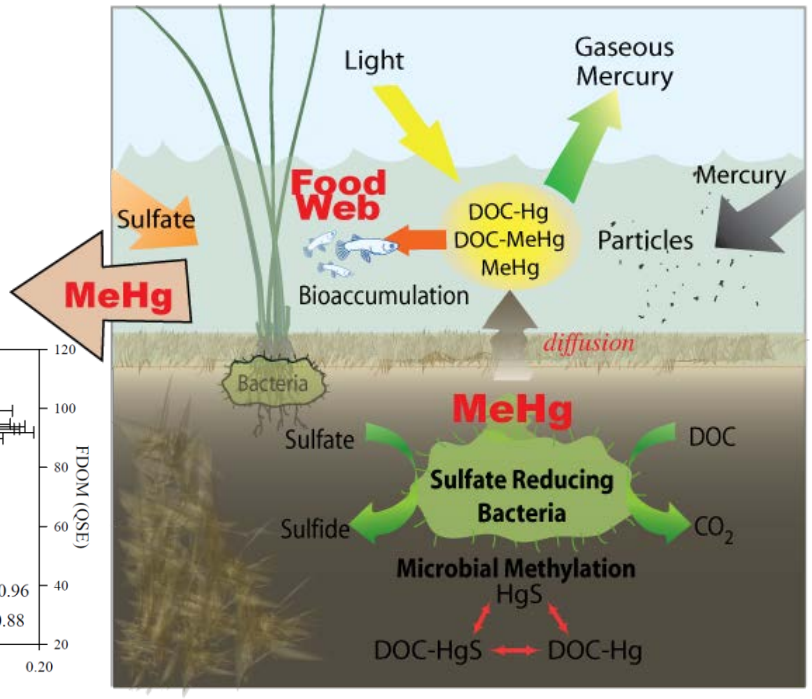


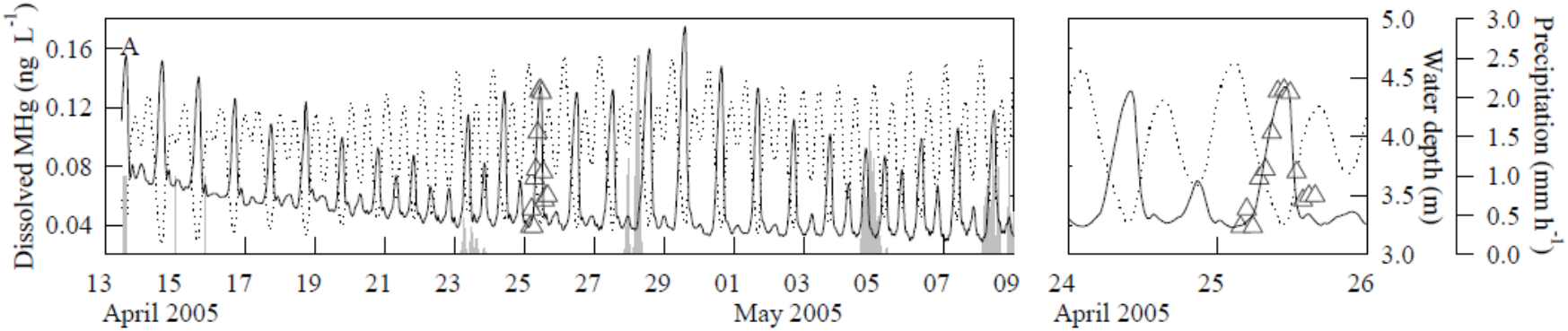
WHAT WE WANT TO KNOW: Methylmercury

Proxy measurements for high resolved MeHg flux from a tidal wetland, Browns Island, CA





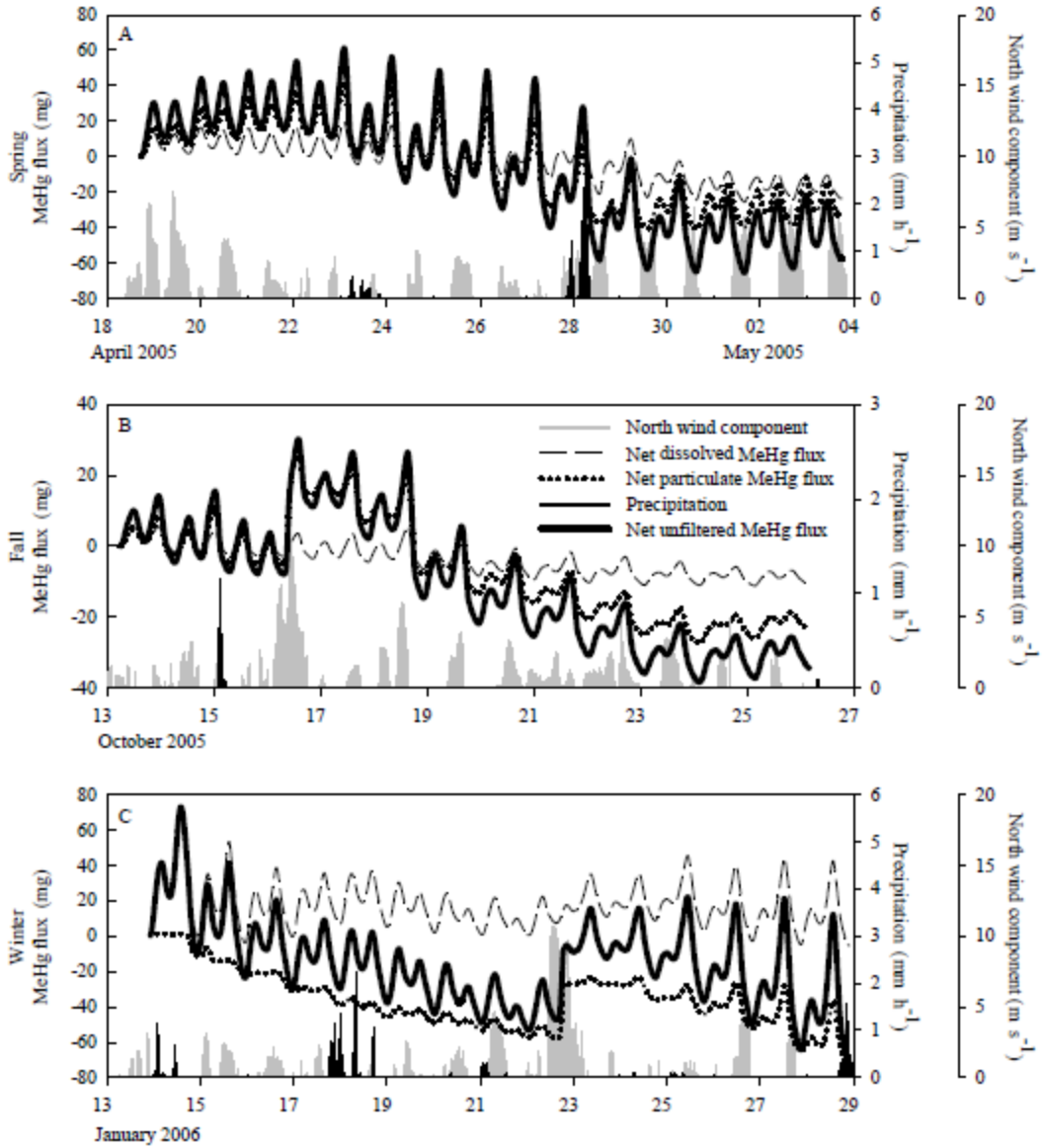




Bergamaschi et al., *2011,*

WHAT WE WANT TO KNOW: Methylmercury

Methylmercury fluxes and yields



YIELDS:

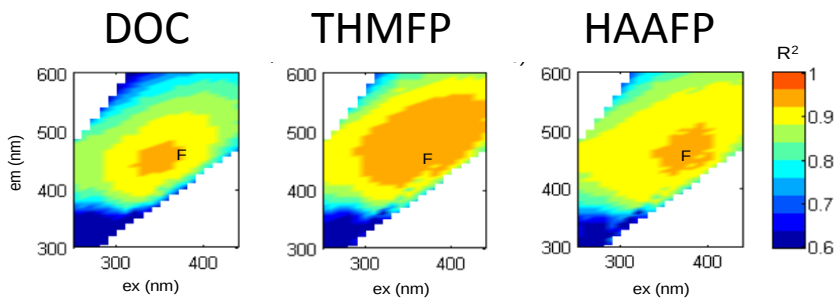
2.5 μg m^{-2} yr^{-1}

4-40 times previously published yields

Representing a potential loading to the Estuary of 80 g yr^{-1}

WHAT WE WANT TO KNOW: Drinking Water

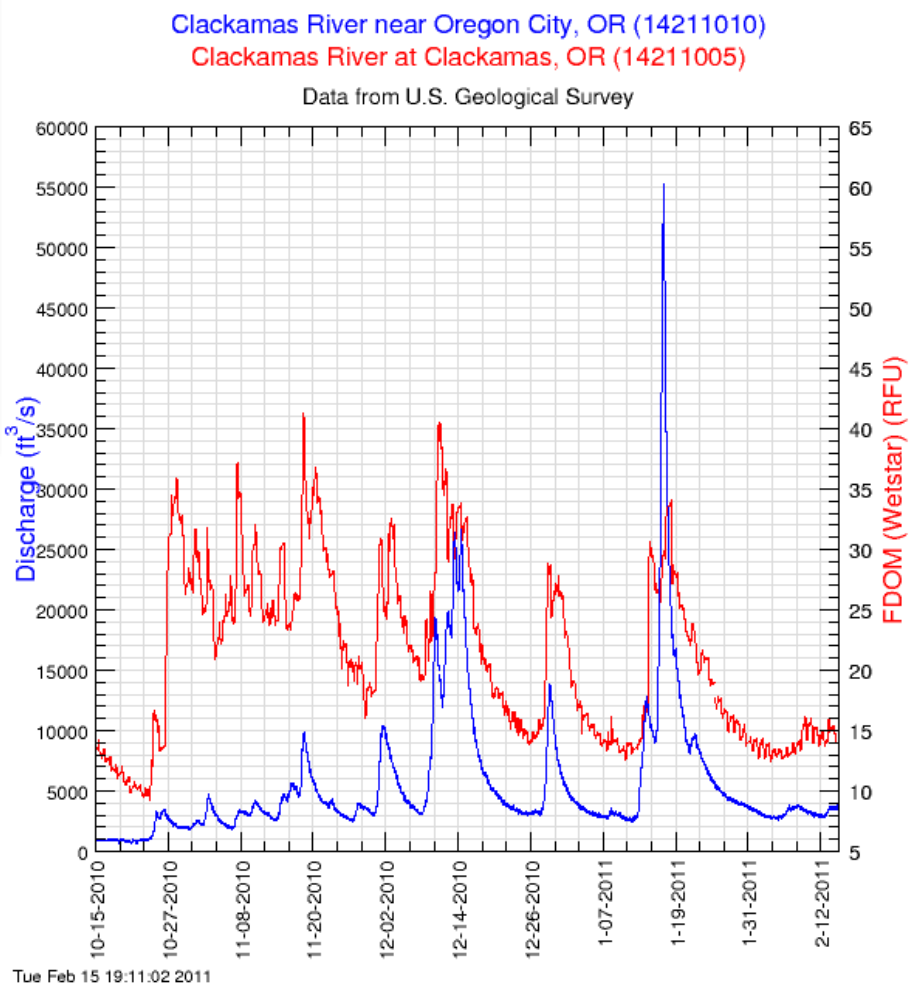
Lab data from the McKenzie River *(left)* and continuous FDOM data from the Clackamas River *(right)*



Orange color indicates highest correlation between fluorescence (R^2>0.95; *n* = 30 samples) (Kraus et al., 2010)

Turner C6 with FDOM and custom optics

(Kraus et al., 2010)



CONCLUSIONS

Why do we need a continuous HF Delta – Estuary network?

- Grab samples alone cannot tell us what we want to know.
- Continuous, co-located, high-frequency measurements are necessary to:
  - Accurately quantify fluxes
  - Differentiate among processes
  - Understand spatial relationships
  - Identify long-term trends
- New methods and instruments make it possible to observe and quantify biogeochemical processes, contaminants, and ecosystem effects IN REAL TIME
- It is now possible to get a more comprehensive picture of habitat and water quality than ever before. We are already doing most of the work…….

WE ARE DOING MOST OF THE WORK ALREADY FOR CONTINUOUS MONITORING IN THE DELTA!!

Measuring Flow: The Master Variable

Stand on a tule island at the junction of two delta channels and you'd think you could tell which way the water was flowing. Surely anything that looks so much like a river naturally flows downstream, from the hills to the sea? But the Delta is not a one-way system, nor is nature entirely at the controls. Throw in ocean tides coming in and out, pumps directing water from here to there, and seasonal ups and downs, and the only people who can really tell which way the water is flowing at any given time or place aren't standing on a tule island. They're sitting in a dark room staring at computer screens showing the minute-by-minute measurements of the USGS flow station network.

The network is pretty comprehensive. Over three decades, and with the help of various state and local agencies, USGS has installed 35 stations at what scientist Jon Burau calls "every hydro-dynamically significant flow split or confluence" in the landscape of the delta's 700 miles of channels (see map). Most of these stations employ a gizmo called a sideward-looking acoustic Doppler current profiler, mounted on a piling, or channel marker. These devices bounce sound waves off particles in the water across entire river channels, measuring flow, also called "discharge," as a volume per time (such as cubic feet of water per second). Small solar panels power the sensors, and help them relay the information they collect to computers in operations rooms and science labs throughout California.

"We happen to have a flowing system, and it's flowing not just in one direction but it's flowing every which way, because of tides, and rivers coming together, and pumping," says Anke Mueller-Solger, Lead Scientist of the Interagency Ecological Program for the Delta Stewardship Council. "Understanding anything in this system must start with a good understanding of flow, and how that interacts with more stationary variables like channel geometry, physical habitat, sediment beds, and point sources of pollution. Flow is a dynamic master variable."

Fresh water flow is also something 25 million Californians rely on — for drinking and irrigation water — in what has been called the "most managed watershed in the country." State and federal water managers use flow station network data to make critical daily decisions about how much fresh water they can pump to cities and farms, and when and where. Wildlife scientists also use this information to protect fish species endangered by pumping and loss of habitat. In California's long history of wrangles over water, many resulting court decisions, biological opinions and water quality standards have become, to some extent, reliant on the numbers spit out by the flow stations.

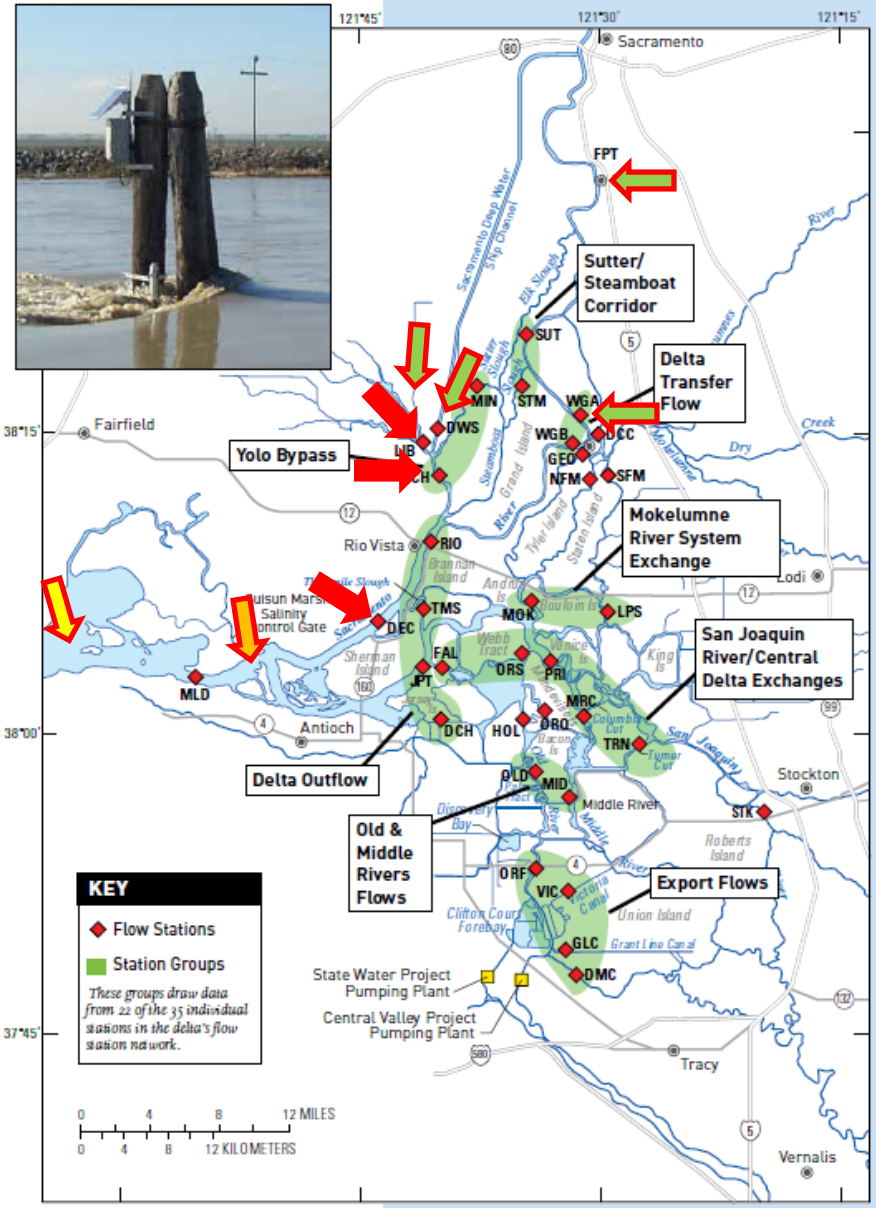
The one number everyone has wanted from these submerged outposts scattered throughout the delta is the "net flow, or the amount of water flowing in a channel with the tidal flows averaged out. In the early days, getting this number involved a lot more than a few clicks on a key pad. The technology to measure the pulse of fresh water moving through a system overwhelmed with twice-daily ocean tides simply did not exist before the mid 1970s. Particularly challenging was to try to extract this number in the 500 meter wide channels in the delta.

But that's exactly what the state's Department of Water Resources (DWR) set out to do in the late 1920s. Researchers first stretched a cable across the channel, called a tag line, then attached their boat to the cable. As the boat moved through 12-24 stations along the cable, they used a device called a Price AA meter to take individual water velocity measurements. By summing the flow curves at each station between tidal peaks, DWR produced a snapshot of net discharge at that time and place.

"These were incredibly labor-intensive, even Herculean, field efforts, working with multiple boats over 24-hour periods, but they did an amazingly accurate job given the technology they had," says USGS scientist Jon Burau.

Eight decades later in the 2010s, measuring net flow involves equally, if not more, complex efforts, but technology and computers do most of the heavy lifting. The biggest challenge overcome by the hydrodynamics team of the USGS California Water Science Center, which runs the network, has been to find a way — through data collection, math and modeling — to isolate the small signal (net flow) from what they

continued to page 8



Location of USGS-operated flow station sites in the Delta. Source: USGS, CWSC

The flow station network developed [illegible] to a series of [illegible] question, how much fresh water was flowing into the delta from the Sacramento River, was answered with the installation of the first hydro-acoustic meter at Freeport in 1978. A decade later, water managers and scientists wanted to monitor the influence of the export facilities on the north-to-south movement of water from central to south delta. So they installed two more acoustic velocity meters at Old River at Bacon Island and at Middle River (1987). In the early 1990s, water project operators installed two stations in the Walnut Grove area, so they could find out how much water was flowing from the Sacramento River into the central Delta through the Delta Cross Channel and Georgiana Slough, the so-called Delta Transfer Flow. Finally, a combination of four stations in the south delta, just upstream of the export pumps, were installed to estimate delta outflow. Below is a description of the groups of stations used to address specific regional scale questions.

Delta Outflow - The sum of the measured flows from stations at Rio Vista (RIO), Three Mile Slough (TMS), San Joaquin River at Jersey Point (JPT) and Dutch Slough (DCH) are used to estimate delta outflow. Delta outflow is a key ecosystem metric because it is a measure of water received by San Francisco Bay (i.e. inputs less exports and consumptive use).

Delta Transfer Flow - The delta transfer flow is computed as the difference between the flows measured at stations WGA and WGB, two flow stations located near Walnut Grove. The calculation helps water managers estimate the amount of Sacramento River water that flows into the central delta through the Mokelumne system (the Delta Cross Channel and Georgiana Slough). The delta transfer flow is critical for maintaining salinity standards in the central delta.

Old and Middle Rivers – The sum of the flows at stations OLD and MID represent the flow to the export facili-

THANKS !