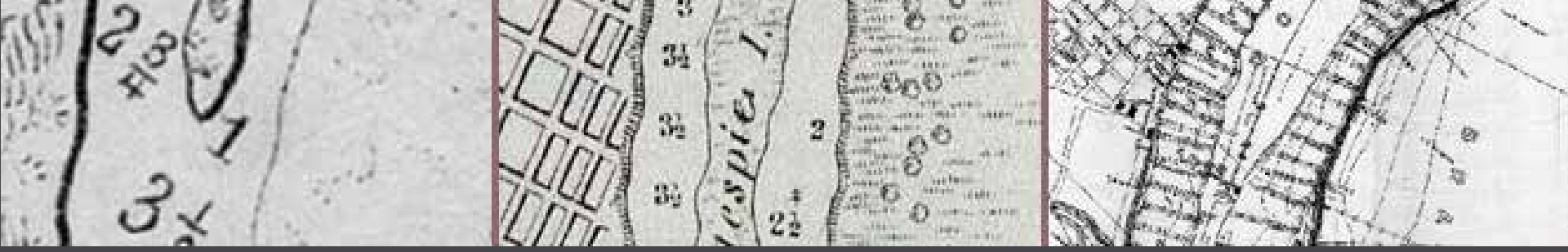
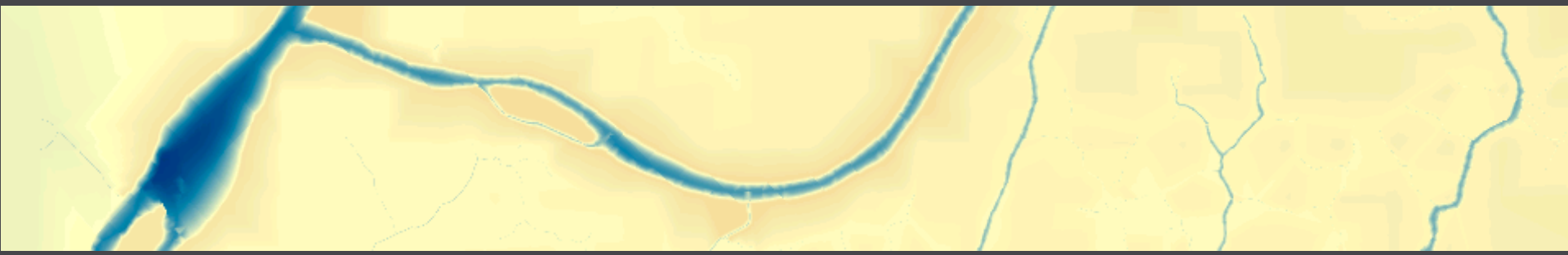


Generating a Historical Bathymetric-Topographic Digital Elevation Model



Robin Grossinger[1], Bill Fleenor[2], Alison Whipple[1,2], Julie Beagle[1], Sam Safran[1], Andy Bell[2], Mui Lay[2]

[1]San Francisco Estuary Institute, [2]UC Davis

SFEI ASC

UC DAVIS Center for Watershed Sciences

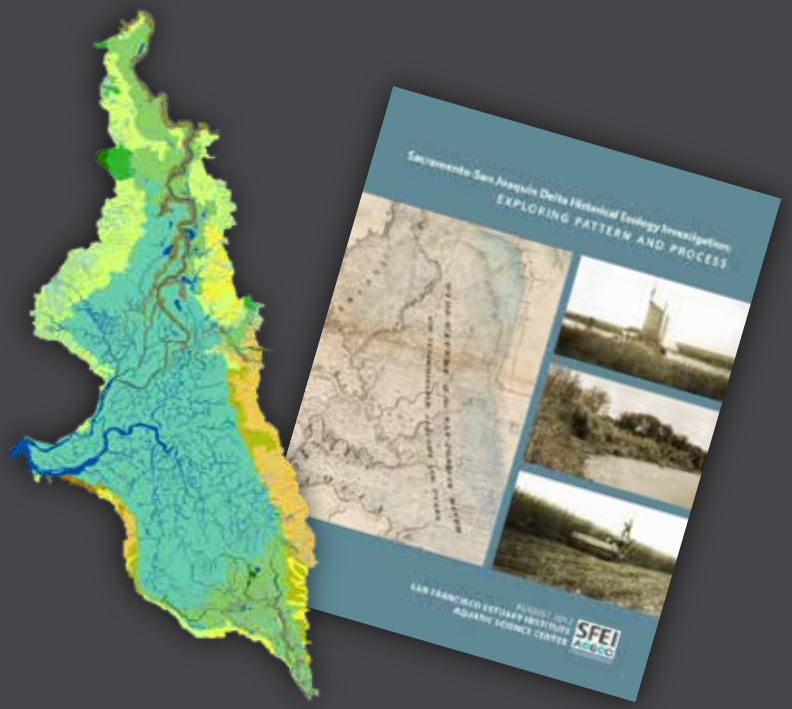
CWEMF 2014 Annual Meeting
February 25, 2014

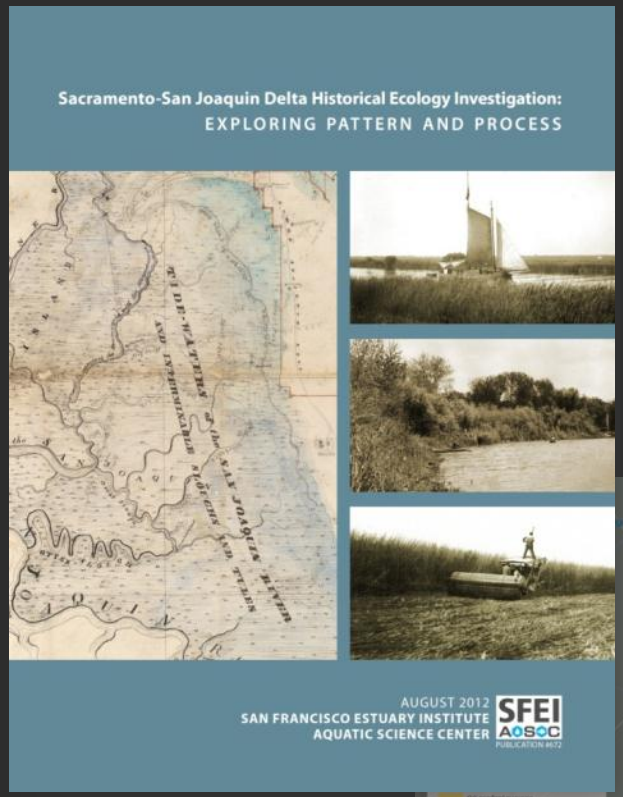
Overview

- Background and Motivation
- Part I: Data Collection and Development
  - Data sources
  - Data preparation
- Part II: Data Interpolation
  - Building the DEM

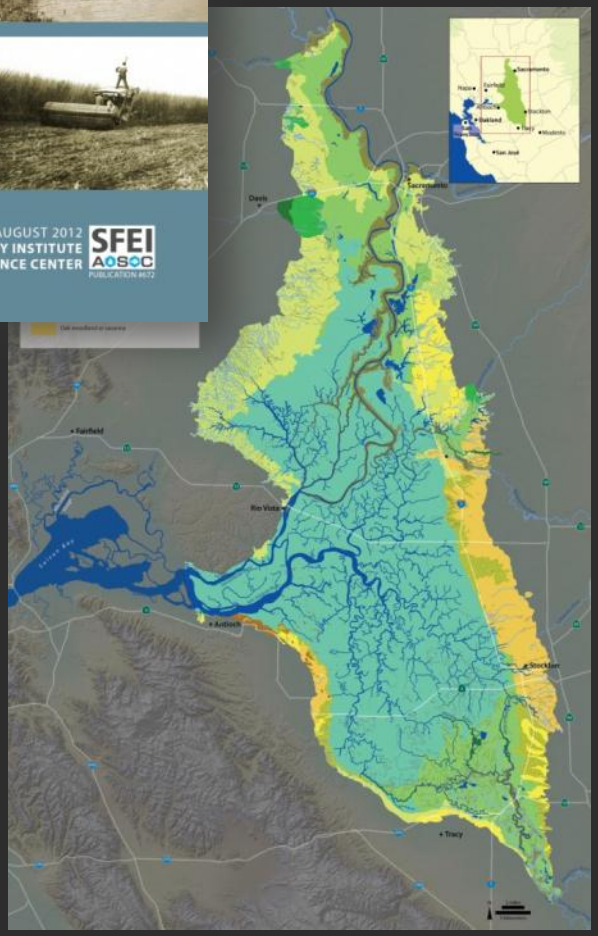
Background and Motivation

- *Motivation:* How to gain further insights of the Delta's altered hydrology and hydrodynamics?
  - Drawing from the Delta Historical Ecology Study
- *Goal:* Transform 2D into 3D data into a historical (ca.1850) digital elevation model
- *Applications:* Hydrodynamic changes, salinity intrusion, tidal marsh dynamics, estimated flood extents, visualizations

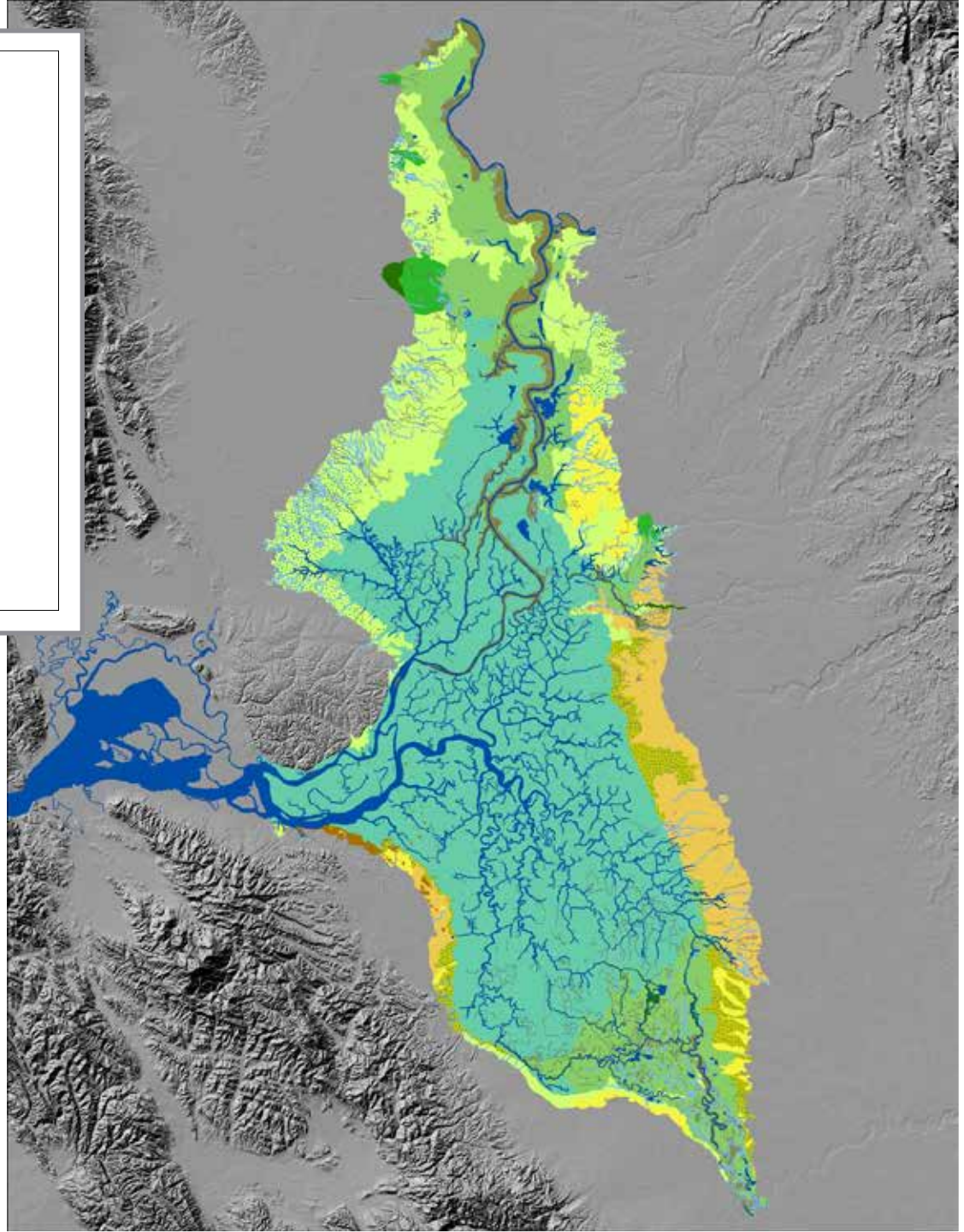




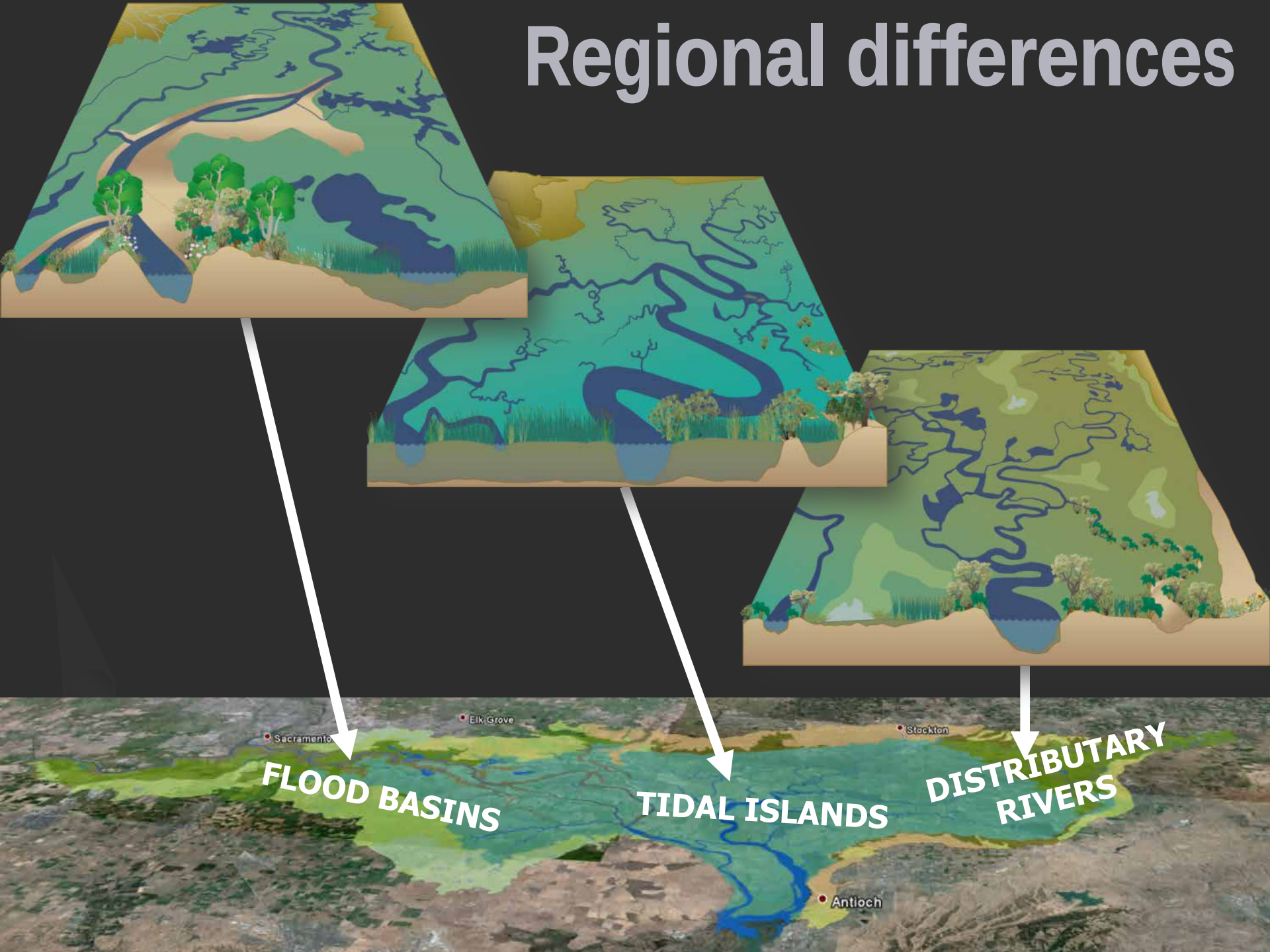
Sacramento-San Joaquin Delta Historical Ecology Investigation: Exploring Pattern and Process *(Whipple et al. 2012)*

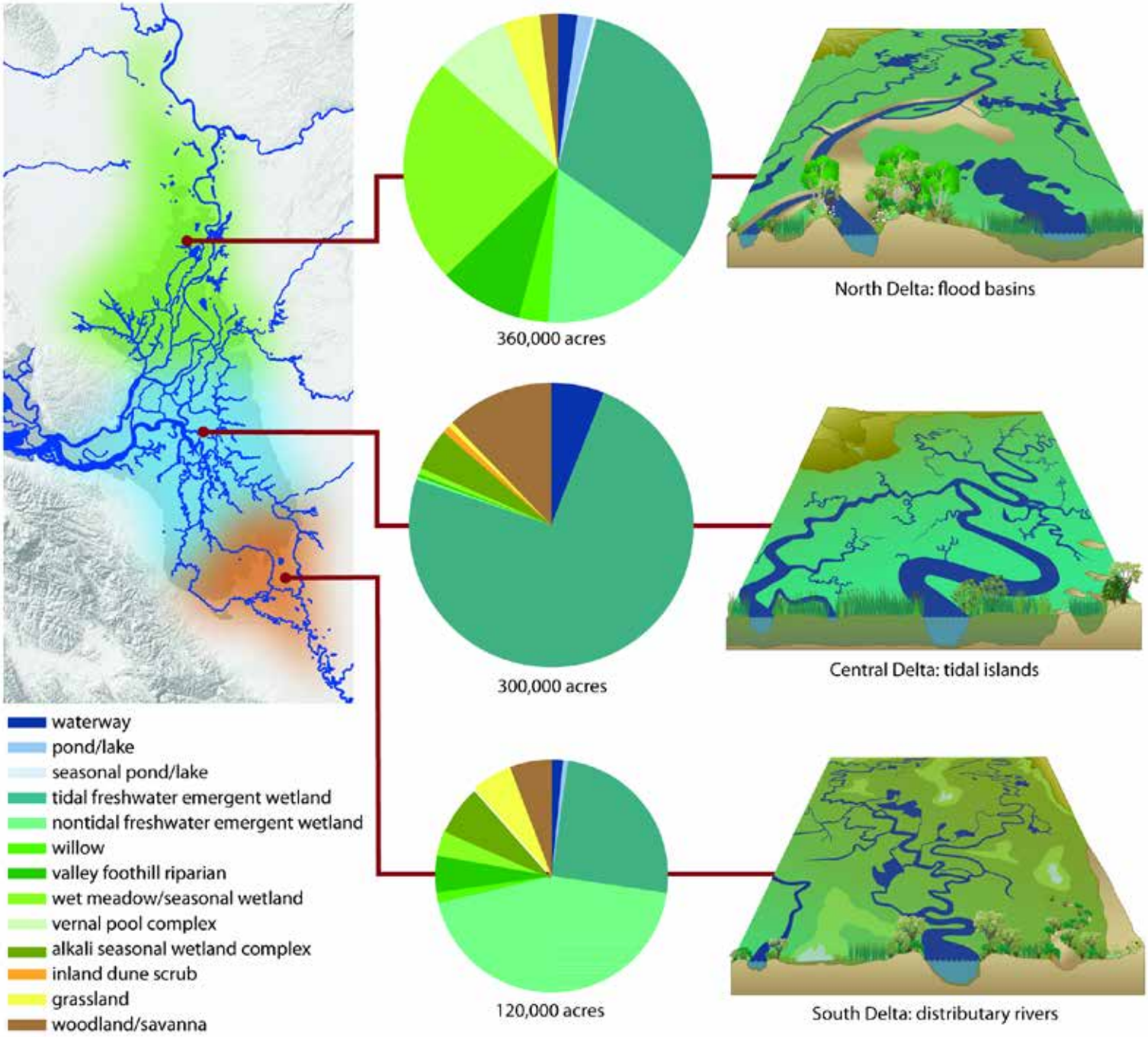


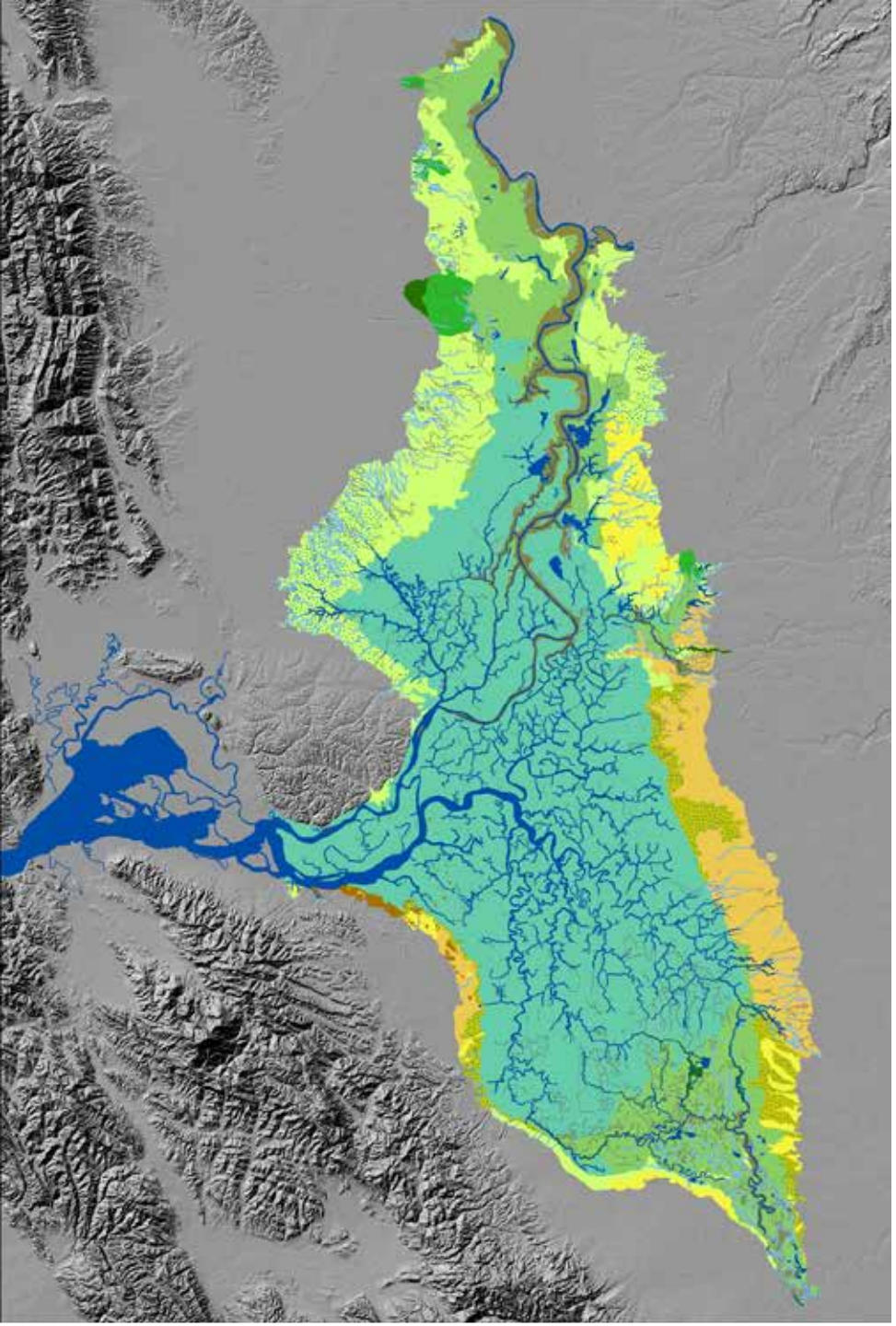
- Funded by Ecosystem Restoration Program (CDFG, NOAA, US FWS)
- Final Report/GIS Available: www.sfei.org/DeltaHEStudy
- Collaboration with KQED QUEST and Stanford's Bill Lane Center for the American West: science.kqed.org/quest/delta-map/

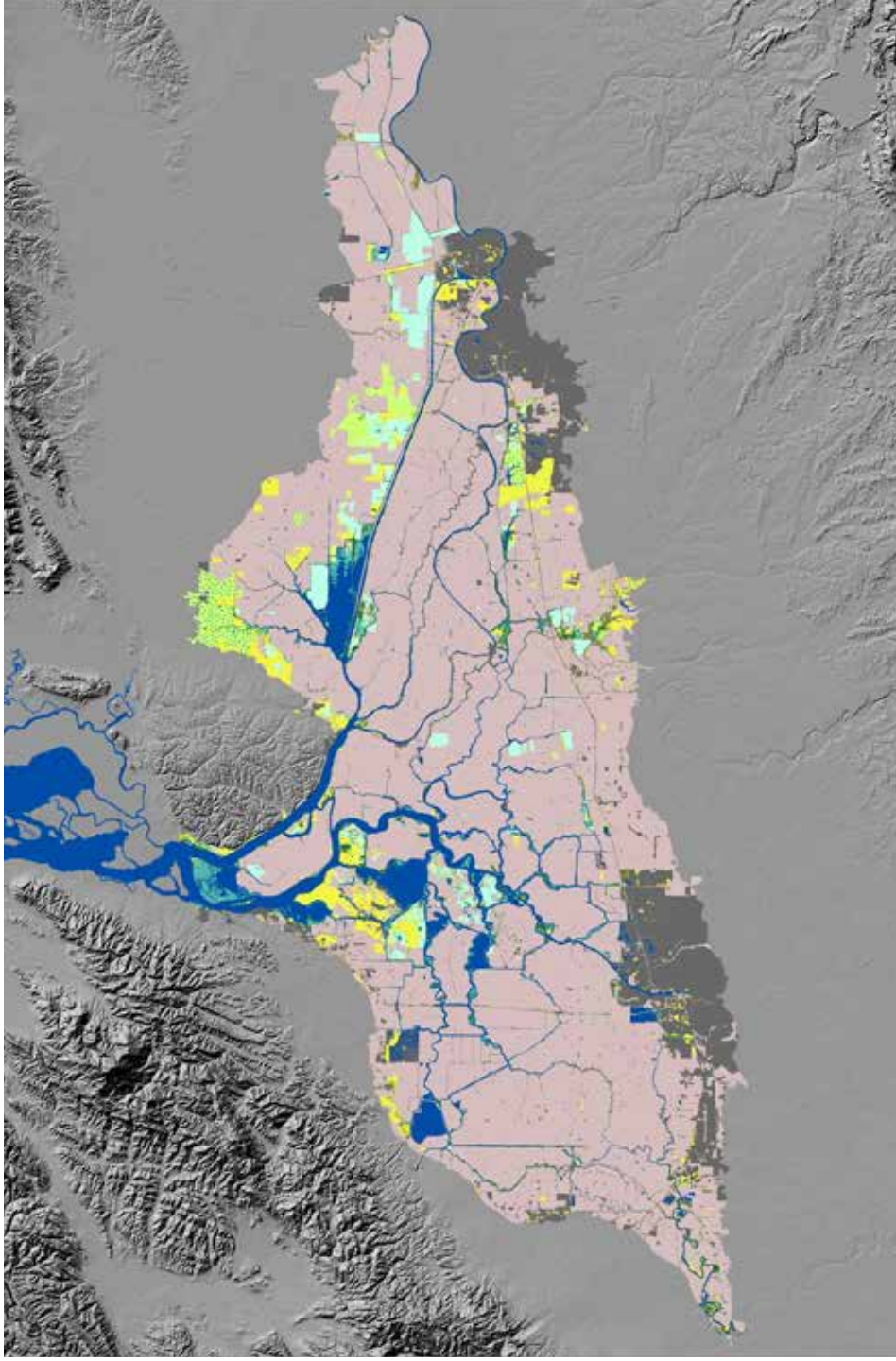


Regional differences



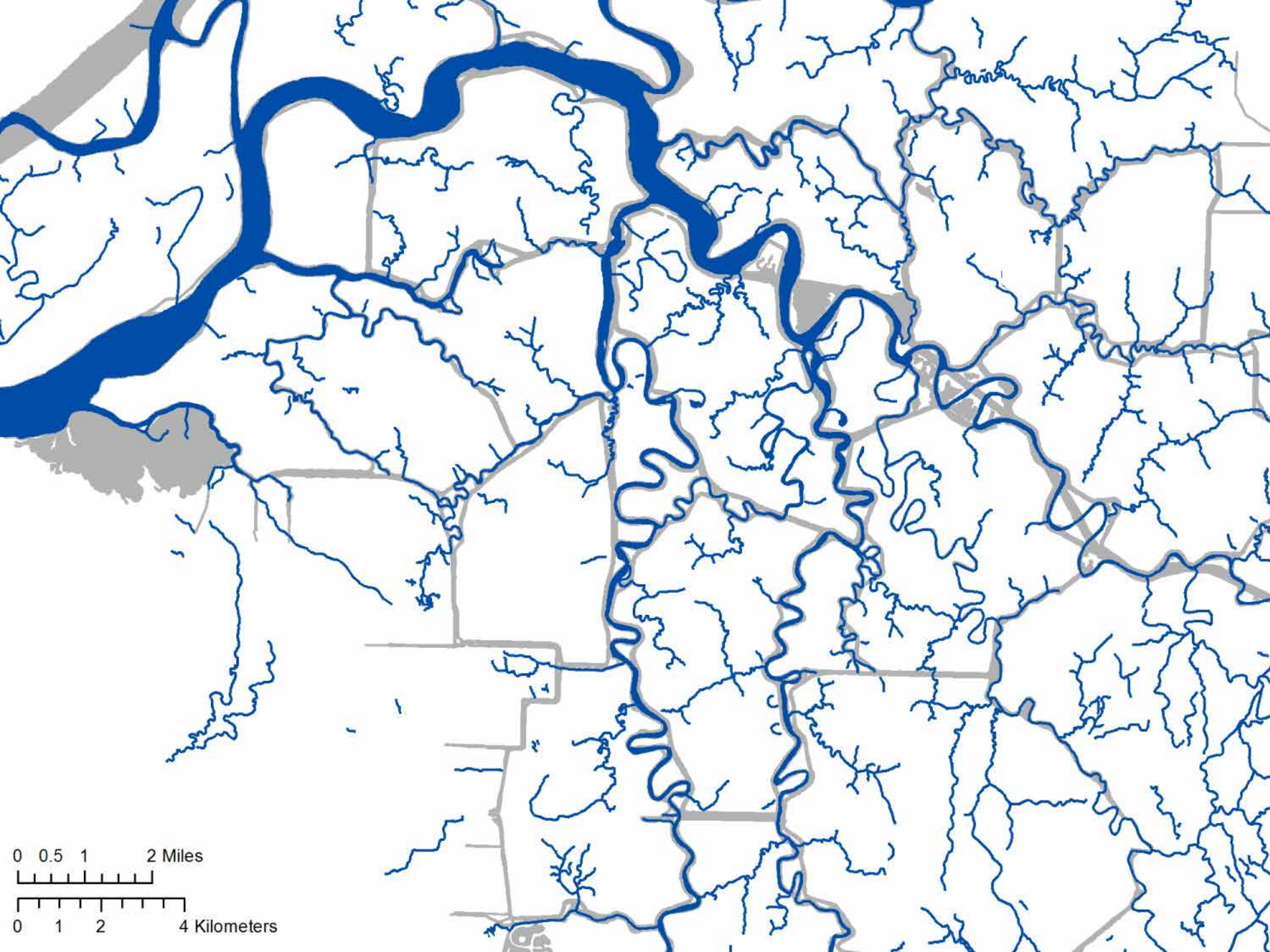

waterway
pond/lake
seasonal pond/lake
tidal freshwater emergent wetland
nontidal freshwater emergent wetland
willow
valley foothill riparian
wet meadow/seasonal wetland
vernal pool complex
alkali seasonal wetland complex
inland dune scrub
grassland
woodland/savanna
360,000 acres
North Delta: flood basins
300,000 acres
Central Delta: tidal islands
120,000 acres
South Delta: distributary rivers

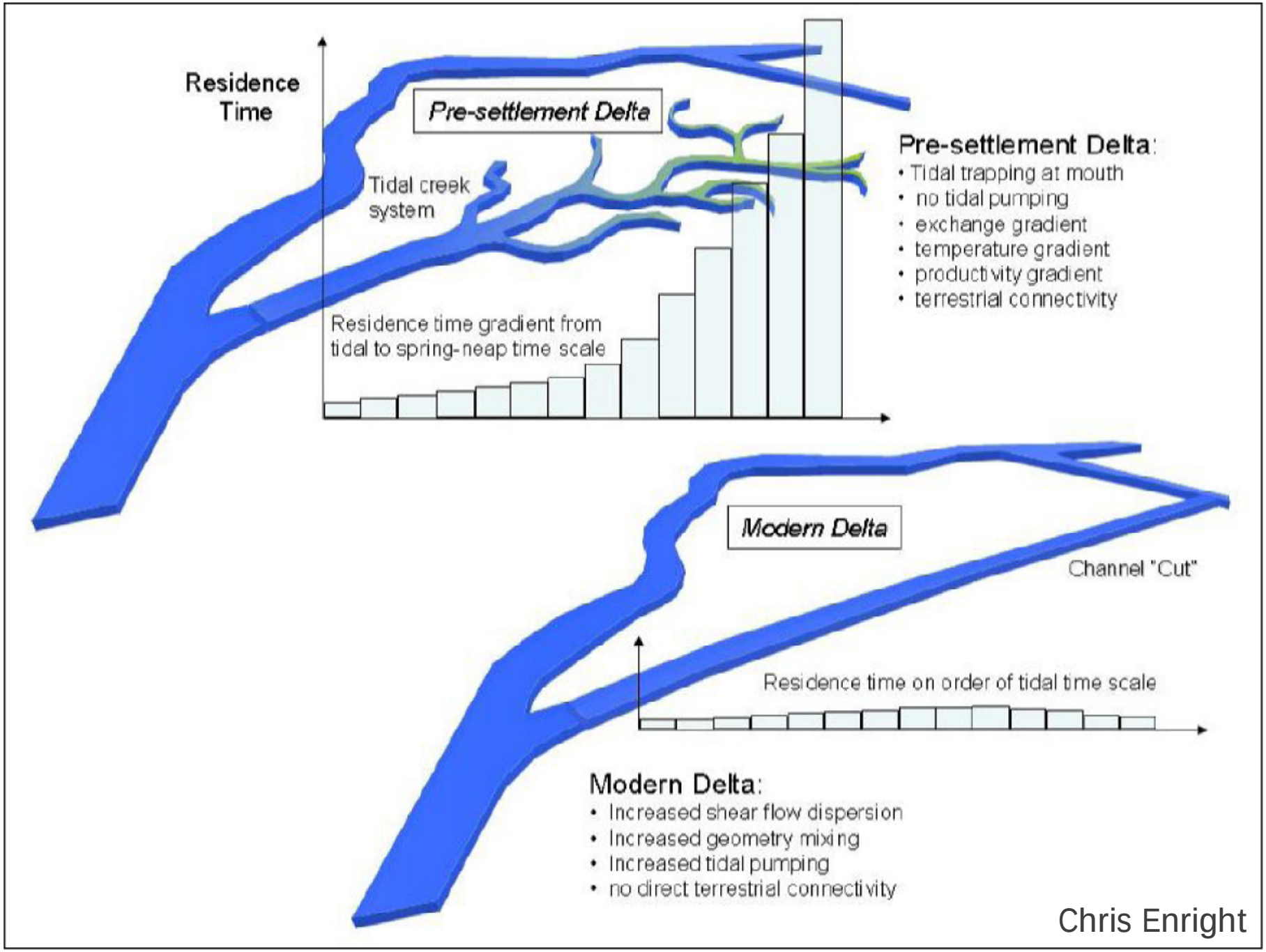




historical

modern

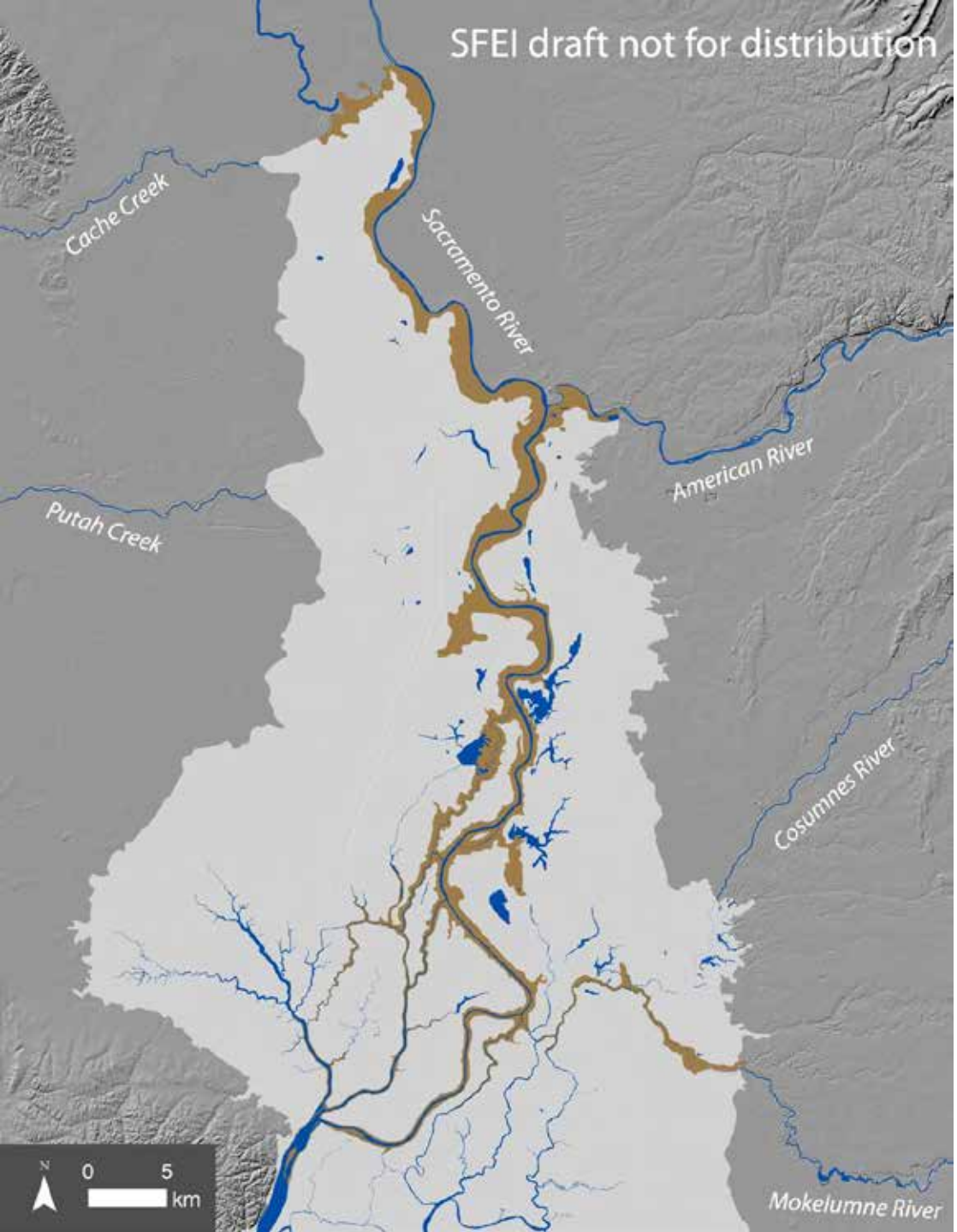

0 0.5 1 2 Miles
0 1 2 4 Kilometers


Residence Time
Pre-settlement Delta
Tidal creek system
Residence time gradient from tidal to spring-neap time scale
Pre-settlement Delta:
• Tidal trapping at mouth
• no tidal pumping
• exchange gradient
• temperature gradient
• productivity gradient
• terrestrial connectivity
Modern Delta
Channel "Cut"
Residence time on order of tidal time scale
Modern Delta:
• Increased shear flow dispersion
• Increased geometry mixing
• Increased tidal pumping
• no direct terrestrial connectivity
Chris Enright

McCurry 1927

photograph of flooding along Sacramento removed due to use restrictions

courtesy California State Library



North Delta
historical inundation

- **natural levees**
- perennial **open water**

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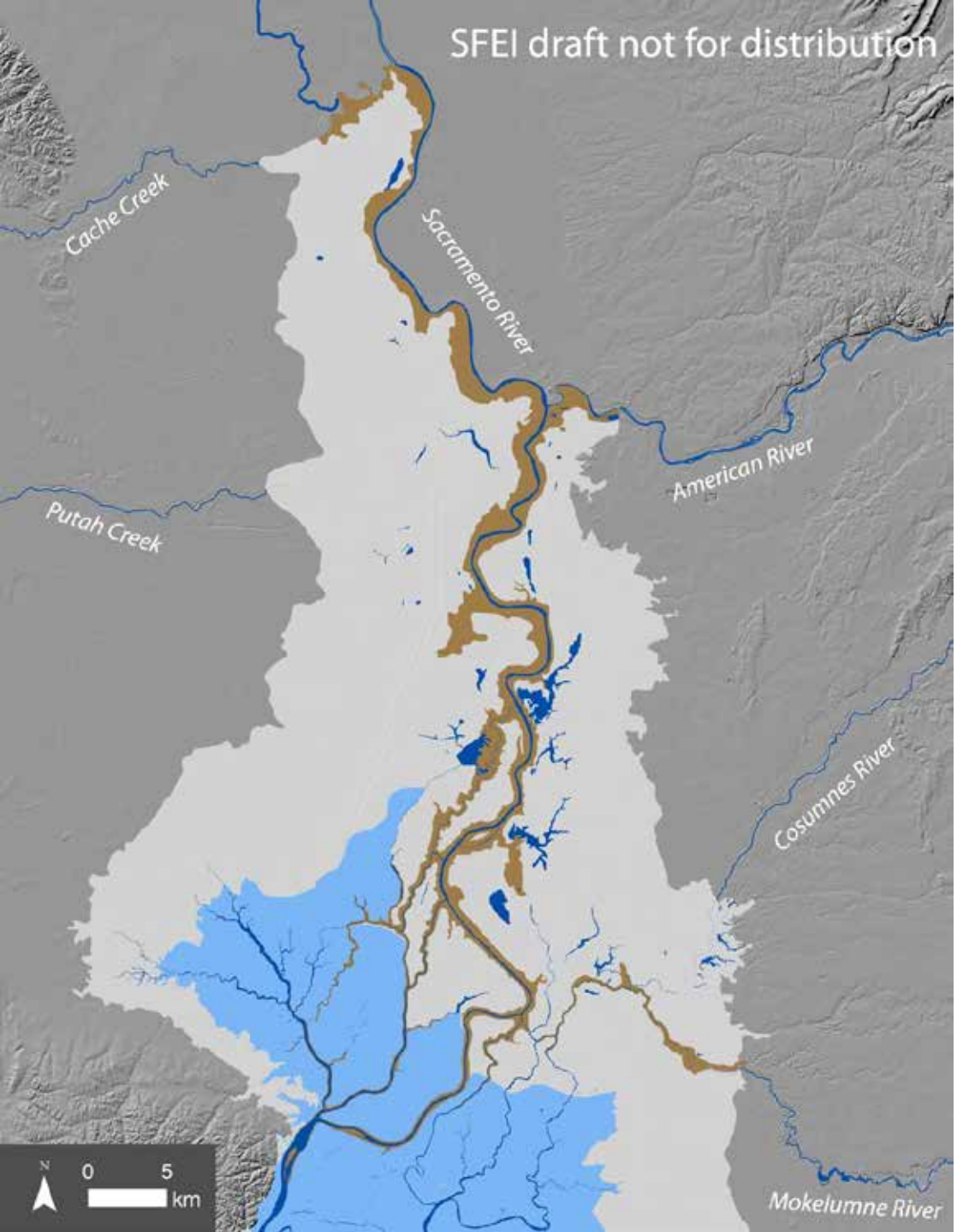
SAN FRANCISCO ESTUARY INSTITUTE & THE AQUATIC SCIENCE CENTER



North Delta
historical inundation

- **natural levees**
- perennial **open water**
- **daily tides**
  - high recurrence (twice daily)
  - low duration (< 6 hrs per event)
  - low depth ("wetted" to a few inches)

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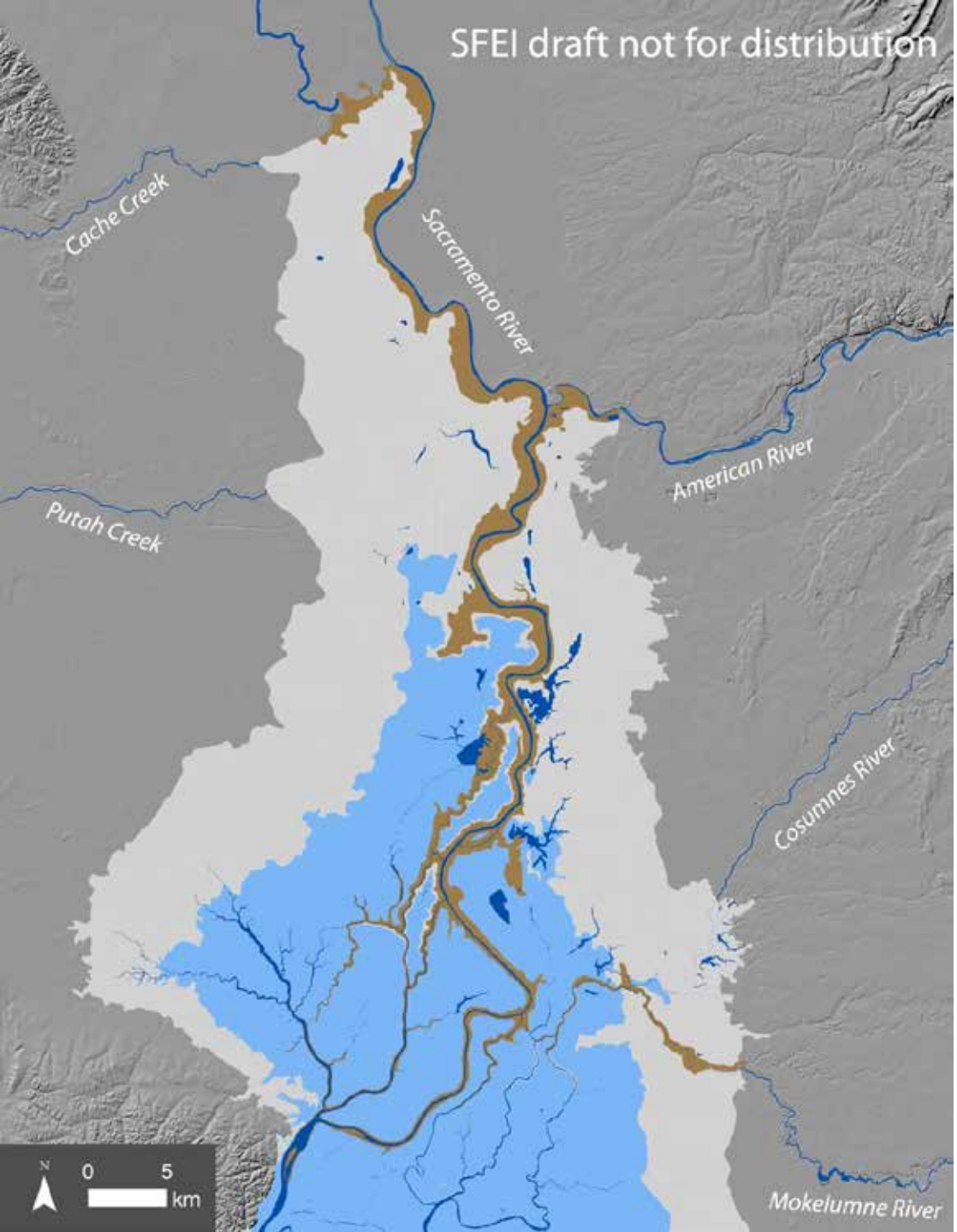

North Delta
historical inundation

- **natural levees**
- perennial **open water**
- **daily tides**
  - high recurrence (twice daily)
  - low duration (< 6 hrs per event)
  - low depth ("wetted" to a few inches)
- **spring tides**
  - high recurrence (bi-monthly)
  - low duration (< 6 hrs. per event)
  - low depth (up to ~1.5 ft)

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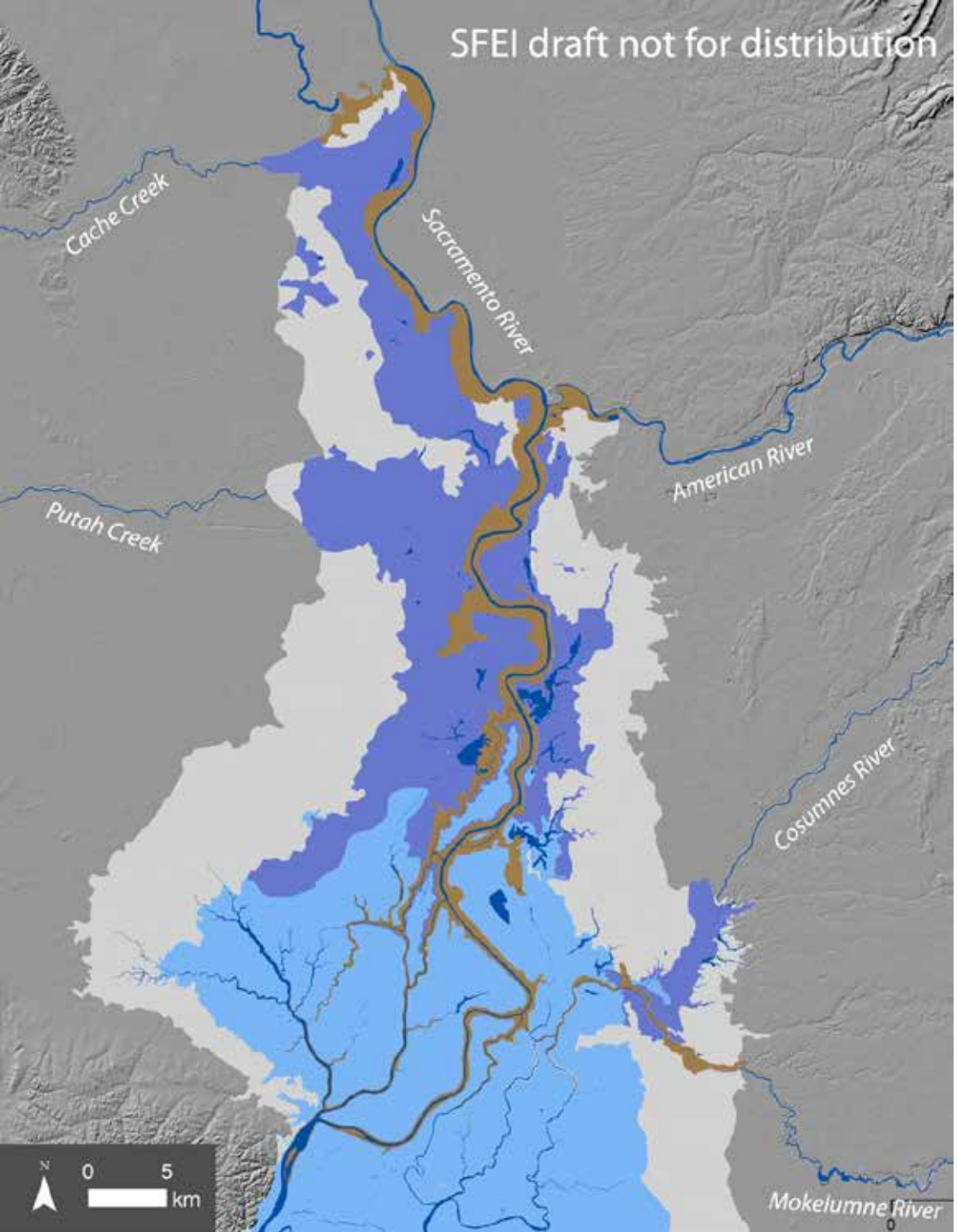

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  - high recurrence (bi-monthly)
  - low duration (< 6 hrs. per event)
  - low depth (up to ~1.5 ft)
- **basin flooding**
  - low recurrence (1 event per year)
  - high duration (persists up to 6 month)
  - high depth (3 – 6 ft)

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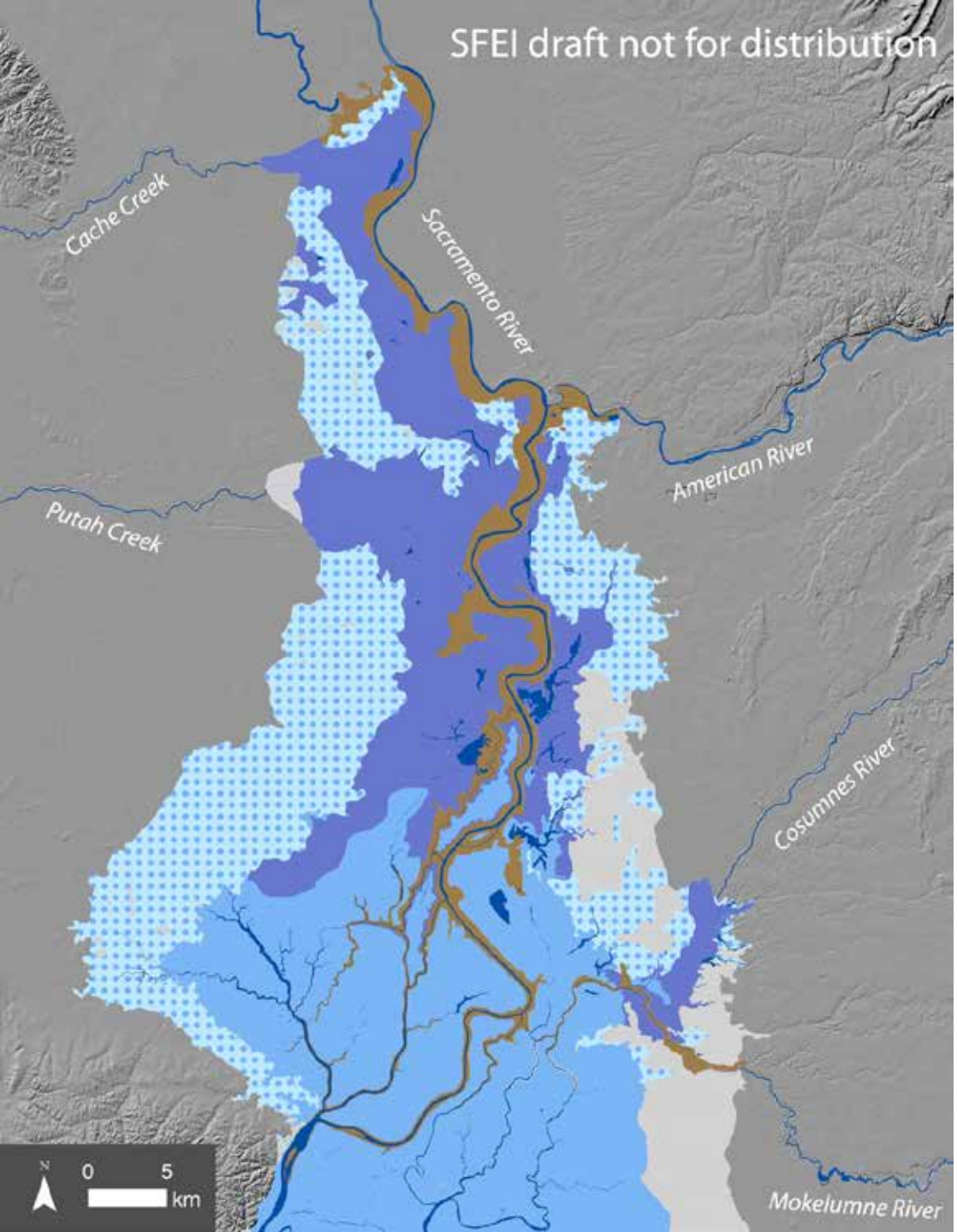

North Delta
historical inundation

- **natural levees**
- perennial **open water**
- **daily tides**
  - high recurrence (twice daily)
  - low duration (< 6 hrs per event)
  - low depth ("wetted" to a few inches)
- **spring tides**
  - high recurrence (bi-monthly)
  - low duration (< 6 hrs. per event)
  - low depth (up to ~1.5 ft)
- **basin flooding**
  - low recurrence (1 event per year)
  - high duration (persists up to 6 month)
  - high depth (3 – 6 ft)
- **seasonal wetlands**
  - intermediate recurrence (< 10 events per year)
  - low duration (days-weeks per event)
  - low depth (inches)

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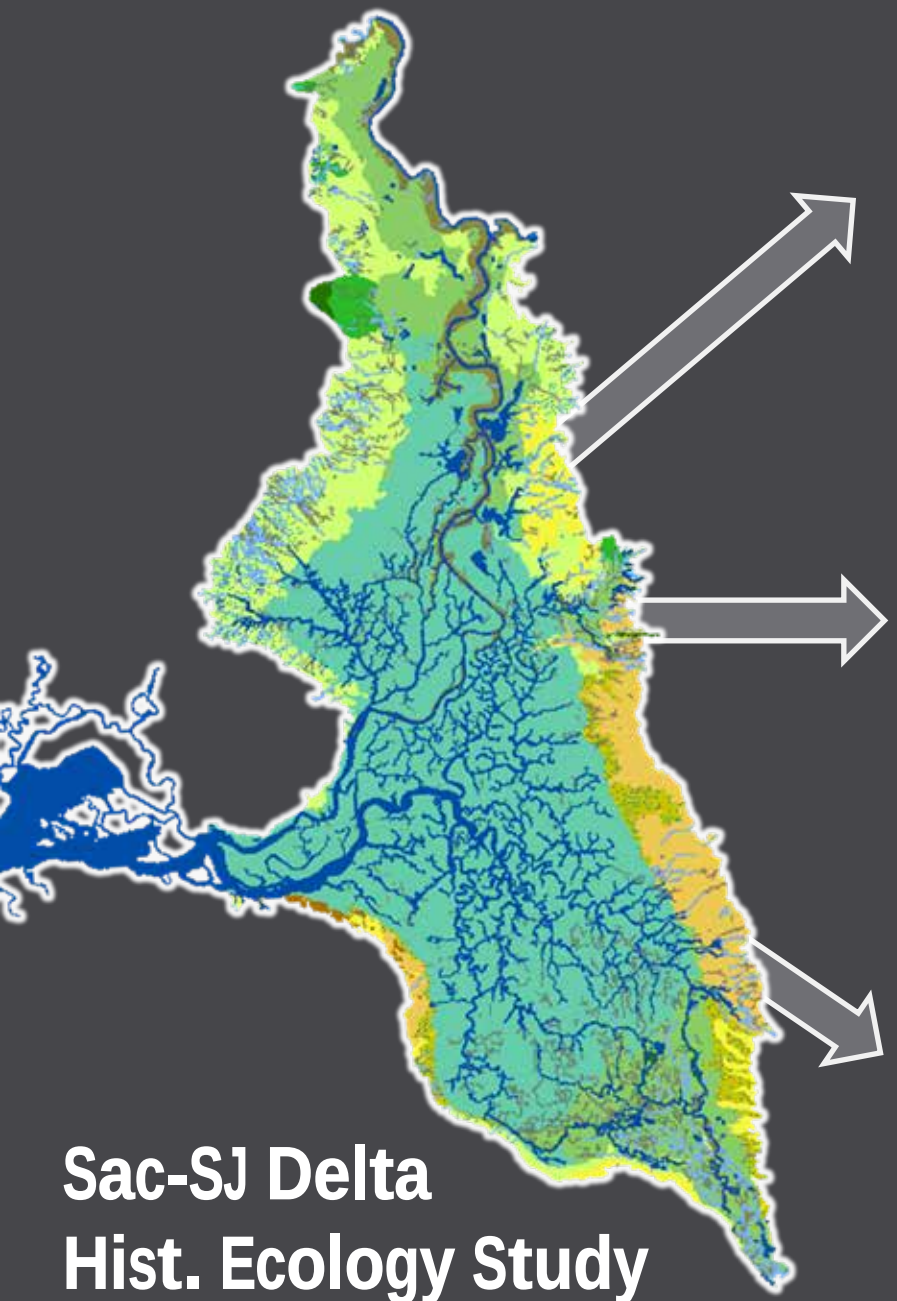


Sac-SJ Delta Hist. Ecology Study

Delta Landscapes Project

- **landscape-scale planning** and guidance
- understanding **ecological functions** offered by historical and modern Delta
- quantified with **landscape ecology metrics**
- quickly became clear that 3rd dimension is critical

Delta Natural Hydrodynamics (Historical DEM)

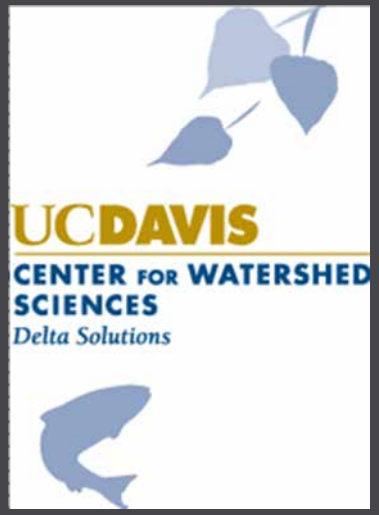
- what happens when the **aquatic envt.** (tidal and fluvial) is expressed across this kind of **physical landscape**?
- depth, volume, inundation, position of environmental gradients

Delta Visualizations

- DEM can be used with 2D habitat types to build large-scale visualizations, animations, engage public

CWS Modeling Motivation

- *Our initial efforts go back to 2010*



Modeling the Historical Sacramento-San Joaquin Delta

William E. Fleenor
Laura Doyle

CWEMF 2011

Model 50 Year Intervals

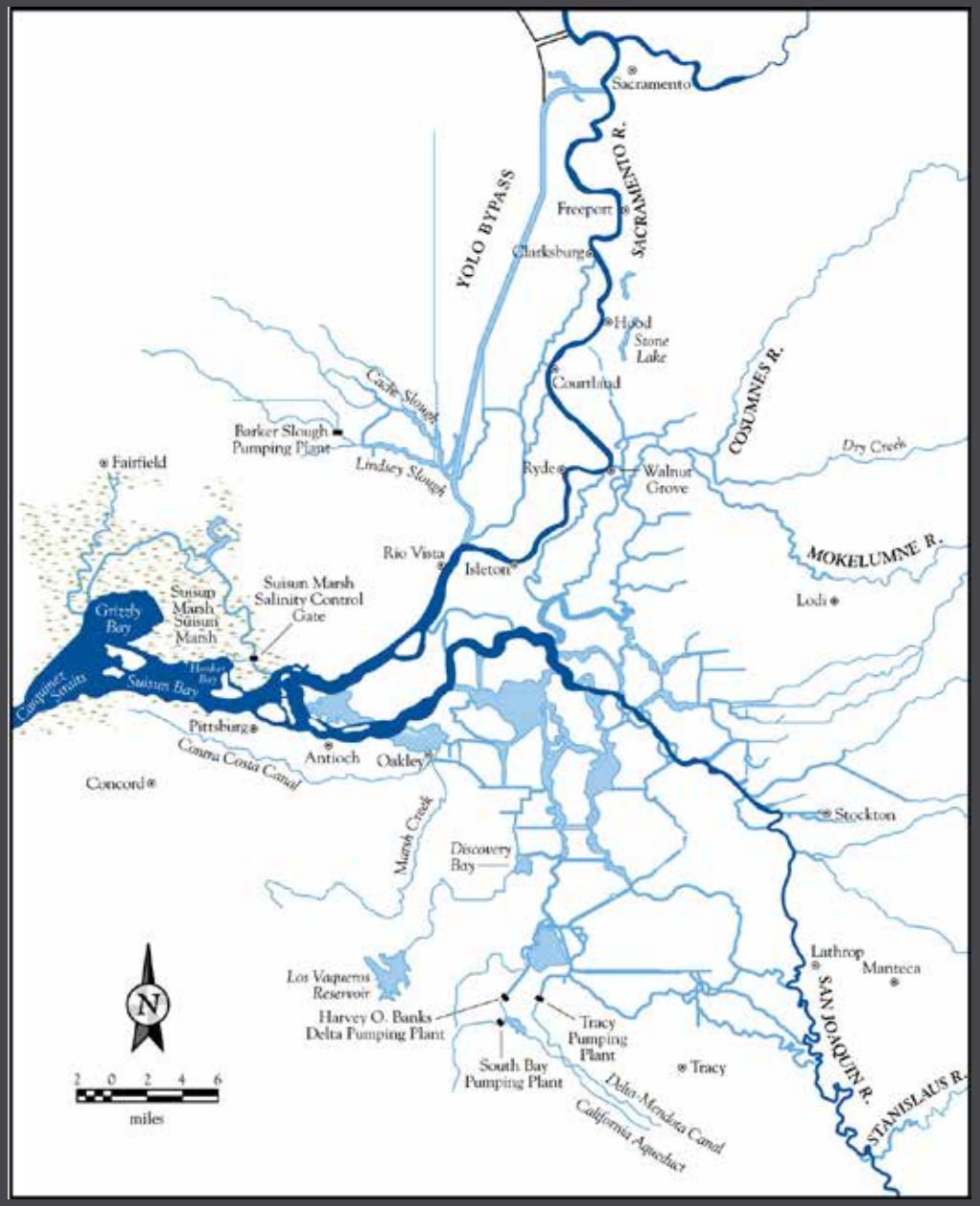
2000 – represent current Delta

1950 – developed Delta but no exports

1900 – partially developed Delta

1850 – pre-development Delta

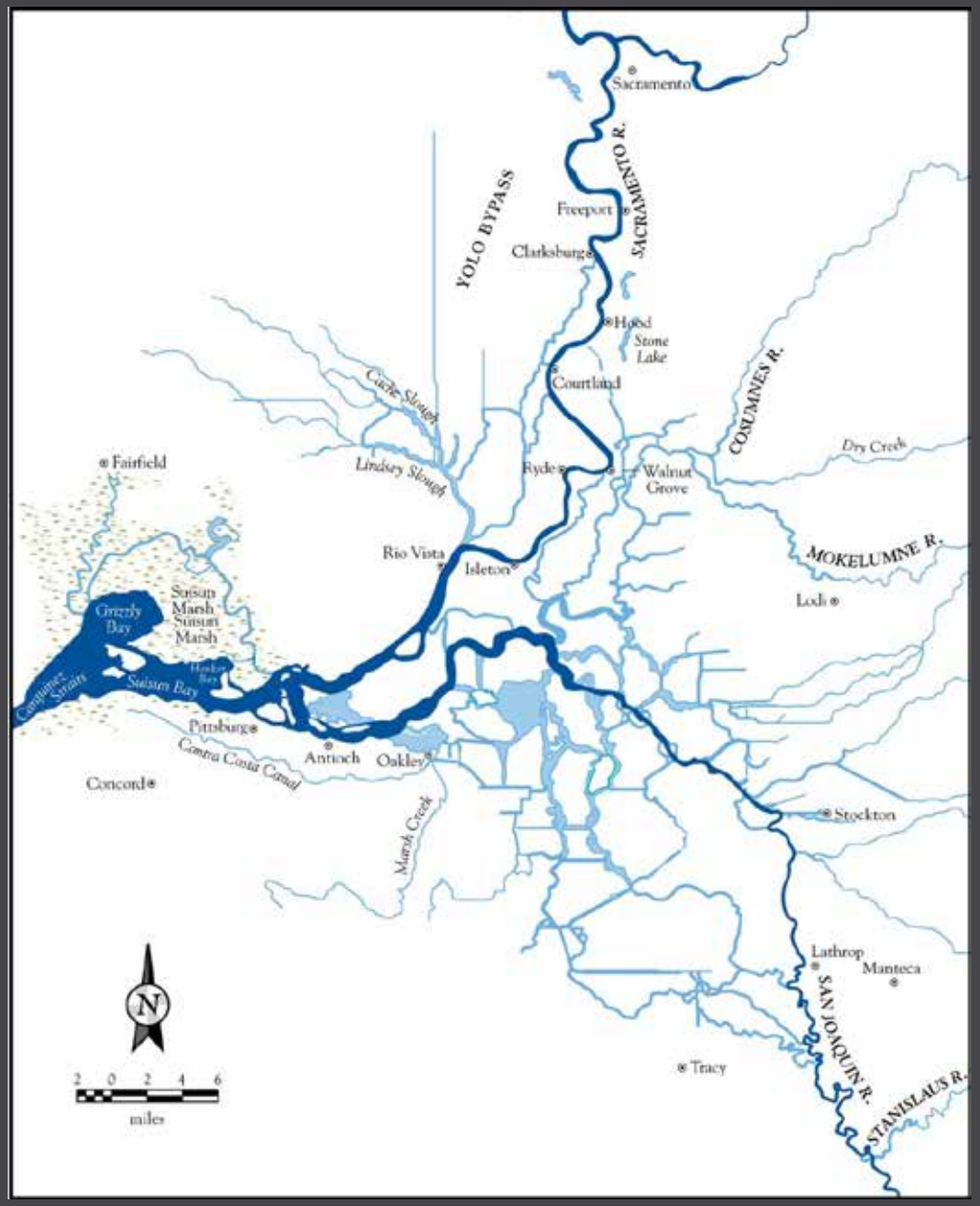
2000


Sacramento
YOLO BYPASS
SACRAMENTO R.
Freeport
Clarksburg
Hood
Stone Lake
Courtland
Cache Slough
COSUMNES R.
Dry Creek
Barker Slough Pumping Plant
Lindsey Slough
Fairfield
Ryde
Walnut Grove
Rio Vista
Isleton
MOKELUMNE R.
Suisun Marsh Salinity Control Gate
Suisun Marsh
Grizzly Bay
Suisun Bay
Carquinez Straits
Lodi
Pittsburg
Antioch
Oakley
Contra Costa Canal
Concord
Stockton
Marsh Creek
Discovery Bay
Lathrop
Manteca
Los Vaqueros Reservoir
Harvey O. Banks Delta Pumping Plant
Tracy Pumping Plant
South Bay Pumping Plant
Tracy
SAN JOAQUIN R.
STANISLAUS R.
Delta-Mendota Canal
California Aqueduct
N
2 0 2 4 6
miles

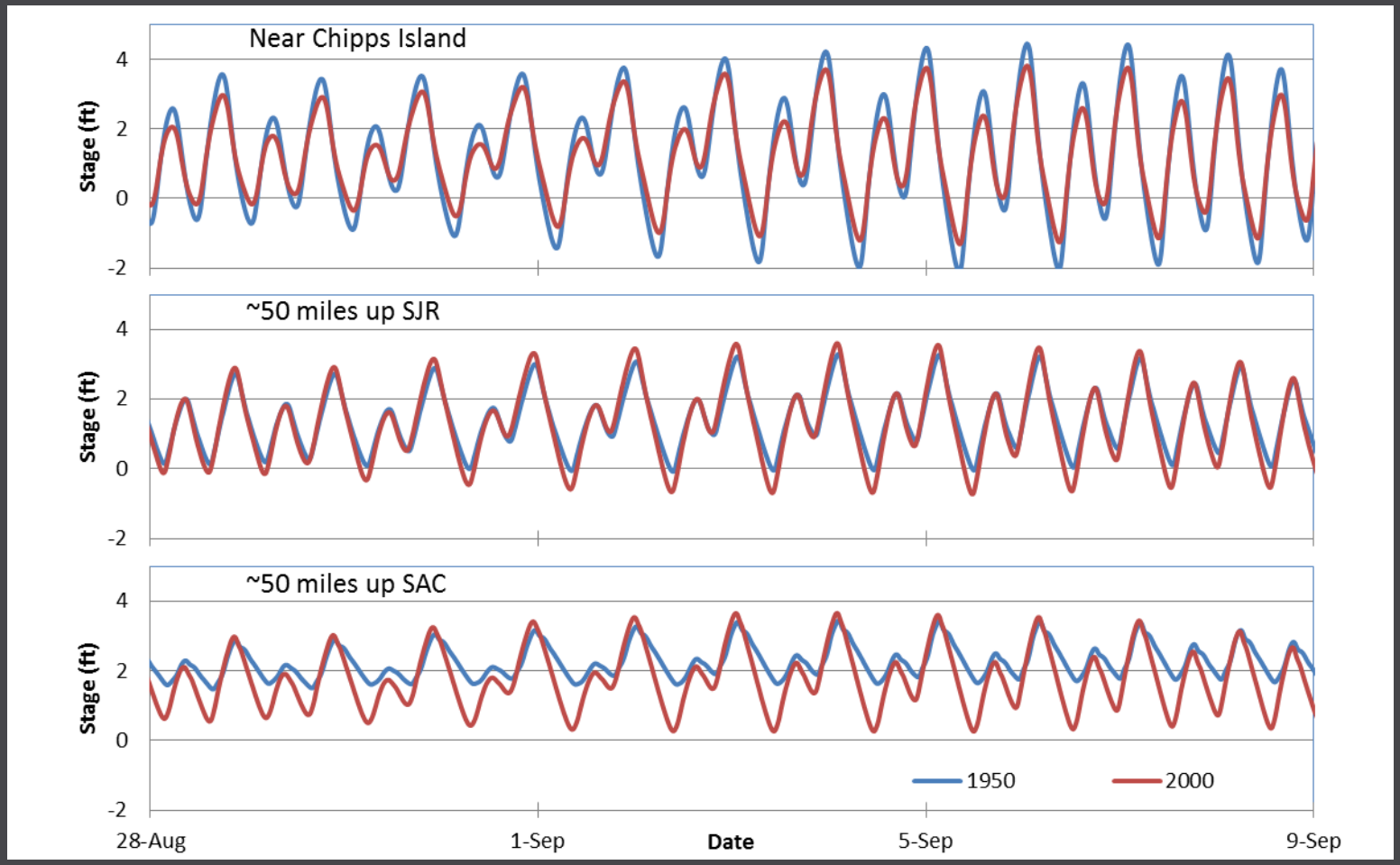
1950

2000 simulation
- No Exports
- No Gates
- No Barriers

RMA2 Bay &Delta
- Less open water
  - Little Franks
  - Mildred Is
  - Liberty intact
- Less dredging
  - SAC ship channel
  - SAC dredging
  - Stockton to 26 ft

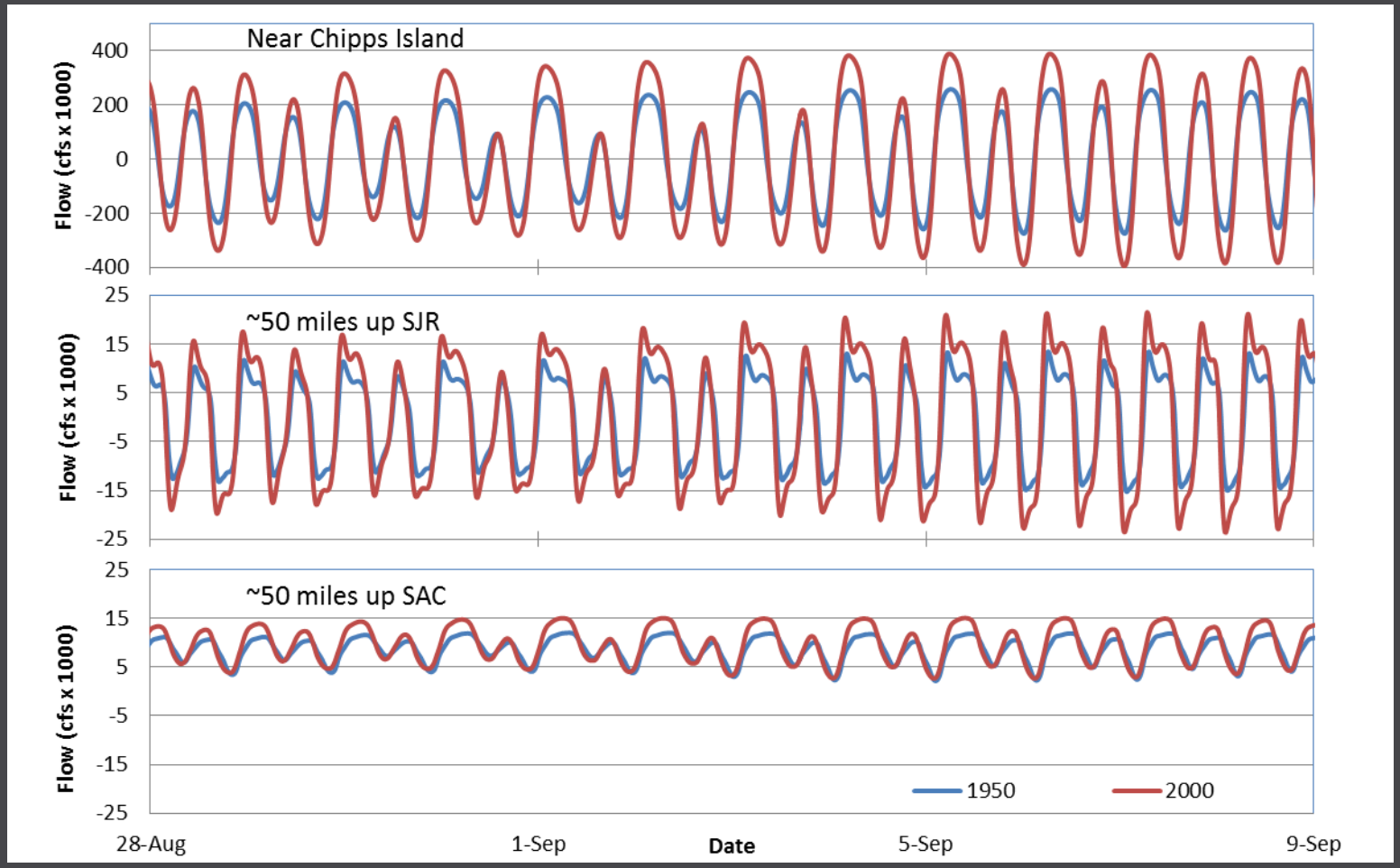


1950 versus 2000



Low Flow Period

1950 versus 2000



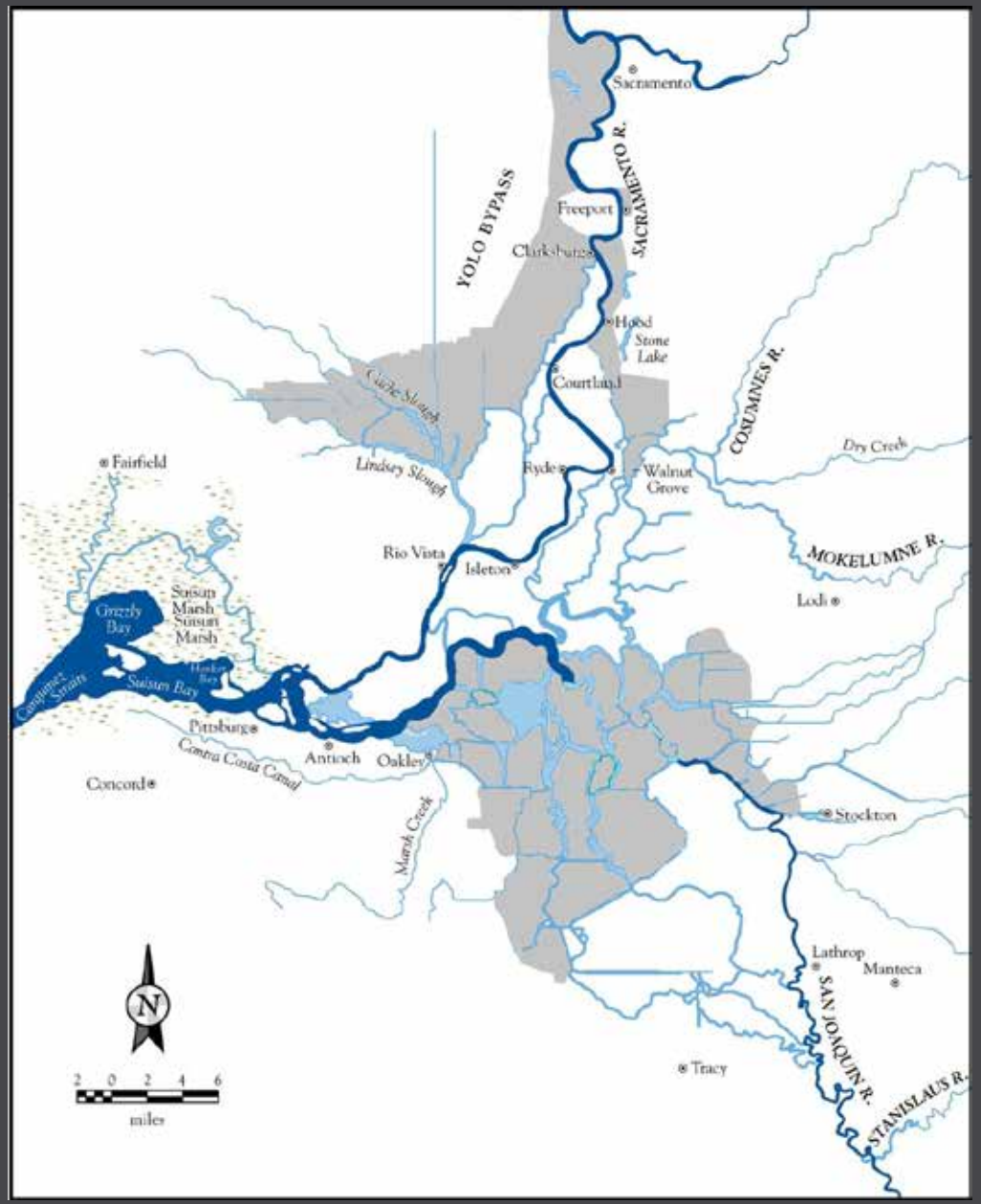
Low Flow Period

1900

2000 simulation

Removed

- SAC widening
- Stockton SC
- Many levees
  - Holland
  - Webb
  - Orwood/Palm
  - Empire
  - King
  - Medford
  - Mandeville
  - Bacon
  - McDonald
  - Shima
  - Bishop
  - M-W Tract



CWS Collaborative Effort

- RMA
  - Fabián Bombardelli
  - Steve Miko
  - Joongcheol Paik
- SFEI
  - Alison Whipple
  - Andy Bell
  - Mui Lay
  - Amber Manfree

Historical Modeling Collaborative Effort

- *SFEI*
  - *Robin Grossinger*
  - *Julie Beagle*
  - *Sam Safran*
  - *Alison Whipple*
- *CWS*
  - *Bill Fleenor*
  - *Fabián Bombardelli*
  - *Steve Miko*
  - *Joongcheol Paik*
  - *Alison Whipple*
  - *Andy Bell*
  - *Mui Lay*
  - *Alexa ???*
  - *Amber Manfree*
- *RMA*
  - *John DeGeorge*
  - *Stephen Andrews*
  - *Stacie Grinbergs*

Part I: Data Collection and Development

Historical bathymetry

- review historical data sources
- discuss caveats

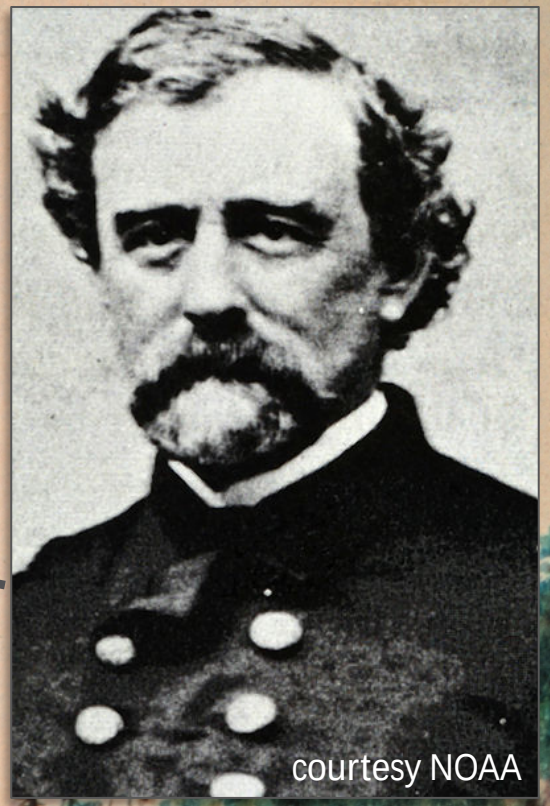
Historical topography

- review historical data sources
- discuss caveats

Dealing with data gaps

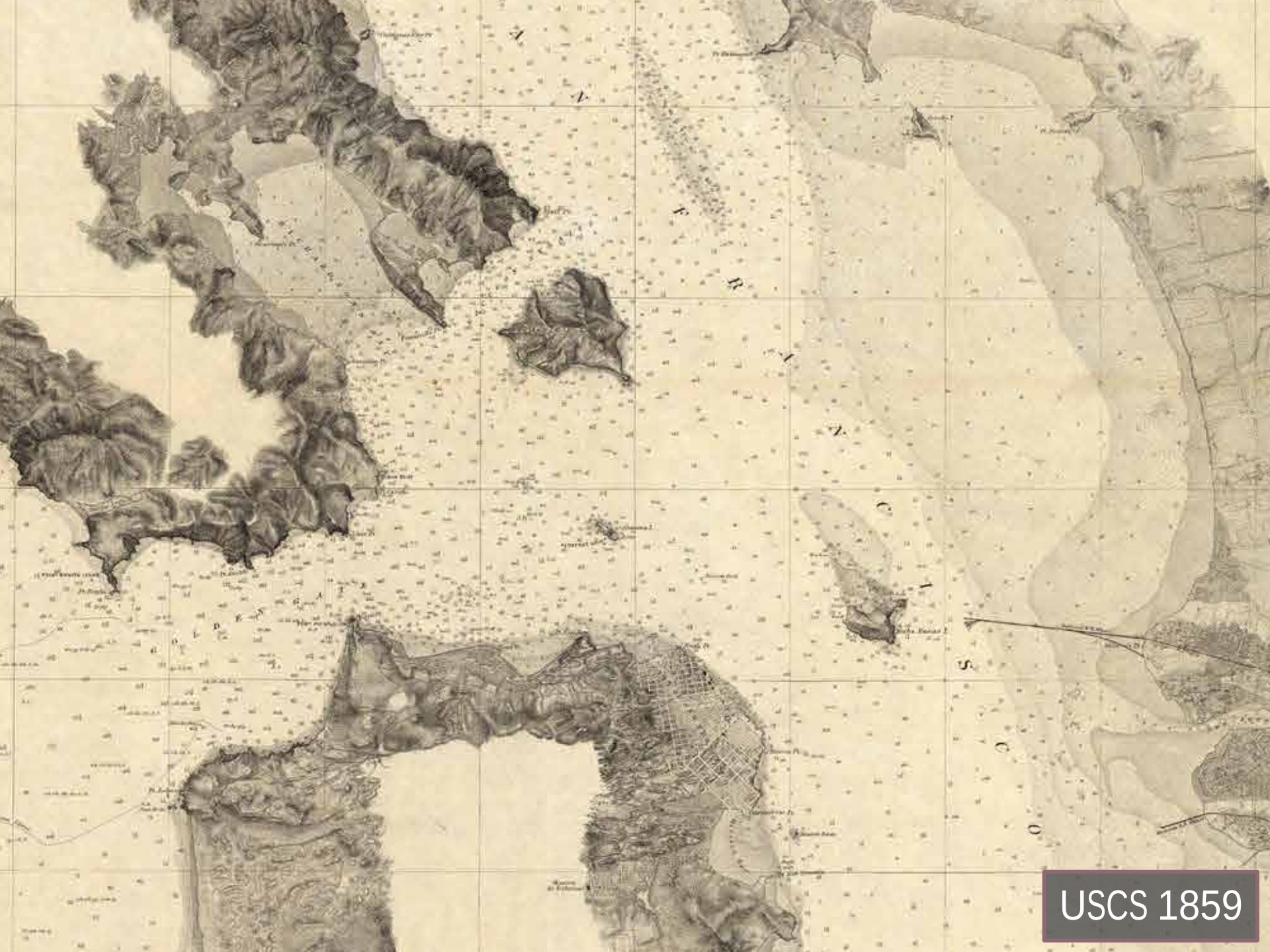
- the Delta is very large, early surveyors only really paid attention to navigable portions
- cannot expect to have consistent, usable data across the entire extent. How best to work with what's available?

Historical bathymetry

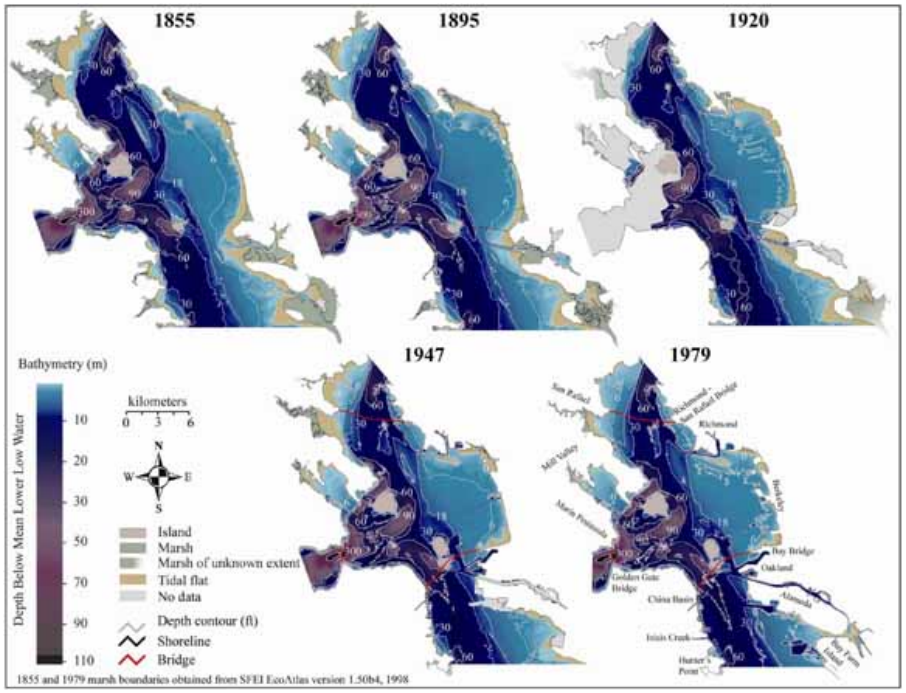

courtesy NOAA

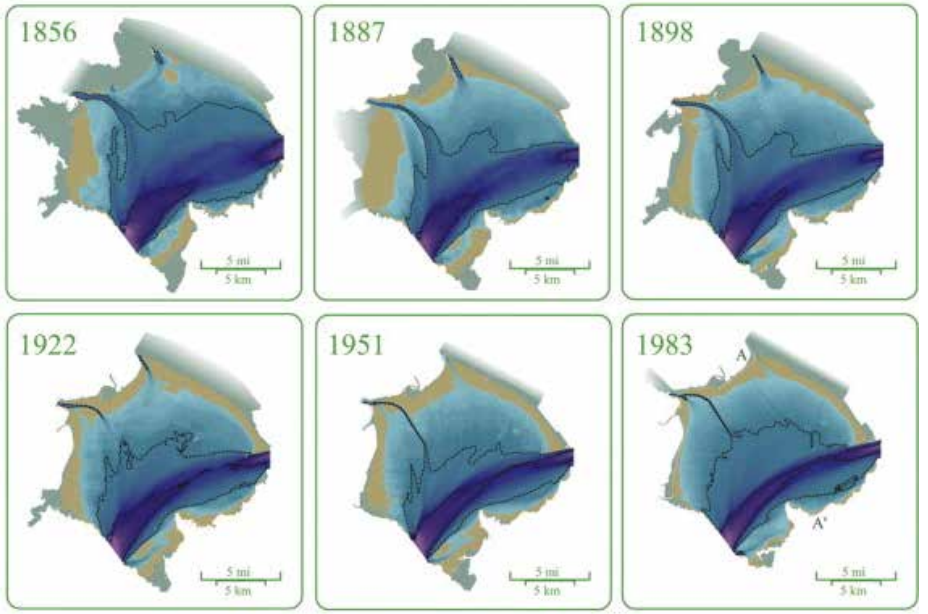
USCS 1857
*not the Delta

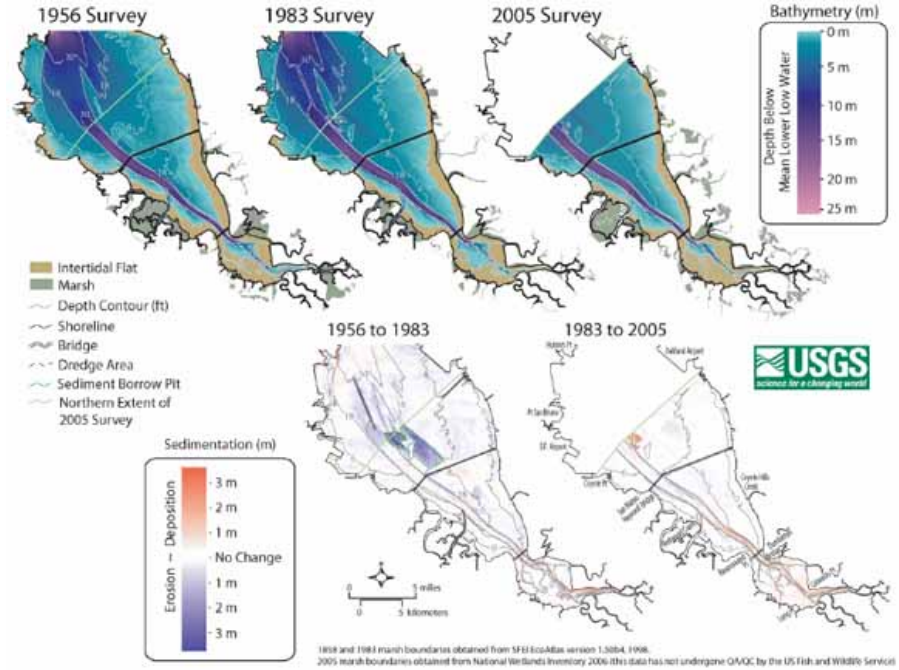
courtesy NOAA

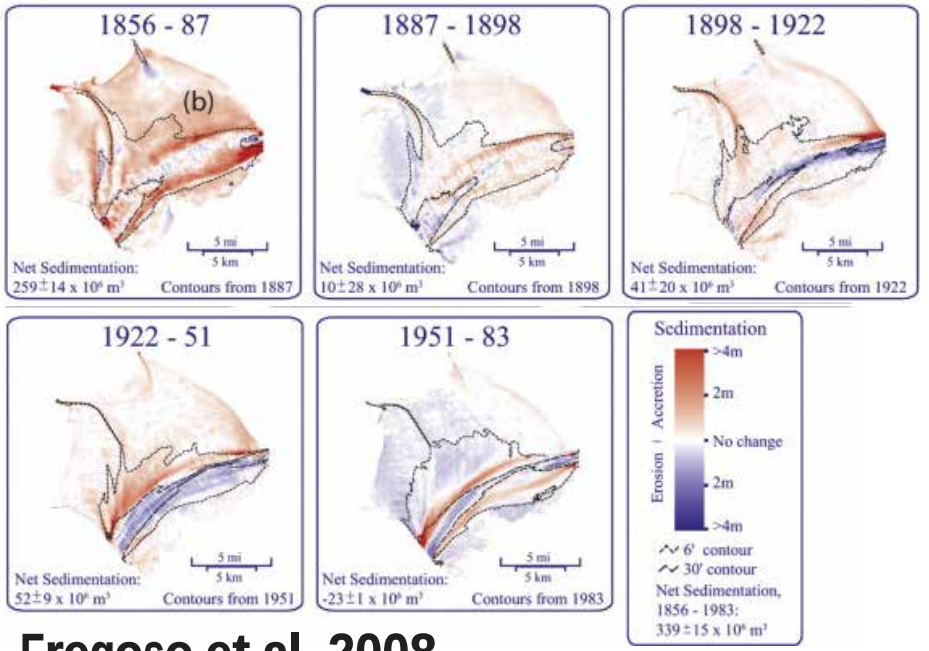


USCS 1859



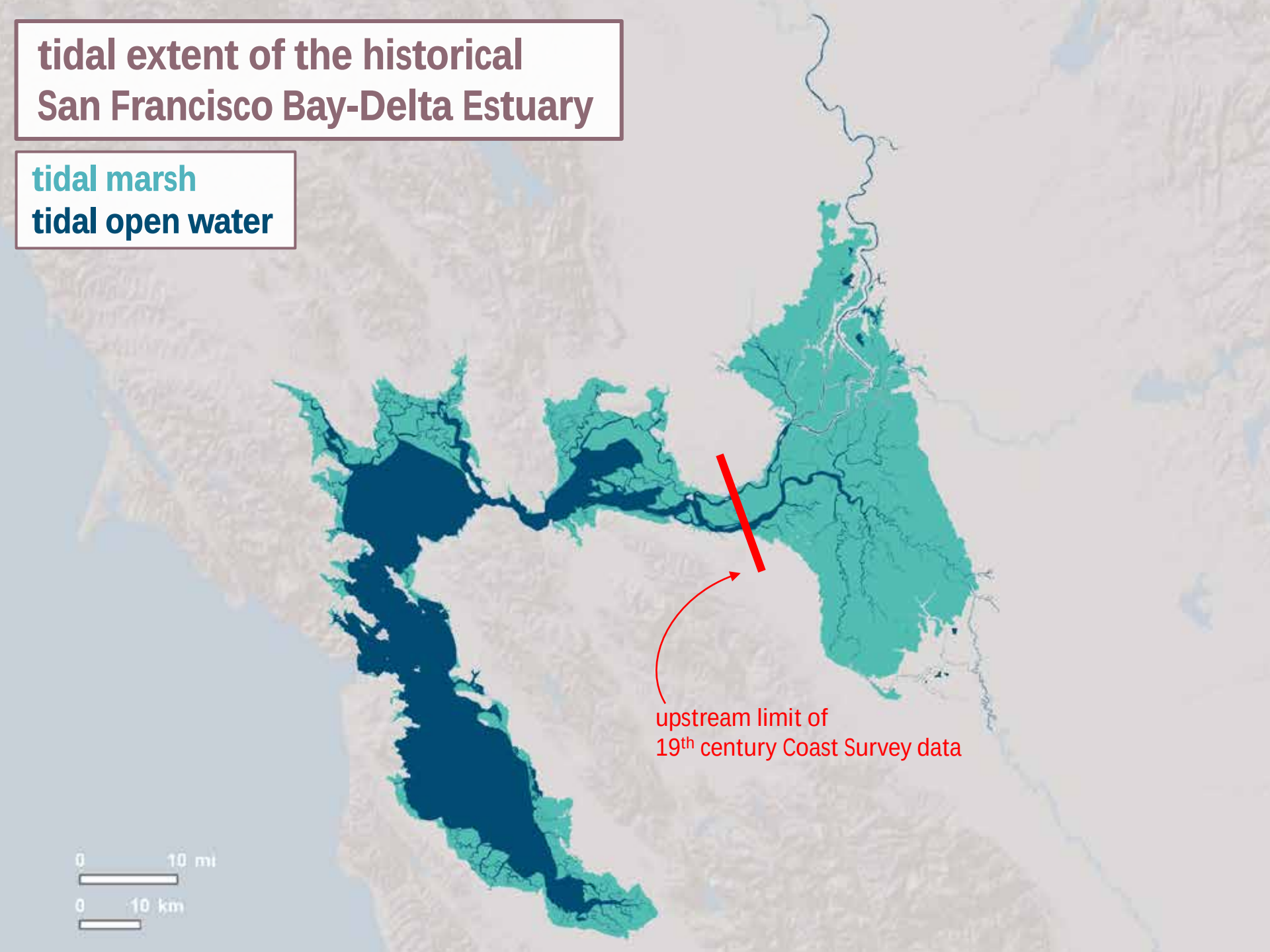






Fregoso et al. 2008

Jaffe & Foxgrover 2006 | Jaffe et al. 2007


tidal extent of the historical
San Francisco Bay-Delta Estuary
tidal marsh
tidal open water
upstream limit of
19th century Coast Survey data
0 10 mi
0 10 km

USCS 1867

1

...wouldn't it be nice if we had this sort of data for the whole Delta?

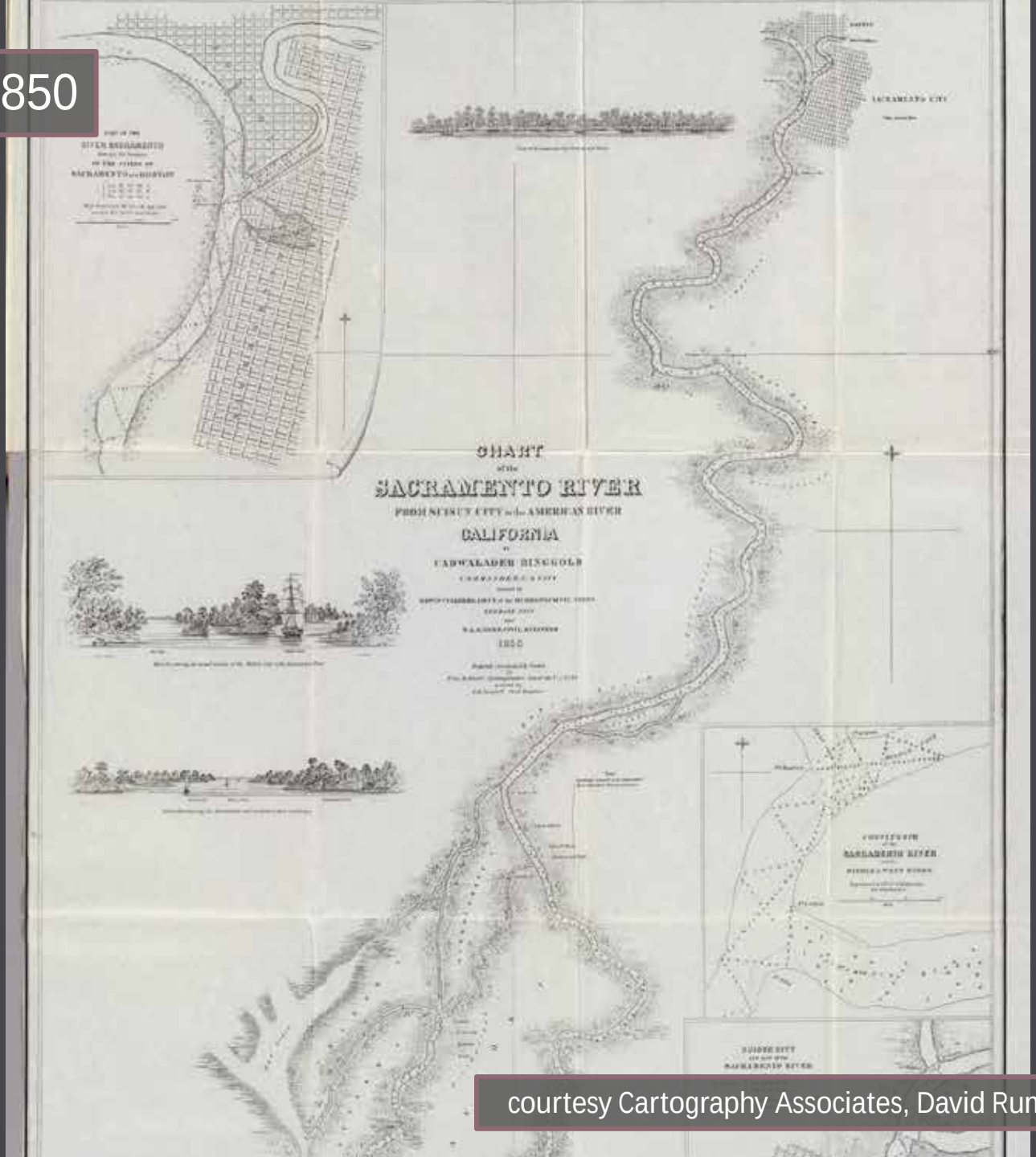
Ringgold 1850

CHART
of
SUISUN & VALLEJO BAYS
with the CONFLUENCE of the
RIVERS SACRAMENTO AND SAN JOAQUIN
CALIFORNIA
BY
CADWALADER RINGGOLD
COMMANDER U.S.NAVY
Assisted by
SAM.R. KNOX, LIEUT. U.S.N.
and
WM. P. McPHERSON & J.HOUK ENGINEERS
1850

courtesy Cartography Associates, David Rumsey Collection

Ringgold 1850

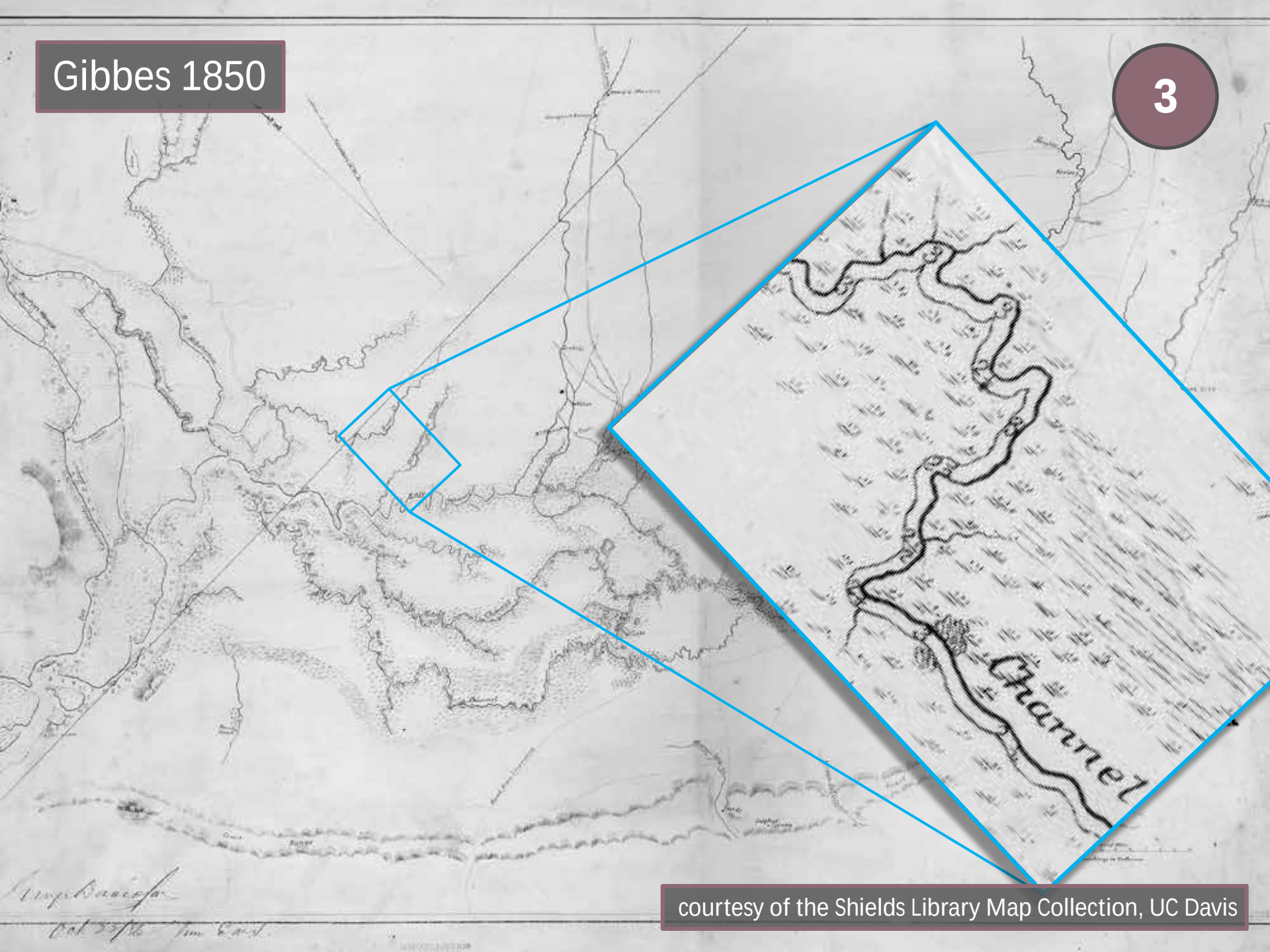
2b



courtesy Cartography Associates, David Rumsey Collection

Gibbes 1850

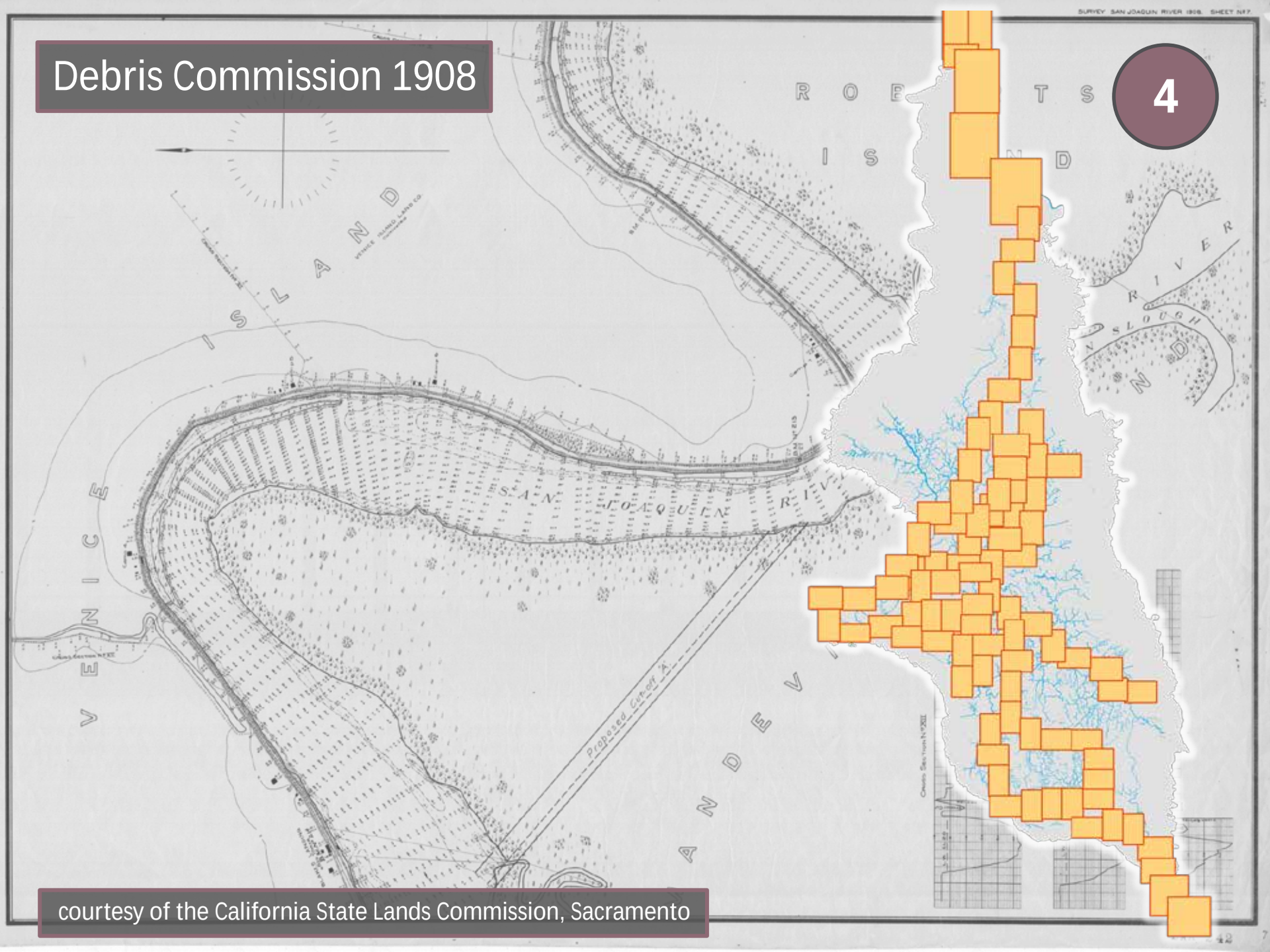
3



courtesy of the Shields Library Map Collection, UC Davis

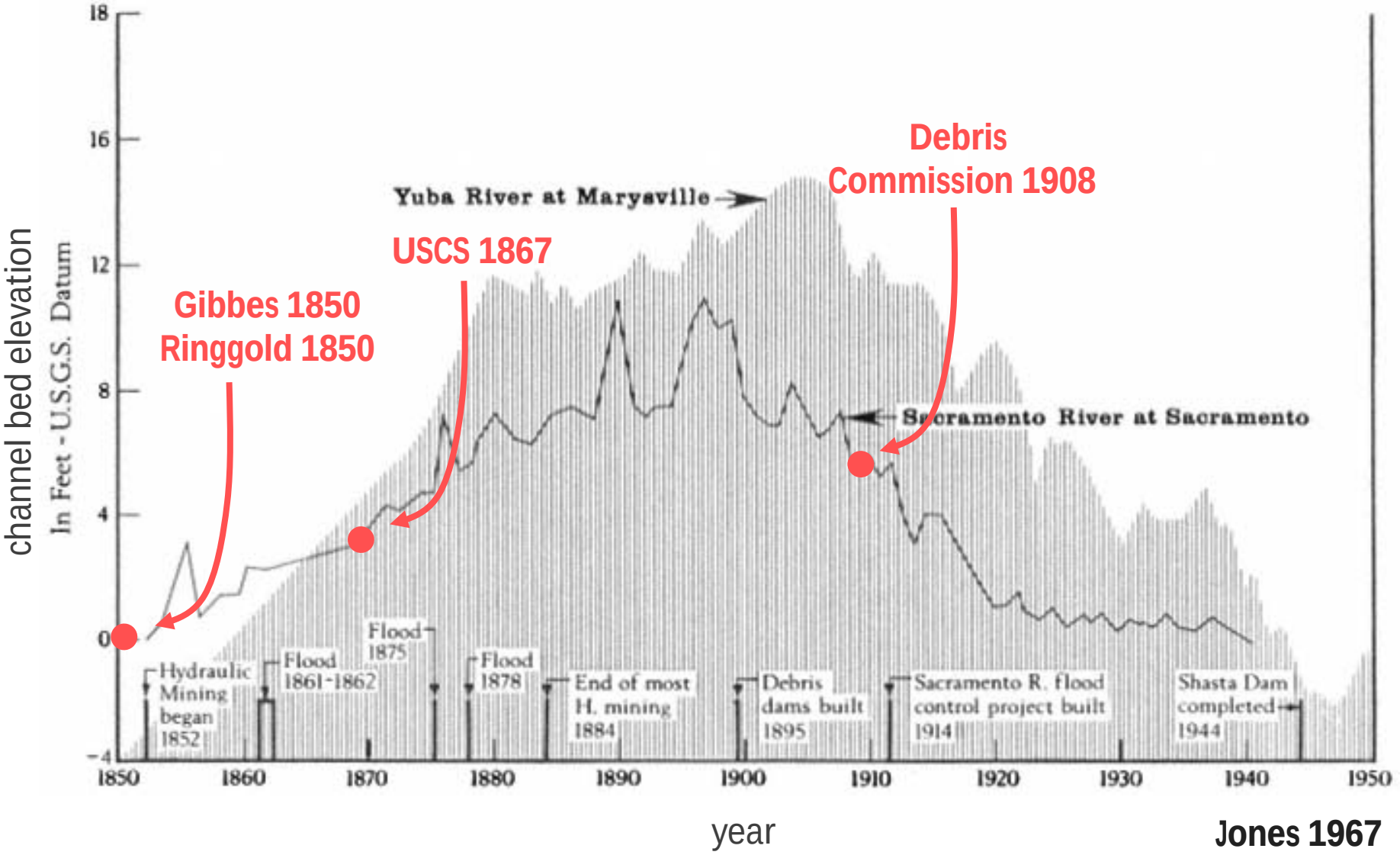
Debris Commission 1908

4



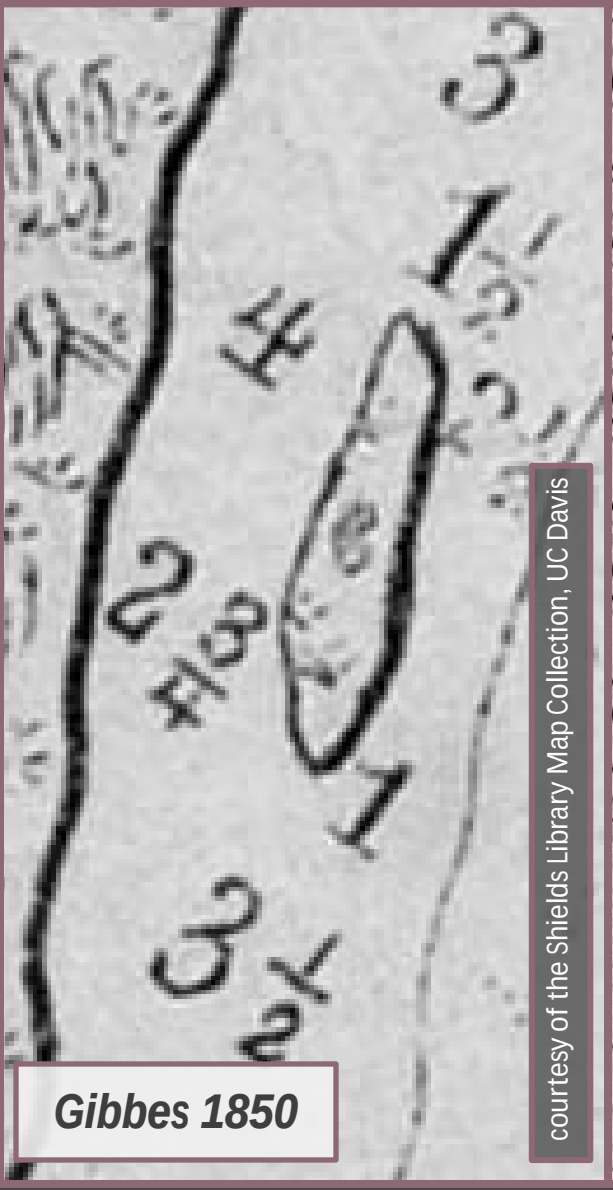
courtesy of the California State Lands Commission, Sacramento

the rise and fall of Delta **channel bed elevations** due to hydraulic mining debris



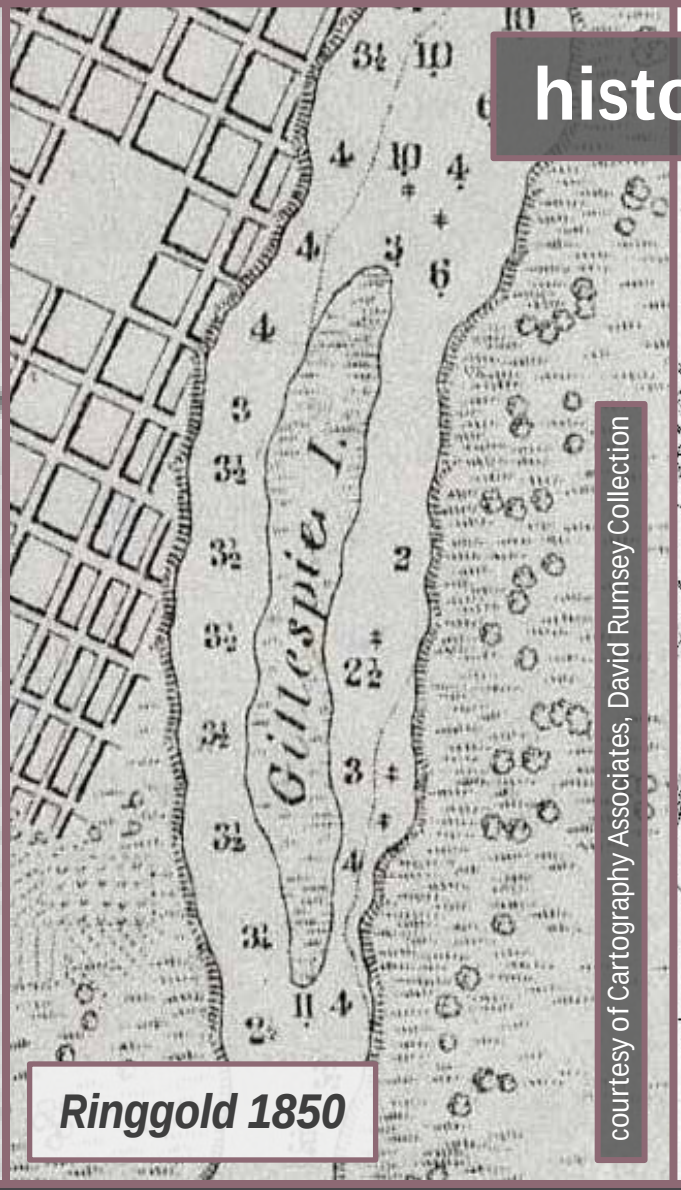
Jones 1967

historical bathymetry



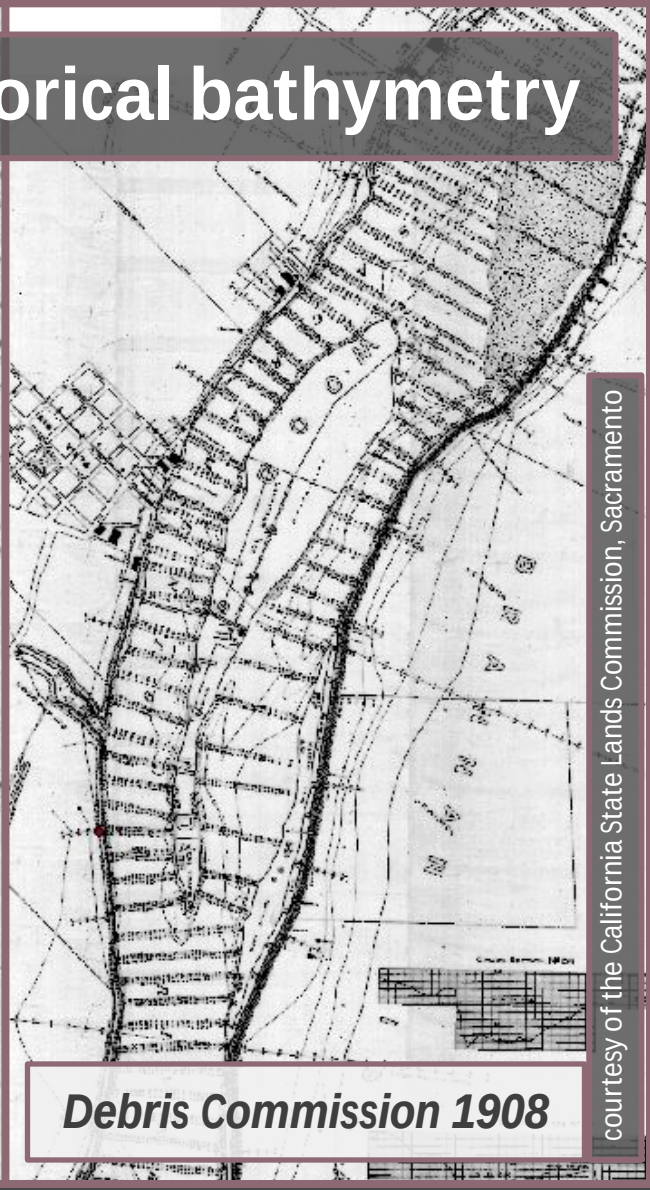
courtesy of the Shields Library Map Collection, UC Davis

Gibbes 1850



courtesy of Cartography Associates, David Rumsey Collection

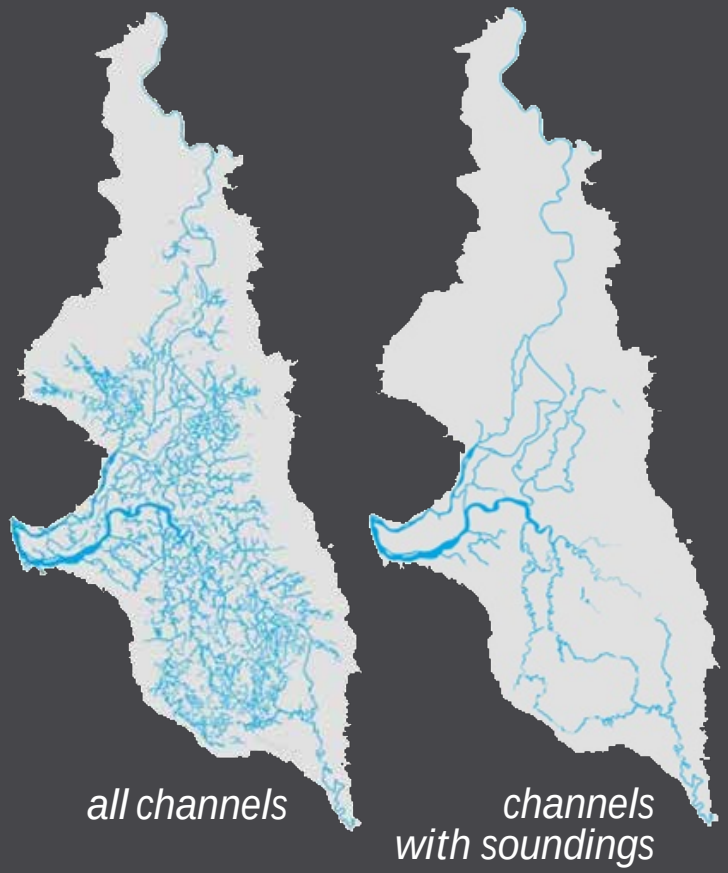
Ringgold 1850



courtesy of the California State Lands Commission, Sacramento

Debris Commission 1908

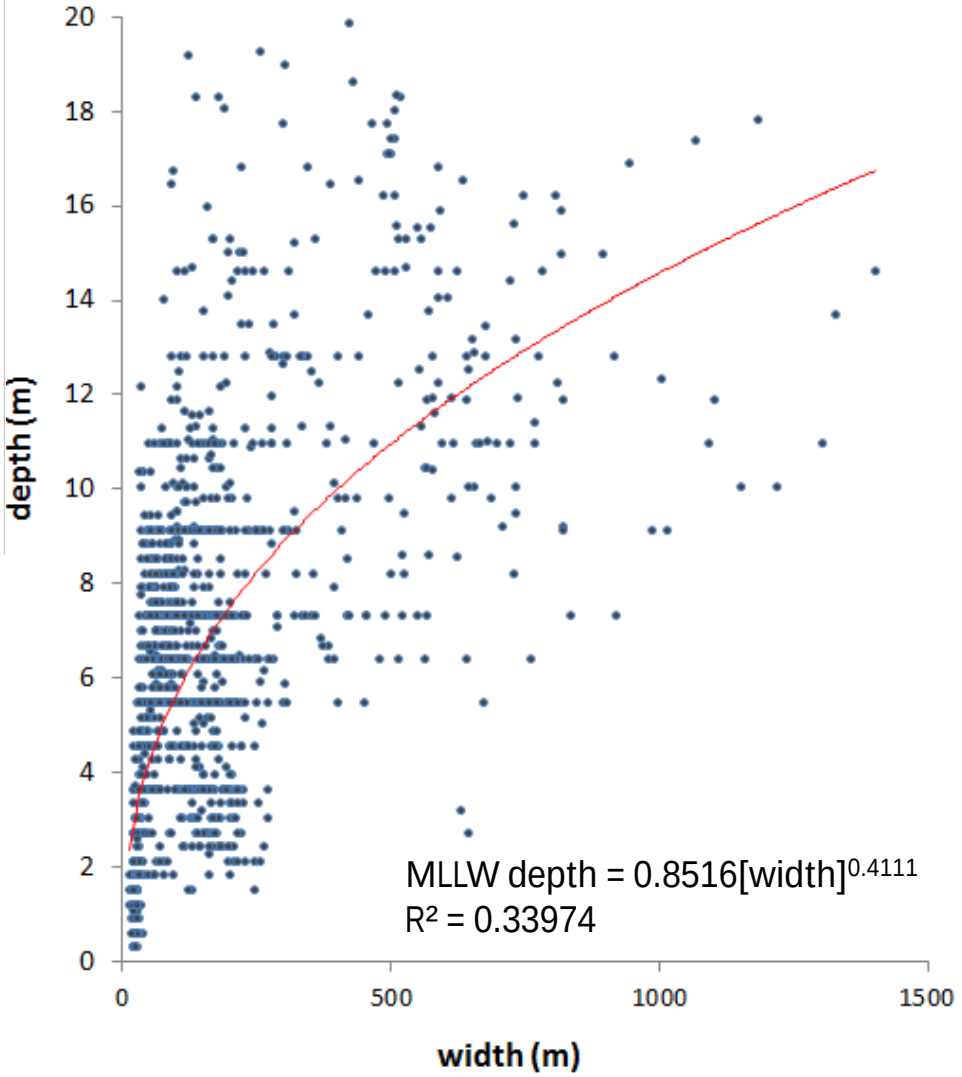
historical bathymetry data compiled from **multiple sources**
with variation **in time period, spatial accuracy, coverage, and sounding density**
(and therefore each source used differently during historical DEM creation)

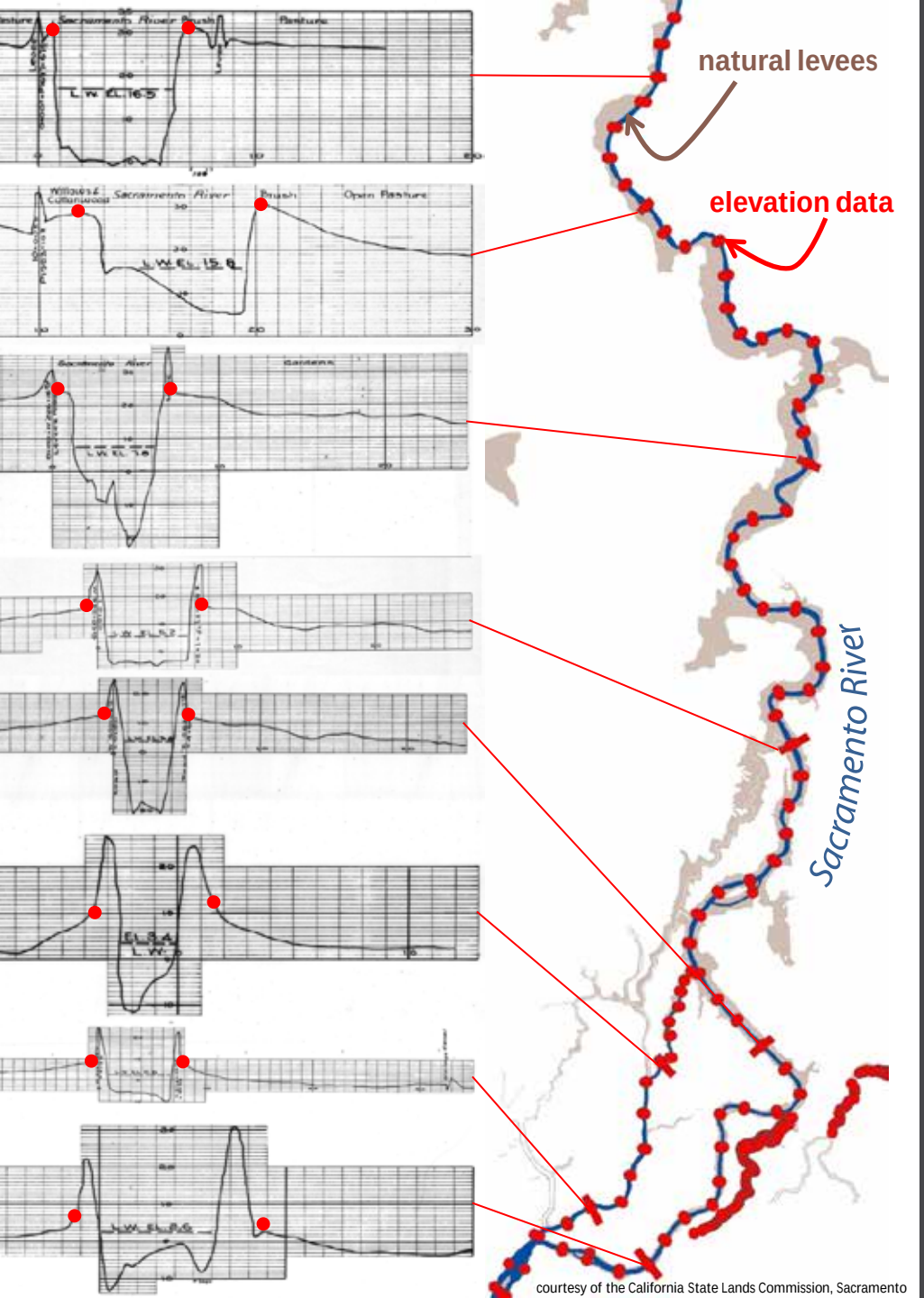


Data source for thalweg depths	Number of soundings
2a) Ringgold 1850	97
2b) Ringgold 1850	426
3) Gibbes 1850	199
4) Debris Commission 1908-1923	762
Total	**1484**

Working with bathymetry data gaps

- Only have **bathymetry for a subset of channels**
- Generally only have **thalweg** depths
- But we know **channel widths**
- Historical width-depth relationship:





courtesy of the California State Lands Commission, Sacramento

historical topography

Natural levees

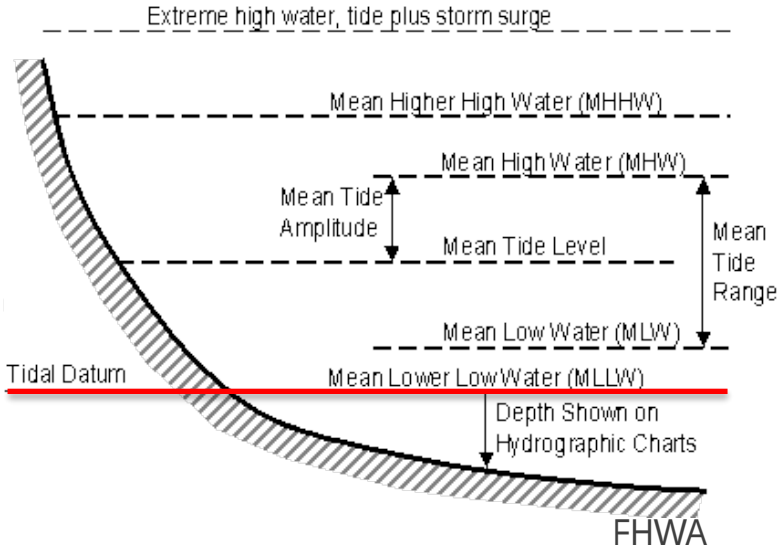
- extent from Historical Ecology layers
- elevations derived from early detailed topographic surveys (Debris Commission 1908-1913)
- Ranged from 30 ft. (near Feather River) to 4 ft. NAVD88 (near Rio Vista) on Sac.
- corroborated with historical written record
- will compare against modern LiDAR (general topography of natural levees still largely intact)

Marsh surface

- extent from Historical Ecology layers
- elevation relative to MSL

converting a historical tidal datum à modern fixed datum

- how do we make each of these datasets (and the depths/elevations they give) speak with one another?
- historical soundings relative to MLLW (a tidal datum)
- hydrodynamic model needs elevations in a modern fixed datum (NAVD88)
- developed interim method to covert historical soundings to NAVD88
  - numerous assumptions
  - currently being refined



converting a historical tidal datum à modern fixed datum

Step #1- *convert mean lower-low water (MLLW) depths to mean sea level (MSL) depths*

Depth at MLLW + 0.5(**historical tidal range**) = depth at mean tide level
≈ depth at mean sea level

Step #2- *reference mean sea level (MSL) depth to mean sea level (MSL) elevation*

What is historical elevation of MSL?
current elevation of MSL (NAVD88) – **sea level rise** (2 mm/year)

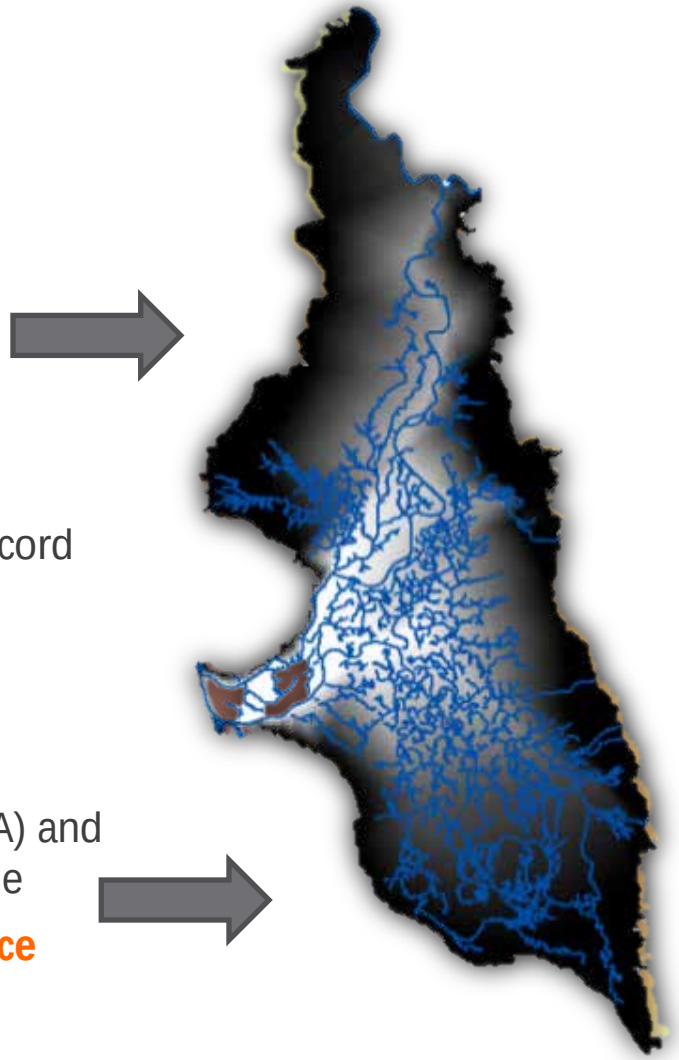
historical MSL elevation (NAVD88) – **historical MSL depth**
= **historical bed elevation (NAVD88)**

converting a historical tidal datum à modern fixed datum

Developing a historical tidal range surface

Historical records of tidal range	Source
"The tide at low water rises about **eight inches** where the west line of Von Schmidt's survey crosses Dry creek."	Gray, 1859
"The tide of the ocean sets back to the height of **two feet** at Sacramento."	McCollum, 1849
"There is tide all the way up to the mouth of Dry Creek at which point it affects it about **an inch**."	Van Scoyk, 1859

- Able to locate or derive **75 tidal range** points from historical record
- Used as **TIN inputs** to generate a **tidal range surface**

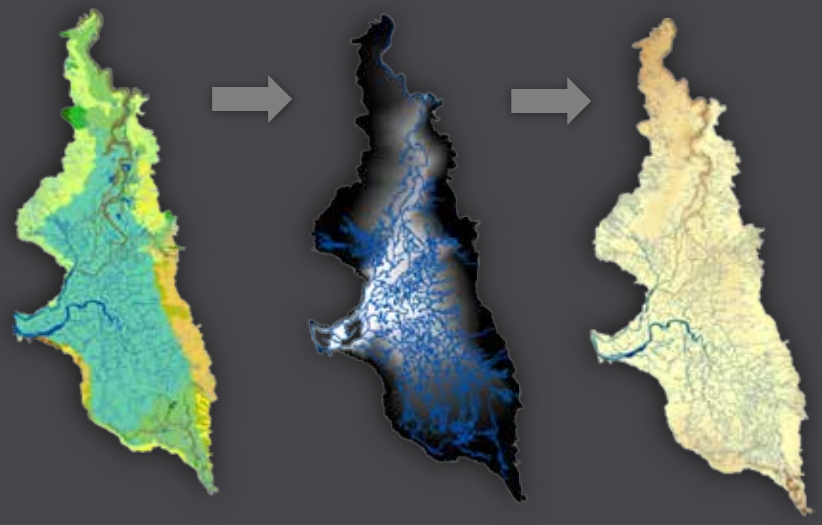


Developing a MSL elevation (NAVD88) surface

- Similar process, but used **published benchmarks** (USGS/NOAA) and Debris Commission **low water elevations** outside of tidal range
- **68 points** used as **TIN inputs** to generate **MSL elevation surface**

Part II: Data Interpolation*

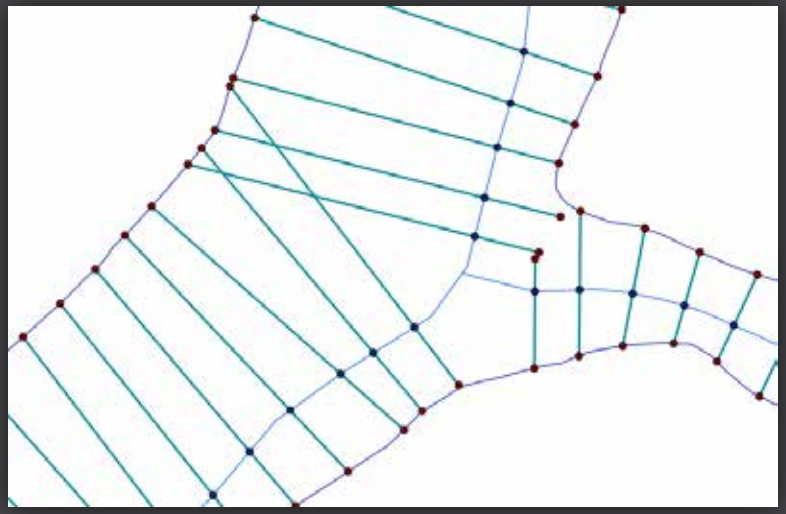
- Bringing together the pieces necessary for a surface
  - *Bathymetry:* parabolic interpolation, data source transitions, conveyance capacity
  - *Topography:* natural levees, marsh height
  - *Datums:* tidal range conversion surface, NAVD88 conversion surface
- Methods must address the unique historical dataset



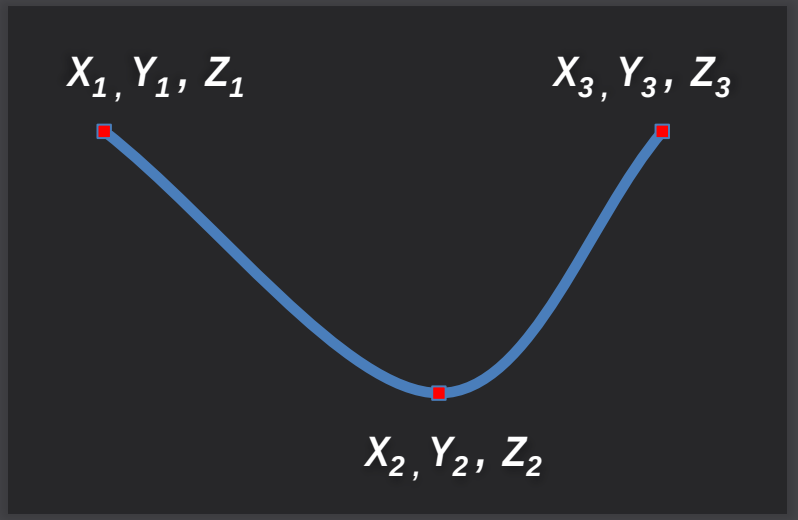
*WORK IN PROGRESS

Applying the parabolic shape

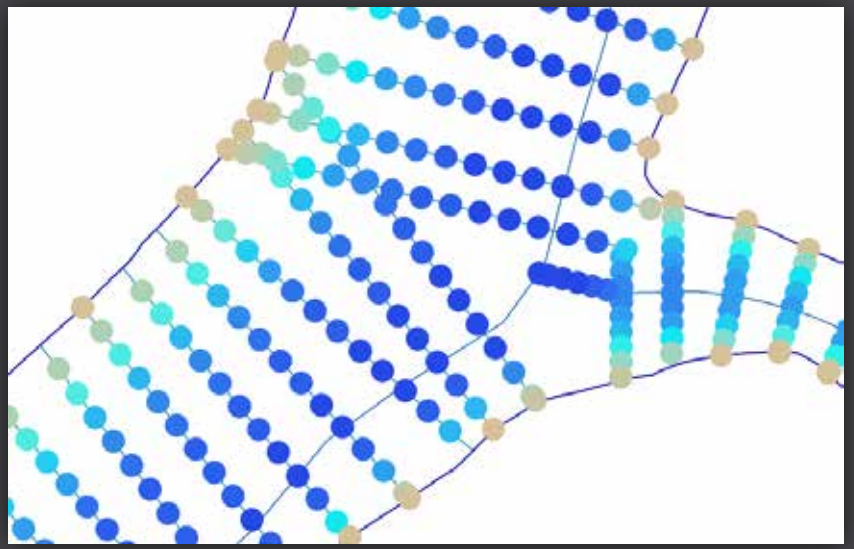
Thalweg line, channel water edges



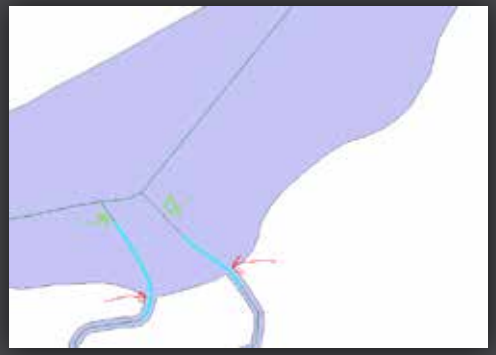
ENVI script inputs



Transects with parabolic shape

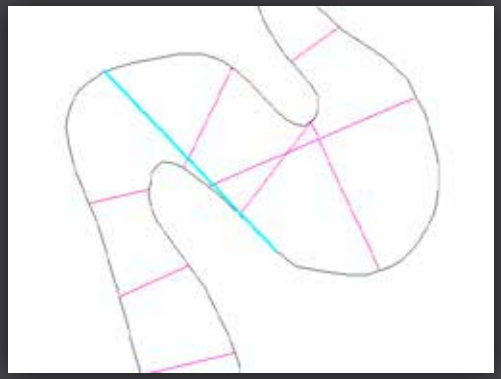


Parabolic shape challenges



Small channels

- Connector segments as “half parabolas”



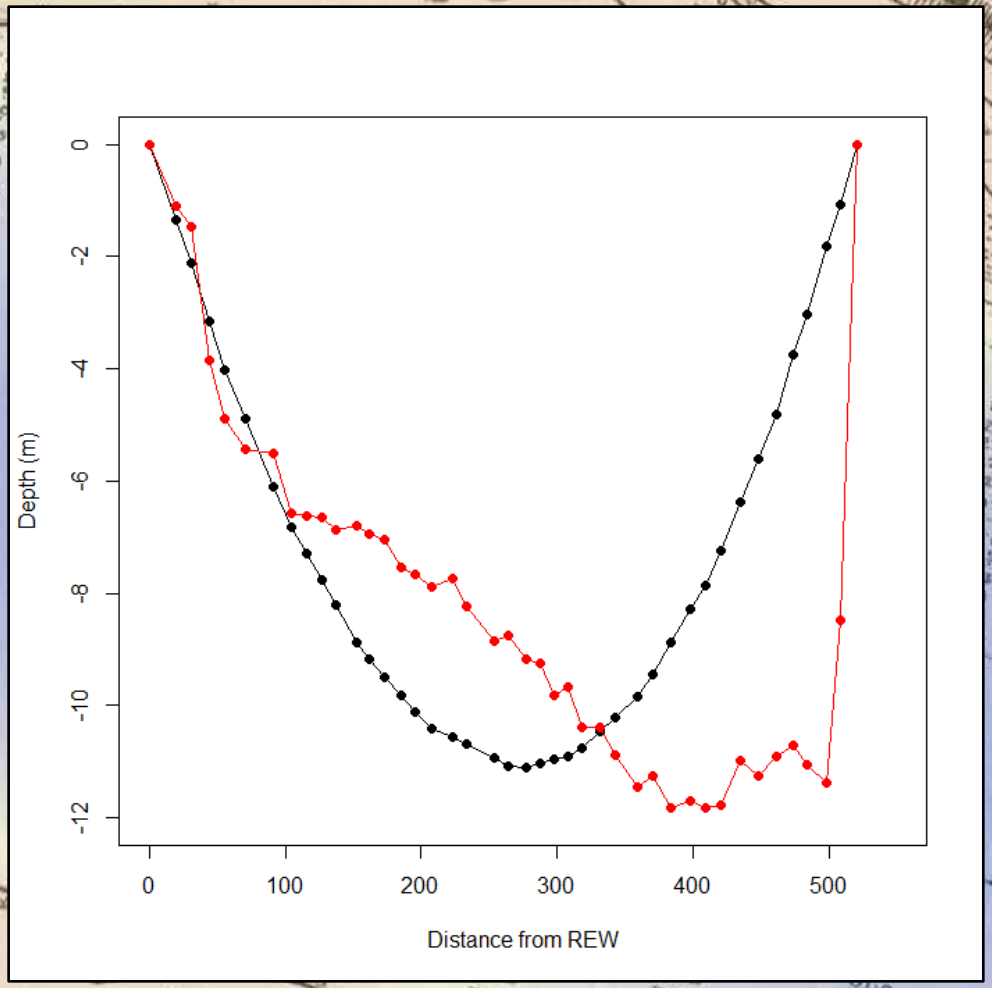
Erratic transects

- Problem transects identified and removed

Islands

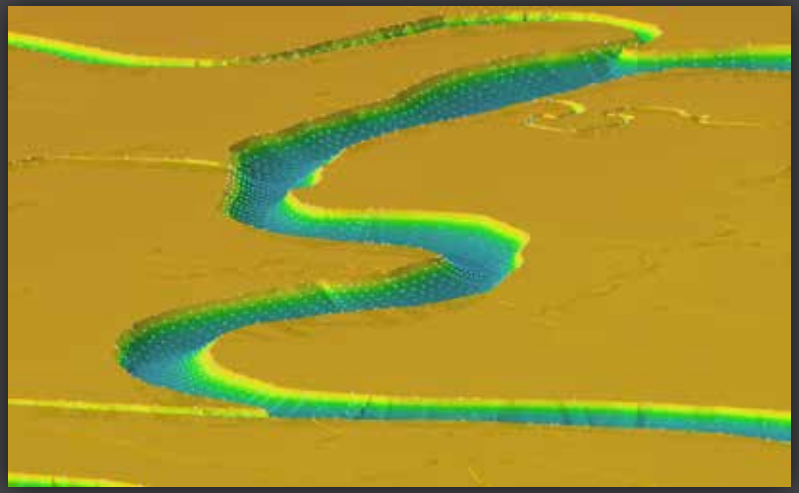
- Manually added thalweg lines

Parabolic channel shape



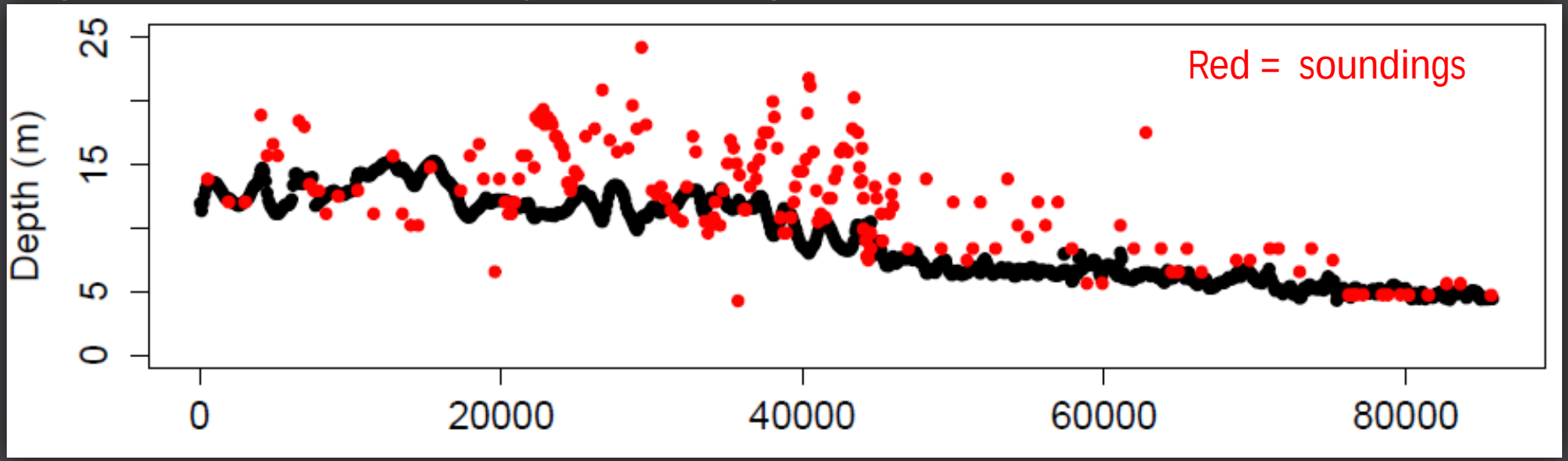
Red: 1908 Debris Commission SH09 cross section

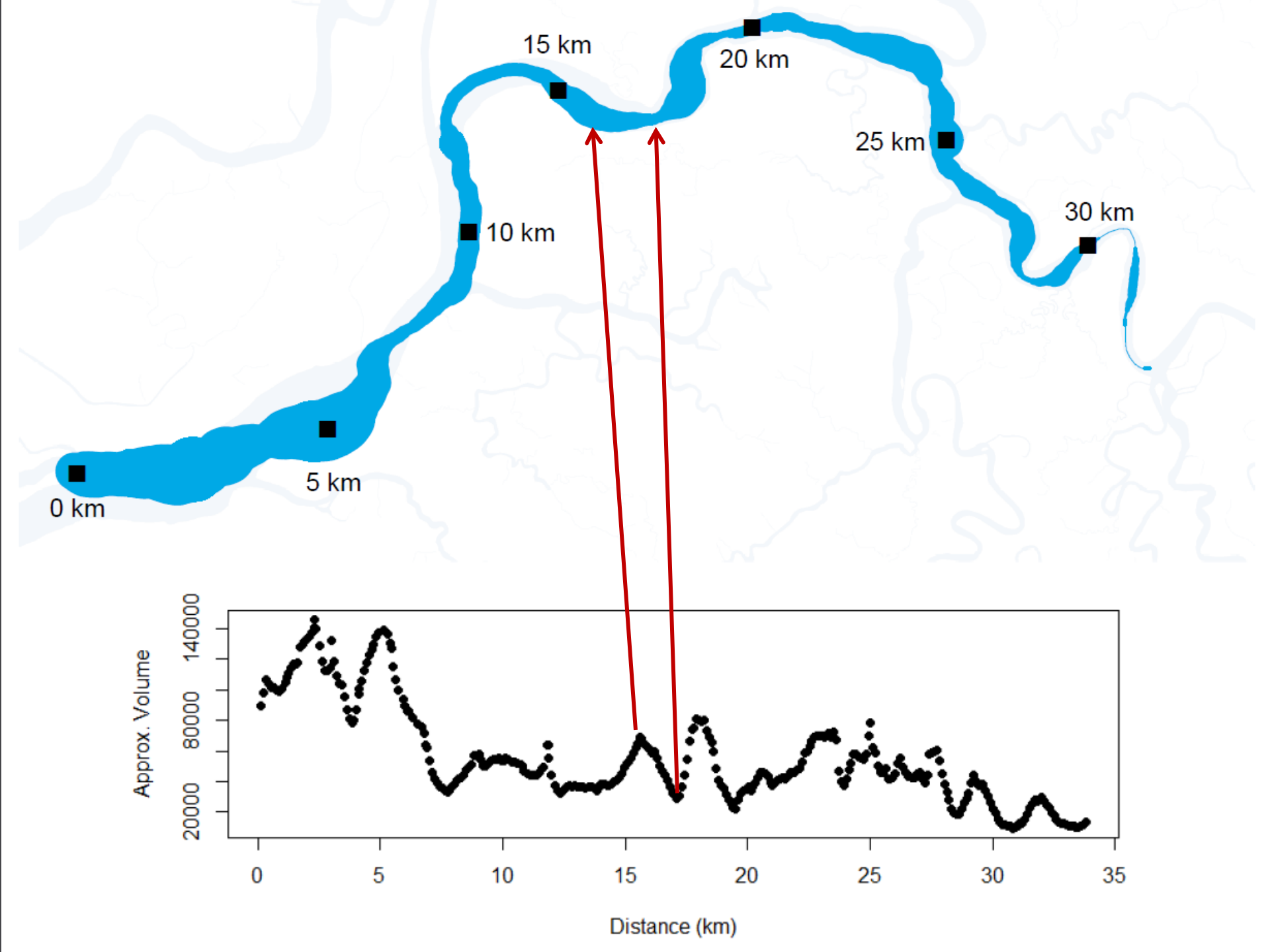
Conveyance



- Width-depth relationship a problem for large channels
  - Channel should deepen where it narrows

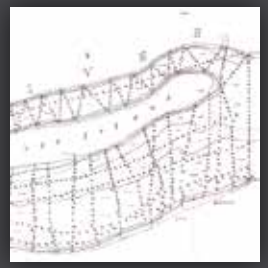
Depth vs river distance along the San Joaquin River



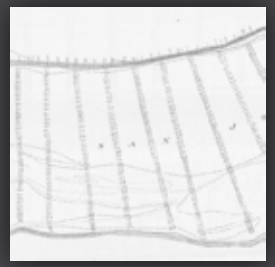

0 km
5 km
10 km
15 km
20 km
25 km
30 km
Approx. Volume
20000
80000
140000
0
5
10
15
20
25
30
35
Distance (km)


Sacramento River
SHERMAN ISLAND
San Joaquin River

Data Transitions

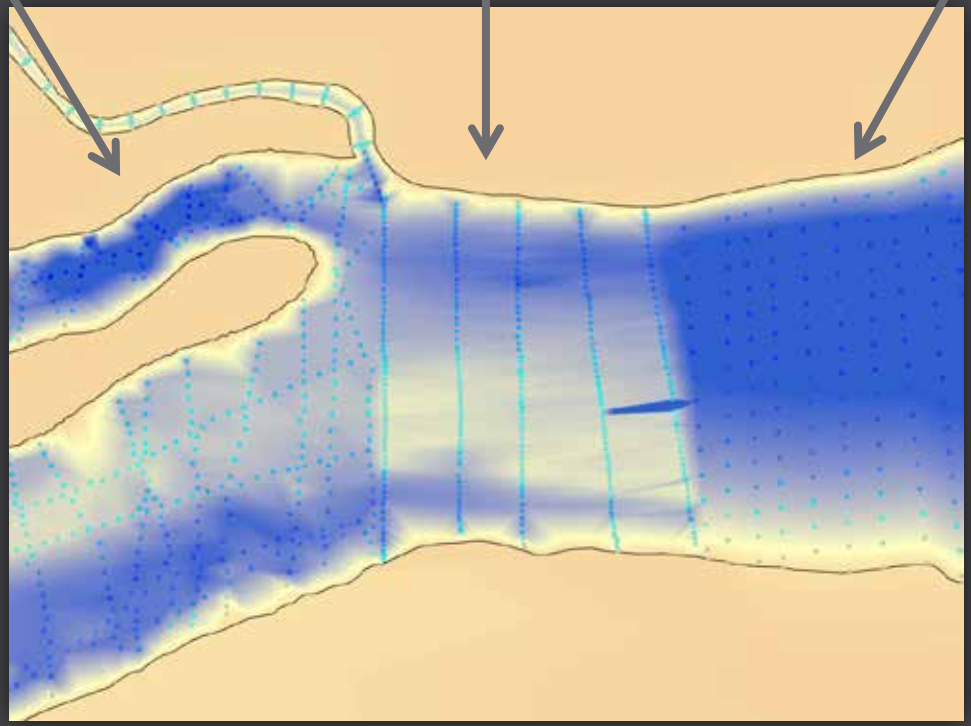


USCS H00935



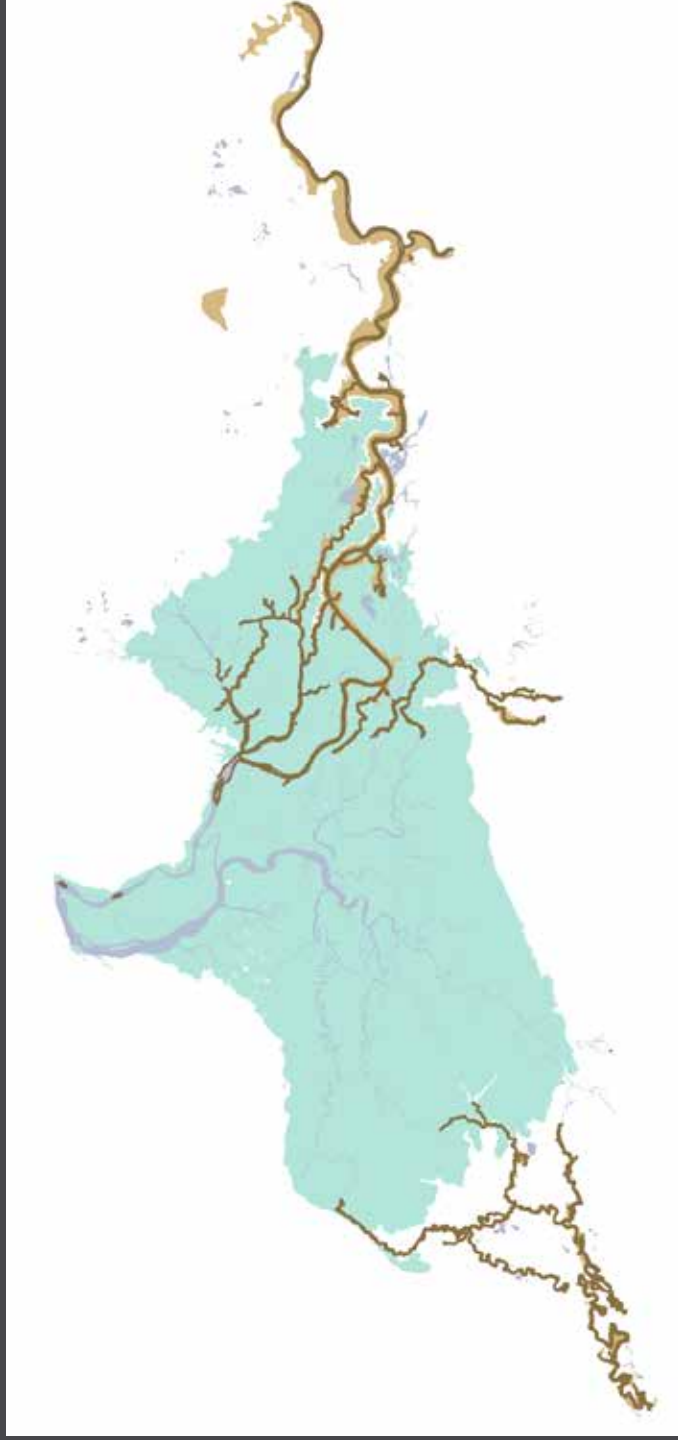
Debris Commission

Parabolas



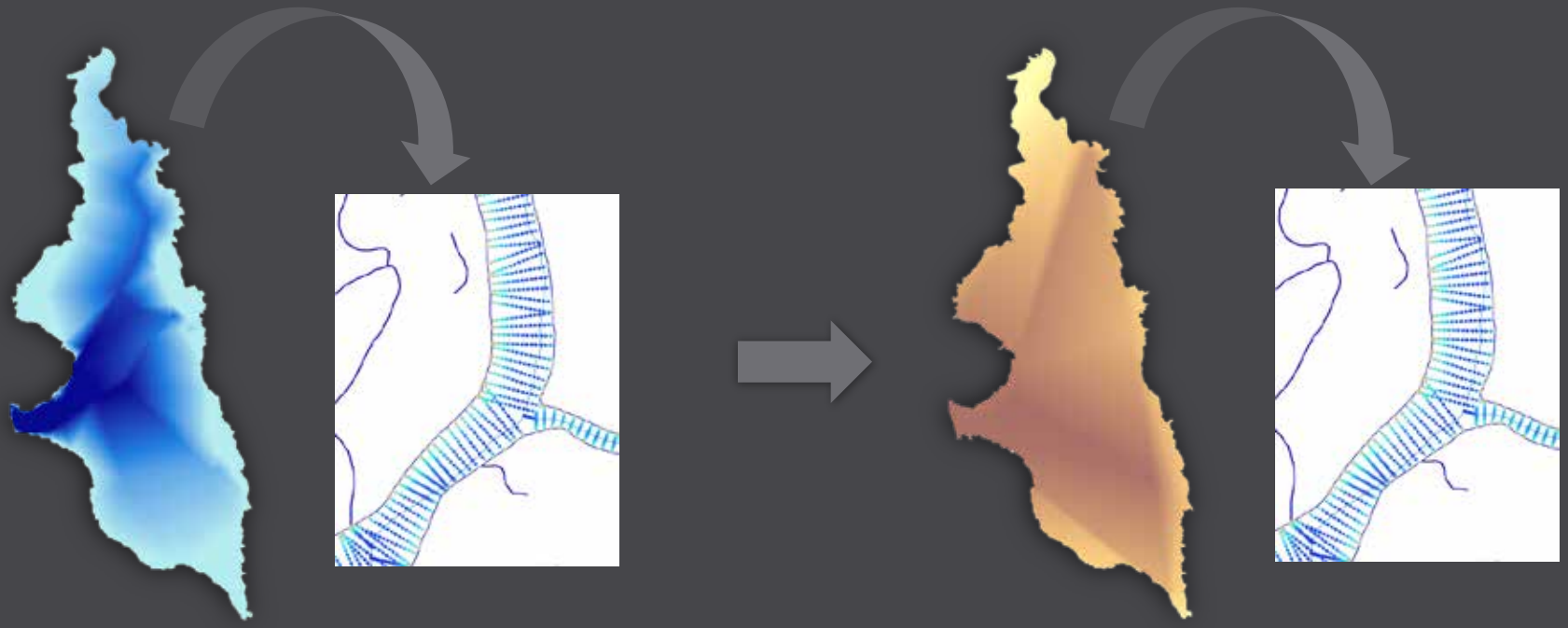
Considering natural levees

- Using natural levee crests and marsh elevation to capture height and basic side slope
- Establishing where water can and cannot move
- Contours likely needed for further shape
- Low-lying banks in tidal wetland needed



Elevation adjustment

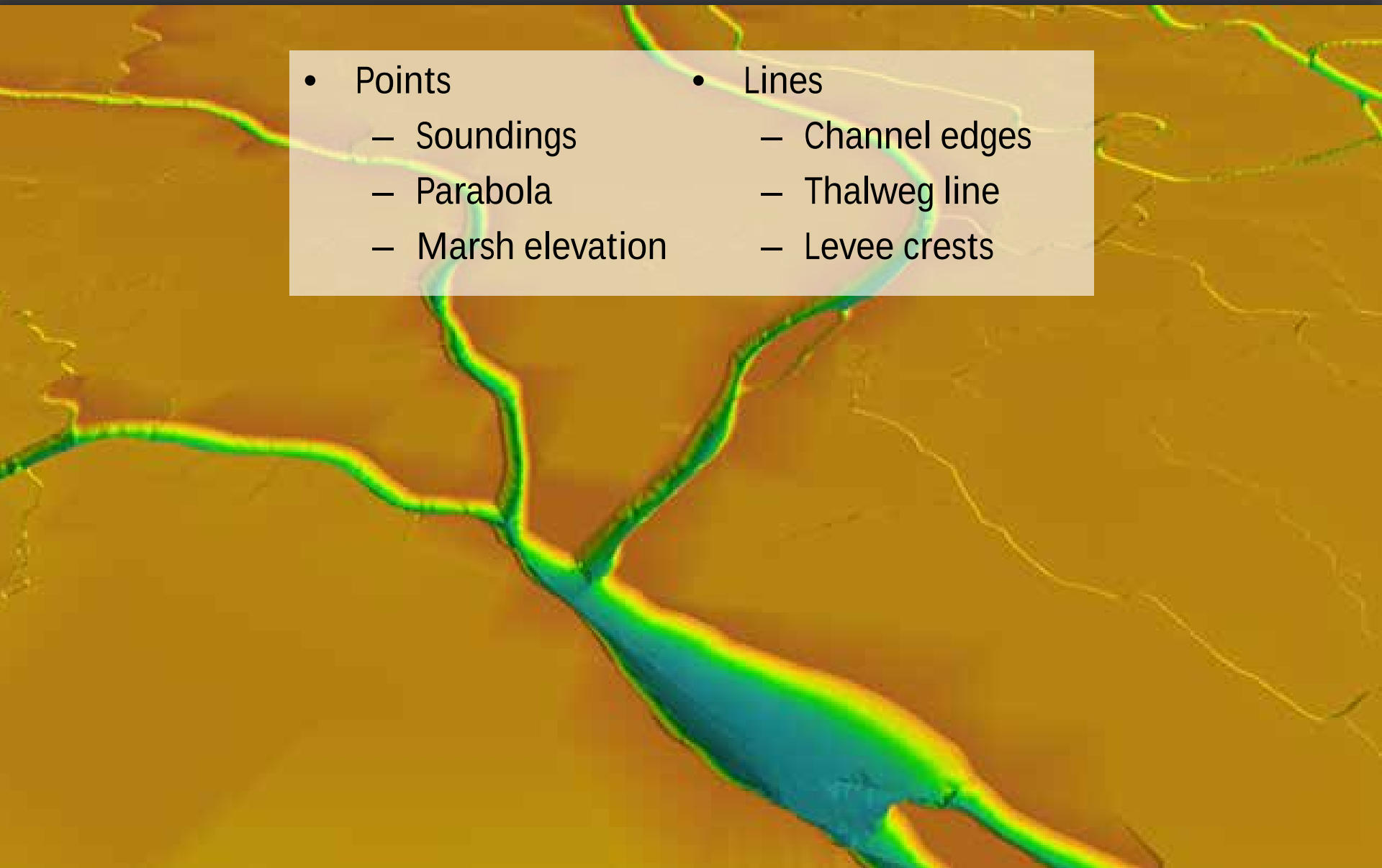
- Apply the surface to convert sounding data to mean sea level
- Next, apply the surface to convert to NAVD88



MLLW to MSL conversion

MSL to NAVD88

Inputs for DEM creation



- Points
  - Soundings
  - Parabola
  - Marsh elevation
- Lines
  - Channel edges
  - Thalweg line
  - Levee crests

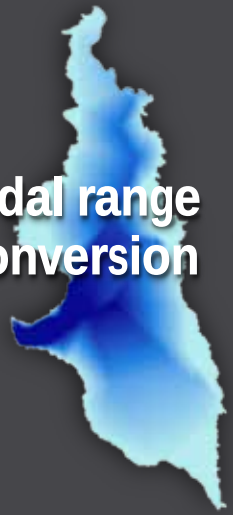
Process summary

Channel lines

Parabola points

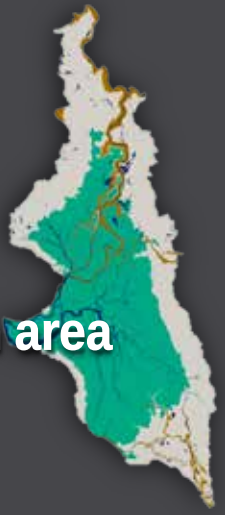
Delta mouth points

Natural levee crests



Tidal range conversion

NAVD88 conversion

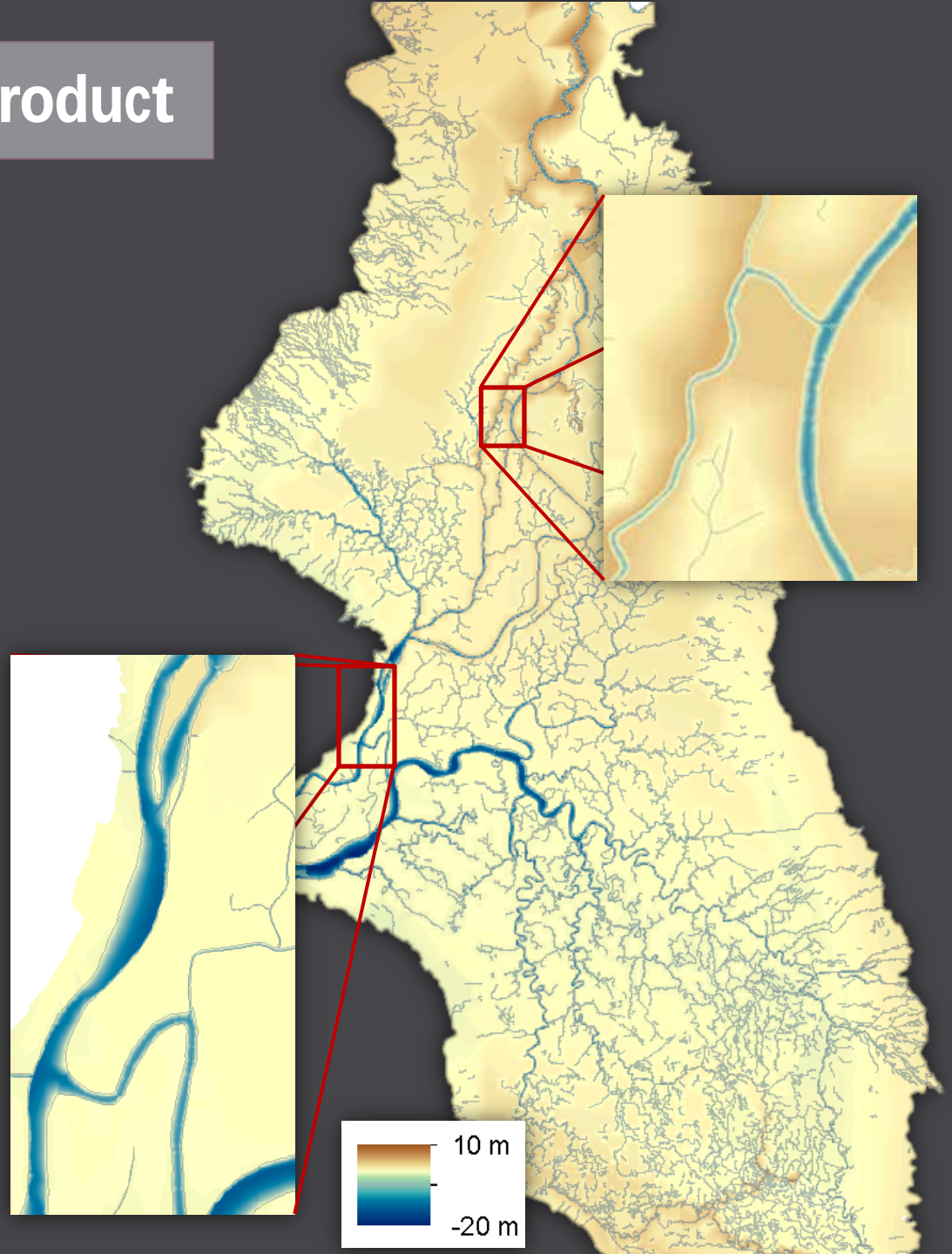


Marsh area

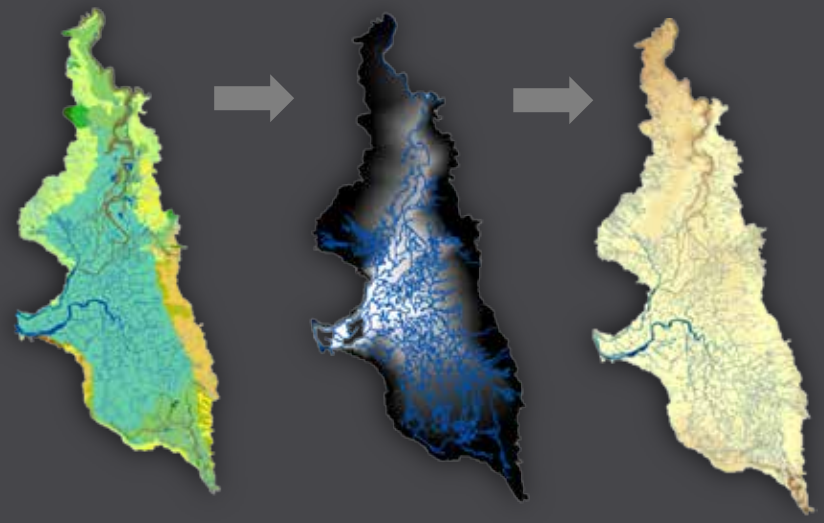
Interim product

Historical DEM interim product

- Current interim DEM version
  - Channel bathymetry plus approximations of natural levees and marsh elevation
- Starting to put it together and hone in on key issues
- Beginning to test with modeling



Next Steps



- More iterations!
  - Working with RMA to prioritize issues to address
- Conveyance
  - Additional data points, thalweg position, interpolation methods
- Datum conversion
  - Use current UnTRIM model elevations
- Contours for natural levees
- Marsh topography, channel banks and other topographic complexities

Thank You!

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