Agriculture and Food Research Initiative:

Rice in the Delta – The Potential to Mitigate Subsidence and Enhance Sustainability

Philip Bachand, Sandra Bachand, **Amy Merrrill, Stuart Siegel, Steve Deverel, Bruce Linquist,** Emilie Kirk, Sara Knox, Rongzong Ye, Matt Espe, Jennifer Morris, Yacov Assa, **Dennis Baldocchi, Leslie Bulter,** Duncan MacEwan, Andrea Brock, Jaclyn Hatala, **Jacob Fleck** and **Will Horwath**

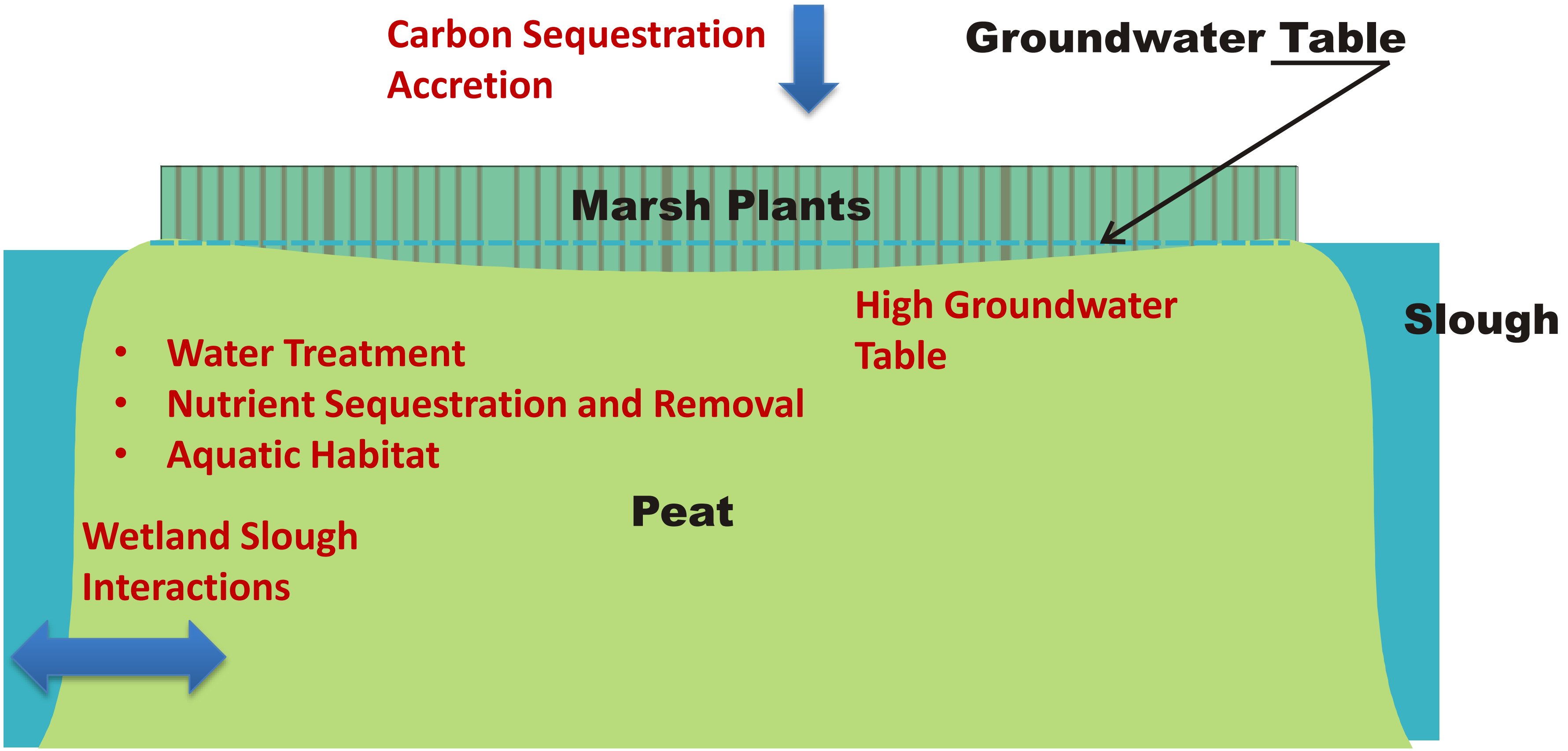
Tetra Tech
530-564-4591
Philip.Bachand@Tetratech.com
www.bachandassociates.com

Bay Delta Conference

Sacramento, CA

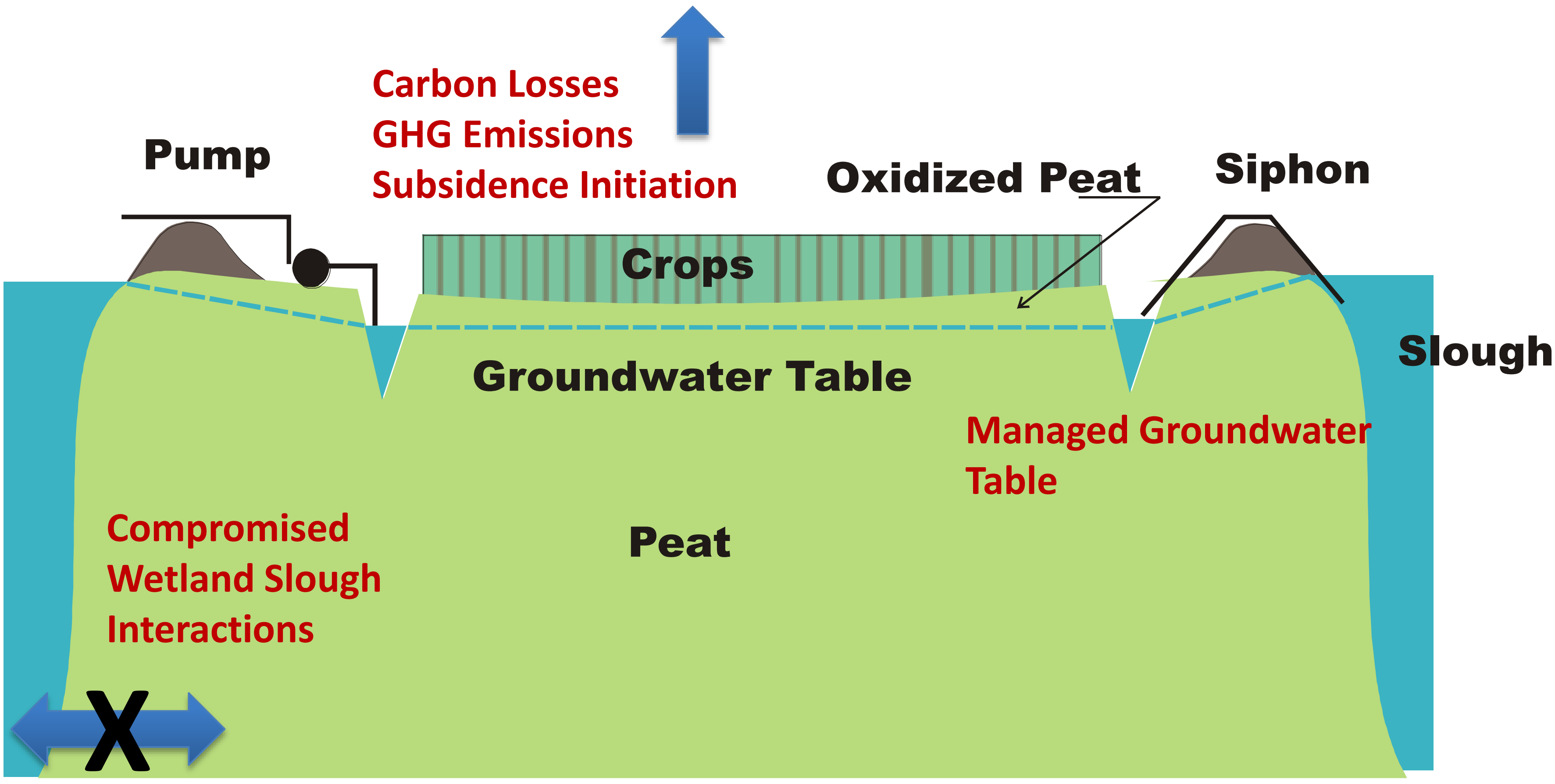
October 29, 2014

Delta Island Model Before Farming



AFRI

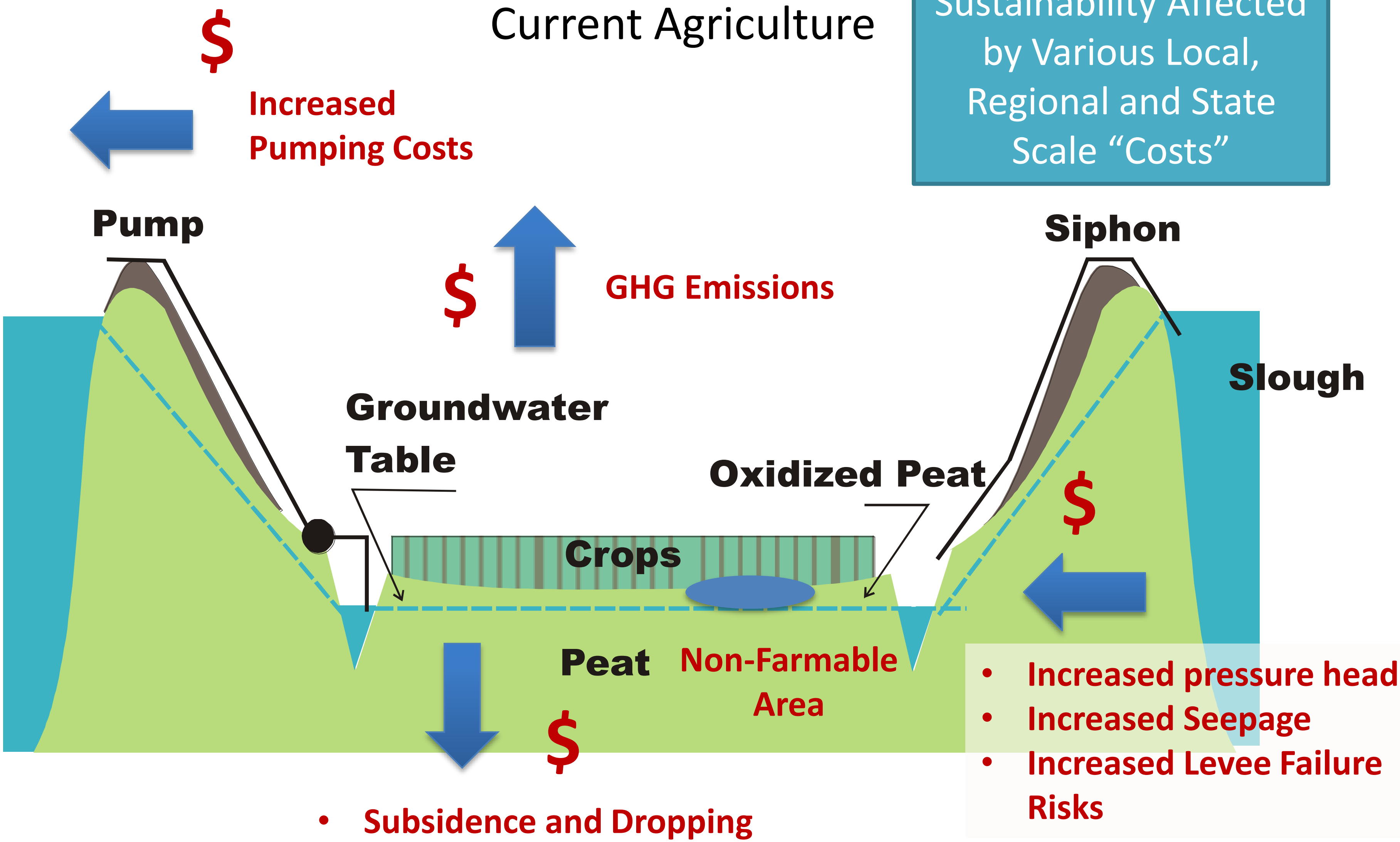
Early Agriculture



AFRI

Current Agriculture

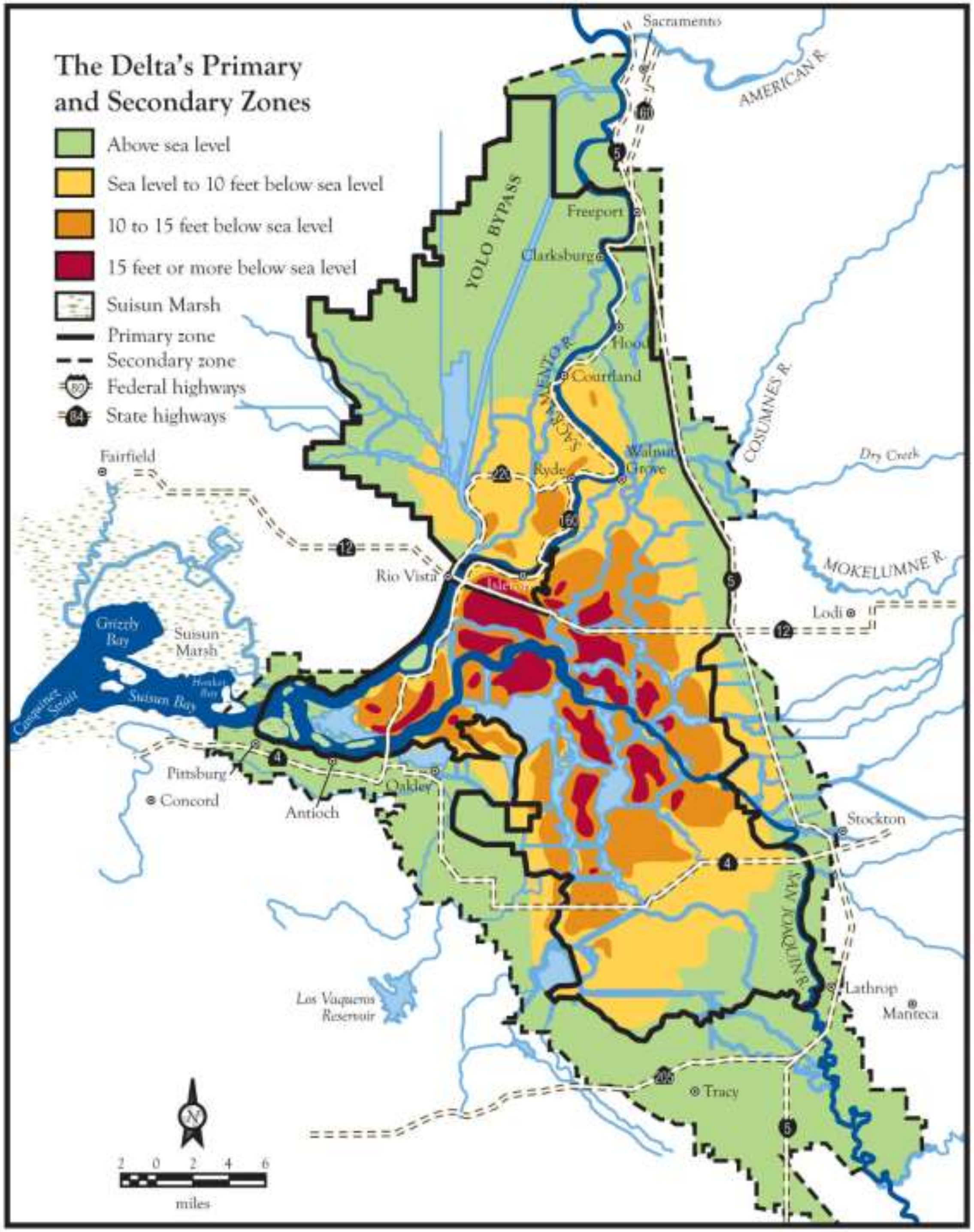
Sustainability Affected by Various Local, Regional and State Scale "Costs"



- Subsidence and Dropping Island Elevations
- Dropping GW Table
- Decreasing Peat Layer

AFRI

Subsidence in the Delta



DRMS: Combined Risks of Failure

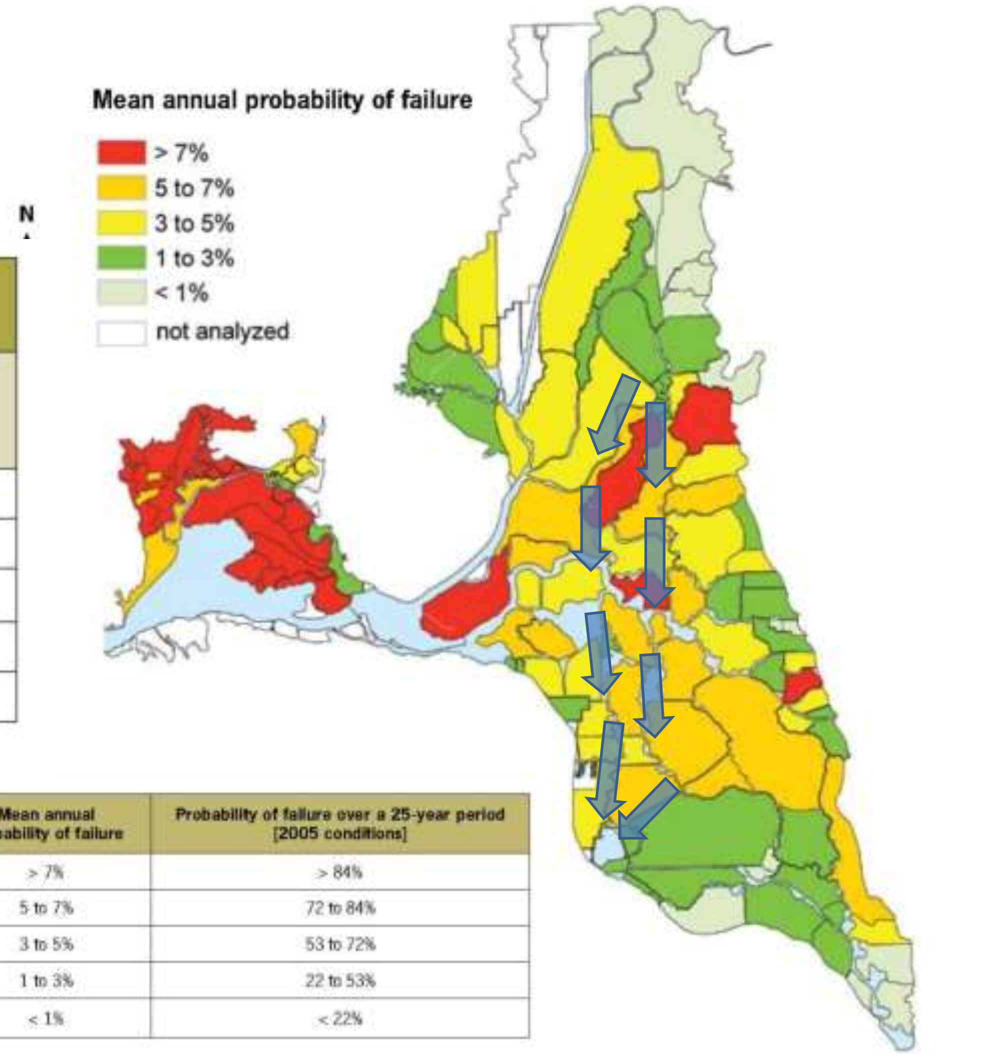
Table 1 – DURATION AND COST OF REPAIRS for earthquake-induced levee failures		
Number of flooded islands	Estimated range of cost of repair and dewatering [$million]	Estimated range of time to repair breaches and dewater [days]
1	43 – 240	136 – 276
3	204 – 490	270 – 466
10	620 – 1,260	460 – 700
20	1,400 – 2,300	750 – 1,020
30	3,000 – 4,200	1,240 – 1,660

Source: DRMS Risk Report [URS/JBA 2008c], Table 13-9

Does not take into account subsidence

COMBINED RISKS

The combined risk of an individual island being flooded due to earthquakes, high water and dry-weather events can be estimated. Considering the probability of levee failures from all hazards under business-as-usual practices, the expected annual probability of island flooding is illustrated in Figure 12. This figure shows that islands in Suisun Marsh and the western and central Delta are the most vulnerable.

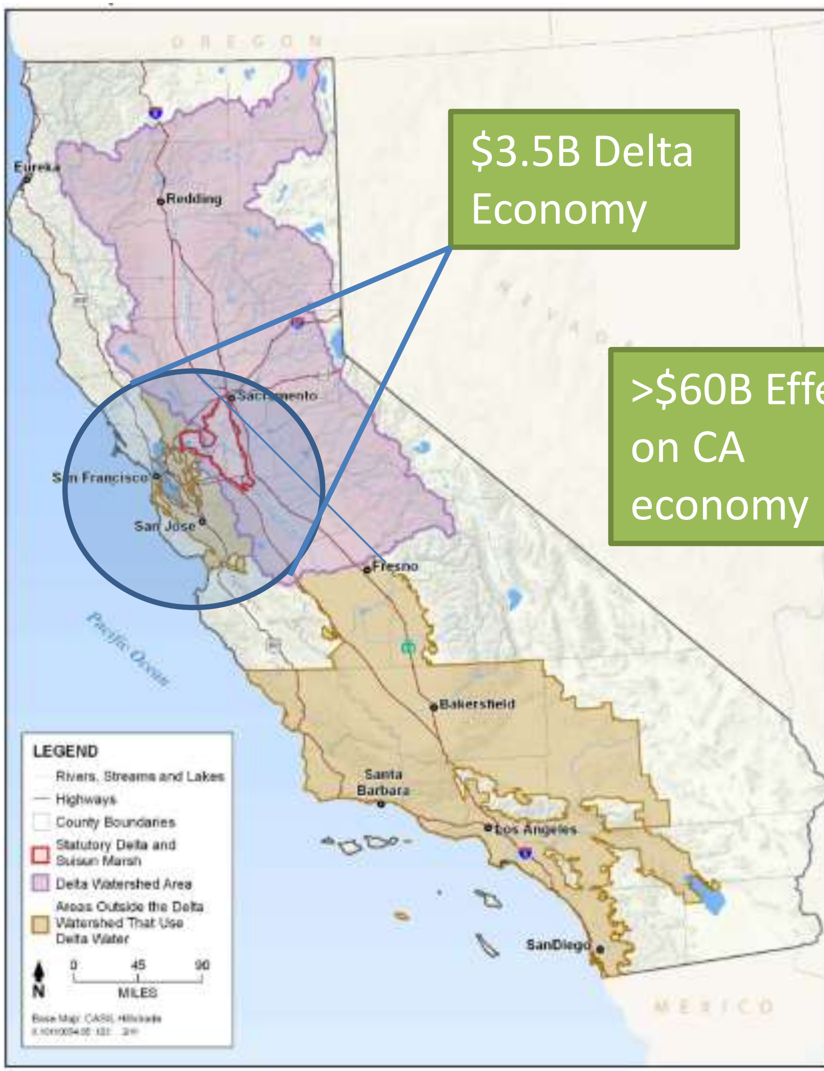


Mean annual probability of failure	Probability of failure over a 25-year period [2005 conditions]
> 7%	> 84%
5 to 7%	72 to 84%
3 to 5%	53 to 72%
1 to 3%	22 to 53%
< 1%	< 22%

Figure 12 Mean annual probability of levee failure in the Delta Region from the combined risk of earthquakes, high water and dry-weather failures [2005 conditions]

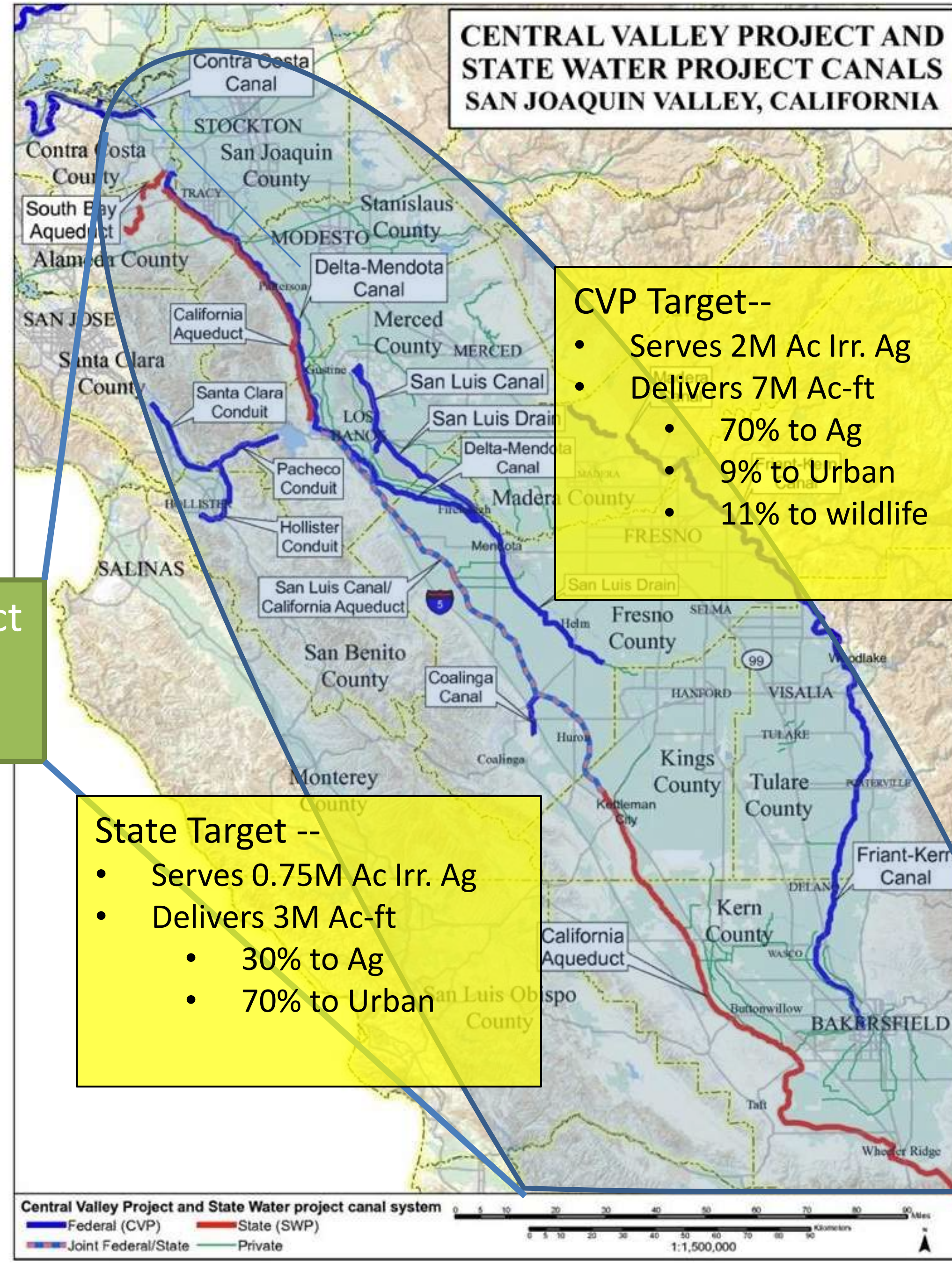
Source: DRMS Risk Report [URS/JBA 2008c], Figure 13-16

Watershed of the Sacramento-San Joaquin Delta and Regions that Use Delta Water



$3.5B Delta Economy

>$60B Effect on CA economy



CVP Target--

- Serves 2M Ac Irr. Ag
- Delivers 7M Ac-ft
  - 70% to Ag
  - 9% to Urban
  - 11% to wildlife

State Target --

- Serves 0.75M Ac Irr. Ag
- Delivers 3M Ac-ft
  - 30% to Ag
  - 70% to Urban

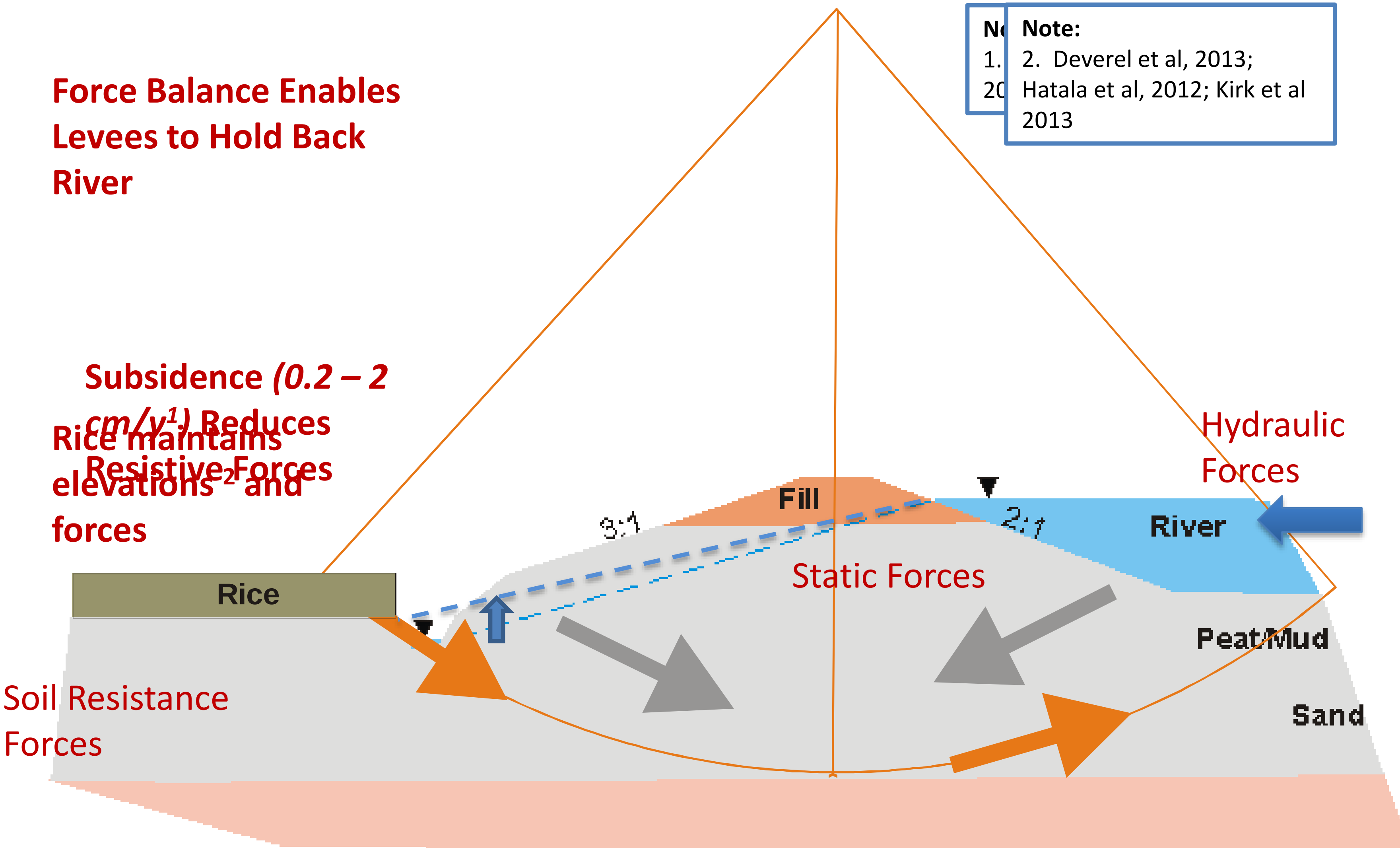
Three Delta Scenarios

1. **B**usiness – **A**s – **U**sual
2. Conveyance Delta (Top Down)
3. Optimized Commons (Bottom Up)
   – Agronomic
   – Water Quality
   – GHG emissions
   – Levees

Scenario 2: Conveyance Delta
(Risk Reduction Driven)

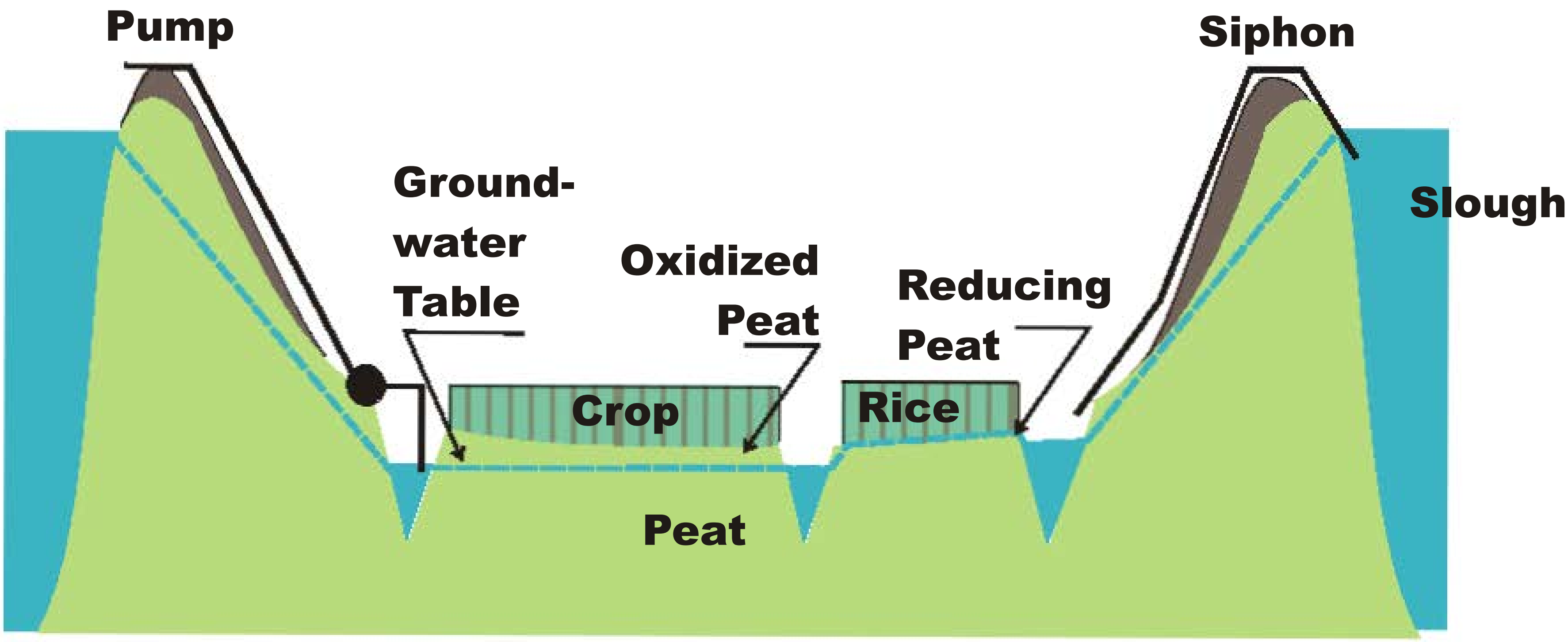
- Conveyance Corridor
- **Rice and Wetlands Placed to Reduce Levee Failure Risks from Subsidence and Sea Level Rise**
- **Primary Benefit & Value → Reducing Risks to CA water supply**
- Failure Risks = $F(x_1, x_2 \ldots.., x_i)$
  - Effects of depth of peat/mud on failure plane
  - Effects of head pressure (water elevation – land elevation)
  - Type of failure: Static, seepage, seismic
  - Island water table
  - Lands uses proximity to levees

Conceptual Model – Levee Force Diagram

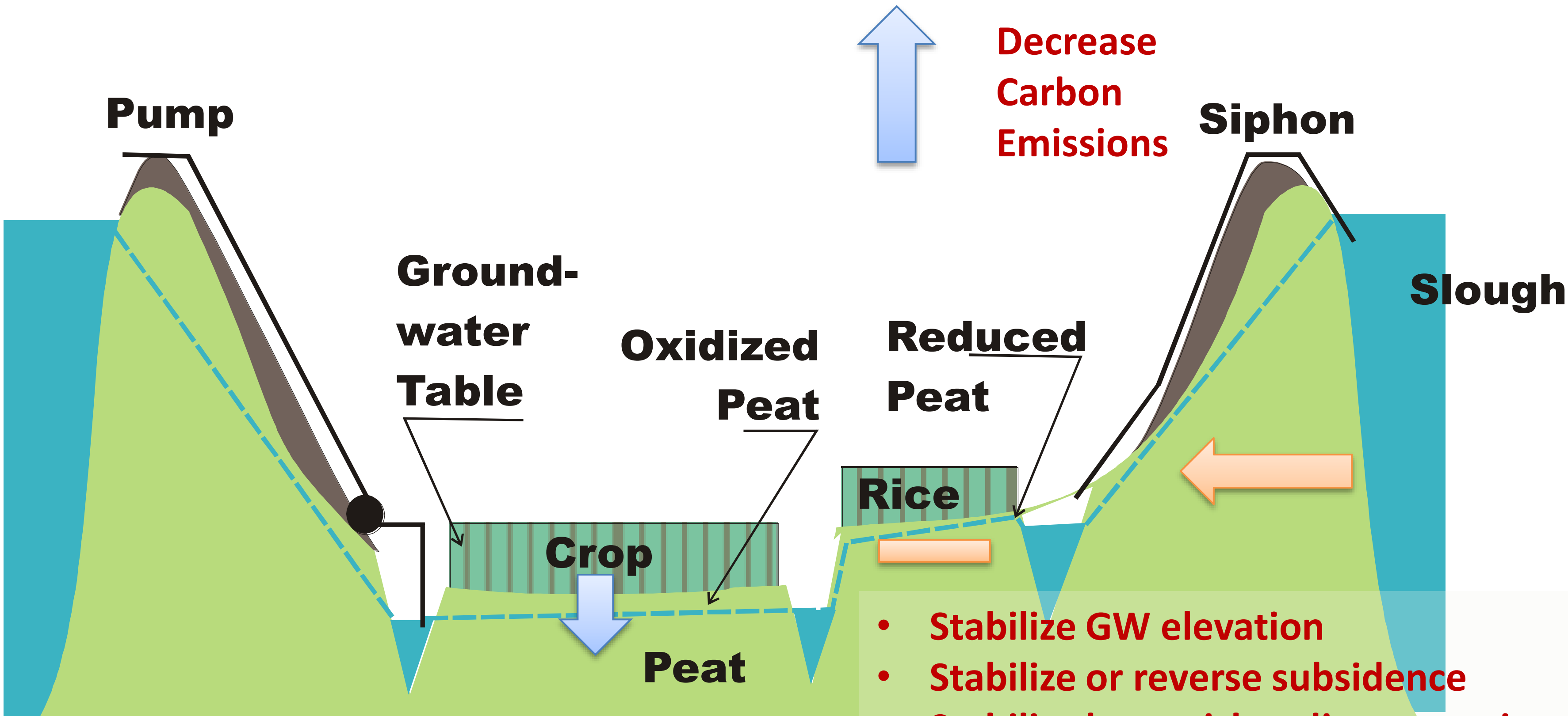


AFRI

Implementing Rice on a Delta Island



Implementing Rice on a Delta Island



- Stabilize GW elevation
- Stabilize or reverse subsidence
- Stabilize levee risks adjacent to rice
- Stabilize Seepage

AFRI

Scenario 3: Optimized Commons

	Local	Regional	State
GHG Emissions		x	
Water Resources Risks and Levees	x	x	x
Water Quality		x	x
Agronomic Sustainability	x	x	
Carbon Sequestration	x	x	

AFRI

Scenario 3: Optimized Commons

	Local	Regional	State
GHG Emissions		x	
Water Resources Risks and Levees	x	x	x
Water Quality		x	x
Agronomic Sustainability	x	x	
Carbon Sequestration	x	x	

GHG Emission = $\sum$GHG Emissions $_l$ =
CO_2 Emission + CH_4 Emissions + N_2O Emissions

GHG Emission$_l$ = $\sum$GHG Emissions $_{l,x,y}$

GHG Emission $_{l,x,y}$ =
F (**Soil Carbon, Hydrology/Redox**, Management, Climate ....) $_{x,y}$

Scenario 3: Optimized Commons

	Local	Regional	State
GHG Emissions		x	
Water Resources Risks and Levees	x	x	x
Water Quality		x	x
Agronomic Sustainability	x	x	
Carbon Sequestration	x	x	

Notes:

- Relies upon same levee failure drivers as Conveyance Delta Scenario
- Considers local/regional costs associated with levee failure:
  - Levee repair
  - Island dewatering
  - Upgrade costs
  - Materials….

AFRI

Scenario 3: Optimized Commons

	Local	Regional	State
GHG Emissions		x	
Water Resources Risks and Levees	x	x	x
Water Quality		x	x
Agronomic Sustainability	x	x	
Carbon Sequestration	x	x	

Delta Agricultural Production (DAP) Model →

- Crop Distribution to achieve maximum return

Delta Acreage=

$\sum Acreage_{crop\ j}$

Acreage crop j = F (….)

- future crop profits and costs
- farmer preferences and expertise
- local climate and environment
- net profit of other crops
- **subsidies**

AFRI

Scenario 3: Optimized Commons

	Local	Regional	State
GHG Emissions		x	
Water Resources Risks and Levees	x	x	x
Water Quality		x	x
Agronomic Sustainability	x	x	
Carbon Sequestration	x	x	

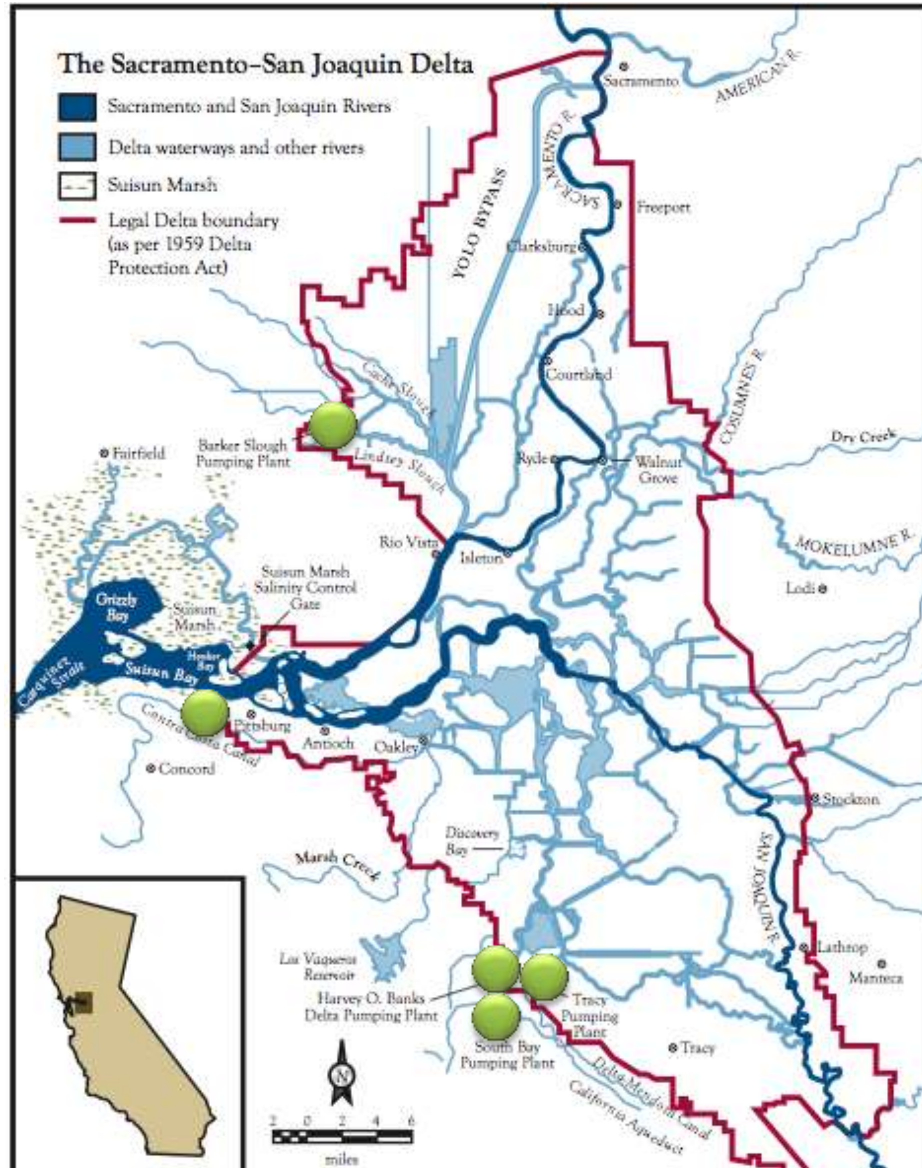
Discharge Loads = $\sum$ Seasonal Load$_I$ = Summer Load + Winter Load

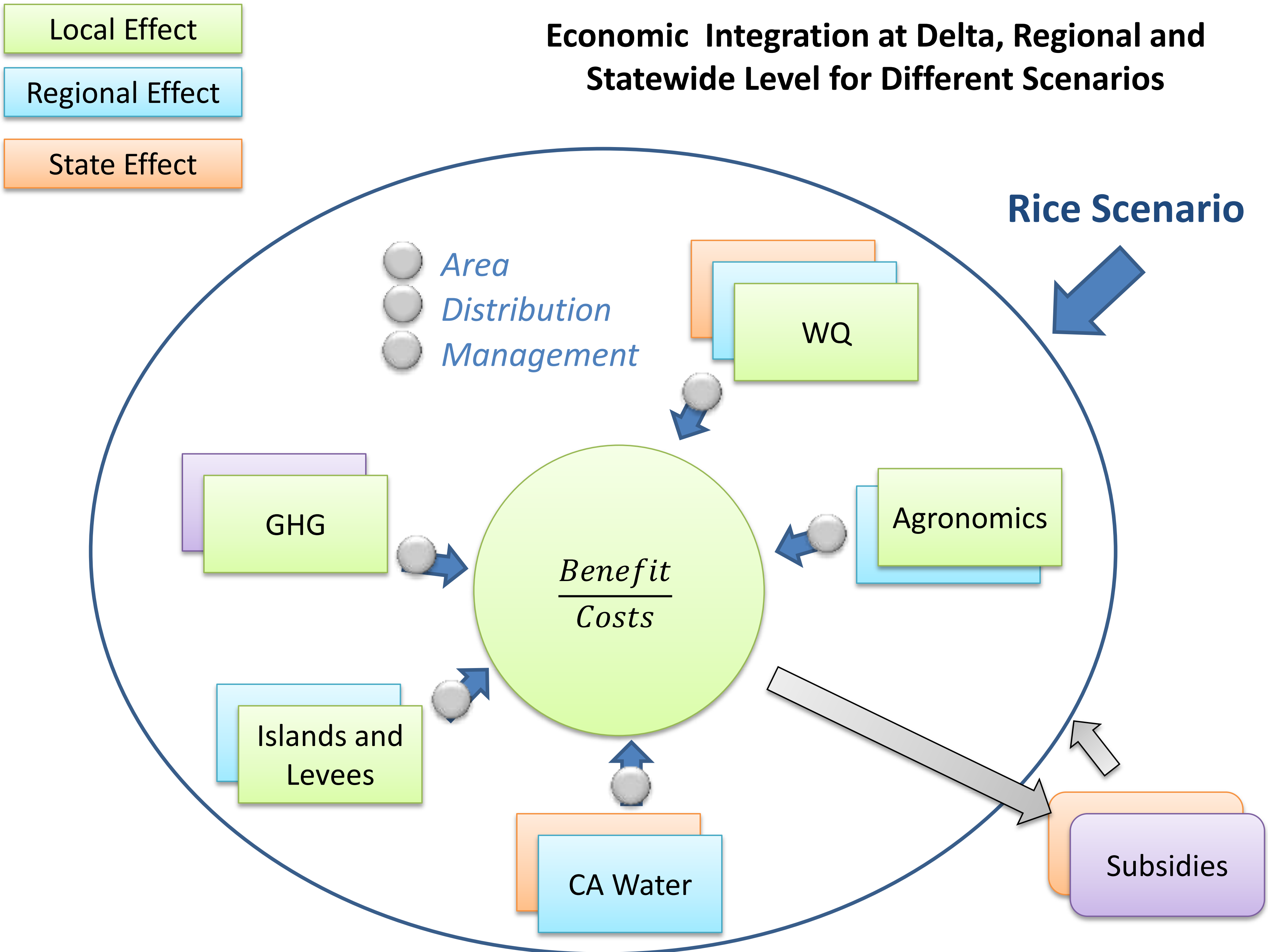
Seasonal Island Load = F(.....)

- Crop Distribution and Acreage on Island
- Island Crop Mosaic
- Island size and elevation
- Management (crop, field, island)

Water Quality Methodology for Each Scenario

- DOC, DBPPs, nutrients, Hg, salinity
- Island Load Importance = Proximity to and Seasonal Requirements at Intake
- Value for Water Quality:
  - Avoided treatment costs
  - TMDL compliance
  - Meeting salinity requirements at intakes



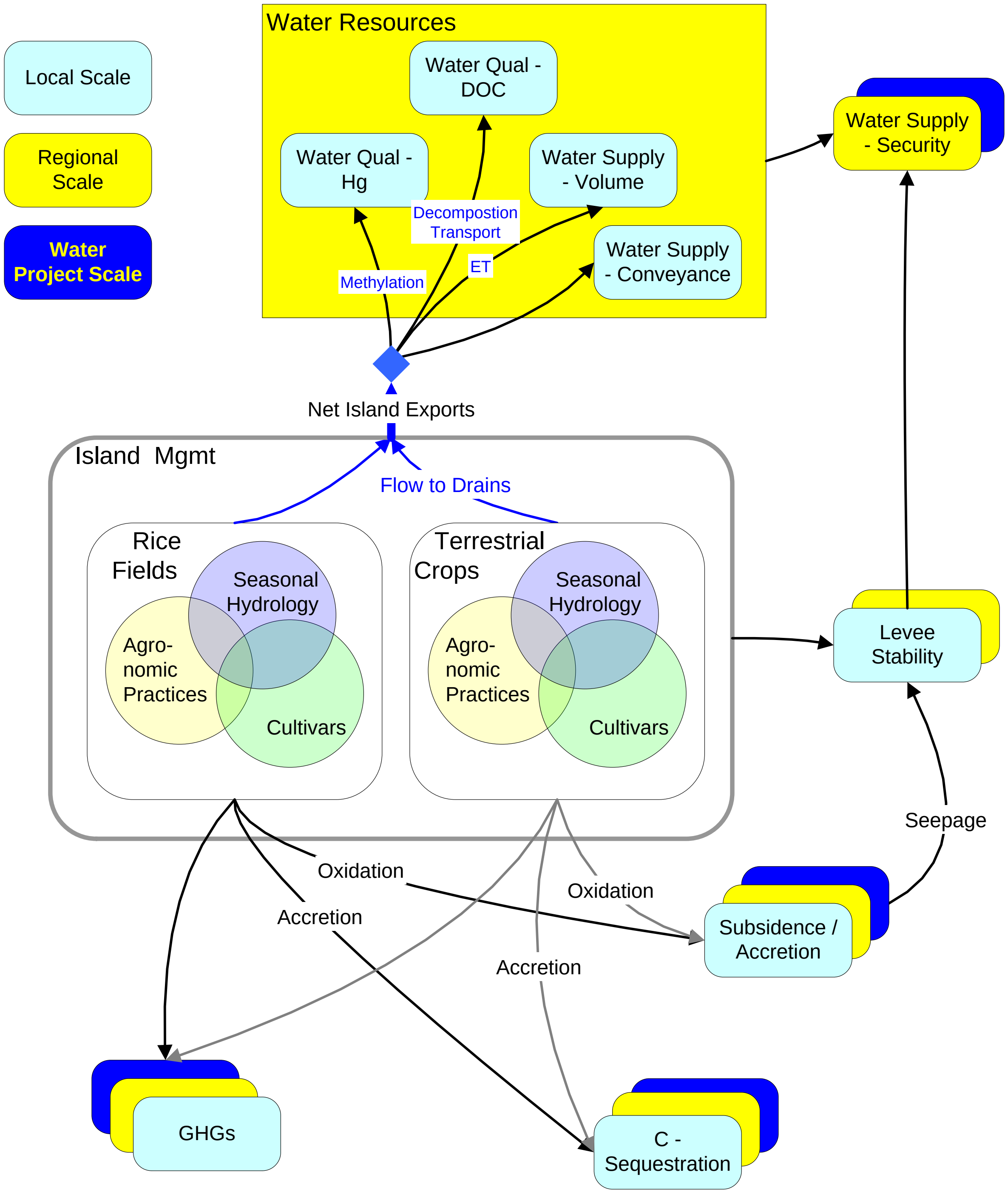


Local Effect
Regional Effect
State Effect
Economic Integration at Delta, Regional and Statewide Level for Different Scenarios
Rice Scenario
Area
Distribution
Management
WQ
GHG
Agronomics
Benefit
Costs
Islands and Levees
CA Water
Subsidies

Summary

- Rice agriculture and wetlands can be a means towards more stable levees and a more sustainable Delta.
- Strong interdisciplinary assessment serves as a planning model for change in the Delta
- Two more years and addressing big picture issues associated with land management in the Delta
- AFRI Posters:
  - Flood Management:
    - R. Gehlke, Delta Science Center. N fertilizer treatments for Delta Rice
  - Human Consequences:
    - R. Ye. Effects of N fertilization and Soil Carbon on GHG emissions from Delta rice
  - Integrative Applied Science
    - N. Stern. Integrating Surface and Shallow Subsurface Hydrologic and WQ interactions in Delta Rice

Questions?



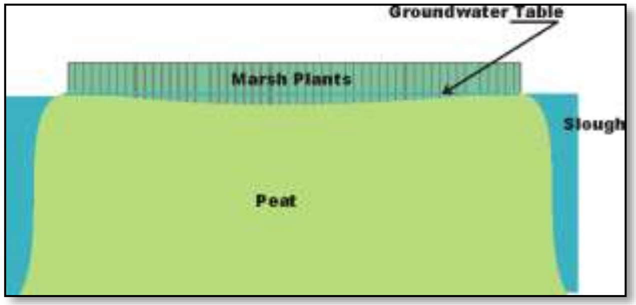
Rice Impacts in the Delta

Drivers:

- Soil Organic Matter
- C:N ratio
- Redox (O2, NO3, Fe, SO4)
- Land Use
- Cultural Practices
- Irrigation
- Climate and Temperature

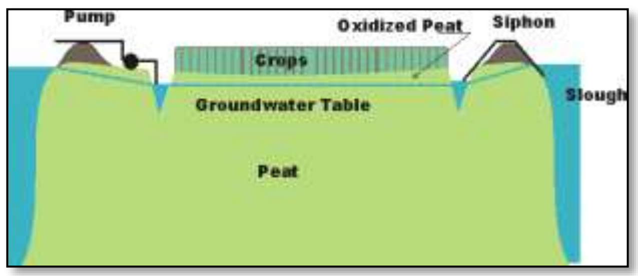
AFRI

Island Transitions from Wetlands to Today's Agriculture

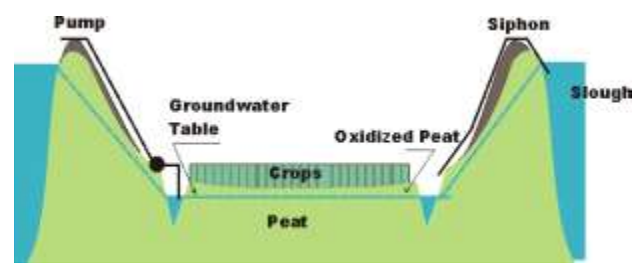


Flooded Marshland

Reclaimed
To Early
Agriculture

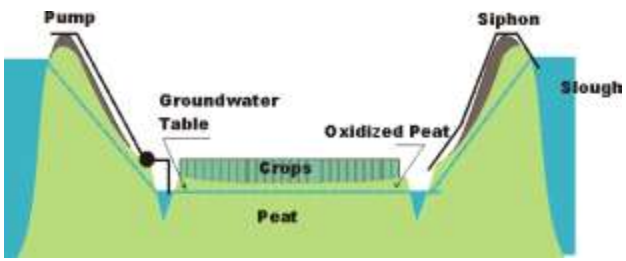


To Current
Agriculture



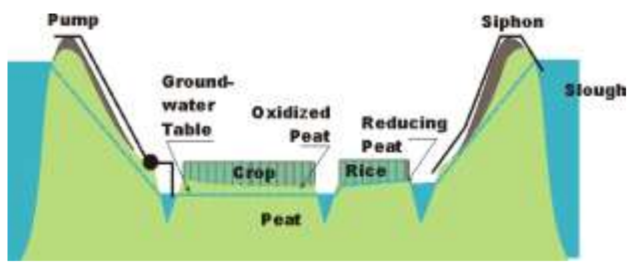
AFRI

Future Opportunities with Rice and Wetlands

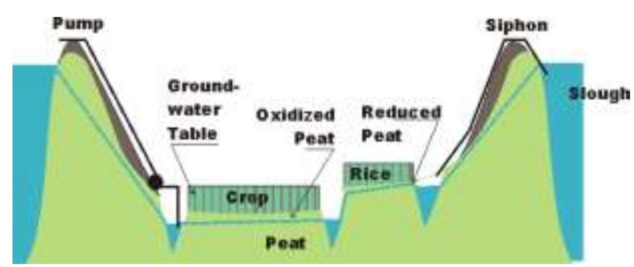


Current
Agriculture

With Rice
(Now)



With Rice
(One Future
Scenario)



AFRI

Delta Economy

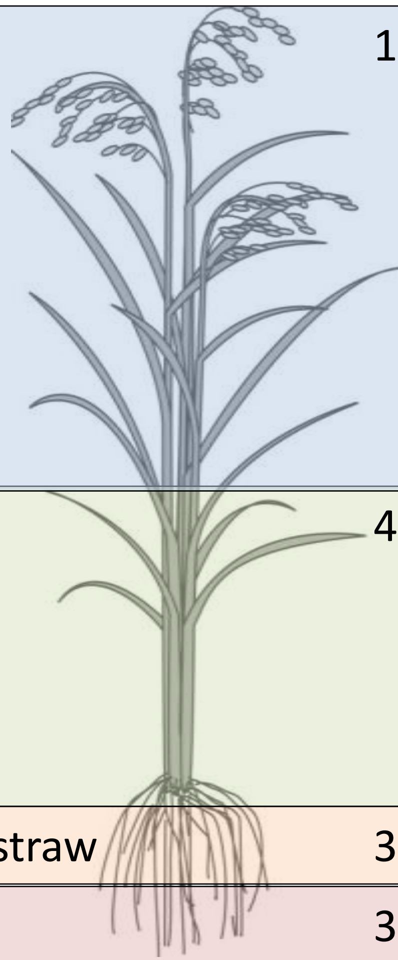
- To the Delta
  - Agricultural Economy (DPC, 2012)
    - $800M direct (DPC, 2012)
    - $2.6B Total w/I Delta ($5.4B Total for CA)
  - Recreation (DPB, 2012)
    - $330M
  - Fisheries (Goldman, 1998)
    - $336M expenditures
- Estimated Annual Economy from Agriculture, recreation and fishing: $3.5B

AFRI

Nitrogen Budget: Relating to Subsidence

Kirk et al (2013)

Field 10 Nitrogen Uptake in 0N plots = 167 kg N/ha



Peat mineralization	121 kg N/ha
Subsurface N	40 kg N/ha
Previous year's rice straw	3 kg N/ha
Irrigation water	3 kg N/ha

Calculations:

121 + 40 kg N/ha
(surface and subsurface)

↓

% N use efficiency

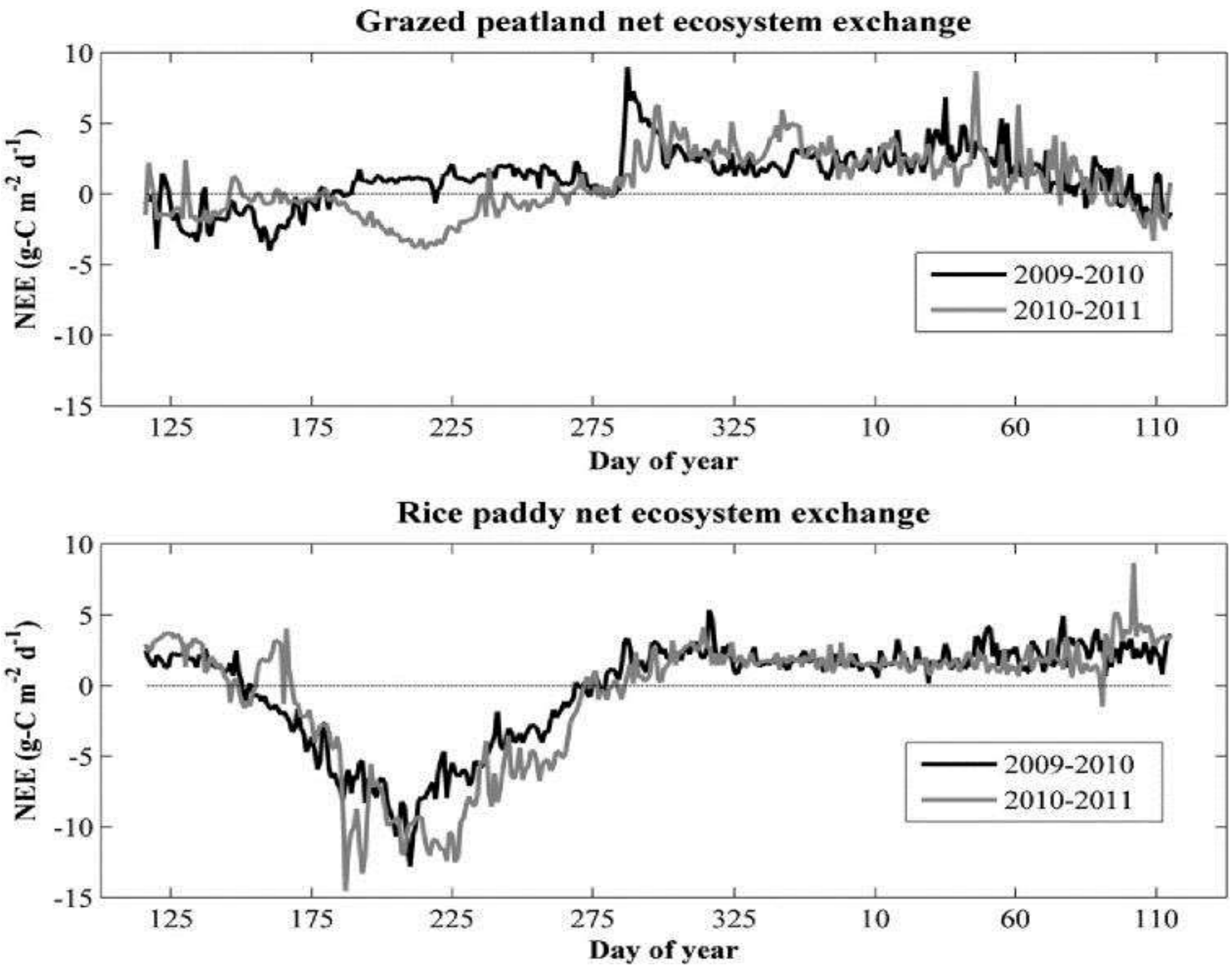
**Assuming NUE from all sources to be equal

↓

kg N/ha mineralized from peat during the growing season

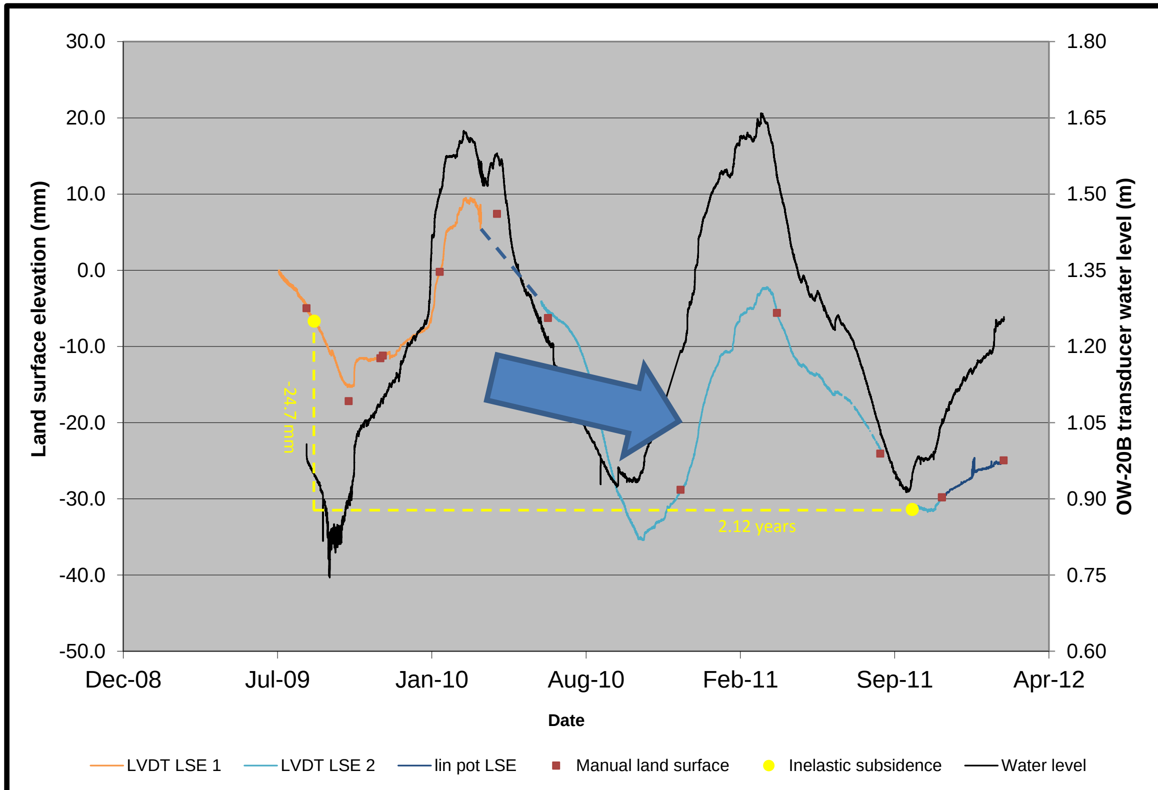
AFRI

Net Ecosystem Exchange (g-C/m2/d) Hatala et al 2012)

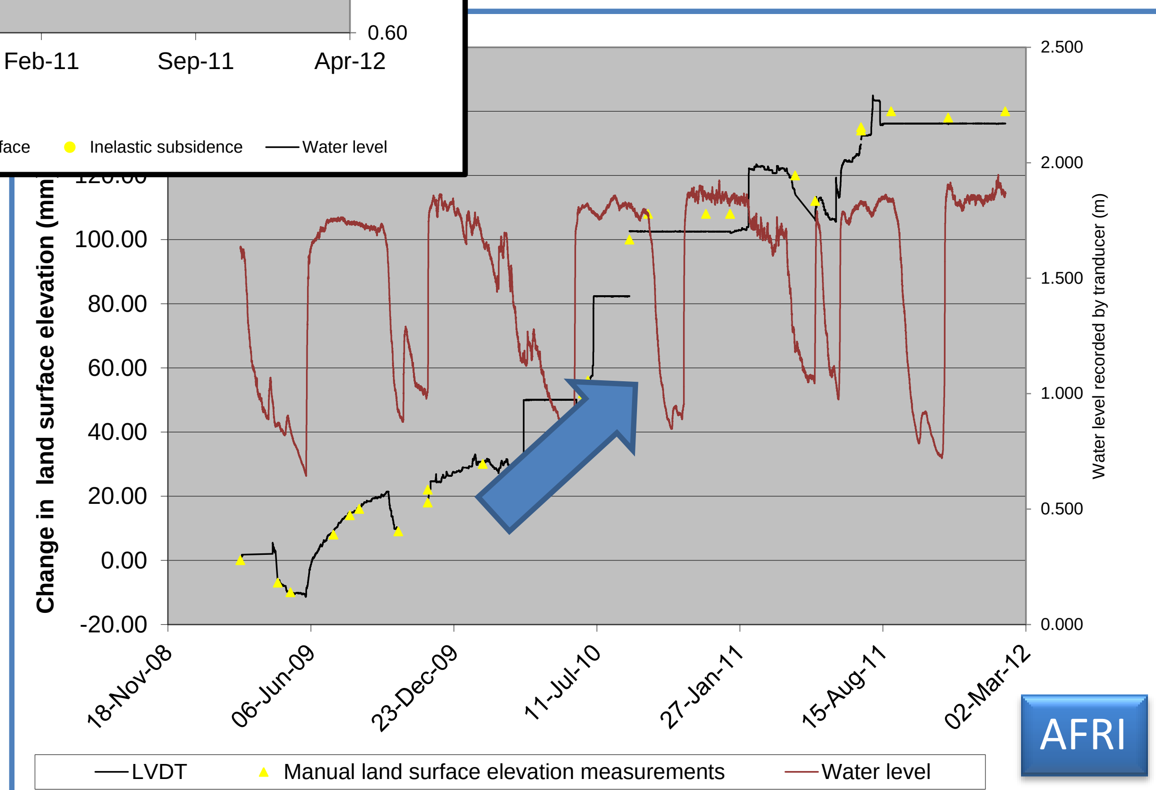


AFRI

Subsidence in Corn and Rice – Deverel et al 2013



Corn Subsiding Approximately 1.2 cm/y



Rice Accreting Approximate 0.4 cm/y

AFRI

Very Small Plot Yields, 2012

Variety	Grain Type	Grain Yield at 14% Moisture lbs/acre	
M105	M	8250	(1)
S102	S	8060	(2)
09Y2141	SWX	7920	(3)
M104	M	7630	(4)
08Y3126	M	7480	(5)
M206	M	7440	(6)
06Y575	L	7430	(7)
11Y1044	L	7180	(8)
CM101	S	6930	(9)
09Y2179	S	6720	(10)
CH202	SPQ	6630	(11)
L206	L	6130	(12)
08Y3310	M	5190	(13)
M202	M	4650	(14)
09Y3887	M	3990	(15)
08Y3269	M	3640	(16)
CH201	SPQ	3520	(17)

(Linquist et al, 2012)

	Summary of Large Plot Variety Trials, Yield (lb/ac)			
Variety	2009	2010	2011	2012
CM-101	9890 a	7580 a	8320 a	7160
S-102	X	6970 a	9310 a	8060
M-104	6440 c	6490 a	9200 a	8040
M-206	7450 b	4467 b	8380 a	6960
M-202	3870 d	X	X	X

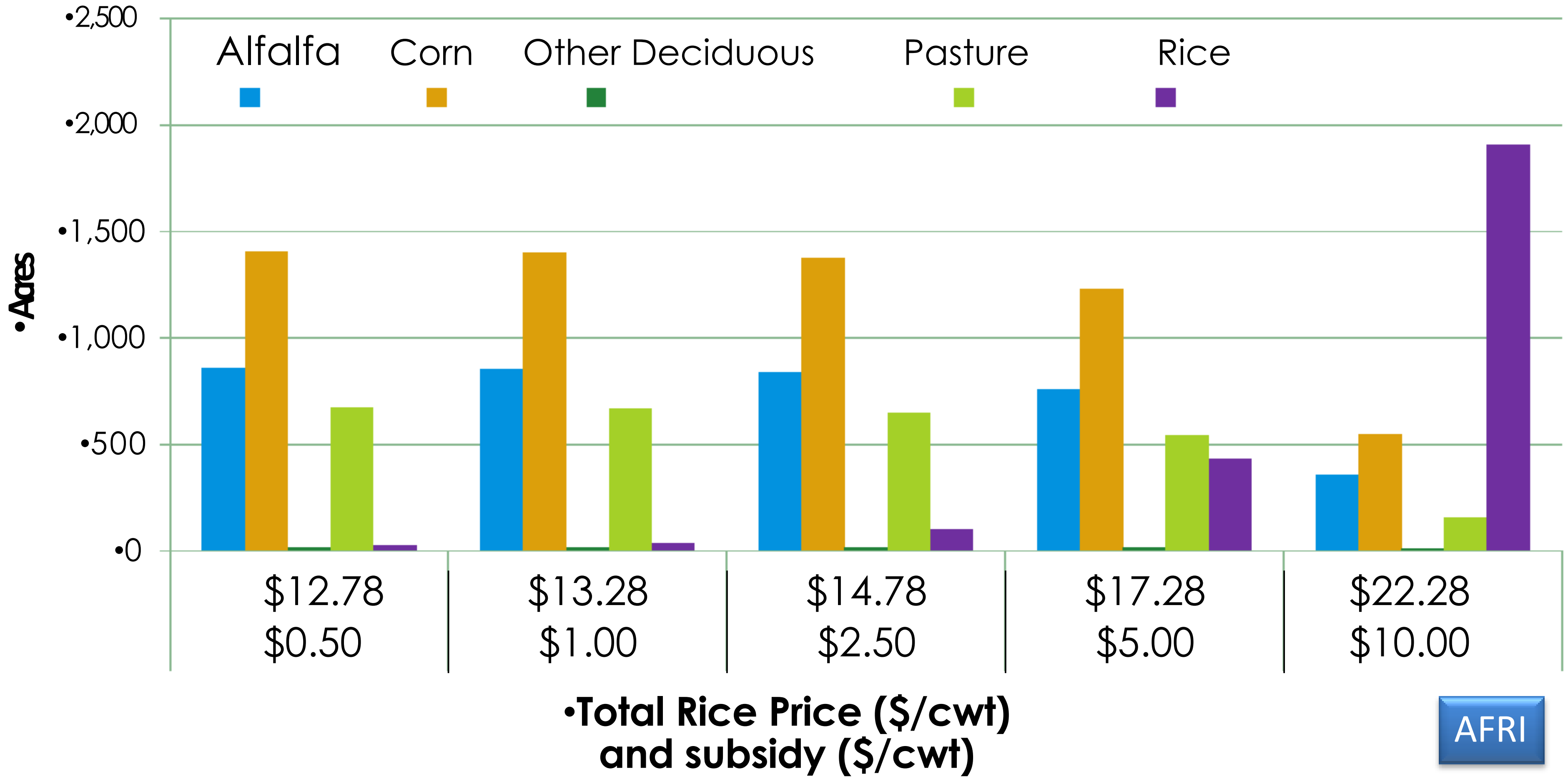
AFRI

MacEwan 2013

Example DAP Analysis

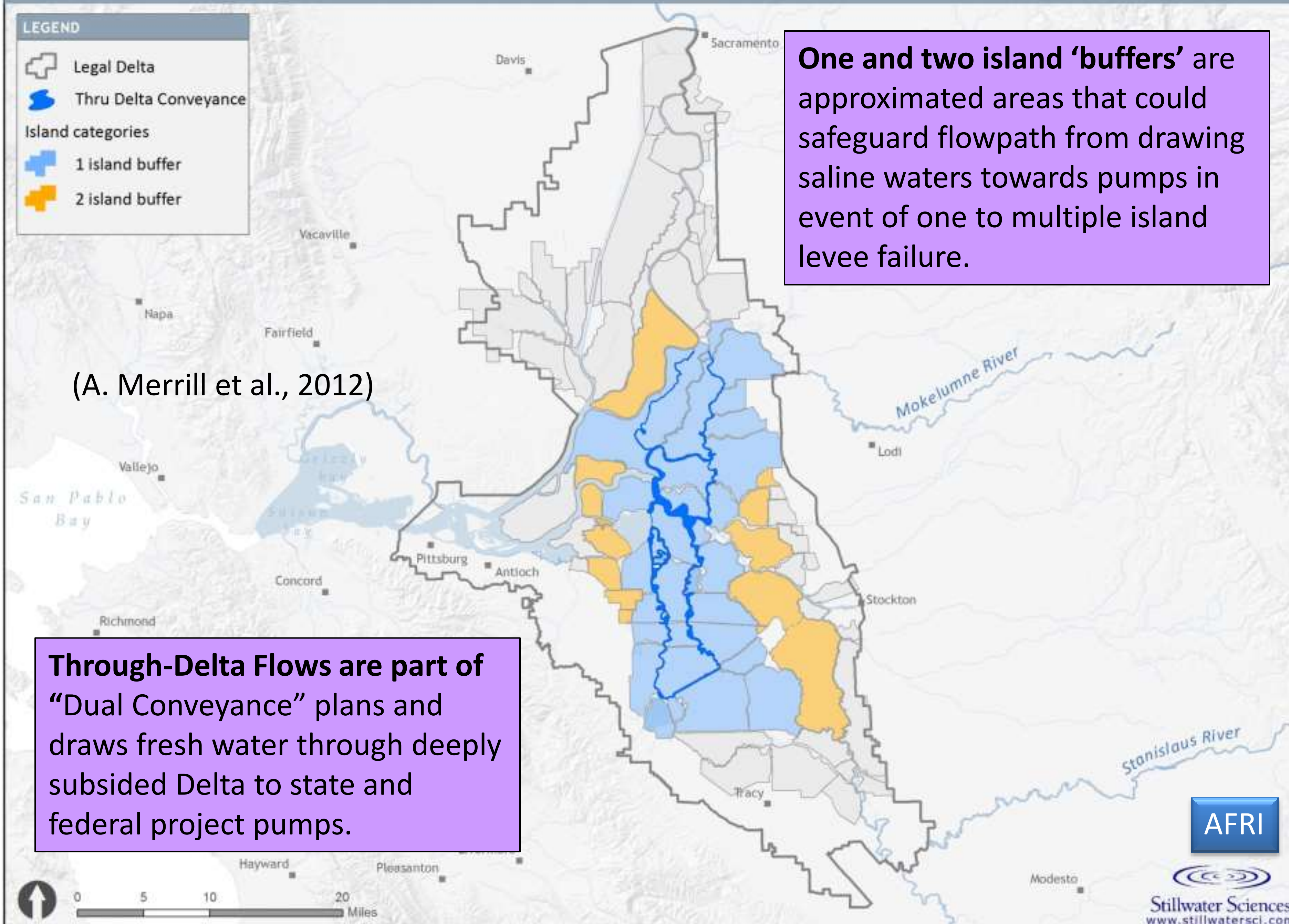
Twitchell Island – rice subsidy (yield-based)

- $0.50 - $10 per cwt



AFRI

Existing Through-Delta Water Conveyance:

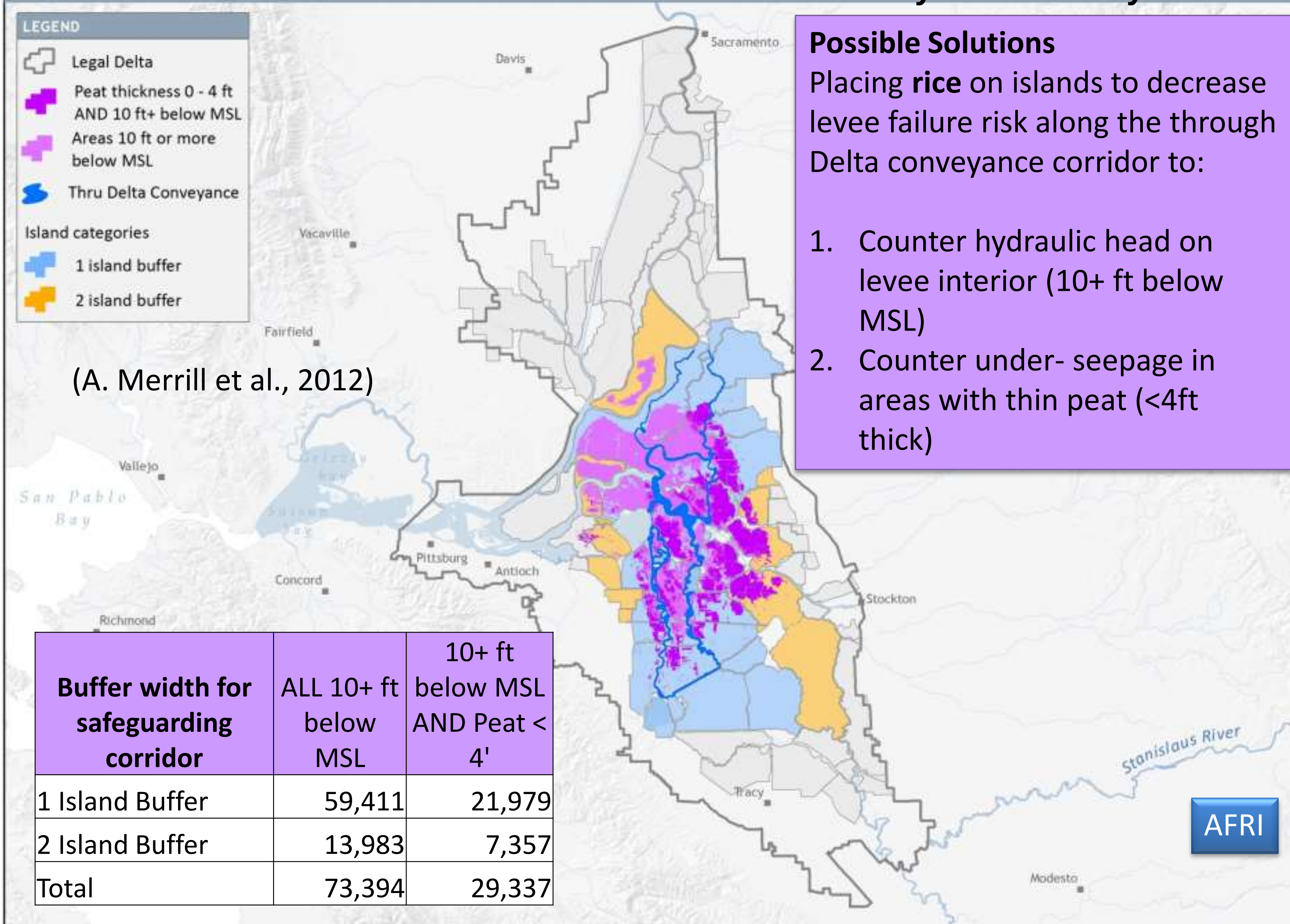


One and two island 'buffers' are approximated areas that could safeguard flowpath from drawing saline waters towards pumps in event of one to multiple island levee failure.

(A. Merrill et al., 2012)

Through-Delta Flows are part of "Dual Conveyance" plans and draws fresh water through deeply subsided Delta to state and federal project pumps.

Possible Solutions for increased Water Conveyance security



Possible Solutions

Placing **rice** on islands to decrease levee failure risk along the through Delta conveyance corridor to:

1. Counter hydraulic head on levee interior (10+ ft below MSL)
2. Counter under- seepage in areas with thin peat (<4ft thick)

(A. Merrill et al., 2012)

Buffer width for safeguarding corridor	ALL 10+ ft below MSL	10+ ft below MSL AND Peat < 4'
1 Island Buffer	59,411	21,979
2 Island Buffer	13,983	7,357
Total	73,394	29,337

AFRI

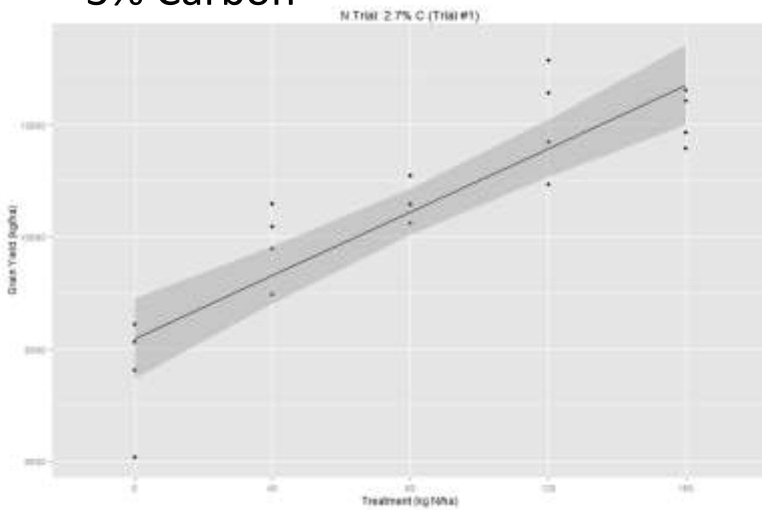
Rice – How Much to Manage Subsidence Risks to Levee Failure?

- Too early to know
  - Estimate of 10,000s of Acres
    - Say 15,000 – 40,000
  - Subsidy likely needed to promote rice
    - High value crops: Tomatos, grapes, etc…
    - Alfalfa ….
    - Past subsidies to promote rice have been about $150/ac (2004/05 Delta Rice Project)
    - Potentially range of $5/sack ($400/ac)
  - Reasonable estimate of $2 – 16M annually to prevent increasing levee subsidence risk through rice subsidy
- **Numbers will be product of AFRI**

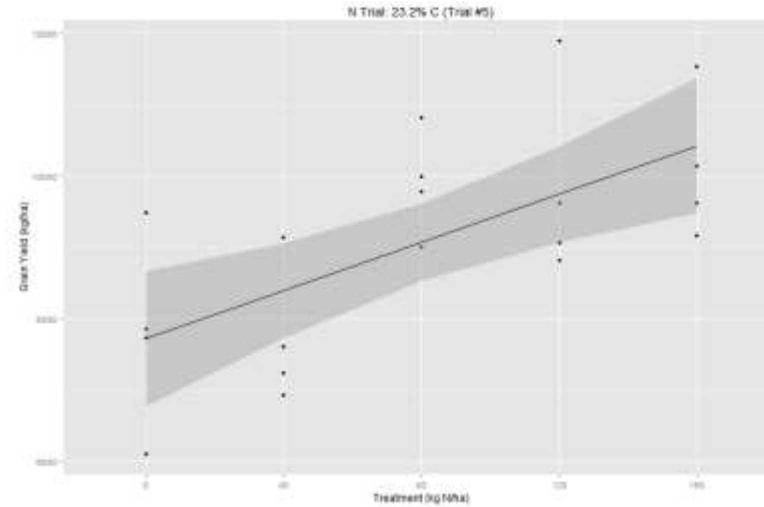
AFRI

Fertilizer and Yield, Espe 2013
Yield Vs N Fertilizer for Delta Soils as % Carbon

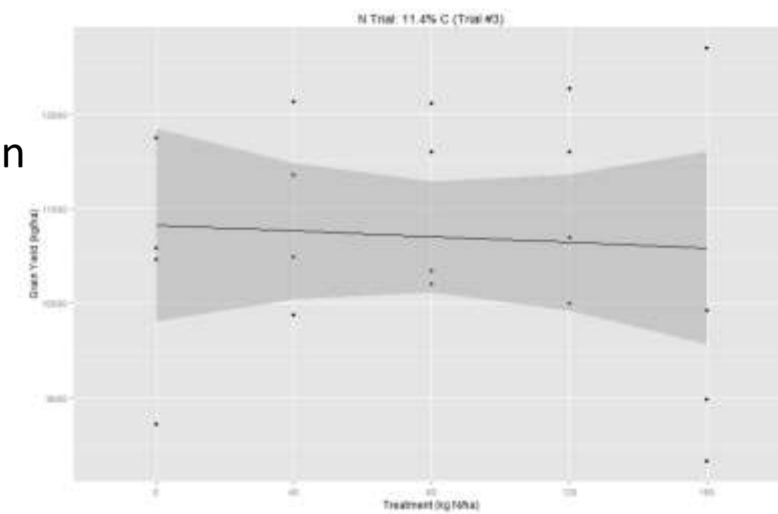
3% Carbon



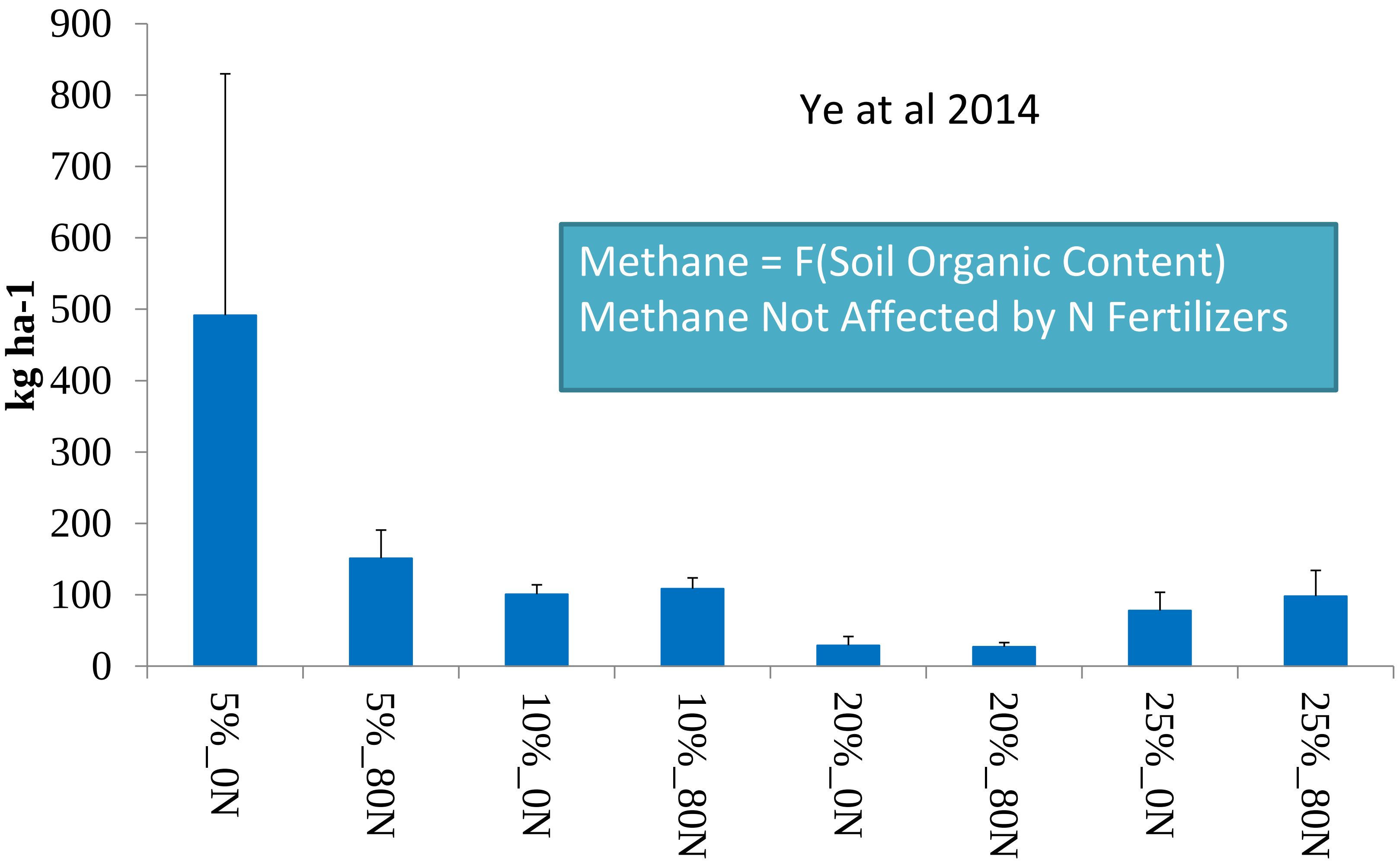
23% Carbon



11% Carbon



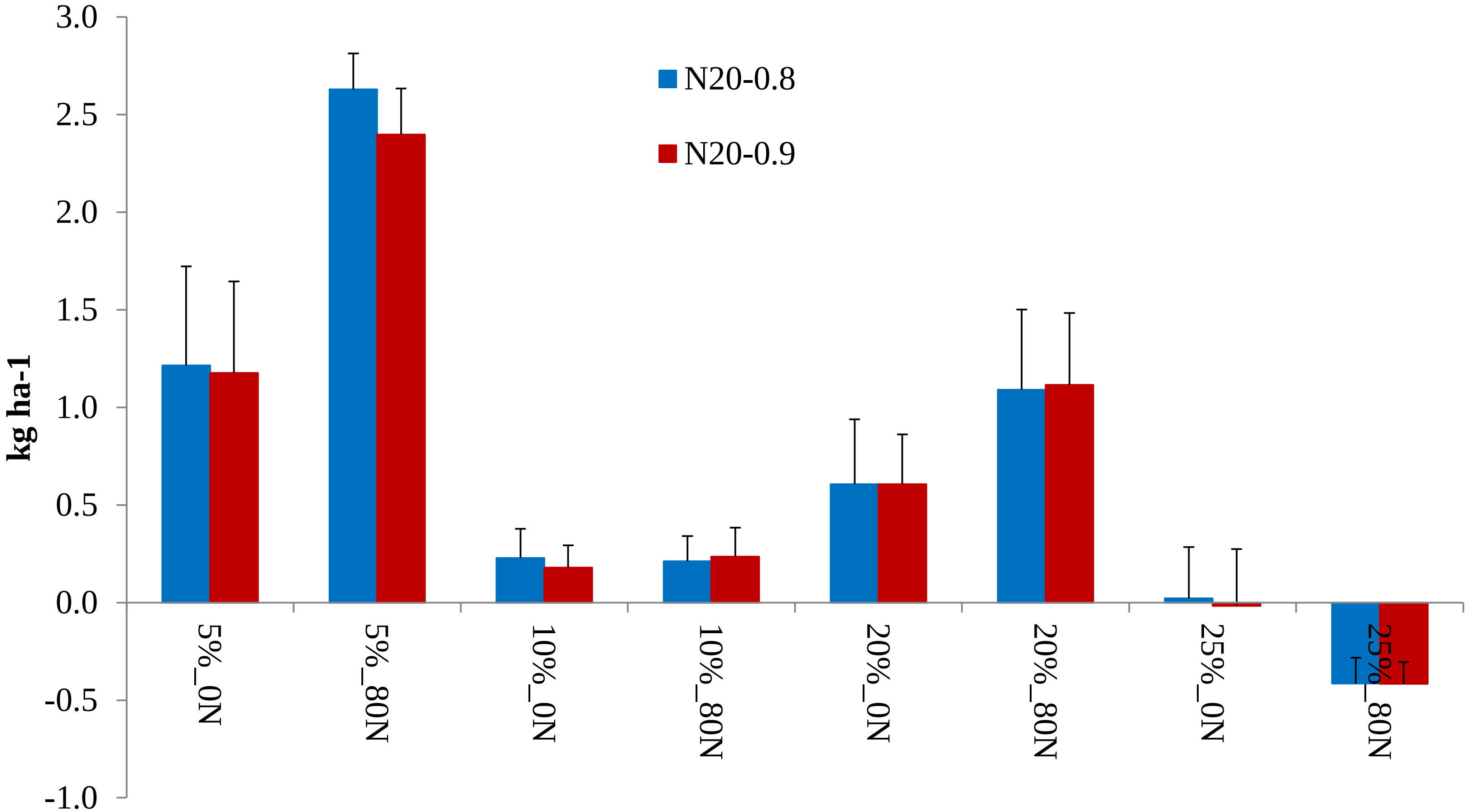
Total CH_4 flux during the growing season



Methane = F(Soil Organic Content)
Methane Not Affected by N Fertilizers

AFRI

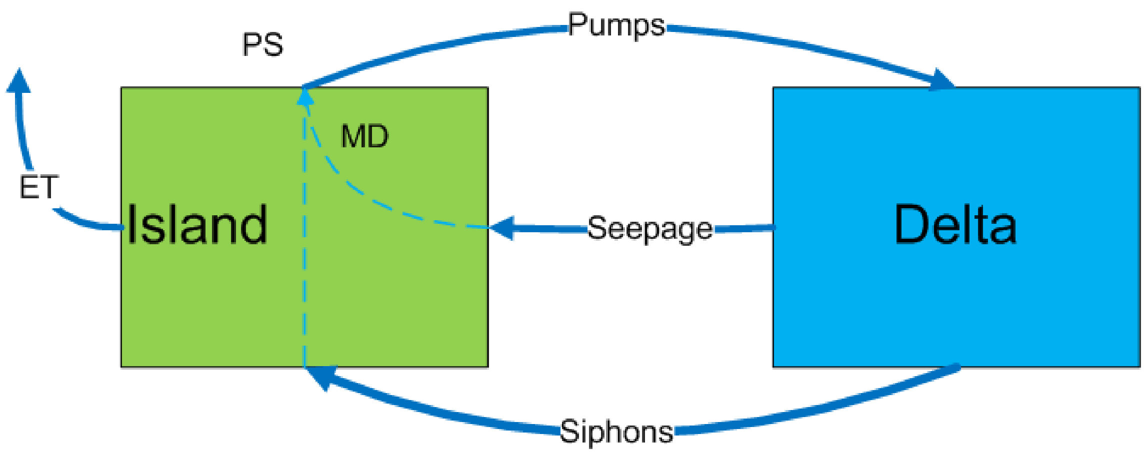
Total N_20 flux during the growing season



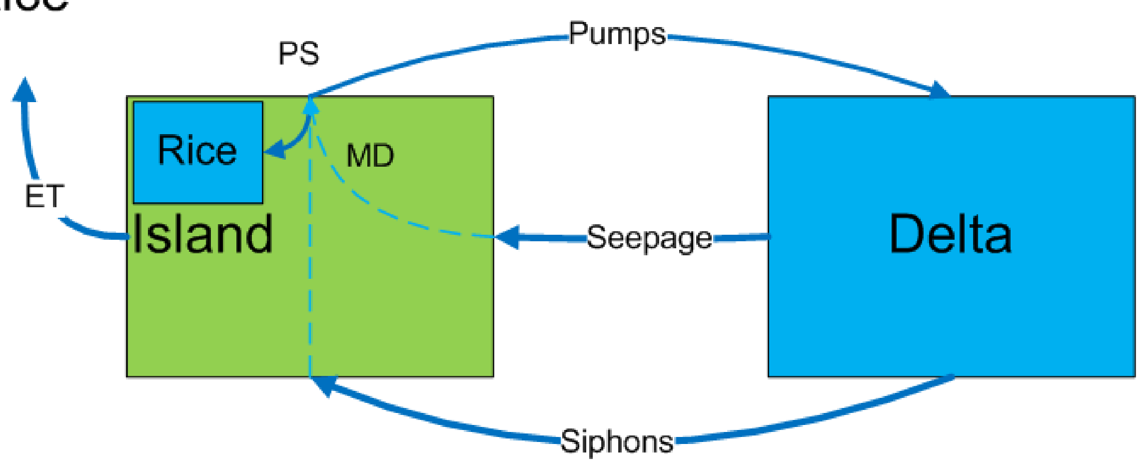
AFRI

Island Hydrologic Model

BAU

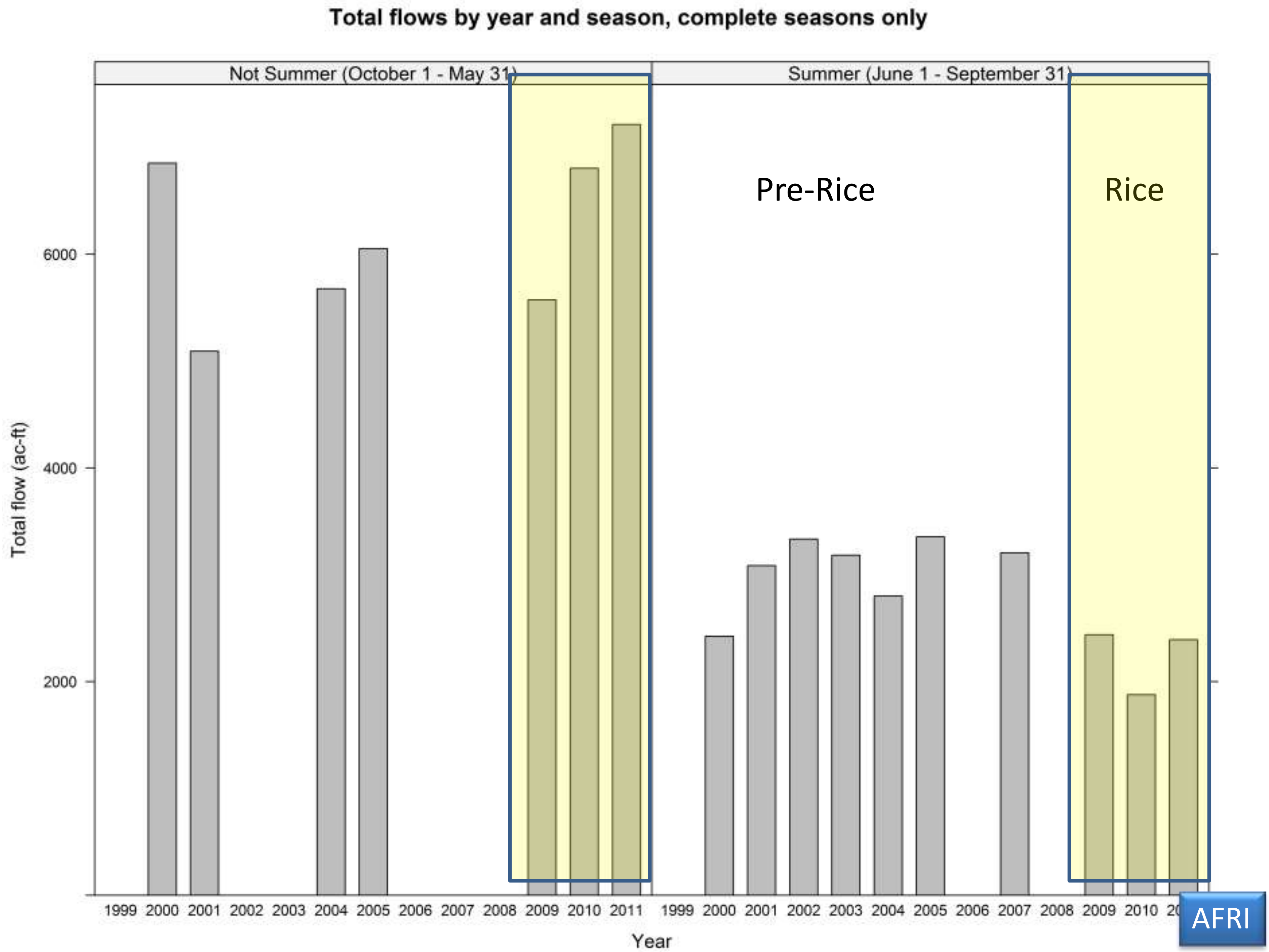


Scenario 1
W/Rice



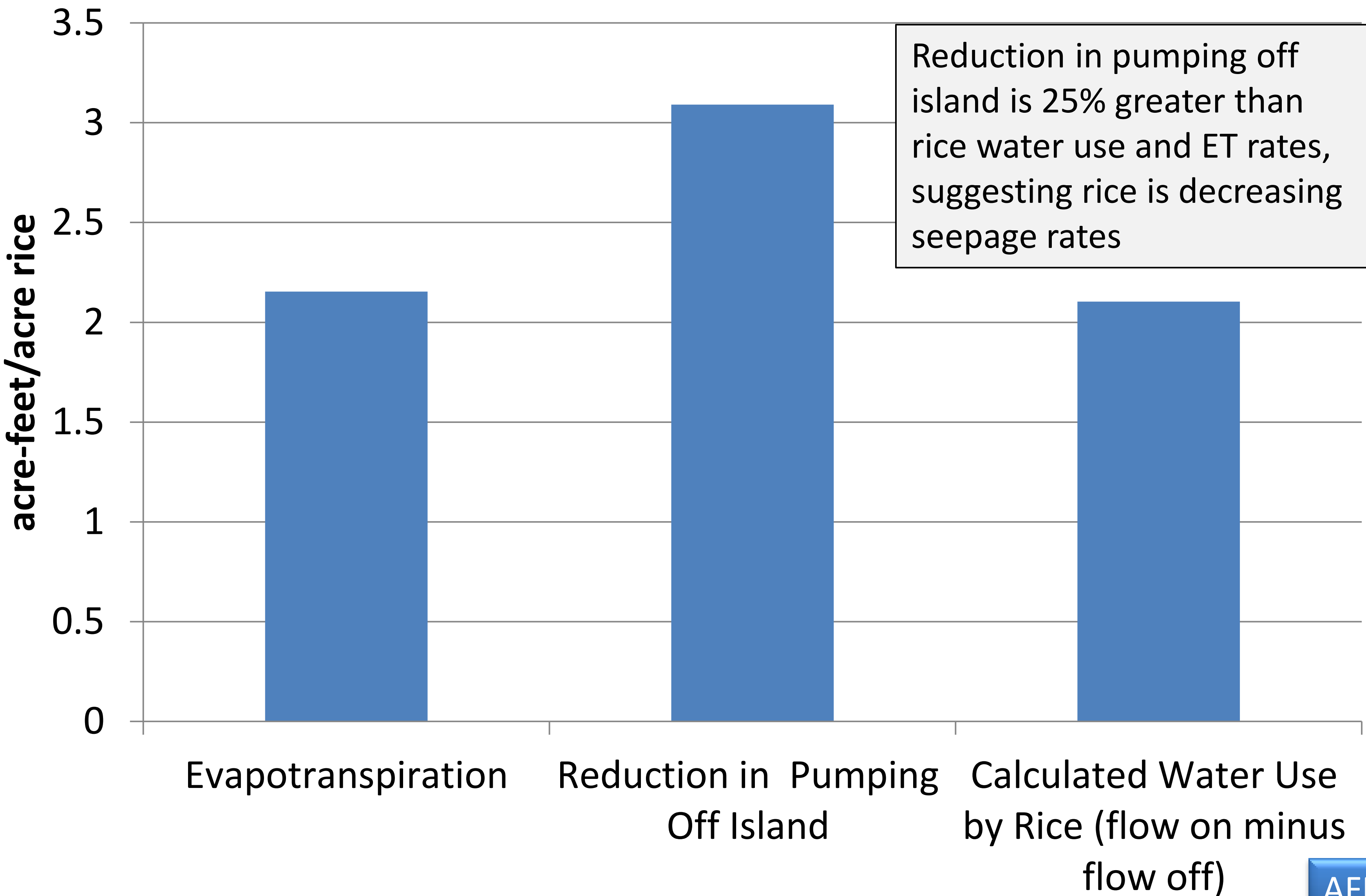
- Reuse Main Drain, Reduce Siphon Demand
- Provide constant sink for Main Drain Water
- Increase Island ET losses

AFRI



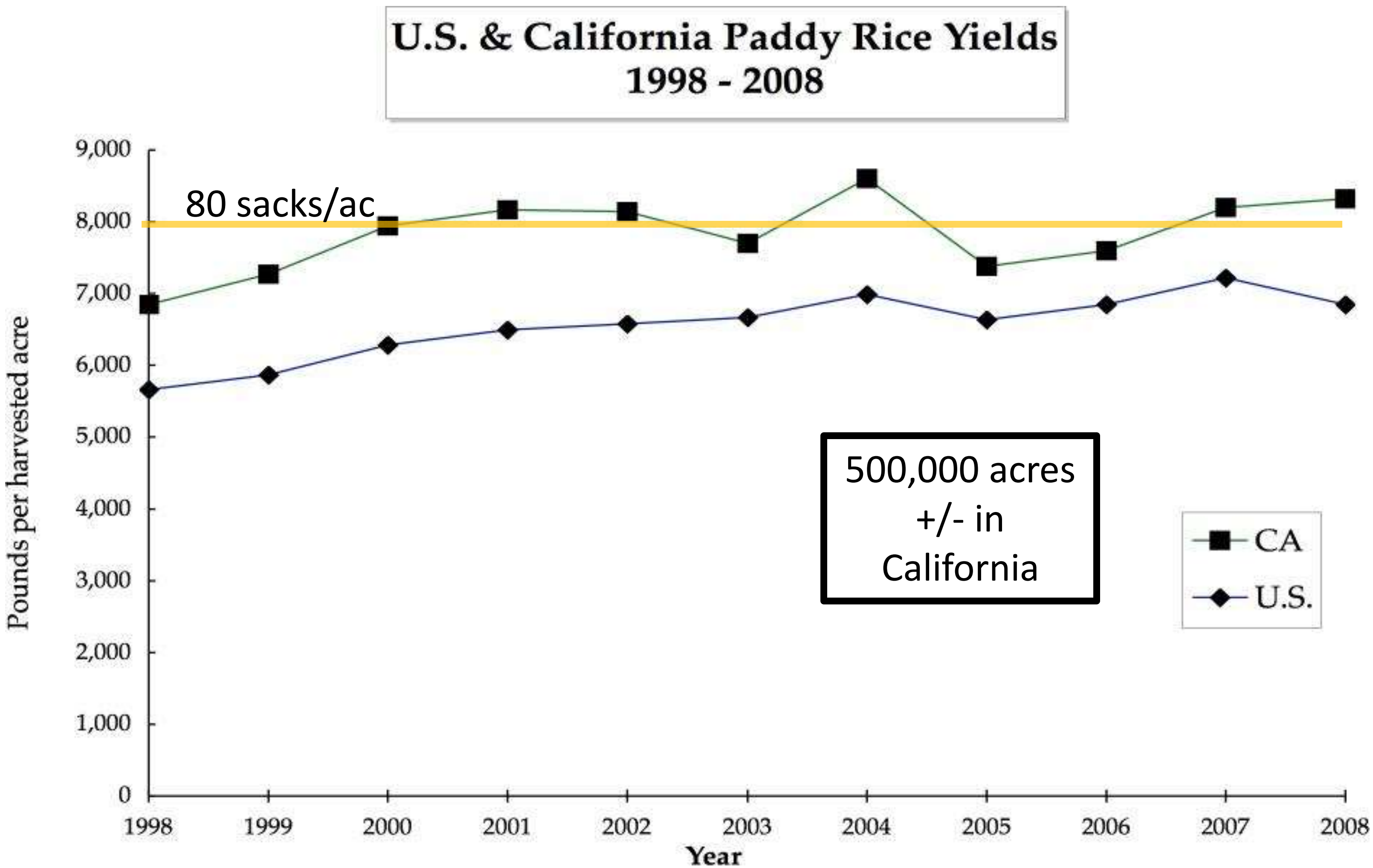
Total flows by year and season, complete seasons only
Not Summer (October 1 - May 31)
Summer (June 1 - September 31)
Pre-Rice
Rice
Total flow (ac-ft)
6000
4000
2000
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
Year
AFRI

Average water use per acre rice, June 1 to Sept 30 2009 - 2011

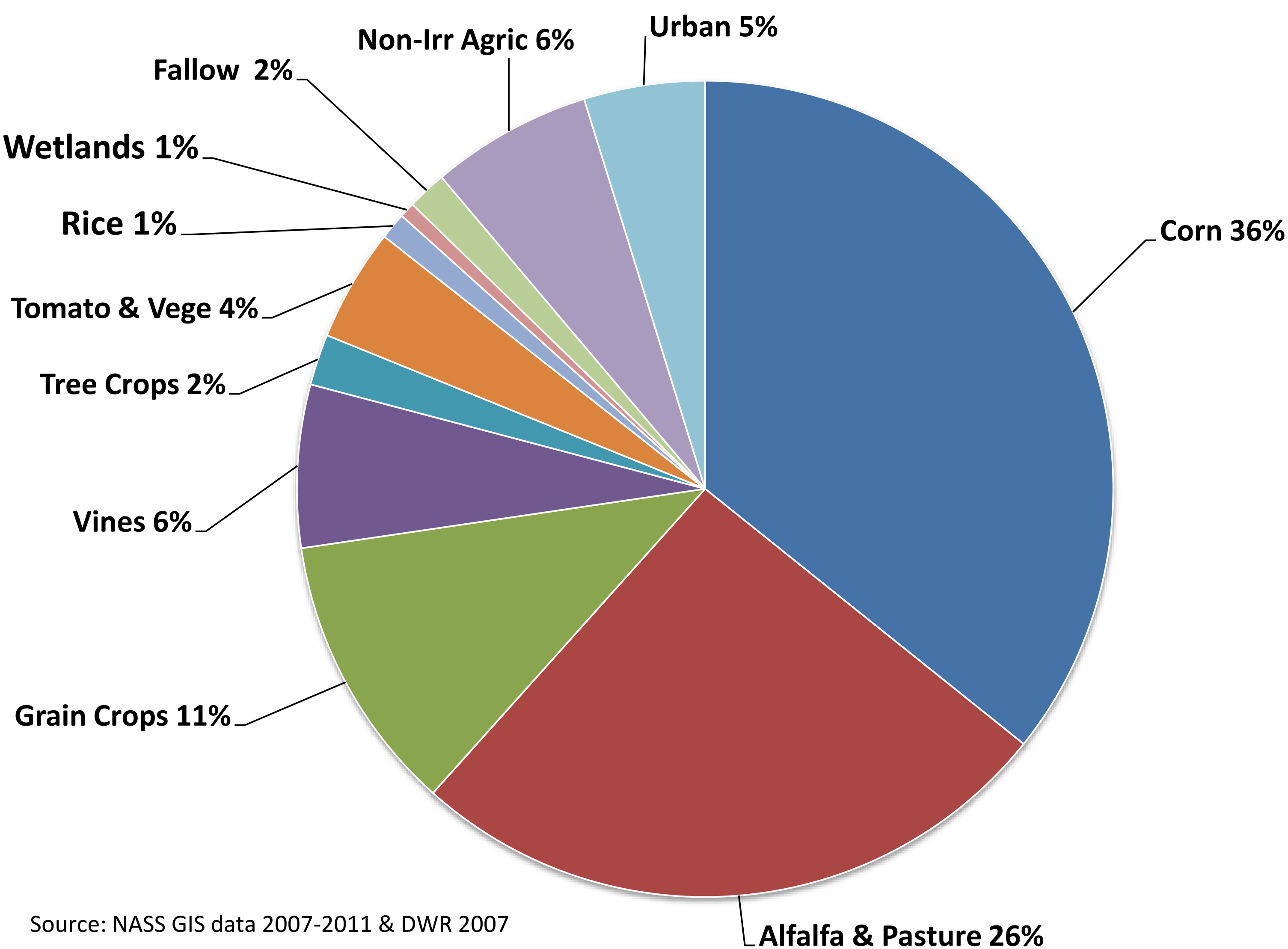


AFRI

U.S and California Paddy Rice Yields (CA Rice Commission, 2009)



Average Land Use in Primary Delta 2007-2012
Total Land Area is about 320,000 acres
(Butler and Zhou, 2012)



Source: NASS GIS data 2007-2011 & DWR 2007

AFRI

High Water Risks

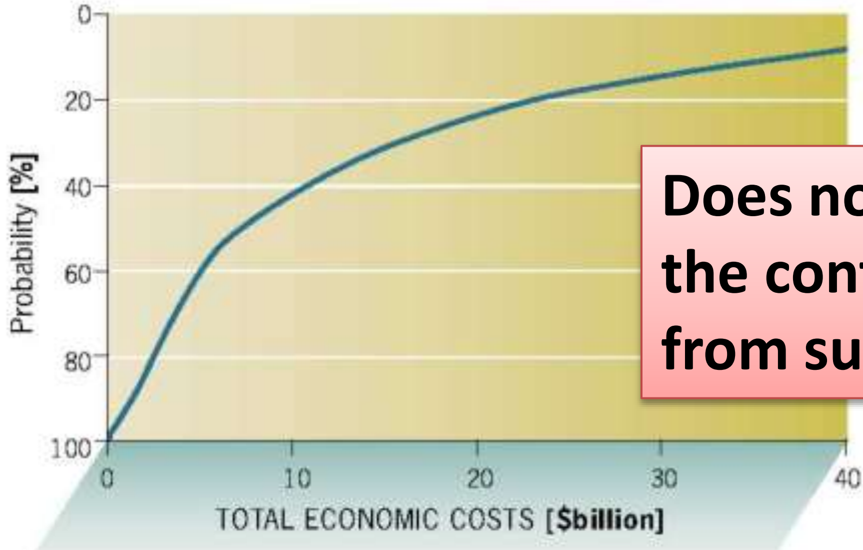


Figure 10a Probability of exceeding an amount in total economic costs due to high water-related levee failures over a 25-year period [2005-2030]

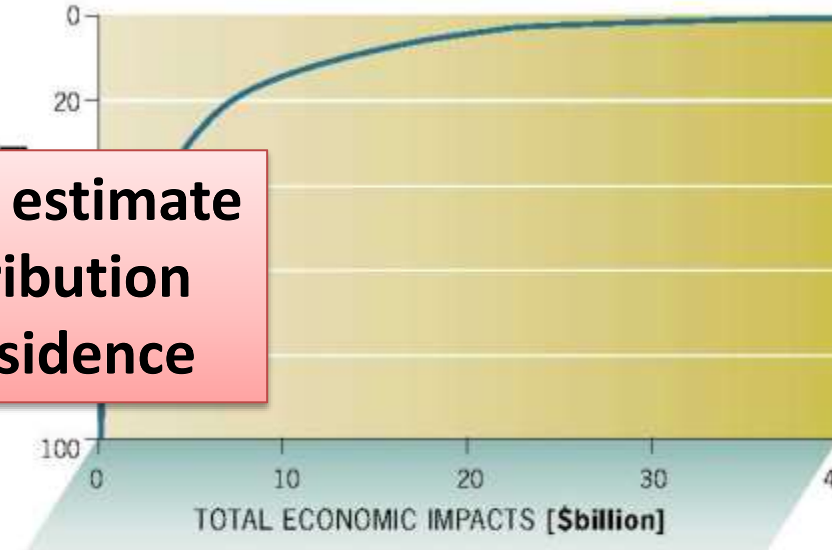


Figure 10b Probability of exceeding an amount in total economic impacts due to high water-related levee failures over a 25-year period [2005-2030]

Does not estimate the contribution from subsidence

Source: Adapted from DRMS Risk Report [URS/JBA 2008c], Figures 13-21a [costs] and 13-21b [impacts]

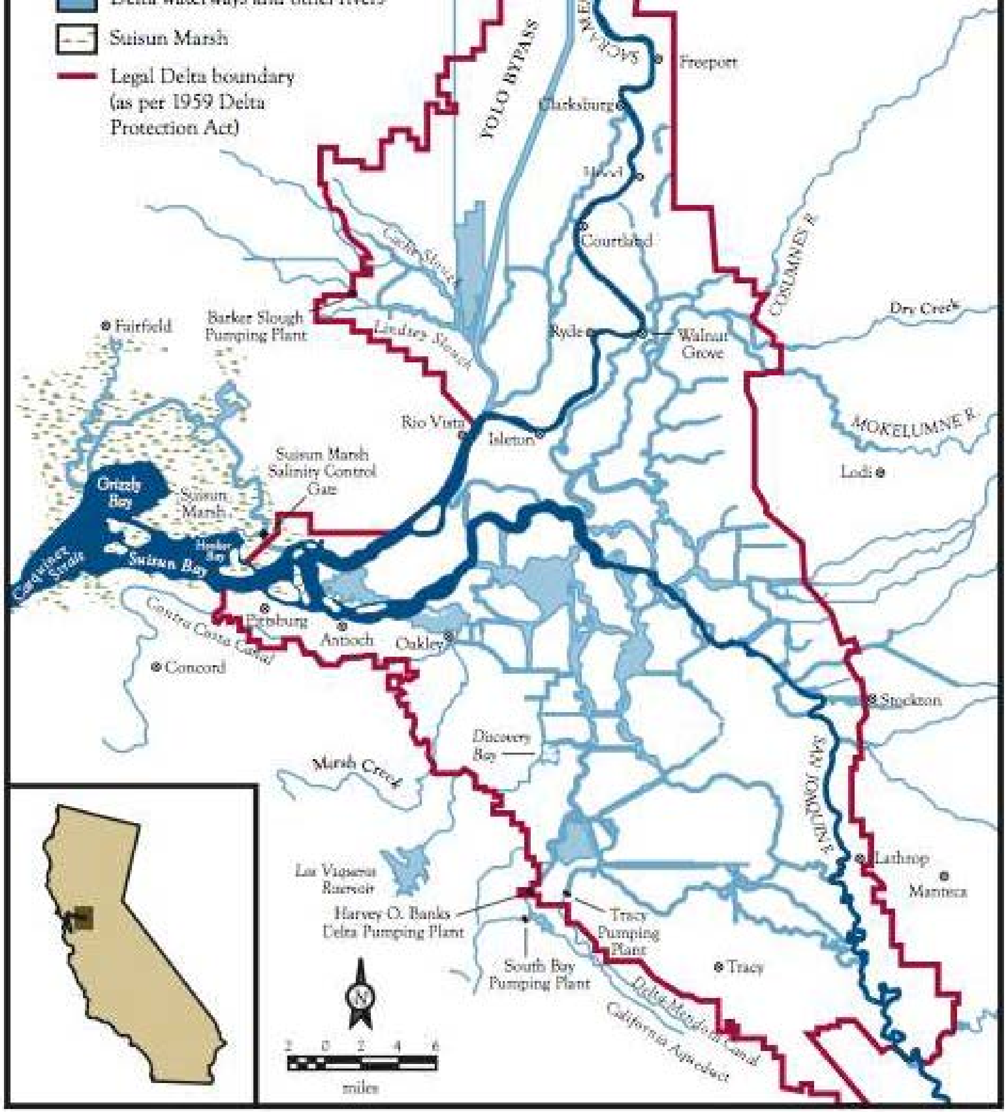
Economic Costs include the direct economic losses associated with the repair of levees, tracts, islands, and infrastructure; the replacement of lost homes and the payment of living expenses for displaced persons; agricultural losses; and the lost water supply to State and federal water contractors and local water districts.

Economic Impacts include the indirect economic losses associated with the loss of potential revenues because of services not provided. These include the loss of revenue that customers of Pacific Gas and Electric Company, Metropolitan Water District of Southern California, railroads and other service providers suffer because they lose the services these companies provide, combined with lost wages and jobs that result because consumers lose these services.

The Delta, Farming and Water

- 100 years of farming and water management has led to deep Delta with ***subsidence*** > 20 ft in some areas
- **Costs** are loss of ***ecosystem services*** and ***O&M costs*** borne by both farmers and by society:
  - Levees / water supply risks
  - GHG emissions
  - Increased energy costs to drain islands
  - Water quality impacts
  - Compromised habitat

Culture of Farming….
With Broad
Implications


Suisun Marsh
Legal Delta boundary (as per 1959 Delta Protection Act)
YOLO BYPASS
Freeport
Clarksburg
Courtland
COSUMNES R.
Dry Creek
Cache Slough
Barker Slough Pumping Plant
Lindsey Slough
Fairfield
Ryde
Walnut Grove
MOKELUMNE R.
Rio Vista
Isleton
Lodi
Suisun Marsh Salinity Control Gate
Grizzly Bay
Suisun Marsh
Suisun Bay
Carquinez Strait
Pittsburg
Antioch
Oakley
Contra Costa Canal
Concord
Stockton
Discovery Bay
Marsh Creek
SAN JOAQUIN R.
Lathrop
Manteca
Los Vaqueros Reservoir
Harvey O. Banks Delta Pumping Plant
Tracy Pumping Plant
Tracy
South Bay Pumping Plant
California Aqueduct
Delta-Mendota Canal
miles

AFRI Grant (2010 – 2016).

Team

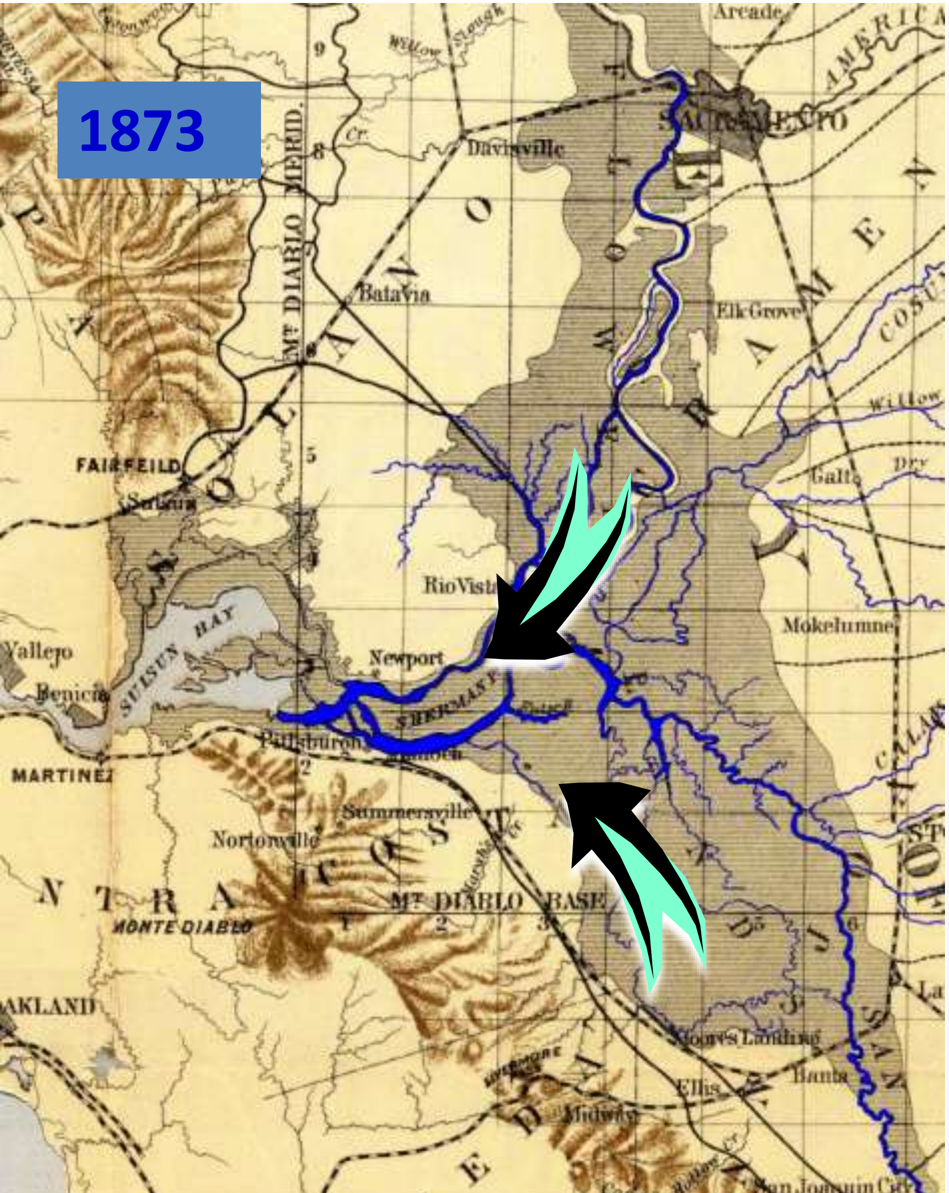
- University of California, Berkeley
  - Dennis Baldocchi (baldocchi@berkeley.edu) . PI - GHGs
  - Jaclyn Hatala (jhatala@berkeley.edu. GHGs
  - Sara Knox saraknox@berkeley.edu; GHGs
- University of California, Davis –
  - William Horwath (wrhorwath@ucdavis.edu). Project Director; GHG; Soils; Nutrients
  - Rongzhong Ye (rzye@ucdavis.edu); GHGs, Soils
  - Bruce Linquist (balinquist@ucdavis.edu). PI. Agronomy; BMPs; Nutrients
  - Emilie Kirk (erkirk@ucdavis.edu. Agronomy; BMPs; Nutrients.
  - Leslie Butler (ljbutler@ucdavis.edu; PI; Economics
  - Lucas Cr Silva (lcsilva@ucdavis.edu); GHGs; Soils
  - Matthew Espe (mespe@ucdavis.edu); Agronomy, BMPs, Nutrients
- United States Geological Survey
  - Jacob A Fleck (jafleck@usgs.gov). PI; Hg
- Tetra Tech, Inc.
  - Bachand, Sandra Sandra.Bachand@tetratech.com; Geotechnical, Hydrology, water quality, BMPs
  - Roy, Sujoy (Sujoy.Roy@tetratech.com); Water quality, Hydrology
  - Stern, Nicole <Nicole.Stern@tetratech.com>; Water quality, Hydrology
- Stillwater Sciences, Inc.
  - Amy Merrill (amy@stillwatersci.com). PI. regional and state scaling, policy
- Wetlands and Water Resources, Inc. / ESA
  - Stuart Siegel (stuart@swampthing.org). PI. regional and state scaling, policy
- Hydrofocus, Inc.
  - Steve Deverel (sdeverel@hydrofocus.com). PI. Hydrology, subsidence
- San Joaquin Cooperative Extension
  - Michelle Leinfelder-Miles Ph. D. (mmleinfeldermiles@ucanr.edu) . Agronomy, extension
- Delta Science Center
  - Roni Gehlke (festfan@comcast.net). Extension. educational outreach
- ERA Economics Modeling
  - Duncan MacEwan (duncan@eraecon.com); Economics

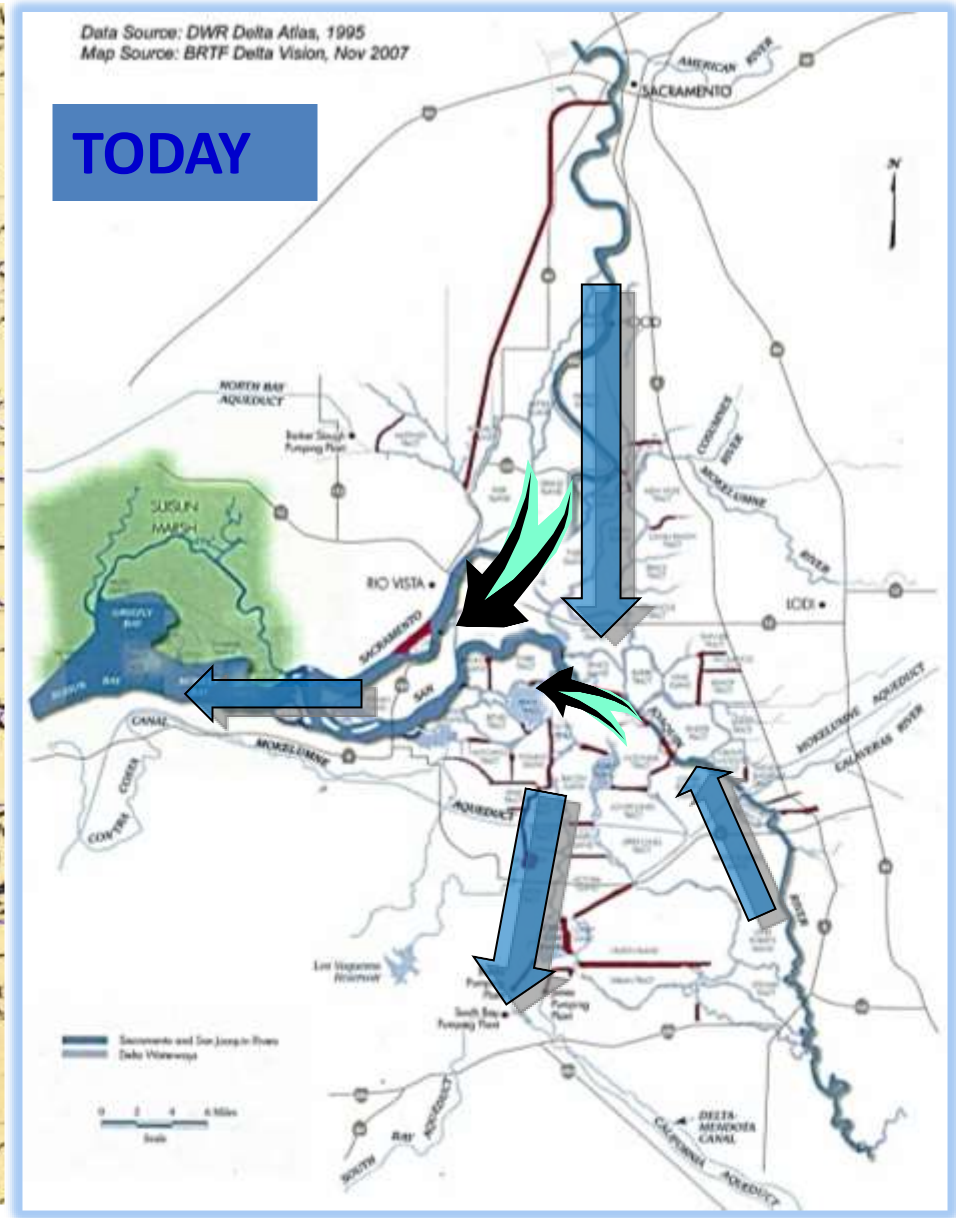
Estimating Subsidence Rates in the Delta

	Elevation Change		Reference	Method
	mm/yr	Ft/50-years		
Corn				
	-12	-2.0	Deverel et al 2013	
	-22	-3.6	Deverel and Leighton, 2010	
	Average	**-2.8**		
Peatlands				
	-1.5 to - 2.6	-0.3	Hatala et al 2012	
	-4.6	-0.8	Deverel and Rojstaczer, 1996	
	-5 to -20	0.0	Deverel and Leighton, 2010	
	Average	**-0.4**		
Rice				
	-1 to -1.4	-0.2	Hatala et al 2012	GHG
	4	0.7	Deverel et al 2013	Direct Measurement
	-3	-0.5	Kirk et al 2013	N budget
	Average	**0.0**		

AFRI

Conveyance and Exports



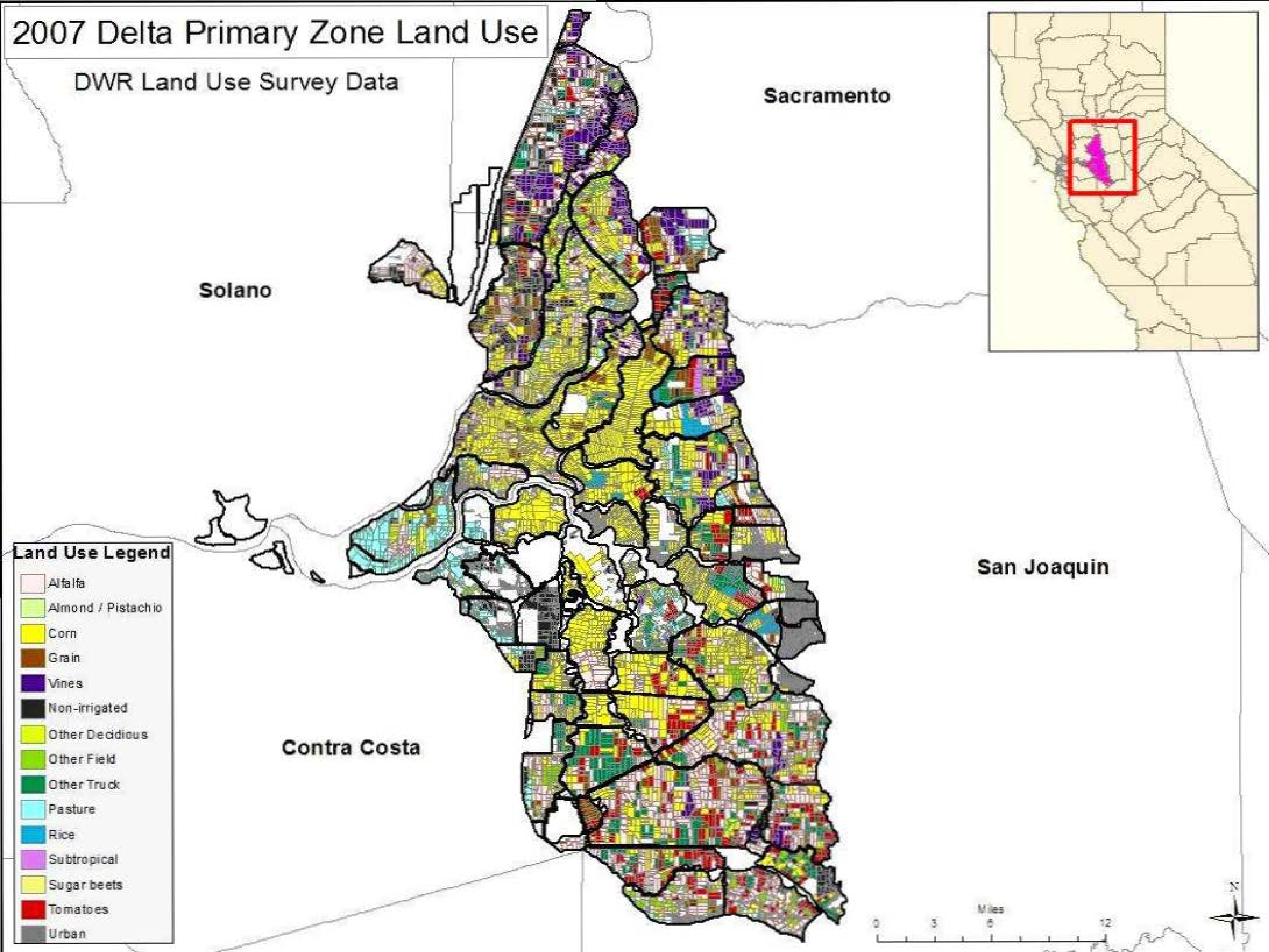


California Economy

- To California:
  - Drinking Water
    - Provides Drinking Water to 22M Californians
      - $3.6B billed by water agencies to households annually
  - Irrigation Water to 2.75M acres outside the Delta
    - Increases land values by about $24B
    - San Joaquin Valley – Ag production and processing 36B annually
  - Dependence upon within Delta Infrastructure
    - Highways, electrical grid, gas, etc….

>$60B

AFRI


2007 Delta Primary Zone Land Use
DWR Land Use Survey Data
Sacramento
Solano
San Joaquin
Contra Costa
Land Use Legend
Alfalfa
Almond / Pistachio
Corn
Grain
Vines
Non-irrigated
Other Decidious
Other Field
Other Truck
Pasture
Rice
Subtropical
Sugar beets
Tomatoes
Urban
Miles
0
3
6
12
N

The AFRI Project:
Rice as a Potential Delta Solution

1. *Large-scale & strategic distribution of rice in the Delta to decrease subsidence and protect CA water supply*

2. *Maximize local, regional and state values:*
    a. *Water Resources*
    b. *Agronomics*
    c. *GHG emissions*
    d. *Water Quality*

AFRI Grant Team (2010 – 2016)

- University of California, Berkeley: **Dennis Baldocchi,** Jaclyn Hatala and Sara Knox
- University of California, Davis:
  - **William Horwath,** Rongzhong Ye, Lucas Silva, Jennifer Morris, Yacov Assa
  - **Bruce Linquist,** Emilie Kirk and Matt Espe
  - **Leslie Butler,** Andrea Brock, Paul Jacobs
- ERA Economics Modeling: Duncan MacEwan
- United States Geological Survey: **Jacob A Fleck**
- Tetra Tech, Inc.: **Philip Bachand,** Sandra Bachand, Sujoy Roy, Nicole Stern
- Stillwater Sciences, Inc.: **Amy Merrill**
- Wetlands and Water Resources, Inc. / ESA: **Stuart Siegel**
- Hydrofocus, Inc.: **Steve Deverel**
- San Joaquin Cooperative Extension: Michelle Leinfelder-Miles
- Delta Science Center: Roni Gehlke
- Hultgren – Tillis Engineers: Kevin Tillis