ESTIMATION OF TOTAL MAXIMUM DAILY LOAD (TMDL) IN AGRICULTURAL WATERSHEDS USING A COMBINED CONTINUOUS AND PERIODIC SAMPLING APPROACH

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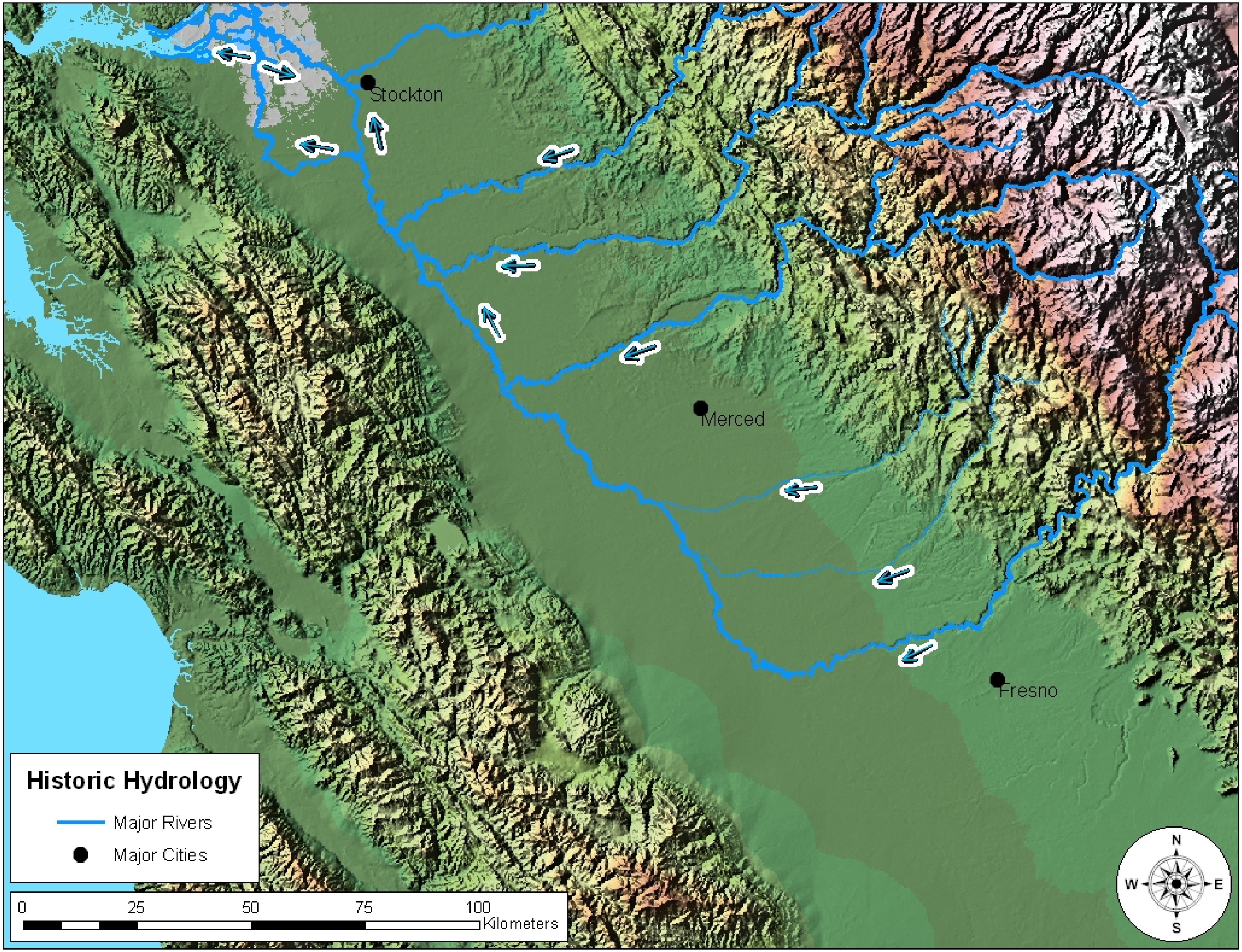
Outline

- **Engineered agricultural ecosystems**
  - TMDLs being applied
  - San Joaquin Valley of California, USA
- **Direct estimation of pollutant loads from watersheds**
  - Total dissolved solids (TDS) as a model
  - Estimation methods for artificial systems
  - Mass load calculations

- Second largest river in California
- Length: 530 km (330 miles)
- Basin area: 83,000 km^2 (32,000 $miles^2$)
- Source elevation: 3,354 m (11,004 feet)


Stockton
Merced
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Historic Hydrology
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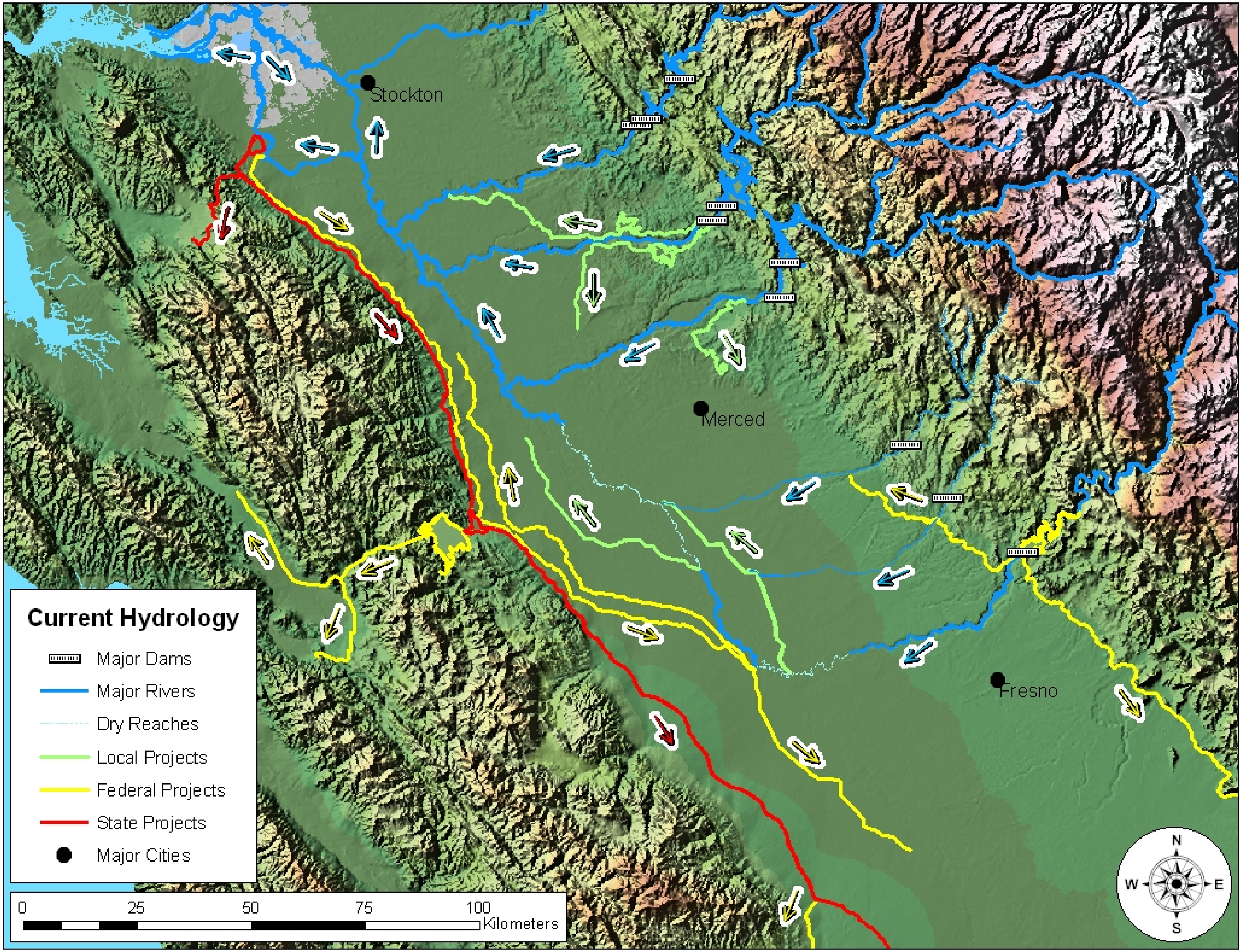
Stockton
Merced
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Current Hydrology
Major Dams
Major Rivers
Dry Reaches
Local Projects
Federal Projects
State Projects
Major Cities
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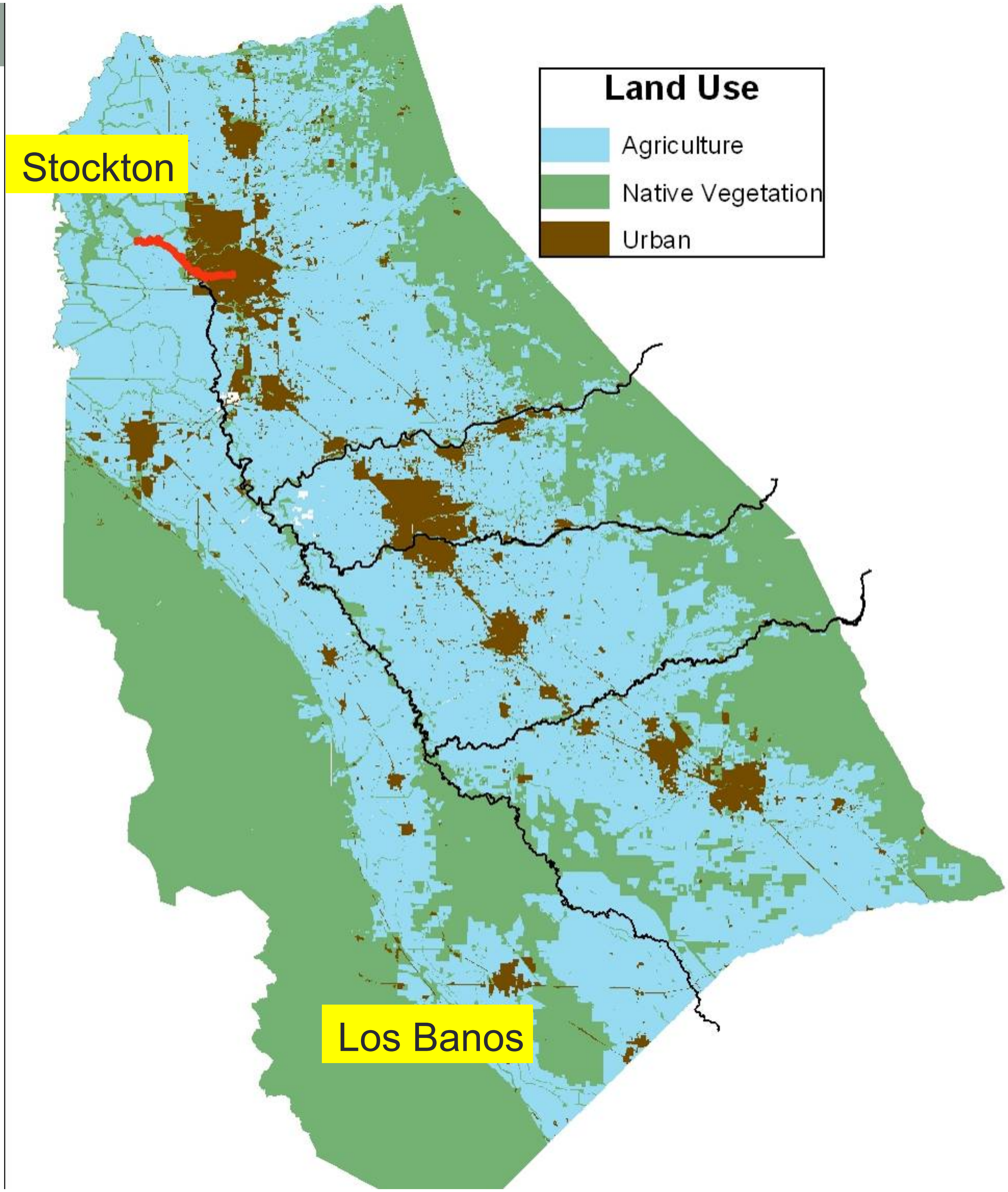
TMDL

- Salts
  - Selenium
  - Boron
  - Nitrate
- Pesticides
- Low dissolved oxygen
- Mercury



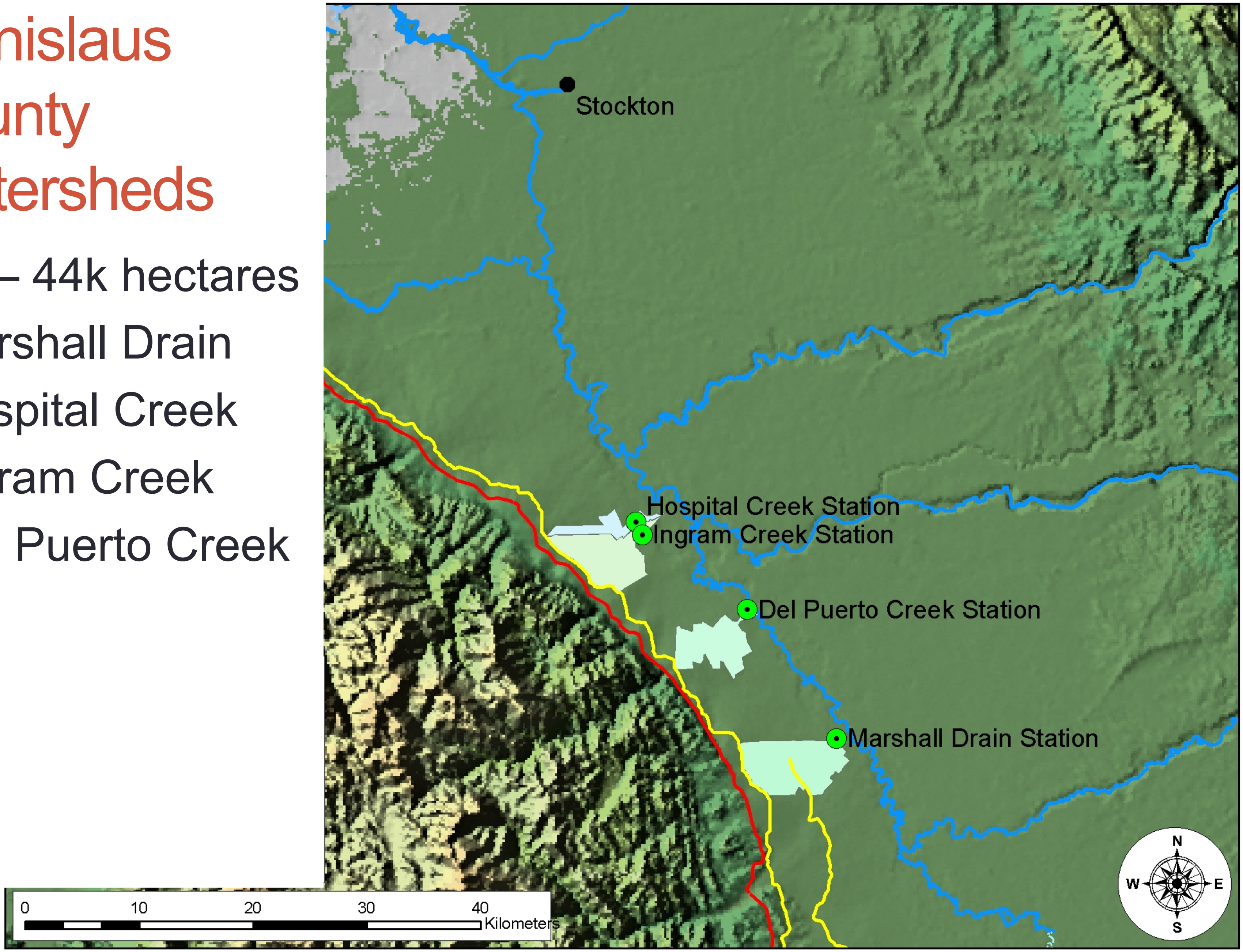
Objectives

- Develop methods for estimating pollutant loads in agro-ecosystems, using grab sample data
  - Artificial system has non-normal data distribution
  - Using TDS as a model pollutant
  - TDS can be measured continuously, therefore true-load is known

- Compare load estimates using grab sample measurements to true-loads determined using continuous flow and TDS measurements
  - Develop methods for non-normal distributions
  - Apply to pollutants that can not be measured continuously

Stanislaus County Watersheds

- 1k – 44k hectares
- Marshall Drain
- Hospital Creek
- Ingram Creek
- Del Puerto Creek



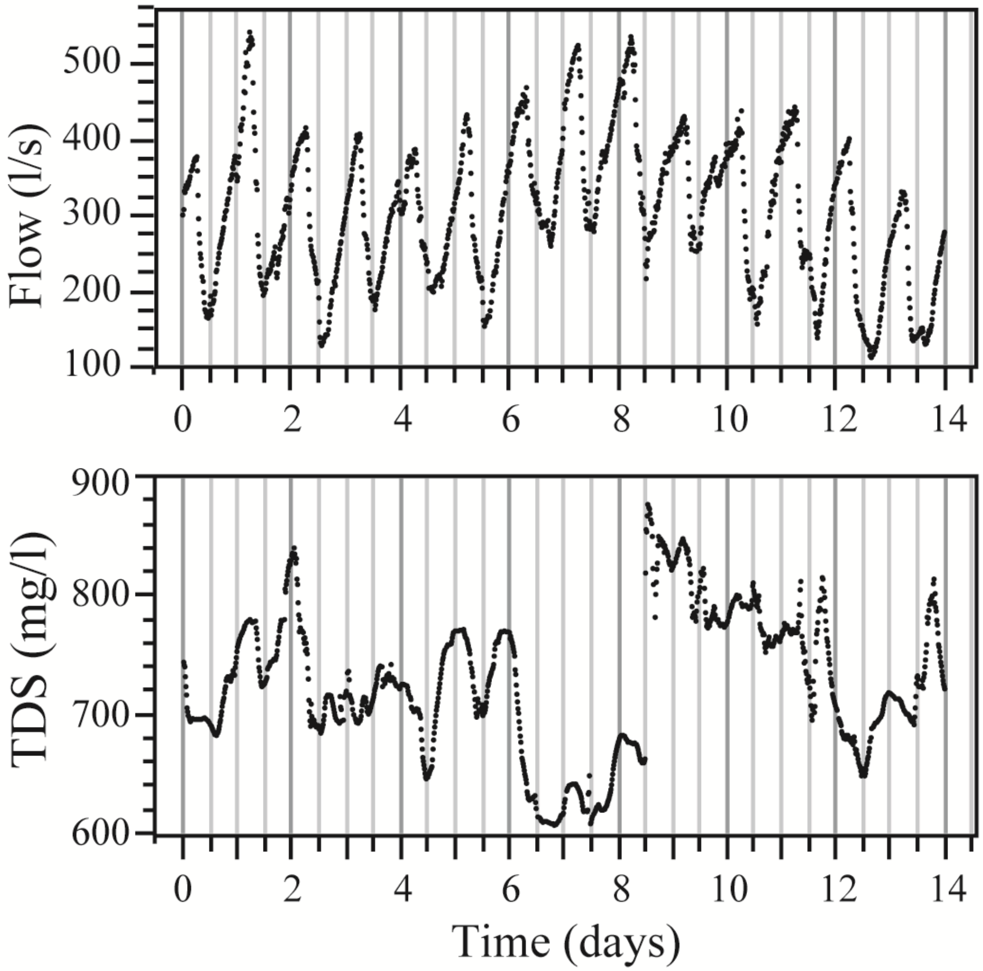
Sampling Strategy

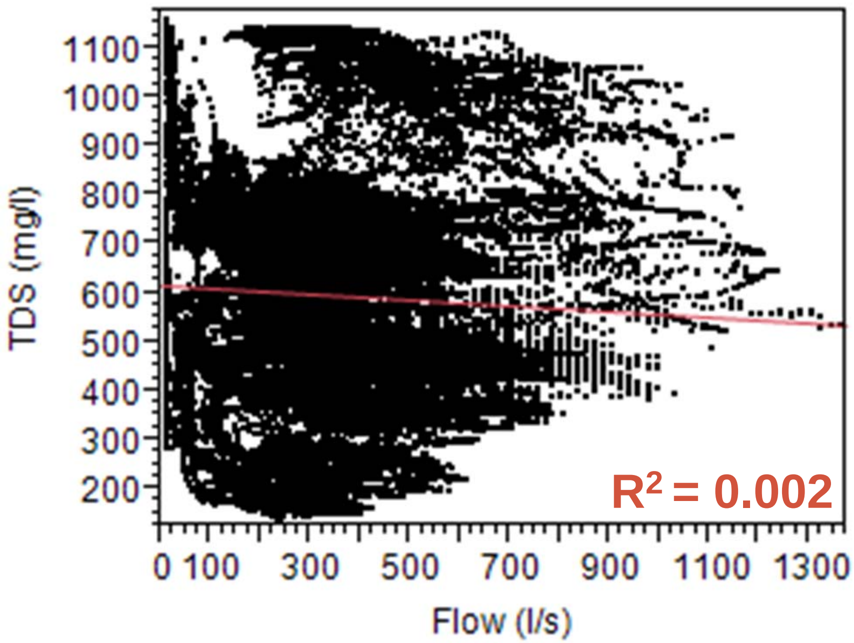
- Irrigation season
  - April 1 to Sept 30
- Field (grab) sampling
  - EC: Sondes (temp-compensated)
  - Flow: Velocity sensors
- Continuous monitoring
  - EC: Sondes (temp-compensated)
  - Flow: Bubblers and data loggers for measuring stage

TDS [mg/l] = 0.64*(YSI EC [µS/cm])

Correlation between TDS & flow

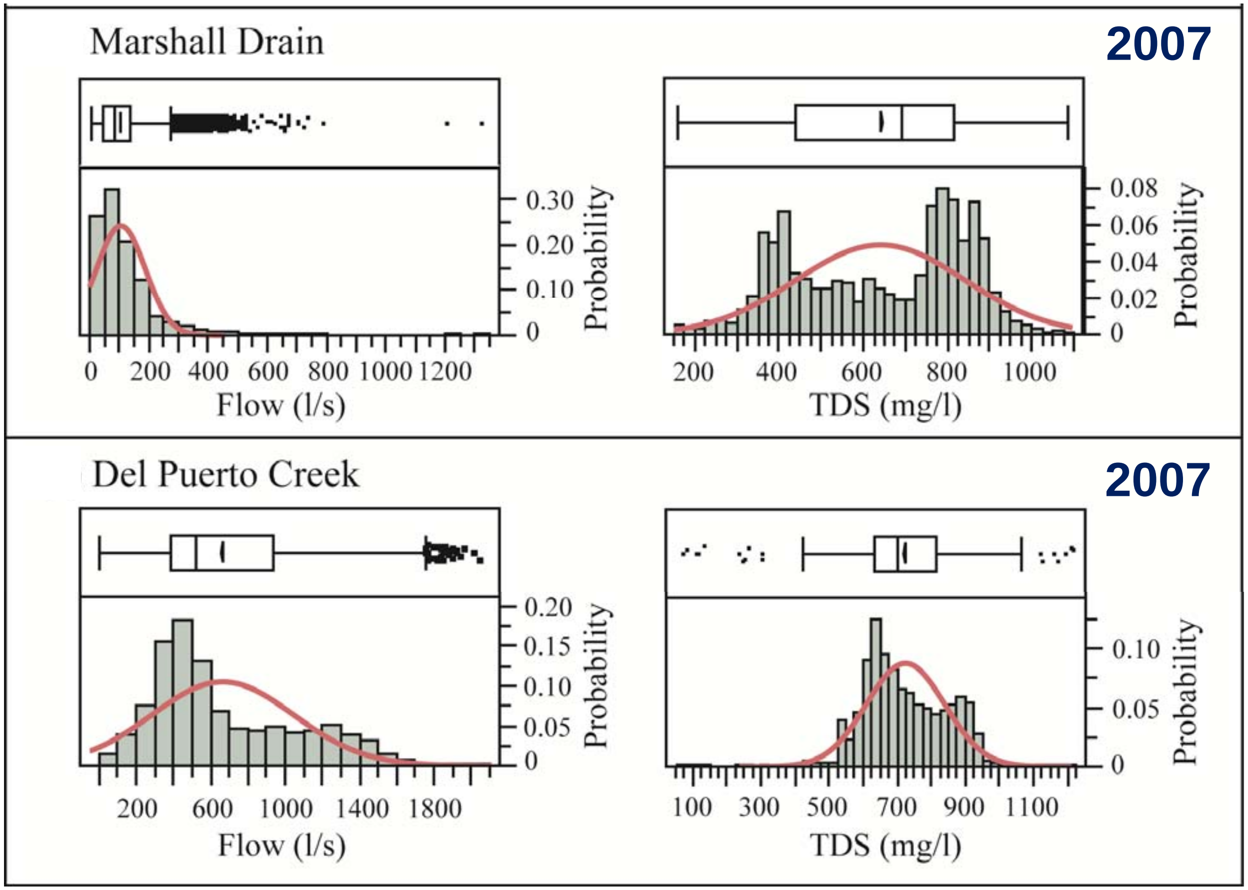
Ingram Creek from April 5 to 18, 2007
15 minute time increments



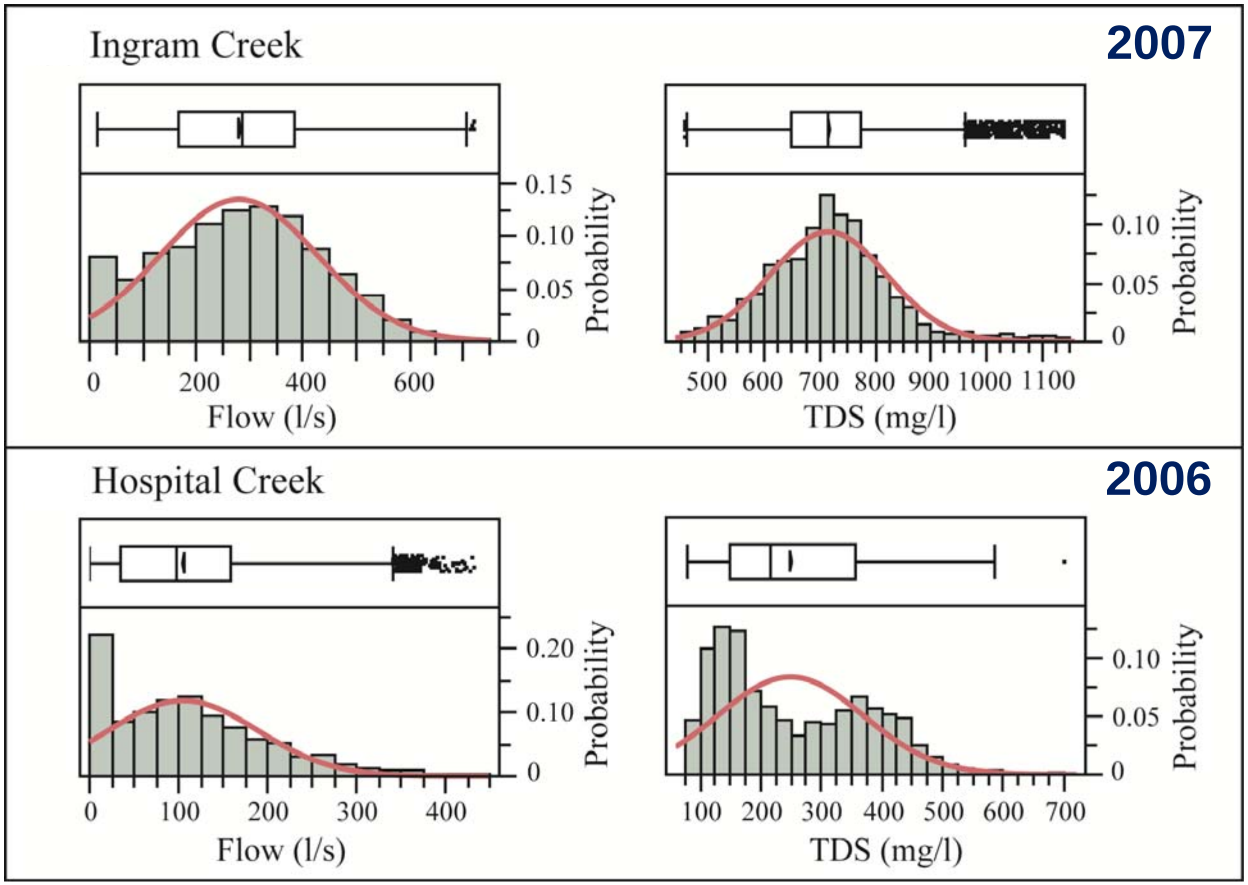


Cannot use a regression model like LOADEST

Flow and TDS histograms during the irrigation season



Flow and TDS Histograms during the irrigation season



Continuous and Grab sampling

	Del Puerto Creek	Hospital Creek	Ingram Creek	Marshall Drain
Irrigation year	2007	2006	2007	2007
Sampling start date	April 7	April 27	April 7	May 10
Sampling end date	Sept 19	Sept 27	Sept 19	July 11
Number of grab samples, *n*	12	10	12	3
Number of continuous samples, N	16,128	14,784	16,128	6,048
Grab sampling frequency	Fixed period, biweekly sampling			Biweekly to monthly

- Can grab sampling measurements be used to estimate TMDLs in watersheds that have non-Normal distributions and no correlation between water quality and flow?
- Do we need continuous flow measurement?

True-load calculation

- Integration method

$$\text{Load}[\text{mass}] = \sum_{i=1}^{N} C_i Q_i \Delta t_i$$

  - C_i = the concentration of sample *i* [mass/volume]
  - Q_i = the flow rate at the time of sample *i* [volume/time]
  - Δt_i = 15 min = the time between consecutive measurements
  - N = number of continuous measurement samples

Grab sampling load estimation

$$\text{Load}_{\text{Grab}}\,[\text{mass}] = \sum_{k=1}^{n} C_k \hat{Q}_k \Delta t_k$$

- C_k = the concentration of sample k [mass/volume]
- Δt_k = the time between grab samples
- n = number of grab samples

- Median-load: $\hat{Q}_k$ = median flow over sampling interval
- Mean-load: $\hat{Q}_k$ = mean flow over sampling interval
- Daily-load: $\hat{Q}_k$ = mean flow over sampling day
- Instantaneous-load: $\hat{Q}_k$ = flow at the time of sampling

Load estimation – past studies

Past Work	Load estimation	Description	Magnitude of % error
Kratzer et al.(2011)	LOADEST	• C_k and Q_k well correlated	30-50%
Domagalski et al.(2008)	LOADEST & sum of storm loads	• C_k and Q_k well correlated • storms in wet season in SJR	Not reported
Fogle et al.(2003)	Instant.-load, Daily-load* & Flow volume	• diurnal fluctuations • periodic grab samples	1-37% (biweekly)
Henjum et al. (2010)	Daily-load & Mean-load	• diurnal fluctuations • periodic grab samples • C_k normally distributed • C_k and Q_k uncorrelated	25-170% & 5-200% (biweekly)
Gulati et al.	Median-load	-- diurnal fluctuations -- periodic grab samples --C_k non-normally distributed -- C_k and Q_k uncorrelated	?

*Close variant to method in this study

Mass load calculations

$$\% \text{ error} = 100 * \left(\frac{\text{load estimate} - \text{'true' load}}{\text{'true' load}} \right)$$

Site	n	Start Date	End Date	True-load	Grab sampling			
					Mean	Median	Instant.	Daily
Del Puerto Creek	12	04/05/07	09/19/07					
Total load (kg)				6,419,619				
% error				-				
Hospital Creek	10	04/27/06	09/27/06					
Total load (kg)				449,383				
% error				-				
Ingram Creek	12	04/05/07	09/19/07					
Total load (kg)				2,955,359				
% error				-				
Marshall Drain	3	05/10/07	07/11/07					
Total load (kg)				357,129				
% error				-				

Summary

- Median-load method agrees with true-load for agricultural watersheds
  - Agrees with mean-load method in most watersheds
  - Better estimate than mean-load in non-normal or infrequently sampled systems
  - Median-load calculation is robust and widely applicable for TMDL applications

- Instantaneous-flow and daily-flow dependent methods poorly estimate true-loads
  - Continuous flow monitoring highly recommended

Acknowledgements

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- San Joaquin River Group Authority
- US Fish & Wildlife Service
- CA Department of Fish & Game
- State Water Resources Control Board

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Mass load calculations

$$\% \text{ error} = 100 * \left(\frac{\text{load estimate} - \text{'true' load}}{\text{'true' load}} \right)$$

Site	n	Start Date	End Date	True-load	Grab sampling			
					Mean	Median	Instant.	Daily
Del Puerto Creek	12	04/05/07	09/19/07					
Total load (kg)				6,419,619	6,708,944	6,776,072	7,553,111	4,110,797
% error				-	4.5	5.6	17.7	-36.0
Hospital Creek	10	04/27/06	09/27/06					
Total load (kg)				449,383	460,665	426,331	384,685	518,524
% error				-	2.5	-5.1	-14.4	15.4
Ingram Creek	12	04/05/07	09/19/07					
Total load (kg)				2,955,359	3,020,627	2,977,851	2,544,750	3,114,532
% error				-	2.2	0.8	-13.9	5.4
Marshall Drain	3	05/10/07	07/11/07					
Total load (kg)				357,129	472,327	341,250	432,588	492,692
% error				-	32.3	-4.4	20.7	37.4