Modeling pesticide transport and BMP implementation in the San Joaquin Valley

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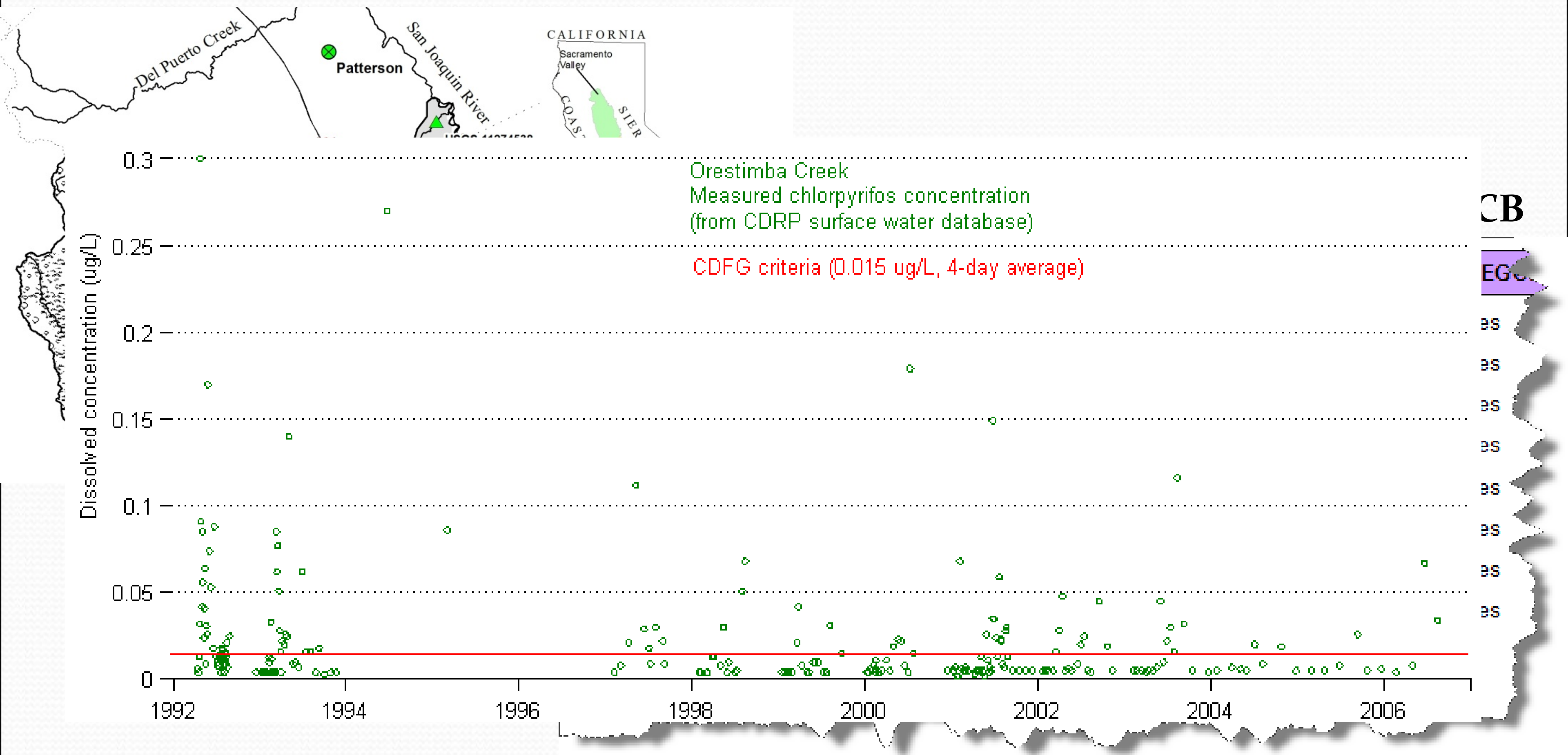
Background and objectives

- **Contamination of pesticides in water and sediment**



Background and objectives

- Contamination of pesticides in water and sediment
- **Best Management Practices (BMPs)**

[1] Preventative BMPs (pesticide management; application management; re-formulation)

[2] Mitigative BMPs:

Grassed waterways

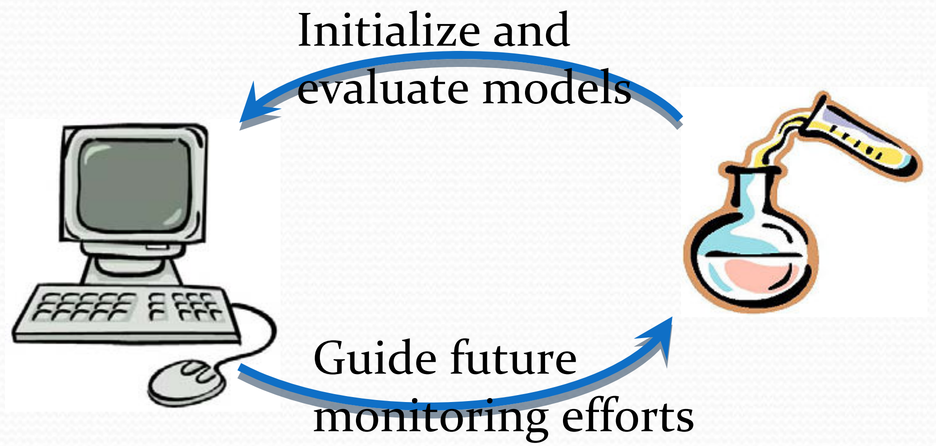
Mixed annual cover crop

Tailwater pond

Riparian buffer

Background and objectives

- Contamination of pesticides in water and sediment
- Best Management Practices (BMPs)
- **Modeling vs. monitoring**
  - Continuous predictions
  - Not limited by site locations
  - Key processes/parameters
  - Scenario analysis



Background and objectives

- Contamination of pesticides in water and sediment
- Best Management Practices (BMPs)
- Modeling vs. monitoring
- **Modeling of pesticide transport and mitigation effectiveness**

- EPA handbook for developing watershed plans

Model development

ArcGIS/ArcObjects	Transport simulation	Evaluation system
▪ Spatial framework ▪ Geo-database development ▪ Spatial analysis ▪ Input preparation ▪ Output visualization ▪ Web-GIS	▪ SWAT model (USDA) ▪ PRZM model (USEPA) ▪ Hydrology simulation ▪ Pesticide transport ▪ Management practices ▪ Weather generation ▪ Plant growth	▪ Statistical evaluation ▪ Stochastic simulation ▪ Model calibration ▪ Model validation ▪ Uncertainty and sensitivity analysis ▪ Scenario analysis

Modeling studies

	Watershed model ▪ Model development ▪ Model evaluation	**Field-scale model** ▪ Linear routing ▪ Eco-system risk analysis
Structural BMPs ▪ Model sensitivity ▪ BMP representation	**Human health risk** ▪ Cumulative risk analysis for 13 OPs	**IPM** ▪ Integrated pesticide management
Climate change ▪ Hydrology ▪ Agricultural runoff	**Soil property** ▪ Soil data processing ▪ Impact on model performance	**Scaling effects** ▪ Spatial delineation ▪ Impact on model performance

Acknowledgement

- California Water Quality Control Board
- Coalition for Urban/Rural Environmental Stewardship (CURES)
- California Department of Pesticide Regulation
- Prof. Minghua Zhang and other colleagues in the AGIS lab @ UCD

Section I: Model Development

Develop a modeling environment for pesticide transport simulation in the San Joaquin Valley

[1] SWAT description

[2] Model settings for the San Joaquin Valley

[3] Model evaluation

[4] Model simulation results

Section II: Management implications

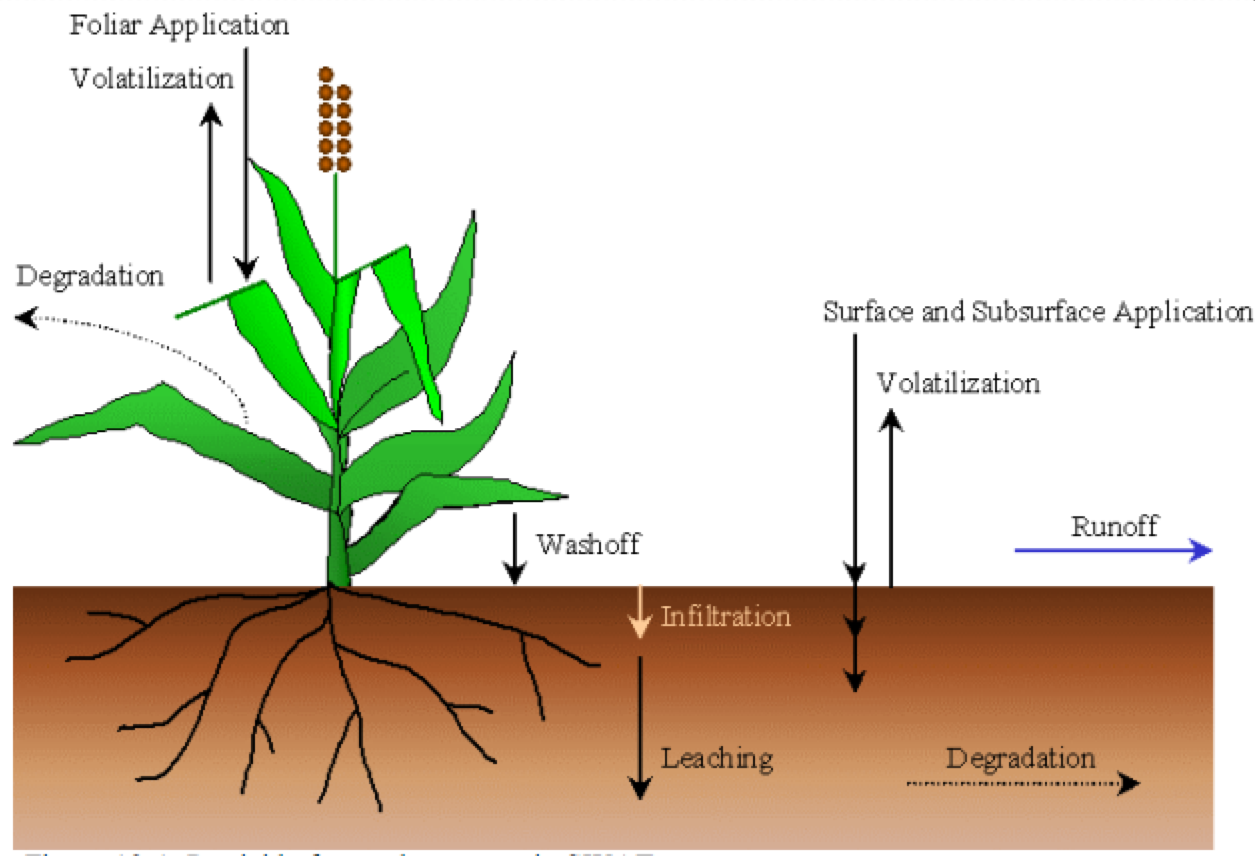
Apply the calibrated model for evaluating management practices

SWAT model

- Soil and Water Assessment Tool, is a surface hydrology and water quality model
- Developed to quantify the impact of land management practices on water quality at large and complex watersheds
- Model inputs: weather, land use, soil, stream network, management (fertilizer, pesticide…)
- Model outputs: stream flow, concentrations of sediment, nutrients, pesticides

Pesticide simulation in SWAT

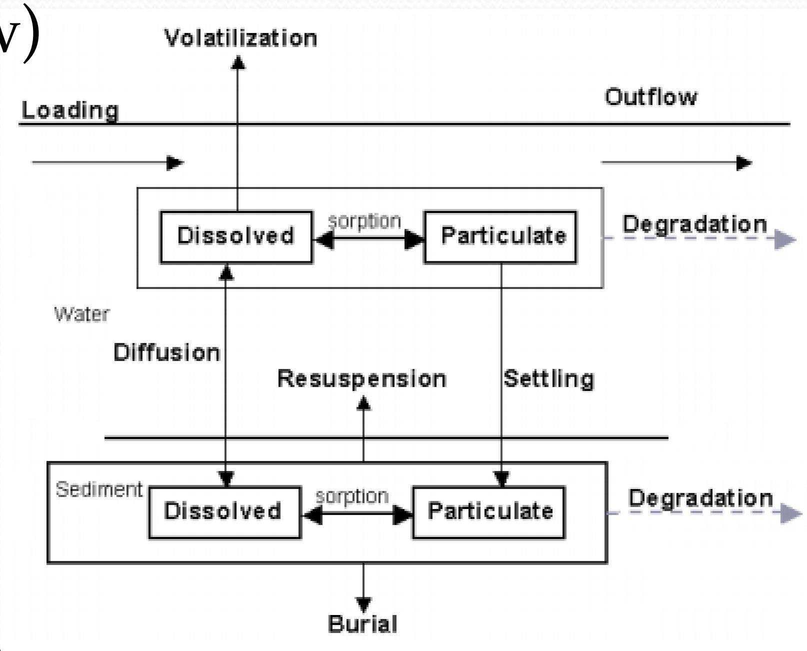
- "**Land phase**": **pesticide transport at field scale, to estimate pesticide outputs from a landscape unit**
- "Water phase"



"Land phase" simulation of pesticide (Neitsch et al., 2005)

Pesticide simulation in SWAT

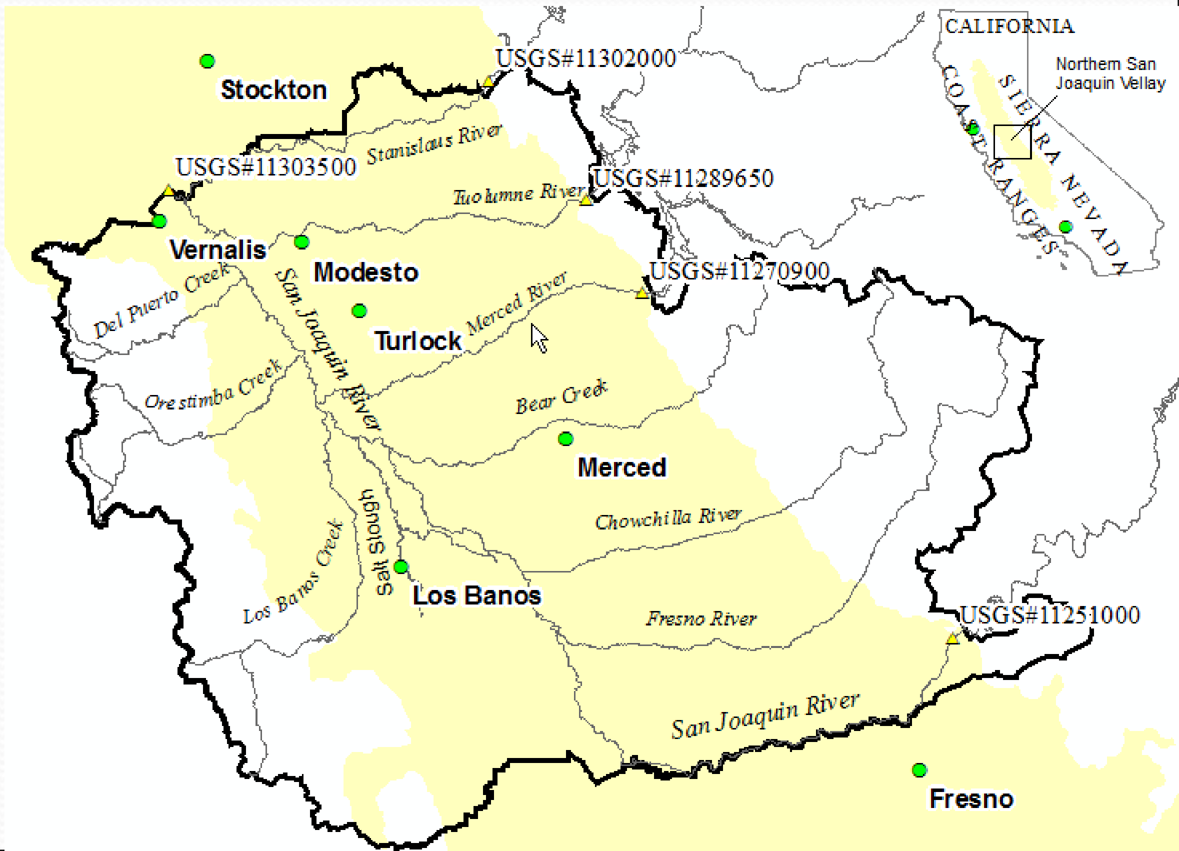
- “Land phase”
- “**Water/routing phase**”: **pesticide transport in stream network, to route pesticide fluxes to a downstream site (e.g., watershed outlet)**
  - Convective movement (outflow)
  - Solid-liquid partitioning
  - Degradation
  - Volatilization
  - Diffusion
  - Settling/resuspension/burial



Landscape characterization

- **Simulation domain**

  Northern San Joaquin Valley watershed



Landscape characterization

- Simulation domain
- **Watershed delineation**

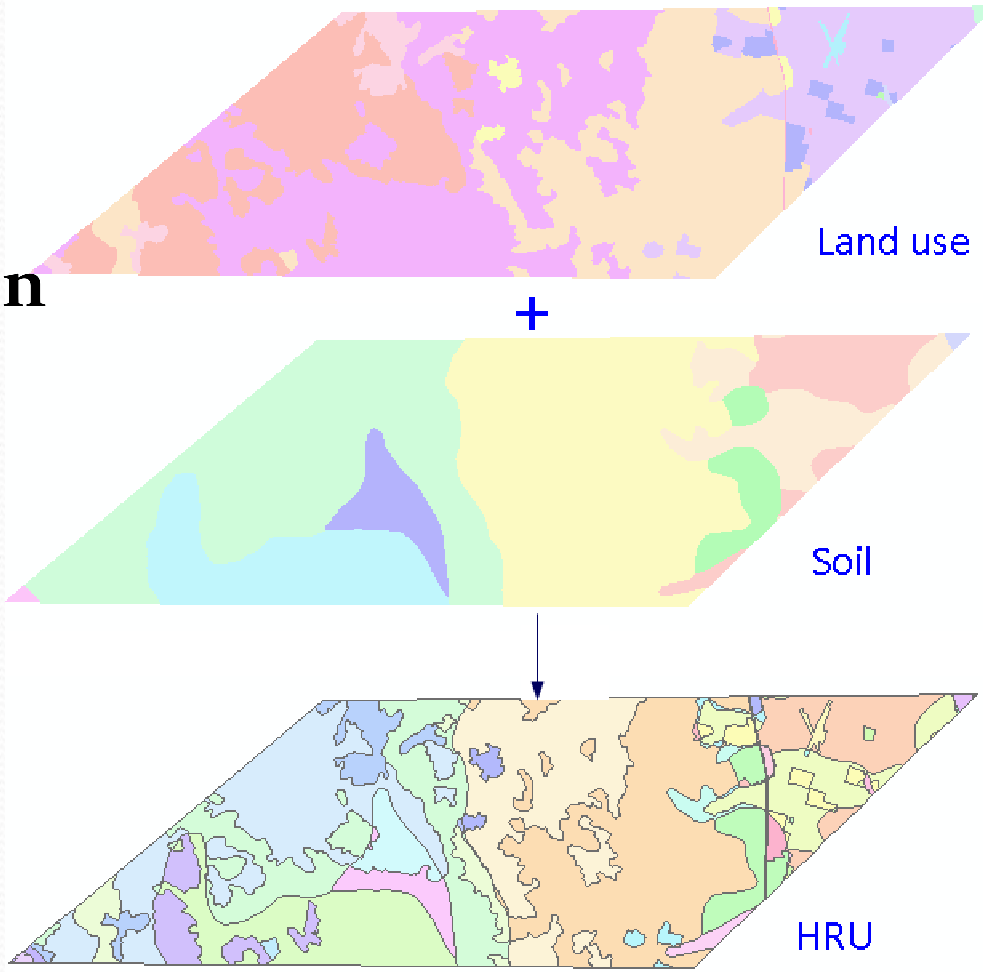
  15 sub-basins (by CVRWQCB)

ID	Name	Areas (km^2)	
		Total	Cropland
1	Vernalis North	23.4	18.2
2	Stanislaus River	569.7	303.6
3	Hospital Creek and Ingram Creek	392.3	115.2
4	Tuolumne River	992.7	261.1
5	Del Puerto Creek	382.4	87.9
6	Northeast Bank	317.8	252.1
7	Spanish Grant Drain	201.8	101.4
8	Turlock Area	459.5	388.0
9	Orestimba Creek	563.2	146.2
10	Stevenson	113.9	85.4
11	West Grassland Basin	1551.1	296.5
12	Merced River	834.0	466.9
13	Bear Creek	2200.2	649.4
14	Salt Slough	2009.7	1075.0
15	Chowchilla & Fresno River	4364.3	1809.6

Landscape characterization

- Simulation domain
- Watershed delineation
- **Hydrologic Response Unit (HRU) distribution**

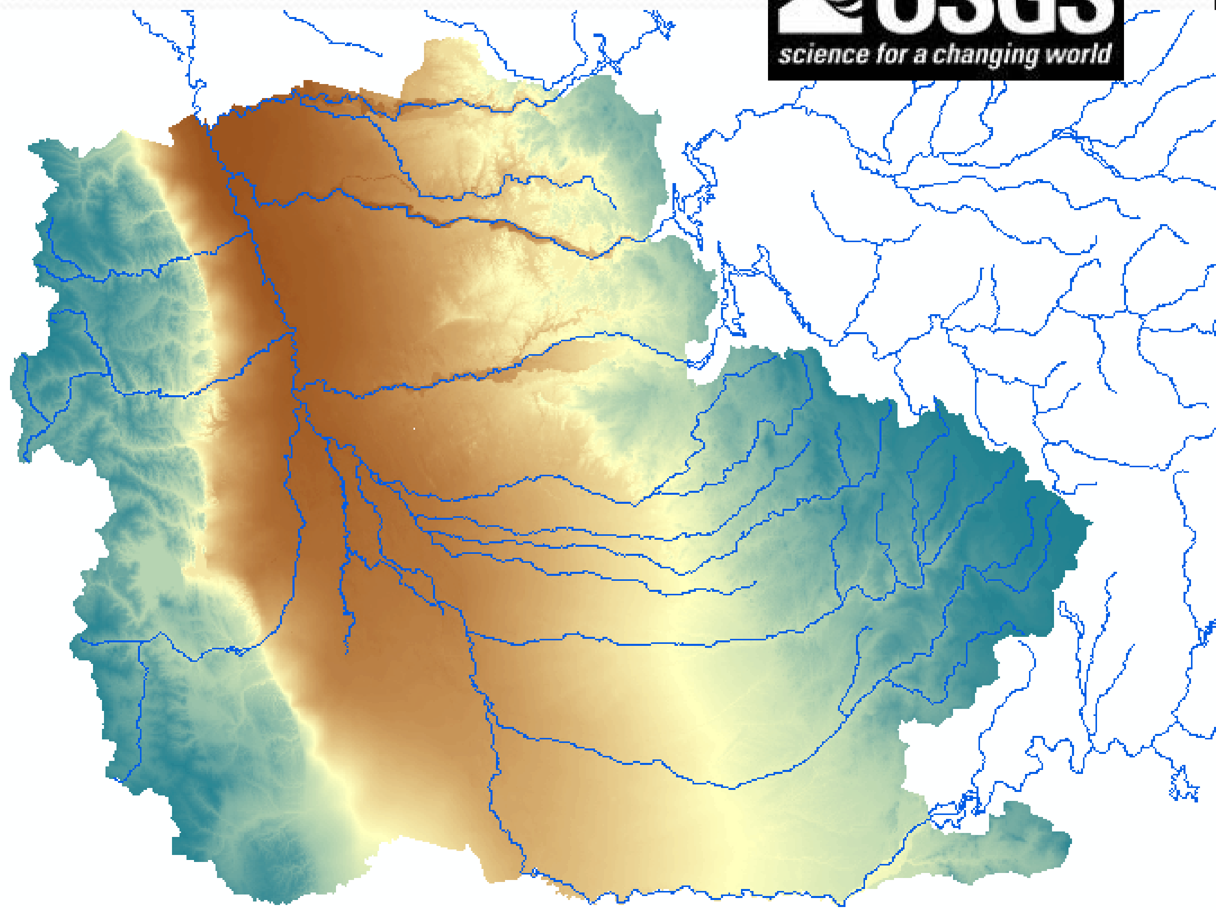
 Overlaying land use and soil maps



GIS databases

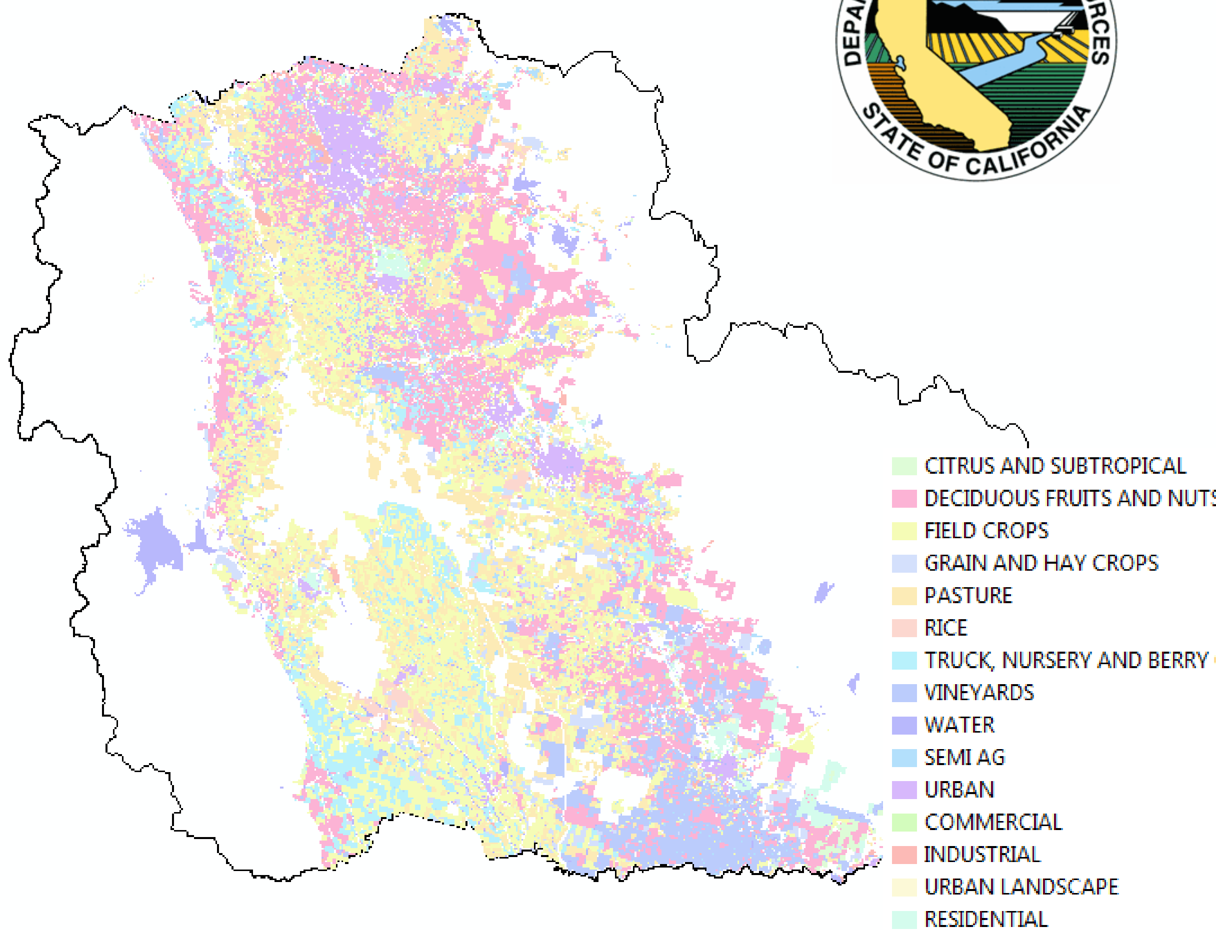
- **DEM and stream network**

USGS
science for a changing world



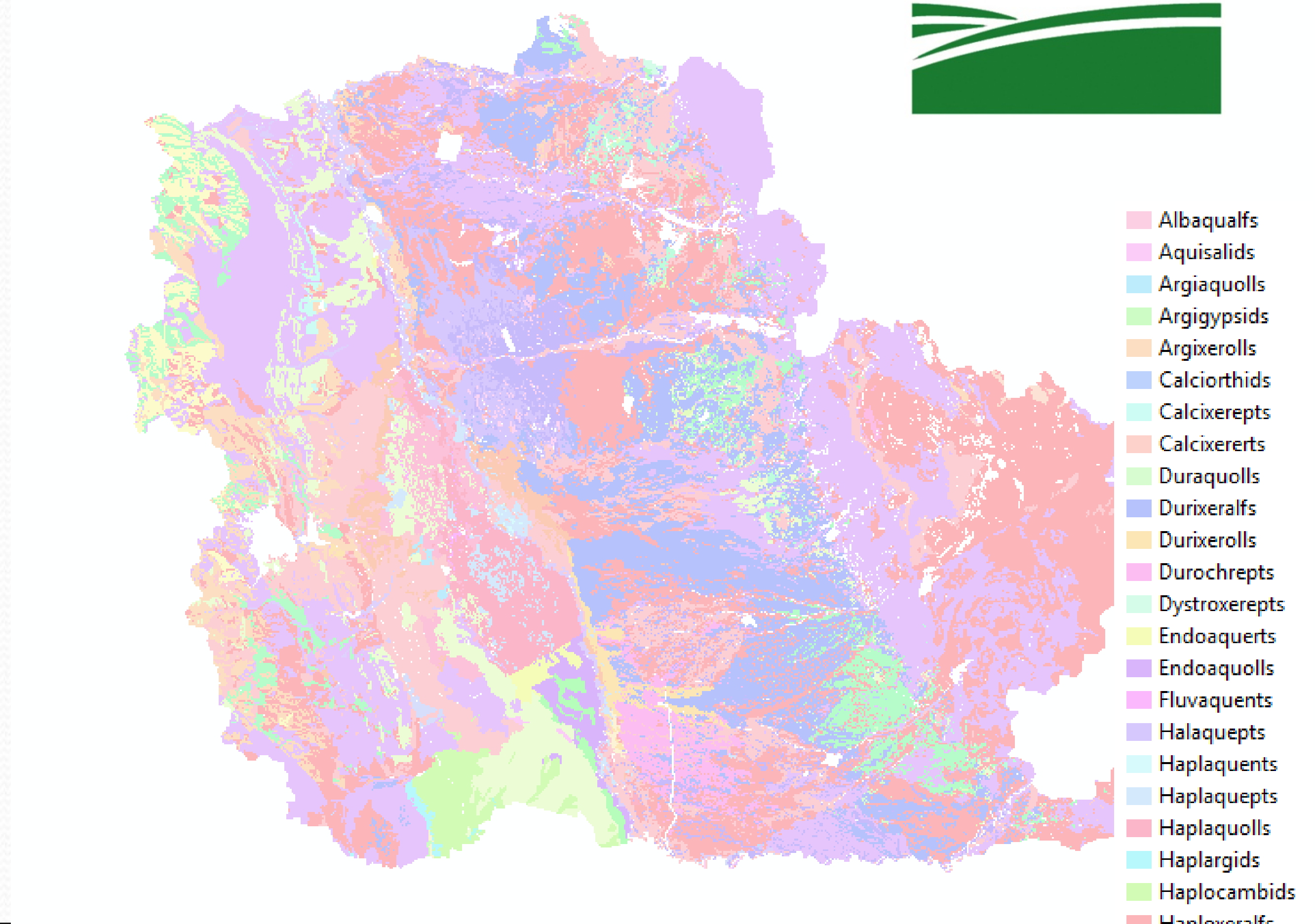
GIS databases

- DEM and stream network
- **Land use**



GIS databases

- DEM and stream network
- Land use
- **Soil**

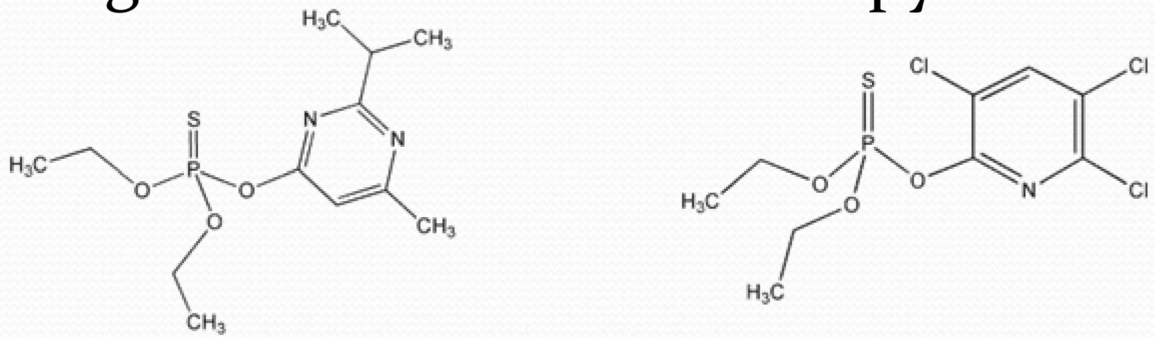


GIS databases

- DEM and stream network
- Land use
- Soil
- **Weather**: CA Irrigation Management Information System (CDWR)
- **Pesticide use**: Pesticide Use Reporting (CDPR)
- **Monitoring data** (CDPR and USGS)
  - Surface Water Database
  - National Water Information System

Simulation design

- Model initialization and parameterization
- Test agents: diazinon and chlorpyrifos



- Daily simulations during 1990 though 2005
- Model calibration
  - Hydrology (stream flow), and
  - Water quality (sediment, nutrients, and pesticides)

Statistical methods

- **Data preparation for model inputs**
  - Descriptive analysis (trend and variability)
  - Spatial aggregation
  - Correlation and regression

Statistical methods

- Data preparation for model inputs
- **Model calibration**
  - Multiple-objective functions
  - Shuffled complex evolution (SCE) algorithm

Statistical methods

- Data preparation for model inputs
- Model calibration
- **Residue variance analysis for model evaluation**
  - Nash-Sutcliffe (NS) coefficient
    - Range: -∞ ~ 1.0
    - Satisfactory modeling: NS> 0.35
    - Good modeling: NS> 0.75
  - Root mean square error (RMSE)
  - Coefficient of determination (R^2)

$$NS = 1 - \frac{\sum_j (O_j - P_j)^2}{\sum_j (O_j - \overline{O})^2}$$

Statistical methods

- Data preparation for model inputs
- Model calibration
- Residue variance analysis for model evaluation
- **Uncertainty/sensitivity analysis**
  - Latin Hypercube sampling
  - Monte Carlo simulation
  - Sensitivity index (in a central difference numerical scheme)

$$S_I = \frac{\partial P}{\partial I}\frac{I}{P(I)} = \frac{P(I+\Delta I) - P(I-\Delta I)}{2\Delta I}\frac{I}{P(I)}$$

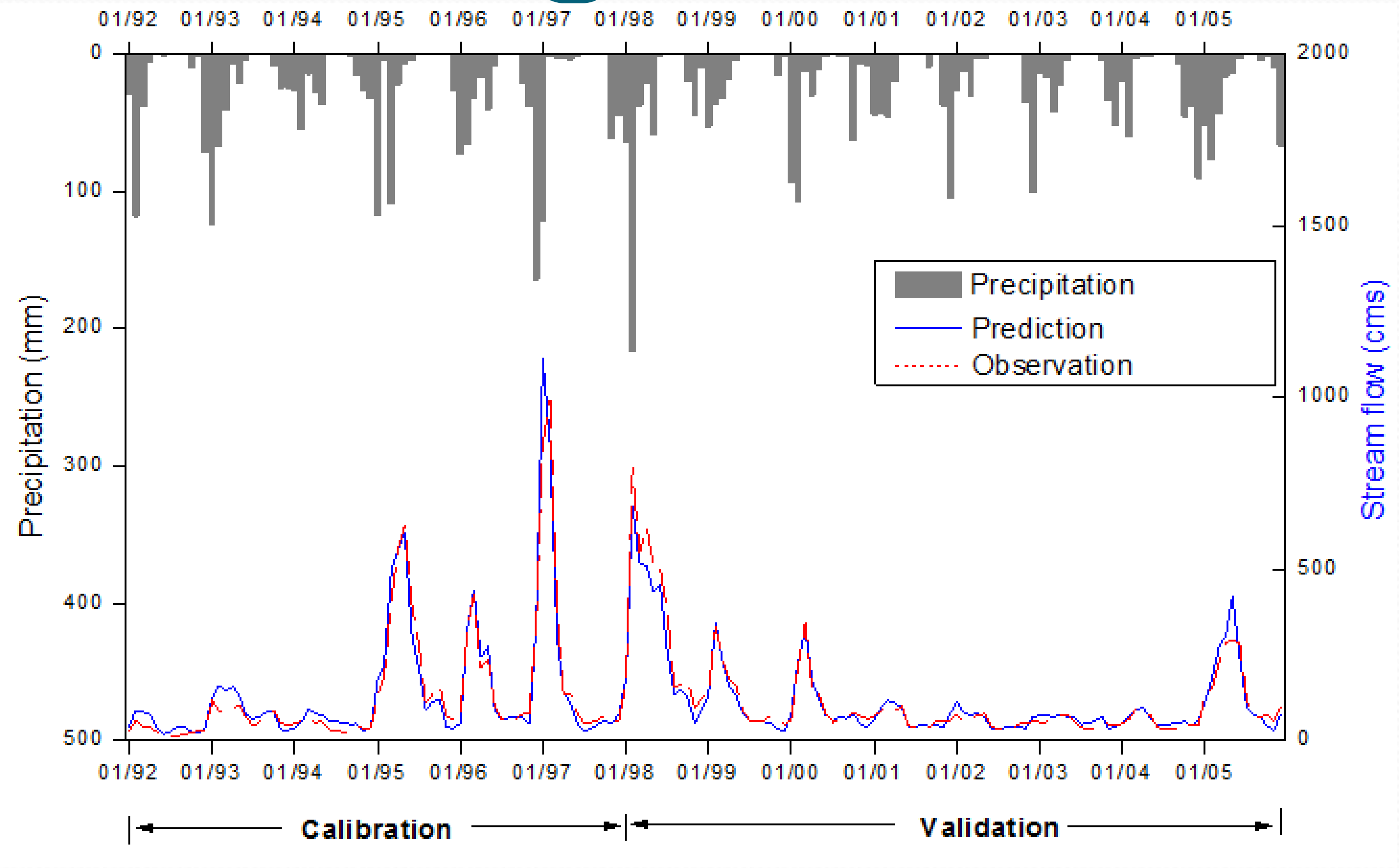
Model evaluation and results

- Calibration/validation at sub-basin outlets

Tributary outlets or river site	USGS ID	Location		Sampling type	
		Latitude	Longitude	Stream flow	Water quality
Merced River	11272500	37.37	-120.93	X	
	11273500	37.35	-120.96		X
Orestimba Creek	11274538	37.41	-120.02	X	X
San Joaquin River at Cross Landing	11274550	37.43	-121.01	X	X
San Joaquin River at Patterson	11274570	37.50	-121.08		X
Del Puerto Creek	11274630	37.49	-121.21	X	
	11274653	37.52	-121.15		X
Tuolumne River	11290000	37.63	-120.99	X	X
Stanislaus River	11303000	37.73	-121.11	X	X
San Joaquin River at Vernalis	11303500	37.68	-121.27	X	X

- Simulation results (taken from: Luo et al., 2008. *Environmental Pollution*, 156:1171-1181)

Stream flow @ watershed



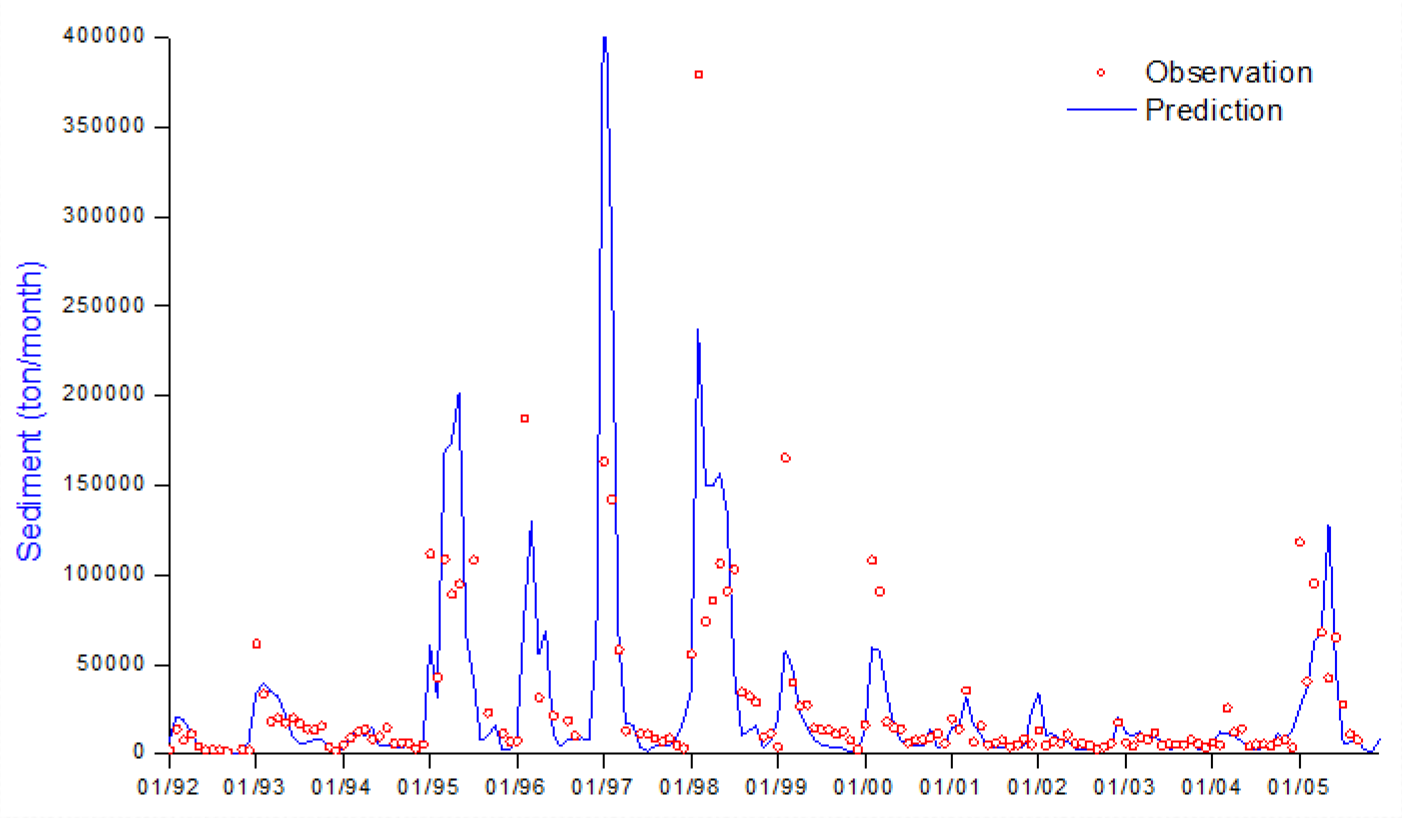
Predicted and observed **stream flow** (m^3/s) in the San Joaquin River at Vernalis during 1992-2005

Stream flows @ subbasins

Tributary or river sites	Calibration (1992-1997)			Validation (1998-2005)		
	NS	R^2	RMSE	NS	R^2	RMSE
Merced River	0.83	0.87	10.2	0.67	0.78	8.8
San Joaquin River at Newman	0.91	0.94	40.6	0.88	0.90	38.6
Orestimba Creek	0.50	0.68	1.2	0.49	0.51	1.7
San Joaquin River at Cross Landing	0.88	0.89	36.0	0.82	0.87	25.7
Del Puerto Creek	0.67	0.71	0.4	0.52	0.56	0.7
Tuolumne River	0.98	0.99	8.7	0.99	0.99	4.6
Stanislaus River	0.98	0.98	4.8	0.95	0.96	4.6
San Joaquin River at Vernalis	0.94	0.94	44.7	0.95	0.95	31.1

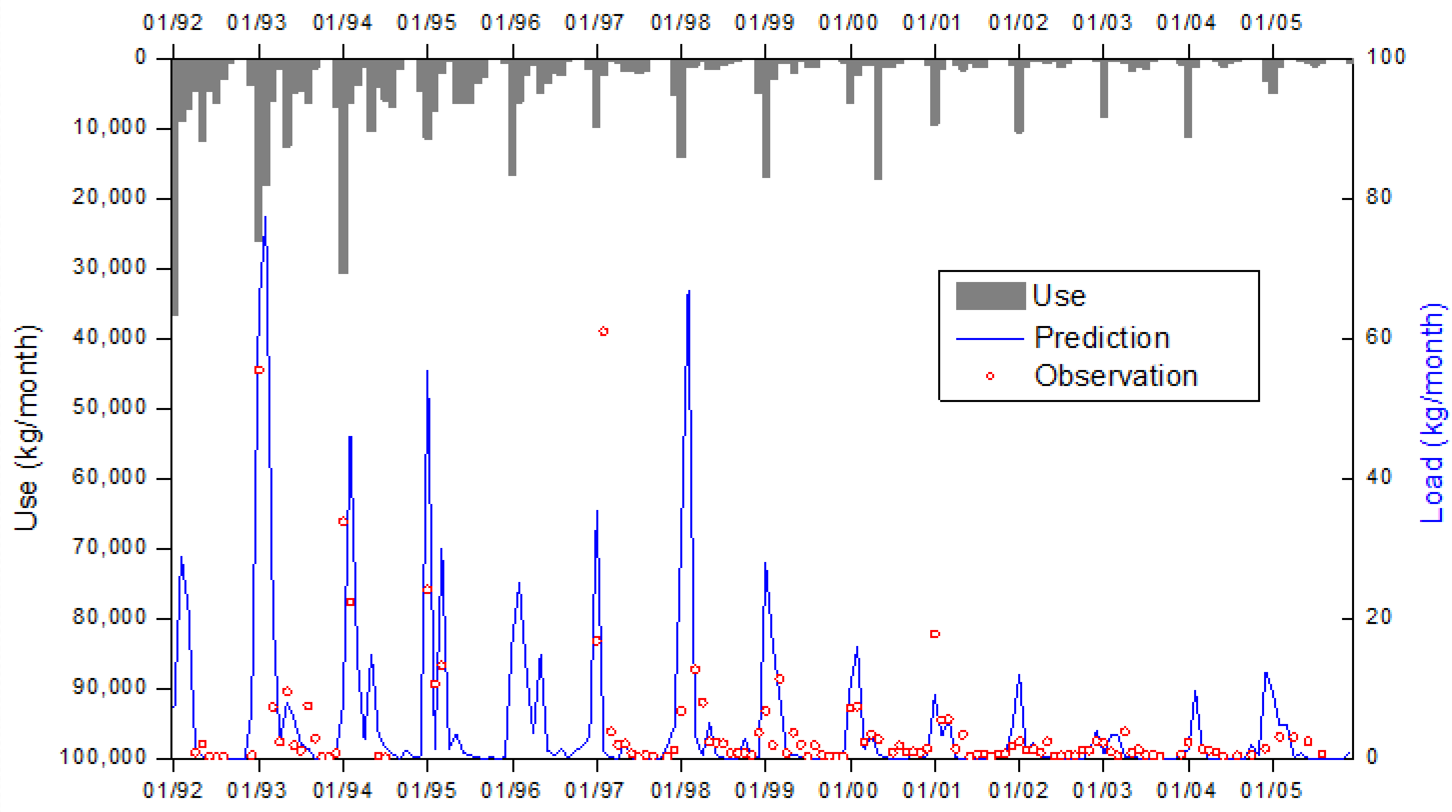
NS is the Nash-Sutcliffe coefficient, R^2 is the coefficient of determination, and RMSE is the root mean square error (m^3/s)

Sediment @ watershed



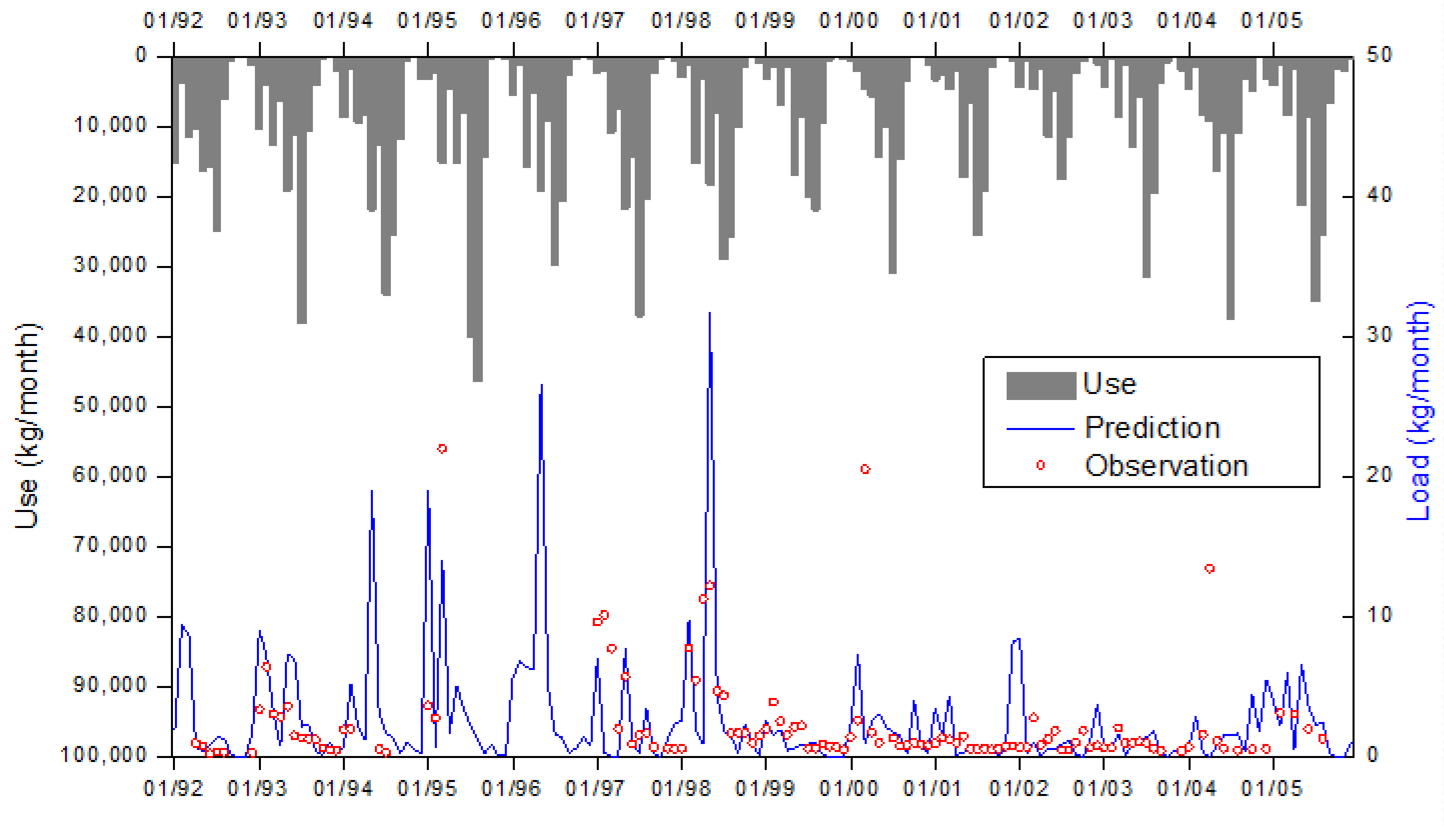
Predicted and observed **sediment load** (kg/month) in the San Joaquin River at Vernalis during 1992-2005

Diazinon @ watershed



Predicted and observed **dissolved diazinon loads** (kg/month) in the San Joaquin River at Vernalis during 1992-2005

Chlorpyrifos @ watershed



Predicted and observed **dissolved chlorpyrifos loads** (kg/month) in the San Joaquin River at Vernalis during 1992-2005

Pesticides @ subbasins

(a) Statistical results for model evaluation

Tributary or river sites	Diazinon			Chlorpyrifos		
	NS	R^2	RMSE	NS	R^2	RMSE
Merced River	0.69	0.85	1.31	0.55	0.79	1.53
Orestimba Creek	0.36	0.82	0.59	0.87	0.89	0.47
San Joaquin River at Vernalis	0.80	0.86	20.10	0.77	0.90	6.83

(b) Means of annual dissolved loads (kg/year)

Tributary or river sites	Diazinon		Chlorpyrifos	
	Observation	Prediction	Observation	Prediction
Salt Slough	7.76	6.62	5.45	6.62
Merced River	4.20	3.77	4.13	3.15
Orestimba Creek	0.79	0.84	0.50	0.44
Del Puerto Creek	0.52	0.44	0.31	0.10
Tuolumne River	5.90	4.71	3.36	3.14
Stanislaus River	4.39	5.71	4.26	4.43
San Joaquin River at Patterson	18.85	18.89	3.89	3.74
San Joaquin River at Vernalis	41.9	38.43	25.36	24.7

Section I, Model Development

Develop an modeling environment for pesticide transport simulation in the San Joaquin Valley

Section II, Management implications

Apply the calibrated model for evaluating management practices

[1] Interpretation of model results

[2] Model sensitivity analysis and simulations for structural BMPs

Modeling for management

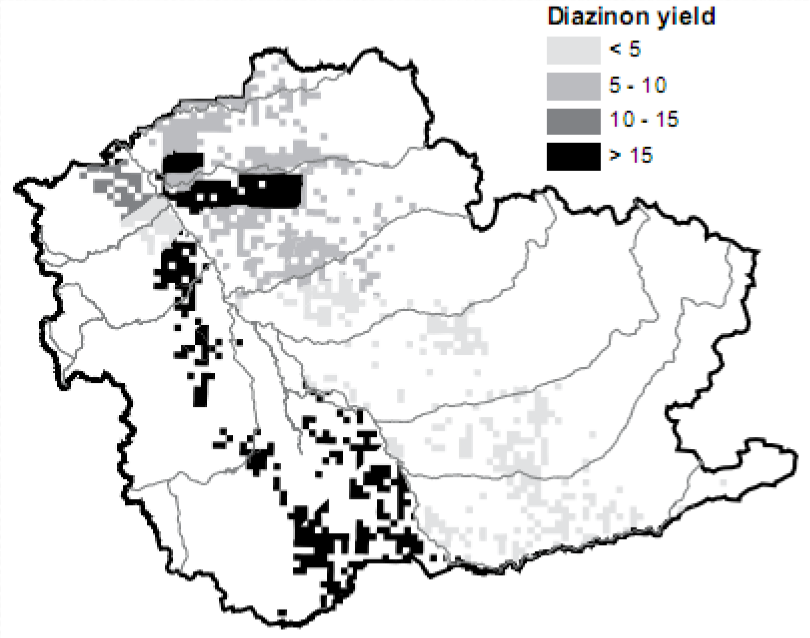
- Determine temporal variation in pesticide yield
- Indicate "hot-spots" of pesticide loadings/exposure
  - Areas with high pesticide use
  - Areas with high pesticide runoff potential
  - Areas contributing to high pesticide concentrations
- Predict effectiveness of pesticide management and structural BMPs in improving water quality
- Conduct scenario analysis for management planning

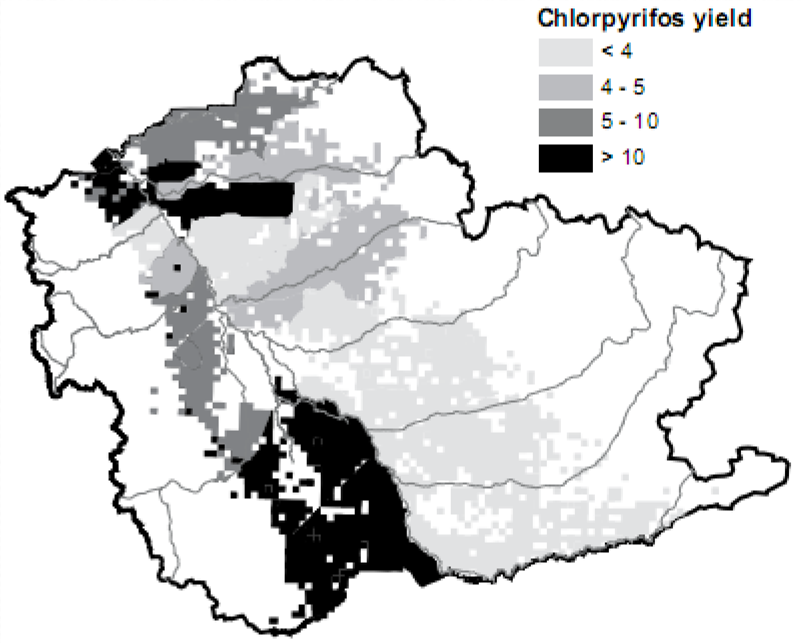
Seasonality

- LAPU (load as percent of use) = load/use
- High LAPU for dormant (wet) season
- Based on simulation of chlorpyrifos during 1992-2005
  - Annual overall LAPU: 0.03%
  - During January and February, LAPU=0.12%
  - 6.6% of chlorpyrifos application in January and February, generating 28.5% of chlorpyrifos load

Spatial distribution

- Higher pesticide runoff potential in the western watersheds of the San Joaquin River





Annual average pesticide yields (g/km²) during 1998-2005 (Luo et al., 2008)

Spatial distribution

- Higher pesticide runoff potential in the western watersheds of the San Joaquin River
- Relationship to topography and soil properties
- Relationship to hydrologic condition
  - Risks to aquatic ecosystem: Exposure events of chlorpyrifos (>0.015 μg/L): 42.2% of 1990-2005 in Orestimba Creek
- Areas with high runoff potential and ecosystem risk were indicated for future monitoring and mitigation efforts

Sensitivity analysis ("land phase")

Parameters		Surface runoff	Sediment yield	Chlorpyrifos		
				Dissolved	Sorbed	Total
BIOMIX	Biological mixing efficiency	-0.01	0.03	-0.01	0.00	-0.01
CN2	SCS runoff curve number for moisture condition II	9.90	8.93	4.72	12.21	9.97
FILTERW	Width of filter strip (m)	0.00	-0.41	-0.27	-0.42	-0.36
HLIFE_F	Half-life on foliage (d)	-	-	0.01	0.01	0.01
HLIFE_S	Half-life in the soil (d)	-	-	0.96	1.08	1.05
HRU_SLP	Average slope steepness	-0.01	1.27	0.17	1.08	0.81
K_{OC}	Organic carbon normalized partition coefficient (L kg^{-1})	-	-	-0.94	0.07	-0.23
OV_N	Manning's "n" for overland flow	0.00	-0.08	0.00	-0.06	-0.04
PND_FR	Fraction of the subbasin area draining into the pond	-0.01	-0.61	-0.10	-0.68	-0.45
SOL_AWC	Available water capacity of the soil layer	0.16	-0.04	0.44	-0.12	0.05
SOL_K	Soil conductivity (mm h^{-2})	-0.06	0.00	0.19	-0.01	0.05
USLE_C	Minimal value of USLE cover and management factor	0.00	0.74	-0.01	0.65	0.45
USLE_K	USLE soil erodibility factor	0.00	0.58	0.00	0.49	0.35
USLE_P	USLE support practice factor	0.00	0.79	-0.01	0.69	0.48

Sensitivity analysis ("water phase")

Parameters		Stream flow	Sediment load	Chlorpyrifos		
				Dissolved	Sorbed	Total
CH_COV	Channel cover factor	0.00	0.07	-0.04	0.02	0.00
CH_EROD	Channel erodibility factor	0.00	0.07	-0.04	0.03	0.00
CH_N2	Manning's "n" value for the main channels	0.00	-0.43	0.04	-0.42	-0.24
CH_S2	Average slope for the main channel	0.00	0.26	-0.02	0.19	0.11
CHPST_REA	Hydrolysis coefficient (d^{-1})	-	-	0.00	0.00	0.00
K_{OC}	Organic carbon normalized partition coefficient (L kg^{-1})	-	-	-0.51	0.27	-0.04
HENRY	Henry's law constant (-)	-	-	-0.02	-0.01	-0.01
SPCON	A linear parameter used in channel sediment routing	-	0.70	-0.13	0.44	0.21

BMP representation with SWAT

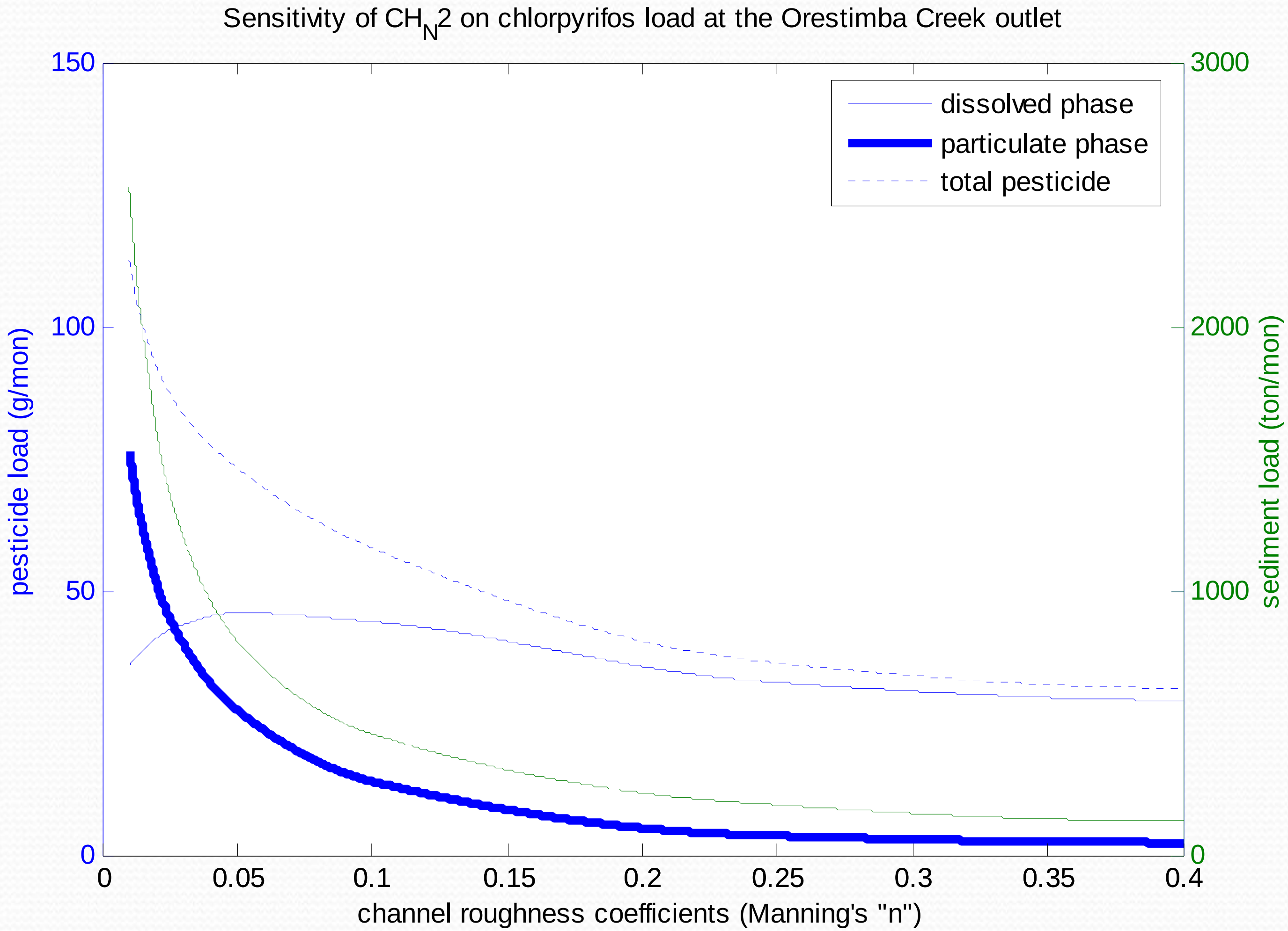
- Simulated by built-in functions in SWAT
  - **Vegetated filter strips**
  - **Sediment ponds**
- Implemented by altering model parameters, *e.g.*,
  - **Residue management**: *reduce* SCS curve number (CN2) and USLE practice factor (USLE_K), *increase* roughness for overland flow (OV_N)
  - **Grassed waterway**: *reduce* channel erosion coefficients (CH_COV and CH_EROD), *increase* roughness for channel flow (CH_N2)

Predicted effectiveness

BMPs		Surface runoff	Stream flow	Sediment		Chlorpyrifos	
				yield	load	yield	load
Residue management	CN2-2 USLE_P=0.55 OV_N=0.2	20%	<1%	47%	8%	32%	22%
Filter strip	FILTERW=5	-	-	59%	14%	56%	48%
Tailwater pond *	50% drainage	-	<1%	38%	4%	31%	19%
Grassed waterway	CH_N2=0.24 CH_COV=0 CH_EROD=0	-	<1%	-	88%	-	54%

•Pond dimensions are determined by USDA NRCS Technical Guide; an operating depth of 2.44 m (8 ft) is used based on field survey.
• Residue management is parameterized for 500 kg/ha residue

Effectiveness of grassed waterway



Conclusions

- SWAT model could be reliably used to simulate monthly hydrologic and water quality parameters in the Lower San Joaquin River watershed;
- Factors for the spatial and temporal variability of OP pesticide loads in surface water
  - Magnitude and timing of surface runoff
  - Magnitude and timing of pesticide applications
  - Soil properties
  - Pesticide properties related to processes in soil

Conclusions

- SWAT model could be reliably used to simulate monthly hydrologic and water quality parameters in the Lower San Joaquin River watershed;
- Factors for the spatial and temporal variability of OP pesticide loads in surface water;
- Management implications
  - Pesticide loads could be significantly reduced by decreasing use amounts during dormant (wet) season
  - Areas with high pesticide yields were identified and could be candidates for further management evaluations

Reference

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Thank You!

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