NITRATE IN GROUNDWATER OF CALIFORNIA AGRICULTURAL REGIONS: ASSESSMENT AND SOLUTIONS

University of California Los Angeles

May 21, 2015

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http://groundwaternitrate.ucdavis.edu

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University of California, Davis
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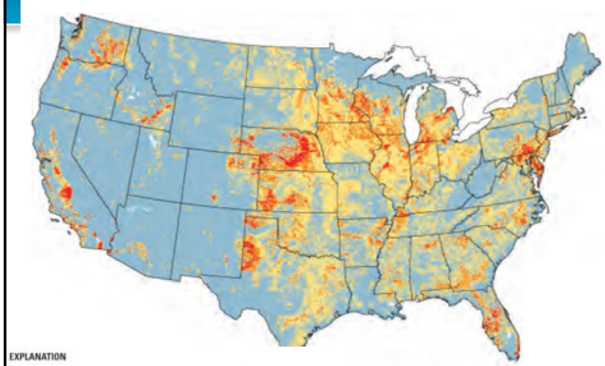
Model for shallow groundwater



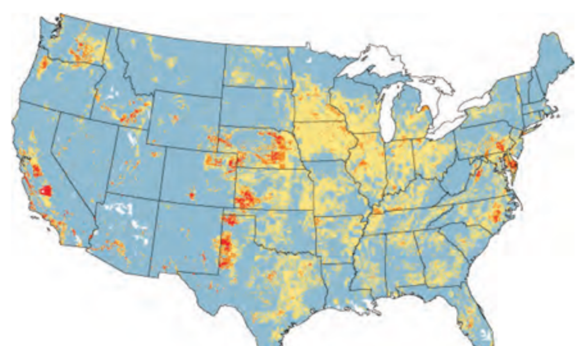
EXPLANATION

Predicted nitrate concentration, in milligrams per liter as N

≤1 | >1–5 | >5–10 | >10 | Missing data

Dubrovsky et al., USGS, 2010

Model for deep groundwater used as drinking water (50-m simulation depth)



EXPLANATION

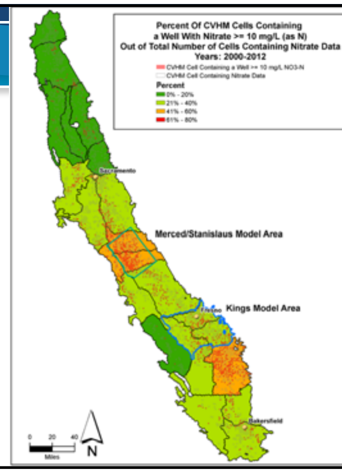
Predicted nitrate concentration, in milligrams per liter as N

≤1 | >1–5 | >5–10 | >10 | Missing data

Dubrovsky et al., USGS, 2010

Nitrate: Impacted regions within the Central Valley

red dots: wells above MCL for nitrate

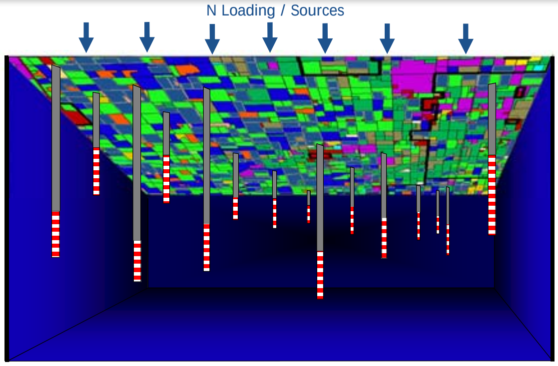


CVSALTS, Tasks 7 and 8 – Salt and Nitrate Analysis for the Central Valley Floor Final Report, December 2013

Figure 7-14

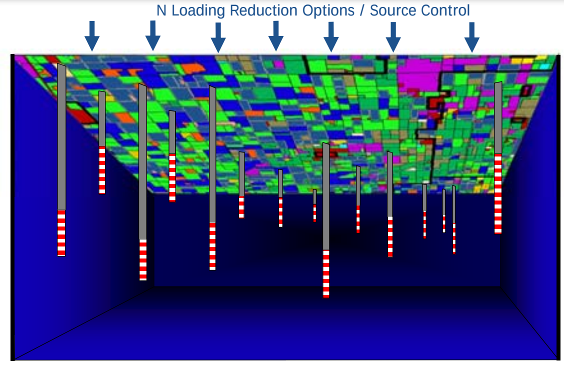
#1: Sources of Nitrate

N Loading / Sources

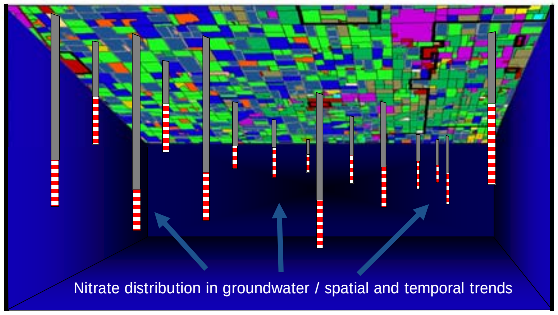


#2: Nitrate Source Reduction

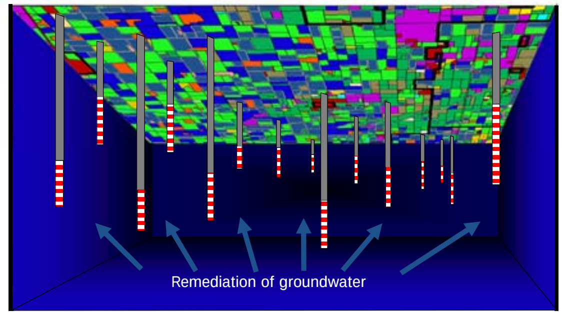
N Loading Reduction Options / Source Control



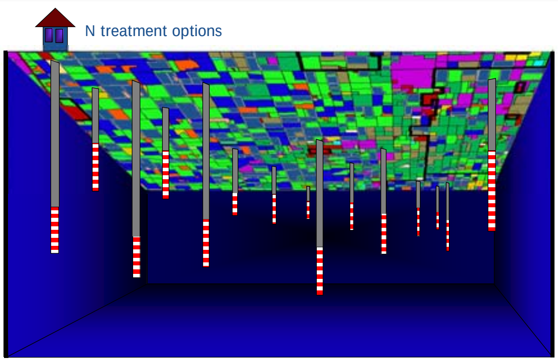
#3: Groundwater Nitrate



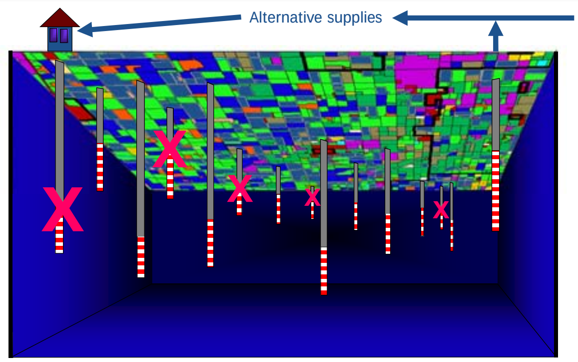
#4: Groundwater Remediation



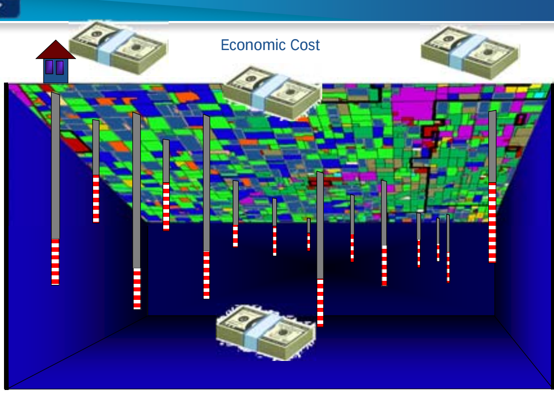
#5: Drinking Water Treatment



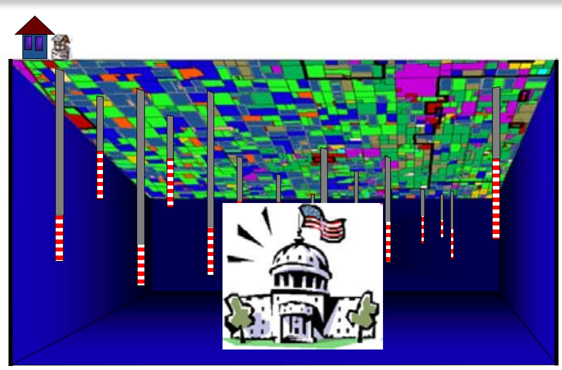
#6: Alternative Supplies



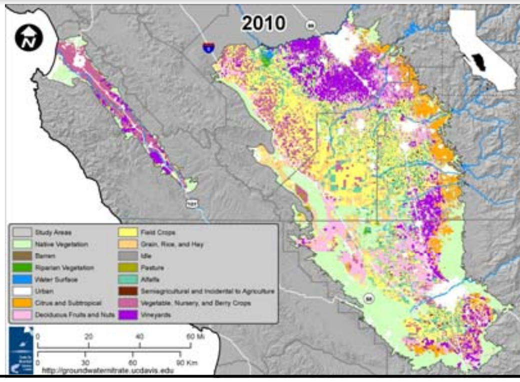
#7: Costs of Actions



#8: Funding and Policy



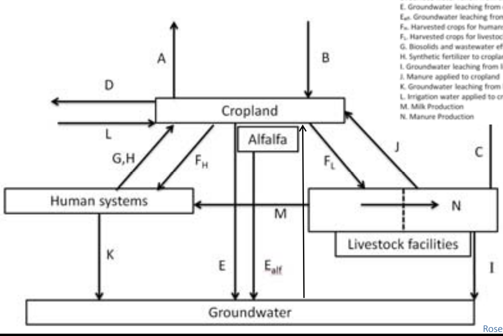
Nitrate Contamination Study Area



Source of Nitrate in Groundwater

Joshua H. Viers, Daniel Liptzin, Todd S. Rosenstock, Vivian B. Jensen, Allan D. Hollander, Alison McNally, Aaron M. King, Giorgos Kourakos, Elena M. Lopez, Nicole De La Mora, Anna Fryjoff-Hung, Kristin N. Dzurella, Holly Canada, Sarah Laybourne, Chiara McKenney, Jeannie Darby, James F. Quinn and Thomas Harter

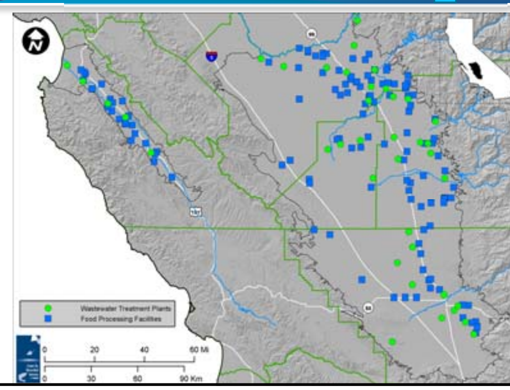
Nitrate Source Assessment



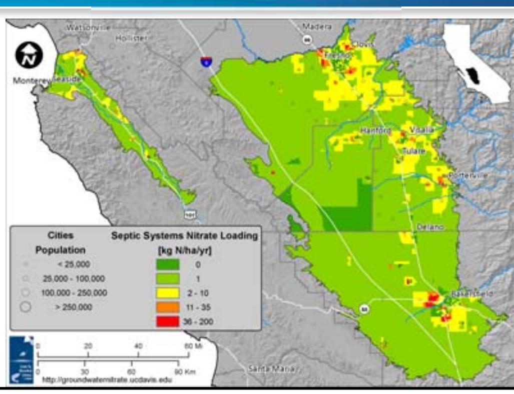
A. Gaseous emissions from cropland
B. Atmospheric deposition to cropland
C. Gaseous emissions from livestock facilities
D. Surface water runoff from cropland
E. Groundwater leaching from cropland except alfalfa
E_{alf}. Groundwater leaching from alfalfa
F_H. Harvested crops for humans
F_L. Harvested crops for livestock
G. Biosolids and wastewater effluent applied to cropland
H. Synthetic fertilizer to cropland
I. Groundwater leaching from livestock facilities
J. Manure applied to cropland
K. Groundwater leaching from human systems
L. Irrigation water applied to cropland
M. Milk Production
N. Manure Production

Rosenstock et al., JEQ, 2014

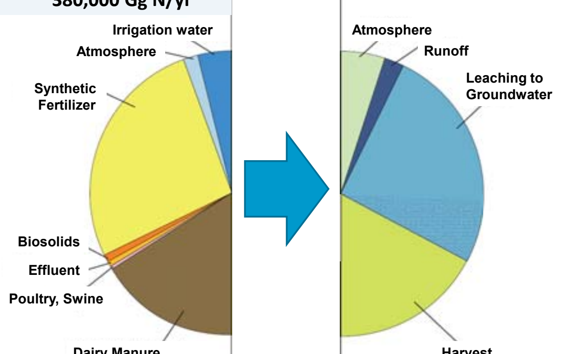
Wastewater Treatment Plants and Food Processors



Septic Systems

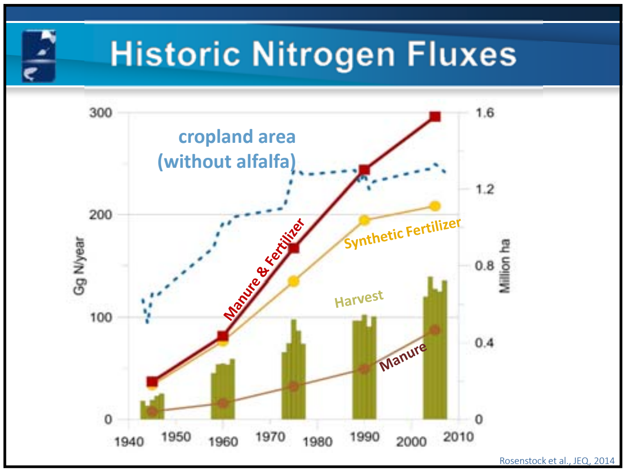


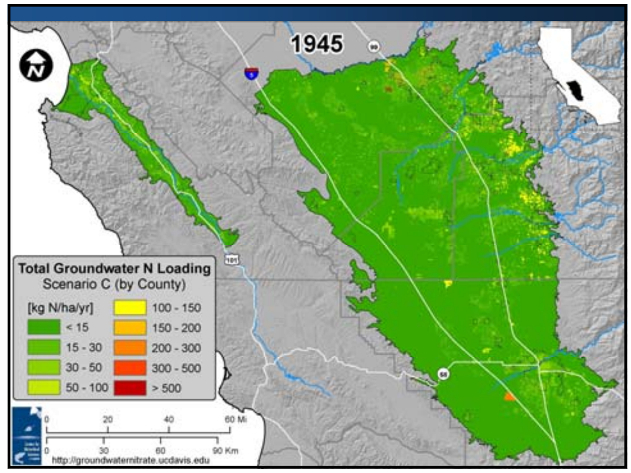
Total Cropland N Inputs:
380,000 Gg N/yr

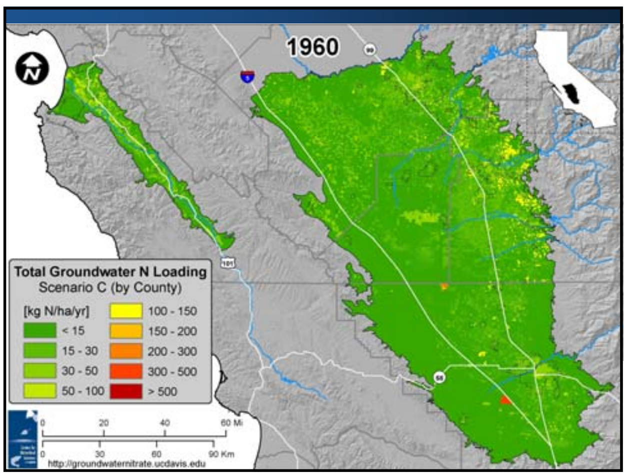


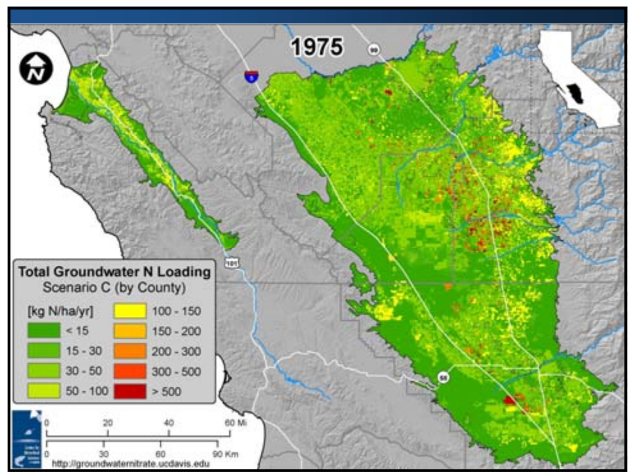
[not including alfalfa cropland]

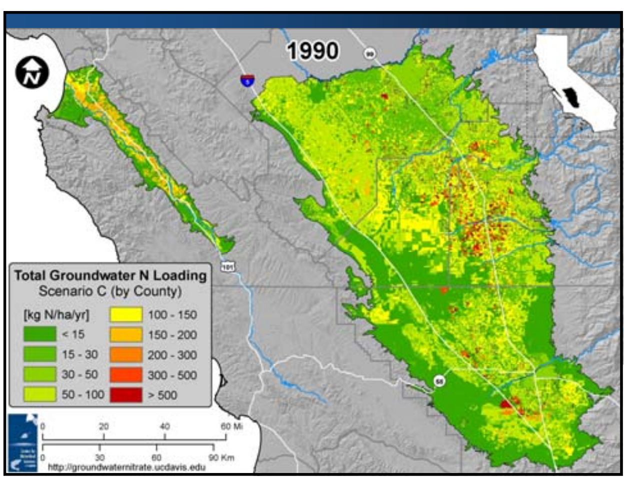
Total Cropland N Outputs:
380,000 Gg N/yr

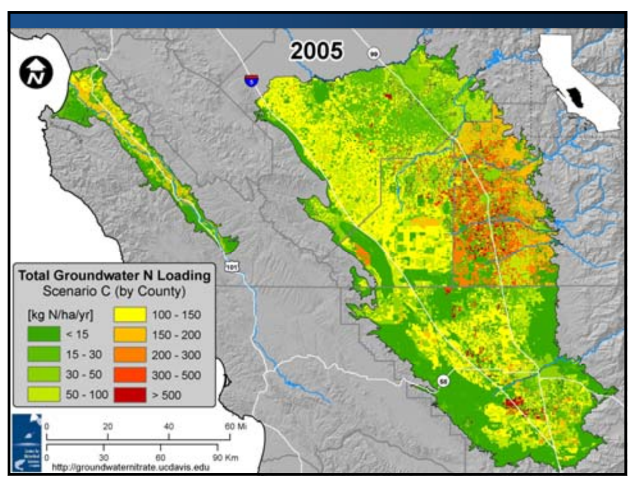

Historic Nitrogen Fluxes
cropland area
(without alfalfa)
Manure & Fertilizer
Synthetic Fertilizer
Harvest
Manure
Gg N/year
Million ha
300
200
100
0
1.6
1.2
0.8
0.4
0
1940
1950
1960
1970
1980
1990
2000
2010
Rosenstock et al., JEQ, 2014

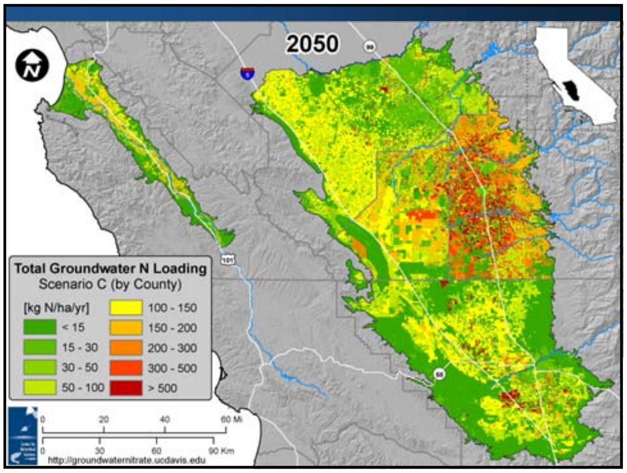

1945
Total Groundwater N Loading
Scenario C (by County)
[kg N/ha/yr]
< 15
15 - 30
30 - 50
50 - 100
100 - 150
150 - 200
200 - 300
300 - 500
> 500
http://groundwaternitrate.ucdavis.edu

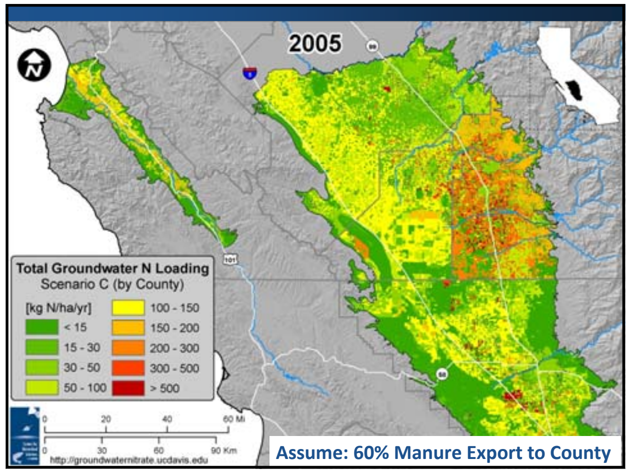

1960
Total Groundwater N Loading
Scenario C (by County)
[kg N/ha/yr]
< 15
15 - 30
30 - 50
50 - 100
100 - 150
150 - 200
200 - 300
300 - 500
> 500
http://groundwaternitrate.ucdavis.edu

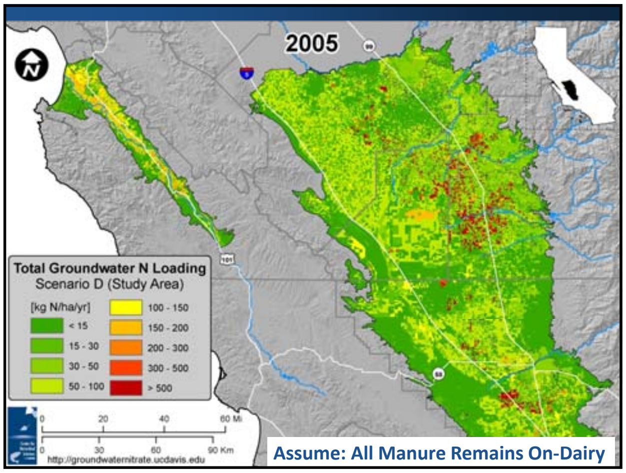

1975
Total Groundwater N Loading
Scenario C (by County)
[kg N/ha/yr]
< 15
15 - 30
30 - 50
50 - 100
100 - 150
150 - 200
200 - 300
300 - 500
> 500
http://groundwaternitrate.ucdavis.edu


1990
Total Groundwater N Loading
Scenario C (by County)
[kg N/ha/yr]
< 15
15 - 30
30 - 50
50 - 100
100 - 150
150 - 200
200 - 300
300 - 500
> 500
http://groundwaternitrate.ucdavis.edu

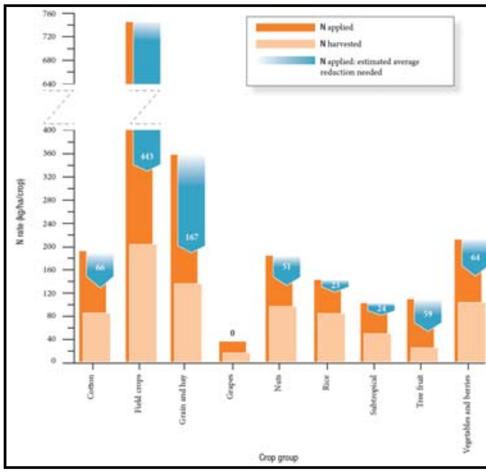

2005
Total Groundwater N Loading
Scenario C (by County)
[kg N/ha/yr]
< 15
15 - 30
30 - 50
50 - 100
100 - 150
150 - 200
200 - 300
300 - 500
> 500
http://groundwaternitrate.ucdavis.edu







PNB
Partial Nutrient Balance



kg N/ha/crop

1 kg N/ha/crop = 0.9 lbs N/ac/crop

Harter, Lund et al, 2012

Agricultural Source Reduction

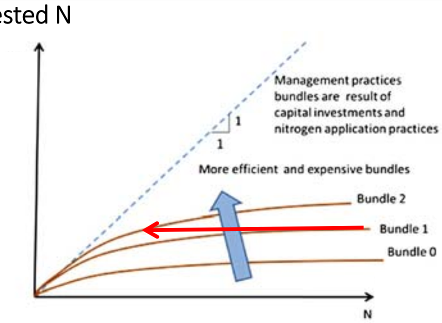
Increase crop N-use efficiency -- Decrease deep percolation

Basic Components	Management Measures	50 Practices
Improve irrigation and drainage systems	✓ Perform system evaluation and monitoring	3
	✓ Improve Irrigation scheduling	4
	✓ Improve irrigation system design and operation	13
	✓ Other irrigation infrastructure improvements	2
Improve fertilizer and manure use	✓ Improve rate, timing, and placement	15
Change crop rotation	✓ Modify crop rotation or grow cover crops	4
Improve storage and handling	✓ Avoid fertilizer material and manure spills during transport, storage and application	9

Dzurella and Pettygrove, 2014

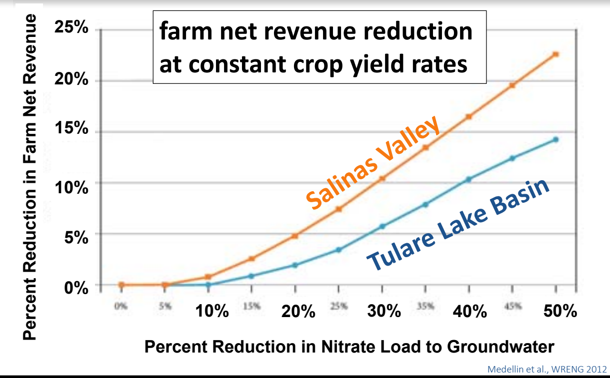
Agricultural Source Reduction: Improving Farm Technology

Harvested N



Applied N

Economics of Source Reduction

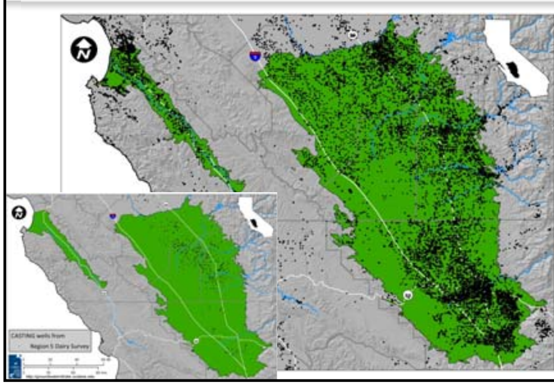


Focus: Water Quality

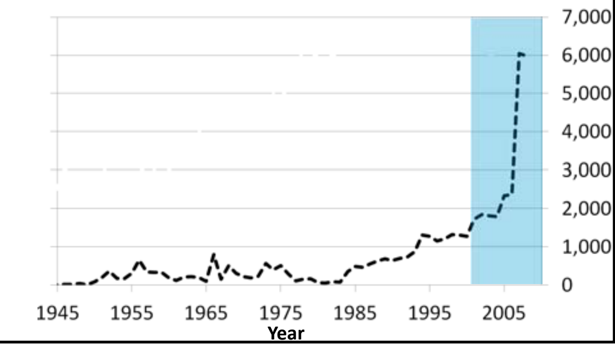
Past and Current: DATA

Dylan Boyle, Aaron King, Giorgos Kourakos, Katherine Lockhart, Megan Mayzelle, Graham E. Fogg and Thomas Harter

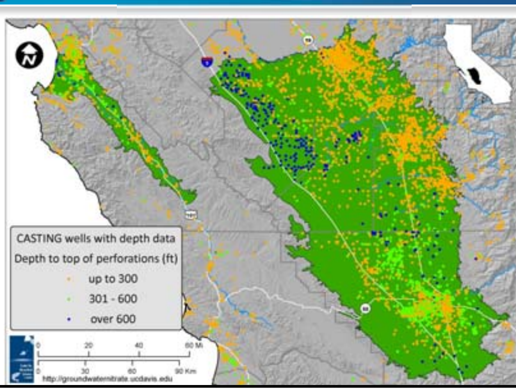
Wells with Known Nitrate Data



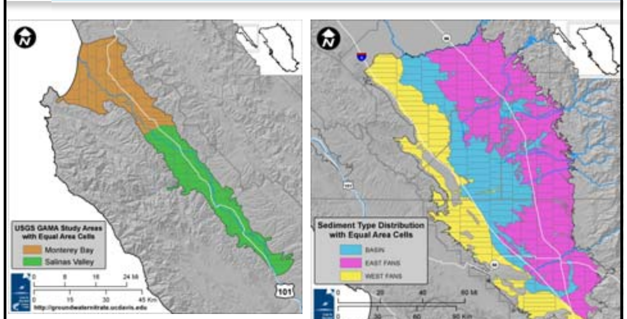
Lack of Historic Data
CASTING Database



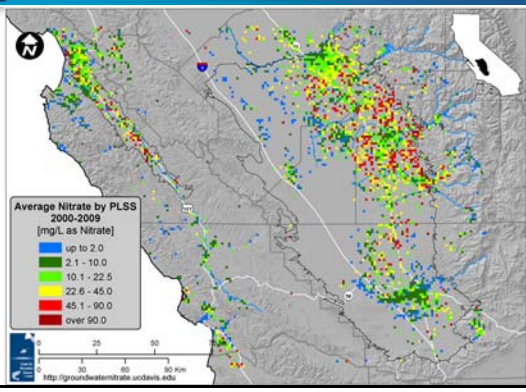
Depth of Wells



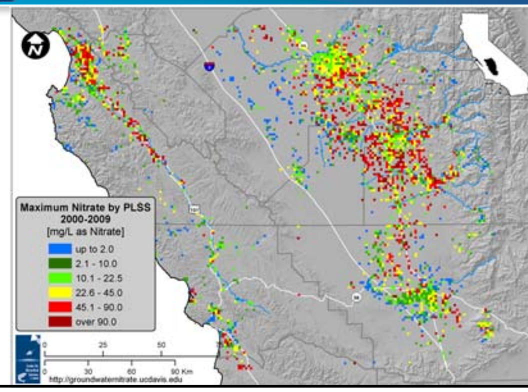
Regionalization & Declustering



Average Nitrate Concentrations by PLSS Section

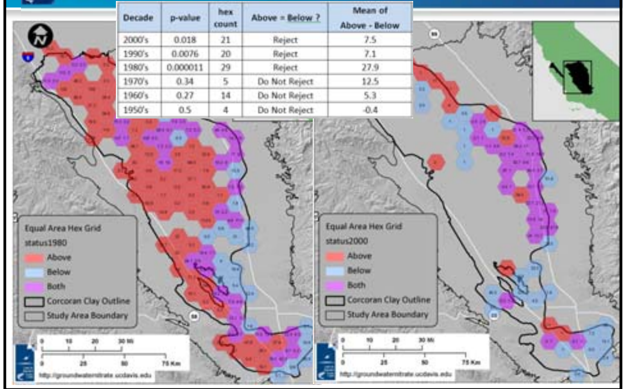


Maximum Nitrate Concentrations by Section

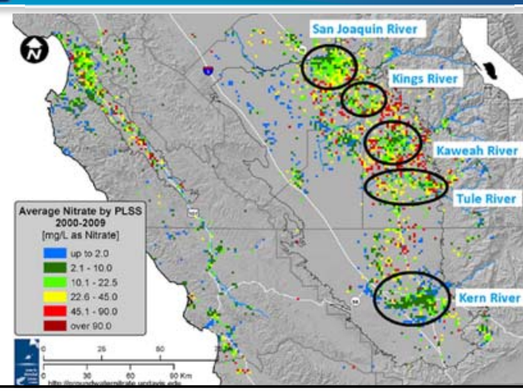


Semi-Confined vs. Confined Aquifer

Decade	p-value	hex count	Above = Below ?	Mean of Above - Below
2000's	0.018	21	Reject	7.5
1990's	0.0076	20	Reject	7.1
1980's	0.000011	29	Reject	27.9
1970's	0.34	5	Do Not Reject	12.5
1960's	0.27	14	Do Not Reject	5.3
1950's	0.5	4	Do Not Reject	-0.4



Spatial Context: Streams?



Depth to Water Table & Soil Type

Region	DPR Groundwater Protection Zone	# of Wells	# Well-Years	Median	> 9 mg/L	> 22.5 mg/L	> 45 mg/L	> 90 mg/L
TLB Eastside Fans	(Outside)	6,661	17,770	13.3	61.4%	33.9%	15.7%	5.0%
	Leaching	647	2,330	16.6	69.4%	40.4%	14.0%	3.8%
	Runoff	814	2,626	32.3	86.3%	64.0%	35.3%	9.7%
	Runoff or Leaching	40	140	20.9	86.4%	45.7%	21.4%	10.0%
TLB Central Basin	(Outside)	903	2,013	6.0	41.6%	24.3%	11.5%	2.8%
	Leaching	7	23	17.0	82.6%	39.1%	39.1%	17.4%
	Runoff	390	800	33.1	88.0%	60.8%	37.5%	13.4%
	Runoff or Leaching	8	19	50.0	89.5%	57.9%	57.9%	26.3%
TLB Westside Fans	(Outside)	89	201	1.8	29.4%	9.0%	2.0%	1.5%
SV-	(Outside)	1091	4,716	14.0	61.2%	35.0%	11.0%	1.6%
Pressure Aquifer,	Leaching	21	73	12.0	61.6%	27.4%	9.6%	0.0%
Eastside, and Monterey Bay	Runoff	4	15	5.0	6.7%	0.0%	0.0%	0.0%
SV-Forebay	(Outside)	160	508	10.0	53.5%	34.1%	20.9%	10.6%
and Upper Valley	Leaching	15	39	12.0	59.0%	38.5%	20.5%	10.3%

Boyle et al., 2012

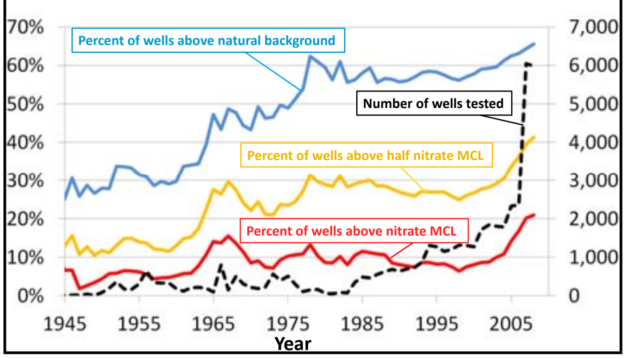
Depth of Well Screen

Region	Well Depth Category	# of Wells	# Well-Years	Median	> 9 mg/L	> 22.5 mg/L	> 45 mg/L	> 90 mg/L
TLB Eastside Fans	Monitoring	298	553	53.8	77.0%	66.0%	52.8%	37.6%
	Domestic	1,749	2,879	27.4	75.3%	55.9%	33.0%	9.6%
	<200', priv.	785	1,143	27.2	78.8%	56.6%	31.7%	7.5%
	<200', all	1,241	4,682	16.5	69.1%	38.1%	15.4%	2.8%
	public	1,597	11,867	12.5	62.0%	26.1%	5.7%	0.8%
TLB Central Basin	Monitoring	114	323	122.2	74.0%	66.6%	61.3%	56.7%
	Domestic	257	387	21.3	63.8%	47.8%	26.9%	8.0%
	<200', priv.	70	71	19.0	67.6%	42.3%	23.9%	4.2%
	<200', all	118	404	16.5	67.3%	34.2%	14.6%	3.7%
	public	148	913	8.0	47.0%	17.1%	6.7%	1.5%
TLB Westside Fans	Monitoring	29	61	62.0	62.3%	59.0%	52.5%	45.9%
	<200', priv.	2	2	24.1	50.0%	50.0%	0.0%	0.0%
	<200', all	3	9	1.5	11.1%	11.1%	0.0%	0.0%
	public	77	189	1.5	28.0%	6.3%	0.0%	0.0%
SV-	Monitoring	170	570	25.6	60.0%	51.2%	43.0%	27.9%
Pressure Aquifer,	Domestic	530	1,970	16.0	65.0%	38.3%	14.0%	2.0%
Eastside,	<200', priv.	108	458	16.0	65.3%	37.6%	13.1%	2.2%
and Monterey Bay	<200', all	146	678	14.6	63.6%	36.3%	10.0%	1.5%
	public	270	1,511	8.1	48.6%	21.6%	4.6%	0.3%
SV-Forebay	Monitoring	10	22	77.2	81.8%	72.7%	59.1%	45.5%
and Upper Valley	Domestic	33	105	22.0	67.6%	49.5%	40.0%	22.9%
	<200', priv.	62	84	36.3	61.9%	56.0%	42.9%	21.4%
	<200', all	79	193	10.0	52.8%	34.2%	22.3%	9.8%
	public	57	296	7.0	42.9%	18.9%	4.4%	0.3%

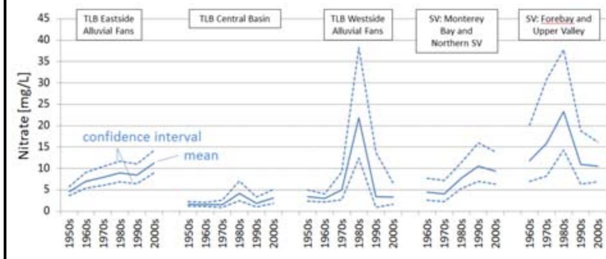
Median and exceedance probability obtained from annual well means, 2000-2010 (temporally de-clustered, spatially not de-clustered).

Boyle et al., 2012

Historic Nitrate Trends, TLB: Exceedance Rate



Decadal Backtransformed Log-Means of Equal Area Medians



De-clustered, back-transformed mean of the logarithm of equal area decadal medians that were computed from ten years of annual well means.

Boyle et al., 2012

Moments of Well Trends

Data Source / Collection Program	Period	Number of Slopes	CI -95%	Mean Slope	CI +95%	Median Slope	Lower Quartile	Upper Quartile
Public Supply Wells (CADWSAP)	total period	2,190	0.18	0.27	0.35	0.08	-0.14	0.54
	1980s	558	-0.20	0.11	0.41	0.02	-0.92	1.24
	1990s	1,311	-0.10	0.04	0.18	0.00	-0.56	0.50
	2000s	1,927	0.21	0.31	0.41	0.11	-0.18	0.66
MCWRA Monitoring Program	total period	206	-0.57	0.41	1.38	0.07	-2.67	3.32
	1990s	171	-0.06	1.12	2.30	0.55	-2.12	5.14
	2000s	59	-2.62	-0.64	1.35	0.00	-5.89	2.77
DPR Domestic Wells – all	2000s	69	-0.91	-0.27	0.38	-0.32	-1.46	1.08
DPR - Leaching zones only	2000s	30	-1.33	-0.20	0.92	-0.47	-1.17	1.08
DPR - Runoff zones only	2000s	39	-1.12	-0.32	0.48	-0.31	-1.49	1.12
Dairy General Order	2000s	2,600	0.17	0.45	0.73	0.11	-2.35	3.78

[1] Regression slopes for each well are computed for the entire period of records ("total period") and, separately, for each decade with at least two measurements on one well. Environmental monitoring wells are excluded.

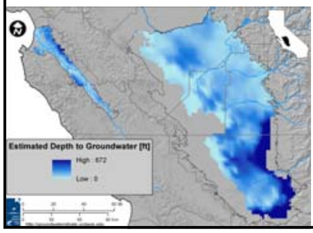
Focus: Water Quality

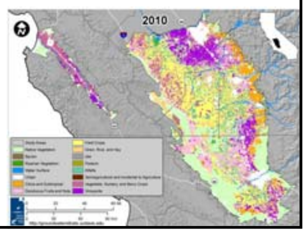
Past, Current, and Future: Modeling

Dylan Boyle, Aaron King, Giorgos Kourakos, Katherine Lockhart, Megan Mayzelle, Graham E. Fogg and Thomas Harter

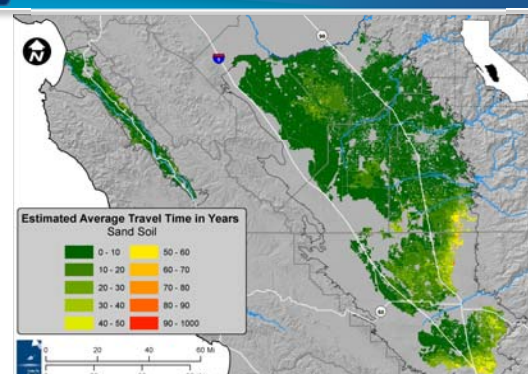
Vadose Zone Residence Time of Nitrate

- Depth to the water table
  +
- Cropland water budgets (deep percolation)
  +
- Soil type

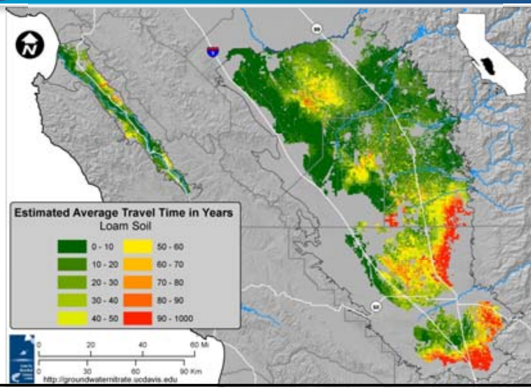




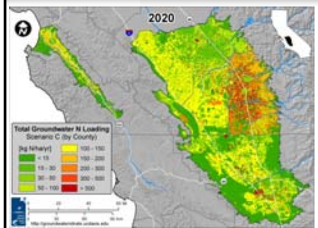
Vadose Zone Travel Time



Vadose Zone Travel Time

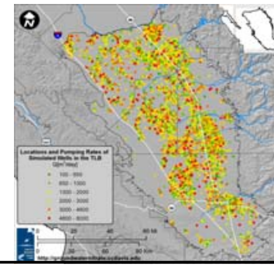


Nonpoint Source Groundwater Modeling

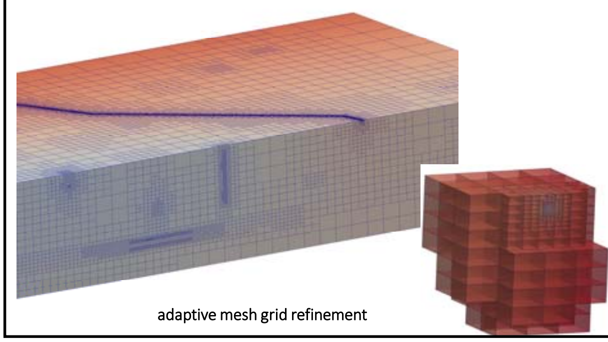


spatio-temporally distributed sources: loading to water table

spatially distributed sinks: wells

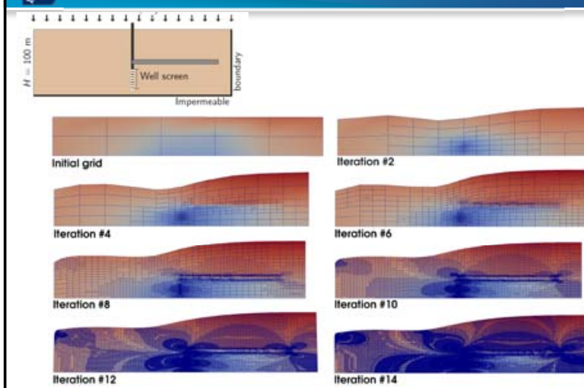


High Resolution Flow Field

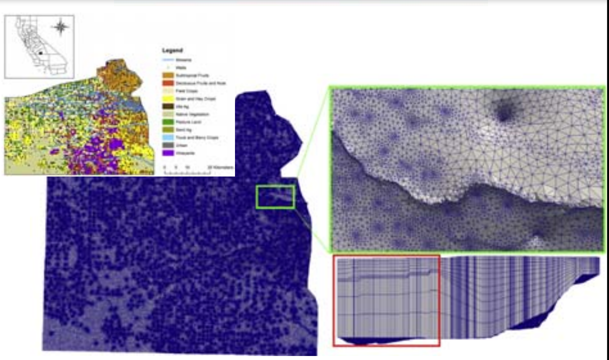


adaptive mesh grid refinement

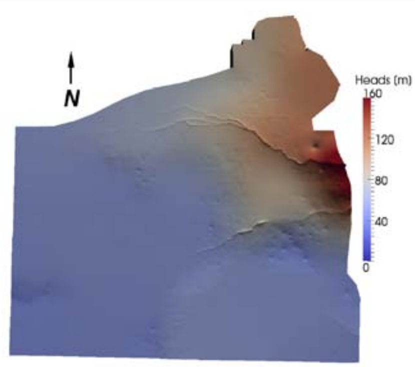
Adaptive Mesh Refinement

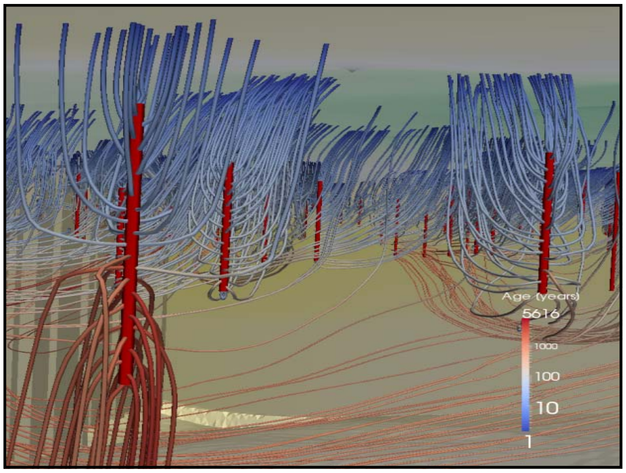


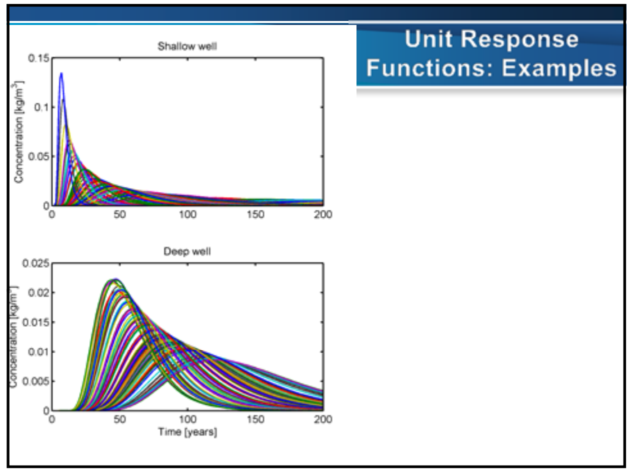
Finite Element Grid

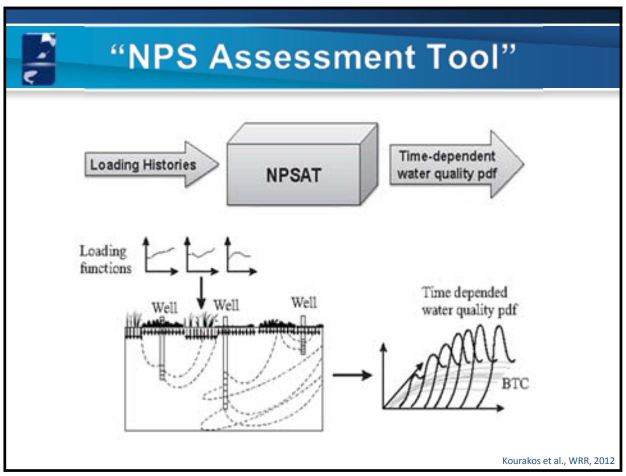


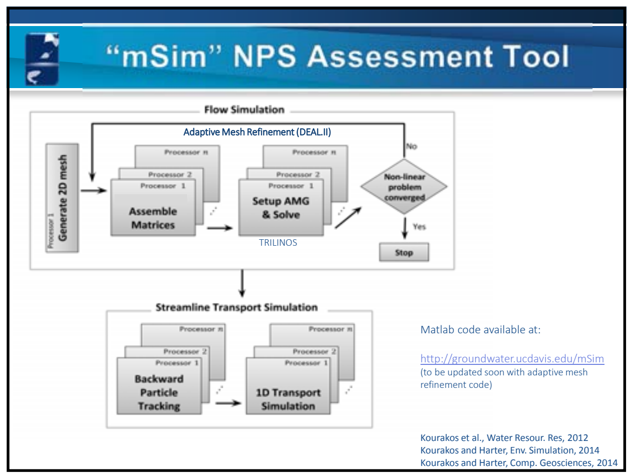
Water Table Distribution

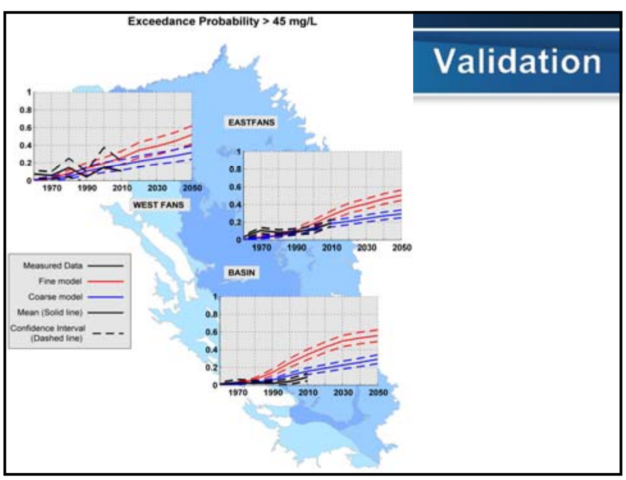


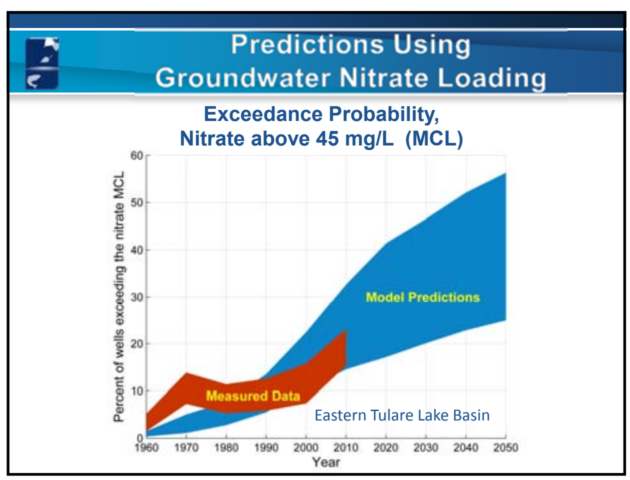

Age (years)
5616
1000
100
10
1


Unit Response Functions: Examples
Shallow well
Concentration [kg/m³]
0.15
0.1
0.05
0
0
50
100
150
200
Deep well
Concentration [kg/m³]
0.025
0.02
0.015
0.01
0.005
0
0
50
100
150
200
Time [years]


"NPS Assessment Tool"
Loading Histories
NPSAT
Time-dependent water quality pdf
Loading functions
Well
Well
Well
Time depended water quality pdf
BTC
Kourakos et al., WRR, 2012


"mSim" NPS Assessment Tool
Flow Simulation
Adaptive Mesh Refinement (DEAL.II)
Processor 1
Generate 2D mesh
Processor n
Processor 2
Processor 1
Assemble Matrices
Processor n
Processor 2
Processor 1
Setup AMG & Solve
TRILINOS
Non-linear problem converged
No
Yes
Stop
Streamline Transport Simulation
Processor n
Processor 2
Processor 1
Backward Particle Tracking
Processor n
Processor 2
Processor 1
1D Transport Simulation
Matlab code available at:
http://groundwater.ucdavis.edu/mSim
(to be updated soon with adaptive mesh refinement code)
Kourakos et al., Water Resour. Res, 2012
Kourakos and Harter, Env. Simulation, 2014
Kourakos and Harter, Comp. Geosciences, 2014

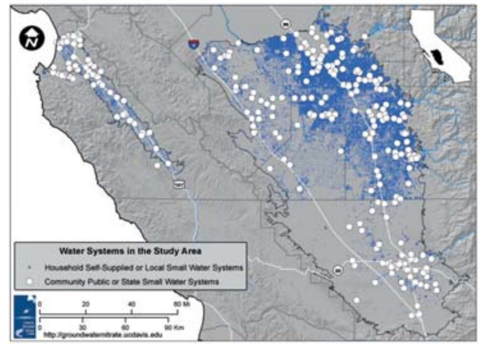

Exceedance Probability > 45 mg/L
Validation
EASTFANS
WEST FANS
BASIN
Measured Data
Fine model
Coarse model
Mean (Solid line)
Confidence Interval (Dashed line)
1970
1990
2010
2030
2050


Predictions Using Groundwater Nitrate Loading
Exceedance Probability,
Nitrate above 45 mg/L (MCL)
Percent of wells exceeding the nitrate MCL
Model Predictions
Measured Data
Eastern Tulare Lake Basin
Year
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
0
10
20
30
40
50
60

Focus: Safe Drinking Water

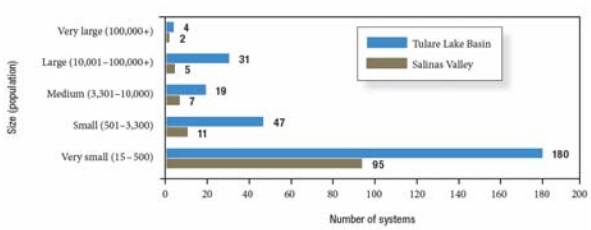
Vivian Jensen, Kristin Honeycutt, Holly Canada, Aaron King, Anna Fryjoff-Hung, Mimi Jenkins, Katrina Jessoe, Jeannie Darby, Thomas Harter, Jim Quinn, Jay Lund

All Water Systems



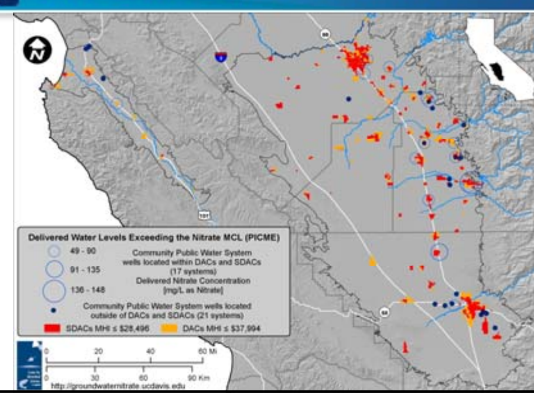
Estimated locations of the area's roughly 400 regulated community public and state-documented state small water systems and of 74,000 unregulated self-supplied water systems. Source: Honeycutt et al. 2012; CDPH PICME 2010.

Community Public & State Small Water Systems

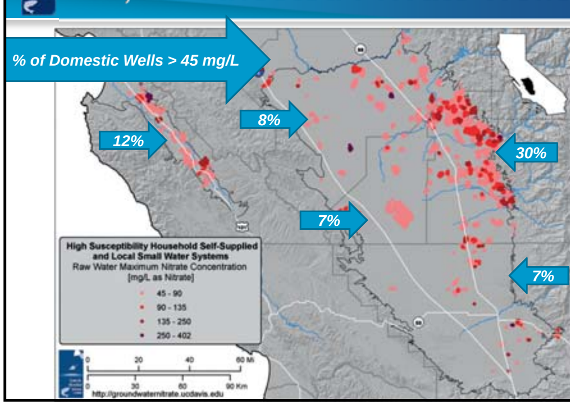


Community public and state-documented state small water systems of the Tulare Lake Basin and Salinas Valley. Source: CDPH 2010.

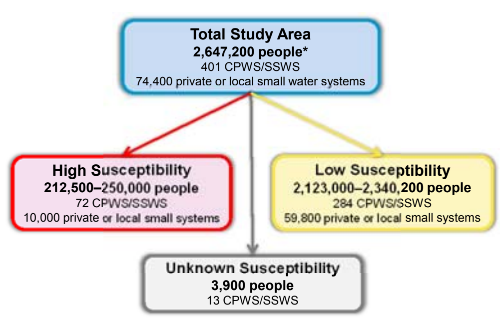
DACs and Delivered Water Quality



10,000 Affected Private Wells



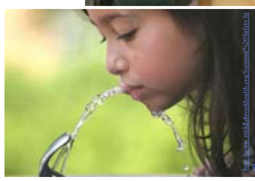
Susceptible Population



*Total study area population includes population served by surface water systems which is not susceptible to groundwater nitrate contamination and is not included in the subsequent susceptibility classifications.

Cost of Safe Drinking Water: $20 - $36 Million / Year (Study Area)

- **Most cost-effective drinking water supply actions:**
  - Blending
  - Treatment (community, point-of-use)
  - Consolidation/regionalization
  - Other alternative supplies
- **Affordability difficult for small communities**
- **Promising revenue sources:**
  - Fee on nitrogen fertilizer use
  - Fee on water use
  - Local compensation under Section 13304 of CA Water Code

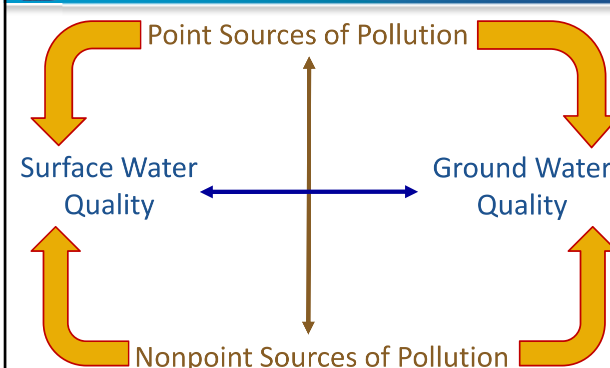


Focus: Policy Options

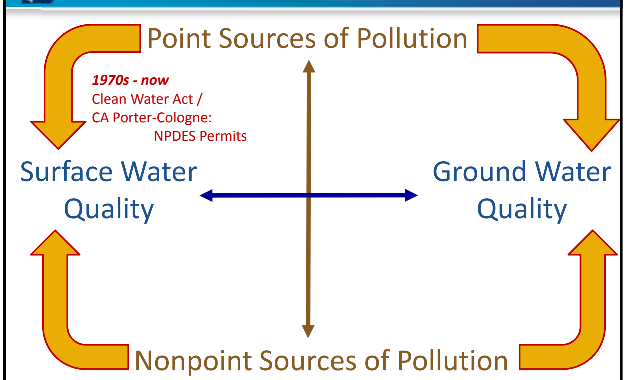
Holly Canada, Katrina Jessoe, Thomas Harter, Jay Lund

Funding and Regulatory Framework

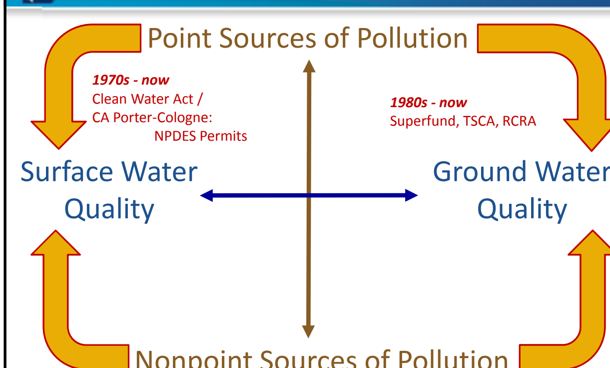
The Source Control Challenge

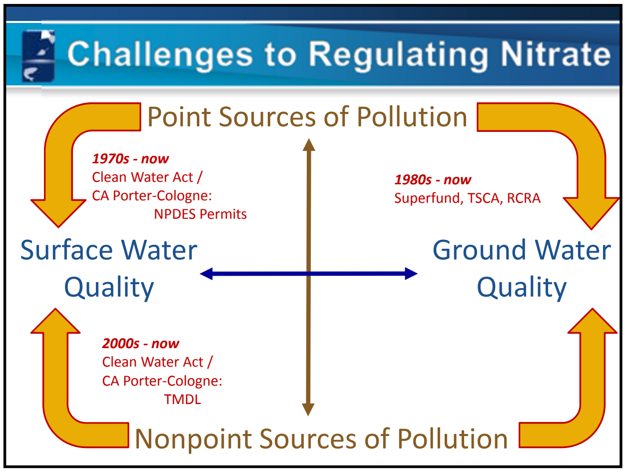


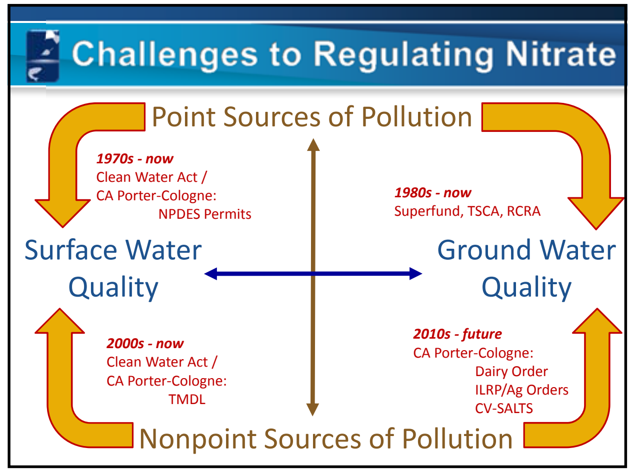
Challenges to Regulating Nitrate



Challenges to Regulating Nitrate




Challenges to Regulating Nitrate
Point Sources of Pollution
1970s - now
Clean Water Act /
CA Porter-Cologne:
NPDES Permits
1980s - now
Superfund, TSCA, RCRA
Surface Water Quality
Ground Water Quality
2000s - now
Clean Water Act /
CA Porter-Cologne:
TMDL
Nonpoint Sources of Pollution


Challenges to Regulating Nitrate
Point Sources of Pollution
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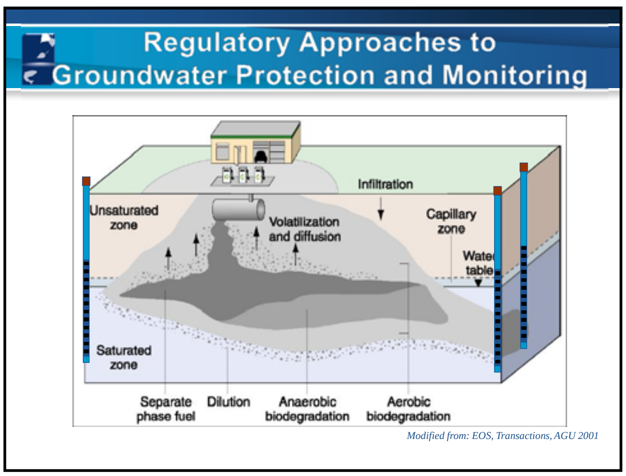
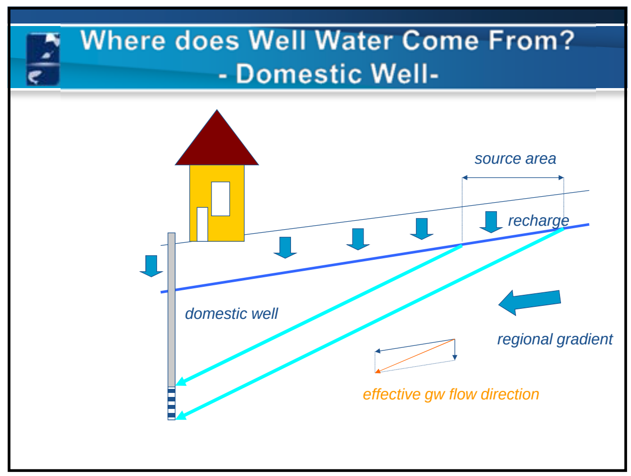
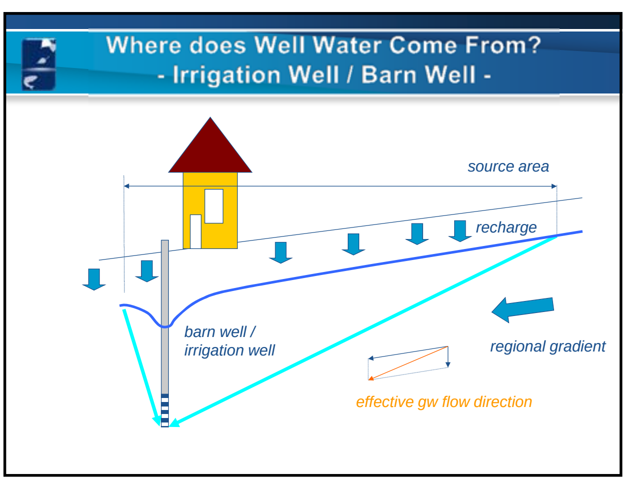
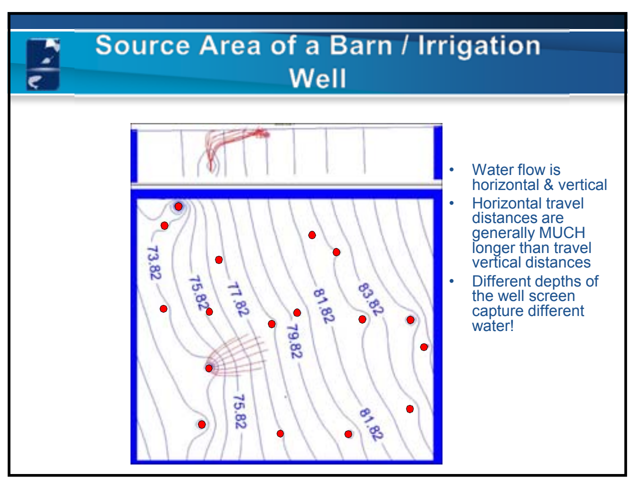
Surface Water Quality
Ground Water Quality
2000s - now
Clean Water Act /
CA Porter-Cologne:
TMDL
2010s - future
CA Porter-Cologne:
Dairy Order
ILRP/Ag Orders
CV-SALTS
Nonpoint Sources of Pollution

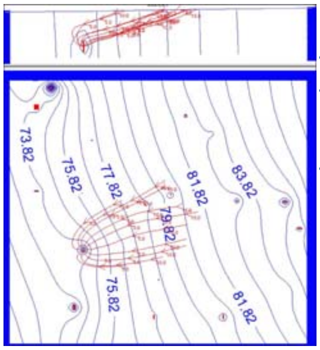

Regulatory Approaches to Groundwater Protection and Monitoring
Infiltration
Unsaturated zone
Volatilization and diffusion
Capillary zone
Water table
Saturated zone
Separate phase fuel
Dilution
Anaerobic biodegradation
Aerobic biodegradation
Modified from: EOS, Transactions, AGU 2001


Where does Well Water Come From?
- Domestic Well-
source area
recharge
domestic well
regional gradient
effective gw flow direction


Where does Well Water Come From?
- Irrigation Well / Barn Well -
source area
recharge
barn well /
irrigation well
regional gradient
effective gw flow direction

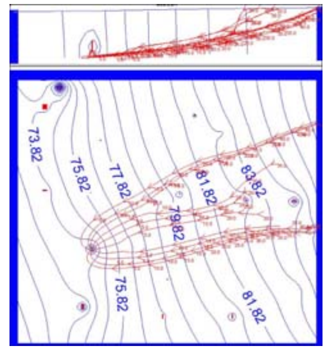

Source Area of a Barn / Irrigation Well
73.82
75.82
77.82
79.82
81.82
83.82
75.82
81.82
Water flow is horizontal & vertical
Horizontal travel distances are generally MUCH longer than travel vertical distances
Different depths of the well screen capture different water!

Source Area of a Barn / Irrigation Well



- Water flow is horizontal & vertical
- Horizontal travel distances are generally MUCH longer than travel vertical distances
- Different depths of the well screen capture different water!

Source Area of a Barn / Irrigation Well



- Water flow is horizontal & vertical
- Horizontal travel distances are generally MUCH longer than travel vertical distances
- Different depths of the well screen capture different water!

Source Area of a Barn / Irrigation Well

Why is Nonpoint Source Pollution Different from Point Source Pollution of Groundwater?

- Scale
  - Millions of acres vs. 1-10 acres
- Intensity
  - Within ~1 order magnitude above MCL vs. many orders of magnitude above MCL
- Hydrologic Function
  - Recharge vs. non-leaky
- Frequency
  - Ongoing/seasonally repeated vs. incidental
- Heterogeneity & Adjacency

Challenges to Regulating Nitrate

Point Sources of Pollution

1970s - now
Clean Water Act /
CA Porter-Cologne:
NPDES Permits

1980s - now
Superfund, TSCA, RCRA

Surface Water Quality

Ground Water Quality

2000s - now
Clean Water Act /
CA Porter-Cologne:
TMDL

2010s - future
CA Porter-Cologne:
Dairy Order
ILRP/Ag Orders
CV-SALTS

Nonpoint Sources of Pollution

Focus: Enforcement Monitoring

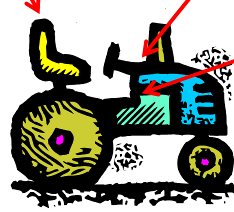
Example of Working with a Regulation: Speed Limit

Responsible Party: **Driver**

Feedback: **Speedometer**

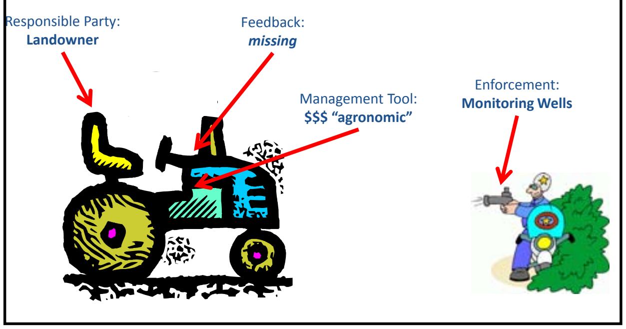
Management Tool: **Brakes**

Enforcement: **Radar Controls**



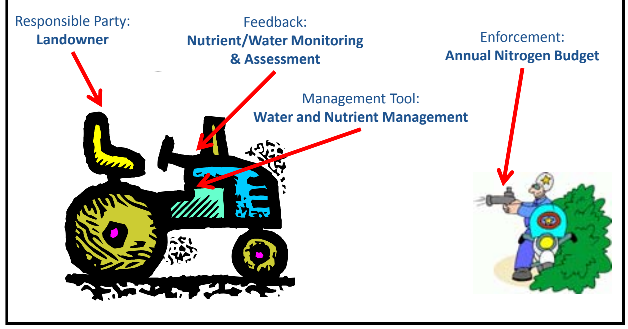
Focus: Enforcement Monitoring

Applying Point Source Approach to Nonpoint Source:



Focus: Enforcement Monitoring

Alternative Monitoring Approach to Nonpoint Source:



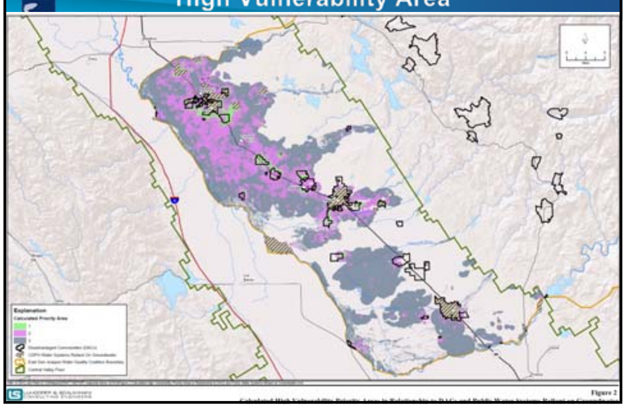
Key Elements to Future "Groundwater" Monitoring of NPS

- Three-track monitoring:
  - Enforcement: Monitor/report key outcomes of farm management practices, e.g., **annual nitrogen budgets** – "proxy" for measuring "groundwater discharge"
  - Research: link "proxy monitoring" to actual groundwater discharge at intensely monitored sites & using models (**mgmt practice evaluation**)
  - Assurance: **Regional trend monitoring** network (e.g., GAMA)

STEP 1: GROUNDWATER ASSESSMENT
High Vulnerability Areas: Key Criteria (ESJV Coalition)

- Hydrogeologically high vulnerability
  - statistical analysis of groundwater nitrate occurrence based on hydrogeology, soils, depth to groundwater, landscape slope, recharge
- Further prioritization (high – 1, medium – 2, low – 3):
  - Exceedances of water quality objectives,
  - Proximity to areas contributing recharge to urban and rural communities that rely on groundwater as a source of supply,
  - Existing field and operational practices that are possibly the cause or source of groundwater quality degradation,
  - The largest acreage commodity types comprising up to at least 80 percent of irrigated agriculture in the high vulnerability areas,
  - Legacy or ambient groundwater conditions,

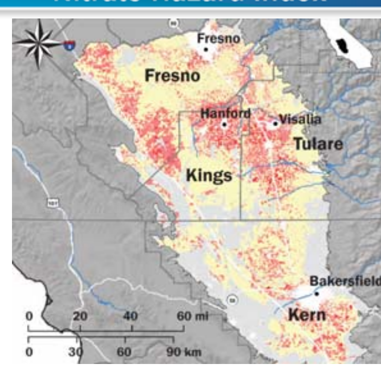
Eastern San Joaquin Valley Coalition: High Vulnerability Area



Another Vulnerability Scheme: Nitrate Hazard Index

Based on:

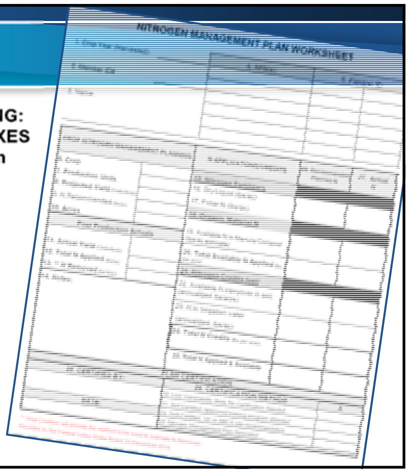
Soil
Crop
Irrigation



Dzurella, Pettygrove et al., Journal Soil Water Conservation, 2015

STEP 2: MONITORING (three-pronged)

A: PROXY MONITORING: FARM NITROGEN FLUXES Eastern San Joaquin Valley



Focus: Enforcement Monitoring

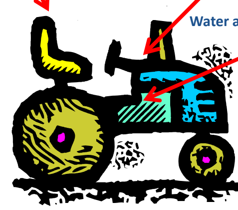
Alternative Monitoring Approach to Nonpoint Source:

Responsible Party: **Landowner**

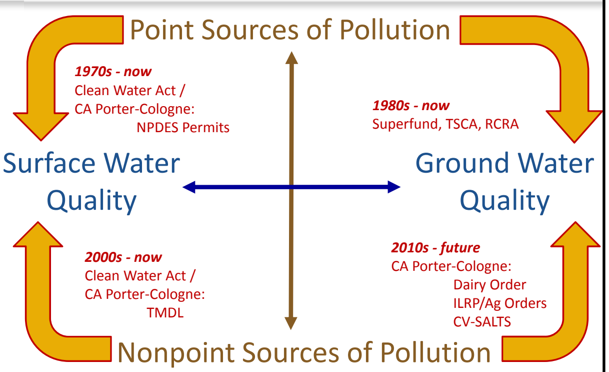
Feedback: **Nutrient/Water Monitoring & Assessment**

Management Tool: **Water and Nutrient Management**

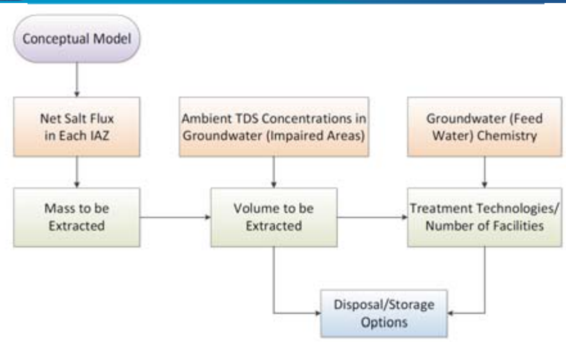
Enforcement: **Annual Nitrogen Budget** + **Management Practice Assessment** + **Regional Trend Monitoring**



Challenges to Regulating Nitrate



Addressing Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS)



CV Salinity Coalition - SSALTS 2 Final Report, 9/2014

Salt removal needed in the Central Valley 2009 Recycled Water Policy, 1968 Antidegradation Policy

Central Valley Zone	IAZ	Acres (x1000)	Square Miles	TDS Loading for IAZ (tons) 50%	Original	200%	GW [TDS] mg/L	Pumped GW [TDS] mg/L	TDS Removed from each IAZ (tons) 50%	Original	200%	Volume Needed to be Removed (MGD) 50%	Original	200%	Volume Concentrate - 90% Efficiency (MGD) 50%	Original	200%	Brine [TDS] mg/L
Northern Central	1	391	611	26,722	53,444	107,320	370	370	26,722	53,444	107,318	47	95	190	5	9	19	3,700
	2	744	1,163	33,625	68,070	135,320	201	201	33,624	68,069	135,317	110	222	442	11	22	44	2,010
	3	712	1,112	138,133	275,481	550,961	583	583	138,131	275,476	550,952	155	310	620	16	31	62	5,830
	4	358	560	27,624	55,248	110,496	761	761	27,623	55,247	110,494	24	48	95	2	5	10	7,610
	5	612	957	26,310	53,295	106,589	329	329	26,310	53,294	106,587	52	106	213	5	11	21	3,290
	6	668	1,044	320,310	640,619	1,280,502	1,060	1,060	320,304	640,608	1,280,481	198	397	793	20	40	79	10,600
	7	342	534	13,572	27,143	54,287	398	398	13,571	27,143	54,286	22	45	89	2	4	9	3,980
Middle Central	8	872	1,362	41,332	82,665	165,329	438	438	41,332	82,663	165,326	62	124	248	6	12	25	4,380
	9	756	1,181	56,668	113,335	226,670	961	961	56,667	113,333	226,667	39	77	155	4	8	15	9,610
	10	180	282	110,518	220,837	441,674	842	842	110,516	220,833	441,667	86	172	344	9	17	34	8,420
	11	425	664	151,320	302,639	605,279	565	565	151,317	302,634	605,269	176	351	703	18	35	70	5,650
	12	346	540	165,527	331,055	662,110	825	825	165,525	331,049	662,099	132	263	527	13	26	53	8,250
	13	1,055	1,648	105,827	211,655	422,147	648	648	105,826	211,651	422,140	107	214	427	11	21	43	6,480
	22	513	801	445,603	890,640	1,781,845	1,160	1,160	445,595	890,625	1,781,815	252	504	1,008	25	50	101	11,600
Southern Central	14	685	1,071	565,557	1,131,114	2,262,984	3,375	3,375	565,548	1,131,096	2,262,946	110	220	440	11	22	44	33,750
	15	911	1,423	119,500	239,001	478,002	1,000	1,000	119,498	238,997	477,994	78	157	314	8	16	31	10,000
	16	306	478	59,029	69,485	90,736	575	575	59,028	69,484	90,734	67	79	104	7	8	10	5,750
	17	364	569	77,841	155,682	310,962	520	520	77,840	155,679	310,957	98	196	392	10	20	39	5,200
	18	869	1,358	119,739	228,940	447,343	598	598	119,737	228,936	447,336	131	251	491	13	25	49	5,980
	19	874	1,365	744,724	1,489,447	2,979,857	11,300	11,300	744,711	1,489,422	2,979,808	43	86	173	4	9	17	113,000
	20	451	705	72,086	140,691	278,400	870	870	72,084	140,689	278,395	54	106	210	5	11	21	8,700
	21	707	1,105	162,101	303,940	588,397	335	335	162,099	303,935	588,387	317	595	1,152	32	60	115	3,350
Total/Average		13,141	20,533		7,084,426					7,084,309			4,620		236	462	913	11,415
				Northern CV	1,173,300				Northern CV	1,173,280					Northern CV	122		
				Middle CV	2,152,825				Middle CV	2,152,790					Middle CV	171		
				Southern CV	3,758,301				Southern CV	3,758,2[illegible]					Southern CV	169		

Pump 4,620 MGD => brine disposal 462 MGD with 11,000 mg/L

CV Salinity Coalition - SSALTS 2 Final Report, 9/2014

Salt removal needed in the Central Valley 2009 Recycled Water Policy, 1968 Antidegradation Policy: Salinity degraded areas only

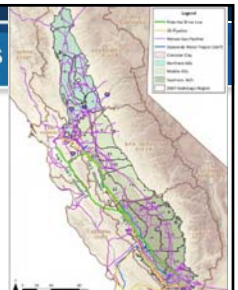
Central Valley Zone	IAZ	Acres (x1000)	Square Miles	TDS Loading for IAZ (tons) 50%	Original	200%	GW [TDS] mg/L	Pumped GW [TDS] mg/L	TDS Removal from each IAZ (tons) 50%	Original	200%	Volume Needed to be Removed (MGD) 50%	Original	200%	Volume Concentrate - 90% Efficiency (MGD) 50%	Original	200%	Brine [TDS] mg/L
Northern Central	1	391	611	26,722	53,444	107,320	370											
	2	744	1,163	33,625	68,070	135,320	201											
	3	712	1,112	138,133	275,481	550,961	583											
	4	358	560	27,624	55,248	110,496	761											
	5	612	957	26,310	53,295	106,589	329											
	6	668	1,044	320,310	640,619	1,280,502	1,060	2,509	320,304	640,608	1,280,481	84	168	335	8	17	33	10,600
	7	342	534	13,572	27,143	54,287	398											
Middle Central	8	872	1,362	41,332	82,665	165,329	438											
	9	756	1,181	56,668	113,335	226,670	961	1,001	56,667	113,333	226,667	37	74.3	149	4	7	15	9,610
	10	180	282	110,518	220,837	441,674	842	1,359	110,516	220,833	441,667	53	106.6	213	5	11	21	8,420
	11	425	664	151,320	302,639	605,279	565											
	12	346	540	165,527	331,055	662,110												
	13	1,055	1,648	105,827	211,655	422,147	648											
	22	513	801	445,603	890,640	1,781,845	1,160	5,845	445,595	890,625	1,781,815	50	100.0	200	5	10	20	11,600
Southern Central	14	685	1,071	565,557	1,131,114	2,262,984	3,375	4,987	565,548	1,131,096	2,262,946	74	148.8	298	7	15	30	33,750
	15	605	1,423	79,360	158,720	317,441	1,000	1,000	79,359	158,718	317,436	52	104.1	208	5	10	21	10,000
	16	306	478	59,029	69,485	90,736	575											
	17	364	569	77,841	155,682	310,962	520											
	18	869	1,358	119,739	228,940	447,343	598											
	19	874	1,365	744,724	1,489,447	2,979,857	11,300	11,300	744,711	1,489,422	2,979,808	43	86.5	173	4	9	17	113,000
	20	451	705	72,086	140,691	278,400	870											
	21	707	1,105	162,101	303,940	588,397	335	1,554	162,099	303,935	588,387	68	128.3	248	7	13	25	3,350
Total/Average		12,835	20,533		7,004,146					4,948,571			916		46	92	182	25,429
				Northern CV	1,173,300				Northern CV	640,608					Northern CV	17		
				Middle CV	2,152,825				Middle CV	1,224,792					Middle CV	28		
				Southern CV	3,678,020				Southern CV	3,083,171					Southern CV	47		

Pump 920 MGD => brine disposal 92 MGD with 25,000 mg/L

CV Salinity Coalition - SSALTS 2 Final Report, 9/2014

Costs of Alternatives

- No action: $6 - $10 billion annually
  - Direct costs: $1 – 1.5 billion/a
  - Production in goods and services reduced by $5 - $9 billion/a (27,000 – 53,000 jobs)
- Alternatives
  - Wells, desalters, brine line for 1.2 MAF/a of salty gw
  - Brine disposal:
    - Treatment in EBMUD WWTP or others
    - New ocean outfall
  - Deep injection / hydraulic fracturing
  - Salt accumulation areas (TLB)
  - Source control
    - Land management
    - BMPs in food processing, industry, urban
- Net cost: $1.7 billion annually
  - Actual cost: $1,400 - $2,200 / af of product water
  - Potential revenue: $ 650 / af of product water
  - Net cost, capital, O&M: $50 billion / 30 years



CV Salinity Coalition - SSALTS 2 Final Report, 9/2014

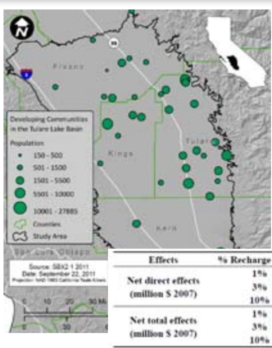
Future of Groundwater Management in Agricultural Regions:

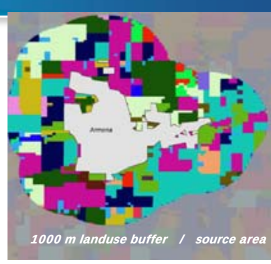
Opportunity for creative solutions to **simultaneously** address

- groundwater supply enhancement
- groundwater quality improvement
- drinking water protection
- economic viability of agriculture

High irrigation efficiency + High nutrient use efficiency + CLEAN groundwater recharge

Example: Agricultural Landuse Buffers





Effects	% Recharge Basins	0/100	10/90	33.3/66.7	50/50	66.7/33.3	90/10	100/0
Net direct effects (million $ 2007)	1%	16.0	11.8	1.9	−5.2	−12.3	−22.1	−26.4
	3%	14.8	10.6	0.9	−6.0	−12.9	−22.6	−26.8
	10%	10.4	6.6	−2.4	−8.8	−15.3	−24.2	−28.1
Net total effects (million $ 2007)	1%	33.6	24.7	3.9	−10.9	−25.7	−46.5	−55.4
	3%	31.0	22.3	1.9	−12.6	−27.1	−47.5	−56.2
	10%	21.9	13.8	−5.1	−18.5	−32.0	−50.9	−59.0

Mayzelle et al. J. of Water, 2015

Sustainable Groundwater Management Act of 2014

SEC. 2.

Section 113 is added to the Water Code, to read:

113.

It is the policy of the state that **groundwater resources be managed sustainably for long-term reliability and multiple economic, social, and environmental benefits** for current and future beneficial uses. Sustainable groundwater **management is best achieved locally** through the development, implementation, and updating of plans and programs based on the best available science.

[emphasis added]

Sustainability = No "Undesirable Results"

10721. Unless the context otherwise requires, the following definitions govern the construction of this part:

(u) **"Sustainable groundwater management" means** the management and use of groundwater in a manner that can be maintained during the planning and implementation horizon **without causing undesirable results**.

(w) **"Undesirable result" means one or more of the following** effects caused by groundwater conditions occurring throughout the basin (Section 10721 (w)):

(1) **Chronic lowering of groundwater levels** indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon. Overdraft during a period of drought is not sufficient to establish a chronic lowering of groundwater levels if extractions and recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods.

(2) Significant and unreasonable **reduction of groundwater storage**.

(3) Significant and unreasonable **seawater intrusion**.

(4) Significant and unreasonable **degraded water quality**, including the migration of contaminant plumes that impair water supplies.

(5) Significant and unreasonable **land subsidence** that substantially interferes with surface land uses.

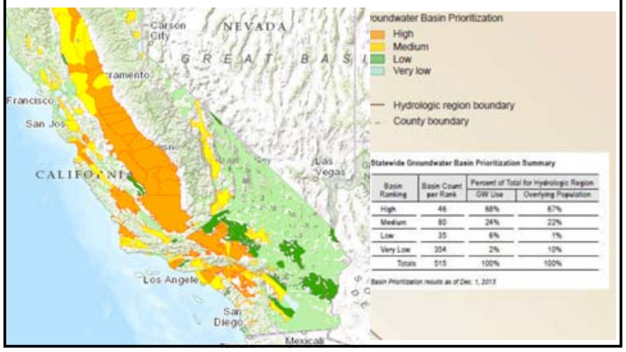
(6) **Surface water depletions** that have significant and unreasonable adverse impacts on beneficial uses of the surface water.

[emphasis added]

Implementation of SGMA

- Establishment of local Groundwater Sustainability Agencies (GSAs)
  - by June 2017
- Preparation of Groundwater Sustainability Plan (GSP)
  - by June 2022 (critically overdrafted basins: 2020)
- Implementation of GSP
  - reach goals by 2042
- Review, technical assistance, and funding by DWR (5 yearly)
- Enforcement by SWRCB

Medium and High Priority Groundwater Basins (CASGEM)



Statewide Groundwater Basin Prioritization Summary

Basin Ranking	Basin Count per Rank	Percent of Total for Hydrologic Region	
		GW Use	Overlying Population
High	46	68%	67%
Medium	80	24%	22%
Low	35	6%	1%
Very Low	354	2%	10%
Totals	515	100%	100%

Basin Prioritization results as of Dec. 1, 2013

Groundwater Management Tools

- Data collection, monitoring, modeling, assessment
- Supply management
- Demand management
- Stakeholder management

Challenges for Regulating Nonpoint Sources of Groundwater

- **SCIENCE NEEDS**
  - NPS source control methods
  - NPS pollution soil/groundwater fate, transport
  - NPS pollution assessment, monitoring tools
- **REGULATORY FRAMEWORK**
  - Enforcement: Paradigm shift in monitoring approaches
- **AGRICULTURE (largest NPS)**
  - Socio-cultural change needed to work within new regulatory framework