SB X2-1
Nitrate in Groundwater
Report to the Legislature

Interagency Task Force Meeting
May 3, 2011

SB X2-1
Nitrate in Groundwater
Report to the Legislature

OVERVIEW AND KEY OUTCOMES

ITF Meeting #2
May 3, 2011

Thomas Harter, Principal Investigator, Professor

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UCD Project Team Leaders

- Jeannie Darby, Water Treatment
- Graham Fogg, Subsurface Hydrology
- Thomas Harter, Subsurface Hydrology
- Richard Howitt, Agricultural Economics
- Katrina Jessoe, Water Quality Economics
- Jay Lund, Water Resources Management
- Jim Quinn, Spatial Data Mgmt. in Environmental Policy
- Stu Pettygrove, Soils and Nutrient Management
- Tom Tomich, Agricultural Sustainability Institute
- Joshua Viers, Spatial Data Management in Environmental Sciences

FUNDING PROVIDED BY:
- **Proposition 84 / SB X 2-1 => CDPH => SWRCB**

UCD Project Team

- Aaron King
- Allan Hollander
- Alison McNally
- Anna Fryjoff-Hung
- Cathryn Lawrence
- Daniel Liptzin
- Dylan Boyle
- Elena Lopez
- Giorgos Kourakos
- Holly Canada
- Josue Medellin-Azuara
- Kristin Dzurella
- Kristin Honeycutt
- Mimi Jenkins
- Nate Roth
- Todd Rosenstock
- Vivian Jensen

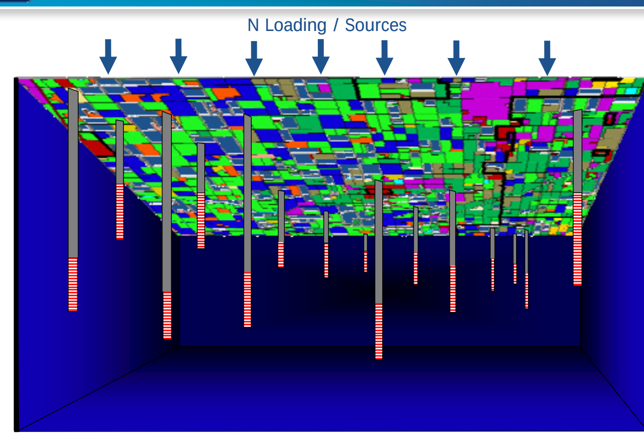
- …many undergraduate students….

Motivation

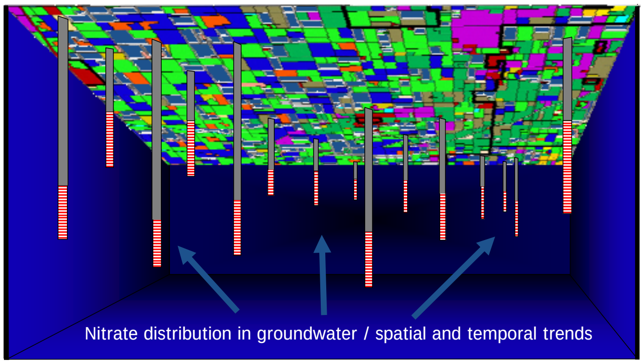
- Nitrate most common groundwater pollutant
- Tulare Lake Basin and Salinas Valley among most affected groundwater basins in CA
- Domestic well water typically untreated / unknown quality
- High nitrate costly to treat for small / disadvantaged communities

How can this be best fixed?

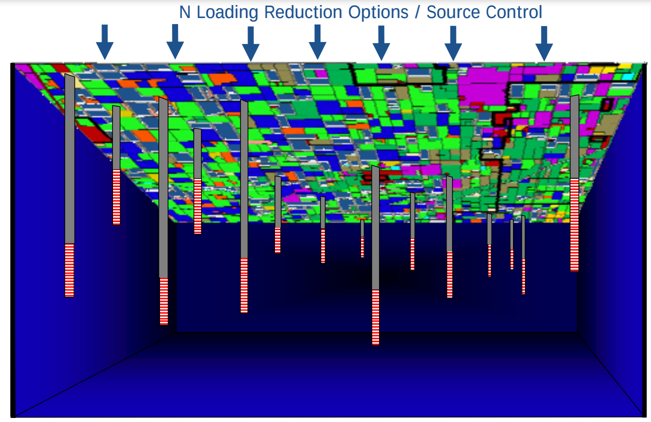
Key Study Outcomes: Issues



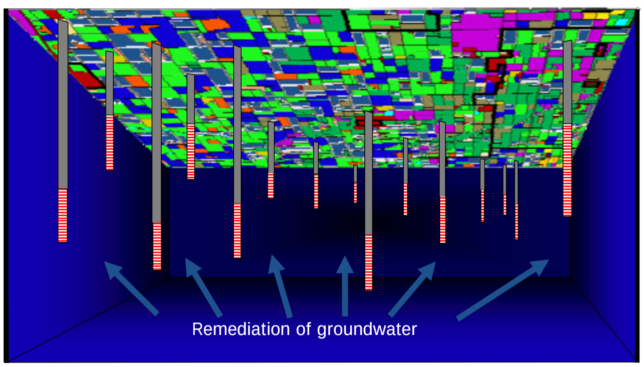
Key Study Outcomes: Issues



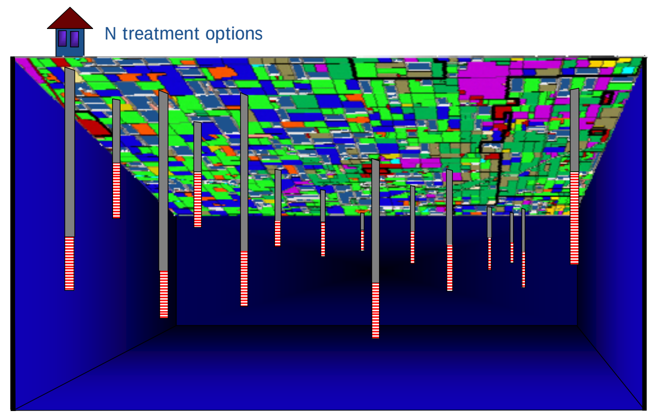
Key Study Outcomes: Actions



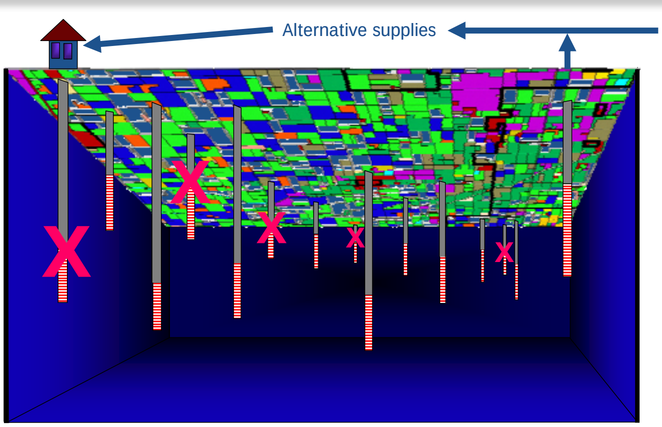
Key Study Outcomes: Actions



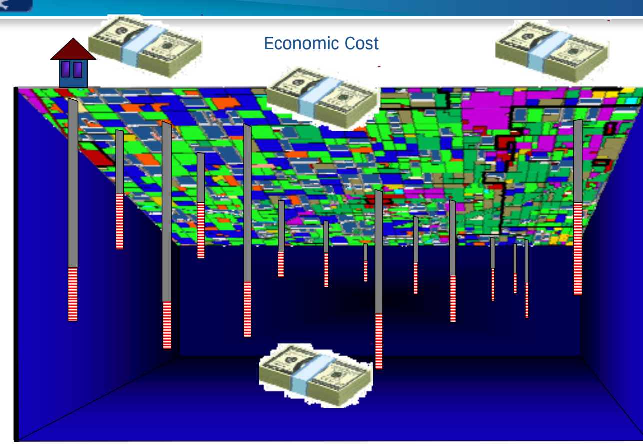
Key Study Outcomes: Actions



Key Study Outcomes: Actions

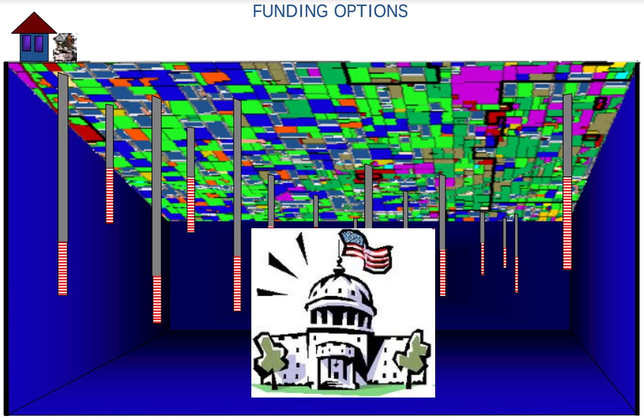


Key Study Outcomes: Costs

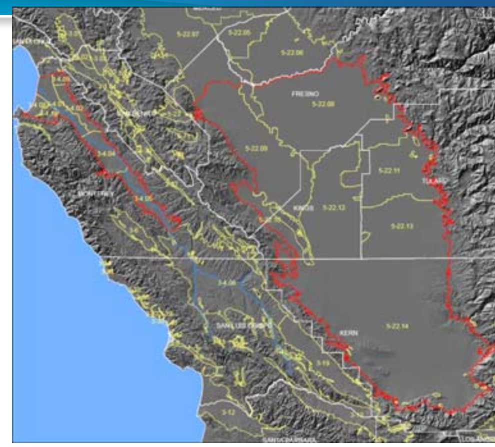


Key Study Outcomes: Funding

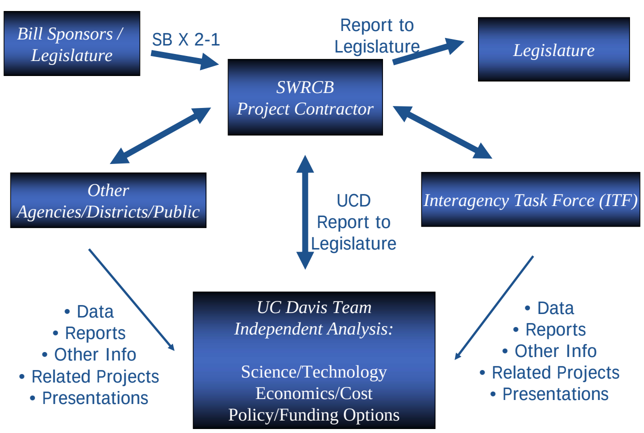
FUNDING OPTIONS



Project Area



UC Davis Role



Timeline

- Data collection and analysis – 2nd Quarter 2011
- Economic and policy analysis – 3rd Quarter 2011
  - **2nd ITF Meeting – May 3, 2011**
- Draft report – September 2011
  - **3rd ITF Meeting – October 2011**
- Final report – December 2011
- SWRCB Report to Legislature – April 2012
- Directed follow-up studies – April 2013

Related Prior/Ongoing Studies

- Nitrate Report to Legislature, 1988
  - Identify nitrate sensitive areas / priority areas for nitrate control programs
  - Establish nitrate management programs / develop best management practices
  - Establish research & demonstration projects on nitrate control (irrigation, fertilizer, manure)
- LLNL Nitrate Report to SWRCB, 2002
  - Current state of approaches to assess nitrate in groundwater
  - Recommendation for improved characterization & assessment (sources, gw age, gw quality)
- USGS National Nitrate Vulnerability Assessment, 2002
- Drinking Water Source Assessment Program, 2003
- Nitrate Hazard Index, 2005
- CV SALTS pilot projects, 2010
- GAMA, ongoing
  - Statewide asssessment of public sources (USGS)
  - Tulare County domestic well survey (SWRCB)
  - Special projects (LLNL)
- CDPH, AB 2222, ongoing
  - Communities with contaminated groundwater as a primary source of drinking water
- UC Davis work on groundwater nitrate (Salinas Valley, CV dairies)
- UC Davis Ag Sustainability Institute: CA Nitrogen Assessment
- ITF and Other Agency Databases / Reports / Studies

integrate into SB X 2-1 report

Related Policy Activities

- Central Valley Dairy General Order
- Central Valley Irrigated Lands Regulatory Program (CV ILRP)
- Central Valley Salt & Nitrate Basin Plan Amendment (CV SALTS)
- Central Coast Agricultural Order Renewal
- Others?

Guidance from SB X 2-1 report

Key Messages

- Nitrate problem will likely worsen and not improve for several decades
- Largest regional sources are agricultural fertilizers and animal wastes; other sources are locally relevant
- Nitrogen loading reductions possible, but will take decades to benefit drinking water sources
- Short-term solutions are blending, treatment, and alternative water supplies
- Treatment is unaffordable for most small communities
- Promising funding options, incentives, and regulatory tools are identified
- Incoherence and inaccessibility of data prohibit better and continuous assessment

Framework for Funding and Regulatory Options

Major Outcome Options (Examples / Possible Evaluations)

ALTERNATIVE	IMPACT			
	Economic Cost	State Budget Cost	Ground-water Nitrate Concen-tration	Social Impact
0. No action alternative (no load reduction, no remediation, current treatment)				
1. Source load reduction[1] only				
2. Source load reduction[1] and complete one-time aquifer remediation				
3. Complete and continuous aquifer remediation only				
4. Source load reduction[1] and limited time (e.g., 40 years) water treatment/alternative water supply				
5. Intermediate source load reduction (slow gw degradation) with continuous alternative water supply/treatment				
6. Water treatment/alternative water supply only, indefinite time-frame				

[1] source load reduction here implies source load reduction to a degree such that any resulting recharge is in compliance with beneficial use designation of the receiving water body.

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LAND USE & POTENTIAL SOURCE LOADING

ITF Meeting #2
May 3, 2011

Kristin Dzurella, Thomas Harter, Anna Fryjoff-Hung, Allan Hollander, Vivian Jensen, Aaron King, Dan Liptzin, Elena Lopez, Alison McNally, Josue Medellin, Stu Pettygrove, Jim Quinn, Todd Rosenstock, Josh Viers

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N Loading

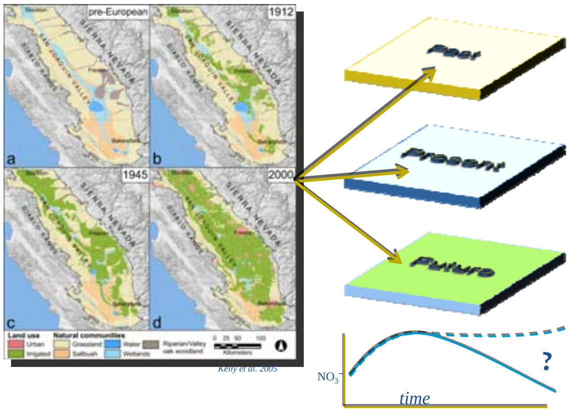
How big is the problem? Where is the problem?

Our scope is in part to determine sources and estimated contributions to groundwater nitrate contamination.

- Land Uses
  - Urban:
    - Sewer / Septic / Imp. Runoff
    - Wastewater Treatment Plants
  - Ag: Cropping Patterns
    - Fertilizer Application
    - N Fixation + uptake *(sources - sinks)*
    - Irrigation
  - CAFOs / Dairies / Food Proc.
- Soils
- Groundwater Basins
  - Aquifer Characterization
  - Recharge Zones
  - Connectivity to Surface Water
- Wells
  - Public Drinking Water
  - Private Domestic
  - Monitoring
  - Irrigation Supply
- Drinking Water Treatment Facilities
  - Water Supply (Facilities, Networks)

(receptors)

N Loading parameterization
Over what time frames?



Potential Nitrate Loss

CROP	Applied N (kg/ha)	Harvested N (kg/ha)	Leached N (kg/ha)
Almonds	201.0	122.7	58.3
Apples	66.7	17.5	42.6
…	…	…	…
Wheat	198.0	131.2	47.1

61 total land use / crop types estimated.

Potential Loss to Groundwater → Nitrate Leaching Load

$N_{leached}$

$= N_{applied} - N_{atm\_losses} - N_{harvested}$

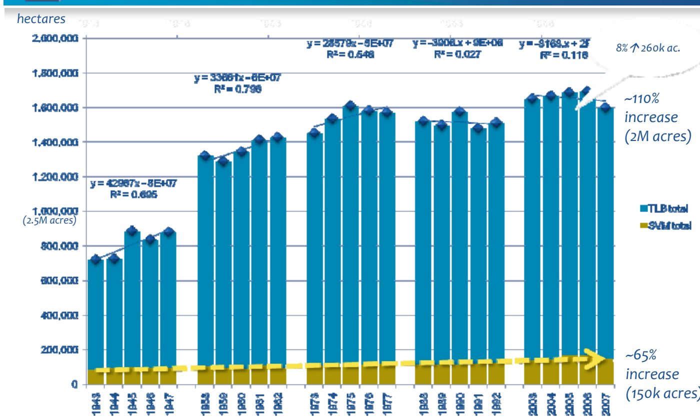
$= 0.9^{*} N_{applied} - N_{harvested}$

- Crop groups were derived from DWR.
- Applied N and Harvested N was estimated from California Nitrogen Assessment (UC Davis ASI).
- Leached N calculations were developed by Lintzin & Harter.

Past Agricultural Land Use

- Time Frame(s):
  - ±2 years (ie 5 year blocks) years every 15 years
    - 1945
    - 1960
    - 1975
    - 1990
    - 2005
- Methods:
  - County level crop use reports
  - Historical USGS maps
- Results:
  - *In Progress*

Growth in Agriculture

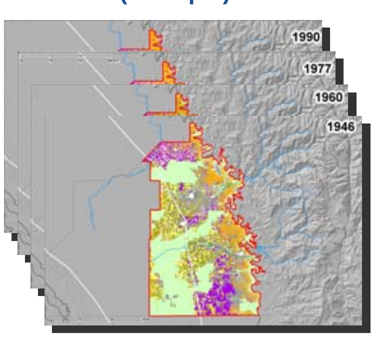


Simulating Historic Crop Maps

Methods

- Use land cover maps and Ag Commissioner reports for total acreage and acreage by crop
- If acreage has increased, prune less suitable or more isolated sites to estimate historic footprint
- If acreage has decreased, add most suitable sites
- Estimate average applications/acre
- Estimate N removed from harvest records
- Estimate surplus N leached from (corrected) difference

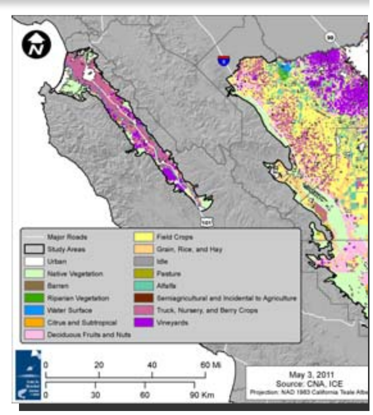
Results (example)



Present

- Time Frame(s):
  - 2000-2010
- Methods:
  - Land Use Estimates (CAML 2.0)
    - Farmland Mapping Monitoring Program (2008) and Dept. Pest. Reg.
    - DWR by county (date varies)
    - Cropland Data Layer from National Agricultural Statistics Service (2009)
    - CDF Multisource Land Cover (2002)
- Results:

Study Basin	Potential N Load Leached (Mg/yr)
Salinas Valley	9,688
Tulare Lake Basin	84,775



Surface Discharges

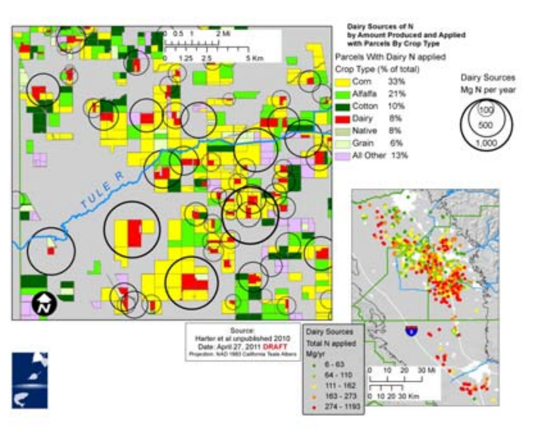
Metric Tons (Mg) of N Applied Annually in facility Discharge	WWTP (90%)	WWTP (est. 100%)	FP (reported)	FP (est. max)
By County				
Fresno	2,328	2,587	303	674
Kern	913	1,014	694	1,541
Kings	127	141	167	372
Tulare	1,580	1,756	91	203
Monterey	313	348	15	33
Basin				
TLB	4,948	5,497	1,255	2,789
SVB	313	348	15	33
Total	5,261	5,845	1,270	2,822

These are preliminary estimates and do NOT include applied solids.

Animal Sources

Preliminary

dairy N loading to land application: 114,000 Mg/yr
dairy N loading directly via corrals and lagoons: 1,000 Mg/yr



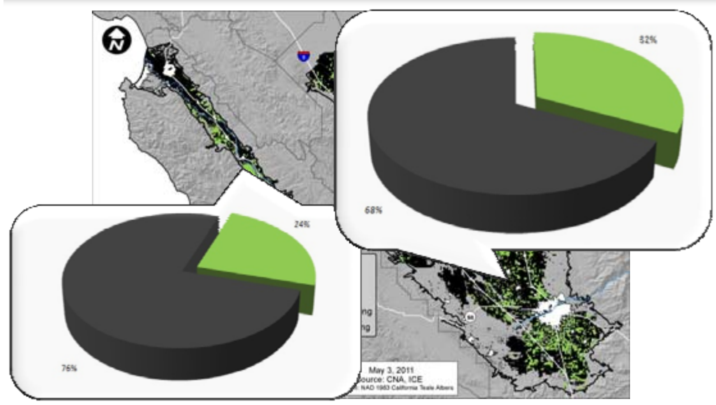
Target Threshold for Nitrate Leaching

We targeted 35 kg/ha/yr of nitrogen as a potential threshold rate for leaching from applied fertilizer.

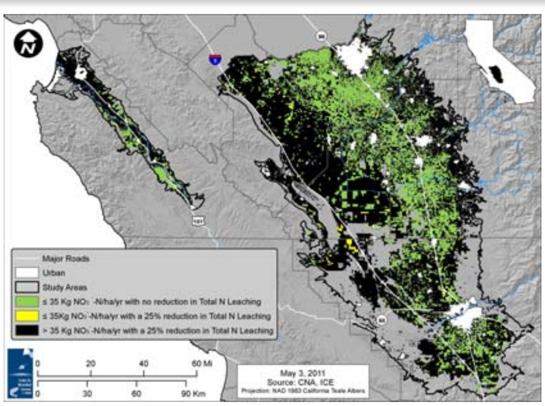
•Where does the 35 kg/ha/yr come from? Average recharge in CA irrigated ag is about 1 acft/ac/yr or 30 cm/yr

•The nitrate-nitrogen MCL (of 10 mg/L) in 30 cm/yr recharge is 30 kg/ha. Add a little over 10% for further atmospheric losses, and we have an estimated value of 35 kg/ha.

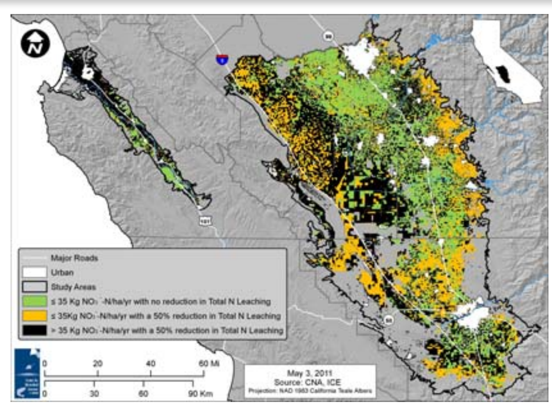
Estimated Nitrate Leaching Potential from Agriculture



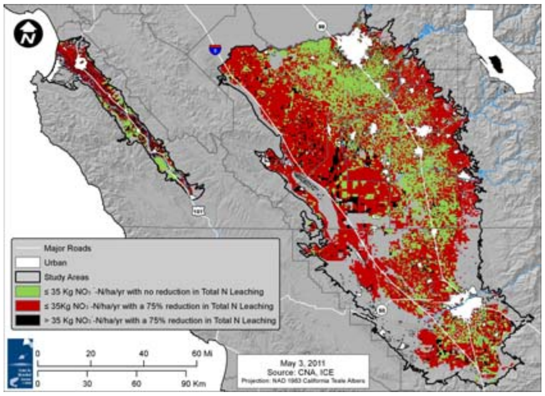
25% Reduction



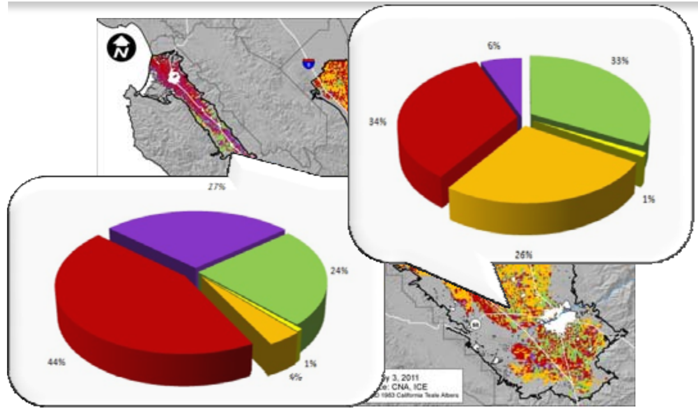
50% Reduction



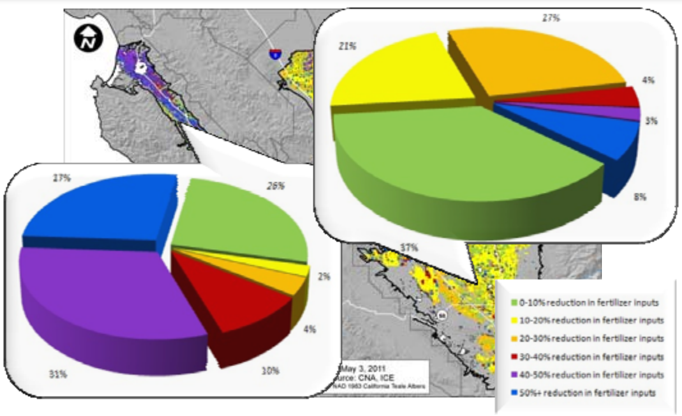
75% Reduction



Estimated Total Reduction in Leached N to achieve 35 kg/ha load target



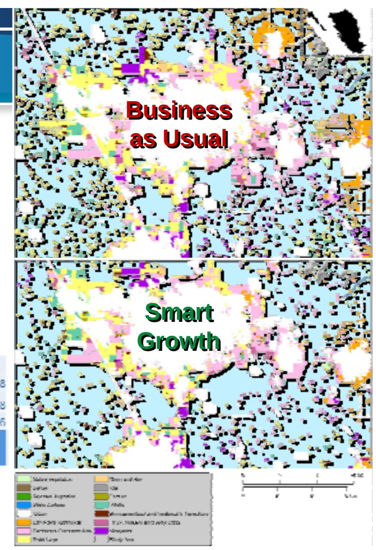
Potential for Reduction in Inputs



Future

- Time Frame(s):
  - 2050
- Methods:
  - UPlan: Based on policy scenarios
  - GIS allocation from demography and transportation attractors
  - Used for 2050 California Regional Blueprints (San Joaquin Valley, Monterey Bay Area Govt's.)
- Results:

Smart Growth	-	Business as Usual	-
Ag Ha Replaced	91,194	Ag Ha Replaced	115,078
Other Ha Replaced	34,374	Other Ha Replaced	40,928
Total Ha Replaced	125,568	Total Ha Replaced	156,006
Ag N Removed (Mg/yr)	6819	Ag N Removed (Mg/yr)	8419



Preliminary Findings

- Agricultural loading is pervasive and dominant source of nitrate throughout the study area and over time (~past 70 years).
- Historical trends portend a legacy of high nitrate losses to groundwater.
- Approximately 33% of the agricultural landscape is at or below 35 kg N / ha groundwater leaching target; however, much higher rates dominate the study area.
- Future urban development is not viewed to alter N balance substantially, but land use policies can affect localized leaching loads (and create trade-offs in agricultural revenue) and curtail domestic dependence on private wells and septic tank based wastewater treatment.

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GROUNDWATER QUALITY

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May 3, 2011

Graham Fogg, Professor
Thomas Harter, Professor
Giorgos Kourakos, Postdoctoral Fellow
Aaron King, Graduate Student
Dylan Boyle, Graduate Student

Department of Land, Air, and Water Resources
University of California, Davis
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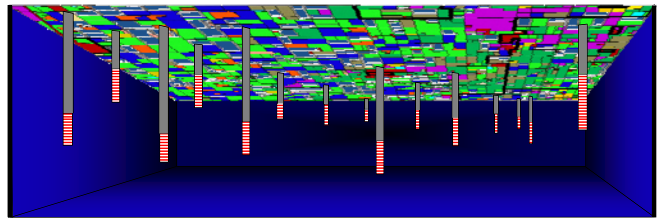
Key Questions to Address

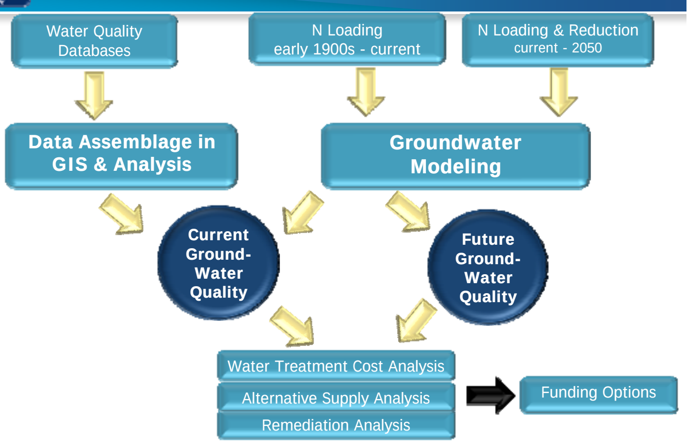
"Who currently has a nitrate problem?"

"Where else do we currently have nitrate problems, but don't know about it?"

"What will the nitrate problem be in the future (2050)?"



Dual Approach

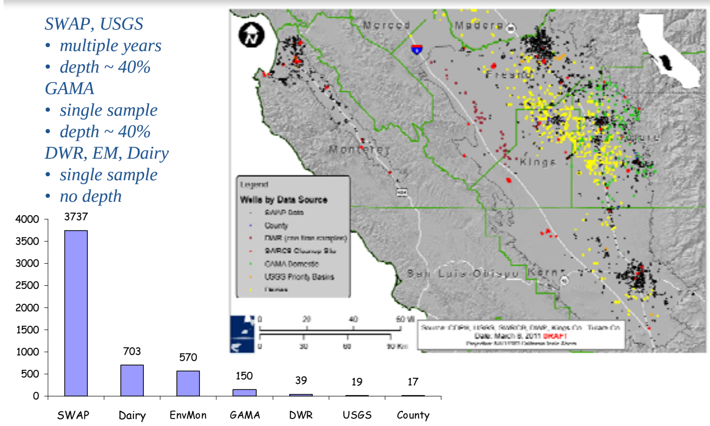


Available Nitrate Data: Sources

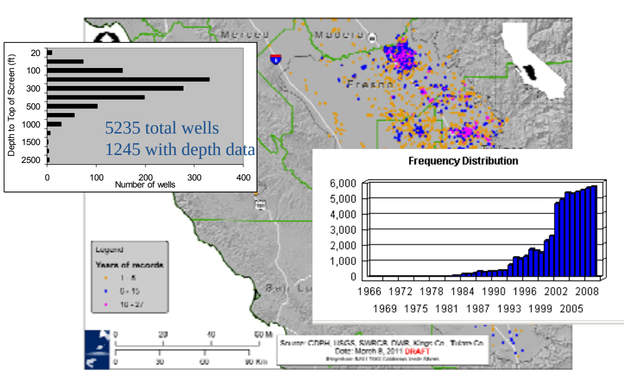
SWAP, USGS
- *multiple years*
- *depth ~ 40%*

GAMA
- *single sample*
- *depth ~ 40%*

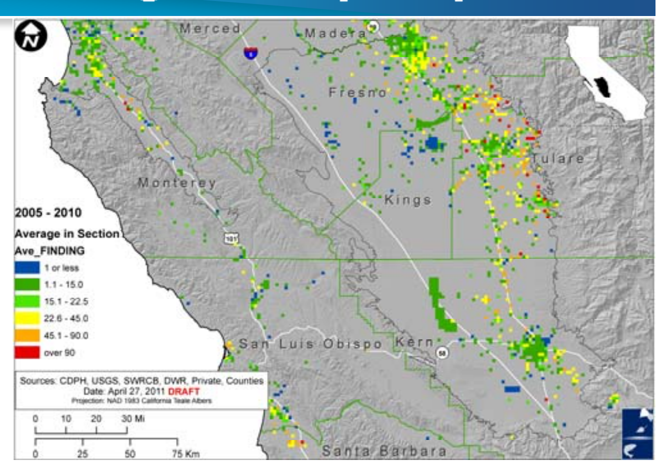
DWR, EM, Dairy
- *single sample*
- *no depth*



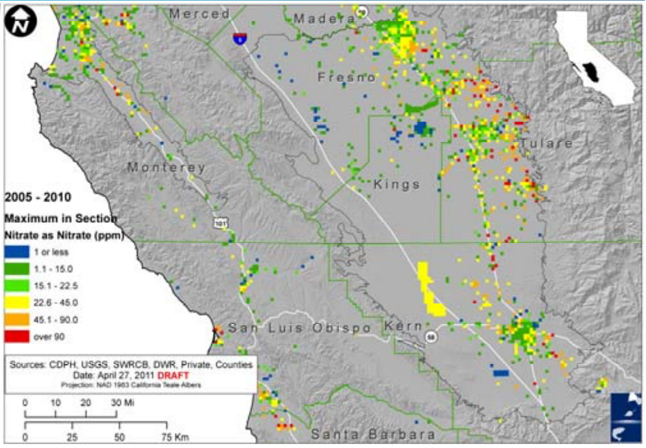
Available Nitrate Data: Period of Record and Depths



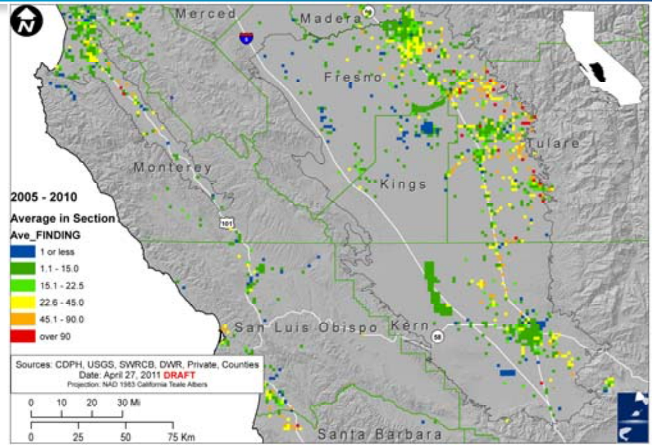
Average Nitrate per Sq. Mile



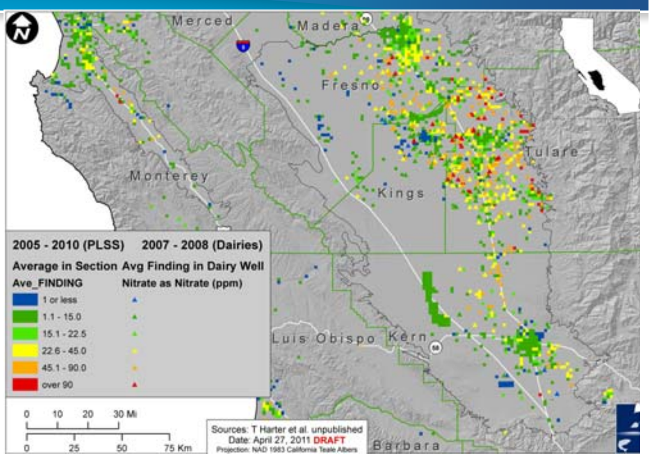
Maximum Nitrate per Sq. Mile



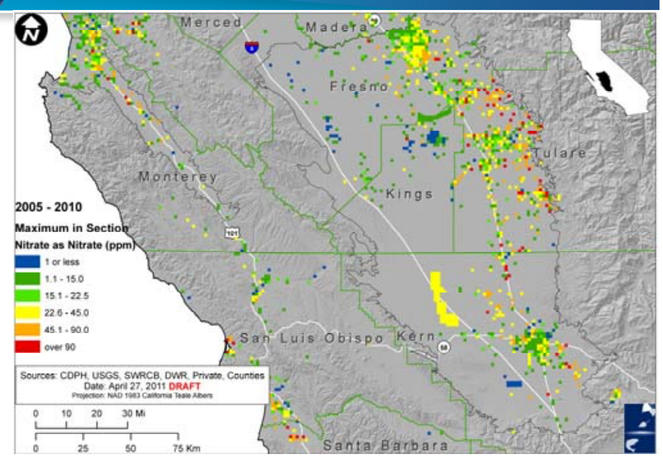
Average: Non-Dairy



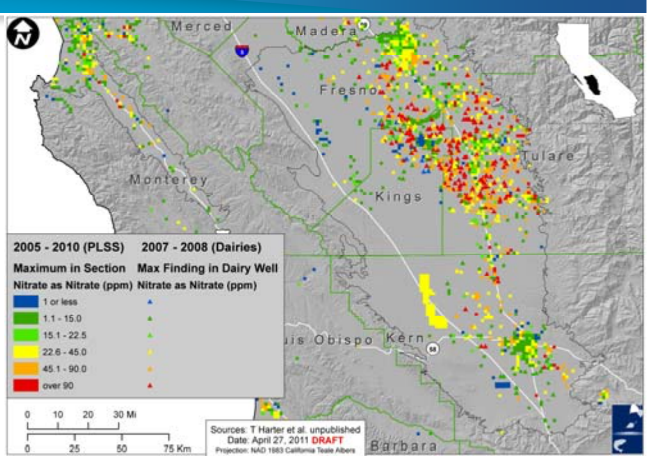
Average: Non-Dairy, Dairy



Maximum: Non-Dairy



Maximum: Non-Dairy, Dairy



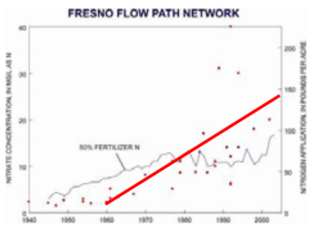
Nitrate in Wells: Long-Term Trends

	Mean Change [mg/L/yr]	Conf. Interval -95%	Conf. interval +95%
Tulare Lake Basin (Tulare County) Public Supply Wells, 1970s-current[1]	0.27 (0.41)	0.17 (0.22)	0.36 (0.59)
Salinas Valley Public Supply Wells, 1970s-current[1]	0.53	0.31	0.77
Salinas Valley Dedicated Monitoring Wells, 1990-current	2.04	1.25	2.82

[1]underlying data: all public water supply well data

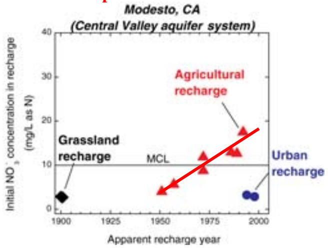
Nitrate in Wells: Long-Term Trends

Shallow Wells



Burow and others, 2007

Deep Production Wells



Burow et al., 2008; McMahon et al., 2008

Nitrate Increase per Year:
~100 mg NO3/L in 50 years ~ 2 mg/L/yr

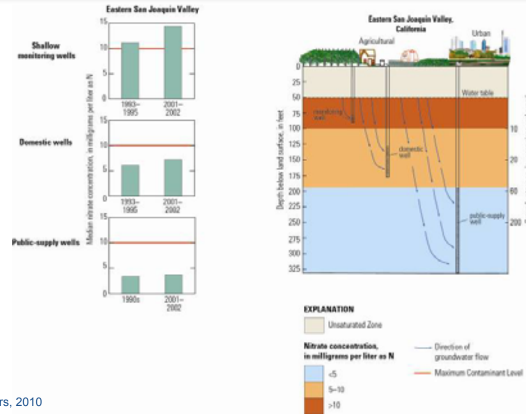
Nitrate Increase per Year:
~60 mg NO3/L in 50 years ~ 1.2 mg/L/yr

Nitrate in Wells: Long-Term Trends

~ 1.3 mg/L/yr

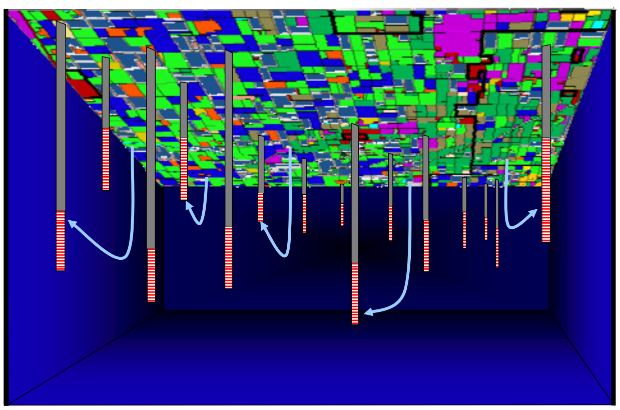
~ 0.7 mg/L/yr

~ 0.2 mg/L/yr

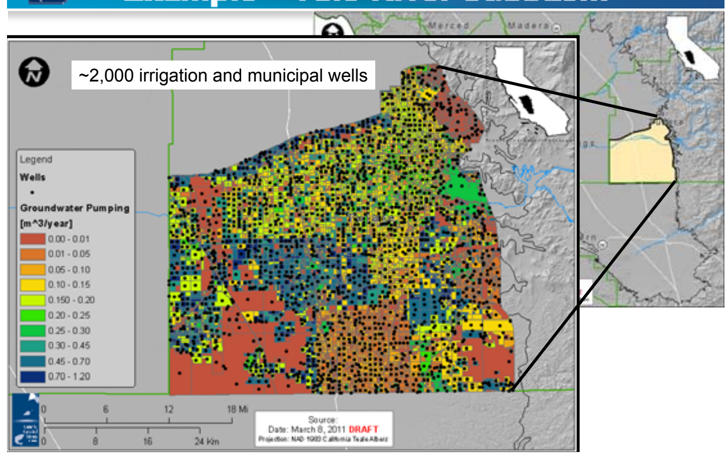


Dubrovsky and others, 2010

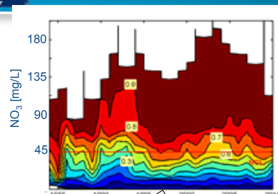
Groundwater Modeling: Conceptual Overview



Groundwater Modeling: Example – Tule River Subbasin



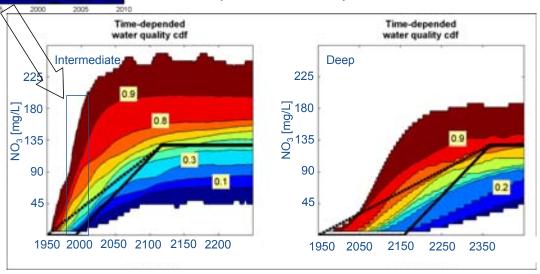
Model Prediction with Current N Loading



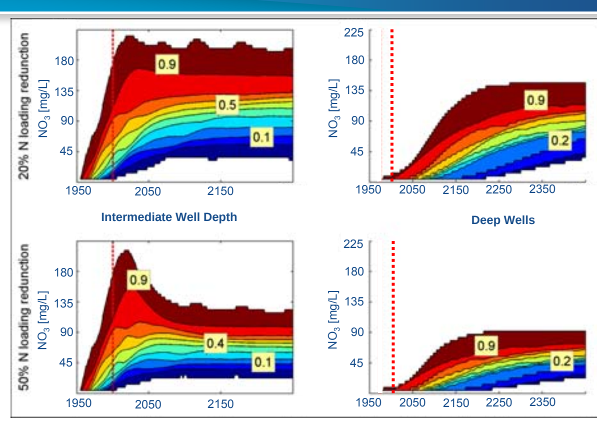
Measured Data

Model predictions:
Frequency Distribution

Preliminary modeling results for conceptual illustration only, subject to further model adjustment and calibration



Future model predictions



Preliminary modeling results for conceptual illustration only, subject to further model adjustment and calibration

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AGRICULTURAL SOURCE REDUCTION

May 3, 2011 Interagency Task Force Meeting

Dept. of Land, Air & Water Resources
Stu Pettygrove, Kristin Dzurella, Ria Debiase
Agricultural Sustainability Institute
Todd Rosenstock, Dan Liptzin
Dept. of Agricultural & Resource Economics
Josue Medellin-Azuara, Richard Howitt

Reducing Transfer of Nitrate to Groundwater from Cropland

- ➡ ❑ **Source reduction**
- ❑ Treatment and blending
- ❑ Alternative supply

Dept. of Land, Air & Water Resources
Stu Pettygrove, Kristin Dzurella, Ria Debiase
Agricultural Sustainability Institute
Todd Rosenstock,
Dept. of Agricultural & Resource Economics
Josue Medellin-Azuara, Richard Howitt

Source Reduction: *Our questions*

- What technologies are available to growers to reduce discharge of nitrate below the root zone?
- What is the potential for increased adoption, and what are the barriers to adoption?
- What is the approximate magnitude of mitigation that can be achieved?

Central premise

Reducing the gap between N applied to land and N removed in the harvested crop will, over time, reduce nitrate loading to groundwater by a similar amount and will eventually lead to reduced concentrations in groundwater.

Hypothetical example
Processing tomatoes

Scenario 1: Current	*(lb N/acre)*	
Fertilizer N applied	220	*Harvest 64% of applied N*
Harvest removal	140	
Balance	**80**	
Scenario 2: Improved		
Fertilizer N applied	190	*Harvest 79% of applied N*
Harvest removal	150	
Balance	**40**	

How does that translate into GW nitrate mitigation?

Hypothetical example

Assume percolation below root zone of 1 ft (30 cm)depth of water

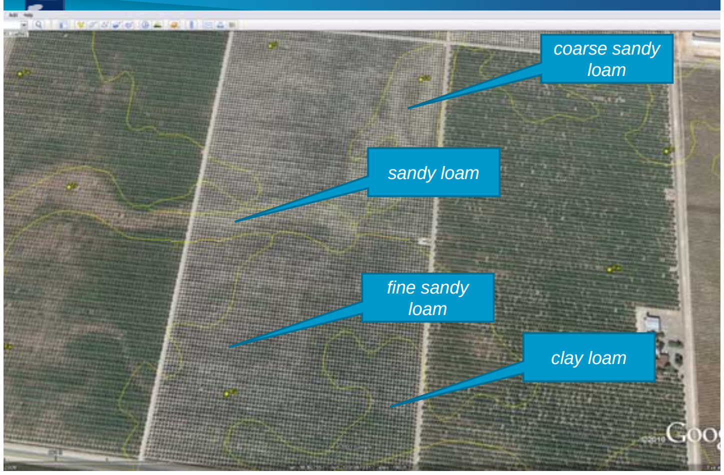
Current:

80 lb N in 1 ft of water = **133 mg/L NO_3**

Improved:

40 lb N in 1 ft of water = **67 mg/L NO_3**

Why not reduce nitrate leaching to zero?



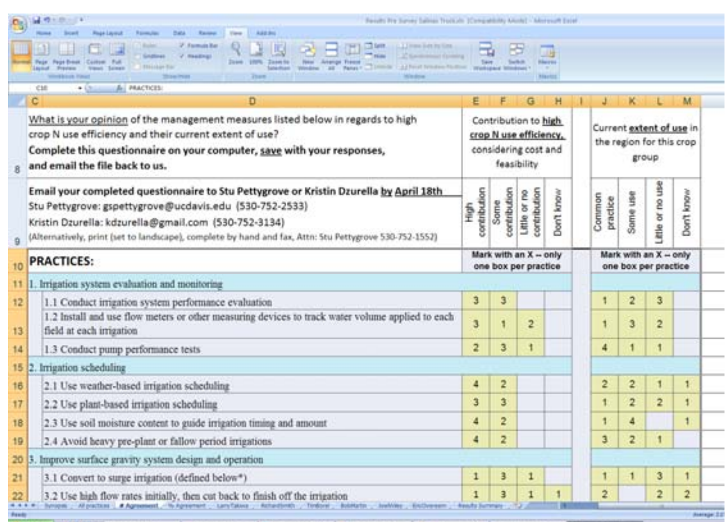
Typical crop N uptake vs. harvest removal

	Pounds of N/acre	
Crop	*Typical crop uptake*	*Removal with harvest*
Processing tomato	240-280	160-180
Celery	190-220	120-150
Cantaloupe	150-180	70-90
Lettuce	110-140	60-80
Spinach	80-100	70-90

T. Hartz, UC Davis. Proceedings of Western Nutrient Management Conference. March 2011.

Source reduction: Project actions

1. List crop- and region-specific practices with mitigation potential (*Lit. review*)
2. Compile range of potential reductions in fertilizer N applications and resulting improvement in N budget balance (*Lit. meta-analysis*)
3. Evaluate feasibility, current extent of use of improved practices (*UCCE/grower/crop adviser "practitioner panels"*)
4. Economic analysis of higher priority bundles of farming practices (*Model response functions*)



What is your opinion of the management measures listed below in regards to high crop N use efficiency and their current extent of use?
Complete this questionnaire on your computer, save with your responses, and email the file back to us.

Email your completed questionnaire to Stu Pettygrove or Kristin Dzurella by April 18th
Stu Pettygrove: gspettygrove@ucdavis.edu (530-752-2533)
Kristin Dzurella: kdzurella@gmail.com (530-752-3134)
(Alternatively, print (set to landscape), complete by hand and fax, Attn: Stu Pettygrove 530-752-1552)

PRACTICES:	Contribution to high crop N use efficiency, considering cost and feasibility: High contribution	Some contribution	Little or no contribution	Don't know	Current extent of use in the region for this crop group: Common practice	Some use	Little or no use	Don't know
	Mark with an X -- only one box per practice				Mark with an X -- only one box per practice			
1. Irrigation system evaluation and monitoring								
1.1 Conduct irrigation system performance evaluation	3	3			1	2	3	
1.2 Install and use flow meters or other measuring devices to track water volume applied to each field at each irrigation	3	1	2		1	3	2	
1.3 Conduct pump performance tests	2	3	1		4	1	1	
2. Irrigation scheduling								
2.1 Use weather-based irrigation scheduling	4	2			2	2	1	1
2.2 Use plant-based irrigation scheduling	3	3			1	2	2	1
2.3 Use soil moisture content to guide irrigation timing and amount	4	2			1	4		1
2.4 Avoid heavy pre-plant or fallow period irrigations	4	2			3	2	1	
3. Improve surface gravity system design and operation								
3.1 Convert to surge irrigation (defined below*)	1	3	1		1	1	3	1
3.2 Use high flow rates initially, then cut back to finish off the irrigation	1	3	1	1	2		2	2

EXAMPLE: Practices for vegetables and berries in Salinas Valley

High mitigative potential, already common in region

- Convert to drip
- Apply fertilizer N in multiple, small doses
- Maintain drip system to eliminate clogging
- Grade fields as uniformly as possible
- Operate sprinklers during least windy periods
- Backflow prevention

EXAMPLE: Practices for vegetables and berries in Salinas Valley

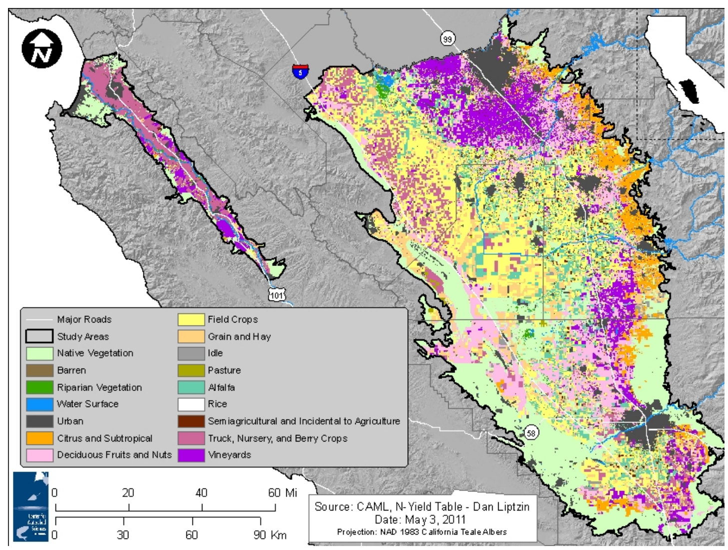
High mitigative potential, not currently in common use

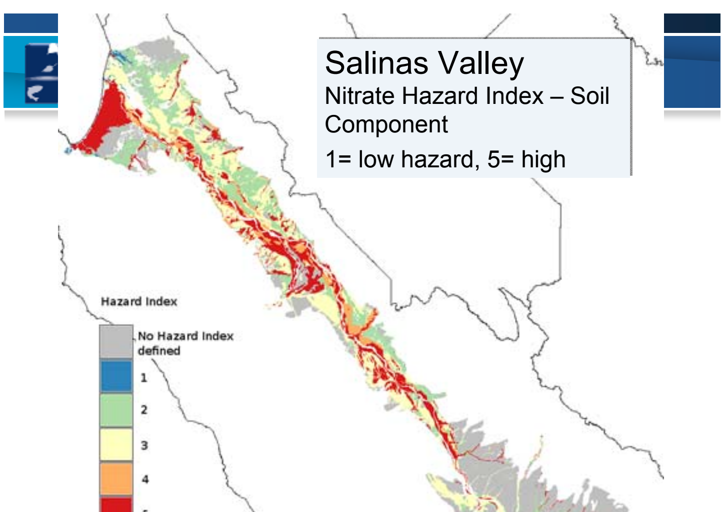
- Weather-based irrigation scheduling
- Adjust N timing based on soil nitrate testing
- Avoid heavy pre-plant irrigations
- Cover cropping

Agronomic practice bundle – Scenario 1

Salinas Valley, lettuce-broccoli, sprinklers to establish stand, then drip irrigated

N INPUT APPLICATION TARGET: Reduce from 300 to 220 lb N/acre per yr		
	New Practices	**Costs & inputs, other barriers**
1. Irrigation system evaluation and monitoring		
1.1	Conduct irrigation system performance evaluation	Consultant services to measure sprinkler and drip irrigation uniformity and application efficiency
1.2	Install and use flow meters or other measuring devices to track water volume applied to each field at each irrigation	Flow meters, installation, software. Management time to review information.
2. Irrigation scheduling		
2.1	Use weather-based irrigation scheduling	Improved software. Training of managers. Irrigator work schedules may be affected. Water supply constraints
14. Improve rate, timing, placement of N fertilizers		
14.1	Adjust N fertilizer rates based on soil nitrate testing	Cost of collection and analysis of soil samples. Management time to interpret results.
14.4	Measure N content of irrigation water and adjust fertilizer rates accordingly	Cost of analysis. Fields irrigated from multiple sources. Management time to interpret results.





Map source: Allan Hollander- Information Center of the Environment, UC Davis

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Nitrate in Groundwater
Report to the Legislature

Agro-economic Analysis of Nitrate Source Reduction Practices

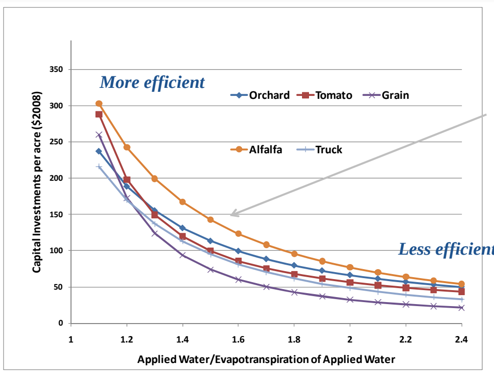
ITF Meeting #2
May 3, 2011

Richard Howitt, Josué Medellin, Jay Lund, Katrina Jessoe
Stuart Pettygrove, Todd Rosenstock, Kristin Dzurella

Conceptual Model

- Agricultural production model for the Salinas Valley and the Tulare Basin
- The crop mix is based on acreage and range in nitrate hazard index
- Assumes substitution between
  - Capital in irrigation efficiency
  - Costs for reduction and Partial Nutrient Balance
- Economic analysis will minimize the costs of limits on leached nitrogen

Constant Yield Tradeoff Function for Irrigation Efficiency



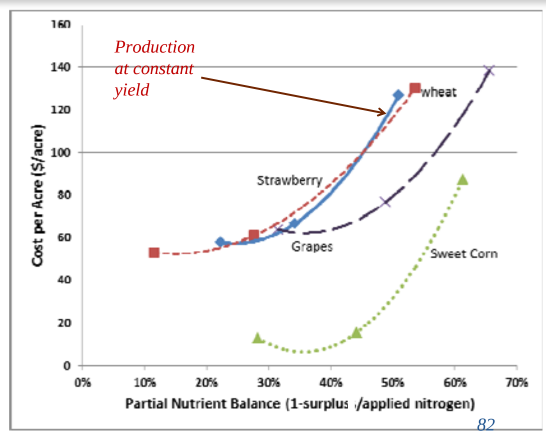
Production at constant yield

Hatchett et al. (1997)

Irrigation efficiency improvements in most cases would require capital investments.

Similar relationship used for applied nitrogen cost reductions at constant yield

1 acre ~ 0.405 ha

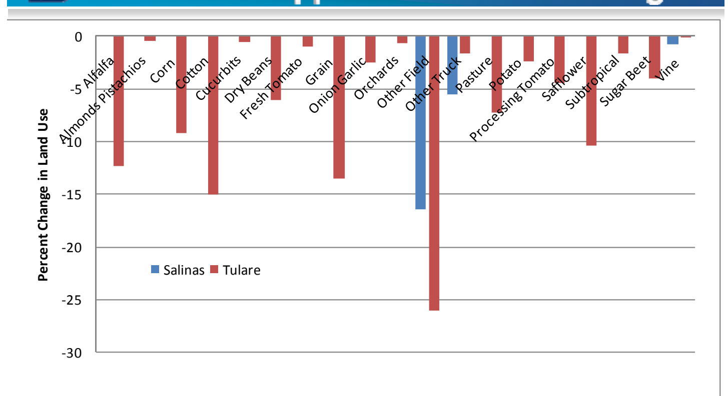


Selected Crop Mix

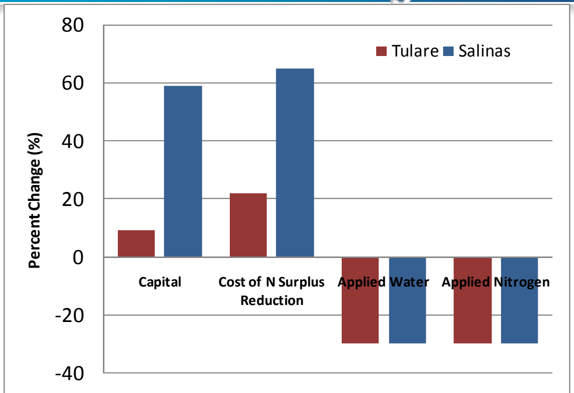
Salinas Valley Areas (acres)		Tulare Basin Areas (acres)	
Vegetable crops (high risk)	92,050	Fruit and Nut	699,000
Lettuce	48,220	Cotton	605,000
Vineyards	47,790	Grain, Hay, Field	634,000
Grain, Hay, Field	22,613	Vineyards	471,000
Artichokes	8,780	Alfalfa	367,000
Strawberries	8,500	Citrus	229,000
Carrots	1,980	Corn	210,000
Orchards	1,790	Tomatoes (process)	133,000
Turf	1,270	Vegetable crops (high risk)	103,500
Corn	215	Carrots	45,500
Total (>85 % coverage)	233,208	Total (>90 % coverage)	3,497,000

1 acre ~ 0.405 ha

Changes in Cropping Patterns 30 % Reduction in Applied Water and Nitrogen



30 % Reduction in Applied Water and Nitrogen



Model refinements

- Information from crop expert panels
  - Plausible practices
  - Cost estimates
- Nitrogen load to groundwater

Conclusions

- Model responds adequately to constraints in applied water
  - Acreages in nitrogen-efficient crops suffer smaller reductions
  - Total cultivated area decreases slightly
- Applied water influences rate of nitrogen leaching into groundwater
- Economic costs of improvements in nitrogen use efficiency (as PNB), are likely to increase at an increasing rate

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Nitrate in Groundwater
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DRINKING WATER TREATMENT

May 3, 2011 Interagency Task Force Meeting

Vivian Jensen, Graduate Student Researcher, CEE
Jeannie Darby, P.E., Professor, CEE

Department of Civil & Environmental Engineering
University of California, Davis
Contact: vjensen@ucdavis.edu
jdarby@ucdavis.edu

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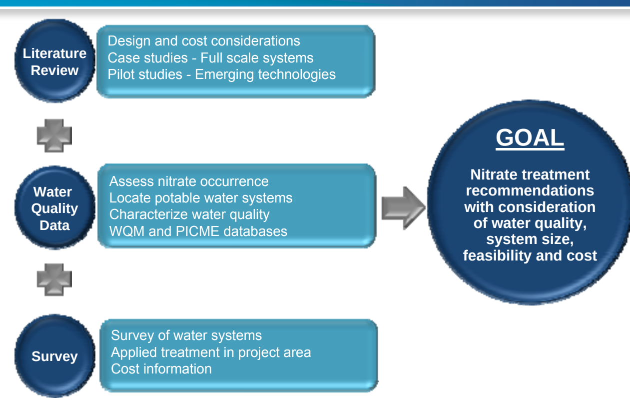

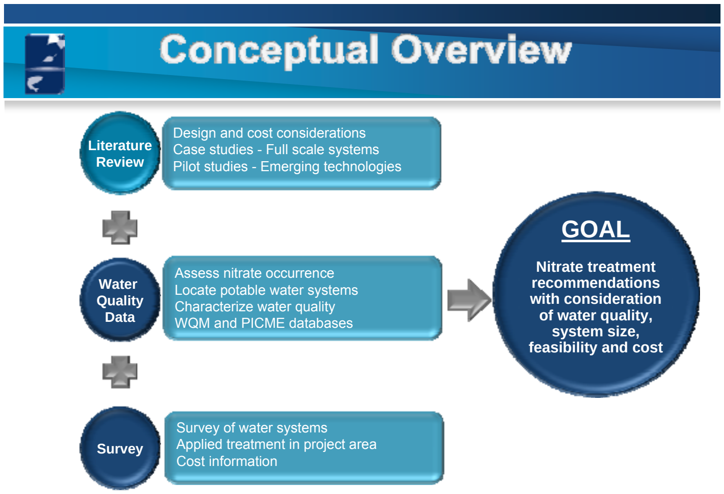
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Pilot studies - Emerging technologies
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Locate potable water systems
Characterize water quality
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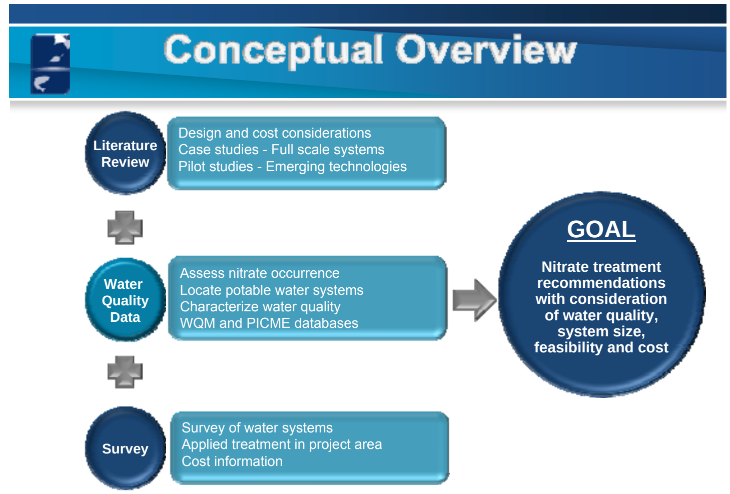
Applied treatment in project area
Cost information
GOAL
Nitrate treatment recommendations with consideration of water quality, system size, feasibility and cost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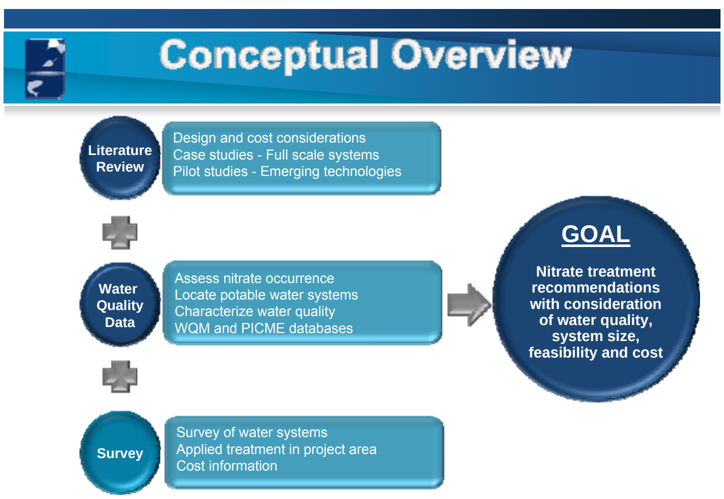
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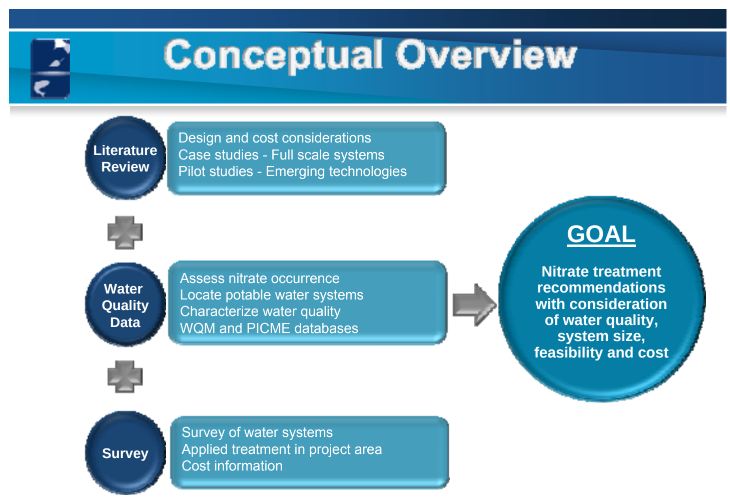
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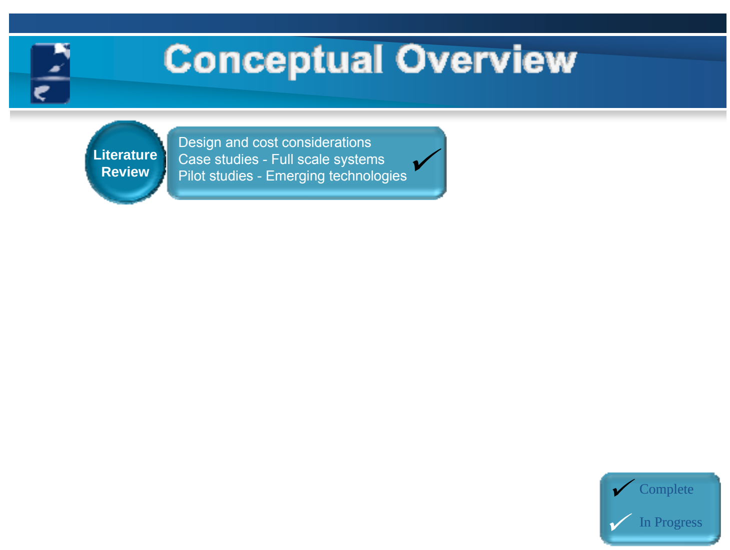
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In Progress

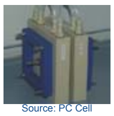
Removal Technologies

Source: Siemens

- Ion Exchange
  - Nitrate displaces chloride on anion exchange resin
  - Resin recharge with brine solution
  - Limitations: sulfate, resin fouling, disposal

Source: Dow Chemical

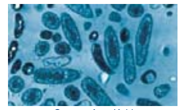
- Reverse Osmosis
  - Water molecules pushed through membrane
  - Contaminants left behind
  - Limitations: membrane fouling, pretreatment, disposal



Source: PC Cell

- Electrodialysis
  - Electric current governs ion movement
  - Anion and cation exchange membranes
  - Limitations: operationally complex, disposal

Reduction Technologies



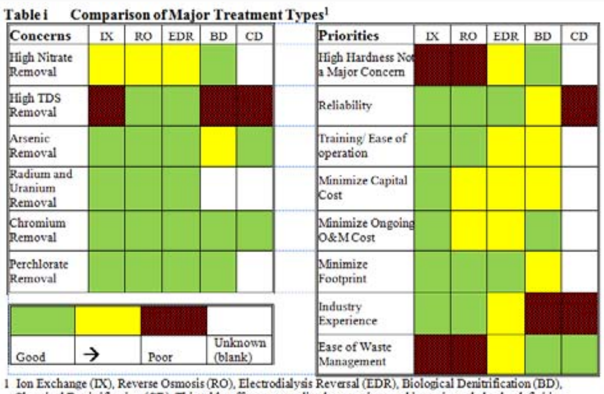
Source: AnoxKaldnes

- Biological Denitrification
  - Bacteria transform nitrate to nitrogen gas
  - Anoxic conditions
  - Requires electron donor (substrate)
  - Limitations: lack of U.S. full scale systems, substrate requirement, post-treatment (filtration, disinfection)

Source: Hepure Technologies

- Chemical Denitrification
  - Metals reduce nitrate to ammonia (typically)
  - Zero-valent iron (ZVI)
  - Catalytic denitrification
  - Limitations: pilot studies only, reduction to ammonia, dependence on temperature and pH

Treatment Options



1 Ion Exchange (IX), Reverse Osmosis (RO), Electrodialysis Reversal (EDR), Biological Denitrification (BD), Chemical Denitrification (CD). This table offers a generalized comparison and is not intended to be definitive; there are notable exceptions to the above classifications.

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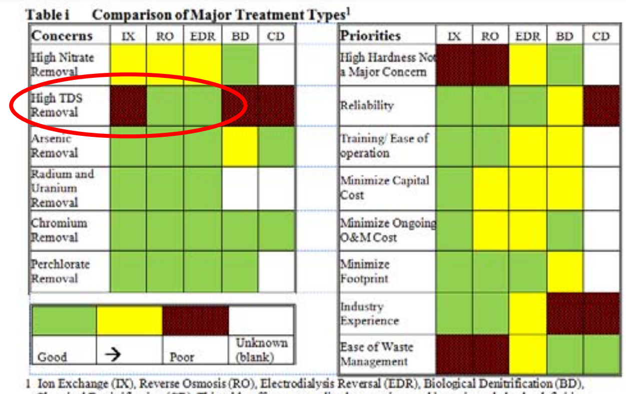

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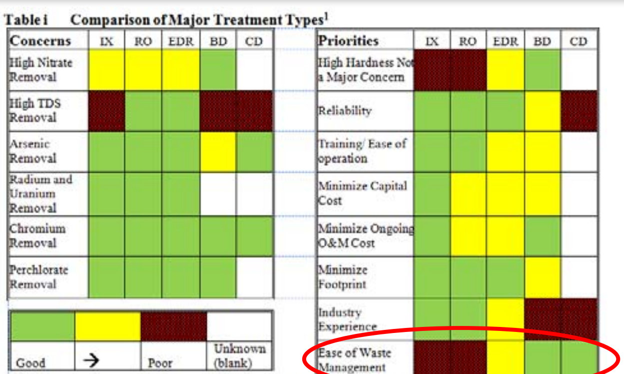

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Treatment Options

Table A.6 Advantages and Disadvantages of the Five Major Treatment Options for Nitrate Removal.

	Advantages	Disadvantages
Ion Exchange	• Years of industry experience, • Multiple contaminant removal, • Selective nitrate removal, • Financial feasibility, • Use in small and large systems, and • The ability to automate.	• The disposal of waste brine, • The potential for nitrate dumping specifically for non-selective resin use for high sulfate waters, • The need to address resin susceptibility to hardness, iron, manganese, suspended solids, organic matter, and chlorine, and • The possible role of resin residuals in DBP formation.
Reverse Osmosis	• High quality product water, • Multiple contaminant removal, • Desalination (TDS removal), • Feasible automation, • Small footprint, and • Application for small and POU applications.	• The disposal of waste concentrate, • Typically high capital and O&M costs, • The need to address membrane susceptibility to hardness, iron, manganese, suspended solids, silica, organic matter, and chlorine, • High energy demands, and • The lack of control over target constituents (complete demineralization).
Electrodialysis/ Electrodialysis Reversal	• Limited to no chemical usage, • Long lasting membranes, • Selective removal of target species, • Flexibility in removal rate through voltage control, • Better water recovery (lower waster volume), • Feasible automation, and • Multiple contaminant removal	• The disposal of waste concentrate, • The need to address membrane susceptibility to hardness, iron, manganese, and suspended solids, • High maintenance demands, • Costs (comparable to RO systems, but may not be cost effective for large systems), • The need to vent gaseous by-products, • The potential for precipitation with high recovery, • High system complexity, and • Dependence on conductivity.
Biological Denitrification	• High water recovery, • No brine or concentrate waste stream (nitrate reduction rather than removal to waste stream), • Low sludge waste, • Less expensive operation,	• The need for substrate and nutrient addition, • High monitoring needs, • Significant post-treatment requirements, • High capital costs, • Sensitivity to environmental conditions (sometimes), • Large system footprint (sometimes),

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POU/POE

From CDPH Emergency Regulations, as of December 21, 2010,

"…a public water system may be permitted to use point-of-use treatment devices (POUs) in lieu of centralized treatment for compliance with one or more maximum contaminant levels… if;

(1) the water system serves fewer than 200 service connections,

(2) the water system meets the requirements of this Article,

(3) the water system has demonstrated to the Department that centralized treatment, for the contaminants of concern, is not economically feasible within three years of the water system's submittal of its application for a permit amendment to use POUs,

… no longer than three years or until funding for the total cost of constructing a project for centralized treatment or access to an alternative source of water is available, whichever occurs first…"

Conceptual Overview

Literature Review — Design and cost considerations; Case studies - Full scale systems; Pilot studies - Emerging technologies ✔

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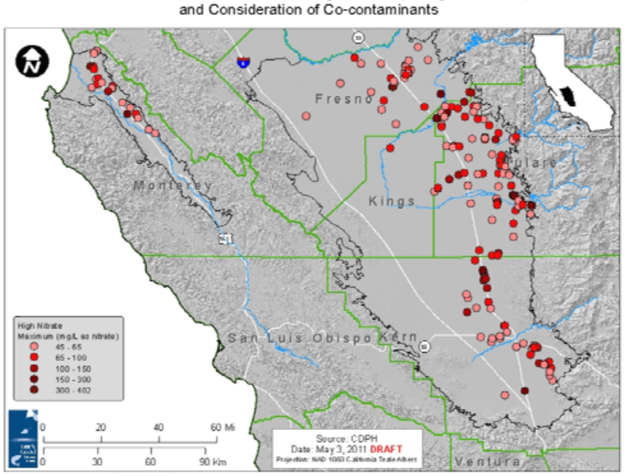
Raw Water Nitrate Levels Exceeding the MCL (45 mg/L as nitrate) and Consideration of Co-contaminants



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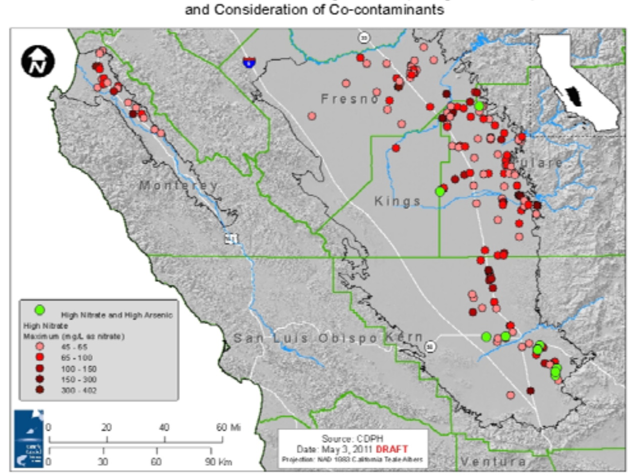

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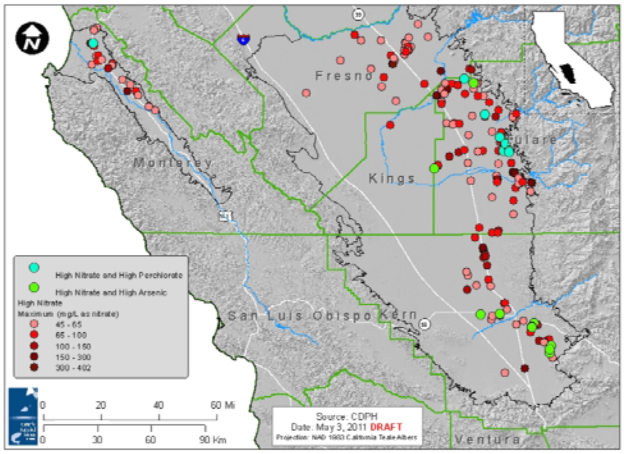

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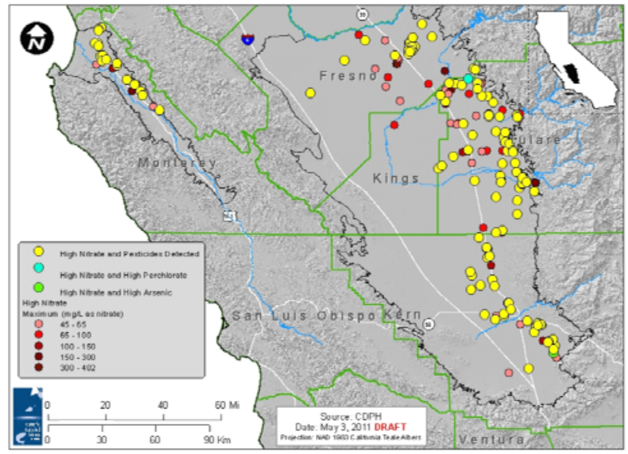

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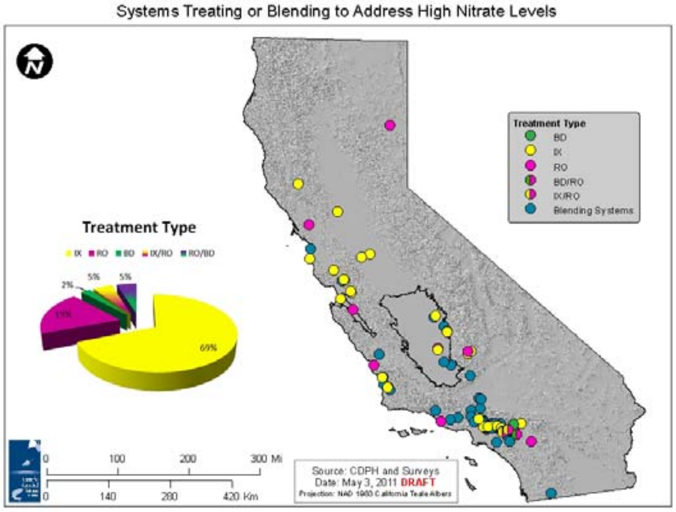
Systems Treating or Blending to Address High Nitrate Levels



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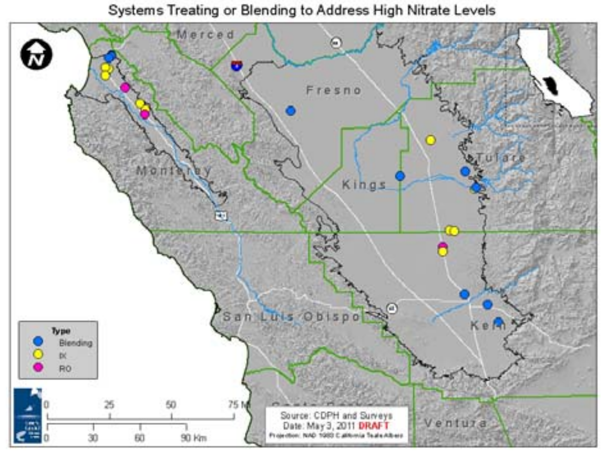

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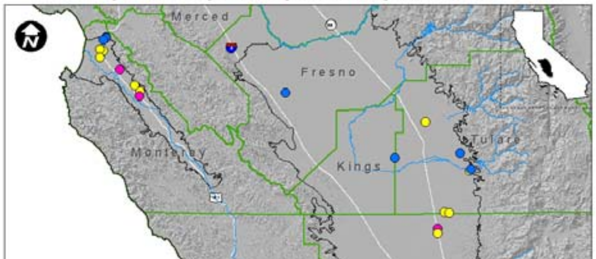
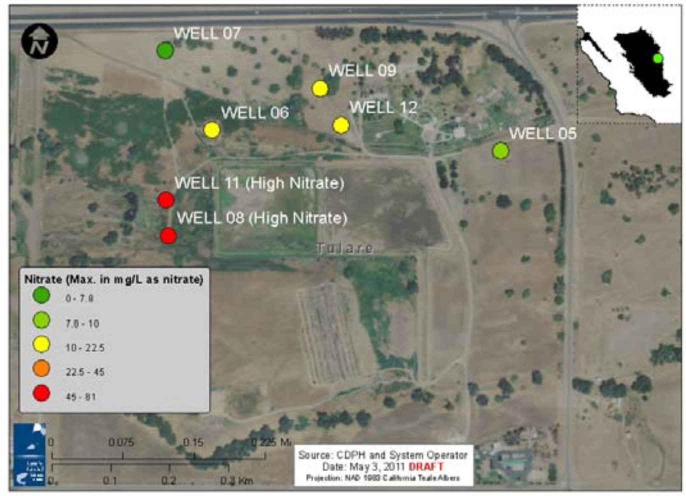


Type	Population Range (Total)	Average Raw Nitrate (mg/L as nitrate) Max	Min	Avg
Ion Exchange	25 – 133,750 (261,200)	71	15	40
Reverse Osmosis	45 – 6,585 (6,760)	75	24	41
Blending	45 – 25,500 (83,475)	64	3	32

Blending Case Study: Water System in Tulare County



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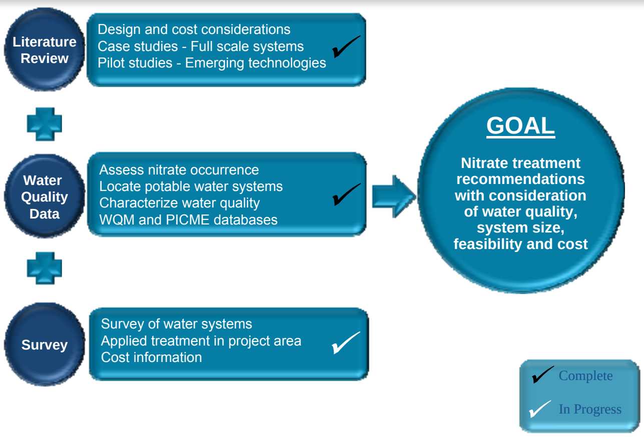

Costs by Technology

Ion Exchange (IX)
Pro: Generally the least expensive
Con: Brine disposal

Reverse Osmosis (RO)
Pro: Wide treatment capabilities
Con: More expensive

Biological Denitrification (BD)
Pro: Long term sustainability
Con: Limited application

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Type	Annualized Capital Cost ($/kgal)	Annual O & M Cost ($/kgal)	Total Annualized Cost ($/kgal)
IX – Literature	0.08 – 0.80	0.15 – 1.25	0.34 – 2.04
IX – Survey	0.06 – 0.94	0.12 – 2.63	0.41 – 2.73
RO – Literature	0.81 – 4.40	1.22 – 2.00	2.32 – 5.86
RO – Survey	0.19 – 3.16	1.15 – 16.16	1.35 – 19.16
BD	0.47 – 0.83	0.30 – 0.94	0.92 – 1.56

Costs by Technology

Ion Exchange (IX)
Pro: Generally the least expensive
Con: Brine disposal

Reverse Osmosis (RO)
Pro: Wide treatment capabilities
Con: More expensive

Biological Denitrification (BD)
Pro: Long term sustainability
Con: Limited application

Type	Annualized Capital Cost ($/kgal)	Annual O & M Cost ($/kgal)	Total Annualized Cost ($/kgal)
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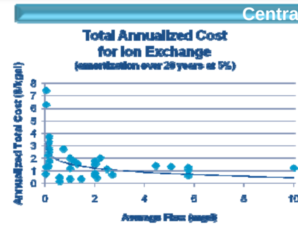
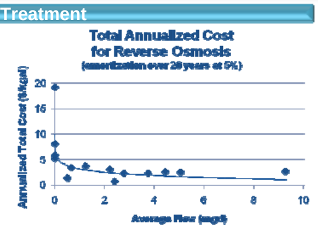
Treatment costs are unique to individual systems based on:

*system size
*treatment type
*nitrate level
*co-contaminants
*blending options
*seasonal variation
*location
*disposal options
*others…

Costs by System Size

Centralized Treatment





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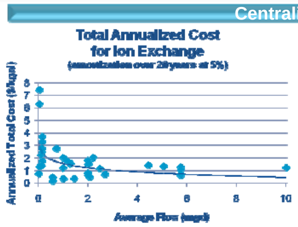

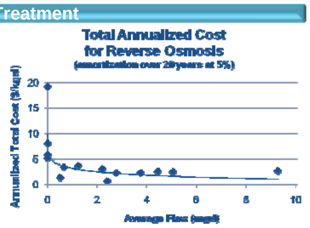

Point-of-Use

	Upfront Investment	Annual Costs	Comments
Ion Exchange	$660-$2425	Salt costs ($3.30-$4.40/bag)	Requires disposal of brine waste, high sodium levels
Reverse Osmosis	$330-$1430	$110-$330/yr + electricity	Requires filter replacement, high maintenance, lower water recovery

(From Mahler et al., 2007)

Preliminary Conclusions

- In the selection of treatment options, the unique needs of each individual water system must be considered.
- A single treatment solution will not fit every community; however, the provision of safe drinking water for all communities can be achieved using currently existing technology.
- Centralized treatment may not be feasible for widespread rural communities, but centralized management (e.g., design, purchasing, and maintenance) could minimize costs.
- Technologies capable of multiple contaminant removal will likely become the dominant choice in the future.

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SB X2-1 Nitrate in Groundwater Report to the Legislature

ALTERNATIVE WATER SUPPLY

May 3, 2011 Interagency Task Force Meeting

Holly Canada, Graduate Student Researcher, CEE
Kristin Honeycutt, Graduate Student Researcher, CEE
Mimi Jenkins, Professional Research Engineer, CEE
Jay Lund, Director of the Center for Watershed Sciences

Department of Civil & Environmental Engineering
University of California, Davis
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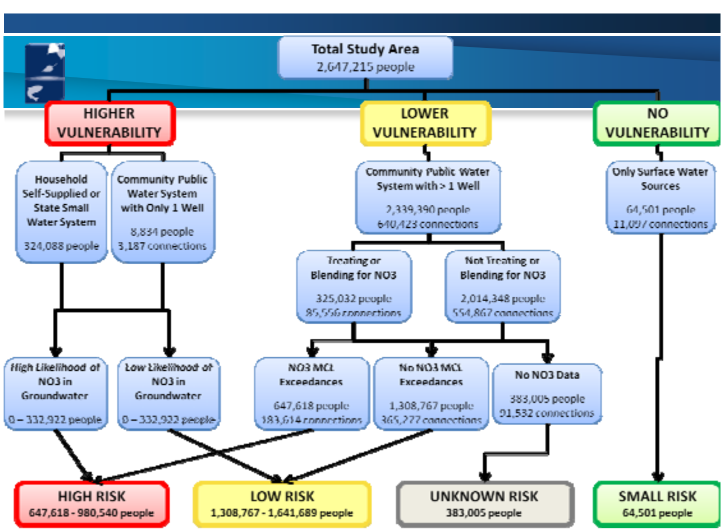
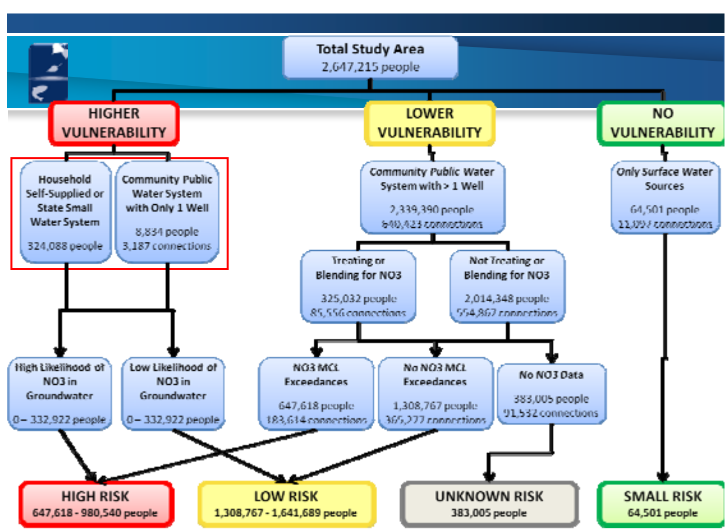
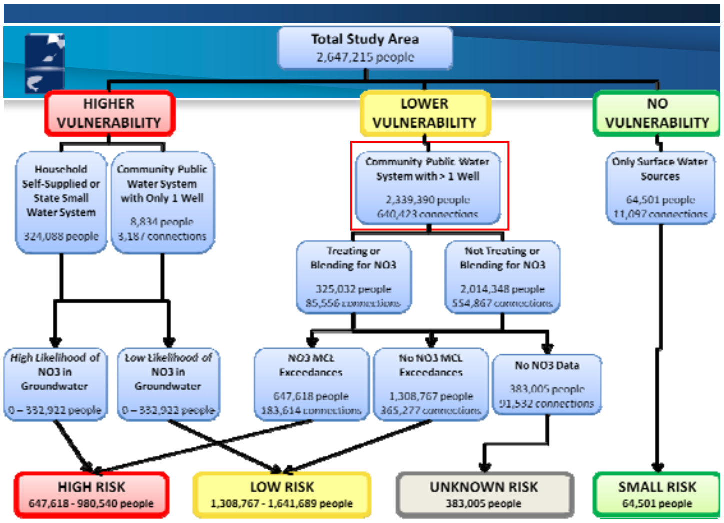
hecanada@ucdavis.edu

Outline

- Susceptibility Breakdown
- CDPH PICME Wells within Study Area
- Groundwater-Reliant Systems Exceeding MCL
- Alternative Water Supply Options
- System Distance and Population Distributions
- Alternative Water Supply Costs






Total Study Area
2,647,215 people
HIGHER VULNERABILITY
LOWER VULNERABILITY
NO VULNERABILITY
Household Self-Supplied or State Small Water System
324,088 people
Community Public Water System with Only 1 Well
8,834 people
3,187 connections
Community Public Water System with > 1 Well
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Only Surface Water Sources
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Treating or Blending for NO3
325,032 people
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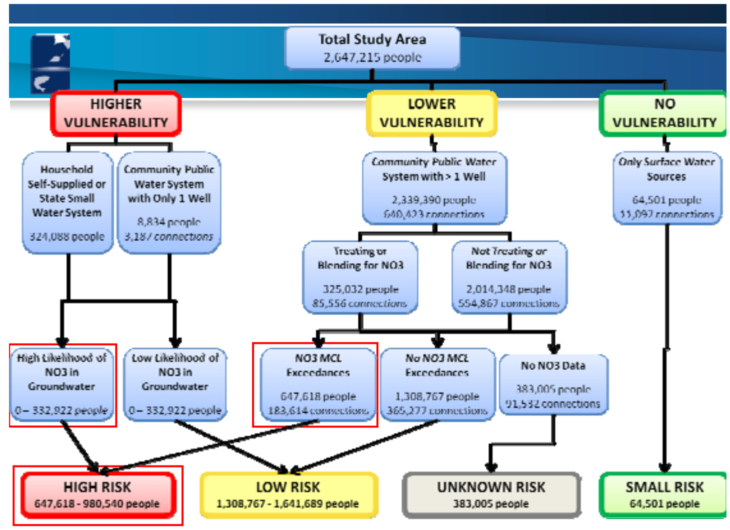
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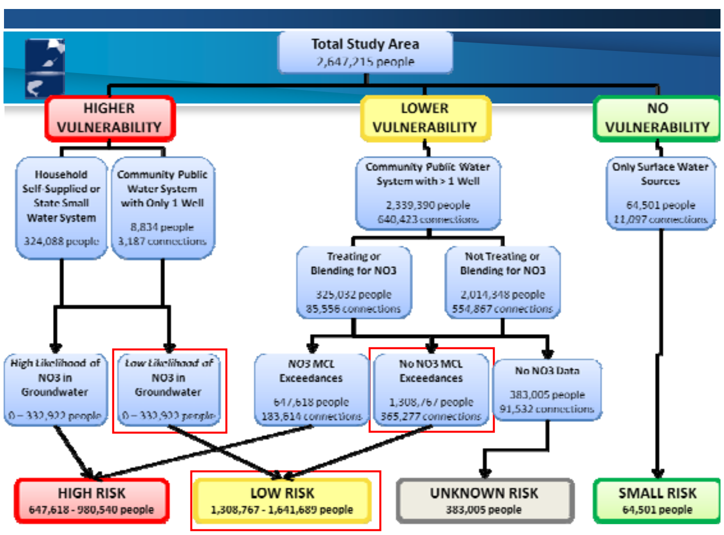
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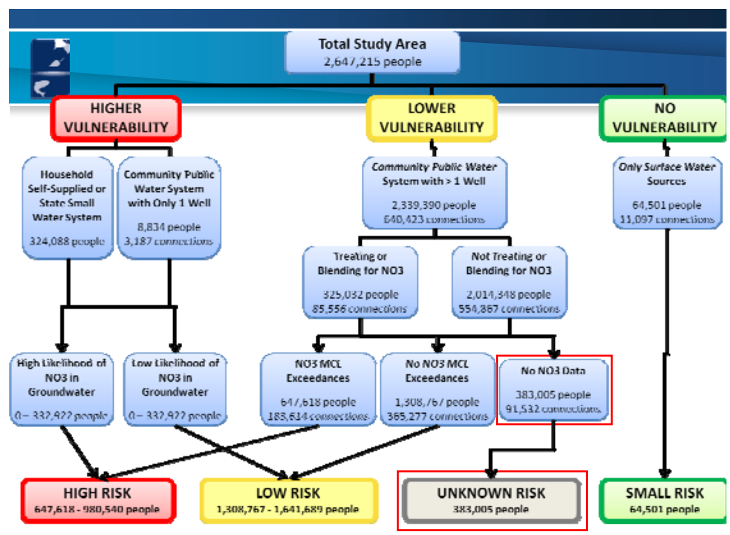
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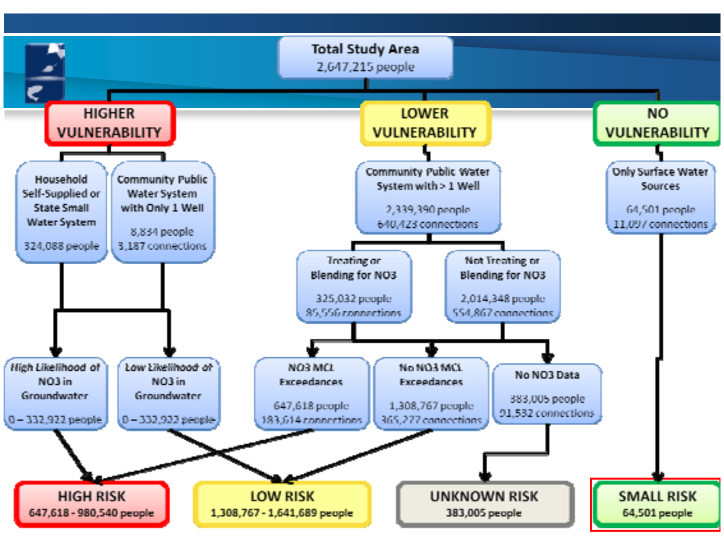
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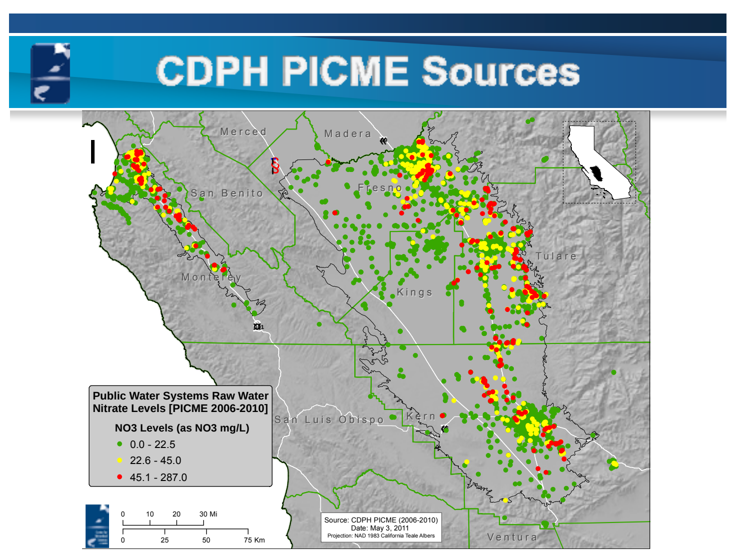
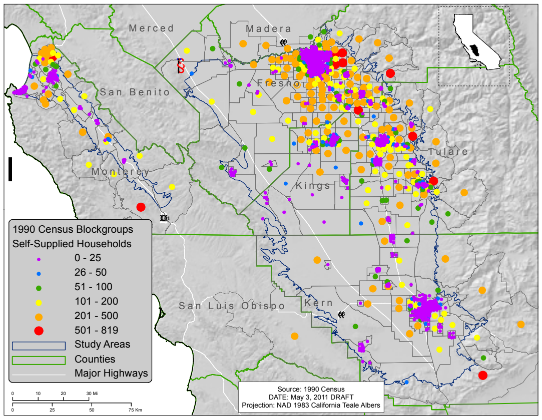
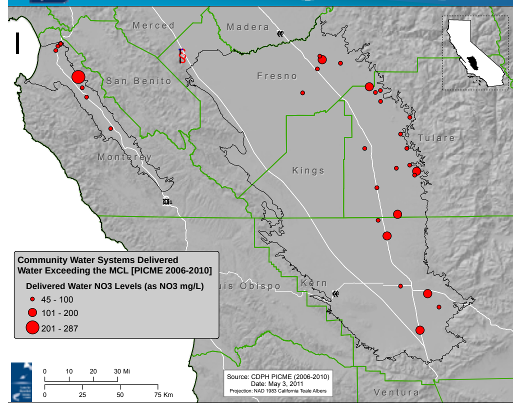

CDPH PICME Sources
Merced
Madera
San Benito
Fresno
Monterey
Kings
Tulare
San Luis Obispo
Kern
Ventura
Public Water Systems Raw Water Nitrate Levels [PICME 2006-2010]
NO3 Levels (as NO3 mg/L)
0.0 - 22.5
22.6 - 45.0
45.1 - 287.0
0 10 20 30 Mi
0 25 50 75 Km
Source: CDPH PICME (2006-2010)
Date: May 3, 2011

Household Self-Supplied Systems



Groundwater-Reliant Systems: Delivered Water Levels Exceeding the MCL [CDPH 2006-2010]



- Exceedance vs. "Violation"
- 10% of the systems have exceeded the MCL since 2006

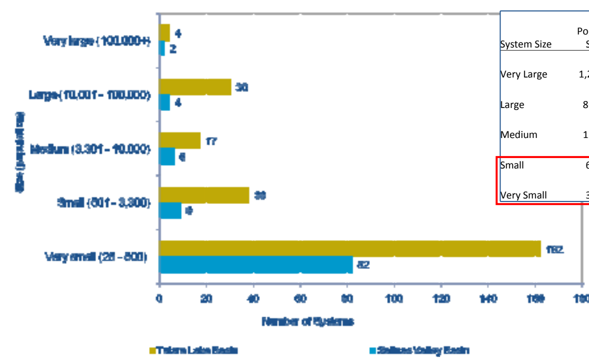
Alternative Water Supply Options

- Improve Existing Source
  - Blending+
  - Drill Deeper or New Well+
  - Community Treatment
  - Household Treatment*
- Create Alternative Supplies
  - Switch to Treated Surface Water
  - Piped Connection to a Better System
    - Existing system
    - New system
    - Regionalization and Consolidation
  - Trucked Water*
  - Bottled Water
- Relocate Households

Ancillary Activities:
+Well Water Quality Testing
*Dual System

Regionalization/Consolidation

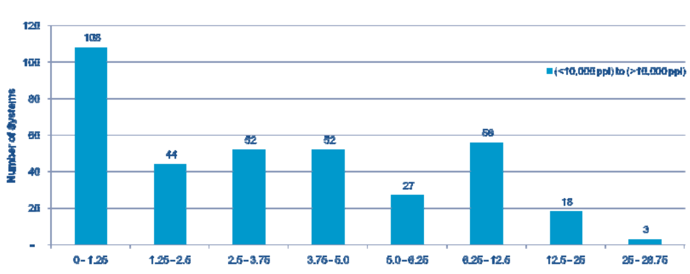
System Distribution by Population Served



System Size	Population Served	% of Total Population on CWS
Very Large	1,230,047	52%
Large	860,892	37%
Medium	155,497	7%
Small	68,246	3%
Very Small	32,852	1%

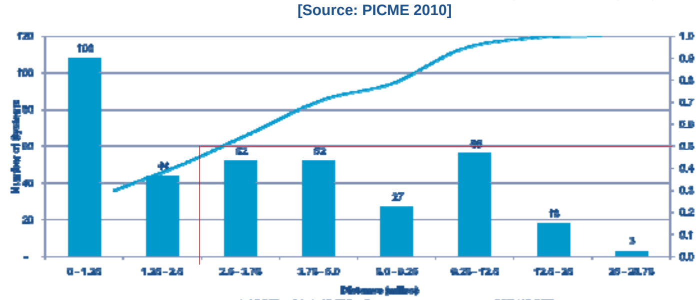
Piped Connection to an Existing System

The Minimum Distance from a Small System to a Larger System [Source: PICME 2010]



Piped Connection to an Existing System

Cumulative Distribution of the Minimum Distance from a Small System to a Larger System [Source: PICME 2010]



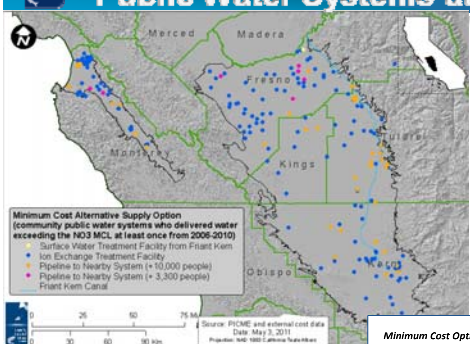
Community Water System Option Costs

System Population Size:	25 people	501 people	3,301 people	10,001 people	100,001 people
Assumed Water Use (mgd):	0.01	0.13	0.75	2.50	25.0
Annualized Total Cost ($/1,000 gal/year):					
Reverse Osmosis	$6	$6	$4	$3	$3
Ion Exchange	$4	$3	$2	$2	$2
New Well Drilling	$22	$6	$3	$2	$1
New Well + 2 Miles of Pipeline	$304	$20	$5	$3	$1
Surface Water Treatment Plant					$1

Community Water System Option Costs

System Population Size:	25 people	501 people	3,301 people	10,001 people	100,001 people
Assumed Water Use (mgd):	0.01	0.13	0.75	2.50	25.0
Annualized Total Cost ($/1,000 gal/year):					
Reverse Osmosis	$6	$6	$4	$3	$3
Ion Exchange	$4	$3	$2	$2	$2
New Well Drilling	$22	$6	$3	$2	$1
New Well + 2 Miles of Pipeline	$304	$20	$5	$3	$1
Surface Water Treatment Plant					$1
Cheapest Option Cost:	*$4*	*$3*	*$2*	*$2*	*$1*
Maximum distance (miles) to a clean water supply where pipeline $ is less than the above cheapest option	*0.5*	*5*	*18*	*42*	*149*

Minimum Cost Option for Community Public Water Systems at High Risk



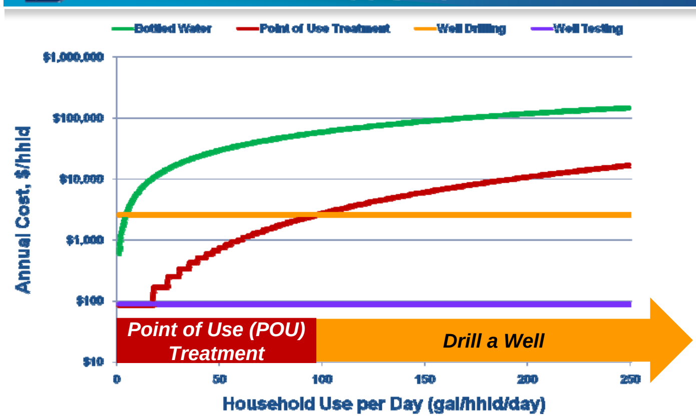
Minimum Cost Option	*# of Community Public Water Systems*	*Total Population*	*Total Annualized Cost*
SW from Friant Kern	1	457,511	$ 2,920,792
Ion Exchange	170	482,194	$ 23,880,344
Pipeline to +10,000 system	36	126,509	$ 1,710,602
Pipeline to +3,300 system	7	6,737	$ 213,912
Drill a new well	0	0	$ 0
TOTAL		**1,072,951**	**$ 28,725,650**

Household Alt Supply Option Costs

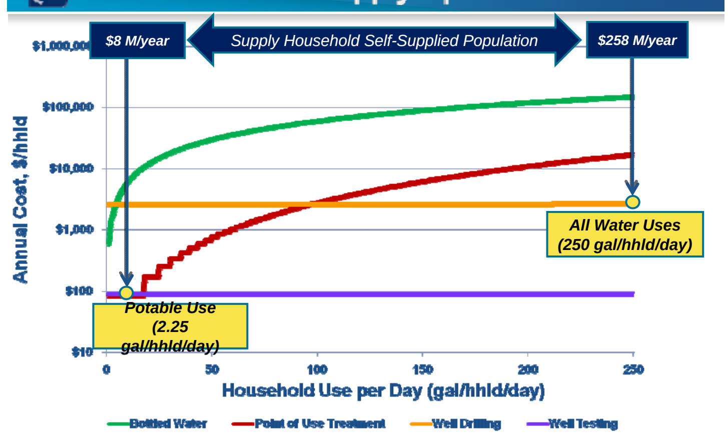
Whole House Options	$/hhld/year	$/1000gal/year
Well Testing	$90	$0.3
Point of Entry (POE) System	$150	$0.5
Deepen Existing Well by 200 ft	$1,000	$4
New Well Drilling (300 ft)	$3,000	$8

End Use Options	$/hhld/year	$/1000gal/year
Point of Use (POU) Systems	$80	$90
Bottled Water	$1,300	$1,500

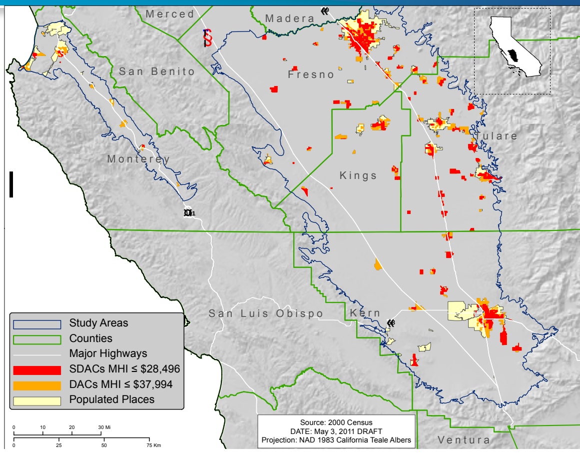
Estimated Household Costs of Water Supply Options



Estimated Household Costs of Water Supply Options



Disadvantaged Communities



Next Steps

- Domestic Wells Analysis
- Complete Alternative Supply Minimum Cost Analysis
- Examine Exceedances on a "Violations" Level

SB X2-1
Nitrate in Groundwater
Report to the Legislature

FUNDING SOURCES & REGULATORY OPTIONS

May 3, 2011 Interagency Task Force Meeting

Holly Canada, Graduate Student Researcher, CEE
Kristin Honeycutt, Graduate Student Researcher, CEE
Mimi Jenkins, Professional Research Engineer, CEE
Katrina Jessoe, Assistant Professor, ARE
Jay Lund, Director of the Center for Watershed Sciences

University of California, Davis
Contact: kkjessoe@ucdavis.edu
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hecanada@ucdavis.edu

Current Funding Sources

- State funding dominated by general bonds
- Small amounts raised from various reg. fees
  - Including a "mill" tax on fertilizer sales
- Fed $ important source of safe drinking & clean water (pollution abatement) investments
- Other non-state, fed and non-profit funds available but often limited, restricted or small
- Recent set-asides for small communities and DACs in some programs

Examples of NO_3 Source Load Reduction Activities Currently Funded

- Conversion from septic to sewer
- Wastewater treatment, upgrades to protect receiving water quality (SW & GW)
- Ag nutrient management education, research & training
- GW quality measurement, monitoring, research
- Planning, e.g., IRWM

NO_3 Alternative Water Supply Activities Currently Funded

- Capital investments as loans and grants for:
  - new supplies, water treatment (POU/POE unclear), replacing aging infrastructure, WUE improvements, metering
- CDPH's SDWSRF main program
- Drinking water source protection projects
- $$ for proposal feasibility, preparation, etc
- TMF capacity building, education
- No funds for O&M, assume ratepayers pay this
- Planning funds for DAC in IRWMP

Observations on Current Funding Sources

- Sustainability and sufficiency of main sources unclear
- No funds for Ag investment in nutrient mgt/NO_3 reduction
- Ag water use efficiency funds to fund NO_3 loading reduction?
- Many small pots of $ for drinking/wastewater for small communities and DACs, scattered, difficult to access
- Nitrate drinking water contamination investment needed statewide, based only on 2010-11 fundable list > $4/person for capital costs only
- No funds for community water supply regionalization feasibility studies and planning

RI: assumptions and limitations

- Focus on regulatory instruments to manage nitrate emissions from non-point sources, especially agriculture
  - Instruments could address emissions from both point and non-point sources
- Qualitative analysis
  - Ranking of regulatory instruments along criteria
  - Analysis rooted in previous case studies
  - Future work could quantitatively compare these instruments
- Analytical dimensions
  - Cost-effectiveness, administrative feasibility, information requirement revenue raising
  - Many potential criteria

RI: analytical criteria

- Cost-effectiveness
  - Abatement (nitrate reduction) costs to meet a nitrate standard
  - How can a standard be achieved at the least cost?
- Administrative costs
  - Bulk of these costs are monitoring and enforcement
  - Costs vary depending on the unit of regulation – few industries or many individuals – and mixing
- Information Requirements
  - What information is needed to implement these regulatory tools?
- Revenue Raising
  - Regulatory instruments and funding options overlap
  - Is a regulatory instrument also a source a funding?

Instruments evaluated

- Technology mandate (non-market instrument)
  - Example: Management practices for pesticides
- Performance standard (non-market instrument)
  - Example: The dairy regulatory program nutrient management plan, which requires the ratio of N applied to N harvested to be less than 1.65
- Cap and trade (market-based instrument)
  - Example: Sulfur dioxide markets in the U.S. to address acid rain; AB 32
  - Overall, a 10% reduction in fertilizer use (5% reduction ha A and 15% ha B)
- Fee (market-based instrument)
  - Example: Mill tax; tax on fertilizer that induces a 10% reduction in fertilizer use
  - With C&T choose a quantity (market determines price) and with a fee choose a price (market determines quantity)

Instruments evaluated

- Information disclosure
  - Example: Consumer confidence reports on drinking water quality (SDWA)
- Liability rules
  - Example: Superfund
- Payment for water quality
  - Analogous to payment for ecosystem services
  - Public pays farmers to not release nitrates or farmer pays gov't to release nitrate
  - Example: Drinking water in NYC; Perrier and Vittel; REDD
- Redesignation of beneficial use
  - Example: Change beneficial use from drinking to another standard

What can be regulated?

- Fertilizer use
  - Regulation on input
  - Advantages: Low administrative costs; low information requirements
  - Disadvantages: Regulating input rather than “pollutant” (i.e. gasoline tax rather than a tax on emissions)
- Nitrate leachate concentration within recharge area of drinking water source
  - Regulation on actual pollutant flux into groundwater recharge area
  - Advantages: Regulate the pollutant of interest; achieve policy objective
  - Disadvantages: High administrative costs (non-uniform mixing); high information requirements; uncertainty in assessing recharge area for specific source
- Other ideas?
  - Nitrate emissions concentration – concentration of nitrate emissions released into source (not account for non-uniform mixing)
  - Nitrate emissions volume – volume of nitrate emissions released into source

Framework for regulatory options

FS: assumptions and limitations

- Focus on sources of funding
  - UCD team does not address how the money should be allocated
  - Treatment, remediation, alternative water supplies
- Provide a list (with explanation) of potential options
  - No analytical criteria – any comments?
  - Create different incentives
- Qualitative exercise
  - Provide examples of funding options
- Comments

Funding options: water fees

- Fixed monthly fee on drinking water for CA residents
- Volumetric fee on drinking water for CA residents
  - Option: Fee for “high quantity” consumers
- Tax on irrigated water
- Fixed fee on agricultural water
- Groundwater pumping fee
- Fee on bottled water (similar to recycling fee)

Funding options: other fees

- Fertilizer tax
- Nitrate emissions tax
- N leachate tax
- Food tax
- Agricultural property tax
- Auctioned fertilizer or nitrate permits (cap and trade)
- Septic tank discharge
- Waste water discharge
- State water bonds

Moving forward

- Final comments on regulatory instruments
  - Analytical criteria
  - Instruments evaluated
- Suggestions on funding sources
  - Analytical criteria
  - Other funding sources
  - Alternative approaches
- Contact: kkjessoe@ucdavis.edu

SB X2-1
Nitrate in Groundwater
Report to the Legislature

Interagency Task Force Meeting
May 3, 2011