Dixon Resource Conservation District

3rd Groundwater Workshop

30 January 2025

Sustainable groundwater quality management in agricultural landscapes - The role of modeling tools

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https://groundwater.ucdavis.edu

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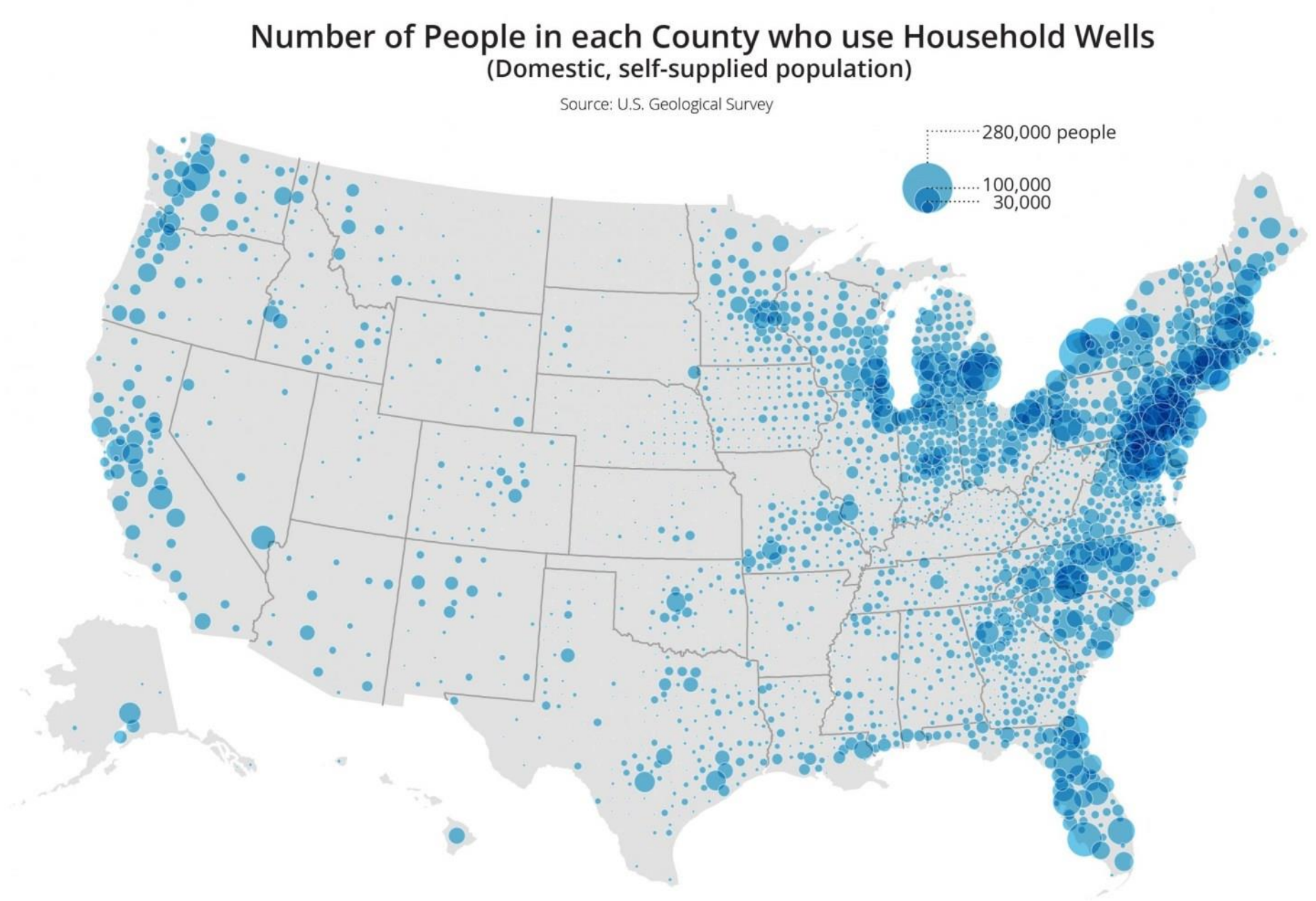
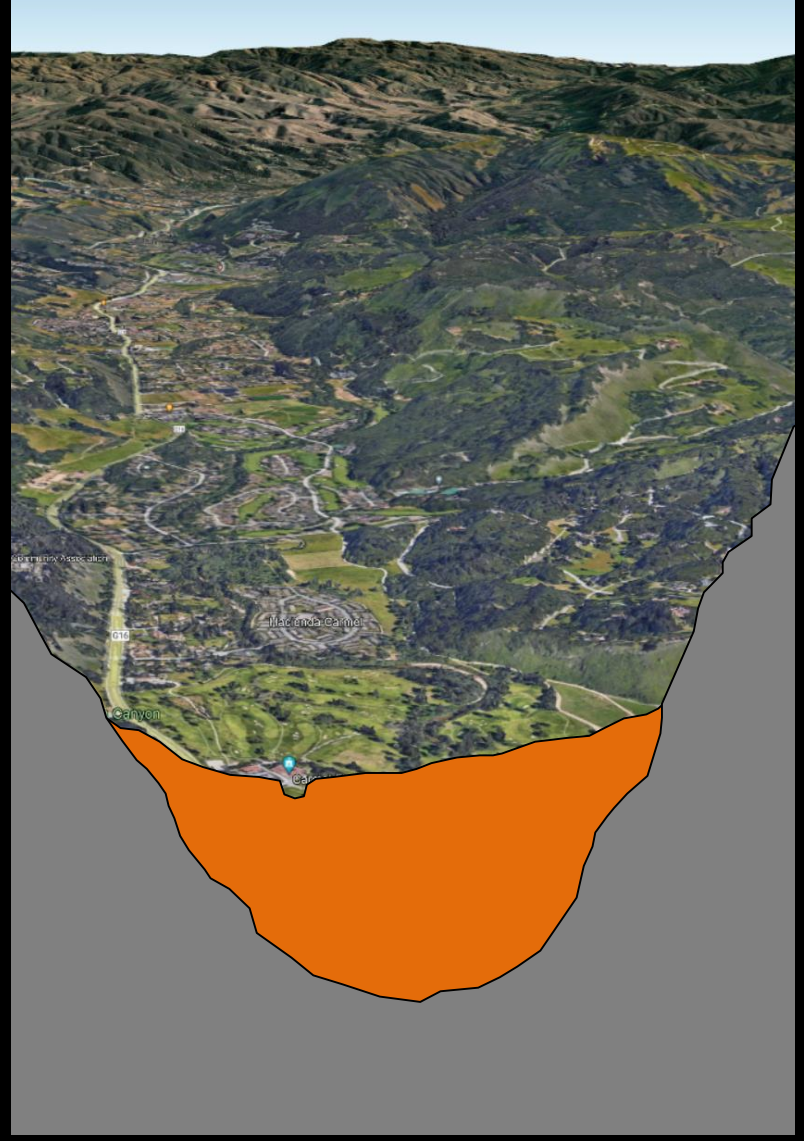
University of California
Agriculture and Natural Resources

Department of
LAND, AIR AND WATER RESOURCES
University of California, Davis
Climate Change • Sustainable Agriculture
Environmental Quality • Landscape Processes



https://www.circleofblue.org/2018/world/infographic-household-wells-in-the-united-states/




WELLS FARGO
Deloitte
ONE WILSHIRE
©Wikipedia

Laura Bliss / Atlantic City Lab

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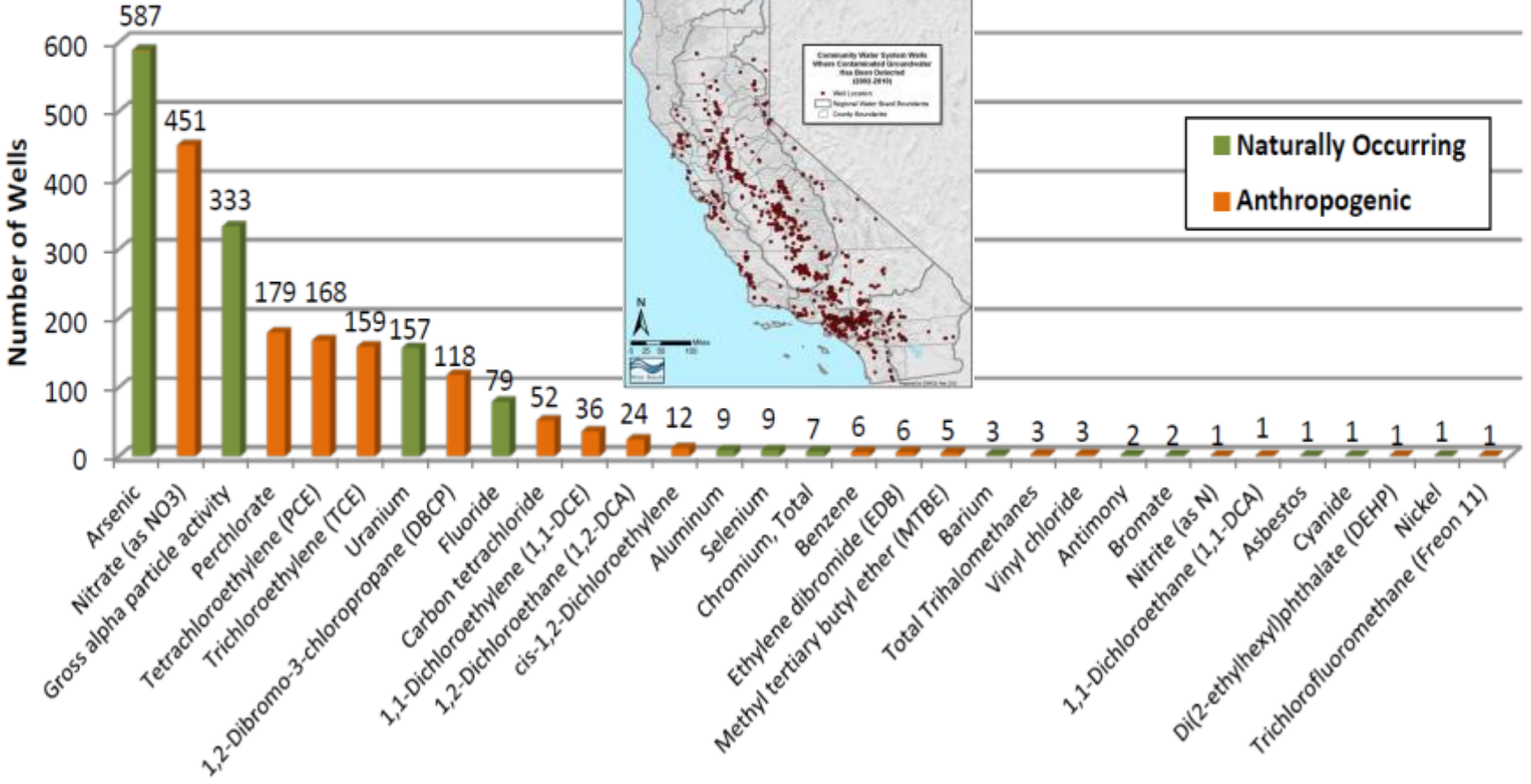
Principal Contaminant Detections: Wells

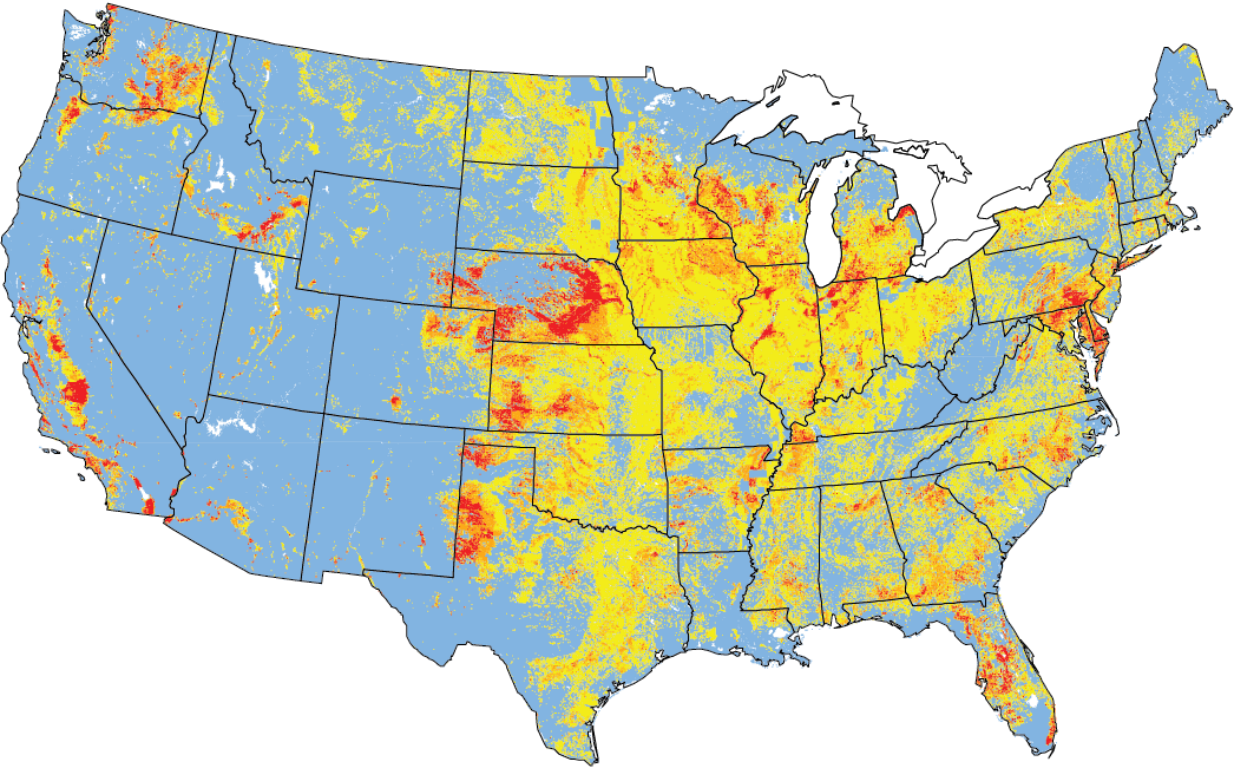
Two or More Detections Above the MCL in Active Wells 2002-2010



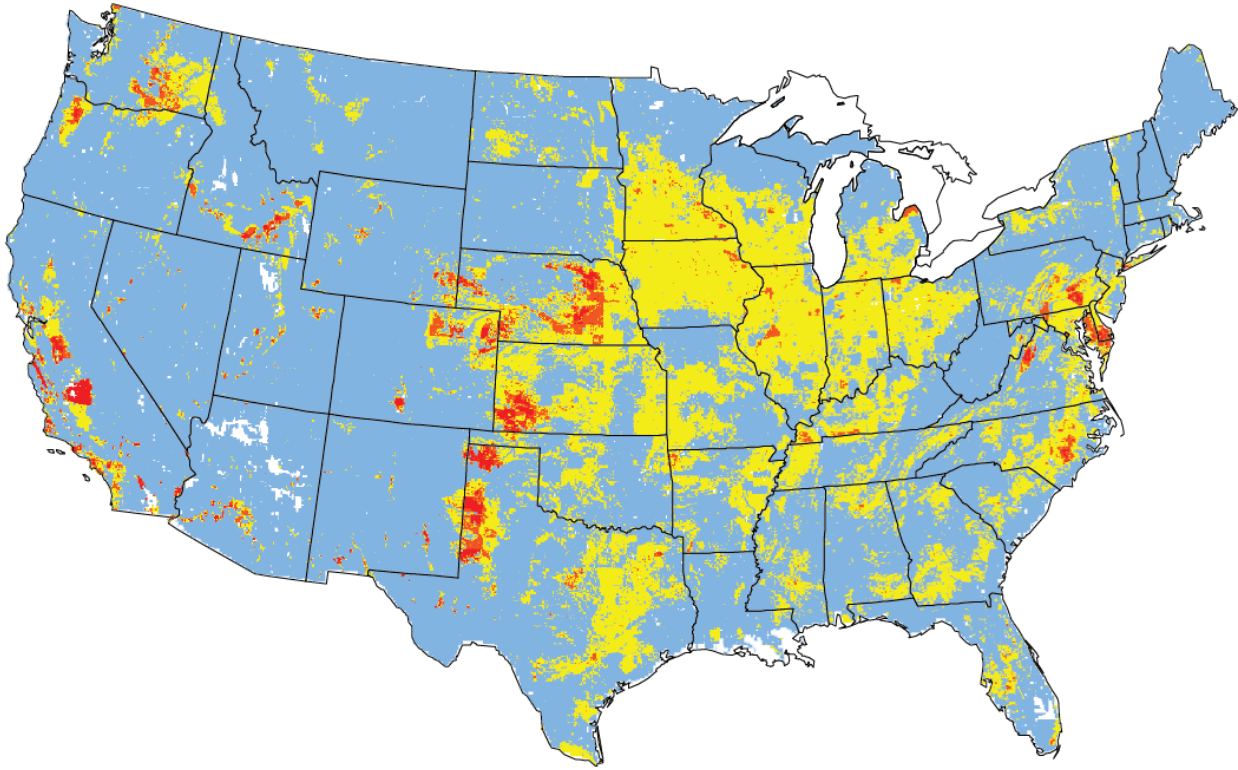
total active public supply wells in California: 8,396
with contaminated groundwater (before treatment): 1,659

State Water Resources Control Board, AB2222 Report to Legislature, January 2013

Predicted nitrate in shallow, recently recharged groundwater



Predicted nitrate in deeper groundwater used for drinking water



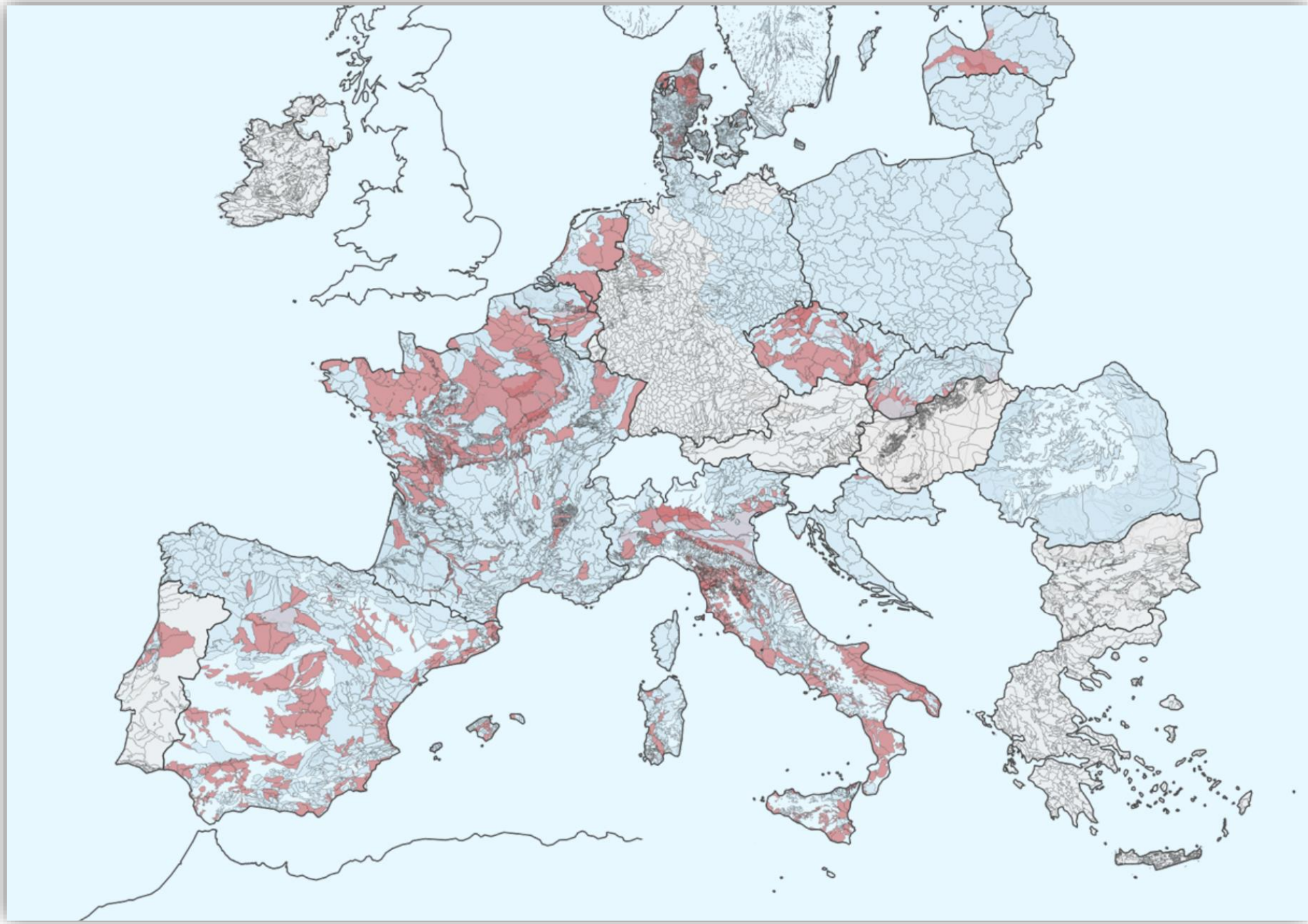
EXPLANATION

Predicted nitrogen concentration, in milligrams per liter as N

- < 1
- 1 to 5
- > 5 to 10
- > 10

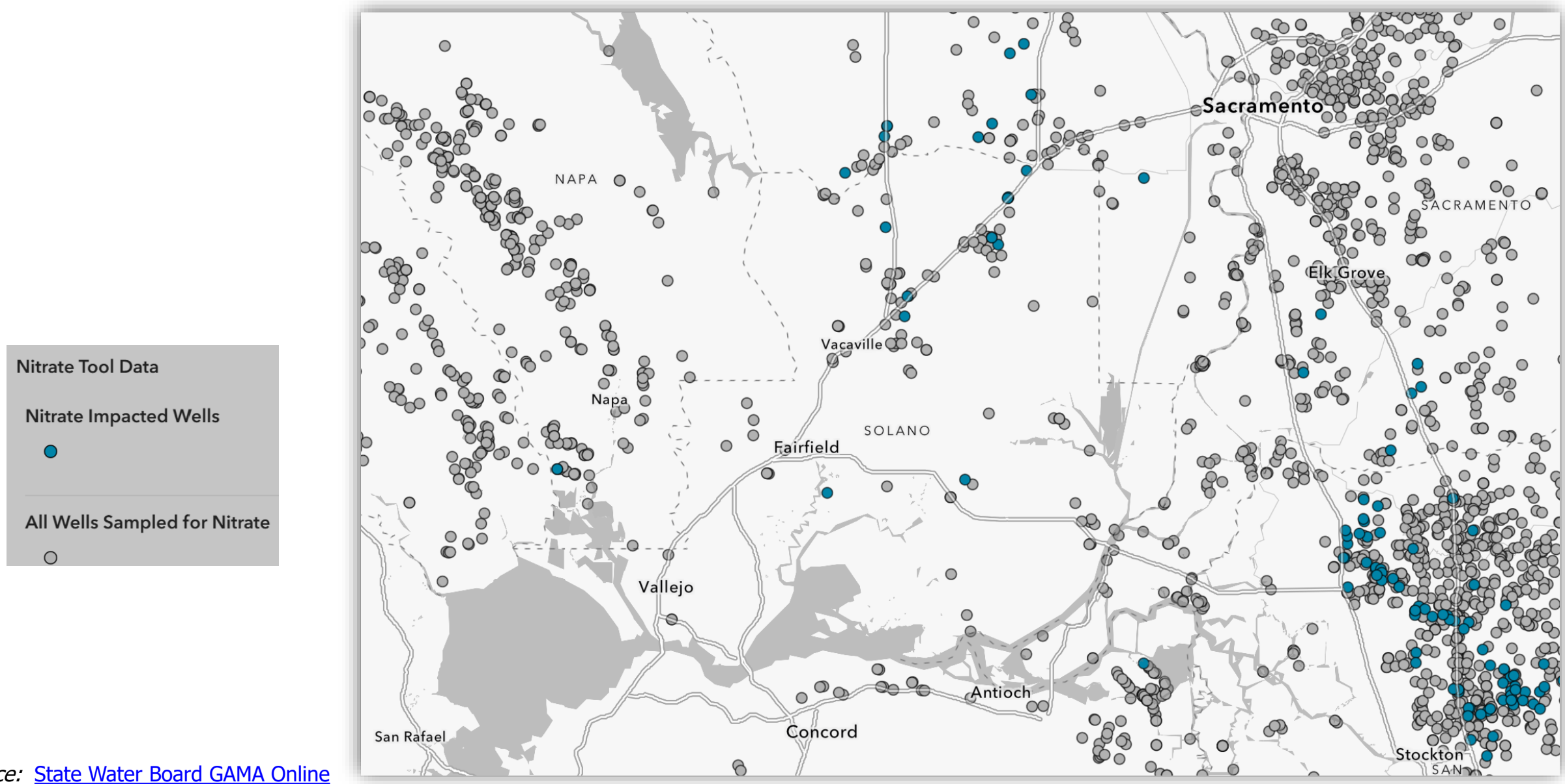
Source: USGS, 2015

Nitrate Pollution of Groundwater is Common in Agricultural Regions around the Globe



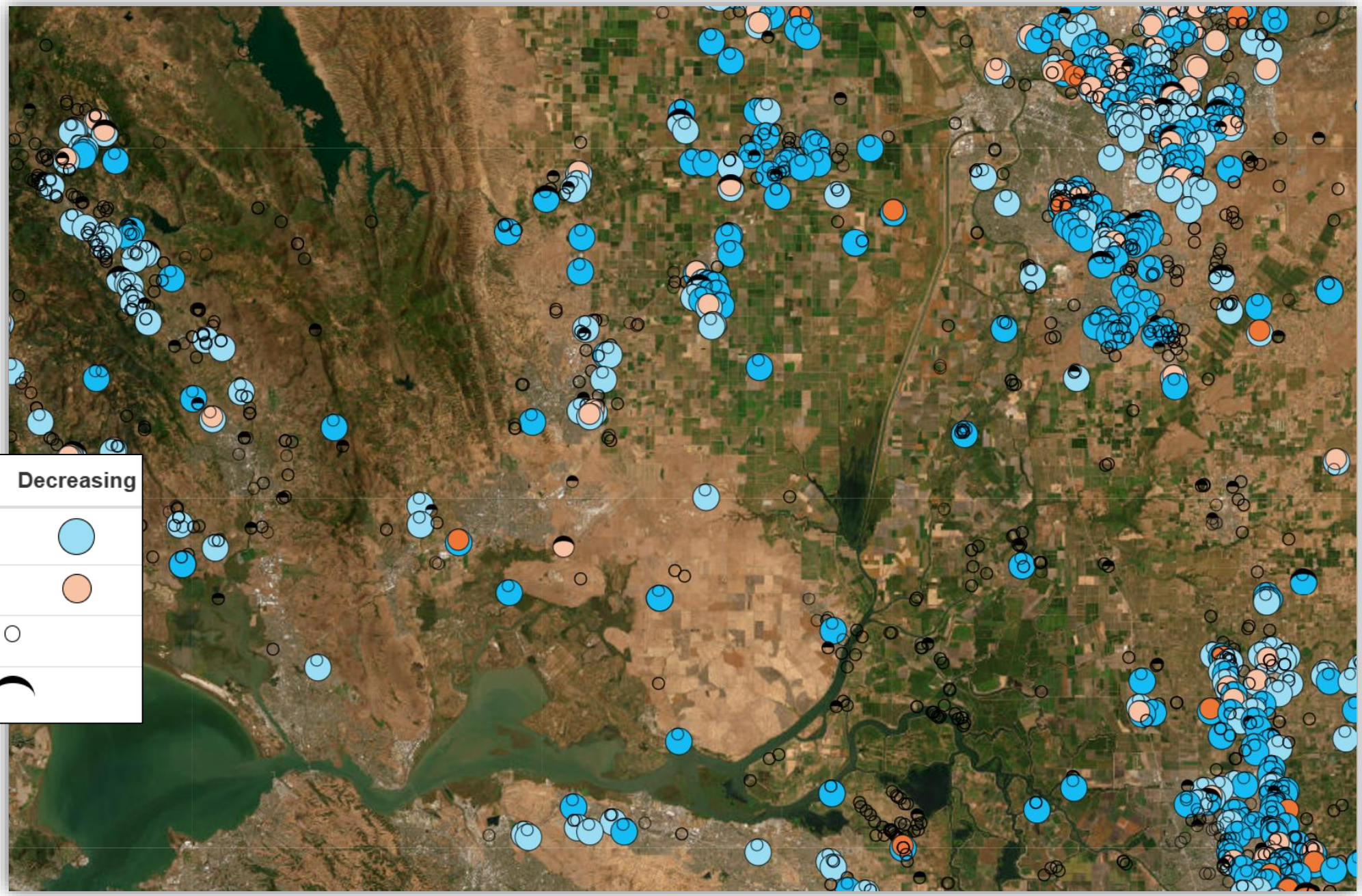
https://EuropeanWaters.eu / European Environment Agency, 2024

Risk of Nitrate Contamination in Domestic Wells and “State Small” Public Water Supply Systems



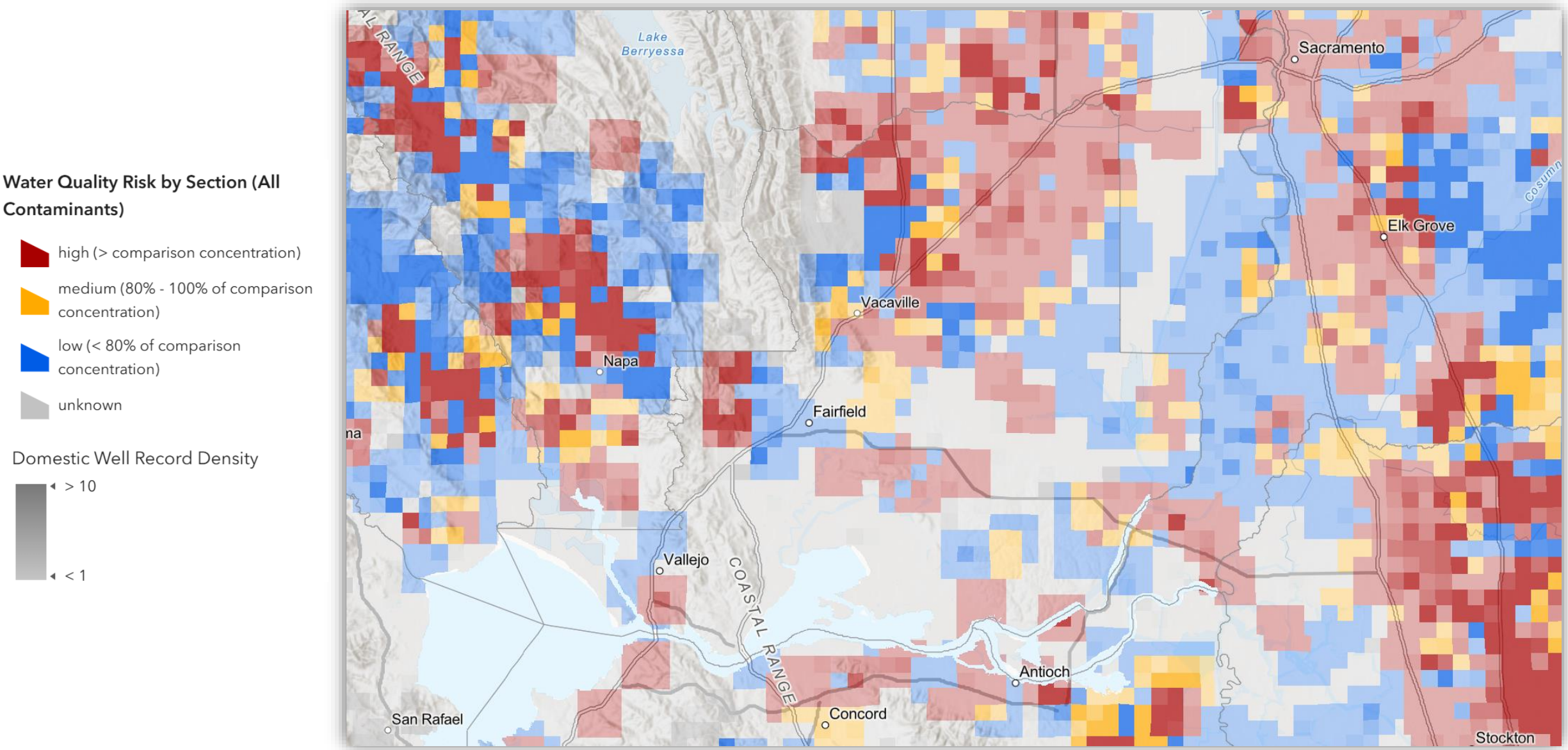
Source: [State Water Board GAMA Online Tools – Is My Well Near a Nitrate-Impacted Well?]

Recent Nitrate Trend



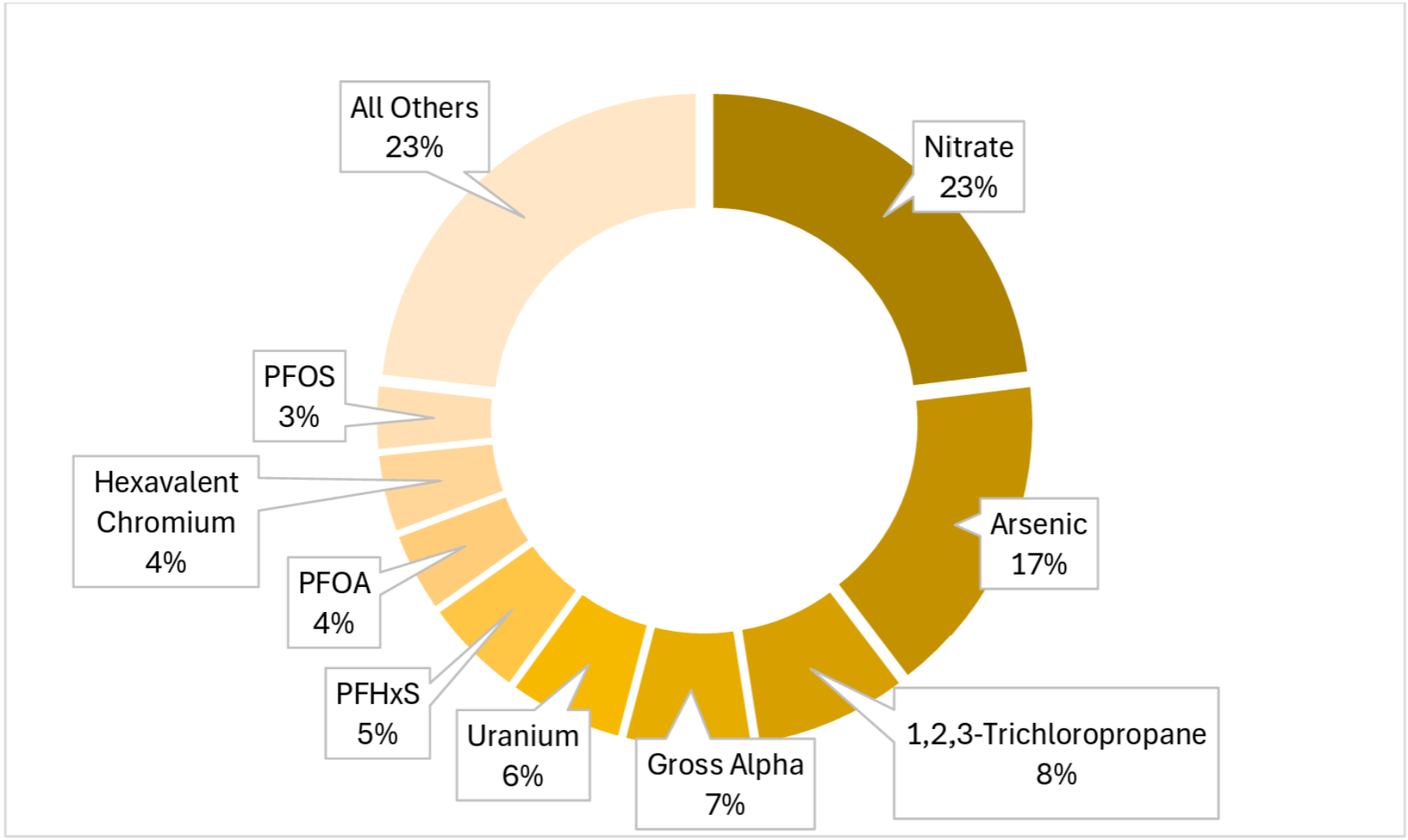
Source: State Water Board GAMA Online Tools –Trend Analysis Tool

Risk of Contamination in Domestic Wells and "State Small" Public Water Supply Systems



Source: [State Water Board GAMA Online Tools – Aquifer Risk Map for Domestic Wells and State Small Systems]

Contaminants in Domestic Wells of High-Risk Aquifer Areas (statewide)

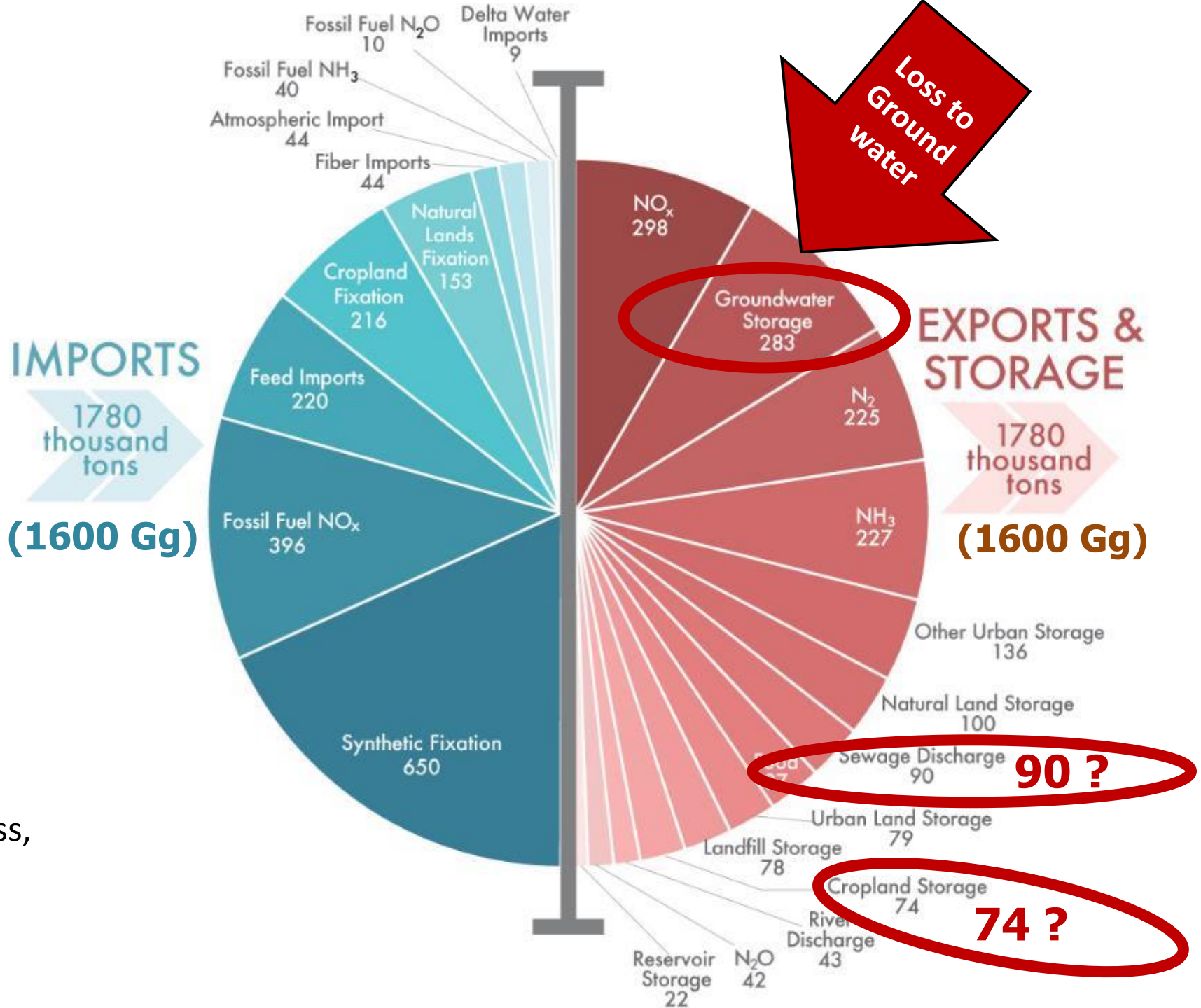


SWRCB, Aquifer Risk Map Methodology, 2025

Nitrate in Groundwater: Where is it from?

California Nitrogen Assessment

1000 short-tons N yr^{-1}



*from:*UC Davis Agricultural Sustainability Institute, UC Press, 2016

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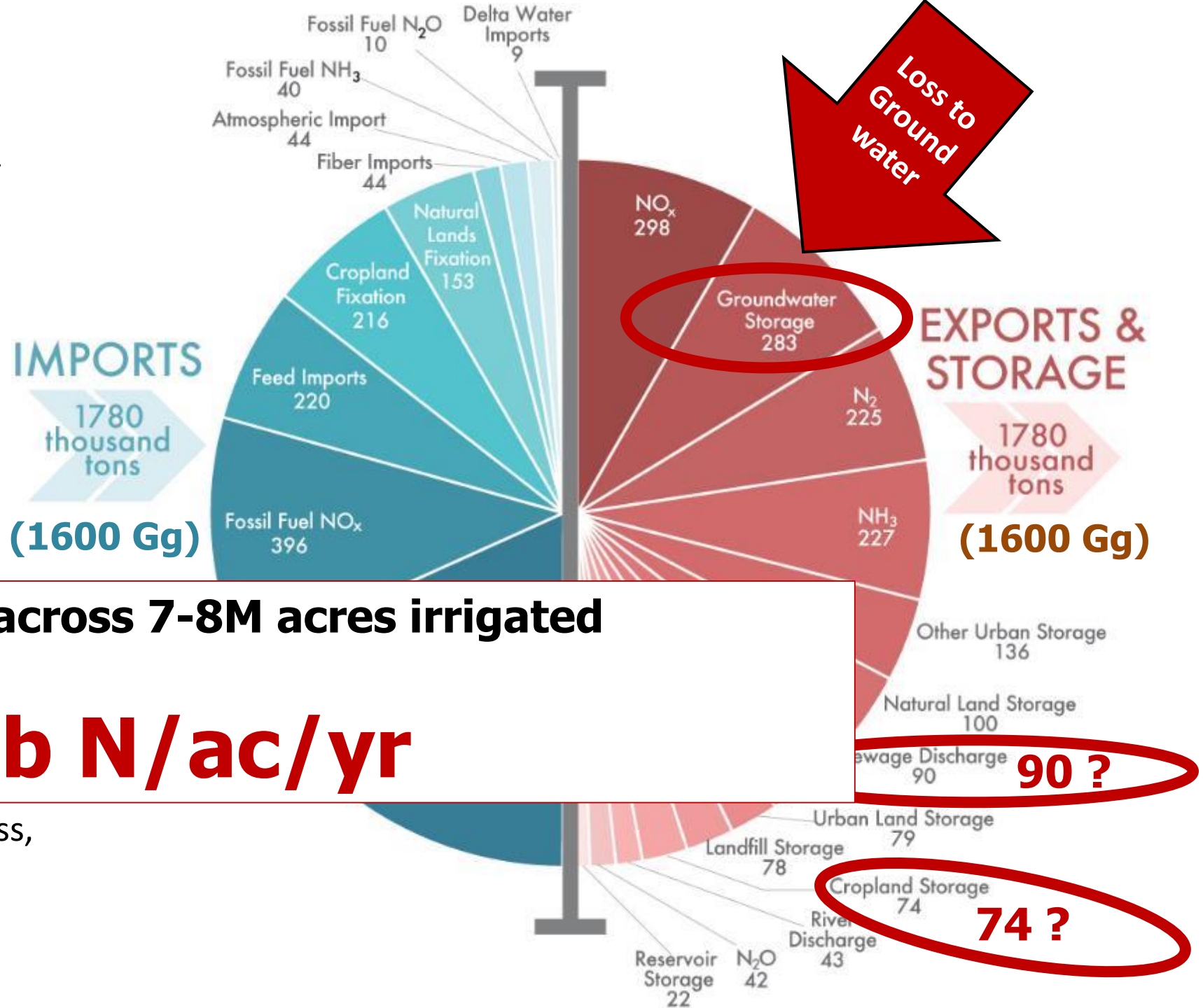
California Nitrogen Assessment

1000 short-tons N yr^{-1}



potential N balance across 7-8M acres irrigated agricultural land:

~75 - 120 lb N/ac/yr

Sustainability Institute, UC Press, 2016

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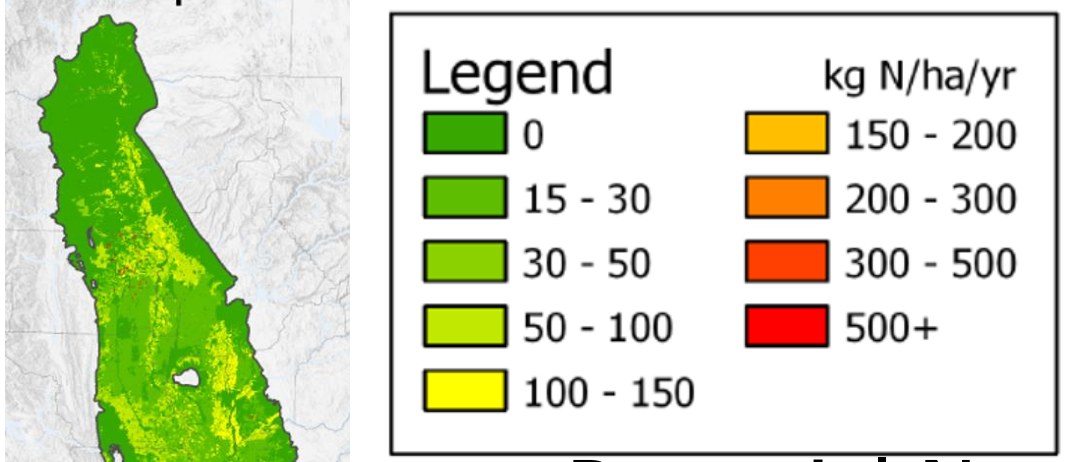
Drinking Water Limit:

45 mg Nitrate /L

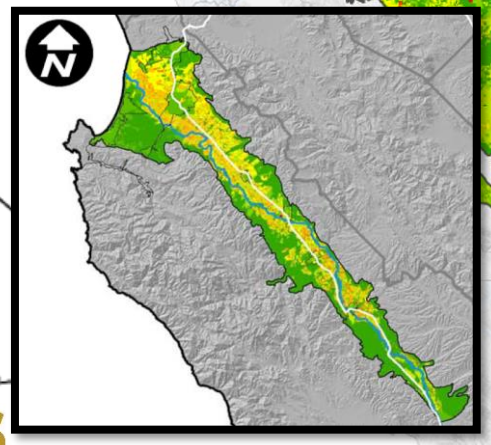
= 10 mg Nitrate-N / L

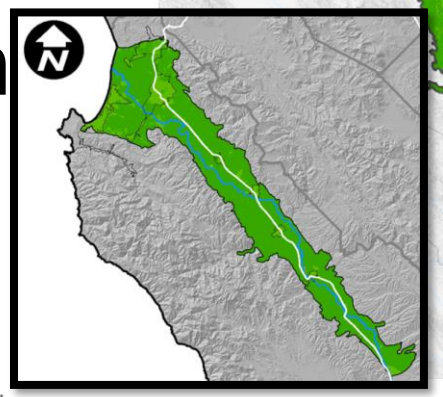
= 27 lb Nitrate-N / acre-foot

Laura Bliss / Atlantic City Lab



Potential N Leaching from Crop and Natural Vegetation





Potential N Leaching from Urban and Industrial Landuse, Dairy Corrals & Lagoons

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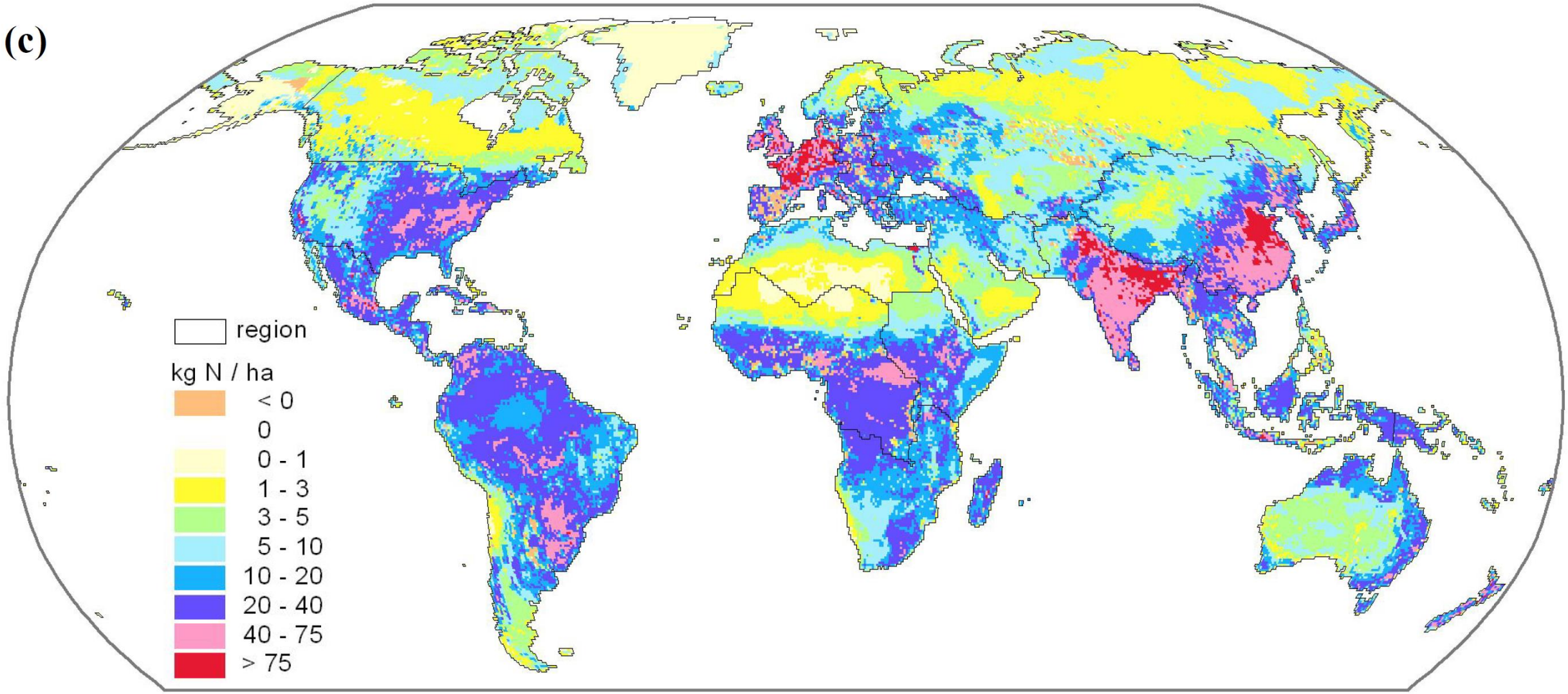
Harter et al., 2017. http://groundwaternitrate.ucdavis.edu

Global Soil Nitrogen Balance at the End of the 20th Century

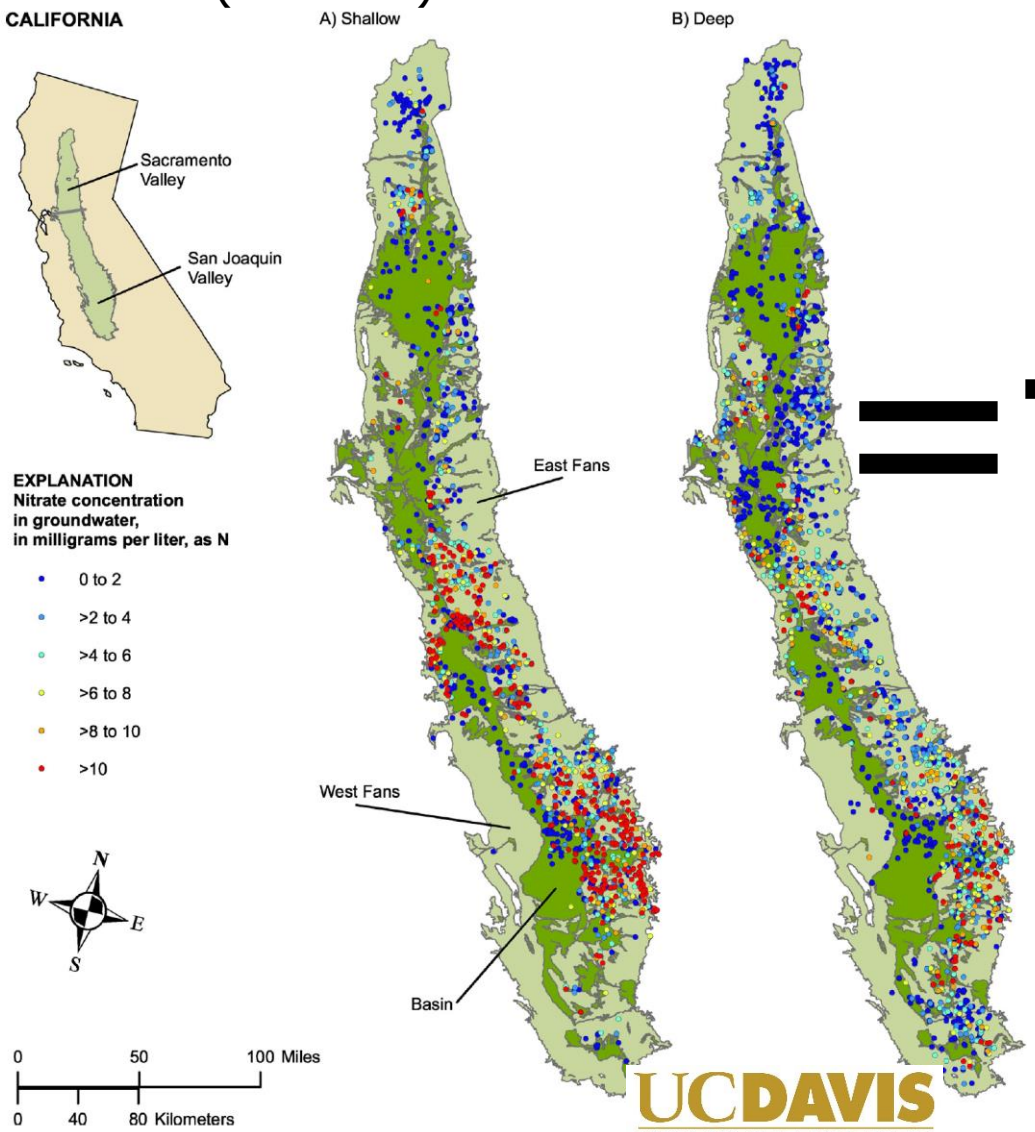


Source: Siebert, 2005

Machine Learning: Well Nitrate(2000 – 2014) as f(Explanatory Variables)

Domestic wells (< 100 m)

Public supply wells (> 100 m)



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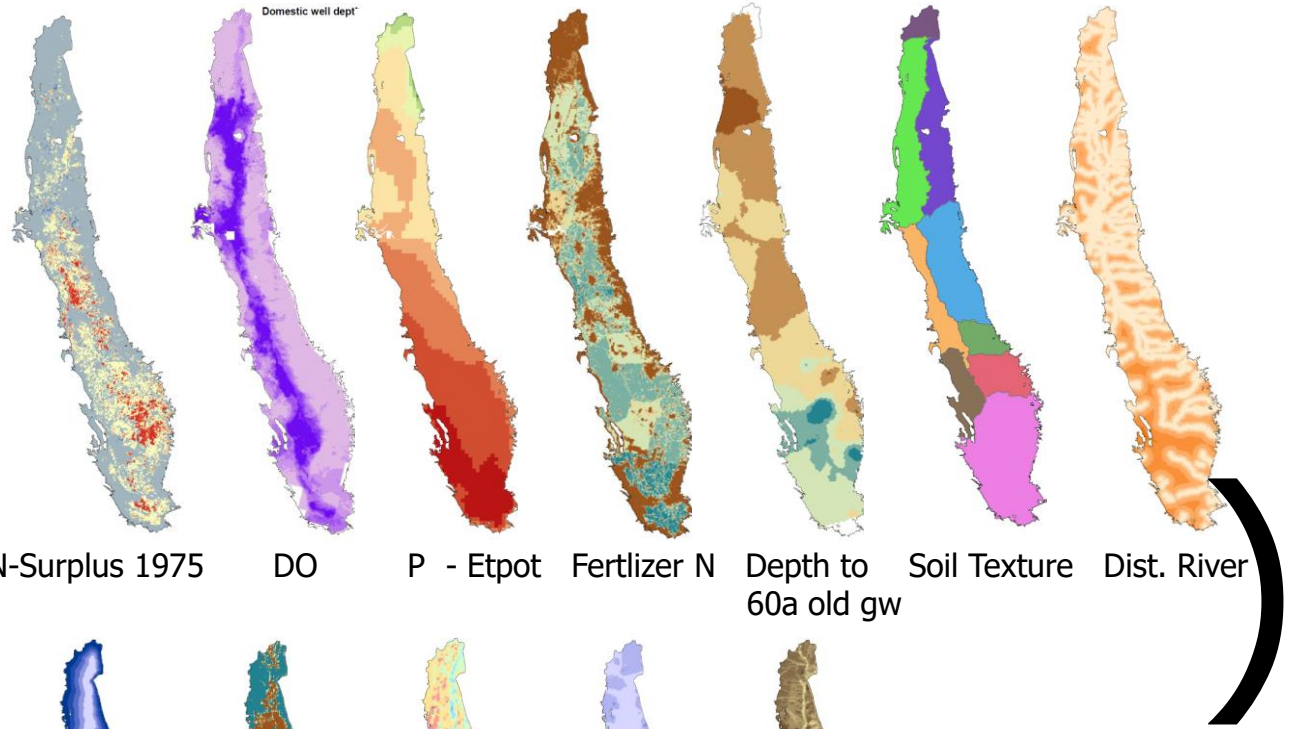
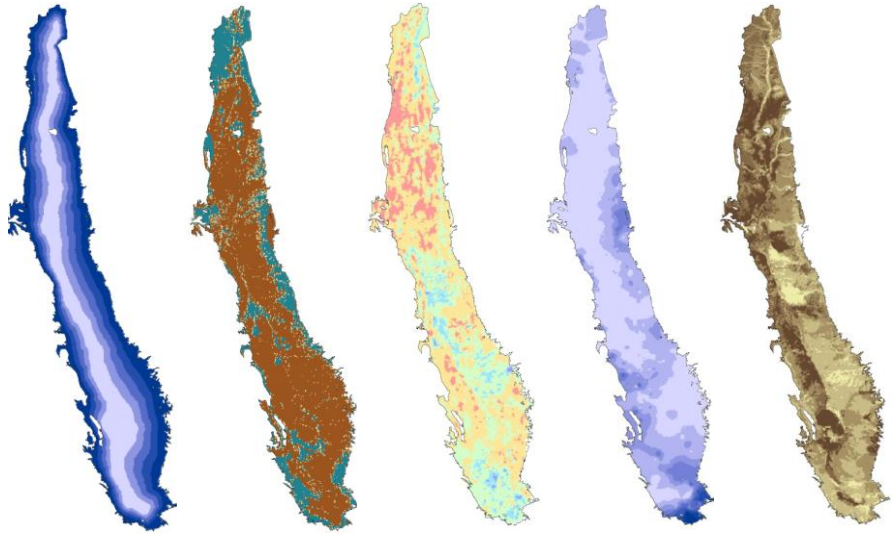


N-Surplus 1975 | DO | P - Etpot | Fertlizer N | Depth to 60a old gw | Soil Texture | Dist. River



Dist. Thalweg | Natural Area | Coarse Soil | Depth to GW | Aquifer Clay

)

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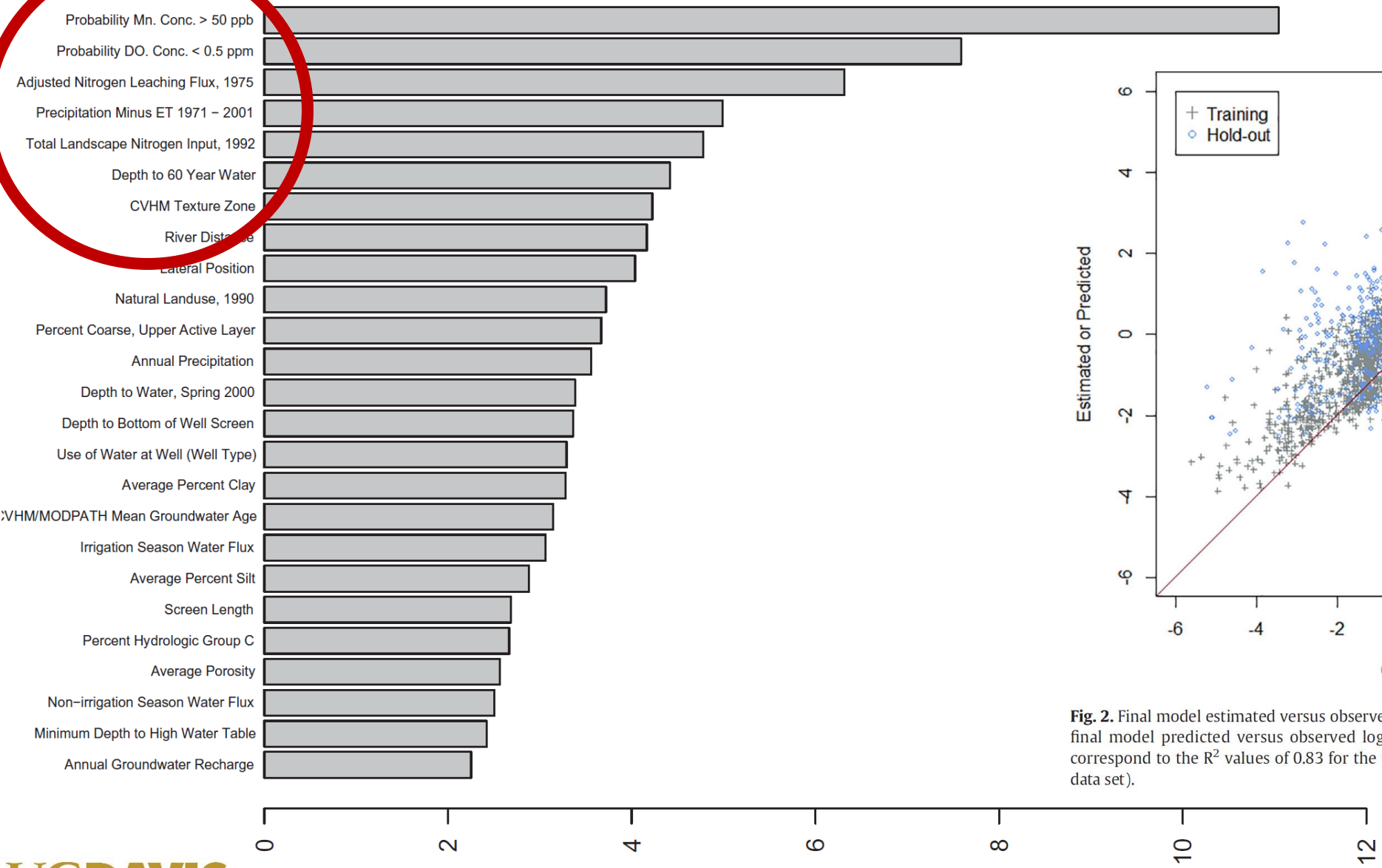
Ransom et al., STOTEN 2017

Machine learning (Boosted Regression Tree) identified major predictors of groundwater nitrate



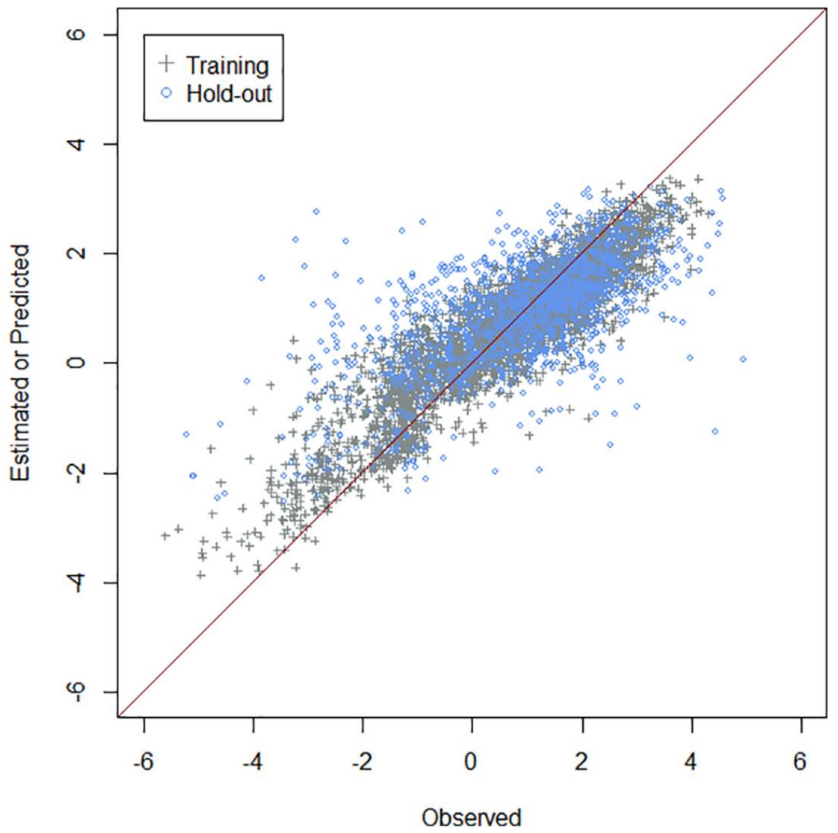


Fig. 2. Final model estimated versus observed log nitrate values (training data set) and final model predicted versus observed log nitrate values (hold-out data set). Plots correspond to the R^2 values of 0.83 for the training data set and 0.44 for the hold-out data set).

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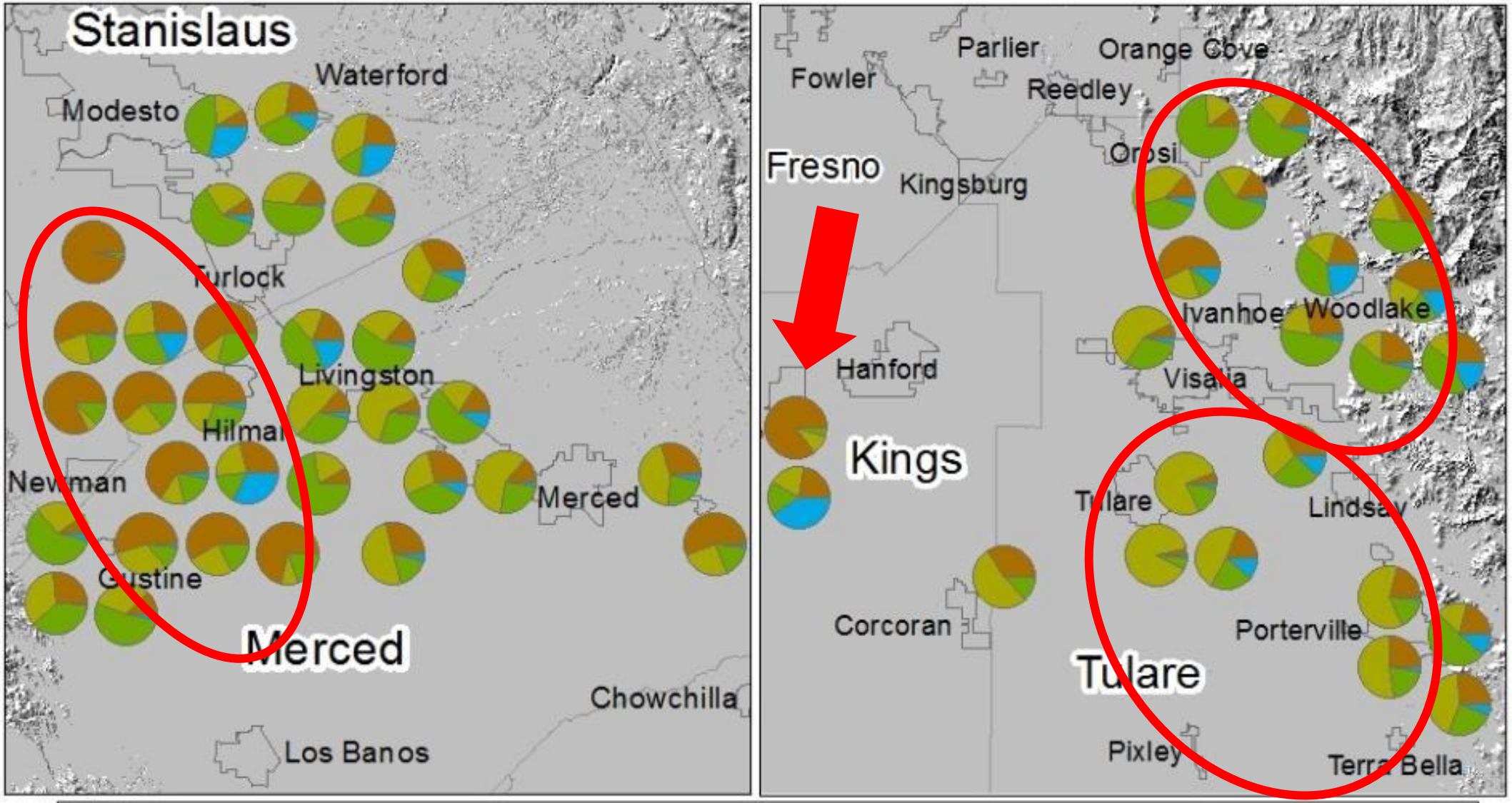
Ransom et al., STOTEN 2017

Nitrate forensics: Bayesian estimation of source fractions

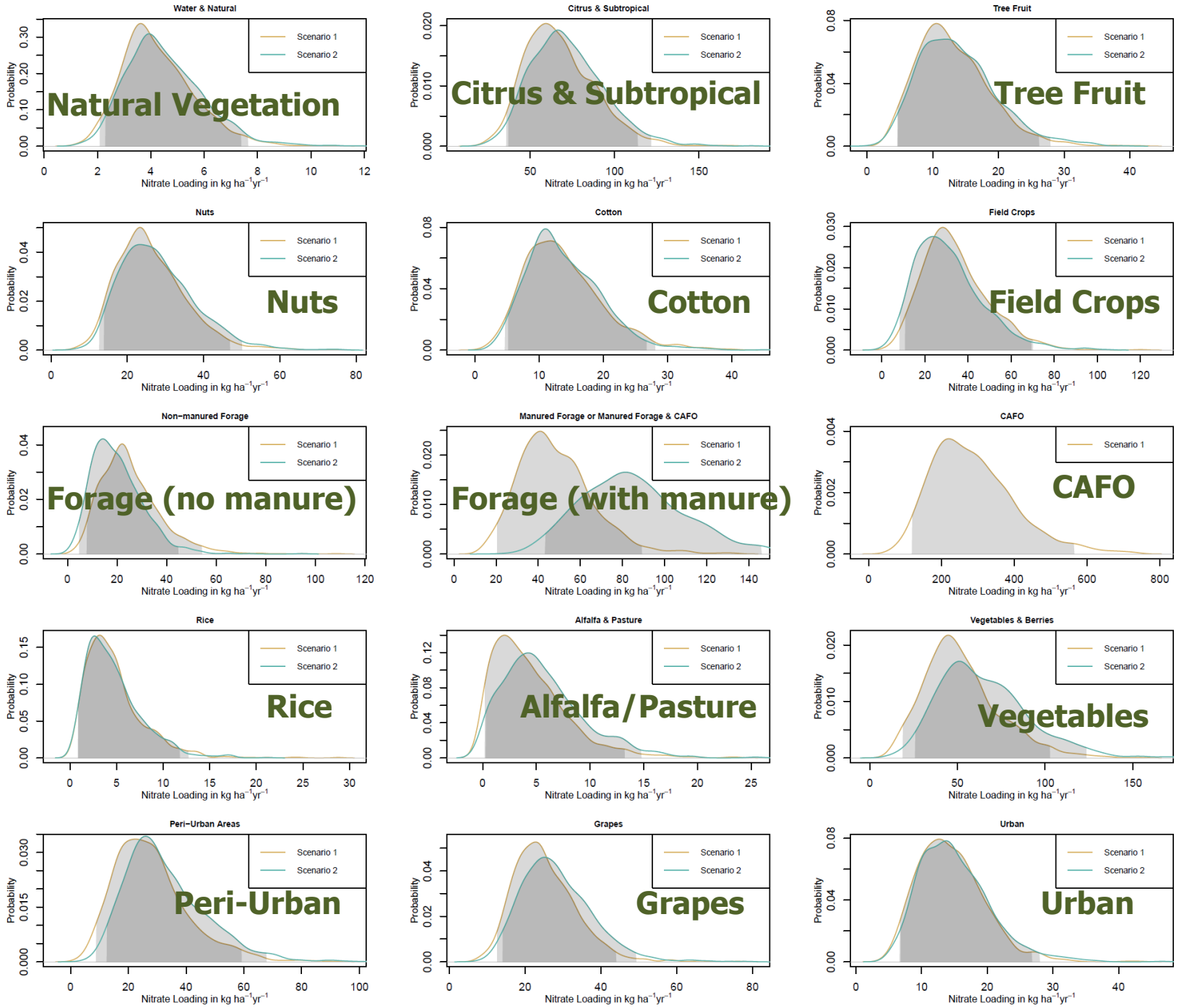


Ransom et al., WRR (2016)

Estimated nitrogen loading pdf at time of recharge
[kg N/ha/yr]

(1970s – 1990s)

by crop / landuse type



Ransom et al., HESS (2018)

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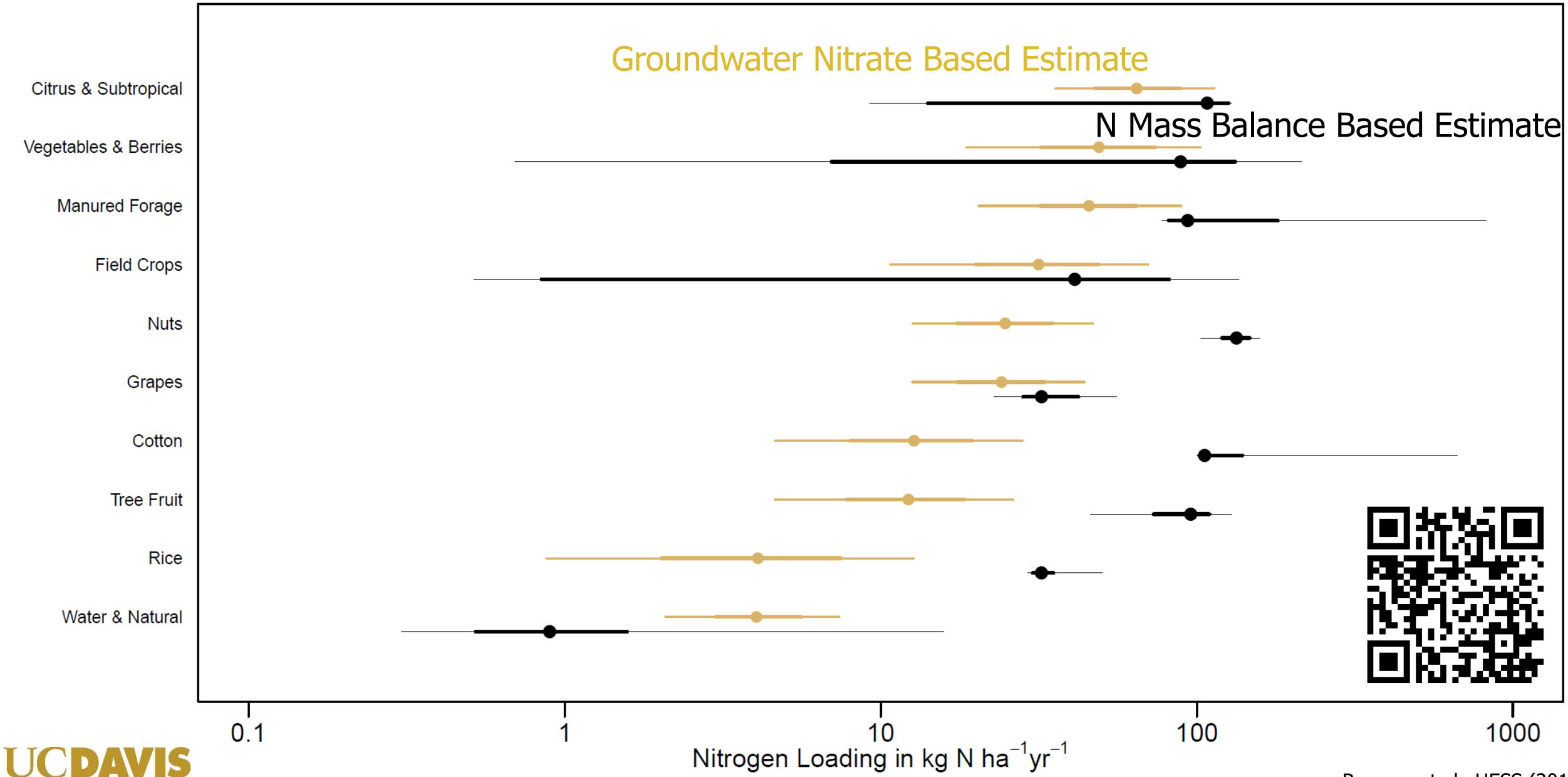
Forensic analysis confirms the mass balance N loading to groundwater for some crops and landuse types



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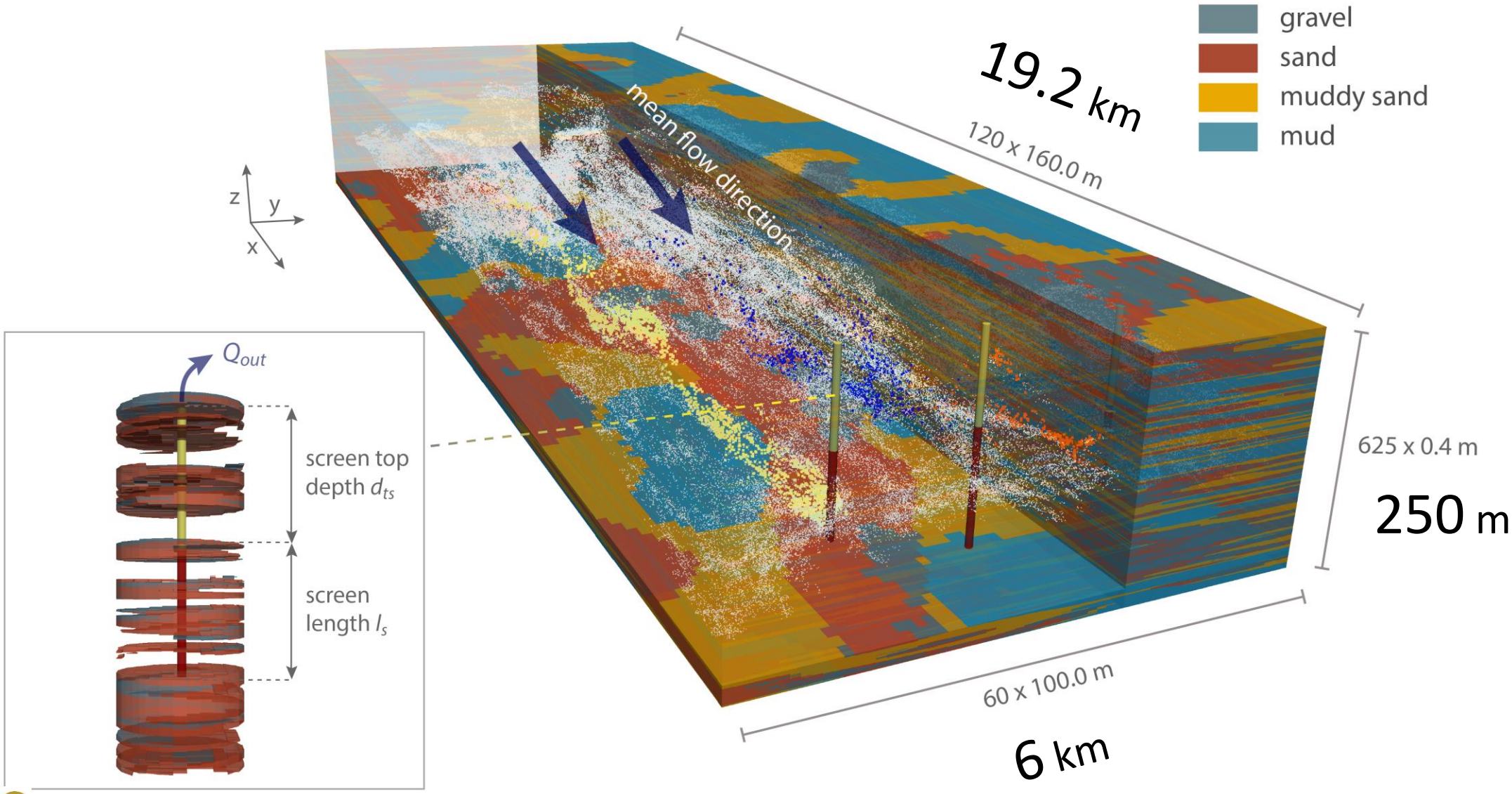
Ransom et al., HESS (2018)

Research programs to develop and assess BMPs: Groundwater Modeling



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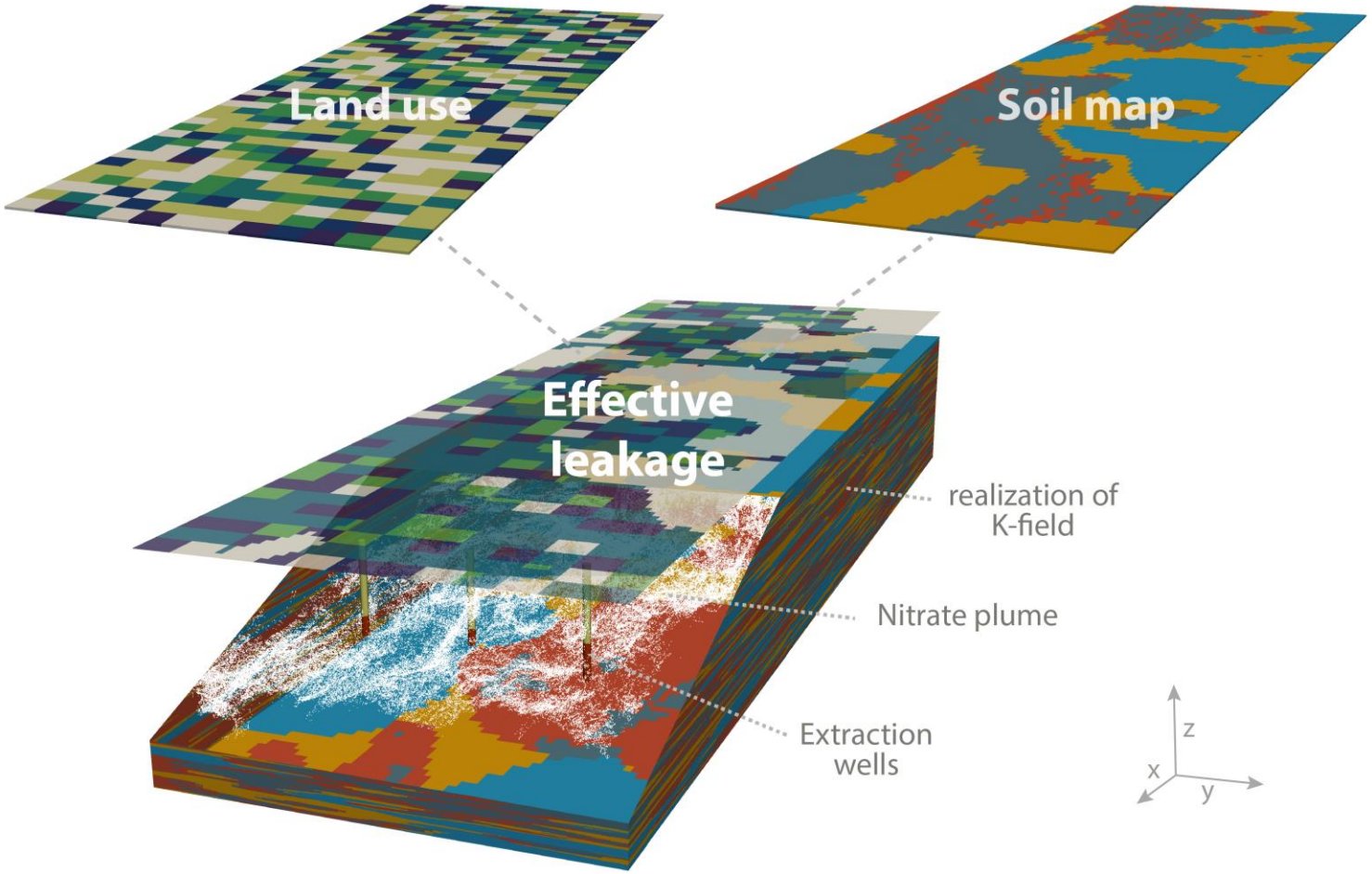
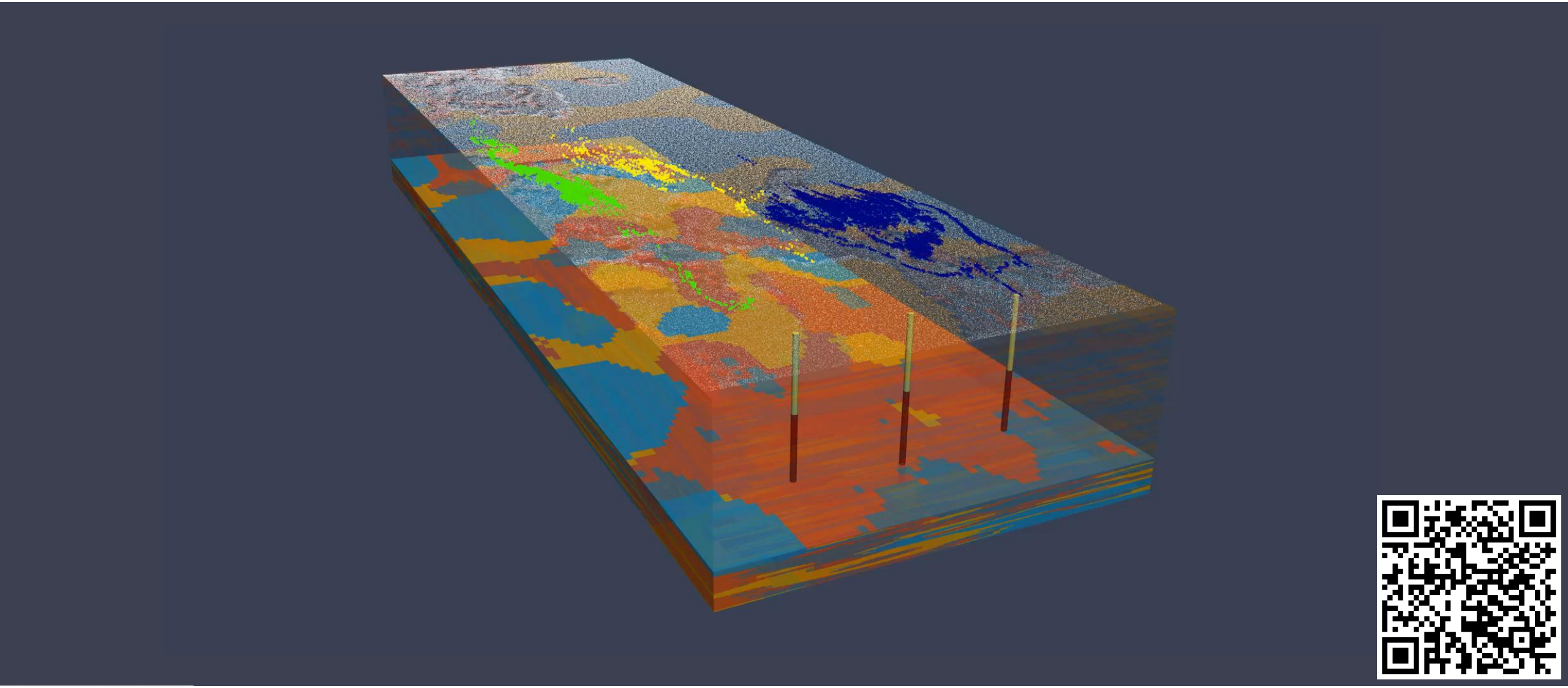
..but we don’t consider just the variability of the aquifer, also that of soils and crop-scape…



Henri and Harter, HESS 2019

What Happens to Nitrogen Surplus When Leached This Year as Nitrate?



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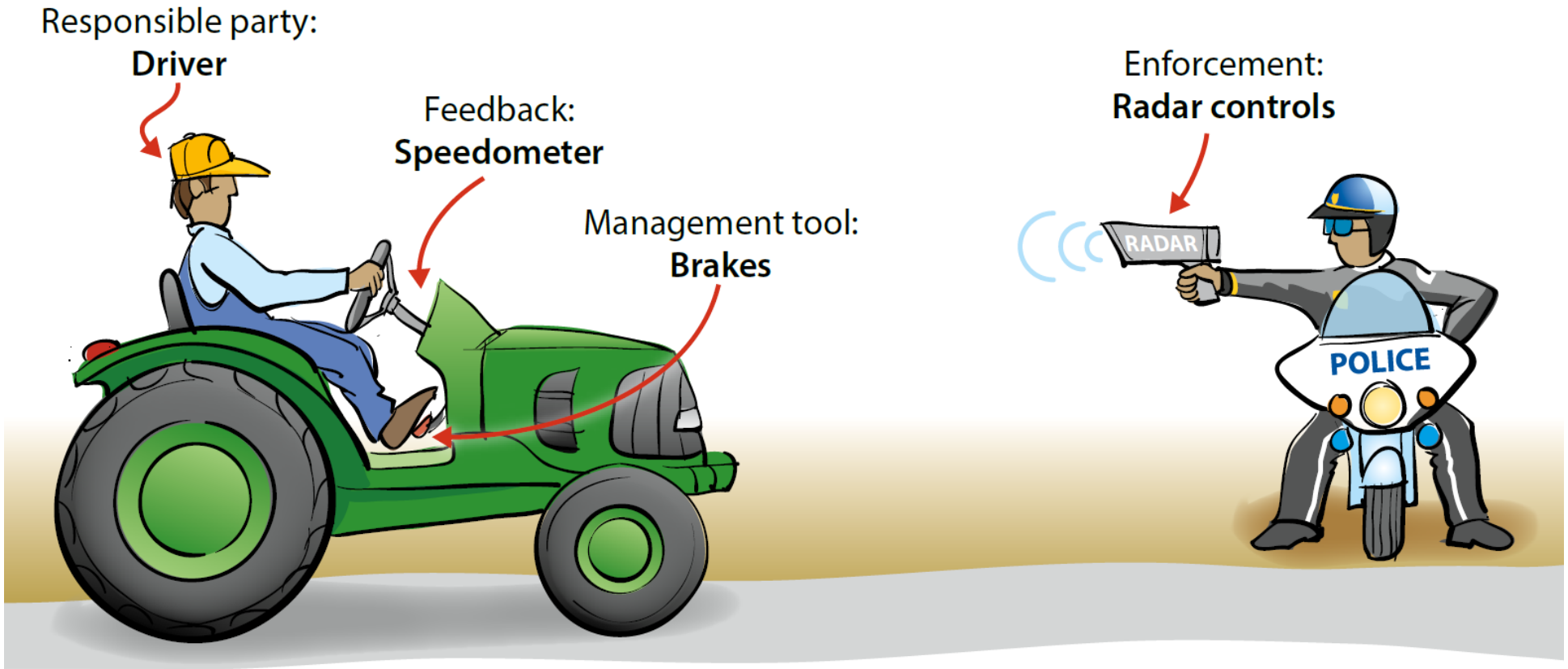
Henri and Harter, WRR 2019

Groundwater Nitrate Sources: What to Do About It?

The Basics of Management Policy & Regulation

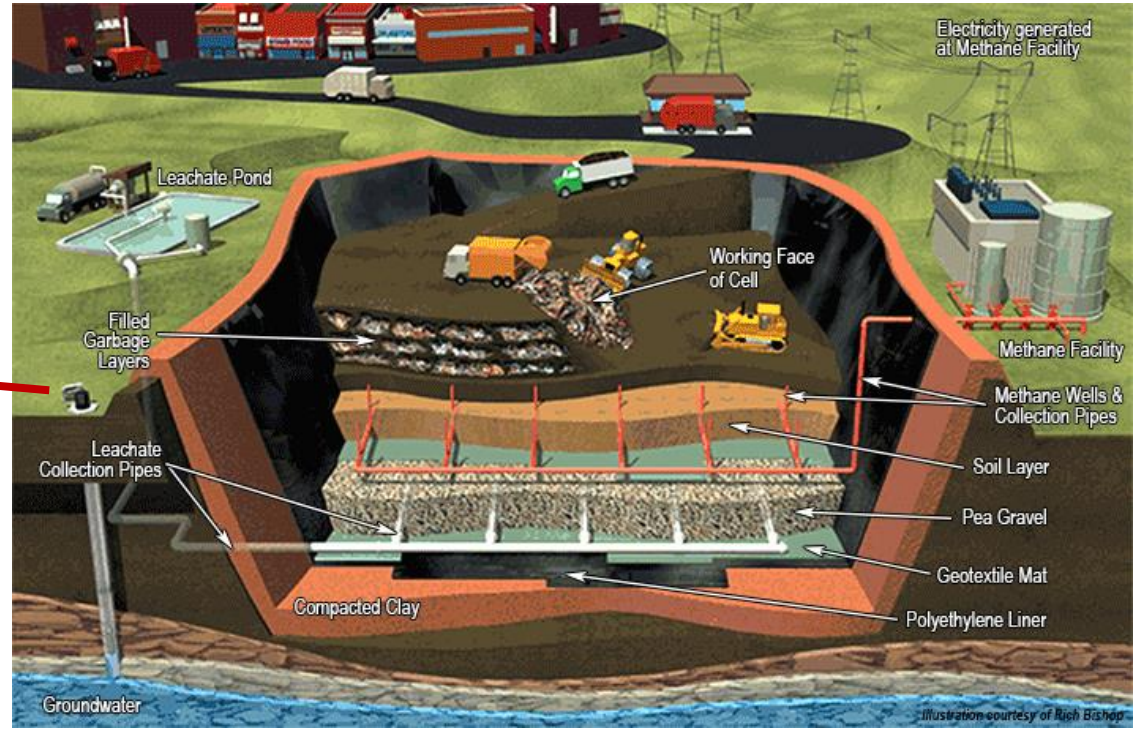
- Identify impacts (human health, environment, economy) and risk drivers
- Identify & prioritize parties to be regulated (universal v structured/categories)



Harter, California Agriculture, 2015

… identify potential polluters, control pollution, remediate, monitor… …

Monitoring Well



California Water Quality Regulations

State Legislation / Statutory Authority:
1969 Porter-Cologne Water Quality Control Act
2002 Sunset of Exemptions for NPS (Agriculture, Urban Stormwater)

State Water Board (Oversight)
9 Regional Water Boards (Planning, Permitting, Policing)

Basin Plan: water bodies (gw & sw), beneficial uses
=> water quality objectives

Discharge Permits
("Orders")

Penalties / Cease and Desist Orders

California – Regulations to curtail groundwater pollution from NPS

Legislative Mandate of the late 1990s:
2002 Sunset of Exemptions for NPS (Agriculture, Urban Stormwater)

new discharge permits / first for agriculture

2000s to current: Surface Water
2007 to current: Groundwater

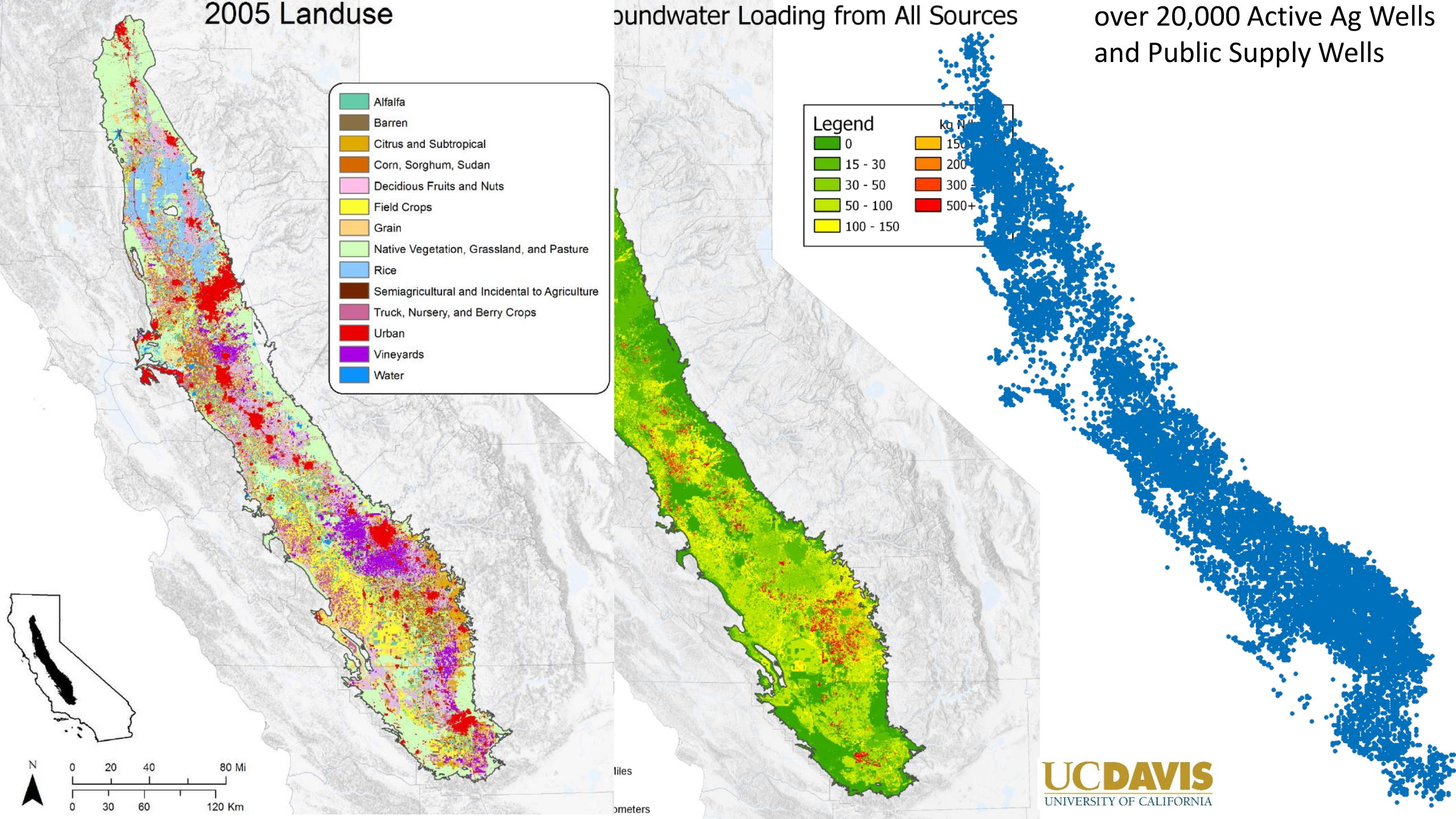
2007 Dairy Order (Central Valley RWB)

2012 Irrigated Lands Regulatory Program (Central Valley RWB)

2012 Agricultural Order (Central Coast RWB)

2018 Revised ILRP (SWB – statewide precedence)

2018 Salt and Nutrient Basin Plan Amendment (Central Valley RWB)


2005 Landuse
Alfalfa
Barren
Citrus and Subtropical
Corn, Sorghum, Sudan
Decidious Fruits and Nuts
Field Crops
Grain
Native Vegetation, Grassland, and Pasture
Rice
Semiagricultural and Incidental to Agriculture
Truck, Nursery, and Berry Crops
Urban
Vineyards
Water
N
0 20 40 80 Mi
0 30 60 120 Km
oundwater Loading from All Sources
Legend
0
15 - 30
30 - 50
50 - 100
100 - 150
150
200
300
500+
over 20,000 Active Ag Wells
and Public Supply Wells
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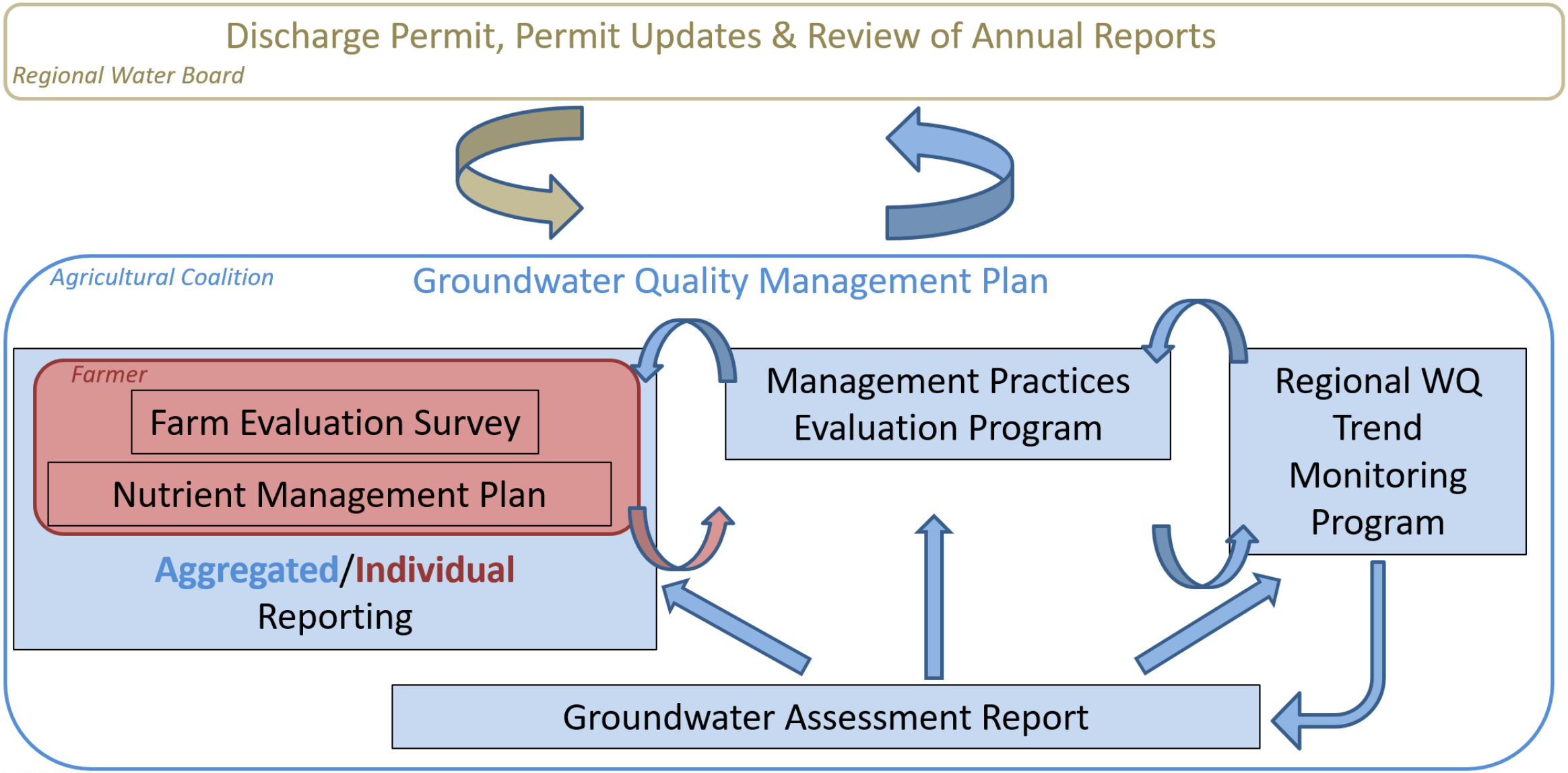
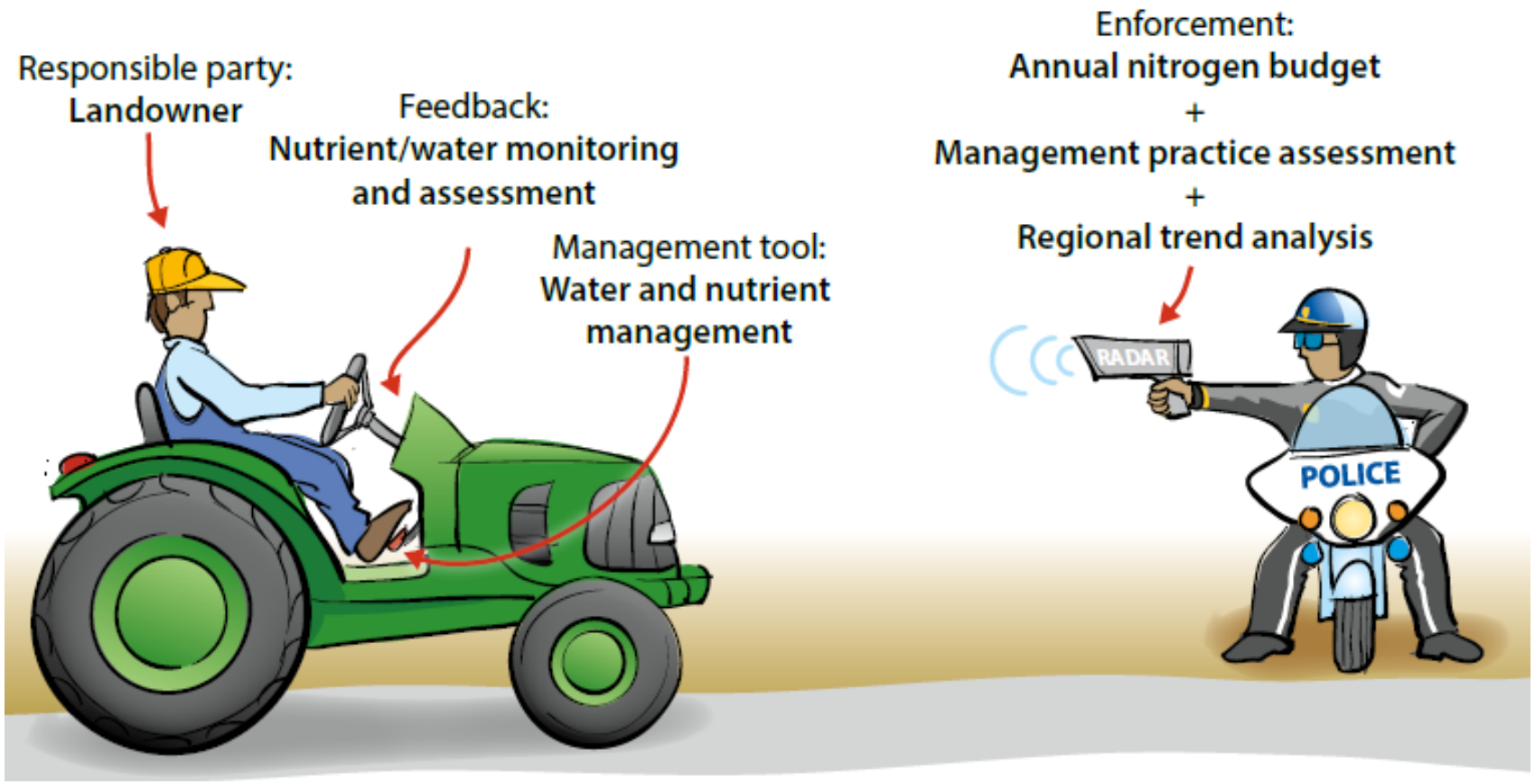
California regulations to curtail groundwater pollution from agriculture: Irrigated Lands Regulatory Program overview



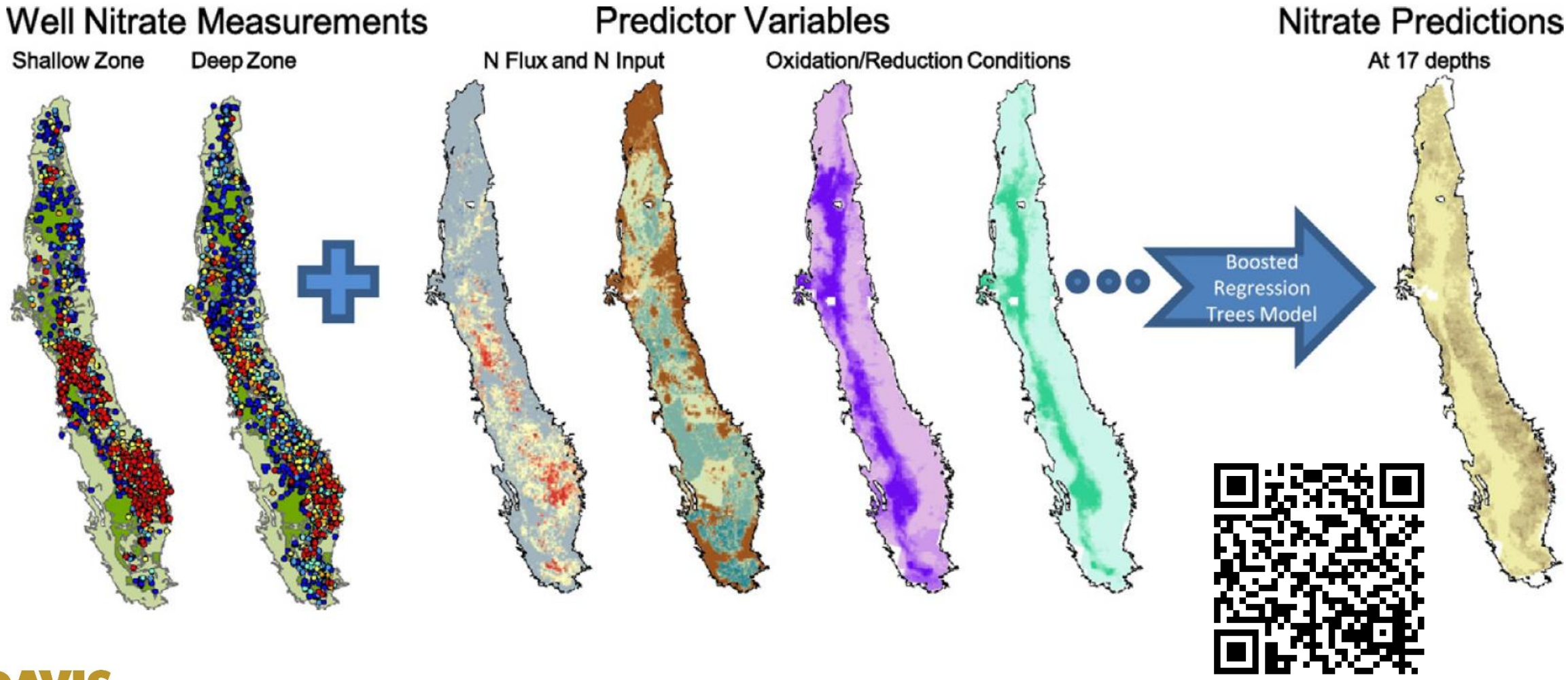
ILRP: Regulating nonpoint sources of nitrate pollution

- Identify impacts and risk drivers: GW Assessment Report
- Identify & prioritize parties to be regulated: high vulnerability areas



Harter, California Agriculture, 2015

Use machine learning to predict nitrate at 1 km scale (Boosted Random Tree)



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Ransom et al., STOTEN 2017

Estimated groundwater nitrate concentration (BRT) at 1 km^2 & 17 depths

Domestic well depth (< 100 m)

Public supply well depth (> 100 m)

EXPLANATION

Nitrate - N (mg/L)

- < 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- > 10

N W E S

0 180 360 Miles

0 160 320 Kilometers

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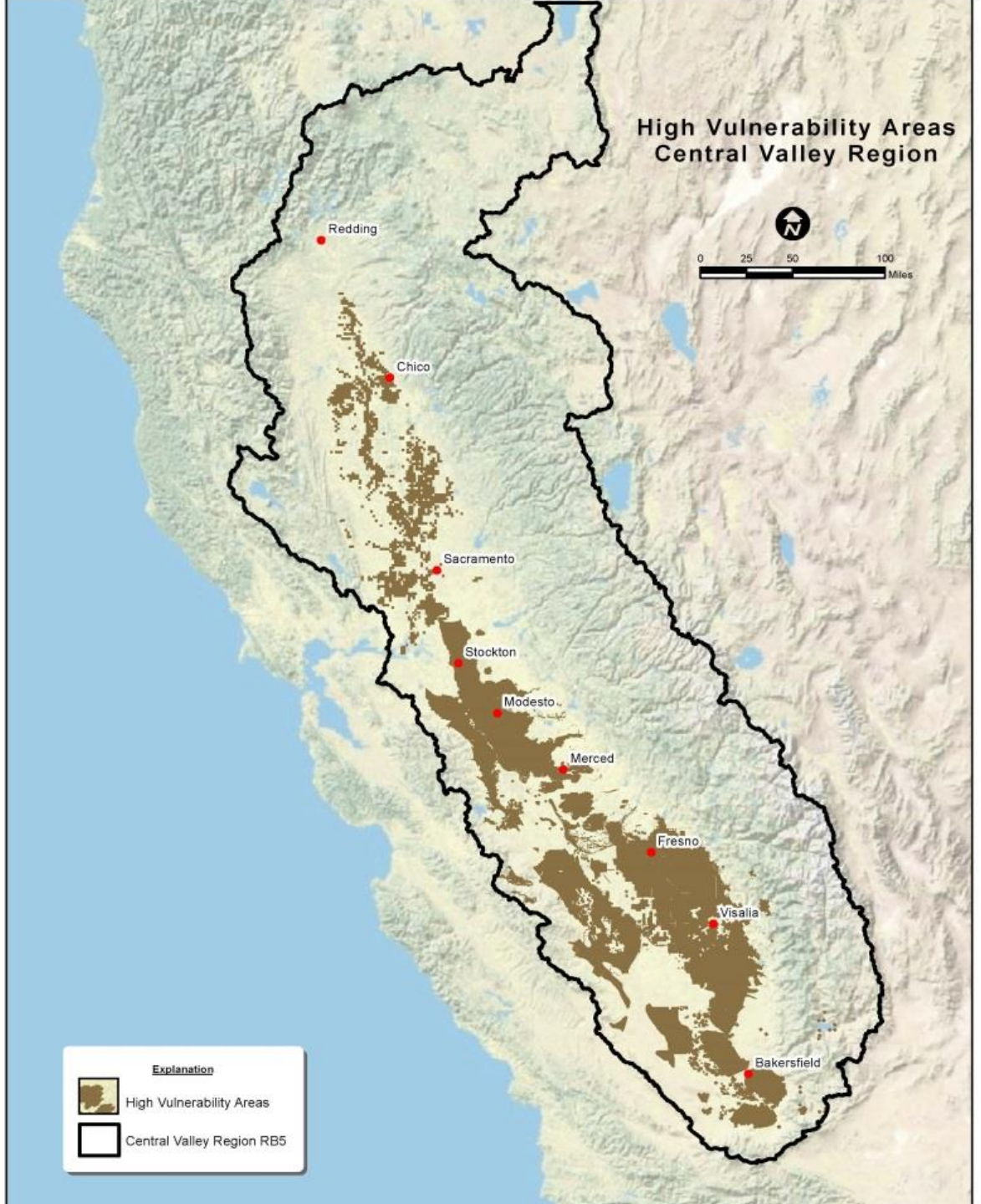
Ransom et al., STOTEN 2017

Overlay measured/predicted nitrate occurrence with community locations

=> High Vulnerability Areas (HVAs) for nitrate

Central Valley, California



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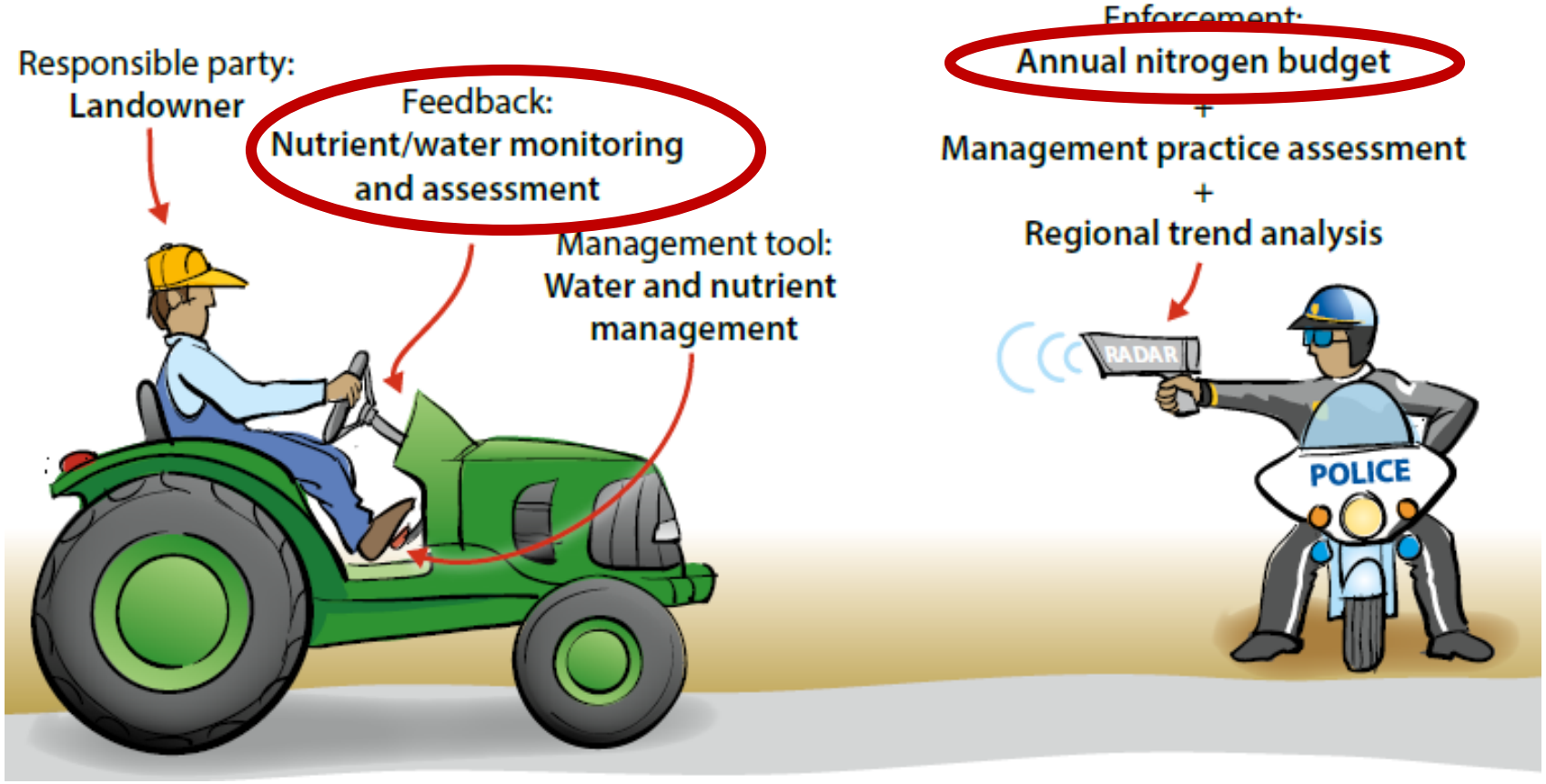

Harter, California Agriculture, 2015

Growers are responsible for compliance

- Obtain coverage (initial application)
- Implement management practices
- Prepare plans and reports on practices
  - Template-based
  - Stay on farm/submit to coalitions (HVAs)

From: Central Valley Regional Water Board, Irrigated Lands Regulatory Program

Grower's
Nitrogen Management Plan:

Annual Nitrogen Budget
Reporting (by field)

NITROGEN MANAGEMENT PLAN WORKSHEET

NMP Management Unit: _____

1. Crop Year (Harvested): _____

2. Member ID# _____

3. Name:

4. APN(s):	5. Field(s) ID	Acres

CROP NITROGEN MANAGEMENT PLANNING		N APPLICATIONS/CREDITS	15. Recommended/ Planned N	16. Actual N
6. Crop		**17. Nitrogen Fertilizers**		
7. Production Unit		18. Dry/Liquid N (lbs/ac)		
8. Projected Yield (Units/Acre)		19. Foliar N (lbs/ac)		
9. N Recommended (lbs/ac)		**20. Organic Material N**		
10. Acres		21. Available N in Manure/Compost (lbs/ac estimate)		
Post Production Actuals				
11. Actual Yield (Units/Acre)		**22. Total Available N Applied** (lbs per acre)		
12. Total N Applied (lbs/ac)		**23. Nitrogen Credits (est)**		
13. ** N Removed (lbs N/ac)		24. Available N carryover in soil; (annualized lbs/acre)		
14. Notes:		25. N in Irrigation water (annualized, lbs/ac)		
		26. Total N Credits (lbs per acre)		
		27. Total N Applied & Available		

PLAN CERTIFICATION		
28. CERTIFIED BY:	**29. CERTIFICATION METHOD**	
	30. Low Vulnerability Area, No Certification Needed	
	31. Self-Certified, approved training program attended	
DATE:	32. Self-Certified, UC or NRCS site recommendation	
	33. Nitrogen Management Plan Specialist	

**Your Coalition will provide the method to be used to estimate N Removed. Approved by the Central Valley Water Board 23 December 2014.

Instruction numbering in this document differs slightly from the NMP template approved by the Water Board to accommodate this publication design.

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ILRP: Regulating nonpoint sources of nitrate pollution

- Identify impacts and risk drivers: GW Assessment Report
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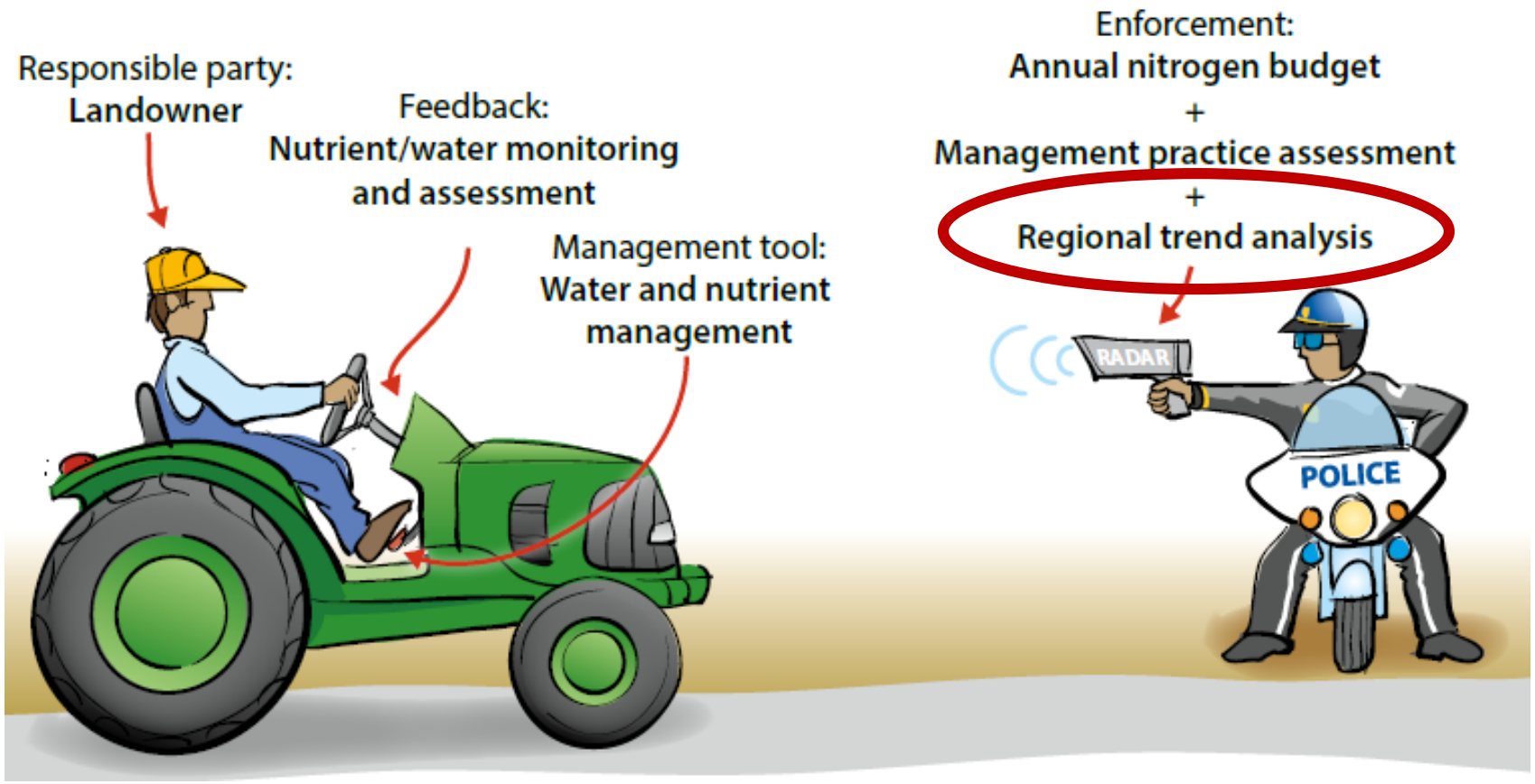

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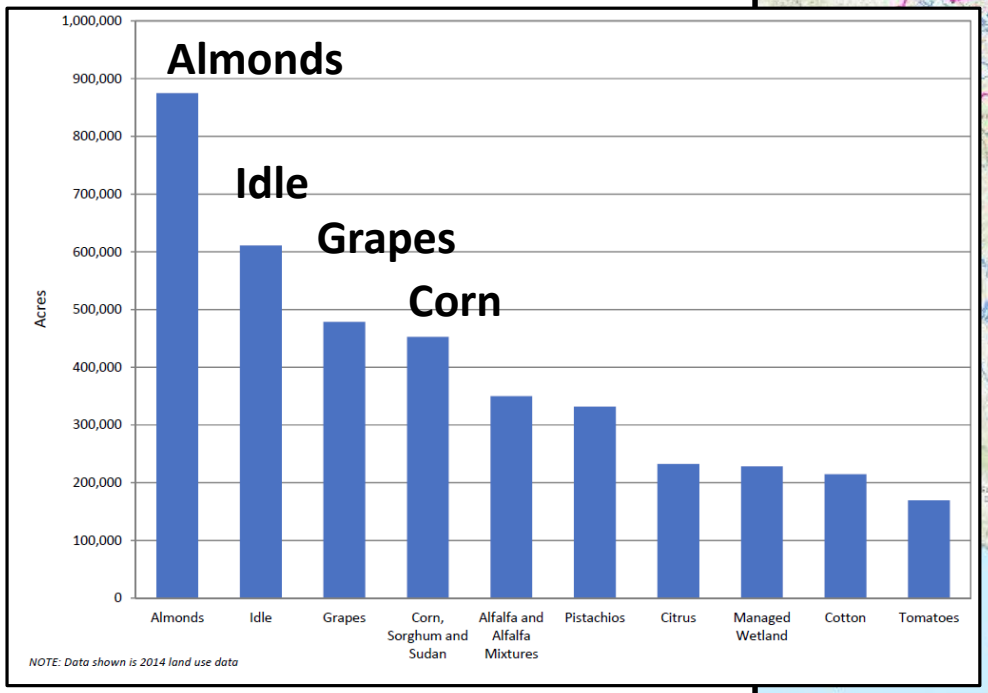
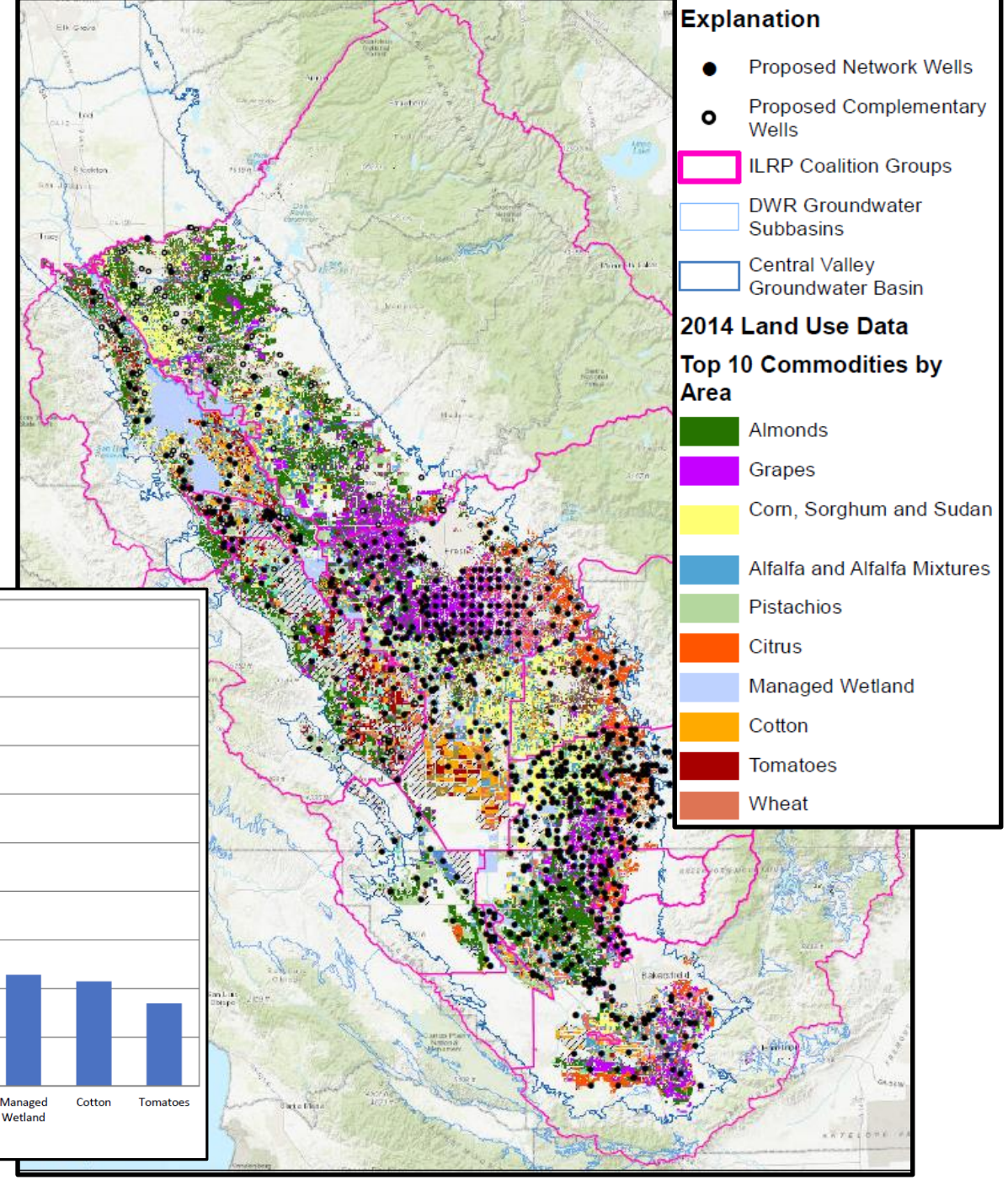
Harter, California Agriculture, 2015

CVGMC Network & Top Commodities

- Almonds: 875,015 ac
- Grapes: 478,751 ac
- Corn: 452,531 ac





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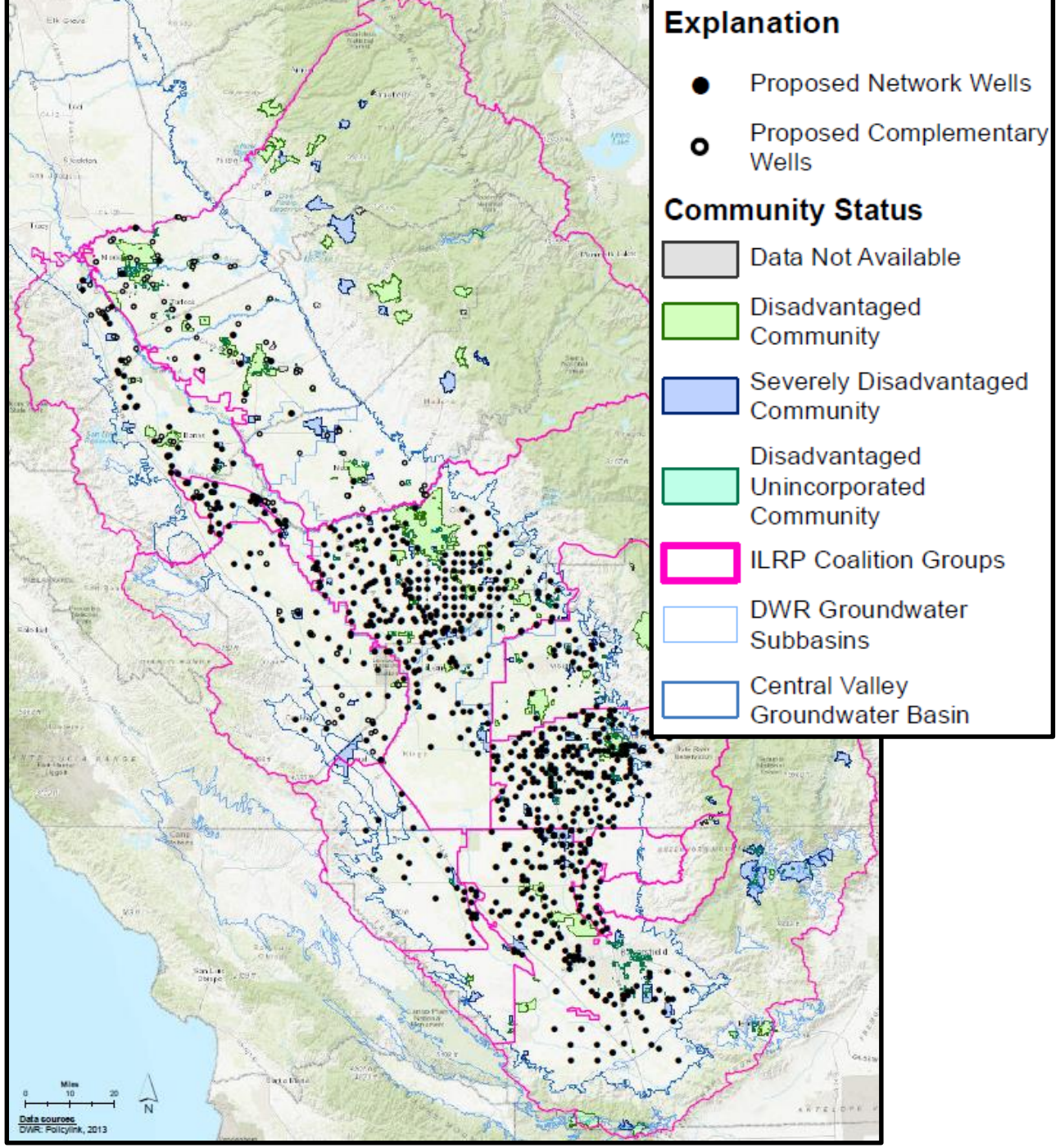
Courtesy of: CVGMC March 27, 2018 Meeting

CVGMC Network and DACs



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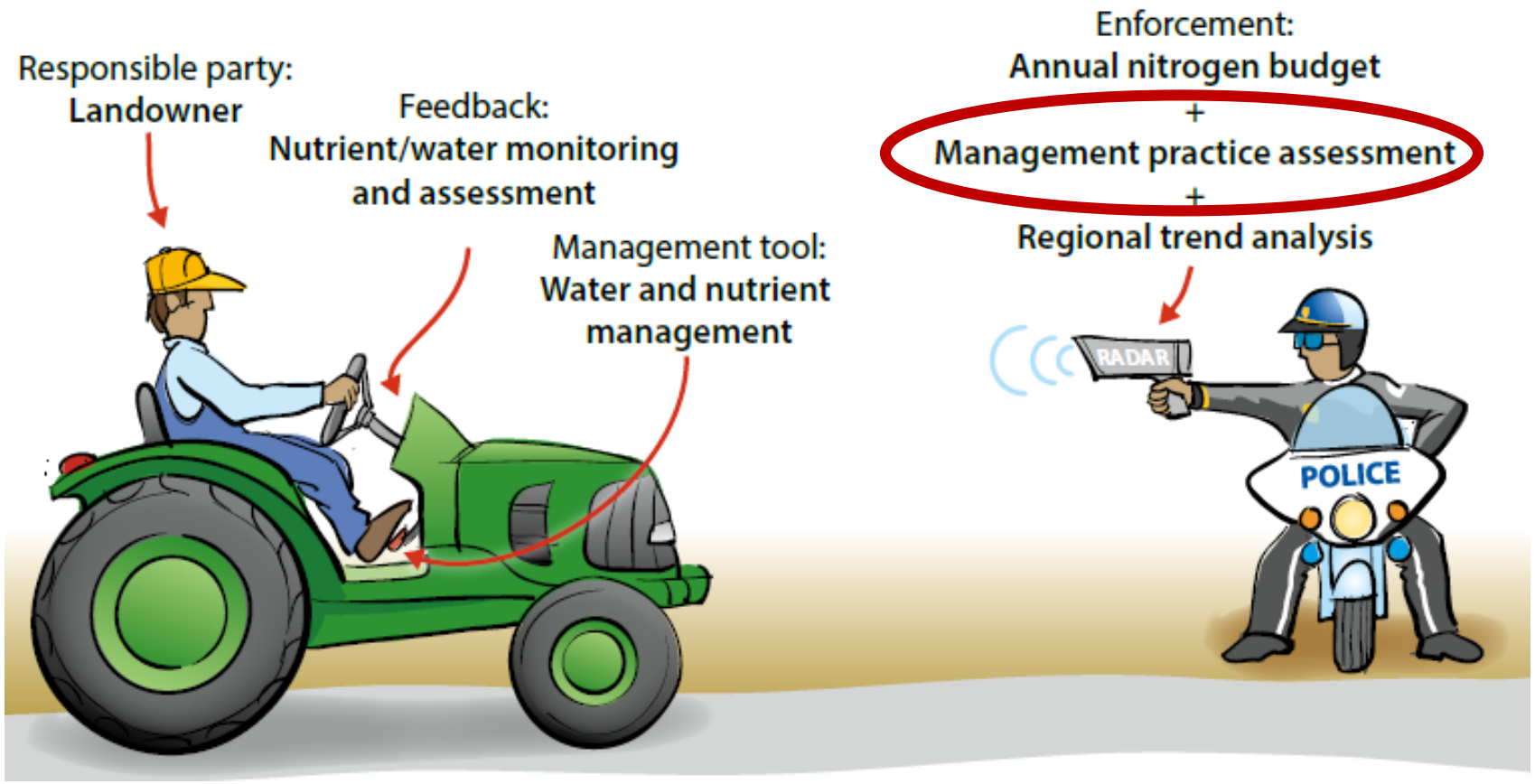
Courtesy of: CVGMC March 27, 2018 Meeting

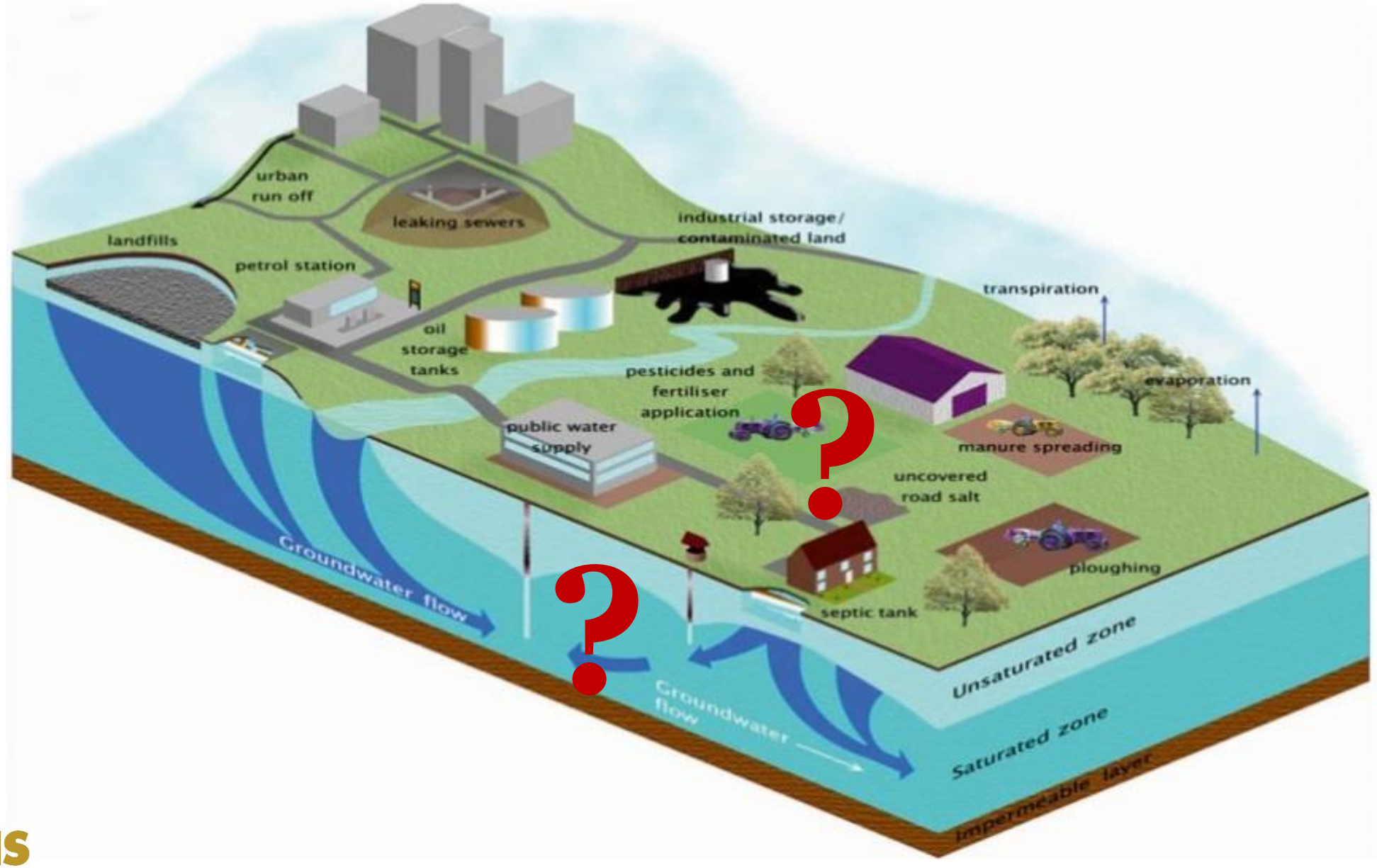
ILRP: Regulating nonpoint sources of nitrate pollution

- Identify impacts and risk drivers: GW Assessment Report
- Identify & prioritize parties to be regulated: high vulnerability areas



Harter, California Agriculture, 2015

Moving forward, two key questions:



… ag's most important pollution control device: water and nutrient management….

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

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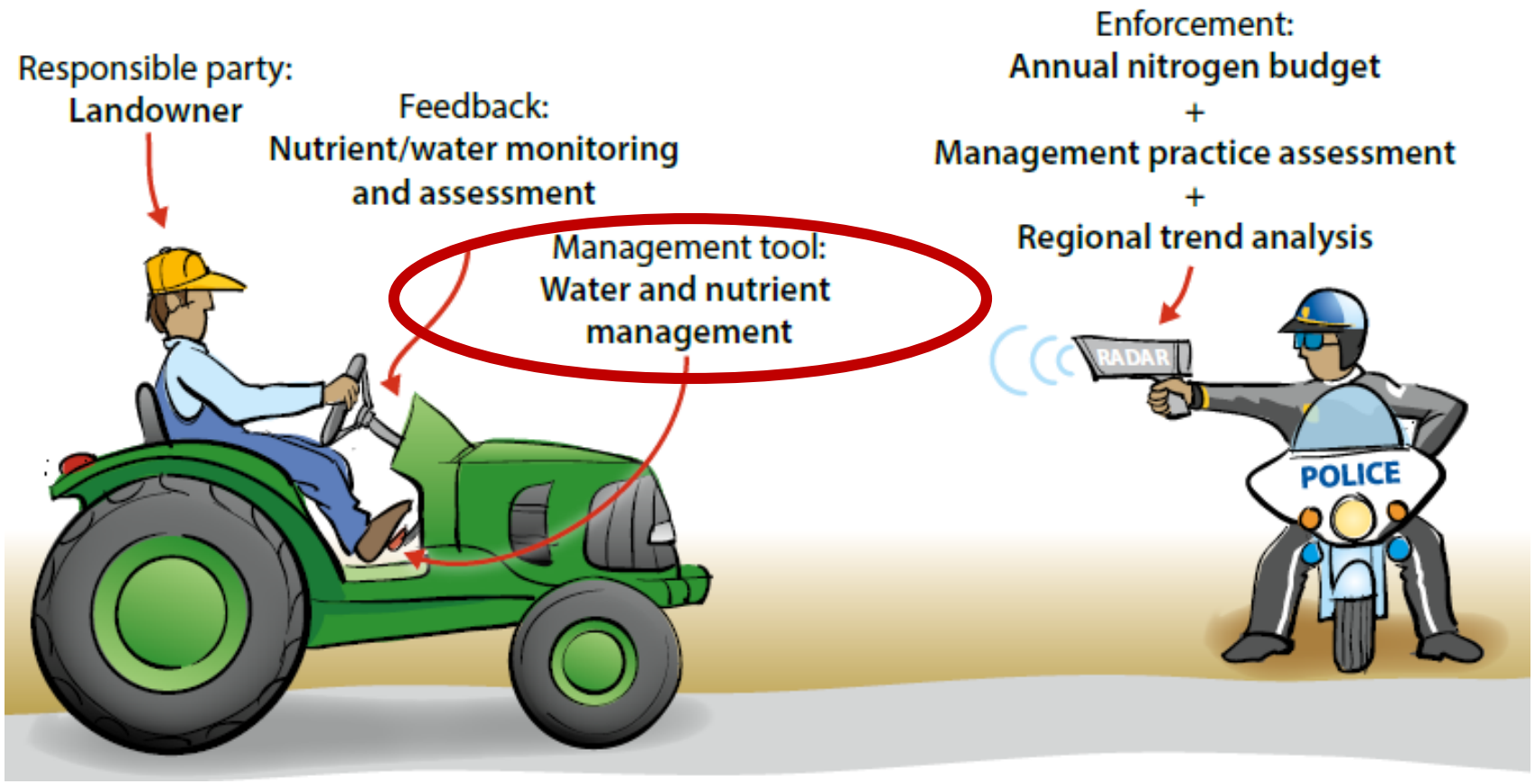
http://groundwaternitrate.ucdavis.edu - Technical Report 3

ILRP: Regulating nonpoint sources of nitrate pollution

- Identify impacts and risk drivers: GW Assessment Report
- Identify & prioritize parties to be regulated: high vulnerability areas



Harter, California Agriculture, 2015

“FORMULA” in lieu of monitoring device: Soil-Crop Modeling (each field, soil)

Soil & Water Assessment Tool | SWAT

mpepTEAM

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Research programs to develop and assess BMPs: Field Sites

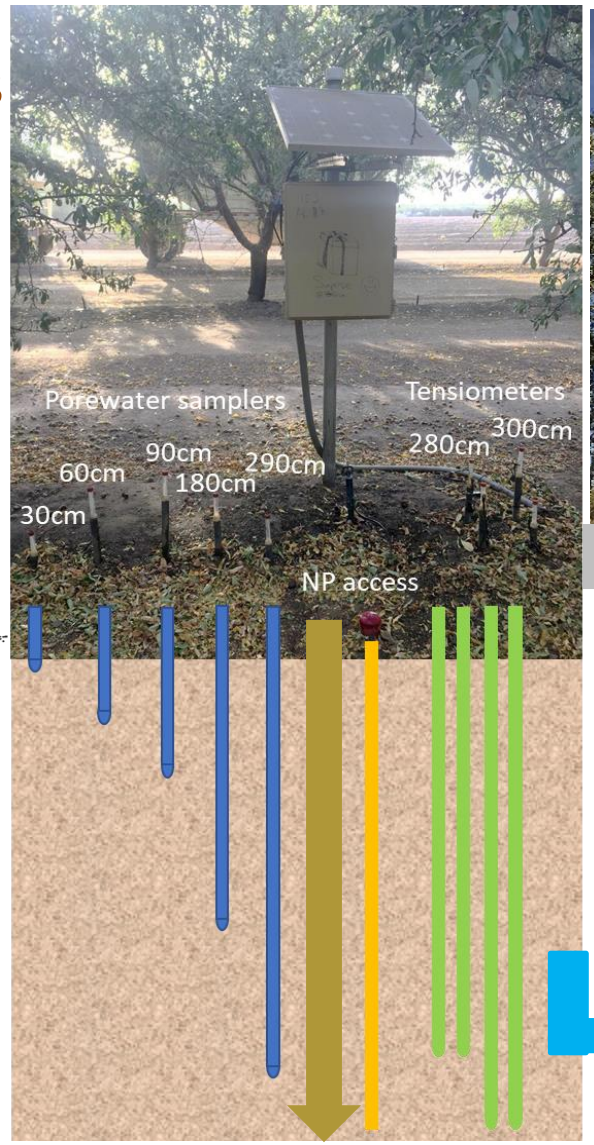
landscape water and N fluxes

(deep) vadose zone water and N fluxes

groundwater N fluxes

N_2O Emission

N Tissue Assimilation



Monitoring NO_3 in root zone

ET

Irrigation & N Fertigation

NO_3 Leaching to Groundwater

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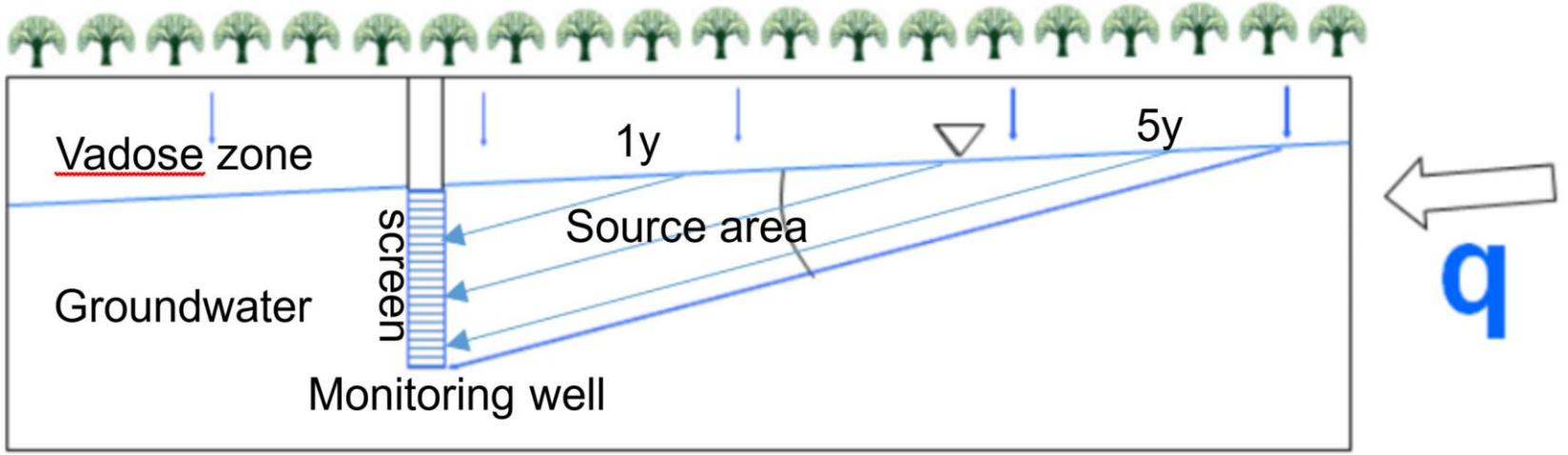
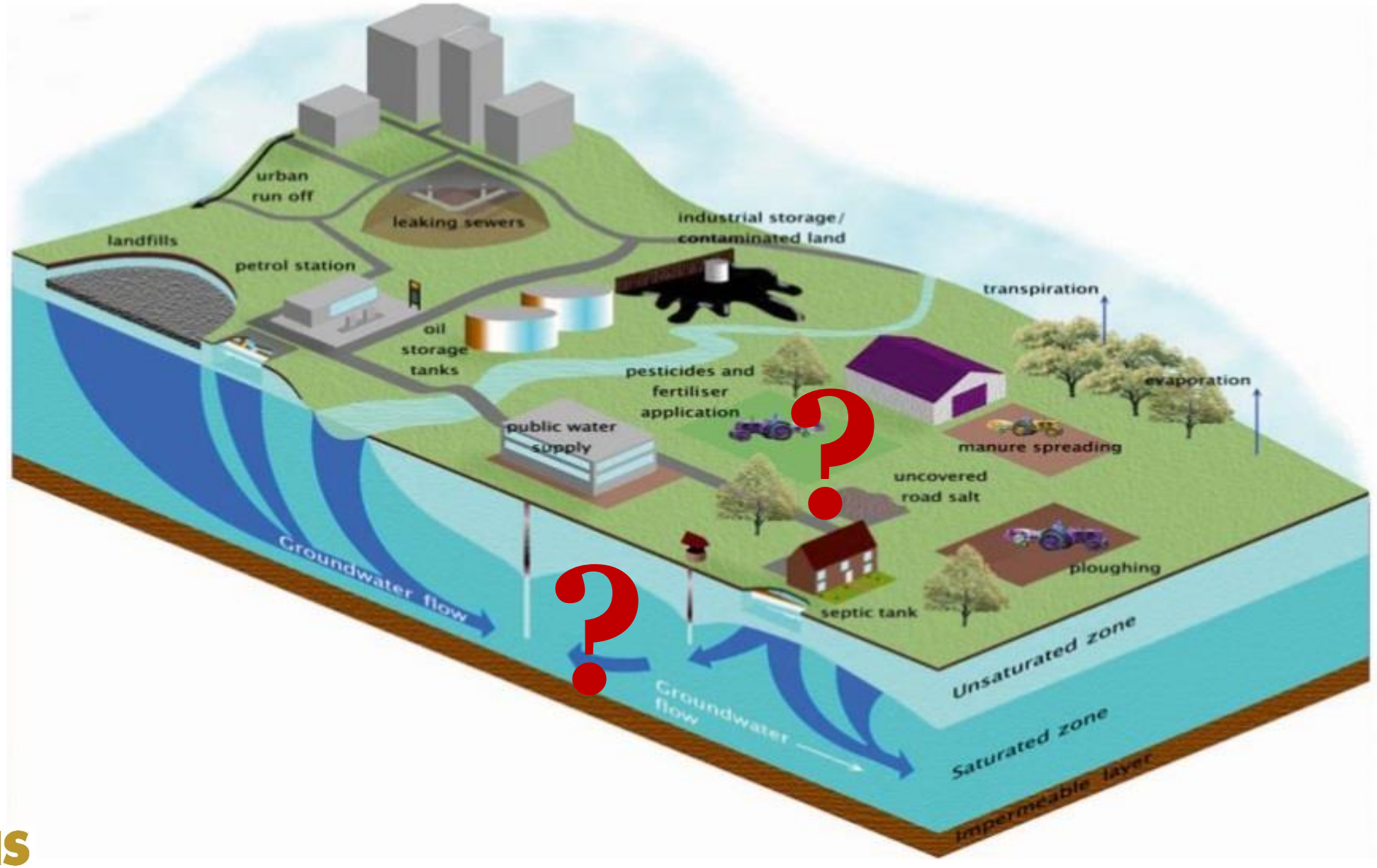
Groundwater monitoring: 20 monitoring wells within top 5 m of groundwater



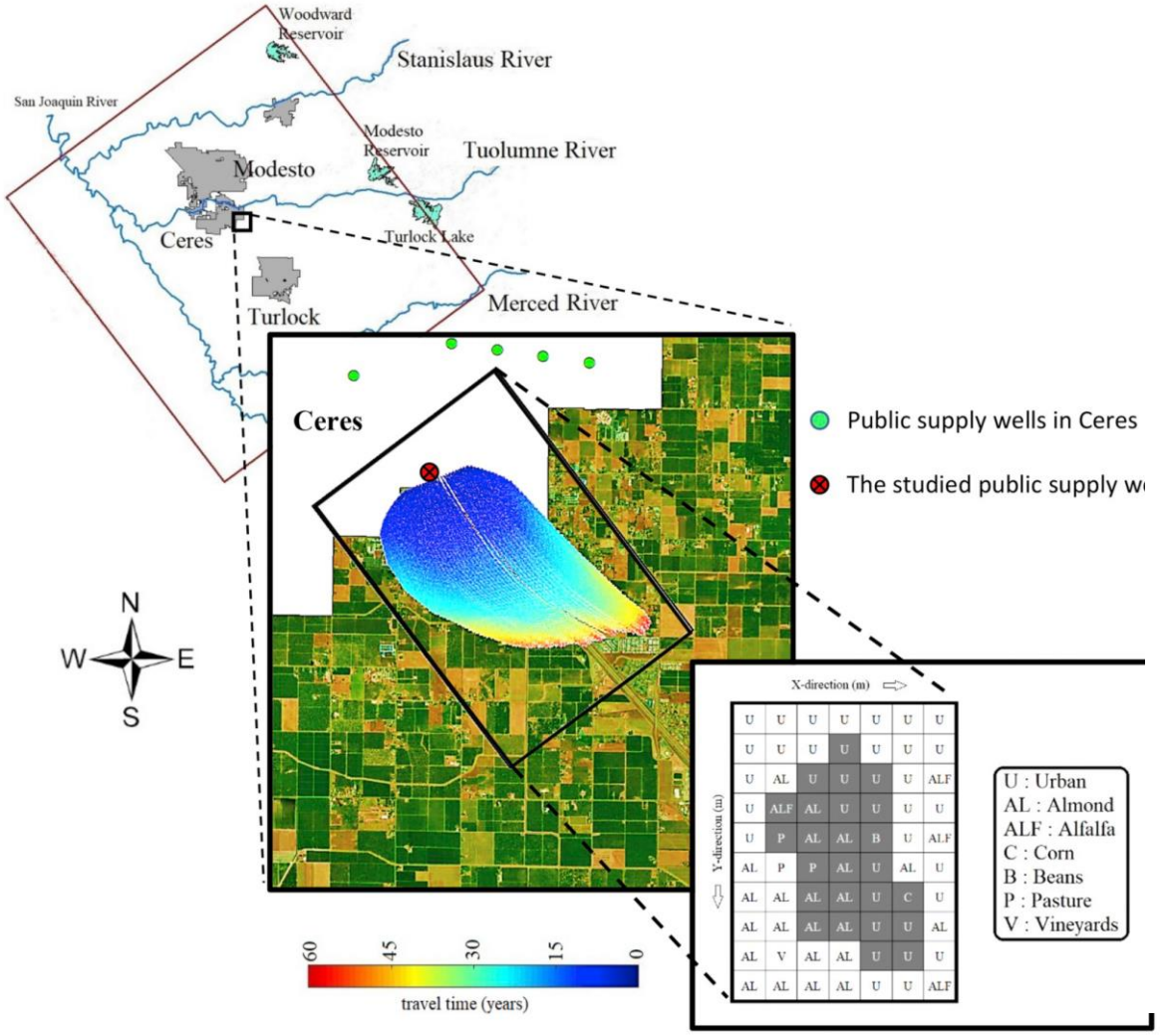
Nitrate in Groundwater:

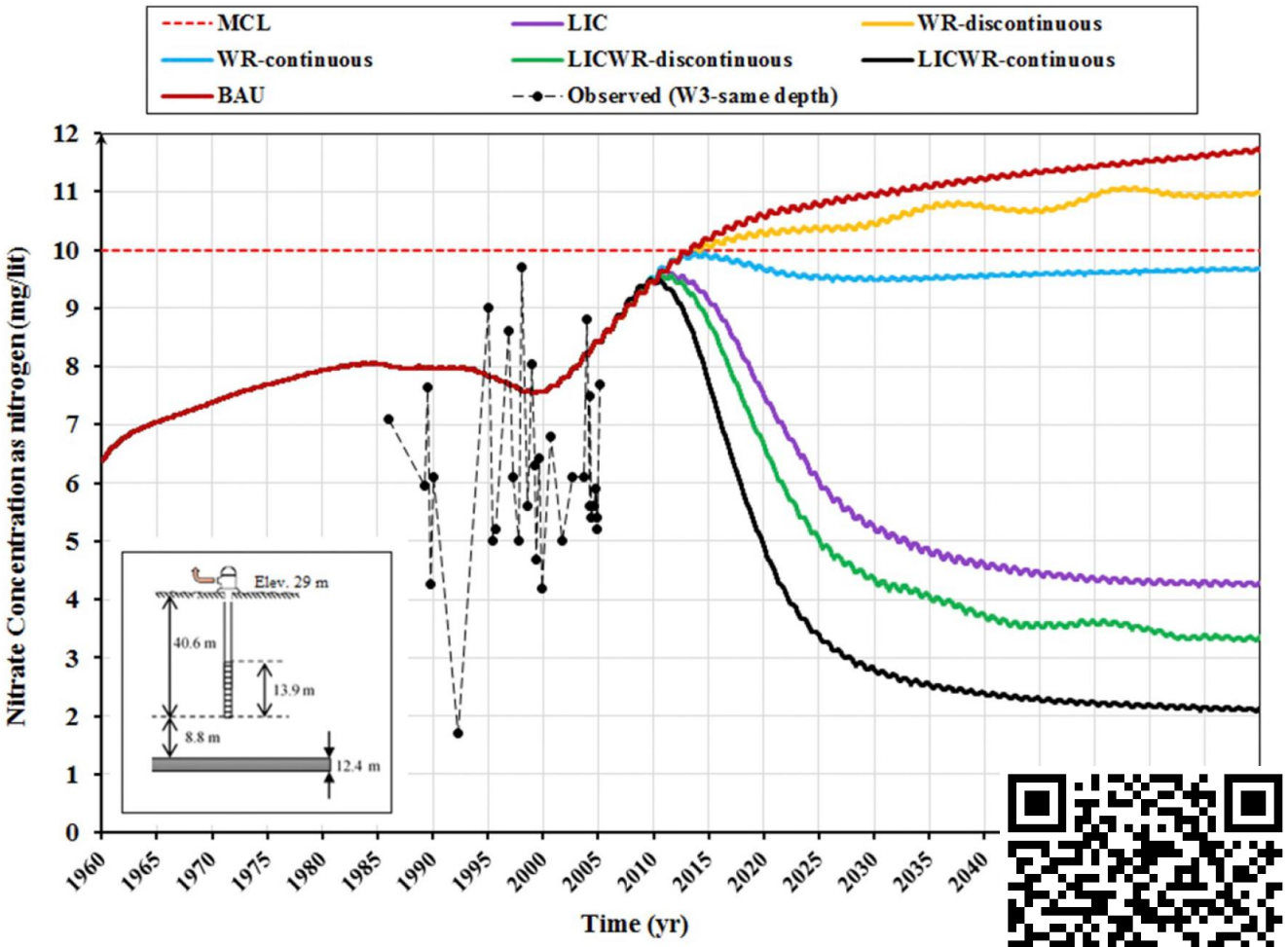
Doing the Best - What Will the Future Bring, When?

Moving forward, two key questions:



Research needs: Assessment of BMP Impacts on Public Supply Well in a Disadvantaged Community





Bastani and Harter, J Contam Hydrol 2019

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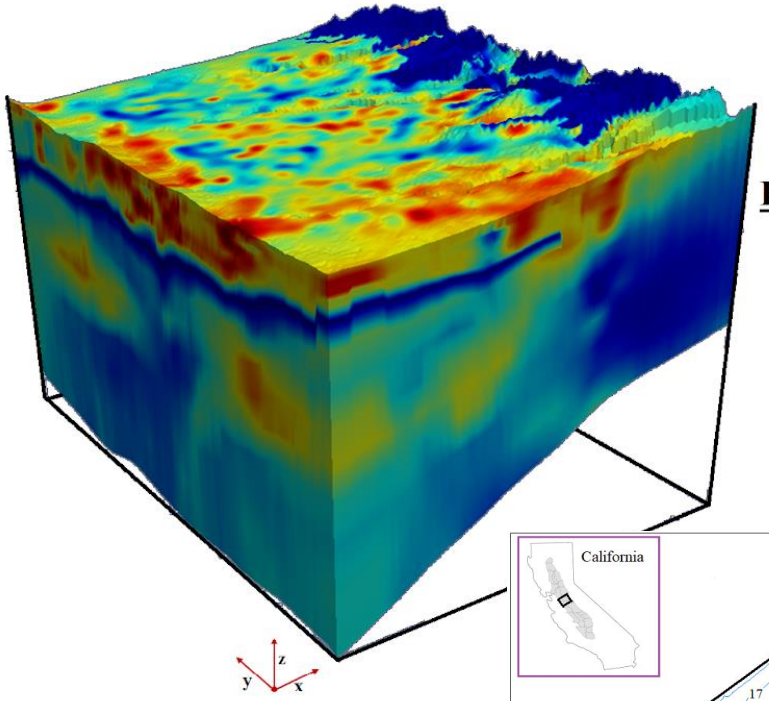
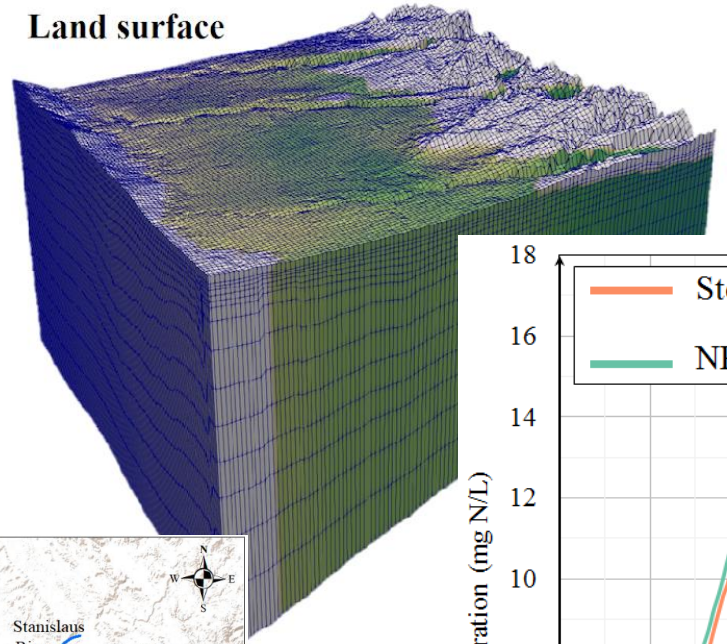
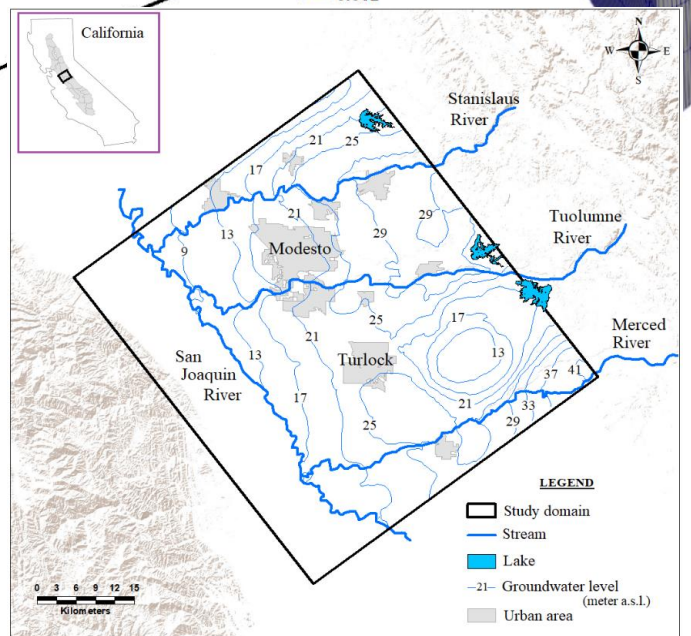
Comparison against most popular (but slow) model software looks good for practical applications

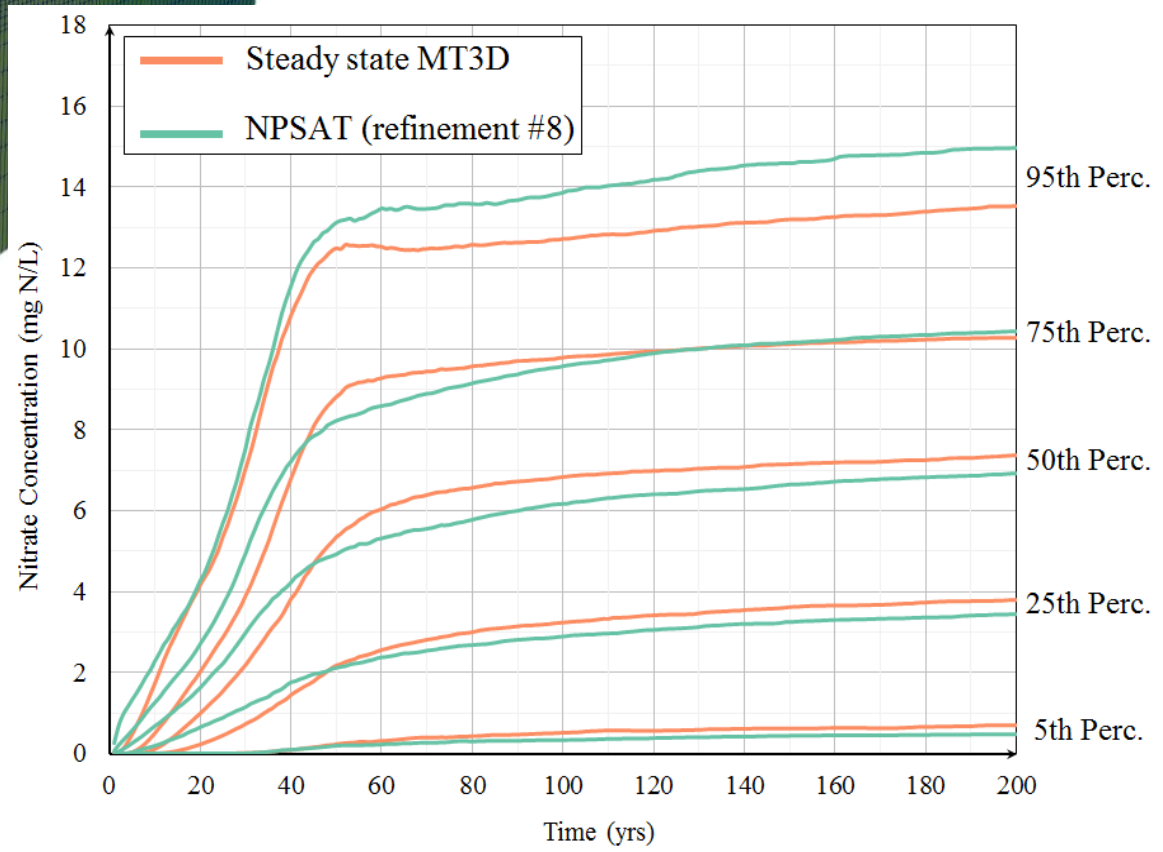






Model Area:
38 miles x 34 miles

MODFLOW-MT3D v NPSAT



Bastani et al, in preparation, 2020

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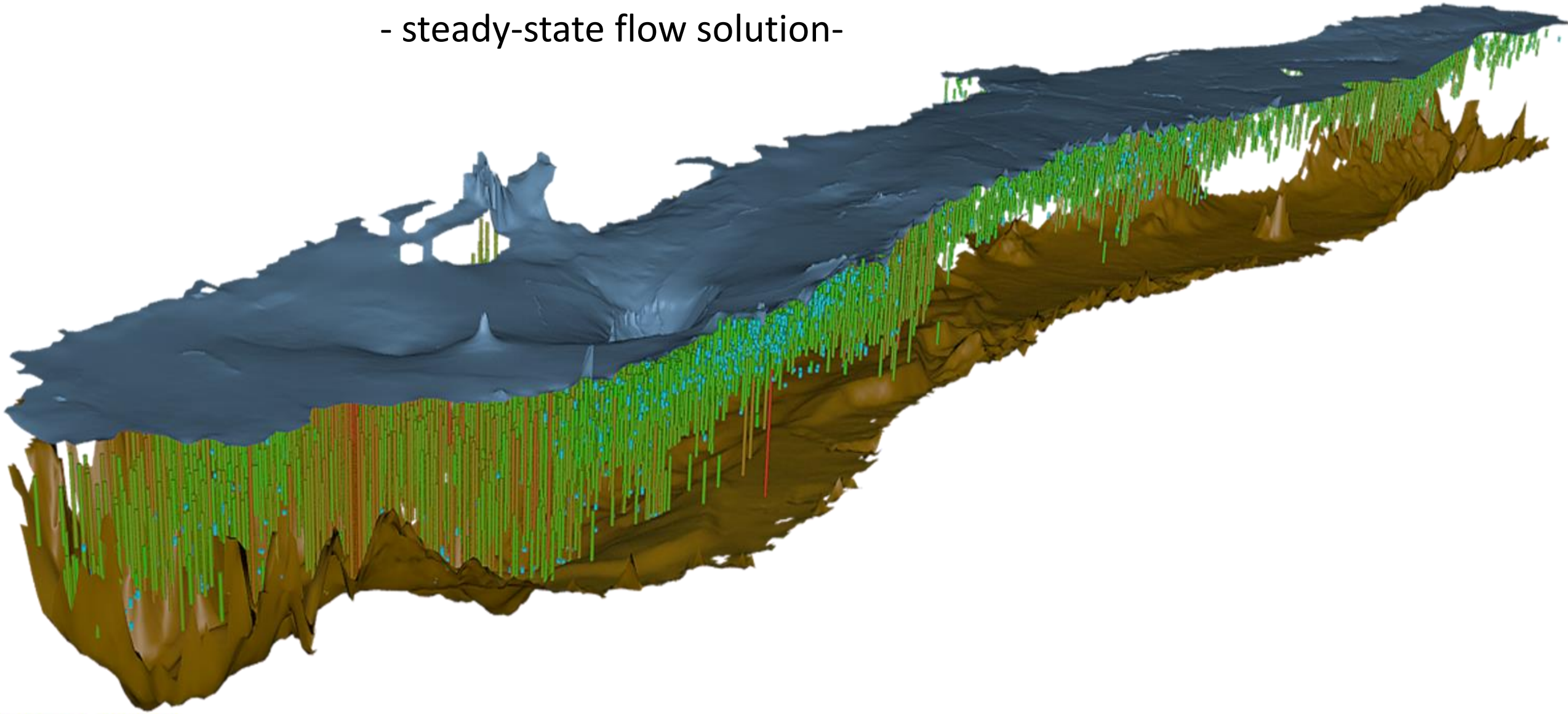
Nonpoint Source Assessment Toolbox (NPSAT):
application to the Central Valley
- steady-state flow solution-



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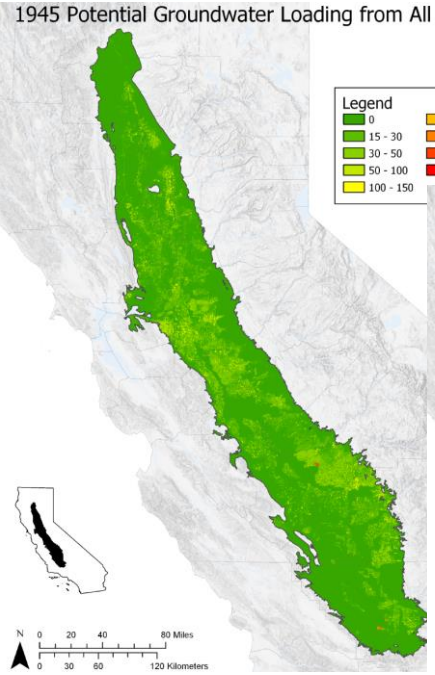
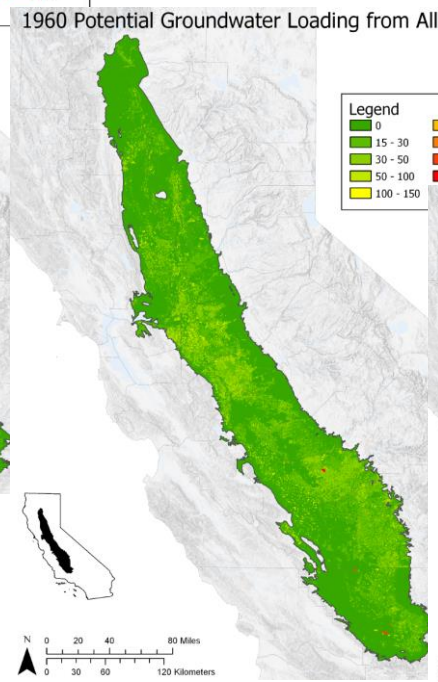
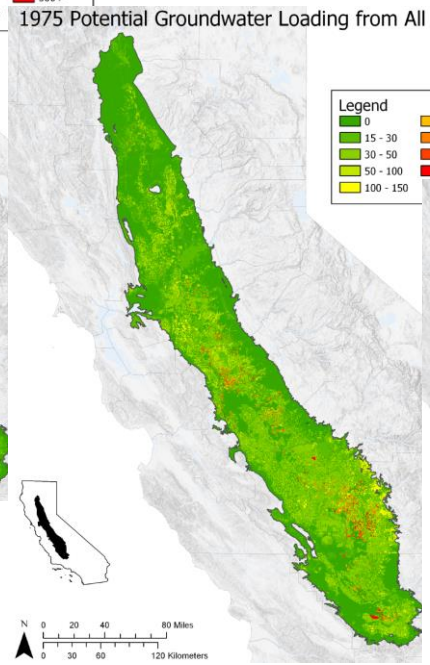
Apply N loading time series at high spatial resolution (50m) to NPSAT



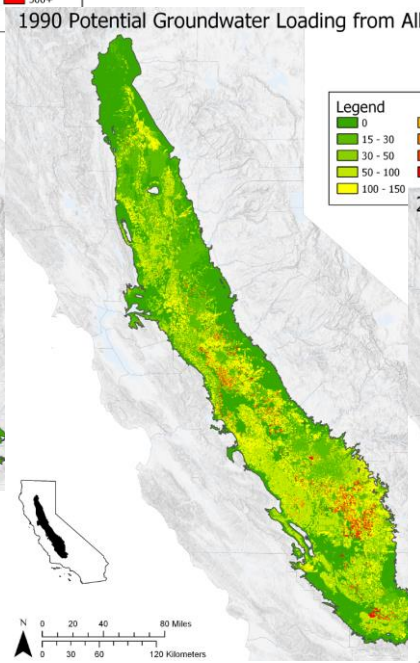
1945



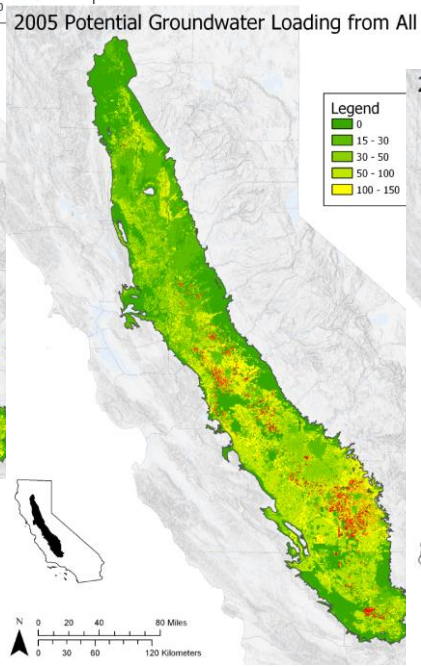
1960



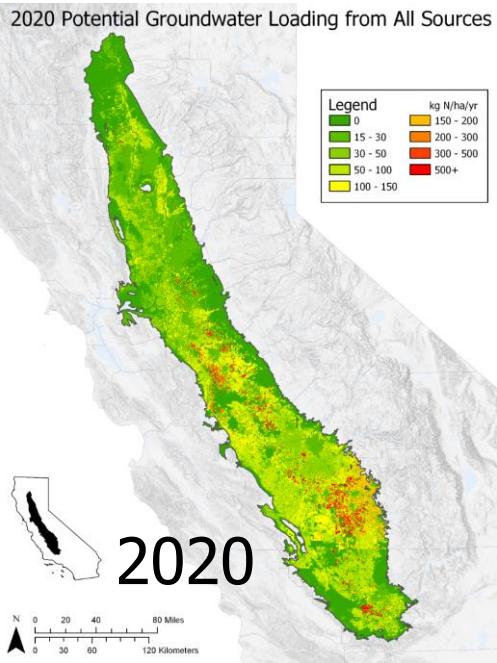
1975



1990



2005

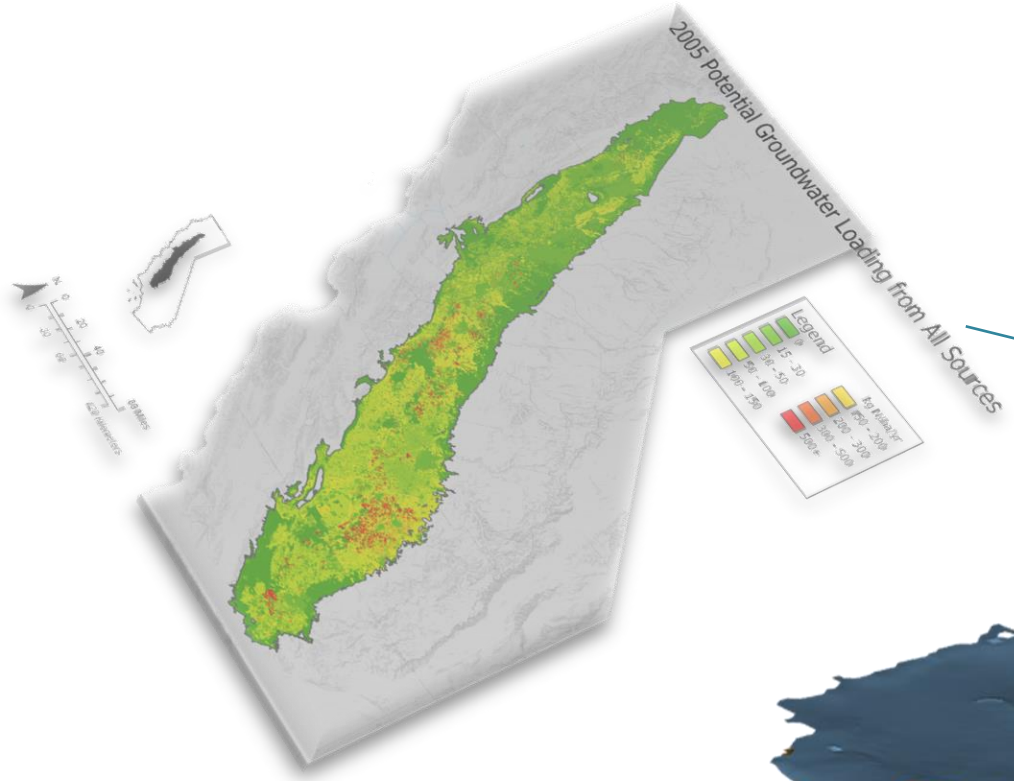


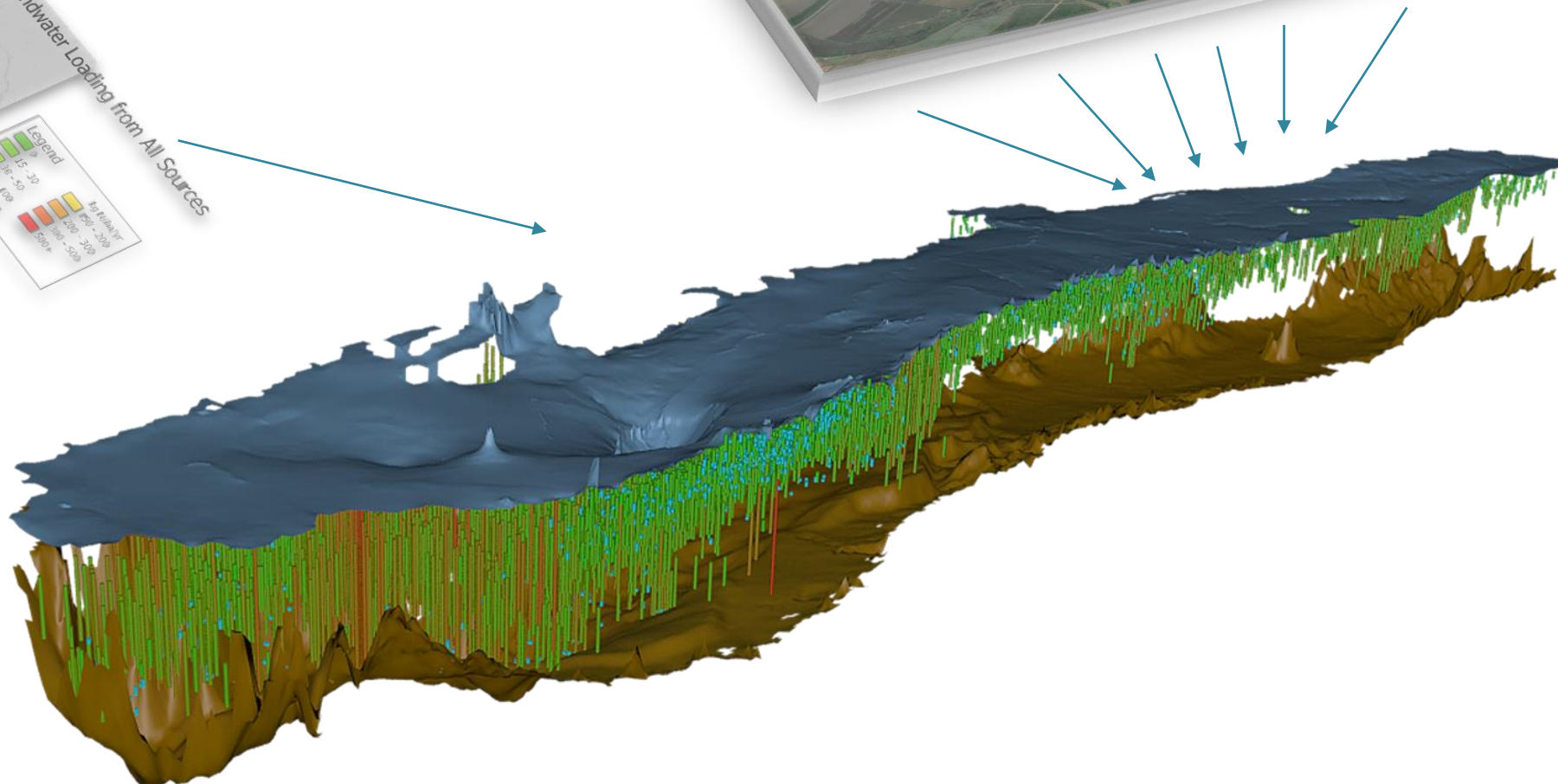
2020

Nonpoint Source Assessment Toolbox (NPSAT):

Couple to SWAT:

nitrate and recharge from bottom of root zone





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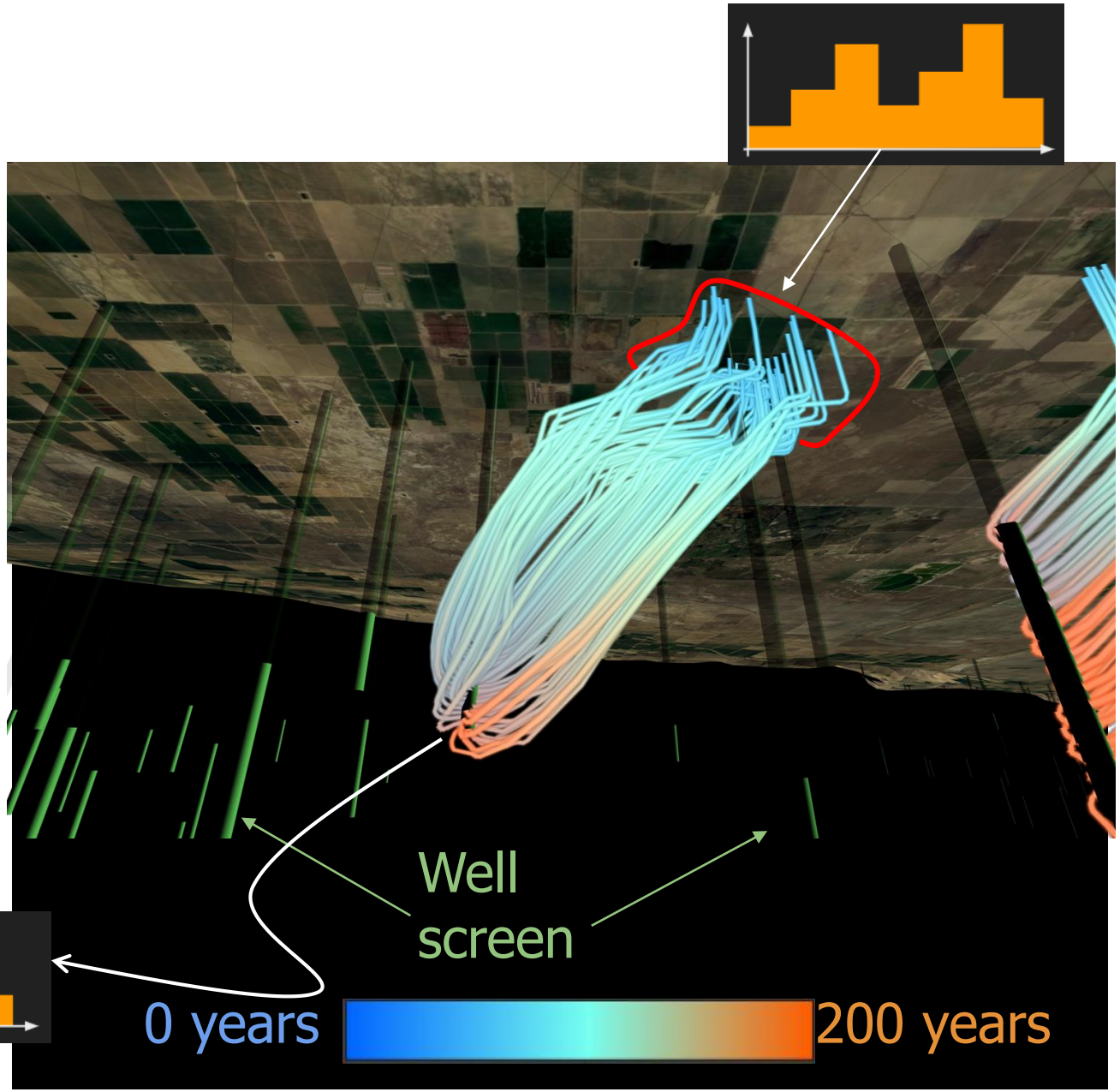
Transport Simulation in the NPSAT Simulation Framework

computationally intensive, but scenario-independent

- 100 particles per well
- Backward particle tracking
  - "Ichnos" software (manuscript in review) – particle tracking in variable meshes
  - Identify the source area for each well
  - Calculate the age of water
  - Porosity is set constant to 10%
- Unit Response functions

- Convolution w/ input history
- Well BTC
- Statistical Summary

computationally fast
input history is user-scenario dependent



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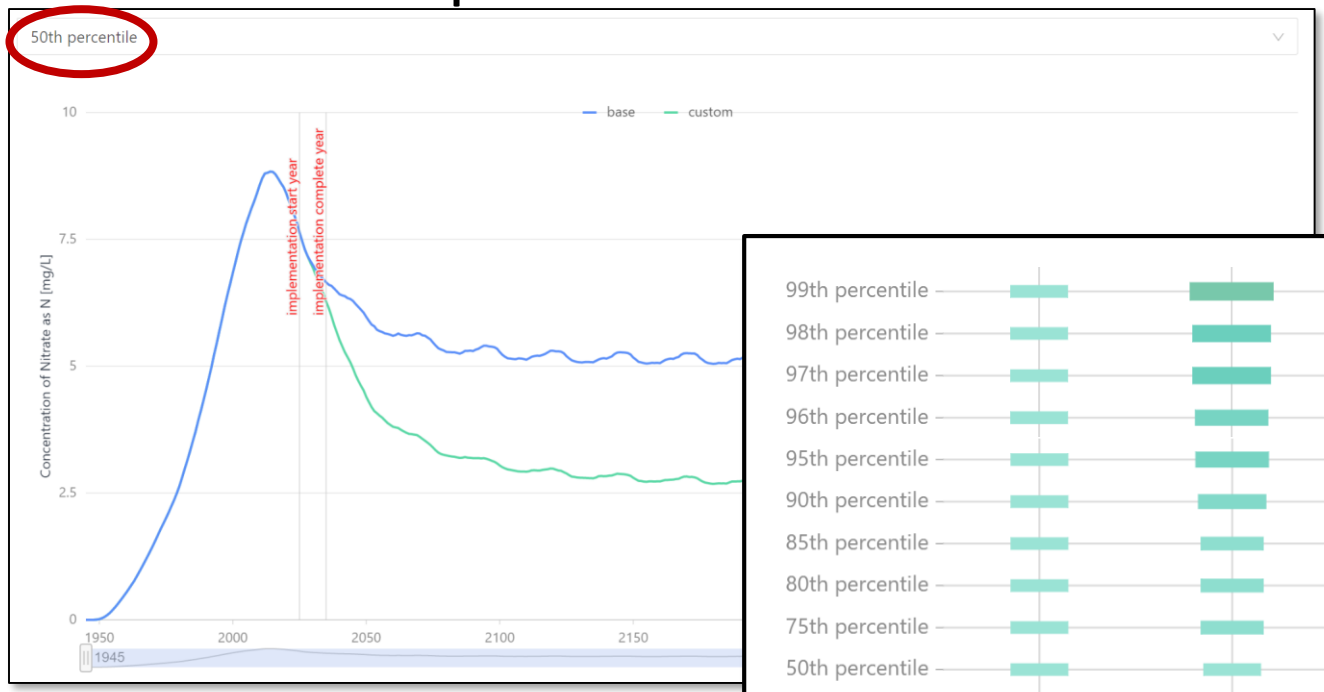
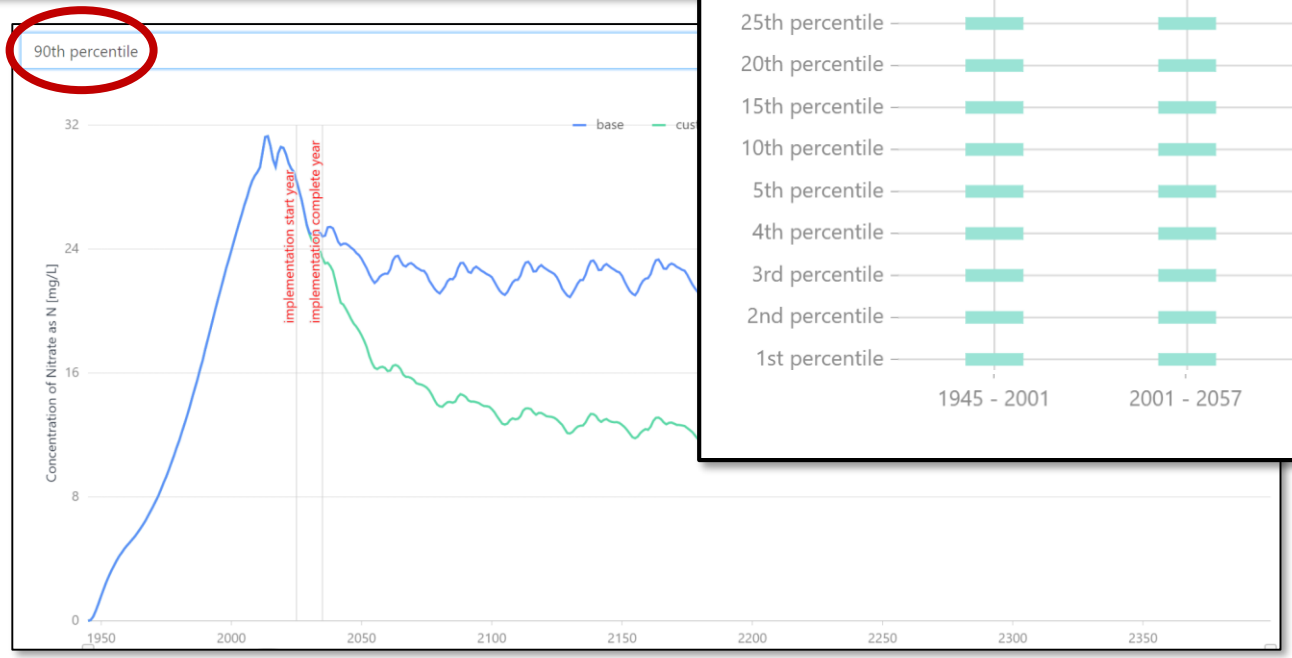
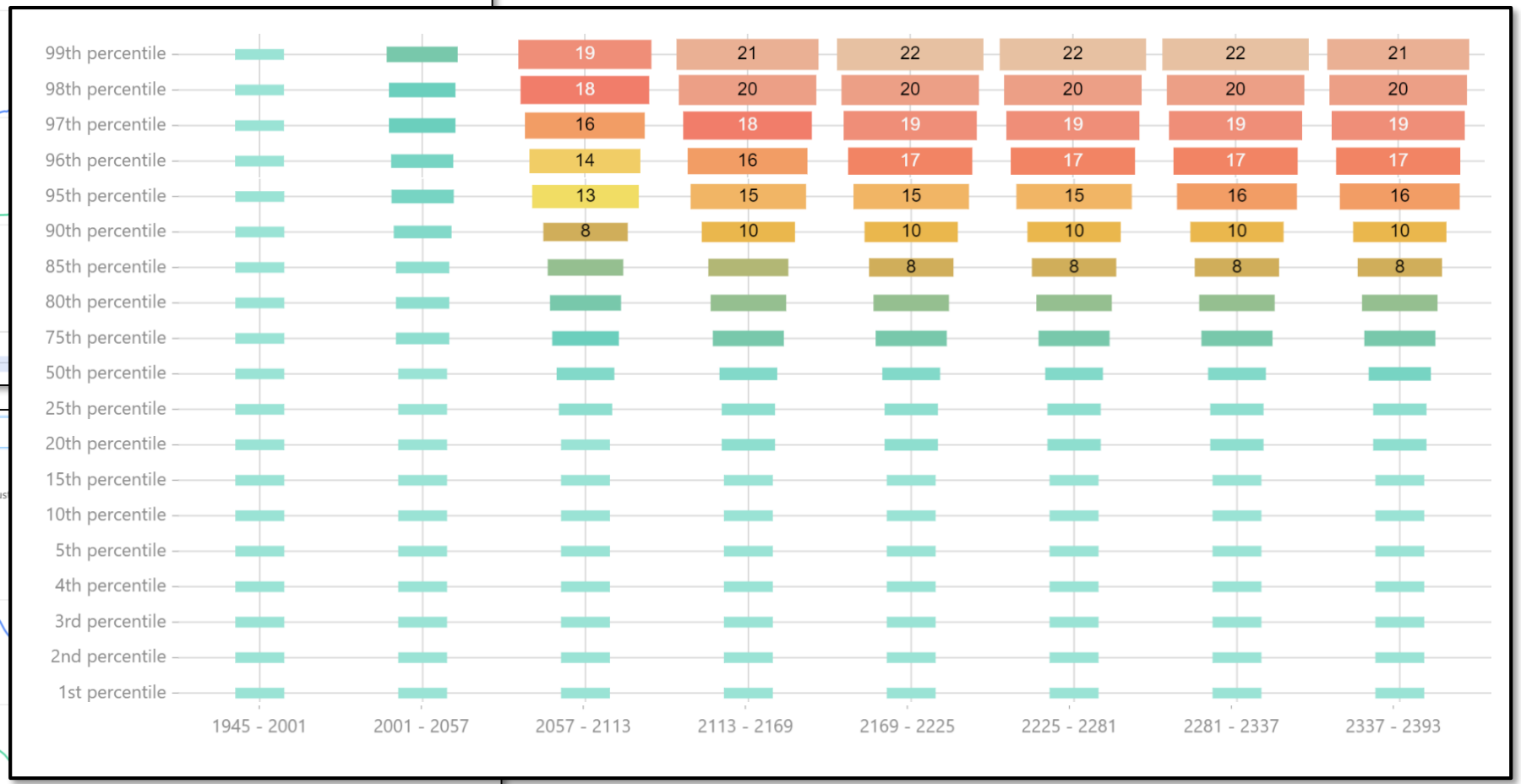
Scenario Comparison

CV-NPSAT web
UCDAVIS





Percentile Distribution of 25-year Reduction in Nitrate-N Concentration



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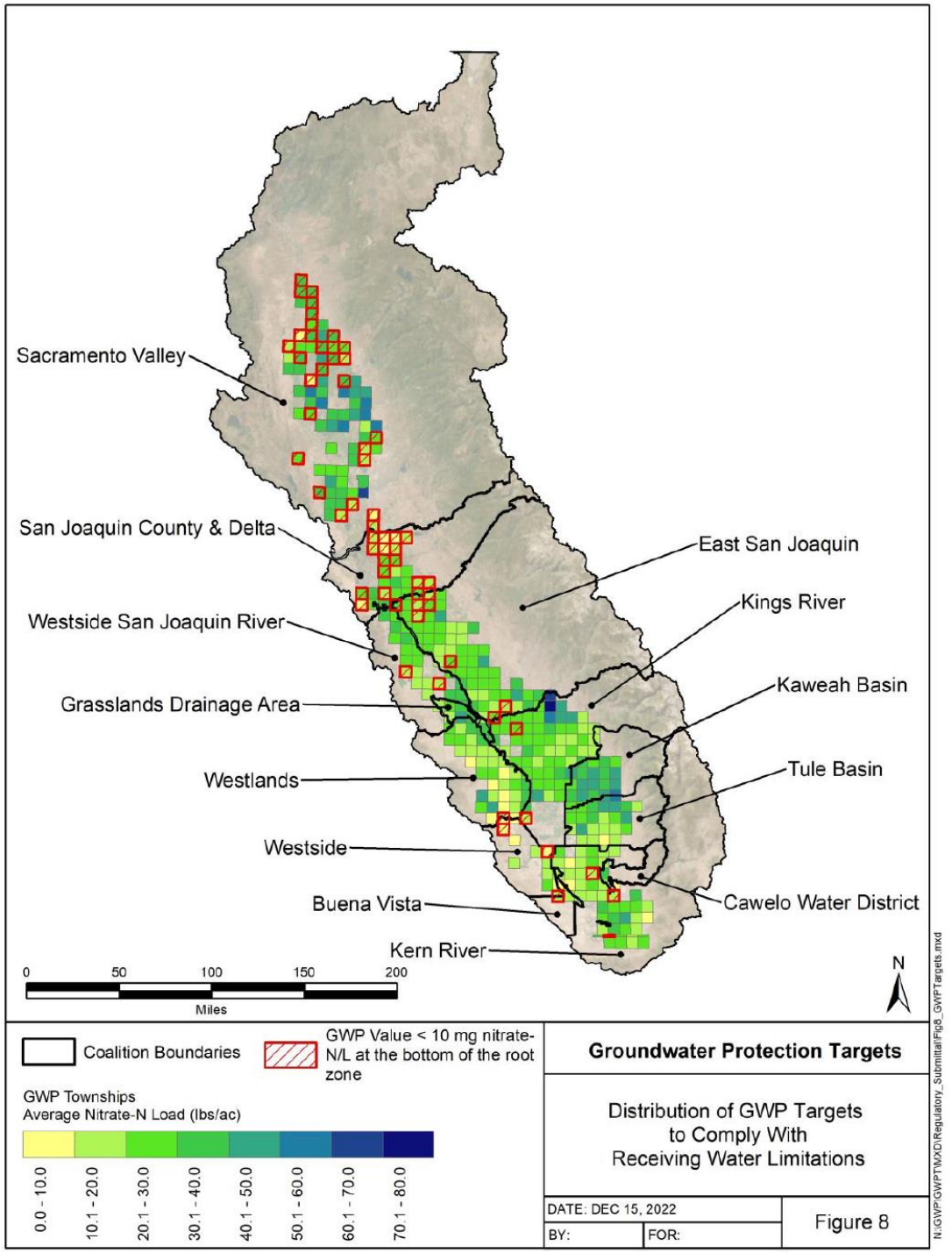
Groundwater Protection Targets



Stakeholder Engagement

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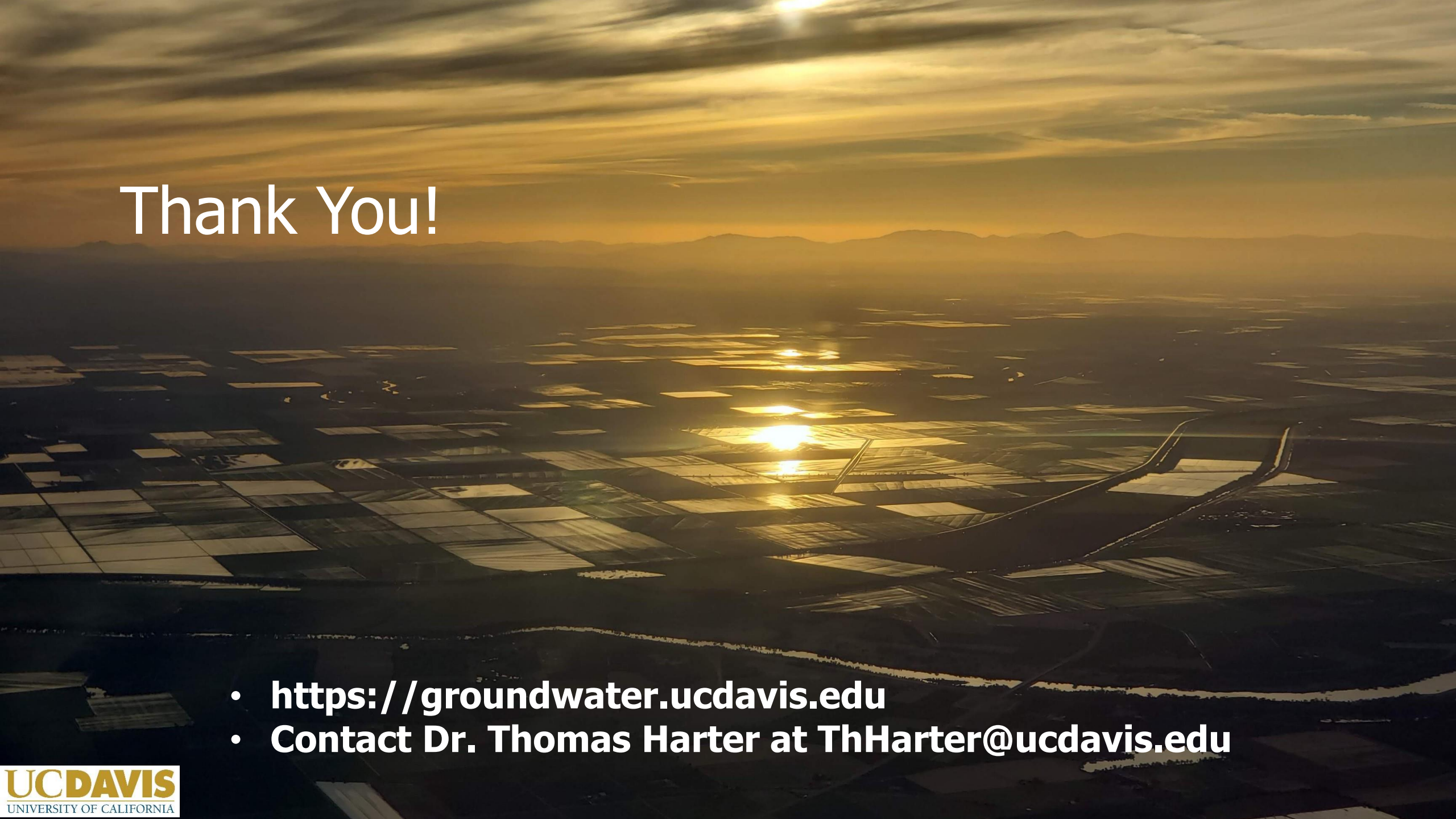

Thank You!

- **https://groundwater.ucdavis.edu**
- **Contact Dr. Thomas Harter at ThHarter@ucdavis.edu**

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