The California Nitrogen Assessment

Agricultural Sustainability Institute at University of California, Davis
UC Sustainable Agriculture Research and Education Program
UC Agricultural Issues Center
Kearney Foundation for Soil Science

Preliminary Facts and Findings - July 2013

What do we mean when we talk about "feeding 9 billion by 2050"?

"Although it may sound straightforward, in practice the question is difficult to address…"

- **Not just a food supply issue; also involves food access and livelihoods.**
- **Cannot even be viewed only in terms of food supply and demand; environmental and social impacts of agriculture are increasingly important.**

Agrimonde: Scenarios and Challenges for Feeding the World in 2050. S. Paillard, *et al.* 2011 (INRA and CIRAD).

Why does nitrogen matter?

Nitrogen has an indispensable role in agricultural production and has played a major role in increased yields.

There are also costs associated with nitrogen application.

- Water and Air Pollution
- Climate Change
- Human Health
- Biodiversity and habitat

Too little N limits ecosystem processes…too much transforms ecosystems profoundly.

N

The California Nitrogen Assessment

Nitrogen is necessary to sustain successful agriculture in California and the nation's food supply.

- **50% of fruits, nuts, and vegetables**
- **21% of dairy**

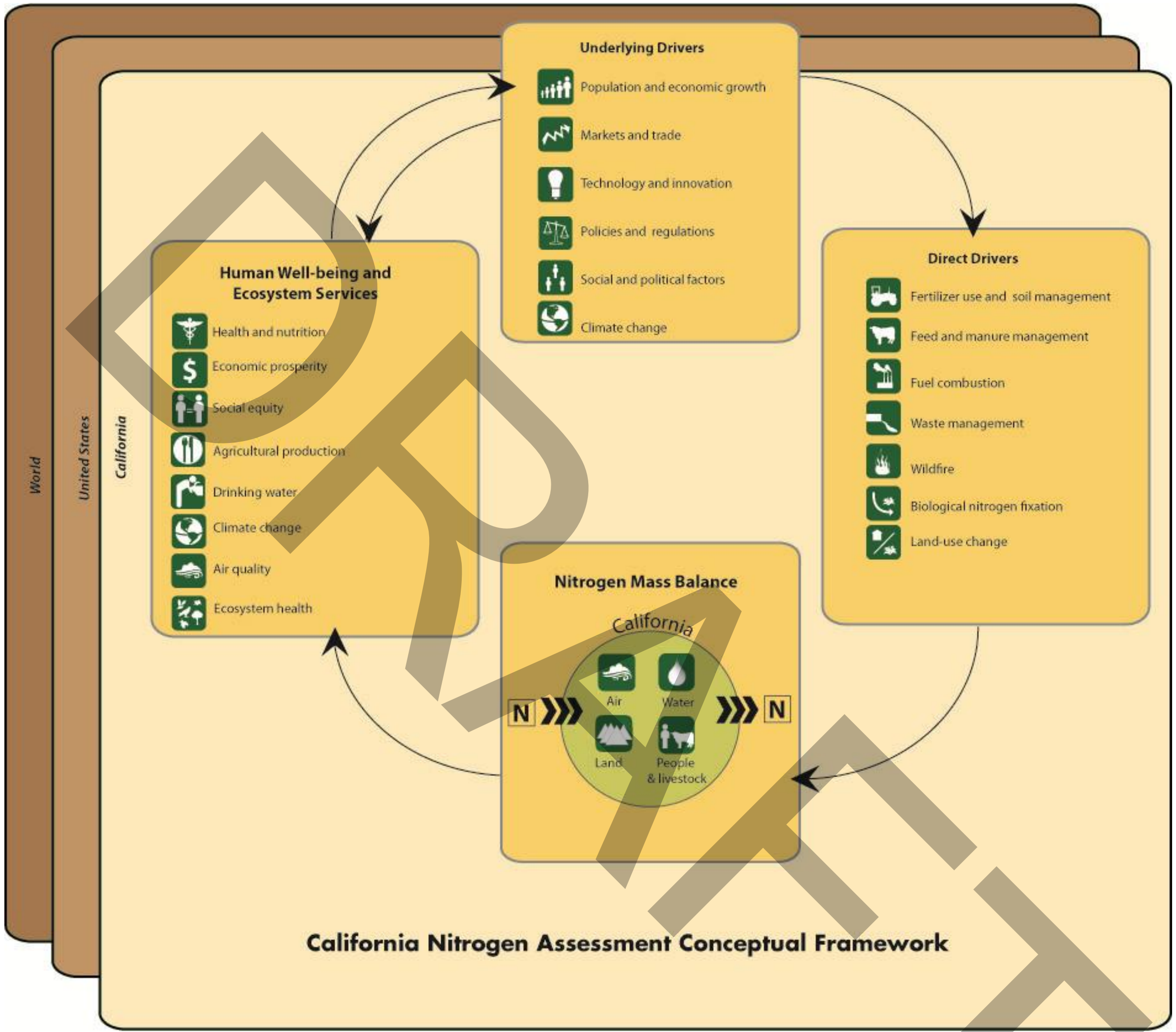
Since 1960, the amount of N used in agriculture on the planet has doubled, as has food production.

- **Much of this N is released to the environment.**

This is the first comprehensive accounting of N flows, practices, and policies for California agriculture.

- **Drivers of N use.**
- **Statewide mass balance of N (for 2005).**
- **Impacts of N on ecosystem services and human well being.**
- **Technological and policy options.**

Major funding for the California Nitrogen Assessment has been provided by the David and Lucile Packard Foundation through a grant in January 2009.



Nitrogen is complex and controversial.
It plays a vital role in food production and also
has consequences for the environment and human health.

Guide to Nitrogen Chemistry

Compound	Form
N_2 : Nitrogen gas	Gas
N_2O : Nitrous Oxide	Gas
NOx (NO, NO_2) : Other N oxides	Gas
NH_3 : Ammonia	Gas
NO_3^- : Nitrate	Water soluble ion

*N_2 is inert, all others are reactive forms of nitrogen.

Assessment Goals and Process

What is an assessment?

An assessment is a critical evaluation of information for purposes of guiding decisions on a complex, public issue.

Stakeholders define the topics and set assessment questions.

An assessment is <u>not</u> a research project, a review paper, or an advocacy piece.

The *process* is as important as the results and outputs produced; credible, useful, and legitimate.

Assessing what is *not known* and *uncertainty* in the data is as important as understanding what is known.

Peer reviewed (researchers and stakeholders).

Source: Millennium Ecosystem Assessment

California Nitrogen Assessment Goals

Gain a **comprehensive view of N flows in the state**, with emphasis on agriculture's roles.

Provide useful insights for stakeholders into the **balance between the benefits of agricultural nitrogen and the effects of surplus nitrogen** in the environment.

Compare options, including practices and policies.

Move beyond "academic business as usual" to more effectively **link science with action** and to produce information that informs both policy and field-level practice.

Stakeholder Engagement

Used multiple avenues to engage with more than 350 stakeholders across 50 organizations.

Generated more than 100 nitrogen-related questions.

Provided data, practical examples, and management options.

Collaborated to create 4 'scenarios' on the future of N management in California agriculture.

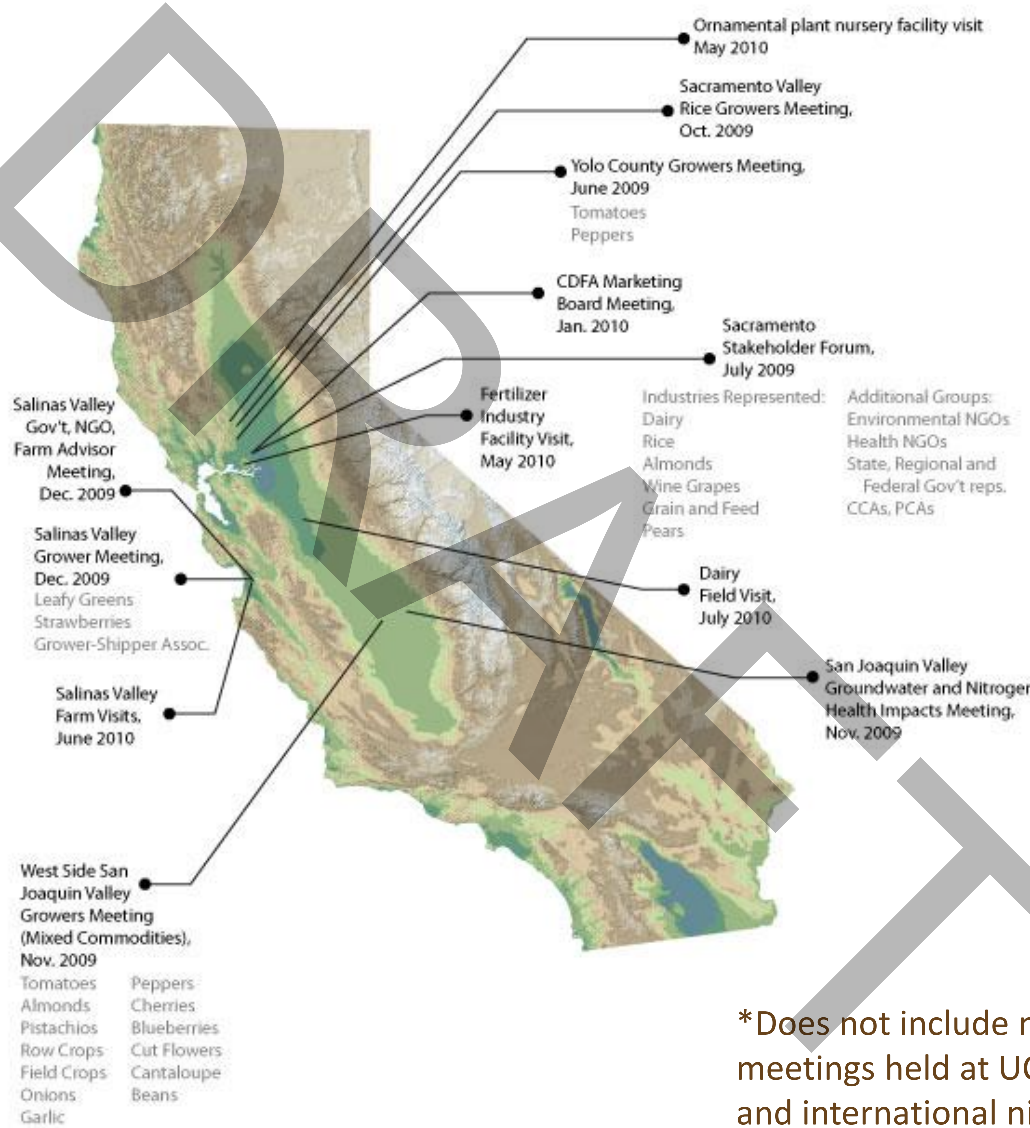
Groups Represented on the Stakeholder Advisory Committee

Stakeholder Advisory Committee

Organizations involved in the stakeholder process of the CNA include:

- California Rangeland Conservation Coalition
- Defenders of Wildlife
- Citrus Research Board
- Organic Fertilizer Association of California (OFAC)
- CA Rice Producer's Group
- California Rice Commission
- California Farm Bureau Federation (CFBF)
- Almond Board of California
- Roots of Change
- Sustainable Conservation
- Community Water Center (CWC)
- Western Growers Association
- Hines Nurseries
- University of California Cooperative Extension (UCCE)
- California Strawberry Commission
- CDFA Fertilizer Research and Education Program (FREP)
- US Environmental Protection Agency (US EPA)
- San Joaquin Valley Air Pollution Control District
- California Water Institute
- Fresh Express/Chiquita
- Western United Dairymen
- McCormack Sheep and Grain
- International Plant Nutrition Institute (IPNI)
- Environmental Defense Fund (EDF)
- Ag Services (Salinas)
- Western Plant Health Association
- California Certified Organic Farmers (CCOF)
- Rominger Brothers Farms
- Community Alliance with Family Farmers (CAFF)
- Fetzer/Bonterra Vineyards
- California Regional Water Quality Control Board, Central Coast Region
- California Climate and Agriculture Network

Where we've been…



*Does not include numerous additional meetings held at UC Davis, and national and international nitrogen .meetings

California Nitrogen Assessment Overarching questions

The CNA is based on stakeholder-driven questions and concerns

- What are the big sources of nitrogen pollution in California?
- What practices are most effective in mitigating nitrogen pollution?
- What are the policy challenges and opportunities?
- What are the impacts of N management on society and human health?

What Drives Nitrogen in California?

Underlying Drivers of California N Flows

Dominant underlying drivers of California's N cycle fall into two broad categories:

- Drivers affecting levels of agricultural production
- Drivers of fossil fuel combustion

Environmental regulations have reduced N pollution from fossil fuel combustion.

To date, policies have had little effect on nitrogen flows in California agriculture.

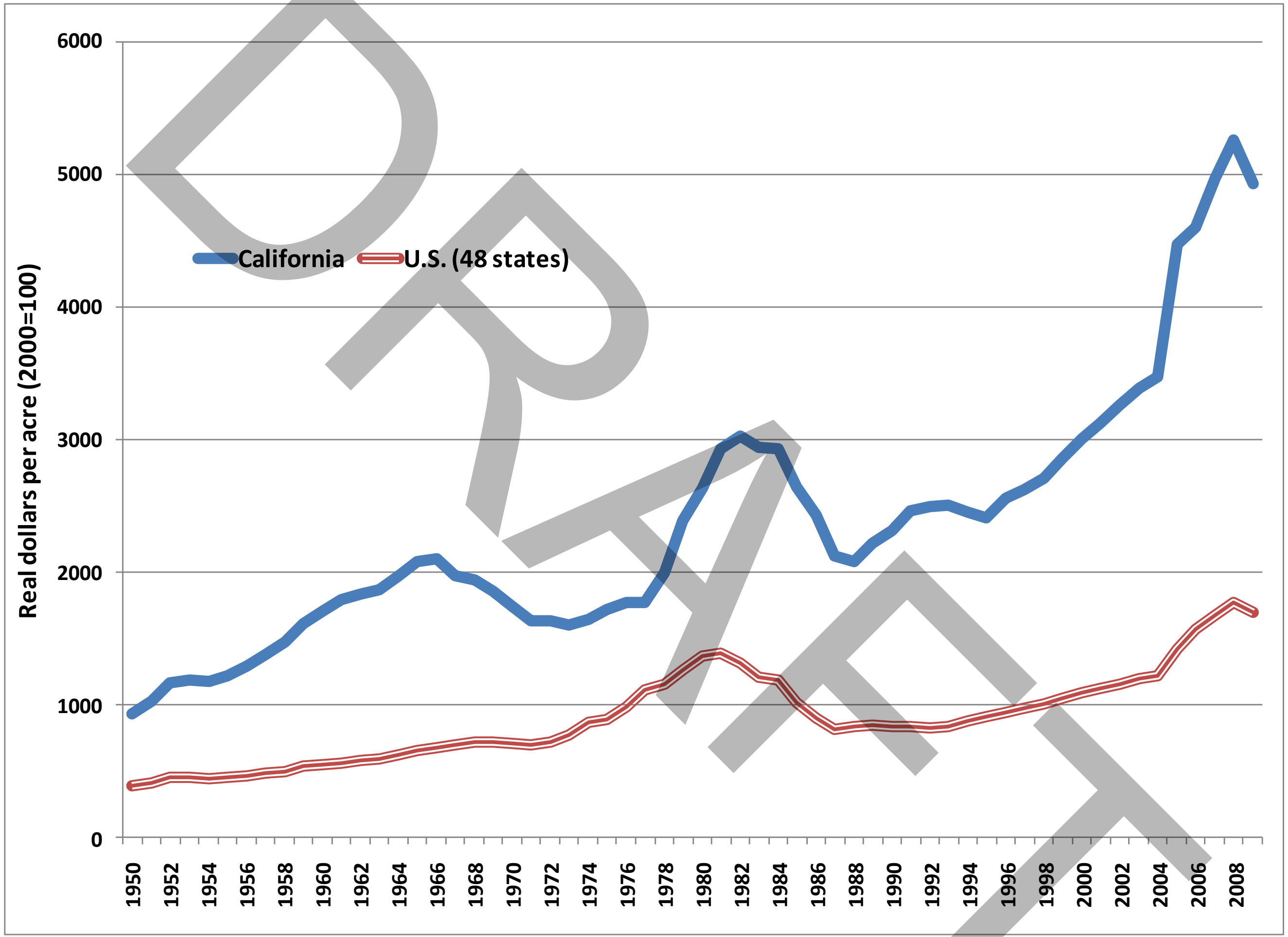
Underlying Drivers: Global

Over the last 50 years, **world population doubled and global income quadrupled.** The resulting increase in global demand for food has been a fundamental driver of expansion of agricultural production in California. **These positive effects on California agriculture are likely to continue.**

Long-term **reduction of transport costs and reduction of international trade barriers** increased access to international markets since the 1950s. **The future course of these drivers is uncertain, particularly regarding energy prices and trade policy.**

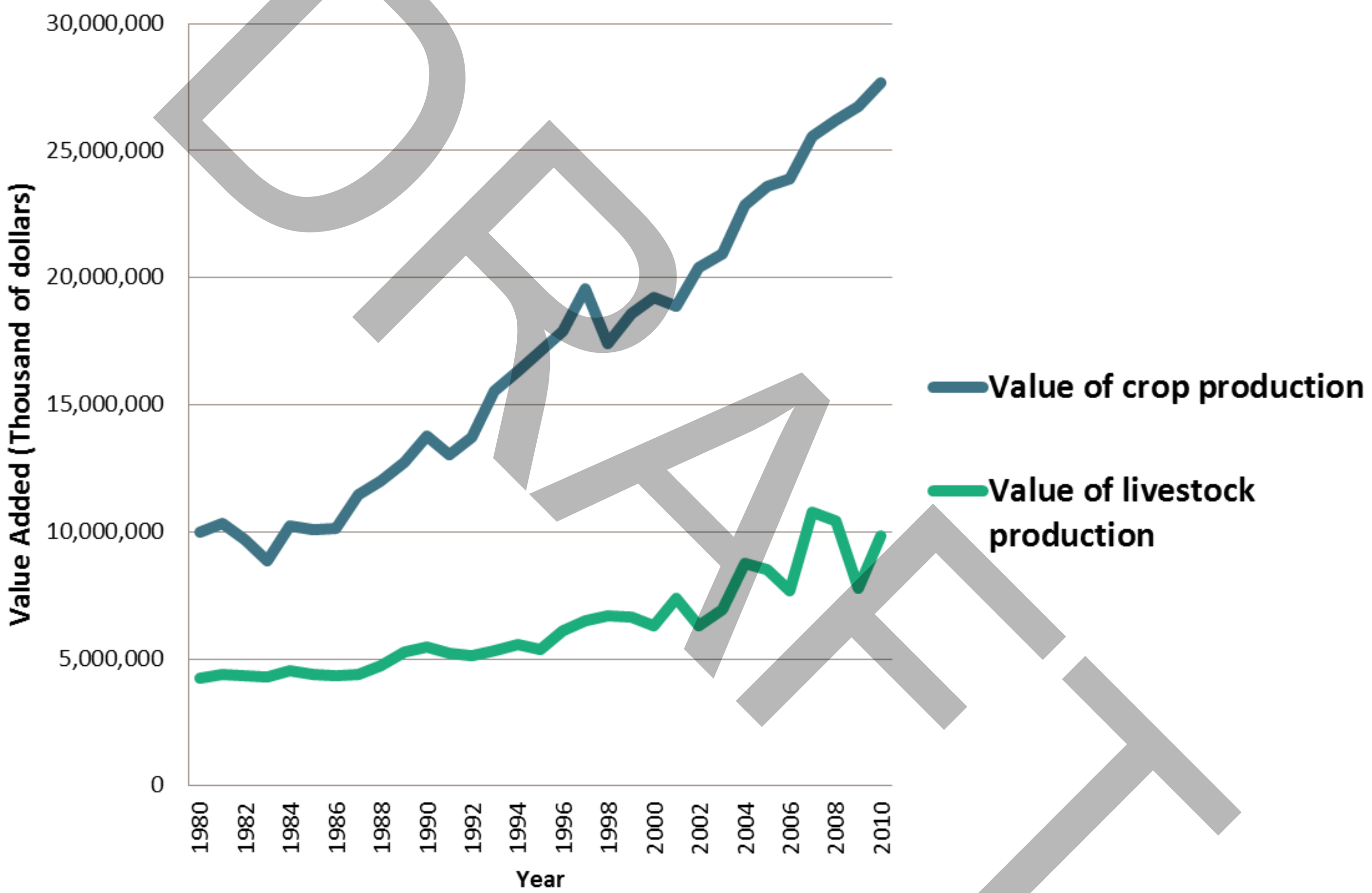
Long-term decline in synthetic N fertilizer prices resulted in a large increase in N use from the 1950s through the 1970s. Thereafter, N prices were relatively stable relative to the prices of crops until 2000. Fertilizer price increases in the past decade have exceeded increases in crop prices. **Uncertainty about synthetic N prices stems directly from uncertainty about energy prices,** including possible effects of climate change mitigation policies on fossil fuels.

Land Value and Land Use Change



Population and economic growth in California have increased non-agricultural use of resources such as land and water. **These negative effects on the level of California's agricultural production are likely to continue.**

Value of CA Agricultural Production



Nevertheless, the **value of California's agricultural production continues to grow**.

Growing Agricultural Productivity

Average Annual Multi-Factor Productivity Growth Rates in California and U.S. Agriculture, 1949-2002

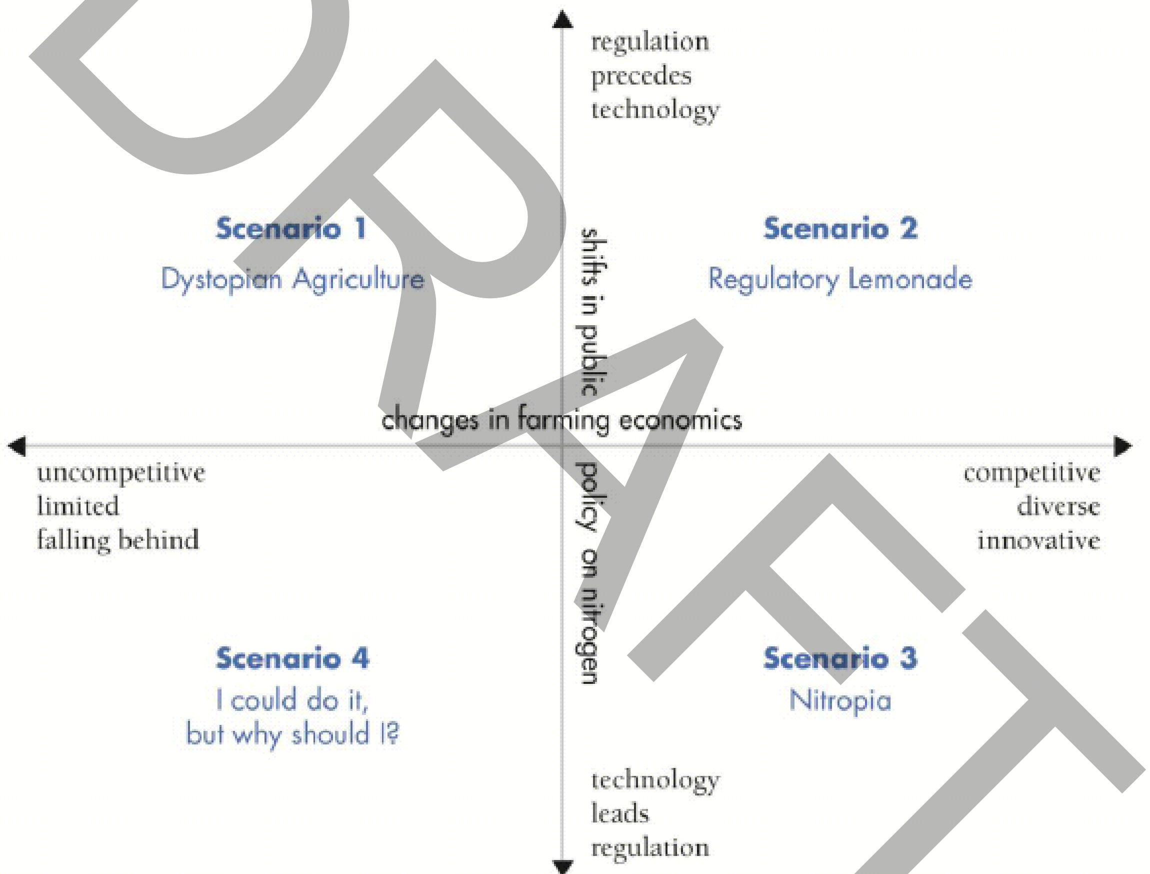
	1949-60	1960-70	1970-80	1980-90	1990-2002
California	1.66	2.22	2.84	1.01	1.24
U.S.	1.89	1.69	2.46	2.07	0.97

Source: Alston, Andersen, James and Pardey 2010,
"Persistence Pays: U.S. Agricultural Productivity Growth and the Benefits from Public R&D Spending"

Technological innovation plays a key role in continuing competitiveness of California agriculture.

How will nitrogen be managed in California agriculture 20 years from now?

CALIFORNIA NITROGEN ASSESSMENT SCENARIO MATRIX



Which future will best allow us to feed 9 billion people and meet goals of sustainability?

Big Direct Drivers

Despite increases in ***fuel combustion*** since 1980 (stationary sources have increased 3 fold), ***emissions have declined steadily***.

Synthetic N Fertilizer sales in California have risen dramatically since World War II and increased by at least 40% since 1970. However, ***consumption has leveled off in the past 20 years***.

Manure management is an important N recycling point in the food system. California's livestock herd has continued to grow, and manure monitoring efforts are underway, but ***the fate of manure is largely unknown at policy-relevant scales***.

Smaller Direct Drivers

Alfalfa yields have increased an average of 53% per ha from 1950-2009, making ***biological nitrogen fixation*** a progressively important input of N to California's land. However, BNF accounts for less than 10% of new N inputs statewide

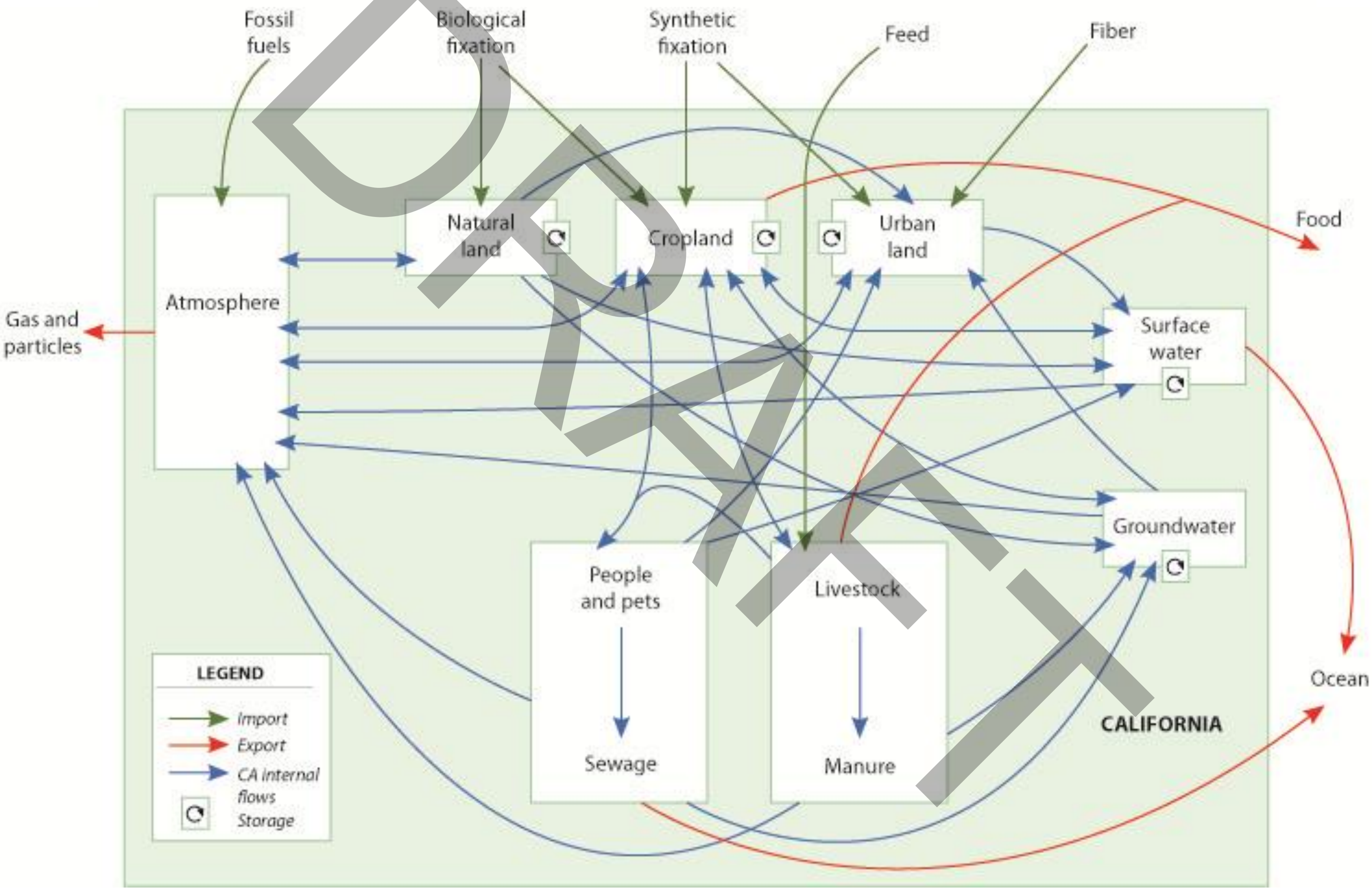
Land use changes, including urbanization and transitions in agricultural land use fundamentally alter N cycling in ways only recently becoming appreciated.

About 77% of food N will enter ***wastewater*** systems and about 50% of wastewater is dispersed in the environment without N removal treatment, though the level of treatment is increasing in CA.

Wildfires cause locally acute N pollution and potentially release soil N reserves into waterways. Drought , fire suppression, and invasive species threaten to increase wildfire intensity.

A Mass Balance of California Nitrogen, *circa* 2005

Flows of Nitrogen in California



Language for describing absolute and relative N flows

Vocabulary for categorizing the absolute and relative magnitude of N flows in the mass balance chapter. A gigagram (Gg) is equivalent to 1 million kilograms.

Absolute Flow (Gg N yr^{-1})	Flow Category	Relative Flow (%)	Fraction category
< 1	Insignificant	1 to 10	Small
1 to 25	Minor	10 to 25	Medium
25 to 100	Moderate	25 to 50	Large
> 100	Major	> 50	Predominant

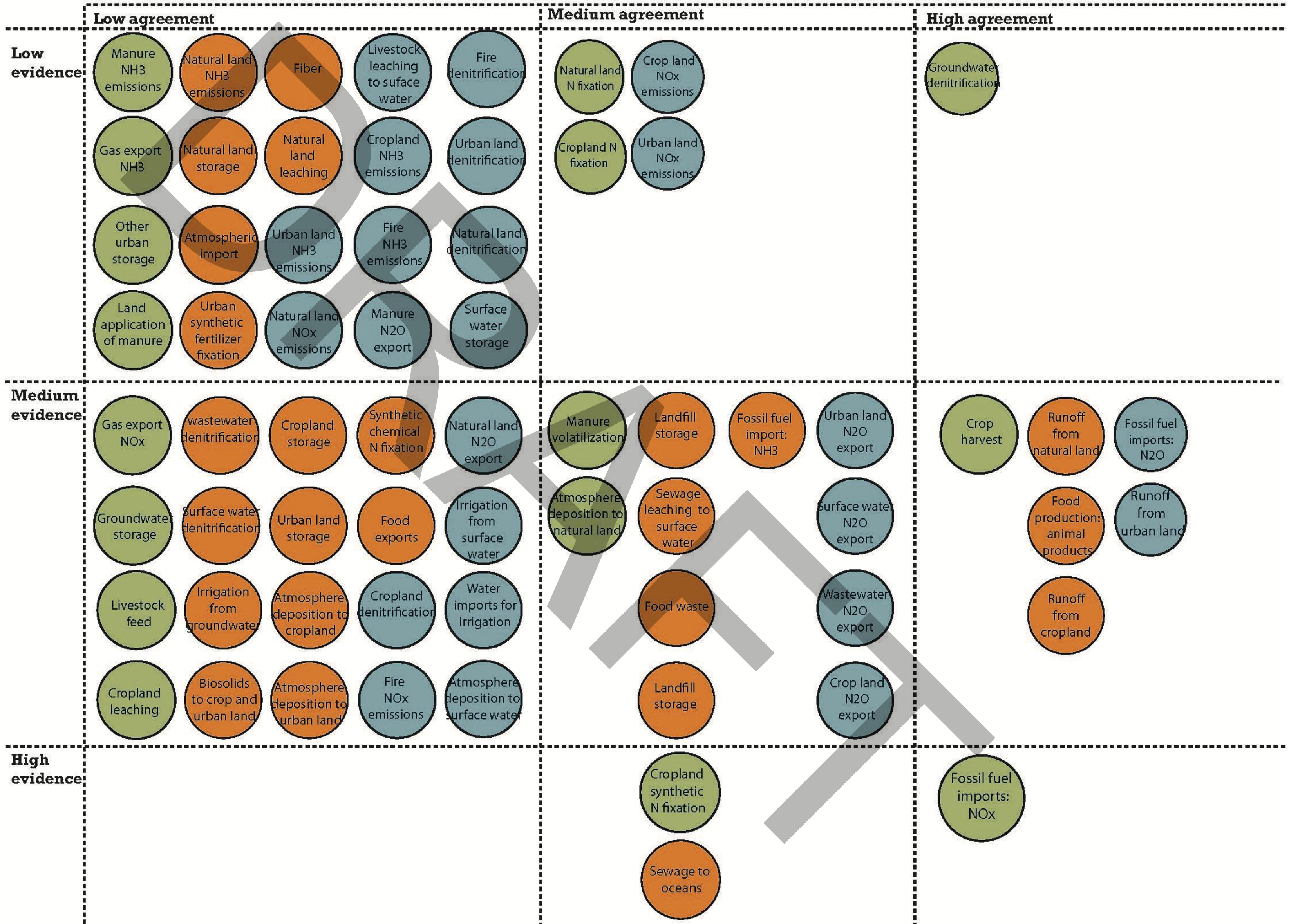
Reserved wording for uncertainty

Level of Agreement	Amount of Evidence			
		Limited	**Medium**	**High**
	Low	Suggested but unproven	Speculative	Alternate explanations
	Medium	Tentatively agreed by most	Provisionally agreed by most	Generally accepted
	High	Agreed but unproven	Agreed but incompletely documented	Well-established

Source: Millennium Ecosystem Assessment

California nitrogen mass balance: Measuring uncertainty

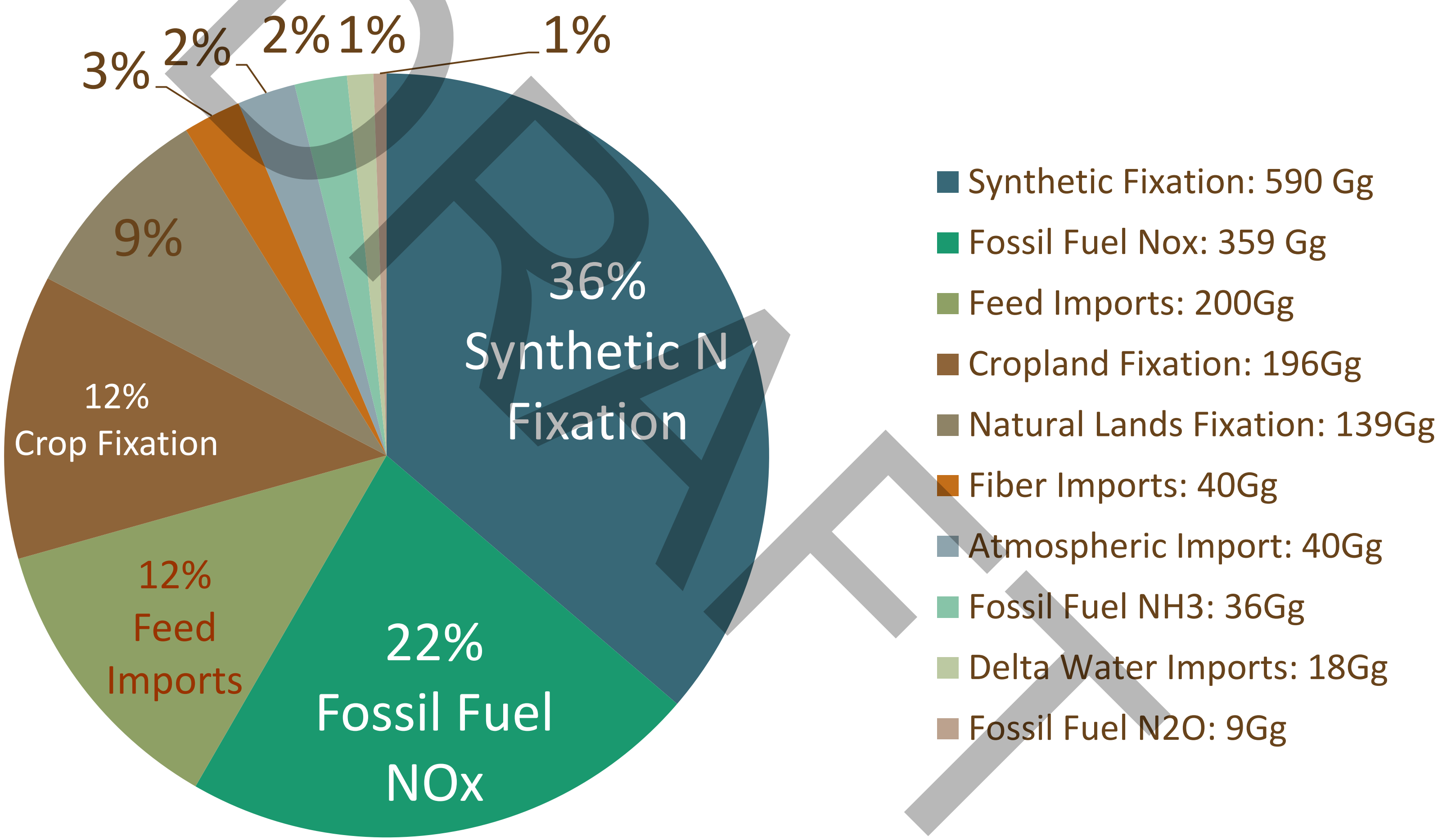
Key: Major flow · Moderate flow · Minor flow



Statewide N Inputs:

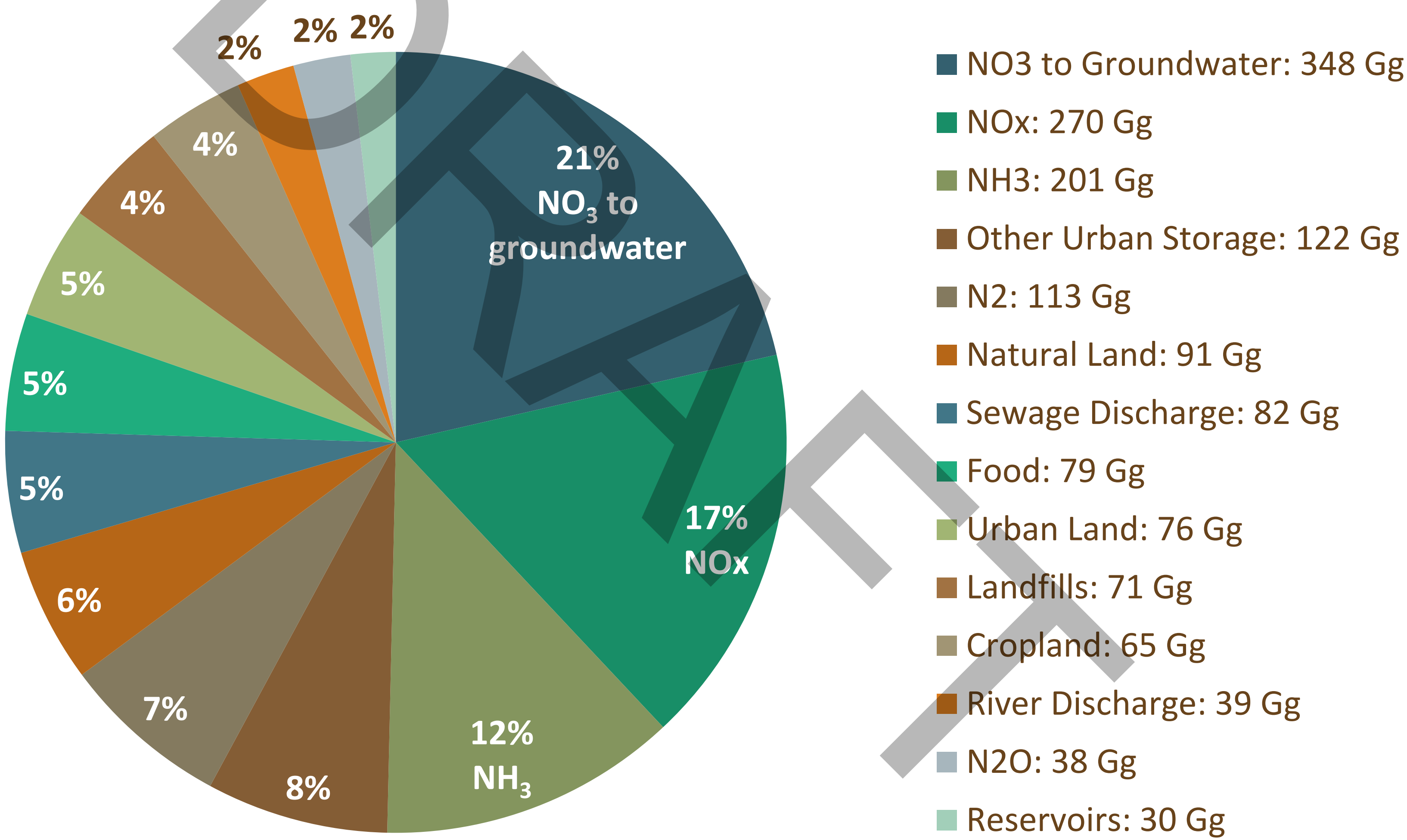
≈1.8 million tons N per year

(1628 Gg N yr^{-1}, roughly 1% of global human N inputs)



Statewide N Outputs and Storage Excluding Groundwater Denitrification

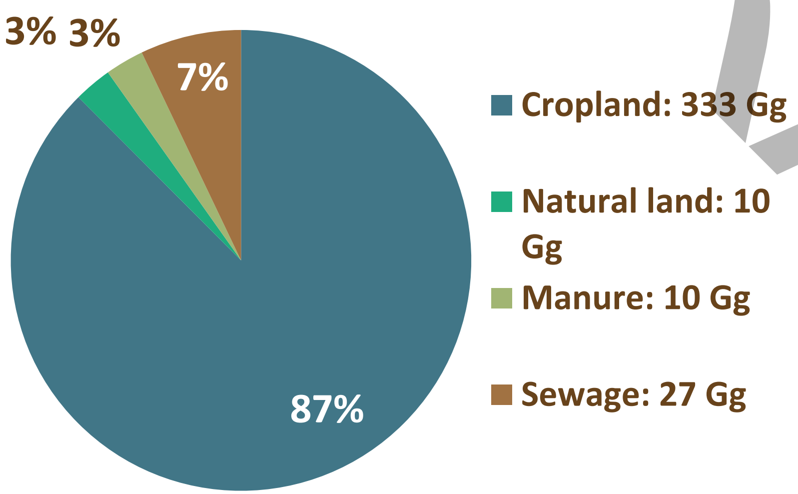
≈1.8 million tons (1626 Gg N yr^{-1})



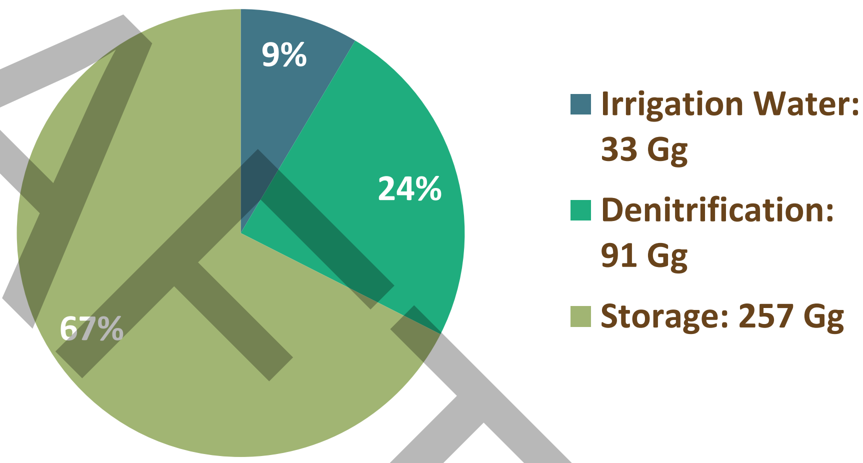
NO_3 Groundwater Mass Balance:

(Net nitrate groundwater storage = 16% of total statewide N)

NO3 inputs to groundwater
380 Gg (418 thousand tons)

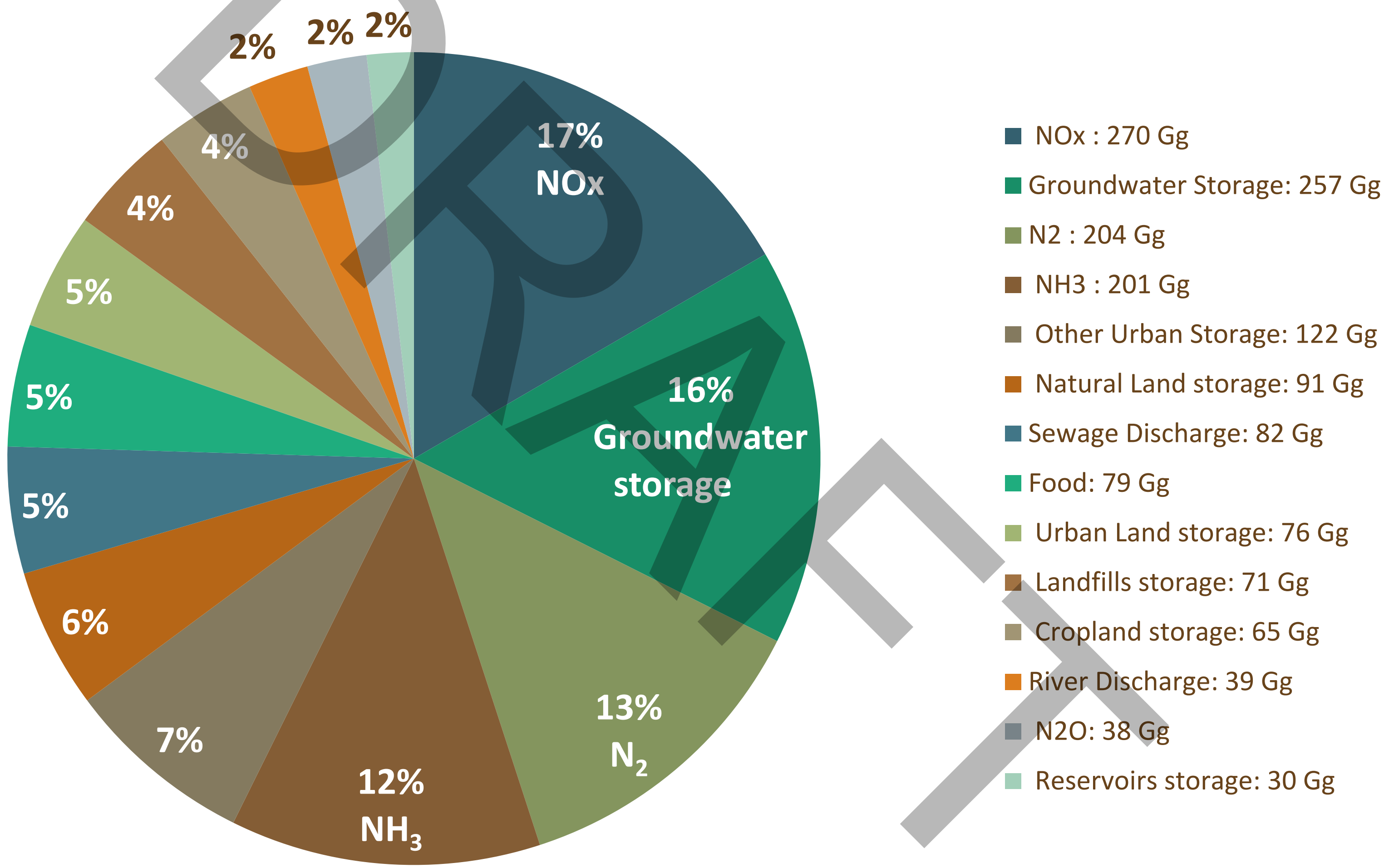


NO3 outputs and net storage
381 Gg (419 thousand tons)

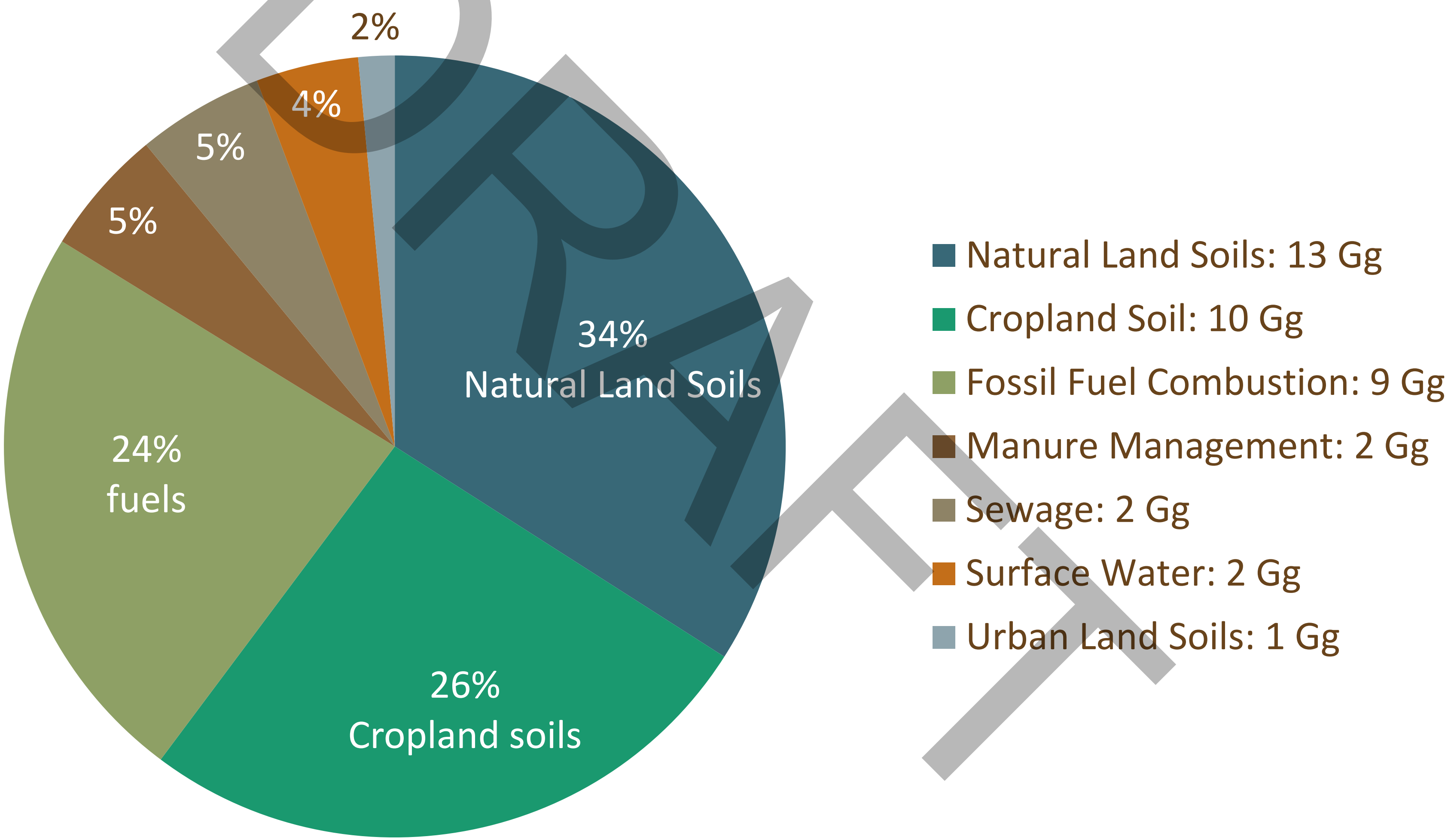


Statewide N Outputs and Storage: Net of Groundwater Denitrification

≈1.8 million tons (1626 Gg N yr^{-1})



N_2O Emissions:
43 thousand tons (39 Gg) N per year
(Nitrous oxide emissions = about 2% of total statewide N inputs)

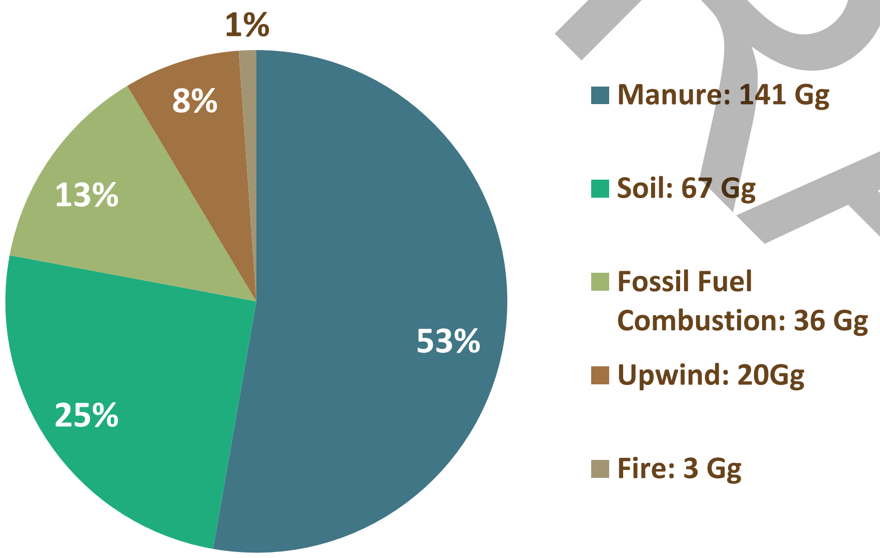


NH_3 Emissions:

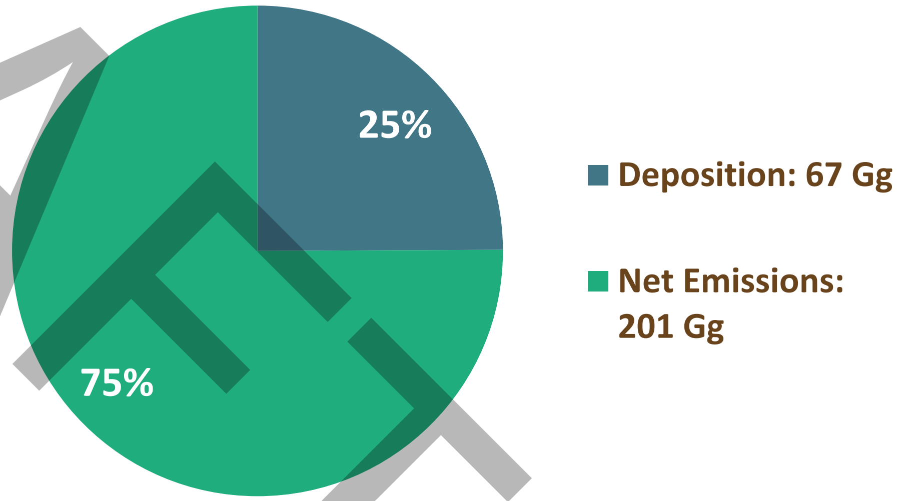
221 thousand tons (201 Gg) N per year

(Ammonia emissions = about 12% of total statewide N inputs)

NH3 emissions
Total: 267 Gg (294 thousand tons)



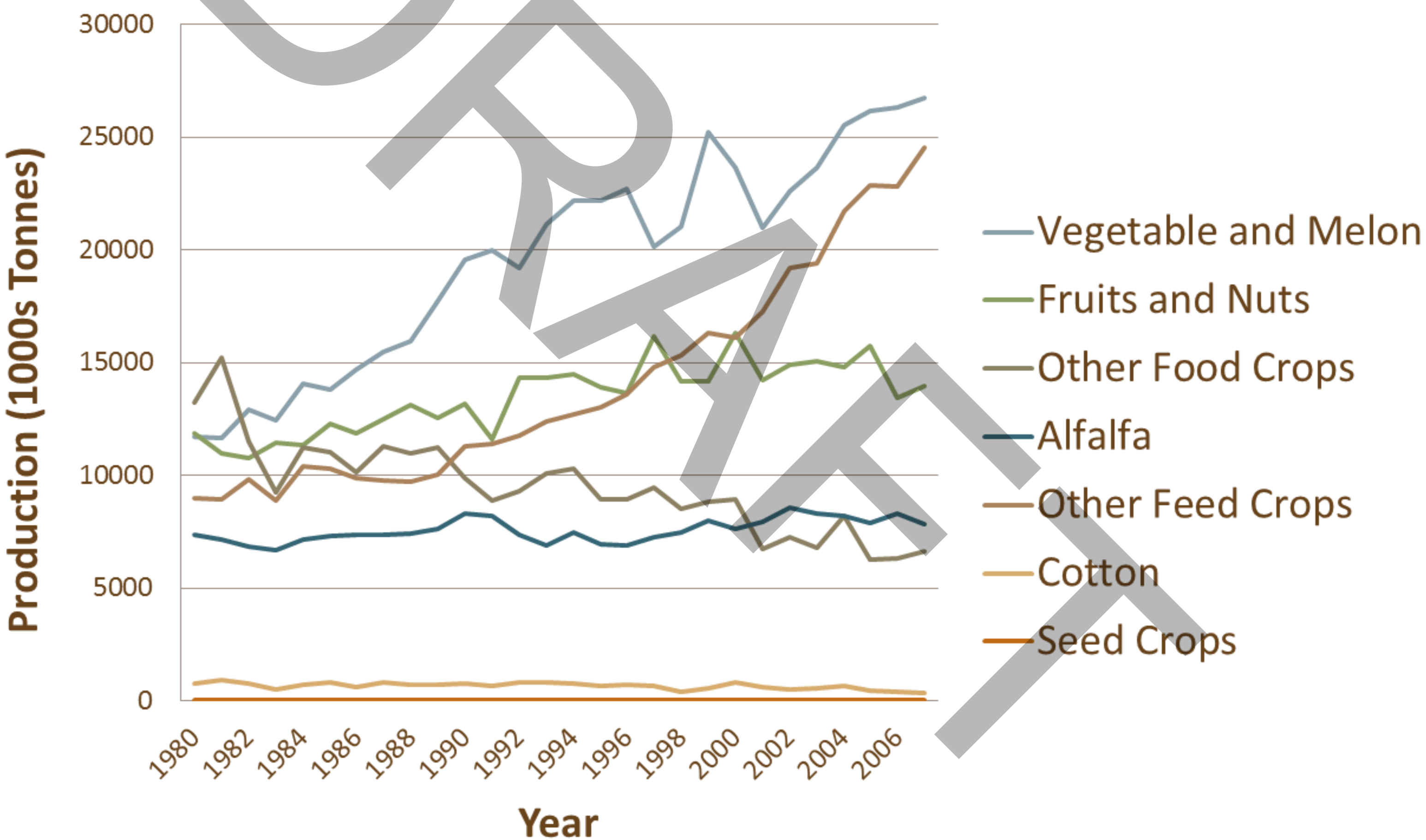
NH3 deposition and net emissions
Total: 268 Gg (295 thousand tons)



Nitrogen's Role in Ecosystem Services and Human Well-Being

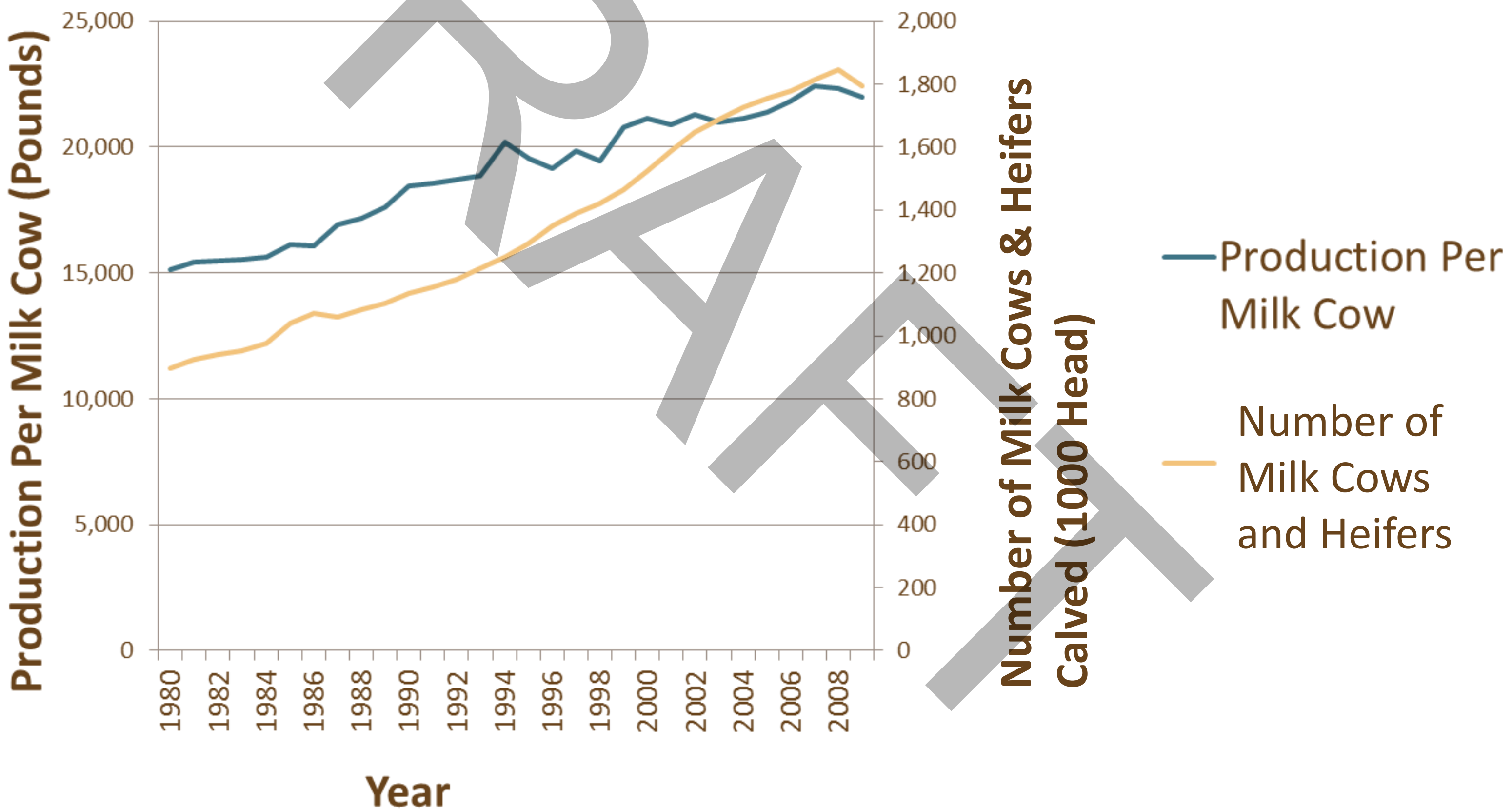
Ecosystem Service: Food Production

Production of major crops in California, 1980-2007



Ecosystem Service: Food Production

California population of milk cows and heifers and production per milk cow 1980 - 2007



Human Well-Being: Nutrition

CA Fruits and Vegetables (50% of US production)

Contribute to under-consumed nutrients - folate, magnesium, potassium, vitamins A, C and K, and dietary fiber.

CA Tree Nuts (almost 100% of US production)

Some evidence that they reduce risk factors for heart disease.

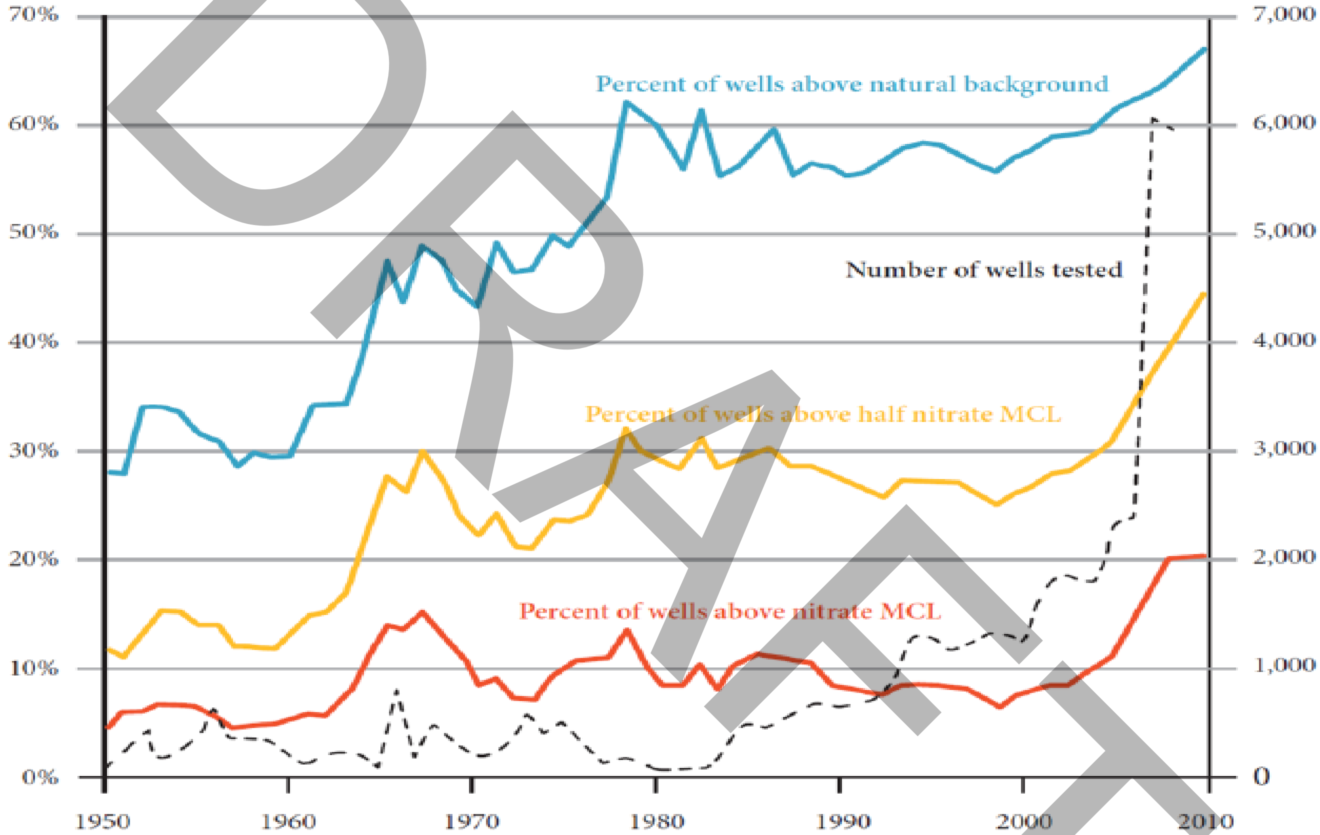
CA Dairy (21% of US production)

Linked to bone health (children and adolescents) and reduced risk of cardiovascular disease, type II diabetes and lower blood pressure (adults).

Caution: higher yields from higher N application has been shown to lower nutrient concentrations in some crops.

Ecosystem Service: Clean Water

Trends in Groundwater Nitrate (Salinas Valley & Tulare Lake Basin)



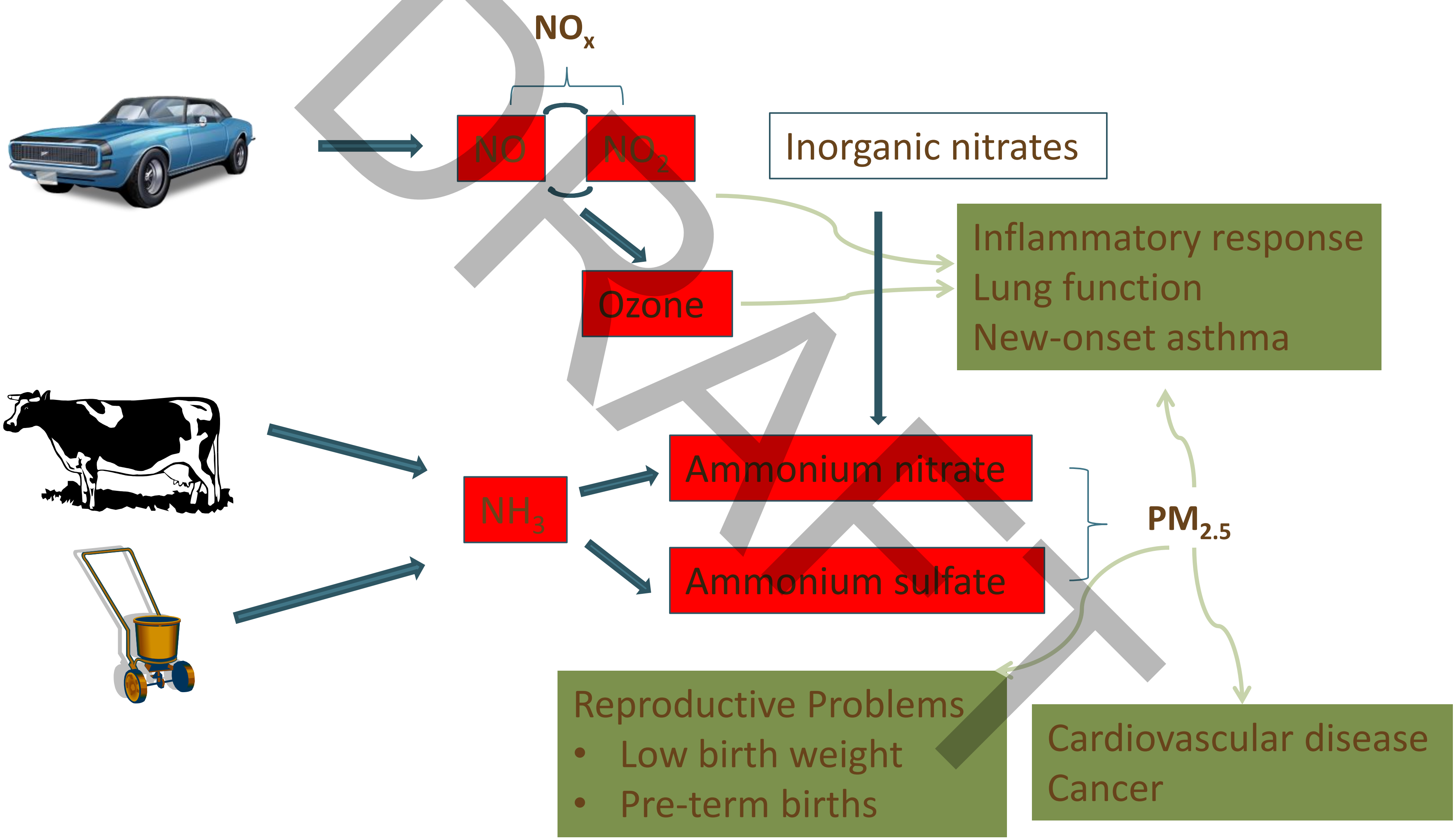
Five-year moving average of the % of wells with average annual NO_3 levels > 9 mg / L (background), 22.5 mg / L (1/2 MCL) and 45mg / L (MCL). Prior to 1990 most wells sampled were public supply wells. In 2007, Central Valley dairies began testing domestic and irrigation wells.

Boyle et al. 2012

Human Well-Being: Health Impacts of Nitrate/Nitrite in Drinking Water and Food

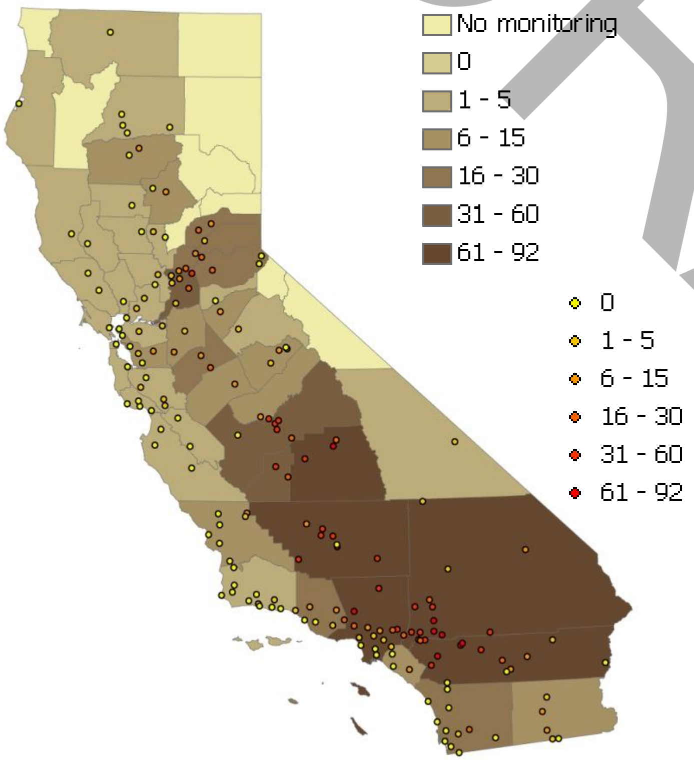
Condition	Level of Uncertainty	References
Foods are major source of nitrate/nitrite	Well-established	Matallana, 2010; Tamme, 2010
Nitrate/nitrite has positive health impacts in some cases	Well-established	Gilchrist, 2011; Lundberg, 2011
Nitrate/nitrite is a risk factor for methemoglobinemia – “Blue Baby Syndrome”	Generally accepted	EPA 1990; Zeman 2002; Sadeq 2008; VanDerslice 2009
Exposure to nitrate/nitrite higher in agricultural areas	Generally accepted	Harter 2009; Boyle et al. 2012
Nitrate/nitrite is carcinogenic	Provisionally agreed by most	IARC, 2010
Lower income and minority communities face higher exposures to nitrate in drinking water	Tentatively agreed by most	Firestone 2006; Balazs 2009
Nitrate/nitrite is associated with adverse birth outcomes	Suggested but unproven	Tabacova et al. 1997, 1998

Ecosystem Service: Clean Air

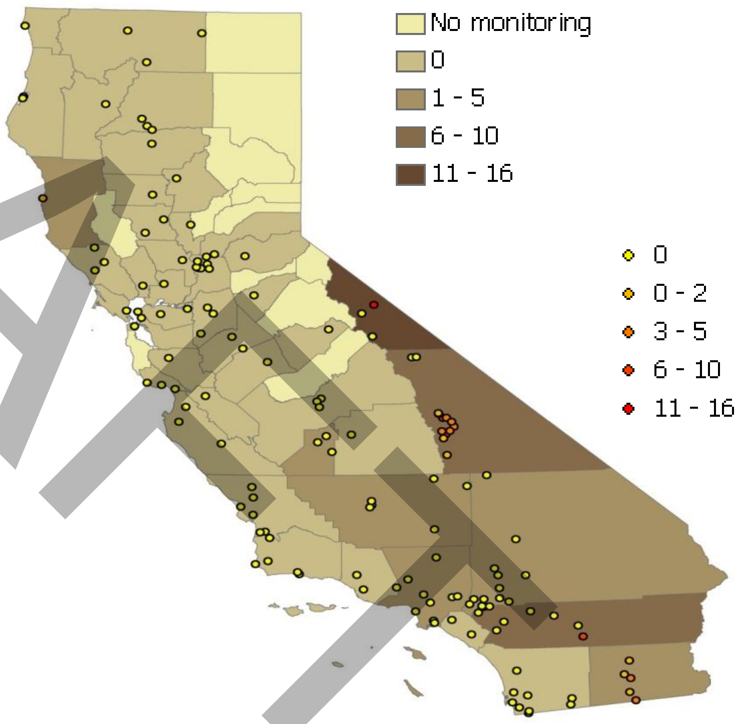


Ecosystem Service: Clean Air

Days With 8-Hour Running Average **Ozone** Levels Above the National Ambient Air Quality Standard, 2009



Days With 24-Hour Average **PM-10** Above the National Ambient Air Quality Standard, 2009



EPA Air Quality System Data Mart

Human Well-Being: The Cost of N-Related Air Pollution

San Joaquin Valley:

- Costs > $1,600 per person per year.
- nearly $6 billion in savings if federal ozone and PM2.5 standards were met.

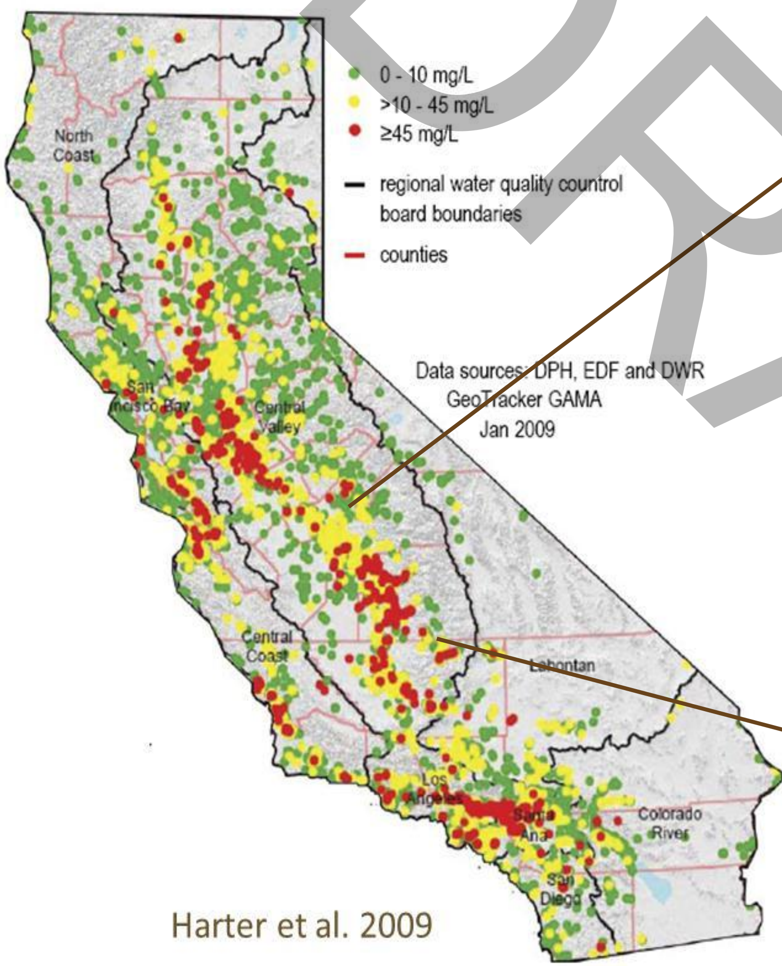
South Coast Air Basin:

- Costs > $1,250 per person per year.
- nearly $22 billion in savings if federal ozone and PM2.5 standards were met.

Hall et al. 2008

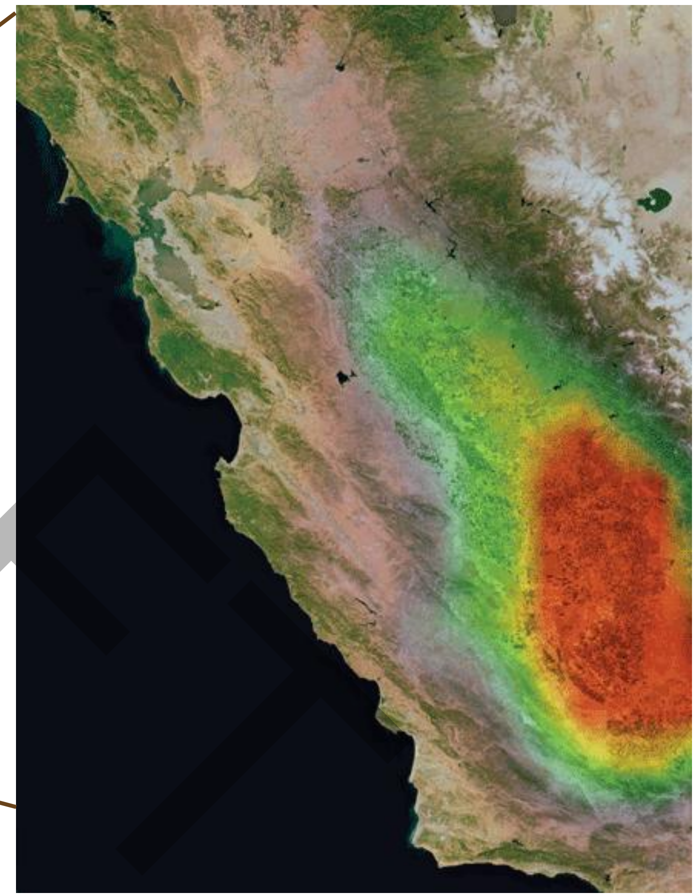
Co-location of Air and Groundwater Pollution: Environmental Justice Concerns

Nitrate in groundwater



Harter et al. 2009

Ammonia in the air



Clarisse et al. 2010

Human Well-Being: Estimated Yield Loss from Ground-Level Ozone in 1993

Crop	Yield loss (%)
Cantaloupe	32.8
Grape, table	29.9
Grape, raisin	26.2
Grape, wine	22.8
Cotton	23.3
Bean, dry	17.5
Onion	10.6
Orange	14
Alfalfa	9.5
Lemon	8.4
Tomato, processing	6.8
Wheat	6.7
Rice	3.9

Other Ecosystem Services

Service	Mechanism of Impact from N	Effects
Swimming	Eutrophication	Beach closures due to algal blooms or fish kills
Fishing	Freshwater acidification	Decline in fish population
Cultural and spiritual values	Freshwater acidification	Decline in aesthetics and value of lakes, streams
	Freshwater eutrophication	Decline of freshwater endangered species; loss of recreation; reduced lakefront property values
	Coastal eutrophication	Recreational use of estuary

Compton et al. 2011

Technical Solutions for Agriculture, People, and the Environment

Key Technical Strategies for Reducing Nitrogen-Related Problems

1. Reducing inputs of new nitrogen

2. Targeting specific transfers of N between environmental systems

3. Adapting to an N-rich environment

Options for Reducing Inputs of New Nitrogen

Increasing N utilization efficiencies in crops and livestock

Changing consumer food choices – livestock with higher N conversion ratios and lower dependence on fertilized feed crops

Reducing food waste

Improving efficiency in transportation & energy sectors

Reducing Inputs of New Nitrogen

N use efficiency in crops is consistently higher in plot and field-scale research trials than on-farm averages.

- California area weighted average **PNB across 33 crops = 54%**
- Some research trials: **PNB as high as 80 – 99%** (almonds, tomatoes)

*Partial **N**utrient **B**alance = N exported/N applied * 100*

(Brown et al. unpub; Bottoms and Hartz 2009)

Examples of key practices:

Soil tests

Modify fertilizer placement and timing

- *Better understood for field and veg crops than tree crops*

Improve irrigation system performance

- *Nitrate leaching more highly correlated with water moving beyond root zone than with total amount of N applied* (Letey et al. 1977, Pratt et al. 1984)

Reducing Inputs of New Nitrogen

Increase N utilization efficiency in livestock

- Smaller potential increases compared to crop N use efficiency
- But even an increase of 4 percentage points could decrease total feed demand to 85% of current levels

Examples of key practices:

Breed animals for high feed conversion efficiency –

- *any more potential?*

Feed management

- *Type and degradability of protein affects amount and form of N excreted*

Options for Targeting Specific N Transfers

A single type of source is generally responsible for more than 50% of each N transfer.

Minimizing volatilization from manure.

Minimizing NO_3- leaching from croplands.

Minimizing N_2O emissions from soils.

Reducing NO_x emissions from fuel combustion.

Transforming wastewater management.

Potential for Mitigation with Current Technologies

Increase fertilizer N use efficiency

Improve manure management

Increase access to wastewater treatment

Reduce fuel emissions

Reduce N released to environment by **25-30%**

Galloway et al. 2008; SAB 2011

Cropland Practices: Mitigation and Tradeoffs

Practices with high scientific evidence and agreement

Practice	Crop yield	NH_3 ↑	N_2O ↑	NO_3 Leaching	NO_3 Runoff	Barriers
Reduce N application	+/-	+	+	+	+	Logistics Cost Info
Cover crops	No effect?	-	+/-	+	+	Logistics Cost
Change N placement/ timing	+	+	+/-	+	+	Cost Info Regs
Edge of field	No effect	No effect	-	+	+	Logistics
Improve irrigation system performance	No effect		+/-	+/-	+	Cost
Increase drainage	+	+	+	-	+	Cost Logistics Info

Adaptive Strategies for an N-rich Environment

Treating drinking water

Switching water uses – nitrate-rich groundwater for irrigation, clean river water for drinking

Increasing adaptive capacity of ag systems

- Adjusting fertilizer applications to account for N in irrigation water
- Selecting ozone-tolerant crops/varieties to prevent yield reductions

Lessons

- Some trade-offs are inevitable
  - The problem of secondary transfers

- The "best solutions" will depend on local conditions

  - Finding these best solutions will require careful monitoring at the field and farm scale, and beyond

Statewide Approaches

Need a comprehensive integration of state-wide monitoring data.

- California Air Resource Board
- State Water Quality Control Board
- Environmental Protection Agency

Existing data should have

- improved access
- uniform and transparent protocols
- assessment of uncertainty

Policy challenges and opportunities

Nitrogen may be a good candidate to pioneer the next generation of integrated environmental policies and regulatory re-organization.

<u>"One size fits all" won't work</u> for nitrogen.

Some opportunities are problem-specific and locally-important:

- **Crop management for groundwater quality**
- **Manure management for air and water quality**

But even technological solutions require an integrated approach to develop appropriate practices combined with policy support

Complexity + diversity + spatial dispersion ➔ high transaction costs

<u>How</u> policy is designed and implemented is as important as <u>what</u> policy targets.

Stakeholder Review Process

Stakeholder Advisory Committee receives the Nitrogen Assessment before the broader stakeholder review begins and ASI begins public response to all stakeholder feedback.

ASI hosts conference call with Stakeholder Advisory Committee to hear feedback.

Major revisions, responses to public comments, and creation of user-friendly materials happens in conjunction with the stakeholder review process.

Following review, ASI will finalize all summary documents and host a series of public workshops at various locations for interested groups.

We will need your input

Scientific review of the California Nitrogen Assessment is ongoing.

The next step will be a stakeholder review, and we are always seeking interested reviewers.

To stay in touch, go to nitrogen.ucdavis.edu for updates.

Thank you!
We look forward to your comments and questions.