The California Nitrogen Assessment

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Collaborating Institutions:

- Agricultural Sustainability Institute at UC Davis
- UC Sustainable Agriculture Research & Education Program
- UC Agricultural Issues Center
- Kearney Foundation for Soil Science
- California Institute for Water Resources
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Californians' quality of life depends on our abundant food and vibrant agricultural landscapes.

All Californians have a stake in a thriving agricultural sector and agricultural communities in our state, both now and for future generations.

Nitrogen is indispensable to the productivity of California agriculture.

And yet, only about half the nitrogen applied ends up where we intend; the balance leaks, polluting our air and water, with detrimental effects on our environment and human health.

Getting California’s nitrogen balance right requires broad collaboration over the coming years, with farmers and ranchers leading the way to produce solutions.

California Nitrogen Assessment Goals

Gain a comprehensive view of N flows in the state

Provide useful insights for stakeholders into the balance between the benefits and negative impacts of nitrogen.

Compare policy and practical options for improvement.

Effectively link science with action to produce information that informs both policy and field-level practice.

Our Role

The CNA is high level approach to nitrogen in California meant as a guide for envisioning the future of nitrogen in agriculture and promoting long-term dialogue.

The CNA does not include an assessment of regulations currently in development.

What an assessment *is*, and what it is *not*:

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

Stakeholders provide the questions that guide the assessment.

What an assessment *is*, and what it is *not*:

An assessment is not a research project.

Most sources and data should already be collected, peer-reviewed, and in the public domain. Gap-filling and new calculations using existing data are permissible.

What an assessment *is*, and what it is *not*:

An assessment is not an advocacy piece; it must be balanced and evidence-based. Assessments frame and weigh policy options rather than making policy recommendations.

What an assessment *is*, and what it is *not*:

The CNA is time bounded. The CNA was launched in 2009 and the text for the final publication was finished in July 2015.

Assessments rely primarily on peer-reviewed publications, for which the time period from the initial research

to final publication commonly extends to two years or more.

The CNA is based on stakeholder questions

What are the big sources of nitrogen pollution in California?

What are the impacts of N management on the environment and human health?

What practices are most effective in mitigating nitrogen pollution?

What are the policy challenges and opportunities?

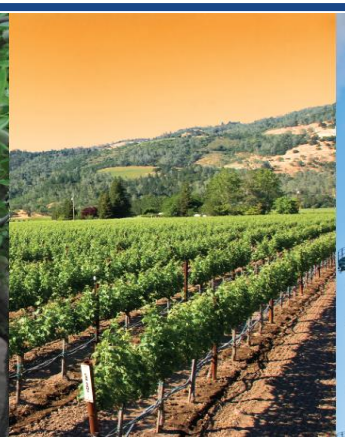
Quantifying Uncertainty

Reserved wording to describe uncertainty

Amount of Evidence

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

Drivers of nitrogen flows in California



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Global Drivers of Nitrogen Cycling

Human population and economic growth

Market opportunities for California commodities

Agricultural production costs and technological change

Policies targeting nitrogen

Fundamental Drivers of Nitrogen Cycling in California

Nitrogen fertilizer use (synthetic & organic sources)

Manure management

Fossil fuel combustion

Industrial processes

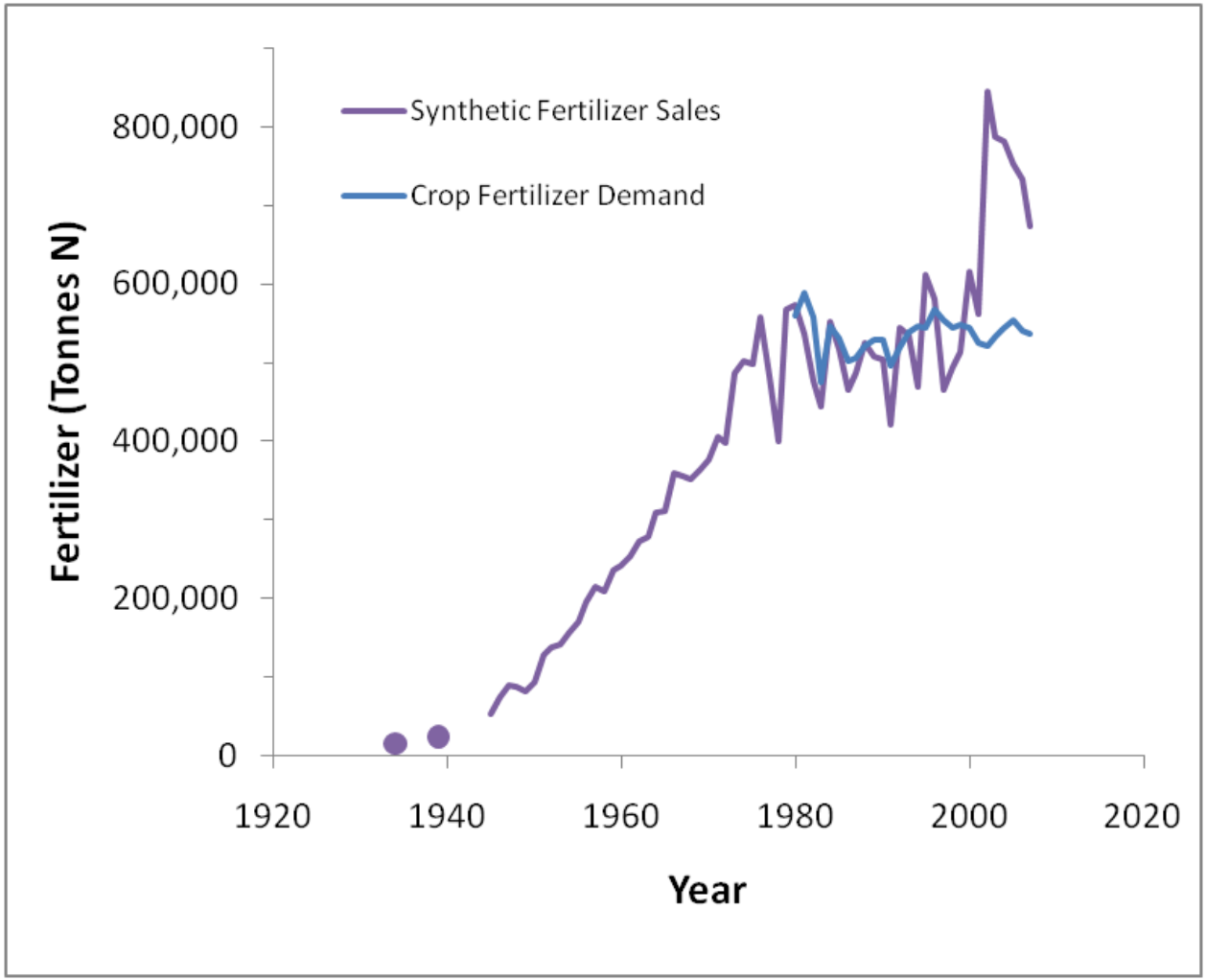
Wastewater management

Changes in land use

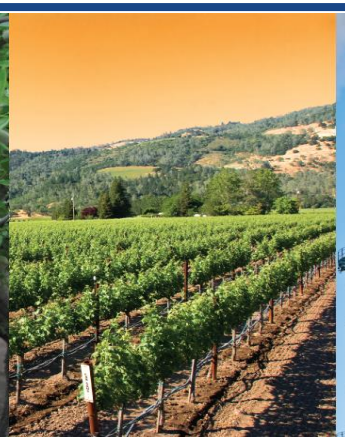
California Fertilizer Use

Since World War II, sales of synthetic N fertilizers increased an average of 5% per year.

Despite uncertainties in recent data, it appears that sales leveled off since the early 1980s. *Source: CDFA (2009)*



A California Nitrogen Mass Balance for 2005



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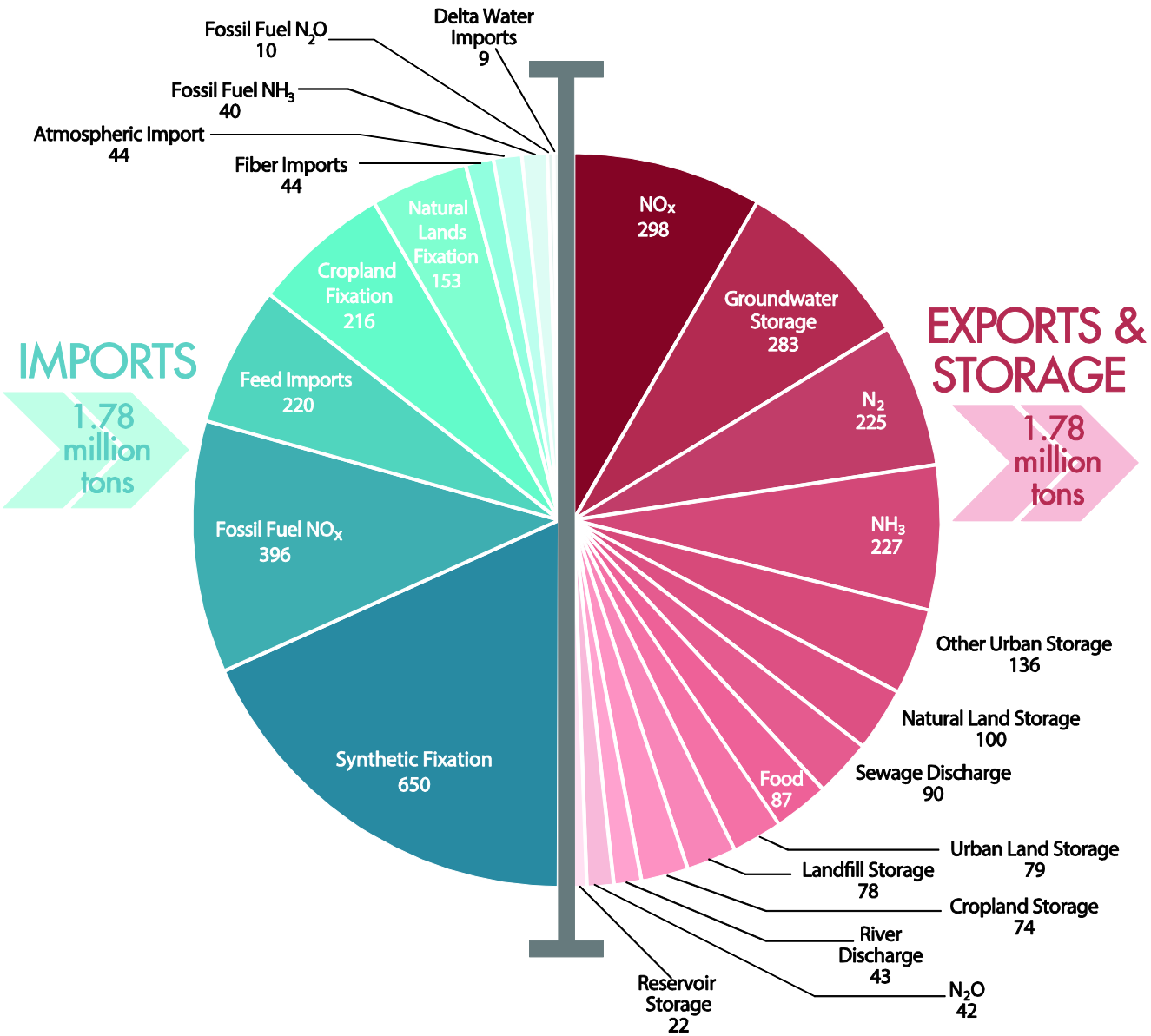
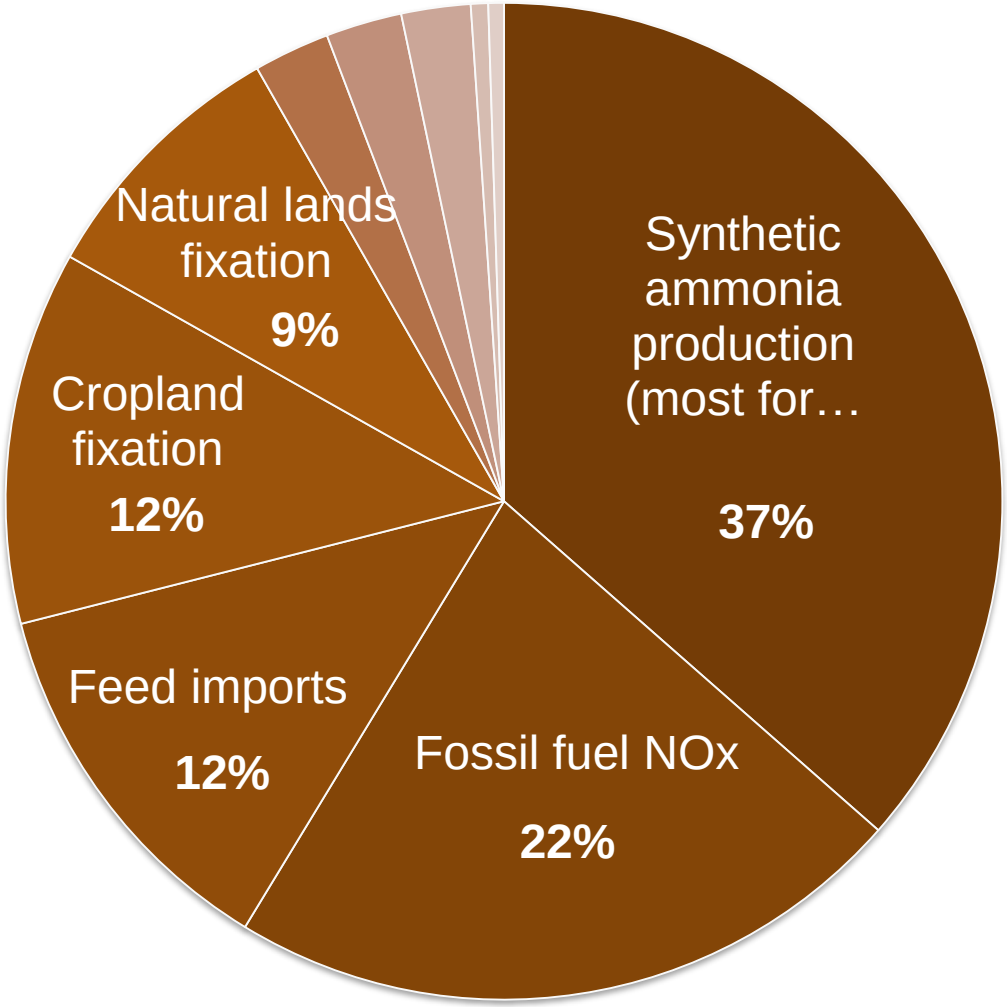
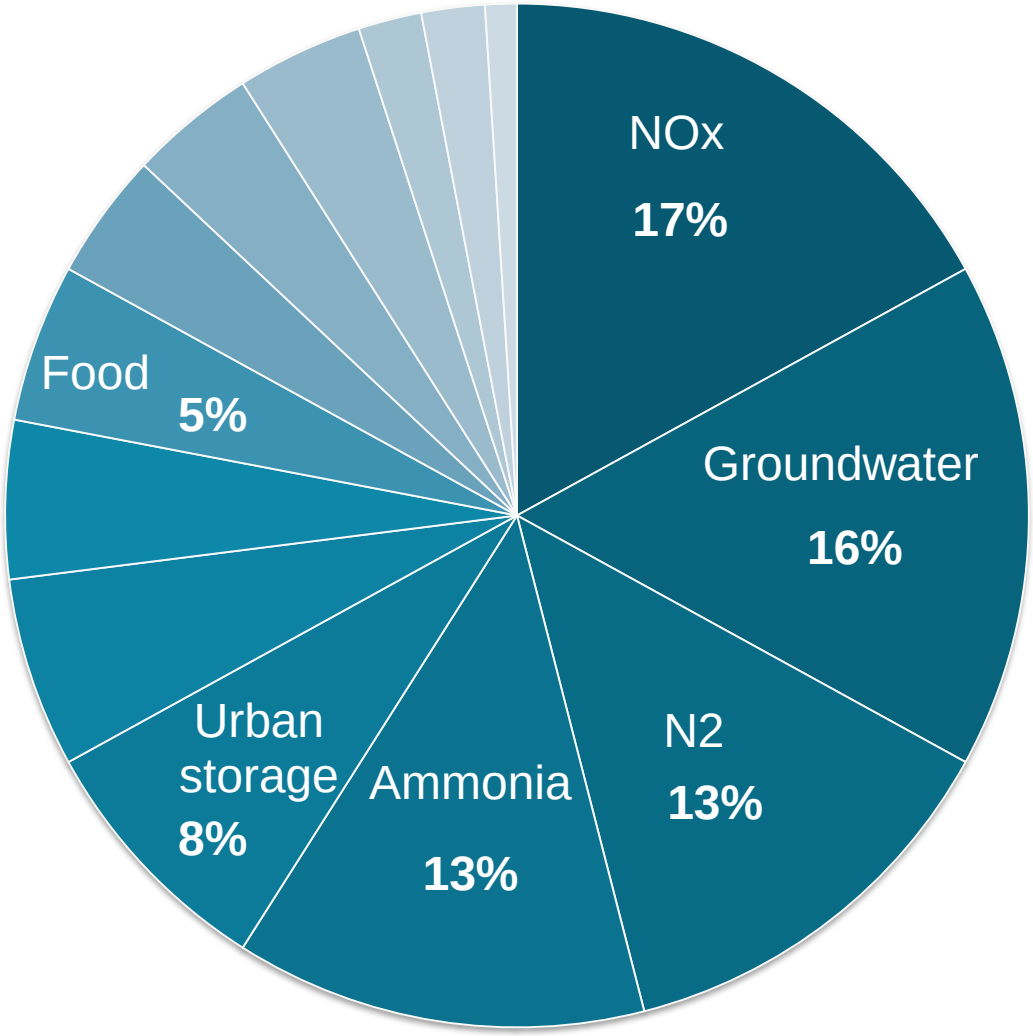
Statewide N inputs = 1.8 million tons/year, roughly 1% of global human N inputs



Statewide N Inputs: 5 largest flows



Statewide N Exports & Storage: 5 largest flows

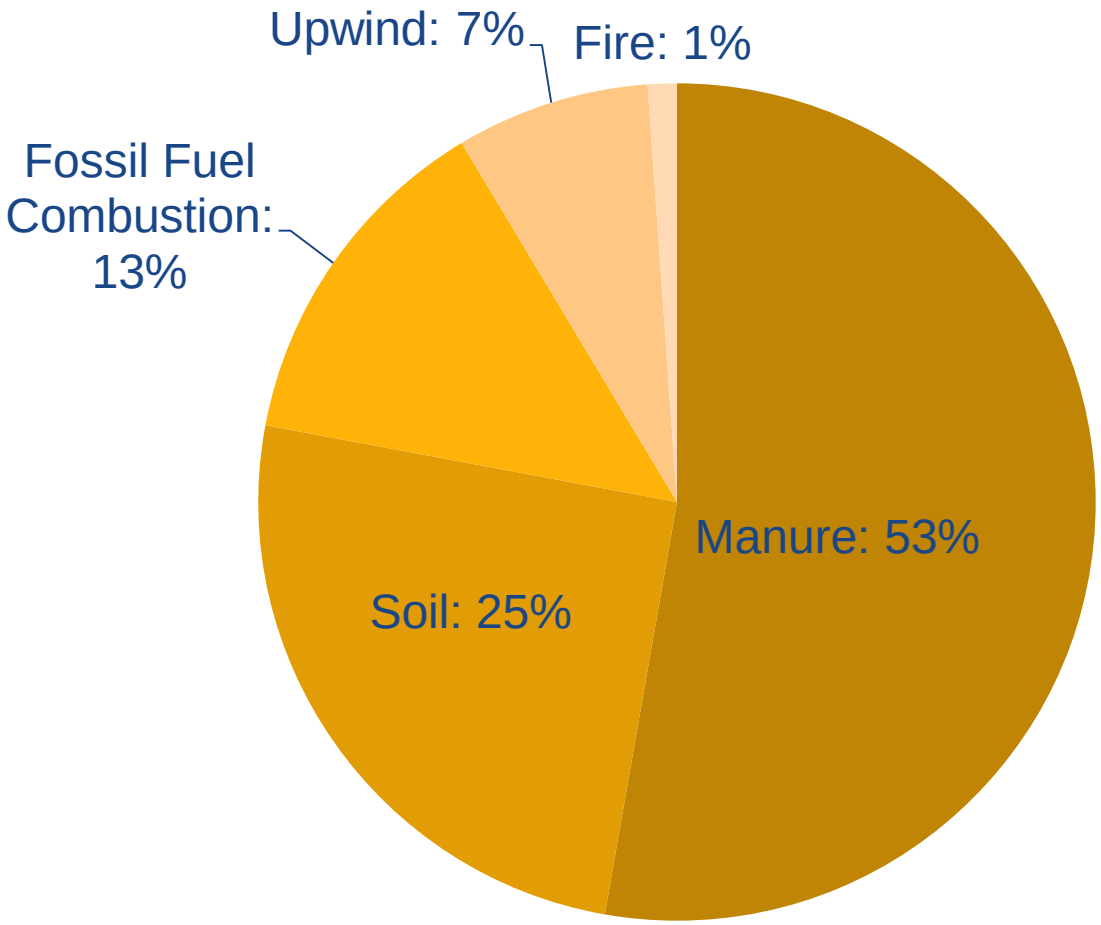


Fossil fuel combustion is the major (40%) source of nitrogen to the atmosphere, with **nitrogen oxides (NOx)** as the predominant (89%) form of fossil fuel emissions.

30% of nitrogen losses are transported downwind from California as **NOx** or **ammonia (NH_3)**, making California a major source of atmospheric nitrogen pollution.

Ammonia flows into CA atmosphere

294 thousand tons (267 Gg) N per year



Agriculture (cropland + livestock) Inputs and Outputs

Inputs

Fertilizer N (32%)**+**
Crop biological N fixation (12%) **+**
feed imports (12%) **=**

56% of all new nitrogen entering CA each year

Outputs

Nitrogen in the **food and fiber** produced by California's crop and livestock systems accounts for only **33% of total annual N outputs from agriculture.**

Two other major flows out of agriculture:

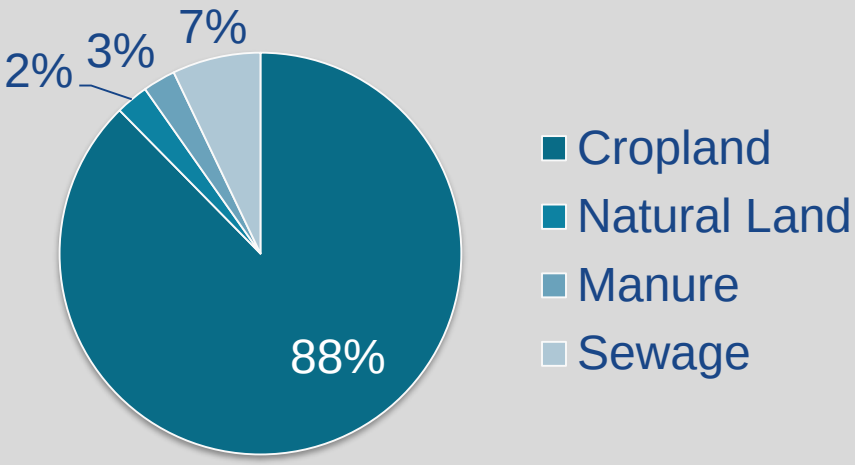
- **Nitrate-N leaching** to groundwater (35%)
- **Ammonia-N** to air (16%)

Groundwater N Mass Balance

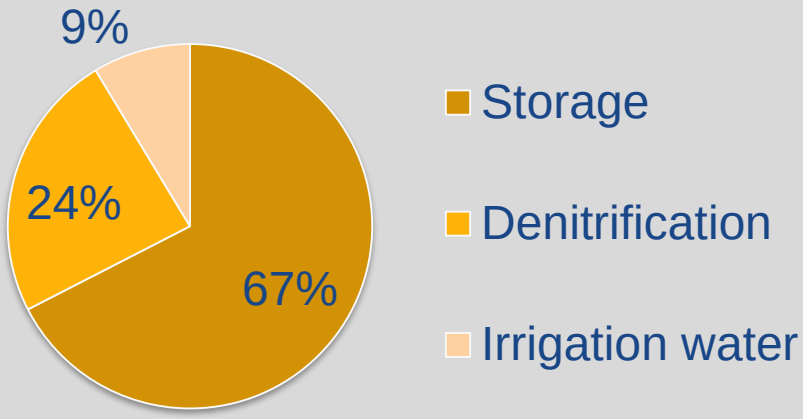
Gross NO_3 groundwater inputs = 23% of statewide N

Net NO_3 groundwater storage = 16% of statewide N

N inputs to groundwater: 418 thousand tons



N outputs + net storage: 419 thousand tons



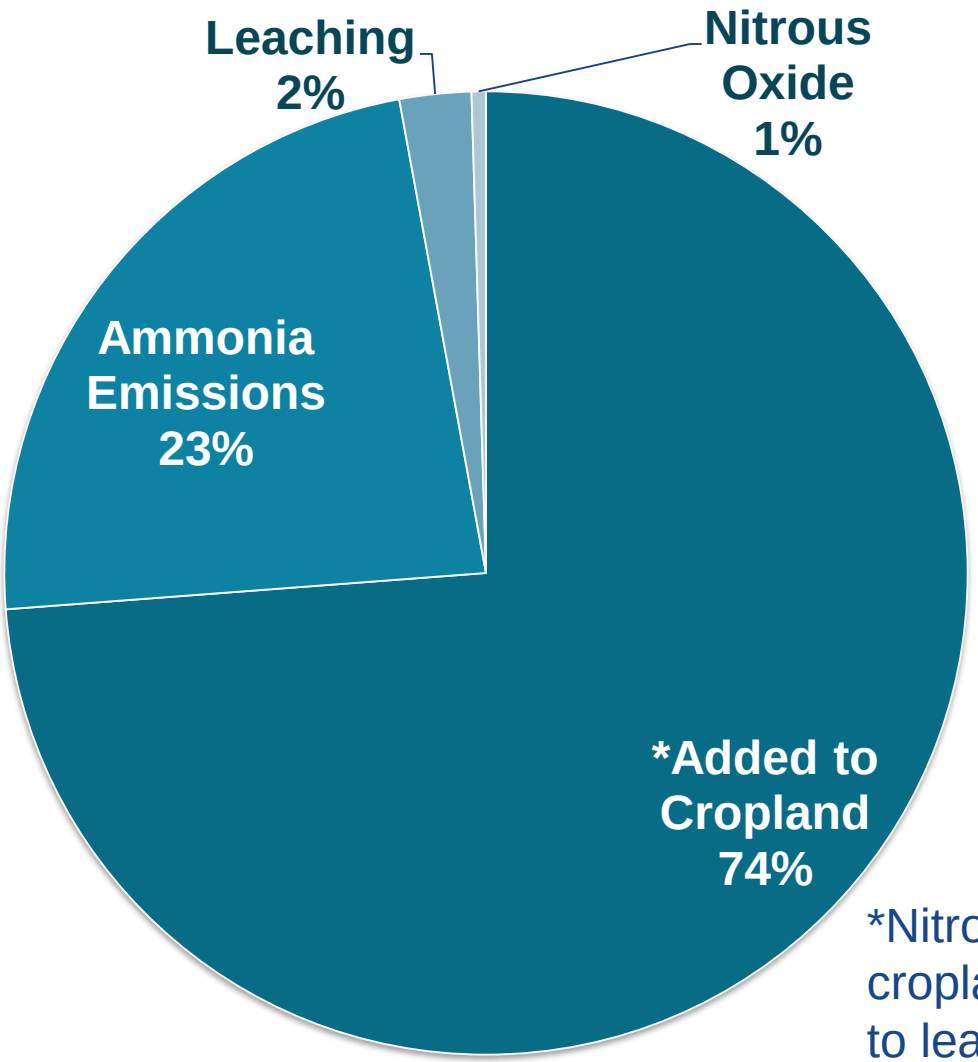
Livestock consume 614,000 tons of nitrogen each year in their feed.

25% of that becomes meat or milk for our consumption; the rest is excreted in manure.

Much of that manure is reapplied to cropland, where its nitrogen has the potential to leach into groundwater.

Some of the nitrogen in manure is released into the air or water or stored in soils.

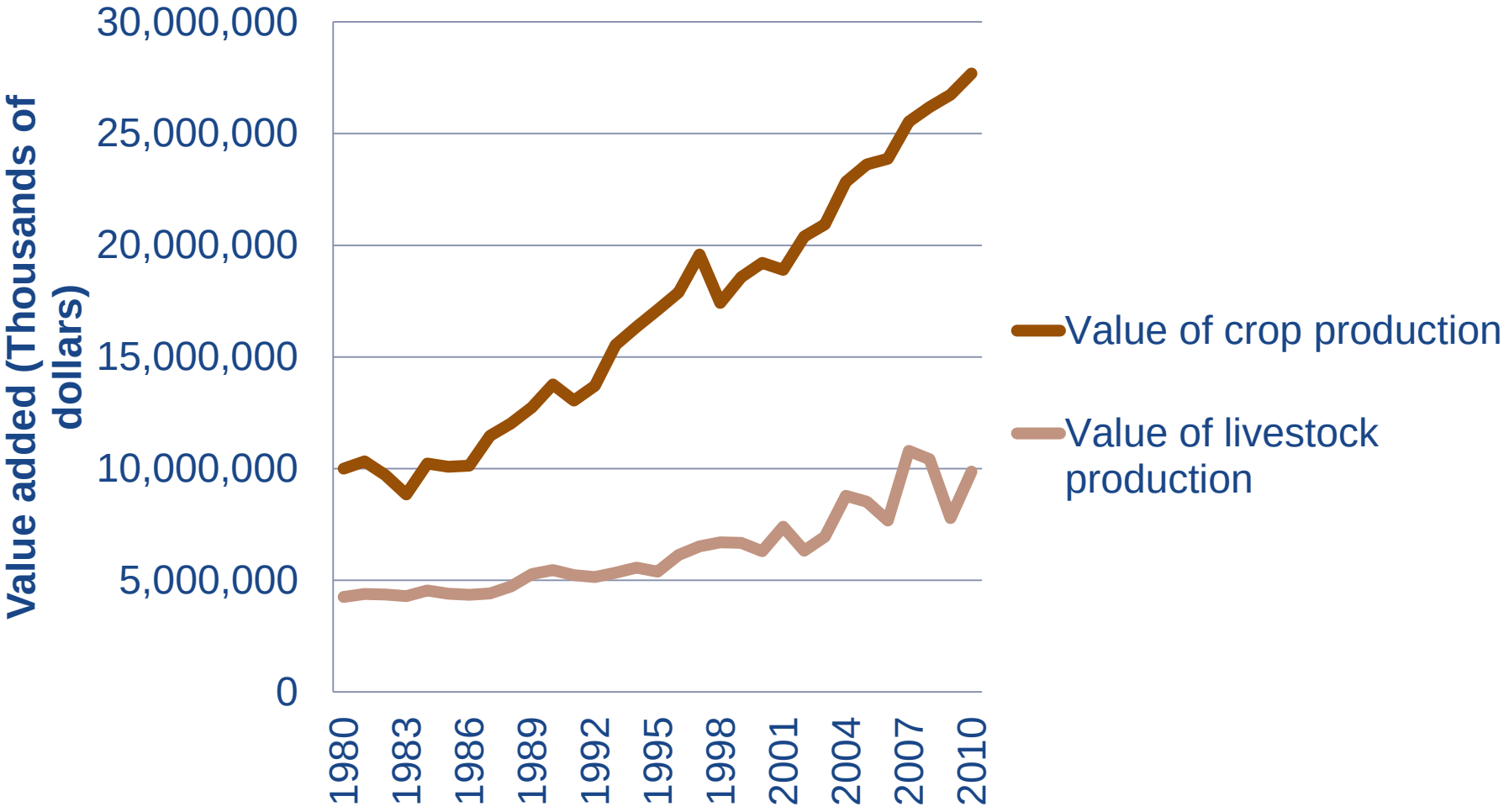
Fate of manure nitrogen from livestock



*Nitrogen added to cropland is susceptible to leaching

Nitrogen’s impact on environment and human health

Value of CA Agricultural Production



The value of California's agricultural production continues to grow.

Nutrition and Human Health

CA Fruits and vegetables – 50% of U.S. production

contribute to many under-consumed nutrients and dietary fiber

CA Tree nuts – almost 100% of U.S. production

Some evidence that nuts are linked to reduced risk for heart disease

CA Dairy – 21% of U.S. production

Linked to bone health, reduced risk of cardiovascular disease and type II

Despite significant declines in nitrogen oxides, ozone, and particulate matter over the past four decades, much of the state's air quality still fails to meet one or more state recommendations set to protect human health. This comes at great health and economic cost.

High levels of nitrate in drinking water can harm human health. Relatively low concentrations of nitrite and nitrate are found in drinking water from the state's surface water.

In contrast, nitrate levels in groundwater have increased over the past several decades, and some parts of the state now exceed federal standards for safe drinking water.

Scientific uncertainty of groundwater nitrate health impacts

	Low Agreement	Medium agreement	High agreement
Low evidence	Nitrate increases risk of adverse birth outcomes		
Medium evidence		Nitrate and nitrite increase the risk of cancer Exposure to nitrate/nitrite in water is higher among low income minority communities in CA	Groundwater nitrate levels in many CA regions have increased over the past 5 decades, and are likely to continue increasing
High evidence		Human exposure to nitrate/nitrite levels is higher in ag regions Nitrate consumption increases the risk of “blue baby syndrome.”	Groundwater nitrate levels are higher in CA’s major ag regions. Foods are an important source of nitrate. Nitrate has some therapeutic health benefits.

People in agricultural areas, particularly those with domestic wells, are more likely to be exposed to high levels of nitrate in their drinking water than those in urban and suburban areas.

Potential health impacts of nitrogen, combined with increasing rates of nitrogen in groundwater and the difficulty of remediating groundwater contamination, create an urgent challenge to protect California's vulnerable communities today.

Additional Impacts

Ozone negatively impacts crop growth

Long-term changes in plant species biodiversity

Encourages invasive plants

Soil acidification

Increased concentration of toxic metals in soils

Technological options for improvement

(1) Reduce need for new N;
(2) Reduce movement of N to other systems

Key Control Points:

Agricultural N Use Efficiency & Cropland Management

Energy and Transportation Sector Efficiency

Manure Management

Wastewater Management

Consumer Choices and Food Waste

Mitigative Effects of **Cropland** N Management Practices on the Fate of Nitroge

Practice	Scientific Certainty of Effectiveness	Potential Negative Trade-Offs
Increasing soil drainage	Well-established	Increases nitrate leaching
Switching to low-volume irrigation		
Field edge vegetation & bio-reactors		May increase N_2O
Reduce N rate	Generally accepted	
N placement and timing		
Switch fertilizer type		May trade nitrate leaching for air emissions
Conservation tillage	Provisionally agreed by most	May immobilize N
Diversify crop rotation	Tentatively agreed by most	
Manage fallow periods – cover crops	Agreed but incompletely documented	
Organic amendments & practices	Speculative	

Mitigative Effects of Dairy Manure Management Practices on the Fate of Nitrogen

Practice	Scientific Certainty of Effectiveness	Potential Negative Trade-Offs
Incorporation below surface	Well-established	Increase nitrate leaching
Solid-liquid separation		
Split applications	Provisionally agreed by most	May increase NH_3, N_2O, NO_x
Precision feeding	Agreed but incompletely documented	
Supplements and hormones		
Anaerobic digestion of wastewater		May increase N_2O, NO_x
Measured applications and flow meters		May increase NH_3, N_2O, NO_x
Frequent manure collection	Agreed but unproven	May increase N2O, NOx
Storage cover for wastewater ponds		
Composting manure solids	Speculative	

Trade-offs of Nitrogen Reduction Efforts

Minimization of ammonia volatilization from manure can **increase** nitrate leaching and nitrous oxide emissions.

Reducing nitrogen oxide emissions from fuel combustion can **increase** ammonia emissions.

Decreasing ammonium and nitrate from wastewater can **increase** nitrous oxide emissions.

Decreasing leaching on croplands **inhibits** flushing of salts.

Assessment of Nitrogen Policy Instruments

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Assessment of Nitrogen Policy Instruments

A policy assessment uses a body of evidence to answer these questions:

- What are the policy goals?
- Have existing policies been successful in achieving their stated goals?
- Why or why not, and at what cost?
- What can we learn from past policy successes or failures in designing future policies?

Policy assessment is not policy advocacy

Assessment of Nitrogen Policy Instruments

Types of policies assessed:

Education
Standards (regulations)
Incentives

Criteria used to assess policy instruments:

Adaptability
Institutional compatibility
Distributional effects
Cost effectiveness
Technological feasibility
Environmental effectiveness

Case study: North Carolina's Neuse River Basin

Goal: reduce N loading by 30% in 6 years

Instrument:

Farmer participation required in 1 of 2 options

- Participate in Local Nitrogen Strategy that would include specific plans for each farm, with a collective 30% reduction in N loadings
- Implement standard best management practices

Impact: Nutrient loading decreased by 42% in 6 years, exceeding goal

Key Lessons:

- Including nonpoint sources was critical in achieving nutrient reduction
- Flexibility is crucial for cos-effectiveness
- Success hinged on collaboration among agencies, stakeholders, and the public

Case study: Mississippi River Basin

Goal: Reduce hypoxic zone to <5000km^2, a 40-50% reduction in N loading

Instrument:

- Voluntary actions with incentives and education, focused on nonpoint source agricultural sources
- States expected to create state-level nutrient reduction strategies

Impact: Goals have not been met. As of 2013, 9 out 12 states involved have developed strategies

Key Lessons:

- Participation in costly voluntary efforts tends to be low in the absence of private returns or compensation
- Establishment of nutrient reduction plans can help clarify challenges and focus research efforts.

Case study: European nitrogen reduction

Water quality goal: Nitrates Directive sets standards for surface and ground water
Air quality goal: Framework Directive on Ambient Air sets standards for NOx, ozone, PM 2.5

Instrument:

- Mandatory practices established for farmers for manure storage, fertilizer application, maximum fertilizer application rates
- Farmers must comply across various environmental regulations in order to receive income support payments (Common Agricultural Policy)

Impact: 55% of rural surface water monitoring shows decreased NO_{3-} Groundwater improvements have been modest and variable between regions

Key Lesson:

- Cross-compliance across environmental regulations to receive income support was a strong financial incentive

Scenarios of the future

How will nitrogen be managed in 20 years in California?

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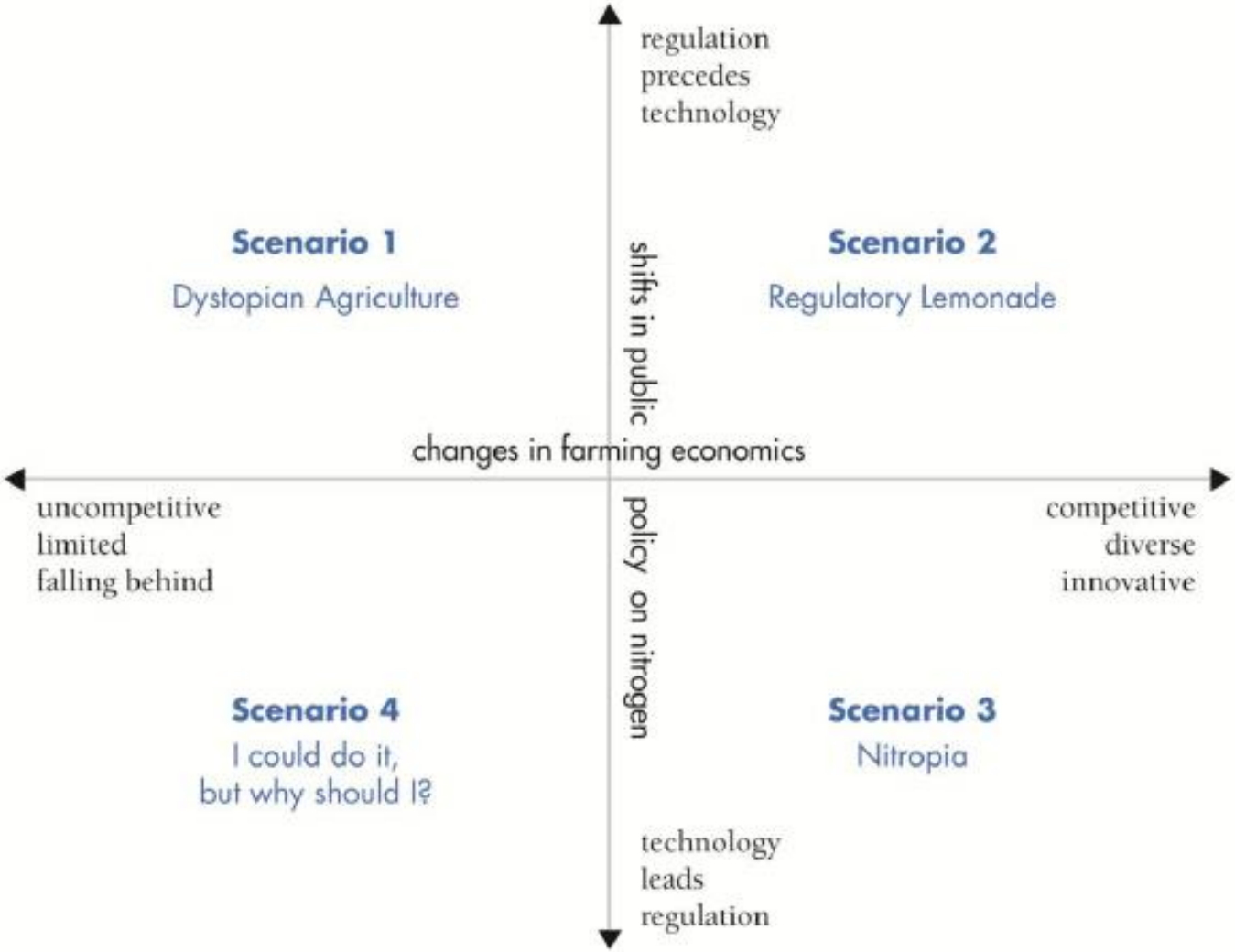
What does the future look like?



The Solution Center for Nutrient Management

ucanr.edu/sites/Nutrient_Management_Solutions

Nutrient management resources and knowledge sharing tools for the California agricultural community

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Thank you!

Find the book, executive summary, and additional materials at **asi.ucdavis.edu/nitrogen**

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