

California Nitrogen Assessment – Draft¹ Table of Contents

Acknowledgements

List of authors, review editors, and scientific reviewers

Glossary

Acronyms and abbreviations

Executive summary

1 Introduction*

- 1.0 Introduction: The California Nitrogen Assessment
- 1.1 Understanding nitrogen
- 1.2 Global perspective
- 1.3 Why California?
- 1.4 Approach: An integrated assessment of nitrogen across science, policy, and practice
- 1.4.1 Ensuring credibility, relevancy, and legitimacy
- 1.4.1.1 A stakeholder-driven approach
- 1.4.1.2 Who was involved in the CNA?
- 1.4.1.3 Review process
- 1.4.2 Dealing with uncertainty
- 1.5 What is the purpose of the California Nitrogen Assessment?
- 1.5.1 The conceptual framework: Roadmap to the assessment
- 1.5.2 Target audience
- 1.6 Conclusion: Complicated issues require integrative solutions
- App.1.1 Who was involved in the California Nitrogen Assessment?
- App. 1.2 Organizations contacted as part of the California Nitrogen Assessment
- App. 1.3 List of scientific and stakeholder reviewers
- App. 1.4 Review editors for the California Nitrogen Assessment
- 2 Underlying drivers of nitrogen in California
- 2.0 Introduction
- 2.1 Human population and economic growth
- 2.1.1 Income growth and patterns of demand for food
- 2.1.2 Population and economic growth in California
- 2.2 Markets for California's diverse commodity mix
- 2.2.1 Market prices and California's commodity mix
- 2.2.2 International trade in California's commodities
- 2.2.2.1 The importance of exchange rates

¹ * Denotes chapter is in development. Titles of sections and sequencing may change but will not affect the overall scope/content. Updated 14 February 2014



CALIFORNIA NITROGEN ASSESSMENT

Agricultural Sustainability Institute, UC Davis UC Sustainable Agriculture Research and Education Program

Transportation costs for agricultural commodities 2.2.2.2 2.2.3 Agricultural and trade policies affecting California commodities 2.2.3.1 Commodity policies of the US and major trading partners 2.2.3.2 US crop insurance policy 2.2.3.3 International trade barriers 2.3 Inputs, resources, and technology in California agriculture 2.3.1 Cost of agricultural land 2.3.2 Cost of irrigation water and water institutions 2.3.3 California's climate: trends and variability 2.3.4 Cost of manure used as fertilizer 2.3.5 Synthetic fertilizer prices 2.3.6 **Energy prices** 2.3.7 Labor costs and agricultural labor institutions 2.3.8 Development and adoption of new technologies 2.4 Policies affecting nitrogen flows in California 2.4.1 Water quality policies 2.4.1.1 Surface water regulations 2.4.1.2 Groundwater regulations 2.4.2 Air quality policies 2.4.3 Climate change policies 2.4.4 Federal conservation programs 2.4.5 Other environmental policies 2.5 Conclusion

3 Direct drivers of California's nitrogen cycle 3.0 Factors controlling the N cycle 3.1 Relative influence of the direct drivers 3.2 Fertilizer use on croplands 3.2.1 Inorganic N fertilizer use on farms 3.2.1.1 Trends in inorganic N use and yields 3.2.1.2 Inorganic N use on major California crops 3.2.2 Organic N use on croplands 3.2.2.1 Trends in organic N use 3.2.2.2 Manure use on croplands 3.2.2.3 Cultivation induced biological N fixation 3.2.3 Agronomic nitrogen use efficiency (NUE) 3.2.3.1 NUE when using inorganic fertilizer 3.2.3.2 NUE when using organic fertilizer 3.3 Feed and manure management 3.3.1 Trends in California livestock production 3.3.2 Dietary N, N-use efficiency, and N excretion 3.3.3 Manure management 3.3.3.1 Manure management within a confined animal feeding operation 3.3.3.2 Manure management for grazing animals 3.3.4 Whole farm N balances Fossil fuel combustion 3.4 3.4.1 Transportation



3.5

3.6

3.7

3.8

Agricultural Sustainability Institute, UC Davis

UC Sustainable Agriculture Research and Education Program

3.4.1.1 Temporal and spatial trends 3.4.1.2 Technological change 3.4.2 Energy and industry (stationary sources) Industrial processes Wastewater management 3.6.1 Publicly owned treatment works (POTWs) 3.6.1.1 Wastewater treatment 3.6.1.2 Trends in wastewater N and treatment 3.6.2 Onsite wastewater treatment systems (OWTS) Land use, land cover, and land management 3.7.1 **Developed** areas 3.7.2 Agriculture 3.7.3 Other land uses: forestry, wetlands, and grasslands and shrublands Universal historical increases but future uncertainty App. 3.1 Average N fertilizer application rates by crop, 1973 and 2005 App. 3.2 Are University N rate guidelines current? Published University of California N fertilizer rate guidelines for select crops App. 3.3 App. 3.4 Trends in crop, soil, and water management Complexity of industrial N processes App. 3.5 N in California's solid waste App. 3.6

4 A California nitrogen mass balance for 2005

- 4.0 Using a mass balance approach to quantify nitrogen flows in California
- 4.1 Statewide and subsystem nitrogen mass balances
- 4.1.1 Statewide nitrogen flows
- 4.1.2 Cropland nitrogen flows
- 4.1.2.1 Cropland N imports and inputs
- 4.1.2.2 Cropland N outputs and storage
- 4.1.3 Livestock nitrogen flows
- 4.1.3.1 Livestock feed
- 4.1.3.2 Livestock manure
- 4.1.4 Urban land nitrogen flows
- 4.1.4.1 Urban land imports and inputs
- 4.1.4.2 Urban land N outputs and storage
- 4.1.5 Household nitrogen flows
- 4.1.5.1 Human food
- 4.1.5.2 Human waste
- 4.1.5.3 Household pets
- Natural land nitrogen flows 4.1.6
- 4.1.6.1 Natural land N imports and inputs
- 4.1.6.2 Natural land N outputs and storage
- 4.1.7 Atmosphere nitrogen flows
- 4.1.7.1 Atmosphere N imports and inputs
- 4.1.7.2 Atmosphere N exports and outputs
- 4.1.8 Surface water nitrogen flows
- 4.1.8.1 Surface water N inputs
- 4.1.8.2 Surface water exports and outputs a



CALIFORNIA NITROGEN ASSESSMENT

Agricultural Sustainability Institute, UC Davis UC Sustainable Agriculture Research and Education Program

- 4.1.9 Groundwater nitrogen flows
- 4.1.9.1 Groundwater inputs
- 4.1.9.2 Groundwater outputs and storage
- 4.2 Mass balance calculations and data sources
- 4.2.1 Fossil fuel combustion
- 4.2.2 Atmospheric deposition
- 4.2.3 Biological nitrogen fixation
- 4.2.3.1 Natural land N fixation
- 4.2.3.2 Cropland N fixation
- 4.2.4 Synthetic nitrogen fixation
- 4.2.4.1 Non-fertilizer synthetic chemicals
- 4.2.4.2 Synthetic fertilizer
- 4.2.5 Agricultural production and consumption: food, feed, and fiber
- 4.2.6 Manure production and disposal
- 4.2.7 Household waste production and disposal
- 4.2.8 Gaseous emissions
- 4.2.9 Surface water loadings and withdrawals
- 4.2.10 Groundwater loading and withdrawals
- 4.2.11 Storage

5 Ecosystem Services and human well-being

- 5.0 Introduction
- 5.1 Healthy food and other agricultural products
- 5.1.1 Role of nitrogen in agricultural production
- 5.1.1.1 Trends in indicators of crop production
- 5.1.1.2 Trends in indicators of livestock production
- 5.1.2 Human well-being and agricultural production
- 5.1.2.1 Food and health
- 5.1.2.2 N management and food quality: the tradeoff between quantity vs. quality
- 5.1.3 Economic benefit of agricultural production
- 5.1.3.1 The importance of food production to California's economy and society
- 5.1.3.2 The importance of California agriculture to US and global food systems
- 5.2 Clean drinking water
- 5.2.1 Trends in indicators of water quality
- 5.2.1.1 Maximum contaminant levels (MCL) for nitrate and nitrite in drinking water
- 5.2.1.2 The chemical and physical basis of nitrogen in drinking water
- 5.2.1.3 Nitrogen in surface water: spatial and temporal trends
- 5.2.1.4 Nitrogen in groundwater: spatial trends
- 5.2.1.5 Nitrogen in groundwater: historic trends and future projections
- 5.2.2 Human exposure
- 5.2.2.1 Consumption of nitrate/nitrite in drinking water and food
- 5.2.2.2 Exposure patterns in California
- 5.2.2.3 Disparities in exposure to nitrate/nitrite in California
- 5.2.3 Human health effects of nitrate/nitrite
- 5.2.3.1 Adverse and beneficial effects
- 5.2.3.2 Interpreting epidemiological evidence
- 5.2.3.3 Methemoglobinemia (blue-baby syndrome)



CALIFORNIA NITROGEN ASSESSMENT Agricultural Sustainability Institute, UC Davis UC Sustainable Agriculture Research and Education Program

5.2.3.4	Birth outcomes and birth defects
5.2.3.5	Cancer
5.2.3.6	Health benefits of ingested nitrate/nitrite
5.2.3.7	Research needs
5.2.4	Economic cost of N in drinking water
5.2.4.1	Costs associated with human well-being
5.2.4.2	Health costs
5.2.4.3	Household costs
5.2.4.4	Cost to public and community water systems
5.3	Clean air
5.3.1	Relationship between nitrogen and air pollutants
5.3.1.1	Emissions of NO_x and NH_3
5.3.1.2	Formation, buildup and decay of tropospheric O_3
5.3.1.3	Sources and formation of particulate matter
5.3.2	Spatial and temporal trends in air pollutants
5.3.3	Patterns of exposure to air pollutants in California
5.3.4	Disparities in exposure to air pollutants
5.3.5	Human well-being and air quality
5.3.5.1	Interpreting epidemiological evidence
5.3.5.2	Evidence of the impacts of NO ₂ , O ₃ , and particulate matter exposure on respiratory health
5.3.5.3	Hospital admissions for respiratory problems
5.3.5.4	Evidence of the impacts of NO ₂ , O_3 , and particulate matter exposure on cardiovascular disease
5.3.5.5	Evidence of the impacts of NO ₂ , O ₃ , and particulate matter exposure on cancer
5.3.5.6	Evidence of the impacts of NO ₂ , O ₃ , and particulate matter exposure on birth outcomes
5.3.5.7	Evidence of the impacts of NO ₂ , O ₃ , and particulate matter exposure on mortality
5.3.5.8	Summary of health impacts of NO_2 , O_3 , and particulate matter
5.3.5.9	Research needs
5.3.6	Economics of air guality
5.3.6.1	Economic costs of air pollution on human health
5.3.6.2	Economic costs of air pollution on crop production
5.4	Climate regulation
5.4.1	Measures of radiative forcing and global climate change
5.4.2	Effects of reactive N on the global climate
5.4.3	Effects of reactive N on N ₂ O emissions
5.4.4	Effects of reactive N on biosphere C stocks and the efflux of CO ₂ and CH ₄
5.4.5	Effects of reactive N on atmospheric gases and aerosols
5.4.6	Future research needs in California
5.5	Cultural services
5.5.0	Introduction
5.5.1	Aesthetic value
5.5.2	Recreational value
5.5.2.1	Aquatic ecosystems
5.5.2.2	Terrestrial ecosystems
5.5.3	Cultural heritage values
5.5.4	Spiritual and religious values
5.5.5	Cultural and spiritual values as motivators for addressing N issues
App. 5.1	California crop categories used in the assessment



CALIFORNIA NITROGEN ASSESSMENT Agricultural Sustainability Institute, UC Davis UC Sustainable Agriculture Research and Education Program

6	Scenarios
6.1	Using Scenarios to establish a common understanding around N in California
6.1.1	The logic behind the scenarios
6.2	Our four scenarios: an overview
6.2.1	Scenario 1: End of agriculture
6.2.2	Scenarios 2: Regulatory lemonade
6.2.3	Scenario 3: Nitropia
6.2.4	Scenario 4: Complacent agriculture
6.3	Alternate futures for nitrogen in California agriculture 2010-2030
6.3.1	Scenario 1: End of agriculture
6.3.1.1	Early years: 2010 to 2017
6.3.1.2	Middle years: 2017 to 2024
6.3.1.3	End vears: 2014 to 2030
6.3.2	Scenario 2: Regulatory lemonade
6.3.2.1	Farly years: 2010 to 2017
6.3.2.2	Middle years: 2017 to 2024
6.3.2.3	End years: 2014 to 2030
633	Scenario 3: Nitronia
6331	Farly years: 2010 to 2017
6332	Middle years: 2017 to 2024
6333	End years: $201/1$ to 2024
634	Scenario A: Complacent agriculture
63/1	Early years: 2010 to 2017
6342	Middle years: 2017 to 2027
6212	End years: 2017 to 2024
0.3.4.3 6 <i>1</i>	End years. 2014 to 2030 Background and process
0.4 6 E	Discussion
0.5	Climate shange and water availability
0.5.1	Clinicate change and water availability
0.5.2	Trigger point analysis: What could move our future from one scenario to another?
0.5.2.1	Scenario 2 to scenario 1. Ello Ol agriculture
0.5.2.2	Scenario 2 to scenario 3: Nitropia
0.5.2.3	Scenario 2 to scenario 4: complacent agriculture
0.0	Responses
Арр. 6.1	Roster of stakeholder participants from workshops
7	Responses: Technologies and practices
7.0	Introduction: critical control points of California's nitrogen cascade
7.1	Limit the introduction of new reactive nitrogen
7.1.1	Agricultural nitrogen use efficiency
7.1.2	Consumer food choices
7.1.3	Food waste
7.1.4	Energy and transportation sector efficiency
7.1.4.1	Fuel combustion in stationary sources
7.1.4.2	Fossil fuel substitution in vehicles
7.1.4.3	Well-to-wheels analysis of biofuels
7.1.4.4	Reduction in travel demand
7.2	Mitigate the movement of reactive nitrogen among environmental systems
7.2.1	Ammonia volatilization from manure



Agricultural Sustainability Institute, UC Davis

UC Sustainable Agriculture Research and Education Program

- 7.2.2 Nitrate leaching from croplands
- 7.2.3 Greenhouse gas emissions from fertilizer use
- 7.2.4 Nitrogen oxide emissions from fuel combustion
- 7.2.4.1 Mobile sources of nitrogen emissions: Light duty vehicles
- 7.2.4.2 Mobile sources of nitrogen emissions: Heavy-duty vehicles, ocean-going vessels, and off-road vehicles
- 7.2.4.3 Stationary sources of NO_x and N₂O
- 7.2.5 Wastewater management
- 7.2.6 Treatment of drinking water
- 7.3 Adapt to a nitrogen-rich environment
- 7.3.1 Alternative sources of drinking water
- 7.3.2 Adaptation of agricultural systems
- 7.4 Synergies and tradeoffs from nitrogen species
- 7.5 The need for integrative solutions
- App. 7A Technical options to control the nitrogen cascade in California agriculture
- App. 7B Supporting material: Explanation of calculations and evaluating uncertainty

8	Responses: Policies and institutions*
8.1	Framing of the California nitrogen policy problem
8.1.1	Overview of nitrogen issues
8.1.1.1	Summary of CNA chapters 2-6: Drivers, issues, and scenarios
8.1.1.2	Summary of CNA chapter 7: Technologies
8.1.1.3	Rationale for focus on agriculture
8.1.2	Policy challenges
8.1.2.1	Individual natures of the main issues
8.1.2.2	Interactions/cascading effects/tradeoffs across issues
8.1.2.3	Potential for policy conflicts across issues
8.2	Overview of available policy instruments for nonpoint source pollution control
8.2.1	Education
8.2.2.	Standards
8.2.3	Economic incentives
8.2.4	Summary
8.3	Experience with nitrogen policy instruments in practice
8.3.1	In California
8.3.1.1	CAFO permitting/NMPs/CDQAP
8.3.1.2	NPS Program
8.3.1.3	Agricultural Water Quality Grants Program
8.3.1.4	Air quality regulations
8.3.2	Elsewhere
8.3.2.1	European Nitrogen Assessment
8.3.2.2	Chesapeake Bay
8.3.2.3	Lake Erie
8.3.2.4	Mississippi River
8.3.2.5	Neuse River Basin
8.3.2.6	Florida Everglades Agricultural Area
8.3.2.7	Selected programs evaluated by State EPA Innovations Task Goup
8.3.3	Summary



CALIFORNIA NITROGEN ASSESSMENT

Agricultural Sustainability Institute, UC Davis UC Sustainable Agriculture Research and Education Program

- 8.4 Framing of assessment criteria for policy instruments
- 8.4.1 Overview of assessment criteria
- 8.4.2 Presentation and discussion of the evaluation matrix
- 8.5 Assessment of policies for nitrogen regulation in California
- 8.5.1 Presentation/discussion of completed matrix for each issue
- 8.5.1.1 Assessment of evidence and consensus
- 8.5.1.2 Evaluation of merit where evidence and consensus is sufficient
- 8.5.2 Long-run considerations
- 8.5.2.1 Emerging abatement technologies
- 8.5.2.2 Improved monitoring/modeling of NPS problems
- 8.6 Potential for integrated nitrogen policy
- 8.6.1 Opportunities and potential benefits
- 8.6.2 Challenges and risks
- 8.6.3 Tradeoffs and complementarities
- 8.6.4 Promising sets of policy instruments and how they would be integrated
- 8.7 Review of promising policy options
- 8.7.1 Evidence/consensus/relative merit
- 8.7.2 Needs assessment