Introducing the California Nitrogen Assessment

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What is this chapter about?

Since 1960, the amount of nitrogen (N) used in agriculture has doubled on the planet, as has food production. With an estimated continued growth in human population and intensifying competition for fresh water, striking a balance between nitrogen's benefits and costs will require significant tradeoffs and a critical investigation of technological and policy options to minimize nitrogen leakage while sustaining vitality of agriculture.

This chapter provides background information to understand the issues related to nitrogen use and management in California agriculture, presents an overview of the research approach and project implementation, and outlines the goals of the California Nitrogen Assessment (CNA). It does not present major findings; these are found in the executive summary. Assessments emphasize legitimacy, credibility, and relevancy; the research and stakeholder engagement process is as important as the results and outputs produced. An assessment looks at existing knowledge and reduces complexity by synthesizing what is known and widely accepted and differentiating it from that which is unknown or not agreed upon. This chapter describes how the California Nitrogen Assessment engaged with stakeholders to establish research priorities and outputs that meet the needs of a wide-range of perspectives, including farmers, government, and environmental and health organizations.

Main messages

Nitrogen is necessary to sustain all life and is often the primary nutrient limiting productivity. Nitrogen is also a critical nutrient required to sustain agriculture in California and the global food supply. As a component of synthetic and organic fertilizer, nitrogen is critical to plant growth and the expansion of crop production. With estimates for world-wide population growth, rising per capita incomes, and agricultural production, the demand for N is likely to intensify in coming years to meet

growing global demands for food. This is also true for California; the state produces more than half of the fruits, nuts, and vegetables grown in the United States and 21% of the dairy commodities.

Since 1960, the amount of nitrogen used in agriculture has doubled on the planet as has food production, with nitrogen in excess of biological demand being released to the environment. The majority of Nitrogen imports to California are in the forms of fertilizer, imported animal feed, fossil fuel combustion, and biological nitrogen fixation. While much of that nitrogen contributes to productive agriculture, excess nitrogen from those sources contributes to surface and ground water contamination and air pollutants such as ammonia and nitrous oxide, a potent greenhouse gas. Striking the right balance between the benefit nitrogen provides to our food supply and the costs it can have on our health and environment demands a critical look at the tradeoffs involved.

This is the first comprehensive accounting of nitrogen flows, practices, and policies for California agriculture at the statewide level. The assessment identifies key drivers of nitrogen use decisions and examines how these drivers influence the statewide mass balance of nitrogen - how much enters the state through new sources and, ultimately, the multiple ways these compounds enter and impact the environment. The assessment tracks nitrogen's impacts on environmental health and human well-being, and examines technological and policy options to minimize nitrogen leakage while sustaining vitality of agriculture.

Rather than generating new research, assessments reduce complexity through the synthesis and integration of a large body of existing information, providing a valuable method for focusing efforts and systematically calling out uncertainty in knowledge. Assessments are designed to be *legitimate* in the eyes of key stakeholders, *relevant* to decision-makers' needs, and scientifically *credible.*

In an assessment, understanding what is not known is just as important as assessing what is known. We have evaluated the quality of the data and note when results are based on very reliable information or data that are less reliable (e.g., due to gaps in information or disagreement in the literature). We employed "reserved wording" to quantify such areas of uncertainty and those areas lacking good data were highlighted as areas where more research and record keeping are needed. Supplemental Datatables describe the sources and approaches used in the assessment, evaluate the level of uncertainty of this information, and highlight where information gaps exist.

The assessment used multiple avenues to engage with more than 350 stakeholders across 50 organizations. Through a participatory research design, stakeholders identified more than 100 nitrogen-related questions that were used to direct research and synthesize priorities, provided data and examples of on-the-ground practices and management options, and developed four 'scenarios' for the future of nitrogen in California agriculture.

The assessment's findings underwent a multi-stage peer review process. This included consecutive reviews by 1) over 40 scientific experts; 2) the Stakeholder Advisory Committee; and 3) an open public comment period. A group of ten review editors (9 chapter review editors and 1 overall review editor) ensured all comments received appropriate attention and response from authors. In addition, a nine-member Technical Advisory Committee provided feedback on preliminary drafts of findings.

1.0 The California Nitrogen Assessment

Since 1960, the amount of nitrogen used in agriculture has doubled on the planet, as has food production (Vitousek et al. 1997; Galloway et al. 2004; MA 2005). With expectations for continued

growth in the human population and per capita consumption, and intensifying utilization of natural resources such as fresh water, striking a balance between the benefits and costs of human nitrogen use will require significant tradeoffs and a critical investigation of technological and policy options to minimize nitrogen losses to the environment while sustaining the vitality of agriculture.

Tracking trends in nitrogen flows, understanding key inputs and outputs, evaluating management options, and devising new regulatory structures that are sensitive to cross-system interactions will be essential to ensuring this balance is attained. Despite increasing awareness of the importance of these tradeoffs, a lack of cohesive knowledge that gives a big-picture view of California's nitrogen system still hampers effective decision-making from policy options down to field-level practices.

The California Nitrogen Assessment is a comprehensive evaluation of existing knowledge about nitrogen science, practice, and policy in the state. Broadly, **the goals of the assessment were to**:

1) Gain a comprehensive view of N flows in California, with emphasis on agriculture's roles.
2) Provide useful insights for stakeholders into the balance between the benefits of agricultural nitrogen and the effects of excess nitrogen in the environment.
3) Compare options, including practices and policies, for improving the management of nitrogen and mitigating the negative impacts of excess nitrogen in the environment.
4) 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.

The assessment is targeted towards a broad audience with diverse and often conflicting perspectives. Throughout the assessment, the level of detail varies, with emphasis placed on those issues and topics identified as being of greatest interest to our stakeholders. We do not offer recommendations, but rather endeavor to synthesize the current scientific understanding, point out

gaps in knowledge, and present a balanced and unbiased understanding of the issues and options for moving forward on key concerns.

This chapter provides a brief background on N and agriculture, presents an overview of the research/synthesis approach and project implementation, and outlines the scope of the California Nitrogen Assessment. It does not present major findings; these are found in the executive summary and in the 'main messages' of each chapter.

1.1 Understanding nitrogen and its global implications

1.2 Understanding nitrogen and its global implications

Dinitrogen gas (N_2) comprises 78% of Earth's atmosphere. However, this form of N is largely unreactive. While all biological species require nitrogen for growth and development, the transformation of N_2 into reactive nitrogen forms (N_r) is required to make it biologically available (Box 1.1). The biological and physical transformations that comprise the global nitrogen cycle can be categorized into three groups which all can result from biotic and abiotic processes: (1) the fixation of atmospheric N_2, (2) the transformations among forms of solid, dissolved, and gaseous forms of Nr in the air, land, and water, and (3) the production of N_2, largely as a result of denitrification (Box 1.2).

[Box 1.1]

[Box 1.2]

Nitrogen gas is converted to N_r naturally in ecosystems through the process of nitrogen fixation—a small amount of nitrogen is fixed abiotically by lightning in the atmosphere and during vegetation fires, but the majority of natural nitrogen fixation is a result of biological activity (Chapter 4). A diverse suite of microorganisms has the capability to fix nitrogen, such as the symbiotic bacteria that form nodules in the roots of leguminous plants. Once Nr has been fixed in an ecosystem, the N can be

assimilated by organisms and converted into living biomass. When the organisms die, the various organic forms of N are transformed back into ammonia (ammonification) and nitrate (nitrification) by specialized groups of microorganisms. Other microorganisms denitrify the nitrate to N_2 with nitrogen oxide gases (NO and N_2O) as intermediate products of the series of enzymatic reactions. In addition to denitrification, ecosystems can also lose N during leaching or surface water runoff containing dissolved forms of organic N and nitrate (NO_3^-). While most ecosystems tend to retain most of their N, some N is transported between ecosystems in groundwater and surface water and in the atmosphere. Superimposed on the natural flows of N, humans created several new flows of N_r and altered the magnitude of others. Fossil fuel combustion, synthetic fertilizer use, increased concentration of livestock, sewage discharge, cultivation of legumes, irrigation, frequency and magnitude of wildfires, and groundwater pumping all alter the amount, the distribution, and the flows of Nr in the environment (Figure 1.1). These flows have both positive and negative consequences for ecosystem health and human well-being. The N cascade conceptual model illustrates that a single molecule of N can have multiple positive and negative effects between the time that it is fixed to the time it is returned to the atmosphere as N_2. (Galloway et al. 2003). Depending on the particular fate of the N that escapes its intended purpose, the costs to ecosystems and human health will vary (Compton et al. 2011; Birch et al. 2011; Chapter 5).

[Figure 1.1]

Human activity has dramatically reshaped the global N cycle in terms of the magnitude of the production of Nr, the availability of N in ecosystems, and the rates of N cycling. It has been suggested that the anthropogenic changes to the N cycle have already crossed a “planetary boundary,” or threshold for stability of Earth system processes (Rockstrom et al. 2009). This limitation of naturally occurring reactive nitrogen led farmers to search for other sources of N. Historically, farmers in the United States (US) relied on the planting of legumes, the local recycling of human and animal wastes, or

the import of inorganic nitrates. However, the development of the Haber-Bosch process in the early 20th century gave humans the ability to commercially fix N_2 from the atmosphere into synthetic N fertilizers. Currently, humans create more N_r than do all of the planet's natural processes combined (Rockstrom et al. 2009). This occurs as a result of three pathways. First, the combustion of fossil fuels unintentionally creates gaseous forms of N_r because there is N in the fuel in the case of coal and because the combustion process can lead to reactions between the N_2 and oxygen in the atmosphere. Second, humans intentionally plant vast acreage of leguminous crops for human and animal consumption. Third, the Haber-Bosch process was invented in the early 20th century, which chemically fixes N but requires significant inputs of energy. At high temperatures and pressure, N_2 gas can be combined with hydrogen to form ammonia (NH_3). The NH_3 can be used as fertilizer as is, or can be reacted further to create other forms of fertilizer, industrial products, and explosives.

Nitrogen is critical to the success of agriculture and more broadly to human health and welfare. The exponential increase in the Haber-Bosch process since the 1940s has revolutionized agriculture, allowing for abundant fertilizer supplies to feed growing human populations. Estimates suggest that roughly half of the human population on earth is supported by Haber-Bosch produced nitrogen fertilizer (Davidson et al. 2012), marking this innovation as one of the greatest achievements of human kind. Since 1960, the amount of nitrogen used in agriculture has doubled on the planet, as has food production (Vitousek et al. 1997; Galloway et al. 2004; MA 2005). And, over half of this perturbation to the N cycle has taken place since 1985, pointing to accelerating rates of global N use by humans (MA 2005). Davidson et al. (2012) found that for 2008, 56% of the major sources of natural and anthropogenic nitrogen inputs to the United States came from agriculture (synthetic N fertilizer and crop biological N fixation). Globally, anthropogenic sources of newly-fixed nitrogen now exceed natural terrestrial sources by at least 50% (Galloway et al. 2008). With continued growth in human population forecasted at 9.3 billion people by 2050 (United Nations 2011) the implications for increased food

production and nitrogen use, as well as resulting effects on the environment and human well-being, are substantial.

Nitrogen's effect on the broader environment also has resulted in many unintended consequences for human and ecosystem health in part because of inefficiencies in the use of N. Only 55% of the intentionally fixed N in the United States makes its way into an intended product (i.e., food, fiber, energy, industry) (Houlton et al. 2013). In agricultural systems the efficiency of the most common grain crops is typically less than 50% (Cassman et al. 2002), which allows the remaining N to escape from the soil as nitrate or in various gaseous forms. This escaped N can alter ecosystem services and damage human health: eutrophication and anoxic "dead zones" in surface waters and coastal areas; harmful algae blooms; high fluxes of nitrous oxide, a potent greenhouse gas; loss of plant biodiversity; enhancing competition from invasive species; and nitrate contamination of drinking water (see Chapter 5). While nitrogen interacts with human health and well-being in a variety of ways, the tradeoffs involved in agricultural nitrogen use highlight many of the key sustainability issues related to the challenges of the 21st century: global climate change, depletion of fossil fuels, and mounting pressure on land, air, and water resources from growing human population and rising incomes. For example, work in Europe estimates that the environmental and human health costs of excess N now exceed the annual benefits of N-use for crop production (Brink et al. 2011). Houlton et al (2013) estimate that agricultural N spillover has resulted in air-quality related damages in the United States that exceed 16 billion US dollars each year and recent studies suggest that an increase in public and private funding on the order of $17 – 34 million per year over many decades will be needed to implement required nitrate mitigation projects for water systems in the Tulare Lake Basin and Salinas Valley (Honeycutt et al. 2012).

1.2 Why California?

California provides an excellent location to study nitrogen because of its diversity. Its ecosystems range from deserts to alpine tundra to coastal evergreen forests. Its population is concentrated in large metropolitan areas, but the majority of the state is rural. California agriculture has both a large livestock and crop component. Further, California is the source of the majority of production for many fruit, nut, and vegetable crops for the United States, and thus carries a lot of the nitrogen burden for many non-Californians. In addition, California is actively dealing with many of the challenges confronting agriculture throughout the United States and internationally: population growth and urbanization (Williams et al. 2005; Landis and Reilly 2004); changing demographics in rural communities (Bradshaw and Muller 1998); flood control and water demand for irrigation (Tanaka et al. 2005); maintaining air, soil and water quality; coping with climate change (Hayhoe et al. 2004; Cavagnaro et al. 2006); responding to domestic and international markets (AIC 2006); and facing increasing regulation. Thus, California exemplifies the biophysical and social context in which this assessment will be both locally relevant and nationally and internationally significant – it encompasses extreme diversity in its agricultural production systems and climatic regions and landscapes, is subject to enormous population pressures and complex social problems, and has pioneered innovative environmental policies.

With the largest and most diverse agriculture in the US, California epitomizes the successes and dilemmas of higher productivity in agriculture. In 2008, California generated $36.2 billion from agriculture, representing 11.2% of national agricultural production with less than 4% of the nation's farmland (CDFA 2010a). The state is vital for domestic consumption with two-thirds of production consumed outside the state. The state produces 21% of the nation's dairy commodities and more than half of the fruits, nuts, and vegetables grown in the US (CDFA 2010b). Agricultural land encompasses about 9.9 million acres, of which 74% is non-woody crops (annual crops such as grains, vegetable, cotton, etc) and 26% woody crops (orchards, vineyards, etc.) (CDFA 2006). Land area in pasture and

rangeland for livestock grazing contributes another 6 million acres. Due to the wet winter/dry summer Mediterranean climate and reliance on irrigation during the main growing season, the way nitrogen is managed in the state is closely tied to water management.

N management is increasingly viewed as one of the great global challenges of the 21st century. It also is garnering increasing attention in California and the need for an assessment of the flows of nitrogen is clear. For example, The California Global Warming Solutions Act of 2006 (Assembly Bill 32) requires the reduction of three major greenhouse gases- carbon dioxide (CO_2), nitrous oxide, and methane(CH_4)) to 1990 levels by 2020 and a further 80% by 2050. This includes mandatory reporting for the largest sectors (e.g., oil, gas, power, cement, landfills) but little attention has been paid to how agriculture fits into this framework. Further, since excess nitrogen can be stored in groundwater (used commonly as drinking water in the state) and is associated with human health problems, clean water policies are becoming an increasing concern and we are seeing a growing trend of regional water boards enforcing stricter regulations on the agricultural sector. With groundwater contamination by nitrates (principally a by-product of fertilizers) becoming a major water quality issue, in February 2013, the State Water Resources Control Board released a suite of fifteen recommendations[1] which underscore the need for cooperative and comprehensive solutions, including new potential legislation.

California is often looked to as a leader on environmental policy and practice and will set an example by moving forward with N legislation. And the CNA provides a timely benchmark for understanding nitrogen sources and flows throughout the state, effects on the environment and human health, and technical and policy options for better management of N, providing a baseline of knowledge for both farmers and policymakers.

[1] The recommendations by the State Water Resources Control Board were informed by a 2012 contracted study by UC Davis, *Addressing Nitrate in California's Drinking Water*, in which the California Nitrogen Assessment collaborated.

1.3 Approach: An integrated assessment of nitrogen across science, policy, and practice

An assessment is a critical evaluation of information for purposes of guiding decisions on complex public issues with topics defined by stakeholders, typically decision makers (MA 2005). Conducted in a transparent manner, assessments reduce complexity by synthesizing what is known and widely accepted from that which is unknown or not agreed upon and they generate results that can only be produced when a large body of existing information is examined. However, an assessment is not just about the results – "getting the process right, from the early stages through to the communication of findings, is essential in order to have an impact" (Ash et al. 2010, p.1) (Box 1.3).

[Box 1.3]

The CNA followed established protocols for integrated ecosystem assessments, a research approach that differs from other scientific methods (Box 1.4). The CNA adapted these global methods to the California scale and found the established methodologies to be even more applicable to a state-level assessment. For example, a key distinction of assessments is responsiveness to stakeholders' needs and it was much more feasible to get a wide range of perspectives 'at the table' in the context of a single state.

[Box 1.4]

Rather than generating new primary data, the assessment looked at existing knowledge to identify what is well-known about agricultural nitrogen and that which is more speculative. A large amount of information already existed on agricultural-related nitrogen in California which had never been looked at as a whole. The CNA adds value by collecting and synthesizing this large body of data,

using it to analyze patterns and trends, assessing the quality of information and knowledge about key issues, and translating and communicating key information.

The assessment was comprised of four distinct phases – 1) design; 2) implementation; 3) review; and 4) dissemination of results (Table 1.1). At all stages, the assessment engaged with stakeholders and collaborators in a variety of ways to foster constructive dialogue and exchange of knowledge and promote transparency in the assessment process.

[Table 1.1]

1.3.1 Ensuring credibility, relevance, and legitimacy

The methodologies of conducting an assessment are different from other scientific research approaches; legitimacy, credibility, and relevance receive equal emphasis, making stakeholder engagement a critical part of the process from start to finish (Box 1.3). When conducting an assessment, the *process* is as important as the findings and outputs produced. Key to achieving these core values was: 1) a strategic stakeholder outreach process, with early engagement designed to help shape the assessment's approach and ensure outputs meet the needs of varied end users; 2) fostering an inclusive process comprising a broad range of views and interests; 3) a rigorous and transparent peer review process; 4) systematic treatment of uncertainty in available data and current scientific knowledge.

1.3.1.1 A stakeholder-driven approach

The assessment was carefully designed to lay the foundation for a network of partnerships, across the scientific community, policy makers, farmers and ranchers, and non-governmental organizations. We employed 'strategic listening' (Pidgeon and Fischhoff 2011) throughout the assessment to ensure we produced credible and robust information that is relevant to target audiences and supports decision making, and to create information and products that address the needs of these partners.

Since the CNA engaged stakeholders from a broad spectrum of backgrounds and interests, we had to present a balance between nitrogen's integral role in food production and its related benefits to society while also acknowledging the potential environmental and human health effects. However, we found that many stakeholders do not even think about nitrogen in these terms. Thus, one of the major outcomes (Box 1.5) of the CNA's stakeholder engagement activities was awareness building and fostering a shared understanding of both the benefits and problems associated with nitrogen and what the key issues are for California.

[Box 1.5]

Stakeholder engagement played a critical role throughout the assessment, from design to implementation, peer review, and the dissemination of results. Throughout this process, we used a wide range of engagement mechanisms (Table 1.1) in an effort to provide a variety of avenues for stakeholder participation that taps into both the breadth of information and diversity of perspectives across the state. As detailed below, this resulted in bi-directional flows of information and feedback from stakeholders directed much of the assessment.

The Stakeholder Advisory Committee (SAC), comprised of 29 representatives (a total of 33 have served throughout the assessment process) from government agencies, environmental and health non-profit organizations, and producers and agricultural commodity groups, represents the constituent groups the assessment is targeted towards (Appendix 1.1). The SAC was intentionally weighted on the side of producers and users due to this group's large role in nitrogen use and management. The SAC provided input on key topics and helped to prioritize the assessment's focal issues, commented on early drafts of key assessment documents, and acted as a liaison between the CNA and members' constituencies. The committee also participated in a facilitated group scenario-building exercise envisioning the future of nitrogen in California agriculture (see Chapter 6).

In addition to interacting with the SAC, the CNA met with groups of growers, farm advisors, government agencies, and environmental and health organizations around California (Figure 1.2). Key engagement mechanisms included multi-stakeholder workshops, small-group consultations with growers, farm visits, industry field trips, and individual contact via phone and email. Altogether, the assessment interacted directly with more than 350 individuals (Figure 1.3). Further, as part of the research process, the assessment contacted almost 110 organizations (Appendix 1.2) to participate in events and to solicit specific information (e.g., estimates of the amount of fertilizer used by growers). Although the level of participation varied, best efforts were made to be inclusive and obtain a diversity of perspectives. Throughout the assessment, updates and information on nitrogen-related events were available to stakeholders and the public through the website of the Agricultural Sustainability Institute.[2]

[Figure 1.2]

[Figure 1.3]

Collectively, the assessment's engagement with stakeholders generated over 100 questions about nitrogen use and its impacts in California that were then synthesized into five overarching research areas to guide the assessment; biogeochemistry, management practices, economics and policy, public health, and communications (Figure 1.4). The synthesized list of questions set the research priorities and acted as a point of reference throughout the assessment; and throughout this report we have identified where key stakeholder questions are answered. While these questions framed the assessment, it was just as important to flag questions or topics that could not be answered due to lack of evidence. Identifying these gaps in information and problems in available data are important contributions to understanding the state of knowledge about nitrogen in California and what is needed to move forward.

[Figure 1.4]

[2] See www.nitrogen.ucdavis.edu

372

373 ***1.3.1.2 Who was involved in the California Nitrogen Assessment?***

374 To ensure scientific credibility, the assessment engaged a broad range of scientists at the University of
375 California (UC) Davis and other institutions through one-on-one contact, focus group meetings, and co-
376 authoring relationships (Appendix 1.2). A nine-member, multidisciplinary Technical Advisory Committee
377 also provided guidance throughout the project. Relationships with contributing authors helped to
378 advance our understanding of issues on a diversity of topics and feedback from the Technical Advisory
379 Committee was provided throughout the assessment. As noted above, the Stakeholder Advisory
380 Committee played a vital role linking research and end users.

381 By including key stakeholders in the governance structure and at the outset to help frame
382 priorities, the assessment established communications channels which provide a framework for long-
383 term collaborations on nitrogen management in California (Figure 1.5; see also Appendix 1.1). The
384 breadth of stakeholders involved in the assessment reflects the complexity of the issues and the wide-
385 ranging implications agricultural nitrogen management has on the environment, human health, and the
386 political-economic climate.

387 [Figure 1.5]

388

389 ***1.3.1.3 Review process***

390 The CNA followed the basic peer review methodology of the Intergovernmental Panel on Climate
391 Change (IPCC 1999) which is a transparent and inclusive process of writing and review[3]. Each chapter of
392 the assessment underwent two- stages of external review: 1) scientific and 2) stakeholder review. First,
393 because the assessment covers a wide range of topics concerning nitrogen in the environment and the

[3] The complete iterative process, include review comments, authors' responses, and editors' feedback will be available at www.nitrogen.ucdavis.edu.

potential roles for agriculture to minimize negative impacts, the CNA relied on 40 subject experts to evaluate the comprehensiveness of the research, balance in presentation of evidence, and validity of the interpretations. After a period of author response, the revised document underwent a second stage of stakeholder review. This included feedback from the members of the Stakeholder Advisory Committee as well as an open public comment period in which stakeholders involved in prior engagement activities played a key role. Throughout this process, chapter review editors with expertise in relevant areas served as independent 'referees' for each chapter to ensure that all comments received appropriate attention and response from the assessment authors and an overall editor also provided feedback and oversight across chapters.

1.3.2 Dealing with uncertainty

Inherent to the assessment process is considerable uncertainty in many of the data sets and research sources. In an assessment, understanding what is not known is just as important as assessing what is known. Throughout the CNA, we have evaluated the quality of the data and note when results are based upon very reliable data or data that are less reliable (i.e., due to gaps in information or disagreement in the literature). Following the models of the IPCC and Millennium Ecosystem Assessment (MA), the assessment employed reserve wording to quantify such areas of uncertainty (Box 1.6). Those areas lacking good data were highlighted as areas where more research and record keeping are needed.

[Box 1.6]

To support the statements and conclusions in the assessment, we developed supplemental data tables. These contain 1) summaries of the sources of data and approaches or methodologies used in the assessment, and 2) a systematic evaluation of the quality of available information. The data tables are organized by broad categories and each lists the specific indicators used in the assessment related to

that topic. To help readers track information across the assessment, relevant sections of the assessment are noted for each indicator in the table.

1.4 What is the purpose of the California Nitrogen Assessment?

Throughout the assessment a conceptual framework was used to structure the research scope and the CNA underwent strategic adaptations based on changing scientific knowledge gathered by the assessment and emerging needs of our stakeholders. The breadth of our stakeholder engagement activities, both in terms of the diversity and inclusiveness of perspectives involved and the range of outreach efforts, resulted in outcomes well situated to address the complexity of nitrogen issues in California agriculture and meet the varying needs of these audiences.

1.4.1 The conceptual framework: Roadmap to the assessment

Modified from the Millennium Ecosystem Assessment, the conceptual framework (Figure 1.6) is a snapshot of the big-picture approach of the CNA, focusing on the reasons that nitrogen flows the way it does, including the human decisions and responses that are involved, as well as the science behind how nitrogen moves through the N-cycle. Strategic actions can take place at almost any point in this framework to respond to negative changes or to augment positive changes (MA, 2003). This framework was developed organically, moving through several models as the research progressed and through consultations with stakeholders.

[Figure 1.6]

The conceptual framework places the nitrogen challenges in California within the context of ecosystem services and human well-being. We first identified important ***underlying drivers*** (see Chapter 2) of nitrogen use decisions - the economic, political, and technological processes that influence human

441 decision making in such a way as to affect nitrogen's passage through California ecosystems. These
442 drivers indirectly affect ecosystems and can cross both temporal and spatial scales. Examples include
443 growth in global demand for California commodities, prices of fuel and fertilizers, population, and
444 demand for transportation. These underlying factors, in turn, influence ***direct drivers*** (see Chapter 3) –
445 the human and natural processes that directly alter the nitrogen cycle. The assessment focused on the
446 six activities in the state that influence, and will continue to influence, N use and emissions, including
447 historical trends in these activities. This includes growth in acreage of high nitrogen-demanding crops,
448 concentration of animals in feedlot dairies, and fossil fuel combustion in vehicles.

449 These drivers, in turn, affect the statewide ***mass balance*** of nitrogen (see Chapter 4) - the
450 quantification of how much N enters the state through new sources, how much of which nitrogen-
451 containing compounds are transformed from one form to another, and ultimately, how much of these
452 varied compounds enter the environment. Conducted for the year 2005, the mass balance calculates the
453 magnitude of nitrogen flows at the statewide level as well as for eight subsystems: cropland; livestock;
454 urban land; people and pets; natural land; atmosphere; surface water; and groundwater. A mass
455 balance approach is useful not only to compare the size of nitrogen flows, but also to identify gaps in
456 understanding about the size and directions of these flows. Knowledge of the relative magnitude of
457 flows can inform management and policy decisions targeting reductions in nitrogen.

458 The changes resulting in ecosystems cause ecosystem services to change and thereby affect
459 human well-being. For example, some of the nitrogen used in agriculture "leaks" from farms, dairies,
460 and fertilized landscapes, and fuel combustion also results in significant releases of nitrogen into the
461 atmosphere, resulting in substantial costs to the environment and human health. These interactions can
462 take place at more than one spatial scale and can cross scales. Similarly, interactions can take place
463 across different time scales. We investigated the impacts on ***environmental health and human well-***
464 ***being*** (see Chapter 5) of these varied forms of nitrogen leakage on five major ecosystem services:

healthy food and other agricultural products, clean drinking water, clean air, climate regulation, and cultural and spiritual values (e.g., fishing, swimming, and biodiversity). Where data exists, we reviewed trends in nitrogen inputs and effects on these ecosystem services, linkages to human health and social equity, and the corresponding economic impacts of these changes to ecosystem services.

Scenarios can help stakeholders deal with controversy and complexity, and they are particularly useful in cases where there is a large amount of uncertainty, as is the case in this assessment. The CNA worked with stakeholders to develop scenarios to facilitate dialogue and consensus of the issues and help focus potential technical and policy responses (see Chapter 6). This exercise led to the development of four distinct scenarios of how nitrogen-relevant technologies and policies might unfold in the next 20 years and how these would affect nitrogen use and impacts. Although the starting perspectives were quite diverse, two areas of uncertainty were emphasized in this process: future profitability of California agriculture and the future course of policy and mechanisms for implementation.

Finally, we examined the state of the science around the most promising ***technical and policy solutions*** to minimize nitrogen leakage while sustaining vitality of agriculture. The assessment does not include prescriptive recommendations. Rather, it utilizes an “if/then” approach, outlining a suite of practices and policy options and the potential effects each would have on agriculture, the environment, and human health. Based on the California nitrogen mass balance, nine critical areas for intervention in the nitrogen cascade were identified. Chapter 7 reviews these critical control points and evaluates related mitigative strategies and technological options to reduce emissions of nitrogen. Chapter 8 examines a variety of policy instruments and approaches and their potential to balance the costs and benefits of nitrogen use, examines how policy changes to protect health and the environment may impact farm economics and food prices, and catalogs the barriers to creating a coordinated and cohesive policy to manage nitrogen that spans regulatory jurisdictions.

1.4.2 Target audience

The assessment contributes to the international understanding of nitrogen cycles, balances (i.e., key inputs and outputs), sources, and effects on the environment and human health. It also clarifies options for technological changes and policy reform. An assessment is a model of research currently under-utilized and the California Nitrogen Assessment provides a practical example that can be used from the local to global scale. For policymakers, this approach may be of particular interest given the high level of stakeholder engagement and focus on transparency and legitimacy in the research process and findings.

As detailed above, the CNA conducted a great deal of outreach to key stakeholder groups in California as part of the project's design and implementation - from the development of research questions and priorities to data collection and feedback on methodologies and findings. Through this process we have developed a network of contacts invested in nitrogen science and management across the state, representing the diversity of the target audience. Primary target audiences include:

- Policy-makers and governmental agencies (California, United States, and globally)
- Agribusiness (processors, distributors, fertilizer producers/distributors)
- Cooperative Extension farm advisors and specialists
- Non-Governmental Organizations (NGOs)- environment, health, and social justice
- Commodity organizations and farmer associations
- Farmers/growers and ranchers
- California citizens
- Scientists and researchers (California, United States, and globally)

Mechanisms to ensure products and outcomes are relevant to the varying, and often conflicting, needs of these stakeholders have been built into the assessment (Table 1.1). Communication and dissemination of the assessment findings will be the final stage in the assessment process. The nitrogen website will be used as an ongoing outreach tool, with interactive information on key findings designed

to facilitate broad understanding of the issues and linkages across the chapters. This will also serve as a dynamic source of emerging information as agricultural nitrogen issues develop in California. Other key communication materials include factsheets, policy briefs, and targeted summaries (e.g., for crop and dairy farmers, cooperative extension, and industry)

1.5. Global implications: Is nitrogen the next carbon?

From the perspective of ecosystem services and human wellbeing, nitrogen shares many attributes that have made carbon – specifically the disruption of the global carbon cycle and resulting potential destabilization of our global climate and related systems, including food production (Vermeulen et al. 2012; IPCC 2014) – the focus of an intense and highly polarized international policy debate. For example, while various forms of each element indisputably play essential roles in natural and social systems, evidence is mounting that for both carbon and nitrogen:

- It is *well established* that human activity now dominates the global biogeochemical cycles for both C and N (MA 2005; Gruber and Galloway 2008; IPCC 2007, 2014).
- Thresholds for unintended consequences for the global climate system and environment are controversial and uncertain; it has been *suggested (but remains unproven)* that emissions of both C and N have crossed the boundaries of "safe operating space" for Earth's life support systems (Rockstrom et al. 2009).
- Shifts in flows within these cycles matter, because their multiple forms and media have very different environmental impacts, with some benign while others are damaging. This is *well established* for nitrogen, with large amounts of evidence ranging across scales from the field level (e.g., Gardner and Drinkwater 2009) to global biogeochemical cycles (Galloway et al. 2008; Canfield et al. 2010).

- It is *generally accepted* that consequences of these shifts – both intended and unintended – are closely linked to and indeed driven by human population growth and prosperity (MA 2005; Steffen 2011).
- It is *well-established* that significant environmentally damaging consequences of carbon emissions and nitrogen leakages are intrinsic features of currently dominant technologies (IPCC 2007; Vermuelen et al 2012; Canfield et al. 2010; Pelletier et al. 2011).
- It also is *generally-accepted* that better balance between intended economic benefits and unintended environmental damage is unlikely under "business as usual" development and requires fundamental changes in major technologies (for example, vehicles, power generation, nitrogen synthesis, agricultural practices) (MA 2005; IPCC 2007; 2014; Canfield et al. 2010; Steffen et al. 2011). The Haber-Bosch process developed in the early 20th Century enabled a shift from large scale natural sources of nitrogen, such as biological fixation and guano (Davis 2013), to ammonia synthesis based on fossil hydrocarbons (natural gas) as a feedstock, which has become a dominant force in both the C and N cycles globally. New approaches to displace the dominant Haber-Bosch process in ammonia synthesis, while minimizing greenhouse gas emissions, still have "a long way to go" (Service 2014).
- Moreover, is *well-established* that significant portions of these environmentally damaging emissions and leakages result from land use and land cover change, meaning they are spatially dispersed and often difficult to monitor – creating particular challenges in the design of mitigation policies that are both effective and efficient. (MA 2005; IPCC 2007; 2014; Sutton et al. 2011; Vermuelen et al. 2012).

These unintended consequences of human-caused changes in carbon and nitrogen cycles are central to some of the greatest challenges of the 21st century, including global climate change, depletion of natural biodiversity, and other mounting pressures on land, air, and water resources. Nitrogen's roles in

these processes are most apparent at regional and continental scales, while destabilization of the Earth's climate system is in many ways the iconic global issue of our time.

1.6. Conclusion: complex issues require sophisticated understanding

Substances like nitrogen pose unique challenges to traditional regulatory frameworks because effects cross traditional media-specific regulatory boundaries (e.g., from air to water). The CNA shows that both the challenges and opportunities for improved nitrogen management depend crucially on context. Due to the mobility of nitrogen and its occurrence in multiple forms, the most efficacious strategy to addressing nitrogen leakage in agriculture will likely be one that integrates across multiple biogeochemical processes, spatiotemporal scales, and nitrogen sources. Such integration will require careful consideration of the technical potential of different farming practices to limit total nitrogen inputs and increase nitrogen use efficiency, while also accounting for the potential tradeoffs that can occur with practices that may limit one form of nitrogen pollution while increasing another. Technology implementation will need to be coupled with smart policies that address such tradeoffs while also recognizing the complex, multi-objective context in which farm managers make on-the-ground decisions to maintain the viability of their operations. By acknowledging and addressing the needs of multiple stakeholders, the CNA identifies areas where we can make progress on these complex issues and provides scientific grounding for decision-makers (policy and in the field) to move forward, utilizing collaborative and integrative approaches necessary to sustain agricultural productivity, economic prosperity, environmental health, and human well-being.

Appendix 1.1 Who was involved in the California Nitrogen Assessment?

Principal Investigators

Sonja Brodt, Academic Coordinator, Agricultural Sustainability Institute, UC Davis
Randy Dahlgren, Director, Kearney Foundation of Soil Science, UC Davis
Kate Scow, Deputy Director, Agricultural Sustainability Institute, UC Davis
Thomas P. Tomich, Director, Agricultural Sustainability Institute, UC Davis

Technical Advisory Committee

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Thomas Harter, CE Specialist, UC Davis
Ermias Kebreab, Professor, UC Davis
Frank Mitloehner, Associate Professor, UC Davis
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Assessment Personnel

Colin Bishop, Communications and Outreach Fellow
Mariah Coley, Program Representative
Antoine Champetier, Policy/Economics Fellow
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Dan Liptzin, Biogeochemistry Fellow
Stephanie Ogburn, Communications and Outreach Fellow
Todd Rosenstock, Best Practices and Technical Options Fellow
Karen Thomas, Senior Writer
Aubrey White, Communications and Outreach Fellow

Stakeholder Advisory Committee

Pelayo Alvarez, California Rangeland Conservation Coalition Program Director, Defenders of Wildlife
Ted Batkin, President (former), Citrus Research Board
Steve Beckley, Executive Director, Organic Fertilizer Association of California
Don Bransford, Chairman (former), CA Rice Producer's Group, California Rice Commission and President, Bransford Farms; member of CA State Board of Food and Agriculture
Renata Brillinger, Executive Director, California Climate and Agriculture Network
Cynthia Cory, Director, Environmental Affairs, California Farm Bureau Federation
Bob Curtis, Associate Director of Agricultural Affairs, Almond Board of California
Michael Dimock, President, Roots of Change
Laurel Firestone, Co-Executive Director, Community Water Center
Hank Giclas, Sr. Vice President, Strategic Planning, Science and Technology, Western Growers Association
Joseph Grant, Farm Advisor, University of California Cooperative Extension, San Joaquin County
Woody Loftis, EPA Liaison, United States Department of Agriculture-Natural Resources Conservation Service
Tim Johnson, President-CEO, California Rice Commission
Matthew Keeling, California Regional Water Quality Control Board, Central Coast Region
David Lighthall, Health Science Advisor, San Joaquin Valley Air Pollution Control District
Karl Longley, Coordinator of Water Resources Programs, California Water Institute
Jim Lugg, Consultant, Fresh Express/Chiquita
Paul Martin, Director of Environmental Services (former), Western United Dairymen)
Albert Medvitz, McCormack Sheep and Grain
Rob Mikkelsen, Western North America Director, International Plant Nutrition Institute
Belinda Morris, Climate and Land Use Program Officer, David and Lucille Packard Foundation
Alberto Ortiz, General Manager, Ag Services (Salinas)
Renee Pinel, President/CEO, Western Plant Health Association
Brise Tencer, Executive Director, Organic Farming Research Foundation
Bruce Rominger, Owner, Rominger Brothers Farms
David Runsten, Policy Director, Community Alliance with Family Farmers
Ann Thrupp, Executive Director, Berkeley Food Institute (BFI) at UC Berkeley
Kathy Viatella, California Water Foundation Program Manager, Resources Legacy Fund

Former members:

Allen Dusault, Program Director, Sustainable Conservation
Ian Greene, Research Programs Manager, California Strawberry Commission
Larry Glashoff, Horticultural Tech Manager, Hines Nursery
Claudia Reid, California Certified Organic Farmers
Edward Hard, CDFA Fertilizer Research and Education Program (former)
Don Hodge, Environmental Protection Specialist, US Environmental Protection Agency

Appendix 1.2 Organizations contacted as part of the California Nitrogen Assessment.

Includes organizations contacted to participate in consultations and to request specific information as part of the research process. While not all participated in the assessment or provided feedback, best efforts were made to be inclusive and obtain a diversity of perspectives. (Listed alphabetically by group)

Government Agencies & Organizations:
California Association of Sanitation Agencies
California Department of Food and Agriculture Fertilizer Research and Education Program (FREP)
California Department of Food and Agriculture Marketing Branch
California Department of Pesticide Regulation
California Department of Water Resources
California Environmental Protection Agency
California Environmental Protection Agency State Water Resources Control Board
California Integrated Waste Management
California Water Resources Control Board
Monterey Bay National Marine Sanctuary
Monterey County Water Resources Agency
National Aeronautics and Space Administration (NASA)
San Joaquin Valley Air Pollution Control District
United States Department of Agriculture (USDA)
United States Environmental Protection Agency Region 9
United States Geological Survey (USGS) California Water Science Center

Health Organizations:
Clean Water Action
Community Water Center
Texas A&M University School of Rural Public Health
The Pacific Institute

Environmental Organizations:
Californians Against Waste
Defenders of Wildlife
Environmental Defense Fund
Environmental Working Group
Food and Water Watch
NewFields
Roots of Change
Sustainable Conservation

Research Organizations:
California Water Institute
The John Muir Institute at UC Davis

Farms, Ranches, Nurseries and Vineyards:
Christensen & Giannini
D'Arrigo Brothers Co.
Earthbound Farm
Ferguson Farming Company
Fetzer/Bonterra Vineyards
Grimmway Farms
Harris Farm
Hines Nursery
John Pryor Co.
McCormack Sheep and Grain
Ocean Mist Farms
Red Rock Ranch
Rio Farms
Rominger Brothers Farms
Woolf Enterprises

Farm-Related Organizations:
American Farmland Trust
California Certified Organic Farmers
California Farm Bureau Federation
Central Coast Water Quality Preservation
Community Alliance with Family Farmers
Grower-Shipper Association
Royal Packing Co.
SureHarvest
Western Growers Association

Fertilizer Industry Groups:
International Plant Nutrition Institute
Organic Fertilizer Association of California
Western Plant Health Association

Other Non-Profit Organizations:
Central Valley Salinity Coalition

The Kearney Foundation of Soil Science
The University of California Agricultural Issues Center
Washington State University, Vancouver

Commodity groups:

Almond Board of California
California Alfalfa and Forage Association
California Apple Commission
California Association of Winegrape Growers
California Cattlemen's Association
California Celery Research Advisory Board
California Citrus Mutual
California Citrus Nursery Program
California Cling Peach Association
California Cut Flower Commission
California Dairy Research Foundation
California Dried Plum Board
California Dry Bean Advisory Board
California Fresh Carrot Advisory Board
California Garlic and Onion Research Advisory Board
California Grape Rootstock Improvement Commission
California Grape & Tree Fruit League
California Leafy Greens Research Board
California Melon Research Board
California Pepper Commission
California Pistachio Board
California Pistachio Research Board
California Potato Research Advisory Board
California Poultry Federation
California Raisin Marketing Board
California Rice Commission
California Rice Research Advisory Board
California Specialty Crops Council
California Strawberry Commission
California Sustainable Winegrowing Alliance
California Table Grape Commission
California Tomato Farmers
California Tomato Growers Association
California Tree Fruit Agreement
California Walnut Commission
California Wild Rice Advisory Board
California Winegrape Inspection Marketing Program
Citrus Research Board
Golf Course Superintendents Association of America
Lodi Winegrape Commission
Napa Grape Growers Association
Northern California Turf and Landscape Council
Nursery Growers Association
Processing Strawberry Advisory Board
Processing Tomato Advisory Board
Southern California Turfgrass Council
Western United Dairymen
Wine Institute

Appendix 1.3 Review Editors for the California Nitrogen Assessment

Chapter Review Editors provided feedback for a specific chapter(s) while the Review Editor provided oversight for the whole assessment.

Review Editor:

Alan Townsend, University of Colorado

Chapter Review Editors:

Chapter 1: Introducing the California Nitrogen Assessment - Neville Ash, United Nations Environment Program

Chapter 2: Underlying drivers of nitrogen flows in California - Eric Lambin, Stanford University

Chapter 3: Direct drivers of California's nitrogen cycle - Eric Lambin, Stanford University

Chapter 4: A California nitrogen mass balance for 2005 - Jim Galloway, University of Virginia

Chapter 5: Ecosystem services and human well-being - Peter Vitousek, Stanford University; Steve Polasky, University of Minnesota; Paul English, CA Department of Public Health

Chapter 6: Scenarios for the future of nitrogen management in California - Monika Zurek, Climate Focus

Chapter 7: Responses: Technologies and practices - Cliff Snyder, International Plant Nutrition Institute

Chapter 8: Responses: Policies and institutions – David Zilberman, University of California Berkeley

Appendix 1.4 List of questions and issues raised by stakeholders

Science and research questions

N & climate intersects

- What is the climate change impact of agricultural N application?
- What does existing science say about how fertilization and irrigation interact to produce nitrous oxide?
- What are the mechanisms by which N application leads to GHG emissions?
- What does the science tell and not tell us about the interactions of fertilizer and water in producing nitrous oxide?
- What about N trading? N credits?
- In uncertain climate conditions (change), what impact would this have on N needs for different crops/regions/etc.?
- Can composting processes lead to greenhouse gas emissions? What measures to prevent N emissions?

Organic practices

- How does organic management impact how N moves through agroecosystems?
- Does using compost as primary fertilizer input lead to reduced N leakages?
- How do organic/sustainable systems manage nitrogen differently? With what differences in quality and quantity?
- What rules to follow: organic N, commercial N, livestock N
- Organic N use: research, utilization, mineralization rate
- Compost as benefit to crop

- What are the food safety implications with use of compost?
- What potential roles can compost play in: 1) Reducing need for synthetic N; 2) Reducing N offgassing during application; 3) reducing N runoff during/after fertilization; 4) stabilizing manure?

Flows

- How does nitrogen flow through California? Can this be graphically represented?
- What parts of Calif. have too much N and what form does this N take?
- Can N flows and losses be quantified?
- What are the major sources of N in California? Can the N from these sources be tracked/tagged?
- From a systems perspective, what parts of N fate can be controlled?
- Are there ways to “tag” nitrate/nitrogen so one can identify what source it is coming from?
- What are the implications for nitrogen flows based on the future scenarios of climate change and water availability?
- Where in the state are the major impacts of too much N? Groundwater, coastal blooms, etc? Is there a map?
- Quantification of nitrogen flows and losses: emissions from N application, groundwater migration, consumption, other.
- Need total systems perspective of N fate – what can be controlled or not
- NO3 sources determination
- What are the geographic areas with the greatest concentrations of N in the environment?

- What is the role of rangelands in N cycling?
- Who are the generators (sources) of N?
- How will we identify if nitrogen overuse occurs?

N and water

- Can water use/conservation practices reduce N leakages?
- How can a farmer minimize movement of NO3 to surface or groundwater?
- What quantity of N in groundwater is "legacy" and how can nitrates in groundwater be mitigated?
- What is the timing between N application and impact on groundwater?
- Legacy N: cause and effect, time between use and impact.
- Impact and response to legacy N pollution, mitigation strategies
- What are the synergies between conservation of N and conservation of water?
- What specific steps should a farmer take to minimize movement of NO3 to surface water or ground water? Is appropriate guidance available for each of these steps?

Non-agricultural

- What are the non-agricultural sources of nitrogen such as vehicles and other combustion and what are their relative impacts?
- What are non-ag sources of nitrogen and what is their contribution to nitrogen flows in California?
- What is the N impact of motor vehicles?
- How does reactive N generated by vehicles and other combustion fit into the total

assessment?

- What is the contribution to N pollution of Ag compared to other sources?

Other

- Are all nitrogen sources evaluated the same?
- Feasibility of achieving endpoints: source-specific, long vs. short term, varied level of investment
- What is the effect of N pollution on wildlife/threatened and endangered species?
- What is realistic in improving efficiency, environmental performance? What's doable?
- Cost of N management: by source, by method, globally to achieve and points
- Efficiency vs. capture and reuse
- Crop quality: N impact on
- What is the role of N in anaerobic systems?
- What are the relative contributors to N loading of Livestock operations compared to crops operations? Crop to crop?

Recommendations

- Is it desirable for assessment to use DWR Bulletin 160-2009 scenarios?
- Don't reinvent the wheel on N use
- Need to recognize existing research and extension work
- Need to consult with UC Davis researchers who study N
- Will the assessment include a white paper on the environmental impact of nitrogen pollution?

Practices and management questions

Current knowledge

- What are current N application recommendations based on?
- What are the most effective ways for dealing with excess nitrogen?
- What are current practices that hold promise for N control?
- What is the best way to measure N efficiency?
- What is the best way to measure N needs?
- Do N recommendations change when shifting from maximizing yield to minimizing N -use?
- What are the most effective solutions demonstrated to date for dealing with excess nitrogen?
- What farming and ranching practices hold promise for nitrogen control?
- Are UC Davis N recommendations based on current production conditions?
- What is the current state of practice in terms of BMPs with Nitrogen/nutrient management? Percent of users quantified (qualified???) in California? How could policy further data collection?
- Do the potential "savings" from limiting N applications outweigh the risk of reduced yields?

Plant health

- How does amount, form, and application timing of N impact crop yields quality, disease and pest resistance? How does it interact with plant varieties?

- Do we know enough about how: 1) amount of N; 2) form of N applied; 3) how it is applied; 4) When it is applied; affects crop yields and crop quality (e.g. keeping quality, flavor components, negative chemical profiles)
- Disease and pest vulnerability with improper N application
- What role does variety selection and plant improvement play in efficiently using N? (either by reducing N needed or by uptaking excess N)
- Risk management in N use – insurance
- What other issues could arise from inadequate or excessive N availability? Ex. Excessive could increase foliar development - increased habitat for pests?

Efficiency/best management practices

- What are the most efficient ways to apply N depending on plant variety and crop type?
- Can managing water differently lead to N efficiencies?
- What are BMPs for reducing air and water emissions from N?
- How can producers of excess N link with producers who need N?
- Which crop sectors/systems are the most inefficient in terms of N fertilizer application? Can they be made more efficient? Can you provide estimates regarding how much overfertilization?
- Most efficient N use application: how do you manage field and plant variability?
- Is more outreach and demo needed to convince ag industry that the benefits of fertigation (sic) outweigh the increased cost of liquid forms of N?
- Process-based N model needs to be turned into a management tool
- Nitrogen and water management
- What are BMPs that both address reduced and direct N2O emissions and indirect N2o

Emissions via water? e.g. reduce leaching through LAND management practices

- What is optimum N application for Crop Health and to Minimize leaching to groundwater? 0.9 - 1.4 x crop uptake?!
- How can producers of excess N (dairies for example) link w/producers that could use N as a soil amendment?
- Can we find ways to reduce overall use of synthetic fertilizers?
- What are the ag practices most suited to conserving N? Least suited?

Other

- What gaps exist in research related to impacts on yield with respect to excess or insufficient N application?
- How will current practices be assessed?
- What is source of info – who does farmer trust?
- Cover crops – work both ways – pull N out and put into soil
- What is the role of other technological work to address N impacts?
- Are there solutions to the problems raised (made apparent) by looking at N?
- What is the best way to measure N efficiency <u>rate</u> or <u>use</u> to forecast needs?
- How to measure changes in cultural practices and past/current nitrogen demands?
- Do University recommendations reflect the N demands of <u>current</u> crop production?

Policy and economics questions

Economic incentives

- Could markets be created that allow farmers to make money for reducing N impact?
- N impact on global warming: opportunity to $
- How are we going to create fiscal and other incentives for the adoption of reactive nitrogen control?
- What kinds of incentives, if any are needed, would speed adoption of better N management?
- Is Ag getting the credit for current use of N?
- What about N trading? N credits?

Regulatory mechanisms

- How can regulations be streamlined so they do not offer competing policies and so that reactive N is not simply displaced into other forms?
- What are the most effective policy instruments to motivate farmers to implement BMPs for nitrogen management?
- How to integrate competing regs!
- How are different regulatory bodies coordinating or not to address nitrogen issues?
- How might policy be used more effectively to both monitor and address non-point source N pollution from the ag sector?
- Are there policy options for reducing auto-based N emissions?
- How will the work of this project tie into the implementation of AB 32 and SB 375?
- How much are policy makers/regulators coordinated on developing a cohesive N policy

that will be workable for N users?

- What are the most effective policy instruments to motivate adoption of BMPs for nitrogen mgmt?
- What are the cities'roles in solving the problem of N?
- Endpoints for nitrogen management – air, water, economic impacts

Cost analysis

- What are the costs and benefits of Nitrogen Use Efficiency Practices?
- What is the cost of the health impacts of excess N in environment?
- What are the costs of N management (by source and by method)?
- Are there cost-effective treatment options for groundwater nitrate contamination?
- What is the feasibility of wellhead protection and regional treatment facilities for communities impacted by high-nitrate levels in drinking water?
- Do solutions to N problems make economic sense?
- What are cost/benefits of NUE practices? Best way to implement these?
- How might N management tools and documentation be structured so they're appropriate for a variety of production models/systems and farm sizes?
- Cost of N management: by source, by method, globally to achieve and points
- How can health impacts be integrated into evaluation of nitrate mitigation alternatives?
- Cost of N management: by source, by method, globally to achieve and points

Other

- Can NUE practices be scaled across a wide range of production models/systems and farm sizes?

- What would happen if we could no longer rely on fossil fuels as N source?
- Solutions need support/technical assistance
- Role of the "social" institutions?
- Social justice implications – emissions, jobs, etc.

Human Health

- What is the state of understanding on the link between nitrates and blue baby syndrome, kidney, spleen and bladder cancers, Alzheimer's, diabetes and Parkinson's.
- What are the food safety implications of elevated levels of N in crops?
- What are safe levels of N in crops (tissue) for humans?
- Can some crops "super-accumulate" N to reach levels that are injurious to consumers?

Communications and outreach

- How do we communicate complexity of N system and problems to public
- What is the understanding among producers & policymakers of N impacts? And what's the gap between myth and reality?
- Are there maps showing impacts of N?
- Who are the stakeholders?
- Are there ongoing outreach efforts to positively incentivize farmers to document their N

use?

- Can tools be developed for farmers to assess N-use efficiency?
- What outreach is being done to farmers regarding N and greenhouse gas issues?

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