

# **BIOGEOCHEMISTRY AND THE CALIFORNIA NITROGEN ASSESSMENT**

## **DRAFT PROGRESS REPORT 12/15/09**

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## II. BIOGEOCHEMISTRY

The goal of the biogeochemistry component is to calculate a mass balance for the state of California. To achieve this we are identifying and quantifying the sources of new inputs of reactive nitrogen and losses of all forms of nitrogen for the state as a whole.

The dominant stocks of nitrogen (N) are stored in plants, soils, and groundwater. Preliminary calculations suggest that aboveground plant biomass represents a stock of approximately 10 million tons of N and the surface soil (top 20 cm) contains 100 million tons of N, while the groundwater storage pool is unknown. While the size of the pools mentioned above may be changing as well, we have focused on the fluxes of N, especially the new inputs of N. These new inputs represent N that is either fixed from  $N_2$  within California or N that is imported in solid, dissolved, or gaseous form from outside the state.

### Inputs

We have defined the following as the terms representing new inputs of reactive N to California

- Biological N fixation (crops and natural lands)
- Fertilizer (synthetic and imported organic)
- N deposition from fossil fuel combustion
- Gross imports of food/feed/fiber

The largest component of N fixation in the state is from alfalfa which is grown on over 1,000,000 acres. The N fixation associated with this crop represents a nitrogen input of 180,000 tons annually (see Table 1, pg. 15). There has been a small increase (~10%) in the amount of alfalfa grown over the last 30 years (Figure 1, at left). While natural lands occupy a much larger acreage than alfalfa, the fixation rate is thought to be much lower representing a new N input of ~100,000 tons. However, this flux represents the only input of reactive N not directly related to human activity.

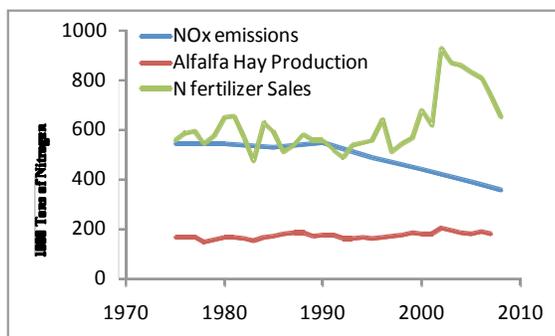


Figure 1. Change over time in the largest new sources of reactive N to California

Synthetic fertilizer sales are quantified by the California Department of Food and Agriculture annually. With the exception of a large jump during the years 2002-2006, the amount of fertilizer sold has varied from 475,000 to 675,000 tons of N (Figure 1). There is a large amount of manure applied in California, but this is not a new source of reactive N in the system as it is accounted for in the animal feed. However, it is possible that there is a small import of other organic fertilizers to the state.

Atmospheric deposition of nitrogen consists of oxidized ( $NO_x$ ) and reduced ( $NH_x$ ) forms of reactive N as a result of both dry and wet deposition. Most of the N deposited is from sources in California as the air is relatively clean coming off the Pacific Ocean. The source of  $NO_x$  is almost exclusively fossil fuel combustion and as such represents a new source of N to California. The source of  $NH_x$  is a mixture of fossil fuel combustion (a new source of N) as well as volatilization of ammonia from fertilizer, manure, and natural soils. This  $NO_x$  is the

dominant form of reactive N in the atmosphere, but has been decreasing steadily over the last decade because of the use of catalytic converters in cars (Figure 1, previous page). There are modeled results of N deposition in the state for 2002 that suggest 223,000 tons of N land in CA, some fraction of that is actually recycled N. However, this value is significantly lower than the  $\text{NO}_x$  production which suggests that California must be exporting  $\text{NO}_x$  to downwind states.

It is very difficult to quantify the gross import of food and feed to California, but we are still attempting to find the data sources that would allow these calculations. However, it is possible to estimate net imports. First, we calculated the N harvested in each agricultural commodity in the state based on the average production for 2003-2007 and the N content for crops and livestock. We compare this value to the daily N requirements of the people, pets, and livestock (dairy cows and broilers). Based on this calculation it appears that while California produced more food than its people consume, there needs to be a net import of almost 300,000 tons on N in feed for animals. Based on railroad waybill data, this feed arrives by train from Iowa and Nebraska and is largely corn and a few other grains. Surprisingly, the feed demand of broilers is even greater than dairy cows even though the value of the chickens is 10 times lower.

## Outputs

We have identified five potential sources of N export from California (see Table 2).

- Soil gas losses
- Fossil fuel combustion export
- Surface water discharge to the ocean
- Groundwater storage
- Wastewater discharge to the ocean

Soil gas losses are likely dominated by the production of inert  $\text{N}_2$ . However, the largest source of the greenhouse gas nitrous oxide ( $\text{N}_2\text{O}$ ) is from agricultural soils related to the use of N fertilizer. We calculate a loss of 14,000 tons of N as  $\text{N}_2\text{O}$  annually both by scaling up from the median  $\text{N}_2\text{O}$  emission rate from the few field measurements in California or using the standard direct emission factor of 1.25% of fertilizer application based on the synthesis of global emissions of  $\text{N}_2\text{O}$  related to fertilizer application (Stehfest and Bouwman 2006). The median of the emission factor based on the field data for California was 1.4%, similar to the global average. A

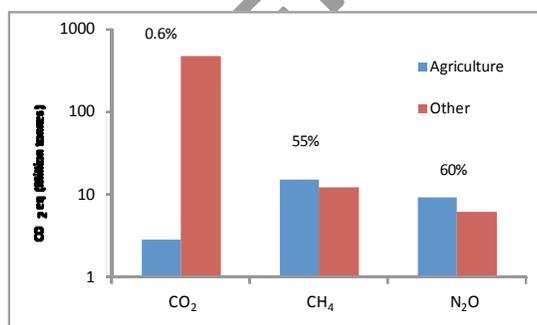


Figure 2. California Greenhouse Gas emissions by gas with the relative contribution of the agricultural sector for each gas.

Source: California Air Resources Board

small amount of  $\text{NO}$  is also emitted from soils, but this is dwarfed by the amount of  $\text{NO}_x$  in the atmosphere from fossil fuel sources. While agriculture is the most important source (60%) of  $\text{N}_2\text{O}$  emitted in California,  $\text{N}_2\text{O}$  is a relatively small contributor (2.8%) to the overall greenhouse gas emissions for the state, and the agricultural sector (5%) is relatively small compared to the overall greenhouse gas emissions (Figure 2, at left).

Our current best estimate suggests that a large fraction of the  $\text{NO}_x$ , and perhaps some  $\text{NH}_3$  as well, is exported from the state as N deposition appears to be lower than the production.

Surface water is a relatively minor export of nitrogen from California. In part this may be due to the relatively small discharge of water from the more highly polluted watersheds such as the Santa Ana. In addition, there are relatively few large discharges of wastewater effluent into rivers in the state.

So far we have not been able to estimate the current loss of nitrate ( $\text{NO}_3^-$ ) from soils from leaching. While there are abundant measures of  $\text{NO}_3^-$  in groundwater, we are still working on finding data on the current leaching rates below the rooting zone to the unsaturated subsoil and groundwater.

Because of the location of the population centers in the state, a relatively large fraction of the wastewater treatment in California is discharged directly into the ocean after the solids have been removed during primary treatment. This flux of at least 82,000 tons of N represents the discharge for approximately 25 million people. The solids which contain 38,000 tons of N are largely recycled to non-food agricultural land and do not represent a loss of N. A very small amount of  $\text{N}_2\text{O}$  and  $\text{N}_2$  are also produced during wastewater treatment.

### **Internal Cycling**

Other internal fluxes are also important to understand. Over 100,000 tons of manure N are produced annually from dairy cows alone. Large quantities of agricultural byproducts, biosolids, and compost are either fed to animals or spread on fields. For a more in depth look at how N is flowing within the state, we will construct mass balances for individual subsystems in the state. For example, we can do input and export calculations for subsystems such as the human food subsystem, the alfalfa-dairy subsystem, or the wastewater subsystem in the same way we did for the whole state to determine where the largest fluxes of nitrogen are occurring and how the subsystems are interacting.

### **Future work**

So far we have compiled a significant number of data sources to get a rough estimate of the N mass balance. At this point, it appears that California is a large sink for nitrogen (we can account for almost 1000 tons more of inputs than outputs). There are several areas where we will focus on improving our estimates:

- 1) The export of  $\text{NO}_x$  and  $\text{NH}_3$  from California.
- 2) Gas losses from soils including natural lands and turfgrass areas (which cover approximately 3 million acres)
- 3) Leaching of  $\text{NO}_3^-$  - below the rooting zone.
- 4) Determination whether California is a net sink for N (i.e. are the inputs and exports so different)
- 5) Assessment of the uncertainty of the data sources
- 6) Identification of hot spots of N and areas at risk

**Table 1: Inputs of new reactive N to California.**

Headings in bold are the sums of the indented subcategories below with the exception of N deposition. The value of 223 tons of N is based on the results of the CMAQ model and the values for NO<sub>x</sub> and NH<sub>x</sub> below are from ARB emission data. The new reactive N in deposition should only come from sources outside of California (i.e. transport across the Pacific Ocean) or fossil fuel combustion in California. Some component of deposition, especially NH<sub>x</sub>, represents internal N cycling within California, e.g. redeposition of ammonia volatilization from livestock manure. At present, however, the modeled estimate of total N deposition is lower than the estimated fossil fuel emissions.

Nitrogen Flow	Nitrogen (1000 tons N)	Calculation
<b>Biological Nitrogen Fixation</b>	<b>290</b>	
Natural Systems	106	Mean rate*area
Ag Systems (Alfalfa)	184	Tonnage*N content
<b>N fertilizer</b>	<b>650</b>	
Synthetic	650	CDFA tonnage reports
Imported Organic	?	
<b>N deposition</b>	<b>223</b>	CMAQ model results
NO <sub>x</sub> from fossil fuel combustion	415	Average of 2000 and 2005 ARB emissions
NH <sub>x</sub> from fossil fuel combustion	30	2005 ARB emission
<b>Net Food/Feed Imports</b>	<b>268</b>	
People Food	202	11 lbs N/person/year
Pet Food	55	8.8 lbs N /dog/ year or 2.4 lbs N/cat/ year
Cow Feed	271	401 lbs N/cow/ year
Chicken Feed	334	2.4 lbs N/chicken/ year
Crop Production	-268	Crop tonnage* Nitrogen content
Milk Production	-95	Milk tonnage * Nitrogen content
Meat/Egg Production	-48	Tonnage*N content
<b>Total Nitrogen inputs</b>	<b>1431</b>	

**Table 2: Total N exports from California.**

Nitrogen Flow	Nitrogen (1000 tons N)	Calculation
<b>Agricultural Soil Gas Losses</b>	<b>132</b>	
N <sub>2</sub> O	13	Mean N <sub>2</sub> O emission * acreage
N <sub>2</sub>	119	Upper limit of N <sub>2</sub> O:N <sub>2</sub> ratio from field measurements
NO	9	Mean NO emission * acreage
<b>Fossil Fuel Combustion Exports</b>	<b>192</b>	
NO <sub>x</sub>	192	Production - Deposition
NH <sub>x</sub>	?	Production - Deposition
<b>Surface Water – Total Dissolved N</b>	<b>27</b>	N concentration * water volume
<b>Groundwater - NO<sub>3</sub><sup>-</sup></b>	<b>?</b>	
<b>Wastewater</b>	<b>92</b>	~20 million people connected to treatment facilities that discharge to the ocean
N <sub>2</sub> O	1	Emission from ARB
N <sub>2</sub>	9	Fixed N <sub>2</sub> O:N <sub>2</sub> ratio as above
NH <sub>4</sub>	82	NH <sub>4</sub> content * discharge to ocean
<b>Total Nitrogen exports</b>	<b>251</b>	

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