Developing and Applying Manure-DNDC: A Process-based Model for Estimating GHG and Air Emissions from California Dairies

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Project Objectives

- Modify an existing "process-based" biogeochemical model for estimating CH_4, NH_3, NO, N_2O emissions from dairy systems in California.
- Collect field data to calibrate and validate this model
- Build GIS databases on soils, climate, dairy locations, and manure management.
- Apply the model to estimate emissions across California. Note: model is designed for both regional and single farm simulations.
- Funding: USDA NRI Air Quality Program and CEC PIER program.

What are Process-based Models?

- Process-based modeling refers to biochemical and geochemical reactions or processes
  - Process modeling, in this case, does **not** refer to AFO practices or components (e.g. dairy drylots or manure lagoons) per se, but
- **Biogeochemical processes**… like decomposition, hydrolysis, nitrification, denitrification, etc…
- True process-based models **do not rely on constant emission factors**. They simulate and track the impact on emissions of varying conditions within components of the dairies (e.g., climate, flush lanes, storage facility, soils).

Role of Process-based Models

- Accurate assessment of air emissions from AFOs with emission factors is difficult due to:
  1. high variability in the quality and quantity of animal waste, and
  2. numerous factors affecting the biogeochemical transformations of manure during collection, storage and field application.
- Measurement programs are essential but expensive and thus have not been extensively implemented.
- Therefore, process-based models that incorporate mass balance constraints are needed to extrapolate air emissions in both space and time (NRC, 2003).

Advantage of Process Models

- GHG inventory/mitigation project design:
  - Define measurement requirements to achieve desired accuracy/uncertainties
  - Assess both short- and long-term emissions (eg. Short term carbon sequestration may lead to long term increases in N_2O).
  - Multi-media (air and water)
- Assessment of site specific mitigation options (dairies are all different…)

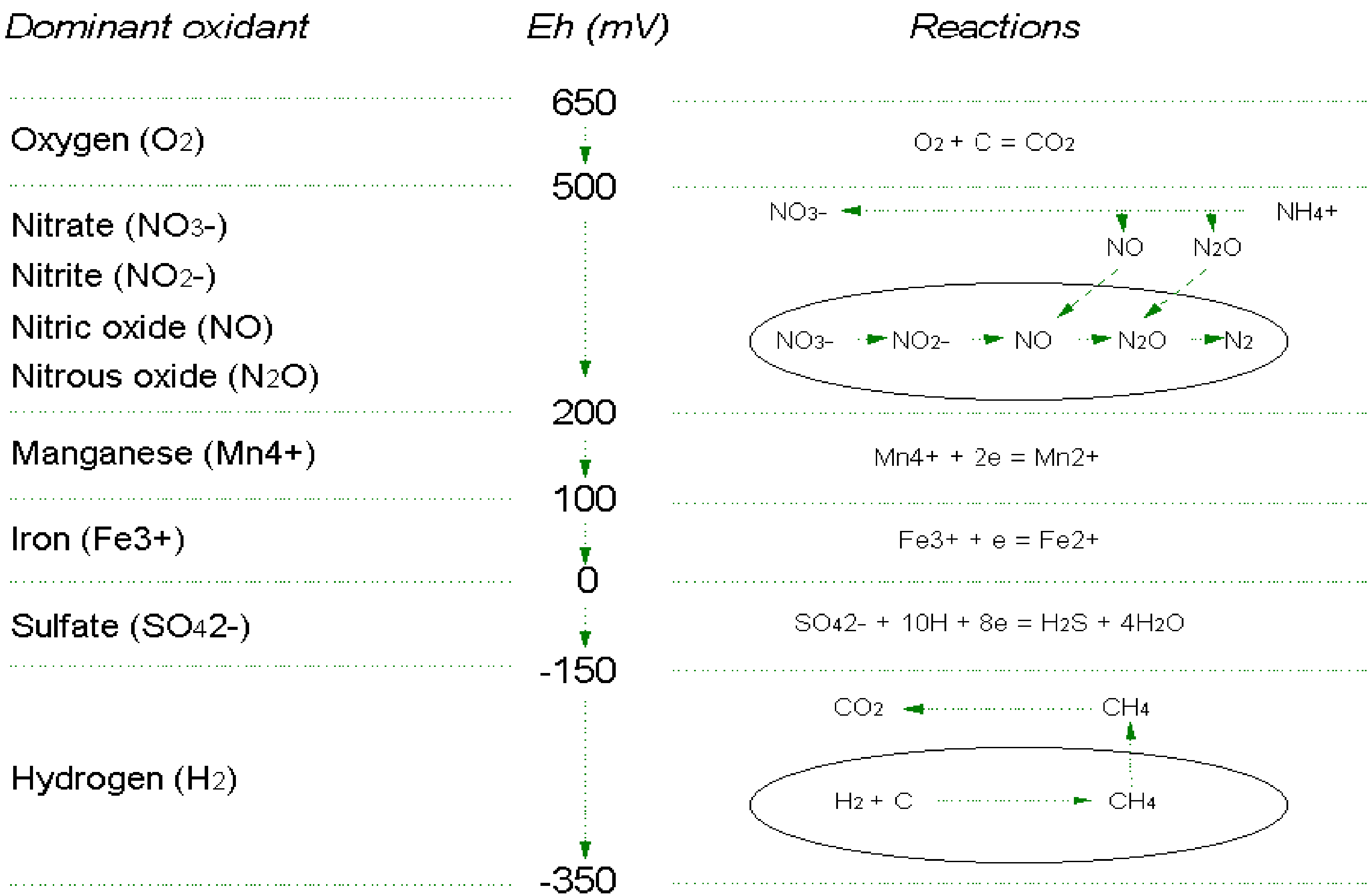
DNDC Model

- DeNitrification-DeComposition, or DNDC, is a process-based biogeochemical model.
  - Contains detailed C and N cycling processes: decomposition, hydrolysis, nitrification, denitrification, ammonium adsorption, chemical equilibriums of ammonium/ammonia, and gas diffusion
  - Provides estimates of CH_4, N_2O, NH_3, NO emissions and N leaching
- Why DNDC?
  - Well tested and has been independently validated across a wide range of agro- and forested ecosystems
  - Developed with management levers (tillage, fertilizer, irrigation, …)
  - Tracks soil redox potential to simulate C and N cycling in both aerobic and anaerobic conditions
  - Requires relatively few input parameters

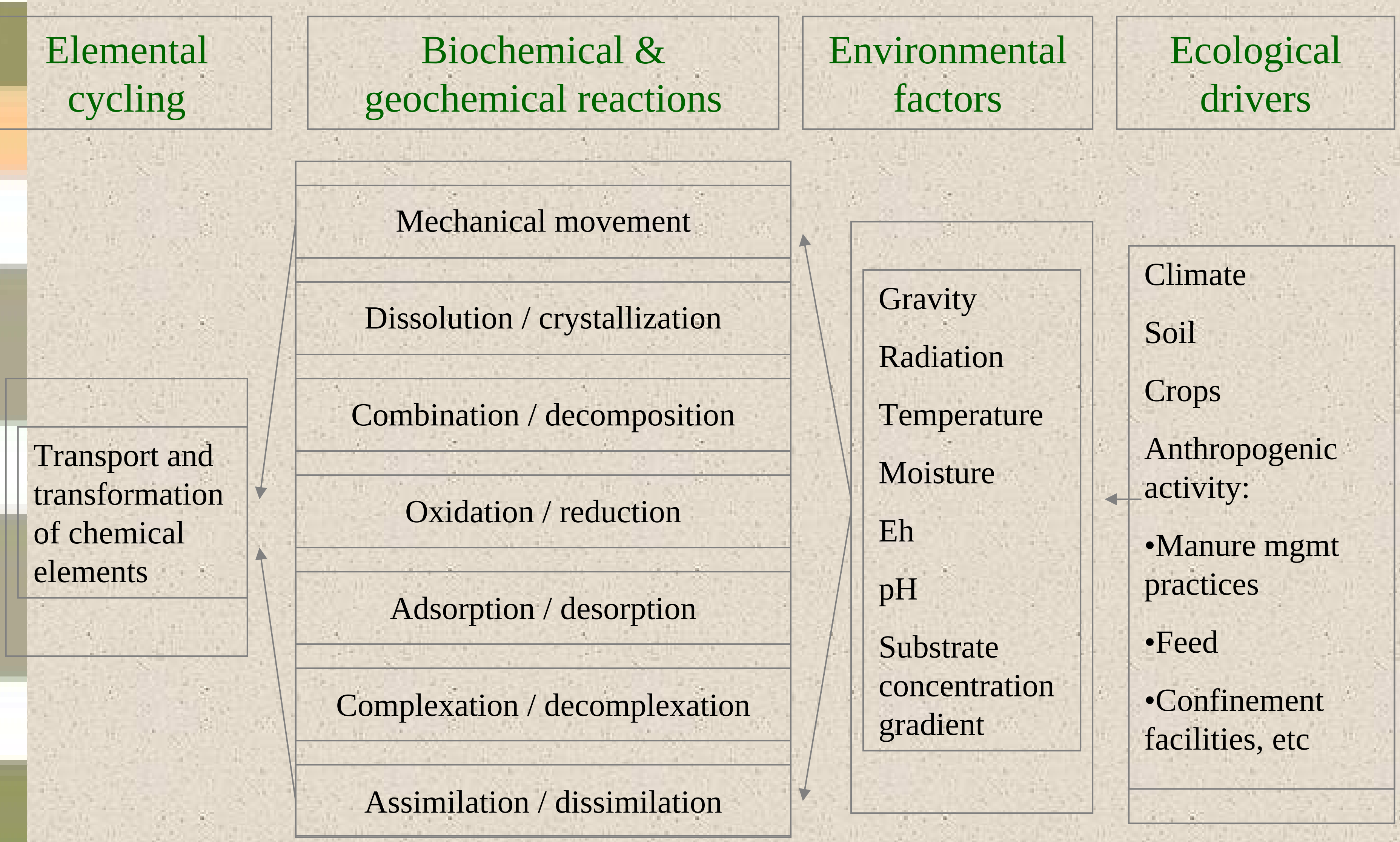
DNDC History

- Development began in 1989 by Changsheng Li for modeling N_2O emissions.
- First published in 1992, first N_2O emission inventory published in 1996.
- Over 50 peer reviewed publications with DNDC.
- Used for national GHG emission inventories in countries worldwide (e.g current NITRO Europe program for cropland, pasture and forest for entire EU).

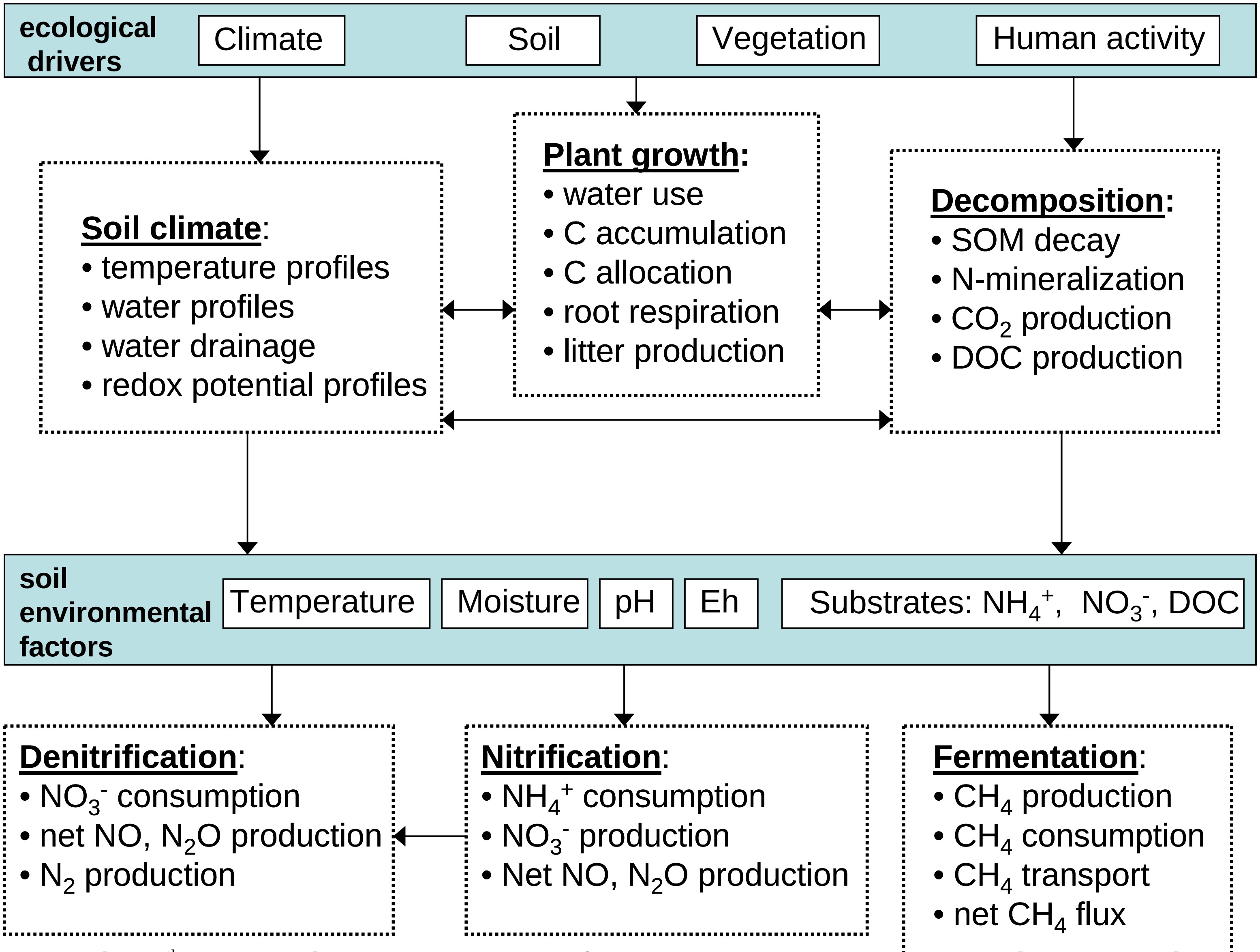
Trace Gas Evolution Driven by Redox Potential (Eh)



Linking Dairy Practices with C and N Biogeochemical Processes:

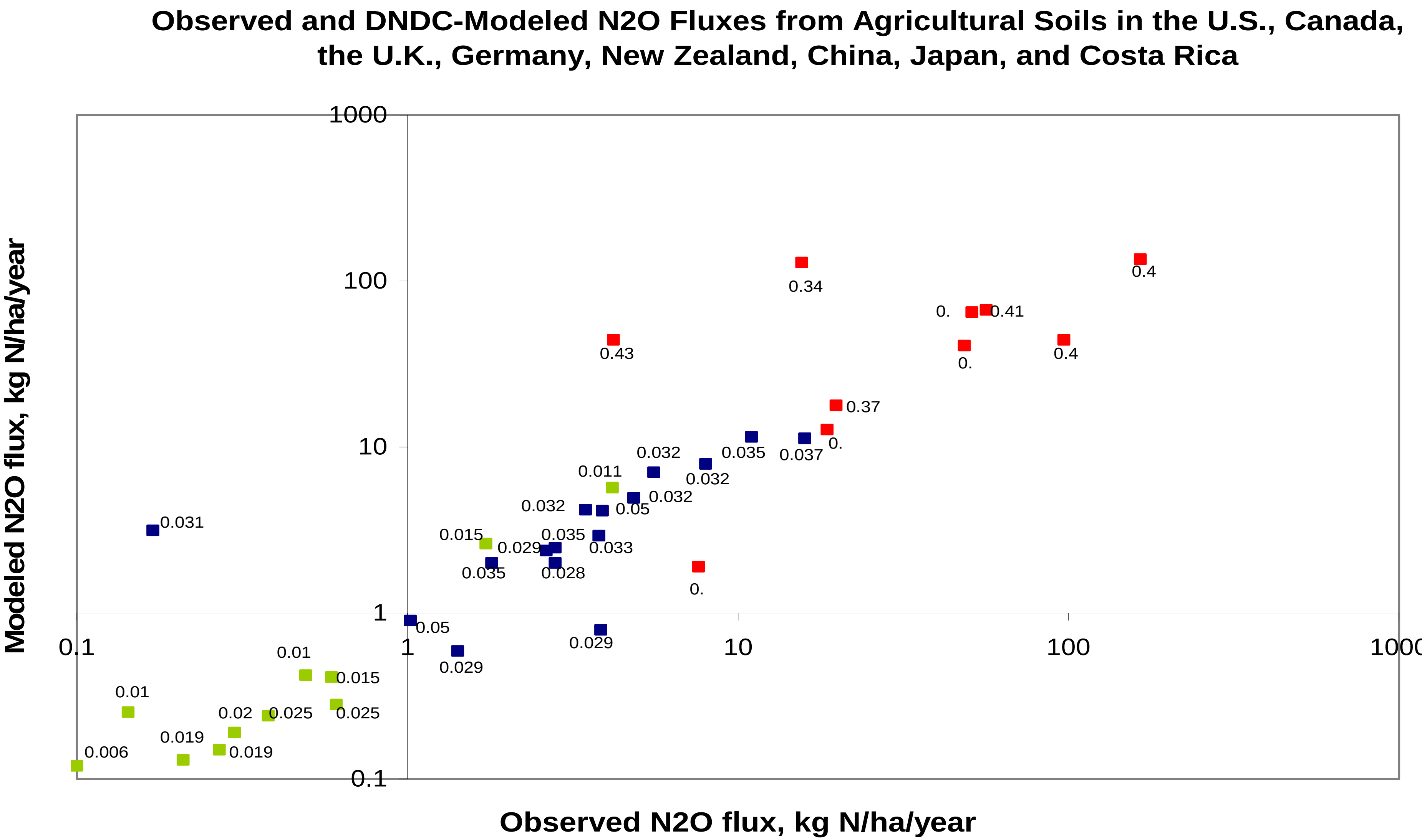


DNDC Model



ecological drivers
Climate
Soil
Vegetation
Human activity
Soil climate:
• temperature profiles
• water profiles
• water drainage
• redox potential profiles
Plant growth:
• water use
• C accumulation
• C allocation
• root respiration
• litter production
Decomposition:
• SOM decay
• N-mineralization
• CO_2 production
• DOC production
soil environmental factors
Temperature
Moisture
pH
Eh
Substrates: NH_4^+, NO_3^-, DOC
Denitrification:
• NO_3^- consumption
• net NO, N_2O production
• N_2 production
Nitrification:
• NH_4^+ consumption
• NO_3^- production
• Net NO, N_2O production
Fermentation:
• CH_4 production
• CH_4 consumption
• CH_4 transport
• net CH_4 flux

N_2O Validation



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Example: Modeling NH_3 Emissions

- Dynamics of NH_3 production is controlled by the several biochemical or geochemical reactions, namely **decomposition, hydrolysis, nitrification, denitrification, ammonium adsorption, chemical equilibriums between N species, and ammonia gas diffusion**.
- In developing a process-based model, it is important to incorporate these fundamental reactions into a computing system to quantify both the spatial and temporal variability and non-linear nature of NH_3 volatilization from agricultural sources.

Ammonia Emission Processes

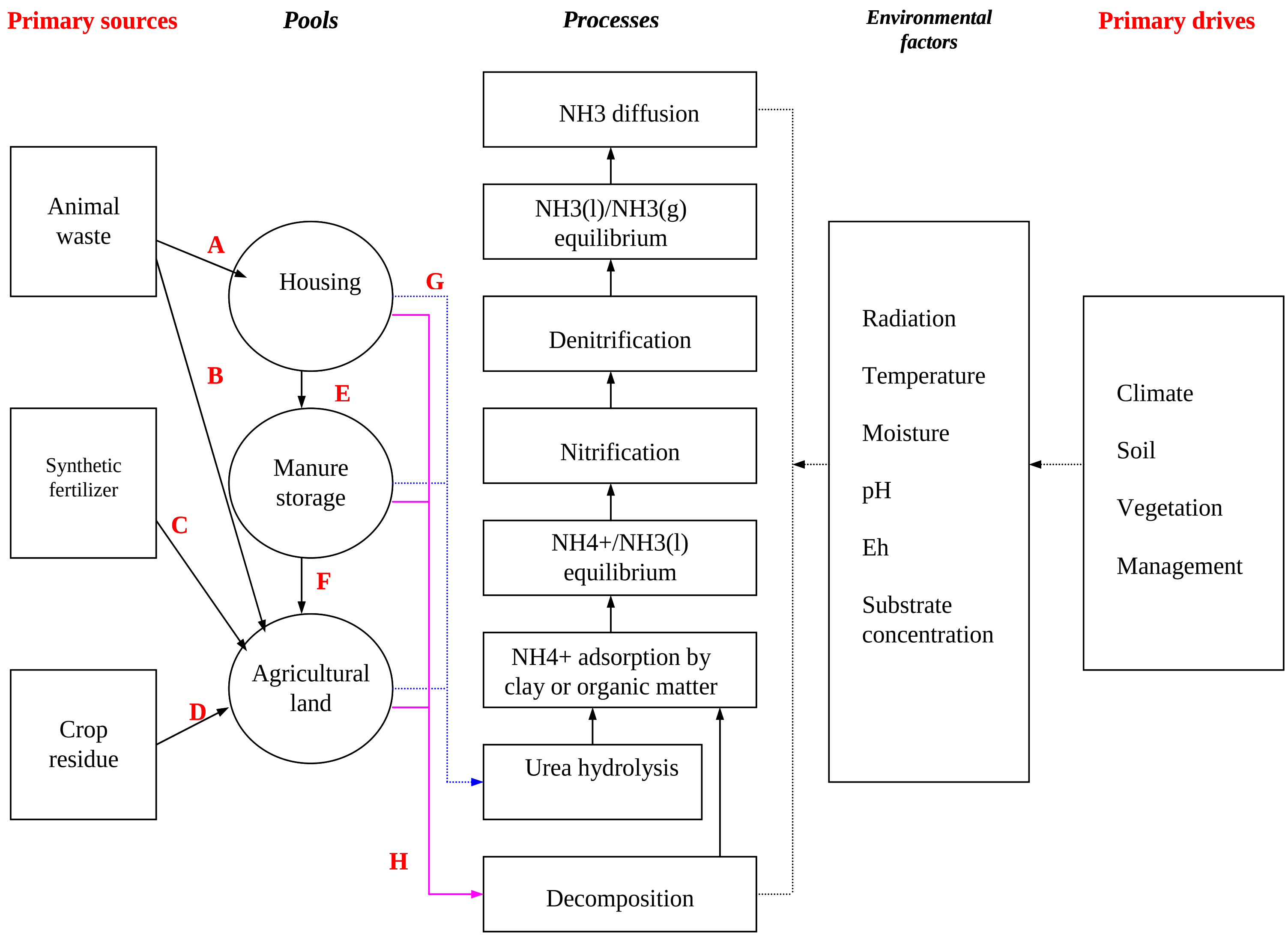


Figure 1. Framework of a process-based ammonia model for agricultural sources. A- Animal housing; B- Grazing; C- Fertilization; D- Crop residue incorporation; E- Manure storage; F- Manure application; G- Dissolved N (e.g., urea etc.) in liquid phase; H- Solid manure or soil organic matter.

ay 15-18.

Manure-DNDC Framework

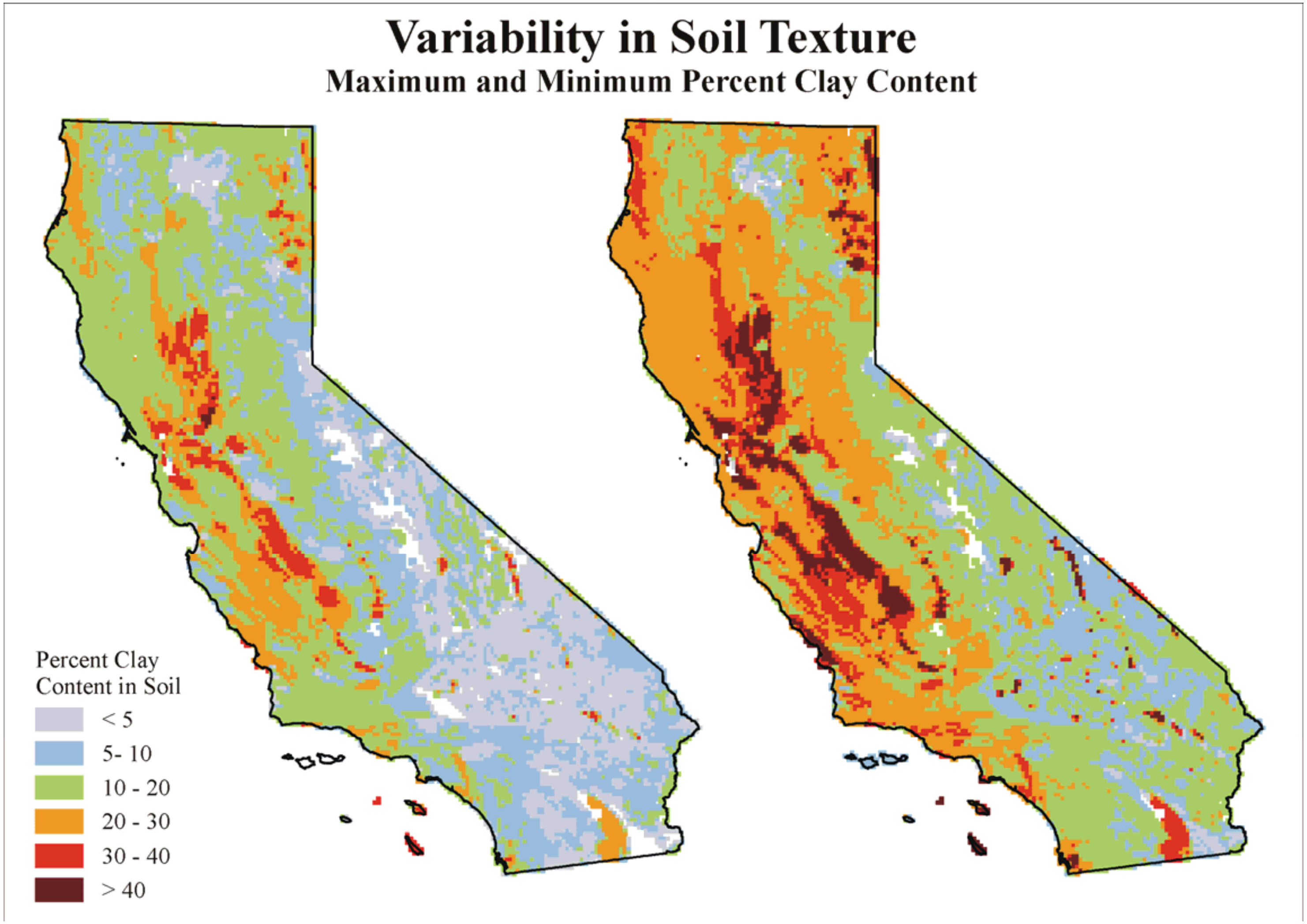
	Manure Production	Manure Storage/Processing	Manure Application
Environmental factors	Air temperature Precipitation Wind speed/direction	Air temperature Precipitation Wind speed/direction	Meteorological data Soil properties Vegetation type
Management factors	Manure quantity and quality Freestall, exercise pens, drylots Temperature Ventilation Duration before removal Removal technique (flushing, scrape)	Temperature Moisture Manure texture Additions Duration before land application	Crop type/rotation Tillage depth Manure application rate Manure C&N content Other fertilization Irrigation Weeding Grazing
Model Simulations	Manure temp., moisture, pH, C&N content Decomposition Denitrification NH_3 volatilization N_2O, NO, N_2, CH_4 emissions N & C leaching	Manure temp., moisture, pH, C&N content Decomposition Denitrification NH_3 volatilization H_2S, N_2O, NO, N_2, CH_4 emissions N & C leaching	Manure temp., moisture, pH, C&N content Decomposition Denitrification N uptake by plants NH_3 volatilization N_2O, NO, N_2, CH_4 emissions N & C leaching

Environmental Factors: Climate Data

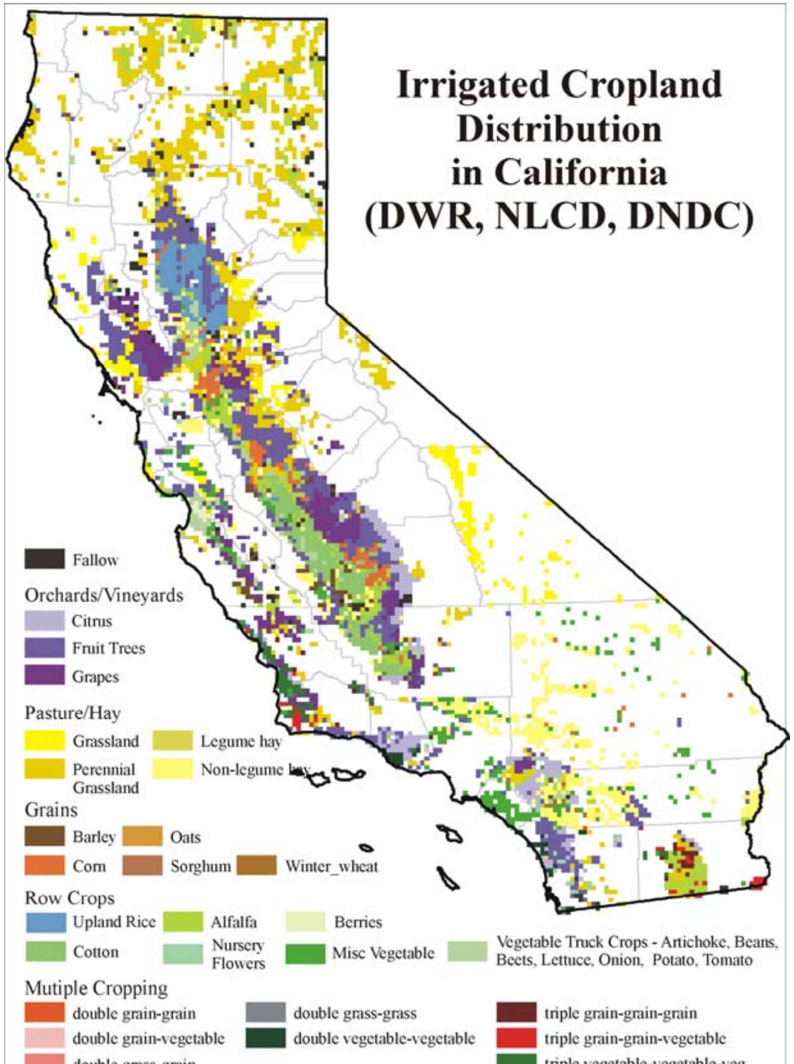
- DAYMET: Gridded (1kmx1km) daily min/max T, precipitation, relative humidity, and solar radiation. Available from 1980.
- CIMIS (California Irrigation Management Information System): station data with hourly Temp, Precip, Radiation, Rel Hum, Wind Speed, …).
- Built automated routines for data mining, QA/QC and pre-processing into Manure-DNDC format.

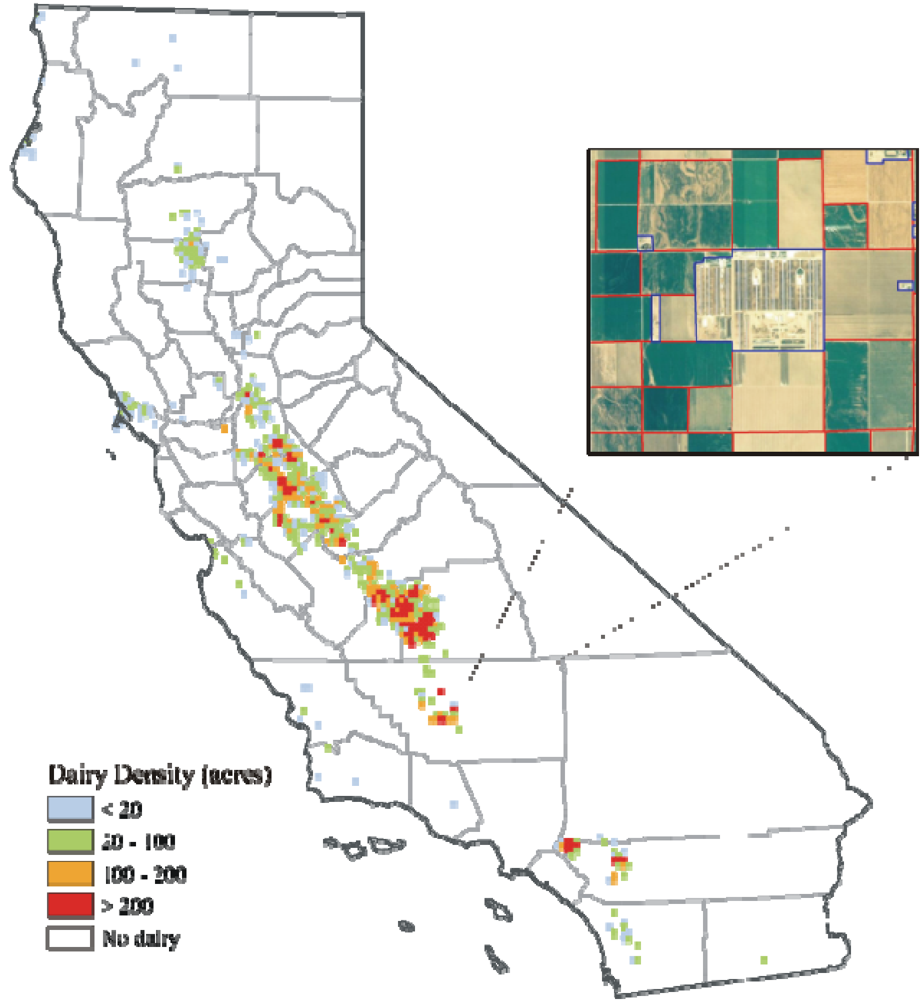
GIS Soils: NRCS Soil Surveys

- STATSGO (1:250K) and SSURGO (1:12k-1:63K)



DWR Land Use Databases





Data Source: California Department of Water Resources land use survey database (http://www.landwateruse.water.ca.gov)

GIS and Site Specificity: Dairy Locations: Aerial Photos

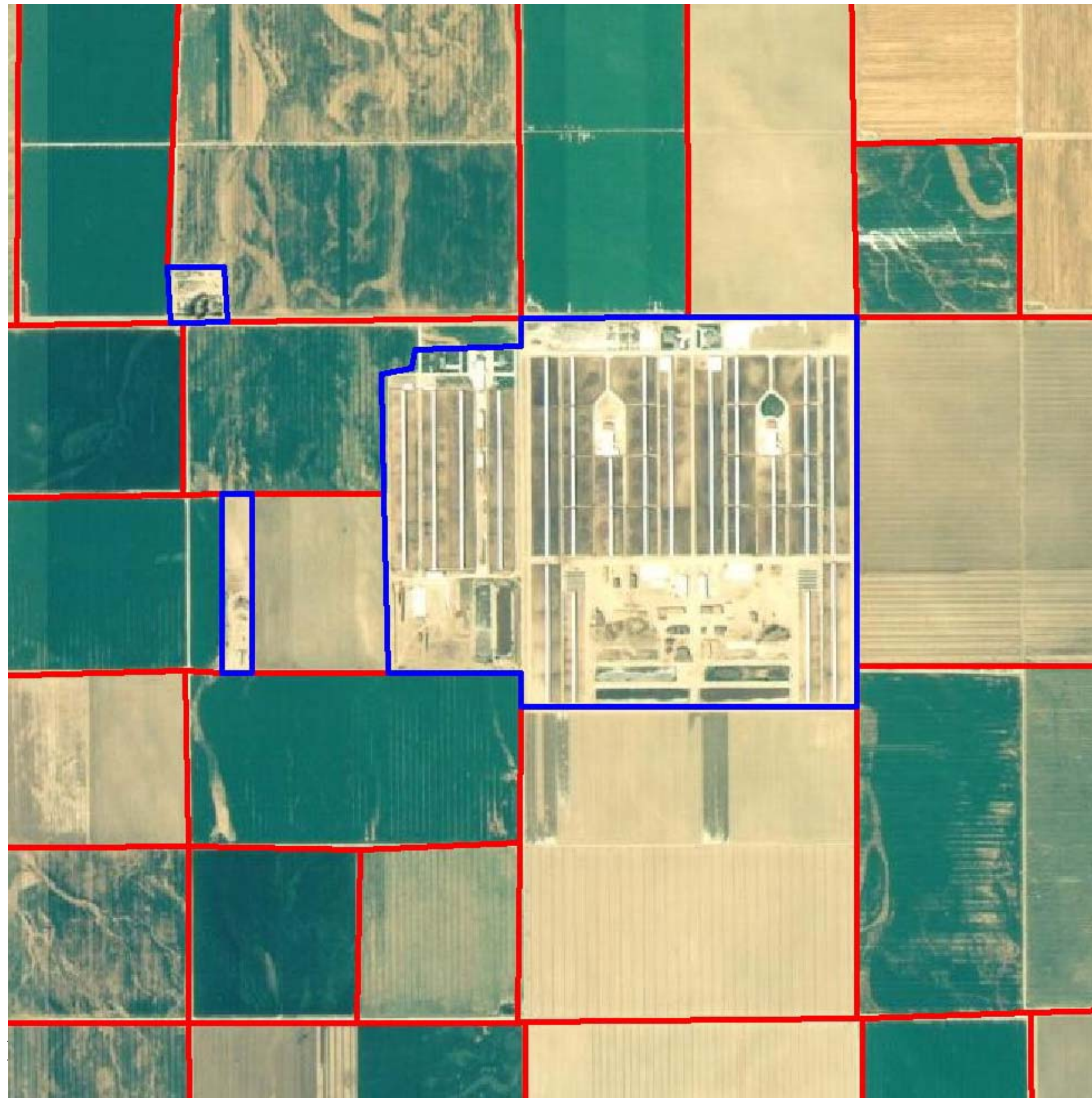
GIS Data on:

Dairy Locations

Soils (soil properties pH, SOC, texture, Bulk density)

Climate (daily/hr T, Precip, rel humidty, Wind, solar radiation)

Merced	429
Stanislaus	409
Tulare	338
Kings	199
San Joaquin	199



Manure Management Statistics

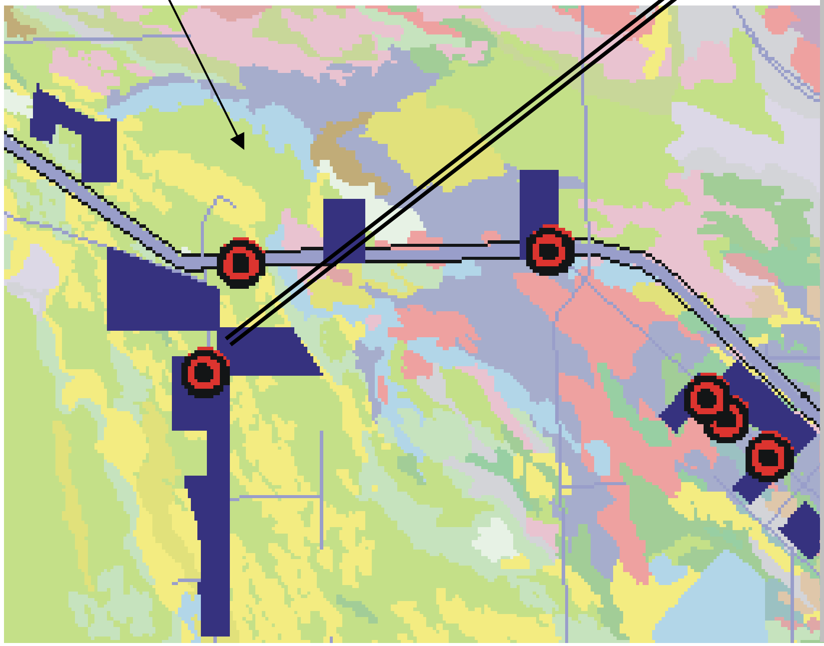
- Objective: build spatially explicit database on
  - Type of dairy: flush, scrape, vacuum, etc
  - Type of housing: free stalls, open corals, etc
  - Manure handling: anaerobic lagoon, aerobic lagoon, anaerobic digester, composting, setting basin, land application, etc.
  - Specifics on storage, treatment, and land application practices, etc.

Sources of Dairy Data

- SJVAPCD Permit data: ~ 1000 permit and/or CMP applications. Data provided by town, full addressing in discussion.
- SCAQMD Permit data: ~250 dairies with addresses.
- CDQAP Mitloehner survey, 50 dairies in Merced County.

Linking dairy with local soils and climate

NRCS Soils: STATSGO and SSURGO. Soil carbon, texture, pH and bulk density



Facility: XYZ Dairy
- **Milk Cows: 990**
- **Dry Cows: 200**
- **Heifers 15-24 mo: 350**
- **Heifers 7-14mo: 280**
- **Heifers 4-6 mo: 120**
- **Calves: 135**

Flush dairy (3x per day) with free stalls, open corrals, and 2 treatment lagoons

28 acres cropland, flood irrigation of slurry, three times per year.

Composting solid manure in windrows, land applied twice per year

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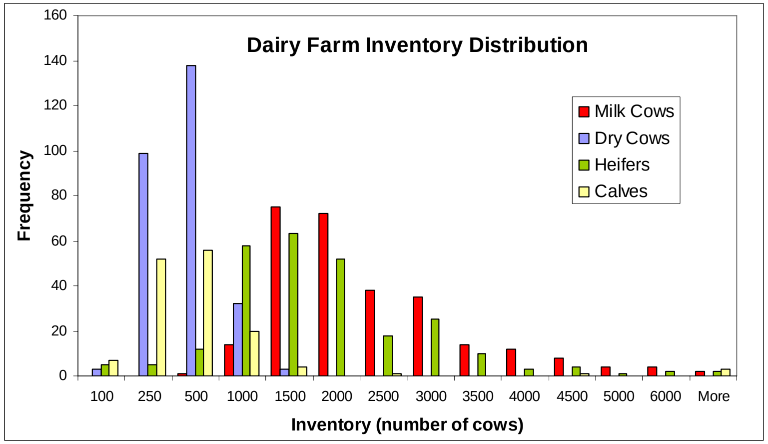
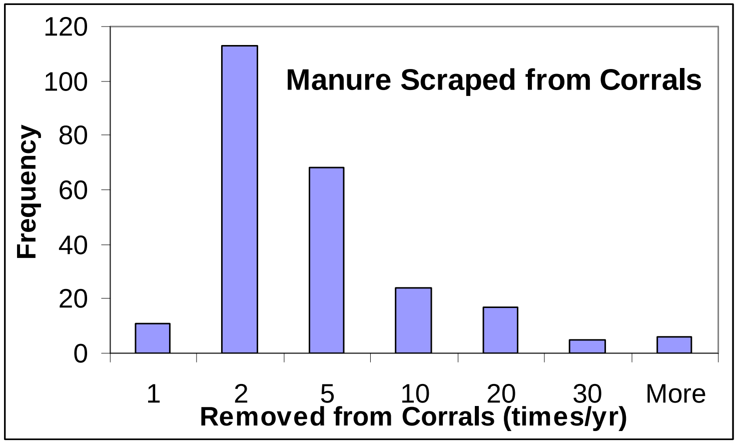
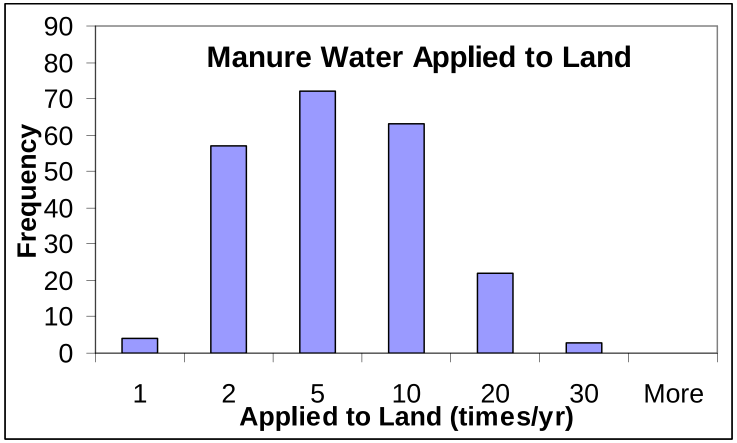
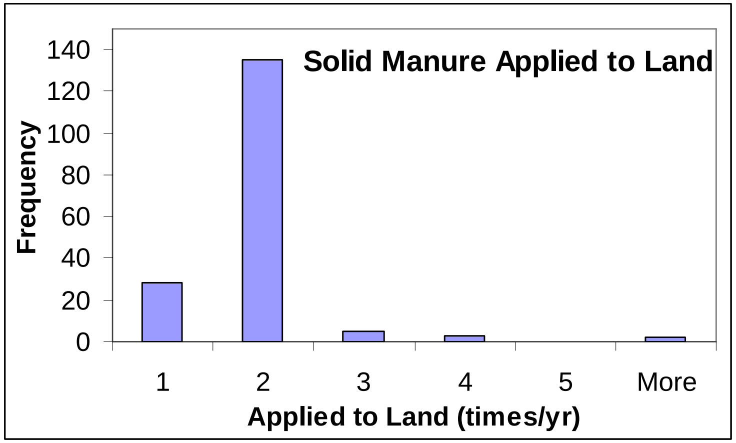
Statistics: SJVAPCD Permit Applications









Expected Project Outcomes

- Validated, biogeochemical process modeling tool for estimating air emissions (CH_4, NH_3, N_2O, NO) and N leaching from California dairies.
- GIS databases on dairies (location, types, herd sizes, manure management, local soils, climate, etc).
- Regional estimates of NH_3 and GHG emissions from California dairies.
- Emission inventory tool for air-district and facility level inventories.