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A Systems Approach to Biofuel Sustainability

Postdoctoral Society Lunch

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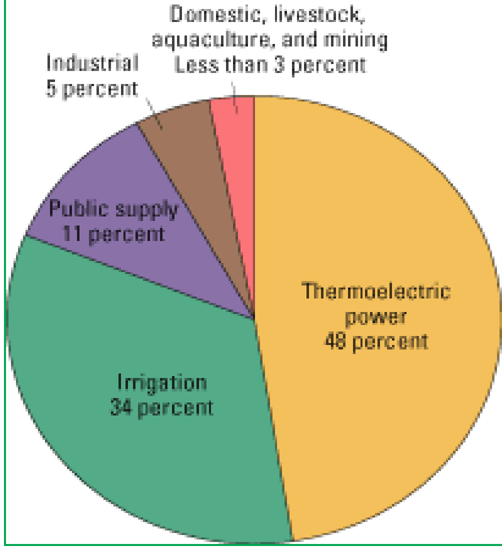
The big picture - inputs and sustainability



- Water

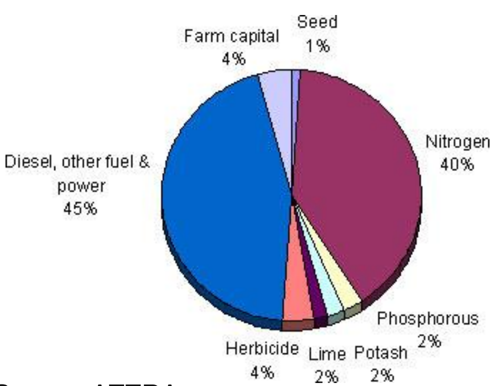
  In the U.S., 1550 Billion L (408 B gallons) of water are withdrawn every day – 34% is for irrigation

- Land use

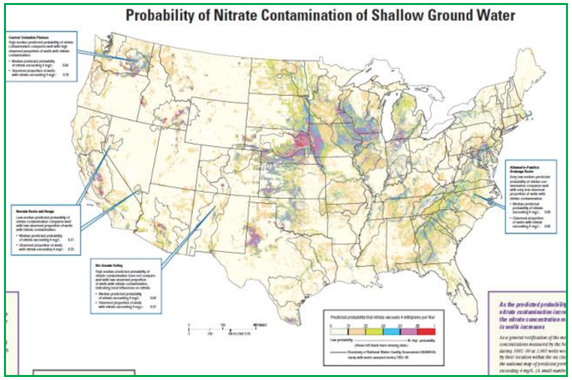
  “If more land is used to make ethanol, somewhere else it will be compensated by other land being cleared to grow food”

  Biofuel production has the potential to increase GHG emissions from changing land use from forests and grass lands to agriculture especially in tropics (Gibbs et al 2008, Searchinger et al 2008, Fargione et al 2008)

- Water quality impacts of agriculture (biofuel and agricultural crops)



Source: ATTRA

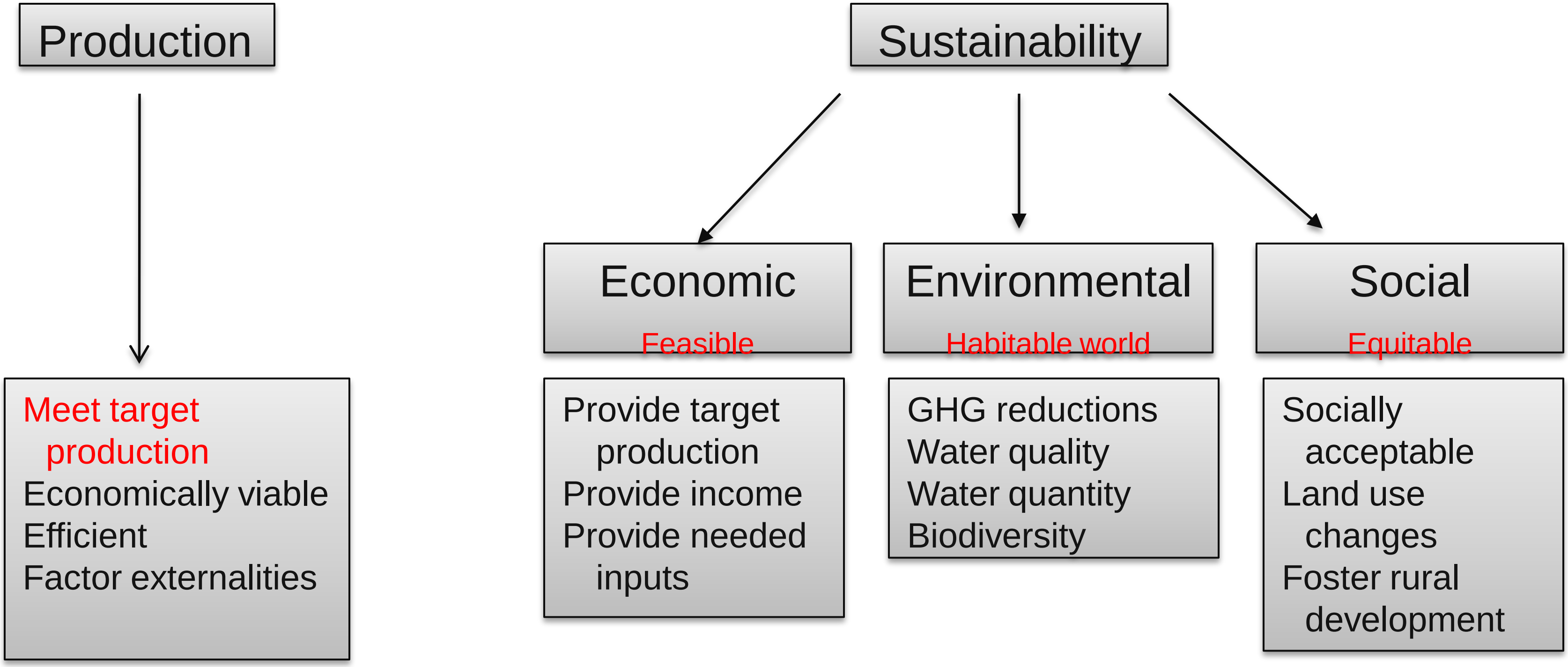


Source: USGS (2005)

Source: USEPA

The problem: Need to grow biomass feedstock sustainably

Sustainability is the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs. (U.S. EPA)



Current research on the sustainability of biofuels – Environmental footprint

Land availability, ecological diversity and water impacts

- Marginal or abandoned agricultural land could contribute on a regional level to available land for biofuels (Campbell et al 2008)
- Ecological impacts could be significant if forest land is converted (Koh, 2008)
- Environmental footprints are different based on the biofuel crop species selected (Zah et al 2008)
- Water quality in streams and rivers could be negatively impacted if biofuel crops are fertilized (Burken et al 2009)
- Water availability could be an issue if biofuel crops use more water than is available(NAS 2008, Burken et al 2009)

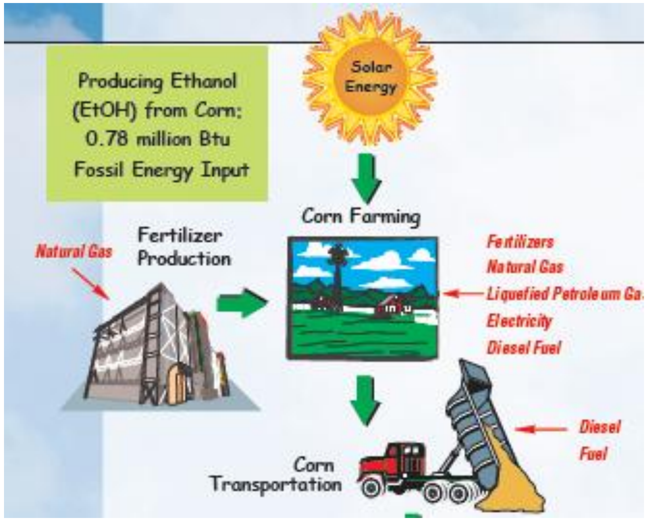
Some of these are current problems in the agricultural sector (water quality, land use, water availability)

The systems perspective

Beyond assessment and mitigation of impacts to designing positive services to the environment to sustain high yields

- **" One sector's waste is another sector's resource "**
- **Converting environmental liabilities to resources**

  double-dipping for benefits.



Excess nutrients cause hypoxic zones….

An environmental concern

Source: USEPA

While fertilizers impact costs and energy balance, GHG emissions. A resource for bioenergy

Source: ANL GREET

Our Research Goals

- Minimize environmental impact or helping in restoration of degraded land and water resources <u>while</u> producing biofuel feedstock

- Find and quantify alternative land and water for biofuel crop production

How we do this

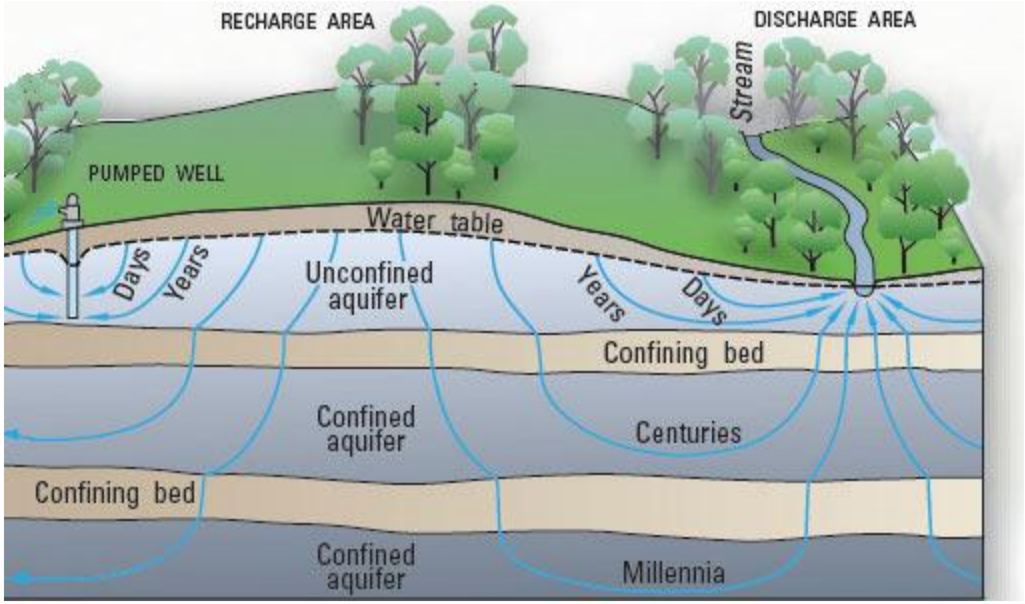
- At the field level
  - Determine in practice how our systems strategy works
  - Evaluate the environmental benefits as a result of this strategy

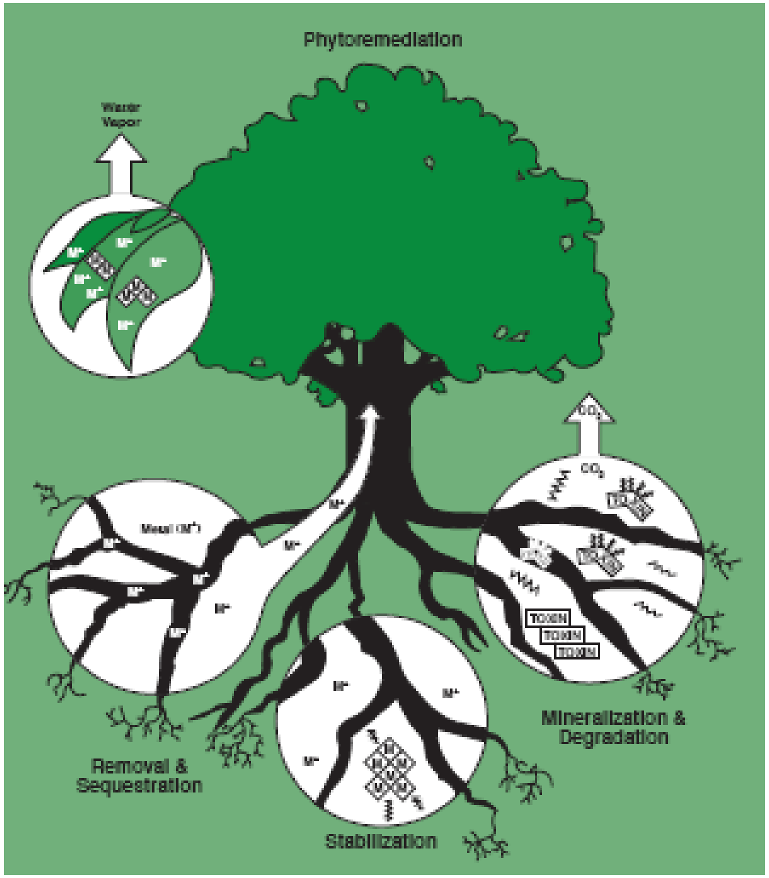
- At the state/regional level
  - Model the spatial distribution and availability of alternative land and water resources to provide a quantitative measure of the opportunity

(source: U.S.DOE)

Cellulosic feedstock and environmental remediation

- Phytoremediation = the treatment of environmental problems through the use of plants.
- Passive reuse of nutrients and degraded water resources to grow biofuel crops

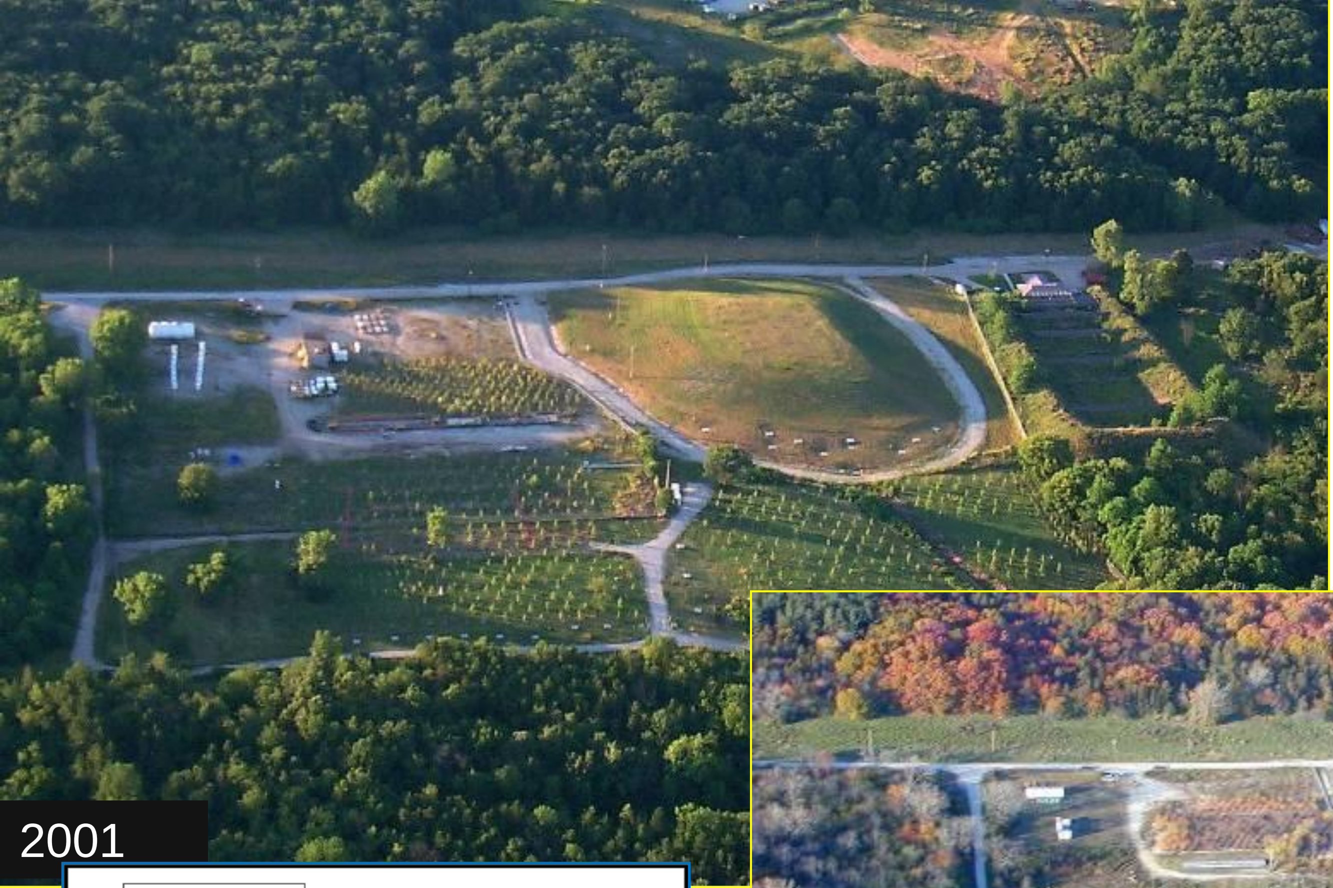


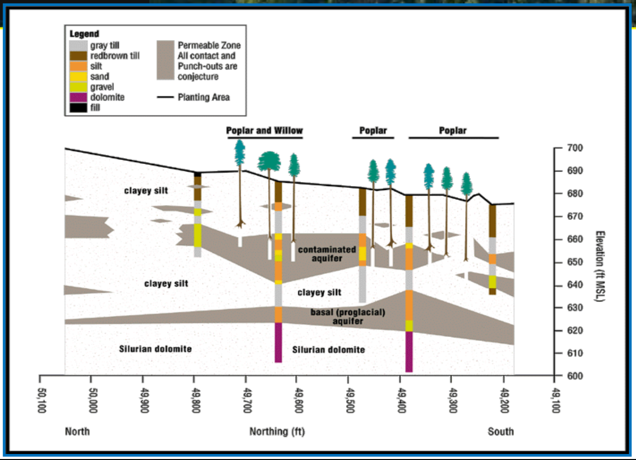


Source: USGS: Http://ga.water.usgs.gov/edu/watercyclegwdischarge.html

The Argonne, IL site

- Soil and groundwater contaminated with chlorinated solvents as a result of past practices
- Phytoremediation (~800 trees) used for treatment



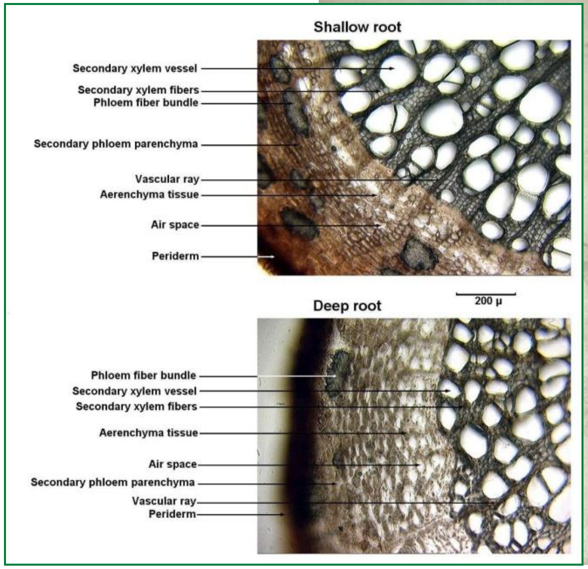


Exploiting the Phreatophytic trait in Cottonwood (Populus deltoides)

- **Water-inefficient trees, have interesting way to avoid drought**

- **Drought stress appears to activate root elongation** in selected genotypes *(an adaptive trait from evolving in riparian ecosystems?)*
  - Root elongation rates may play a significant role in drought tolerance, as fast-elongating genotypes can follow a declining water table while slow-elongating ones die off.

- **Large porous air tissue (aerenchyma) found in deep roots and not in surface roots to adapt to poor oxygen conditions**



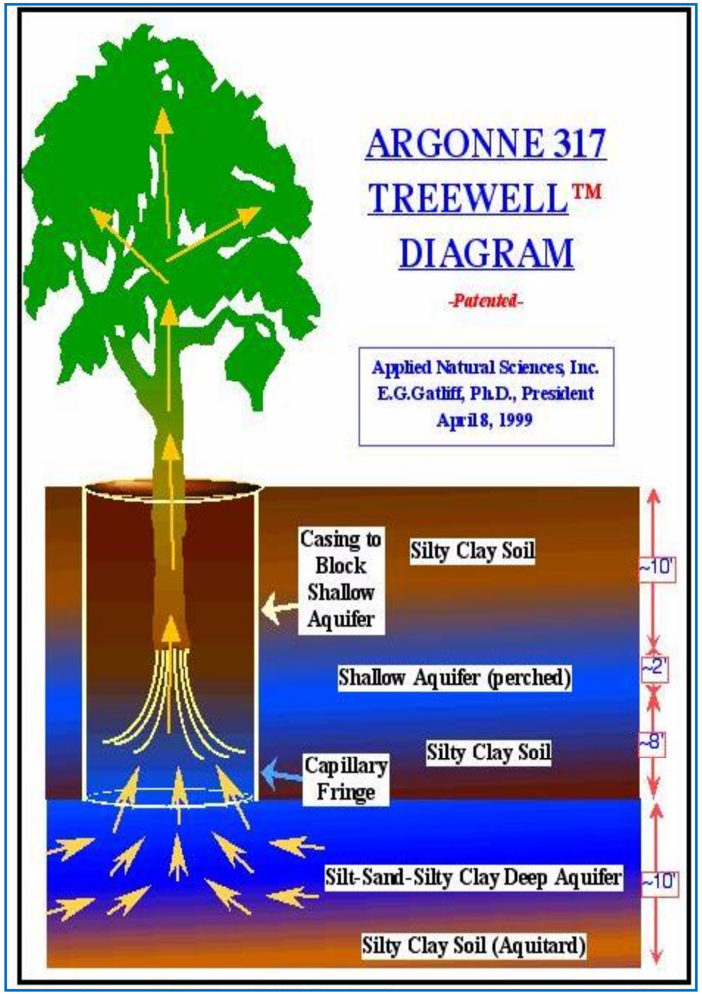
Managing rooting depth in Populus spp

- Activating the deep rooting response:

  Genetically enabled, environmentally activated.

  – Now: by engineering their growth conditions
  – Tomorrow: genetic engineering

Unique opportunity to determine rooting depth through tracer studies

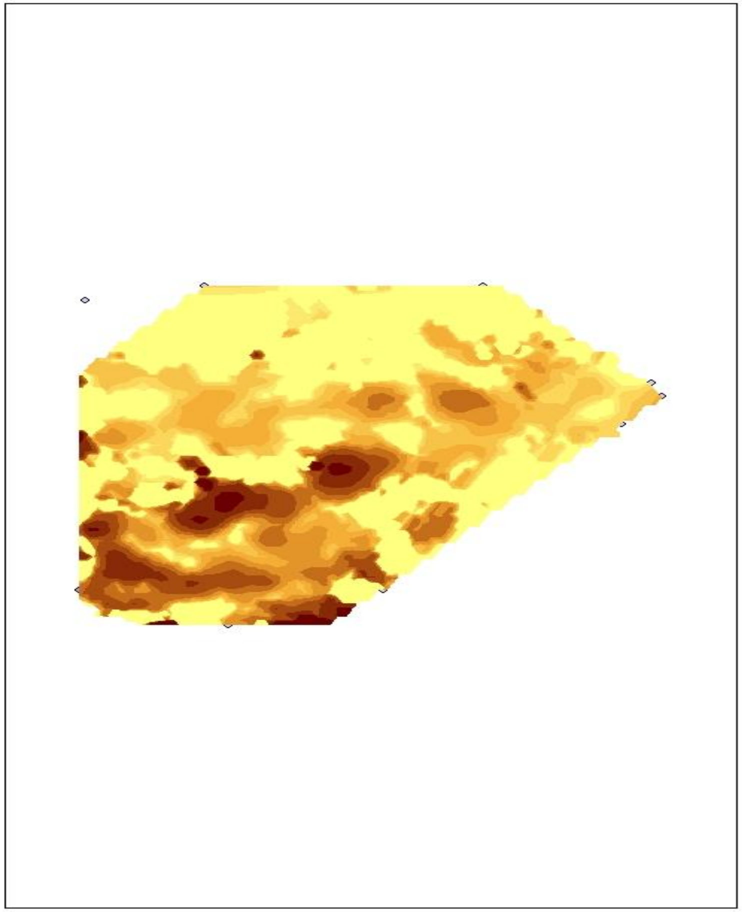


Useful clues from tree tissue analysis

• Collect tree tissue samples to determine access to degraded water (contaminated groundwater at this site)
• Approximately 240trees sampled

• Samples analyzed using a 4 hour extraction into the headspace at 90C
• Injection into a 5890 HP GC with ECD

Results from the field



- Used the geostatistics tool, universal kriging, to develop maps of the tree data

- Trees clearly showed that they are taking up the chemicals and hence the degraded water
- Land used here is marginal as it is contaminated land that is not being used for other purposes

Trichloroethylene (TCE) plume map from tree branch tissue samples

Sizing the opportunity

Spatial analysis on model state (Nebraska)

Inventorying land resources at the state/regional level:

Alternative sources of land that are not in competition for food:

Marginal land as CRP land

- Land resources considered to date are CRP, fallow and idle crop land
  - 39 million acres available across nation; 8% of available agricultural land base (455 million acres) (ORNL Billion Ton study, 2005)
  - 312 million tons of biomass from all available CRP land (~8 tons/acre)
  - This would meet ~30% of the demand required to convert 30% of the energy needs of the US from fossil fuels

Riparian and roadway buffer strips

- Roadway strips used in California for runoff capture (Caltrans, 2008)
- Riparian buffers used in Sweden for nutrient capture (Borjesson, 1999)
- Buffer strips width range from 15 ft to 150 ft

Inventorying water resources at the state/regional level: methods

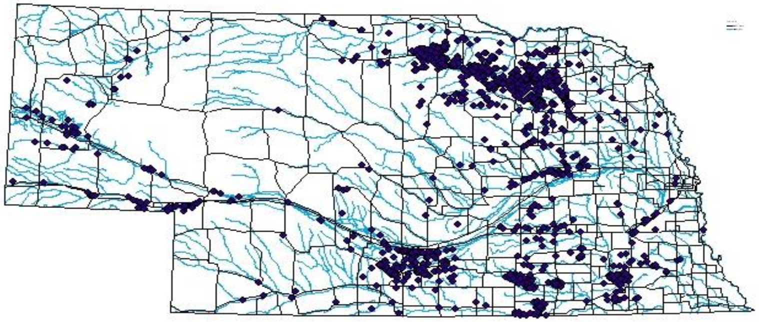
Alternative sources of water that are not in competition for other uses such as irrigation, drinking water

- Nitrate contaminated groundwater
  - Approximately 13% of shallow groundwater in the United States is contaminated with nitrate (Nitrate in groundwater, USGS report 2001)
- Reclaimed municipal wastewater for growing willow crops (Borjesson and Berndes 2006).
- Wastewater from livestock farms – will depend on quality

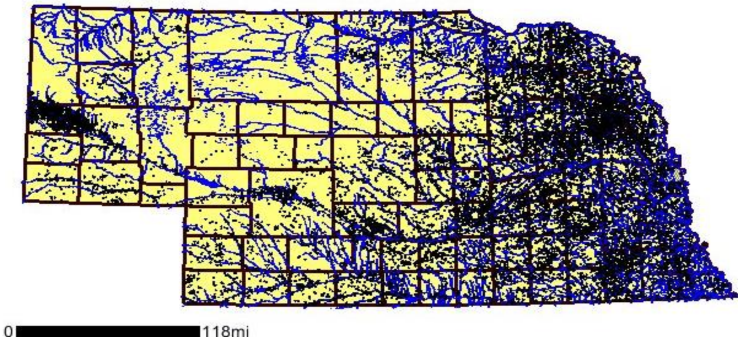
Data sources

- Nebraska Dept of Environmental Quality databases for nitrate-contaminated groundwater, livestock and wastewater locations and contaminated land
- USDA NASS database for CRP land
- ESRI databases for roadways, rivers
- Used ArcGIS v9.3 to develop maps of these resources

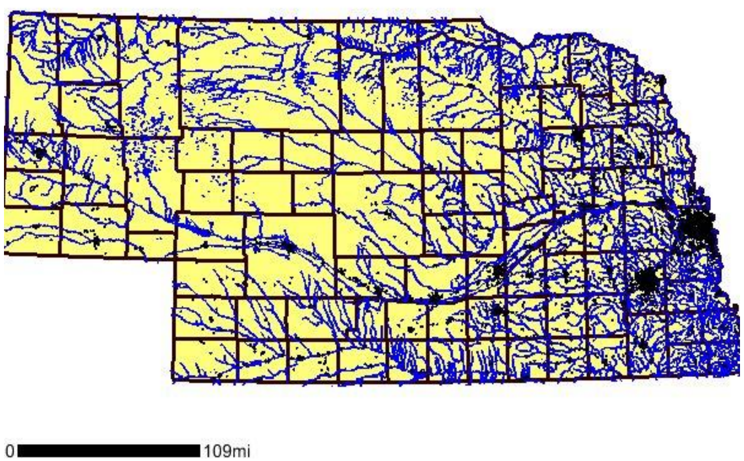
Results: Spatial analysis of resources for Nebraska



Nitrate contaminated groundwater (source: NDEQ 2005)



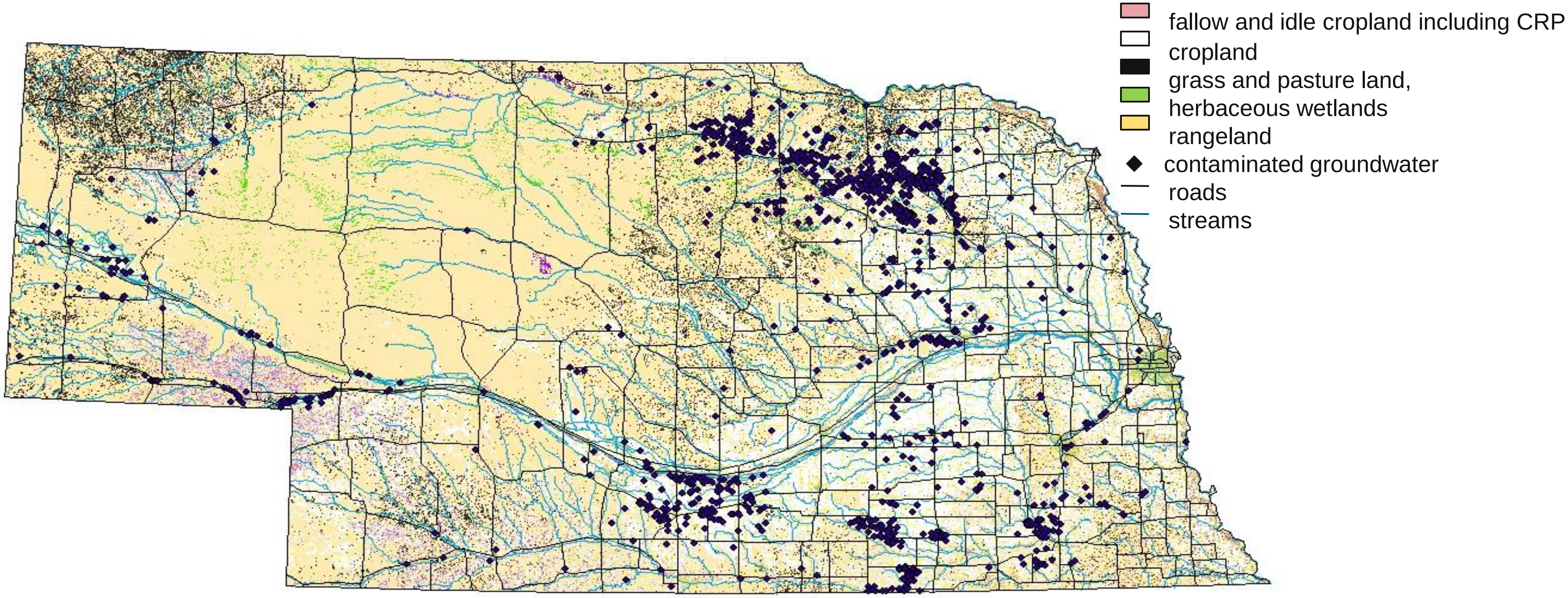
Livestock facilities (source: NDEQ 2008)



Municipal wastewater facilities (source NDEQ 2008)

Type of land	Area (million acres)		
Marginal agricultural land	1.5 ± 0.3		
		Buffer width (10m)	Buffer width (50 m)
	Length ($m*10^6$)	Area (million acres)	Area (million acres)
Major roadways	16.7 ± 0.9	0.082	0.414
Minor roadways	195.1 ± 10.6	0.964	4.82
Perennial streams	28.6 ± 1.3	0.098	0.493
Seasonal streams	102 ± 5	0.507	2.13

Overlap of marginal land and water resources



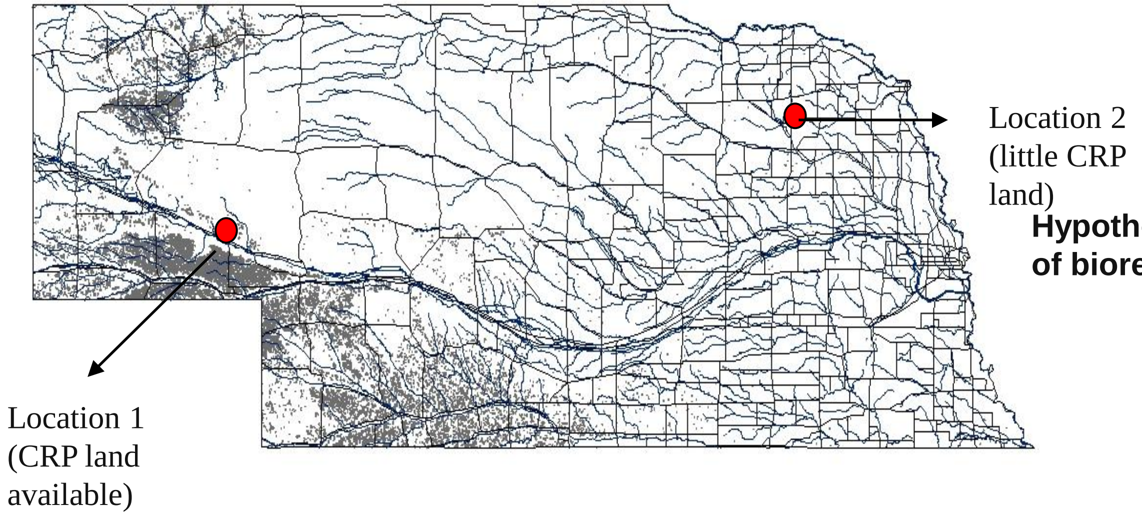
Riparian and roadway buffer strips overlap 48 – 50% with degraded groundwater resources

Little overlap between the areas of nitrate contaminated groundwater, livestock facilities and CRP land (2% of CRP land overlaps)

Resource recovery by N-scavenging perennials (woody, other) could address surface and groundwater quality and GHG emissions through direct and indirect N_2O control.

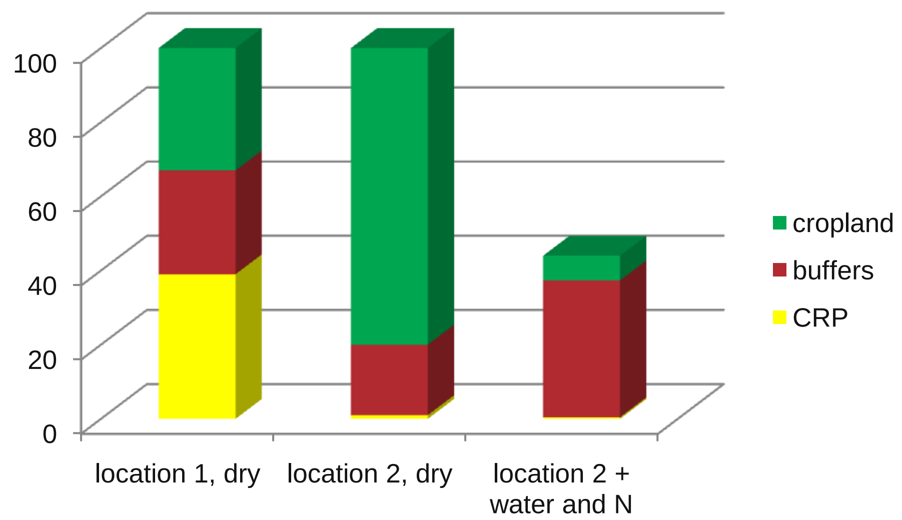
Intensification of feedstock supply to biorefineries

assuming a 25 mile radius supply area, for a 80 MGY ethanol plant (~2200 t/day biomass)



Hypothetical locations of biorefineries

Acreage required (thousand acres) to supply a 80 MGY ethanol plant



Summary

- Land use
  - Riparian buffer strips and roadway strips in combination with nitrate contaminated groundwater
  - Using buffer strips and marginal land could increase the contribution of biofuels to Nebraska's energy demands to 22% from 2%
- Water use
  - Water for irrigating biofuel crops available from livestock farms and from contaminated groundwater sources
  - Water quality benefits
    - Contaminated aquifers improved through nitrate removal – Clean aquifer reserved for other uses
    - Buffer strips could intercept run-off to the rivers and from roadways, thus protecting water quality for other purposes
- Other benefits
  - Nutrients (nitrate and phosphorus) obtained from alternative water source; thus fertilizer requirements are reduced as well as cost/energy inputs of biofuel crops
  - Ecological diversity may be enhanced

Acknowledgements

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Questions?

Thank you!