Grand Challenges For Crop Production And Irrigation

Endangered Species

Non-point Pollution

Ecosystem Health

Watershed Management

Profitable Agriculture

Global demand for crops projected to grow dramatically as population/income continues to rise

Feed the World

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Biological Systems Engineering

University of Nebraska, Lincoln
Derrel Martin,
Biological Systems Engineering

Water-Food-Energy-Environment Nexus

Urban, Agriculture, Instream Flow

Water Security
Food Security
Energy Security
Ecosystem Security

Growing Population, Climate Change, …

Habitat, Biodiversity, Ecosystem Services, …

Biofuels, Hydropower, Energy Demand, …
What do you see in this picture?
• Many Perspectives
• Some of my thoughts.
Economic Impact of the Ability of Nebraska Agriculture to Irrigate - The Case of 2012

- 31,221 fewer jobs
- $11.0 billion in lower Output
- $5.5 billion in lower Total Value-Added
- $3.3 billion in lower Labor Income

<table>
<thead>
<tr>
<th>Impact Type</th>
<th>Employment</th>
<th>Labor Income</th>
<th>Total Value-Added</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Effect</td>
<td>-</td>
<td>($2,131,837,655)</td>
<td>($3,307,799,895)</td>
<td>($7,083,745,522)</td>
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<tr>
<td>Indirect Effect</td>
<td>(13,550)</td>
<td>($529,417,314)</td>
<td>($1,070,608,174)</td>
<td>($1,938,585,249)</td>
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<tr>
<td>Induced Effect</td>
<td>(17,672)</td>
<td>($643,189,735)</td>
<td>($1,150,415,492)</td>
<td>($1,947,118,568)</td>
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<tr>
<td>Total Effect</td>
<td>(31,221)</td>
<td>($3,304,444,704)</td>
<td>($5,528,823,562)</td>
<td>($10,969,449,338)</td>
</tr>
</tbody>
</table>

Drought Year
Good Commodity Prices
Probably Higher Impact than Normal

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Irrigation Development

Active Irrigation Wells ~ 93,000
$6-8 Billion Investment

Major development occurred in 70’s, but growth continues at about 2000 wells per year

Active Irrigation Wells (8/2012) = 93087
- 16% of National Irrigated Land is in Nebraska
- 90% of water withdrawal is for irrigation

Probably more than 9 million acres now

Agricultural Land Irrigated in 2007
Source: National Agricultural Statistical Service
Groundwater Level Changes Since Predevelopment

Aquifer Going Dry??

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Cumulative Groundwater Depletion 1900 Through 2008

Where is groundwater overdraft occurring?

≈ 4000 km³ in High Plains Aquifer

Saturated Thickness of Aquifer Defines Volume of Water Available

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Depletion as Fraction of Saturated Thickness of the Aquifer
(McGuire, 2011)

Depletions in southern High Plains > 50% of saturated thickness

Small area in Nebraska > 25% of saturated thickness

Aquifer Going Dry??

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### Characteristics of the High Plains Aquifer (McGuire, 2009)

<table>
<thead>
<tr>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>CO</td>
<td>8.6</td>
<td>79</td>
<td>120</td>
<td>3.7%</td>
<td>-17.4</td>
<td>14.5%</td>
</tr>
<tr>
<td>KS</td>
<td>17.5</td>
<td>101</td>
<td>320</td>
<td>9.8%</td>
<td>-63</td>
<td>19.7%</td>
</tr>
<tr>
<td>NE</td>
<td>36.6</td>
<td>342</td>
<td><strong>2,130</strong></td>
<td><strong>65.5%</strong></td>
<td><strong>-21.4</strong></td>
<td><strong>1.0%</strong></td>
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<tr>
<td>NM</td>
<td>5.4</td>
<td>51</td>
<td>50</td>
<td>1.5%</td>
<td>-10.3</td>
<td>20.6%</td>
</tr>
<tr>
<td>OK</td>
<td>4.2</td>
<td>130</td>
<td>110</td>
<td>3.4%</td>
<td>-12.2</td>
<td>11.1%</td>
</tr>
<tr>
<td>SD</td>
<td>2.7</td>
<td>207</td>
<td>60</td>
<td>1.8%</td>
<td>-0.6</td>
<td>1.0%</td>
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<tr>
<td>TX</td>
<td>20.4</td>
<td>110</td>
<td>390</td>
<td>12.0%</td>
<td>-140.1</td>
<td>35.9%</td>
</tr>
<tr>
<td>WY</td>
<td>4.6</td>
<td>182</td>
<td>70</td>
<td>2.2%</td>
<td>-2.3</td>
<td>3.3%</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>190</td>
<td>3,250</td>
<td></td>
<td>-267.5</td>
<td>8.2%</td>
</tr>
</tbody>
</table>

*Drainable Water in NE ≈ Half of Volume of Lake Michigan*
## Changes in High Plains Aquifer (1950 - 2011)

<table>
<thead>
<tr>
<th>State</th>
<th>Area-Weighted Water-Level Change, feet</th>
<th>Change In Water Storage, millions acre-feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colorado</td>
<td>-12.9</td>
<td>-14.8</td>
</tr>
<tr>
<td>Kansas</td>
<td>-23.5</td>
<td>-58.2</td>
</tr>
<tr>
<td>Nebraska</td>
<td>0.7</td>
<td>1.1</td>
</tr>
<tr>
<td>New Mexico</td>
<td>-15.2</td>
<td>-8.2</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>-11</td>
<td>-7.5</td>
</tr>
<tr>
<td>South Dakota</td>
<td>1.9</td>
<td>0.2</td>
</tr>
<tr>
<td>Texas</td>
<td>-38.9</td>
<td>-136.5</td>
</tr>
<tr>
<td>Wyoming</td>
<td>-1.1</td>
<td>-0.7</td>
</tr>
<tr>
<td>High Plains Aquifer</td>
<td>-13.9</td>
<td>-224.6</td>
</tr>
</tbody>
</table>

60% of Total Volume Depleted in Texas & 26% in Kansas

---

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Pumping From An Unconfined Aquifer
Where does the water come from?

Volume Depletion

Radial Flow

Well Discharge

Static Water Level

Pumping Water Level

Drawdown

Base of Aquifer
Affect of Pumping on Stream Flow

**Without Pumping**

Base flow → Contribution of Groundwater to Streamflow Depends on Height of Water Table Above Streambed ($H$)

**With Pumping**

Original Water Table

Water Table After Long-Term Pumping

$H$

Pump Discharge

Cone of Depression (not major factor unless very close to stream)

Major affect on baseflow is due to the drop of the static water level.
Cumulative Flow Changes in Republican River Basin

- No change in precipitation trend
- Decreasing portion of precipitation as streamflow
- Not all impact is due to irrigation, other land use practices influence outflow
- Need methods to assess all changes

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Impact today resulted from past actions, maybe decades ago
Shared Watersheds Exacerbates Conjunctive Management

Maintenance of Instream Flow is THE Issue for Downstream State/User
Endangered/Threatened Species → Big Instream Demand Flows for Non-Threatened Species May Also Increase

Colored watersheds are affected by endangered or threatened species

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Water Control Programs in Nebraska

- Allocation Programs Limit Volume of Pumpage Over a Period of Time
- Expansion Limits Restrict Development of New Wells or New Irrigated Areas
- Upper Big Blue Considering Allocation Program
- Other Western States Have Similar Issues/Programs

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Nebraska energy use for irrigation - 2007

- Approximately 8.6 million irrigated acres
- Use about 40 gallons of diesel fuel per acre per year
- About 1/3 of wells use diesel engines to lift and pressurize water
- If all land was irrigated with diesel powered engines:
  - About 340 million gallons of diesel fuel per year
  - @ $3/gallon > $1 billion per year for diesel fuel
- One of the largest uses of energy in agriculture
Nebraska’s Water Supply (average conditions)

- ~ 88% of Precipitation Goes to Evapotranspiration
- ~ 6% of Precipitation Goes to Increased Stream Flow
- ~ 8% of Evapotranspiration due to Irrigation

Precipitation = 575 mm/year

Surface Water Inflow = 23 mm/yr

ET = 505 mm/yr

Surface Water Outflow = 58 mm/year

Other Consumptive Use = 33 mm/yr

Irrigation Sustainability vs Sustainable Development

Seems simple but there are many questions and unintended consequences.

1. What to sustain, economy, ecosystems, …?
2. Balance upstream (rural) opportunity vs downstream thirst?
3. **What to do with ground water?**
4. What management timeframe?
5. Property rights versus “Community” good?
6. Define “Adaptive Management” strategy and benchmarks?
7. Need a systematic approach that is well conceived.
Activities Affecting Watersheds

- Groundwater Pumpage
- Farming Practices – Reduced Tillage, Less Runoff, More ET
- Terraces
- Reservoirs
- Cropping Patterns → Land Use Change
- Irrigation Efficiency
- Deficit Irrigation
- Expansion of Riparian Species that May Use More Water
- Biofuel Expansion
- Future Augmentation Projects to Capture “Flood” Flows
- …..

Need to assess all of these to manage the watershed

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Resource Management Tradeoffs

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Classic Tradeoff

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Performance Indices

Water Footprint
(Volume of Water/Unit Food):
• What is alternative use of land?
• How would the alternative land use affect the watershed?
• Useful but misleading??

Water Use Efficiency or Water Productivity:

\[
WUE = \frac{Yield}{Irrigation \ Water \ Withdrawn} = \frac{Crop}{Drop}
\]

= \frac{Irrigated \ Yield - Rainfed \ Yield}{Irrigation \ Water \ Withdrawn}

• More useful but
• Does not show how to improve
• Where to spend efforts?
• Maximizing WUE \rightarrow \text{ Don’t irrigate}
• How to feed 9 billion people?

Water Footprint is High Here
What Else To Do With Land?
Breaking Down Water Use Efficiency - Productivity

\[
\frac{\text{Yield}_{\text{irr}} - \text{Yield}_{\text{rainfed}}}{\text{Trans}_{\text{irr}} - \text{Trans}_{\text{rainfed}}}
\]

Genetics

Agronomy

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Biological Systems Engineering
Breaking Down Water Use Efficiency - Productivity

\[
\frac{\text{Trans}_{\text{irr}} - \text{Trans}_{\text{rainfed}}}{\text{ET}_{\text{irr}} - \text{ET}_{\text{rainfed}}}
\]

Field Practices

- Reduced Tillage
- Residue Management
- Improved Water Application
- Deficit Irrigation

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Derrel Martin,
Biological Systems Engineering

Breaking Down Water Use Efficiency - Productivity

\[
\frac{\text{ET}_{\text{irr}} - \text{ET}_{\text{rainfed}}}{\text{Root Zone Storage}}
\]

Utilize Soil Water for Beneficial Uses

- Measure & Manage Soil Water
- Measure & Predict Evapotranspiration
- Schedule Irrigations

Irrigation Scheduling

Checkbook Method

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Breaking Down Water Use Efficiency - Productivity

Root Zone Storage
Irrigation Application

Maximize Efficiency of Application

Better Accounting of Where the Water Goes

ET
Surface Loss

Transpiration
Droplet Evaporation
Overspray and/or Drift
Canopy Evaporation

Soil Evaporation

Infiltration
Runoff Redistribution
Deep Percolation

Nebraska
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Breaking Down Water Use Efficiency - Productivity

Irrigation Application
Withdrawal

Control Water to Maximize Beneficial Use and Protect Water Quality
Opportunities for Improvement

River and Watershed Systems and Management

On-Farm Systems & Management

Plant Productivity
& Water Use

Where does the water go?
Must be interdisciplinary.
Need better accounting tools.

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Innovation

New Applications for Existing Systems

New Products

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Soil Water Monitoring

Excellent Recent Developments to Improve Management to Conserve Water and Energy, and Protect Water Quality

Satellite Communication

Sensors

Data Logger

Wireless Network

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**Decision Support Systems**

- Technology outpacing ability to manage
- Important role is to develop management aids
- Need on-farm and watershed tools
- Stronger interdisciplinary efforts
- More modesty in promotion
- Need to integrate individual developments

[websoilsurvey.nrcs.usda.gov]

Variable Rate Irrigation

[SoyWater]

[Water Optimizer]

[Hybrid-Maize]
Management for Soil Protection and Water Conservation

Continue evolution of tillage for soil, water and energy conservation
CRP reverting to cropland → what are the impacts?
How does it affect streamflow?
Impact of Land Use on Streamflow

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Increase Irrigation Efficiency

1. Reduces Runoff, Deep Percolation and Labor Input
2. Can Apply Smaller Depths When Water Is Needed
3. Could Irrigate More Land or Land That Was Previously Impractical
4. Diminishes Energy Use And Groundwater Pollution

But, What Is The Impact Of Increased Efficiency On The Watershed?

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• Manage watersheds by accounting for where the water goes.
• Developing tools for water transfers and offsets to meet instream flow needs
Benefits of Technology

Past improvements irrigator focused, not watershed

- Improvements not always beneficial to watershed
- Innovation for watershed enhancement is possible
- Hopefully win-win advancements
- Who will pay for watershed technology?
# Examples of Impact of Land Use at Farm and Watershed Levels

<table>
<thead>
<tr>
<th>Practice / Impact</th>
<th>Crop Production</th>
<th>Streamflow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved Irrigation Efficiency</td>
<td>🌼🌼🌼🌼</td>
<td>🥷愫愫愫愫</td>
</tr>
<tr>
<td>Runoff Reduction</td>
<td>🌼🌼🌼🌼</td>
<td>🥷愫愫愫愫</td>
</tr>
<tr>
<td>Deep Percolation Reduction</td>
<td>🌼🌼🌼🌼</td>
<td>🥷愫愫愫愫</td>
</tr>
<tr>
<td>Evaporation Reduction</td>
<td>🌼🌼🌼🌼</td>
<td>🥷愫愫愫愫</td>
</tr>
<tr>
<td>Improved Irrigation Scheduling</td>
<td>🌼🌼🌼🌼</td>
<td>🥷愫愫愫愫</td>
</tr>
<tr>
<td>Conservation Tillage:</td>
<td>🌼🌼🌼愫愫</td>
<td>🥷愫愫愫愫</td>
</tr>
<tr>
<td>Enhanced Infiltration – Less Runoff</td>
<td>🌼🌼🌼愫愫</td>
<td>🥷愫愫愫愫</td>
</tr>
<tr>
<td>Increased Crop ET and Productivity</td>
<td>🌼🌼🌼愫愫</td>
<td>🥷愫愫愫愫</td>
</tr>
<tr>
<td>Reduced Evaporation from Soil</td>
<td>🌼🌼🌼愫愫</td>
<td>🥷愫愫愫愫</td>
</tr>
<tr>
<td>Canal Lining and Automation</td>
<td>🌼🌼🌼愫愫</td>
<td>🥷愫愫愫愫</td>
</tr>
<tr>
<td>Seepage and Spill Reduction</td>
<td>🌼🌼🌼愫愫</td>
<td>🥷愫愫愫愫</td>
</tr>
<tr>
<td>More Water Delivered</td>
<td>🌼🌼🌼愫愫</td>
<td>🥷愫愫愫愫</td>
</tr>
<tr>
<td>More Water Retained in Storage</td>
<td>🌼🌼🌼愫愫</td>
<td>🥷愫愫愫愫</td>
</tr>
</tbody>
</table>
Must Focus on Needs of Clients / Stakeholders

- Our clients are not all the same
- We have to design for variability and acceptance

Private ownership of 93% of land in Great Plains

Must consider how stakeholders are affected
<table>
<thead>
<tr>
<th><strong>Need Based Issues</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Groundwater / streamflow depletion due to pumping → Sustainability</td>
</tr>
<tr>
<td>2. Groundwater pumping allocation → Deficit irrigation</td>
</tr>
<tr>
<td>3. Limitations on irrigation development → Transfer programs</td>
</tr>
<tr>
<td>4. Streamflow &amp; recharge reduction from land use changes</td>
</tr>
<tr>
<td>5. Competition agricultural, environmental, ecological, and domestic</td>
</tr>
<tr>
<td>6. Consumption of energy for pumping water</td>
</tr>
<tr>
<td>7. Improve productivity for burgeoning global need for food and fuel</td>
</tr>
<tr>
<td>8. Great Plains applies to semi-arid &amp; subhumid areas around world</td>
</tr>
</tbody>
</table>

**Avoid chasing opportunities**
What an Exciting Future – Think of the Possibilities
Look at Recent Developments

GMO Crops
Encapsulated Fertilizer
Soil/Plant Monitoring
Satellite Communication
Auto Steer Vehicles

ET from Remote Sensing
Variable Rate Irrigation
Monitoring with Unmanned Vehicle

How do we put it all together

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You've said enough

Thank You, Questions?

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