Integrated Assessment of Climate Change Impact in Typical Agricultural River Basin of the Midwestern US

Hyunhee An*, Hua Xie
J. Wayland Eheart and Edwin Herricks
EPA Region 5 Chicago, July 14, 2004
Projects

- US. EPA Star program: Award No. EPA R827451-01

Publications


- Hyunhee An and W Eheart, Investigation of Trading of stream withdrawal permits in traditionally humid areas, Annual meeting of EWRI, Roanoke, VA, May 19-22, 2002

- Hua Xie and J. W. Eheart, Assessing Vulnerability of Water Resources to Climate Change in Midwest, Annual meeting of EWRI, Philadelphia, PA, June 23-26, 2003

- Hyunhee An and J. W Eheart, Evaluations of regulatory programs that constrain water withdrawals based on a regulated riparian legal foundation, Annual meeting of EWRI, Salt Lake City, UT, June 27-July 1, 2004

- Hua Xie and J. W. Eheart, Implications of Climate Change for a Typical Agricultural River Basin of the Midwestern US, Annual meeting of EWRI, Salt Lake City, UT, June 27-July 1, 2004
Mackinaw River Basins

Legend
- **Watershed Boundary**
- **Major Streams**

Scale:
- 0 20 40 60 80 100 Kilometers
- 0 20 40 60 Miles
- 0 30 60 90 120 Kilometers
Study Basin: Economy & Ecology
1. Selection of climate change scenarios
2. Mitigation efforts: irrigation, alternative crops
3. Selection of criteria to demonstrate impacts: LF and Profits
4. Model Run and analysis
1. Selection of
Climate change scenarios
Two GCMs for climate change scenarios

(National Assessment Synthesis Team, 2000)

More frequent droughts with irregular rainfall
Canadian Model

Temperature & Precipitation

Data Source: Oklahoma City, OK

Atmospheric CO2

Increased use of fossil fuels ➞ 700 ppm by 2100

National Assessment Synthesis Team, 2000
Climate change scenarios

1. Current climate
   - Bloomington, IL, 1963-1992

2. Future climate
   - Oklahoma City, OK 1963-1992 (CO2= 350ppm)
   - Oklahoma City, OK 1963-1992 (CO2= 700ppm)
2. Mitigation efforts
Basin response to climate change

Plant biomass development
Evapotranspiration
Precipitation
Crop yield
Irrigation
Streamflow

Photo from Jian-Ping Suen
Mitigation efforts

- Irrigation

- Alternative crops
  - Corn
  - Soybean
  - Double cropping (Soybean + winter wheat)
3. Selection of criteria to demonstrate impacts:

- Low flow frequency
- Profits
Criterion 1
Vulnerability of Regional Water Resources:
Low flow frequency

Low flow standard $Q_{10}$
**Criterion 2**

**Impacts on agricultural economy**

- Farmers’ aggregate Profits

\[
\text{profits} = \sum_t \sum_i (Y_{it} \times CP - IR_{it} \times VIRC_{it} - FIRC_{it} - NIRC_{it}) \times A_i
\]

- \(Y_{it}\) = crop yields (bushel/ha-yr)
- \(CP\) = Crop market price ($/bushel)
- \(IR_{it}\) = the amount of irrigation (mm/yr)
- \(VIRC_{it}\) = variable irrigation cost ($/ha-mm)
- \(FIRC_{it}\) = fixed irrigation cost ($/ha-yr)
- \(NIRC_{it}\) = Non-irrigation cost for crop production ($/ha-yr)
Assessment Framework

<table>
<thead>
<tr>
<th>Scenario</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current climate +</td>
<td>Future climate + un-</td>
<td>Future climate +</td>
<td></td>
</tr>
<tr>
<td>un-irrigated</td>
<td>irrigated agriculture</td>
<td>irrigated agriculture</td>
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<tr>
<td>Criteria</td>
<td>Profits &amp; Low flow frequency</td>
<td>Profits &amp; Low flow frequency</td>
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<tr>
<td>The direct effects</td>
<td>The effects of irrigation</td>
<td></td>
<td></td>
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<tr>
<td>of climate change</td>
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<tr>
<td>Alternative crops –</td>
<td>Corn / Soybean / Soybean + winter wheat</td>
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</tbody>
</table>
4. Model Runs and Analysis
SWAT (Soil & Water Assessment Tool)

- SWAT is a river basin scale hydrological and agricultural model
- Predicts water movement, impacts of land management practices in a watershed with varying landuse and soil types under given climate
Model performance – Corn Yields

USDA: US Department of Agriculture

FBFM: Illinois Farm Business Farm Management Association
Model Performance - Hydrograph


Streamflow (m$^3$/s)

- Observed
- SWAT
Results
Results - corn yields

- IL (350ppm): Baseline
- OK (350ppm): -20%
- OK (700ppm): 16%
## Field experiments

<table>
<thead>
<tr>
<th>CO2</th>
<th>Corn yields (ton/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>370ppm</td>
<td>9.4</td>
</tr>
<tr>
<td>550ppm</td>
<td>11.8</td>
</tr>
</tbody>
</table>

*Uribelarrea et al., 2003*
**Profits – Cumulative distribution**

![Cumulative distribution graph showing fraction less than profits (in $/ha-yr) for different conditions.](image_url)
Low Flow Frequencies - CDF
near Congerville

Low Flow Days

Fraction Less Than

- IL-no irr(350ppm)
- OK-no irr(350ppm)
- OK-irr-SW+GW(350ppm)
- OK-irr-SW(350ppm)
- OK-no irr(700ppm)
- OK-irr-SW+GW(700ppm)
- OK-irr-SW(700ppm)
Low Flow Frequencies - CDF
near Green Valley
## Alternative crops – Profits

<table>
<thead>
<tr>
<th>($/ha-yr)</th>
<th>Corn</th>
<th>Soybean</th>
<th>Double cropping</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL-noirr</td>
<td>219.20</td>
<td>268.32</td>
<td>-</td>
</tr>
<tr>
<td>OK-no irr(350ppm)</td>
<td>54.85</td>
<td>148.26</td>
<td>150.23</td>
</tr>
<tr>
<td>OK-irr(350ppm, capital costs)</td>
<td>37.18</td>
<td>48.56</td>
<td>27.76</td>
</tr>
<tr>
<td>OK-irr(350ppm, no capital costs)</td>
<td>198.24</td>
<td>209.62</td>
<td>188.82</td>
</tr>
<tr>
<td>OK-no irr(700ppm)</td>
<td>349.26</td>
<td>474.82</td>
<td>534.13</td>
</tr>
<tr>
<td>OK-irr(700ppm, capital costs)</td>
<td>200.04</td>
<td>317.28</td>
<td>374.15</td>
</tr>
<tr>
<td>OK-irr(700ppm, no capital costs)</td>
<td>361.09</td>
<td>478.34</td>
<td>535.20</td>
</tr>
</tbody>
</table>
## Alternative Crops – Low flow frequency

<table>
<thead>
<tr>
<th></th>
<th>Corn</th>
<th>Soybean</th>
<th>Double cropping</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL</td>
<td>4.83</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OK-noirr(350ppm)</td>
<td>27.97</td>
<td>17</td>
<td>28.07</td>
</tr>
<tr>
<td>OK-irr-SW+GW(350ppm)</td>
<td>48.77</td>
<td>24.4</td>
<td>39.43</td>
</tr>
<tr>
<td>OK-irr-SW(350ppm)</td>
<td>58.67</td>
<td>37.37</td>
<td>49.43</td>
</tr>
<tr>
<td>OK-no irr(700ppm)</td>
<td>0.23</td>
<td>0.00</td>
<td>0.83</td>
</tr>
<tr>
<td>OK-irr-SW+GW(700ppm)</td>
<td>5.83</td>
<td>1.13</td>
<td>0.83</td>
</tr>
<tr>
<td>OK-irr-SW(700ppm)</td>
<td>5.93</td>
<td>1.13</td>
<td>0.83</td>
</tr>
</tbody>
</table>
**Summary**

<table>
<thead>
<tr>
<th></th>
<th>OK climate [CO_2]=350ppm</th>
<th>OK climate [CO_2]=700ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agricultural Productivity</strong></td>
<td>Worse</td>
<td>Same / better</td>
</tr>
<tr>
<td><strong>Low flow frequency</strong></td>
<td>Worse</td>
<td>Worse</td>
</tr>
</tbody>
</table>

**Alternative crops** – similar results as corn
Implications

- Climate change could leave basins more or less unchanged
- Irrigation could threaten health of aquatic systems
  ➔ Regulatory program to control surface water withdrawals in IL
Limitations

- Uncertainty
  - climate change scenarios
  - Down-scaling techniques
  - Model adequacy for simulating elevated CO$_2$
  - Model adequacy for simulating double cropping
Acknowledgements

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Questions??

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