From the cornbelt to the north woods; understanding the response of Minnesota watersheds to climate change

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BBE Department
1. Background

- **Differential response of MN watersheds to climate change** (John Nieber, co P.I.)
  - Funded by WRC/USGS grant
  - Genesis - to understand difference between north and south; to understand gap between Q:P ratio, rainfall change and streamflow change
Outline

1. Background and approach
2. Rainfall and streamflow trends, before and after 1980; IHA and Q:P analysis
3. Causes of streamflow change
4. Application to Future
5. Management implications
6. Discussion and Next Steps
Approach: learning from recent response to climate change

Climatology perspective

Hydrology perspective: on-the-ground (or streambed)
Comparing recent (30 yrs) climate change to GCM predictions

- GCMs: more variability, flooding and drought
- Southern vs. northern MN response
- Large floods not increased significantly
- Low to mod. High flows have increased
- Variability decreased (c.v.)
- Northern MN – earlier snowmelt runoff; greater winter flow
The other inconvenient truth
Jon Foley (IonE)

- Climate change doesn’t happen in isolation
- Other impacts can override climate change “signature”
  - Land-use / drainage change
  - Groundwater withdrawal: Rio Grande
  - Long-term oscillations
2. Methods

• Focus on hydrologic processes /water budget, not any single component.
  - Rainfall-runoff \((Q: P)\) ratio
  - Indicators of Hydrologic alteration (IHA) stats
  - Variability (c.v.)
  - Intermittent vs. perennial flow

• Modeling of soil water balance with SWAP

• Identify management issues by region
Research questions

• How has Q:P ratio changed by region and season?
• How have timing, volume, duration and frequency changed as well as magnitude?
• How well does past inform us about future streamflow trends?
• What are the management implications of these findings?
3. Findings: precipitation trends

- Trends since 1980 by climate regions
- Statewide trend

| Precipitation change in Minnesota and Wisconsin since 1980 in cm of annual rainfall |
|-----------------------------------------------|-----------------------------------------------|
| Wisconsin | pre-1980 annual mean (cm) | post-1980 annual mean (cm) | Annual change (cm) | % change |
| NW WI      | 76.9                        | 81.0                        | 4.02               | 5.2%     |
| NC WI      | 81.1                        | 82.4                        | 1.29               | 1.0%     |
| NE WI      | 76.4                        | 79.7                        | 3.31               | 3.8%     |
| WC WI      | 78.2                        | 85.5                        | 7.30               | 9.1%     |
| C WI       | 78.7                        | 83.4                        | 4.68               | 5.9%     |
| EC WI      | 73.3                        | 78.7                        | 5.43               | 7.4%     |
| SW WI      | 82.1                        | 89.0                        | 6.86               | 8.3%     |
| SC WI      | 80.1                        | 89.3                        | 9.21               | 11.5%    |
| SE WI      | 78.8                        | 87.4                        | 8.61               | 10.9%    |
| Minnesota  |                            |                             |                    |          |
| NW MN      | 66.2                        | 60.2                        | 4.00               | 9.0%     |
| NC MN      | 63.8                        | 66.3                        | 2.48               | 3.9%     |
| NE MN      | 76.4                        | 79.7                        | 3.31               | 4.3%     |
| WC MN      | 78.2                        | 85.5                        | 7.30               | 9.3%     |
| C MN       | 65.9                        | 73.8                        | 7.93               | 12.0%    |
| EC MN      | 70.4                        | 77.5                        | 7.13               | 10.1%    |
| SW MN      | 62.1                        | 71.1                        | 9.05               | 14.6%    |
| SC MN      | 71.5                        | 81.8                        | 10.31              | 14.4%    |
| SE MN      | 75.8                        | 85.9                        | 10.16              | 13.4%    |
Annual Precip - South Central MN

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Streamflow response in recent past

- IHA stats used to compare 1980-2008 to pre-1980
  - magnitude
  - mean
  - duration
  - timing, frequency
  - environmental flows
  - extreme flows

- Why differential response between North and South?
- Runoff is a function of many variables
The doctrine of extremes

- Engineering hydrology has focused on extremes
- Ecological hydrology concerned with timing, duration, volume also

Blue Earth River - mean monthly flow

1940-1979
1980-2008

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Streamflow magnitude

- % change to mean annual flow

<table>
<thead>
<tr>
<th>Watershed</th>
<th>% change</th>
<th>Dominant land cover in watershed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue Earth</td>
<td>+81.8%</td>
<td>agricultural</td>
</tr>
<tr>
<td>Bois Brule</td>
<td>-2.6</td>
<td>Northern forest</td>
</tr>
<tr>
<td>Brule</td>
<td>-1.7%</td>
<td>northern forest</td>
</tr>
<tr>
<td>Buffalo</td>
<td>+41.8%</td>
<td>mixed</td>
</tr>
<tr>
<td>Chippewa</td>
<td>-12.5%</td>
<td>northern forest</td>
</tr>
<tr>
<td>Des Moines</td>
<td>+127.0%</td>
<td>agricultural</td>
</tr>
<tr>
<td>Little Fork</td>
<td>+7.66</td>
<td>northern forest</td>
</tr>
<tr>
<td>Minnesota</td>
<td>+79.8%</td>
<td>agricultural</td>
</tr>
<tr>
<td>Mississippi (at G.R)</td>
<td>+20.4%</td>
<td>northern forest</td>
</tr>
<tr>
<td>Mississippi (at St. Paul)</td>
<td>+54.1%</td>
<td>mixed</td>
</tr>
<tr>
<td>Oconto</td>
<td>-9.3%</td>
<td>northern forest</td>
</tr>
<tr>
<td>Pigeon</td>
<td>-3.6%</td>
<td>northern forest</td>
</tr>
<tr>
<td>Red</td>
<td>98.5%</td>
<td>agricultural</td>
</tr>
<tr>
<td>Red Lake</td>
<td>+32.30%</td>
<td>mixed</td>
</tr>
<tr>
<td>Root</td>
<td>+60.10%</td>
<td>mixed</td>
</tr>
<tr>
<td>Sugar</td>
<td>+24.2%</td>
<td>agricultural</td>
</tr>
<tr>
<td>St. Croix</td>
<td>+2.0%</td>
<td>northern forest</td>
</tr>
<tr>
<td>Sturgeon</td>
<td>1.15%</td>
<td>northern forest</td>
</tr>
<tr>
<td>Yellow Medicine</td>
<td>103.0%</td>
<td>agricultural</td>
</tr>
</tbody>
</table>

Table 2: changes to mean annual streamflow. Percentage change from 1980-2008 time period compared to pre-1980 period. The pre-1980 stream flow record ranges from 47 to 90 years.
Median monthly flows

(aggregate of sites)
Mean monthly flow change

Mean monthly flows for Minnesota River @ Mankato between 1903-2007

Q (cfs)

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

1980-2007
1903-1979
1903-1950
1990-2007
1903-1929
1903-1925

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Flow duration

Minnesota River @Mankato
Low flow trends
(median of low daily flows for month)

North - Sturgeon River
Pink 1980-2010; Blue 1940-1980

South - Minnesota River
Pink 1980-2010; Blue 1940-1980
Timing

- Northern forested watersheds: winter low flow increases, earlier snowmelt
- Southern Ag: peaks - no consistent trends
- Increased summer flows, decreased “drawdown” period
Extreme events

- # of low and high pulses
  - No sig. diff in north
  - Fewer low flow pulses in most southern MN rivers

- Extreme flows (floods and droughts) e.g. about 10 year flood. No sig. increase

Root River large floods
Variability of flow

- Coefficient of variation (c.v.) declined at all sites
  - Yellow Medicine: -40% (4.0 to 2.4)
  - Bois Brule: no sig change (0.48 to 0.42)
- Groundwater-fed streams more stable
- Eastern forest region less variable than prairie / Great plains
Q:P ratio

- Why use Q:P?
- Indicator of change in hydrologic process

<table>
<thead>
<tr>
<th>Watershed name</th>
<th>Region (climate division)</th>
<th>Rainfall-streamflow ratio</th>
<th>Significance level</th>
<th>Significant at $\alpha = 0.10$</th>
<th>Significant at $\alpha = 0.05$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue Earth</td>
<td>SC MN</td>
<td>15.5%</td>
<td>24.6%</td>
<td>0.0023</td>
<td>yes</td>
</tr>
<tr>
<td>Bois Brule, WI</td>
<td>NW WI</td>
<td>41.0%</td>
<td>39.1%</td>
<td>0.3323</td>
<td>no</td>
</tr>
<tr>
<td>Buffalo</td>
<td>WC MN</td>
<td>14.0%</td>
<td>18.3%</td>
<td>0.0117</td>
<td>yes</td>
</tr>
<tr>
<td>Chippewa, WI</td>
<td>NC, NW WI</td>
<td>43.2%</td>
<td>37.6%</td>
<td>0.0528</td>
<td>yes</td>
</tr>
<tr>
<td>Des Moines</td>
<td>SC MN</td>
<td>10.5%</td>
<td>21.2%</td>
<td>0.0004</td>
<td>yes</td>
</tr>
<tr>
<td>Little Fork</td>
<td>NC MN</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Minnesota</td>
<td>SW, SC MN</td>
<td>9.8%</td>
<td>17.5%</td>
<td>0.0000</td>
<td>yes</td>
</tr>
<tr>
<td>Miss - St. Paul</td>
<td>C, NC, MN</td>
<td>14.8%</td>
<td>21.1%</td>
<td>0.0003</td>
<td>yes</td>
</tr>
<tr>
<td>Miss-Grand Rapids</td>
<td>NC MN</td>
<td>17.8%</td>
<td>20.0%</td>
<td>0.1786</td>
<td>no</td>
</tr>
<tr>
<td>Oconto, WI</td>
<td>NE WI</td>
<td>36.9%</td>
<td>32.7%</td>
<td>0.0106</td>
<td>yes</td>
</tr>
<tr>
<td>Pigeon</td>
<td>NE MN</td>
<td>42.0%</td>
<td>38.4%</td>
<td>0.1970</td>
<td>no</td>
</tr>
<tr>
<td>Red</td>
<td>NW MN</td>
<td>5.7%</td>
<td>10.4%</td>
<td>0.0000</td>
<td>yes</td>
</tr>
<tr>
<td>Red lake</td>
<td>NW MN</td>
<td>13.0%</td>
<td>15.2%</td>
<td>0.1230</td>
<td>no</td>
</tr>
<tr>
<td>Root</td>
<td>SE MN</td>
<td>25.2%</td>
<td>33.7%</td>
<td>0.0000</td>
<td>yes</td>
</tr>
<tr>
<td>St. Croix, WI</td>
<td>EC MN, NW WI</td>
<td>39.1%</td>
<td>36.6%</td>
<td>0.2323</td>
<td>no</td>
</tr>
<tr>
<td>Sturgeon</td>
<td>NC MN</td>
<td>33.5%</td>
<td>32.5%</td>
<td>0.6666</td>
<td>no</td>
</tr>
<tr>
<td>Sugar, WI</td>
<td>SC WI</td>
<td>28.2%</td>
<td>30.9%</td>
<td>0.0702</td>
<td>yes</td>
</tr>
<tr>
<td>Yellow Med</td>
<td>WC MN</td>
<td>5.6%</td>
<td>9.8%</td>
<td>0.0019</td>
<td>yes</td>
</tr>
</tbody>
</table>
Q:P significance (annual mean)
Significant Q:P changes by season

Summer

Fall
Q:P by month in Blue Earth River

Monthly mean precip. at Mankato
4. Causes of streamflow change

Not directly addressed in this study (see Engstrom and Schottler)

Climate

Land-cover change

Direct hydrologic alteration

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5. Future Streamflow trends

GCM predictions
• Hotter and drier
• More variable

But:
• E.T. vs P.E.T.
• Thresholds
• How long to reverse trend in south?
• Oscillations?

• SWAP (Soil Water Atmosphere Plant)
• H. Stefan – SWAT model
6. Management implications

• Quantity / Quality
  – Not just peaks important for TMDLs
• Geomorphology and sediment transport
• Ecology
  – Suitability of in stream habitat
  – Life cycle of organisms (timing, duration)
    • Turtle nesting
    • Cottonwood reproduction
Water quantity

• Changes to low flow/baseflow and intermittency
• Changes to median – high flows
Changes to flow duration
Geomorphic impacts of recent trends in southern MN

• Increased bank erosion/Channel widening
  – Increased duration of saturation
  – Increased mass wasting
  – Decreased revegetation

• Increased nutrient loading rates
Volume impacts: channel widening
Water quality impacts

• Total maximum daily loads link Quantity and Quality

• More flow = more pollution transport of dissolved substances
  – Nitrates
  – Sediment and Phosphorous less clear
  – Temperature and Oxygen related to flow level too
Stream temp impacts on fish
(Westenbroek, WI USGS)

**Coldwater**
- All 3 Decline
- Median -95.2%
- 1 Extirpated

**Warmwater**
- 4 Decline
- 4 No Change
- 23 Increase

**Coolwater**
- All 16 Decline
- Median -79.7%
- 5 Extirpated

**Median 34.0%**

Stream length gained or lost (%) vs. 50 Species
Ecological impacts

Study of life cycles of riverine organisms:
Assessing the Impacts of Hydrologic Alteration on Riverine Turtle Habitat – DNR SGCN grant
Wildlife impacts – turtle habitat

- Sandbars used for nesting
- Duration, timing and frequency of exposure changes
- Sediment regime change?
- Reduced nesting time; delay
Management issues

• General GCM predictions:
  – Increased flow variability
  – Greater ET (or at least P.E.T.)
  – Greater flood peaks

• Regional impacts—Driftless Area
  – Floods from tropical storm remnants (e.g. 2007-2008)
  – Cold water fisheries
Regional impacts:
South and West MN

• Minnesota Basin
  – Increased streamflow
  – Sediment and nutrient loads
  – Future thresholds towards decrease?

• Red River Basin
  – Flooding
  – Soil moisture
Northern Forest Regions

• North central forested lakes
  – Changes in forest cover/interception
  – Water quality of lakes

• North Shore streams
  – High gradient streams, shallow bedrock, low base-flow
  – Loss of forest-Development pressure
  – Sport fisheries and summer low flow

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Discussion & next steps

• What specific knowledge involving hydrologic processes is needed to make more accurate predictions with models?
• Downscaling and regionalization
• What do we know now that can be acted upon?
• Questions??
• Answers??