Streamflow Changes in the Upper Mississippi River Basin

Keith Schilling, Iowa DNR - Geological Survey, Iowa City, Iowa

Why is this important?

- MR is the longest and largest river in N. America covering all or parts of 31 states and 2 provinces
- MR and its basin provide important habitat for fish, wildlife and living ground for American people
- Human activities have greatly altered this river ecosystem
- Much of the basin is intensively cultivated and cultivation has reduced biodiversity, altered biogeochemistry, and impacted regional climates and basin hydrology.
- Many tributaries deliver substantial amounts of sediment, nutrients, and contaminants into the river contributing to many problems, including Hypoxia of the Gulf of Mexico.
- It is important to know the difference in amounts of nutrients and contaminants carried by surface runoff and baseflow order to effectively and efficiently deal with the problems.

Is the MR flow increasing?

We selected 8 USGS gauging stations and checked their Q

Station 1 – 4: Along the MR
Station 5 – 8: Outside the MR basin

Q at 4 USGS stations along MR since 1940s: An increasing trend

1. Clinton, IA: 45%
2. St. Louis, MO: 31%
3. Memphis, TN: 35%
4. Vicksburg, MS: 38%

Q at 4 USGS stations outside the MR basin since 1940s: Constant or decreasing

5. Columbia River at Dalles, WA:
6. Rio Grande River at Sun Felipe, NM:
7. Savannah River at Augusta, GA:
8. Susquehanna River at Harrisburg, PA:
What we observed…

• Large increases in Q were observed in most stations since 1940s around the red area;
  • these increases are statistically significant ($p < 0.01$)
• But increasing Q is not observed in some stations, i.e., Arkansas River.
• Increasing Q is not observed in some major rivers outside the MR basin;
• The finding of increasing Q is consistent with other studies
  • Lins and Slack (1999)
  • Schilling and Libra (2003)

What has caused increased streamflow?

• Precipitation has increased - P increased about 7% during the last 60 years
• However, increasing P alone not sufficient to explain magnitude of increase
• Fundamental change in rainfall/runoff relationship – Q increasing at greater rate than increasing P alone can explain
• Changes in land use/land cover

How has agriculture changed?

• In Iowa, changes in agricultural land use began around 1940
• Soybean acreage increased from 1 to 11 million acres from 1940 to 2000
• With corresponding increase in corn acreage, row crop acreage in Iowa increased approximately 30–40% from 1940-2000
How has the agriculture changed?

- Watershed scale

<table>
<thead>
<tr>
<th>Percentage of Land in Corn and Soybeans (by County)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0%</td>
</tr>
<tr>
<td>1920</td>
</tr>
</tbody>
</table>

- Regional scale - Iowa

Continental Scale: Mississippi River Basin

<table>
<thead>
<tr>
<th>Soybean acres (x 1000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>1940</td>
</tr>
</tbody>
</table>

What has changing land cover done to watershed hydrology?

<table>
<thead>
<tr>
<th>LAND COVER</th>
</tr>
</thead>
<tbody>
<tr>
<td>STREAM NITRATE</td>
</tr>
<tr>
<td>STREAMFLOW (BASEFLOW)</td>
</tr>
</tbody>
</table>

Difference in ET between perennial vs. annual crops

Single crop ET coefficients (Kc)

Estimated crop ET = Kc * PET

<table>
<thead>
<tr>
<th>Cover</th>
<th>Initial</th>
<th>Mid-season</th>
<th>Late season</th>
</tr>
</thead>
<tbody>
<tr>
<td>trees</td>
<td>0.5</td>
<td>1.10</td>
<td>0.65</td>
</tr>
<tr>
<td>pasture</td>
<td>0.4</td>
<td>1.5</td>
<td>0.85</td>
</tr>
<tr>
<td>grass</td>
<td>0.85</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>corn</td>
<td>0</td>
<td>1.2</td>
<td>0.35</td>
</tr>
<tr>
<td>soybeans</td>
<td>0</td>
<td>1.15</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Food and Agriculture Organization of the United Nations, 1992
LONG-TERM WATER BALANCE FOR THE MR BASIN

\[ P = Q + ET \]

- \( P \) – Precipitation
- \( Q \) – River flow
- \( ET \) – Evapotranspiration

Effect of land use change on river flow

- A basin covered by perennial grass
  \[ P_p = Q_p + ET_p \]
  \[ ET_p > ET_r \]
  \[ Q_r < Q_p \]

Q before 1940 is smaller than Q after 1940.

Effect of land cover on groundwater recharge (R)

\[ R = Q_b = \Delta S \]

- \( \uparrow \) more \( ET_p \)
- \( \uparrow \) less \( ET_r \)
- \( \downarrow \) less \( R_p \)
- \( \downarrow \) more \( R_p \)

Over long period of time \( \Delta S \rightarrow 0 \) and thus \( R = Q_b \)

\[ R_p > R_r \] so \( Q_b > Q_p \)

Thus, changing land cover from perennial to seasonal crops would result in an increase in baseflow.

What else has accompanied changing land use patterns?

- Tile drainage
What else has accompanied changing land use patterns?

• Improved conservation practices

Relation of land use to baseflow

Plot studies

Corn and soybeans have greater drainage and less ET than perennial grasses


Prediction of Baseflow using Multiple Linear Regression

\[ Q = 0.645(\text{RAIN}) + 0.0607(\%\text{SAND}) + 0.0519(\%\text{RC}) - 16.3 \]

\[ Q_b = 0.247(\text{RAIN}) + 0.047(\%\text{SAND}) + 0.063(\%\text{RC}) + 0.0142(\text{PERM}) + 0.0528(\%\text{ALLUV}) - 11.2 \]

Schilling and Wolter, JAWRA, 2006

Relation of land use to baseflow

Historical evidence – Raccoon River watershed scale

Seasonal Changes

Sig. increases in Q, Qb in all months but Feb, Mar
Largest increases occurring in Apr – July
Increasing Qb relative to P in all months but Feb and Mar
Streamflow changes in Raccoon River significantly correlated to changing land use patterns

Historical evidence – regional scale - Iowa
Baseflow increased in Iowa since mid-20th century

Q, BF & OF at 4 major tributaries in MR basin since 1940

Seasonal changes in Mississippi River at Keokuk
Relation of Baseflow in Mississippi River to Increasing Soybean Production

![Graph showing the relation between baseflow and soybean fractional area](image)

Zhang and Schilling, J. Hydrol., 2006

**Groundwater discharge as baseflow provides main source of nitrate to streams**

*For example, in two central Iowa watersheds, export of nitrate occurred primarily with baseflow (61-68%)*

![Graphs showing discharge and nitrate N](image)

Schilling and Zhang, J. Hydrol, 2004

**Baseflow contribution to N-loads in Raccoon River**

![Graph showing baseflow contribution to N-loads](image)

66.7% of nitrate delivered by baseflow

Schilling and Zhang, J. Hydrol, 2004

**Tile Drainage Contributes to Baseflow and Nitrate Concentrations and Loads**

![Images of tile drainage and water flow](image)
Relation of Row Crop Land Use to Nitrate Concentrations

\[ y = 0.1077x - 0.812 \]
\[ R^2 = 0.6501 \]

Schilling and Libra, JEQ, 2000

Historical Perspective
Nitrate concentrations in Iowa’s streams have increased since the mid-20th century

Conclusion
Changing land cover from perennial mixed cropping systems to row crops of corn and soybeans increased baseflow and has likely contributed to increasing nitrate-N losses from the agricultural Midwest.