Using a multi-method approach to quantify the spatial extent and hydrologic and water quality effects of subsurface tile drainage at local and regional scales

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30,000 – 10,500 years

- Pre-Illinoian Till
- Illinoian Till
- Wisconsinan Till
In the early 1800s, Iowa contained about 10 to 15 million ha of wetlands. About 99% of that acreage is gone.
Hydrologic Alterations – Wetland Drainage

Hand digging tile, Boone Co., IA, ca 1914
Source: "An Iowa album: a photographic history, 1850-1920" by M. J. Bennett, University of Iowa Press, Iowa City, Iowa.

Excavating a large ditch using steam power, circa 1910.

Major Periods of Drainage Development in the U.S.

Timeline showing primary periods of drainage development in the United States. Drainage development rates stabilized during the depression and war years (1920 to 1945) and again after 1960.
Why tile?

**Straight from the industry:**

- *Single best reason – increase crop yield*
- *Lower water table, reduces plant stress due to high moisture*
- *Increase land value*
- *Ease of field work*
- *Extra growing days*
Soils Requiring Tile Drainage

Comparison of criteria for soils requiring tile drainage

Upland hydric soils in the Iowa and Cedar River basins
Color infrared aerial photography with tile lines digitized in blue and drainage district mains in green. Total length of tiles is approximately 56 miles; total drainage district main is 3 miles.
Quantifying the magnitude and extent of tile impacts

• Spatial mapping using historical aerial photographs
• Field monitoring at a local scale
• Hydrograph separation
• Watershed modeling
• Scaling up impacts from local to regional scales
Tile Mapping Process

- Digitize line where tile is located
- Create Polygons over areas that cover a larger extent (pattern tile)
- Compile various statistics for both the amount of tile and the location found.

Figure 2: The process of digitizing tile lines and the area covered in ArcMap. First image is pre digitization, second has lines, third has the polygon.
Middle Cedar Tiling in HUC12s

- 2016 - 2,048,162.20 meters/1273 miles
- 2007 - 1,831,128.37 meters/1138 miles
- 2002 - 727,185.01 meters/452 miles

Last 10 years: average of ~1200 miles of new tile installed every year
Tile Impacts at a local farm scale

- Quantified the nutrient export from tiles and groundwater to a perennial stream
- Eight tile outlets, nine groundwater wells and the receiving stream were monitored
Geophysics

Water levels and stage
Nutrient loads from field were dominated by tile drainage

<table>
<thead>
<tr>
<th></th>
<th>NO3-N</th>
<th>OP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tile concentration (mg/l)</td>
<td>11.7</td>
<td>0.39</td>
</tr>
<tr>
<td>GW concentration (mg/l)</td>
<td>6.6</td>
<td>0.17</td>
</tr>
<tr>
<td>Tile load</td>
<td>28.81 kg/day</td>
<td>13.12 g/day</td>
</tr>
<tr>
<td>GW load</td>
<td>0.21 kg/day</td>
<td>0.04 g/day</td>
</tr>
<tr>
<td>Fraction of annual load from Tiles</td>
<td>99.3%</td>
<td>99.7%</td>
</tr>
<tr>
<td>Fraction of annual load from GW</td>
<td>0.7%</td>
<td>0.3%</td>
</tr>
</tbody>
</table>

Fraction of water discharge (98.7% from tiles):
Tiles = 2,470 m³/day
Groundwater (MODFLOW) = 32 m³/day
Quantifying tile drainage in the Boone River watershed

- 2,370 km²
- 90% row crop cultivation
- 75% of soils mapped as hydric

Two methods used:
1. End member mixing model
2. SWAT model
End Member Mixing Model

Three equations, where:
Q = flow
Bf = baseflow (digital filter)
C = N concentration

\[ Q_{BR} = Q_{gw} + Q_t + Q_{surf} \]
\[ Q_{Bf} = Q_{gw} + Q_t \]
\[ Q_{BR} C_{BR} = Q_{gw} C_{gw} + Q_t C_t + Q_{surf} C_{surf} \]

NO3-N concentrations measured using in-stream Nitratax sensor
SWAT Model

- **2,212 HRUs**
- **Good calibration/validation statistics for model**

<table>
<thead>
<tr>
<th>Model testing phase</th>
<th>Time period</th>
<th>Annual R²</th>
<th>Annual NSE</th>
<th>Monthly R²</th>
<th>Monthly NSE</th>
<th>Daily R²</th>
<th>Daily NSE</th>
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</thead>
<tbody>
<tr>
<td>Calibration (15-year)</td>
<td>1999-2013</td>
<td>0.97</td>
<td>0.93</td>
<td>0.91</td>
<td>0.93</td>
<td>0.77</td>
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<td>Validation (15-year)</td>
<td>1984-1998</td>
<td>0.98</td>
<td>0.95</td>
<td>0.94</td>
<td>0.96</td>
<td>0.82</td>
<td>0.81</td>
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<tr>
<td>Entire duration (30-year)</td>
<td>1984-2013</td>
<td>0.95</td>
<td>0.95</td>
<td>0.92</td>
<td>0.92</td>
<td>0.79</td>
<td>0.78</td>
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</tbody>
</table>

aThis table is adapted from Table 3 in Valcu-Lisman et al. (2017) and was also reported in Gassman et al (2017b).
Tile contribution to streamflow

Tri-linear diagram shows relative contributions from three main water sources

EMMA = 46%
SWAT (Boone) = 54%
SWAT (Lyons) = 66%
Tiles dominate from April to June
Scaling of tile contributions

Tile drainage contributes to basin-scale water yields at scales ranging from a field scale to 16,000 km$^2$ of the heavily tiled Des Moines Lobe of central Iowa.
Conclusions

• It is difficult to determine the extent of drainage in Iowa but mapping suggests tiles are continuing to be installed.
• In heavily-tiled areas of central Iowa, flow from drainage tiles contributes 95-99% of annual water yield and N and OP loads at a farm scale.
• Tile drainage often accounts for one-half of the annual watershed discharge at scales ranging from 40 to 16,000 km².
• Developing a better understanding is needed if mitigation and control strategies are going to be successfully targeted to reduce downstream nutrient export.