Groundwater flow model for Western Chippewa County

Including analysis of water resources related to industrial sand mining and irrigated agriculture

Chippewa County Board Meeting
Chippewa Falls, WI - May 14th 2019

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Project team
– WGNHS
– USGS
– Chippewa Co. LCFM

Stakeholders group
– All active sand mining companies
– WI Farmers Union
– WI DNR
– Trout Unlimited
– Local farmers and citizens

Study overview

• Started fall 2012
  – Project team
  – WGNHS
  – USGS
  – Chippewa Co. LCFM

• 5-year study effort
  – Technical investigation and modeling
  – Outreach and reporting
Study overview

Frac sand mining

Water used to wash sand, transport sand onsite and control dust

Study overview

Irrigated agriculture

Municipal supply
Study overview

- Why do we care?
  - Pumping in upland areas near headwaters of streams
  - Intensifying water-use practices
  - Changes to landscape and implications for groundwater recharge
  - Long-term water resource management and sustainability

Water-use practices

1980

2014

Recent intensification in water use
Changes to landscape

Groundwater recharge implications

Expansion of industrial sand mining

Data collection

Driller's records

Geologic outcrops

Permitted mines
Application received
Data collection

- Borehole geophysics
- Streamflow surveys
- Infiltration testing
- Water-use records

Hydrostratigraphic interpretation

- Aquifer
- Aquitard
- Sandstone (aquifer)
- Shale (aquitard)
- "No flow"
Scenario testing – Mine build-out

For modeling scenarios,
- Mine footprints will expand within mineable Wonewoc (shaded purple)
- Recharge will be modified according to recharge modeling results
- Recharge is expected to decrease over short-term
- Recharge is expected to rebound or increase over long-term

Hypothetical mining sequence

Mine build-out development maps showing (A) mineable sandstone resource (Wonewoc) segmented into 155 hypothetical mines (approx. 150 acres each), (B) areas suitable for wells at each mine site (more than 1,200 ft from a stream), and (C) hypothetical 3-step development sequence for each mine.
Scenario testing – *Mine build-out*

Baseflow change…

Continuous mine development  
Following reclamation

Scenario testing – *Irrigated ag. build-out*

Area to right = “Potentially irrigable land”

Soil properties:
- slopes 0-12%
- excessively to mod. well drained

Land use properties:
- currently ag (hay/pasture or row crop)

Next steps:
- Overlay q-q section (40 acre) grid
- Calculate percentage of potentially irrigable lands for each 40 acre grid
Grid cells with > 70% potentially irrigable land were sampled as potential fields for future irrigation.

Cells < 1,200' from a stream were removed from consideration.

Took into account local farmer knowledge about lands unsuitable for irrigation.
Key conclusions

• Water-resource takeaways
  – **Headwater streams are most sensitive** to groundwater withdrawals and changes in recharge associated with sand mining and irrigation
  – Baseflow is expected to decrease as groundwater withdrawals increase or recharge rates decline
  – Simulated reductions in baseflow lower the baseline of streamflow from which natural seasonal variability will occur
  – Carefully planned expansion of water withdrawals and mine reclamation could help mitigate some of the simulated effects:
    • Locate pumping as far away as possible from sensitive streams,
    • Stagger mine development over time,
    • Reclaim mined areas to high-infiltration land cover and land uses that enhance macropore development and limit compaction.

Groundwater flow model for Western Chippewa County

To find out more visit the
WGNHS website: www.wisconsingeologicalsurvey.org
Or,
Chippewa County website: co.chippewa.wi.us/lcfm, click on the link “Chippewa County Groundwater Study”
Today’s outline

- Study overview
- Data collection and hydrostratigraphy
- Estimating groundwater recharge
- Groundwater model development
- Future scenario testing
Study overview

- **Started fall 2012**
  
  Project team
  - WGNHS
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  Stakeholders group
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- **5-year study effort**
  - Technical investigation and modeling
  - Outreach and reporting

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Study overview

- **Frac sand mining**

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Municipal supply

Irrigated agriculture

• Why do we care?
  – Pumping in upland areas near headwaters of streams
  – Intensifying water-use practices
  – Changes to landscape and implications for groundwater recharge
  – Long-term water resource management and sustainability
Recent intensification in water use

Changes to landscape

Expansion of industrial sand mining
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Data collection

- **Bedrock geology** *(WGNHS)*
  - Northwest WI (1987)
  - West Central WI (1988)
  - 1:250,000 scale

- Good framework but relatively small-scale mapping
Data collection

- **Glacial geology** *(WGNHS)*
  - Chippewa County (2007)
  - Barron County (1986)
  - 1:100,000 scale

- **Well construction reports** *(DNR)*

  - Driller’s descriptions of cuttings in the field
Data collection

- **Well construction reports** *(DNR)*
- Driller’s descriptions of cuttings in the field
- Provides information about
  - Depth to bedrock
  - Depth to Precambrian rock
- **Hydrogeologic data**
  - Estimates of hydraulic conductivity (well development)
  - Water levels (for calibration)

**Data collection**

**Geologic logs** *(WGNHS)*

- Cuttings from municipal supply or other high-capacity wells
- Evaluated by WGNHS geologists in the laboratory
- Many recent cutting sets have been obtained directly within the study area
- Higher quality than drillers logs
Data collection

Outcrops

Irvine Park in Chippewa Falls
Contact: Precambrian Granite and Mount Simon Fm. (Cambrian)

South of Colfax above Hwy 40
Contact: Tunnel City Gr. and Wonewoc Fm.
Data collection

Outcrops (in active mines)

Superior Silica Sands Mine, Hwy 64 at DD
Contact: Tunnel City Gr. and Wonewoc Fm.

Data collection

Geophysical logs

- Detailed profiles of geology and hydrogeology
- Allows for hydrogeological characterization
Data collection

Collecting a geophysical log

High-capacity well
Western Chippewa County

Data collection

Geophysical log of a 320' irrigation well

Video log still:
looking down hole

Picture taken 200' below surface

Video log still:
looking at wall of hole

4"
Hydrostratigraphic interpretation

Plan view showing bedrock units
(unconsolidated materials not shown)

Profile along A-A' showing all units
(unconsolidated materials are in brown)
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Recharge (R) is water that enters the groundwater system

\[ R = Precipitation - Runoff - Interception - Evapotranspiration \]
Estimating recharge

Soil-water-balance (SWB) model based on:

- Soil type
- Surface topography
- Soil-water storage
- Land use
- Climate data

Estimated annual average recharge, 1950 - 2010

- Annual precipitation
  - Average 31 inches
  - Min. 17 inches
  - Max. 45 inches

- Annual recharge
  - Average 8.2 inches
  - Min. 2.5 inches
  - Max. 14 inches

1993 = average weather year

About 27% of precipitation recharges groundwater
Effect of soil and land use

Recharge fluctuates at each mine site due to variations in weather...

Recharge in mined and reclaimed areas

Conceptual model of mine development and reclamation

Development and reclamation schedule

<table>
<thead>
<tr>
<th>Years</th>
<th>1 - 5</th>
<th>6 - 10</th>
<th>11 - 15</th>
<th>16 - 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area 1</td>
<td>quarry</td>
<td>early reclaimed</td>
<td>early reclaimed</td>
<td>mature reclaimed</td>
</tr>
<tr>
<td>Area 2</td>
<td>existing</td>
<td>quarry</td>
<td>early reclaimed</td>
<td>early reclaimed</td>
</tr>
<tr>
<td>Area 3</td>
<td>existing</td>
<td>existing</td>
<td>quarry</td>
<td>early reclaimed</td>
</tr>
</tbody>
</table>
Infiltration rate (inches/hour)

Forest A1 Top
Forest A2 Top
Forest A2 Bottom
Forest B1 Midslope
Forest B2 Top
Forest B3 Top
Forest B4 Bottom

Prairie 1 Top
Prairie 1 Bottom
Prairie 2 Bottom
Grass 1 Top
Grass 1 Bottom
Cornfield 1 Top
Cornfield 1 Bottom
Soybean 1 Top
Soybean 1 Bottom
Alfalfa 1 Top
Alfalfa 1 Bottom
Alfalfa 2 Top
Alfalfa 2 Bottom

Reclaimed 0 Yr Prairie 1
Reclaimed 0 Yr Prairie 2
Reclaimed 1 Yr Oats 1
Reclaimed 1 Yr Oats 2
Reclaimed 2 Yr Prairie 1
Reclaimed 2 Yr Prairie 2
Reclaimed 12 Yr Prairie 1
Reclaimed 12 Yr Prairie 2
Reclaimed 20 Yr Prairie 1
Reclaimed 20 Yr Prairie 2
Reclaimed 30 Yr Prairie 1
Reclaimed 30 Yr Prairie 2

Infiltration

Change (inches/year)

5 years
10 years
15 years
20 years
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model |ˈmädl|
noun

• a simplified description, esp. a mathematical one, of a system or process, to assist calculations and predictions.

ORIGIN late 16th cent. (denoting a set of plans of a building): from French modèle, from Italian modello, from an alteration of Latin modulus (see modulus).

from: New Oxford American Dictionary
Building a MODFLOW Model: Basics

- Start with a basemap
- Focus in on area of interest
- Extend out to hydrologic boundaries
- Add a computational grid

Building a MODFLOW Model: Streams and Elevation

- Focus in on the stream network
- Assign streams to model cells
- Routing water downstream/downhill
Building a MODFLOW Model: Hydrostratigraphy

Start with a basemap
Focus in on area of interest
Extend out to hydrologic boundaries
Add a computational grid
Add streams
Convert hydrostratigraphy to model layers

Model Layers

50x vertical exaggeration

10x vertical exaggeration
Building a MODFLOW Model: Recharge

Add groundwater recharge from the Soil-Water-Balance model

Darker colors = higher recharge

Building a MODFLOW Model: Water Use

Add groundwater wells to simulate pumping for mines, towns, and agriculture

2013 high-capacity well provided by the WI DNR; Locations refined by WGNHS
Building a MODFLOW Model: Initial Simulation

Use estimated property values
• permeability
• recharge

Simulate water levels… and baseflows

Building a MODFLOW Model: Calibration

Add stream baseflow targets
△ Gaging stations
● Synoptic measurements

Add water level targets ●
**Groundwater model results**

**Calibration**

**Water levels**

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Long-term reclamation following continuous mine development

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Scenario testing – *Irrigated ag. build-out*

**Baseflow change using Null-Space Monte Carlo**

- **Median change in baseflow**
- **Standard deviation**
Chippewa County Groundwater Study

Thank you! Questions?

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WGNHS: Publications & resources

• State and county maps
• General interest maps
• Fact sheets

Frac sand Fact Sheet - 2014

WGNHS: Publications & resources

• State and county maps
• General interest maps
• Fact sheets
• Outreach activities
• Direct engagement with counties and other stakeholders
Today’s outline

• Brief overview of the groundwater study
• Subsurface data collection and hydrostratigraphy
• Water-use data and trends
• Estimating groundwater recharge
• Groundwater model development
• Future scenario testing
• Questions?

Scenario testing – Mine build-out
Scenario testing – *Mine build-out*

Figure D: County-State-SEA Parcels Removed

Figure F: Unfeasible Areas Removed

Scenario testing – *Irrigated ag. build-out*

Figure 3: High-capacity wells

Figure 4: High-capacity wells classified by the DNR as irrigation wells

Attachment: Groundwater Presentation Report for CB 05-14-19 (5003: WGNHS Groundwater Study)
Scenario testing – *Irrigated ag. build-out*

**Figure 2**  
**Figure 3**

**Figure 4**  
**Figure 5**

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**Attachment:** Groundwater Presentation Report for CB 05-14-19 (5003 : WGNHS Groundwater Study)
Groundwater Use in Wisconsin: 2013 Withdrawals

Water Use Focus in Chippewa County

Time-lapse video of high-capacity well installations

Well record compiled from Wisconsin DNR records
Why Does Water Use Matter?

- Groundwater and surface water are connected

Water Use & ‘Capture’

- Capture depends on aquifer geometry and properties, and the well’s pumping rate & proximity to streams (including depth)

- Difficult to measure due to natural variability
- Quantify capture using physically based models

from Alley, Reilly, and Franke, USGS Circular 1186, 1999
### Water-use practices

<table>
<thead>
<tr>
<th>Well Depth</th>
<th>Pump rate</th>
<th># Wells</th>
<th>Season</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 - 400’</td>
<td>20 - 95 million gal. per year, per well</td>
<td>5</td>
<td>10 months ~ Feb - Nov</td>
</tr>
<tr>
<td>150 - 300’</td>
<td>80 - 90 million gal. per year, per well</td>
<td>6</td>
<td>Year round</td>
</tr>
<tr>
<td>100 - 300’</td>
<td>&lt;10 - 30 million gal. per year, per well</td>
<td>31</td>
<td>5 months ~ May - Sept</td>
</tr>
</tbody>
</table>

#### Well information provided by WDNR

- **Tunnel City**
- **Wonewoc**
- **Eau Claire**
- **Mount Simon**
- **Precambrian**

#### Stratigraphic framework

**Quaternary**
- **Tunnel City**
- **Wonewoc**

**Eau Claire**
- **Mount Simon**

**Precambrian**

#### Generalized cartoon of sand mining operations (1/7)
Generalized cartoon of sand mining operations (2/7)

Generalized cartoon of sand mining operations (3/7)
Generalized cartoon of sand mining operations (4/7)

Generalized cartoon of sand mining operations (5/7)