# The Little Plover River Groundwater Model

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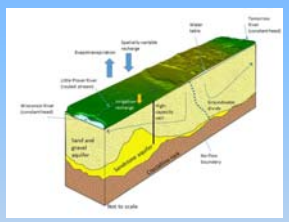
## This talk presents…

**Objectives and report status…**


**How the model was constructed…**



**Model use examples…**

# Objectives

- This project developed the following:

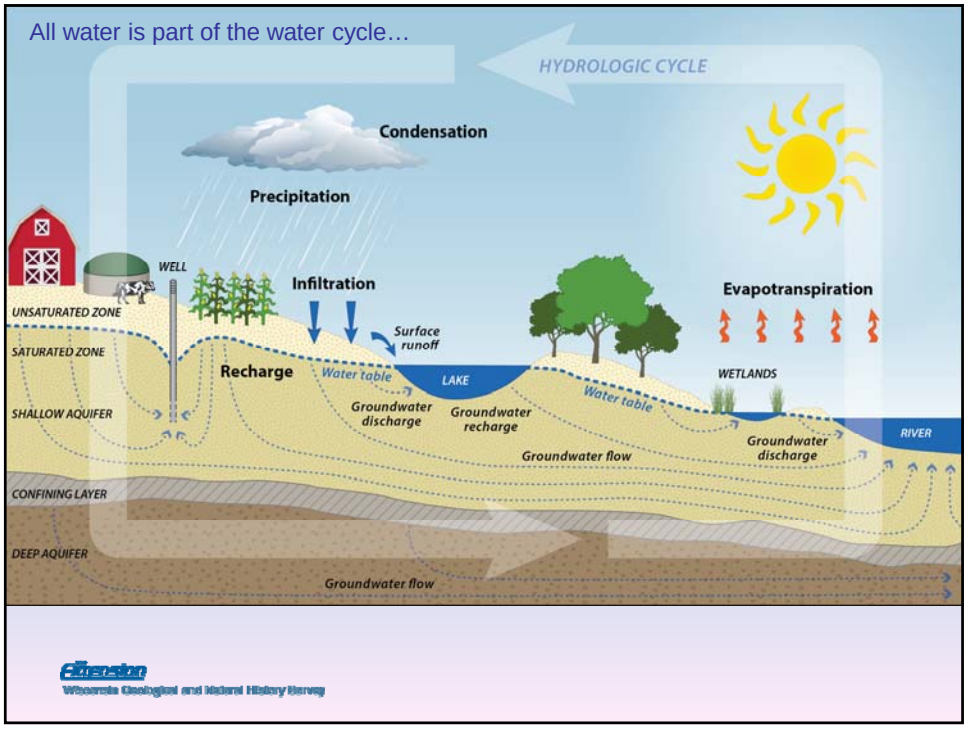
1. A groundwater flow and optimization model as a science-based expert system for decision support of water management in the Little Plover River Basin. The Little Plover is a pilot location to evaluate techniques that might later be expanded to the entire central sands region.
2. A platform to demonstrate fundamental scientific constraints inherent to the hydrologic system and context for the costs and benefits for differing scenarios.
3. An educational tool for fostering science-based discussion for both the public and the technical community.

# What the model doesn't do…

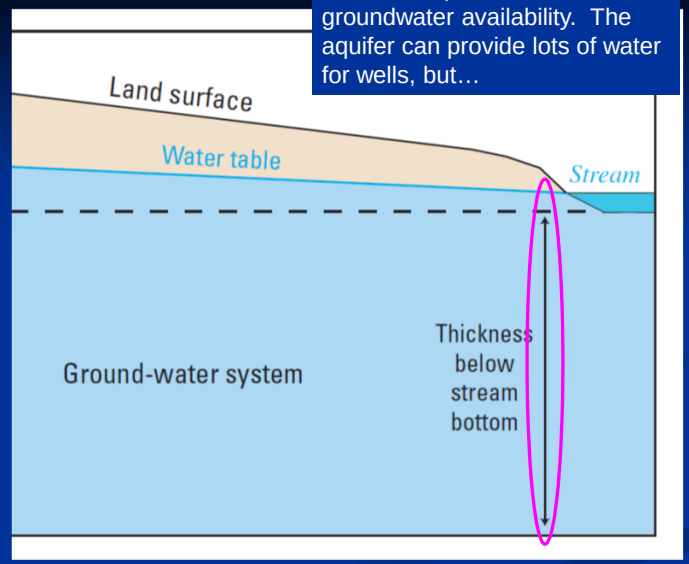
1. Create any more water.
2. Make decisions.
3. Solve all your problems.

It is a tool for supporting planning and decision making.

All water is part of the water cycle…



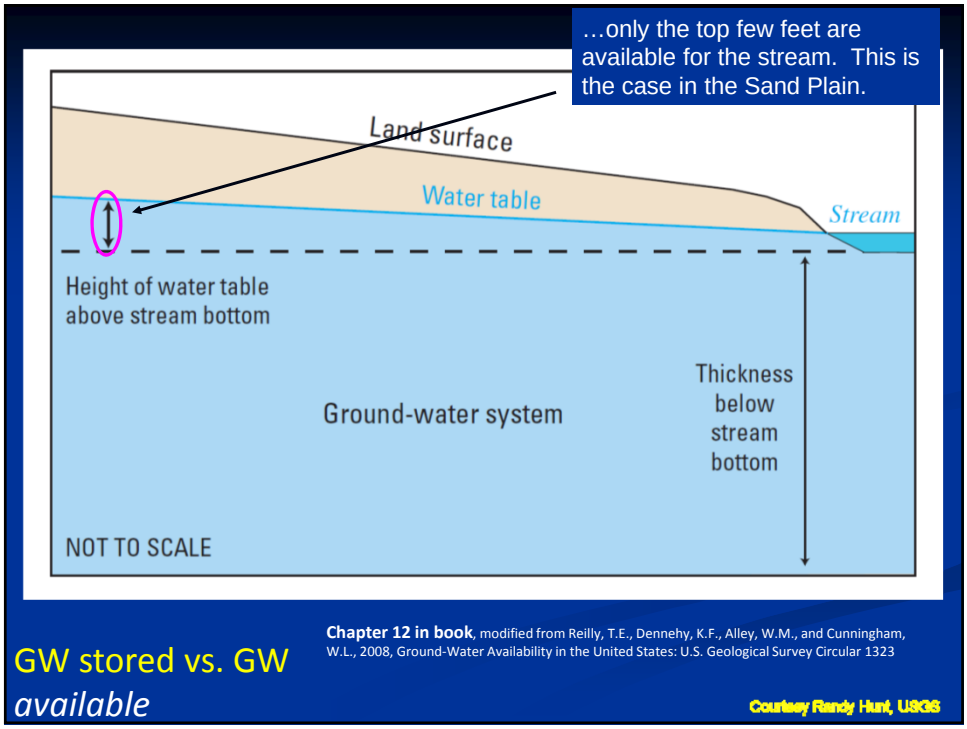

A misconception about groundwater availability. The aquifer can provide lots of water for wells, but…

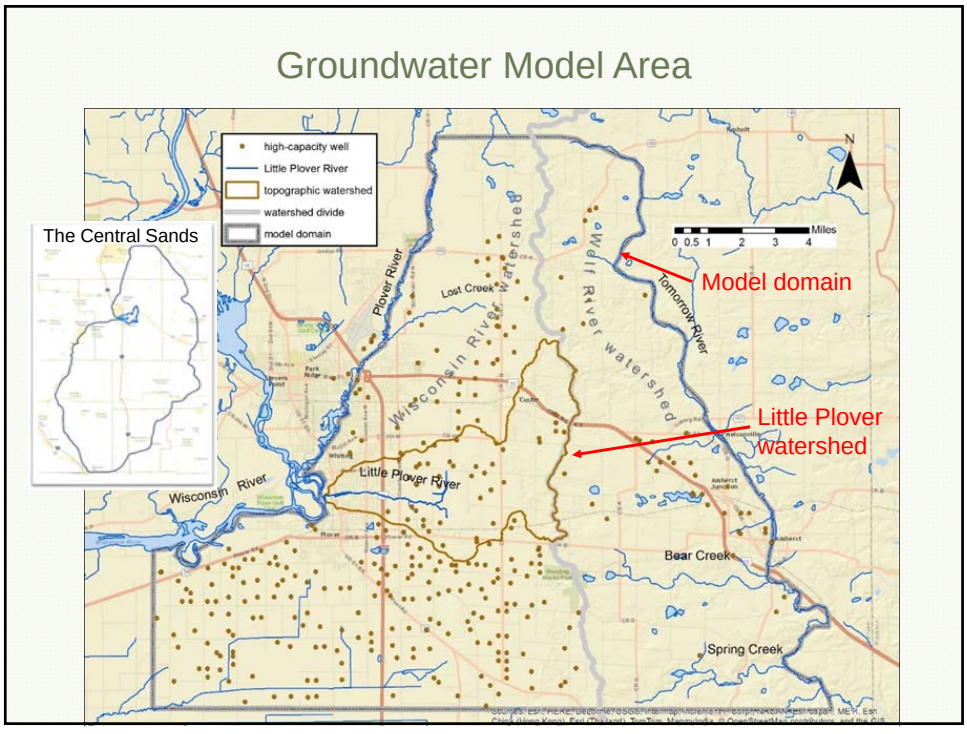



**GW stored**

**Chapter 12 in book**, modified from Reilly, T.E., Dennehy, K.F., Alley, W.M., and Cunningham, W.L., 2008, Ground-Water Availability in the United States: U.S. Geological Survey Circular 1323

Courtesy Randy Hunt, USGS


…only the top few feet are available for the stream. This is the case in the Sand Plain.
Land surface
Water table
Stream
Height of water table above stream bottom
Ground-water system
Thickness below stream bottom
NOT TO SCALE
GW stored vs. GW *available*
**Chapter 12 in book**, modified from Reilly, T.E., Dennehy, K.F., Alley, W.M., and Cunningham, W.L., 2008, Ground-Water Availability in the United States: U.S. Geological Survey Circular 1323
Courtesy Randy Hunt, USGS

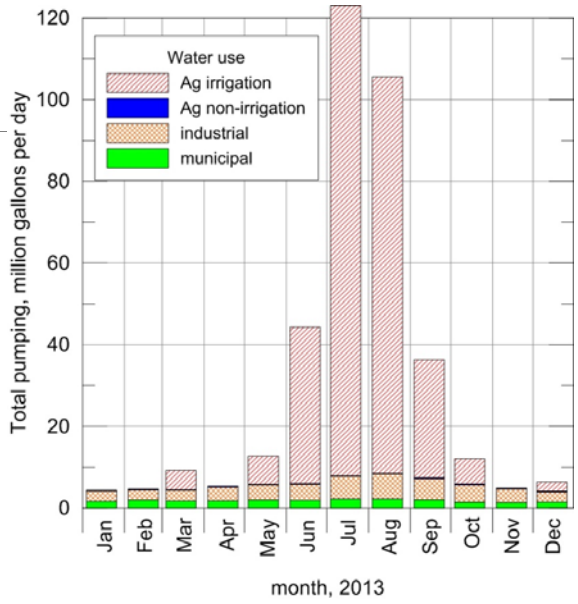

Groundwater Model Area
high-capacity well
Little Plover River
topographic watershed
watershed divide
model domain
The Central Sands
Model domain
Little Plover watershed
Plover River
Lost Creek
Wisconsin River watershed
Wolf River watershed
Tomorrow River
Wisconsin River
Little Plover River
Bear Creek
Spring Creek
N
Miles
0 0.5 1 2 3 4

# Monthly Water Use

## 2013

Water use in the basin varies through the year, driven mostly by irrigation pumping during the growing season.

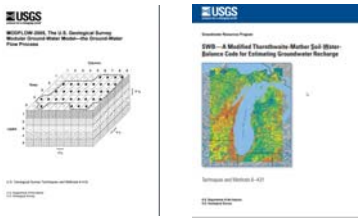
424 Hi-cap wells in model




# Some modeling acronyms…

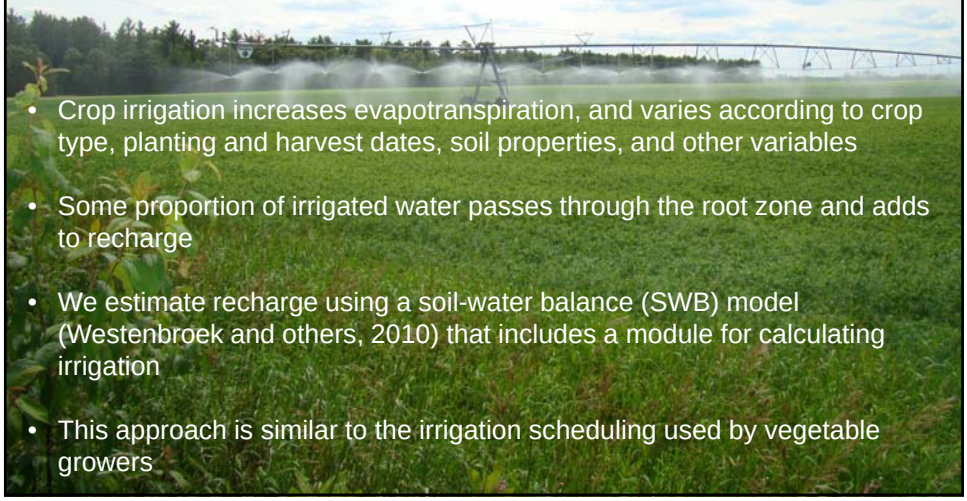
"MODFLOW"- The *Modular Groundwater Flow Model* code or software developed by the U.S. Geological Survey. This is the most widely used and accepted groundwater modeling code in the world.

"SWB"- The *Soil Water Balance* code developed by the Wisconsin Geological and Natural History Survey and U.S. Geological Survey.



# Closing the water balance

- Evaluating the relationships between recharge, evapotranspiration, and irrigation is essential for the success of this project.



- Crop irrigation increases evapotranspiration, and varies according to crop type, planting and harvest dates, soil properties, and other variables
- Some proportion of irrigated water passes through the root zone and adds to recharge
- We estimate recharge using a soil-water balance (SWB) model (Westenbroek and others, 2010) that includes a module for calculating irrigation
- This approach is similar to the irrigation scheduling used by vegetable growers

# SWB & MODFLOW: Modeled in Series Connected by Recharge

**Recharge** = Precipitation + Irrigation – $ET_{Non\text{-}irrigated}$ – $ET_{Irrigated}$ + Δ Runoff + Δ in Soil Moisture

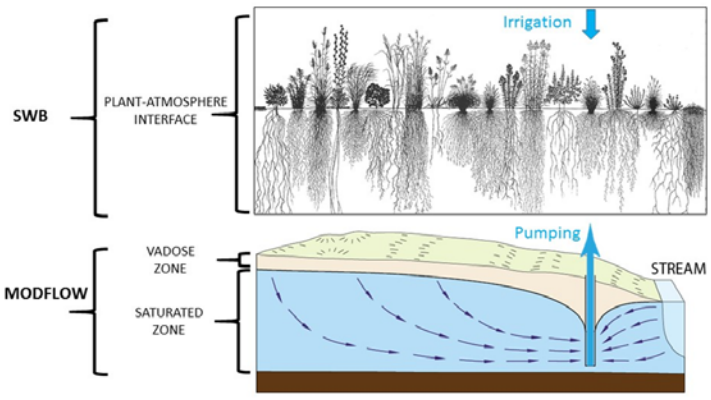
*Infiltrates through the soil and reaches the groundwater table - **DEEP DRAINAGE***

**SWB Input:**
- Climate
- Irrigation
- Land use/cover
- Topography
- Soil characteristics

**SWB Output**
- **Recharge**

**MODFLOW Input:**
- **Recharge**
- Layer elevations
- Stratigraphy
- Hydraulic conductivity
- Stream characteristics
- Pumping

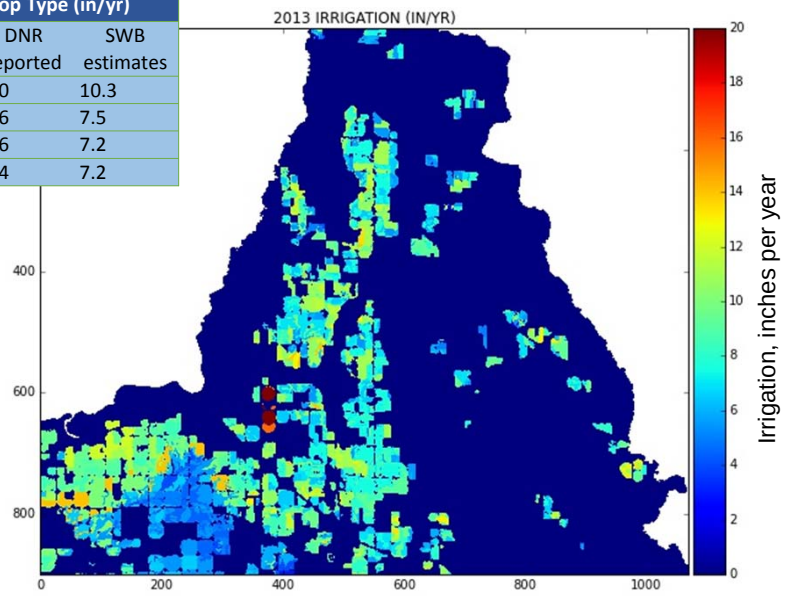
**MODFLOW Output**
- Water levels
- Stream flows




- In **MODFLOW**, all input parameters (including recharge) adjusted across reasonable ranges to obtain **best-fit** flow model
- Calibrated to **transient conditions;** provide measure of model **sensitivity** to **recharge** and other input parameters

Figure by M. Kniffin

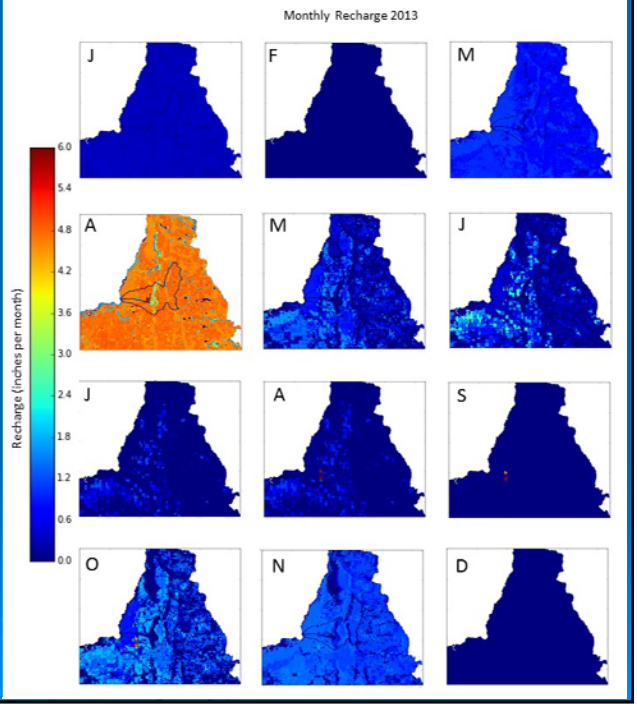
| 2013 Annual Average Irrigation per Irrigated Crop Type (in/yr) | | |
|---|---|---|
| **Crop Type** | DNR reported | SWB estimates |
| **Potatoes** | 9.0 | 10.3 |
| **Corn** | 8.6 | 7.5 |
| **Sweet Corn** | 7.6 | 7.2 |
| **Snap Beans** | 7.4 | 7.2 |



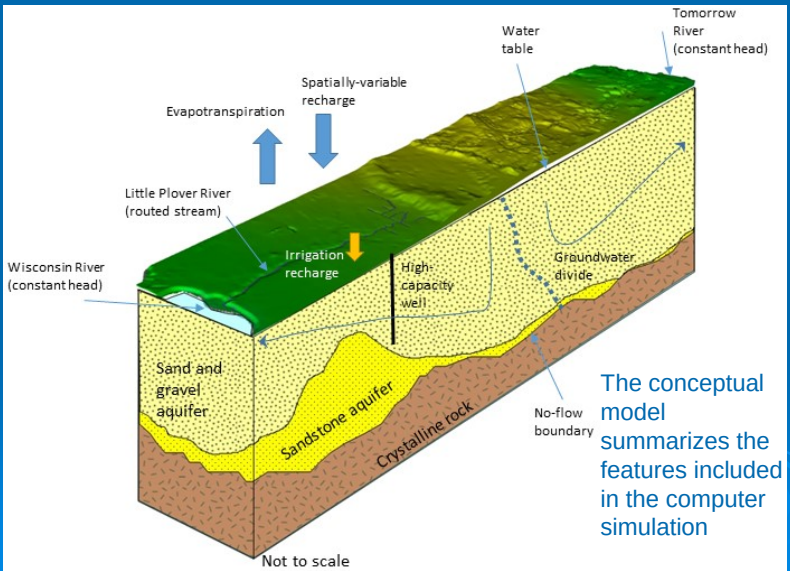

## 2013 Recharge by month

Color bar is from 0 to 6 inches/month

- Little or no recharge in winter
- Maximum recharge in April
- Recharge beneath irrigated fields in summer
- Annual mean recharge for 2013 = 8.7 inches.



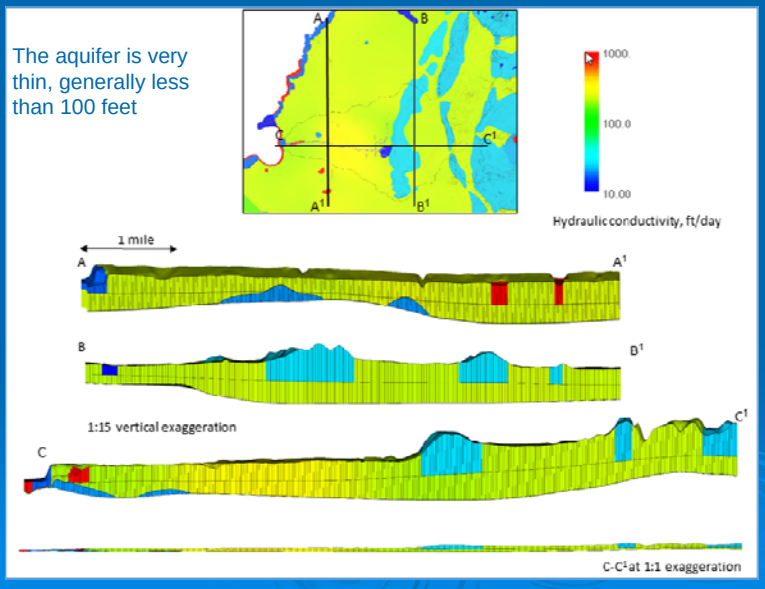
# Conceptual model




The conceptual model summarizes the features included in the computer simulation

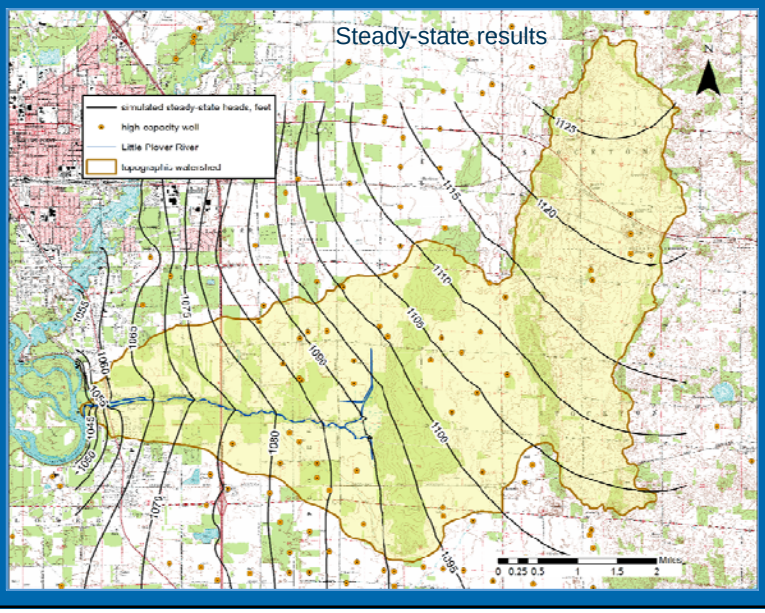
# Model cross sections

The aquifer is very thin, generally less than 100 feet



## Calibrating the flow model

We compare simulated water levels and stream flows to field measurements to be sure the model can simulate reality.

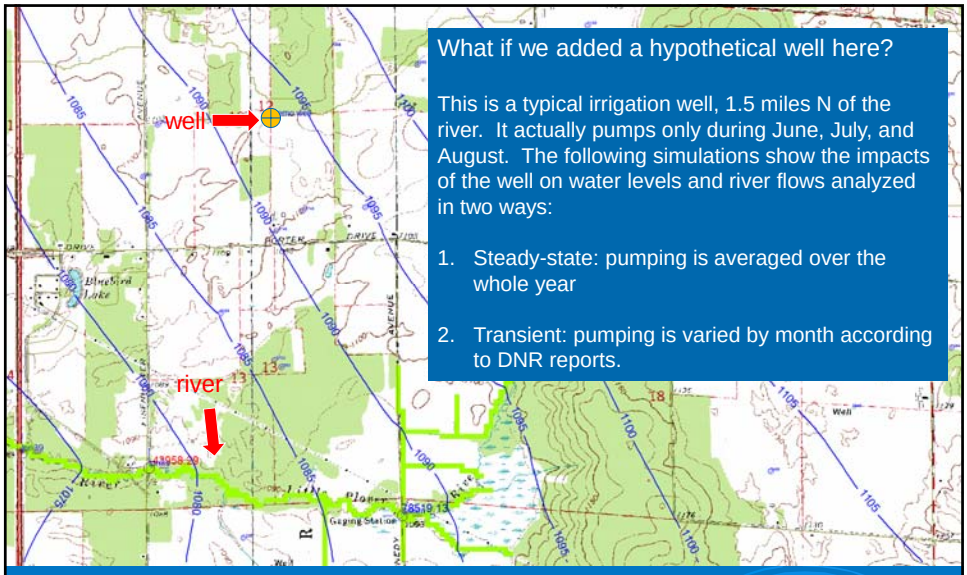



# Using the model

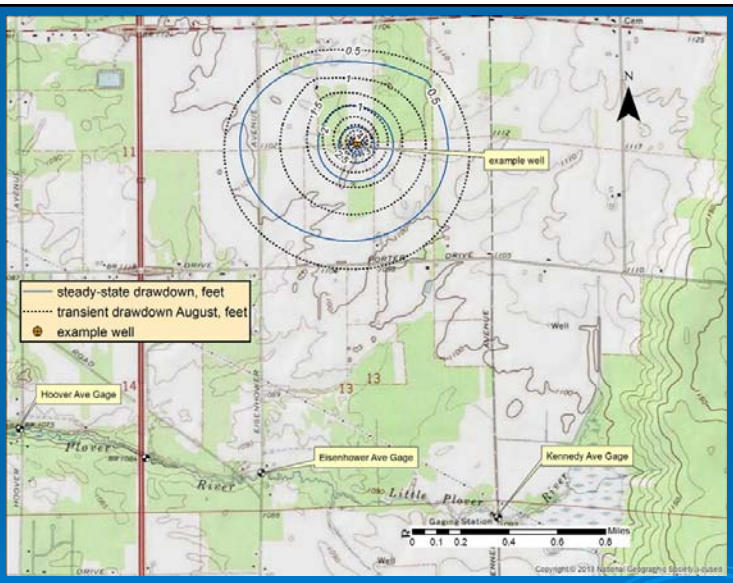
The model can be used to evaluate alternative management scenarios, such as reducing pumping of specific wells or changing land use or irrigation rates.

Here we present two examples:

1. Simulating a single new well.
2. Determining where groundwater discharging to the river originates.

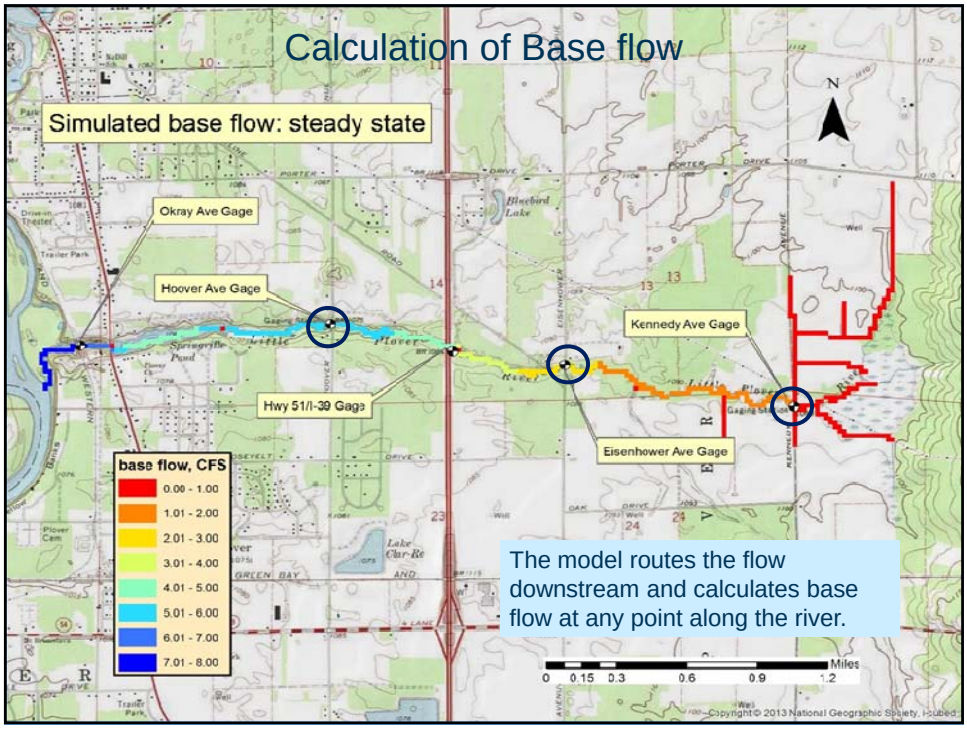



Example: adding a single well; how does it affect the river?

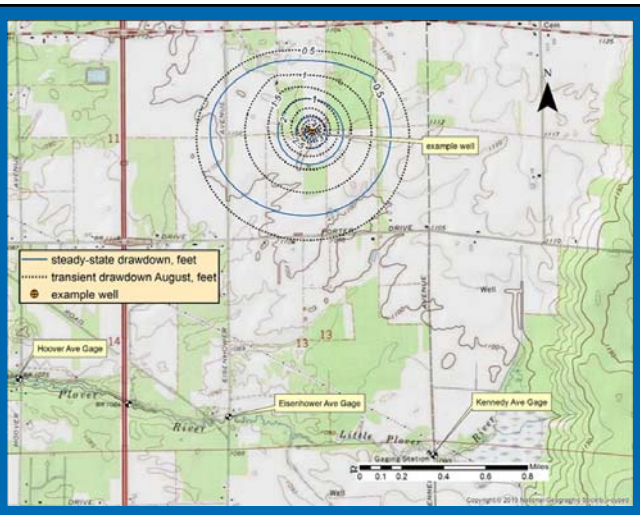



Hypothetical well about 1.5 miles north of the river. If pumped steadily at pro-rated rates, the steady-state drawdown at the well is several feet, and the cone of depression is about half a mile across.

## Calculation of Base flow




The model routes the flow downstream and calculates base flow at any point along the river.

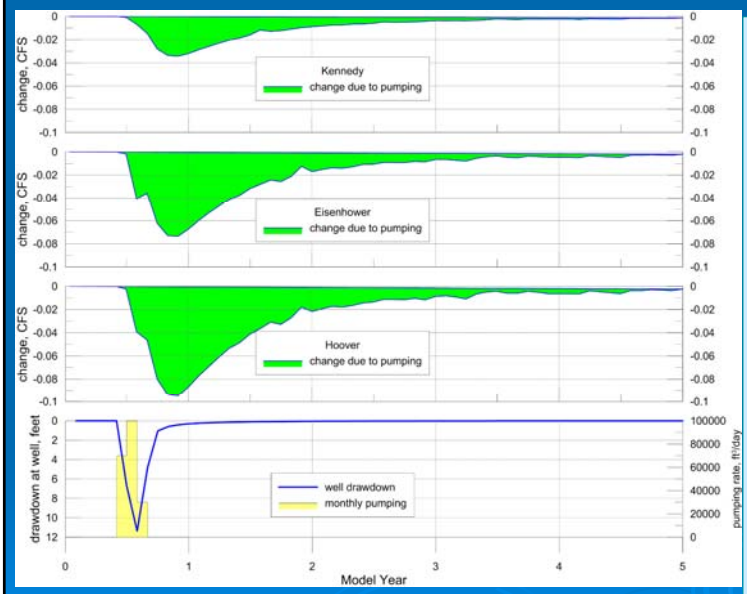



How the well affects the river:

At steady state, 54.5% of the well discharge is water that would otherwise have discharged to the Little Plover River.

This represents a base flow decline of 0.15 CFS at the Hoover gage.

| Gage site | Baseline baseflow, CFS | Baseflow with well, CFS | change, CFS | change, ft3/d | % change | % of well discharge |
|---|---|---|---|---|---|---|
| Steady-state, Q=23,800 ft³/day | | | | | | |
| Kennedy | 2.24 | 2.14 | 0.10 | 8640 | 4.5 | 36.3 |
| Eisenhower | 2.43 | 2.32 | 0.11 | 9504 | 4.5 | 39.9 |
| Hoover | 5.74 | 5.59 | 0.15 | 12960 | 2.6 | 54.5 |

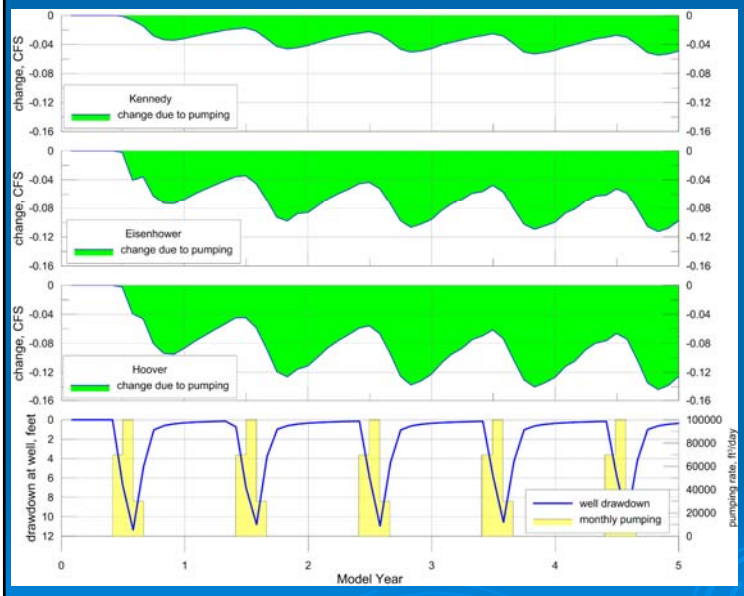



Change in base flow and drawdown in response to pumping a single well.

There is a delay of weeks to months between changes in pumping and impacts to the river.

Note that drawdown recovers much faster than streamflow.

Transient response




Note that if pumping is repeated year after year the river never fully recovers, although the well nearly does.

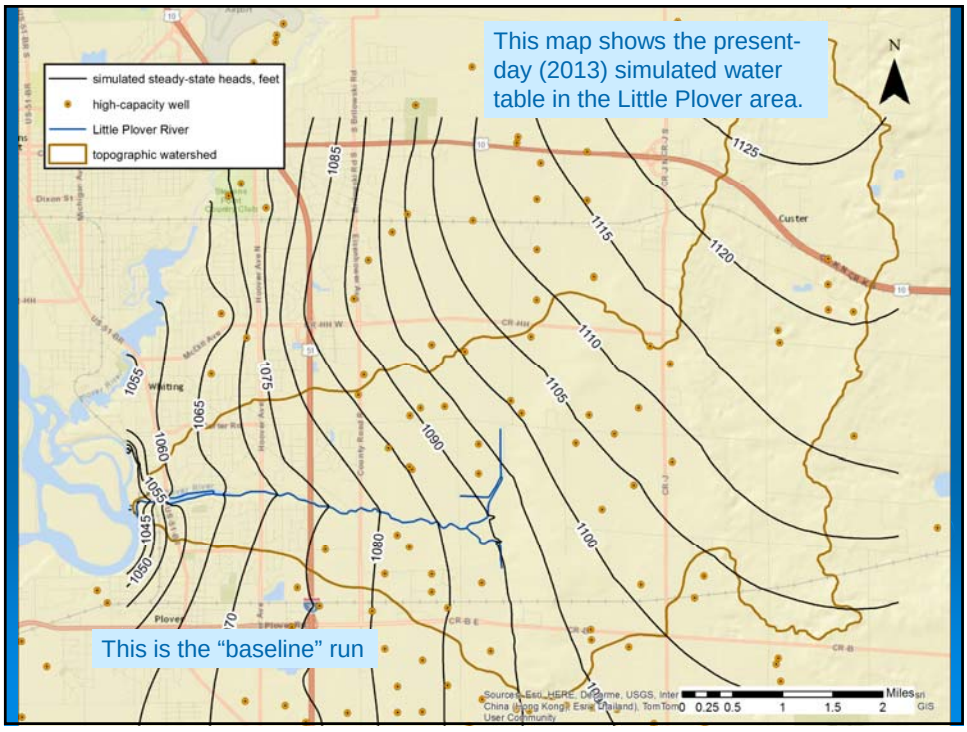
Transient response

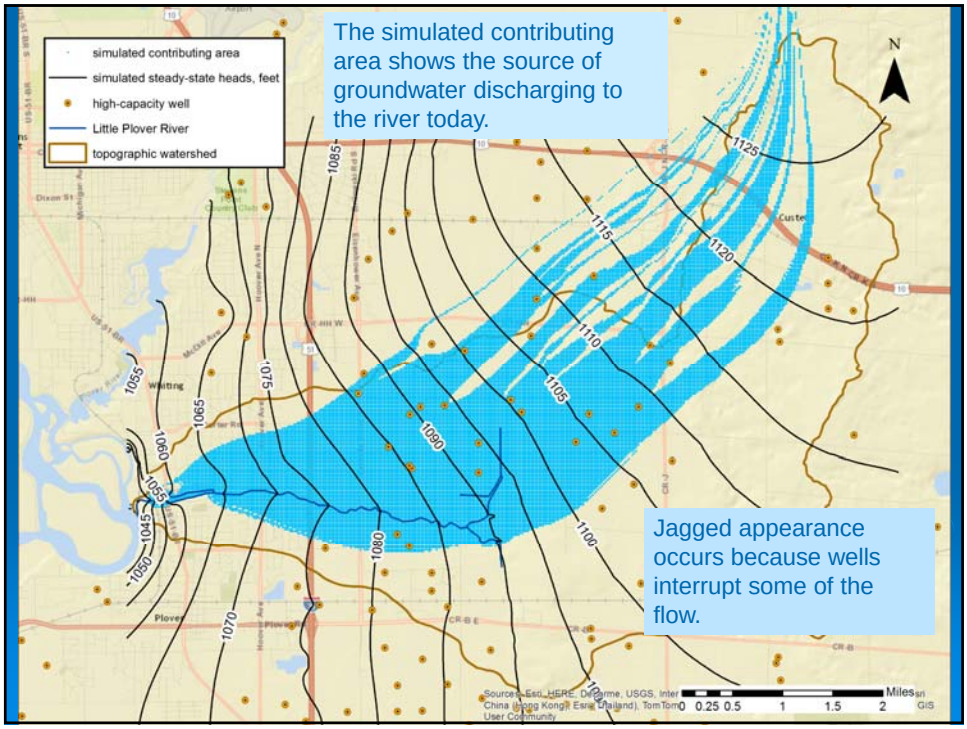
## What is the cumulative impact of existing pumping on the Little Plover River?

This is a difficult question, because it depends on many variables, including:

- Land use
- Well construction and pumping history
- Crop type, planting and harvest dates (changes every year)
- Irrigation practices (varies between Growers and between years)
- Timing of land use change
- Variations in weather
  - Long-term (decades)
  - Short-term (weeks or months)

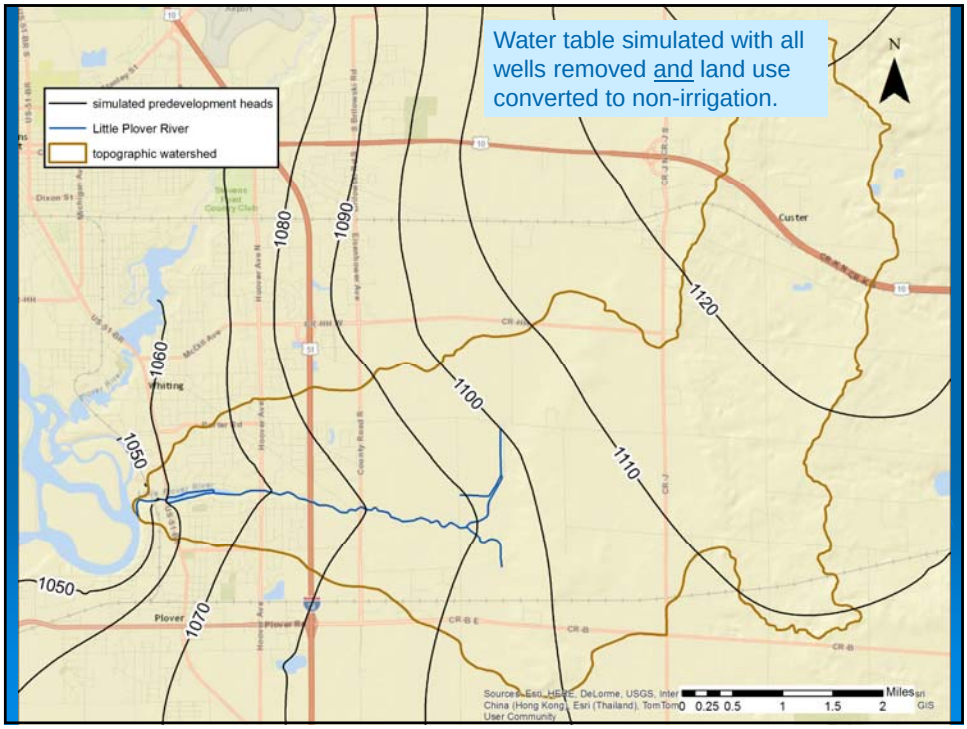
However, we can use the model to estimate the impacts…

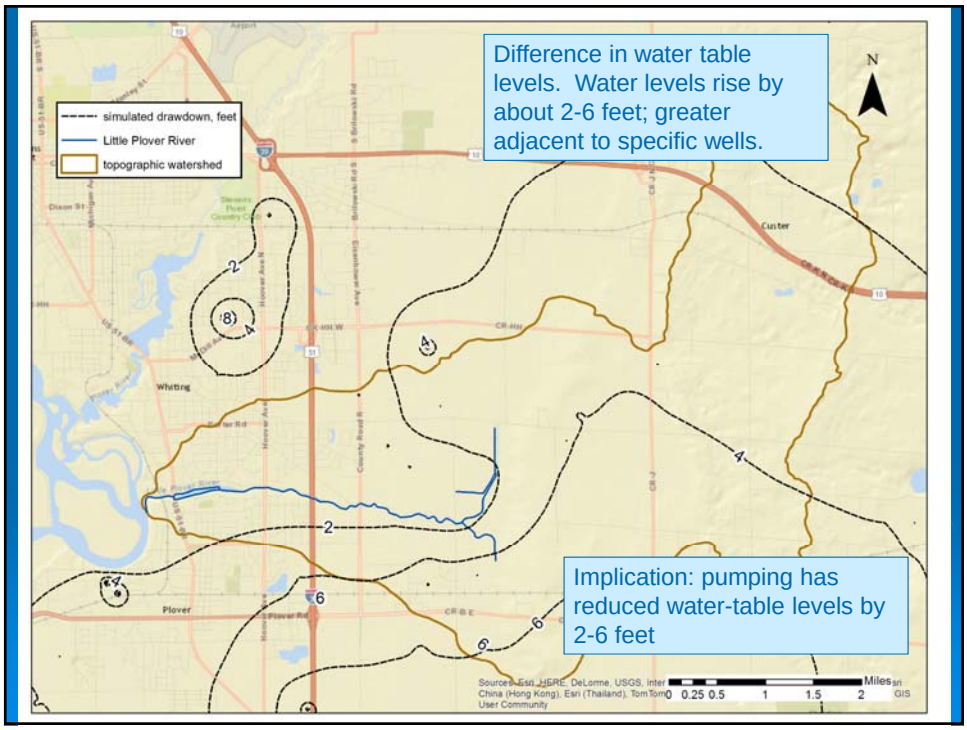


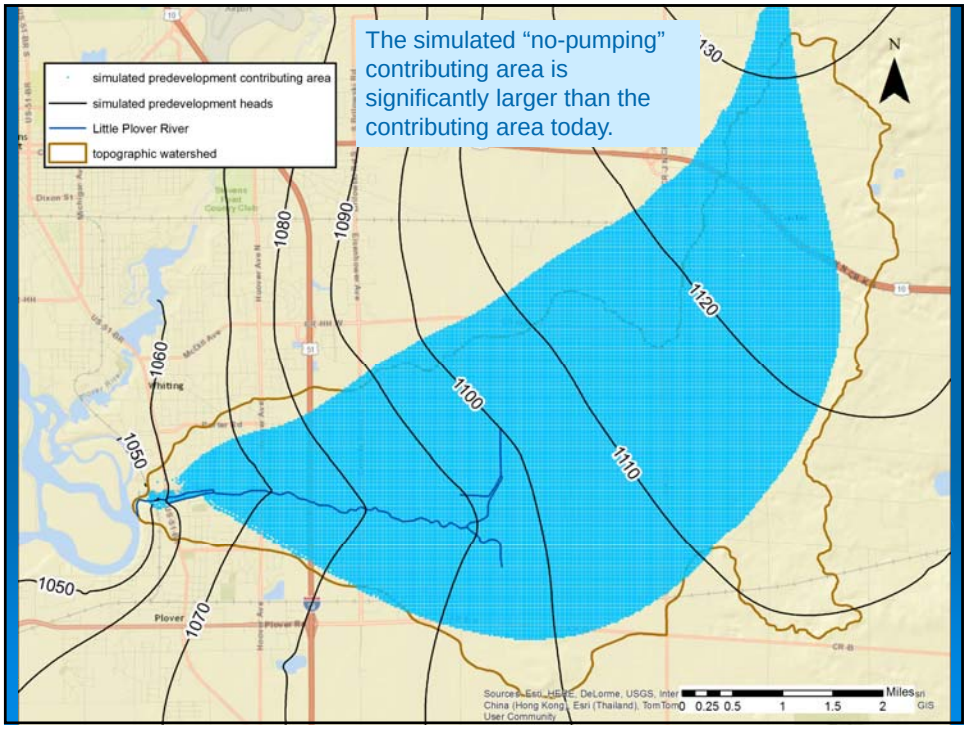



Now remove all the wells and change recharge to non-irrigated land use….

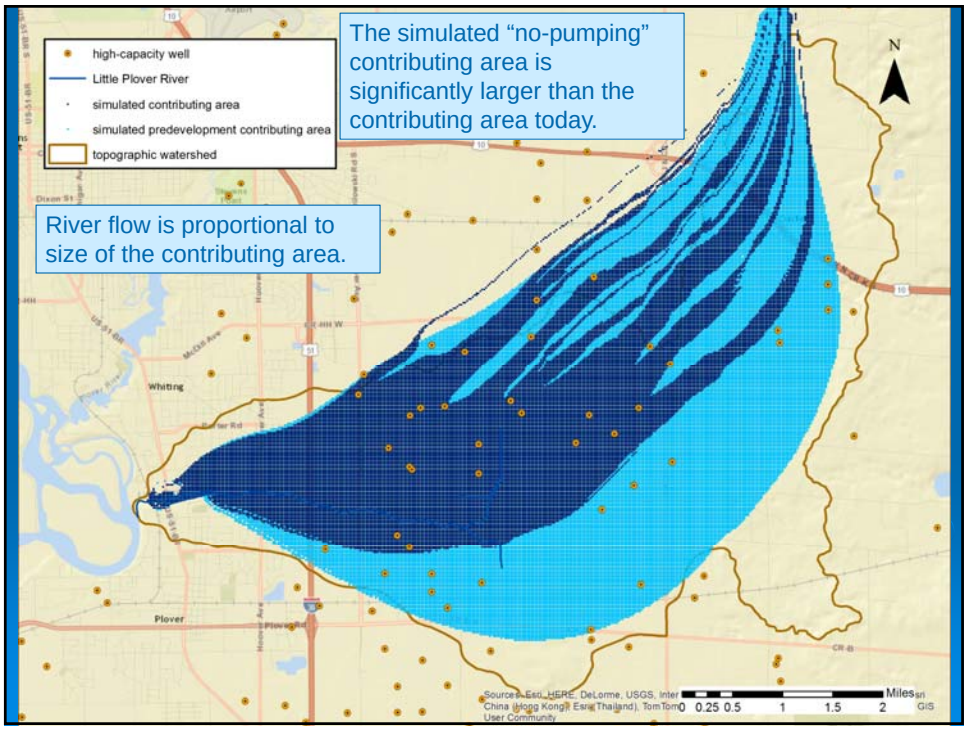
….this gives us an approximation of pre-pumping conditions…


Water table simulated with all wells removed and land use converted to non-irrigation.
simulated predevelopment heads
Little Plover River
topographic watershed
1050
1060
1070
1080
1090
1100
1110
1120
Whiting
Plover
Custer
N
0 0.25 0.5 1 1.5 2 Miles


Difference in water table levels. Water levels rise by about 2-6 feet; greater adjacent to specific wells.
simulated drawdown, feet
Little Plover River
topographic watershed
2
4
6
8
Whiting
Plover
Custer
N
Implication: pumping has reduced water-table levels by 2-6 feet
0 0.25 0.5 1 1.5 2 Miles




The simulated "no-pumping" contributing area is significantly larger than the contributing area today.




The simulated "no-pumping" contributing area is significantly larger than the contributing area today.

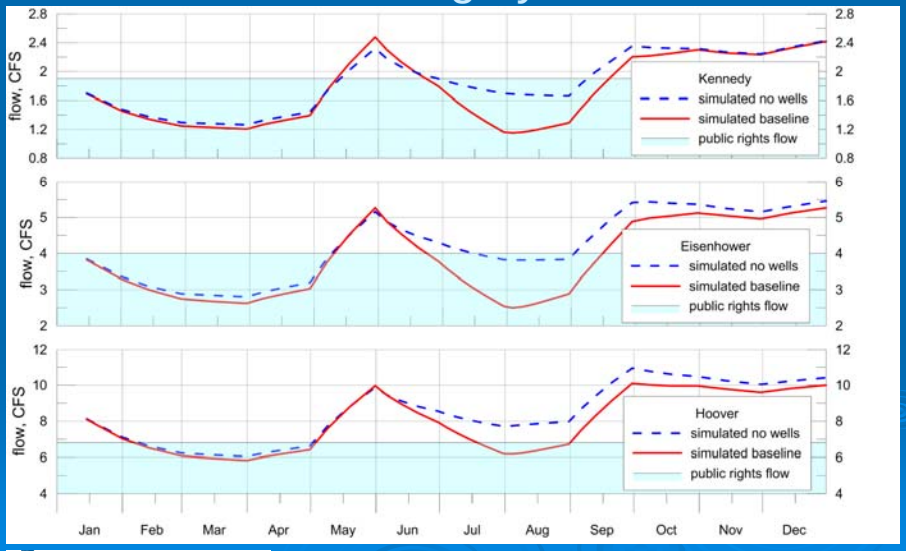
River flow is proportional to size of the contributing area.

# Steady-state simulated flows

| | Flows | | | Basin recharge | | Basin Pumping | | Basin streamflow | |
|---|---|---|---|---|---|---|---|---|---|
| Simulation | Kennedy | Eisenhower | Hoover | | | | | | |
| | cfs | cfs | cfs | cfs | in/yr | cfs | in/yr | cfs | in/yr |
| present day | 2.2 | 2.4 | 5.7 | 16.2 | 10.3 | 5.3 | 3.4 | 7.3 | 4.7 |
| pre-development | 2.8 | 5.7 | 10.1 | 13.5 | 8.6 | 0.0 | 0.0 | 12.1 | 7.7 |
| change | -0.6 | -3.3 | -4.4 | | | | | -4.8 | |
| Percent change | -21% | -58% | -44% | | | | | -40% | |

Under *steady-state* conditions, the model indicates that under no pumping and non-irrigated land use the average flow would *increase* by approximately 0.6 to 4.4 cfs at the gaging sites along the Little Plover River during an "average" year (similar to 2013).

# Transient simulated flows in an average year



# Key Findings about the Little Plover

The river is closely connected to the groundwater system; vulnerable to impacts from nearby pumping.

Irrigation accounts for about 80% of total water use in the basin, primarily during the summer.

Land use and crop patterns affect recharge rates, which in turn affect groundwater levels and stream flows.

River base flow is proportional to the groundwater contributing area, and the contributing area was greater under pre-development conditions than current.

There can be a delay of weeks to months between changes in pumping and impacts on the river, depending on the distance between the well and the river.

# LPR model and report are…

**Complete**, but **not yet released** to the public

**Undergoing** the **peer review** process

**Next steps for LPR model project**

- Report and model editing/revision and approval by reviewers
- Release of model and user guide to public
- Technical workshop or webinar on model use
- Final report publication

# Looking to the larger central sands…

The techniques developed here are readily transferable to model construction in the remainder of Wisconsin's central sand plain.

Research on field measurements of recharge should continue.

Measurements of groundwater discharge and water level fluctuations are critical for successful and robust model calibration.

If groundwater model development moves to the southern central sands there is a data gap in western Waushara County, where no modern geologic maps exist. WGNHS geologists will potentially map this area during 2017 or 2018 if funding becomes available

# Mike Fienen, U.S. Geological Survey

## Optimization and Depletion Potential