Ups and Downs at Valley Creek:

The influence of climate, urbanization, and ground-water withdrawals on baseflow of a trout stream in eastern Minnesota

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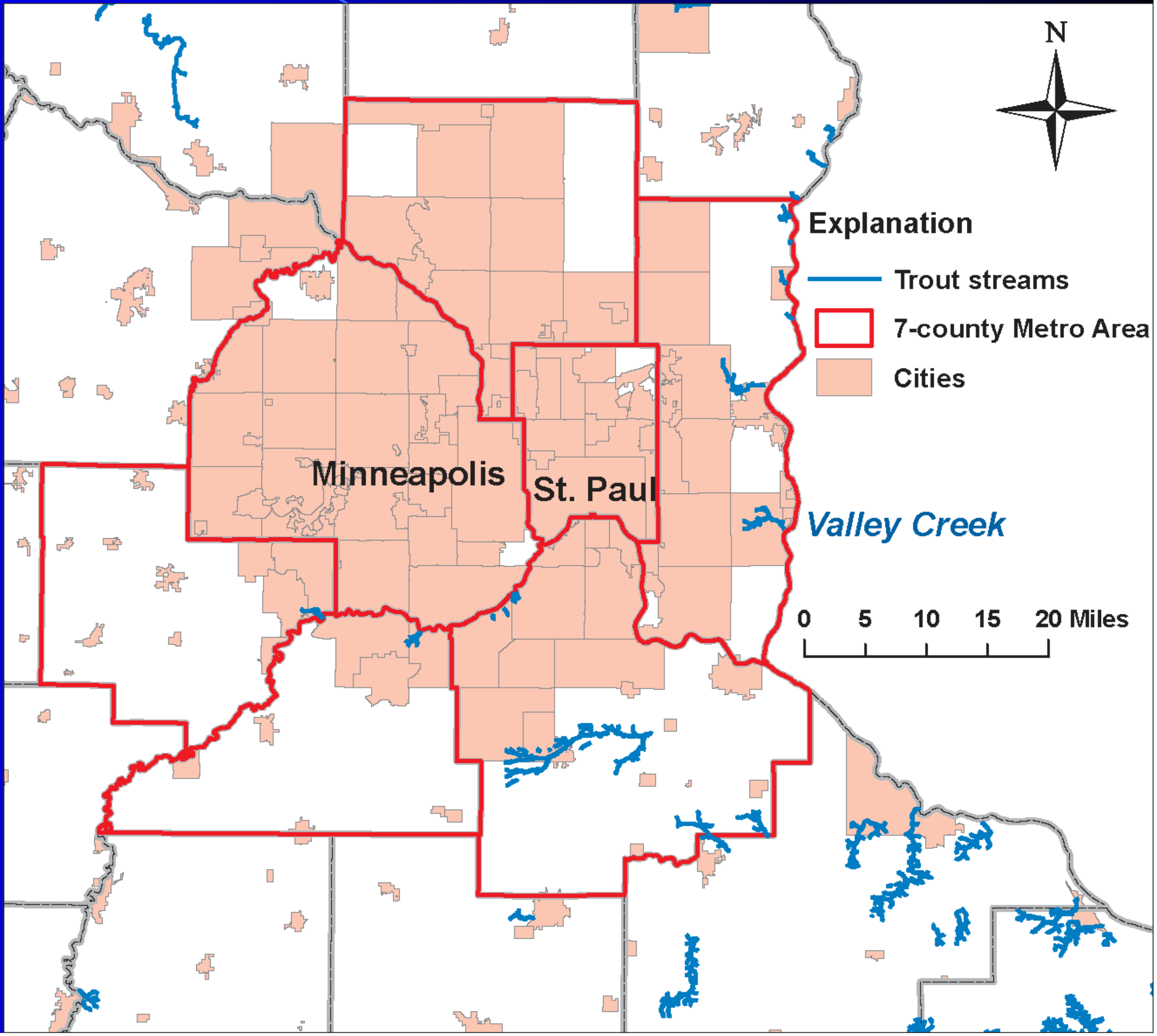
Outline:

- Why Valley Creek?
  - Background & ground-water dependence
- Factors that could impact baseflow
  - What proxies are available?
- Regression models of baseflow as a function of these proxies.

Valley Creek is a state-protected trout stream

- Only a few trout streams remaining in the Twin Cities metro area
  - Maintains important biodiversity
- Valley Creek has healthy self-reproducing trout populations



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Valley Creek has 3 species of stream trout

Native brook trout ...

... and a couple of aliens:

Rainbow trout

Brown trout

Trout habitat requirements

- **Cool, equable water**
  - **Cool in summer (about 10-20 deg C). Keeps DO high.**
  - **Stays well above freezing in early spring to promote egg development**
- **Coarse stream bed**
  - **Facilitates spawning**
  - **Supports aquatic macroinvertebrate food source for trout**
- ***Conclusion is that trout streams in the Midwest require strong baseflow driven by groundwater discharge***
  - ***GW about = mean annual T***
  - ***Strong baseflow removes fines from stream bed***

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Protecting trout stream = Protecting its baseflow

= both Quantity and Quality (esp. proportion relative to surface runoff)

Thanks to Bill Herb, U of M SAFL: http://troutstreamresearch.safl.umn.edu/

Factors affecting baseflow:

- **Climate**
  - Monthly to interannual weather variability
  - Water balance P – ET determines water available for recharge and runoff
- **Urbanization**
  - Affects partitioning between recharge and runoff
- **Ground-water withdrawals**
  - Captures flow from part of aquifer that formerly contributed to the stream

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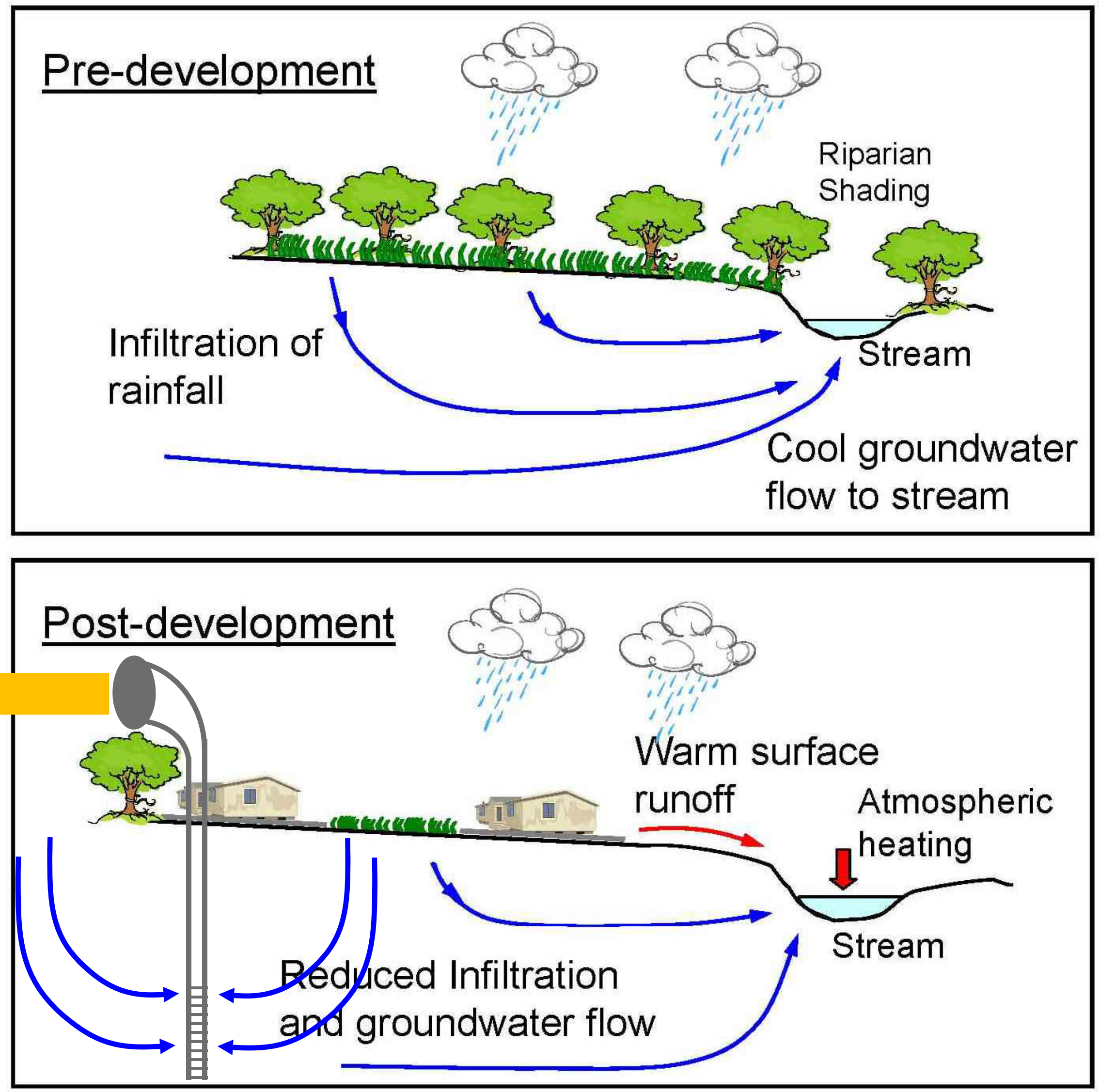

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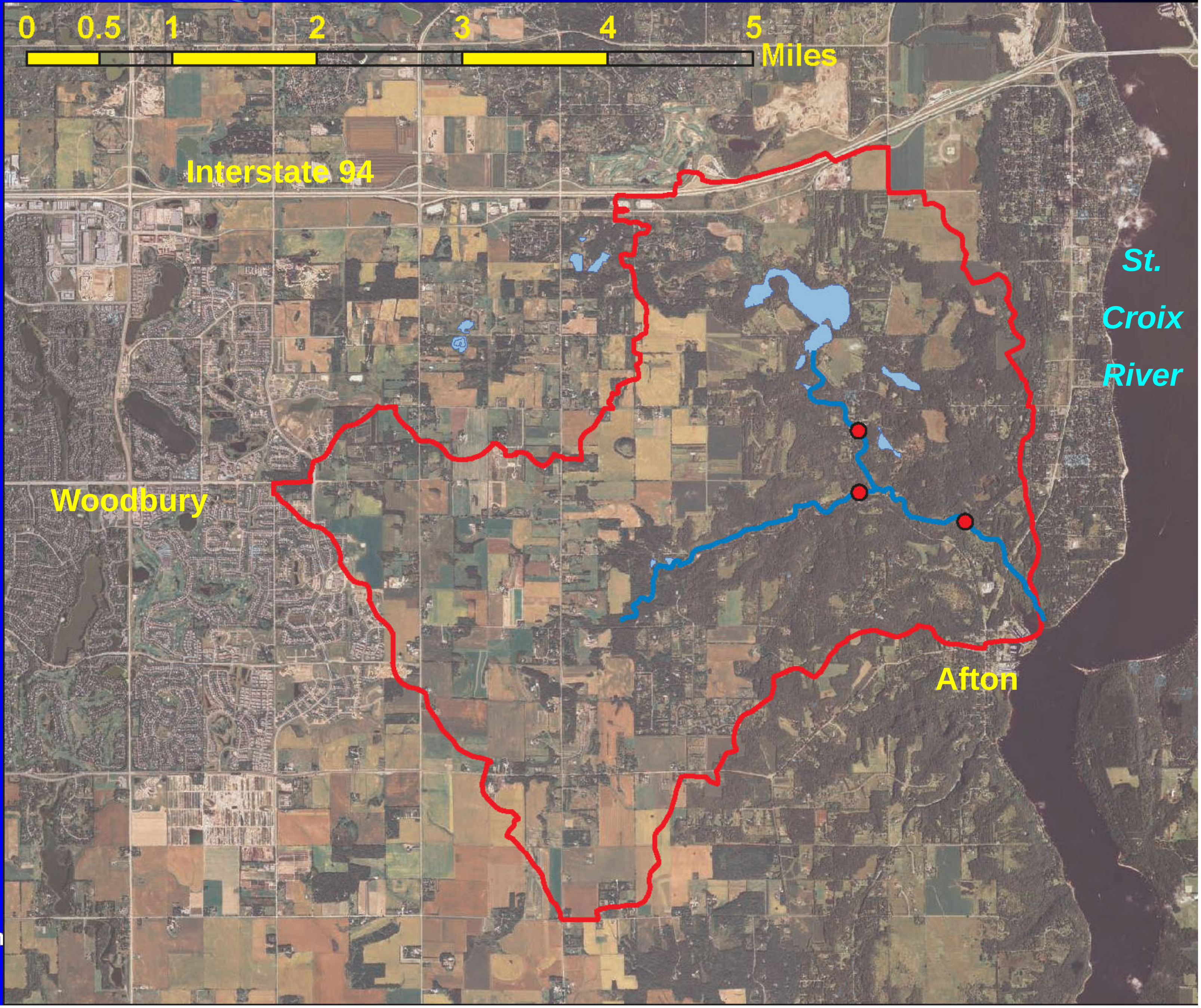
Valley Creek surficial watershed & sampling points

About 37 km^2



2010 FSA photo

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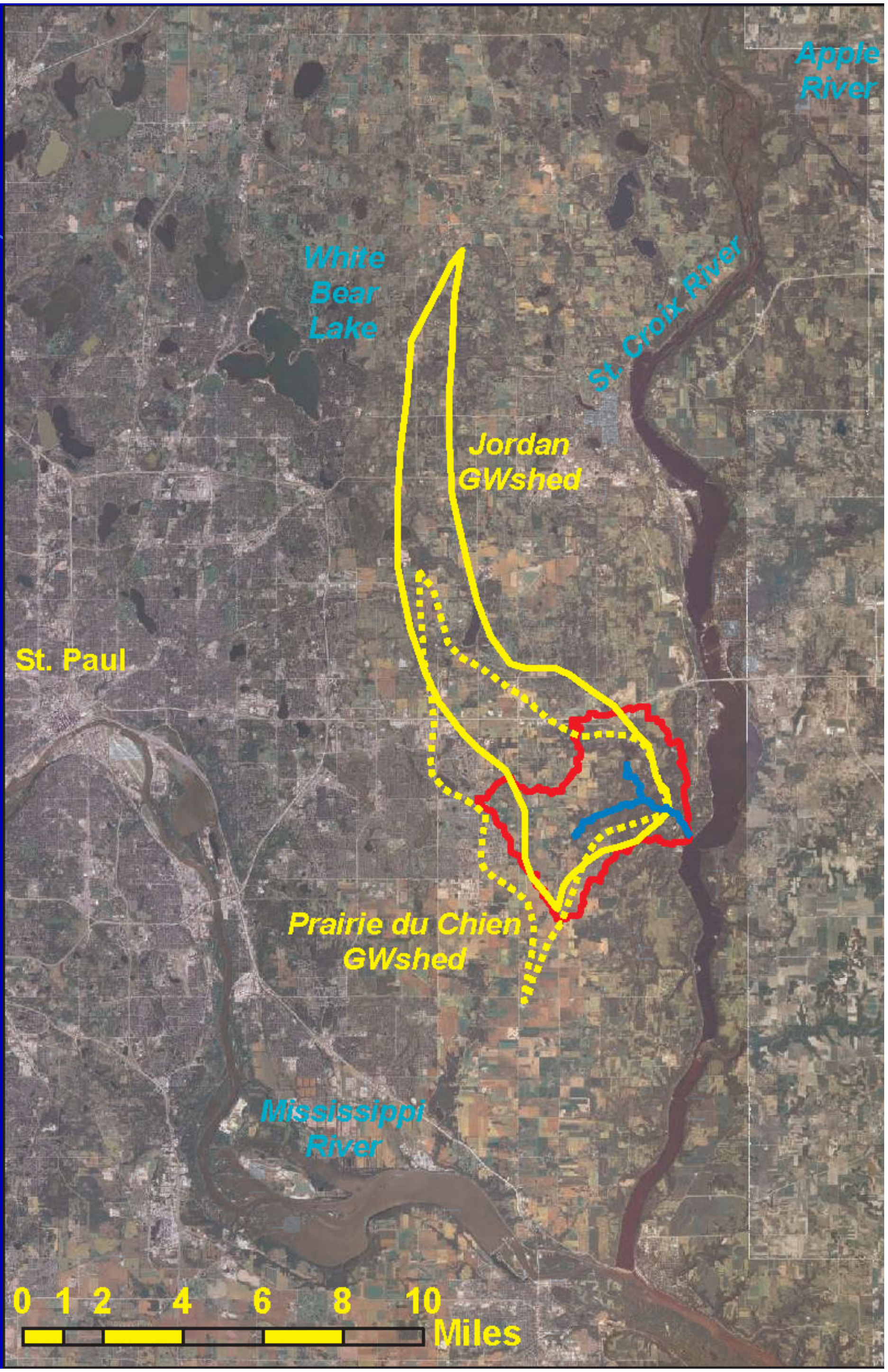
Valley Creek ground-watershed(s)

- **Estimated from static water levels recorded in County Well Index**
- **Prairie du Chien limestone / dolostone**
  - **About 60 km^2**
  - **~10 inches of recharge (lots)**
- **Jordan sandstone**
  - **About 80 km^2**
  - **~7.6 inches of recharge (still lots)**



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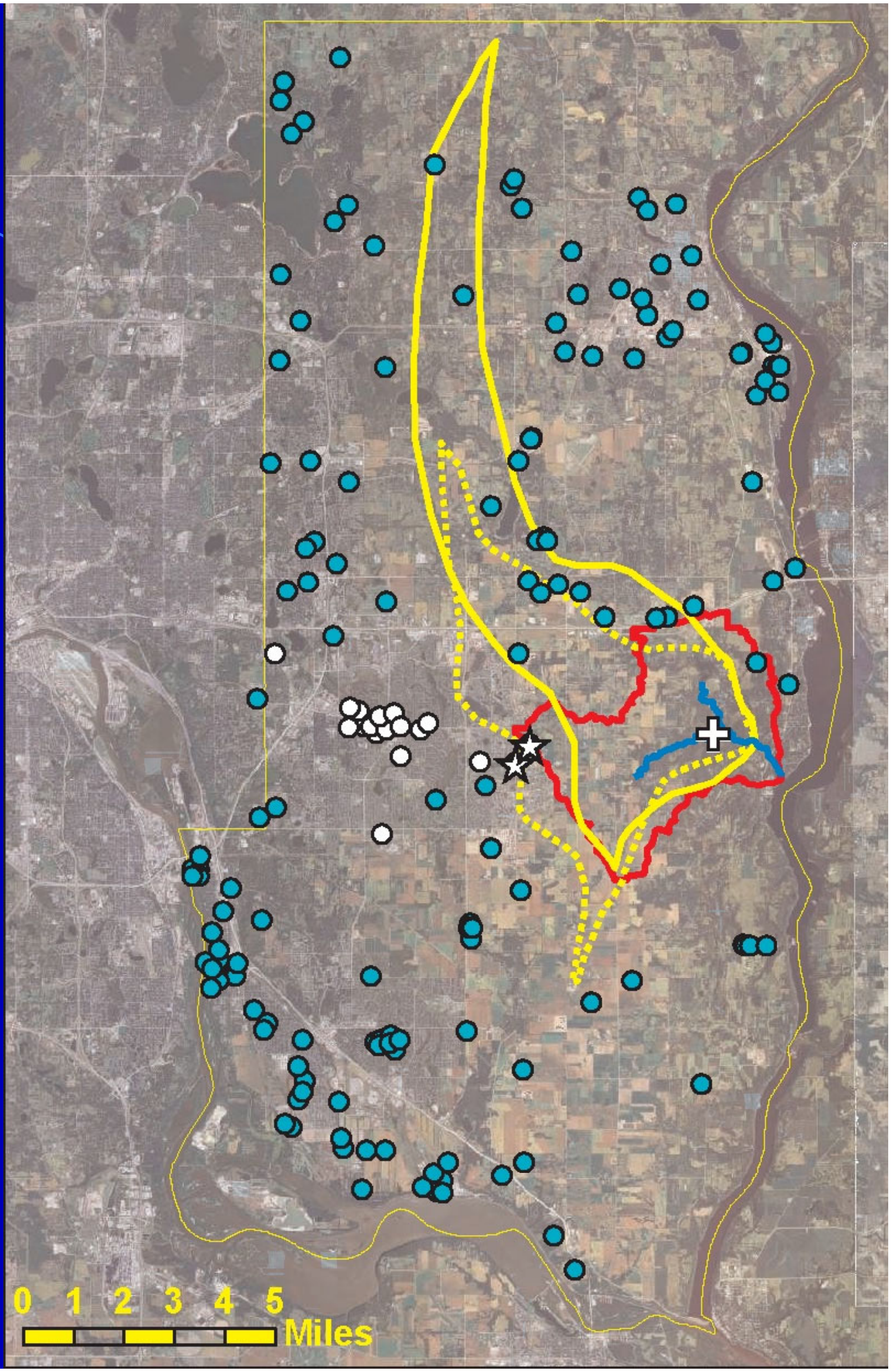
Permitted wells in south Washington County

- **Data from MDNR**
  - **214 wells, 12BG/yr (2006-10)**
- **Who uses the water?**
  - **23% Woodbury**
  - **20% 3M**
  - **12% Cottage Grove**
  - **9% Oakdale**
  - **7% Stillwater**
- **Woodbury wells = white**
  - **Cluster = Tamarack well field**
  - **Stars = East well field (2003+)**
- **For wells within 1 km of ground-watershed boundaries:**
  - **3.6 cfs total (35 wells)**
  - **2 cfs from Woodbury E (55%)**



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How large is pumping relative to baseflow of Valley Creek?

- **Valley Creek flows**
  - **Median Q = 17.27 cfs (1976-2003)**
  - **Baseflow = 17.26 cfs (1999-2003)**
  - **What is "natural" baseflow??**
- **Amount of Pumping (2006-10)**
  - **Near GWshed = 3.6 cfs**
  - **Woodbury East = 2 cfs**
    - **~12% of VC baseflow**
- **What are the contributing areas?**
  - **If Valley Creek GWshed = 70 km^2**
  - **Then Woodbury E GWshed = 8.1 km^2**
- ***Are these pumping rates enough to materially impact the baseflow of Valley Creek? How do we know?***
  - ***Modeling***
  - ***Monitoring***

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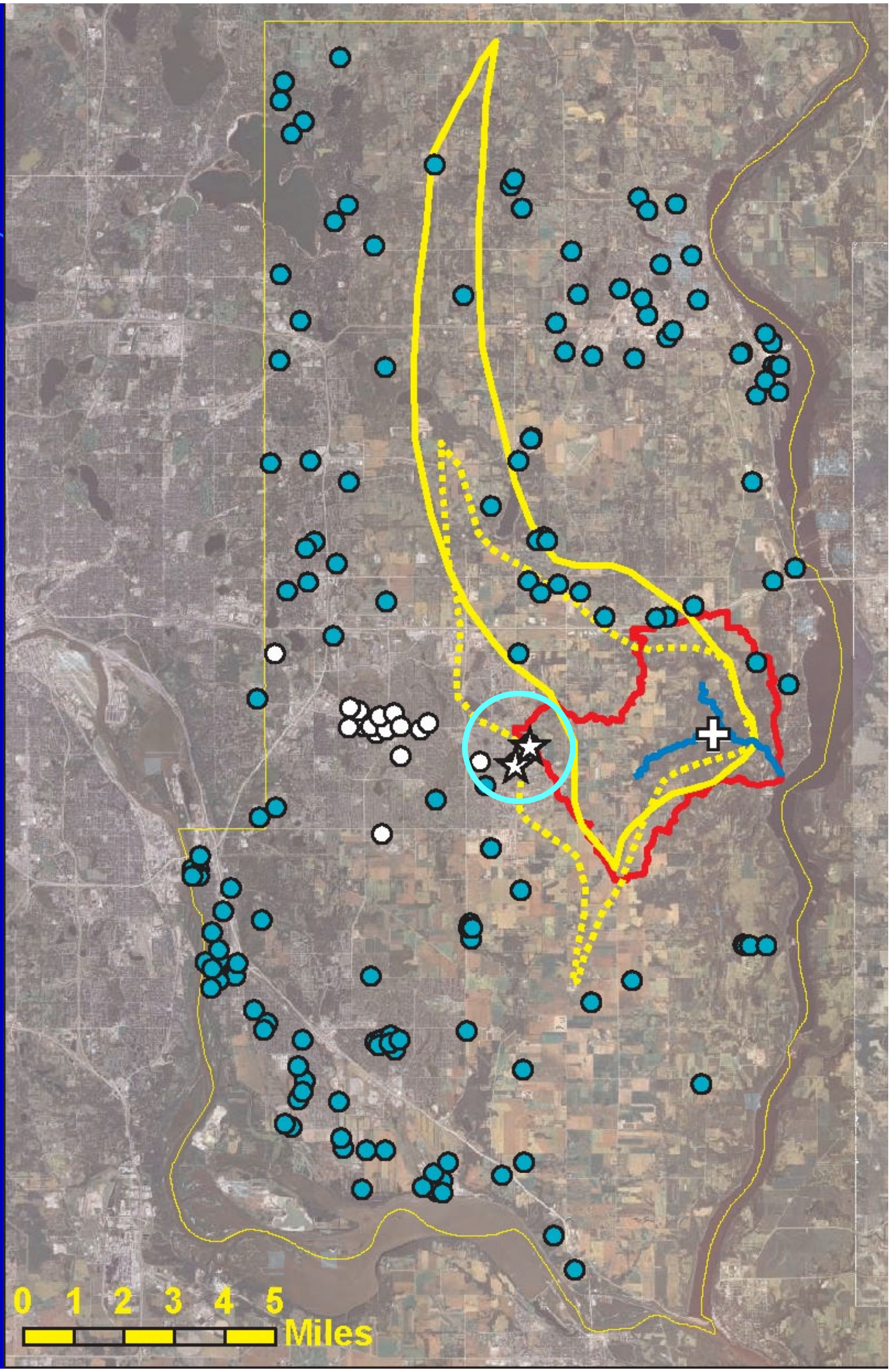
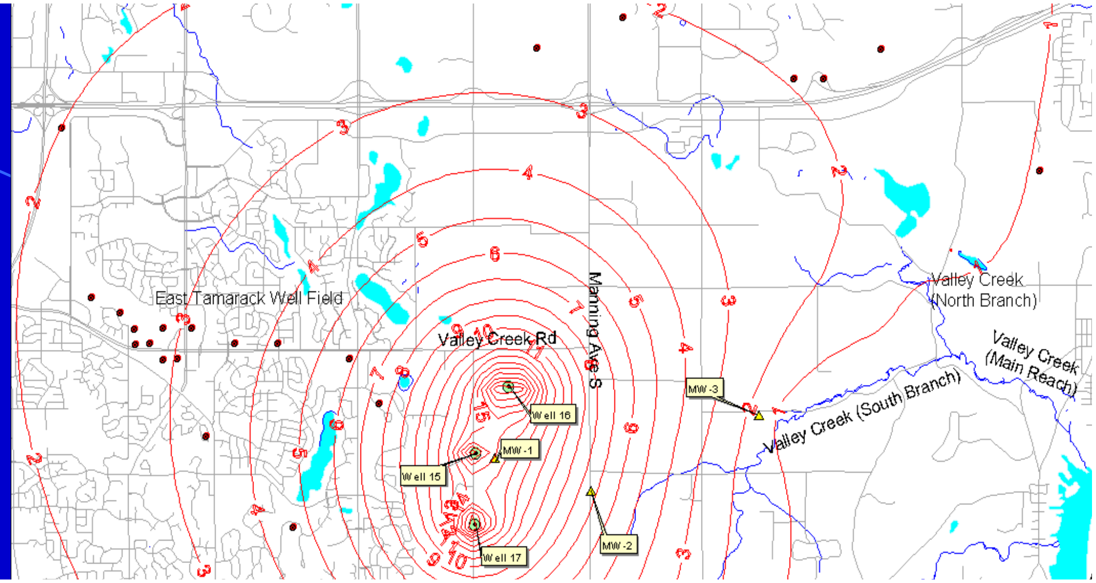
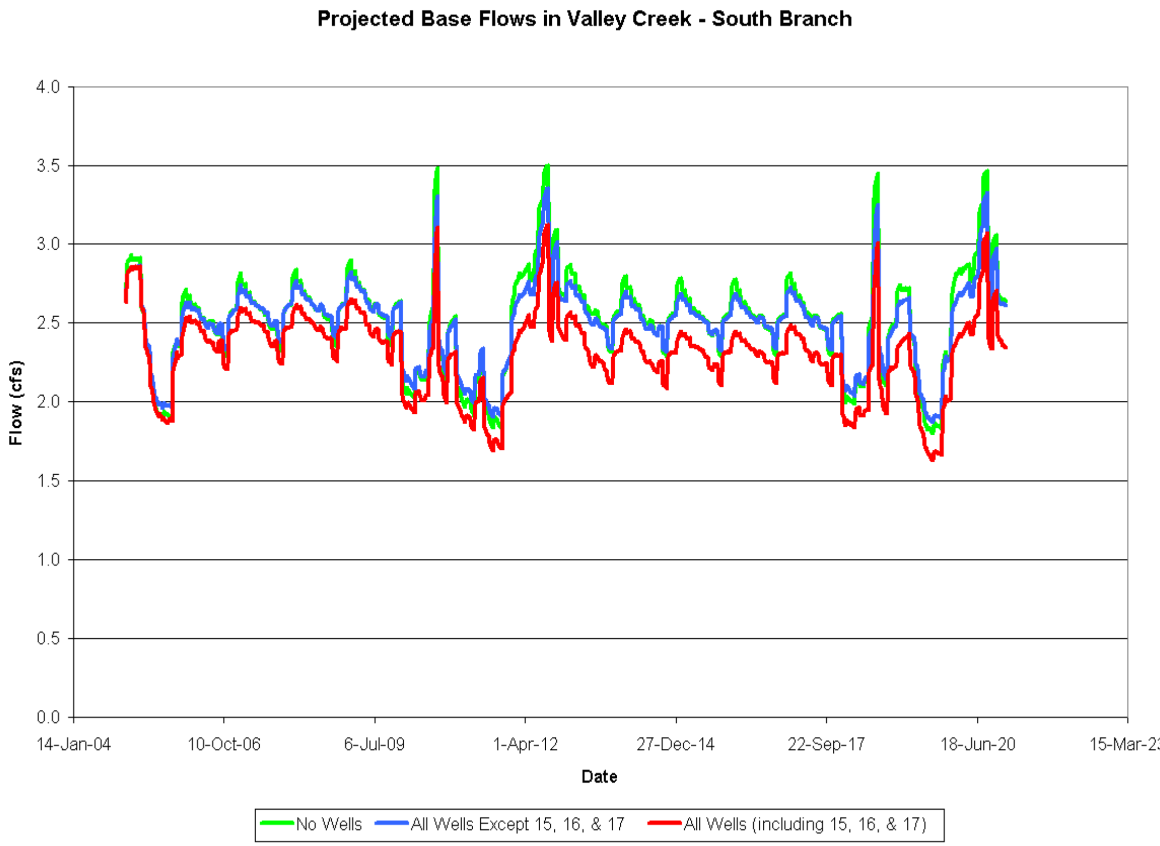


MIKE-SHE model of south Washington County

- **by Ray Wuolo, Barr Eng.**
  - 2005. Intercommunity Groundwater Protection: Sustaining Growth and Natural Resources in the Woodbury/Afton Area. Development of a Groundwater Flow Model of Southern Washington County, Minneesota. Final report to the LCCMR. 125 pp + figures.





- **Conclusions**
  - "Natural" baseflow isn't much different than modern
  - 3 water-supply wells pumping at typical rates would reduce baseflow in Valley Creek by about 0.5 cfs or less – about within the range of flow measurement error.

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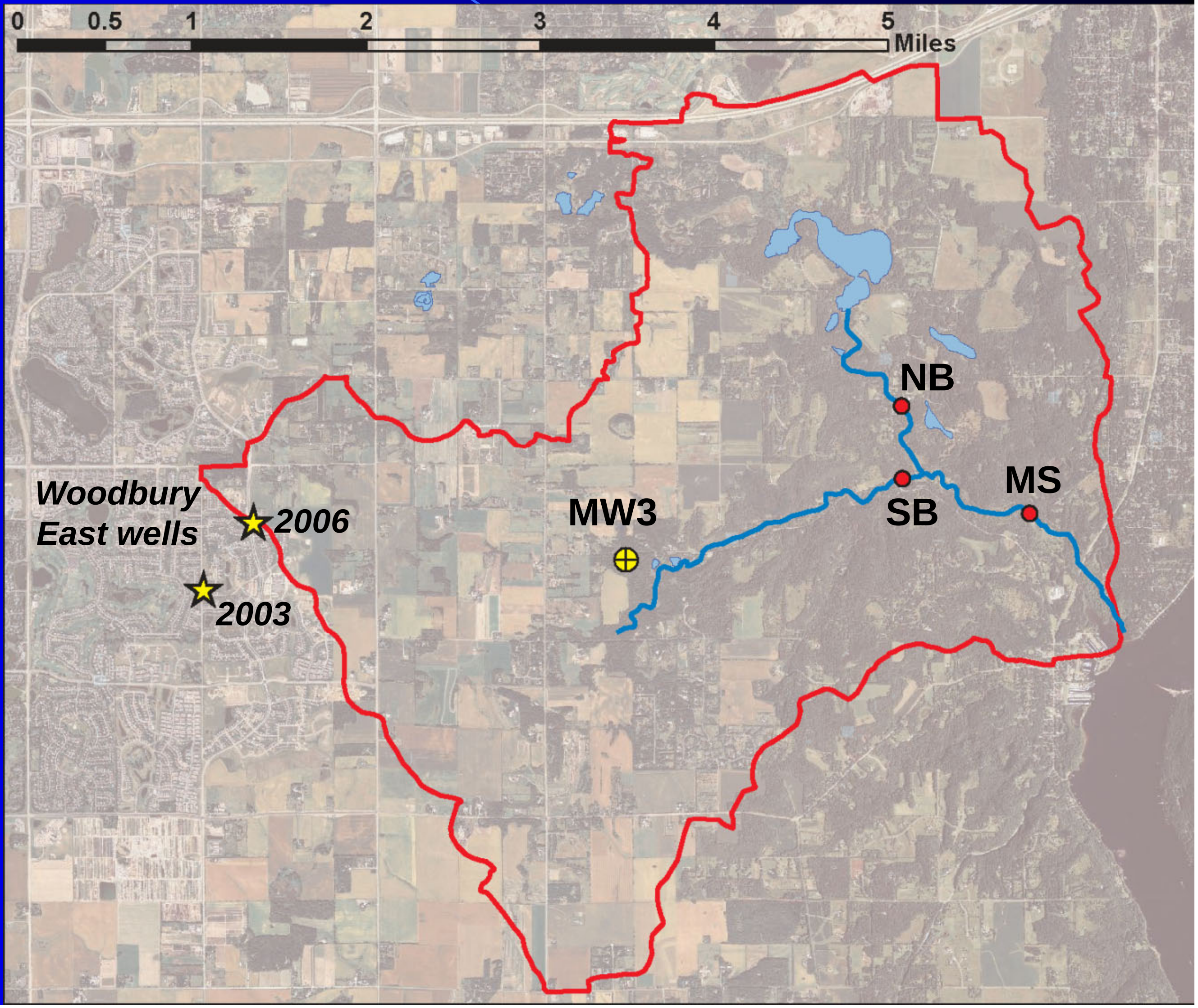
Monitoring: *Can we measure any impact of the wells yet? Can we tease apart influence of climate, urbanization, and pumping?*

- **Three flow monitoring sites**
  - **Main stem (MS)**
    - **Spot 1976-98, Cont. 1999+**
  - **South Branch (SB), Cont. 1998 +**
  - **North Branch (NB), Cont. 1998 +**

- **Monitor well nest 3 (MW3), multiple aquifers, 2003 +**
  - **Water table**
  - **Prairie du Chien**
  - **Jordan**



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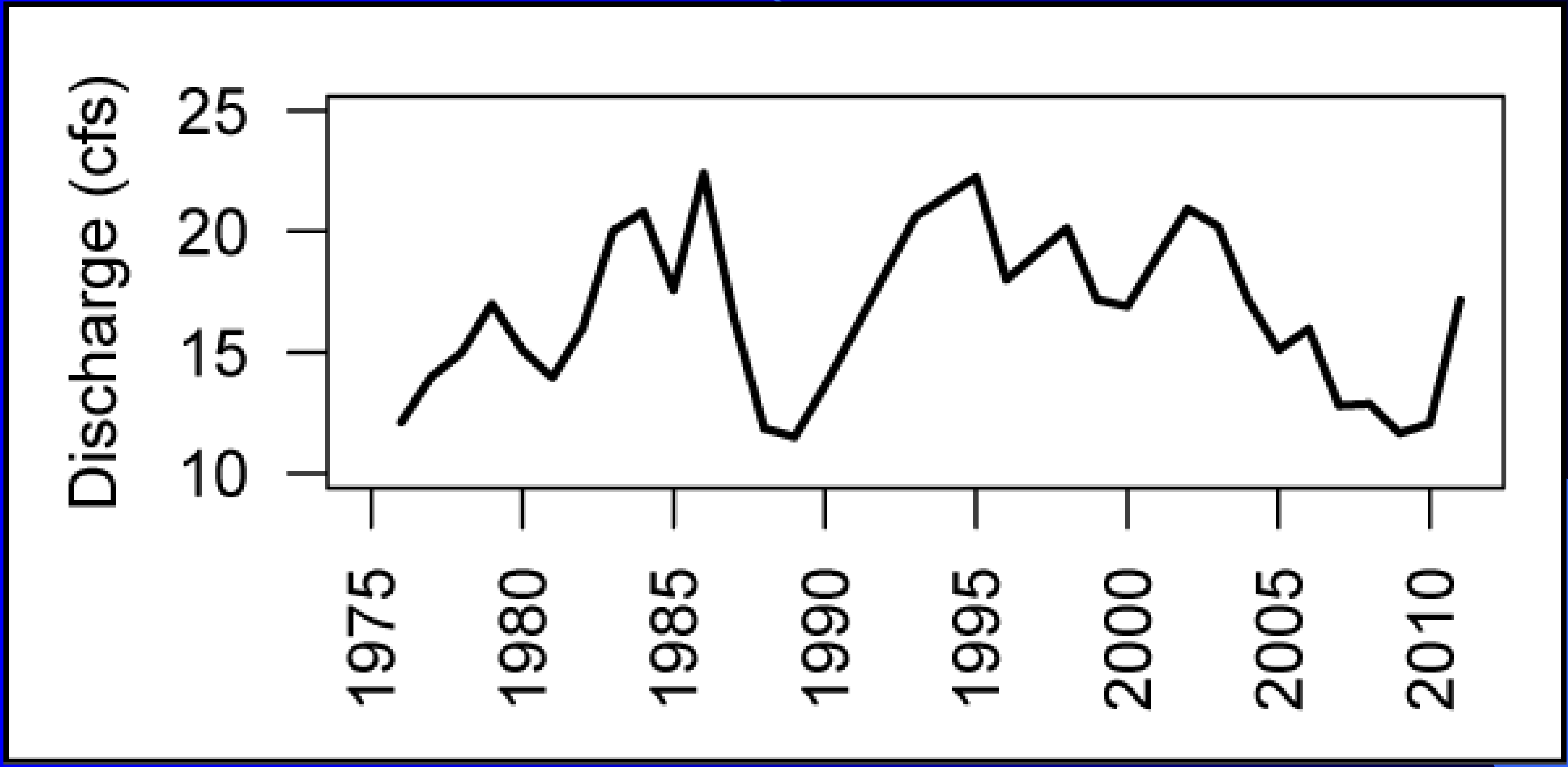
What data are available for the factors that affect Valley Creek baseflow?



- **Climate**
- **Urbanization**
- **Pumping**

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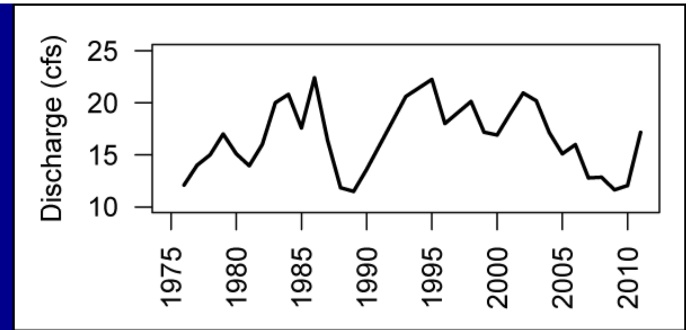
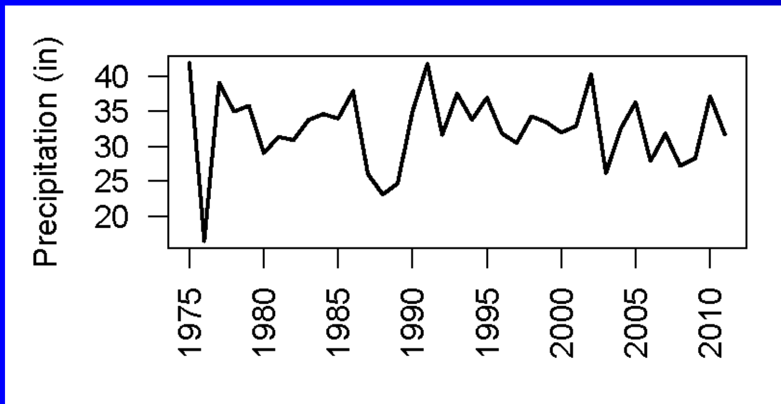
Climate Data:

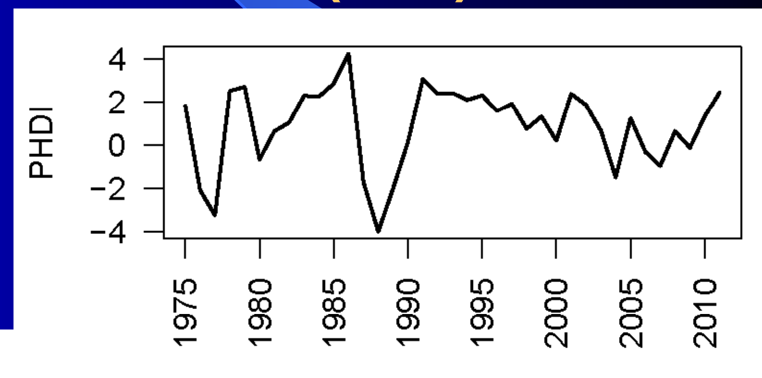
Our Target = Valley Creek baseflow or median flow



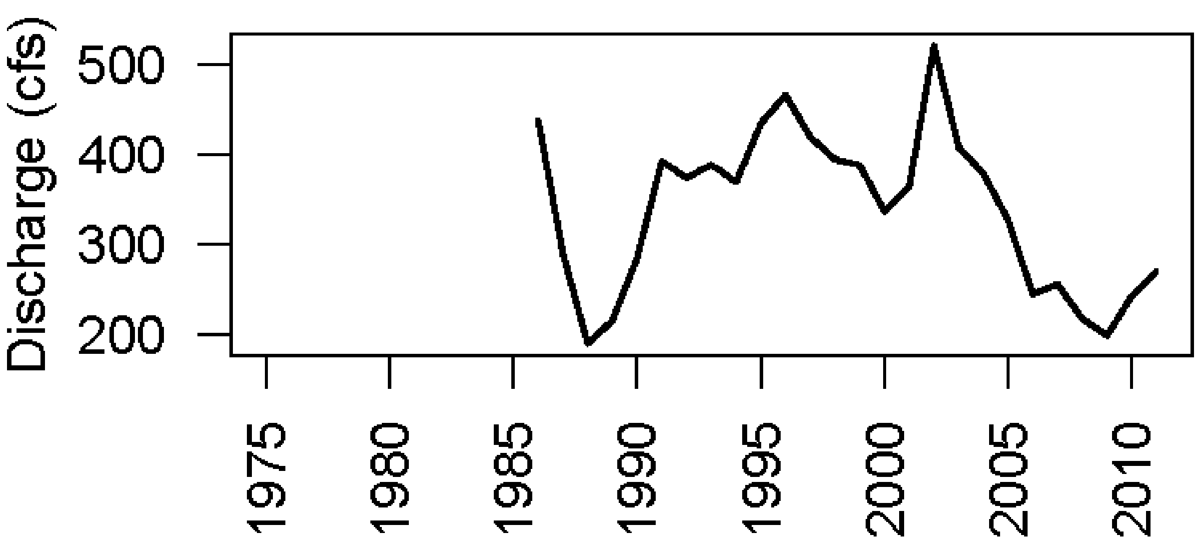
Precipitation (Washington County average)



Palmer Hydrologic Drought Index (PHDI)

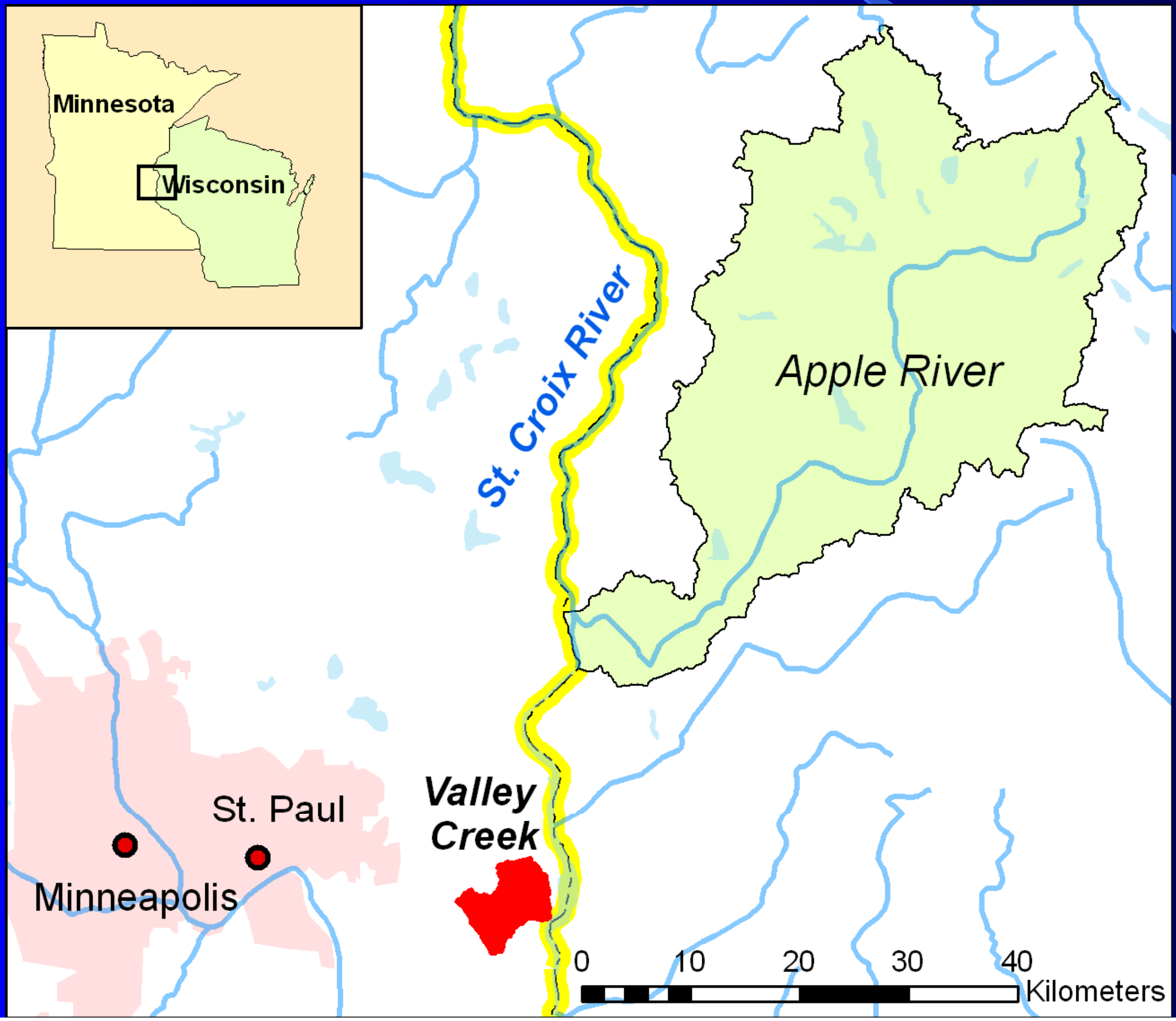


Apple River Q (median or baseflow)



Why the Apple River?

- -- Reasonably close to Twin Cities and Valley Creek
- -- Minimal impacts to its watershed hydrology:
  - -- Little urbanization
  - -- Insignificant hydrologic alteration from agricultural irrigation and drainage
- -- Long flow record (1914-1970 & 1986-present)



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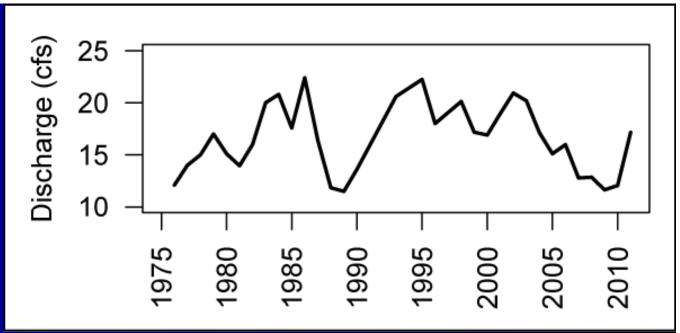
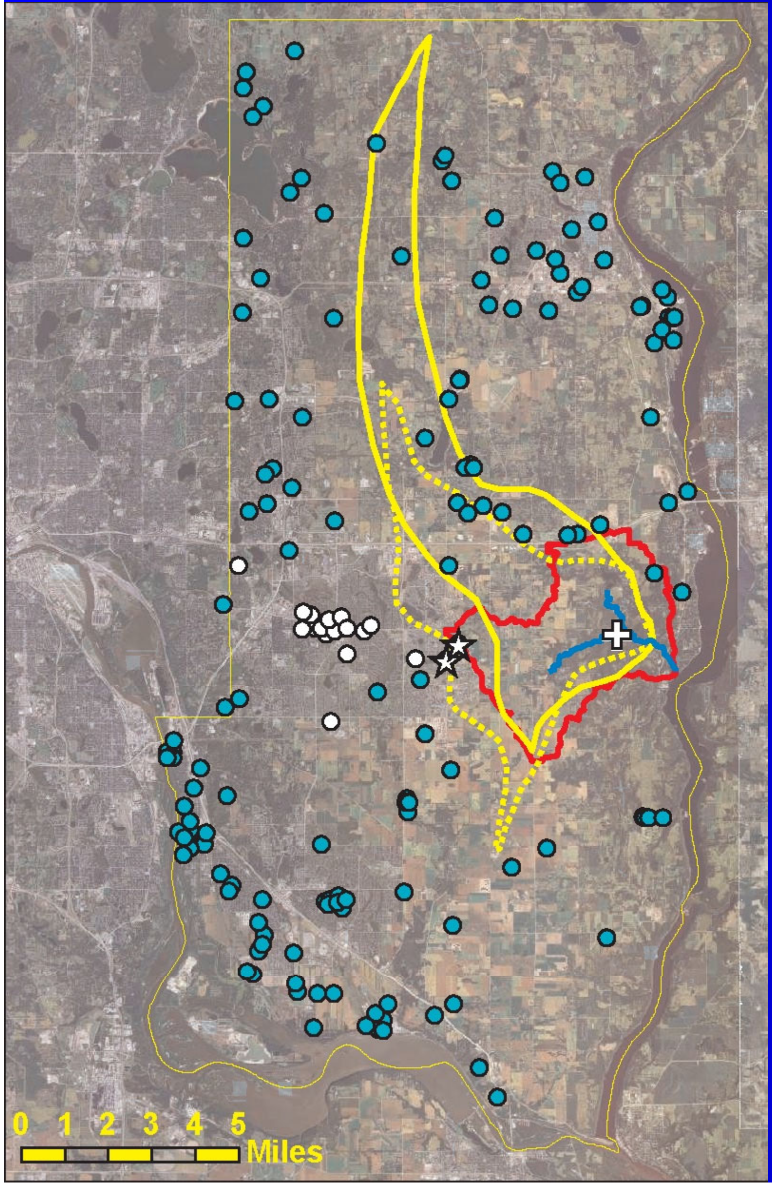
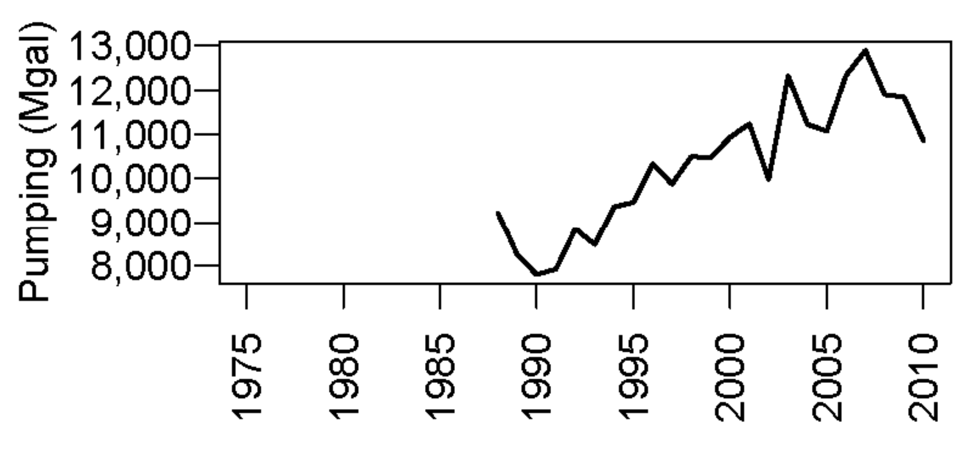
Urbanization Data = Regional Pumping

Our Target = Valley Creek baseflow or median flow

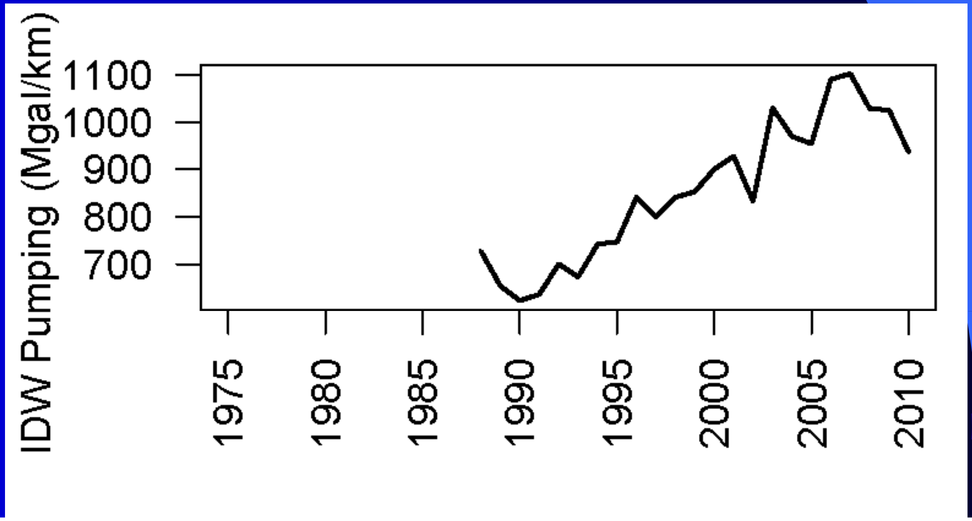




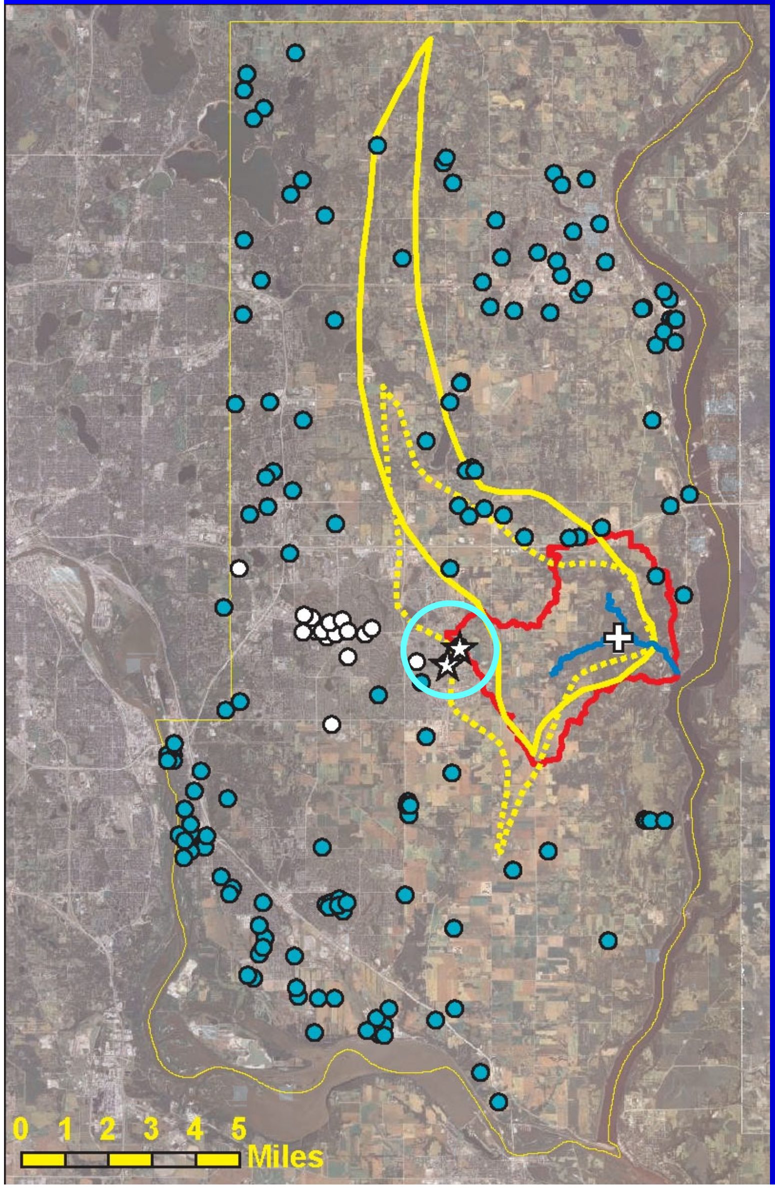
Regional Pumping



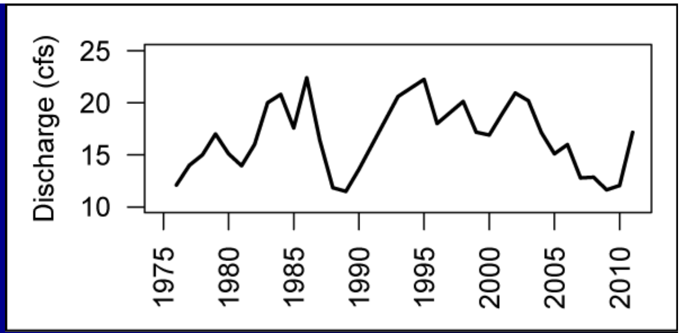
Regional Pumping, Inverse-Distance Weighted



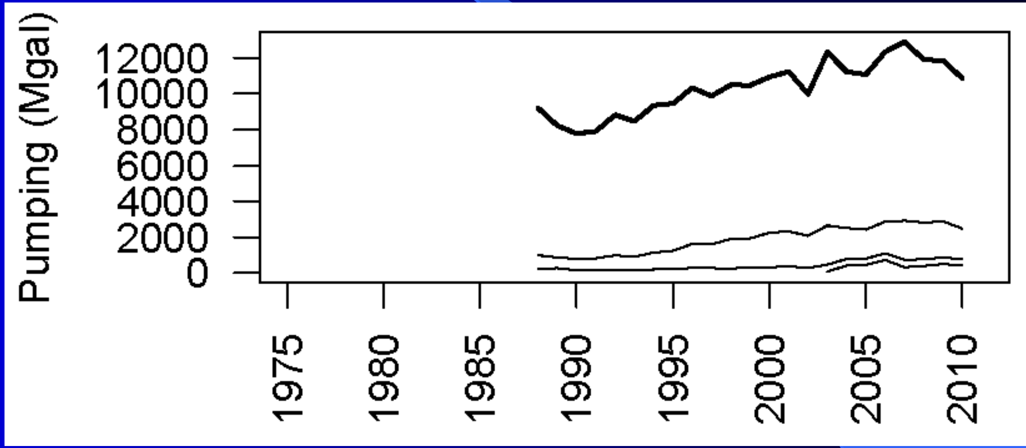
Local Pumping:



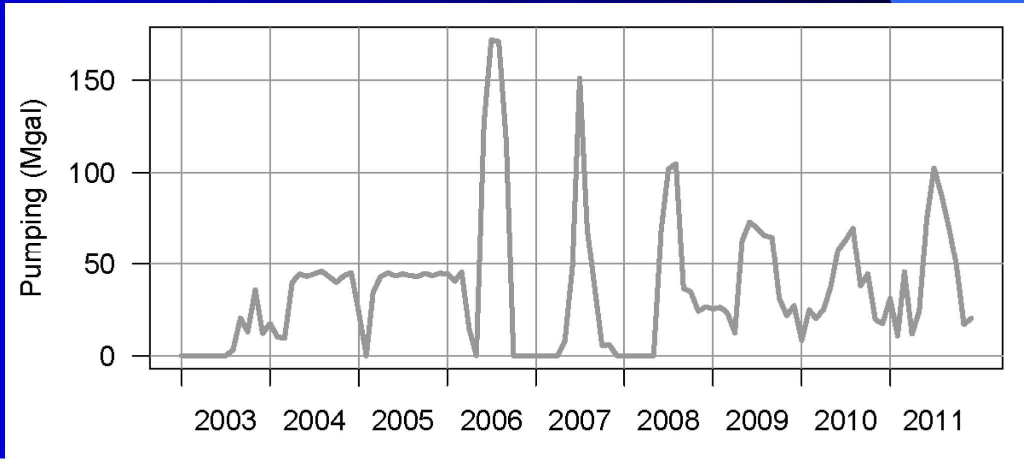
Our Target = Valley Creek baseflow or median flow



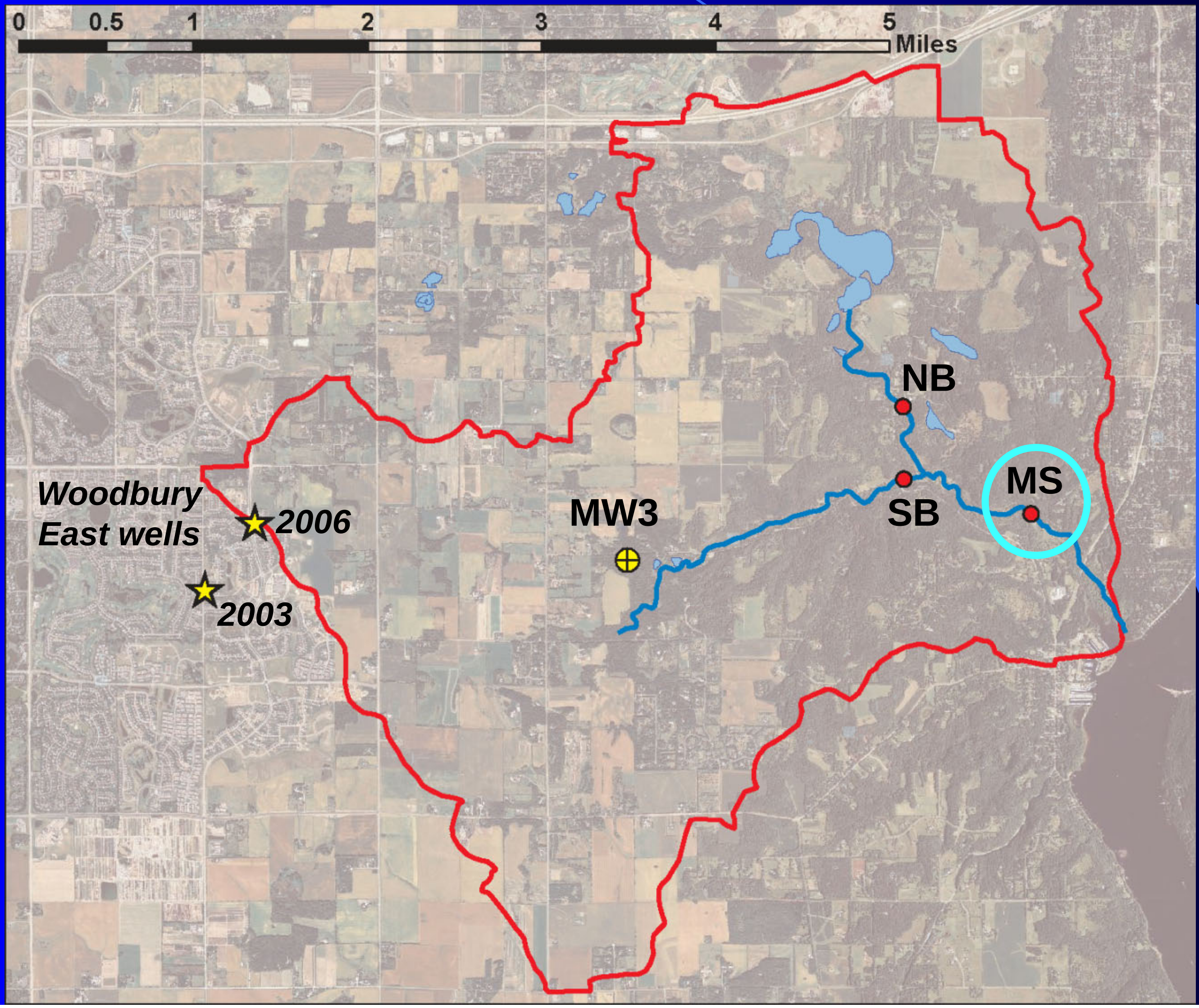
Woodbury wells, relative to all others



Monthly pumping, Woodbury East well field



Results: *First – annual data for median flows on the main stem*



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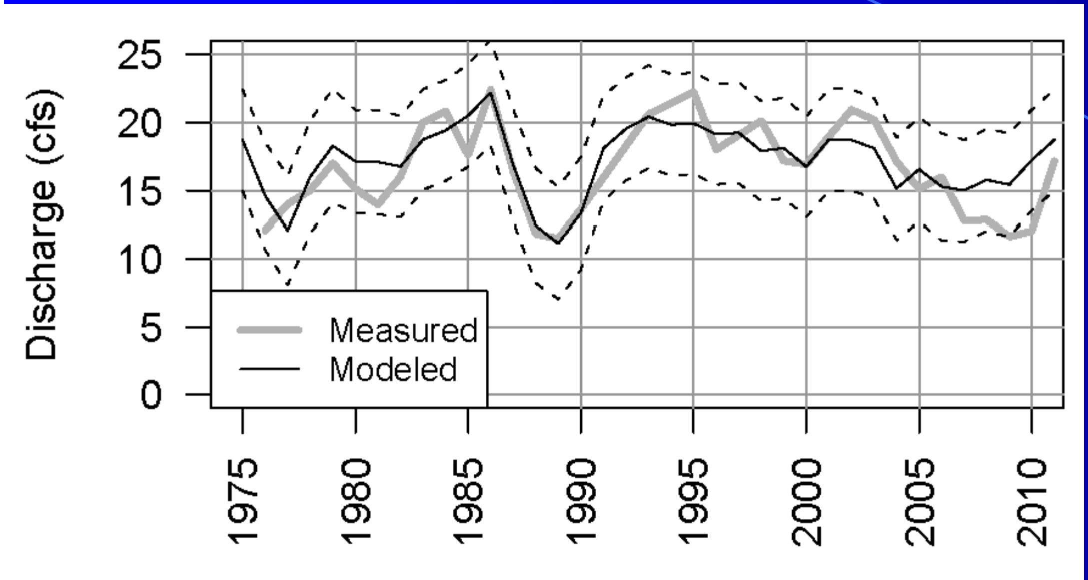
Results: Annual median flow, Valley Creek main stem

Valley Creek, main stem median Q = f(PHDI lagged by 0, 1, & 2 yrs)   R2 = 0.74

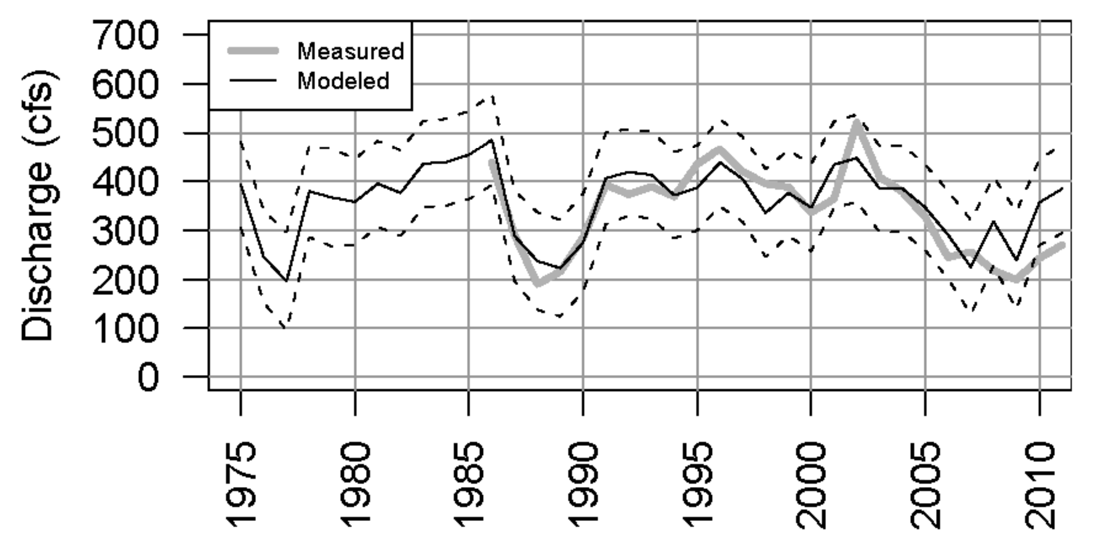


!!! NOTE !!!

-- Measured values = thick gray line

-- Modeled (predicted) values = thin black line, bounded by dashed prediction interval

Apple River median Q = f(PHDI lagged by 0 & 2 yrs)   R2 = 0.78



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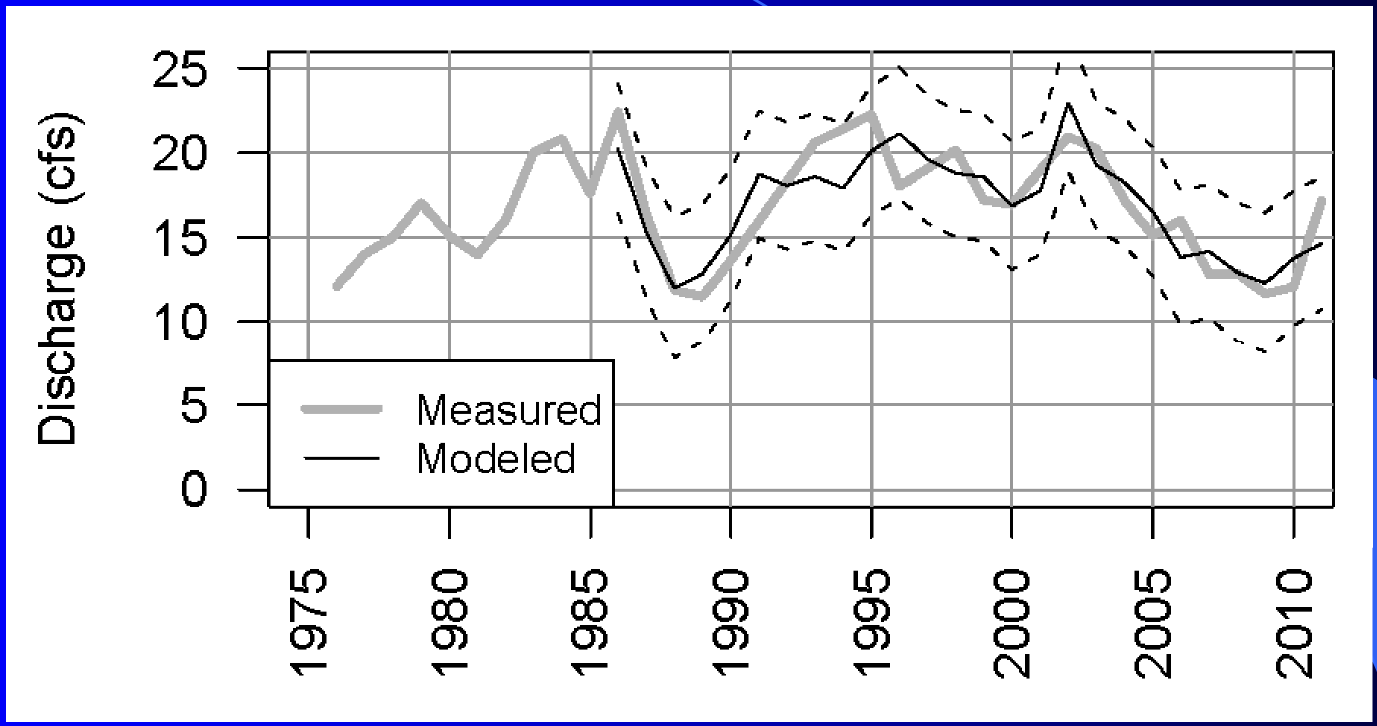
Results: Annual median flow, Valley Creek main stem

Valley Creek, main stem median Q = f(Apple median Q)   R2 = 0.76

Simple linear regression of flows – no lags needed



Adding Regional Pumping or Local Pumping to the equation did not significantly improve the fit.

So on the annual time series at the watershed outlet the effect of pumping is not (yet) evident.

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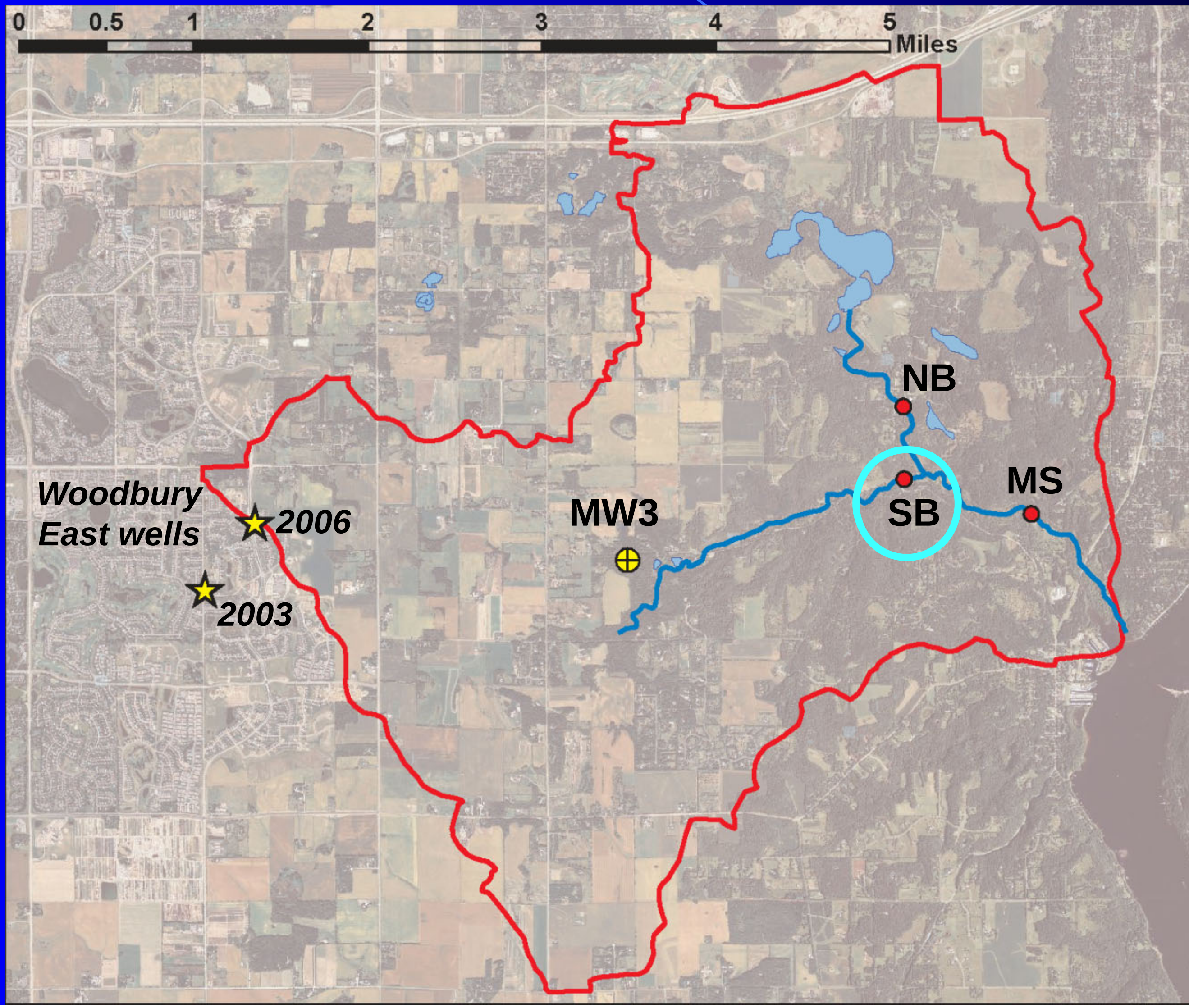
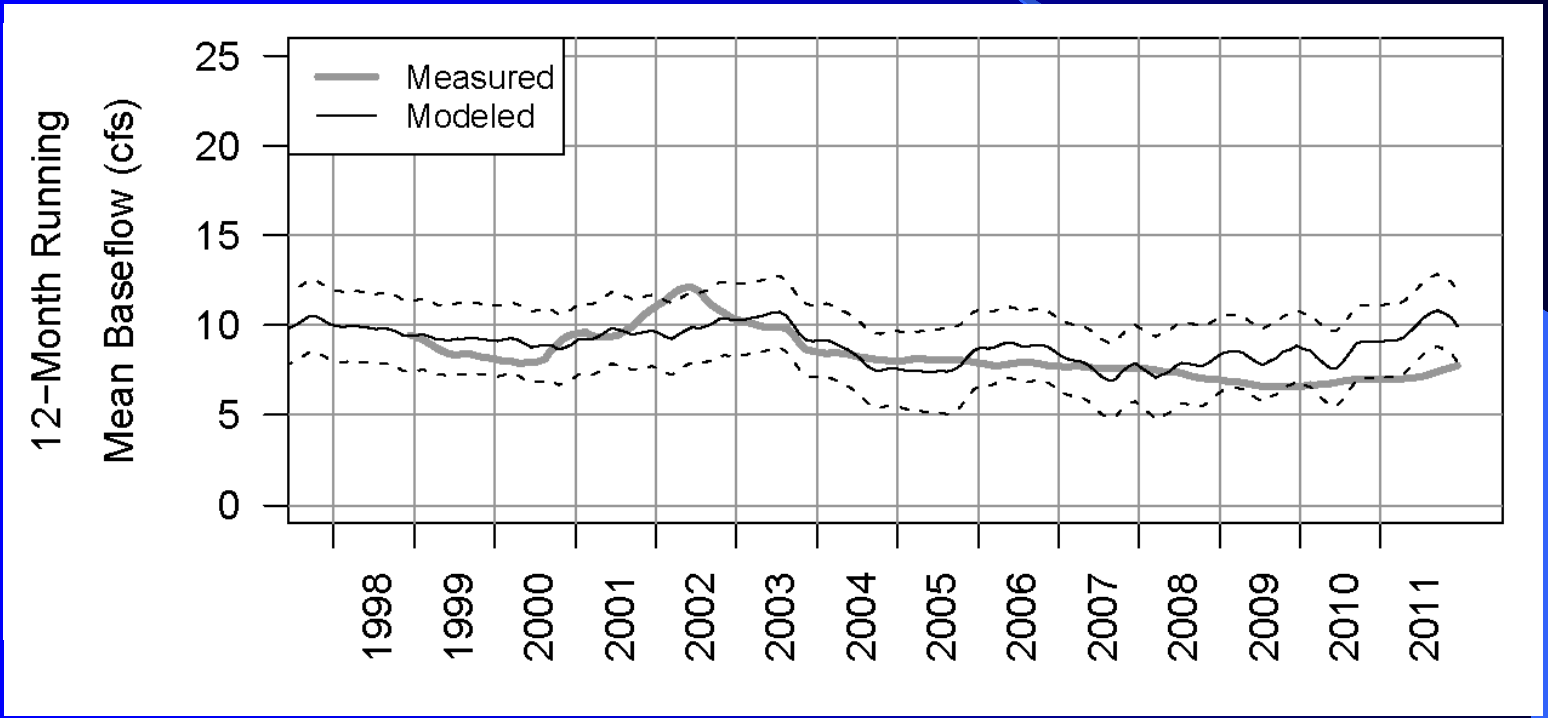
Results: *Second – monthly data for baseflows on the South Branch*



Results: Monthly baseflow, South Branch Valley Creek

12-month running mean base flow = f(PHDI lagged by 3, 12, & 24 months)
R2 = 0.37



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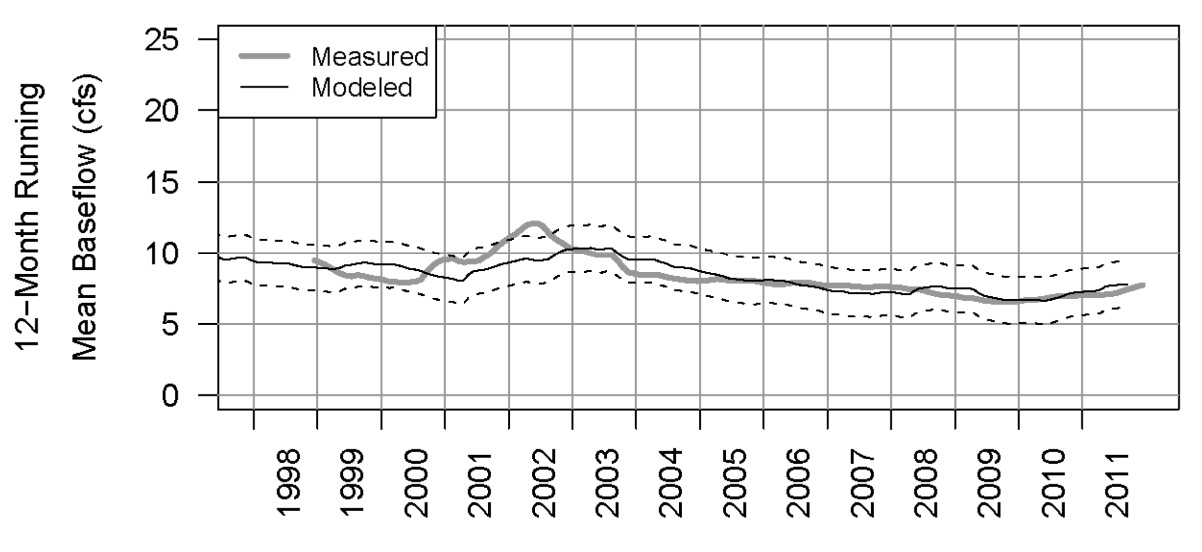
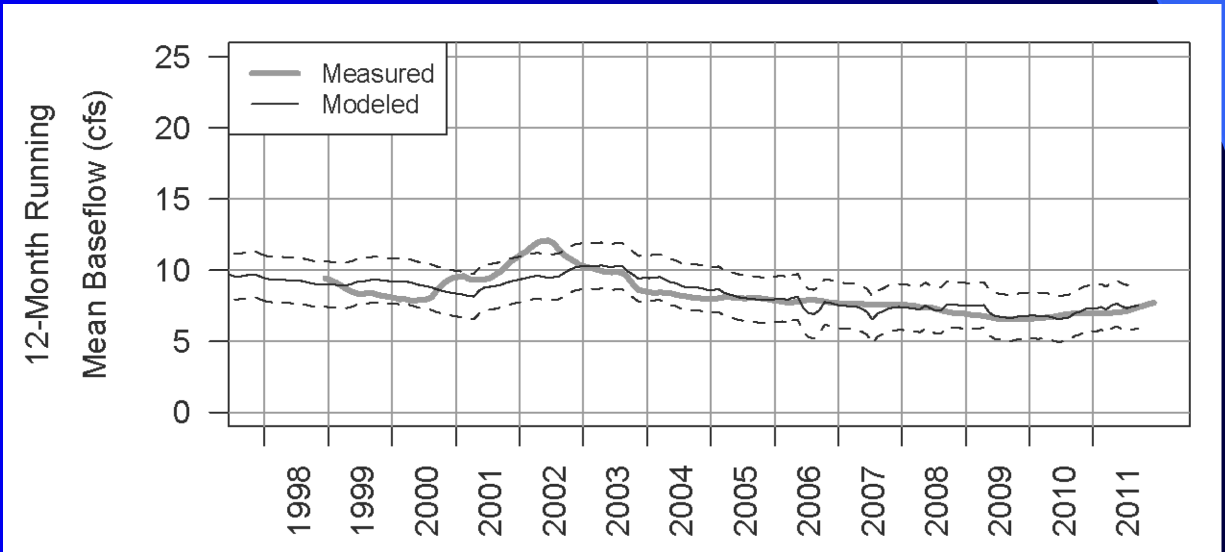
Results: Monthly baseflow, South Branch Valley Creek

12-month running mean base flow = f(Apple 12-mon RM BF) R2 = 0.63



12-month running mean base flow = f(12-mon RM Apple BF + 12-mon RM Woodbury East Pumping) R2 = 0.66

Is pumping significant?



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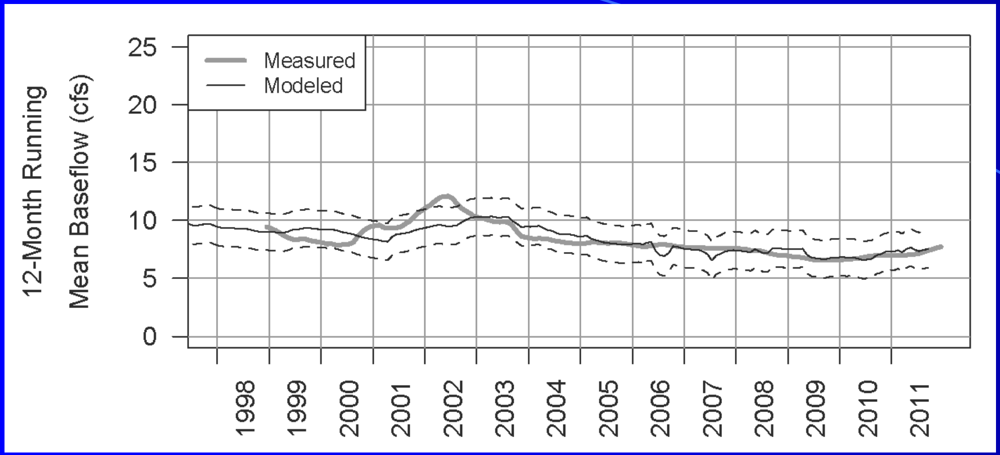
Results: Monthly baseflow, South Branch Valley Creek



The statistics suggest that the pumping coefficient is significant... (!)

For all data as 12-month running means:

South Branch baseflow =

5.94 + 0.009089*Apple baseflow – 0.0178*Woodbury East pumping

The coefficient represents the change in baseflow (cfs) per unit of groundwater pumped (Mgal/mon).

The average 12-month RM mean pumped recently (2009-11) is about 40 Mgal/mon, implying a 0.7 cfs reduction in baseflow.

This number is highly uncertain, but within the ballpark of that estimated by Wuolo's model.

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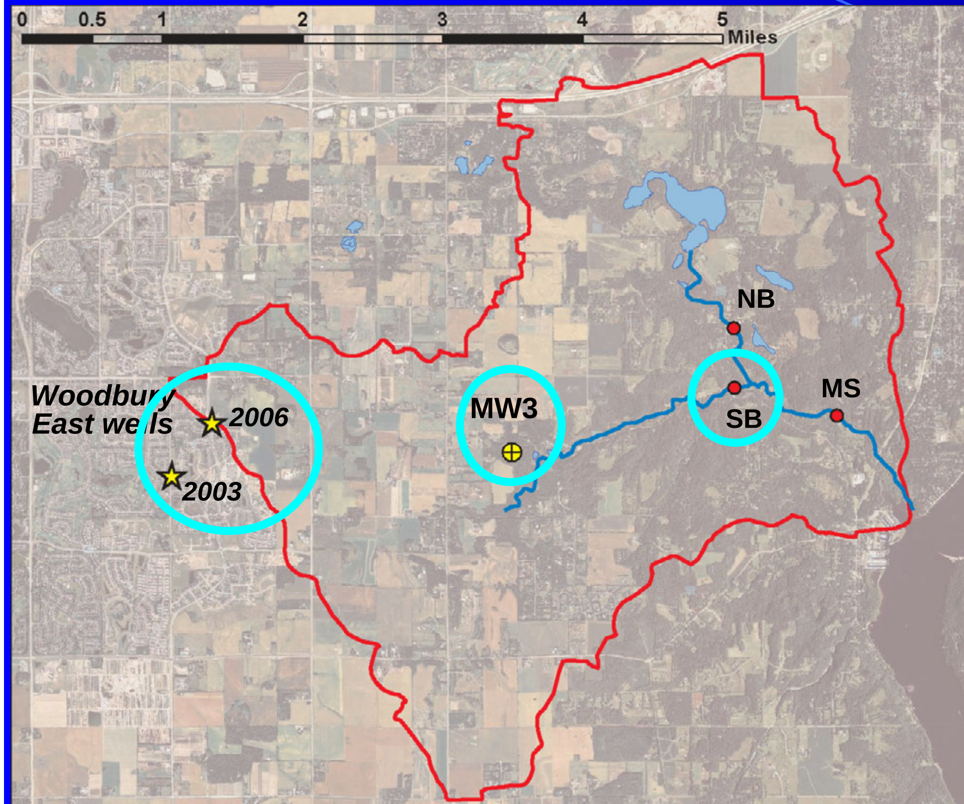
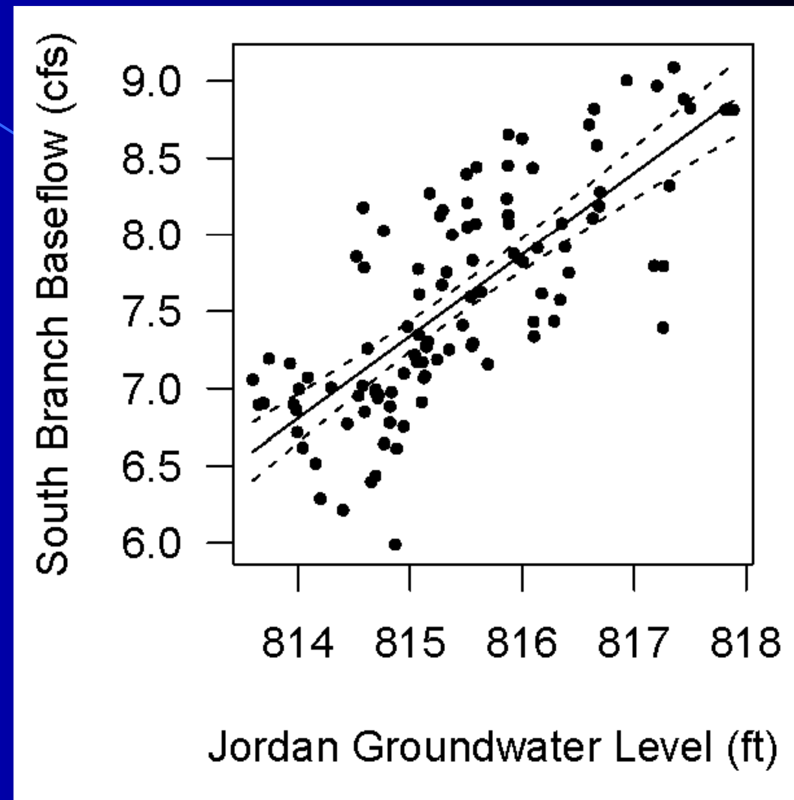
Results: Monthly baseflow, South Branch Valley Creek: Relation to groundwater head, pumping, and climate





South Branch baseflow =
-426.25 + 0.53*Head in Jordan aquifer at monitor well 3 ($R2 = 0.57$)

⇒South Branch baseflow changes by 0.53 cfs per foot of change in the Jordan aquifer head

⇒Can we predict a change in head as a function of climate and pumping, to predict flow from this equation?

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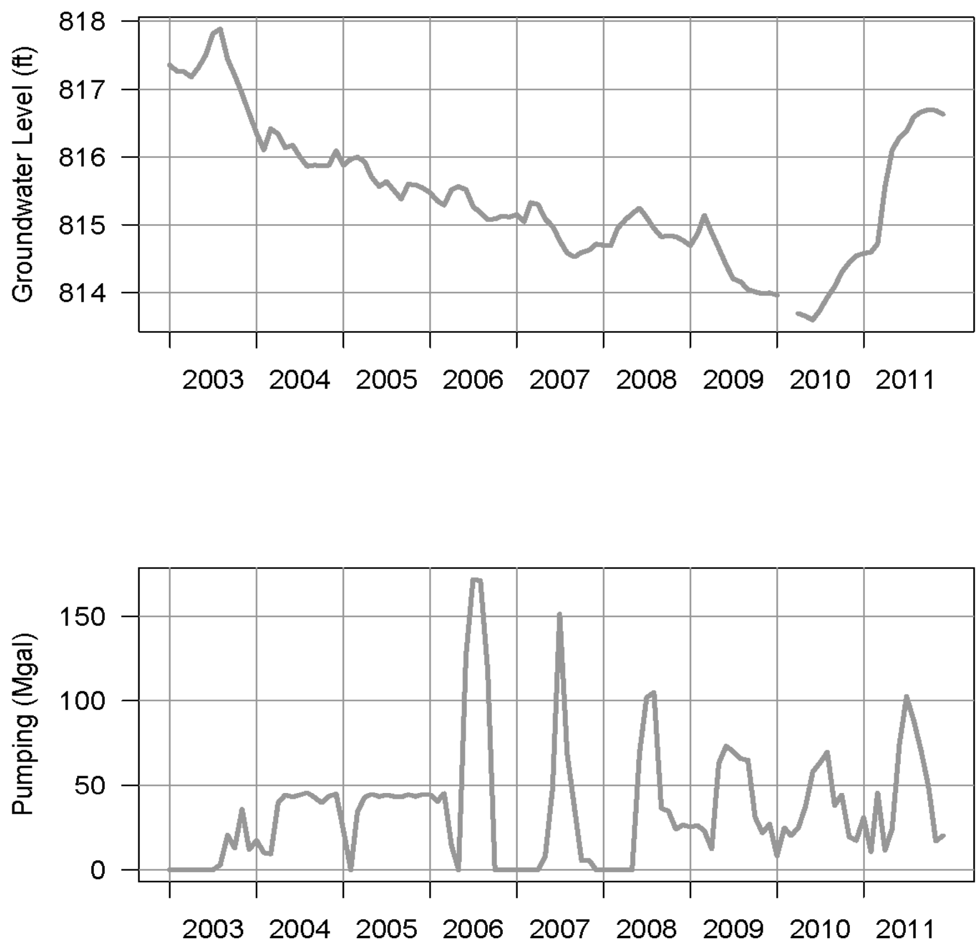
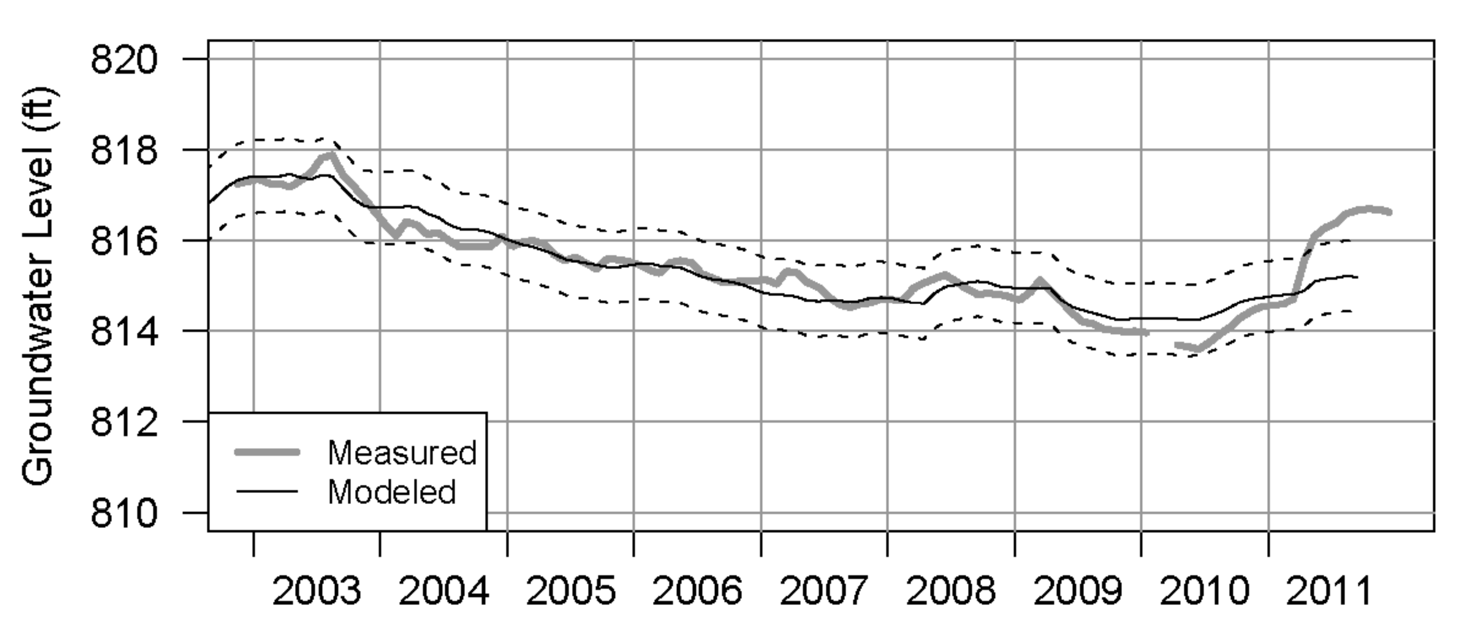
Results: Monthly baseflow, South Branch Valley Creek: Relation to groundwater head, pumping, and climate

Can we see a change in head as a function of pumping?
Maybe... Maybe not...



Results: Monthly baseflow, South Branch Valley Creek: Relation to groundwater head, pumping, and climate

The fit of MW3 heads to the Apple River flow, as a proxy for climate, is good (R^2 = 0.85):



If we assume all negative deviations from the model are due to pumping – Then:

maximum negative deviation = -0.65 ft * 0.53 cfs/ft = -0.34 cfs

average negative deviation = -0.23 ft * 0.53 cfs/ft = -0.12 cfs

These highly uncertain values are within the same ballpark as Wuolo's model and baseflow regression.

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Summary & Conclusions:

- **Fluctuations in Valley Creek baseflow are principally related to monthly to interannual variability in climate**
  - ***Apple River flow is an excellent proxy for climate, as processed by watershed hydrologic processes***
- **At annual time scales, no influence from regional or local pumping was evident**
  - ***This does not disprove the influence of pumping; rather, the pattern of pumping was not needed to explain the variability in stream flow.***
- **At monthly time scales, a minor effect from local pumping may be present, but this remains uncertain.**
  - ***Flow deviations would be in the range of 0.1 to 0.7 cfs, if real.***

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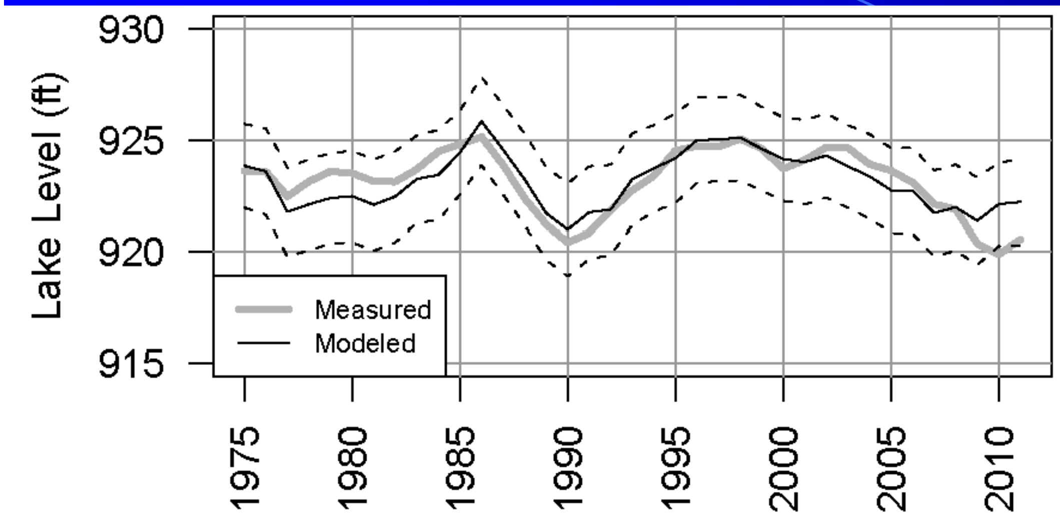
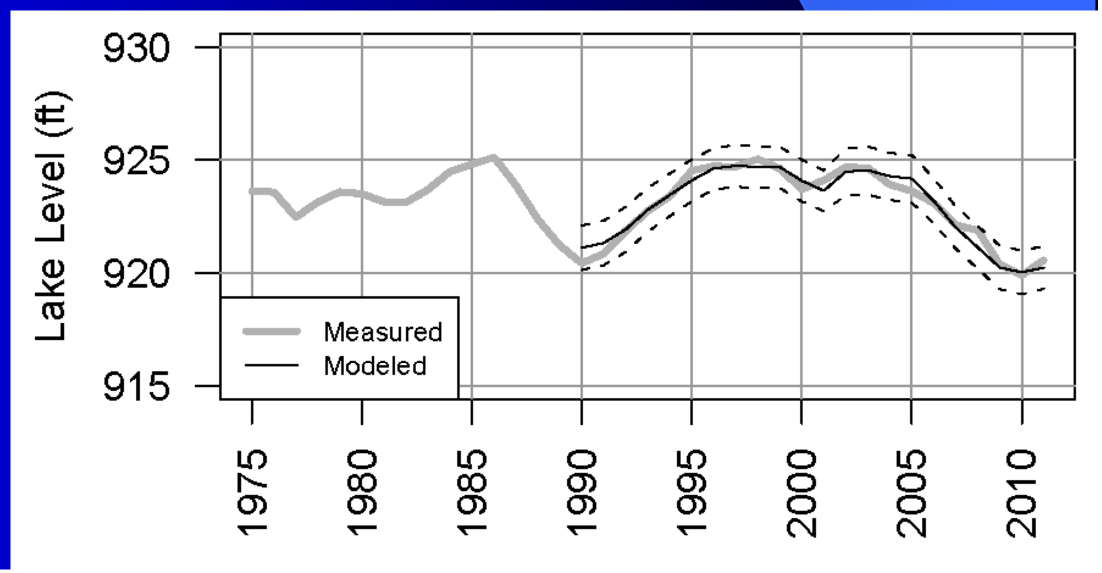
Addendum: White Bear Lake levels

White Bear Lake level = f(PHDI lagged by 0, 1, 2, 3, 4, 5, & 7 years); R2 = 0.71



White Bear Lake level = f(Apple River annual median flow, lagged by 0, 1, 2, 3, & 4 years); R2 = 0.96

Adding the regional pumping signal was non-significant for both models.



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