Spatial and Temporal Variability of Ground-Water Recharge in Minnesota Using Multiple Methods

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U.S. Department of the Interior
U.S. Geological Survey

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Recharge in the Context of Ground-Water Sustainability

- Long-term droughts almost always result in *reduced recharge*, increased pumping, and declines in ground-water (GW) levels
- Climate change is an underemphasized factor affecting GW sustainability that could *change recharge rates* due to changes in precipitation, temperature, vegetation, ET rates, and pumping
- Increased pumping can result in *increased recharge*, induced from a nearby surface-water body
- Lower recharge rates will result in larger wellhead protection areas

Reference: Sustainability of ground-water resources, USGS Circular 1186

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Study Objectives

- Quantify recharge to unconfined aquifers in Minnesota:
  - (a) using multiple methods
  - (b) representing different time and spatial scales
- Compare results of the methods
- Attempt to "up-scale" the site specific estimates to regional values

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Recharge Estimation Methods Used

Site-Specific Methods

- Unsaturated-zone water balance (analogous zero-flux plane method)
- Ground-water level fluctuation (water-table fluctuation)
- Ground-water age dating

Regional Methods

- Multiple regression/GIS analysis of stream baseflow recharge, precipitation, STATSGO soils data
- Compilation of existing calibrated GW flow models
- Percent of precipitation

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Unsaturated-Zone Water Balance (zero-flux plane) Method

Bemidji, Williams Lake, MSEA sites

Temporal variability in recharge

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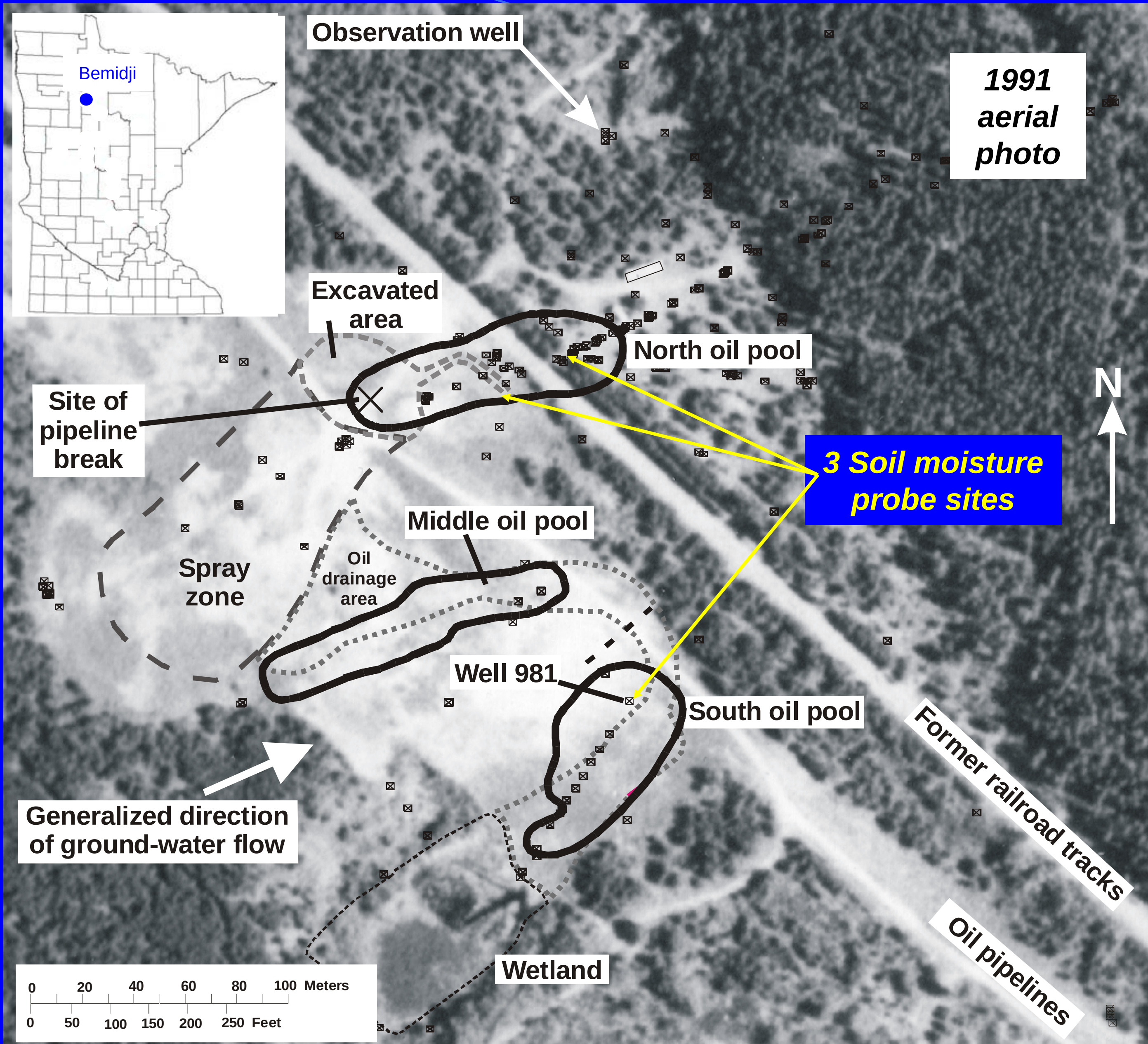

Approximate extent of oil, August 1998 modified from Lakehead Pipe Line Co., written commun., 1998

Layout of Bemidji crude-oil spill site

USGS Toxics Substances Hydrology Program Research Site

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Bemidji Site – "North Pool"

Soil-moisture data collected continuously from 1998-present

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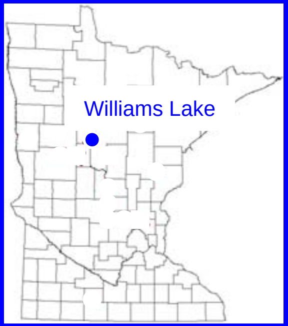
Williams Lake Site

Don Rosenberry pointing to the location of the buried probes

Soil-moisture data collected continuously from 1998-present



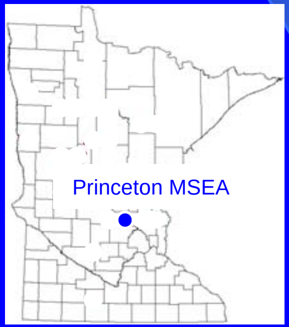
USGS Shingobee Headwaters Aquatic Ecosystems Project (SHAEP)

Princeton MSEA – Agricultural Research site

View of upland site

Telephoto view from lowland site to upland site

Soil-moisture data collected continuously at upland and a lowland sites from 1992-95



USGS Toxics Substances Hydrology Program Research Site

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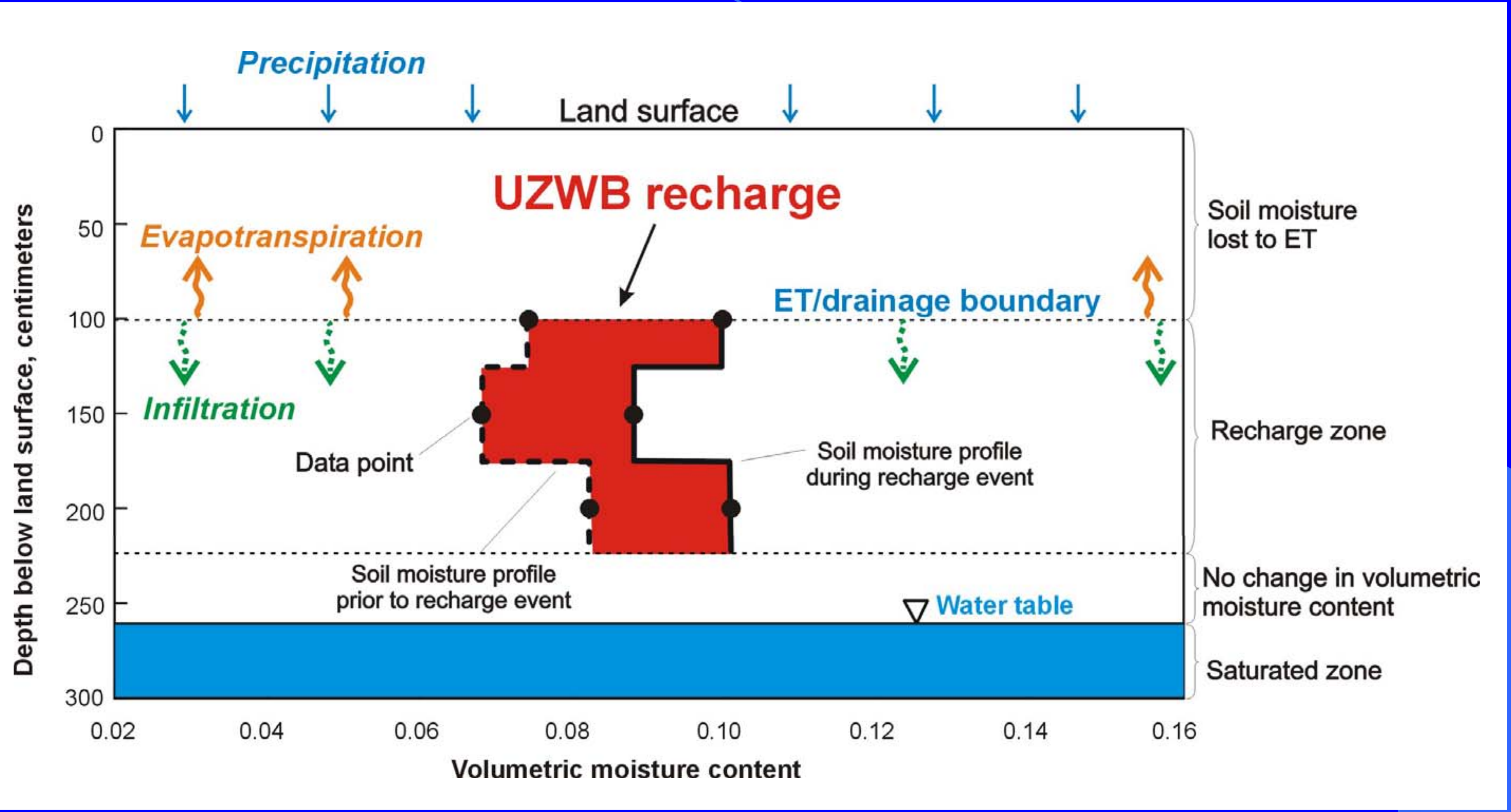
Unsaturated-Zone Water Balance



Conceptualized diagram

Modified from Delin and Herkelrath (2005)

Water-Table Fluctuation (WTF) Method

Continuous data available from 36 wells at five different sites

Weekly data from 45 wells

Temporal variability in recharge

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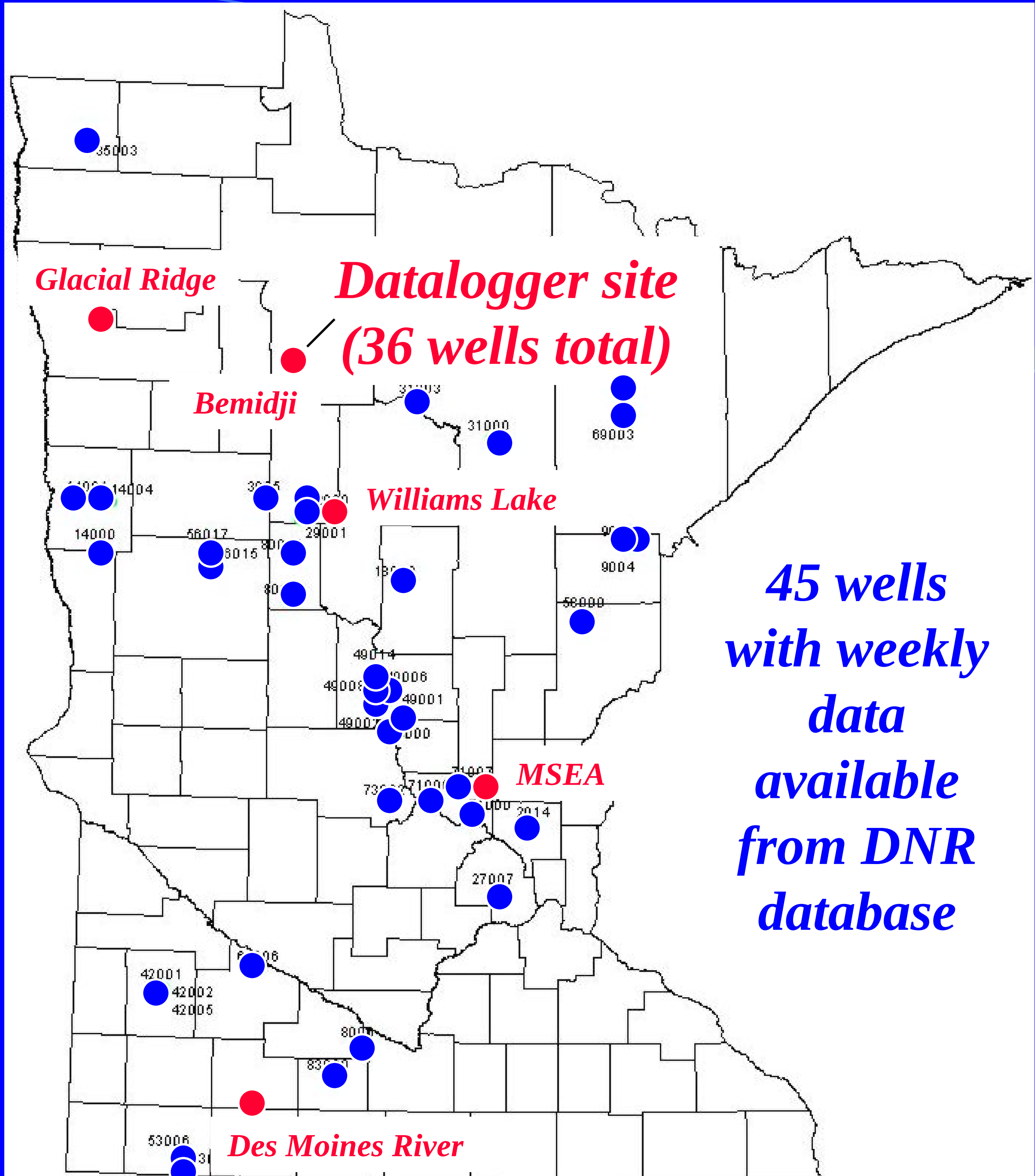

Statewide Analysis

WTF Method – Graphical Technique

Water-Table Fluctuation Method

The water-table fluctuation (WTF) method is based on the premise that rises in ground-water levels in unconfined aquifers are due to recharge, calculated as:

$$\underline{\text{Recharge}} = Sy \times (dh_t)$$

where *Sy* = specific yield, and

dh_t = difference between peak of rise and low point of extrapolated recession curve at the time of the peak

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Multiple WTF Approaches Utilized

- Graphical
- RISE program (Rutledge, 2003)
- Master Recession Curve (MRC)

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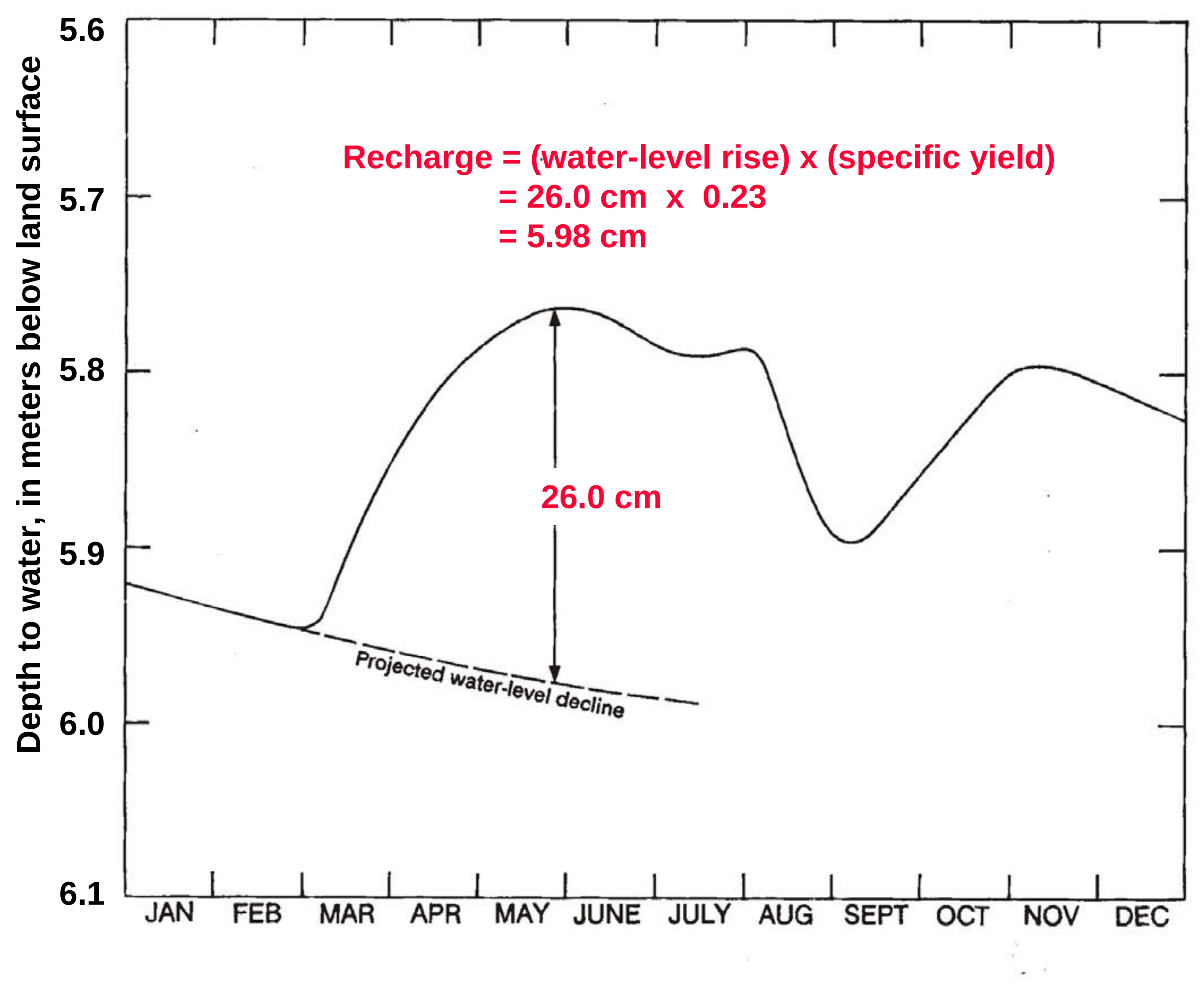
Graphical Approach to WTF Method



Example graph from Delin (1990)

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RISE Program Approach

- Simple program that calculates the daily rise of water level in an observation well
- The input data can be read right out of USGS ADAPS database or can be created from datalogger files
- Incremental (daily) rises in water level are summed and multiplied by specific yield to obtain recharge
- Notes:
  - Declines in water level do not affect the recharge calculation
  - The program makes no allowance for the (projected) baseline recession that would have occurred in the absence of recharge

Al Rutledge, USGS, electronic communication, 2003

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Master Recession Curve Approach

- Develop a list of recessions (periods during which ground-water elevation continually decreased) using the FALL program (Rutledge, 2003)

- The minimum recession duration is selected (10 days)

- MRC is developed from individual recessions using the non-linear regression model of theoretical recession rates

- Apply MRC to the annual daily record, summing recharge as the difference between the projected MRC and the daily ground-water elevation multiplied by specific yield

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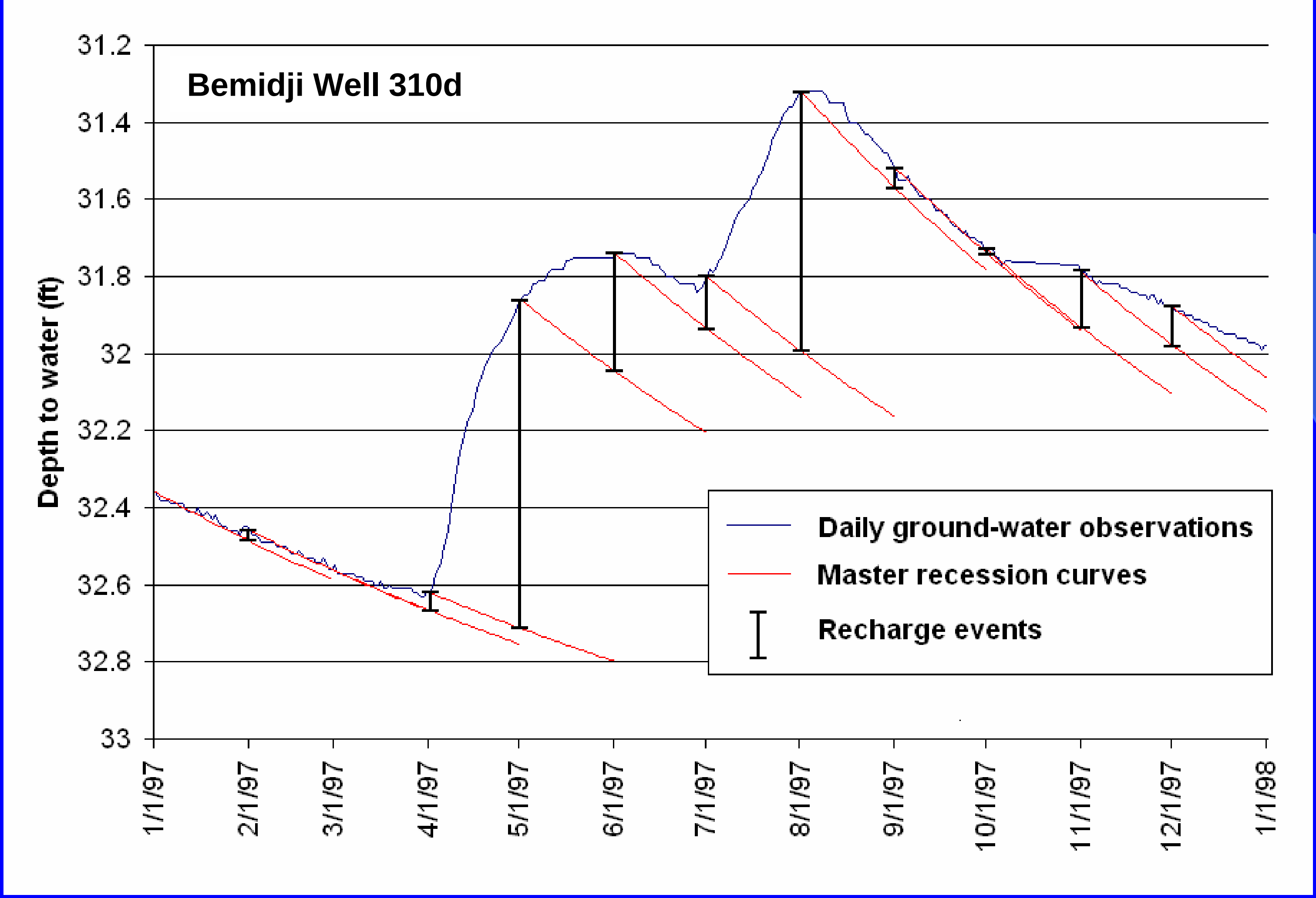
Master Recession Curve Example Application



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Ground-Water Age Dating Method

Average recharge, spatial variability

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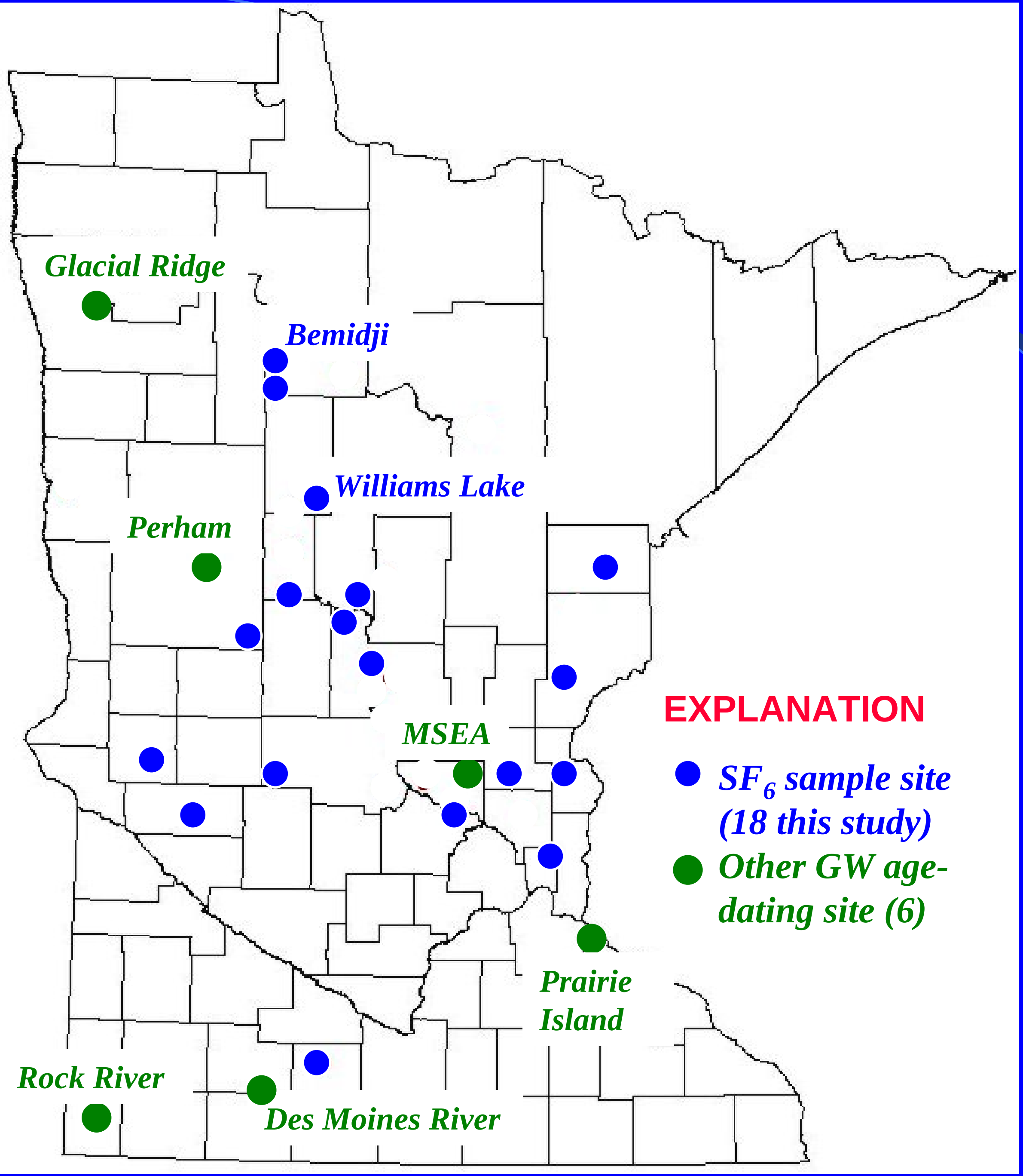
Wells Sampled for GW age dating



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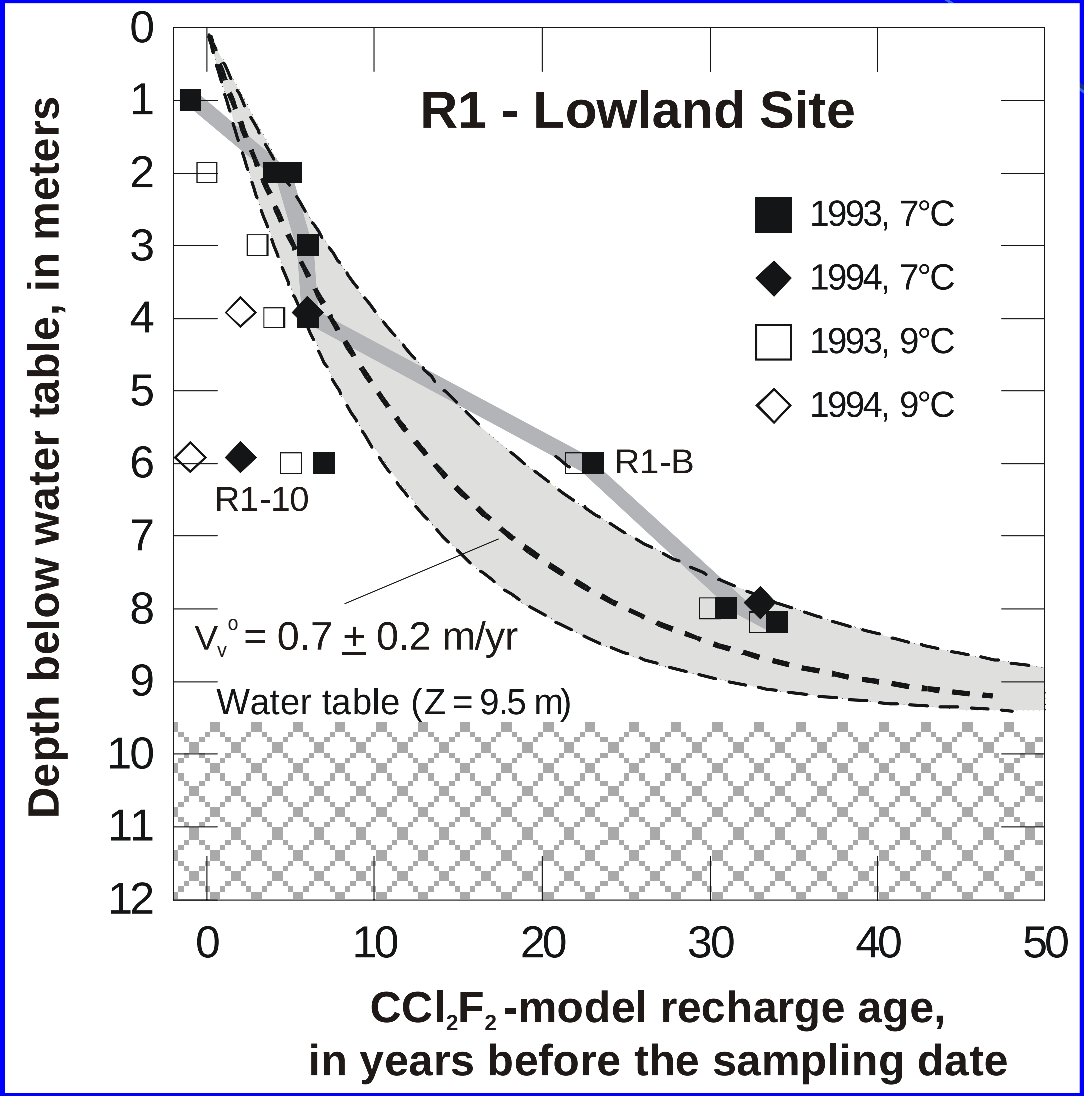
Ground-Water Age Dating Method



Recharge = GW velocity x porosity

Example from Princeton MSEA site using CFC data

SF_6 and ^3H-^3He techniques can also be used; min. time resolution of ~1 year BP

From Delin et al. (2000)

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Regional Regression Recharge (RRR) Method

Regression/GIS Analysis of Streamflow, STATSGO Soils, and Precipitation Data

Spatial variability of recharge (extended to entire State)

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Gaging Station/Basin Selection: RRR Method

- Evaluated records from 120 gaging stations
- Criteria reviewed:
  - length of record,
  - common periods of record,
  - missing data,
  - size of basin,
  - avoidance of control structures
- 39 stations selected based on these criteria

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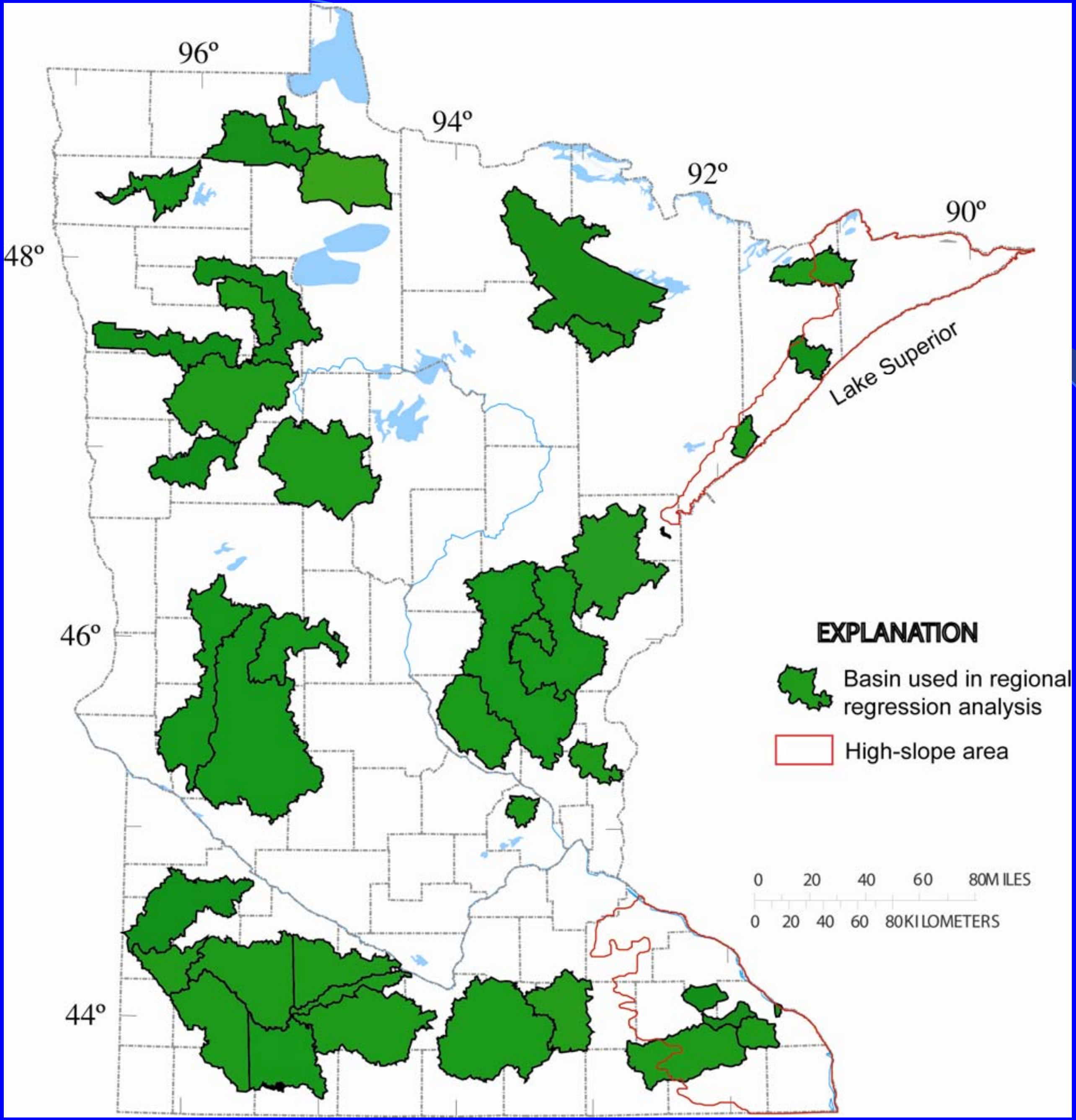
39 Basins Used in RRR Analyses



Limited coverage imposes some errors in the recharge estimates, primarily in high-slope areas

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RRR Methodology

- Recharge estimates made for the 39 selected watersheds using the RORA program (Rutledge, 2000)
- Regression equation developed based on:
  - recharge from RORA baseflow analyses,
  - precipitation,
  - specific yield computed from STATSGO,
  - percent lake coverage in basin
- Final step: create recharge map of MN using GIS based on running a regression analysis on the data sets

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Results and Methods Comparison

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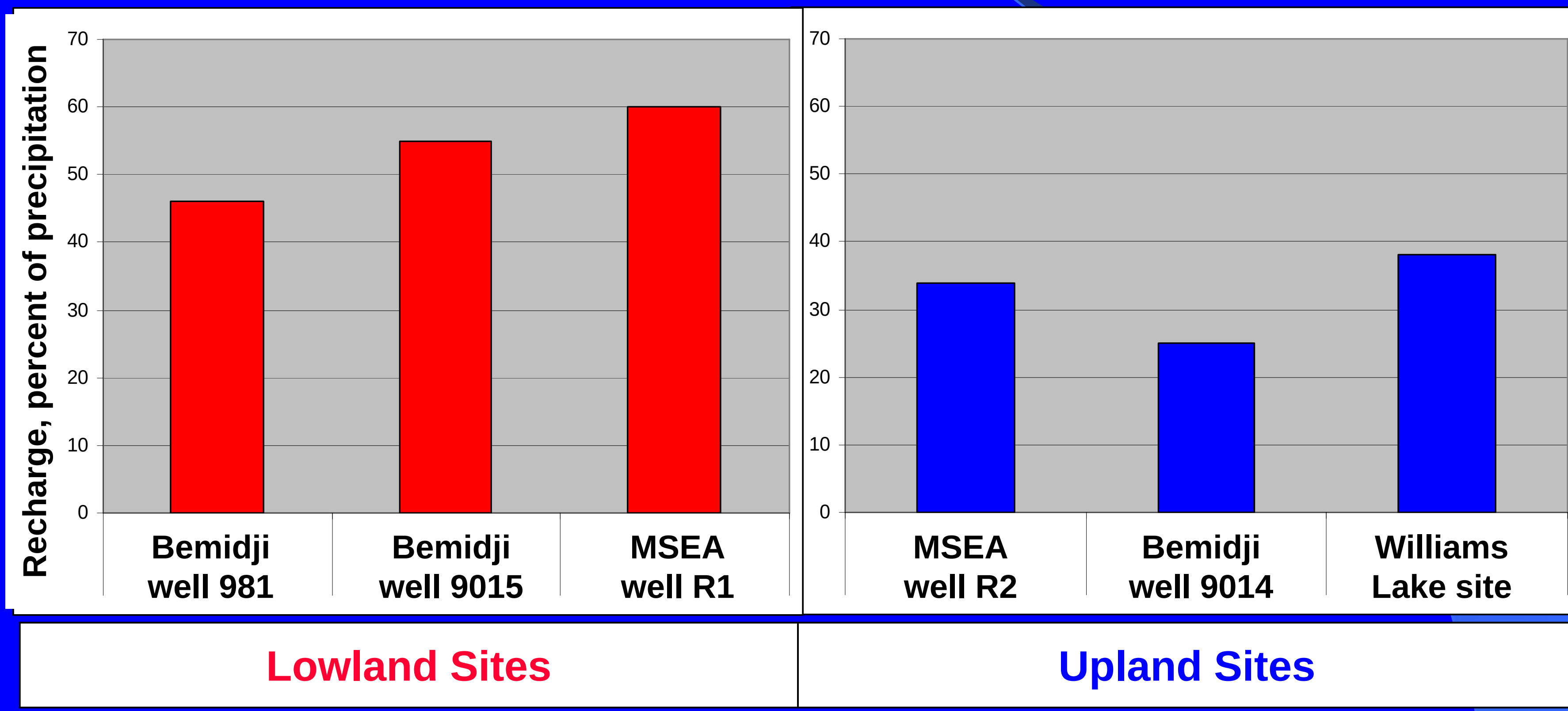
Unsaturated Zone
Water Balance Method Results



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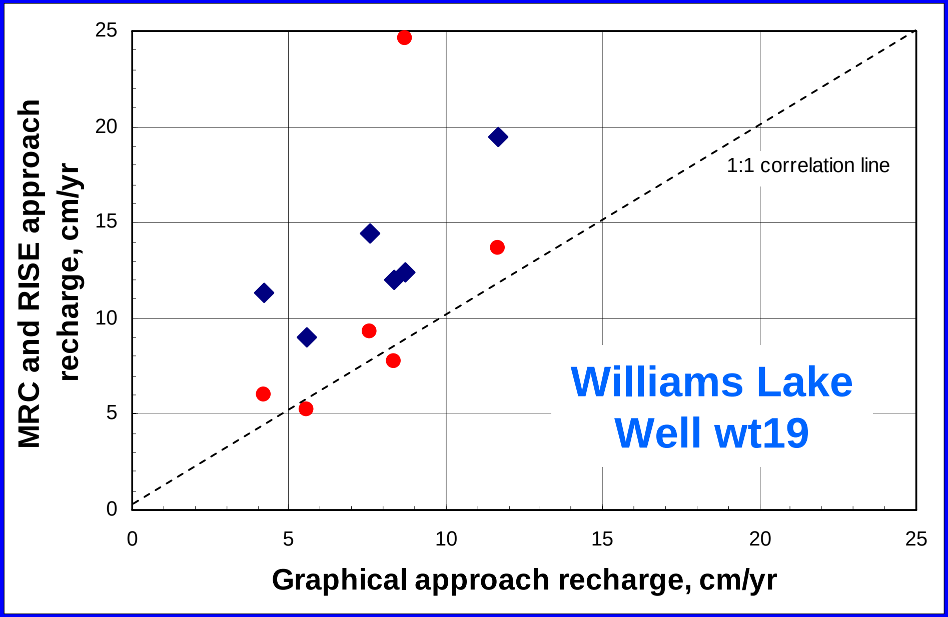
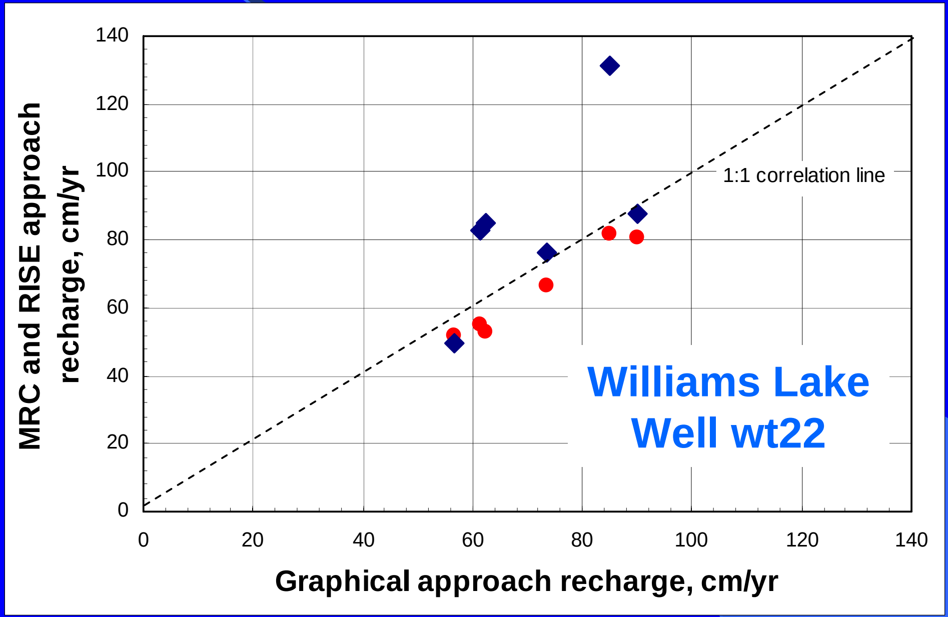
WTF Method – Example Plots of Graphical vs. MRC and RISE Approaches





Rech. % of precip: 15 % ~100 %

UZ Thickness: 5 m 2 m

- MRC method
- RISE method

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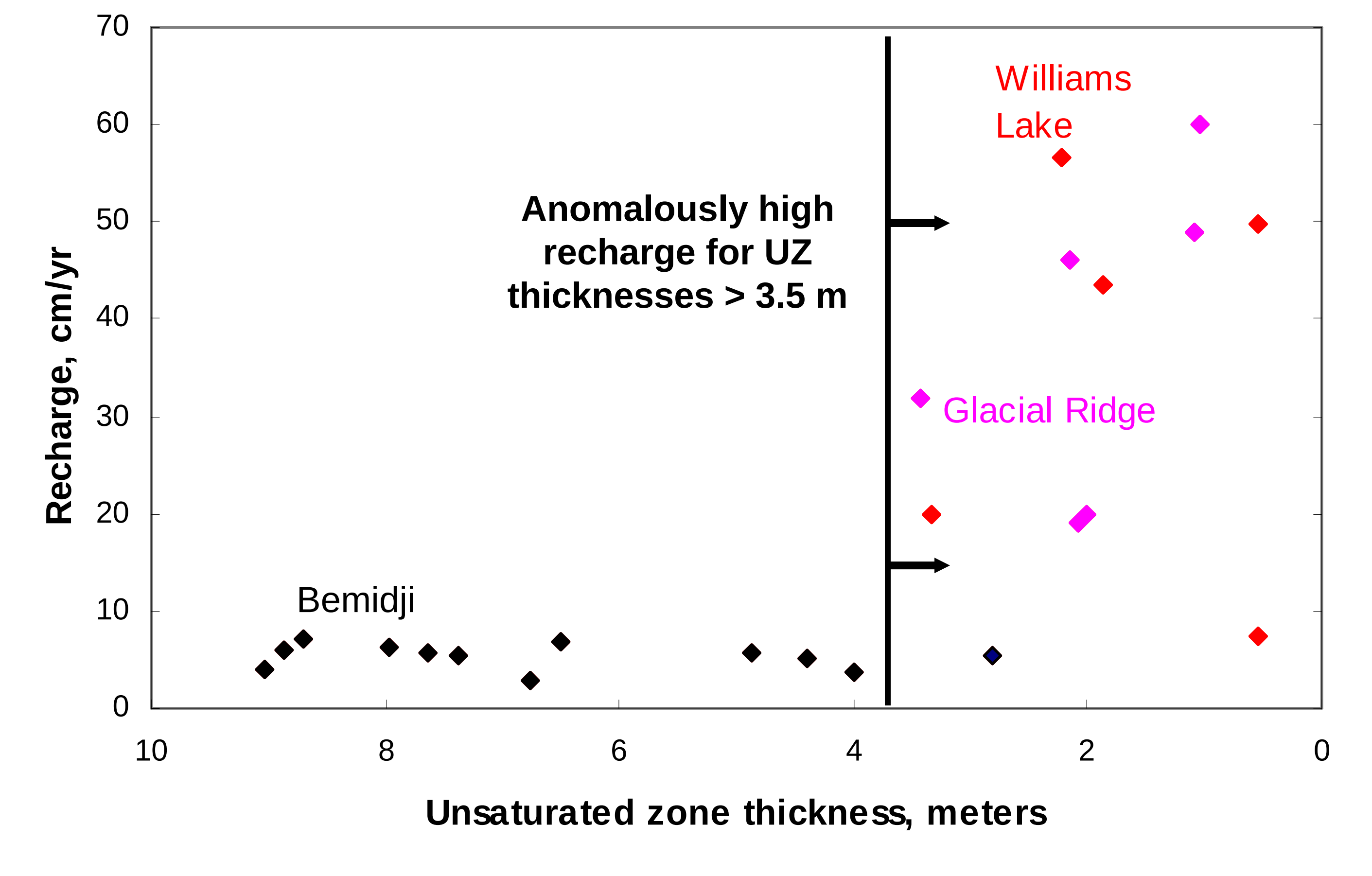
Relation Between WTF Graphical Approach Recharge and UZ Thickness



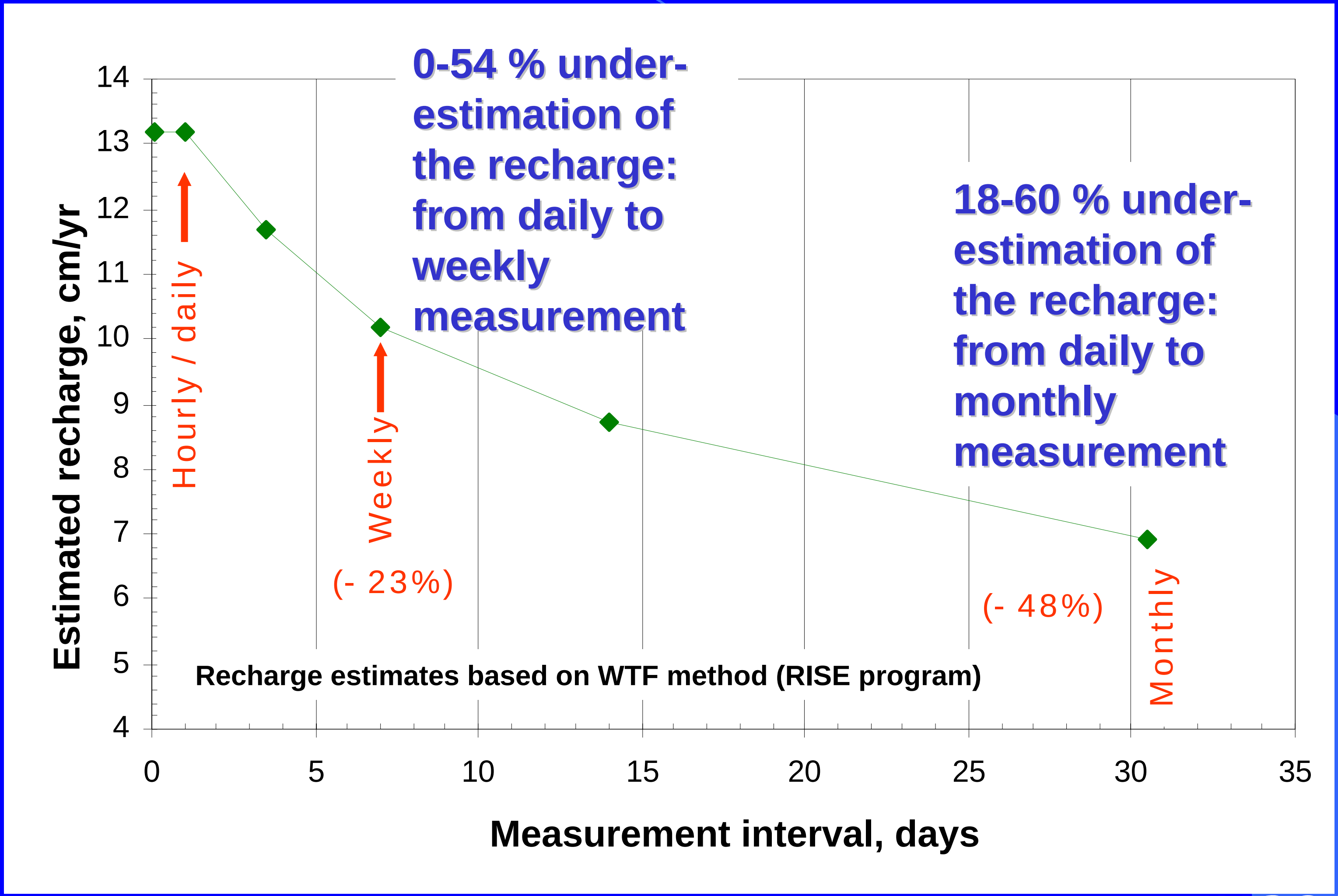
2003 data

Graphical approach

23 wells total

Effects of Measurement Interval on Recharge Estimates

No change in estimated recharge going from hourly to daily measure



1993 datalogger data from MSEA well R2 near Princeton, MN

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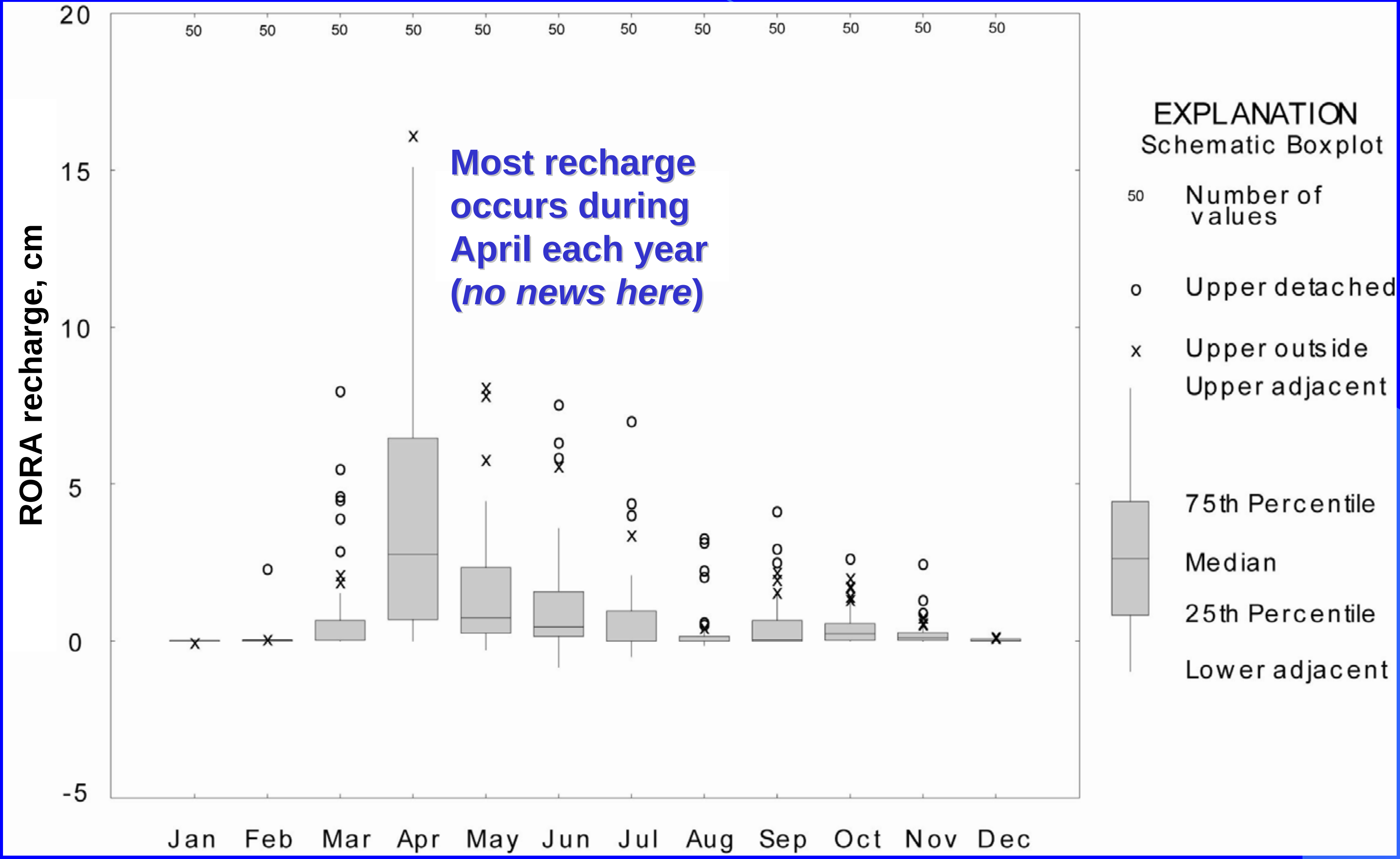
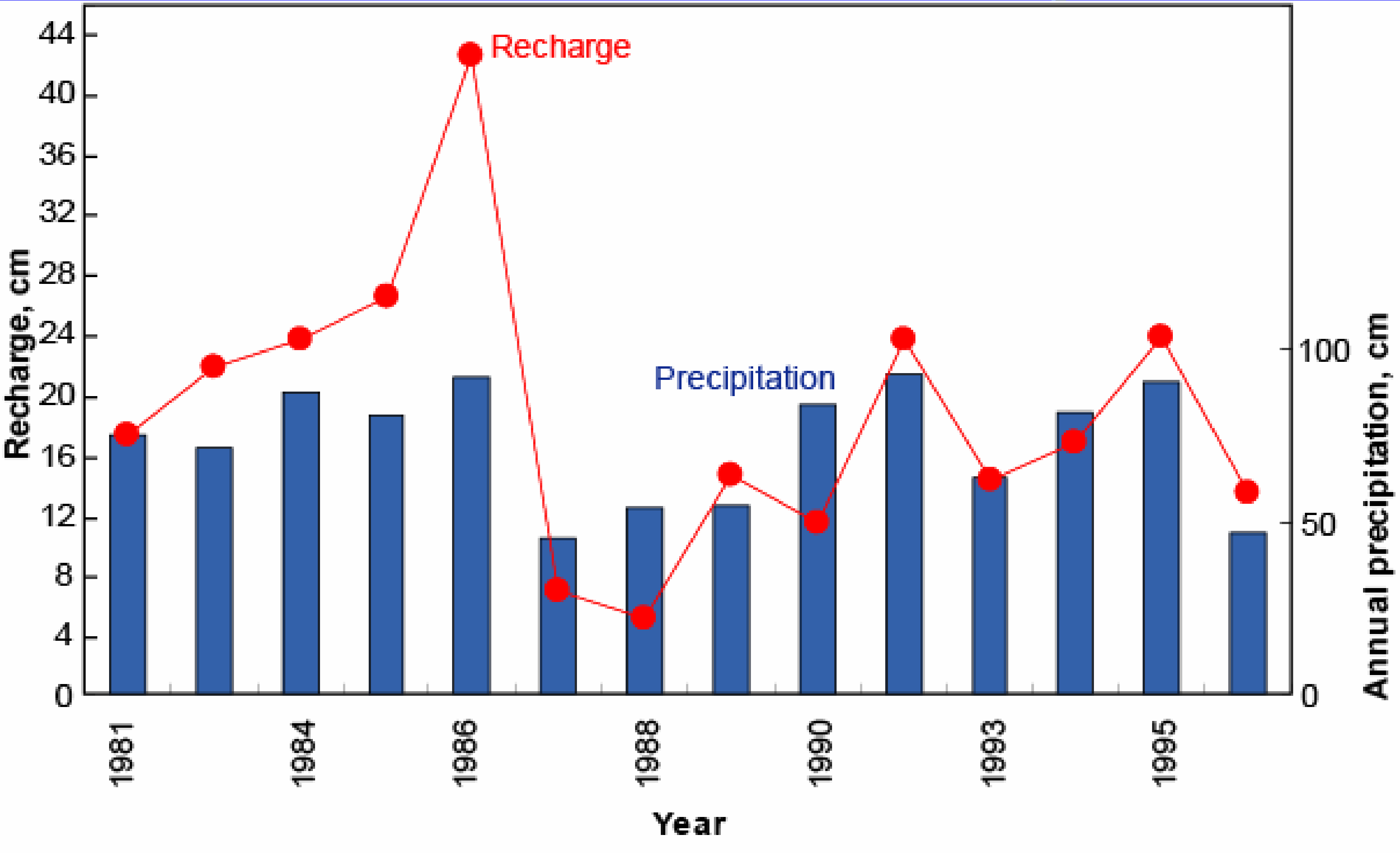
Monthly Recharge in Minnesota Based on RORA

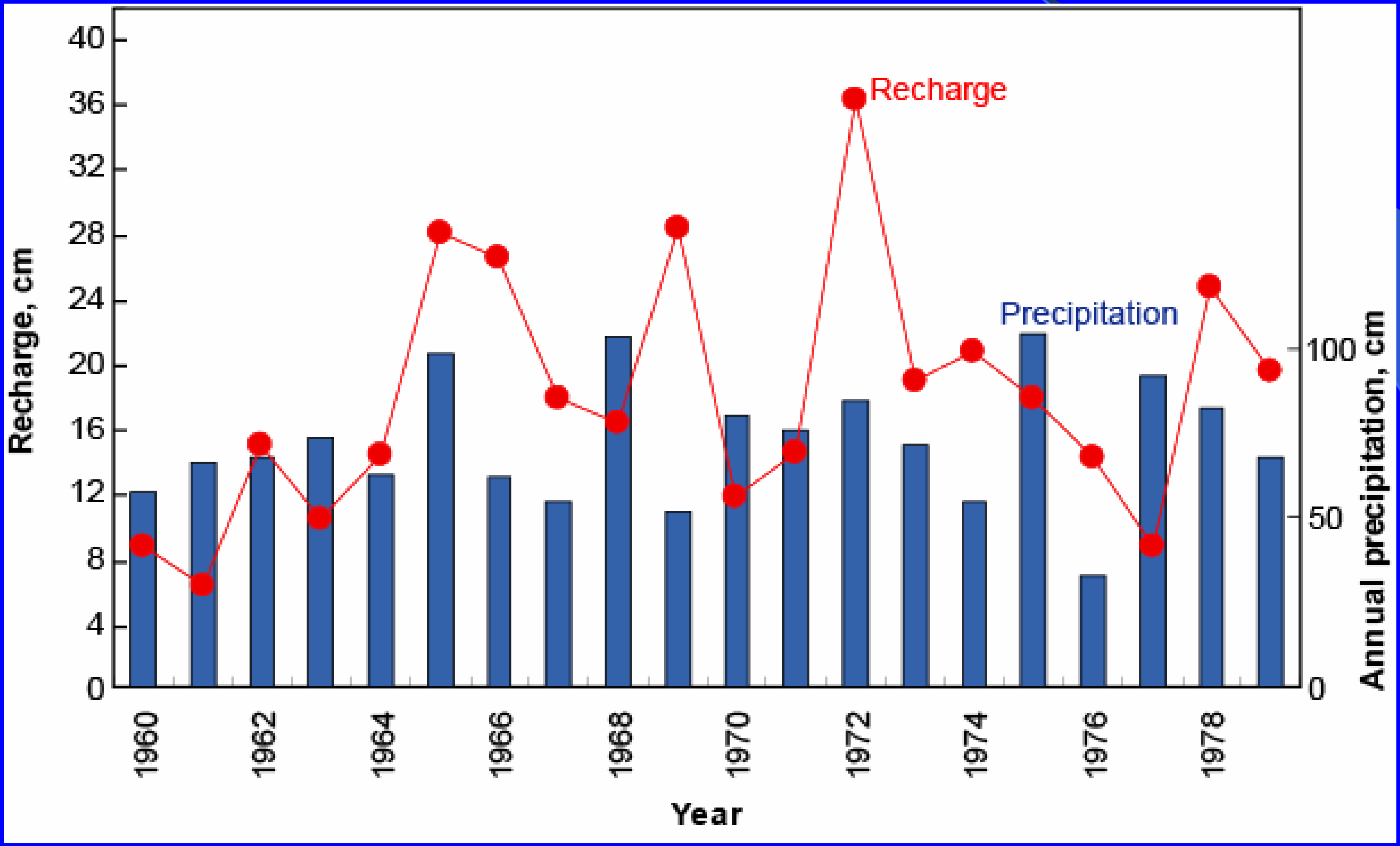


Temporal Variability in Annual RORA Recharge – Knife River near Mora



Relatively good correlation $R^2 = 0.52$

Temporal Variability in Annual RORA Recharge – Snake River near Pine City



Relatively poor correlation $R^2 = 0.21$

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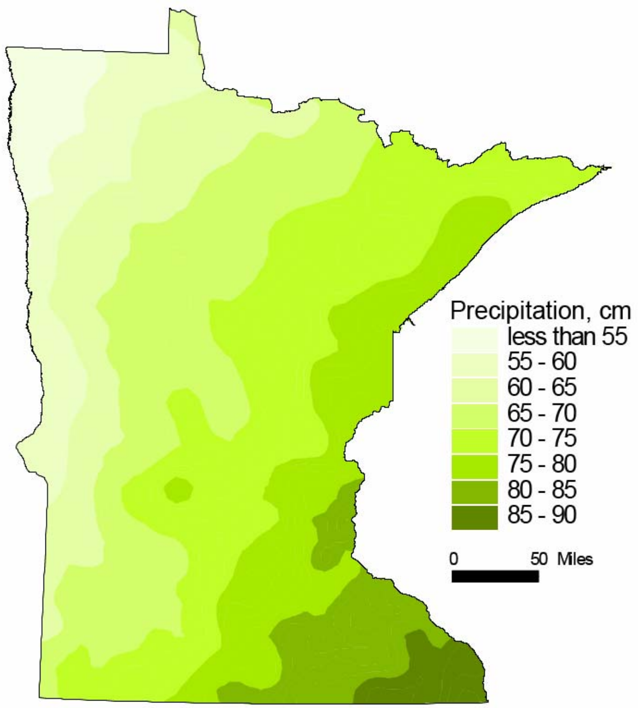
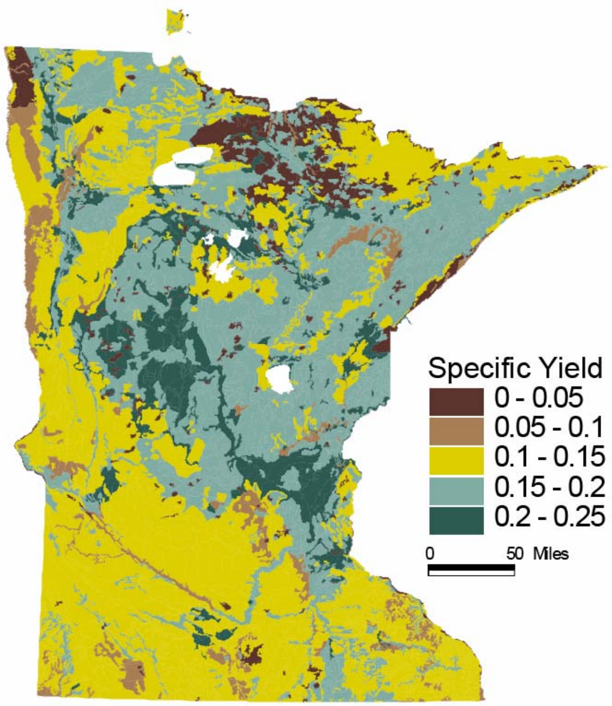
Spatial Data Sets Used in Regional Regression Recharge Analysis



Average annual precipitation, 1971-2000



Specific yield from Rosetta analysis of STATSGO data

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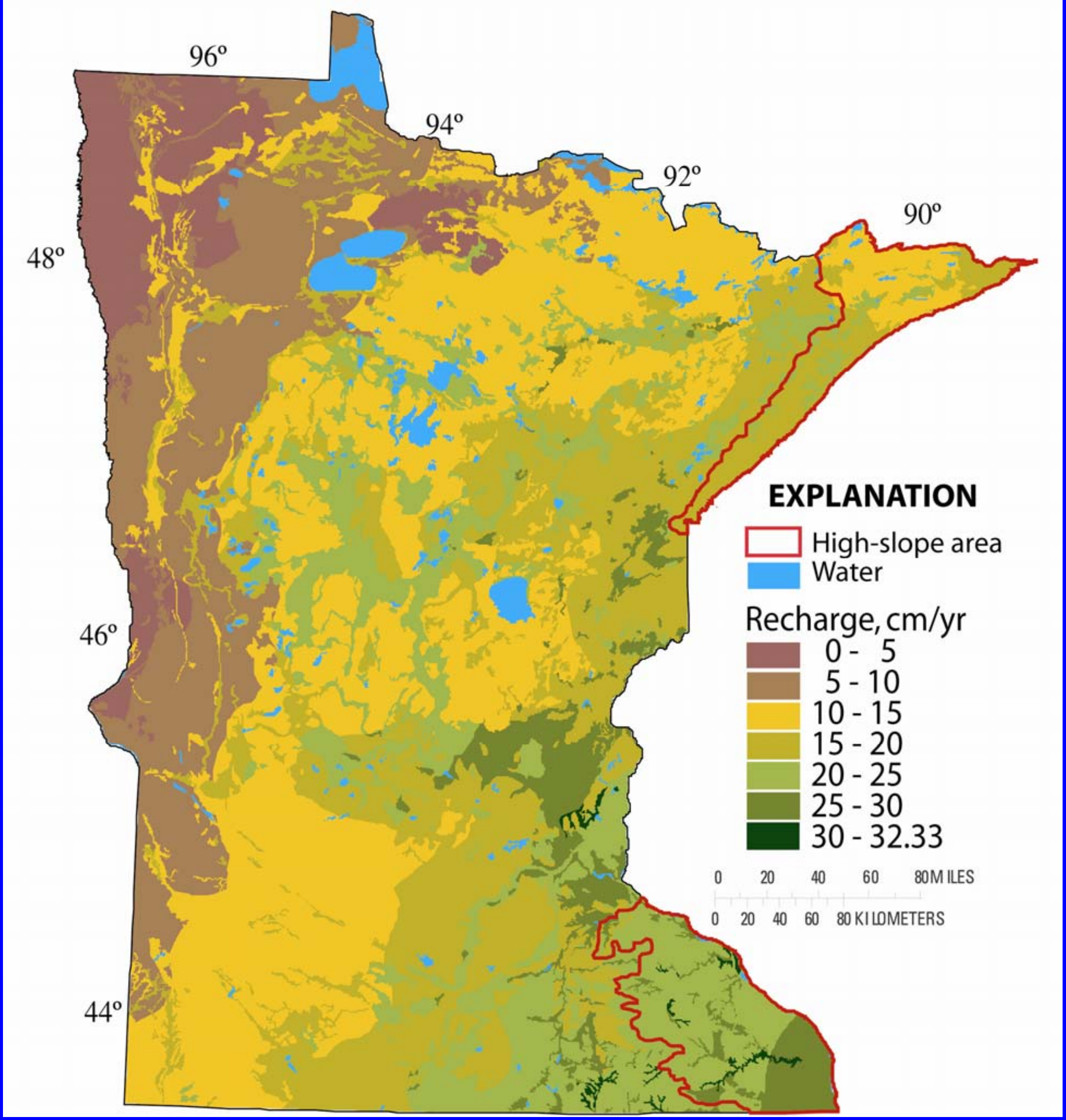
RRR Method

Average Annual Recharge to Unconfined Aquifers



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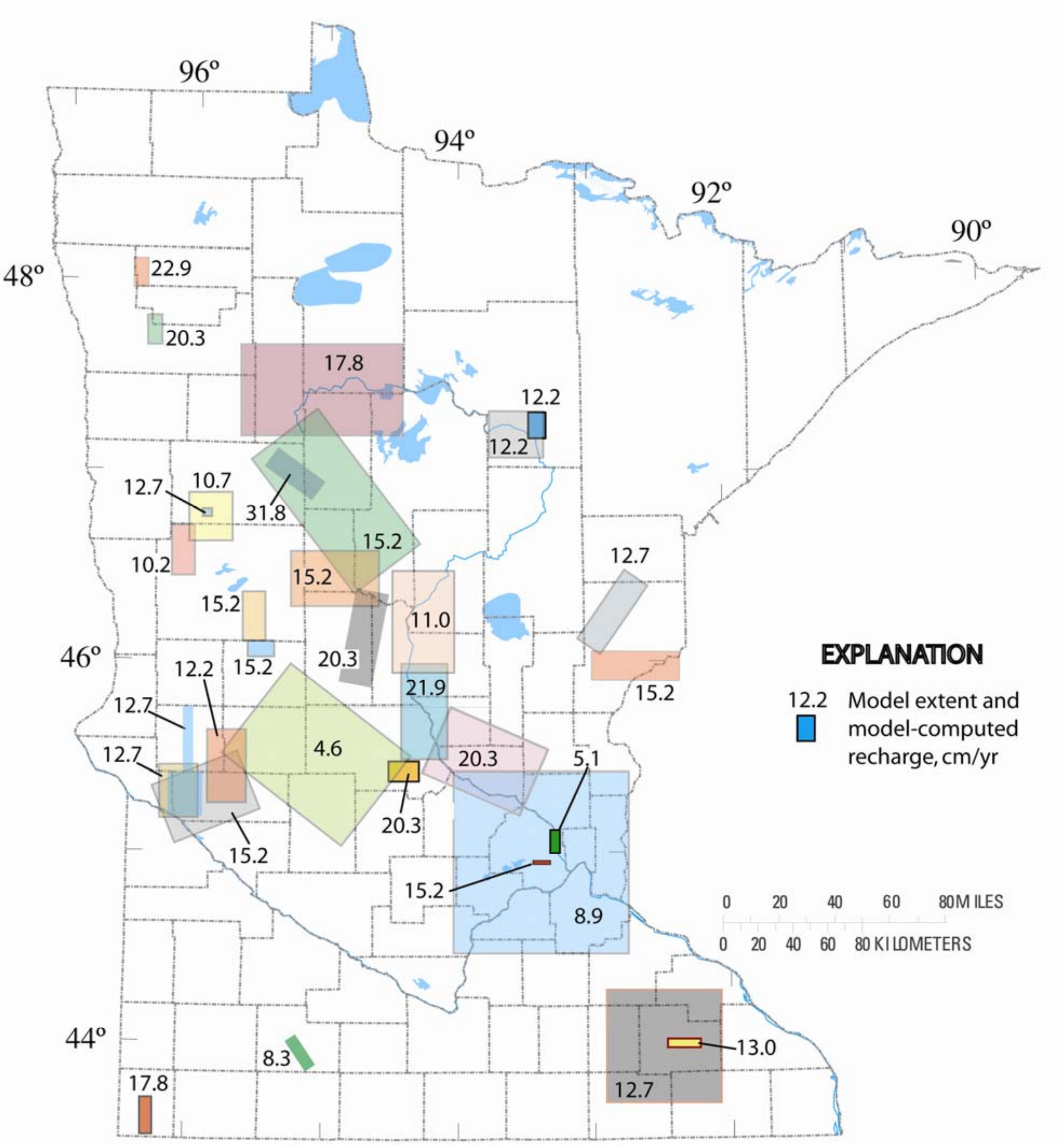
Recharge Based on Calibrated USGS Ground-Water Flow Models



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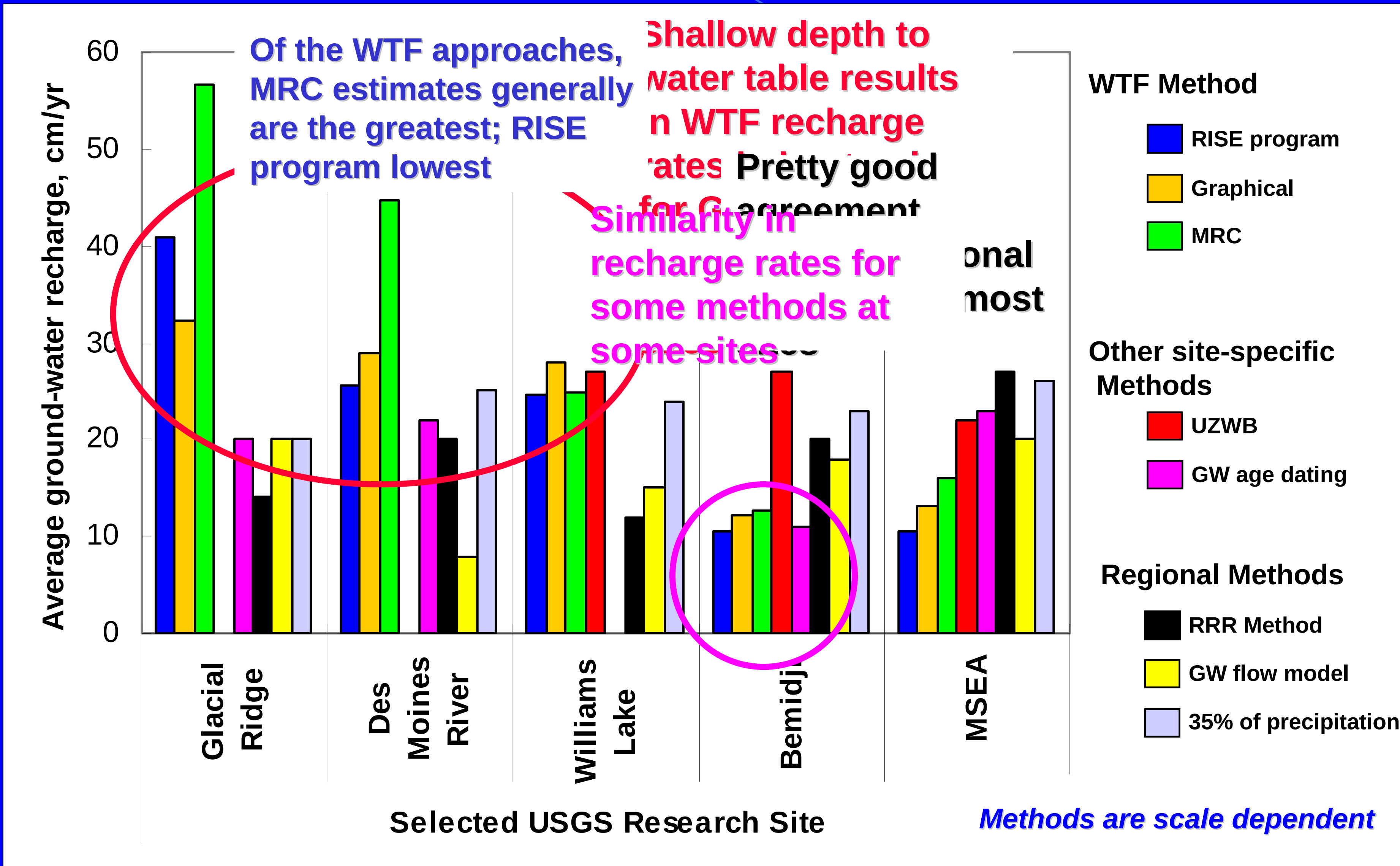
Comparison of Average Recharge Rate Computed at Each Site



Preliminary Conclusions

- Recharge based on the 3 WTF approaches are similar, however:
  - MRC estimates are generally greatest
  - RISE estimates are generally lowest
- Recharge is underestimated when water-levels are measured less frequently than once per week
- Recharge estimation challenging / inaccurate in areas of shallow depth to water table (< ~3.5 m)
- The RRR method provides reasonable recharge estimates (e.g. - adequate for initial GW flow models, for example)
- Results underscore benefits of applying multiple recharge estimation methods; scale dependency

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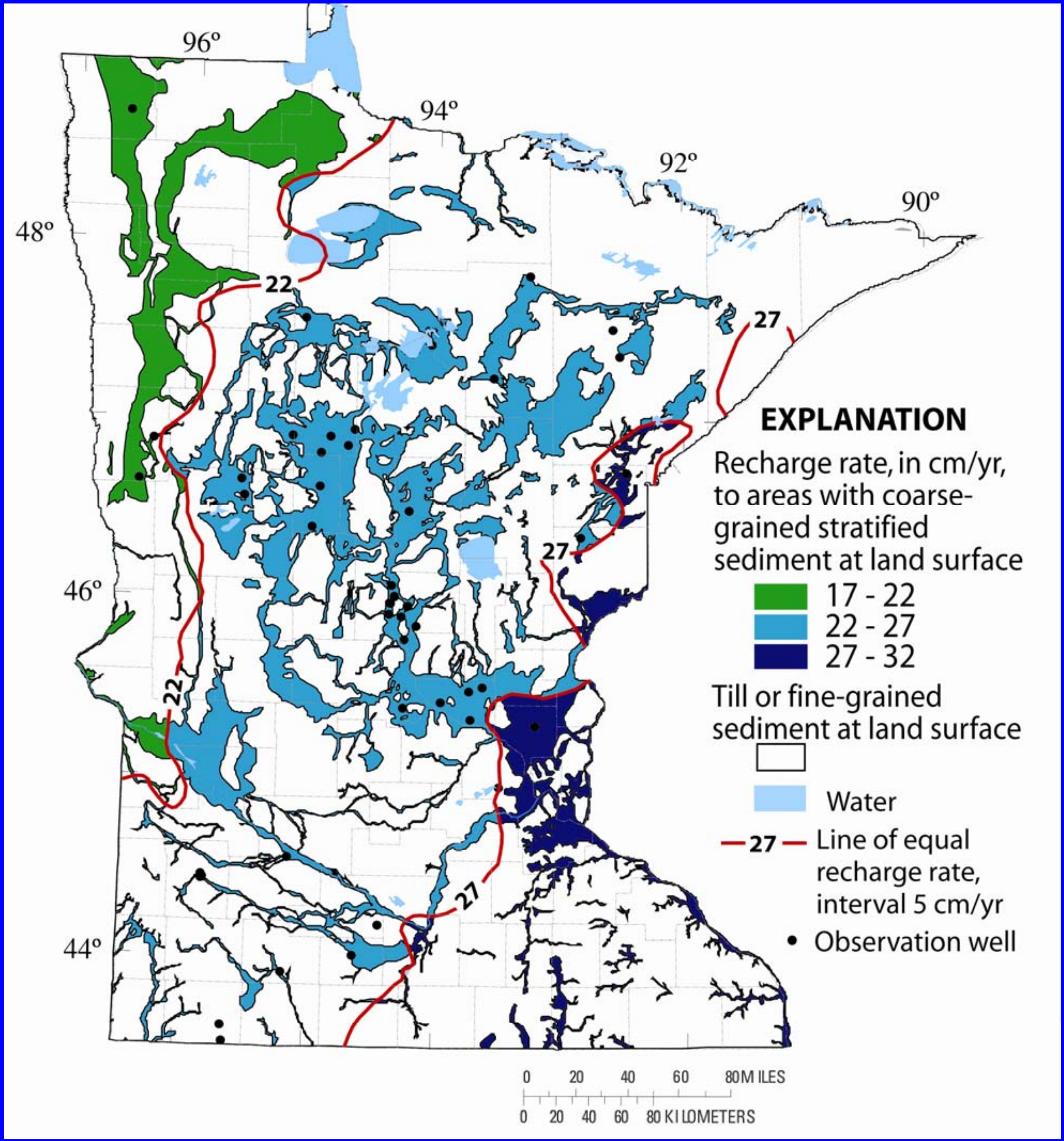
Please check out our posters
in the poster session tomorrow

The end

Average Annual Recharge to Unconfined Aquifers



Estimated as:
R = 0.35 * (1971-2000 average precipitation)