Enhanced Data-Driven Assessments of Hydraulic Capture Zones

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TAKE-HOME MESSAGE:

Union of

Physical and Statistical Approaches

is Greater than

Sum of the Parts

Outline of Talk

- Context

- Straightforward Extensions

- More Involved Extensions

- Examples

- Concluding Remarks

P&T Evaluation (per EPA 2002)

- Evaluate plume capture

- Perform and interpret treatment process monitoring

- Perform and interpret groundwater monitoring

- Evaluate extraction well performance

- Evaluate injection well performance

Multiple Lines of Evidence

- Compare actual pumping rates to plan
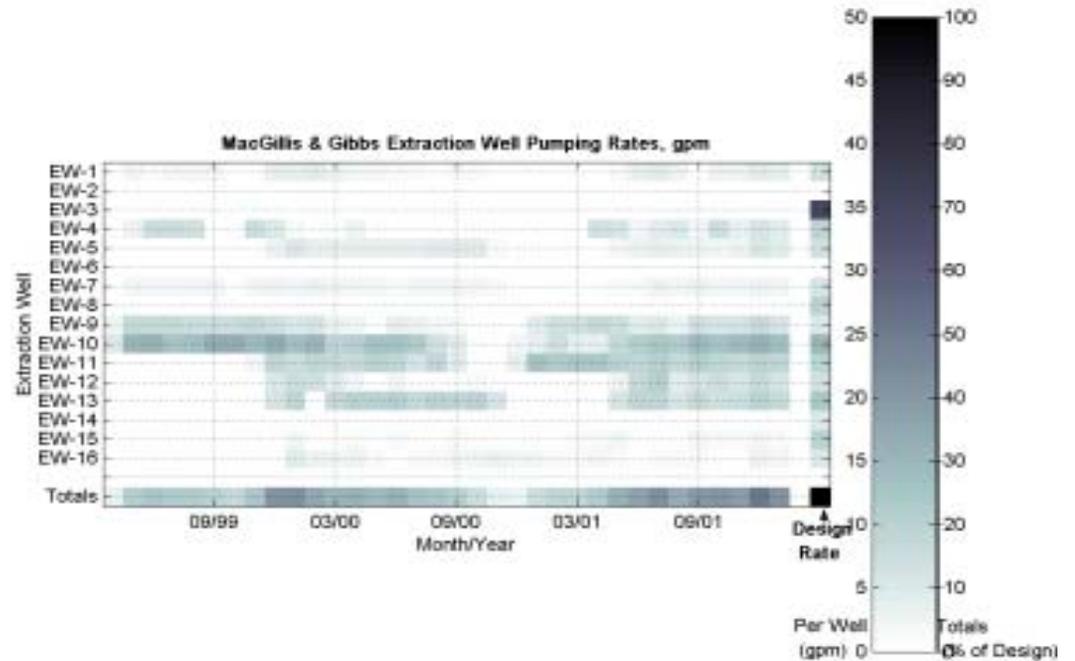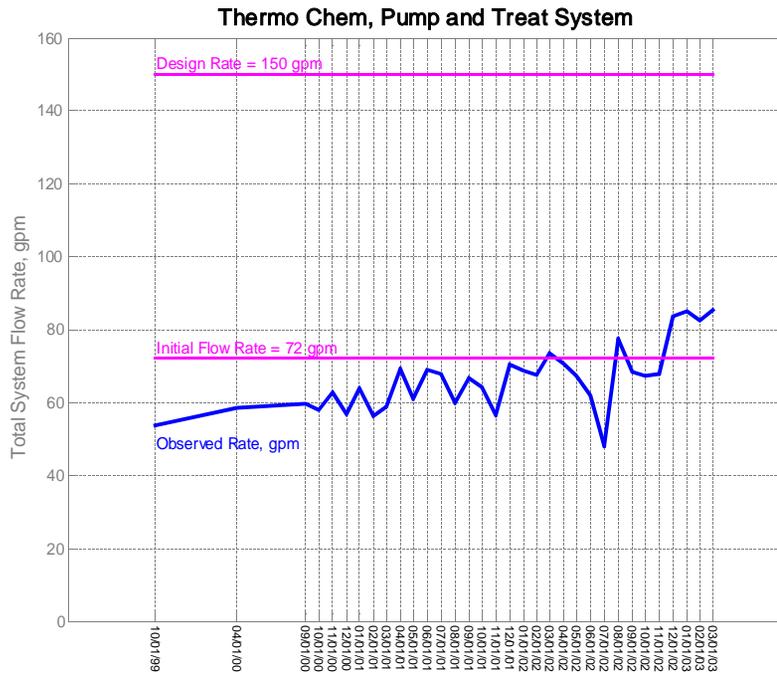
- Compare actual heads to plan

- Compare gradients or fluxes

- Compare chemistry data
  for contradictions

Previous Talk—Tonkin *et al.*

Kriging with Trend (= Universal Kriging) modified to
include "log" terms centered
on each pumping or injection well

- Observed Head Data

- Kriging with Linear Trend

- Estimation

- Gradients

- Particle Tracking

→

- Observed Head Data

- Kriging with Linear Trend *Superposed with Sum of Analytical Thiem Well Solutions**

- Estimation

- Gradients

- Particle Tracking

*Thiem well equation:
   2D, confined, steady,
   fully-penetrating, no leakage
   or storage effects or well losses

Extensions

- *Straightforward* —Analytical forecast model

  – More complicated regional head "model"

  – Well losses

  – Partial penetration

  – Water table conditions

- *More Involved* —Numerical forecast simulator

  – Heterogeneous material properties

  – Irregular lithology

  – Variable source/sink contributions

Approach to Create Head Map

For each monitoring event, have observed locations and observed heads $h^o(x^o)$

Two mapping methods:

1. Use a method that creates a head map from the observations $G(h^o(x^o))$

2. A calibrated forecast model (e.g., Thiem or MODFLOW) can create the head map h^f

Improved Map—Blend

- Use a weighted average of the two maps

$$h^a = (1-W)G(h^o) + W\,h^f$$

  Weights may vary from point to point.

- Rearrange

$$h^a = G(h^o) + W(h^f - G(h^o))$$

  $W=0$➔Observations only, $W=1$➔Forecast only

- How do we select weights?

Selection of Weights

- *Ad hoc*

- Distance from observations

- Statistical

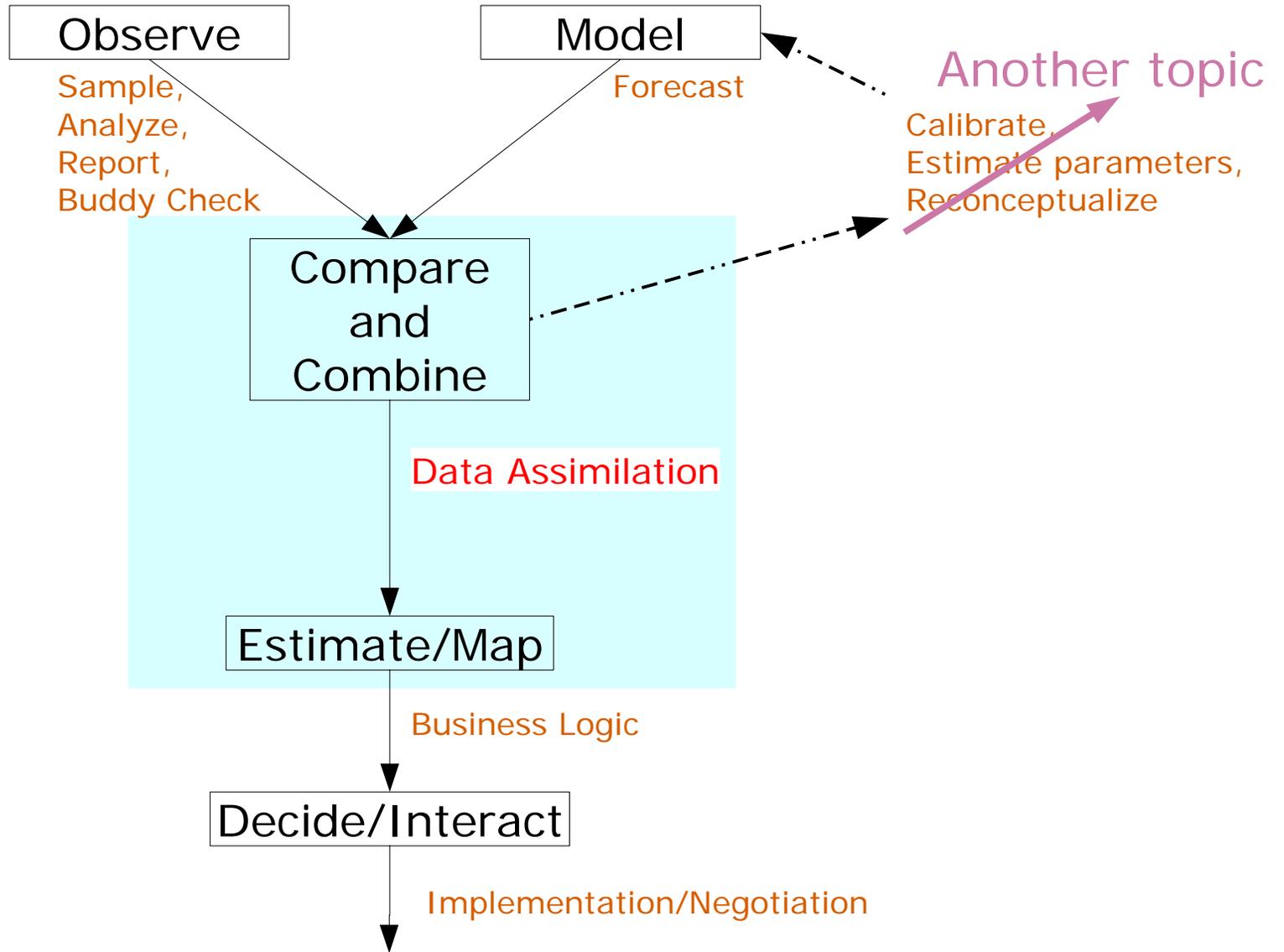- Notice structure of update equation:
$$h^a = G(h^o) + W(h^f - G(h^o))$$
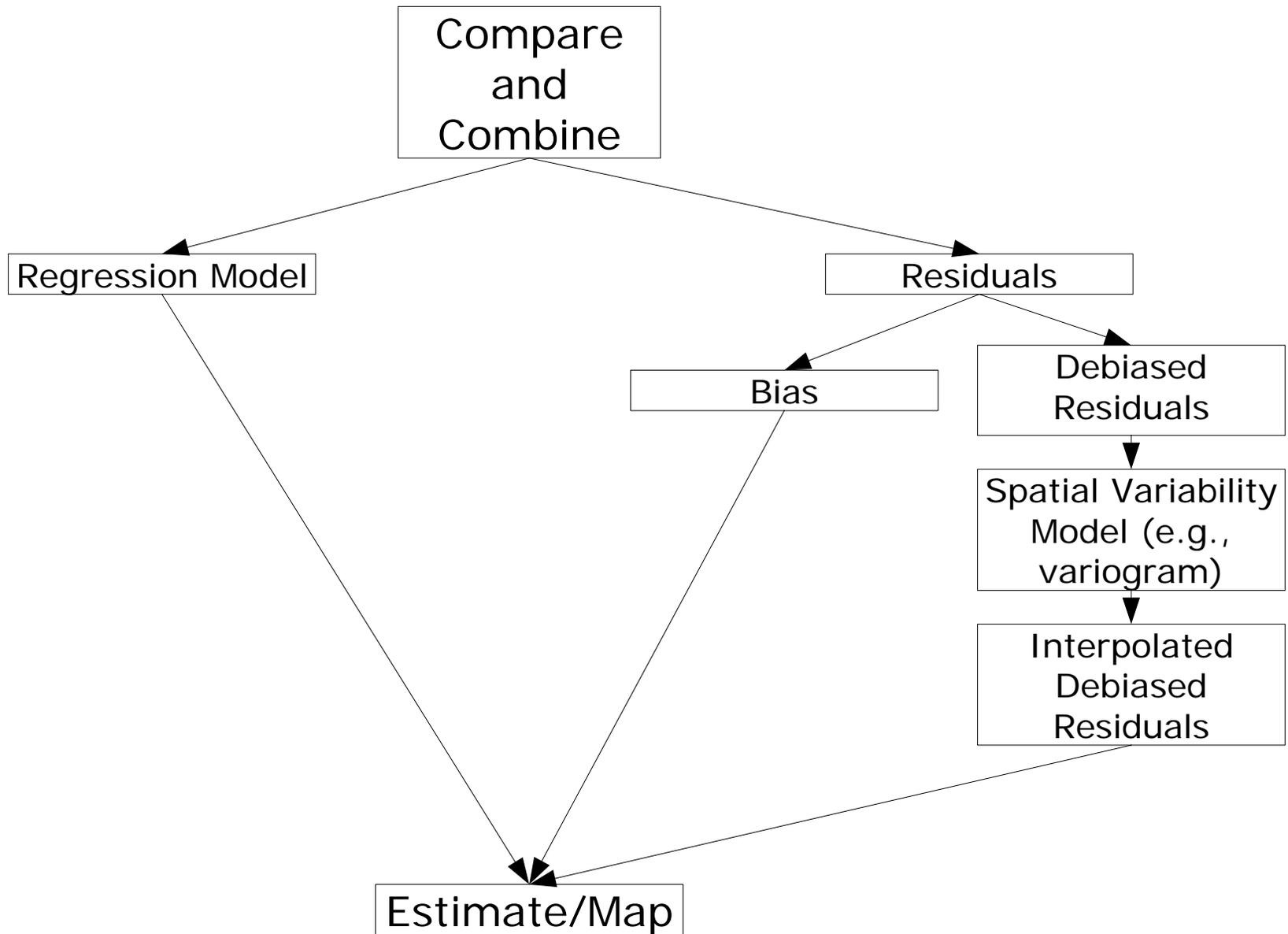Base value + (weight X residuals)

  Kalman Filter—allows covariance info

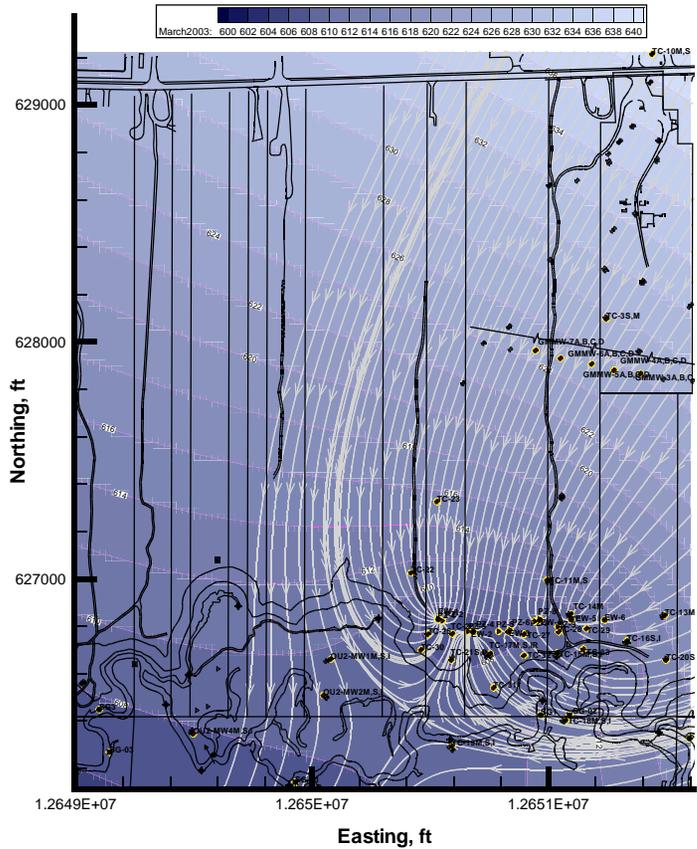- Under many assumptions, interpret weights as resulting from *kriging the residuals*.
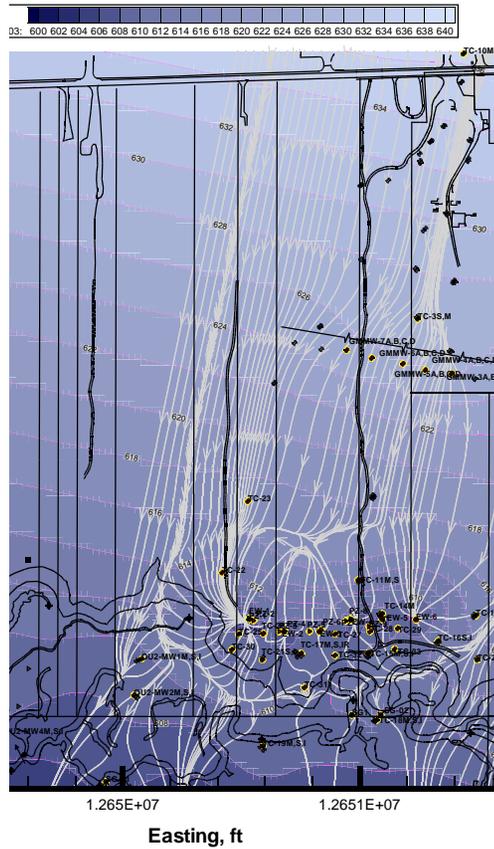
Process

Observe

Sample,
Analyze,
Report,
Buddy Check

Model

Forecast

Another topic

Calibrate,
Estimate parameters,
Reconceptualize

Compare
and
Combine

Data Assimilation

Estimate/Map

Business Logic

Decide/Interact

Implementation/Negotiation
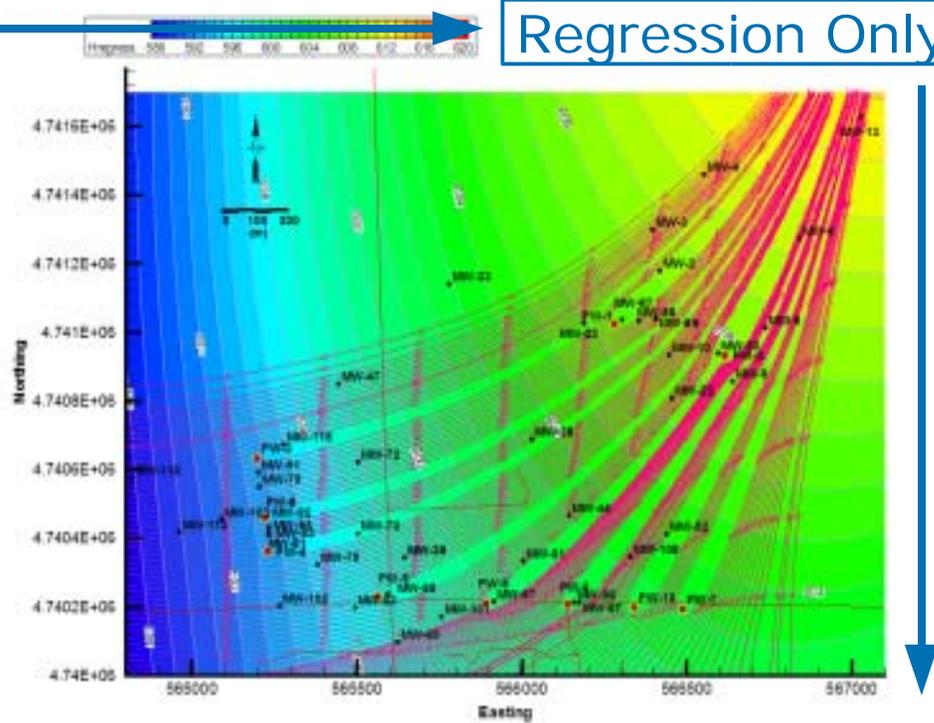
More Details

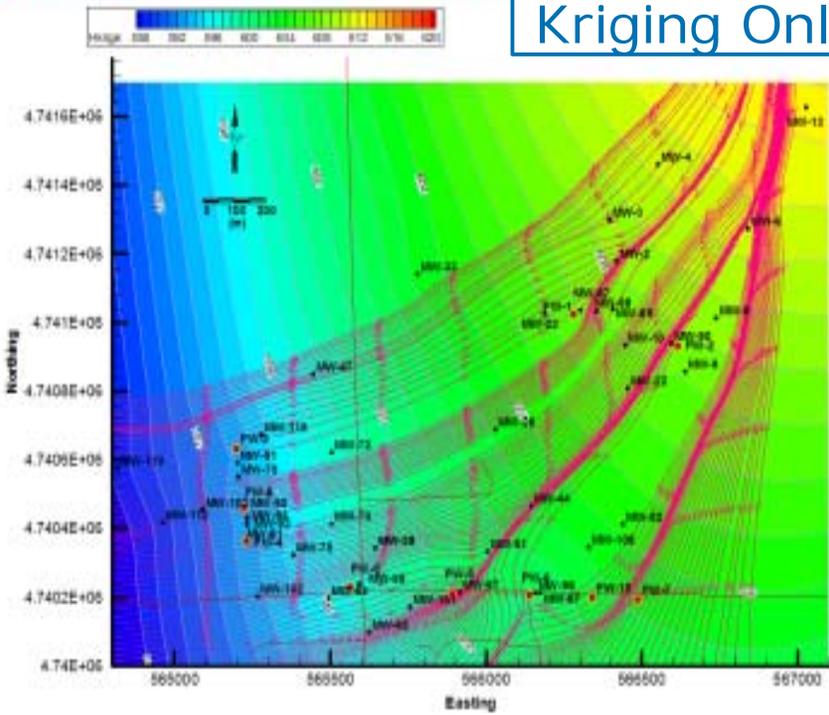# Examples Using Analytical Models

Regression Only
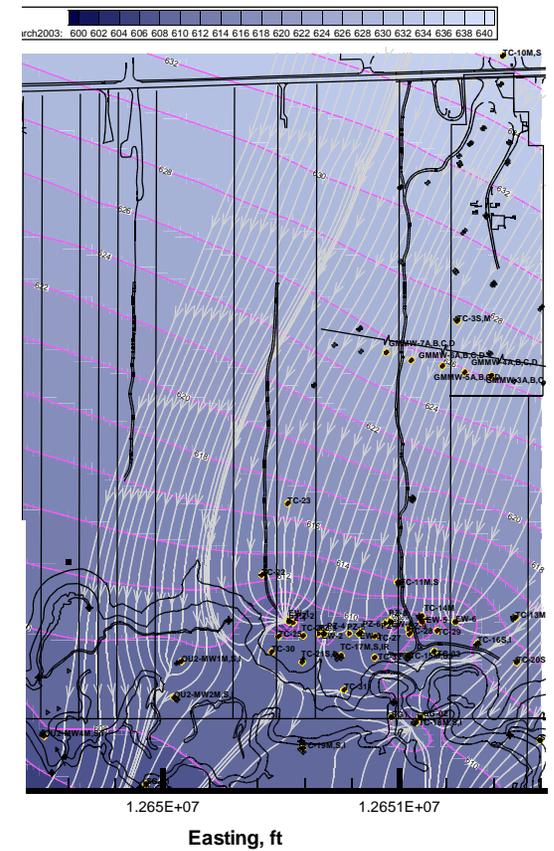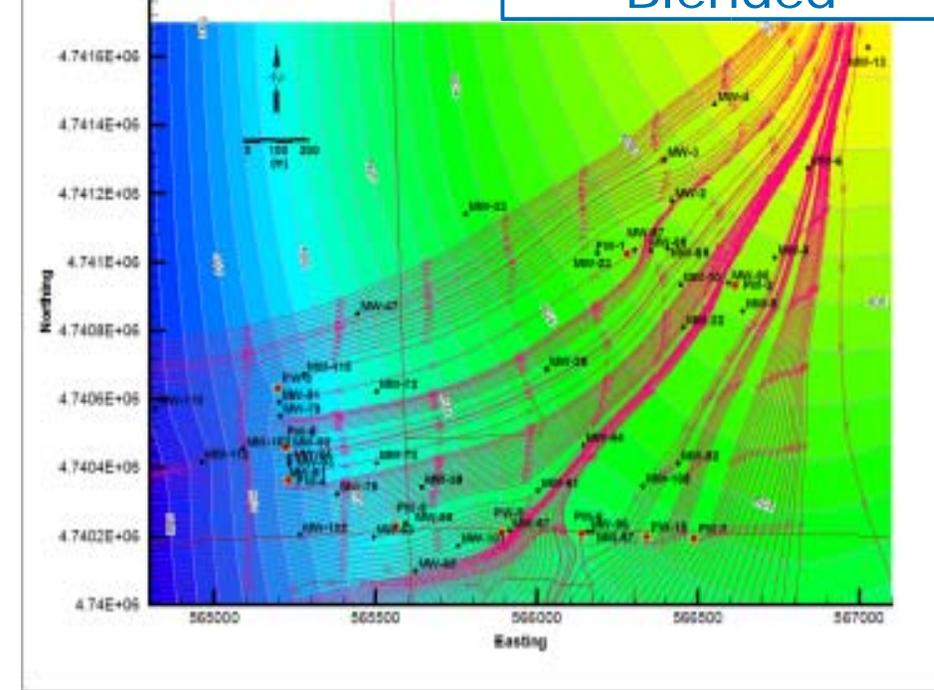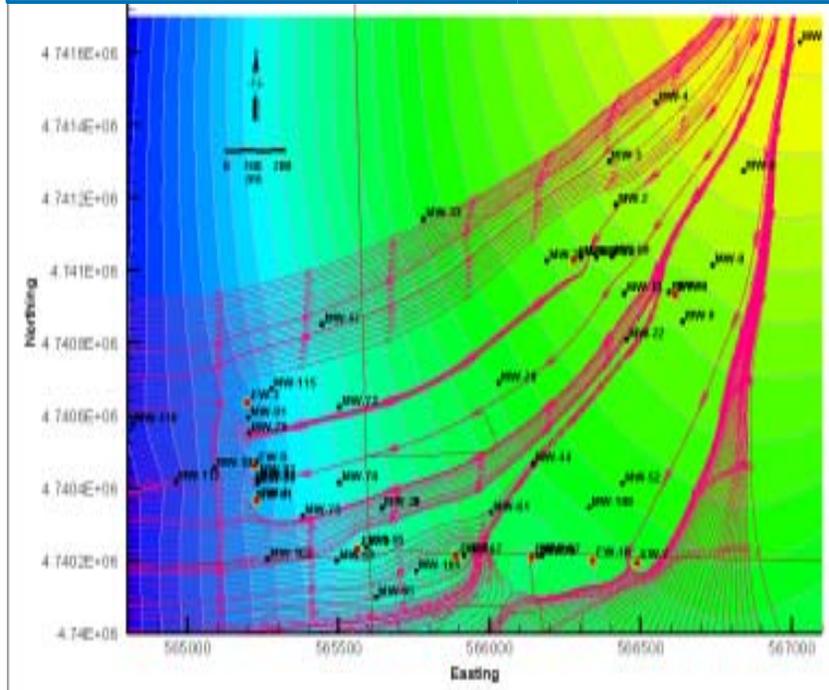
Kriging Only

Blended

Kriging Only

Regression Only

Blended *with* estimated in-well heads
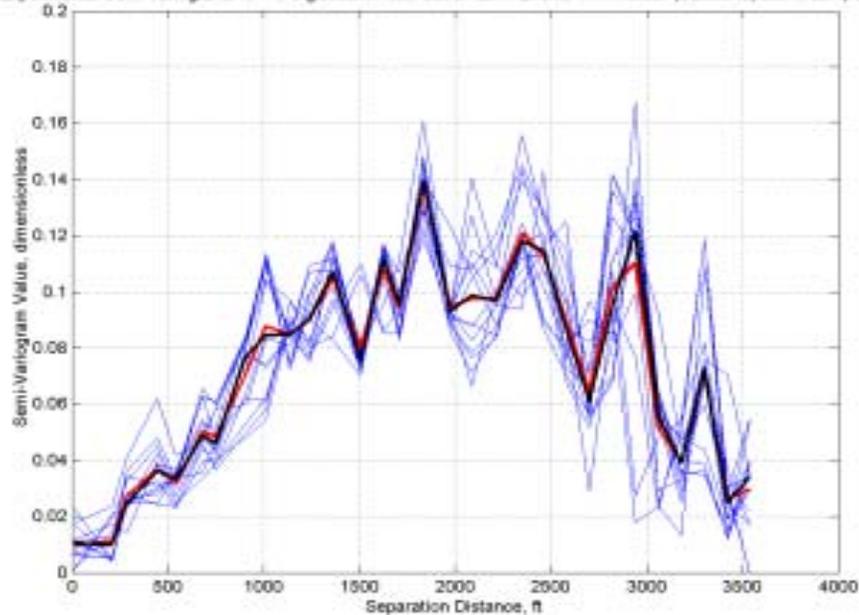
Blended

Example Using Numerical Models

Kriged Head Data

Kriged Head: 865 870 875 880 885 890 895 900 905 910

Example Using Numerical Models

Modflow Head Data
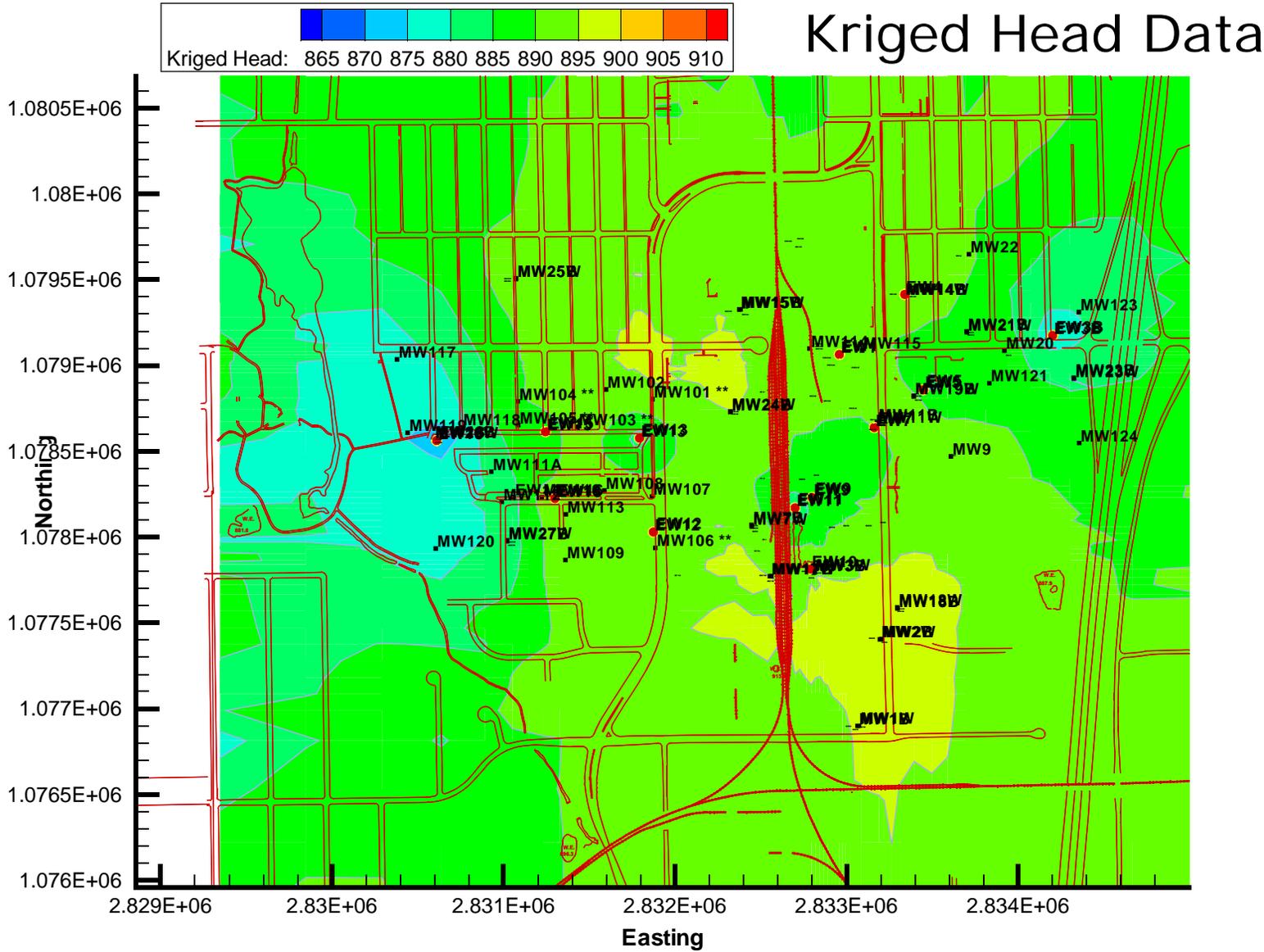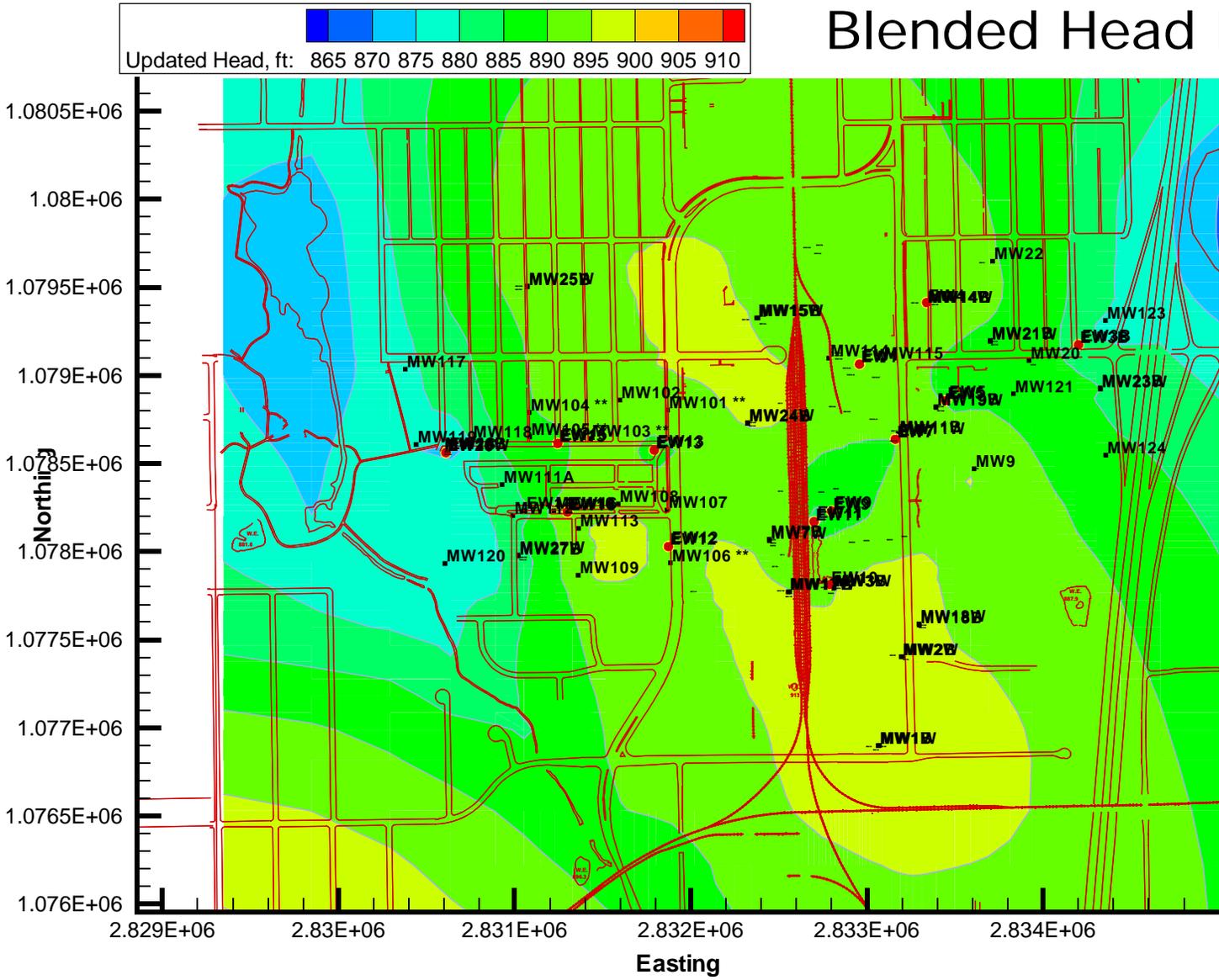
Variography of Residuals

15 monitoring events—
filtered out events with too
few observations

15 monitoring events
summarized with current
data

Example Using Numerical Models
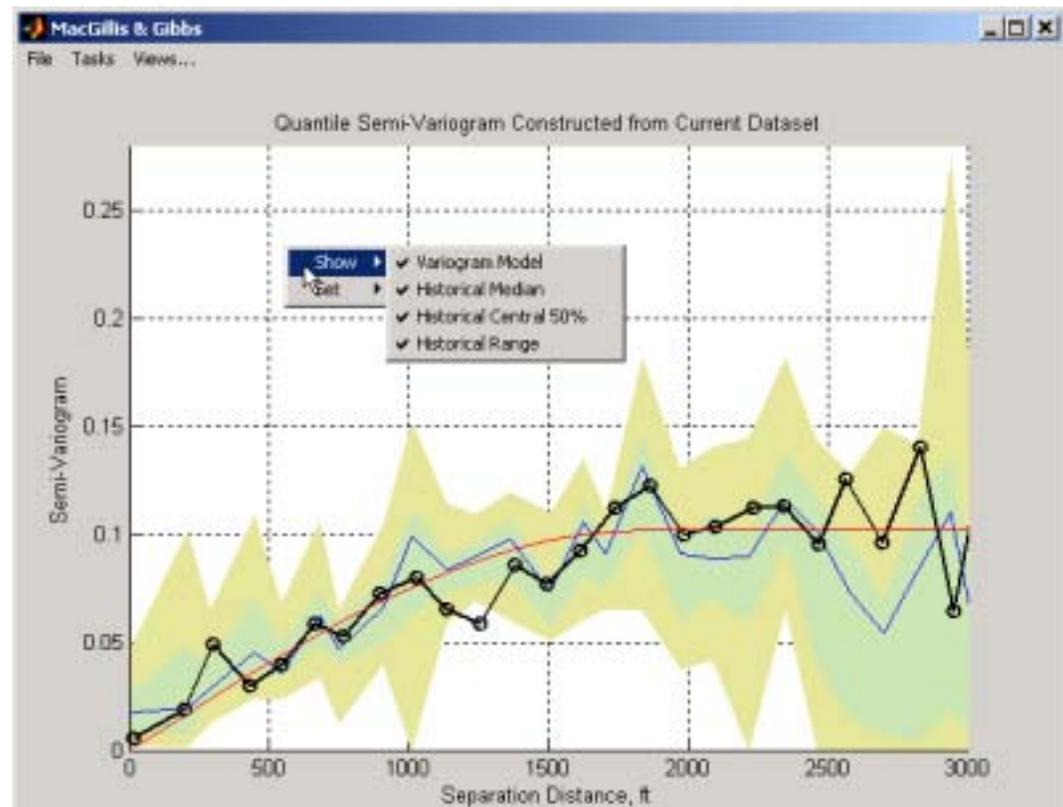
Blended Head Data

Example Using Numerical Models

Blended Head Data

Wrapup

- Union of physical and statistical approaches is greater than sum of the parts

- Data are perfection challenged.

- Models are perfection challenged.

- Interpretations are perfection challenged.

- Decisions are perfection challenged.

  → Validation, robustness, observability are key.