


# **Data Assessment and Assimilation to Evaluate Performance of Groundwater Remedies**

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**“Too much information running through my brain  
Too much information driving me insane**

**Too much information running through my brain  
Too much information driving me insane...”**

**--- Sting, *Ghost in the Machine*, 1981**






**RPMs have too much information flowing across their desk to fully digest it all.**

**Program is moving past the investigation and remedy determination stage.**

**Program is entering a data-intensive Post Construction/Long-Term Monitoring stage.**






## Problem


- How to evaluate the effectiveness or progress of a clean-up?
- How to process and understand the voluminous amount of monitoring data that increases with each passing year?

## Solution

- Collection:** Obtain data in a standardized electronic format (Region 5 EDD, Multimedia EDD)
  - Assembly:** Assemble all info relevant to site cleanup in a “Remedy Performance and Compliance (RPC) Report”
  - Analysis:** Perform standardized and normalized analyses that management and staff can use to evaluate Superfund remedy progress and cleanup effectiveness
- 



# **Determining if Groundwater Releases are “Under-Control and Stabilized” for Groundwater Extraction Systems**

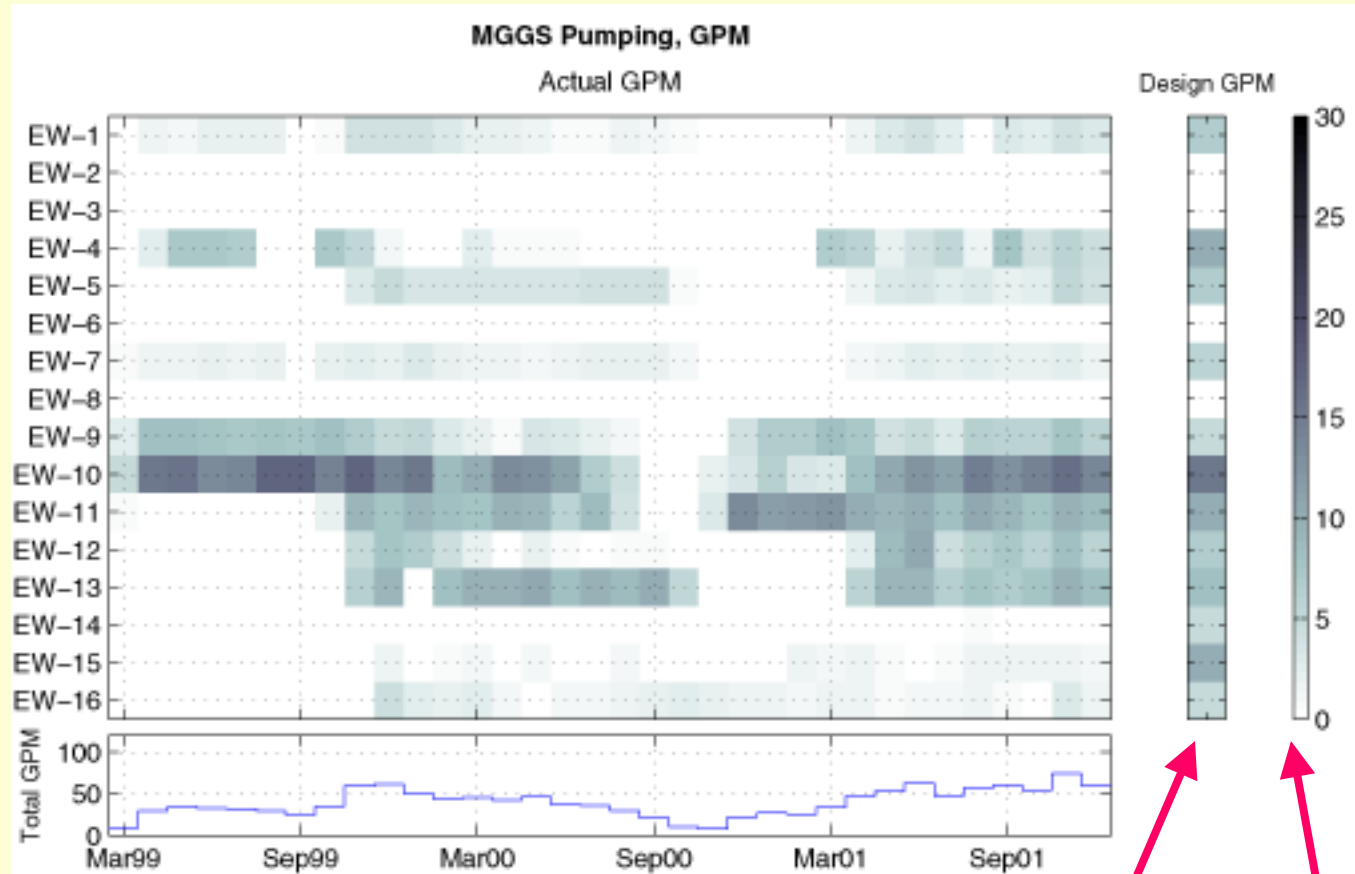
- What are current monthly-averaged pumping rates vs. the designed pumping rates?
  - What does the current water levels show?
  - What is the current extent of the area of capture vs. designed capture area?
  - What is the current target area needing to be captured?
  - What are areas of uncertainty?
- 

# Designed pumping rate vs. Monthly-average rate

Individual Wells

System Extraction Rate

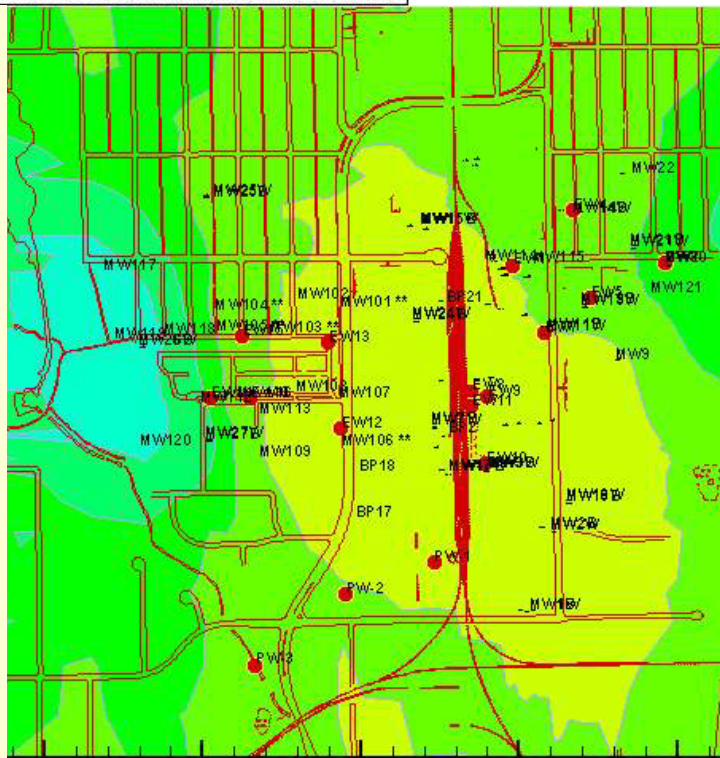
Sampling Events



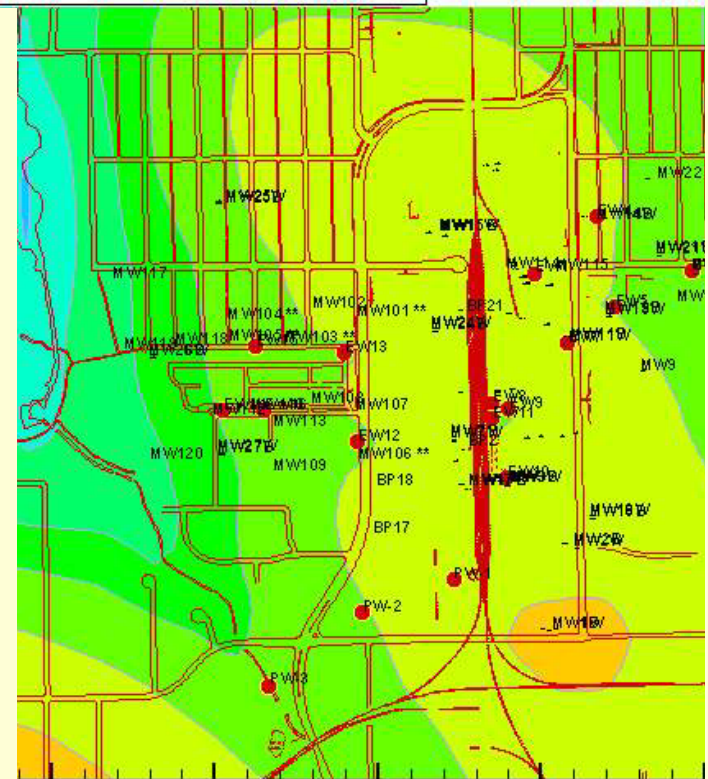
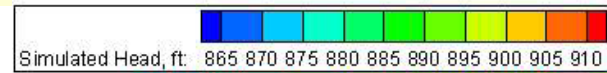
Design Rates

Colormap

# What do current water levels show?



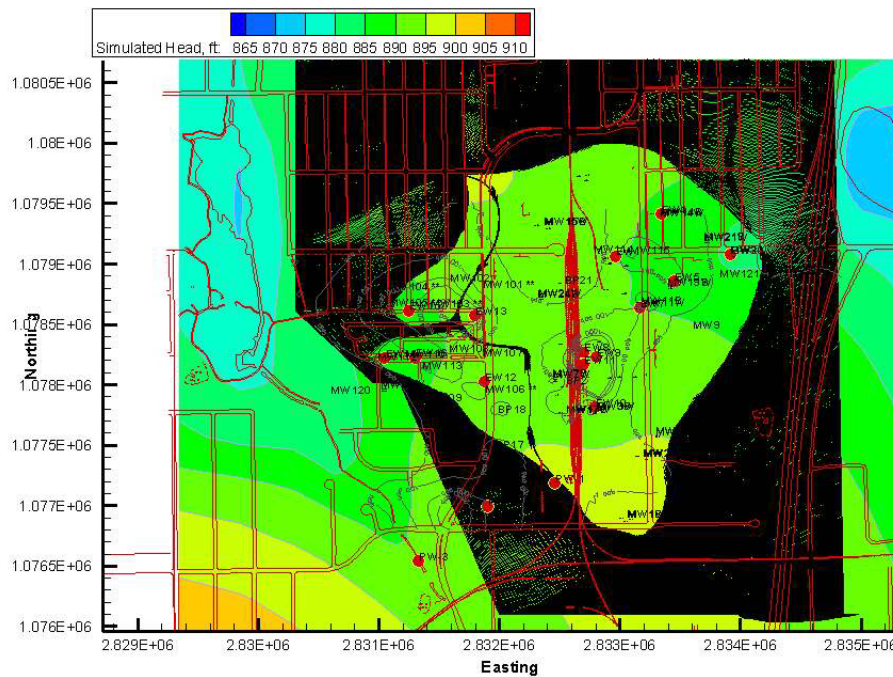
Using monitoring data and kriging



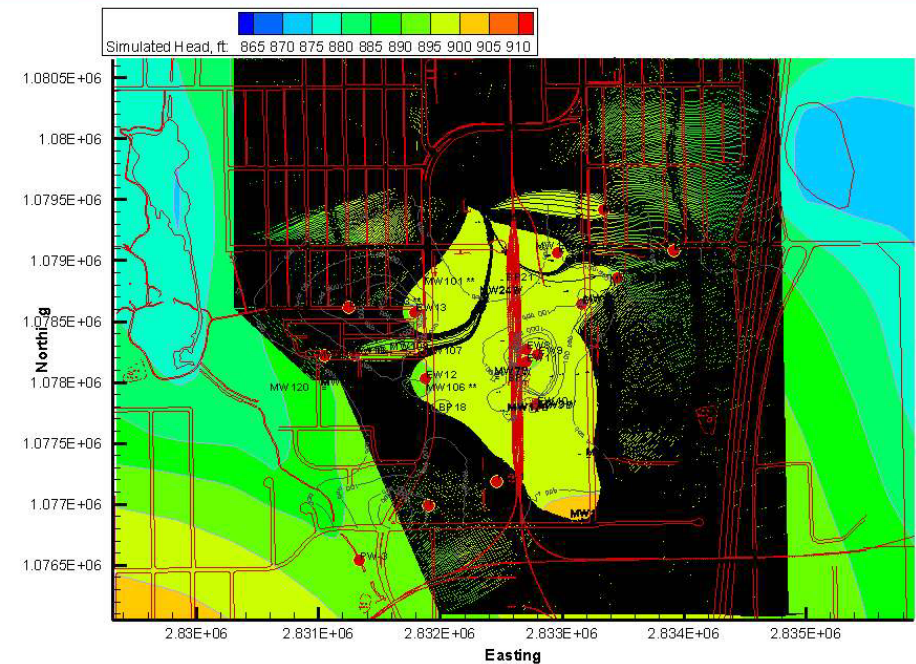
Using model and black-box current pumping rates

# What is the current extent of the capture area vs. designed capture area?

→ Need to use the actual rates of pumping



Using Design rate of 144 total GPM

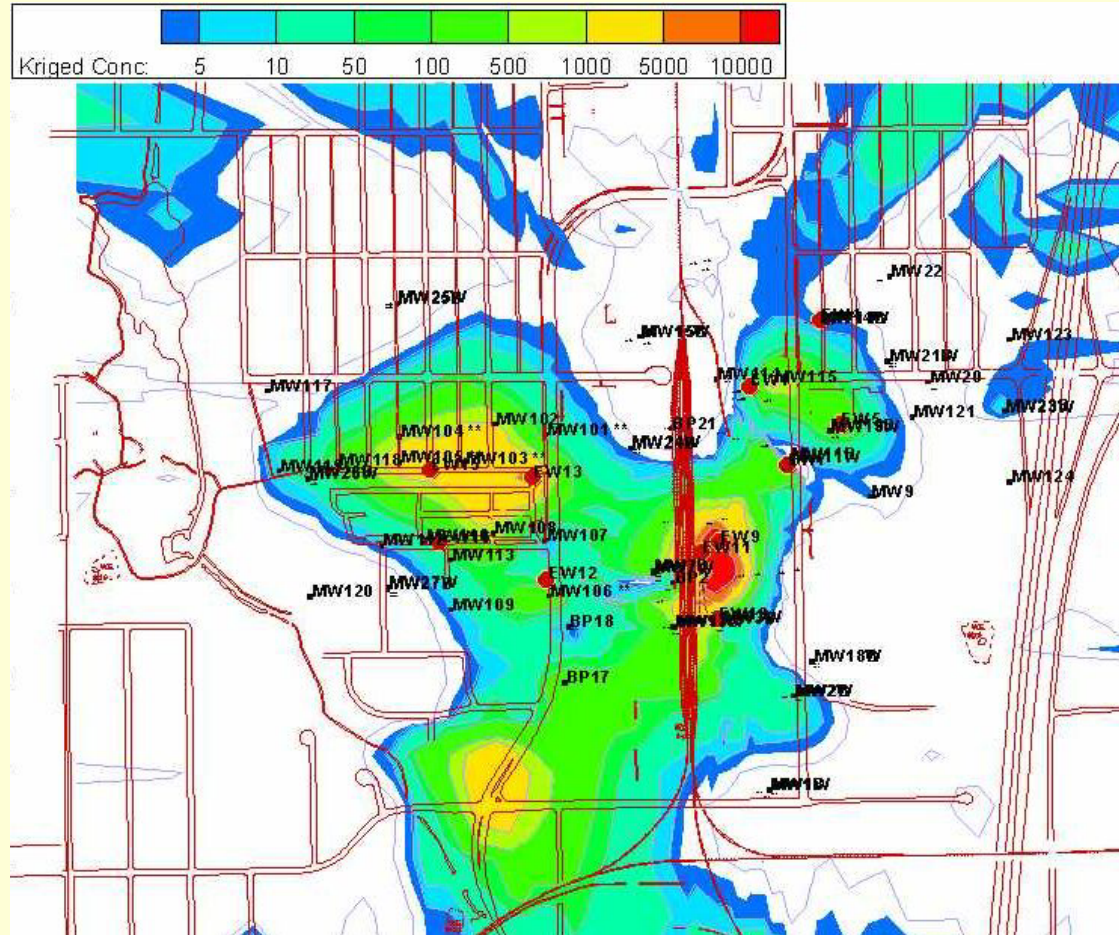


Using Monthly Avg. of 95 total GPM



# What is the current Target Area needing to be captured?

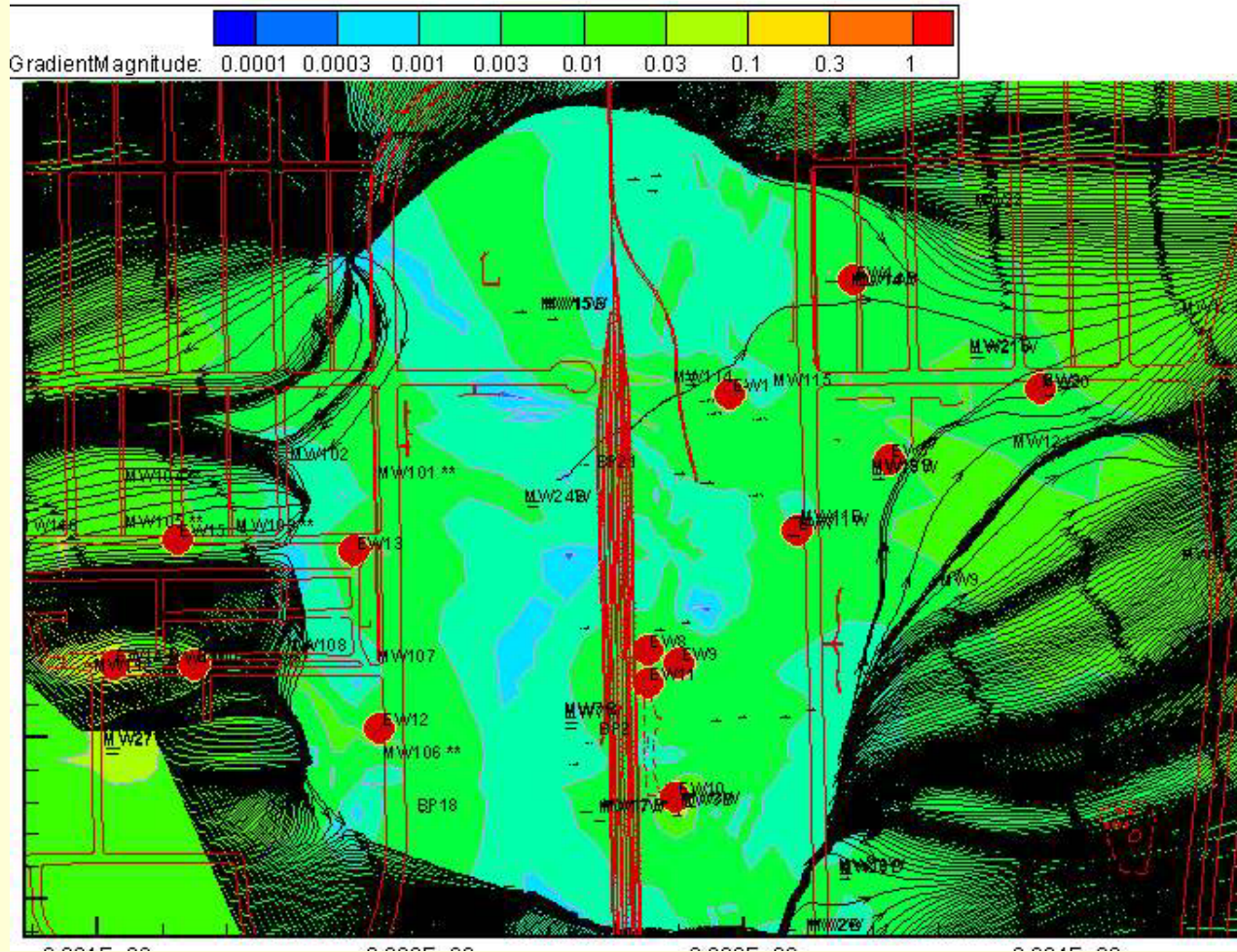
Determine for each round of data



Target is 1 ppb PCP concentration contour.

# What are areas of uncertainty?

Flow directions are less reliable  
when the hydraulic gradient becomes flat






# **OPDATE Tool to Help Determine Current Capture Zone**

## **Approach**

- 1) Use Actual Monitoring Head Data**
- 2) Use Groundwater Flow Model**
- 3) Update:                    Model Forecast of Head with  
                                      Current Head Measurements**
- 4) Determine:                Capture Area based on  
                                      Updated Estimate of Head**

**Not a modeling or parameter estimation task---  
focus is assessing current conditions (heads)**



# Remedy Performance Assessment/Capture

**WANT TO COMPARE**  $h \leftrightarrow h^*$

where

$h$  = actual head in field

$h^*$  = remedy target head

**ACTUALLY COMPARE**  $h^a \leftrightarrow h^*$

where

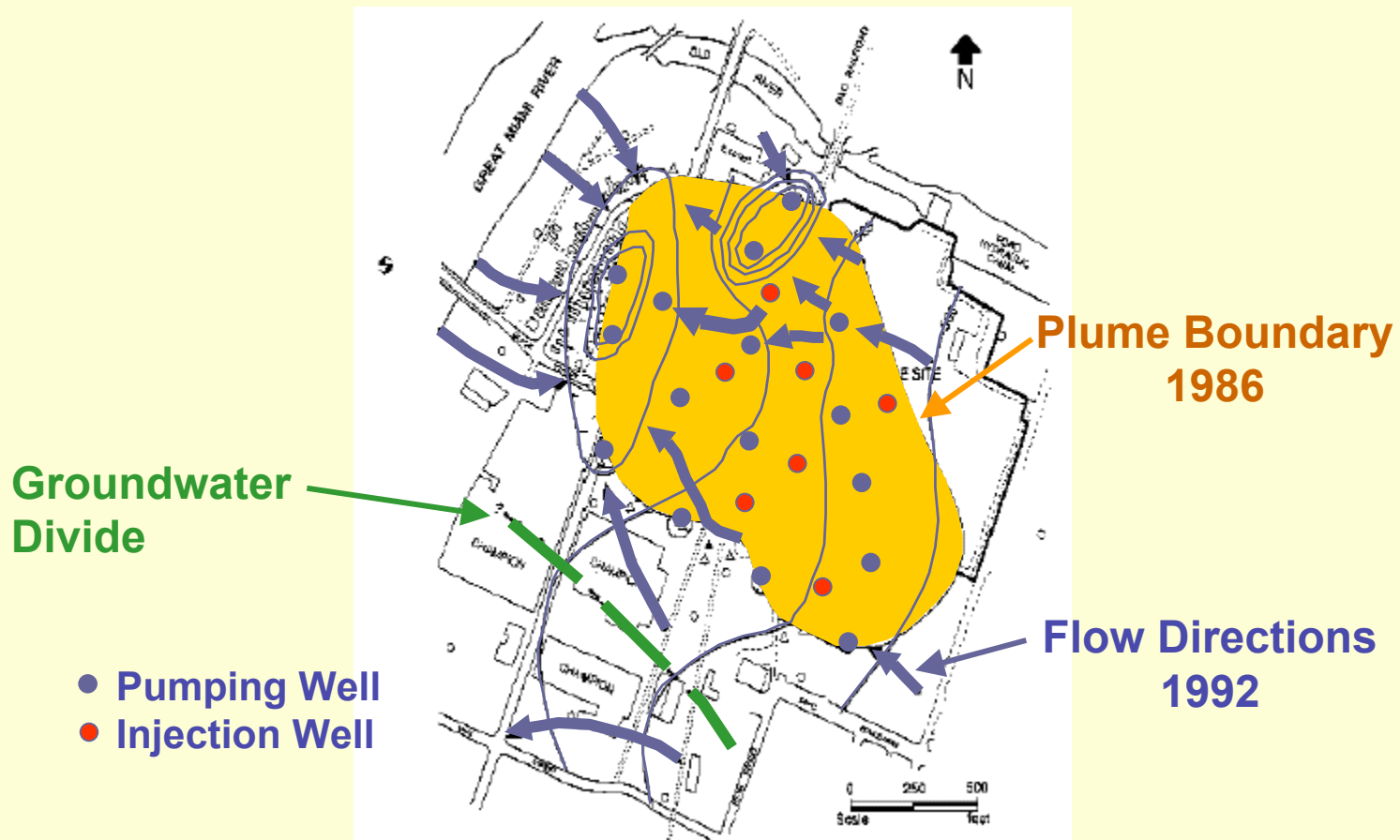
$h^a$  = approximate/estimated head in field

$h^*$  = remedy target head

# P&T Remedy Performance Assessment

[Cohen et al., EPA/600/R-94/123, 1994]

*CHOOSE THE  $h^*$  (Remedy Target Head)*



# Estimating “Actual” Head

- Deterministic interpolation → Uninformed prior + observations

$$\underbrace{h^a}_{\text{analysis}} = K_1 \cdot \underbrace{h^{obs}}_{\text{observation}} \quad \text{E.g., “Krige the Data”}$$

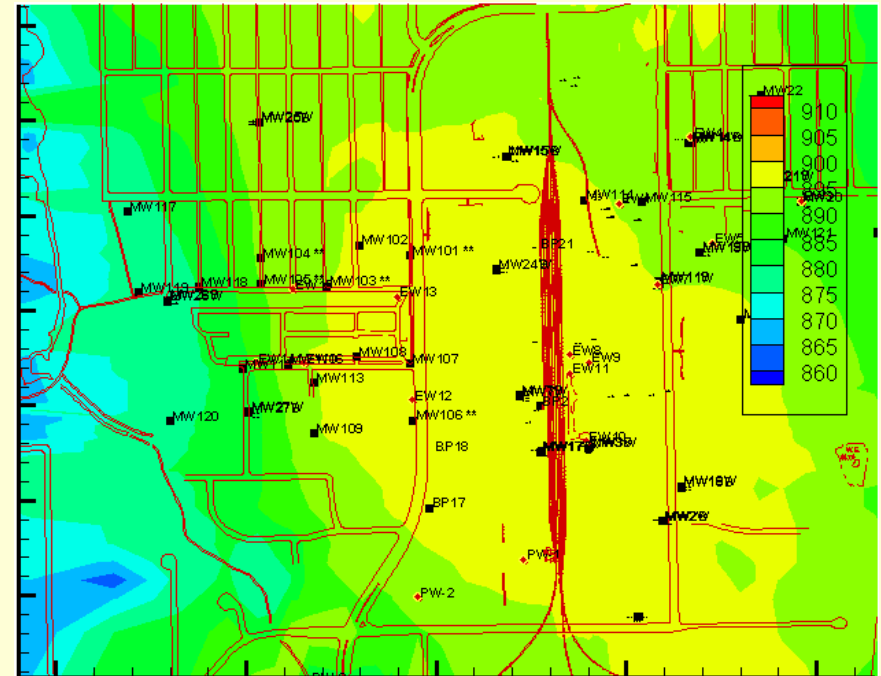
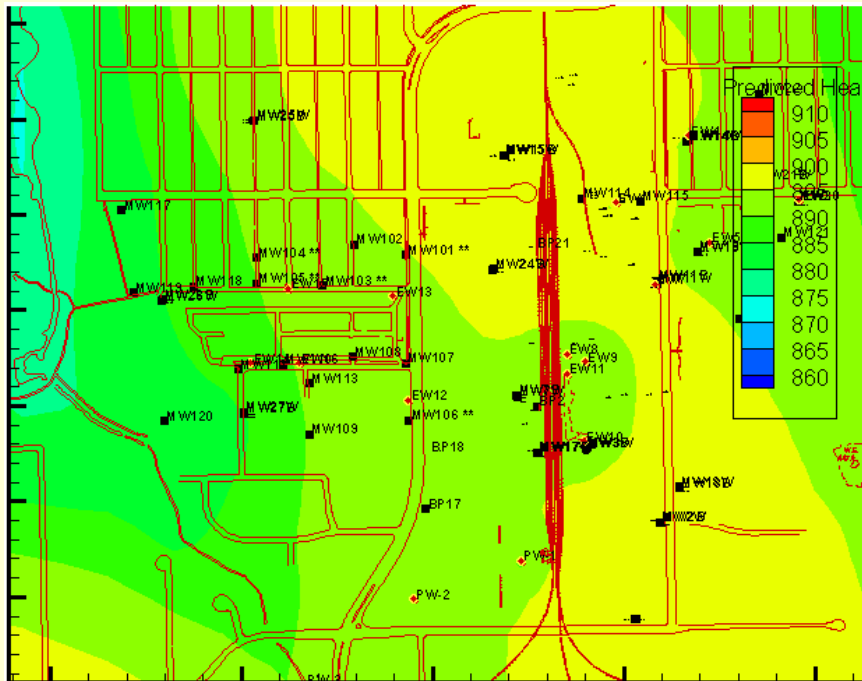
- Simulation model forecast → Informed prior

$$h^a = h^f \quad \text{“Model the Site”}$$

# Head Estimation for Capture Analysis

$h^f$  (simulation model)

$h^a$  (interpolated observations)



Bias, Pumping well effect, Physical principles

CAN WE GET THE BEST OF BOTH APPROACHES??

# Estimating “Actual” Head in OPDATE

“Perform Data Assimilation”

- Update+interpolation → Informed prior+observations

$$\underbrace{h^a}_{\text{posterior}} = \underbrace{h^f}_{\text{prior}} + \underbrace{K_2 \cdot \varepsilon}_{\text{update}}$$

where

$$\underbrace{\varepsilon}_{\substack{\text{observation-forecast} \\ \text{error}}} = \underbrace{h^{obs}}_{\text{observation}} - \underbrace{M \cdot h^f}_{\text{predicted observation}}$$

OR use nonparametric approach, e.g.,

Transform the data

$$q = Q(\varepsilon)$$

Calculate transformed updates

$$K_3 \cdot q$$

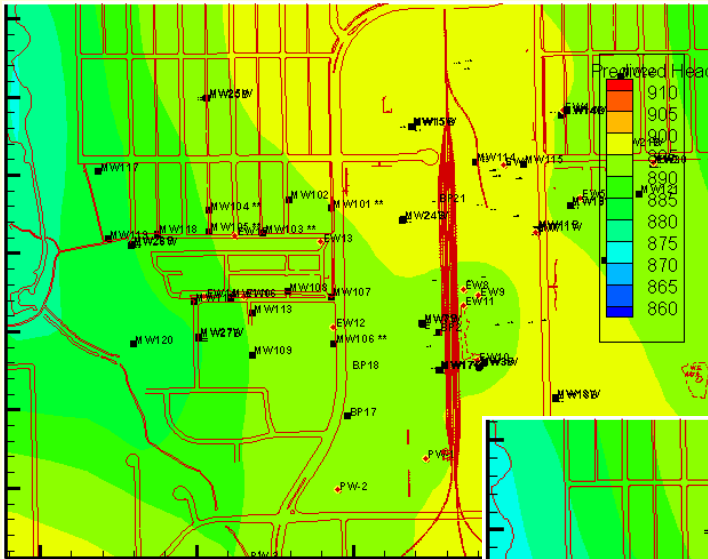
Then convert to heads and update the heads

$$h^a = h^f + Q^{-1}(K_3 \cdot q)$$

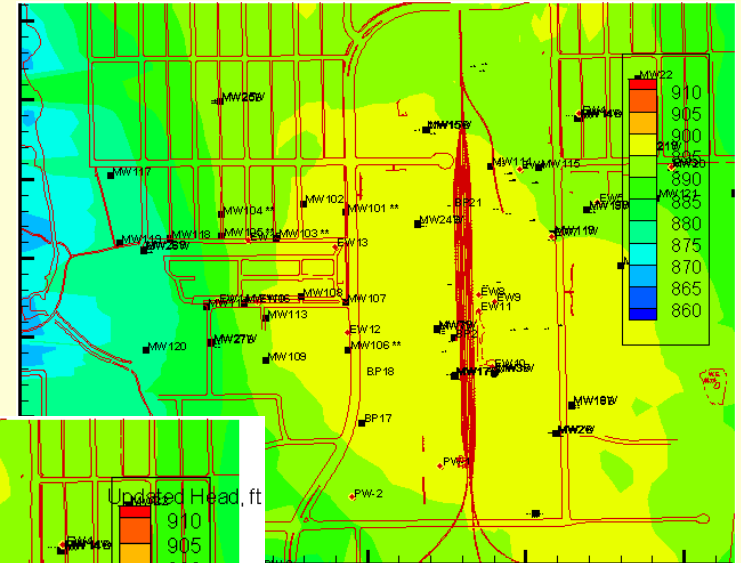


# Estimating “Actual” Head

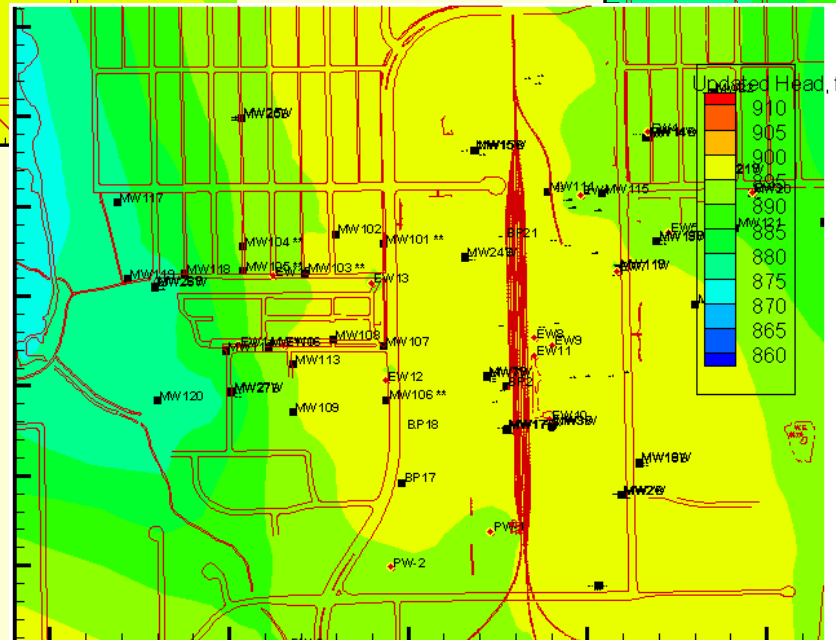
Combine Model...



...with Monitoring Data



...to Get the Updated “Actual” Head



# OPDATE Tool to Help

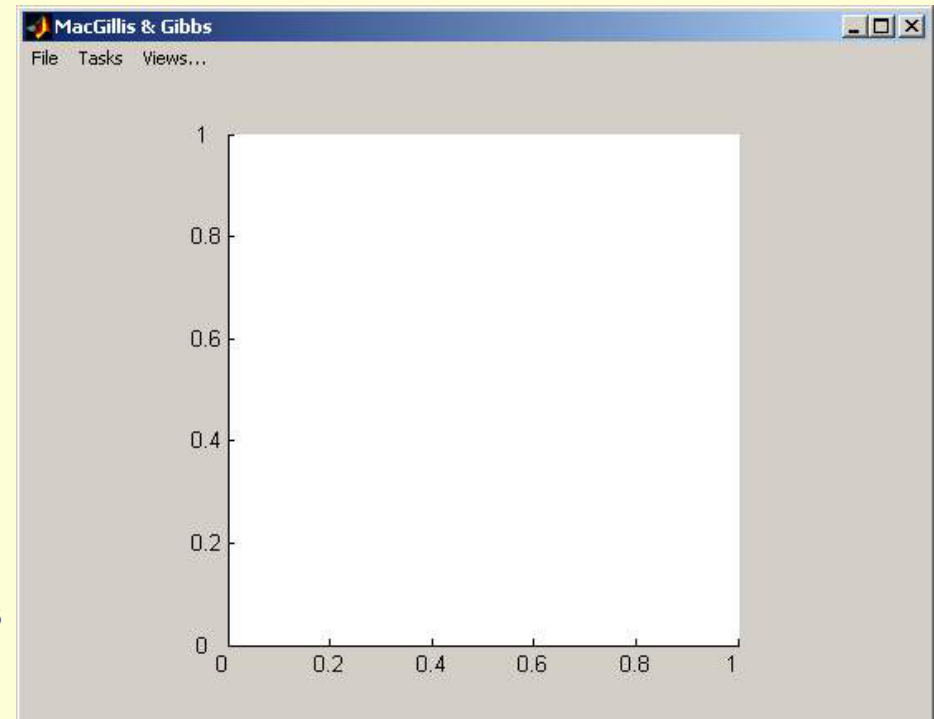
## Determine Current Capture Zone

### Performs Automatically

- 1) *Data Assimilation* analysis
- 2) Capture zone determination
- 3) Interactive particle traces
- 4) Target plume determination
- 5) Flat gradient determination
- 6) Flow gradient vectors

### Needs

- 1) Site groundwater flow model
- 2) File of current extraction rates
- 3) File of current head measurements
- 4) File of current contaminant concentrations
- 5) Tecplot viewer application
- 6) Initial site setup step



# OPDATE Tool

## Step 1

- a) Load data sets and run.  
If pumping rates are different, then flow model is re-run
- b) Load head observations.  
Outliers are noted

The screenshot displays the MacGillis & Gibbs software interface. The main window has a menu bar with 'File', 'Tasks', and 'Views...'. A task list window is open, showing the following steps:

1. Load Settings
2. Reset Q / Run Simulator
- 3. Load Field Observations**
4. Perform Updating
5. Export Results

A red progress bar is visible below the task list. In the foreground, an 'Outliers in observation data' dialog box is displayed with a yellow warning icon. The text in the dialog reads:

It appears there are ==> 3 <== outliers in the head data.  
Well IDs are as follows:  
Mw26W  
Mw26B  
Mw118

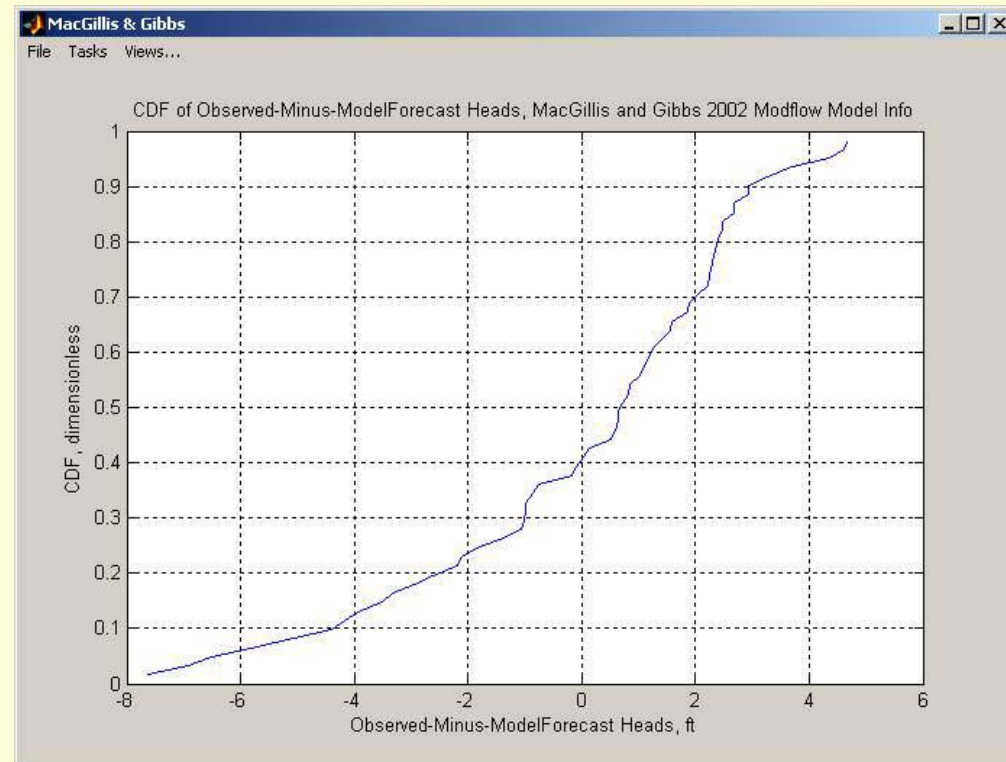
An 'OK' button is located at the bottom of the dialog. The background shows a graph with a y-axis ranging from 0 to 0.4 and an x-axis ranging from 0 to 1.

# OPDATE Tool

## Step 2

- a) **Residuals of observed heads minus model forecast heads are determined**
- b) **Bias is calculated as mean of residuals**
- c) **Residuals are transformed into quantiles for purposes of geostatistics with no assumptions of normality**

## Continuous Distribution Function of Residuals



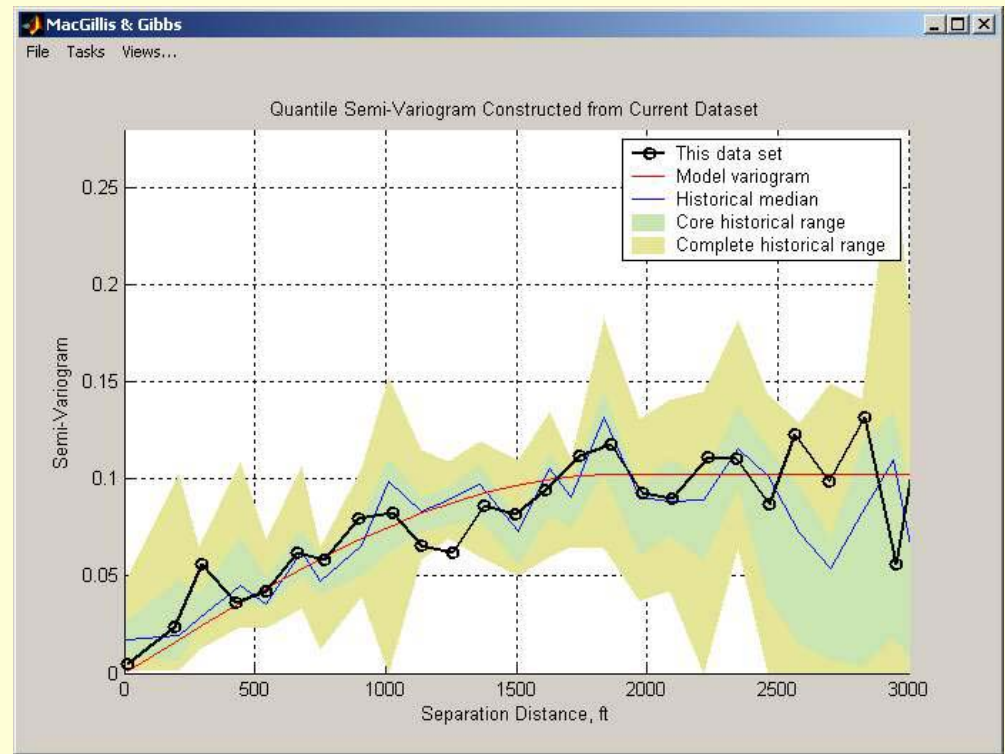
# OPDATE Tool

## Step 3

a) Experimental semi-variogram calculated

b) Operator needs to check if model variogram is appropriate

Evaluation of historical data.



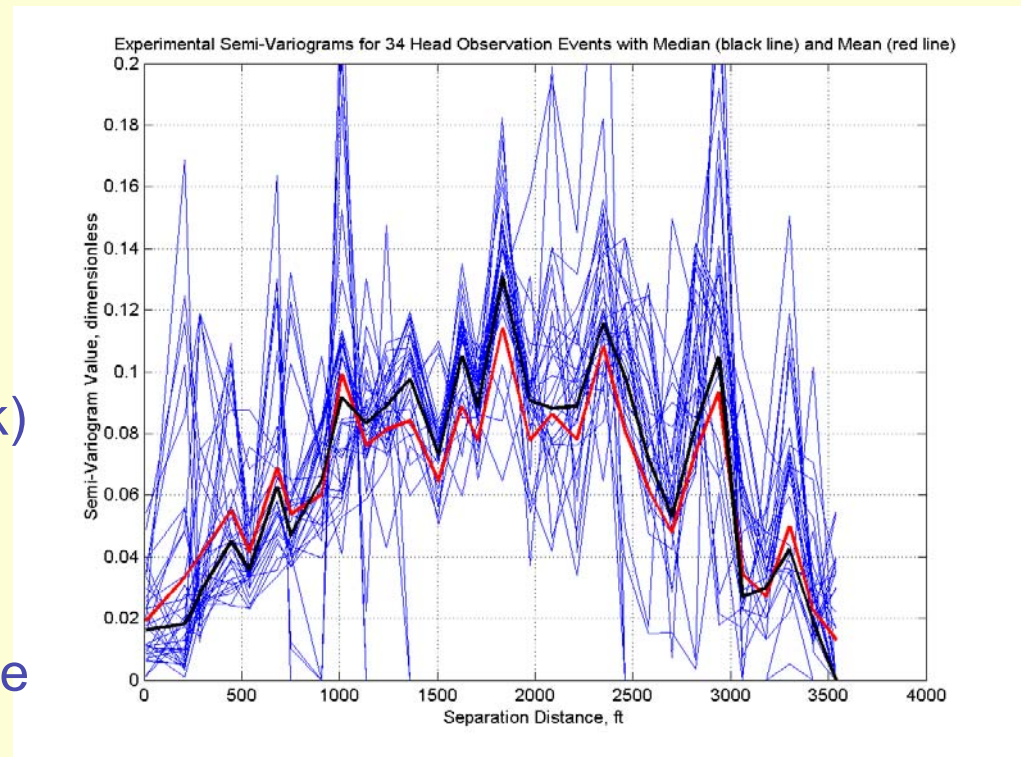
# OPDATE Tool

## Construction of Model Variogram

Experimental variograms from 34 observation events (8 years of sampling rounds) are shown with blue lines

Mean (red line) and median (black) experimental variograms are also shown

Much of the variogram noise is due to incomplete head data sets



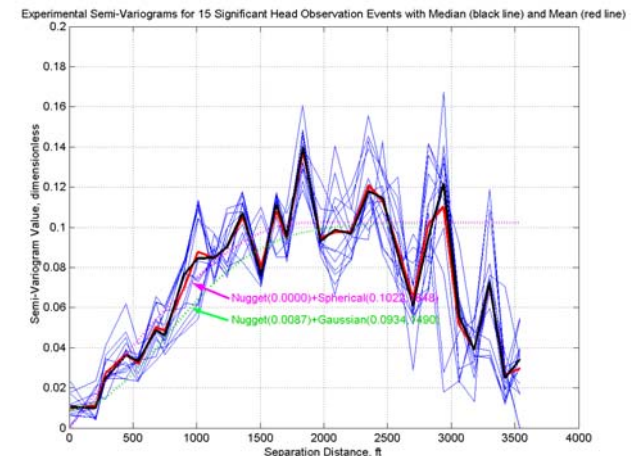
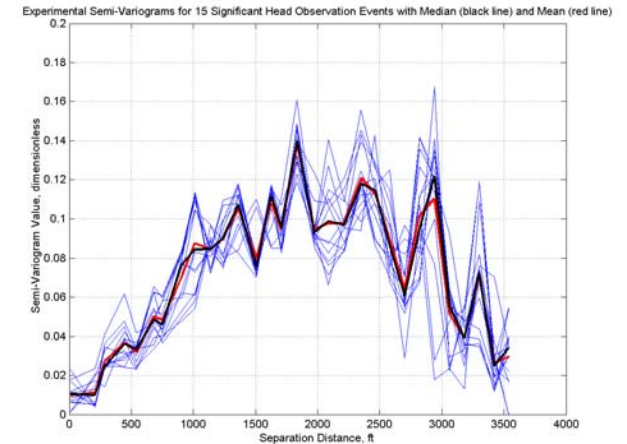
# OPDATE Tool

## Construction of Model Variogram

**15 complete observation events  
used to construct the  
model variogram**  
**Spherical model variogram  
used in updating software**

	<b>Gaussian with nugget</b>	<b>Spherical with nugget</b>
Nugget	0.0087	0.0000
(Partial) Sill	0.0934	0.1022
Range, feet	1490	1848
Fitting Error (RMS)	0.01494	0.01522

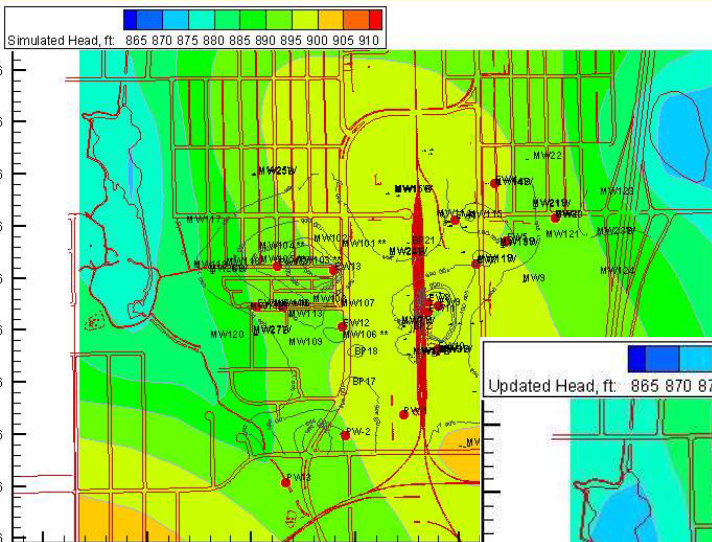
Parameters for two model variograms obtained by fitting median of experimental variograms.



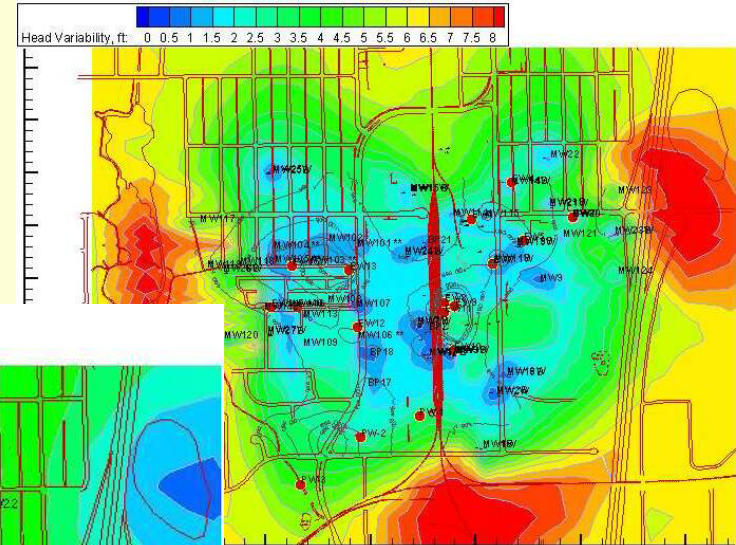
# OPDATE Tool

Step 4) Automatically populates Tecplot with formatted results

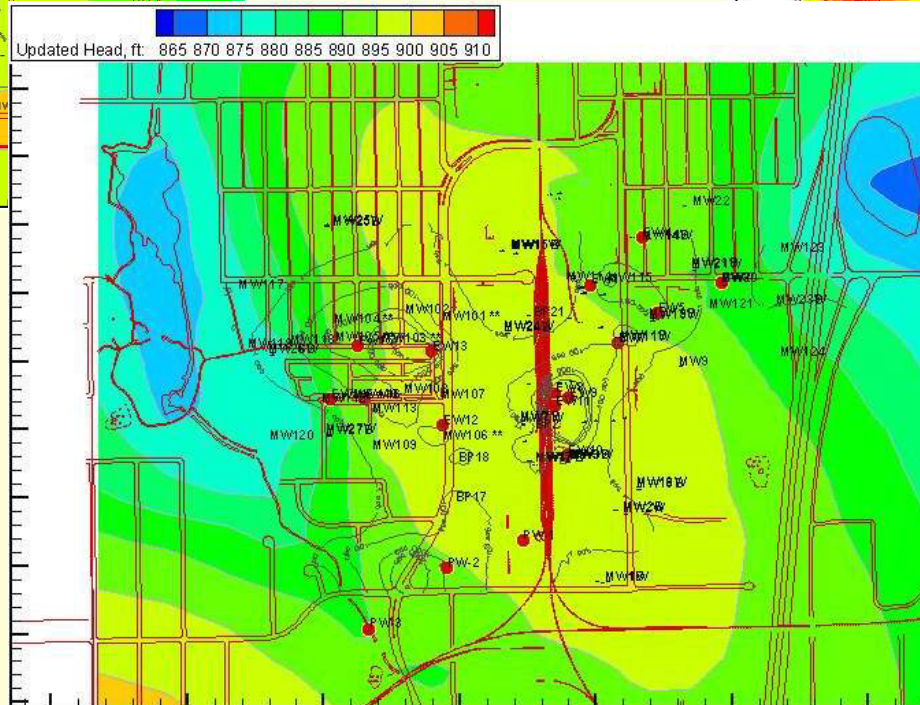
a) Model...



b) ... + Correction...



c) ...= Updated Heads

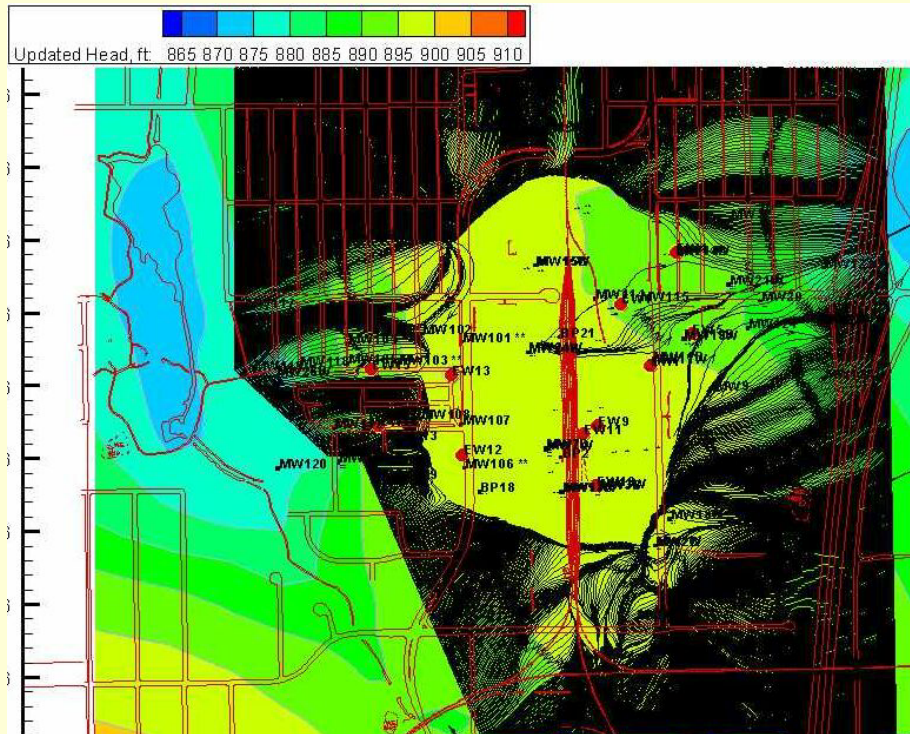




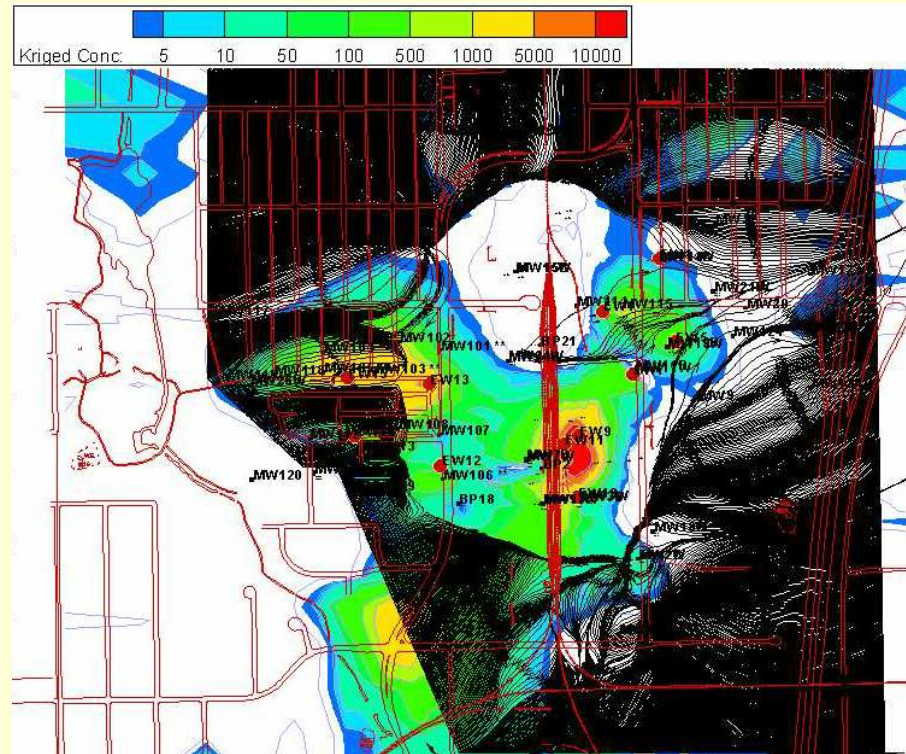
# OPDATE Tool

## Step 5 Show Area of Capture

a) Heads in background



b) PCP Concentration in background

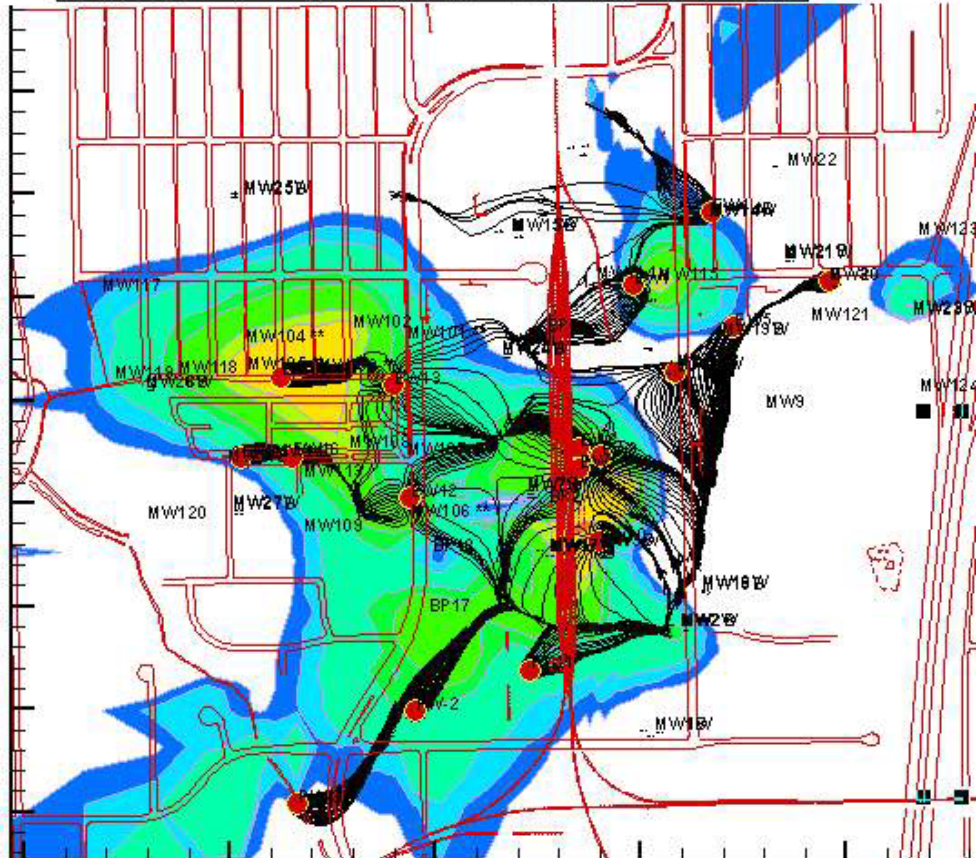
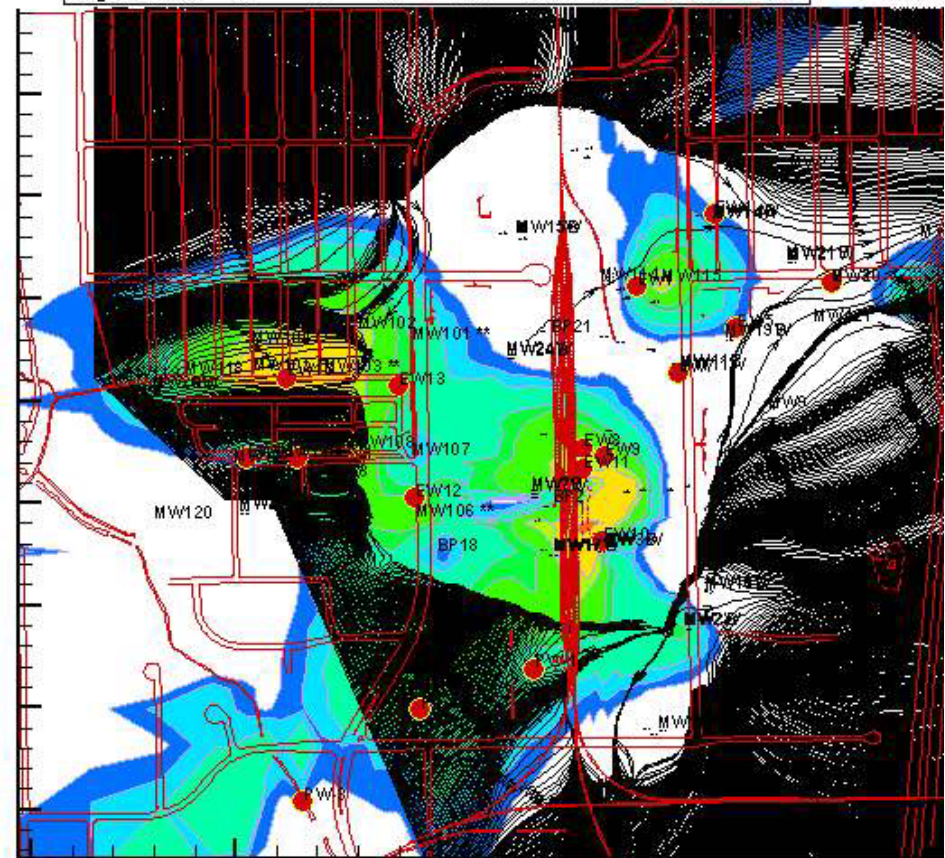
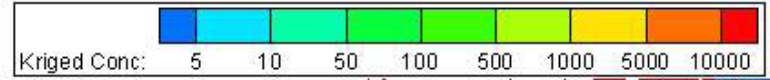
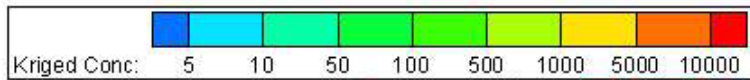


# OPDATE Tool

## Step 5 Show Area of Capture

### a) "Escapee" method

### b) Traditional method



## Step 5

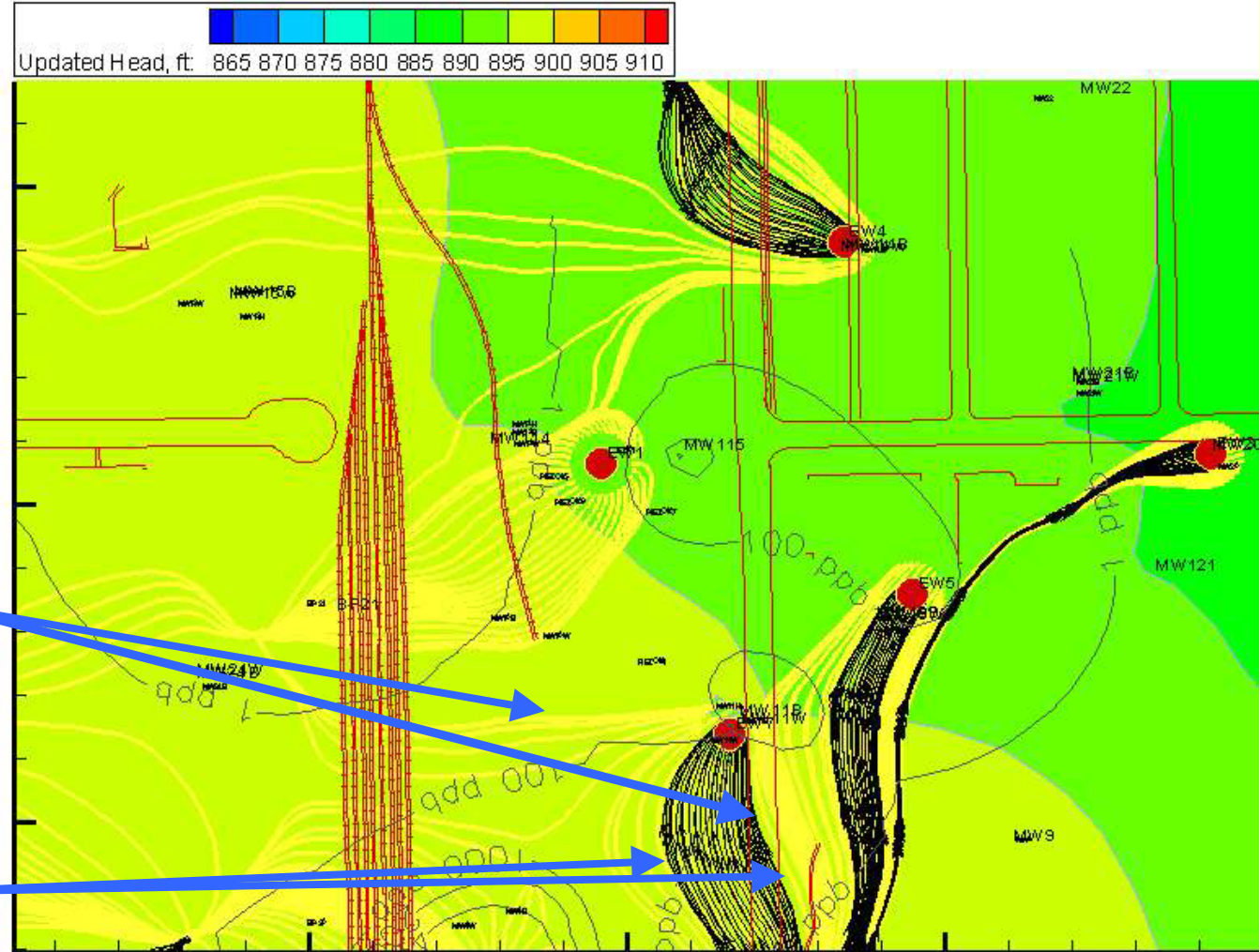
# OPDATE Tool

Issues with the traditional method used to determine capture

Size of launch circle and # of particles effect estimated capture zone

Wide Yellow capture from 50 foot circle

Narrow Black capture from 25 foot circle

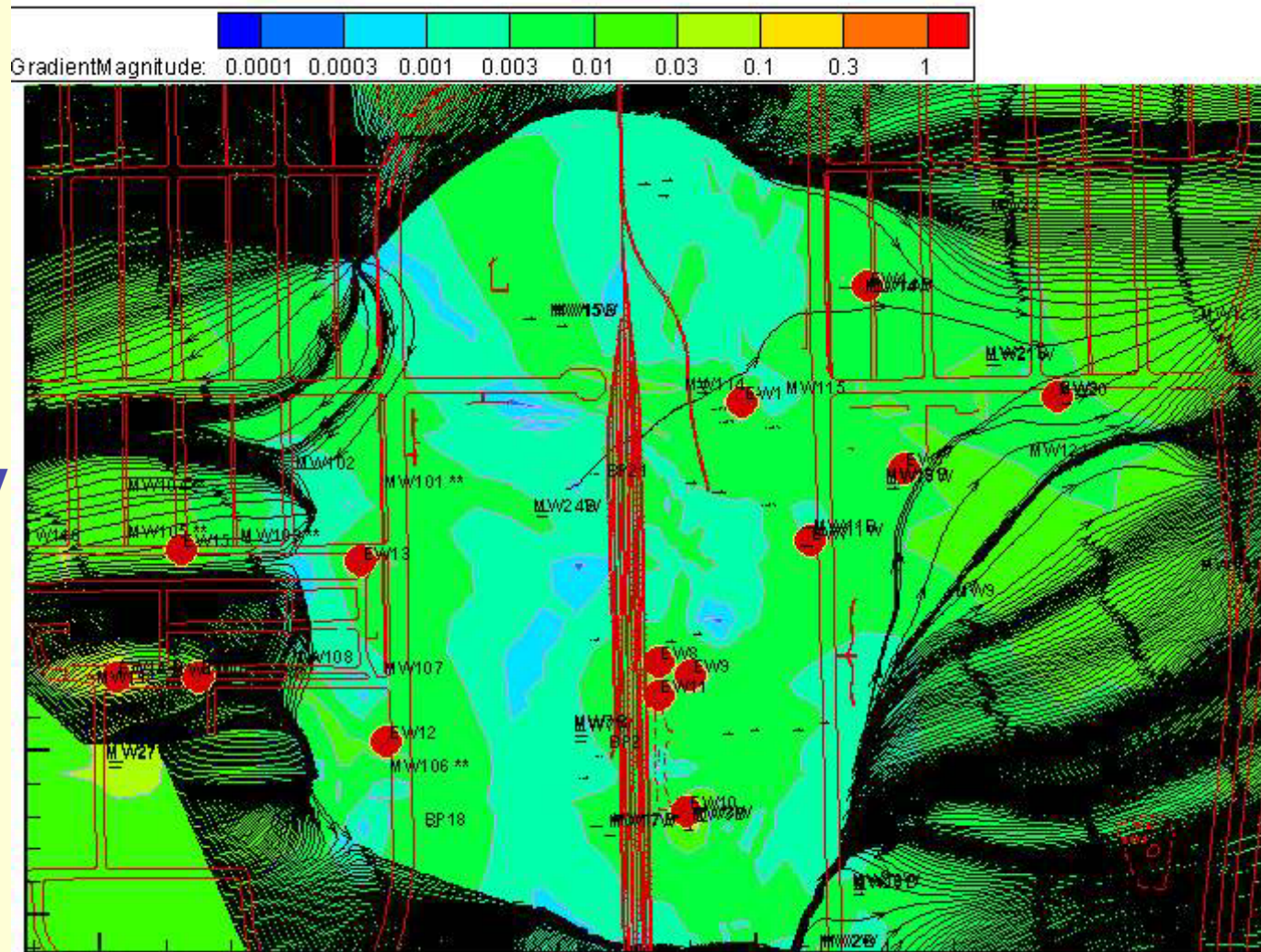


# OPDATE Tool

## Step 6

Show Area of  
Uncertainty

Areas with  
gradient below  
0.003 have a  
high uncertainty





# Conclusions

Moving to Post-construction/Long-term monitoring stage

Managing periodic or episodic data sets

**Collection**—move to standards-based electronic reporting

**Assembly**---ensure reports are sufficiently comprehensive

**Analysis**---investigate *performance* with compliance

What is current state of system? What was anticipated state of system?  
What is anticipated end-point and “roadmap”? Is current state compatible with these?

New tools leverage characterization/design work products

