Sufficiency analysis *before* and *after* detection of a leachate plume from a municipal landfill

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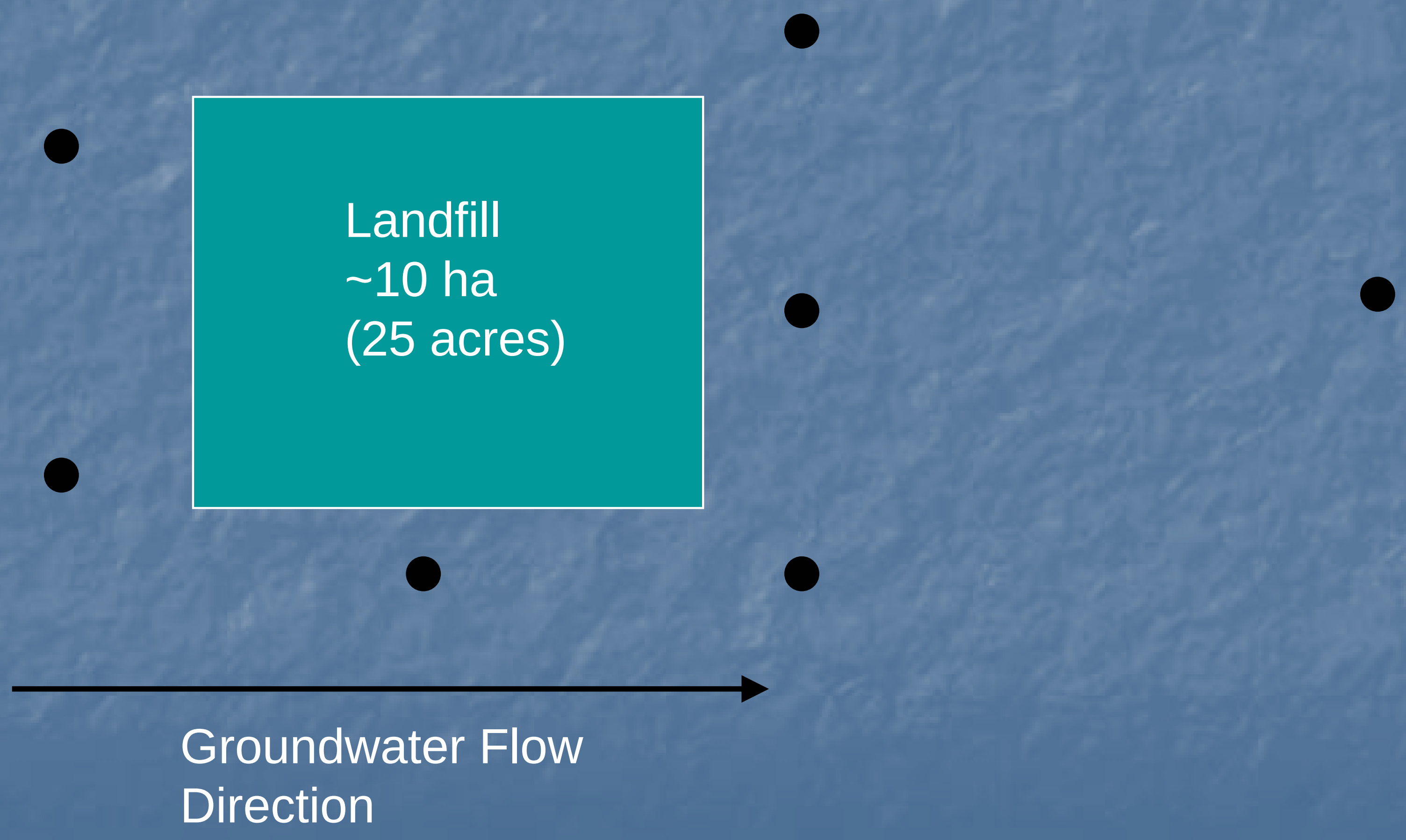
Motivation

- Owners/operators
  - Establish Cost-Effective monitoring designs
    - Minimum required monitoring wells
    - Minimum samples and analyses
    - Optimized long term monitoring (LTMO)
- Regulators
  - Establishing monitoring plan that achieves design objectives
    - Sufficient number of upgradient and downgradient wells
    - Sufficient sampling frequency
  - Tiered monitoring
    - 40+ regular parameters
    - 100+ supplemental parameters
  - Statistical Comparisons
    - Temporally
    - Spatially

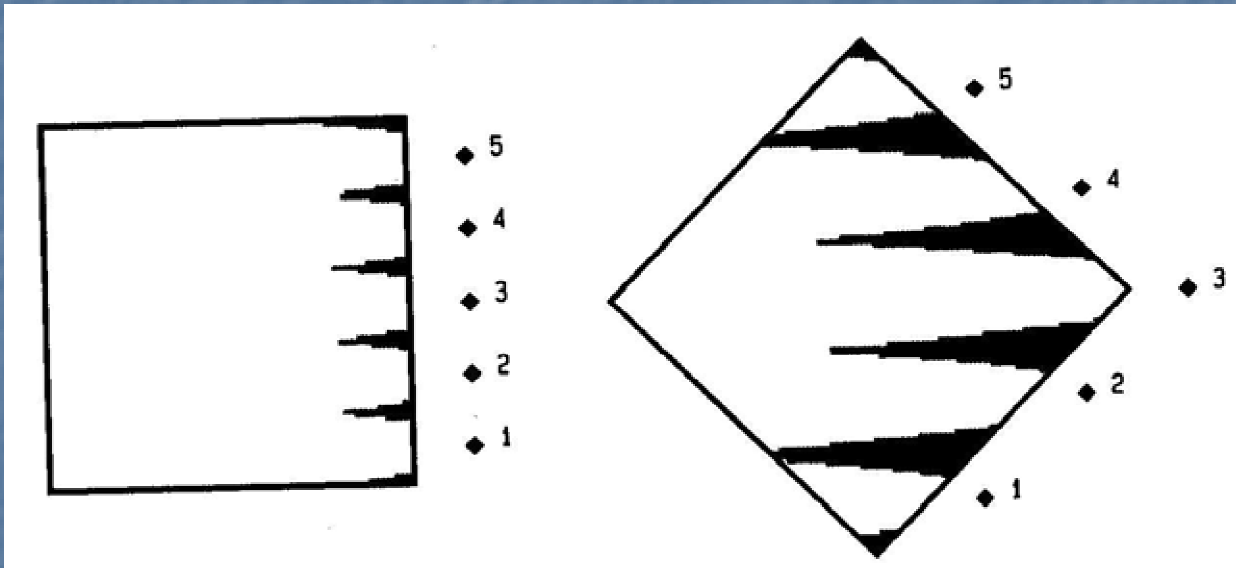
How do we balance monitoring cost and risk?

Typical unlined municipal landfill well design:



Site-specific Well Locations

- P.F. Hudak (1999)
  - 1.5 ha (3.7 acres)
  - Wells sited using equidistant approach
  - Detection efficiency decreases with increasing cross gradient width



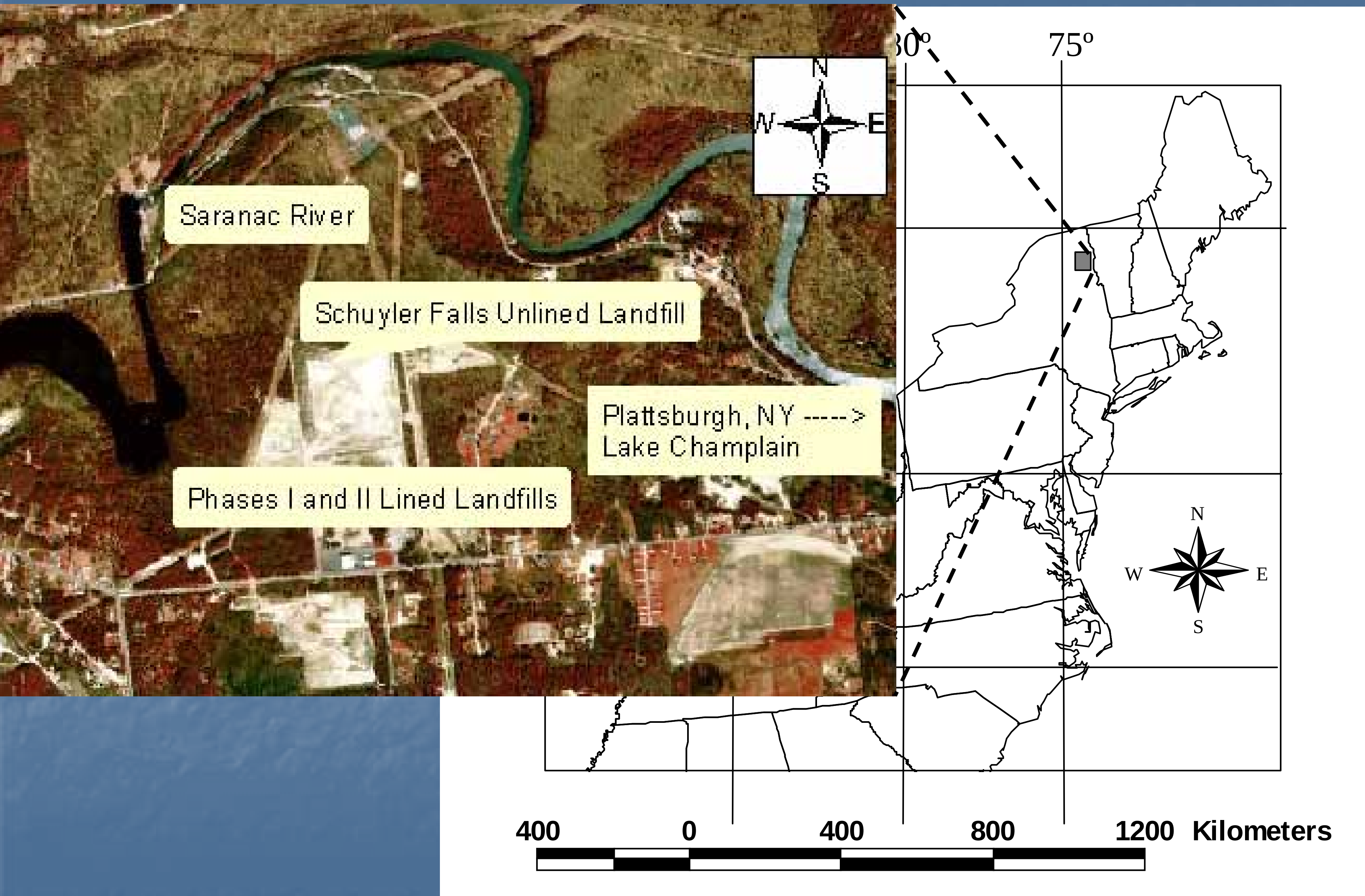
[P.F. Hudak, *Inter. J. Environ. Studies*, 1999]

Worth of Data

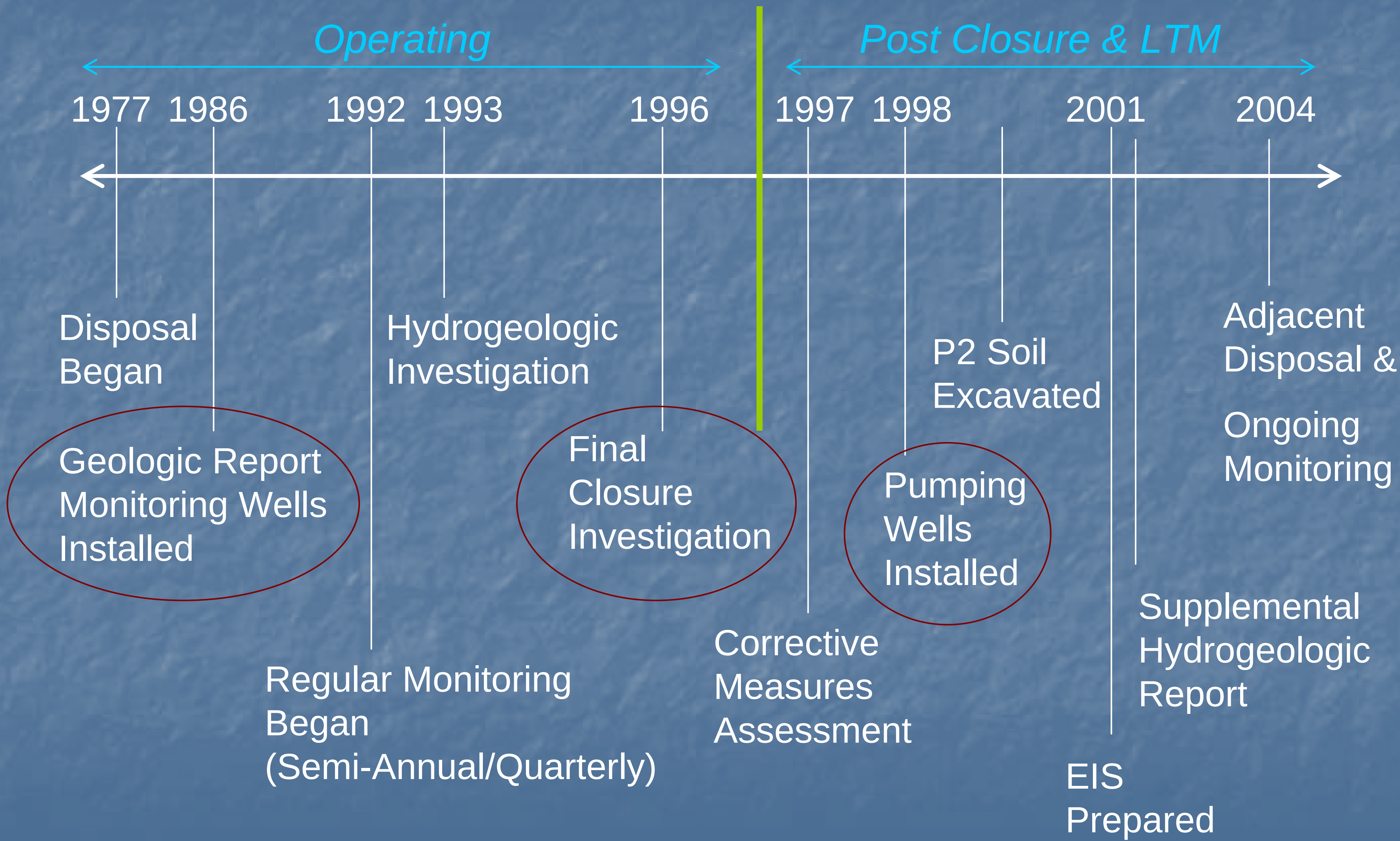
1) Do a sufficient number of monitoring locations exist to determine that a regulatory concentration was not exceeded at specified spatial locations?

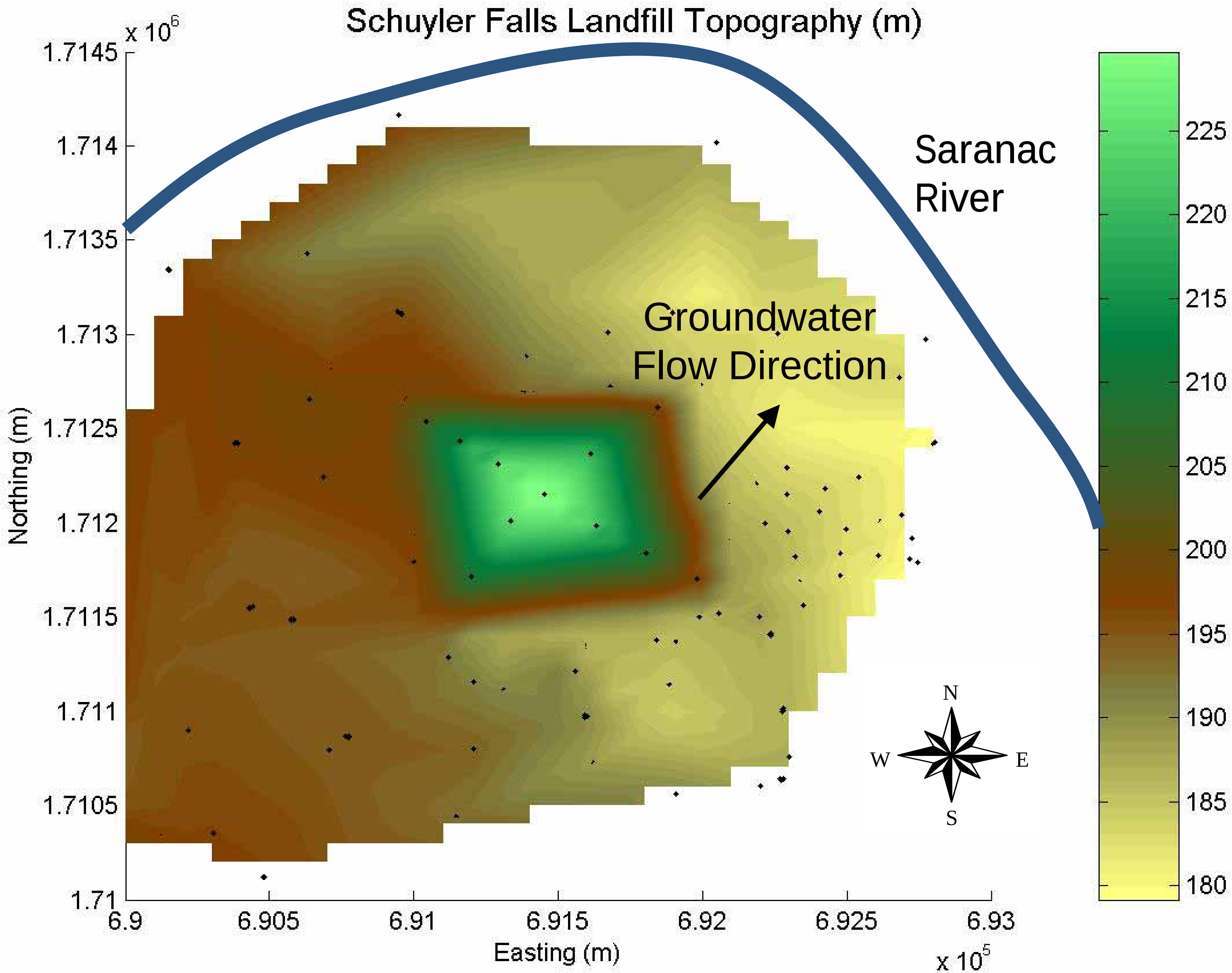
2) Is current sampling frequency sufficient (or redundant) at existing monitoring locations?

Site Location

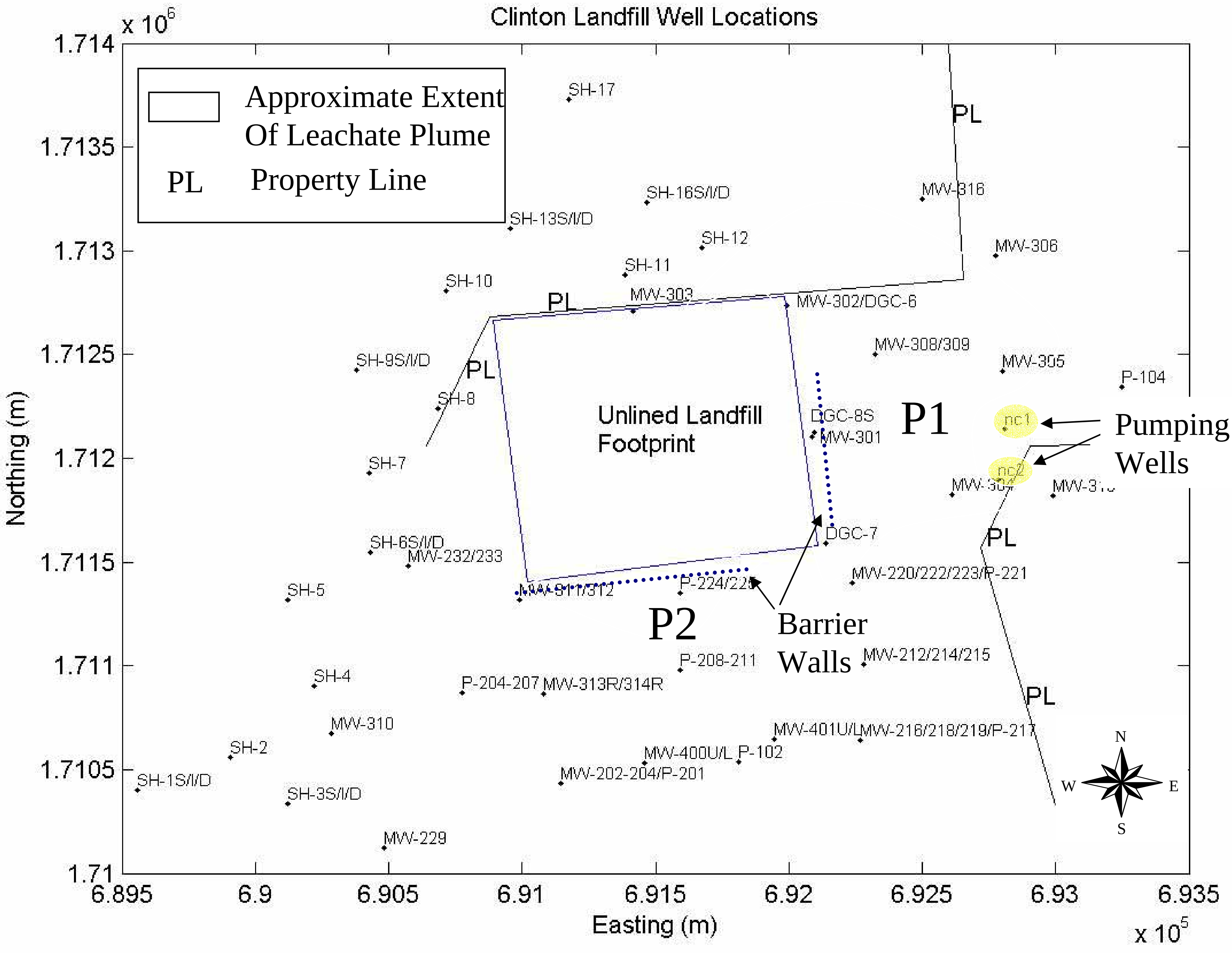


Site Timeline





Schuyler Falls Landfill Topography (m)
x 10^6
1.7145
1.714
1.7135
1.713
1.7125
1.712
1.7115
1.711
1.7105
1.71
Northing (m)
6.9
6.905
6.91
6.915
6.92
6.925
6.93
Easting (m)
x 10^5
Saranac
River
Groundwater
Flow Direction
N
W
E
S
225
220
215
210
205
200
195
190
185
180


Clinton Landfill Well Locations
x 10^6
1.714
1.7135
1.713
1.7125
1.712
1.7115
1.711
1.7105
1.71
Northing (m)
6.895
6.9
6.905
6.91
6.915
6.92
6.925
6.93
6.935
Easting (m)
x 10^5
Approximate Extent Of Leachate Plume
PL Property Line
Unlined Landfill Footprint
P1
P2
Pumping Wells
Barrier Walls
nc1
nc2
PL
SH-17
SH-16S/I/D
SH-13S/I/D
SH-12
SH-11
SH-10
MW-303
MW-316
MW-306
MW-302/DGC-6
MW-308/309
MW-305
P-104
SH-9S/I/D
SH-8
DGC-8S
MW-301
SH-7
DGC-7
SH-6S/I/D
MW-232/233
MW-220/222/223/P-221
SH-5
MW-311/312
P-224/225
P-208-211
MW-212/214/215
SH-4
P-204-207
MW-313R/314R
MW-310
MW-401U/L
MW-216/218/219/P-217
SH-2
MW-400U/L
P-102
SH-1S/I/D
MW-202-204/P-201
SH-3S/I/D
MW-229
N
W
E
S

Outline of Analysis

1. Broke sampling data into two periods
2. Evaluated spatial correlation and estimated concentrations at snapshots in time
3. Calculated the t-test statistic and power

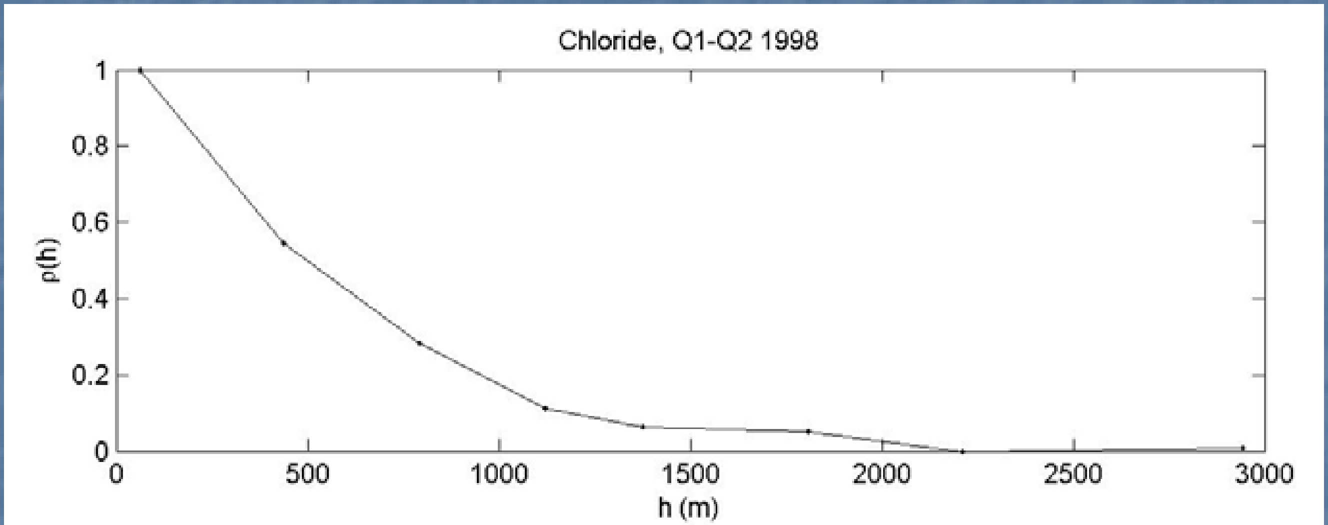
Time Period Characteristics

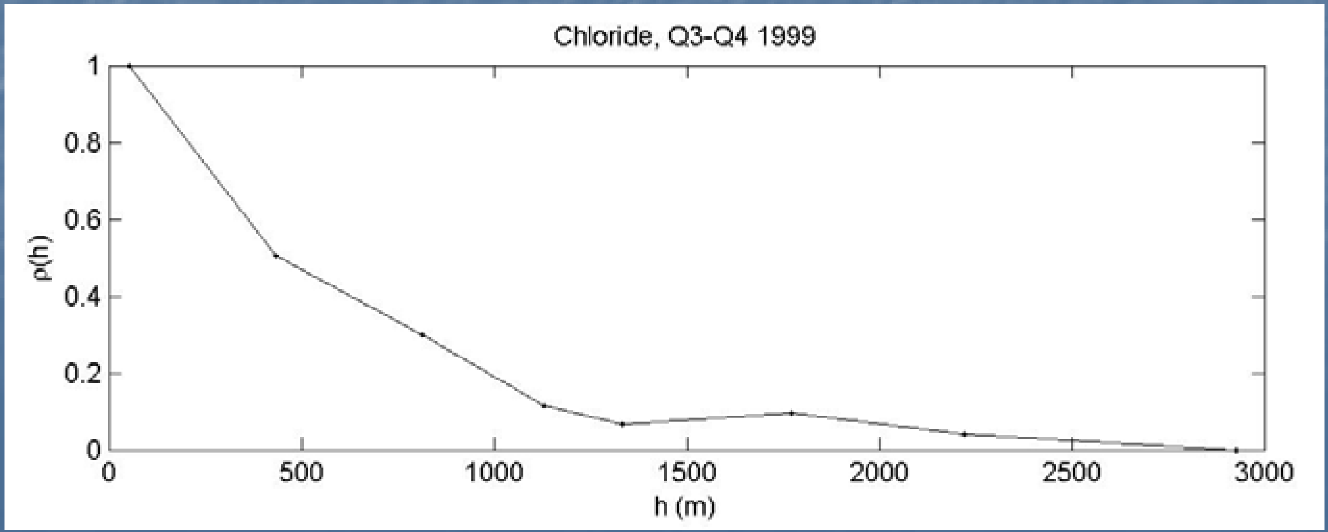
- ***T1: 1986-1997***
  - Before remediation
  - Active Landfill
  - 13 wells
  - 6 to 17 sampling events
  - 2 to 500 mg/L Chloride means
- ***T2: 1998-2003***
  - Remediation Pumping & Barrier Walls Installed
  - Closed Landfill
  - 28 wells
  - 3 to 23 sampling events
  - 2 to 900 mg/L Chloride means

Spatial Continuity & Estimation

$$\rho(h) = \frac{\frac{1}{N(h)} \sum_{(i,j)|h_{i,j}=h} (v_i v_j - m_{-h} m_{+h})}{\sigma_{-h}\sigma_{+h}}$$

- Normalized between 0-1
- May be applied to less-continuous parameters





Test statistic calculation

- One sample t-test (σ unknown)

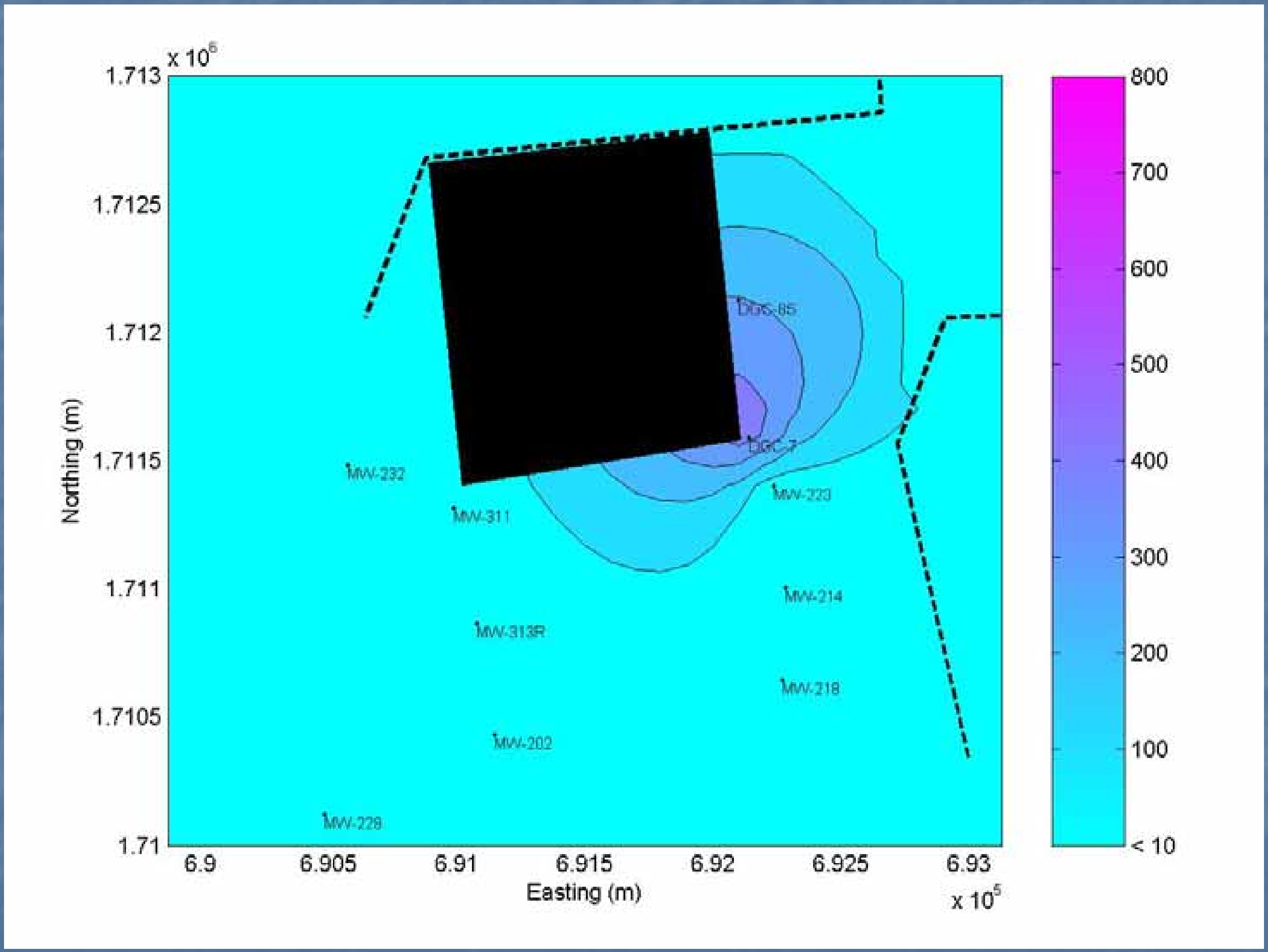
$$z = \frac{\bar{y} - \bar{\mu}_o}{\frac{\sigma}{\sqrt{n}}}$$

$$H_o : \mu = \mu_o$$
$$H_A : \mu > \mu_o$$

$$\mu_o = 100 \; mg / L$$
$$\sigma = 10 \quad mg / L$$

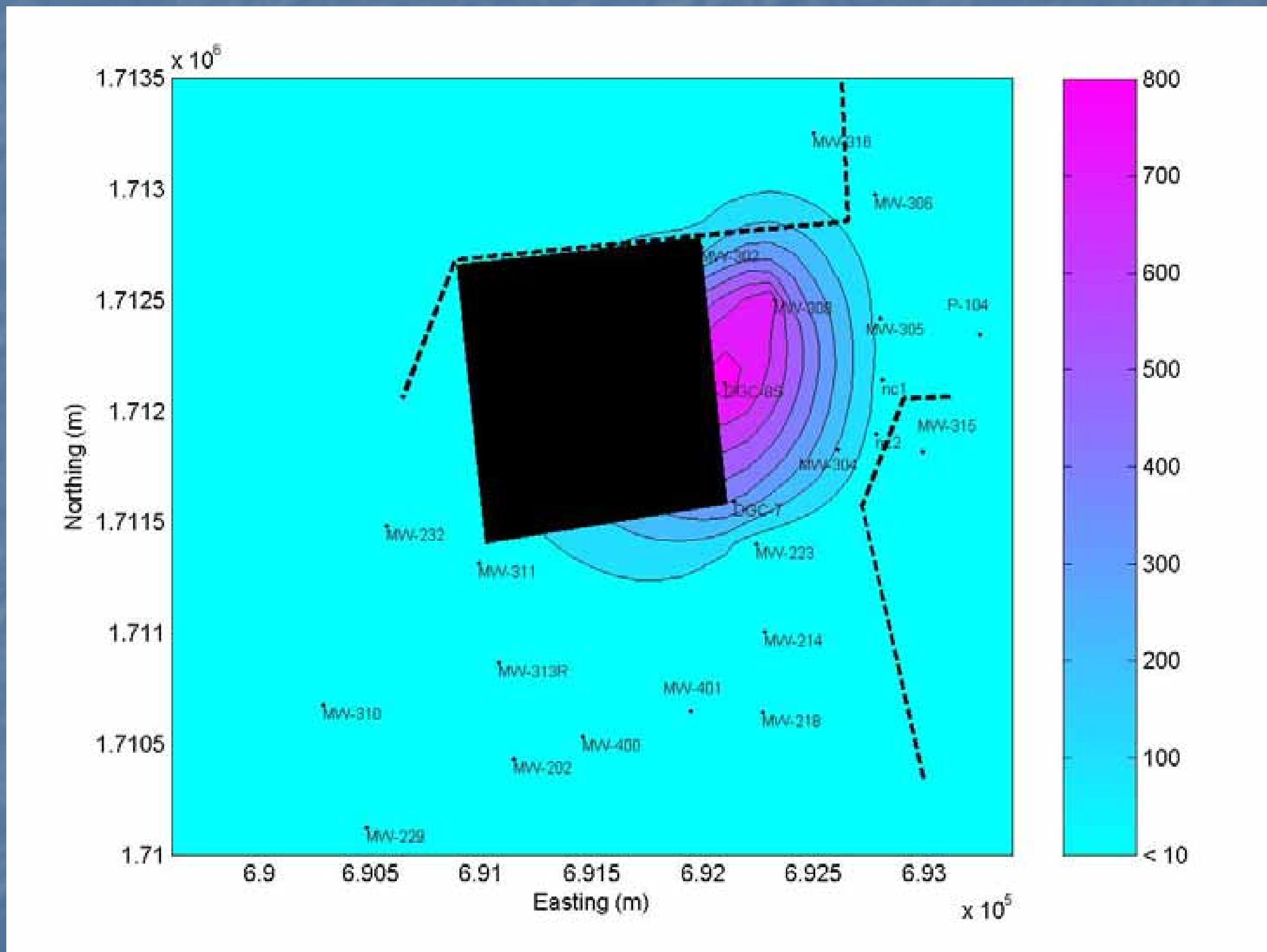
- Solve for test statistic (*z*) and p-value

Mean Chloride Concentration for T1



T1: Pre-Closure

Mean Chloride Concentration for T2



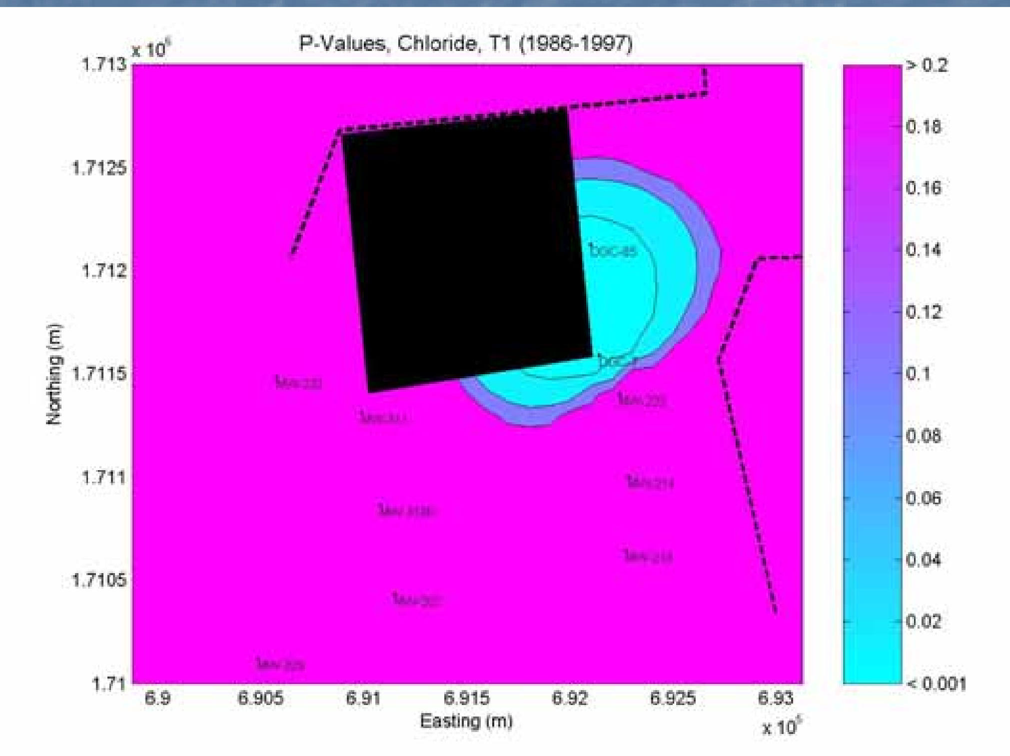
T2: Closure/LTM

Power Analysis Review

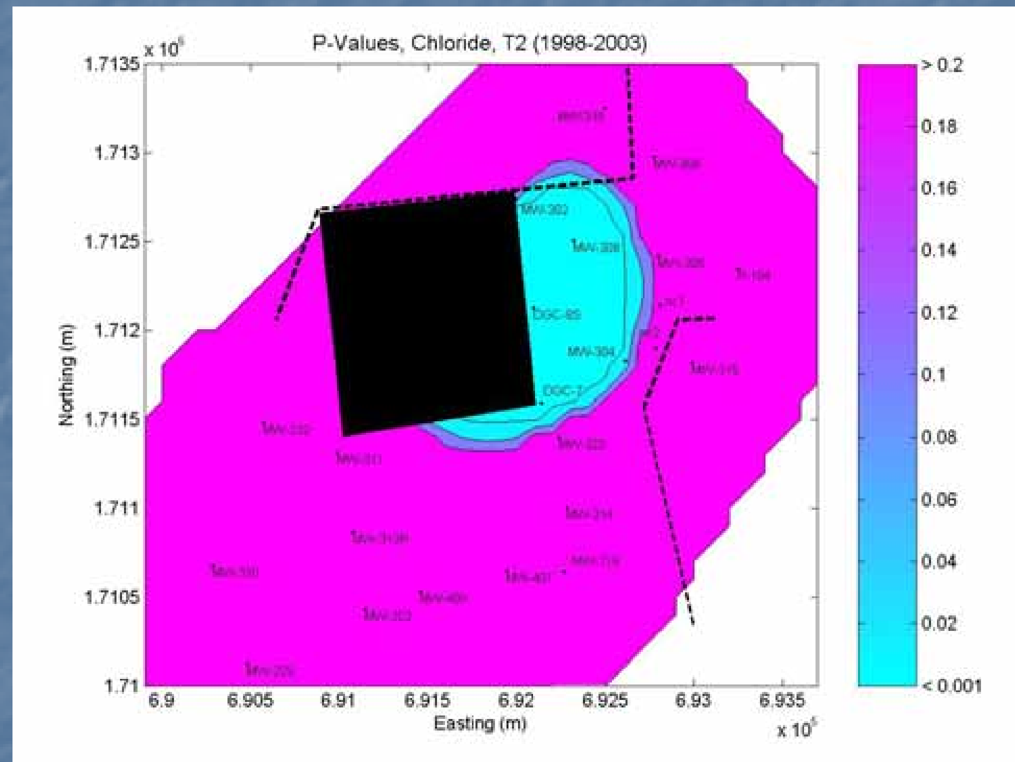
Our Decision	H_o: (μ=100 mg/L) is true	H_A: (μ>100 mg/L) is true
Accept H_o	Correct Decision	Type II Error β
Accept H_A	Type I Error α	Correct Decision

Probability of Type I Error

T1: Pre-Closure



T2: Closure/LTM



P(Type I Error), α typically 0.01

Power calculation

- One sample t-test power calculation (σ unknown)

$$\phi = \sqrt{\frac{n}{2}}\frac{\Delta}{\sigma}$$

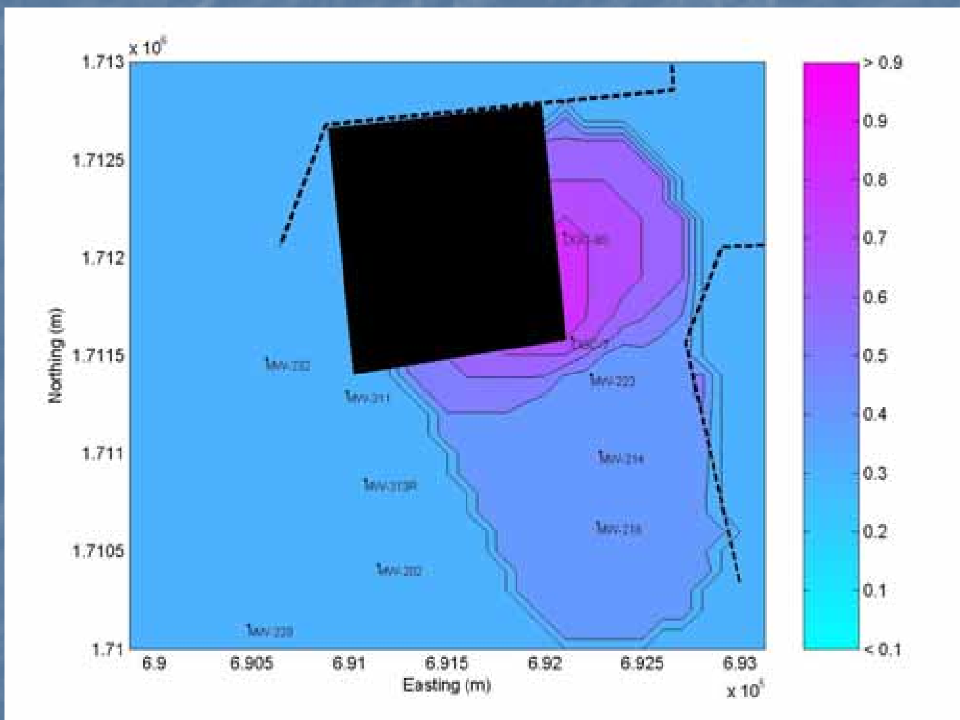
$$\Delta = \mu_1 - \mu_o$$

$$\mu_1 = 200\ mg/L$$
$$\mu_o = 100\ mg/L$$
$$\sigma = 10\ \ mg/L$$

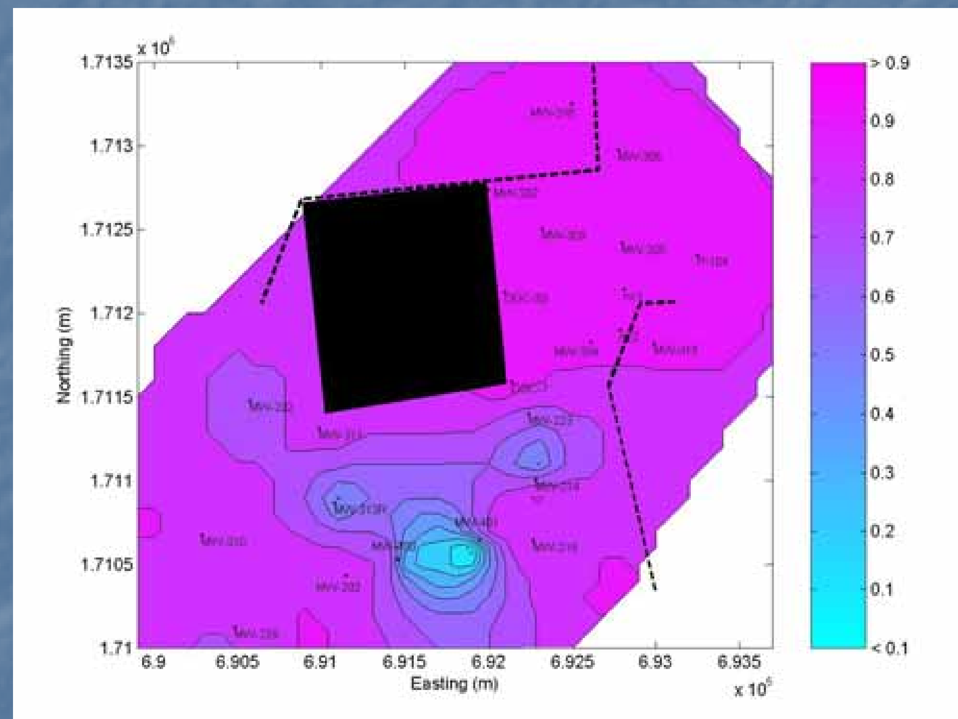
- Solve for ϕ and power

Power Analysis (Δ =100 mg/L)

T1: Pre-Closure



T2: Closure/LTM

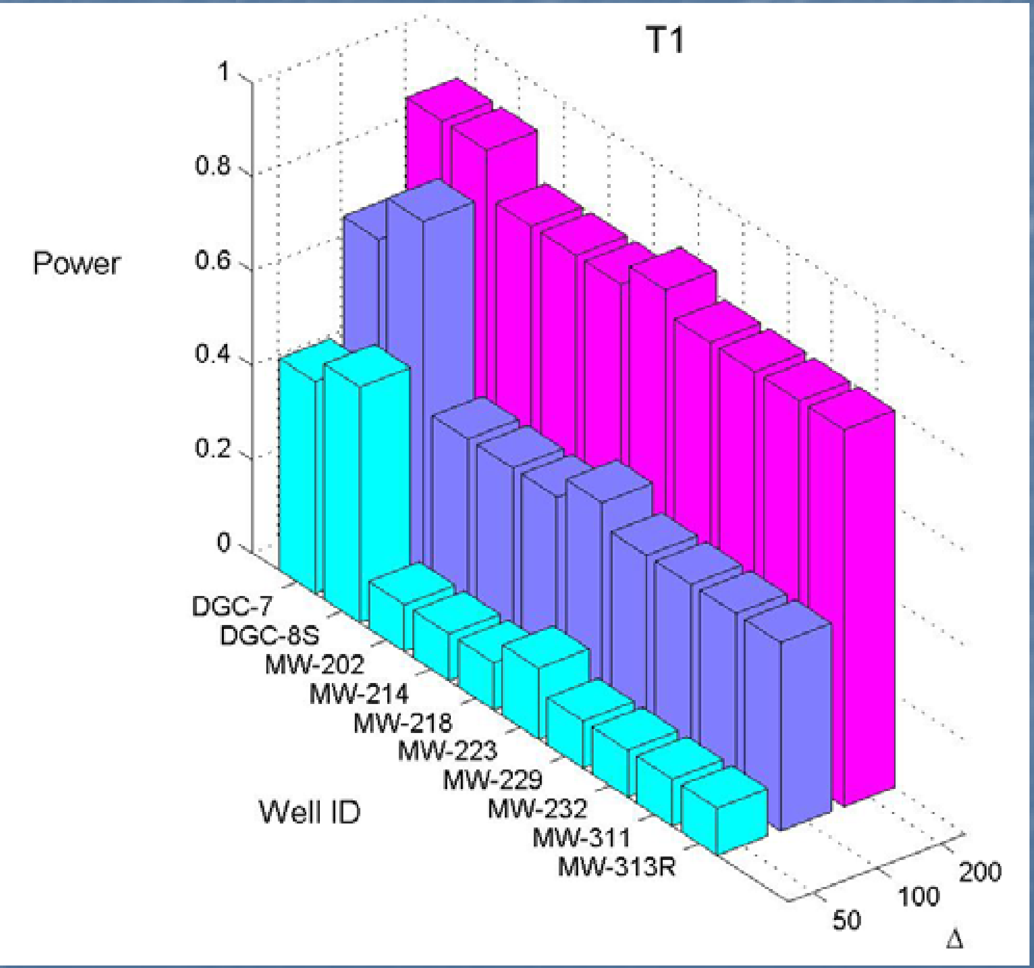


Power = 1-P(Type II Error) typically 0.9, β = 0.1

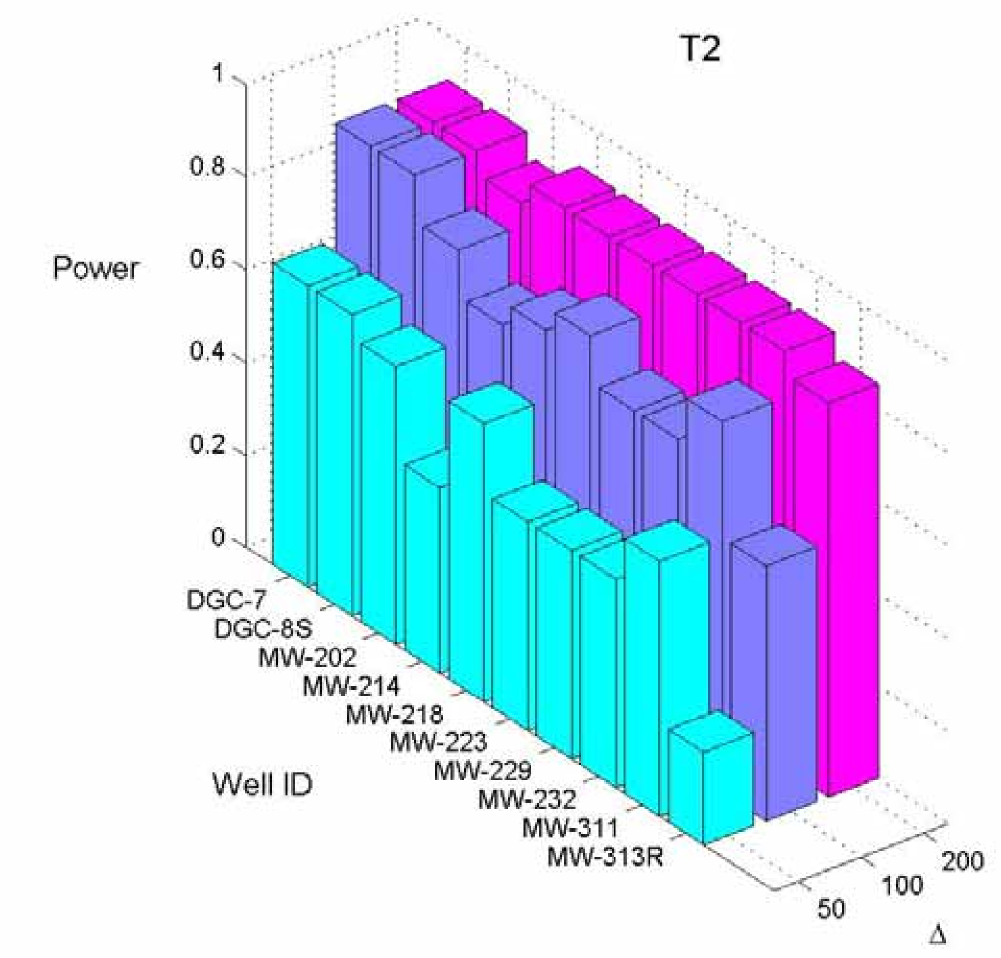
Conclusions

Do a sufficient number of monitoring locations exist?

T1: Pre-Closure



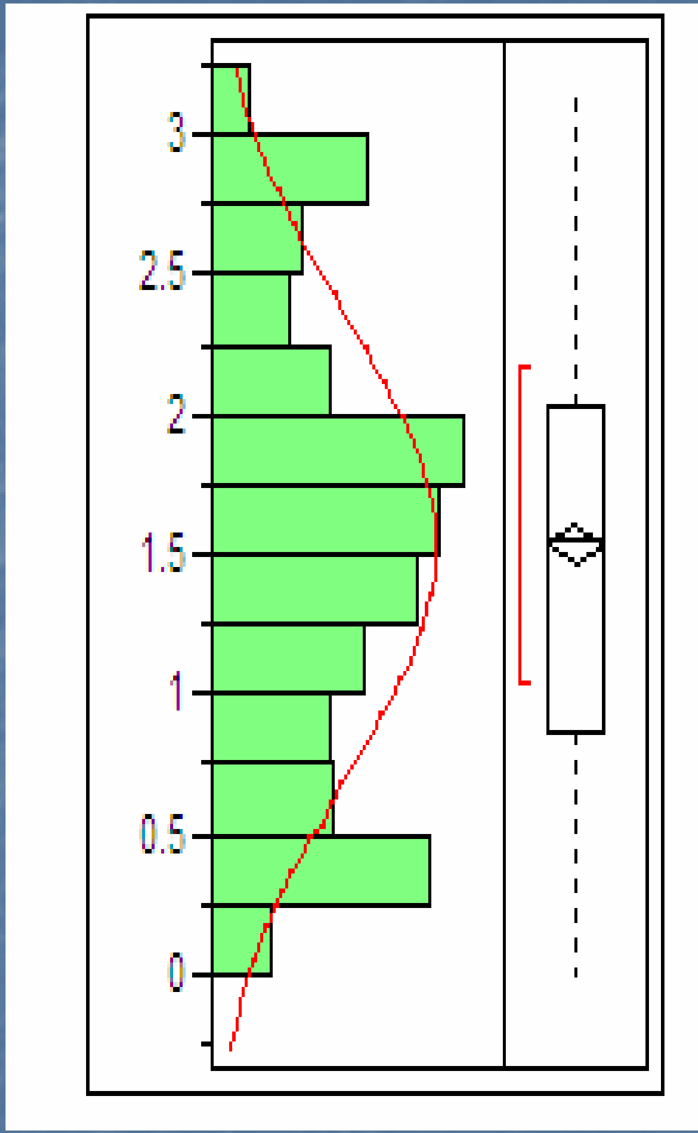
T2: Closure/LTM



Changes in Power with Changes in Δ

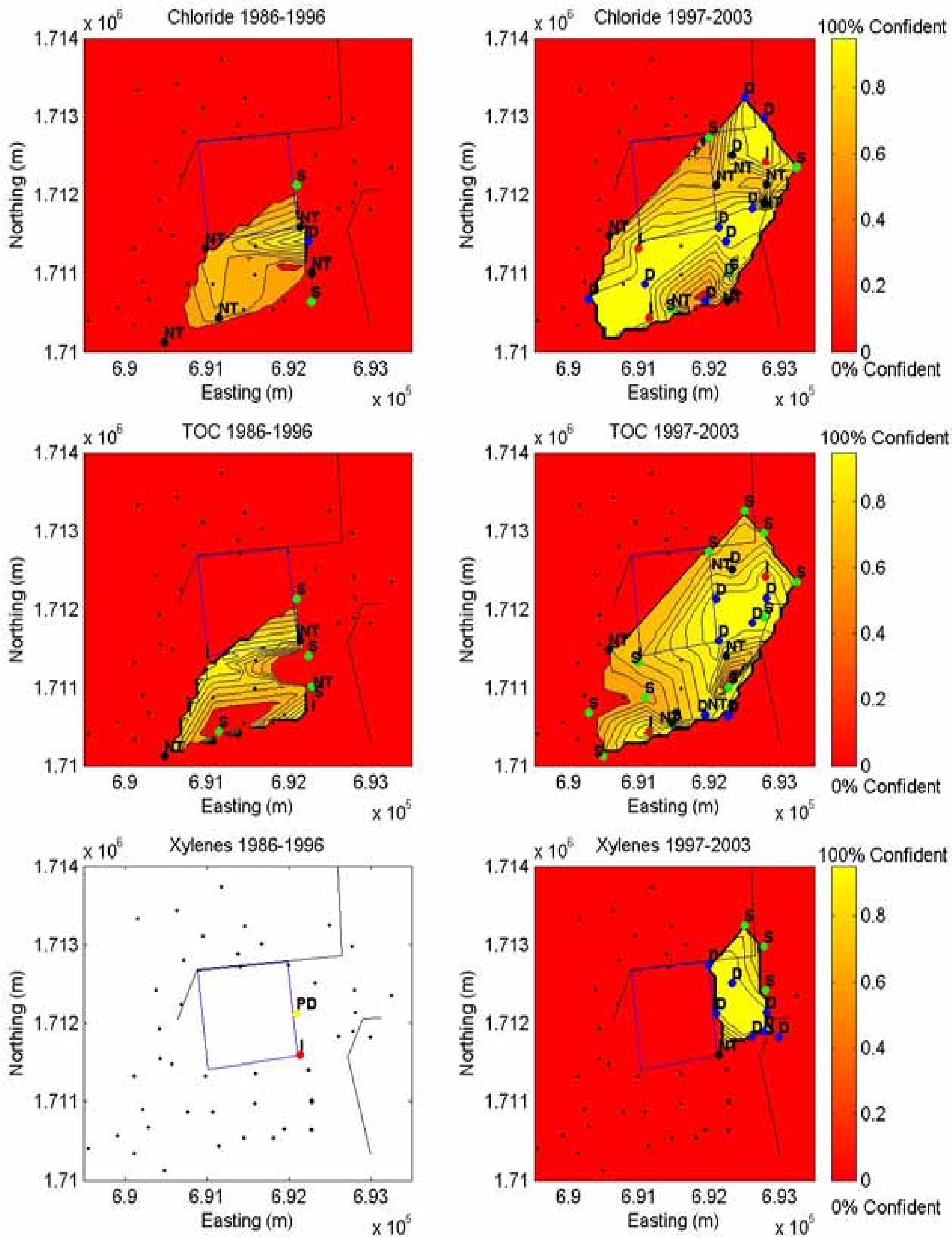
Summary/Future Work

- Chloride vs. Other Parameters (Xylene)
  - Low Power to detect changes of 50 mg/L
  - Extremely low powers to detect changes in μg/L (ppb)
- Multivariate t-tests, can we add power?

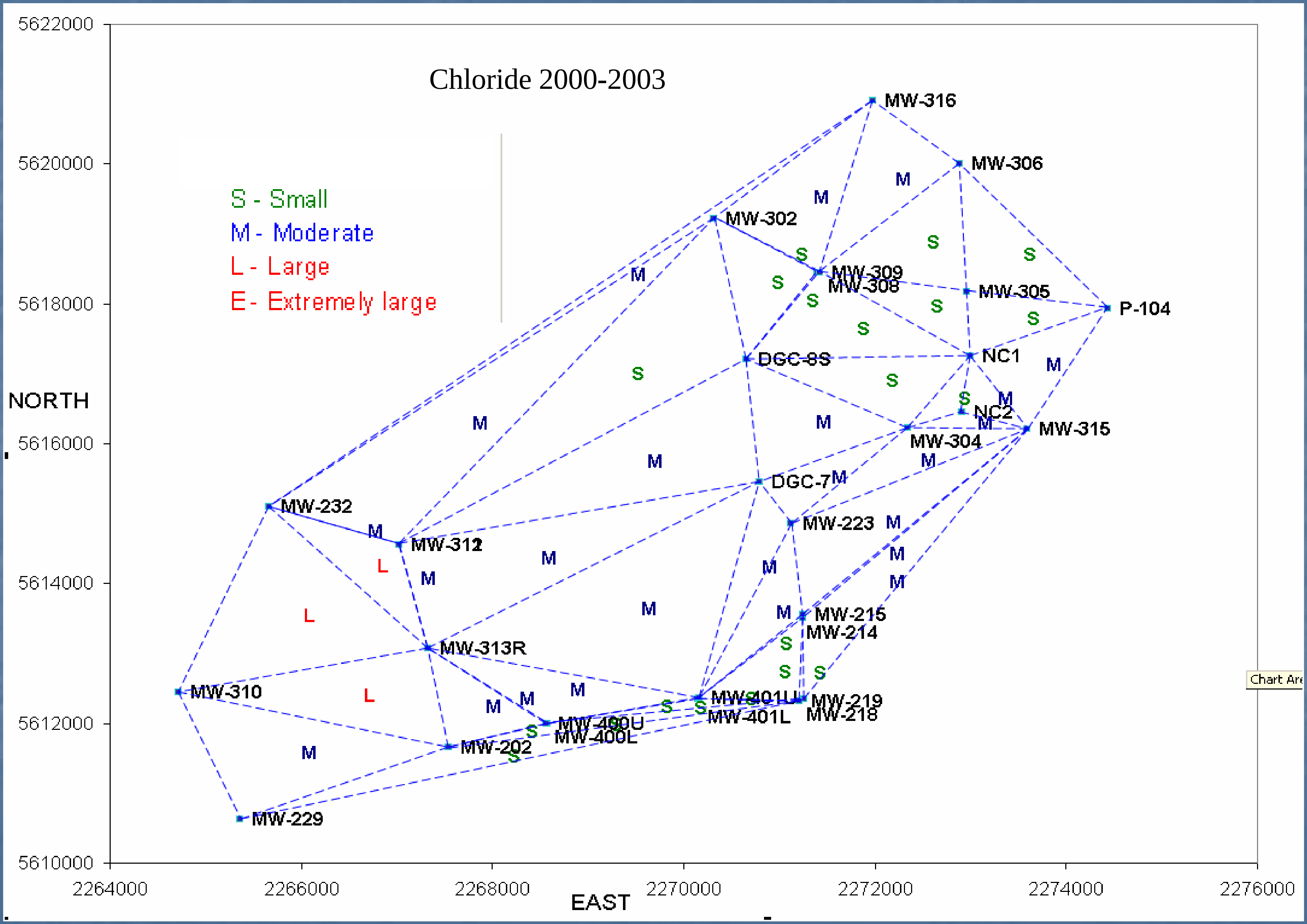


3
2.5
2
1.5
1
0.5
0

Confidence in Hydrochemical Trends

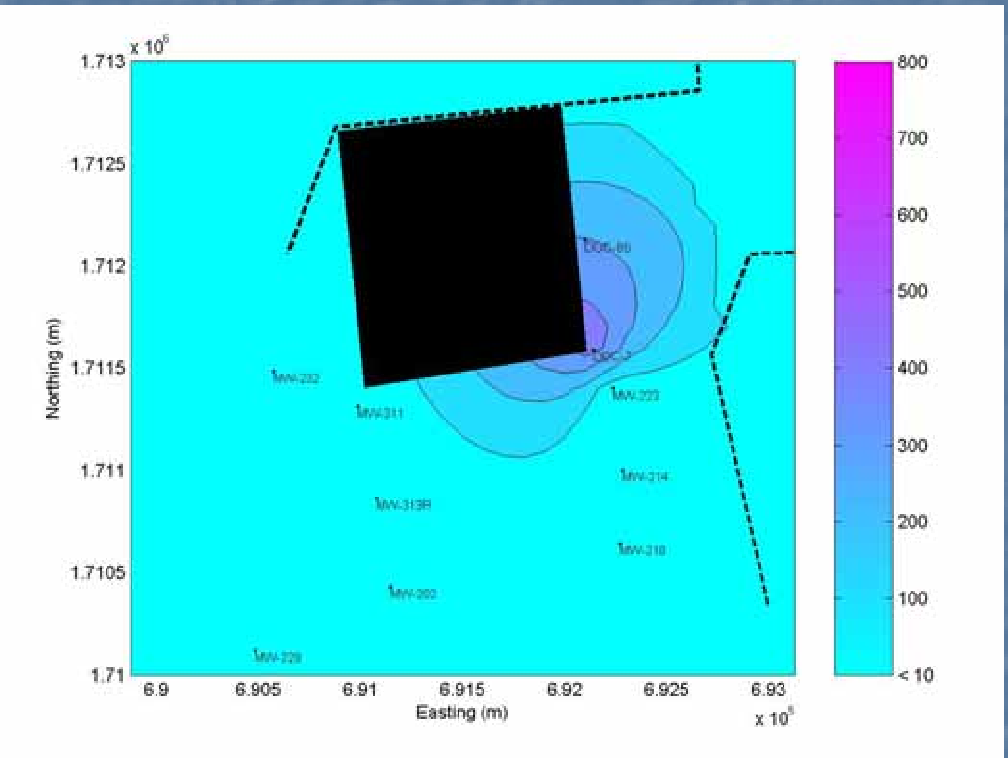


Slope Factors: MAROS



Mean Chloride for two time periods

T1: Pre-Closure



T2: Closure/Remediation