BASEWIDE GROUNDWATER MONITORING PROGRAM OPTIMIZATION AND VISUALIZATION VANDENBERG Air Force Base

Presented by:

Sally Liu

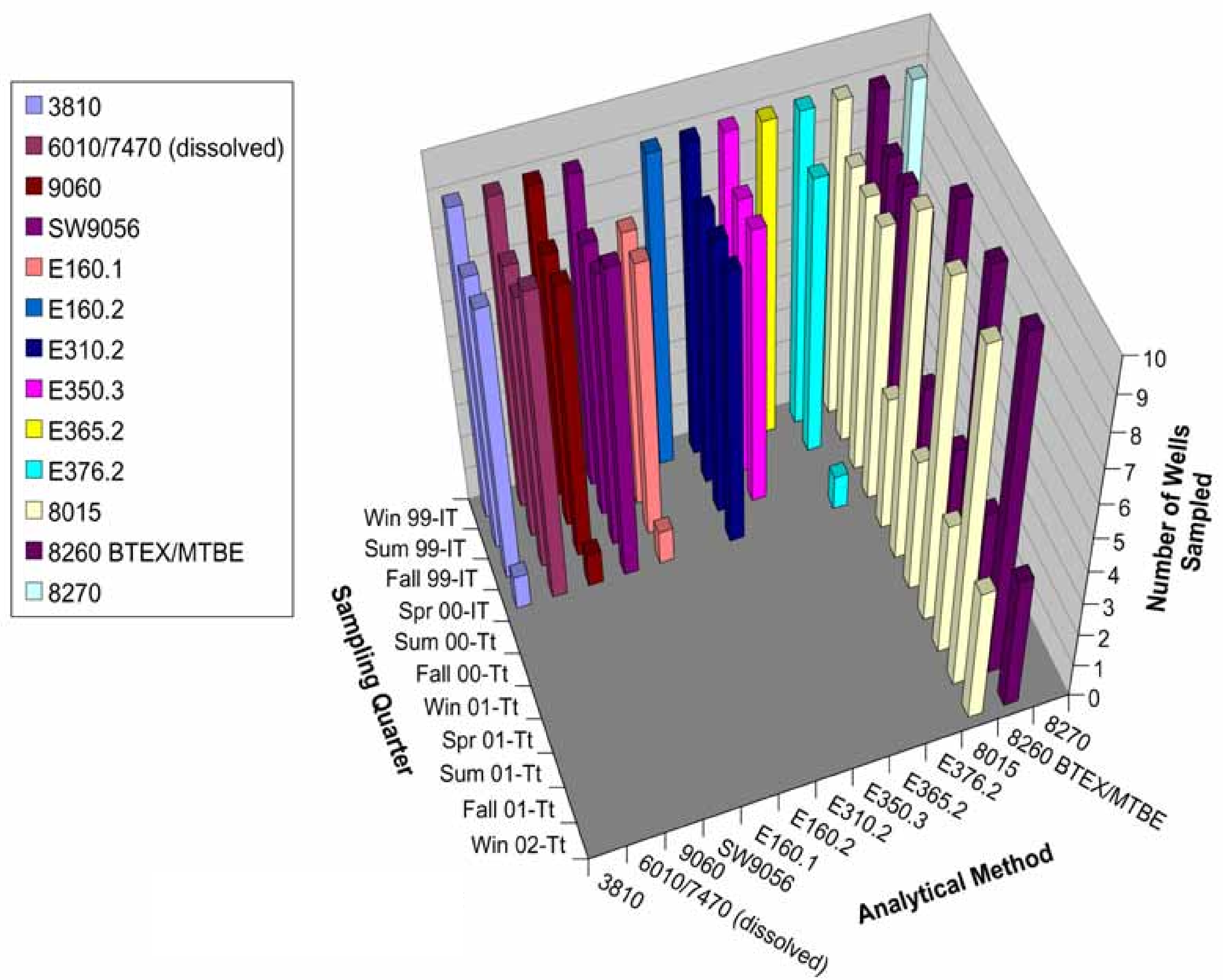
TETRA TECH

15 June 2004

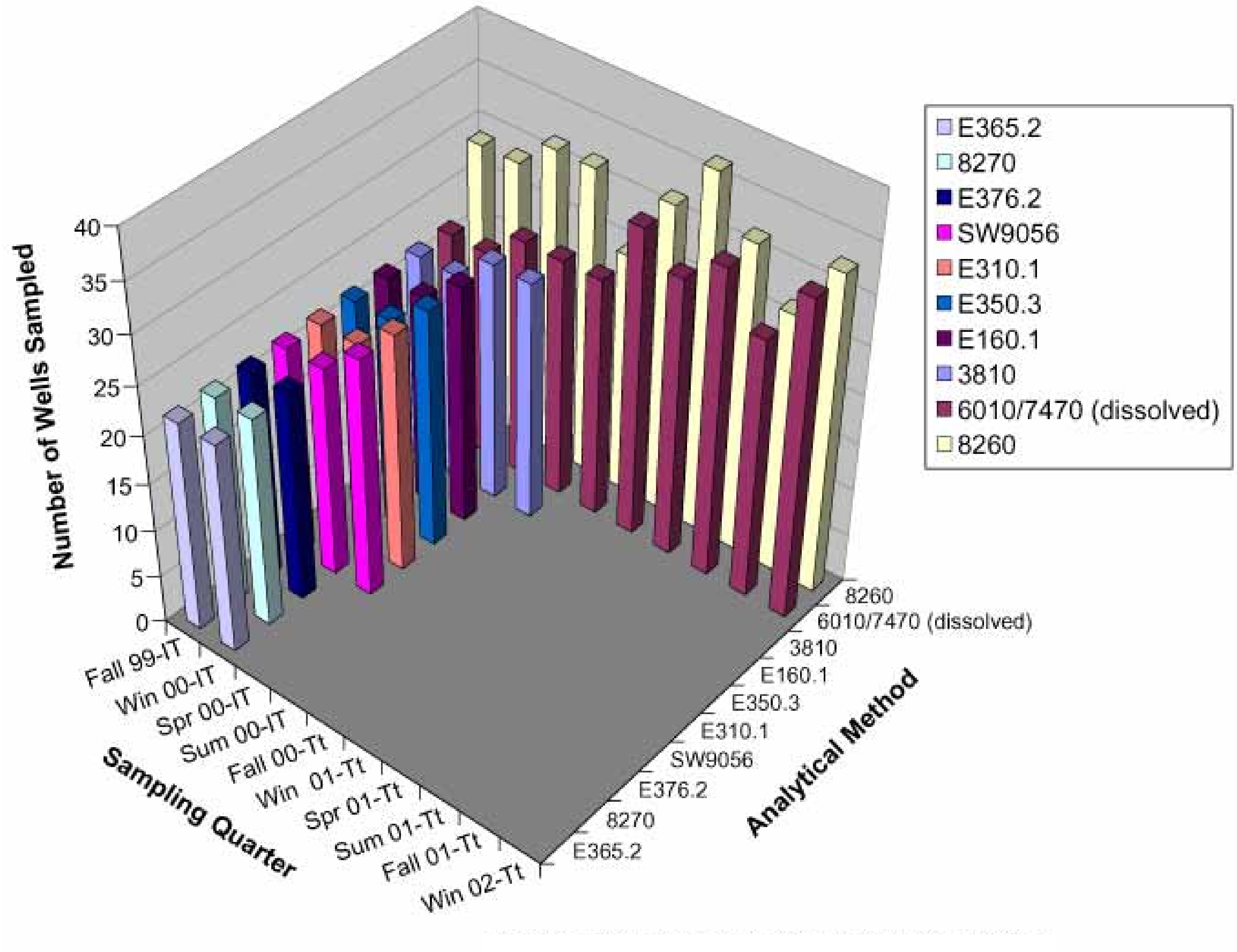
Agenda

- ❑ **Introduction**
- ❑ **Approach to Optimization**
  - Optimization of BGMP LTM using AFCEE protocol
  - Visualization of plume and groundwater conditions
  - Temporal trend analysis of plume movement
  - Geostatistical analysis of plume mass, size, and movement
- ❑ **Site History of BGMP Sampling**
- ❑ **Optimization Analyses for 14 Site or Site Clusters**
  - Sites 1, 2, 3, 8/9/10 Cluster, 13/14/28 Cluster, 19, 20 Area 1, 20 Area 2&3, 25/26/39/40 Cluster, 27, 31, 32/35 Cluster, 33, 60
- ❑ **Closing Remarks/Questions**

VAFB Site 60 Groundwater Monitoring History



VAFB Site 8 Cluster Groundwater Monitoring History



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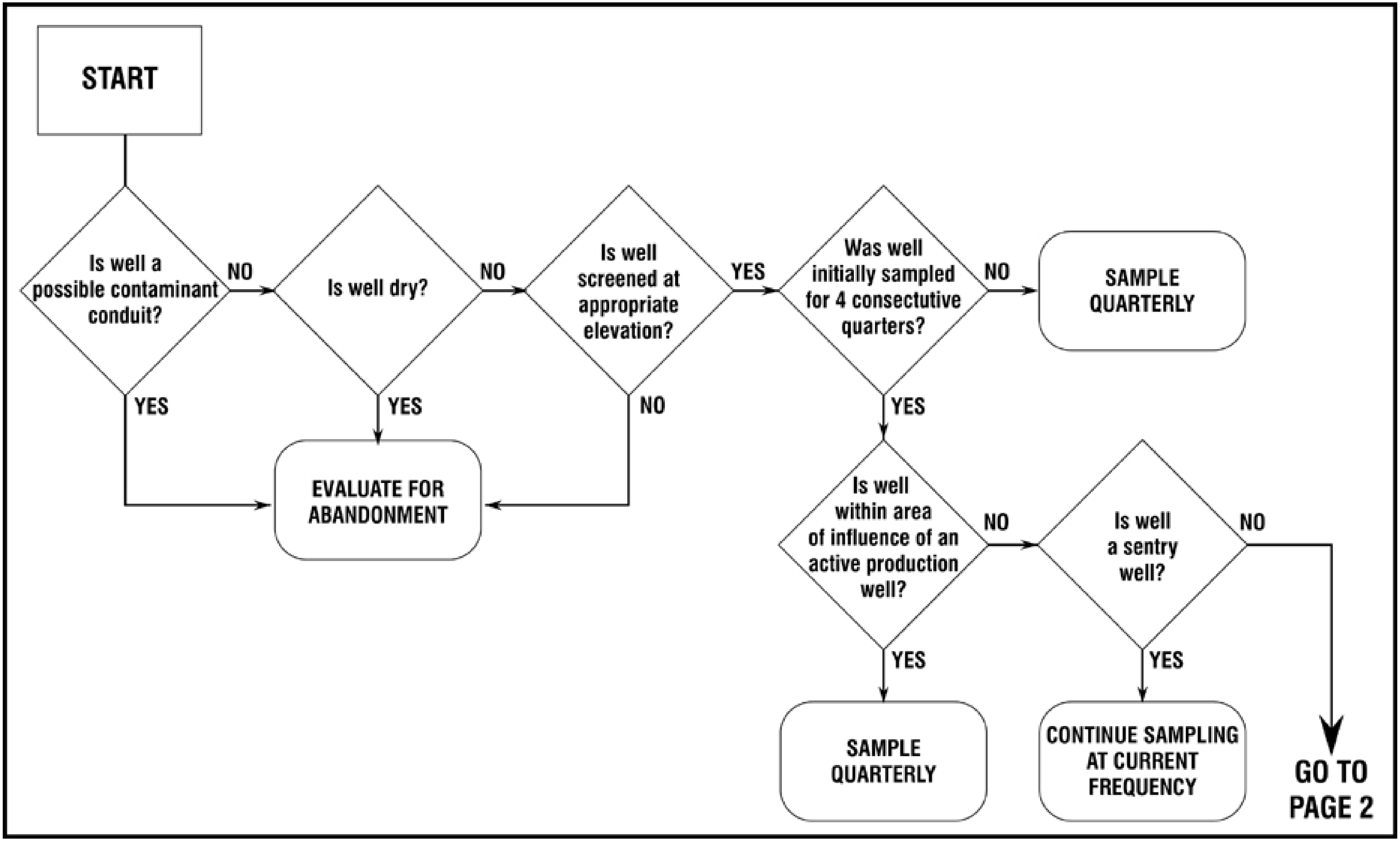
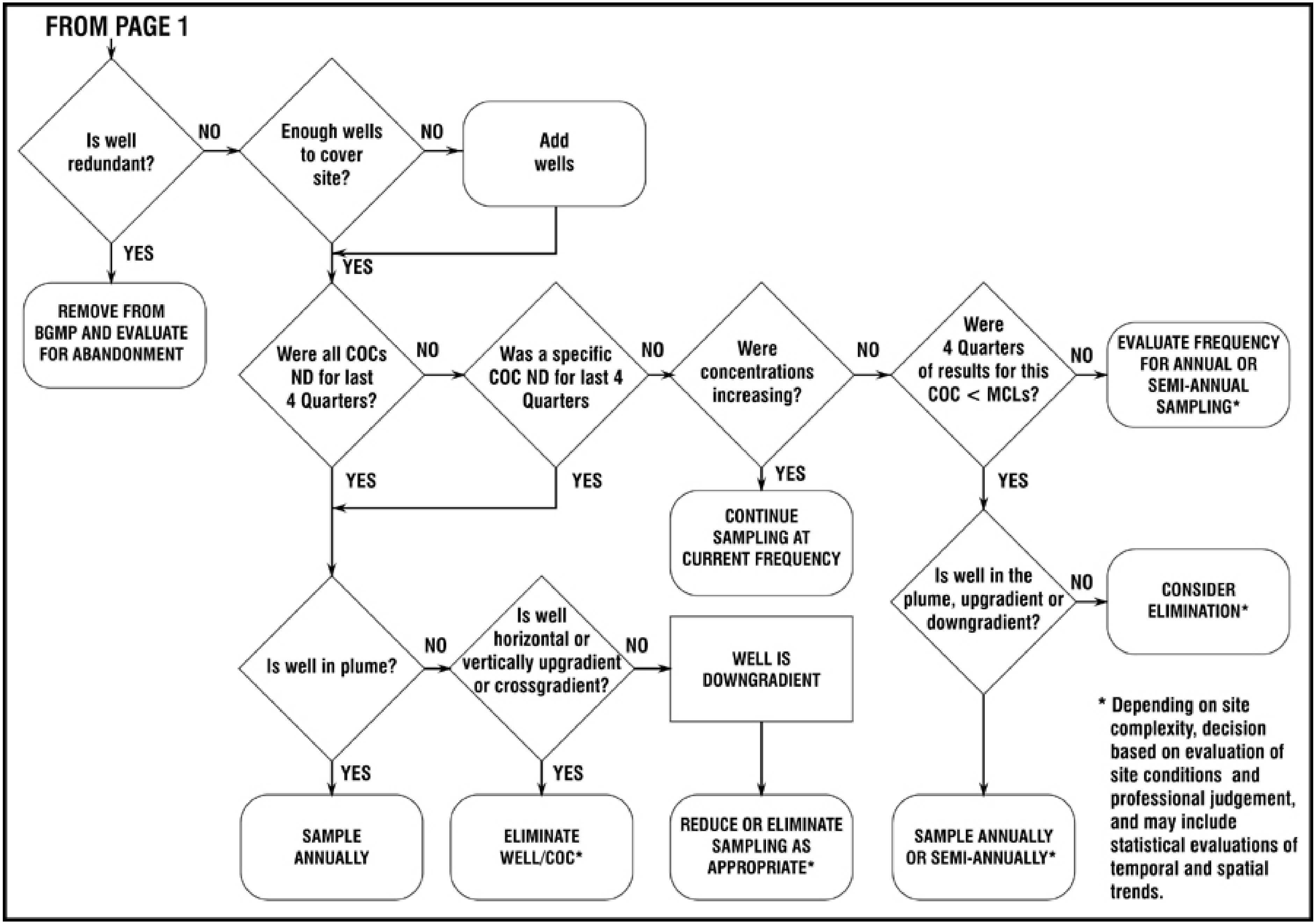
Approach to Optimize VAFB BGMP

- **Follow Guidance**
  - Long-Term Monitoring Optimization Guide (AFCEE, 1997)
  - Monitoring and Remediation Optimization System (MAROS) (AFCEE, 2000)
  - Four main decision rules discussed with AFCEE
- **Document the Existing LTM Program**
  - Present sampling history
  - Present groundwater conditions
  - Document LTM requirements
  - Document existing LTM
- **Decision Rule Process for**
  - Well elimination
  - New well placement
  - Optimal sampling frequency
  - COC/Analyte elimination
  - **Development of VAFB-Specific Optimization Decision Tree**
- **Analytical Support Tools**
  - Visualization: EMAGIS, AVS
  - Time trend analyses: EMAGIS, MAROS
  - Geostatistical analyses: Vertical Mapper

VAFB BGMP Optimization Decision Tree



Optimization Decision Tree *(cont.)*



Groundwater Plume Visualization

❑ Goal

- Provide additional/alternative views of existing LTM program data

❑ Process

- Depict the conceptual site model
(i.e., well locations, groundwater table, bedrock)
- Present COC plumes with 2-D or 3-D views
(e.g., isoconcentration contours, bubble plots, or pie charts)
- Present site groundwater animation

Temporal Trend Analysis

❑ Goal

- Determine if plume location is stable or moving
- Support decisions on sampling frequency
- Support decisions on COC/analyte elimination

❑ Process

- Perform Mann-Kendall test for trend of COCs in each well
- Perform Sen’s slope estimate to determine magnitude of increasing or decreasing trend over time
- Calculate Coefficient of Variation to determine stable trend
- Spatially relate well trends with location within plume
- Apply AFCEE MAROS decision tree for determining sampling frequency

Geostatistical Analysis

❑ Goal

- Determine if plume mass is increasing or decreasing, if plume location is stable or moving, and if plume size is expanding or shrinking
- Support decisions on sampling frequency
- Support decisions on well redundancy, new well addition

❑ Process

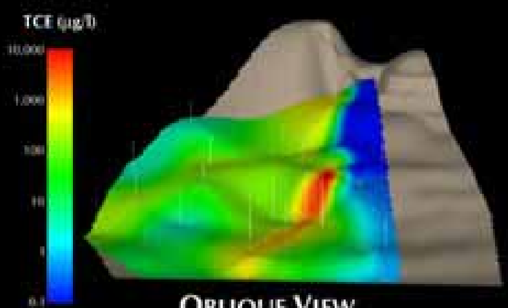
- Use kriging to estimate spatial uncertainty (variance)
  - Areas of low uncertainty may indicate well redundancy
  - Areas of high uncertainty may indicate need for new wells
- Depict plume spatial trends with contour plots, bubble, or pie charts
- Estimate plume mass over time
- Identify center of plume mass (location) and size (variance) of plume

Site 8 Cluster Optimization Analysis

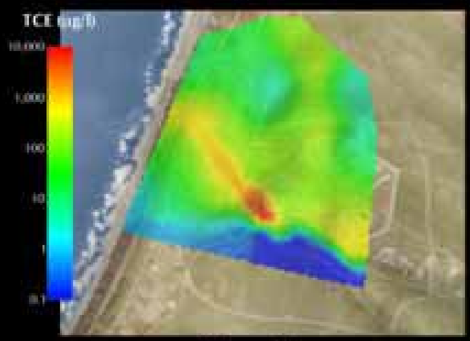
- **Key COCs**
  - TCE, 1,1-DCE, cis-1,2-DCE, trans-1,2-DCE
- **Visualization of COC plume**
  - 3-D visualization of conceptual site model and TCE plume
  - Chlorinated solvents pie chart
- **Time Trend Analysis**
  - Mann-Kendall/Sen's Slope/Covariance
  - MAROS decision tree to determine sampling frequency
- **Geostatistical Analysis**
  - Estimate spatial uncertainty (variance)
  - Determine sampling frequency
  - Estimate plume mass over time
  - Identify center of plume mass (location) and size (variance) of plume
  - Eliminate redundant wells/Identify new well locations

Vandenberg Air Force Base
Installation Restoration Program Site 8 Cluster
Space Launch Complex (SLC) 4 East, SLC 4 West, Spring Canyon Pond

BGMP Fall 2001 TCE Distribution in Groundwater



Oblique View

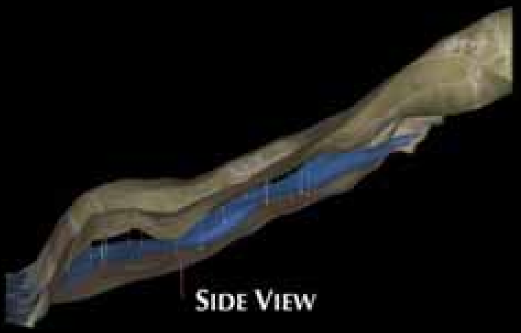


Plan View

Aerial Photograph

Overlaying a Digital Elevation Model
(with 5x vertical exaggeration)

BGMP Fall 2001 Groundwater Surface and Bedrock Surface with Existing Well Network



Side View

Oblique View

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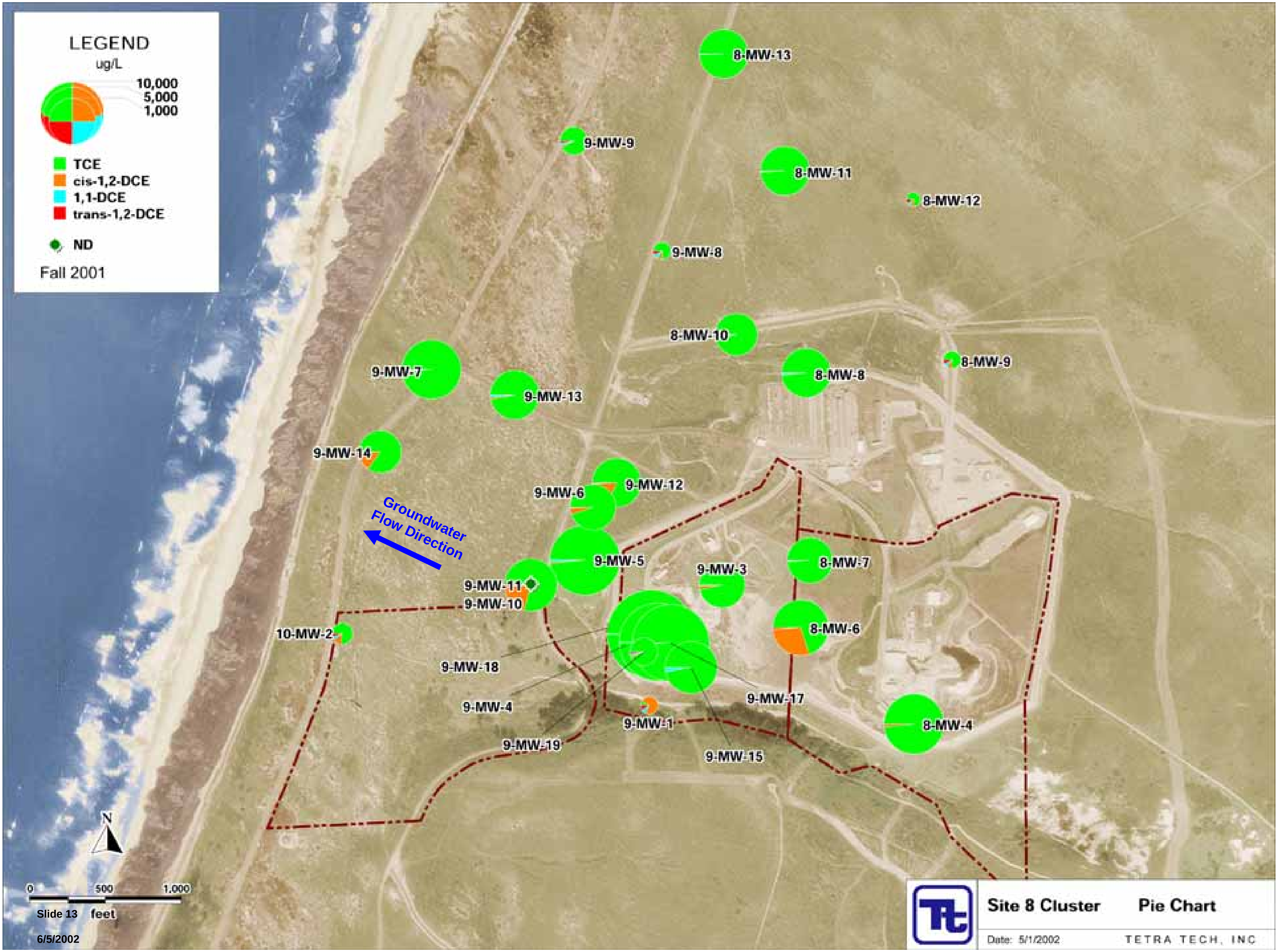
LEGEND
ug/L
10,000
5,000
1,000
TCE
cis-1,2-DCE
1,1-DCE
trans-1,2-DCE
ND
Fall 2001
8-MW-13
9-MW-9
8-MW-11
8-MW-12
9-MW-8
8-MW-10
8-MW-9
9-MW-7
8-MW-8
9-MW-13
9-MW-14
9-MW-12
9-MW-6
Groundwater Flow Direction
9-MW-5
9-MW-3
8-MW-7
9-MW-11
9-MW-10
10-MW-2
8-MW-6
9-MW-18
9-MW-17
9-MW-4
9-MW-1
8-MW-4
9-MW-19
9-MW-15
N
0
500
1,000
feet
Site 8 Cluster
Pie Chart
Date: 5/1/2002
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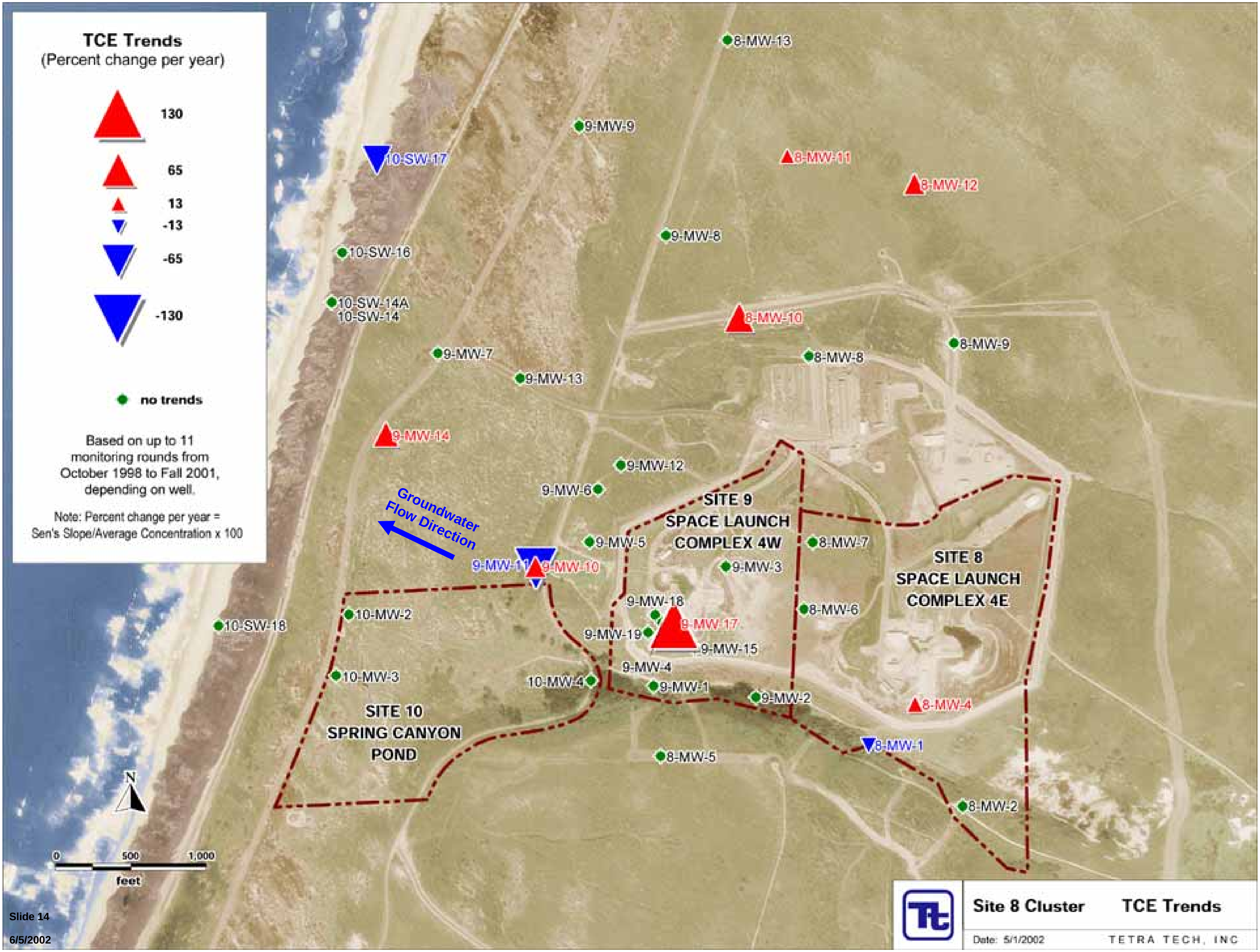
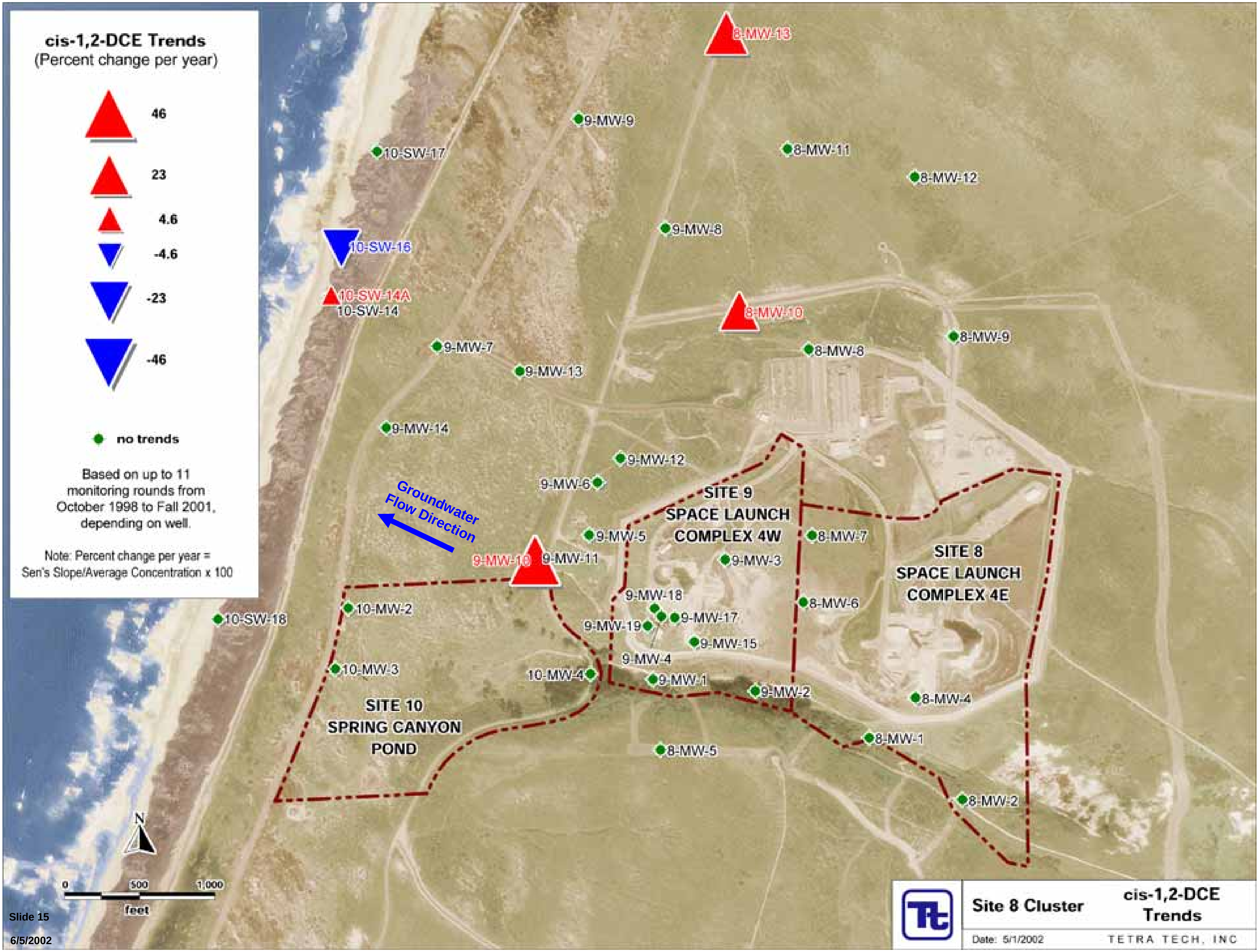


Site 8 Cluster TCE Trends

Date: 5/1/2002 TETRA TECH, INC

Slide 14

6/5/2002


cis-1,2-DCE Trends
(Percent change per year)
46
23
4.6
-4.6
-23
-46
no trends
Based on up to 11 monitoring rounds from October 1998 to Fall 2001, depending on well.
Note: Percent change per year = Sen's Slope/Average Concentration x 100
8-MW-13
9-MW-9
10-SW-17
8-MW-11
8-MW-12
9-MW-8
10-SW-16
10-SW-14A
10-SW-14
8-MW-10
8-MW-9
9-MW-7
8-MW-8
9-MW-13
9-MW-14
9-MW-12
9-MW-6
SITE 9
SPACE LAUNCH
COMPLEX 4W
Groundwater
Flow Direction
9-MW-5
8-MW-7
9-MW-16
9-MW-11
9-MW-3
SITE 8
SPACE LAUNCH
COMPLEX 4E
9-MW-18
10-MW-2
8-MW-6
10-SW-18
9-MW-17
9-MW-19
9-MW-15
9-MW-4
10-MW-3
10-MW-4
9-MW-1
9-MW-2
8-MW-4
SITE 10
SPRING CANYON
POND
8-MW-1
8-MW-5
8-MW-2
N
0
500
1,000
feet
Site 8 Cluster
cis-1,2-DCE Trends
Date: 5/1/2002
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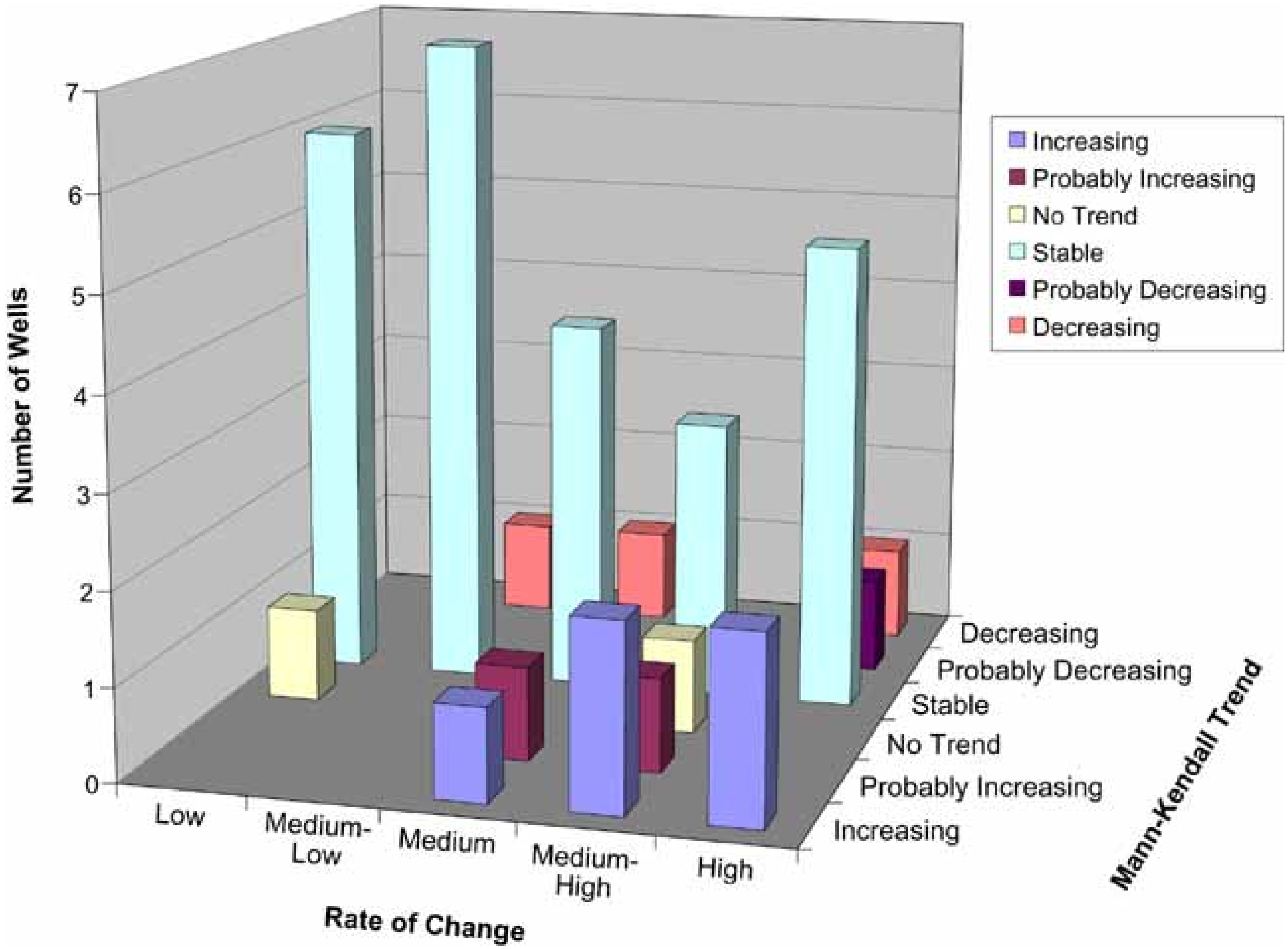
VAFB Site 8 Cluster
Decision Matrix for Sampling Frequency Based on Time Trend Analysis



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VAFB Site 8 Cluster
Decision Matrix for Determining Sampling Frequency
Results Based Upon Time Trend Analysis Only

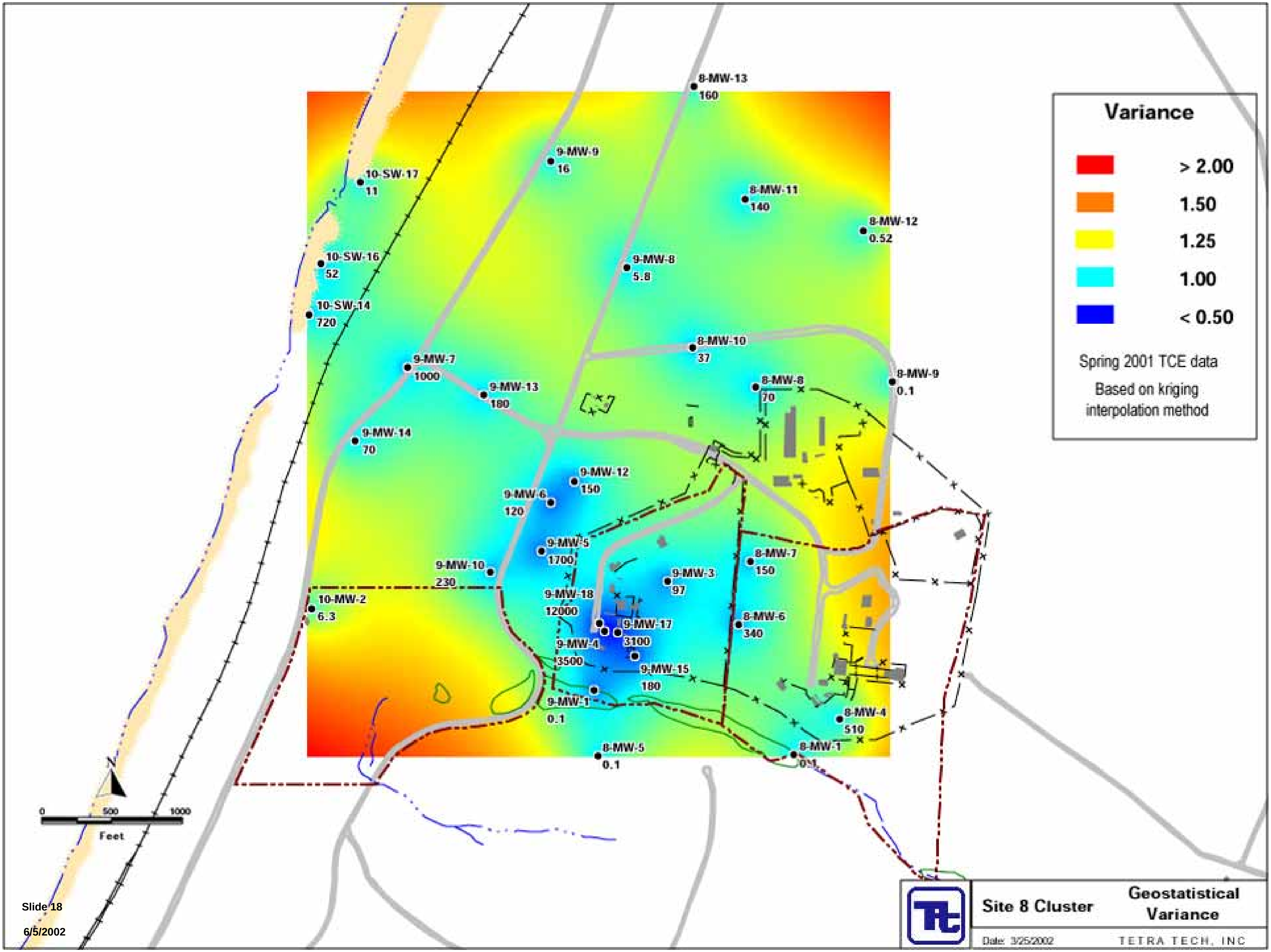
RATE OF CHANGE

MANN KENDALL TREND	High	Medium-High	Medium	Medium-Low	Low
Increasing	2	2	1		
Probably Increasing		1	1		
No Trend		1			1
Stable	5	3	4	7	6
Probably Decreasing	1				
Decreasing	1		1	1	

Based upon AFCEE Monitoring and Remediation Optimization System (MAROS) Guidance, 10/16/2000.

Sampling Frequency:

- Quarterly (12)
- Semi-annual (6)
- Annual (20)


Variance
> 2.00
1.50
1.25
1.00
< 0.50
Spring 2001 TCE data
Based on kriging interpolation method
8-MW-13 160
9-MW-9 16
10-SW-17 11
8-MW-11 140
8-MW-12 0.52
10-SW-16 52
9-MW-8 5.8
10-SW-14 720
8-MW-10 37
9-MW-7 1000
9-MW-13 180
8-MW-8 70
8-MW-9 0.1
9-MW-14 70
9-MW-12 150
9-MW-6 120
9-MW-5 1700
8-MW-7 150
9-MW-10 230
9-MW-3 97
9-MW-18 12000
10-MW-2 6.3
8-MW-6 340
9-MW-17 3100
9-MW-4 3500
9-MW-15 180
9-MW-1 0.1
8-MW-4 510
8-MW-5 0.1
8-MW-1 0.1
N
0 500 1000
Feet
Site 8 Cluster
Geostatistical Variance
Date: 3/25/2002
TETRA TECH, INC

Kriging Method of Interpolation

Kriging

- Kriging is a weighted-moving-average interpolation method where the set of weights assigned to samples minimizes the estimation variance, which is computed as a function of the variogram model, the locations of the samples relative to each other, and to the point being estimated.

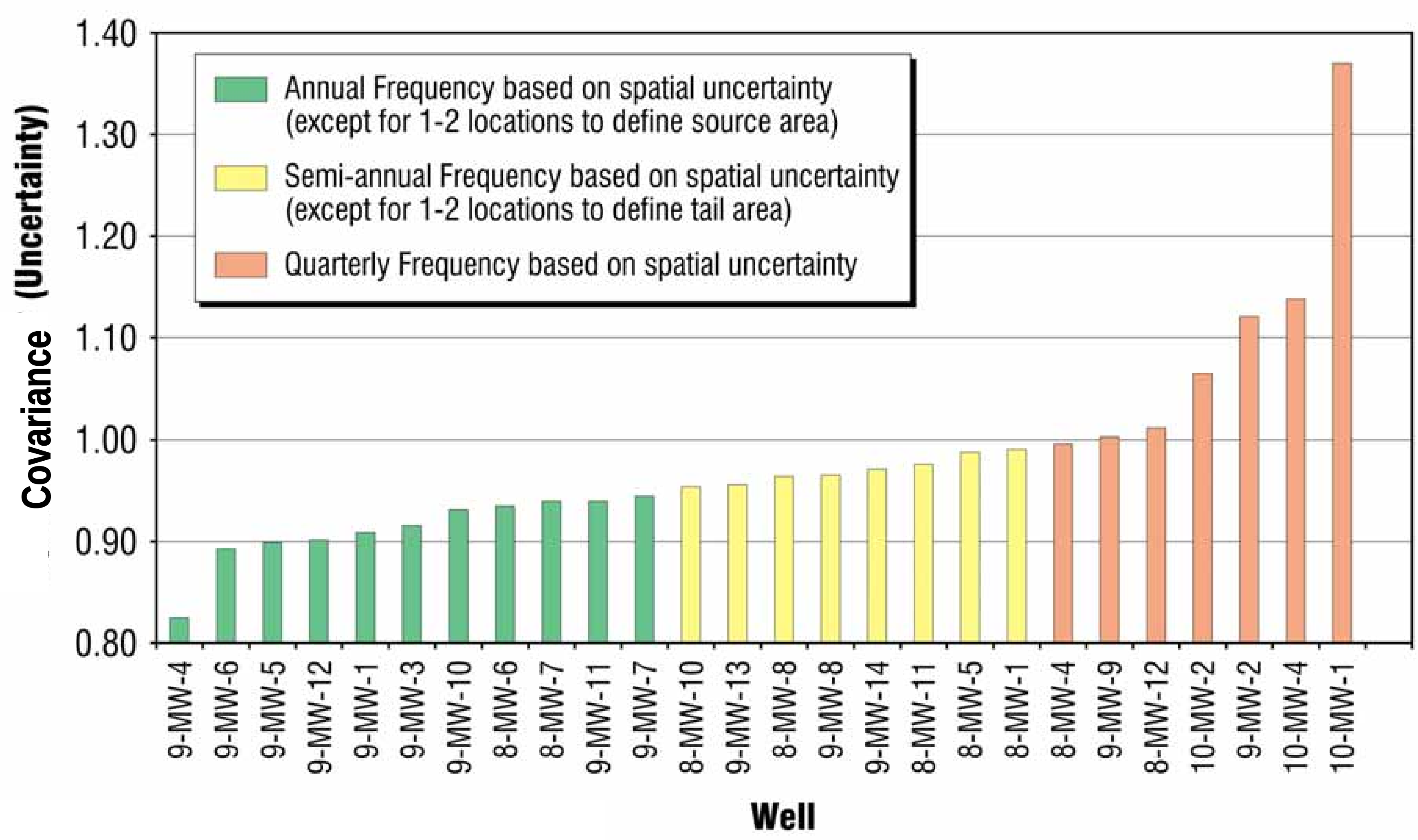
Data Analysis

- Data were log transformed
- Data fit to an exponential variogram model using a nugget of 0.3 and a sill of 2.4 (both log10 concentration), and a range of 1872 (feet)

Key Assumptions

- Data are log-normal distributed
- Local means are not necessarily closely related to the population mean
- Exponential variogram is an appropriate data model

VAFB Site 8 Cluster
Estimated Uncertainty at Each Well Location



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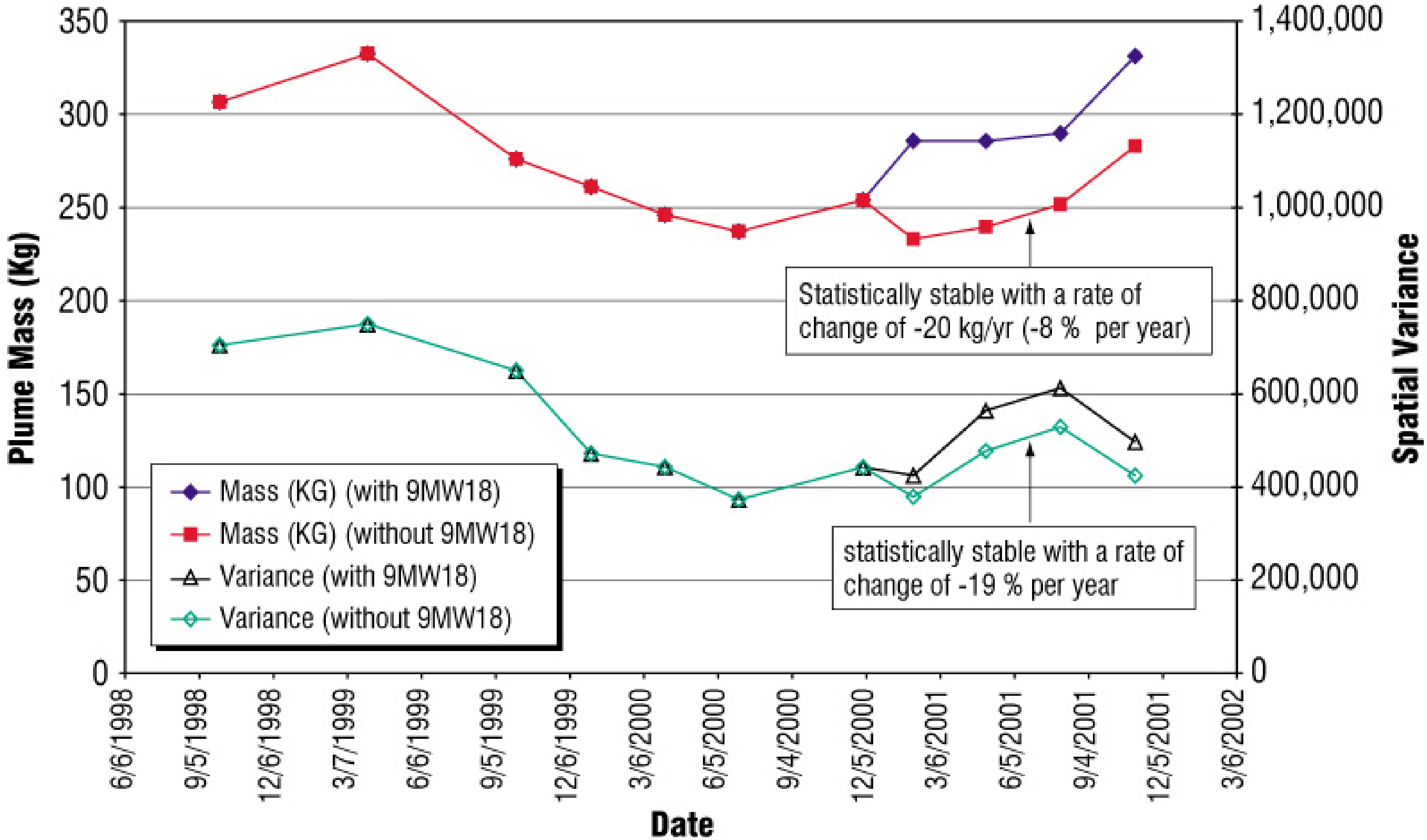
VAFB Site 8 Cluster Plume Mass and Spatial Variance (plume spread)



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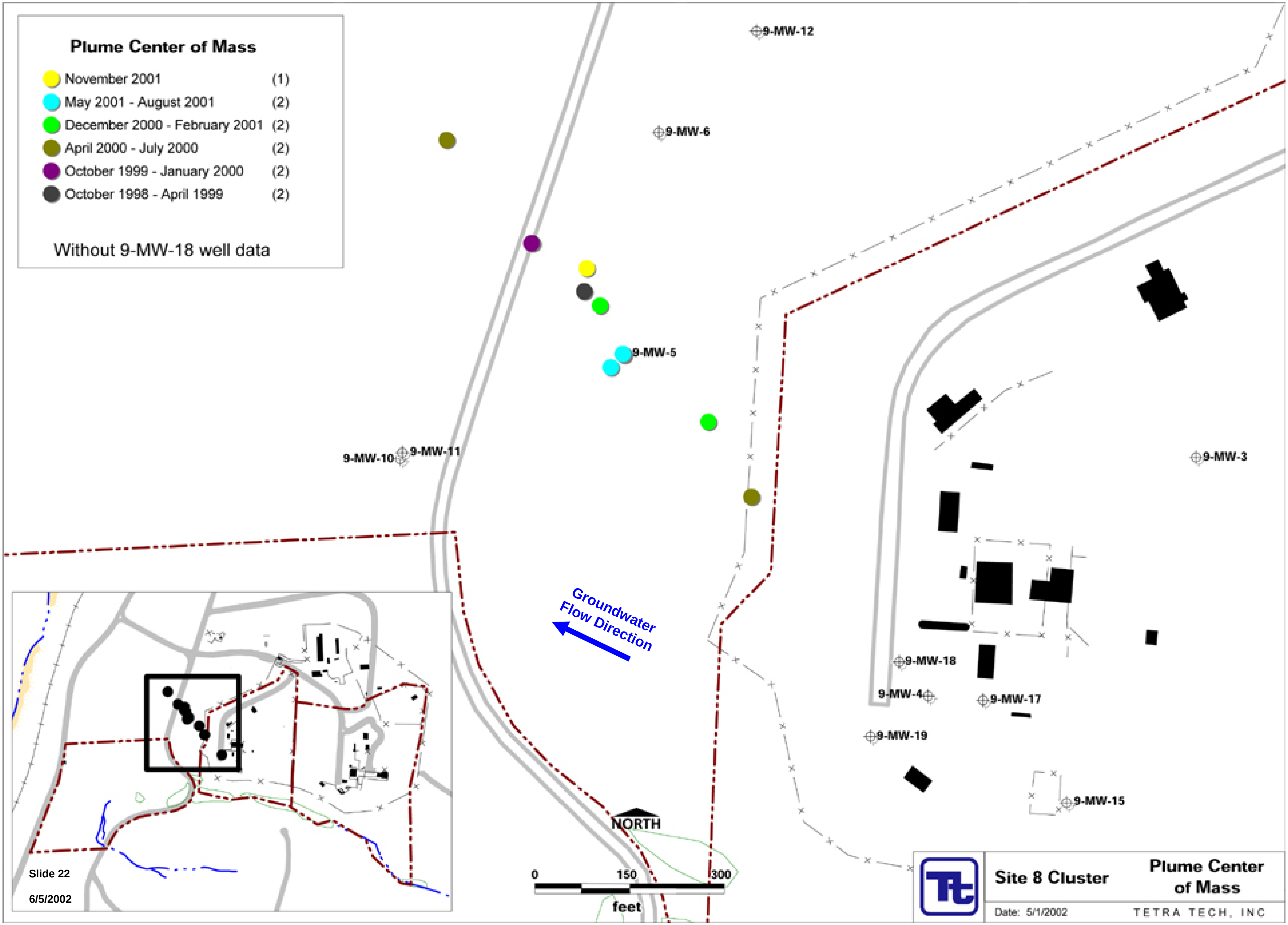

Plume Center of Mass
November 2001 (1)
May 2001 - August 2001 (2)
December 2000 - February 2001 (2)
April 2000 - July 2000 (2)
October 1999 - January 2000 (2)
October 1998 - April 1999 (2)
Without 9-MW-18 well data
9-MW-12
9-MW-6
9-MW-5
9-MW-10
9-MW-11
9-MW-3
9-MW-18
9-MW-4
9-MW-17
9-MW-19
9-MW-15
Groundwater
Flow Direction
NORTH
0
150
300
feet
Slide 22
6/5/2002
Site 8 Cluster
Plume Center
of Mass
Date: 5/1/2002
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Recommended Monitoring Well Sampling Frequency for VAFB Site 8 Cluster

Well	Type	Temporal Trends	Spatial Trends	Other Factors (e.g., MCLs, sentry wells)	Recommended Frequency	Winter 2002 Frequency	Comments
9-MW-4	So	A	A	E	Eliminate	Q	Do not need all Site 9 So wells
8-MW-1	CG	A	S	A	A	A	Clean CG well; cis hit in Fall01
8-MW-2	UG/B	S	A	A	A	A	
8-MW-5	CG/B	A	S	A	A	A	
8-MW-6	DG	A	A		A	Q	
8-MW-7	DG	A	A		A	Q	
8-MW-8	DG	A	S		A	Q	
9-MW-1	CG	S	A		A	Q	
9-MW-2	CG/B	A	Q	A	A	A	Nearly clean CG/BG well
9-MW-3	DG	A	A		A	Q	
9-MW-5	DG	A	A		A*	Q	
9-MW-6	DG	A	A		A*	Q	
9-MW-7	DG	A	A		A*	Q	
9-MW-11	DG	Q	A		A	Q	Bedrock well; sporadic hits
9-MW-12	DG	A	A		A*	Q	
9-MW-13	DG	A	S		A*	Q	
9-MW-15	DG	A	A		A*	Q	
9-MW-18	So	A	A	E	A	Q	Use as Site 9 So well #1
10-MW-3	CG	Q	A	A	A	A	Nearly clean CG, slight TCE hits
10-MW-4	CG	Q	Q		A	A	
10-SW-14	DG	S	A		A	A	
10SW14A	DG/S	Q	Q		A	A	
10-SW-16	DG/S	S	Q		A	A	
10-SW-17	DG/S	Q	Q		A	A	
10-SW-18	CG	A	Q	A	A	A	Nearly clean DG/CG well
8-MW-9	UG/B	Q	A	S	S	Q	Nearly clean UG background well
8-MW-10	DG	Q	S		S	Q	
8-MW-11	DG	S	S		S	Q	
9-MW-8	DG	Q	S	S	S	Q	Not a sentry well
8-MW-4	So	S	Q	Q	Q	Q	Only Site 8 source well
8-MW-12	UG/CG	Q	Q		Q	Q	
8-MW-13	DG/G	A	Q	Q	Q	Q	sentry well w/constant, high TCE; Need DG well
9-MW-9	DG/G	A	Q	Q	Q	Q	sentry well w/constant TCE; Need DG well
9-MW-10	DG	Q	A		Q	Q	
9-MW-14	DG/G	Q	S	Q	Q	Q	sentry well
9-MW-17	So	Q	A	E	Q	Q	Use as Site 9 So well #2
9-MW-19	So	Q	Q		Q	Q	Demark vertical extent of source
10-MW-2	DG/S	A	Q	Q	Q	Q	sentry well

Notes:
Well Classification: UG=upgradient DG=downgradient CG=crossgradient B=background S=sentry SO=source E=potential extraction well
A=annual (24 of 38) S= semiannual (4 of 38) Q=quarterly (9 of 38)
A*=annual; return to quarterly for 1 year prior to remediation to establish preremediation conditions

Site 8 Cluster Optimization Analysis

❑ Conclusions & Recommendations

- Main plume stable
- Northern plume expanding
- Reduce sampling frequency
  - 24 wells annual sampling
  - 4 wells semiannual sampling
  - 9 wells quarterly sampling
- Eliminate redundant well
  - 9-MW-4
    - Stable time trends
    - Spatially redundant: 9-MW-4 in source area cluster of 3 wells
    - Concentrations correlated to associated cluster wells
- Add wells downgradient of 8-MW-13, 9-MW-9 to define downgradient extent of plume

Closing Remarks/Questions?

- Formalization of VAFB BGMP Decision Tree
- Ongoing decision-making on well optimization, as documented in each BGMP quarterly report
- Biennial review of BGMP
- Open for Questions...