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San Antonio, Texas
Promoting Readiness through Environmental Stewardship

MAROS Decision Support System for Optimizing LTM Programs:

Application to Fort Lewis Logistics Center

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Team Members and Funding

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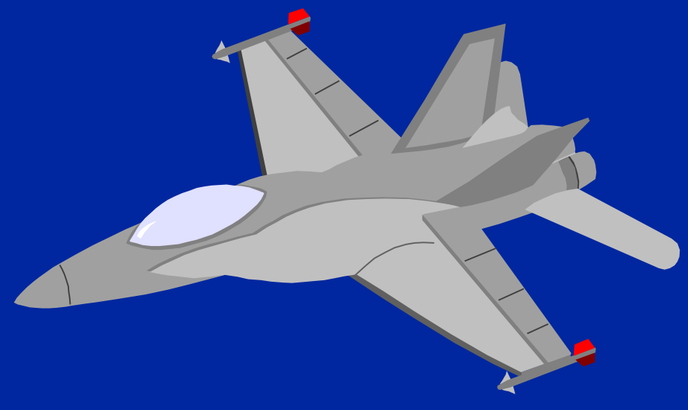
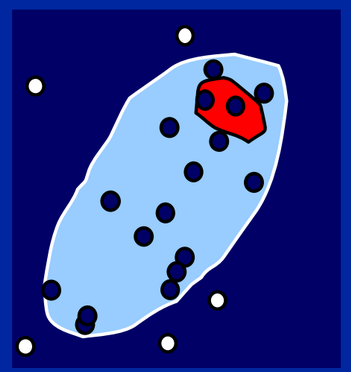


Funded by AFCEE Tech Transfer Division

Long-Term Monitoring Calculus

	Number of Sites		*Cost Per Well*		*Number of Wells*		*Frequency, Duration of Sampling*		Data management & reporting
LTM Cost ($)	=		X		X		X		X	
Addressed By This Tool?	*NO*		*NO*		*YES*		*YES*		*YES*	

Key Concept: Knowledge of Plume Trend Can Translate into LTMP Cost Savings

Example 1:

expanding, chlorinated, fast gw

More Intensive LTMP: MORE wells, MORE frequent

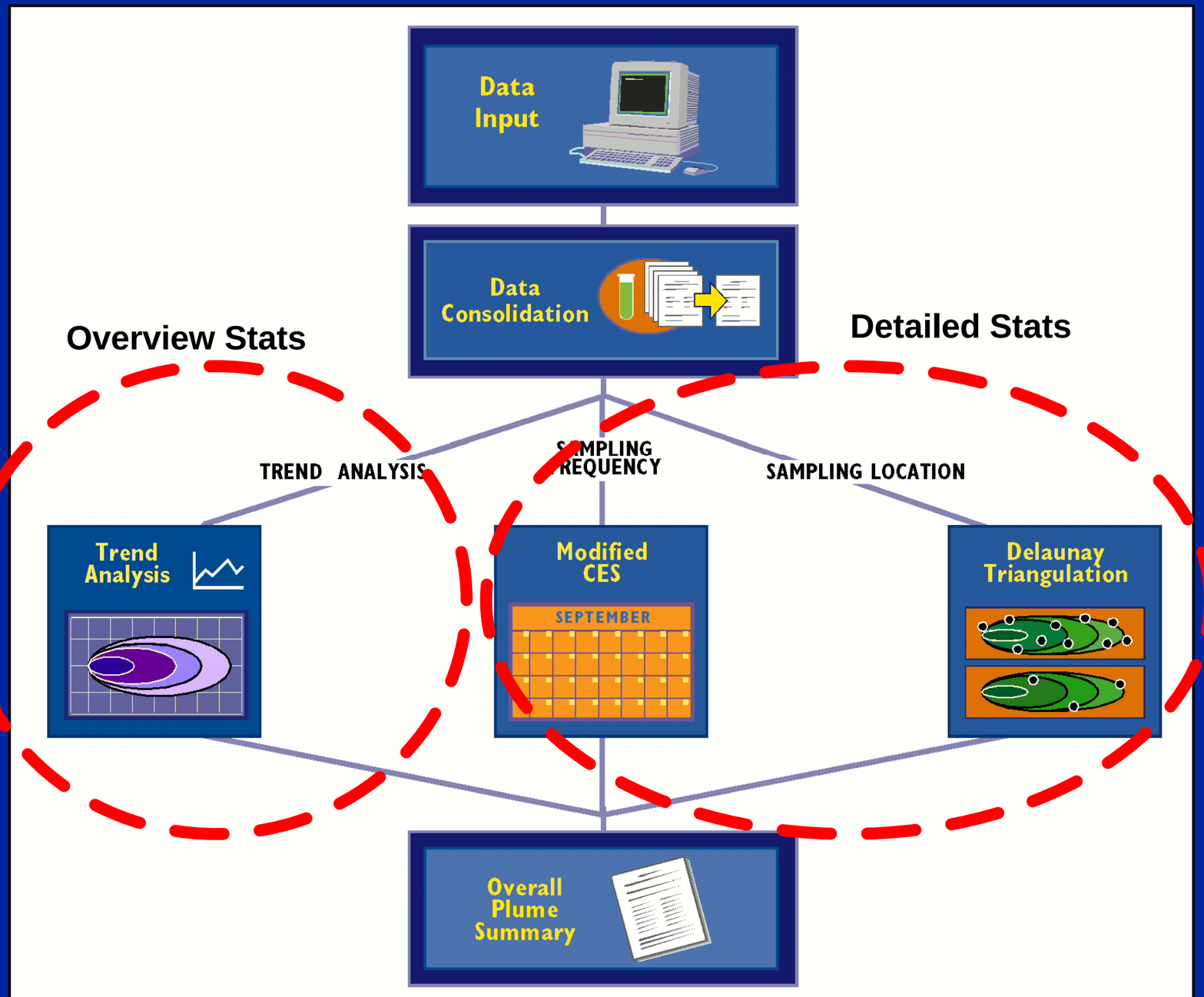
Example 2:

shrinking, BTEX slow gw:

Less Intensive LTMP: FEWER wells, LESS frequent

MAROS provides a first-cut blueprint for a LTMP

MAROS Analysis Road Map



- **Database Input**
- **Automated Data Consolidation**
- **Optimization Tools:**

  Overview Stats:

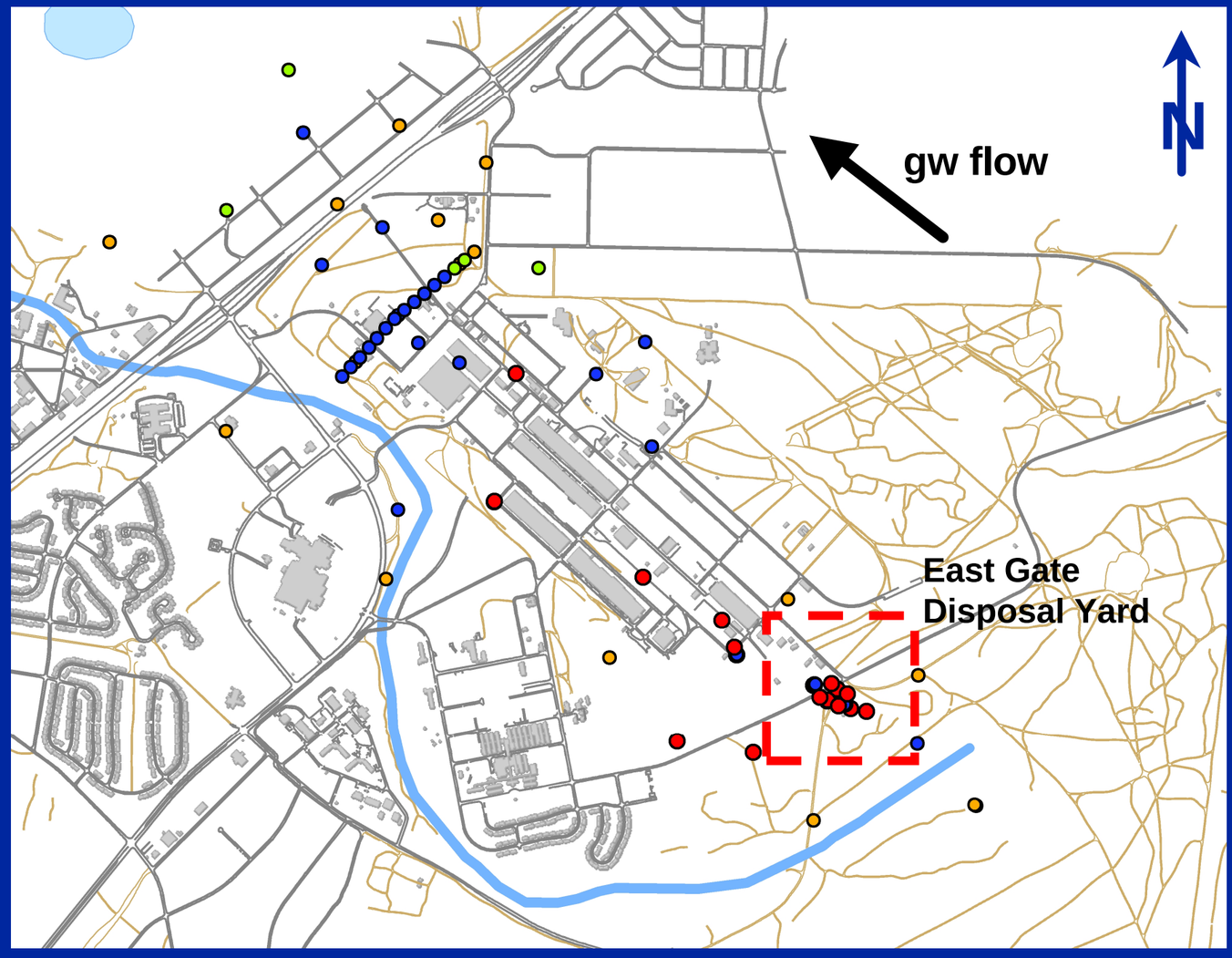
  - ***Plume Trend Analysis***
  - ***Moment Analysis***

  Detailed Stats:

  - ***Well Redundancy***
  - ***Well Sufficiency***
  - ***Data Sufficiency***

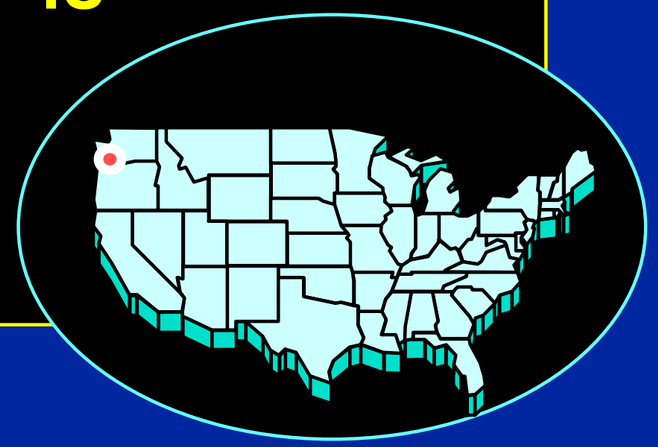
Site Description

- MAROS Analysis performed on a TCE plume monitoring network, Fort Lewis Logistics Center, Pierce County, Washington
- TCE used as a degreasing agent until 1970's
- Chlorinated solvents: historically TCE up to 250 mg/L, NAPL present
- Plume Length: 10,000 ft
  Plume Depth: 60 – 80 ft
- Under Active Remediation: pump and treat system in since 1995

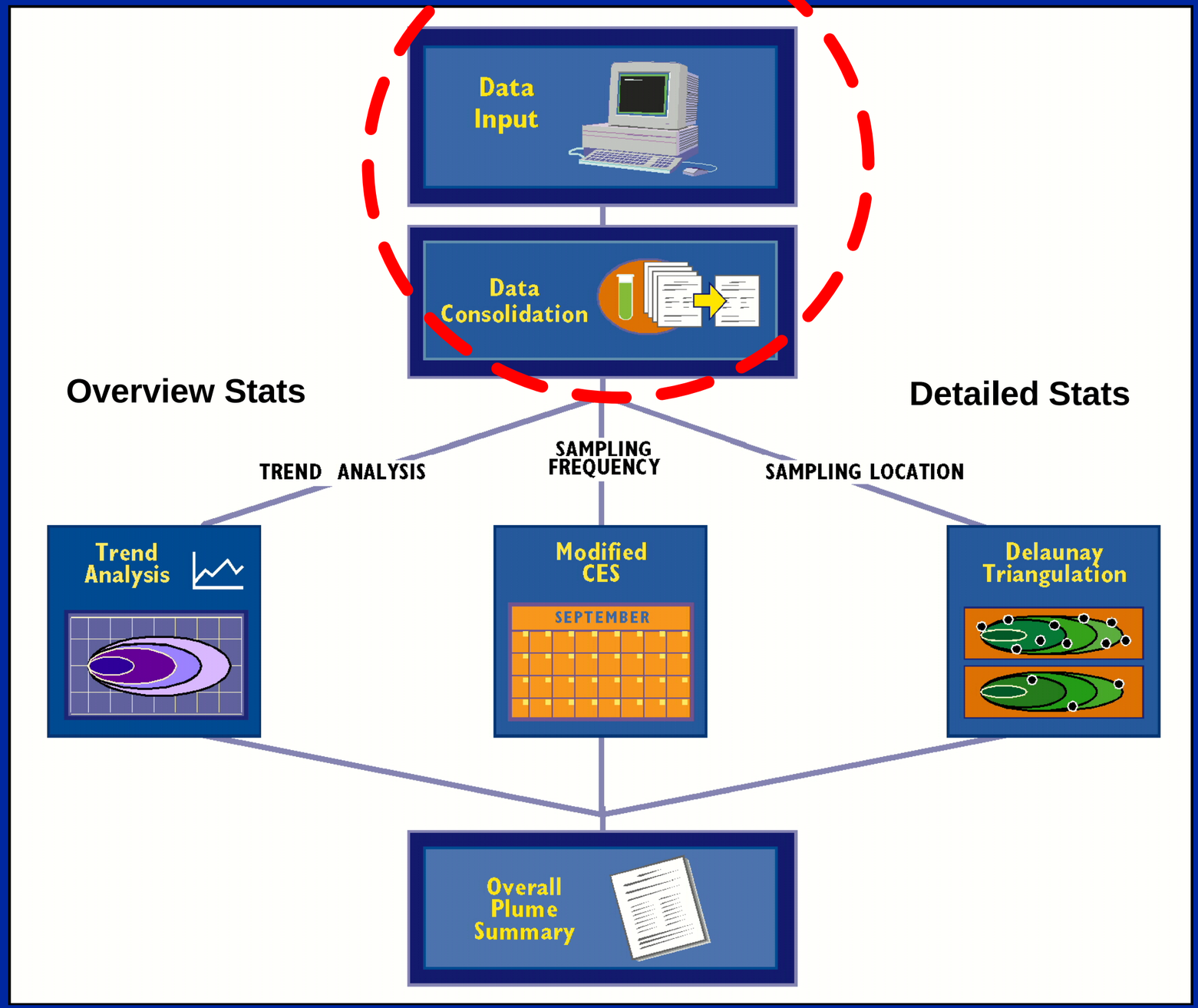


Hydrogeologic/Well Network Parameters

PARAMETER	
Representative Media Type	Outwash Sand and Gravel
Depth to Water (ft, BGS)	10 – 30
Saturated Thickness (ft)	Upper Zone: 60
GW Seepage Velocity (ft/yr)	550
Extraction Wells	Upper Zone: 21
Monitoring Wells	Upper Zone: 43
Quarterly monitoring	
7 years of sampling data	



MAROS Analysis Road Map



- **Database Input:** Excel or Access Files, Archive files, simple updates
- **Automated Data Consolidation:** Dups, ND's, and J Flag Values
- **Optimization Tools:**

  Overview Stats:

  - *Plume Trend Analysis*
  - *Moment Analysis*

  Detailed Stats:

  - *Well Redundancy*
  - *Well Sufficiency*
  - *Data Sufficiency*

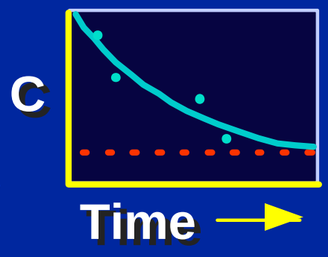
MAROS Data Input:
Data Requirements and Analysis Methods

Data Requirements

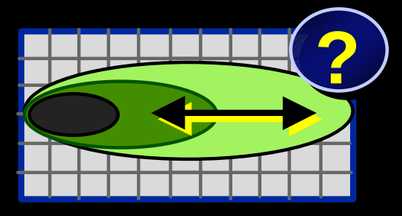
Historical measurements of plume concentrations: multiple sampling events (including upgradient, downgradient, and 2 or more plume wells.)

Data Consolidation

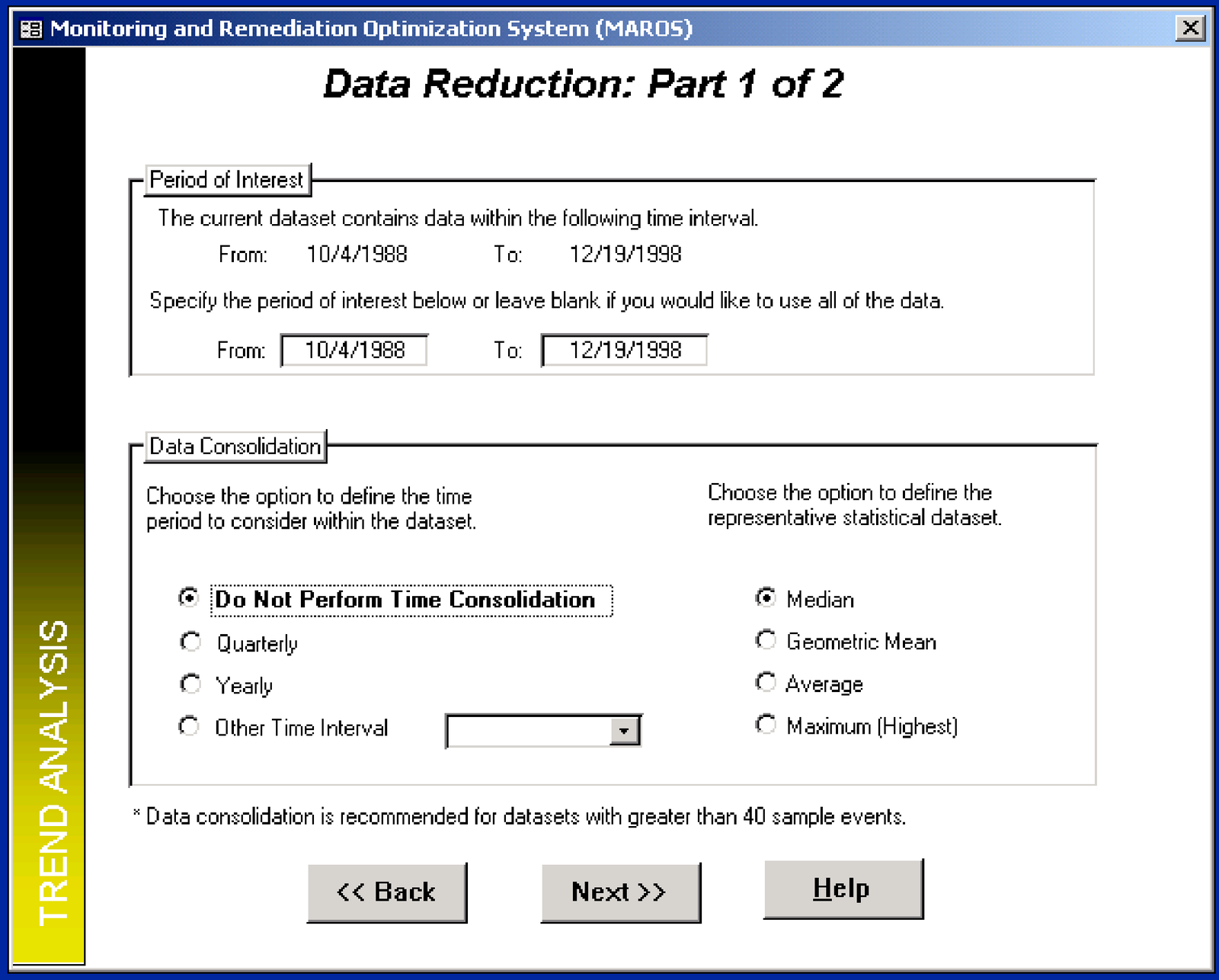
Assign representative results for sample events: non-detects, duplicates, trace levels, and irregularly sampled wells.



GOAL: **Establish plume status as stable, shrinking, or expanding based on historical data.**



Data Input & Data Reduction



Well Network Input Data:

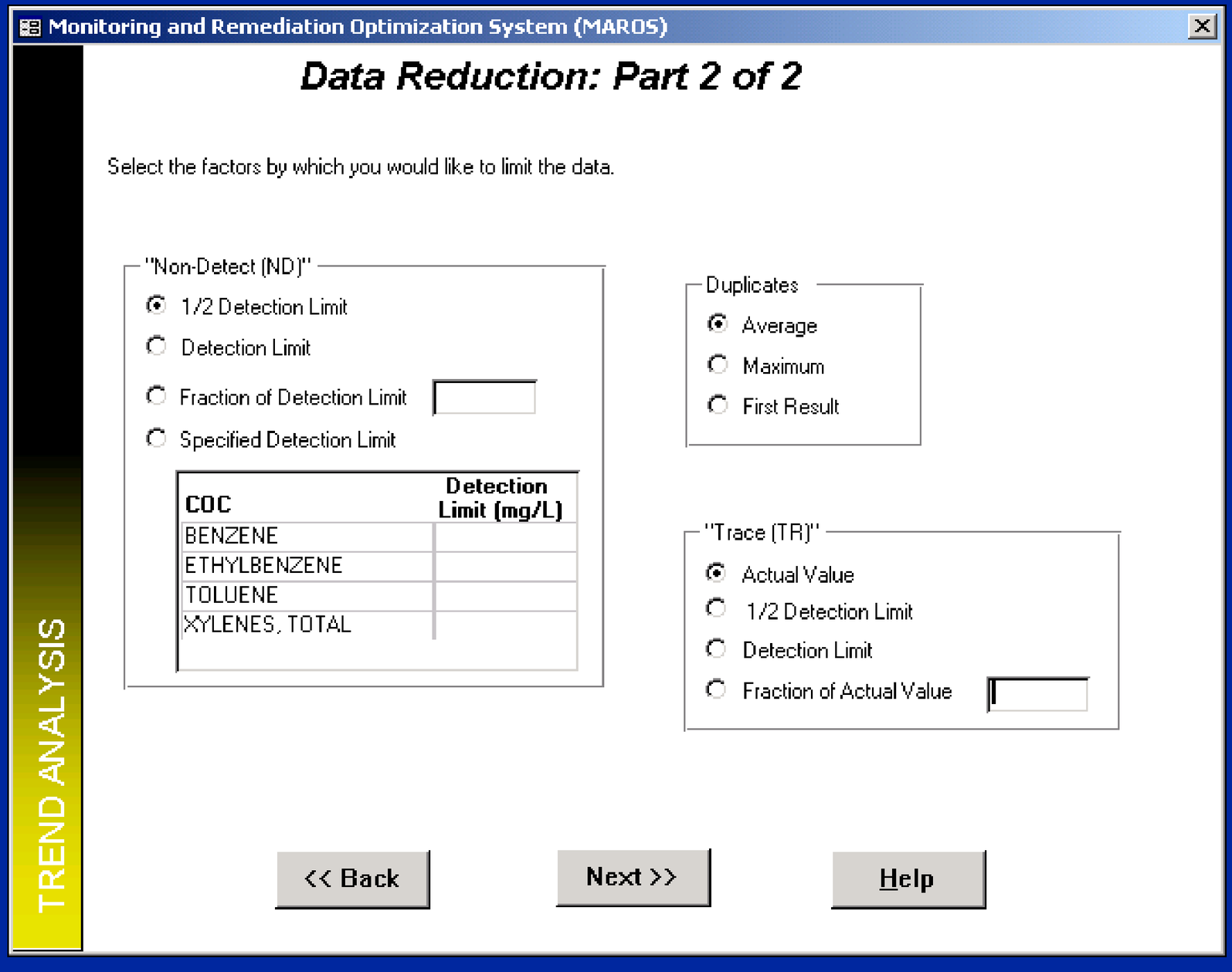
- 10 Source Wells
- 33 Tail Wells
- 21 Extraction Wells

Data Consolidation:

- Post-remediation start-up data:

  1995 – 2001
- One COC for site: TCE
- No Time Consolidation

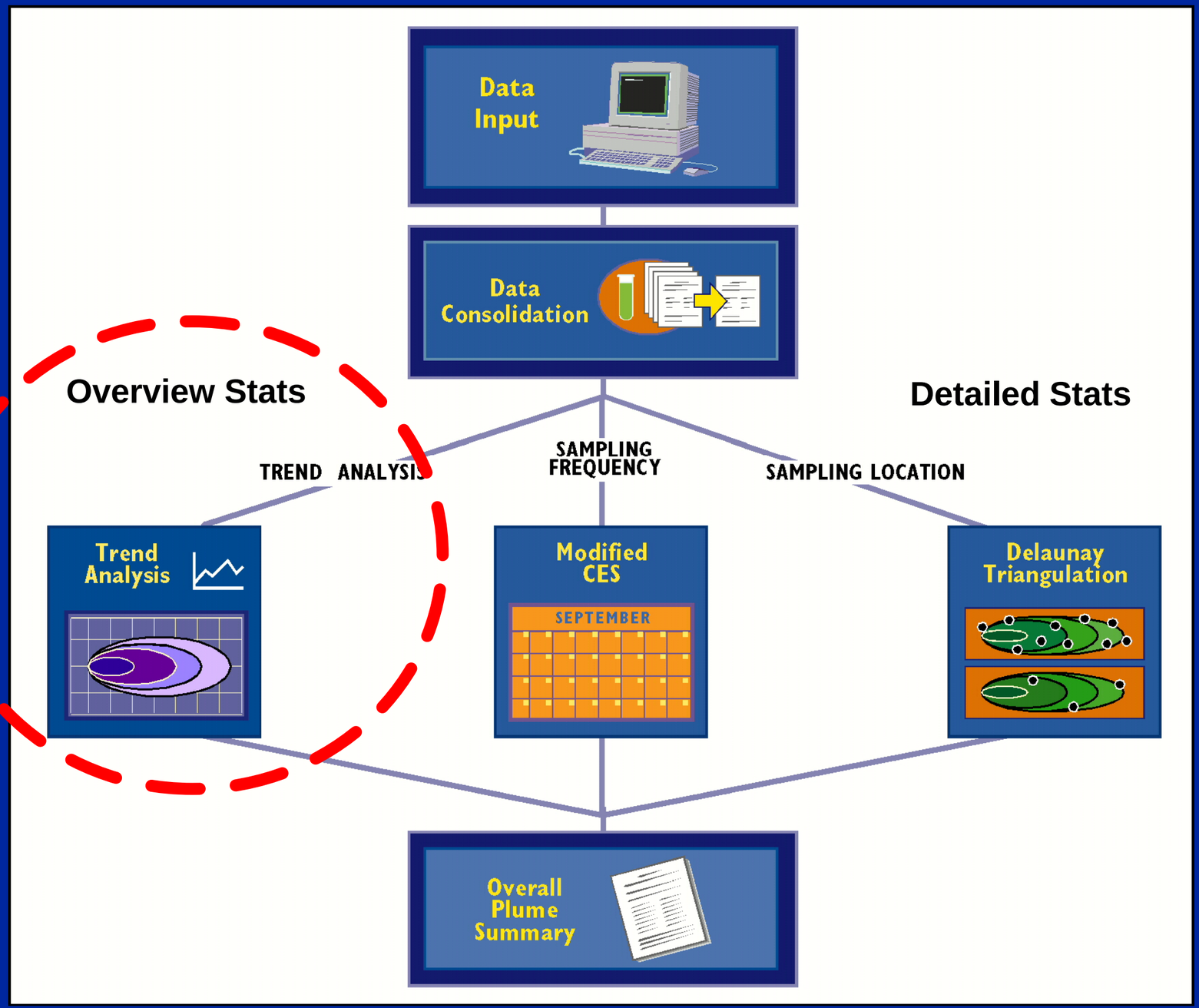
Data Reduction



Data Consolidation:

- Non-detect values set to minimum detection limit.
- Average Duplicates
- Trace Values set to actual values

MAROS Analysis Road Map

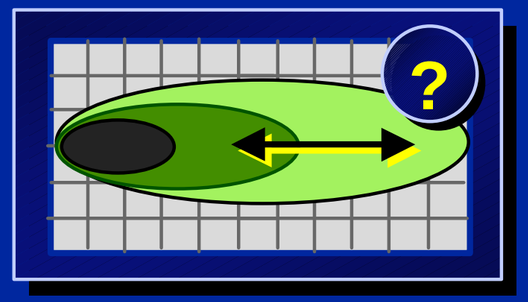


- **Optimization Tool:**
  - ***Overview Stats: Plume Stability and Individual Well Trend Analysis:* Conc. vs. Time Data, Simple Stats, Moment Analysis**

MAROS Temporal Trend Analysis

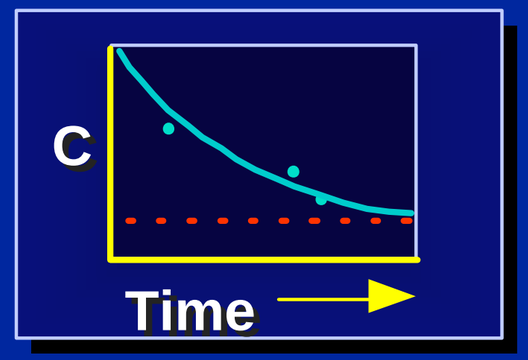
WHAT

Define ground water plume status as stable, shrinking, or expanding.



HOW

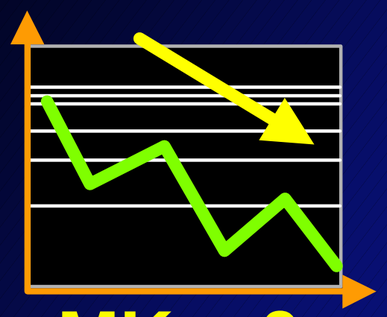
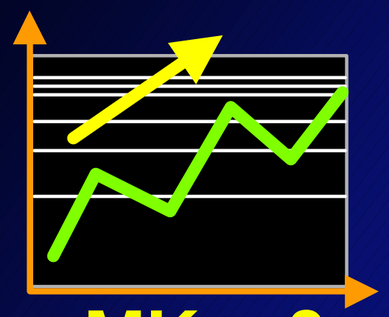
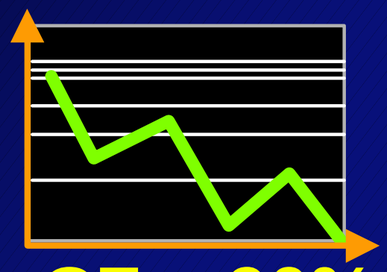
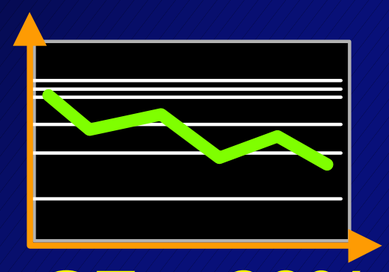
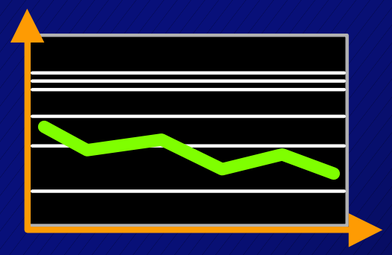
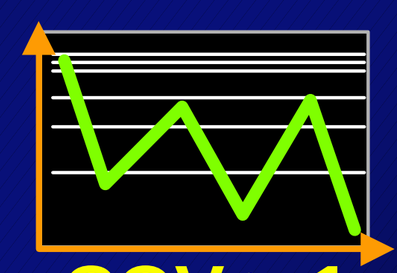
Evaluate historical concentration measurements in ground water.



WHEN

Always apply based on sufficient historical data.

Interpretation of Mann-Kendall Tests

MK Statistic (S)	 **MK < 0** **Decreasing Trend**	 **MK > 0** **Increasing Trend**
Confidence Factor (CF)	 **CF > 90%** **Strong Trend**	 **CF < 90%** **Weak Trend**
Coefficient of Variation (COV)	 **COV < 1** **Stable Trend**	 **COV > 1** **Fluctuating Trend**

Mann-Kendall Analysis

Monitoring and Remediation Optimization System (MAROS)

TREND ANALYSIS

Mann Kendall Statistics

The Mann-Kendall Analysis is used for analyzing a single groundwater constituent, multiple constituents are analyzed separately. Each "tab" below shows the statistics for one constituent.

See manual text or "Help" for description of trend determination method.

BENZENE | ETHYLBENZENE | TOLUENE | XYLENES, TOTAL

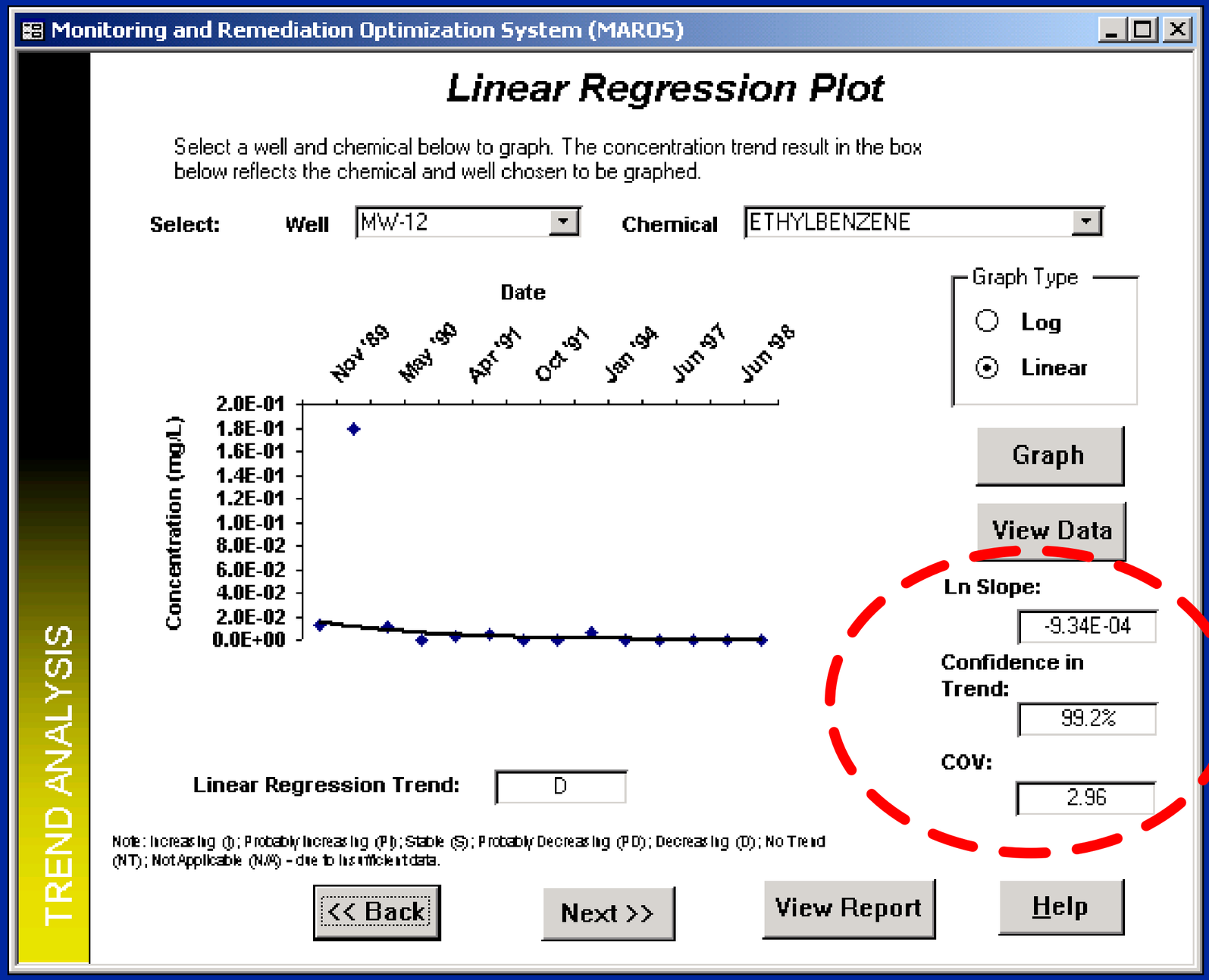
Statistical Analysis Results. Last column is the result for the trend.

Well	S/T	COV	MK (S)	Confidence in Trend	Concentration Trend
MW-15	S	0.000	0	42.3%	S
MW-14	S	1.606	-50	99.9%	D
MW-13	S	1.106	-53	99.8%	D
MW-12	S	1.591	-68	100.0%	D
MW-1	S	1.701	-15	98.5%	D
MW-8	T	0.985	-11	70.5%	S
MW-7	T	0.249	-7	62.6%	S
MW-6	T	0.000	0	47.8%	S

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T); COV (Coefficient of Variation); MK(S) Mann-Kendall Statistic

<< Back | Next >> | View Report | Help

Linear Regression Analysis



Mann-Kendall and Linear Regression Analysis Results

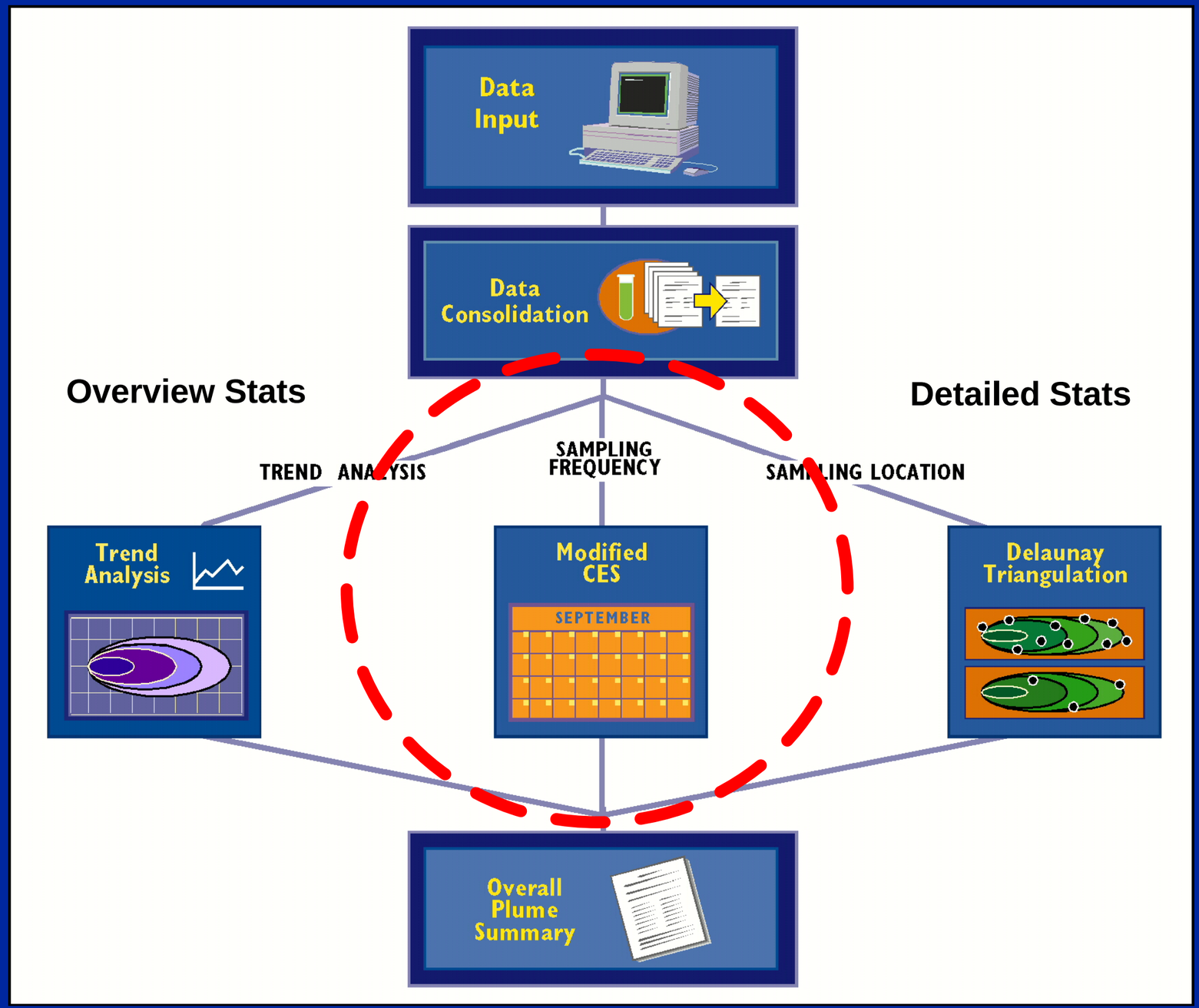
MAROS Trend Analysis		
Well Type	**PD, D, S**	**I, PI**
Source	6 of 10 (60%)	4 of 10 (40%)
Tail	15 of 33 (45%)	11 of 33 (33%)
Extraction	18 of 21 (85%)	2 of 21 (9%)

- Increasing (I)
- Probably Increasing (PI)
- No Trend (NT)
- Stable (S)
- Probably Decreasing (PD)
- Decreasing (D)

Moment Analysis Results

Mann-Kendall Trend Analysis		
Moment Type	**Trend**	**Comment**
0th: Mass Estimate	**Increasing**	• Extraction system moving high concentration groundwater from source zones to nearby monitoring wells OR •Change in monitoring wells sampled
1st: Center of Mass	**Stable**	**Only slight movement forward or backward along the direction of groundwater flow.**
2nd: Plume Spread	**Decreasing**	**Indicates that wells representing very large areas both on the tip and the sides of the plume show decreasing concentrations.**

MAROS Analysis Road Map

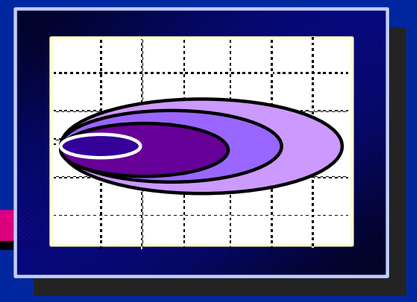


- **Optimization Tools:**
  - ***Sampling Location:*** ***Well Redundancy***

Cost Effective Sampling (Ridley, 1998)

Overview: Estimate lowest frequency of sampling for a monitoring location but still provide enough information for regulatory and remedial decision making.

Sampling Frequency



Modified CES Steps:

- Approximate frequency based on recent (6 events) trends – consider ROC and MK results
- Adjust frequency based on overall trends – consider MK results
- Reduce frequency based on risk (MCL for COC)

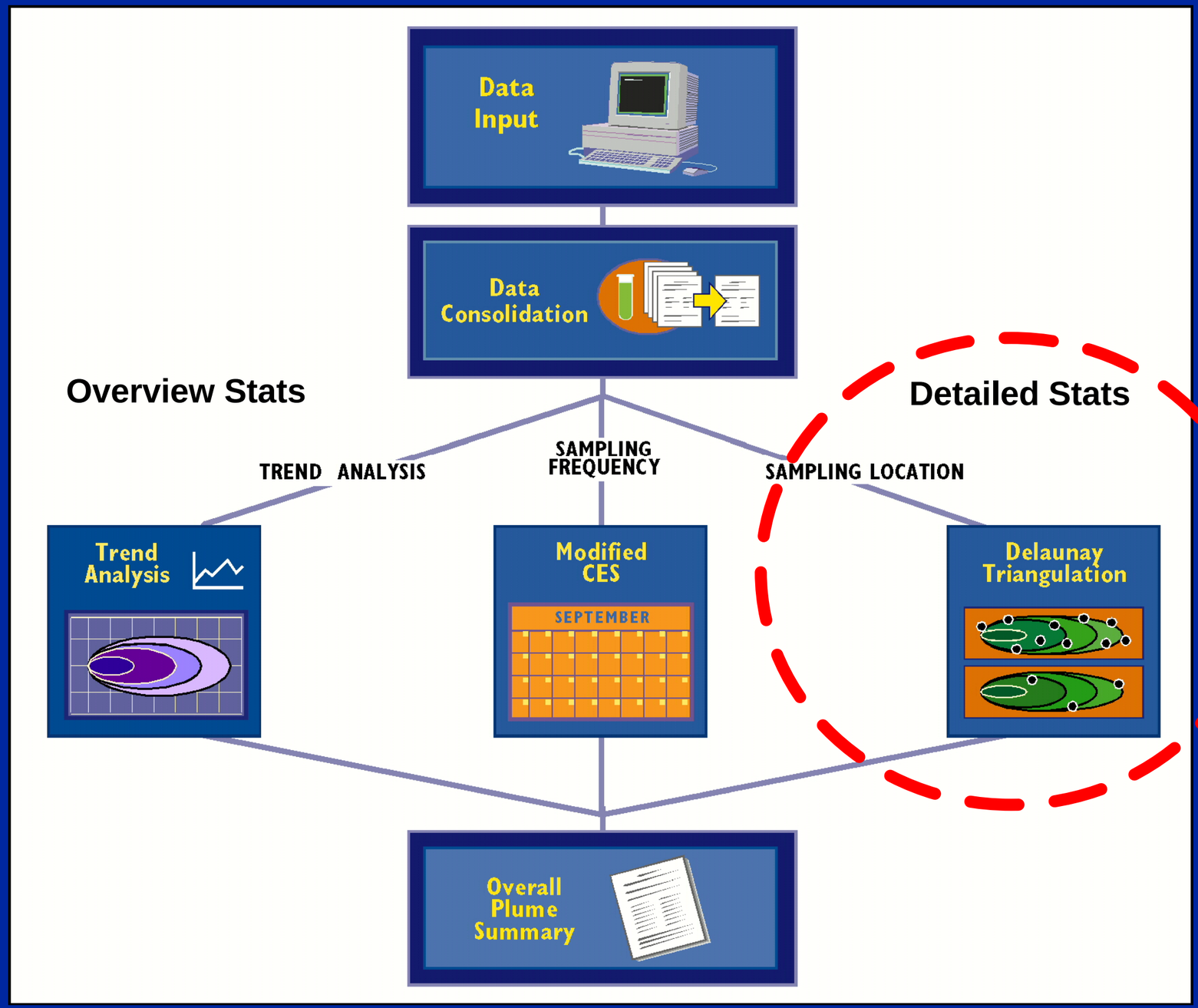
* Linear Regression used for ROC and Mann-Kendall Analysis used to assess trends. Consider both Magnitude and Direction of the Rate of Change (ROC)

Sampling Frequency Analysis Results

Frequency Analysis: Modified CES			
Monitoring Wells	**Current Sampling Frequency**	**Recommended Sampling Frequency**	**Number of Wells**
Group 1	Quarterly	Annual	16
Group 2	Quarterly	Semiannual	3
Group 3	Quarterly	Quarterly	12 (No Change)
Group 4	Quarterly	Biennial	7

Note: Cost Effective Sampling (CES)

MAROS Analysis Road Map



- **Optimization Tools:**
  - ***Sampling Location:*** ***Well Redundancy***

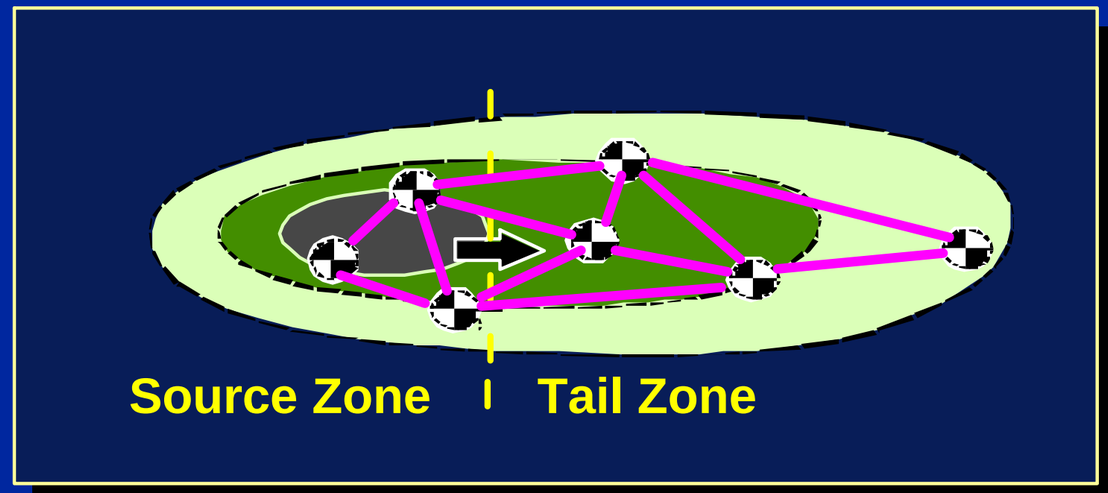
Well Redundancy and Sufficiency Analysis

Delaunay Method:

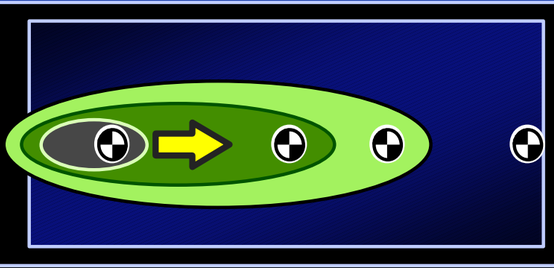
• Evaluate significance of current sampling locations in monitoring network (eliminate "redundant" wells)

OR

•Add wells in areas of the well network with high level of plume concentration uncertainty.



Key Point: **Does estimated concentration change if well is removed?**

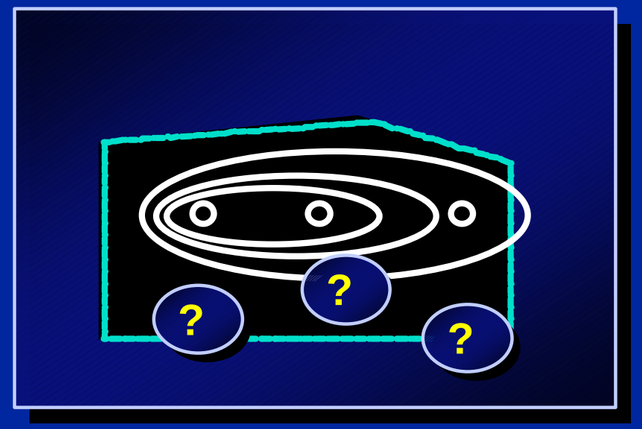


Well Redundancy Analysis

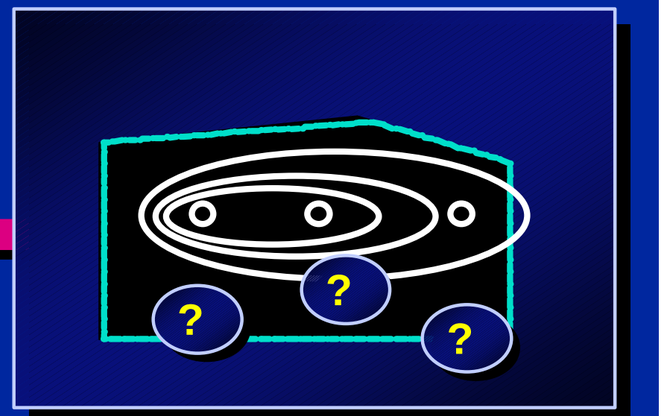
Information Loss?

Compare before network information before elimination and after

- **Average Concentration Ratio**
- **Area Ratio**
- **Slope Factor Ratio → 1 , information loss minimal, well is possible candidate for elimination.**
- **Slope Factor Ratio → 0, information loss significant, well should be maintained in the well network.**

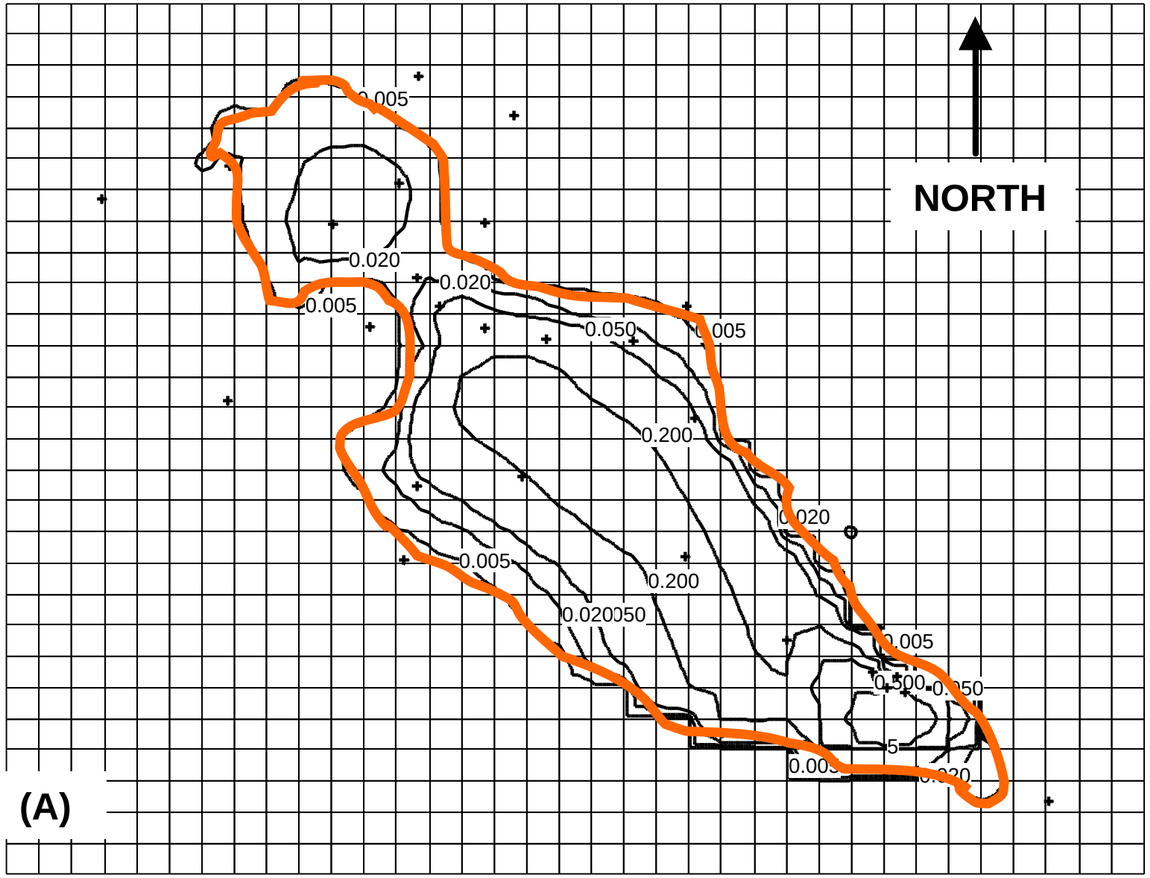


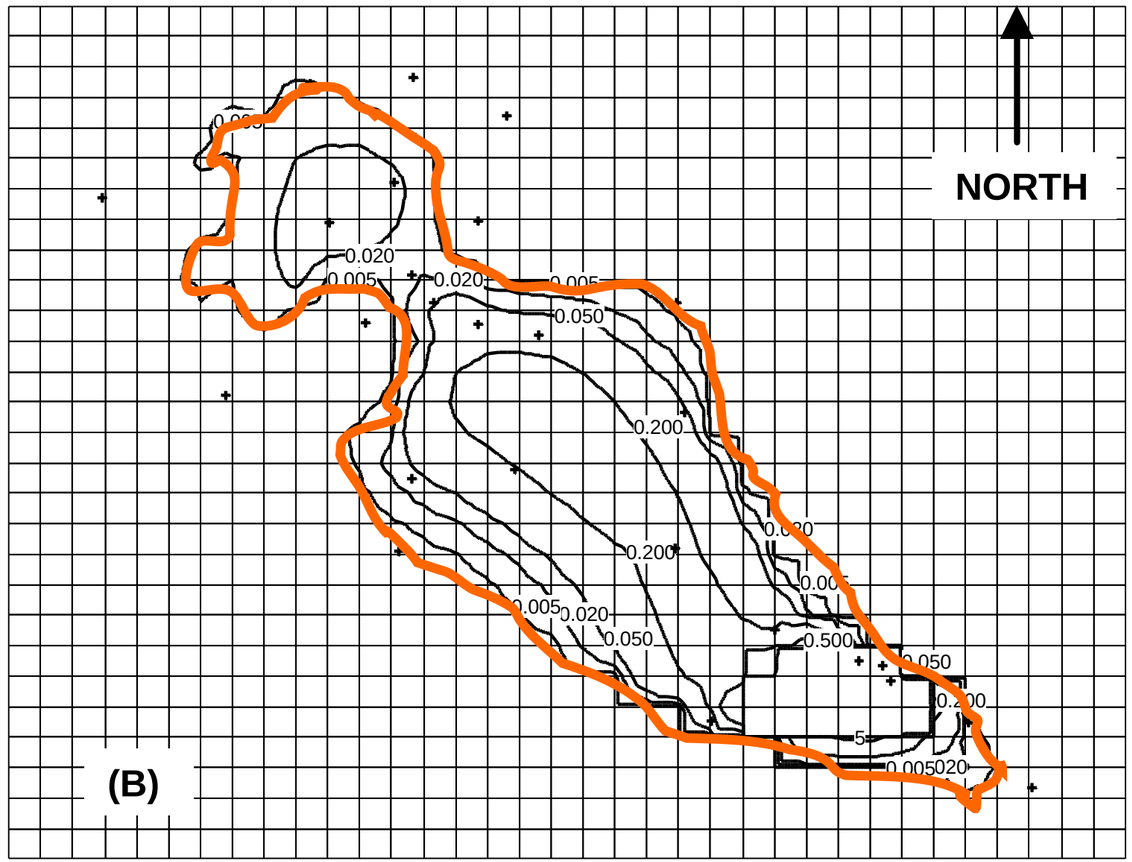
Well Redundancy Analysis Results



Summary	Before Optimization	After Optimization
Redundancy reduction	38 wells	8 candidates for removal
Removal Candidates	LC-136b, LC-137a, LC-149d, LC-19b, LC-19c, LC-44a, LC-51 and LC-66a	

Visual Comparison of TCE Plumes



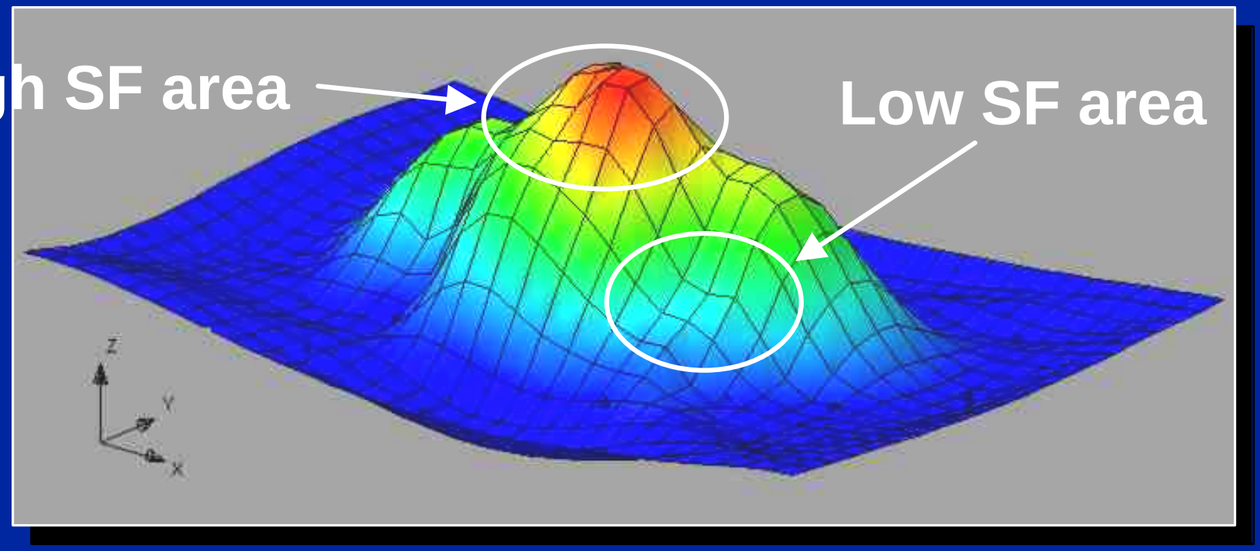


(A) September 2001
Before Optimization

(B) September 2001
After Optimization

Well Sufficiency Analysis

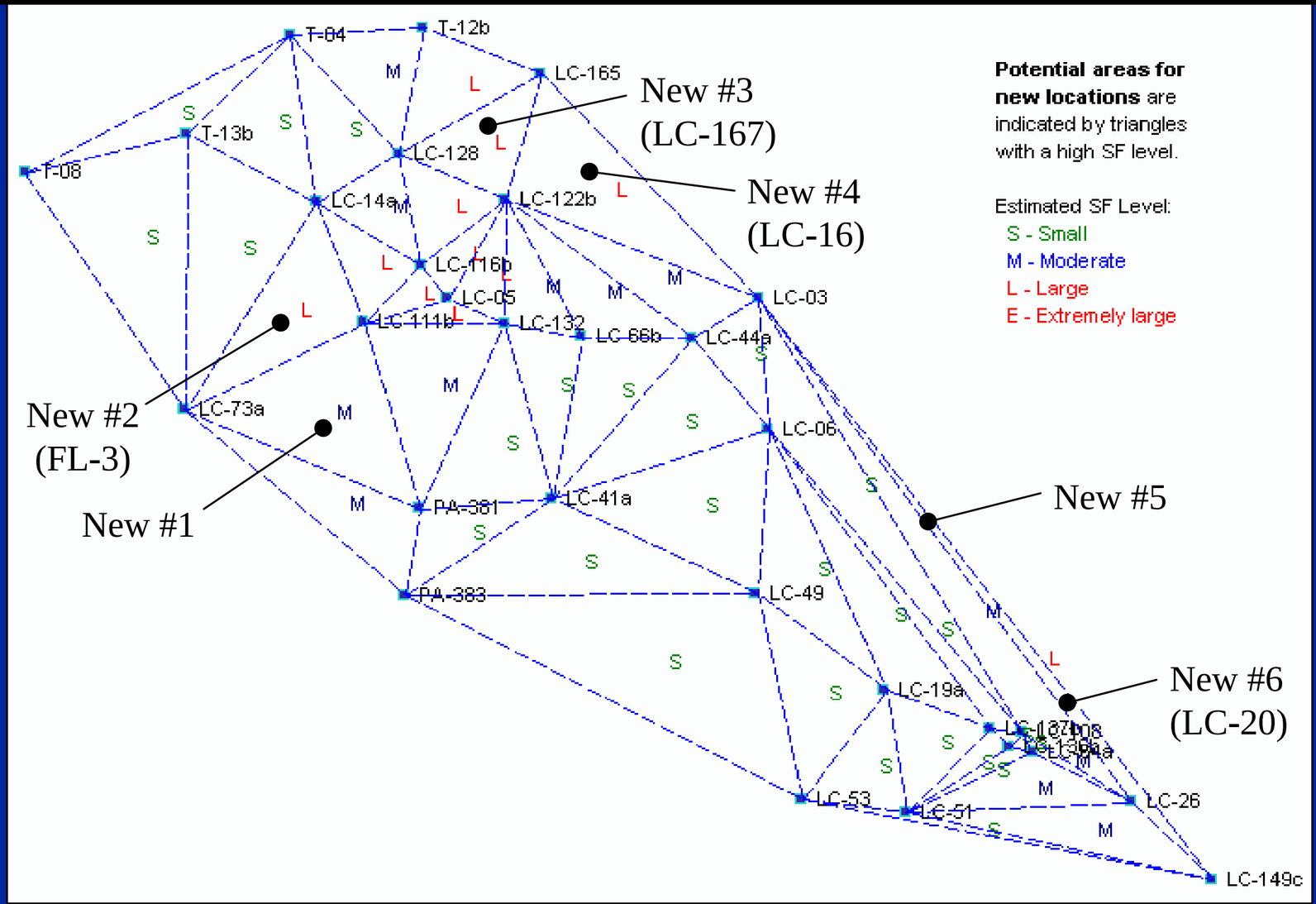
Generate estimation uncertainty plot based on SF values



High SF areas → High estimation error → Possible need for new locations

Low SF areas → Low estimation error → No need for new locations

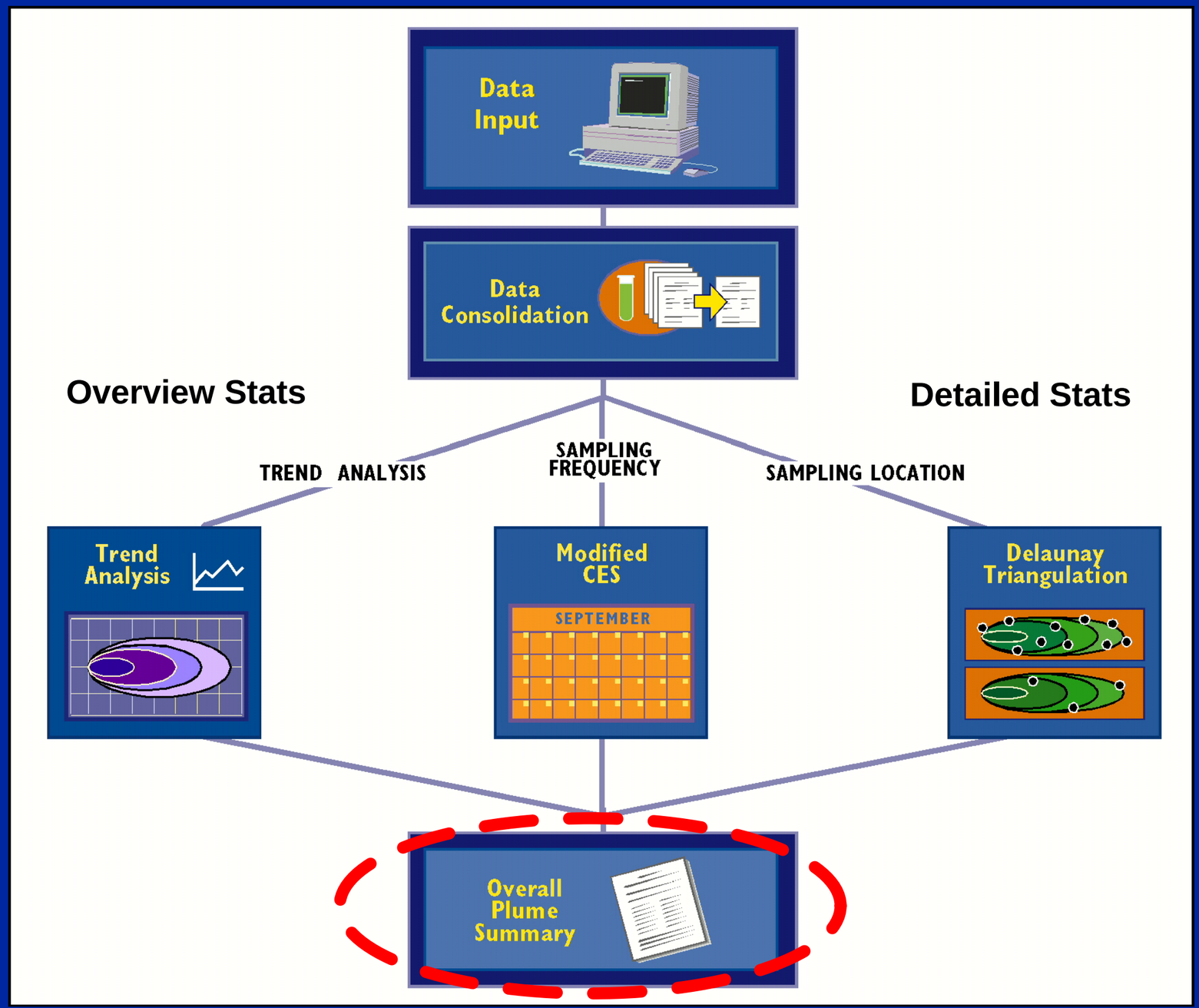
Well Sufficiency Analysis Results: New Sampling Locations



6 new wells are proposed inside the well network

Note: Only applicable for areas inside the well network

MAROS Analysis Road Map

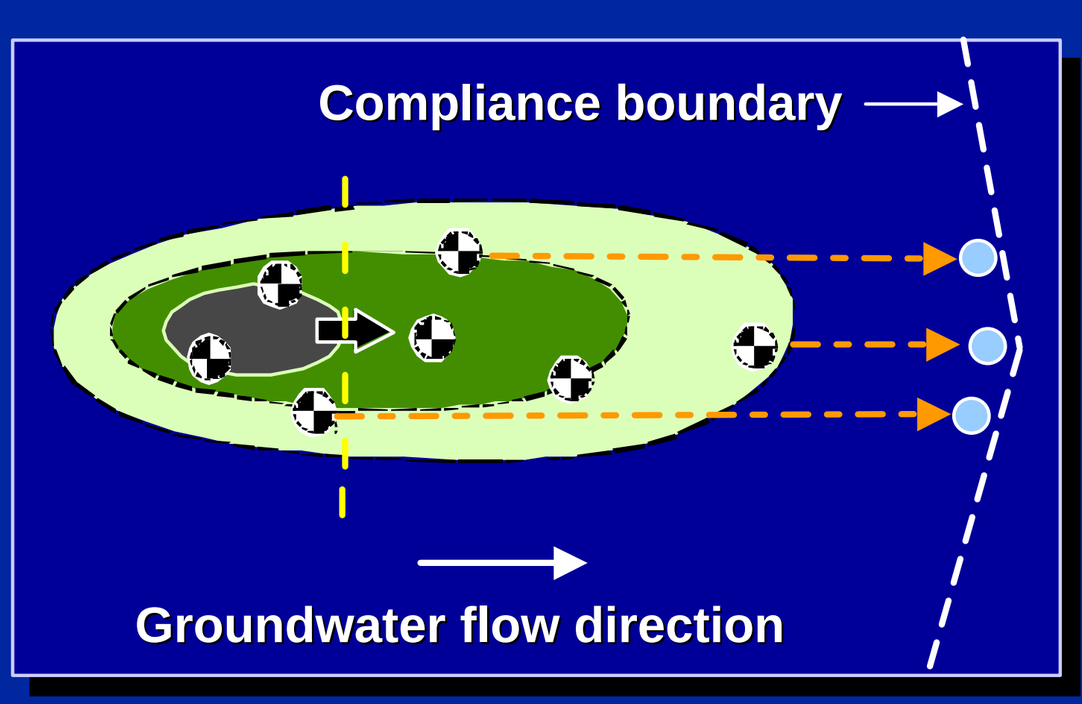


- **Optimization Tools:**
  - ***Data Sufficiency:*** ***Power Analysis***

Data Sufficiency: Power Analysis

Risk-based goals require cleanup standards be met at the compliance boundary

- Establish **"virtual" wells** at the compliance boundary
- **Project** concentrations at these "virtual" wells
- Perform statistical **power analysis** with these projected concentrations

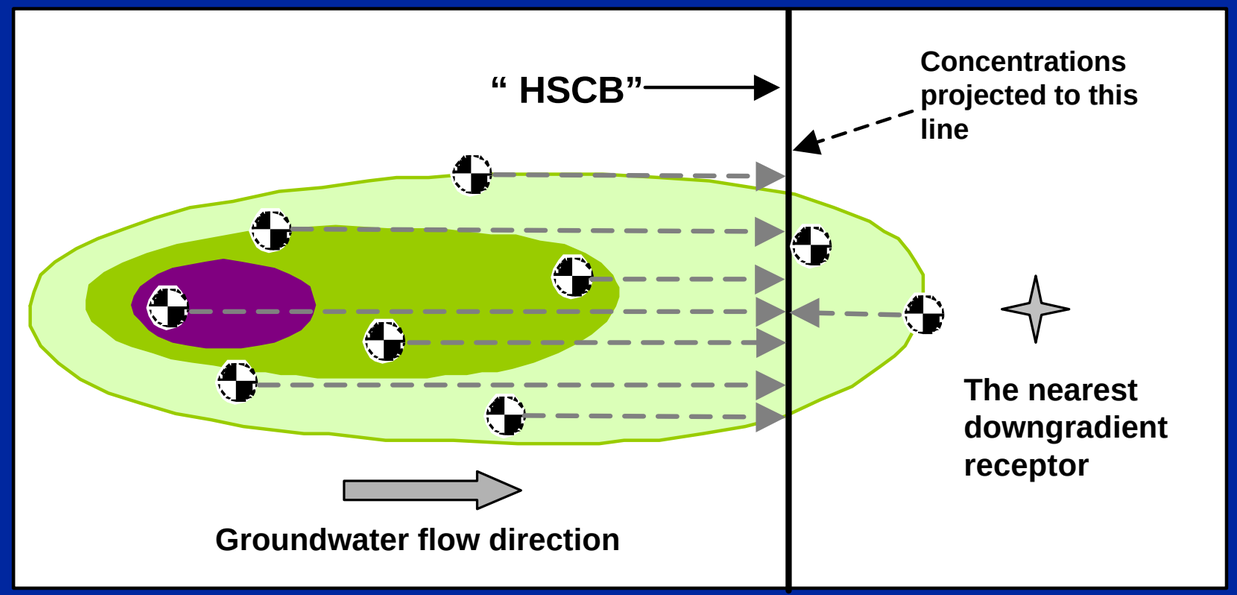


Data Sufficiency Analysis – Results

Risk-based site cleanup status

1000 ft down-gradient	2000 ft down-gradient
Close to Statistically protected	Statistically Protected

Conclusion: The site monitoring system is sufficient to accurately reflect the location of the plume relative to the compliance boundary



HSCB: Hypothetical Statistical Compliance Boundary

MAROS Application Conclusions

1 Plume Stability

- Plume Stable to Decreasing

2 Frequency Analysis

- Majority of wells can be sampled Annually

3 Well Redundancy Analysis

- Remove 8 monitoring wells

4 Well Sufficiency Analysis

- Add 6 new monitoring wells

5 Data Sufficiency

- Currently Statistically Protected 2000 ft downgradient

Conclusions and Future Work

- **MAROS 2.0 software has been applied to optimize the Upper Aquifer groundwater long-term monitoring plan at the Fort Lewis Logistic Center, approximate Cost Savings: $58 K per year.**
- **EPA Geostatistical Study: To compare MAROS 2.0 with other optimization methods to find out its merits and shortcomings.**
- **MAROS Version 2.0 (release 3/02)**

AFCEE Tool - download at www.gsi-net.com