MAROS 2.1
Decision Support Tool

Software Training

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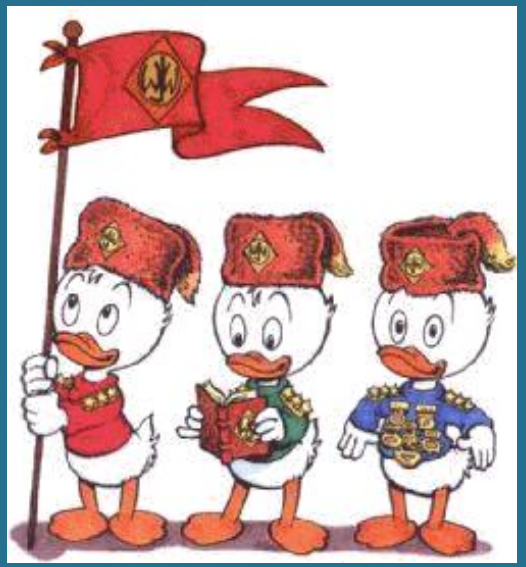

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What is MAROS?

Monitoring and Remediation Optimization Software

- **Database application MS Access** → ***YES***
  - Simple statistical and heuristic tools
  - Not mathematical optimization
  - Modular
  - Simple database input
  - Employed after site characterization and remediation activities are largely complete

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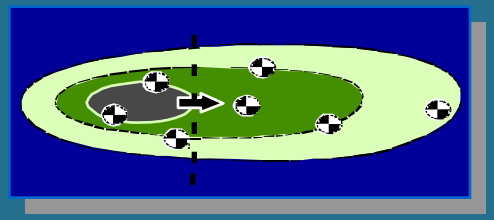
MAROS Software Objectives

- **Optimize *existing* long term monitoring plan**
  - Site and COC specific optimization
  - Spatial and temporal optimization
  - Standardized framework for LTMO
  - Conceptually simple, widely applicable

- **Quantitative evaluation can improve dialog between stakeholders**



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Am I ready for MAROS?

Is the site fully characterized?

- Plume delineated for all units?
- Hydrology known?
- > 8 sample events of monitoring data ?
- Data well organized?
- Is modeling complete?

→ **YES**

Remediation complete?

- Active remediation complete?
- Regulators approve remediation?
- MNA and Pump & Treat ongoing (OK)?
- No surprises!

→ **YES**

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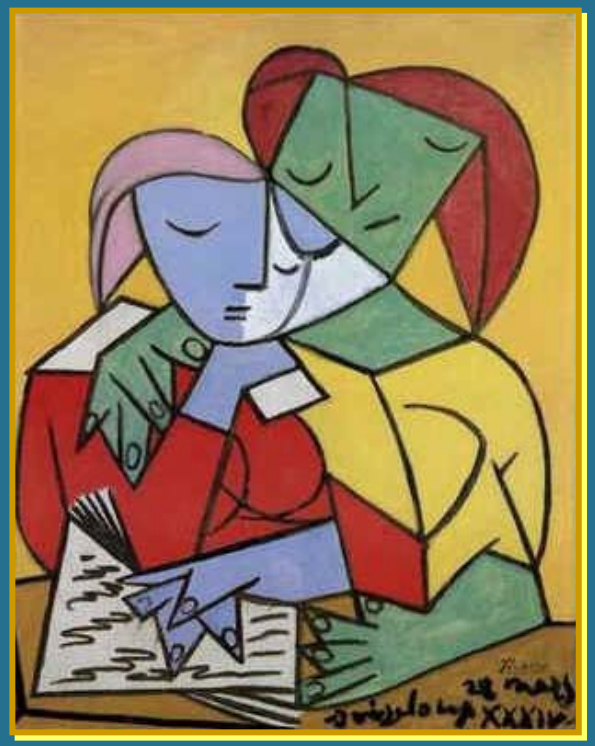
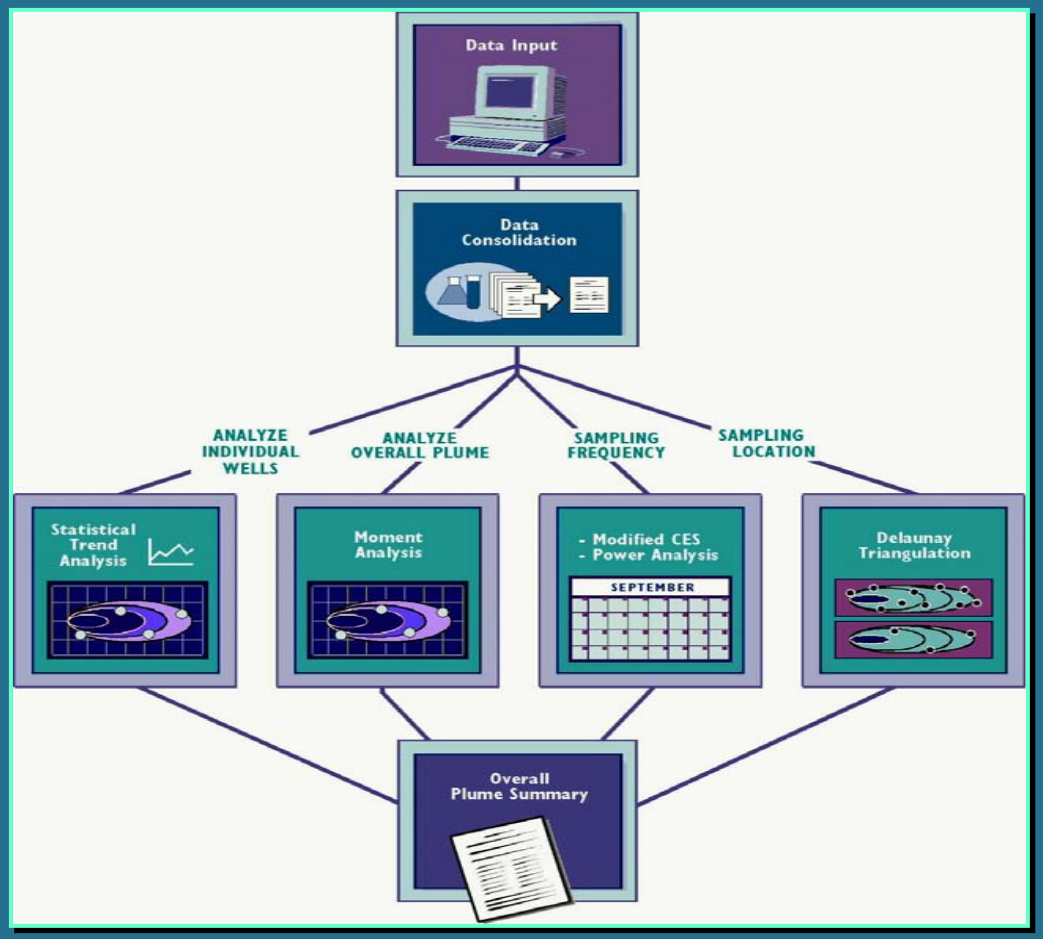
Limitations of MAROS

- Site modeled as a single plume
- Two-dimensional analysis
  - Different units analyzed separately
  - Multiple sources analyzed separately
- Simplifies and consolidates data
- Does not evaluate plume outside of current network
- Does not include purely regulatory requirements

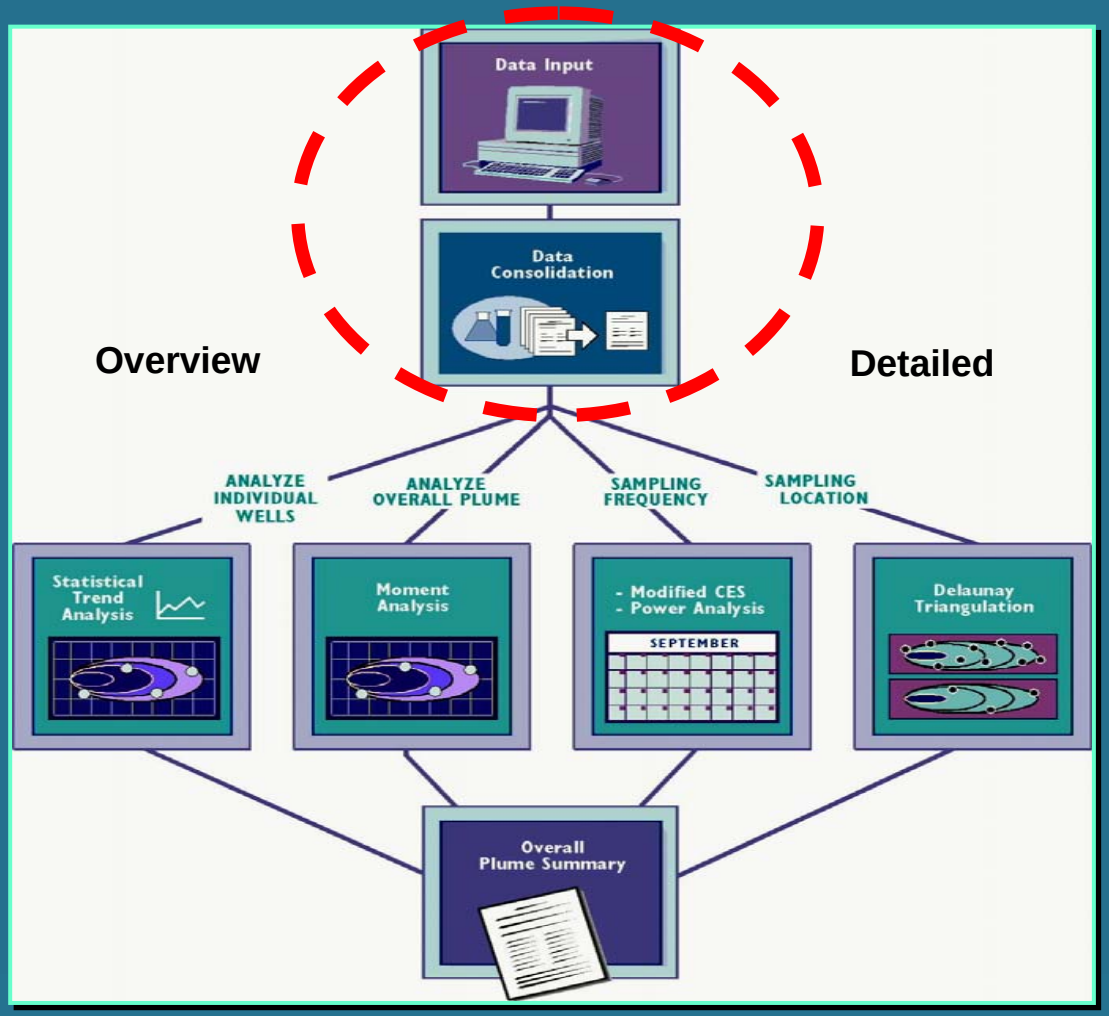


MAROS Modules



- **Database Input:**
- **Automated Data Consolidation**
- **Optimization Tools:**
  - ***Plume Trend Analysis***
  - ***Moment Analysis***
  - ***Well Redundancy***
  - ***Well Sufficiency***
  - ***Sample Frequency***
  - ***Data Sufficiency***

MAROS Input and Consolidation



- Database Input
  - Excel or Access Files, Archive files, simple updates
- Site Details
  - Size and composition of plume

Clean-up your data!

99% of Work-- Good Electronic Data File!

- Spelling counts!
- Numbers should be numbers
- Non-detect result is null
- One well—one name—one location
- Simple data Qualifiers (ND or TR)
- Estimate detection limit if missing
- Remove non-essential data including physical parameters (pH, redox, temperature, nitrate)
- Separate different groundwater units

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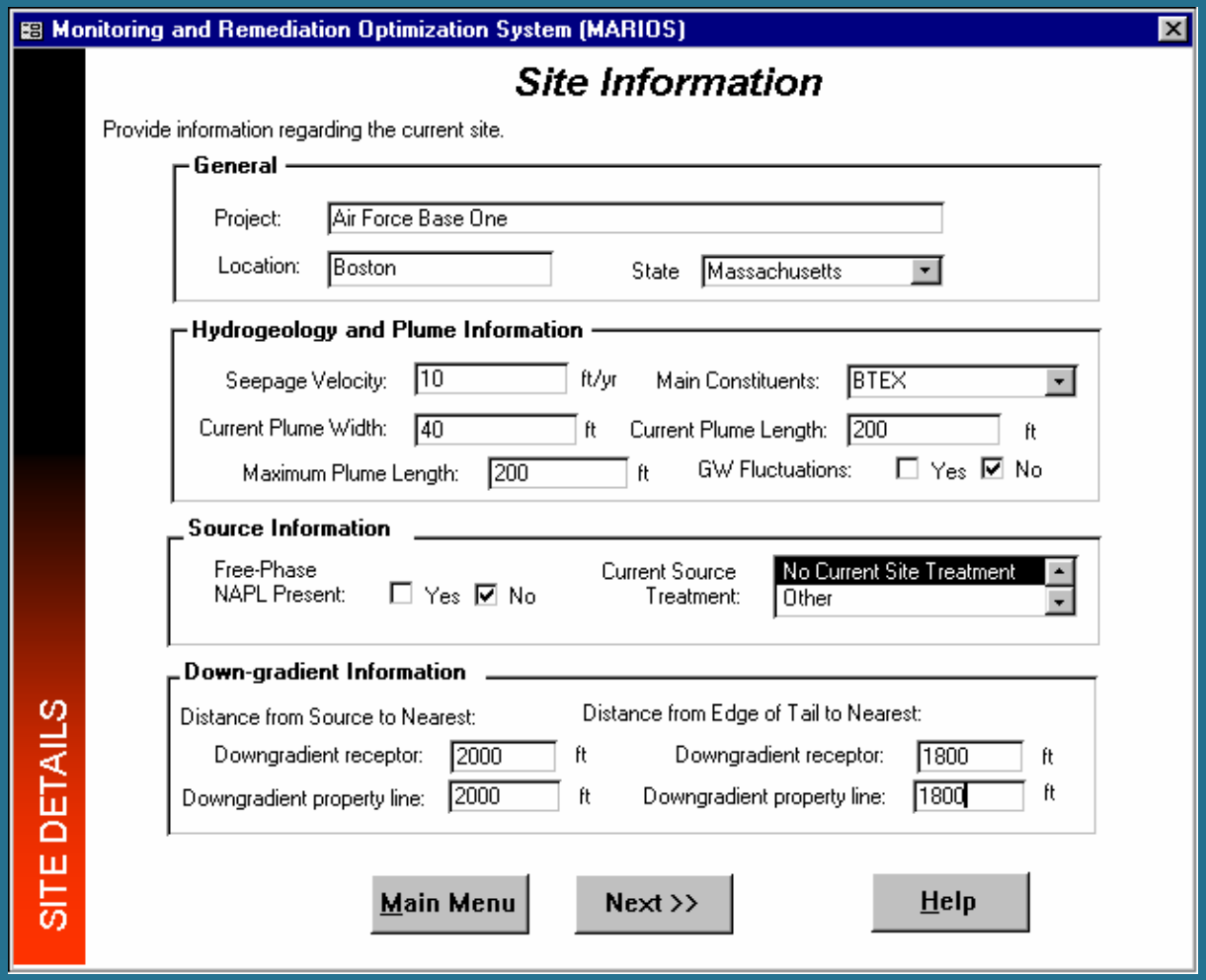
Site Details



Hydrology Data:

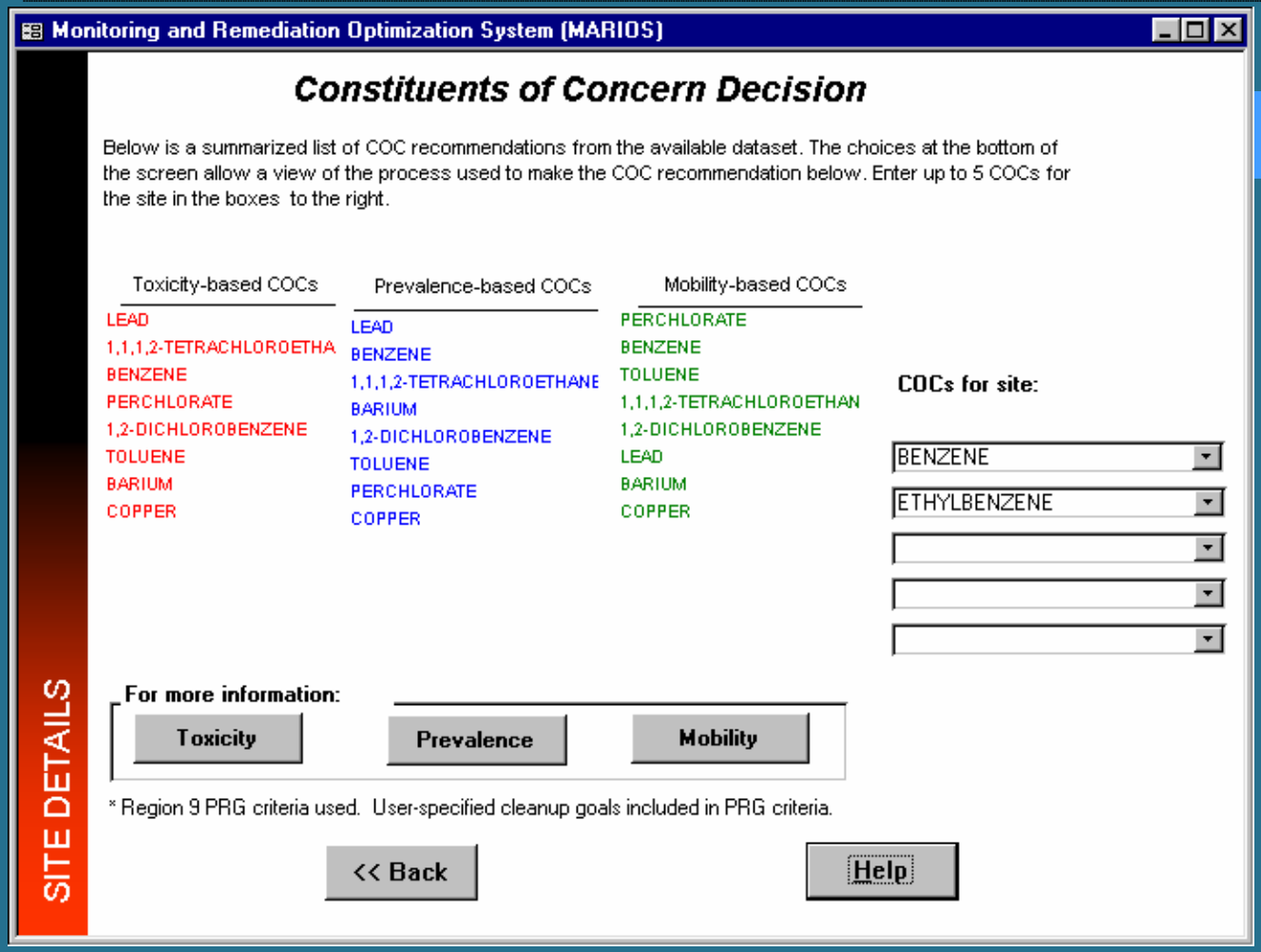
- Seepage Velocity
- Plume Width
- Constituent Class

Source and Downgradient Information:

- Distance to receptors
- Remedies in place

Data used in heuristic evaluations

Constituents of Concern

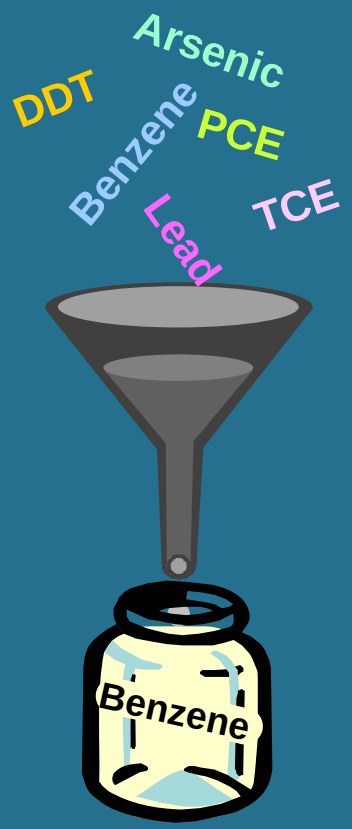


Constituent Choice:

- Up to 5 COCs for site
- Module to help choose COCs based on Risk Evaluation, choice of PRGs
- Report can be helpful

Constituents of Concern: Advice

- Choose and rank 2-3 constituents of highest priority
  - Mobility
  - Toxicity
  - Prevalence
- The highest priority compounds lead the overall monitoring strategy
- Possible to perform separate analyses



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MAROS Software Demonstration

- *Activity 1*
  - Download and save software
- *Activity 2*
  - Import Archive File
  - View Data Import features
- *Activity 3*
  - View Site Details data entry forms
  - View COC Decision screens
  - Create Archive File

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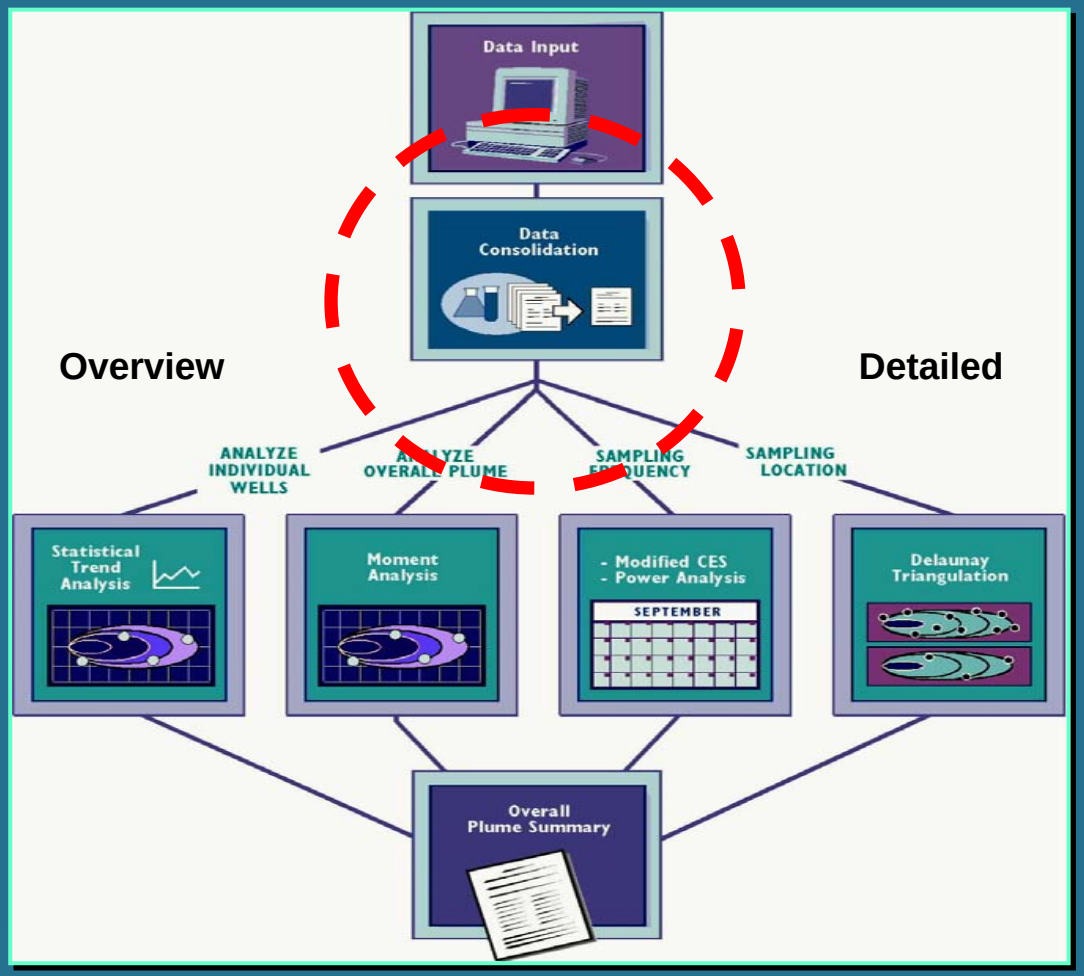
MAROS Plume Analysis



Data Consolidation:

- Non-detect values set to minimum or 1/2 detection limit.
- Average Duplicates
- Trace Values set to actual values
- Time Consolidation

Thoughts on Consolidation

- Total knowledge of plume is not possible.

- Characterization of the plume is complete —
  - Seasonality known
  - Hydrology is known
  - Significant COCs known
  - Source areas known

- MAROS reveals broad trends—so individual Data points are less significant

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MAROS Software Demonstration

- *Activity 4*
  - Data Consolidation
  - Limit time span of analysis
  - View options for data consolidation by time
  - Choose values for non-detects, duplicates and trace concentrations
  - View data graphically

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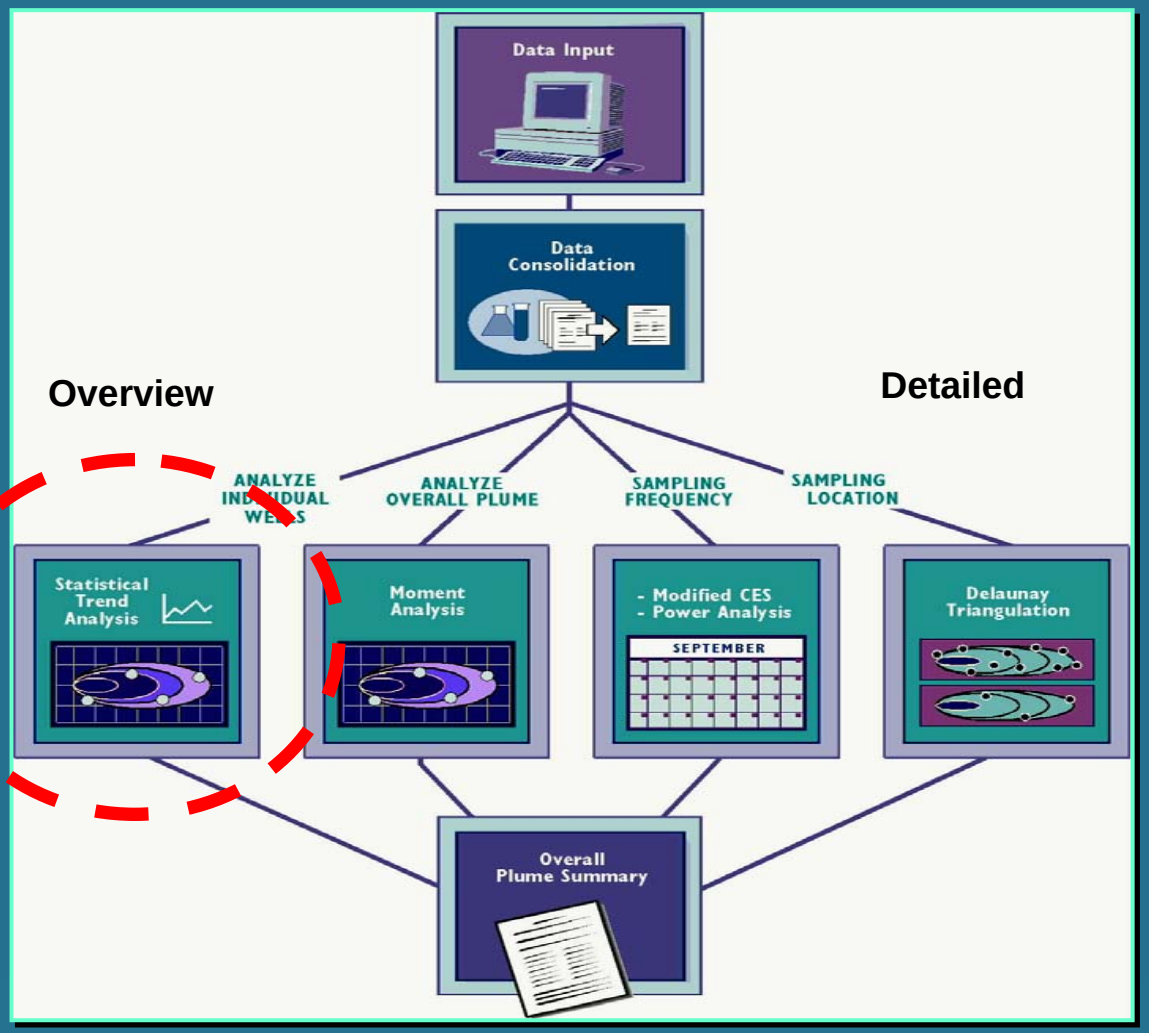
MAROS Plume Overview



•Optimization Tool:

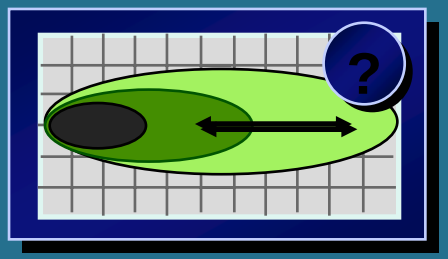
–Overview Stats: Plume Stability and Individual Well Trend Analysis:

–Conc. vs. Time Data, Mann-Kendall and Linear Regression Analysis

MAROS Temporal Trend Analysis

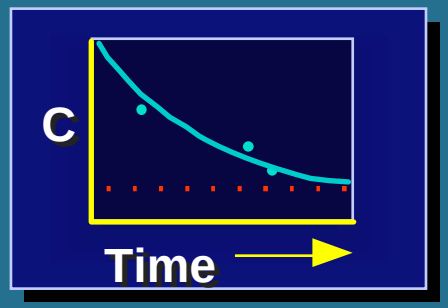
WHAT

Define ground water plume status as stable, increasing, or decreasing.



HOW

Evaluate historical concentration measurements in ground water.



WHEN

Always apply based on sufficient historical data.

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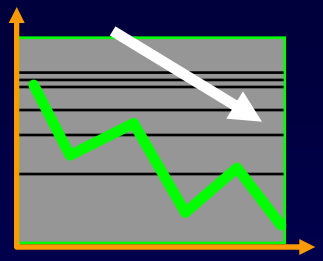
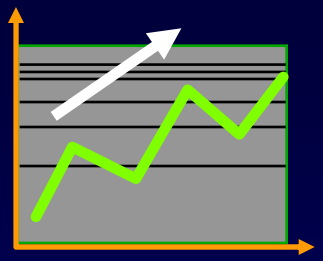
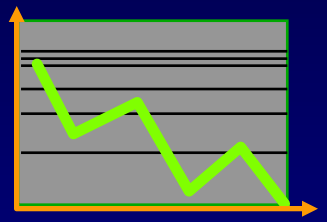
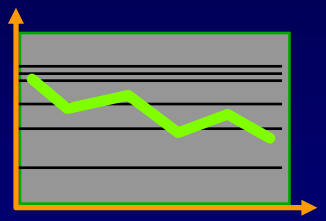
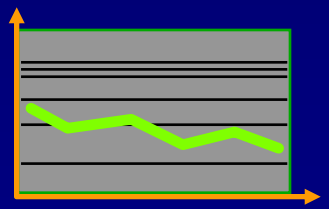
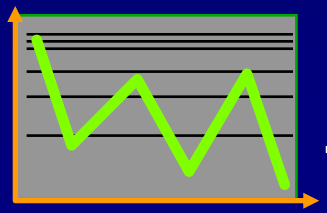
Mann-Kendall Test: Approach

	Event 1	Event 2	Event 3	Event 4	Event 5	TOTAL POINTS
	13.95	42.08	33.90	33.67	18.05	
Compare To Event 1		+ 1	+ 1	+ 1	+ 1	+ 4
Compare To Event 2			- 1	- 1	- 1	- 3
Compare To Event 3				- 1	- 1	- 2
Compare To Event 4					- 1	- 1
					S =	- 2

Conclusion: decreasing trend

Interpretation of Mann-Kendall Tests

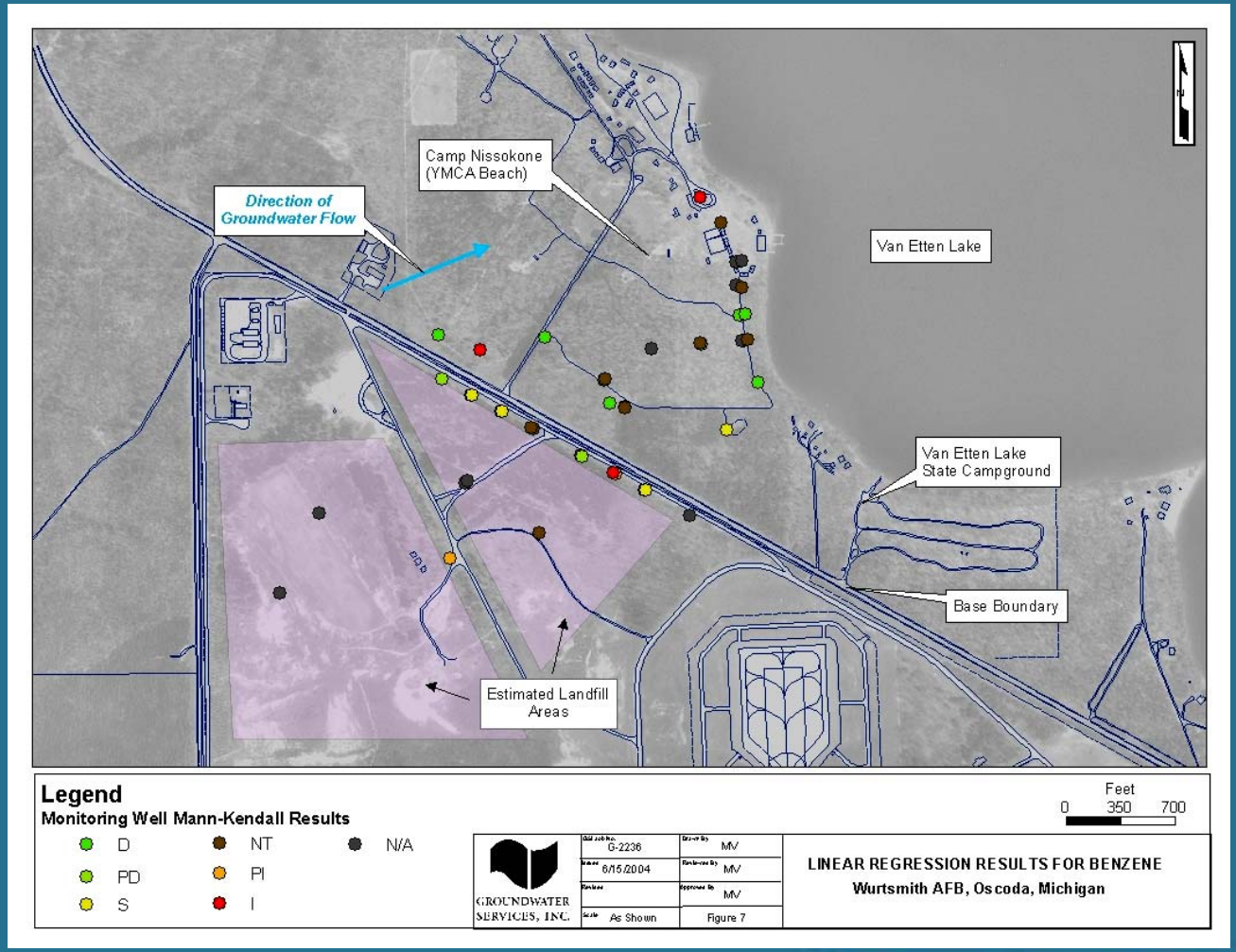
MK Statistic (S)	 MK < 0 Decreasing Trend	 MK > 0 Increasing Trend
Confidence Factor (CF)	 CF > 90% Strong Trend	 CF < 90% Weak Trend
Coefficient of Variation (COV)	 COV < 1 Stable Trend	 COV > 1 Fluctuating Trend

Mann-Kendall Test Results: Interpretation

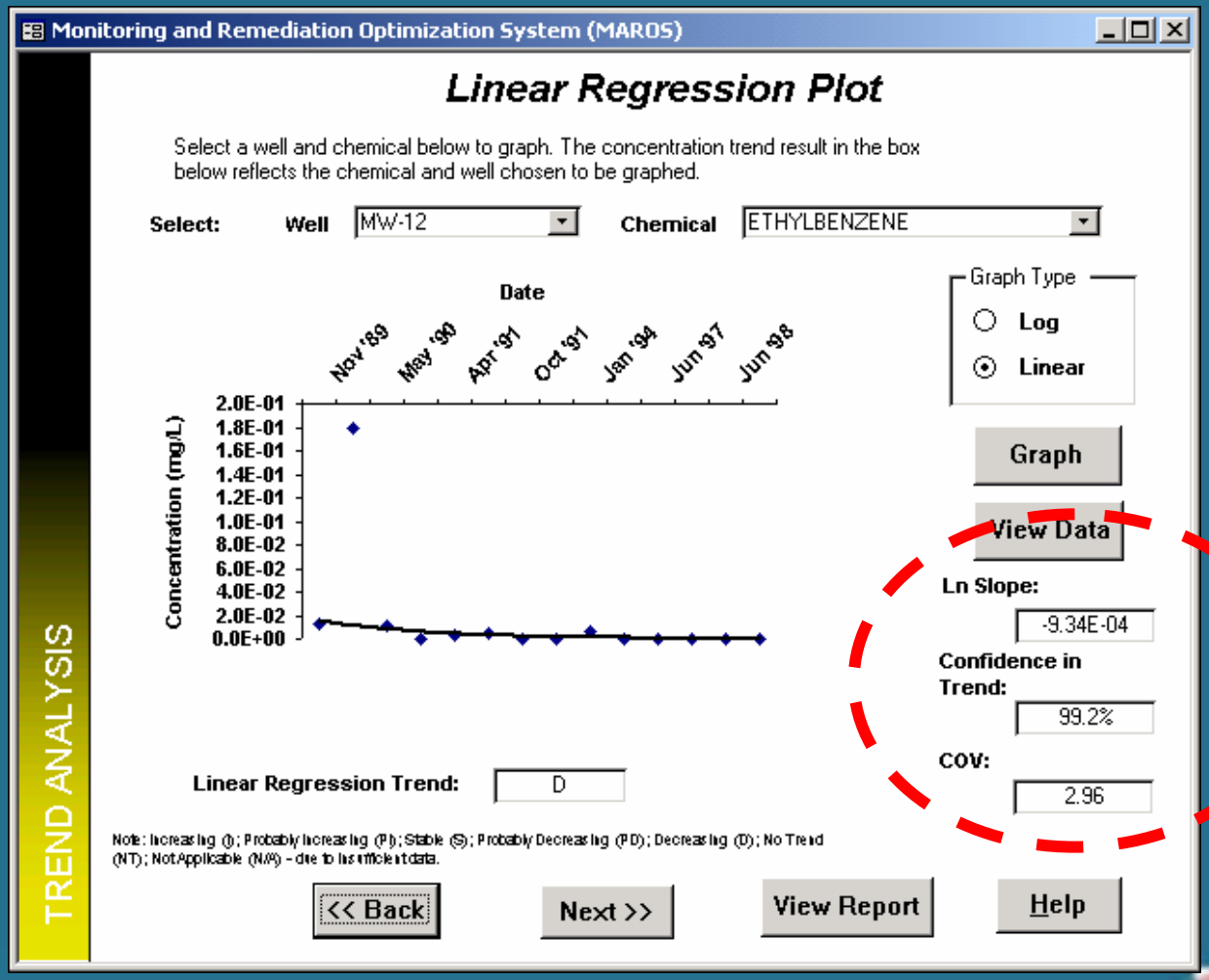
		Confidence Factor		
Mann-Kendall Statistic		CF > 95%	90%<CF<95%	CF < 90%
	S < 0	*Decreasing*	*Prob. Decreasing*	If COV < 1, *Stable* If COV > 1, *No Trend*
	S > 0	Increasing	Prob. Increasing	No Trend

Mann-Kendall Analysis

Results can tie in with Spreadsheet and GIS applications.



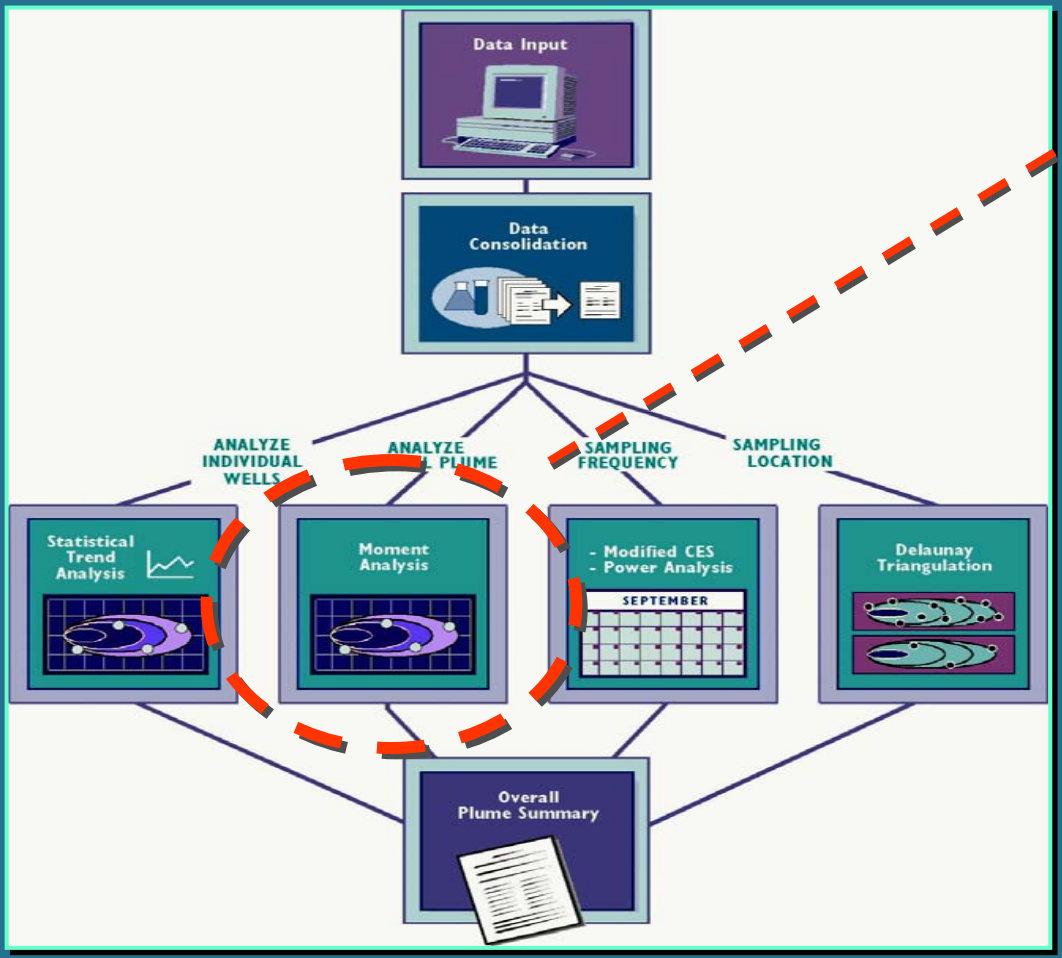
Linear Regression Analysis



MAROS Software Demonstration

- *Activity 5*
  - MAROS Statistical Plume Analysis
  - Mann-Kendall Trend Analysis
  - Linear Regression
  - Trend Reports

MAROS Moment Analysis Module



Moment Analysis

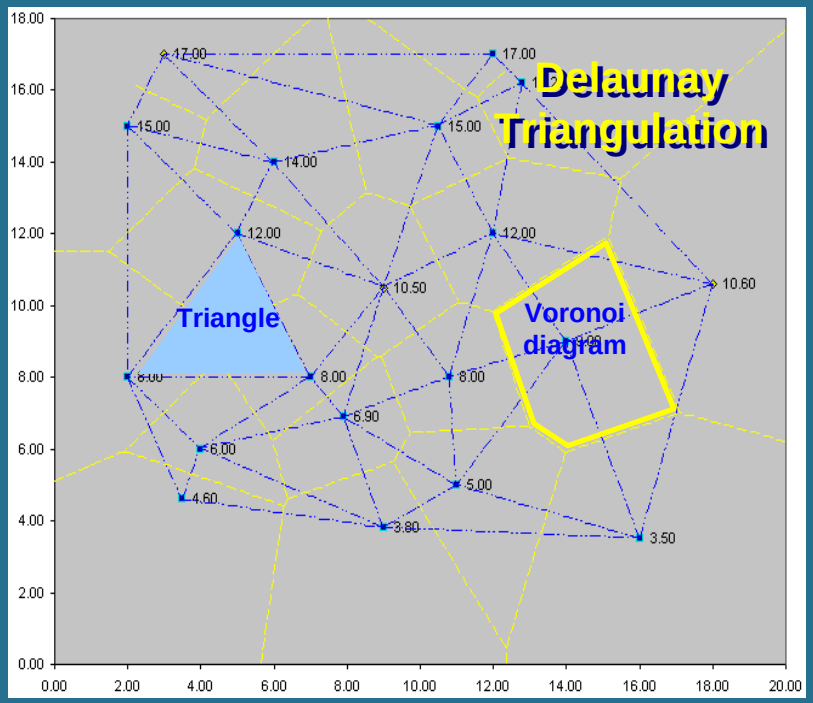
- Approximates
  - Total Mass,
  - Center of Mass
  - Spread of Plume
- Evaluation of Plume Stability Using Moment Trends

MAROS Moment Analysis Estimate

Moment Analysis

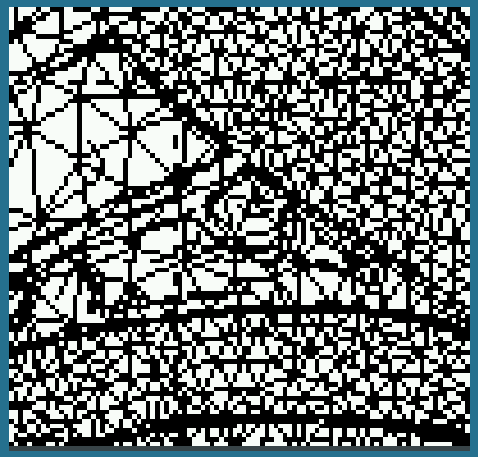
Current Version:

- Numerical approximation, not exact calculation
- Mass estimate built on Delaunay Triangulation
- Updated in MAROS 2.1



Delaunay Method

- Mesh creation method
- 2-D Triangles are constructed from ‘nodes’ corresponding to well locations
- No triangles are created outside the area of wells (no apron of concentration)
- For each triangle, average concentration and centroid is calculated



Delaunay Method

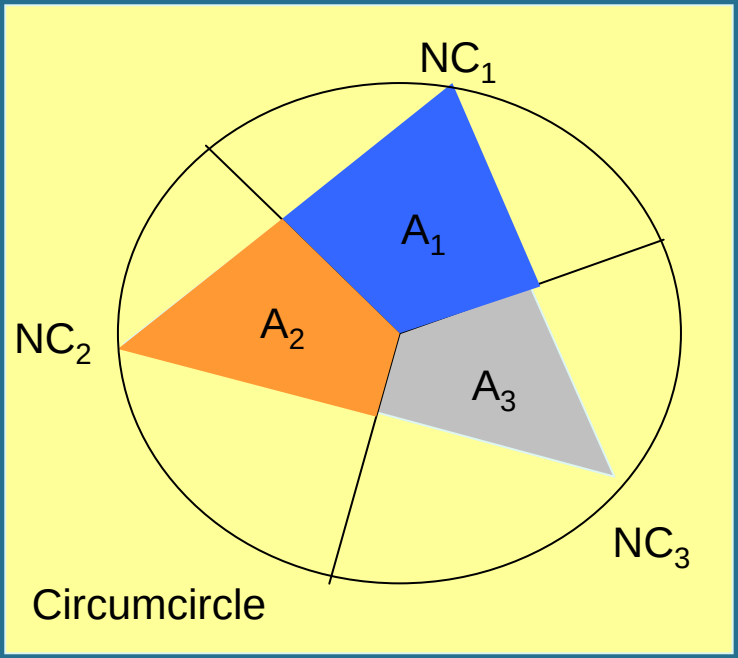
$$TC_i = \frac{NC_1 \cdot A_1 + NC_2 \cdot A_2 + NC_3 \cdot A_3}{A_1 + A_2 + A_3}$$

Where,

$NC_{1,2,3}$ = Concentration at each node

$A_{1,2,3}$ = Area of each sub-part

TC_i = Total average concentration



MAROS Moment Analysis Module

Zeroth Moment Estimates

Total Mass from sum of all triangles (kg)

$\sum$[(Average concentration in triangle) * (Area of triangle) * (porosity) * (saturated thickness)]

Estimates *Trend* of

Total Mass over time→ D, PD, S, PI, I, NT

MAROS Moment Analysis Module

First Moment Estimates

Center of Mass (ft from source)

∑[(Coordinates of Center of triangle) * (porosity)*(Average Concentration)*(Saturated Thickness)*(Area)] /Total Mass

Estimates *Trend* of

Center of Mass in Geographic coordinates→ D, PD, S, PI, I, NT

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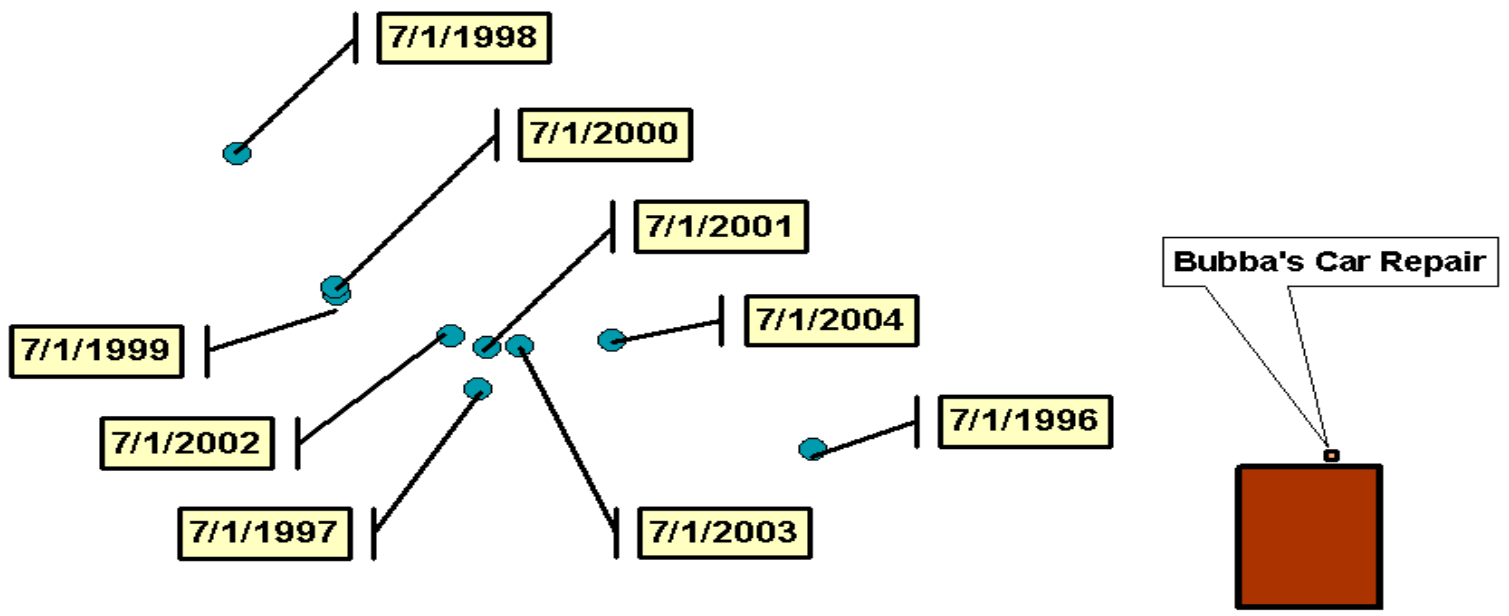
MAROS Moment Analysis Module

Benzene Center of Mass Over Time



MAROS Moment Analysis Module

Second Moment Estimates

Spread of Mass (ft^2)

$S\sum[(X-Xc)^2$ * (Average Concentration) * (Saturated Thickness) * (porosity) * (Area)] /Total Mass

Estimates *Trend* of:

Spread of Mass→ D, PD, S, PI, I, NT

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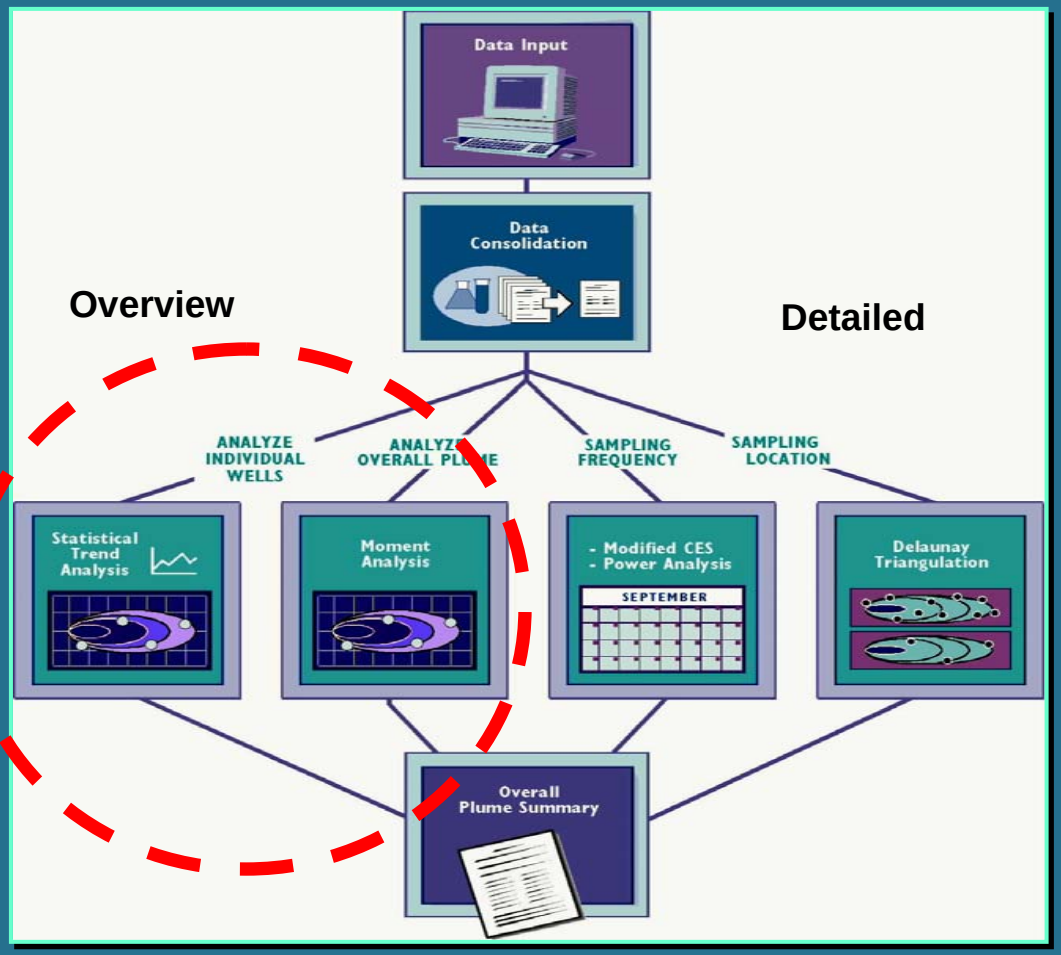
MAROS Software Demonstration

- *Activity 6*
  - MAROS Moment Analysis Estimates
  - Zeroth, First and Second Moment Estimates
  - Visualize First Moments
  - Moment Trend Evaluations

MAROS Overview Module



Overview of Trends

Overview:

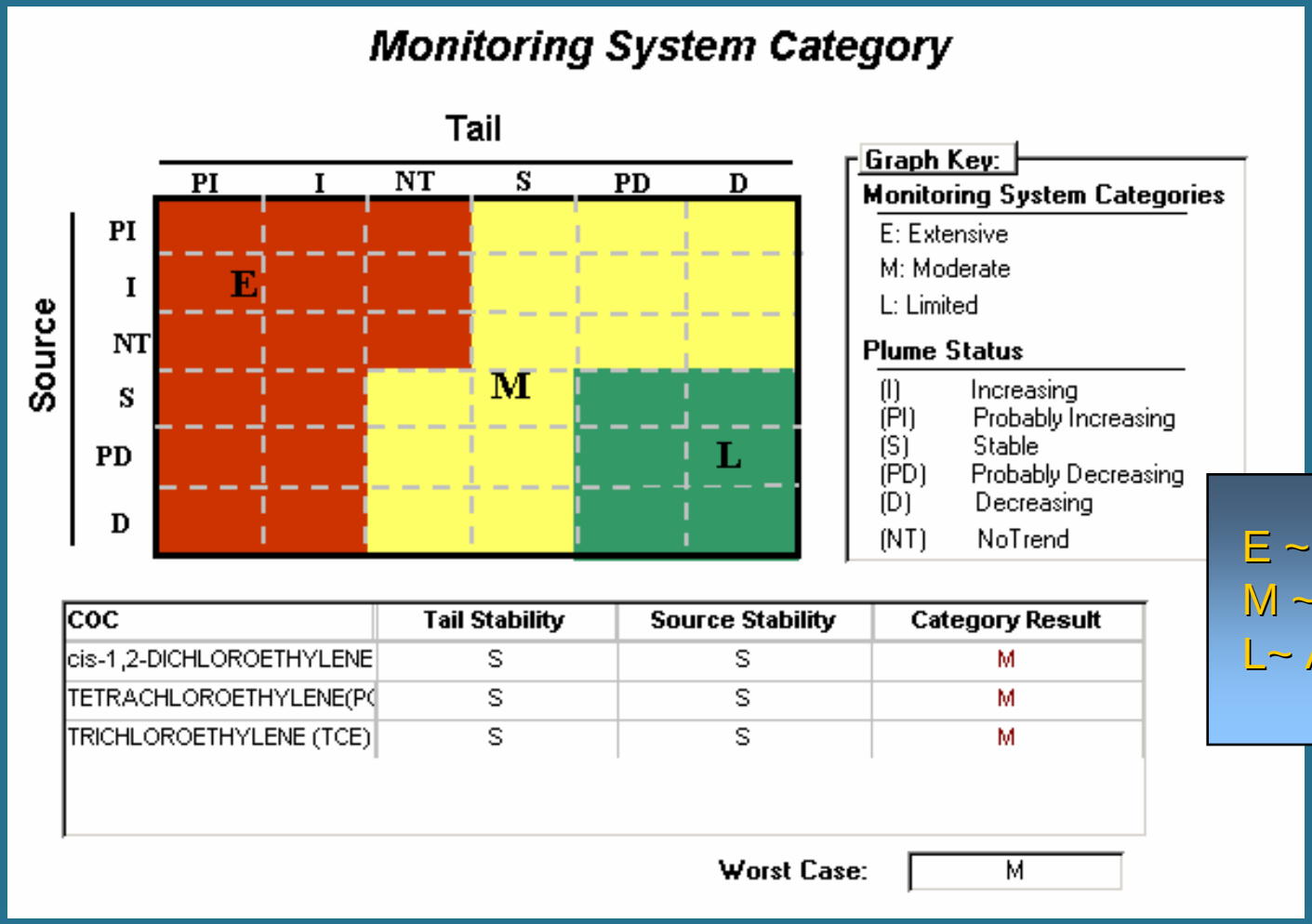
Summary of Trends from Statistical and Moment Analysis

Information Weighting

Monitoring categories

Heuristic relationships

MAROS Overview Module



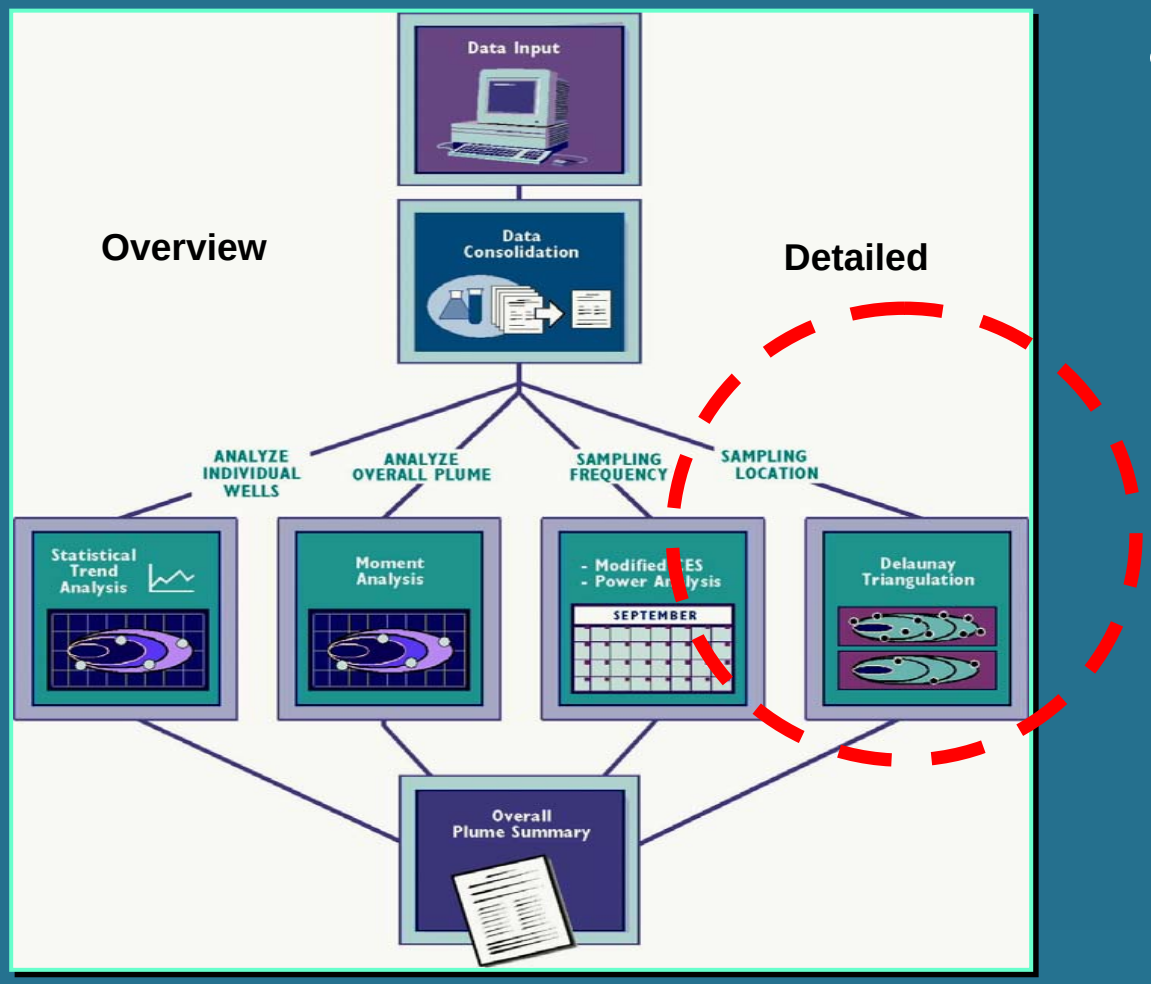
General recommendations based on Trend Analyses for Source and Tail

E ~ Quarterly to Semi-Annual
M ~ Semi-Annual to Annual
L~ Annual to Biennial

MAROS Software Demonstration

- *Activity 7*
  - Information Weighting/ Well Weighting
  - Monitoring System Category
  - Site Results Report

MAROS Spatial Analysis Module



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

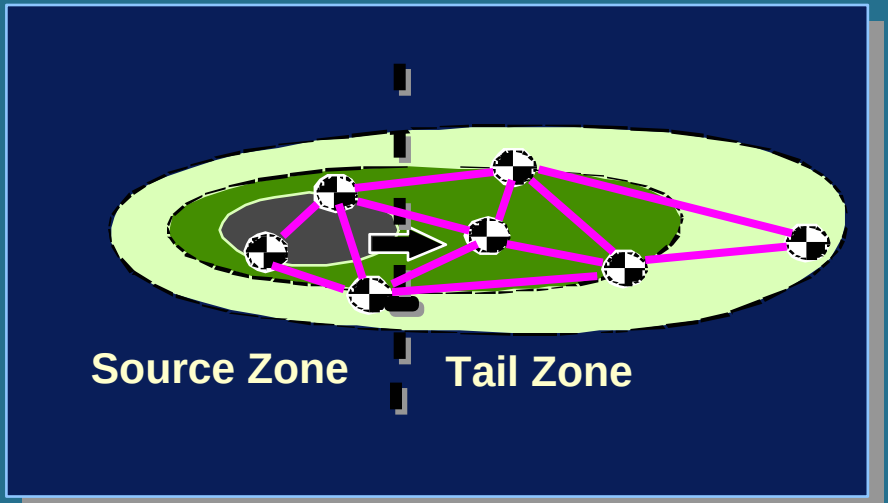
Well Redundancy / Sufficiency Analysis

Delaunay Method

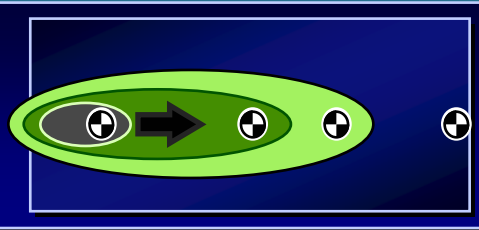
- **Eliminate "redundant" wells**

  OR

- **Add wells in areas with high concentration uncertainty.**



KEY POINT: Does estimated concentration or area change if well is removed?



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Location Analysis – Key Concepts

- Current sampling locations are not equally important in providing the needed information
- Locations that contribute least to concentration estimation can be eliminated
- Areas with large estimation errors are where new wells can be placed

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Location Analysis – Key Concepts

- Determine important locations
  Define Slope Factor (SF) = difference between measured and estimated concentration at each location

- Locations that contribute to concentration estimation
  Define Average Concentration Ratio (CR) and Area Ratio (AR) to compare information loss before and after well elimination

- Areas with large estimation errors
  Define Slope Factor (SF)

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Slope Factor

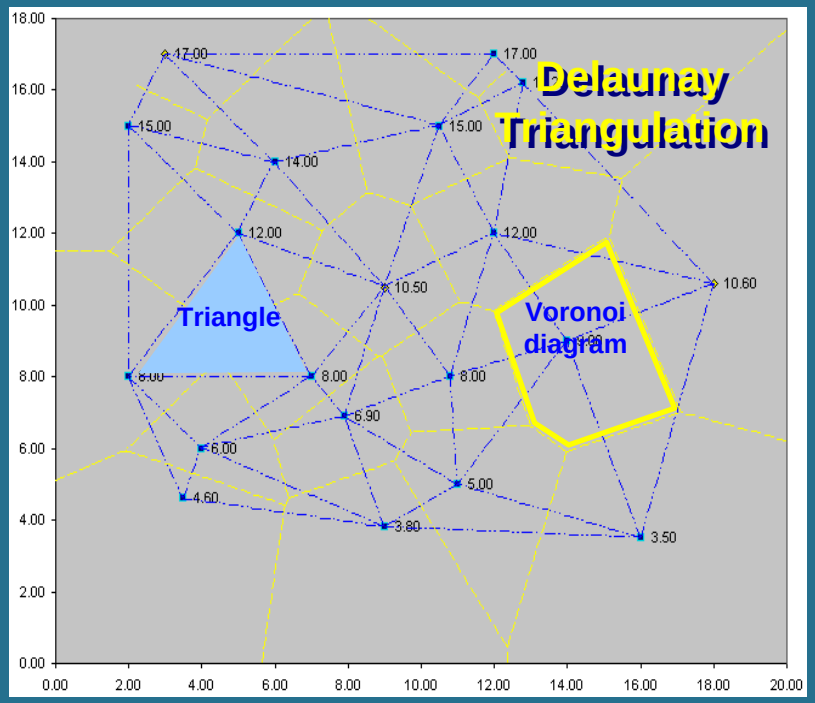
Calculate Slope Factor (SF) as

$$SF_i = \left| \frac{EC_i - NC_i}{Max\ (EC_i, NC_i)} \right|$$

Estimated concentration of node:

$$EC_i = \left[\sum_{j=1}^{M} NC_j \cdot \frac{1}{d_{ij}} \right] \Bigg/ \left[\sum_{j=1}^{M} \frac{1}{d_{ij}} \right]$$

where, *M* = number of triangles surrounding the node



SF → 1, well is important; SF → 0, well is not important

Measures of Information Loss

Concentration Ratio

$$CR = \frac{C_{avg,\ Current}}{C_{avg,\ Original}}$$

The average concentration of plume is

$$C_{avr} = \sum_{i=1}^{N} TC_i \cdot TA_i \Big/ \sum_{i=1}^{N} TA_i$$

Area Ratio

$$AR = \frac{A_{Current}}{A_{Original}}$$

Ratios close to 1, information loss minimal

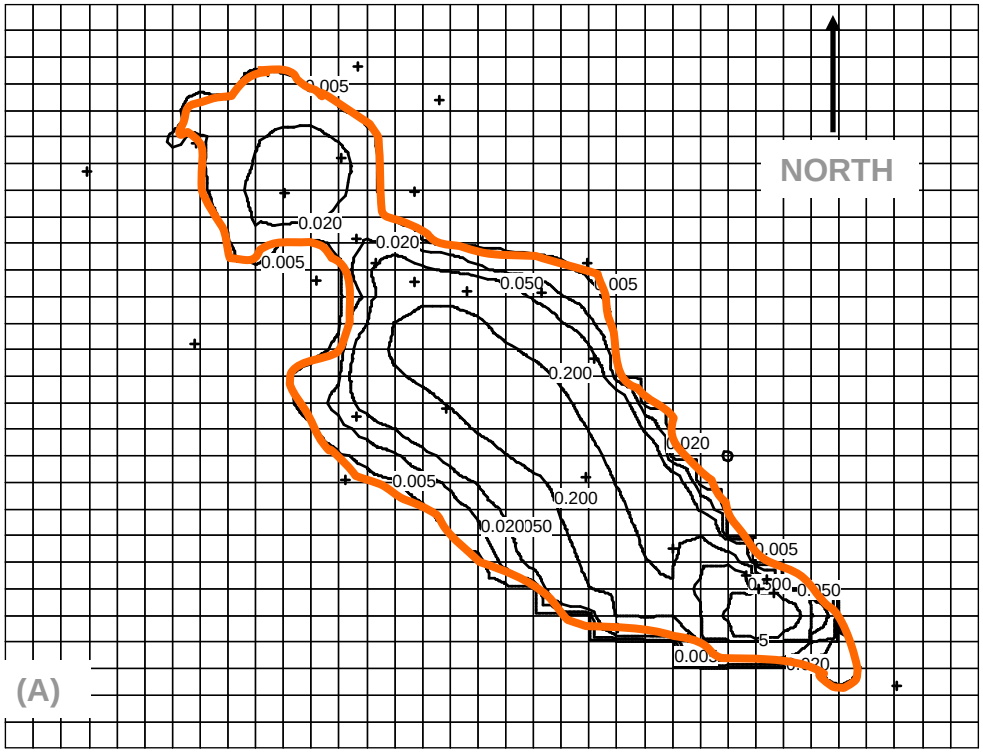
Ratios far from 1, information loss significant

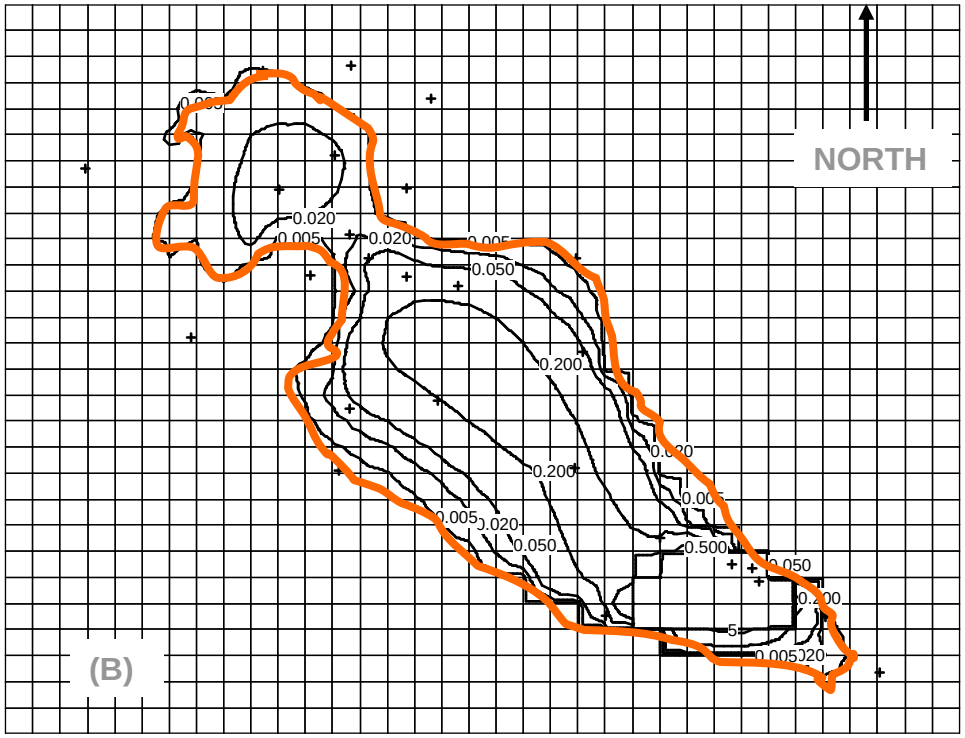
Well Elimination Decision Matrix

Decision Rule: Eliminate insignificant wells without causing significant information loss

Sampling Location Elimination Status		
Interpretation	**SF → 0 (Perfect estimation)**	**SF → 1 (High estimation error)**
CR and/or AR << 1 (Significant information loss)	**Keep**	**Keep**
CR → 1 and AR → 1 (Less Information loss)	**Eliminate**	**Keep**

Visual Comparison of TCE Plumes



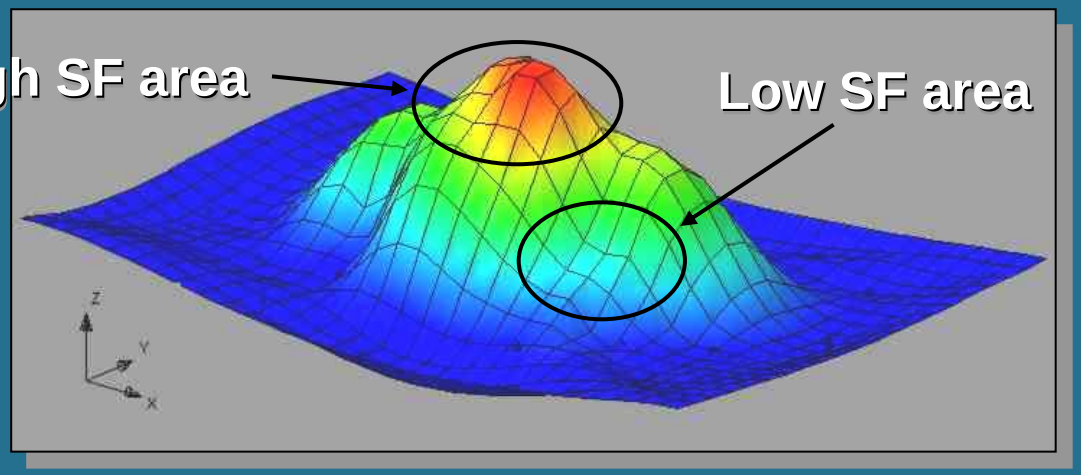


(A) September 2001
32 Wells

(B) September 2001
28 Wells

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 Elimination and New Location: Advice

- Only areas within the network are analyzed
- Does not evaluate regulatory, cultural, social, political reasons for locating a well
- Compliance points/Regulatory requirements not included
- If plume not delineated — cannot recommend exact new location for well outside network

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MAROS Software Demonstration

- *Activity 8*
  - Sampling Location Analysis
  - Well Redundancy Analysis
  - Site Results Report
  - Well Sufficiency Analysis

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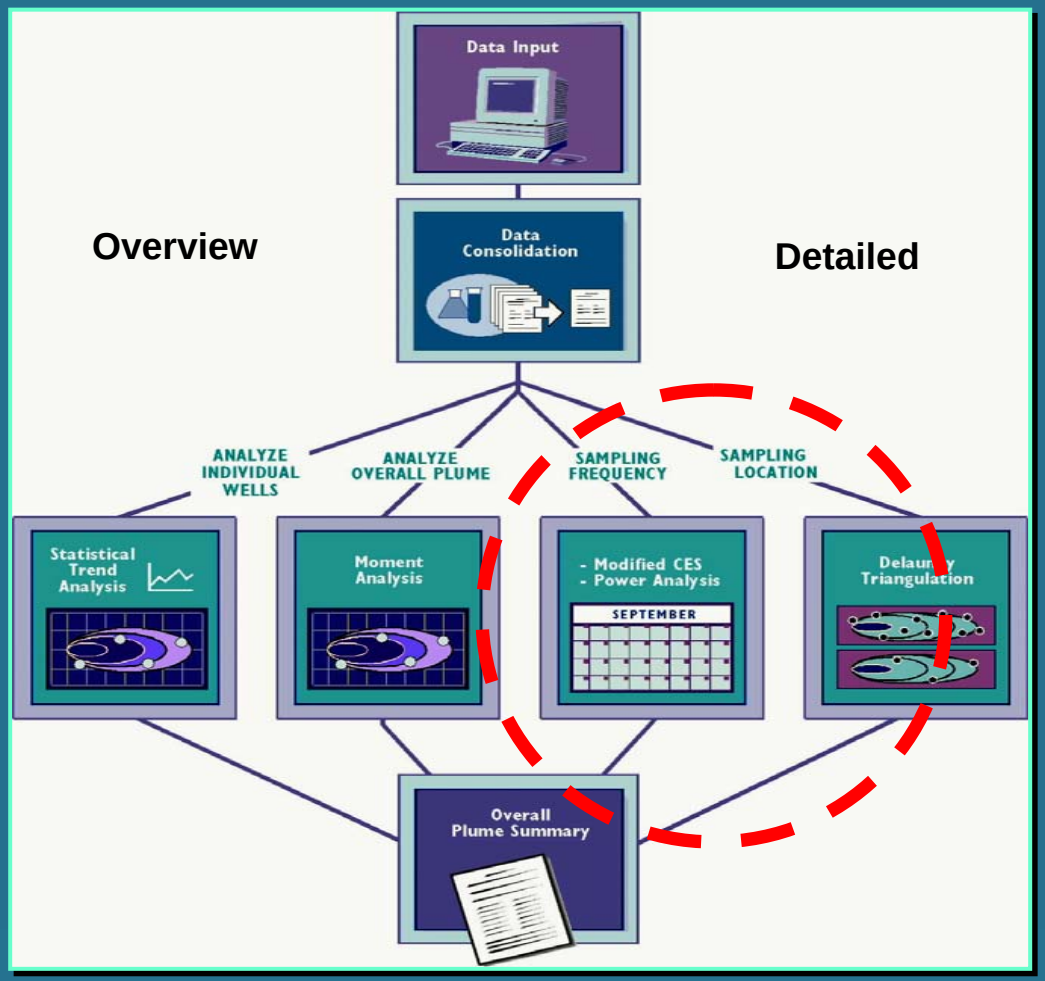
MAROS Frequency Analysis Module



- Optimization Tools:

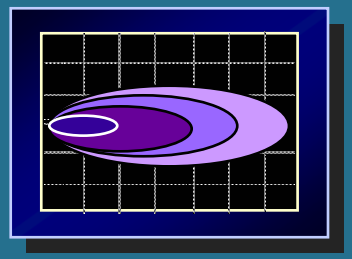
  –*Sampling Frequency: Modified CES*

  (Ridley et al., 1998)

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

Sampling Frequency

Cost Effective Sampling



- Recent and Overall trends considered
- Rate of Change (ROC) of concentration sets frequency
- Variability determined from distribution-free Coefficient of Variation (COV)
- Decision logic based on
  - Concentration vs. MCL
  - Previous monitoring frequency
  - Some qualitative analysis

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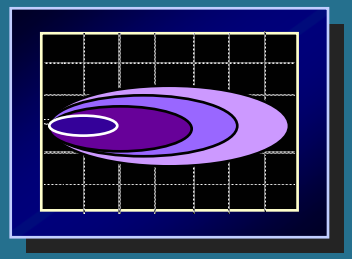
Sampling Frequency

Modified CES



- Recent (6 events) trends – considered
- Mann-Kendall trend replaces Dist.-free COV
- ROC and COV– the magnitude and uncertainty of trend based on simple linear regression
  - High, Med-High, Medium, Med-Low, Low

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

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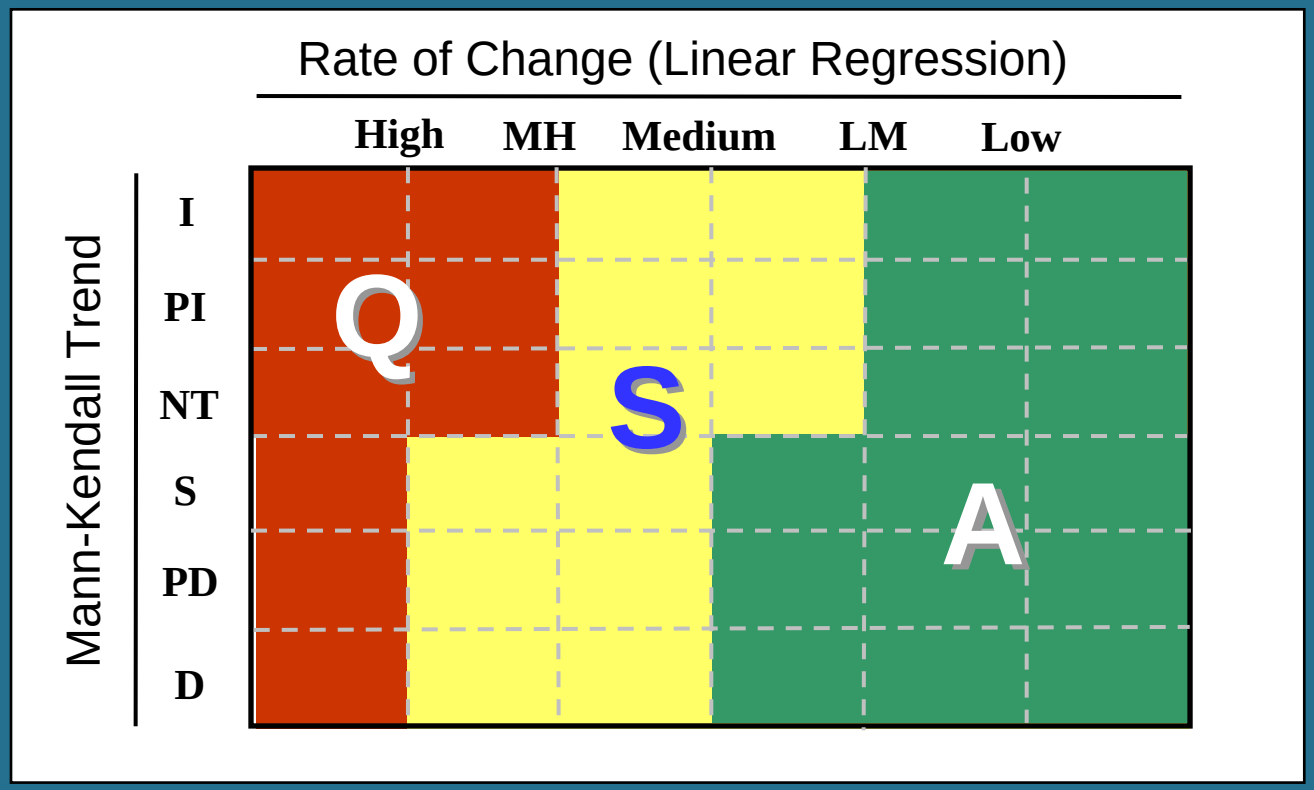
Sampling Frequency – Decision Map

Sampling Frequency

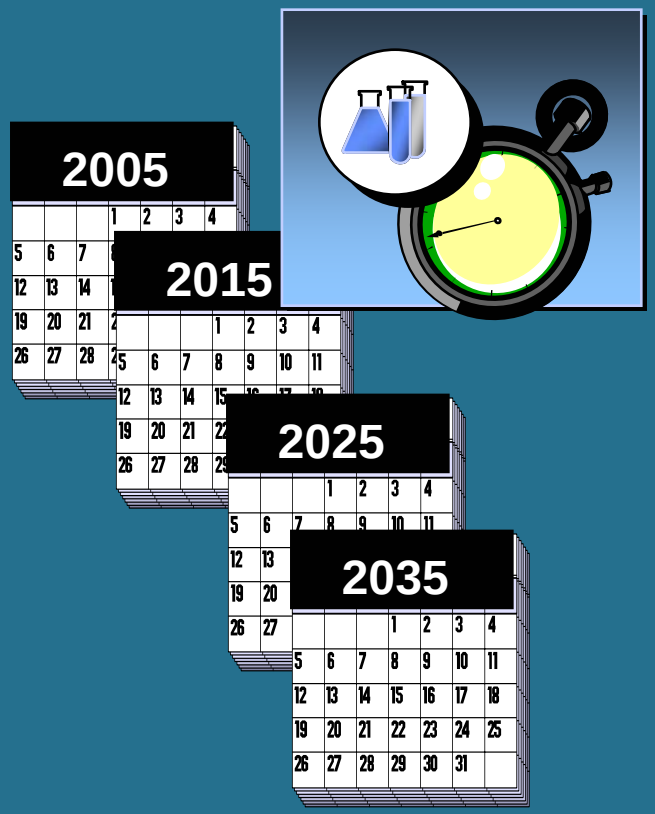
Q: Quarterly
S: Semiannual
A: Annual



Note: These are preliminary suggestions — Review unique site issues before final recommendation!

Sampling Frequency: Advice

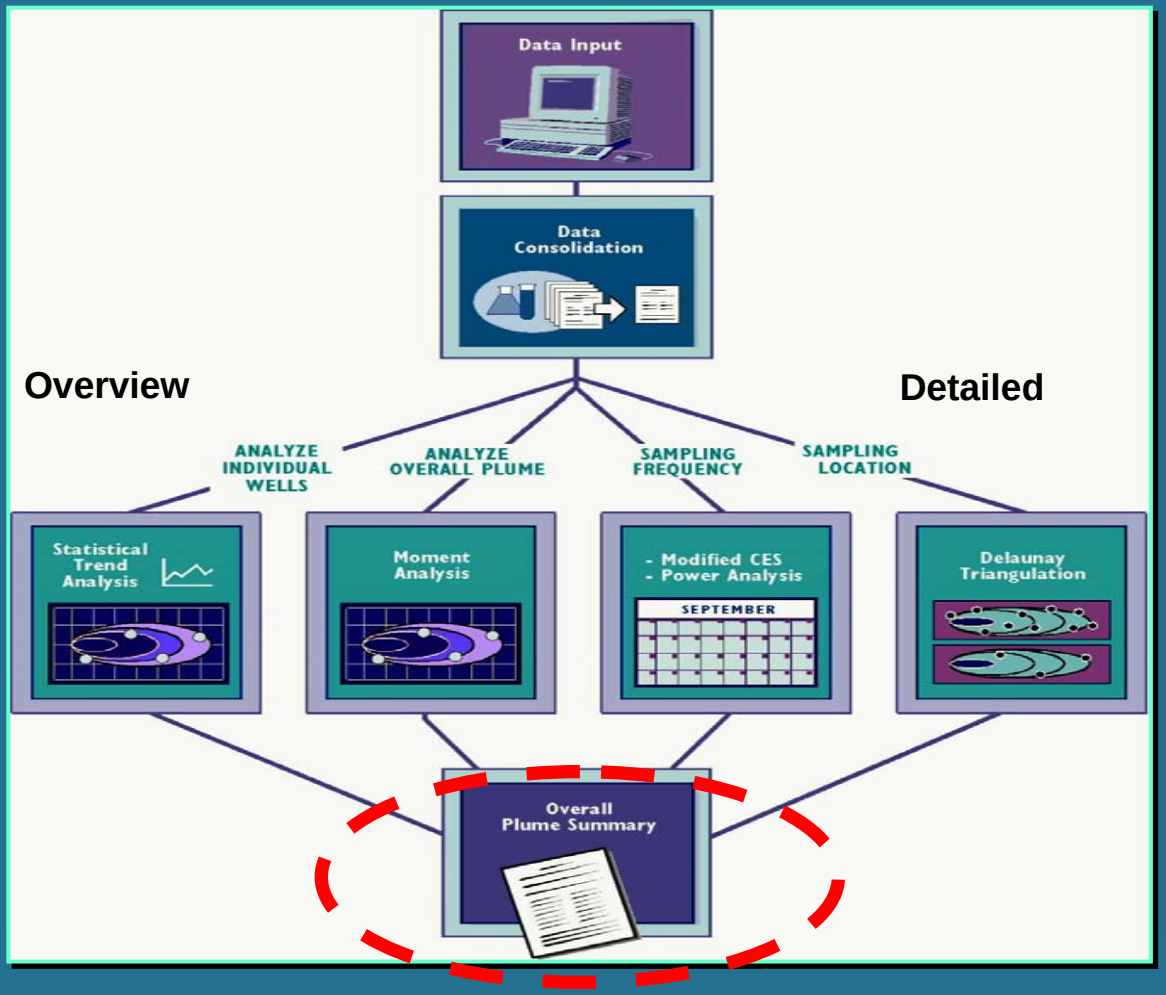
- Multiple COCs give different results
  - Consider priority of constituent
  - Rate of change at well vs. MCL
- Evaluate results
  - Length of monitoring history
  - Above or below Screening # (MCL)
  - Detections and Detection Limits
- Many wells have short history
- Regulatory issues/Compliance wells
- Network should be re-evaluated periodically



MAROS Software Demonstration

- *Activity 9*
  - Sampling Frequency Analysis
  - Set Options for Slope Factors and CR and AR
  - Interpret Results

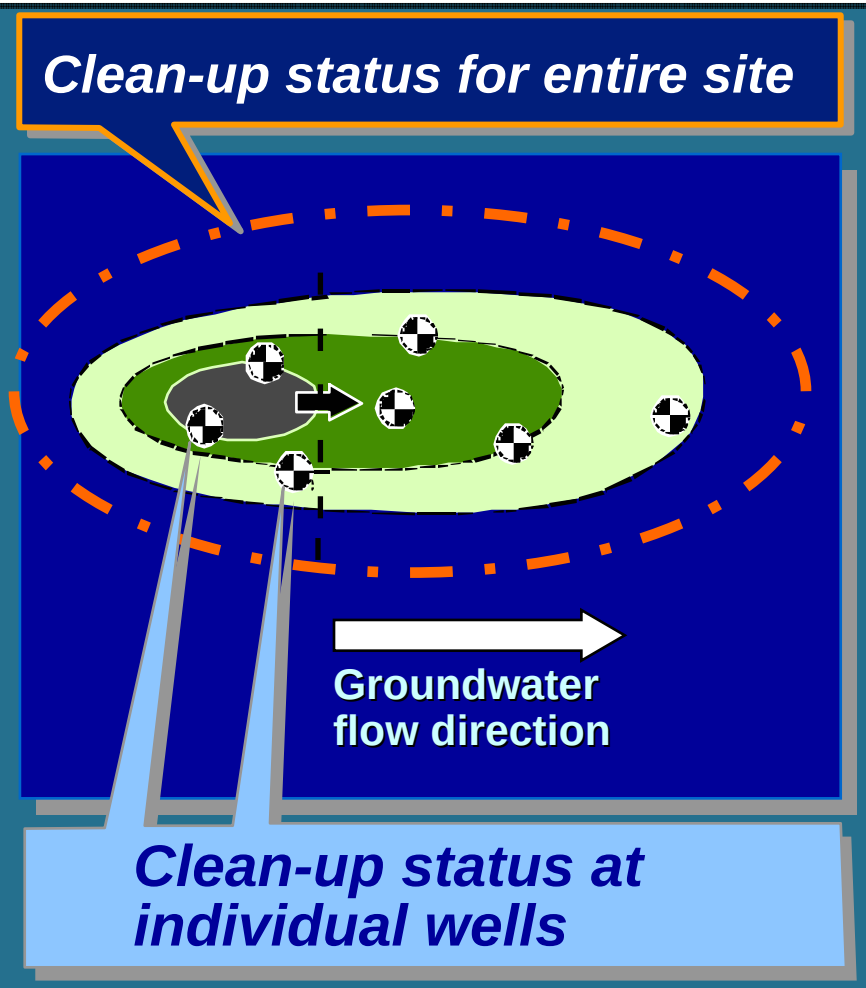
MAROS Data Sufficiency



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

Data Sufficiency: Purpose

1. Increase confidence in monitoring results to detect subtle changes in concentration
2. Detect individual points where sampling is inadequate



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Data Sufficiency: Warning

1. Statistical standard for well clean-up is very high.
2. Do not use module if you do not fully understand the statistics, as they can be misapplied.
3. Plume clean-up method uses simple regression to project concentrations, and may not be applicable to your site.

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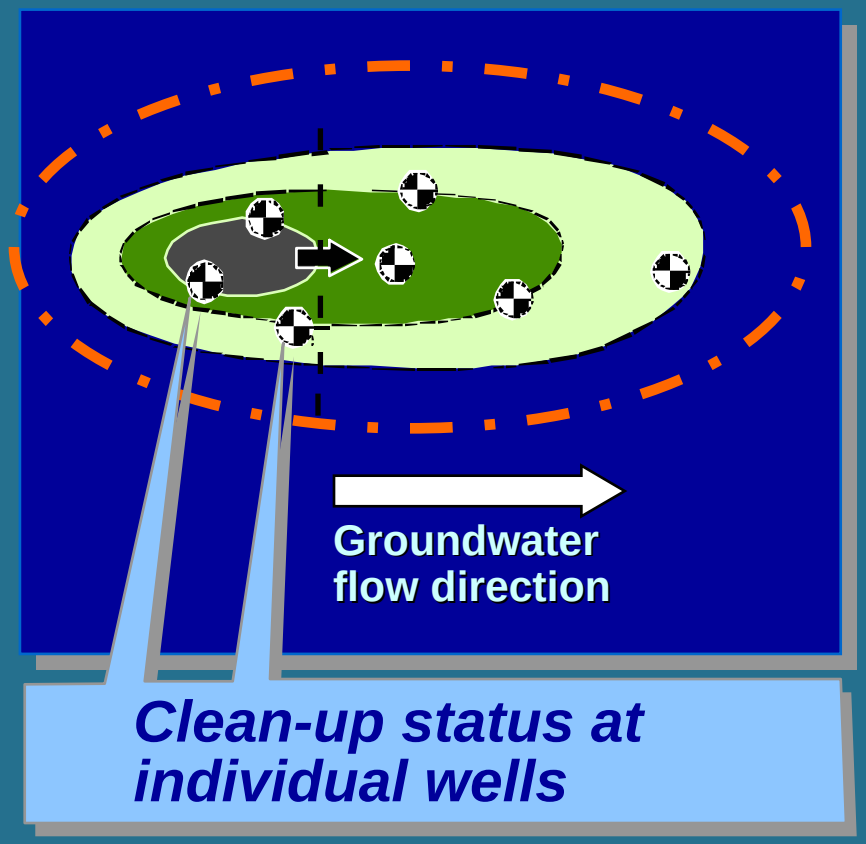
Data Sufficiency: Individual Wells

1. Sequential T-Test and probability of correctly identifying contaminated well to determine if clean-up is 'Attained'

2. Optional Power Analysis Uses Student's T-test — is well statistically below MCL?

   Expected # of samples to reach Power.



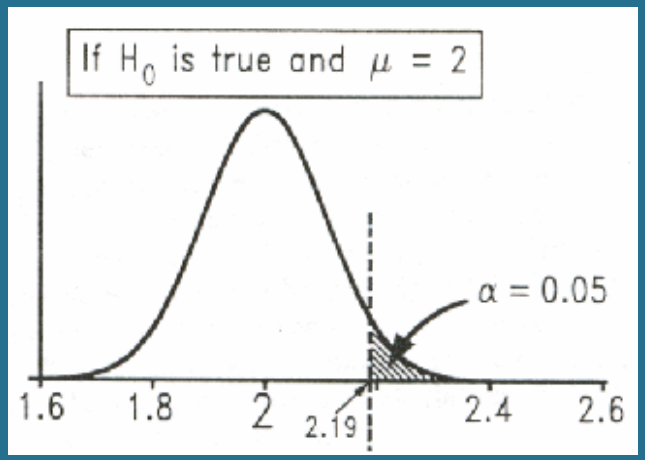
USEPA, 1992

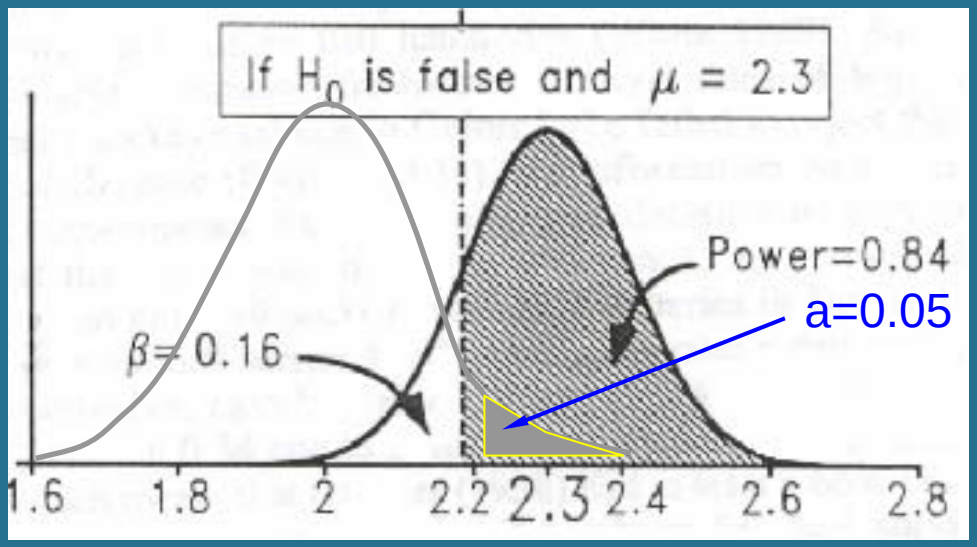
Statistical Power – Graphical Illustration

Hypotheses: $H_0: \mu = 2.0;\ H_1: \mu \neq 2.0$

Test error rates: $\alpha = 0.05;\ \beta = 0.16$

Effect size: $\dfrac{\Delta\mu}{\sigma}$ $(\Delta\mu = 0.3)$





Statistical Power Analysis – Example 1

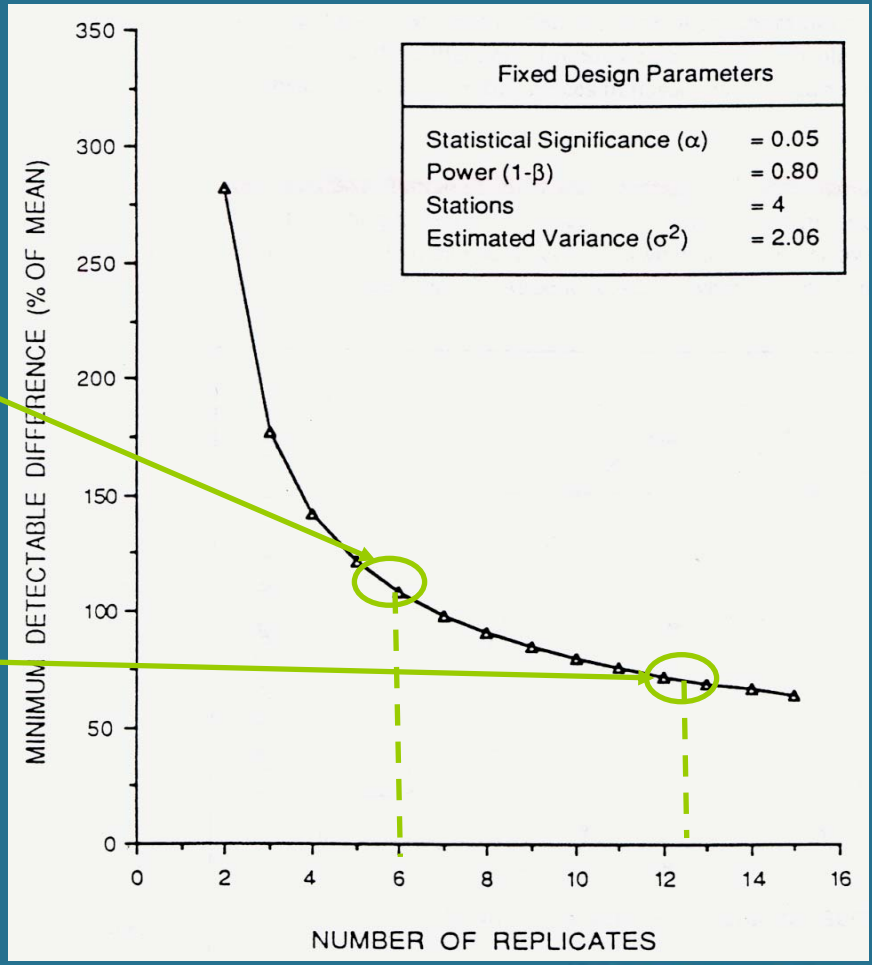
Minimum detectable difference vs. Sample size

120% Δm

Small sample size → *Low resolution*

80% Δm

Large sample size → *High resolution*



Statistical Power Analysis – Example 2

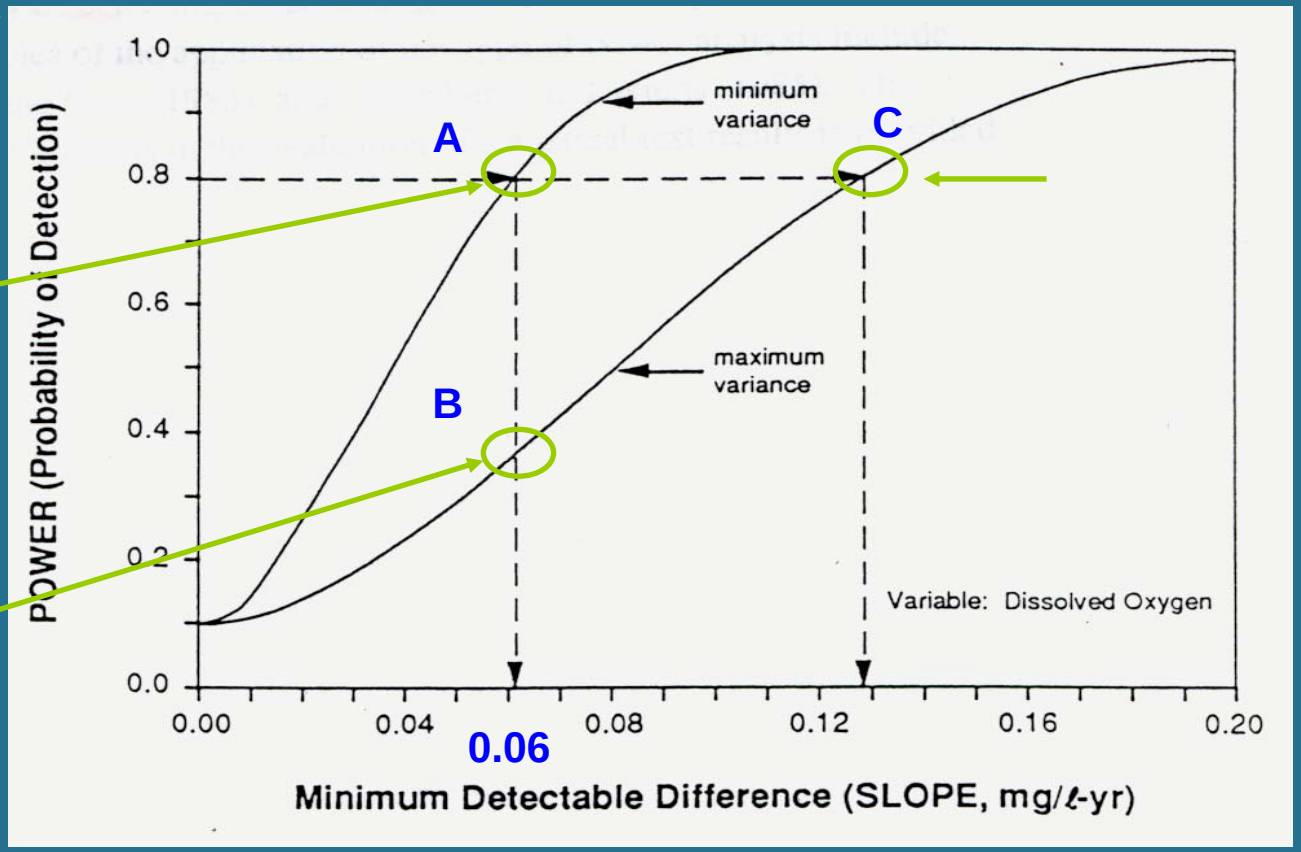
Statistical power vs. *Minimum detectable difference at different levels of uncertainty*

Power = 0.8

Low uncertainty → high power

Power = 0.35

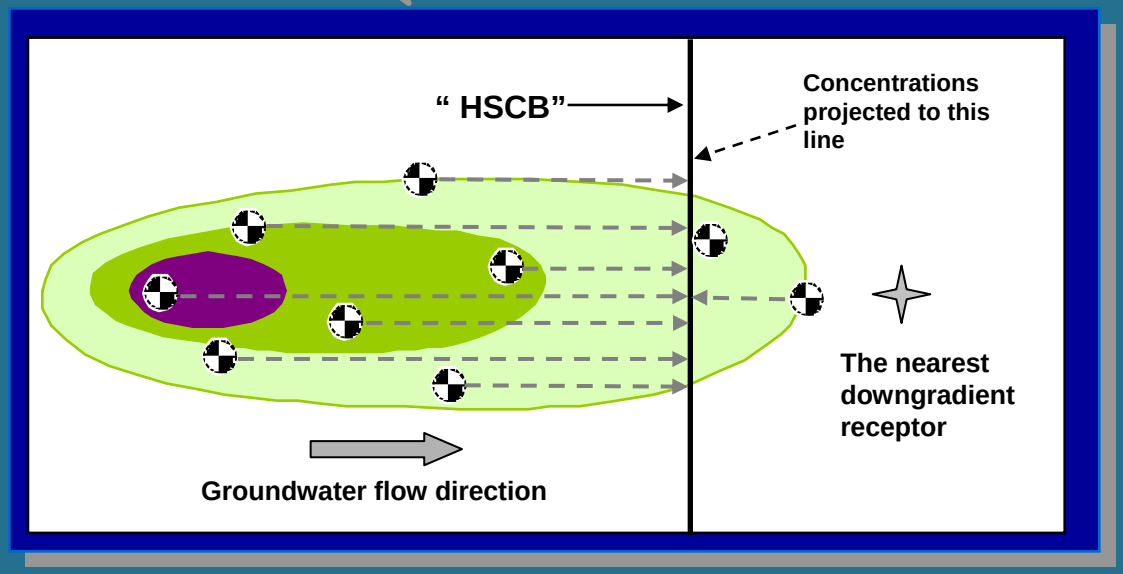
High uncertainty → low power



Data Sufficiency: Site Clean-up

1. Regress centerline wells
2. Predict concentrations at hypothetical statistical compliance boundary (HSCB).
3. Project concentrations at HSCB for all other wells
4. Power Analysis to determine clean-up status of plume.

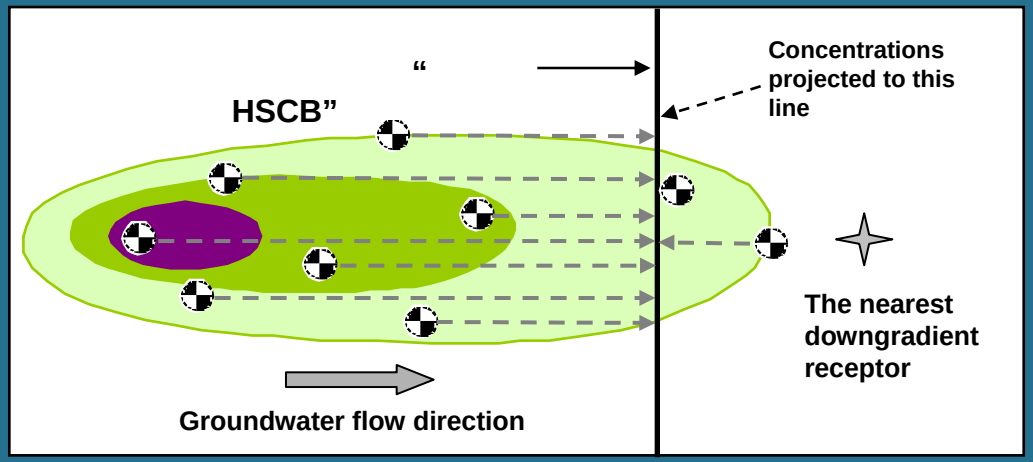
Clean-up status for entire site



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 .

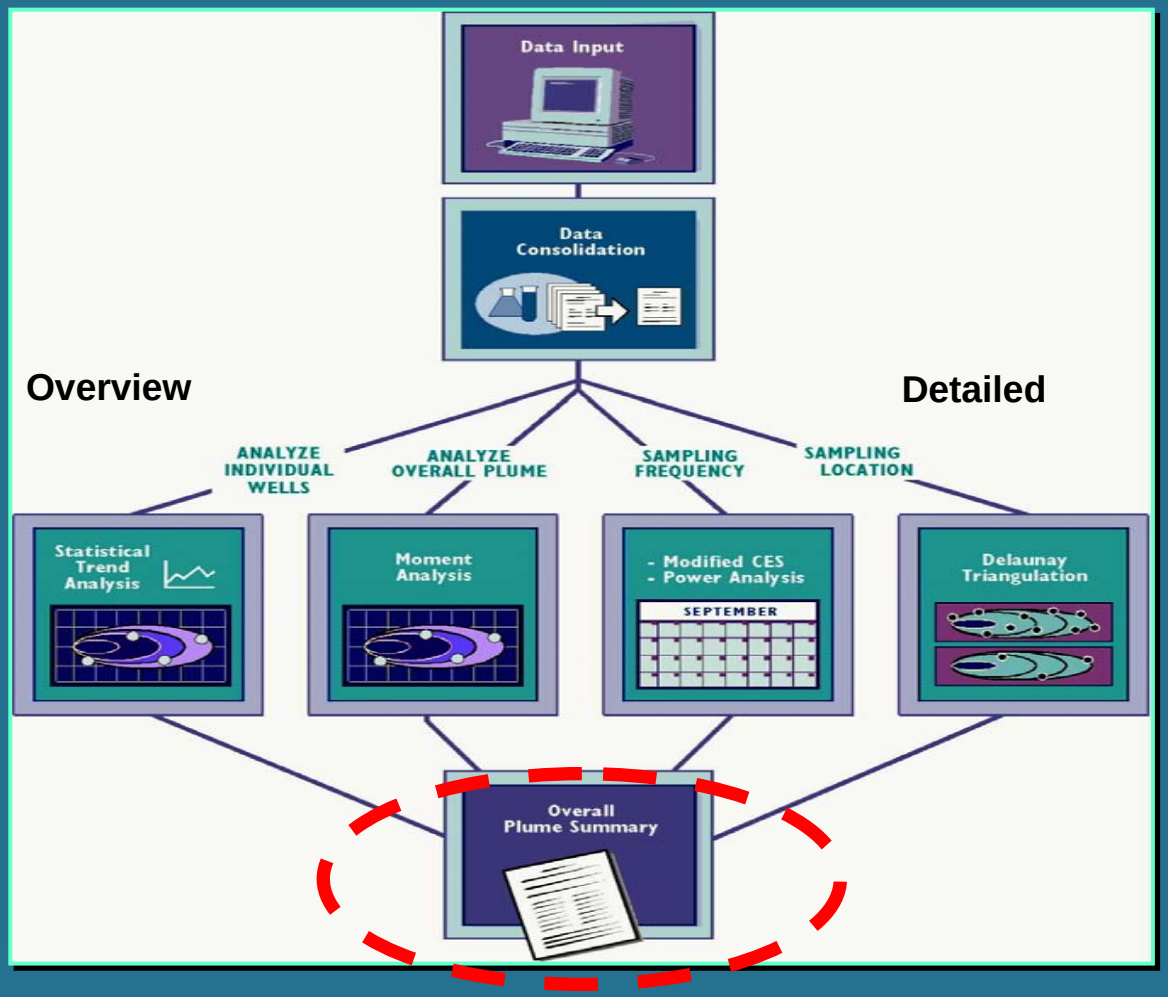


HSCB: Hypothetical Statistical Compliance Boundary

MAROS Software Demonstration

- *Activity 10*
  - Data Sufficiency Analysis
  - Set Options for Target Clean-up and Power
  - Interpret Results

MAROS Output



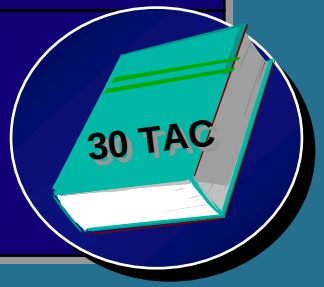
- Graphs, Reports and Tables
- Output DB File

MAROS Software Demonstration

- *Activity 11*
  - Reports
  - Graphs
  - Output File

MAROS Interpretation: Advice

1. Prepare data and Prioritize COCs
2. Establish lines of evidence
3. Compare across COCs
4. Evaluate lines of evidence; compare with other site details
5. Identify Regulatory and Qualitative issues



LTMO

What I like about MAROS!

- Modular—many lines of evidence
- Transparent—algorithms are mathematically understandable.
- Simplifies large quantities of data.
- Output hard copy, reports, electronic files.
- Free!

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

(Don't forget the manual!)