REMTECH 2006

A Defensible and Unbiased Approach for Confirming Effective Removal of Contaminated Soil for Remedial Excavations

by
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Background…1

- To confirm effective cleanup for a remedial excavation a confirmatory sampling plan is necessary.
- However, not all Provinces have provided guidance on confirmatory sampling plans…

Background…2

- **For example:**
  - **BC – 10 m grid for walls and floor of UST excavations**
  - **Ontario – 5 m grid for walls, 10 m grid for floor of UST excavations**
- **Rationale for these grid requirements is not provided.**

Environmental Sampling Plans

- **Usually based either on:**
  - **Professional judgement and "expert" opinion**
- **Or**
  - **Statistically defensible decisions**

Judgemental Sampling

- **Strengths:**
  - **Focussed – can avoid areas of no apparent interest**
  - **Greater control over sampling costs**
- **Weaknesses:**
  - **Depends on quality of judgement**
  - **Variability in quality and reliability**
  - **Difficult to defend statistically – how many samples should be taken?**

Sometimes it is obvious where to sample.


Sometimes it is not.
50

Statistical Sampling Plans…1

- **Strengths**
  - **Statistics based – valid inference to population parameters, e.g. mean and variance**
  - **Can quantify performance – probability of detection or confidence limit**
  - **Can optimize design – balance between uncertainty and cost**

Statistical Sampling Plans…2

- **Weaknesses**
  - **More complicated process – more difficult to explain**
  - **Usually more samples – higher costs**
  - **Cannot be used for point sources, e.g. PHC-impacted groundwater plume**
  - **Limited to populations where values are not spatially or temporally correlated**

A Short History of SSP

- 1948 Freeman et al. Sampling Inspection
- 1972 Singer. ELIPGRID – a FORTRAN program to locate elliptical hot-spots
- 1977 – 1982 PNL TRAN-STAT Bulletins
- 1984 Zirschky & Gilbert. Detecting hot spots at hazardous-waste sites
- 1987 Gilbert. Statistical Methods for Environmental Pollution Monitoring – The BOOK!
- 1990s USEPA / DOE DQO Process

Statistically Defensible Decisions - Procedure

1. Develop a conceptual site model
2. Formulate null hypothesis, H_0: e.g. “Site is dirty” (Regulators view)
3. Arrive at decision by testing H_0 statistically
4. Bound decision errors
5. Obtain an adequate number of samples and sample locations

VSP

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A tool for developing statistical sampling plans:

Visual Sampling Plan (VSP)

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VSP – Visual Sampling Plan

- Tool to develop systematic statistics-based sampling plans
- Developed by PNNL in 2001
- Currently Version 4.6b
- For soil, sediment, surface sampling – not groundwater (yet)
- Web site: http://dqo.pnl.gov/index.htm
- VSP training courses held a few times per year

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VSP 4.6

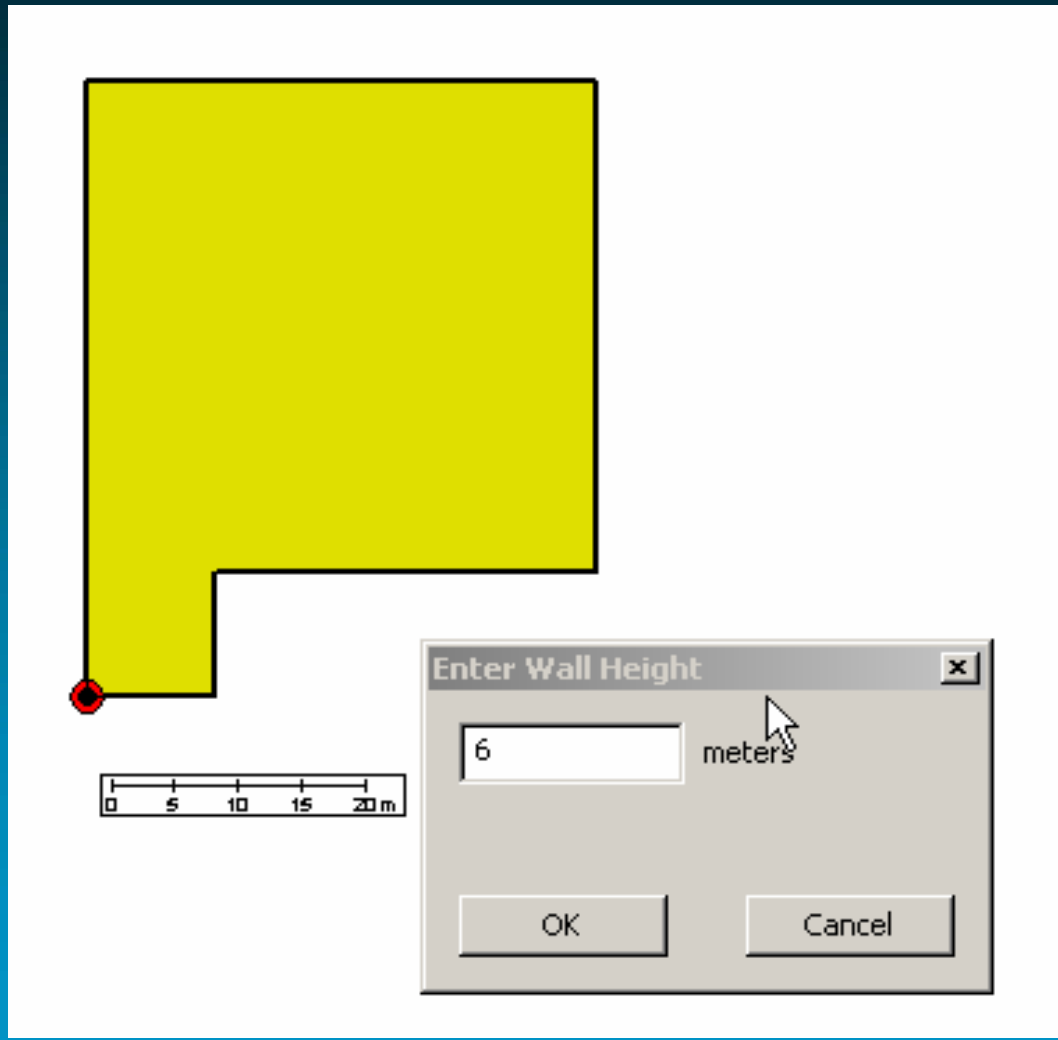
- **Addresses part of the 7-step EPA DQO process:**
  - **Specifies limits on decision errors**
  - **Optimizes design of sampling plan**
- **Determines:**
  - **How many samples are needed?**
  - **Where should the samples be taken?**
- **Performs some statistical evaluations**

How to Use VSP?

- **Examples to illustrate developing a sampling plan:**
  1. **Sampling remedial excavation walls to determine probable “hot spot” size**
  2. **Determining grid size for given “hot spot” size & probability of detection**
  3. **Sampling a study area for remedial excavation requirements**

Example 1 – Excavation Wall for UST Removal

- **Plan View:**
  - Approximately 40 m x 40 m
- **Wall height:**
  - 6 m



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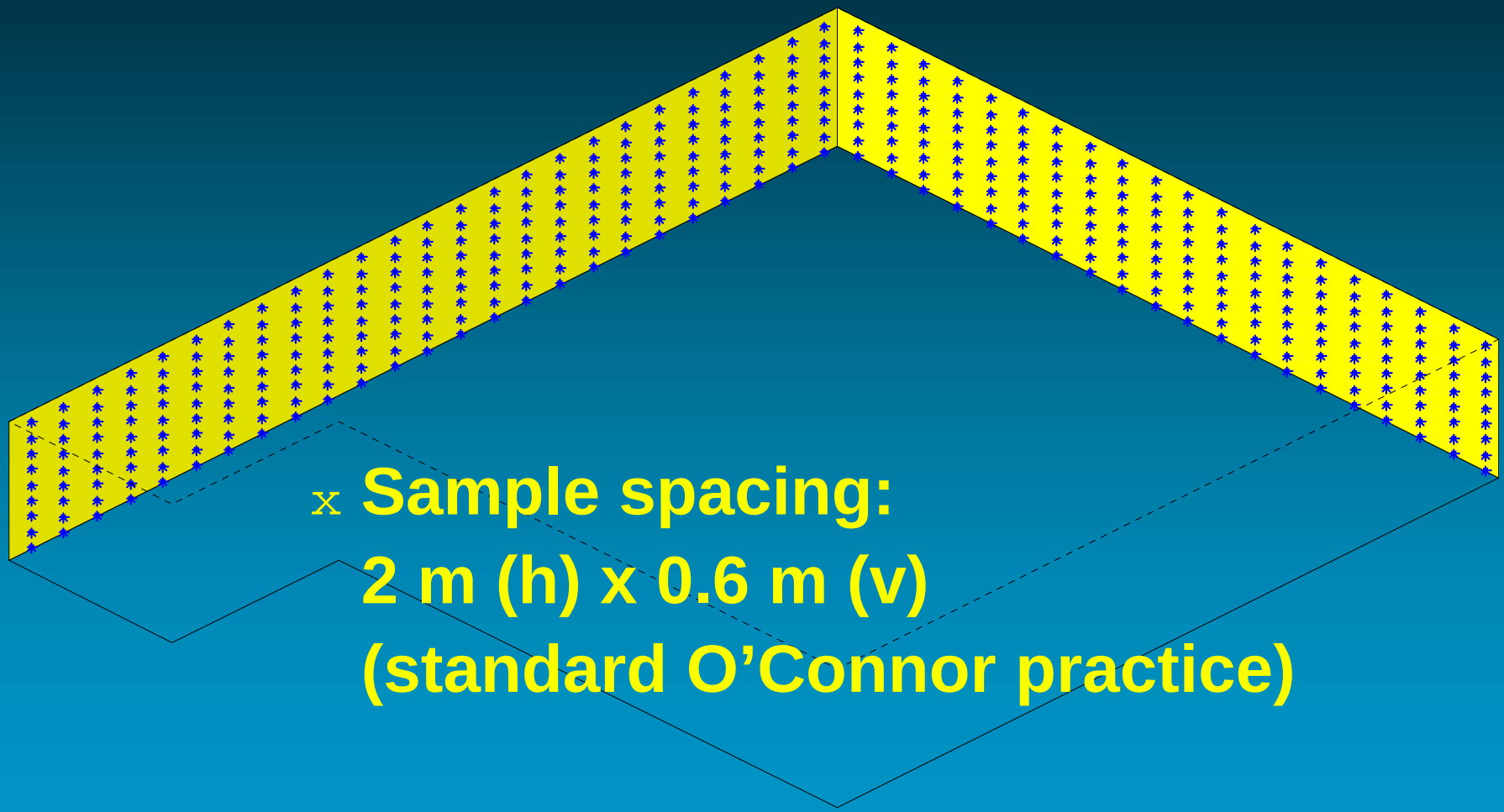
Ex.1 - Grid Sampling on Walls

Room 1



- **Sample spacing:**
  2 m (h) x 0.6 m (v)
  (standard O'Connor practice)

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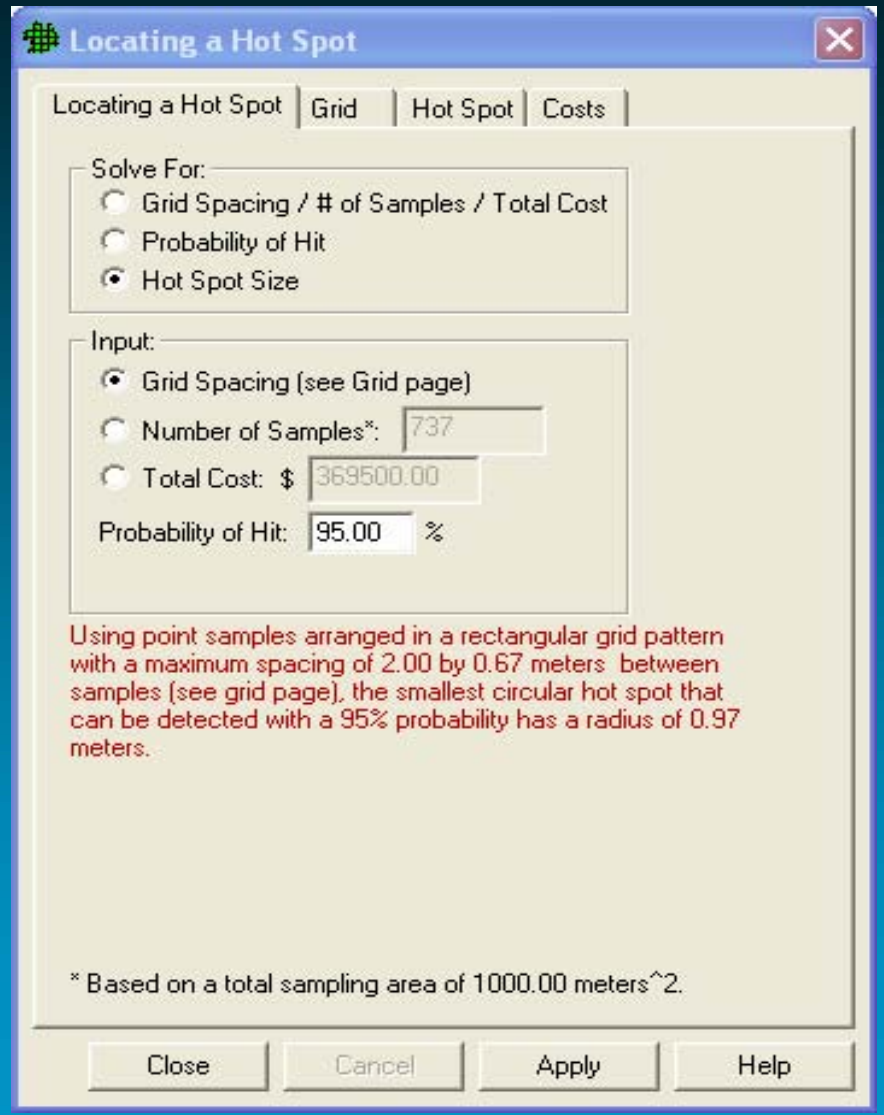
Ex.1 - Performance of Grid

- Using a 2 m x 0.67 m grid, we can detect circular hot spots 0.97 m radius (min.) with a probability of 95%
- Area of hot spot = 2.95 m^2



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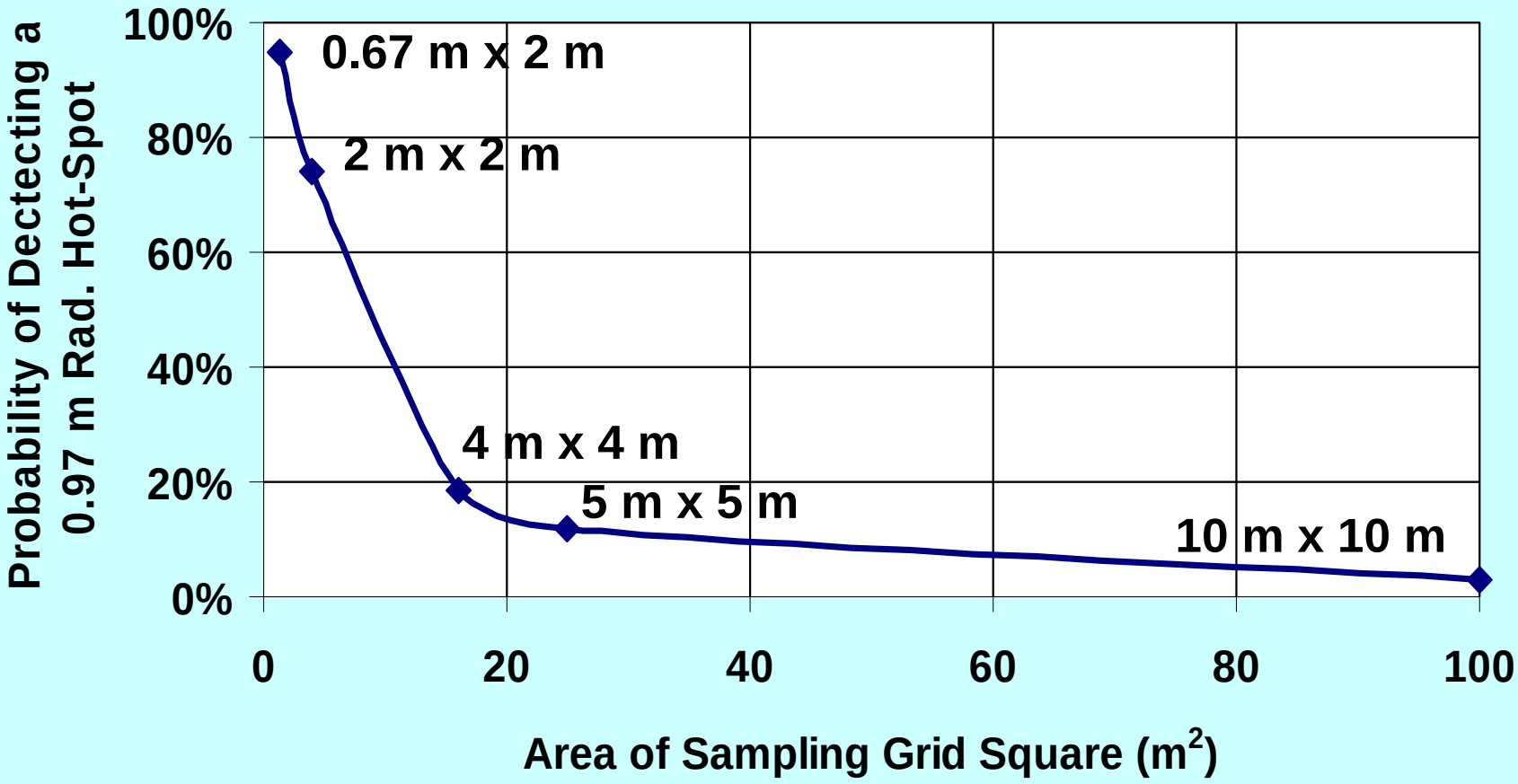
Grid Size vs. Probability of Detection



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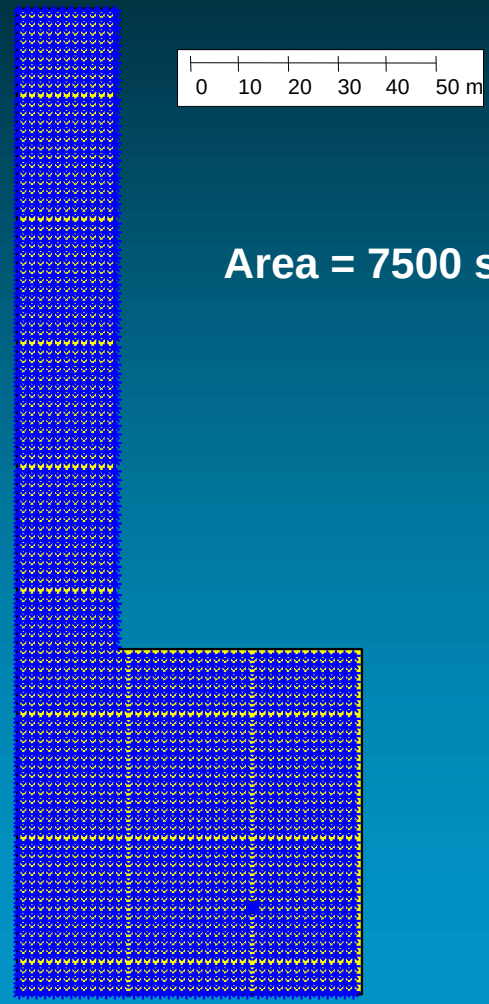
Example 2 – Grid to Locate Hot Spots

- To locate hot-spots ≥ 1.0 m radius at 90% probability
- Requires a square grid of 1.8 m spacing
- And 2,332 samples



Area = 7500 sq.m.

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Ex. 2 - Refinement to the Sampling Grid

- If *p(A)* : (probability of encountering a sample > criterion) can be determined *a priori*
- Grid spacing can be modified based on conditional probability (Gilbert, 1987, p. 127)

Use of *a priori* probability, *p(A)*

- To locate 1.0 m radius hot spots in area of 7500 m^2 with 90% probability:

p(A)	≥50%	20%	15%	10%
Grid Spacing (m)	1.8	2.4	3.0	10.5
No. Samples	2,332	1,302	835	73

Example 3 – Surficial Excavation for Metal Impacts

- **Purpose:**
  - To determine the extent of a surficial excavation to remove metal impacts from top 0.3 m
- **Performance criteria:**
  - Hot-spots to a maximum size of 1 m radius will be removed with a 90% certainty

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Example 3 - Procedure

- Sample site to determine *a priori* probability *p(A)*
- Determine actual sampling grid size
- Establish step-out sampling methodology
- Complete sampling and analyses
- Check to ensure frequency of exceedance is not > *p(A)*
- Lay out area to be excavated

A Priori Probability

- **Procedure**
  - Carried out pilot test using a 10 m square grid
  - Obtained samples in the top 0.3 m using a Geo-probe rig and sampler
- **Results from laboratory analyses indicated *p(A)* = 15%**
  - Therefore a 3 m grid would be sufficient

p(A)	≥50%	20%	15%	10%
Grid Spacing (m)	1.8	2.4	3.0	10.5

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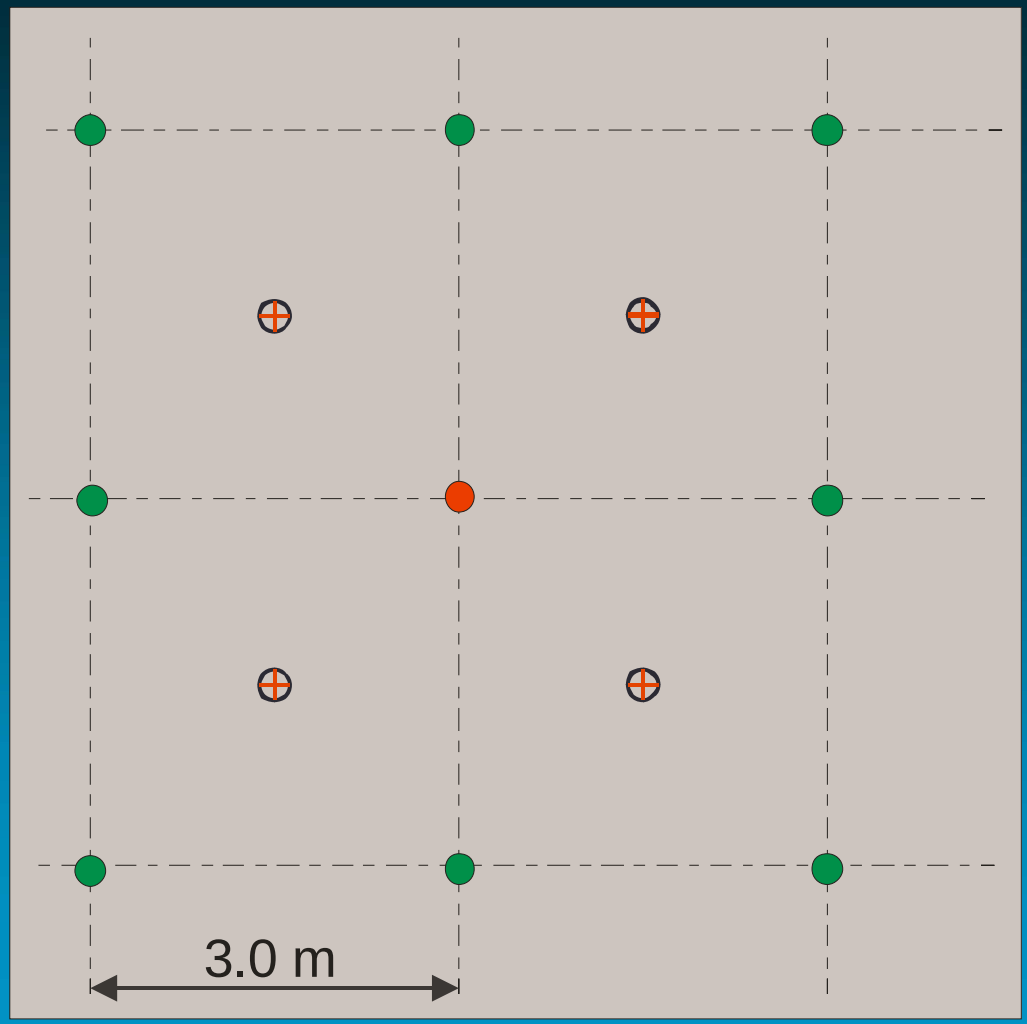
Step-Out Sampling Procedure



- Initial Sampling Grid Point without Chemical Exceedance
- Initial Sampling Grid Point with Chemical Exceedance
- Additional Step-Out Sampling Point

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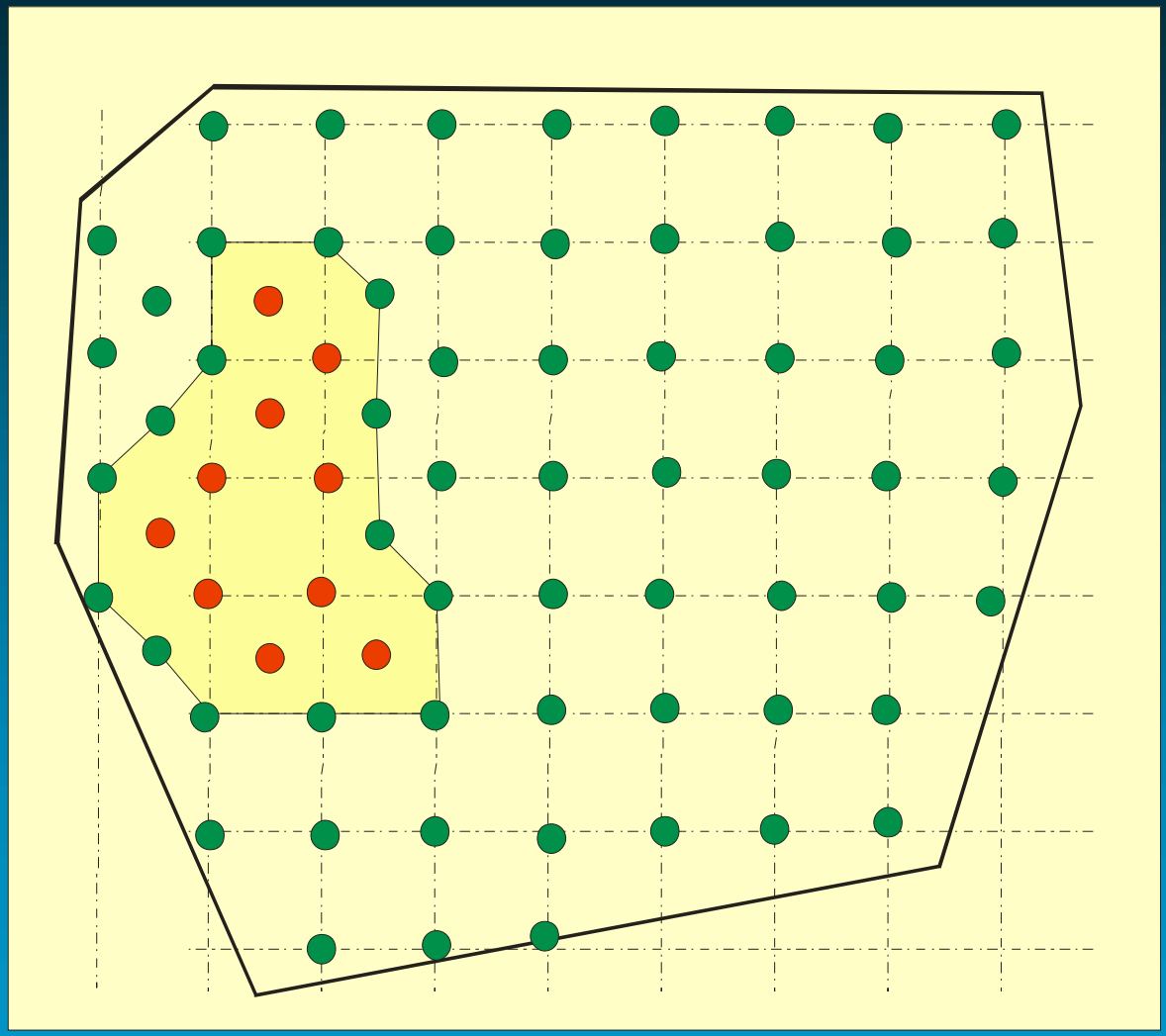
Establish Extent of Excavation



- Sampling Grid Point without Chemical Exceedance
- Sampling Grid Point with Chemical Exceedance
- Region to be Excavated

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Concluding Remarks….1

- Statistical sampling plans can be used to assist in reaching excavation goals
- VSP is a useful tool for developing statistically defensible sampling plans
- Current limitations include:
  - Only applicable for areal impacts

Concluding Remarks…2

- Need to be used with appropriate judgement and knowledge – don't accept results blindly
- REMEMBER - GIGO

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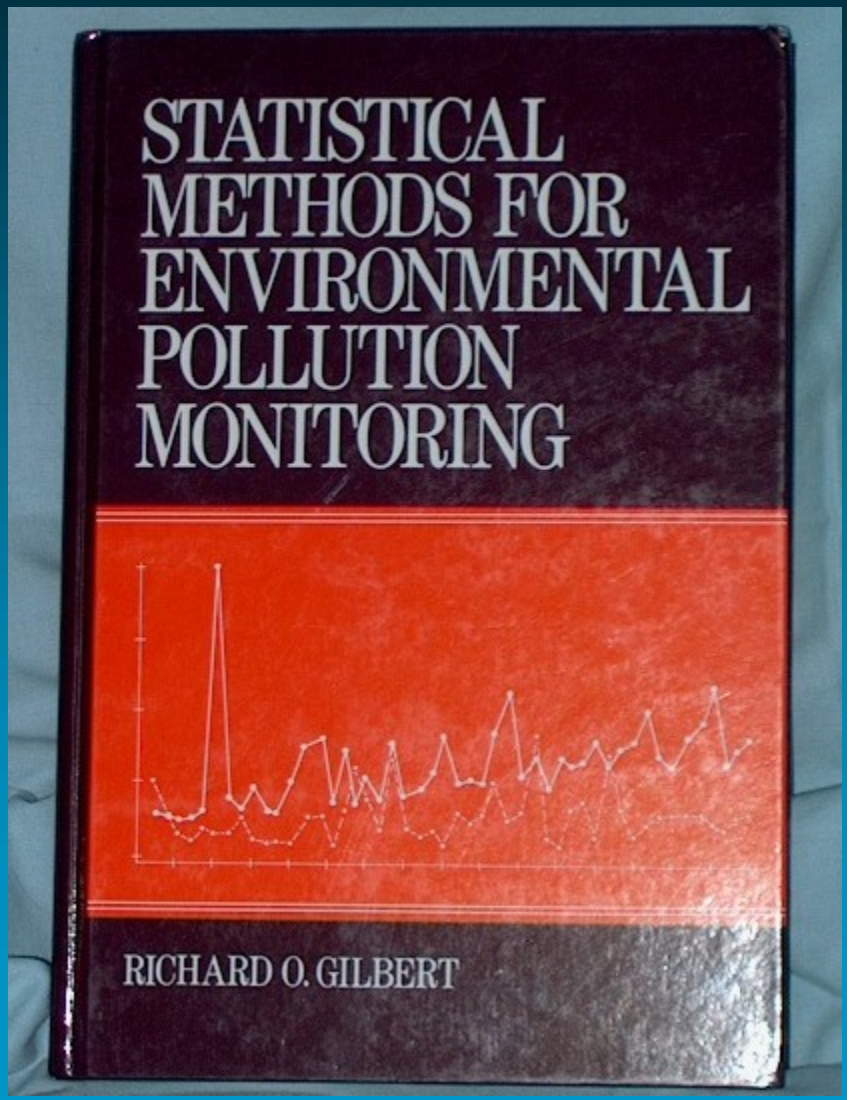
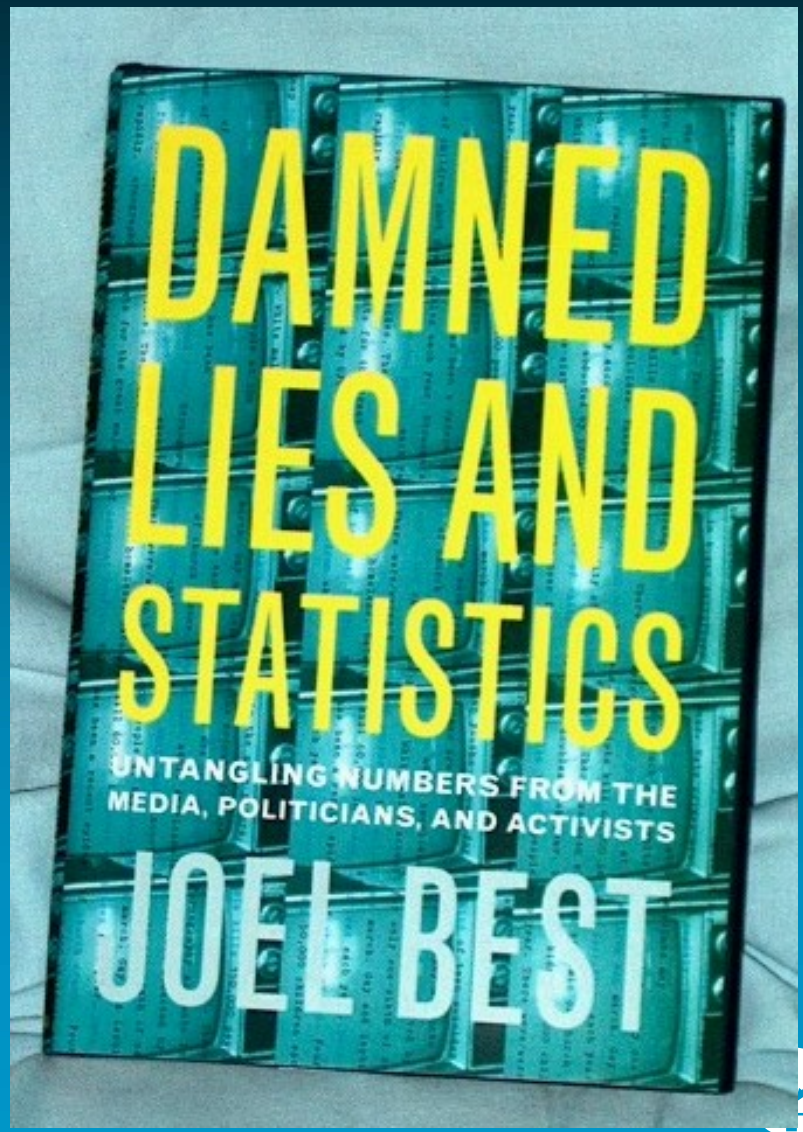
References…


STATISTICAL METHODS FOR ENVIRONMENTAL POLLUTION MONITORING
RICHARD O. GILBERT


DAMNED LIES AND STATISTICS
UNTANGLING NUMBERS FROM THE MEDIA, POLITICIANS, AND ACTIVISTS
JOEL BEST

“It is easy to lie with statistics, but easier to lie without them.”

- Frederick Mosteller,
founding chairman of Harvard University's statistics department

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Thank you!

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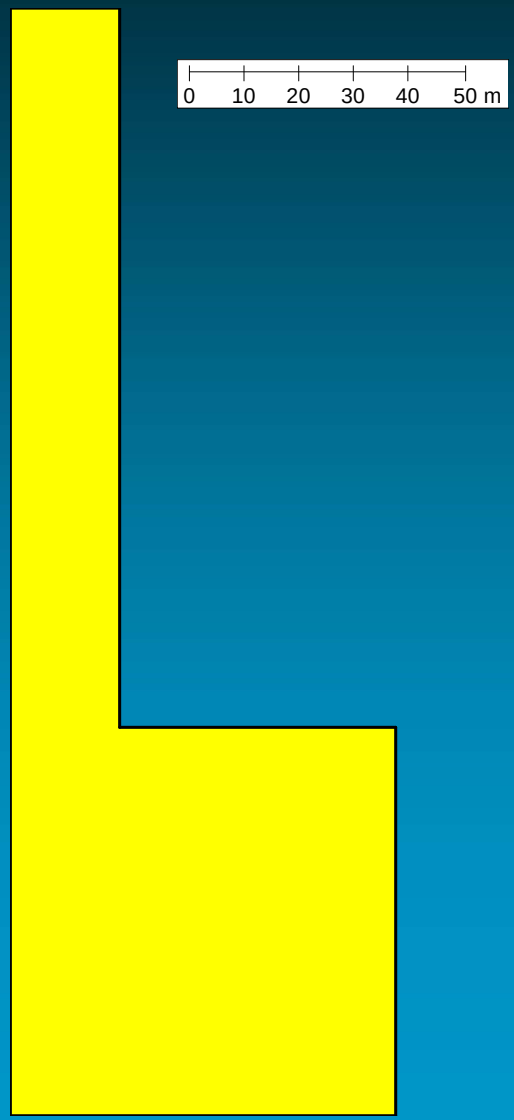
Example 2 – Remedial Excavation Requirements



- Area: 7500 m^2
- 200 m long
- 70 m wide (max.)

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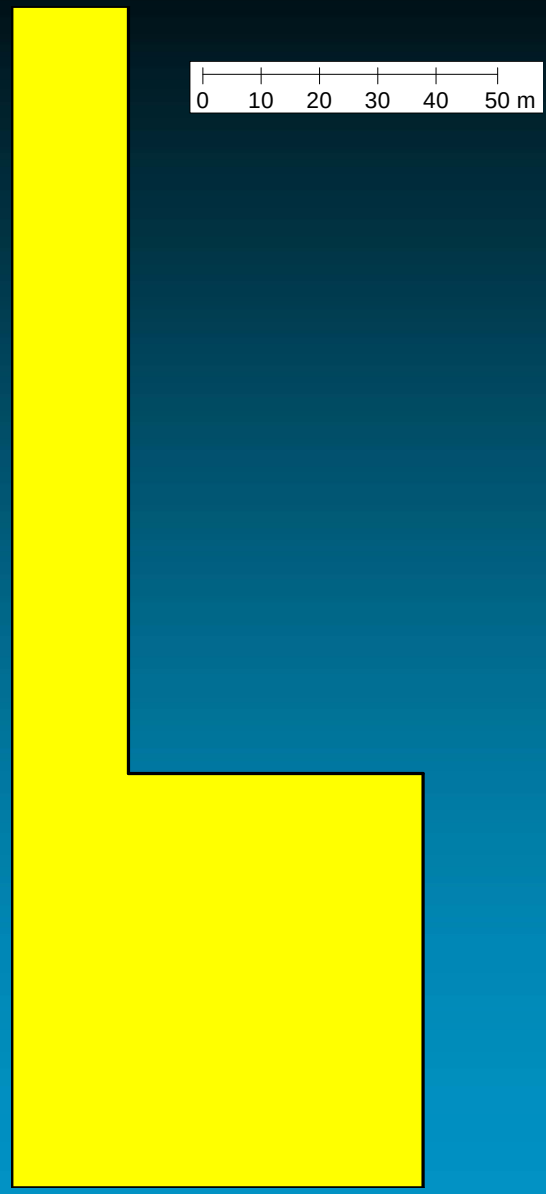
Ex.2
Step 1 –

Import .dxf



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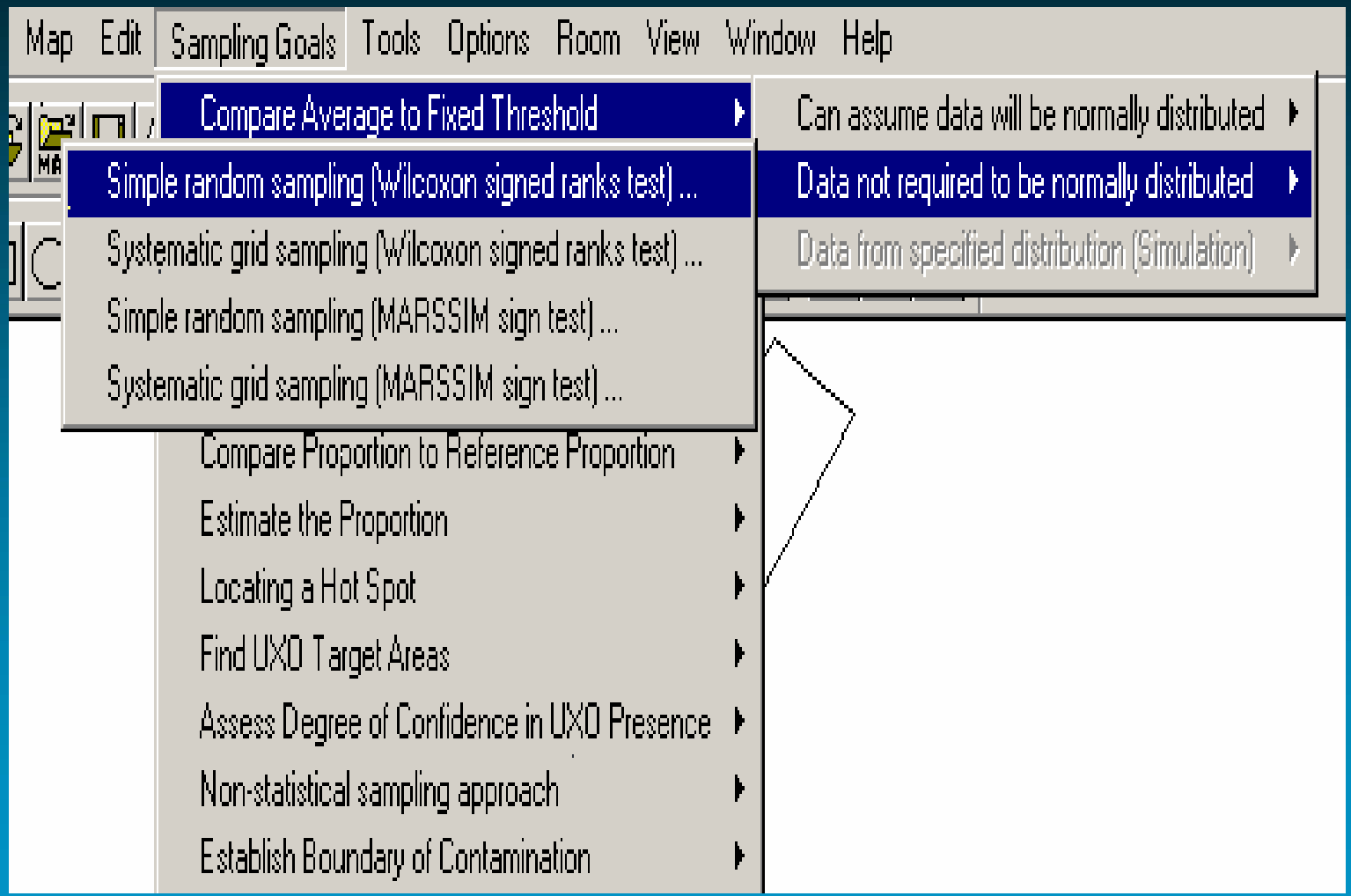
Ex.1 Step 2 – Sampling Goals



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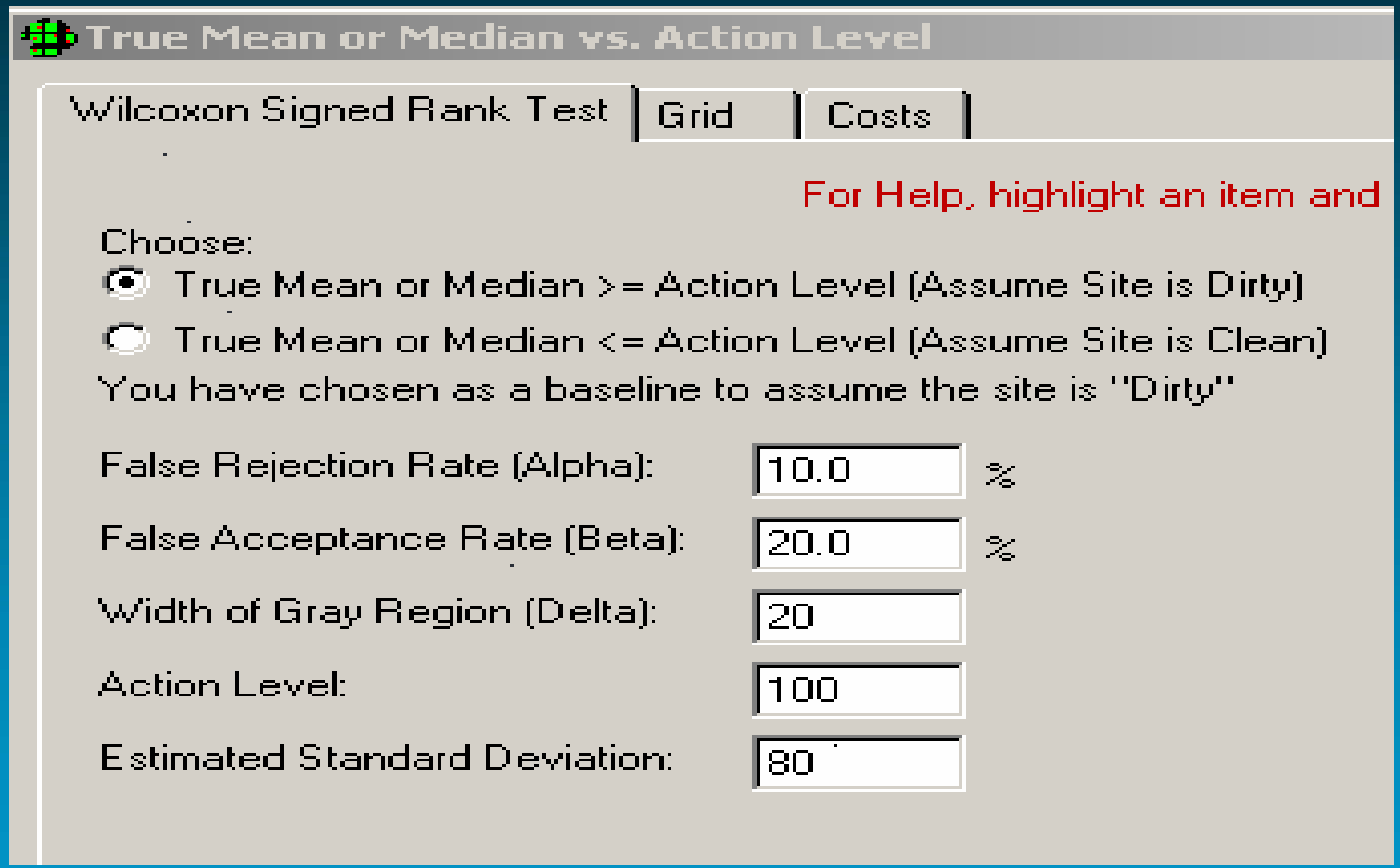
Ex.2 Step 3 – Decision Parameters



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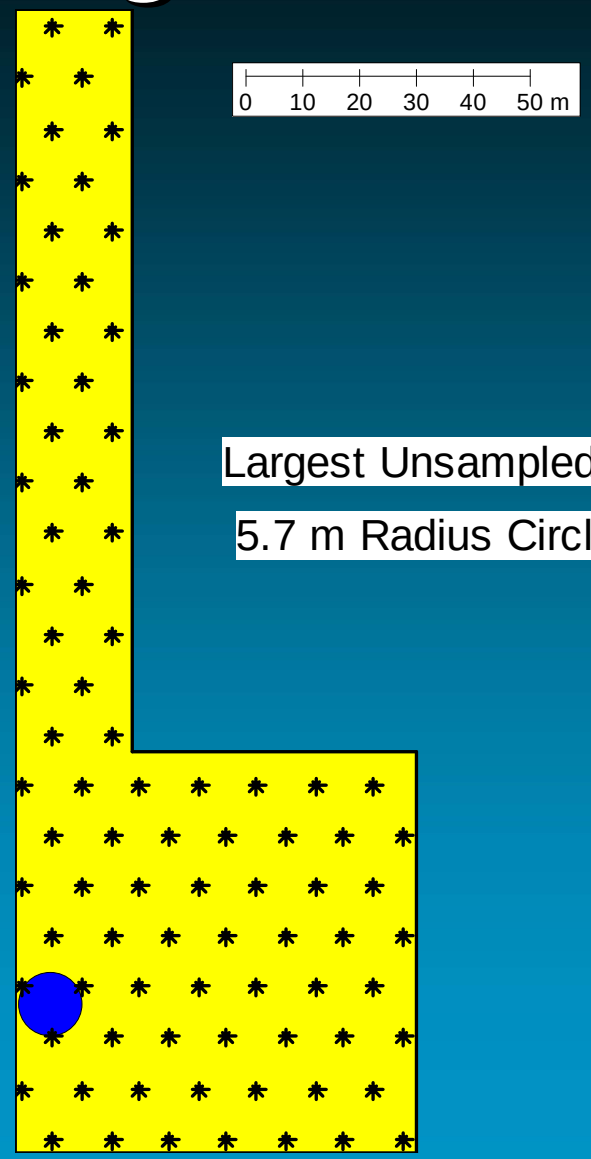
Ex.2 Step 4 - Sampling Grid

- 86 locations
- 10.2 m Δ grid
- Largest unsampled area: 5.7 m radius circle
- 5.1 m radius hotspot at p = 90%



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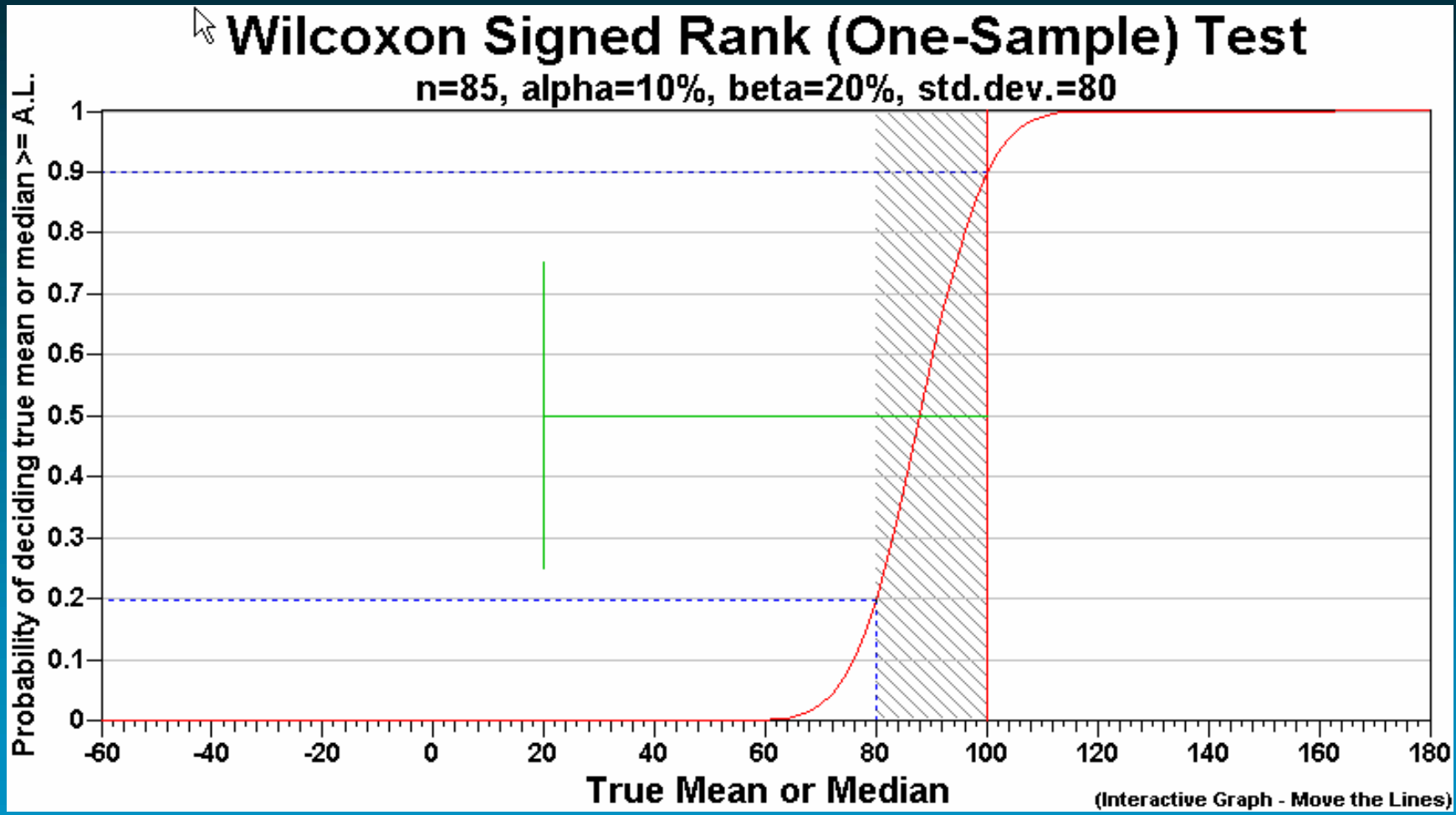
Ex.1 – Step 5 DPGD



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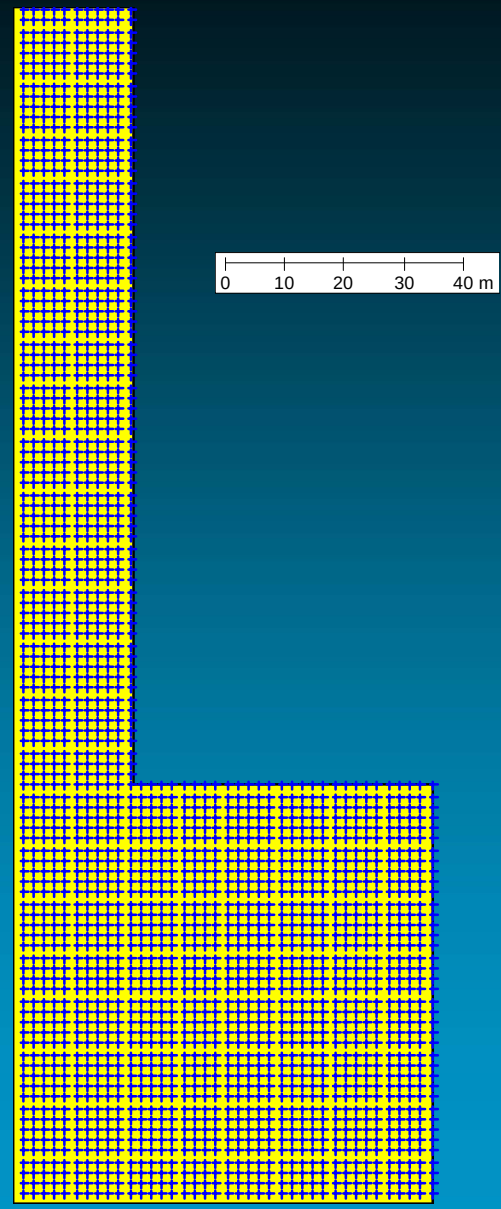
Number of Samples

- Based on a symmetric (not necessarily normal) population
- Changes with α, β and s.d.
  - Proportional to $(\text{s.d.})^2$
- Inversely proportional to width of gray region (δ) – uncertainty of the threshold value

Locating Hot-Spots

- To locate a hot-spot 1.0 m radius at p=90%
- Need a 1.8 m square grid
- ~2300 samples
- However ...



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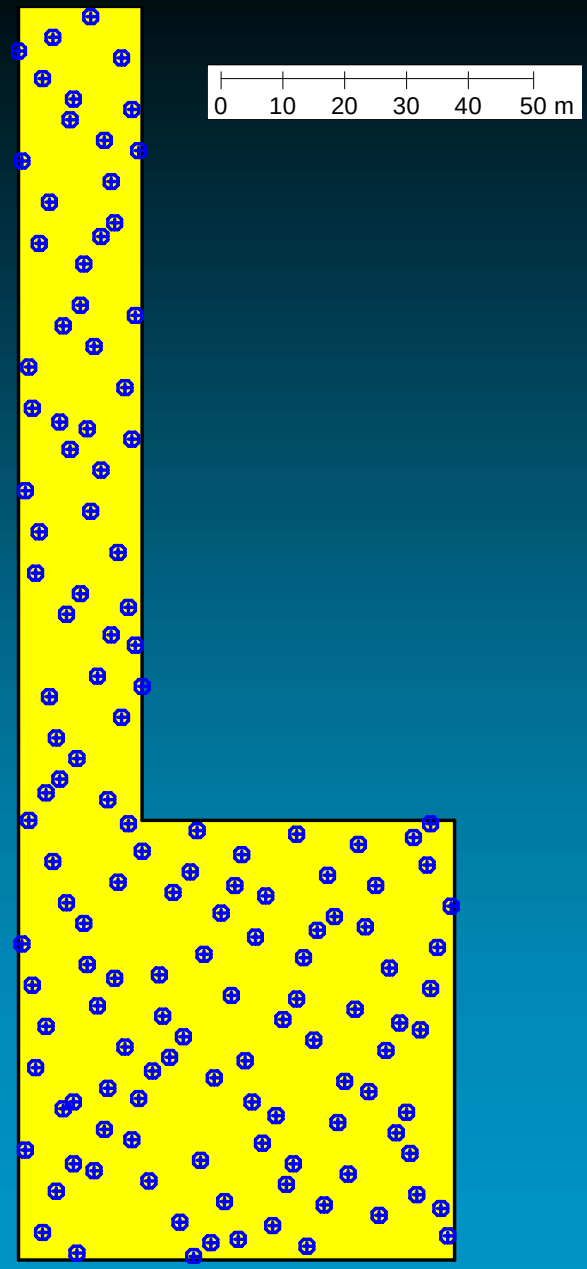
Example 2 – Quasi-Random Sampling



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Sampling Goals in VSP

- Compare sample mean to a criterion
- Compare sample mean to a referenced average
- Estimate the population mean
- Construct confidence interval on the mean
- Detecting hot spots
- ...(7 additional sampling goals)

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Probability of Detection:

95%

Grid Size		Grid Area	Hot-Spot		Unsampled Area (m2)
x (m)	y (m)		Min. Radius (m)	Area (m2)	
0.67	2	1.34	0.97	0.74	3.01
2	2	4.00	1.20	1.13	5.67
4	4	16.00	2.40	4.52	24.01
5	5	25.00	3.00	7.07	37.64
10	10	100.00	6.00	28.27	154.10

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