Overview of Guidance on Surveys for Subsurface Radiological Contaminants

Technical Bases for the Development of Guidance

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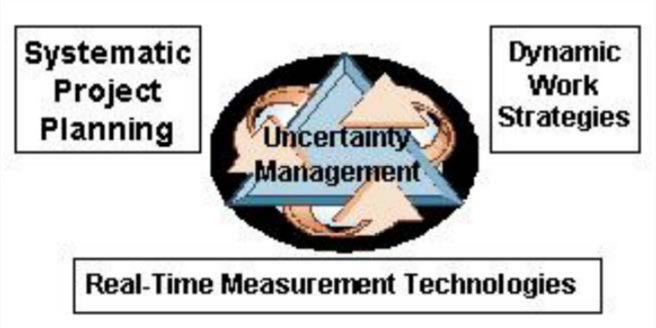
Some Technical Issues To Be Addressed

1. Introduction
2. Survey Approaches for Different Types of Licensees
3. Derived Concentration Guideline Levels
4. Implications of NUREG-1757, Volume 2
5. Stages of the Subsurface Decision Framework
6. Geospatial Modeling Tools
7. Statistical Methods and Tests
8. Geospatial and Statistical Methods
9. Assessing Background and Scenario B
10. Evaluations of Large Soil Excavations and Equipment
11. Treatment of Uncertainty and Data Sufficiency
12. Elevated Areas and Hot Spots

Key References

- EN ISO 18557:2020, “Characterization Principles for Soils, Buildings and Infrastructures Contaminated by Radionuclides for Remediation Purposes”
- ANSI/ANS-2.17-2010, “Evaluation of Subsurface Radionuclide Transport at Commercial Nuclear Power Plants”
- NUREG/CR-7021, “A Subsurface Decision Model for Supporting Environmental Compliance”

Survey Approaches



Triad Approach

- ISO and ANSI standards summarize approaches needed for different types of NRC-licensed sites (e.g., reactors vs. materials sites)
- Data Quality Objectives (DQO) Process EPA QA/G-4
- Triad: Conceptual site model (CSM)
- A CSM uses all available historical and current information to manage decision uncertainty
- MARSSIM connects to the Triad approach through the DQO process

Triad, DQOs, and MARSSIM

- The DQO process focuses primarily on data collection, while the Triad approach emphasizes decision-making and other site-related activities deemed to be within the scope of "systematic project planning"
- In Triad, an accurately maintained and updated CSM can be employed to decide how classical statistics and geostatistics will be used for evaluating data
- MARSSIM focuses on demonstrating compliance during the final status survey, which follows historical assessment scoping, characterization, and any necessary remedial actions

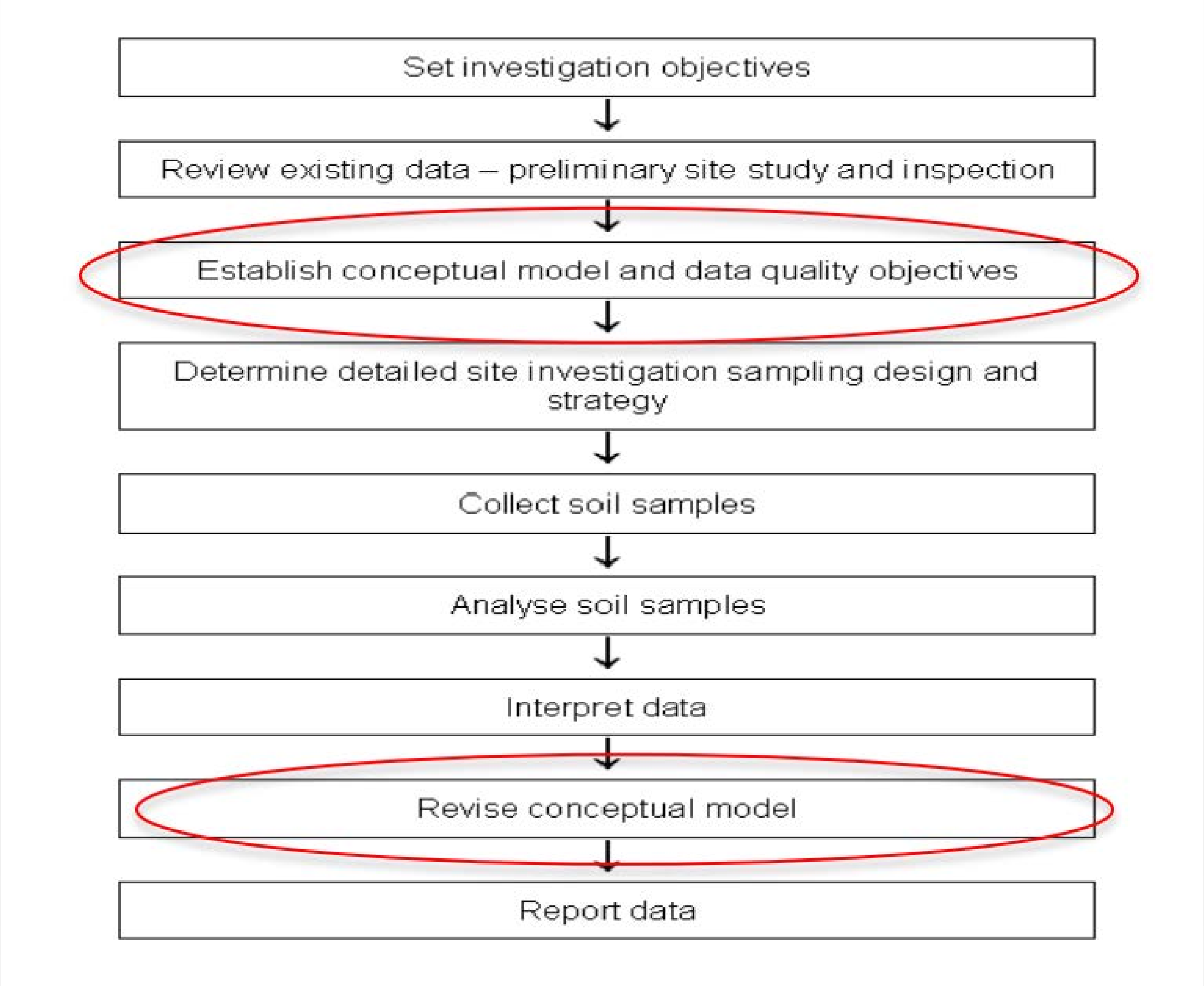
Conceptual Site Model (CSM)

- Triad activities are based on the management of *decision uncertainty*
  - Systematic project planning
  - Dynamic work strategies
  - Real-time measurement technologies (to support real time decision-making)
- Misconceptions that Triad:
  - Is nothing new
  - Increase regulatory workload
  - Always less costly
  - Has inadequate quality assurance/quality control
  - Is the same as the DQO process
  - May need the guidance of an experienced Triad practitioner

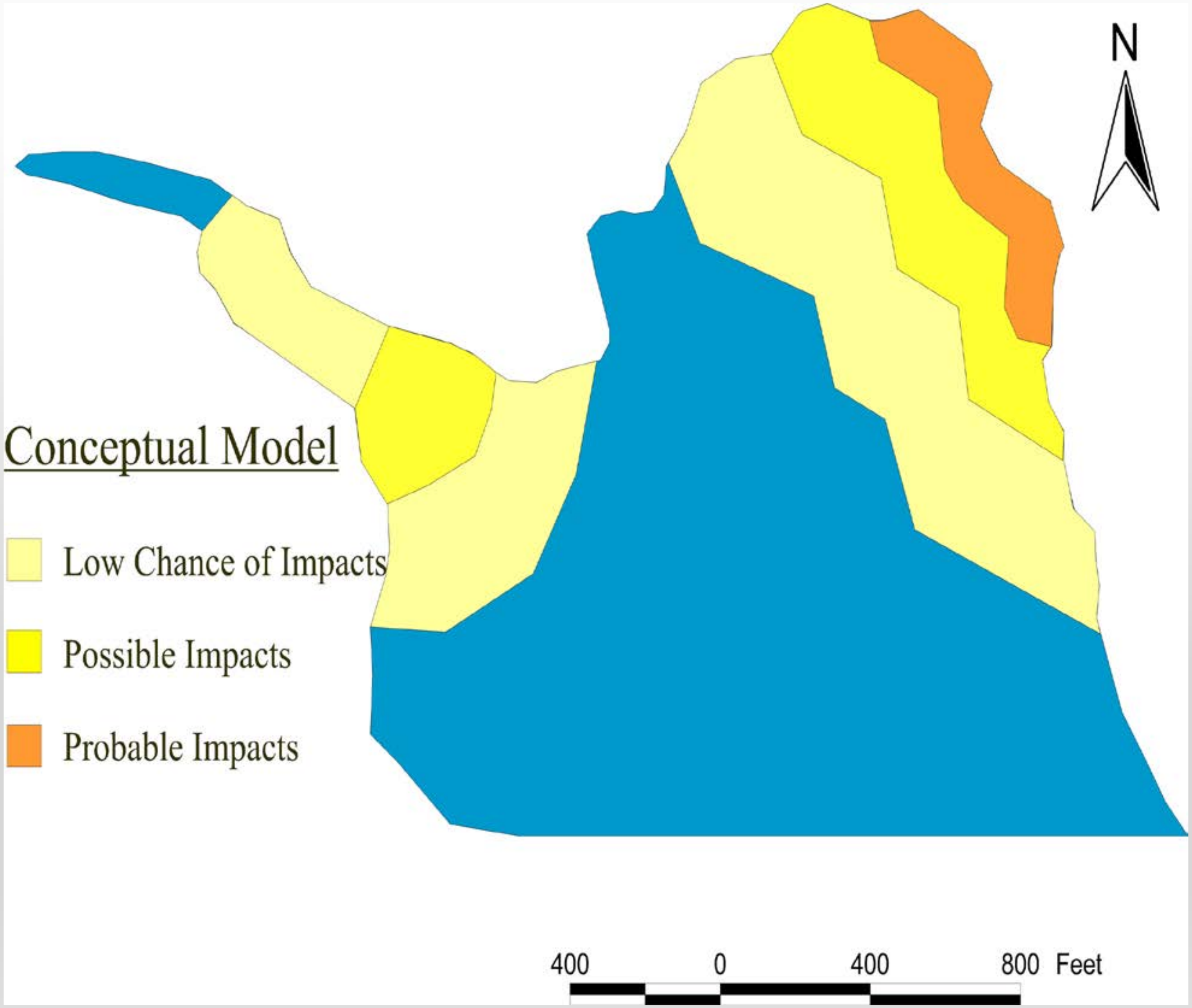
Conceptual Site Model

- A CSM delineates and summarizes:
  - How contamination occurred
  - What is happening to it
  - Who might be exposed to it
  - What might be done to mitigate that exposure
- An accurate CSM is the basis for confident decisions about risk and remediation
- The CSM is used as a primary tool in NUREG/CR-7021

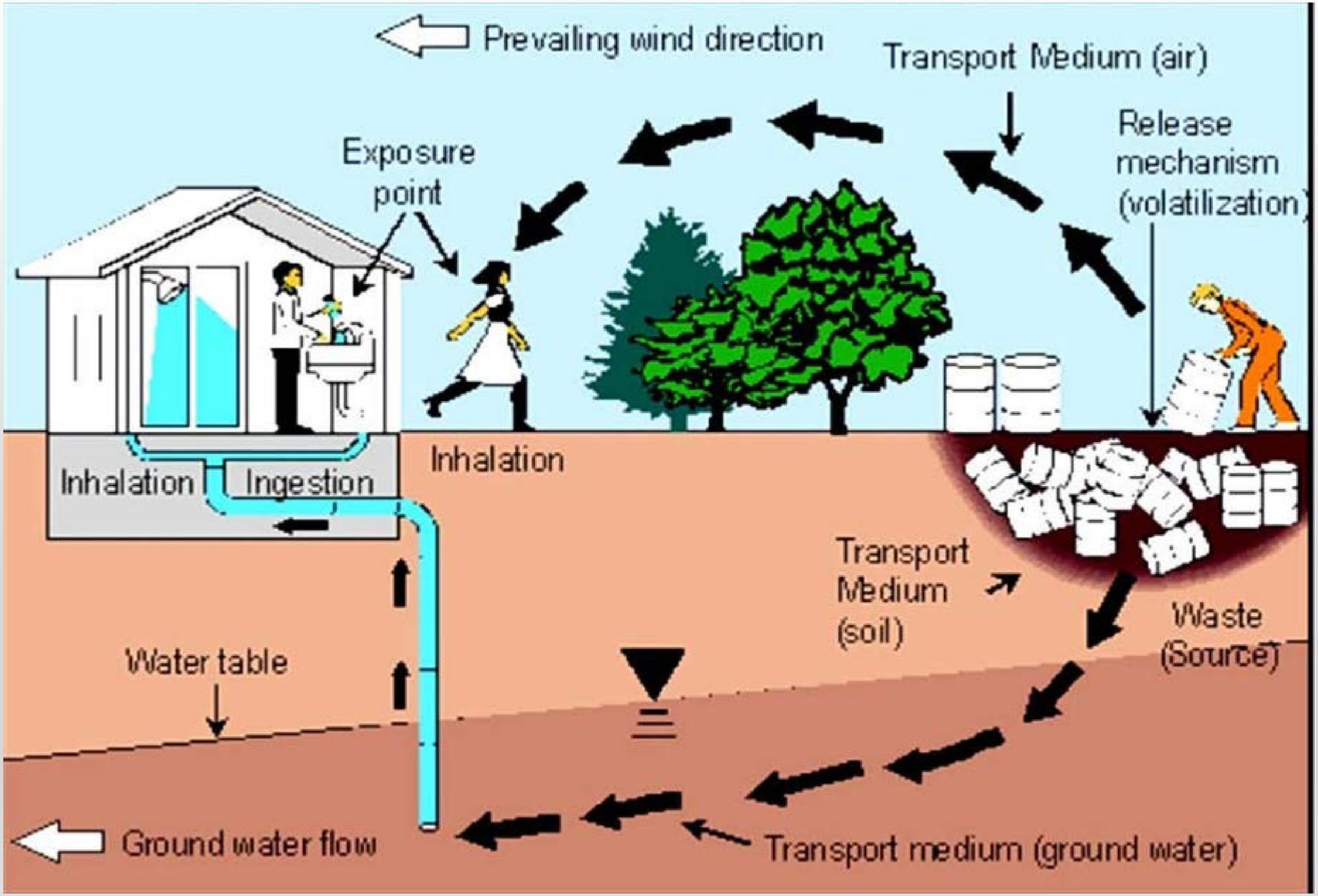
CSMs Are Similar to DQOs But with Broader Application



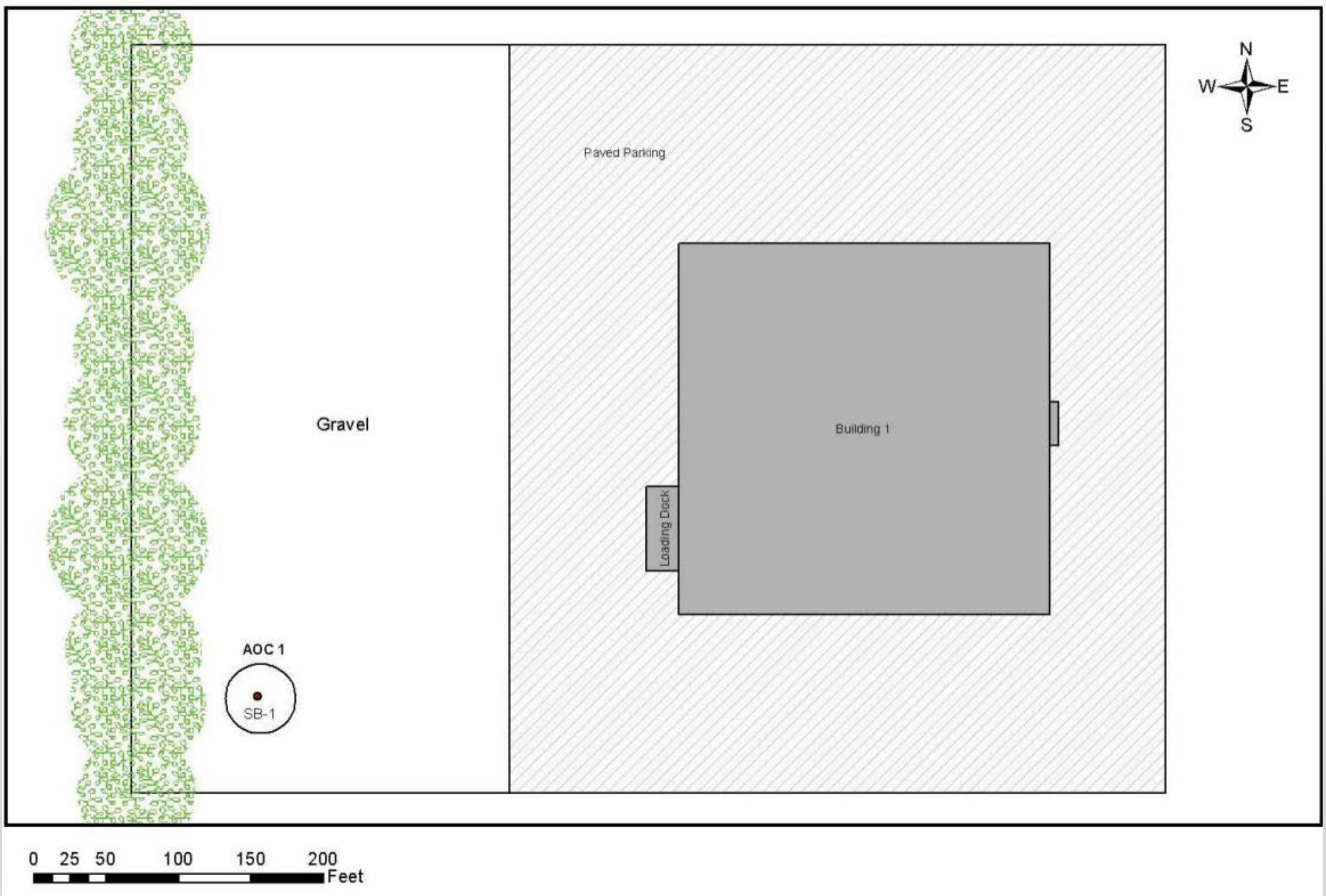
Potential Impacted Areas on a CSM Map Using Historical Site Assessment Information



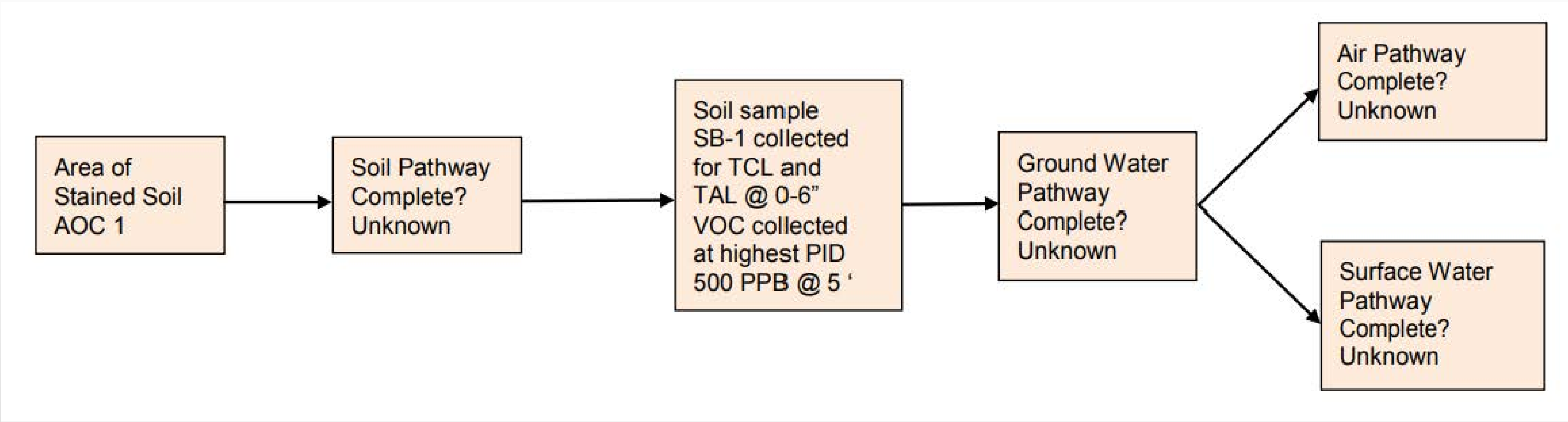
CSM for Exposure: USACE EM1-12 (2012)



CSM: Single Area of Concern Near a Building



Conceptual Site Model

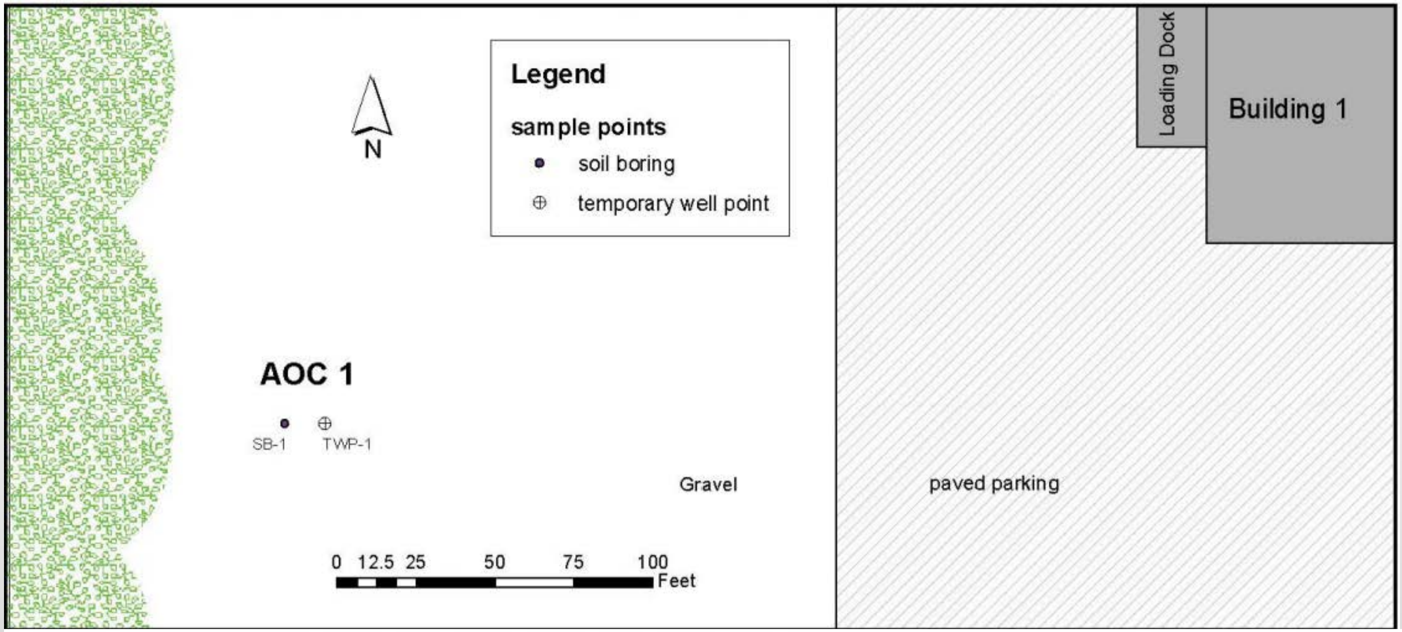


Area of Concern (AOC) 1 is an area of stained soil/gravel less than 25 square feet. AOC 1 is the only AOC on site. Review of aerial photographs, Sanborn maps, and staff interviews indicate no other potential discharges. Surrounding properties are zoned commercial/industrial.

Actions Taken: Soil samples collected for target compound list plus tentatively identified compounds (TICs)/Target Analyte List (TCL + TICs/TAL). Volatile organic compounds (VOCs) sample collected at 5 feet based on the highest photoionization detector reading. All other parameters collected at 0–6 inches.

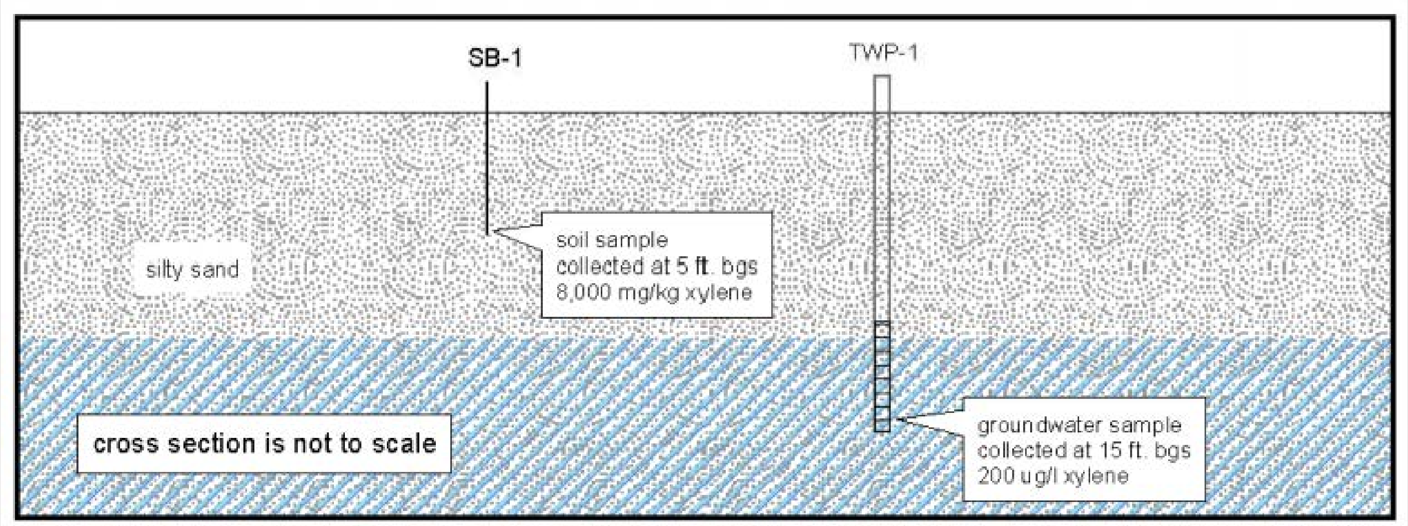
Impacted Media: Based on staining, soil is expected to be impacted. Groundwater has a potential impact, while air (>200 feet to structure) and surface water (>200 feet to closest feature) are unlikely to be impacted.

CSM: Sampling Conducted

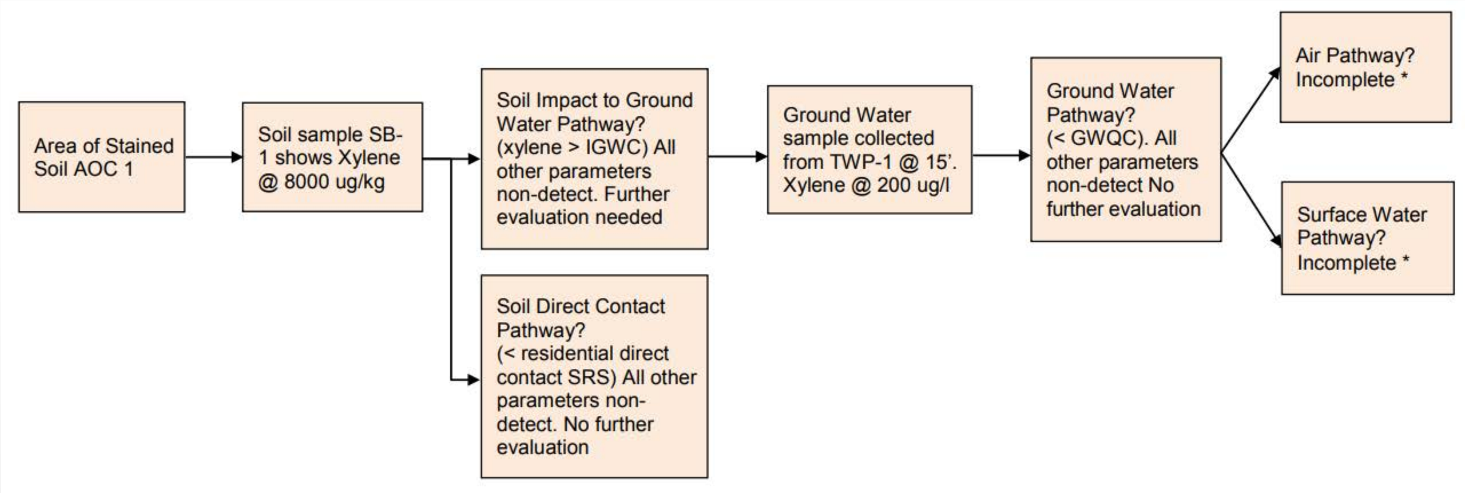


SB-1	
Depth	PID reading
0-4 ft.	100 ppb
4-5 ft.	500 ppb
5-7 ft.	100 ppb
7-10 ft.	ND

SB-1 VO sample collected at 5 ft.
All other constituents collected at 0-6 inches



CSM Flowchart



AOC 1 is an area of stained soil/gravel less than 25 square feet. AOC 1 is the only AOC on site. Review of aerial photographs, Sanborn maps, and staff interviews indicate no other potential discharges. Surrounding properties are zoned commercial/industrial.

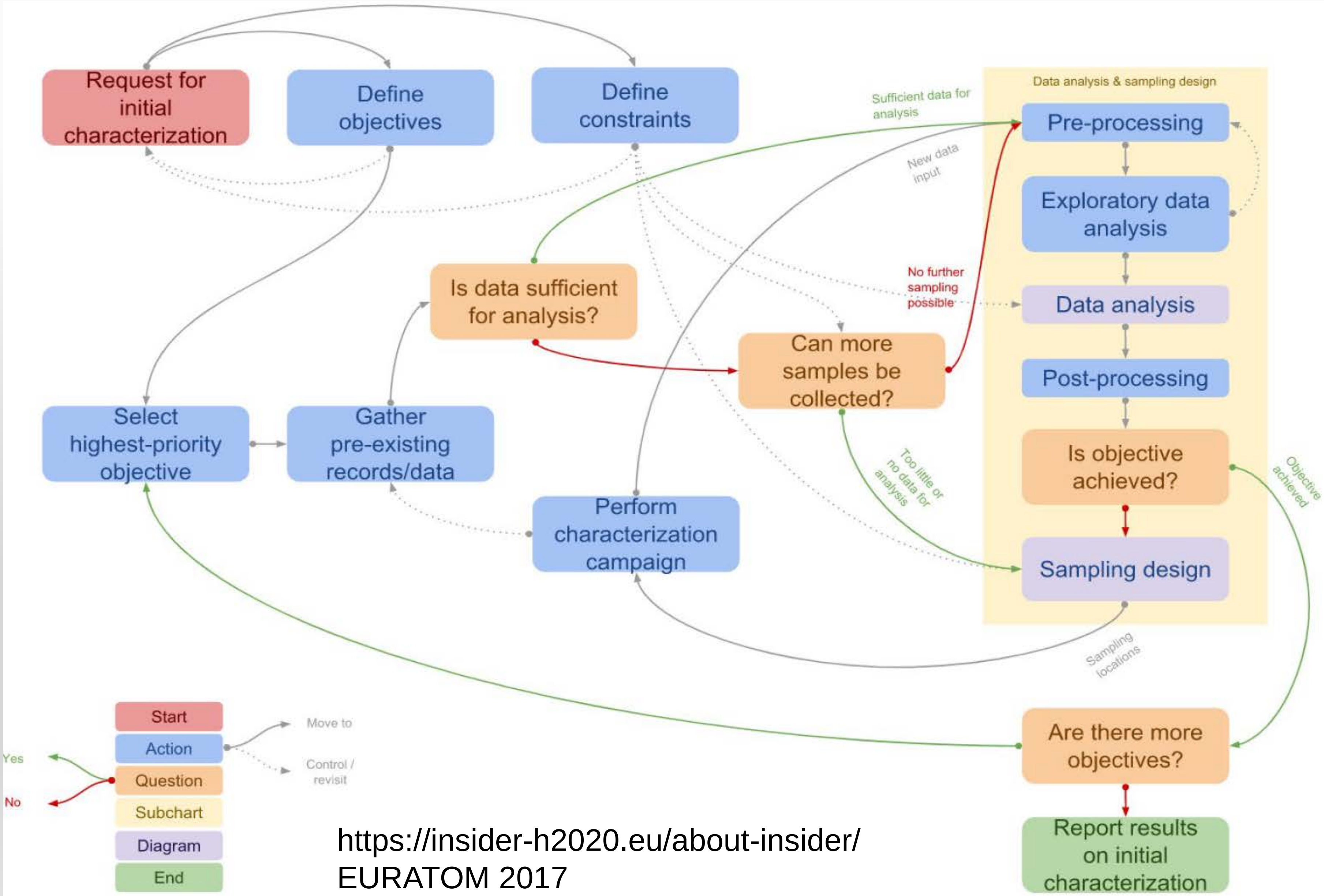
Actions Taken: Soil samples SB-1 collected at 5 feet for VOCs showed 8,000 ug/kg of xylene. All other parameters are non-detect. Groundwater sample collected at 15 feet for VOCs. Sample contained 200 ug/l of xylene.

Impacted Media/Pathway:
Soil Direct Contact: All parameters below direct contact criteria.
Soil Impact to Groundwater: Xylene above default soil IGWC; therefore, groundwater investigated.
Groundwater: Xylene detected below GWQC.
Air: Pathway incomplete.
Surface water: Pathway incomplete.

INSIDER

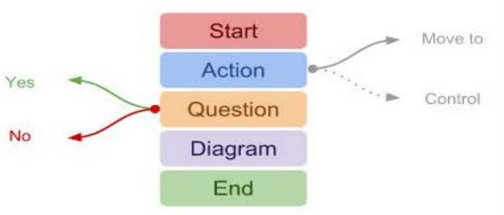
https://insider-h2020.eu/about-insider/
EURATOM 2017

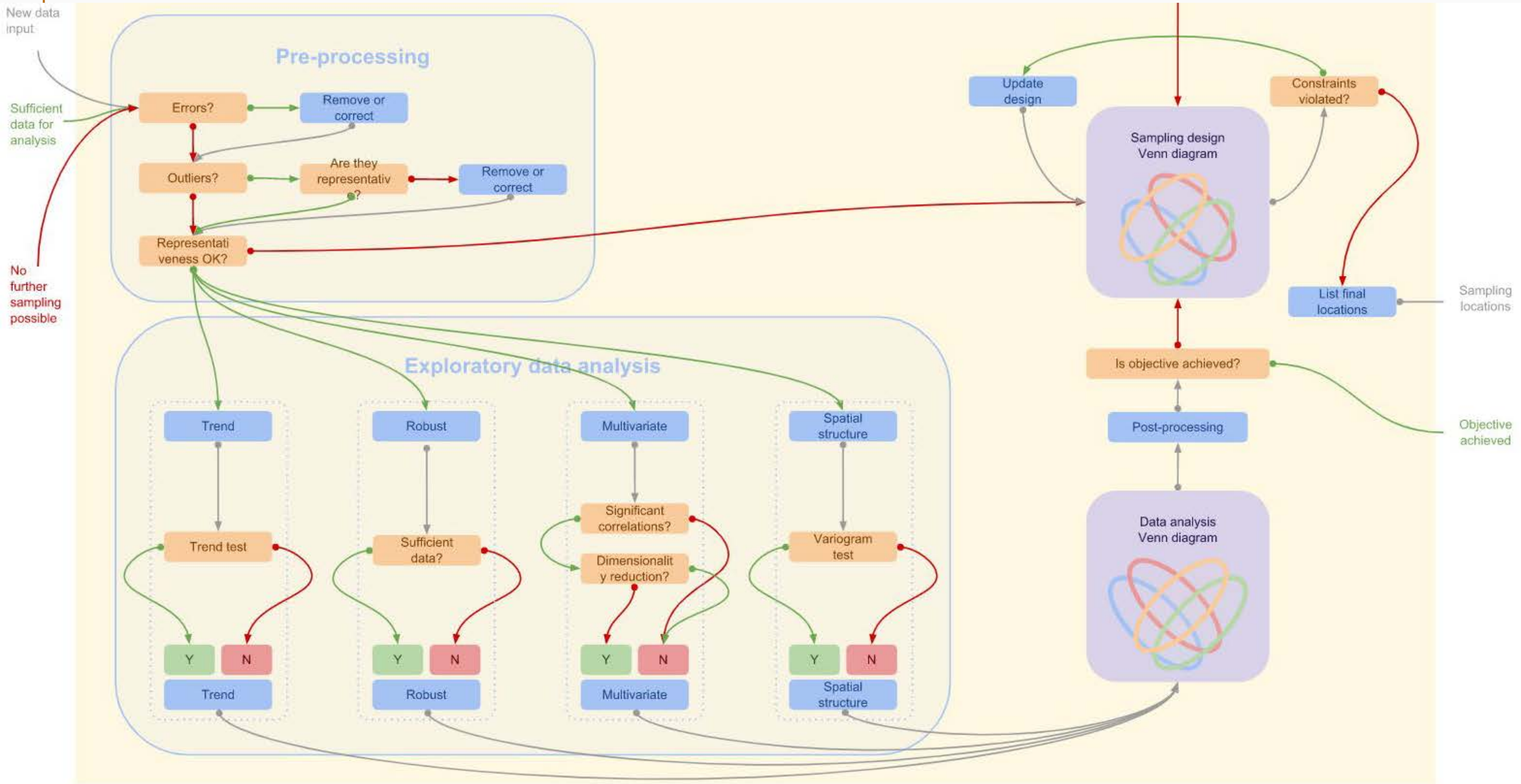
INSIDER Strategy



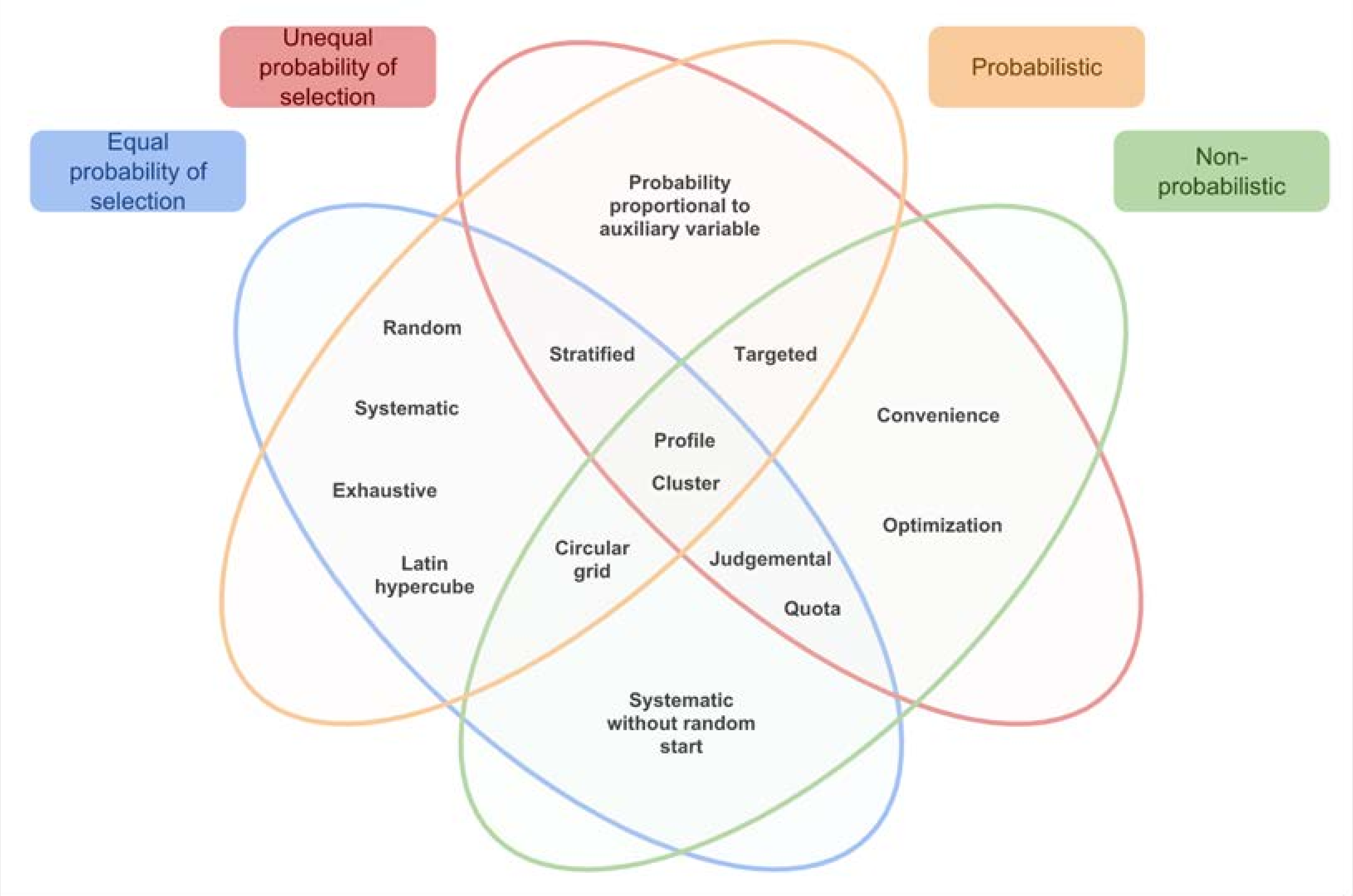
https://insider-h2020.eu/about-insider/
EURATOM 2017

INSIDER: Data Analysis & Sampling Design

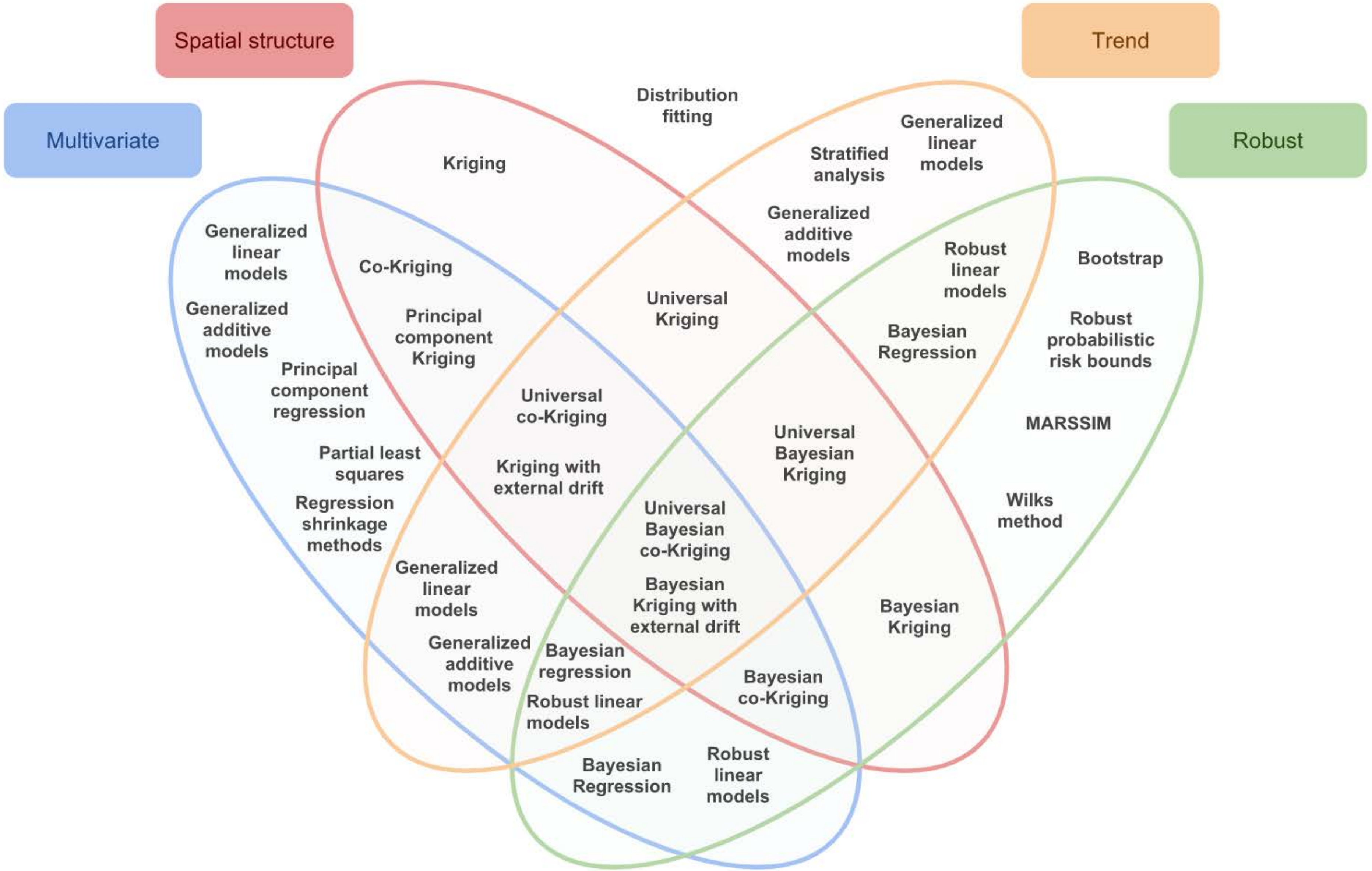




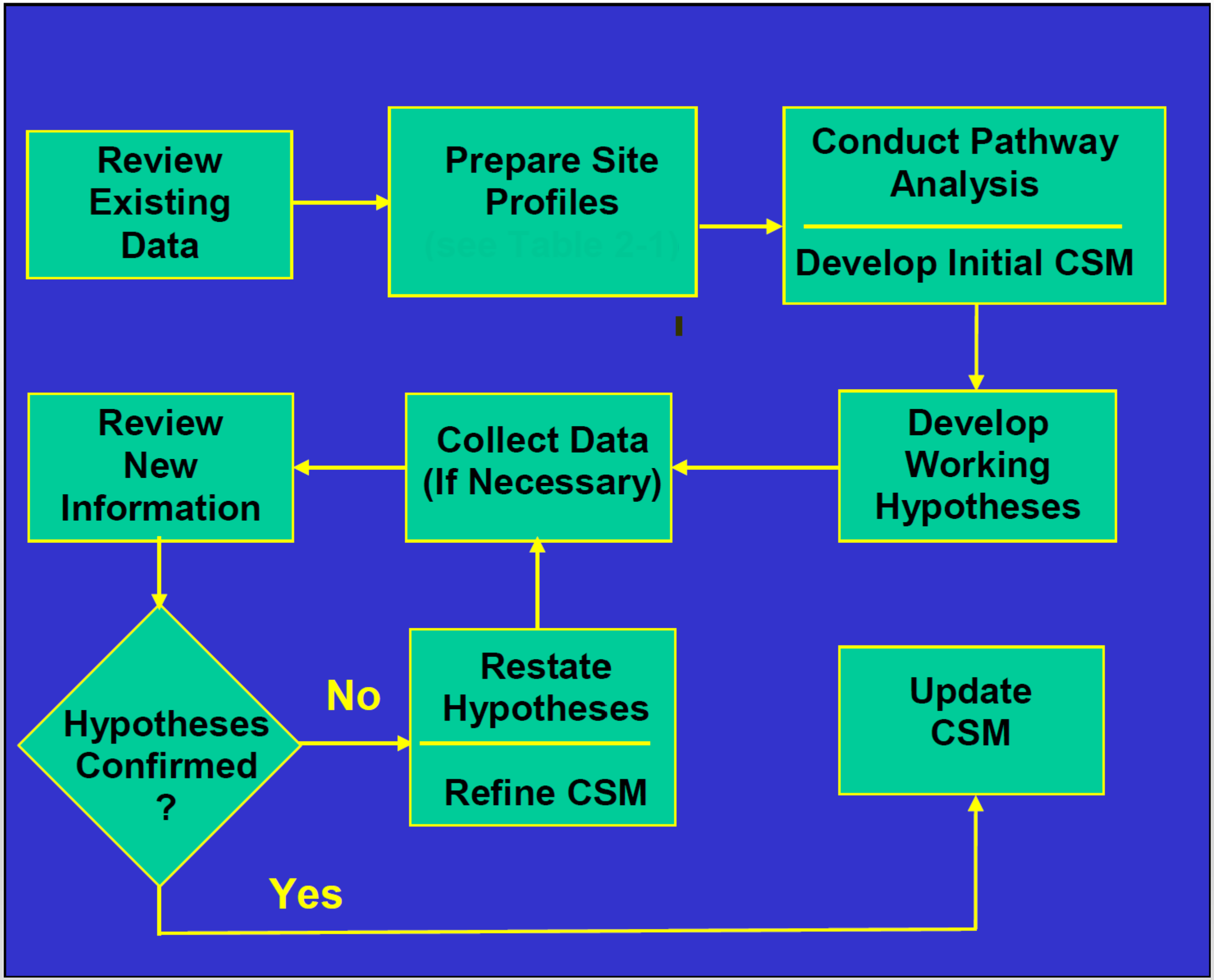
INSIDER Sampling Design



INSIDER: Data Analysis



CSM Iterative Development Process



1- State the Problem

- CCM is a mapping of the site with continuous estimates of activity levels and the uncertainty of those values
- At each stage in the survey process (Scoping → FFS), an updated Contamination Concern Map (CCM) is constructed
- The CCM is not a schematic or diagram but a spatially explicit, numerical model that may require the use of geographical mapping tools (e.g., GIS) and other spatial modeling software to implement

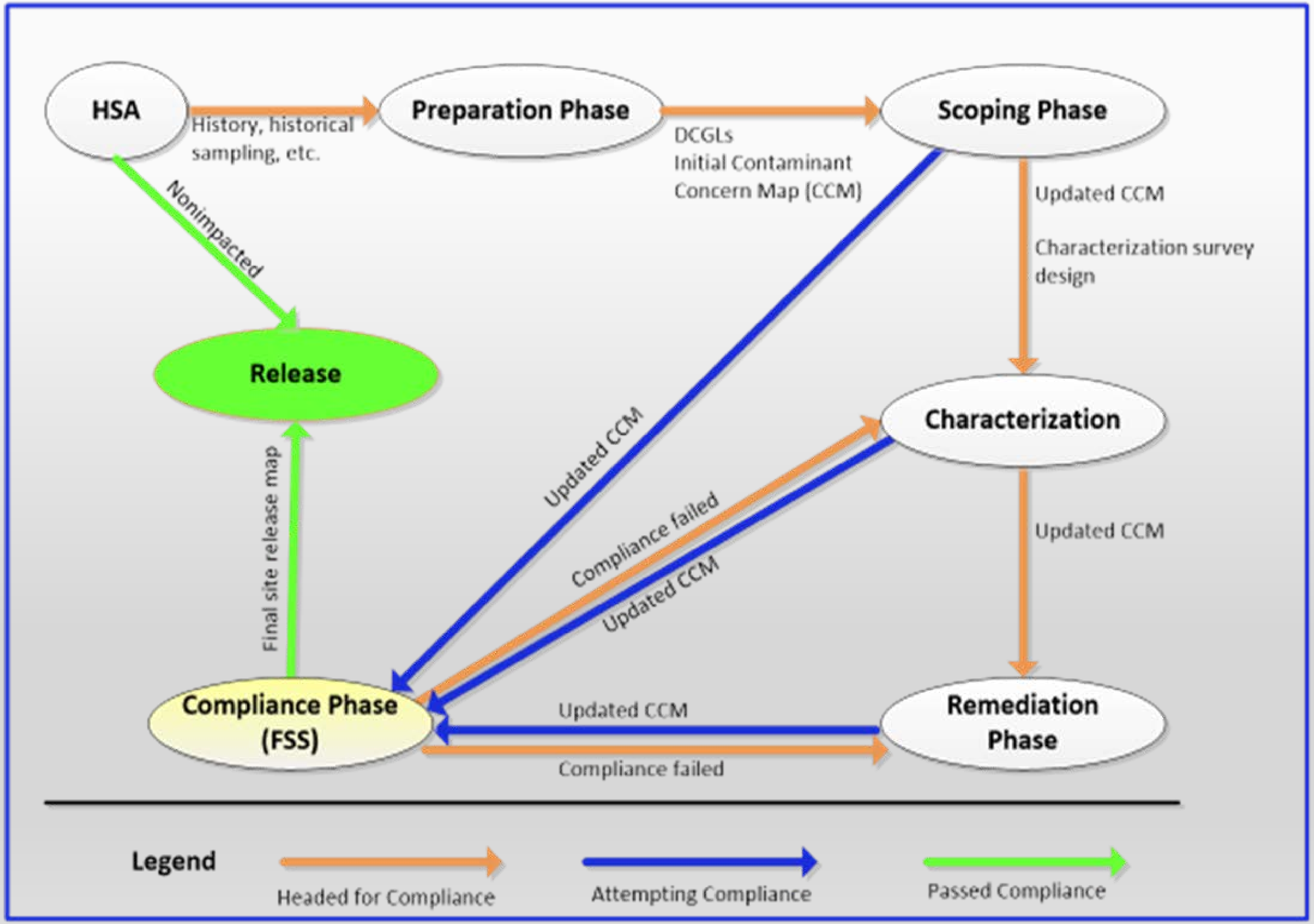
1- State the Problem (cont.)

- Information intensive sampling (hard data) that sampling would provide is replaced and/or augmented with all auxiliary forms of available and useable data. Hard data is based on measurable quantities from reliable sources and methodologies.
- Interpolation tools (such as kriging) can be used to produce a continuous CCM. The relationship between measurements at nearby hard data locations is exploited to extract more information from the data set.

1- State the Problem (cont.)

- "Soft data" is based on qualitative observations such as rankings, expert judgment, and employee interviews. Such information may be considered "surrogate" values. Such may not be as accurate and precise as hard data but are generally less costly to obtain.
- Hard and soft data may be combined mathematically (e.g., co-kriging) to produce a model of the probability of exceeding an established decision across a site or survey unit. Modeled values can also direct the placement of secondary samples and update the CSM.

Radiation Investigation Flow Chart



Complexities of Subsurface Sampling

- In the subsurface, all radionuclides essentially become hard to detect
- Soil types may vary more than surface soils
- Sampling at depth requires special sampling tools
- Samples are taken from a core for testing at an analytical laboratory
- Samples are taken at several different depth intervals to define the vertical extent of the residual radioactivity in the vadose zone and into ground water or fractured rock

2 - IDENTIFY THE GOAL OF THE STUDY

- Historical Site Assessment
  - Preliminary: the initial CCM and preliminary CSM
- Scoping
  - Estimate a reasonable number and location for scoping samples
- Characterization
  - Estimate both the extent and volume of the contaminated media, construct an AOC map
- Remedial Action
  - Use the AOC map to aid the remedial action design
- Final Status Survey
  - Latest CCM is used as the basis for developing a compliance survey

Complexities of Subsurface Sampling

- Number and location of soil core samples
  - For each location, the number and depth of subsamples within each soil core must also be specified
  - Cross contamination among vertical layers must be avoided
  - In case of boring tool refusal, an alternative should be specified

3 - IDENTIFY INFORMATION INPUTS

- Exposure scenarios needed for decision-making
  - Dose modeling is used to determine action levels/DCGLs
  - Select appropriate sampling and analysis methods to match the assumptions and parameters of the model
- Additional pathways need to be considered
  - Intruder scenarios
  - Construction of buildings
  - Groundwater
- NRC-accepted computer codes for developing DCGLs
- NUREG-1757, Volume 2, contains primary references for the definition of RESRAD parameters

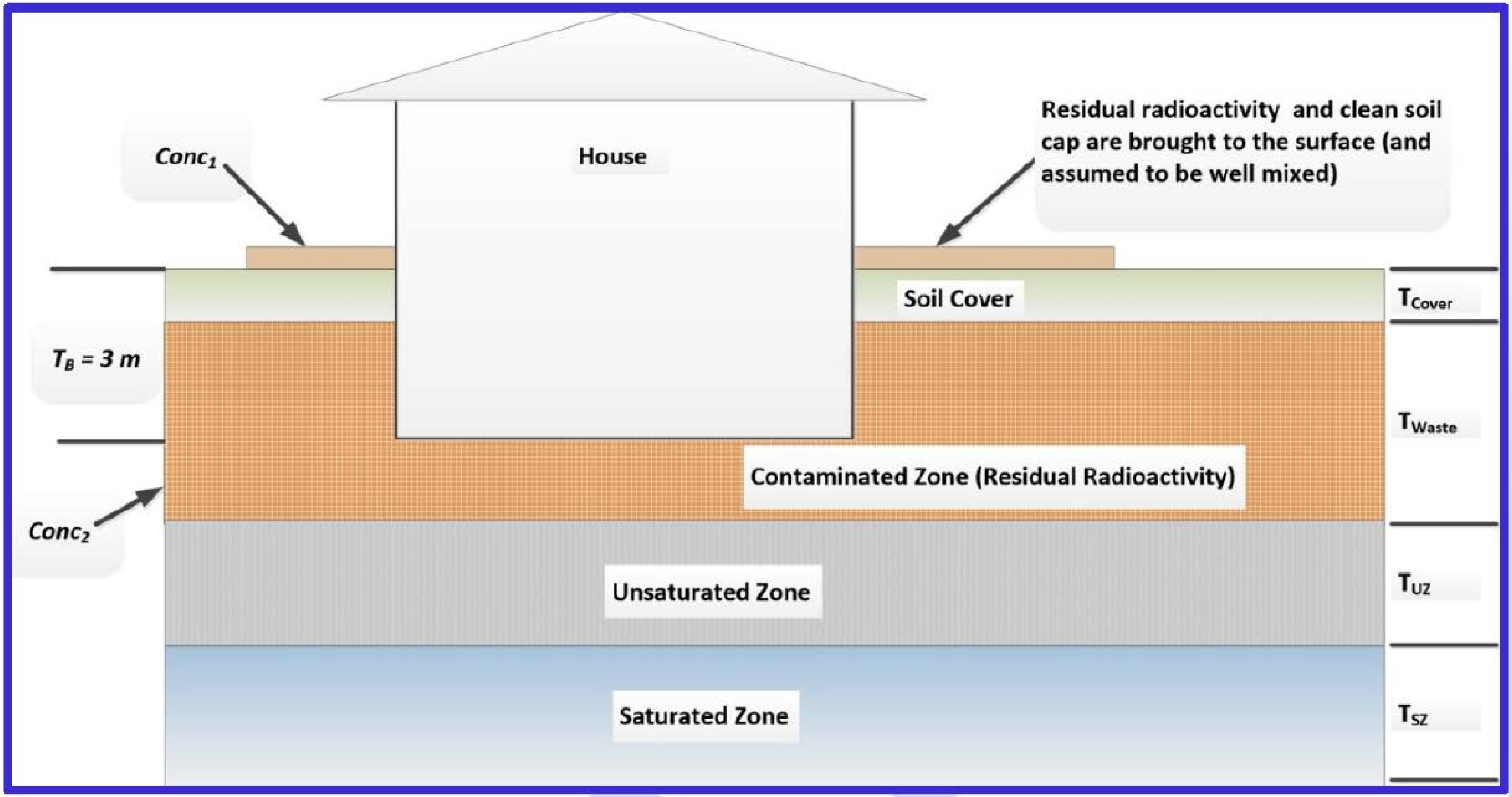
Derived Concentration Guideline Levels

- What should a release criterion be?
  - The average concentration in a volume? …in a survey unit?
  - The maximum concentration in a volume? …in a survey unit?
  - The probability of exceeding the DCGL?
  - A percentile of the concentration distribution at a location?
  - The release criterion should be consistent with the quantity calculated by the dose model.

Derived Concentration Guideline Levels (cont.)

- NUREG-1757, Volume 2, Revision 2, exposure scenarios for buried materials:
  - Basement excavation (residual radioactivity within 3 meters of the subsurface considering erosion) and other scenarios if residual radioactivity is found deeper in the subsurface (e.g., well drilling)
  - Large backfilled subgrade structures (e.g., containment basements at a reactor site)
- NUREG/CR-7268, “User’s Manual for RESRAD-OFFSITE Code Version 4,” Volume 1, considers three possible subsurface soil configurations:
  - Contaminants above the water table
  - A portion of the primary contamination in the water table
  - All of the primary contamination within the water table
  - However, RESRAD ONSITE and OFFSITE do not address existing groundwater contamination outside of the source area

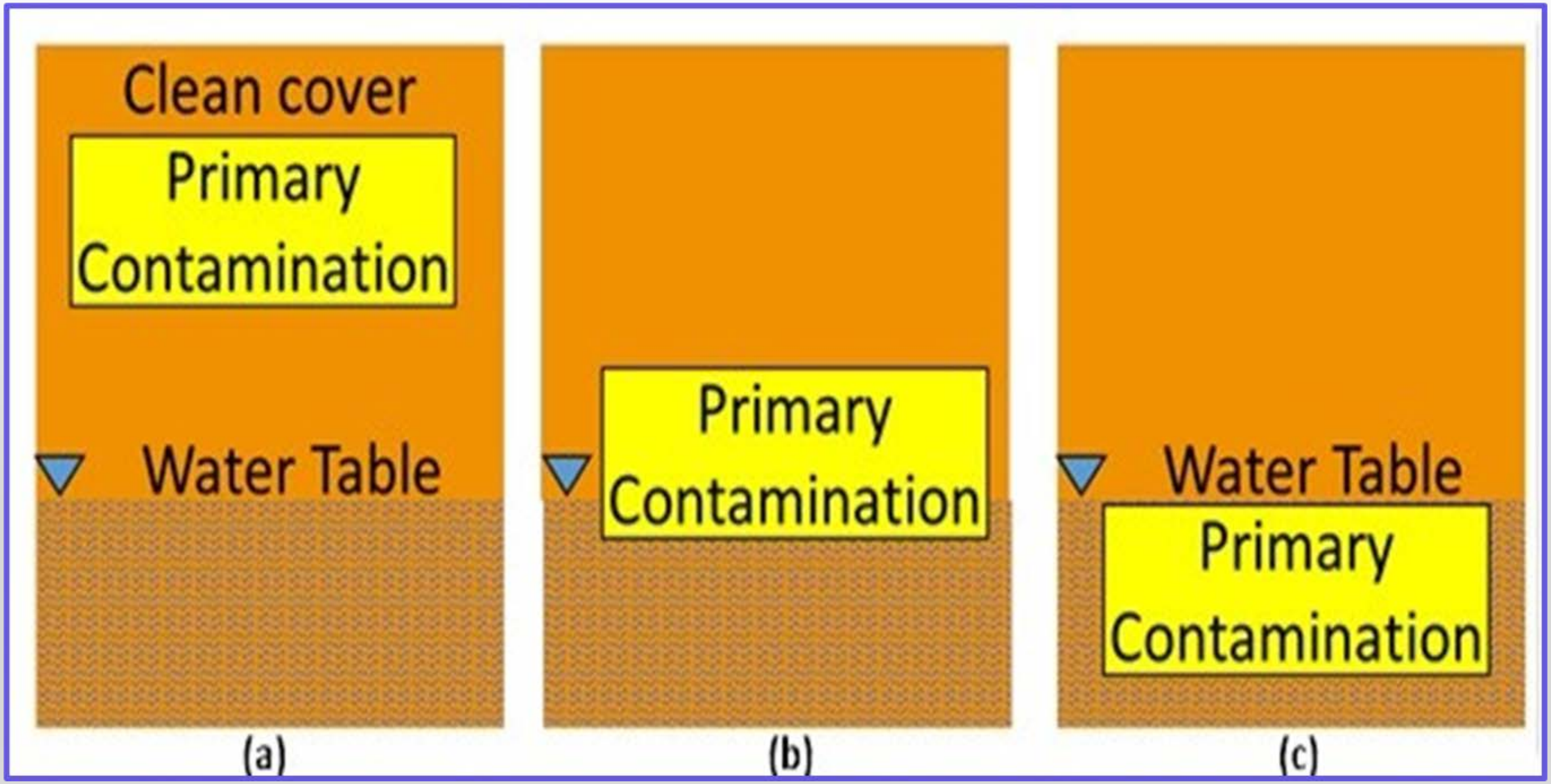
Subsurface exposure scenarios



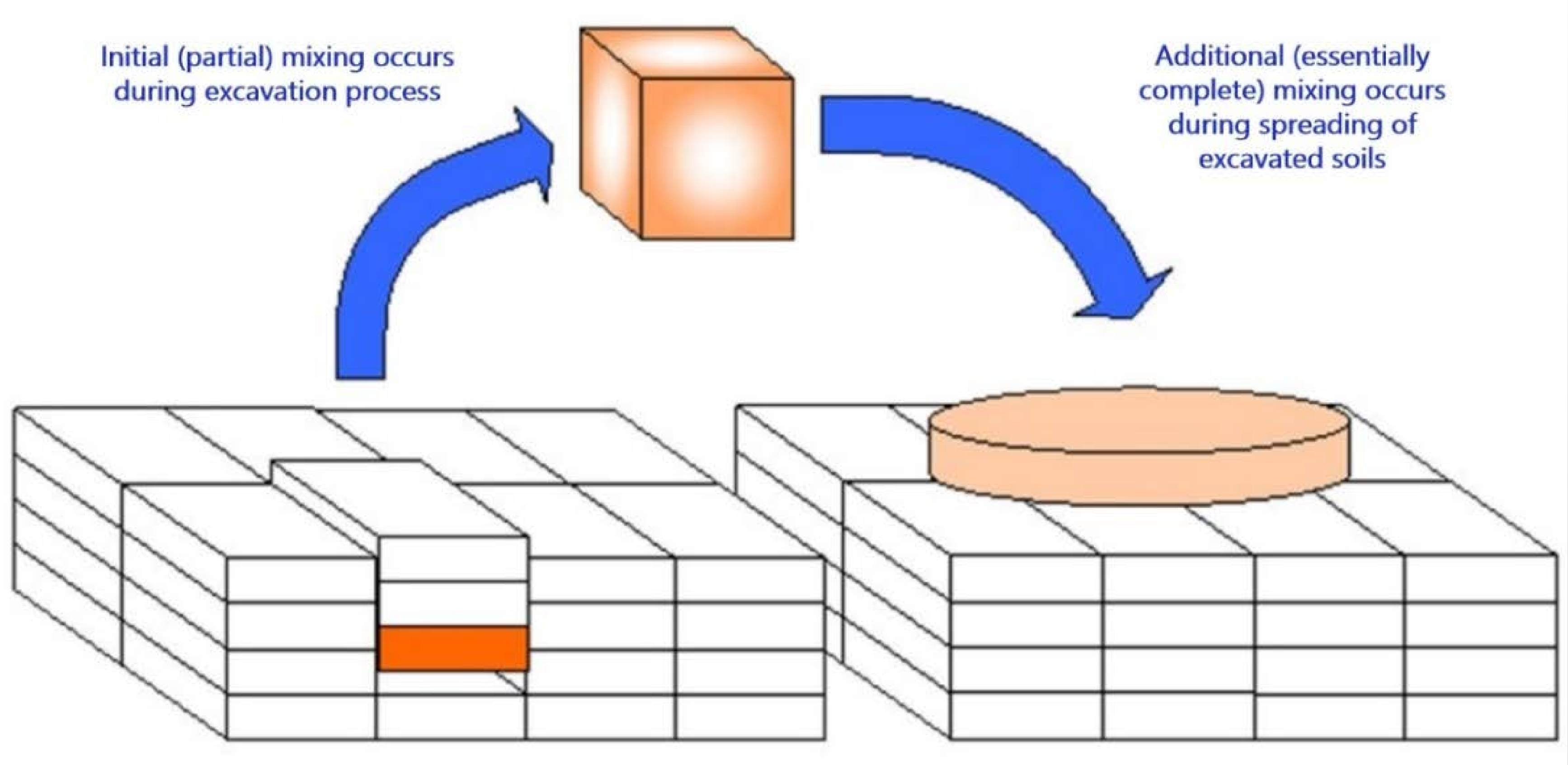
Derived Concentration Guideline Levels

- What is an elevated volume?
- Can a layered approach be used for excavations?
- Multiple subsurface layers or strata considered individually and then the cumulative risk from the multiple layers or strata is assessed

RESRAD: Three Possible Subsurface Soil Configurations



DCGLs for Buried Waste



Derived Concentration Guideline Levels

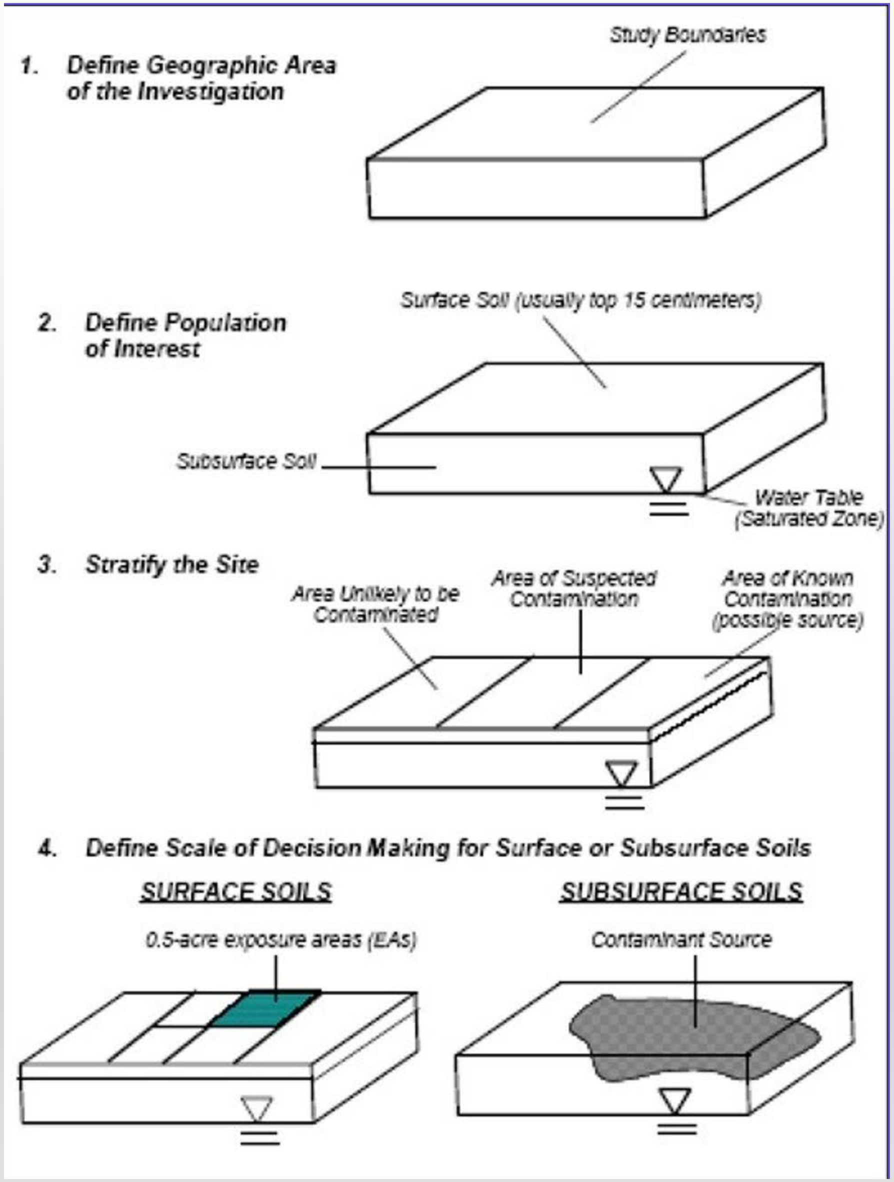
- Guidance that distinguishes between surface a DCGLw (wide area) and a subsurface DCGLv (volumetric) may be needed
  - Different classes of survey units may apply to the surface of the excavation vs. the walls of the excavation or surface soils
- Multiple DCGLs may be needed depending upon the radionuclides present, applicable exposure scenarios, and actual site conditions
  - May be beneficial to develop separate DCGLs for cases such as deep subsurface residual radioactivity because of the importance of the groundwater pathway
  - Using multiple DCGLs may be more straightforward where different sources are present (e.g., residual radioactivity at the surface vs. residual radioactivity associated with buried material or from deep subsurface spills or leaks that may contain mixtures of radionuclides)

4 – DEFINE THE BOUNDARIES OF THE STUDY

- MARSSIM survey units may not directly apply to the subsurface
  - Define a survey unit
  - Define the size of a subsurface survey unit
  - Define survey unit classifications

    (non-impacted, impacted Class 1, 2, 3)
  - Must a subsurface survey unit align with the surface survey unit it is beneath?
  - What, if any, are the requirements for a reference area?
- MARSAME is an example of applying MARSSIM concepts to very different kinds of survey units

Subsurface Survey Unit: Example



Large Soil Excavations and Equipment

- Evaluate methods to survey large subsurface soil excavations
  - Excavation experiences across the industry are inconsistent in handling layers and volumes just above the DCGL
  - Lessons learned include topics for dose modeling, characterization, and remediation
- Survey soils for reuse in large excavations
- Use of conveyor belts and other soil sorters; what DCGL is appropriate? $DCGL_W$? $DCGL_V$? Other?
- Can surface $DCGL_W$s be applied to excavation sides and layers? When material is brought to the surface?
- Can licensees correctly identify the class of all survey units, impacted or not impacted? Areas that need remediation?

5 - DEVELOP THE ANALYTIC APPROACH
Geospatial Modeling Tools – Key References

- Electric Power Research Institute (EPRI) (2016) “Guidance for Using Geostatistics to Develop Site Final Status Survey Program for Plant Decommissioning”
- Stewart, R., C. Welsh, T. Purucker, P. Goovaerts, C. Gogolak, D. Stewart (2009) An Introduction to Spatial Analysis and Decision Assistance (SADA) User’s Guide for Version 5, University of Tennessee
- Matzke, B.D., J.E. Wilson, L.L. Newburn, S.T. Dowson, J.E. Hathaway, L.H. Segol, M. Bramer, and B.A. Pulsipher (2014) Visual Sample Plan (VSP) Version 7.0 User’s Guide Pacific Northwest National Laboratory Report PNNL-23211, Richland, Washington

Geospatial Modeling Tools EPRI Review

- Evaluated 17 two- and three-dimensional geospatial modeling tools
- SADA and VSP were chosen for further study
- Both have a suite of geostatistical tools
- Are concerned with both sampling design and analysis
- Specifically support MARSSIM data analysis
- SADA is not currently supported, while VSP is
- SADA is three dimensional, while VSP is two dimensional
- NUREG/CR-7021 makes much use of SADA for examples
- Both are “freeware” but have a steep learning curve

SADA and VSP

- Whatever the tool, the use of geostatistics will need software, support, training and/or a subject matter expert
- There is a balance to be struck between the depth of analysis and ease of use
- Variogram fitting is part of the kriging procedure and is probably the most difficult, but the variogram may not need to be very accurate
- The variogram specifies the weights to be given values measured nearby a given location; the nearer measurements contribute more to the weighted average than further locations
- VSP supports more classical statistical methods compared to SADA, although it also contains geostatistical methods outside of the MARSSIM module
- SADA supports more geostatistical methods compared to VSP

6 - SPECIFY PERFORMANCE OR ACCEPTANCE CRITERIA (DECISION RULES, HYPOTHESIS TESTS)

- How should a decision rule be formulated?
  - Assume the survey unit meets release criteria unless proved otherwise (MARSSIM Scenario B) or
  - Assume the survey unit does not meet release criteria unless proved otherwise (MARSSIM Scenario A)
  - If there is a wide variability in reference areas, should there be an indistinguishable from background test?
- Appendix G to NUREG-1757, Volume 2, contains examples of Scenario B for three-dimensional data

SPECIFY PERFORMANCE OR ACCEPTANCE CRITERIA FOR ELEVATED MEASUREMENT COMPARISON (EMC)

- Should there be an EMC for the subsurface?
- Since scanning is not possible, every radionuclide in the subsurface is “hard-to-detect”
- MARSSIM does not directly address the issue of “hard-to-detect” radionuclides
  - MARSSIM considers that elevated areas the size of the space between discrete sampling locations will be found with essentially 100% probability as calculated using ELLIPGRID
  - An elevated area that is smaller will have some risk of being missed by the sampling grid. Again, the probability of detection can be calculated by ELLIPGRID. In the DQO process will determine the risk that is deemed acceptable

SPECIFY PERFORMANCE OR ACCEPTANCE CRITERIA FOR EMC (cont.)

- Geostatistics and other interpolation methods cannot find locations that exceed the largest value of the measurand unless there is some soft data that can drive higher concentrations (e.g., dry deposition data can extrapolate higher wet concentrations where the rainfall rate is higher)
- If indicator kriging is used to develop a probability distribution for the residual radioactivity, then a high percentile (e.g., 95%) may also extrapolate the data to higher concentrations; of course, this will require that the release criterion is expressed as an action level for that percentile

SPECIFY PERFORMANCE OR ACCEPTANCE CRITERIA FOR DATA UNCERTAINTY

- Statistically rigorous quantitative application of measurement quality objectives in MARSAME and MARLAP apply equally well to field measurements of radiation and radioactivity, although MARSSIM Revision 1 did not include such objectives explicitly
- Essential guidance for measurement uncertainties in the ISO GUM (ISO IEC Guide 98-3 2008(E), “Uncertainty of Measurement,” Part 3, “Guide to the Expression of Uncertainty in Measurement”)
  - De facto standard for estimating the uncertainty associated with measurements of any type
  - GUM methodology essential for the assessment of measurement uncertainty but not previously treated in MARSSIM

SPECIFY PERFORMANCE OR ACCEPTANCE CRITERIA FOR DATA UNCERTAINTY (cont.)

- MARLAP Volume III, Chapter 19, gives applications and examples for radiological analytical chemistry measurements
  - Recommends that all radioanalytical laboratories adopt the terminology and methods of the GUM for evaluating and reporting measurement uncertainty
  - This recommendation could be extended to apply to the determination of uncertainty of subsurface sample measurements, whether laboratory or field instrument measurements
- Software programs to perform the calculations to determine the combined standard uncertainty of a measurement:
  - GUMCalc
    - Report provides an example uncertainty calculation using GUMCalc in contrast with a more labor-intensive hand calculation approach
  - NIST Uncertainty Machine
  - GUM Workbench version 1.4 (commercial)

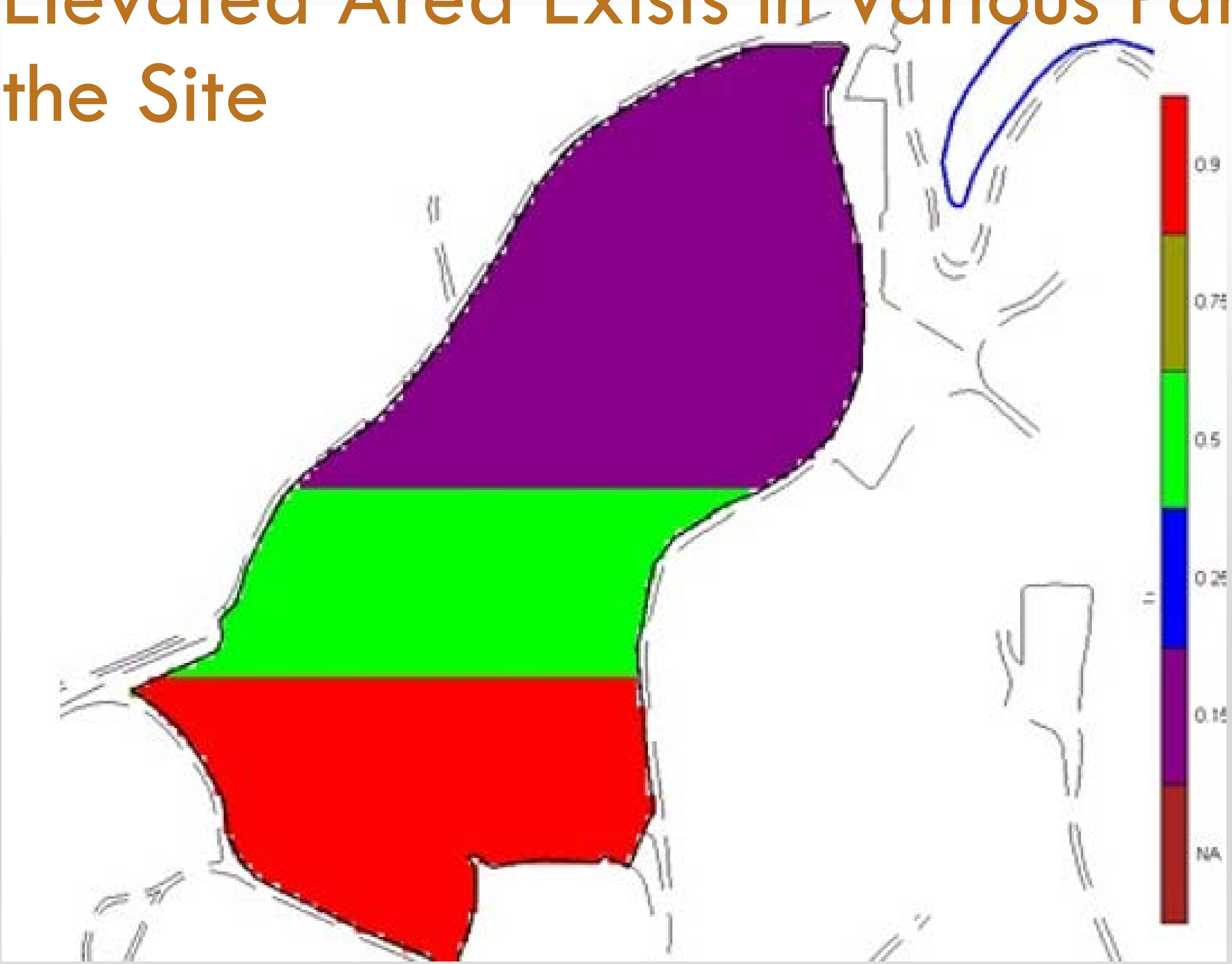
7 - DEVELOP THE PLAN FOR OBTAINING DATA

- As usual, the key issue for sample planning is "how many samples are enough?"
- To answer this question, there must be some measurable benefit for each addition sample taken
- In MARSSIM Scenario A, a minimum number of samples will be needed to achieve the desired Type I and Type II error rates α and β
- Once this number is reached, each additional sample results in the benefit of higher power (1-β)
- For the subsurface, a measure analogous to the power of the hypothesis test vs. sample size is desired

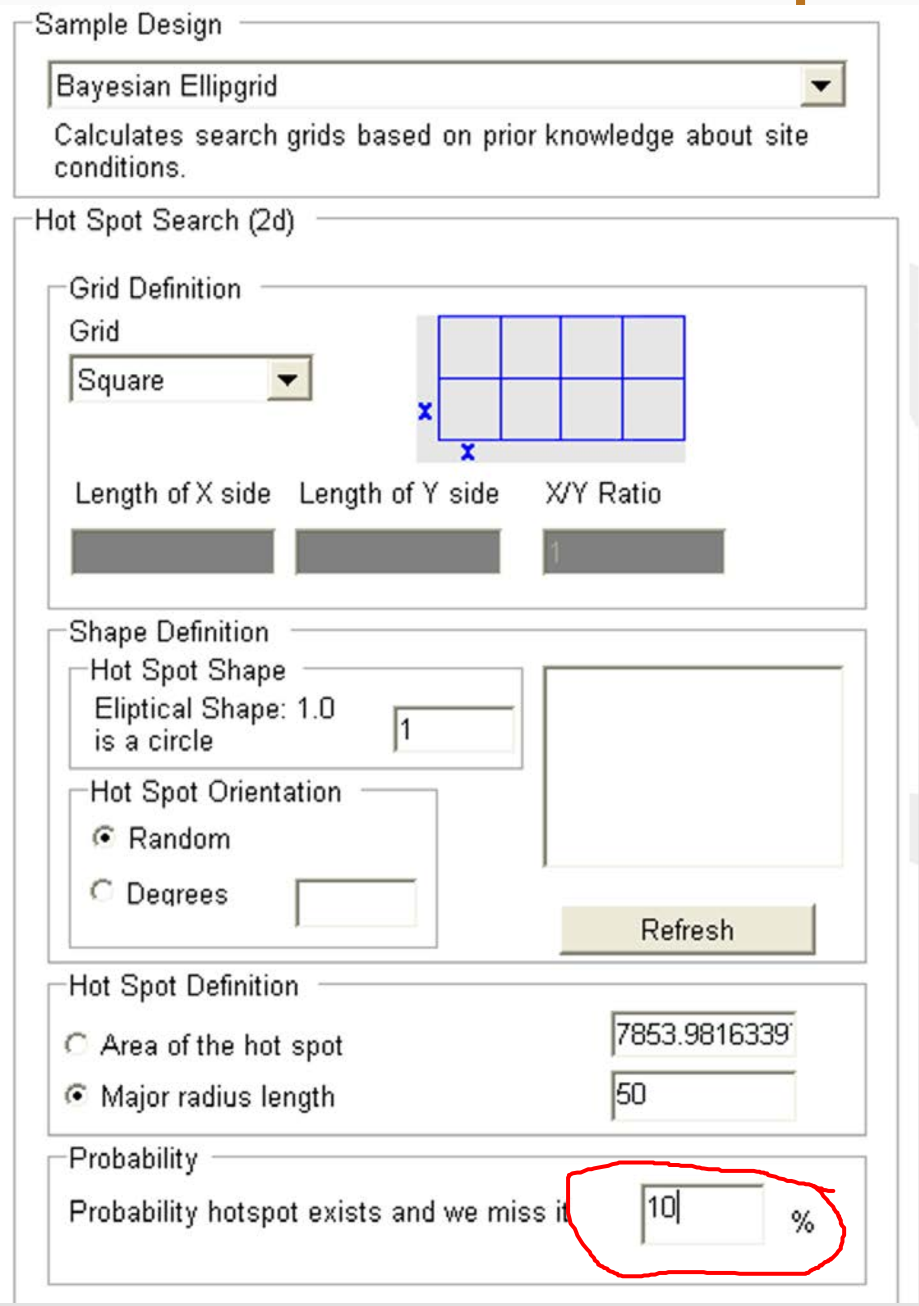
DEVELOP THE PLAN FOR OBTAINING DATA: A BAYESIAN APPROACH

- SADA uses a survey design called “check and cover” using a parameter called a “p-median,” but it has not been tested and is not currently implemented
- An alternative method for an initial survey design, also using SADA, is the Bayesian ELLIPGRID formulation
- Using information from the Historical Site Assessment, a map of the site indicating the likelihood of an elevated area existing in various parts of the site

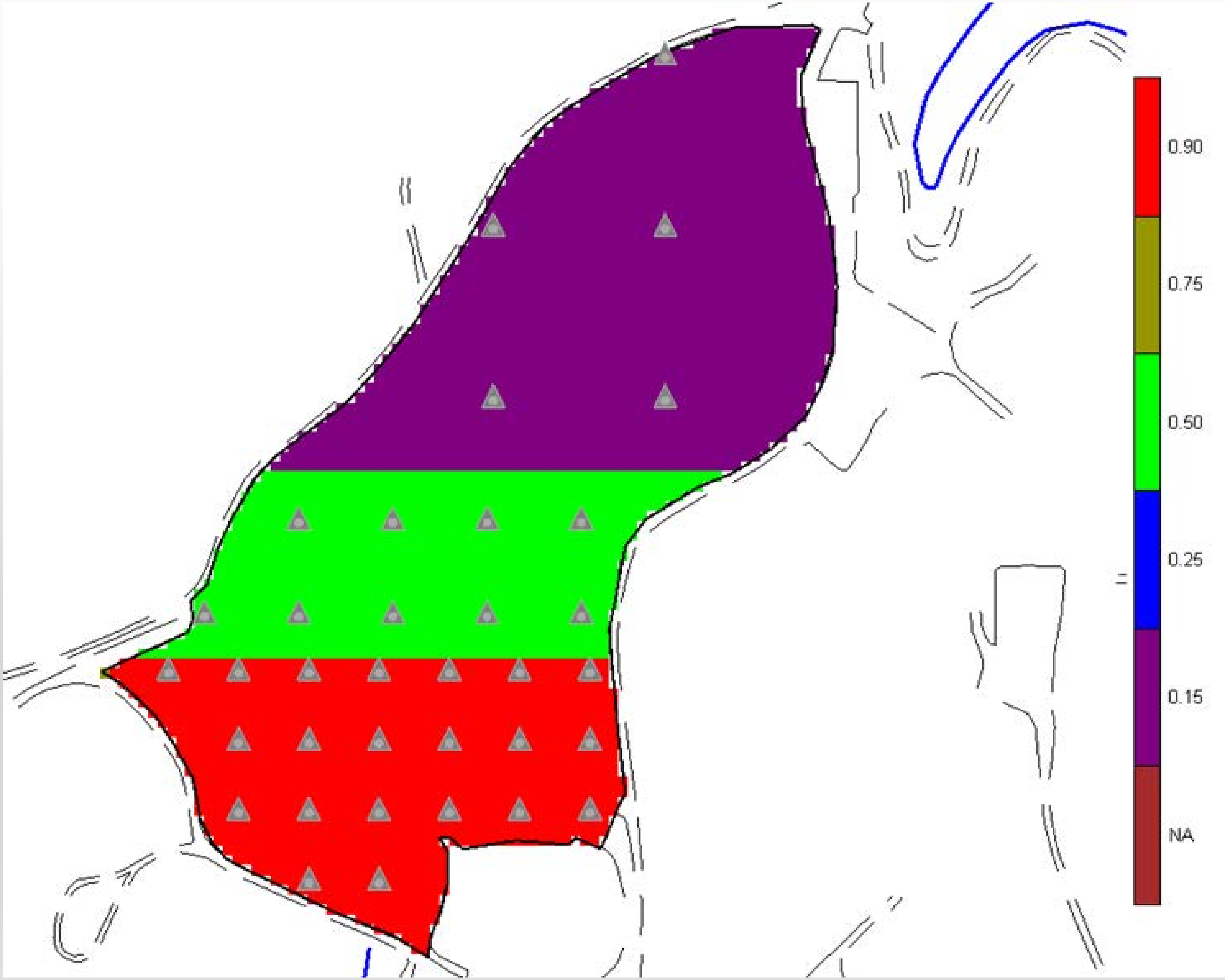
Bayesian ELLIPGRID: Likelihood of an Elevated Area Exists in Various Parts of the Site



Bayesian ELLIPGRID: SADA Input



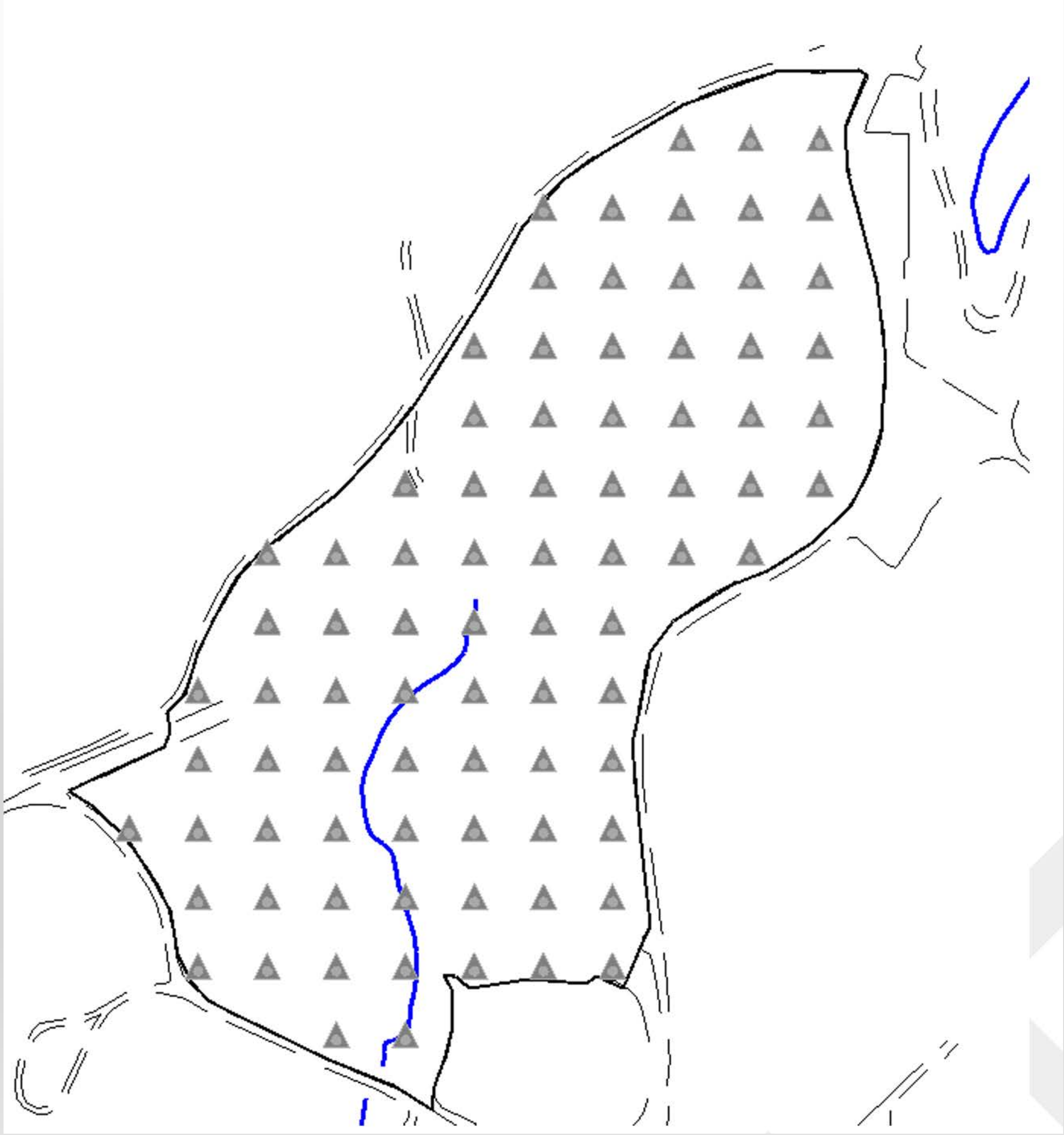
Initial Survey Design: 37 Samples



Bayesian ELLIPGRID

- The 37 measurements “kick-start” the process
- In SADA, the Bayesian prior probabilities can be “painted” on the site map
- Using the results from these 37 sample measurements, a secondary sampling design can be planned

Without Prior Probabilities: 87 Samples



Markov Bayes and Cokriging

- Cokriging allows other data types that are correlated with the contaminant of concern to support a geospatial model
  - Rather than ordinary cokriging, an indicator cokriging approach is used, whereby hard data are first converted to 0s or 1s depending on whether they exceed a specified criterion. The cokriging method is then applied to these 0s and 1s along with the user-defined prior-probability map. This results in an updated probability map that contains the influences of both the hard and soft data.
  - In SADA, a prior probability map must first be created
    - This is done by creating a user-defined map and then choosing the interview “Update My Probability Map.”
  - Suppose the soft prior probability map data (see user-defined maps) is represented by Y. Let I represent the indicator transformed hard sample data being interpolated.
    - Indicator Transform: Hard data transforms to 0 if the measured value is less than or equal to the decision criteria, and 1 otherwise
  - In the correlation modeling step, a correlation model is developed for the indicator transformed data set.

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