CL:AIRE

The Importance of Data Quality in Contaminated Land Work

Thursday 27th April 2006

Flett Theatre,
Natural History Museum,
London

0945 – 1025	**Registration and Coffee**
1025 – 1030	**Welcome and Introduction** *Mr Jeremy Randall, RAW Consulting*
1030 – 1100	**An Introduction to Data Quality: What is it? When is it Important?** *Dr Martyn Dunk, Remediation Manager, Exxon Mobil*
1100 – 1130	**Sources of Uncertainty and How to Manage Them** *Professor Mike Ramsey, University of Sussex*
1130 – 1200	**Managing Analytical Errors in the Lab – MCerts and Data Quality** *Professor Clive Thompson, ALcontrol Laboratories*
1200 – 1230	**Improving Data Quality Within the UK Regulatory Framework** *Bob Barnes, Environment Agency of England and Wales*
1230 – 1400	**Lunch**
1400 – 1500	**A US Perspective: Using the Triad Approach to Improve Decision Quality** *Dr Dan Powell, US Environmental Protection Agency*
1500 – 1530	**Experiences of Improving Data Quality in the UK** *Chris Sandground, IKM Consulting*
1530 – 1545	**Introduction to FASA (Field Analytical Suppliers Association)** *Perry Guess, IPM – NET*
1545 – 1615	**Discussion and Close**

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Cybersense

SEVERN TRENT ENVIRONMENTAL LEADERSHIP STL

Thames Water

Biographical Note

Professor Mike Ramsey

Mike Ramsey if Professor of Environmental Science and Director of the Centre for Environmental Research at University of Sussex. After degrees in Chemistry & Geology, and Analytical Geochemistry, he worked for 3 years in the Mining Industry in Zambia, and then 20 years in various research and teaching posts at Imperial College London. He has published over 100 scientific papers, mainly on aspects of uncertainty in sampling and in measurement, and the effects of this uncertainty on decision making. Current research project include investigation of uncertainty from sampling of contaminated land (DTI/CLAIRE funded) and contaminated food (FSA funded). He is currently Chair of both the Eurachem/Eurolab/Citac/Nordtest Working Group on Uncertainty from Sampling, and the RSC/AMC (Royal Society of Chemistry/ Analytical Methods Committee) Sub-committee on Sampling Uncertainty and Quality.

Sources of Uncertainty
and how to manage them

Prof Michael H Ramsey
Centre for Environmental Research,
School of Life Sciences,
University of Sussex, Brighton, UK

Overview

- Contaminated land work – how reliable? how much U?
- What is Uncertainty ? – relationship to data quality
- How to estimate U – and its sources + *Case Studies*
- What are benefits of knowing U?
  - Using U info in interpretation – *not just for data accept/reject*
  - e.g. making on-site/ *in-situ* measurements acceptable + *Case Study*
- Managing U – e.g. how to reduce U – *if required*
- Cost of estimating U *versus* cost of ignoring U = ***Savings***
- Conclusions

Contaminated land work – **How reliable? How much U?**

Sampling Proficiency Test (SPT)

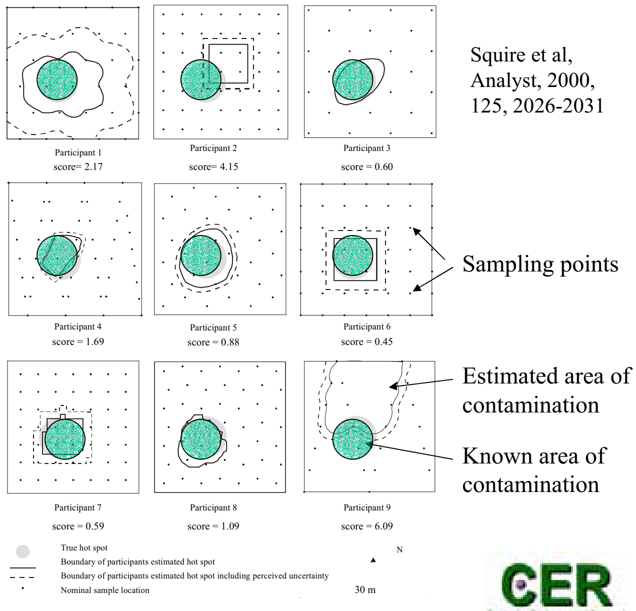
– multiple samplers

- gives **estimate of U**

-larger than estimated with Duplicate Method,
- but more realistic

- includes sampling bias

Squire et al, Analyst, 2000, 125, 2026-2031



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Assessing the reliability of site investigations – *using uncertainty*

- How can we assess reliability of measurements?
  - Never get 'true values' of concentration
- Know the range within which the true value lies?
  = the **Uncertainty** (U of measurement)
- U is key parameter of data quality *(includes most others)*
  - includes random and systematic effects. U ≠ precision
  - *Not the uncertainty* <u>*between*</u> *sampling locations – used in CLR7*
- Doesn't assume measurements or sampling are correct
  - *Gives user info on quality (not left in the lab!)*

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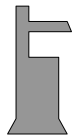
Assessing the reliability of site investigations – *using uncertainty*

- Measurement begins at the time of sampling (not just in lab)
  - Becomes evident with the use of *in situ* measurements
  - so Uncertainty arises from Sampling and Analysis

PXRF-



$$U_{meas} = \sqrt{U^2_{samp} + U^2_{anal}}$$

- Reliability of investigation not guaranteed purely by use of high quality lab (e.g. MCERTS)
  - Most uncertainty often in the sampling – usually unknown
    - Not the uncertainty quoted by the lab = U_{anal}

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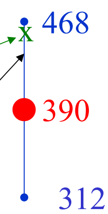
Uncertainty of measurement (U)

- The range that contains the true value
  - *e.g. U =20% on measurement of 390 mg/kg Pb*
  - *Range of U = 390+20% =468 mg/kg*
    to 390-20% =312 mg/kg
- We can never know the true value *(could be 460 mg/kg)*
- Effect on comparison with threshold value of 450 mg/kg
  - *i.e. Measured value 390 mg/kg is <u>below</u> the threshold value*
    True value 460 mg/kg is <u>above</u> the threshold value
    Measured value gives 'false negative' classification



- All we need to know is how far from the truth we might be
  - *e.g. with 19/20 chance if being right = 95% confidence*
- How can we estimate uncertainty of measurements – including that from sampling?

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Options for Estimating U

- *Two broad approaches:- Empirical and Modelling,*
- *To be described in new Eurachem/Eurolab/Citac/Nordtest Guide,*
- *here discuss just…*

- ***4 Empirical methods***
  - based on replication of measurements, either within or between organisations = *'top down'*

Method #, name	Samplers	Protocols	
1. Duplicate	1	1	←Discussed here
2. Multiple Protocols	1	Multiple	
3. CTS*	Multiple	1	
4. SPT**	Multiple	Multiple	←*Quick mention*

*CTS = Collaborative Trial in Sampling = same protocol
**SPT = Sampling Proficiency Test = different protocols

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Components of uncertainty - SAMPLING + *analytical*

Error/Effect Type→	**Random** *(**P**recision)*		**Systematic** *(**B**ias)*	
Process ↓	Symbol	*Estimate using:-*	Symbol	*Estimate using:-*
Analysis	P_{anal}	e.g. duplicate analyses	B_{anal}	e.g. reference materials CRM
Sampling	P_{samp}	duplicate samples	B_{samp}	?? RST, IOST

RST = Reference Sampling Target
IOST =Inter-organisational sampling trial

•Precision and Bias of methods *(info often available in labs AQC)*

- used to estimate

•Uncertainty of measurements

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Components estimated by 4 Methods

#	Method	Samplers	Protocols	Components estimated			
				P_{anal}	B_{anal}	P_{samp}	B_{samp}
1	Duplicates + CRMs	1	1	**Y**	**Y**	**Y**	**No**
2	protocols + CRMs	1	multiple	**Y**	**Y**	**between protocols**	
3	CTS* + CRMs	multiple	1	**Y**	**Y**	**between samplers**	
4	SPT** (+CRMs optional)	multiple	multiple	**Y**	**Y**	**between protocols +between samplers**	

Limitation of Duplicate Method

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Estimation of uncertainty in a routine site investigation - Case Study #1

• Site with mine waste (Sn/Cu in Cornwall)

• Routine Site Investigation + U estimation

• Proposed new use – housing with gardens

• Dominant contaminant – Arsenic

• Sampling method – 16 trial pits, one per garden

– one sample at 0.5m depth, another at 1.5m

- designed by SI company – not ideal

•Uncertainty estimated - using Duplicate Method

- 8 duplicated samples – in balanced design

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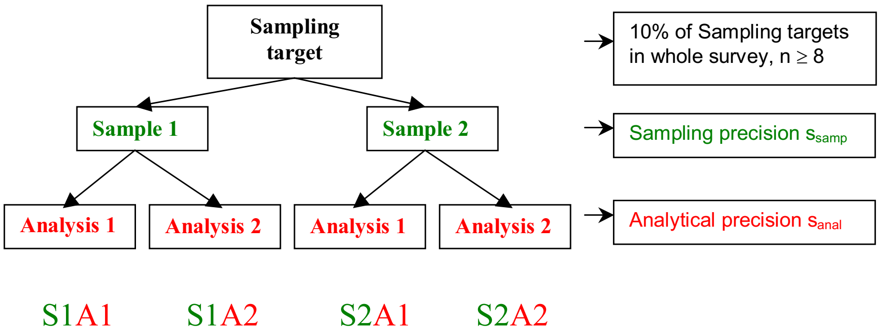
Balanced Sampling Design

used in the Duplicate Method



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Video of duplicate sampling

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Duplicate Results at Mine Site

Locations	Arsenic concentration mg/kg S1A1	S1A2	S2A1	S2A2
1	144	144	153	153
2	459	477	412	457
3	343	419	314	342
4	325	315	124	134
5	**654**	**723**	**125**	**139**
6	704	676	675	778
7	20428	19908	837	878
8	257	288	137	138

Provisional site-specific threshold value – 500 mg/kg

-which sites are reliably under this value ? **(#5?)**

- use these values to estimate U, using robust ANOVA

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Sources of uncertainty - *Mine Waste Site*

- Uncertainty: Sampling 130 mg/kg, Analysis 32 mg/kg
- Measurement uncertainty = 134 mg/kg
- = **65% of concentration value (at 95% confidence)**

- Proportion of U caused by **sampling**
  $= 100*s^2_{samp}/s^2_{meas} = 100*130^2/134^2 = 94.4\%$ *- dominant source*

- Proportion of U caused by **analysis**
  $= 100*s^2_{anal}/s^2_{meas} = 100*32^2/134^2 = 5.6\%$

same as 100% – 94.4%

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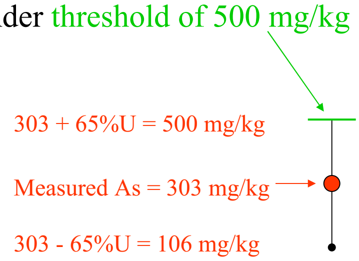
Using uncertainty in interpretation-

Mine Waste Site

- Only locations under 303 mg/kg are reliably under threshold of 500 mg/kg



- only two locations #1 & #8 are uncontaminated (S1A1 = 144 & 257 mg/kg resp.)
- *More details in CL:AIRE Technical Bulletin #7*

- How much U is acceptable – to make measurements fit-for-purpose (FFP)?
  - use OCLI method (Optimised Contaminated Land Investigation)

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Judging Fitness-For-Purpose (FFP)

using OCLI method.

- Estimates the Fitness-for-purpose (FFP) of measurements overall,
  - this then sub-divided to estimate FFP of analytical and sampling separately.
- Considers the cost of measurement,
  - and the potential cost of misclassification (end-use).
- Details in Ramsey M.H., Taylor P. D. and Lee J.C. (2002) J. Environmental Monitoring, 4, 5, 809 - 814.

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The OCLI equation

$$E(L) = C\,[1 - \Phi(\varepsilon_1 / s_{meas})] + D/s^2_{meas}$$

Where:

E (L) – expectation of financial loss

s_{meas} – measurement uncertainty

C – consequence costs (e.g. potential losses resulting from misclassification)

Φ – standard normal cumulative distribution function

ε1 – error limit = │ T-c │

(T = threshold value, c = contaminant concentration)

D – combined optimal cost for sampling and analysis.

(equation adapted from Thompson and Fearn, 1996).

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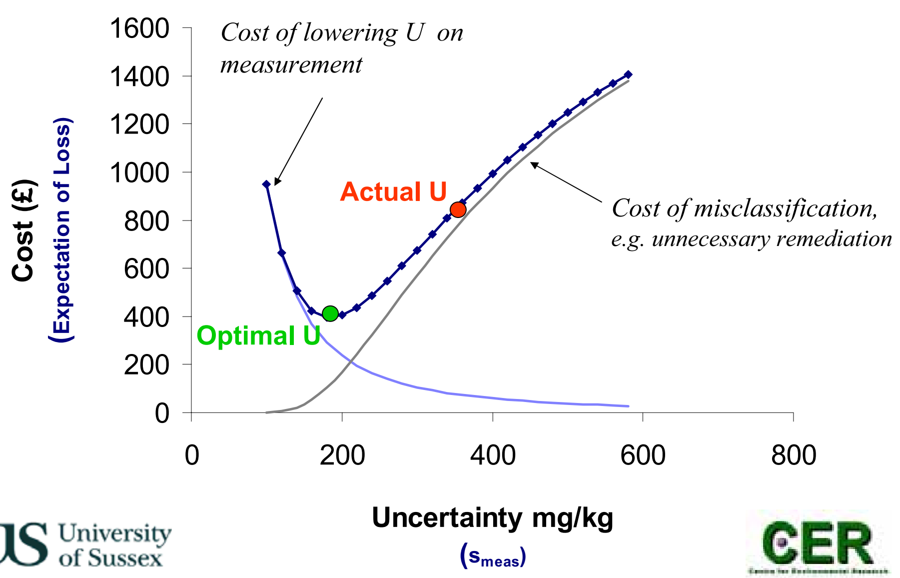
Acceptable level of Uncertainty?



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OCLI at Cornish Mine Site – for housing development

Remediation Scenario 1: barrier and 1m topsoil cover.

OCLI Input parameters:-

- c = 500 mg kg^{-1} total As. *(for false positive classification – true value really < 400)*
- T = 400 mg kg^{-1} total As (site-specific RA).
- L_{sample} = £30 per sample.
- $L_{analysis}$ = £10 per sample.
- C = £6,000 per sample location.
- s_{meas} = 130 mg kg^{-1} at 0.5 m

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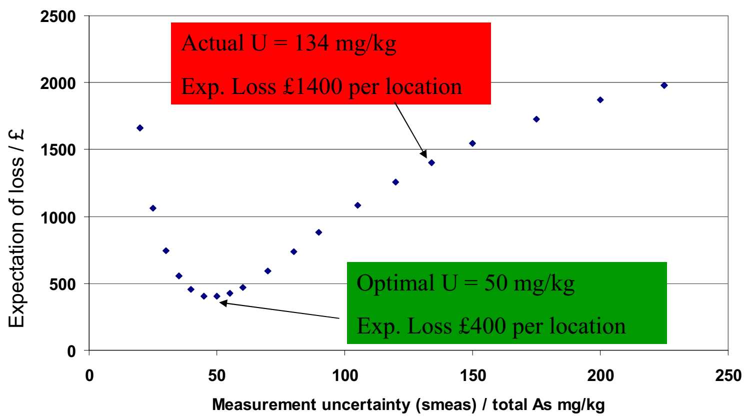
Actual v Optimal U – at Cornish Mine Site



Overall saving of £12,300 on whole development

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Reducing Uncertainty

- Measurement strategy is sub-optimal (from OCLI)

Actual U (smeas) = 134 mg/kg As
Optimal U = 50 mg/kg As
- to reduce loss from £1400 to £400 = £1000, = £12K on whole site

How can this be achieved?

- uncertainty dominated by sampling = 94% of measurement uncertainty

- Use Sampling Theory to predict mass required to reduce U
- $m \propto 1/s_{samp}^2$

Therefore 4-fold sample composite at each location
Should reduce U by a factor of $\sqrt{4} = 2$
Predicted s_{samp} = 130 / 2 = 65mg/kg As (gives s_{meas} = 72 mg/kg)
Using OCLI: 72 mg/kg As E(L) = £555 – *close enough to optimum?*

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6 Case Studies at contrasting sites

Site#	Source of Pollution	End use	Prime contaminant	Sampling method	U%	Prop Samp	Prop Anal
1	Mine Sn/Cu *(0.5m)*	Housing	Arsenic	Trial Pit	65	94	6
2	Gasworks waste	Public access	Lead	Trial Pit	51	93	7
3	Infill after WWII Bombing	Private gardens	Lead	Window	25	99.9	0.1
4	Gasworks	Commercial Dev.	Total PAH	Trial Pit	186	<1	>99
5	Railway sidings	Public access	Copper	Trial Pit	158	Not separated to save cost	
6	Ex-firing range	Housing	Lead	Hand auger	75	72	28

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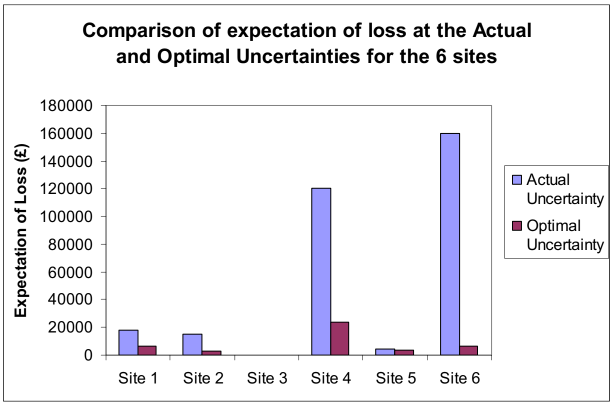
Loss at Actual v Optimal U – for 6 Case Studies



Saving of £150K
across Site 6

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Case Study #2 + *In situ* measurement

- Nature reserve -**West London**
- Ex-Firing range.
- Measurements of Pb concentration in topsoil.
- 100x100m site.
- 2000µg g^{-1} Pb Threshold (ICRCL open space - current in 2002).

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In-situ P-XRF measurements.

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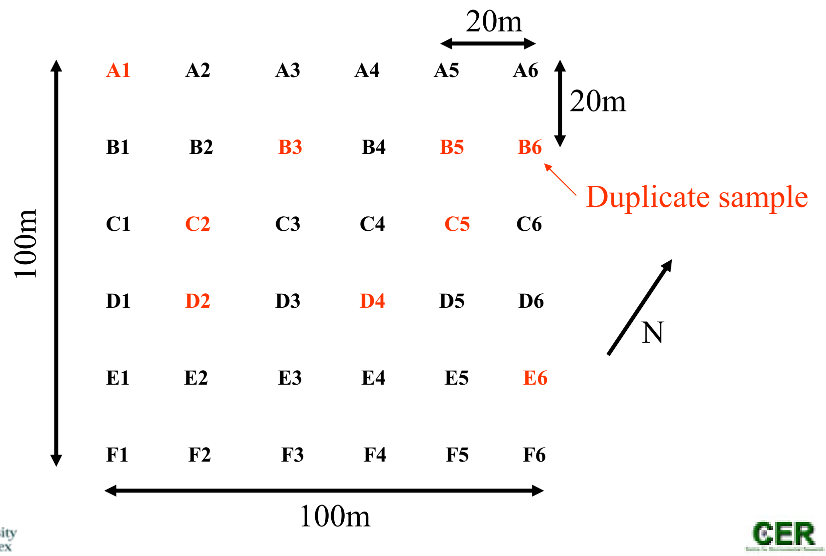
Sampling design for survey.



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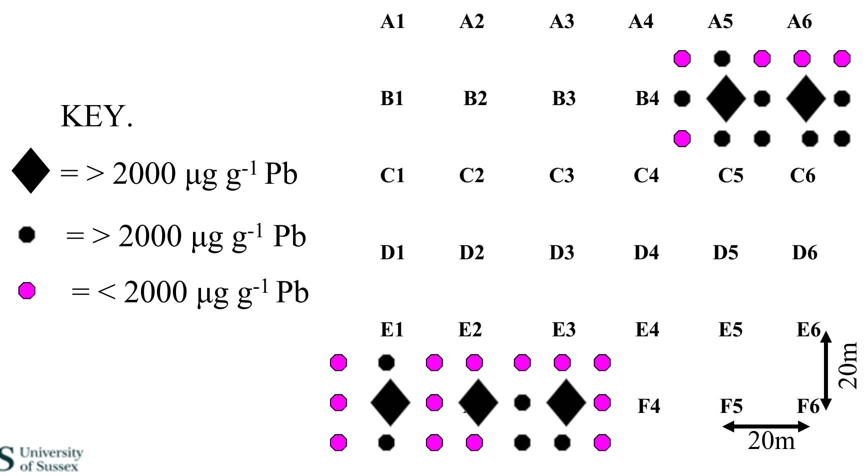
Results for *in-situ* investigation.



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Removal of topsoil samples for *ex-situ* analysis.

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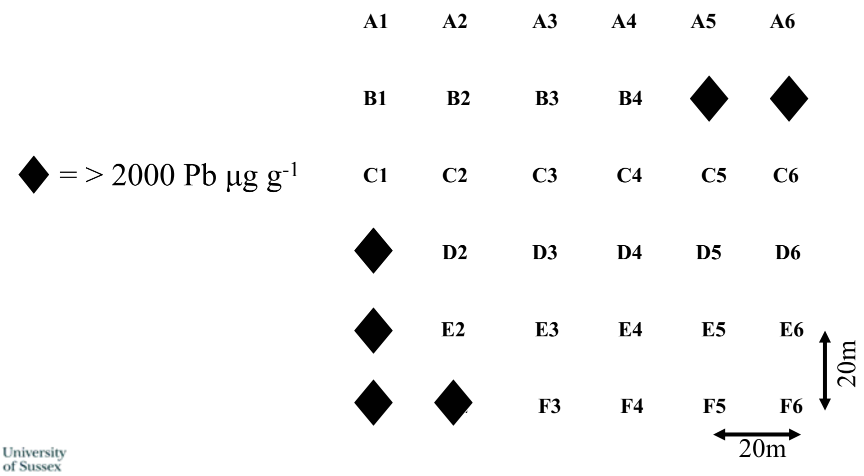
Results for *ex-situ* investigation.



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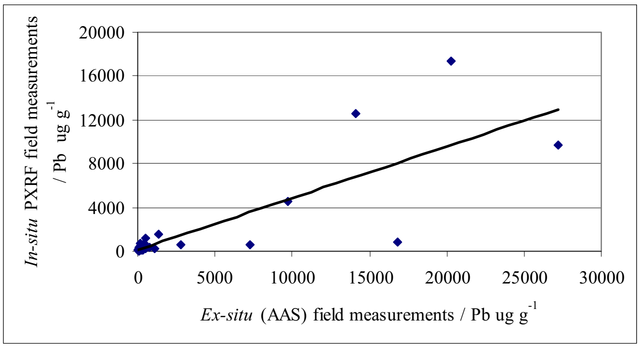
‘Bias’ between *in situ* and *ex situ*



In situ Pb = 0.47(±0.05) x *Ex situ* Pb   Bias = -53% (±5)

-caused by soil moisture and roughness (and depth difference)

-Did not affect spatial pattern of Pb = relative

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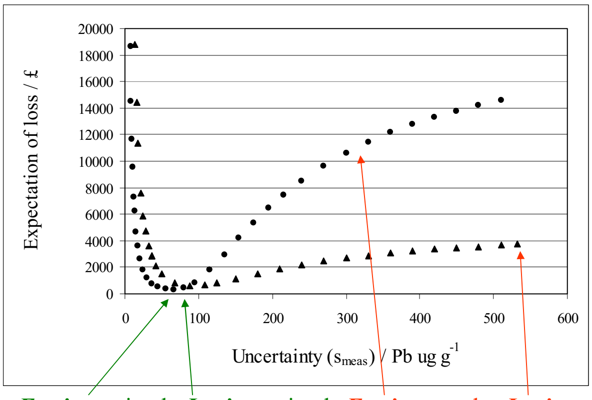
Which is more cost effective?



Ex situ optimal uncertainty	***In situ*** optimal uncertainty	***Ex situ*** actual uncertainty	***In situ*** actual uncertainty
68 ug g^{-1}	88 ug g^{-1}	311 ug g^{-1}	533 ug g^{-1}
		£11,000	**£3,700**

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Conclusions & Benefits

- Uncertainty is inevitable in site investigation
- Simple method available to measure this uncertainty
  - Shown to be applicable to wide range of sites/contaminants
  - Commercial labs may offer a package to facilitate use
  - Show size of U for first time – e.g 25-186%
  - *And that this arises mainly from the sampling*
  - Applicable to waters, gases, wastes and rock, not just soils
- Once U is known, more reliable decisions can be made on how to develop the site
- Estimating U cost money initially, but often saves money overall
  - *e.g. £12,300 at Mine-waste site*
  - *£150,000 at Site 6*

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Conclusions & Benefits (2)

- Knowing U allows:-
  - Decision on whether U optimal for minimum financial loss
    - Using OCLI
  - More reliable classification of sites (and waste)
  - Reduces overall costs
    - Less unnecessary remediation
    - Fewer delays from discovery of further contamination
    - Less chance of litigation from undetected contamination
    - Enables use of *in situ* measurements, low cost/ high U *(e.g. West London)*
      - from more rapid decisions – more cost-effective overall
  - Rational allocation of resources
    - To measurements overall
    - And to sampling versus chemical analysis
      - More money on sampling, less on analysis = cheaper investigation
  - Know quality of sampling – *not just assumed correct*

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Conclusions (3)

- Role for U estimation in routine site investigation
- Need for clearer guidance from regulators on:-
  - Whether reporting of U will be accepted/helpful
  - Whether there will be a move to requirement for certified samplers (as in Scandinavia)
- Need for development of rugged decision support tools

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Acknowledgements

- Co-workers
  - Paul Taylor, Sharon Squire, Katy Boon
- Research funding
  - DTI Partners in Innovation STBF/004/00034C
  - CL:AIRE Research Project RP4
  - Engineering and Physical Science Research Council
- DTI/CL:AIRE Steering Committee members include:-
  - Environment Agency (Bob Barnes),
  - British Nuclear Fuels plc. (Rob Gordon),
  - Shell Global Solutions (UK) (Dr Gordon Lethbridge),
  - Atkins (David Nancarrow),
  - Southern Testing (Dr Joe Kelly)
  - Brighton & Hove City Council (Paul Slaughter)
  - SecondSite Property (Dr Steve Wallace)

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Mine Waste Site – ANOVA output

CLASSICAL ANOVA RESULTS

Mean = 1626.875

Standard Deviation (Total) = 4959.0068

	Geochemical	Sampling	Analysis
	-----------	--------	--------
Sums of Squares	3.6183133E8	3.7326515E8	149251
Standard Deviation	1121.6108	4829.5352	96.582542
Percentage Variance	5.1155814	94.84649	0.037932186

ROBUST ANOVA RESULTS:

Mean = 409.93396

Standard Deviation (Total) = 278.76849

	Geochemical	Sampling	Analysis	Measurement
	-----------	--------	--------	-----------
Standard Deviation	244.60779	129.8943	31.723255	133.71199
Percentage Variance	76.99335	21.711652	1.2949952	23.006649
Relative Uncertainty	-	63.373282	15.477252	**65**.235869

(% at 95% confidence)

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Biographical Note

Professor Clive Thompson

Over the last 35 years, Clive Thompson has gained very broad experience in the management of environmental laboratories. He is Chief Scientist at ALcontrol Laboratories and has previously managed laboratories at Yorkshire Water and Severn Trent Water. He was awarded the 2003 Society of Chemical Industry (SCI) Environmental medal for distinguished and sustained achievement in the areas of preservation, improvement or understanding the environment. He serves on a number of national and international committees relating to environmental analysis. He also ran the LEAP Proficiency Scheme for over 10 years, until it was sold to MAFF (CSL) in 2000. ALcontrol Laboratories employs over 1000 staff in the UK and over 1000 staff in the Netherlands, France, Sweden, Germany, Denmark and Belgium. It has ten laboratories in the UK and Eire and is one of the largest contract contaminated land analysis / air and water analysis / food analysis laboratory organisations in Europe.

Managing Analytical Errors in the Lab: - MCERTS and Data Quality

K. Clive Thompson

Chief Scientist

ALcontrol Laboratories

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ALcontrol Laboratories 1

Disclaimer

The views expressed in this presentation are solely those of the author and not necessarily those of ALcontrol Laboratories

ALcontrol Laboratories 2

Managing Analytical Errors in the Lab: - MCERTS and Data Quality

1) Introduction and Background
2) Sampling Issues
3) MCERTS
4) Perceived Problems with MCERTS
5) Conclusions

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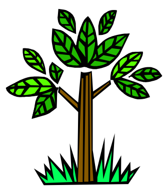
1) Introduction and Background



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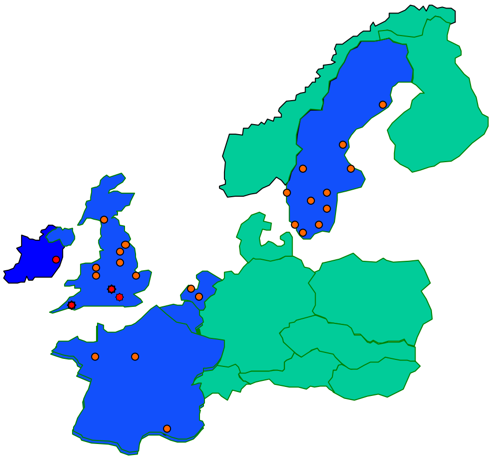
ALcontrol Group

European locations



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Key Criteria for Analysis:-

All samples and results should be fit for the intended purpose

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Prior to MCERTS (1)

- Concerns were voiced about quality of contaminated land analysis
- EAGLE group set up by 12 major commercial laboratories in mid-1996
- Discussion points: - Legislation; UKAS; Contest PT scheme performance; harmonisation of methods; comparability of laboratory data; work to overcome lack of reference materials; liaison with regulators
- Well-proven regulatory drinking water analysis system that gave fit for purpose results in place already.

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Prior to MCERTS (2)

- ISO 17025 alone was not adequate to ensure fit for purpose results
- The Environment Agency were approached by EAGLE and MCERTS evolved on the lines of the successful DWI system.
- MCERTS has effectively evolved by consensus and continues to evolve. Version 3 due out very shortly.

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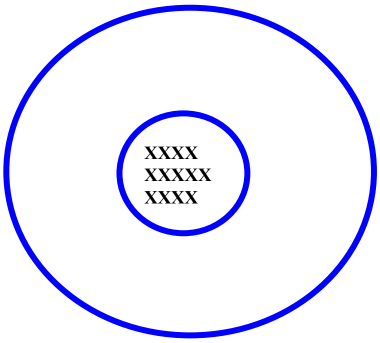
GOOD PRECISION, NEGLIGIBLE BIAS



True result	Actual results
10	9.8
	10.2
	9.9
	10.1
	10.0

Desired Analysis Results

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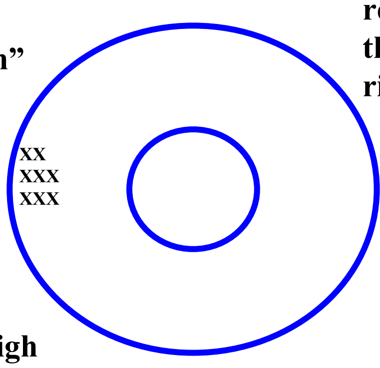
GOOD PRECISION, SIGNIFICANT BIAS

"Precise Rubbish"

"The repeat analysis result is the same therefore it must be right!!!"



The more complex the sample matrix, the larger the likely bias

Do not equate high precision with accuracy

Effect of Method Bias

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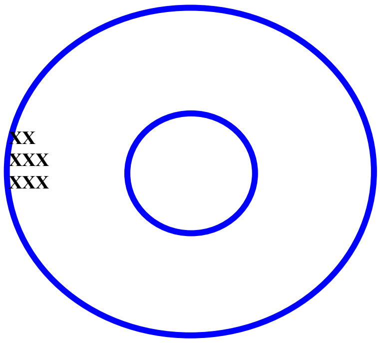
GOOD PRECISION, SIGNIFICANT BIAS



True result	Actual results		
10	3.8		
	4.2		
	3.9		
	4.1		
	4.0		

Effect of Method Bias

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Matrix Variations

- **For regulatory drinking water the matrix variation is just from: - ~ 99.8 – 100% water**
- **Contaminated soils have a huge matrix variation. (sandy; loamy; clayey; peaty; limestone; slag; iron-rich etc.)**
- **The problem is to develop robust methods which will work with all types of contaminated soil.**

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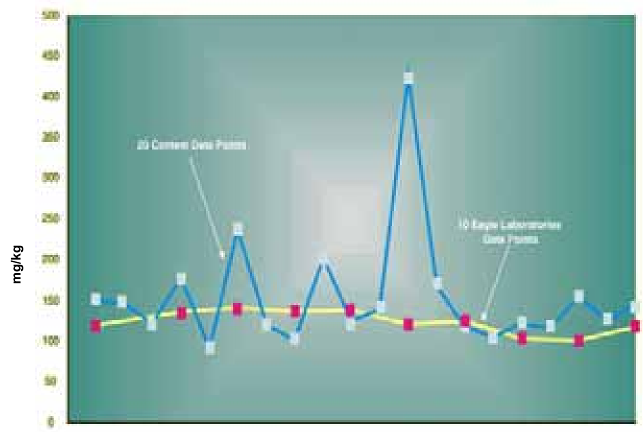
Comparability of Data:- Contest v EAGLE Labs (1)

TOTAL ZINC IN PREPARED SOIL



LAB.	EAGLE	CONTEST
1	120	150
2	136	144
3	141	124
4	138	178
5	139	86
6	122	237
7	125	120
8	103	101
9	101	191
10	118	126
11		139
12		430
13		169
14		128
15		106
16		122
17		117
18		155
19		126
20		145
MEAN	124	155
RANGE	101-141	86-430

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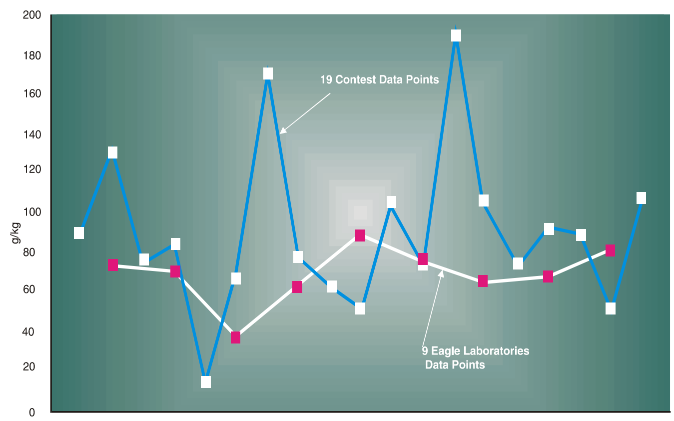
Comparability of Data:- Contest v EAGLE Labs (2)

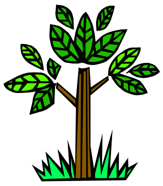
TOTAL PAHs IN PREPARED SOIL



LAB.	EAGLE	CONTEST
1	74.1	88.9
2	71.6	131.4
3	38.0	75.9
4	61.3	84.1
5	88.1	15.3
6	75.1	68.1
7	63.4	170
8	70.3	79.6
9	81.5	980*
10		61.2
11		53.9
12		103.9
13		77.2
14		191
15		114
16		74.2
17		95.9
18		91
19		54.9
20		113
MEAN	73.1	136.2
RANGE	61.3-88.1	15.3-980

Sampling Issues

(Not part of the MCERTS Standard)



ALcontrol Laboratories 15

17

Sampling Considerations (1)

- **Typical mass of samples used for a given analysis = 1 - 10g**
- **Fraction of site actually analysed = 10^{-6} - 10^{-7} %**

(i.e. as little as one ten millionth of a percent or 1mg (half a pinhead!) for every tonne of relevant soil!!!)

- **Hence importance of fit for purpose sampling**

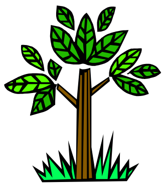
ALcontrol Laboratories 19

Sampling Considerations (2)

- **The sample preparation protocol is an integral part of the analysis result.**
- **This important criteria is often overlooked by users of the results**
- **If the analytical error is less than 33% of the total error, no point in improving it.**

ALcontrol Laboratories 20

MCERTS



ALcontrol Laboratories 21

Monitoring Certification Scheme (MCERTS 1)

As part of the development of MCERTS, the Agency has introduced a scheme for the chemical testing of contaminants in soil by establishing a register of qualifying laboratories.

Qualification is by third party accreditation to Agency performance requirements based on the European and international standard EN ISO/IEC 17025:2000. Full implementation commenced 1st March 2005

ALcontrol Laboratories 22

Monitoring Certification Scheme (MCERTS 2)

- **The MCERTS laboratory performance standard has been developed to provide an explanation and interpretation of the generally stated requirements of EN ISO/IEC 17025: 2000 for the chemical testing of contaminants in soils.**
- **There is an MCERTS Steering Committee with wide representation. The minutes are available to all commercial laboratories and feedback is encouraged**
- **MCERTS does not cover sampling or in-situ testing**

ALcontrol Laboratories 23

Monitoring Certification Scheme (MCERTS 3)

- **Part IIA of the Environmental Protection Act 1990 (implemented in 2000) and the Pollution Prevention and Control (England and Wales) Regulations 2000 require testing to establish the concentration of particular contaminants in soil.**
- **The Agency and Local Authority regulators will rely upon the data produced by laboratories to make key regulatory decisions. It becomes increasingly important, therefore, that the data produced are reliable, and uncertainties associated with their production are explicitly stated.**

ALcontrol Laboratories 24

EA Monitoring Certification Scheme (MCERTS 4)

- The MCERTS register of accredited laboratories is maintained by the Agency and UKAS. This information is available on the UKAS web-site.
- Accreditation is not generic.
- If a laboratory were to seek accreditation for one particular parameter, it would then not be able to analyse any other parameters under MCERTS.
- There is an MCERTS Steering Committee chaired by the EA with wide representation. The minutes are available to all commercial laboratories and feedback is encouraged.

ALcontrol Laboratories 25

EA Monitoring Certification Scheme (MCERTS 5)

Benefits of MCERTS

- Establishing a level playing field based on the Agency's requirements, in the form of a MCERTS performance standard;
- Sending a clear message that the production of defensible data for the chemical testing of contaminants in soils is a crucial component of the Environment Agency's regulatory requirements;
- Non-MCERTS site assessment data will be rejected;
- Providing assurance to all stakeholders including contractors, regulators, laboratories and the public on the reliability of analytical data generated under MCERTS

ALcontrol Laboratories 26

EA Monitoring Certification Scheme (MCERTS 6) Reporting requirements

- Relevant information to be reported includes:
- location of sample, including depth where necessary;
- unique sample code or reference;
- ***nature of sample***
- name of laboratory, including sub-contracting laboratory where necessary; date/time sample taken;
- date sample analysis completed;
- parameter analysed, including whether sample preserved or stabilised on site;
- whether analysis carried out on air-dried or "as submitted" basis;
- result of analysis on dry-weight basis;
- other relevant comments, for example, visual characteristics of sample.

ALcontrol Laboratories 27

EA Monitoring Certification Scheme MCERTS 7)

(Requirements of MCERTS

- **Methods not prescribed. Performance prescribed (In Europe there is a tendency to prescribe the use of CEN/ISO methods)**
- **Bias; precision and %recovery target**
- **Comprehensive method validation protocol**
- **QCs 5 - 20% of the total number of "solutions"**

ALcontrol Laboratories 28

MCERTS Version 3

- MCERTS Version 3 will be released in 2006 and will incorporate all briefing notes within the revised standard.
- The contents of the briefing notes are effectively part of the standard
- The standard will continue to evolve via the MCERTS Steering Board

Alcontrol Laboratories 29

Comparison of Contest Rounds 38 (Oct 2002) and 45 (Jan 2005) with MCERTS Performance Requirements

Parameter	MCERTS Total Allowable Error (%)	Contest Median Concn mg/kg	MCERTS Lowest acceptabl e concn (mg/kg)	MCERTS Highest acceptab le concn (mg/kg)	MCERTS % unsatis-factory results	
(Soil matrix unless stated otherwise)						
WS sulphate (1:2)	40	4079	2447	5711	15	Oct-02
WS sulphate (1:2)	40	3485	2091	4879	8.5	Jan-05
Water sol chloride	40	6086	3652	8520	28	Oct-02
Water sol chloride	40	263	158	368	6.7	Jan-05
TPH	60	2783	1113	4453	32	Oct-02
TPH Feb 2005	60	857	343	1371	31	Jan-05
Benzo-[a]-pyrene	60	12	4.8	19.2	24	Oct-02
Benzo-[a]-pyrene	60	14.6	5.8	23.6	3	Jan-05

Alcontrol Laboratories 30

Selected Metals

Required MCERTS Performance Characteristics

Parameter	Precision (%)	Bias (%)
arsenic	7.5	15
boron (water soluble)	7.5	10
cadmium	7.5	10
copper	7.5	10
chromium	7.5	10
lead	7.5	10
mercury	7.5	10
nickel	7.5	10
organotin cmpds	15	30
zinc	7.5	10

ALcontrol Laboratories 31

Selected Inorganics

Required MCERTS Performance Characteristics

Parameter	Precision (%)	Bias (%)
easy-lib cyanide	15	30
complex cyanide	15	30
sulphide	15	30
sulphate	10	20
sulphur	10	20
thiocyanate	15	30

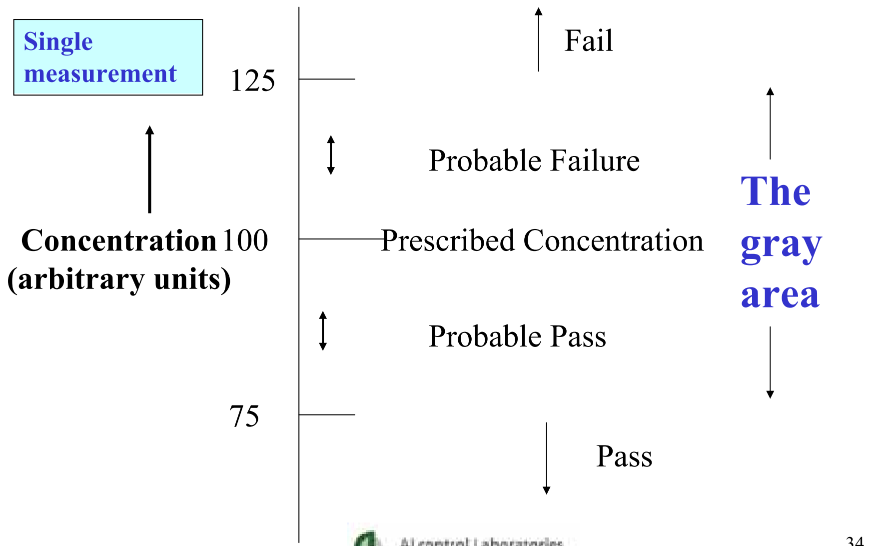
ALcontrol Laboratories 32

Selected Organics

Required MCERTS Performance Characteristics			
Parameter	Precision	Bias	
	(%)	(%)	
benzo[a]pyrene	15	30	
chlorobenzene	15	30	
dioxins	15	30	
dichloromethane	15	30	
hydrocarbons	15	30	
nitroaromatics	15	30	
pentachlorophenol	15	30	
phenols	15	30	
PAHs	15	30	
PCBs	15	30	

ALcontrol Laboratories 33

Result Confidence Limits MCERTS Metals



ALcontrol Laboratories 34

Result Confidence Limits
MCERTS Soil Organics

Single measurement

160 — Fail

Probable Failure

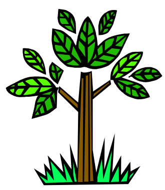
Concentration (arbitrary units) 100 — Prescribed Concentration

Probable Pass

40 — Pass

ALcontrol Laboratories 35

Perceived Problems with MCERTS



ALcontrol Laboratories 36

Perceived Problems: - Empirical Methods (1)

- An empirical method is a method where the actual method protocol defines the result.
- Examples are leaching methods, water soluble sulphate, water soluble boron; soluble metals; bioavailability testing
- Empirical methods typically only detect 0.1 – 10% of the total amount of the analyte.
- Thus, unlike total methods, empirical method analyte extraction protocols should be prescribed.

ALcontrol Laboratories 37

Perceived Problems: - Empirical Methods (2)

- Total analysis results should be independent of the method. In general slight method modifications should have little effect upon the results
- Empirical (e.g. leaching and bioavailability / bioaccessibility) analysis results are critically dependent on the analyte extraction protocol used. Even slight protocol modifications (speed of shaking) can have drastic effect upon the results obtained.
- Empirical methods are often used for risk assessment and the limited amount of proficiency test data indicates a significant number of these results are unfit for purpose.

ALcontrol Laboratories 38

Perceived Problems: - Empirical Methods (3) Some Examples

- **All leaching tests*** including BS EN 12457; water soluble sulphate and chloride**
- **Bioaccessibility (bioavailability) tests**
- **Water soluble boron**
- **Total petroleum hydrocarbons (TPH)**
- **Sulphide**

***** Once a leaching test has been performed any validated non-empirical final detection method can be used. (e.g. ICP-MS for metals).**

ALcontrol Laboratories 39

Perceived Problems with MCERTS (1)

- **Not prescriptive enough in some areas**
- **Lack of common soil reference materials**
- **Still not a level playing field wrt assessment**
- **Lack of prescribed methods for empirical parameters**
- **Lack of empirical parameter reference materials**

ALcontrol Laboratories 40

Perceived Problems with MCERTS (2)

With respect to metal CRMs: -

- **73 CRM samples submitted in method validation data to EA**
- **24 from CMI 7000 series**
- **17 LGC**
- **11 RTC-CRMs**
- **9 GBW**

ALcontrol Laboratories 41

Perceived Problems with MCERT (2) Relevant Reference Materials

- **The availability of characterised relevant contaminated soil reference materials is rather limited**
- **If a range of approved materials were developed and their use as QC materials was prescribed in regulation across the UK (and EC), this would be a great step forward in improving quality of environmental analysis**
- **It would also help to ensure a level playing field if these results had to be electronically reported to regulators and were closely audited by assessors**

ALcontrol Laboratories 42

Perceived Problems with MCERTS (3)

- **There is a general lack of understanding of the MCERTS standard by many consultants and Local Authorities**
- **This is likely to change once the EA reject the first site investigation with non-MCERTS accredited analysis results**
- **Also some Local Authorities are starting to require MCERTS accredited data**

ALcontrol Laboratories 43

Perceived Problems: - BS EN 12457 Part 3 (1)

- **BS EN 12457-3:2002 Part 3: Two stage batch test at a liquid to solid ratio of 2 l/kg and 8 l/kg for materials with a high solid content and with a particle size below 4 mm (without or with size reduction)**
- **Very complex leaching method specified in EA document Guidance on Sampling and Testing of Wastes to Meet Landfill Waste Acceptance Procedures Version 1 April 2005**

ALcontrol Laboratories 44

Perceived Problems: - BS EN 12457 Part 3 (2)

- L/S10 values from the two step test (BS EN 12457 Part 3) are required for assessing compliance with waste acceptance criteria leaching limit values at L/S10 for: As, Ba, Cd, Cr, Cu, Hg, Ni, Mo, Pb, Sb, Se, Zn, Cl, F and SO_4, phenol index, TDS and DOC in mg kg^{-1} dry residue
- This test is mandatory for assessing compliance with the waste acceptance criteria for inert, hazardous and stable, non-reactive hazardous landfill.

ALcontrol Laboratories 45

Perceived Problems: - BS EN 12457 Part 3 (3)

- First liquid-solid separation step
  Allow the suspended solids to settle for 15 min ± 5 min.

  Filter the first eluate almost completely over a 0,45 µm membrane filter using a vacuum or pressure filtration device (4.2.3). Rinsing of the filter with water or another solvent is not allowed after filtration.
- This is not readily achievable for most samples

ALcontrol Laboratories 46

Perceived Problems: - BS EN 12457 Part 3 (4)

- **When filtration as specified above is not possible in less than one hour with an eluate flow rate of at least 30 ml/cm^2/hour, a liquid-solid separation procedure, specific for the considered case, shall be applied and reported in details in the test report. A recommended procedure is given in annex E. The specific procedure shall not include the use of additives.**
- **NOTE It is always recommended to try first to filtrate and then to centrifugate.**
- **NOTE Such specific liquid-solid separation procedure can include settling, pre-filtration on coarser filter, centrifugation, filtration on large size membrane filter, filtration at high pressure, filtration at increasing high pressure following a first period without pressure, etc. (This should not be part of a standard)**

ALcontrol Laboratories 47

Perceived Problems: - BS EN 12457 Part 3 (5)

- **There may be technical reasons for using the one-step tests (parts 1 and 2) instead of the two-step test, e.g. where the samples are not suitable for serial leaching (see Appendix C4.1).**
- **Technical reasons precluding use of BS EN 12457-3:2002:- Serial batch tests not feasible: - some sludges and organic or clay-rich samples generate eluates which are unsuitable for multiple-step tests due to blinding of the filters during separation of the sample during the first leaching step. If centrifugation is also unsuccessful, and L/S2 leaching is technically possible single-step leaching at both L/S2 (BS EN 12457-1) and L/S10 (BS EN 12457-2) may be undertaken.**

ALcontrol Laboratories 48

Perceived Problems: - BS EN 12457 Part 3 (6)

- **Solids separation steps and transfer of solids for second extraction**
- **Lack of reference materials**
- **Poor CEN validation performance data for this method. Typically 100% "Reproducibility limit".**
- **Lack of proficiency testing**
- **The (highly variable) results are often used to make decisions with very high financial implications.**
- **Trying to set up a workshop with the EA**

ALcontrol Laboratories 49

Performance Data

Contest Round 38 Max/Min Results

Parameter	Median (mg/kg)	Min (mg/kg)	Max (mg/kg
Cu	98	66	155
B(WS) E	3.8	0.2	10.9
Pb	121	96	219
SO_4(WS)1:5 E	8316	1664	11678
TPH E	2783	18	7410

E = Empirical Method

ALcontrol Laboratories 50

Comparison of Contest Round 45 (Jan 2005) against the MCERTS Performance Requirements

Parameter	No. labs	No. failures	% failures	Concn (mg/kg)
Phenanthrene*	31	1	3.2%	30.8
TPH**	26	8	30.8%	857
WS Boron***	28	21	75.0%	3.2
Sulphide****	21	9	42.9%	33.3
Total Sulfate	24	4	16.7%	10965

* Acceptable results range 12.3 to 49.3 mg/kg
* *Acceptable results range 343 to 1371 mg/kg
* **Acceptable results range 2.8 to 3.5 mg/kg
* ***Acceptable results range 13 to 53 mg/kg

ALcontrol Laboratories 51

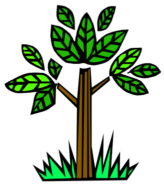
Tuesday 10th October 2006 at BSi, London, 389 Chiswick High Road, London, W4 4AL in conjunction with ISO TC 190 Soil Charaterisation Annual Meeting

Benefits of MCERTS for Chemical Testing of Soil: How will this benefit stakeholders?

The aim of this seminar is to fully update UK and overseas delegates on the background to MCERTS and most importantly allow an open and frank discussion of the full implications of MCERTS on contaminated land analysis with the Environment Agency.

ALcontrol Laboratories 52

Conclusions



ALcontrol Laboratories

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Conclusions

1. **MCERTS is a great step forward**
2. **Liaison between the EA and labs in developing MCERTS has proved invaluable**
3. **Consider the same specified reference materials for all MCERTS labs**
4. **Need to address the empirical method issue**
5. **Need to address the BS EN 12457-3 :2002 issue. (Workshop proposed with EA)**

ALcontrol Laboratories

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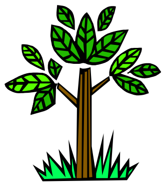
The End!!!

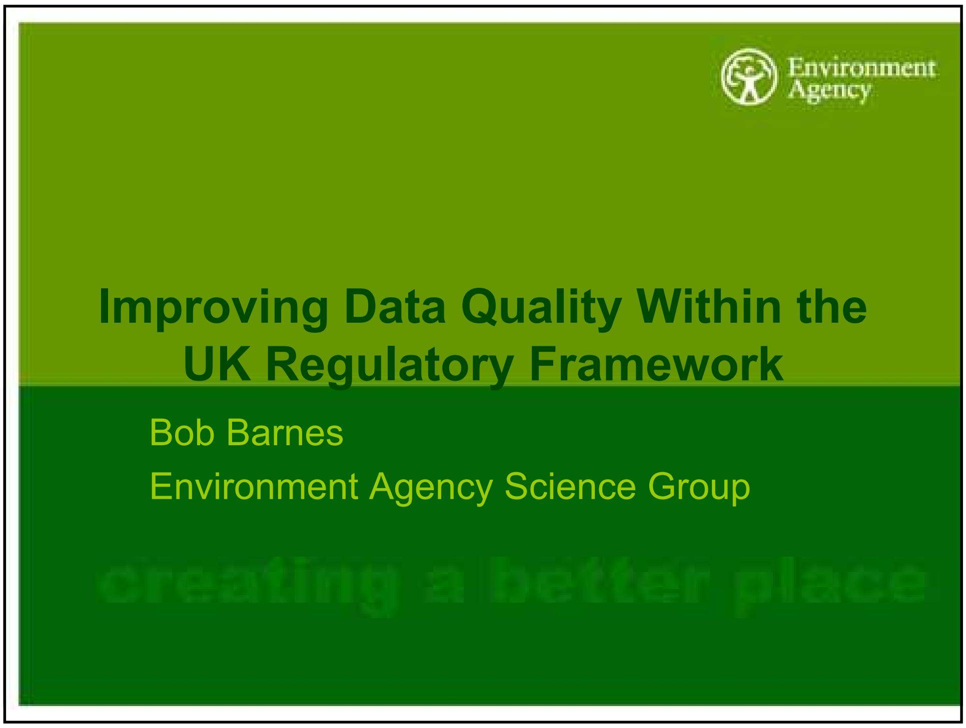


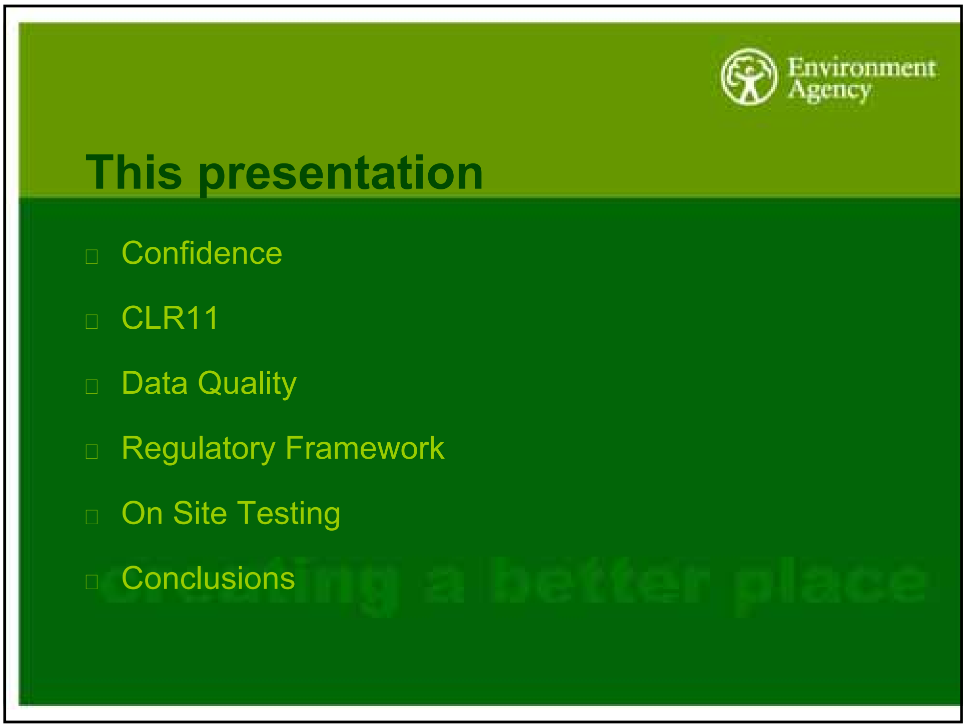
ALcontrol Laboratories 55

Biographical Note

Bob Barnes

Bob Barnes is a Senior Scientist working within the Integrated Catchment Science group of the Environment Agency. He has worked for the Agency for 14 years, 10 of which he was the Contaminated Land Officer for Hampshire and the Isle of Wight. He joined the Science group 4 years ago as part of the then National Groundwater and Contaminated Land Centre. His duties cover issues relating to the characterisation of land contamination and is currently working on projects around the bioaccessibility of metals in soils, on-site analytical techniques and sampling.


Environment Agency
Improving Data Quality Within the UK Regulatory Framework
Bob Barnes
Environment Agency Science Group
creating a better place


Environment Agency
This presentation
Confidence
CLR11
Data Quality
Regulatory Framework
On Site Testing
Conclusions
creating a better place


Environment Agency
CONFIDENCE
(or Back to Basics?)
creating a better place


Environment Agency
Confidence in
Measurements / data,
Risk Assessment,
Remedial processes,
Decisions:
Through a quality process
creating a better place

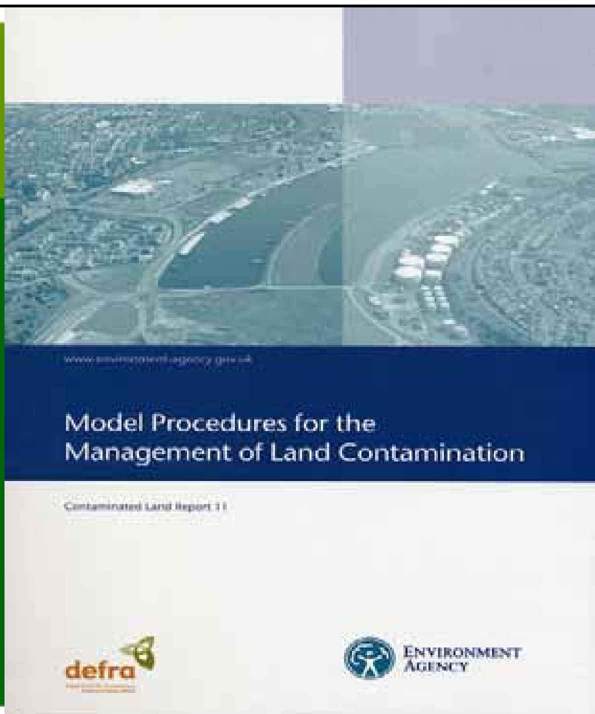
Environment Agency

Quality

- Quality = Performance to Requirements
- **So what are your requirements?**
- Only know through a structured Risk Management Framework
- Depends upon where you are in the Framework

creating a better place

Environment Agency



Environment Agency

What is CLR11?

The technical risk management framework for dealing with land contamination in the UK;

- Part 1 - Details the process for risk assessment, options appraisal and implementation of remediation;
- Part 2 - Technical information to support the process;
- Part 3- Sources of further information and guidance.

creating a better place

Environment Agency

Quality Data

- To perform to requirements, data must have:
  - Relevance,
  - Sufficiency,
  - Reliability, and
  - Transparency

creating a better place

Environment Agency

MCerts Standard

- Application of BS EN ISO/IEC 17025:2000
- Key Requirements:
  - Contract Review
  - Bias and Precision Targets
  - Quality Control
  - Validation
  - Uncertainty of Measurement

creating a better place

Environment Agency

MCerts Policy

- Applies to all Labs and procurers of analytical services where results are submitted for regulatory purposes
- Agency will only accept data from MCerts accredited methods / laboratories

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Environment Agency

Measurement Uncertainty

- Comprises analytical uncertainty (AU) and sampling uncertainty (SU)
- SU >> AU
- More samples = reduced uncertainty
- More samples = more cost
- Better quality data = lower overall project cost or at least a more defensible decision

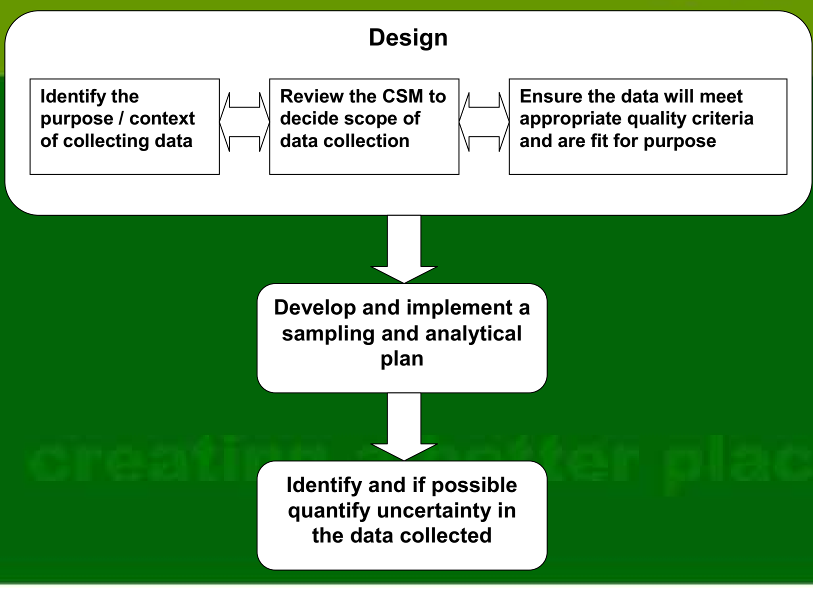
Environment Agency

On Site Testing

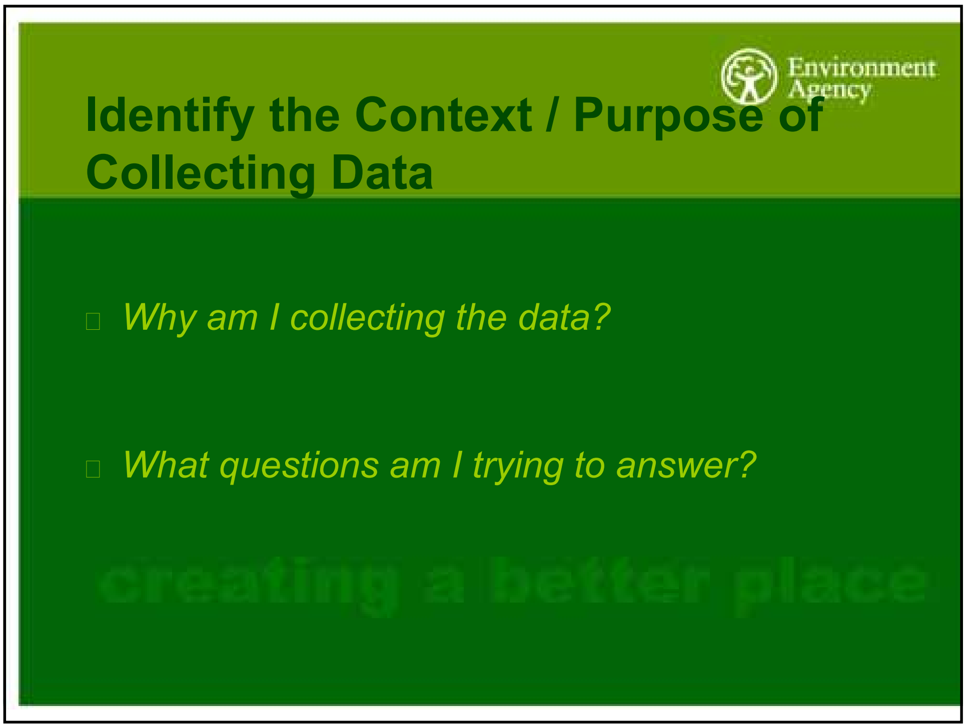
- Potentially has a place during all phases of the risk management process
- Used in conjunction with laboratory analysis when regulatory decisions are required
- Can improve data quality by providing other lines of evidence
- Used in site screening can greatly improve the quality of sampling and analysis

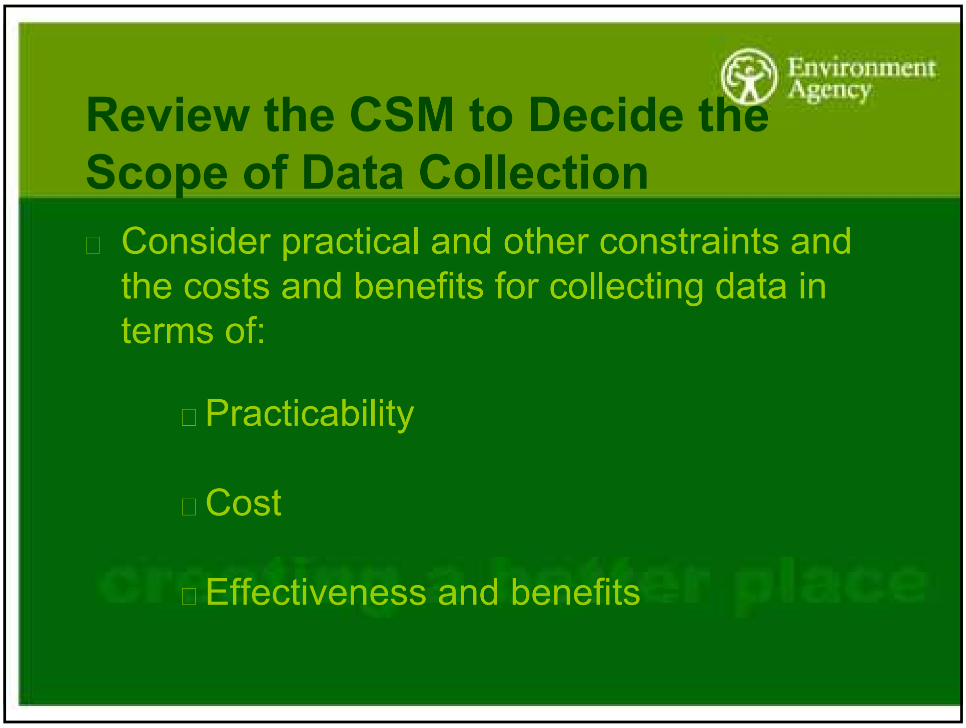
Incorporating the results of on-site testing into risk management

- Methods limitations need to be fully understood - LOD, interferences: moisture content, organic material, clay content, pH etc
- Do you understand what the results mean and how to interpret them?
- Do you understand what they don't mean?
- Will a third party (especially the regulator)?
- Standard Operating Procedures and QA/QC to increase confidence in the results...



Bob Barnes


Environment Agency
Identify the Context / Purpose of Collecting Data
Why am I collecting the data?
What questions am I trying to answer?
creating a better place


Environment Agency
Review the CSM to Decide the Scope of Data Collection
Consider practical and other constraints and the costs and benefits for collecting data in terms of:
Practicability
Cost
Effectiveness and benefits
creating a better place

Ensure the Data Collected Meet Appropriate Quality Criteria and are Fit for Purpose

Environment Agency

- Relevance
- Sufficiency
- **Reliability**
- Transparency

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Develop and Implement a SAP

Environment Agency

- Pull those design elements together into a sampling and analytical plan
- We're looking to build confidence
- by justifying what has been done within appropriate QA/QC

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Environment Agency

Conclusions

- Agency supports development and use of on-site testing for land contamination
- Useful at many stages of the risk management process
- Can lead to time and cost savings and better quality of investigations and increased confidence in risk management decisions
- Need to understand what the results mean
- Standard Operating Procedures and QA/QC to meet data quality needs

creating a better place

Environment Agency

Any questions?

bob.barnes@environment-agency.gov.uk

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Biographical Note

Dr Daniel M. Powell

Dan leads efforts to promote the use of innovative investigation and clean-up technologies at hazardous waste sites in a number of U.S. programs. He coordinates and leads team efforts to promote innovative characterization and monitoring approaches (Triad) throughout the U.S. waste programs. Dan manages the two major programs responsible for supporting the application of Triad approaches across EPA waste programs. Over the past 16 years, Dan has developed many waste site cleanup information resources for both technical and non-technical audiences, and has managed a number of projects to support the application of the Triad approach at a variety of hazardous waste cleanup and reuse sites. Dan has been with the Technology Innovation Program, now part of the Office of Superfund Remediation and Technology Innovation, since 1990. He has been with the U.S. EPA since 1988.

Dan received his Masters of Public Administration from the Woodrow Wilson School of Government at the University of Virginia in 1988, and he graduated *summa cum laude* with his Bachelor of Arts degree in political science and urban studies from Roanoke College (Salem, VA) in 1985.

A U.S. Perspective: Using the Triad Approach to Improve DECISION Quality

CL:AIRE Conference

The Importance of Data Quality in Contaminated Land Work

Thursday, April 27, 2006

Daniel Powell

Chief, Technology Integration and Information Branch

Office of Superfund Remediation and Technology Innovation

United States Environmental Protection Agency

(703) 603-7196

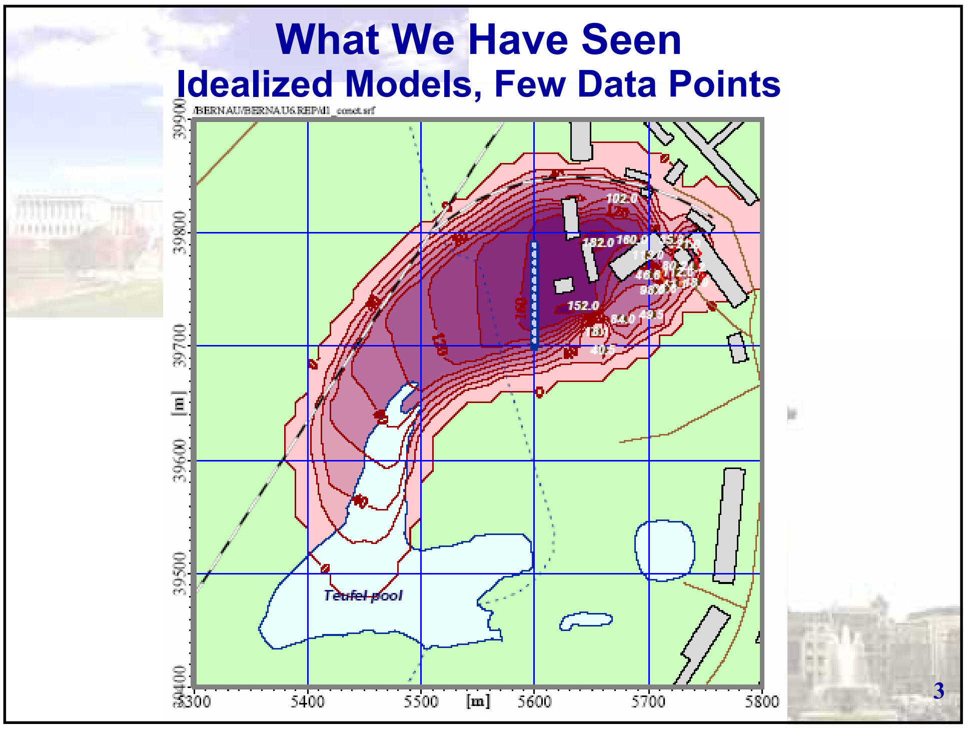
powell.dan@epa.gov

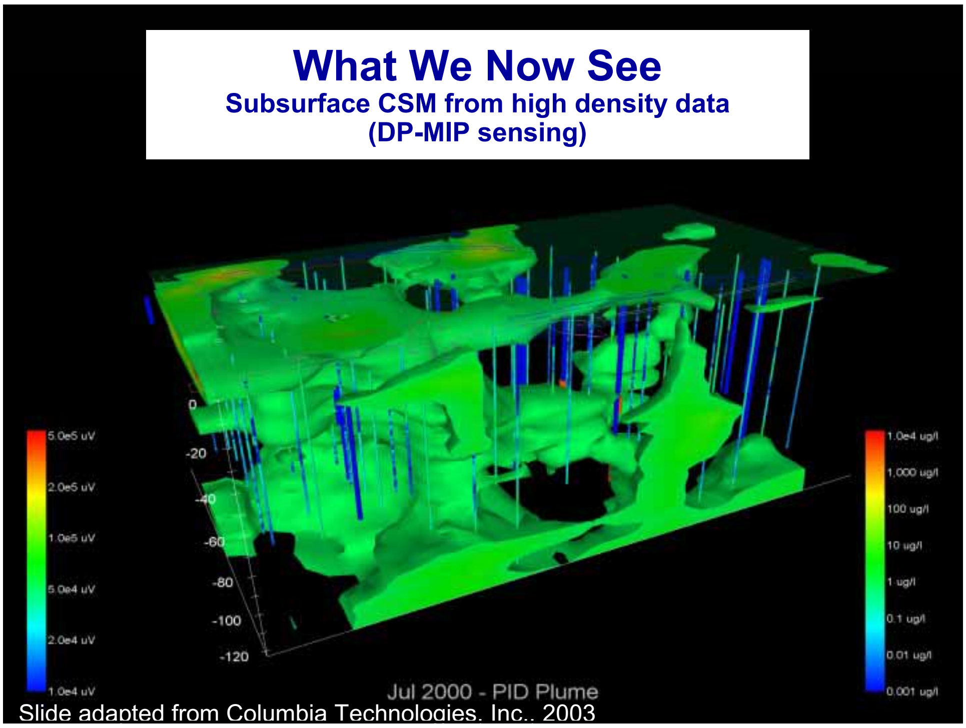
1

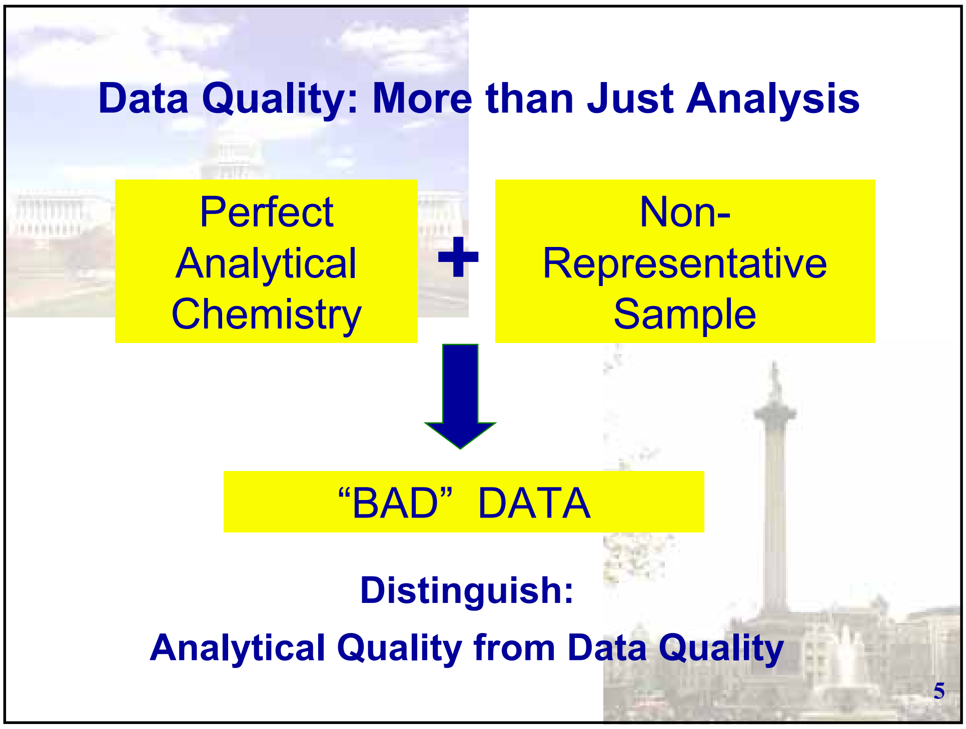
Problem Statement

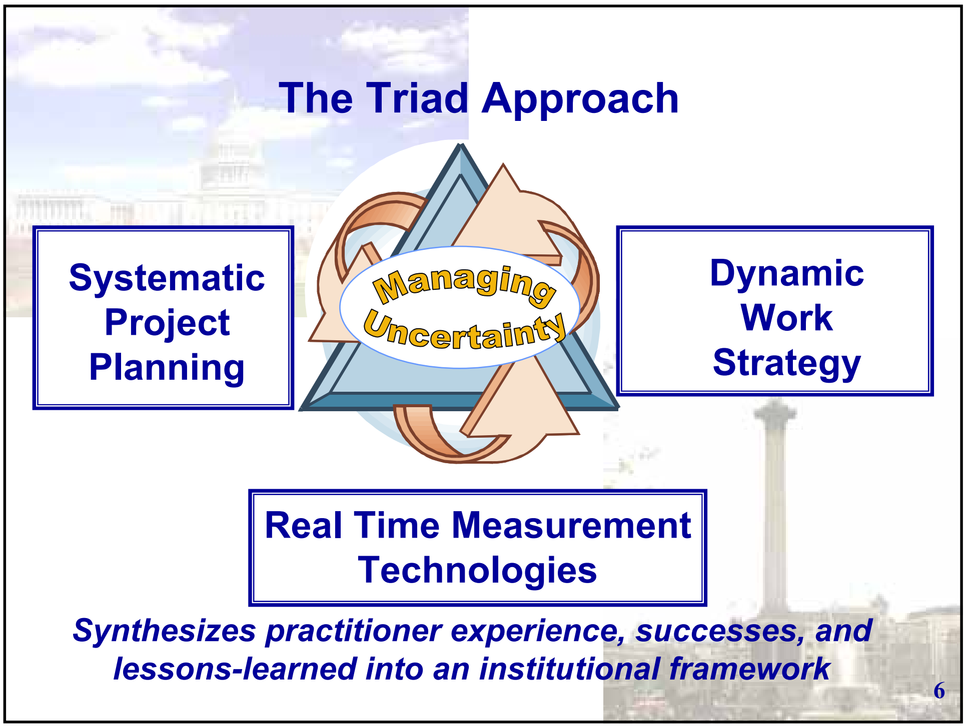
- Perception: contaminated sites cost too much and take too long to cleanup
  - » Unexpected findings
  - » Regulatory processes
  - » Investigation – mobilization after mobilization; never enough data
  - » Cleanup – systems do not work as planned
- Unfortunately, that perception has basis in common experiences, often due to:
  - » Inadequate understanding of site conditions
  - » Insufficient management of **ALL** sources of uncertainty
  - » Lack of tools sufficient to affordably manage uncertainties

2


What We Have Seen
Idealized Models, Few Data Points
Teufel pool
3


What We Now See
Subsurface CSM from high density data
(DP-MIP sensing)
Jul 2000 - PID Plume
Slide adapted from Columbia Technologies, Inc., 2003


Data Quality: More than Just Analysis
Perfect Analytical Chemistry
+
Non-Representative Sample
“BAD” DATA
Distinguish:
Analytical Quality from Data Quality
5


The Triad Approach
Systematic Project Planning
Managing Uncertainty
Dynamic Work Strategy
Real Time Measurement Technologies
Synthesizes practitioner experience, successes, and lessons-learned into an institutional framework
6

Triad Guiding Principles

- Thorough and inclusive systematic planning process
  - » Determines what types of data are required
  - » Evaluate whether the site could benefit from:
    - —A dynamic work strategy
    - —Real time measurement technologies.
- Transparent, open, and honest discussion of
  - » Uncertainty management
  - » Data representativeness
  - » Site closure strategies

7

Triad Guiding Principles

- Emphasis on use of a conceptual site model (CSM)
  - » Continually evolving
  - » Updated through a dynamic work strategy
- Maximized use of:
  - » Innovative (rapid) sampling tools
  - » Field measurement technologies
  - » Data management technologies
  - » Supports uncertainty management strategies that address matrix heterogeneity.

8

Triad Guiding Principles

- Integrated project teams:
  - » Effective communication
  - » Trust
  - » Open discussion of individual interests and goals,
  - » Diverse expertise in the appropriate fields
  - » “Social capital”: building a clear vision of goals, exit strategies

9

The Triad and Data Quality

- Intensive systematic planning ensures project decisions and goals focused on exit strategy
- Experienced chemist an intimate member of planning and field teams
  - » Sets type and frequency of analytical QC procedures to ensure data reliability
- Explicitly address significant sources of uncertainty impacting data
- Collaborative data sets (multiple lines of evidence)

10

The Triad and Data Quality

- Conceptual Site Model (CSM) used to capture heterogeneity and physical reality
  - » Mediates the mismatch between sampling/analytical scales (grams, liters) an project decisions (kilograms, kiloliters)
  - » Recognizes and addresses reality of complex relationships of multiple populations

11

Systematic Planning Is Essential to…..

- Identify key decisions, decisionmakers, needs
- Identify and address (all sources of) uncertainty
- Develop data collection accordingly
- Adjust expectations according to:
  - » Evolving site needs
  - » New information
  - » Budget
  - » Schedule
  - » Community needs, goals
- Guide open, rational discussions on assessment, cleanup and reuse
  - » Possibilities
  - » Strategies

12

Examples of Decisions

- Presence or absence of contamination
- Types of contamination, contaminants of concern
- Extent (relevant to site goals)
- Location and extent of hot spots
- Costs/approaches of cleanup
- Receptors/pathways
- Cleanup levels (relevant to reuse)
- Areas to develop for specific uses
- Performance of remedy
- Disposal options

13

Conducting Site Activities Without a Systematic Approach

•Without end-use in mind, systematic focus for data collection, must start over, fill gaps, and refit data as move through process

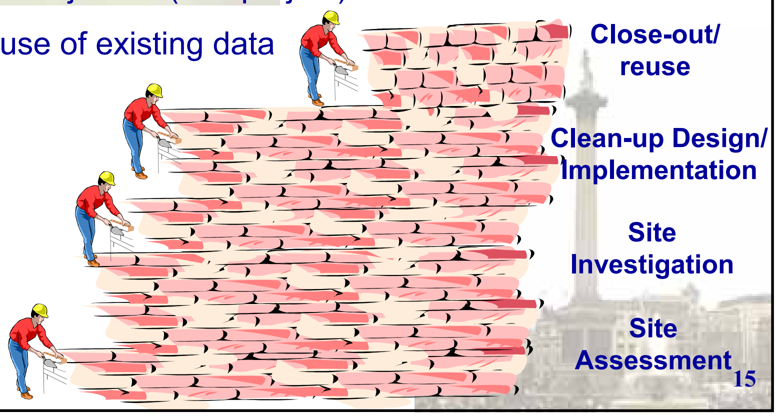
•Each "phase" becomes an end to itself (multiple projects)

•Data collected for each phase may or may not be useful in subsequent phases

14

Benefits of "Triad," Systematic Approach: Building on Existing Information

- Each phase focuses on needs of subsequent work, requirements
- Data focuses on decisions which focus on site objective (one project)
- Maximize use of existing data



15

Understanding the Context of Cleanup

Reuse Plans, Goals

Drive

Decisions:
- Cleanup goals
- Data (type, quality)
- Tolerable uncertainty

Determine

Approaches to:
- Assessment
- Investigation
- Cleanup Design, Implementation
- Closeout, Long-Term Operations and Maintenance

Tools for:
- Sampling, Analysis, Visualization
- Cleanup/Remediation
  - Containment
  - Treatment
  - Controls
- Monitoring, maintenance

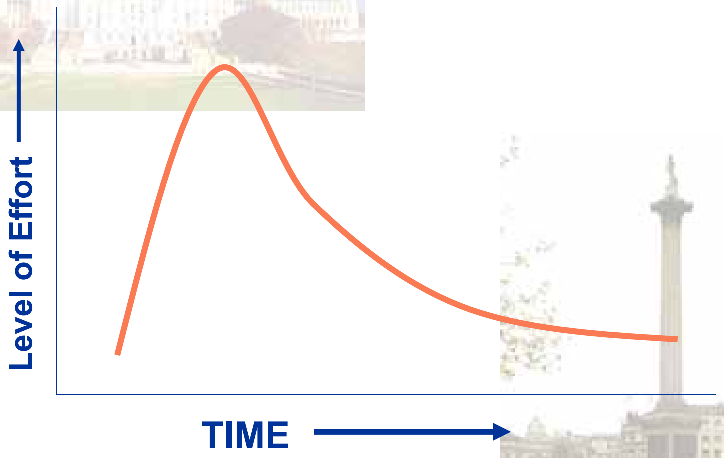
16

So How Is Triad "Planning" New?

- A formalized, integrated package that restructures how project planning and implementation are done:
  - » Focus: Identify and manage decision uncertainty
  - » Focus: Recognize the impacts of heterogeneity
  - » Front-loaded (anticipate vs. react)
  - » Conceptual Site Model essential; evolution guides field efforts
  - » Integrated project team (understand data user needs)
  - » Start with end in mind (where are we going)
- Second generation approach maximizing improvements and advances in
  - » Knowledge
  - » Technologies

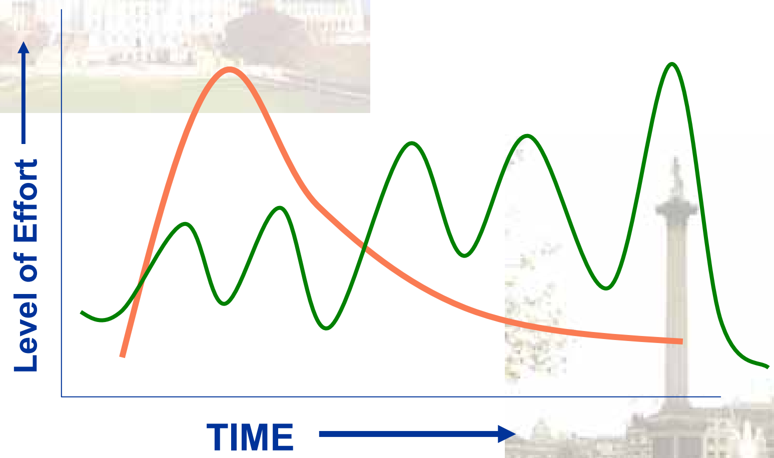
17

Triad LOE vs. Project Lifecycle



18

Triad LOE vs. Traditional Cleanup Work



19

Social Capital Important to Triad Projects

- The "people" aspects of a project just as critical to project success as science and technology aspects
- Term includes trust, tolerance, collaboration toward a common project vision
- Triad systematic planning encourages participants to
  - » Share knowledge and insights
  - » Test assumptions, beliefs, and personal perspectives
  - » Evaluate legal, budgetary, and technical constraints
  - » Achieve clarity about where disagreements lie
  - » Negotiate over concerns and interests

20

Social Capital Important to Triad Projects

- Facilitation needed if team doesn't possess the necessary social skills or if conflict and distrust too ingrained
- Uncooperative participants means Triad probably not a viable option for project management

21

The Concept of Uncertainty

- A broad term, generally used to convey the idea of something that is unknown or lacking sufficient confidence
- Triad recognizes and addresses specific uncertainties
  - » Decision uncertainty relates to the confidence and scientific defensibility of decisions about:
    - —Contaminant concentrations, presence and extent, transport
    - —The likelihood of intolerable exposures, and
    - —The most cost-effective means to achieve risk-reduction

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The Concept of Uncertainty

- Triad recognizes and addresses specific uncertainties
  - » Data Uncertainty relates to the ability to draw confident decisions based on the data set in hand. Uncertainties in a data set result from:
    - —Analytical Uncertainty: uncertainty introduced into decision making by the limitations of analytical preparation and determination methods, include analytical bias, lack of precision, and susceptibility to interferences (analytical selectivity)
    - —Sampling Uncertainty: refers to all non-analytical method factors contributing to a lack of confidence in data result caused primarily by the interaction of heterogeneity and too few sample numbers to assess the impacts of that heterogeneity

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The Concept of Uncertainty

- **Key Point:** Where sophisticated analytical methods are available for environmental analysis, more data uncertainty stems from sampling error and sampling uncertainty as a consequence of:
  - » Environmental heterogeneity
  - » Complex populations than from analytical limitations

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Why Emphasize Decision Uncertainty?

- Inherent in environmental decision making
- Always need to be managed
- Essential for accelerated progress
  - » Helps make decisions when "perfect information" is not available
  - » Resolution of all uncertainties or unknown conditions is unlikely
  - » Triad encourages distinction between significant and insignificant uncertainties to focus resources
- Triad encourages teams to evaluate tradeoffs
  - » Counteracting uncertainties (RA contingency planning)
  - » Reducing uncertainties (additional data collection)

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When Do You Evaluate and Manage Uncertainties?

- In work planning:
  - » based on existing data,
  - » based on understanding of programmatic expectations, and
  - » as part of program development for a large site with multiple problems.
- During any necessary investigations:
  - » as new data become available, and
  - » as conceptual site model becomes sufficient to focus on likely response actions.

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When Do You Evaluate and Manage Uncertainties? (cont.)

- During remedy evaluation:
  - » as key performance and technology characteristics are evaluated.
- During remedy implementation:
  - » based on results of monitoring and observations during implementation.
- Throughout all phases:
  - » as basis for more effective communication about why work is being conducted, and
  - » to assist with identifying appropriate acquisition strategies.

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Sources of Uncertainty in Data Results

Sampling Uncertainties

Uncertainty in Sample Support + Uncertainty in Sample Location + Uncertainty in Sample Preservation + Uncertainty in Sub-sampling

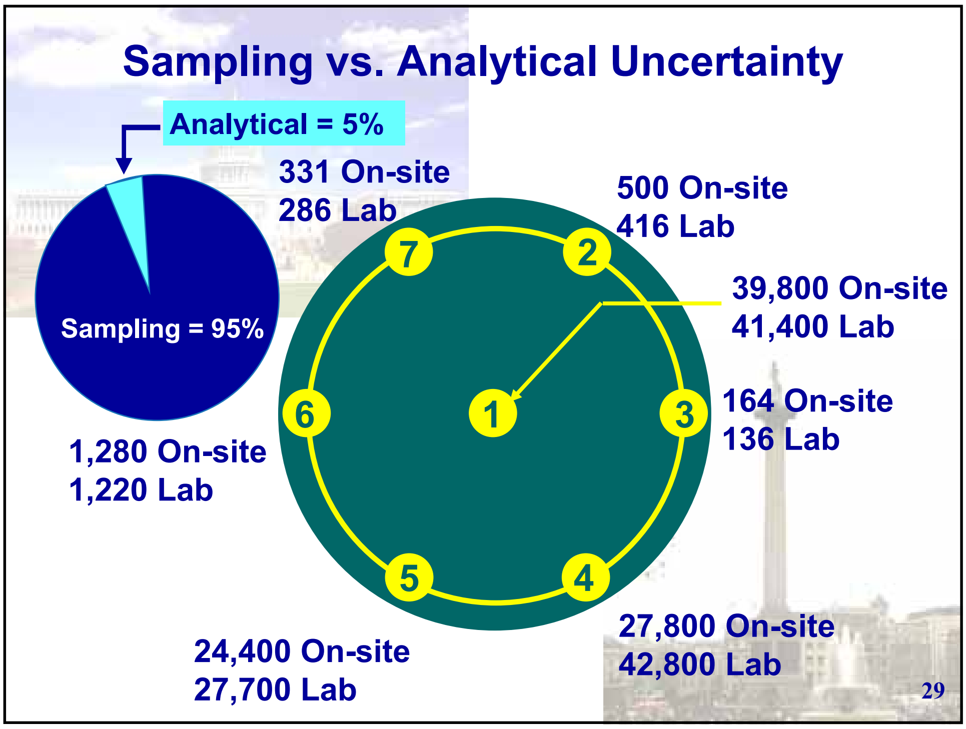
PLUS

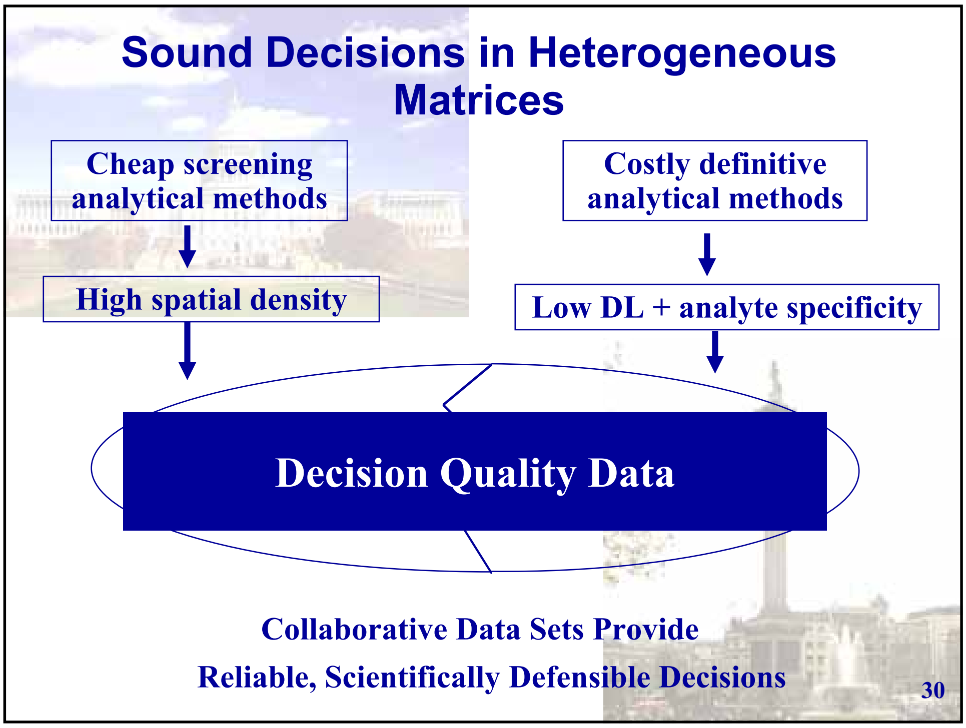
Analytical Uncertainties

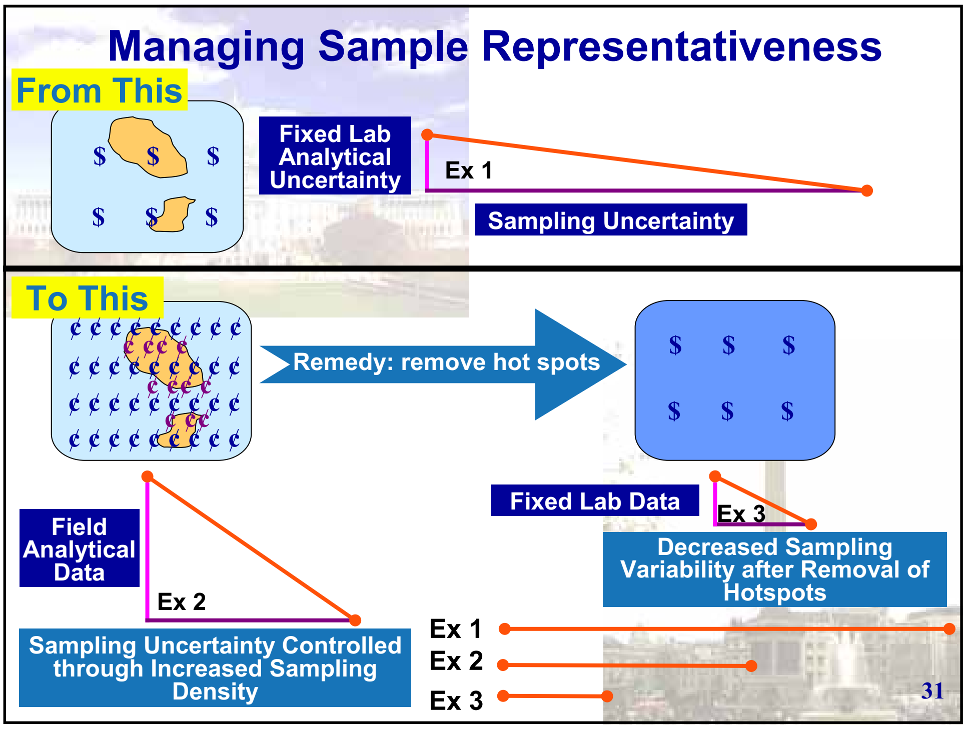
Uncertainty in Sample Preparation + Uncertainty in Extract Cleanup + Uncertainty in Extract Analysis = **Total Uncertainty In Data Results**

e.g., Method 8270

28


Sampling vs. Analytical Uncertainty
Analytical = 5%
Sampling = 95%
331 On-site
286 Lab
500 On-site
416 Lab
39,800 On-site
41,400 Lab
164 On-site
136 Lab
1,280 On-site
1,220 Lab
24,400 On-site
27,700 Lab
27,800 On-site
42,800 Lab
1
2
3
4
5
6
7
29


Sound Decisions in Heterogeneous Matrices
Cheap screening analytical methods
High spatial density
Costly definitive analytical methods
Low DL + analyte specificity
Decision Quality Data
Collaborative Data Sets Provide
Reliable, Scientifically Defensible Decisions
30



Dynamic Work Strategies

- Real-time, decision-making in the field
- Real-time analysis makes possible, field analytics makes economical
- Experienced, senior technical personnel (scientists & engineers) needed in the field
- Regulator-approved decision trees
  - Flexible work plans
    - Alternate contracting options
    - Regulator, senior staff involvement
  - Adaptive sampling and analysis plans
  - Evolve the CSM to maturity
- Seamless flow of site activities → fewer mobilizations

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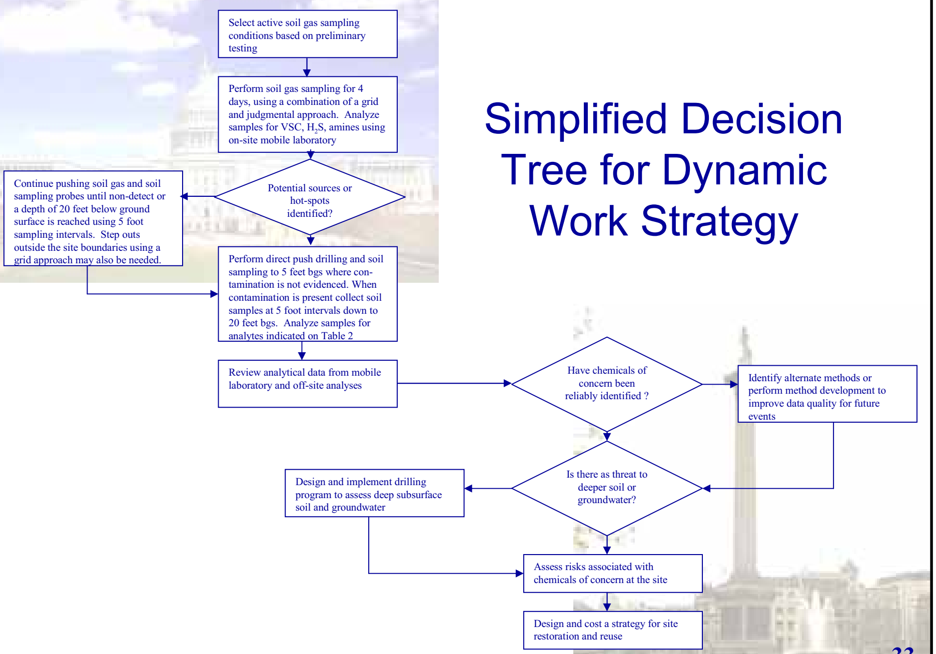
Simplified Decision Tree for Dynamic Work Strategy



33

Real-Time Analytical and Sampling Technologies

- Field analytical, rapid sampling, mobile labs, quick turnaround off-site all allow real-time or near real time analysis
- Rapid turnaround results support dynamic decisionmaking
- Lower costs of field methods support increased density (address sampling uncertainty)
- Field results guide confirmation (address analytical uncertainty)
- Decision support software can help organize and process data, plan field activities

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The Triad is NOT…

- …written in all caps (not an acronym!)
- …just about using field analytical! (Warning: Just using field analysis does not mean they used the Triad approach!)
- …a way to justify using field analysis without using proper QC (MUST have data of known/ documented quality!)
- …just about using a dynamic/flexible work plan (must actively manage decision uncertainty!)
- …a license to write vague work plans or escape regulatory oversight or accountability.

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The Triad IS about…

- Improving project quality by actively managing DECISION uncertainty using new tools & strategies
- Constructing accurate CSMs (as a primary Triad product!) to support cost-effective decisions
- Avoiding uncertainty in communications with solid documentation and unambiguous terminology
- Cultivating professional competence & multidisciplinary teams ("allied environmental professionals")

36

Triad Challenge-Where is it applicable?

Common refrain: *I agree with Triad, but it won't work at my site because Triad only works at a (insert choice) and my site is a (insert choice):*

- Big site
- Small site
- Federal site
- Brownfields site
- Superfund site
- Complex site
- Simple site
- Operating site
- Abandoned site
- Chemical site
- Petroleum site
- Investigation site
- Cleanup site
- Contentious site

OR: *I'd like to use Triad, but the* (insert, laws, regs, policy, contracting officer, public, lawyers, etc.) *won't let me.*

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No Triad Stereotypes, Please

- All elements of Triad may not work at all sites, but the systematic planning concepts do apply to all sites
- Triad works particularly well at/in:
  - Sites where source(s) unknown or not easily defined
  - Sites with multiple sources, contaminant populations exist
  - Sites where significant debate on results, approaches is occurring
  - Area-wide investigation, cleanup scenarios
  - Sites where closure has been difficult
  - Sites where selected remedy is not working as planned
  - Soil removal sites where disposal costs highly sensitive to contaminants/concentrations

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Triad: Real World Applications

- Brownfields sites
  - » Milltown, NJ
- Resource Conservation and Recovery Act (RCRA)
  - » Lockheed Martin Facility
- Superfund sites
  - » McCormick and Baxter
- UST Sites
  - » South Dakota
- State Cleanup sites
  - » Wenatchee Tree Fruit
- Department of Defense
  - » Avon Park, FL (USAF)
- Department of Energy
  - » Ashland FUSRAP Site

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Summary/Cost Savings

- Average Time Savings: almost 2 years
  - —Minimum: 6 months
  - —Maximum: 3 years
- Average Cost Savings : 45% reduction in costs
  - —Minimum: 35%
  - —Maximum: 50%
    - –Ex: One DoD site reported a cost avoidance of $2.5M and 3 years saved
- All profiled projects have cited reduced costs and time savings due to: fewer mobilizations, shortened work schedule, and greater data density that reduces uncertainty at site

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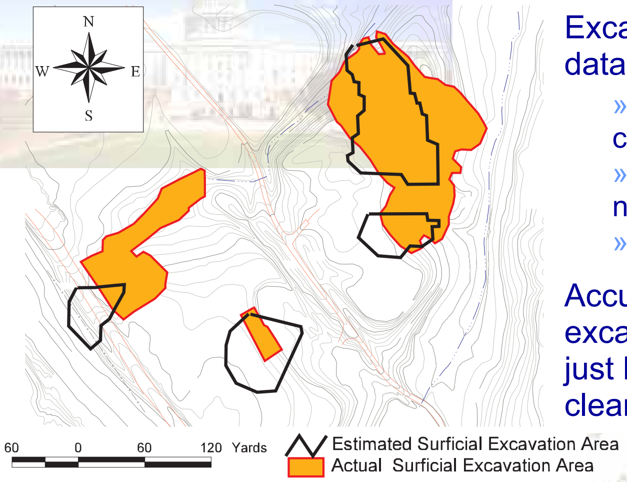
Ashland 2 DOE FUSRAP (1998) Tonowanda, NY



Excavation based on RI data would have:

- »removed ~4,000 c.y. compliant soil
- »missed ~8,000 c.y. non-compliant soil
- »same issues at depth

Accurate CSM + precise excavation saved ~$10M just by not excavating clean soil.

Adapted from Argonne, 2002 http://cluin.org/download/char/ASAPs_ITSR_DOE-EM-0592.pdf

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Ashland 2 Success

- Fast: 1.5 yr to closure
  - » Jul-Dec 1998: 6-month integrated characterization and removal
  - » Aug 1999: complete post-remediation testing and documentation.
  - » Sept 1999: backfill and CERCLA site closure.
- Effective
  - » Proof: 430 post-remedial samples; 99% compliant
- Efficient
  - » Proof: 146 composite samples to characterize the 45,500 yd^3 disposed soil; 97% exceeded the clean-up criteria.

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Poudre River Site

- Located next to the city center
- City wants to build a new 50,000 sq ft Rec Center on the Site
- Currently a 20,000 sq ft Rec center and day care center located on the Site
- Site is location of former municipal burn landfill down gradient from MGP and USTsBlack coal tar discovered in the river
- Landfill/UST/MGP related dissolved plume discharge to the river
- Vapor Intrusion to buildings/playing surfaces

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Past Traditional Studies

- Over 5 years of investigative studies at the site were inconclusive showing
  - » No apparent link between MGP/USTs and coal tar observed in river
  - » The EPA and City were at a standstill with PRPs and the State of Colorado for cleanup of the site and closure of the landfill

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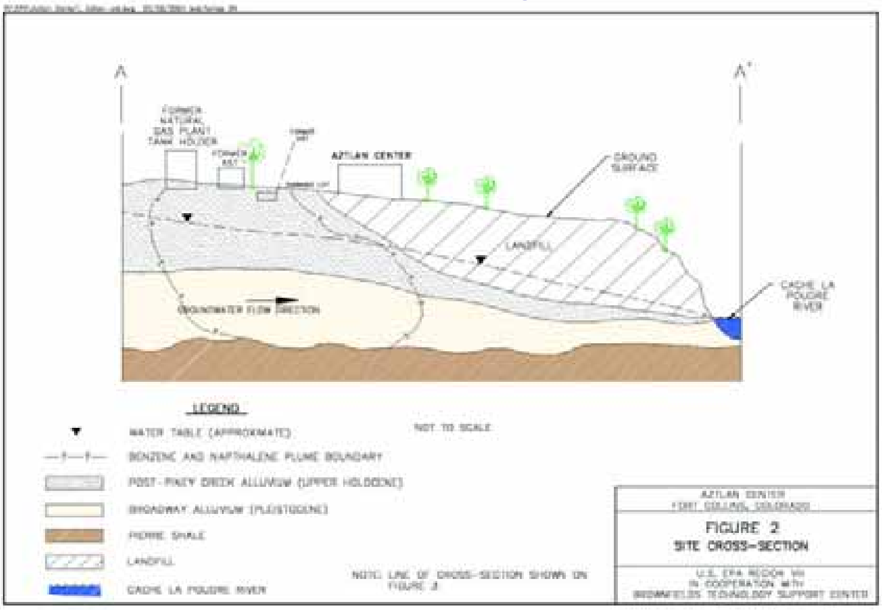
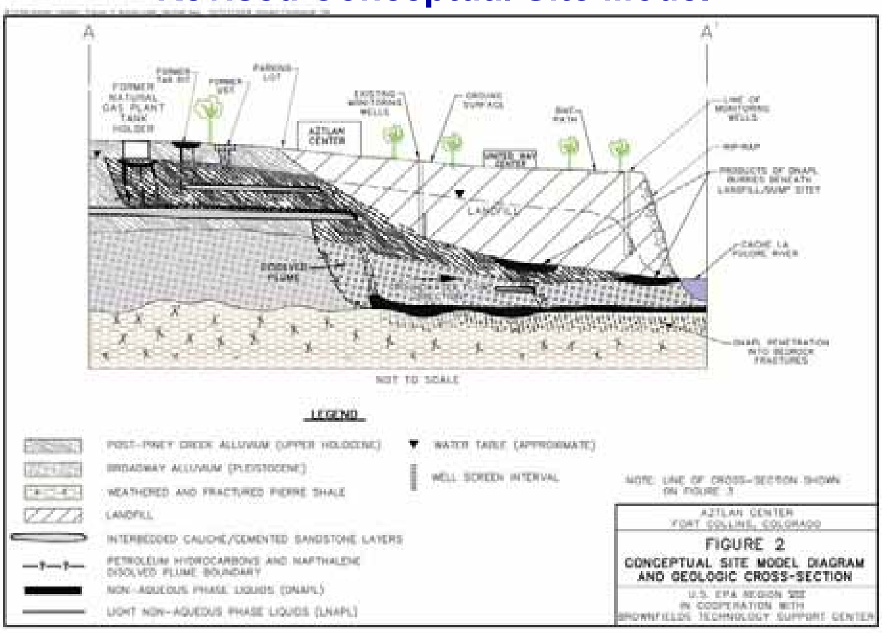
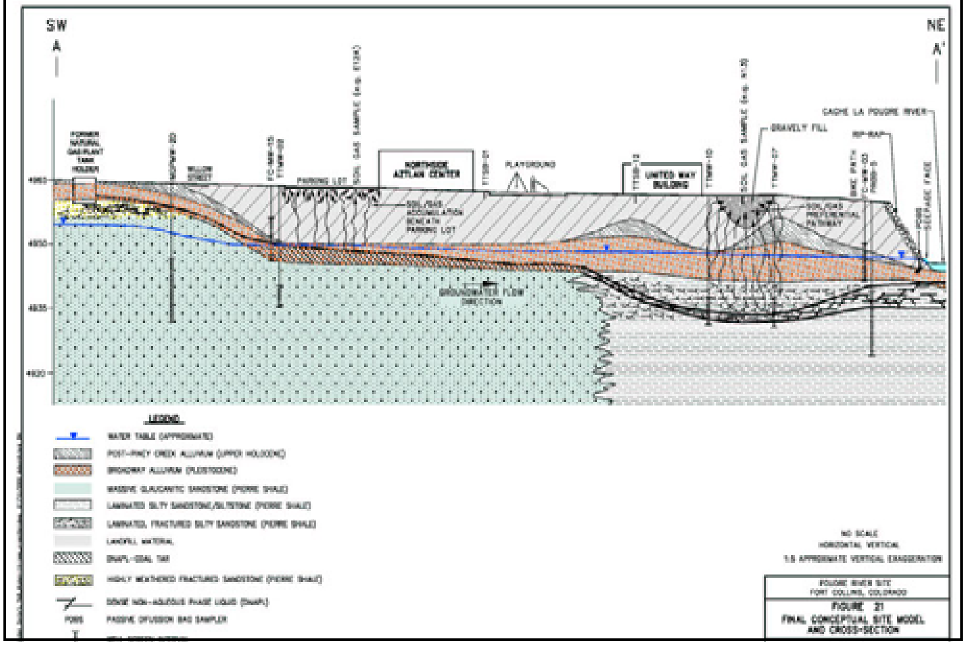
The Preliminary CSM



Revised Conceptual Site Model



Final CSM



Project Results Summary

- The CSM was used to select innovative and traditional technologies to identify the pathway for MGP/UST discharge to the river
- A sheet pile wall and groundwater extraction gallery has been constructed down into bedrock to intercept the MGP and landfill related contamination
- Stakeholders and PRPs have cooperated throughout the process expediting the cleanup dramatically through use of the Triad

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Case Study of Tree Fruit Project: Results

- Action required to achieve clean closure
  - » 390 tons of soil removed (56 tons incinerated; 334 tons landfilled)
  - » vs. 708 tons if removed all soil
- Time
  - » Single mobilization: <4 months of field work to complete site closure
- Costs
  - » Projected: ~$1.2M; Actual: $589K
  - » Savings:~50%
- Happy client, regulator, and stakeholders

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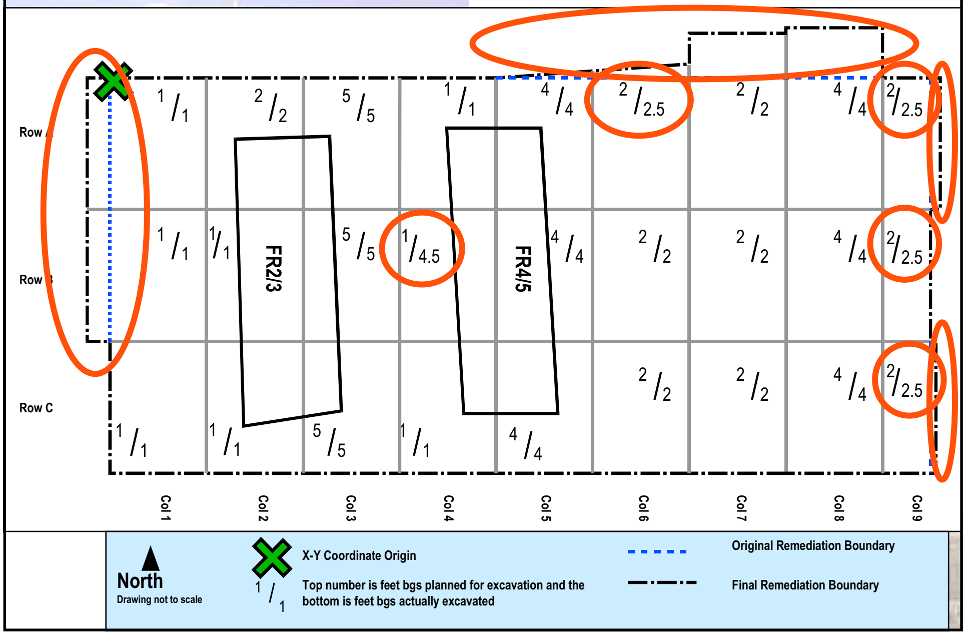
Final CSM: Lateral and Vertical Removals



Key Online Sources-Comprehensive

- Triad Resource Center
  - » http://www.triadcentral.org
- Hazardous Waste Cleanup Information (CLU-IN) Internet Site
  - » http://cluin.org/triad
- EPA Internet site
  - » http://www.epa.gov
- Federal Remediation Technologies Roundtable
  - » http://www.frtr.org
- Brownfields Technology Support Center
  - » http://www.btsc.org
- Interstate Technology Regulatory Council (ITRC)
  - » http://www.itrcweb.org

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Triad Overview | Triad Management | Regulatory Information | Technical Components | User Experiences | Reference/Resources

Triad Systematic Planning Dynamic Work Strategies Real-Time Measurements

"The NJDEP supports and encourages the use of the Triad for sites undergoing investigation and remediation within the Site Remediation and Waste Management Program where feasible."

Joseph Seebode
New Jersey Department of Environmental Protection
Assistant Commissioner for Site Remediation and Waste Management

Multiagency support for Triad

Triad Resource Center

TRIAD: A SMARTER SOLUTION TO SITE CLEANUP

The Triad is an innovative approach to decision-making for hazardous waste site characterization and remediation. The Triad approach proactively exploits new characterization and treatment tools, using work strategies developed by innovative and successful site professionals. The Triad Resource Center provides the information hazardous waste site managers and cleanup practitioners need to implement the Triad effectively.

- **Triad Overview**
- **Triad Management**
- **Regulatory Information**
- **Technical Components**
- **User Experiences**
- **References/Resources**

Glossary

FAQs

Acronyms

www.triadcentral.org

Training Information

- Remediation and characterization
  - » Internet seminars
    - —http://cluin.org/studio/seminar.cfm
    - —Live and interactive
    - —Low time commitment (2 hours)
    - —No travel commitment
    - —Archived
    - —163 seminars since 1998, over 21,000 participants, from over 900 cities in over 40 countries
- Classroom
  - » http://www.trainex.org
  - » http://www.ert.org

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Biographical Note

Chris Sandground

Christopher Sandground has worked with IKM Consulting Ltd for 8 years as Remediation Manager, predominantly in contaminated land investigations, remediation design and remediation project management. With IKM, he was one of the first UK users of on-site chemical testing kits and equipment for remediation projects.

Christopher's work has included managing remediation projects on petro-chemical facilities, oil refineries, former petrol station sites and a range of former industrial facilities. This work has taken him throughout the UK and to Azerbaijan. His remedial design experiences, which centre on providing cost effective innovative solutions to clients, range from traditional dig and dump to bioremediation.

IKM Consulting Ltd

Experiences of Improving Data Quality in the UK

Christopher Sandground

IKM Consulting

Winner 1998
Best New Business

Winner 1999
Most Competitive Business
(up to 25 employees)

ISO 9001 : 2000
REGISTERED FIRM

INVESTOR IN PEOPLE

IKM Consulting Ltd

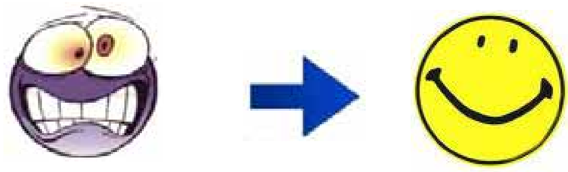
Welcome to this presentation by IKM Consulting Ltd.

We provide Civil and Structural Engineering, Architectural, Health & Safety and Environmental services to a range of organisations.

IKM

Introduction

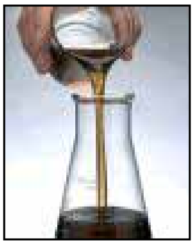
- Meaningful
- Real-time SI
- Control

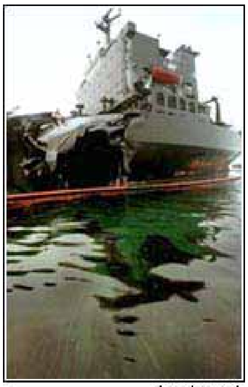


IKM

Types

Organics





(AP/Photo)

Immunoassay

IKM

Turbidity

IKM

UV Fluorescence

IKM

Gas Chromatography

IKM

Metals

IKM

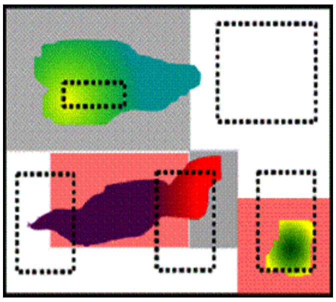
Uses

IKM

Site Investigation

Delineation

IKM



Health & Safety

IKM

Remediation

Correlation, Accuracy and Precision

Benefits

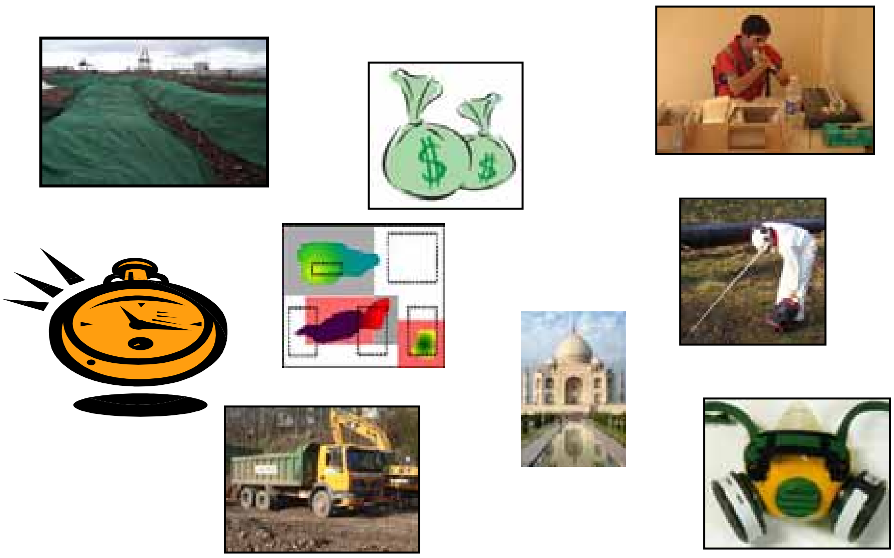
Case Studies

Former Plastics Complex

Pipe coating yard – Baku, Azerbaijan

Bertram Street

Conclusions



Biographical Note

Mr Perry Guess

Mr Perry Guess is Associate Director for Technology Transfer and Networking for IPM-Net, based at the University of Oxford. After obtaining an MSc and BSc, Mr Guess was a Consultant Project Manager at Pera (Production Engineering Research Association) for eight years. Mr Guess has also acted as a consultant for several UK government initiatives aimed at assisting industry attain competitive advantages, he was an industrial biotechnology specialist for the BioWise programme and was an advisor to Small Business Services officers for the assessment of environmental projects bidding for near-market funding.

Mr Guess became the Associate Director for Technology Transfer and Networking at the inception of FIRSTFARADAY in 2001 based at Pera and relocated to the University of Oxford in 2004. Continuing this role within FIRSTFARADAY and now IPM-Net, he is the primary interface between IPM-Net and its Industrial Member Group and is responsible for converting their aspirations, issues and offerings into business opportunities through the activities and service assistance of IPM-Net. He is extensively involved in several European initiatives aimed at assisting the Environmental Service Sector understand, access and develop research projects and the development of pan-European funding mechanisms for the Contaminated Land Sector.

Introduction to FASA (Field Analytical Suppliers Association)

Perry Guess

Integrated Pollution Management
Knowledge Transfer Network

Knowledge Transfer Networks
A DTI business support solution
Delivered through the Technology Programme

FASA

Field Analytical Suppliers Association

Perry Guess

Chairman, FASA
and
Associate Director of Technology Transfer and Networking, IPM-Net

Funded by Government, Regional Development Agencies, Devolved Administrations and Research Councils

Integrated Pollution Management
Knowledge Transfer Network

Knowledge Transfer Networks
A DTI business support solution
Delivered through the Technology Programme

Content

- Introduction to the Integrated Pollution Management Knowledge Transfer Network (IPM-Net)
- What is FASA?
- Objectives of FASA
- FASA Deliverables for 2006
- FASA Workshop
- Benefits for FASA Members
- Benefits for the contaminated land community
- Current Structure of FASA

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Integrated Pollution Management
Knowledge Transfer Network

Knowledge Transfer Networks
A DTI business support solution
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Integrated Pollution Management Knowledge Transfer Network (IPM-Net)

IPM-Net assists industry to meet the demands of regulatory and business drivers for the integrated management and remediation of environmental pollution. Drawing together organisations that deal with environmental pollution in land, waste and water, IPM-Net enables businesses to become more competitive, create jobs, increase wealth and enhance the position of UK environmental industries in the global marketplace.

- **Supporting innovation and technology development**
  Delivering cost effective, sustainable solutions
- **Accessing knowledge and technology transfer**
  Developing business opportunities, contacts and collaborations
- **Developing skilled personnel**
  Enhancing staff and company performance.

www.ipm-ktn.com

Funded by Government, Regional Development Agencies, Devolved Administrations and Research Councils

Integrated Pollution Management
Knowledge Transfer Network

FASA

Knowledge Transfer Networks
A DTI business support solution
Delivered through the Technology Programme

What is FASA?

- New UK Association for the contaminated land sector
- Promote, educate and support the more widespread and appropriate use of field analysis for contaminated land management
- Act as an central, independent technical voice for the regulator and industry
- Comprise suppliers of field analytical tools
- Held under the umbrella of IPM-NET as a technology network
- Funded by field analytical sector and supported by IPM-Net

Funded by Government, Regional Development Agencies, Devolved Administrations and Research Councils

Objectives of FASA

- Promote the APPROPRIATE use of field analytical tools.
- To develop and deliver:
  - best working practises
  - FASA verified techniques and procedures
- Provide an information resource on available technologies and their application – *website*
- Provide training in the operation and application of field tools – *workshops*
- Support the efforts of regulators, industry and laboratories to integrate field tools
- Act as a forum for suppliers to exchange information and best practise
- Identify R&D needs of industry and encourage development of new useful technologies
- Interact with appropriate UK and overseas organisations and committees

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Integrated Pollution Management
Knowledge Transfer Network
FASA
Knowledge Transfer Networks
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FASA Deliverables for 2006

- Website - act as a portal for technical information, training, and forum for information exchange
- Training workshops across the UK
- Dissemination programme through conferences, exhibitions and press releases
- Members meetings to plan future activities and programmes

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Perry Guess

Integrated Pollution Management
Knowledge Transfer Network

FASA
Knowledge Transfer Networks
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FASA Workshops

- Scheduled four, one day events around the country between June and October 2006
- Case studies and practical demonstrations of the most common field analytical technologies
- For industry and public sector to gain a broader practical understanding of the use of field tools
- Provide an overview for consultants, contractors, land owners and local authorities of the use and value of field tools for contaminated land management
- Organised by FASA through IPM-Net with inputs from key suppliers and regulators

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Integrated Pollution Management
Knowledge Transfer Network

FASA
Knowledge Transfer Networks
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FASA Workshop Programme

Welcome and Introduction
Mr Perry Guess, IPM-Net and FASA Chairman

The use of field analytical tools in the UK regulatory framework
Dr Bob Barnes, Environment Agency

Overview of available field tools
Mrs Anna Whittaker, Cybersense

Case study one: Portable XRF
Mr John Hurley, Niton UK

Case study two: Portable GC-MS
Mr Marc Wakelin, Ificon UK

Case study three: *In situ* geoprobes
Mr Darren Cook, Fugro

Case study four: On-site chemical test kits
Mr Richard Simmonds, SDI

Case study five: Portable PID
Mr Philip Saxton, Rae Systems

Demonstration surgery

Practical integration of field tools into site investigation and remediation projects
Mr Nick Moodie, Cybersense

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Integrated Pollution Management
Knowledge Transfer Network

FASA

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FASA Workshop Location

London - June 2006

Birmingham - July 2006

Bristol - September 2006

Manchester - October 2006

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Integrated Pollution Management
Knowledge Transfer Network

FASA

Knowledge Transfer Networks
A DTI business support solution
Delivered through the Technology Programme

Benefits for FASA Members

- Provides an independent forum to define and develop this emerging analytical sector
- Any supplier with UK representation can join and members work between themselves to deliver on overall objectives of FASA through IPM-Net
- Opportunity for field analytical specialists to work together to develop best practise and verified techniques and procedures
- Quarterly meetings, web-based information exchange forum, newsletters
- First members meeting scheduled for Tuesday 11th July 2006

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Introduction to FASA (Field Analytical Suppliers Association)

Perry Guess

Integrated Pollution Management
Knowledge Transfer Network

FASA
Knowledge Transfer Networks
A DTI business support solution
Delivered through the Technology Programme

Benefits for the contaminated land community

- A focal point to gain information on field analytical techniques
- Access to independently verified information – by the membership and IPM-Net
- Access to best practice, training and knowledge transfer
- Technical support for the selection and application of field analytical tools
- An independent communication link to the suppliers of field analytical tools
- Technology transfer process to enable more cost-effective contaminated land management

Funded by Government, Regional Development Agencies, Devolved Administrations and Research Councils

Integrated Pollution Management
Knowledge Transfer Network

FASA
Knowledge Transfer Networks
A DTI business support solution
Delivered through the Technology Programme

Current Structure of FASA

CHAIRMAN

Perry Guess – Associate Director Technology Transfer and Networking, IPM-Net

FOUNDING CO-ORDINATING MEMBERS

Rae Systems UK Ltd

Fugro UK Ltd

SDI Europe Ltd

Niton UK Ltd

Inficon UK Ltd

Cybersense Biosystems Ltd

Funded by Government, Regional Development Agencies, Devolved Administrations and Research Councils


Integrated
Pollution
Management
Knowledge Transfer Network
FASA
Knowledge Transfer Networks
A DTI business support solution
Delivered through the Technology Programme
Thank you for your attention
I look forward to seeing you at a
FASA workshop…
Funded by Government, Regional Development Agencies, Devolved Administrations and Research Councils

Sponsors Information Section

Cybersense
leading field analysis

Cybersense is a technology-based company which specialises in the development and integration of field analytics for more cost-effective contaminated land management.

When used in concert with fixed lab testing, integrating field analytical techniques into projects produces a streamlined analytical approach. More timely, defensible datasets can enable project costs to be reduced by 20-50% whilst at the same time dramatically improving decision confidence.

Product Supply

Experienced users of field analytical tools can buy their hardware and consumables direct from us. We have the widest range of analytical tools available for hire or purchase including:

- Immunoassays
- toxicity assays
- UV fluorescence
- PID/FID
- Chemical test kits
- X-ray fluorescence
- Portable GC/MS
- In situ probes

Training and Technical Support

Cybersense provides both on-site and in-house training programmes in the use and application of specific field tools. Authorised users of our tools have access to a dedicated team of technical support specialists.

Project Solutions

Cybersense acts as a specialist analytical partner. Project planning is crucial to focusing analytics on decision-making. We have developed an innovative evaluation methodology (**CyPlans**™) which allows us to technically and economically assess the value of applying field analytics to specific situations. The output is a more cost-effective and accurate analytical solution for the client.

Data management is a key element of Cybersense's project solution. We have developed a novel data management tool called **DUMAT**™. This software enables both field and fixed lab data to be integrated and focused on project decisions where errors associated with measurement and analysis are quantified and managed. This brings, for the first time, a dimension of certainty to data for contaminated land work.

Cybersense provides project planning expertise, tools, data management, and support from the tendering phase all the way through to project close-out.

Environment

Contaminated Land

ALcontrol Laboratories are a rapidly expanding European company with 20 laboratories in the Netherlands, the UK, Ireland, France and Sweden, with a turnover in excess of 100 million Euros. As one of the largest independent testing laboratories in Europe, ALcontrol provides a service to the environmental (water, soil, air and oil) and food markets. For further information on ALcontrol please visit our website www.alcontrol.co.uk

Contaminated Land Laboratories
In the UK and Ireland we have three state of the art contaminated land laboratories analysing soils, associated waters, and gases, all three have on site sampling teams who work alongside our clients. ALcontrol Geochem is based in Hawarden outside Chester, ALcontrol Technichem is based in Langley near Heathrow and in Ireland the laboratory is based in Ballycoolin near Dublin.

Accreditation and Analyses
All three laboratories are UKAS accredited, with MCERTs accredited analyses being offered by ALcontrol Geochem and ALcontrol Technichem. A statement of our capabilities is available on request or please visit our website for further information.

Samples from Overseas
ALcontrol Geochem holds a DEFRA licence for the importation of samples from abroad. 10% of our turnover is from work outside of Europe.

Couriers
We offer overnight or same day collections. Where possible for same day collections we use our own dedicated courier service with the drivers operating out of Chester, Langley, Bellshill, Scotland and Dublin, for overnight services we use a national courier with a success rate of over 95%.

Customer Focused
We pride ourselves on the quality of the service provided to our customers, allocating dedicated points of contact to each client. This is common throughout the three laboratories

ALcontrol Laboratories

ALcontrol Geochem employs over 300 staff and occupies 85,000 sq ft.

ALcontrol Technichem employs over 60 staff and occupies 23,000 sq ft.

ALcontrol Dublin employs over 45 staff and occupies 8,000 sq ft.

We also have laboratories in Conwy, Rotherham, Birmingham, Glasgow and Newcastle-under-Lyme providing testing for oil, potable water, air, and asbestos. For further information please visit our website

www.alcontrol.co.uk

Contact Details

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Fax: 01244 528 701

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Email: victoria.ferguson@alcontrol.co.uk
Mobile: 07720 468 535

ALcontrol Technichem
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Langley
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Tel: 01753 212 500
Fax: 01753 212 501

Contact: Kate Wiley
Email: kate.wiley@alcontrol.co.uk
Mobile: 07813 922 628

ALcontrol Dublin
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Ballycoolin
Dublin 11

Tel: 00 353 1 882 9893
Fax: 00 353 1 882 9895

Contact: Caitriona Lynch
Email: caitriona.lynch@alcontrol.ie
Mobile: +353 (0) 868331126

ALcontrol Laboratories

SEVERN TRENT ENVIRONMENTAL LEADERSHIP **STL** Leaders in Environmental Testing

a guide to STL

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F: +44 (0)24 7685 6575

Email:
sales@stl-ltd.com

Website
www.stl-ltd.com

Contact:
Jon Wadley – Sales Manager

Main Business Activity:

STL is a leading commercial environmental testing company, performing a broad range of tests, monitoring and sampling for multi national organisations through to privately owned companies.

Business Sectors:

These include:
Local Authorities & Government Agencies, Environmental Consultants & Consulting Engineers, Water & Waste Treatment Companies, Industrial Process Companies & Utilities.

STL, the UK's leading commercial laboratory provides a range of comprehensive and expert analysis for monitoring all elements of the water cycle, the waste process, contaminated land testing, landfill assessment, asbestos, emissions measurements and microbiological investigation for health and hygiene products, pharmaceuticals, cosmetics and other manufactured products.

quality

Our commitment to quality is demonstrated by our investment in our staff, test equipment & infrastructure. Analysis from our laboratories is supported by validated test methods, documented standard operating procedures and stringent analytical performance precision and accuracy criteria, all backed by the assurance of complete customer confidentiality.

Each of our laboratories is accredited to ISO 17025, through the United Kingdom Accreditation Service (UKAS) for a wide range of testing. For particular activities at the Group's sites, we are certificated to both ISO 9001 and ISO 14001. STL is MCERTS accredited for the chemical analysis of soils. The quality of our ecotoxicology & biodegredation testing is assured through compliance with Good Laboratory Practice (GLP).

Quality assurance is underwritten by extensive participation in several external proficiency testing schemes, such as AIMS, Aquacheck, Advantica, Contest, Crypts, HPA & QM.

Through STL's Source division, we offer a site monitoring and sampling service for monitoring water, land, air, landfill gases, dust, noise and vibration.

centres of excellence

We have significantly invested in developing "Centres of Excellence" at our laboratories; each one specialising in a specific area of analysis with the aim of achieving a high level of analytical capability and maximising customer service.

with you every step of the way

STL manages the entire analytical process for its clients, including quotations, bottle preparation, courier provision, sample reception, project management, analysis and results.

Our DEFRA soils import licence means that STL can save you time and inconvenience on international projects.

air

Process and landfill gas monitoring and testing

water

Sampling and analysis from all parts of the water cycle

product

Analysis of natural and manufactured products

land

Sampling and testing for a complete contaminated land assessment

Types of analysis provided
Potable Water
Borehole Water
Surface Water
Groundwater
Bathing Water
Bottled Water
Potable Water Microbiology
Cryptosporidium
Legionella pneumophila
Water and Food Microbiology
Urban Wastewater
Effluents
Landfill Leachate
Contaminated Land
Environmental Biology
Pharmaceutical Microbiology
Ecotoxicology Studies
Quantitative Suspension Testing

Methods and Instruments
Colorimetry by Konelab
FTIR
IR
GC-ECD
GC-FID
GC-FPD
GC-PDD
GC-MS
Head Space with GCMS
Purge & Trap with GCMS
HPLC-ECD
HPLC-Fluorescence
LCMS
Ion Chromatography
Hydride Generation & AFS
Pharmaceutical Microbiology
Microscopy
ISE
Potentiometry
Titrimetry

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INVESTOR IN PEOPLE