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Continuous Ground-Gas Monitoring Best Practice

Simon Talbot - MD GGS

The Geological Society

West Midlands Group

14 May 2019

Presentation Content

1. The ground-gas hazard
2. Key properties of ground-gases
3. Spot monitoring and continuous monitoring
4. Additional lines of evidence and interpreting flow data
5. Continuous monitoring for validation
6. Gorebridge case study
7. Summary

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Loscoe Explosion, 1986 - 3 people injured

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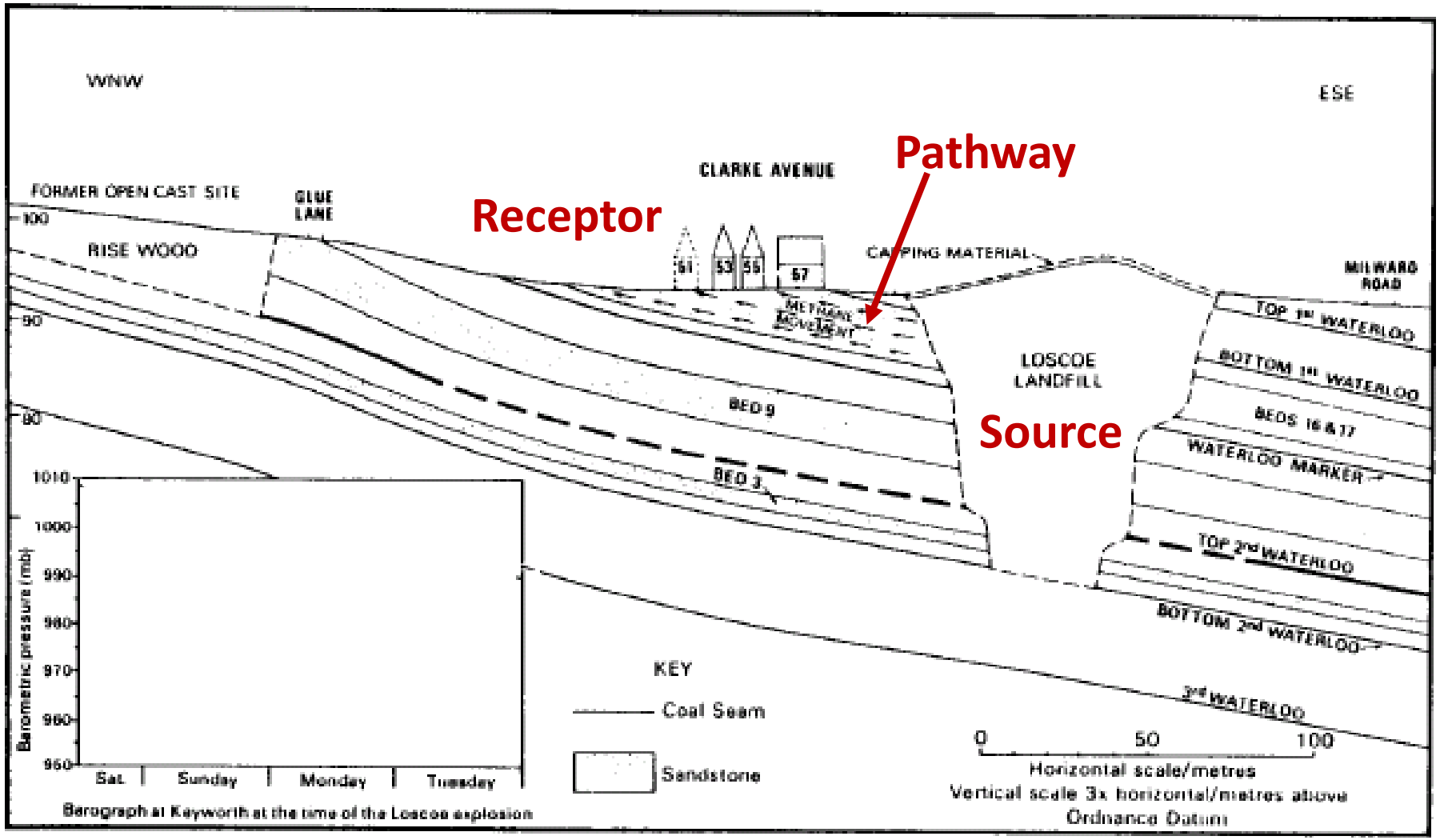
Loscoe Public Inquiry



CIRIA 130, 1995

Source - Pathway - Receptor

Driving mechanism

Pollutant Linkage

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Gorebridge Incident

- New housing estate built in 2009

- 7 Sept 2013 council tenants overcome by gas and taken to hospital. Families decanted to alternative accommodation
- April 2014 IMT set up

- 64 Homes demolished in 2016

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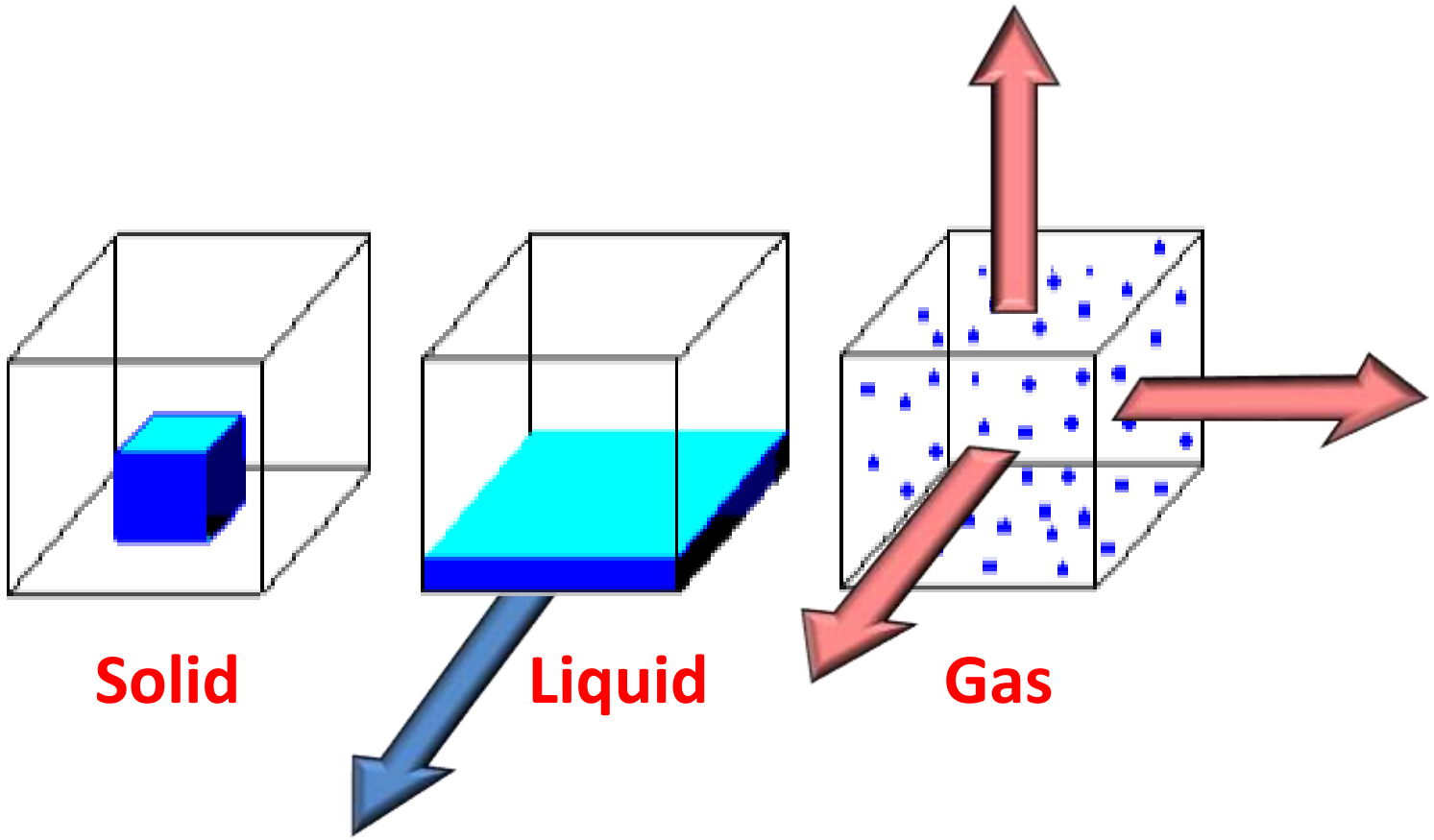
Environmental monitoring challenges



Viscosities at STP:

- **Water** **8.9 x 10^{-4} kg/(ms)**
- **Air** **1.8 x 10^{-5} kg/(ms)** **50 times lower**

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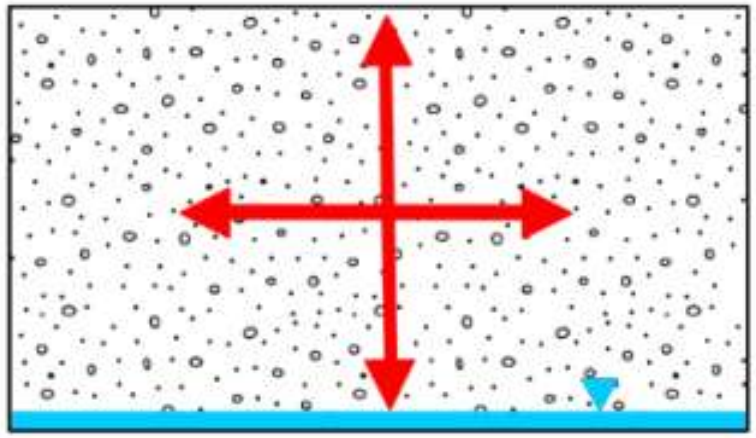
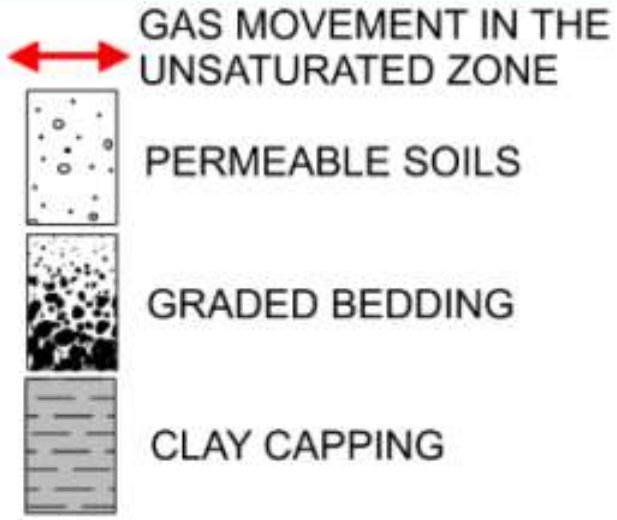
Permeability Anisotropy





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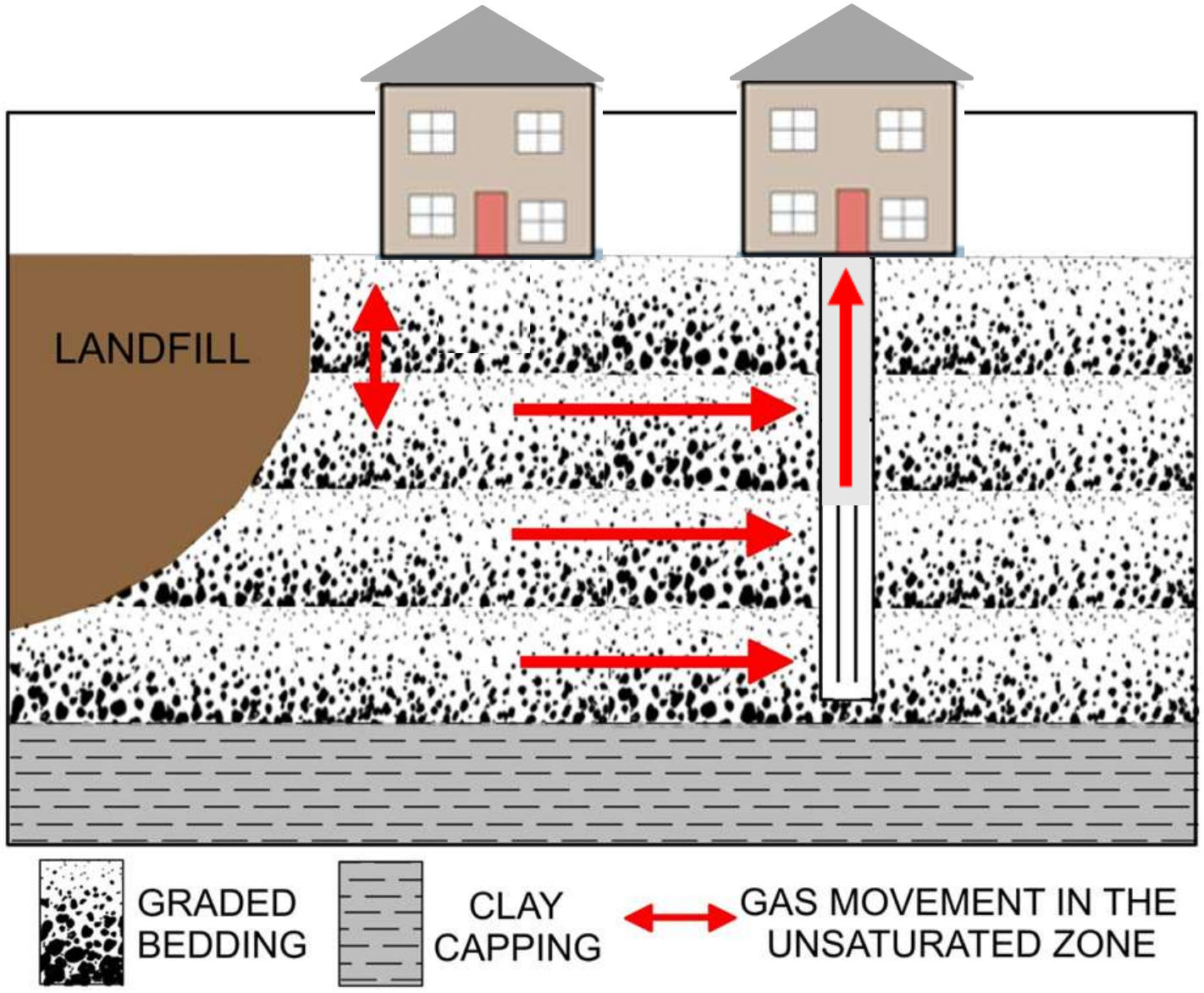
Permeability anisotropy and borehole monitoring



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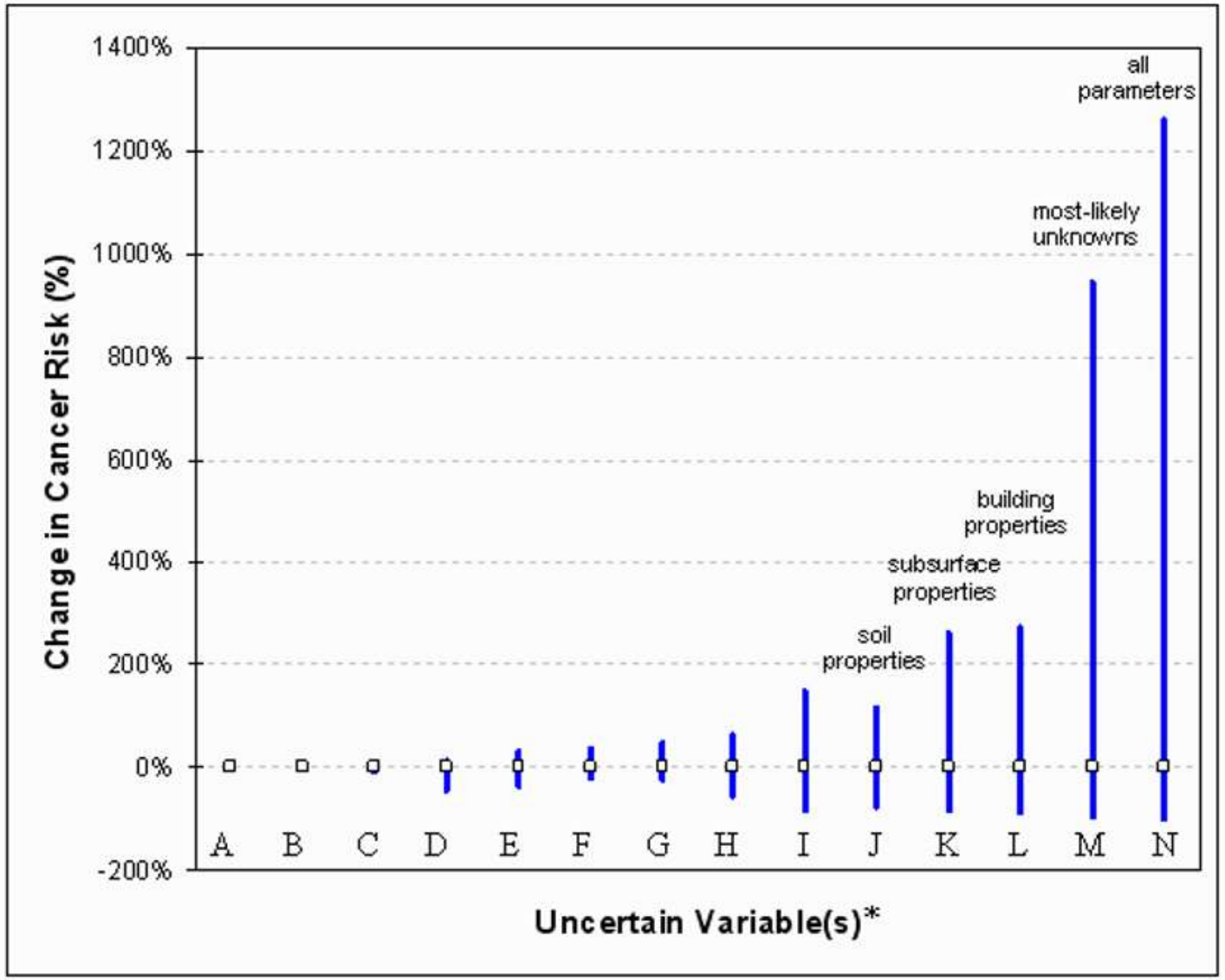
Using Johnson-Ettinger vapour risk model



"An apparent increase in simulated cancer risk caused by the uncertainty introduced from the input parameters was as much as 1,285%"

Weaver J.W. et al. Uncertainty and the Johnson-Ettinger Model for Vapor Intrusion Calculations. EPA/600/R-05/110. September 2005.

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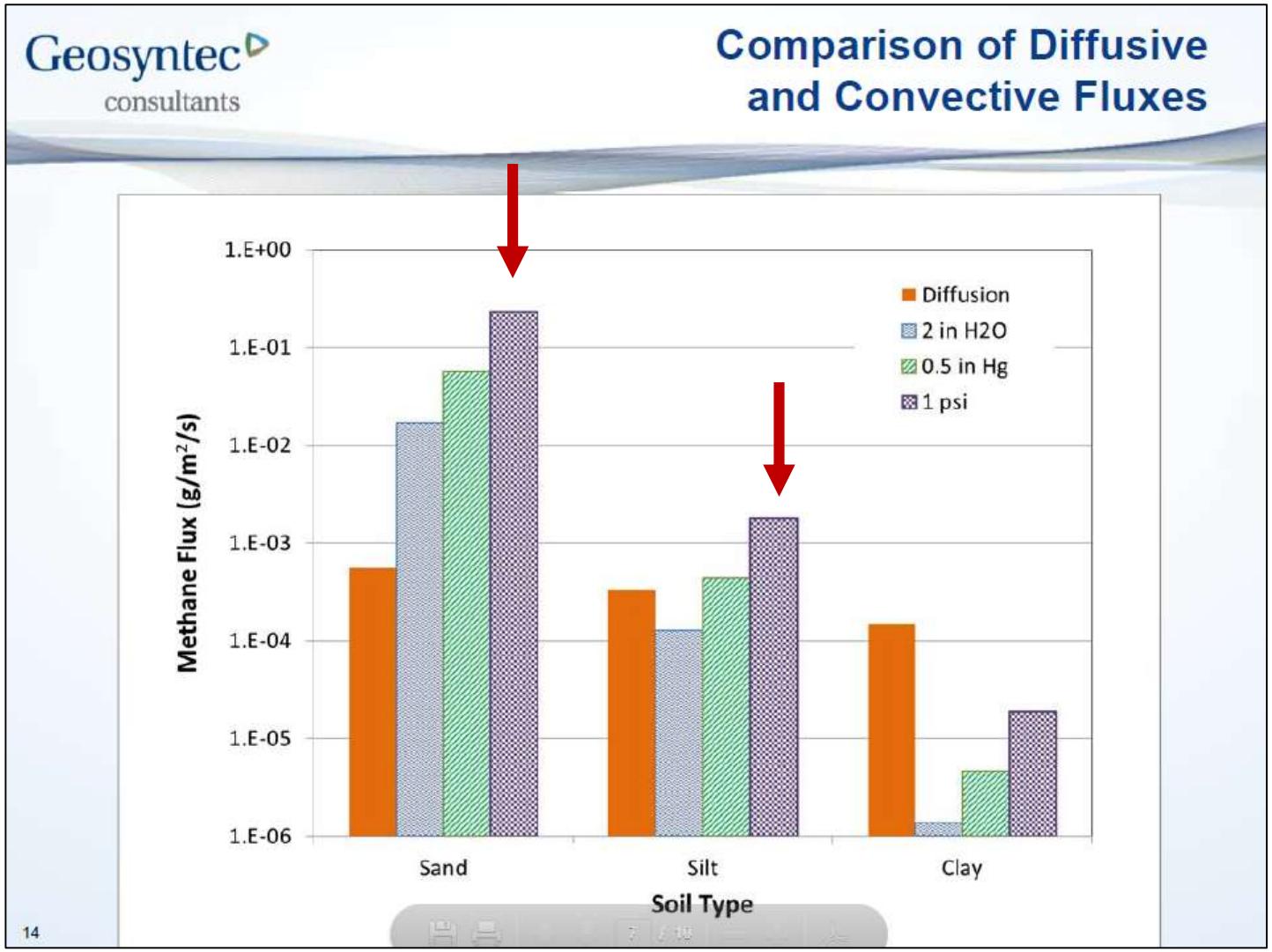
Diffusion vs pressure driven flow



Ettinger R. and Kerfoot H. Evaluating the Vapor Intrusion Pathway for Methane. AEHS 22nd Annual Conference, San Diego, California, 21.3.12

1 psi pressure driven flow greater than diffusion by:

~ 1,000 times - Sands

~ 100 times - Silts

Diffusion only greater in clay soils

Model is you must - Measure if you can!

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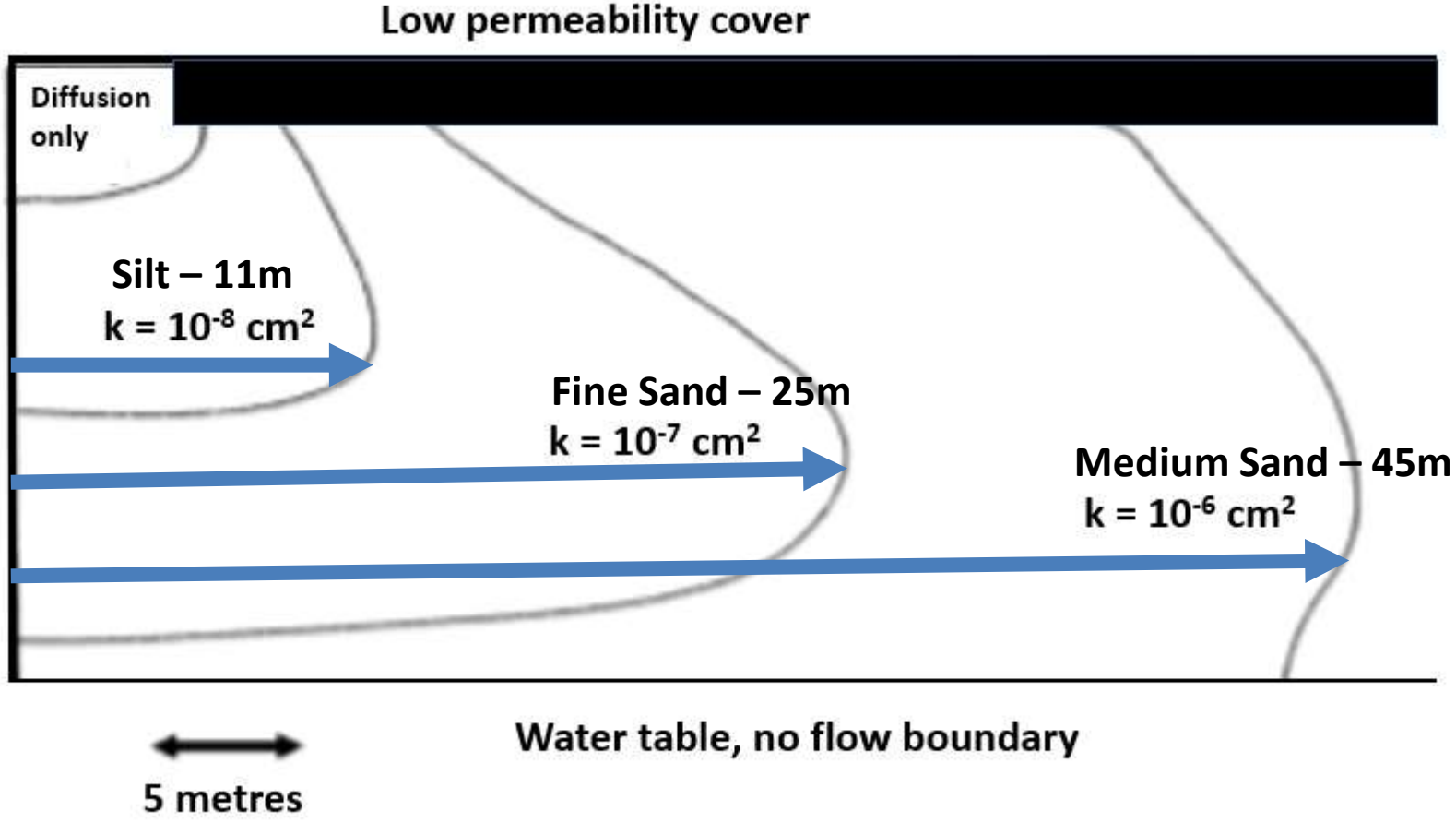
Pressure as a Migration Driver



- 2D finite element analysis - 25mb pressure fall over 24 hours
- 45m lateral migration within medium sand

Massmann J. and Farrier D.F. 1992. Effects of barometric pressure on gas transport in the vadose zone. Water Resources Research, Vol.28, No. 3. 777-791.

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Dissolved gases in groundwater

Solubilities at STP:

- **Methane** **25 mg/l**
- **Carbon dioxide** **1,450 mg/l** **58 times more soluble!**

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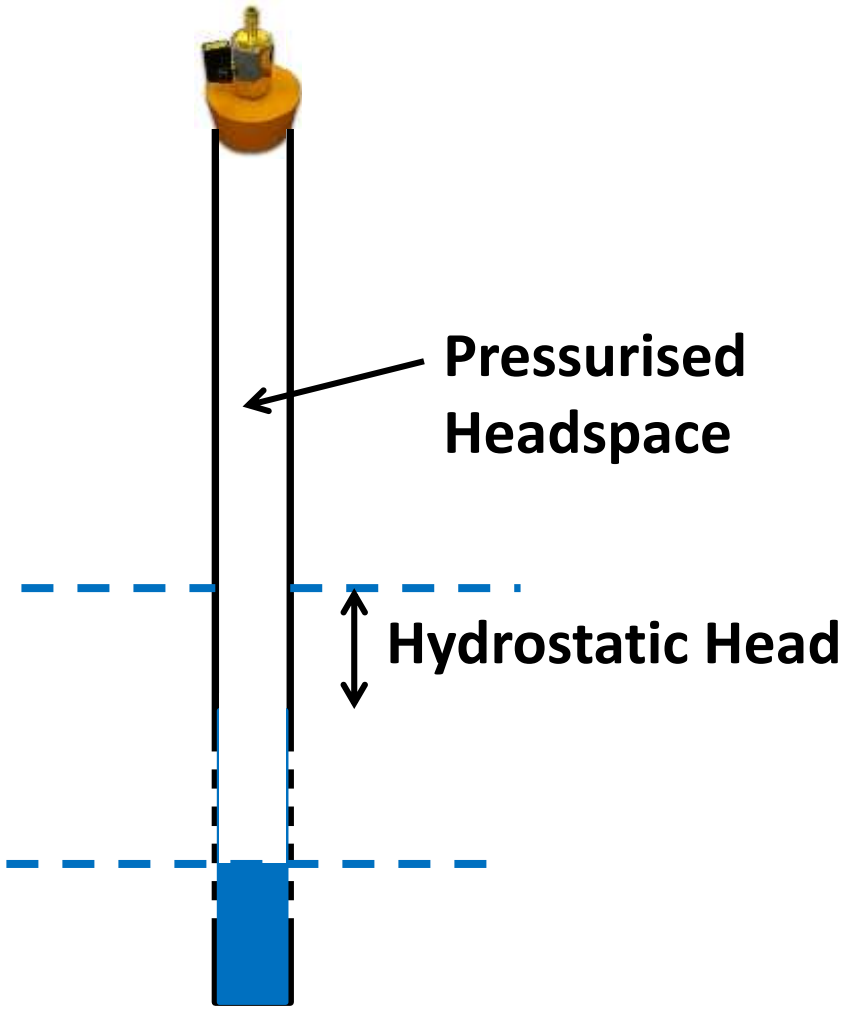
Piston Effect and flow readings



1. Low pressure weather system passes over site
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3. Small volume of methane degasses and builds up in headspace
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    a) High gas concentration
    b) High borehole flow

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Traditional Spot Monitoring

Exploratory hole	Time	Response zone range	Water level	Base level	Atm. pressure	CH_4		LEL		CO_2		O_2			H_2S		Flow	
		(m)	(m bgl)	(m bgl)	(mbar)	(%)		(%)		(%)		(%)			(ppm)		(l/hr)	
						peak	steady	peak	steady	peak	steady	high	steady	low	peak	steady	peak	steady
BH08	08:45	5.0-6.0	3.08	5.90	1000	0.3	0.0	2.6	0.0	0.0	0.0	20.2	20.2	20.2	0	0	0.0	0.0
BH09	12:55	5.0-6.0	1.86	6.03	999	0.8	0.4	20.0	14.0	19.0	9.6	6.7	6.0	6.0	0	0	-12.0	0.0
BH11*1&6	08:35	3.0-4.3	3.28	4.30	1000	18.8	4.0-18.8	+++	+++	0.0	0.0	8.0	2.4-8.0	2.4	0	0	0.0	0.0
BH12	14:15	6.5-7.5	1.55	6.85	998	0.0	0.0	0.0	0.0	0.4	0.4	20.2	20.2	20.2	0	0	0.9	0.0
BH13	12:35	3.0-4.0	*4	4.05	1000	0.0	0.0	0.0	0.0	0.5	0.5	18.3	18.3	18.3	0	0	0.0	0.0
BH15	10:35	3.5-4.5	2.40	4.36	1000	0.8	0.0	18.0	0.0	2.2	0.9	19.5	19.5	19.5	0	0	0.0	0.0
BH16*3	13:30	1.0-4.0	2.46	2.55	999	0.0	0.0	0.0	0.0	0.3	0.3	20.1	20.1	20.1	0	0	4.0	0.0
BH18	10:05	4.0-5.0	2.40	4.64	1000	0.9	0.9	15.2	15.2	2.9	2.3	15.2	15.2	15.2	0	0	0.0	0.0
BH19	14:05	12.5-13.5	1.27	13.50	999	0.0	0.0	0.0	0.0	0.0	0.0	20.2	20.2	20.2	0	0	48.0*5	0.0
BH23*3	13:55	5.0-6.0	1.62	5.10	999	0.0	0.0	0.0	0.0	0.2	0.2	20.5	20.5	20.5	0	0	10.5	0.0
BH26	09:50	7.0-8.0	2.10	7.82	1000	0.4	0.4	10.6	10.6	4.6	4.6	15.8	15.8	15.8	0	0	0.0	0.0
BH29	09:26	1.0-5.0	0.80	5.05	1001	0.0	0.0	0.0	0.0	0.8	0.8	20.1	19.9	19.9	0	0	0.0	0.0
BH30*3	11:20	9.0-10.0	1.83	7.75	1000	0.0	0.0	0.0	0.0	0.3	0.3	20.4	20.4	20.4	0	0	-15.8	0.0

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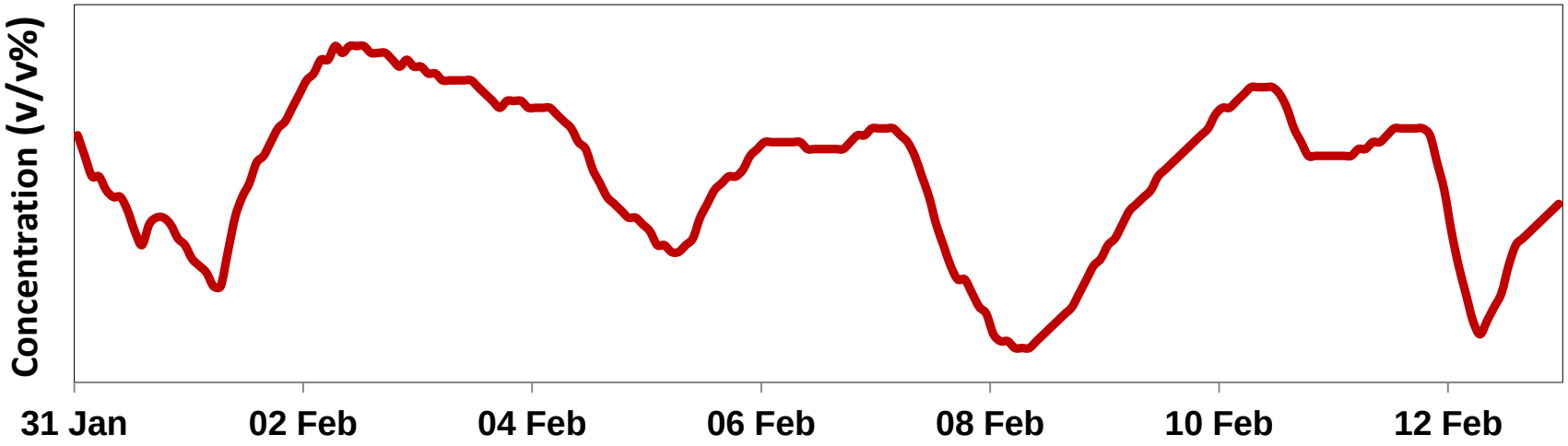
Continuous Monitoring

When the frequency of monitoring **exceeds** the frequency of change of the measured parameter, the monitoring can be termed **'continuous'**



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Continuous Ground-Gas Monitoring

1st Generation
In-borehole device
GasClam®

2nd Generation
In-borehole device
Gas Sentinel®

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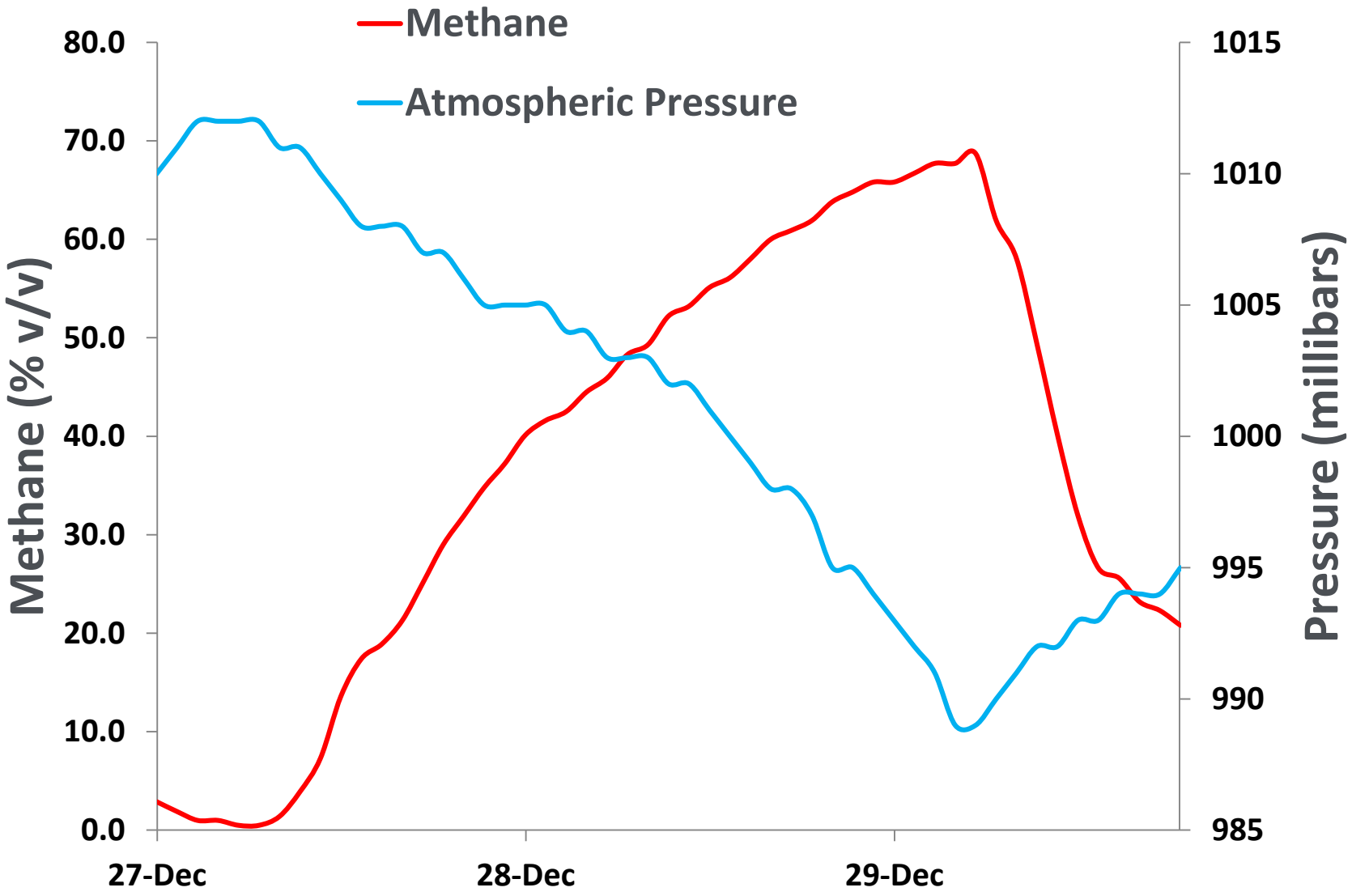
Atmospheric Pressure as a Ground-Gas Driver



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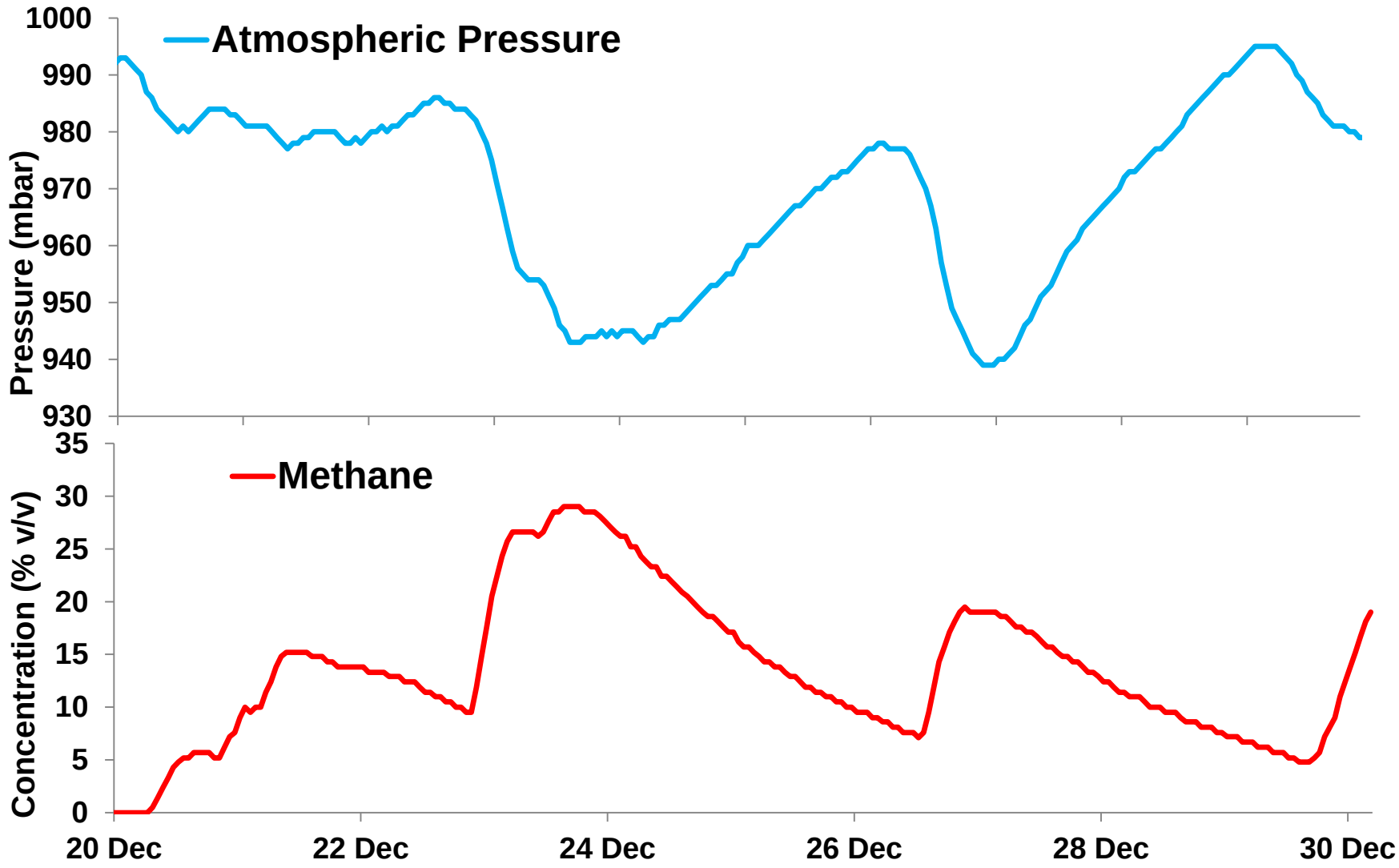

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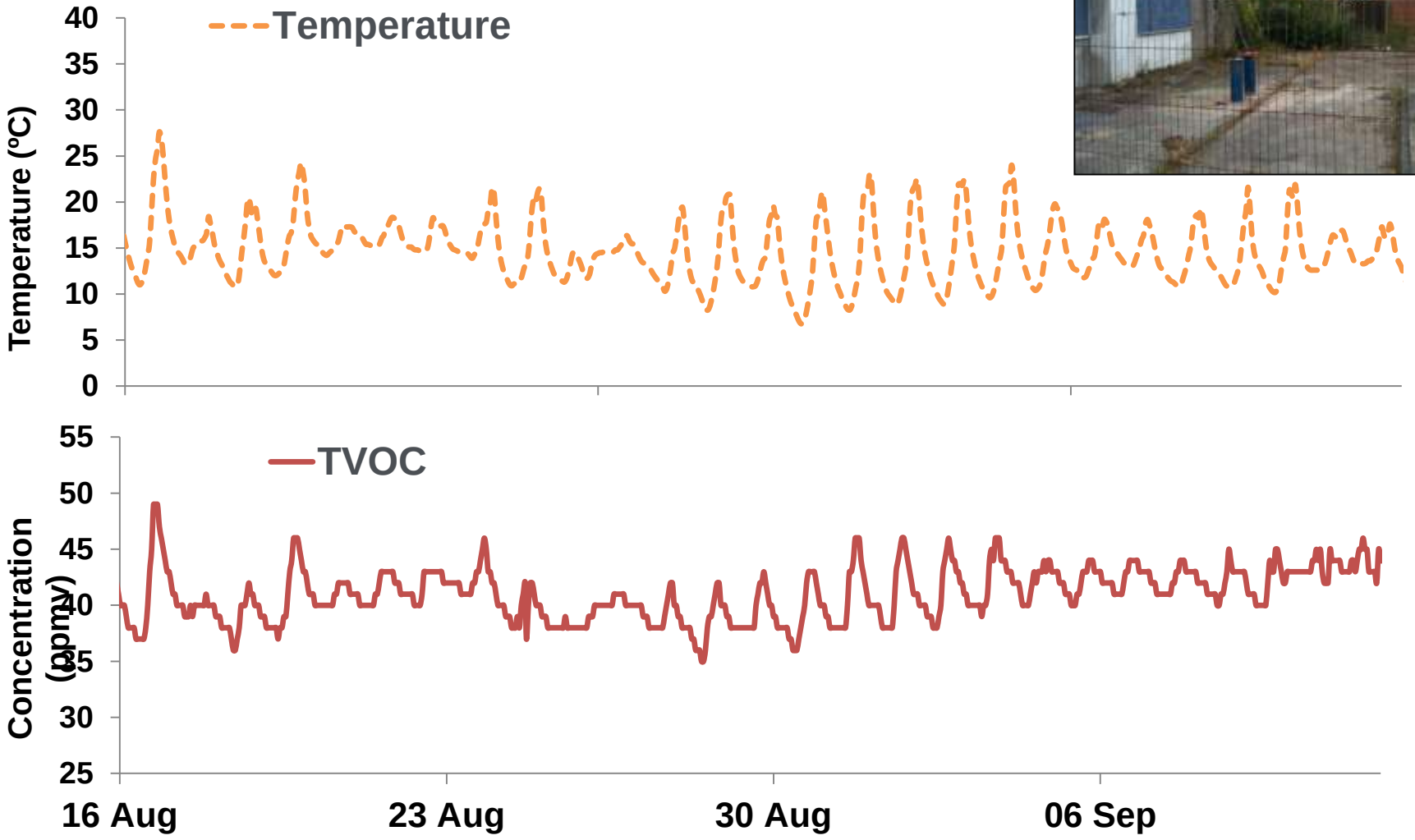
Temperature as a Ground-Gas Driver



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Water Level as a Ground-Gas Driver

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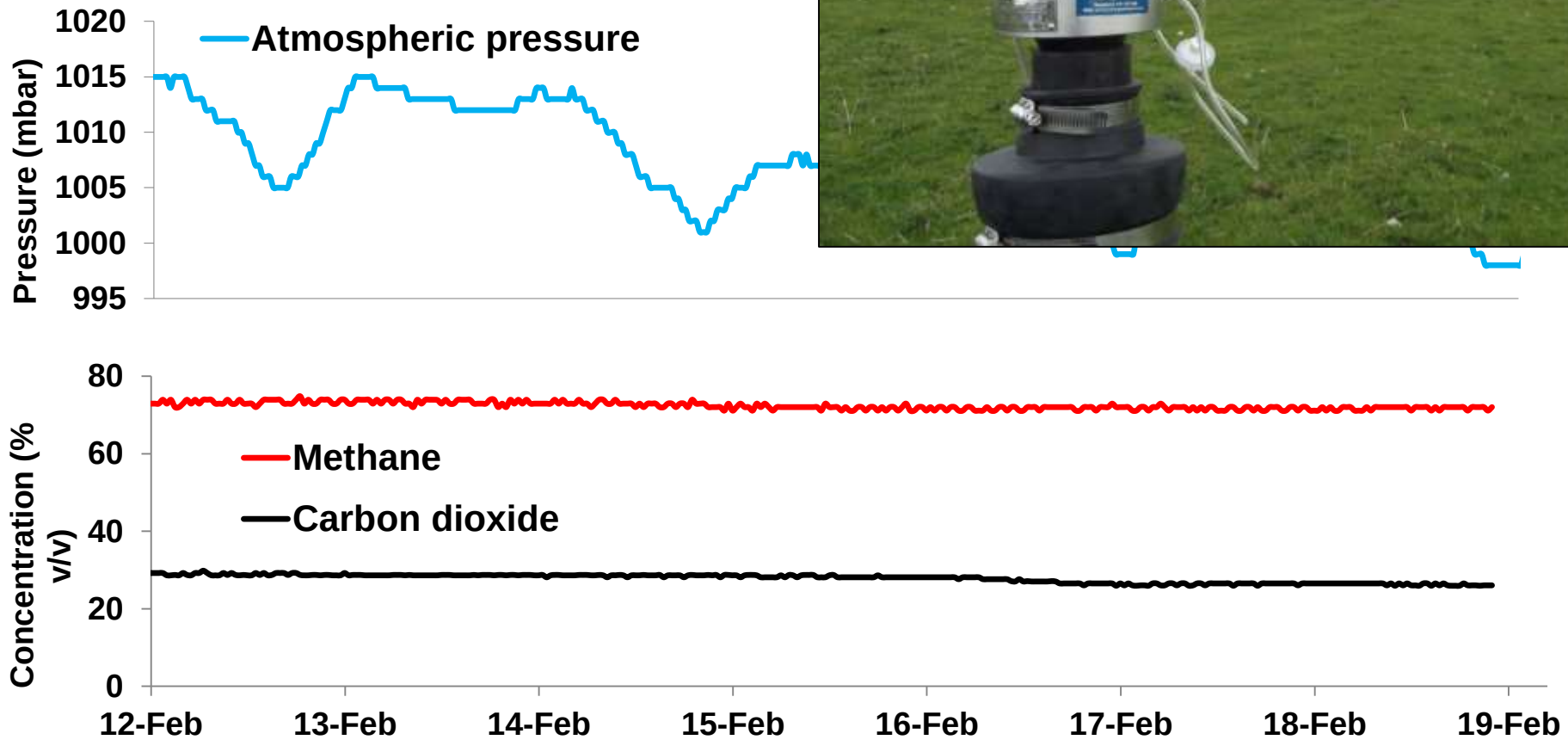
What's happening here?



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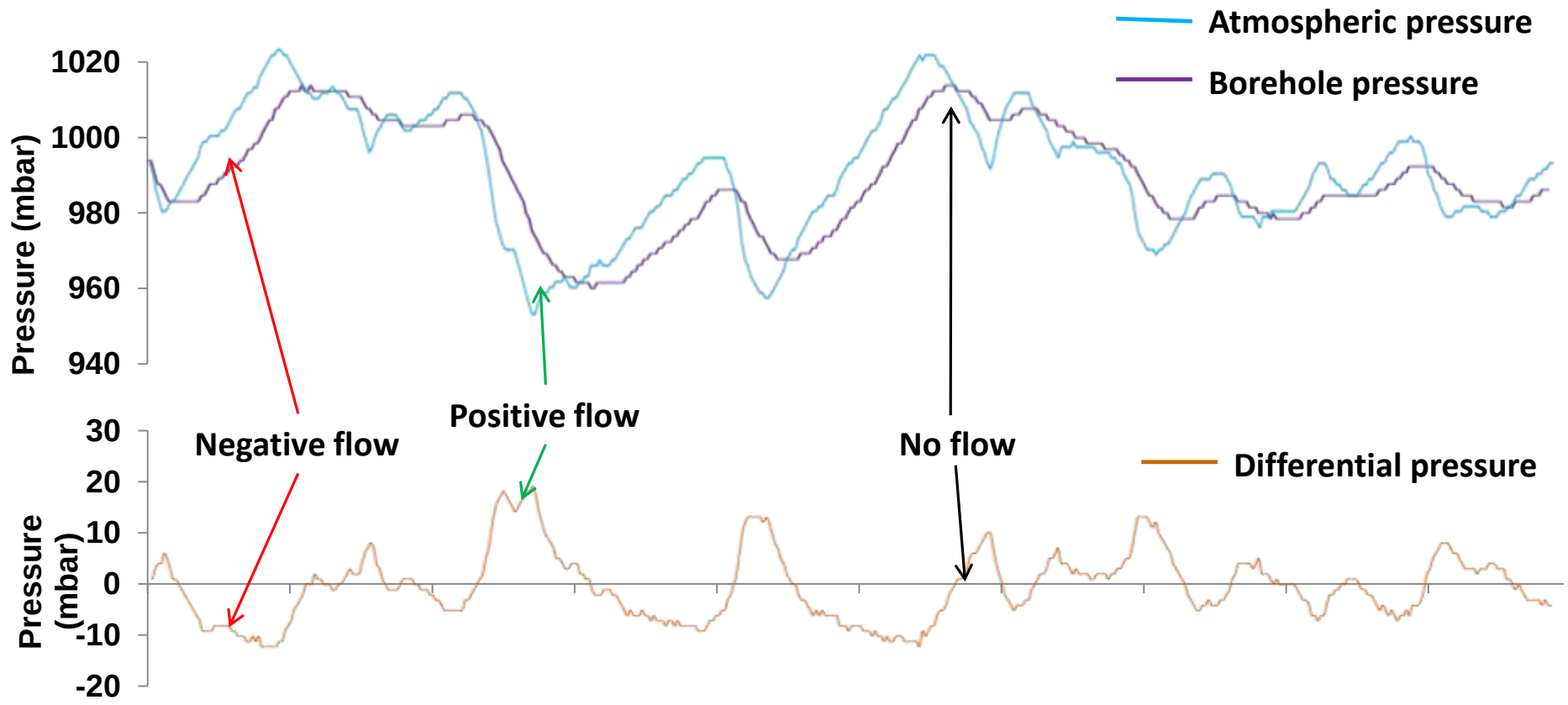
Additional Lines of Evidence cont.
Differential Pressure Assessment



'Barometric Pumping'

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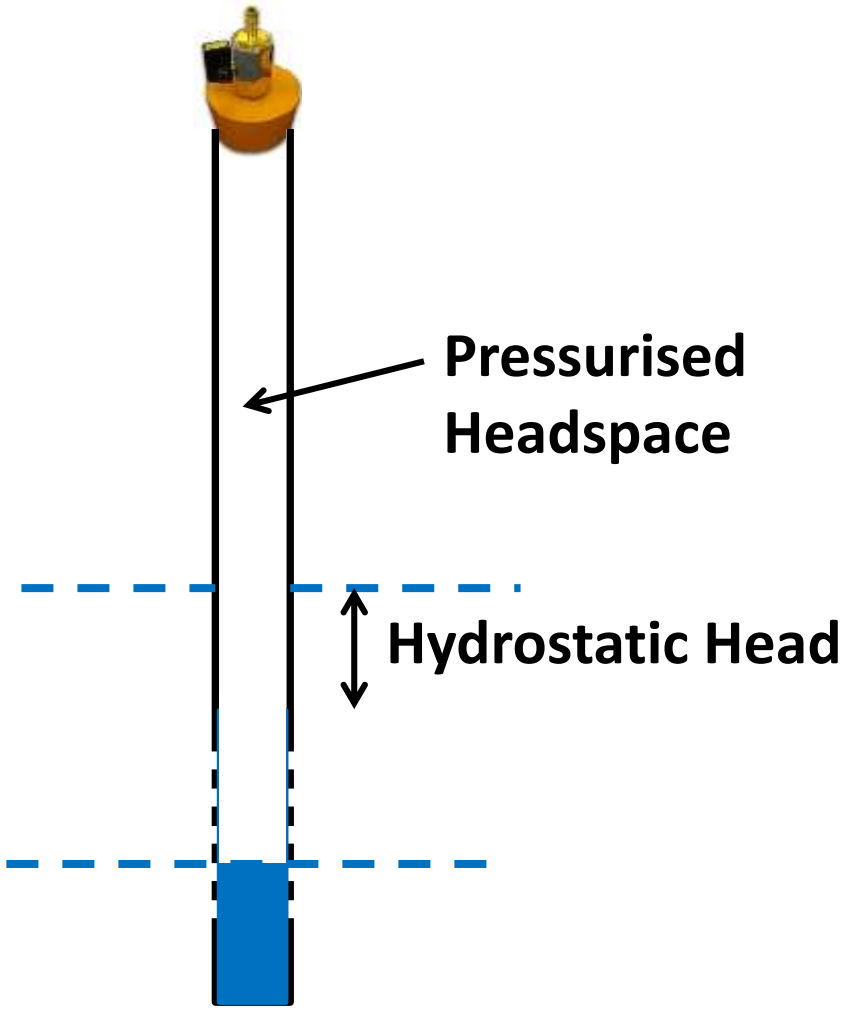
Piston Effect and flow readings



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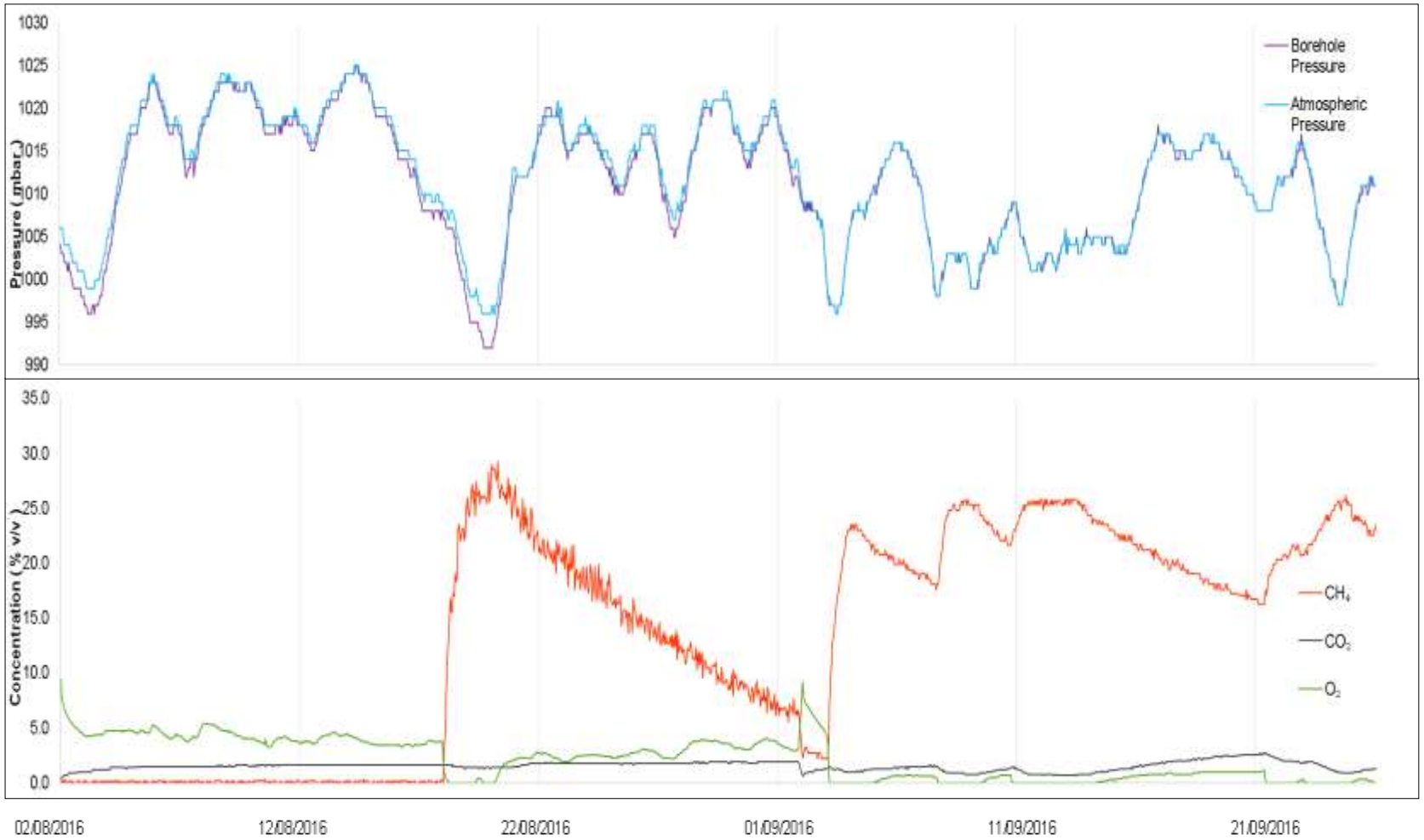
Dissolved gases



Solubilities at STP:

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GGS Gas Sentinel® telemetry

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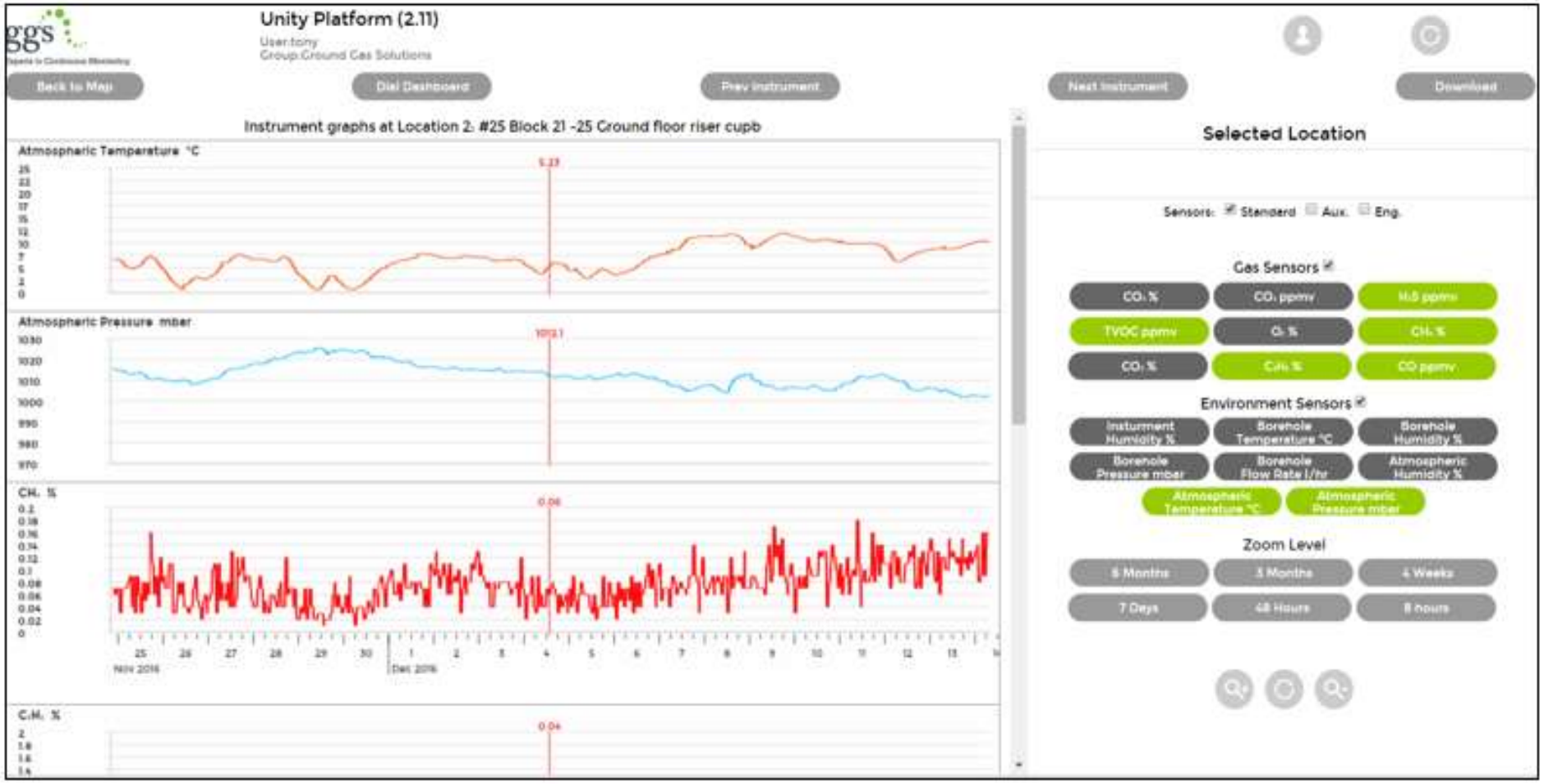
GGS Gas Sentinel®



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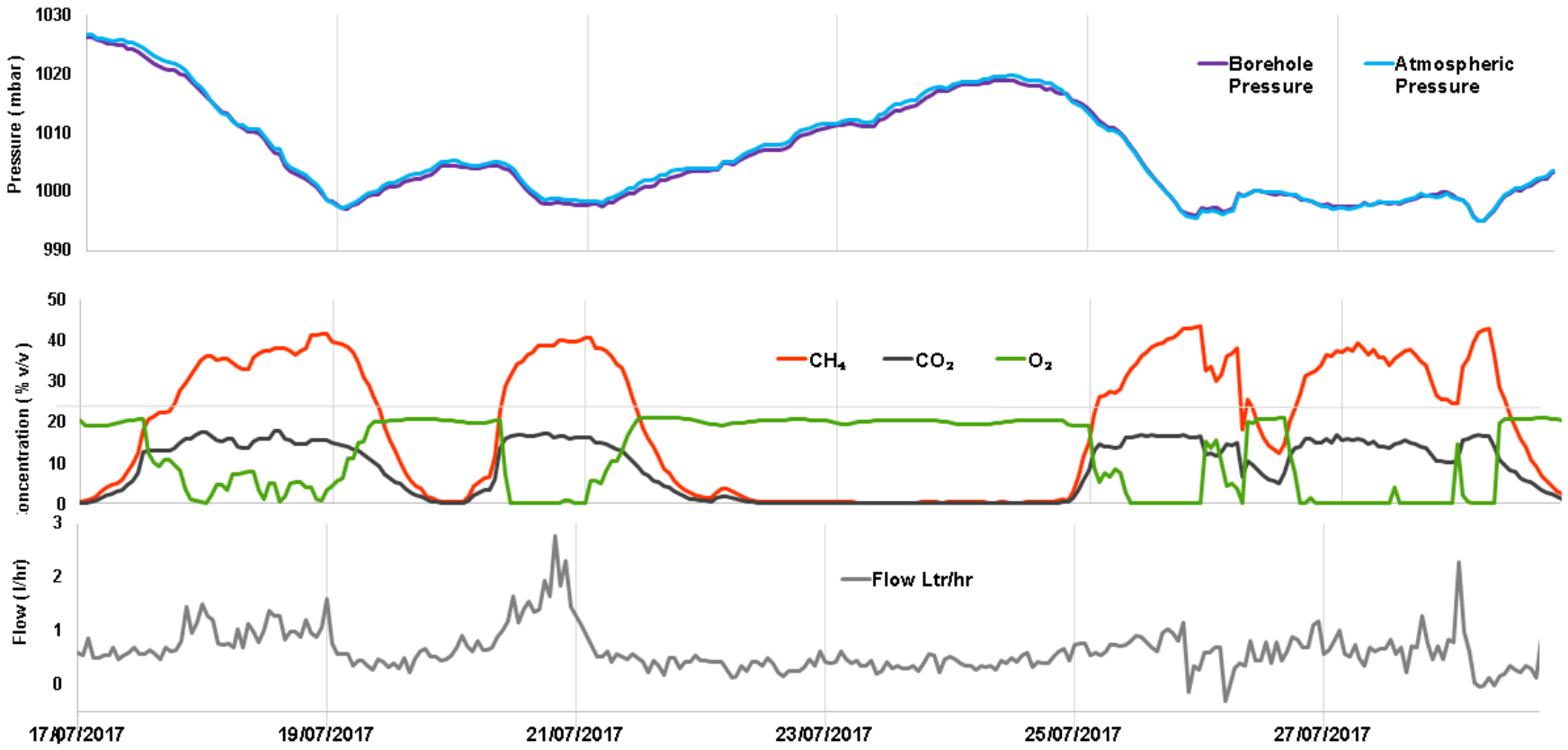
GGS Gas Sentinel®



Continuous Flow

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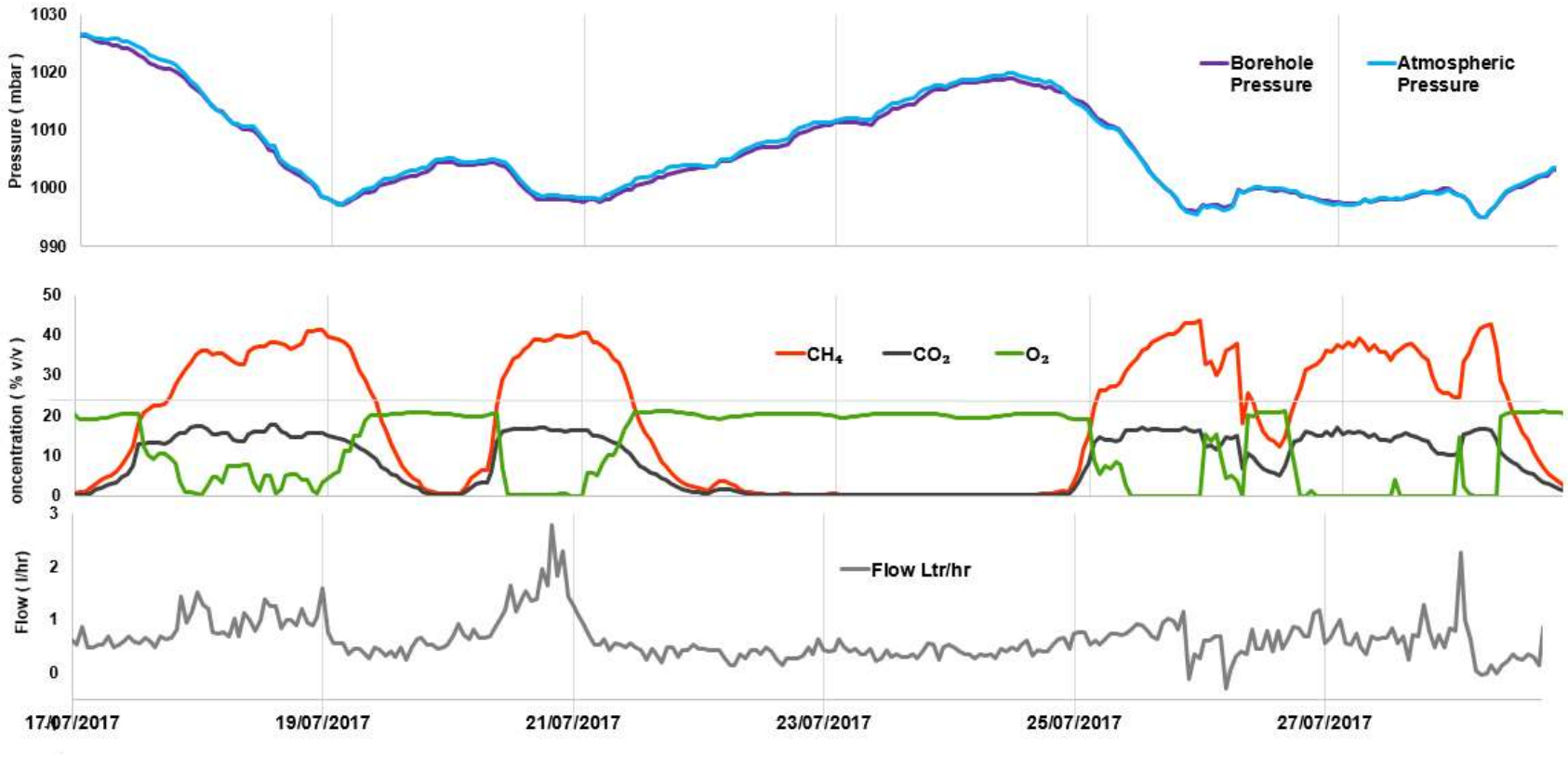
GSV with Continuous Data



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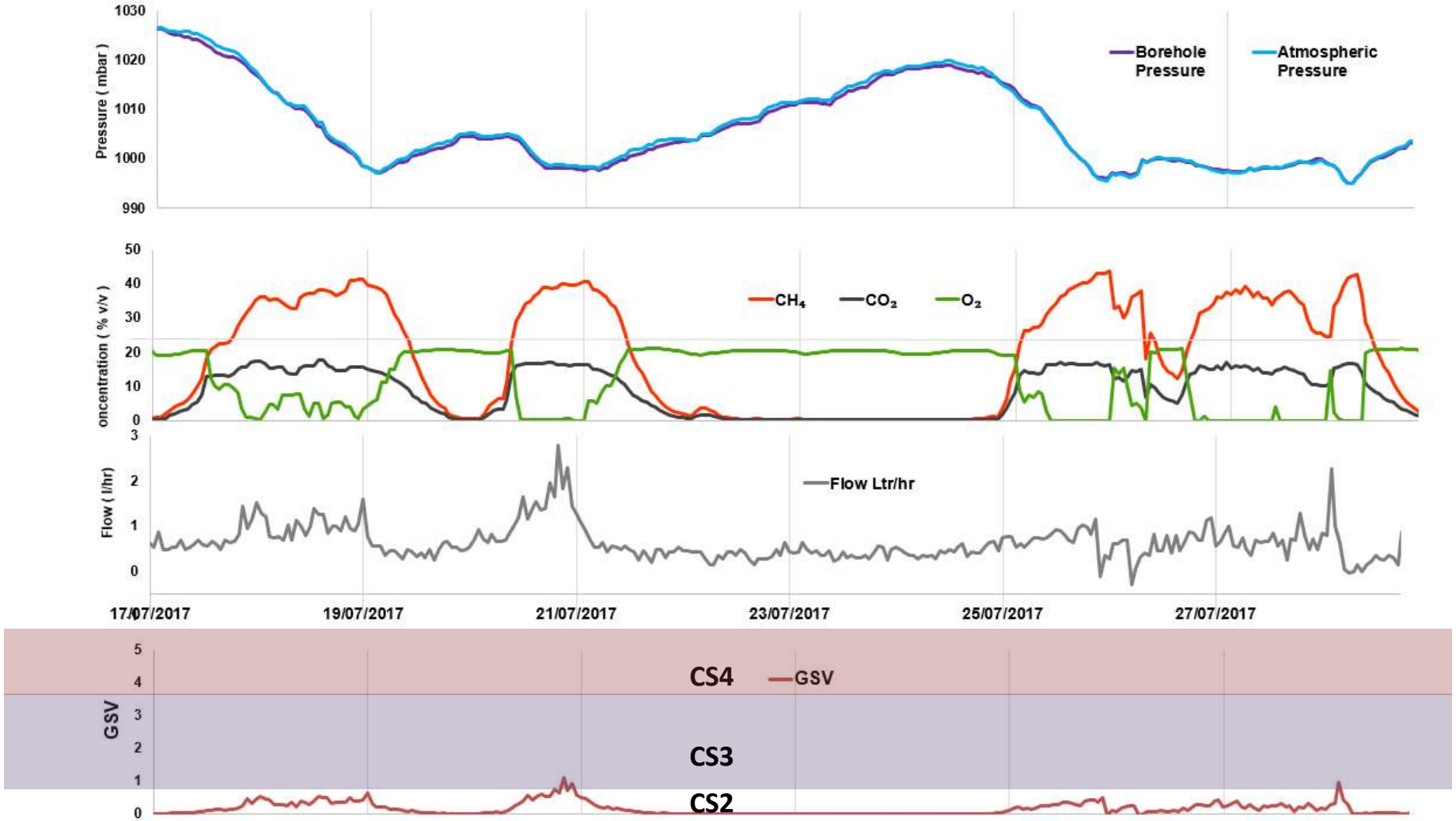

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Atmospheric pressure data from Manchester, UK from 6/9/16 to 20/9/18

138 falls greater than 8 mb

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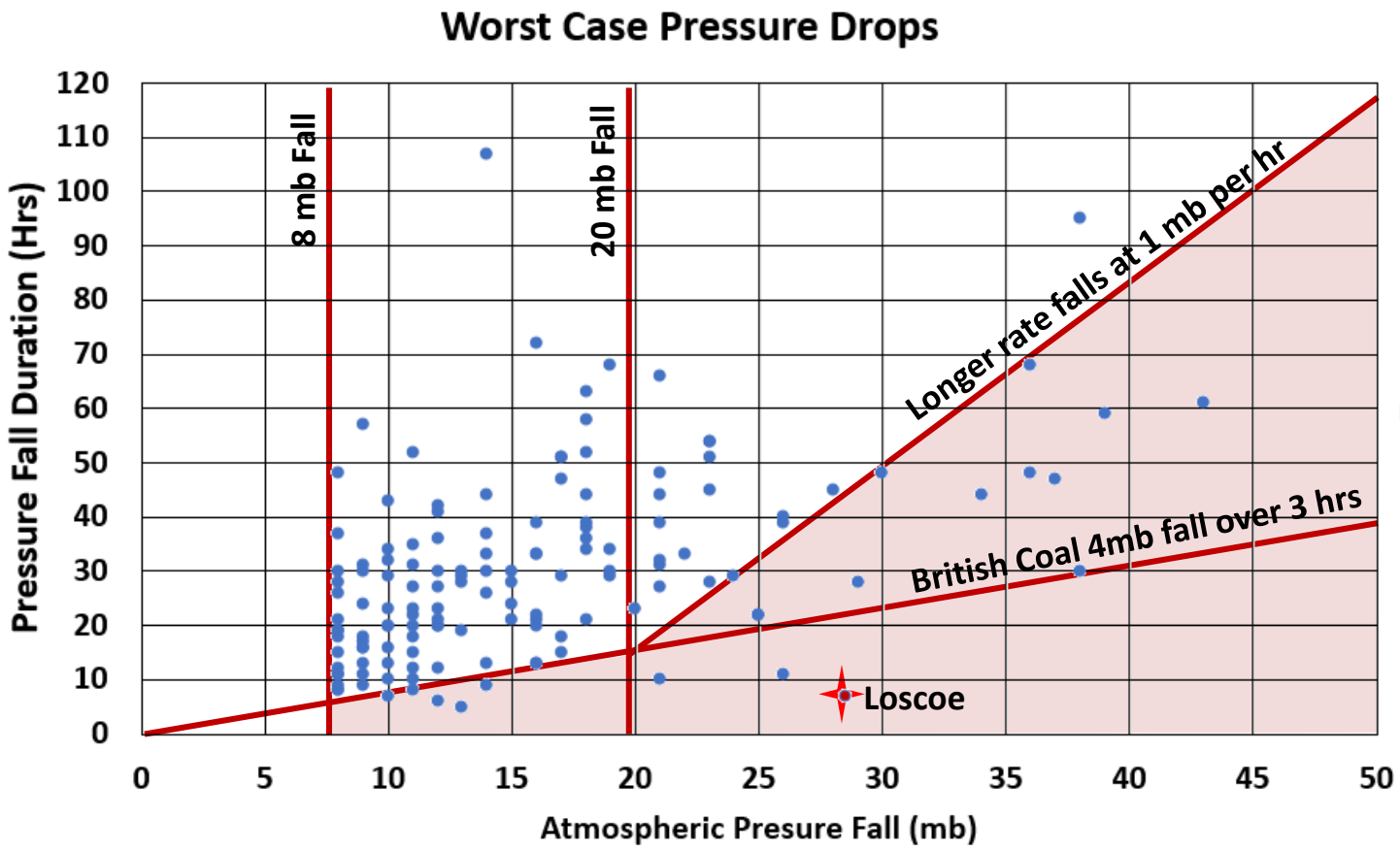

	Pressure Fall (mb)	Time (Hrs)	Rate of Fall (mb/Hrs)
n	138	138	138
Max	43	107	2.60
Min	8	5	0.13
Mean	15.8	30.6	0.64
Median	14	28.5	0.53
St Dev	7.6	17.5	0.40
95th	34.3	61.3	1.28
90th	25.3	52	1.08
80th	21	44	0.82
75th	19	39	0.76

Worst-Case Zone

Top quartile 19 mb fall likely occurs every 3 weeks

A 'significant' worst case pressure drop will usually be captured within a 4 week period (in the UK)

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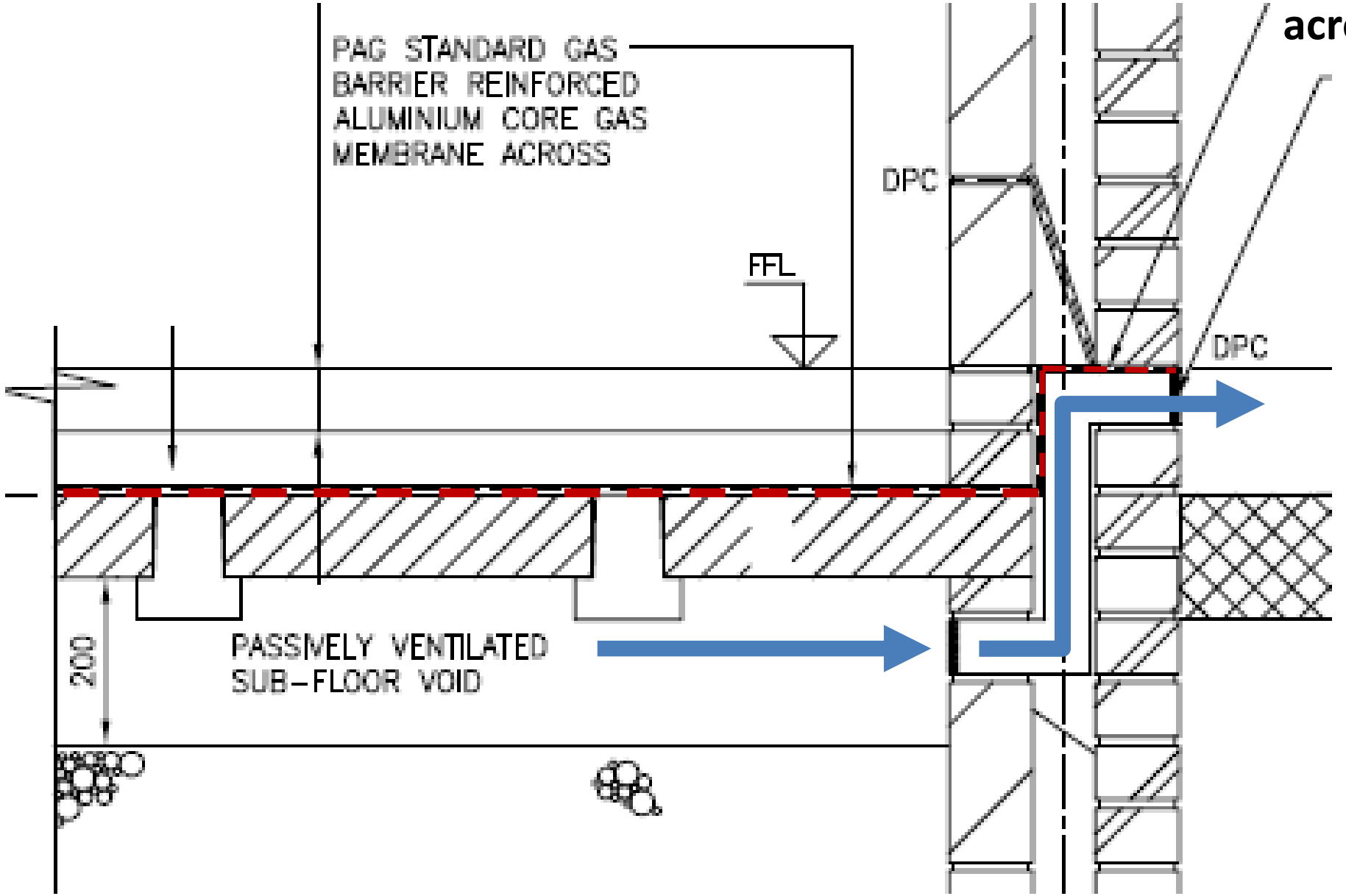
Protection in practice

Membrane continues across cavity



Free air flow through ventilated void (periscope vent)

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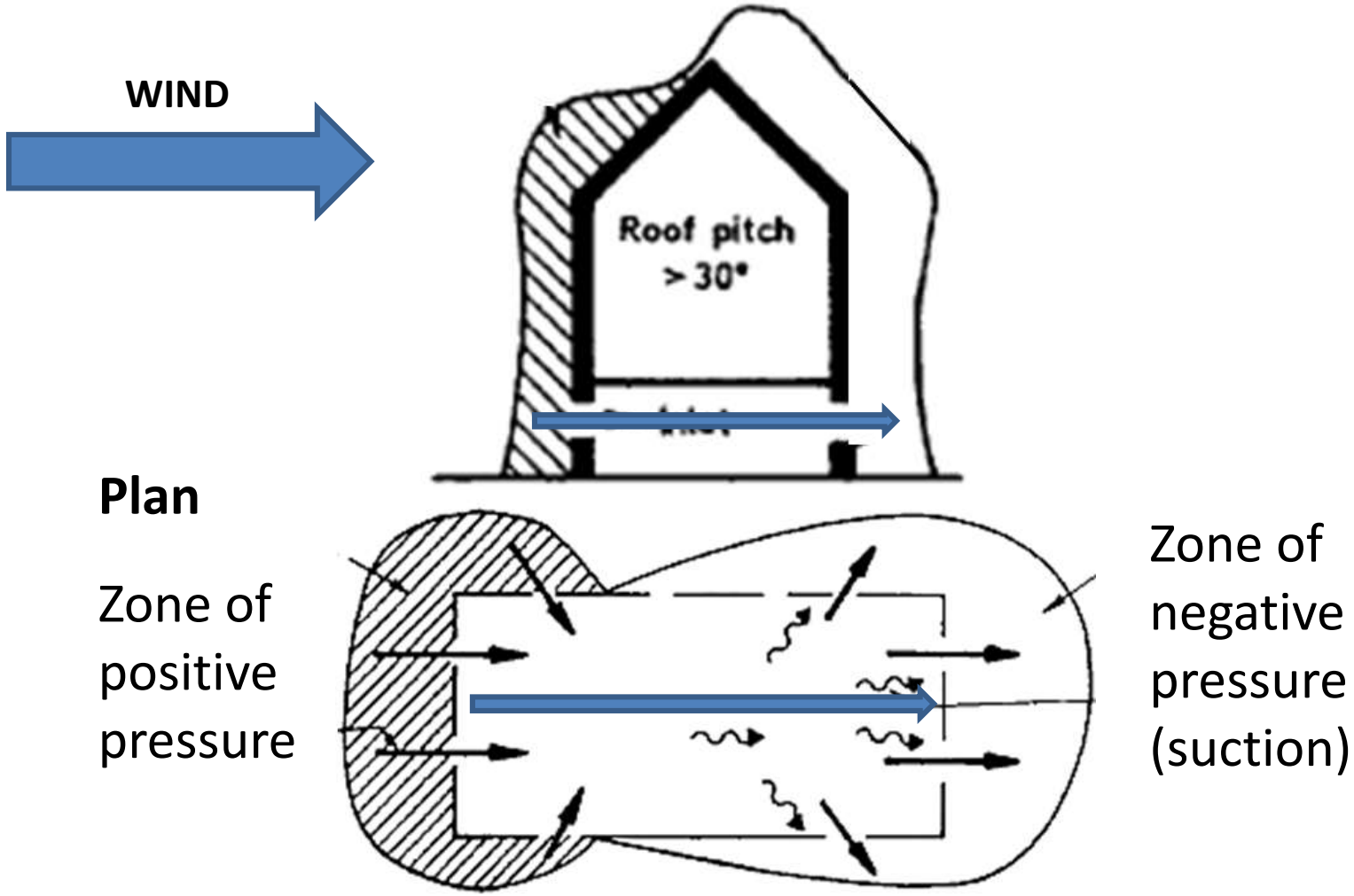
Principle of Passive Dilute and Disperse in Ventilated Void



After CIRIA 149, 1995

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Simple design is best

- **Sub-floor ventilation**
- **Membrane**

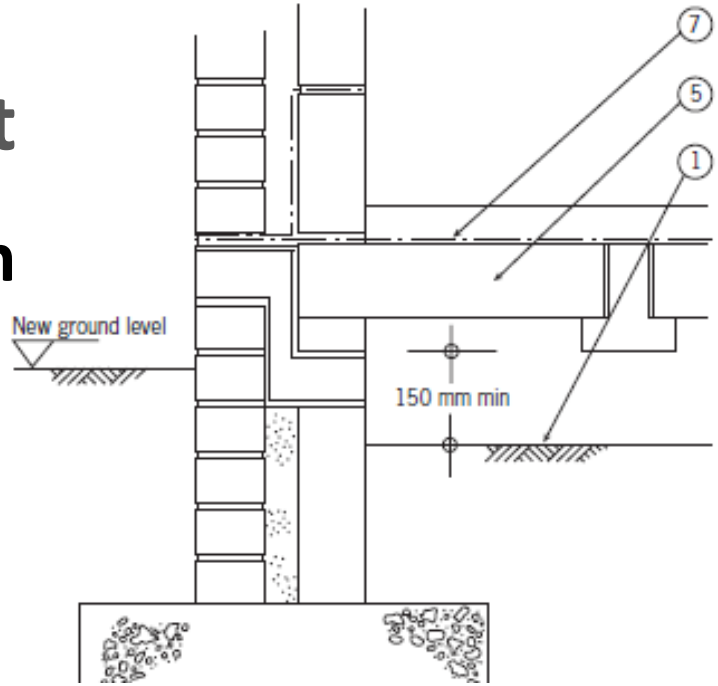

Photo curtesy of PAGeotechnical Ltd

Qualified membrane installation

National Occupational Standards
VR 612 and VR 613

NVQ level 2 qualification in gas membrane installation

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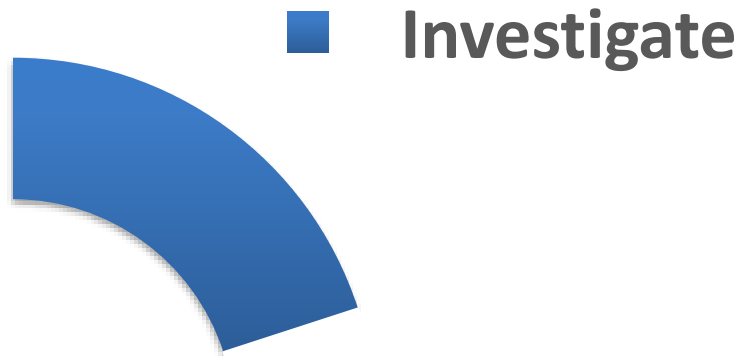
Building Gas Protection



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Building Gas Protection

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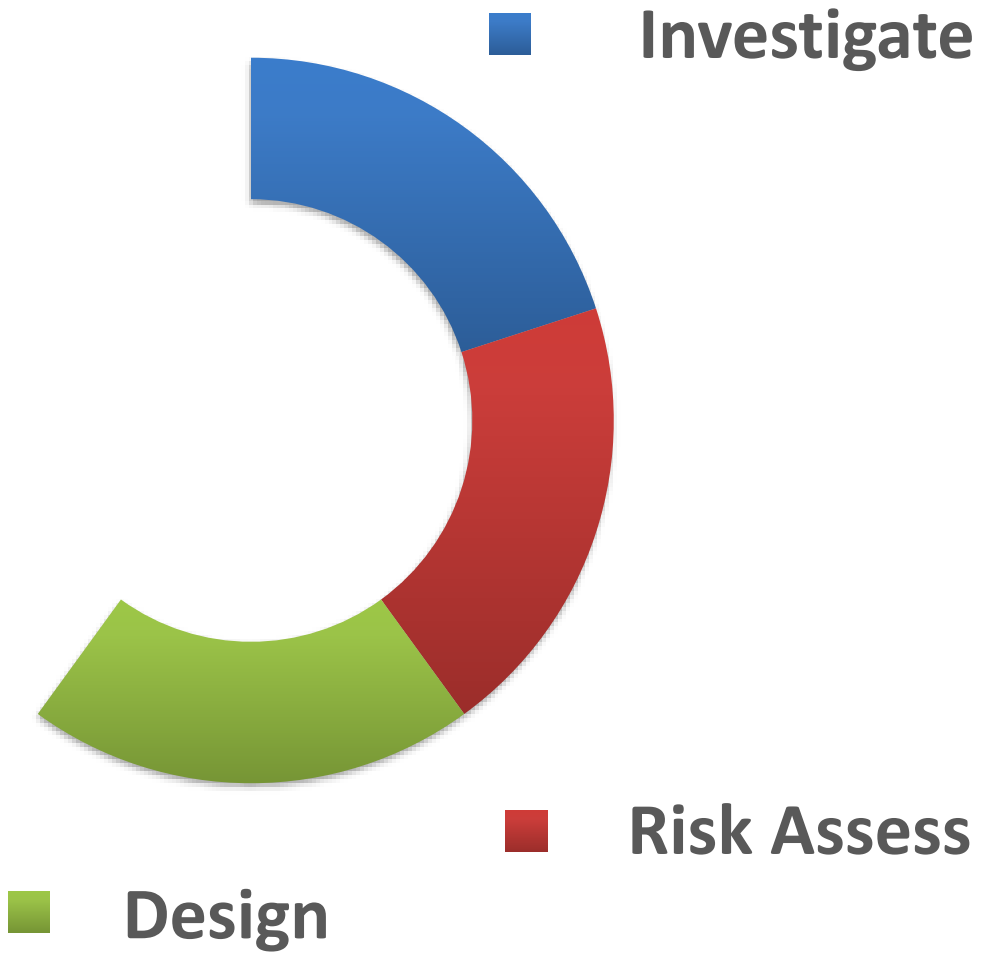

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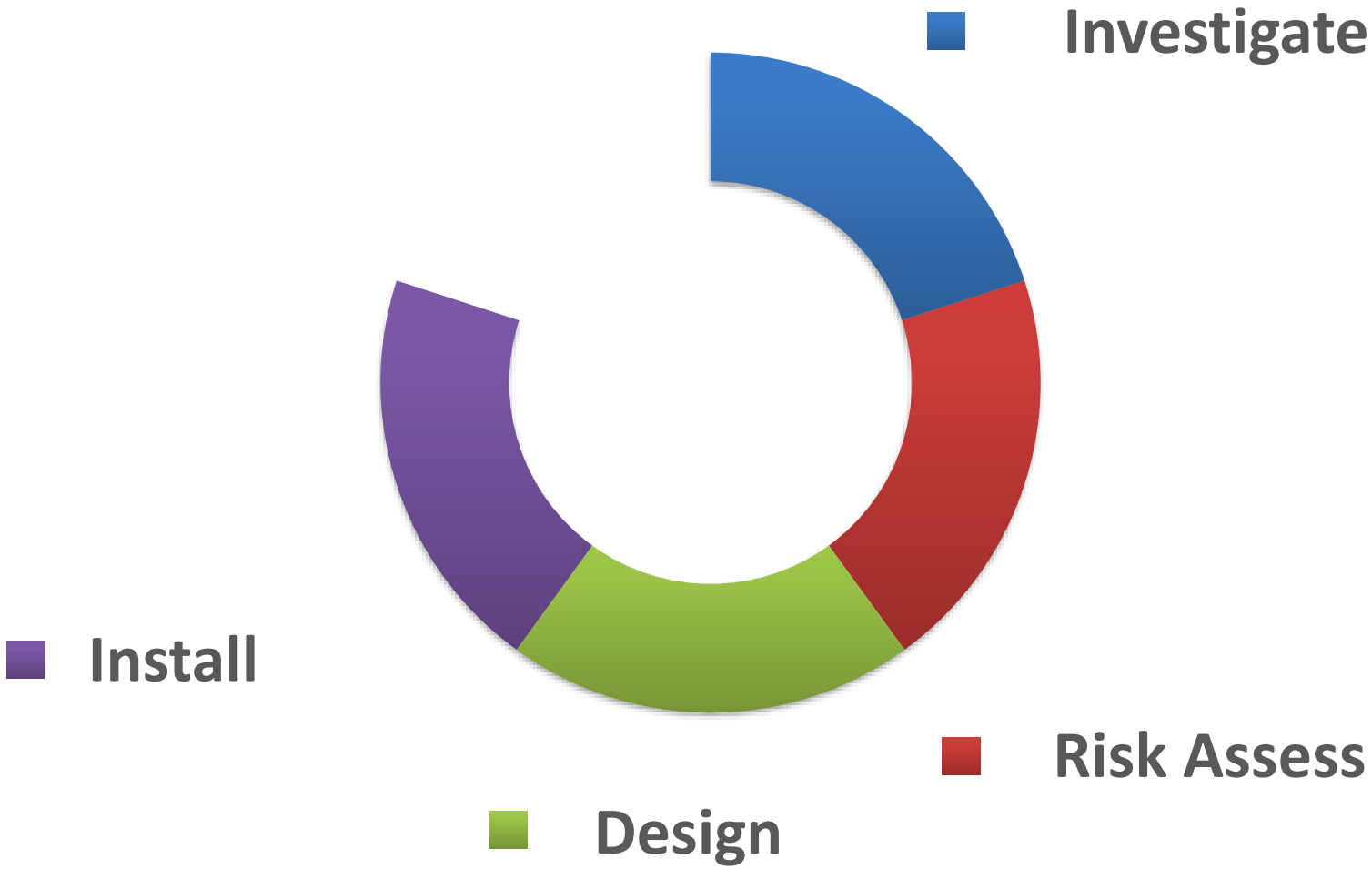

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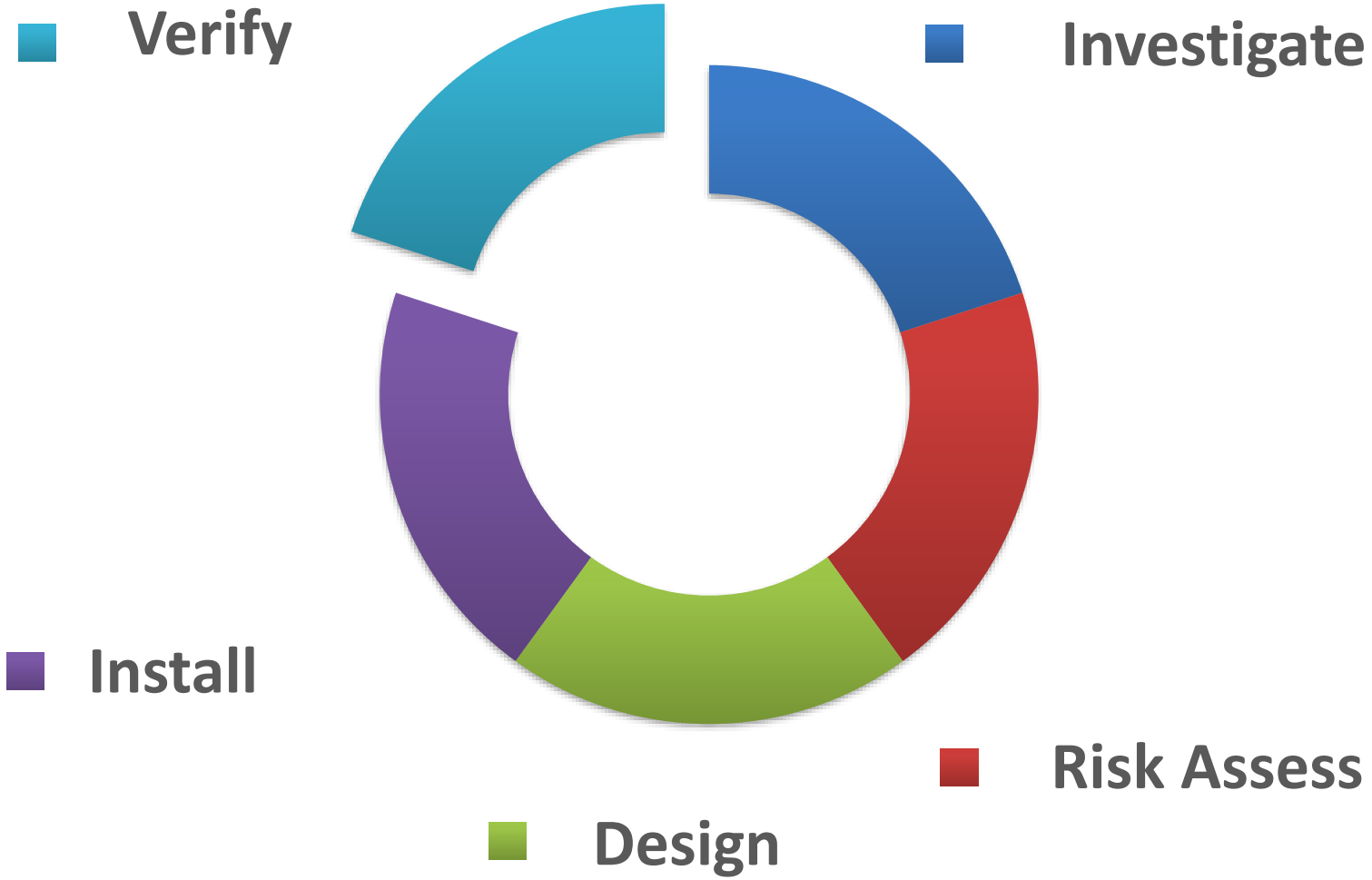

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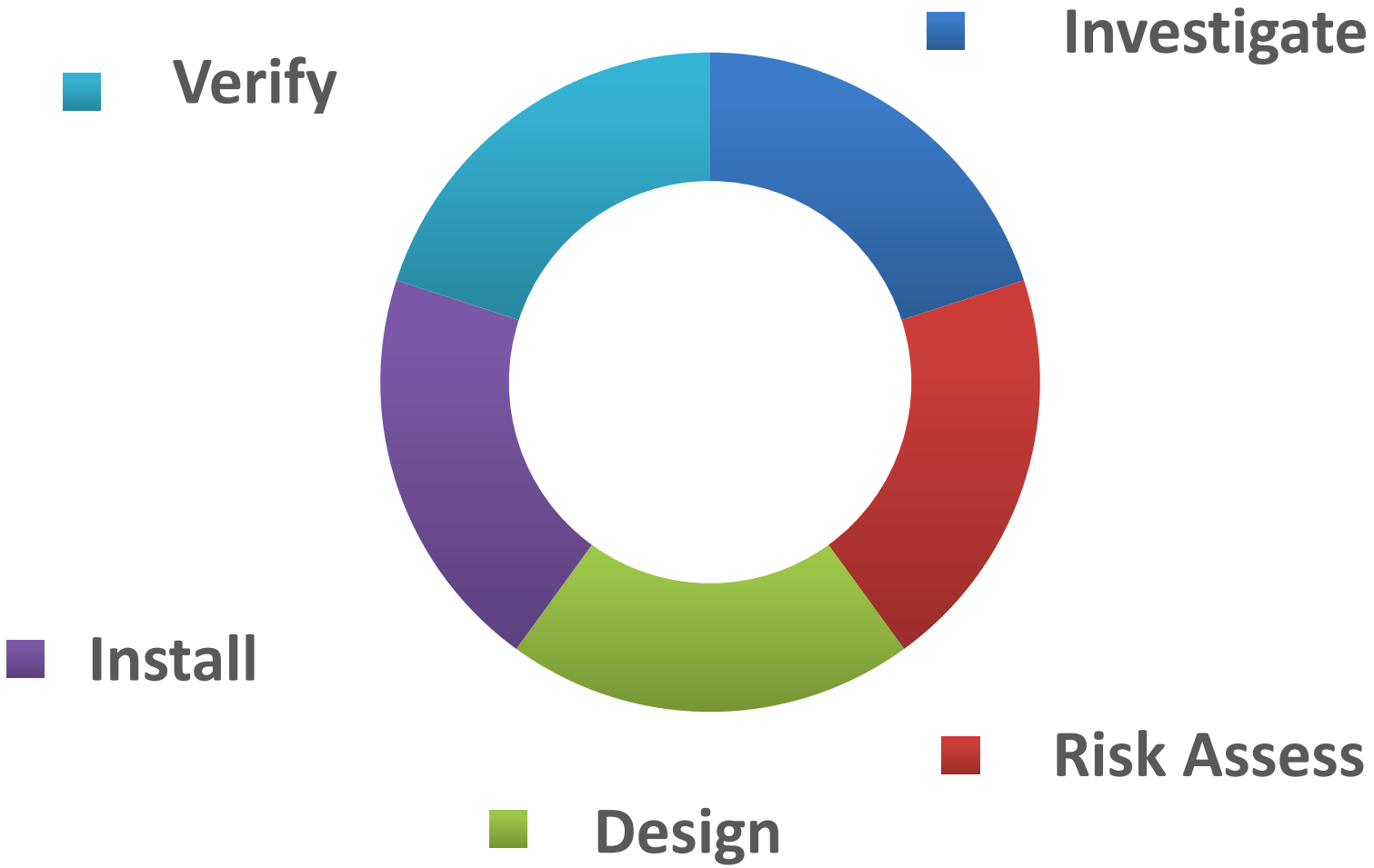

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Building Gas Protection

Investigate

BS8576: 2013

CIRIA - C665

Risk Assess

Design

BS8485 2019 BRE 414 2001

Install

Verify

CIRIA C735 2014

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Unqualified membrane installation

e.g. ground-worker

Photo curtesy of PAGeotechnical Ltd

Membrane not installed across wall cavity

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Ventilation blocked by sleeper wall

Periscope vents not connected to void

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Installation trashed by follow on trades

Photo curtesy of PAGeotechnical Ltd

Service penetrations not sealed

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D. Sub-floor ventilation performance monitoring

Check sub-floor void ventilation (downwind side)

Install sampling line to continuous monitoring device (e.g. Gas Sentinel)

[N.B. Non destructive test]

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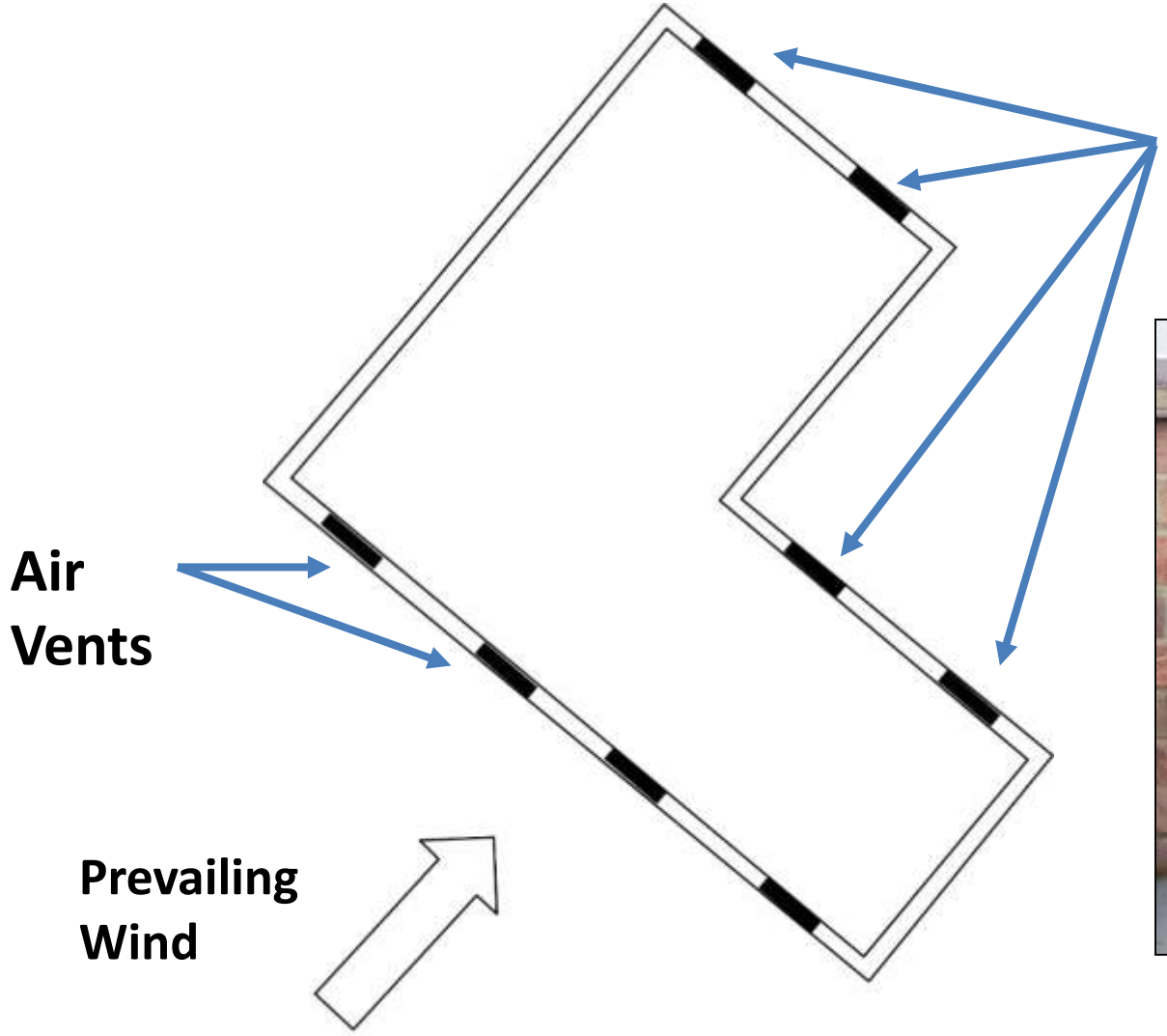
Principle of Sub-floor ventilation performance monitoring



Continuous monitoring on the down-wind side

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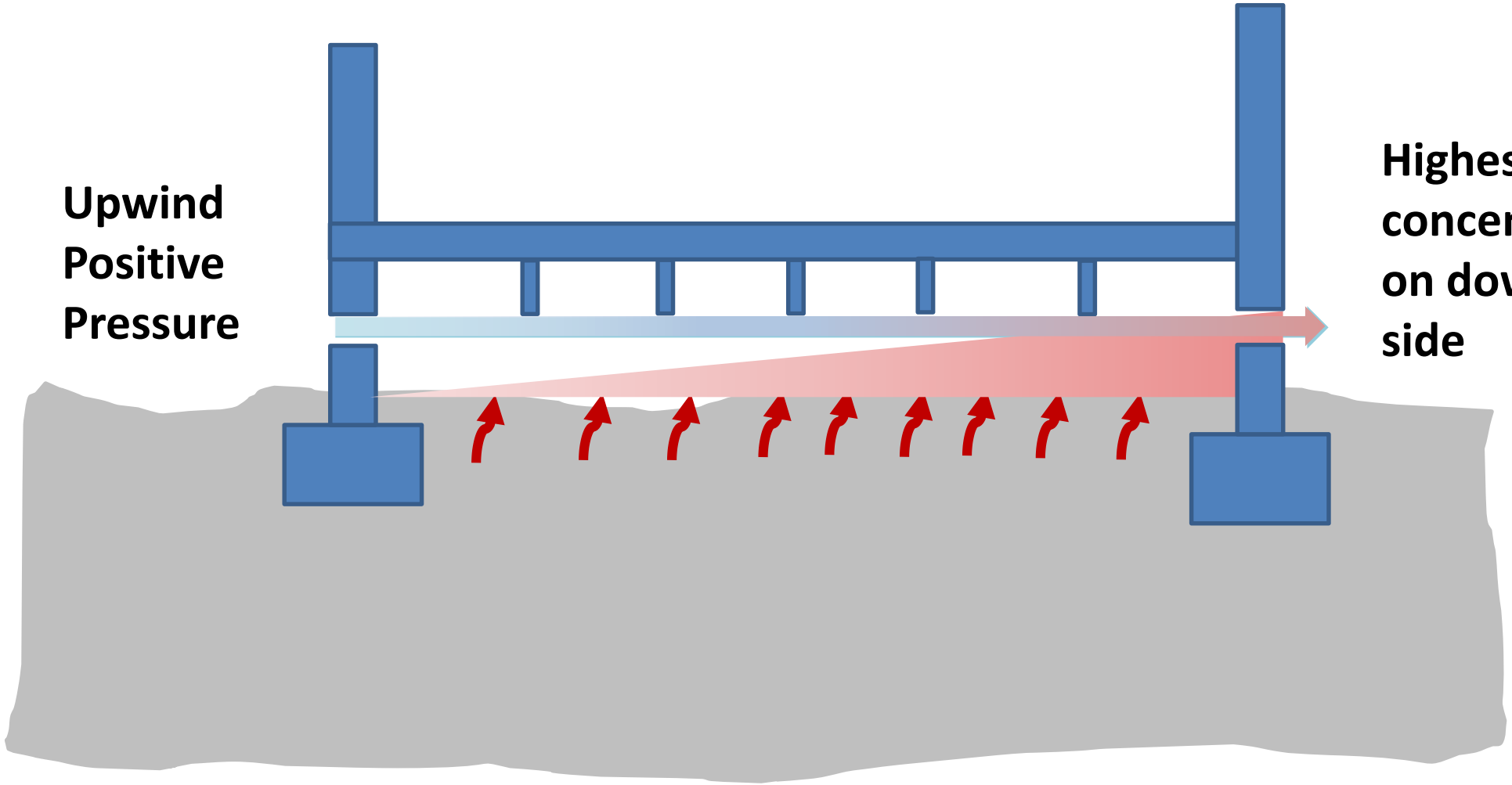

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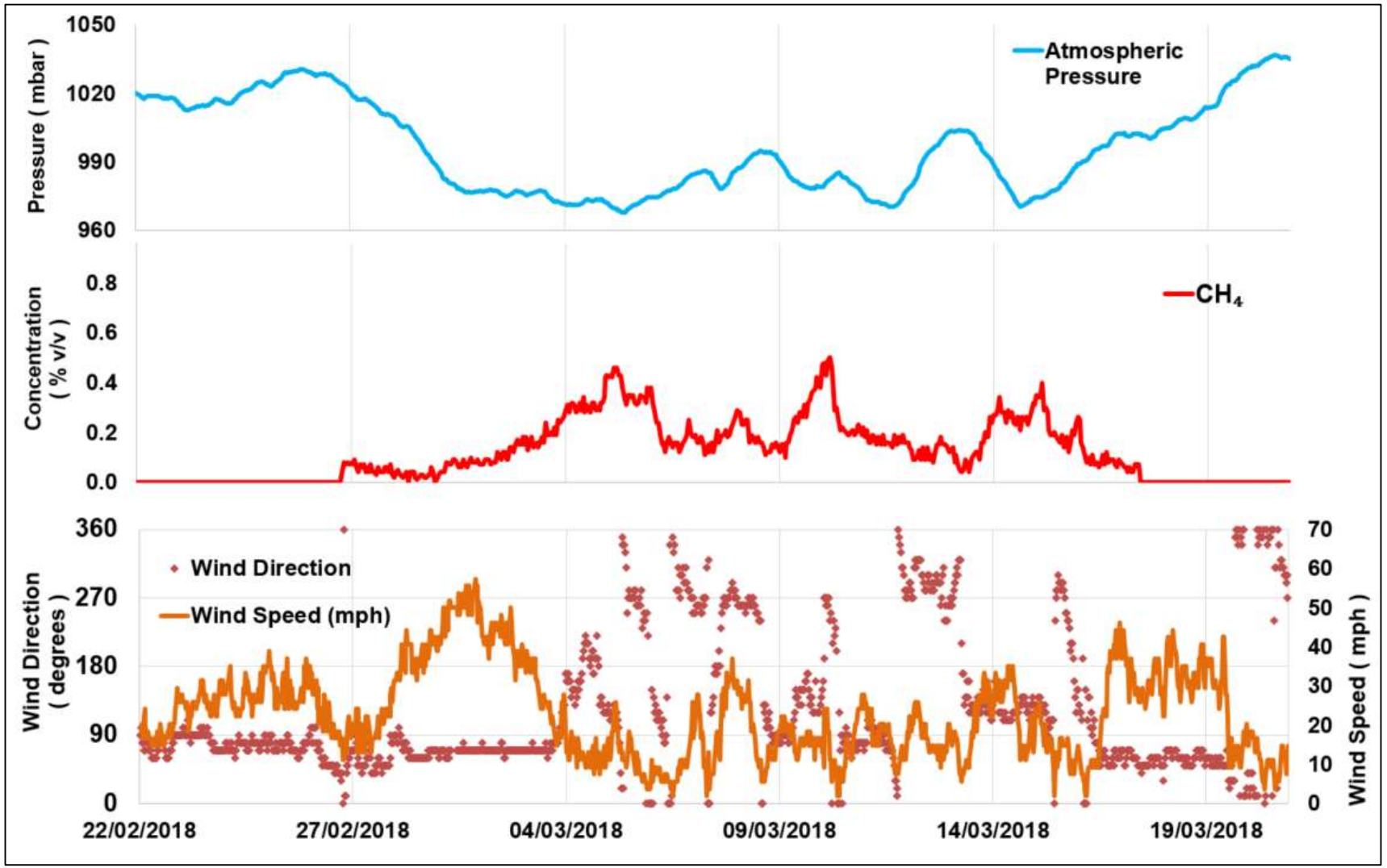
Sub-floor Void Monitoring



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Sept 2013 - Gorebridge

- Tenants in council properties overcome by gas and taken to hospital
- Houses evacuated

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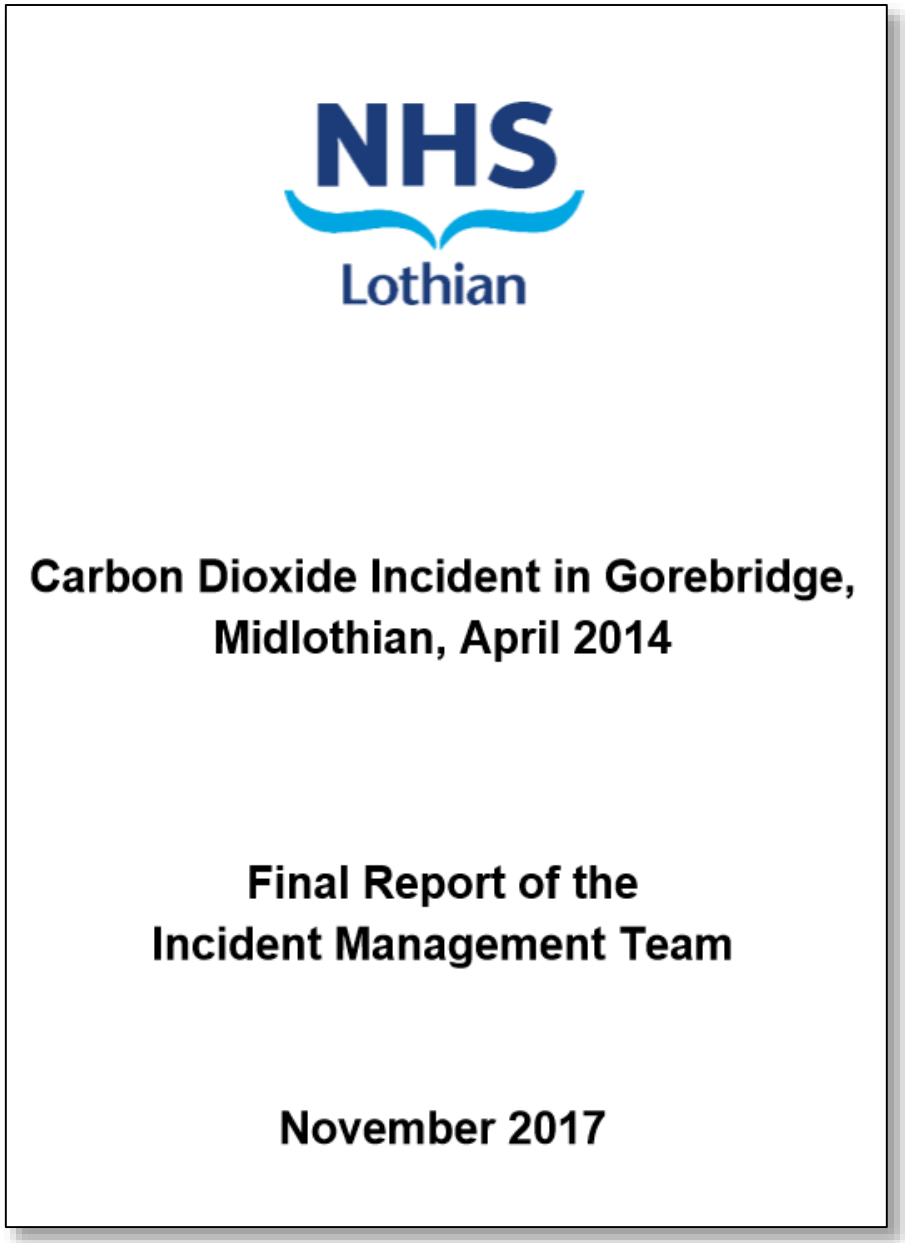

Chronology

- 2006 Desk Study identifies possible mines gas
- 2006 SI & Risk Assessment doesn't find ground-gas
- Consultants conclude 'low ground-gas risk' – no gas protection measures required
- 2009 sixty four homes built
- Sept 2013 first residents taken to A&E
- April 2014 IMT set up
- by Sept 2014, 22 people had attended A&E or local GP

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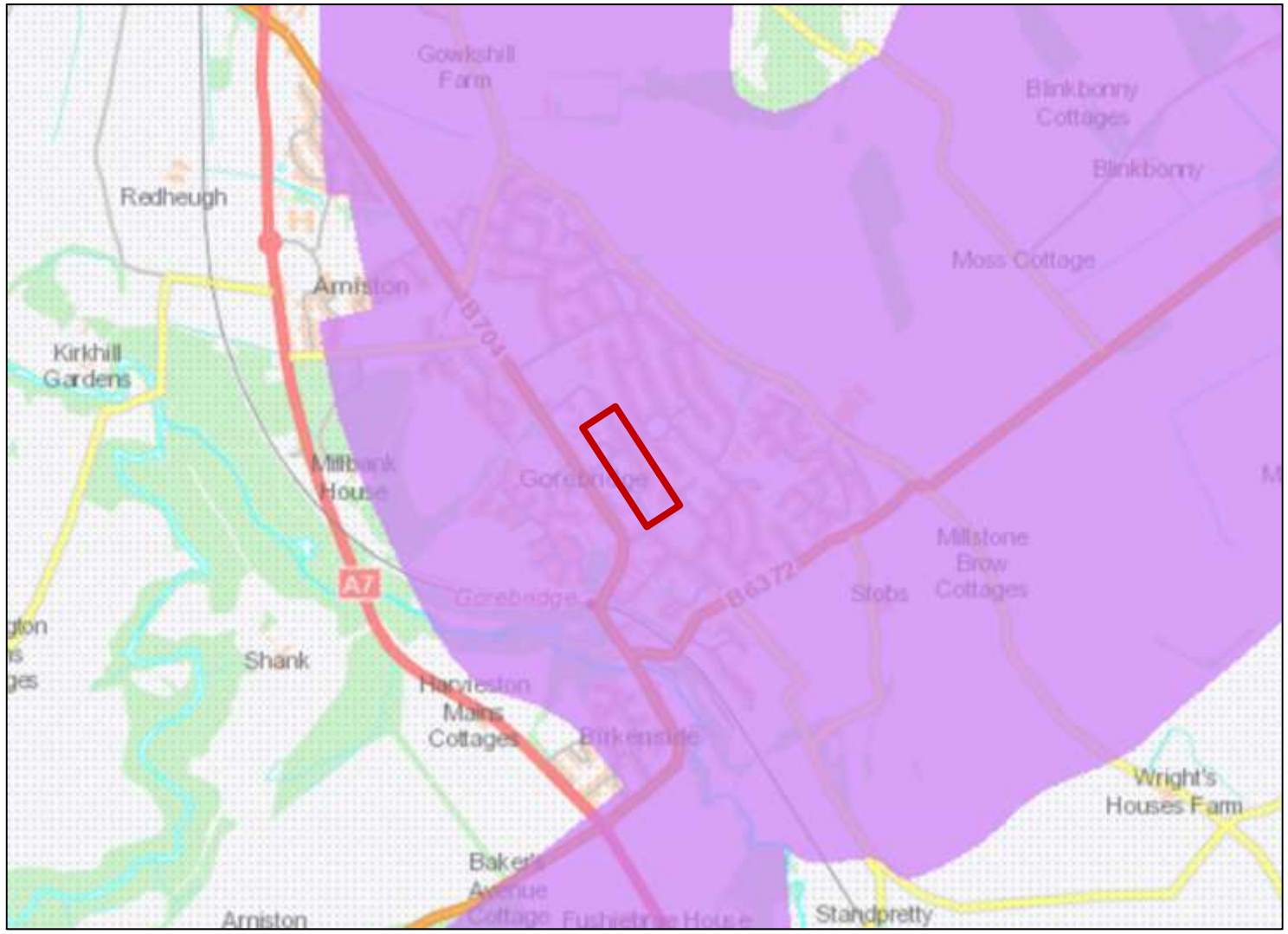
Gorebridge – Coal mining in the area



The Coal Authority

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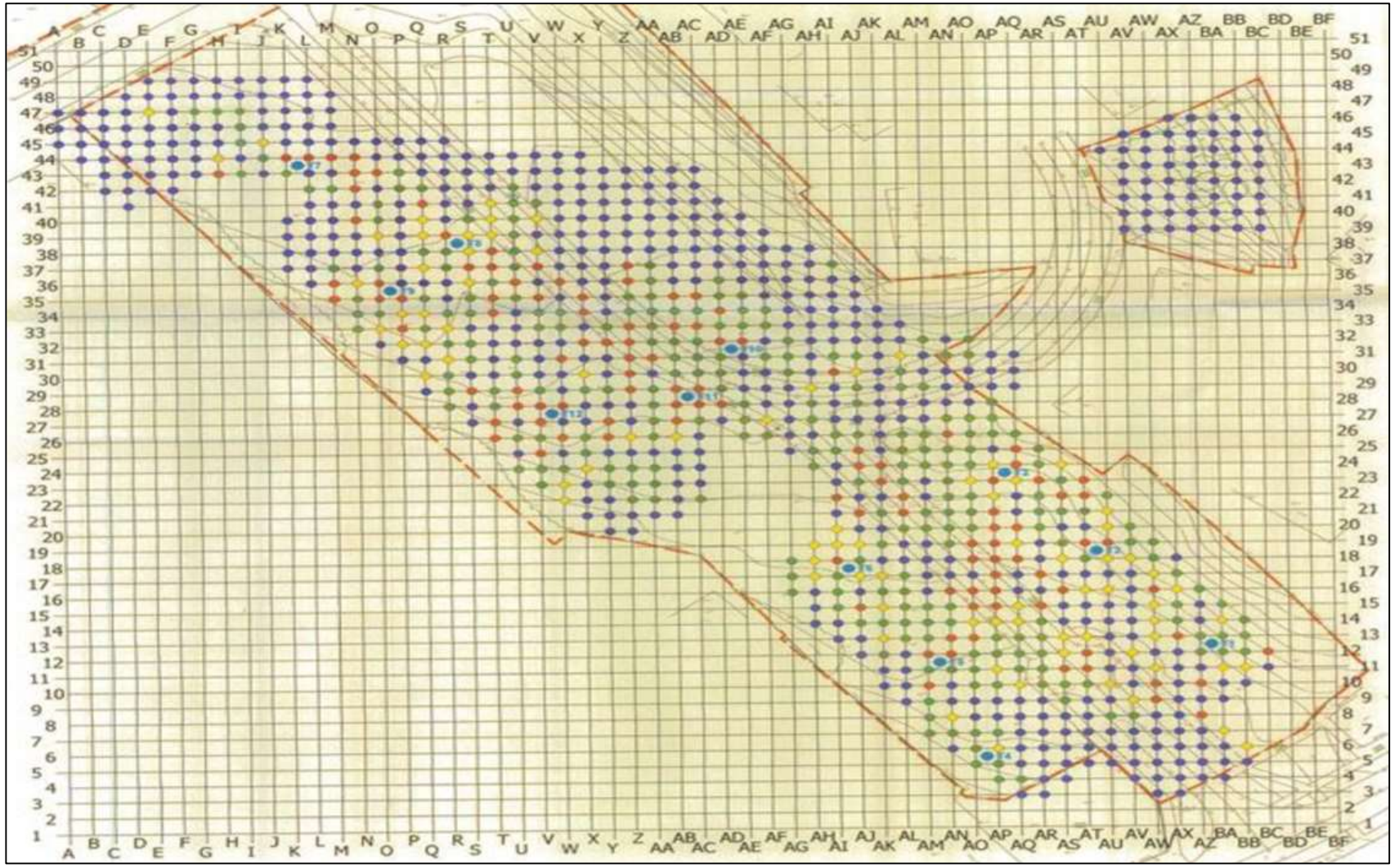
Coal Working Drilling & Grouting Stabilisation



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2013/14 Coal Authority Investigations

87 Newbyres Crescent found to have:

- **8%** $C0_2$ in downstairs toilet
- **12%** $C0_2$ in Lounge (where son had been sleeping)
- **19%** CO_2 beneath kitchen flooring
- **21%** CO_2 measured in hole drilled through raft
- **23%** CO_2 in wall cavity

Borehole drilled to the shallowest coal seam at 13m bgl:

- **25.1 %** CO_2 & **4.6%** O_2
- **No grout was found in the coal seam**

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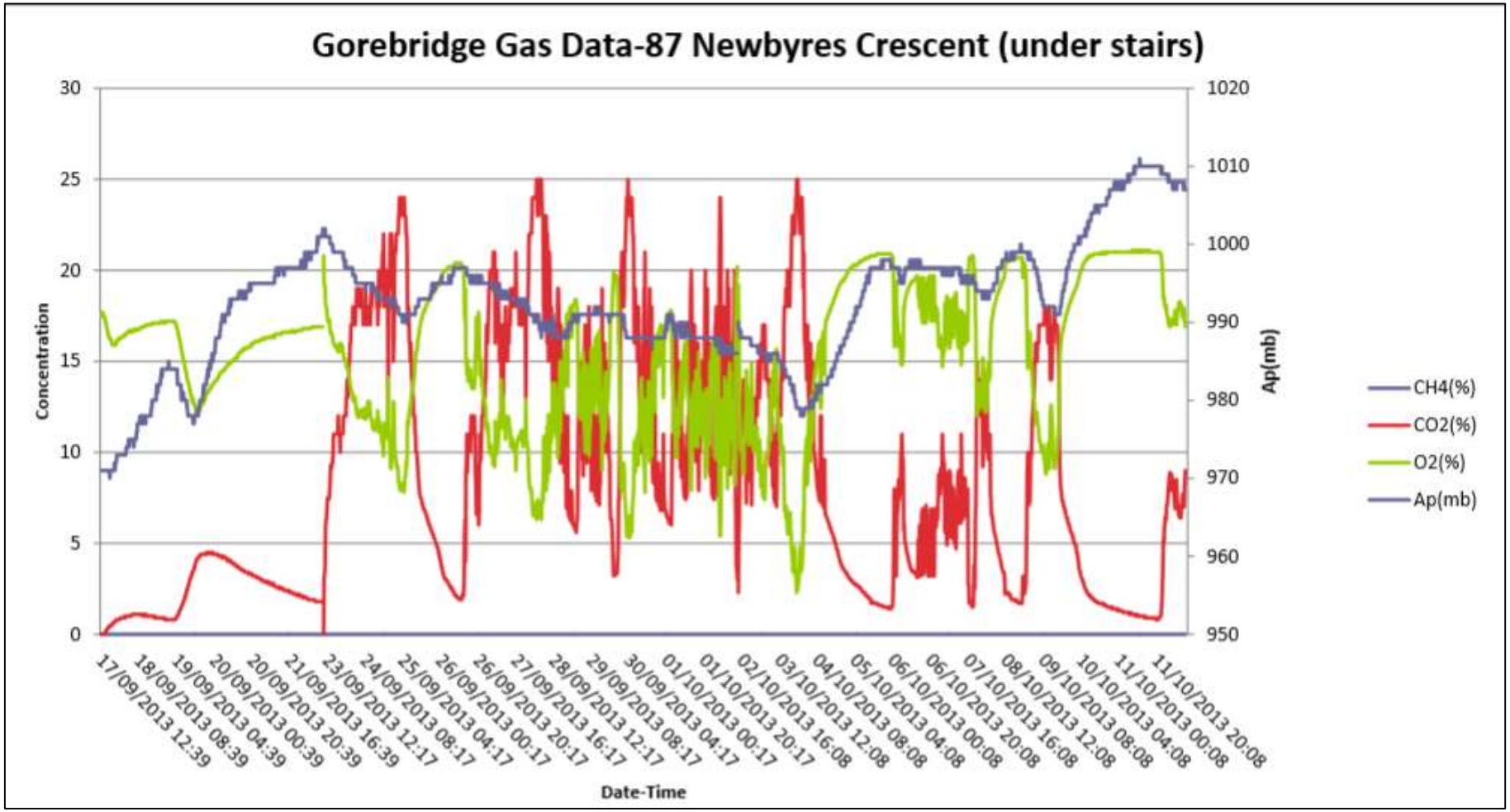
Continuous gas monitoring



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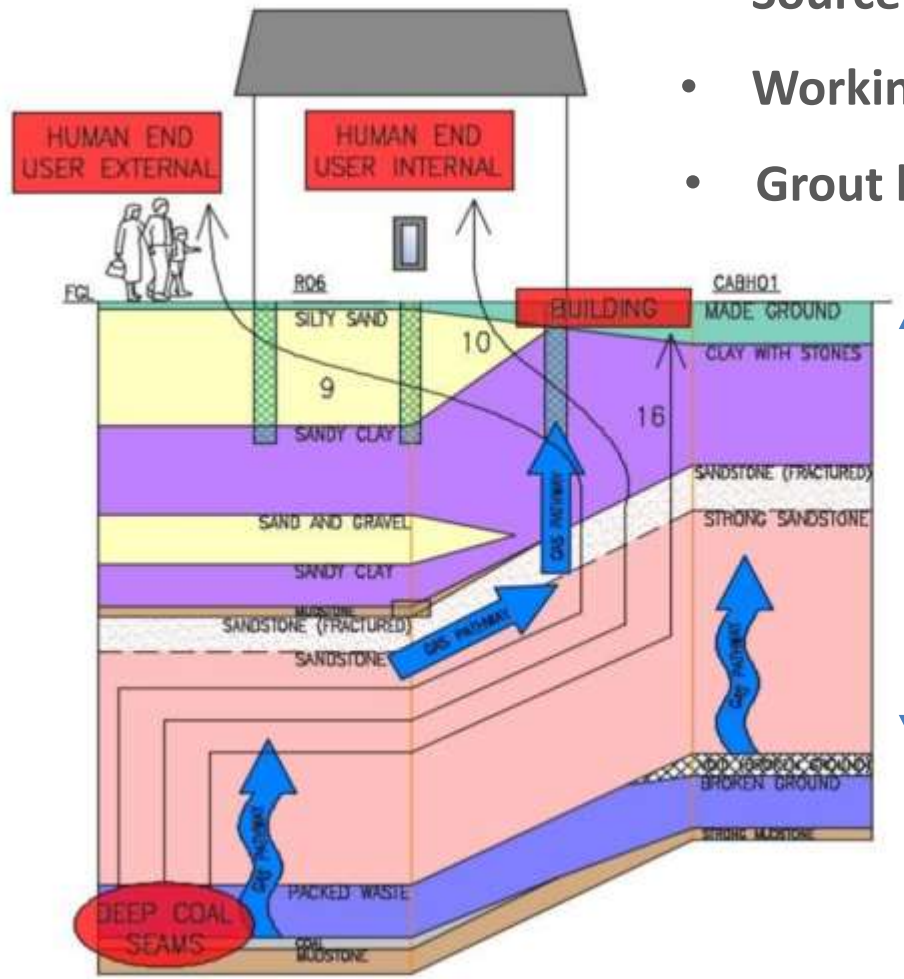
2017 IMT Report Conclusions



(IMT Report – from Fairhurst)

- Source confirmed as worked coal seam
- Workings not fully grouted
- Grout holes beneath houses possibly not sealed

3-4m

- SI boreholes beneath houses possible not sealed
- Vibro stone column foundations

c13m

- Service entries through raft not sealed
- No gas protection measures installed

- Highest CO2 associated with falling atmospheric pressure

"Was this was an entirely preventable incident?"

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Presentation Content

1. The ground-gas hazard
2. Key properties of ground-gases
3. Spot monitoring and continuous monitoring
4. Additional lines of evidence and interpreting flow data
5. Continuous monitoring for validation
6. Gorebridge case study
7. Summary

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Convincing clients to use continuous monitoring

Time savings:

- CS3 site – monitoring period reduced from 3 months to 3 weeks
- CS5 site monitoring period reduced from 12 months to 3 months

Avoid demolition and rebuild costs:

- Sub-floor monitoring sometimes only option

Avoid litigation

- Don’t do a Gorebridge

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GGS Gas Sentinel®

Features
Continuous concentrations
Continuous environmental
Extended battery life
Telemetry
Continuous flow
Expert support
Secure installation

Only British designed and made continuous in-borehole device

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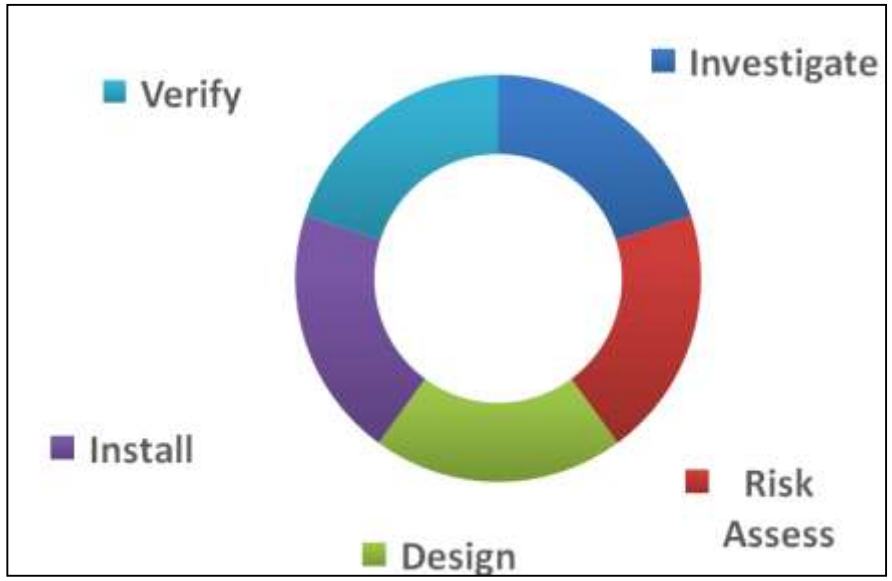
In Summary



- All the elements of ground gas protection are important
- Continuous monitoring has come of age
- Better quality monitoring data informs less conservative risk assessments and more cost effective solutions

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2nd Generation
In-borehole device
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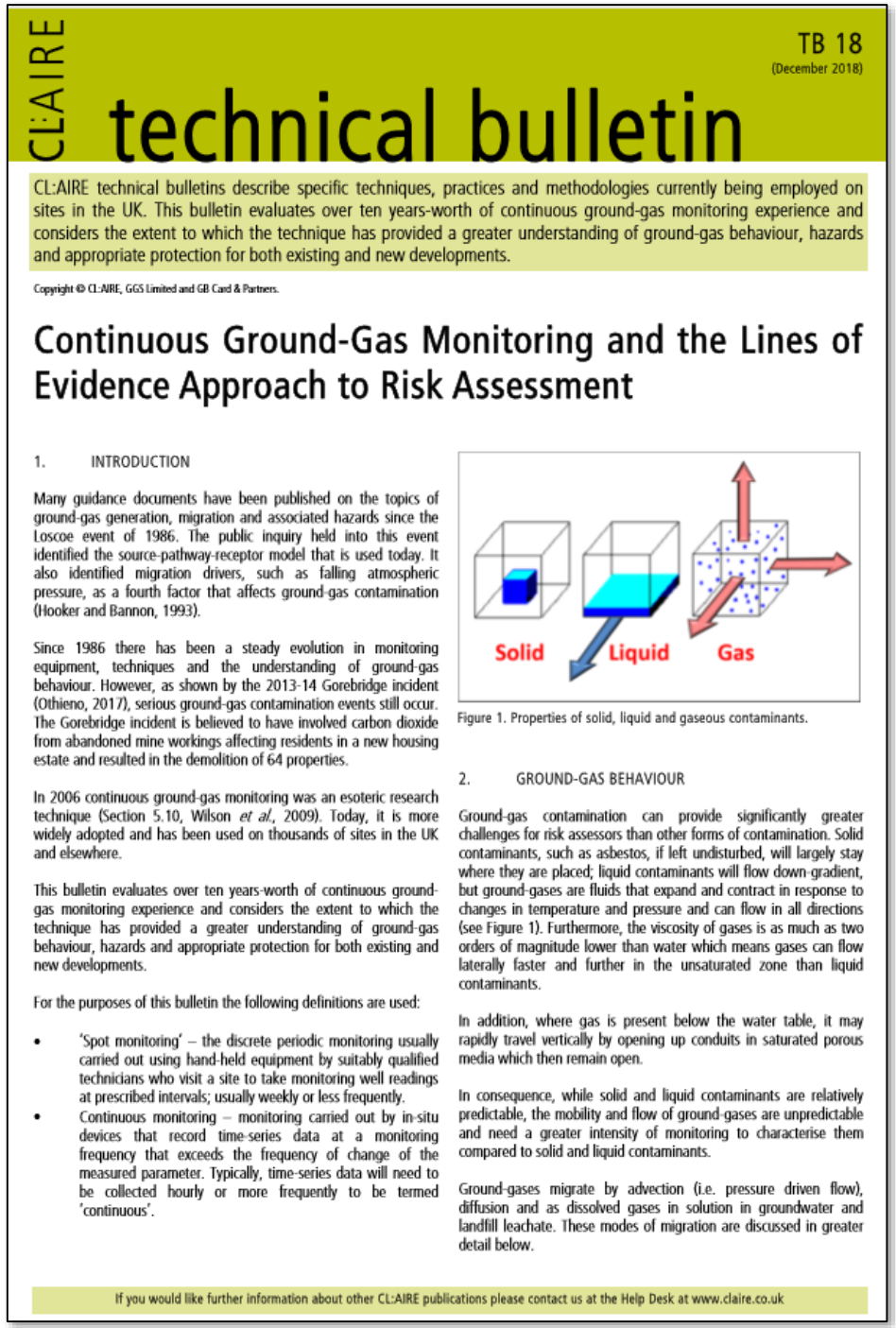

CL:AIRE

TB 18
(December 2018)

technical bulletin

CL:AIRE technical bulletins describe specific techniques, practices and methodologies currently being employed on sites in the UK. This bulletin evaluates over ten years-worth of continuous ground-gas monitoring experience and considers the extent to which the technique has provided a greater understanding of ground-gas behaviour, hazards and appropriate protection for both existing and new developments.

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Continuous Ground-Gas Monitoring and the Lines of Evidence Approach to Risk Assessment

1. INTRODUCTION

Many guidance documents have been published on the topics of ground-gas generation, migration and associated hazards since the Loscoe event of 1986. The public inquiry held into this event identified the source-pathway-receptor model that is used today. It also identified migration drivers, such as falling atmospheric pressure, as a fourth factor that affects ground-gas contamination (Hooker and Bannon, 1993).

Since 1986 there has been a steady evolution in monitoring equipment, techniques and the understanding of ground-gas behaviour. However, as shown by the 2013-14 Gorebridge incident (Othieno, 2017), serious ground-gas contamination events still occur. The Gorebridge incident is believed to have involved carbon dioxide from abandoned mine workings affecting residents in a new housing estate and resulted in the demolition of 64 properties.

In 2006 continuous ground-gas monitoring was an esoteric research technique (Section 5.10, Wilson *et al*, 2009). Today, it is more widely adopted and has been used on thousands of sites in the UK and elsewhere.

This bulletin evaluates over ten years-worth of continuous ground-gas monitoring experience and considers the extent to which the technique has provided a greater understanding of ground-gas behaviour, hazards and appropriate protection for both existing and new developments.

For the purposes of this bulletin the following definitions are used:

- 'Spot monitoring' – the discrete periodic monitoring usually carried out using hand-held equipment by suitably qualified technicians who visit a site to take monitoring well readings at prescribed intervals; usually weekly or less frequently.
- Continuous monitoring – monitoring carried out by in-situ devices that record time-series data at a monitoring frequency that exceeds the frequency of change of the measured parameter. Typically, time-series data will need to be collected hourly or more frequently to be termed 'continuous'.

Figure 1. Properties of solid, liquid and gaseous contaminants.

2. GROUND-GAS BEHAVIOUR

Ground-gas contamination can provide significantly greater challenges for risk assessors than other forms of contamination. Solid contaminants, such as asbestos, if left undisturbed, will largely stay where they are placed; liquid contaminants will flow down-gradient, but ground-gases are fluids that expand and contract in response to changes in temperature and pressure and can flow in all directions (see Figure 1). Furthermore, the viscosity of gases is as much as two orders of magnitude lower than water which means gases can flow laterally faster and further in the unsaturated zone than liquid contaminants.

In addition, where gas is present below the water table, it may rapidly travel vertically by opening up conduits in saturated porous media which then remain open.

In consequence, while solid and liquid contaminants are relatively predictable, the mobility and flow of ground-gases are unpredictable and need a greater intensity of monitoring to characterise them compared to solid and liquid contaminants.

Ground-gases migrate by advection (i.e. pressure driven flow), diffusion and as dissolved gases in solution in groundwater and landfill leachate. These modes of migration are discussed in greater detail below.

- **Based on 12 yrs experience**
- **Highlights include:**
  - Ground-gas behaviour
  - Best practice in continuous monitoring
  - Additional lines of evidence
  - Continuous flow monitoring
  - Dissolved and free gas interactions
  - Risk assessment using continuous data

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Thank you

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