Research and Development in Sanitation Worldwide

without data it is just an opinion …

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UNIVERSITY OF KWAZULU-NATAL

BORDA

ETHEKWINI MUNICIPALITY

WATER RESEARCH COMMISSION

Ten Most Important Reasons for Sanitation

- Public Health
- Public Health
- Public Health
- Public Health
- Public Health
- Public Health
- Public Health
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- Public Health
- Public Health

Excreta Facts and Figures

	Units	Urine	Faeces	Toilet paper	Black water (urine + faeces)
wet mass	kg/person.y	550	51	8.9	**610**
dry mass	kg/person.y	21	11	8.5	**40**
nitrogen	kg/person.y	4	0.55		**4.5**
phosphorus	kg/person.y	0.36	0.18		**0.55**

Vinnerås et al. 2006

most pathogens are in the faeces
most nutrients are in the urine

Excreta Plus Flush Water

	Units	Black water (urine + faeces)	Black water + Flush water
wet mass	kg/person.y	**610** →	**18,000**
dry mass	kg/person.y	40	**40**
nitrogen	kg/person.y	4.5	**4.5**
phosphorus	kg/person.y	0.5	**0.5**

all pathogens are in the water!

Excreta Characteristics

Key design criteria	Median value
Faeces	
Faecal wet weight (g/cap/day)	128
Faecal dry weight (g/cap/day)	29
Stool Frequency (motions/24 hours)	1.1
Total Solids (%)	25
VS (% of TS)	89
COD (g/cap/day)	71
Nitrogen (g/cap/day)	1.8
Protein (g/cap/day)	6.3
Lipids (g/cap/day)	4.1
Carbohydrate (g/cap/day)	9
Fibre (g/cap/day)	6
Calorific value (kcal/cap/day)	132
pH	6.6
Urine	
Urine wet weight (L/cap/day)	1.4
Urine dry weight (g/cap/day)	59
Urination frequency (urinations/24 hours)	6
Nitrogen (g/cap/day)	11
Calorific value (kcal/cap/day)	1701
pH	6.2

C. Rose, A. Parker, B. Jefferson & E. Cartmell (2015): The characterisation of faeces and urine; a review of the literature to inform advanced treatment technology, Critical Reviews in Environmental Science and Technology,

DOI: 10.1080/10643389.2014.1000761
http://dx.doi.org/10.1080/10643389.2014.1000761

Brief History of Modern Wastewater Plant Modelling

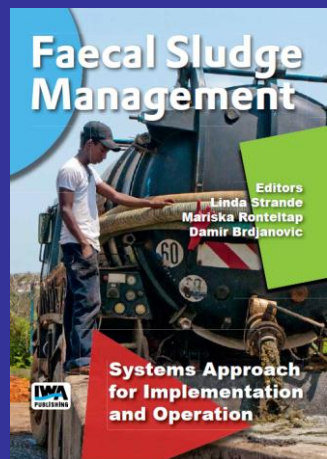
- **1966** - Activated sludge modelling started at the University of Cape Town
- **1982** - IAWPRC Task Group on Mathematical Modelling for Design and Operation of Activated Sludge Plants (ASM1)
- Mid **‘80s** to mid **‘90s** bio P removal became popular
- **1995** - Activated Sludge Model No 2 published (ASM2)
- **1999** - ASM2d published
- **2000** - ASM3 published
- **2002** - Anaerobic Digestion Model 1 (ADM1)
- **2006** - first Plant-wide model
- **2014** - Commercially available Plant-wide Models

Public Toilet and Septic Tanks

Ratios (g/g)	Public toilets	Septic tanks	Medium strength municipal wastewater
VSS:TSS	0.65-0.68	0.50-0.73	0.60-0.80
COD:BOD_5	5.0	1.43-3.0	2.0-2.5
COD:TKN	0.10	1.2-7.8	8-12
BOD_5:TKN	2.2	0.84-2.6	4-6
COD:TP	109	8.0-52	35-45
BOD_5:TP	17	5.6-17.3	15-20

Simple starting materials result in different waste characteristics!

Can the transformation mechanisms be unraveled?



Most of the experience and data is from the Global North and has limited applicability to the Global South

In the Global North sanitation has been part of a planned and incremental process which developed over decades

The Global South has a vast backlog, unplanned development and limited resources

Can this Approach Work in Developing Countries?

- **New** external design constraints
  - Cultural preferences and acceptability
  - Environment
    - water
    - temperature
    - energy
    - resource recovery / circular economy
  - Finances
  - Rapid and unplanned growth
- Regional priorities
  - South America – wastewater treatment
  - Africa and Asia – faecal sludge management

New Transformative Processes

- Biological
  - zooplankton / phytoplankton
  - insects
  - worms
  - plants
  - fish
- Thermal, evaporation, drying and combustion
- Chemical reactions

Bill & Melinda Gates Foundation
a Game Changer

- Brought the challenges of sanitation into the open
- Introduced new thinking
  - science and data driven
  - role for private sector
- Caught attention of governments

Sanitation is sexy

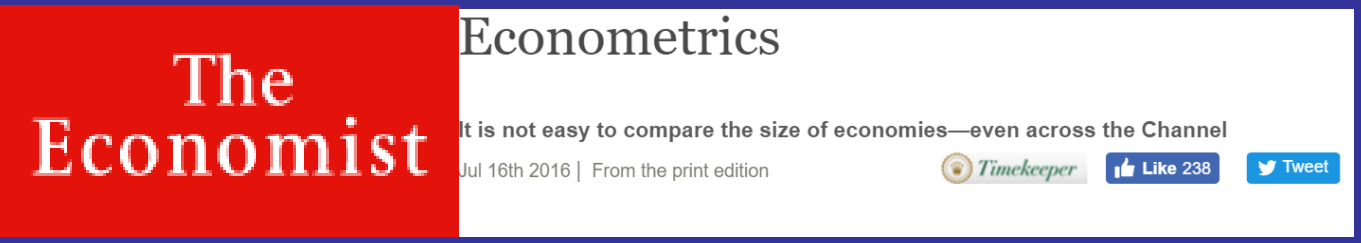
Different Approaches Require Different Data

- Mechanisms, kinetics and stoichiometry of the new transformation processes
- Separation and assessment of the products
- Odour control
- New classes of physical data
- Excreta in a biorefinery context
- Value extraction

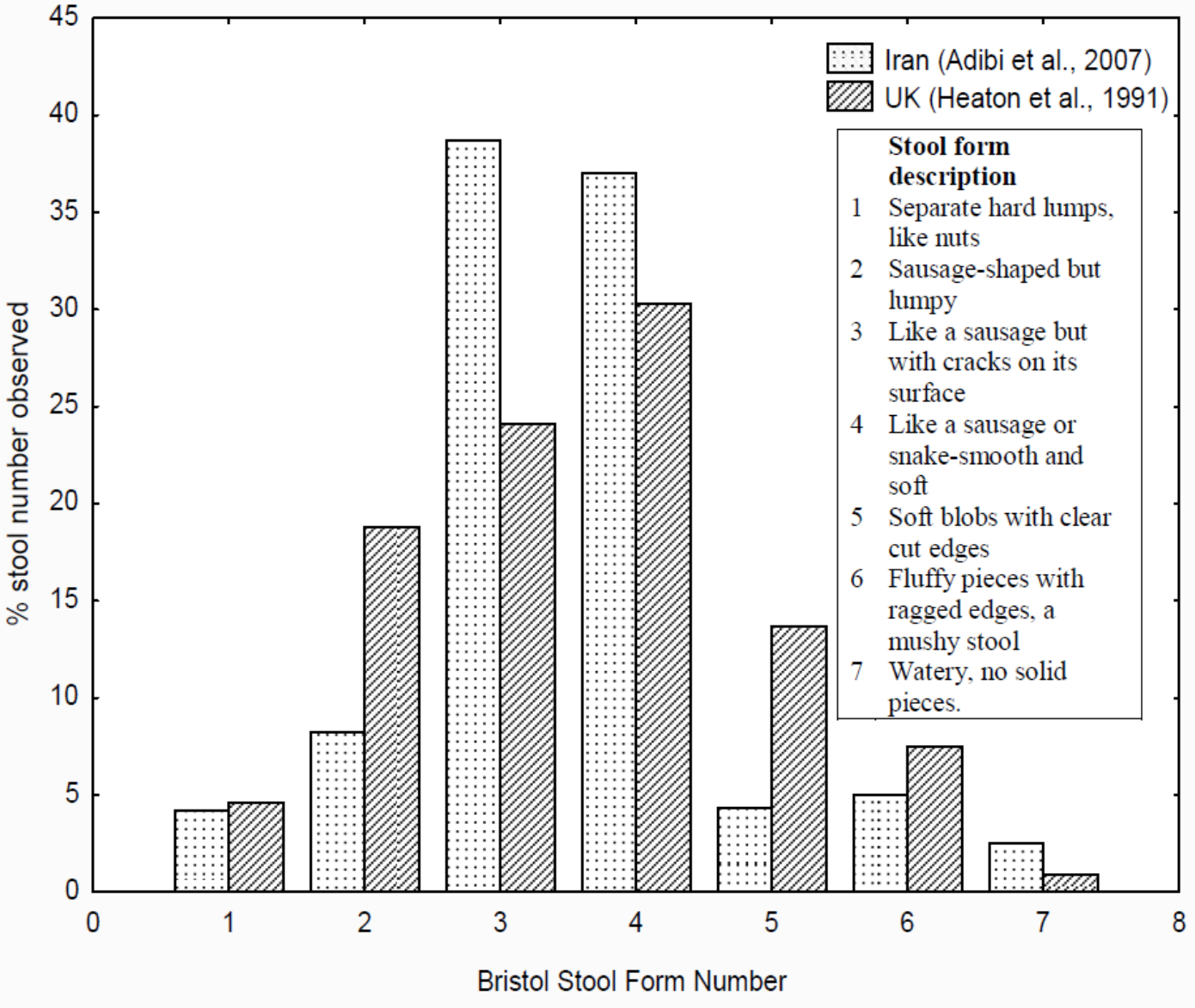
What is the Value of Faeces?

Even economists are interested in faecal sludge!!

…added over $180m to India's GDP, assuming an "evacuation rate" of 0.3kg a day for goats and rather more for sheep …



Stool Consistency Distribution



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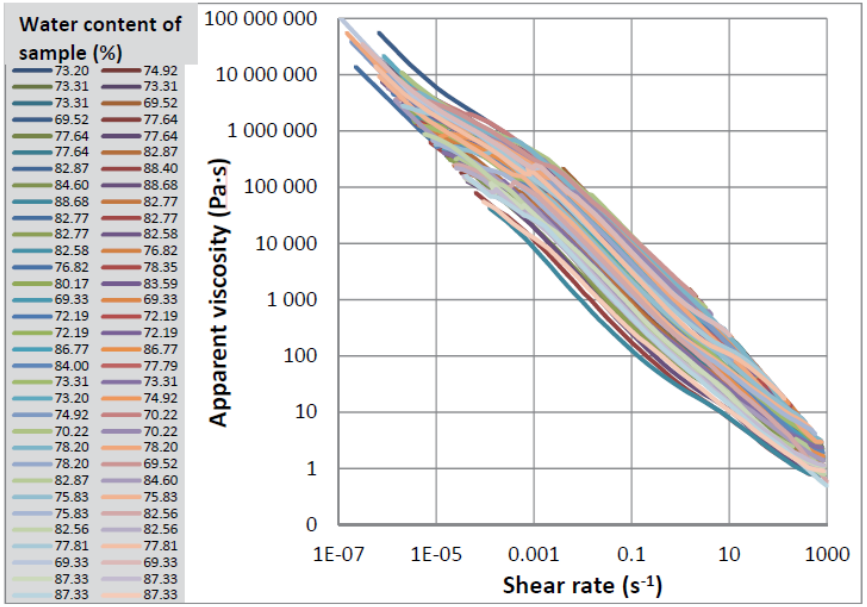
Viscosity Fresh Faeces

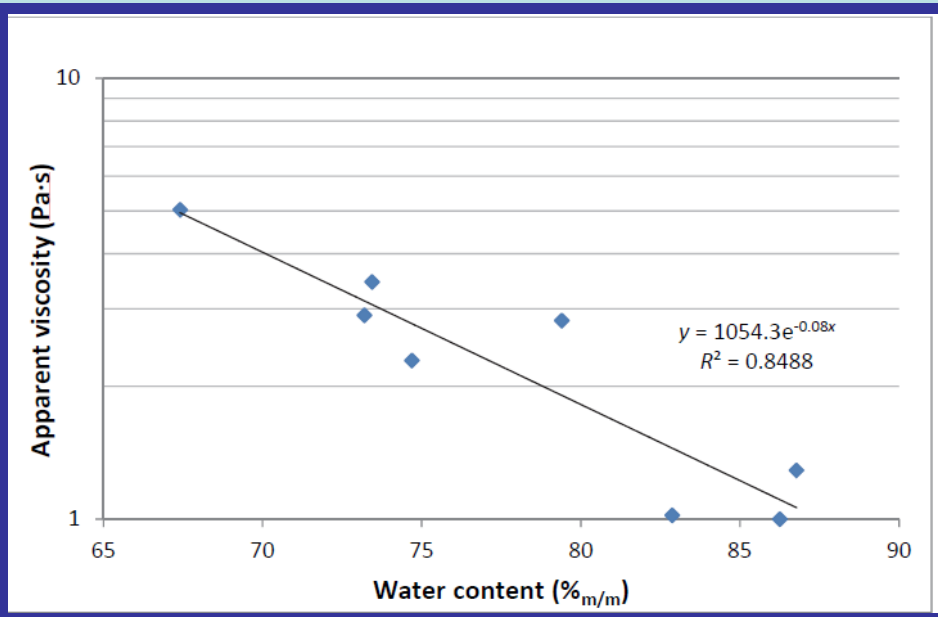


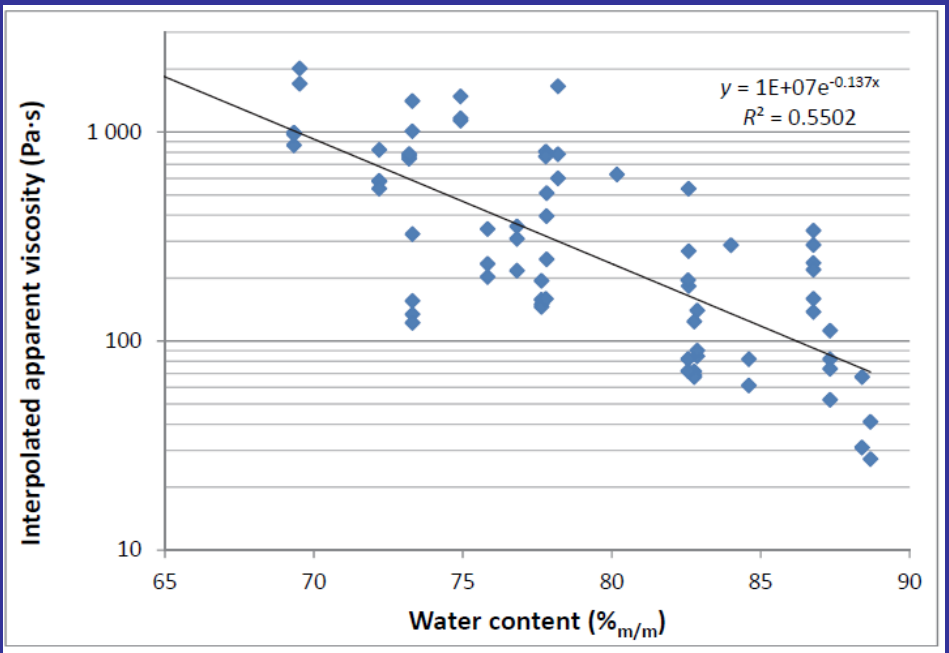
Woolley, SM, Cottingham, RS, Pocock, J and Buckley, CA (2014), **Shear rheological properties of fresh human faeces with different moisture content.** Water SA Vol. 40 pp 273 – 276.

Reinvented toilets need to transport fresh faeces or pump digested faeces from a pit

Changes in Viscosity of Fresh Faeces

Variation in apparent viscosity of fresh human faeces of sample on a dry basis (applied shear rate of 1 s_{-1} at 25°C)





Apparent viscosity of fresh human faeces after 1 h of shearing at 100 s1 for various moisture contents (at 25°C)

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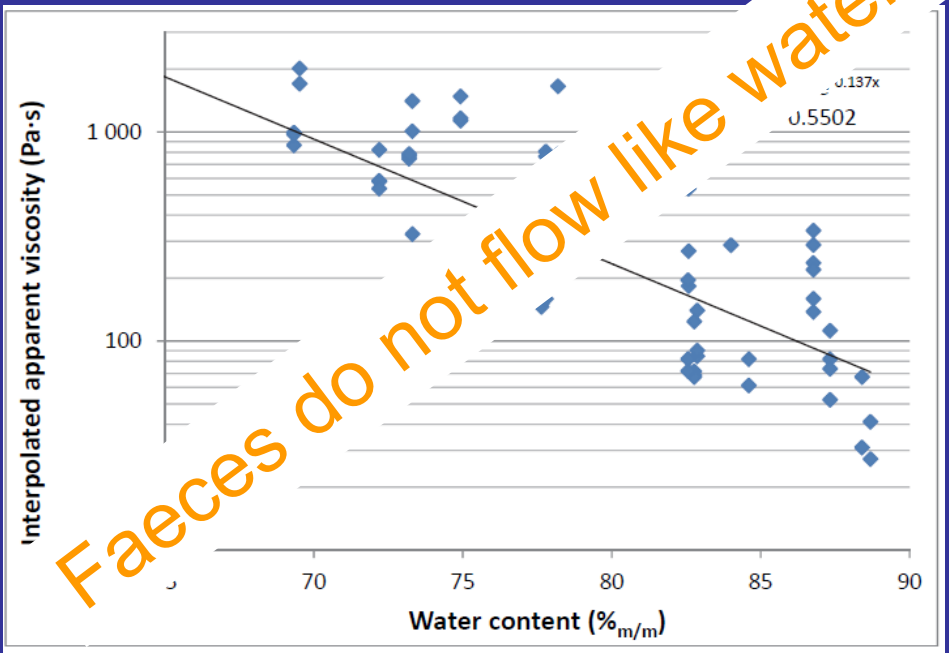
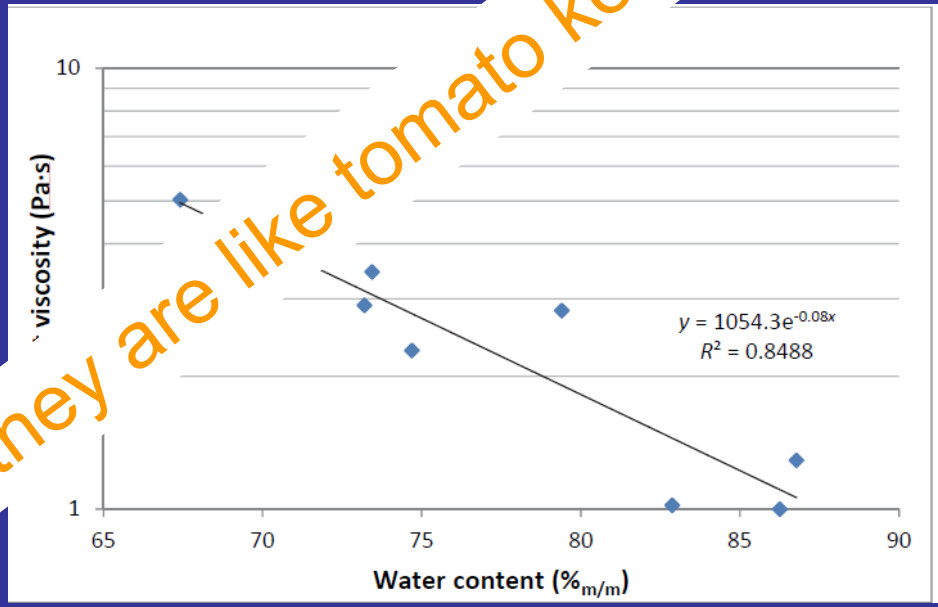


Faeces do not flow like water – they are like tomato ketchup



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Odour with Diarrhea

Normal

Sample No.	Acetic acid	Propionic acid	Butyric acid	*iso*-Valeric acid	*n*-Valeric acid	Pyridine	Pyrrole (ppb)
1	< 1	< 1	0.24	0.03	0.01	8	2
2	< 1	2	0.02	0.01	0.01	6	3
3	< 1	< 1	0.08	0.01	0.01	8	2
4	10	1	0.20	0.03	0.01	5	1
5	5	5	0.11	0.05	0.01	9	1
6	< 1	11	0.12	0.04	0.01	8	3
7	4	< 1	0.15	0.10	0.05	10	1
8	7	7	0.30	0.01	0.01	1	1
9	3	< 1	0.35	0.02	0.04	5	1
10	< 1	< 1	0.02	0.01	0.01	2	2
Ave	3	3	0.16	0.03	0.02	6	2

With diarrhea

Sample No.	Acetic acid	Propionic acid	Butyric acid	*iso*-Valeric acid	*n*-Valeric acid	Pyridine	Pyrrole (ppm)
11	497	2.8	2.0	0.03	0.77	0.10	0.01
12	600	3.5	3.0	0.30	0.90	0.20	0.03
Ave	549	3.1	2.5	0.32	0.84	0.15	0.02

Sato, H, Morimatsu, Kimura, T, Moriyama, Y Yamashita, T and Nakashima, Y (2002). Analysis of Malodorous Volatile Substances of Human Feces. *Journal of Health Science,* **48**(2) pp179 - 185

Odour with Diarrhea

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(ppb)

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3	< 1	< 1	0.08	0		8	2
4	10	1	0.20		0.01	5	1
5	5	5	0.11		0.01	9	1
6	< 1	11	0.12		0.01	8	3
7	4	< 1	0		0.05	10	1
8	7	7		0.01	0.01	1	1
9	3	< 1		0.02	0.04	5	1
10	< 1	< 1		0.01	0.01	2	2
Ave	3		16	0.03	0.02	6	2

With diarrhea

(ppm)

Sample No.	A…	…ionic acid	Butyric acid	*iso*-Valeric acid	*n*-Valeric acid	Pyridine	Pyrrole
11		2.8	2.0	0.03	0.77	0.10	0.01
		3.5	3.0	0.30	0.90	0.20	0.03
	+9	3.1	2.5	0.32	0.84	0.15	0.02

Odour control will become a major issue

Sato, …matsu, Kimura, T, Moriyama, Y Yamashita, T and Nakashima, Y (2002). Analysis of Malodorous Volatile Substances of Human Feces. *Journal of Health Science,* **48**(2) pp179 - 185

Trash

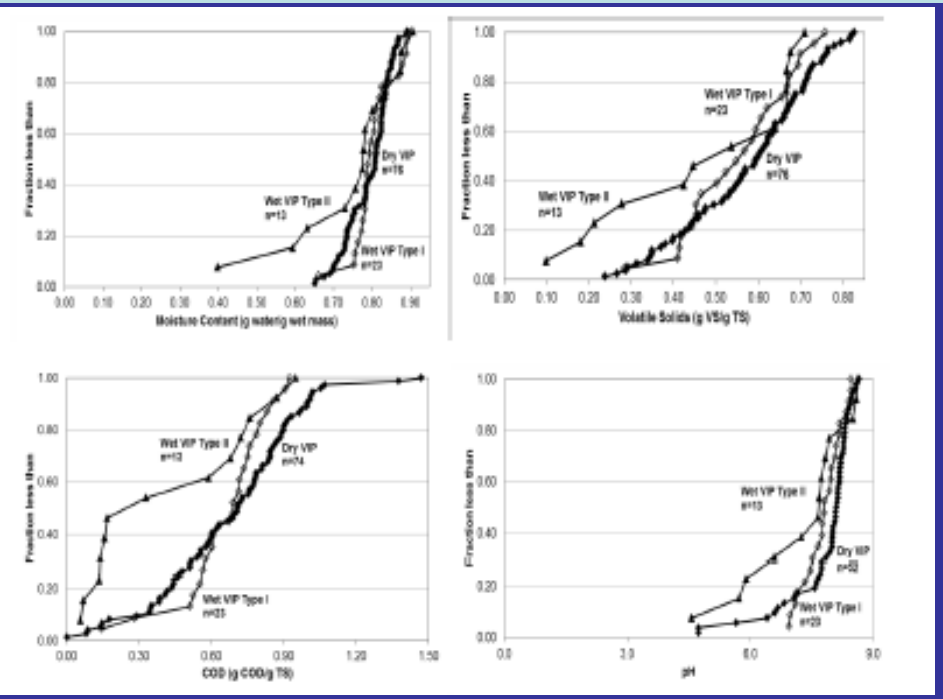
Screenings from the Niayes faecal sludge treatment plant in Dakar, Senegal (photo: Linda Strande). Faecal Sludge Management: A systems approach for implementation and operation

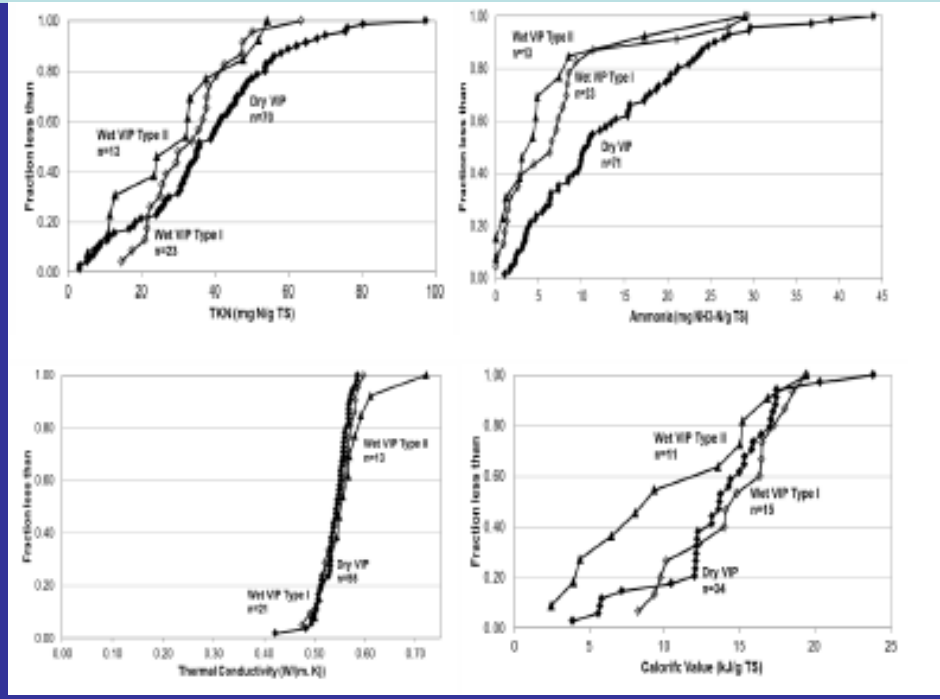
Trash

Is trash a technical challenge or a behavioral challenge?

Sc[illegible]rom the Niayes faecal sludge treatment plant in Dakar, Senegal (photo: [illegible]rande). Faecal Sludge Management: A systems approach for implementation a[illegible] operation

Dry and wet VIPs – moisture, volatile solids, COD, pH NH_4 TKN thermal conductivity and calorific value





Zuma, L 2015. MScEng dissertation, University of KwaZulu-Natal (submitted)

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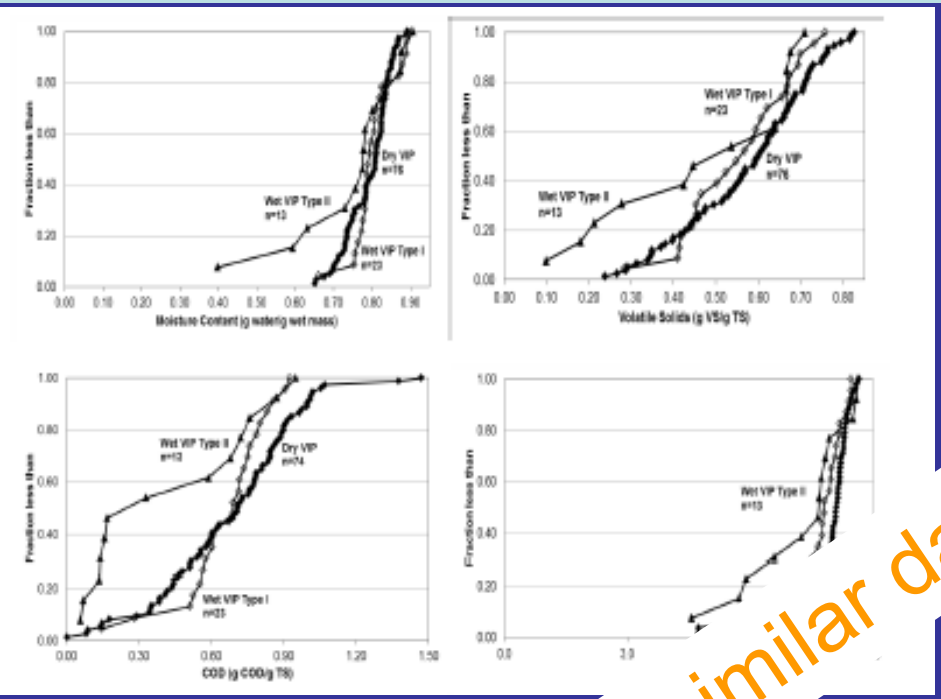
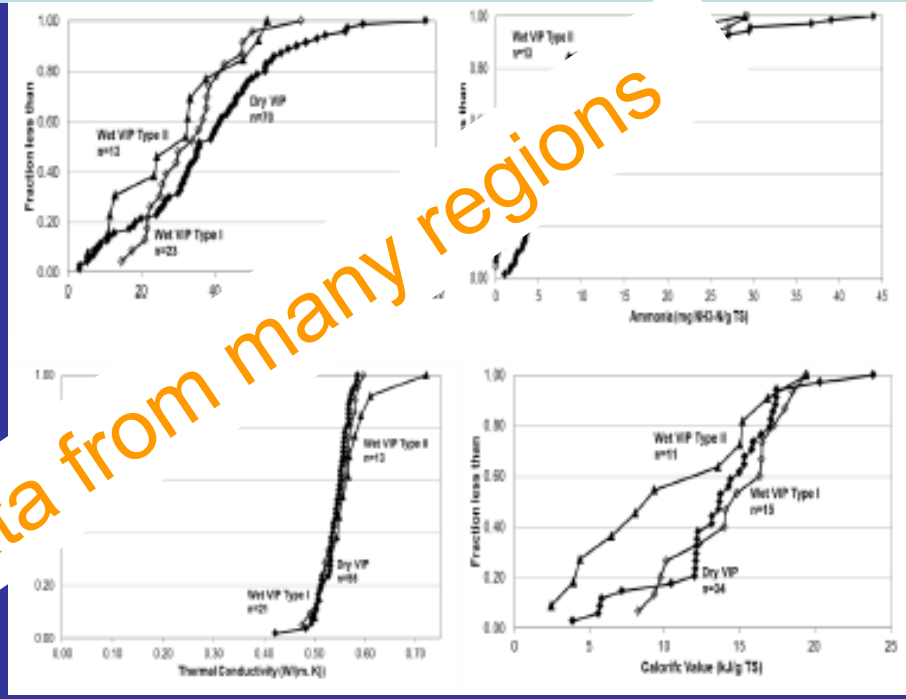
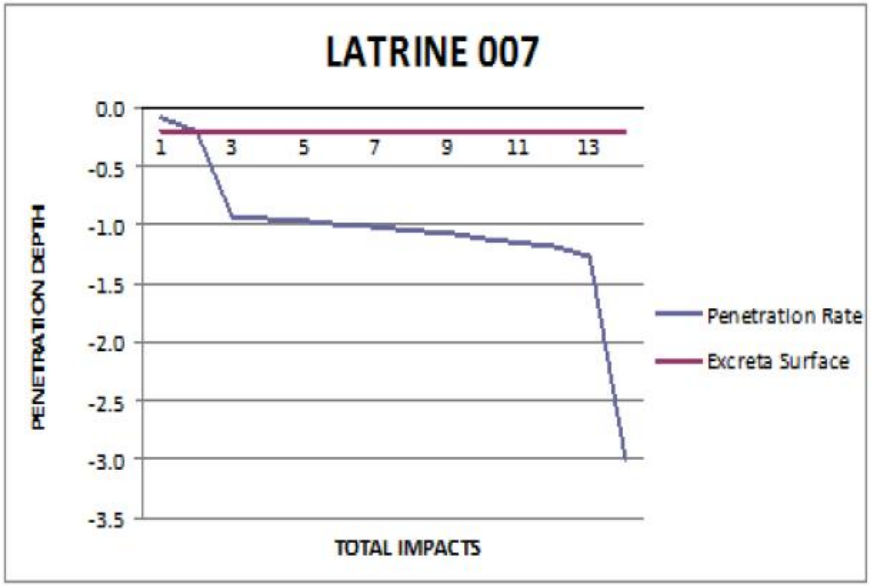


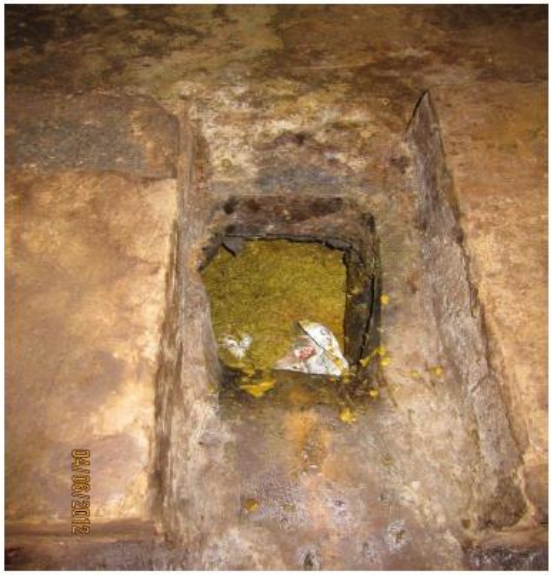


Need to obtain similar data from many regions

Zuma, L 2015. MScEng dissertation, University of KwaZulu-Natal (submitted)

Penetrometer and VIPs (ii)





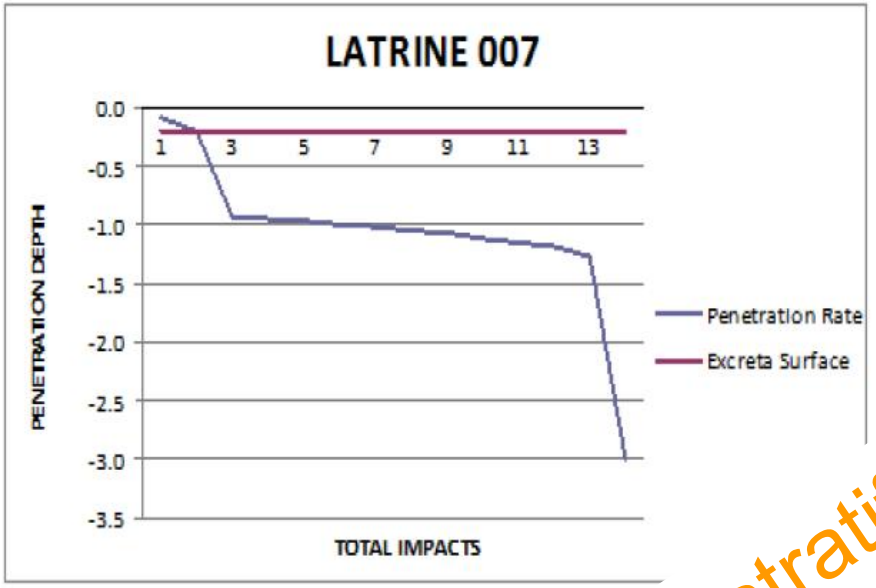
Samples taken from a single pit latrine

By hand at 1 m

Approx 1.4 m

By Gulper at 2 m

Penetrometer and VIPs (ii)



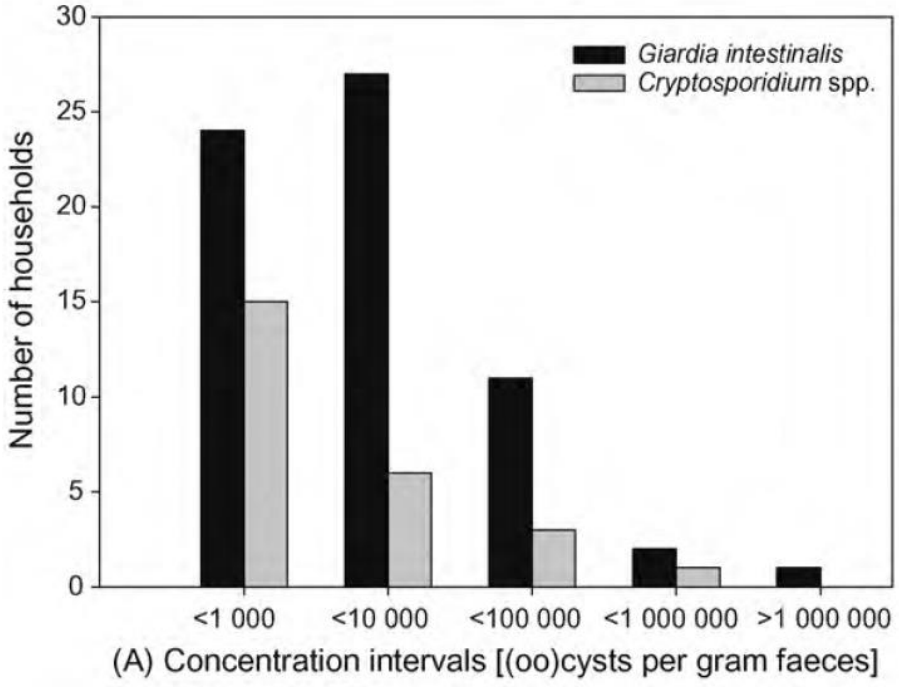
How does stratification occur?

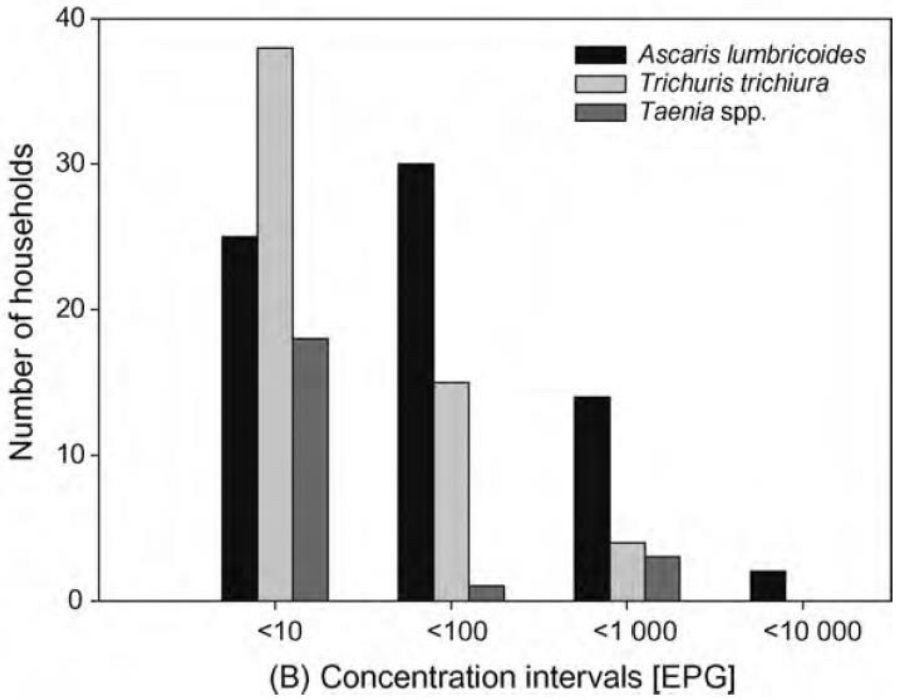
Samples taken[illegible] single pit latrine

By hand at 1 m [illegible]1.4 m

By Gulper at 2 m

Helminths in VIP Toilets in Durban

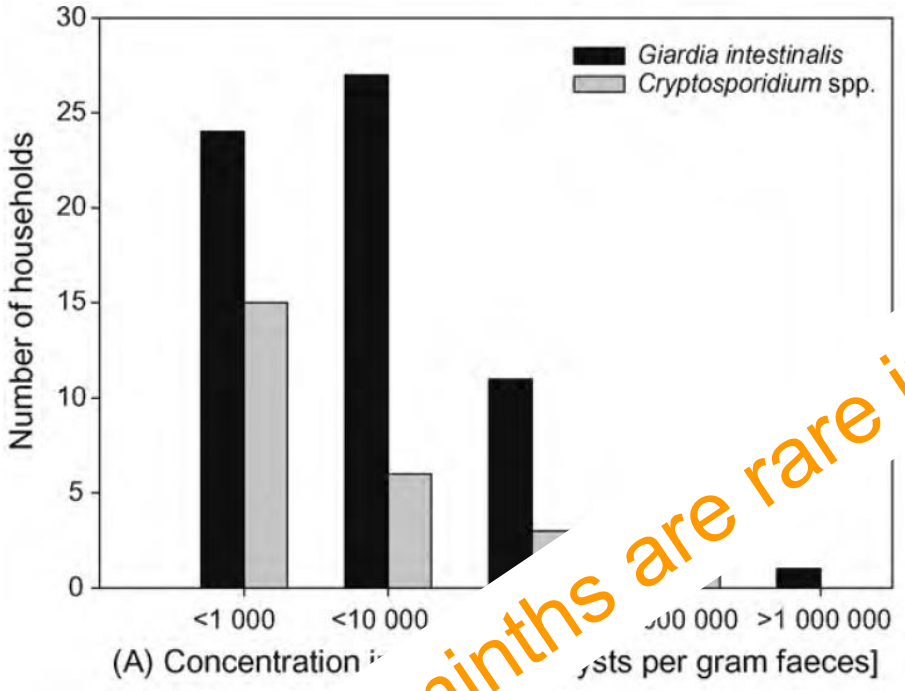


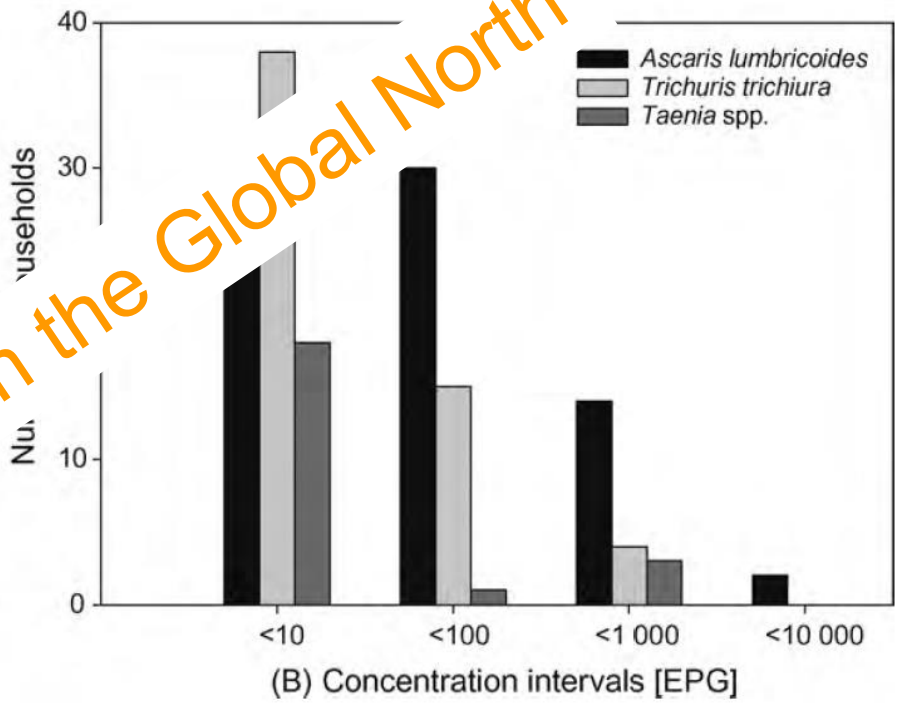


Distribution of the concentrations for samples positive for (A) G. intestinalis and Cryptosporidium spp. and (B) the helminths.

Transactions of the Royal Society of Tropical Medicine and Hygiene 104 (2010) 646–652

Helminths in VIP Toilets in Durban





Helminths are rare in the Global North

Distribution of concentrations for samples positive for (A) G. intestinalis and Cryptosporidium spp. and (B) the helminths.

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VIP Sludge Drying

Diffusivity: 7.8×10^{-8} - 2.1×10^{-7} m^2/s

Thermal conductivity : 55 W/m.K (79% moisture)

0.04 W/m.K (dry)

Calorific value: 11 to 13 MJ/kg sample

VIP Sludge Drying

Diffusivity: 7.8×10^{-8} - 2.1×10^{-7} m^2/s

Thermal conductivity : 55 W/m.K (79% moisture)

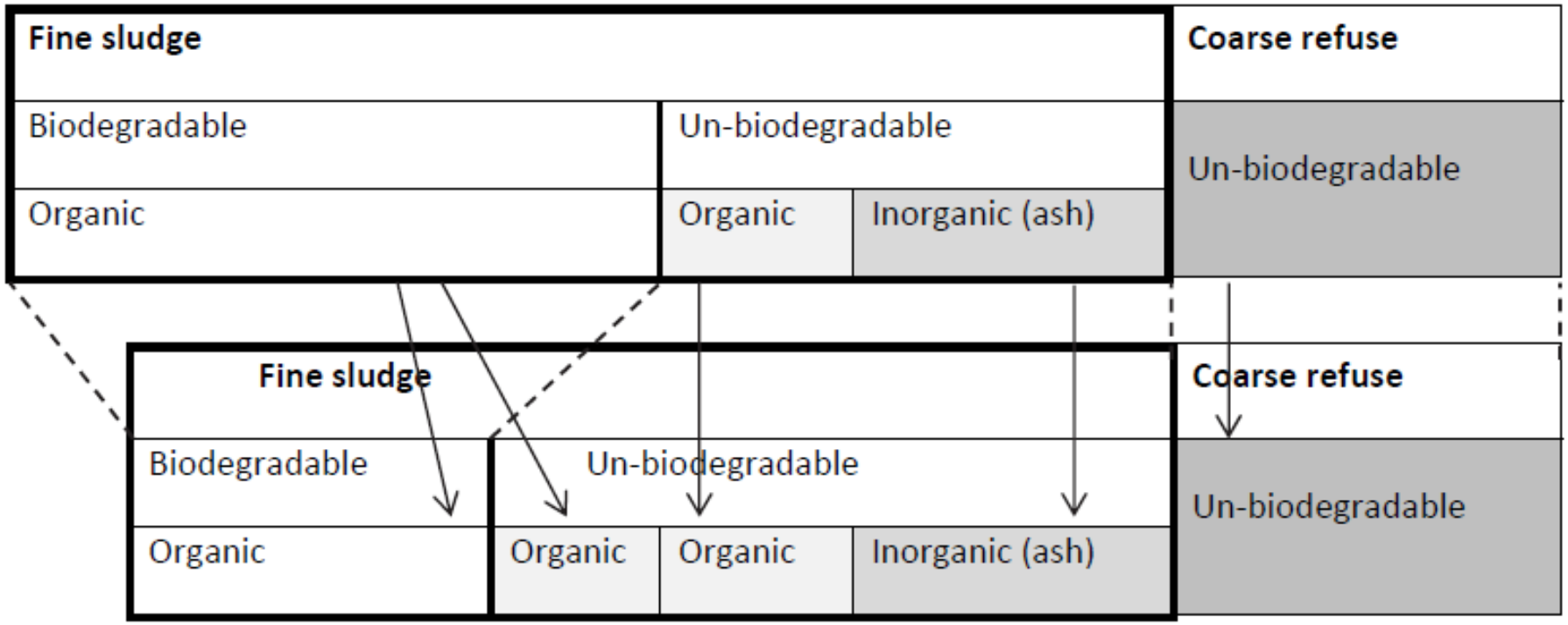
0.4 W/m.K (dry)

Calorific value 11 to 13 MJ/kg sample

Data necessary for the design and sizing of equipment

VIP Sludge Degradation

- Trash can be 25% of the volume
- Biodegradability decreases with depth



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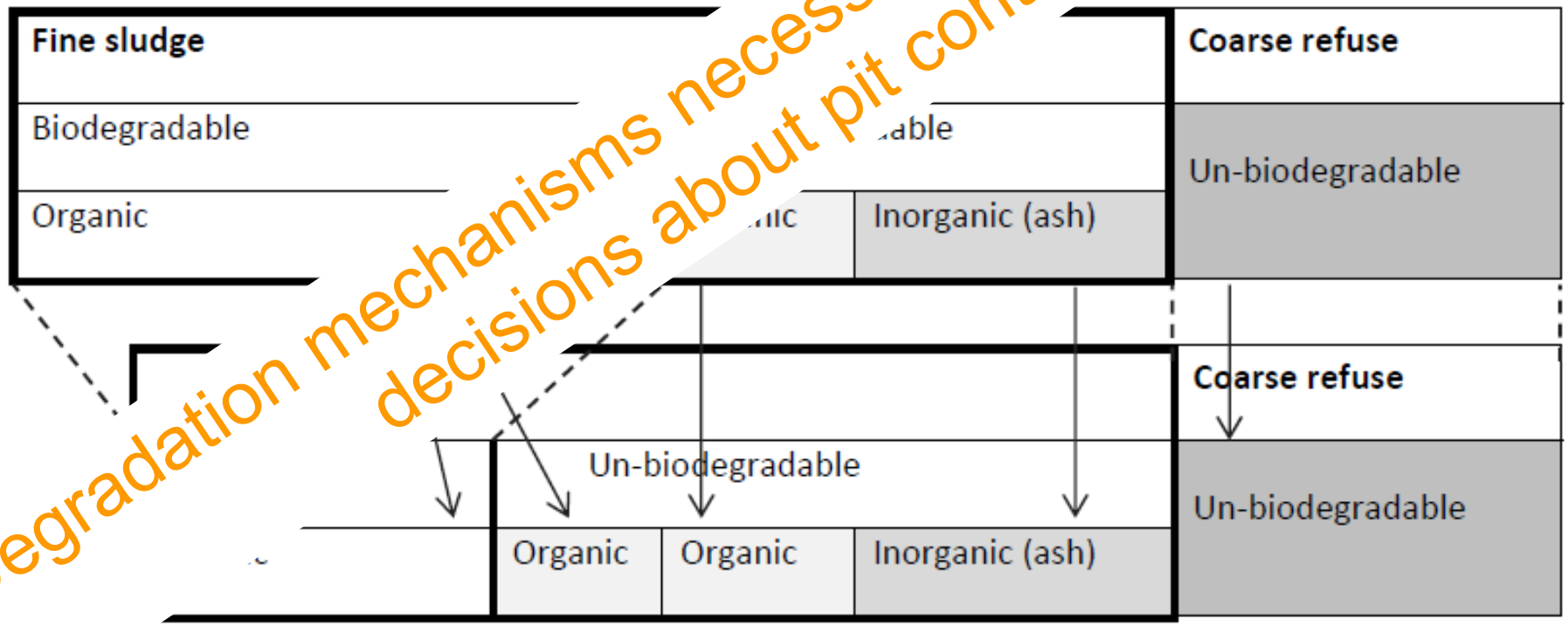
VIP Sludge Degradation

- Trash can be 25% of the volume
- Biodegradability decreases

Degradation mechanisms necessary to make informed decisions about pit contents



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Other Aspects to Consider

- Need for ***Standard Methods for FSM***
- Sampling
- Sample preservation and transboundary transport
- Safety, heath and hygiene
- Ethics and permissions
- Analyses from other regions
- Establish more faecal sludge laboratories
- Extend the range of analyses

Proposed Research Strategy
learn together by doing incrementally

- Municipality / local university partnership
  - access to excreta
  - early stage technology transfer
  - co-production of knowledge
- Quantify current excreta streams
- Implement stage 1 of treatment process
- Quantify, evaluate the results
  - conceptually modify stage 1 process
- Design and implement stage 2 process
- … etc

Learning by doing

Acknowledgements

- **Funders**
  - **Bill & Melinda Gates Foundation, Water Research Commission, eThekwini Water and Sanitation, Eawag, London School of Hygiene and Tropical Medicine, Borda.**
- **BMGF grantees for sharing their data**

http://prg.ukzn.ac.za/