How fast do pits fill up? Empirical evidence and mathematical models

Kitty Foxon, Chris Brouckaert and Kirsten Wood

Pollution Research Group

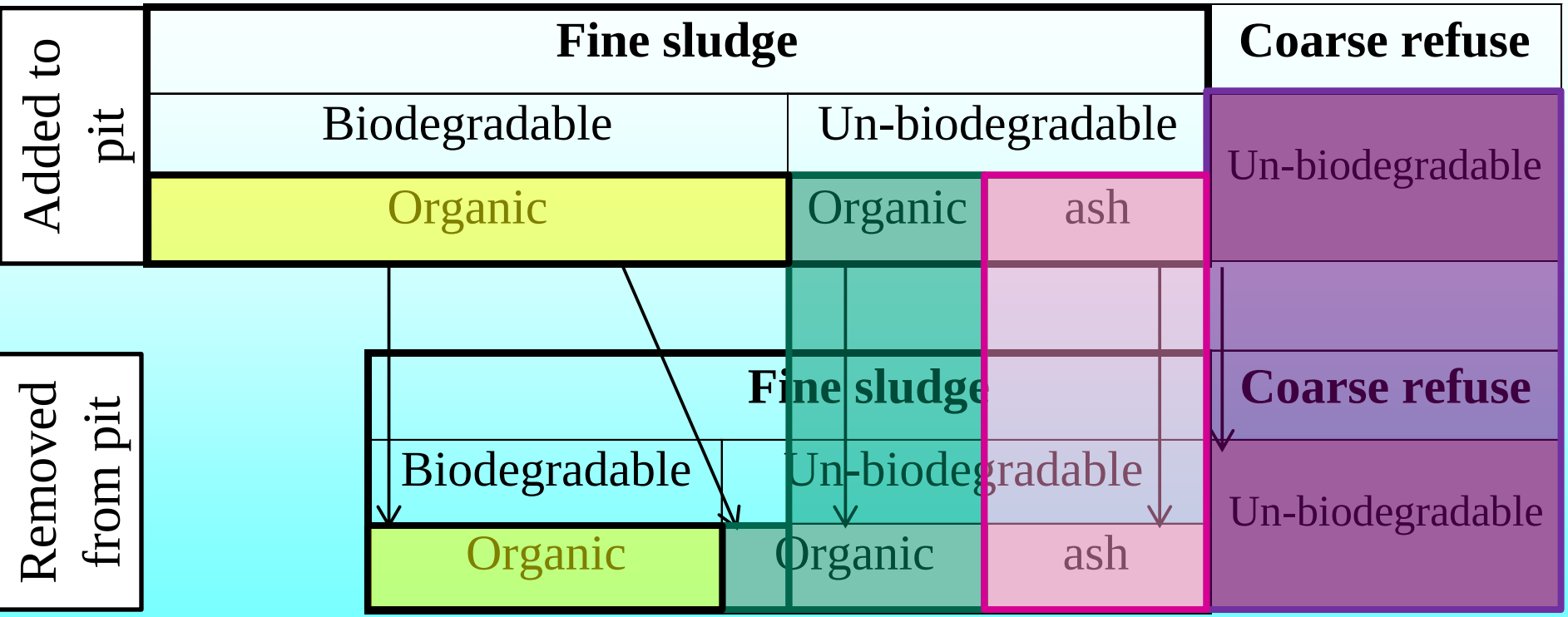
Which pit processes need to be considered in a model

- Filling
  - Faeces, urine, toilet paper, household waste
- Biodegradation
  - Aerobic surface layer
  - Anaerobic when covered
- Water transfer
  - Exchange with groundwater
  - Site specific

Overview of investigation

- Material balance model
  - Addition, biodegradation, accumulation
- Detailed field measurements
  - 2 pits sampled during emptying
  - COD, water and ash profiles
- Additional measurements
  - 16 pits in eThekwini
- Filling rates from other SA studies

Structure of pit filling model



(Relative volume changes not to scale)

Model equations

Volume as a function of age

$$V(t,T) = R_u \cdot T \int_t^T f_u(\tau) \cdot \phi(\tau) d\tau$$

$$= R_u \left[\left(1 + k \frac{\nu_{b0}}{\nu_{u0}} \right) (T - t) + \left((1-k) \frac{\nu_{b0}}{\nu_{u0}} \right) \frac{(e^{-rt} - e^{-rT})}{r} \right]$$

Fraction biodegradable at each depth

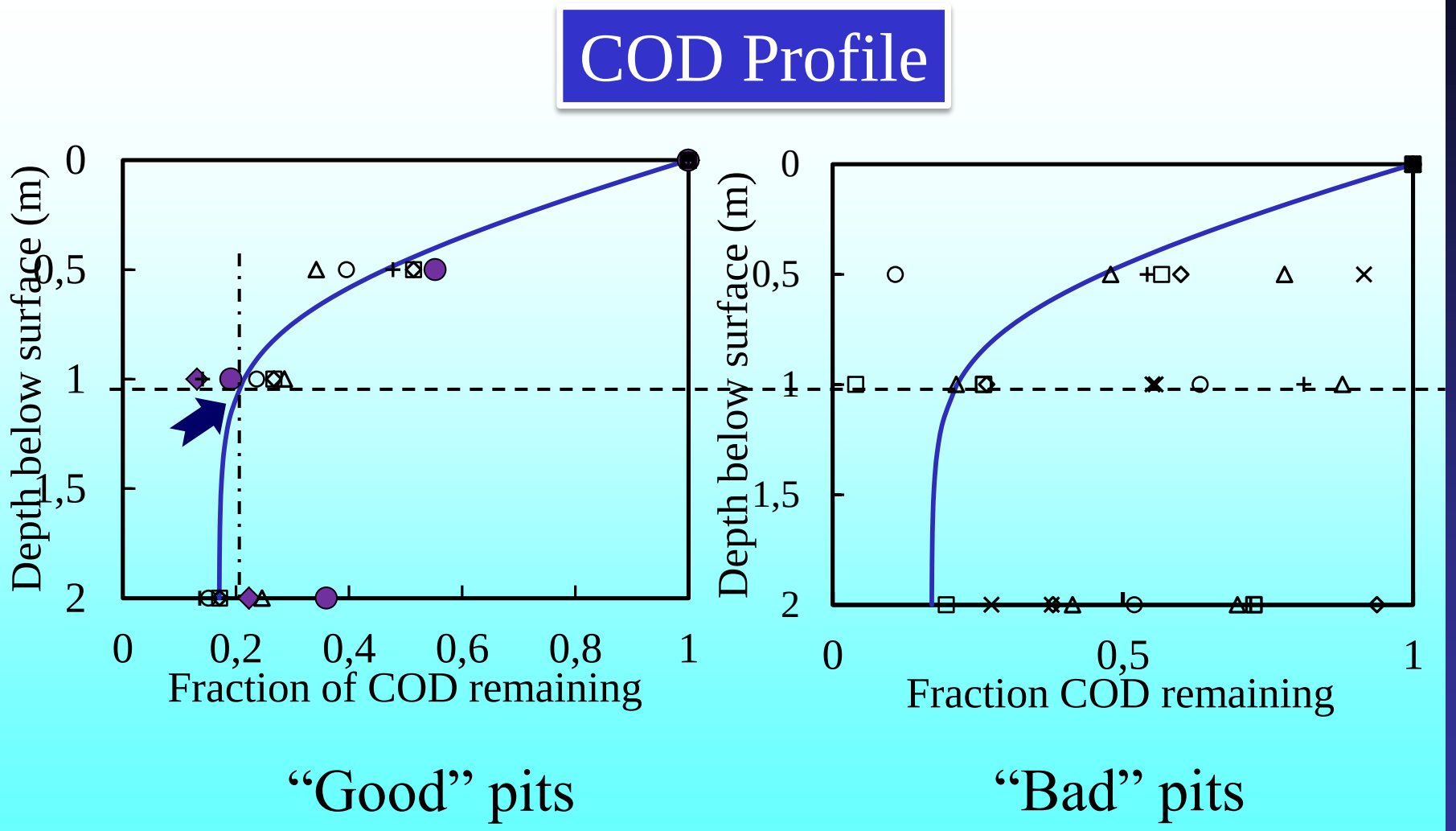
$$\beta(\theta) = \frac{\nu_b(\theta)}{\nu(\theta)} = \frac{\nu_{b0} \cdot e^{-r\theta}}{\nu_{u0} + k \cdot \nu_{b0} + (1-k)\nu_{b0} \cdot e^{-r\theta}}$$

$$= \frac{\frac{\nu_{b0}}{\nu_{u0}} e^{-r\theta}}{1 + k \frac{\nu_{b0}}{\nu_{u0}} + (1-k) \frac{\nu_{b0}}{\nu_{u0}} e^{-r\theta}}$$

Assumptions in model definition

- Surface material is *effective* feed
  - Aerobic surface degradation could not be modelled
- Fixed water content (measured average value)
  - Water exchange could not be modelled
- Constant addition rate and composition
  - No historical information apart from date of construction

Calibration: how organics change

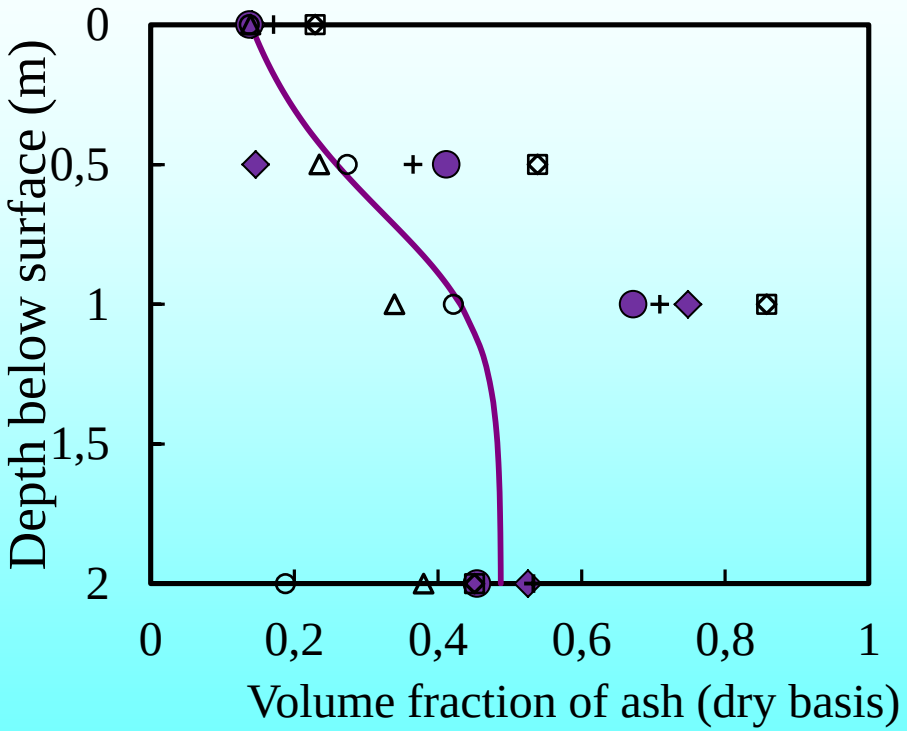


"Good" pits

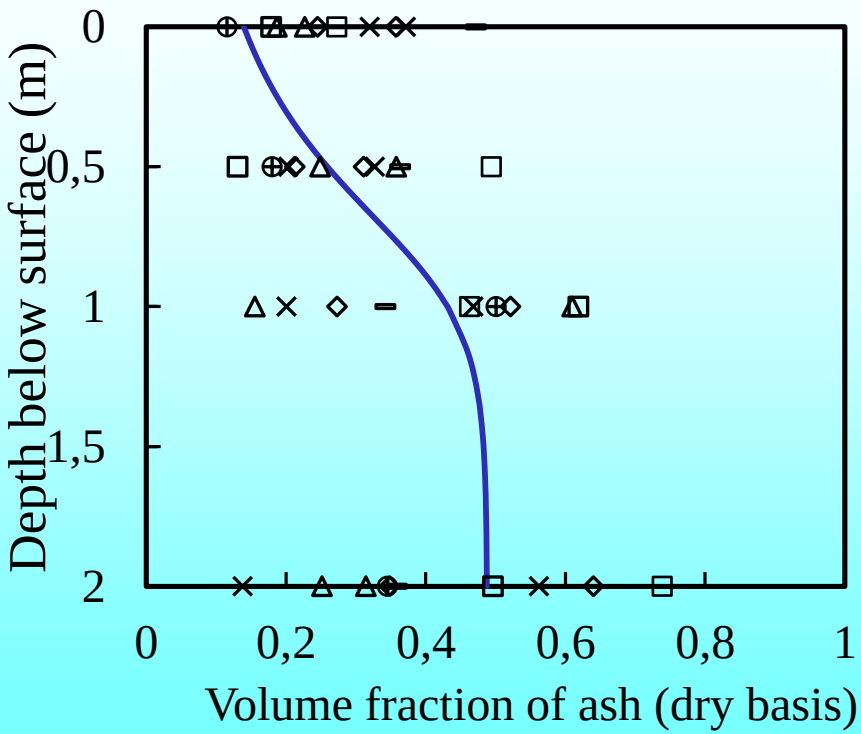
"Bad" pits

Calibration: – what's left behind

Ash Profile



"Good" pits

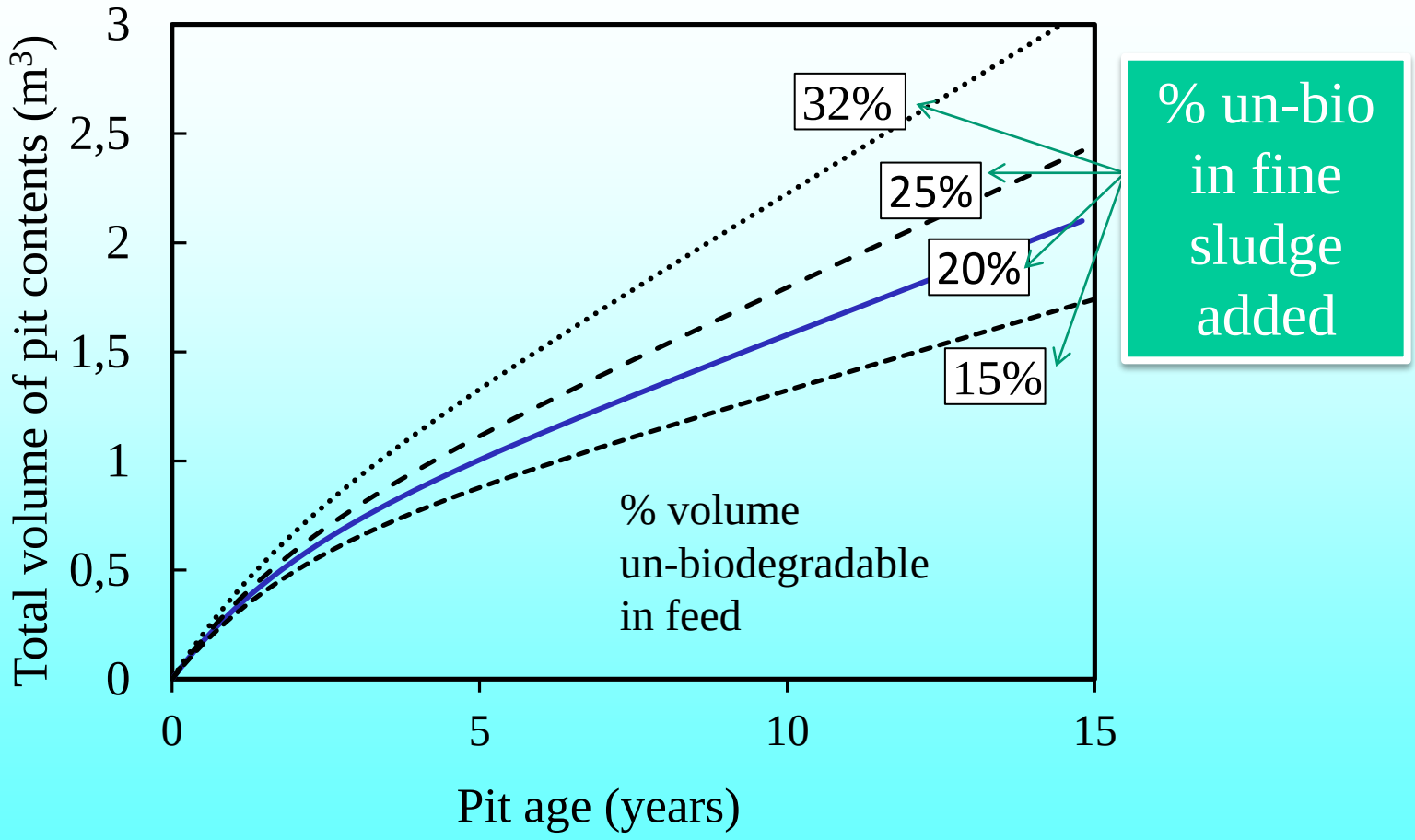


"Bad" pits

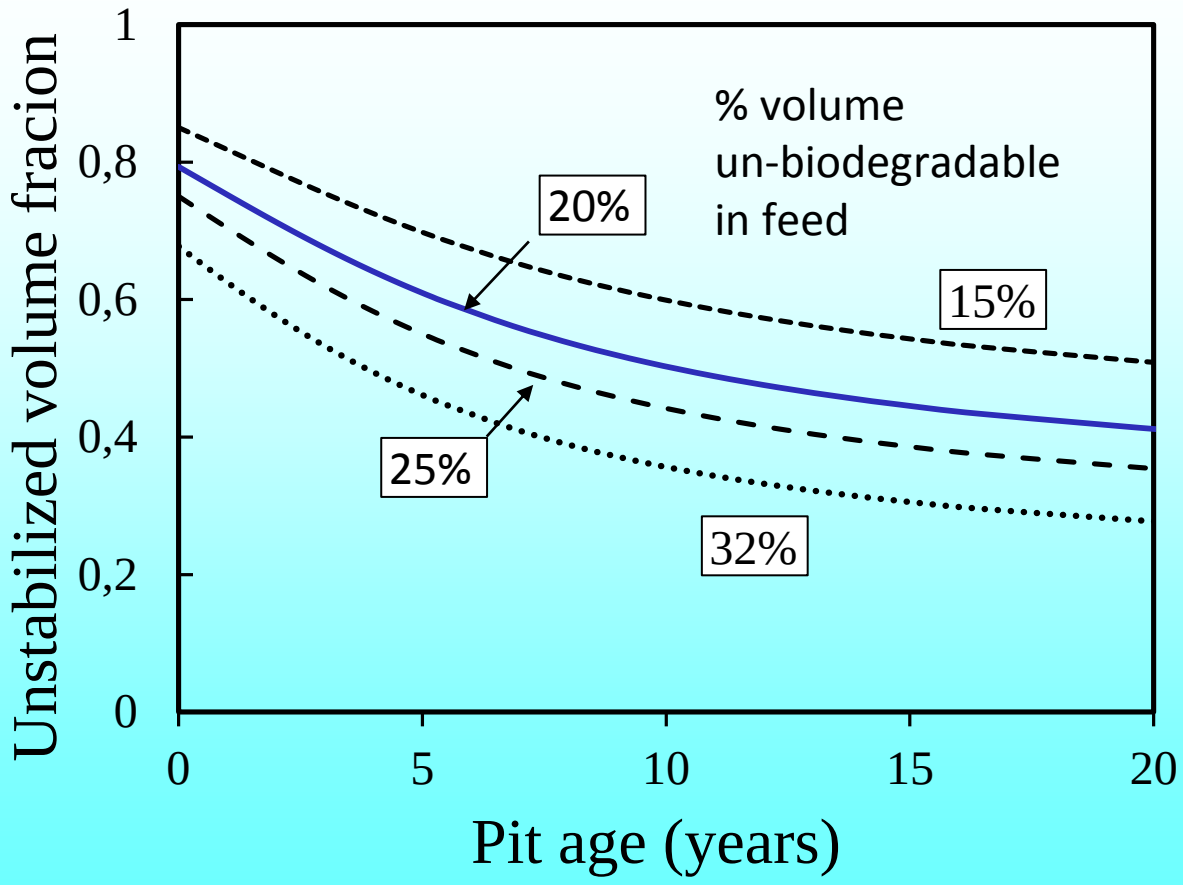
Scenarios: What does the model predict?

- Pit content depends on user behaviour
- Represented in model as un-biodegradable fraction of feed.
  - 20% by volume for reference pits
- Predict pit filling rate and composition
  - Constant refuse addition rate

Accumulated volume: Fine sludge

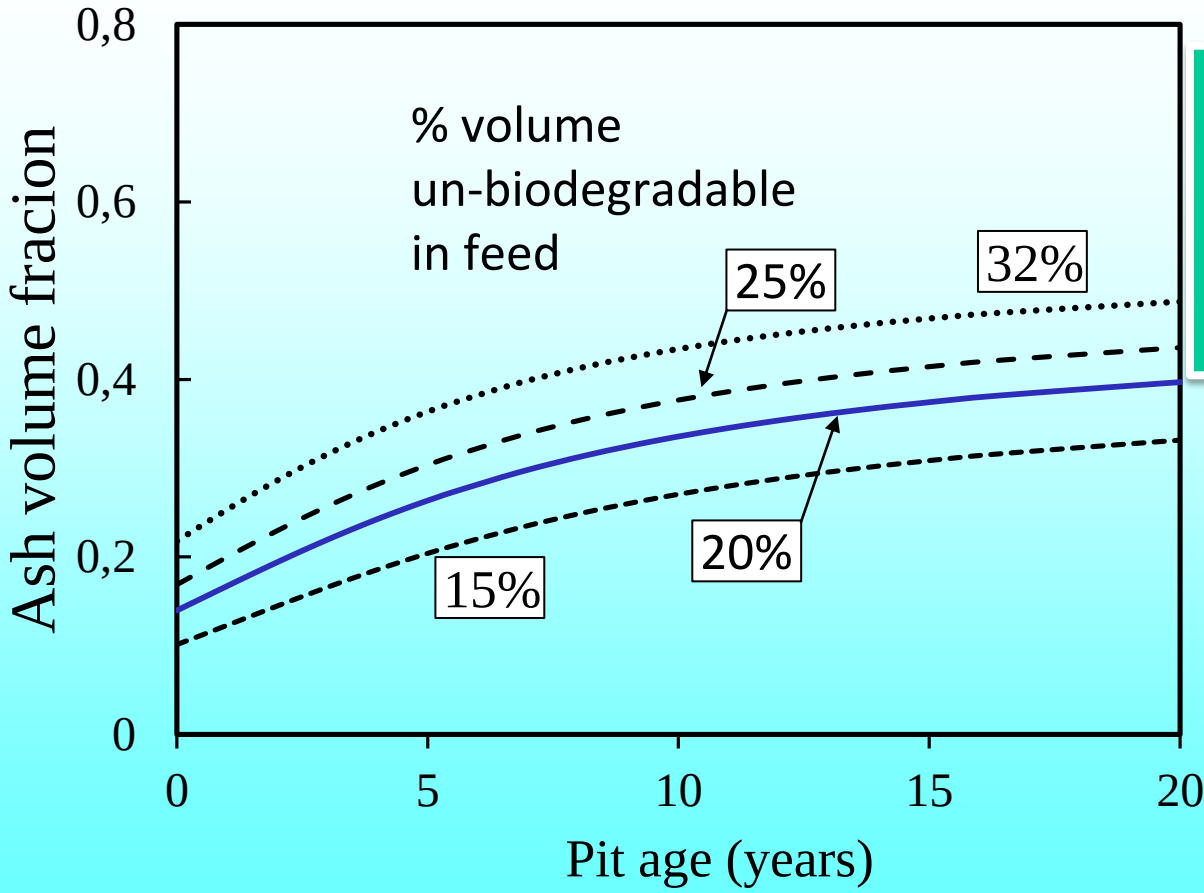


Average Biodegradable fraction



% un-bio in fine sludge added

Average ash fraction



% un-bio in fine sludge added

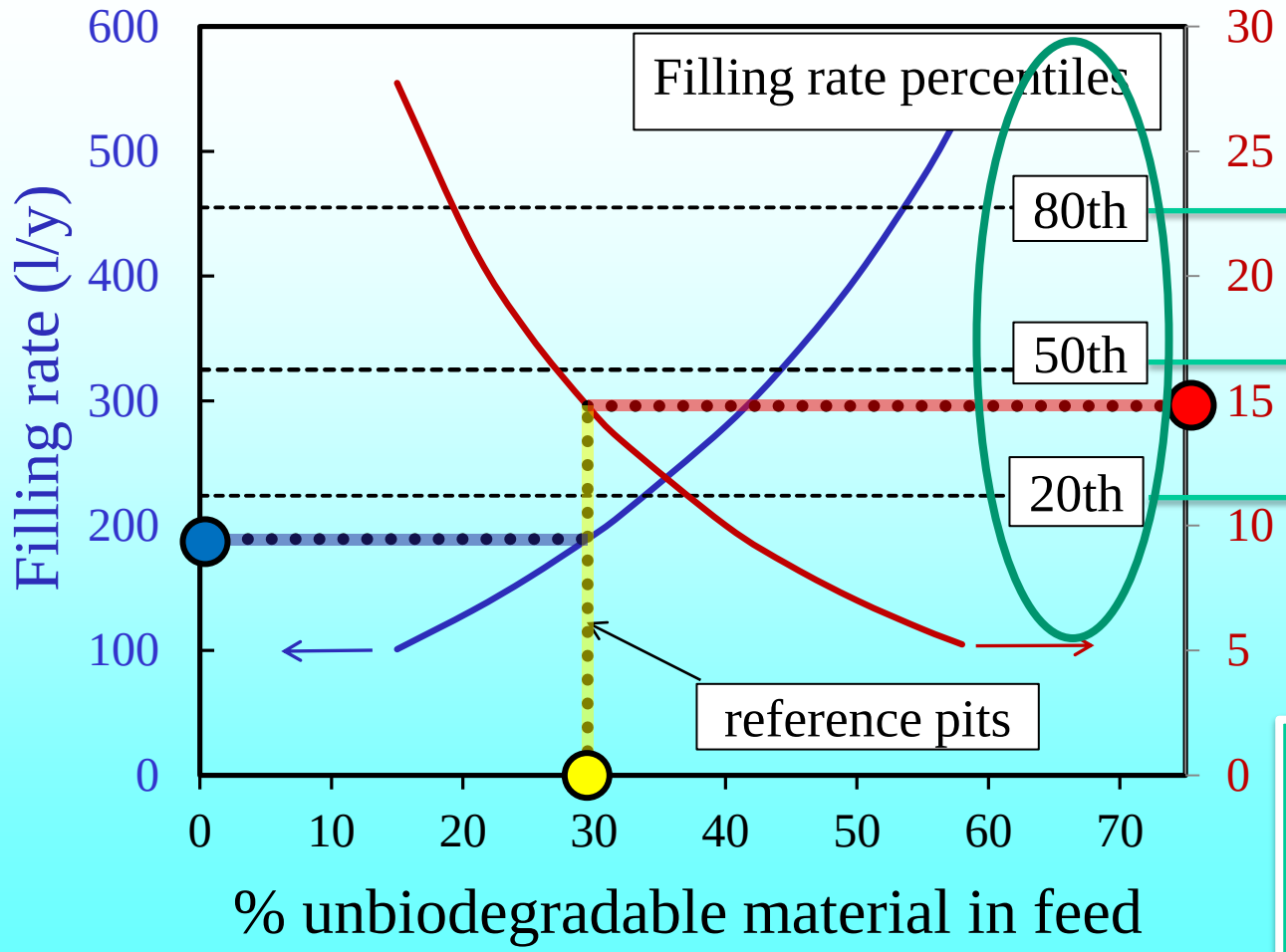
How are filling rates calculated?

- Model focus: changes in fine sludge fraction
- Coarse refuse addition rate estimated independently.
- Coarse refuse assumed unbiodegradable: accumulation rate = addition rate
- Filling rate = rate of accumulation of fine sludge + rate of addition of coarse refuse

Comparing model to filling rate studies

- Undertaken in various parts of SA
- Wide range of rates, represented here by 20th, 50th and 80th percentile values.
- Per person rates unreliable, so compared to model on a per pit basis.

Filling rate comparison



N=789

69ℓ/p.y

49ℓ/p.y

32ℓ/p.y

ℓ/p.y=ℓ per person.year assuming 6.6 people per pit

Conclusions

- Model : degradation *after* initial aerobic degradation
- Sophisticated modelling not justified.
- Systematic variation of organics and ash with depth.
- Biodegradable content decreases with age.
- Municipal solid waste removal!
- Design emptying cycle/pit depth for
  - required sludge characteristics
  - Max pit life
  - Ease of emptying etc.

Acknowledgements

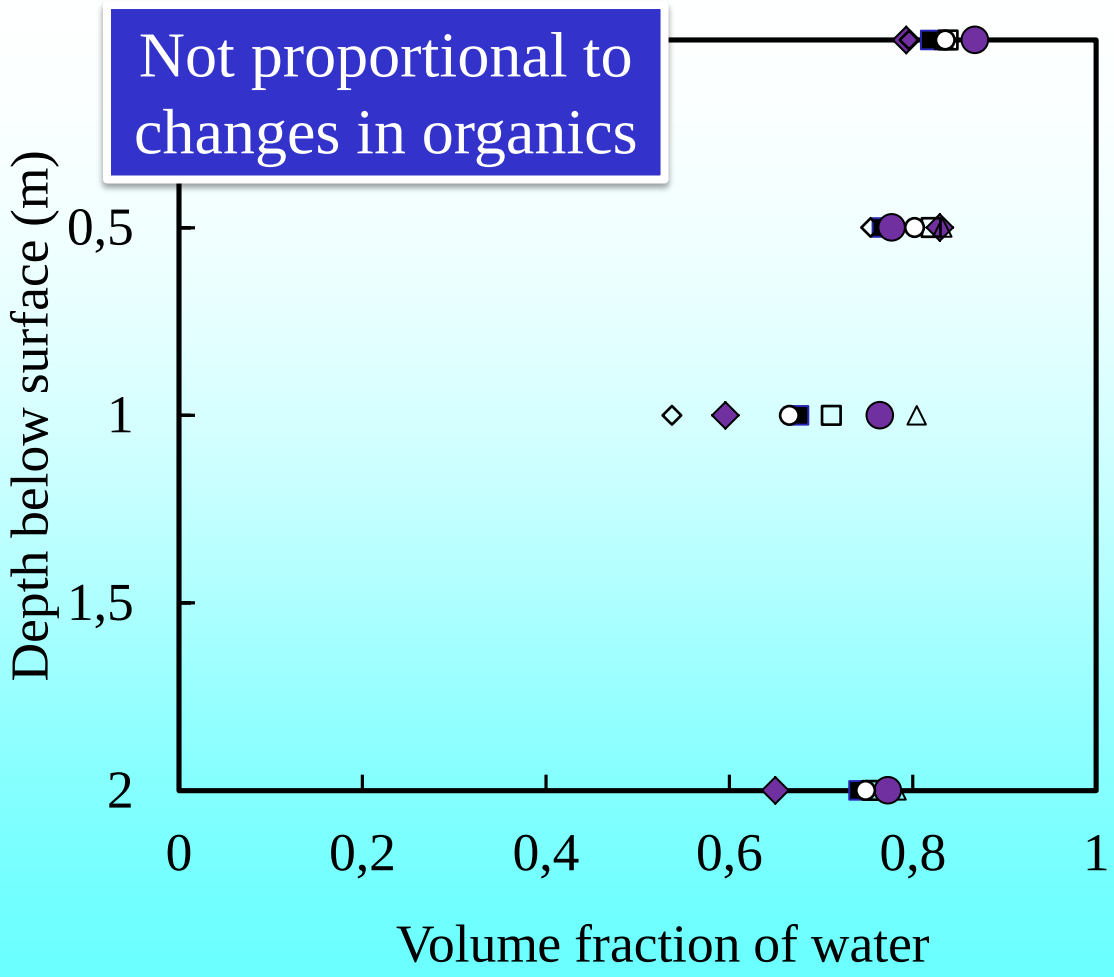
The authors thank the London School of Hygiene and Tropical Medicine (who received a grant from the Bill and Melinda Gates Foundation), the South African Water Research Commission, eThekwini Water and Sanitation Services and Partners in Development (Pty) Ltd for financial and technical support of this work.


Pollution Research Group

Additional slides for questions

MODELLING VIP FILLING RATES

Assumption validation: Water content



Pit latrines in eThekwini

- VIPS inherited when metro formed in 1999
- 45 000 pits emptied by 2011
- Average of 14 years in operation
- Proposed 5 year emptying cycle.

Model parameter values

	Model parameter	Value	units
Rate of addition	Fine sludge (dry)	0.182	ℓ/d
	Fine sludge (wet)	0.942	ℓ/d
	Coarse refuse (dry)	0.025	ℓ/d
	Coarse refuse (wet)	0.13	ℓ/d
Composition	Fine sludge un-biodegradable fraction (dry basis)	21%	m^3/m^3
	Inorganic ash in sludge (dry basis)	14%	m^3/m^3

Model parameter values – compare to actual addition

	Model parameter	Value	units
Rate of addition	Fine sludge (dry)	0.182	ℓ/d
	Fine sludge (wet)	0.942	ℓ/d
	Coarse refuse (dry)	0.025	ℓ/d
	Coarse refuse (wet)	0.13	ℓ/d
position	Fine slu	21%	m^3/m^3

For family of 7 at 300g excreta & ACM per person /day +coarse refuse

2.23ℓ/d

= 815 ℓ/year

Average fill rate ref pits: <200ℓ/year
Average fill rate 50th percentile: ~320 ℓ/year

Accumulate between ¼ and ½ of material added after 14 years

Elucidating unbiodegradable fractions

- Reference pits
  - Fine sludge: feed = 21% unbiodegradable
  - Coarse refuse: final volume = 25% unbiodegradable
    - Corresponds to about 12% of feed
    - (fraction of total grows as total decreases)
  - Total feed unbiodegradable =

    21% of 88% + 12%

    ≈30%