

Activity 4b: Reducing uncertainty in the use of non-destructive, indirect measurement with LPR

Activity researchers : Tony Wells (UoN) and Sarath Kodagoda (UTS)

In collaboration with: Phil Ferguson of PCA Echologics



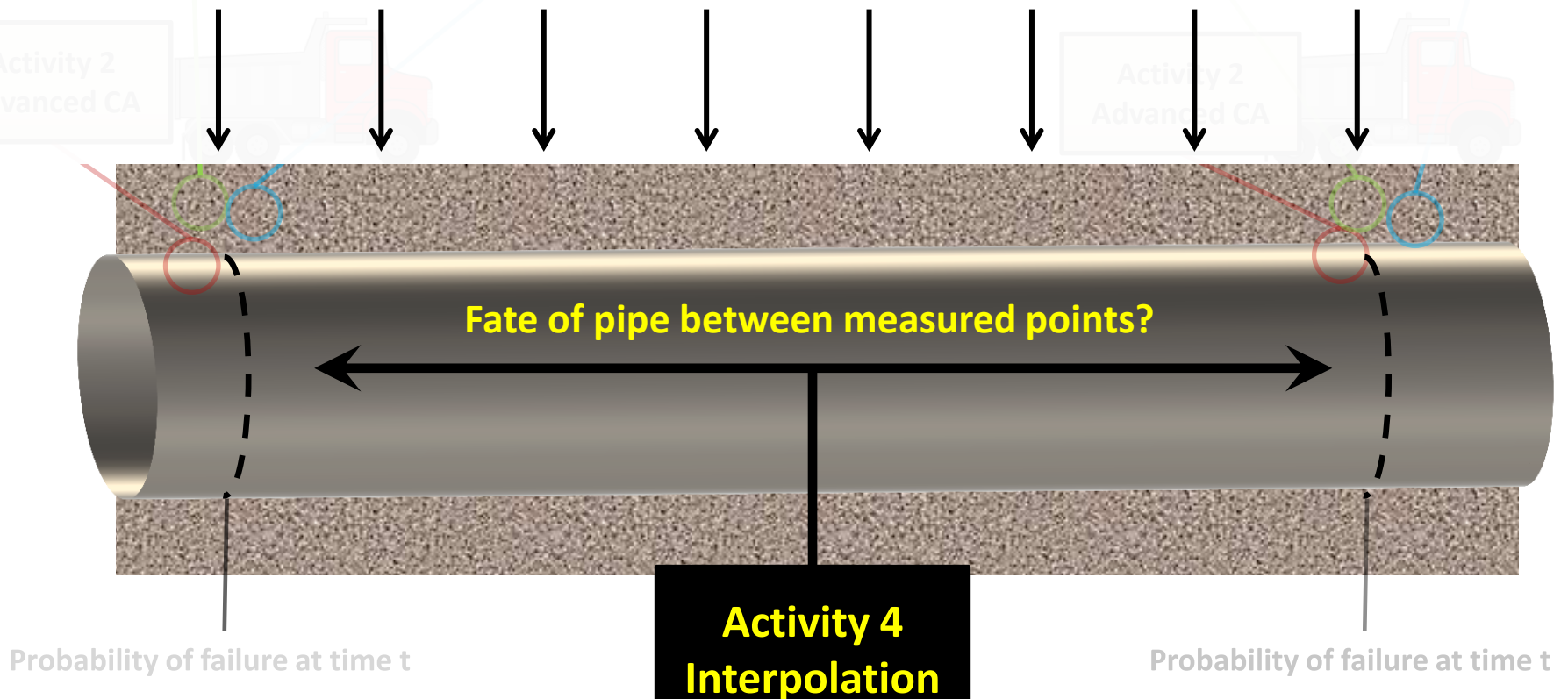
Plan of today's talk

Discussion of Activity 4b - Reducing uncertainty in the use of LPR

- **Background**
- **Uncertainty in LPR**
- **Improving the model (if time)**

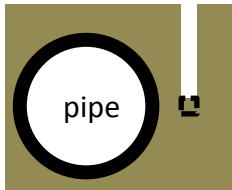
Why are we looking at LPR in Activity 4?

LPR – cheap, easy, shown to correlate well with corrosion

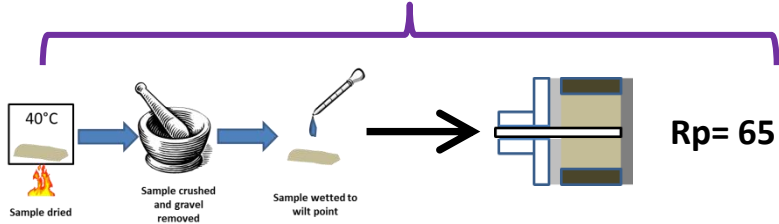


The LPR process

Soil Sampling



Soil Preparation and testing



Modelling

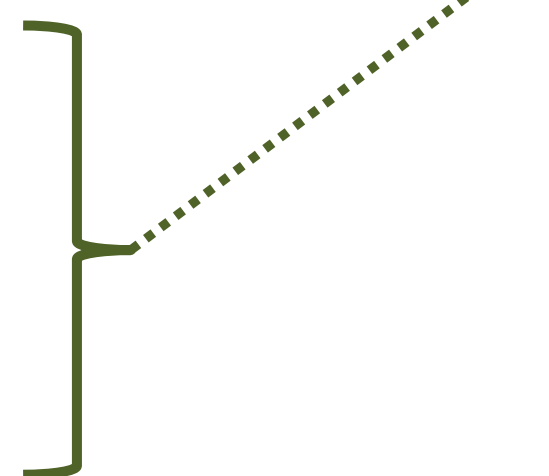
Rp= 65

$$\ln(\text{Pit rate}) = -0.564 - 0.0159 * R_p$$

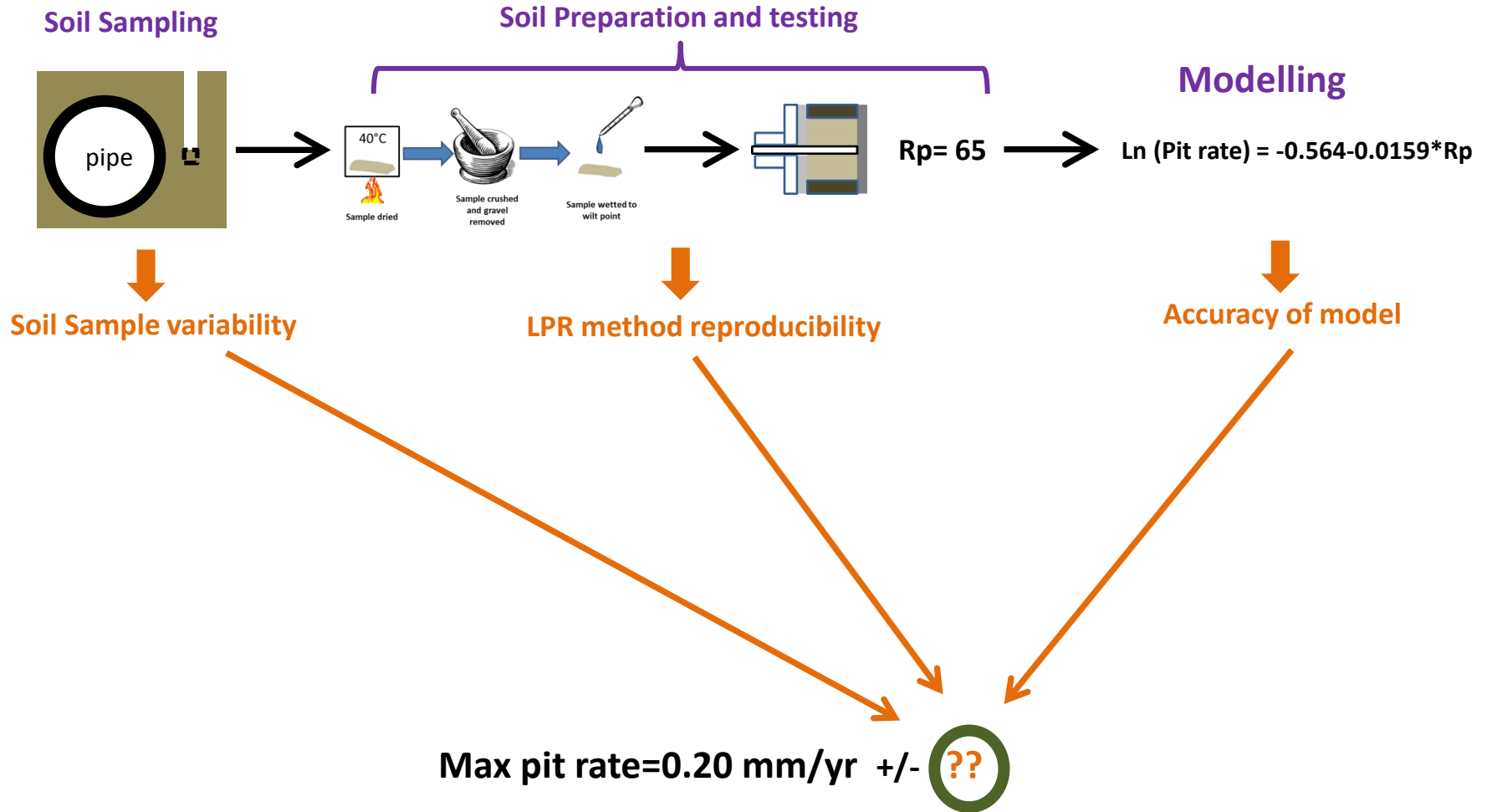
Aims of this activity

1. Current level of uncertainty?
2. What extra information can we add to reduce prediction uncertainty and improve corrosion predictions?
3. Developing a model using that extra information to reduce uncertainty?

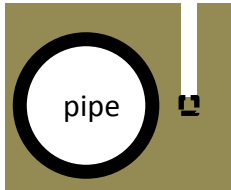
Max pit rate=0.20 mm/yr +/- **??**



The LPR process



Soil Sampling



Soil Sample variability



Vertical variability

Samples taken from 3 sites along the Verona St test bed

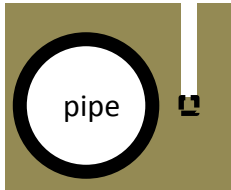


**Trial 3 pit 1 west
(silty/med/light clay)**

**Trial 3 pit 1 east
(med/silty/light clay)**

**Trial 2 pit 1 west
(sandy clay loam/light/light clay)**

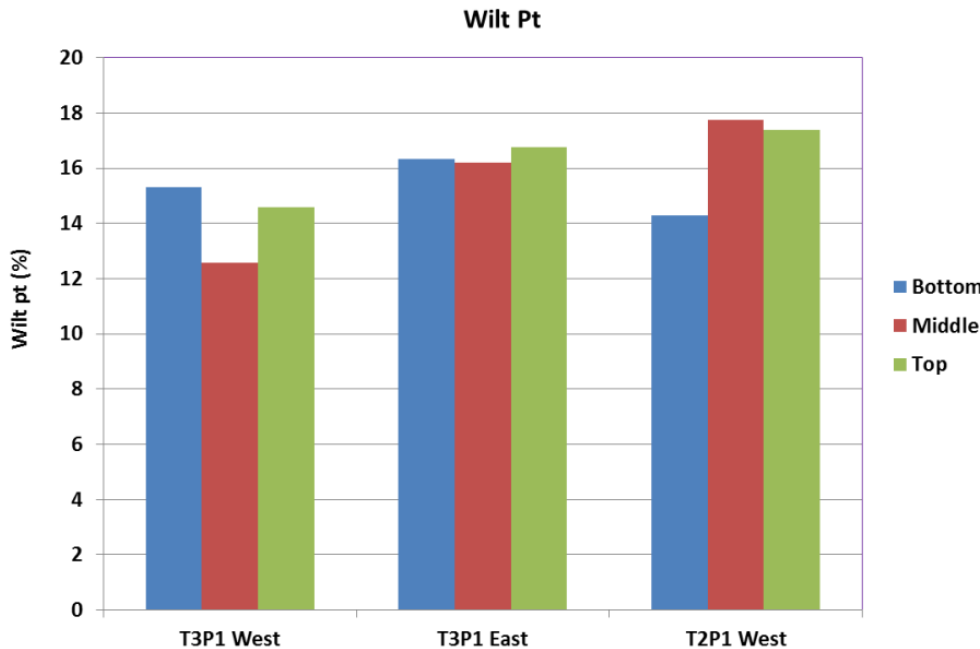
Soil Sampling



Vertical variability

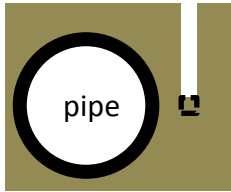


Soil Sample variability



- Wilt pts quite reproducible

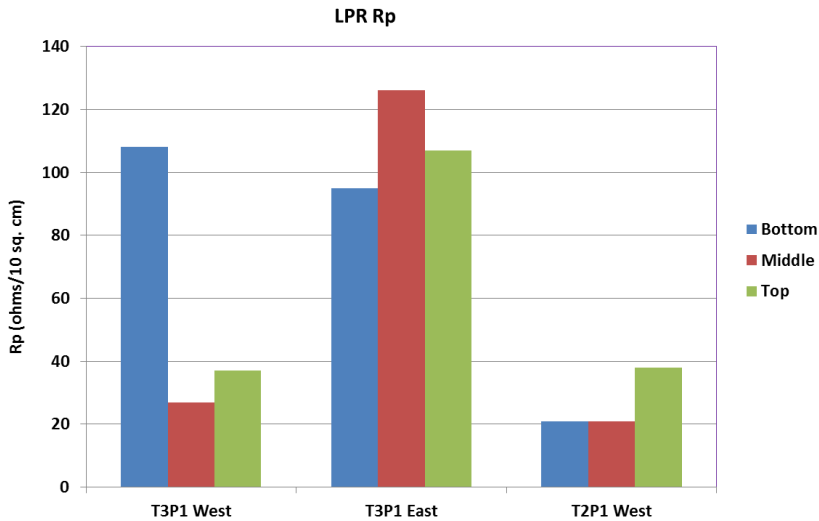
Soil Sampling



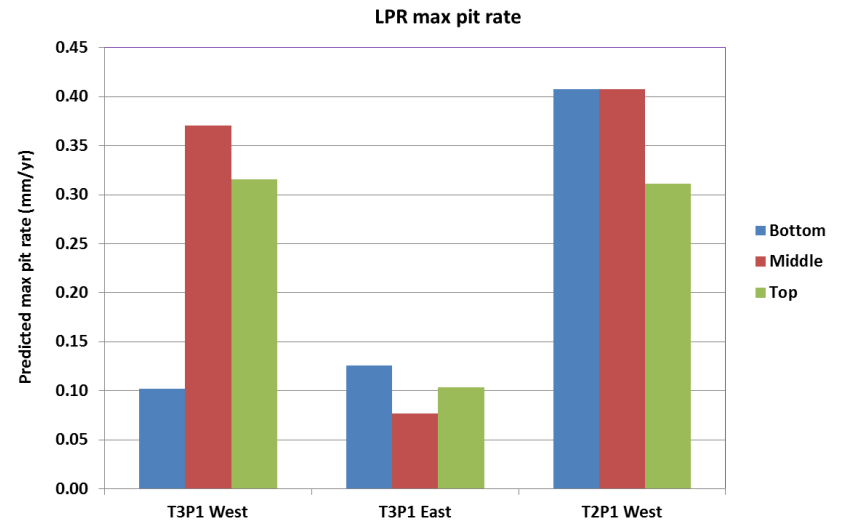
Vertical variability



Soil Sample variability

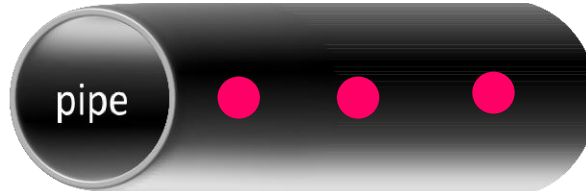
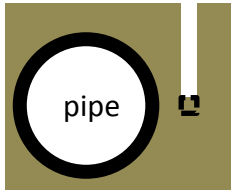


Average uncertainty = +/- 40%



Average uncertainty = +/- 30%

Soil Sampling

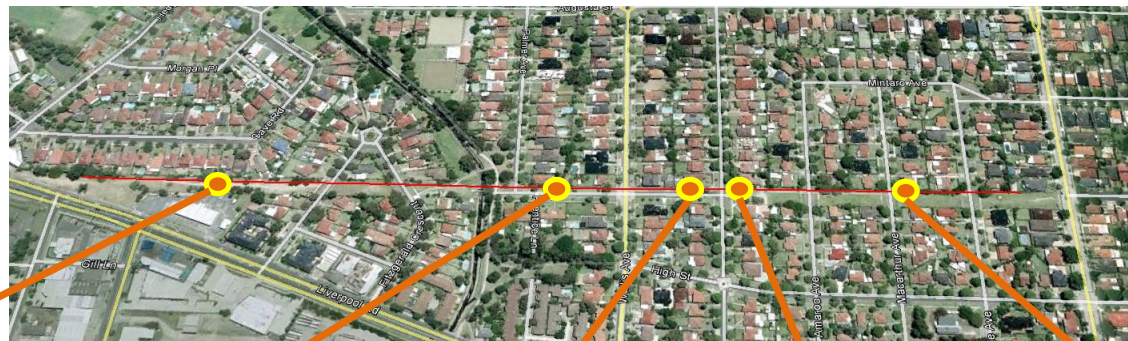


Horizontal variability



Soil Sample variability

Samples taken from 5 pairs of sites along the Verona St test bed



**Trial 3 pit 1 E&W
(light/light clay)**

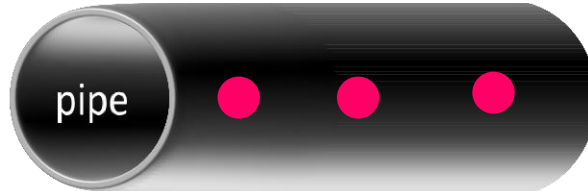
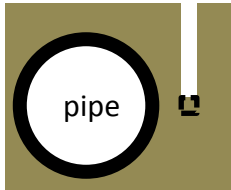
**Trial 2 pit 2 E&W
(med/light clay)**

**Trial 3 pit 2 E&W
(light/light clay)**

**Trial 3 pit 3/4 E&W
(light/silty clay)**

**Trial 2 pit 5 E&W
(sandy/light clay)**

Soil Sampling

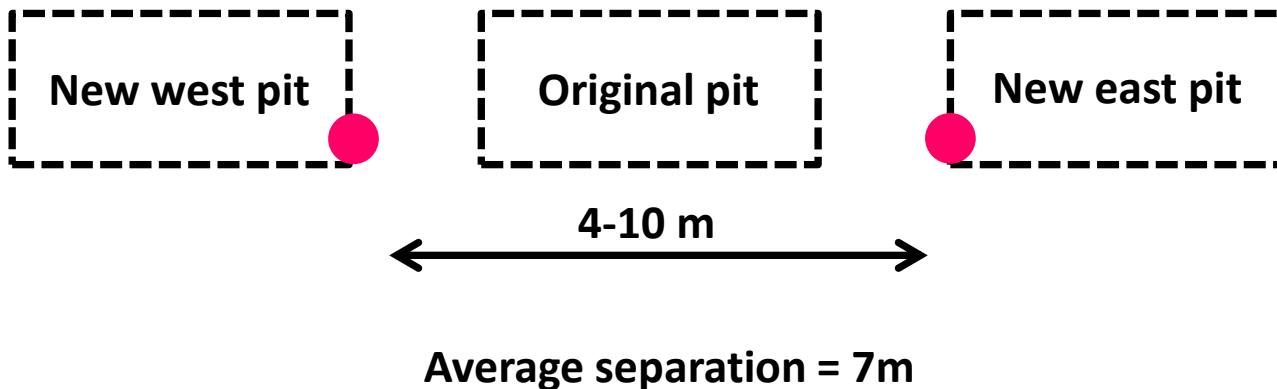


Horizontal variability

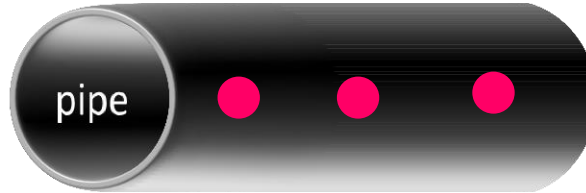
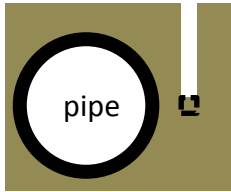


Soil Sample variability

Samples taken from 5 pairs of sites along the Verona St test bed



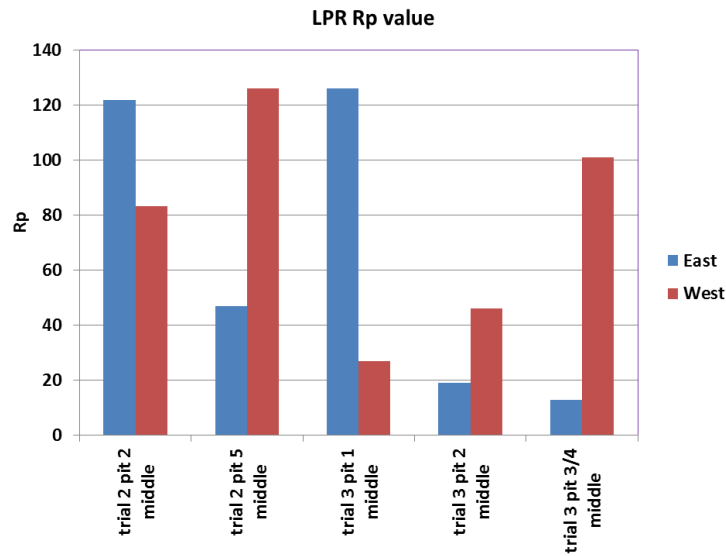
Soil Sampling



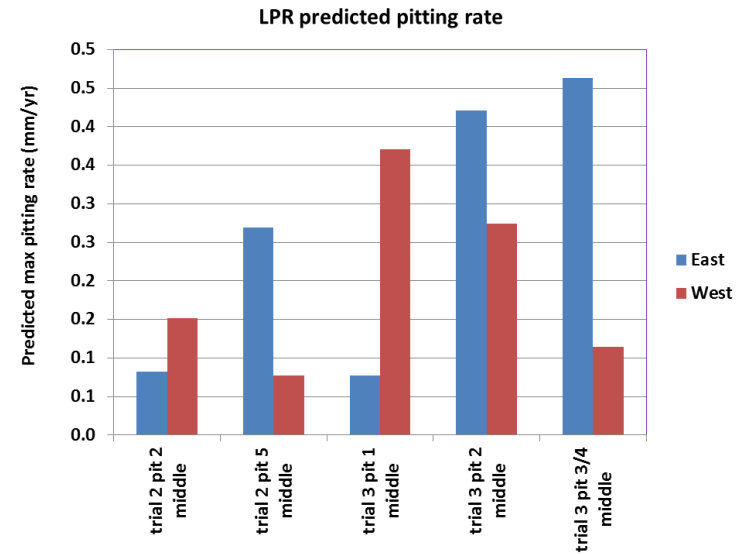
Horizontal variability



Soil Sample variability

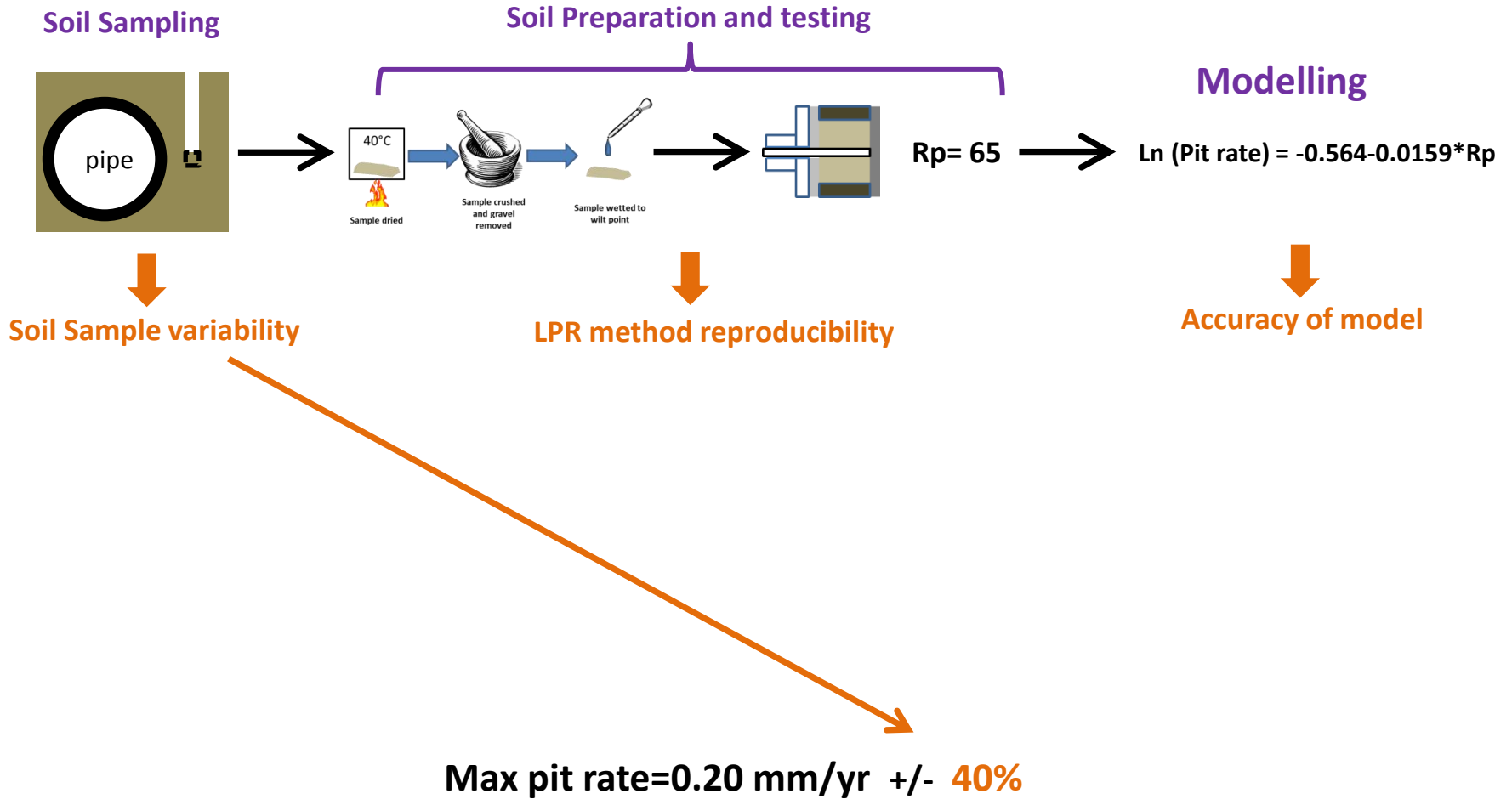


Average uncertainty = +/- 50%



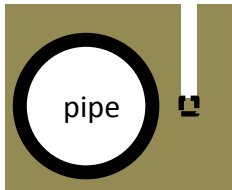
Average uncertainty = +/- 45%

The LPR process

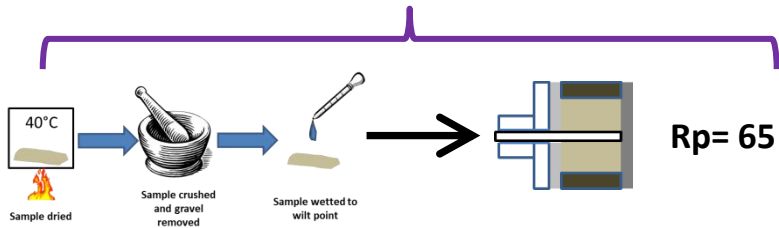


The LPR process

Soil Sampling



Soil Preparation and testing



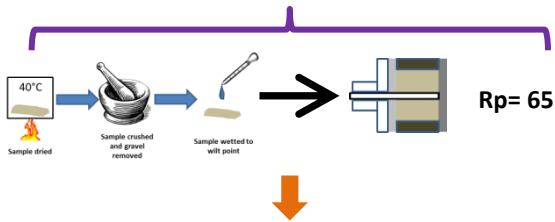
Modelling

$R_p = 65$ → $\ln(\text{Pit rate}) = -0.564 - 0.0159 * R_p$



LPR method reproducibility

Soil Preparation and testing

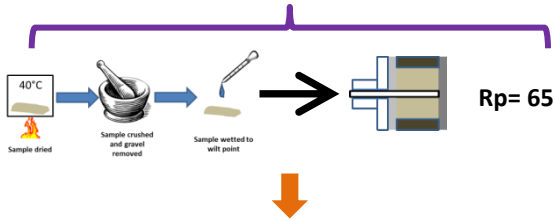


LPR method reproducibility

Uncertainty in Rp value for single sample

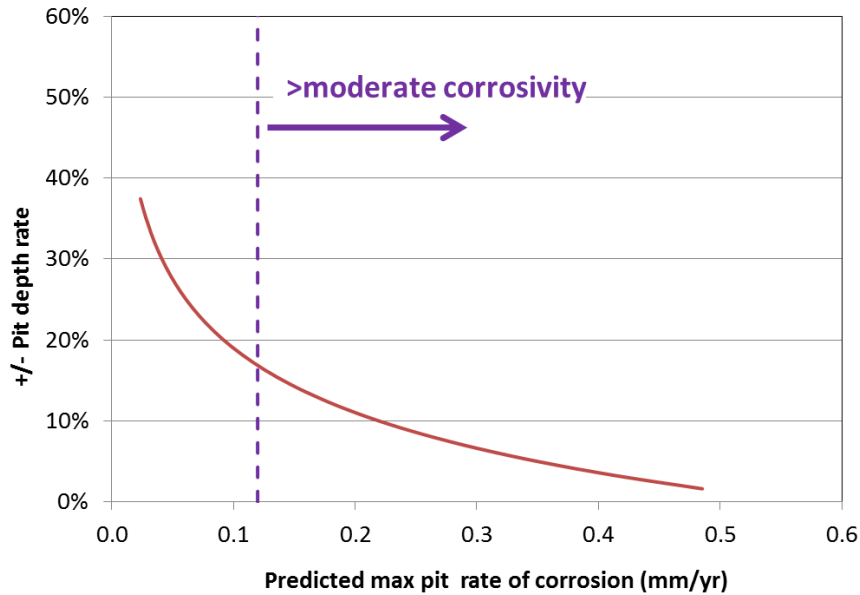
- PCA echologics – CoV = 10% for 3 or more subsamples from same overall sample
- Matt Dafter work – average CoV (13 samples × 5 runs each) = 13.5%
- CoV = coefficient of variation = Standard deviation / mean (% spread of data)

Soil Preparation and testing



Uncertainty in Rp value for single sample

LPR method reproducibility



10% Uncertainty in generated Rp value

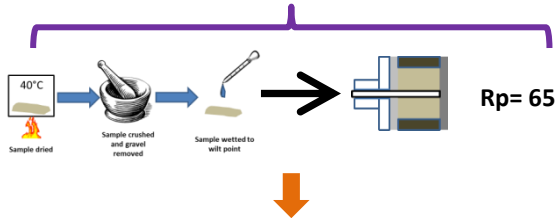


5-15% uncertainty in final corrosion rate prediction
(at moderate to severe corrosion conditions)



Uncertainty = 1 to 2mm for max pit depth
(Verona St test bed)

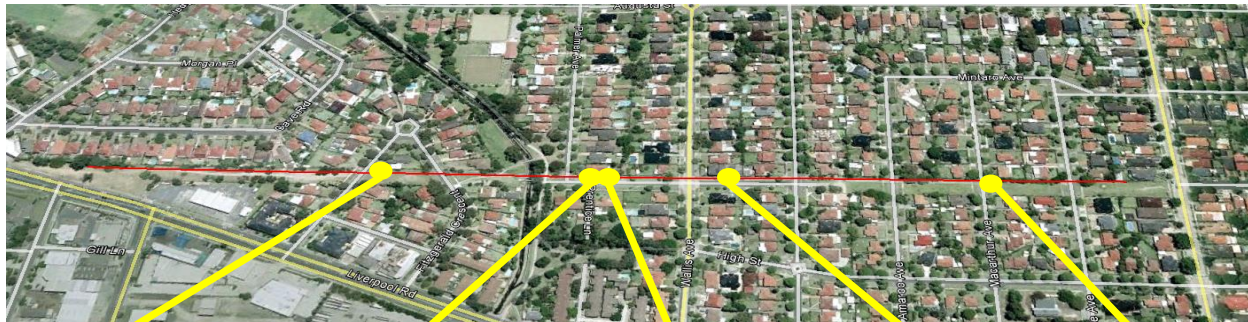
Soil Preparation and testing



Uncertainty in R_p value for single sample

LPR method reproducibility

Blind repeat testing of Verona St test bed samples from 5 sites



Trial 5 pit 1/2
(med clay)

Trial 2 pit 2 West
(light clay)

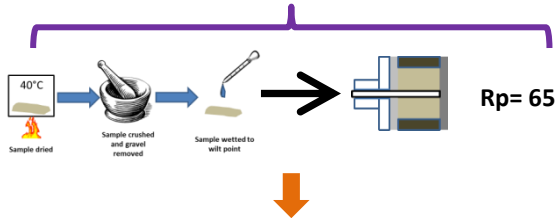
Trial 2 pit 2 East
(med clay)

Trial 5 pit 3
(sand)

Trial 2 pit 5
(light clay)

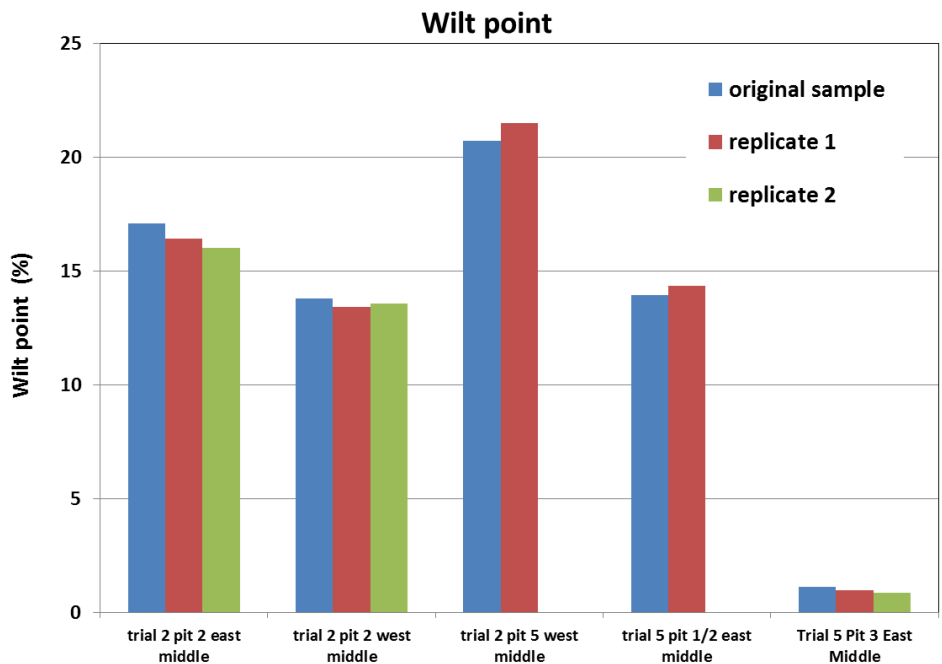
- Repeat samples from soil removed at 5 sites along the test bed were sent for testing at PCA
- PCA was not aware of the nature of the samples
- Samples were not completely identical due to clay nature so some sample to sample variation was possible (slicing and dicing only)

Soil Preparation and testing



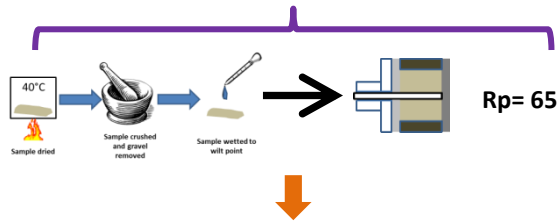
Uncertainty in Rp value for single sample

LPR method reproducibility



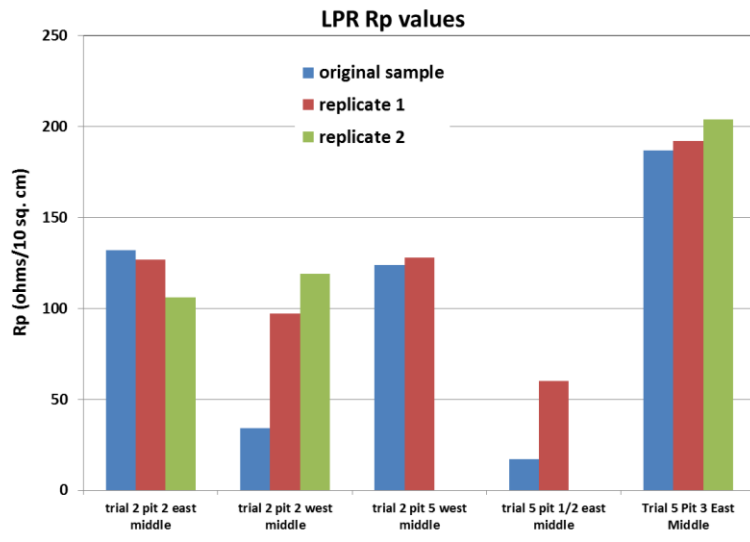
- Again wilt pts quite reproducible

Soil Preparation and testing

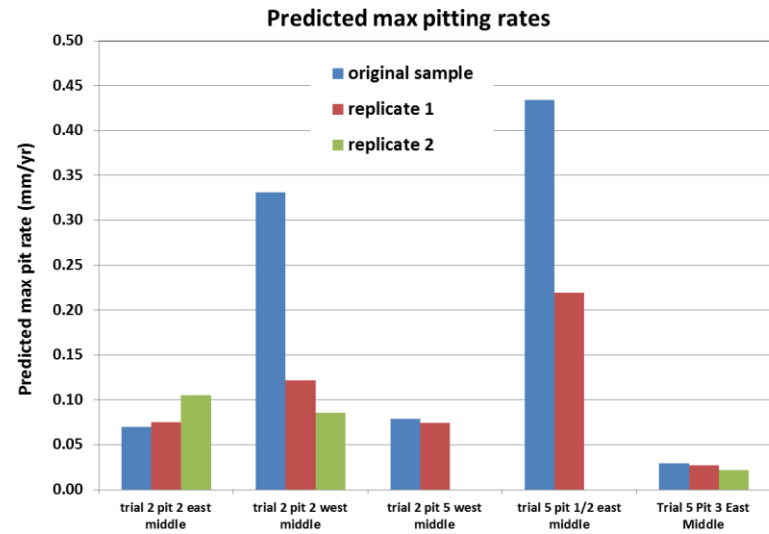


Uncertainty in Rp value for single sample

LPR method reproducibility



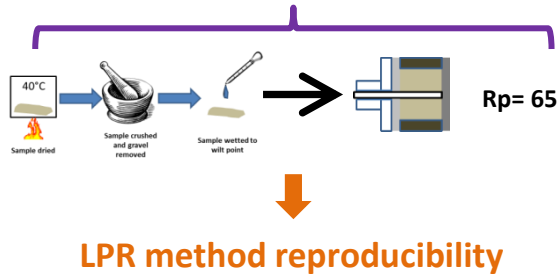
Average uncertainty = +/- 30%



Average uncertainty = +/- 30%

But results quite variable

Soil Preparation and testing

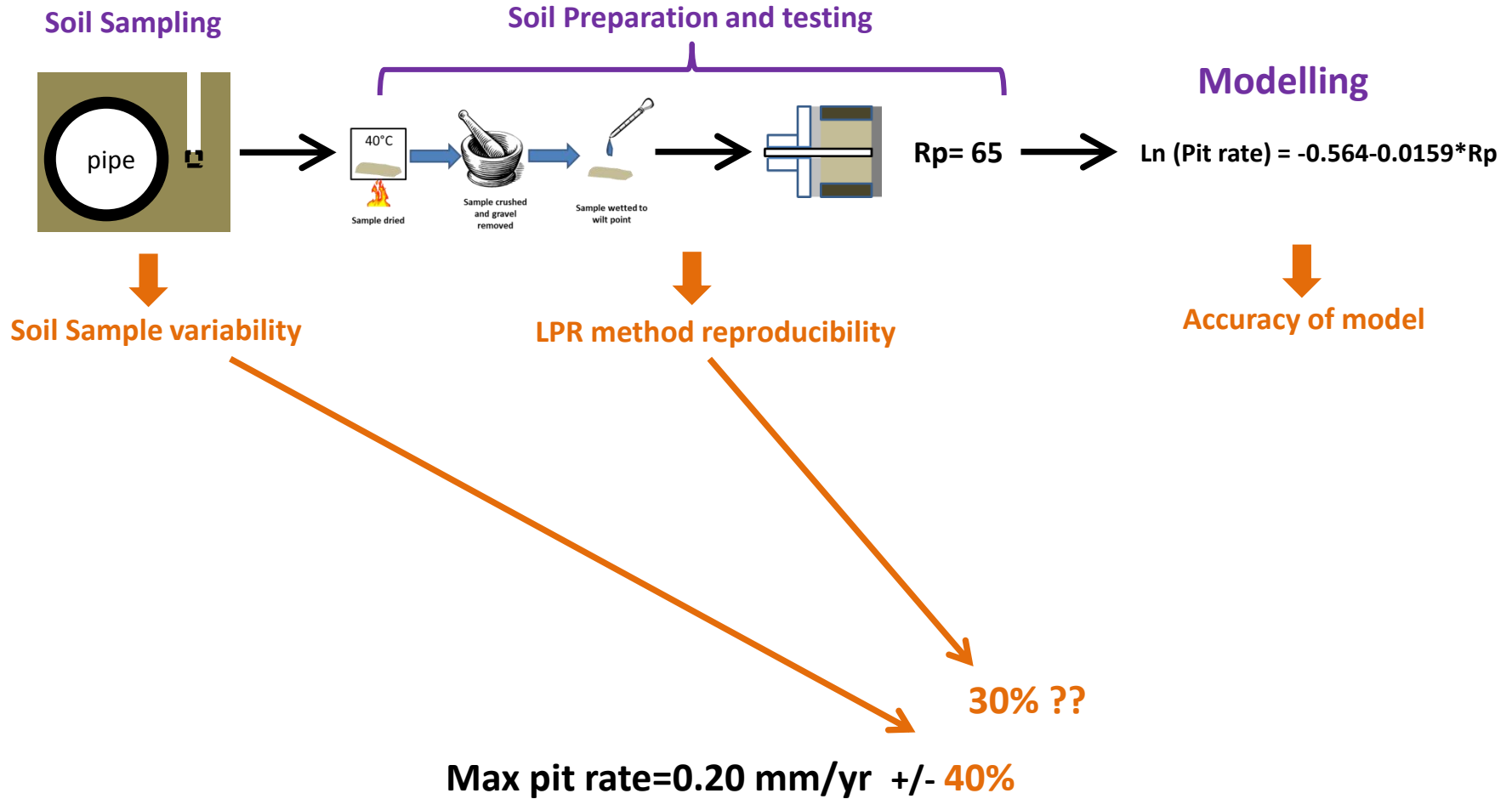


Uncertainty in Rp value for single sample

Limited number of blind replicates suggest:

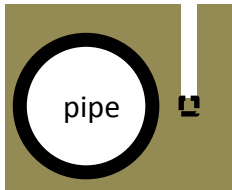
- Uncertainty of ~30% in CR prediction from a single sample
- Were repeat samples true replicates?
 - **Perhaps not (not possible to rifle clay samples)**
 - If this is the case uncertainty we see here due to micro variation in soils + uncertainty in method
- Need to repeat exercise under more controlled conditions to verify

The LPR process

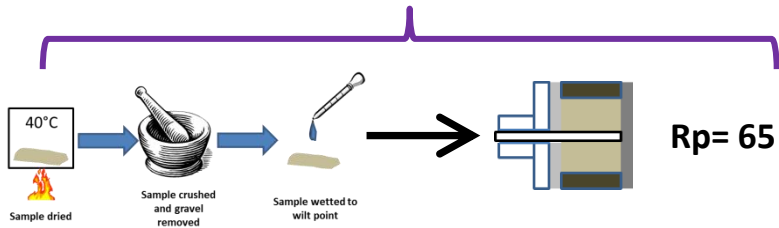


The LPR process

Soil Sampling



Soil Preparation and testing



Modelling

$R_p = 65$ → $\ln(\text{Pit rate}) = -0.564 - 0.0159 * R_p$

↓
Accuracy of model

Original formulation based on 30 cast iron pipe samples

For the equation $\ln(\text{pit rate}) = A + B * R_p$ $R^2 = 0.723$

We still as yet have not found the original data

Why important?



Modelling

$$\ln(\text{Pit rate}) = -0.564 - 0.0159 * R_p$$

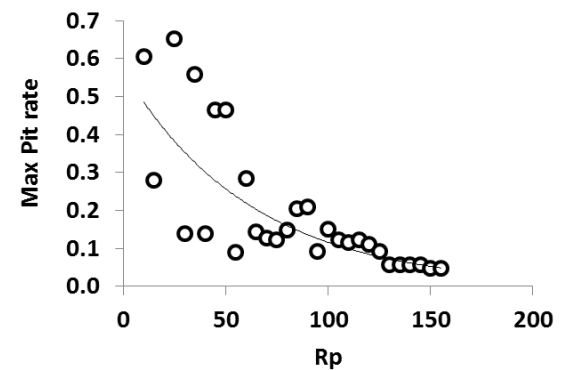
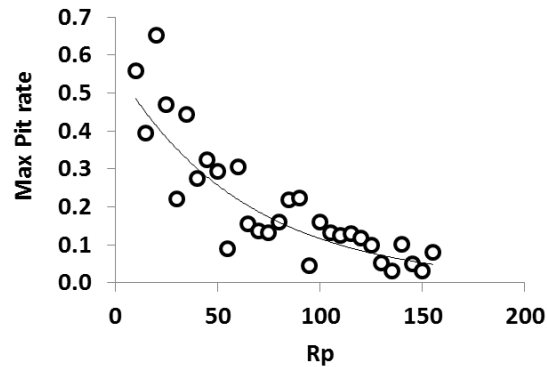
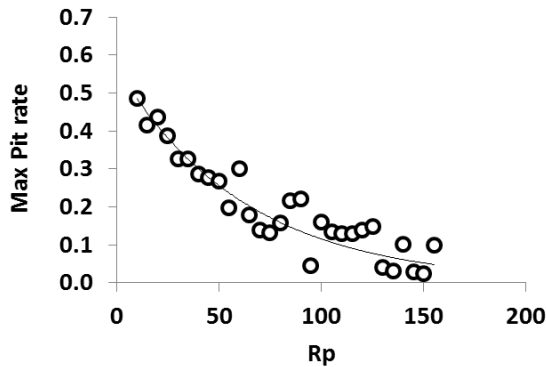


Accuracy of model

All of the below

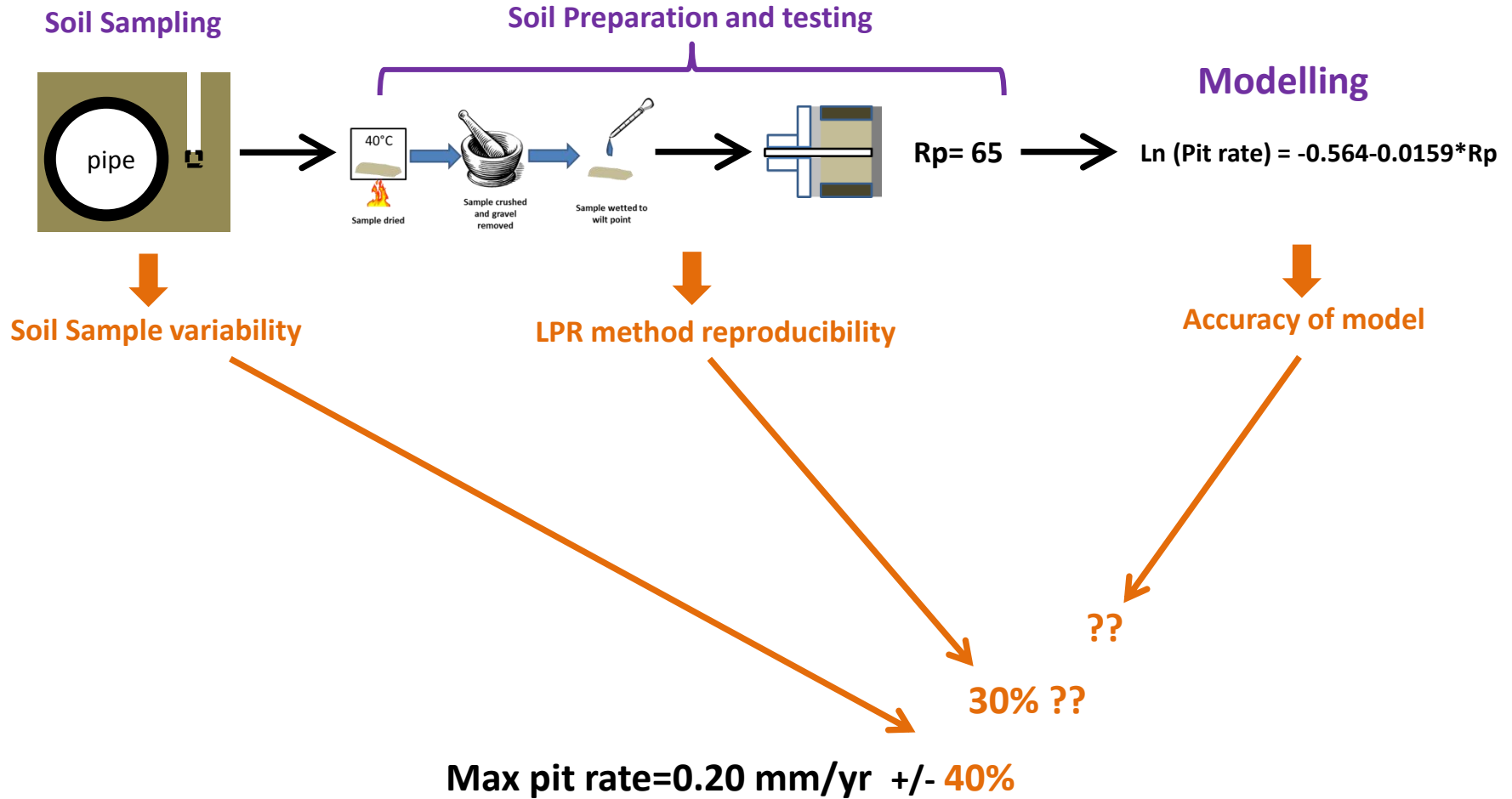


$$\ln(\text{Pit rate}) = -0.564 - 0.0159 * R_p \quad r^2 = 0.723$$

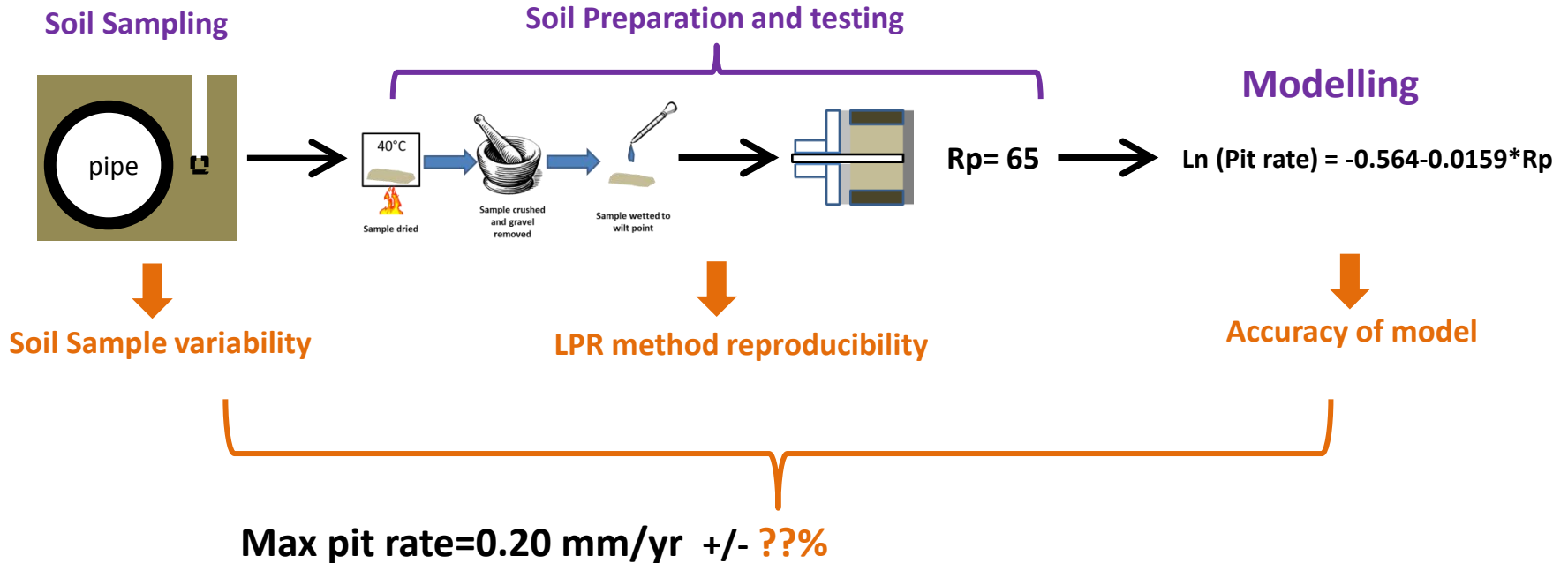


Av error in predictions:	45%	43%	35%
Av error in v. corrosive env:	4%	28%	60%
Av error in corrosive env:	15%	36%	58%

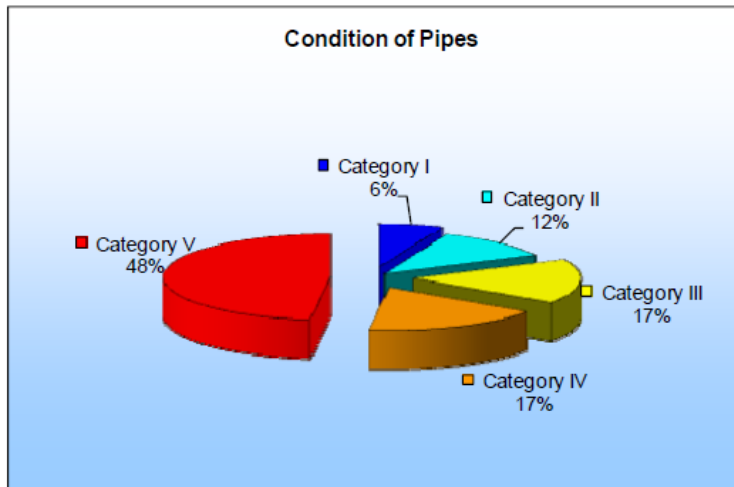
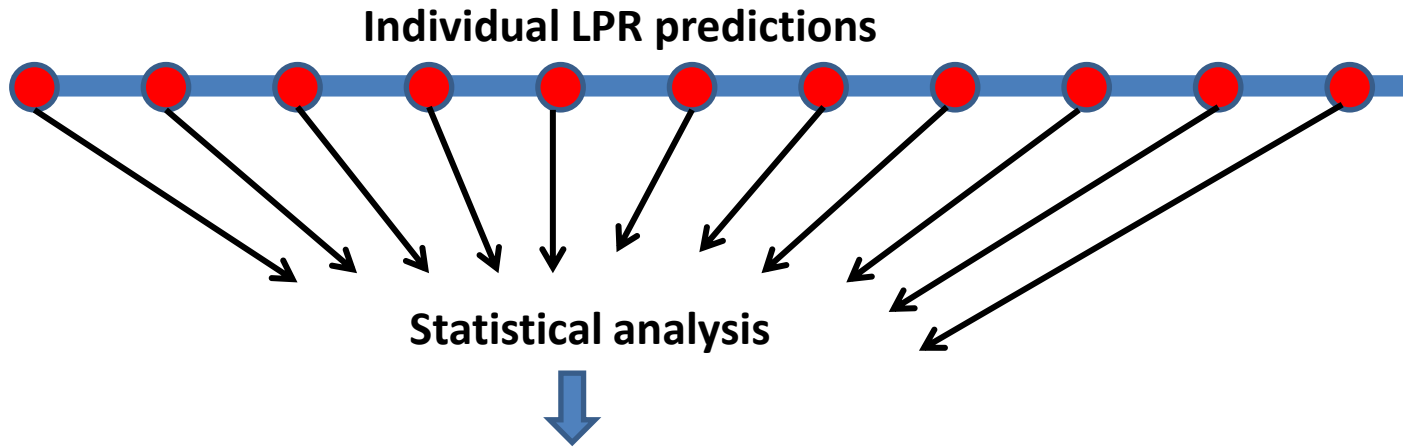
The LPR process



The LPR process



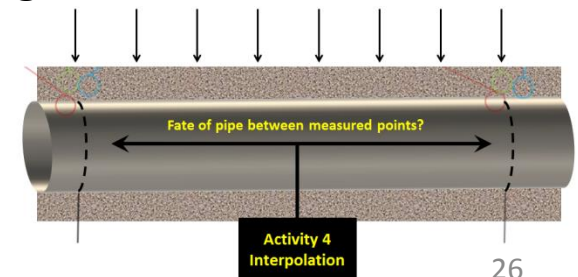
- Altogether a fair degree of uncertainty in **any one measurement**
- This is recognised by PCA and the LPR results are statistically managed to provide the final pit rate distribution data along a section of pipe



**How are uncertainties reflected
In final LPR breakdown of pipe condition?**

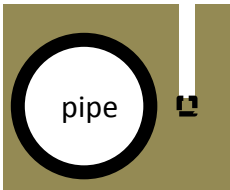
Future (final) work to determine LPR uncertainty:

- Track down the original algorithm data -> distribution of modelling uncertainty
- Get fine details of statistical methodology from PCA
- Then test effect of individual uncertainties in the stated final pipe condition distribution reported (monte carlo approach?)
- What we have learnt however is that LPR probably works best when predicting CA over longer lengths of pipe
- LPR may not be so good if used to predict CA on short sections unless high sample resolution used (i.e. need many measurements for good statistical analysis)

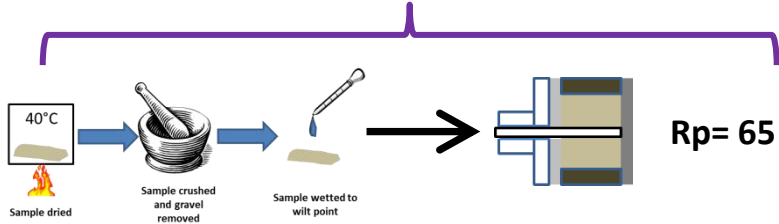


The LPR process

Soil Sampling



Soil Preparation and testing



Modelling

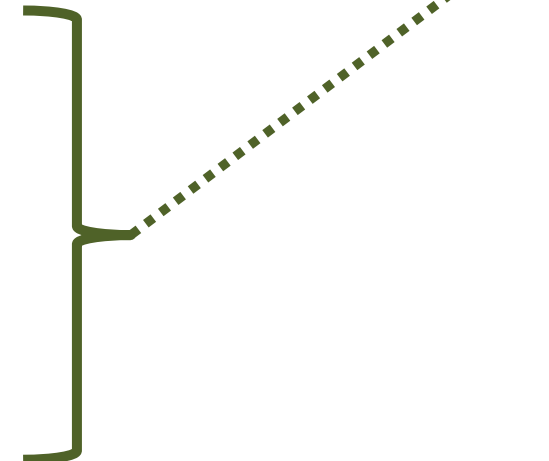
Rp= 65

$$\ln(\text{Pit rate}) = -0.564 - 0.0159 * R_p$$

Aims of this activity

1. Current level of uncertainty?
2. What extra information can we add to reduce prediction uncertainty and improve corrosion predictions?
3. Developing a model using that extra information to reduce uncertainty?

Max pit rate=0.20 mm/yr +/- **??**



What extra information can we add to reduce prediction uncertainty and improve corrosion predictions?

Two approaches taken:

- (1) LPR from a theoretical standpoint
- (2) LPR from a practical standpoint

Factors that should be examined for inclusion in LPR model to reduce uncertainty:

- (1) Method of pipe manufacture
- (2) Age of the pipe
- (3) Soil moisture level
- (4) Backfill type and quality

Is there enough data for model development??:

- LPR analysis + soil moisture + age/manufacture method of pipe + backfill information+ a valid measurement (most likely laser scanning) of pipe to determine max pit depth.
- Not enough yet for ML analysis