THE UNIVERSITY OF NEWCASTLE AUSTRALIA

TAC meeting June 2015 Activity 3 presentation

Robert Petersen

Rob Melchers

Outline

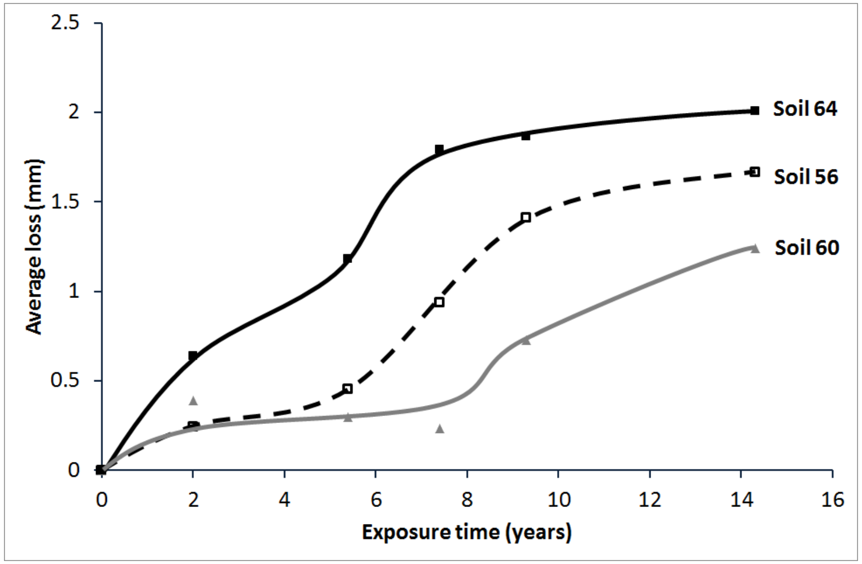
- Background and aims
- Overview of previous work
- Current work analysing influence of N, P, Cl on corrosion
- Future work

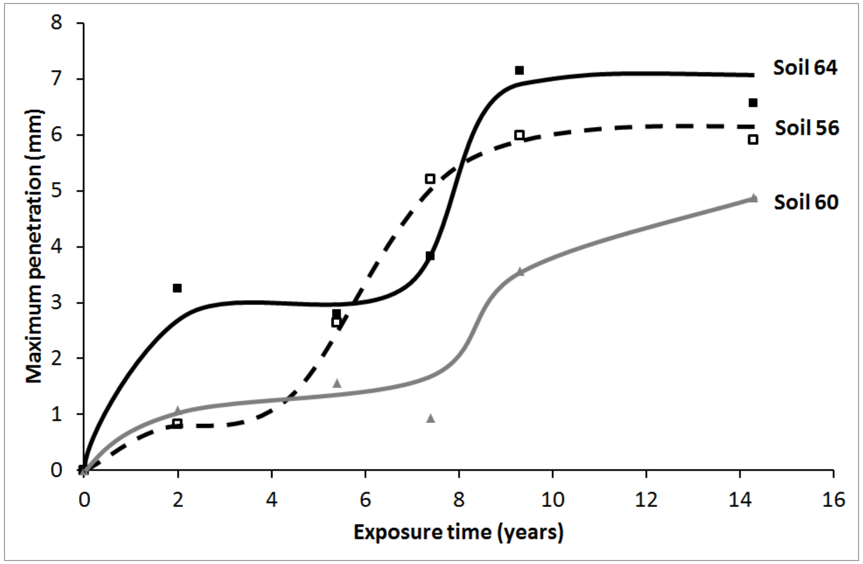
Background and aims

- Aim - develop models for external corrosion depth as a function of time and soil environment
- Looking at old, large diameter cast iron cement lined pipes

Overview of progress to date (1)

- We first observed corrosion in a soil follows a bi-modal trend with time (typical for 50+ soils – Romanoff 1957)

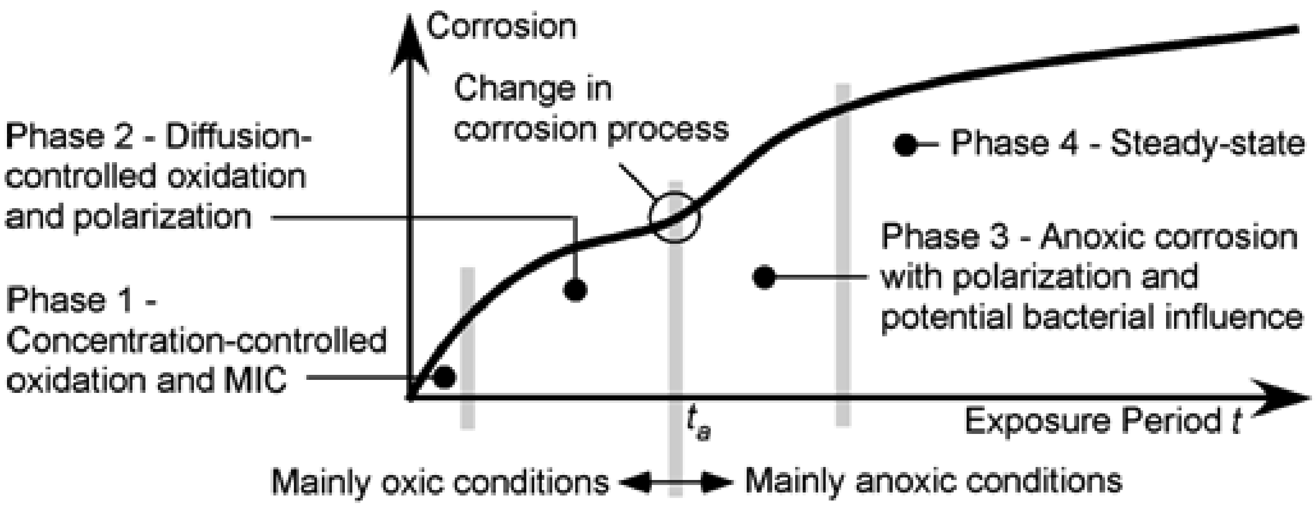




THE UNIVERSITY OF NEWCASTLE AUSTRALIA

Overview of progress to date (2)

- From this evidence we then argued the bi-modal behaviour is a result of corrosion following these phases:



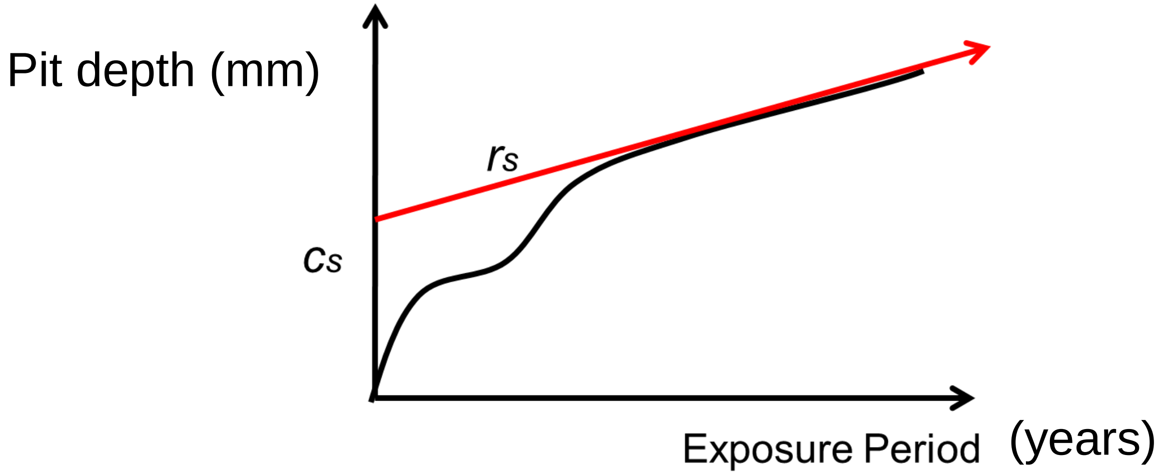
Overview of progress to date (3)

- And then we looked at all of the soil corrosion factors identified by others
- Soil type, moisture, aeration, MIC, among others
- And assessed their theoretical influence on the long-term corrosion rate
- Moisture, compaction and nutrient levels were identified as main variables back then

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

Overview of progress to date (4)

- We then proposed the following relationship for corrosion depth as a function of time
- With the height and slope of the line a function of the soil environment



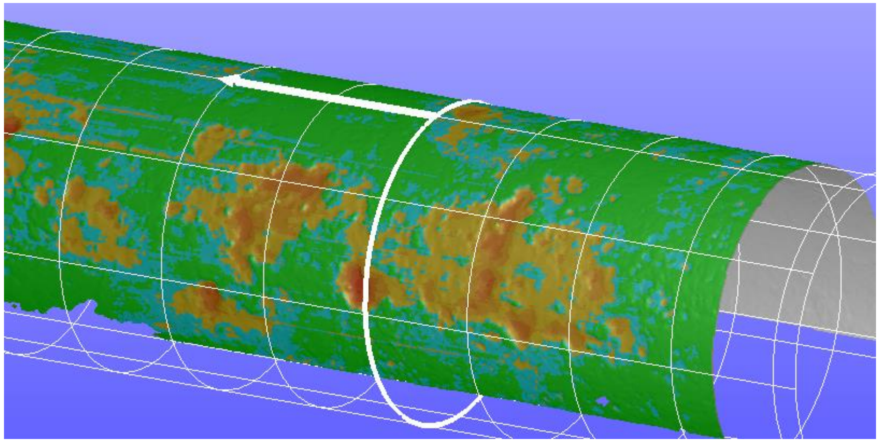
- We asked for data of long-term corrosion losses and soil conditions to calibrate it (protocol)

Overview of progress to date (5)

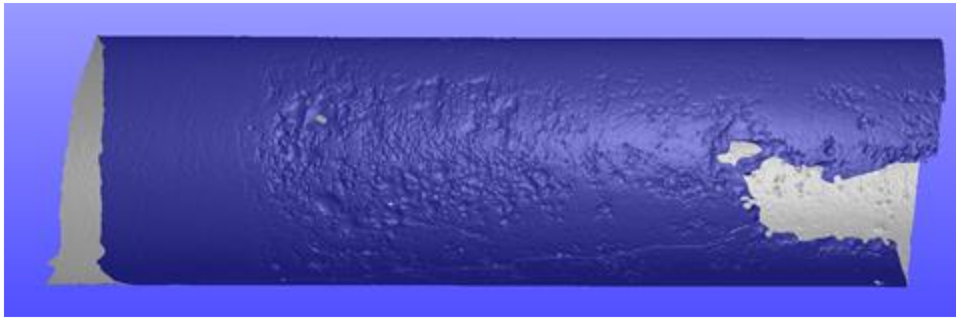
- We have collected new data from the following sources using the data collection protocol:
- HW Pilot study (2013) (~20 sites)
- SW Breaks (2013/2014) (~10 sites)
- Test Bed (2014) (~10 sites)
- Perth WC (2014) (2 sites)
- At most of these sites we have collected high quality data – 3d scans of corroded pipe surface + soil testing results

Overview of progress to date (6)

- HW pilot study



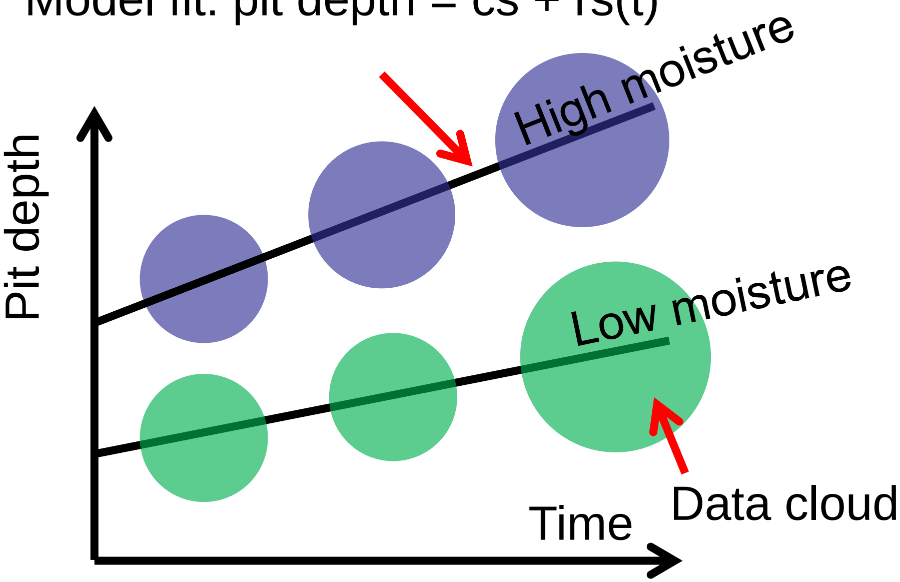
- SW breaks



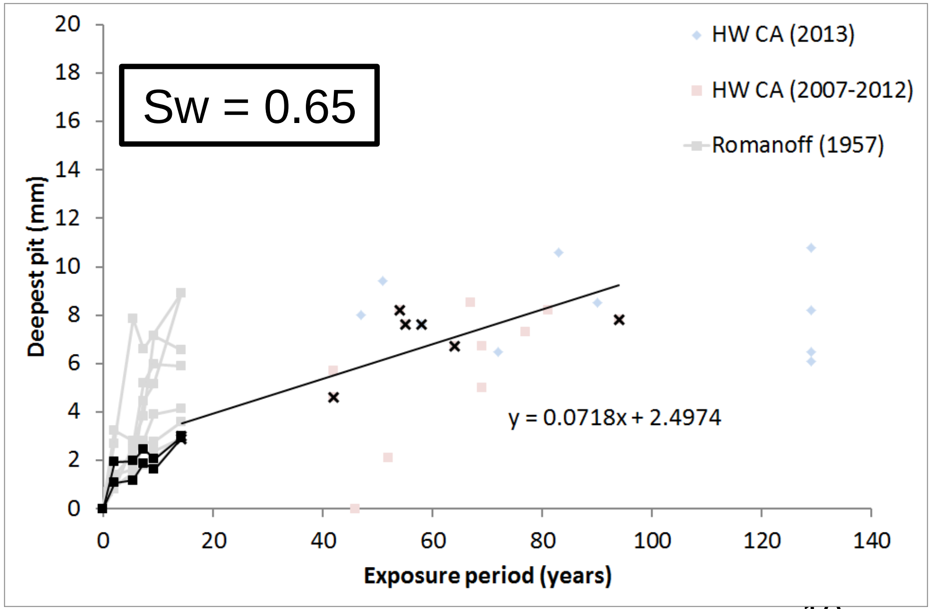
Previous model calibration (1)

- Initial model calibrations only considered the influence of soil moisture (measured as a degree of saturation)
- Data sets were grouped by moisture and straight lines were fit to the data

Model fit: pit depth = cs + rs(t)



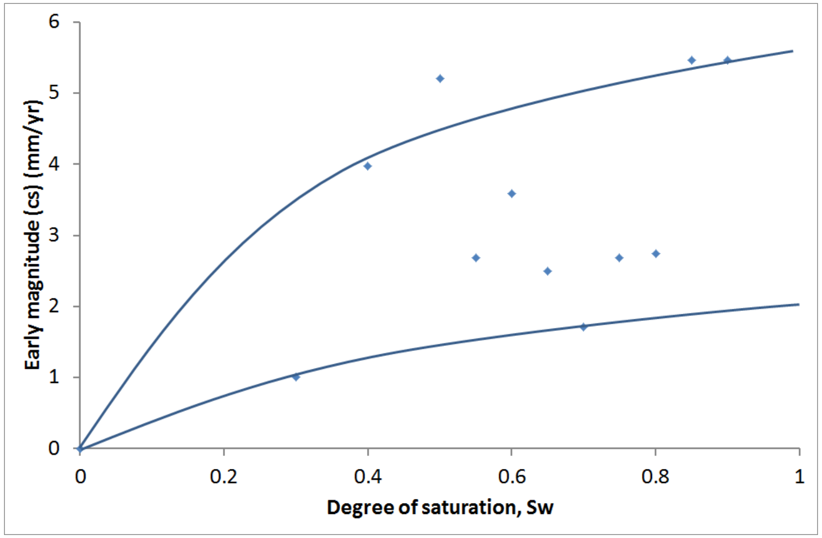
Concept

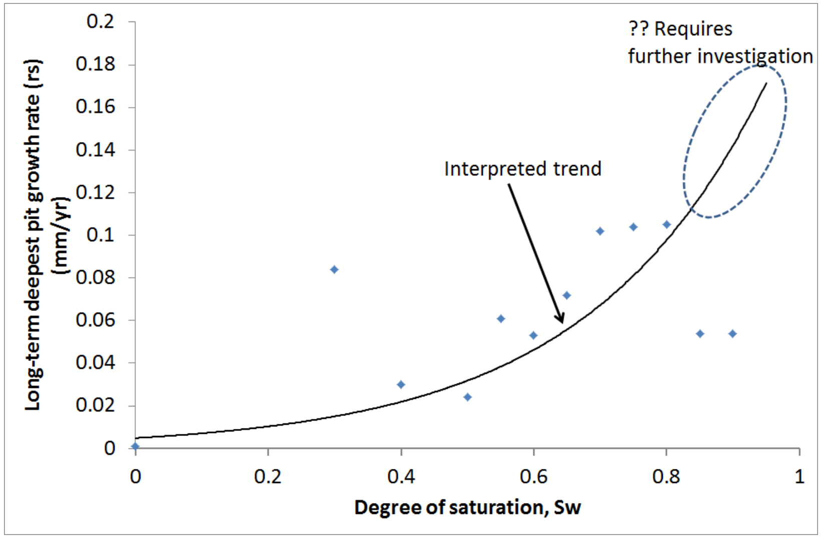


Actual

Previous model calibration (2)

- Model parameters cs and rs as functions of degree of saturation.
- Note variability. Expected variability to be due to the influence of additional variables (see next slide)



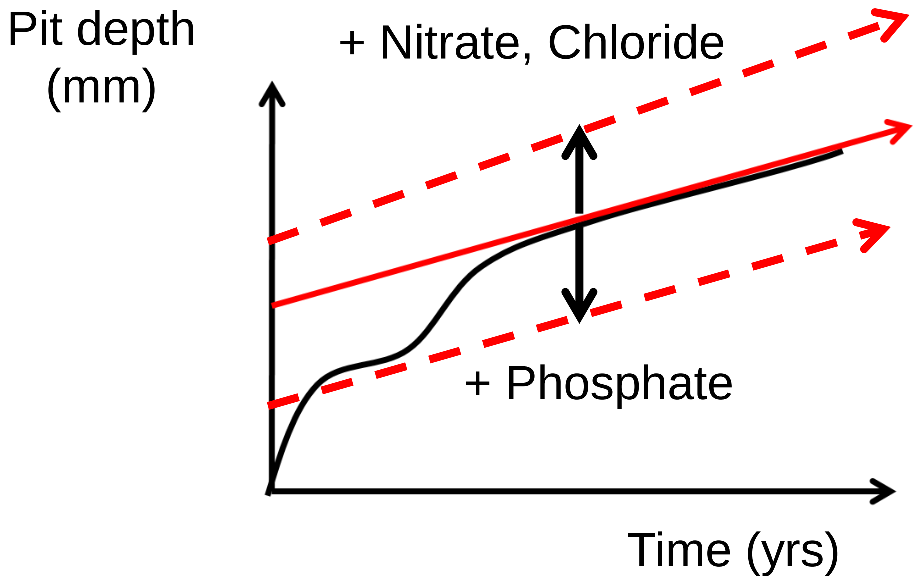


Current work

- Studying the influence of additional variables on the long-term corrosion of buried cast iron
- Recent analysis of the combined collected data indicates variation in corrosion is a result of the following additional variables:
- Nitrates (limiting nutrient)
- Phosphates (nutrient, but also an inhibitor)
- Chlorides

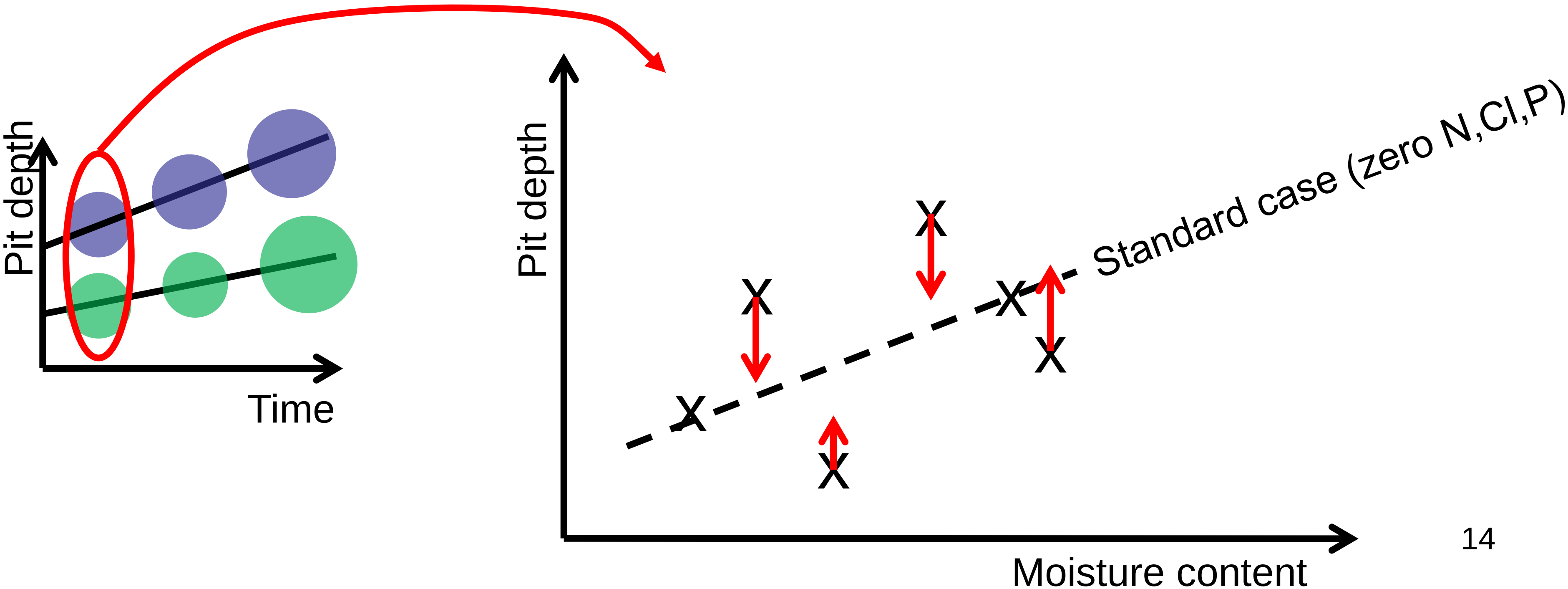
Current approach (1)

- Expected influence of variables based on simplified linear model:



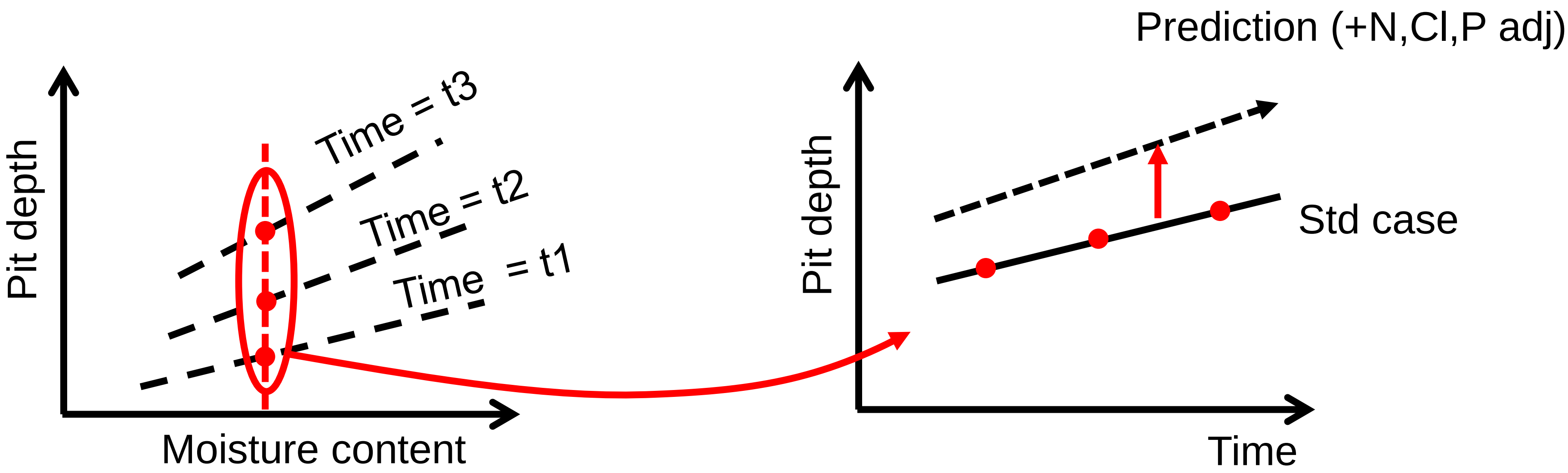
Current approach (2)

- Estimate influence of parameters and correct data back to a standard case with zero N, Cl, P
- Then see how standard case varies with moisture



Current approach (3)

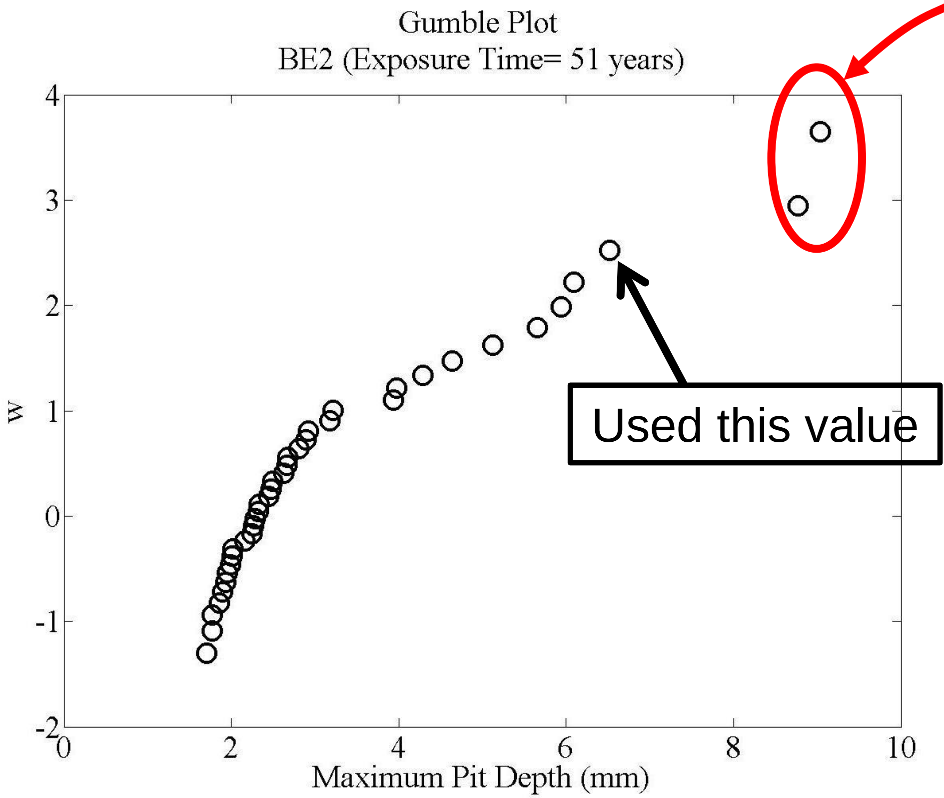
- To predict corrosion for local conditions work backwards from std case & add corrections back on



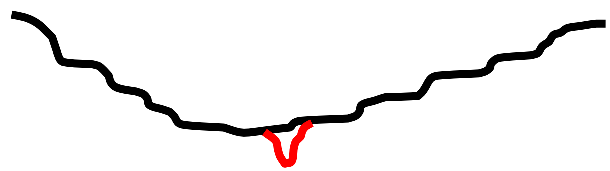
Standard cases (zero N,Cl,P)

Pit depth adjustment

- Before adjustments for N, Cl, P made, outlier extreme pit depths removed

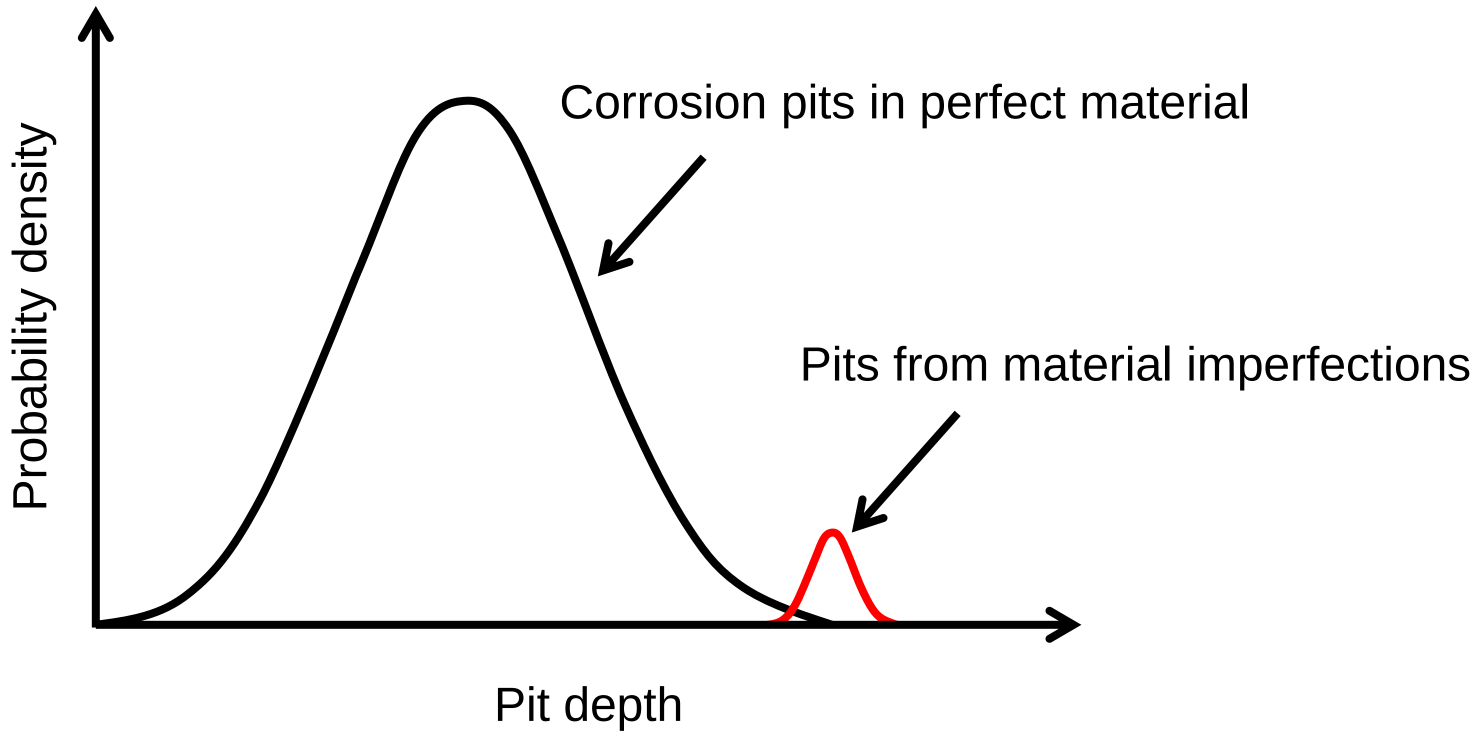


Outliers.
Considered to be result of small material imperfections



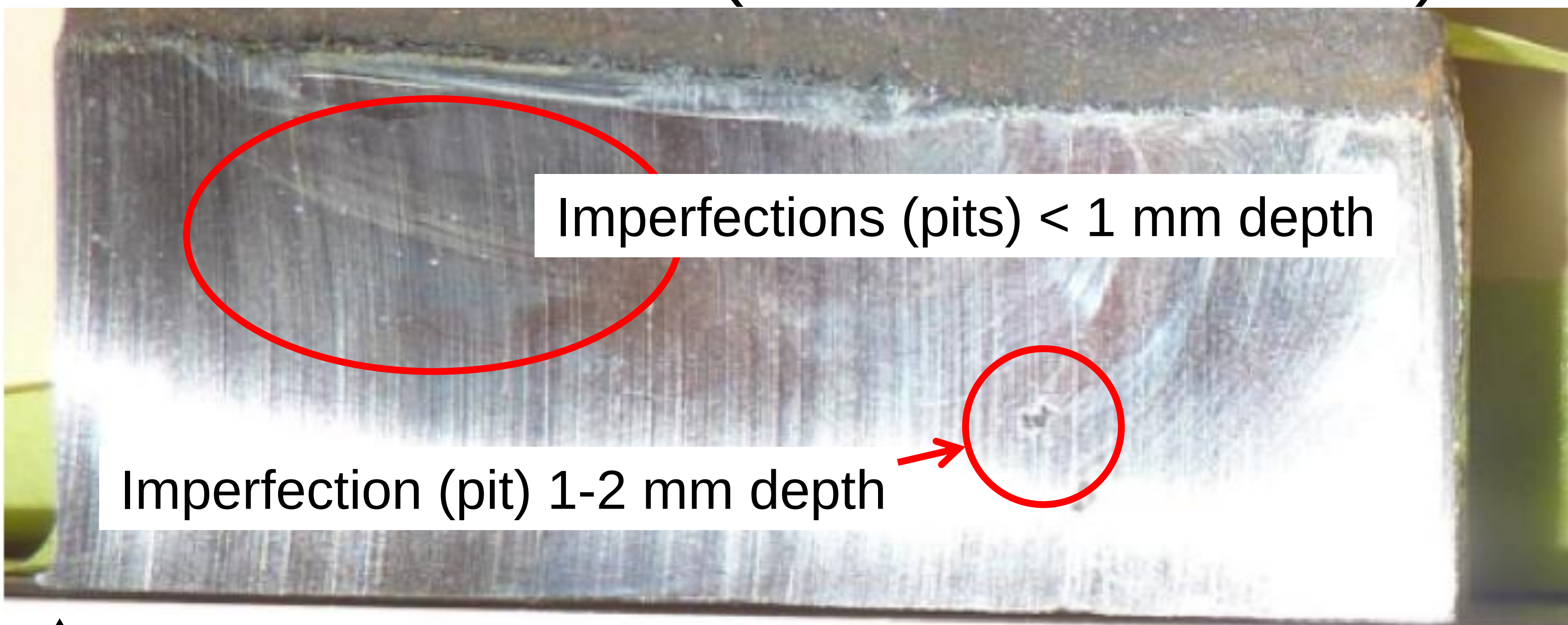
Probability density function

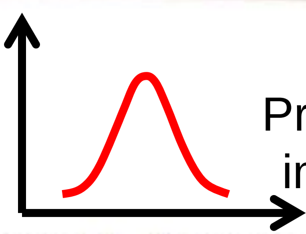
- Separate probability functions for corrosion pits in perfect material and material imperfections



Centre for Infrastructure Performance and Reliability

Example of material imperfections Sectioned cast iron (uncorroded surface)



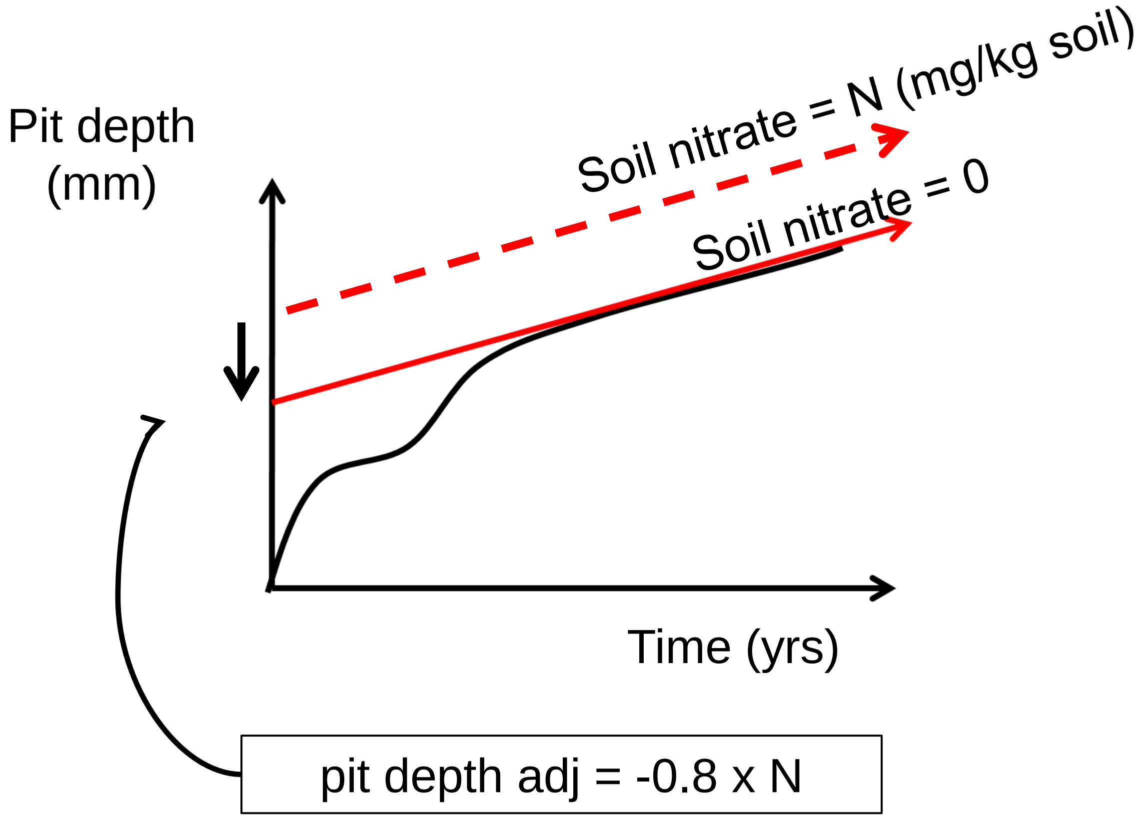


Probability function - imperfection depth

PhD Currently quantifying PDF by taking x-sections of SW pipes

Nitrate (nutrient) adjustment (1)

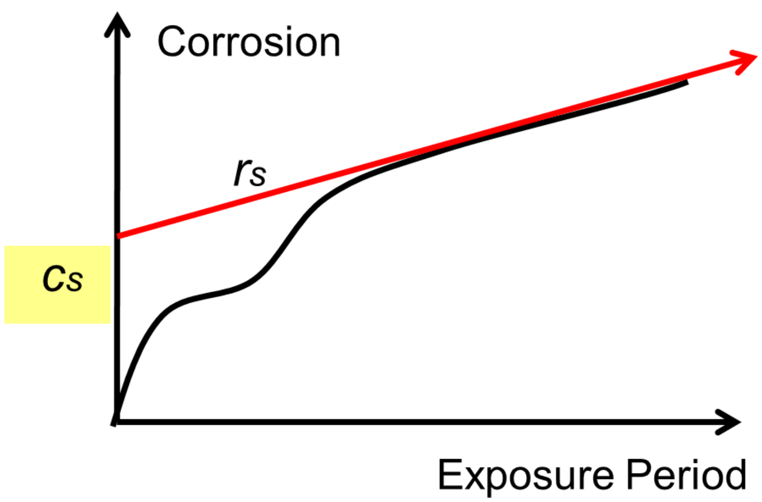
- Estimate for N adjustment

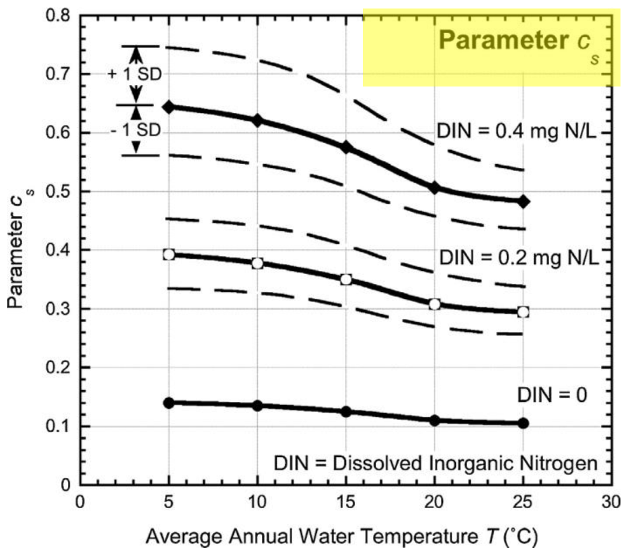


THE UNIVERSITY OF NEWCASTLE AUSTRALIA

Nitrate (nutrient) adjustment (2)

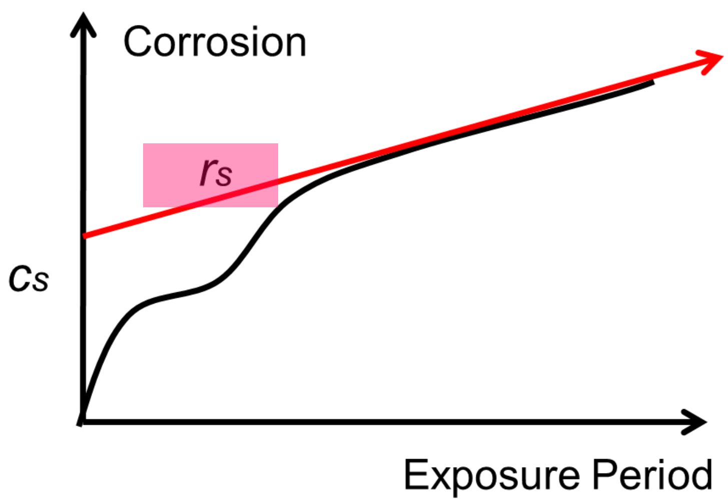
- Based on findings from recent work (Melchers 2014)
- Influence of dissolved inorganic nitrogen (DIN) on the corrosion loss of structural steel immersed in seawater

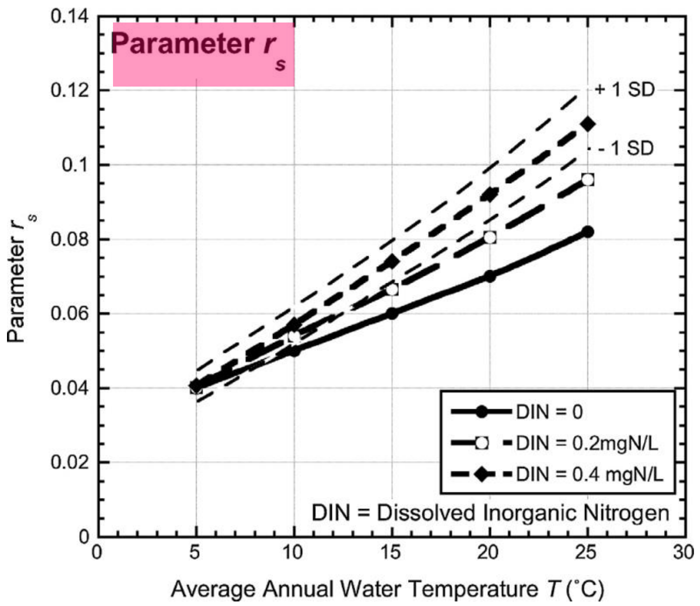




Nitrate (nutrient) adjustment (3)

- Based on findings from recent work (Melchers 2014)
- Influence of dissolved inorganic nitrogen (DIN) on the corrosion loss of structural steel immersed in seawater





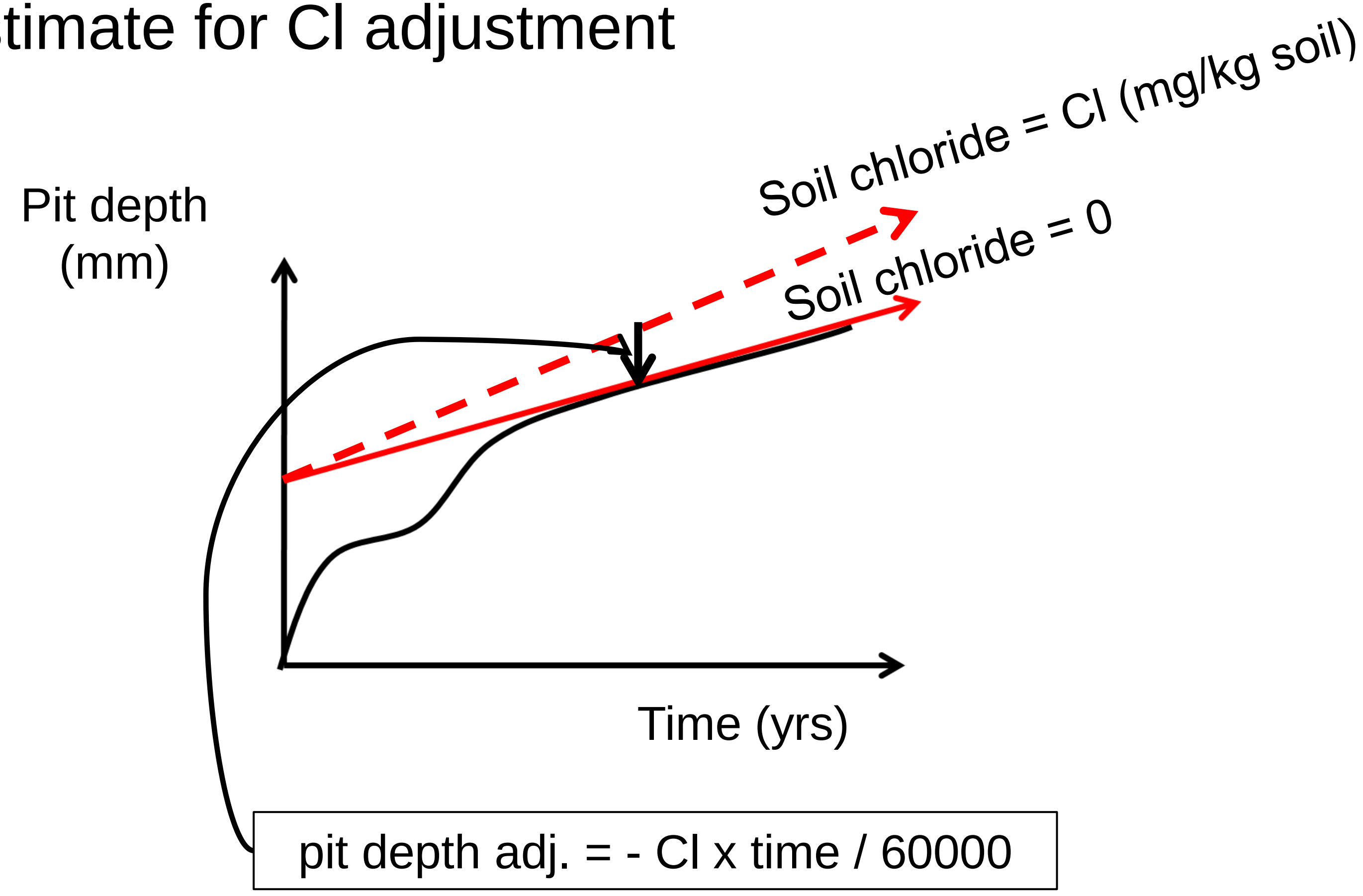
Nitrate (nutrient) adjustment (4)

- Main assumptions in determining N adjustment:

1. Main component of DIN = Nitrates (N) in long term
2. Nitrate (N) is the limiting nutrient in a soil
3. Long-term corrosion mechanisms at the corrosion surface (under rusts) are the same for immersion and soil environments
4. Thus expect similar influence of N on long-term corrn.
5. Main effect of N is on parameter cs (rs ignored)

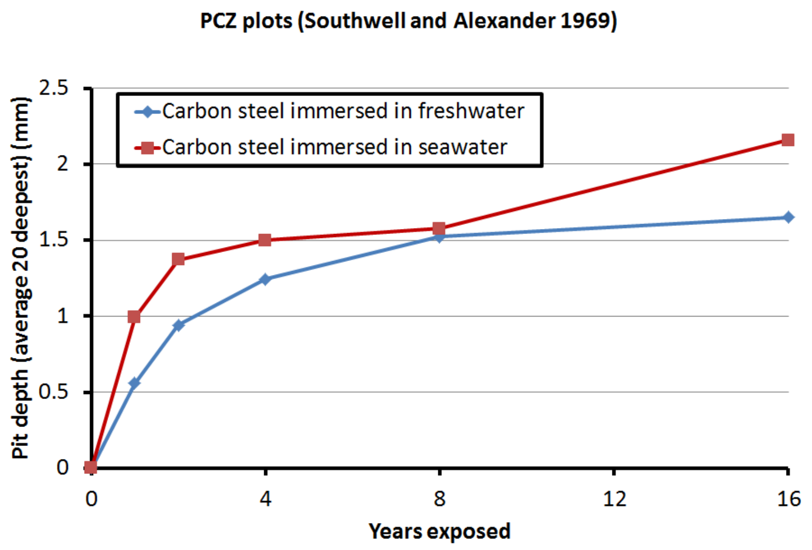
Chloride adjustment (1)

- Estimate for Cl adjustment



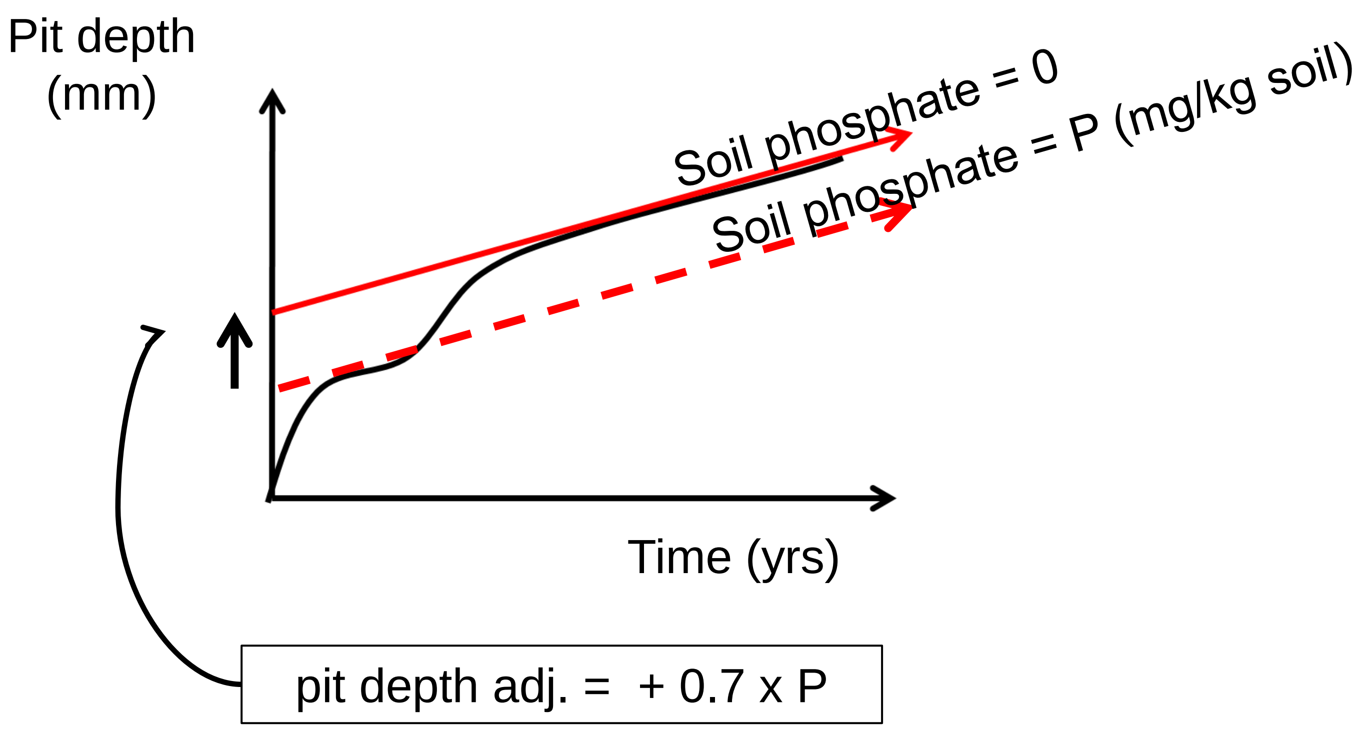
Chloride adjustment (2)

- Based on long-term corrosion rates of carbon steel in fresh and seawater immersion from Panama Canal Zone (Southwell and Alexander 1969)
- Assumed similar effect for long-term corrn. Cl in soils



Phosphate adjustment (1)

- Estimate for P adjustment



Phosphate adjustment (2)

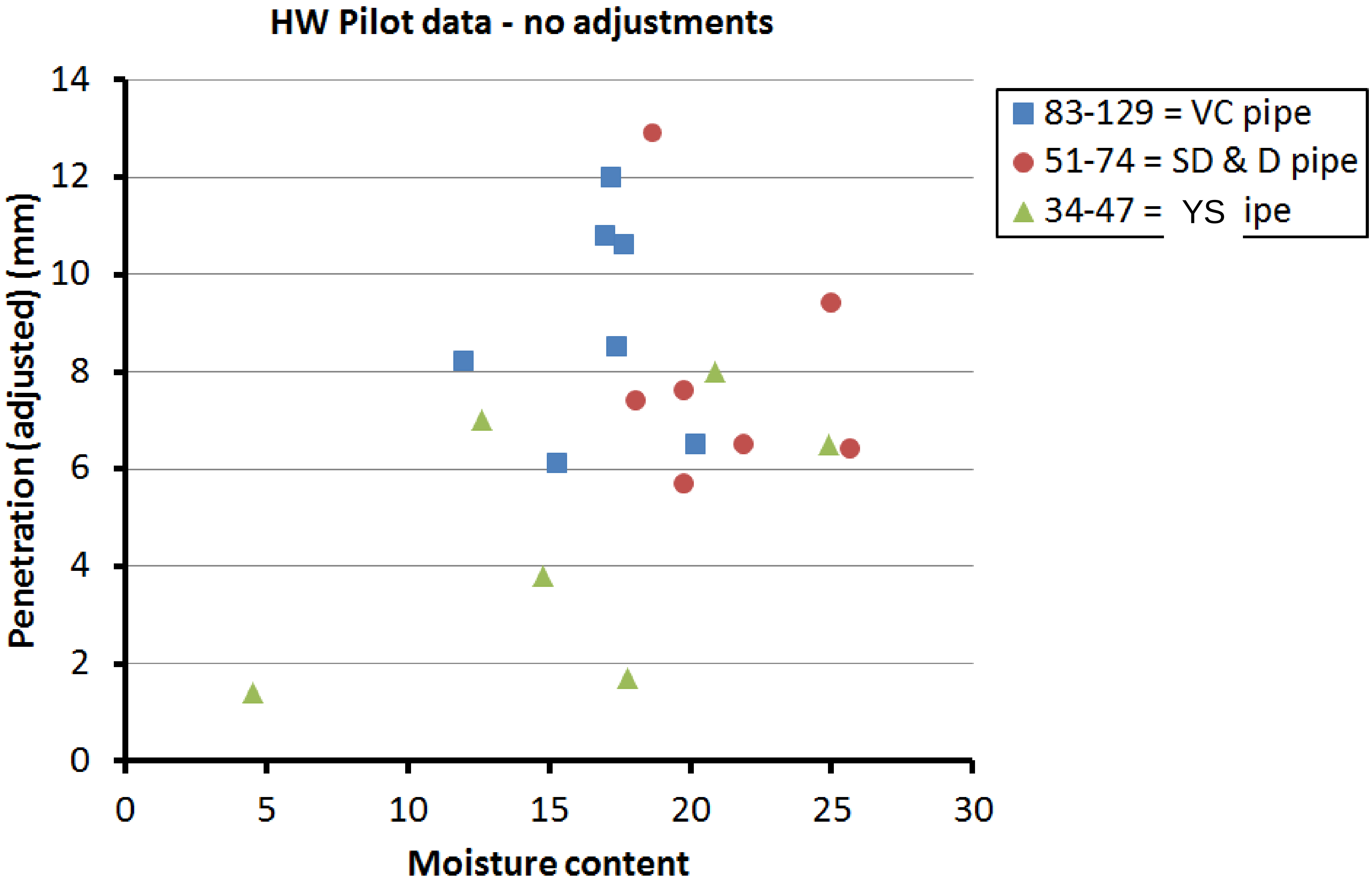
- Phosphates are known inhibitors
- No quantitative data available
- Adjustment based on calibration to HW pilot study data (sites RT1, RT2 and WS2)

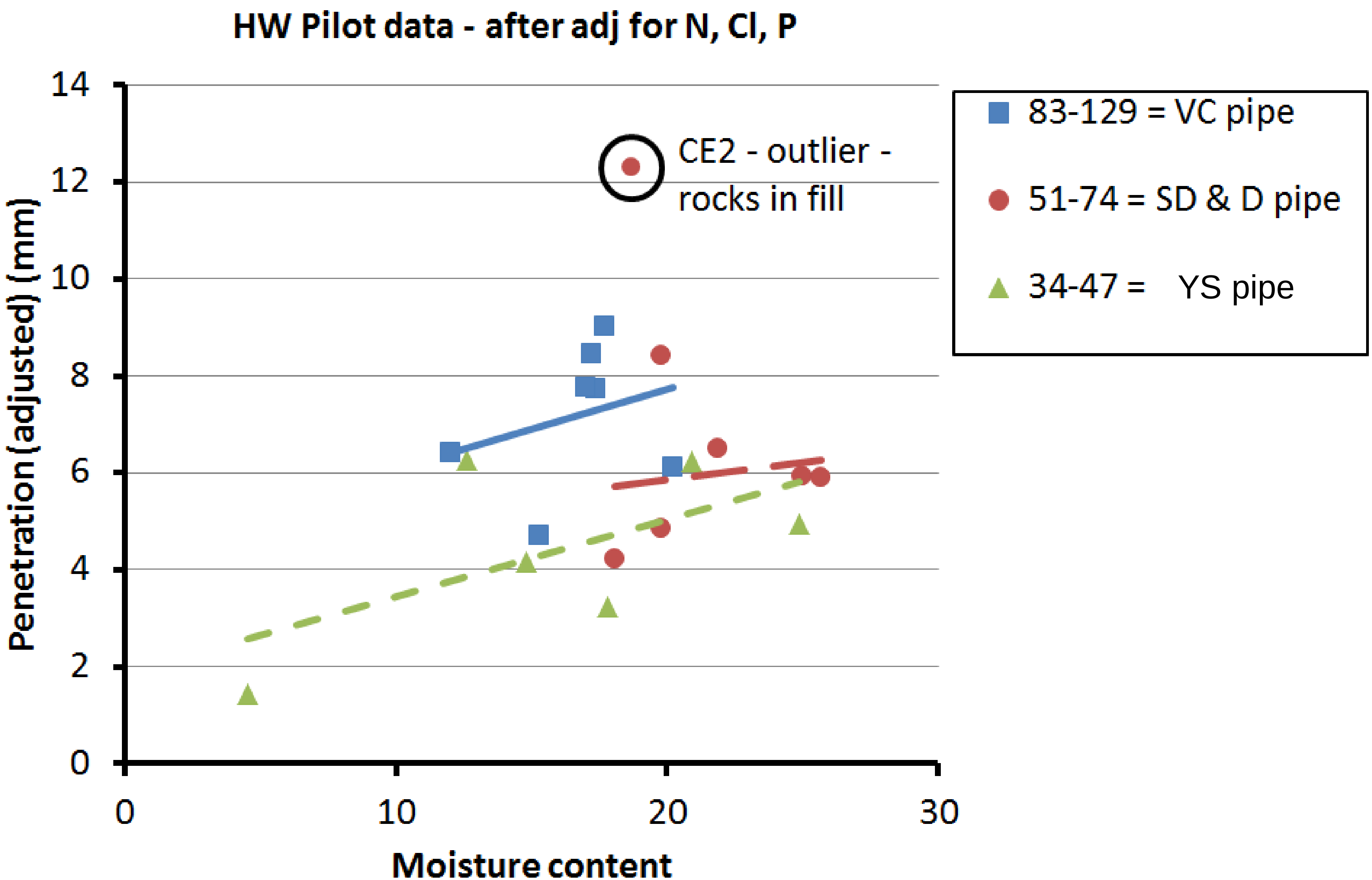
Results (1)

- Adjustments first applied to HW Pilot data
- (results in next two slides. 1st no adj, 2nd with adj)
- Data separated into three age categories:
  - 83-129 yrs (all vertically cast pipes)
  - 51-74 yrs (super delavaud and delavaud pipes)
  - 34-47 yrs (Yennora spun pipe)
- With the adjustments to the data the scatter in results are reduced
- Trends show corrosion gets worse as moisture content increases

Centre for Infrastructure Performance and Reliability

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

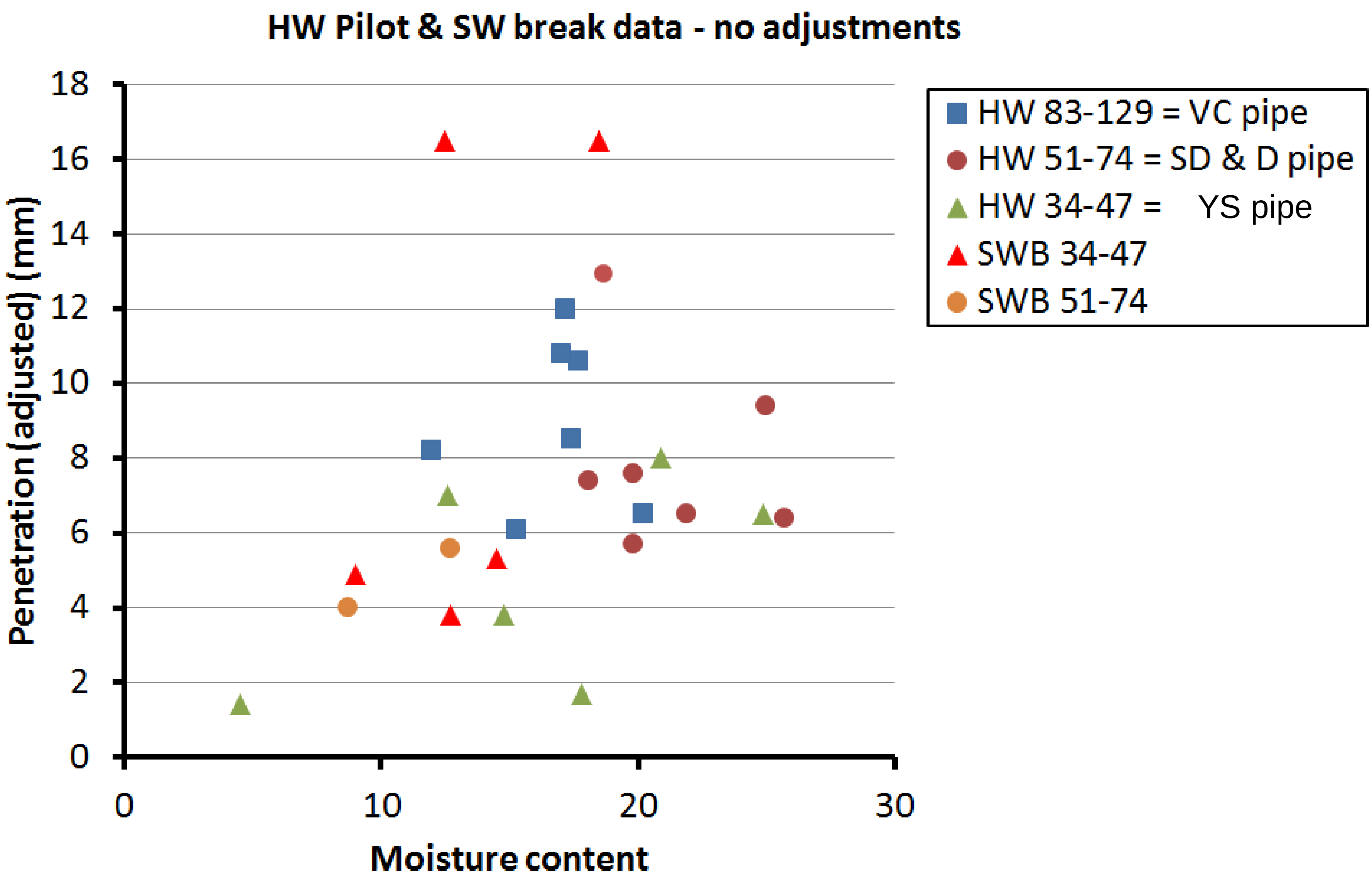



HW Pilot data - after adj for N, Cl, P
Penetration (adjusted) (mm)
0
2
4
6
8
10
12
14
0
10
20
30
Moisture content
CE2 - outlier - rocks in fill
83-129 = VC pipe
51-74 = SD & D pipe
34-47 = YS pipe

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

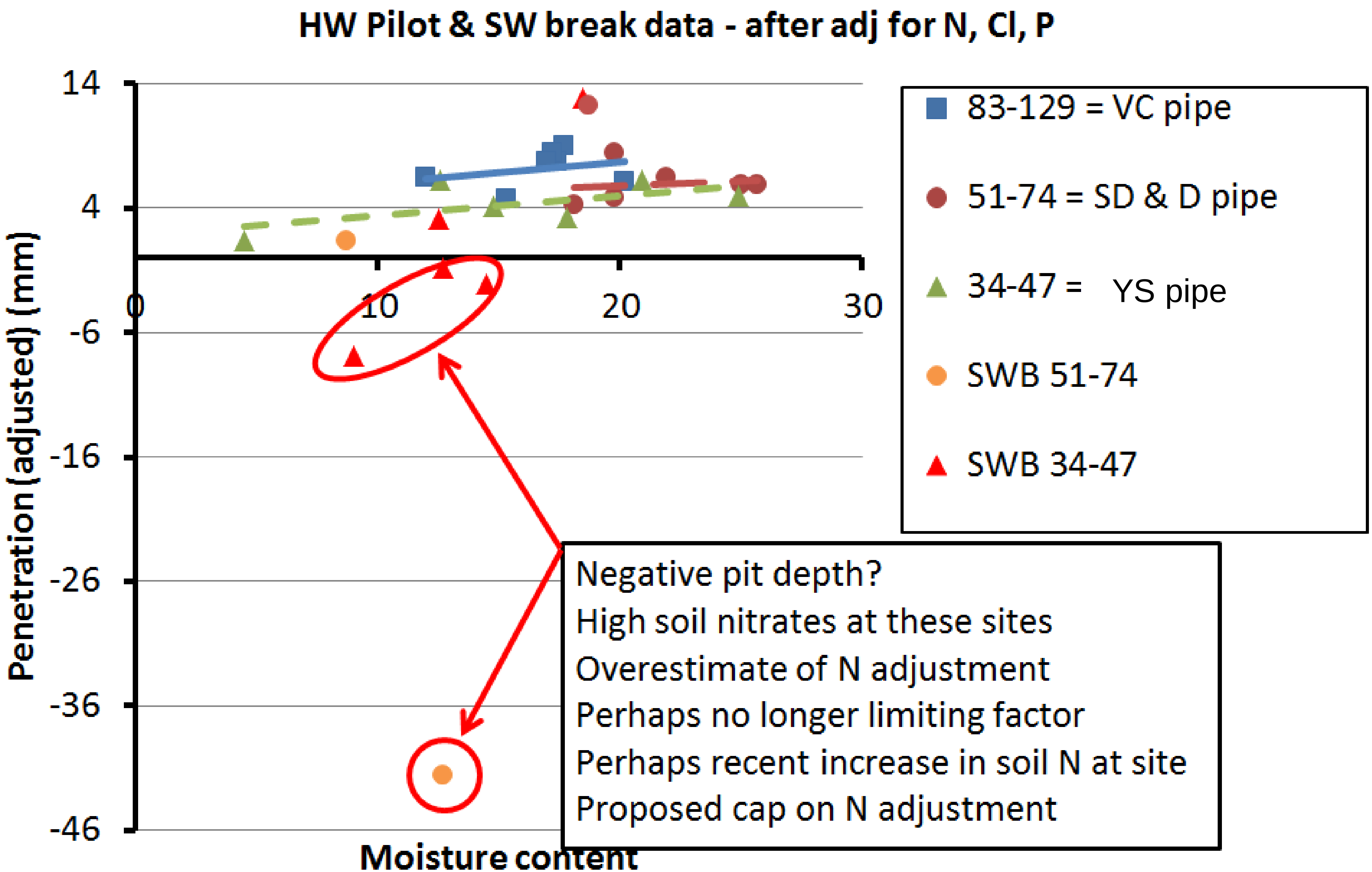
Results (2)

- Adjustments then applied to SW break data
- (results in next two slides. 1st no adj, 2nd with adj)
- Data again separated into three age categories:
  - 83-129 yrs (all vertically cast pipes)
  - 51-74 yrs (super delavaud and delavaud pipes)
  - 34-47 yrs (Yennora spun pipe)
- Some data points became negative due to a high nitrate adjustment
- Likely that Nitrate is no longer the limiting factor for these cases


HW Pilot & SW break data - no adjustments
Penetration (adjusted) (mm)
18
16
14
12
10
8
6
4
2
0
0
10
20
30
Moisture content
HW 83-129 = VC pipe
HW 51-74 = SD & D pipe
HW 34-47 = YS pipe
SWB 34-47
SWB 51-74

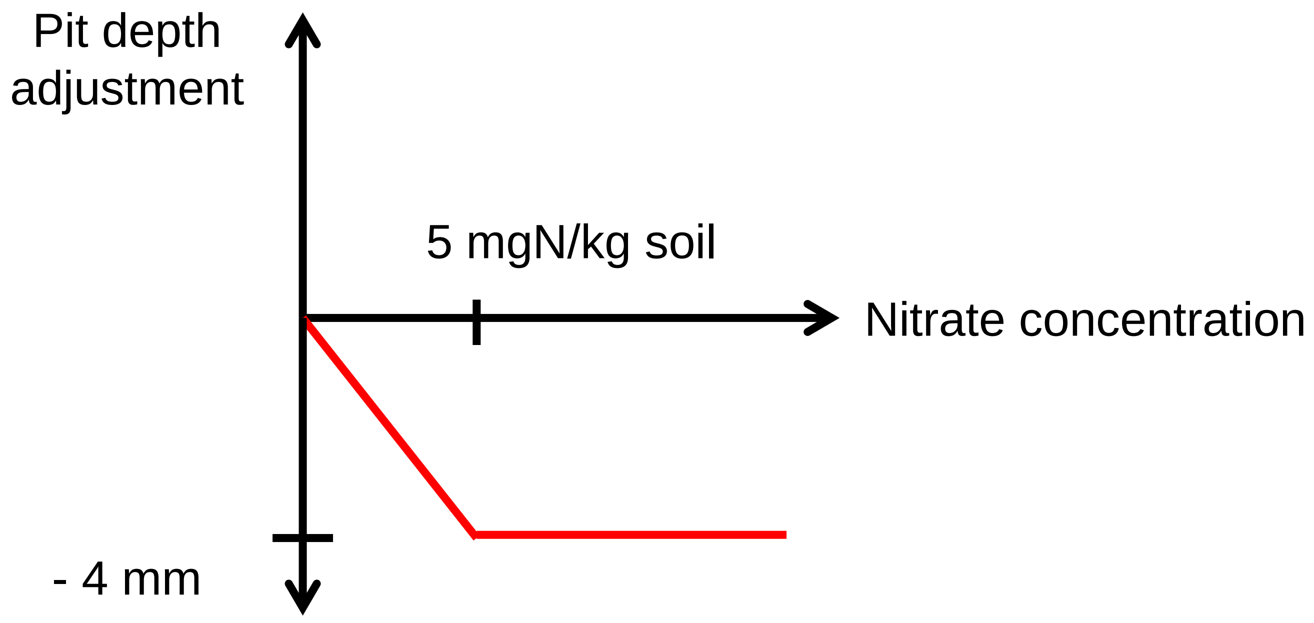
Centre for Infrastructure Performance and Reliability

THE UNIVERSITY OF NEWCASTLE AUSTRALIA



Results (3)

- We calibrated the nitrate adjustment to the SW break data by proposing a cap on the nitrate adjustment

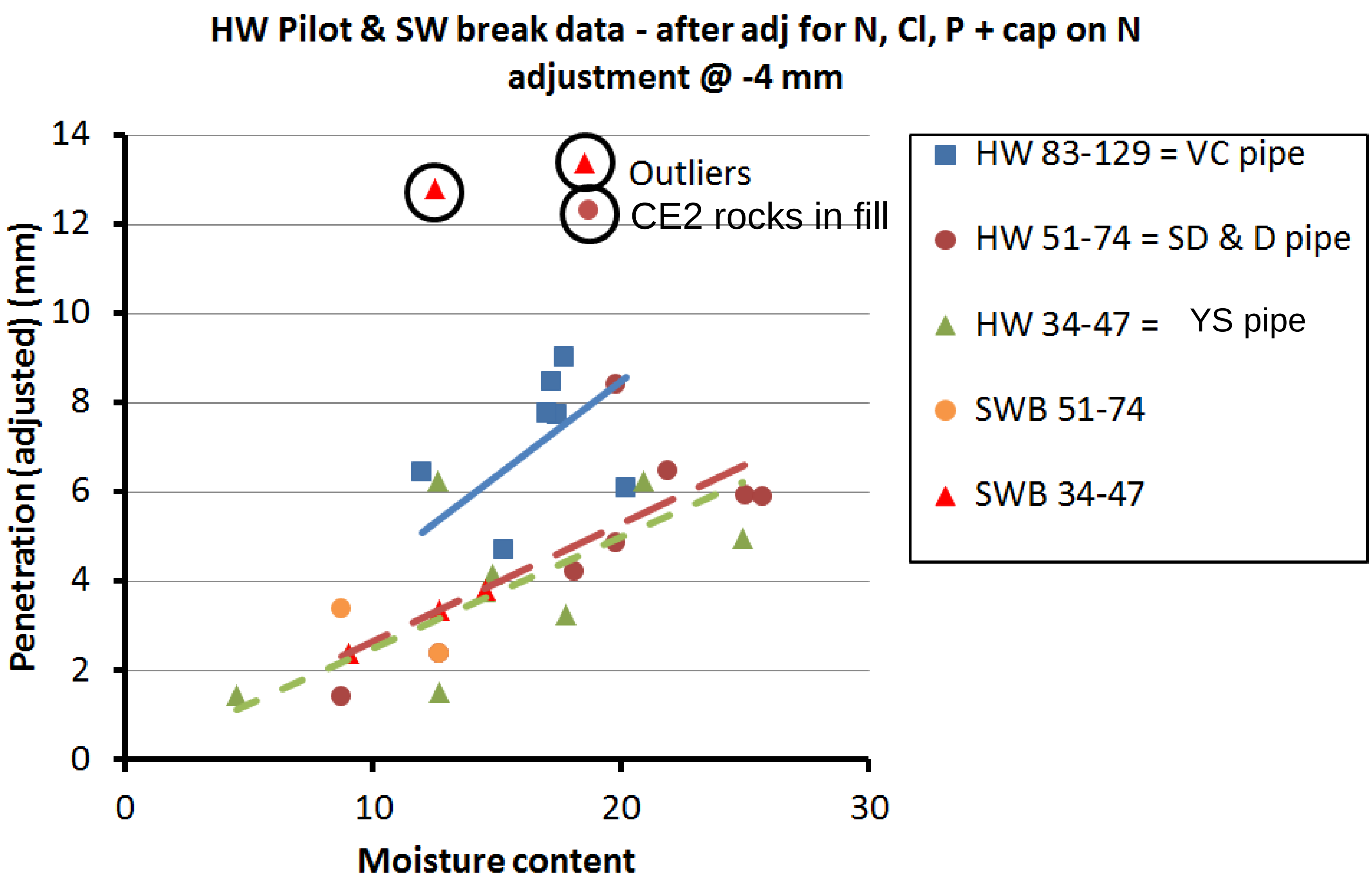


THE UNIVERSITY OF NEWCASTLE AUSTRALIA

Results (4)

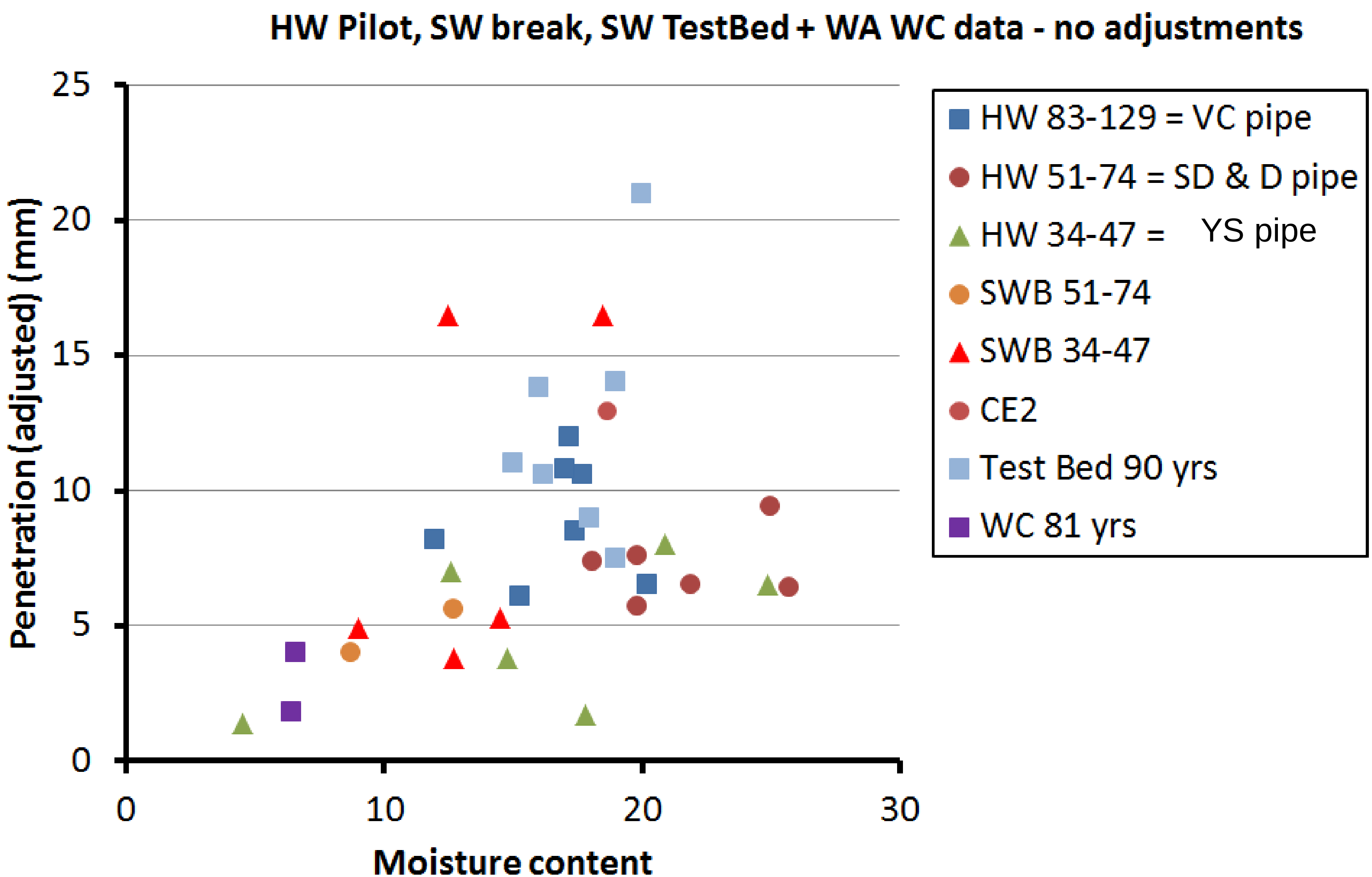
- Results on the next slide show the adjusted data with the revised nitrate adjustment
- Trend lines show corrosion increases as moisture content increases as expected
- Some outliers, not following the common trends have been highlighted

Centre for Infrastructure Performance and Reliability

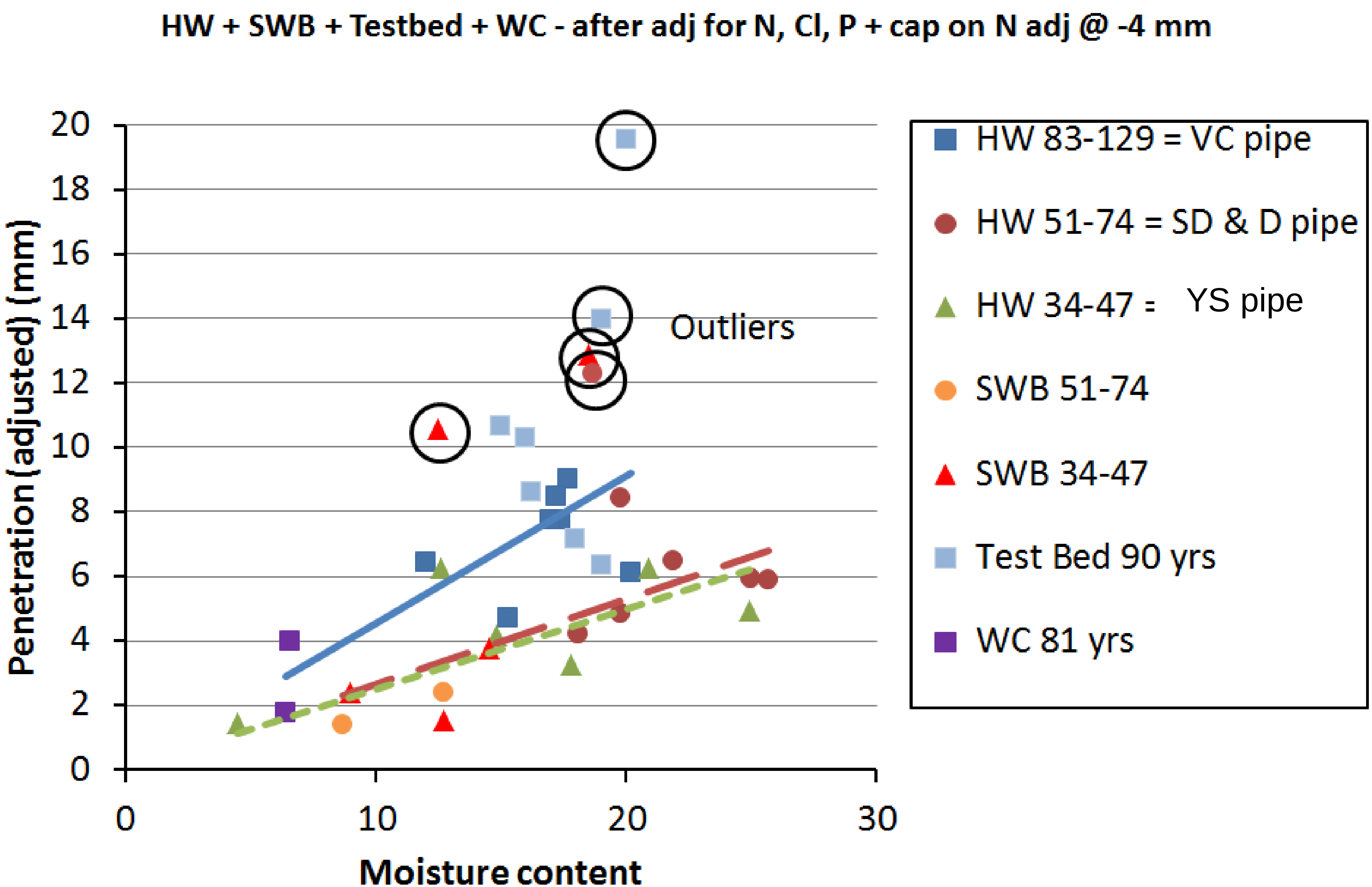


Results (5)

- Adjustments then applied to all data (HW, SW Break + Test Bed + WC CA data)
- (see next two slides)
- Majority of data points follow consistent trend
- Corrosion increases with moisture
- Longer term data more scattered
- Outliers highlighted


HW Pilot, SW break, SW TestBed + WA WC data - no adjustments
Penetration (adjusted) (mm)
0
5
10
15
20
25
0
10
20
30
Moisture content
HW 83-129 = VC pipe
HW 51-74 = SD & D pipe
HW 34-47 = YS pipe
SWB 51-74
SWB 34-47
CE2
Test Bed 90 yrs
WC 81 yrs

Centre for Infrastructure Performance and Reliability



Discussion - corrections

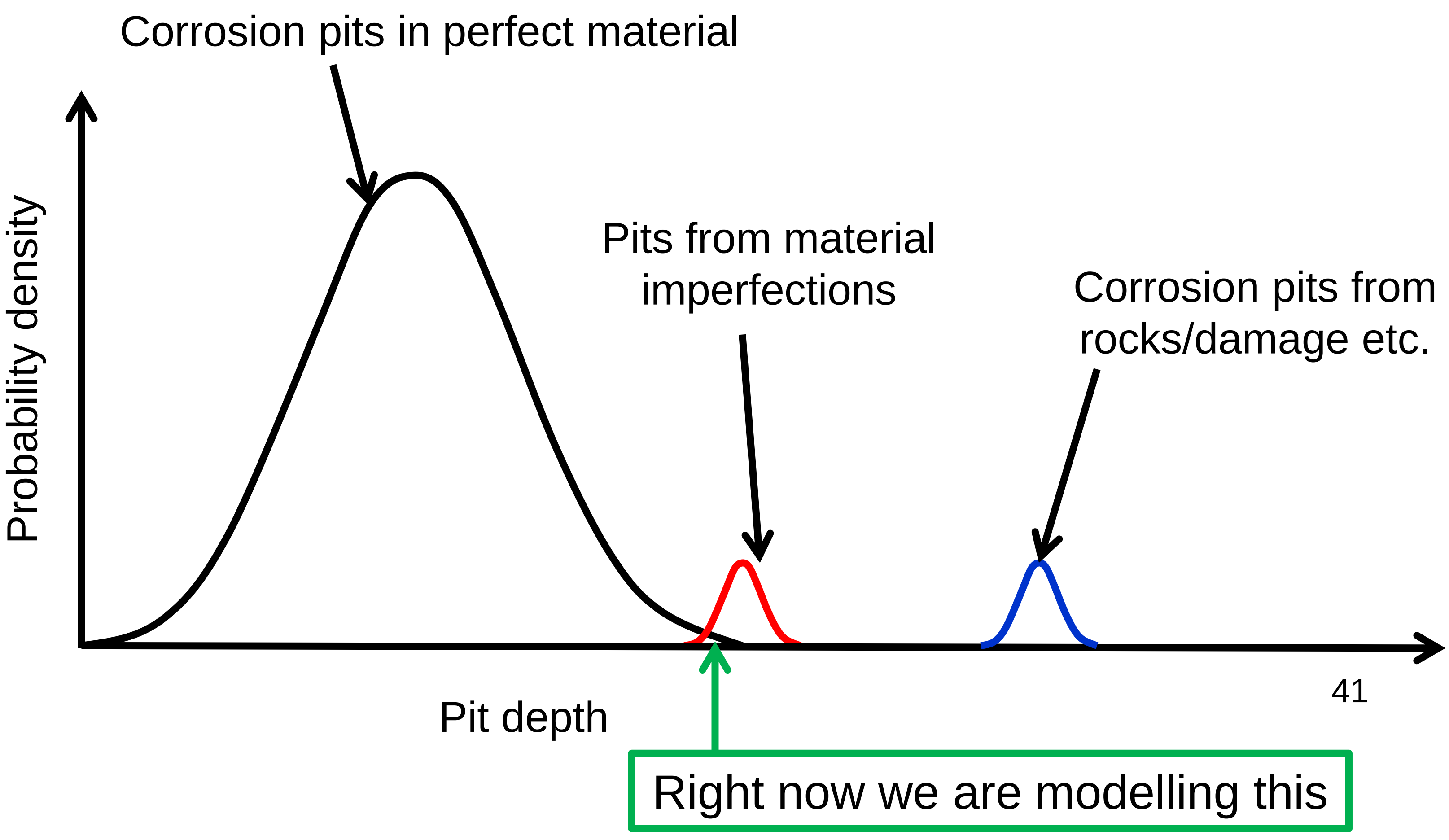
- Proposed corrections reduce scatter in pit depths
- Trends for corrected pit depths as a function of moisture content are as expected
- Current work accounts for the influence of N, Cl, P on pit depths in soil
- Current approach captures approx. 90 % of cases (Outliers account for approx. 10 % of data)

Discussion - outliers

- From previous work noted rocks in fill, poor quality backfill, and pipe damage leads to increased corrosion
- Possible reasons for large corrosion at outliers (case of CE2 resolved – rocks in fill)

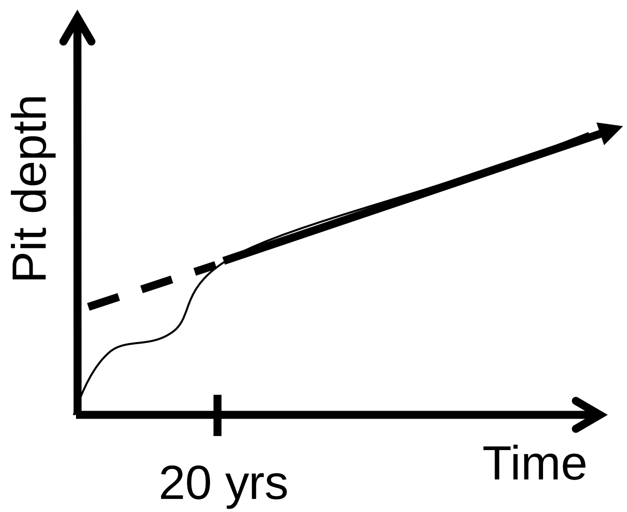
Rope marks

Discussion – probability density (pipe surface pits)



Discussion – Model derivation

- Some more work is required to validate the proposed adjustment factors
- Once they have been validated a model can be derived
- The long-term corrosion model will look like this:



Pit depth = cs +rs (time)

cs = fn (mc, N, P)

rs = fn (mc, cl)

[Time > 20 yrs]

Discussion – historical data

- In past we have looked at using historical data to calibrate model - Romanoff (1957)
- Good data to observe corrosion vs time trends (looked at exhaustively – ACA 2015 paper), but…
- Bad data for calibration of model parameters
- Why?
  - No N, P data. Limited moisture data.
  - No pit stat data – cant isolate corrn. w/o imperfections
- So we focus on new data collected with protocol – relevant soil parameters & 3D scan for pipe stats

Future work

- Further work involves:
- Validating and refining the correction factors
- Derivation of a corrosion loss model from the results