Session 3

GEOTECHNICAL ASPECTS OF DAMS

An investigation and assessment of embankment stability at Daer Reservoir - R Morrin and M Sullivan

Slurry trench cut-off wall and permeation grouting of Chapel House Embankment Dam, Cumbria - C Pailing

Prevention of Internal Erosion in Homogeneous Dams - A Case Study - N Bennett and M Edmondson

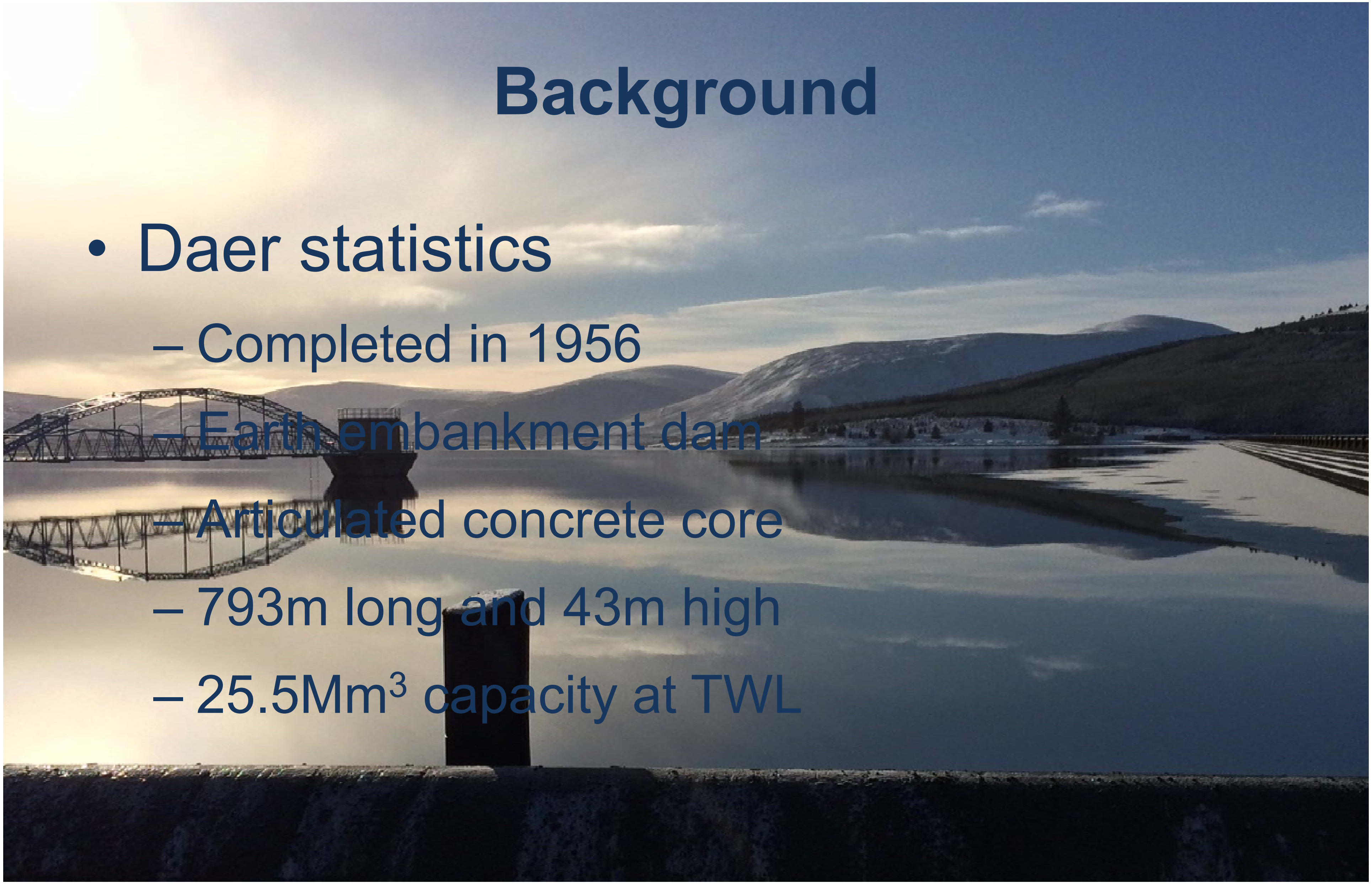
Retrofit of Fibre Optics for Permanent Monitoring of Leakage and Detection of Internal Erosion - J Dornstädter

Discussion

An investigation and assessment of embankment stability at Daer Reservoir

Ross Morrin (Scottish Water),
Matthew Sullivan, Alex Macdonald,
Chris Holt (all Jacobs UK Ltd)

8th September, 2016

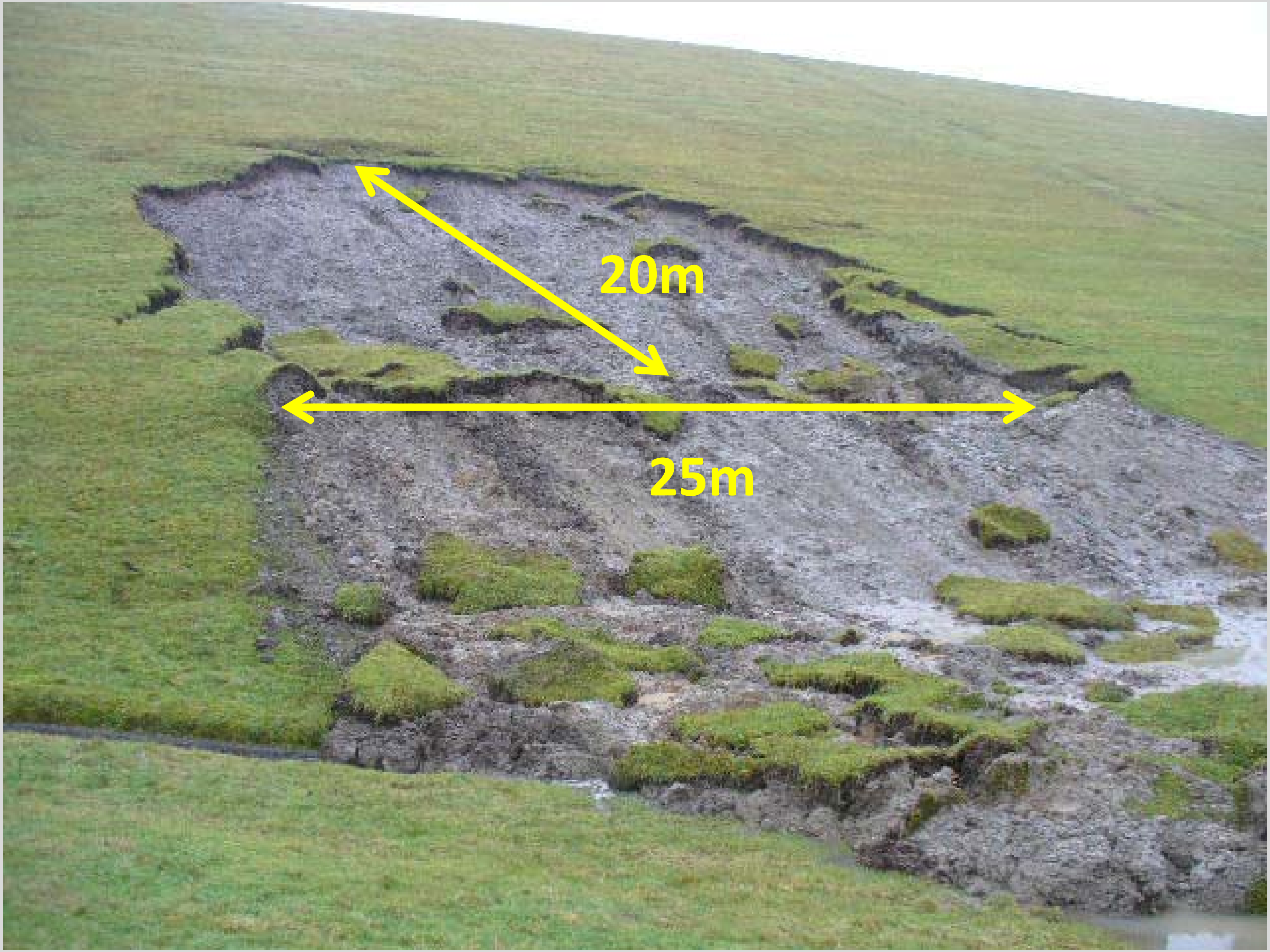


Background

- Daer statistics
  - Completed in 1956
  - Earth embankment dam
  - Articulated concrete core
  - 793m long and 43m high
  - 25.5Mm^3 capacity at TWL

Background

- The incident
  - Notification


20m
25m

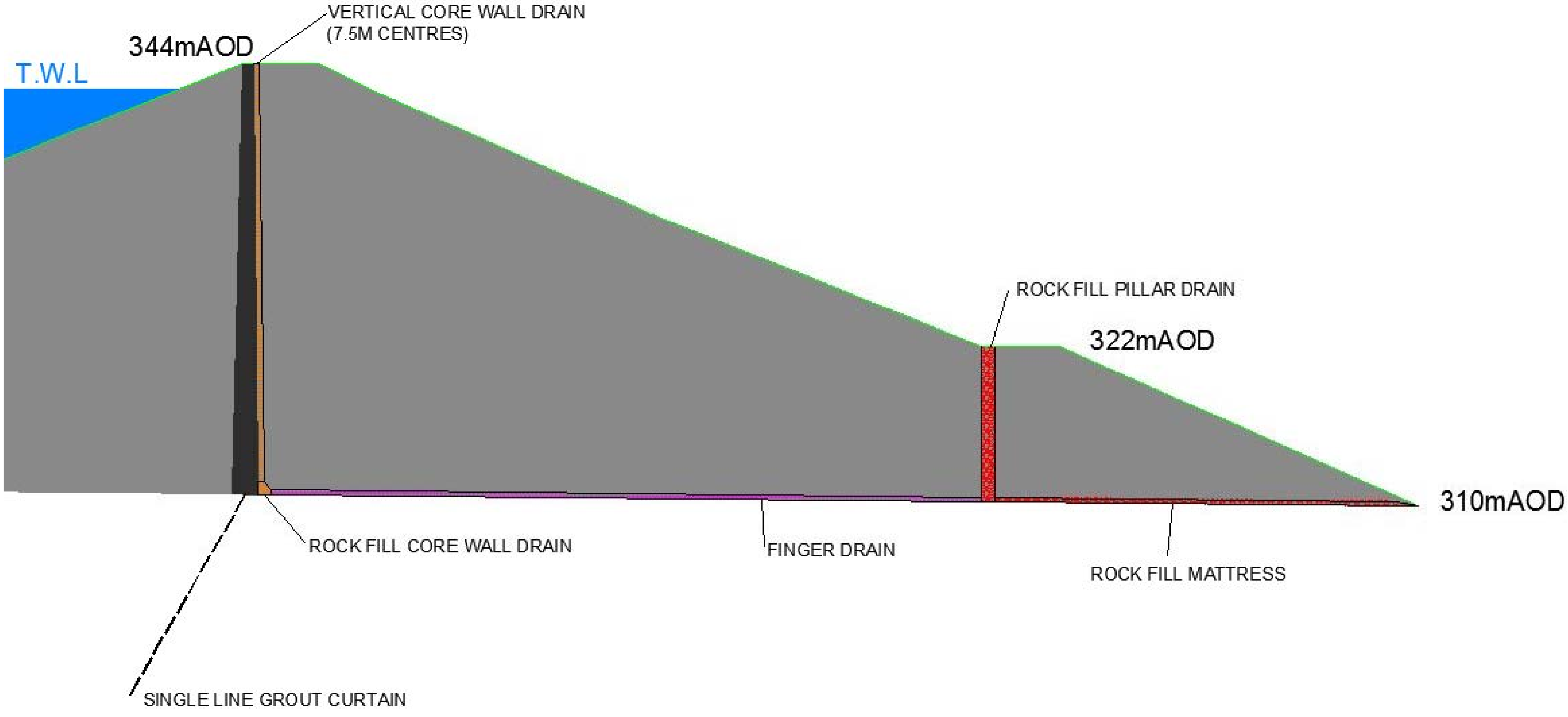
Background

- The incident
  - Notification
  - Immediate response
  - Repairs

Background

- The incident
  - Notification
  - Immediate response
  - Repairs
  - Scour operation

Schematic Cross Section



Scottish Water

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Investigation and Reporting

- Ground Investigation
  - AIMS:
    - To investigate the ground conditions in and around the area of the slip including the nature and engineering properties of the embankment fill;
    - To establish the general phreatic level and presence of perched water levels within the embankment; and
    - To identify if there was leakage of water through the core wall

Scottish Water

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Ground Investigation

Boreholes

Trial Pits

Hand pits & CCTV survey (drainage)

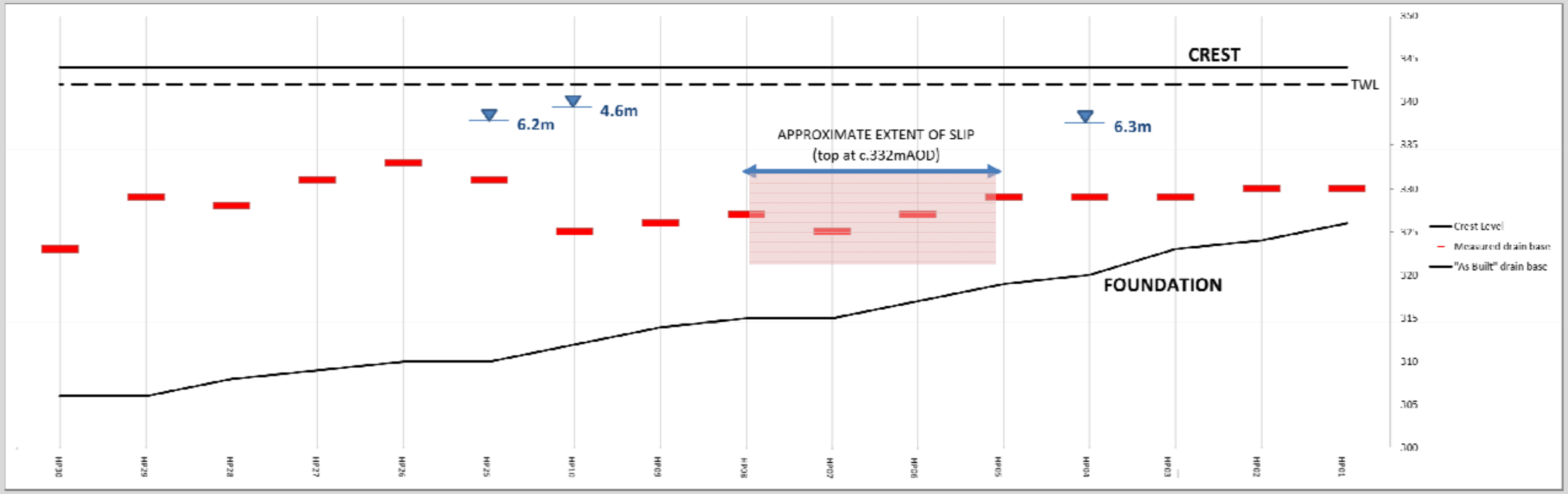
Groundwater monitoring and inclinometer installations

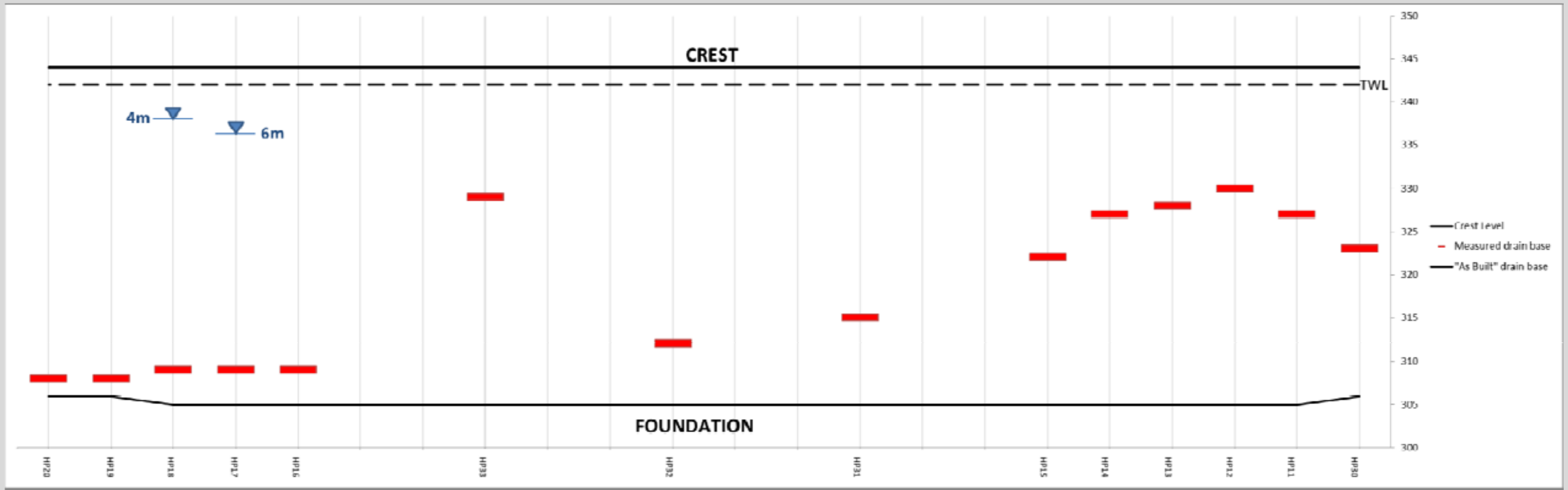
Rock Mapping

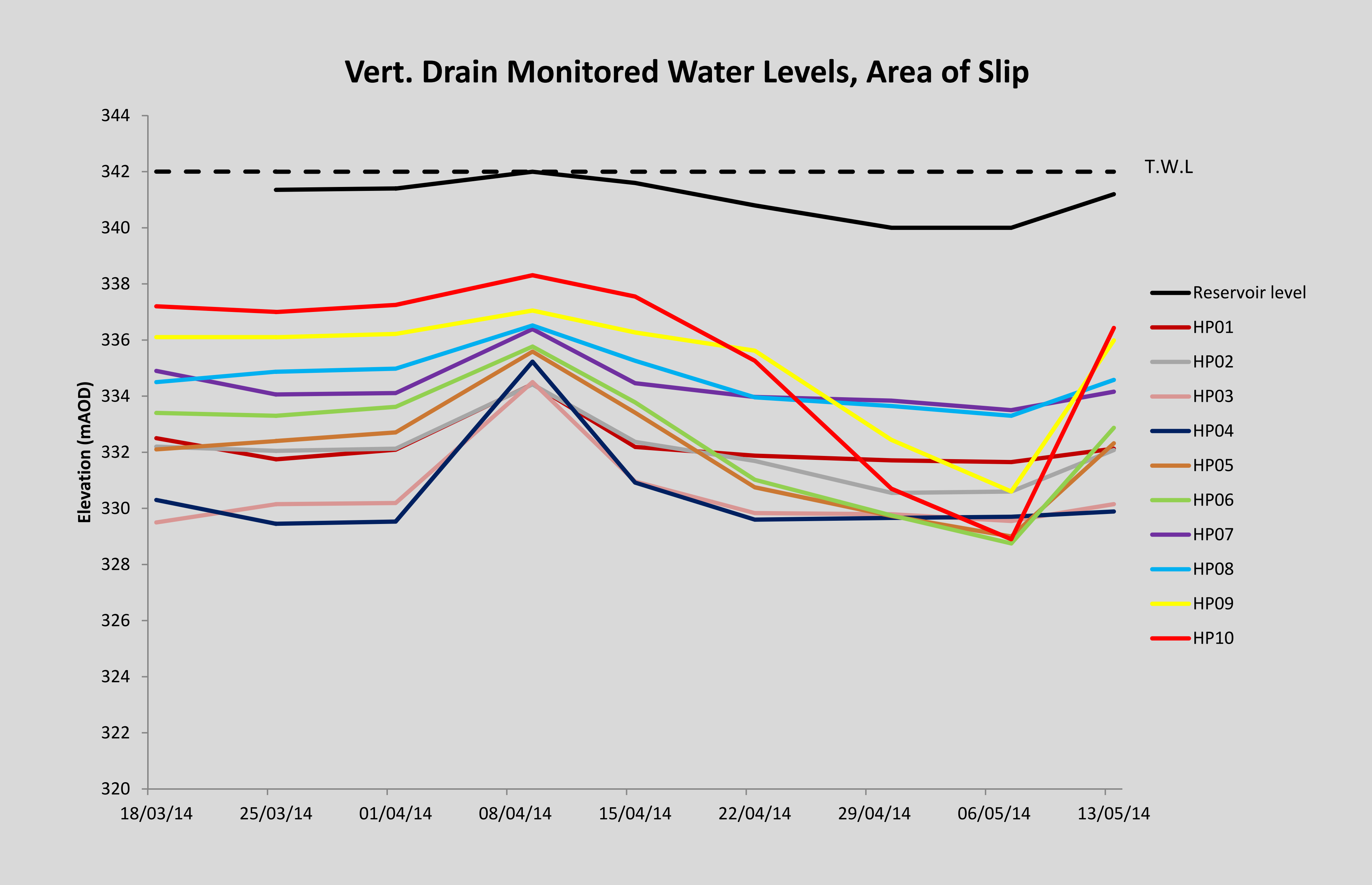
Ground Investigation – Key Findings

- Leakage of water through core wall
- Limitations of drainage system
- Embankment (area of slip):
  - thick topsoil layer;
  - near surface saturated zone;
  - re-worked granular glacial fill.
- Groundwater:
  - generally low phreatic level;
  - shallow, perched groundwater
- Shear strength properties
- Postulated leakage pathway

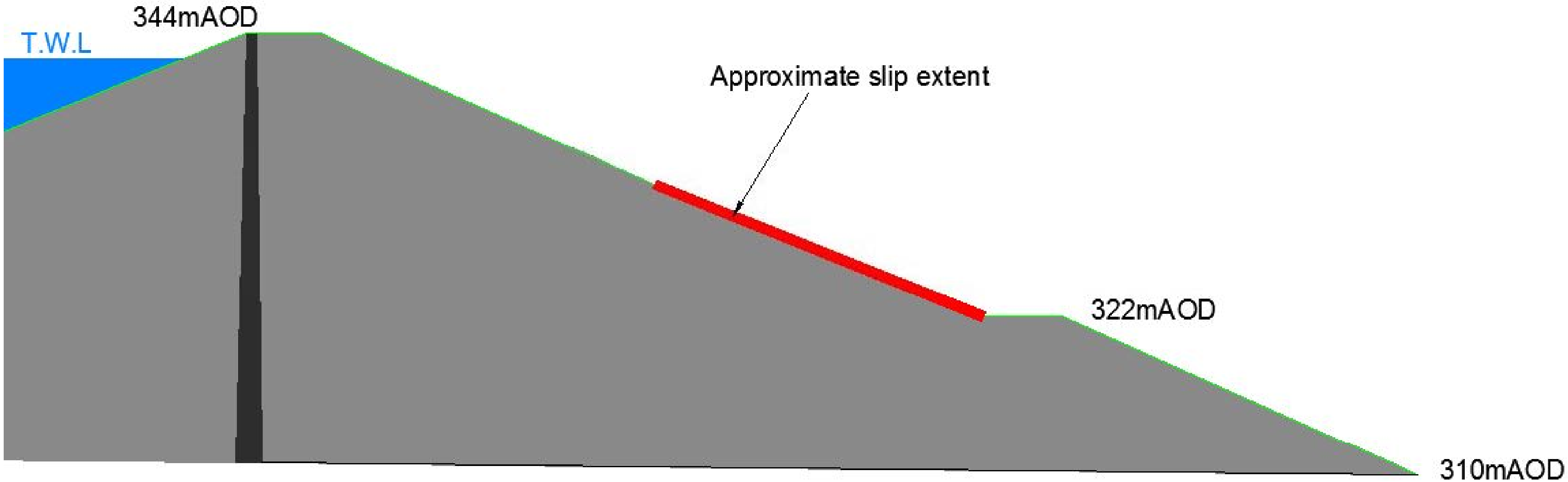
Longitudinal Section – core wall vertical drains



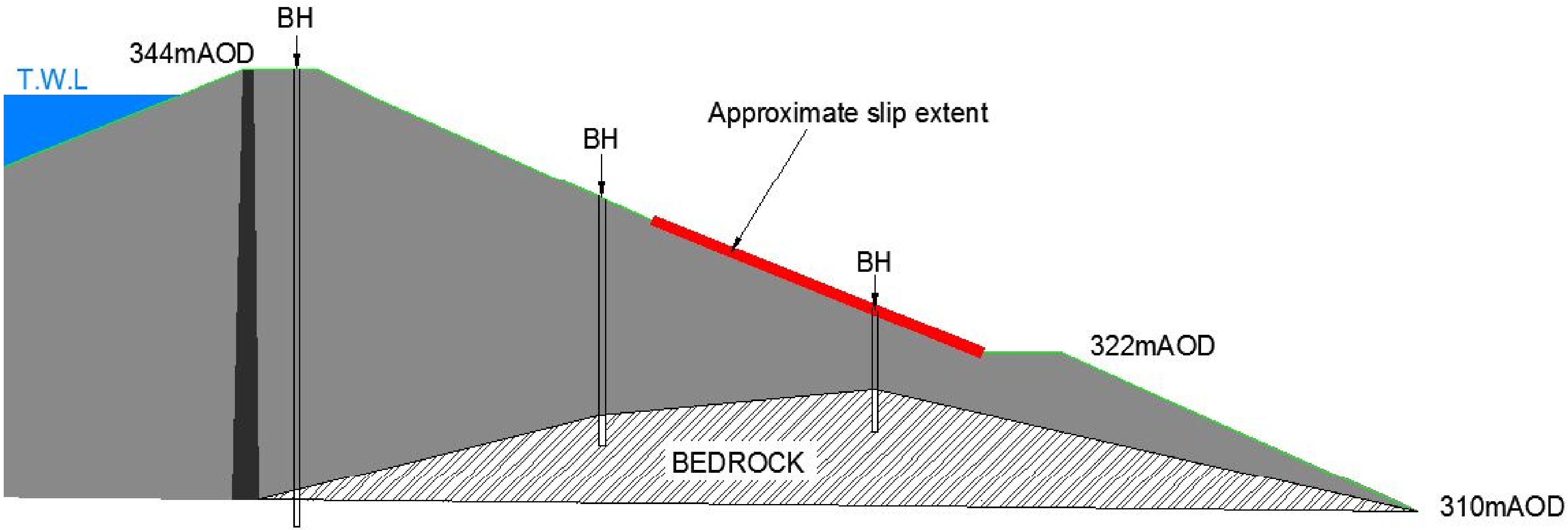



Vert. Drain Monitored Water Levels, Area of Slip
Elevation (mAOD)
344
342
340
338
336
334
332
330
328
326
324
322
320
18/03/14
25/03/14
01/04/14
08/04/14
15/04/14
22/04/14
29/04/14
06/05/14
13/05/14
T.W.L
Reservoir level
HP01
HP02
HP03
HP04
HP05
HP06
HP07
HP08
HP09
HP10

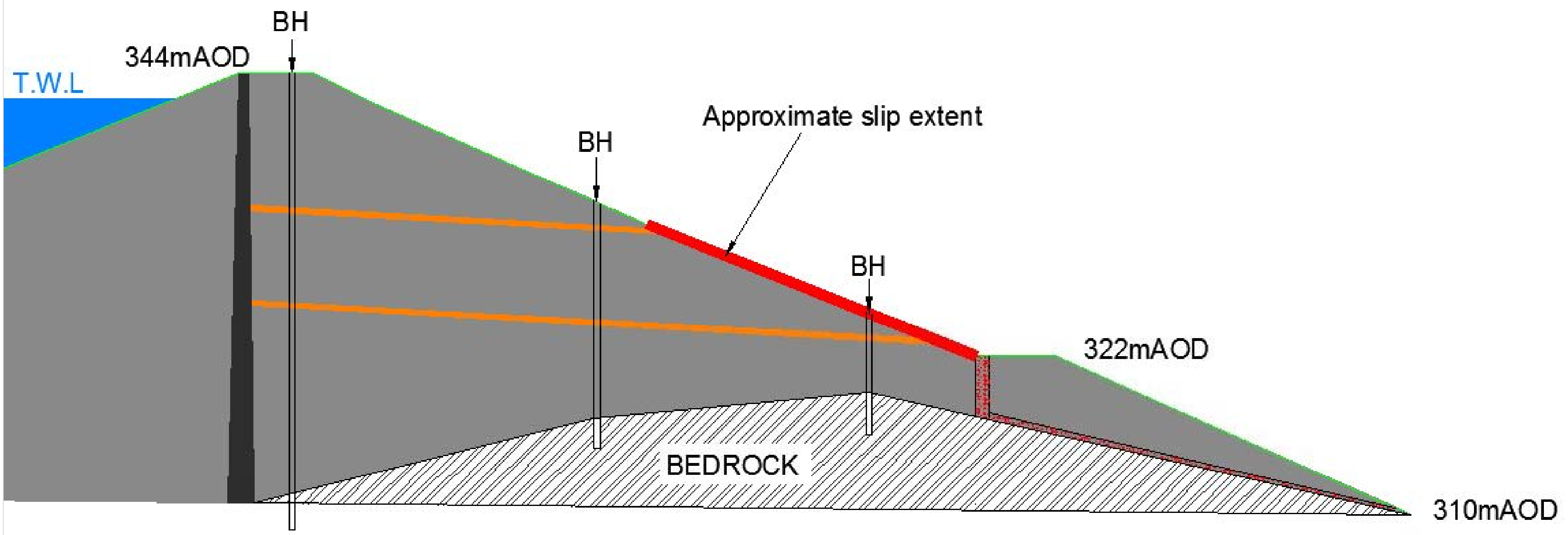
Cross Section – area of slip



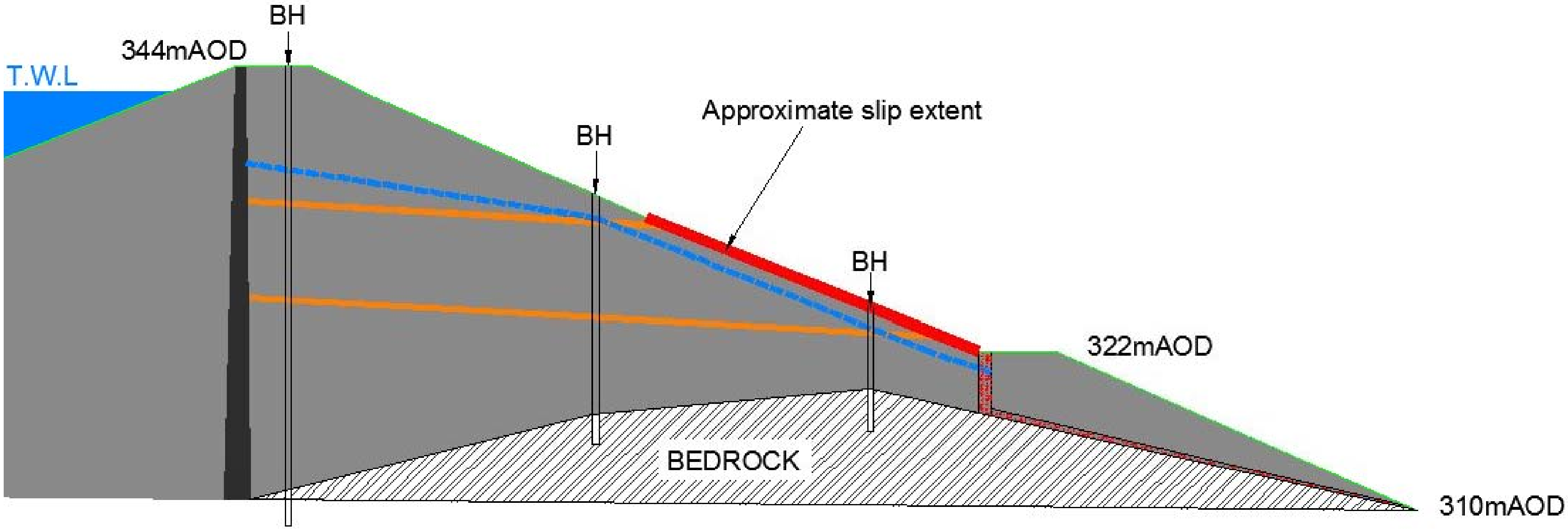
Cross Section – area of slip



Cross Section – area of slip



Cross Section – area of slip

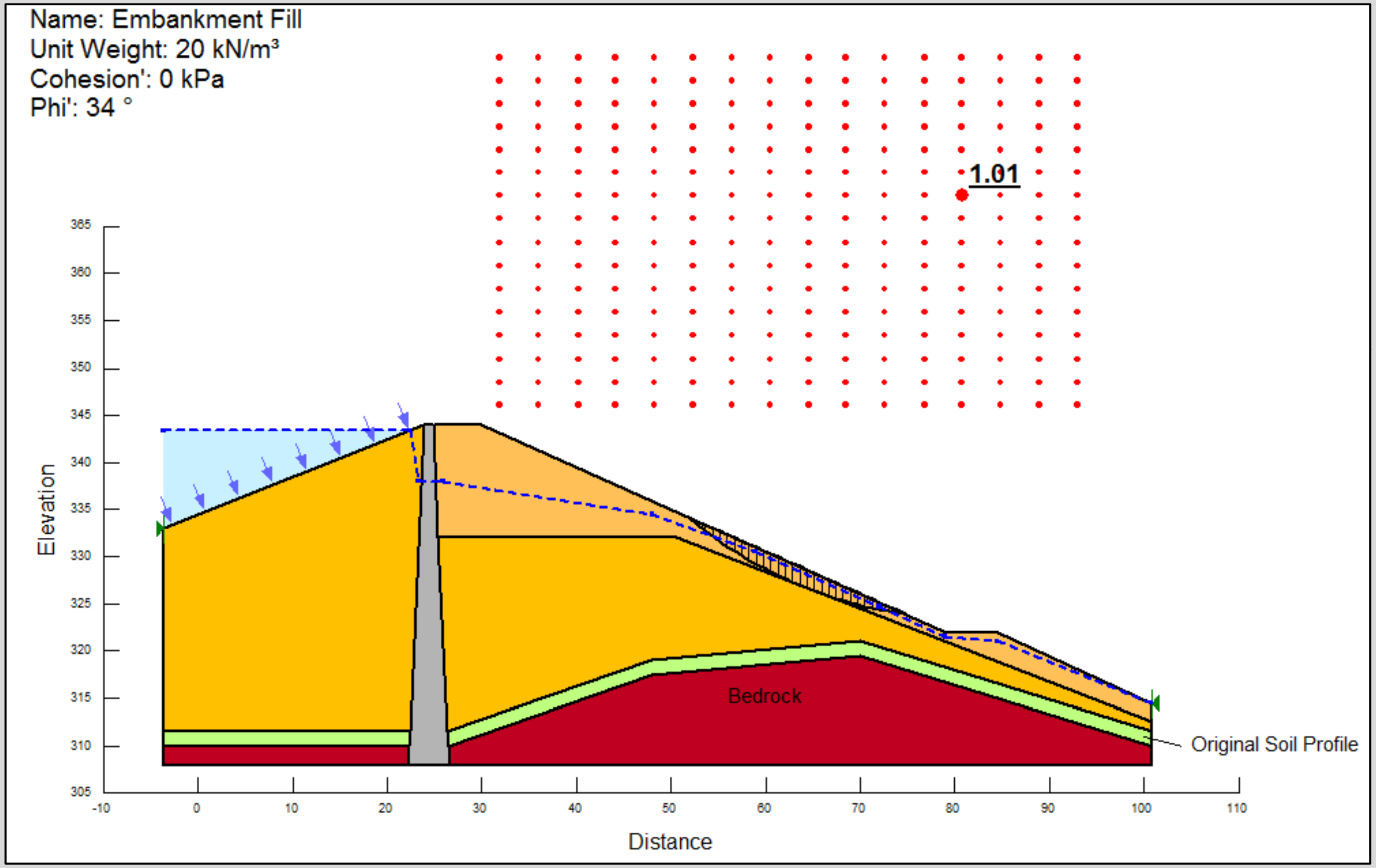


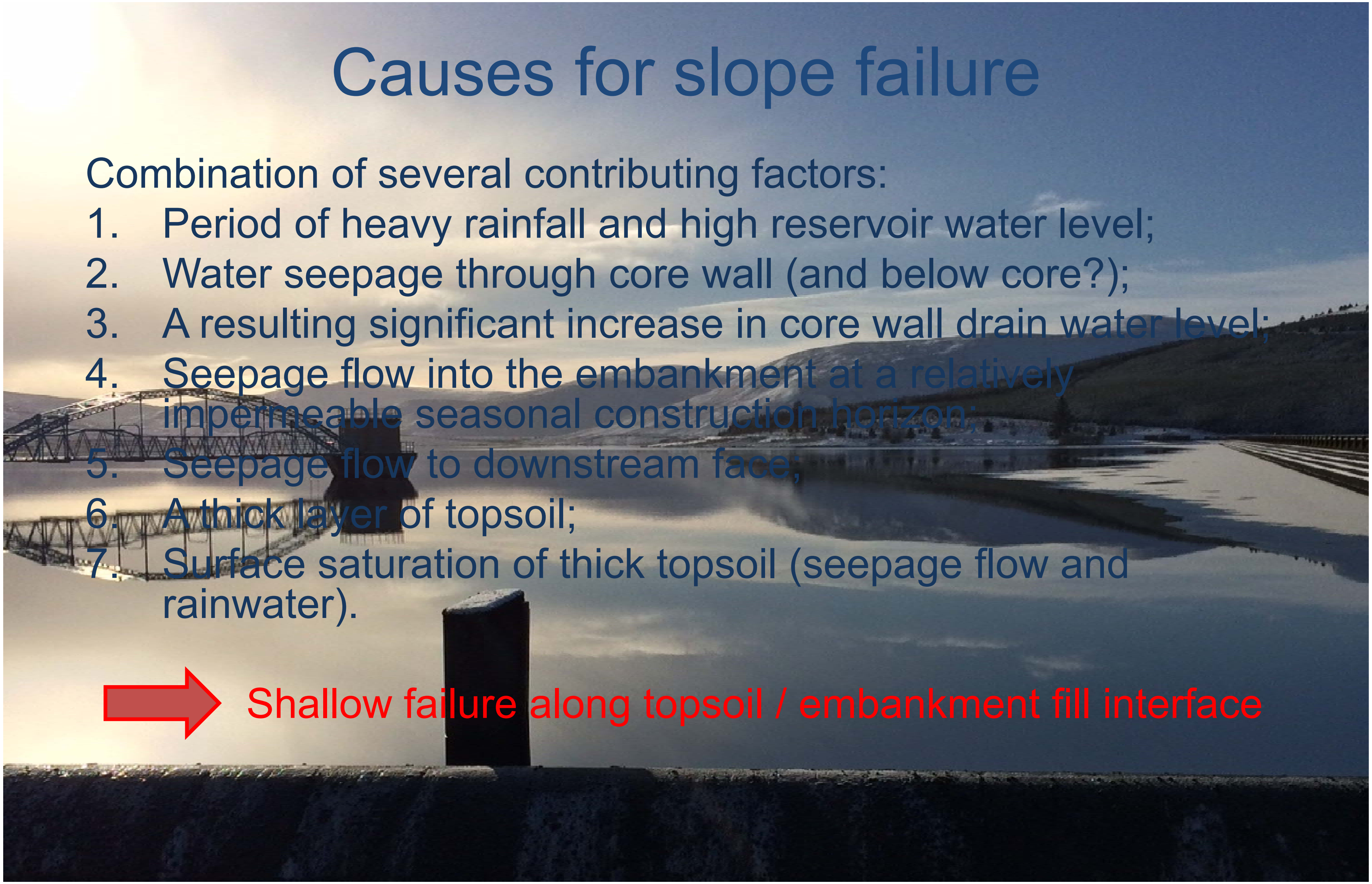
Slope Stability

Case No.	Scenario	Shear Strength		Slip depth	Factor of Safety
		c’	Φ’		
1	Dry embankment - Best case scenario. Well-drained embankment.	0kPa	32	Very shallow	1.40
2	Saturated embankment - Worst case scenario. High phreatic surface.	0kPa	32	Deep	0.99
3	Postulated failure condition - The likely ground & groundwater conditions.	0kPa	32	Shallow	0.93
4		0kPa	34	Shallow	1.01

Postulated failure condition

- Shallow surface slip
  - φ=34^0 (conservative lower value from borehole correlations) – FoS 1.01
  - φ=32^0 (worst case from borehole correlations) – FoS 0.93





Causes for slope failure

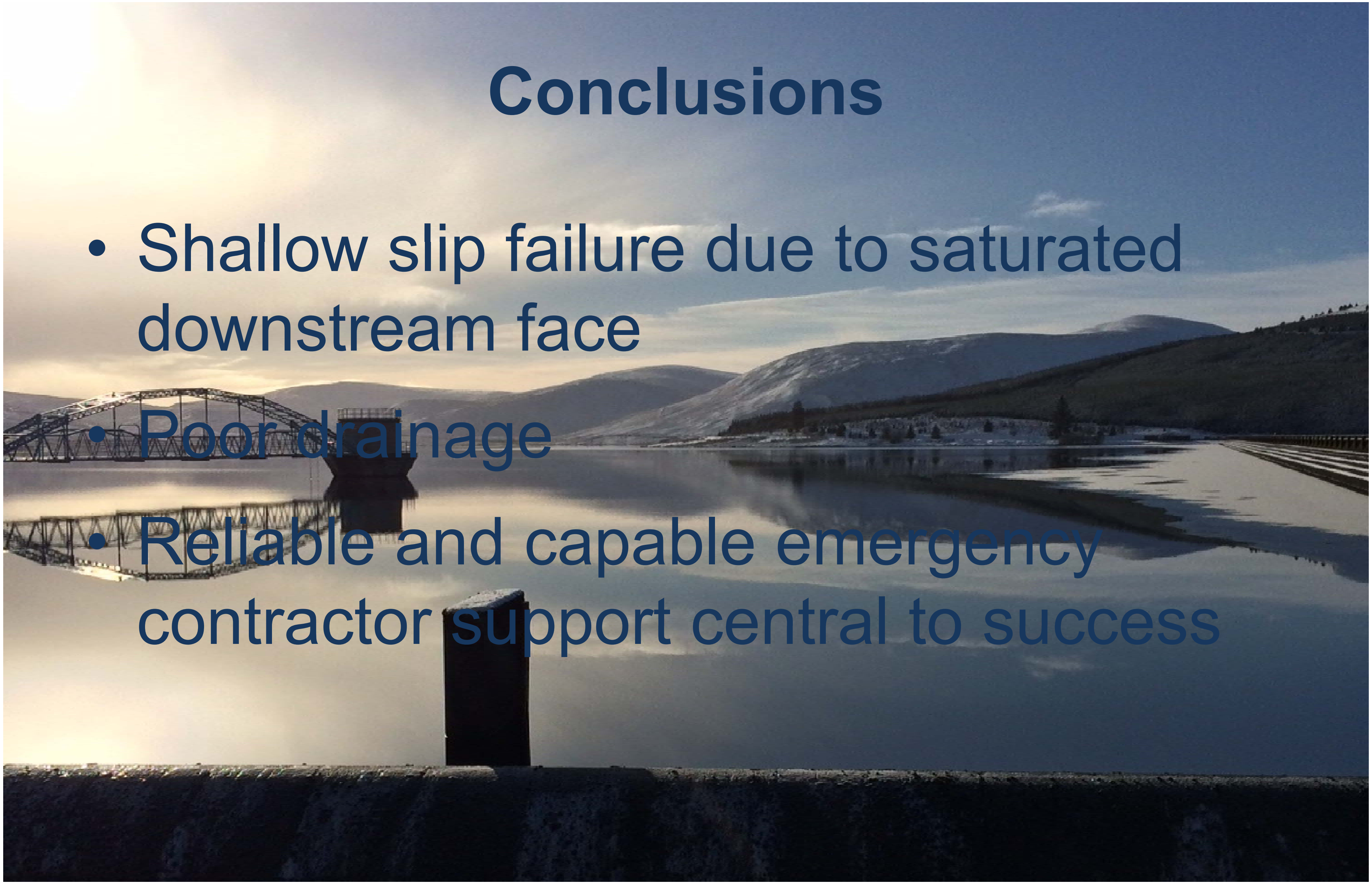
Combination of several contributing factors:

1. Period of heavy rainfall and high reservoir water level;
2. Water seepage through core wall (and below core?);
3. A resulting significant increase in core wall drain water level;
4. Seepage flow into the embankment at a relatively impermeable seasonal construction horizon;
5. Seepage flow to downstream face;
6. A thick layer of topsoil;
7. Surface saturation of thick topsoil (seepage flow and rainwater).

→ Shallow failure along topsoil / embankment fill interface

Actions and Next Steps

- Willowstick survey
  - 3 distinct leakage paths identified
  - Leakage below the concrete core
- Drainage improvements
  - New herringbone drainage system
  - Pillar drains and berm drain
  - New drainage collection chamber



Conclusions

- Shallow slip failure due to saturated downstream face
- Poor drainage
- Reliable and capable emergency contractor support central to success

Chapel House Embankment

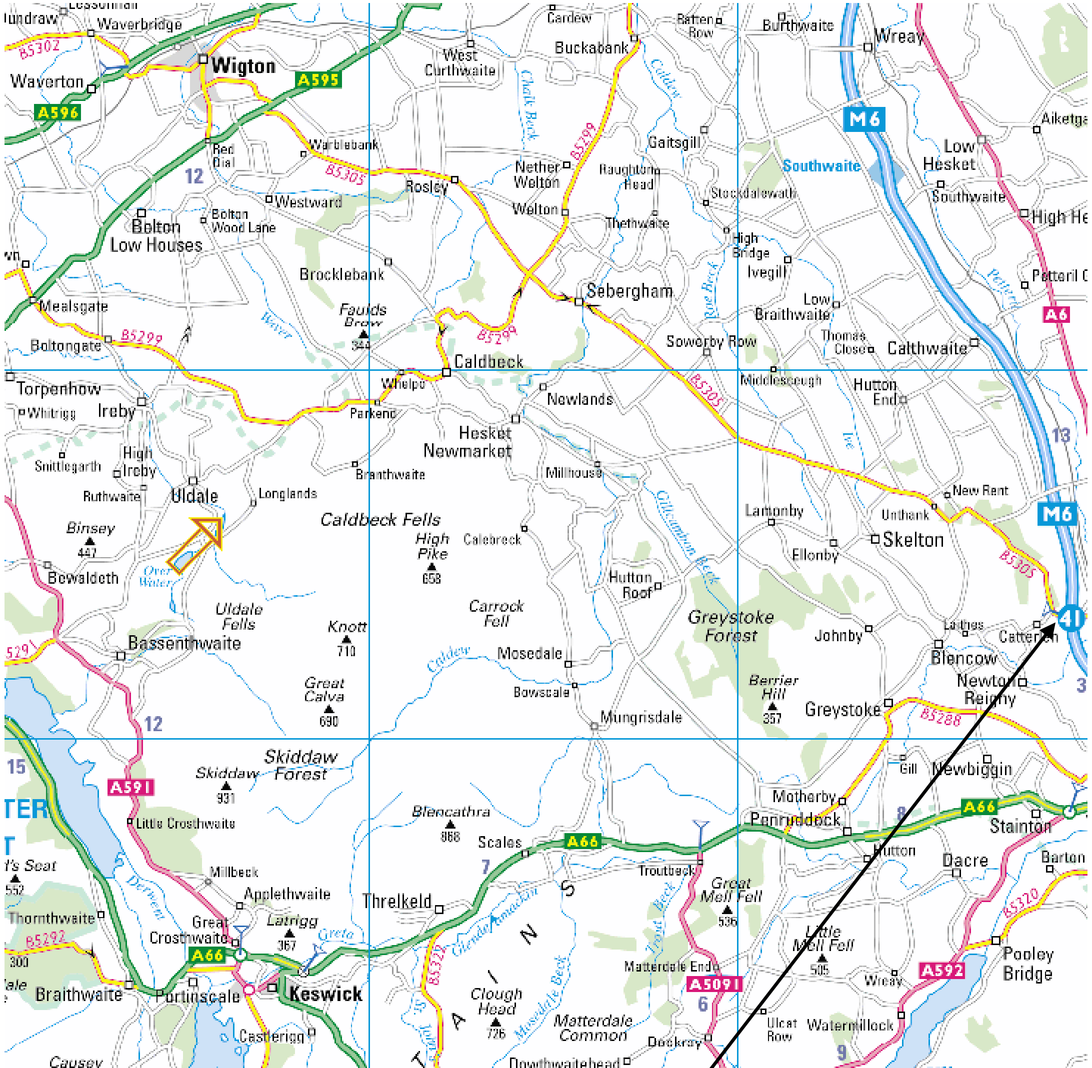
Slurry trench cut-off wall and permeation grouting

Chapel House Embankment

Slurry trench cut-off wall and permeation grouting of Chapel House Embankment Dam, Cumbria

- Location
- History and construction of embankment
- Historic seepage and inspection recommendations
- Ground investigation works
- Failure Paths and Solution Development
- Design
- Construction and monitoring
- Results and Validation

Chapel House Embankment: Location



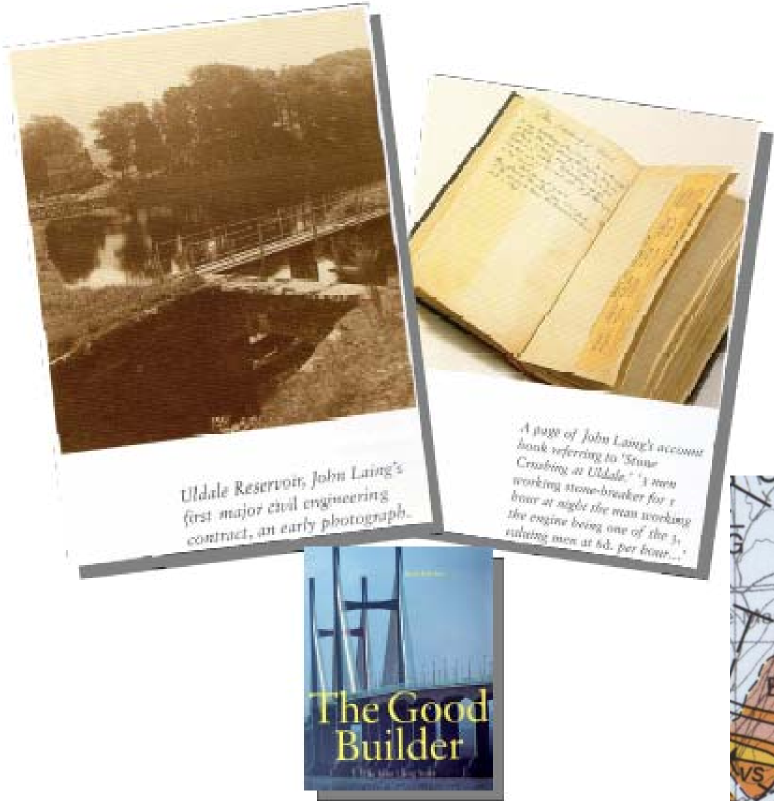
Narrow access road to Chapel House

Restricted access across embankment. Pinch-point on spillway bridge 4.5m.

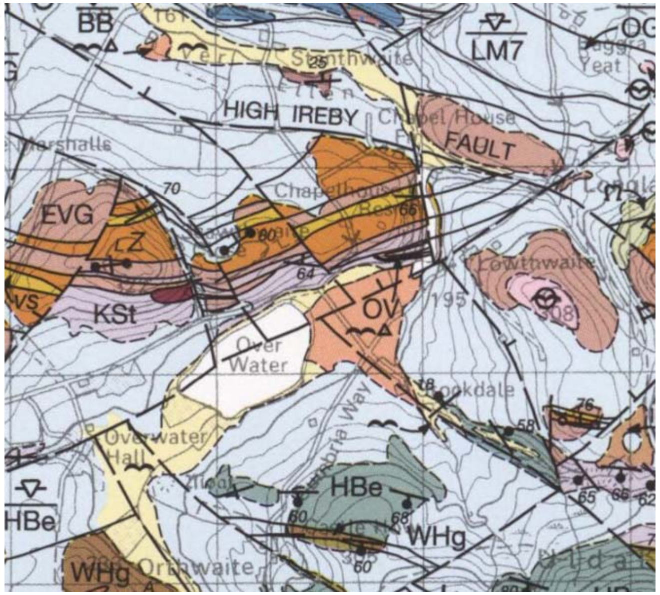
Approx. 44 miles to junction 41 of M6

Chapel House Embankment: History & Construction

Vital water supply

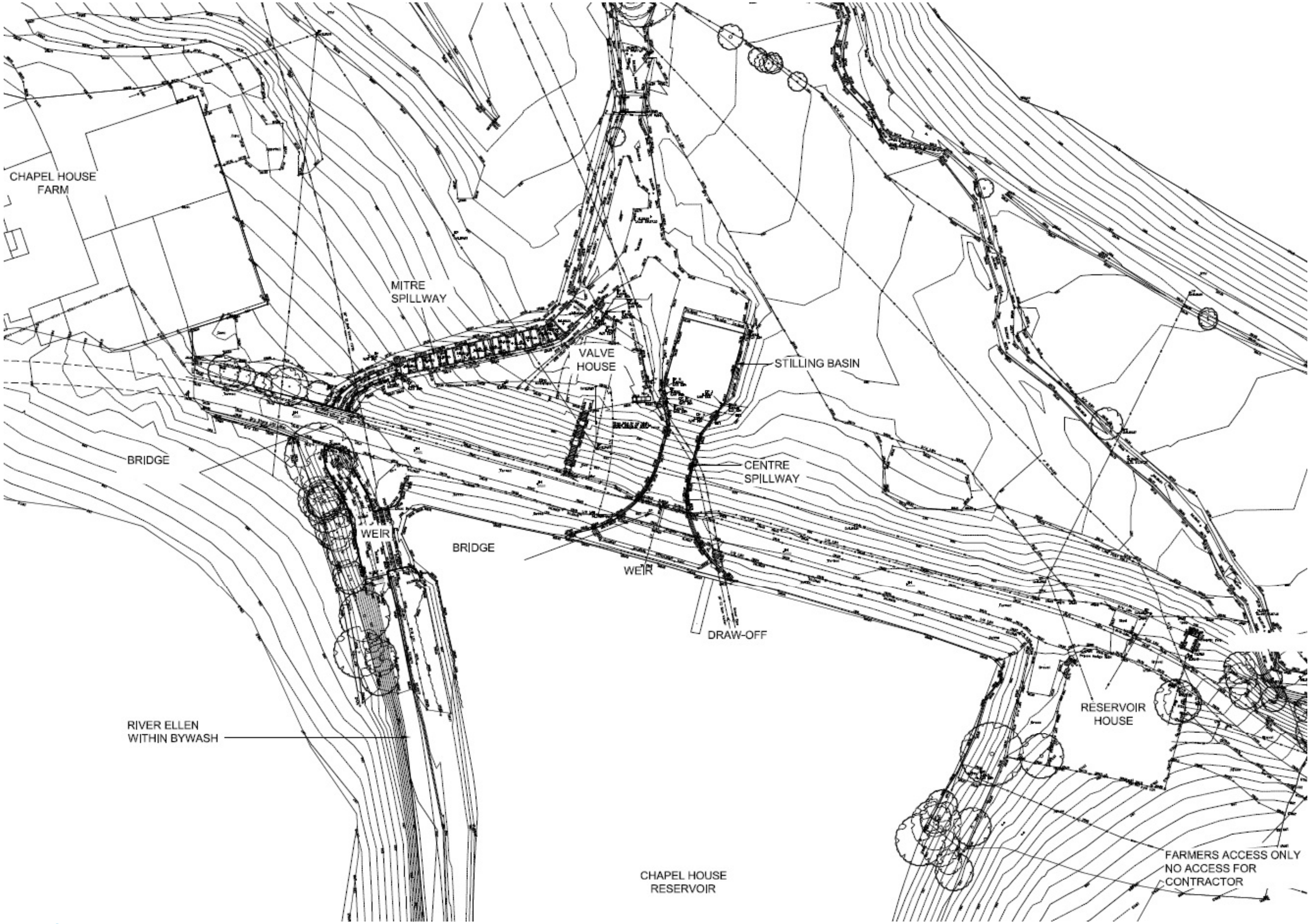


Reference to Chapel House in *'The Good Builder; the John Laing Story'* indicated the embankment was constructed in 1902 from local material using horse and cart



Extract from BGS Sheet 23 Cockermouth, Solid & Drift 1:50,000 1997

Chapel House Embankment: History & Construction



Chapel House Embankment: Seepage

Localised wet patches and extensive reed growth around stilling basin and toe of embankment

Total of 10 drains/pipes installed over the years to monitor seepage on the downstream face

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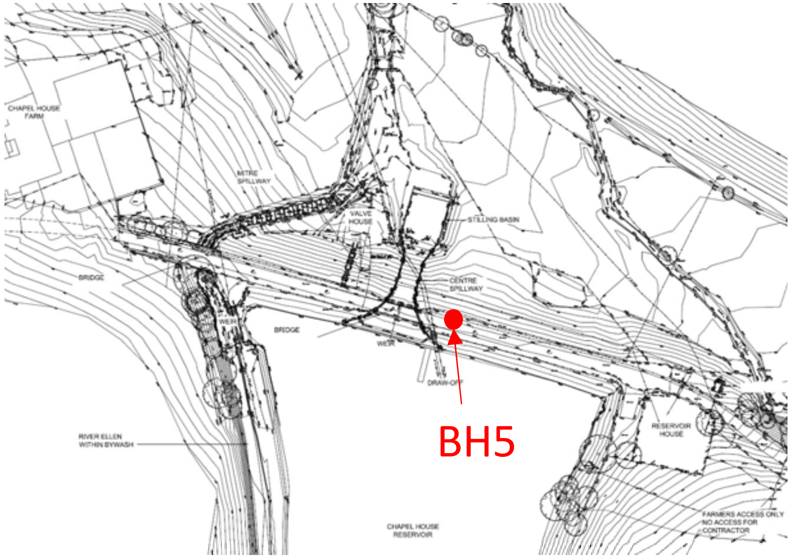
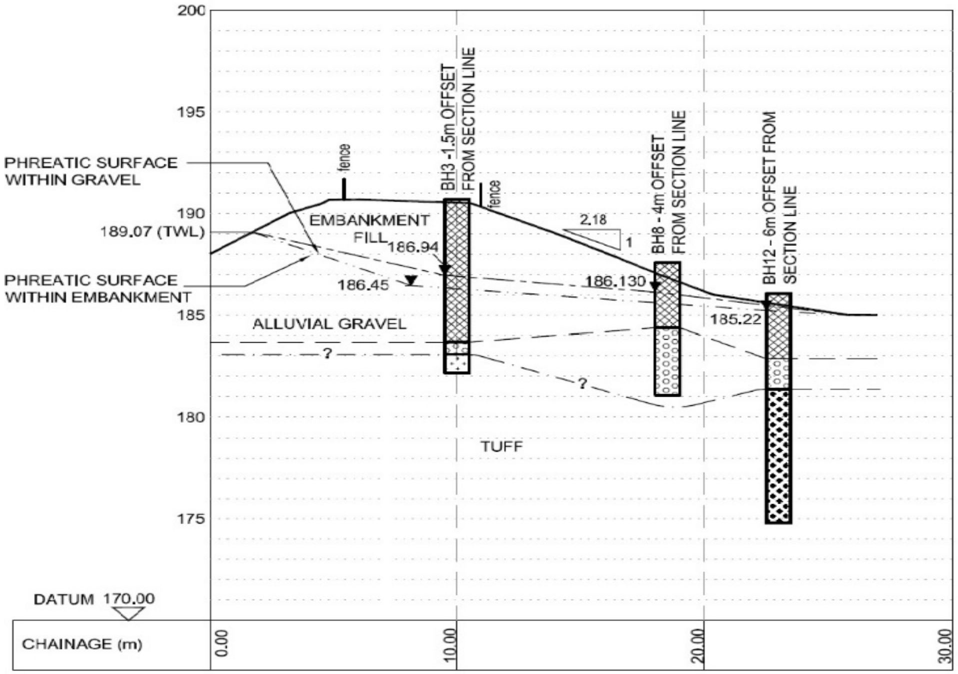
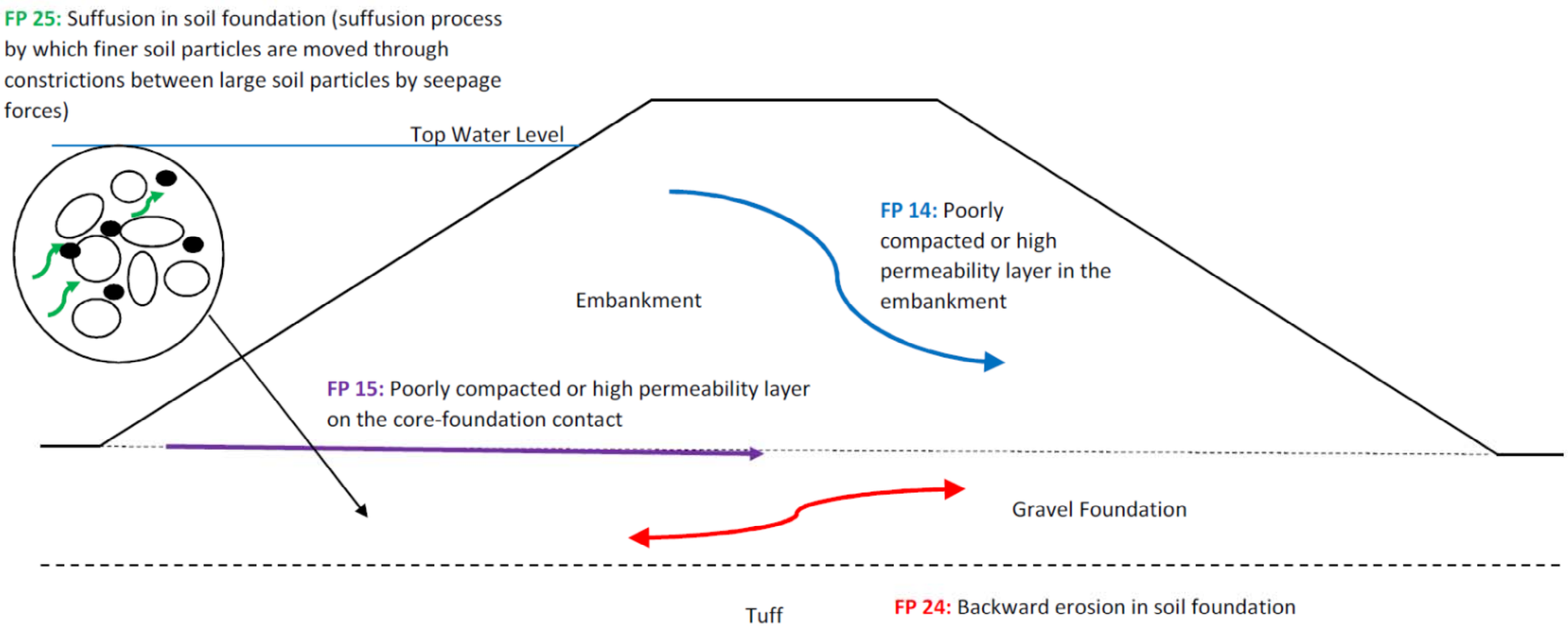
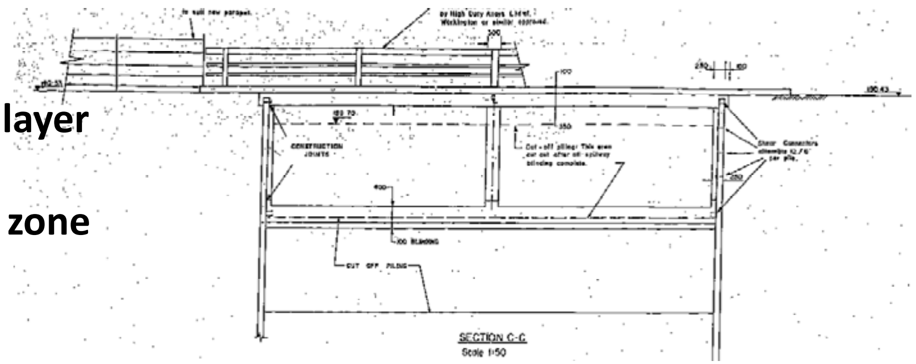
Chapel House Embankment: Ground Investigation





Chapel House Embankment: Failure Paths

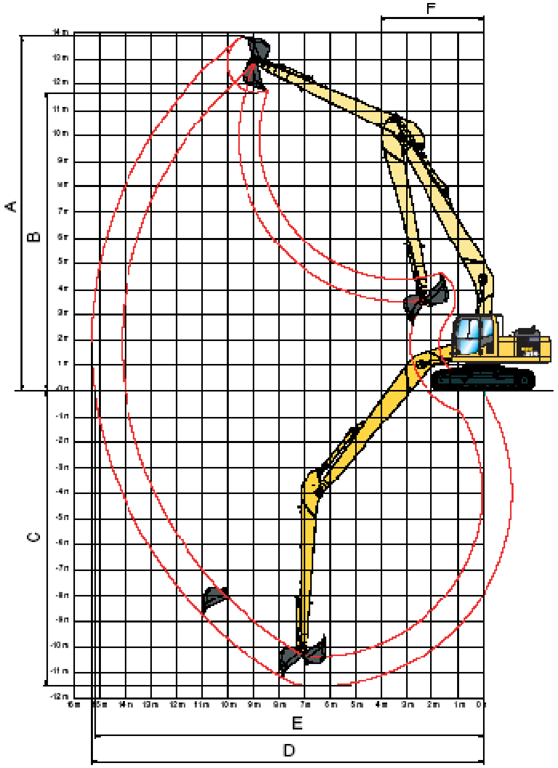




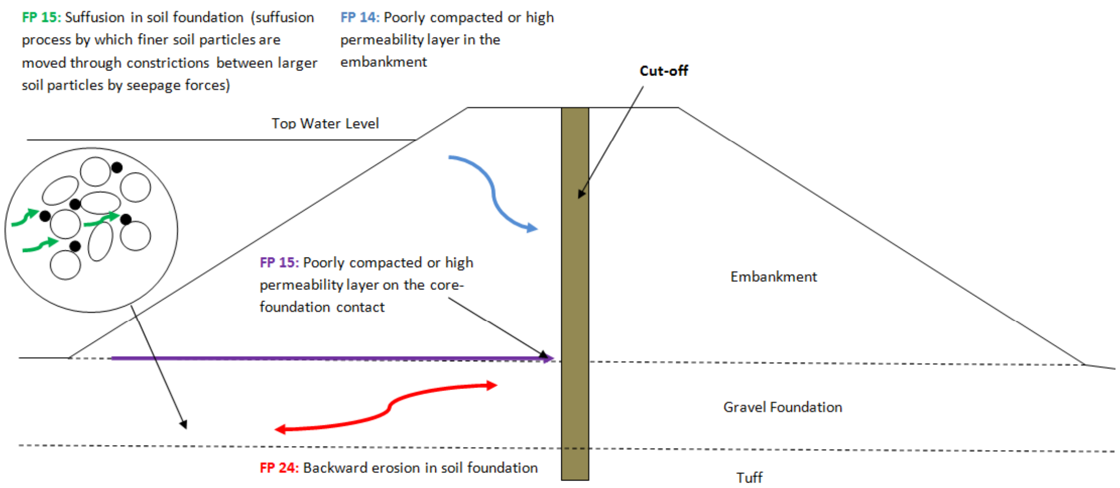
In addition to the above Failure Paths (FP):

- **FP18 Poorly compacted or high permeability layer around conduit through the embankment**
- **FP20 Poorly Compacted or high permeability zone associated with a spillway abutment wall**
- **FP21 Crack/gap adjacent to spillway**

Chapel House Embankment: Solution Development



Constructability: depth of trench determined by size of excavator that could be used on the crest and maximum reach



CHAPEL HOUSE IR

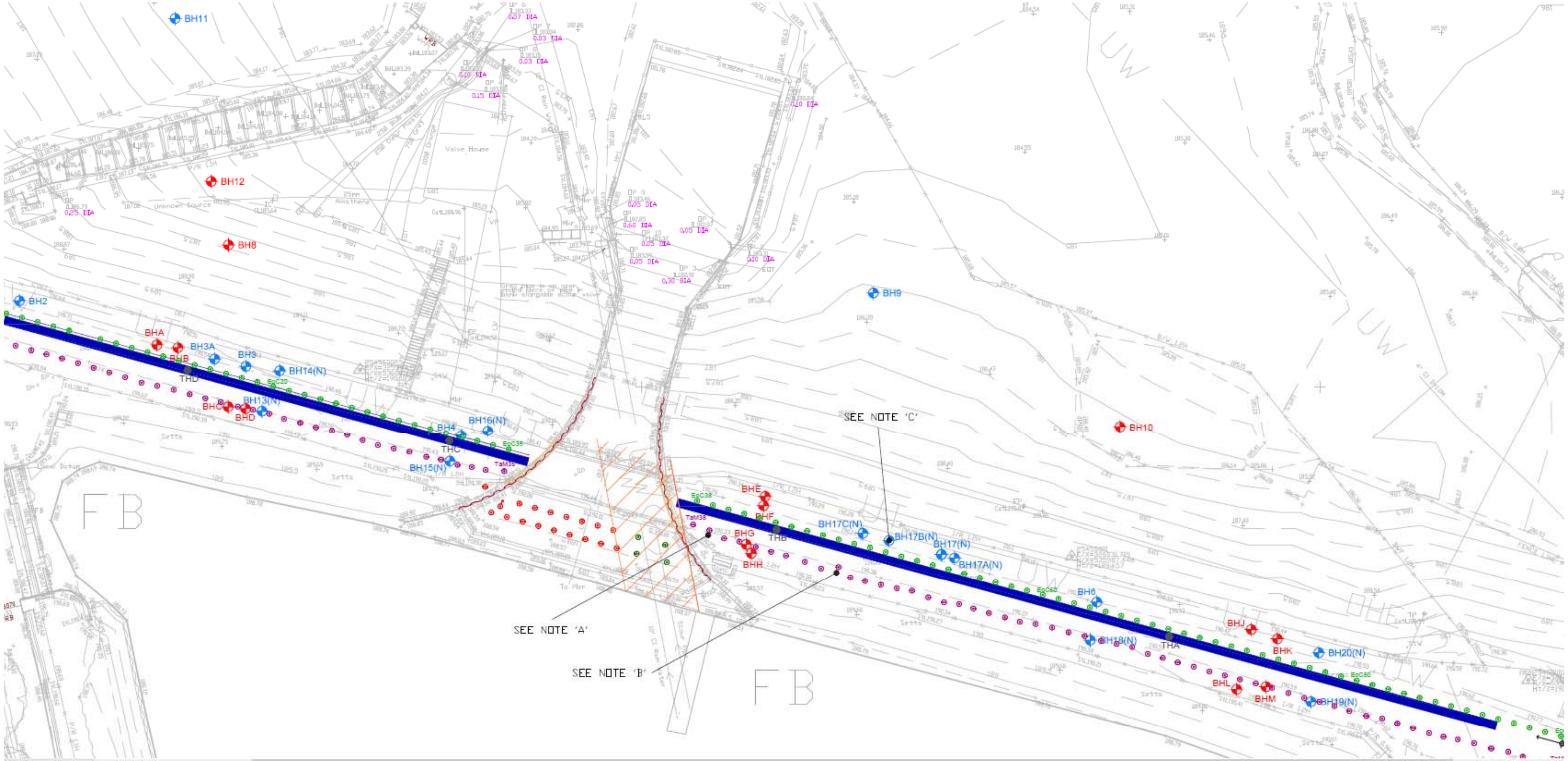
SUMMARY OF PROBABILITIES AND PROPOSED REMEDIAL SOLUTIONS

Initiation Mech.	Failure Path	Summary Description	Probability of Failure (see key for colour coding)	Proposed Works	Probability of Failure (see key for colour coding)
IM14	FP14	Poorly compacted or high permeability layer in the embankment	3.48E-02	Slurry trench wall through embankment	2.26E-07
IM15	FP15	Poorly compacted or high permeability layer on the core-foundation contact	1.74E-03	Slurry trench wall and contact grouting (tube-a-manchette (TaM) grout injection holes) between base of slurry wall into the soils foundation	1.74E-05
IM18	FP18	Poorly compacted or high permeability layer around a conduit through the embankment	4.34E-03	Tube-a-manchette (TaM) grout injection holes around scour pipe	4.34E-05
IM20	FP20	(New Spillway) Poorly compacted or high permeability zone associated with a spillway or abutment wall	3.04E-02	Slurry wall to extend to spillway additional grouting adjacent to spillway Grouting below the spillway using a grid of tube-a-manchette (TaM) grout injection holes.	5.22E-06
IM21	FP21	(New Spillway) Crack/gap adjacent to a spillway or abutment wall	2.83E-01	Grouting below the spillway using a grid of tube-a-manchette (TaM) grout injection holes	1.71E-06
IM24	FP24	Backward erosion in the soil foundations	7.76E-03	Contact grouting between base of slurry wall into the soils foundation	7.84E-06
IM25	FP25	Suffusion in soil foundations	4.85E-02	Contact grouting between base of slurry wall into the soils foundation	4.90E-05

KEY

- Intolerable region (red)
- ALARP region (amber)
- Tolerable region (green)

Chapel House Embankment: Design



Chapel House Embankment: Construction & Monitoring

Long reach excavator installing slurry trench with vacuum excavator removing arisings

TaM grouting across central spillway, reservoir level maintained

Monitoring of embankment during construction Works

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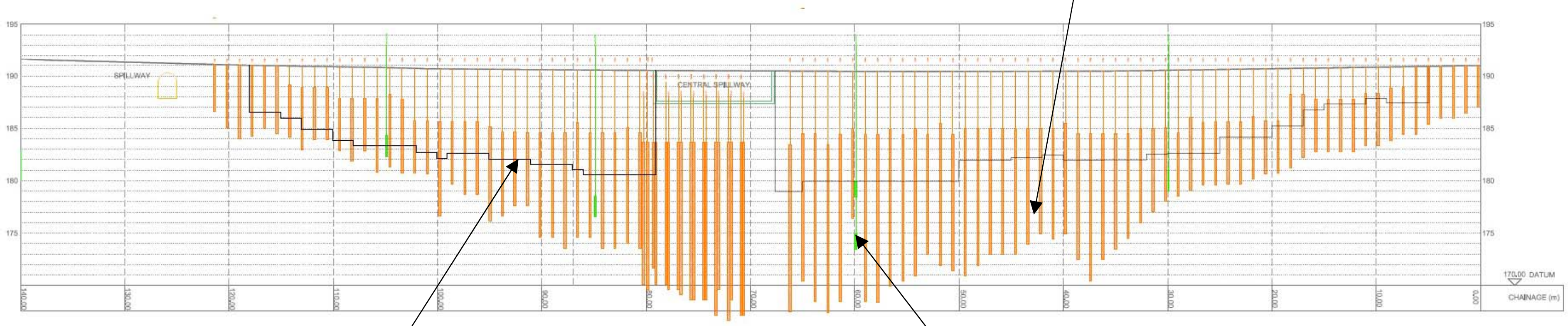
Chapel House Embankment: Results & Validation

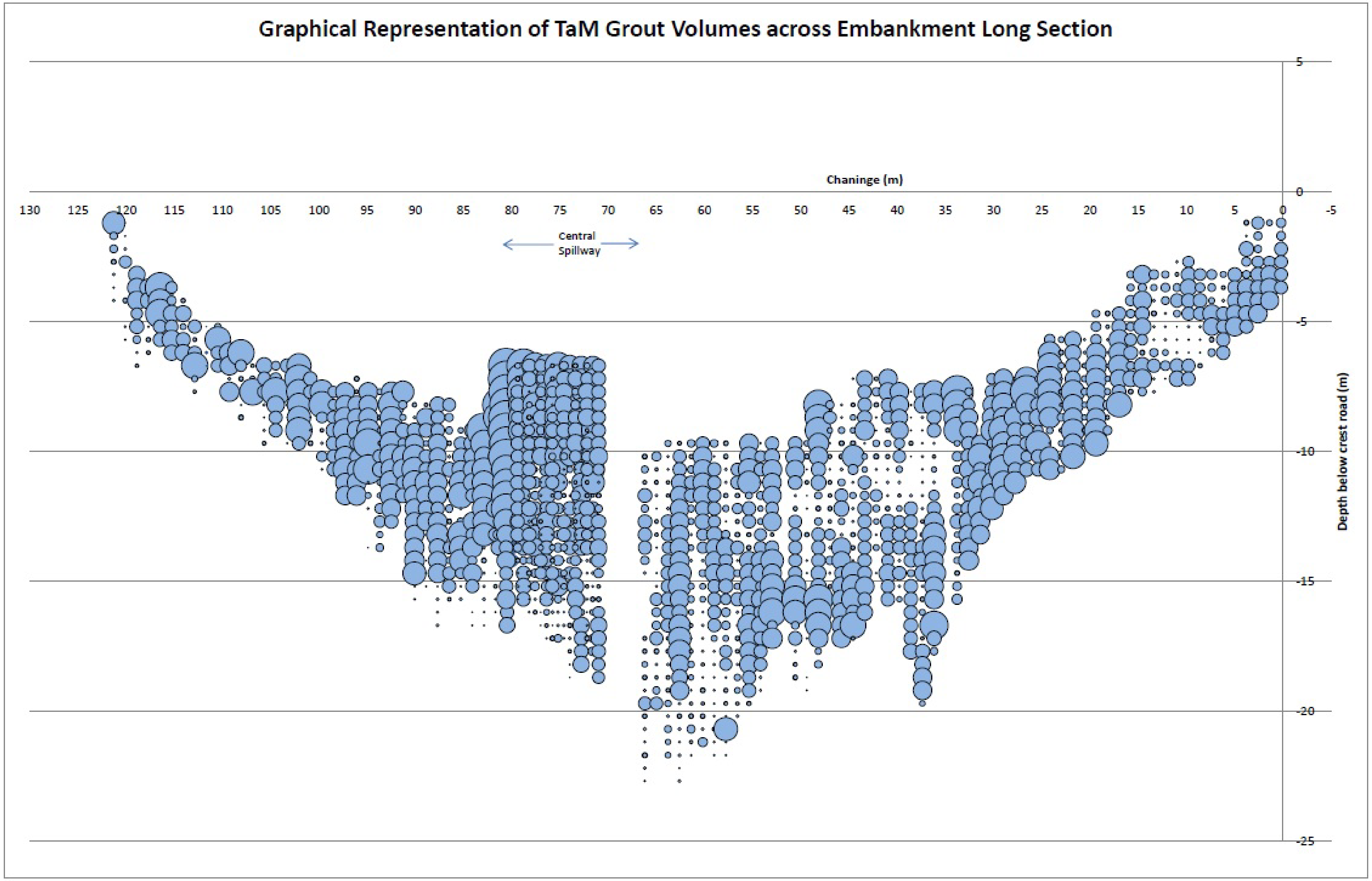
TaM injection holes showing extent of injection points



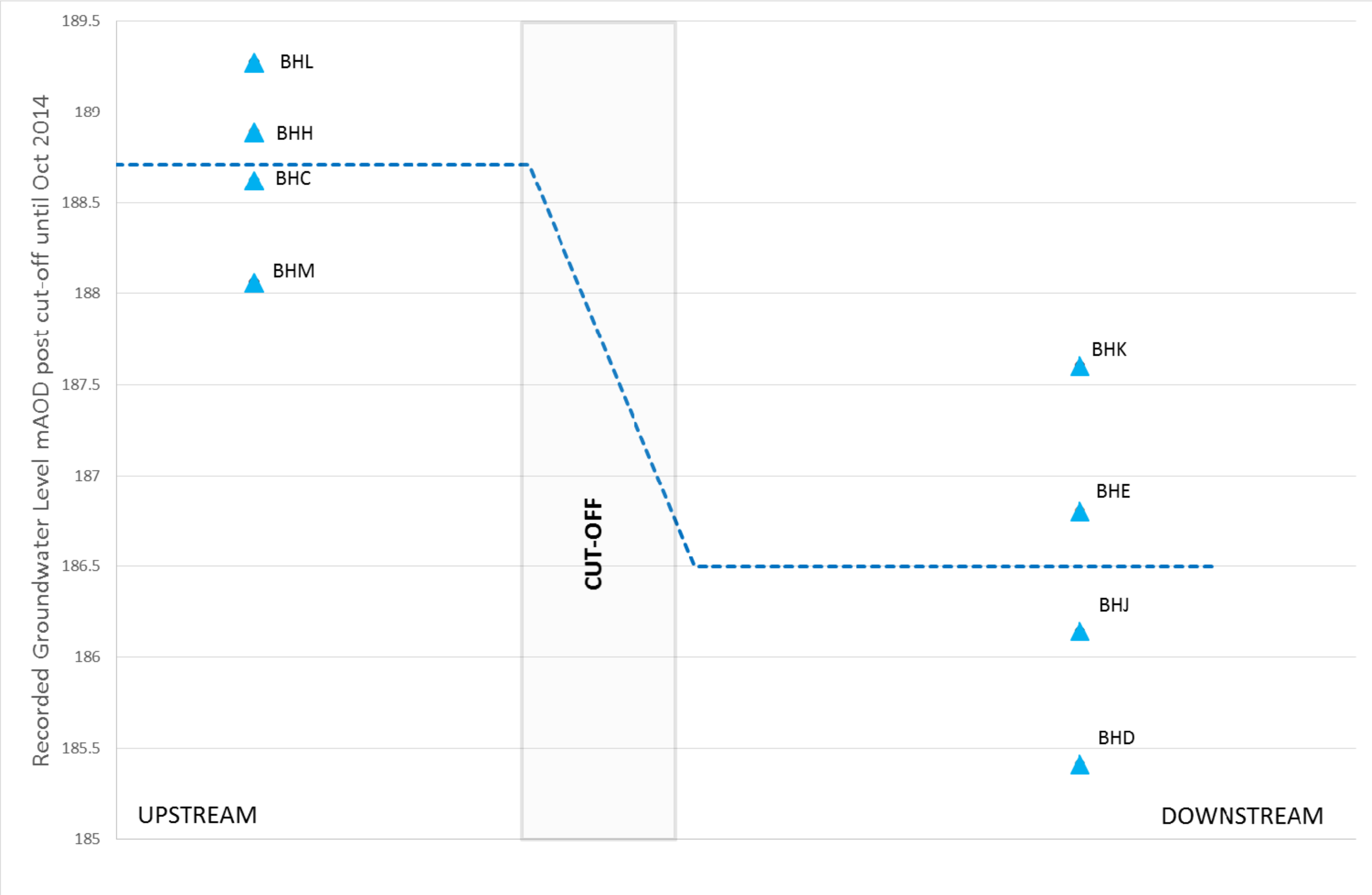
Profile line showing extents of slurry trench wall

Validation holes for in-situ permeability testing

Chapel House Embankment: Results & Validation



Chapel House Embankment: Results & Validation



Thank you

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Prevention of Internal Erosion in Homogeneous Dams - A Case Study

Session 3: Geotechnical aspect of dams

Mott MacDonald Bentley & United Utilities

Natalie Bennett (MMB) & Mark Edmondson (MMB)

Portfolio Risk Assessment

- UU's Earth Embankment Dams
  - 140 Earth-fill embankment dams
  - Many of a homogeneous construction

- 'PRA' Assessment
  - UNSW method
  - Risk based
  - Assesses seepage, stability, flooding & seismic impact
  - Probability of Failure > 1:10,000 years = 'Intolerable'
  - Used in conjunction with UU's 'Toolbox' assessment

Blackstone Edge, Whiteholme & Springs IRs

	Year Built	Dam Height	Dam Length	Failure Probability	Risks
Blackstone Edge	1803	14m	350m	3.57×10^{-4}	• Poorly compacted layer around a conduit • Flow into a conduit
Whiteholme	1816	16.2m	1300m	1.35×10^{-2}	• Cracking in the crest • Poorly compacted layer around a conduit
Springs	1830	13.7m	786m	1.09×10^{-3}	• Poorly compacted layer in the embankment and around a conduit • Flow into a conduit

Blackstone Edge & Whiteholme

Blackstone Edge

Whiteholme

Scheme Drivers

Risk of wash out of fines into or along the outlet tunnel

Geology

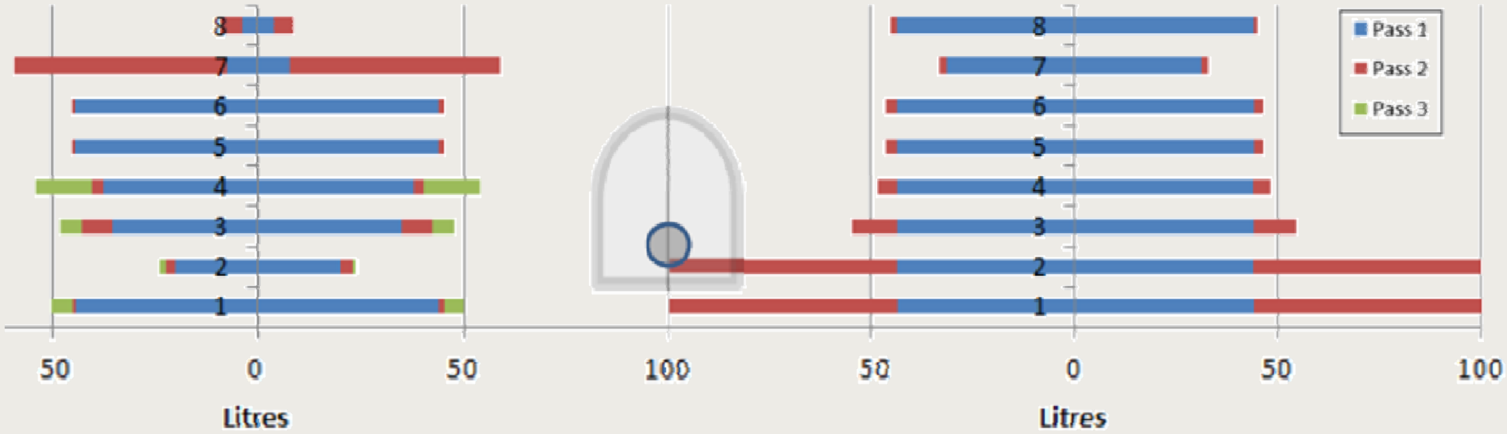
Homogeneous dams, comprising layers of sand and peat, overlaying gritstone

Scope of Works

Grouting from the embankment crest at both sites and infilling the tunnel at Blackstone Edge

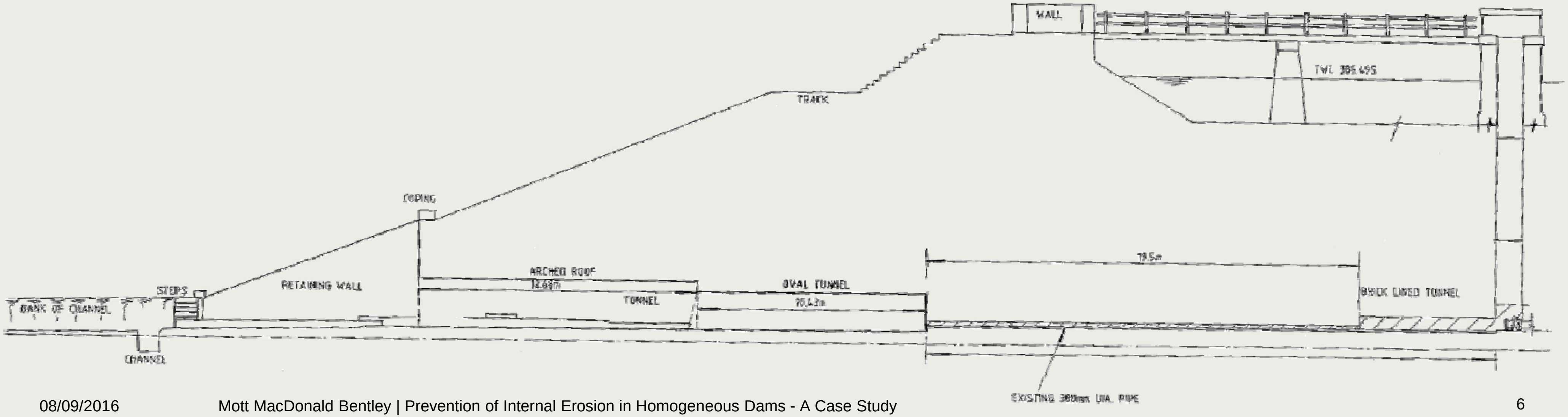
Blackstone Edge

- Permeation Grouting
  - Rotary open hole drilling
  - Grid of boreholes to form a ‘collar’ around the pipe
  - Falling head permeability tests
  - Tube-à-Manchette grouting
- Challenges
  - Grout loss into tunnel
  - Inability to ‘thicken’ the grout mix



Blackstone Edge

- Tunnel In-fill
  - Pointing to fill voids
  - Blockwork headwall
  - Inlet breather pipework
  - In-filling undertaken in discrete ‘Horizons’ using cementitious grout
  - Bentonite slurry used in the top horizon following installation of a TaM tube & then 'displaced‘



Whiteholme

- Permeation Grouting
  - Combination of rotary open hole drilling and auger drilling
  - Grid of boreholes to form a ‘collar’ around the pipe
  - Grout incorporated colouring for validation purposes
  - End of case grouting
- Validation
  - Validation borehole
    - Cable Percussive Boring
    - Undisturbed U100 sampling
  - Evidence of coloured grout

Springs Reservoir

Scheme Drivers

Wash out of embankment fines

Geology

Dam comprises sandy gravelly clay overlying glacial till deposits over gritstone

Scope of Works

Sheet pile cut-off wall and partial embankment face filter blanket and associated filtered toe drainage

Springs Reservoir

- Sheet Piling Solution
  - Piles installed into the embankment crest to provide a ‘cut off’ barrier
  - Steel interlocking piles used with a clutch sealant

Springs Reservoir

- Sheet Piling Methodology
  - Piles driven to depths of 6m to 8m
  - Initially driven using an excavator with Movax vibrating hammer attachment
  - Design depth then achieved by using a Doosan Air Hammer

Springs Reservoir

- Filter Blanket
  - Three layers: 250mm filter layer; 250mm drainage layer; 200mm filter layer
- Associated Toe Drainage

Thank you

Prevention of Internal Erosion in Homogeneous Dams - A Case Study

Mott MacDonald Bentley & United Utilities

Natalie Bennett (MMB) & Mark Edmondson (MMB)

Retrofit of Fibre Optics to existing Dams

Jürgen Dornstädter & David Dutton

Bend optimised fibres inside GTC temperature probes

(Patent DE19621797)

Three recent projects

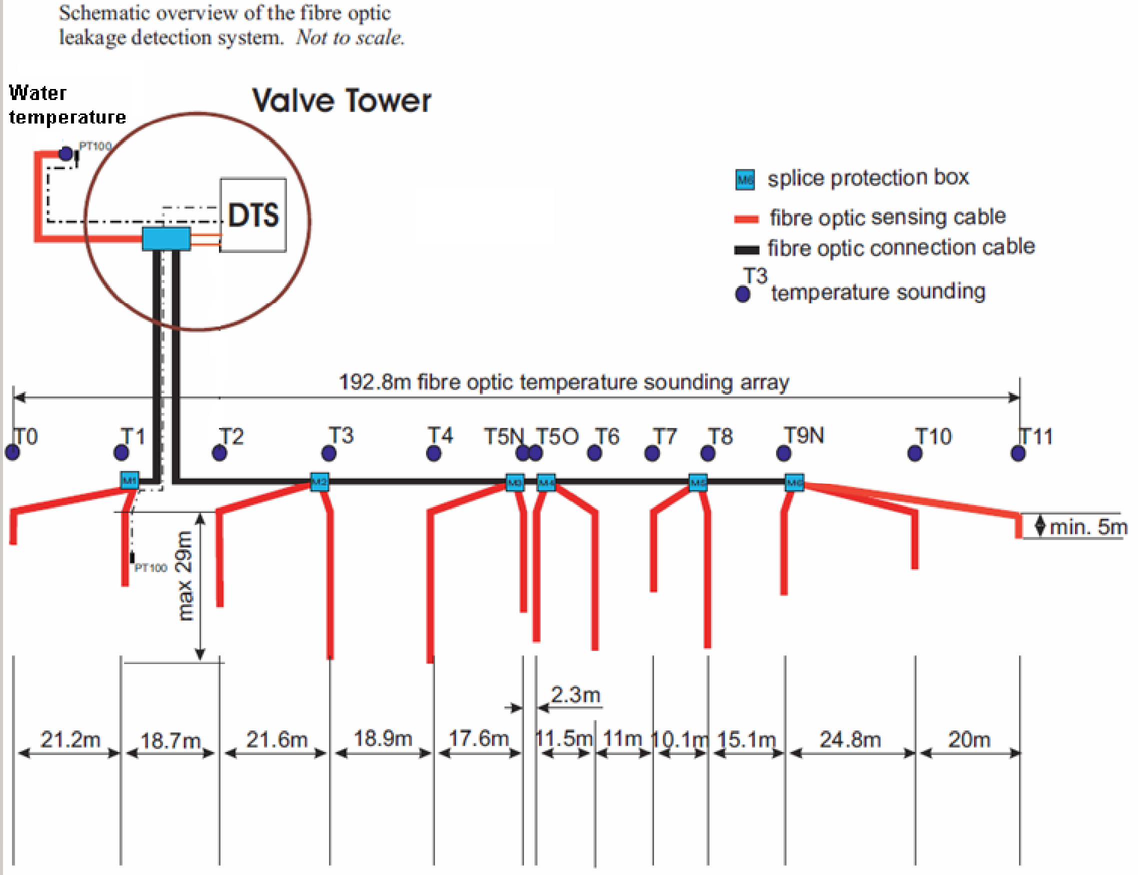
Dam A

Dam C **Dam B**

Retrofit of Fibre Optics to existing Dams

Example

Layout sketch



Retrofit of Fibre Optics to existing Dams

Installation

Temperature sounding array on downstream slope close to edge of crest.

Picture shows auxiliary scaffolding along installation trench.

Retrofit of Fibre Optics to existing Dams

Installation

The red fibre optic sensing cable with bend optimised fibres is inserted into the metal pipe of the temperature probe.

The installation is protected by a large diameter PVC tube. The red fibre optic cable continues to a splice protection box.

splice protection box

Installation

Termination of bend optimized fibre optic cable.

Installing fibre optic cable for water temperature sensing

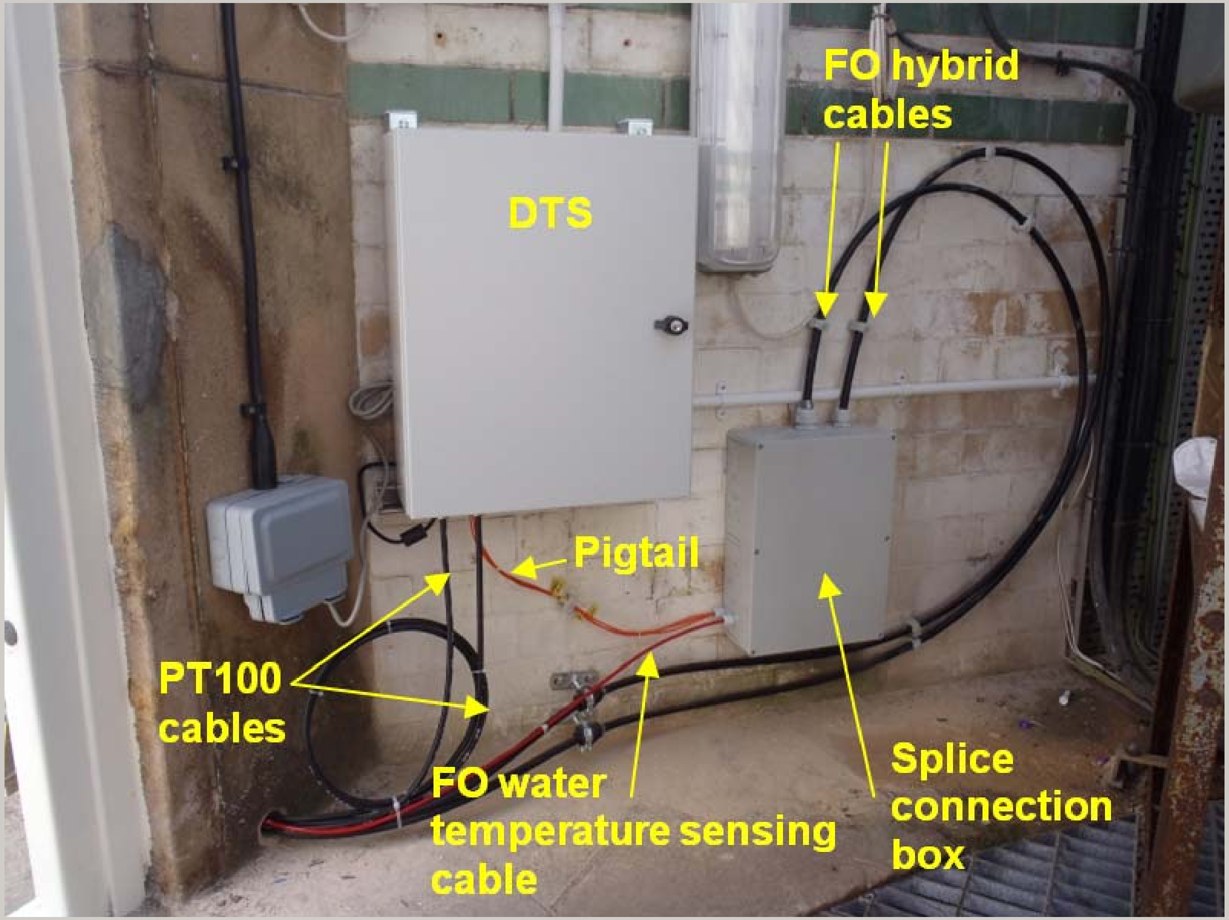
End of Installation

Out of sight and well protected leak detection system after completion of installation

Retrofit of Fibre Optics to existing Dams

Instrumentation

Overview



Retrofit of Fibre Optics to existing Dams

Dam C

37 temperature probes, 16m – 17m deep, but last metre of data is not shown (distorted values).
-> measurements to 15m – 16m depth

+ 430m fibre optic cable at downstream toe of embankment

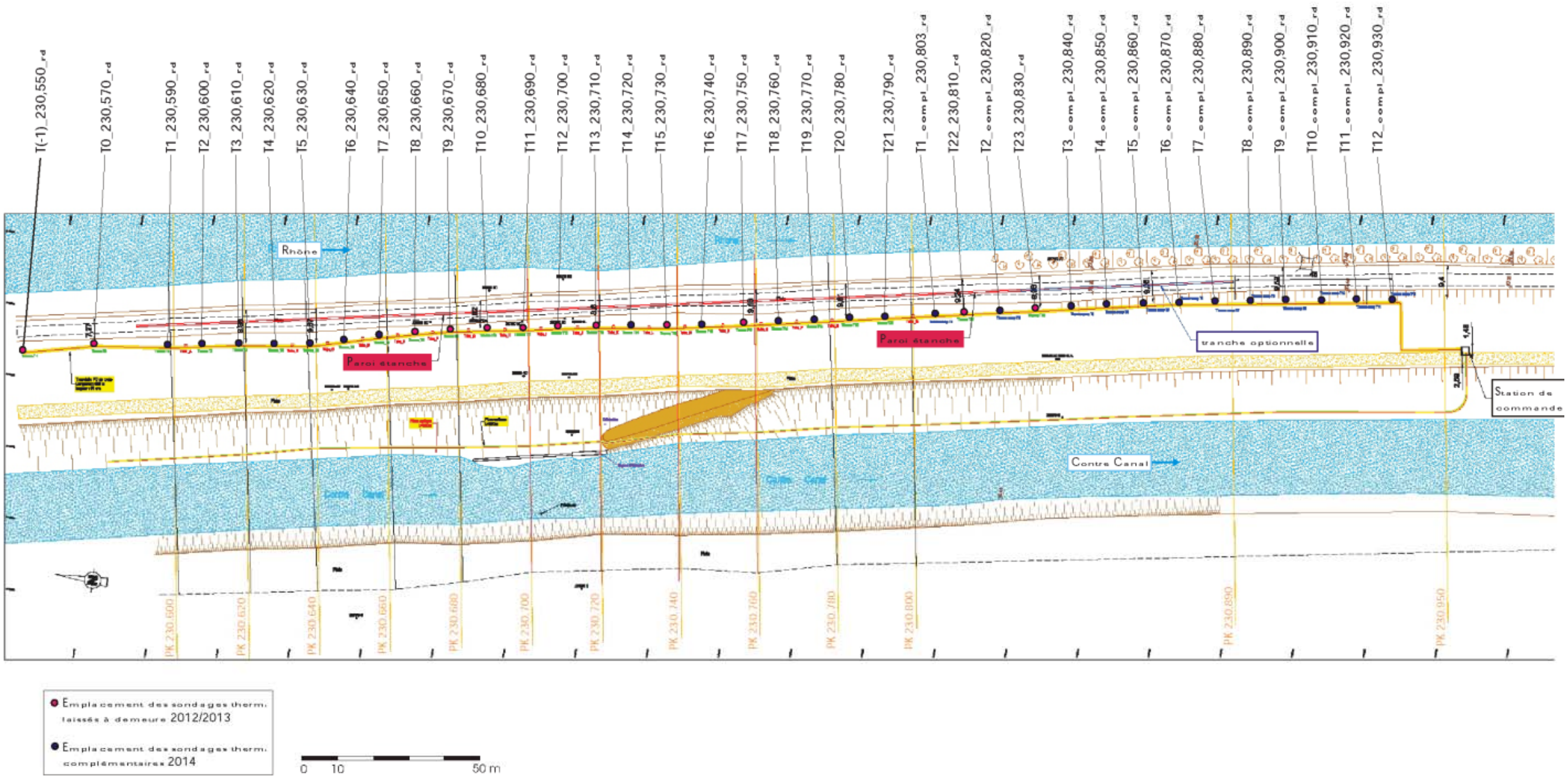
4 fibres (single end measurements)

4 channel, 2 km DTS

Computer for data processing on site, results are transfered to GTC office server using internet connection via mobile network router

Retrofit of Fibre Optics to existing Dams

T-1 T0 T1 T2 T3 T4 T5 T6 T7 T8 T9 T10 T11 T12 T13 T14 T15 T16 T17 T18 T19 T20 T21 T1+ T22 T2+ T23 T3+ T4+ T5+ T6+ T7+ T8+ T9+ T10+ T11+ T12+



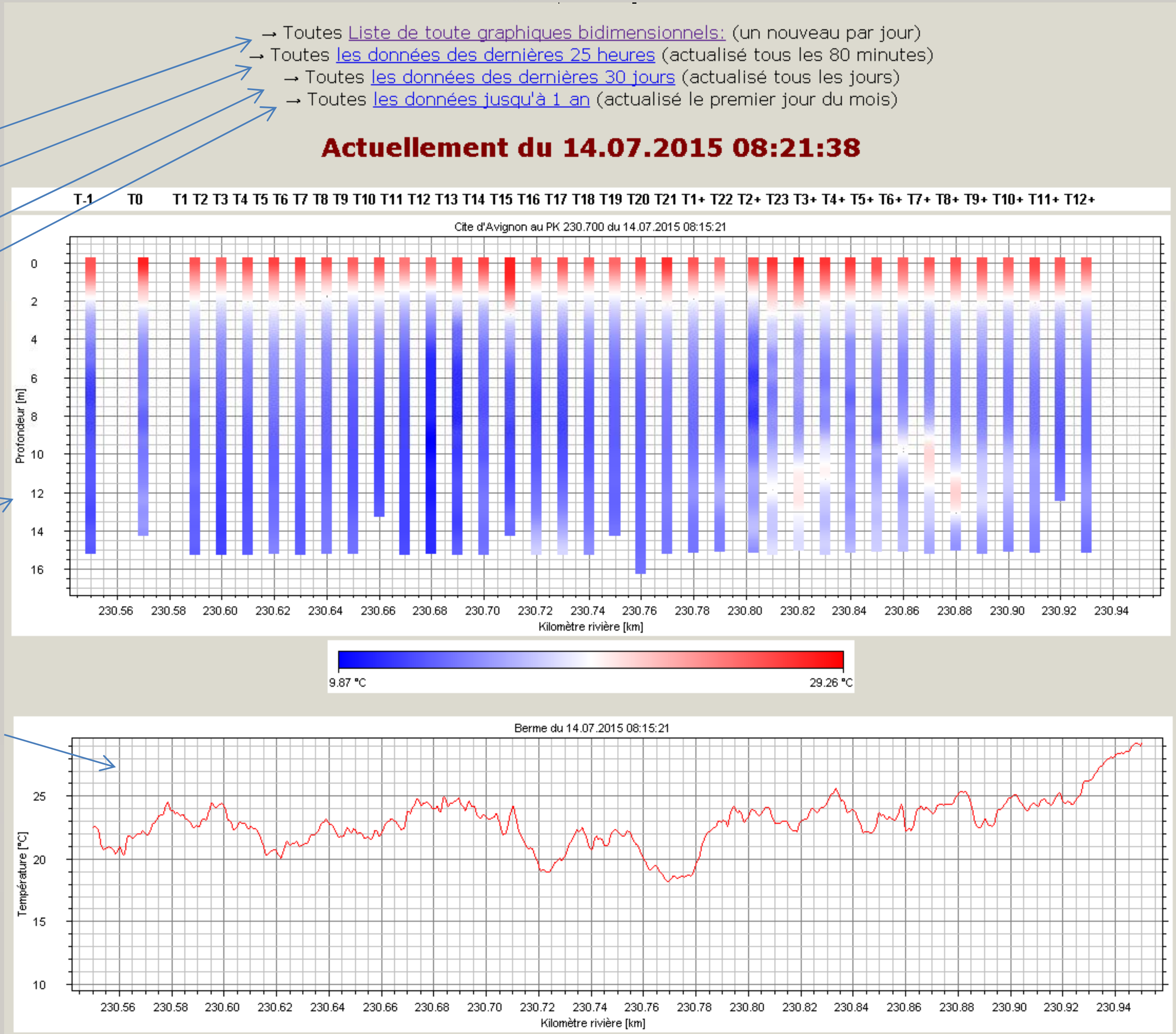
Retrofit of Fibre Optics to existing Dams

Dam C

2D-graphics
24h-data
Monthly-data
Yearly-data

37 temperature soundings (updated every 80 minutes)

Downstream toe

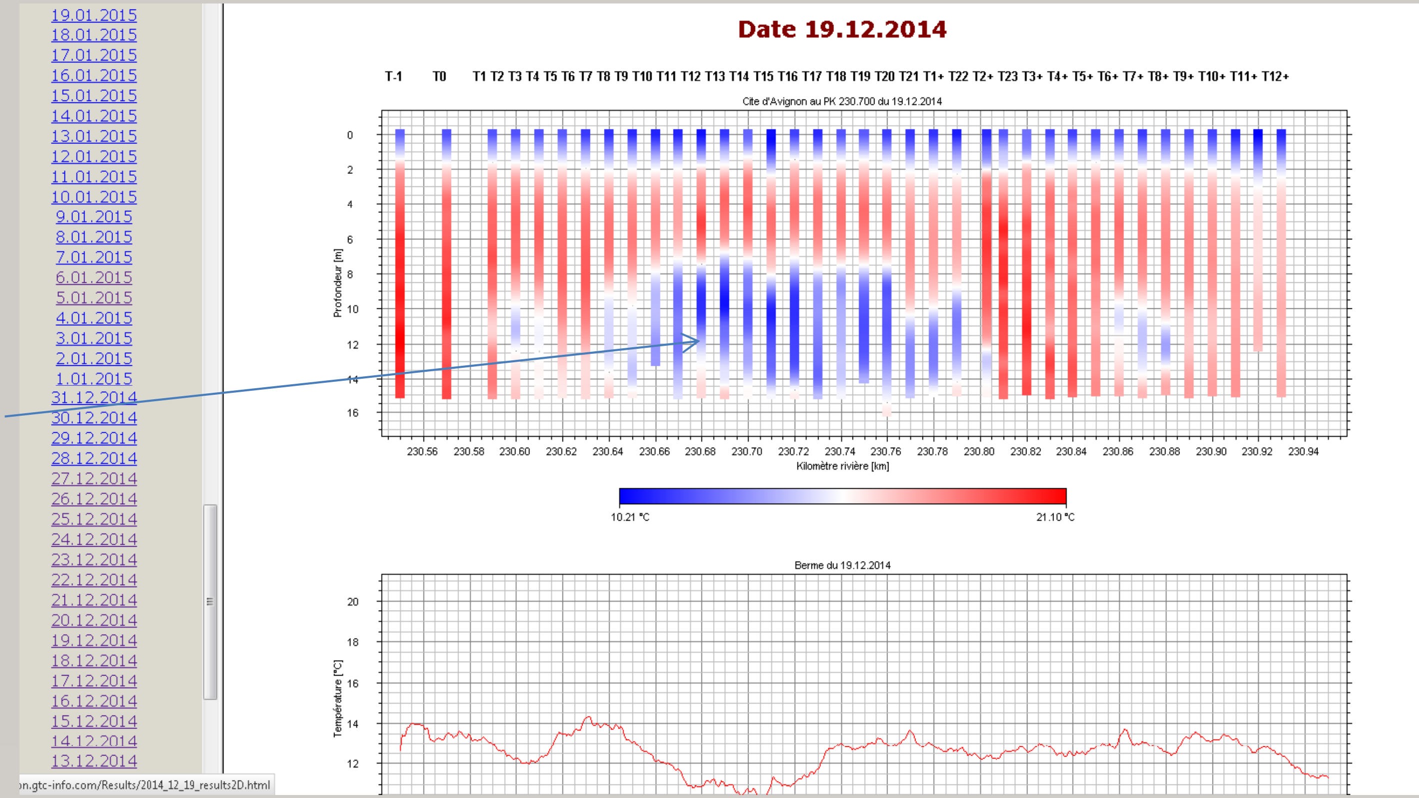


Retrofit of Fibre Optics to existing Dams

Dam C

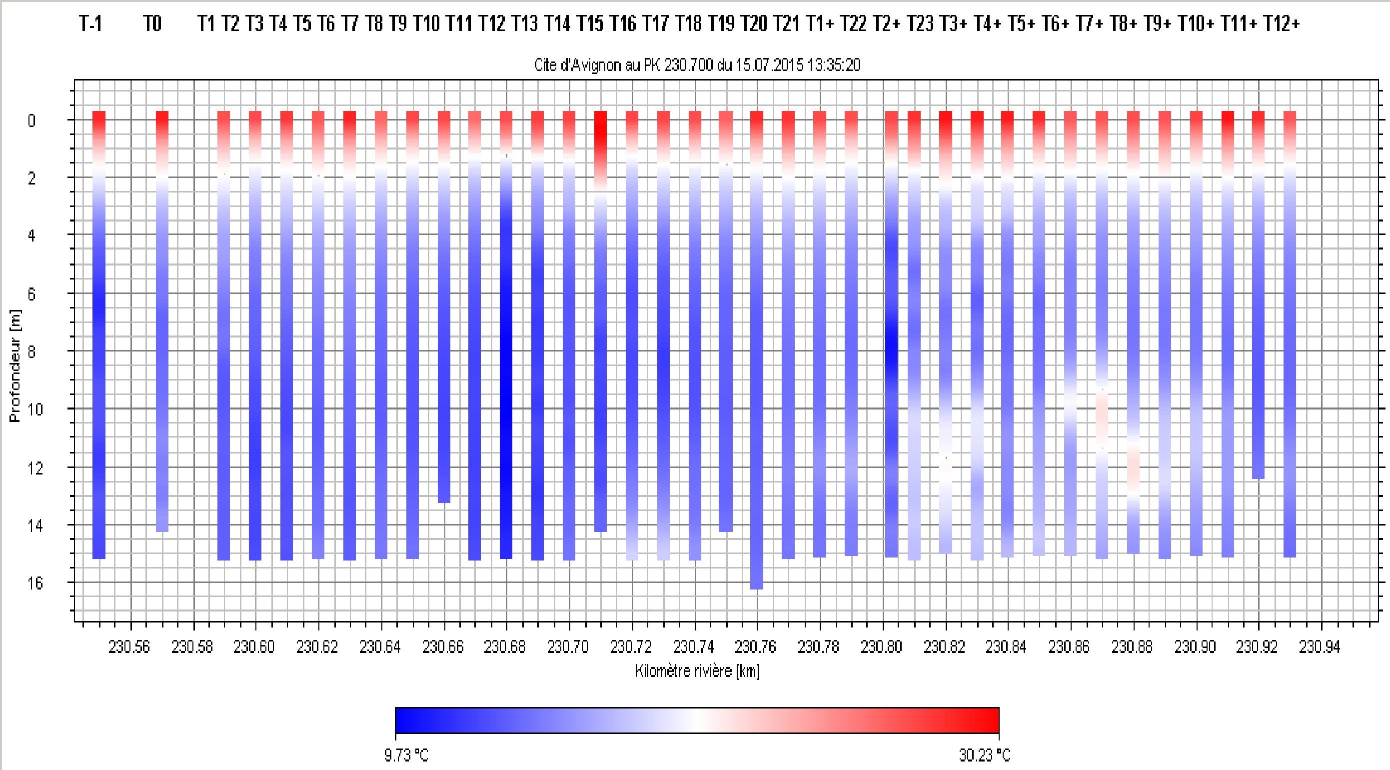
List of daily 2D-graphics

Clear indication of significant leakage of ‘cold’ river water in December 2014



Retrofit of Fibre Optics to existing Dams

Following the construction of a new cut-off wall to seal the embankment in spring 2015, the recorded temperature distribution in summer 2015 shows no leakage through the embankment or its foundations



Retrofit of Fibre Optics to existing Dams

Thank you for your attention!

Session Chairman: Pam Rigby
Technical Reporter: Andrew Thompson

An investigation and assessment of embankment stability at Daer Reservoir (Morrin *et al*, p 125 of the Proceedings)

Question: Tim Blower, (Mott MacDonald)
Firstly thank you for a clear explanation of an interesting case study. My first question is, presumably you did a two-dimensional analysis for the slip but did you consider three-dimensional aspects in your back analysis?

Response: Matthew Sullivan, (Jacobs UK Ltd)
We took a cross section through the area of the slip and carried out a two dimension analysis

Question: Tim Blower, (Mott MacDonald)
My second question is in relation to the remedial measures did you consider installing vertical drainage to penetrate/breach the low permeability layer that had been formed during construction?

Response: Ross Morrin (Scottish Water)
Vertical drainage through the low permeability layer was not considered due to the length of the dam (800m), the time is would take and also the depth to reach other seasonal layers within the dam. On site it is relatively clear to see the (wet) horizon along the dam and we have taken initial steps to successfully capture anything that is coming through from the horizon and below. Over the last 12 months we have finished the installation of the drainage and the saturated areas on the surface have significantly reduced.

Question: Jack Meldrum, (Mott MacDonald)
Did you look for and find any information on the history and original construction of the embankment? Was there anything useful? Particularly considering that stability berms are often added to dams of this age as a result of problems?

Response: Ross Morrin, (Scottish Water)
We were quite lucky as there is a detailed paper written that describes the construction of the dam and a comprehensive set of as built drawings. There was no reference or comment to any issues relating to stability of the embankment in the sources but they did provide a good of the construction of the dam and the sequence of works

Question: Dr Christine McCulloch, (University of Oxford)
Who raised the initial alarm about the landslip on the embankment? Was he there by chance or was that his purpose? Sometimes it is by chance that somebody sees these things and time is of the essence in such a situation.

Response: Ross Morrin, (Scottish Water)
He was a contractor working on turbines located on the dam and was luckily there for a good period. That wouldn't usually be the method we use for us finding out about such incidents. In addition the dam also has a treatment works associated with it so operational staff are there at all times anyway.

Slurry trench cut-off wall and permeation grouting of Chapel House Embankment Dam, Cumbria (Pailing *et al*, p139 of the Proceedings)

Question: John Foster, (Mott MacDonald)
Was there any special detail for the concrete centre spillway and the interface with the new slurry trench wall?

Response: Clare Pailing , (United Utilities)
The slurry trench wall did not extend across the central spillway so we had a slurry wall on either side of the spillway and additional grout holes drilled diagonally which overlapped beneath the central spillway. There is an area against the spillway wall which could not be reached by the sheet piles so we did additional grouting in this area also.

Prevention of Internal Erosion in Homogeneous Dams - A Case Study (Bennett *et al*, p 111 of the Proceedings)

Question: Martin Airey, (Mott MacDonald)
I note there are two components to the works at Blackstone Edge, first the permeation grouting and secondly the filling of the culvert tunnel. I just wonder whether any consideration was given to the need for the filling of the tunnel or perhaps there was an option to keep it open as a means of carrying out future surveillance and monitoring the effectiveness of the grouting around it?

Response: Natalie Bennett, (MMB)
Different methods were originally considered by the client however it was decided that it was a better approach by utilising the same method at both dams (Blackstone Edge and Whiteholme).

Response: Pamela Rigby, (United Utilities)
When the toolbox analysis was carried out on Blackstone Edge there were two internal erosion mechanisms that we were trying to reduce the risk of failure. The first was flows carrying eroded material around the outside of the conduit and the second is flows carrying eroded material into the conduit via cracks. So the project was to reduce the risk of erosion for both mechanisms and take the total risk of the dam out of the intolerable zone. In addition it was redundant pipe and we no longer needed to access the tunnel

Retrofit of Fibre Optics for Permanent Monitoring of Leakage and Detection of Internal Erosion (Dornstädter & Dutton, p165 of the Proceedings)

Question: Alan Brown, (Stillwater Associates)
For the two UK dams what was the purpose of the investigation (e.g. investigation of a potential problem or monitoring)? What flow velocity was inferred from the temperature measurements?

Response: Jürgen Dornstädter, (GTC Kappelmeyer)
Unfortunately I'm not allowed to speak too much about the two UK dams, however the flow velocities that are recorded now are below the level of detection for the instrumentation (less than 10^{-7} m/s). So no risk!

Question: Alan Brown, (Stillwater Associates)
What is the frequency of monitoring?

Response: Jürgen Dornstädter, (GTC Kappelmeyer)
There is permanent continuous monitoring with data acquisition every hour.