Leakage Surveys Ltd - Willowstick UK

Willowstick

DR ANDY HUGHES

Toddbrook Incident

Leakage Surveys Ltd - Willowstick UK

Kenya, May 2018


Emergency
Medical Services

Where ca we user Willowstick?

- Groundwater location
- Groundwater separation
- Environmental pollution
- Deep excavations
- Tunnel inflows
- Dam leakages /seepages
- Leaks from conduits

Leakage - Willowstick

Yes or No

Plan & Elevation

Leakage or Groundwater?

Intrusive of not ?

Other options

Temperature probes

Other resistivity methods

GPR

Etc

I’ve not found them to be as effective

No holes

Immediate results

Down to 300m

Targetted remedial works

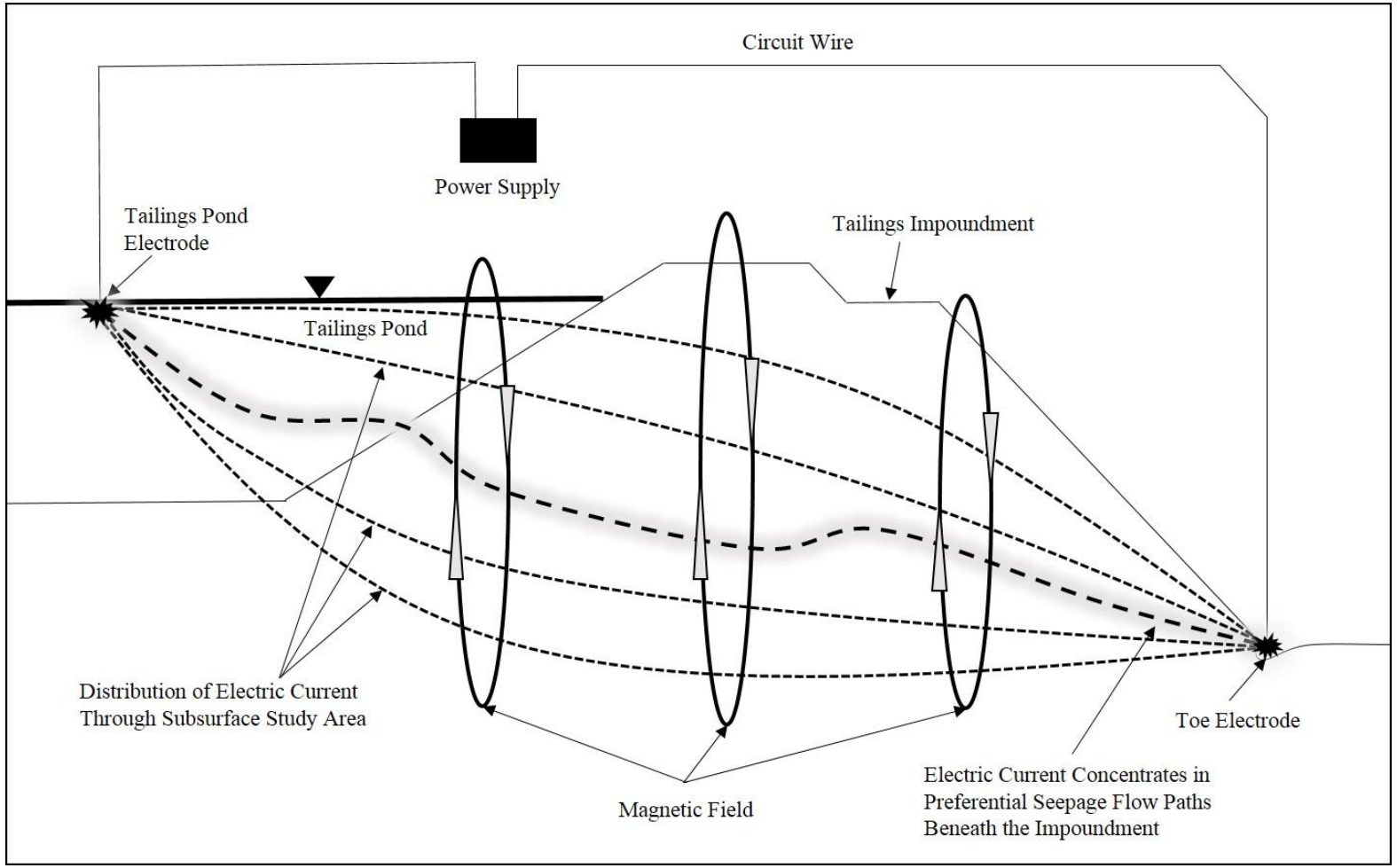
Uses of Willowstick

- Reactive
- Sudden leaks etc

- Proactive
- Have we any leaks?

- Asset Management
- Part of PRA

Survey layout



Steps to get data results and two dimensional maps

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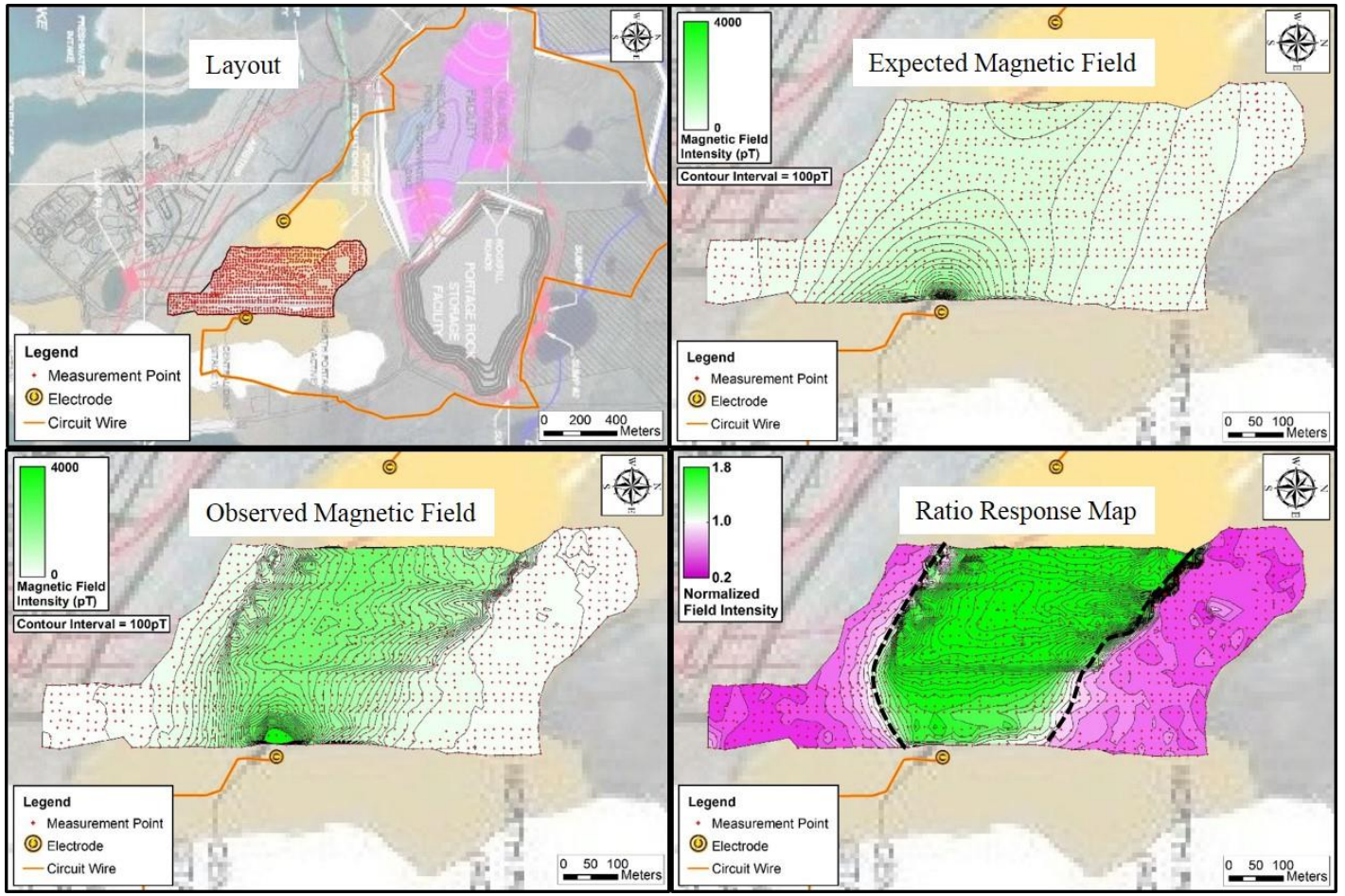
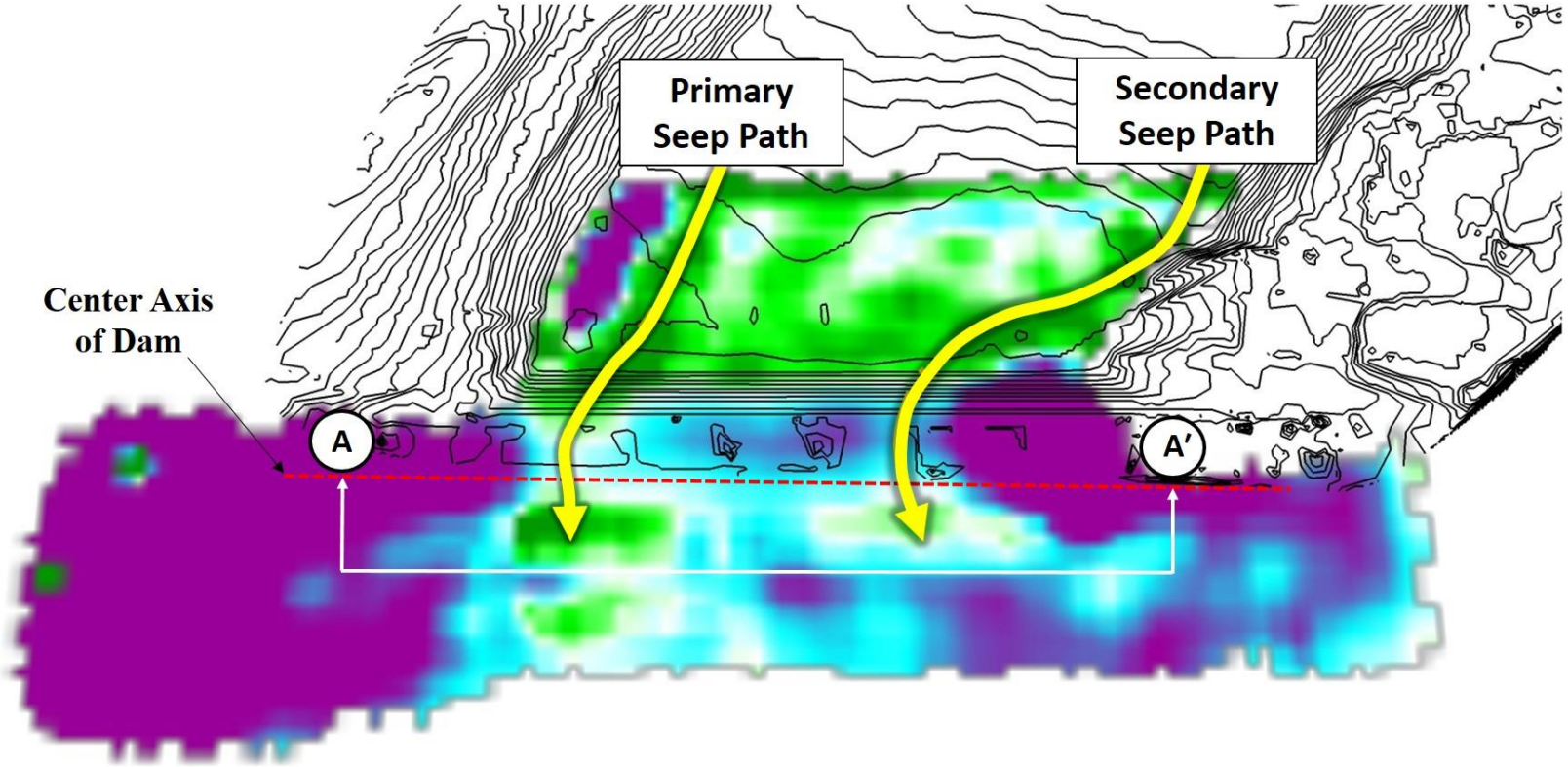
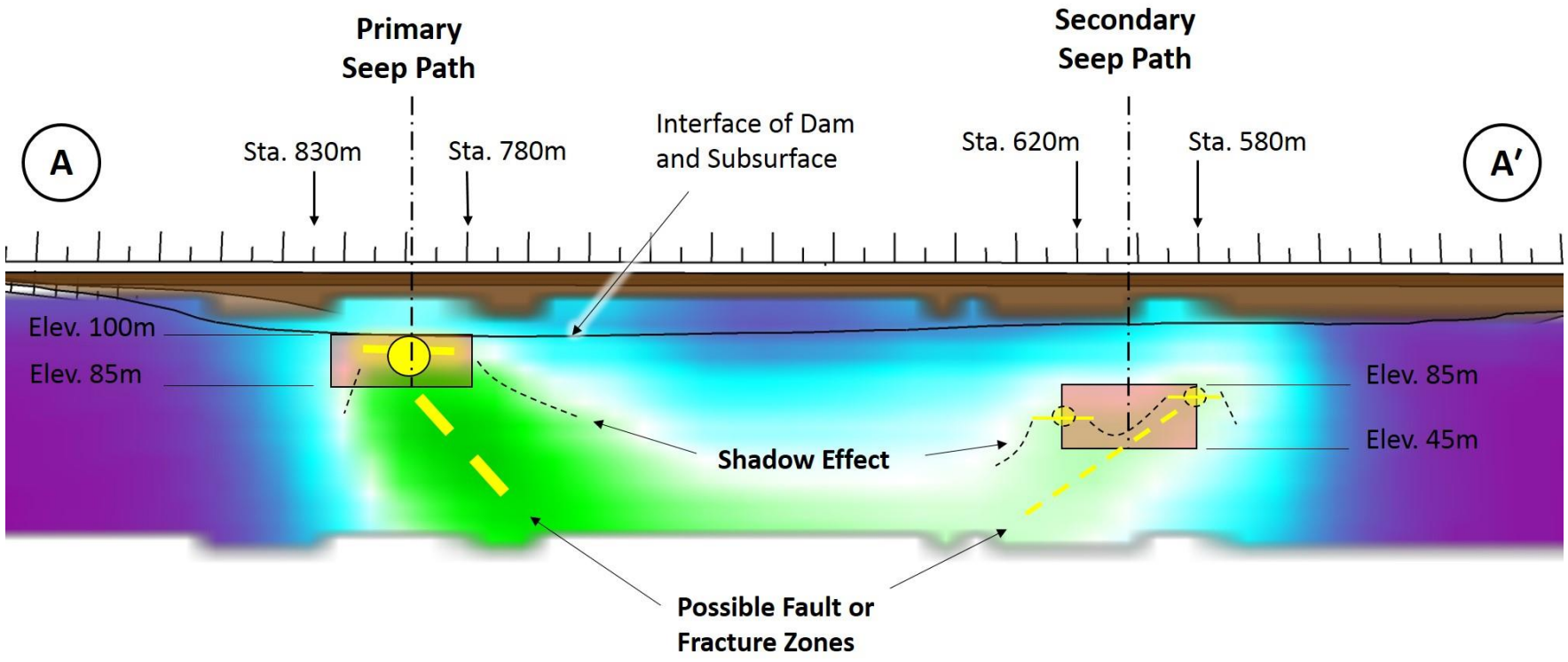


A primary and secondary seepage path identified under the dam plan

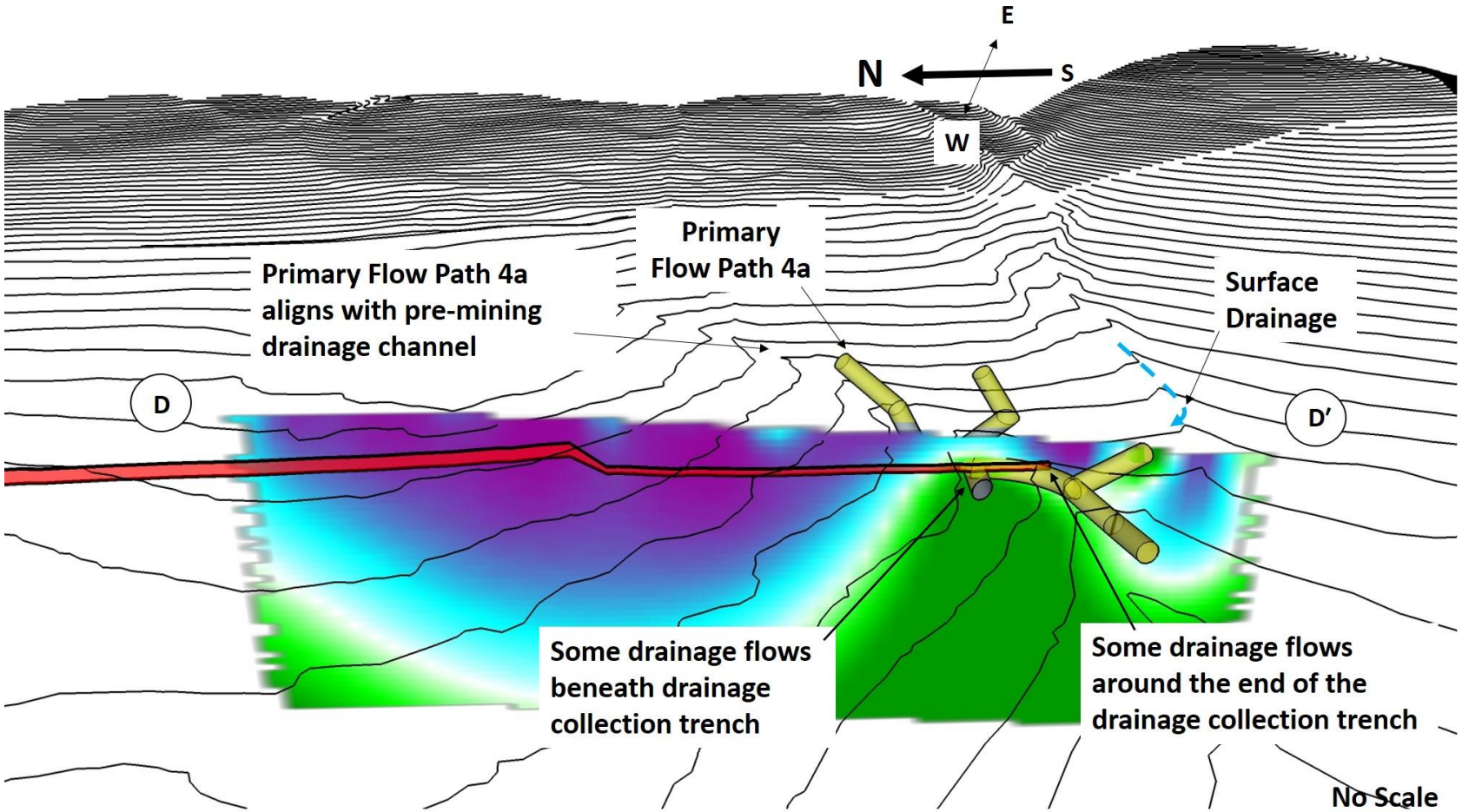


Seepage path elevations



Plan view of Phase 1 flow paths

Model slice with seepage flow path



Risk Assessment

- the modern buzz phrase
- the bane of our lives?
- but has it a use in ensuring the safety of dams?

Risk Assessment

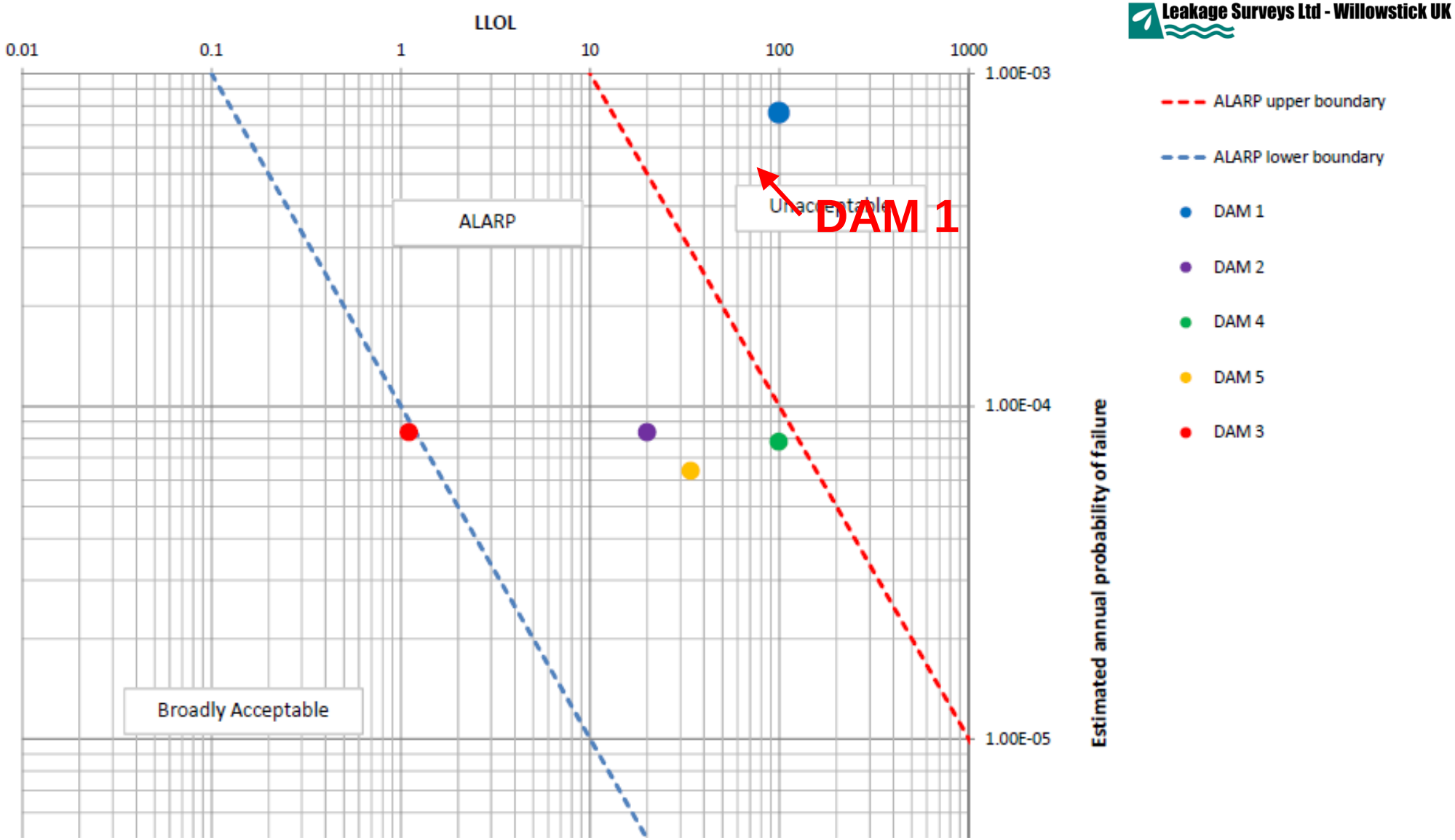
- Individual dam
- Everyone wants a number

- Portfolio Risk Assessment (PRA)
- Much more relevant

Risk Assessment

Portfolio Risk Assessment

Name of Dam	Internal Erosion	Slope Stability	Foundation Failure	Total Probability	Ranking
Dam 1	7.58E-04	2.80E-06	3.40E-06	**7.64E-04**	1
Dam 2	2.93E-05	4.25E-05	8.00E-07	**8.36E-05**	2
Dam 3	2.93E-05	4.25E-05	8.00E-07	**8.36E-05**	3
Dam 4	6.50E-05	5.90E-06	3.40E-06	**7.82E-05**	4
Dam 5	5.39E-05	2.80E-06	3.40E-06	**6.40E-05**	5



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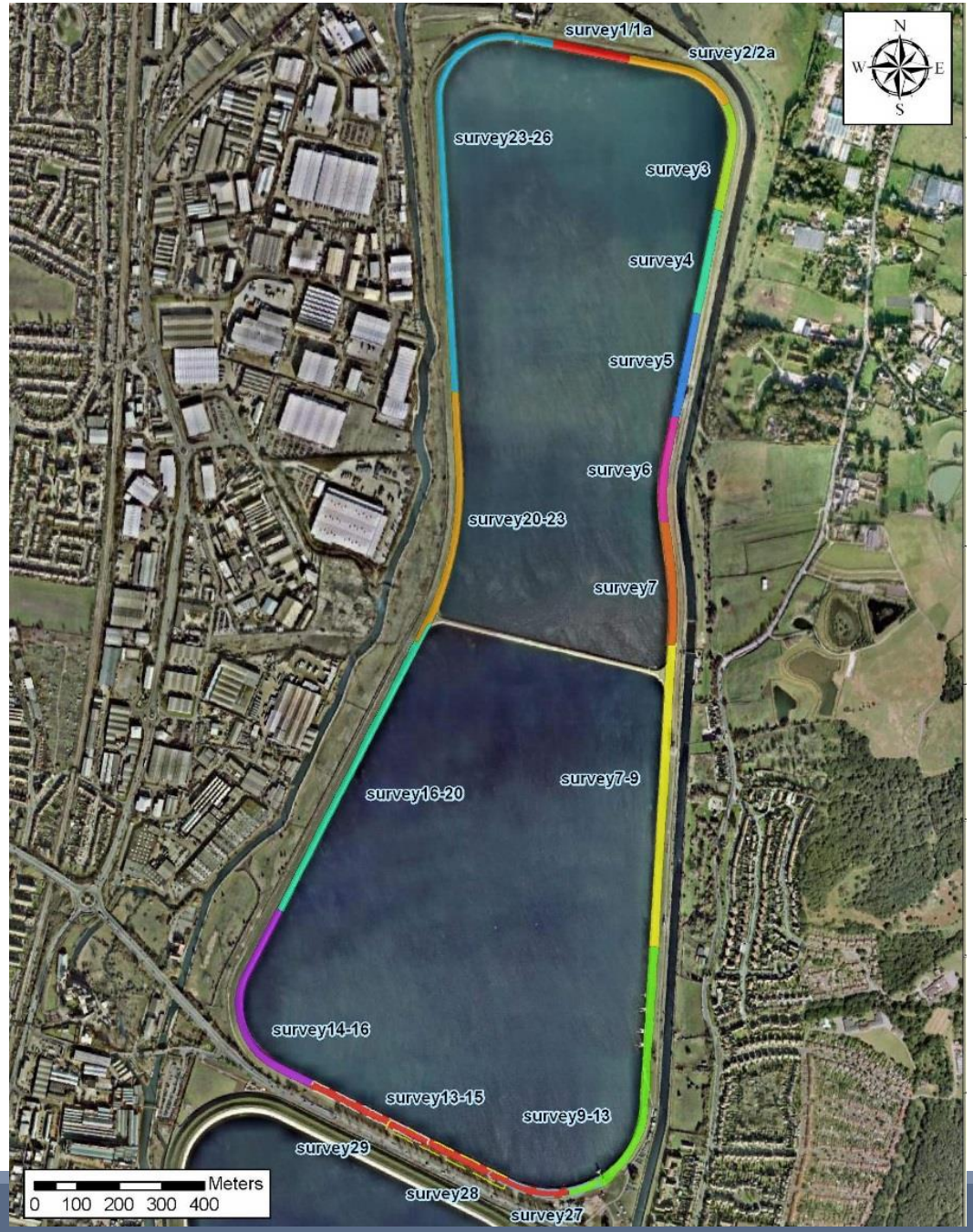
Risk Assessment

Two Choices

- Move by reducing probability?
- Move by moving people?


survey1/1a
survey2/2a
survey23-26
survey3
survey4
survey5
survey6
survey20-23
survey7
survey7-9
survey16-20
survey14-16
survey13-15
survey9-13
survey29
survey28
survey27
N
W
E
S
Meters
0 100 200 300 400

Island Barn

Known leak

Cross Section

Based on the above a diaphragm wall of around 100 m in length, 18 m deep and 0.6 m wide is likely to be sufficient to cut off the seepage identified in this area, as shown in Figure 6 and Figure 7.

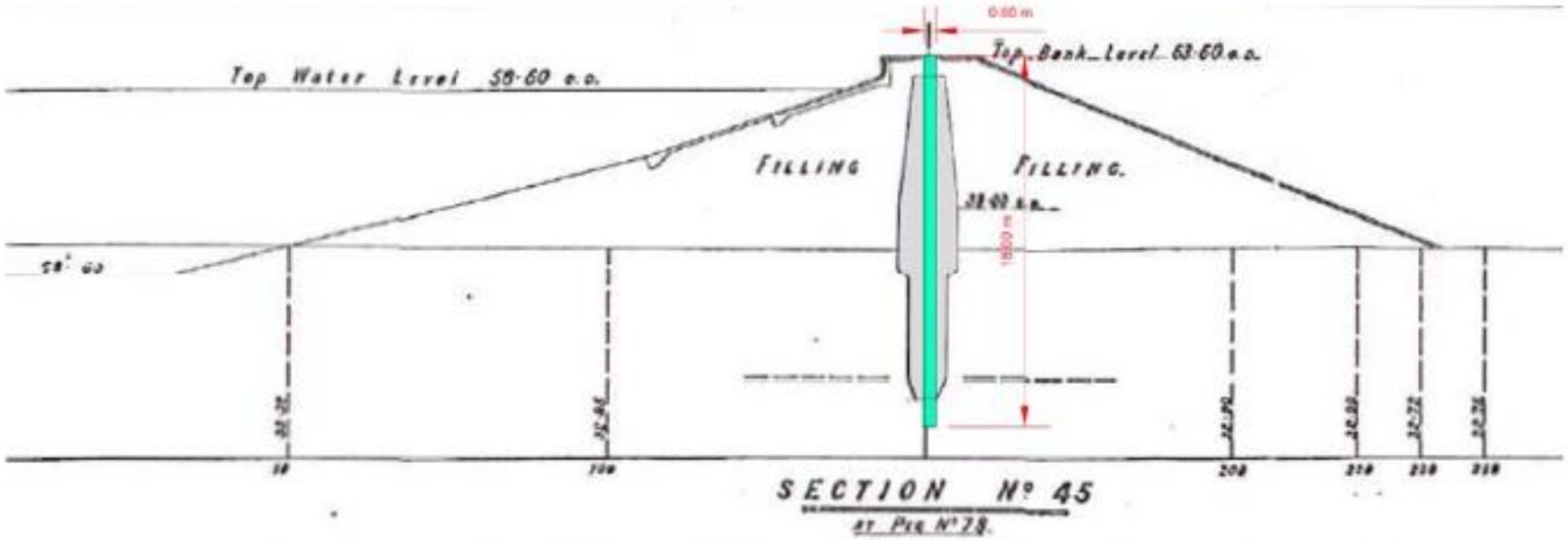
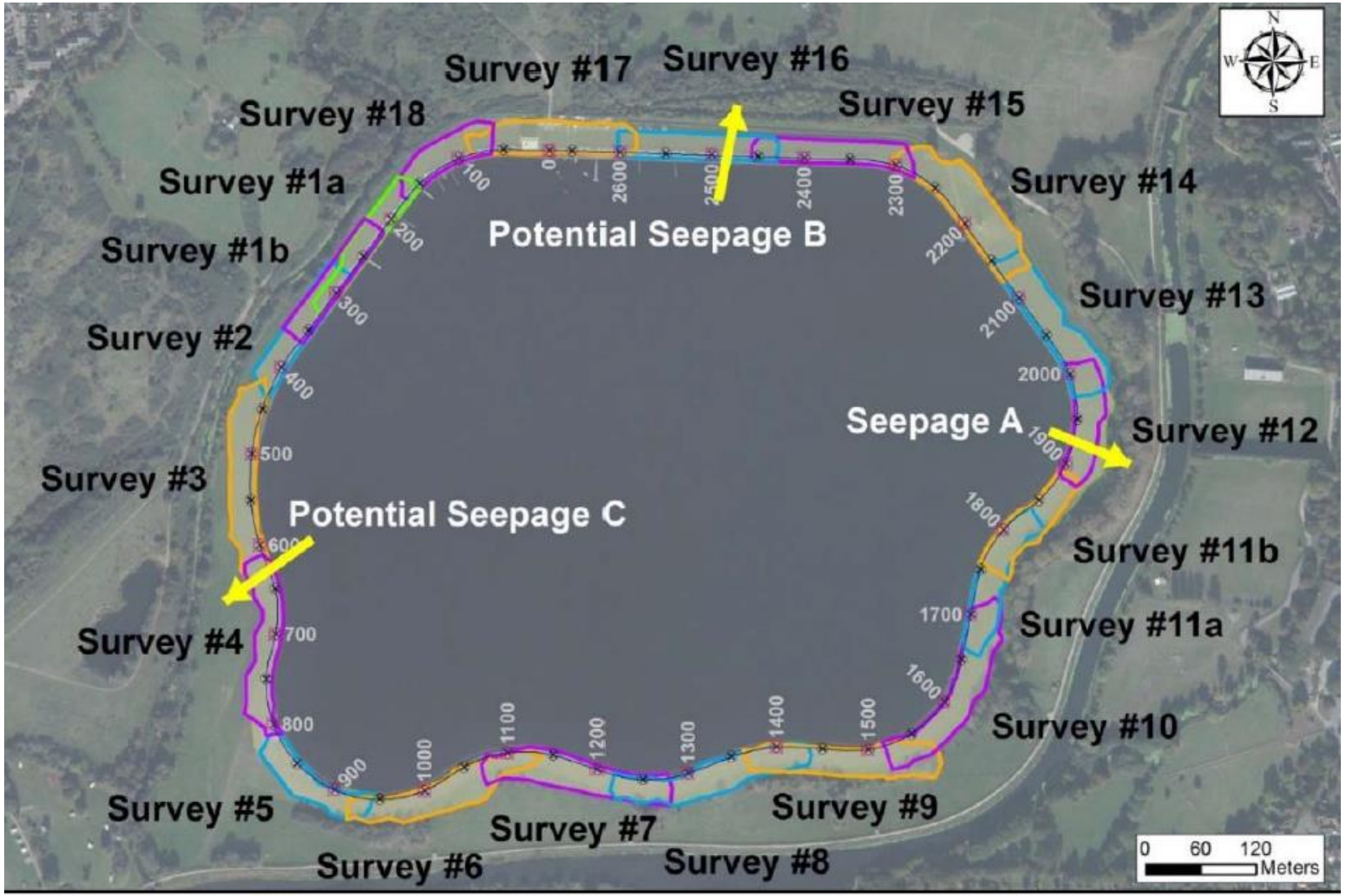


Figure 7 No. 16 Cross Section, including proposed diaphragm wall

Survey


Island Barn Reservoir Sailing
ISLAND BARN RESERVOIR
River Ember
Google
River Ember
SURVEY AREA

This showed 3 leaks



Owner

- Decided to do repairs
- Reduce level of probability

Risk Reduction

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BEFORE WILLOWSTICK

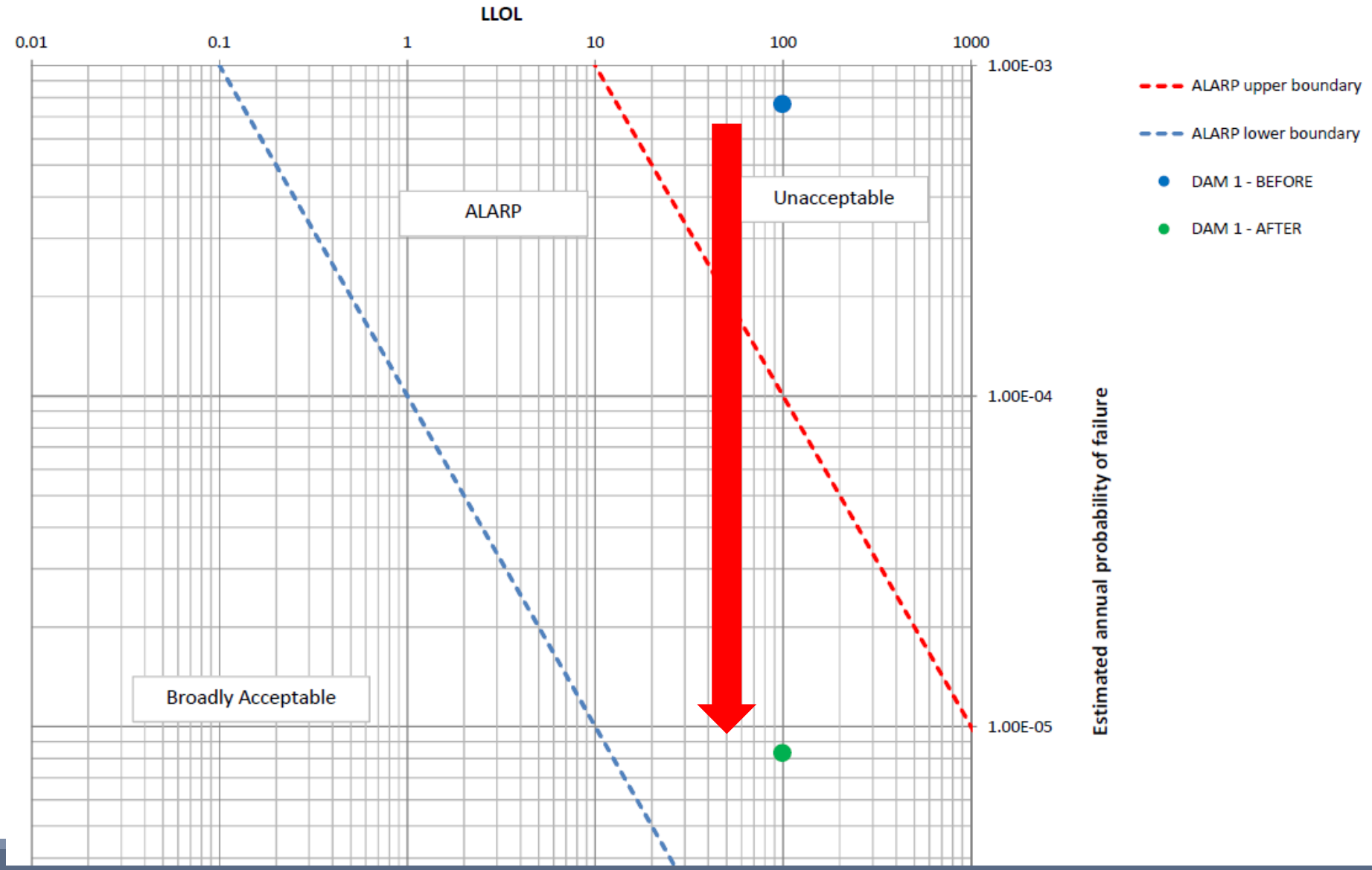
Name of Dam	Internal Erosion	Slope Stability	Foundation Failure	Total Probability
Dam 1	**7.58E-04**	2.80E-06	3.40E-06	**7.64E-04**

AFTER WILLOWSTICK

Name of Dam	Internal Erosion	Slope Stability	Foundation Failure	Total Probability
Dam 1	**2.12E-06**	2.80E-06	3.40E-06	**8.32E-06**

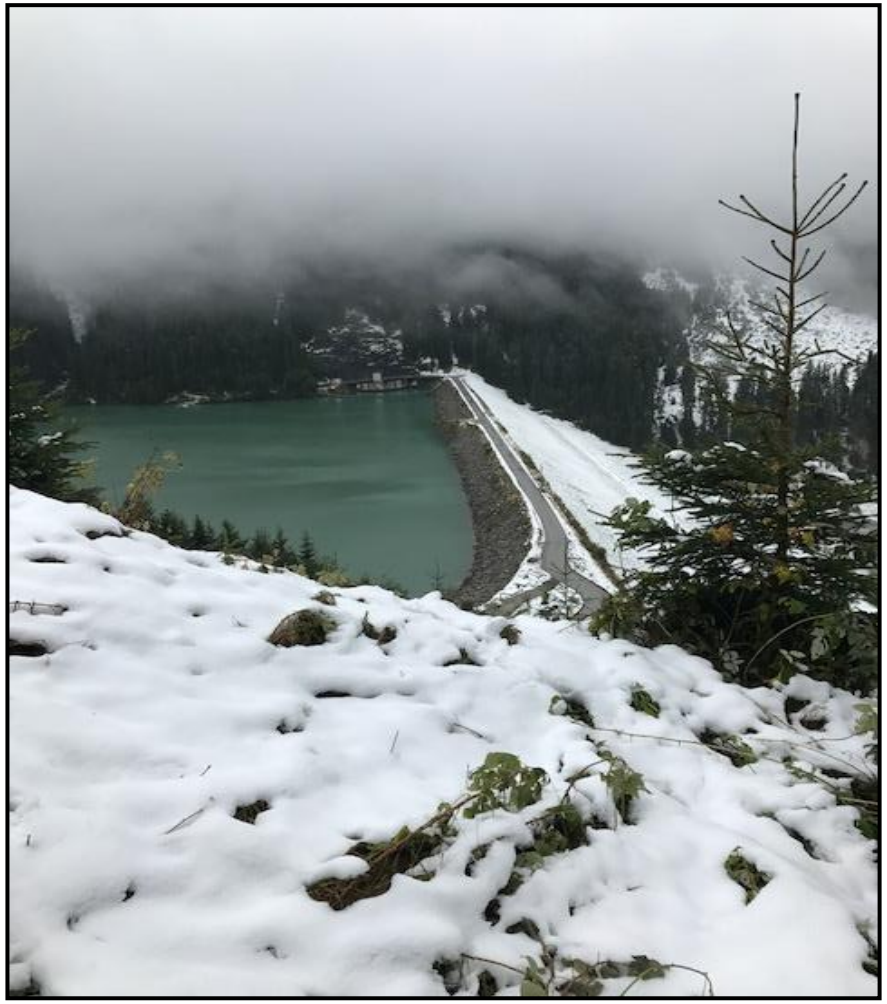
Probability Reduction

Leakage Surveys Ltd - Willowstick UK



Case Studies

Durlaßboden Dam - Austria

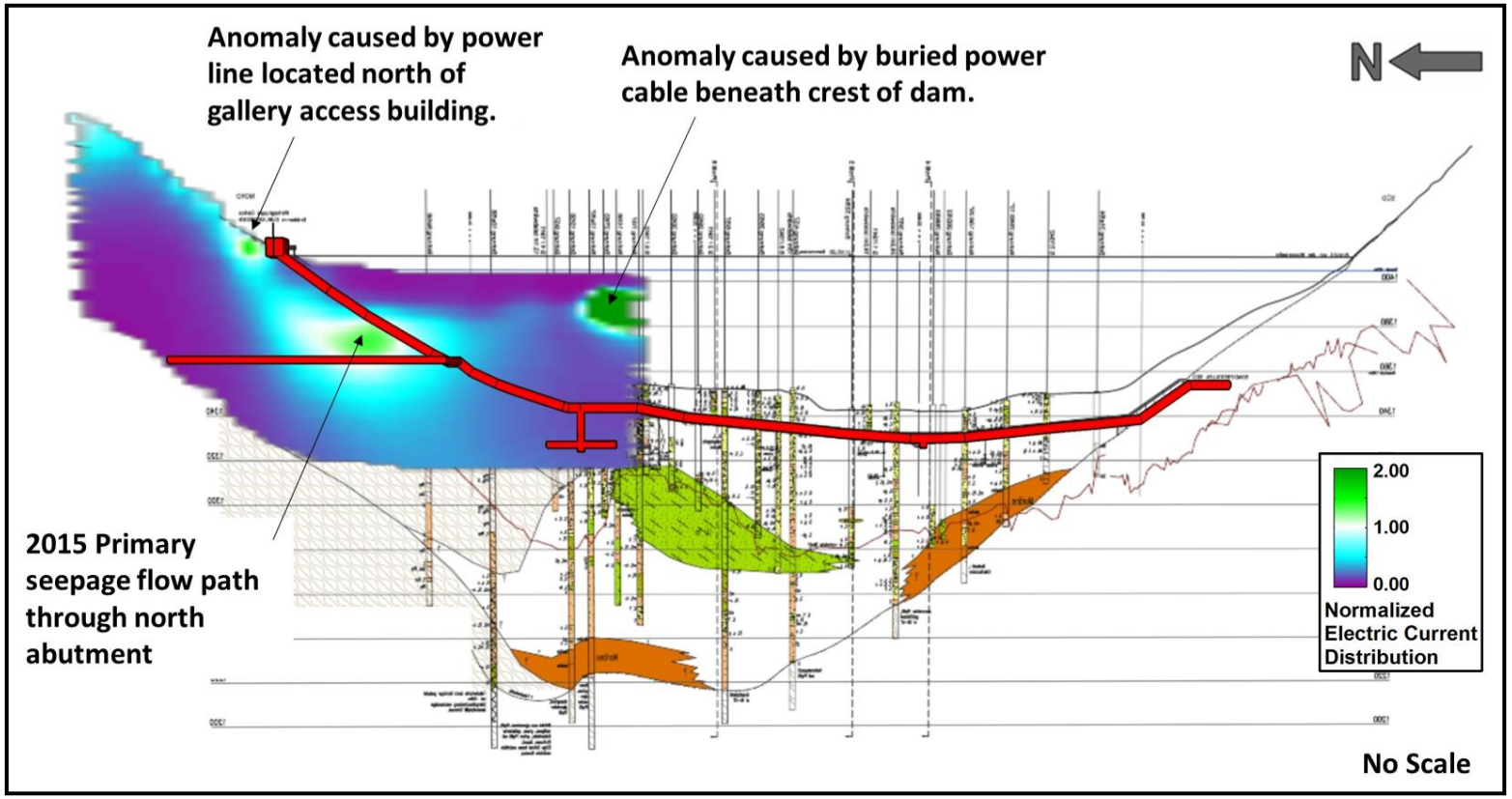


Project Location Map

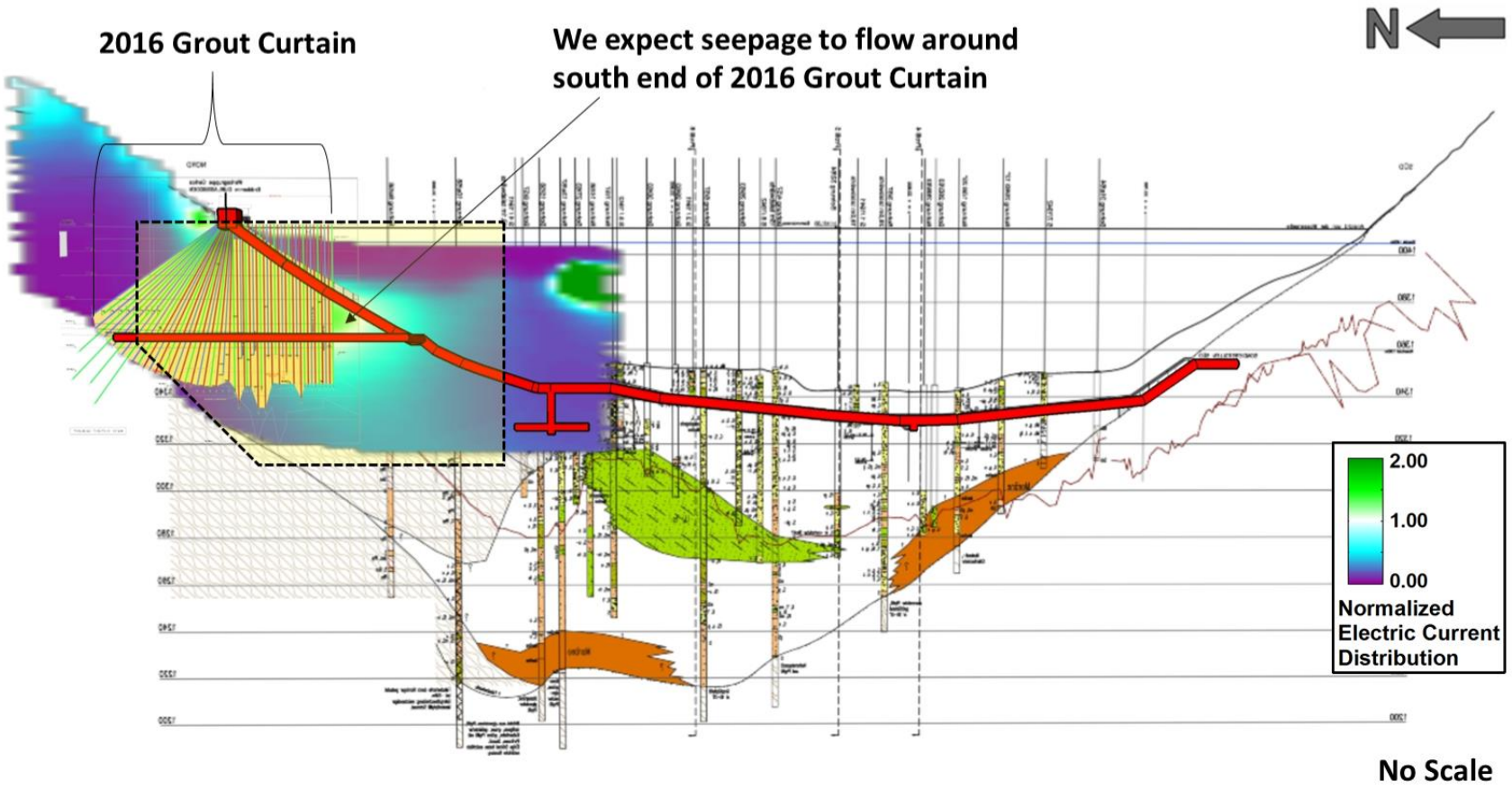
Durlassboden - Austria

Leakage Surveys Ltd - Willowstick UK

The 2015 Investigation (Survey 3) detected a seepage flow path in the north abutment, as shown in this longitudinal section beneath the crest

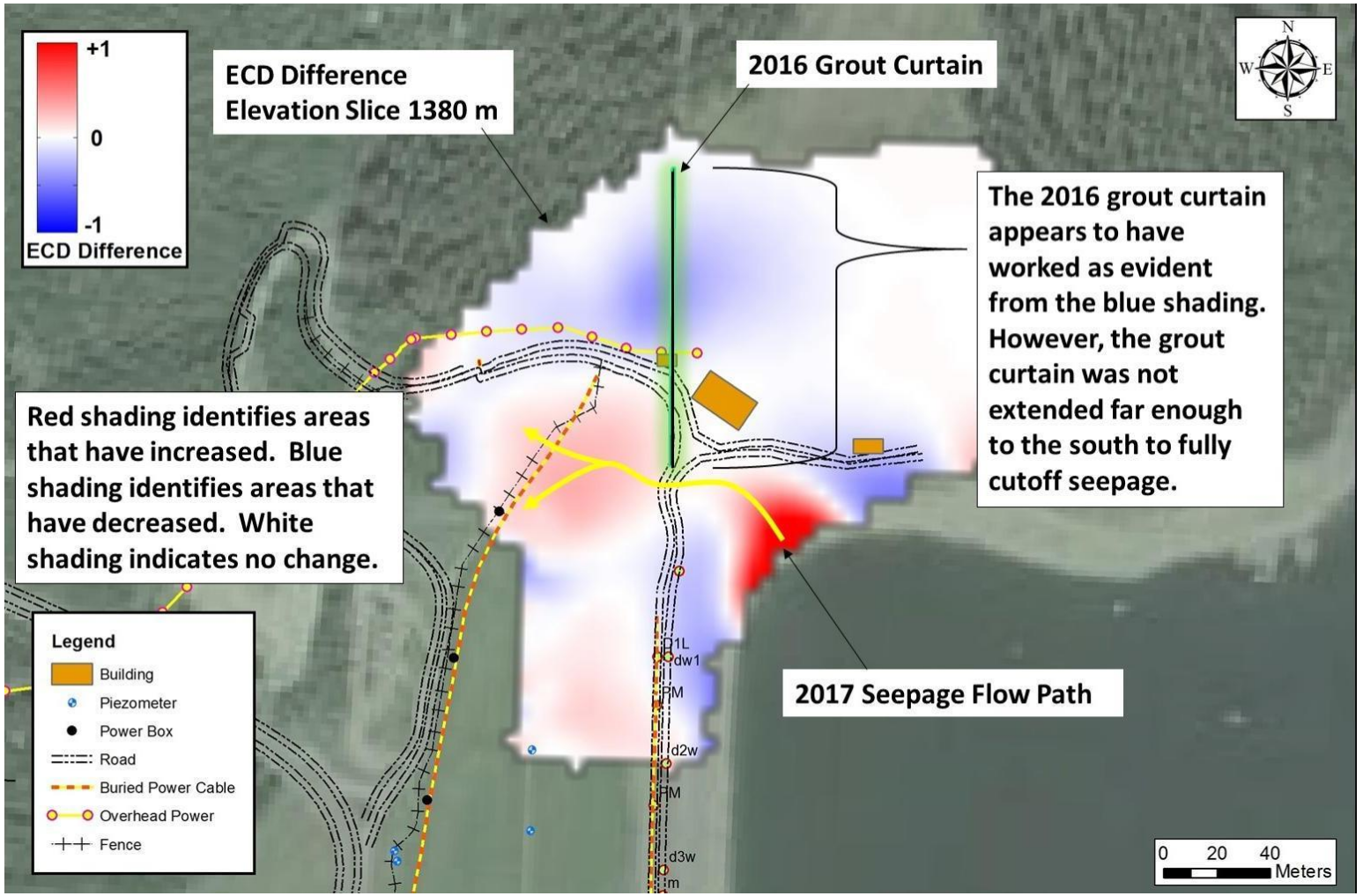


Location of the 2015 recommended target area and the 2017 grout curtain

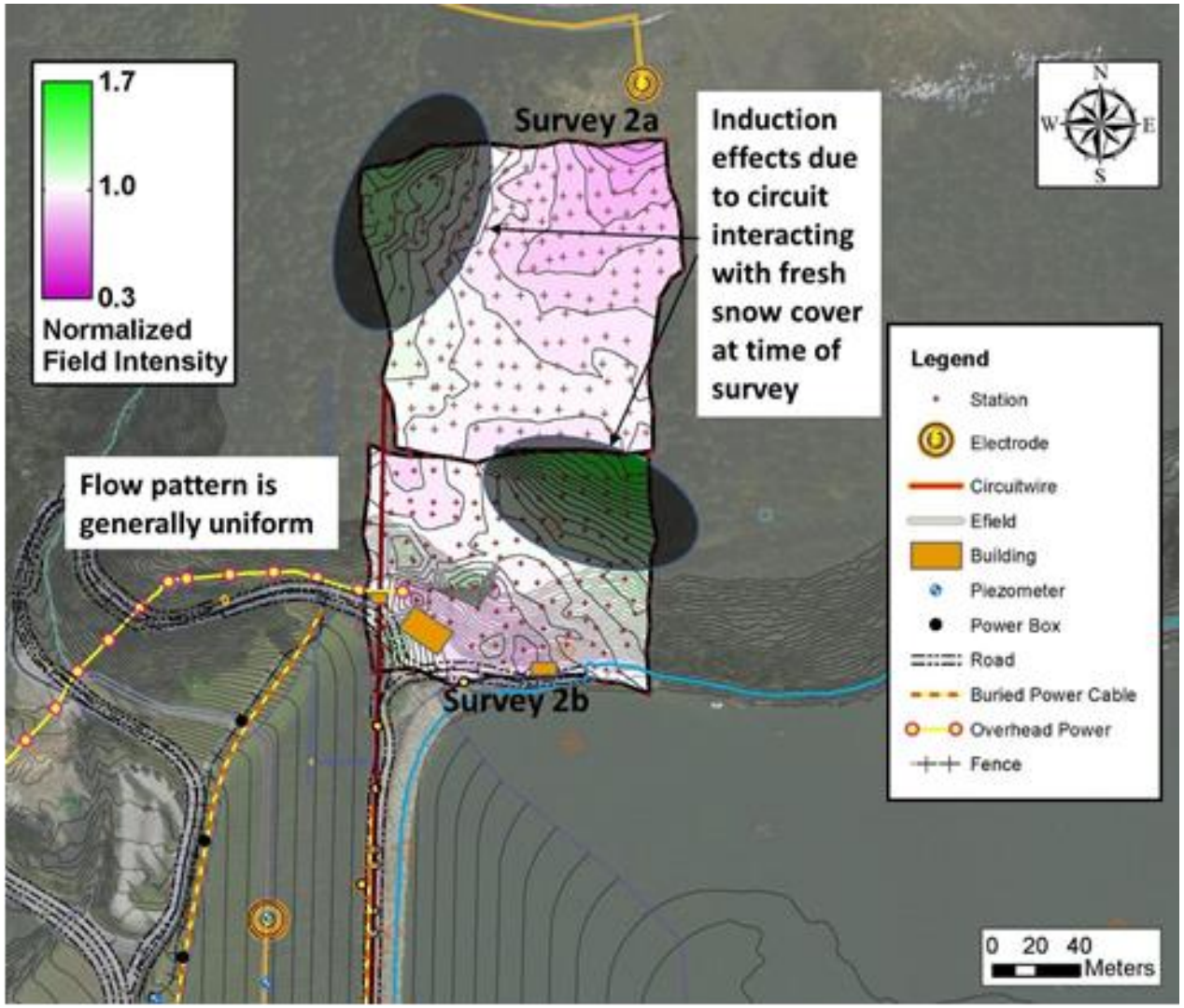


Willowstick UK instrument at the toe of the dam

A path of increased electric current occurs just south of the new grout curtain



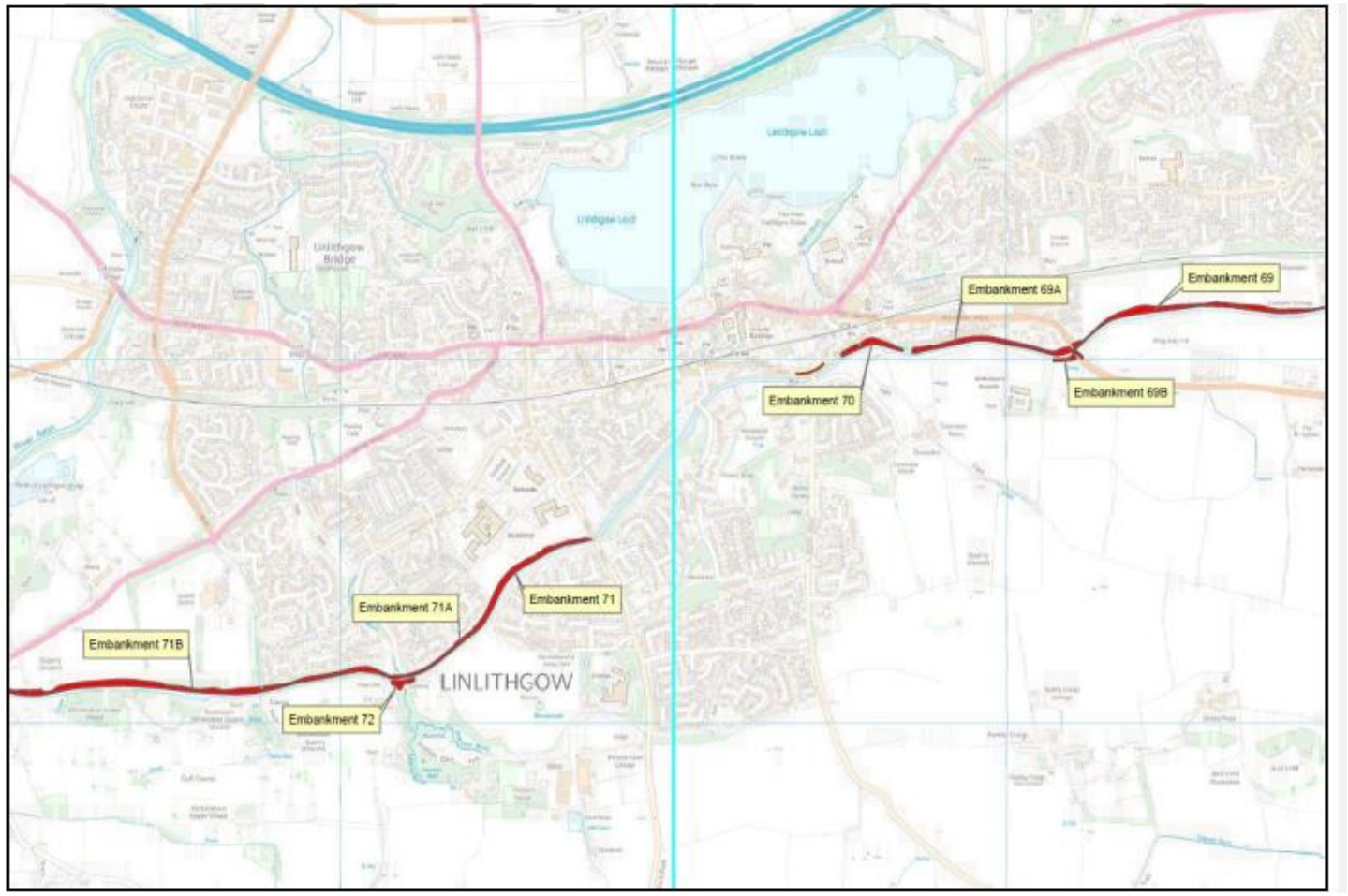
Ratio response maps of Surveys 2a and 2b, showing no signs of seepage



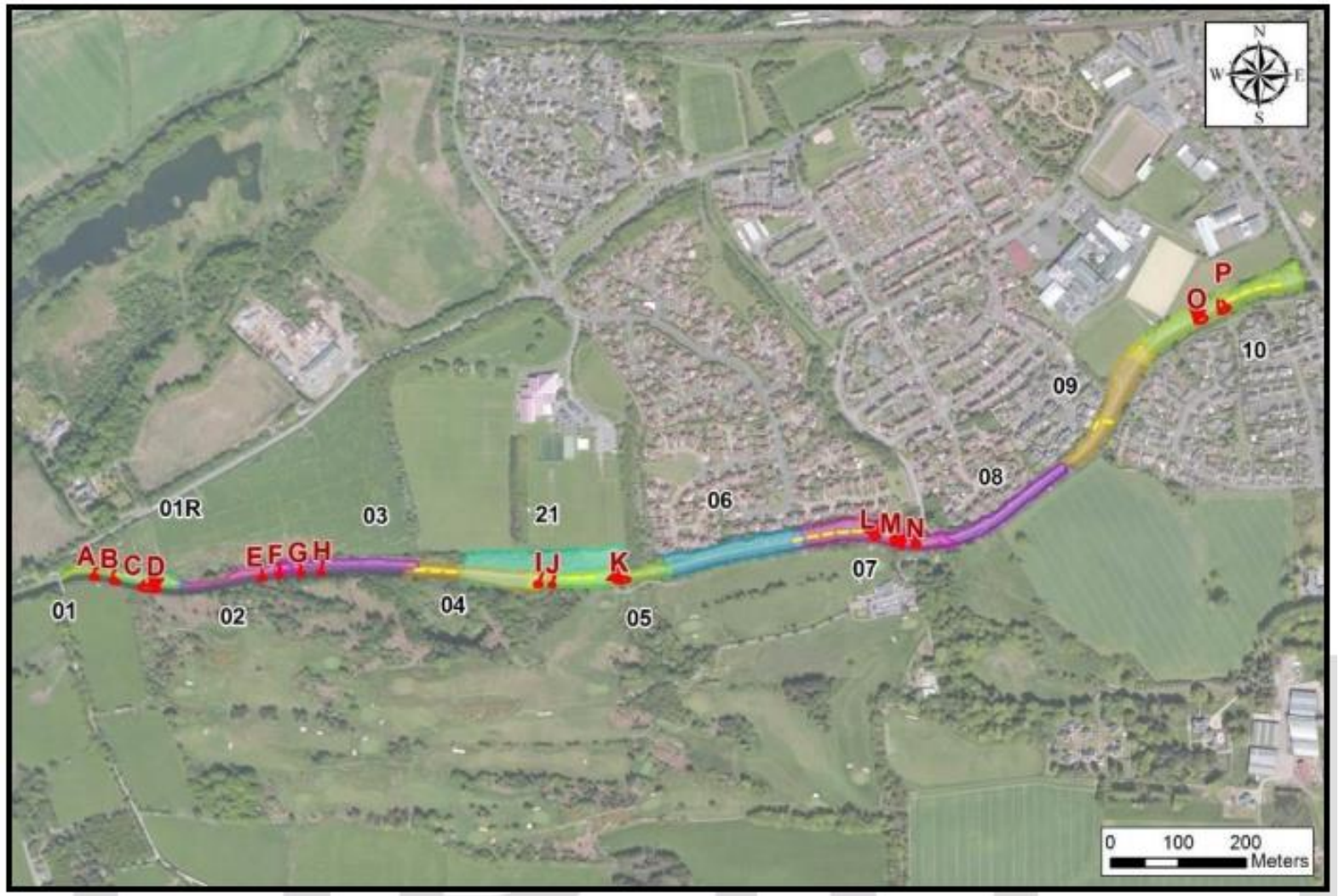
Investigation of Linlithgow Canal Embankments, Scotland

Leakage Surveys Ltd - Willowstick UK

Site Map (Courtesy of Scottish Canals)



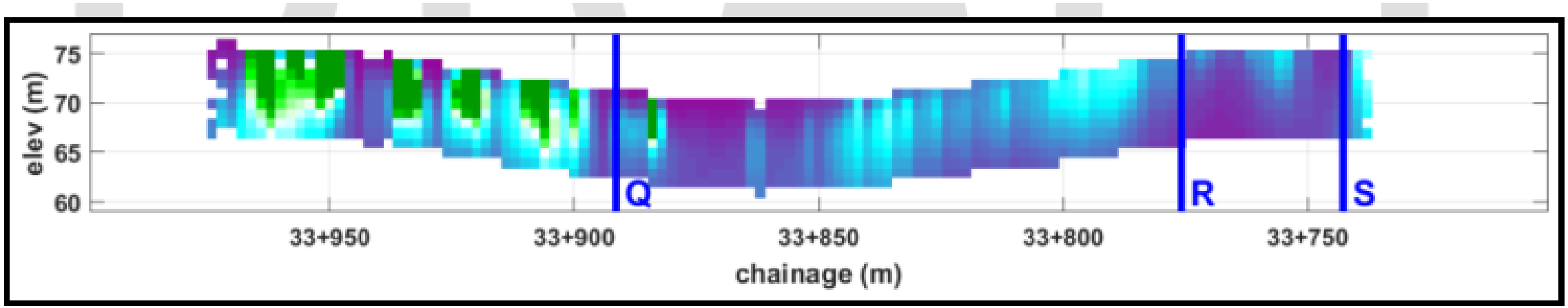
West Canal Study Area Seepage Locations



East Canal Study Area Seepage Locations

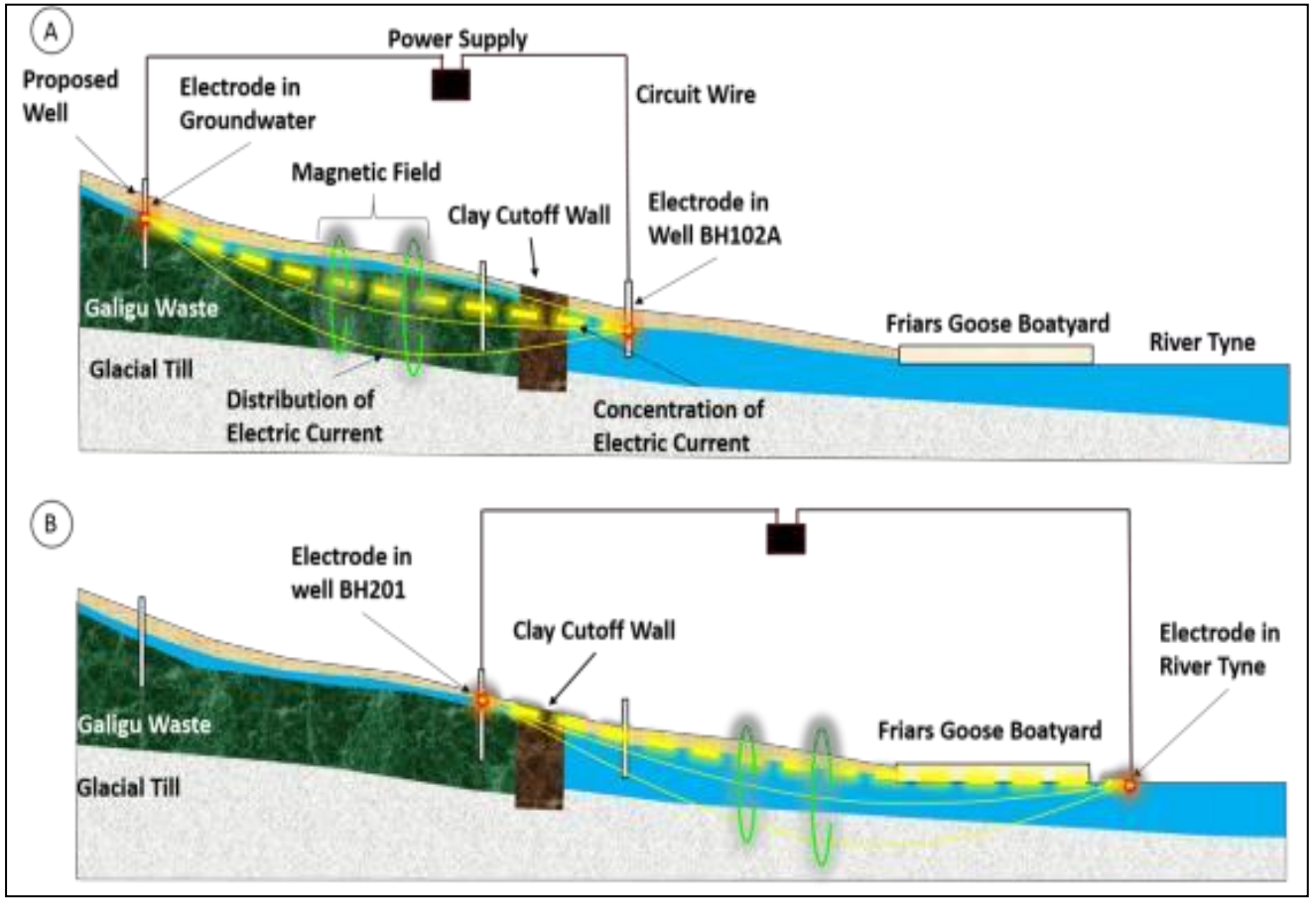
Manifestation of leakage correlating to Seepage area Q

Cross sectional analysis of seepage paths Q, R and S with depth through the canal embankment



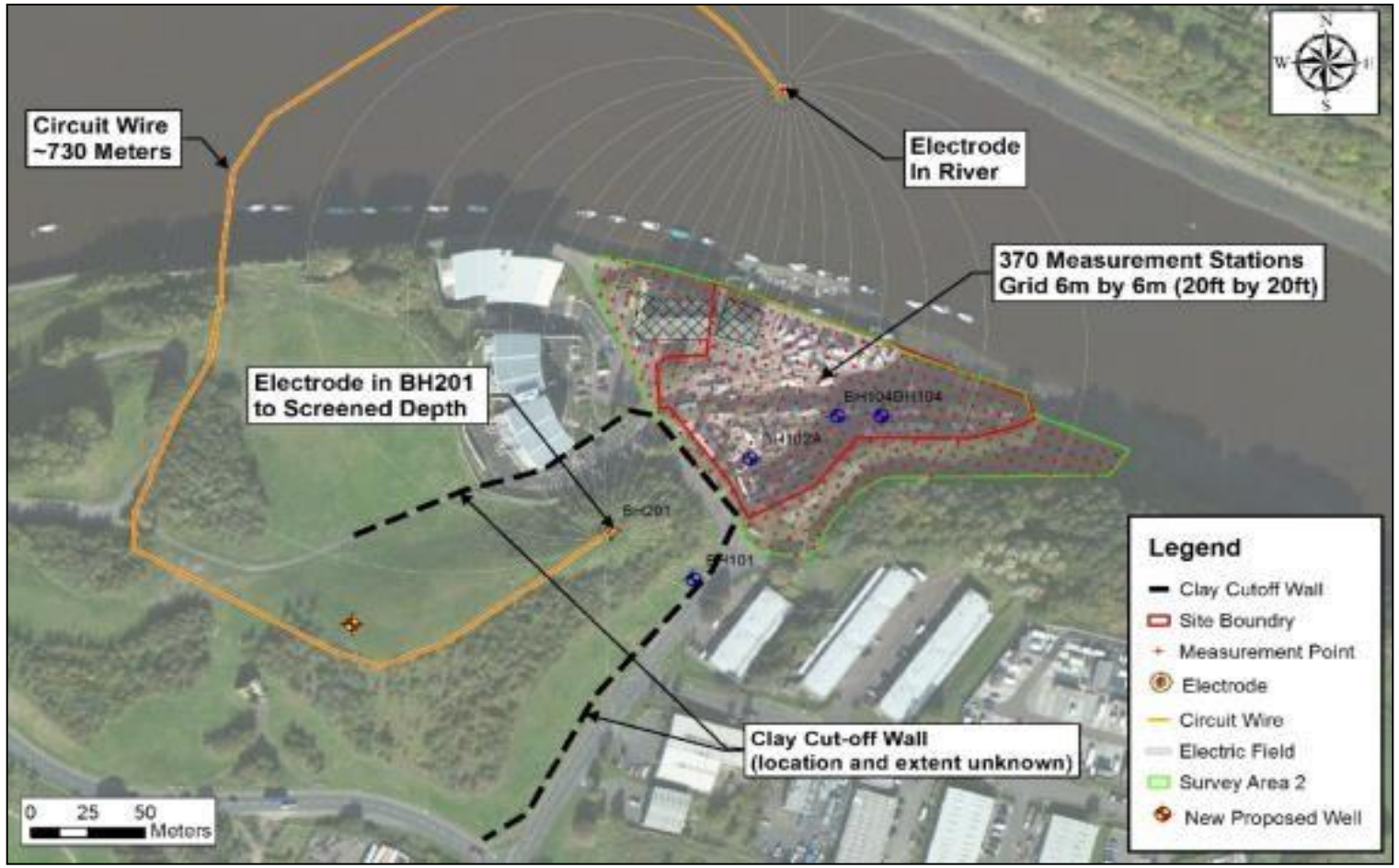
Gateshead Town Centre Proposal

Horizontal Dipole Cross-Section for Survey 1 (Example A) and Survey 2 (Example B)



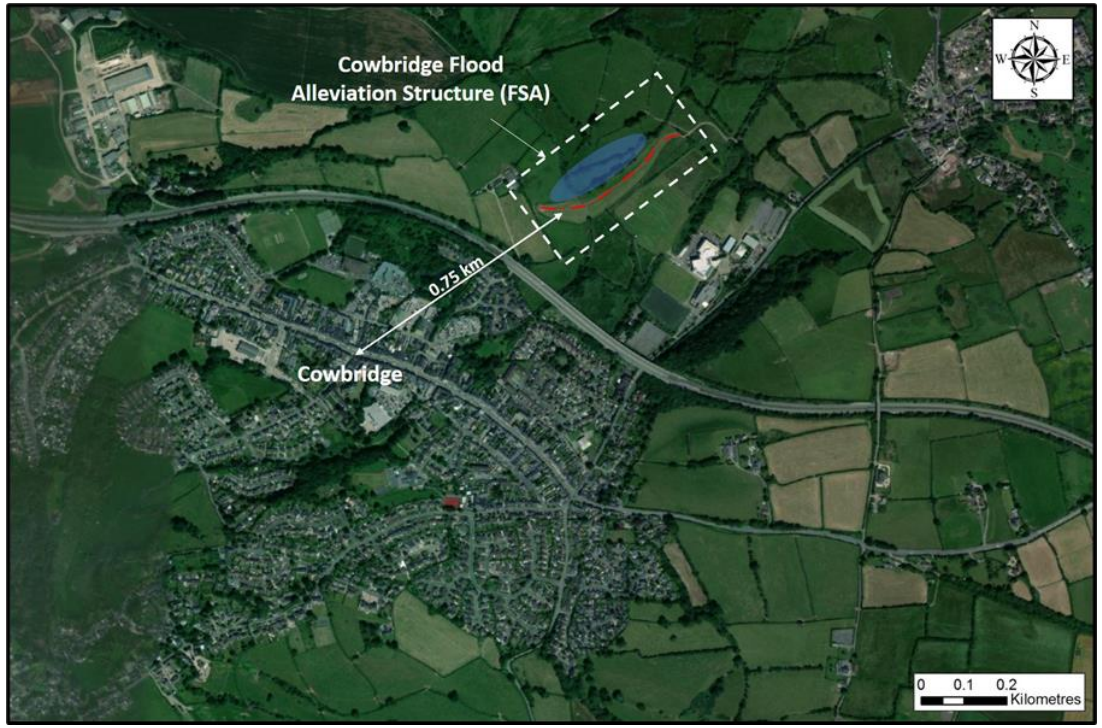
Plan view of Surveys 1 and 2

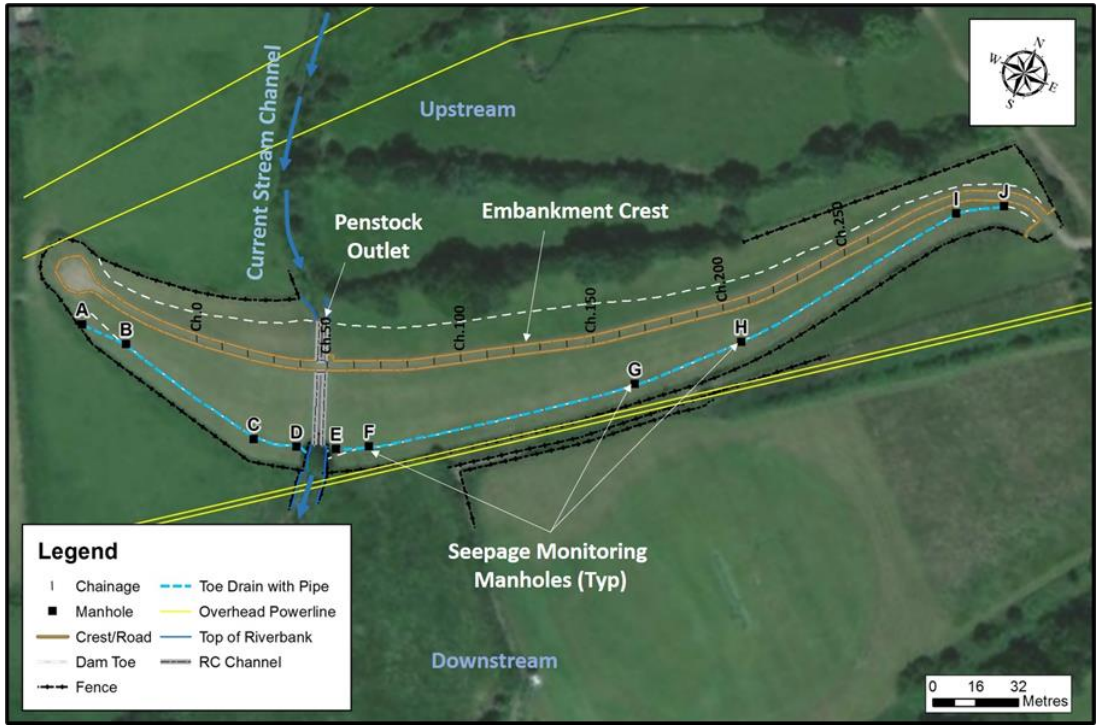
Plan View of Survey 1



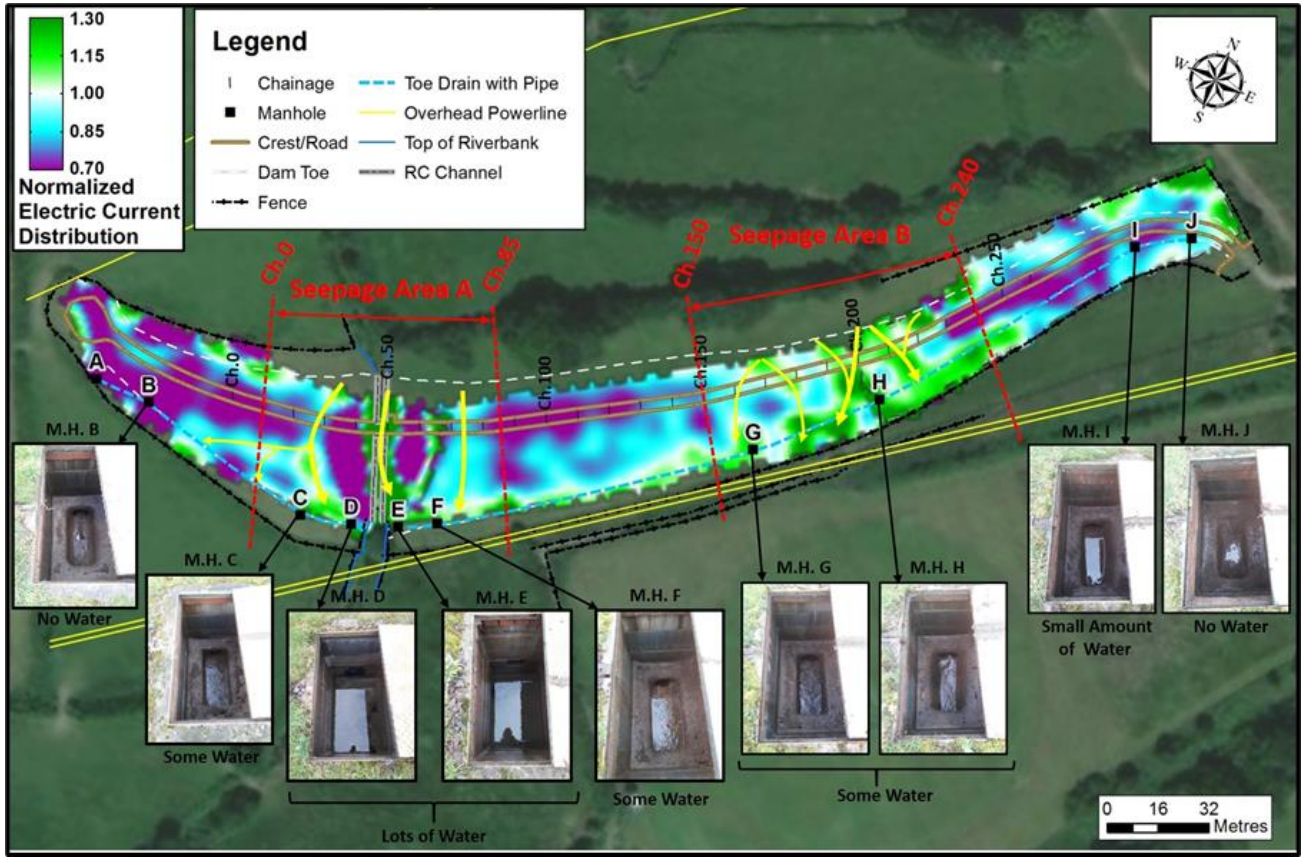
Plan View of Survey 2

Cowbridge

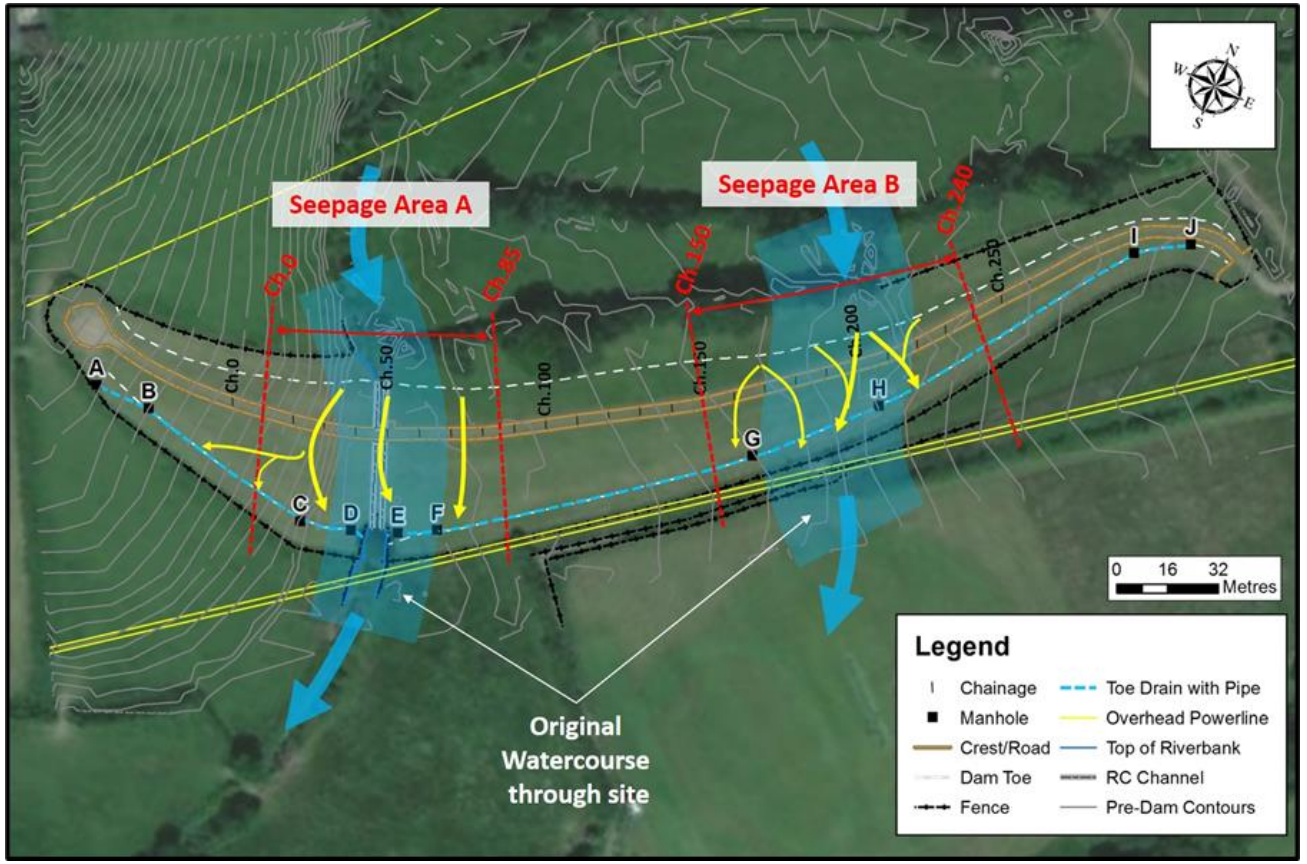

Cowbridge Flood
Alleviation Structure (FSA)
0.75 km
Cowbridge
N
W
E
S
0 0.1 0.2
Kilometres


Current Stream Channel
Upstream
Penstock
Outlet
Embankment Crest
Ch.0
Ch.50
Ch.100
Ch.150
Ch.200
Ch.250
A
B
C
D
E
F
G
H
I
J
Seepage Monitoring
Manholes (Typ)
Downstream
Legend
Chainage
Manhole
Crest/Road
Dam Toe
Fence
Toe Drain with Pipe
Overhead Powerline
Top of Riverbank
RC Channel
0 16 32
Metres

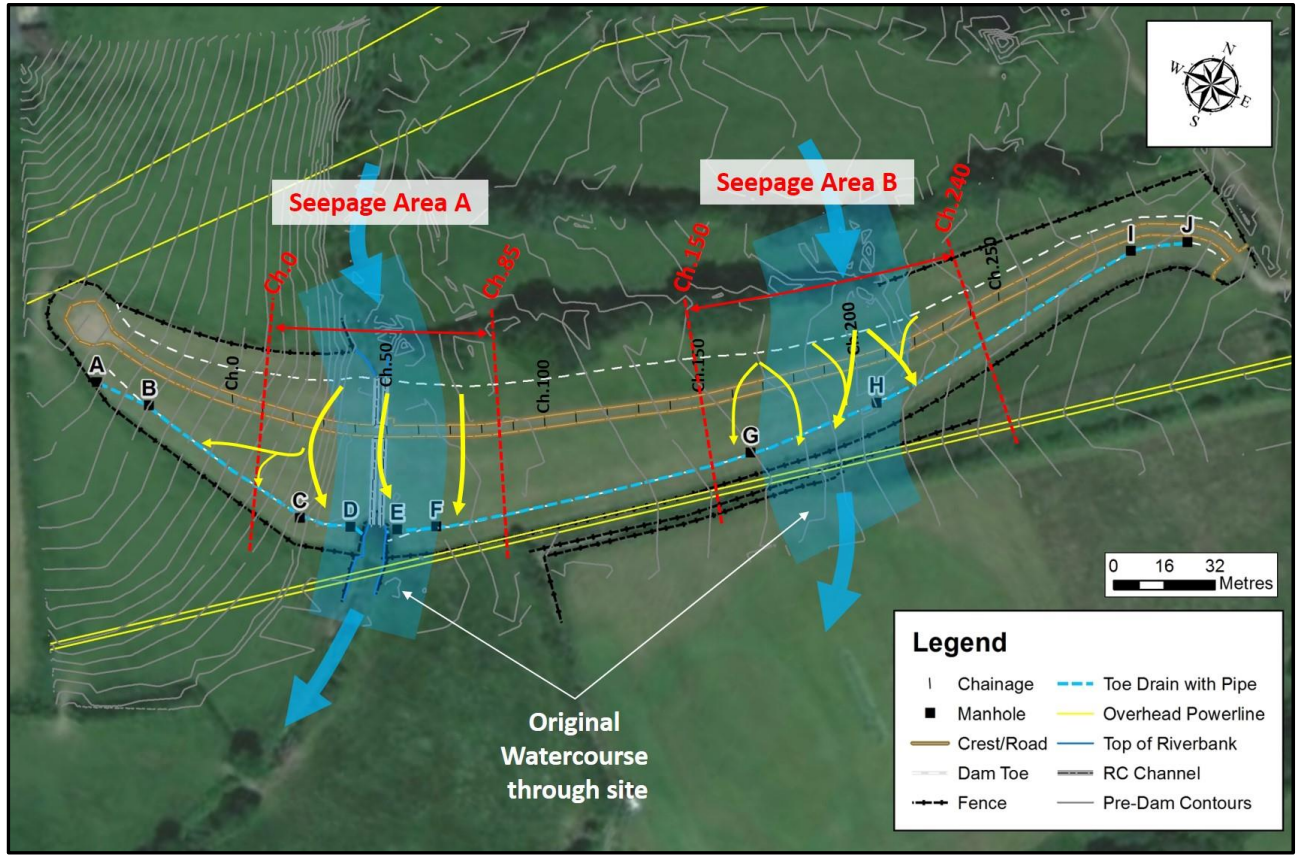
Summary of Investigation (plan view)



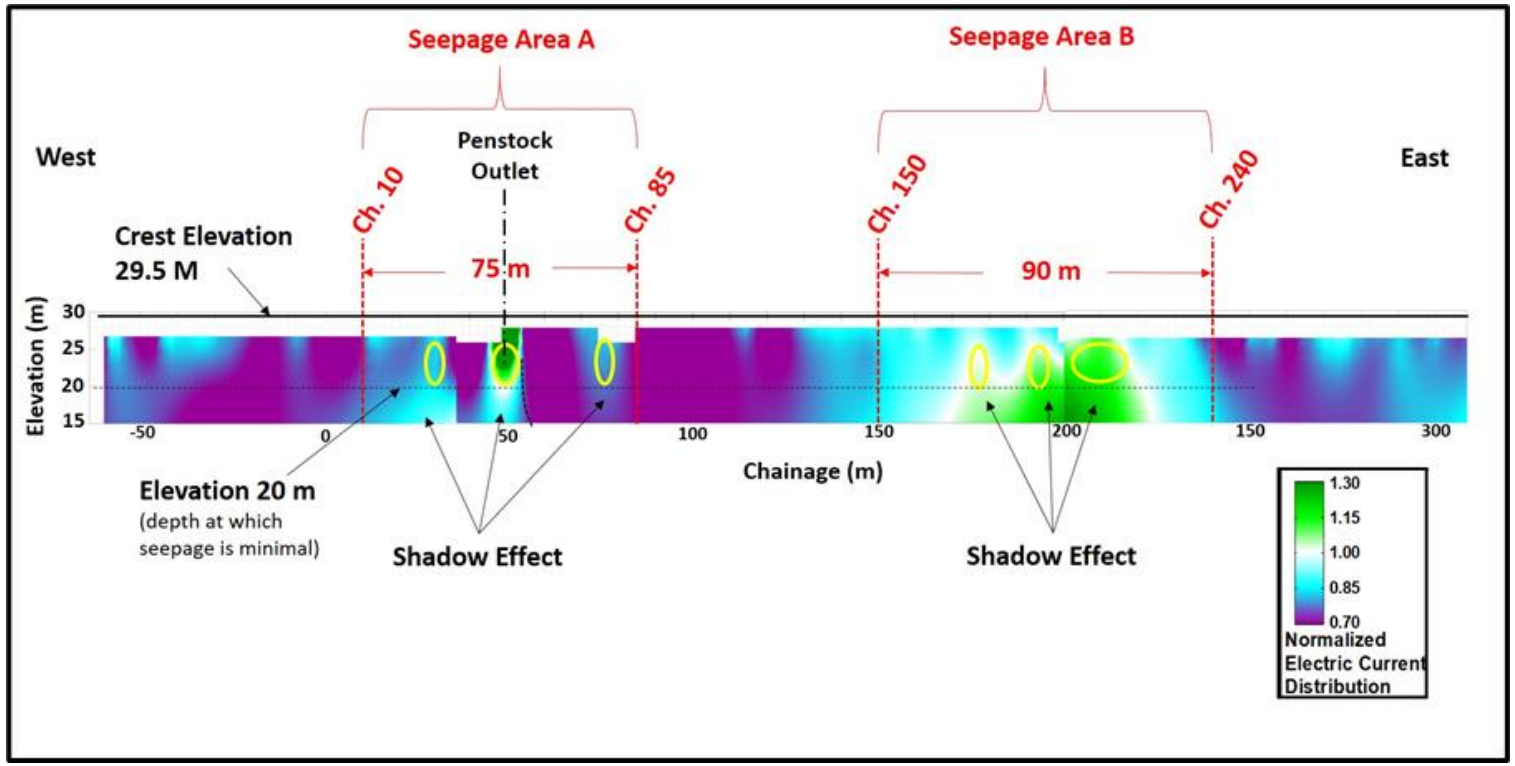
Seepage Areas A and B in comparison to Original Watercourses based on Pre-construction Contours



Seepage Areas A and B in comparison to Original Watercourses based on Pre-construction Contours



Summary of Results (longitudinal profile view looking upstream)



Risk Management & Mitigation

What keeps an Asset Manager up at night?

- Not knowing what I don't know! (The stuff I do know, I know how to handle).
- The fear of being in the news! Public relations nightmare.
- The fear of lawsuits and significant fines and penalties

Leakage Surveys Ltd - Willowstick UK

Willowstick Solution to Risk Management

We help with sleeping better at night!

- Knowledge – the good, bad, and ugly
- Vision – 1000 feet/300 metres under
- the ground surface
- Decision-Making Ability – targeted remediation efforts

Plan view of Phase 2 flow paths

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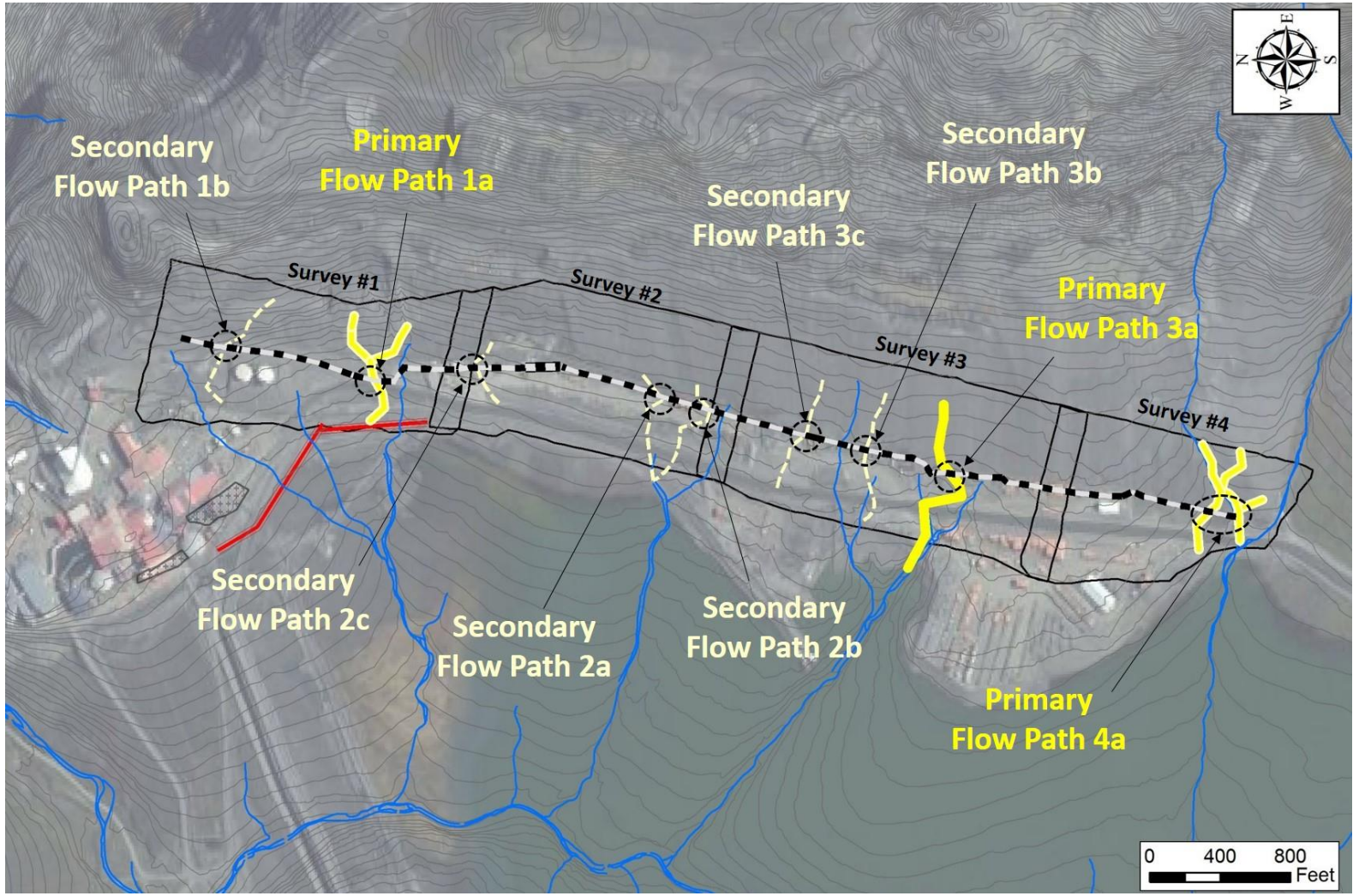
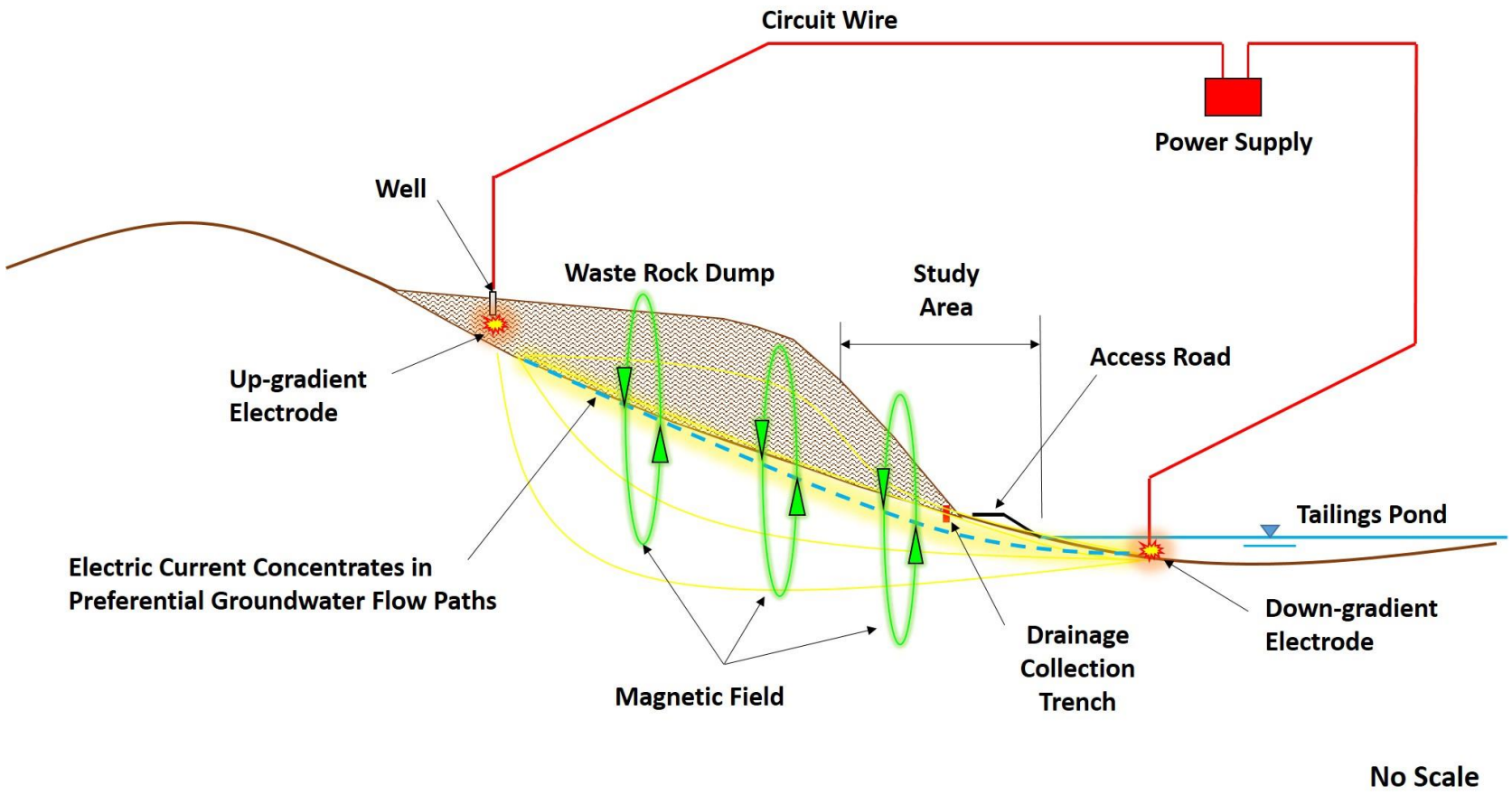


Cross section of survey layout



Risk Assessment

- It’s a tool
- Part of the toolbox
- Only as good as the information from which it is derived
- Uncertainty

Risk Assessment

- Do the numbers mean anything?
- Rubbish in rubbish out?
- Are they comparable?

Risk Assessment

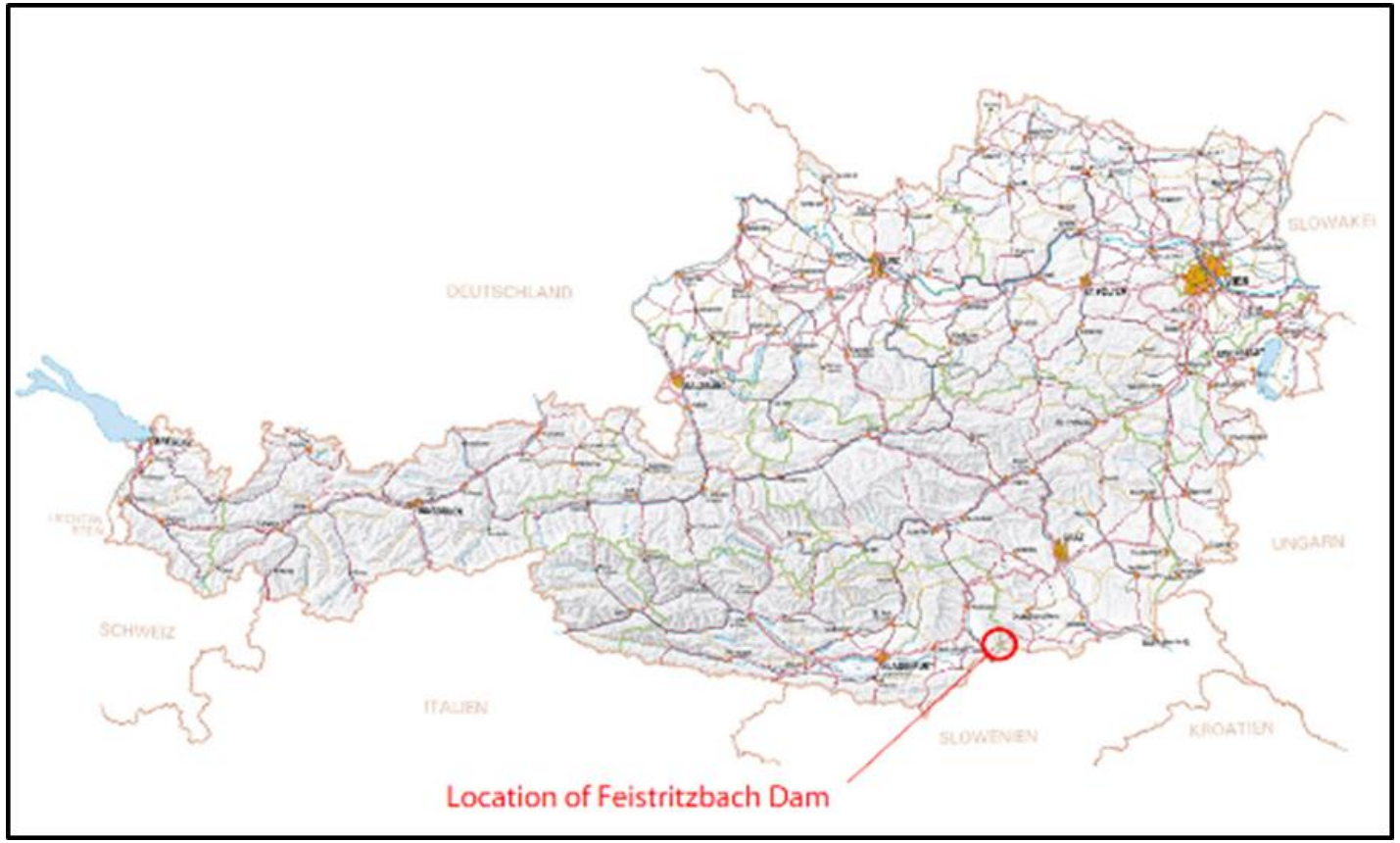
- One of the tools
- Value – understand levels of uncertainty
- Levels of understanding

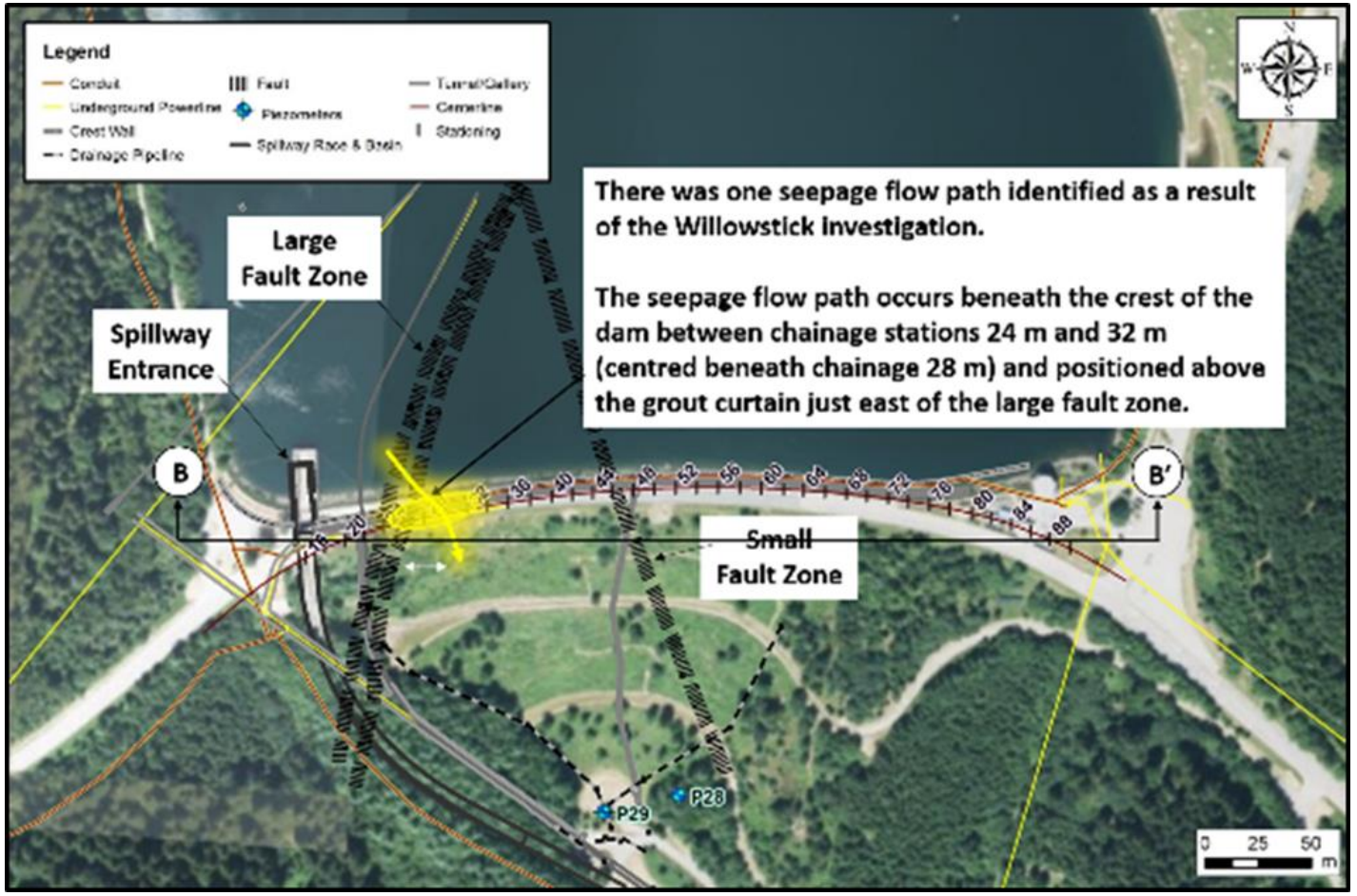
Risk Assessment

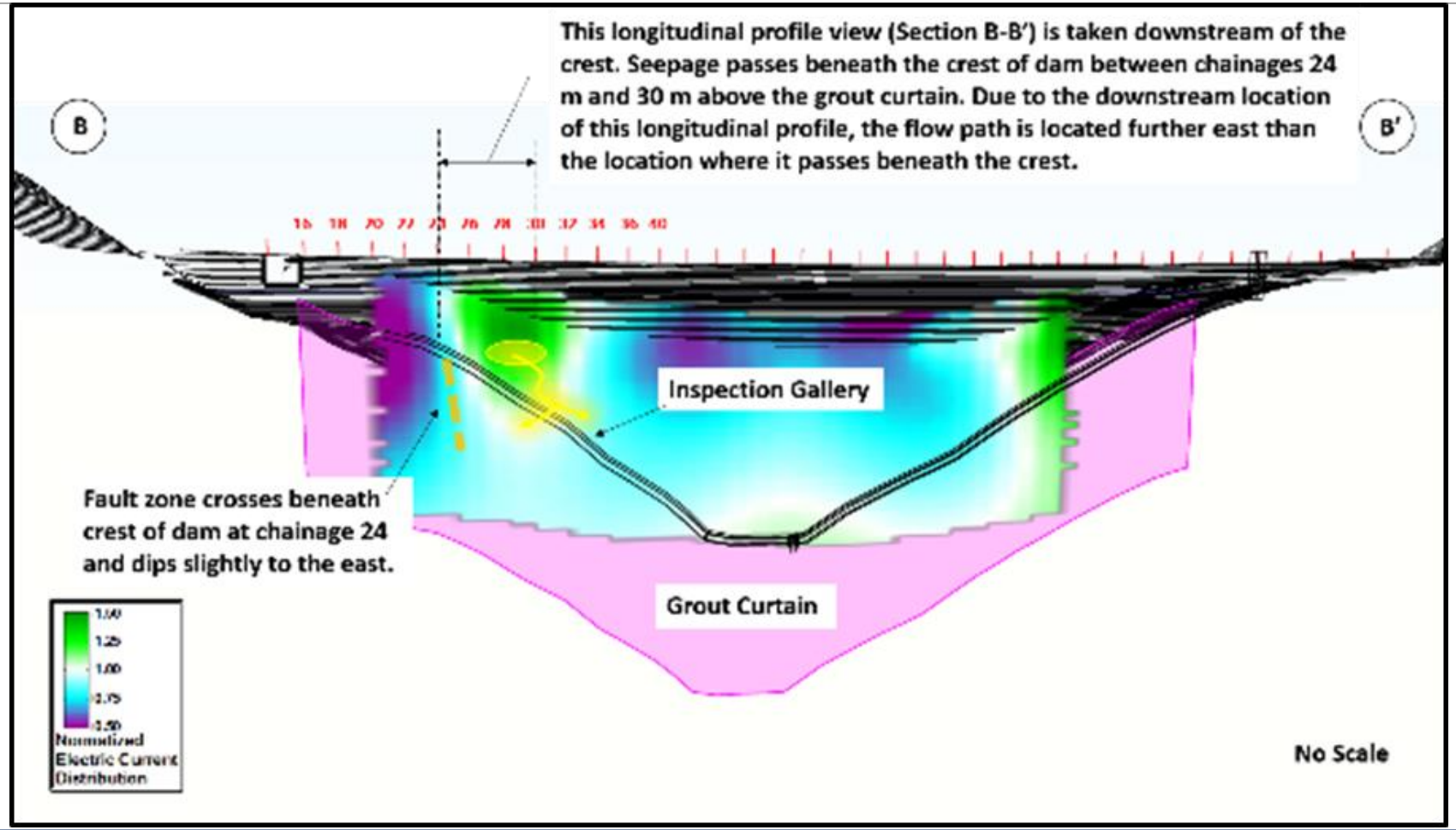
- Be careful
- Understand levels of uncertainty
- Willowstick can reduce level of uncertainty with regard to leakage
- Allocation of limited resources to other more needy dams
- Targeted remedial works

Feistritzbach Dam Austria

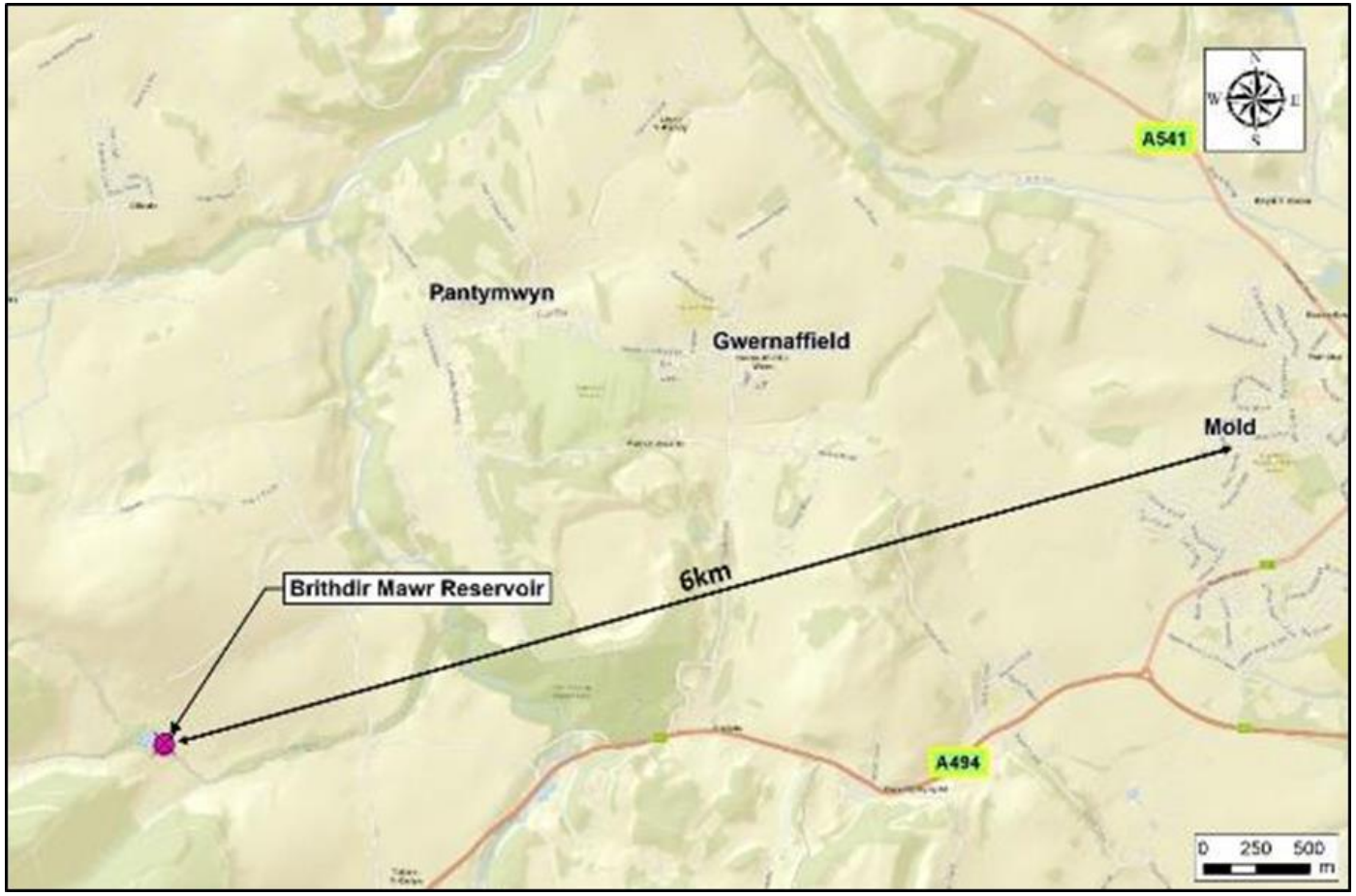
Leakage Surveys Ltd - Willowstick UK

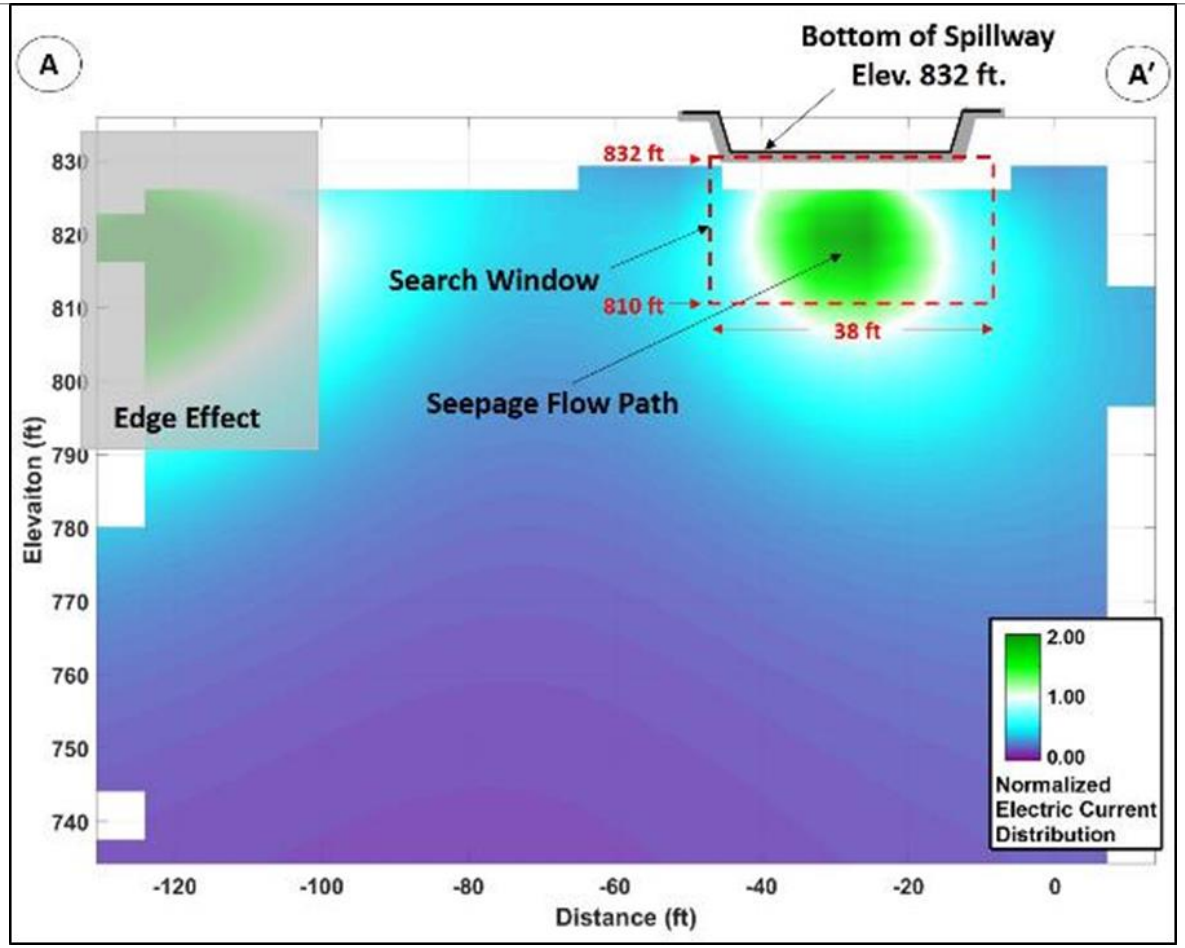


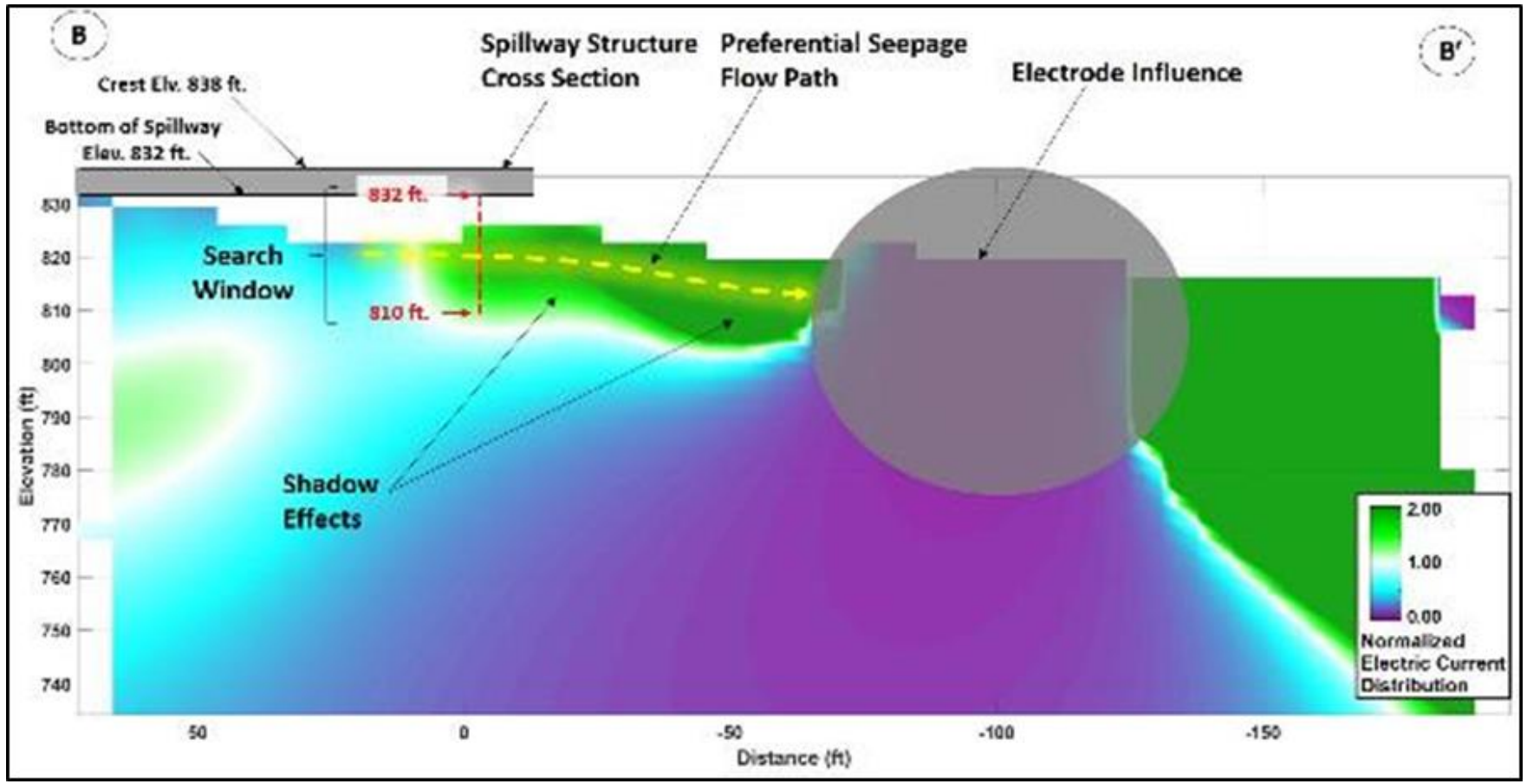

Legend
Conduit
Underground Powerline
Crest Wall
Drainage Pipeline
Fault
Piezometers
Spillway Race & Basin
Tunnel/Gallery
Centerline
Stationing
There was one seepage flow path identified as a result of the Willowstick investigation.
The seepage flow path occurs beneath the crest of the dam between chainage stations 24 m and 32 m (centred beneath chainage 28 m) and positioned above the grout curtain just east of the large fault zone.
Large Fault Zone
Spillway Entrance
Small Fault Zone
B
B'
P29
P28
0 25 50
m


This longitudinal profile view (Section B-B') is taken downstream of the crest. Seepage passes beneath the crest of dam between chainages 24 m and 30 m above the grout curtain. Due to the downstream location of this longitudinal profile, the flow path is located further east than the location where it passes beneath the crest.
B
B'
Inspection Gallery
Fault zone crosses beneath crest of dam at chainage 24 and dips slightly to the east.
Grout Curtain
Normalized Electric Current Distribution
No Scale

Brithdir Mawr Wales




A
A'
Bottom of Spillway
Elev. 832 ft.
832 ft
810 ft
38 ft
Search Window
Seepage Flow Path
Edge Effect
Elevaiton (ft)
830
820
810
800
790
780
770
760
750
740
-120
-100
-80
-60
-40
-20
0
Distance (ft)
2.00
1.00
0.00
Normalized
Electric Current
Distribution


B
B'
Spillway Structure Cross Section
Preferential Seepage Flow Path
Electrode Influence
Crest Elv. 838 ft.
Bottom of Spillway Eleu. 832 ft.
832 ft.
810 ft.
Search Window
Shadow Effects
Elevation (ft)
830
820
810
800
790
780
770
760
750
740
50
0
-50
-100
-150
Distance (ft)
2.00
1.00
0.00
Normalized Electric Current Distribution

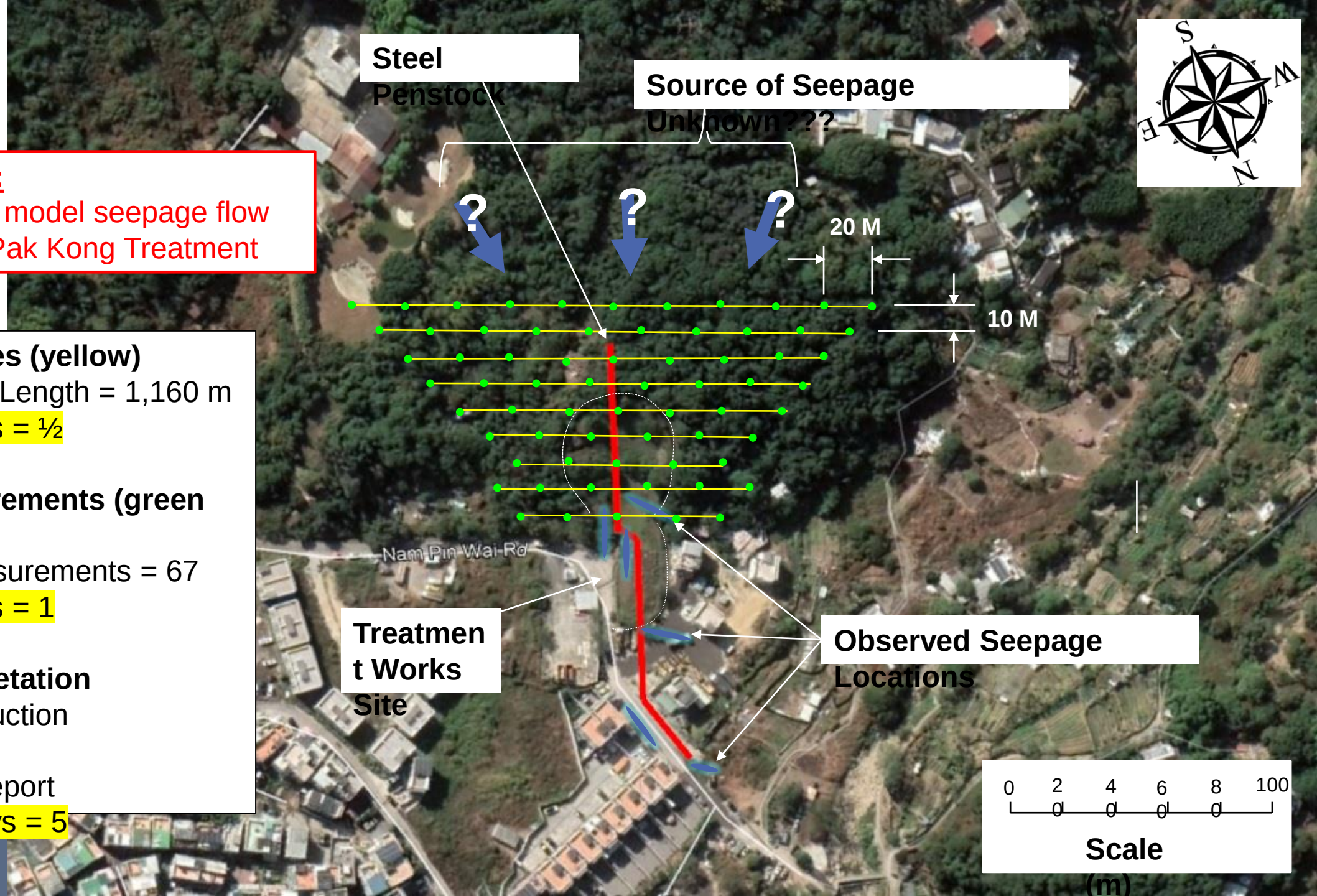
Pak Kong Treatment Works

Study Objective:
Identify, map and model seepage flow paths infiltrating Pak Kong Treatment Works

Gamma Lines (yellow)
- Total Line Length = 1,160 m
- Field Days = ½

RAP Measurements (green dots)
- Total Measurements = 67
- Field Days = 1

Data Interpretation
- Data Reduction
- 3D Model
- Written Report
- Office Days = 5



Willowstick Technologies, LLC - Introduction

Since 2004, Willowstick has specialized in identifying, mapping and modeling preferential groundwater flow paths and patterns and has completed nearly 400 major groundwater mapping projects worldwide. These projects range from applications in source development, mining, dams, environmental, geothermal and many other groundwater related applications. Willowstick utilizes three different and unique geophysical exploratory methods to provide unrivaled insight regarding groundwater flow paths and patterns. The three methods include:

1. Willowstick Method (an active electrical based technique),
2. Resonance Acoustic Profiling Method RAP (a passive seismic method),
3. Radiometric Scintillation Counter or Gamma Method (a passive method tuned for water sensitivity).

Geophysical Journal International

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Advance Access publication 2018 July 06
GJI Geomagnetism, rock magnetism and palaeomagnetism

Magnetometric resistivity: a new approach and its application to the detection of preferential flow paths in mine waste rock dumps

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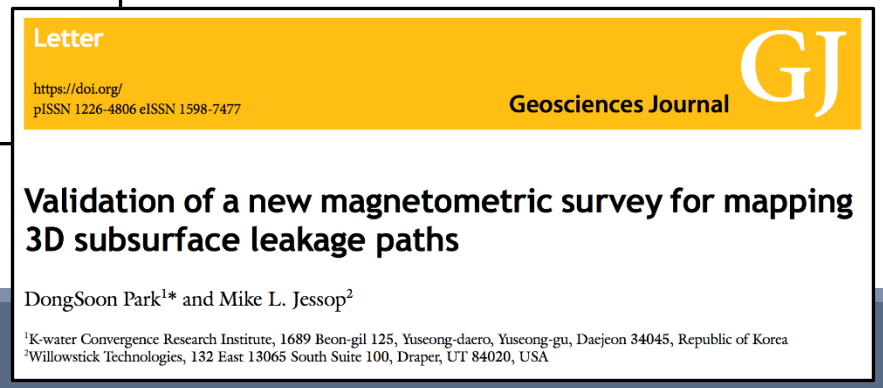
[2] *Université de Rouen, M2C, UMR* 6143, *CNRS, Morphodynamique Continentale et Côtière, Mont Saint Aignan, France*
[3] *Université Savoie Mont Blanc, CNRS, IRD, IFSTTAR, ISTerre,* F-73000 *Chambéry, France. E-mail: andre.revil@univ-smb.fr*



Letter

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Geosciences Journal GJ

Validation of a new magnetometric survey for mapping 3D subsurface leakage paths

DongSoon Park[1]* and Mike L. Jessop[2]

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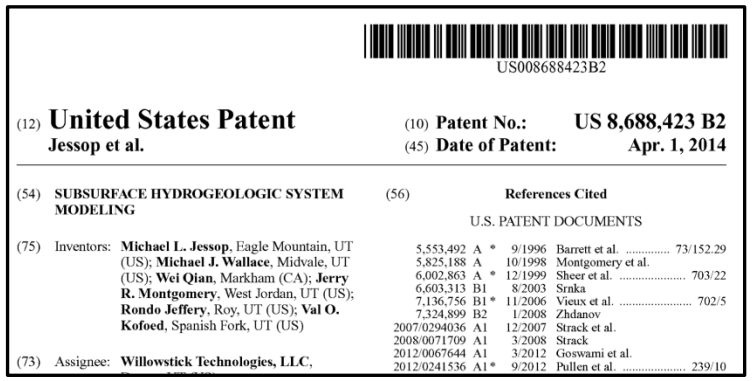
[2]Willowstick Technologies, 132 East 13065 South Suite 100, Draper, UT 84020, USA



US008688423B2

(12) **United States Patent**
Jessop et al.

(10) **Patent No.: US 8,688,423 B2**
(45) **Date of Patent: Apr. 1, 2014**

(54) **SUBSURFACE HYDROGEOLOGIC SYSTEM MODELING**

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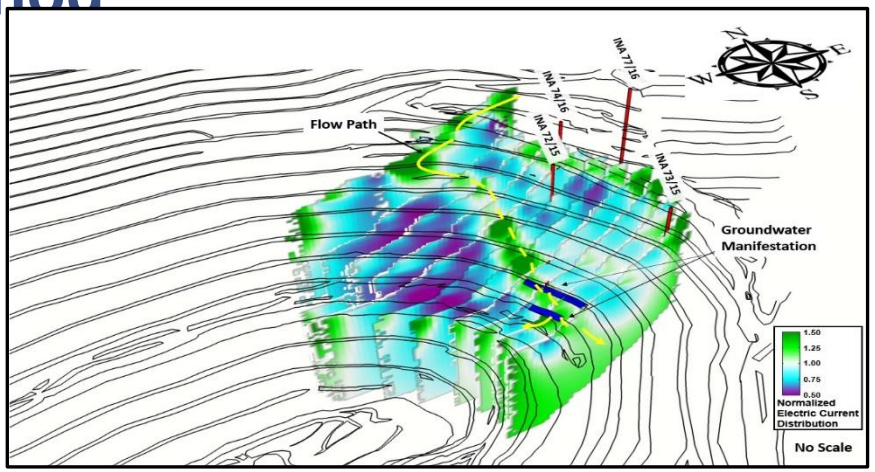
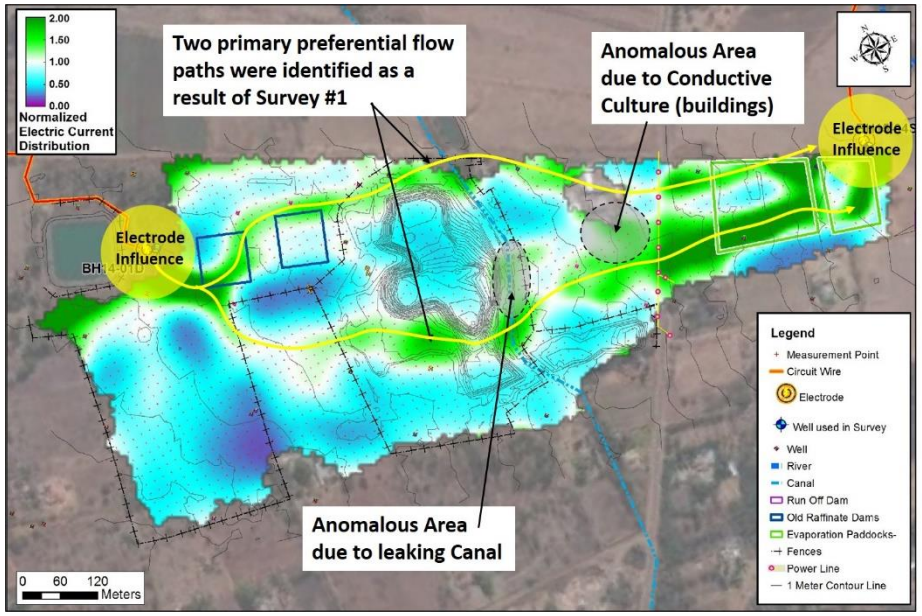
The Willowstick Method



Brazil – Groundwater Infiltration into Open Pit Mine



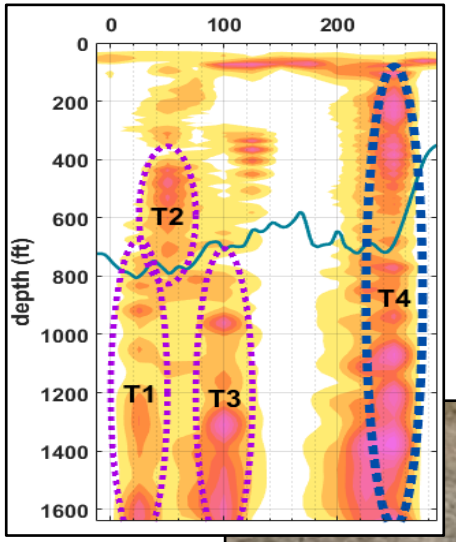
Africa – Contaminant Flow away from Surface Mine

Willowstick Method Overview

The application of the Willowstick method is fundamentally based on the principle that groundwater increases the conductivity of earthen materials through which it flows. As the "injected" signature electric current flows between strategically placed electrodes (located upgradient and downgradient of the study area), it concentrates in the more conductive zones (i.e., in areas of highest transport porosity) where groundwater preferentially flows through the subsurface. We then measure and model the magnetic fields generated from the subsurface electric current to identify preferential electric current flow paths and patterns. We compare the measured magnetic field data to the predicted magnetic field—based on a model of the subsurface conductivity environment and the given electrodes—for the survey setup to identify any variations from the background model and to resolve areas of anomalous electric current density. This information is used to interpret where preferential groundwater flows are located through the subsurface study area.

Resonance Acoustic Profiling (RAP) Method Overview

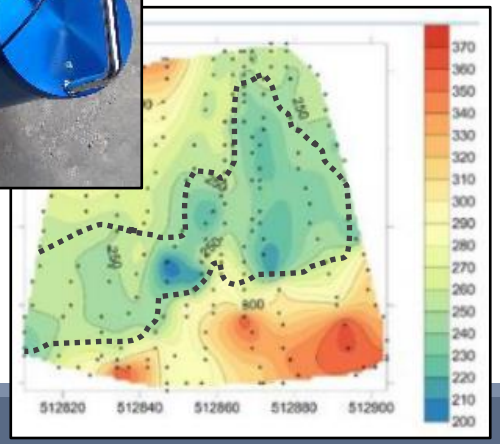
This system detects structural weakness in rocks and is apt at locating weak or fractured zones of high permeability with fair accuracy to depths as deep as 4,000 feet. The flexing of earth's crust due to interplanetary tidal forces creates continuous micro-seismic activity which is the source energy for this passive seismic method. Resonance from low-velocity zones, as indicated by the RAP signal at this site, are predominantly interpreted as weak, fractured rock or secondary porosity that can facilitate hydraulic conductivity.



Resonance Acoustic Profiling (RAP) Passive Seismic

Radiometric Gamma Scintillation Counter (Gamma) Method Overview

This system measures the aggregate gamma emissions from the subsurface rocks below the sensor. Most importantly, the signal dips in places where water accumulates enough to diminish the signal—especially vertically, such as in fracture/faulted zones—making it an excellent tool to use in conjunction with RAP to discriminate wet versus dry fracture zones. Because this system takes measurements in free space, much larger areas can be covered in shorter time, making it the "scouting" tool to generate prospect areas that can be further studied, qualified or ruled-out as the case may be.



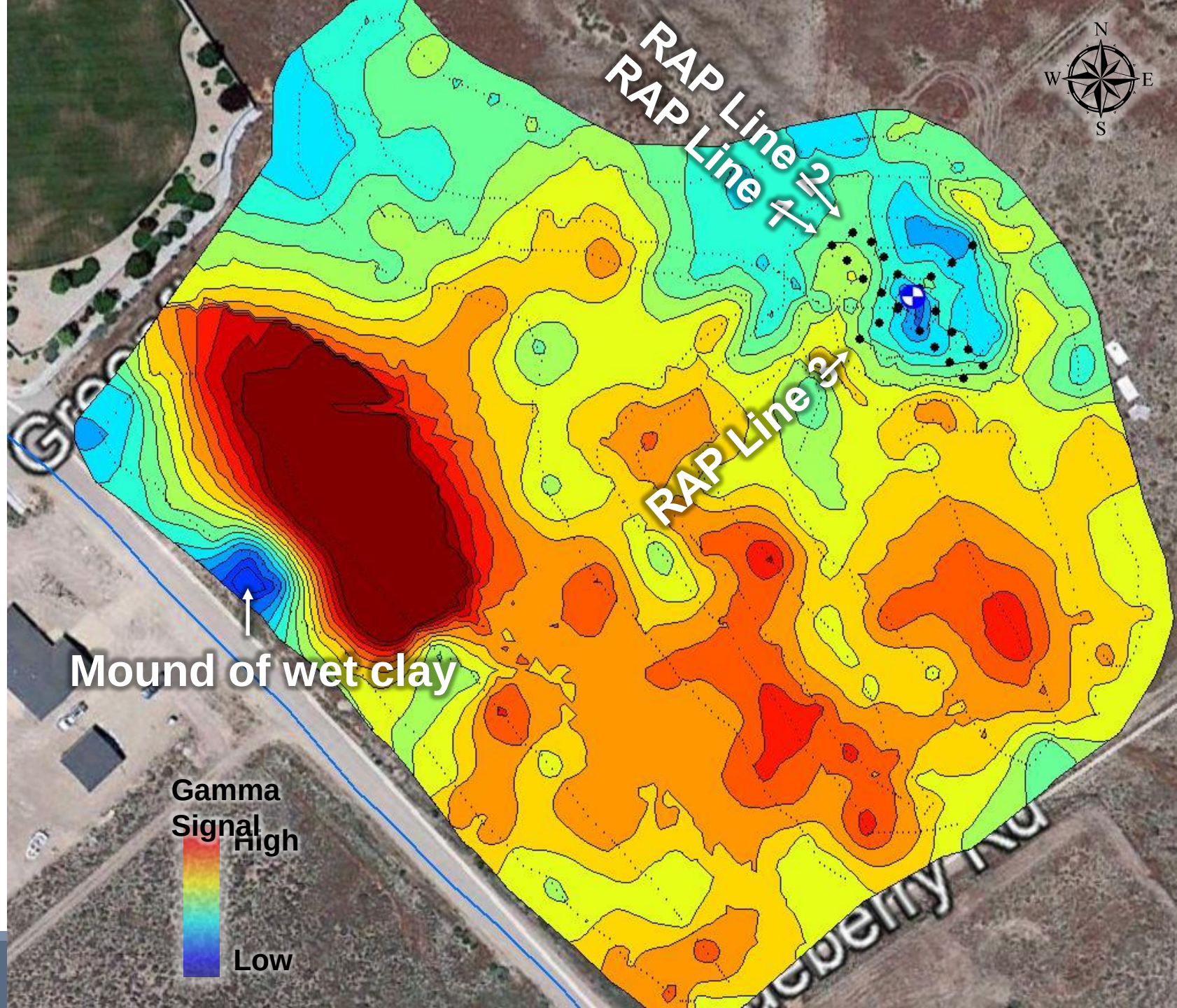
Radiometric Gamma "water" indicator

Example #1
Proof of Concept Study

Prior to initiating a city-wide groundwater characterization study, the City desired to prove the Gamma and RAP techniques before moving forward with the overall investigation. As a result, a Gamma and RAP Proof-of-Concept survey was performed over the small piece of property with known subsurface characteristics before initiating a city-wide investigation.

The Figure to the right presents the Gamma results as part of the Proof-of-Concept study.

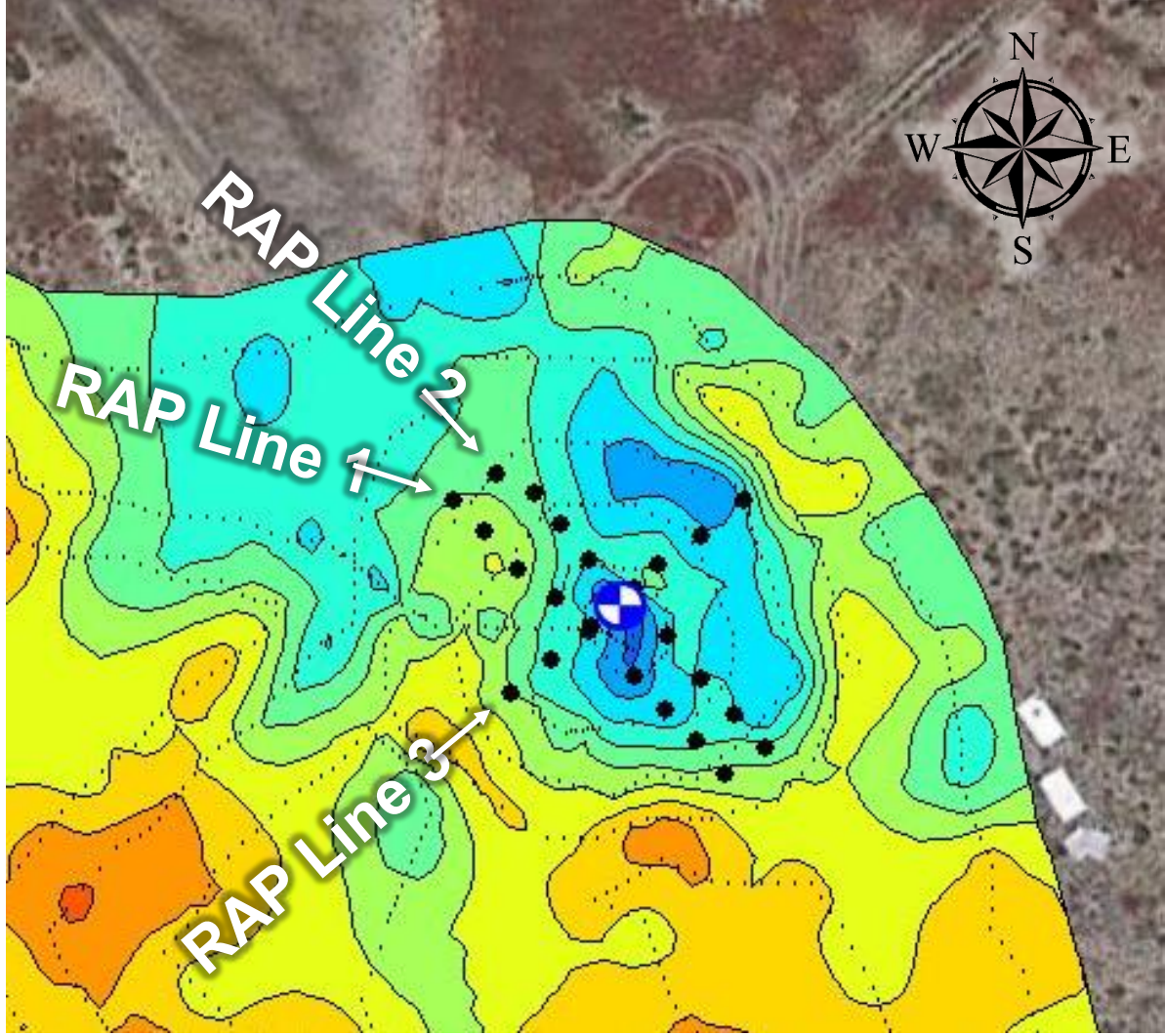
The gamma system measures the aggregate gamma emissions from subsurface rocks and soil. Most importantly, the signal drops where water occurs in permeable (fracture) zones in earth's crust (i.e., blue shaded areas), making it an excellent tool to use in conjunction with the RAP system (as will be shown) to locate highly permeable (fracture) zones *with* high water content.



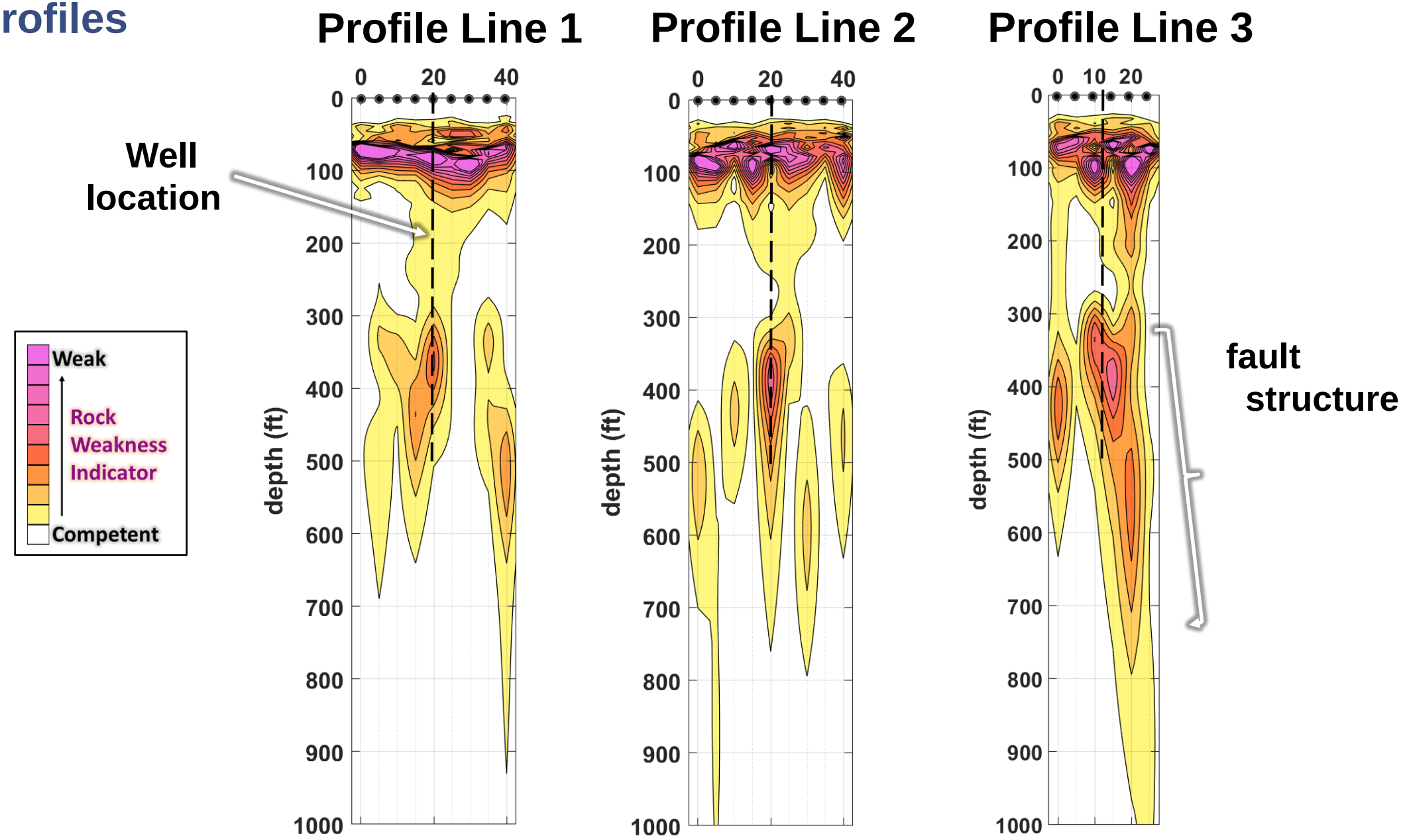
willowstick

Example
Proof of Concept Study Continued…

After identifying an area that indicates the presence of groundwater, the RAP method was used to refine and pinpoint groundwater production zones. The RAP system detects structural weakness in rocks and is apt at locating weak or fractured zones of high permeability with fair accuracy to depths as deep as 1,200 m. The flexing of earth's crust due to interplanetary gravitational forces creates continuous micro-seismic activity which is the source energy for this passive seismic method. Resonance from low-velocity zones, as indicated by the RAP signal are predominantly interpreted as weak, fractured rock or secondary porosity that can facilitate hydraulic conductivity.

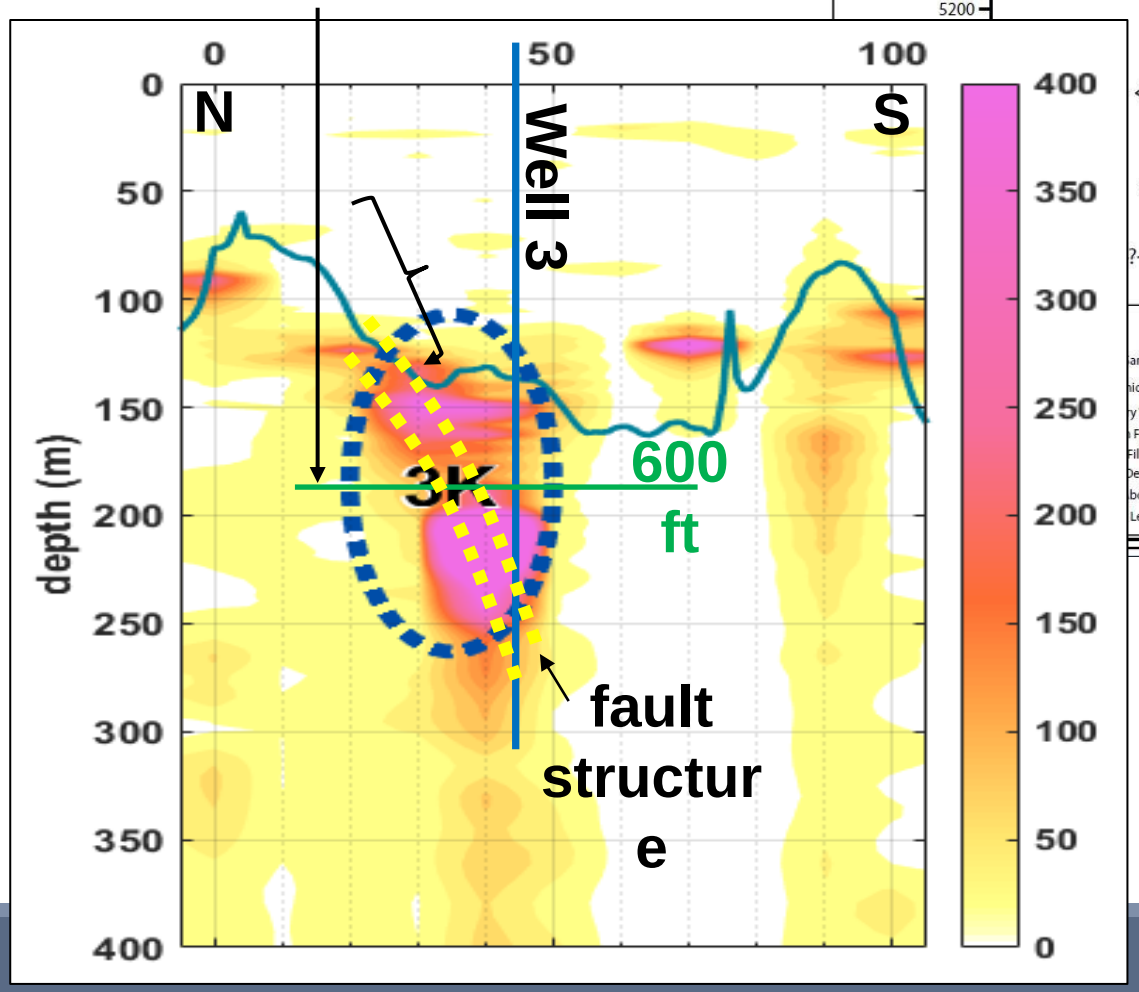


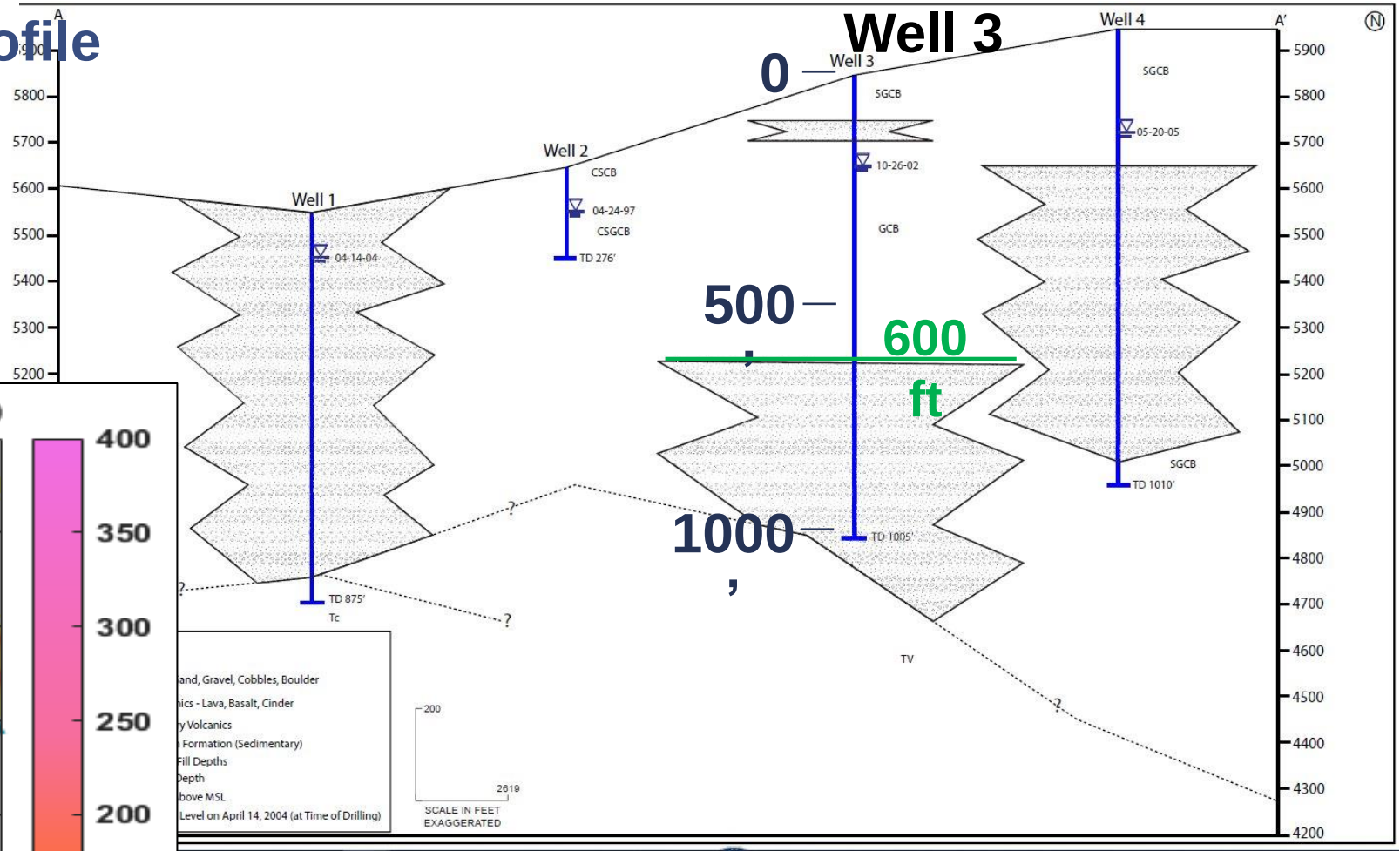
RAP Profiles



Well Log Compared to RAP Profile

Well log and RAP both indicate a highly fractured zone at 600 ft depth (entering fault structure)





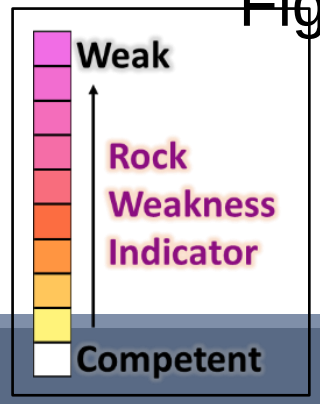
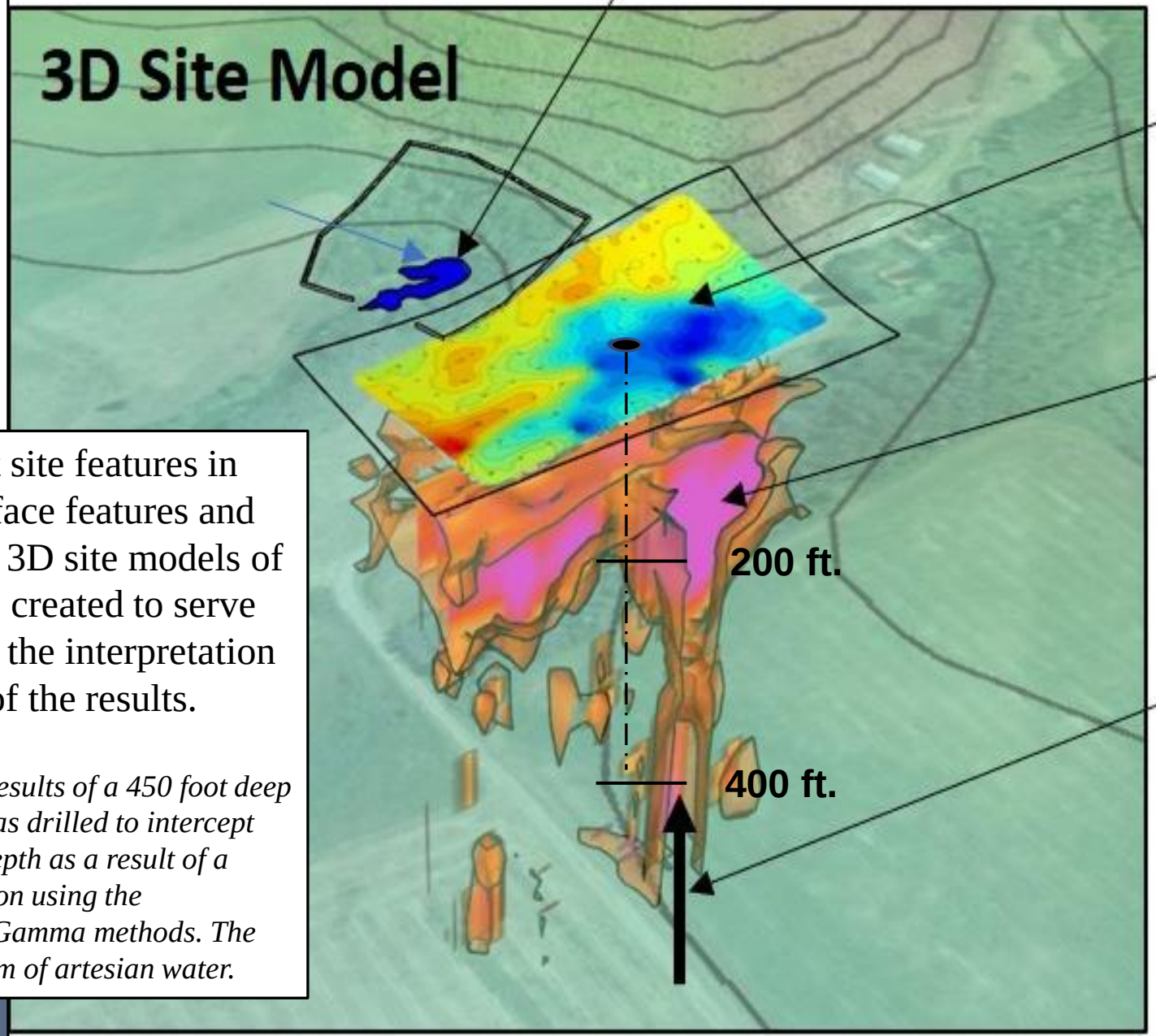


Figure 3 of 2013 Hydrogeological Study (Iron Springs Corporation, 2013)

Gamma and RAP Results

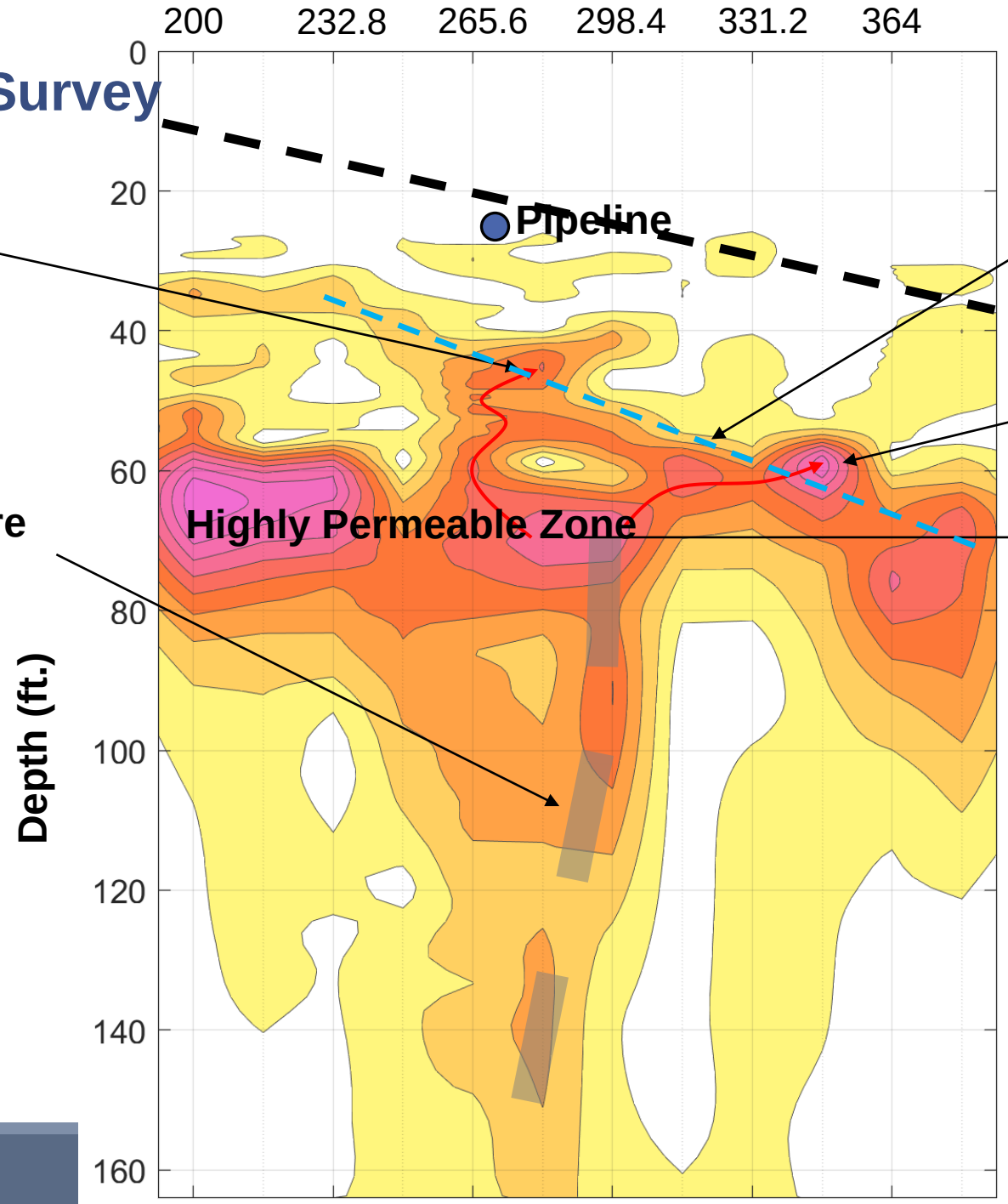
3D Site Model



To show pertinent site features in relation to subsurface features and anomalous zones, 3D site models of the subsurface are created to serve as helpful tools in the interpretation and presentation of the results.

This figure shows the results of a 450 foot deep production well that was drilled to intercept groundwater flow at depth as a result of a Willowstick investigation using the Willowstick, RAP and Gamma methods. The well produces 2800 gpm of artesian water.

Example #2
Seepage Flow Path Survey



Elev. 3778 ft.

Lubricated Slip Plane where a paleo landslide once occurred.

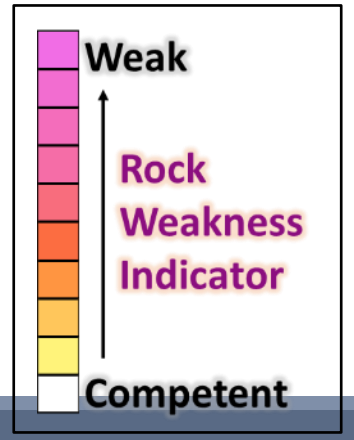
Seepage Manifesting at Wet Spot

Seepage Manifesting In Drainage Blanket

Fracture Zone

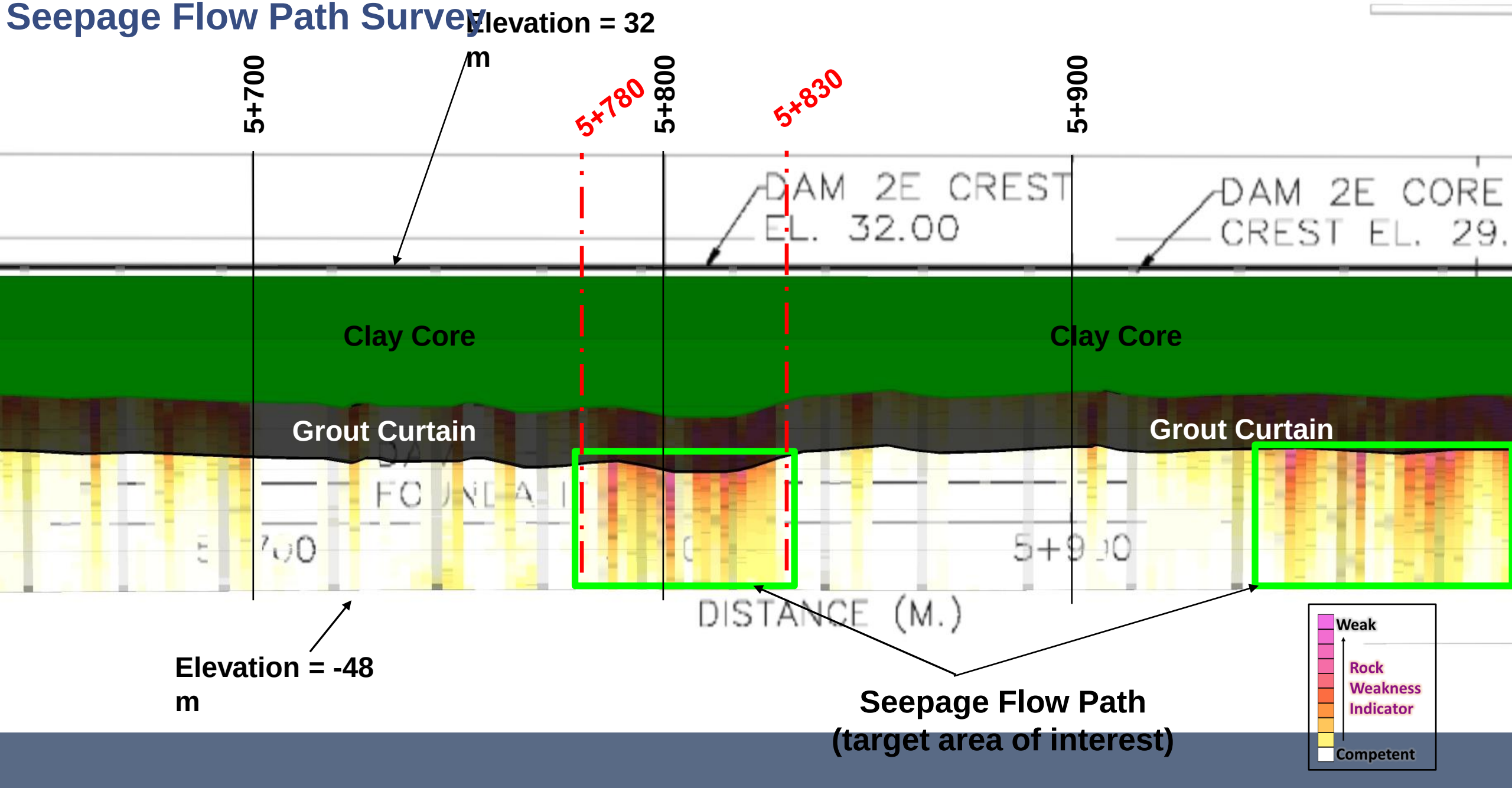
Elev. 3705 ft.

RAP Scale

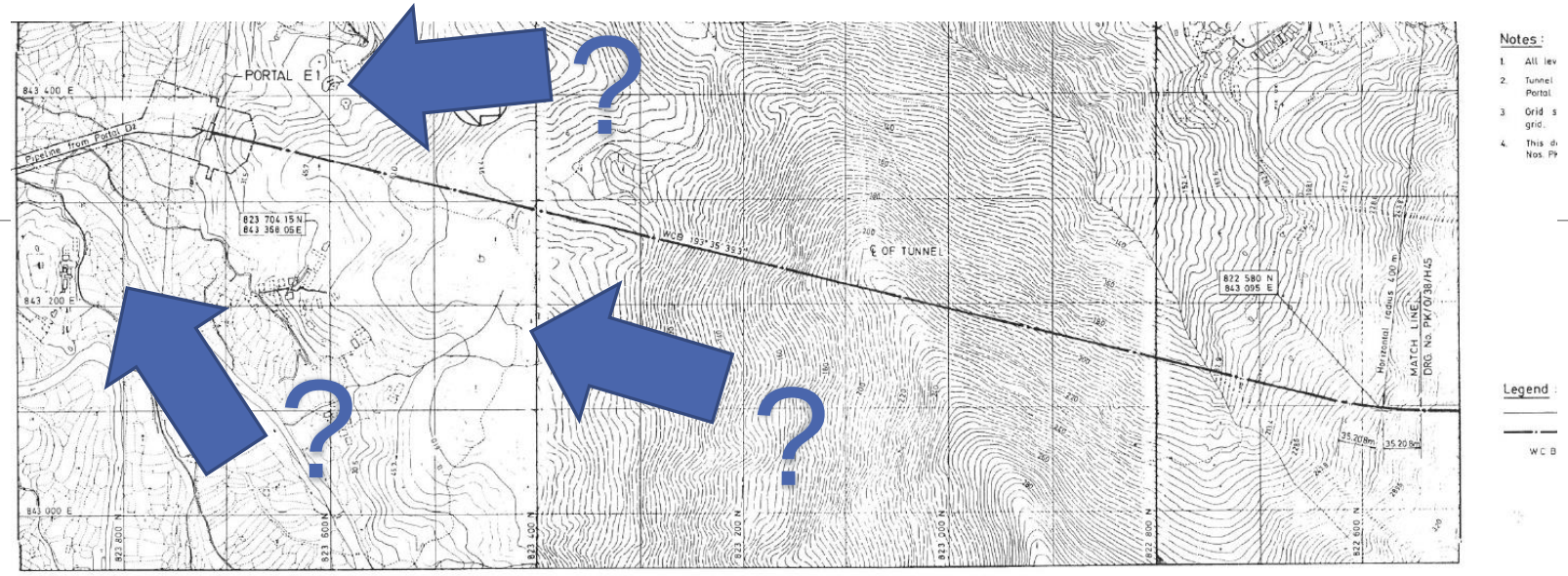


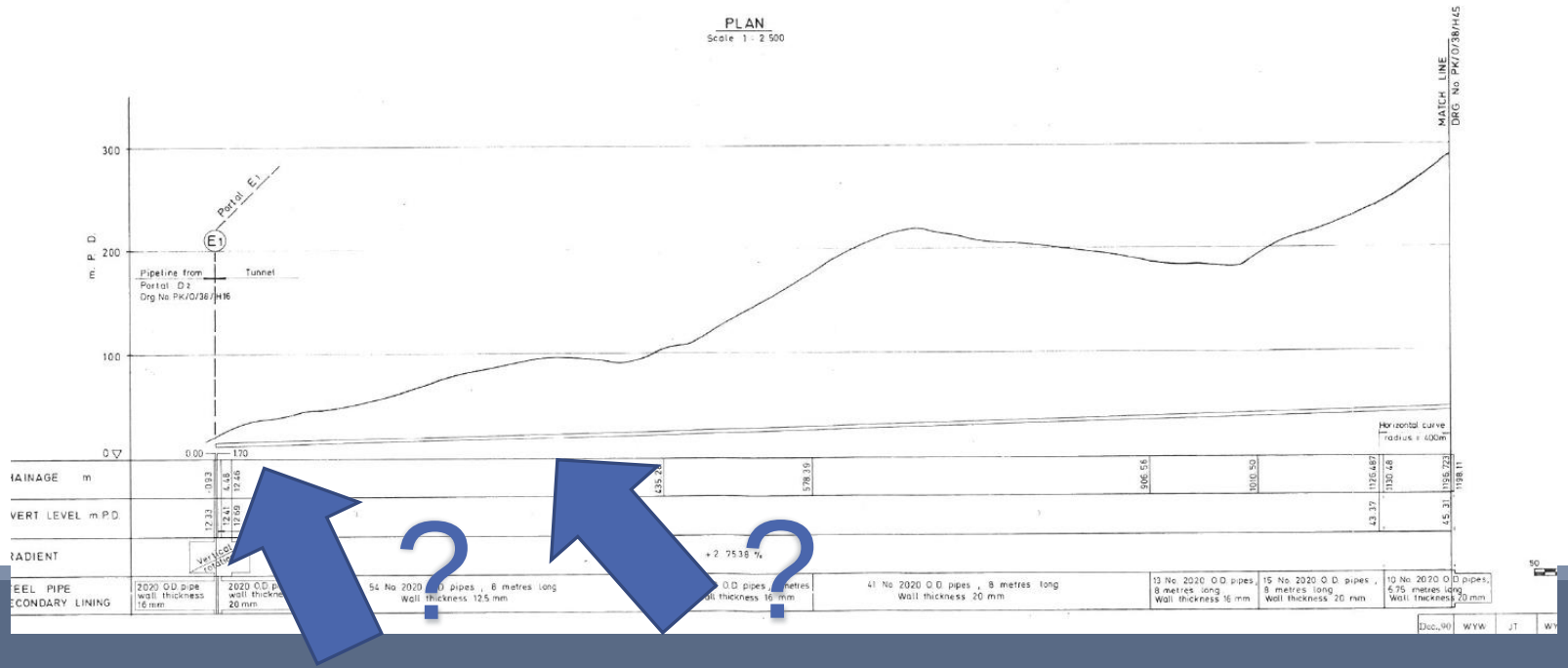
Example #3

Seepage Flow Path Survey



Pak Kong Treatment Works





Pak Kong Treatment Works

Study Objective:
Identify, map and model seepage flow paths infiltrating Pak Kong Treatment Works

Gamma Lines (yellow)
- Total Line Length = 1,160 m
- Field Days = ½

RAP Measurements (green dots)
- Total Measurements = 67
- Field Days = 1

Data Interpretation
- Data Reduction
- 3D Model
- Written Report
- Office Days = 5