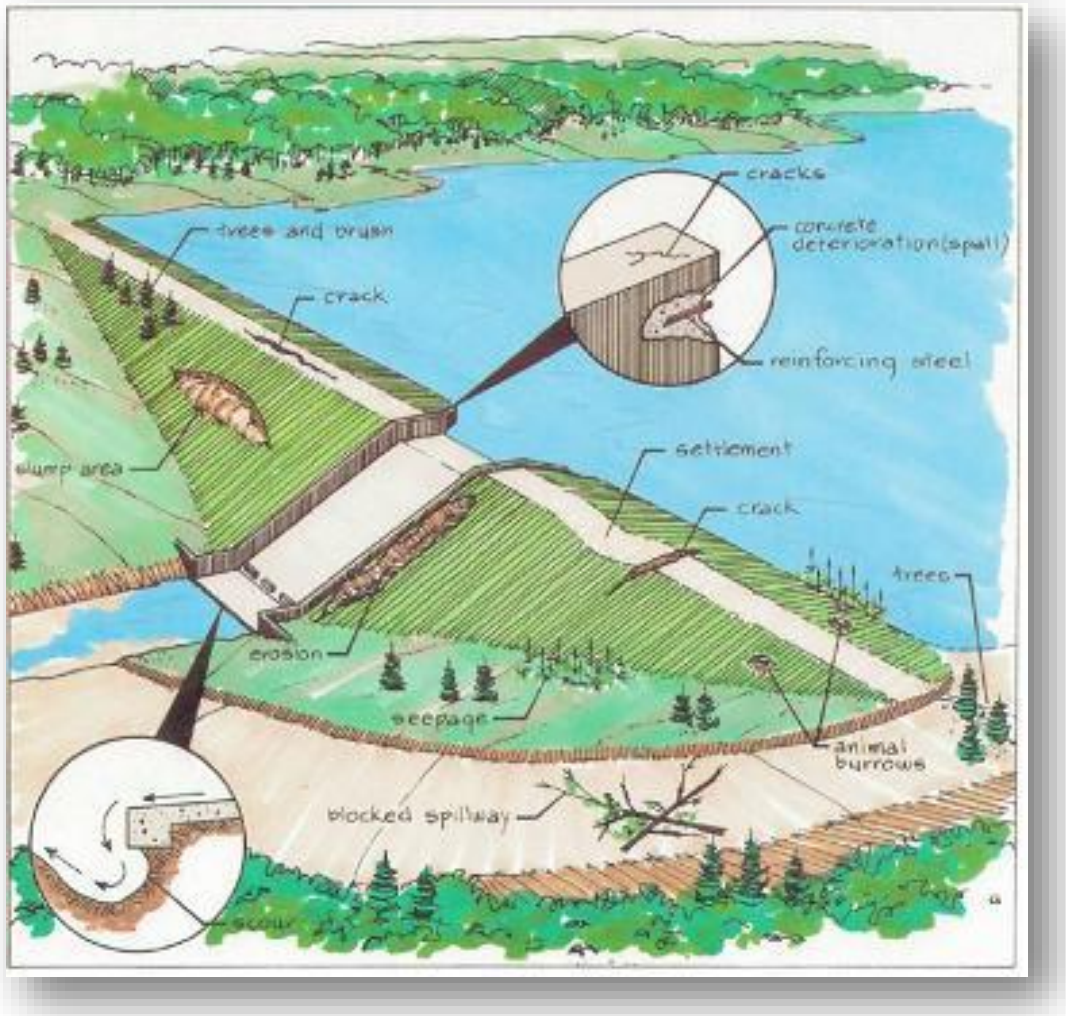
Geophysical Investigations for Dam Safety

Rapid & Cost Effective Investigations & Monitoring of Dams



AF Academy

Dr. Sanjay Rana

About AF Academy

AFA provides training & knowledge sharing platform to decision & policy makers, working professionals, operating level personnel and aspiring students willing to specialise in technical sector through mediums of trainings & courses.

Visit https://www.afacademy.org/ for details of all offered online courses

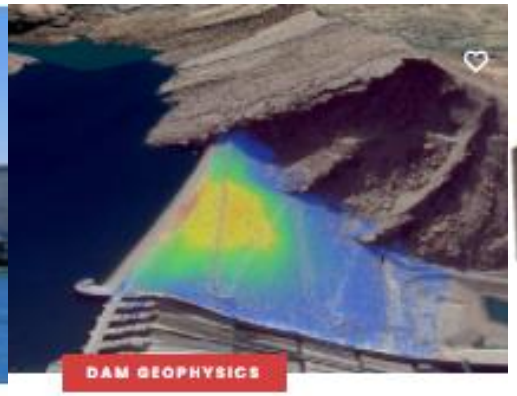
Online Courses (https://www.afacademy.org/)

by AF Academy

3 MONTH'S ADVANCED ONLINE COURSE ON GROUND PENETRATING RADAR

by AF Academy

Certificate Course on Dam and Network Safety Assurance



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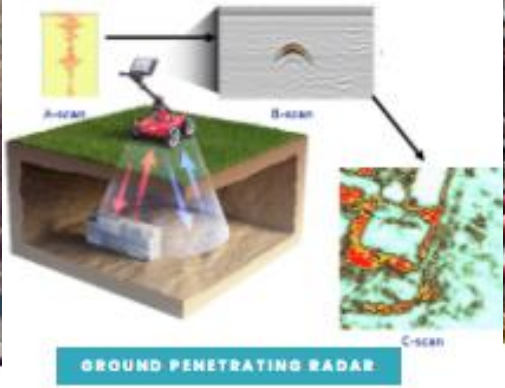
3 Month's Online Course on Dam Geophysics



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3 Month's Online Course on Ground Penetrating Radar

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Online Certification Program on Subsurface Utility Engineering - All 3 Levels

Latest Course Added

1. **Online Certificate Course- Crosshole Seismic Test, Downhole Seismic Test & Crosshole Seismic Tomography**
2. **Online Certificate Course- Electrical Resistivity Imaging**

PARSAN- Technology Partner

- Only company in India providing complete dam geophysical solutions (>70 dams investigated)
- Highly experienced and trained staff.
- Offices in Delhi, Bhopal, Kolkata, Bahrain, Saudi Arabia (Associate).
- Work experience in India, Nepal, Bhutan, Bangladesh, Singapore, Oman, Afghanistan, Saudi Arabia, Bahrain, Kuwait…….

PARSAN

UNITED REGISTRAR OF SYSTEMS URS ISO 9001

UKAS QUALITY MANAGEMENT 005

एन एस आई सी NSIC ISO 9001 : 2008

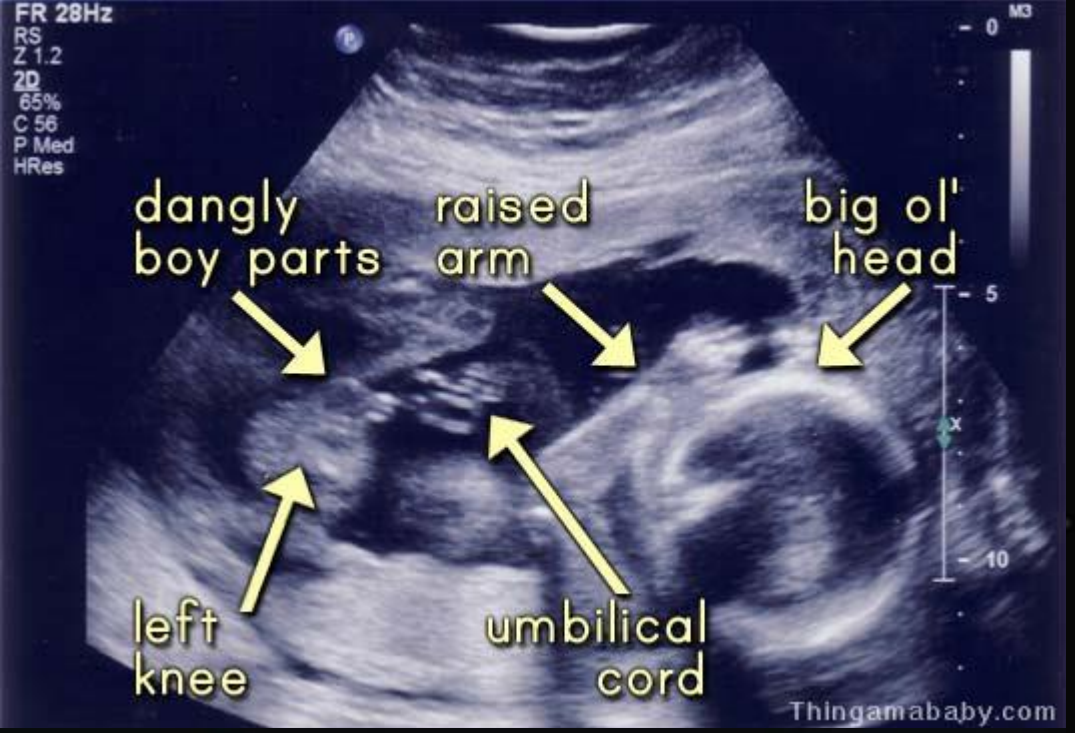
About Speaker (Dr. Sanjay Rana)

- Professional Geophysicist, with **31 years** of work experience. Chairman AF Academy & Managing Director, PARSAN, An engineering geophysics company
- **Gold Medalist**, University of Roorkee (Now IIT-Roorkee)
- Member of various working committees for development of Code of Practices and Standards, **including IRC**.
- **Pioneered use of Dam Geophysics in India in 1998.**
- Successfully used integrated geophysical approach for investigations across flowing rivers & for dam safety
- Completed geophysical investigations of **72 hydro power** projects.
- Extensive experience of Geophysical Investigations of Dams **(Concrete, Masonry & Earthen)**
- Geophysical investigation of Dams- **>90 dams**
- **Principal author of 'Guidelines on Geophysical Investigation of Dams'.**

The Engineer’s first problem in any design situation is to discover what the problem really is


Tools are available
Use them
Don’t be scared, your job is still safe!
No thanks!
We are too busy
Too busy to improve?

Geophysical Investigations……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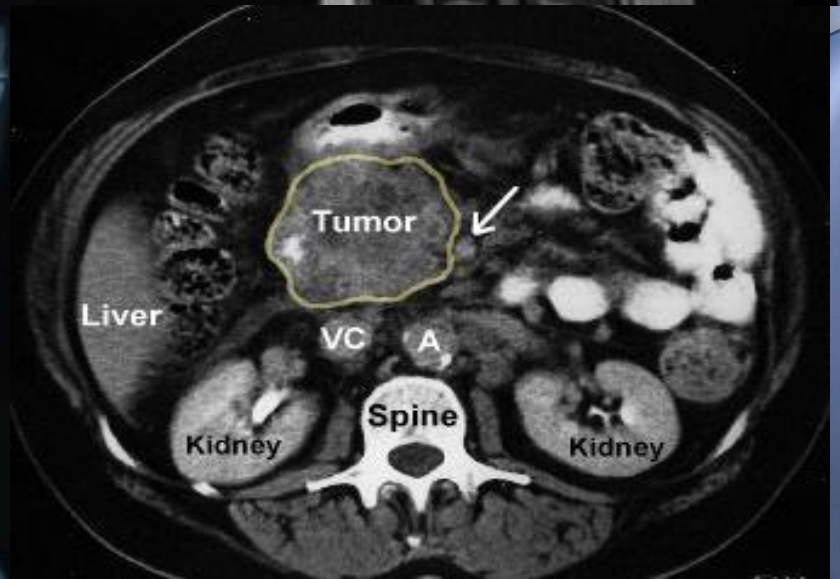
raised arm
big ol' head
left knee
umbilical cord
Thingamababy.com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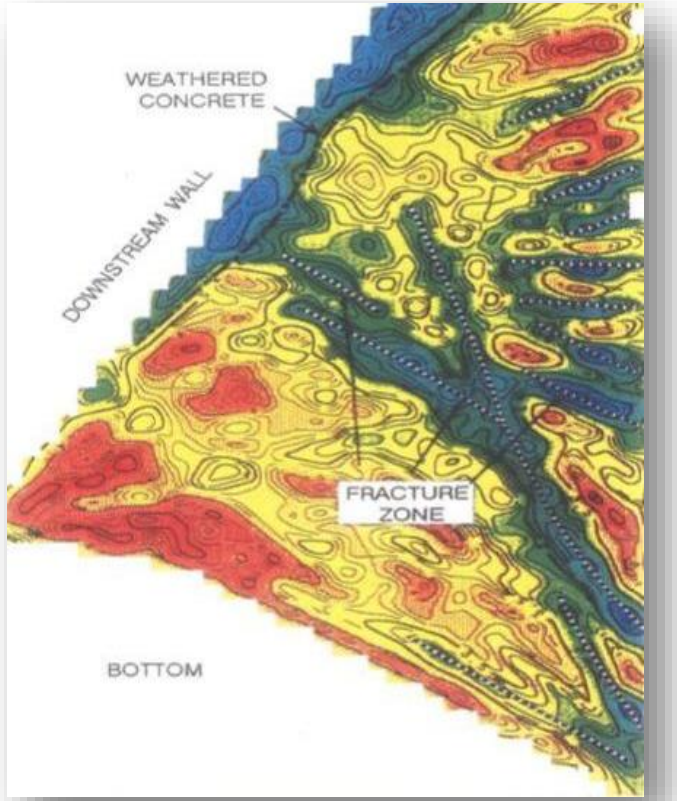
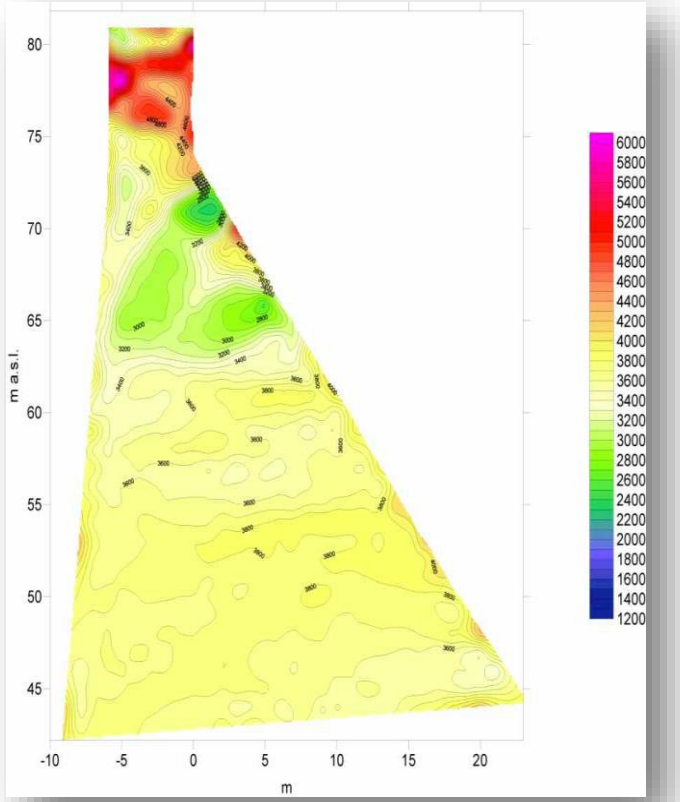

WEATHERED CONCRETE
DOWNSTREAM WALL
FRACTURE ZONE
BOTTOM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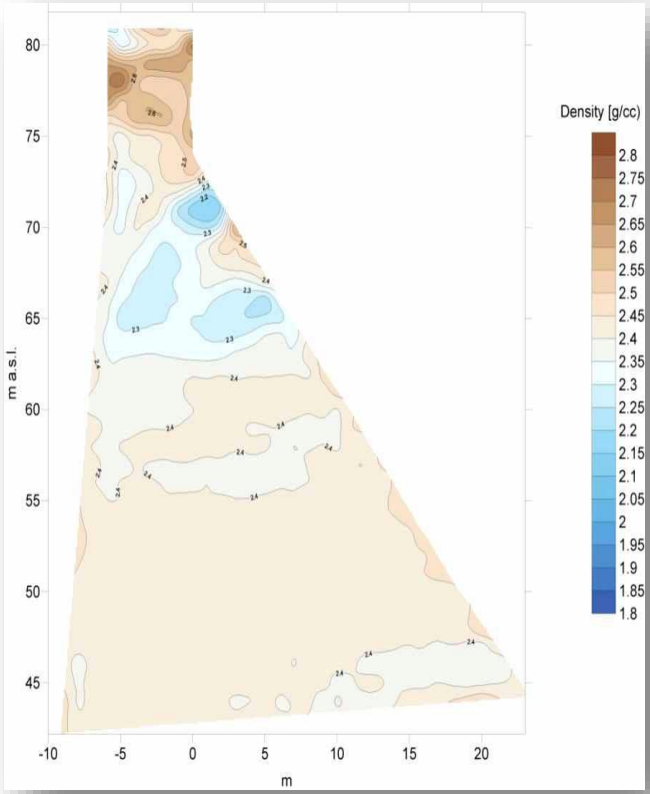
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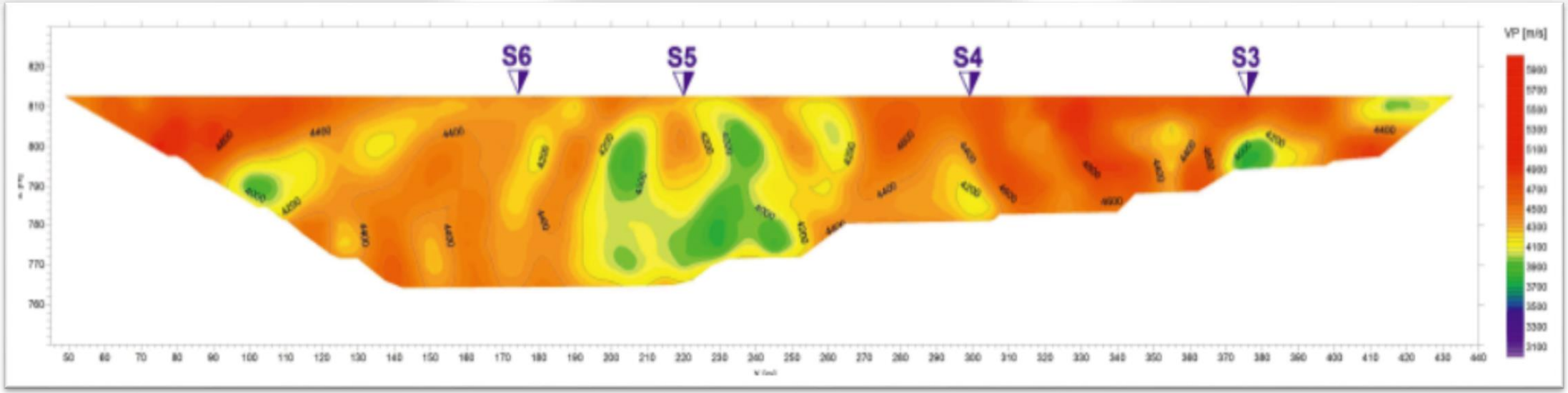
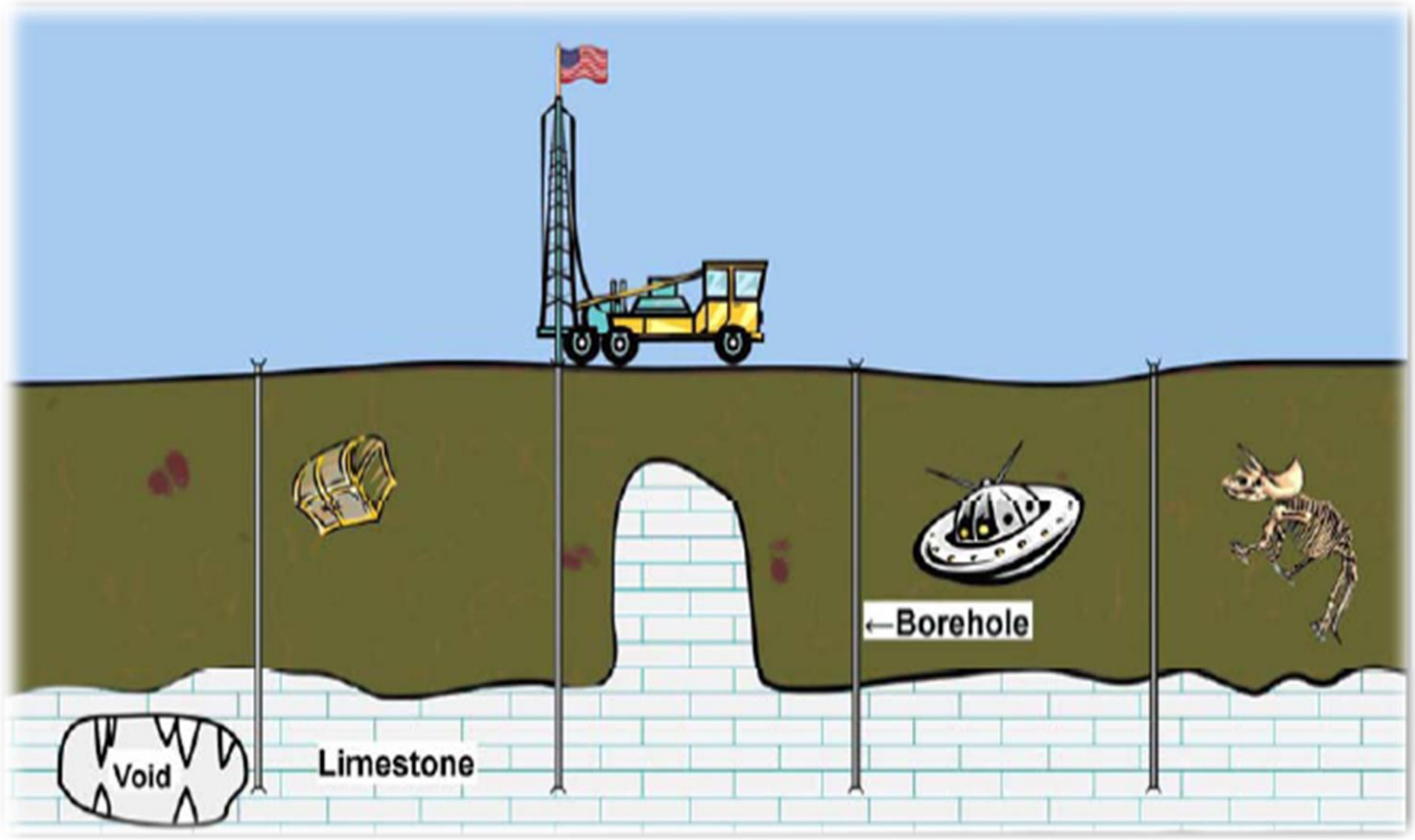

S6
S5
S4
S3
VP [m/s]

Why Use Geophysics…….

- Low Cost
- Rapid Coverage
- Continuous information
- Optimization of dill holes
- Minimization of ‘Surprises’
- Early stage application…Better planning, smooth execution.

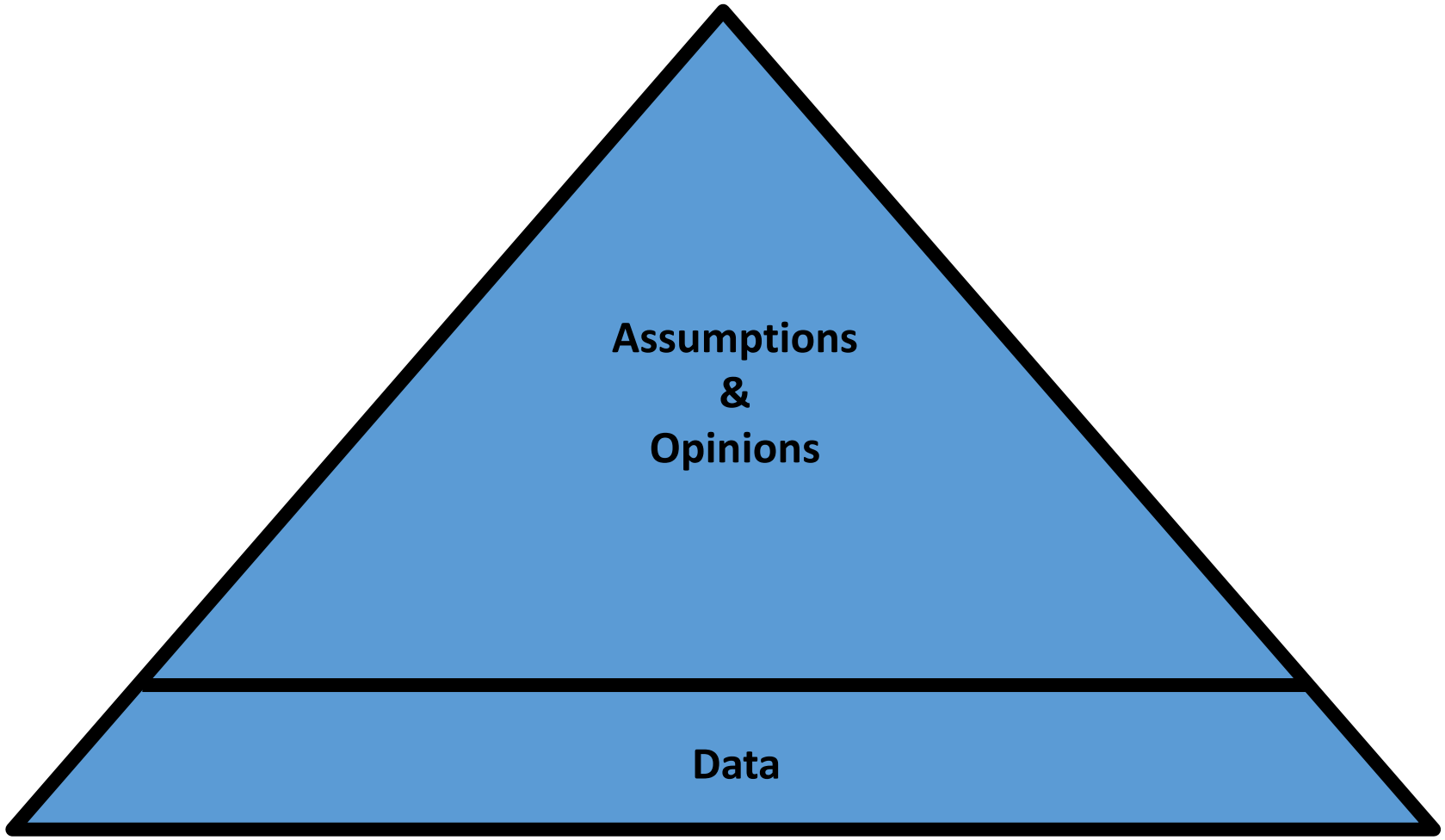


Dam Investigations

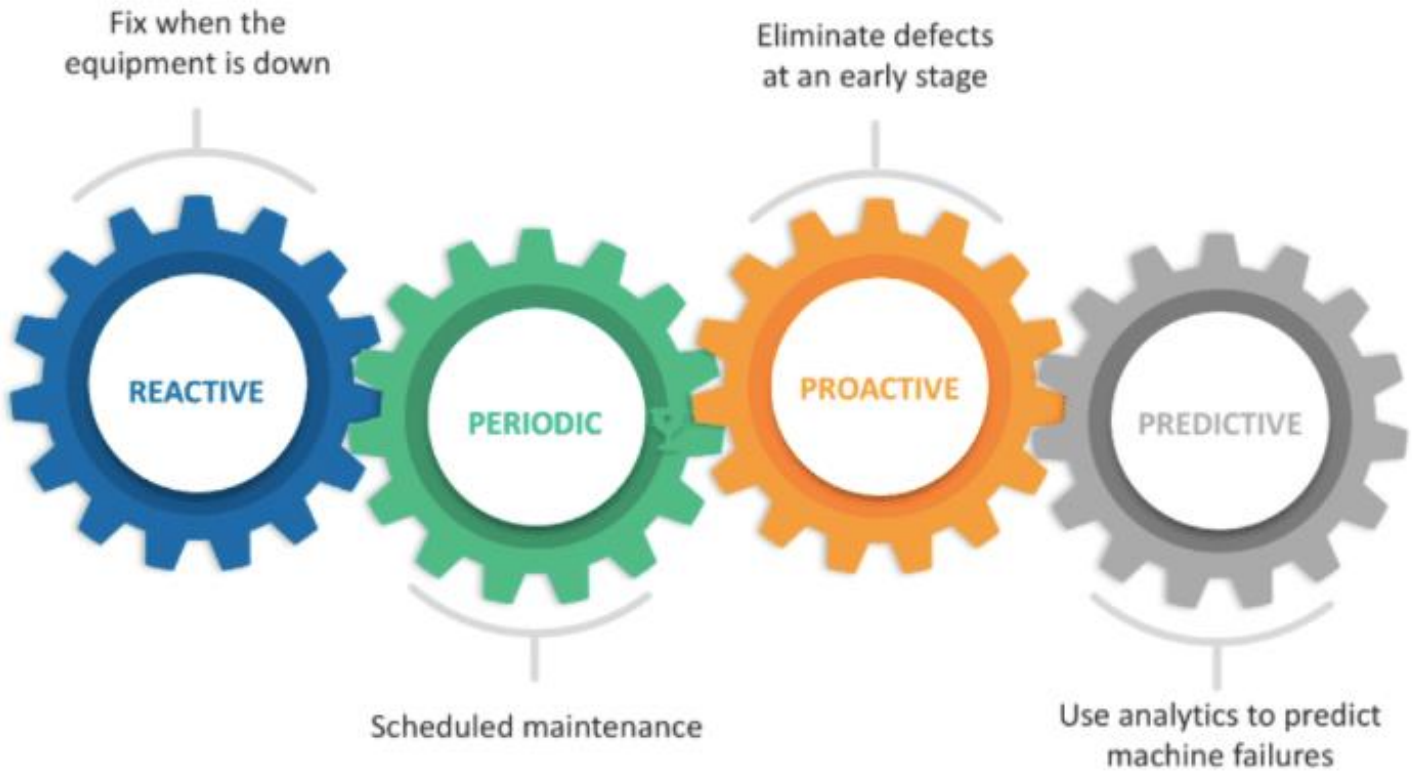
Present Scenario...

- Surface only
- Inspector Dependent
- Standards?

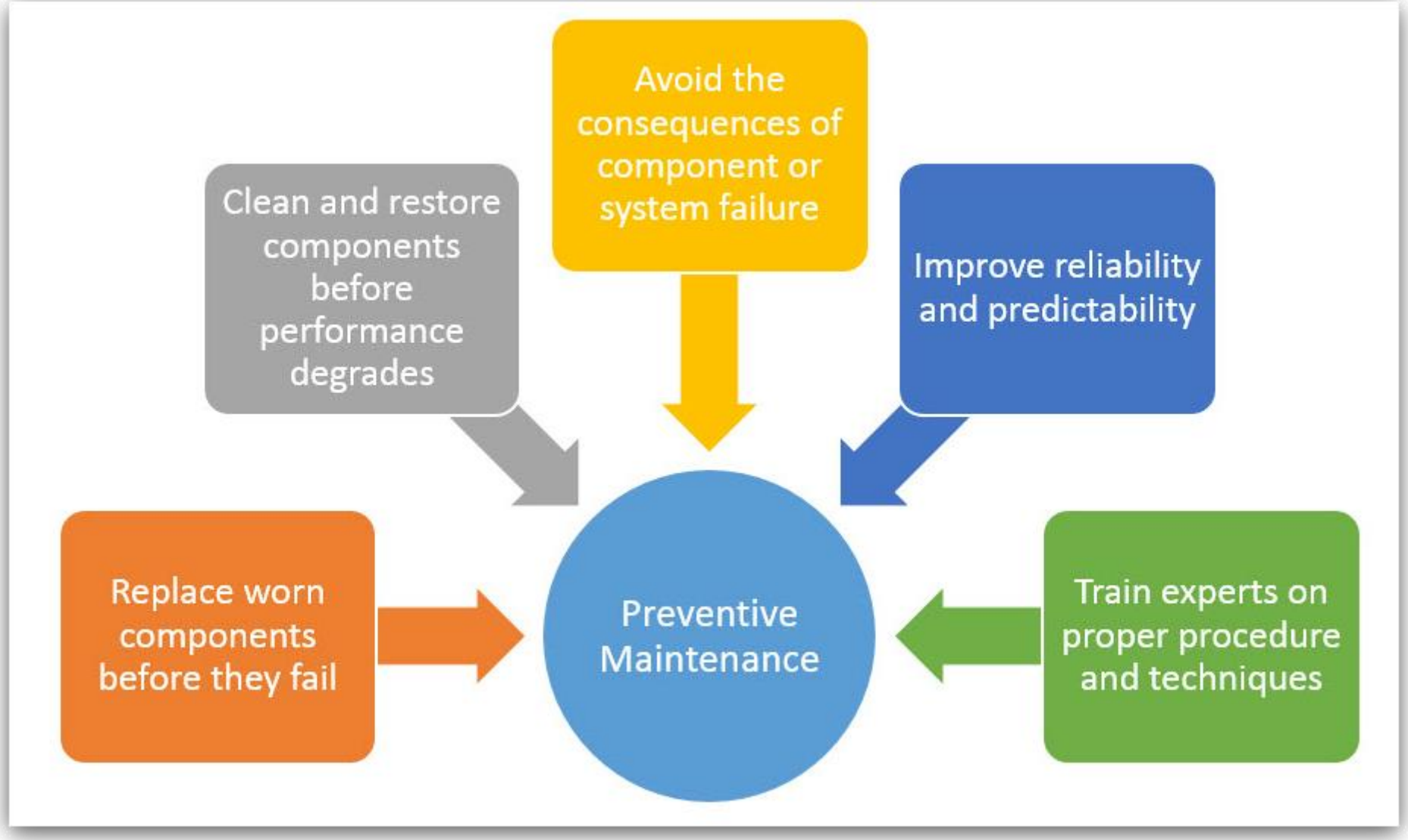
Traditional Approach?



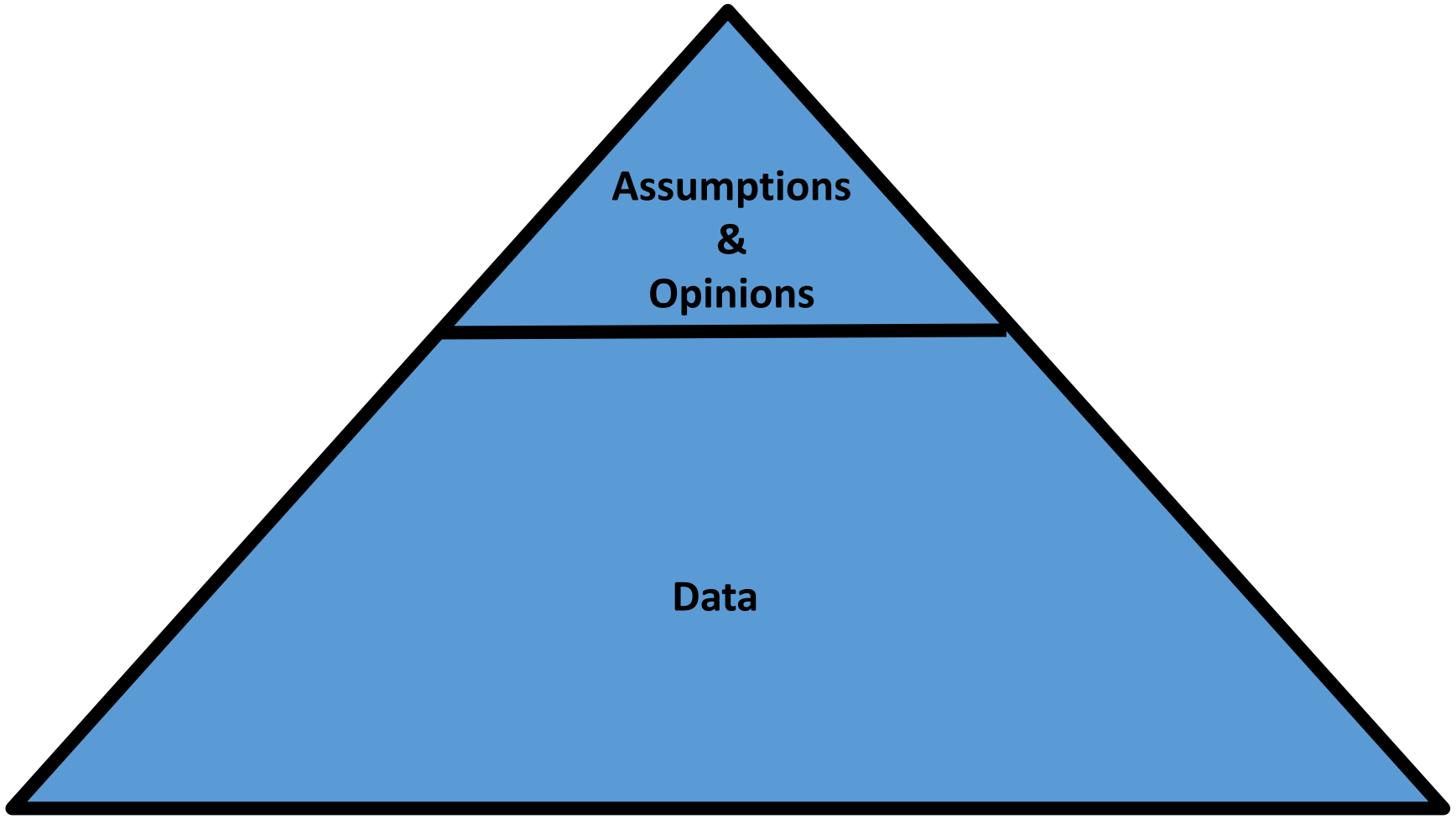
Machine Maintenance Approach…



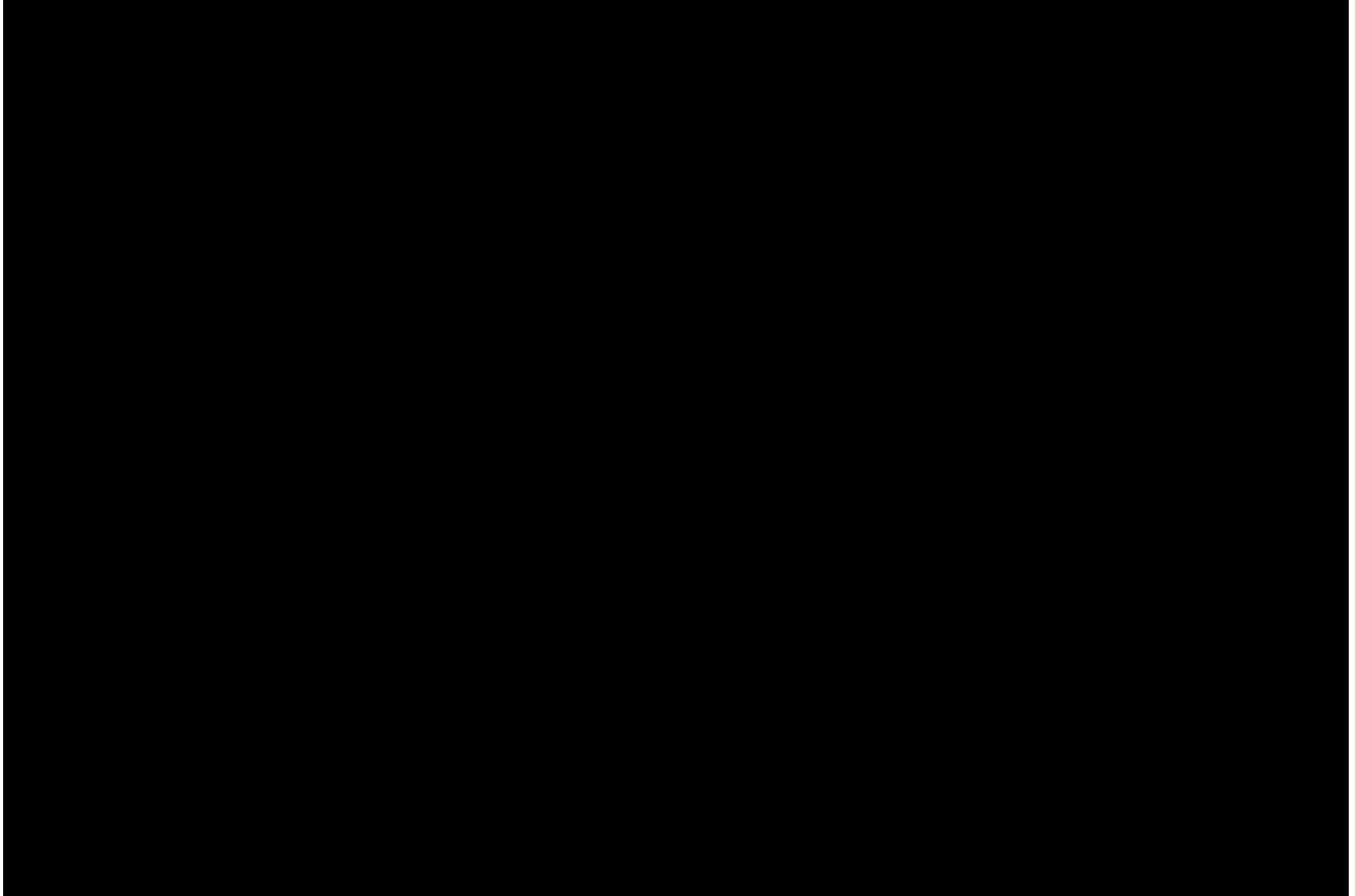
Machine Preventive Maintenance Approach…



Proposed Approach?



Importance of Timely Detection…Video



Solution???

Timely Detection…

How???

Dam Geophysics

Why Geophysics for Dams?

- Most suitable method for regular health checks of dams
- Early detection of problems
- Totally non-destructive, extremely suitable for structures like dams
- Helps design rehabilitation programs better and accurately
- Helps assess success of rehabilitation measures undertaken
- Identification of damaged areas inside the body dam
- Identification of not visible fractures and voids
- Identification of zones of seepages

⇨ More information + Low Cost + Quick

Available Solutions…

GEOPHYSICAL METHODS	ISSUES AND CONCERNS						
	CONCRETE DAM		EARTH EMBANKMENT DAMS			MASONRY DAMS	
	CRACKS	DEGRADATION	WATER LEAKS	LANDSLIDE	SINK HOLES	WATER LEAKS	STRENGTH
Electrical Resistivity			■	■		■	
Streaming Potential			■	■		■	
Georadar	■	■	■	■	■	■	
Radar Tomography	■	■	■		■	■	
Seismic Tomography	■	■	■		■		■
Seismic Refraction			■			■	■
ReMi		■		■			■

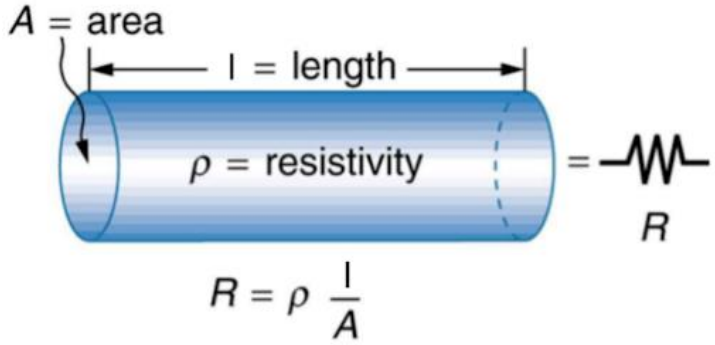
Which Technique/ Tool?

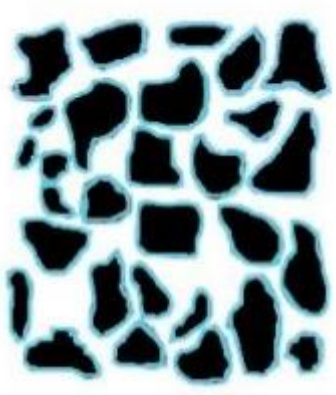
- Objective of Investigation
- Resolution required
- Depth penetration required
- Physical property to be defined
- Geometry of Dam
- Nature of target & host material

Electrical Resistivity Imaging

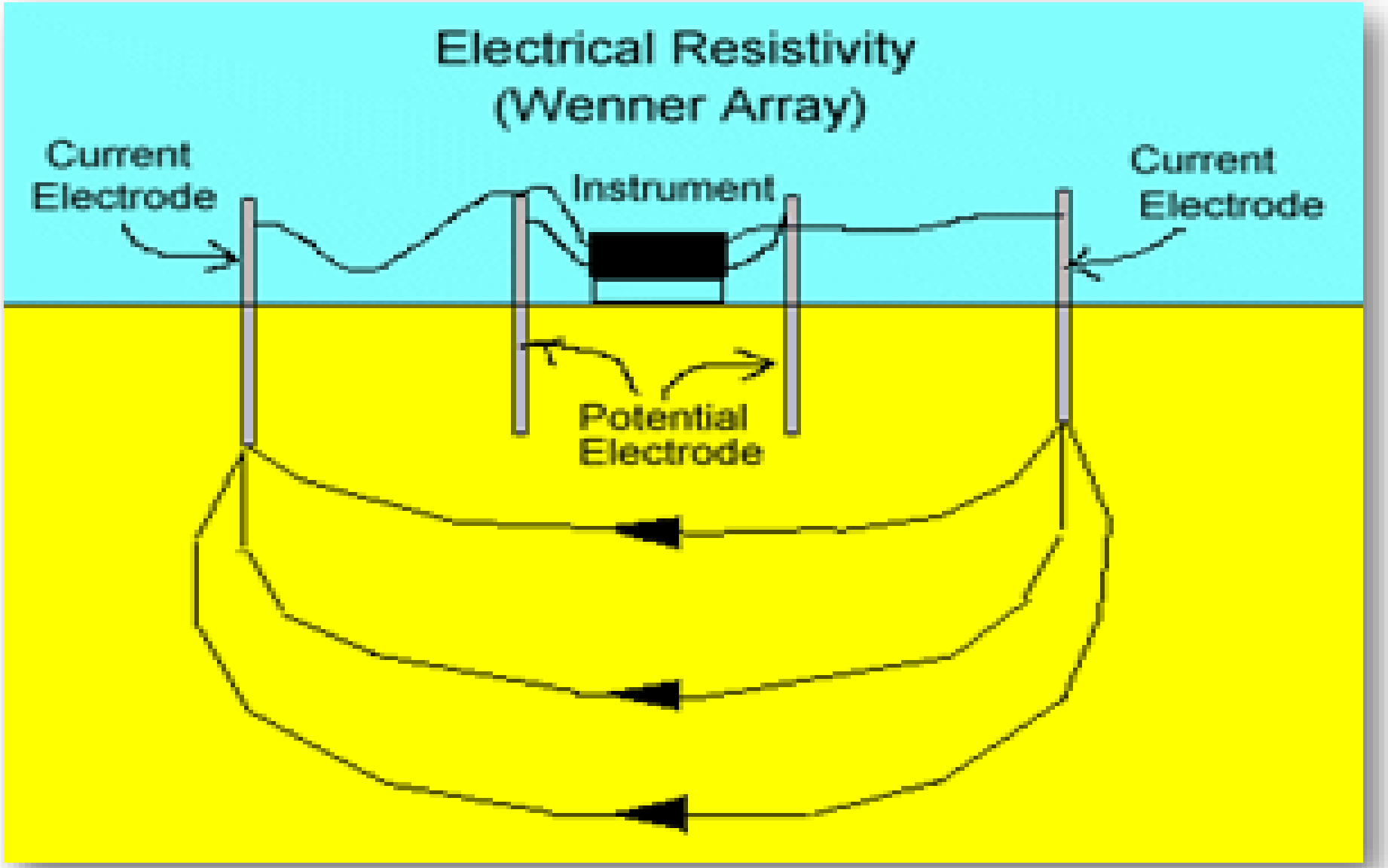
Application of Electrical Resistivity Imaging- Dams…

- Presence of water/ moisture primarily changes conductivity of dam material.
- Provides vertical sections of electrical properties
- Excellent method to detect saturated zones
- Excellent method to detect leakage paths

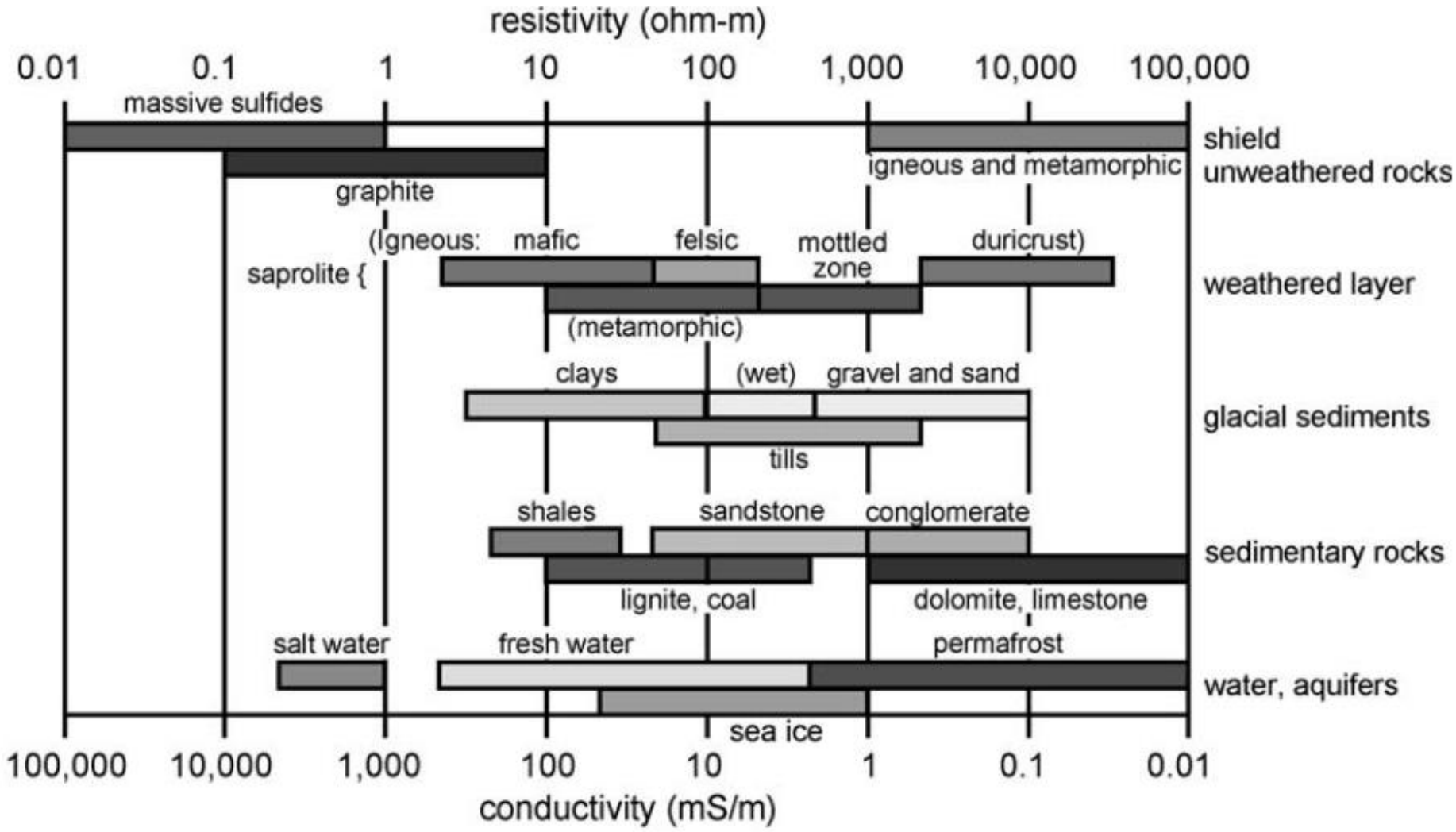




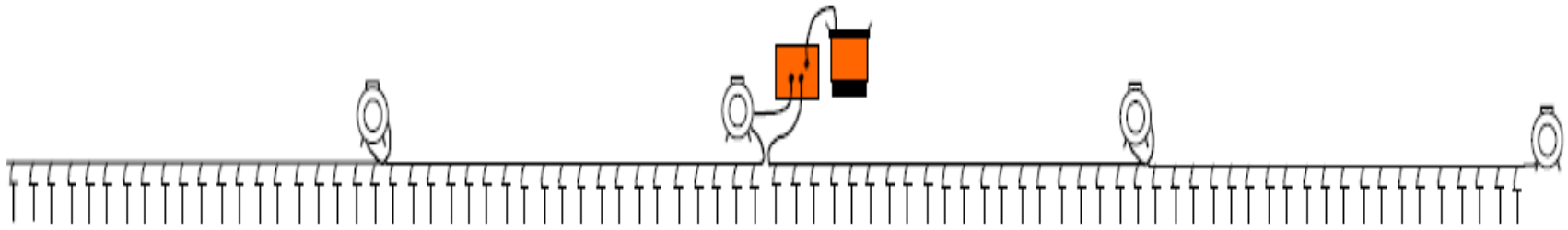
Electrical Resistivity Method…

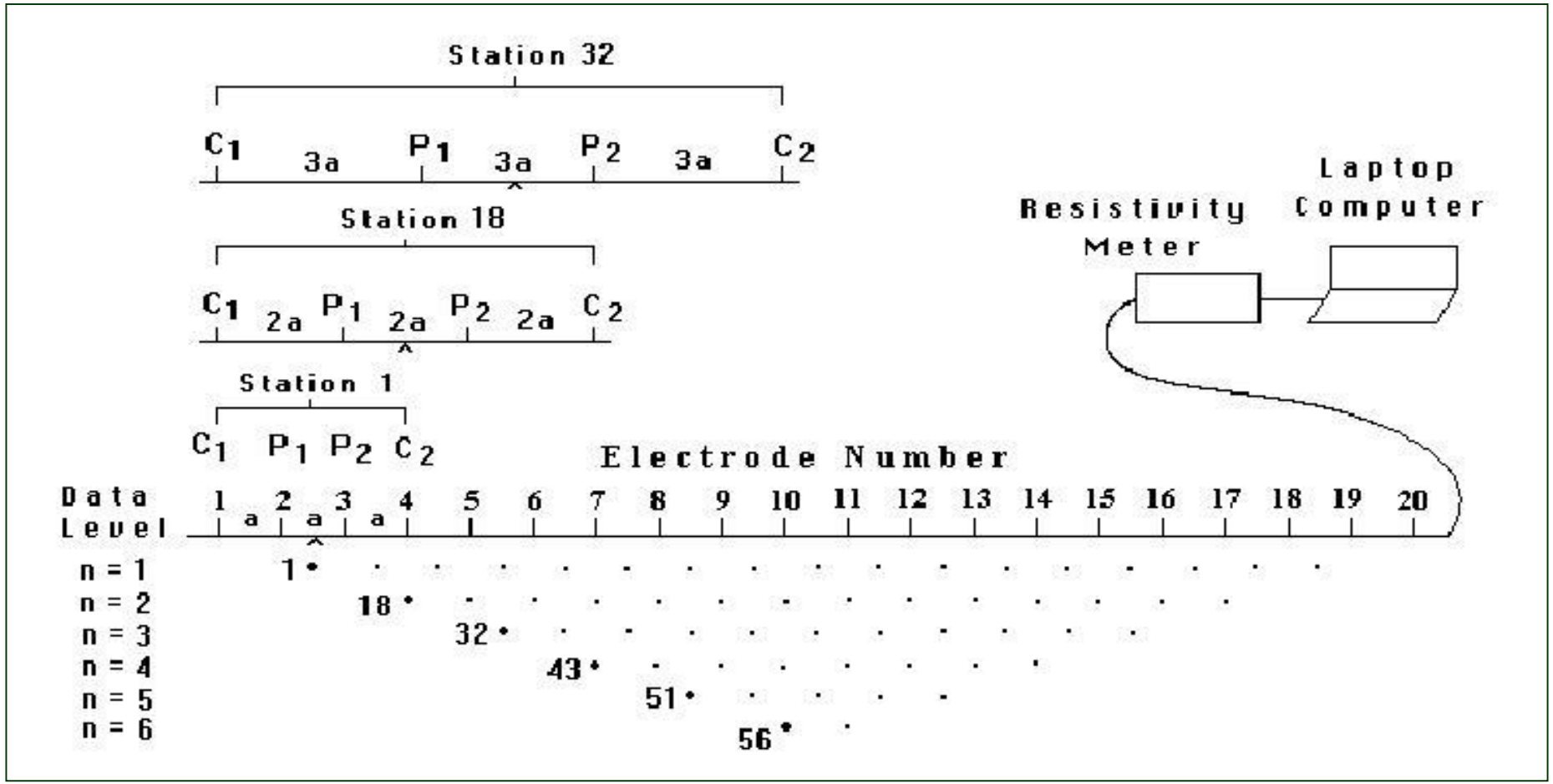


Electrical Resistivity Values…

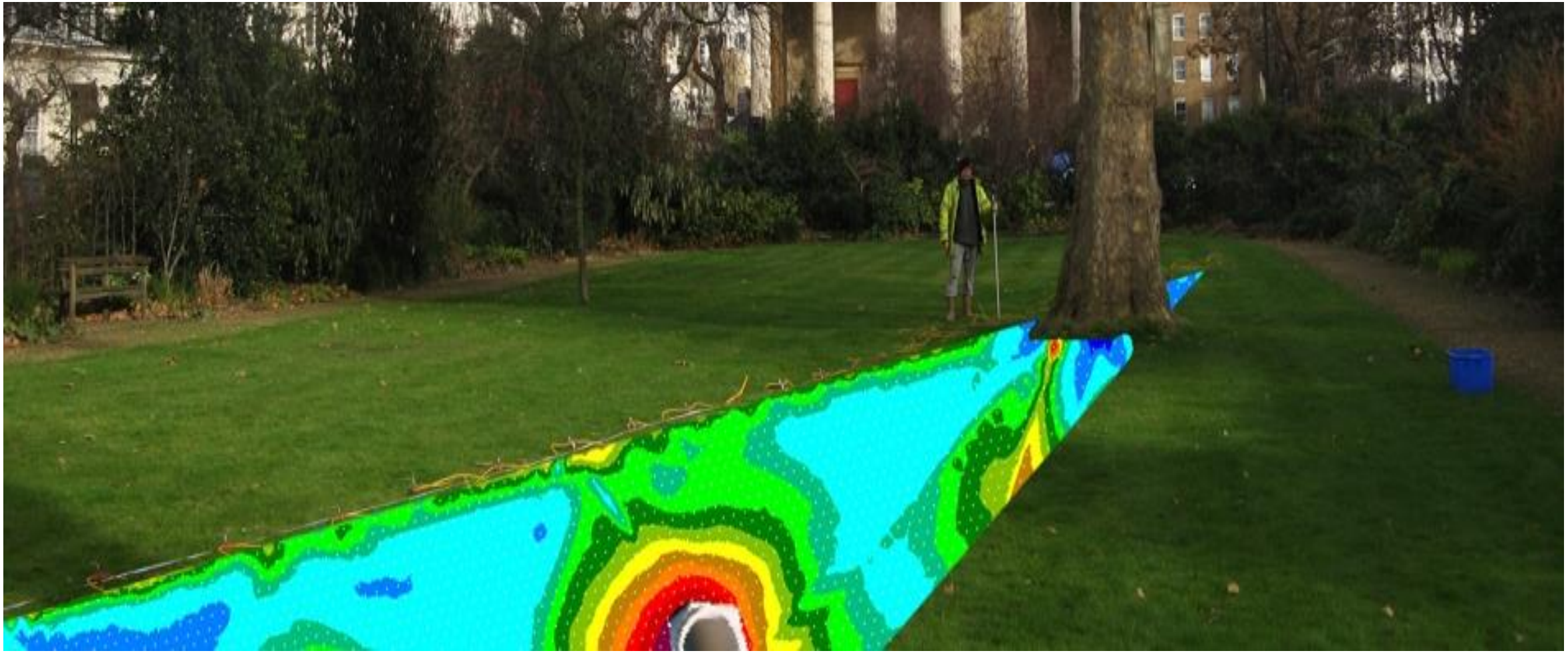


Electrical Resistivity Imaging…



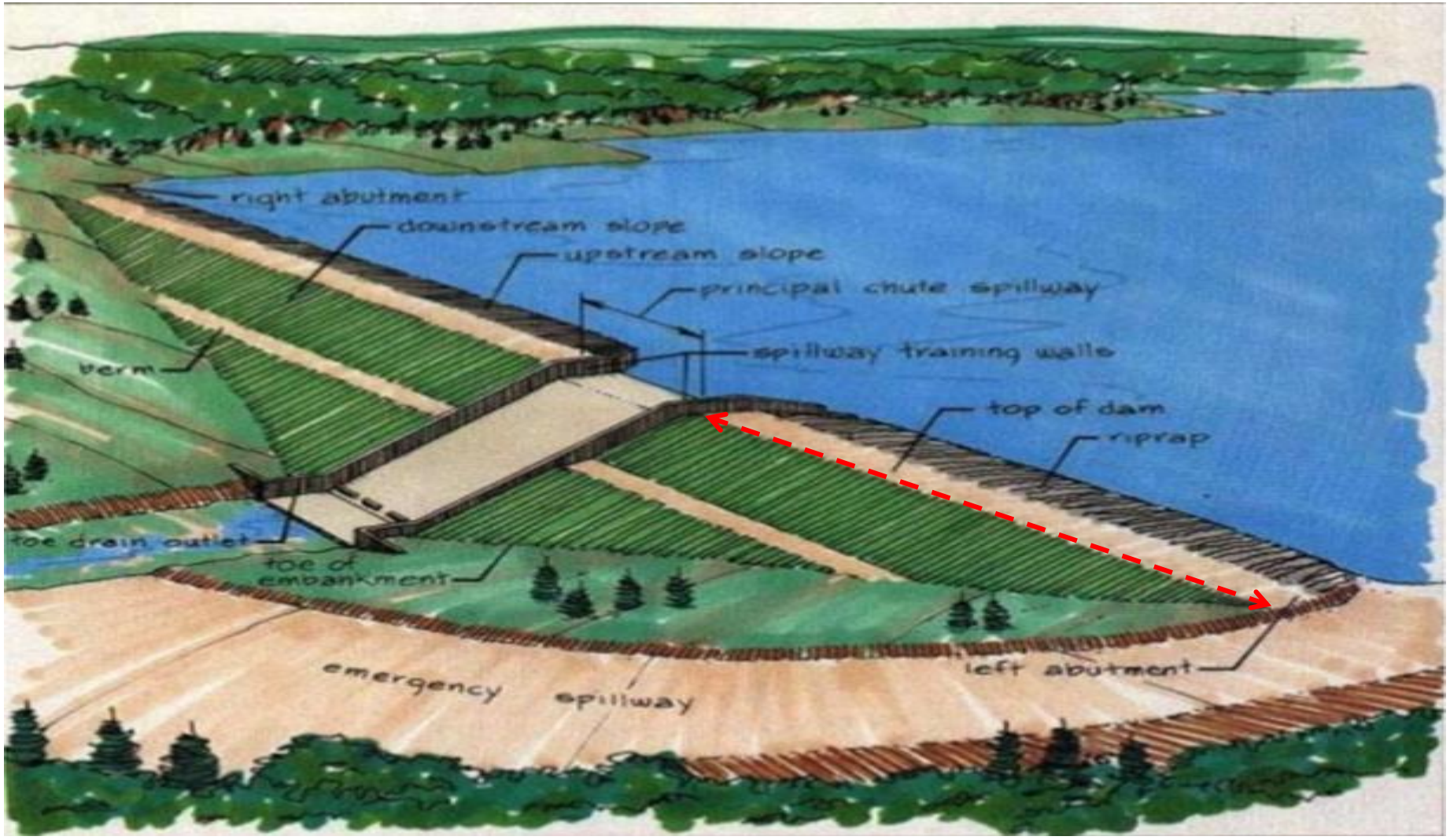


2D Resistivity Section of Subsurface...



Typical Line Layout on Dam...

Typical Line Layout on Dam...



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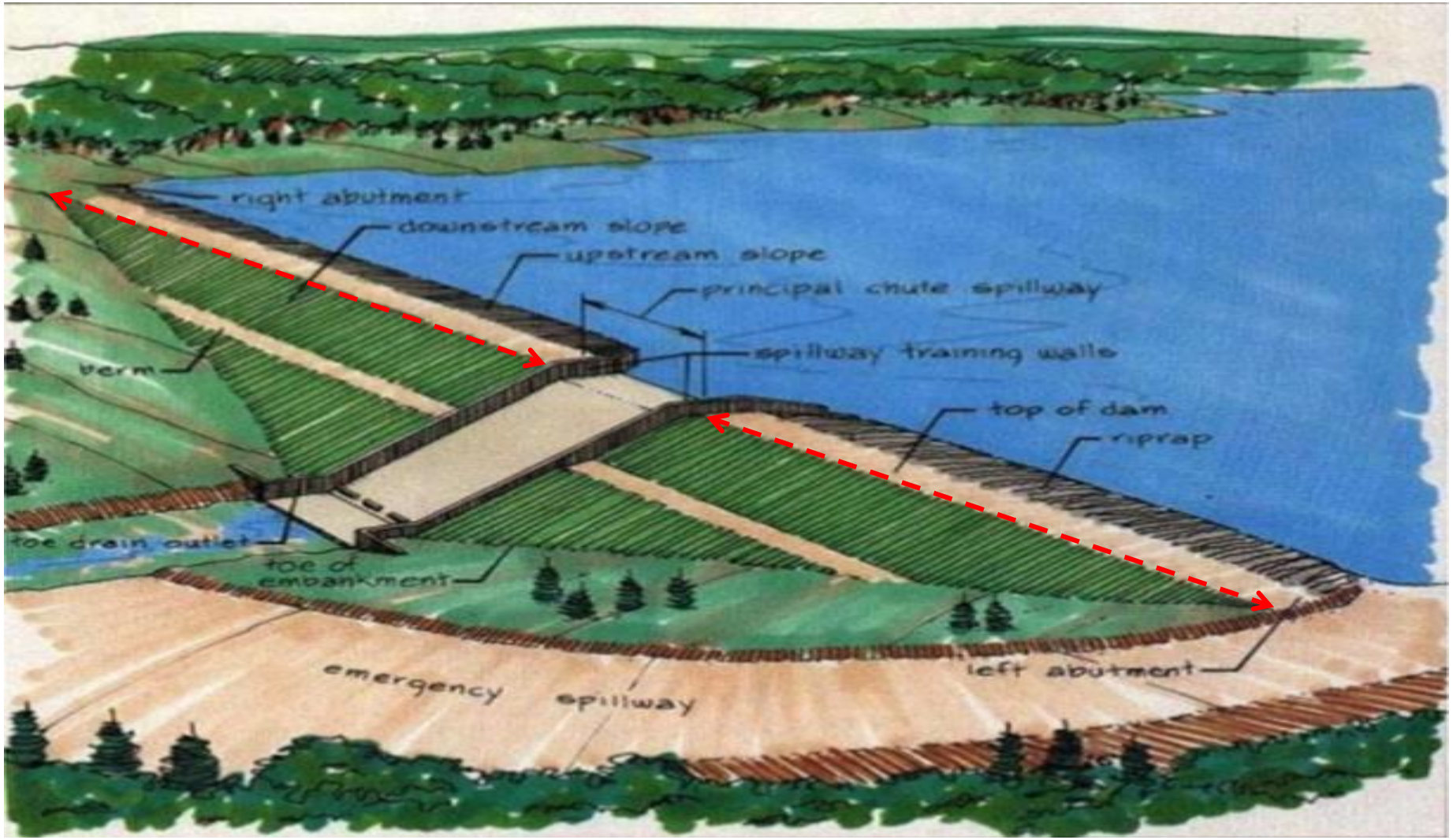

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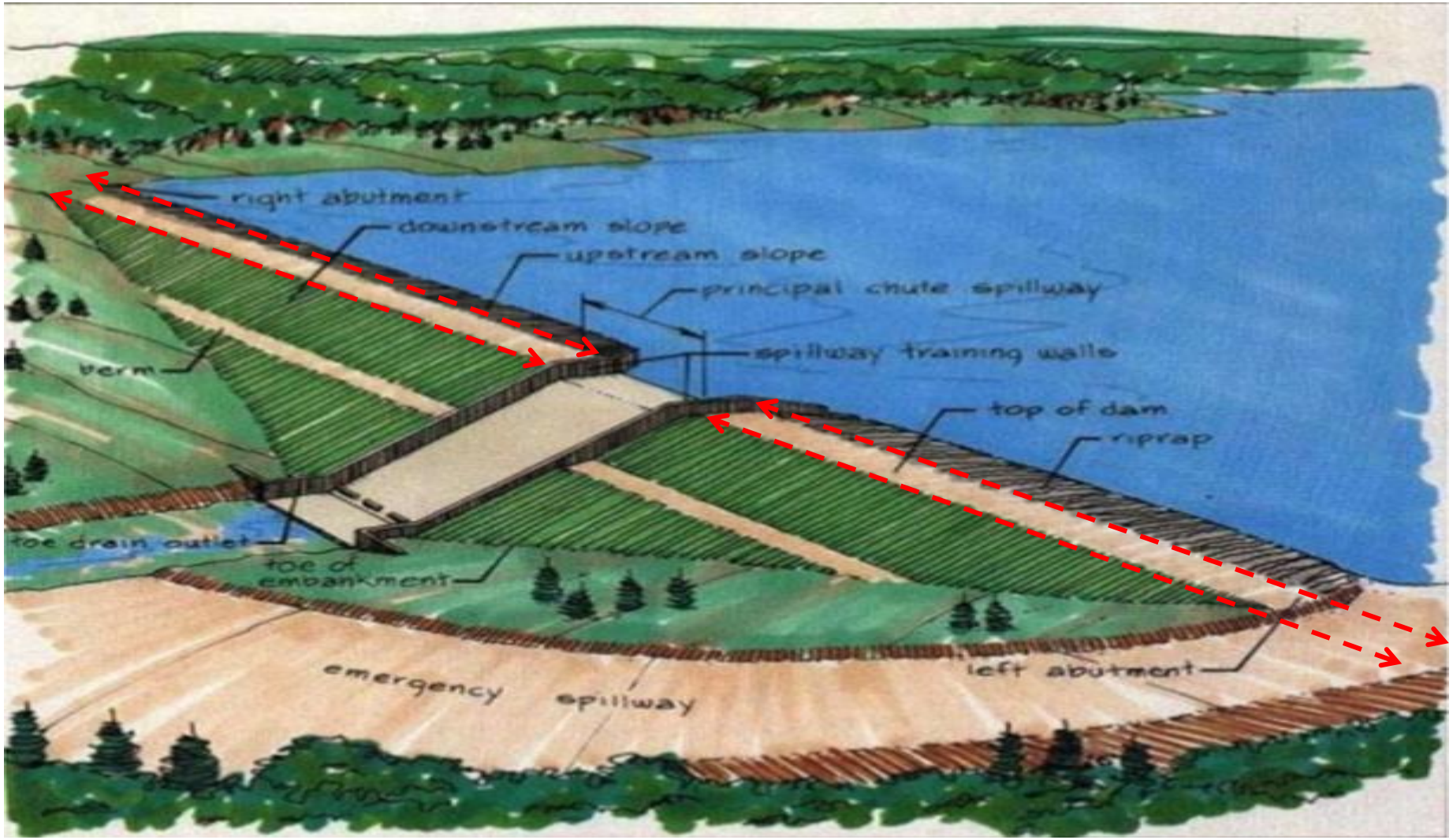

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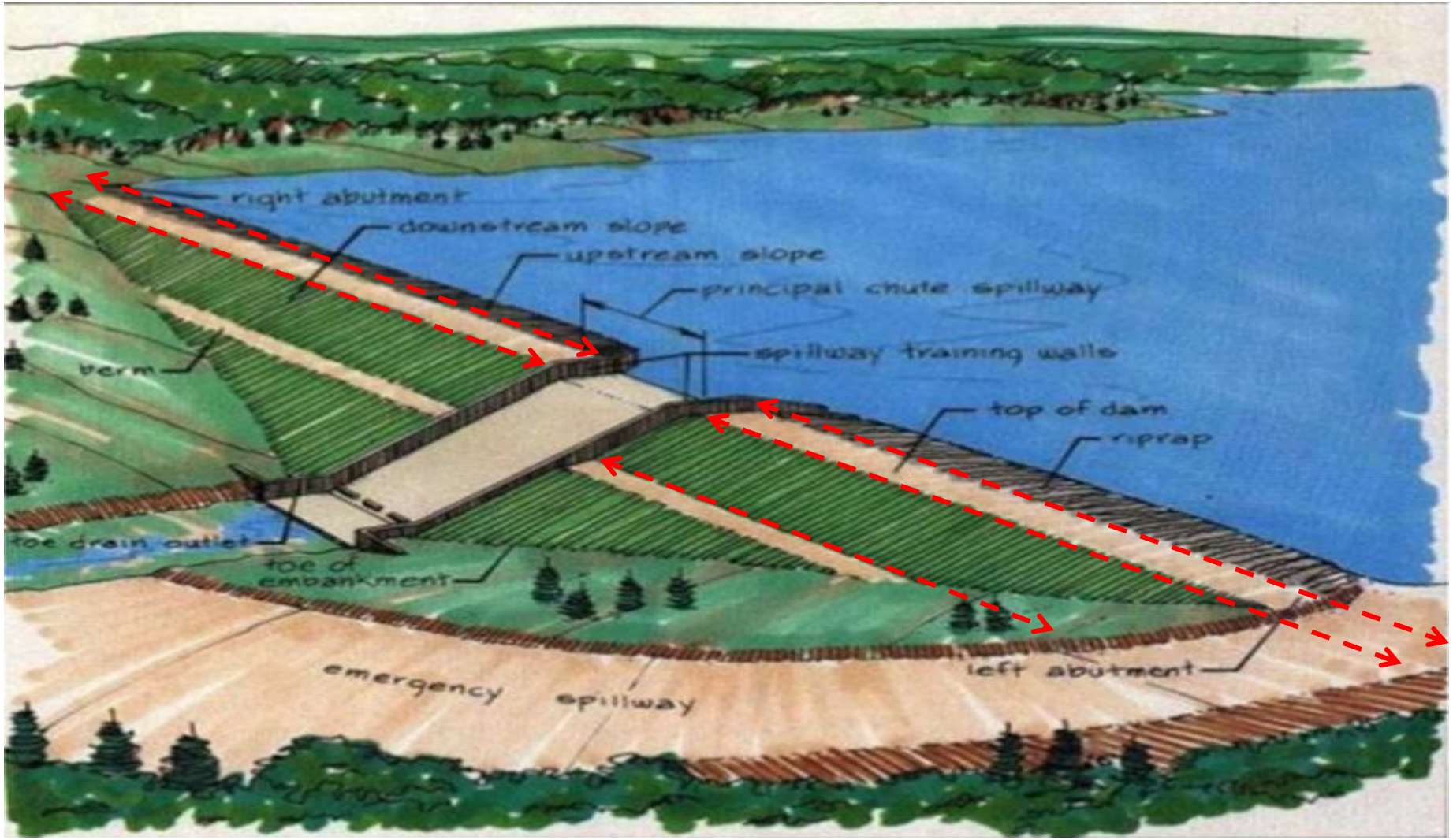
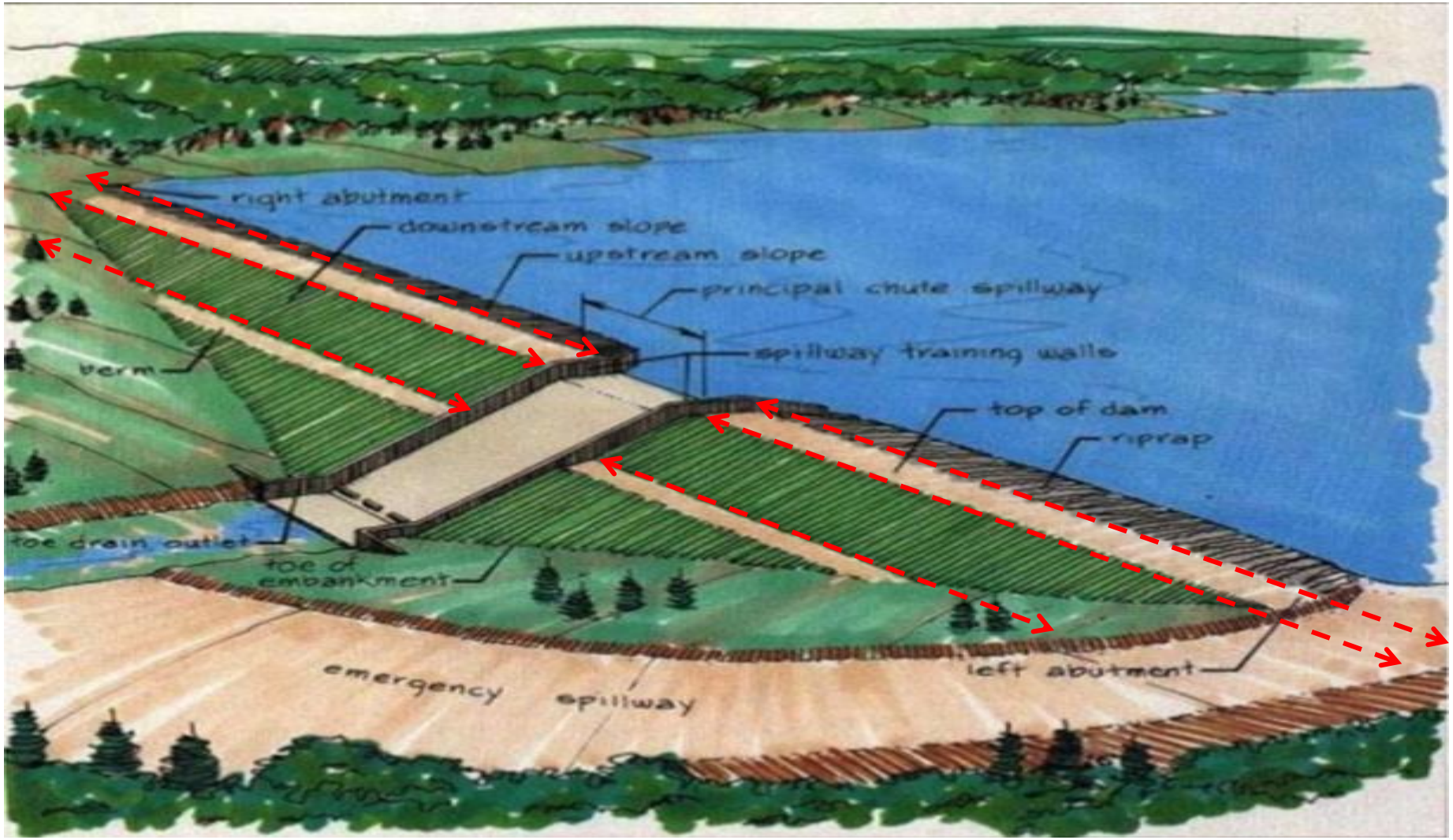


Typical Line Layout on Dam...



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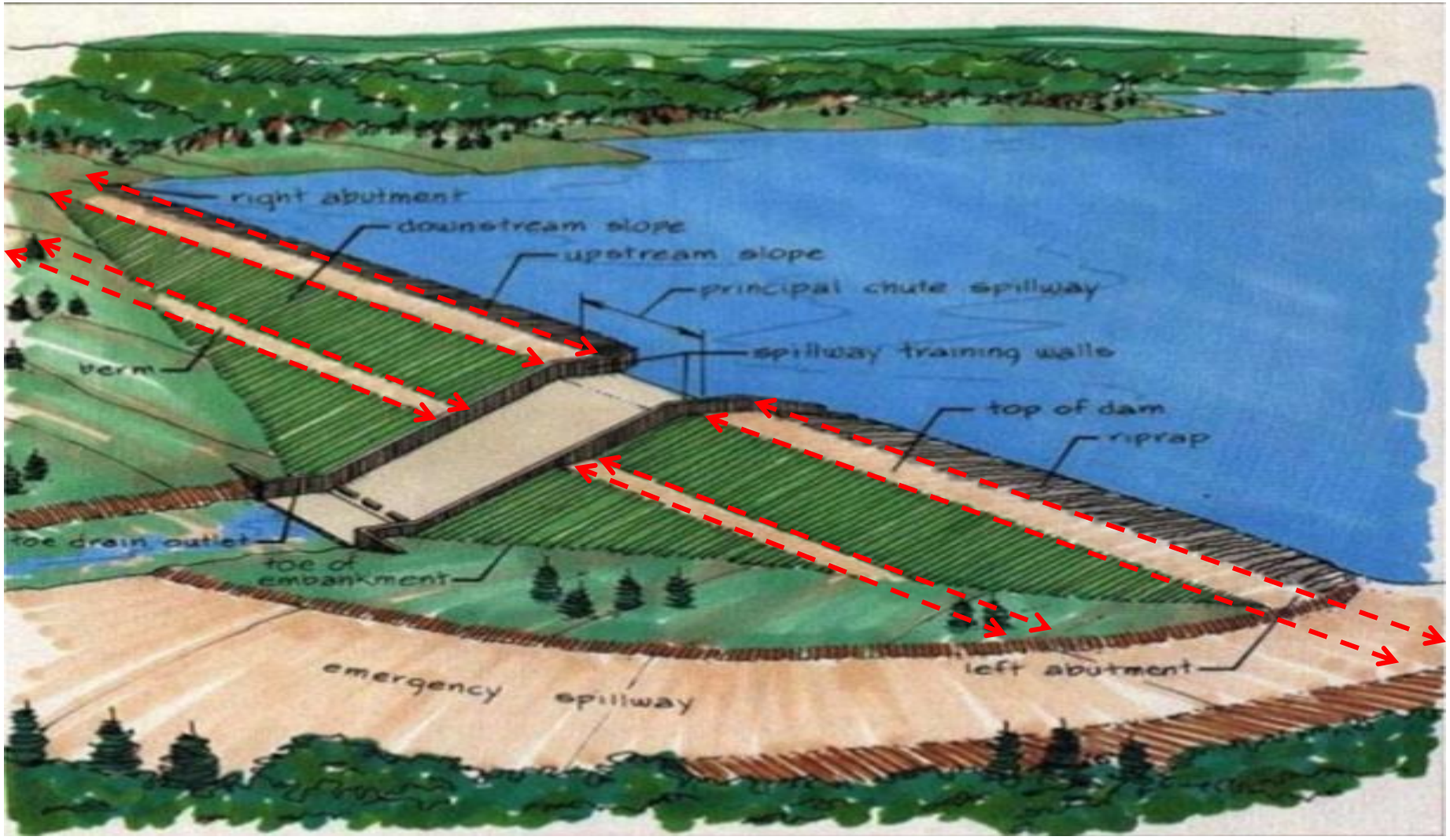
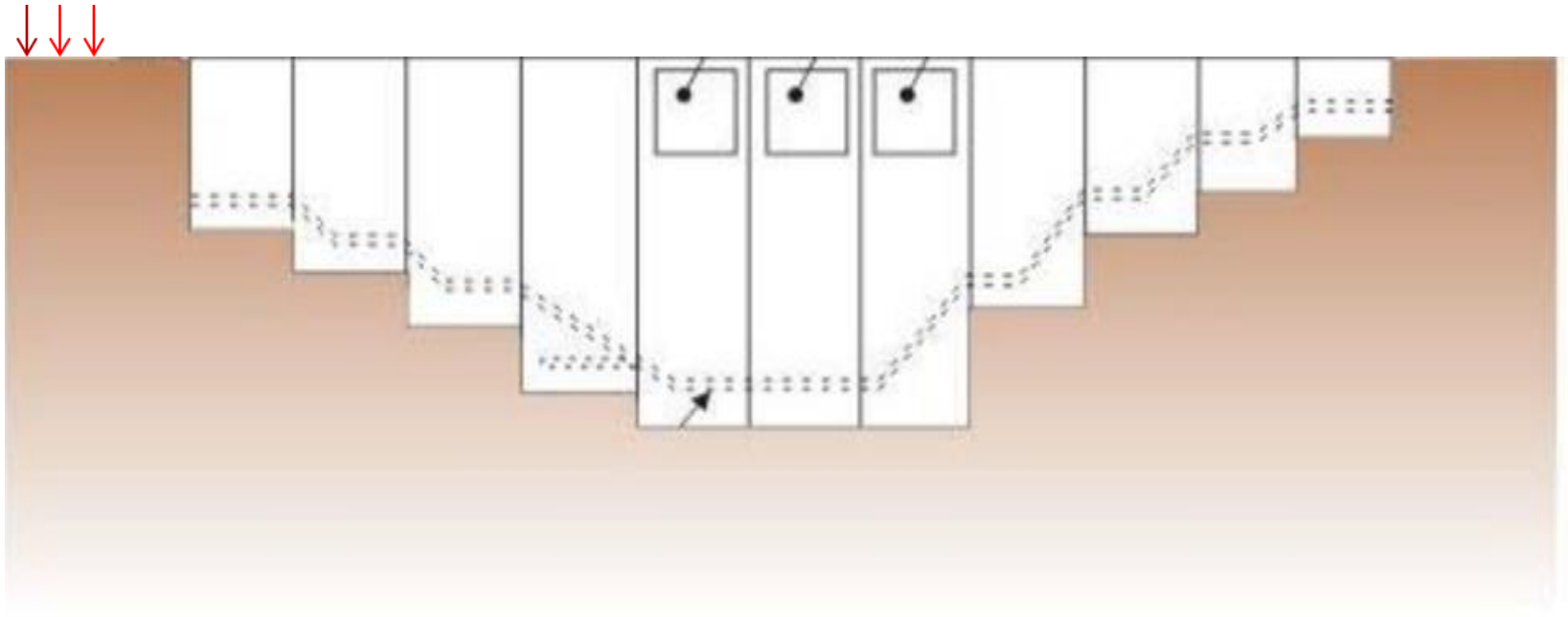
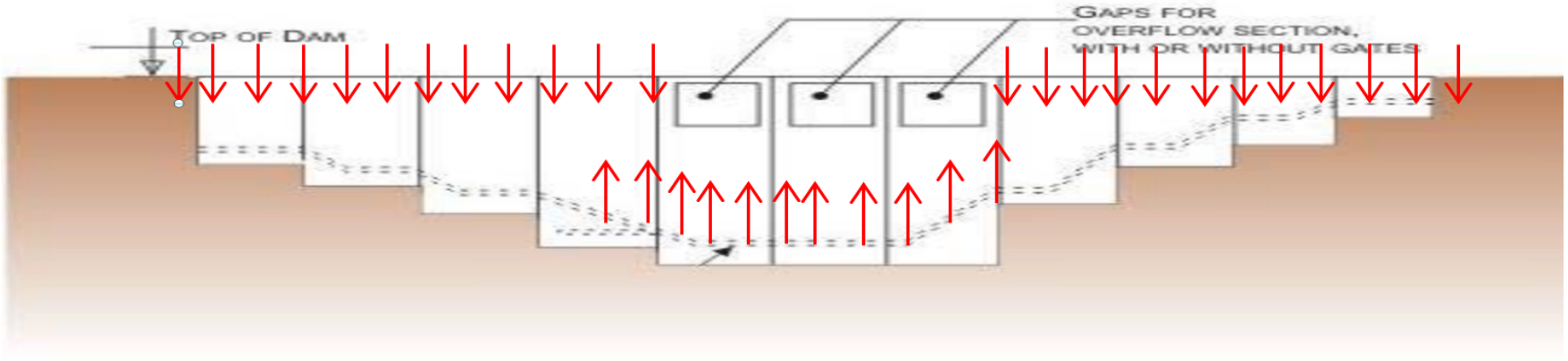


Typical Line Layout on Dam...



Typical Line Layout on Dam...



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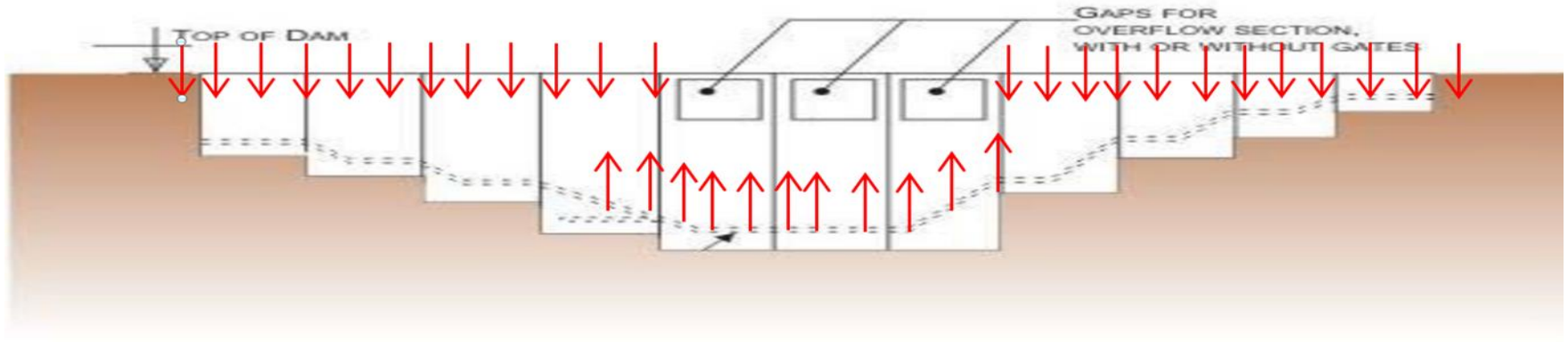
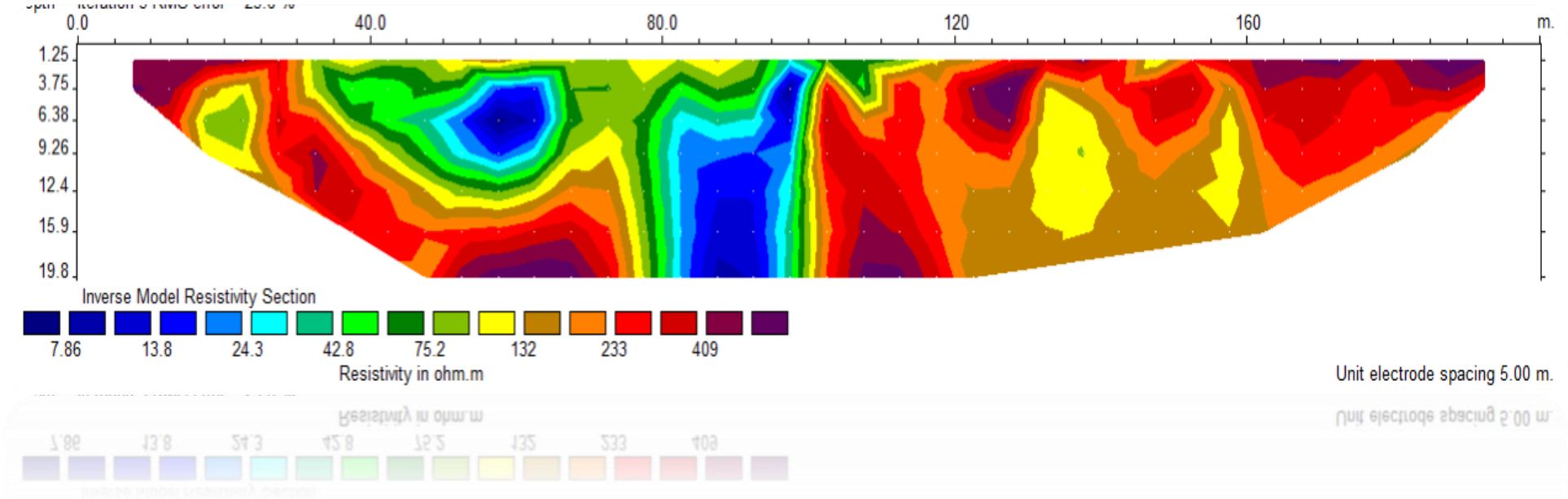
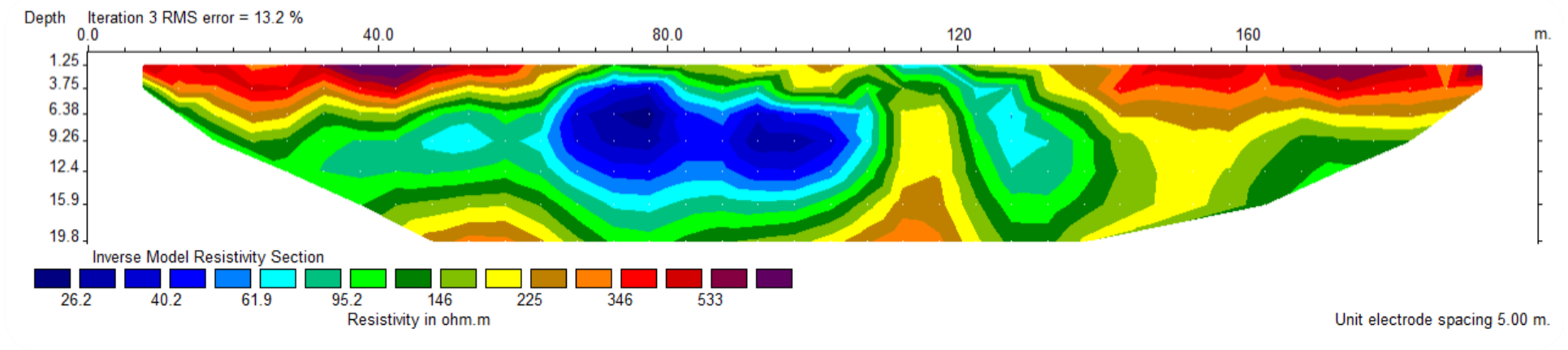


Electrical Resistivity Imaging setup on paved dam top...

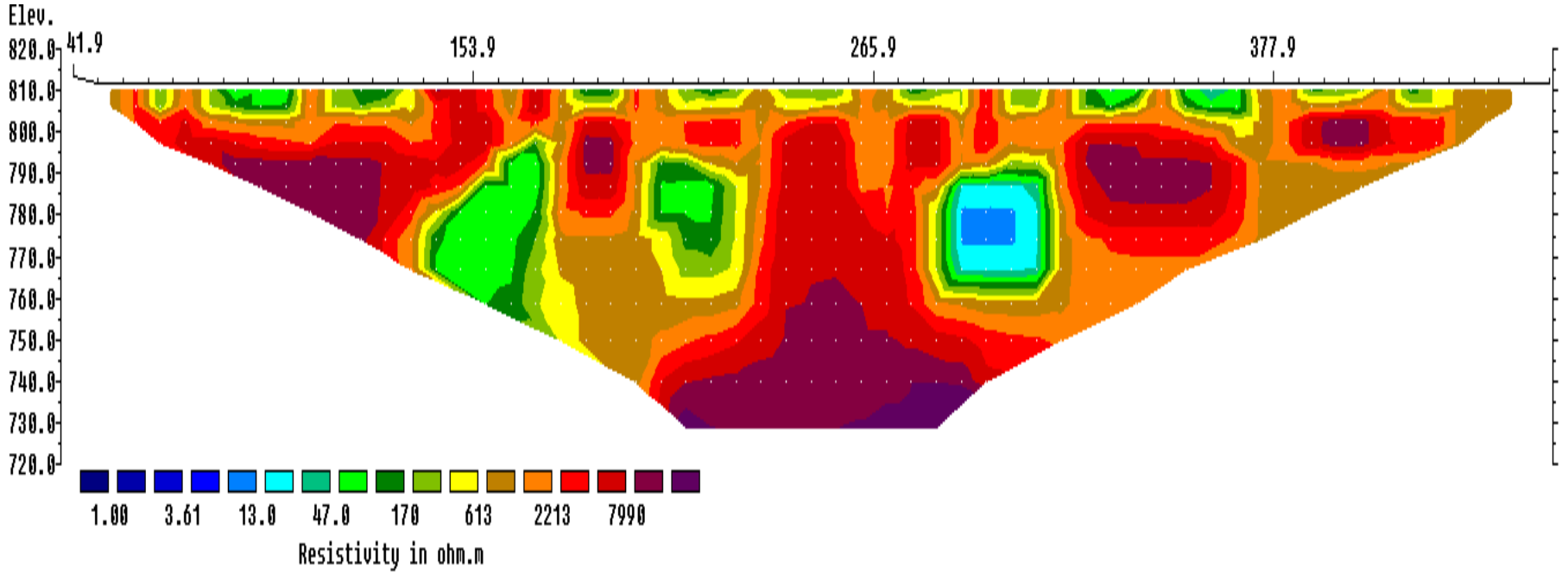
Electrical Resistivity Imaging Results...



Electrical Resistivity Imaging Results...

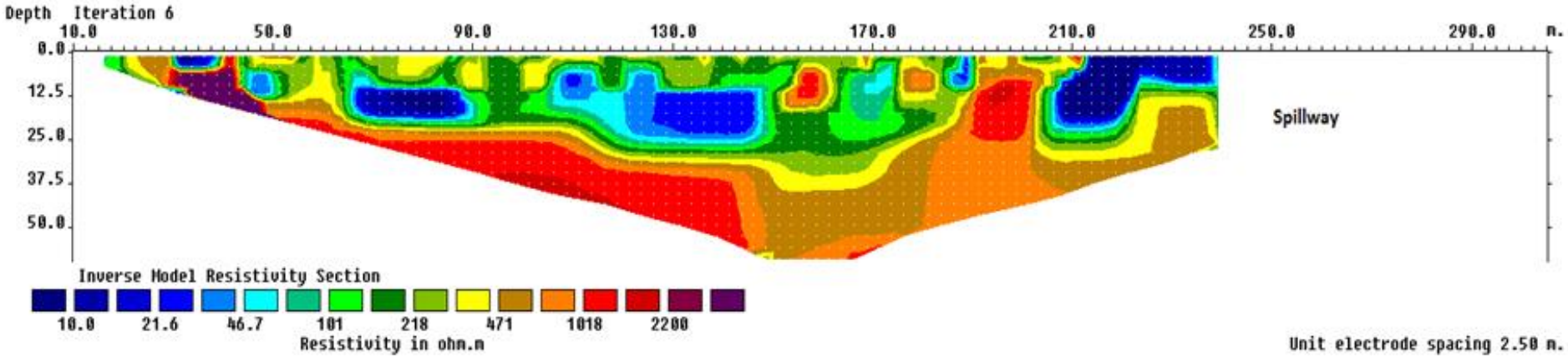


Electrical Resistivity Imaging Results...

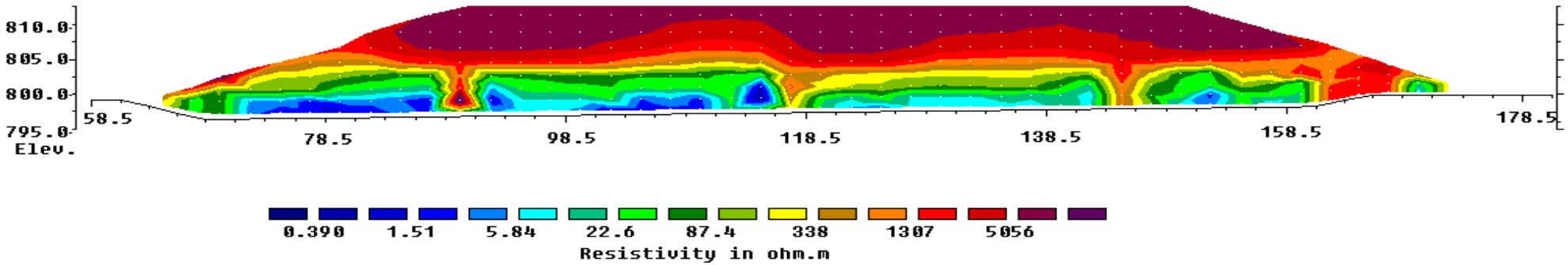


Electrical Resistivity Section from dam crest of a masonry dam Showing Zone of Saturation (Green & Blue)

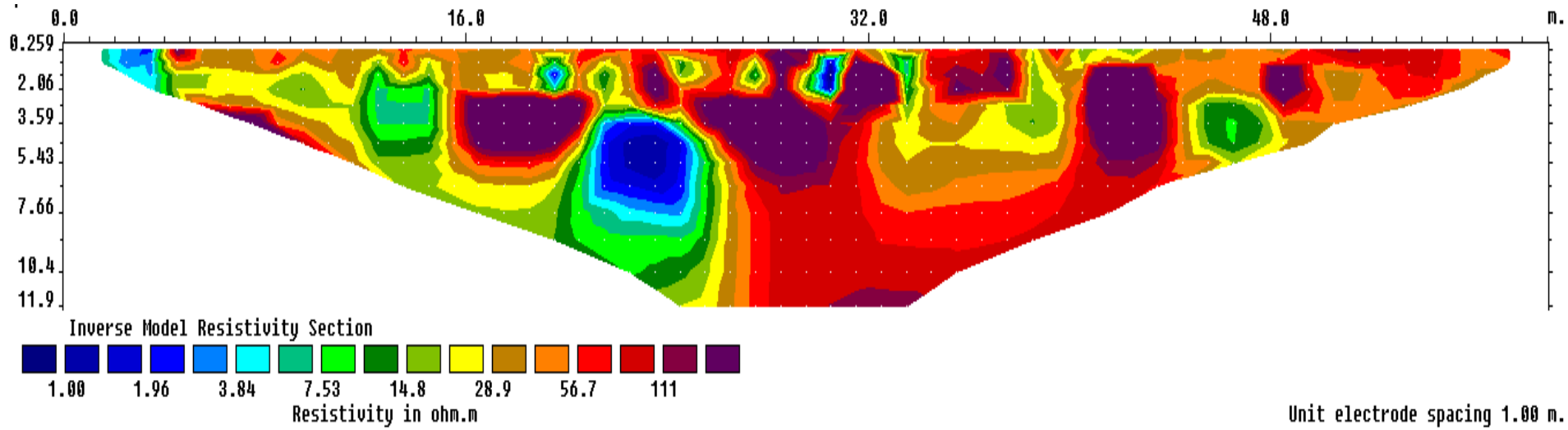
Electrical Resistivity Imaging Results...



Electrical Resistivity Imaging Results...




MANITOU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Inverse Model Resistivity Section
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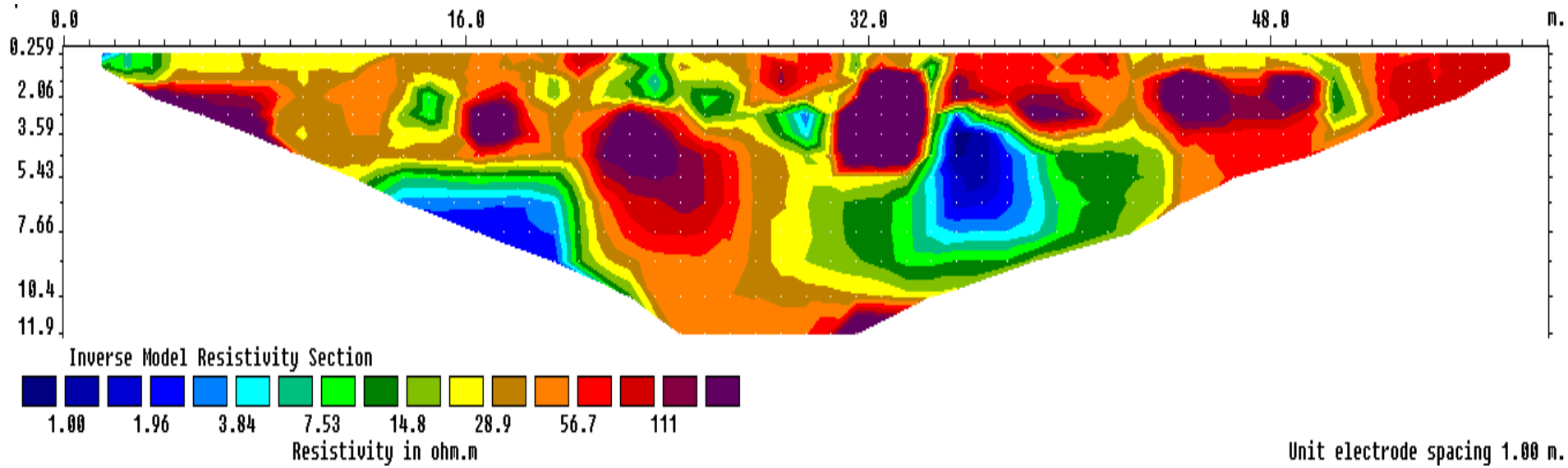
Resistivity in ohm.m
Unit electrode spacing 1.00 m.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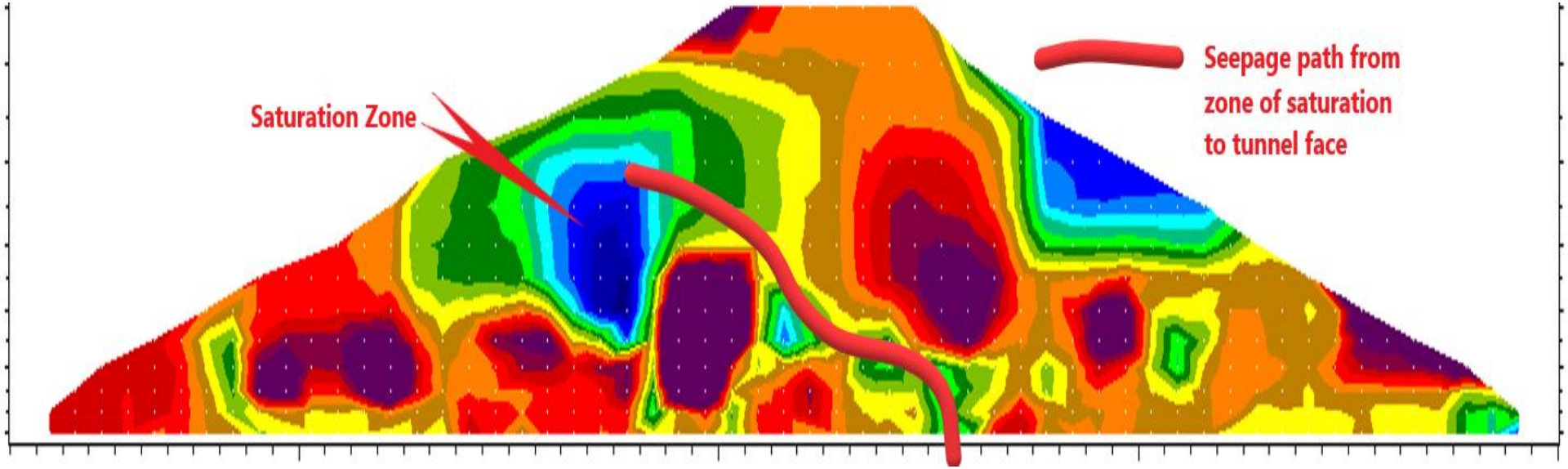
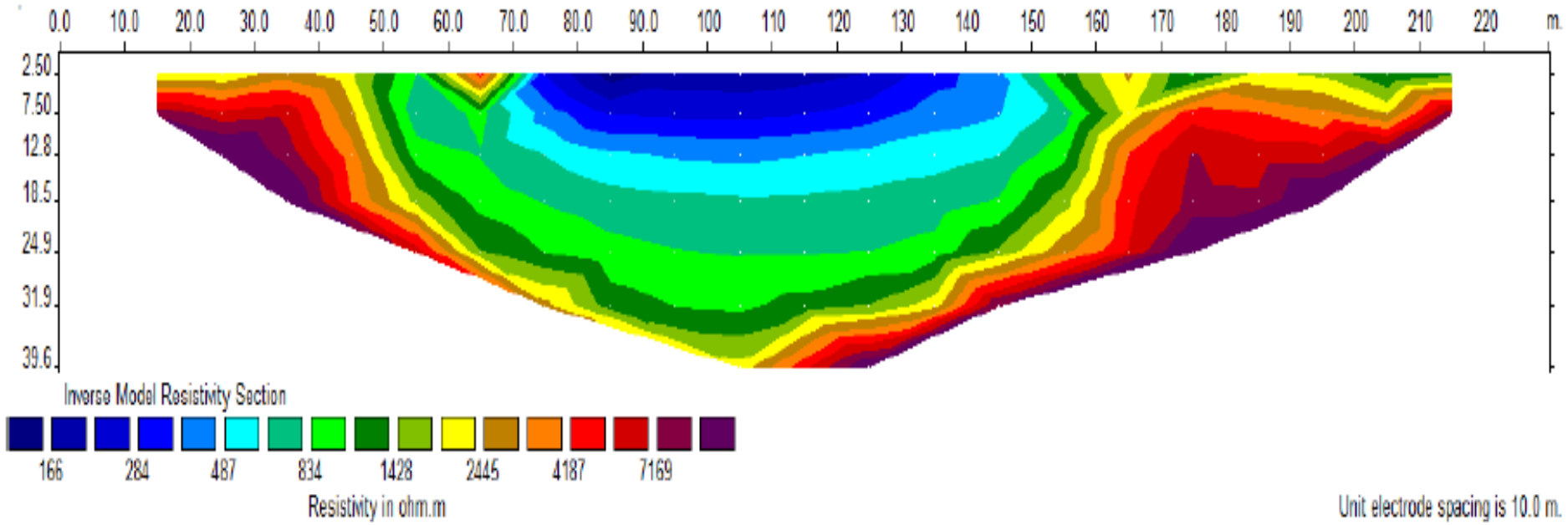
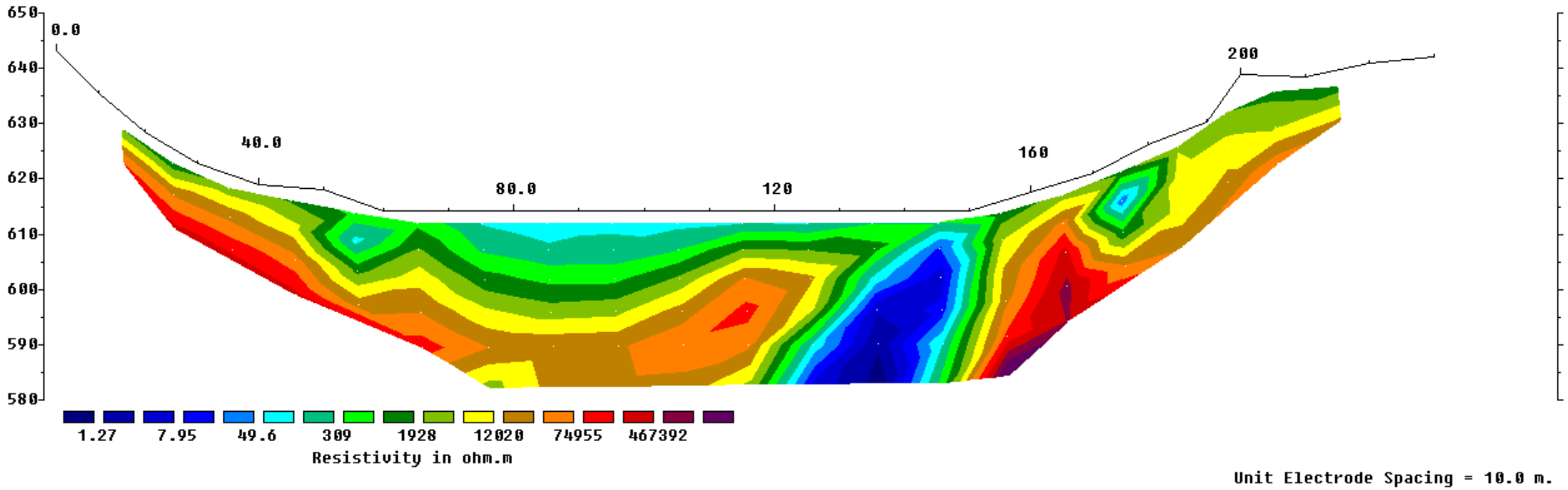

Saturation Zone
Seepage path from
zone of saturation
to tunnel face

Electrical Resistivity Imaging Results...

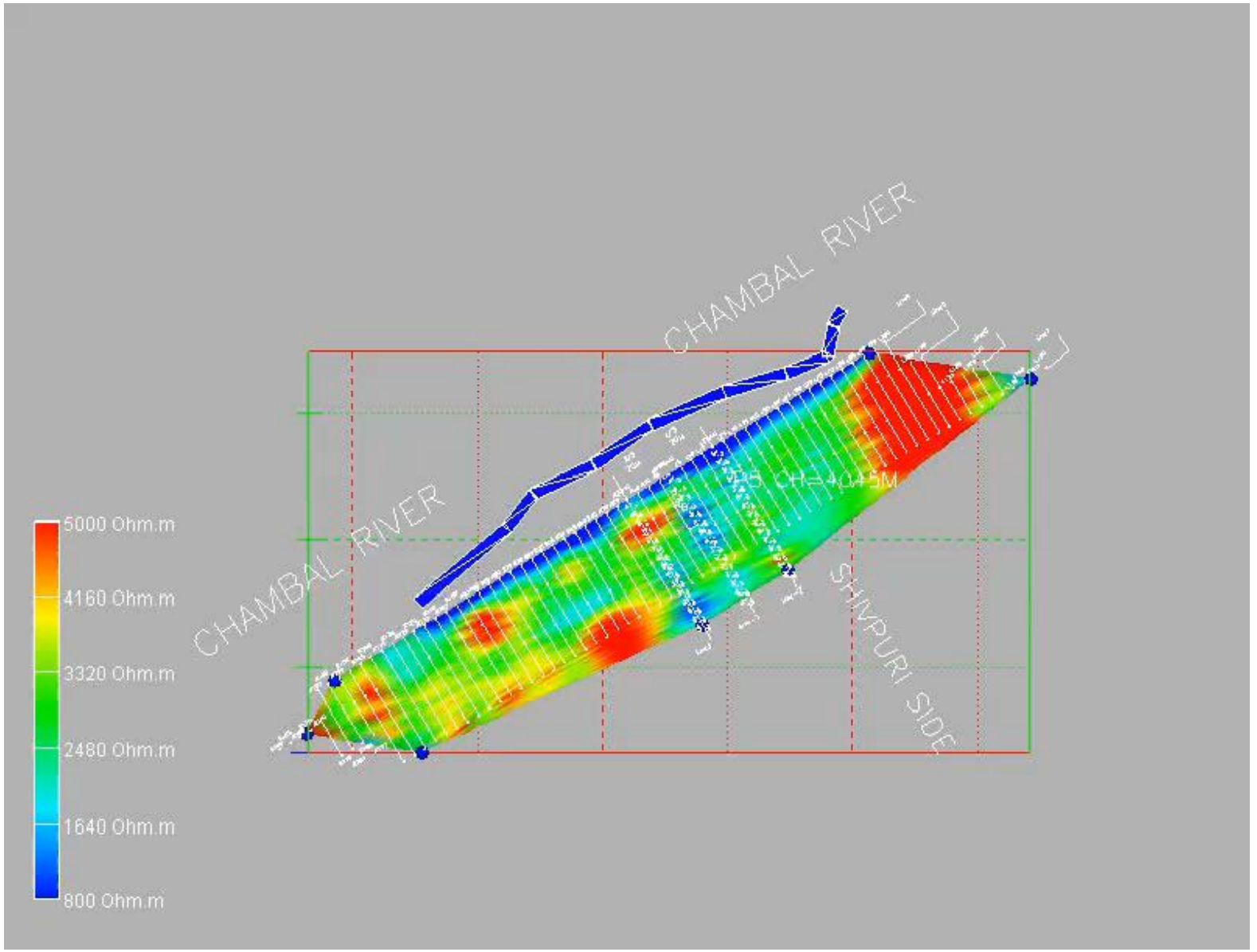
Electrical Resistivity Imaging Results...



Electrical Resistivity Imaging Results...



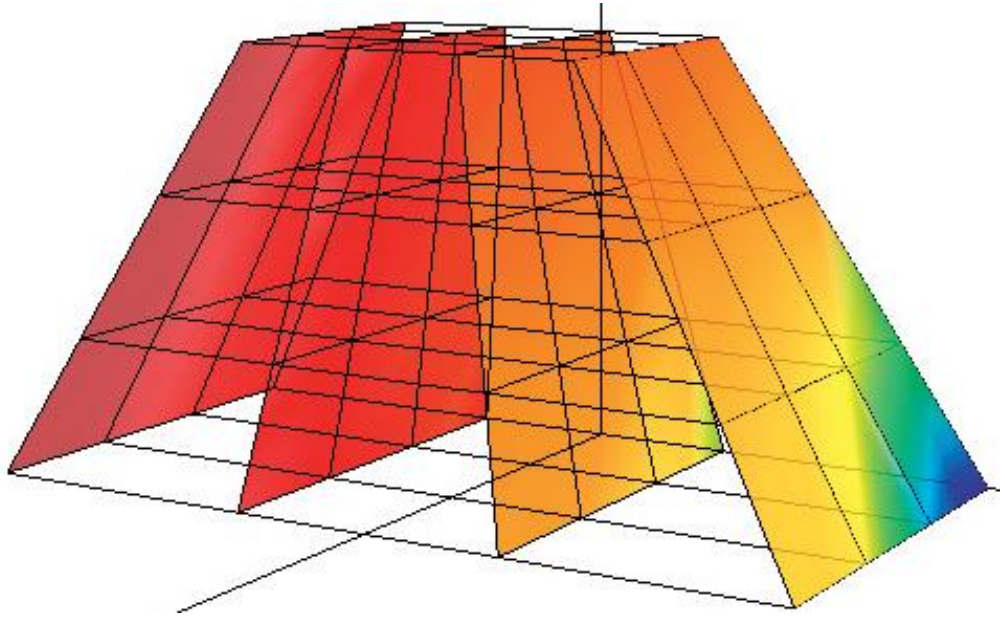
Electrical Resistivity Imaging Results- 3D Volume...



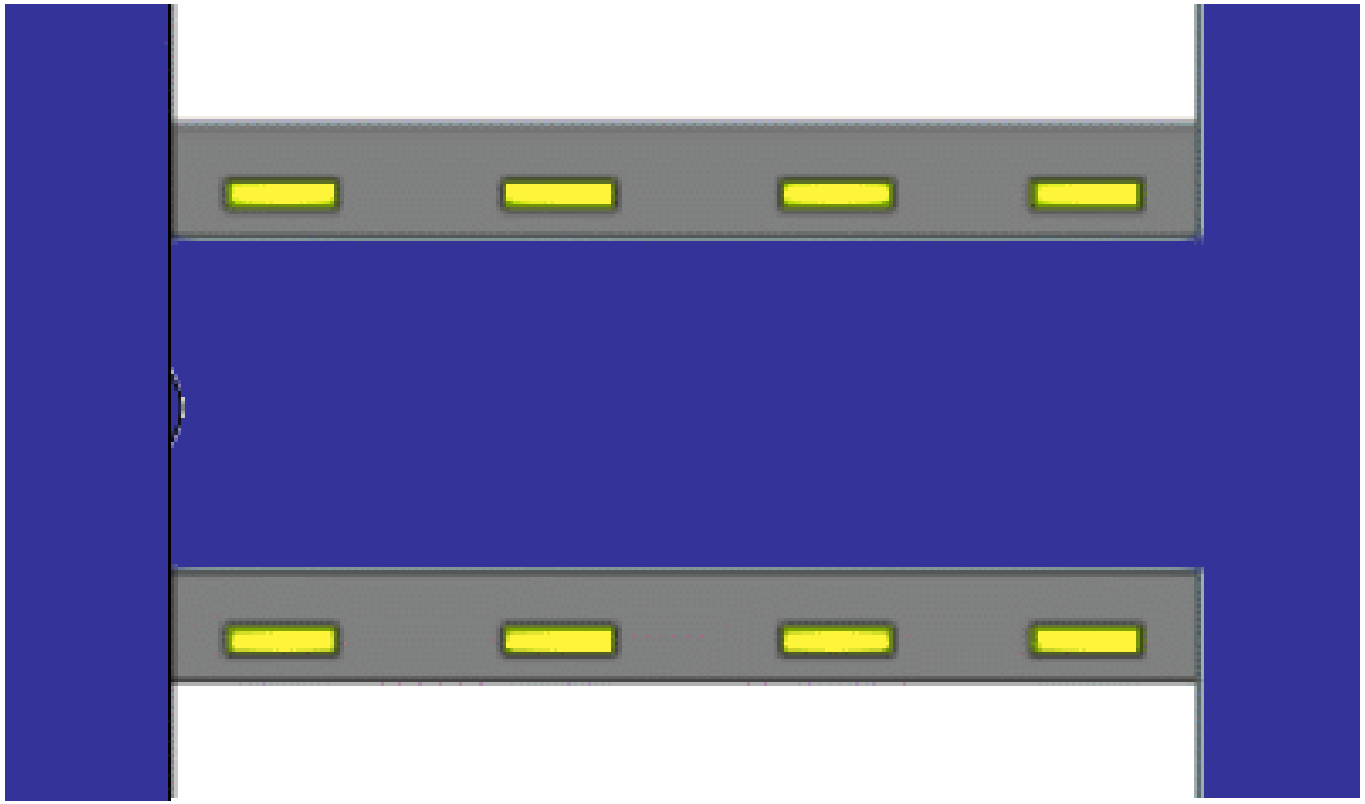
Streaming Potential

Application of Streaming Potential- Dams…

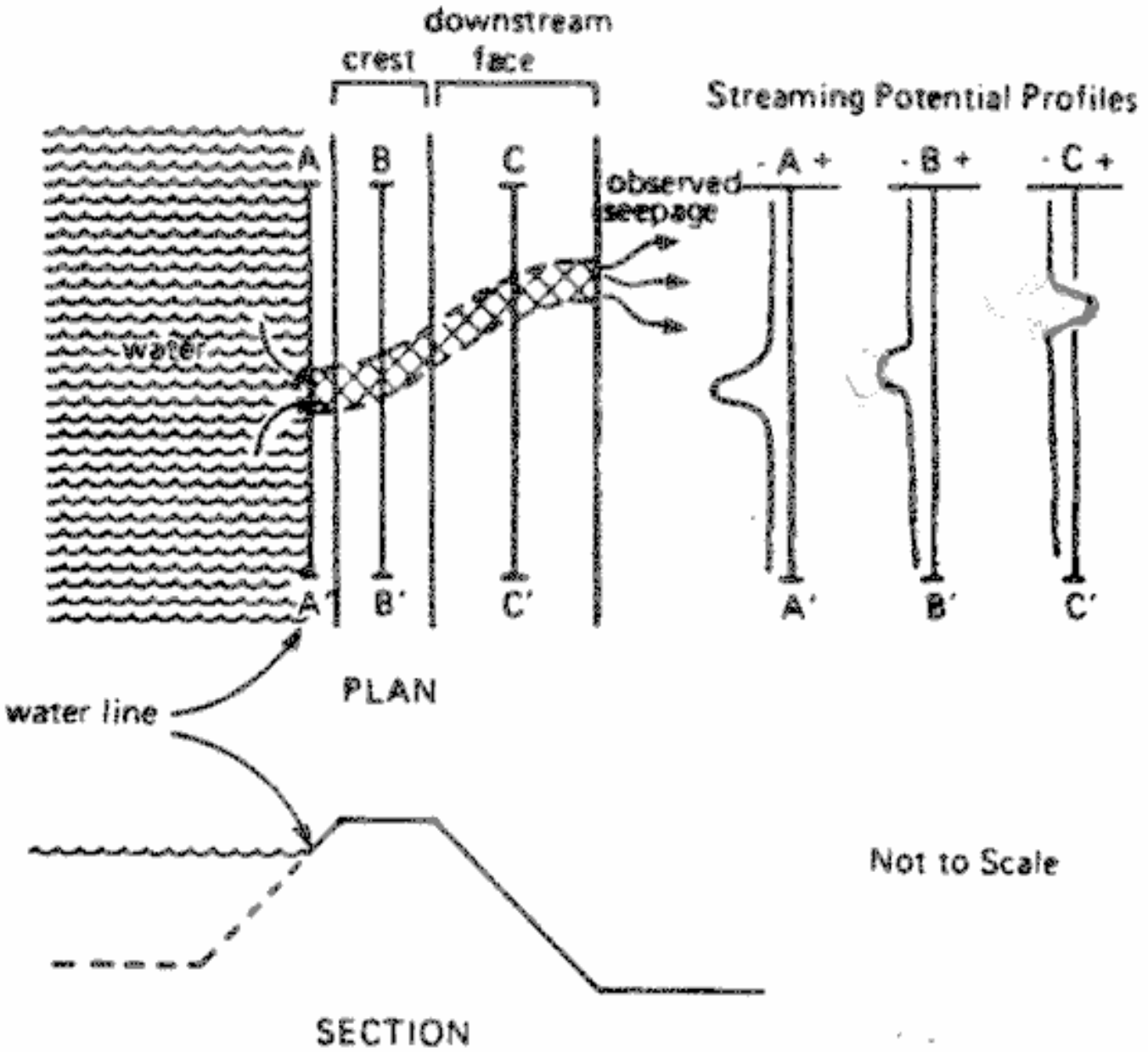
- Potential Due to Flow
- Natural Potential
- Flow paths determination
- Qualitative Results
- Interpreted with other methods



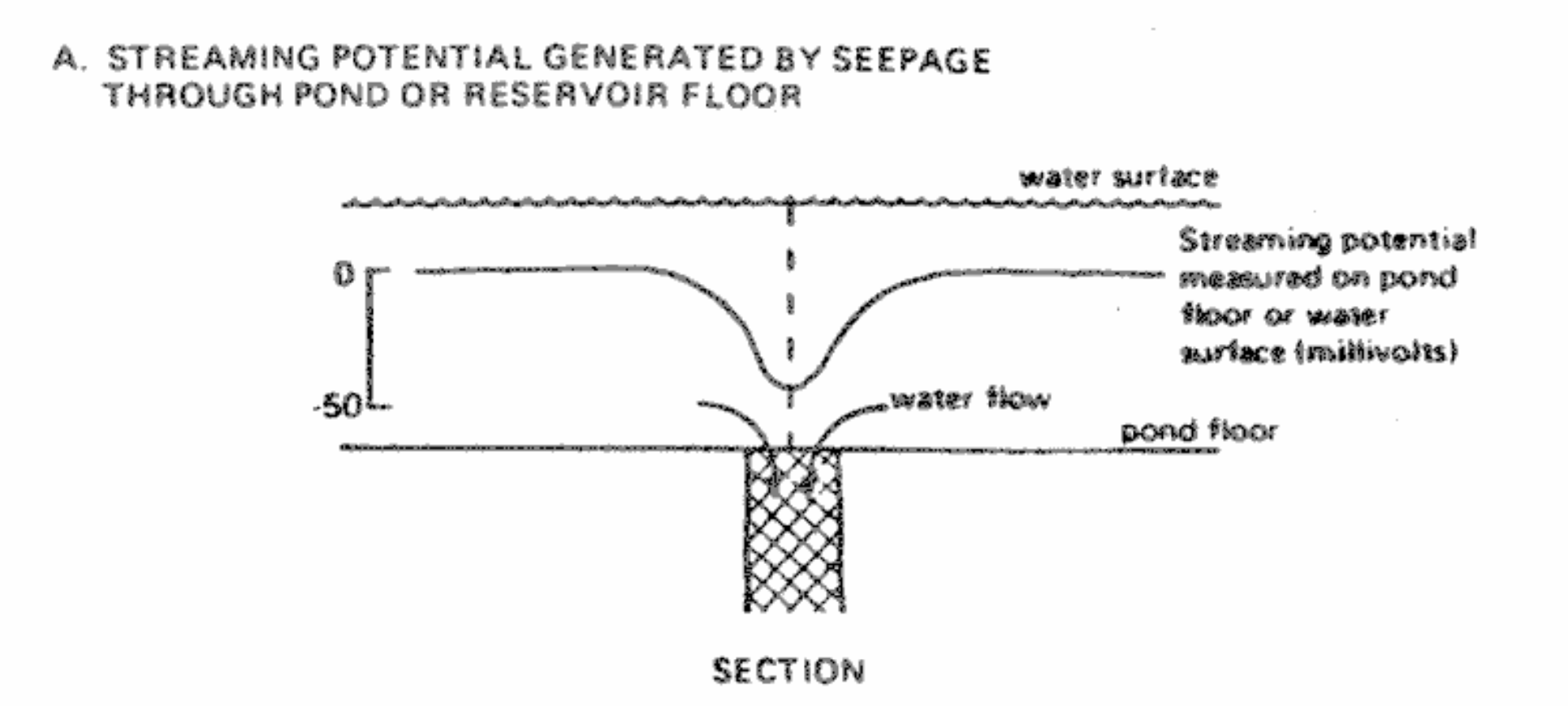
Streaming Potential- Basic Principle…



Streaming Potential by Dam Seepage…

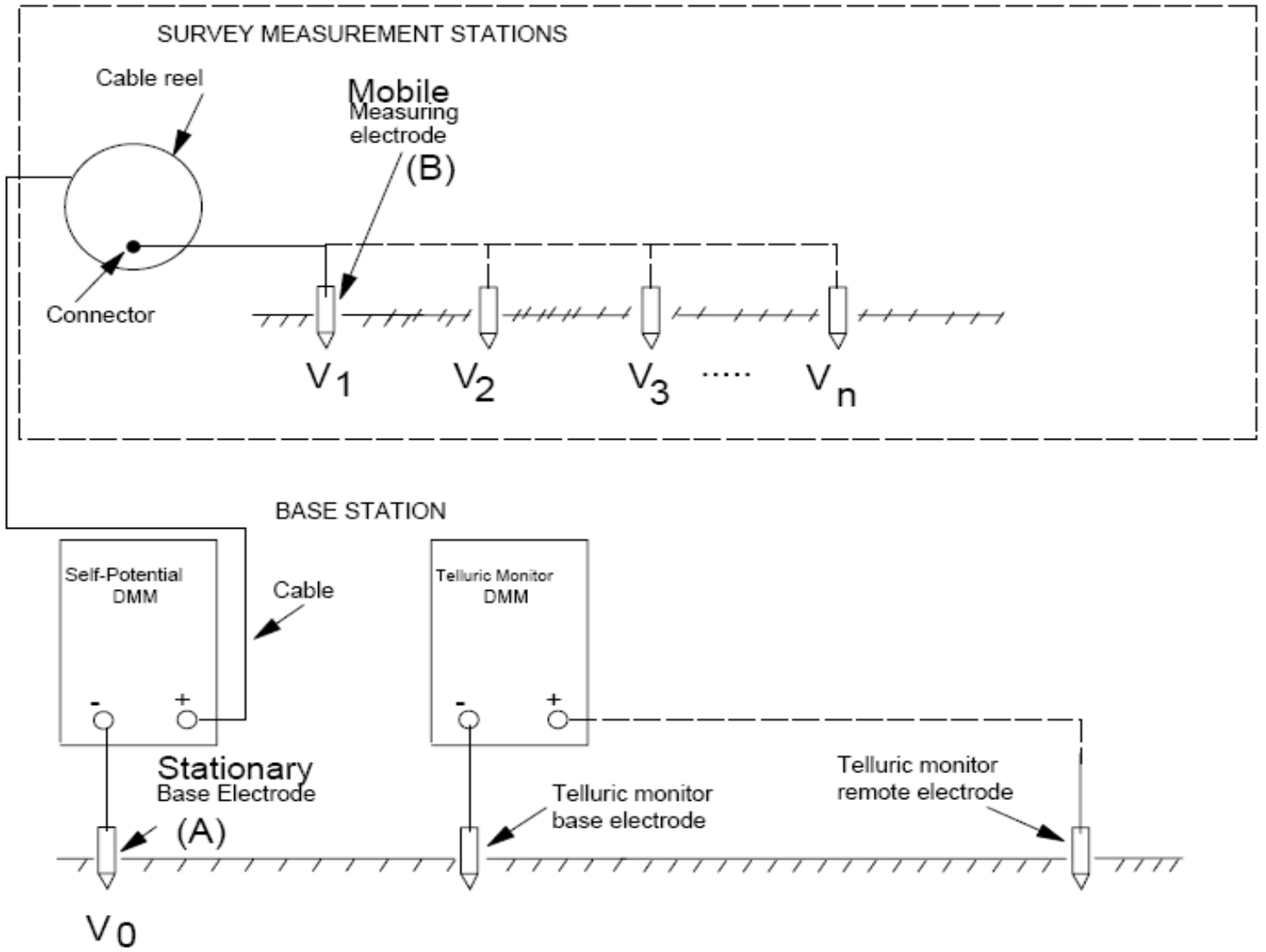


Streaming Potential by Seepage from Reservoir Floor…

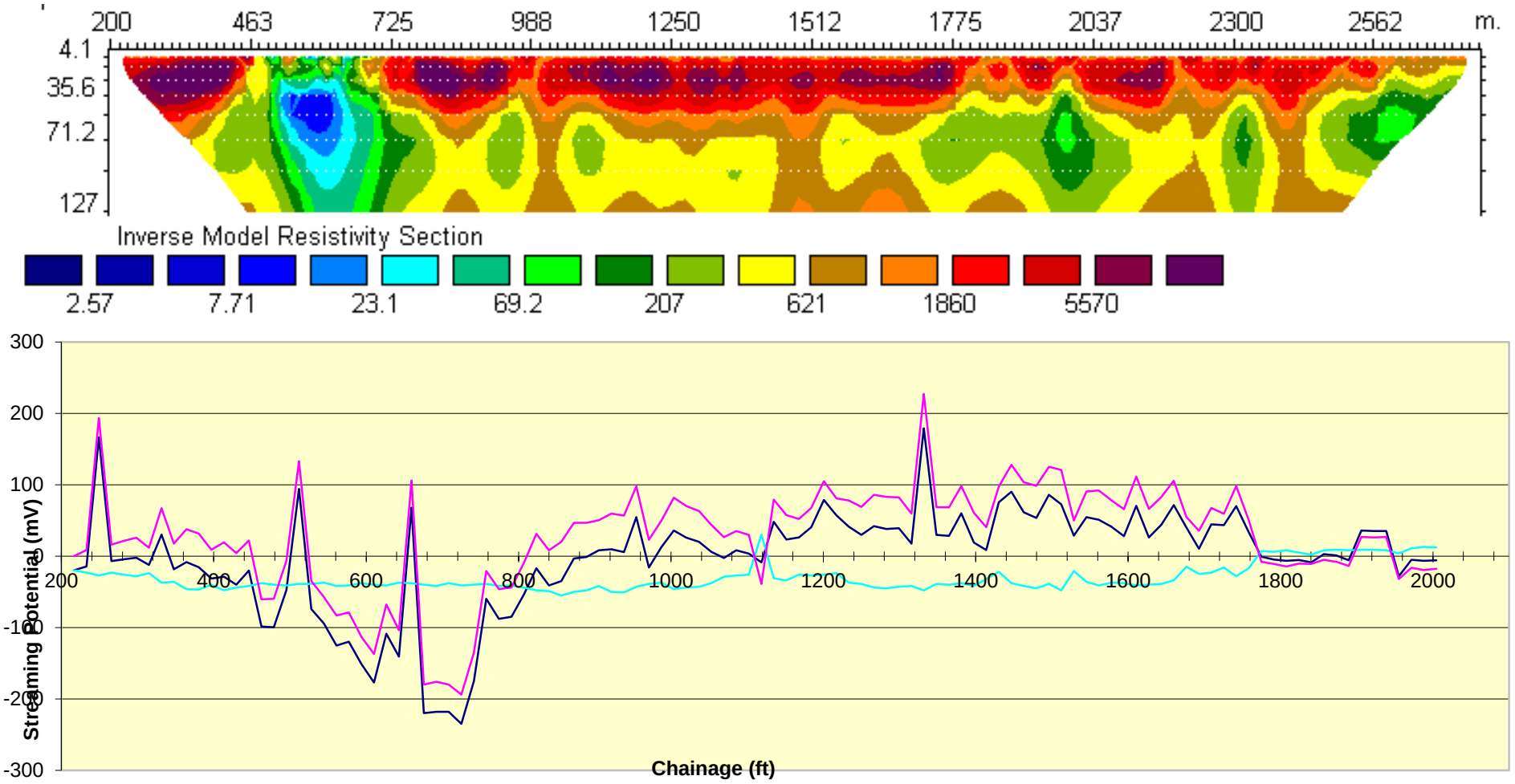


Non-Polarising Electrodes for SP Measurement

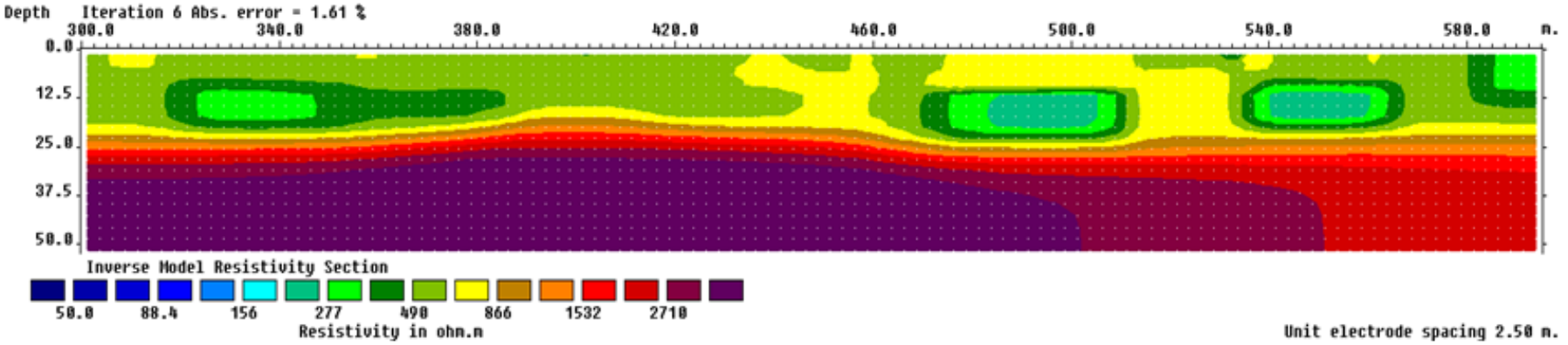
SP Measurement Procedure

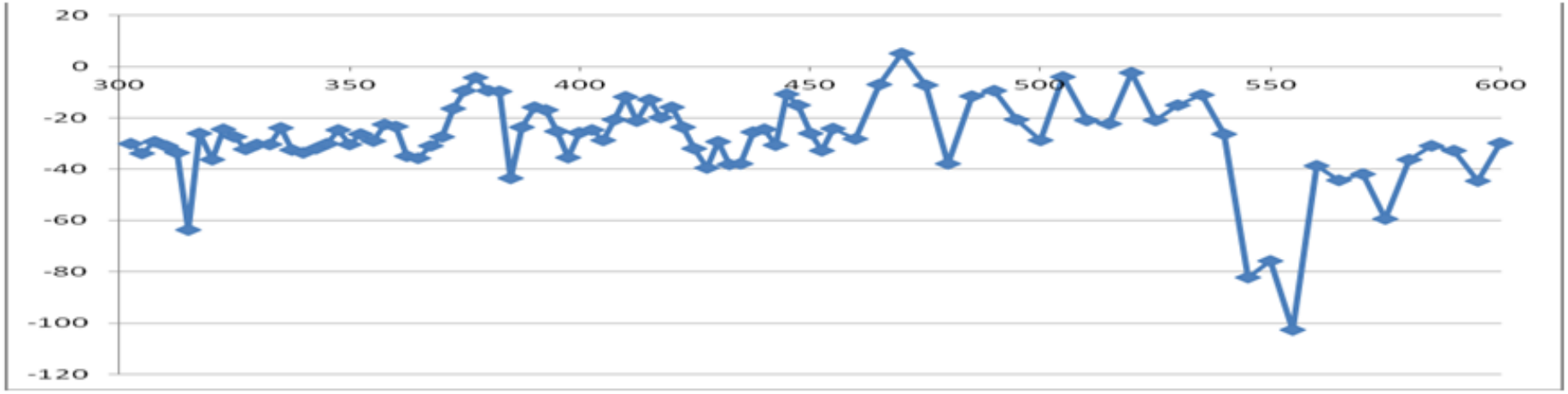


SP Results (with ERI)…



SP Results (with ERI)…



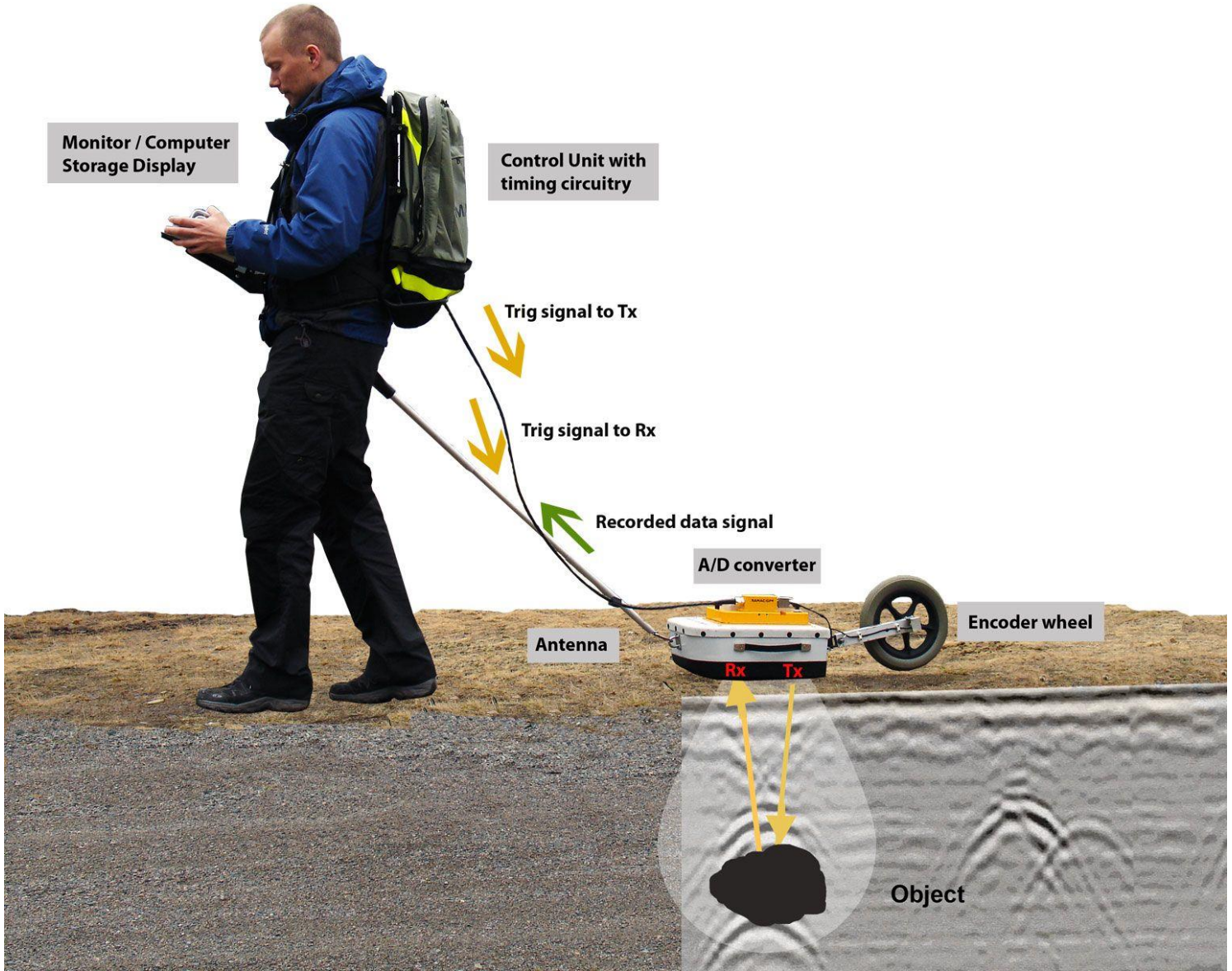


Ground Penetrating Radar

Application of GPR- Dams…

- Used for Stratigraphic Profile, buried objects
- Principle- EM Reflections
- Used in Dams for
  - Characterizing internal structure
  - Soft Zones, heterogeneities
  - Sub Bottom Profiles of Reservoirs
  - Detection of cavities

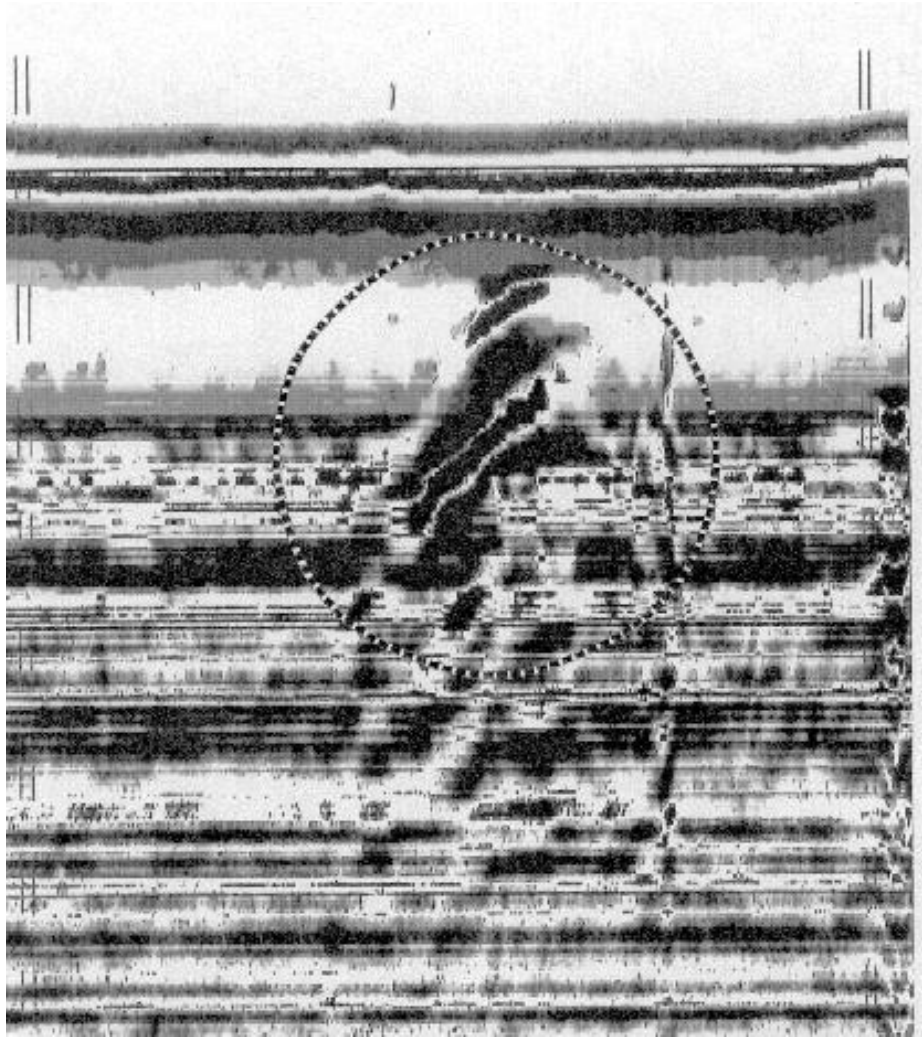
GPR- Basic Principle…



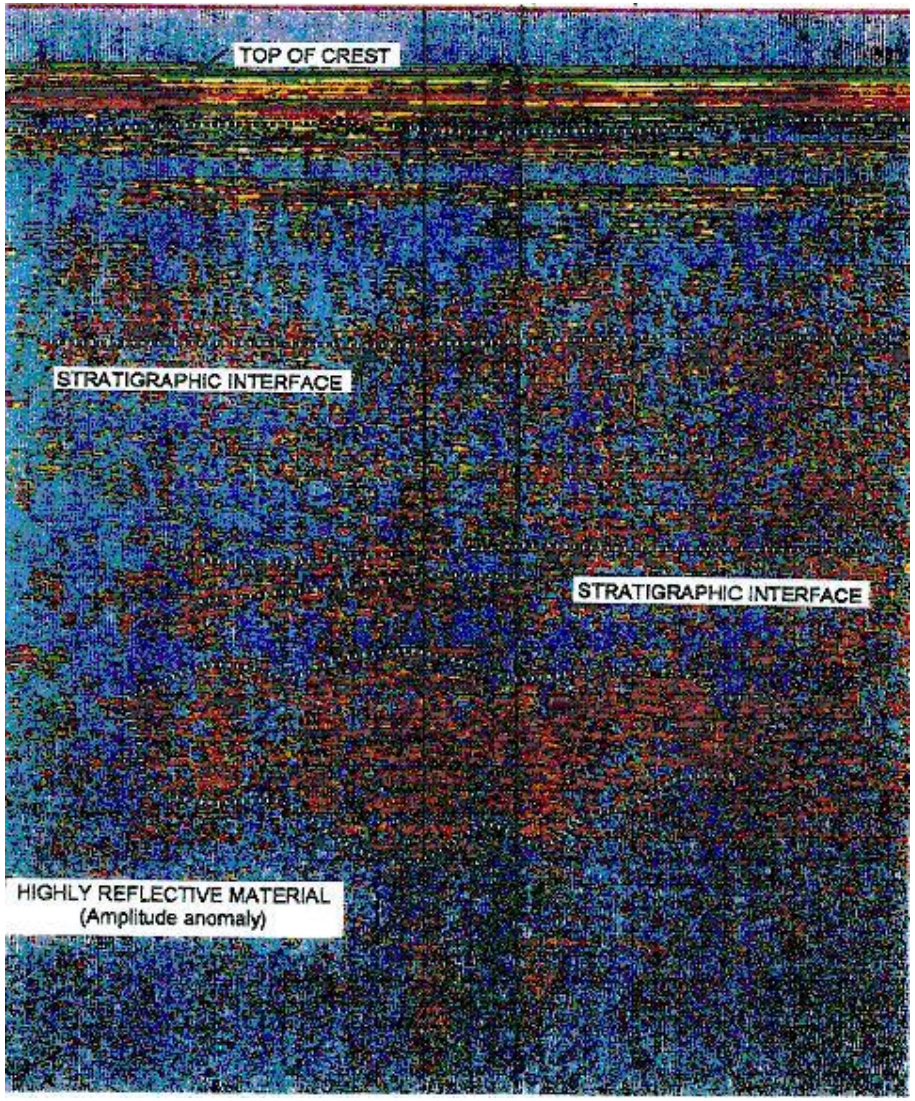
GPR- Data Acquisition…

GPR- Data Acquisition…

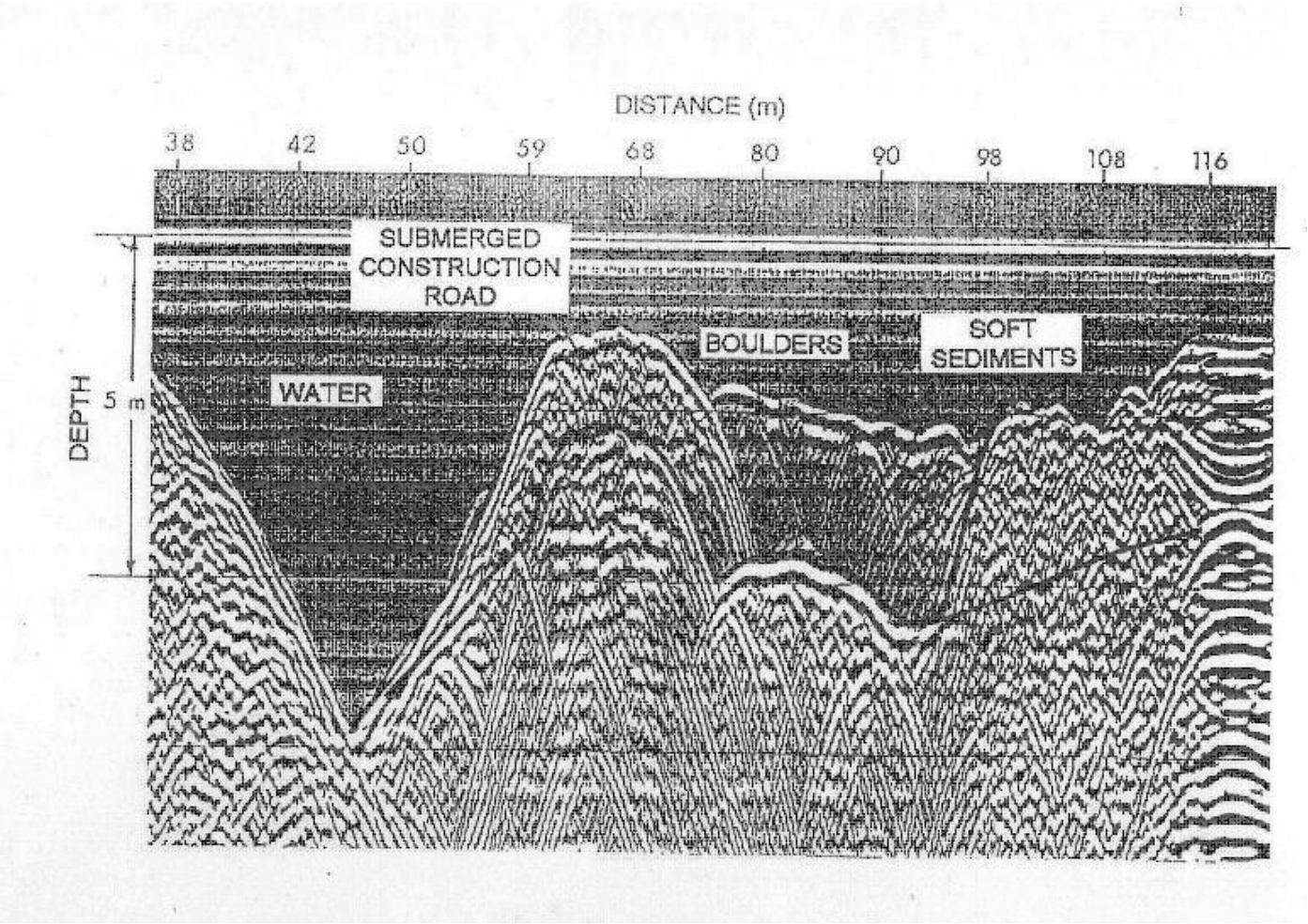
GPR- Results (Cavity)…



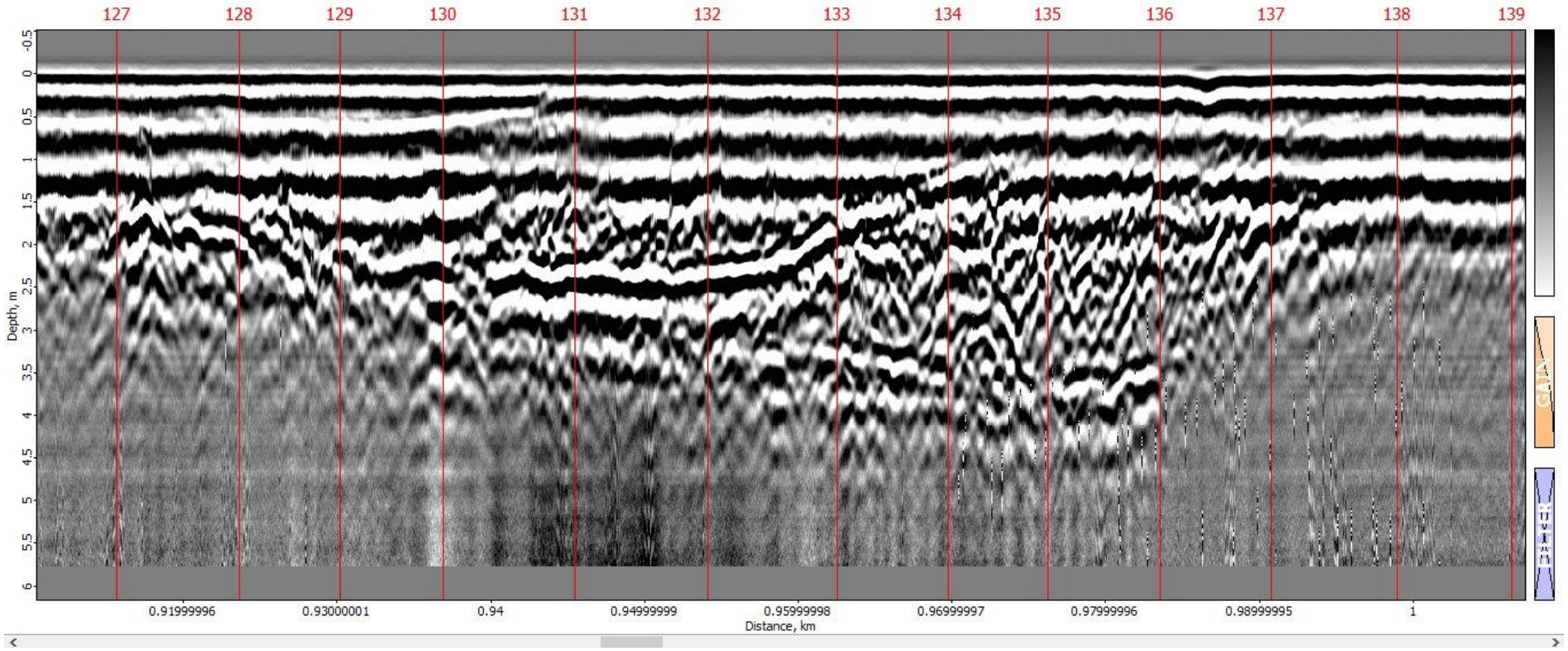
GPR- Results (Interfaces)…



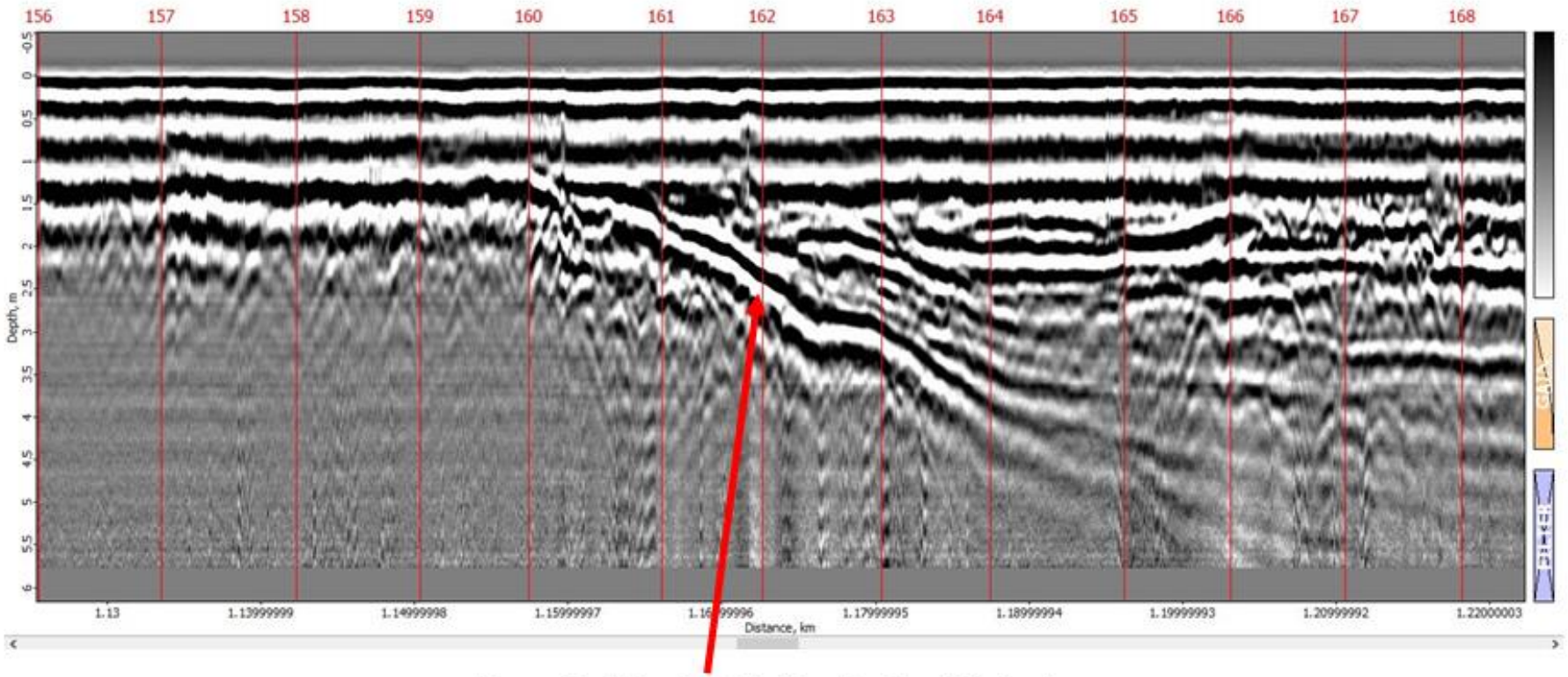
GPR- Results (Reservoir Survey)…



GPR- Results (Interfaces)…

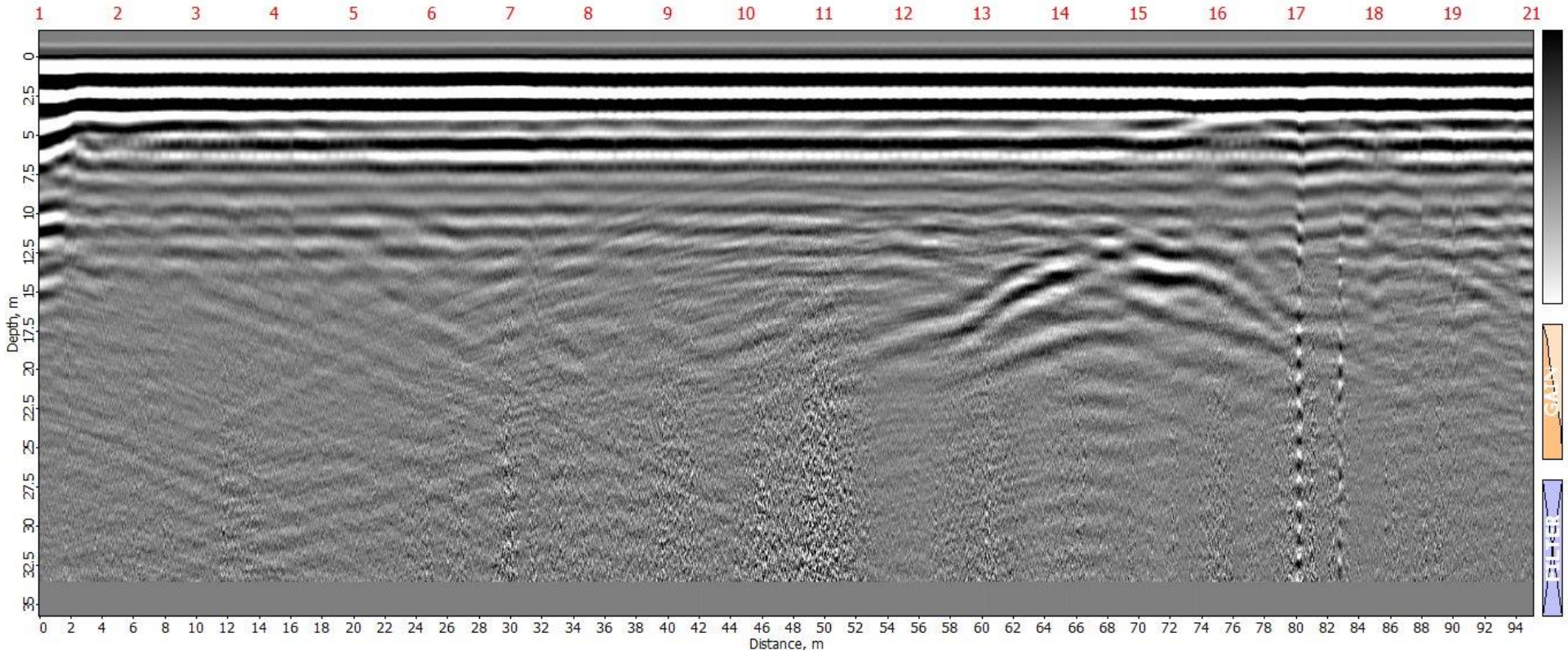


GPR- Results (Interfaces)…

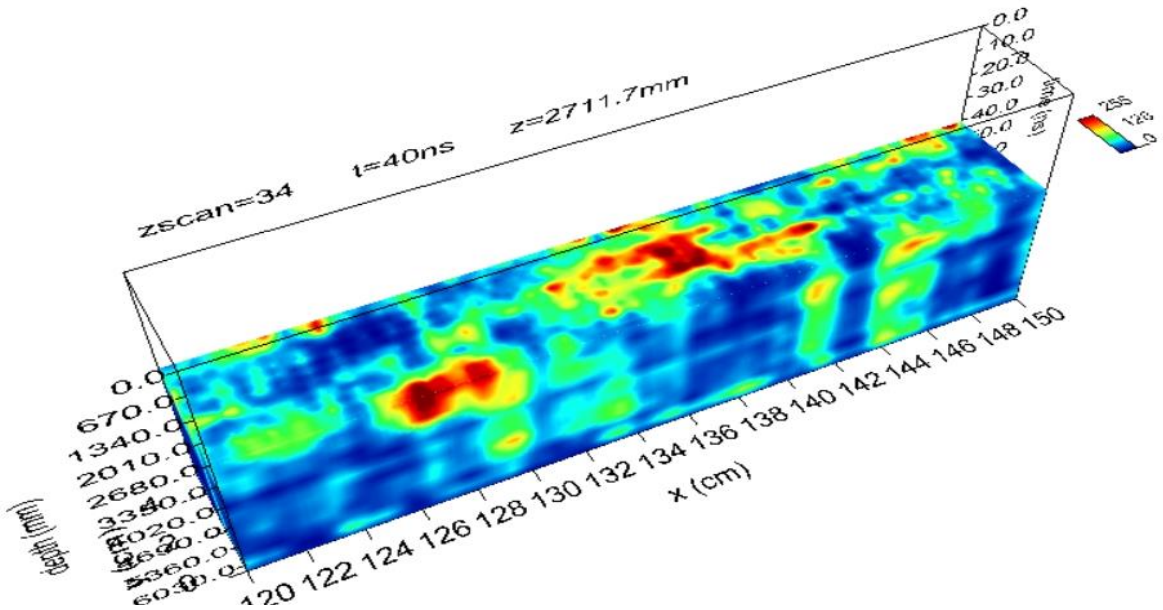


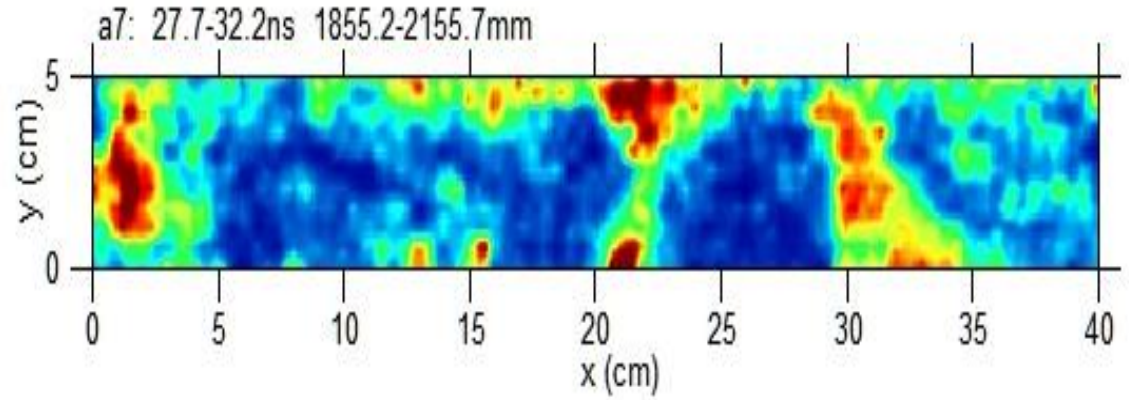
Example: Dipping Shallow bedrock/ interface

GPR- Results (Cavity)…

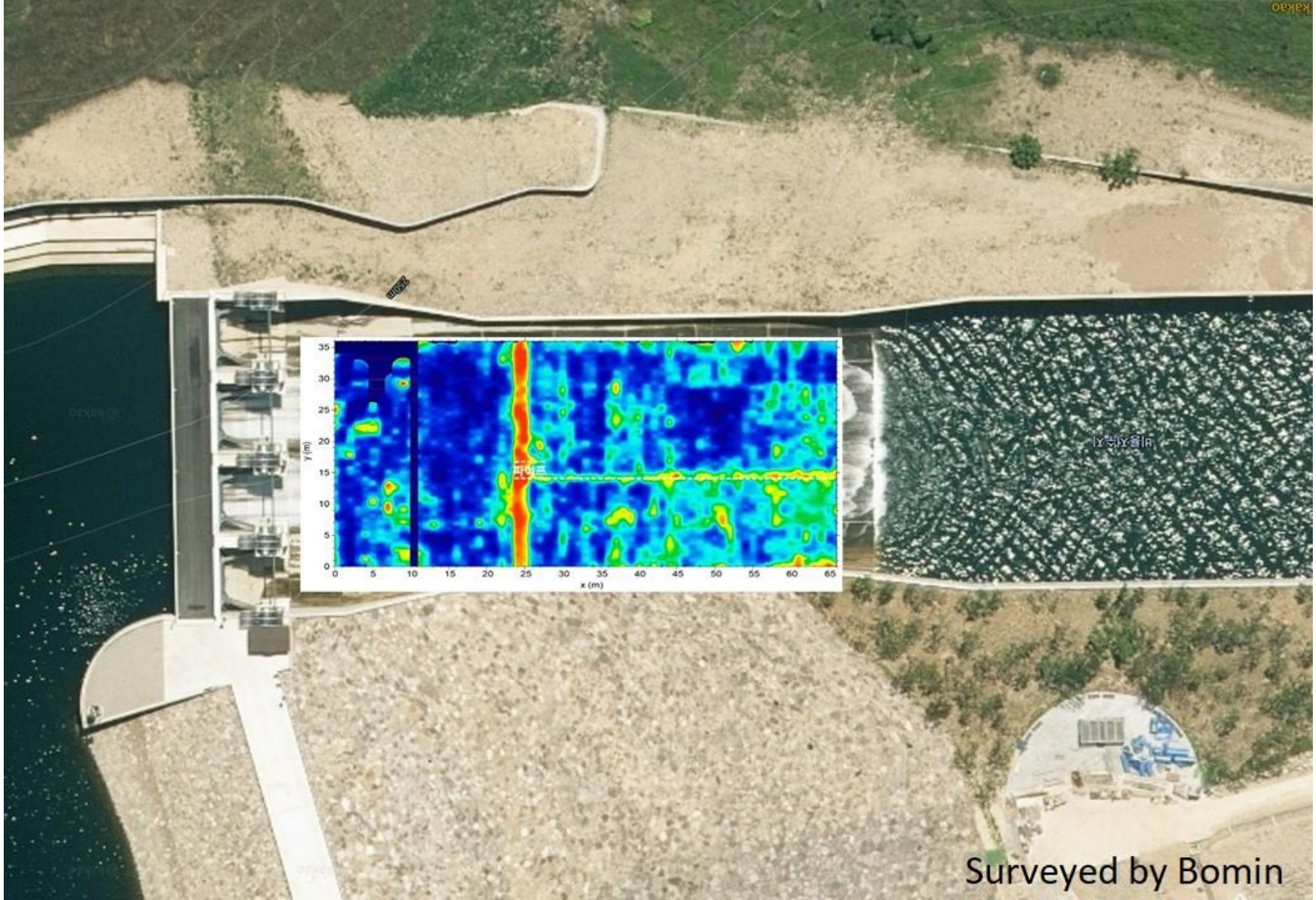


GPR- Results (3D Volume & Time Slice)…






L-67
L-01
N
비룡저수지
kakao
Surveyed by Bomin


y (m)
x (m)
Surveyed by Bomin

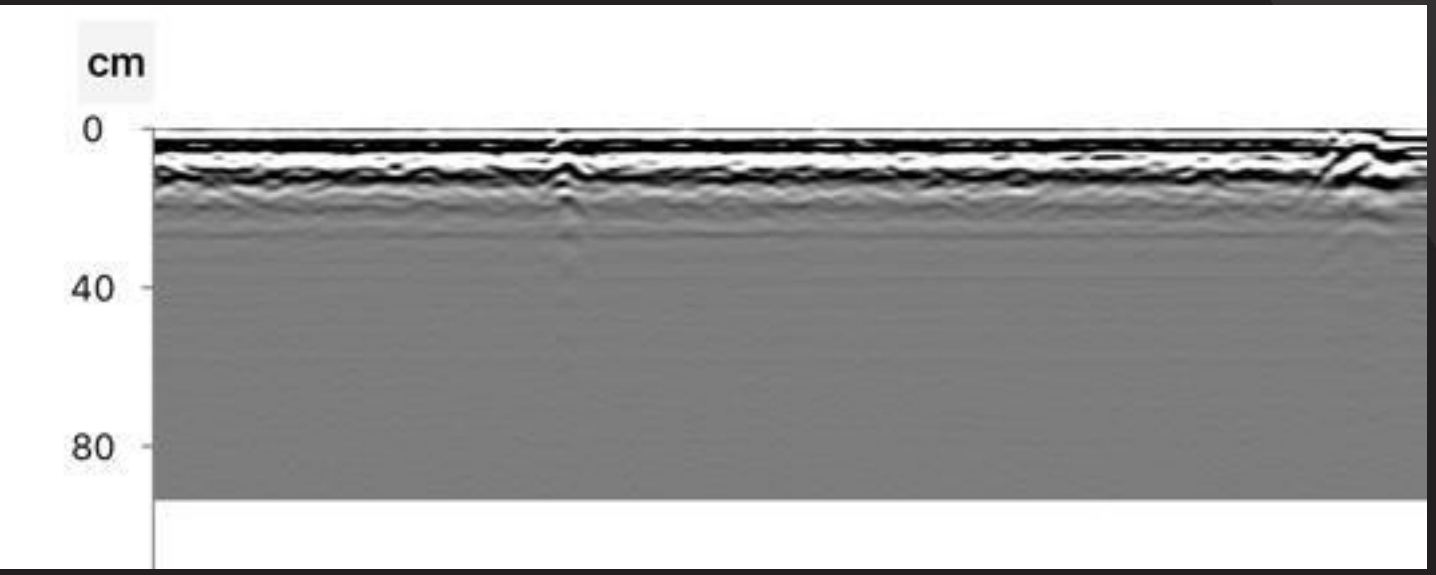
NDT Inspection of Head Raise Tunnel at Parbati Dam, India. Case Study

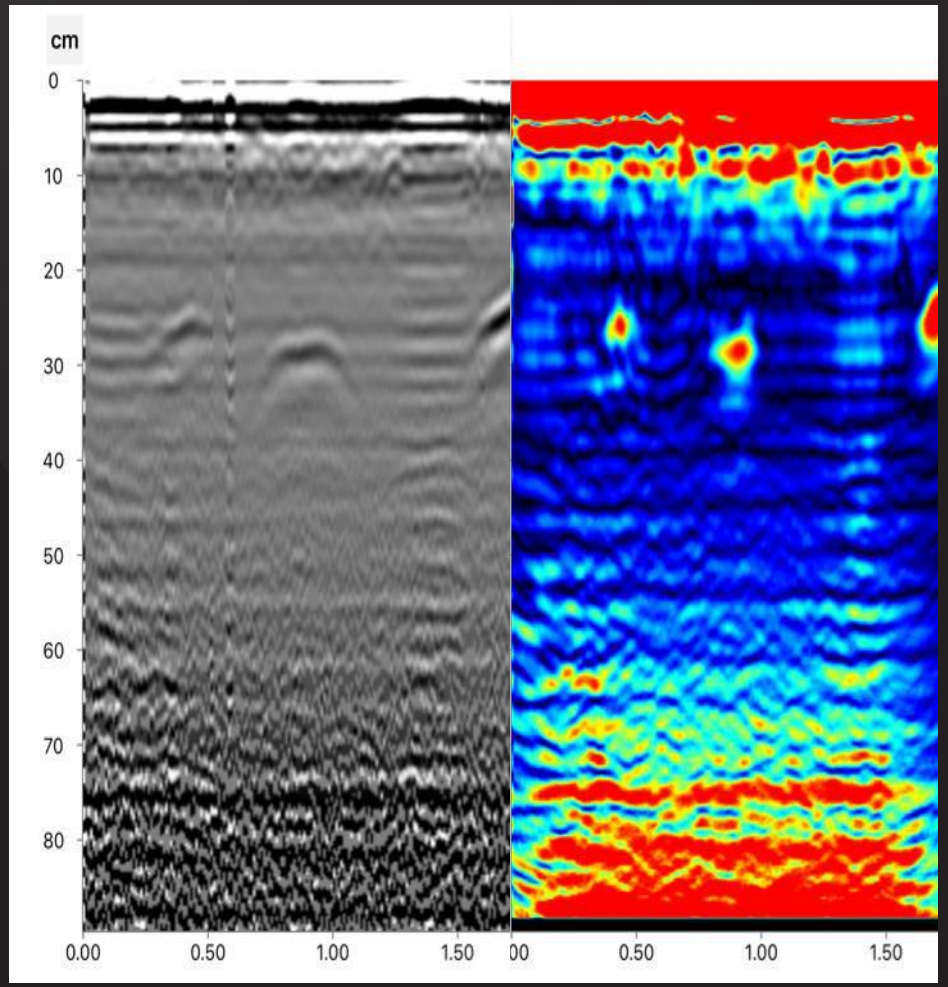
The test conducted by both Pundit PD8000 &Proceq GP8000 in Adit-II(Face-IV), TBM site.

The rock type around this site is Quartzite falling in Class-III category, as per RMR Classification.

The tunnel lining is of minimum 400mm thickness.

GPR data

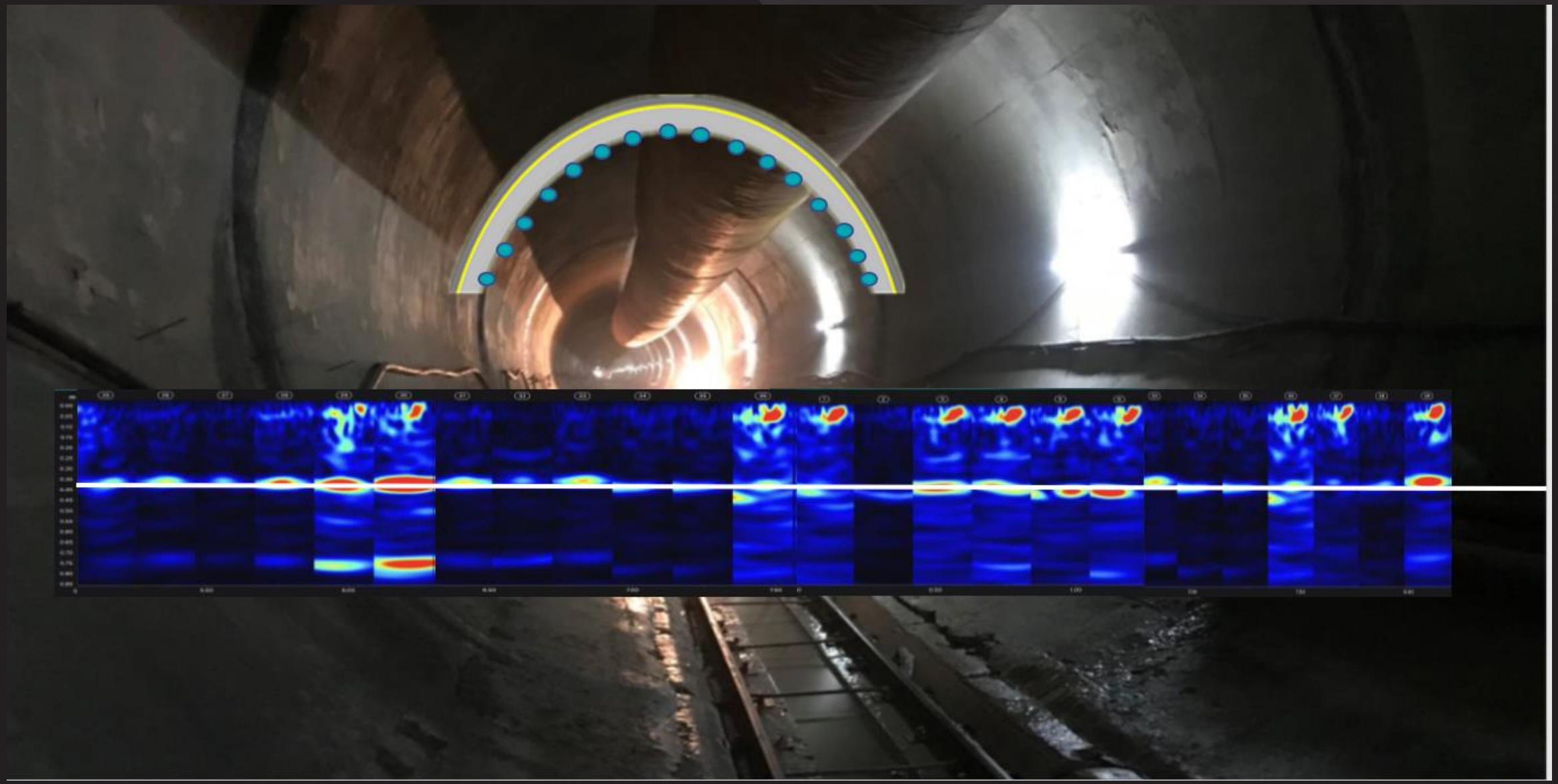


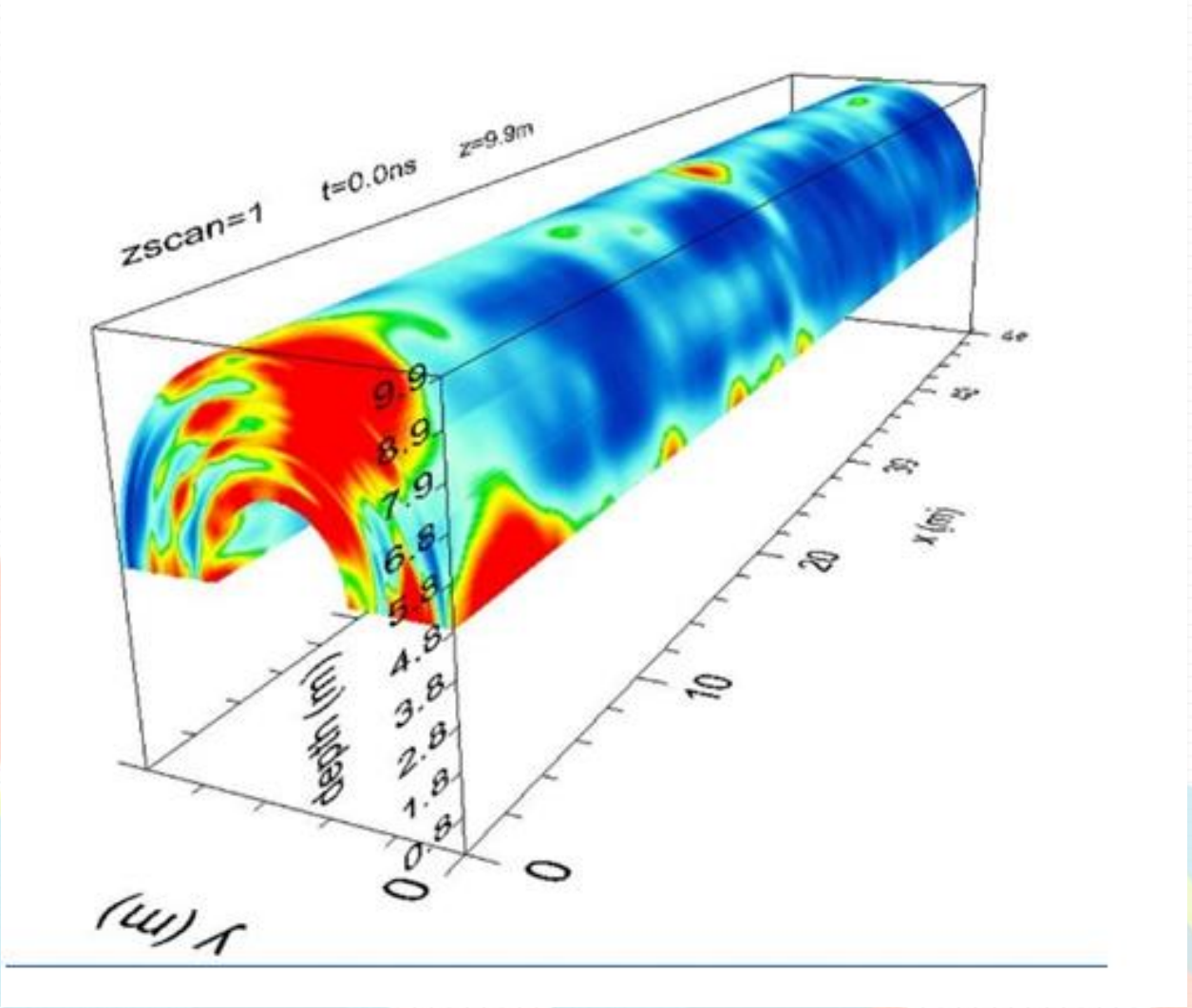


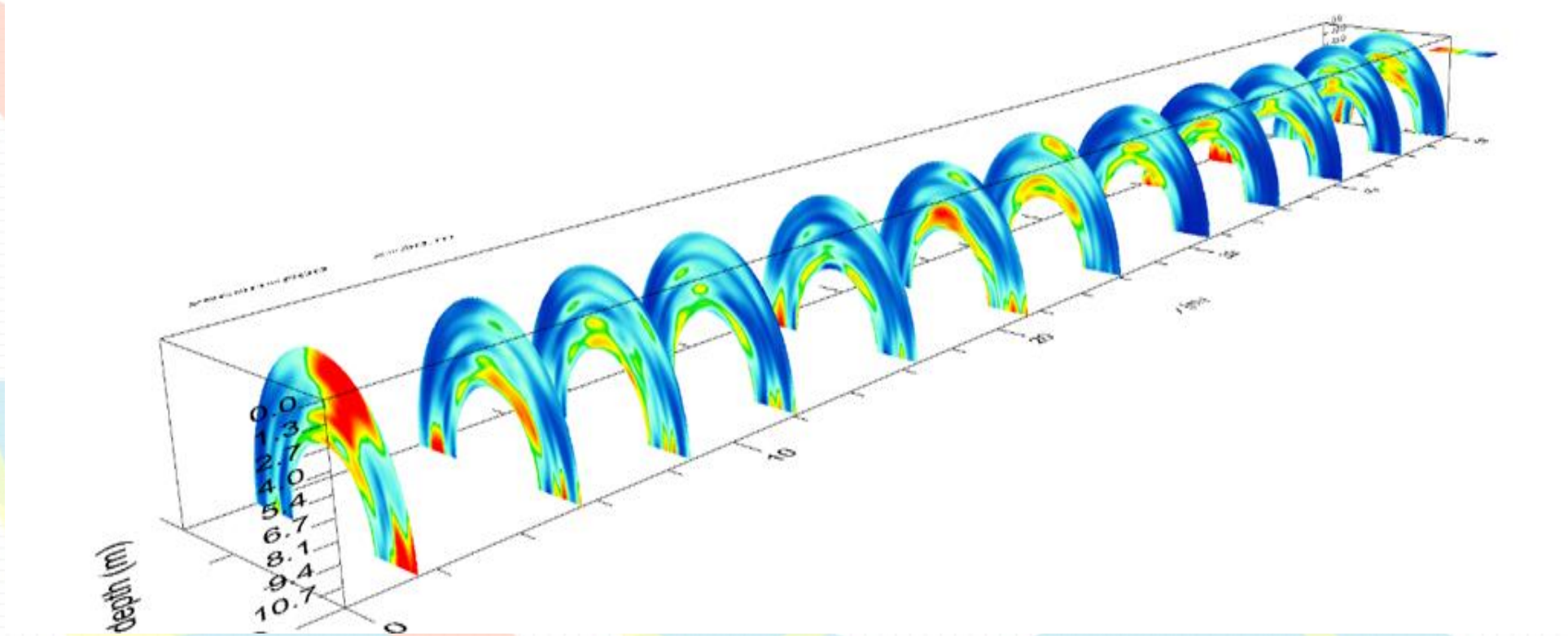
Left and right images shows the GPR data results on unreinforced casted-in-place concrete lining and reinforced concrete lining respectively.

Embedded rebars with cover at 22 to 25cm depth, center reflectors are indicating two overlapping rebars

Ultrasonic pulse-echo data




zscan=1
t=0.0ns
z=9.9m
9.9
8.9
7.9
6.8
5.8
4.8
3.8
2.8
1.8
0.8
0
10
20
x(m)
y (m)


depth (m)
0.0
1.3
2.7
4.0
5.4
6.7
8.1
9.4
10.7
0
10
20

GPR- Stilling Basin…

GPR- Stilling Basin…

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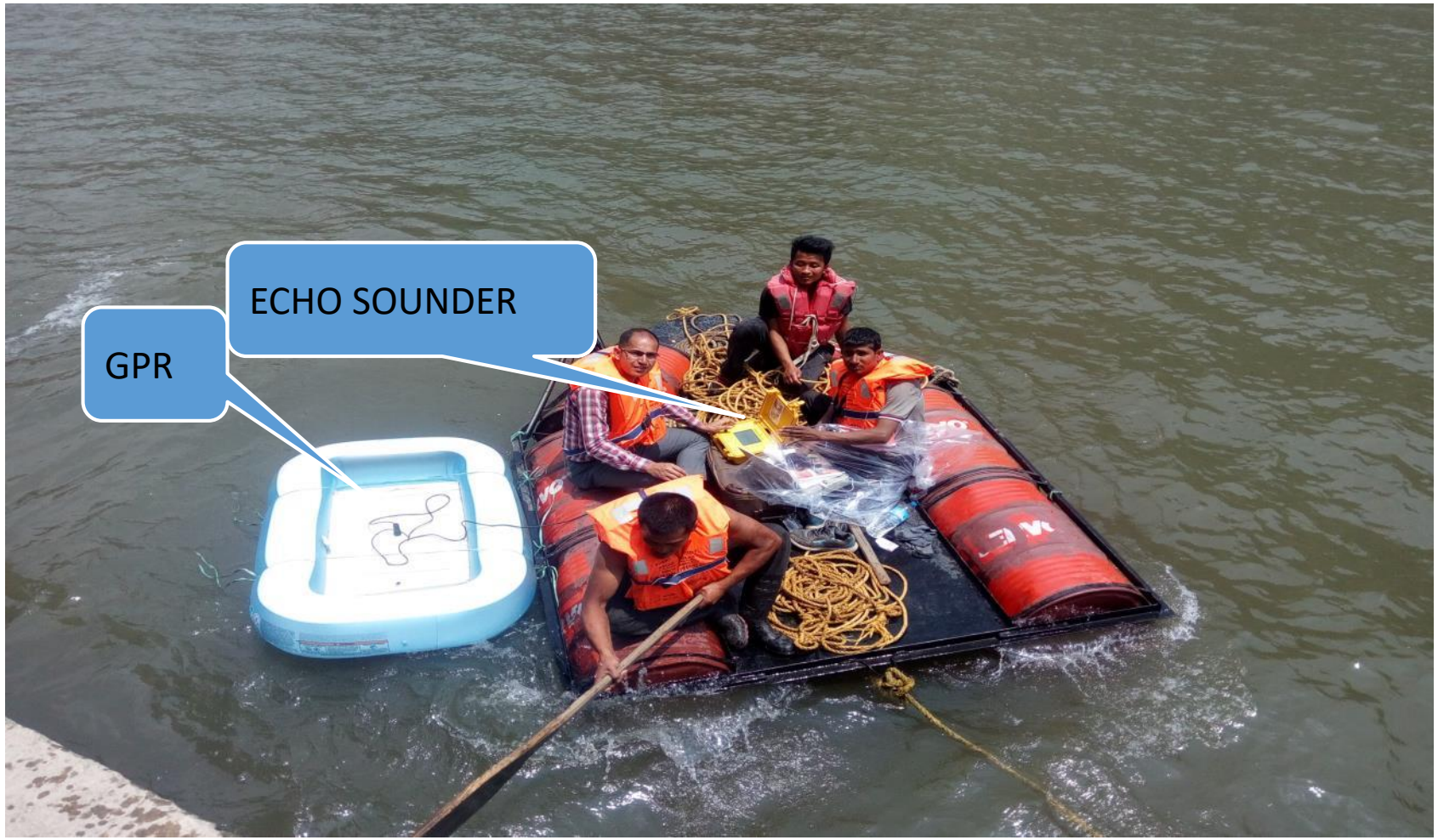
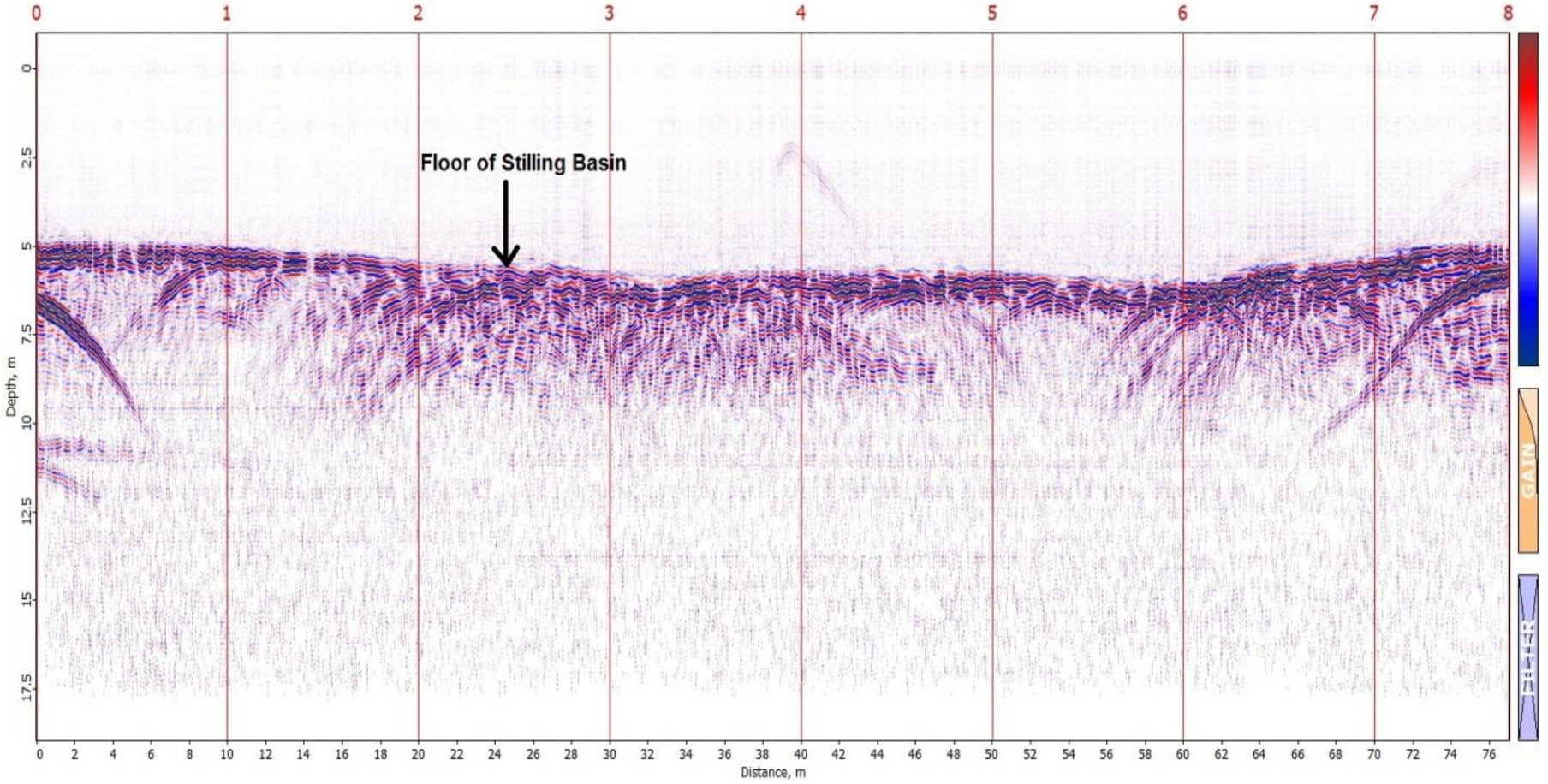
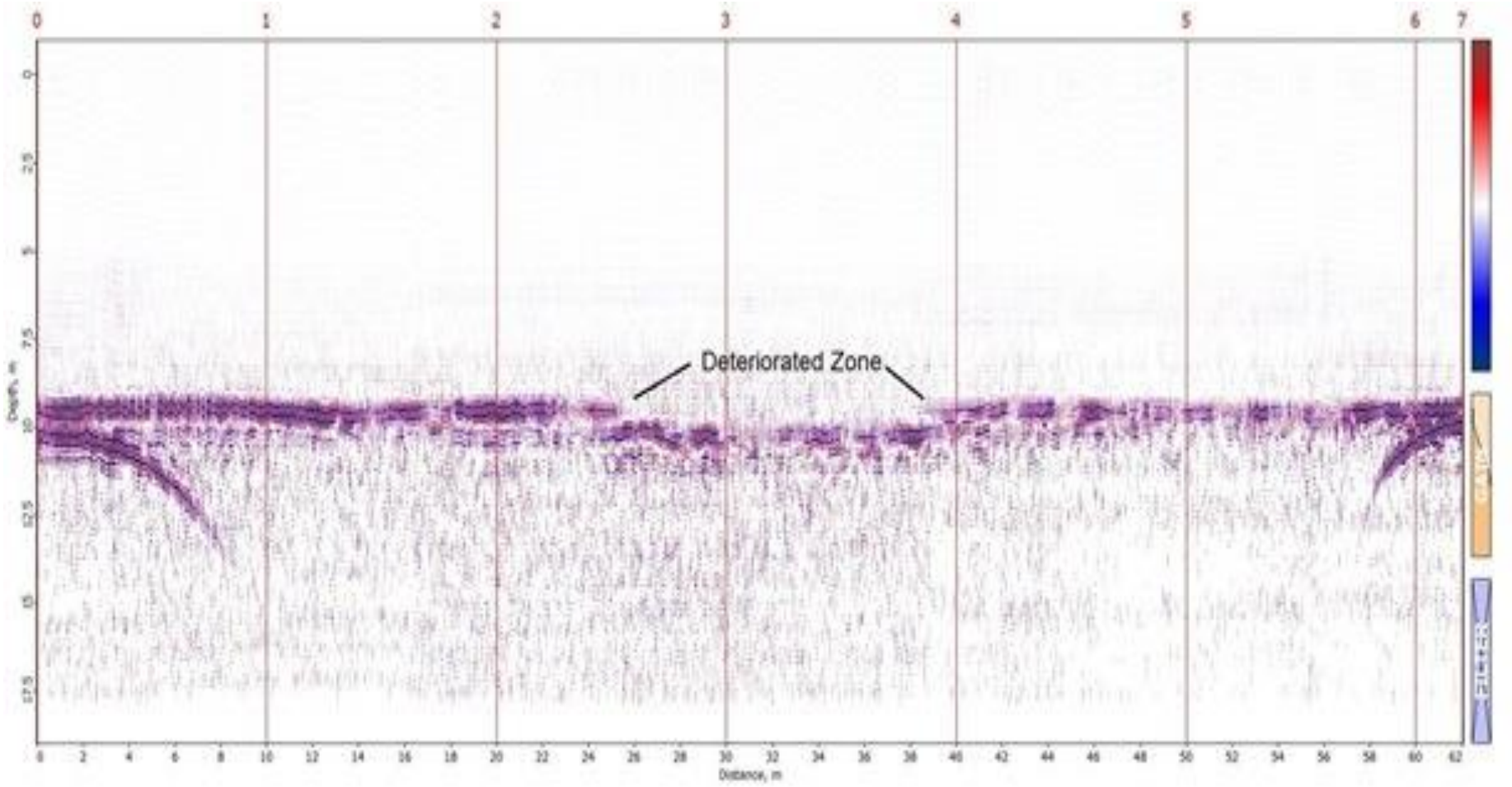
GPR- Stilling Basin…



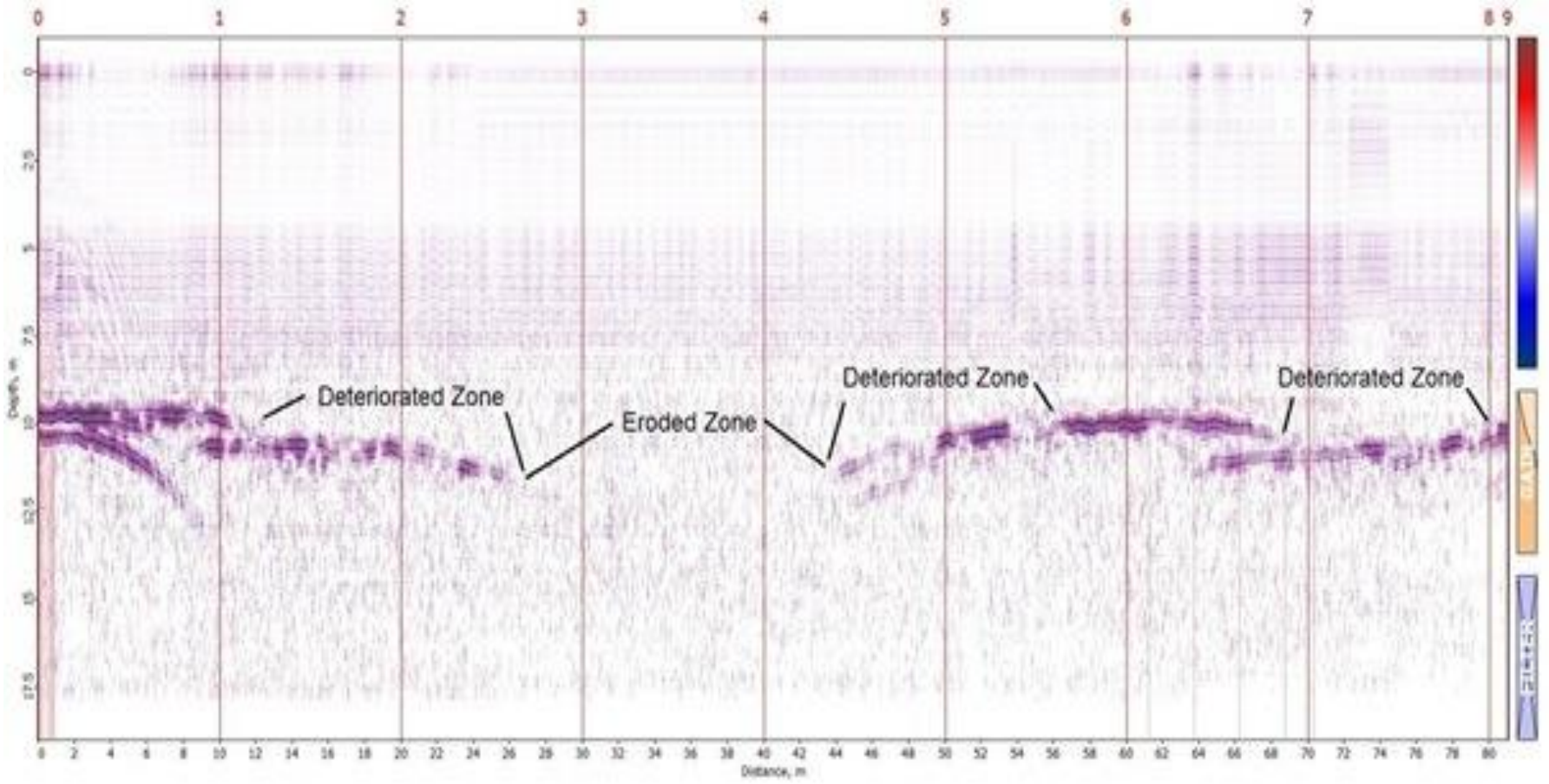
GPR- Results (Stilling Basin)…



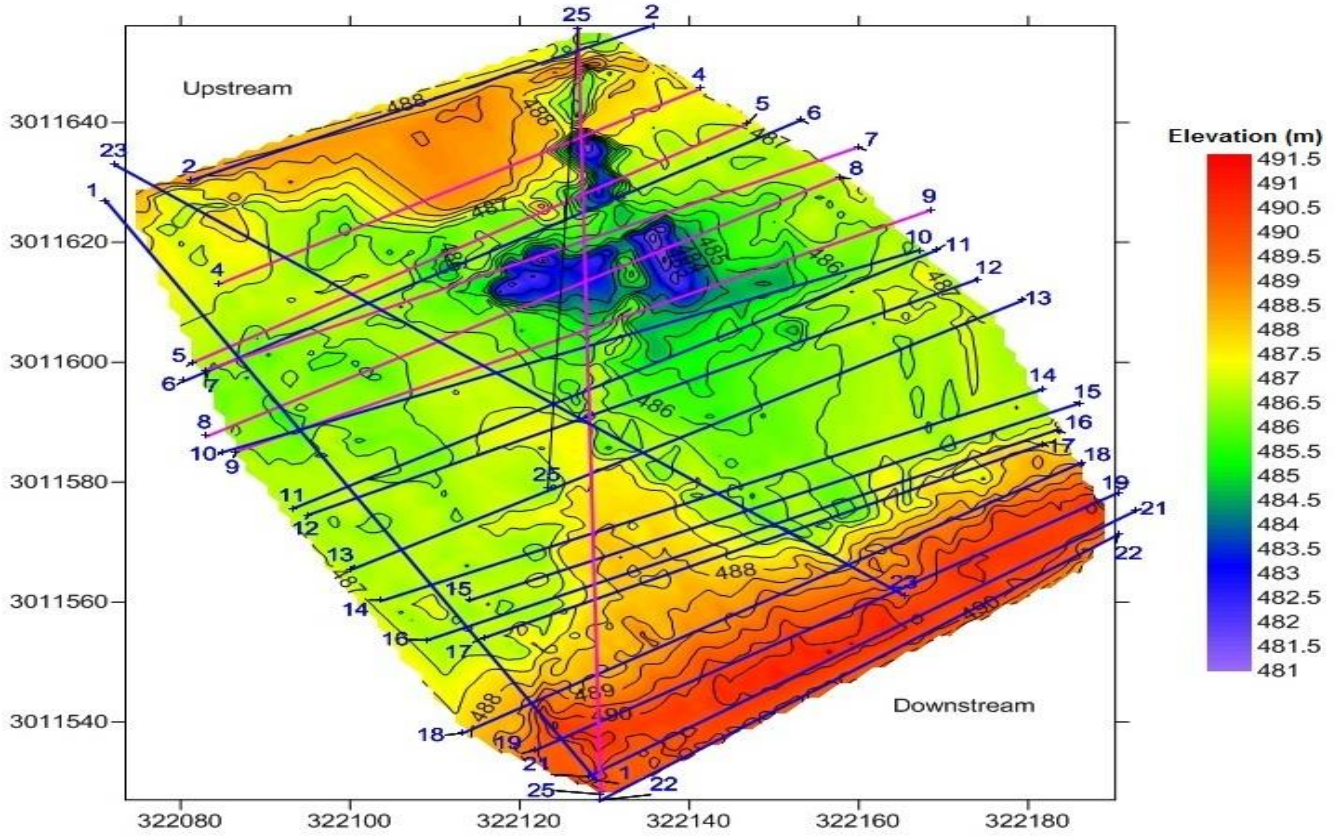
GPR- Results (Stilling Basin)…



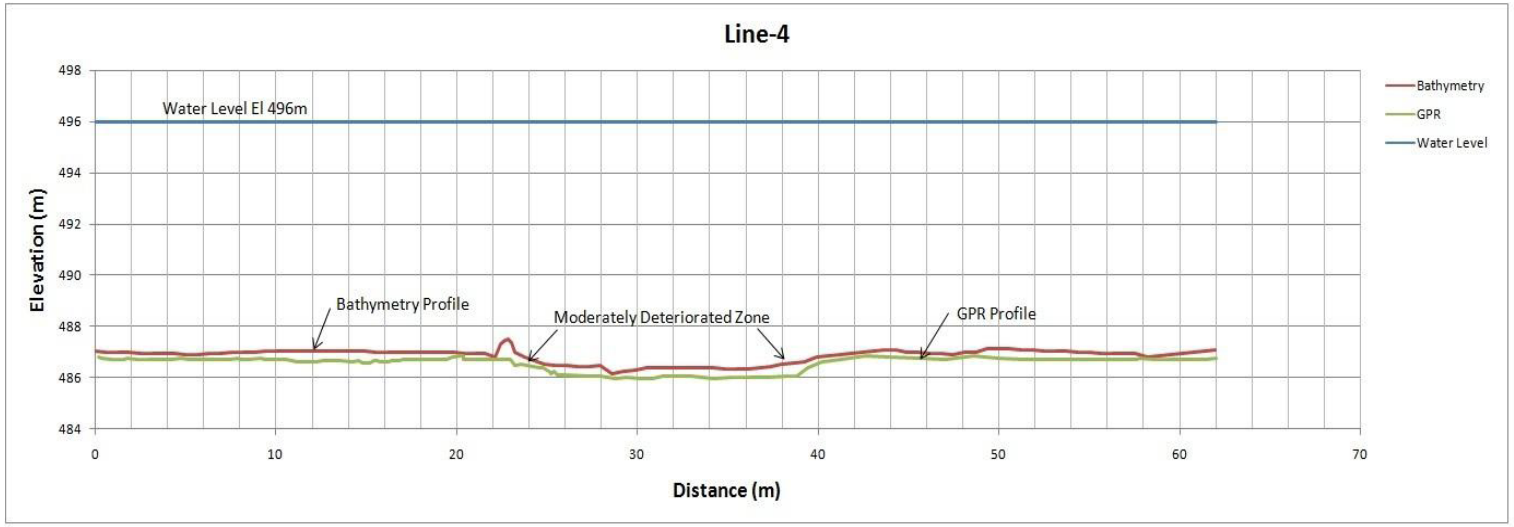
GPR- Results (Stilling Basin)…

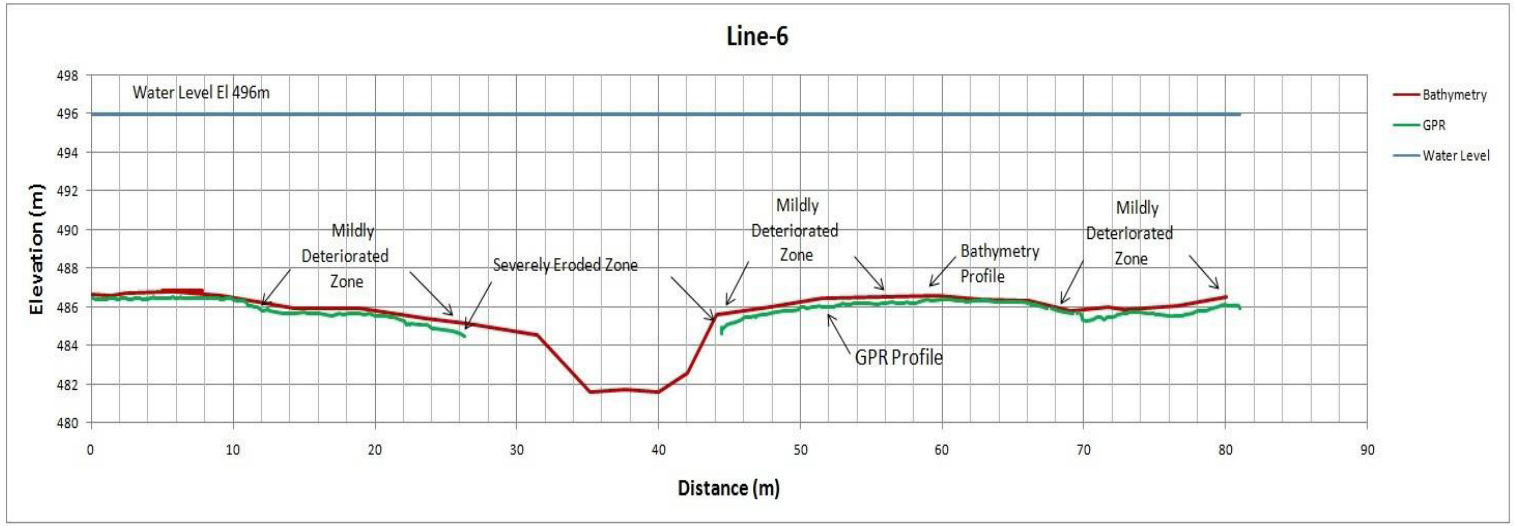


GPR- Results (Stilling Basin)…



GPR- Results (Stilling Basin)…

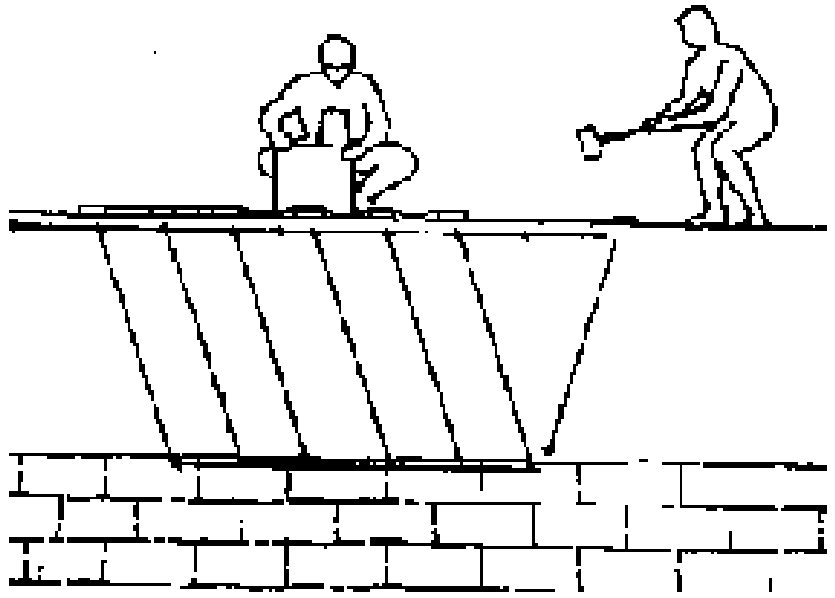




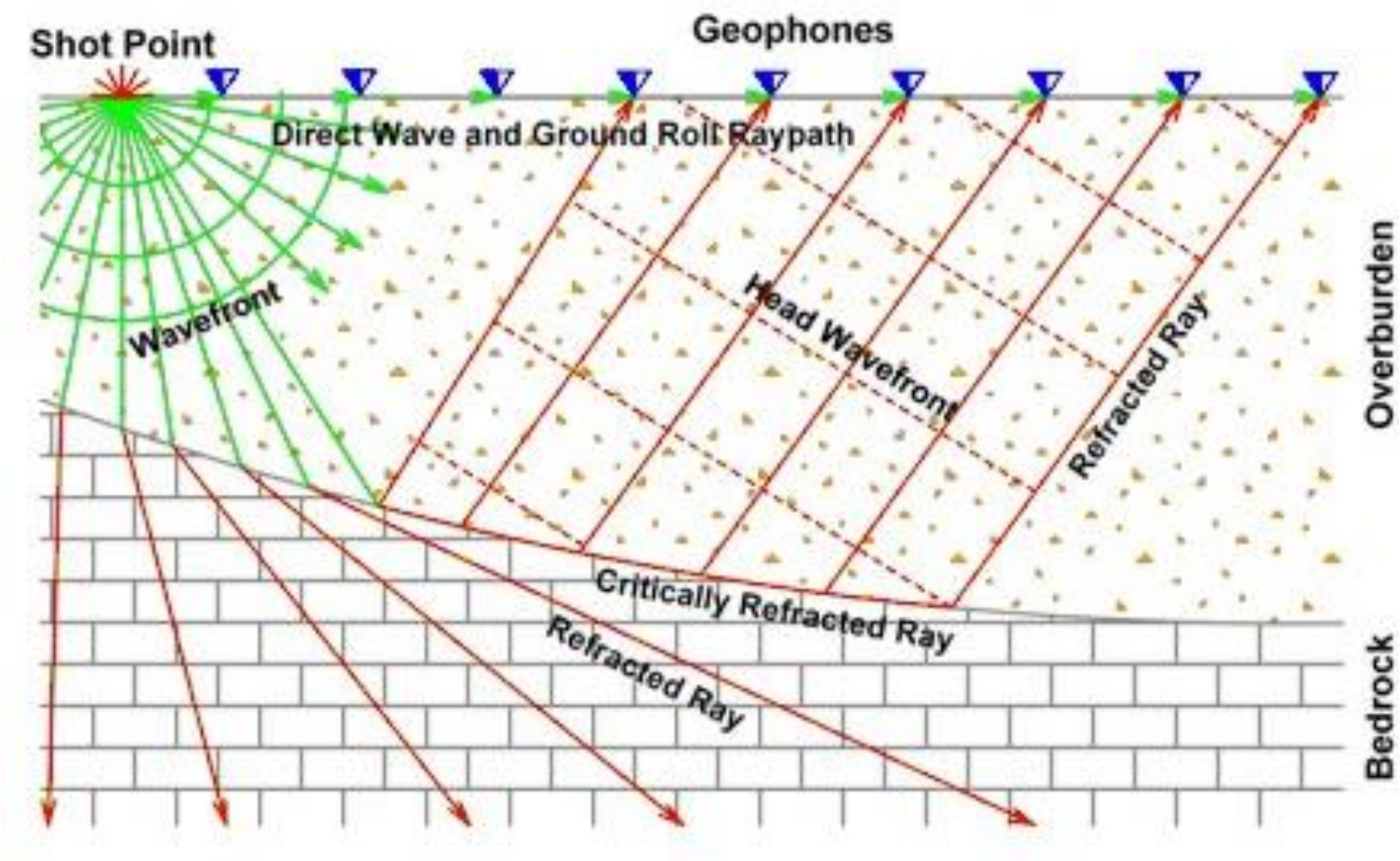
Seismic Refraction

Application of Seismic Refraction- Dams…

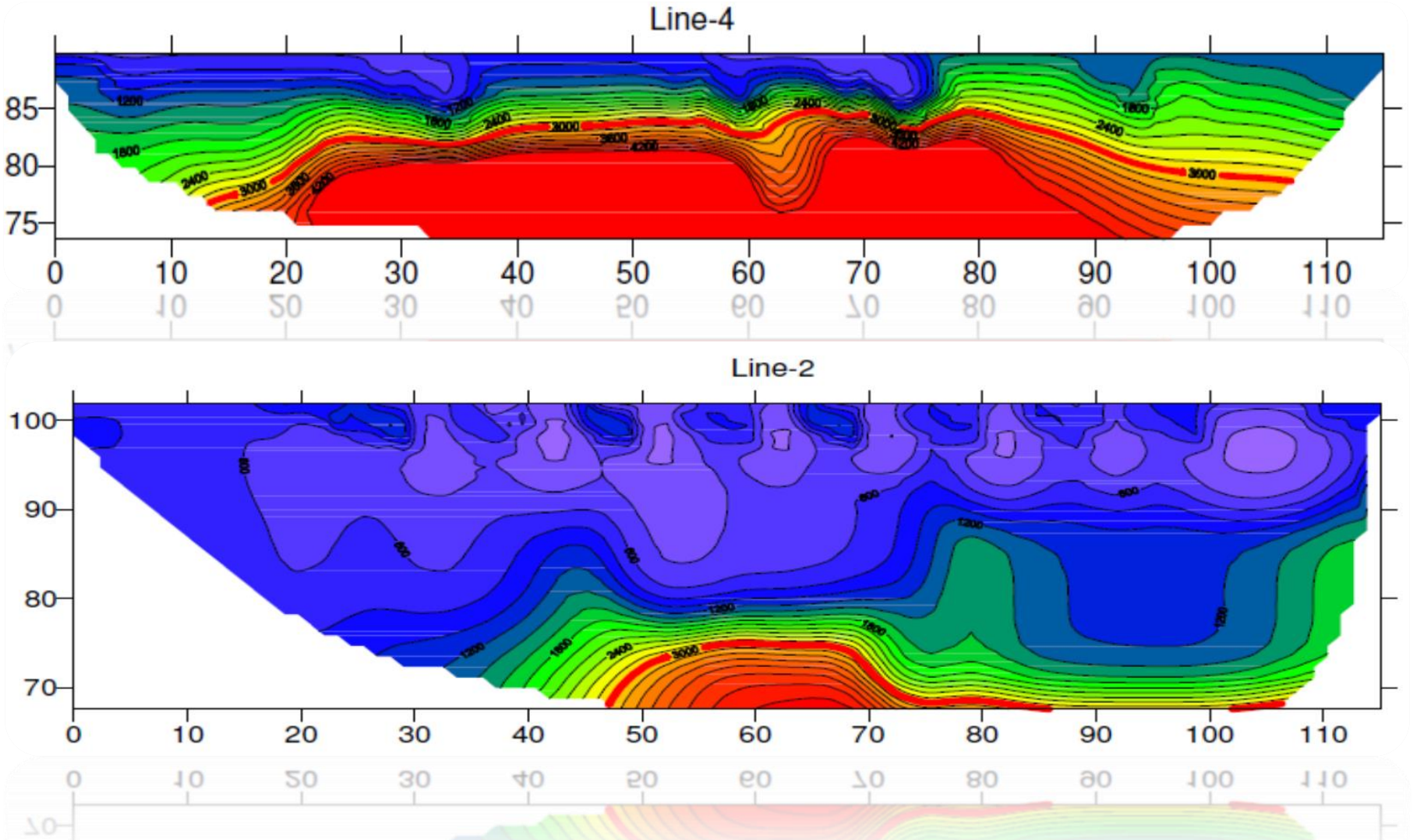
- Undertaken from dam top
- Two or more parallel profiles on dam top and downstream side
- Provides P wave velocity- Strength of subsurface material
- Bedrock mapping
- Phreatic line determination
- Seepage zone identification
- Post construction QC tool



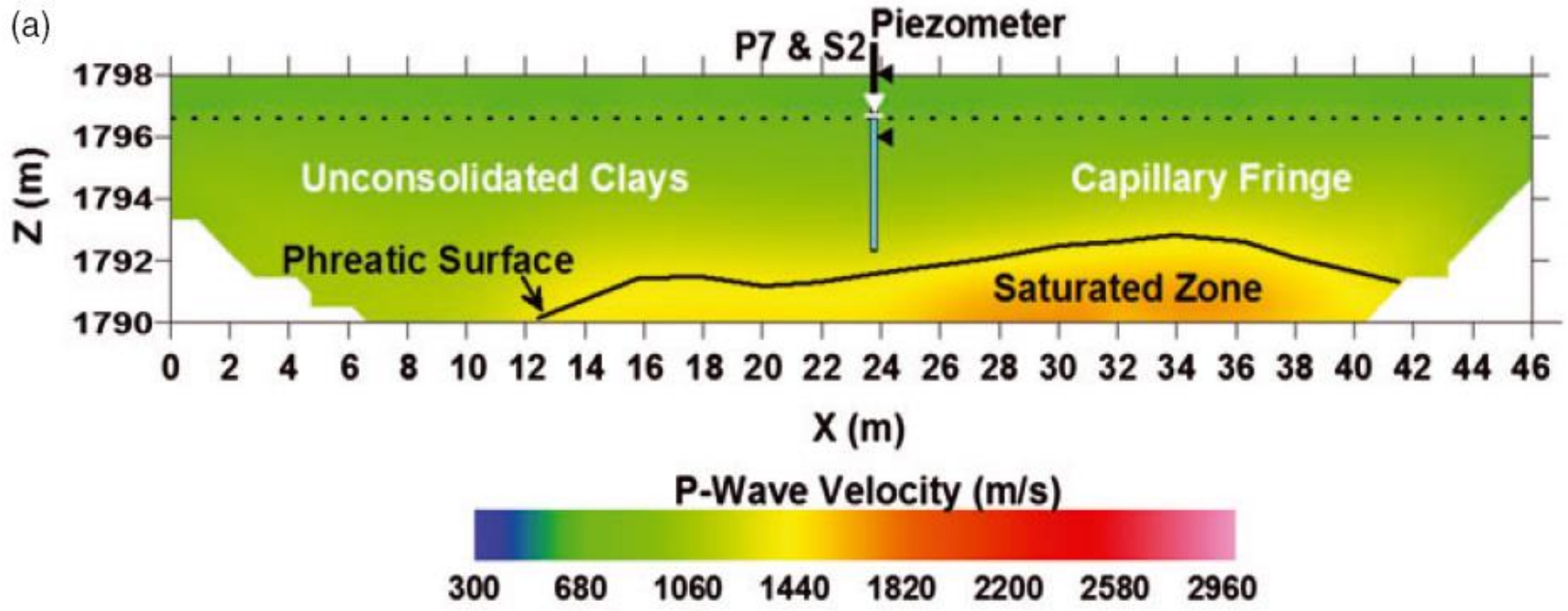
Seismic Refraction- Basic Principle…



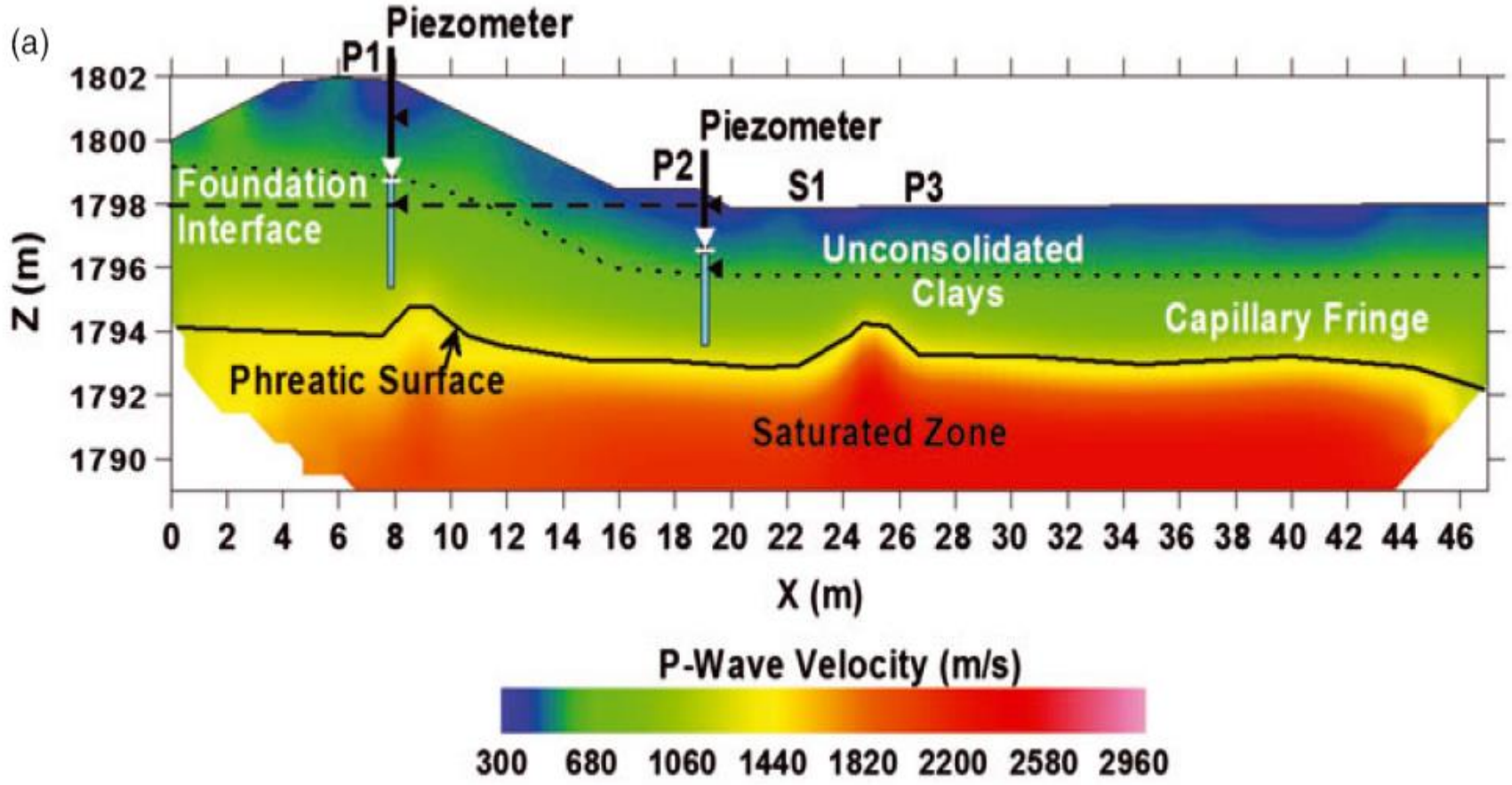
Seismic Refraction- Dam Body Velocity Model…



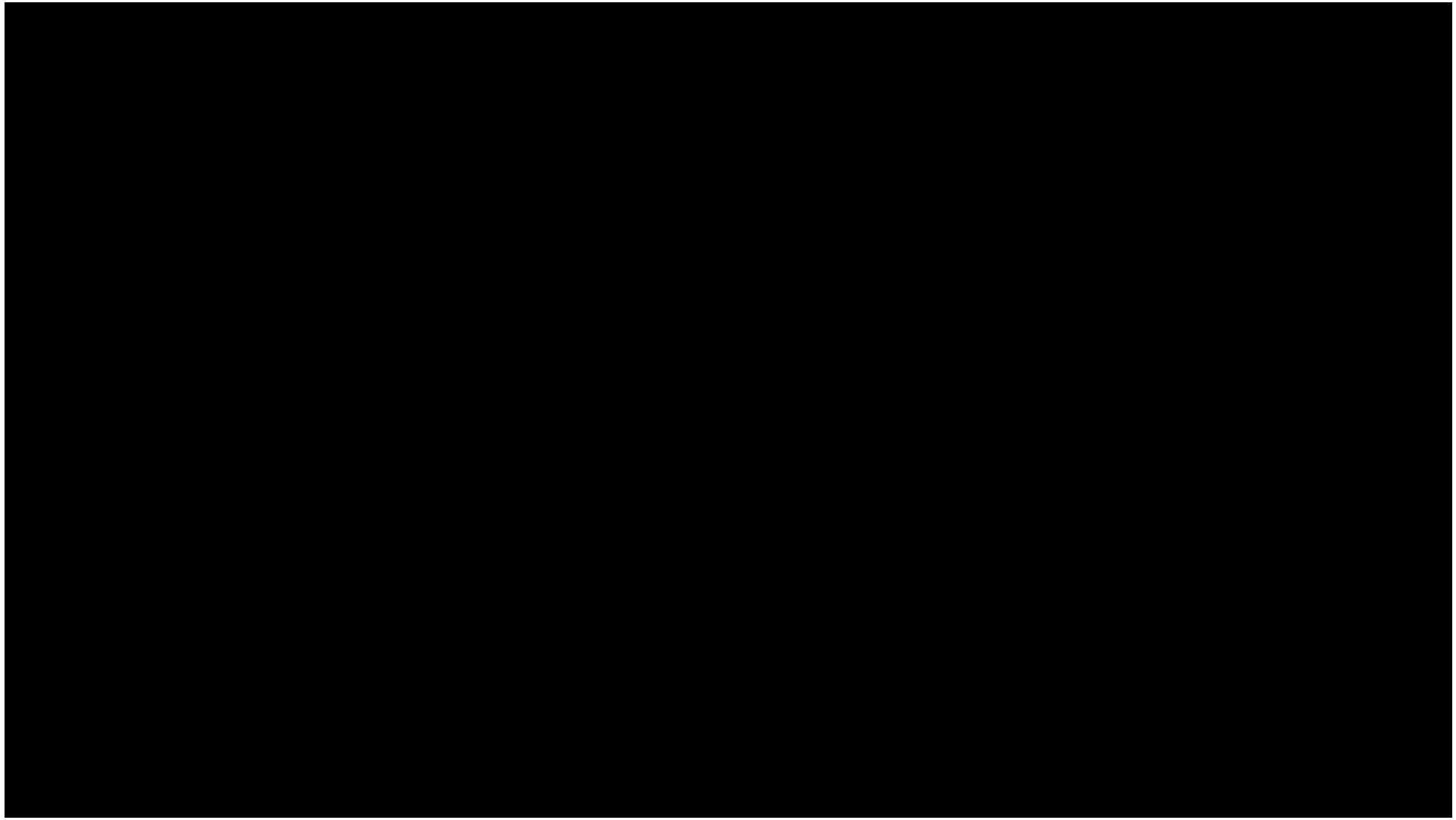
Seismic Refraction- Phreatic Surface…



Seismic Refraction- Phreatic Surface…



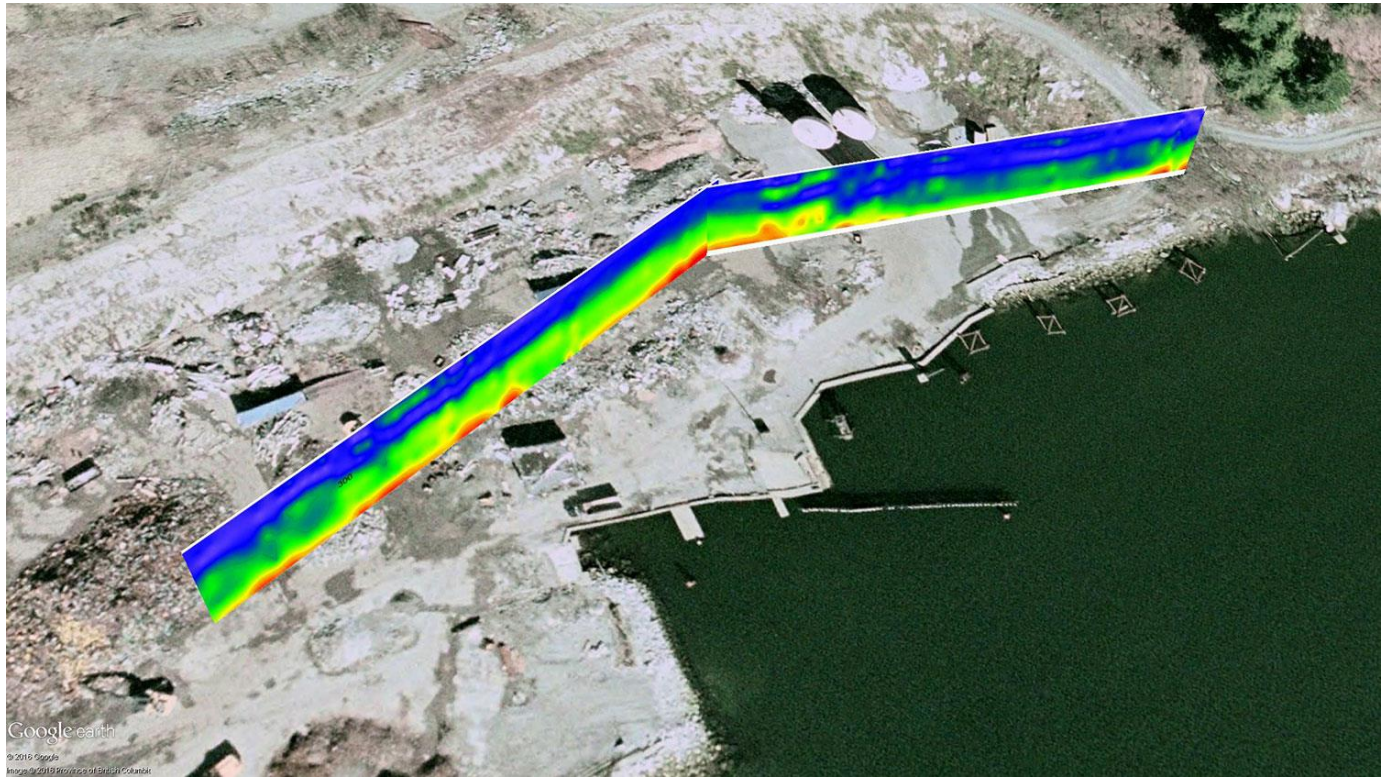
Importance of Phreatic Line…



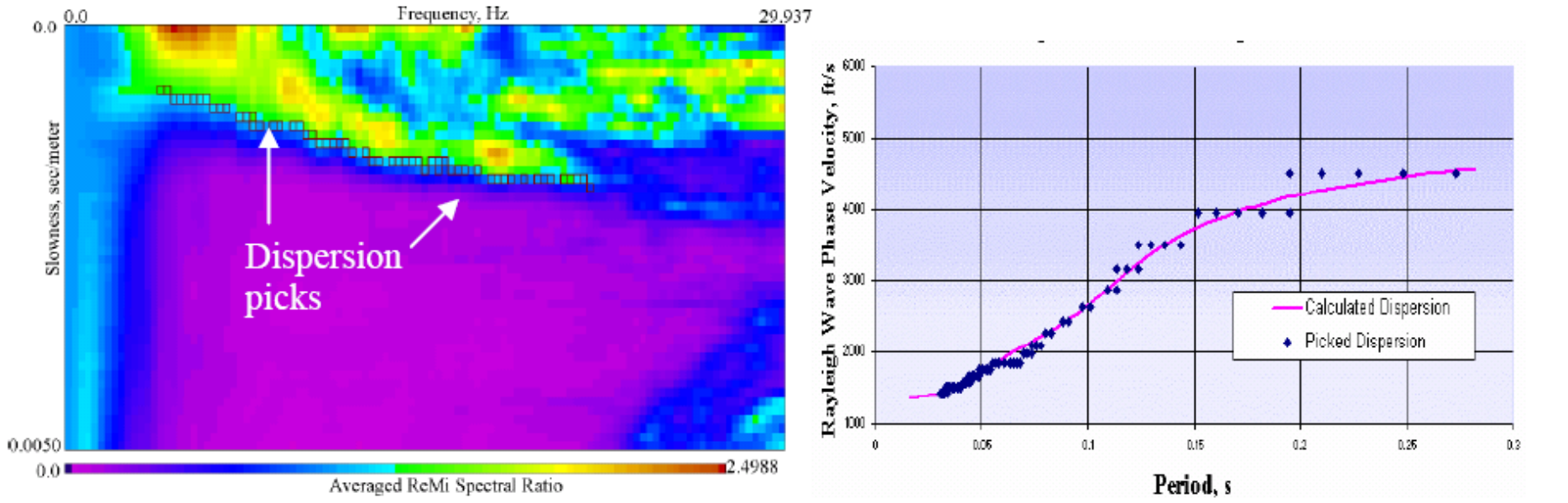
ReMi/ MASW

Application of Remi/ MASW- Dams…

- Provides S Wave Velocity of subsurface- Stiffness
- Undertaken from dam top
- Used for earthquake site response
- Used for liquefaction analysis
- Mapping of subsurface and estimating strength of embankment
- Identification of subsidence zones

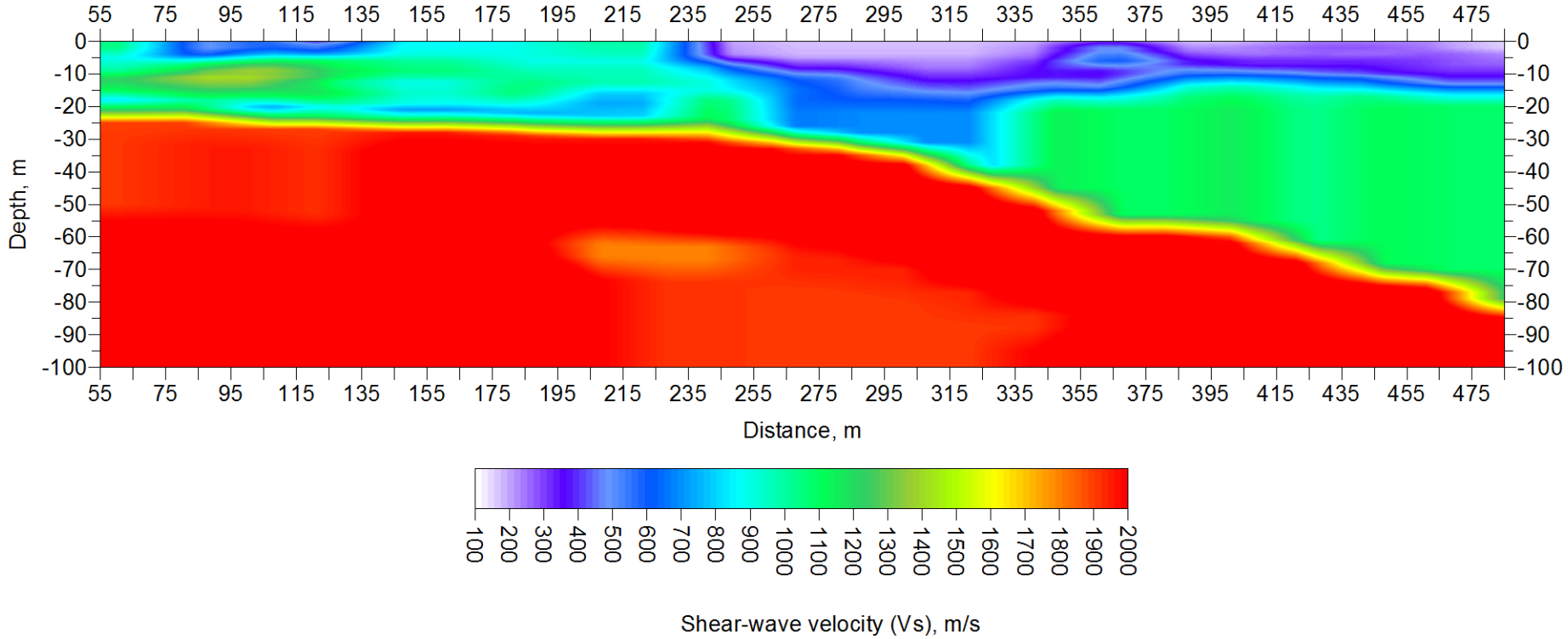


Basic Principle…

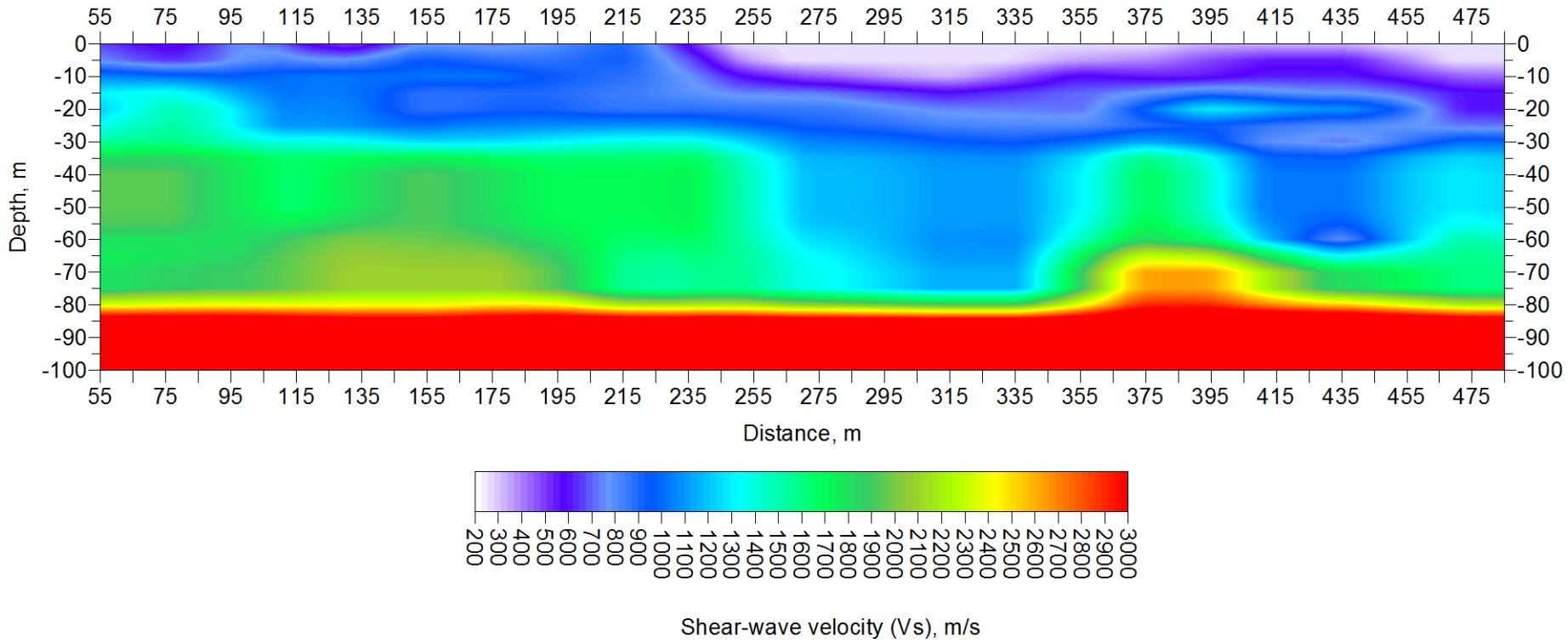


Shear-wave dispersion curve derived from ambient seismic noise, shown on the left, is picked and modeled (right panel)

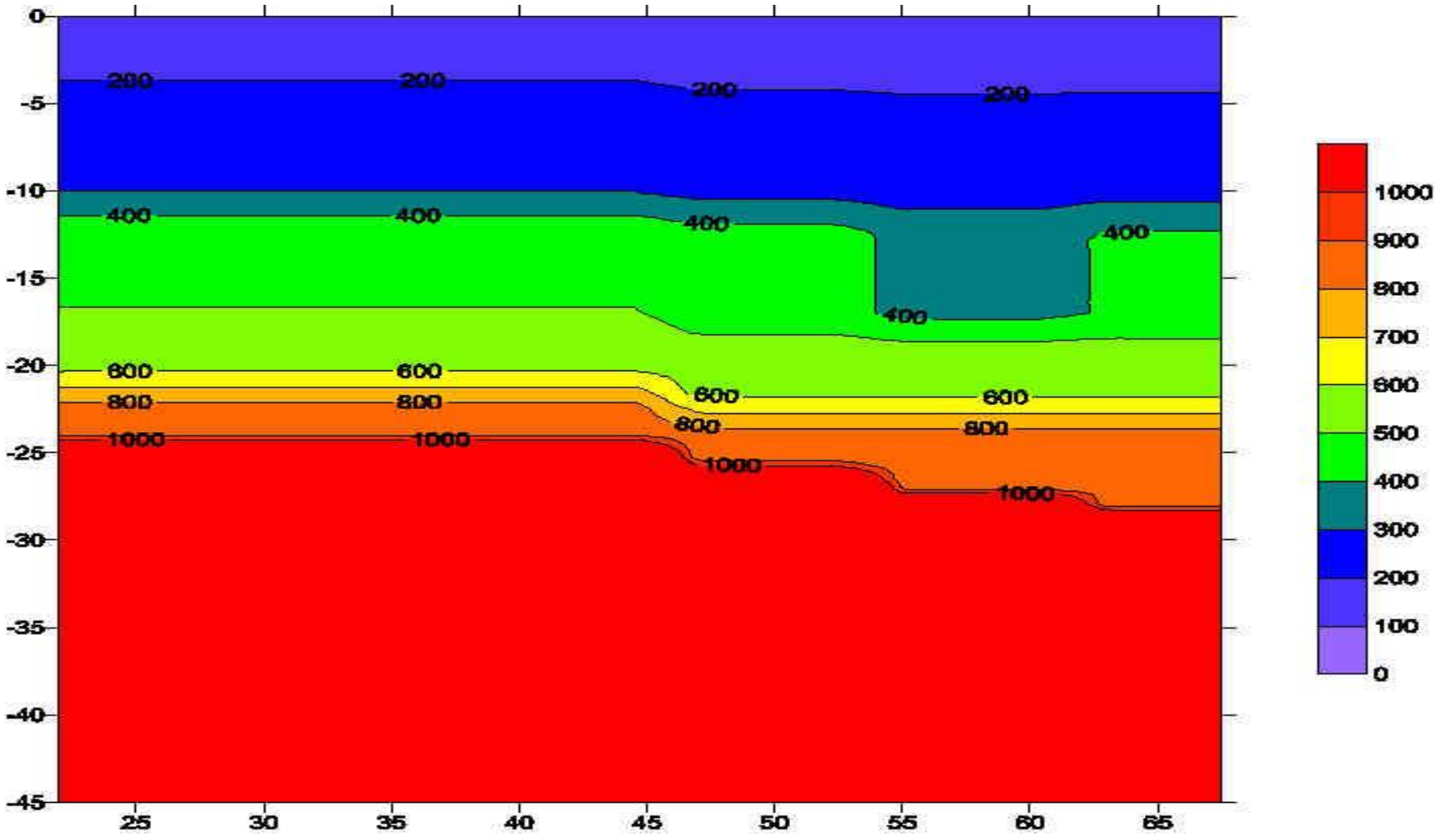
ReMi Results…



ReMi Results…



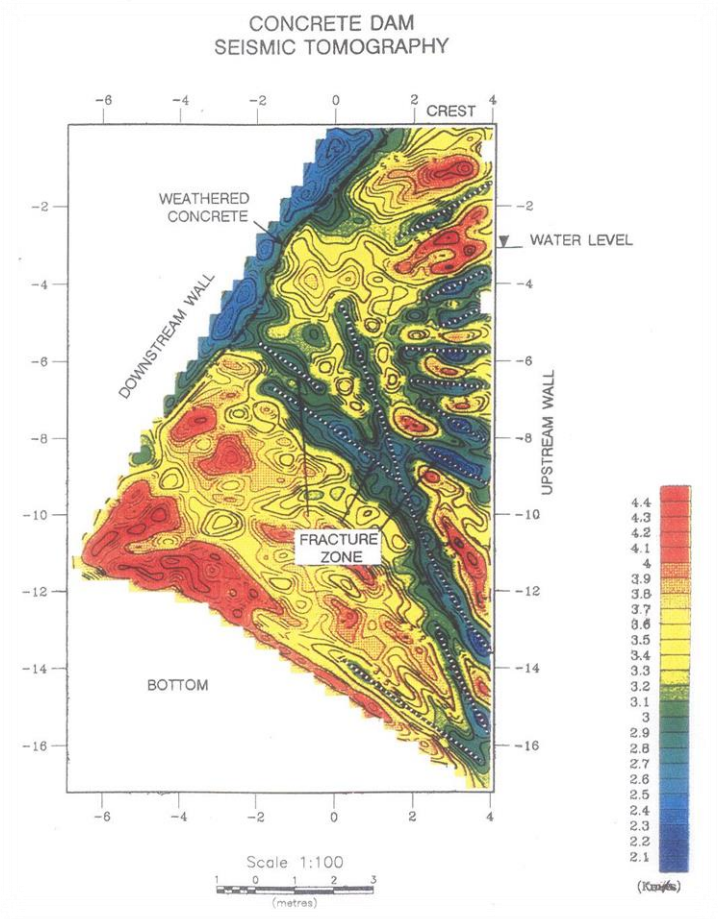
ReMi Results…



Seismic (Sonic) Tomography

Application of Seismic Tomography- Dams…

- Provides high resolution images of dam interior
- Provides P wave velocity- Directly linked to strength & Density
- Done between two faces
    - Between dam top and gallery
    - Between upstream and downstream face
- Possible to pin-point defect zones within the dam
- Enables grout quantity estimation
- Determines treatment success by pre and post treatment study



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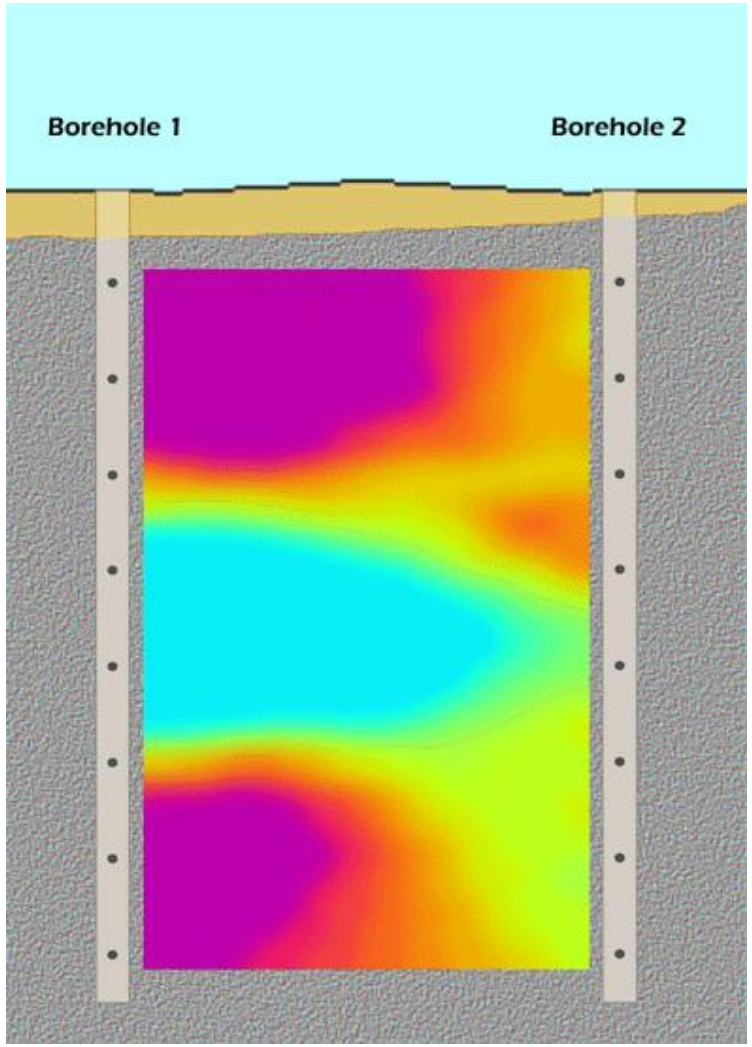
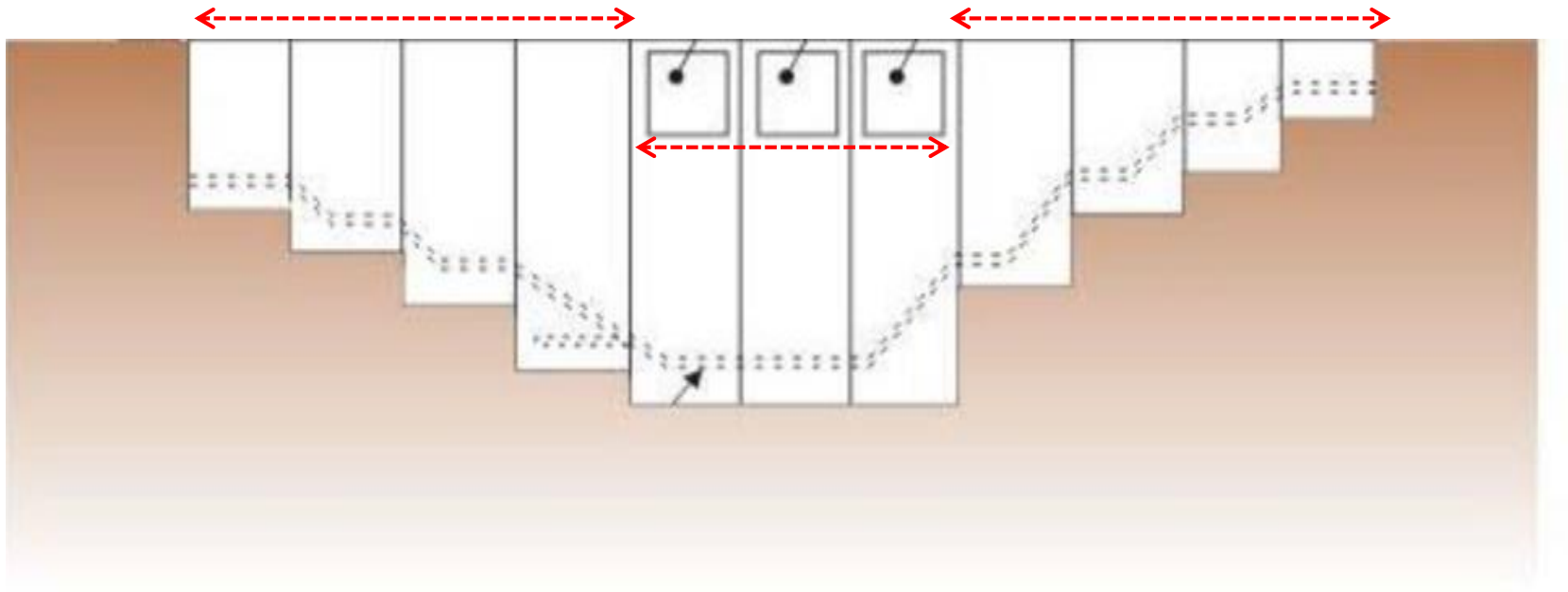


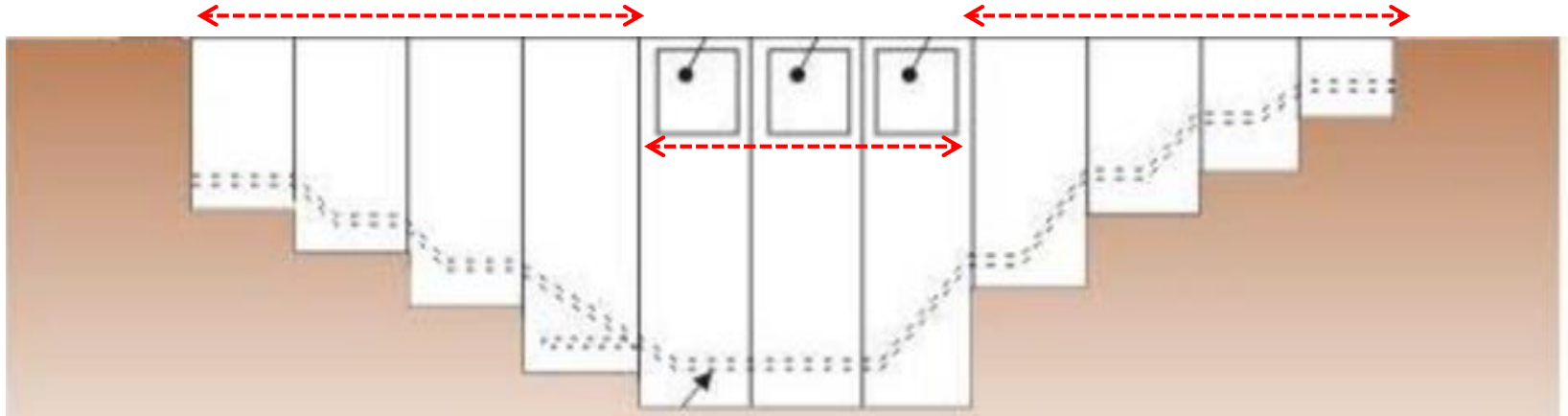
L-Section Tomography…

Transmitter / Shot Points – Dam Top & Spillway Crest



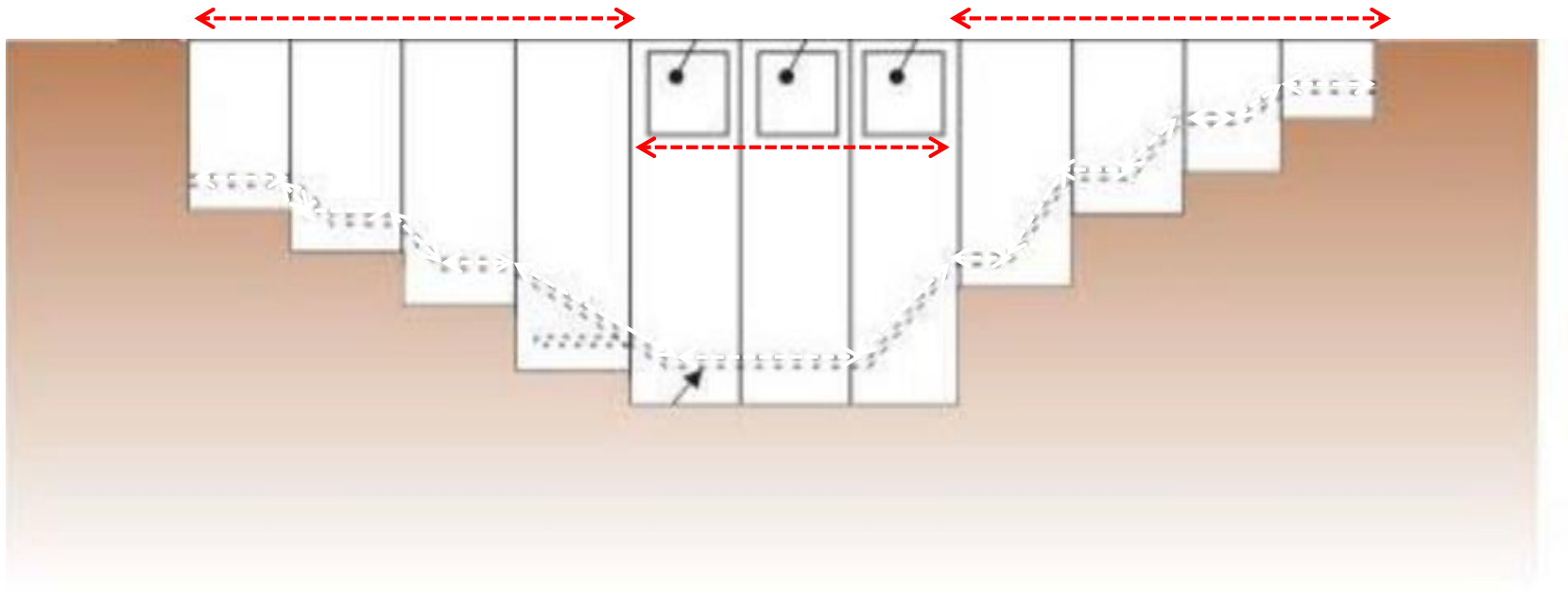
L-Section Tomography…

Transmitter / Shot Points – Dam Top & Spillway Crest



L-Section Tomography…

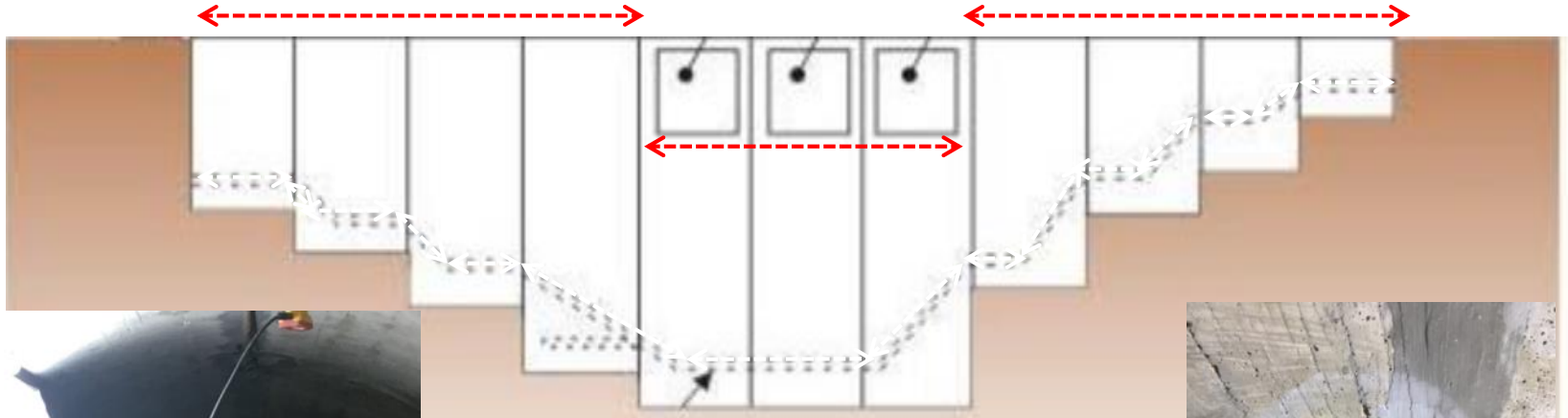
Transmitter / Shot Points – Dam Top & Spillway Crest



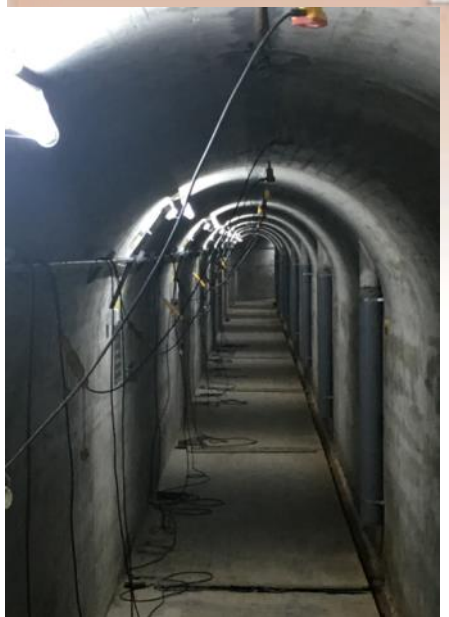
Receiver Points – Dam Gallery Crown

L-Section Tomography…

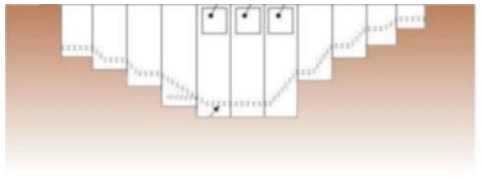
Transmitter / Shot Points – Dam Top & Spillway Crest

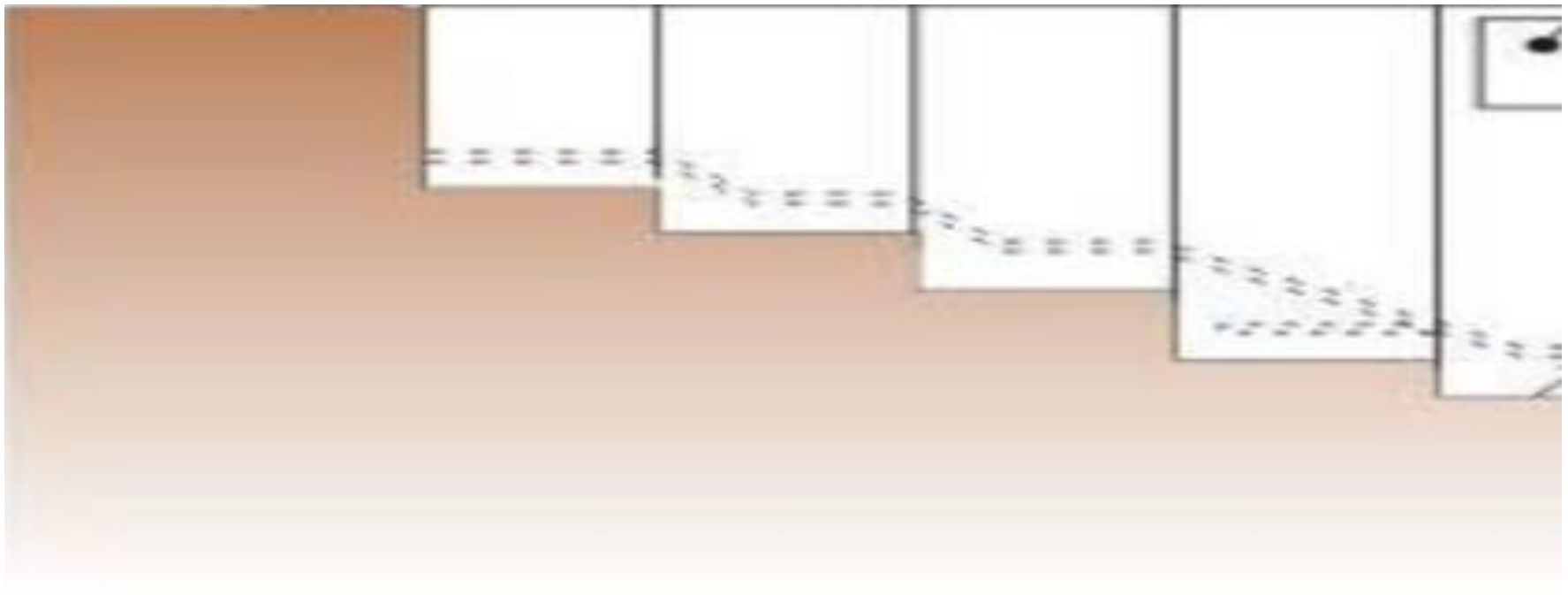


Receiver Points – Dam Gallery Crown

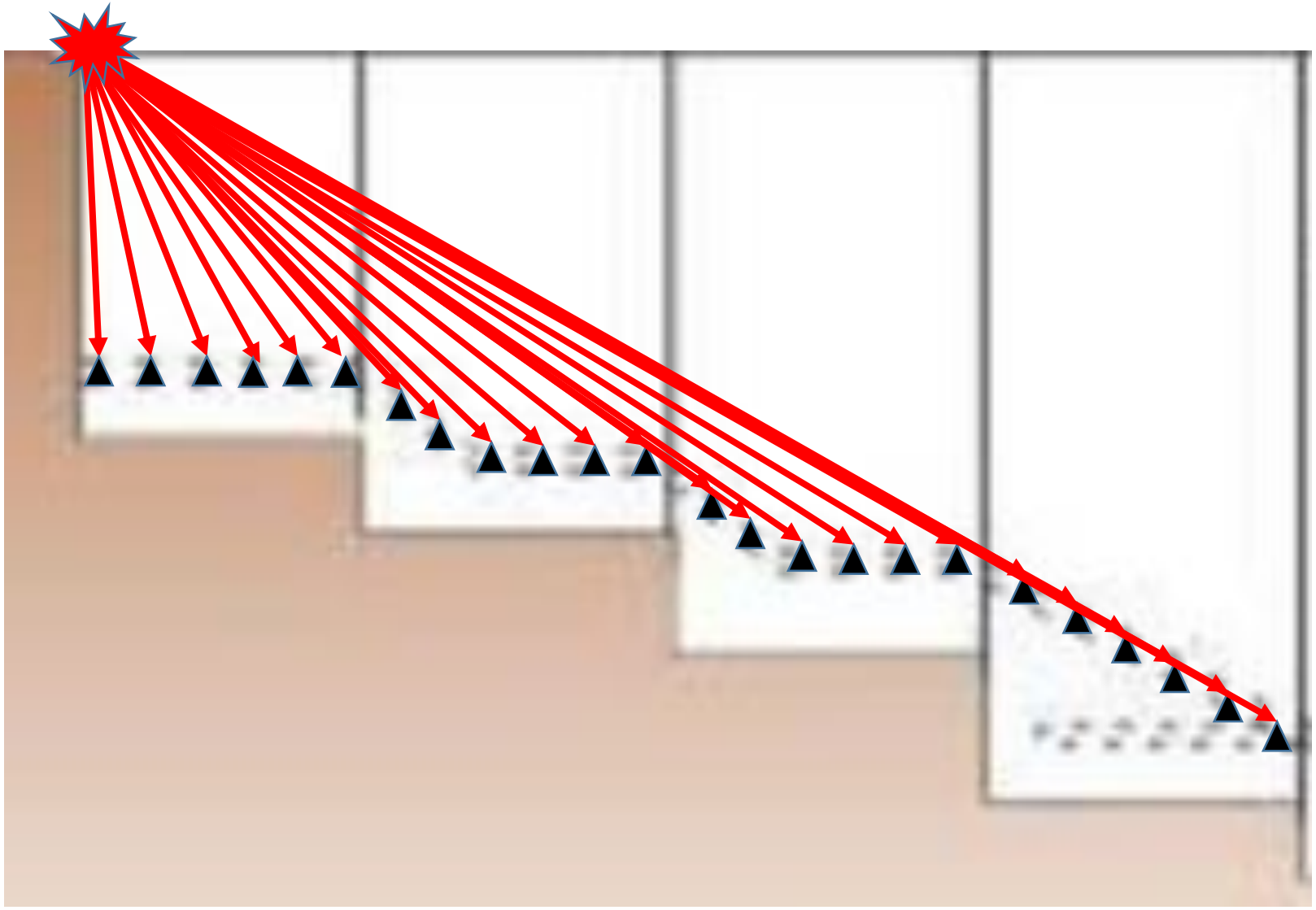


L-Section Tomography…

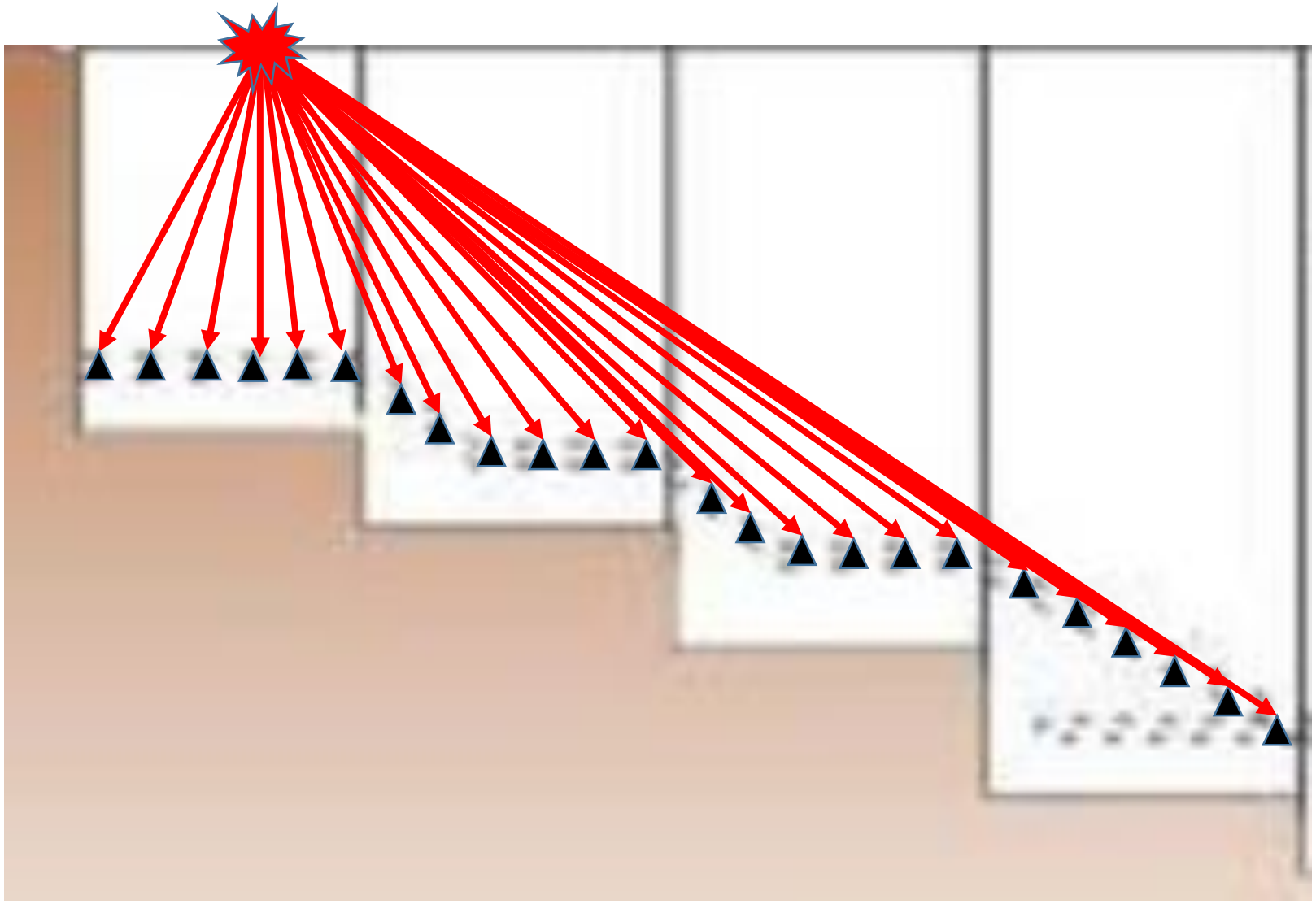




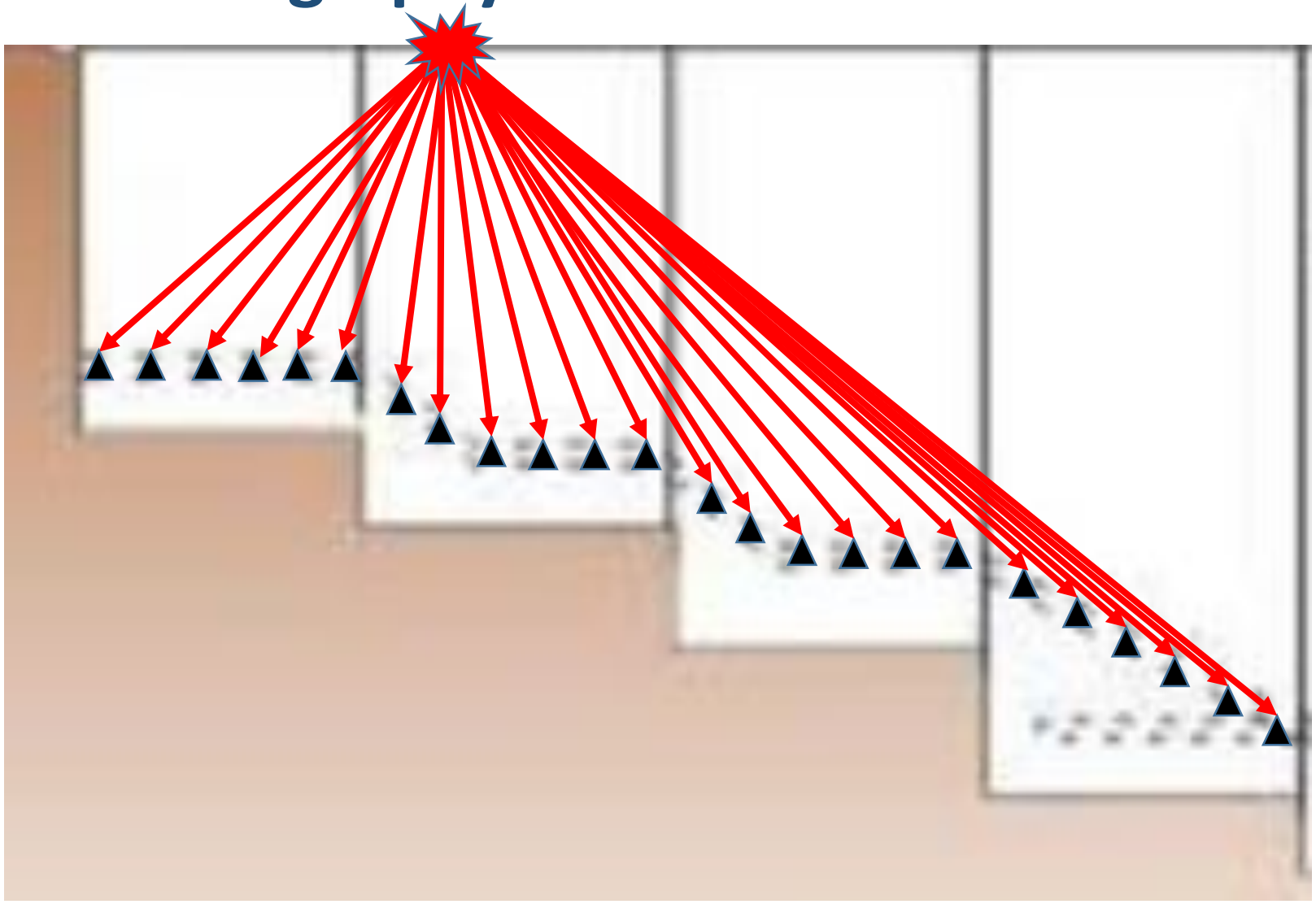
L-Section Tomography…



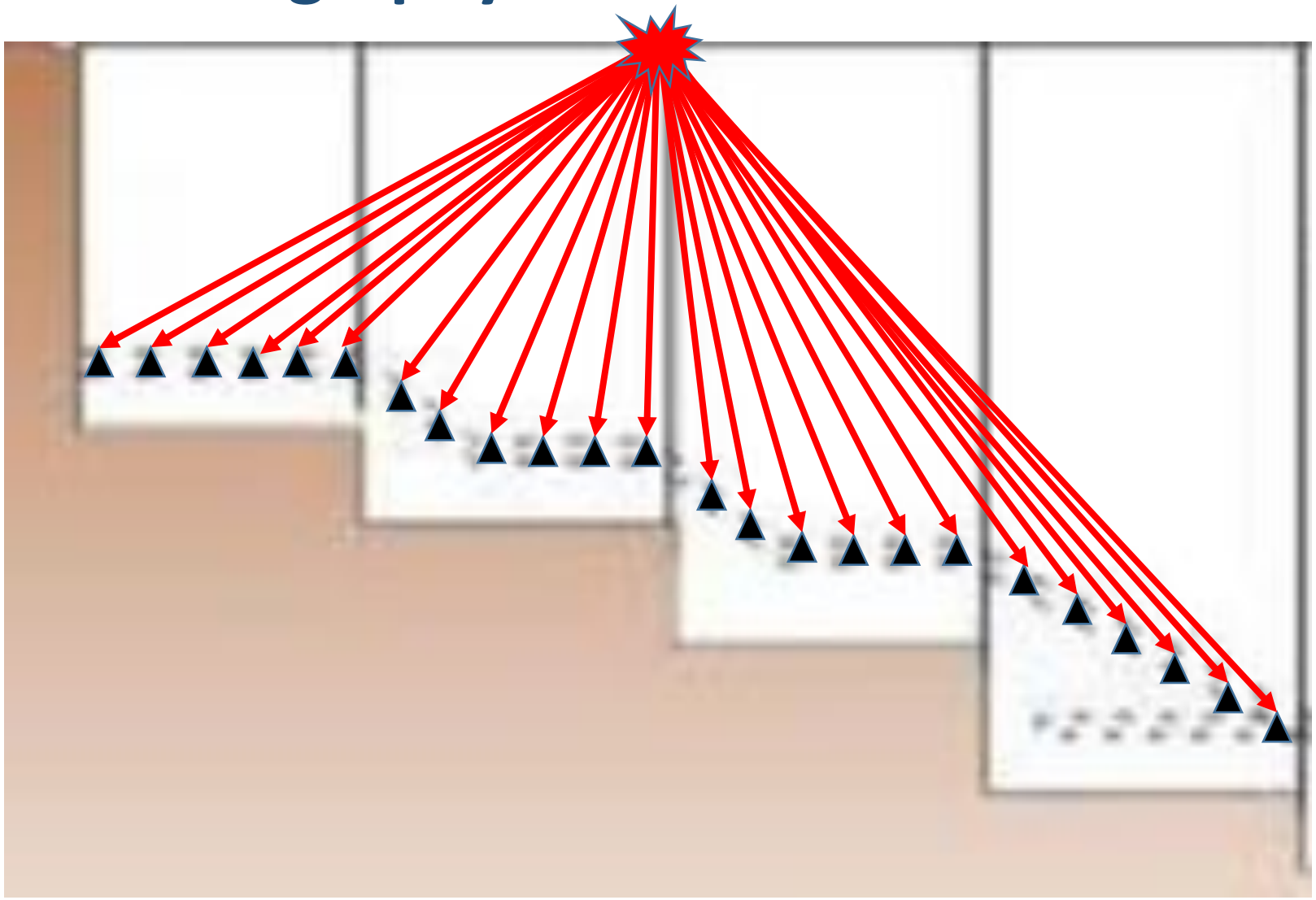
L-Section Tomography…



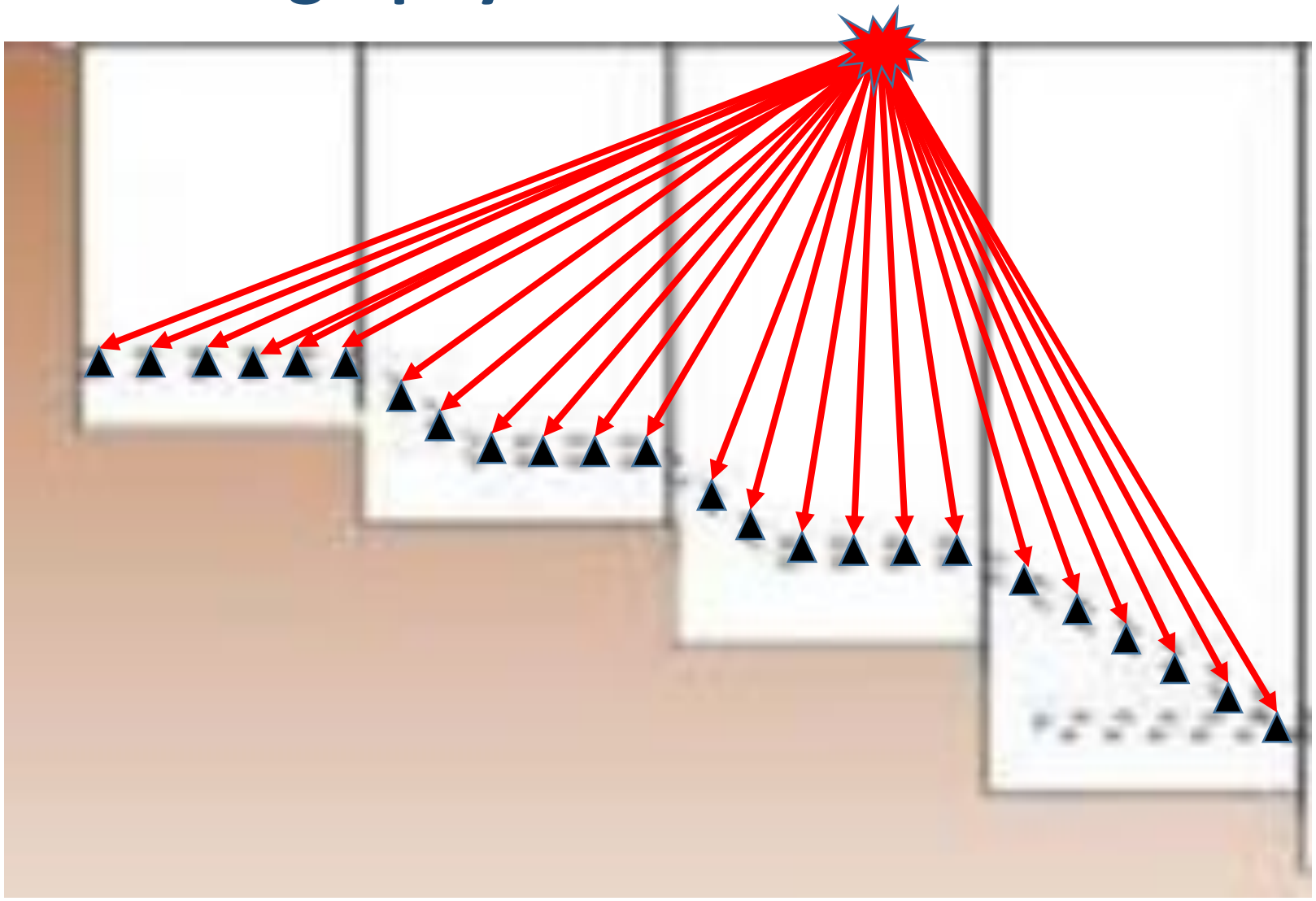
L-Section Tomography…



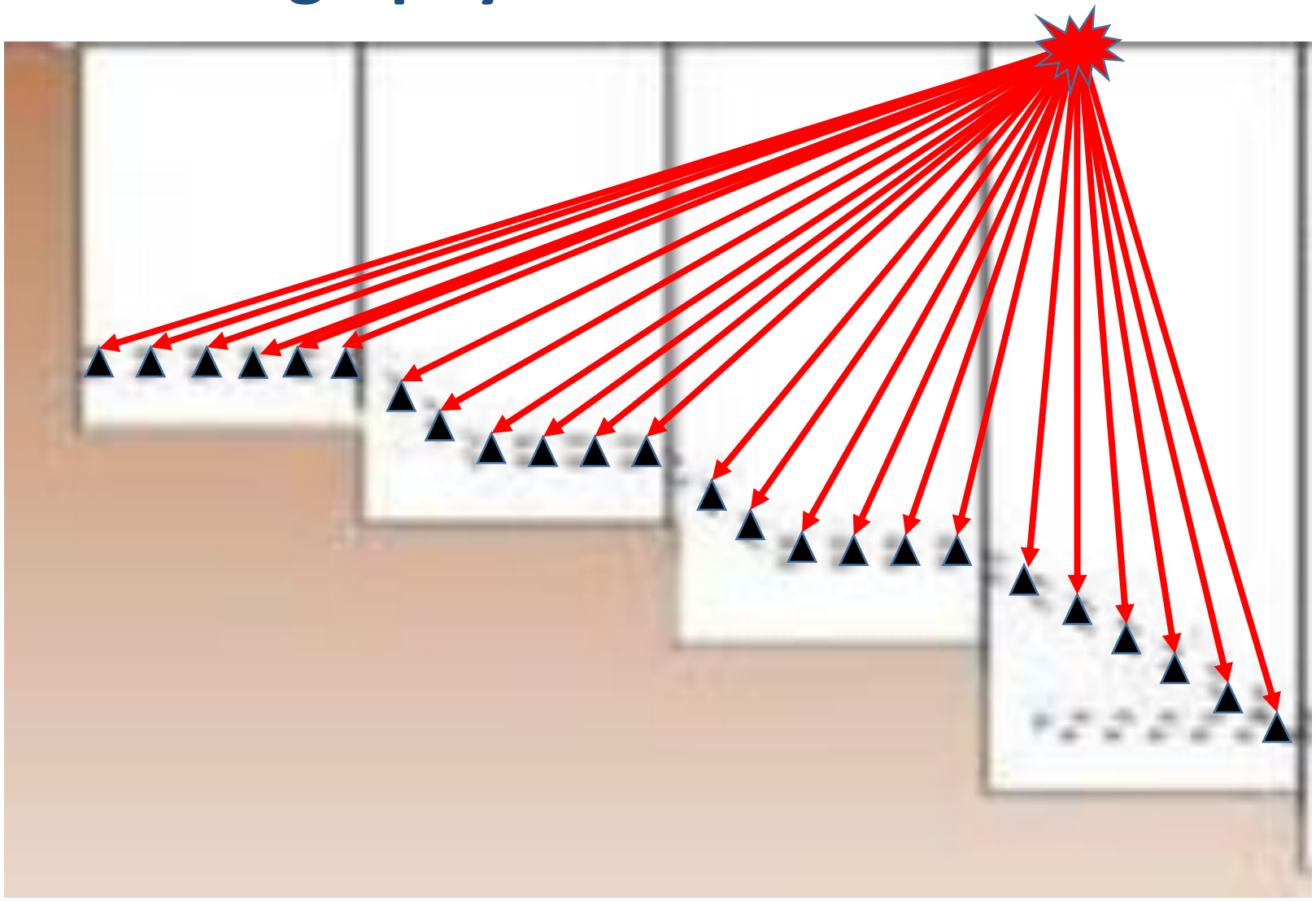
L-Section Tomography…



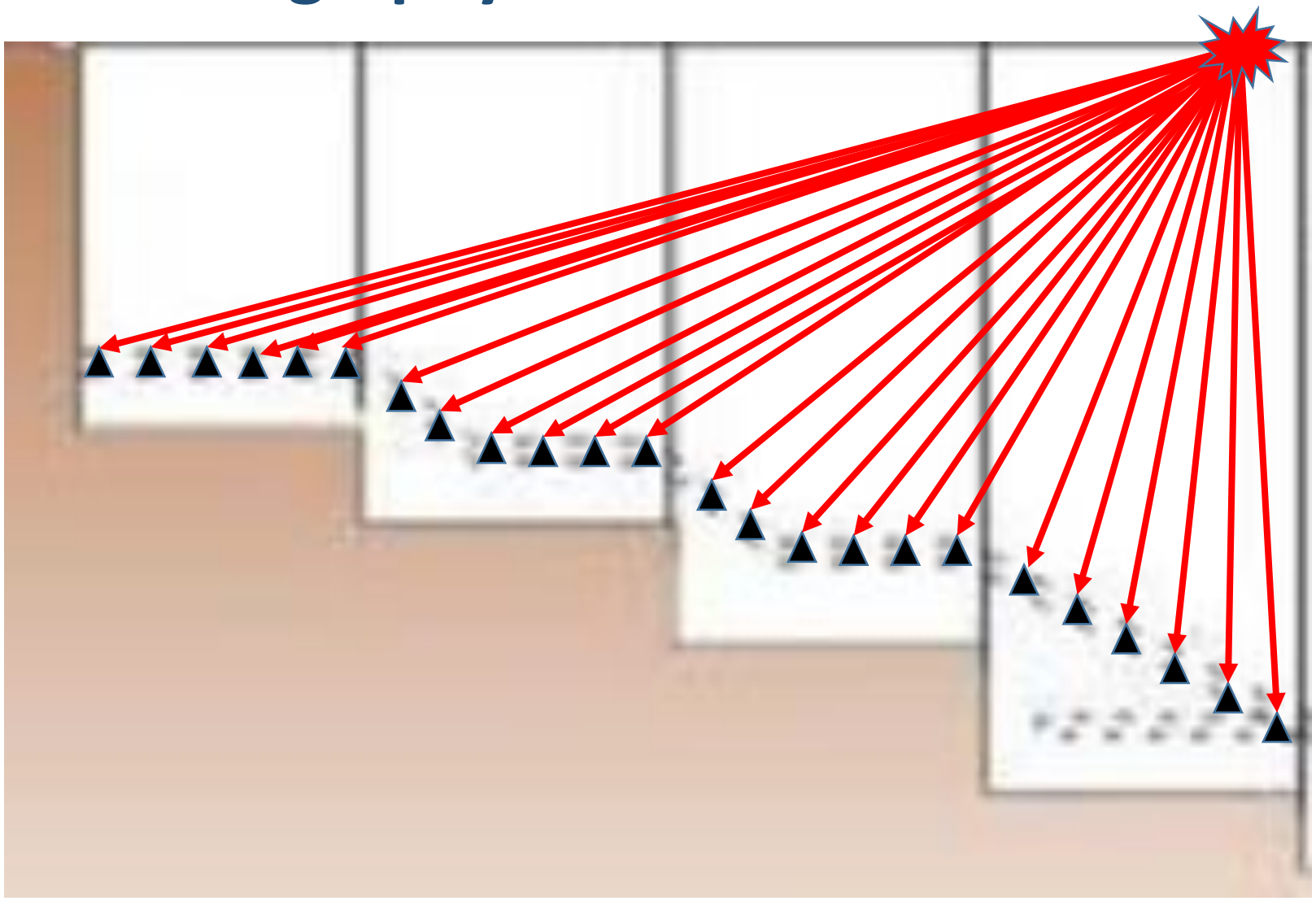
L-Section Tomography…



L-Section Tomography…

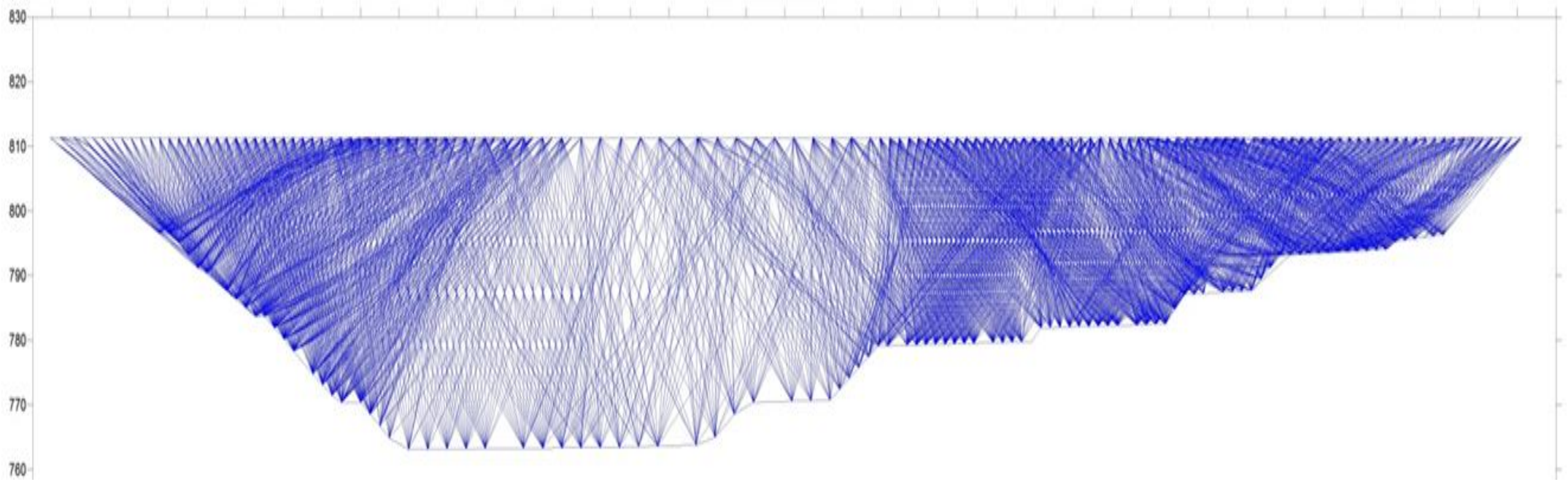


L-Section Tomography…

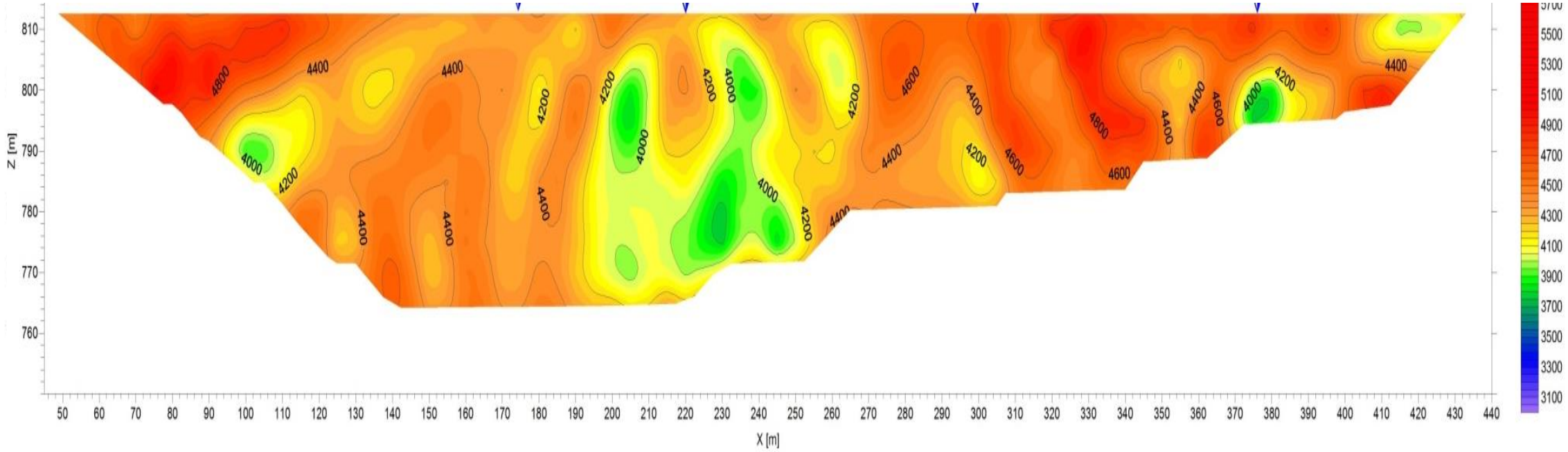


L-Section Tomography…

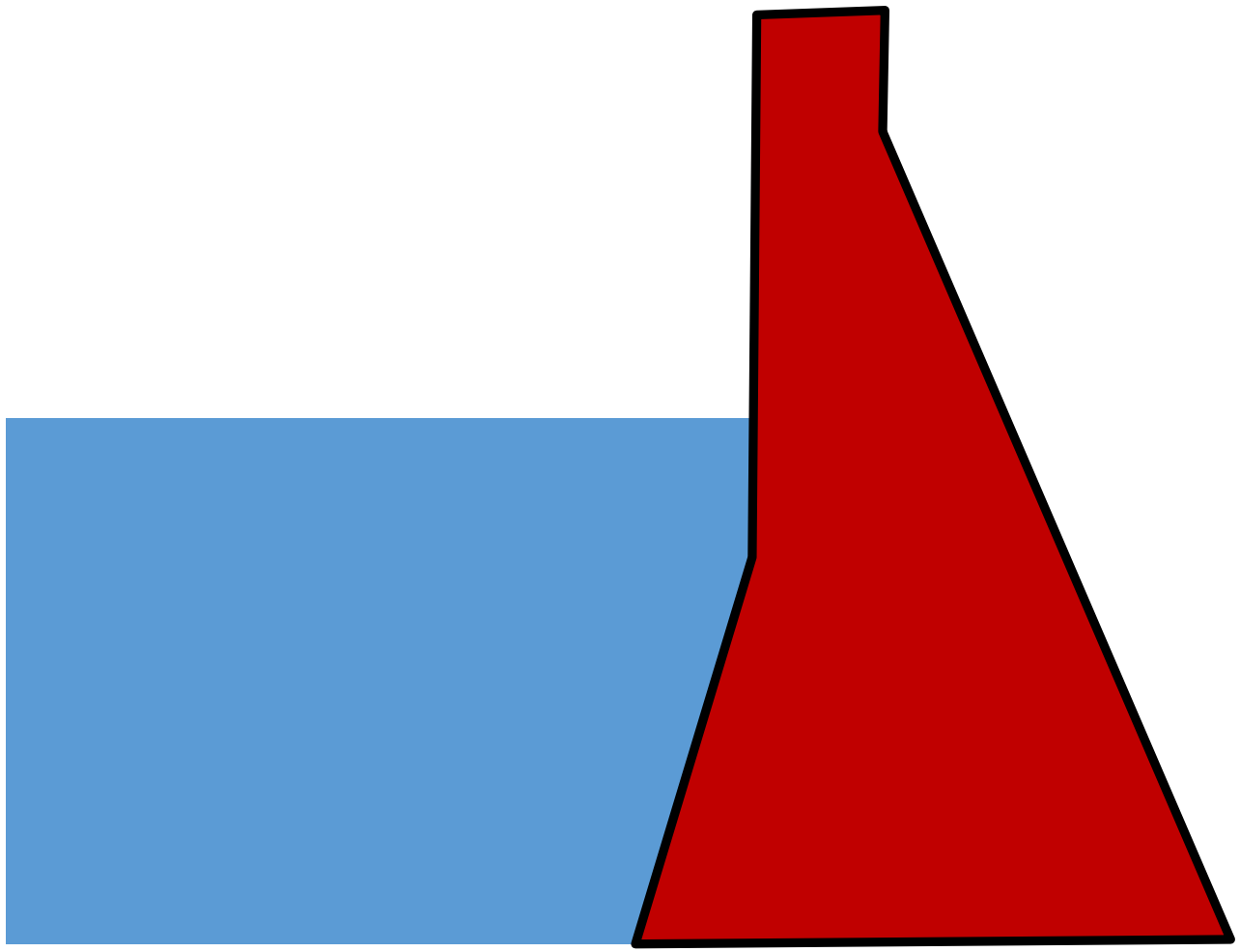
L-Section Tomography…Ray Path Coverage



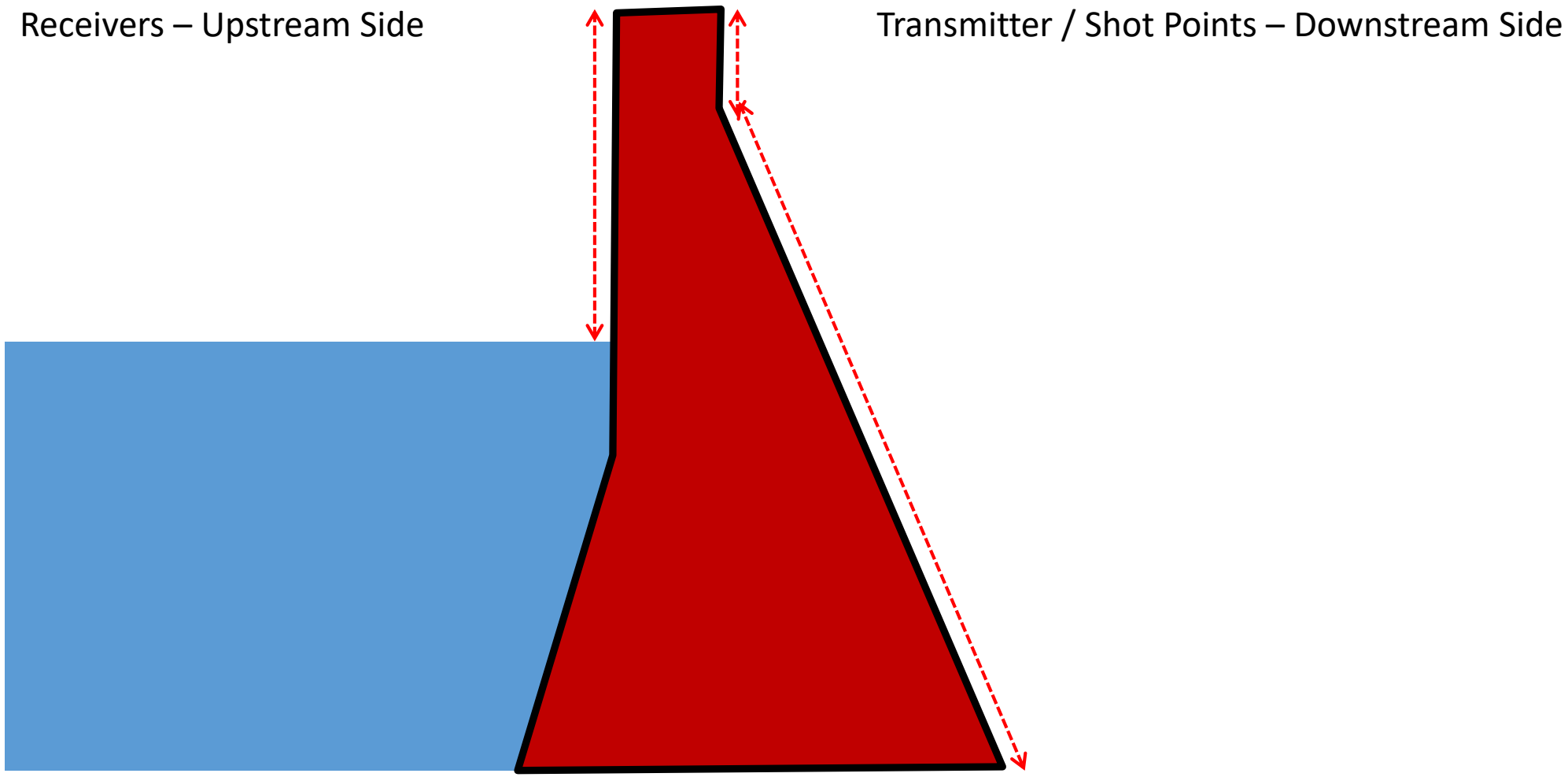
L-Section Tomography…Inversion & Velocity Model



Cross Face Tomography…

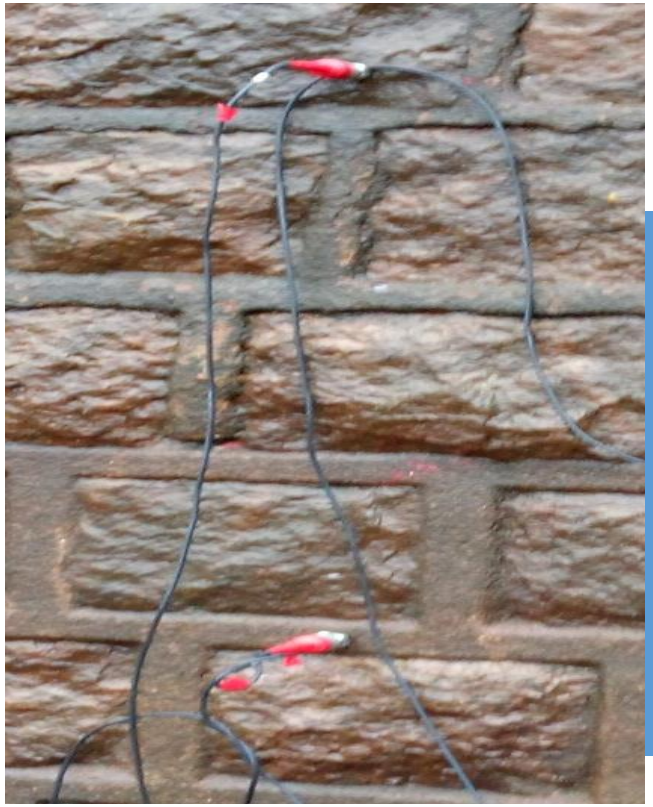


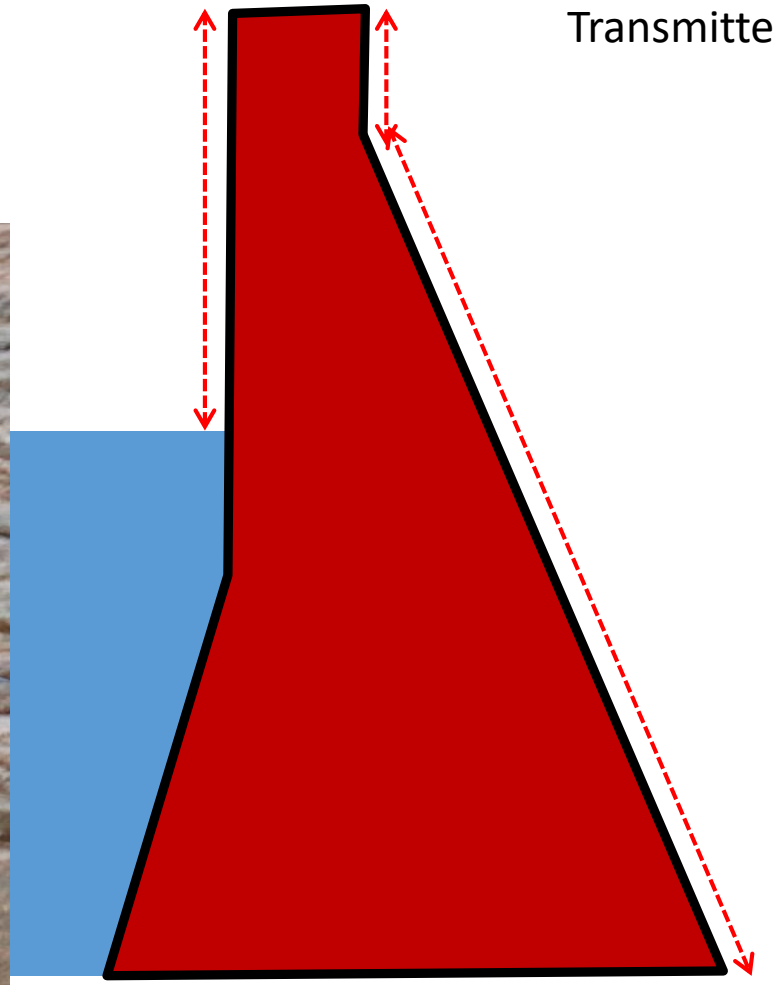
Cross Face Tomography… Above water area



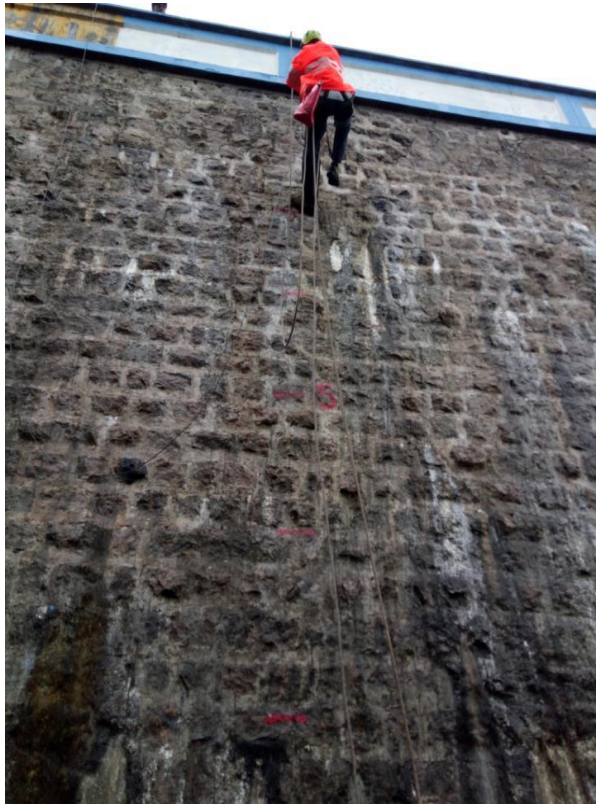
Cross Face Tomography… Above water area

Receivers – Upstream Side

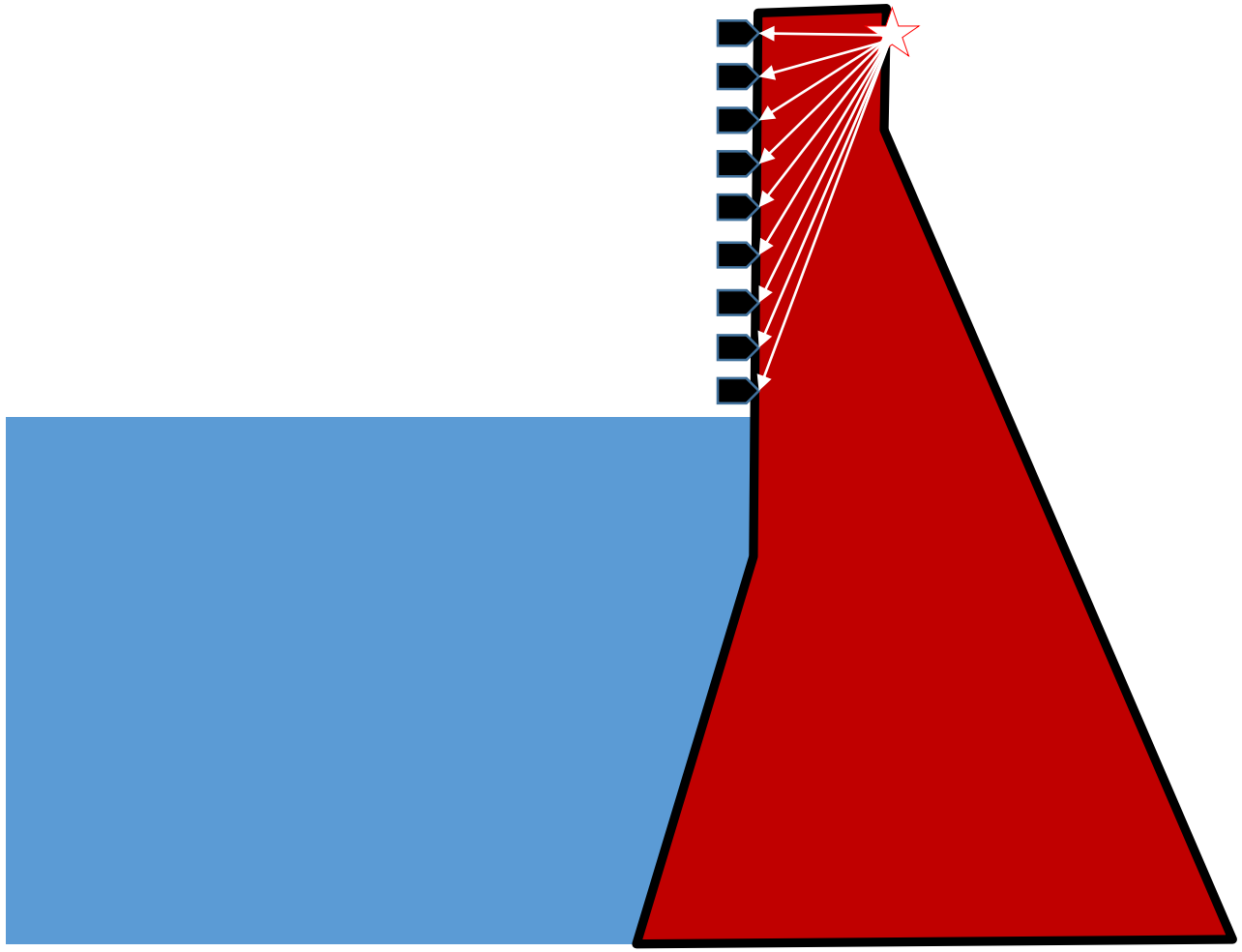




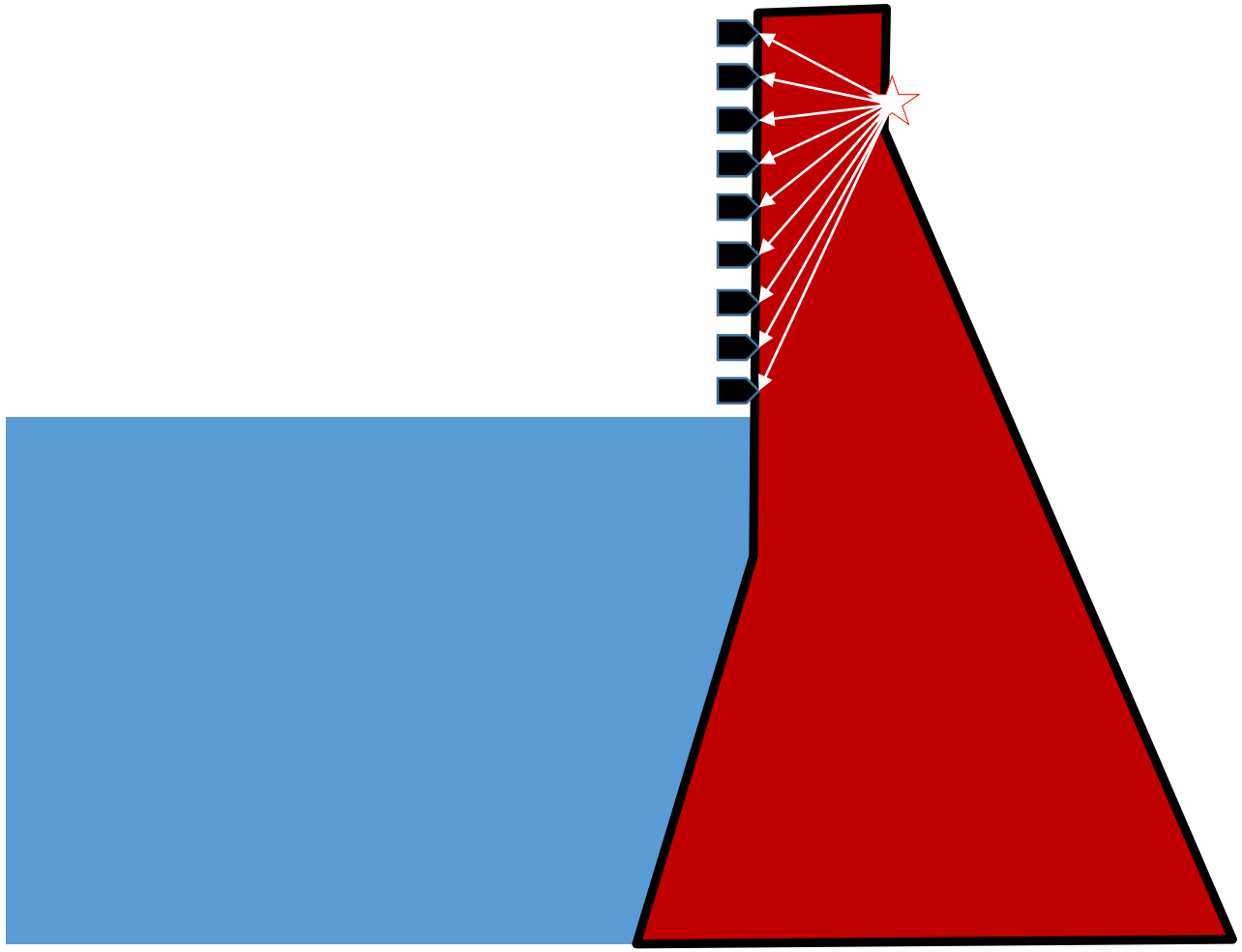
Transmitter / Shot Points – Downstream Side



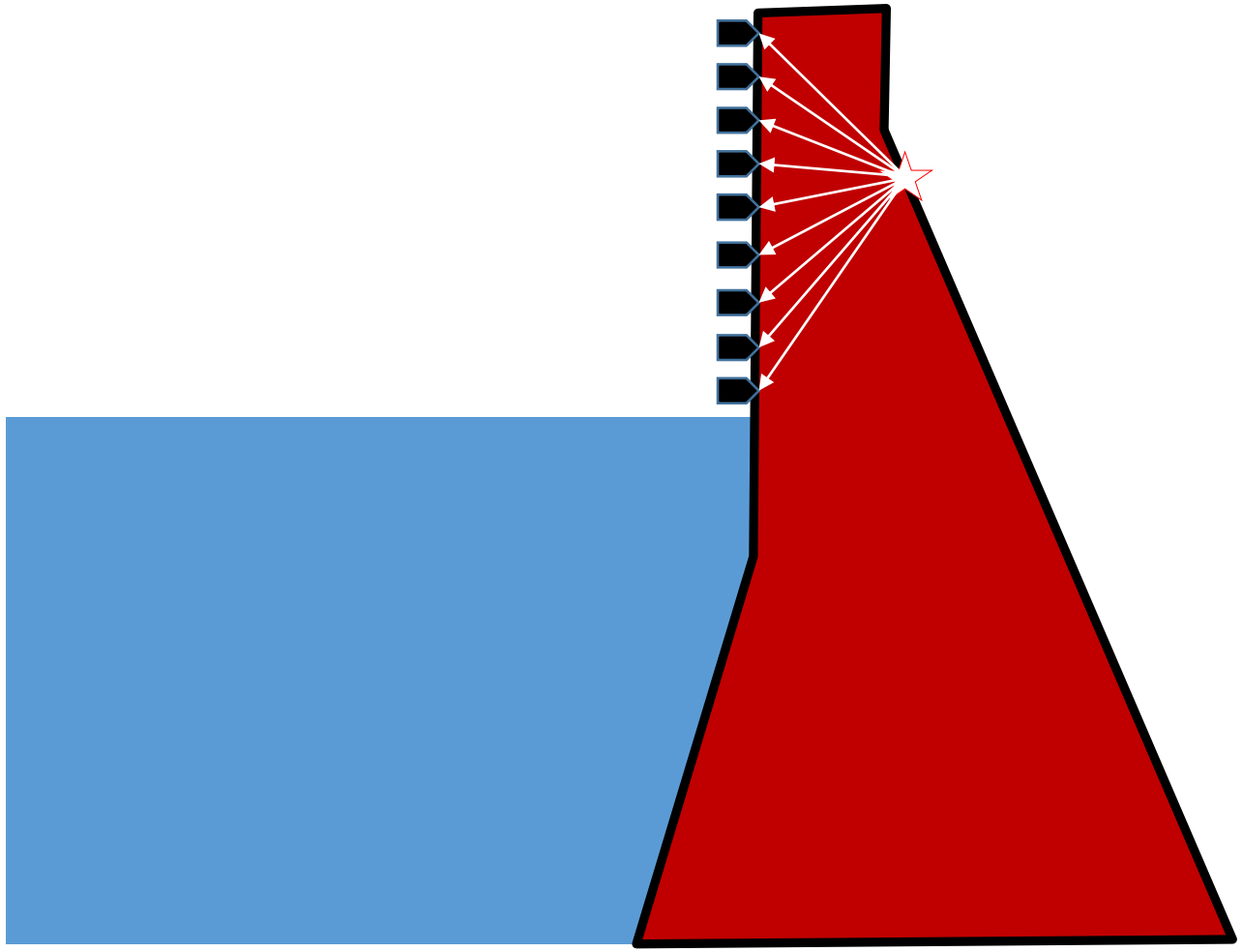
Cross Face Tomography… Above water area



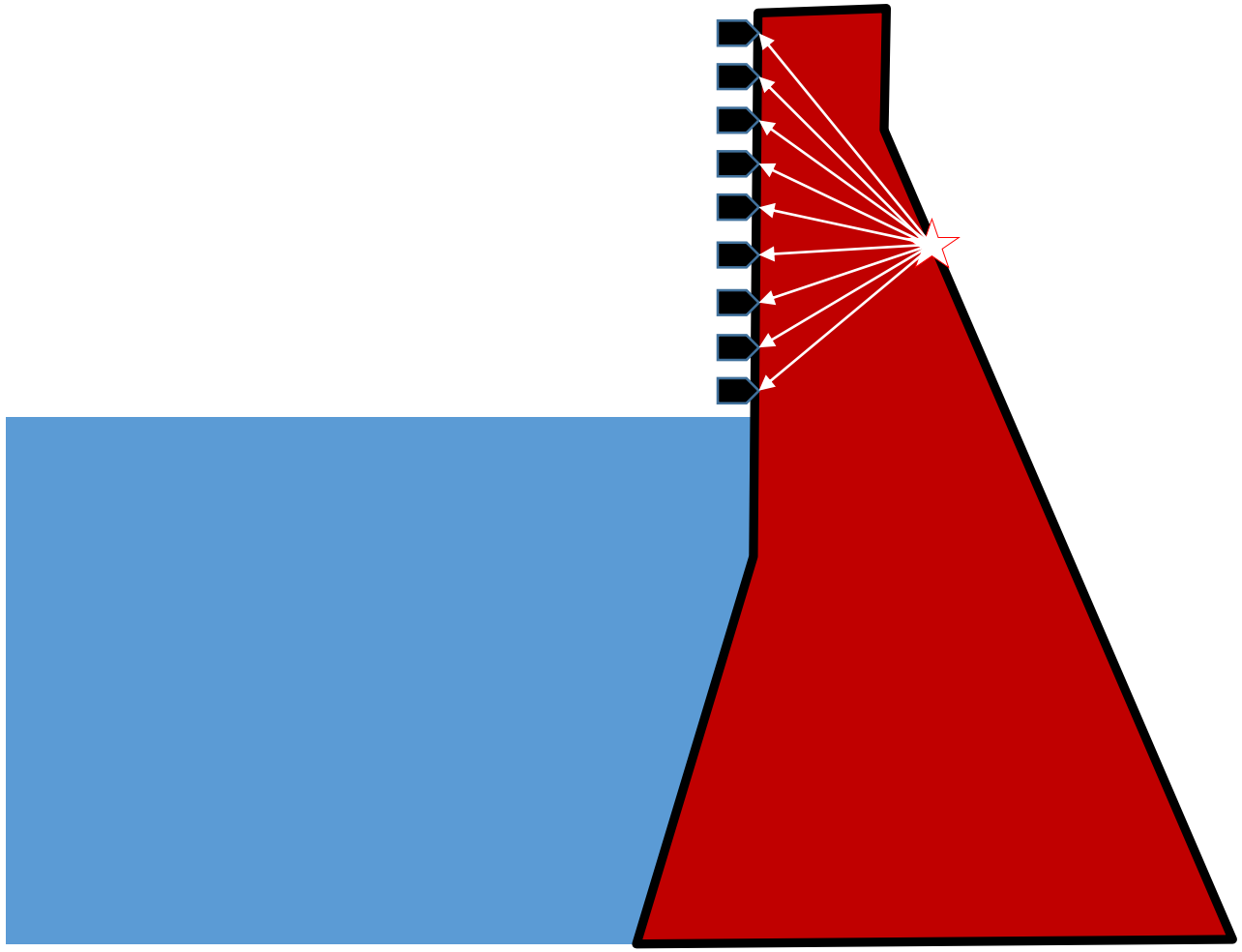
Cross Face Tomography… Above water area



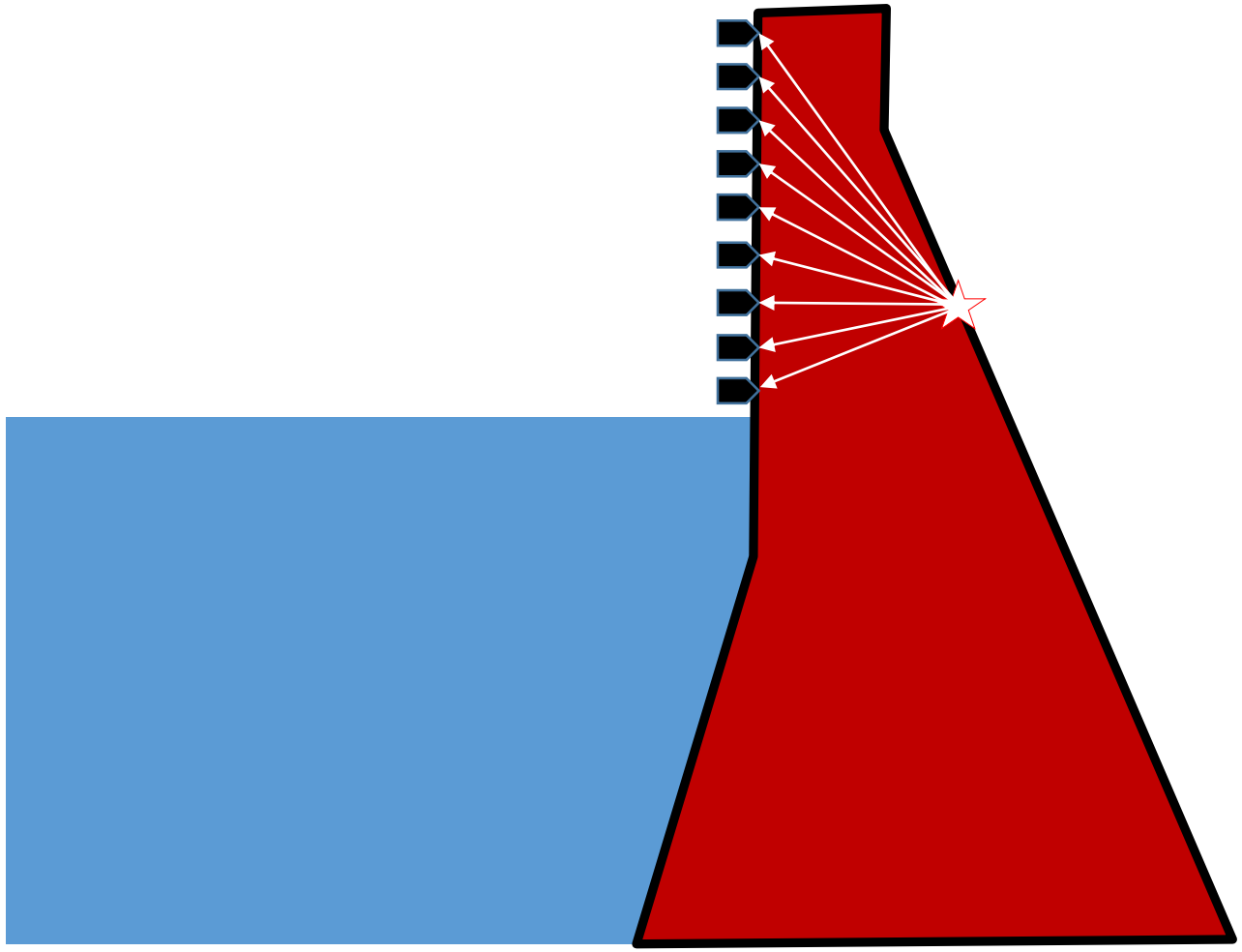
Cross Face Tomography… Above water area



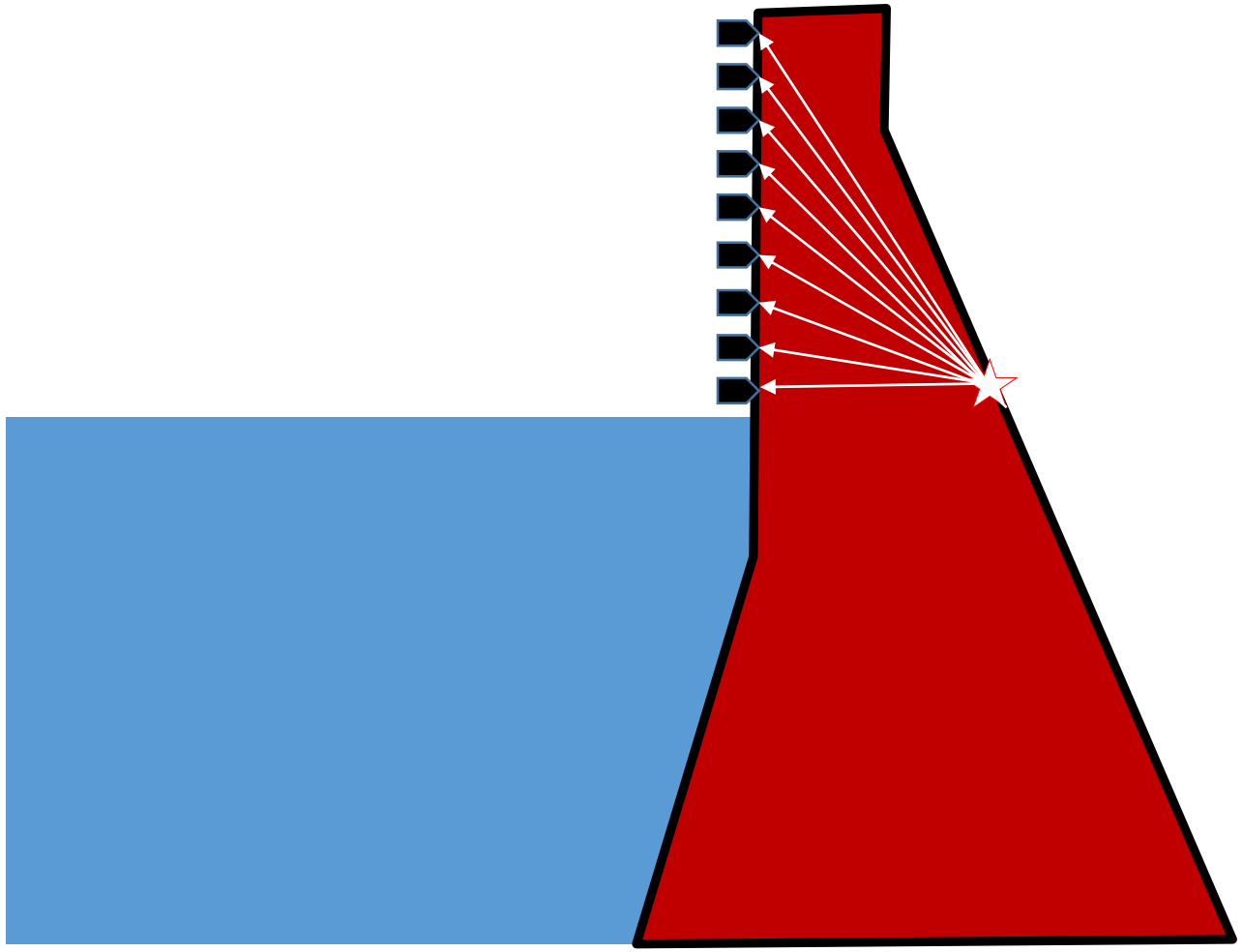
Cross Face Tomography… Above water area



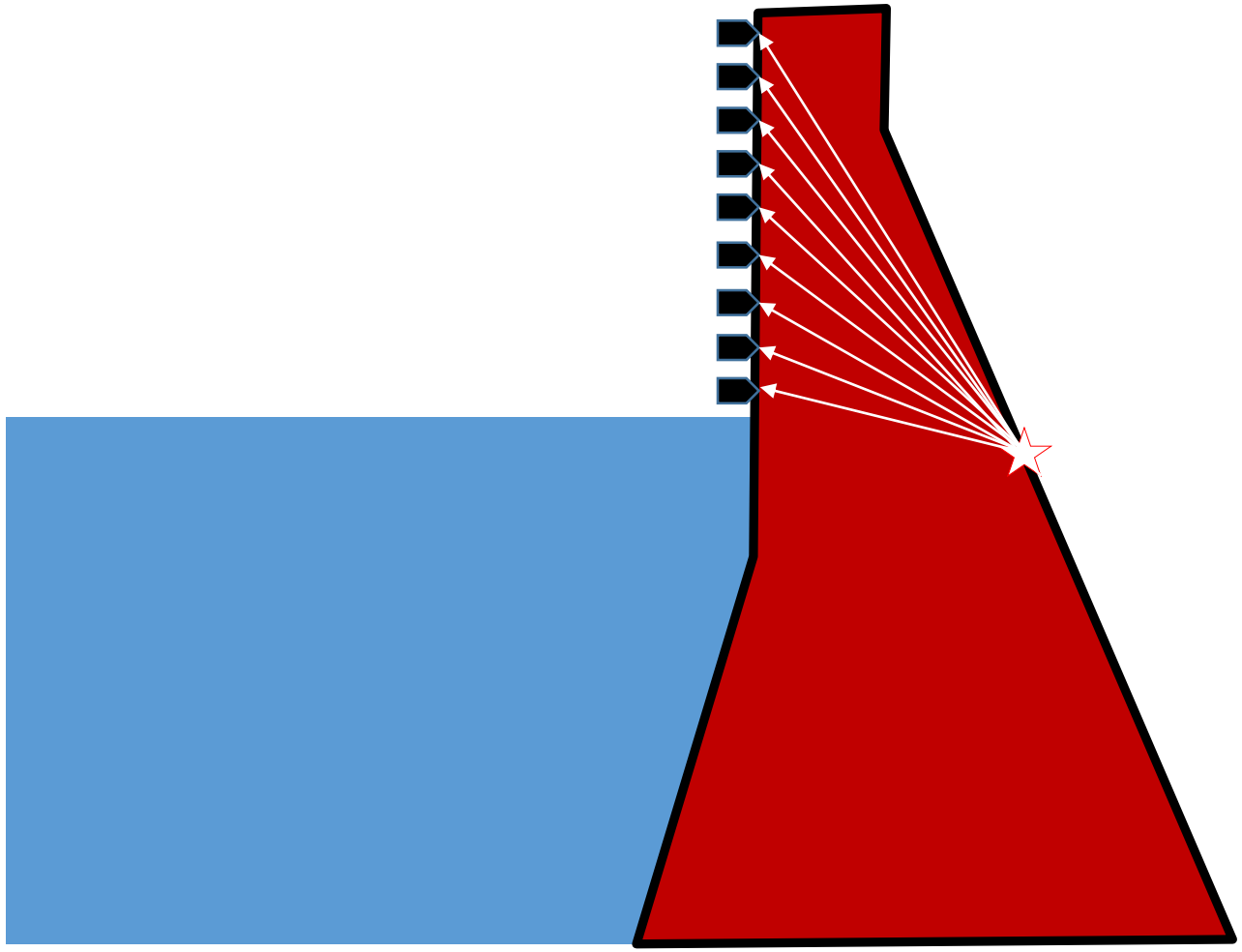
Cross Face Tomography… Above water area



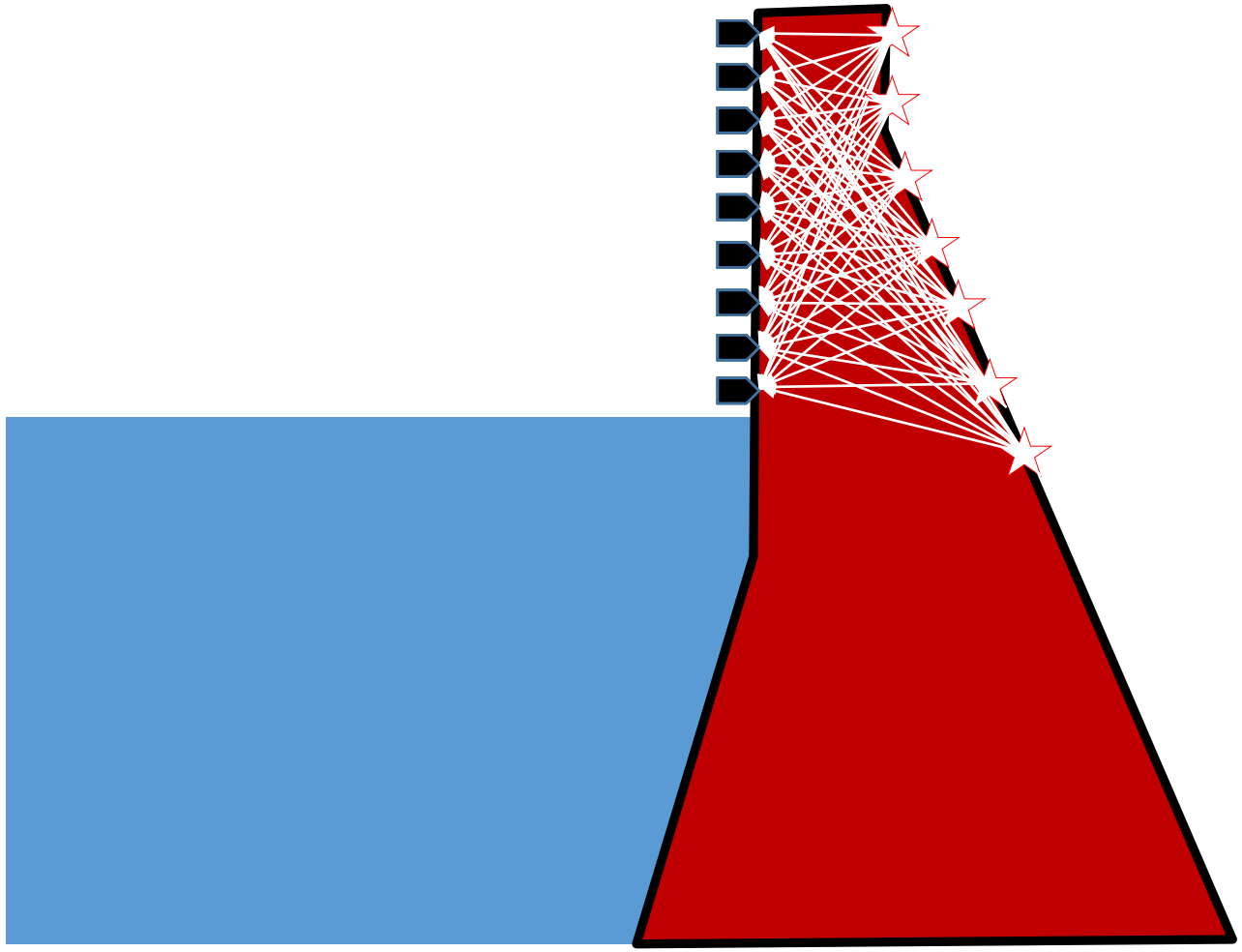
Cross Face Tomography… Above water area



Cross Face Tomography… Above water area



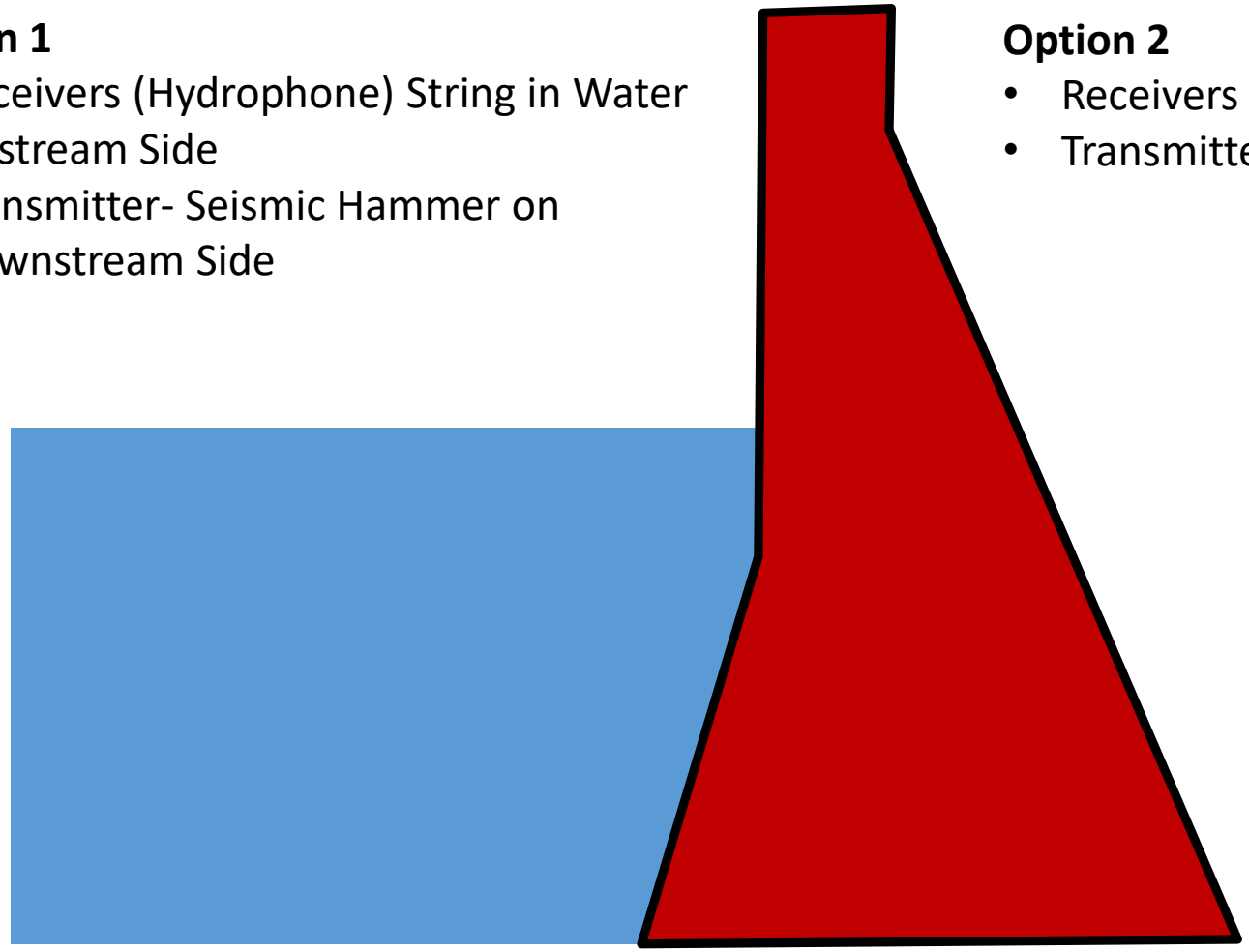
Cross Face Tomography… Above water area



Cross Face Tomography… Under water area

Option 1

- Receivers (Hydrophone) String in Water Upstream Side
- Transmitter- Seismic Hammer on Downstream Side



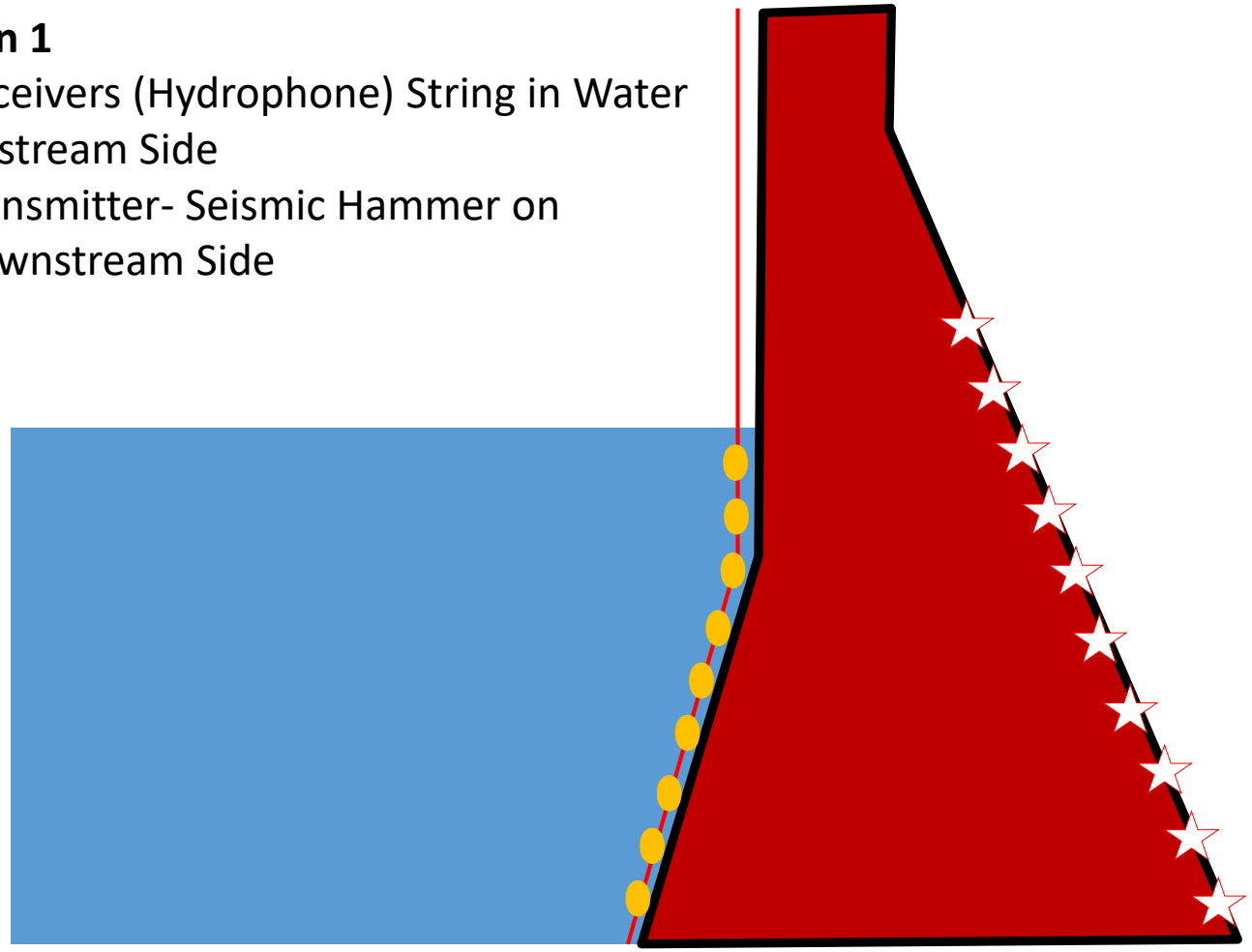
Option 2

- Receivers – Geophones on Downstream side
- Transmitter- Sparker on Upstream Side

Cross Face Tomography… Under water area

Option 1

- Receivers (Hydrophone) String in Water Upstream Side
- Transmitter- Seismic Hammer on Downstream Side



Cross Face Tomography… Under water area

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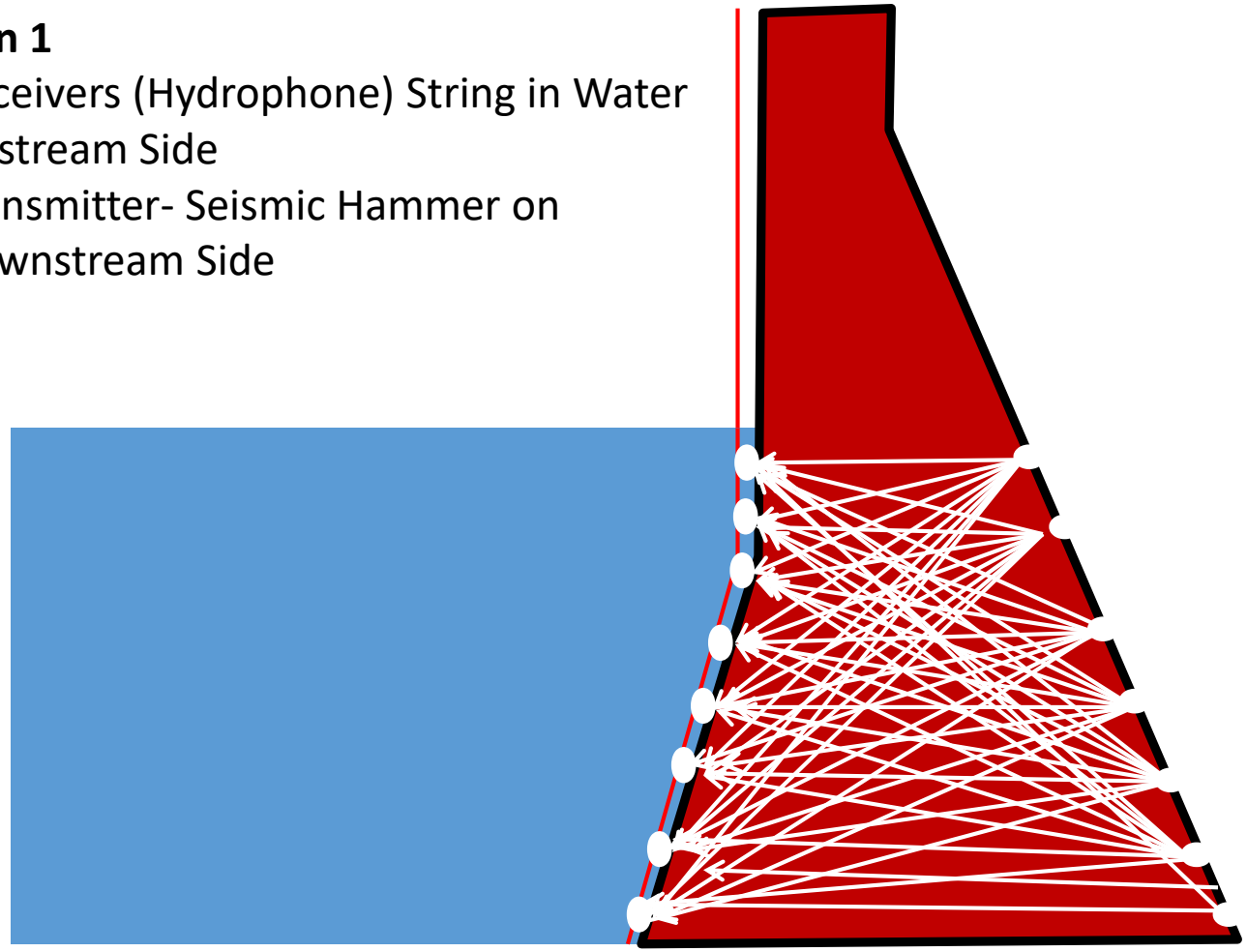
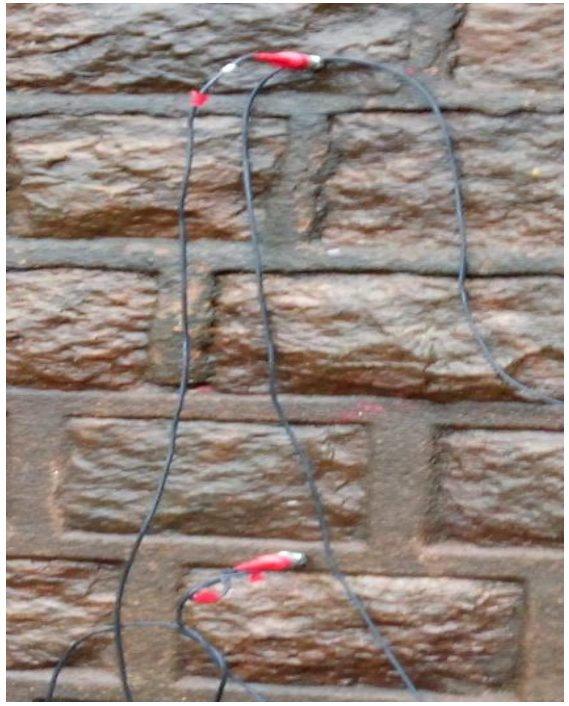


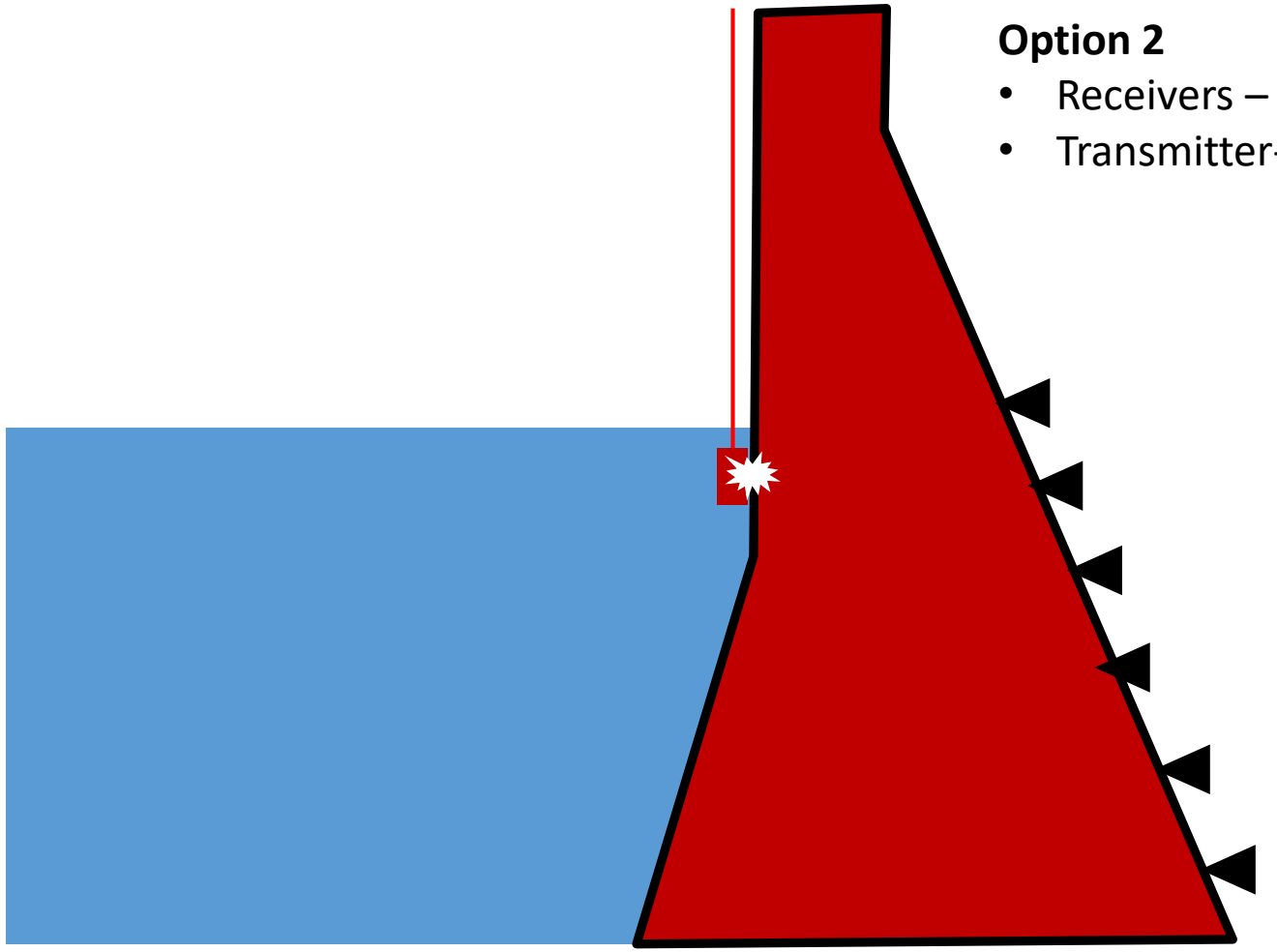
Cross Face Tomography… Under water area

Option 2

- Receivers – Geophones on Downstream side
- Transmitter- Sparker on Upstream Side



Cross Face Tomography… Under water area



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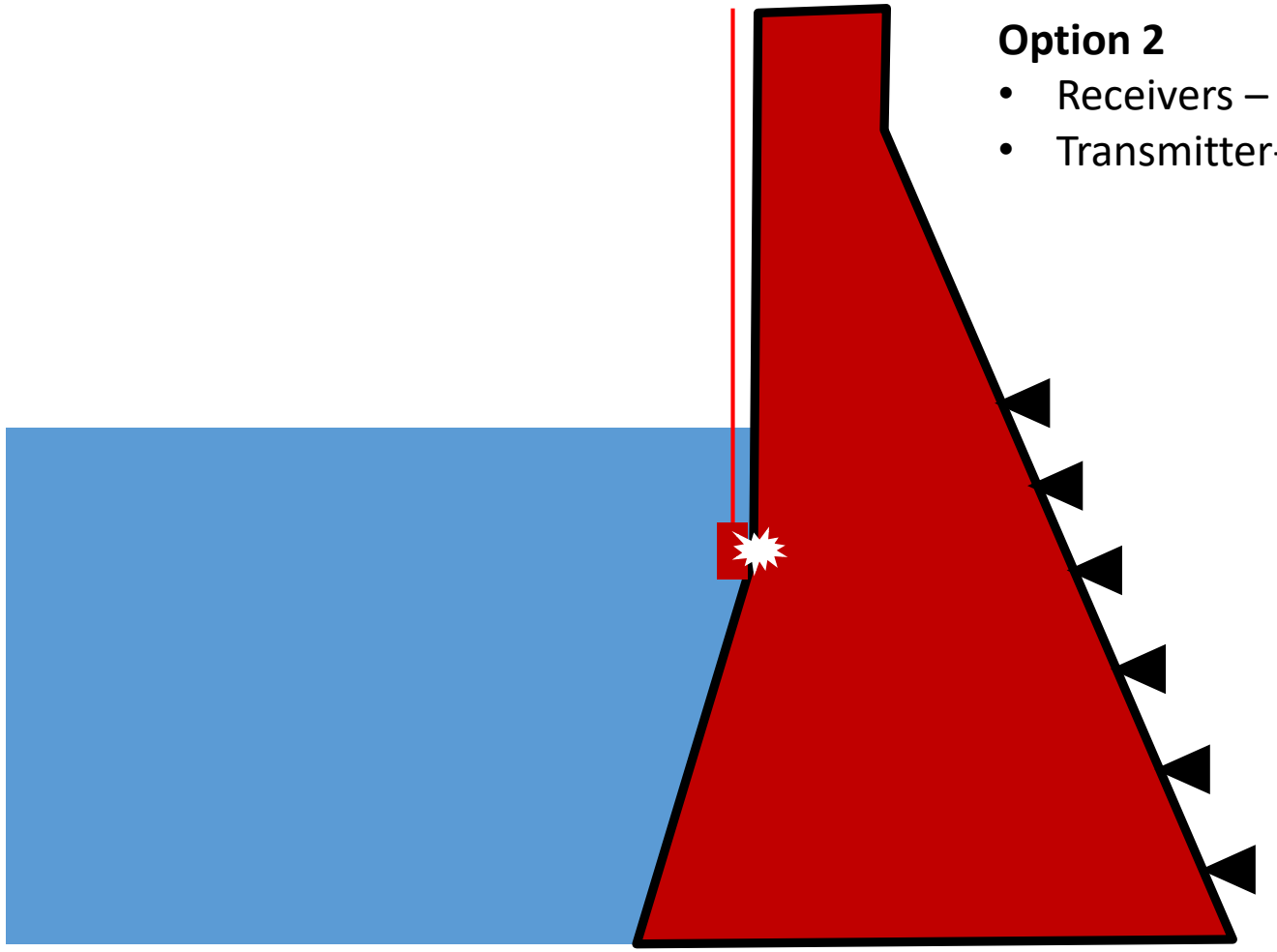
Cross Face Tomography… Under water area



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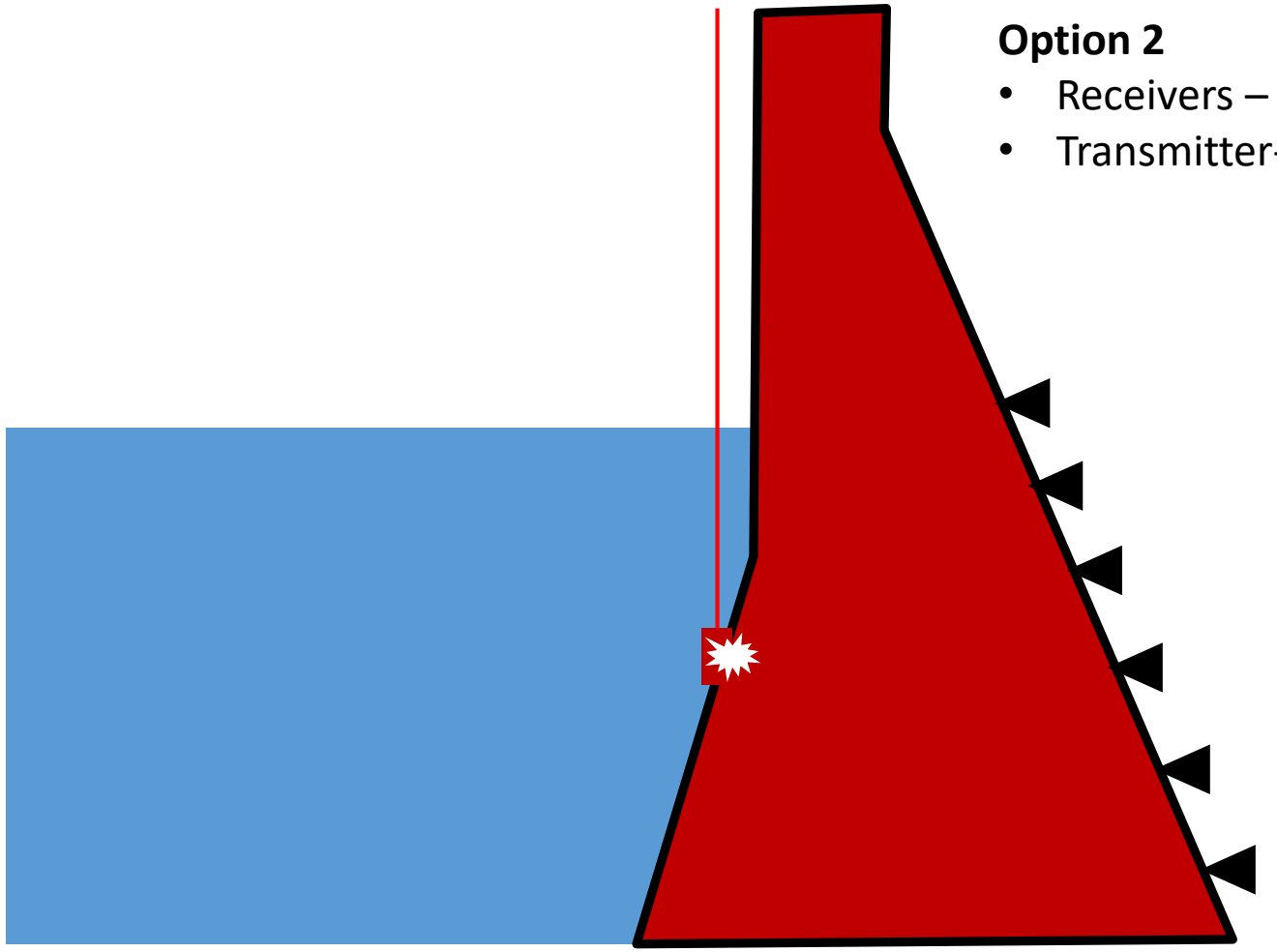
Cross Face Tomography… Under water area



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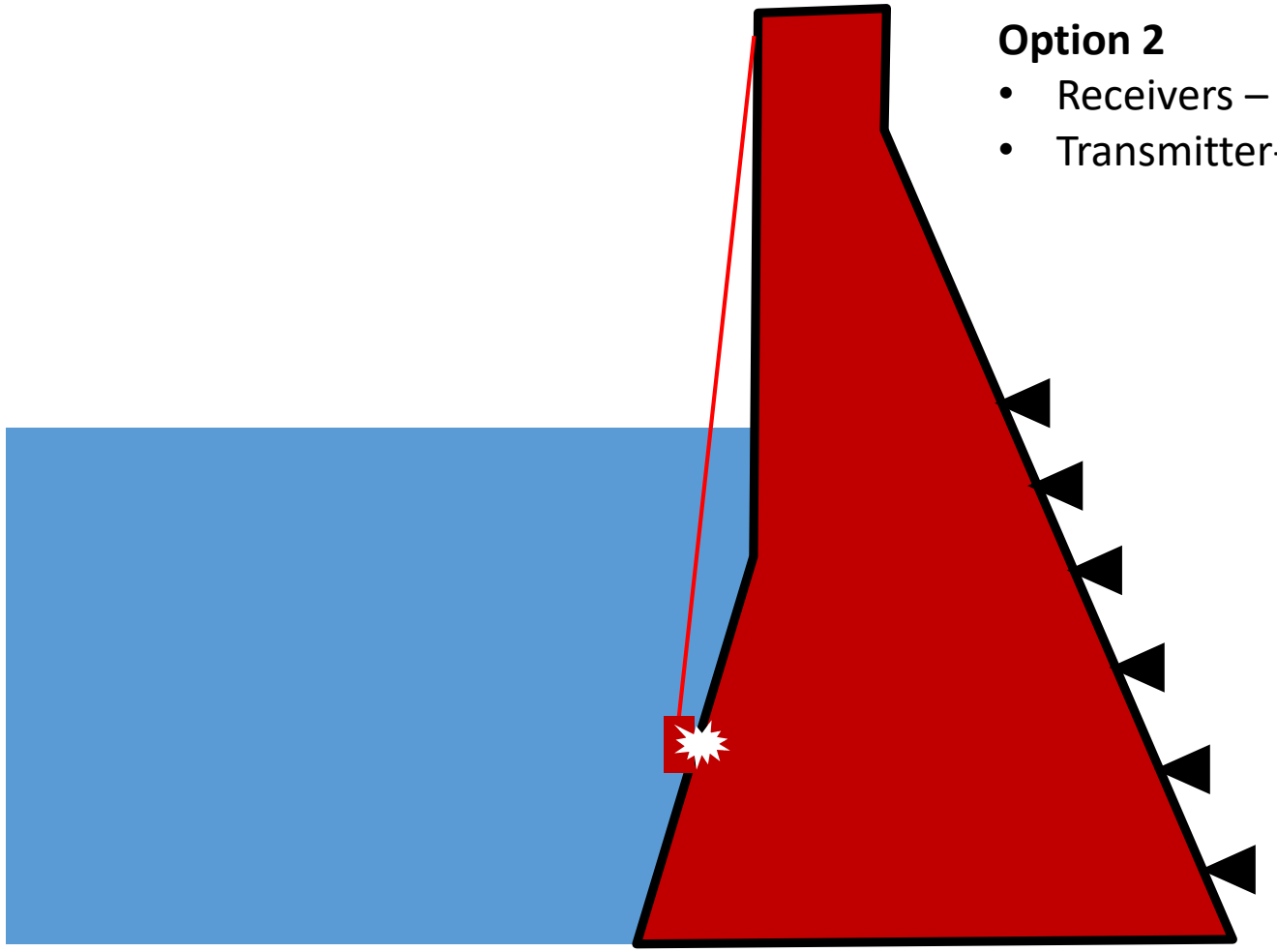
Cross Face Tomography… Under water area



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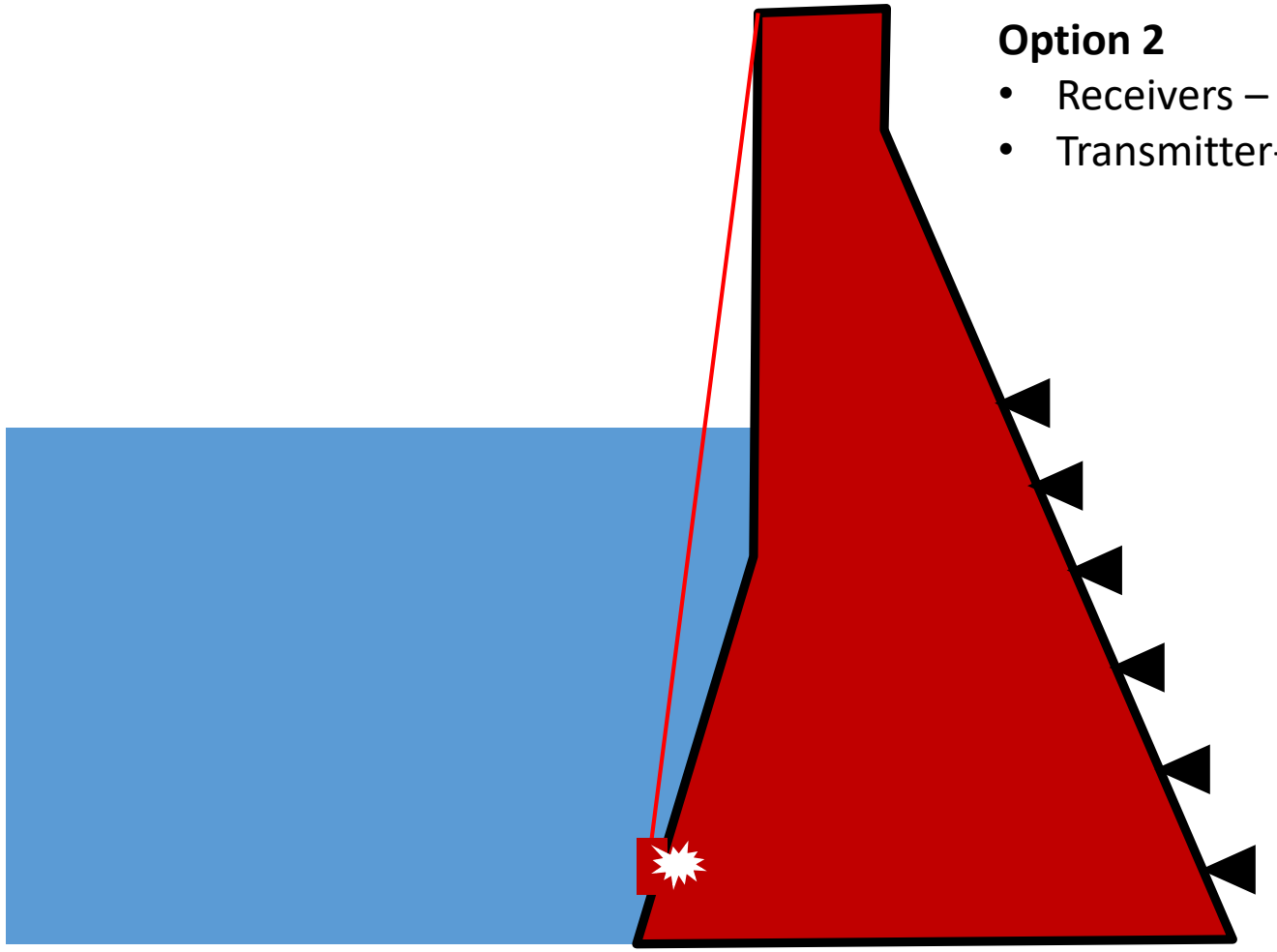
Cross Face Tomography… Under water area



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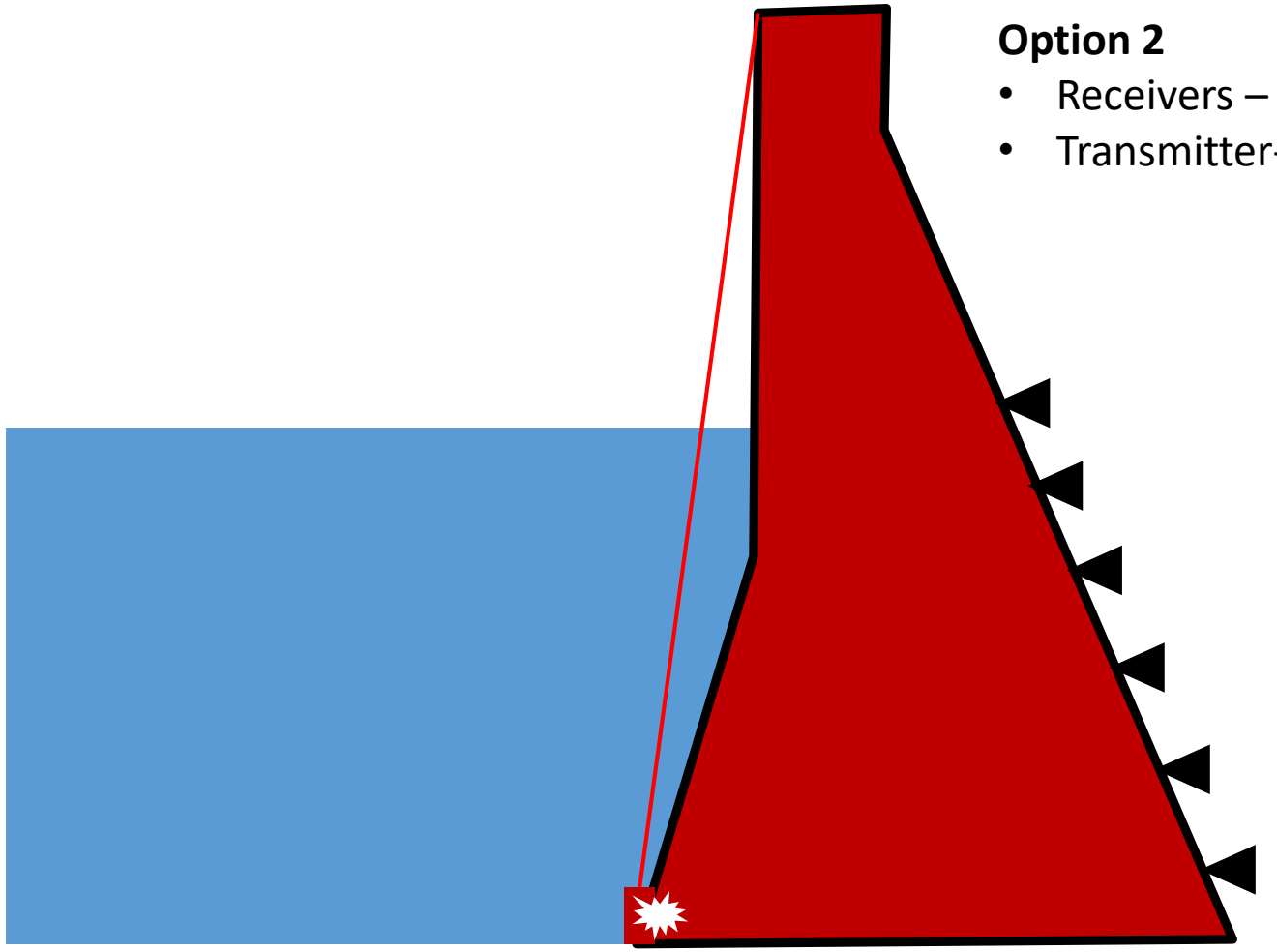
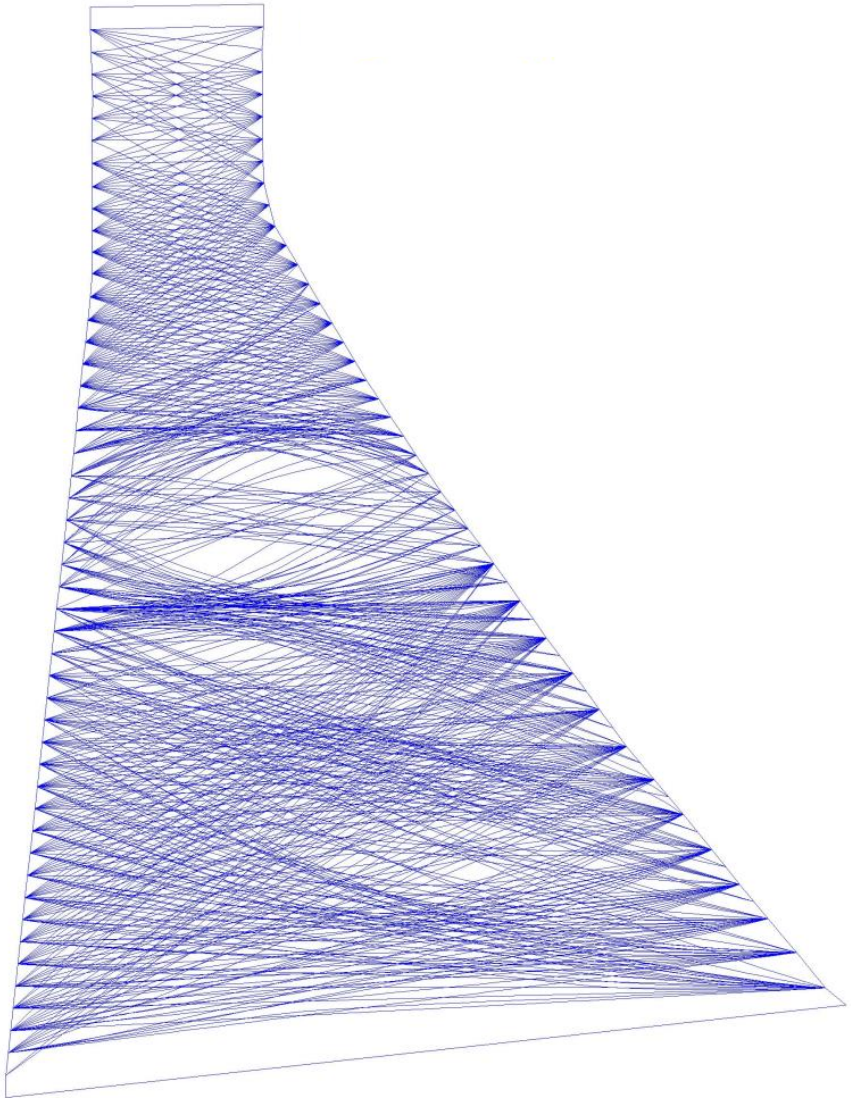
Cross Face Tomography… Under water area



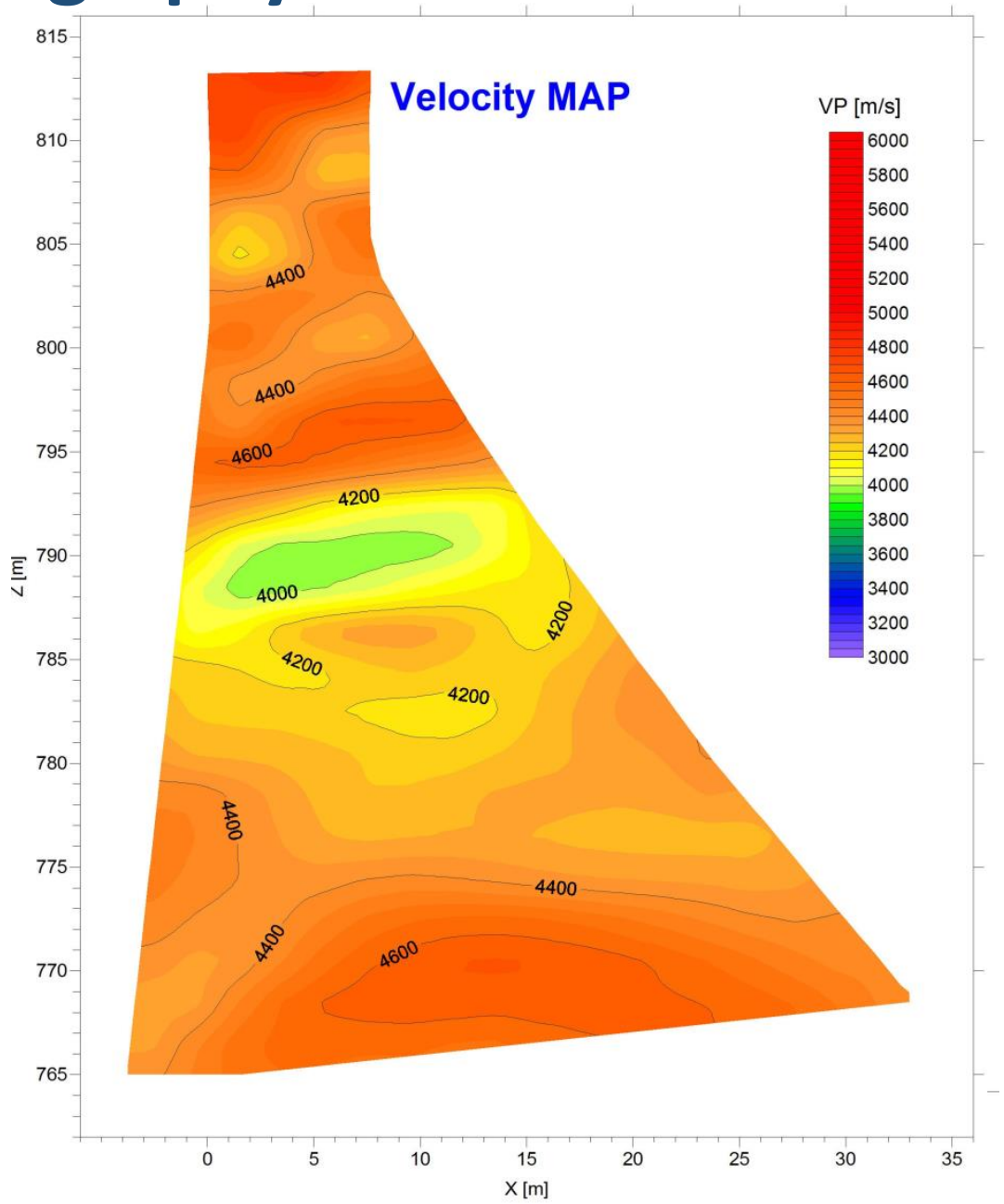
Option 2

- Receivers – Geophones on Downstream side
- Transmitter- Sparker on Upstream Side

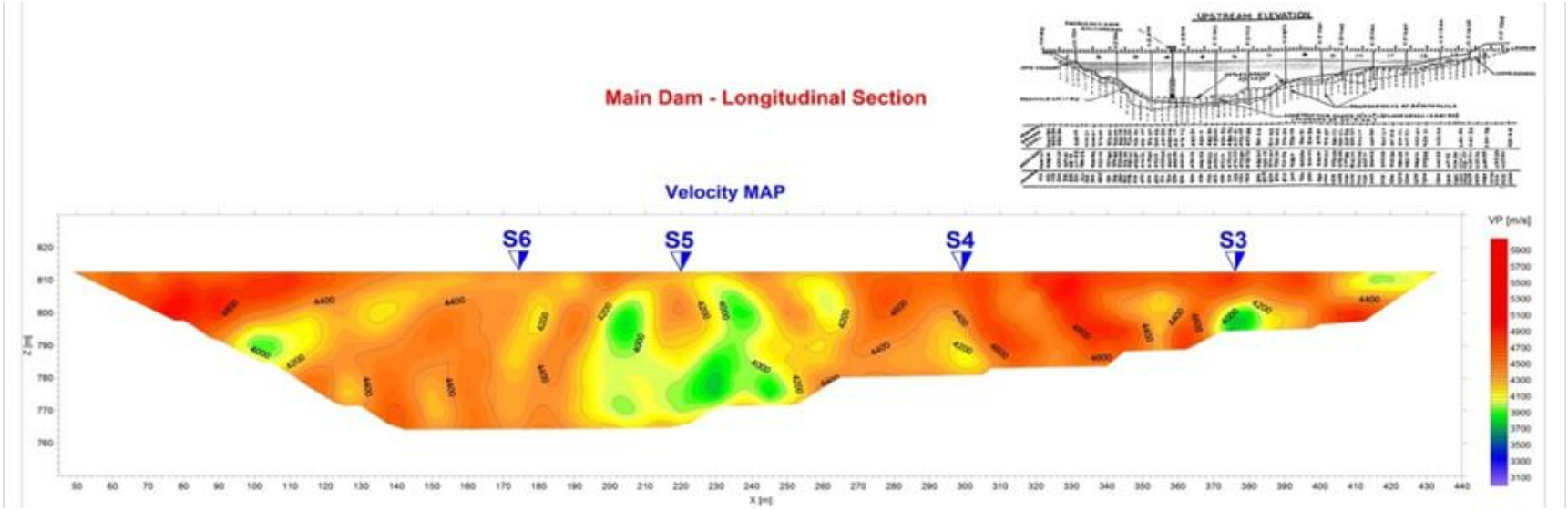
Cross Face Tomography… Ray Coverage

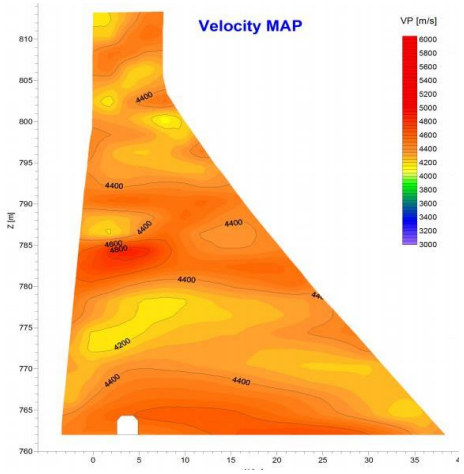


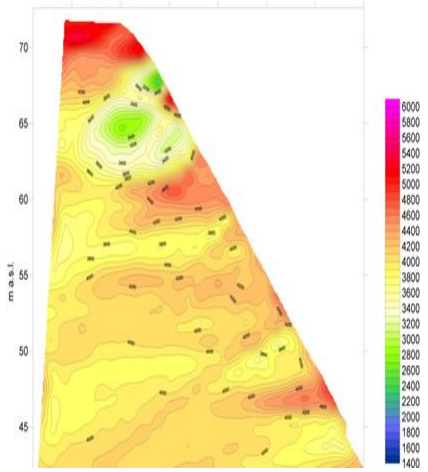
Cross Face Tomography… Inversion & Velocity Model

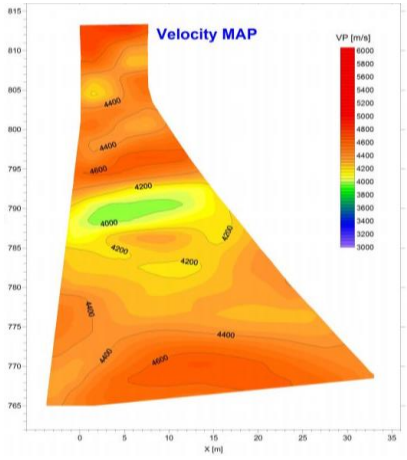


Cross Face Tomography… Results



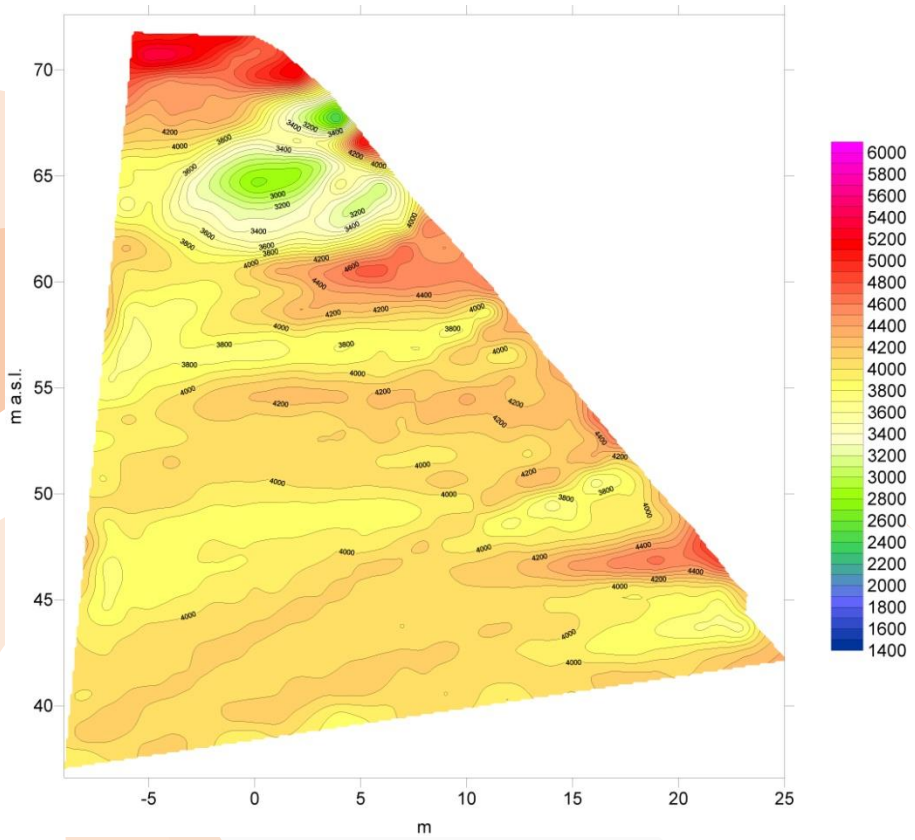




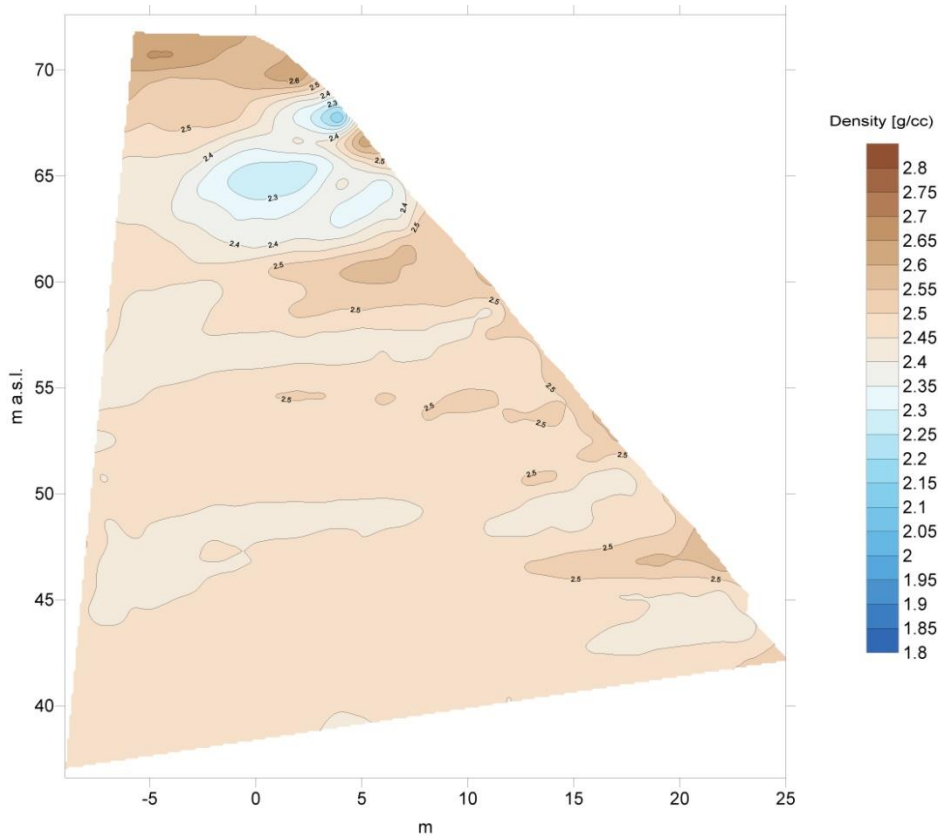


Cross Face Tomography… Results

Velocity tomography

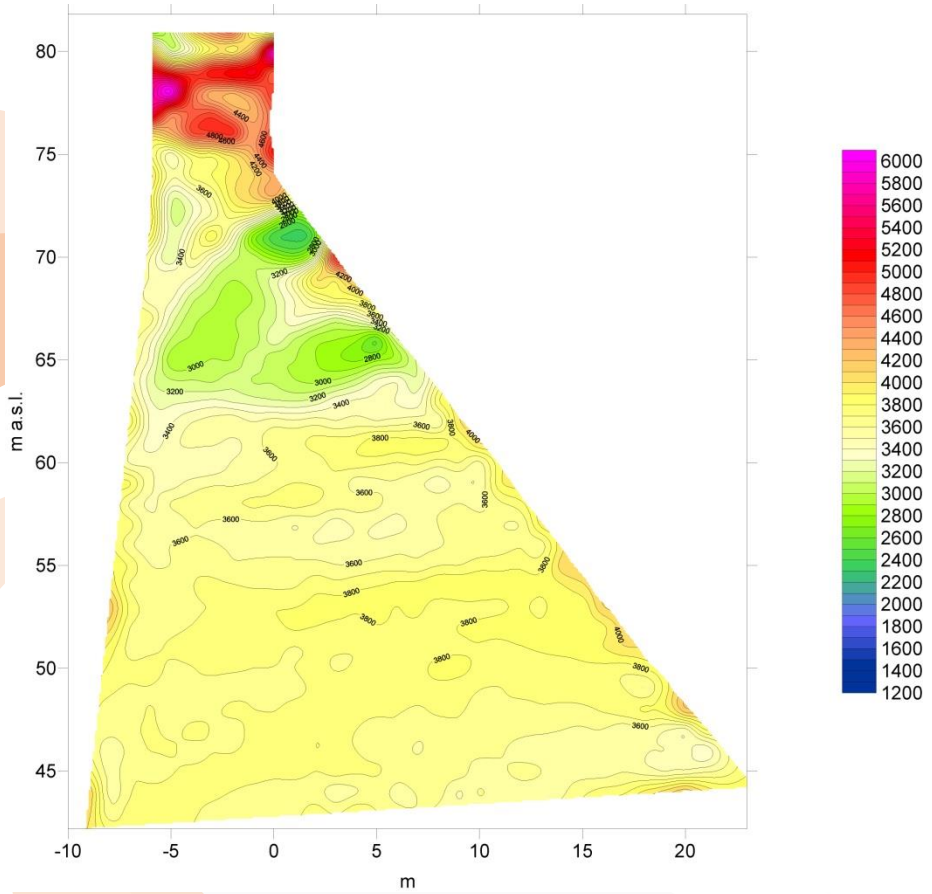


Density tomography

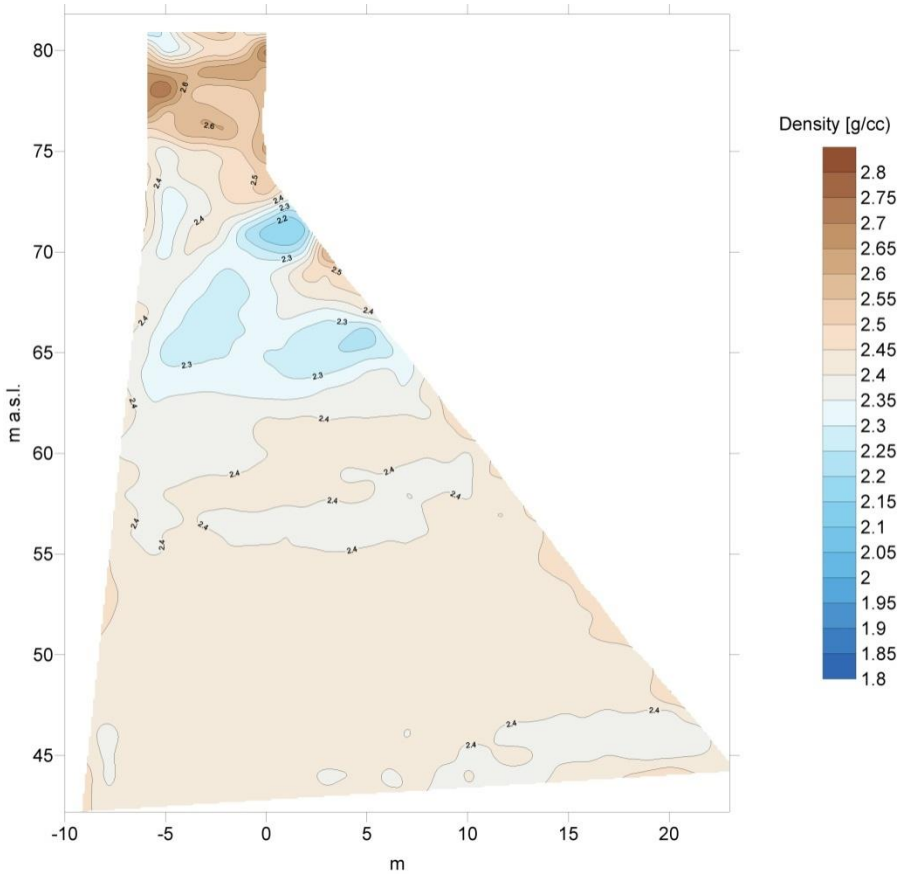


Cross Face Tomography… Results

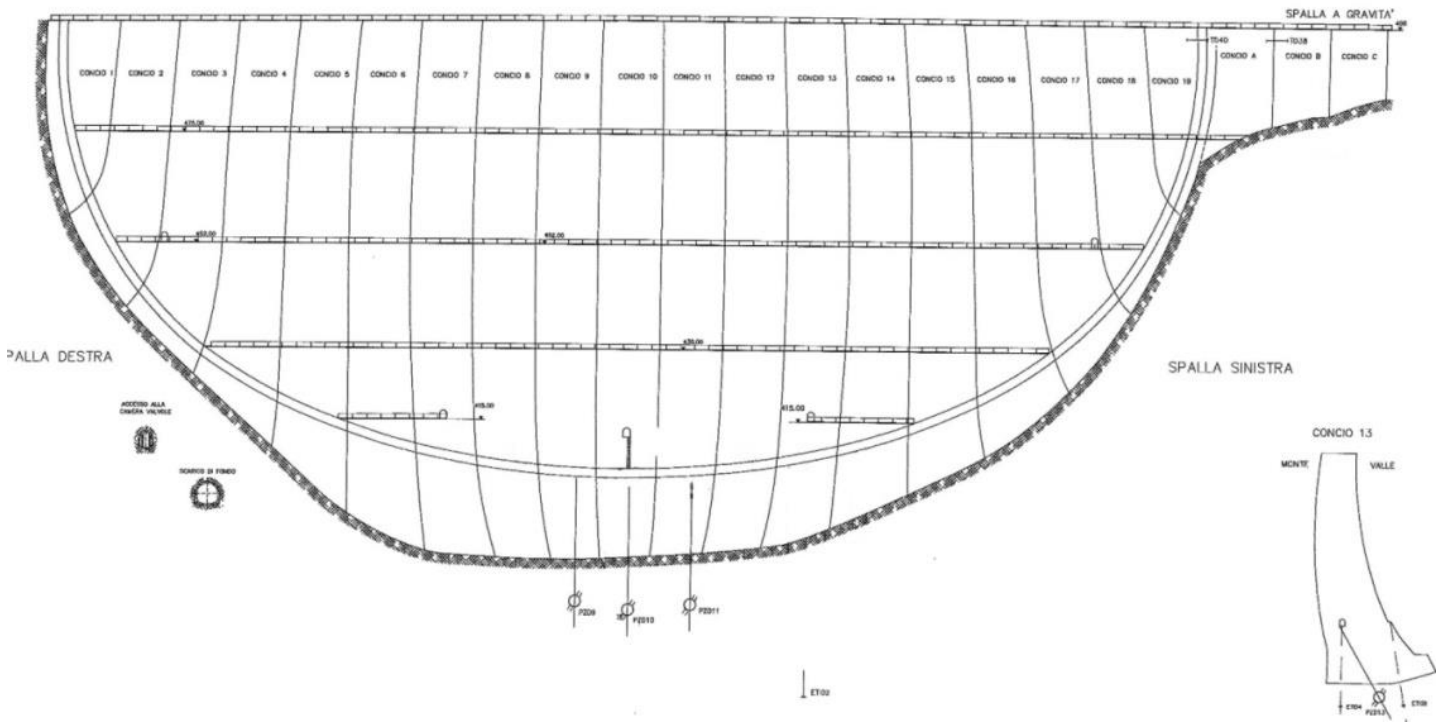
Velocity tomography



Density tomography



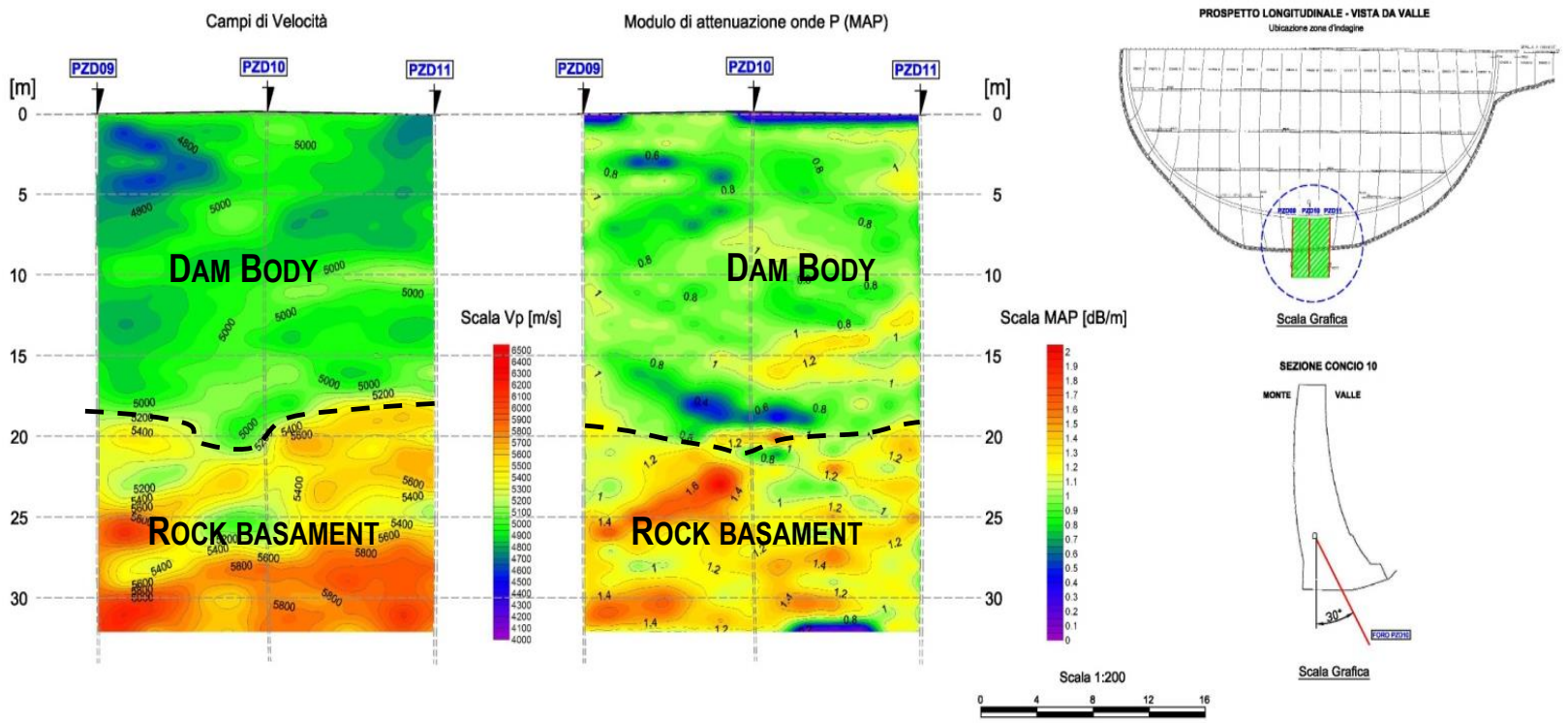
Arc dam- A study of contact between Dam and bedrock



Arc dam- A study of contact between Dam and bedrock

P waves velocities

Attenuation Modules



When do you need to investigate your dam?

- It is desirable to have a 'base line' data of dam **soon after completion of dam.**
- For older dams, **this time is 'now**'.
- Before designing **rehabilitation** plan
- After carrying out rehabilitation works (**to check efficacy**)
- ‘Changes' in physical properties are much easier to interpret than one time measurement values.
- Under 'normal' conditions, such measurements should be **repeated every couple of years** as a routine dam inspection program.

Key Points…

- Most suitable method for regular health checks of dams
- Early detection of problems
- Totally non-destructive, extremely suitable for structures like dams
- Helps design rehabilitation programs better and accurately
- Helps assess success of rehabilitation measures undertaken
- Identification of damaged areas inside the body dam
- Identification of not visible fractures and voids
- Identification of zones of seepages

⇨ More information + Low Cost + Quick

Geophysical Investigations for Dam Safety

Rapid & Cost Effective Investigations & Monitoring of Dams

Thank You

AF Academy

Dr. Sanjay Rana