ELECTRICAL RESISTIVITY IMAGING OF PREFERENTIAL FLOW THROUGH SURFACE COAL MINE VALLEY FILLS

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INTRODUCTION

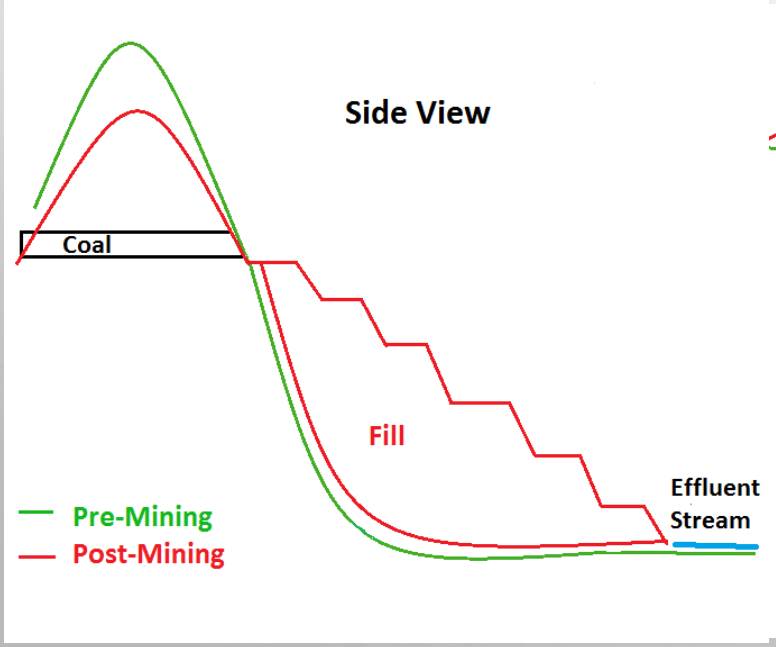
Appalachian surface coal mines often result in valley fill construction, in which tons of excess overburden is pushed into adjacent valleys and burry headwater streams.

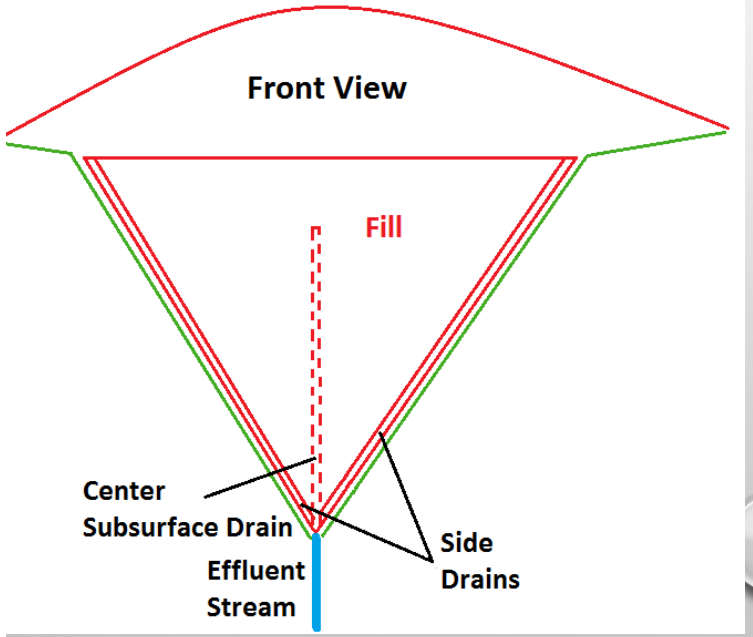
Valley fills have consequences:

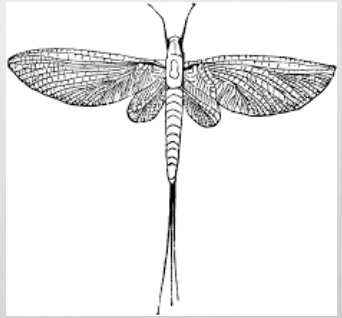
<u>Hydrologic:</u>
Flashier hydrograph
Increased baseflow
Unnatural flowpaths

<u>Water Quality:</u>
Increased Total Dissolved Solids (TDS)*
Increased pH
Heavy Metals

<u>Ecological:</u>
Loss of Aquatic Biodiversity







* TDS often measured via Specific Conductance (SC) which is related to electrical conductance.

INTRODUCTION

Known

- General valley fill construction methods
- TDS/SC is generated via weathering of carbonate rocks
- Valley fills are the surface mine structure that contribute most to TDS/SC
- Point measurement (infiltration, groundwater, precip and streamflow) studies have tried to classify valley fill hydrology
- Preferential flow has been assumed but not visualized

Hawkins and Aljoe, 1992
Wunsh et al., 1999
Miller and Zegre, 2014
Zegre et al., 2014
Caruccio and Geidel, 1984
Hawkins and Aljoe, 1992
Wunsh et al., 1999
Cormier et al., 2013
Evans et al., 2014
Wangerud et al., 2006

Unknown

- How fill structure influences hydrology and water quality
- Mechanism with which valley fills contribute to increased TDS/SC
- Extent of preferential flow (proportion of precip., path, depth)

Intersection of Geology and Hydrology

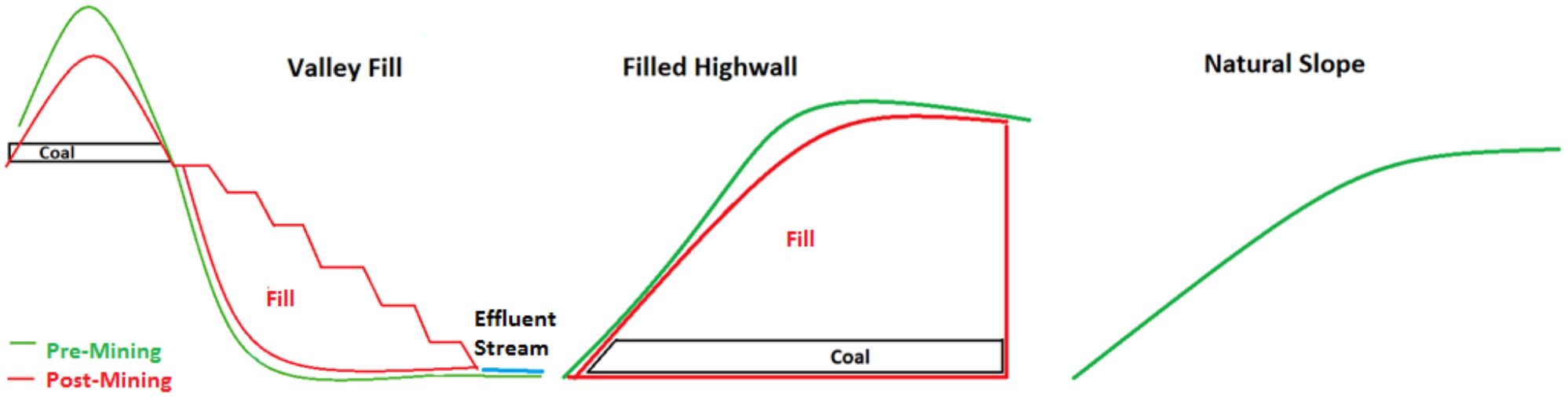
OBJECTIVES

To develop an approach to successfully use ERI on the valley fill to:

1) Image the fill's geologic structure and compare that structure to a filled highwall slope and an unmined slope

2) Image movement of subsurface stormflow within the fill and determine whether it is a uniform wetting front or preferential flow

Goal: This and related studies could eventually decrease TDS in effluent streams



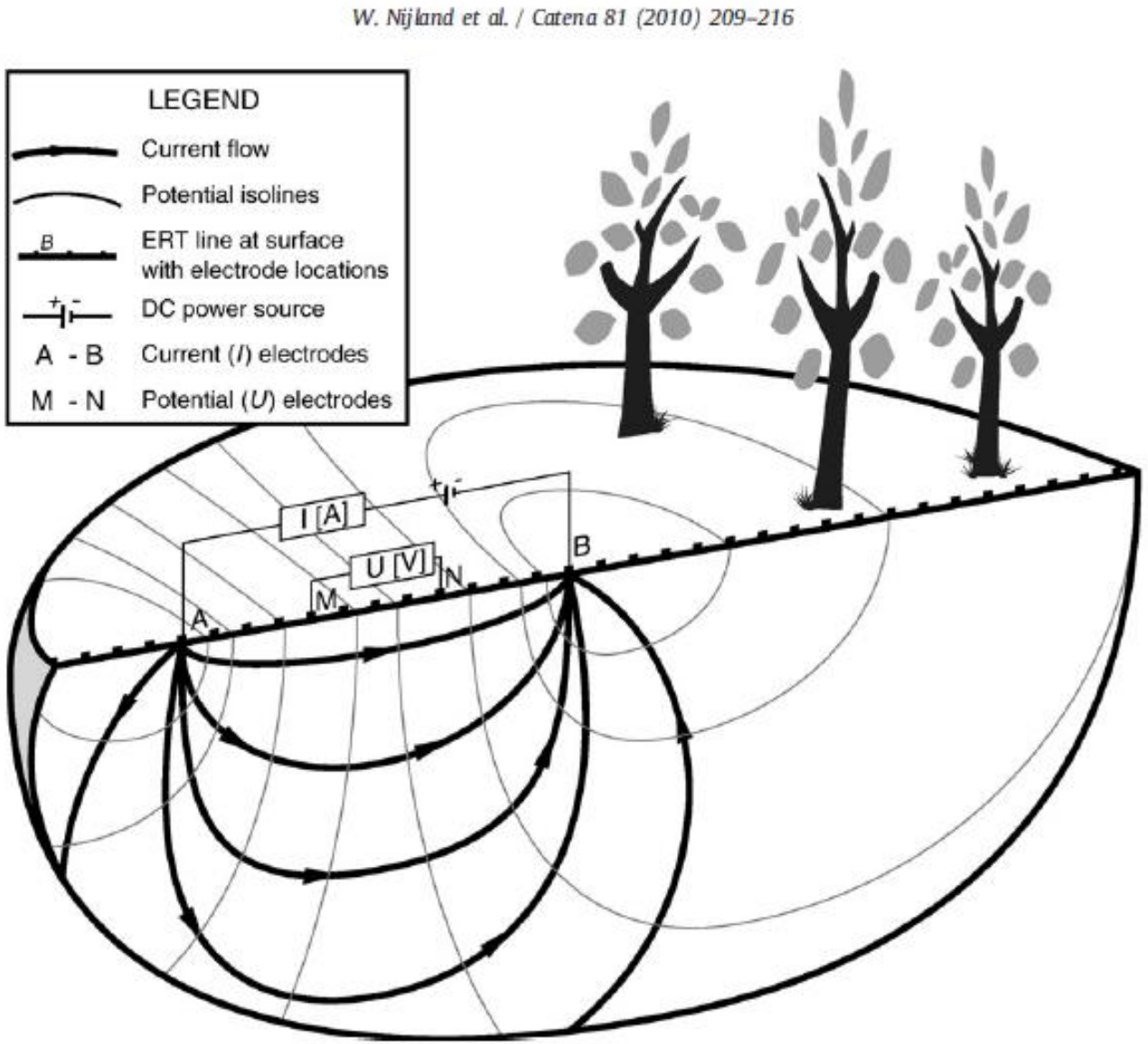
ELECTRICAL RESISTIVITY IMAGING (ERI)

Electrical – Uses electric current
Resistivity – Inherent material property of the ability to resist electric current (inverse of conductance)
Imaging – Produces a 'map' of a slice of the subsurface, known as a tomogram

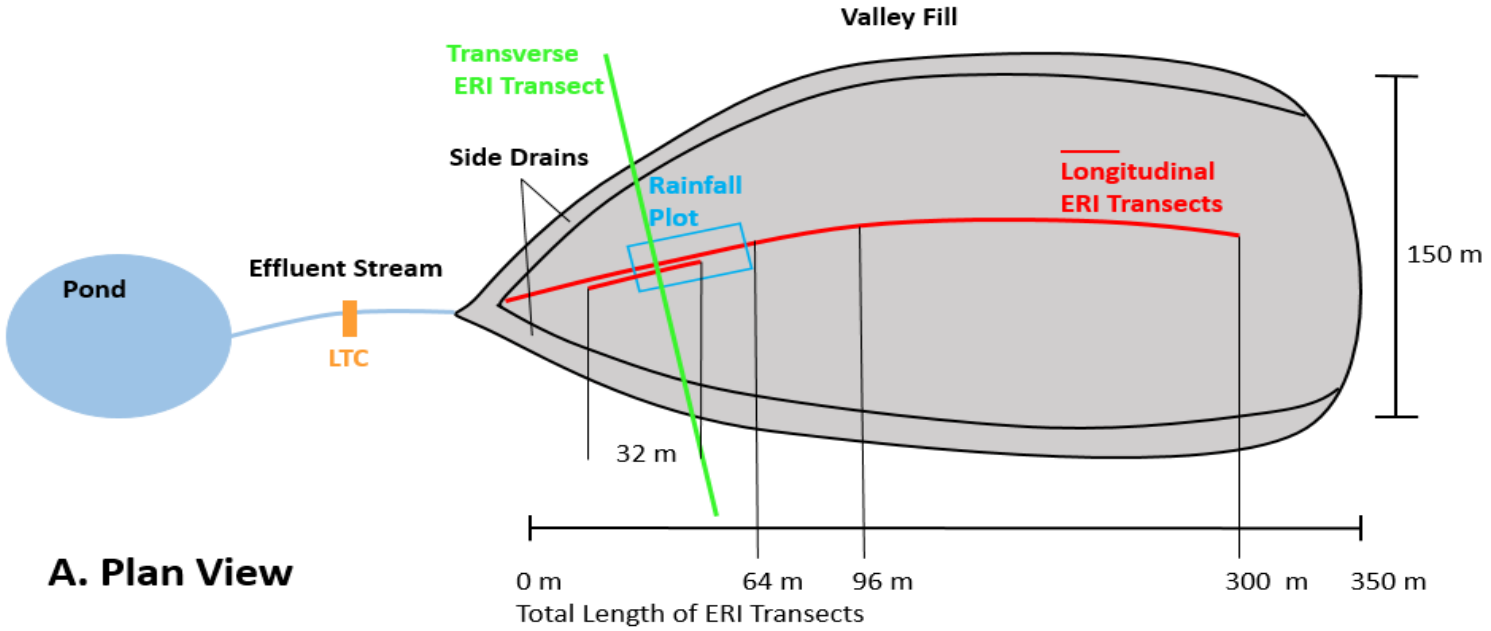
<u>Why?</u>
Non-Invasive
Congruent – no interpolation between points
Detects change in multiple dimensions – spatially and temporally
New – Never before used on Valley Fill

<u>How?</u>
Data collection – field study with artificial rainfall experiments
Inversion – Modeling of collected field data and creation of tomogram image

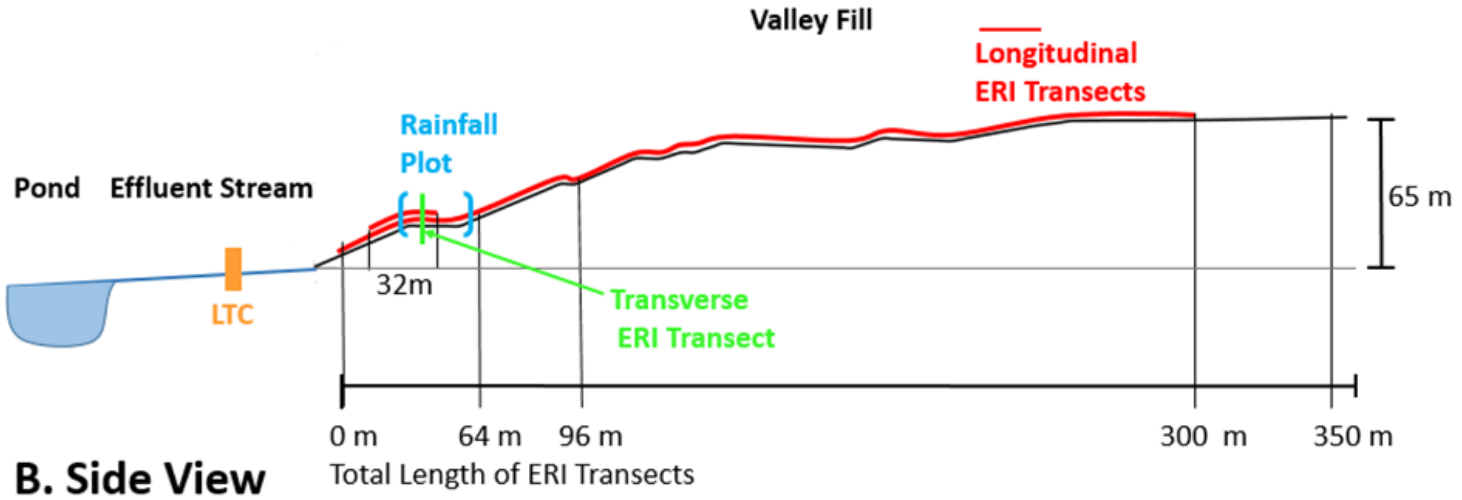
VISUAL OF SUBSURFACE CURRENT INJECTION



EXPERIMENTAL SET-UP



A. Plan View



B. Side View

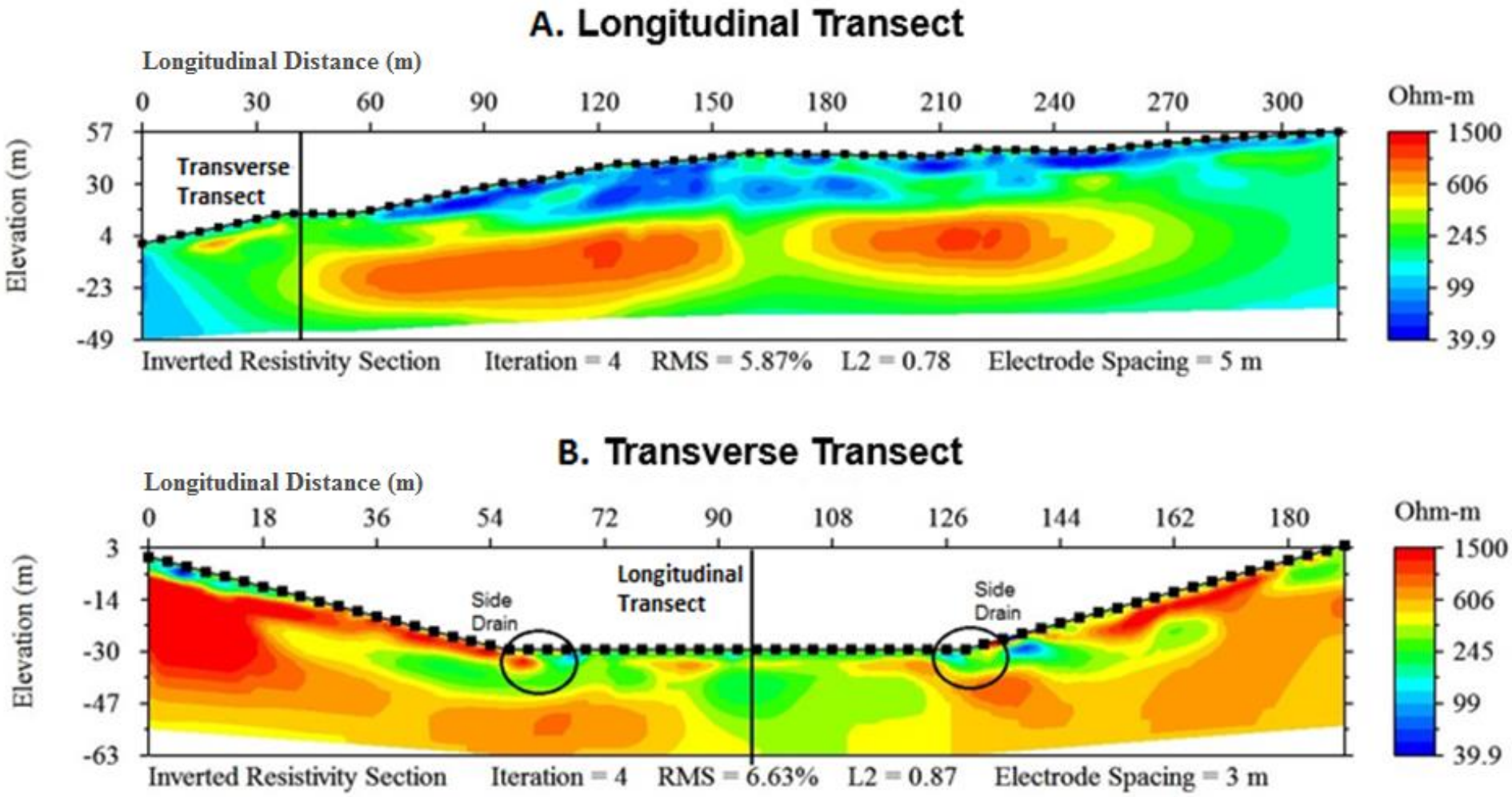
OVERVIEW OF SURVEYS COMPLETED

Survey Series	Date	Electrode Spacing (m)	Transect Length (m)	Rainfall Duration (hr)	Time Between Surveys (hr)	Pre-rainfall Dry Time
Longitudinal (dry)	7/31/2014	5	300	N/A	N/A	4 days
Longitudinal (wet)	5/23/2014	5	300	N/A	N/A	2 hours
Transverse (dry)	5/22/2014	3	190	N/A	N/A	4 days
Artificial Rain 2.5m (RN1X)	6/30/2014	2.5	160	2:15	1:00	5 days
Artificial Rain 2.5 m (RN2X)	7/10/2014	2.5	160	2:15	0:45	1 day
Artificial Rain 1.5m (RN4X)	7/17/2014	1.5	96	5	1:15	2 days
Artificial Rain 1.5m (RN6X)	8/1/2014	1.5	96	3	1:00	1 day
Artificial Rain 1.0m (RN3X)	7/11/2014	1.0	64	2:15	0:45	16 hours
Artificial Rain 0.5m (RN5X)	7/31/2014	0.5	32	2:15	0:45	4 days
Highwall (dry)	8/13/2014	2.0	128	N/A	N/A	2 days
Natural Slope (dry)	11/15/2014	2.0	128	N/A	N/A	7 days

Valley Fill

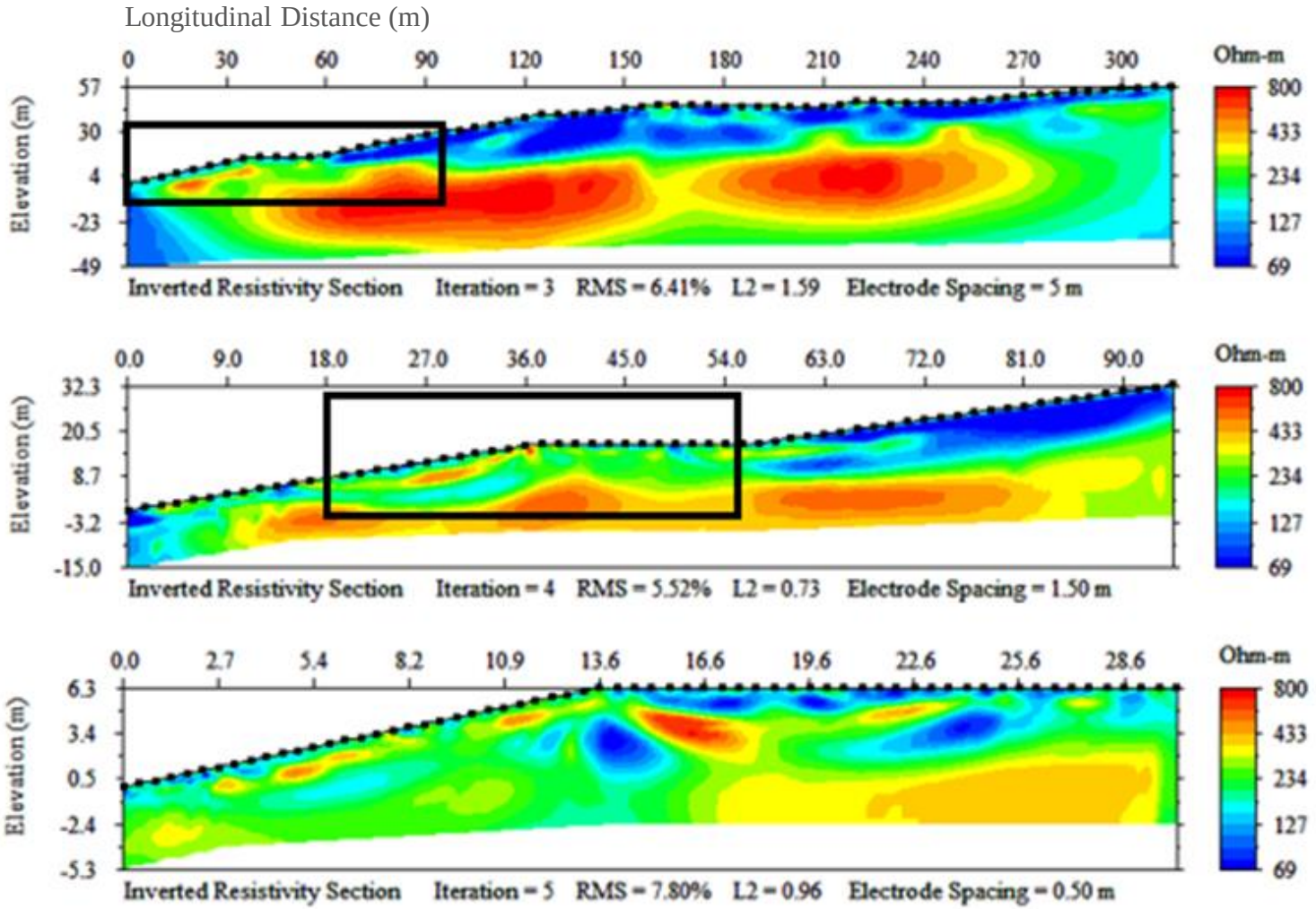
Other

RESULTS I – VALLEY FILL GEOLOGY



- **Large scale individual resistivity tomograms show electrical resistivity (Ohm-m) where areas of greater electrical conductivity are blue.**
- They are taken in dry conditions and show the subsurface structure of the fill.
- Elevation (y-axis) is relative.

RESULTS II – GEOLOGIC HETEROGENEITY



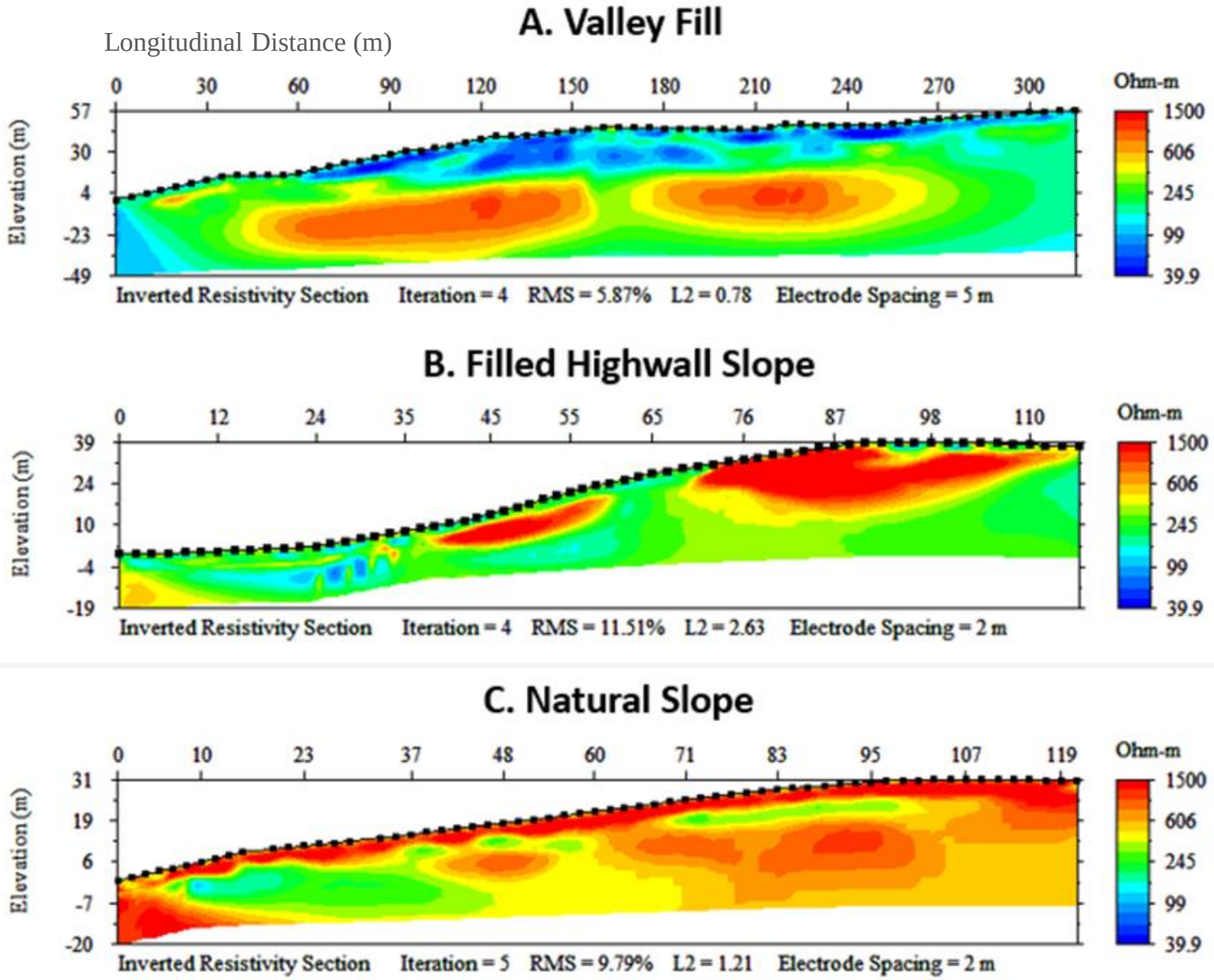
A.
300 m transect

B.
96 m transect

C.
32 m transect

- **Individual resistivity tomograms showing electrical resistivity (Ohm-m) where areas of greater electrical conductivity are blue.**
- Similar patterns of heterogeneity indicate that ERI picks up multiple scales of heterogeneity.
- Black box outlines in each panel show the extent of the panel immediately beneath.

RESULTS III – GEOLOGIC LANDFORM COMPARISON



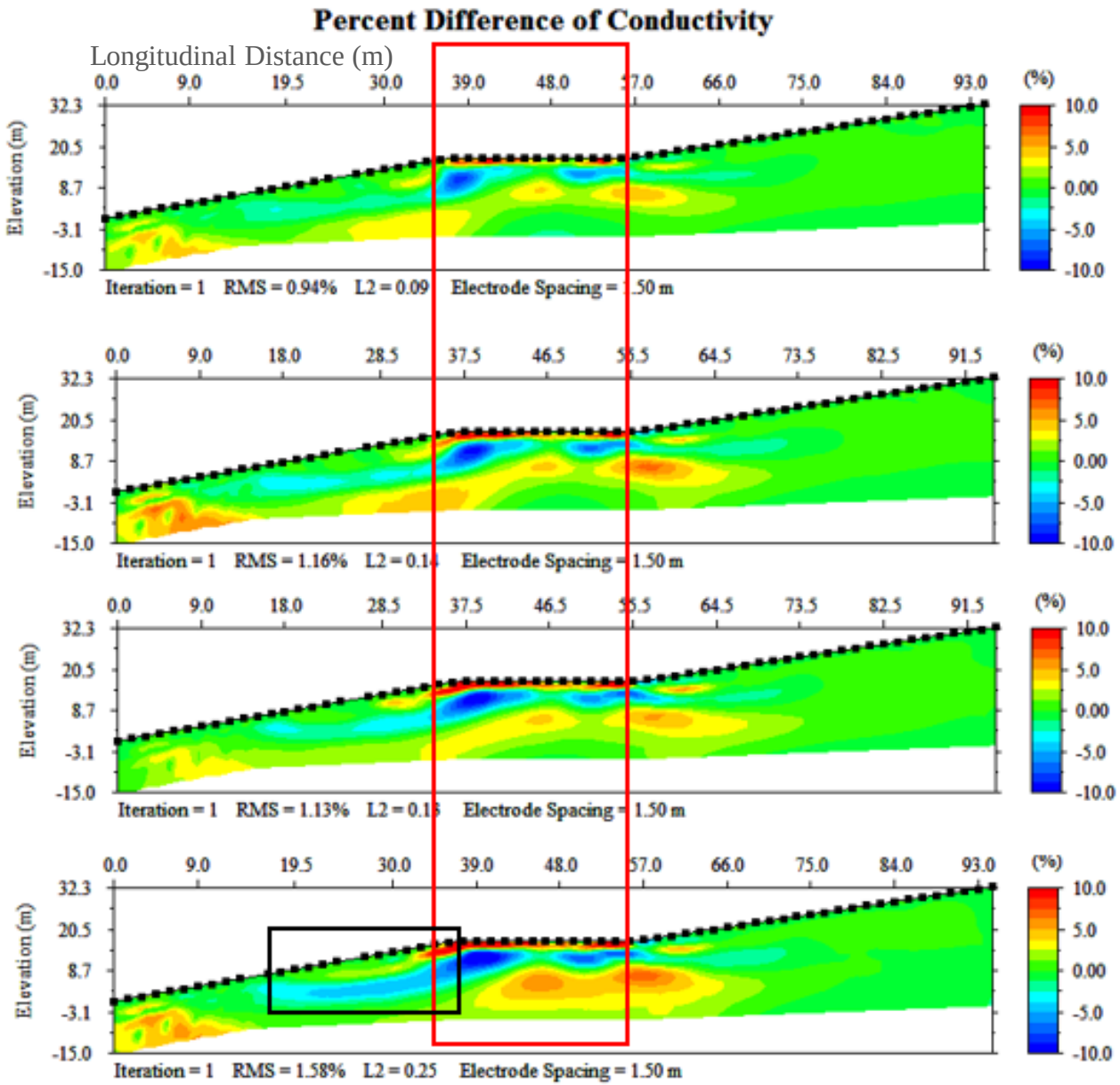
- **Individual resistivity tomograms showing electrical resistivity (Ohm-m) where areas of greater electrical conductivity are blue.**

- Structural differences between the three types of landscapes were captured in the ERI surveys.

  The Filled Highwall slope had large rocks near the the surface, which disrupted some of the data collection

  The Natural slope had a large amount of woody debris near the surface, and bedrock with more smooth transitions beneath

RESULTS IV – LARGE SCALE HYDROLOGY



A.
RN41-42
t = 1:15–0:00

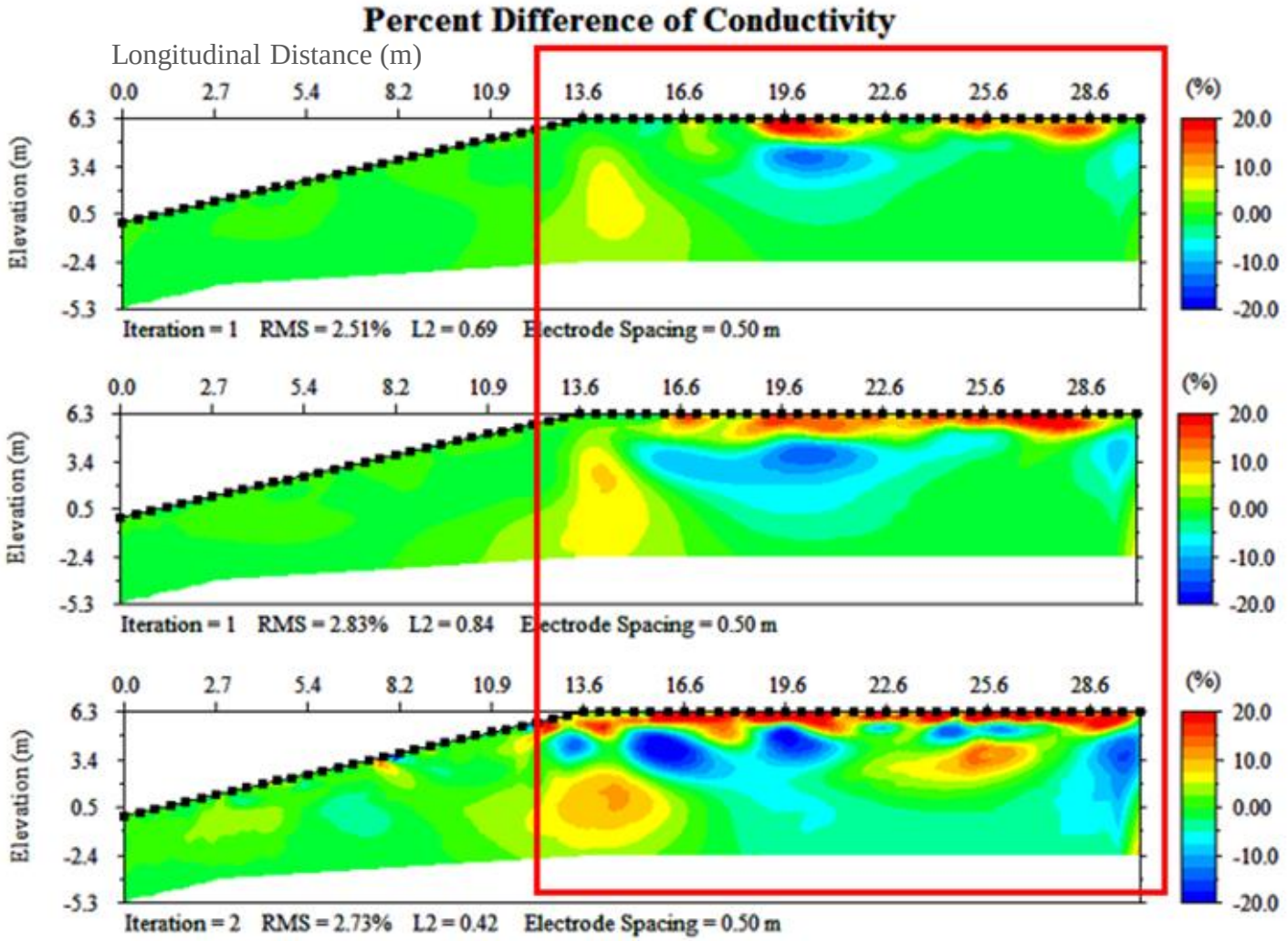
B.
RN41-43
t = 2:30–0:00

C.
RN41-44
t = 3:45-0:00

D.
RN41-45
t = 5:00-0:00

- **Time-Lapse Inversion of Artificial Rainfall Experiment with 1.5 meter spacing (RN4X).**
- Tomograms show percent change in electrical conductivity (%) where areas of greater change in electrical conductivity are red.
- Infiltration of conductive rainwater has already begun at 1:15, and continues up to 5:00 with preferential flow developing within the black box.

RESULTS V – SMALL SCALE HYDROLOGY



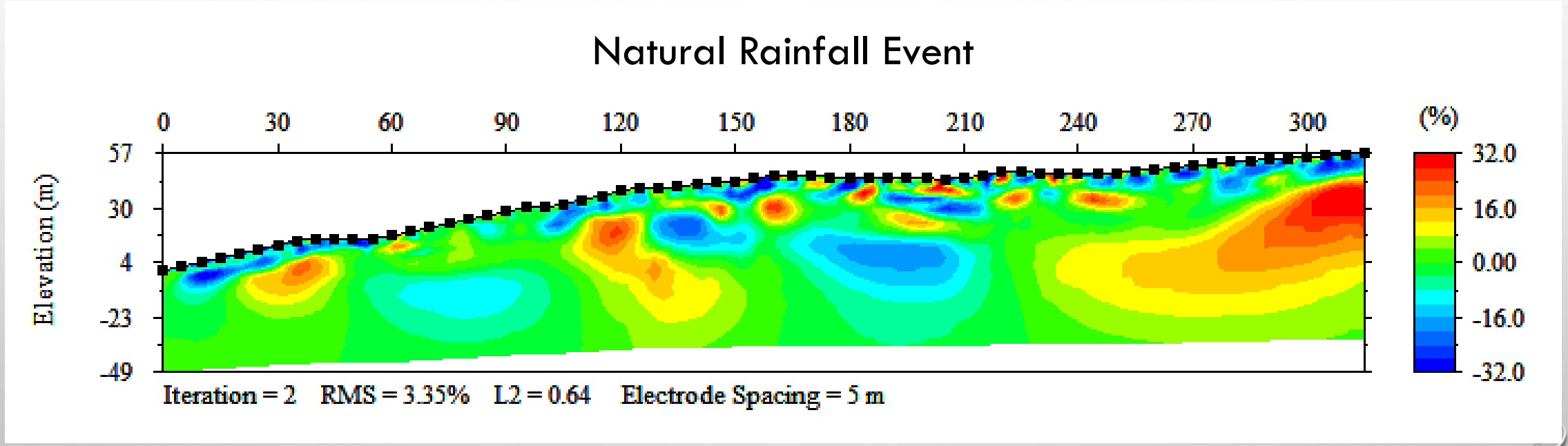
A.
RN52-53
t = 0:45-0:00

B.
RN52-54
t = 1:30-0:00

C.
RN52-55
t = 2:15-0:00

- **Time-lapse Inversion of artificial rainfall experiment with 0.5 meter spacing (RN5X).**
- Tomograms show percent change in electrical conductivity (%) where areas of greater change in electrical conductivity are red.
- These tomograms reveal saturated conditions at the surface and infiltration beneath meters 15 and 25.

RESULTS VI - ENTIRE FILL HYDROLOGY



CONCLUSIONS

Methods: ERI is a **capable investigation technique** in the valley fill environment.

ERI can **visualize** both subsurface structure and the infiltration of water spatiotemporally.

Geology: Subsurface **structures** of three landforms **vary in accordance with construction type.**

Valley Fill – Smaller soil-like rocks in upper layer with large boulders/voids below

Filled Highwall – Large rocks near surface with finer fill below and between

Natural Slope – Thick layer of woody debris overlain on cohesive bedrock

Hydrology: Water ponds on compacted surface and infiltrates along **vertical and horizontal preferential flowpaths**. Vertical preferential flow is up to 20 meters deep in 1:15. Horizontal preferential flow stays within 5 meters of the surface.

Limited infiltration and preferential flow means that **much of the fill volume may not experience stormflow,** thus perhaps both stormflow and groundwater flow are important for TDS. **Future ERI studies could monitor experimental fill designs,** such as those with inert conduits to safely transmit groundwater.

ACKNOWLEDGMENTS

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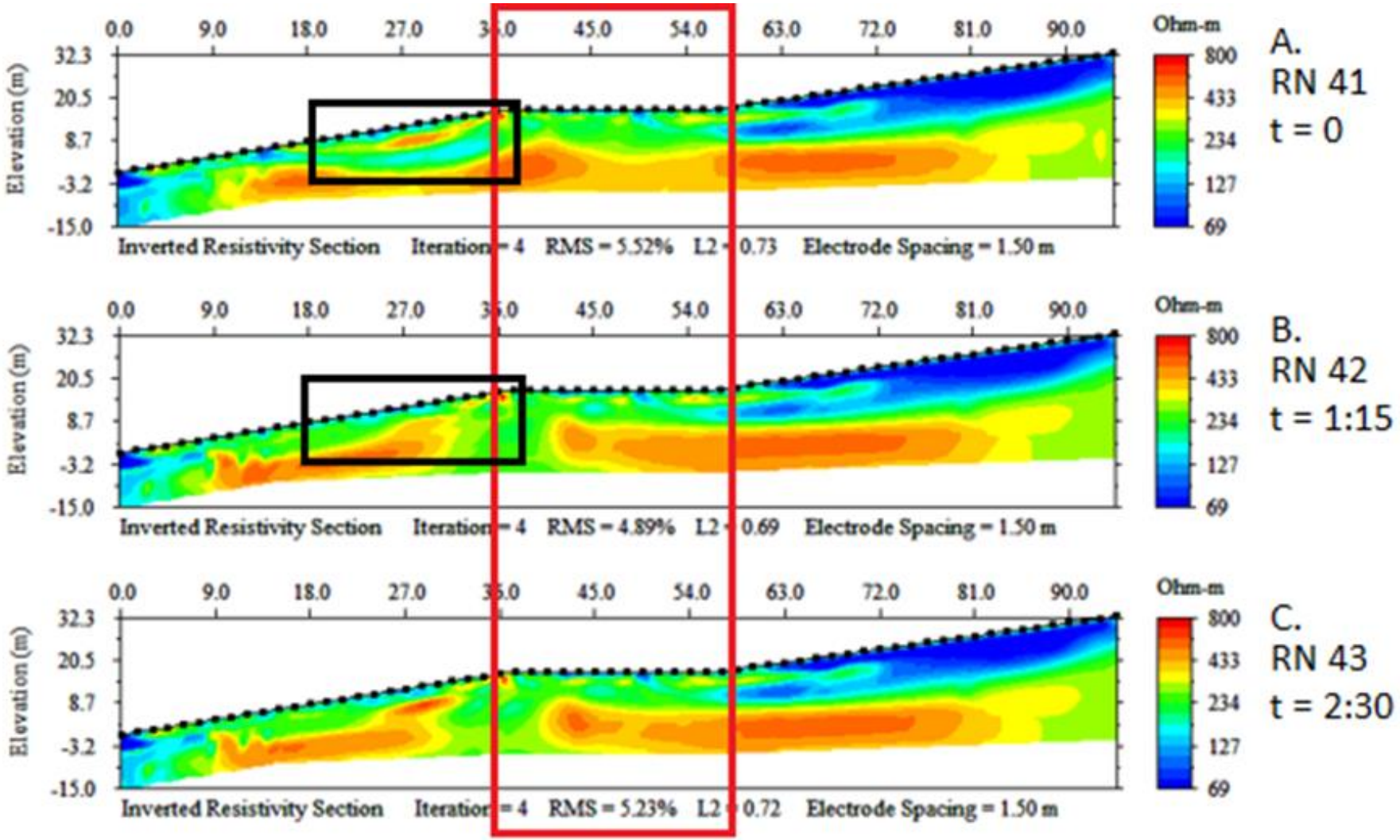
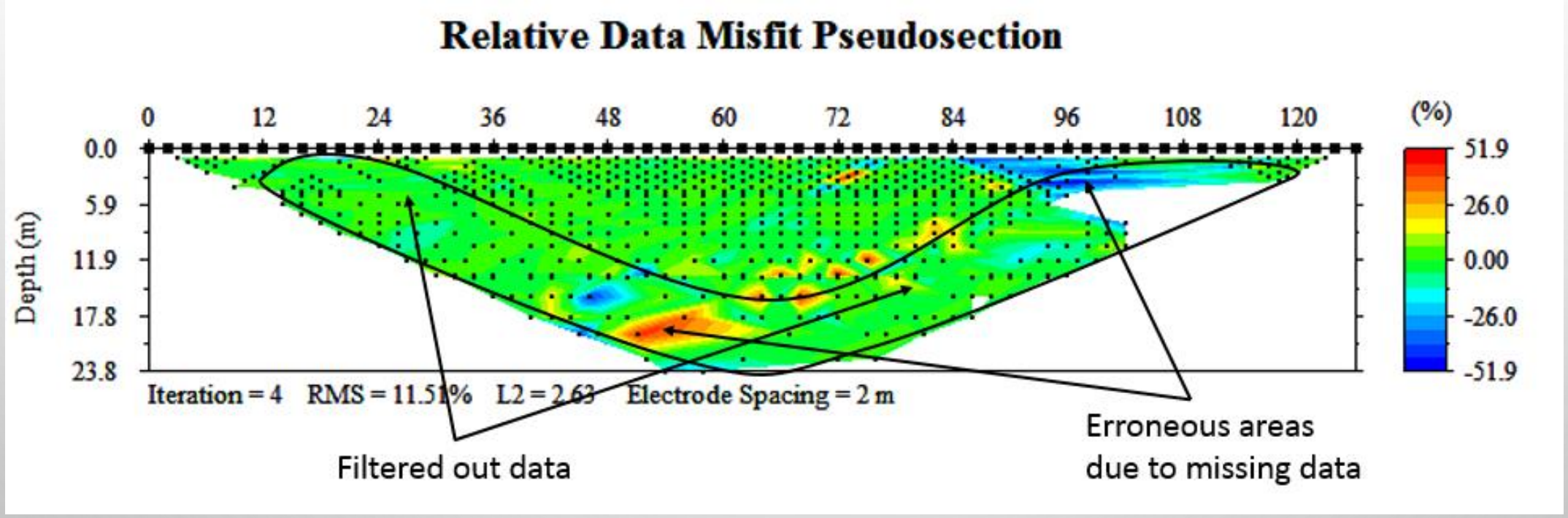
QUESTIONS?

RESULTS – ARTIFICIAL RAINFALL EXPERIMENT

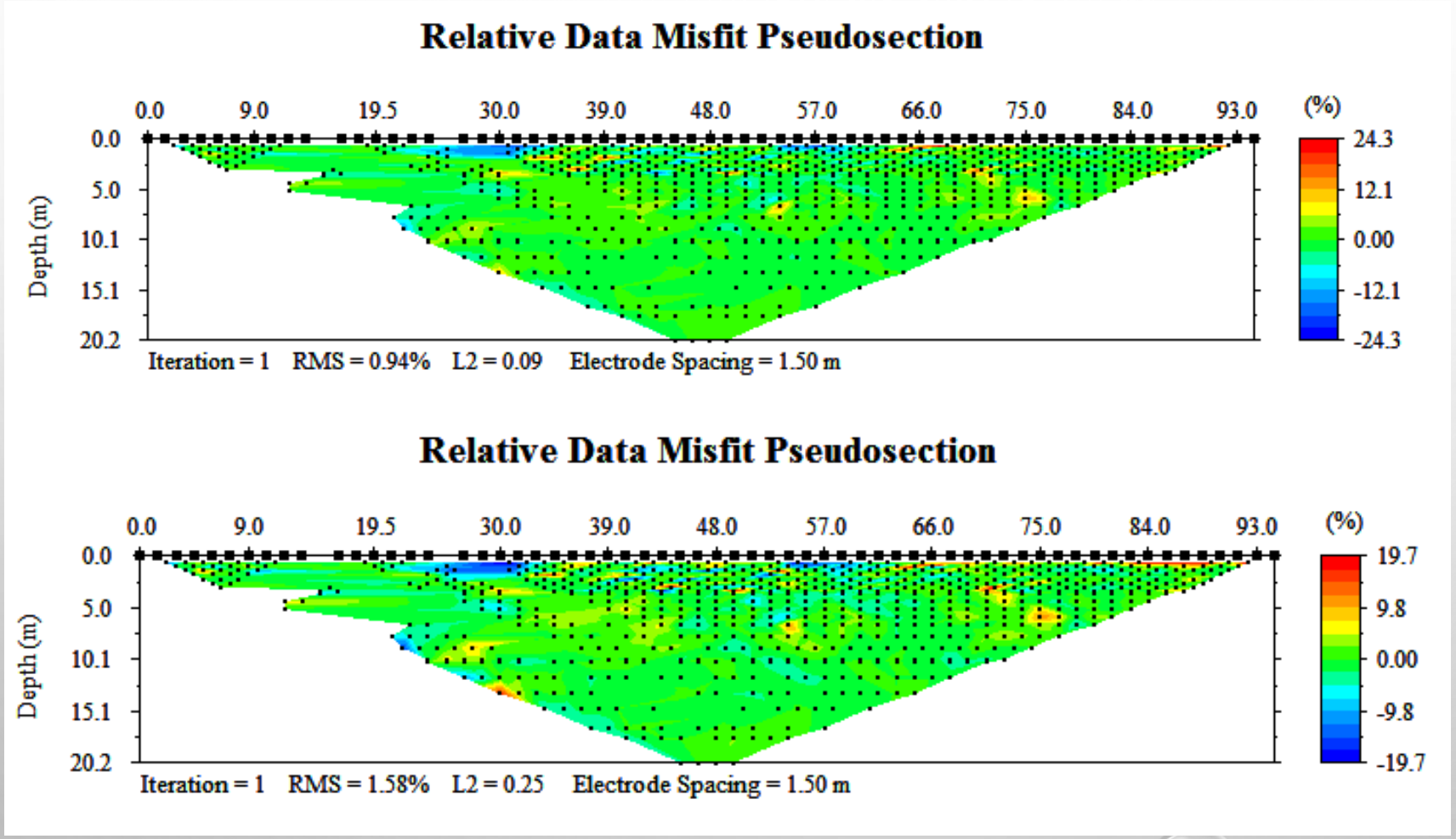


- Individual resistivity tomograms showing electrical resistivity (Ohm-m) where areas of greater electrical conductivity are blue.
- These displays that water infiltration can be seen in individual resistivity tomograms.

FILLED HIGHWALL SLOPE MISFIT



MISFIT OF RN42-41 AND RN45-41



RN42-41 Misfit

RN45-41 Misfit