REMOTE SENSING APPLICATIONS IN GEOTECHNICAL ENGINEERING

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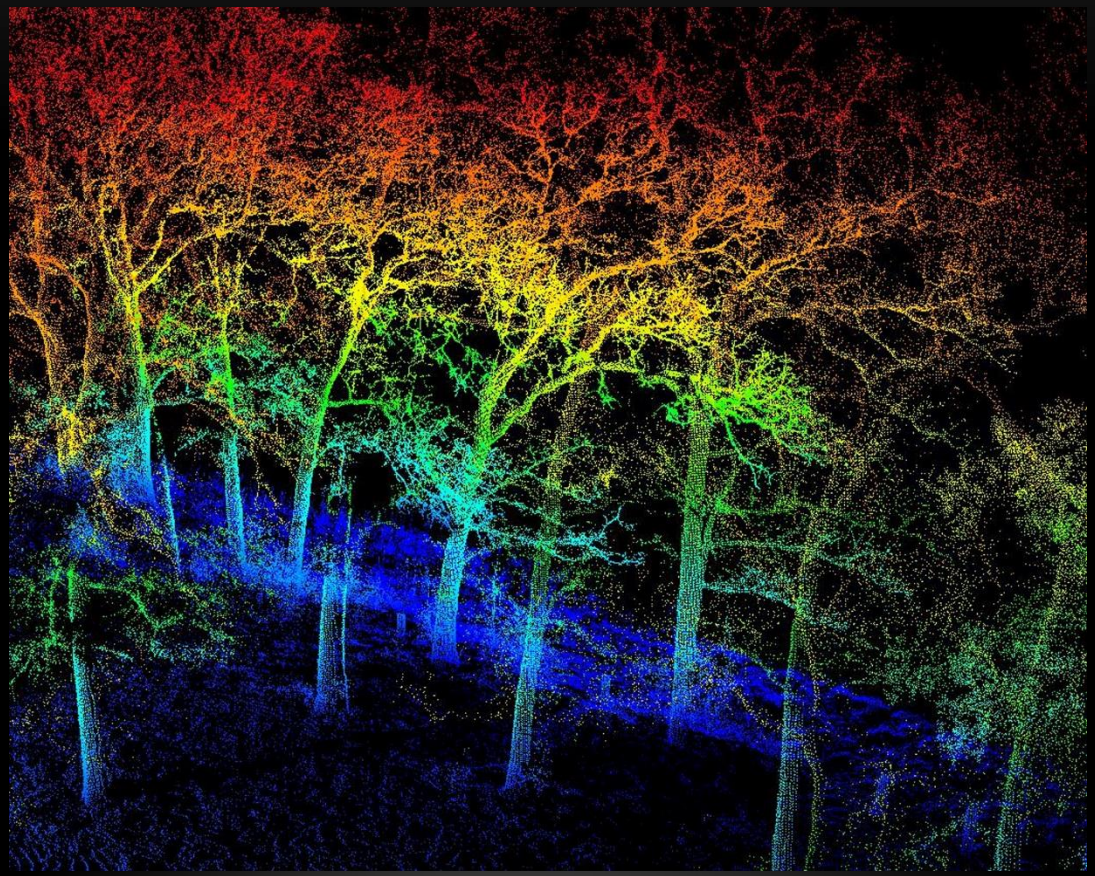
MDOT
Michigan Department of Transportation

PRESENTATION OVERVIEW

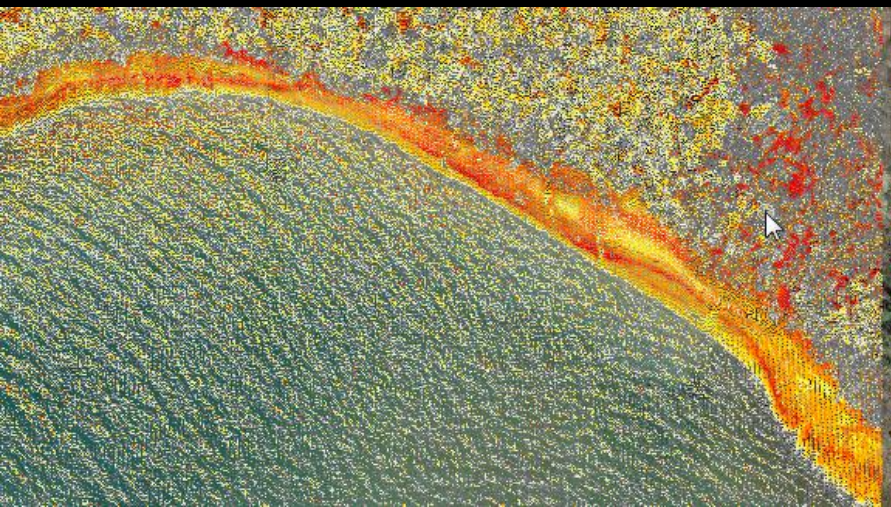
- GENERAL OVERVIEW OF REMOTE SENSING TECHNOLOGIES
- DISCUSS THREE CASE STUDIES USING LiDAR
  - CASE STUDY I – TERRESTRIAL OR GROUND BASED LIDAR
  - CASE STUDY II – MOBILE LIDAR
  - CASE STUDY III – AERIAL LIDAR
- LESSONS LEARNED AND KEY POINTS

REMOTE SENSING
A DIFFERENT WAY TO VIEW A PROBLEM



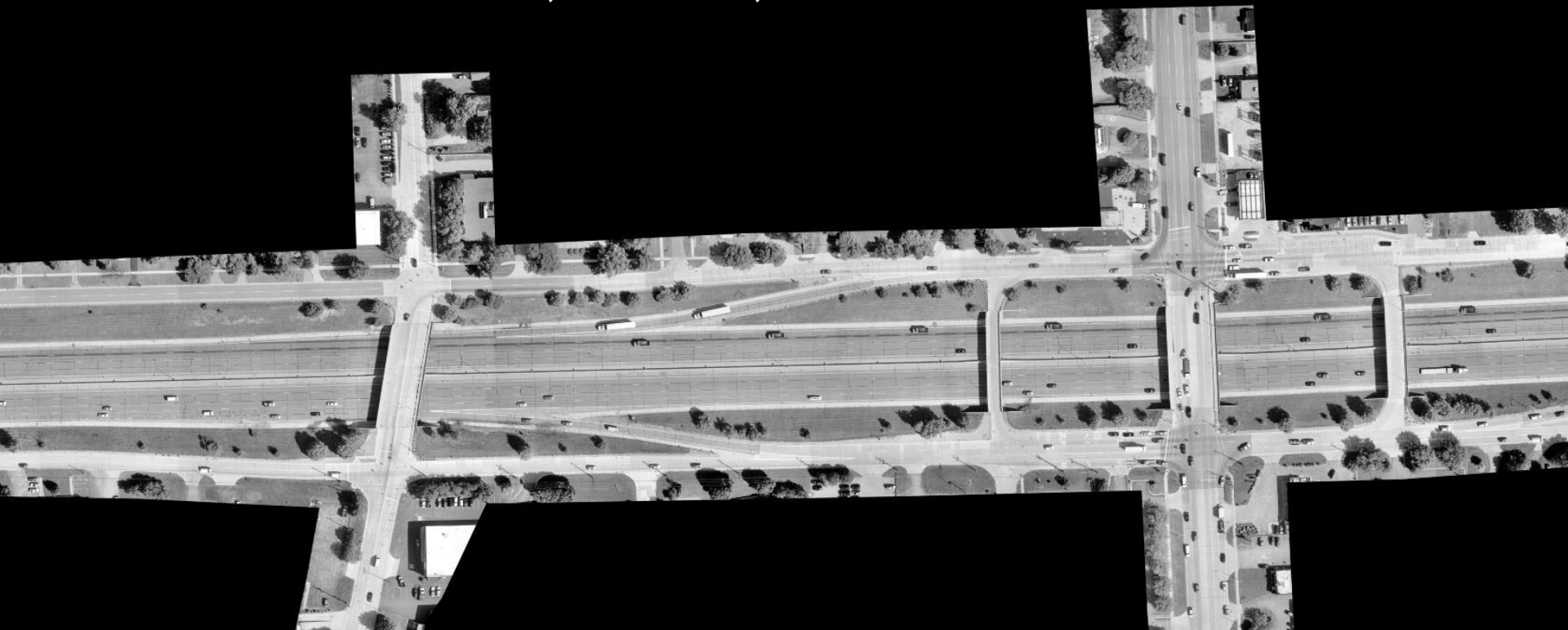
TYPES OF REMOTE SENSING

- Aerial Imagery / Orthophotos
- LiDAR
  - Terrestrial (tripod mounted)
  - Mobile (vehicle mounted)
  - Aerial (fixed wing, helicopter, or UAV)



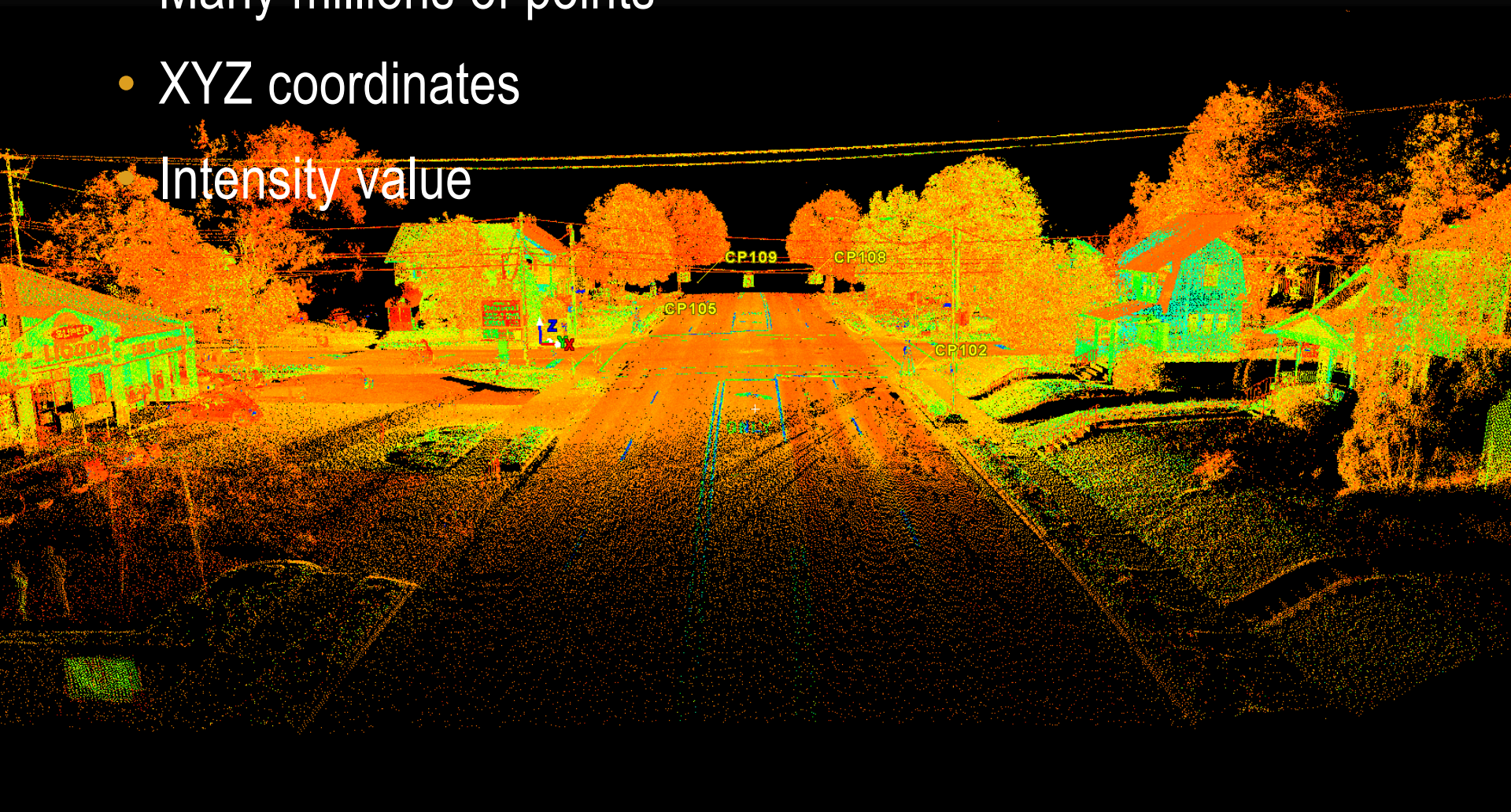
AERIAL IMAGERY / ORTHOPHOTOS

- Accurate
- View features relative to each other
- Issues with trees, weather, sun



LIDAR (LASER PULSE)

- Many millions of points
- XYZ coordinates
- Intensity value

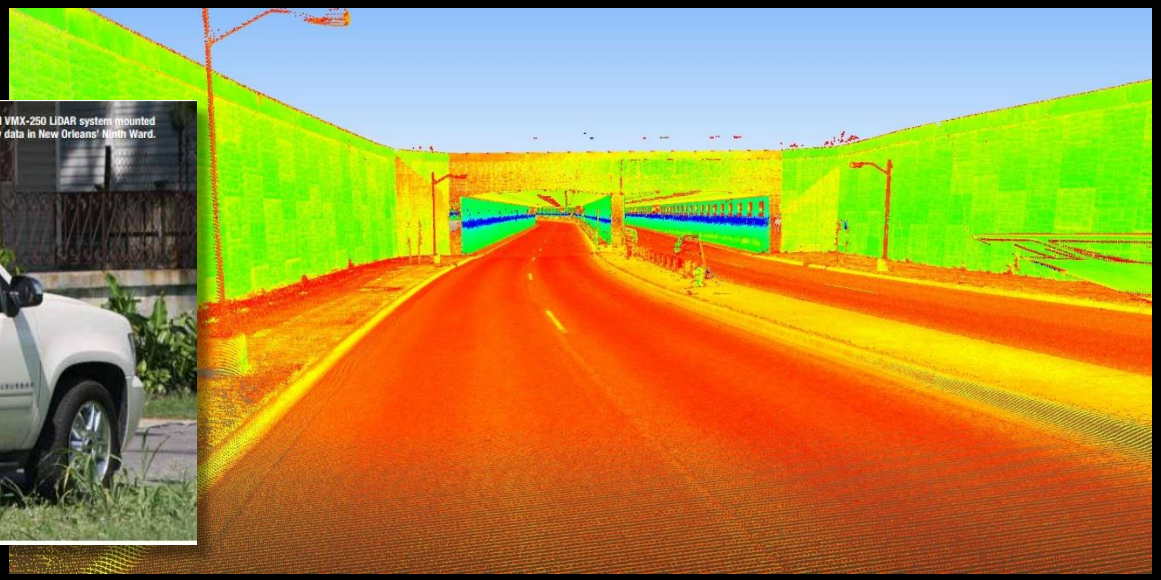


LIDAR: TERRESTRIAL

- MDOT owns
- High accuracy
- High resolution
- Small projects

LIDAR: MOBILE

- MDOT contracts
- Highway speeds
- Large-scale corridor mapping projects
- More expensive, but costs offset by speed and quantity of data collection

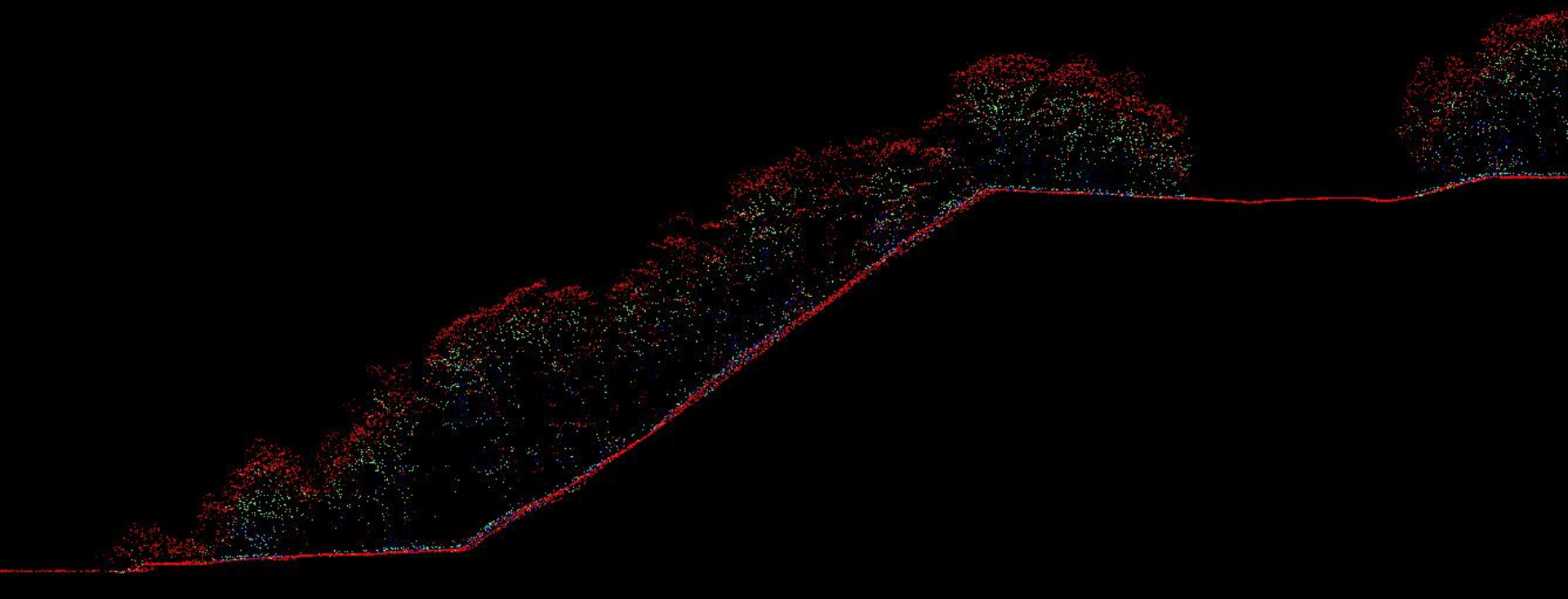


LIDAR: AERIAL

- MDOT contracts
- Slightly Lower Accuracy & Resolution
- Large-scale regional projects; hydrological studies
- Project planning importance

LIDAR

- Independent of sun angle
- Some data collected through foliage

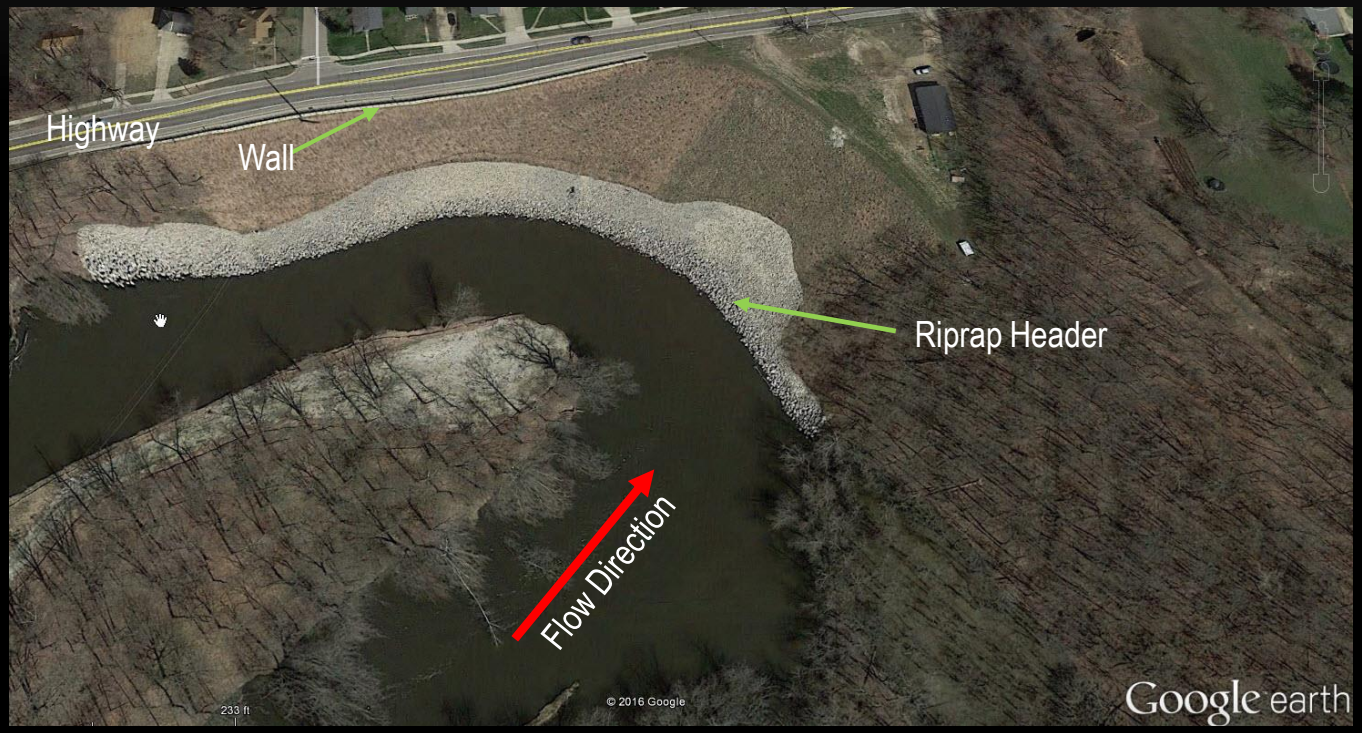


CASE STUDIES

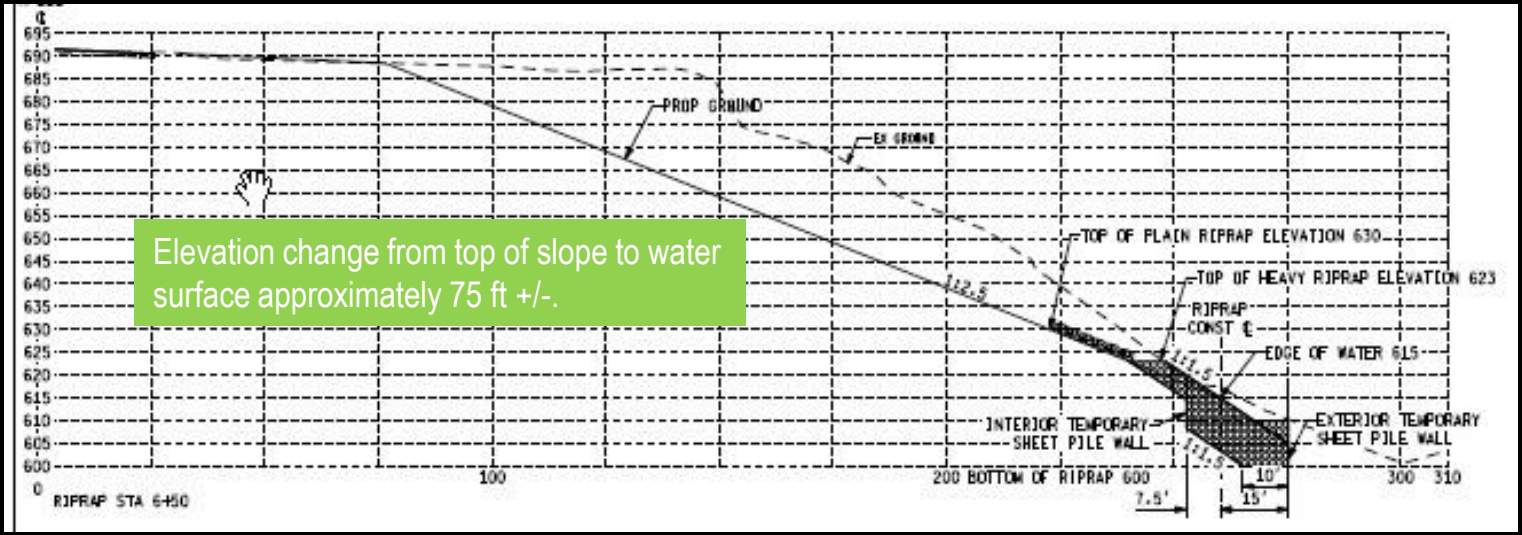
- Case study 1: Southwest Region Slope Stabilization
  - Terrestrial LiDAR
- Case study 2: M-10 Corridor
  - Mobile LiDAR
- Case study 3: Lake Michigan North Shore Slope
  - Aerial LiDAR

CASE STUDY I - SOUTHWEST REGION SLOPE

SLOPE – KALAMAZOO RIVER LAYOUT

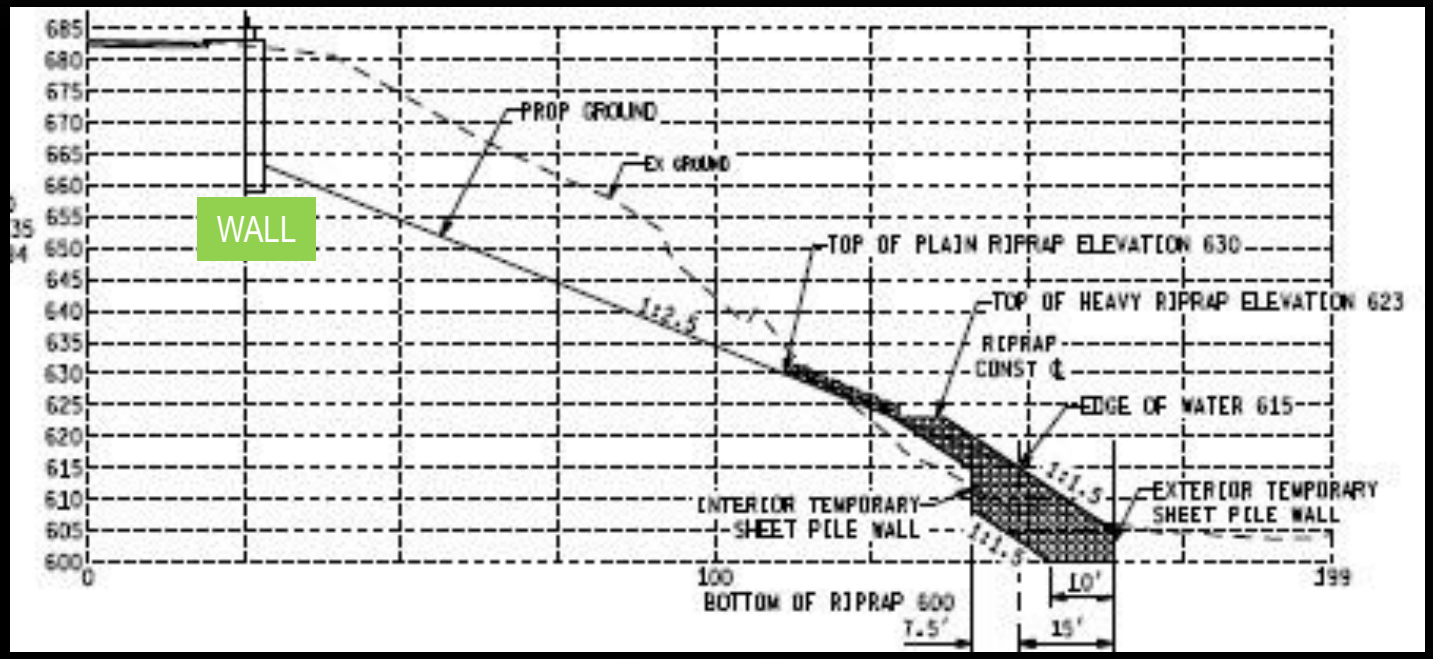


CROSS SECTION 1



Elevation change from top of slope to water surface approximately 75 ft +/-.

CROSS SECTION 2



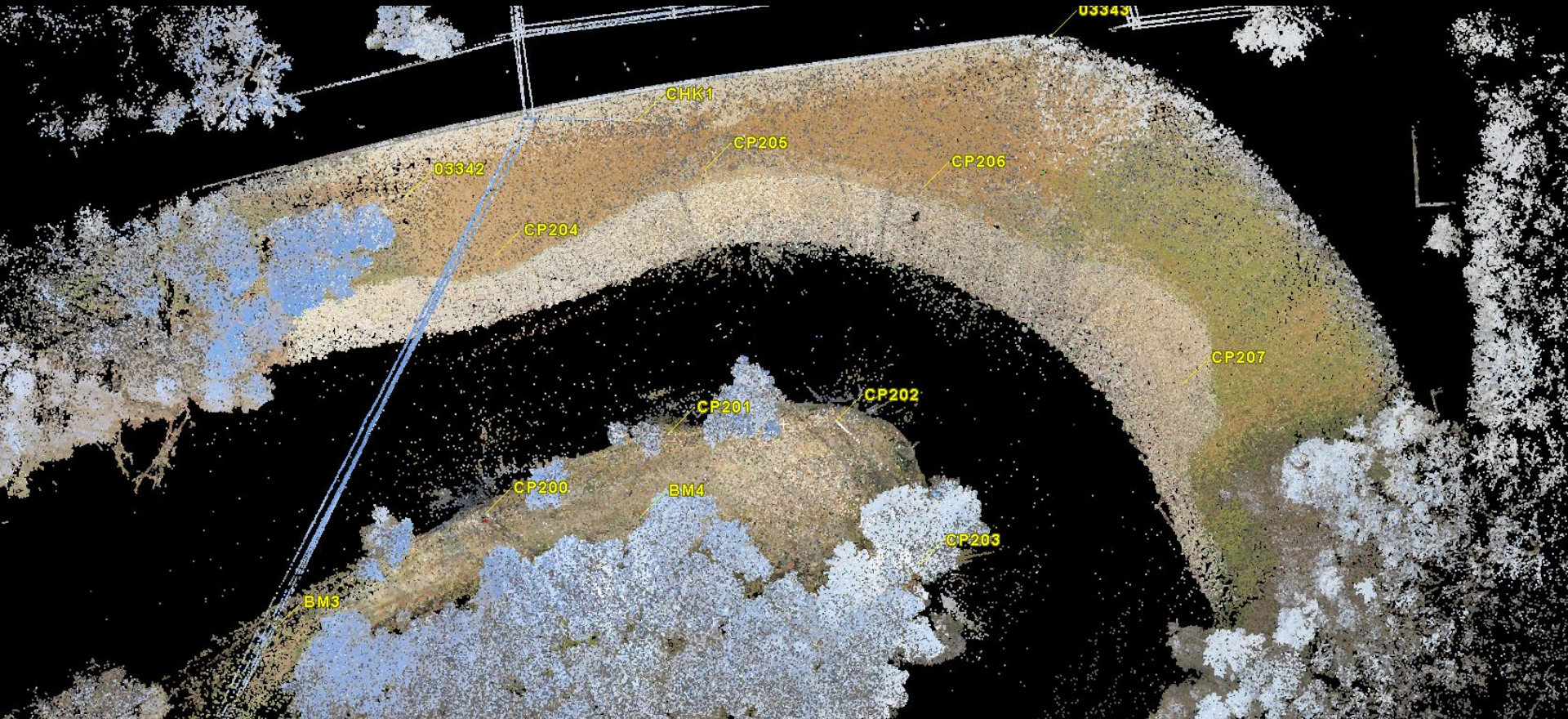
RIPRAP SLOPE TOE AND HEADER – LOOKING WESTERLY

CASE STUDY 1
SOUTHWEST REGION SLOPE STABILIZATION

- Baseline Scan: March 2013
- Scan #2: April 2013
- Scan #3: August 2013
- Scan #4: August 2015
- Scan #5: April 2016

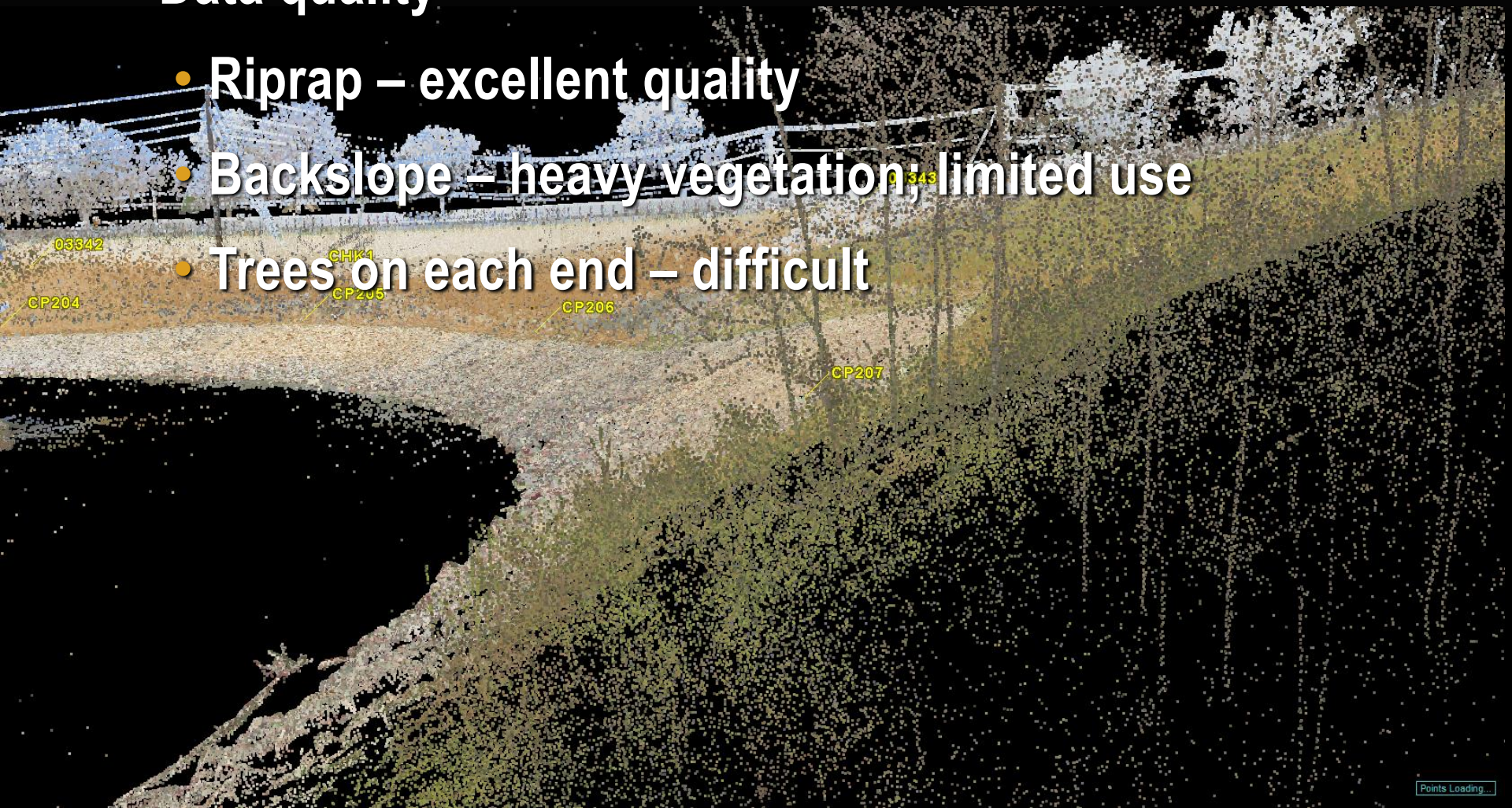
CASE STUDY 1
SOUTHWEST REGION SLOPE STABILIZATION

- Originally 4 scan locations
- Increased to 6 locations recently



CASE STUDY 1
SOUTHWEST REGION SLOPE STABILIZATION

- **Data quality**
  - **Riprap – excellent quality**
  - **Backslope – heavy vegetation; limited use**
  - **Trees on each end – difficult**



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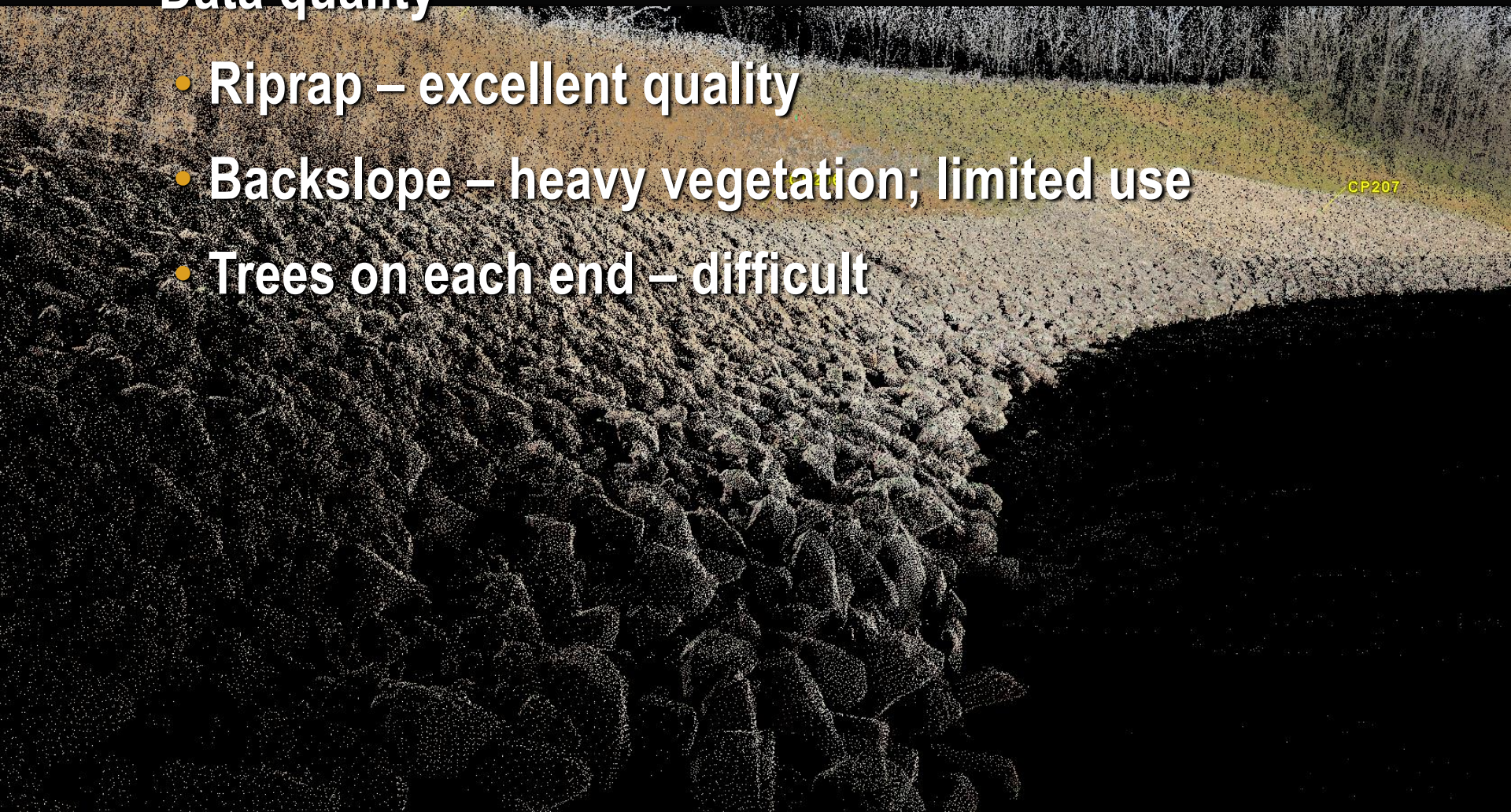
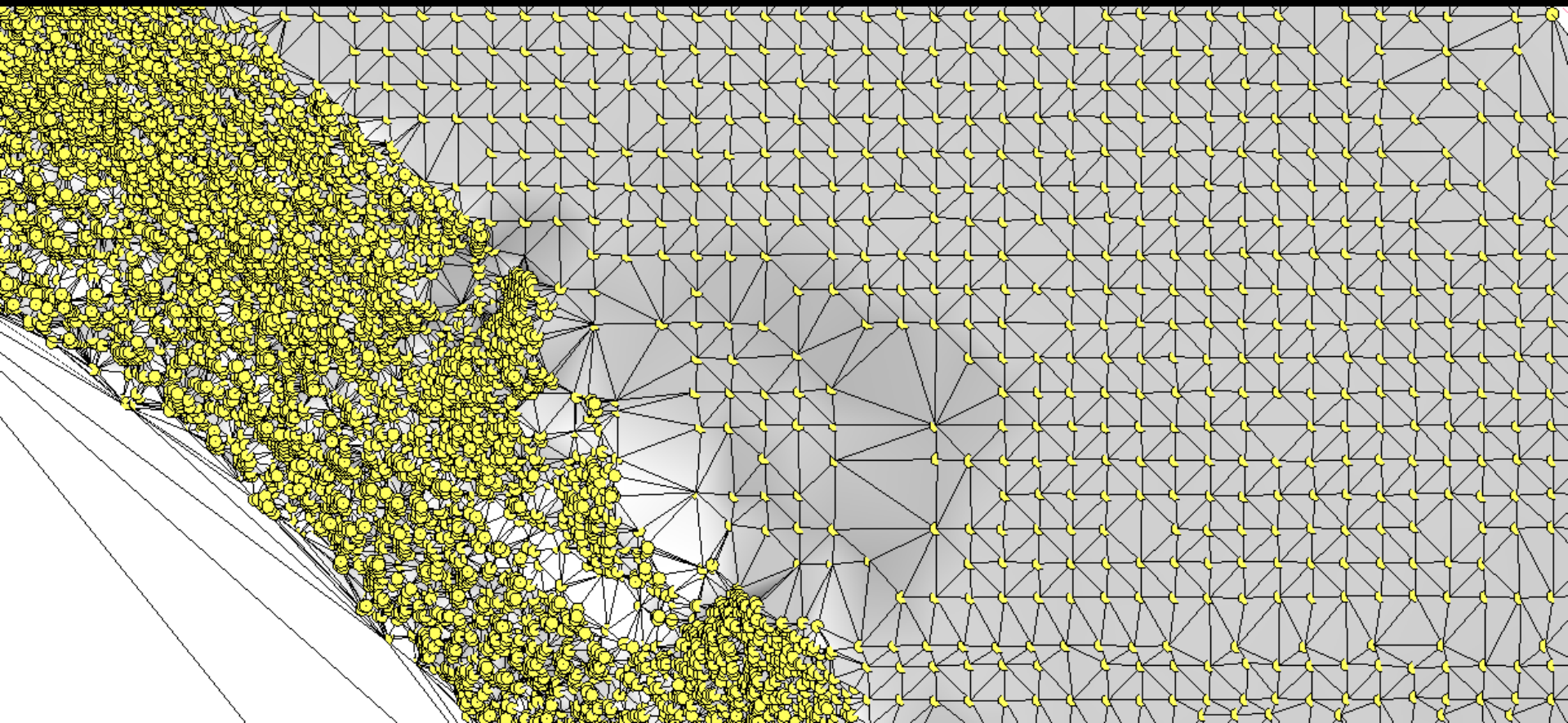


CASE STUDY 1
SOUTHWEST REGION SLOPE STABILIZATION

- Data processing
  1. TopoDOT Elevation Grid



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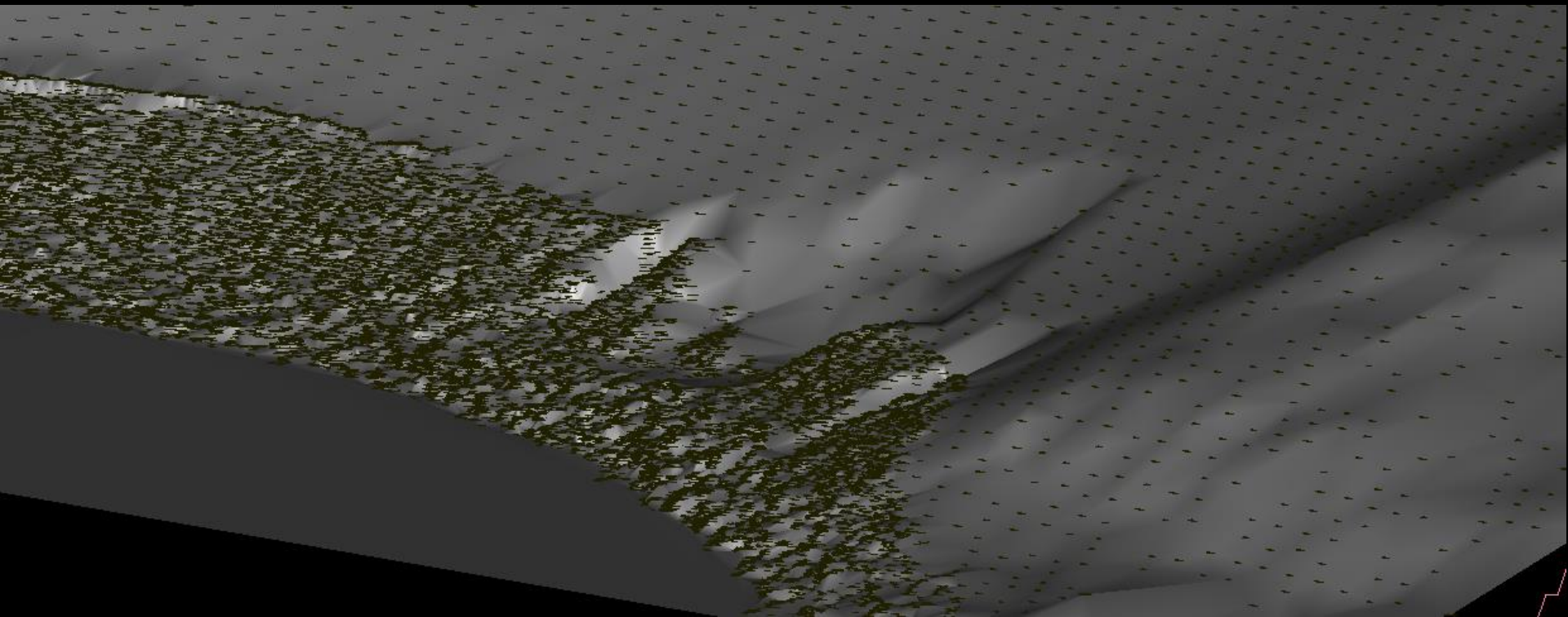
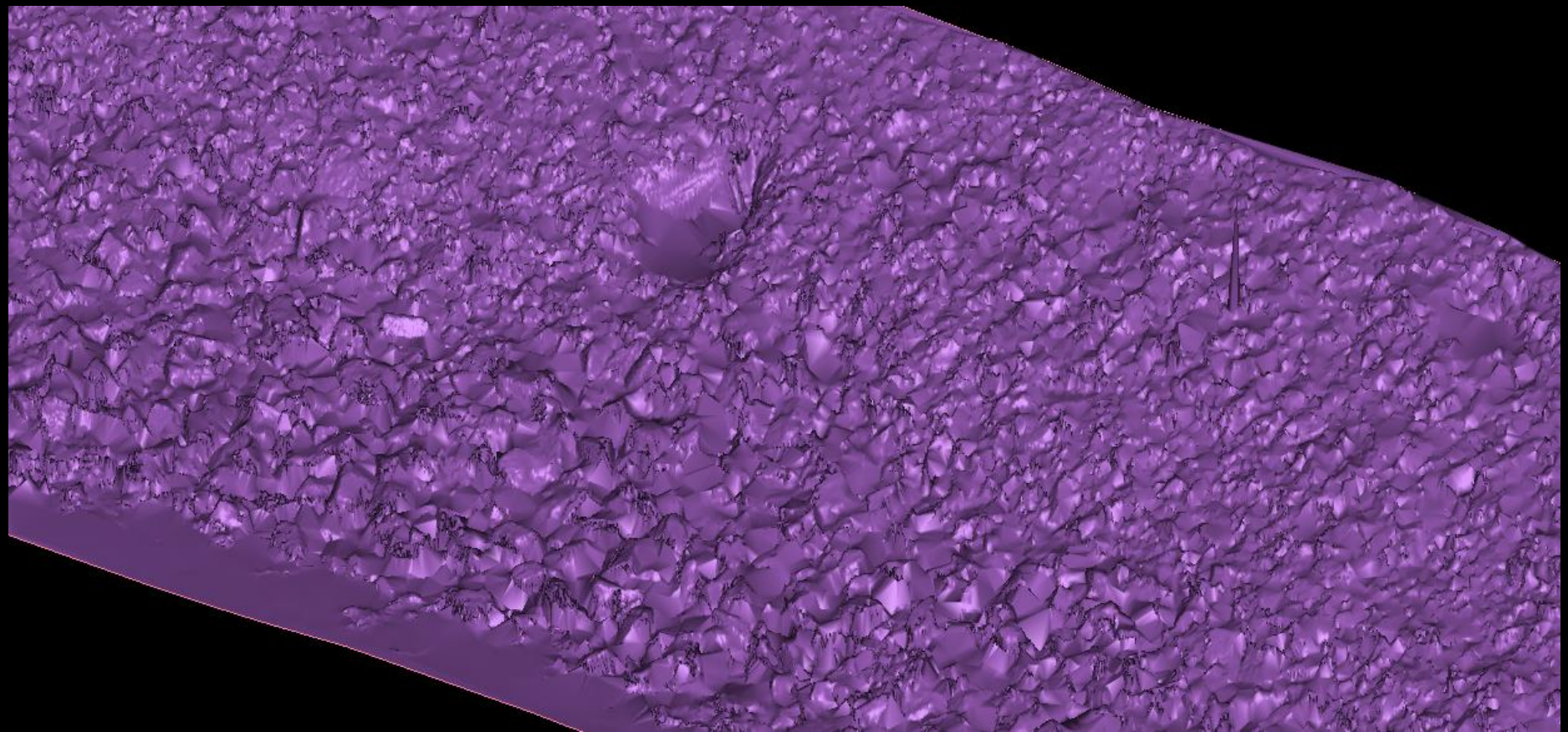


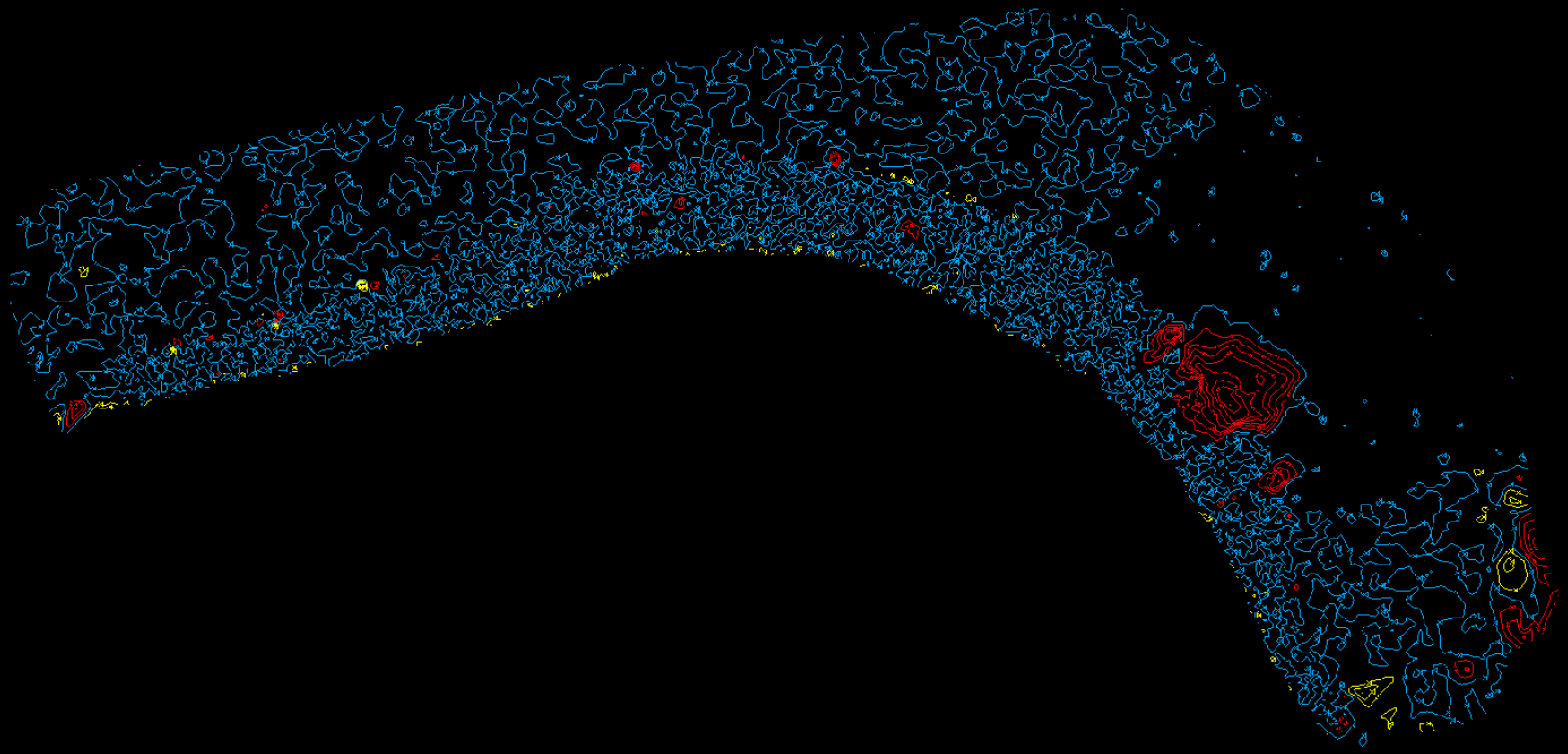
CASE STUDY 1
SOUTHWEST REGION SLOPE STABILIZATION

- Data processing
  2. Terrain surface from LiDAR



CASE STUDY 1
SOUTHWEST REGION SLOPE STABILIZATION

- Deliverables



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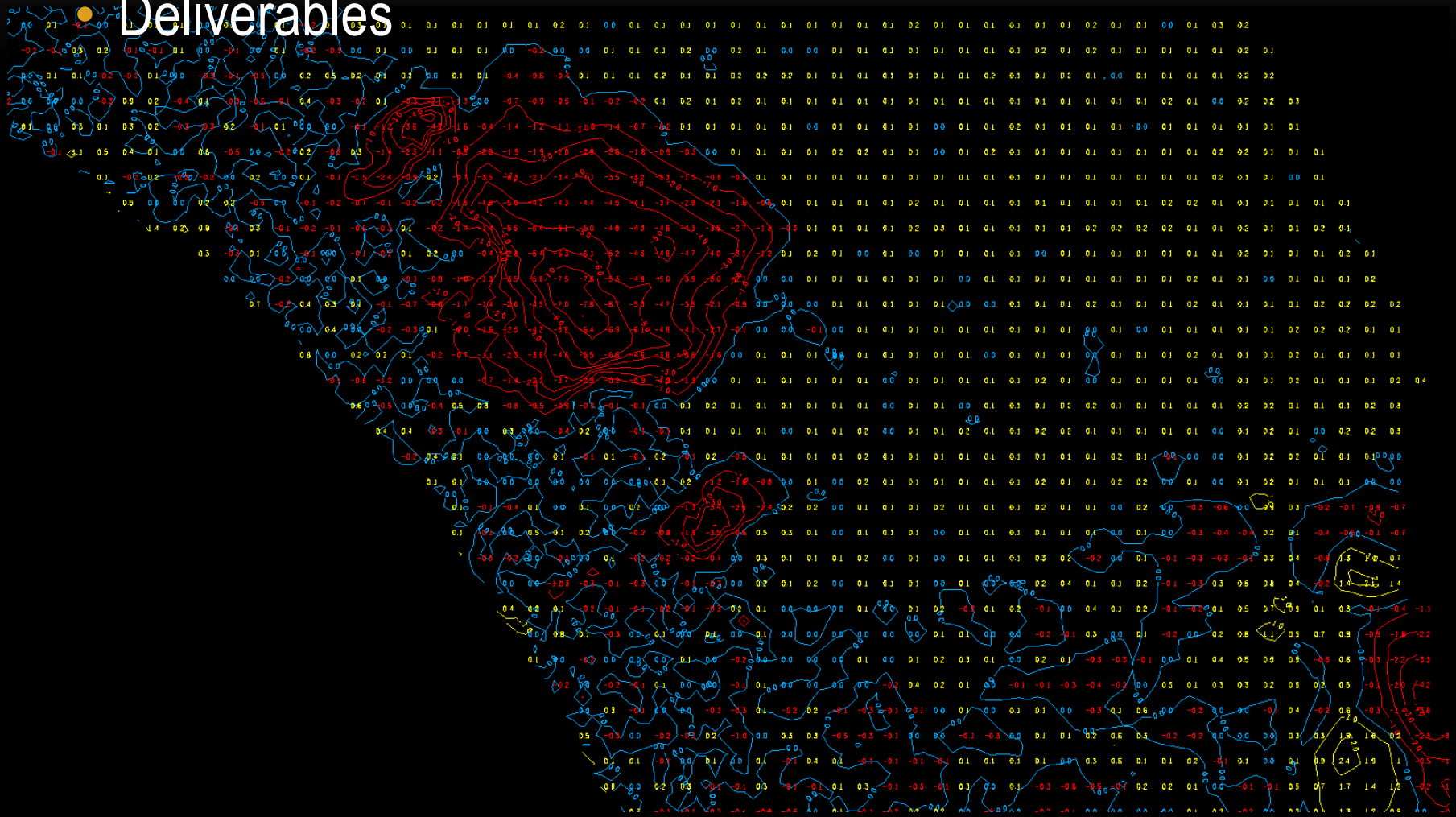

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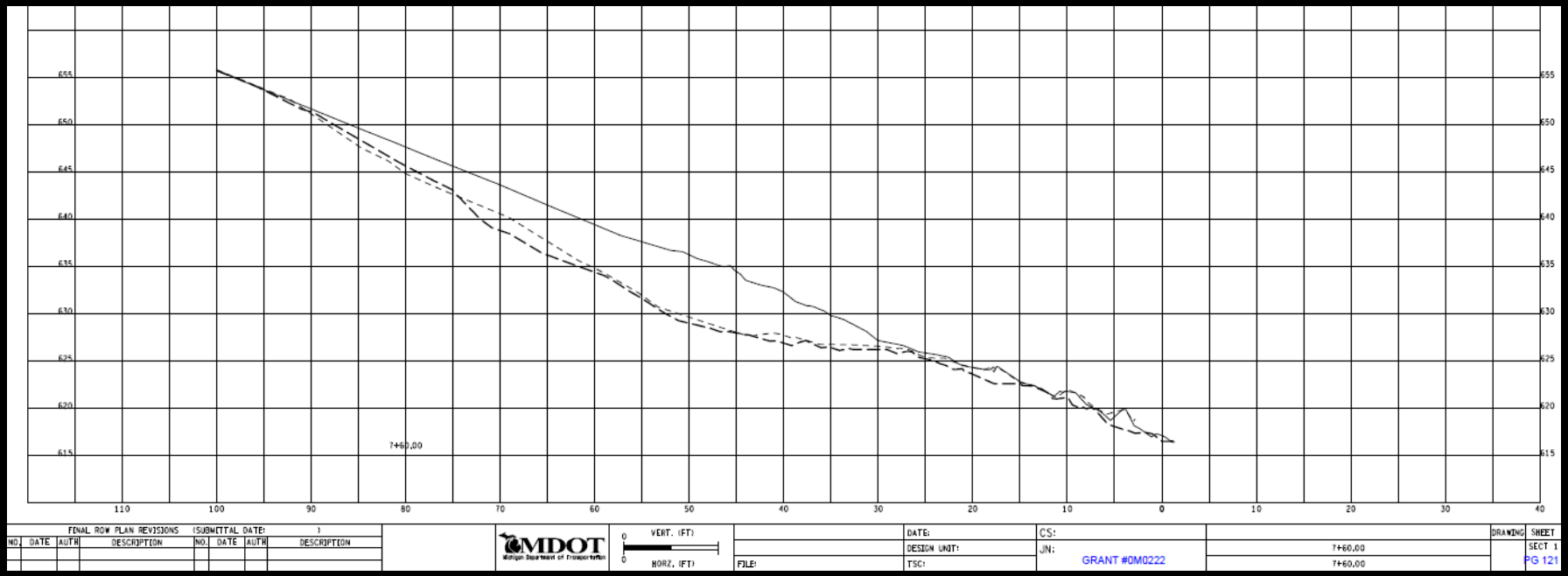

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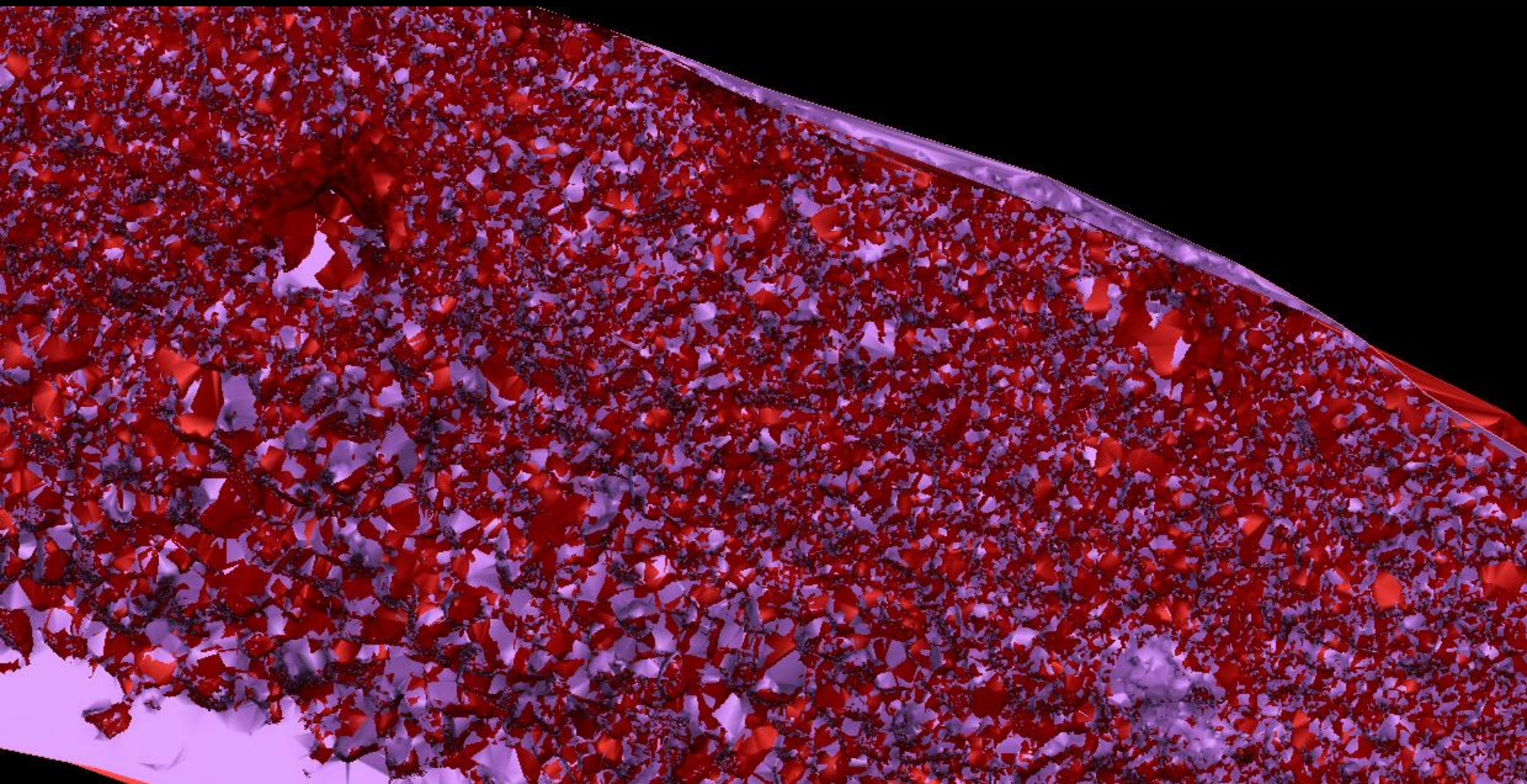

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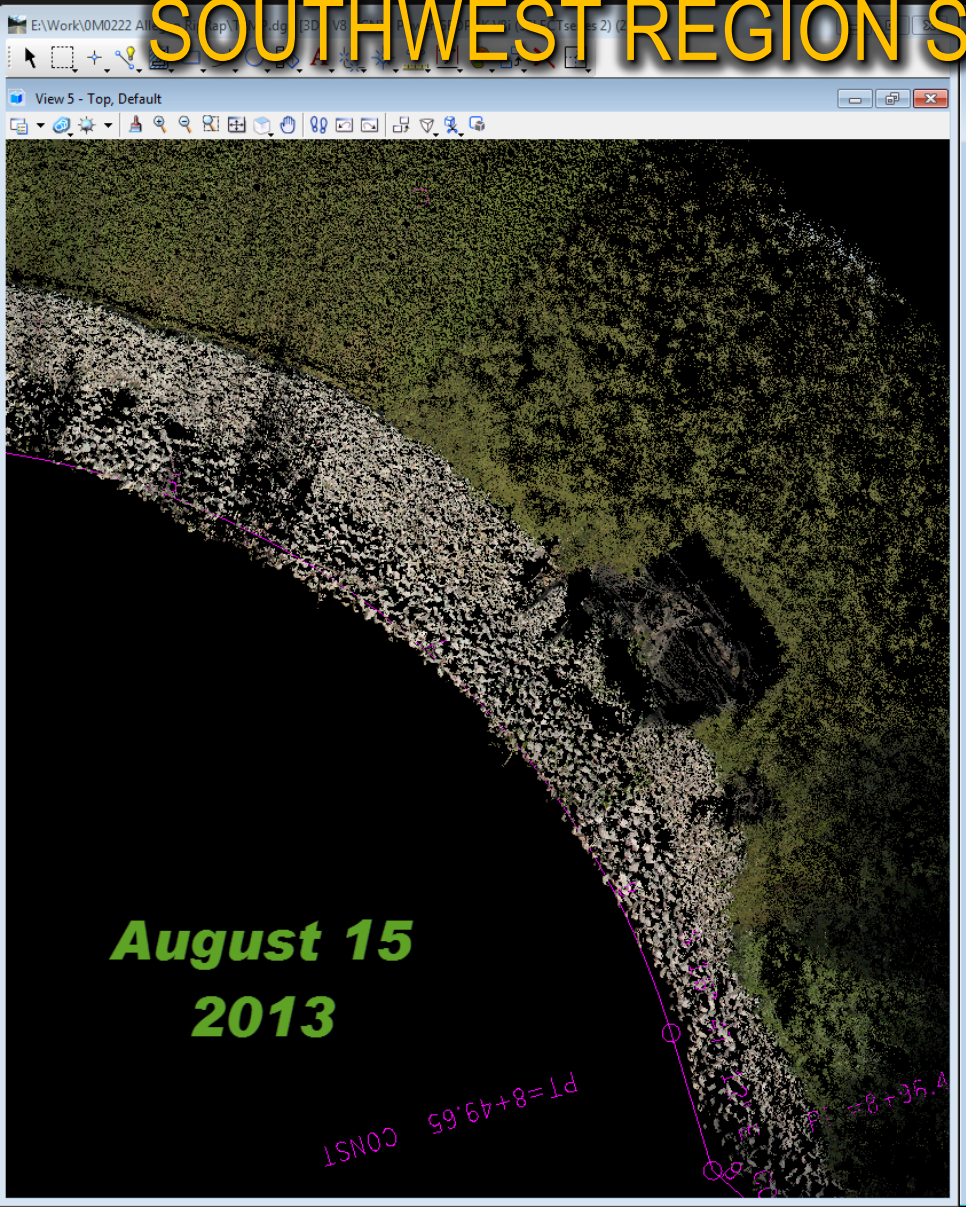

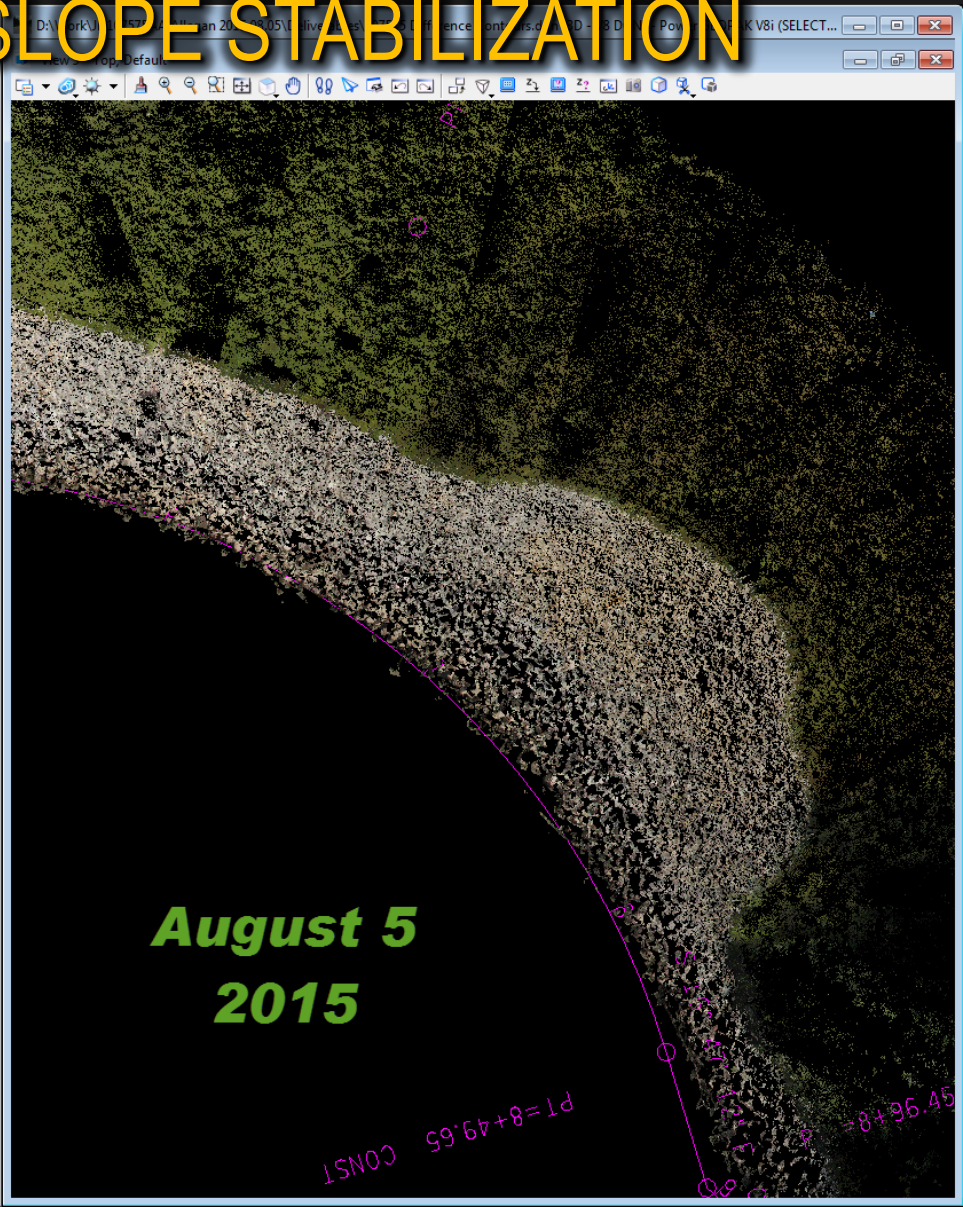

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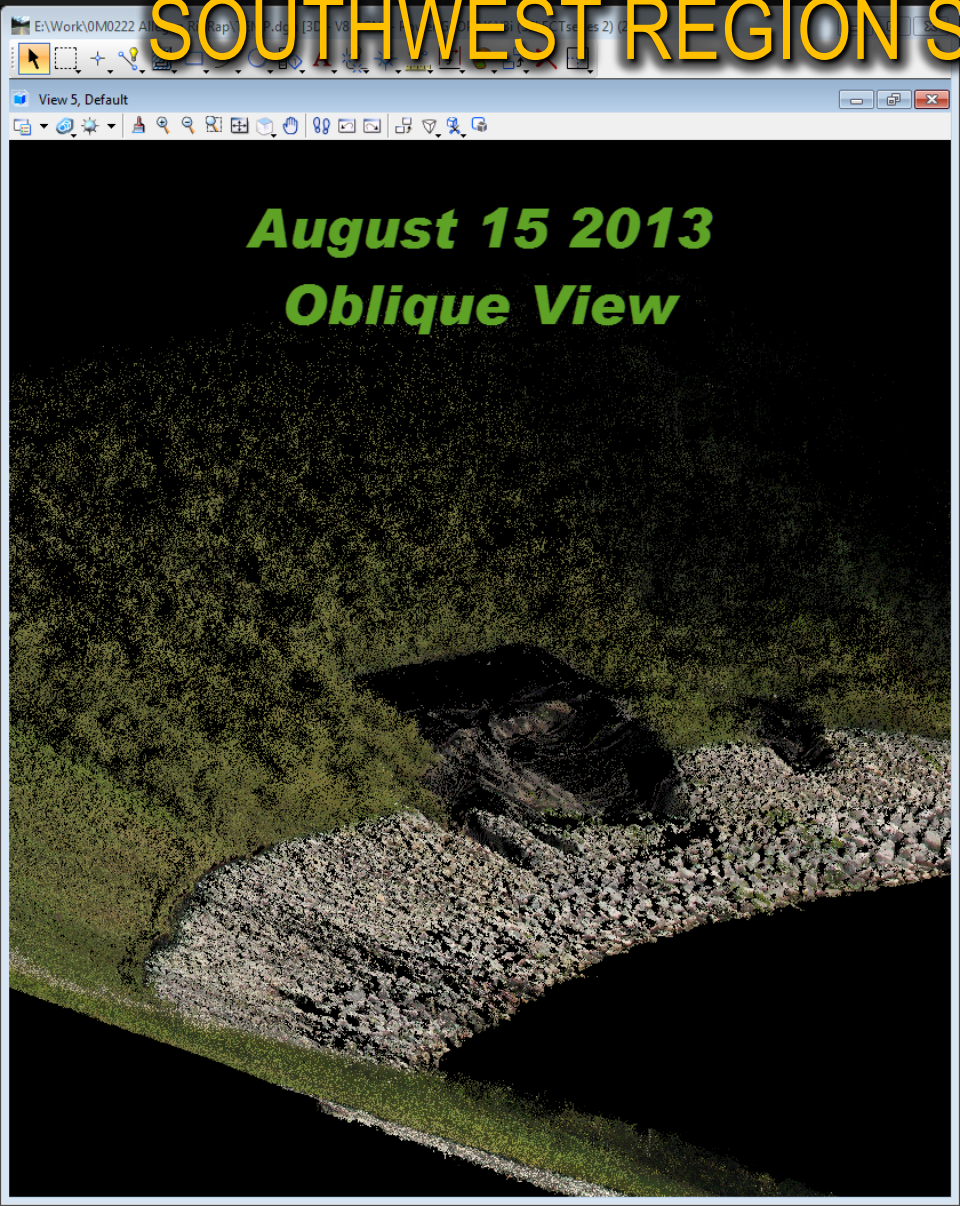
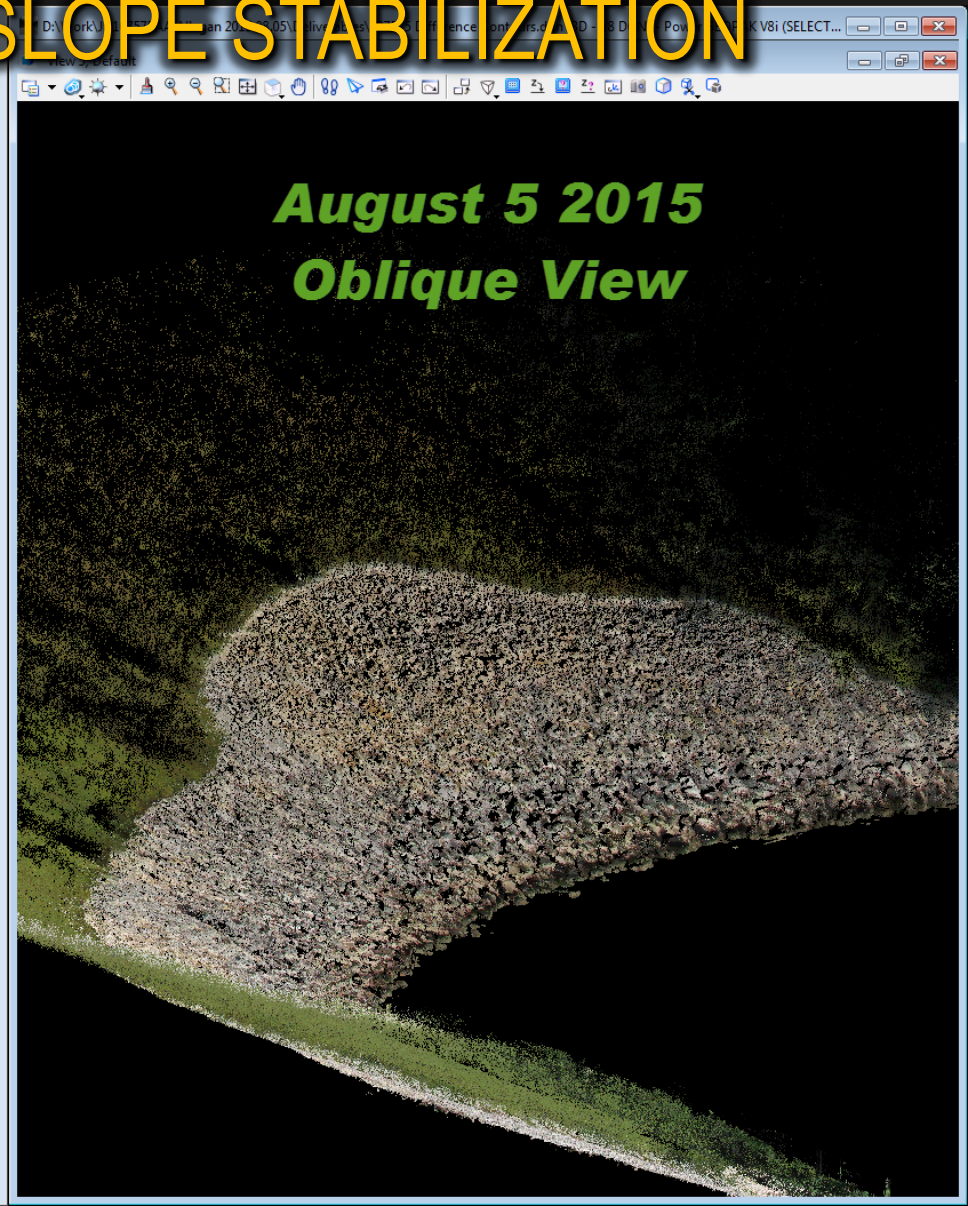
SOUTHWEST REGION SLOPE STABILIZATION



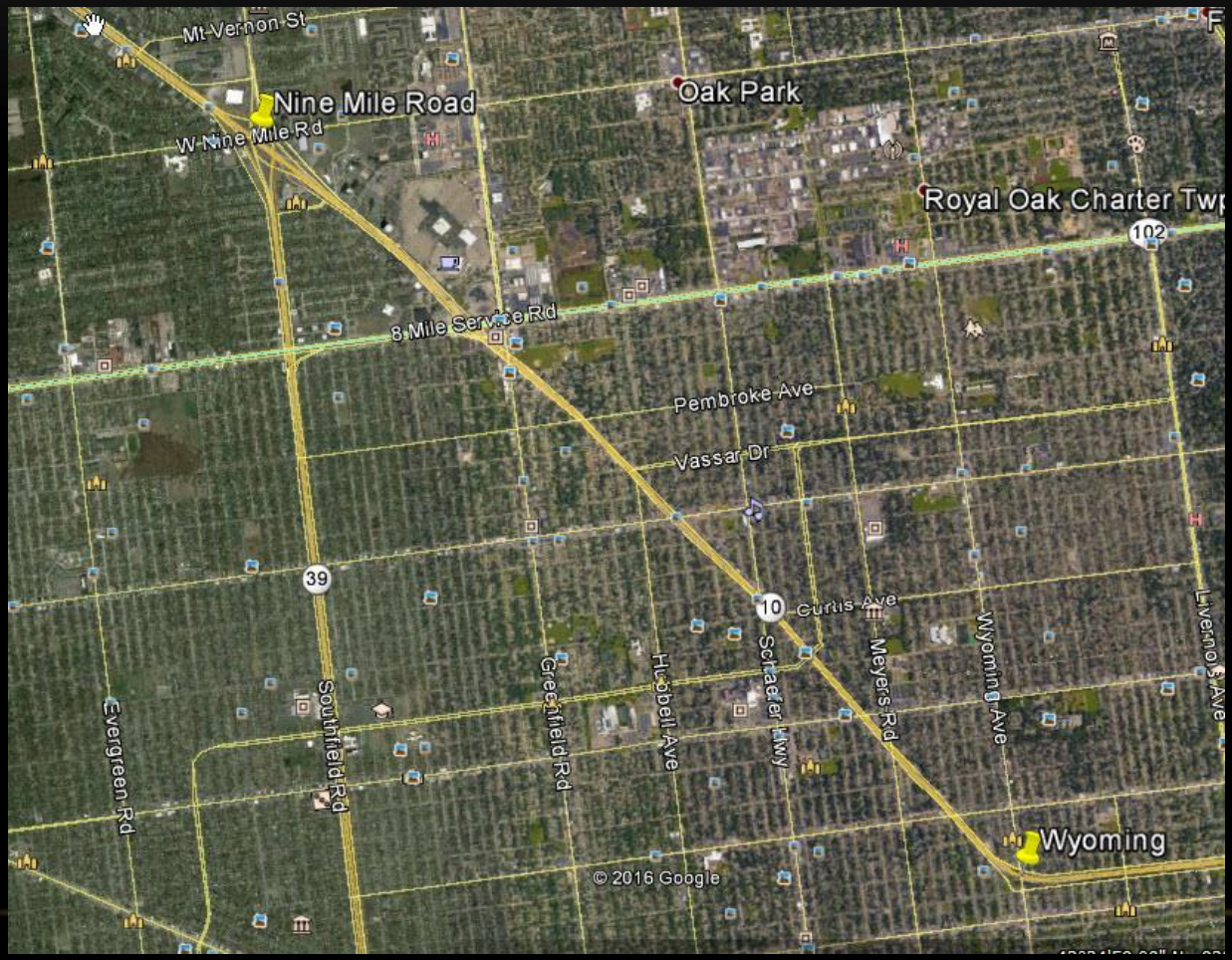


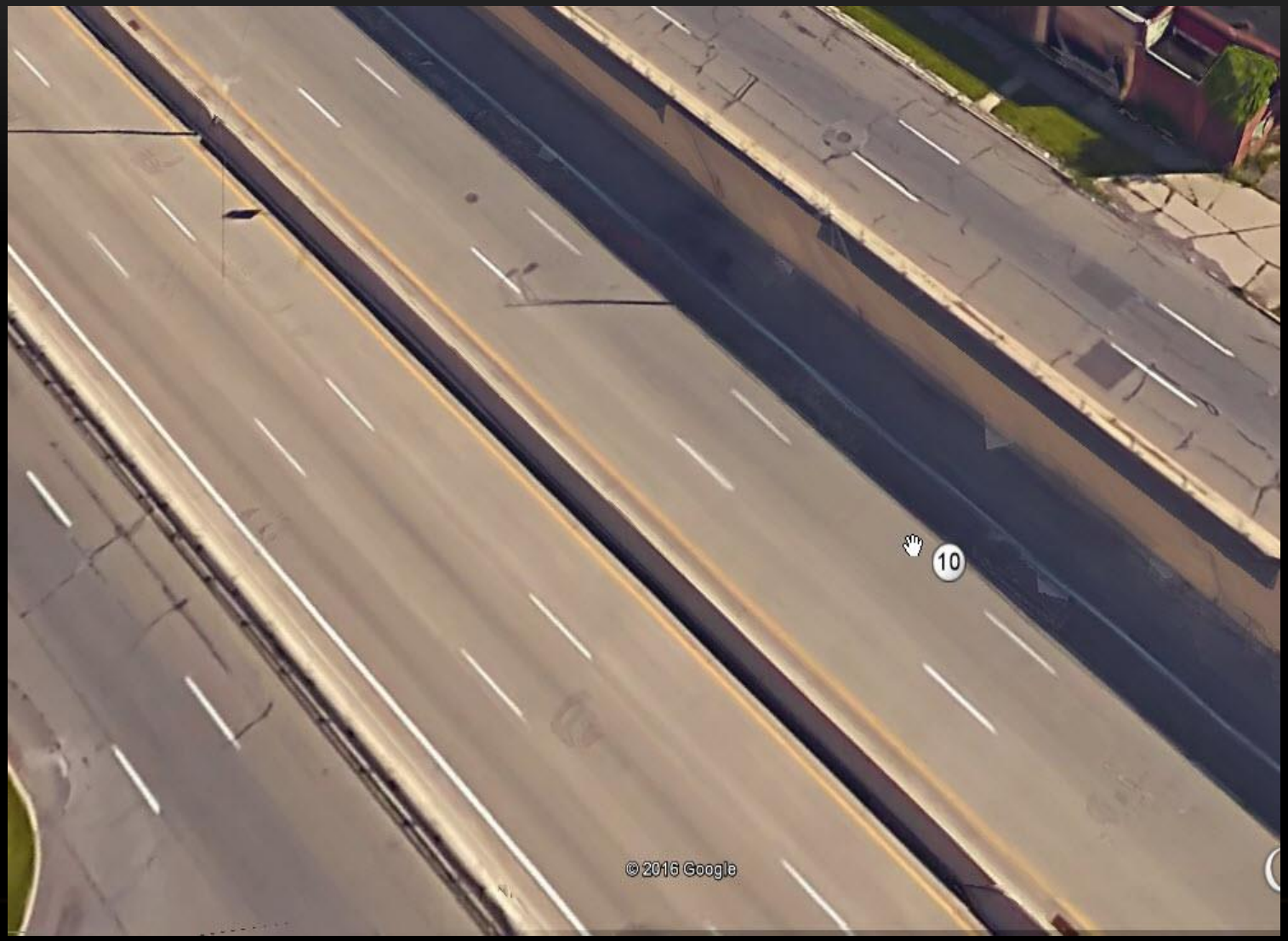
CASE STUDY #2
M-10 LODGE FREEWAY MOBILE LIDAR

Photo by: Hubbell Roth & Clark, Inc.

PROJECT LOCATION – DETROIT, MI

WYOMING AVENUE NE TO NINE MILE ROAD

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UNIQUE RETAINING WALL DESIGN

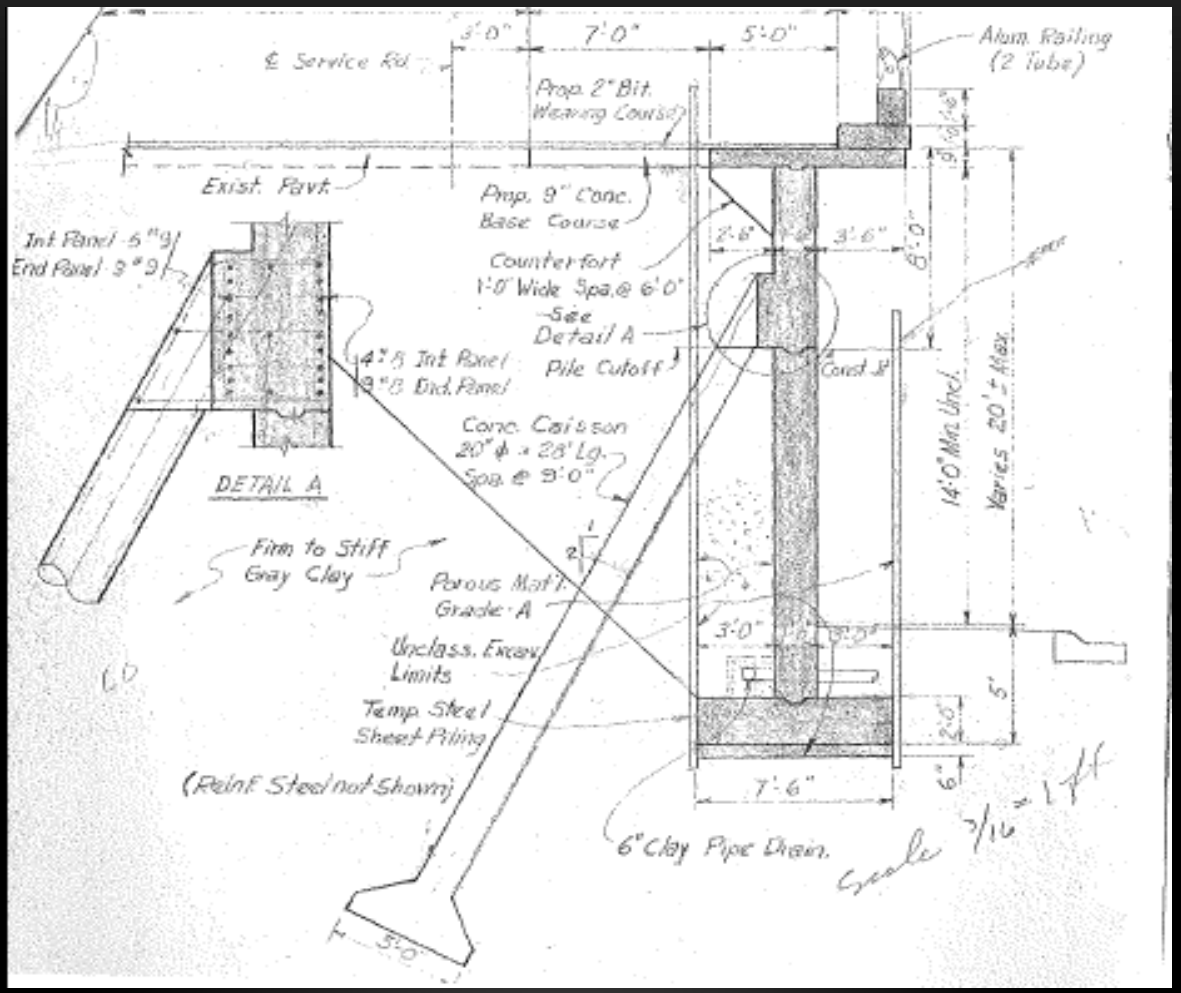


Photo by: Hubbell Roth & Clark, Inc.

THIS DESIGN WAS A NEW WAY TO BUILD IN 1962

OH, AND ALL, TOO

Brains, Tests & Time Equal Xway Extension

Expressway construction is just getting too complicated.

Before you can put one together these days, you have to know how to build a wall.

steel cylinders in the holes, and filled the cylinders with concrete. These are the anchors.

* * *

NOW THEY'RE USING motor-driven jacks to try to

hour cycles of test ing the stress b each hour. This the point at anchor will snap.

So far the been completed on

$257 per foot vs. $305 per foot saved $2,281,000

M-10 RETAINING WALL FROM SERVICE DRIVE

5.5” DIFFERENTIAL

4” OFFSET AT THE CONSTRUCTION JOINT

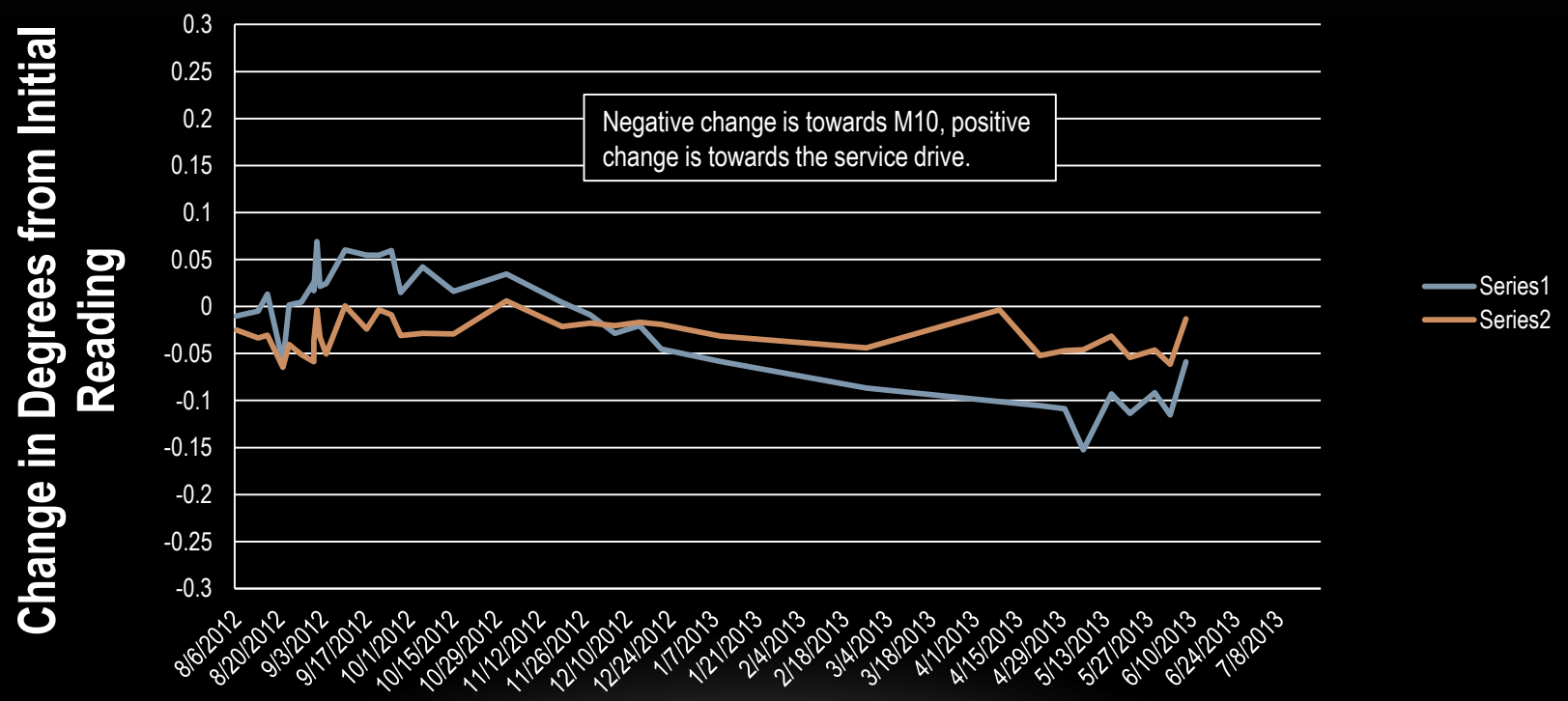
INVESTIGATION INTO CAUSE OF MOVEMENT

- Soil borings
- Underdrain inspection
- Well
- Monitoring with tilt sensors

Well Log	
DATE	WATER ELEVATIONS
8/21/2012	20.4'
8/22/2012	20.4'
8/24/2012	20.4'
9/7/2012	20.4'
9/21/2012	20.5'
10/1/2012	20.4'
10/24/2012	20.4'
11/15/2012	20.4'
12/6/2012	20.5'
1/10/2013	20.4'
2/12/2013	20.4'
3/6/2013	20.4'
4/9/2013	20.4'
5/14/2013	20.4'
5/24/2013	20.4'
5/28/2013	20.4'
6/10/2013	20.27'
6/14/2013	20.37'
6/20/2013	20.37'

NOTES:Tilt monitor locations 1-7 are at the top of the wall on the service drive side. Locations 8-9 are 8 feet above M10 on the face of the wall.
Wall expansion joints
James Couzens Fwy
John C Lodge Fwy
Lodge Fwy
James & Schaefer Gas & More
Pickford Ave
Schaefer Hwy
1
2
3
4
5
6
7
8
9
10
20 ft
10 m
Map
Traffic
Imagery ©2013 Google, Map data ©2013 Google
Edit in Google Map Maker
Report a problem

WALL MONITORING USING TILT METERS



SPRING OF 2013 EMERGENCY EXCAVATION

3 ¾” SEPARATION IN CENTER BAR

CORROSION IN REINFORCING STEEL

FINDINGS FROM WALL REPLACEMENT

- Corrosion and cracks in the caissons
- Broken post tensioning bars
- Corrosion in the steel between the footing and the stem of retaining wall
- The need for a monitoring system for the 4.5 miles (one way) of retaining wall

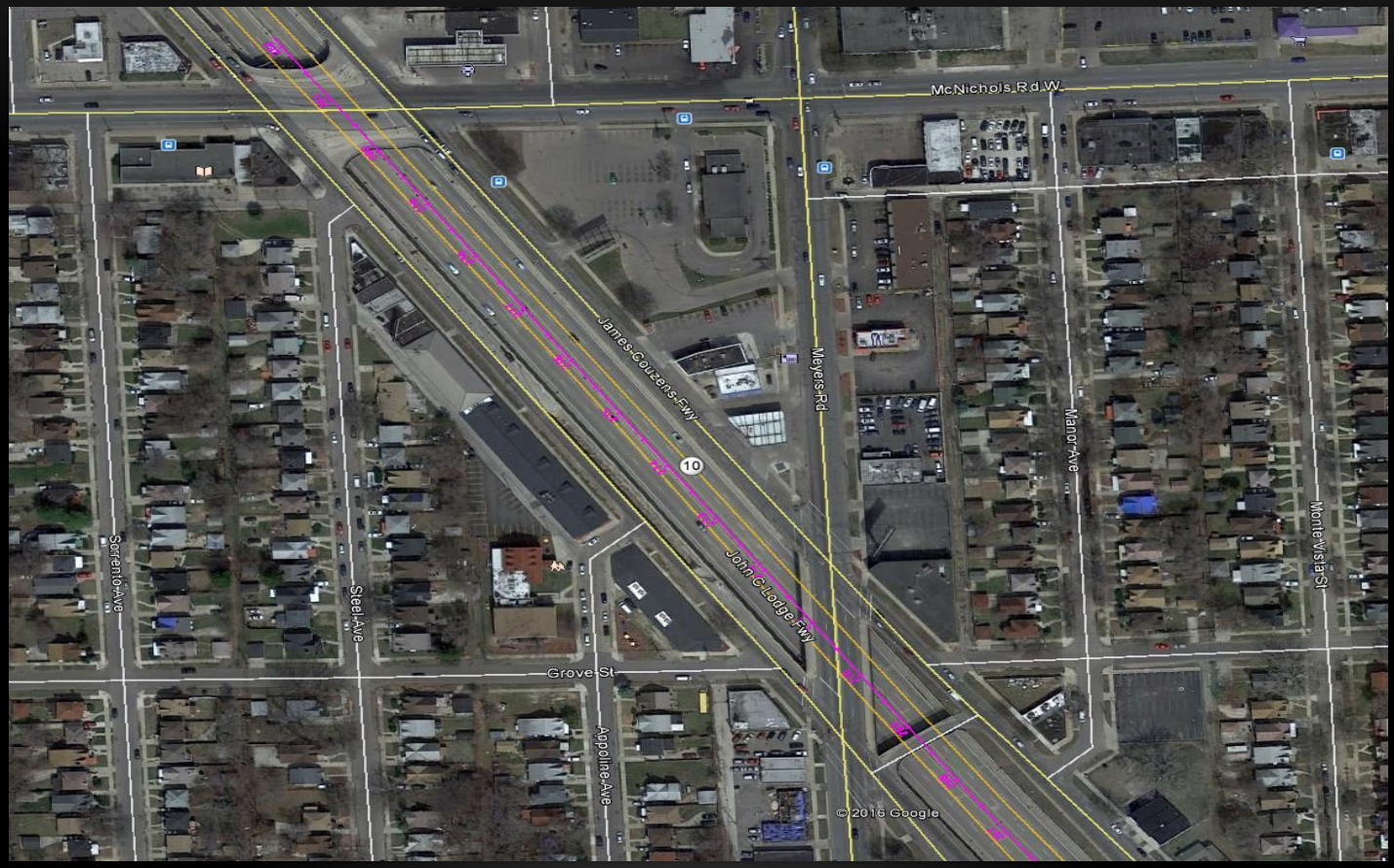
A PLAN FOR THE FUTURE

- Replace this section of wall with a cantilever retaining wall.
  - Cost of $1,600,000 for 200ft.
  - Cost for entire corridor at this price is $309,000,000.
- Additional areas of distress were found along 4.5 mile (one way) corridor and tilt sensor monitors were installed.
- A consultant was selected to study the walls and provide recommendations for the most cost effective repair and provide a monitoring plan using mobile LiDAR.

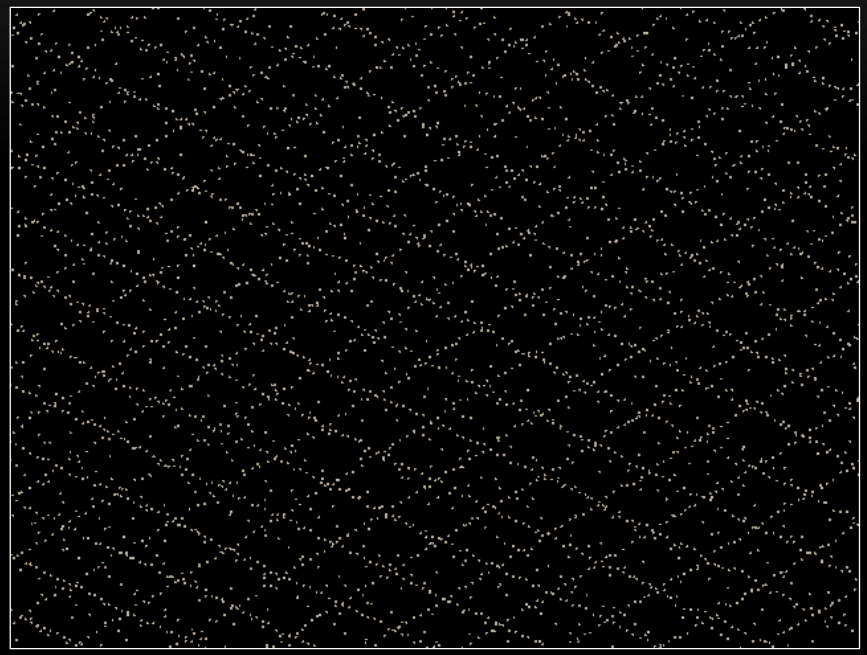
MOBILE LIDAR

- Project spanned over a 2 year time period (in 2014 & 2015)
- Utilized Mobile LiDAR with multiple pass technique
- Collected data at highway speeds with zero disruption to daily traffic.
- Identifiable anomalies in the ranging error
- Dual head LiDAR scanner was critical to allow for “forward and backward” looking data.

AREA OF ANALYSIS STA 268+30 TO STA 282+10



COLLECTION



PROCESS

- Using in house developed software, SSI compared multiple passes between 2014 to ensure equipment was calibrated and ranging errors met project specifications.
- The same process was performed for the 2015 scan data.
- Once the 2014 and 2015 scans were validated independently, the two datasets were compared to show critical areas

2014 COMPARISON BETWEEN PASSES

268+40	268+50	268+60	268+70	268+80	268+90	269+0	269+10	269+20	269+30	269+40	269+50	269+60	269+70	269+80	269+90	270+0
0.008	0.008	0.008	0.004	0.010	0.013	0.006	0.014	0.005	0.007	0.007	0.005	0.007	0.006	0.005	0.010	0
0.002	0.000	-0.005	-0.002	-0.008	-0.001	0.002	-0.002	0.000	-0.003	0.002	-0.002	0.007	-0.001	0.005	0.003	0
0.001	0.000	0.000	0.000	-0.004	-0.002	-0.001	-0.003	0.001	-0.004	-0.001	-0.001	0.006	-0.002	0.005	0.003	0
0.002	0.001	-0.006	-0.004	-0.001	-0.003	0.000	0.000	-0.001	-0.004	-0.002	0.000	0.003	-0.004	0.004	0.002	0
-0.005	0.001	0.004	0.000	-0.001	-0.006	0.002	-0.002	-0.002	-0.007	-0.002	0.002	0.003	-0.004	0.000	0.001	0
0.000	-0.001	0.001	0.000	-0.004	-0.004	0.000	-0.001	0.001	-0.004	0.001	-0.003	0.005	-0.003	0.003	-0.004	0
-0.008	0.002	0.001	-0.003	-0.005	-0.006	0.000	-0.003	0.000	-0.004	0.003	-0.005	0.003	-0.003	0.003	0.003	-0
-0.007	0.003	0.002	0.000	-0.010	-0.003	-0.002	0.000	0.001	0.001	0.006	-0.002	0.002	0.001	0.003	0.001	0
0.000	0.004	-0.005	-0.001	0.008	0.000	0.001	-0.007	-0.001	-0.002	0.005	0.003	0.005	0.000	-0.001	0.002	0
-0.002	0.008	0.008	0.002	0.004	-0.005	-0.006	-0.011	-0.001	-0.001	0.005	-0.001	0.003	0.002	-0.003	0.003	0
-0.002	-0.001	0.000	0.000	-0.003	-0.006	-0.003	-0.014	-0.003	-0.004	0.005	0.001	0.004	0.003	-0.002	0.005	0
-0.005	0.004	0.001	0.001	-0.010	-0.009	0.003	-0.008	-0.002	0.001	0.004	-0.003	0.004	0.005	0.000	0.007	0
-0.004	0.004	0.003	0.000	-0.004	-0.008	0.001	-0.008	0.003	-0.001	0.006	0.001	0.001	0.001	0.001	0.010	0
-0.003	0.006	-0.002	-0.001	0.005	-0.009	0.002	-0.008	0.002	0.000	0.007	0.003	0.000	0.004	0.000	0.008	0
-0.004	0.003	0.005	0.001	0.004	-0.005	-0.003	-0.007	0.000	0.002	0.007	0.002	0.003	0.004	-0.001	0.004	0
-0.004	0.000	0.004	-0.001	-0.002	-0.008	0.000	-0.002	-0.002	-0.001	0.004	0.002	0.004	0.004	0.002	0.006	0
0.000	-0.003	0.003	0.001	-0.002	-0.013	-0.002	-0.005	-0.005	-0.002	0.007	-0.002	0.004	0.004	-0.002	0.002	0
-0.001					-0.008	-0.002	-0.002	-0.001	-0.003	0.006	0.002	0.007	0.001	0.002	0.003	0
0.002					-0.006	-0.001	0.001	0.001	-0.001	0.006	0.000	0.006	0.001	0.003	0.008	0

The results from the 2014 "control" comparison show a maximum ranging error of 0.02' and a mean ranging error or 0.01'. These ranging errors are all within the specified ranging error of the scanner used.

2015 COMPARISON BETWEEN PASSES

271+80	271+90	272+0	272+10	272+20	272+30	272+40	272+50	272+60	272+70	272+80	272+90	273+0	273+10
0.008	0.013	0.011	0.004	0.006	0.010	0.010	0.006	0.005	0.005	0.014	0.012	0.013	0.018
-0.002	-0.001	-0.001	-0.004	-0.003	0.000	0.003	-0.001	-0.002	-0.002	0.000	-0.005	0.001	0.002
0.001	0.000	0.000	-0.003	-0.001	0.001	0.001	0.001	-0.001	-0.004	-0.002	-0.001	0.000	0.004
-0.003	-0.001	-0.002	-0.001	-0.002	0.001	-0.001	-0.001	-0.002	-0.004	-0.001	0.001	0.000	0.004
-0.001	0.000	0.001	-0.001	0.001	-0.001	0.002	-0.001	-0.002	0.001	-0.004	0.004	-0.001	0.001
0.001	-0.001	0.001	0.004	0.001	-0.002	-0.005	0.001	-0.002	0.003	-0.001	-0.001	-0.003	0.002
0.000	0.000	0.002	0.000	-0.001	-0.002	0.000	0.003	-0.002	0.002	0.000	0.001	0.005	0.006
0.003	0.002	0.004	0.004	0.004	0.006	0.000	-0.004	-0.005	0.003	0.002	0.000	0.003	0.004
-0.004	0.000	-0.002	0.002	-0.006	0.002	0.006	-0.001	0.000	0.000	-0.004	-0.003	-0.002	0.002
0.000	0.002	0.001	-0.004	0.001	0.004	0.000	-0.004	0.001	-0.005	-0.008	0.002	-0.001	-0.002
-0.008	-0.001	0.003	-0.001	0.004	0.000	-0.002	-0.005	-0.002	-0.003	-0.004	0.003	0.000	-0.002
-0.004	0.006	-0.003	0.001	-0.003	0.003	0.006	-0.004	0.000	-0.002	-0.004	-0.002	0.001	0.011
0.001	-0.001	-0.001	0.001	-0.001	0.003	0.002	-0.001	0.000	0.005	-0.002	-0.002	0.009	0.018
-0.003	0.006	0.011	-0.003	-0.002	0.006	-0.001	-0.003	0.001	-0.001	-0.002	-0.002	0.013	0.013
0.001	-0.005	0.007	0.002	0.001	0.003	-0.002	0.006	0.001	0.002	-0.001	0.012	0.009	0.015
-0.001	0.002	0.010	0.002	-0.003	0.010	0.008	-0.001	0.002	-0.001	0.000	0.008	0.011	0.016
0.005	-0.013	0.008	0.000	-0.004	-0.004	0.010	-0.006	-0.001	0.001	0.009	0.008	0.009	0.016
			-0.002	0.001			-0.002	0.004	0.004	0.014	0.008	0.012	0.014

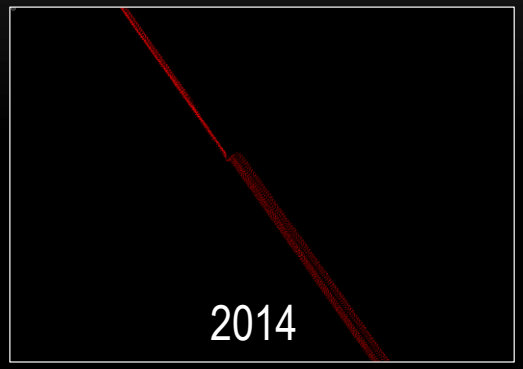
The data also shows that the maximum ranging error remains below 0.02' which proved the ranging errors are "good"

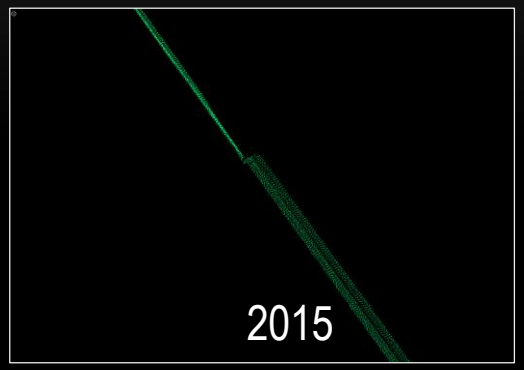
2014 VS. 2015 SCAN DATA COMPARISON

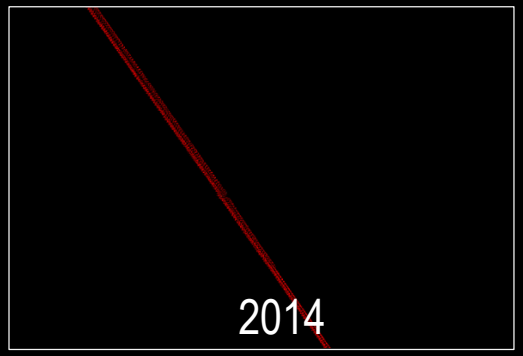
AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL
273+20	273+30	273+40	273+50	273+60	273+70	273+80	273+90	274+0	274+10	274+20	274+30	274+40	274+50	274+60
0.011	0.009	0.072	0.079	0.074	0.074	0.069	0.067	0.064	0.064	0.062	0.058	0.023	0.021	0.026
-0.003	-0.007	0.072	0.079	0.074	0.074	0.068	0.067	0.064	0.063	0.062	0.057	0.023	0.015	0.020
-0.004	-0.007	0.070	0.072	0.072	0.064	0.069	0.066	0.063	0.064	0.061	0.055	-0.006	0.013	0.018
-0.003	-0.001	0.071	0.069	0.065	0.064	0.067	0.062	0.062	0.058	0.057	0.058	-0.003	0.013	0.026
-0.004	-0.003	0.064	0.065	0.064	0.059	0.067	0.061	0.056	0.054	0.053	0.054	0.015	0.015	0.021
0.002	0.004	0.061	0.062	0.061	0.059	0.059	0.056	0.057	0.053	0.051	0.052	0.007	0.017	0.022
0.008	0.008	0.055	0.059	0.057	0.055	0.055	0.052	0.052	0.053	0.049	0.049	0.010	0.021	0.021
0.008	0.003	0.051	0.060	0.059	0.061	0.058	0.043	0.060	0.052	0.044	0.052	0.009	0.015	0.014
0.009	0.004	0.051	0.057	0.053	0.052	0.051	0.047	0.048	0.049	0.046	0.045	0.008	0.016	0.021
0.007	0.005	0.048	0.049	0.049	0.046	0.040	0.044	0.041	0.042	0.044	0.039	0.014	0.013	0.022
0.006	0.008	0.040	0.053	0.045	0.041	0.045	0.046	0.041	0.041	0.039	0.037	0.014	0.016	0.024
0.007	0.006	0.041	0.045	0.043	0.041	0.040	0.041	0.038	0.039	0.032	0.039	0.013	0.019	0.019
0.011	0.009	0.035	0.047	0.038	0.033	0.040	0.038	0.028	0.039	0.032	0.035	0.010	0.012	0.019
0.010	0.007	0.029	0.041	0.031	0.033	0.031	0.028	0.027	0.032	0.028	0.032	0.008	0.012	0.015
0.008	0.008	0.026	0.028	0.026	0.029	0.027	0.027	0.023	0.026	0.023	0.028	0.011	0.019	0.016
0.007	0.008	0.026	0.038	0.028	0.021	0.020	0.020	0.015	0.024	0.022	0.022	0.011	0.014	0.010
0.005	0.006	0.022	0.035	0.024	0.020	0.018	0.025	0.016	0.020	0.021	0.005	0.013	0.008	0.009
0.011	0.007	0.027	0.021	0.024	0.009	0.013	0.010	0.013	0.014	0.019	0.004	0.010	0.006	0.008

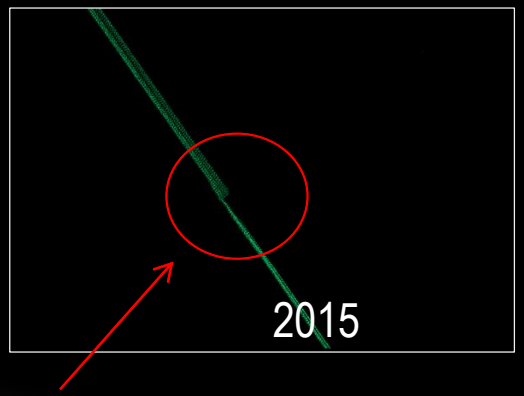
Any results over the established ranging noise error of +/- 0.02' was considered to be a potential area of movement. The data clearly shows movement between stations 273+40 and 274+30.

DATA COMPARISON









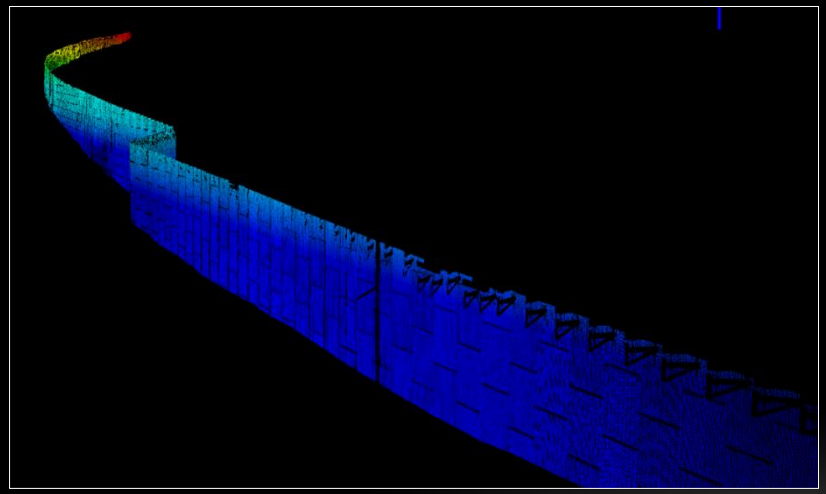
This joint was identified as a critical area and confirmed by visual inspection.

PROJECT RECAP

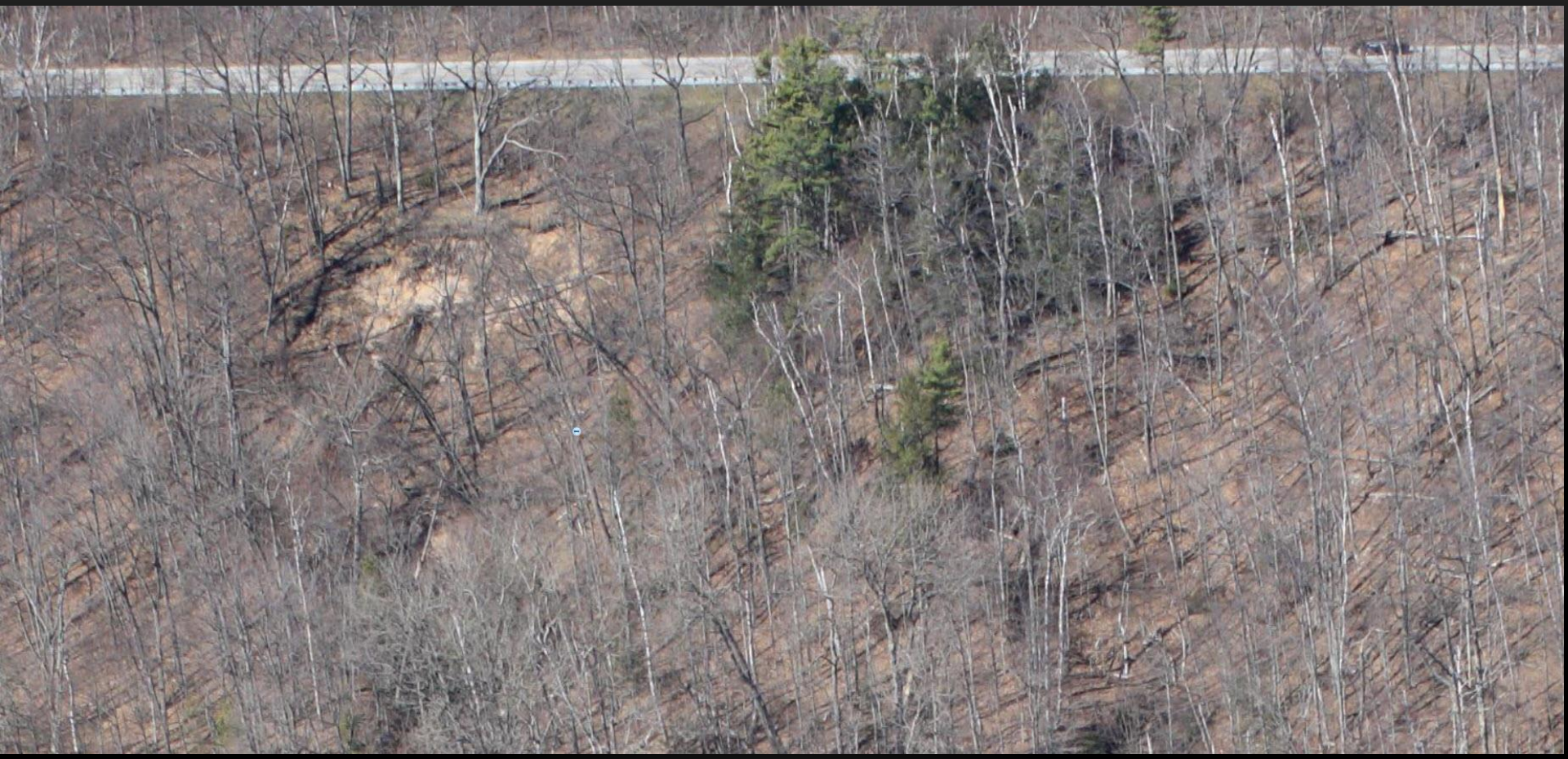
- This method was developed to quickly identify potential areas of movement along large stretches of freeway.
- SSI's method also eliminated field crews exposure to dangerous traffic conditions while also protecting the driving public.
- This project also provided lessons learned to be considered moving forward on future projects.

MOVING FORWARD

SSI's program can be used to identify and target specific areas of concern resulting in much more efficient data collection. Once critical areas are identified further investigation and repair can be done.

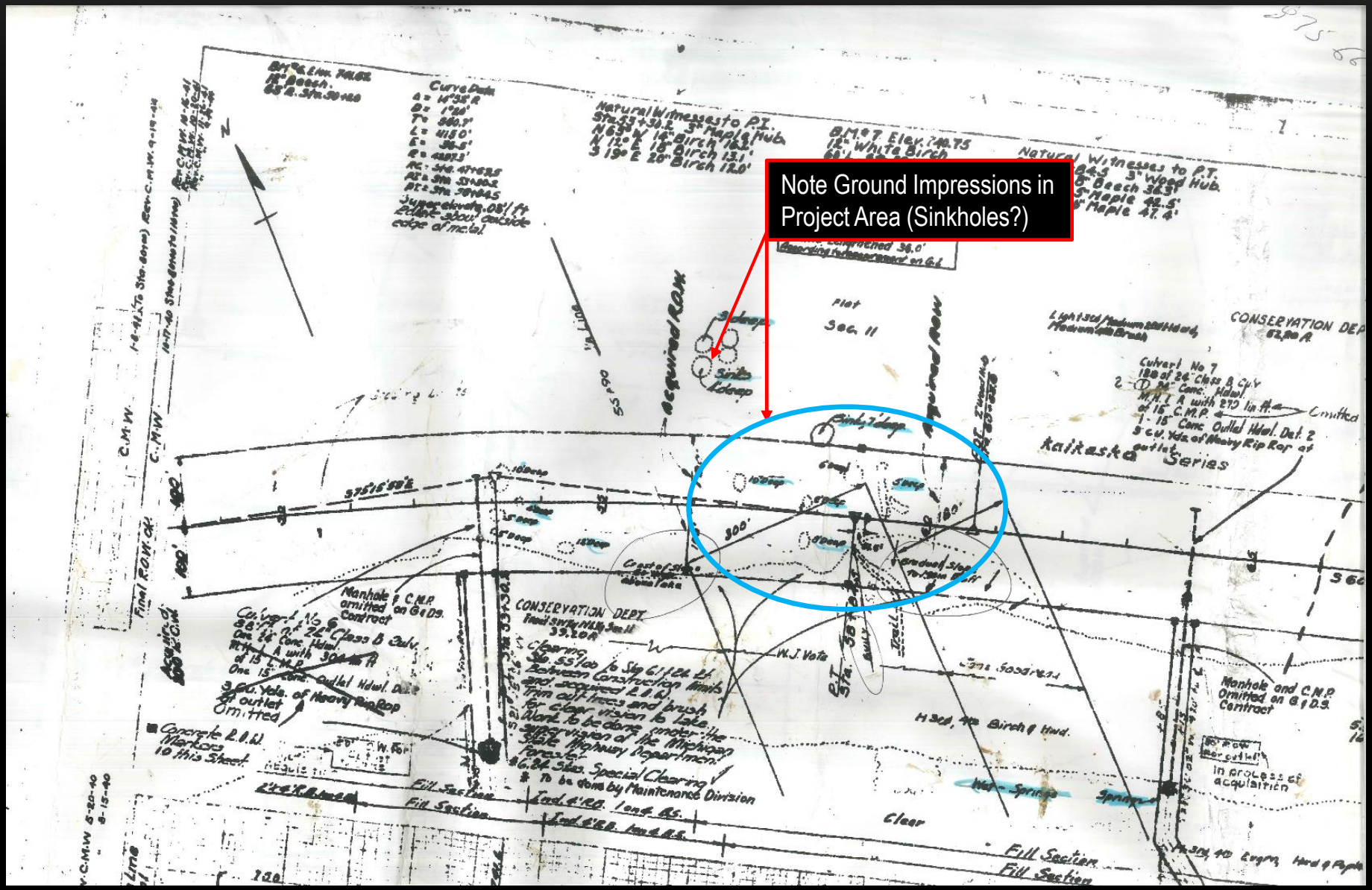


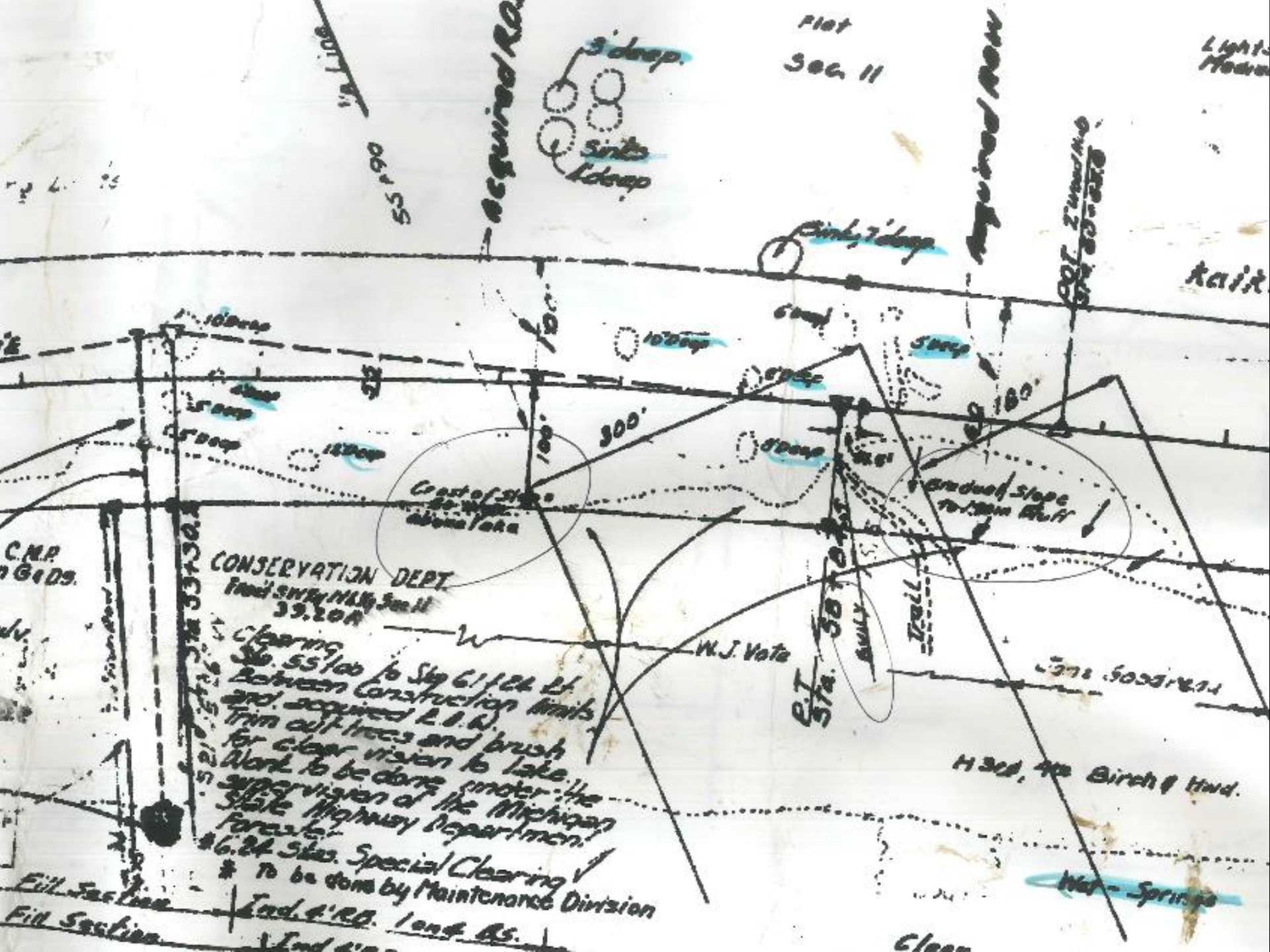
CASE STUDY III, LAKE MICHIGAN NORTH SHORE SLOPE



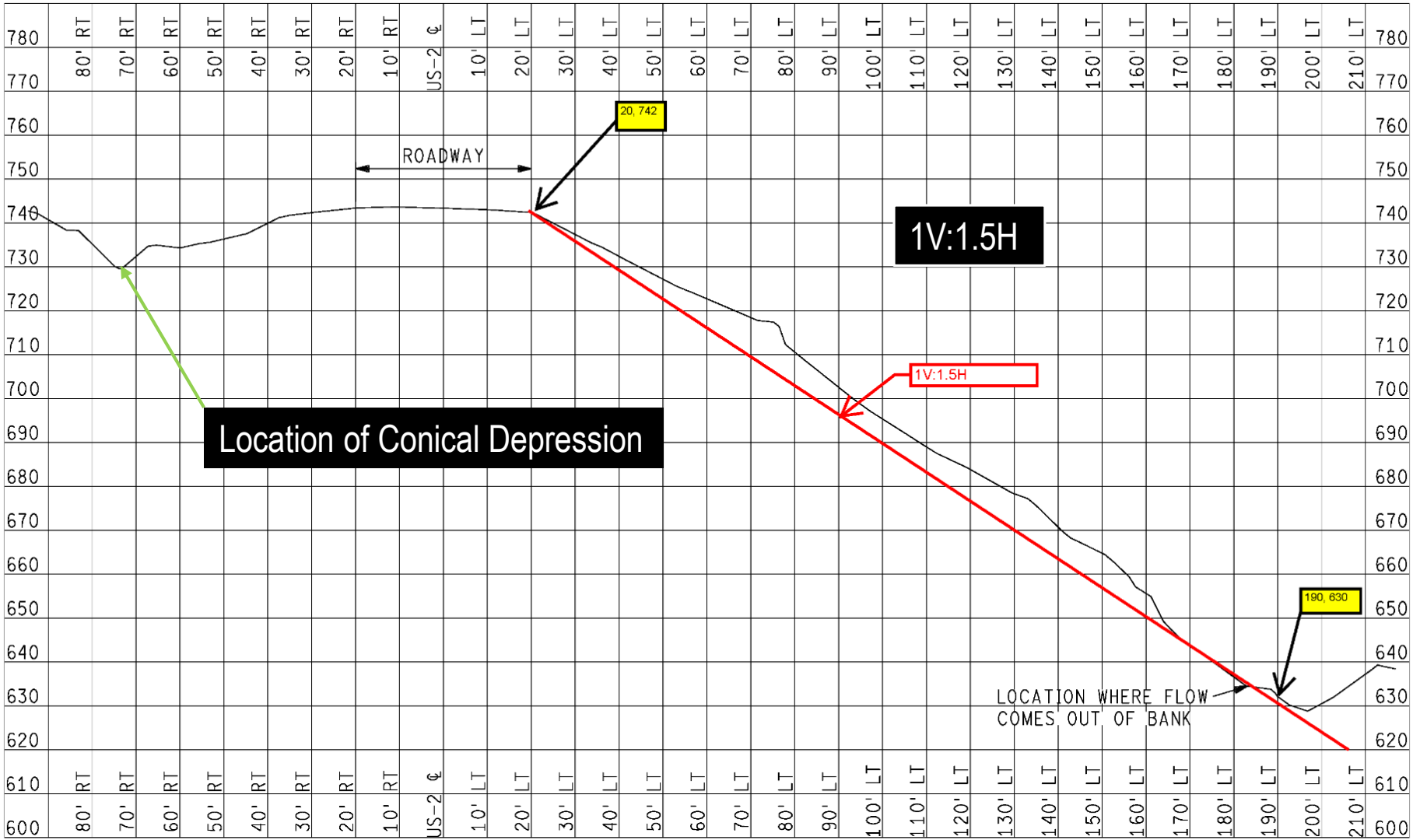
PASS
WITH
CARE

DESIGN PLAN SHEET – 1940'S




Acquired Rd.
Acquired Row
Flat
Sec. 11
3' deep
Sinks 1' deep
Sinks 3' deep
10' deep
5' deep
Cost of slope be wider above lake
300'
100'
160'
gradual slope to main bluff
CONSERVATION DEPT.
Fred Swift N½ Sec. 11
39.20 A
Clearing
Sta. 55/00 to Sta 61/24 Lt.
Between Construction limits
and acquired R.O.W.
Trim off trees and brush
for clear vision to lake.
Work to be done under the
supervision of the Michigan
State Highway Department
Forester.
$6.24 Sta. Special Clearing
* To be done by Maintenance Division
W. J. Vote
Trail
Bluff
Birch & Hwd.
Wet - Springs
Fill Section
End 4' RR. 1 on 4 BS.
Clear

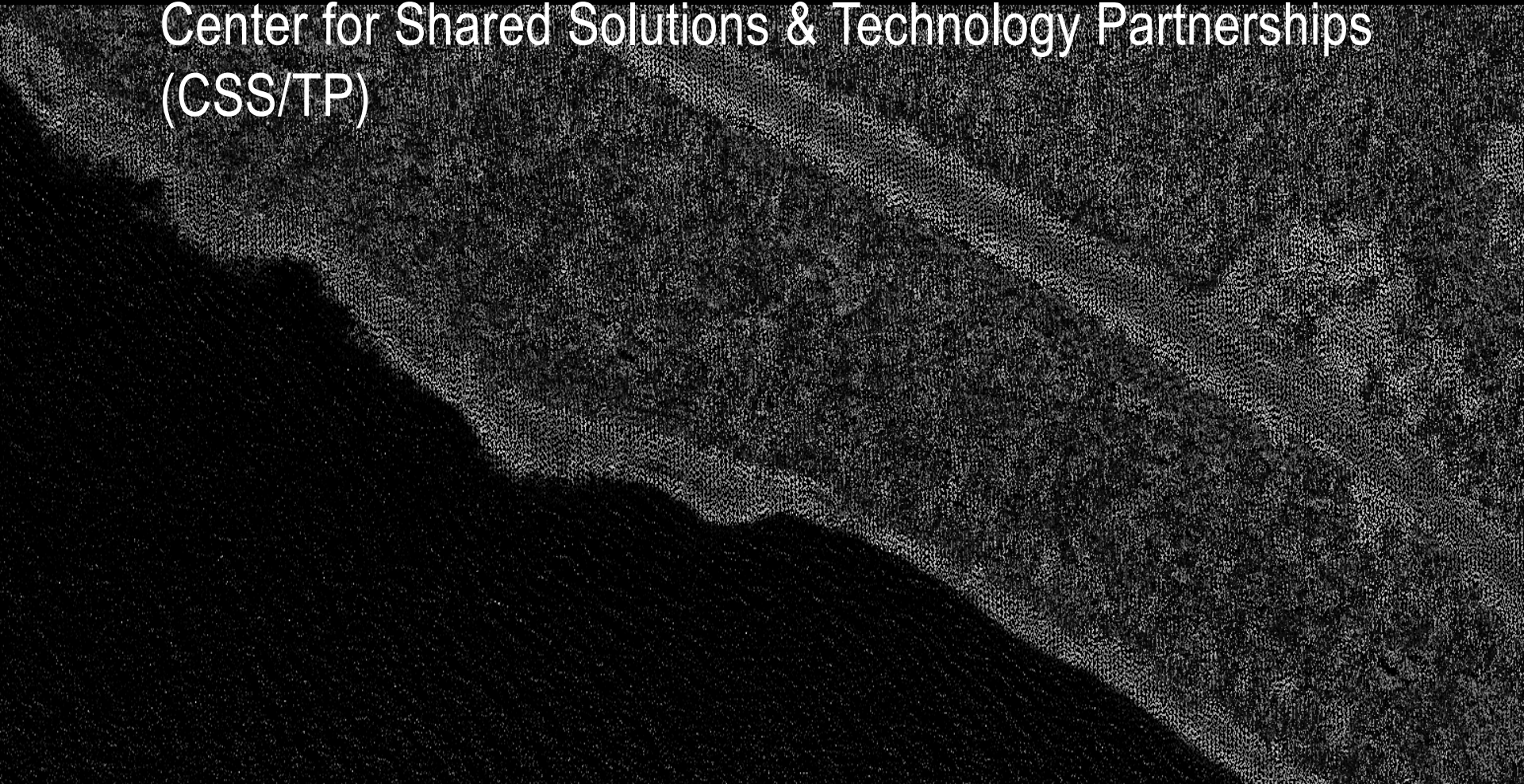
TYPICAL CROSS SECTION – LOOKING EAST



- SUMMARY OF OBSERVATIONS:
  - VISUAL SETTLEMENT OF ROADWAY
  - SLOPE ADJACENT TO ROADWAY IS SLOUGHING
  - OLD PLANS SHOW “SINKS”
- WHAT OPTIONS ARE THERE TO OBTAIN ADDITIONAL CORRIDOR INFORMATION?
  - AERIAL LIDAR
- HOW WILL IT BE USED IN ANALYSIS AND DETERMINATION OF REMEDIATION OPTIONS?

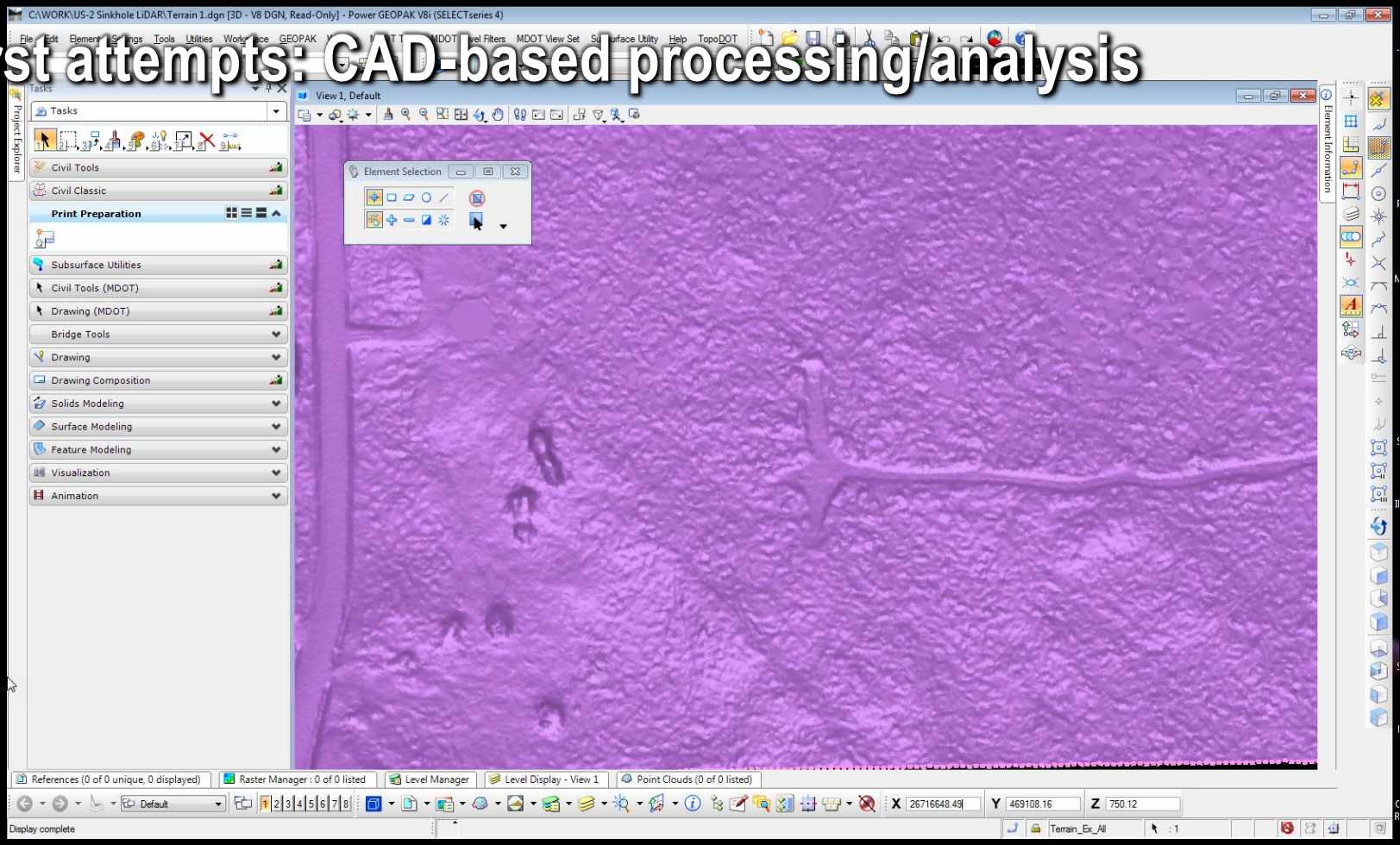
CASE STUDY 3
LAKE MICHIGAN NORTH SHORE SLOPE

- Aerial LiDAR data obtained from State of Michigan Center for Shared Solutions & Technology Partnerships (CSS/TP)



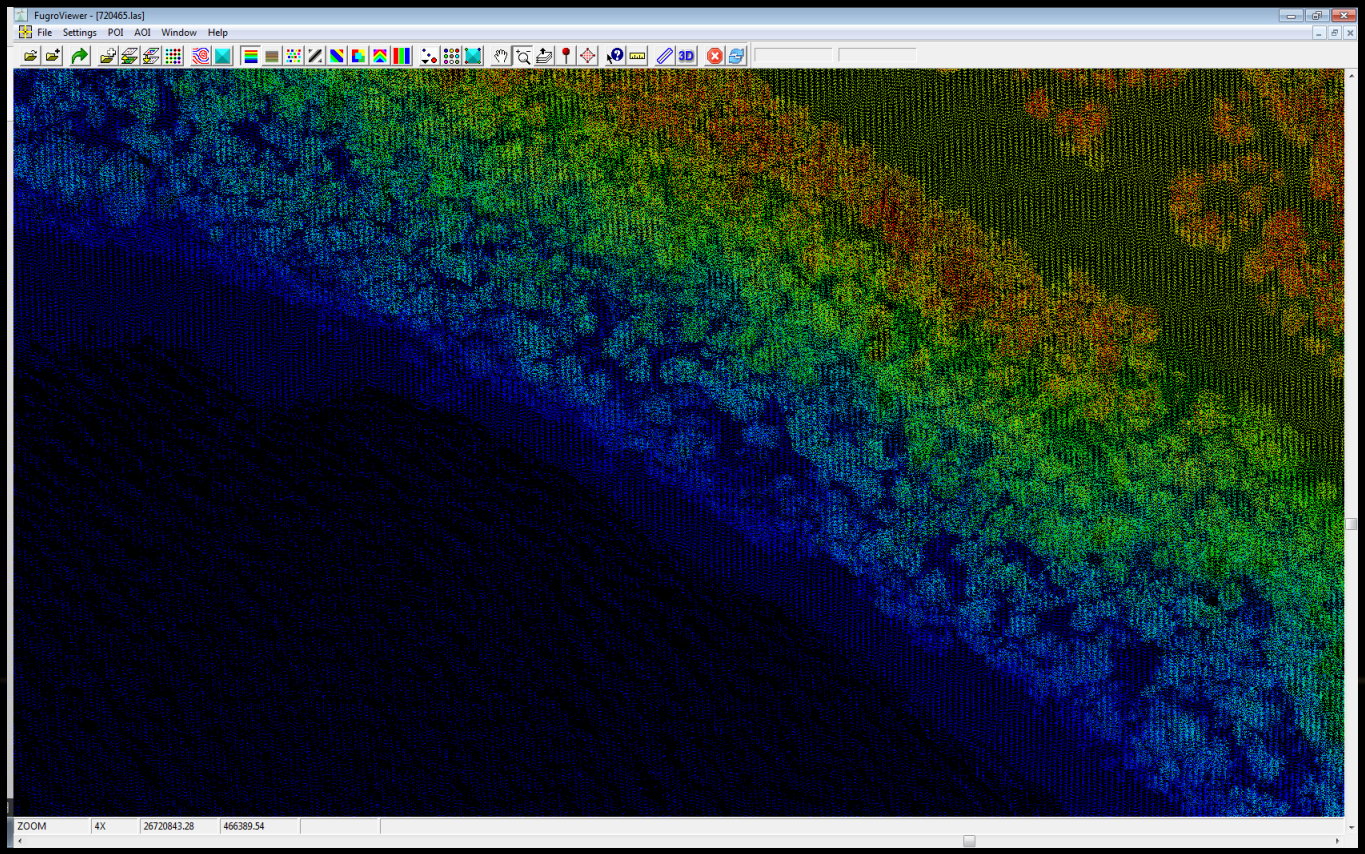
CASE STUDY 3
LAKE MICHIGAN NORTH SHORE SLOPE

- **Data processing… lots of data!**
- **First attempts: CAD-based processing/analysis**



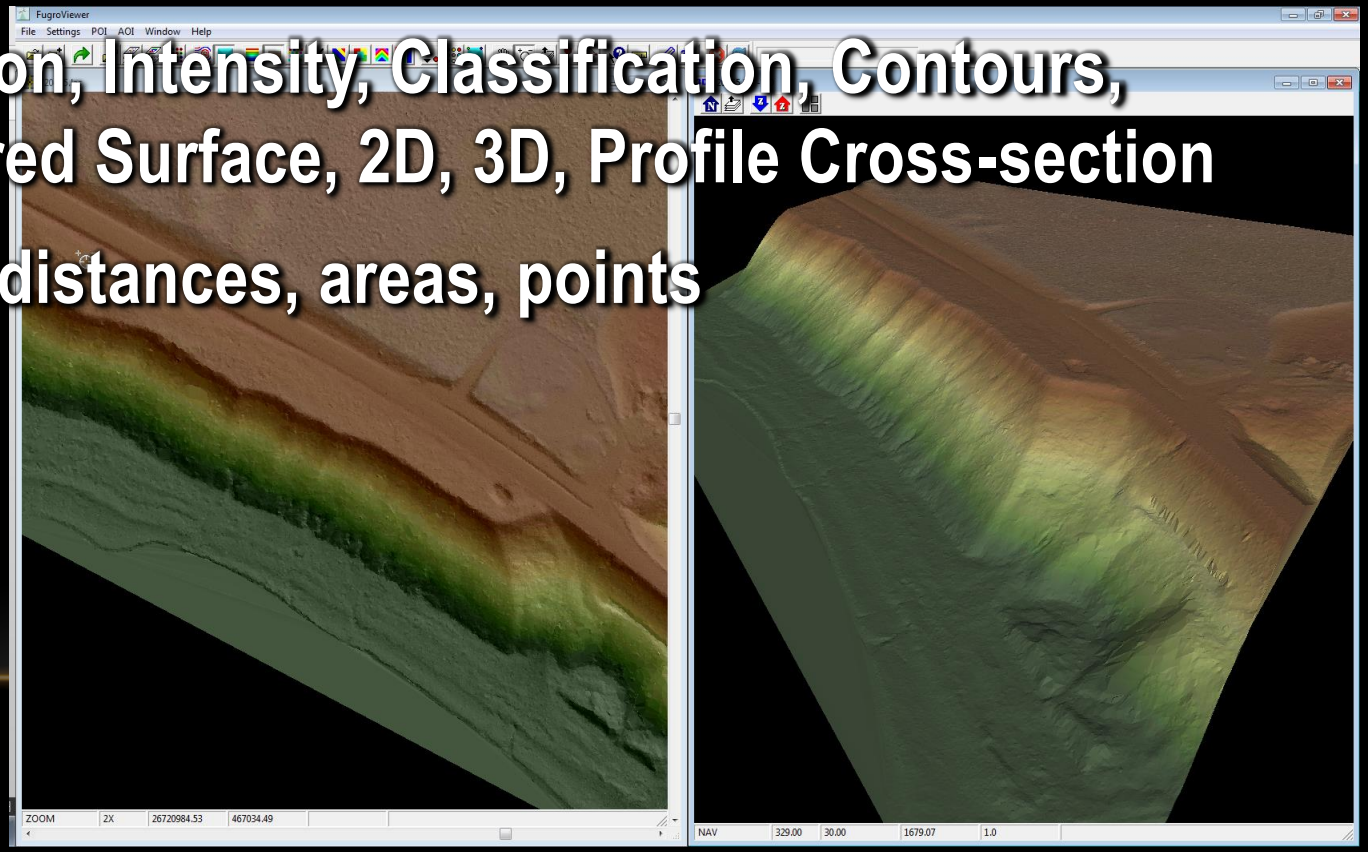
CASE STUDY 3
LAKE MICHIGAN NORTH SHORE SLOPE

- FugroViewer viewing and analysis
  - Fast; decimates data if needed



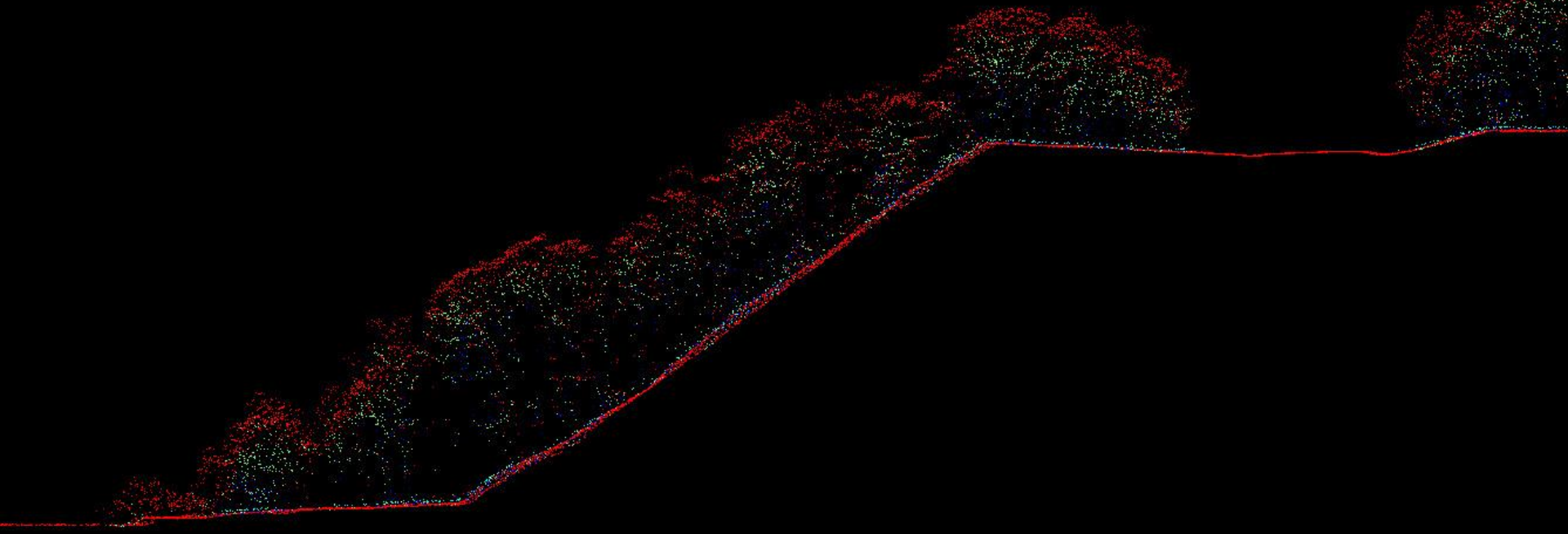
CASE STUDY 3
LAKE MICHIGAN NORTH SHORE SLOPE

- **FugroViewer viewing and analysis**
  - **Many options to view**
    - **Elevation, Intensity, Classification, Contours, Rendered Surface, 2D, 3D, Profile Cross-section**
  - **Measure distances, areas, points**



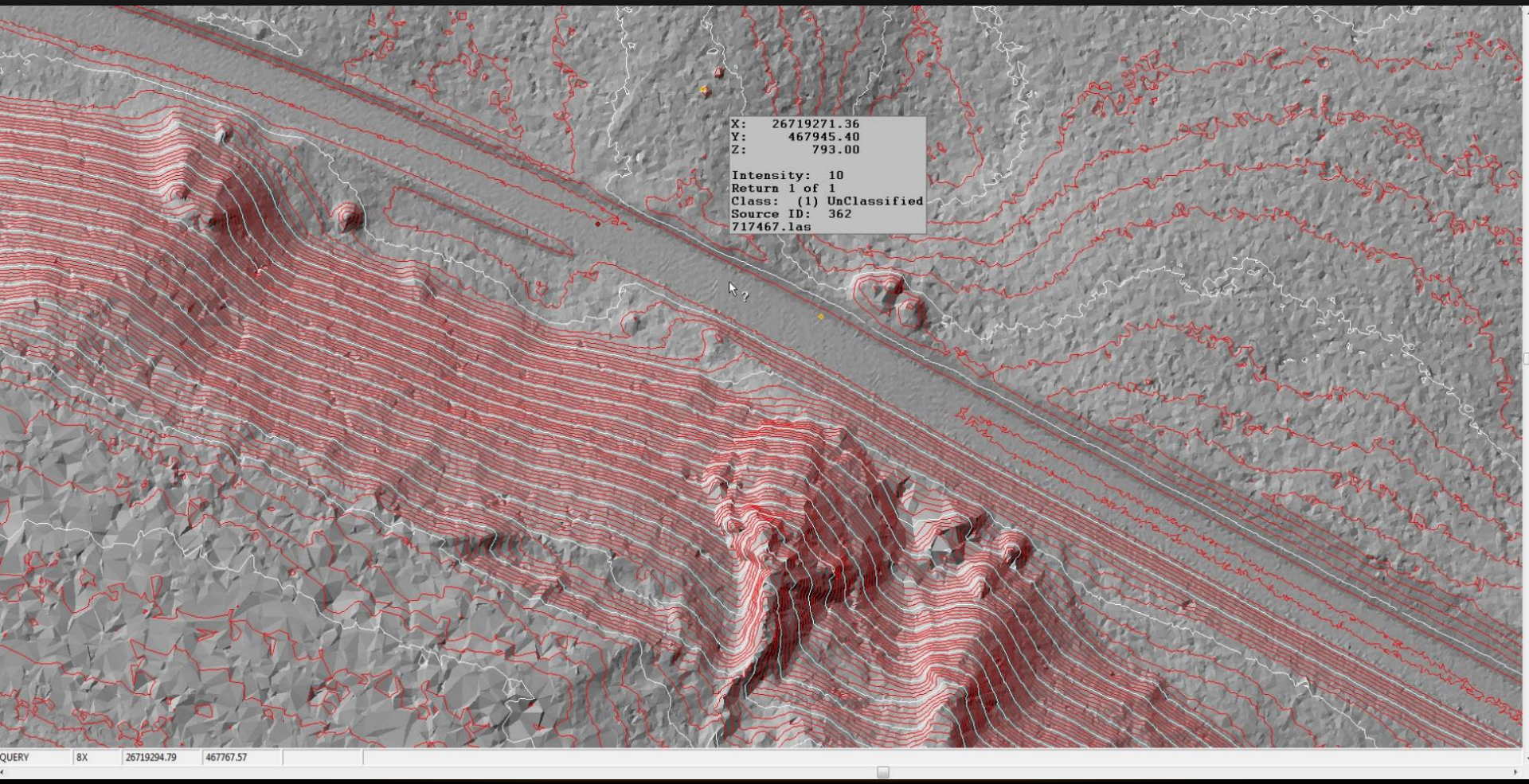
CASE STUDY 3
LAKE MICHIGAN NORTH SHORE SLOPE

- **FugroViewer viewing and analysis**
  - **Many options to view**
    - **Elevation, Intensity, Classification, Contours, Rendered Surface, 2D, 3D, Profile Cross-section**

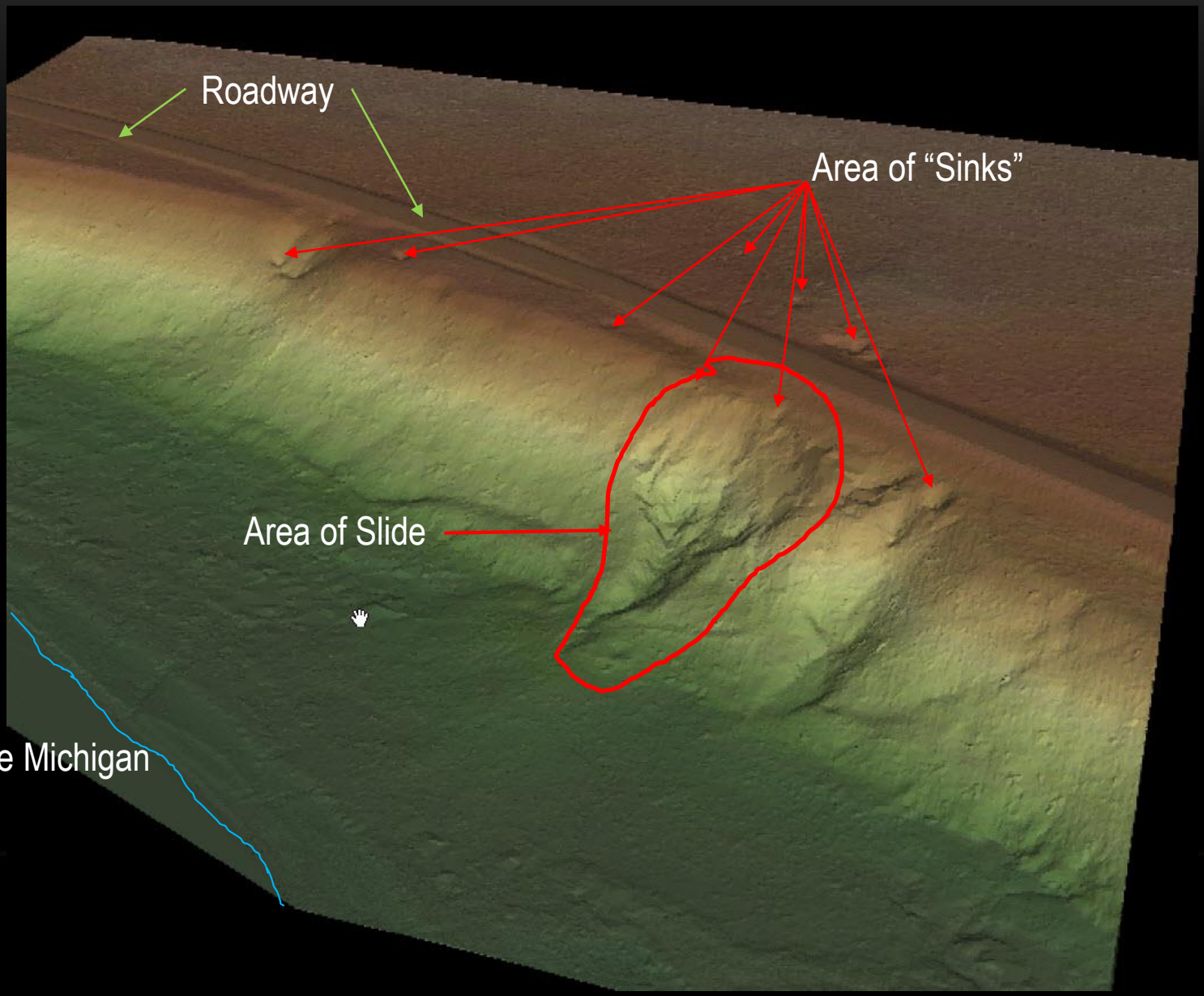


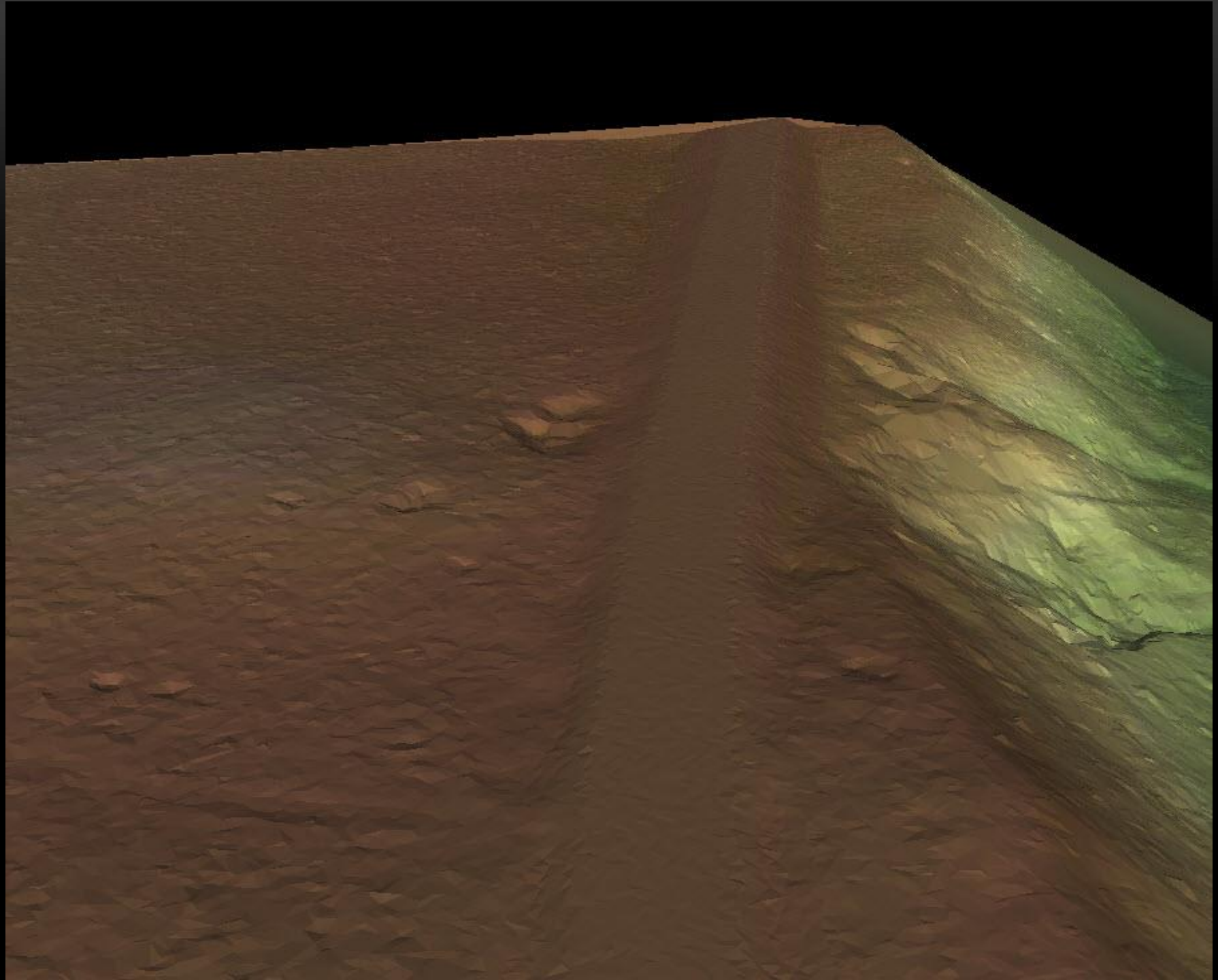
SINKHOLES ON AROUND SLIDE

- 2D TOPOGRAPHY MAP
- POINT QUERY OPTION

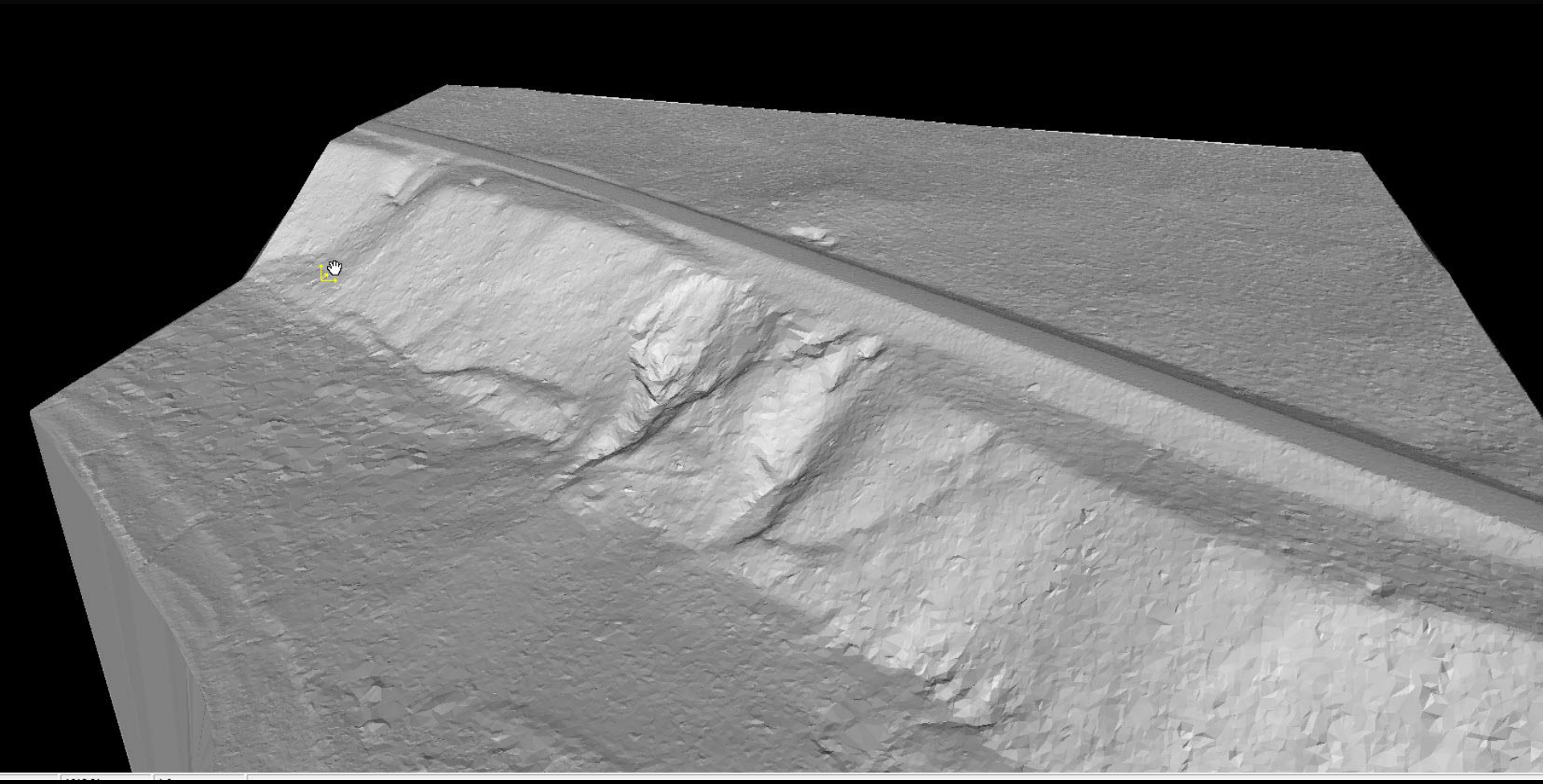


3D VIEW WITH FUGRO SOFTWARE – EARTH TONE

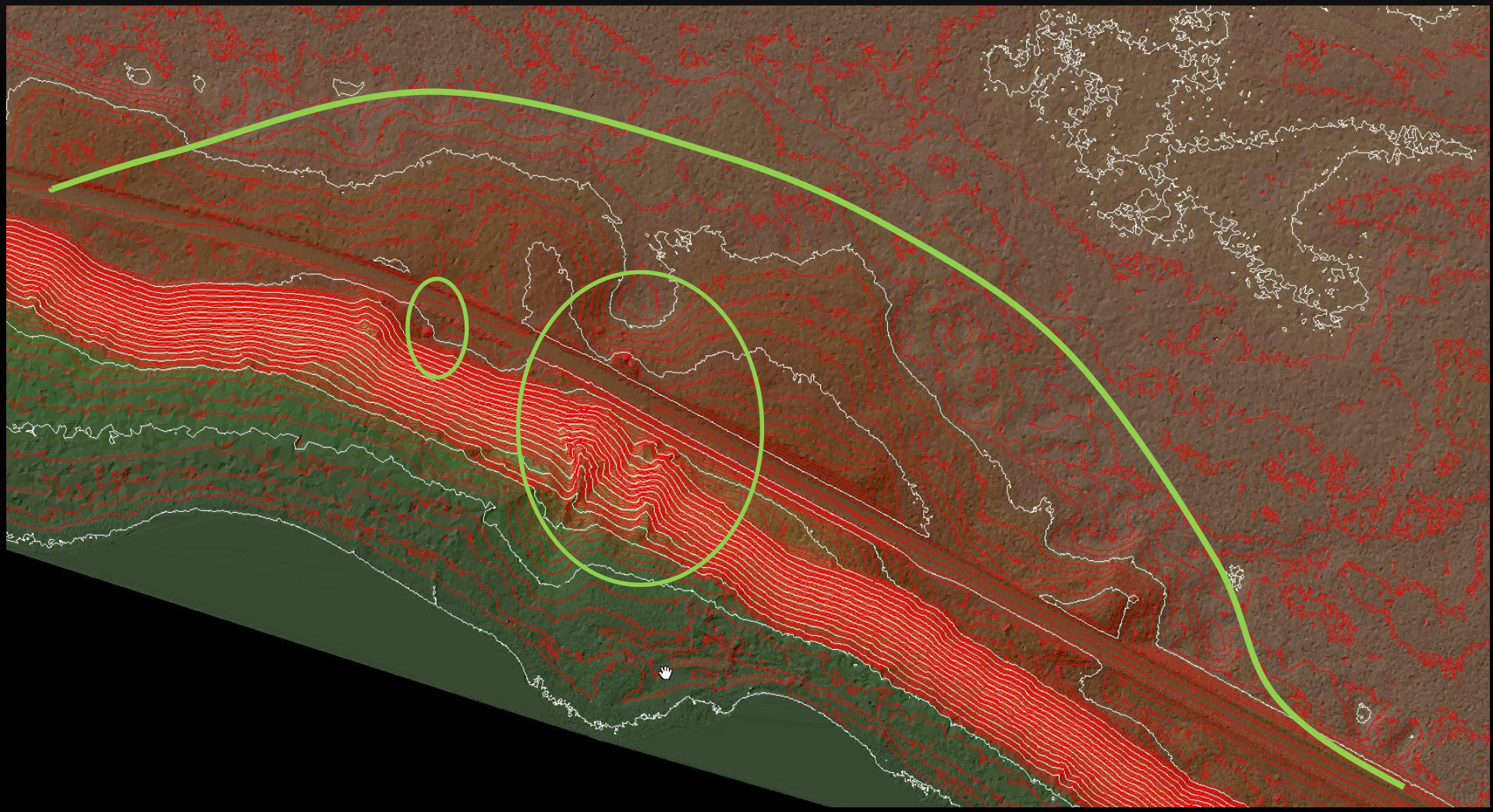




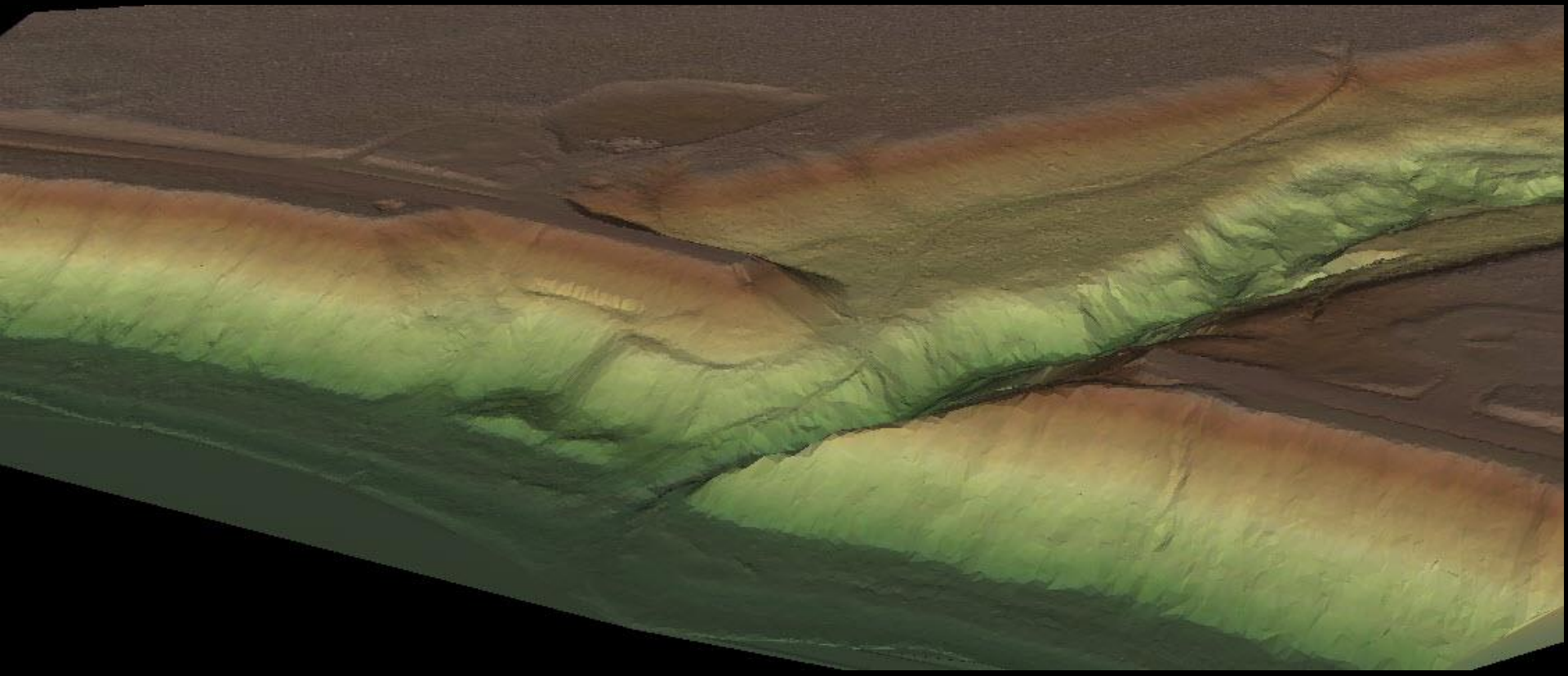
3D VIEW WITH FUGRO SOFTWARE – GRAY SCALE

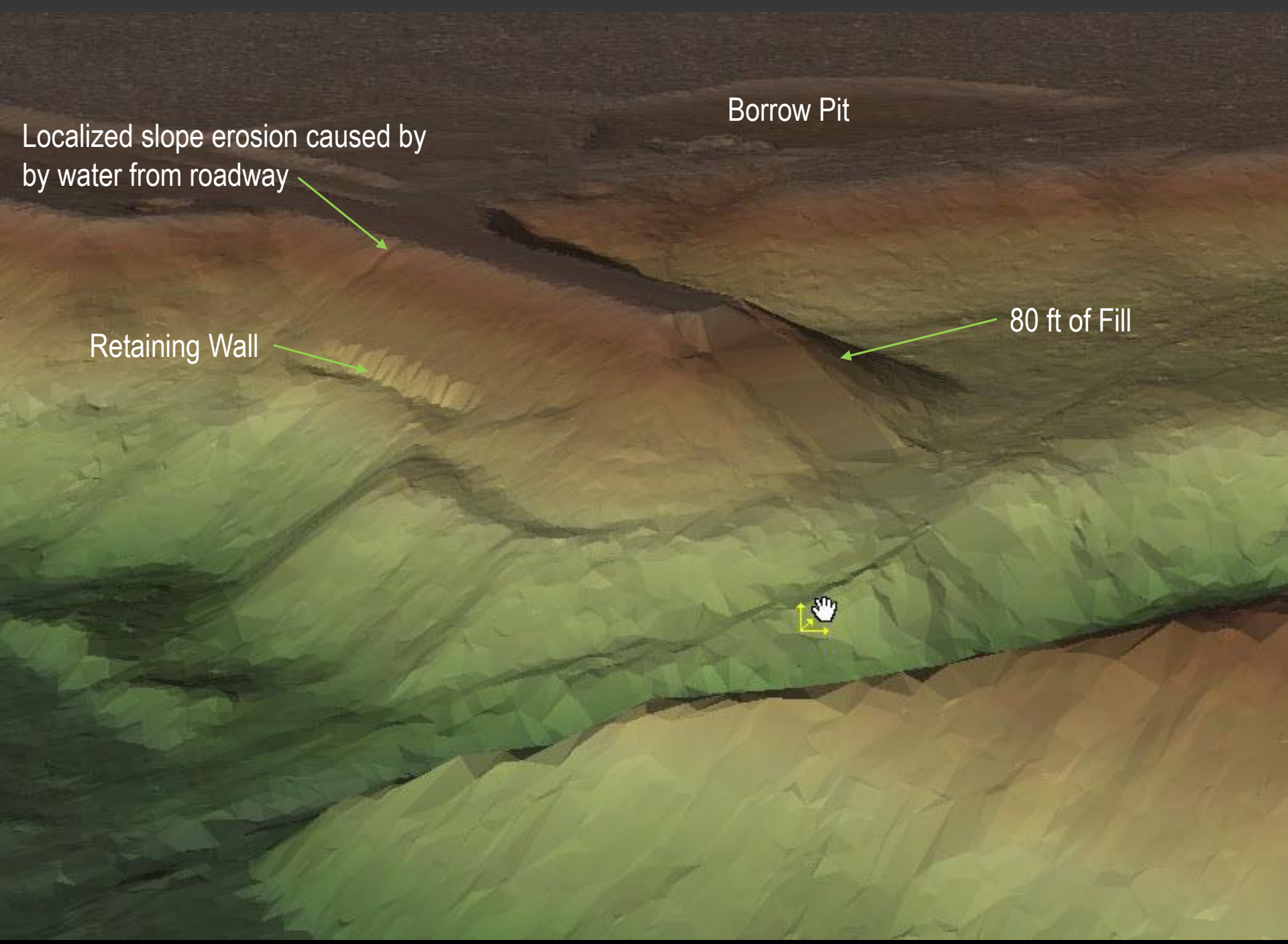


PRELIMINARY PLANNING AND DESIGN
DETERMINE PRELIMINARY QUANTITIES AND COST ESTIMATION



MDOT
Michigan Department of Transportation



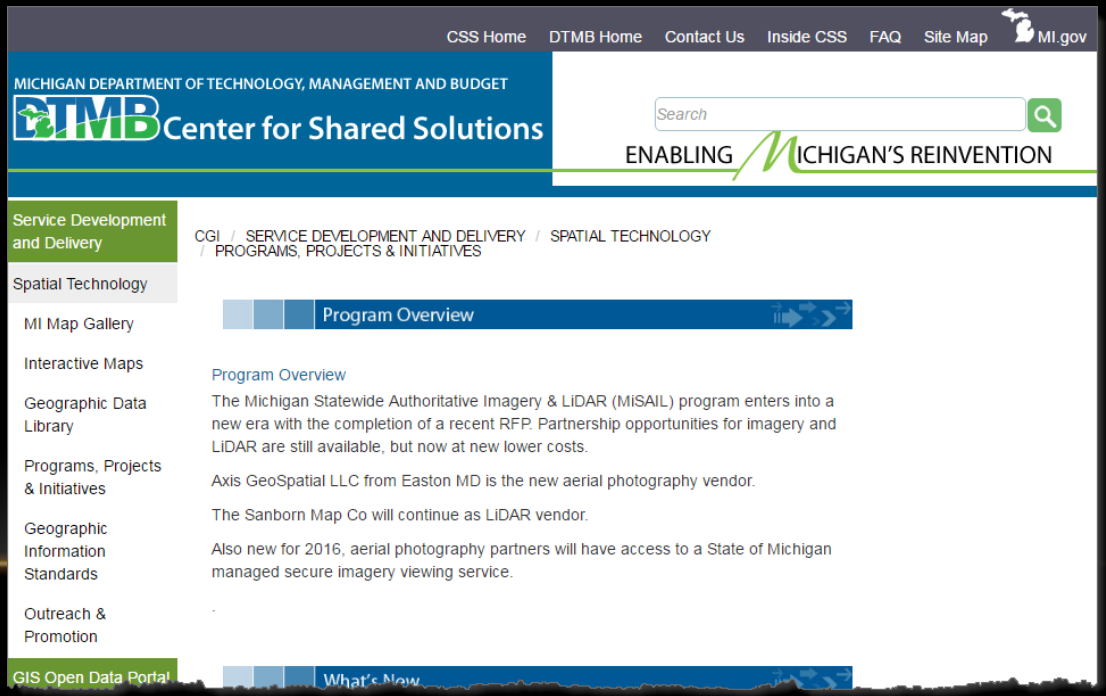

Borrow Pit
Localized slope erosion caused by
by water from roadway
80 ft of Fill
Retaining Wall

AVAILABLE RESOURCES

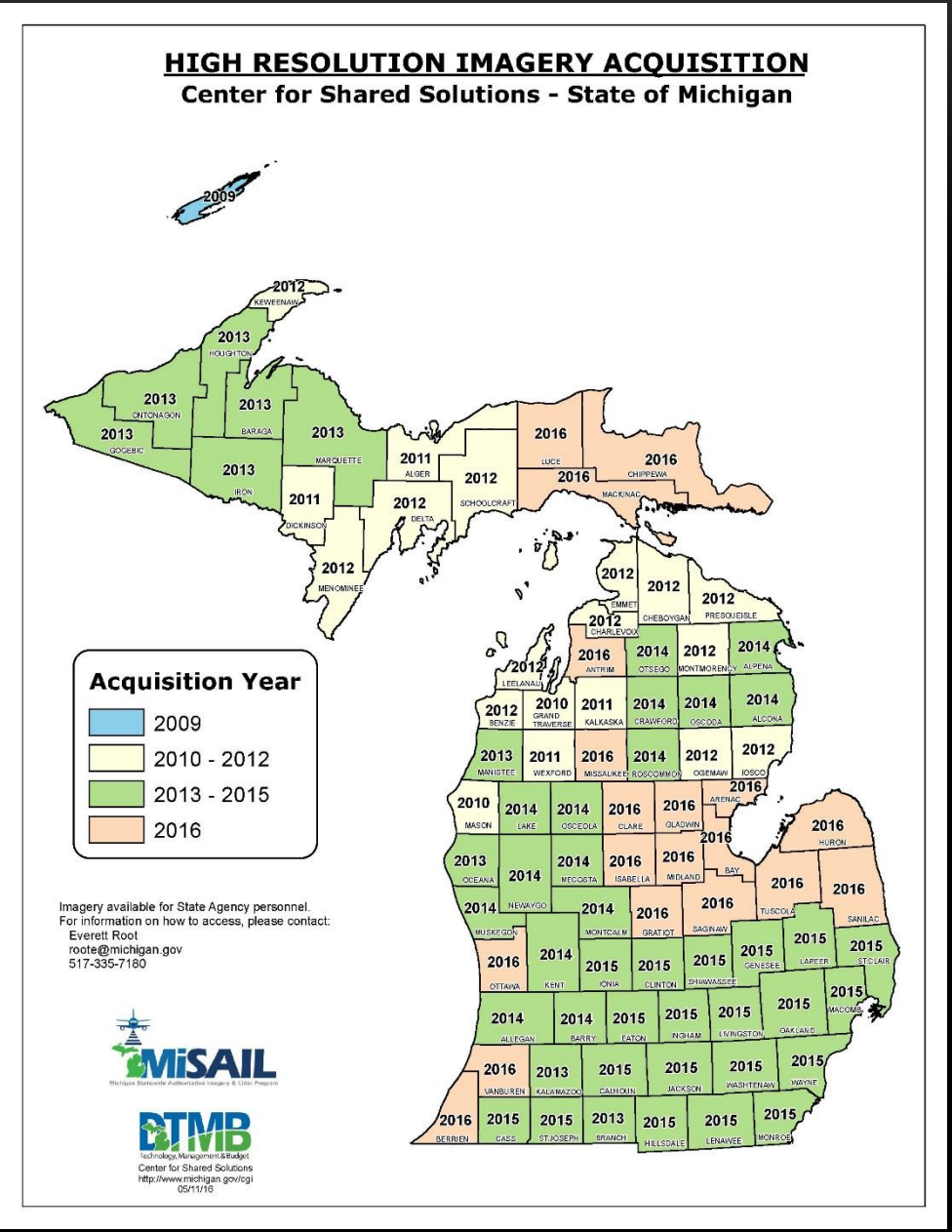
- MiSail: Michigan Statewide Authoritative Imagery & LiDAR Program (Michigan CSS/TP)
- Aerial Imagery since 2004
- Aerial LiDAR since about 2009

RESOURCES: MISAIL

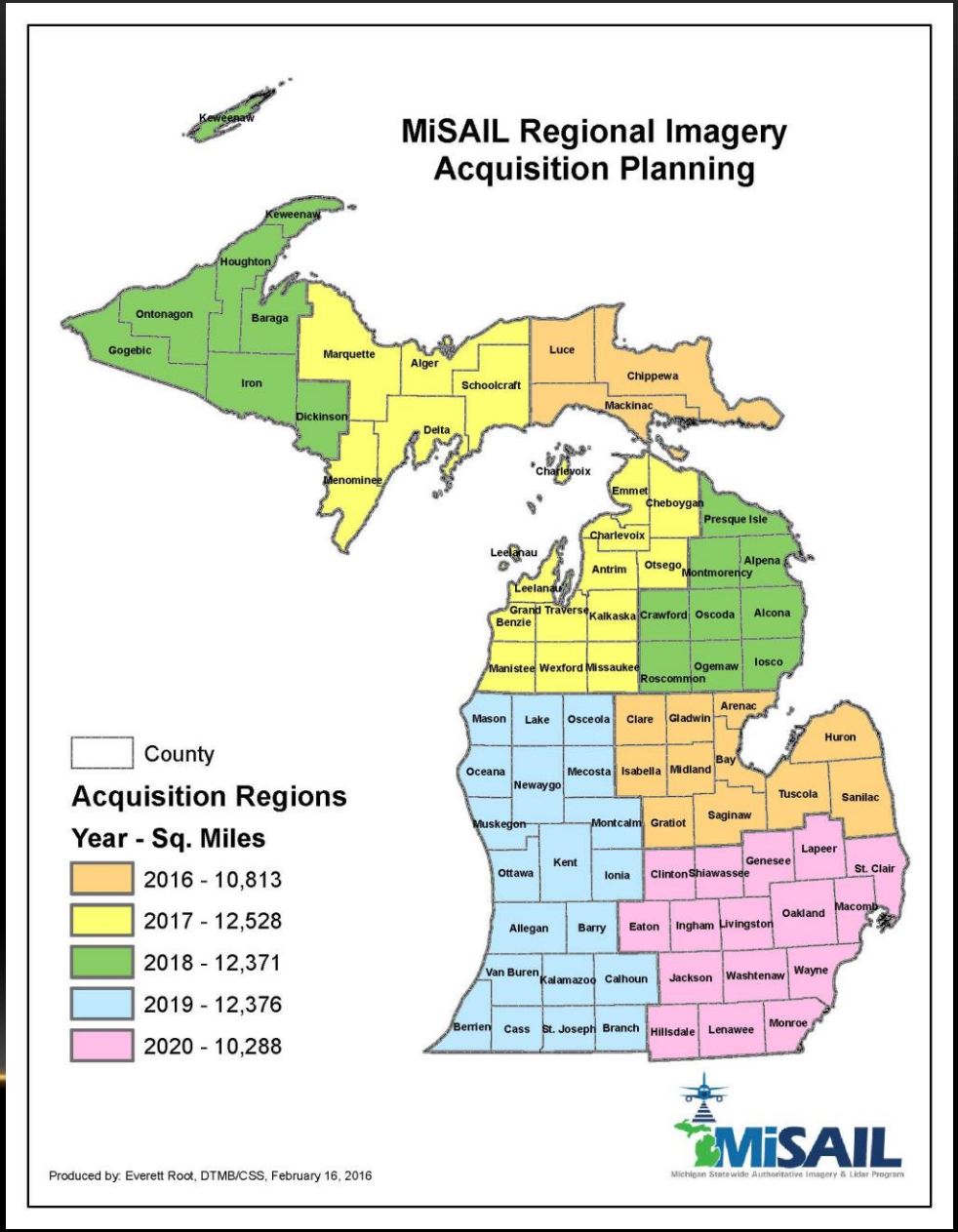
- MiSail Web Site: http://www.michigan.gov/cgi/0,4548,7-158-52927_53037_12699_63834---,00.html



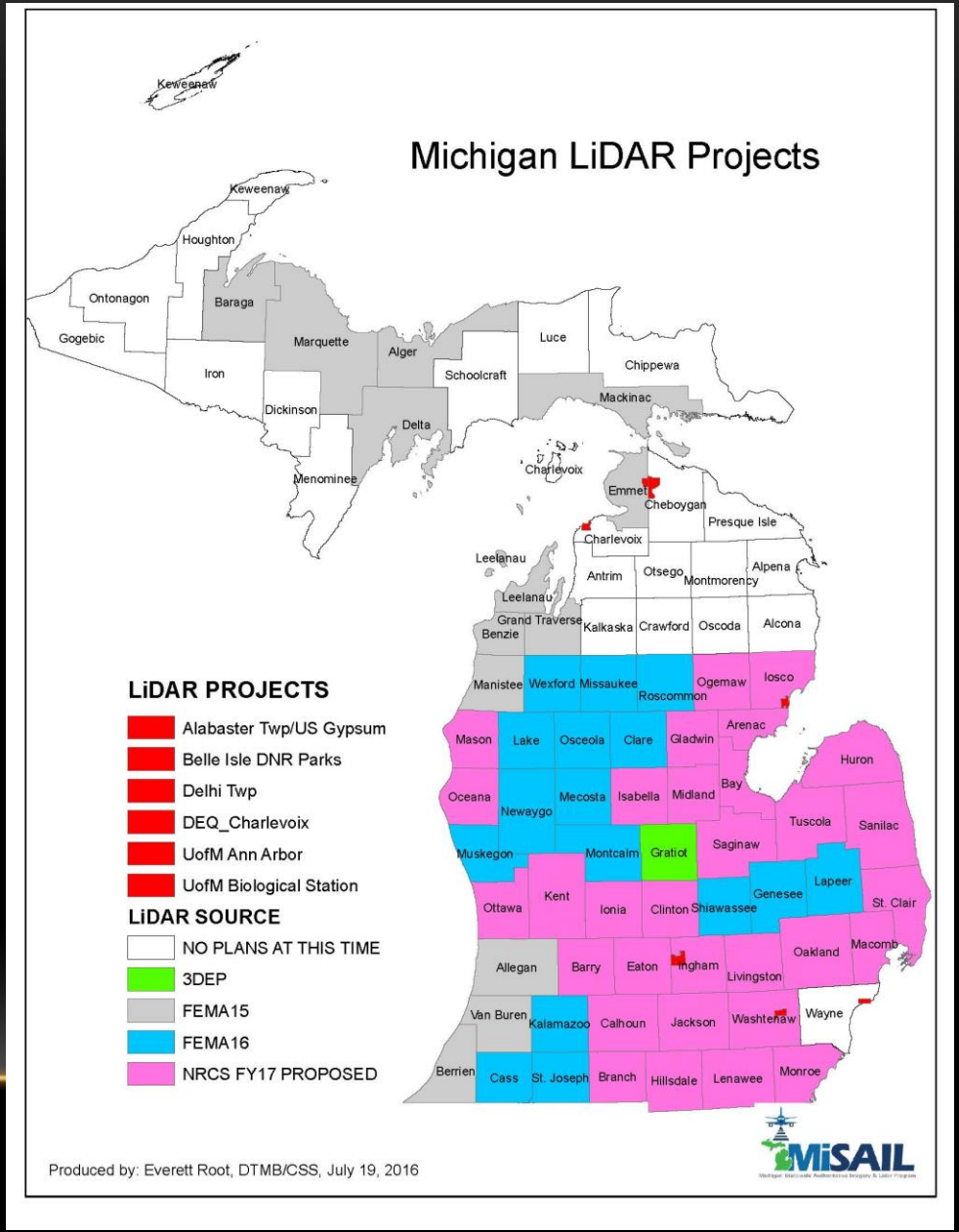
RESOURCES: MISAIL



RESOURCES: MISAIL



RESOURCES: MISAIL



LESSONS LEARNED AND KEY POINTS

- FOR LONG TERM SITE MONITORING AND DATA COLLECTION, INVEST IN GOOD REPEATABLE SURVEY CONTROL.
- LIDAR COLLECTION IS EXTREMELY USEFUL IN HARD TO ACCESS AREAS. SIGNIFICANTLY REDUCES THE NUMBER OF MAN HOURS NEEDED TO COLLECT DATA.
- FUGRO SOFTWARE IS POWERFUL AND A NON- REMOTE SENSING EXPERT CAN USE IT TO IDENTIFY AREAS OR ITEMS OF INTERESTS.
- AERIAL LIDAR PROVIDES ACCESS TO LARGE AMOUNTS OF TOPOGRAPHY AND ANAMOLY DATA RELATIVELY QUICKLY. ALLOWS ENGINEER TO SWIFTLY GAIN KNOWLEDGE OF SITE PRIOR TO SITE RECONNAISSANCE OR SHORTLY THEREAFER.
- LEVEL OF CONFIDENCE IN AERIAL LIDAR ACCURACY IS GOOD AND DATA MAY BY SUITABLE FOR USE IN PRELIMINARY/CONCEPTUAL DESIGN PURPOSES?
- SURVEY STAFF CAN ADD VALUE, BUT THE TOOLS ARE MOST POWERFUL IN THE USERS' HANDS
- MOBILE LIDAR ALLOWS FOR QUICK DATA COLLECTION DEPLOYMENT AND CAN PROVIDE INFORMATION OVER A LONG PROJECT LENGTH.

FUTURE

- Continue to inform users of remote sensing technology advances
- Continue to inform users of potential survey products

QUESTIONS?