Westlake US 2
Received 7/3/2024

TSX/PAZ Satellite Update
InSAR Subsidence
June 28, 2024

Lonquist comment:

The PAZ satellite from the TSX/PAZ constellation (4 & 7-day revisit) passed by Sulphur on Friday June 28. We received the dataset Monday and noted that latest datapoint is again closer to the respective trends in each AOI. This supports the characterization of the negative trend deviation observed in the 6-17-2024 displacement data as a low-quality outlier. The attached report has been prepared for reference.

Submitted by: Nathaniel Byars (Lonquist)

TSX/PAZ Satellite Update

Continuous InSAR Monitoring of Ground Displacement At Westlake Caverns and Western Dome Flank

Sulphur Mines Salt Dome

Prepared for:
Westlake Chemical

Prepared by:
Lonquist & Co., LLC
8591 United Plaza Blvd.
Suite 280
Baton Rouge, LA 70809

Dataset
Satellite Source
TerraSAR-X - PAZ Constellation
Most Recent Image Date
Friday, June 28, 2024

Analysis Report Date:

July 3, 2024

Dataset Information

Satellite Source	TerraSAR-X - PAZ Constellation
Revisit Frequency	4 and 7 days
Most Recent Image Date	Friday, June 28, 2024
Dataset Image Count	93
Dataset Time Range	January 24, 2023 - June 28, 2024
Dataset Length	1.43 Years
Satellite Line-of-Sight (LOS)	37° East of Vertical (Viewing site from the East)

Analysis Methodology

Time Series Charts

Trend lines were calculated for the averaged displacement values within each AOI. Both a nonlinear (quadratic) and linear regression were applied to each AOI point group to identify rates of change in LOS displacement. These trends are displayed in the Time Series section of this report.

Contour Maps

A nonlinear (quadratic) and linear trend was also calculated for each individual measurement point across the analysis region. Nonlinear trend values for each point were used to generate Velocity and Acceleration contour maps to convey the spatial distribution of the calculated movement. The linear trend values for each point (which lack an acceleration component) were used to generate an additional Velocity contour map. Negative velocity values indicate subsidence or westward movement and positive velocity indicates uplift or eastward movement. Negative acceleration values indicate increasing rates of subsidence, increasing westward movement, or slowing eastward movement and positive acceleration values indicate slowing rates of subsidence, slowing westward movement, or increasing eastward movement.

Observations

The negative trend deviation observed in the majority of the AOIs in the 6-17-2024 dataset was determined to have been caused by atmospheric influences and is being charaterized as a low-quality outlier. The displacement measurements from the most recent two datasets (6-24 and 6-28-2024) are nearer to the trend in all AOIs.

Recent data has begun to indicate a negative acceleration of varying magnitudes across most of the AOI point groups evaluated. This is most evident in the trend acceleration values in the westernmost AOIs and in the mapped contours on the western side of AOI 2 and AOI 3. This suggests that marginal increases in subsidence rates may be occuring in this area of the dome. Seasonal effects are believed to contribute to fluctuations above and below the trend lines for each AOI and may play a siginficant role in the gradual changes that are being observed.

STATE OF LOUISIANA
NATHANIEL L. BYARS
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PROFESSIONAL ENGINEER

Date Signed: July 3, 2024
Austin, Texas

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Principal Engineer
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InSAR Data Sources

InSAR Data

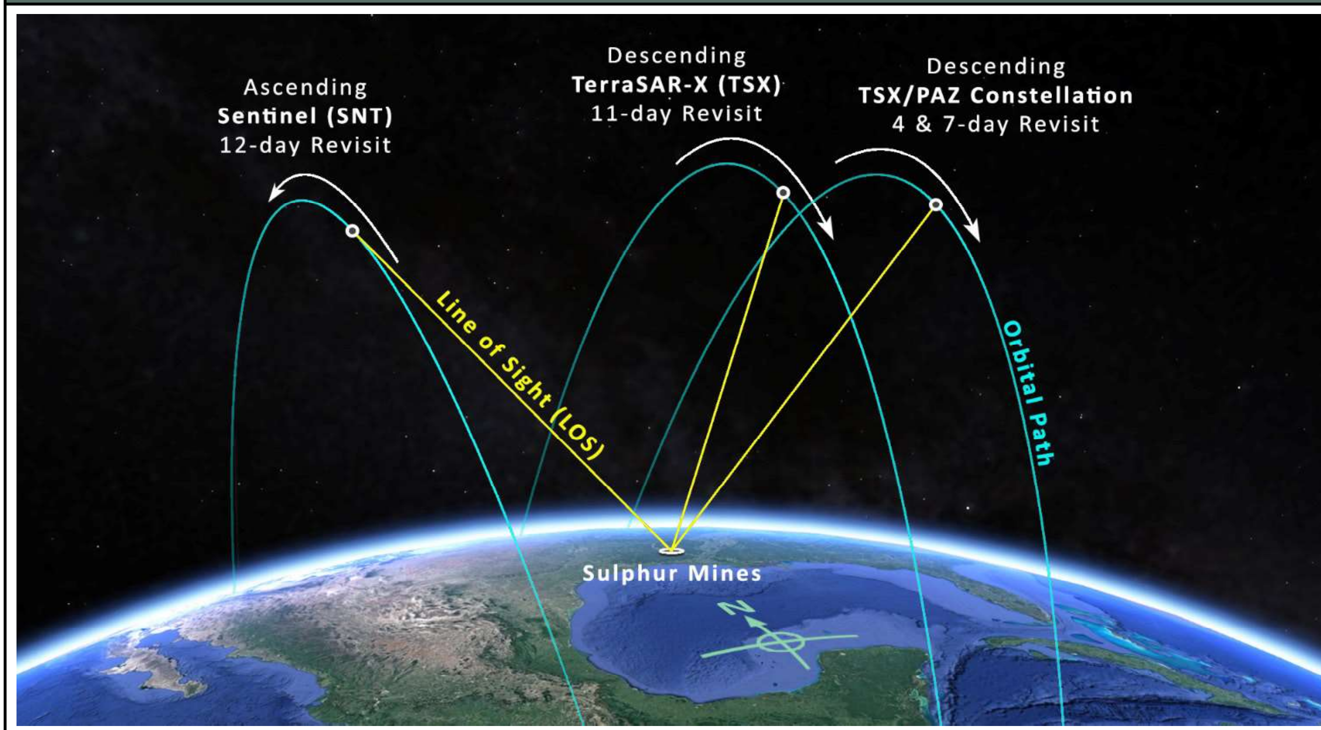
Interferometric Synthetic Aperture Radar (InSAR) is the most well established method to continually evaluate small, normally undetectable, ground movement over a large area. Radar imagery collected via satellites over successive orbital passes is used to identify and define measurement points on the ground. Objects or ground features providing a stable reflection of radar energy such as buildings, roads, and infrastructure produce the highest quality measurement points. InSAR analysis identifies the change in distance between the satellite and each measurement point over time relative to a stable reference point within the imaged area.

Satellite Sources

Two InSAR datasets are being used to evaluate subsidence over the Sulphur Mines Salt Dome. These datasets provide Line-of-Sight (LOS) displacment measurements from both ascending and descending orbits. An ascending orbit denotes the satellite's longitudinal course from south to north as it passes over the site, while a desceding orbit denotes the satellite is moving from north to south.

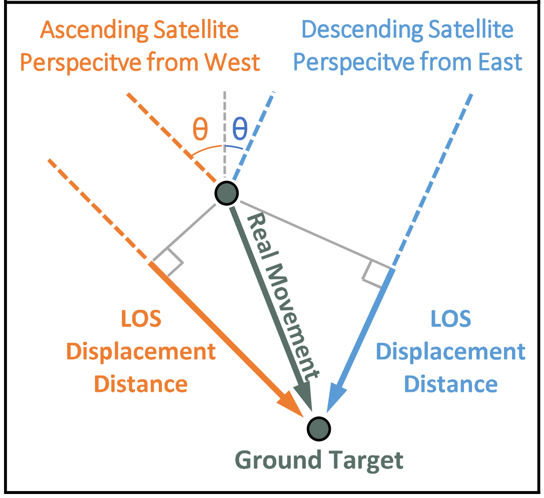
The first dataset comes from a low-resolution Sentinel-1 (SNT) satellite on an ascending orbit that captures data from the west of the site on a 12-day frequency. The second comes from a pair of high resolution satellites that share the same descending orbit and capture data from east of the site. These are a TSX satellite and the PAZ satellite (TSX/PAZ constellation), both with an 11-day revisit frequency. Their orbits are offset with the PAZ satellite passing over the site 4 days after the TSX satellite. Prior to May 2023, data was captured from a different high-resolution TerraSAR-X (TSX) satellite on a descending orbit that captured data from the east of the site on an 11-day frequency. The transition was made for the increased data frequency that resulted from a 4 and 7-day revisit period. The image below depicts the orbital paths of the satellites in relation to the Sulphur Mines Salt Dome.

Satellite Orbital Diagram



InSAR Line-of-Site (LOS) Data

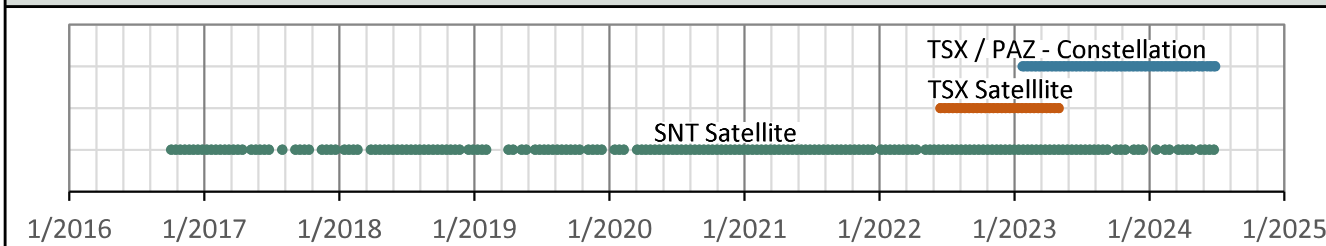
LOS displacement measurements refer to a change in distance between the satellite sensor and the ground target. Measurement positions on the west side of the Sulphur Dome are are known to be experiencing some eastward movement toward the dome center due to the geometry of the subsidence basin. The InSAR satellites view the site from eastward and westward positions so LOS measurements are understood to convey a movement distance that is not purely vertical. The diagram to the right illustrates the geometric relationship between the theoretical Real movement of a ground target and LOS displacement measurements from two different satellite viewing directions.



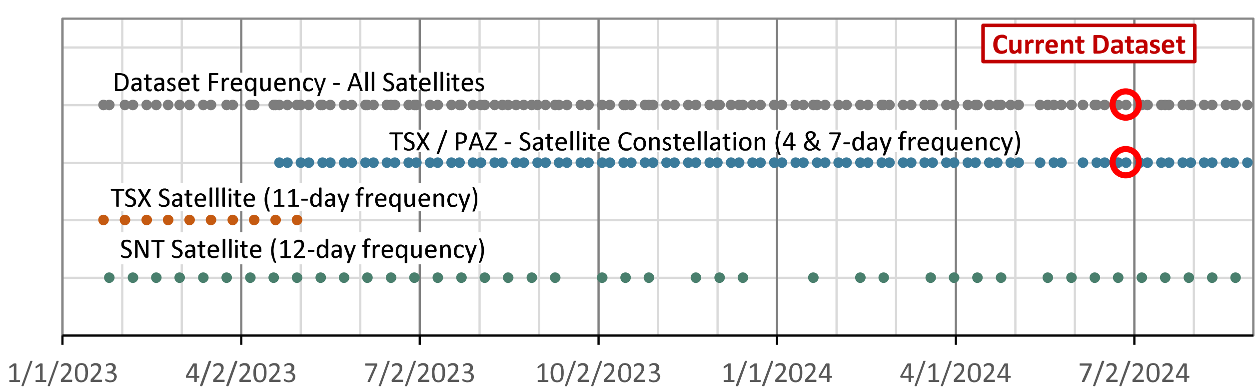
Satellite Properties & Image Frequency

Satellite and Data Properties	SNT	TSX	TSX/PAZ Constellation
Band (Wavelength)	C-band (2.20 in)	X-band (1.22 in)	X-band (1.22 in)
Track	T136	T29	T67 & T120
Pixel resolution	65 x 16 ft	3 x 3 ft	3 x 3 ft
Revisit frequency	12 days	11 days	4 & 7 days
Orbit (LOS Angle, θ)	Ascending (43^o)	Descending (17^o)	Descending (37^o)
Data Start Date	10/4/2016	6/16/2022	1/24/2023
Measurement error range	± 0.20 in	± 0.03 in	± 0.03 in

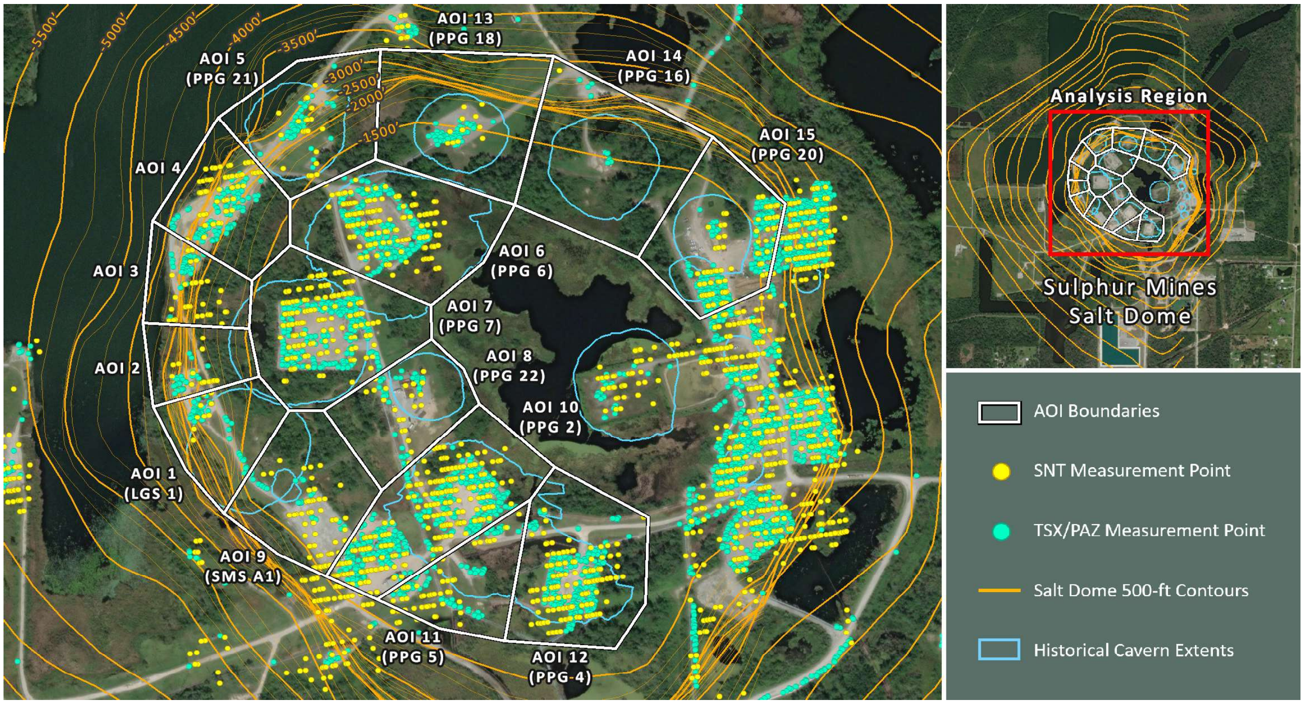
Dataset Measurement History



Dataset Update Frequency



AOI Boundaries & InSAR Measurement Points

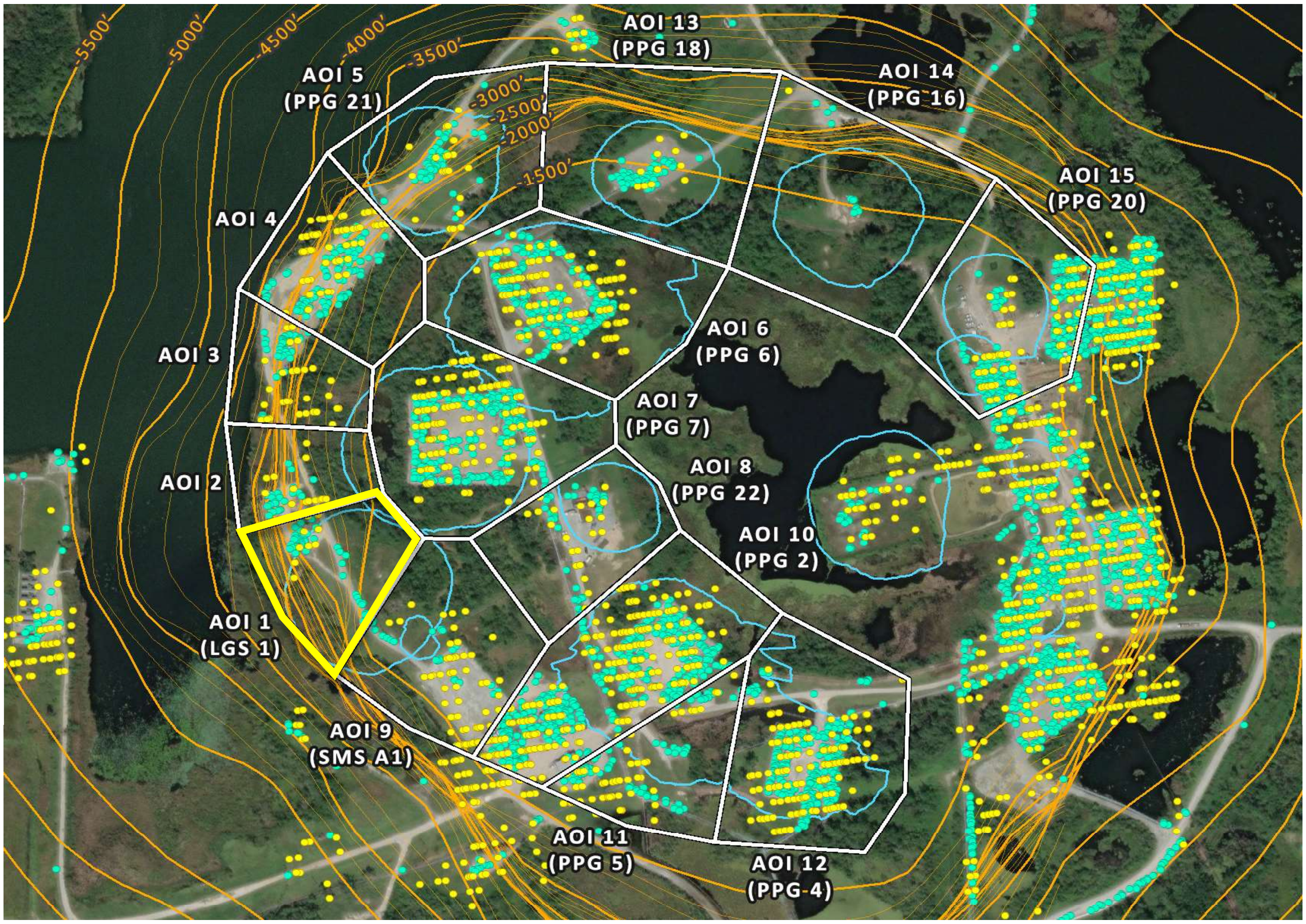


Subsidence Monitoring Areas of Interest (AOIs)

To visually convey and evaluate trend consistency for the displacement time series of each ground target, measurment points were grouped and their displacement values were averaged. The point groups are referred to as Areas of Interest (AOIs) in this analysis and their boundaries are depicted on the above map. The below table lists the trend values calculated in each AOI for the dataset evaluated in this report.

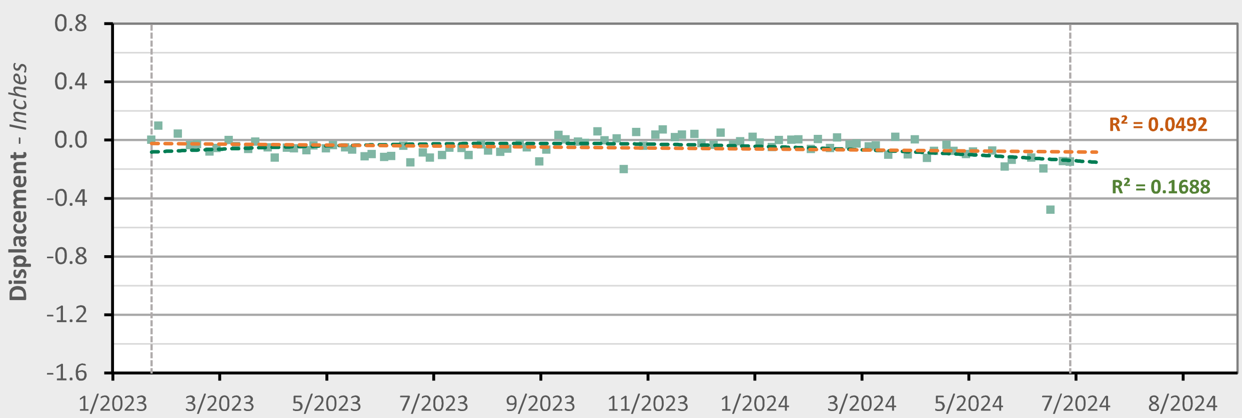
AOI Name	TSX/PAZ (6/28/2024)	LOS Velocity (in/yr)		LOS Acceleration (in/yr^2)	
	Point Count	Nonlinear	Linear	Nonlinear	Linear
AOI 1 *(LGS 1)*	42	-0.28	-0.04	-0.34	0.00
AOI 2	24	-0.33	-0.02	-0.43	0.00
AOI 3	40	-0.48	-0.03	-0.63	0.00
AOI 4	102	-0.25	+0.03	-0.39	0.00
AOI 5 *(PPG 21)*	47	-0.30	-0.18	-0.17	0.00
AOI 6 *(PPG 6)*	212	-0.58	-0.40	-0.24	0.00
AOI 7 *(PPG 7)*	216	-0.51	-0.28	-0.33	0.00
AOI 8 *(PPG 22)*	36	-0.62	-0.56	-0.08	0.00
AOI 9 *(SMS A1)*	23	-0.07	-0.23	+0.23	0.00
AOI 10 *(PPG 2)*	404	-0.68	-0.54	-0.19	0.00
AOI 11 *(PPG 5)*	85	-0.48	-0.44	-0.05	0.00
AOI 12 *(PPG 4)*	262	-0.83	-0.80	-0.05	0.00
AOI 13 *(PPG 18)*	52	-0.56	-0.42	-0.19	0.00
AOI 14 *(PPG 16)*	11	-0.28	-0.63	+0.49	0.00
AOI 15 *(PPG 20)*	224	-0.90	-0.94	+0.05	0.00

AOI 1 *(LGS 1)* - Location Map



AOI 1 *(LGS 1)* - Displacement Time Series

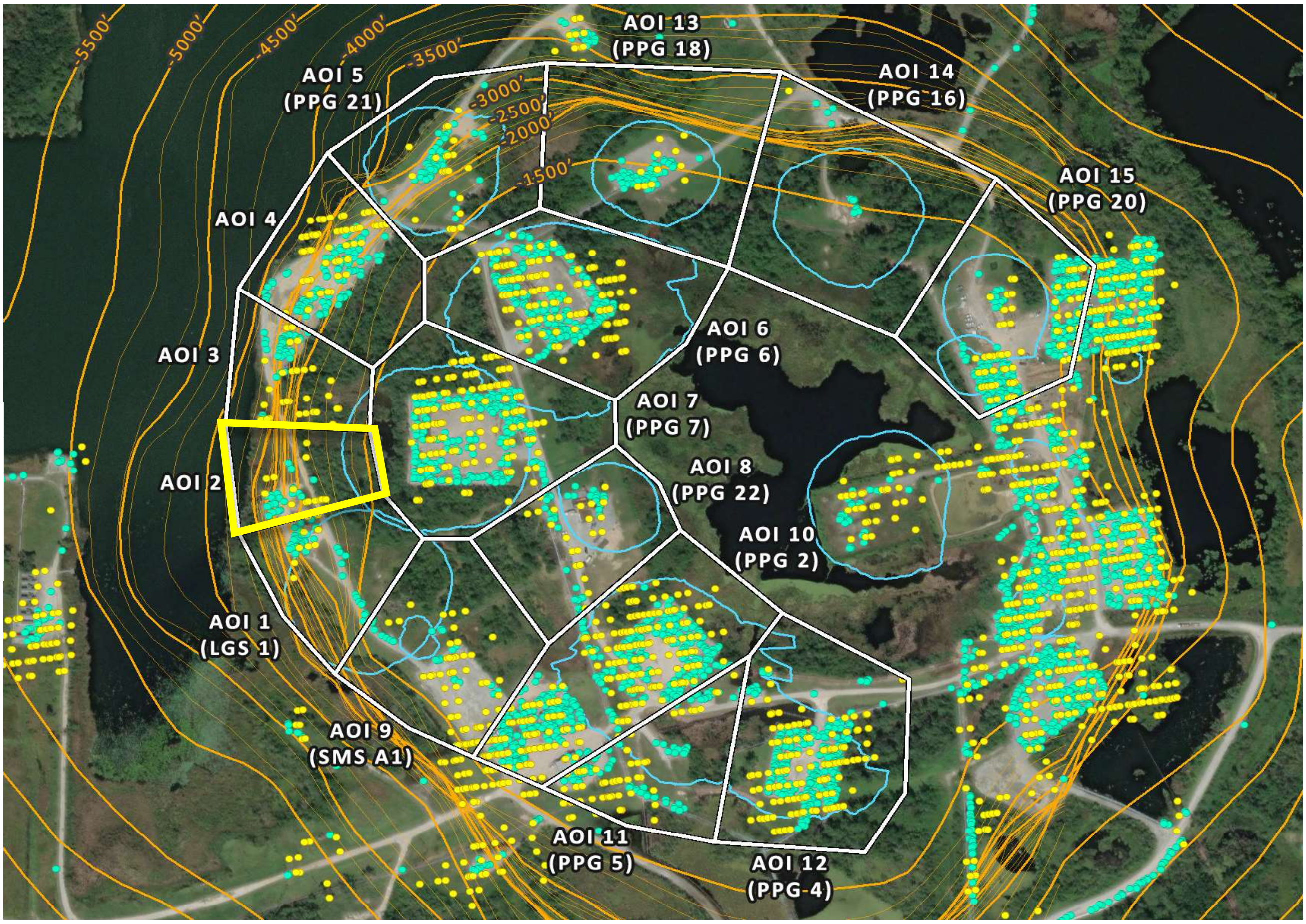
TSX/PAZ (6/28/2024) Point Count: **42**



	Nonlinear Trend		Linear Trend	
Velocity:	-0.28	in/yr	-0.04	in/yr
Acceleration:	-0.34	in/yr^2	0.00	in/yr^2

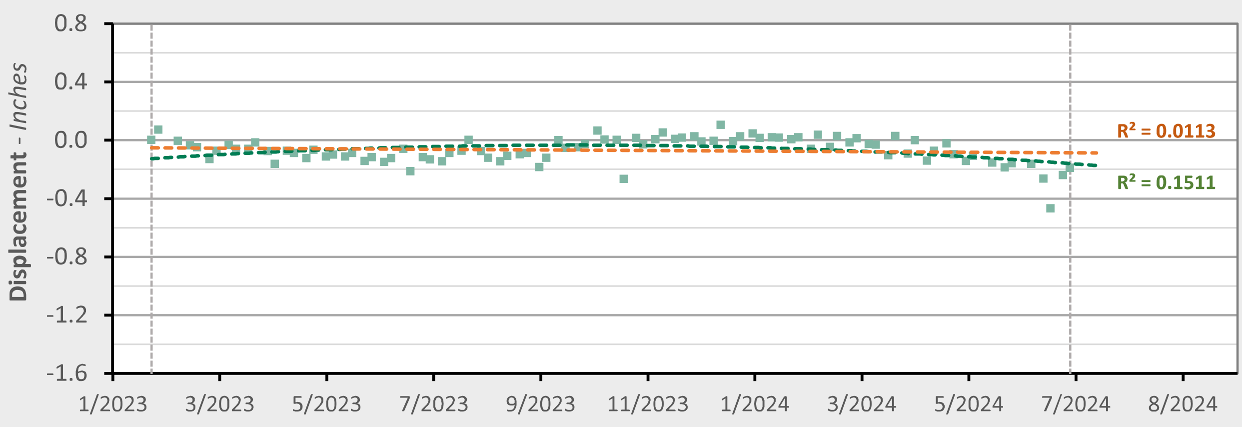
LOS Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

AOI 2 - Location Map



AOI 2 - Displacement Time Series

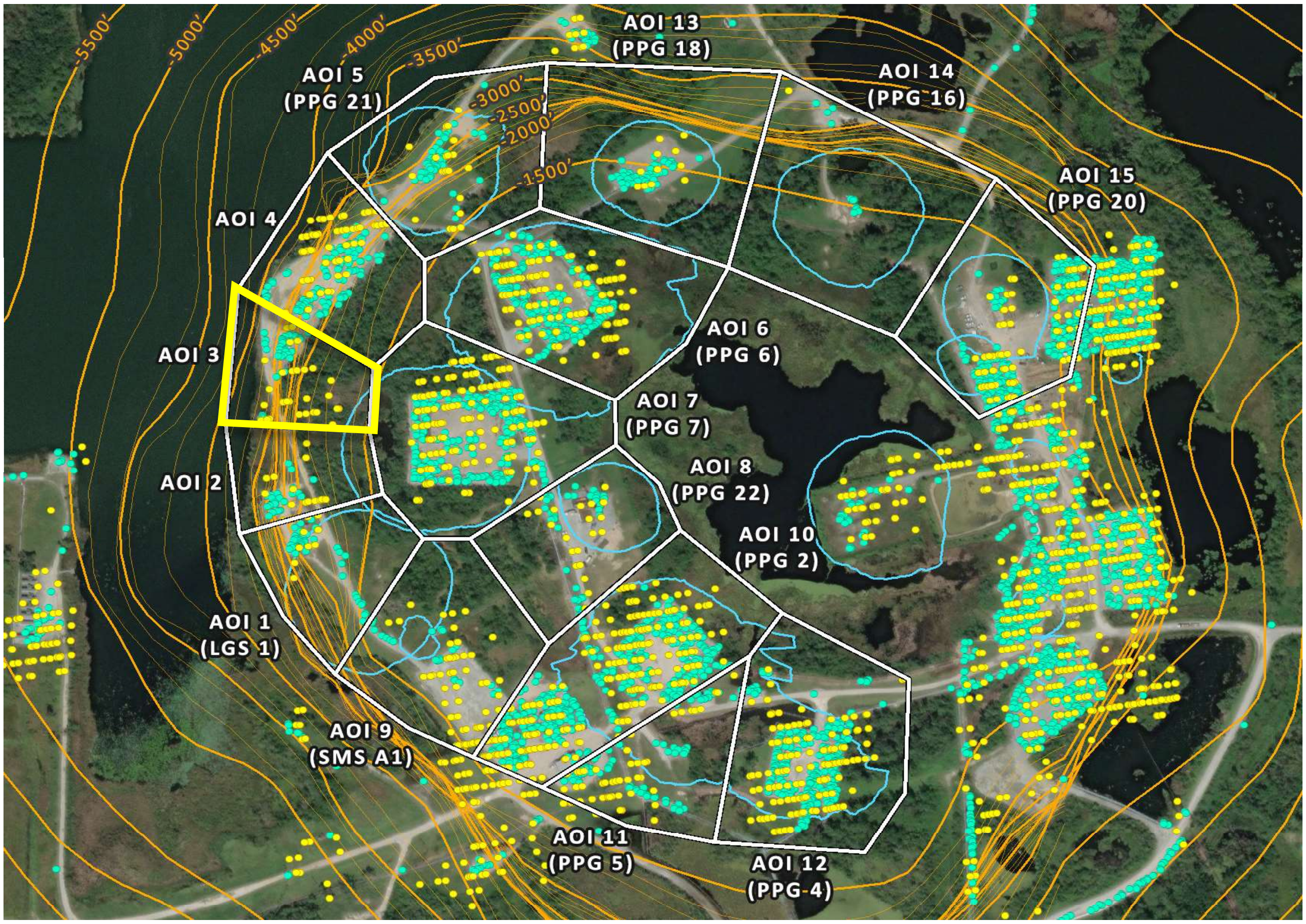
TSX/PAZ (6/28/2024) Point Count: 24



	Nonlinear Trend		Linear Trend	
Velocity:	-0.33	in/yr	-0.02	in/yr
Acceleration:	-0.43	in/yr^2	0.00	in/yr^2

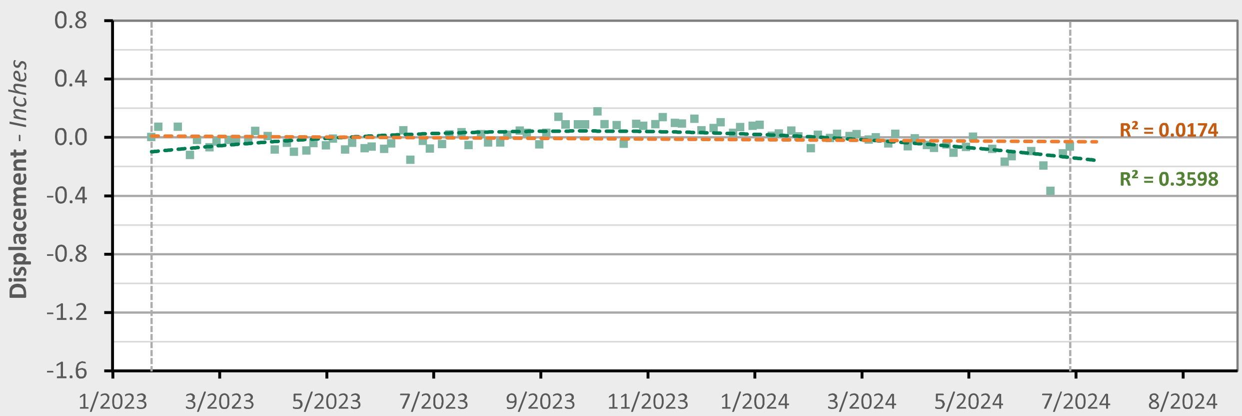
LOS Displacement Measurement — Nonlinear Trend Line (Quadratic Regression) — Linear Trend Line (Linear Regression)

AOI 3 - Location Map



AOI 3 - Displacement Time Series

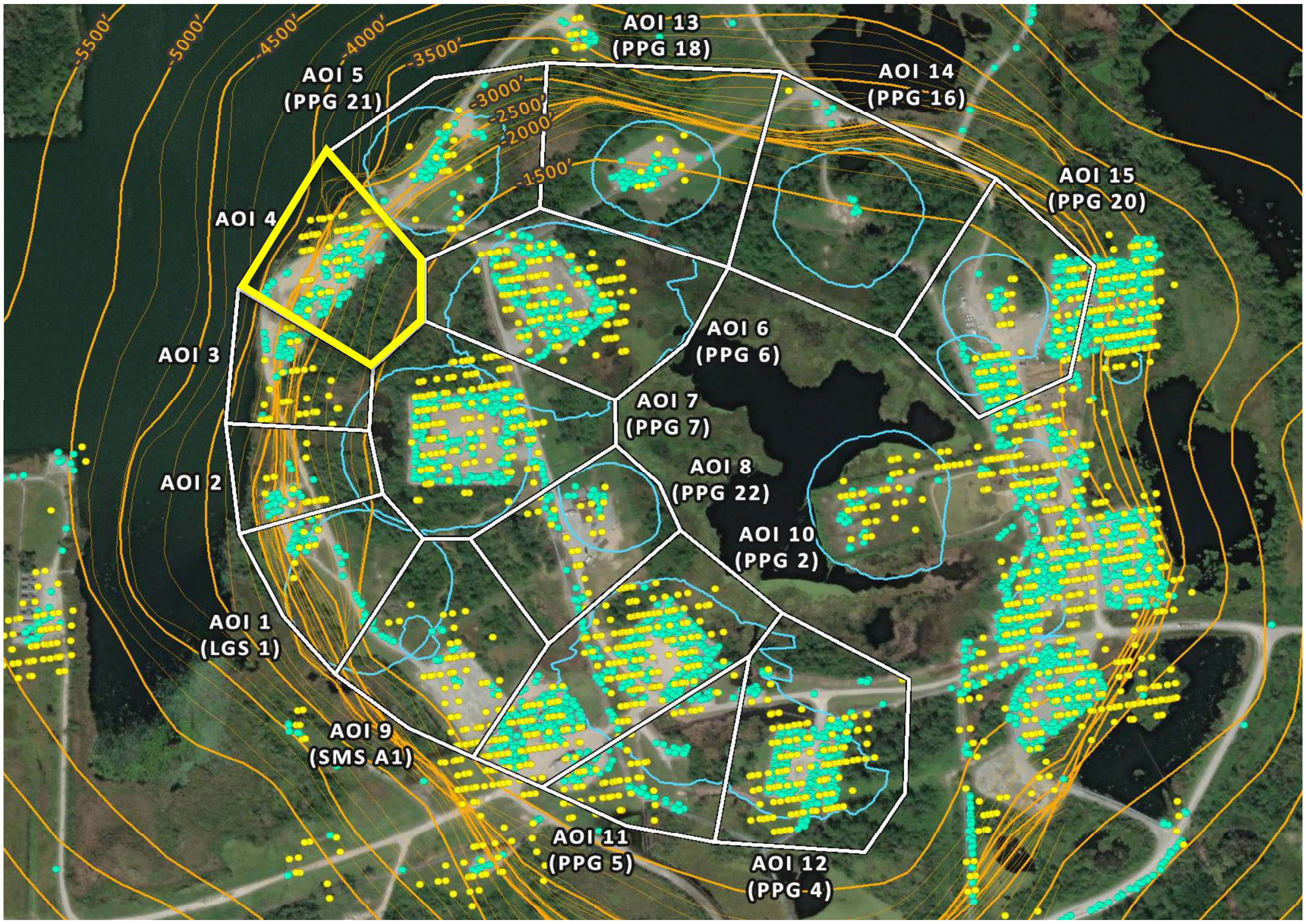
TSX/PAZ (6/28/2024) Point Count: **40**



	Nonlinear Trend		Linear Trend	
Velocity:	-0.48	in/yr	-0.03	in/yr
Acceleration:	-0.63	in/yr^2	0.00	in/yr^2

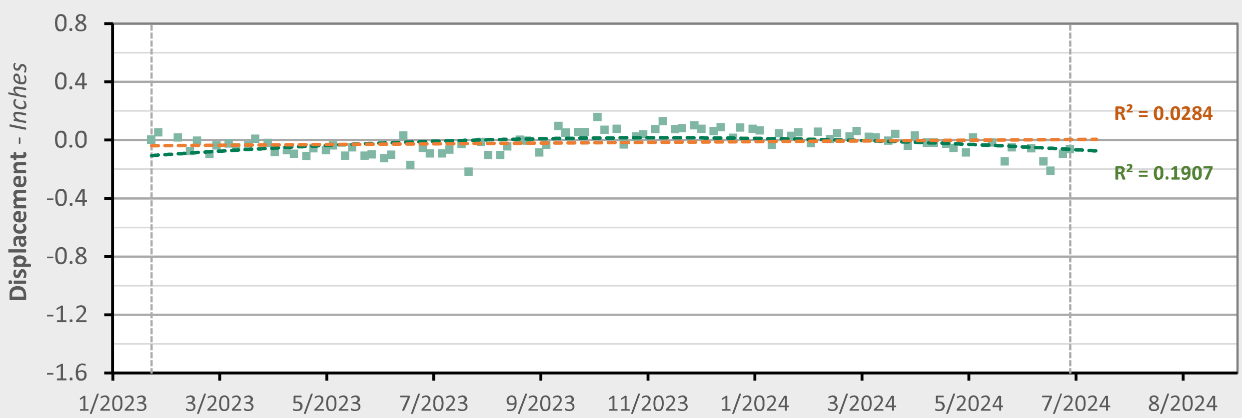
LOS Displacement Measurement — Nonlinear Trend Line (Quadratic Regression) — Linear Trend Line (Linear Regression)

AOI 4 - Location Map



AOI 4 - Displacement Time Series

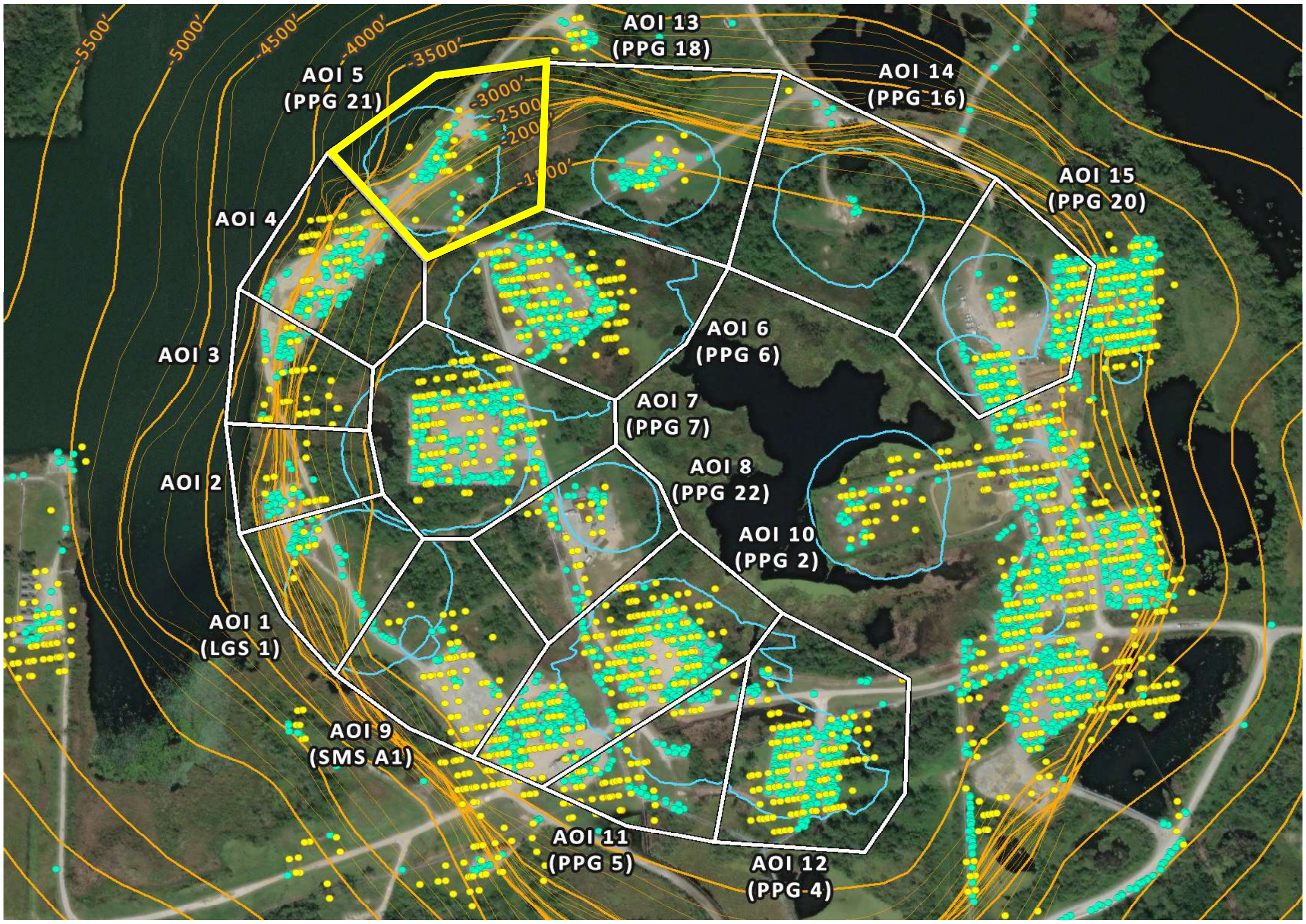
TSX/PAZ (6/28/2024) Point Count: **102**



	Nonlinear Trend	Linear Trend
Velocity:	-0.25 in/yr	+0.03 in/yr
Acceleration:	-0.39 in/yr^2	0.00 in/yr^2

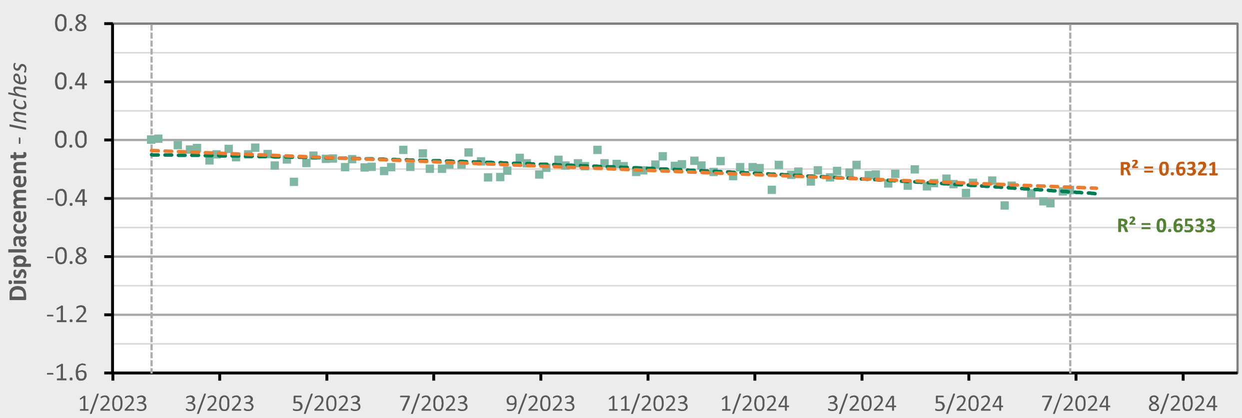
LOS Displacement Measurement — Nonlinear Trend Line (Quadratic Regression) — Linear Trend Line (Linear Regression)

AOI 5 *(PPG 21)* - Location Map



AOI 5 *(PPG 21)* - Displacement Time Series

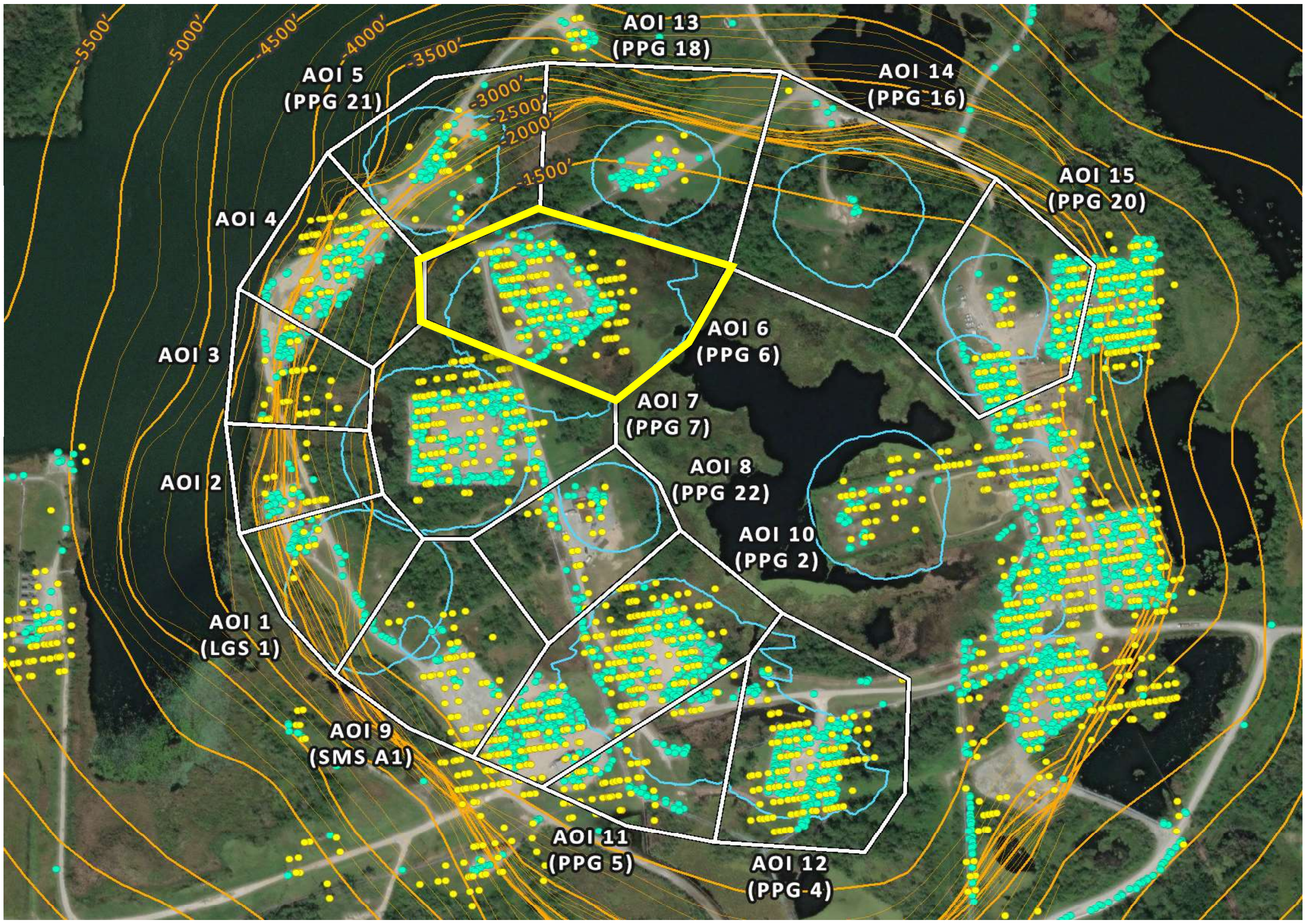
TSX/PAZ (6/28/2024) Point Count: 47



	Nonlinear Trend	Linear Trend
Velocity:	-0.30 in/yr	-0.18 in/yr
Acceleration:	-0.17 in/yr^2	0.00 in/yr^2

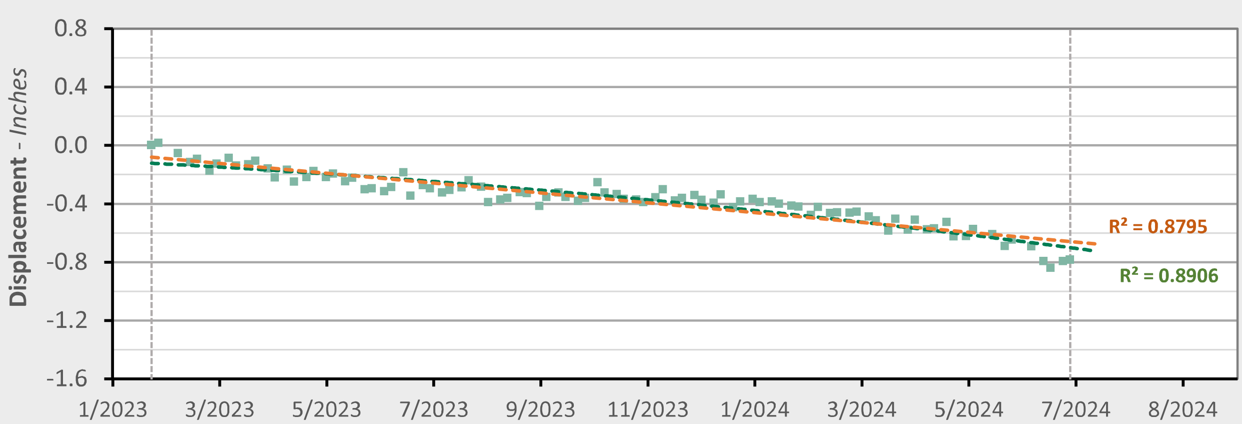
LOS Displacement Measurement — Nonlinear Trend Line (Quadratic Regression) — Linear Trend Line (Linear Regression)

AOI 6 *(PPG 6)* - Location Map



AOI 6 *(PPG 6)* - Displacement Time Series

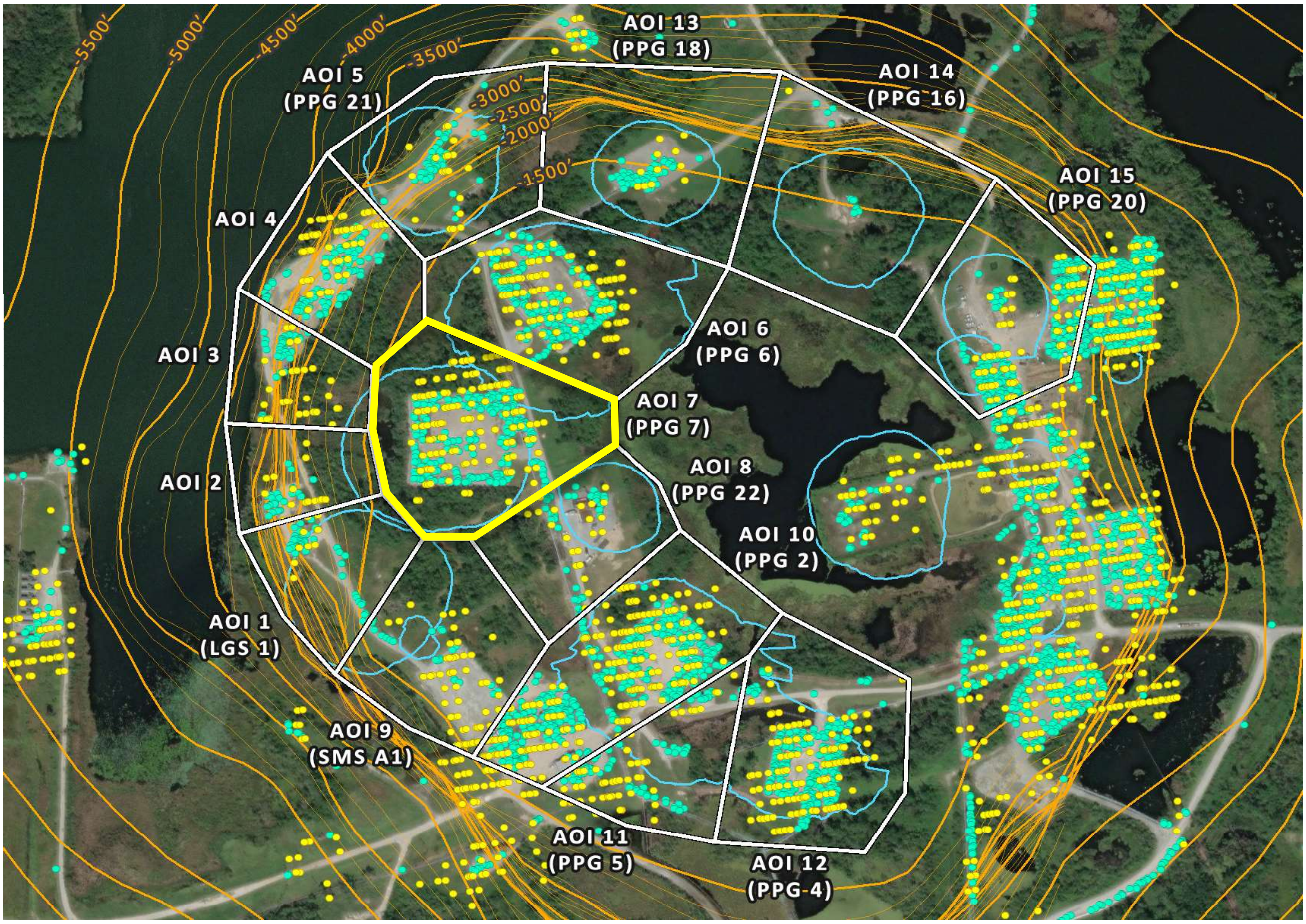
TSX/PAZ (6/28/2024) Point Count: **212**



	Nonlinear Trend	Linear Trend
Velocity:	-0.58 in/yr	-0.40 in/yr
Acceleration:	-0.24 in/yr^2	0.00 in/yr^2

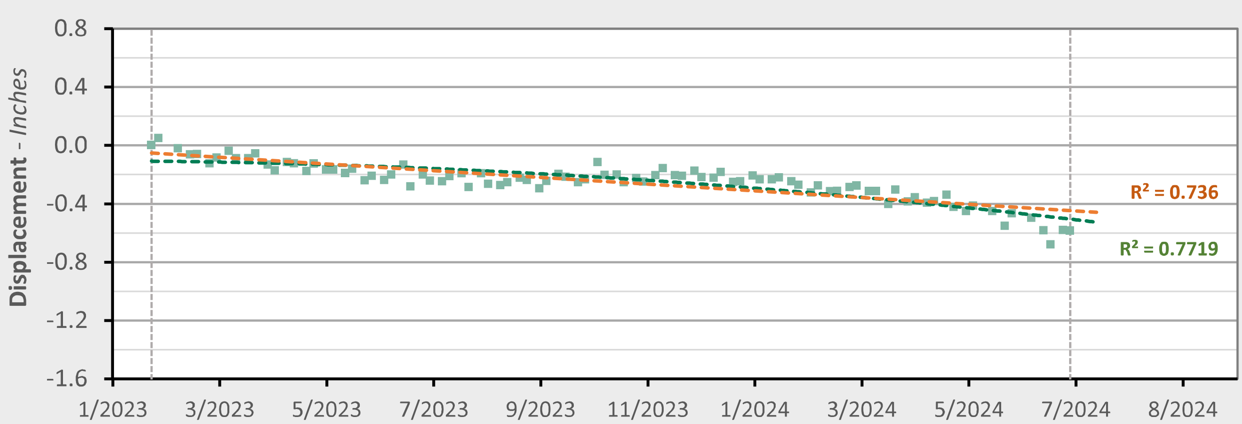
LOS Displacement Measurement — Nonlinear Trend Line (Quadratic Regression) — Linear Trend Line (Linear Regression)

AOI 7 *(PPG 7)* - Location Map



AOI 7 *(PPG 7)* - Displacement Time Series

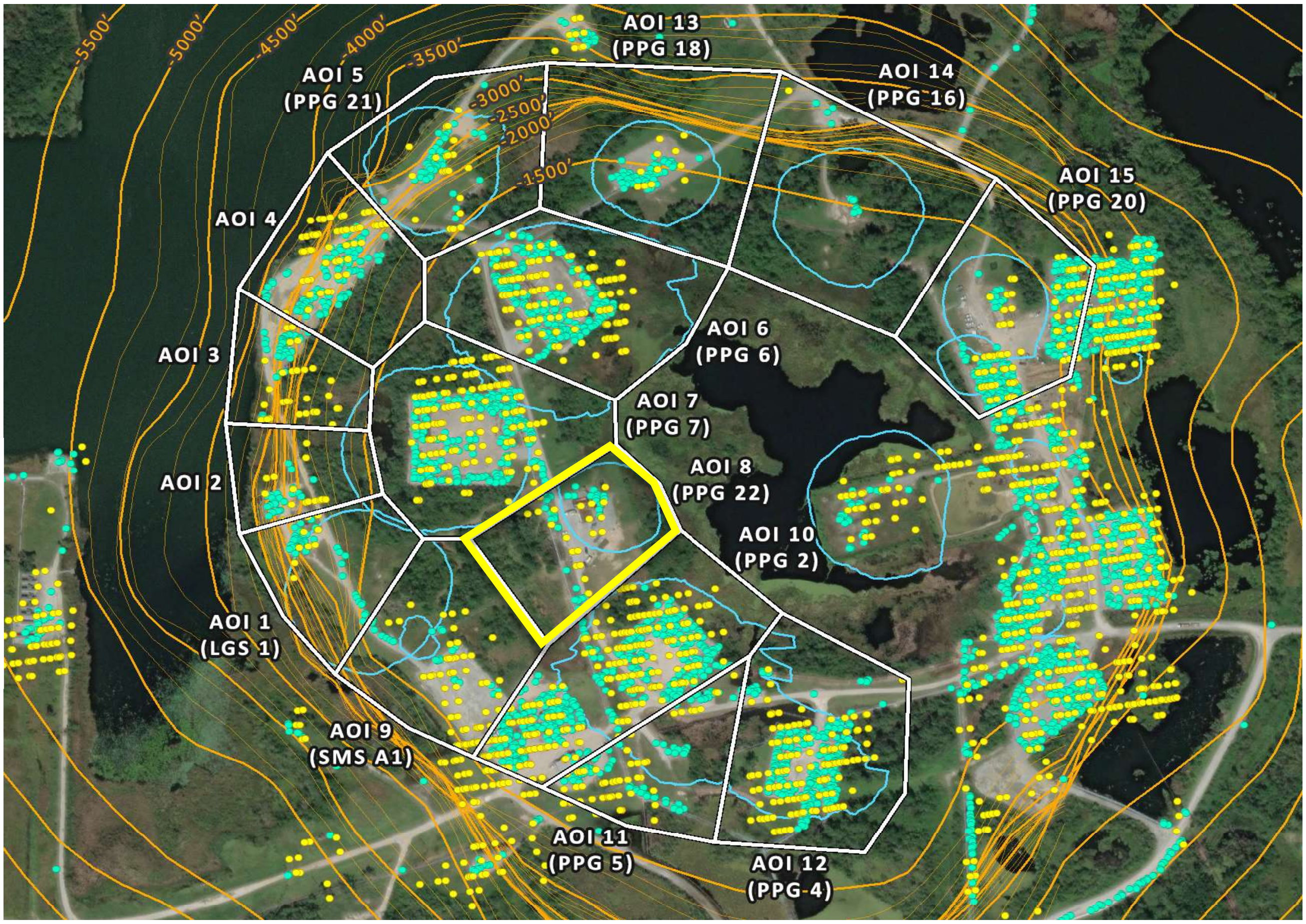
TSX/PAZ (6/28/2024) Point Count: **216**



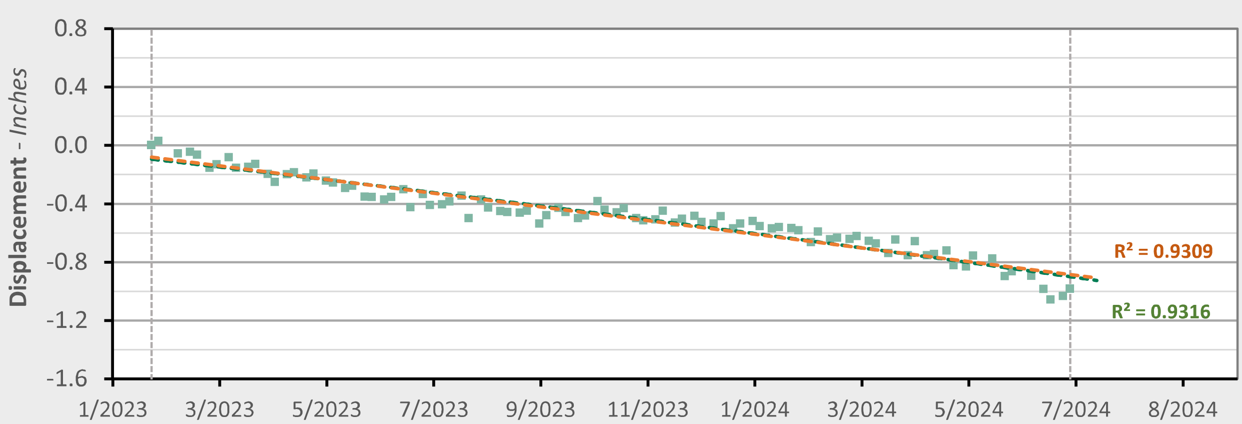
	Nonlinear Trend	Linear Trend
Velocity:	-0.51 in/yr	-0.28 in/yr
Acceleration:	-0.33 in/yr^2	0.00 in/yr^2

LOS Displacement Measurement | Nonlinear Trend Line (Quadratic Regression) | Linear Trend Line (Linear Regression)

AOI 8 *(PPG 22)* - Location Map



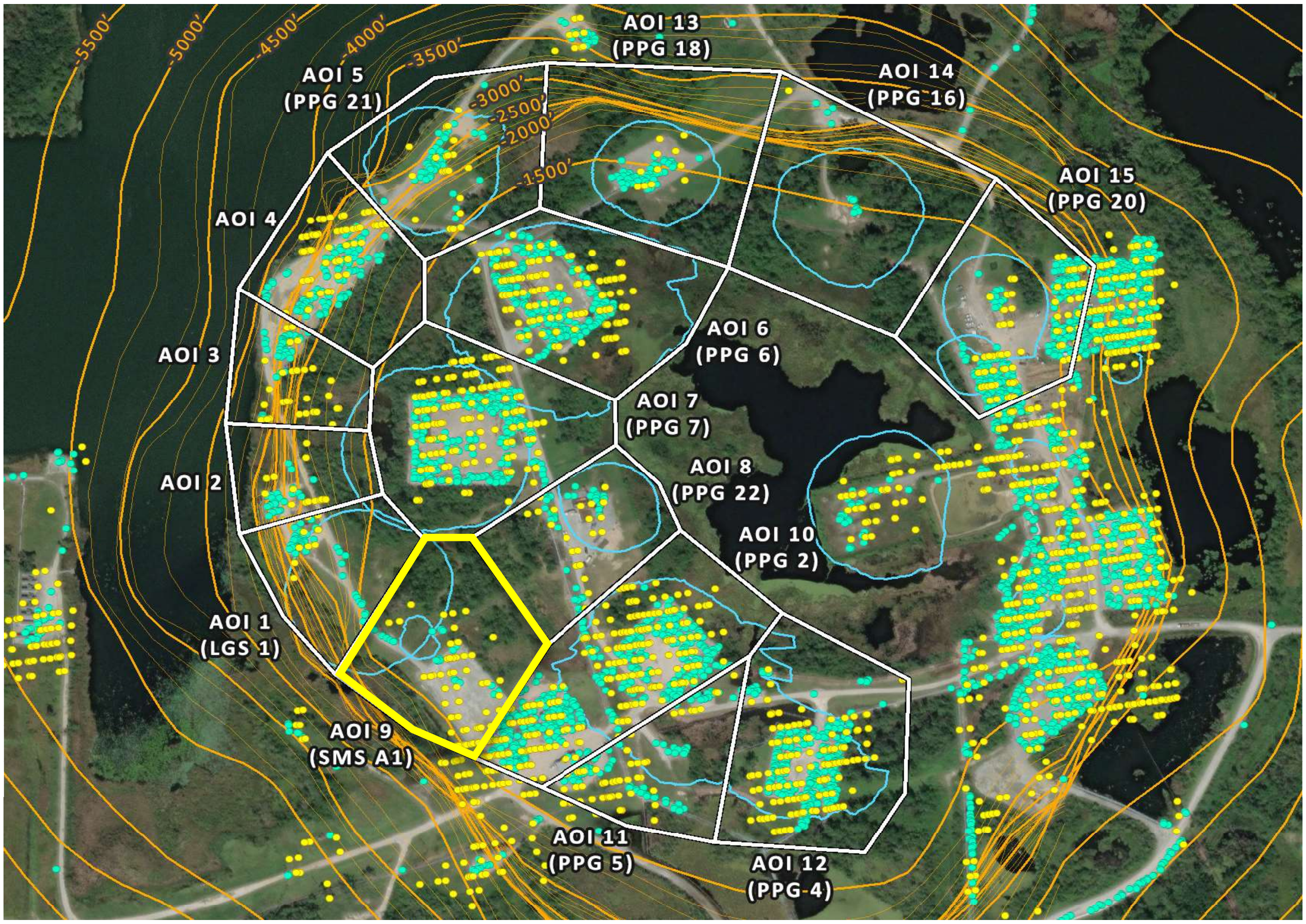
AOI 8 *(PPG 22)* - Displacement Time Series TSX/PAZ (6/28/2024) Point Count: 36



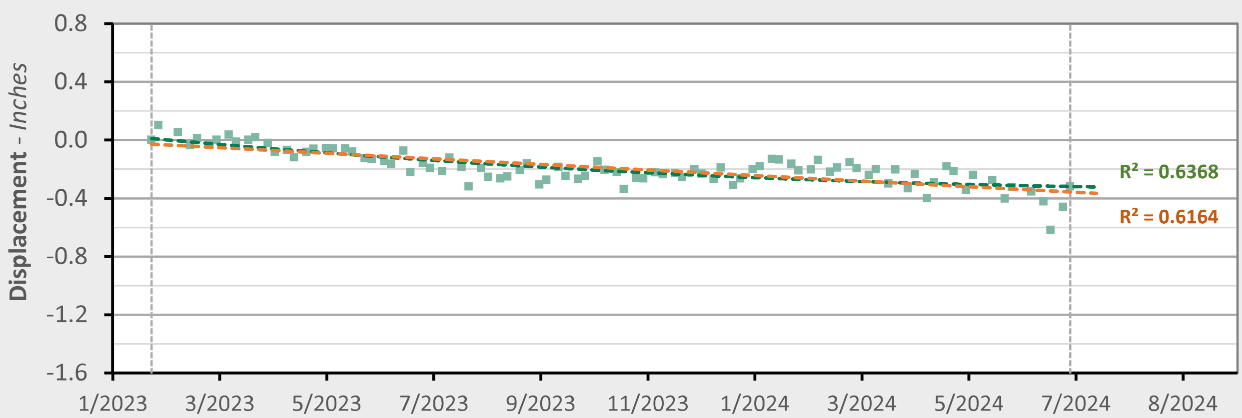
	Nonlinear Trend	Linear Trend
Velocity:	-0.62 in/yr	-0.56 in/yr
Acceleration:	-0.08 in/yr^2	0.00 in/yr^2

LOS Displacement Measurement — Nonlinear Trend Line (Quadratic Regression) — Linear Trend Line (Linear Regression)

AOI 9 *(PPG A1)* - Location Map



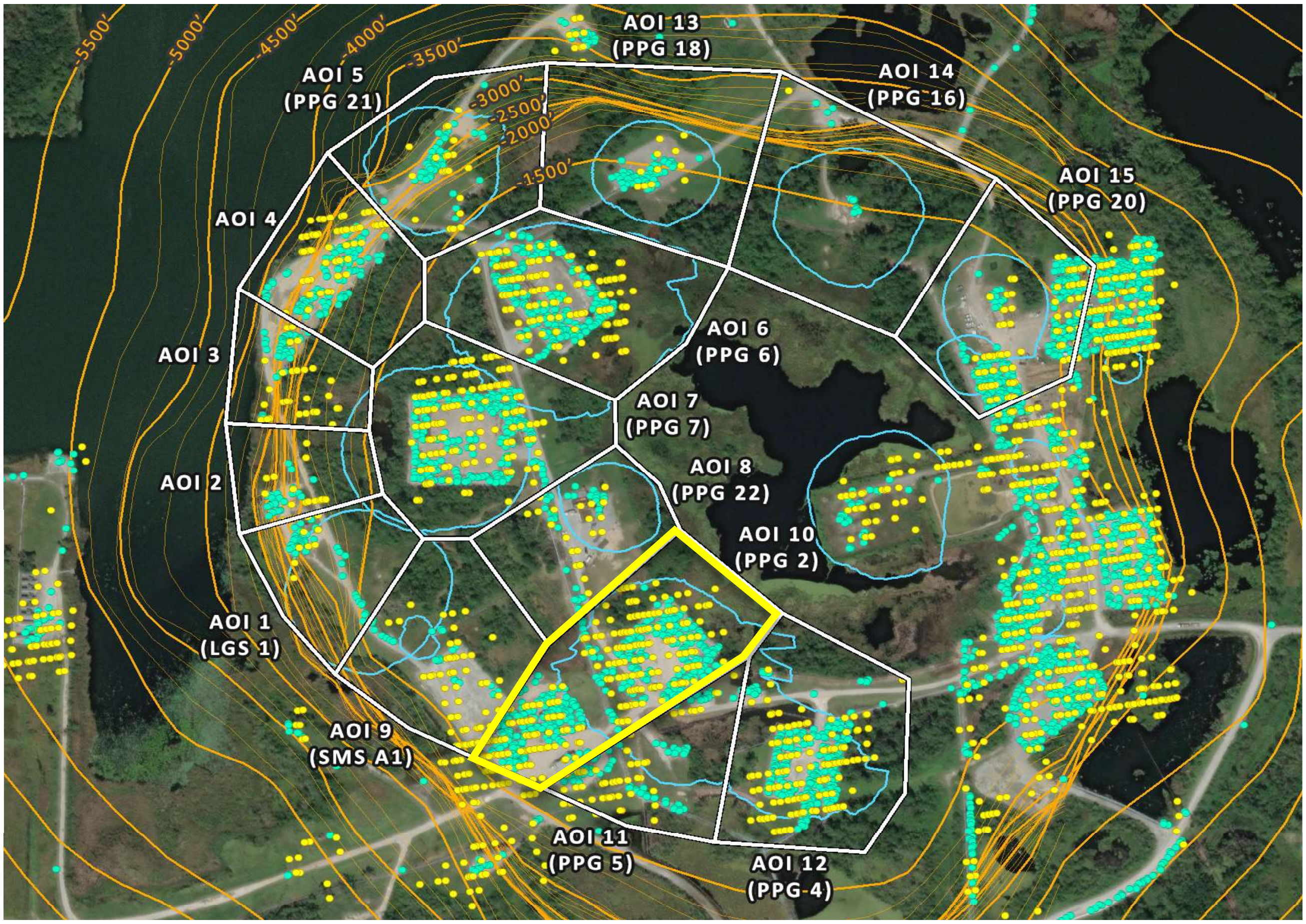
AOI 9 *(SMS A1)* - Displacement Time Series TSX/PAZ (6/28/2024) Point Count: 23



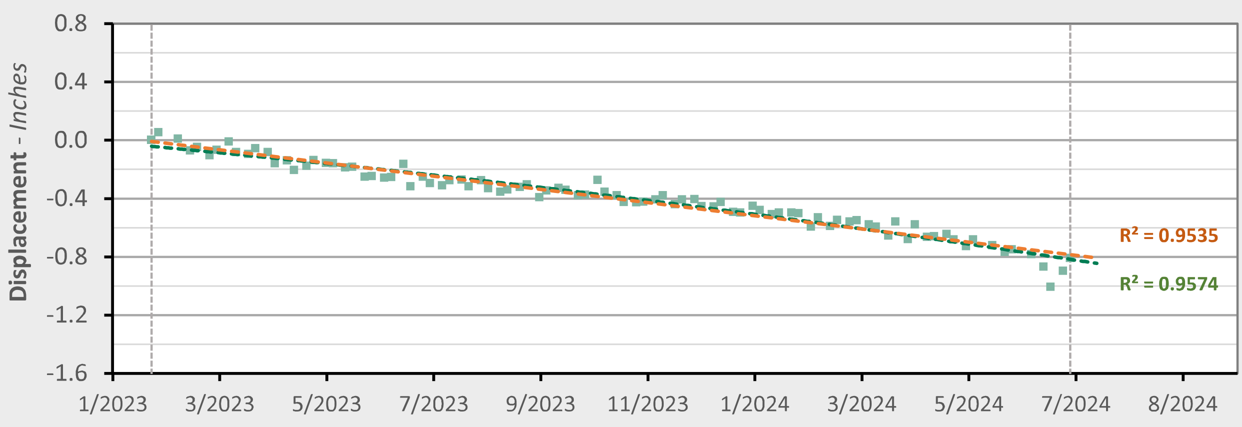
	Nonlinear Trend	Linear Trend
Velocity:	-0.07 in/yr	-0.23 in/yr
Acceleration:	+0.23 in/yr^2	0.00 in/yr^2

LOS Displacement Measurement — Nonlinear Trend Line (Quadratic Regression) — Linear Trend Line (Linear Regression)

AOI 10 *(PPG 2)* - Location Map



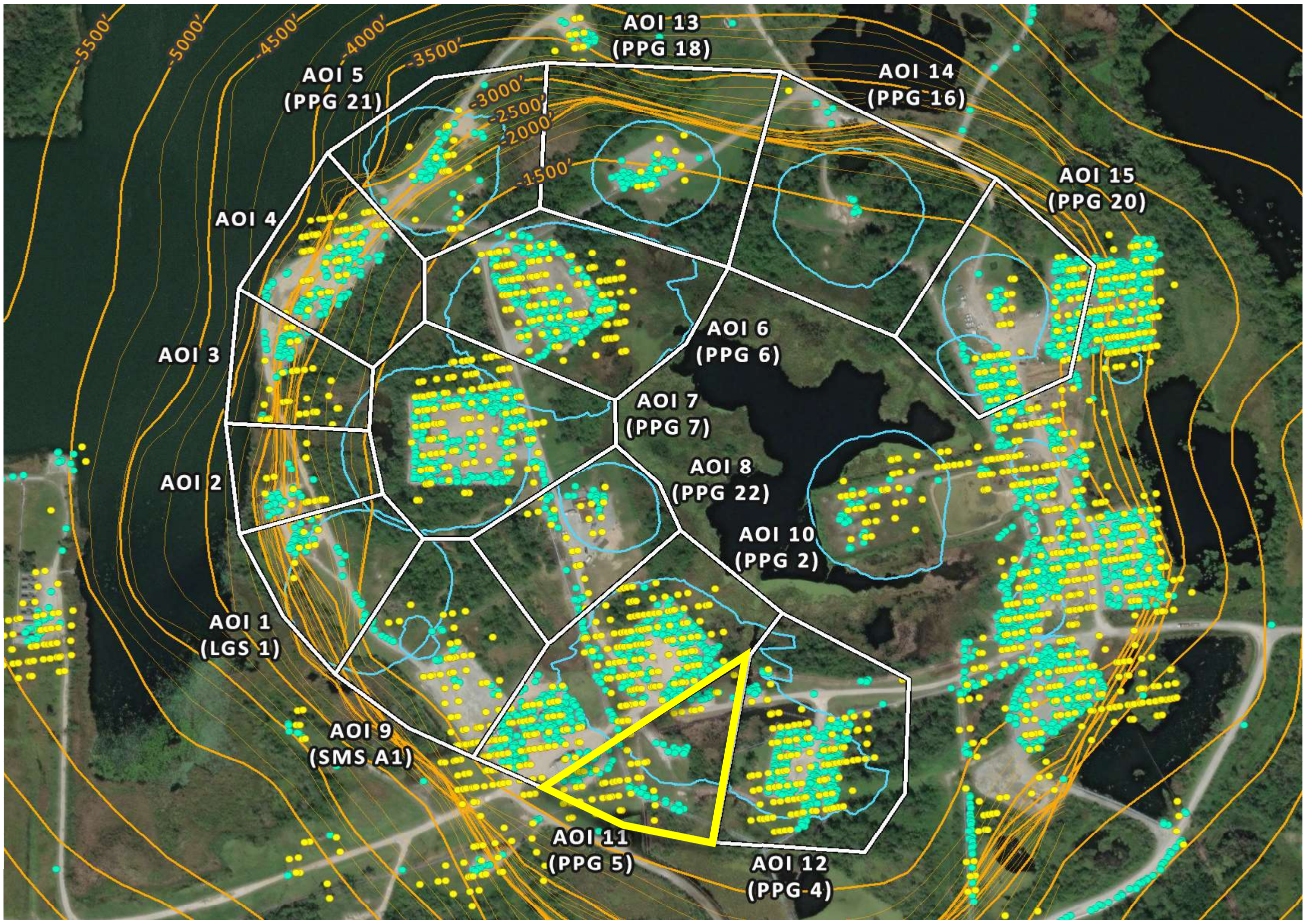
AOI 10 *(PPG 2)* - Displacement Time Series TSX/PAZ (6/28/2024) Point Count: 404



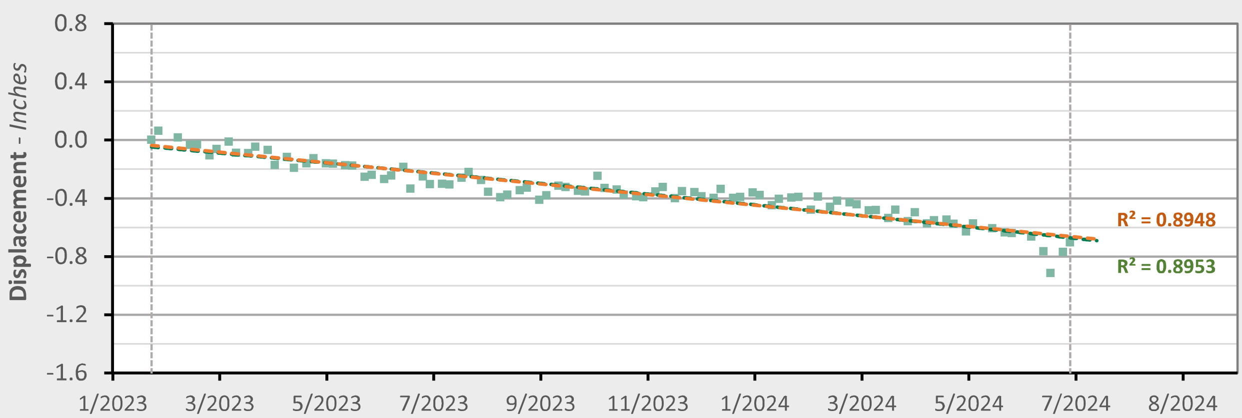
	Nonlinear Trend	Linear Trend
Velocity:	-0.68 in/yr	-0.54 in/yr
Acceleration:	-0.19 in/yr^2	0.00 in/yr^2

LOS Displacement Measurement — Nonlinear Trend Line (Quadratic Regression) — Linear Trend Line (Linear Regression)

AOI 11 *(PPG 5)* - Location Map



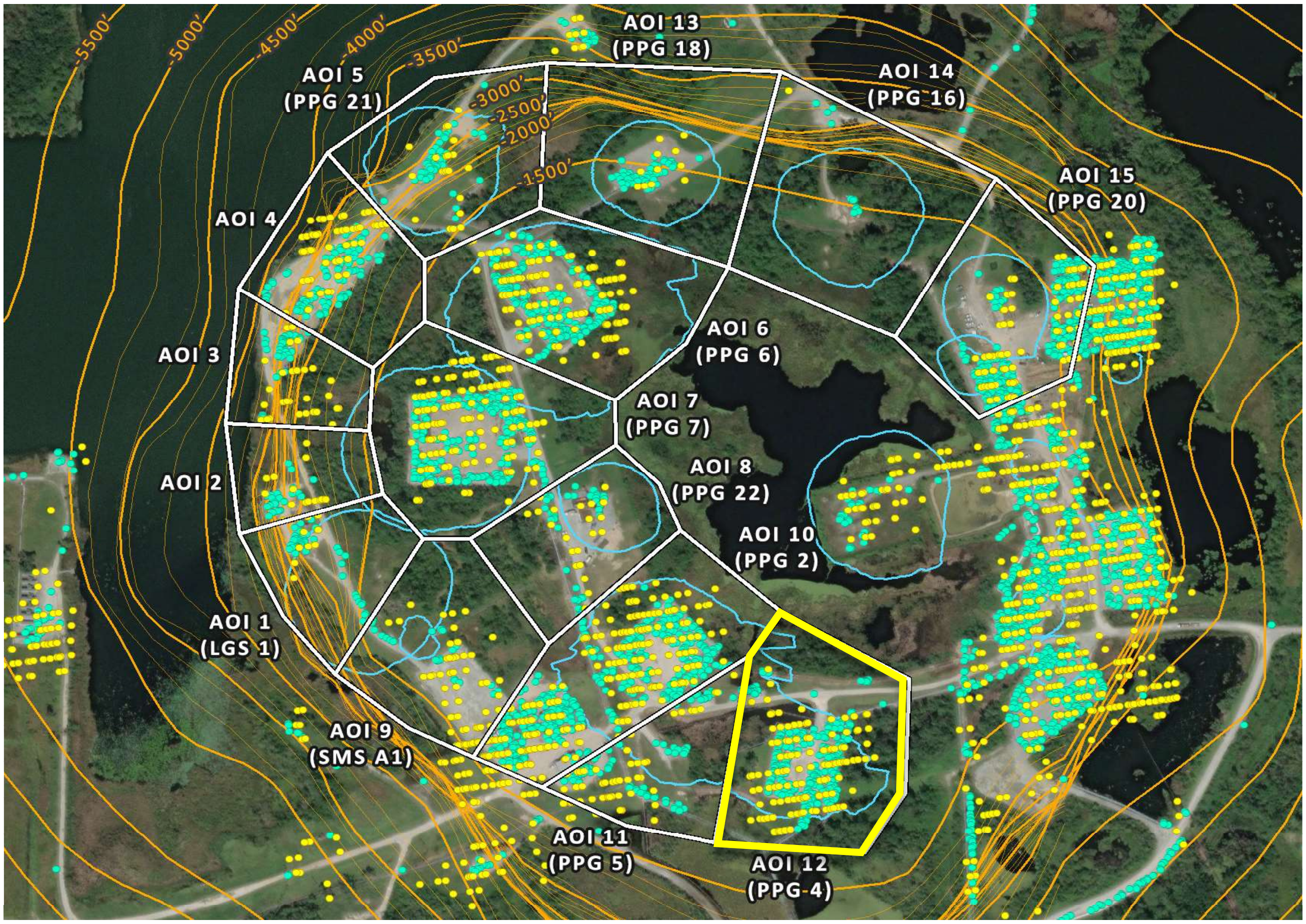
AOI 11 *(PPG 5)* - Displacement Time Series TSX/PAZ (6/28/2024) Point Count: 85



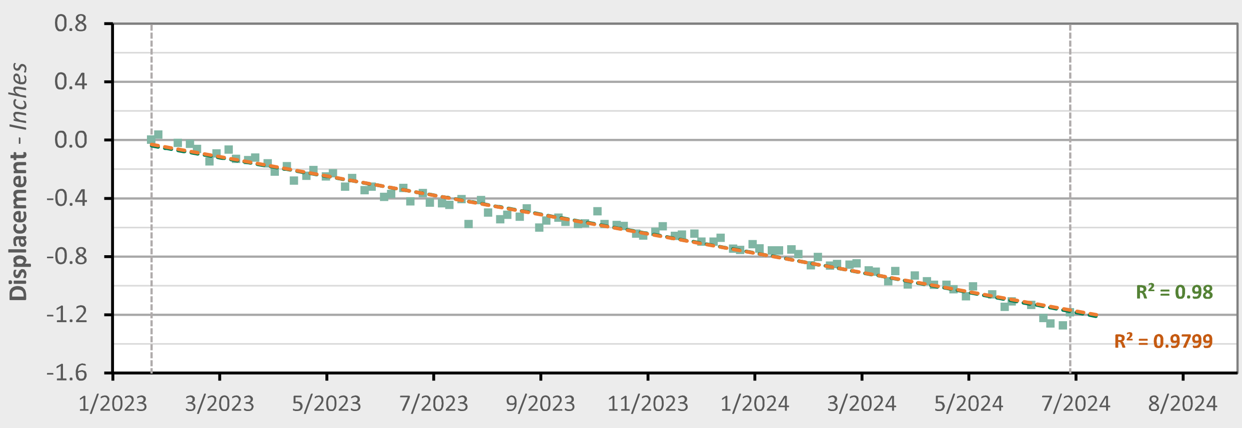
	Nonlinear Trend	Linear Trend
Velocity:	-0.48 in/yr	-0.44 in/yr
Acceleration:	-0.05 in/yr^2	0.00 in/yr^2

LOS Displacement Measurement — Nonlinear Trend Line (Quadratic Regression) — Linear Trend Line (Linear Regression)

AOI 12 *(PPG 4)* - Location Map



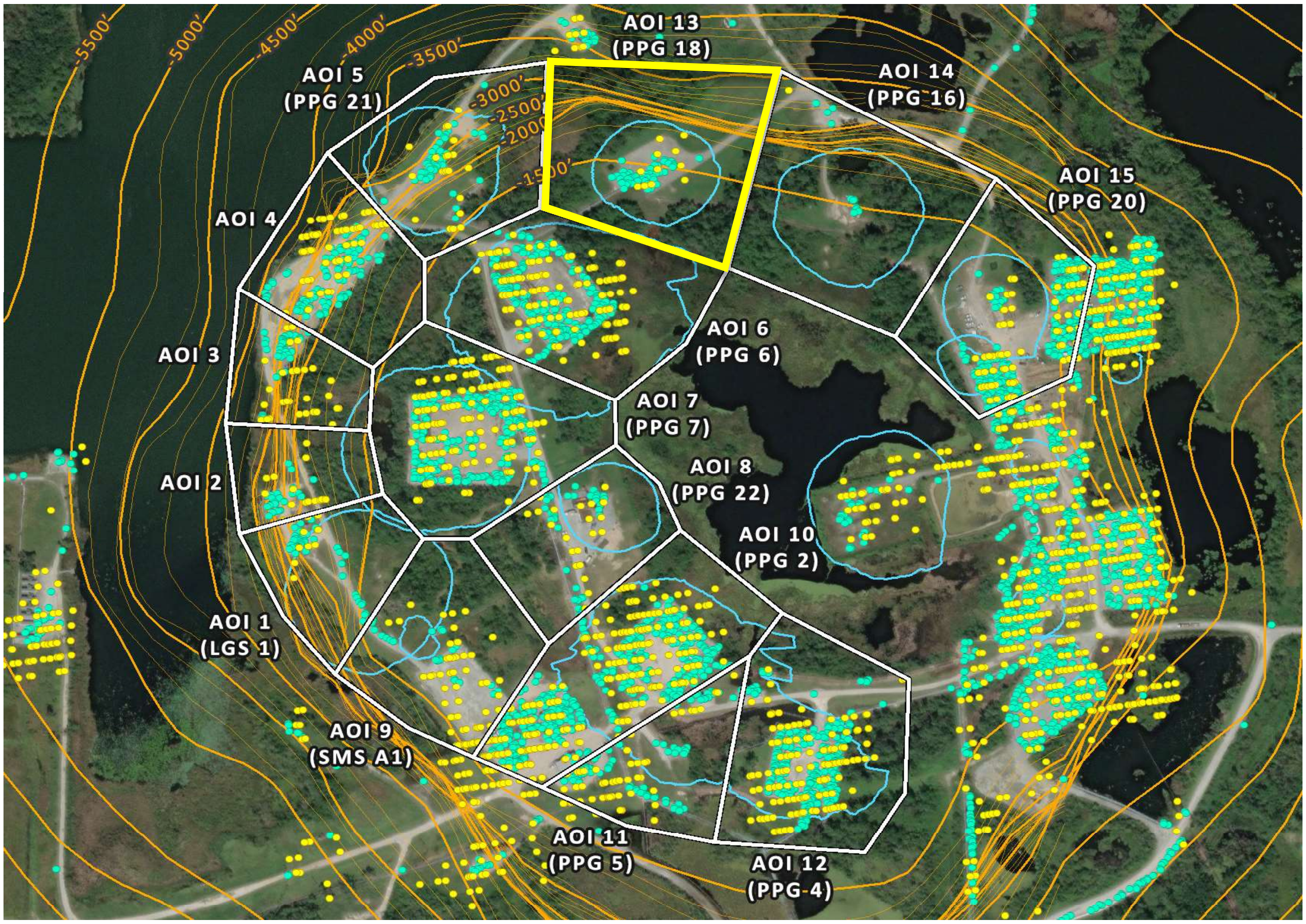
AOI 12 *(PPG 4)* - Displacement Time Series TSX/PAZ (6/28/2024) Point Count: 262



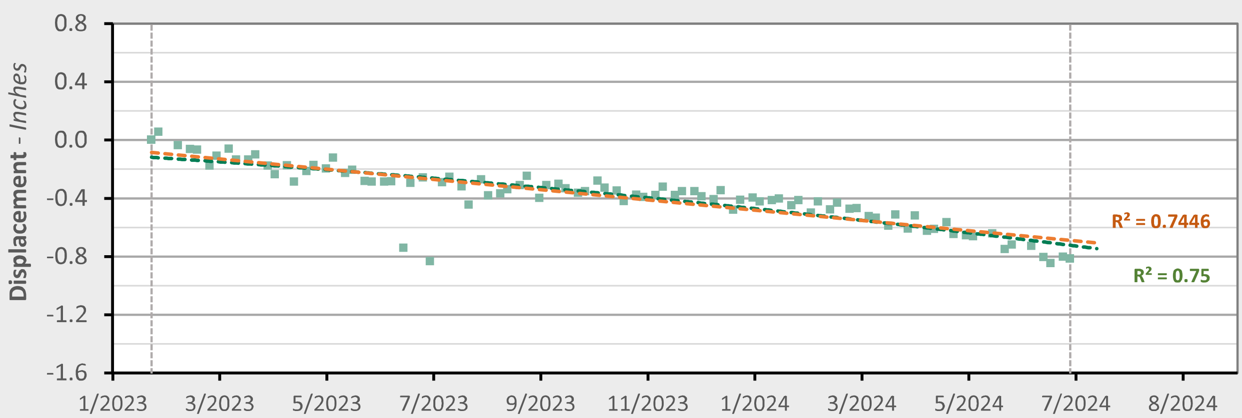
	Nonlinear Trend	Linear Trend
Velocity:	-0.83 in/yr	-0.80 in/yr
Acceleration:	-0.05 in/yr^2	0.00 in/yr^2

LOS Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

AOI 13 *(PPG 18)* - Location Map



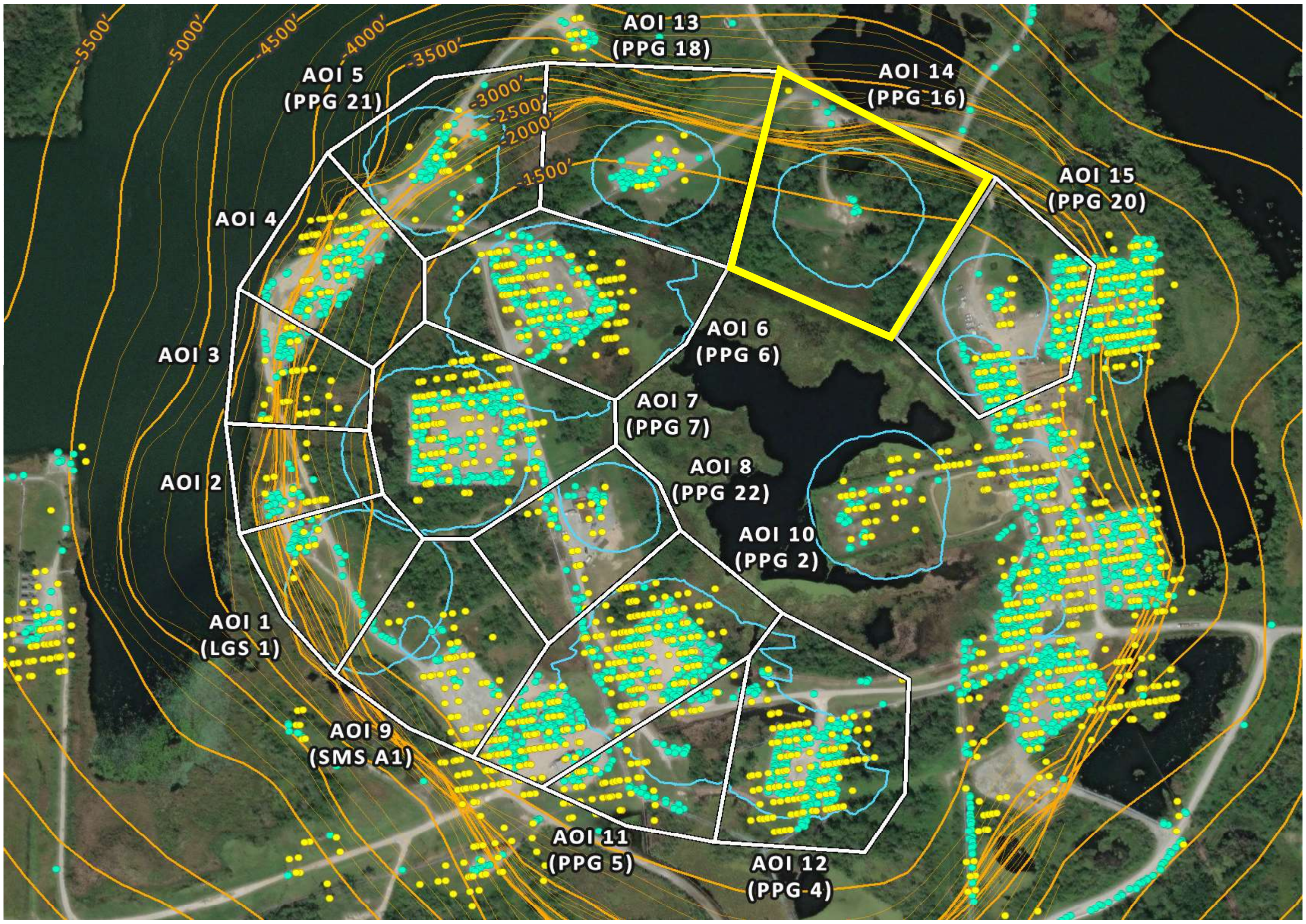
AOI 13 *(PPG 18)* - Displacement Time Series TSX/PAZ (6/28/2024) Point Count: 52



	Nonlinear Trend		Linear Trend	
Velocity:	-0.56	in/yr	-0.42	in/yr
Acceleration:	-0.19	in/yr²	0.00	in/yr²

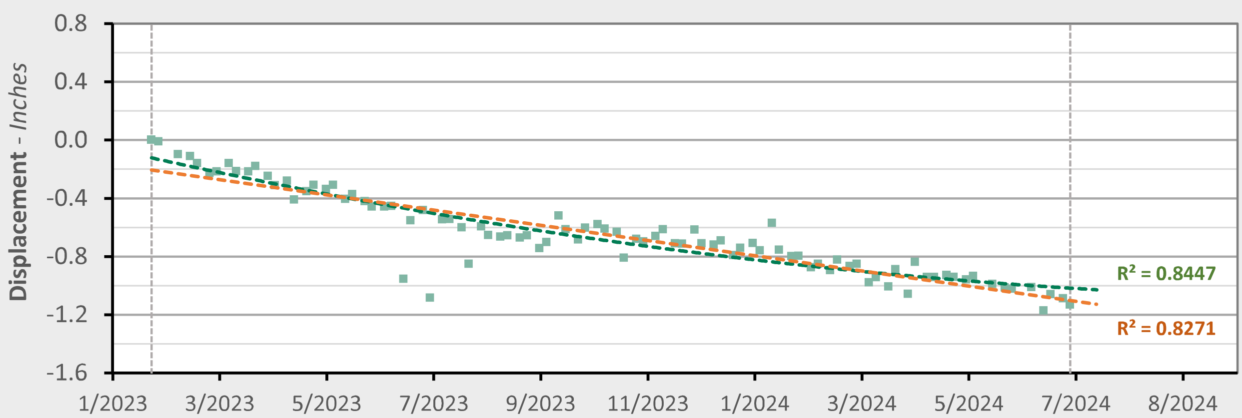
LOS Displacement Measurement — Nonlinear Trend Line (Quadratic Regression) — Linear Trend Line (Linear Regression)

AOI 14 *(PPG 16)* - Location Map



AOI 14 *(PPG 16)* - Displacement Time Series

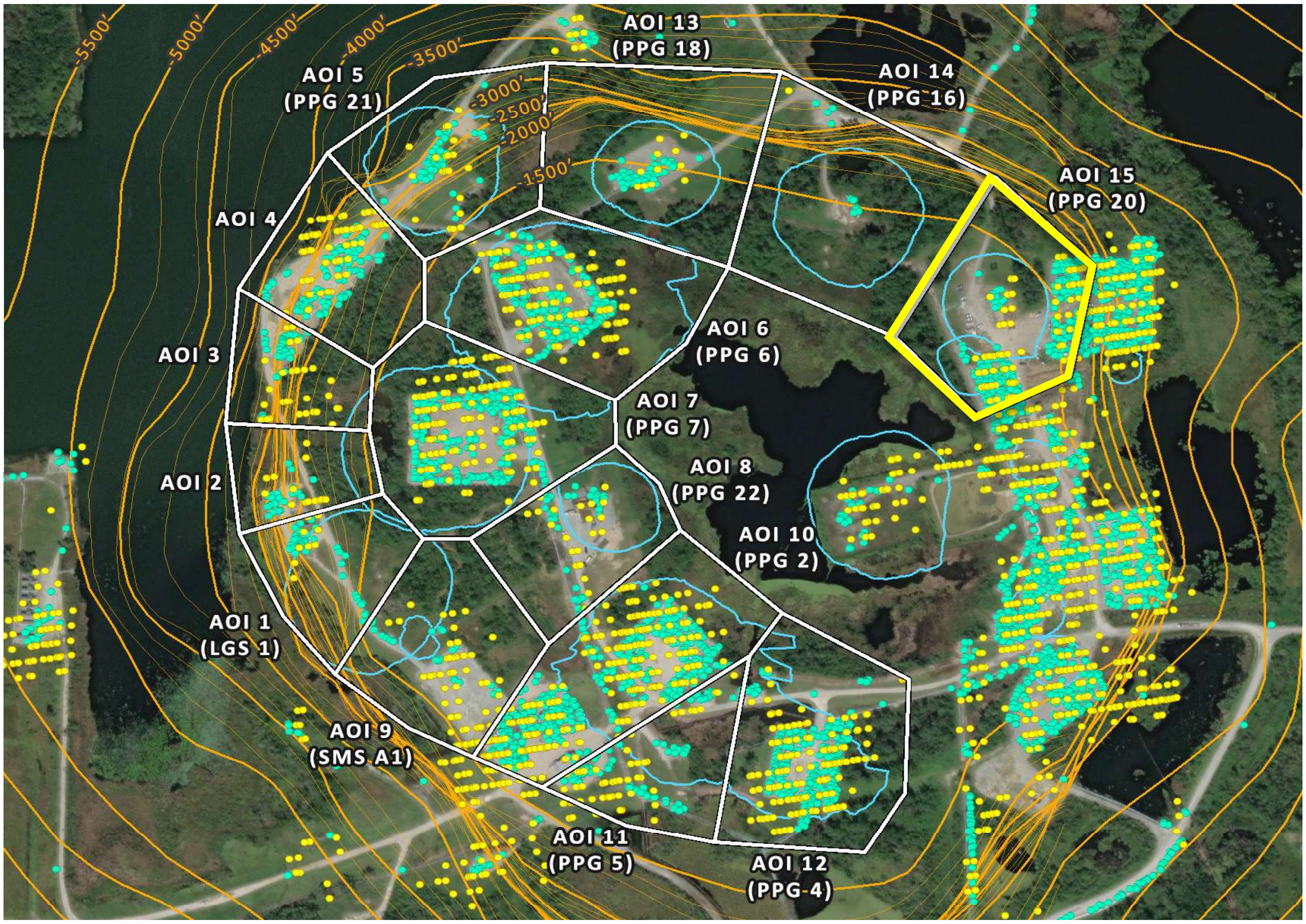
TSX/PAZ (6/28/2024) Point Count: **11**



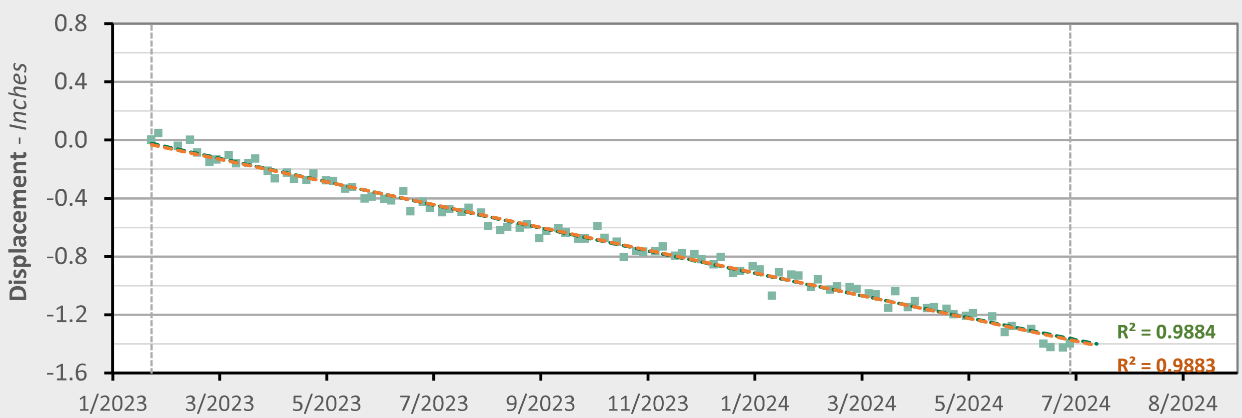
	Nonlinear Trend		Linear Trend	
Velocity:	-0.28	in/yr	-0.63	in/yr
Acceleration:	+0.49	in/yr^2	0.00	in/yr^2

LOS Displacement Measurement — Nonlinear Trend Line (Quadratic Regression) — Linear Trend Line (Linear Regression)

AOI 15 *(PPG 20)* - Location Map



AOI 15 *(PPG 20)* - Displacement Time Series TSX/PAZ (6/28/2024) Point Count: 224



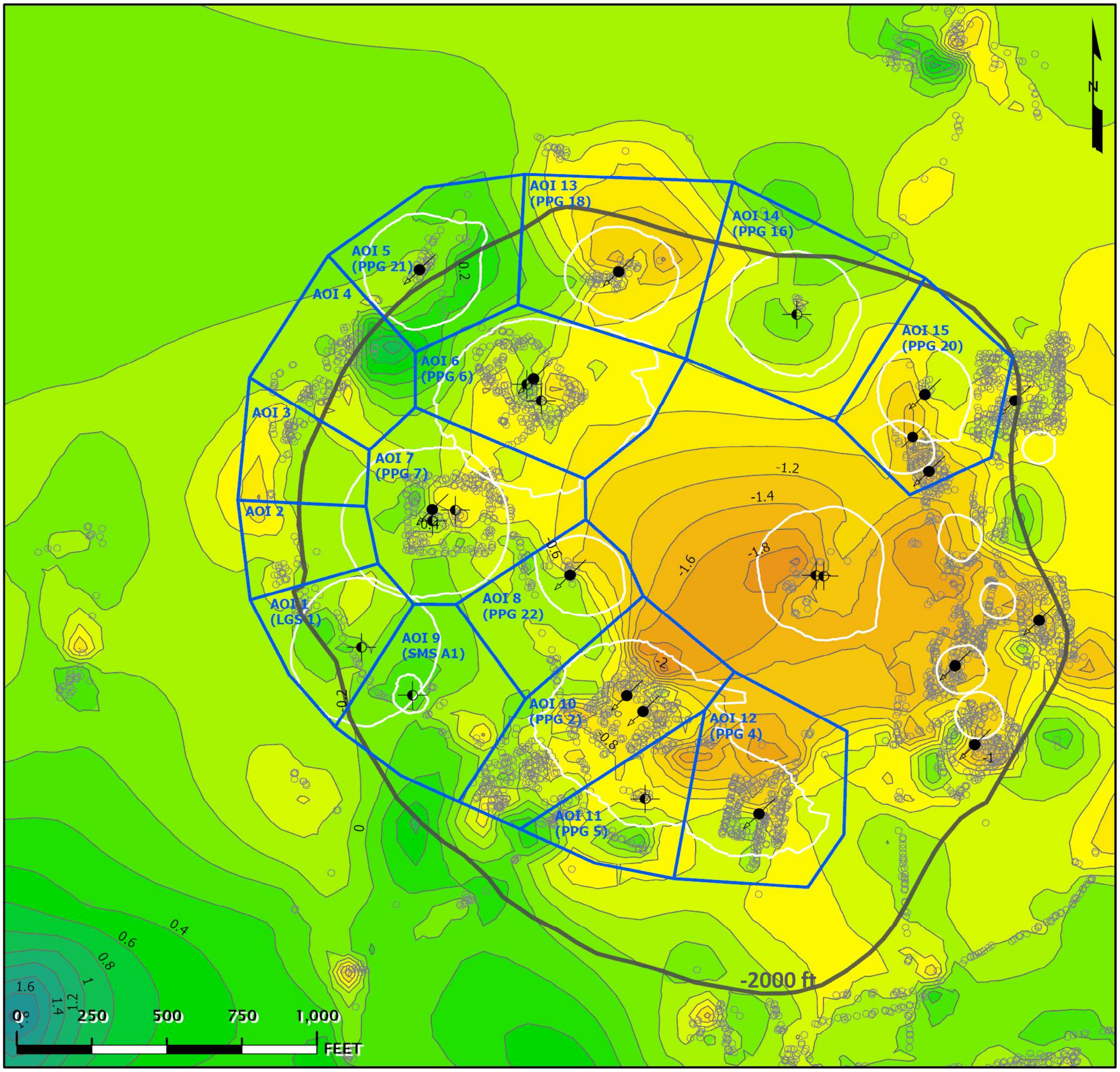
	Nonlinear Trend	Linear Trend
Velocity:	-0.90 in/yr	-0.94 in/yr
Acceleration:	+0.05 in/yr^2	0.00 in/yr^2

LOS Displacement Measurement | Nonlinear Trend Line (Quadratic Regression) | Linear Trend Line (Linear Regression)

TSX/PAZ Data (01/24/2023 - 06/28/2024)

Nonlinear Velocity Contours

As of date: 06/28/2024



-3.0 -2.0 -1.0 0.0 +1.0 +2.0 +3.0 Inches/year

AOI Boundary · InSAR LOS Measurement Point · Contour (0.2)

Historical Cavern Extent · Top of Dome (-2000 ft Contour)

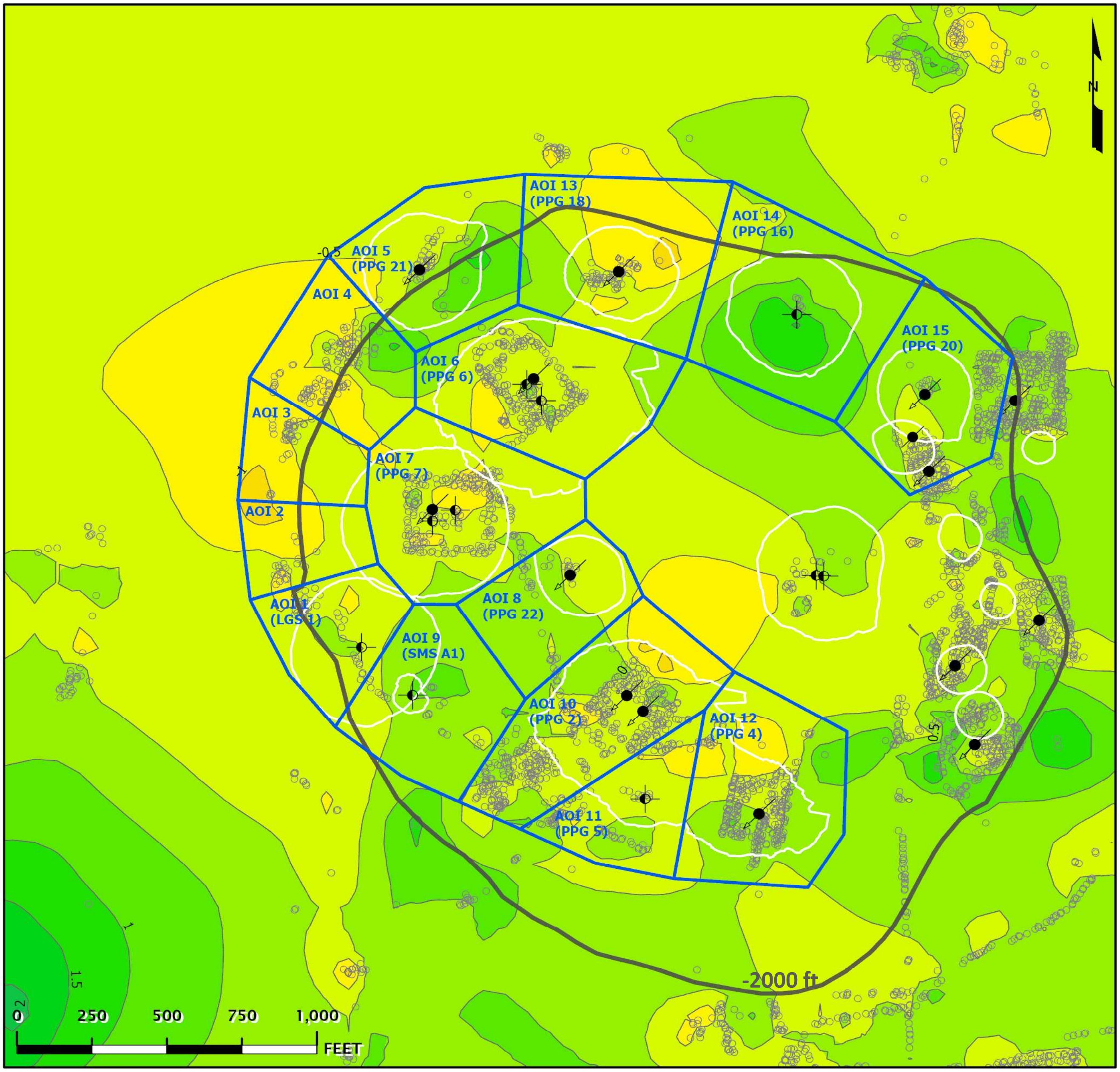
Cavern Well Surface Locations

09 - Active - Injection · 29 - Dry and Plugged

TSX/PAZ Data (01/24/2023 - 06/28/2024)

Nonlinear Acceleration Contours

Date range: 01/24/2023 - 06/28/2024



-6.0 -4.0 -2.0 0.0 +2.0 +4.0 +6.0

Inches/year^2

AOI Boundary | InSAR LOS Measurement Point | Contour (0.5)

Historical Cavern Extent | Top of Dome (-2000 ft Contour)

Cavern Well Surface Locations

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TSX/PAZ Data (01/24/2023 - 06/28/2024)

Linear Velocity Contours

Date range: 01/24/2023 - 06/28/2024