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RE: Review of Nineteenth (19th) Re-measure of Elevations at Monitoring Benchmarks and Monitoring Points Along the Water Line Segments W1A and W2A in the Woodlands, Texas

Dear Aaron:

This letter provides INTERA's review of the March 2025 re-measure of elevations for monitoring benchmarks and monitoring points along the water line Segments W1A and W2A in The Woodlands, Texas. This review is provided in Attachment A. Attachment A also includes a review of the water line tolerances along Segments W1A and W2A compared to land subsidence.

The work was performed under Master Professional Services Agreement Contract No. 23-0053-A and under Work Order 3. The technical lead for this task is Dr. Steven Young.

Respectfully submitted,

Steven C Young

Steven Young, PHD
Professional Geologist
INTERA Incorporated

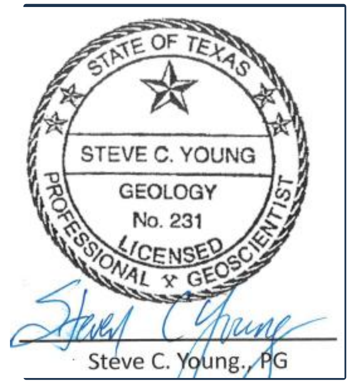
Enclosure

ATTACHMENT A

Review of Nineteenth (19th) Re-measure of the Elevations at Monitoring Points and Monitoring Benchmarks along Water Line Segments W1A and W2A

Geoscientist Seal

Dr. Steven C. Young, performed or supervised all services associated with preparing Attachment A. The geoscientific services included the writing the text, data analysis, tabulation of results, and construction of figures. I am employed by INTERA Incorporated in Austin, Texas. INTERA is Professional Geoscience firm, with registration number 50189. Dr. Young professional geoscience registration number is 231.



Overview of Nineteenth (19th) Re-measure of the Elevations at Monitoring Points and Monitoring Benchmarks along Water Line Segments W1A and W2A

In March 2015, an SJRA contracted surveyor began measuring elevations of monitoring points and monitoring benchmarks along the water line segments W1A and W2A. Since March 2015, the SJRA contracted surveyor has re-measured the elevations of the monitoring points and monitoring benchmarks along the water line segments W1A and W2A. In March 2025, the SJRA contracted surveyor performed the Nineteenth re-measurement.

Figure 1 shows the locations of the water line segments W1A and W2A and the four monitoring systems. Each of the monitoring systems consists of monitoring points or monitoring benchmarks. Monitoring benchmarks terminate in the ground and are used to measure elevation changes in the soil. Monitoring points terminate on top of a pipe or a pipe casing and are used to measure the elevation changes of the water line. The Egypt Fault Monitoring System and the Big Barn Fault Monitoring System consists only of monitoring points. The Segment W1A Monitoring System and Segment W2A Monitoring System consist of only monitoring benchmarks.

Figure 2 is a satellite map that shows the San Jacinto River Authority (SJRA) Groundwater Reduction Plan (GRP) water line and the faults that have been identified in the vicinity of water line segments W1A and W2A by Fugro (2012). The lateral extent of the Egypt, Big Barn, Jones, and suspected Panther Branch faults reported by Fugro (2012) are represented by the georeferenced fault lines. In their study, Fugro (2012) did not extend the suspected Panther Branch Fault across the SJRA GRP water line route. INTERA mapped the interpolated portion of the suspected Panther Branch Fault in Figure 2 in 2021 based on an evaluation of the monitoring benchmark elevation for Segment W2A and aerial photographs of scarp locations in the parking lot of The Woodlands High School.

In 2023, Lockwood, Andrews & Newman, Inc (LAN) performed a phased assessment to determine the significance of the cracked and repatched paving in the Woodlands High School parking lot. The LAN(2023) assessment included the geophysical logging of four boreholes, each between 310 and 320 feet deep. The four boreholes were located between Research Forest Drive and the Woodland High School parking lot. One boring was located on the stationary side of the suspected fault, and the other three boreholes were located on the downthrown side of the suspect fault. Based on the consistent elevations of four stratigraphic markers at each borehole, LAN (2023) concludes that their assessment did not identify a subsurface fault.

The shallowest stratigraphic markers identified in the boreholes occur at elevation of 184 ft msl to 185 ft msl, which is at a depth of about 44 feet below ground surface (bgs). The GRP transmission pipeline is buried at an approximate depth of 10 ft bgs. Based on the information in the LAN(2023) report, INTERA has determined that if the scarp locations in the Woodland High School were associated with a fault trace, the underlying fault can be considered, for all practical purposes, as an inactive fault for evaluating subsidence as a risk to the structural integrity of the GRP transmission pipeline.

Measurements from the Nineteenth (19th) Re-measure of the Monitoring Points and Monitoring Benchmark Elevations for Evidence of Land Subsidence

The March 2025 survey represents the Nineteenth (19th) re-measure of the elevations since their initial measurements in March 2015. Re-measurements were made about every six months until March 2024. After March 2024, re-measurements are currently planned for every 12 months for the next several years. Table 1 shows the re-measured elevations for the monitoring benchmarks located near the Egypt Fault that comprise Segment W1A Monitoring System. Table 2 shows the re-measured elevations for the monitoring points that comprise the Egypt Fault Monitoring System. Table 3 shows the re-measured elevations for the monitoring points that comprise the Big Barn Fault Monitoring System. **Table 4** shows the re-measured elevations for the monitoring benchmarks located near the suspected Panther Branch Fault that comprise the Segment W2A Monitoring System.

Table 1 Elevations for the Egypt Fault Monitoring Benchmarks along SJRA Segment W1A Monitoring Survey for March 2015, March 2024, and March 2025

Point ID	Measured Elevation			Calculated Differences	
	(a) Initial Survey March, 2015 Elev.(ft msl)	(b) March 2024 Elev. (ft msl)	(c) March 2025 Elev. (ft msl)	March 2025 minus March 2015 (c) - (a)	March 2025 minus March 2024 (c) - (b)
MbM-1	189.24	189.24	189.25	0.01	0.01
MbM-2	189.27	189.27	189.28	0.01	0.01
MbM-3	189.45	189.43	189.43	-0.02	0.00
MbM-4	189.73	189.72	189.73	0.00	0.01
MbM-5	190.41	Destroyed	Destroyed	na	na
MbM-6	190.26	Destroyed	Destroyed	na	na
MbM-7	188.81	188.80	188.82	0.01	0.02
MbM-8	188.28	188.27	188.29	0.01	0.02
MbM-9	187.93	187.92	187.93	0.00	0.01
MbM-10	187.76	187.75	187.76	0.00	0.01
MbM-11	188.00	187.80	187.80	-0.20	0.00
MbM-12	187.77	187.75	187.76	-0.01	0.01
MbM-13	187.50	187.49	187.50	0.00	0.01
MbM-14	187.75	187.73	187.74	-0.01	0.01
MbM-15	188.49	188.48	188.49	0.00	0.01
MbM-16	187.86	187.83	187.85	-0.01	0.02
MbM-17	189.31	189.29	189.30	-0.01	0.01
MbM-18	189.75	189.72	189.74	-0.01	0.02
MbM-19	189.32	189.29	189.31	-0.01	0.02
MbM-20	188.55	188.52	188.53	-0.02	0.01

note: na= not applicable

Table 2 Elevations for Monitoring Points Along SJRA Segment W1A for March 2015, March 2024 and March 2025 at Existing Fault Protection System Egypt Fault

Station/Description	Measured Elevation			Calculated Differences	
	(a) Initial Survey March 2015 Elev.(ft msl)	(b) March 2024 Elev. (ft msl)	(c) March 2025 Elev. (ft msl)	March 2025 minus March 2015 (c) - (a)	March 2025 minus March 2024 (c) - (b)
Sta 103 + 72 Top Square Nut on 2” Steel Cap	187.20	187.20	187.19	-0.01	-0.01
Sta 103 + 82 Top 2” Steel Pipe (NO CAP)	186.93	186.93	186.92	-0.01	-0.01
Sta 108 + 70 Top Square Nut on 2” Steel Cap	190.28	190.23	190.22	-0.06	-0.01
Sta 108 + 80 Top 2” Steel Cap	190.31	190.27	190.26	-0.05	-0.01

Table 3 Elevations for Monitoring Points along SJRA Segment W2A for March 2015, March 2024, and March 2025 at Existing Fault Protection System Big Barn Fault

Station/Description	Measured Elevation			Calculated Differences	
	(a) Initial Survey March 2015 Elev. (ft, msl)	(b) March 2024 Elev. (ft msl)	(c) March 2025 Elev. (ft msl)	March 2025 minus March 2015 (c) - (a)	March 2025 minus March 2024 (c) - (b)
Sta 9 + 25 Top 2” Steel Cap	177.81	177.81	177.81	0.00	0.00
Sta 9 + 35 Top 2” Steel Cap	177.74	177.73	177.74	0.00	0.01
Sta 9 + 85 Top 2” Steel Cap	176.73	176.69	176.70	-0.03	0.01
Sta 9 + 95 Top 2” Steel Cap	176.78	176.75	176.75	-0.03	0.00

Table 4 Elevations for Monitoring Benchmarks that Straddle the Suspected Panther Branch Fault along SJRA Segment W2A Monitoring Survey for March 2015, March 2024, and September 2025

Point ID	Measured Elevation			Calculated Differences	
	(a) Initial Survey March 2015 Elev. (ft, msl)	(b) March 2024 Elev. (ft msl)	(c) March 2025 Elev. (ft msl)	March 2025 minus March 2015 (c) - (a)	March 2025 minus March 2024 (c) - (b)
MbM-1	142.59	142.49	142.48	-0.11	-0.01
MbM-2	142.80	142.69	142.68	-0.12	-0.01
MbM-3	143.31	143.19	143.18	-0.13	-0.01
MbM-4	143.35	143.21	143.20	-0.15	-0.01
MbM-5	143.85	143.74	143.73	-0.12	-0.01
MbM-6	144.14	144.05	144.04	-0.10	-0.01
MbM-7	144.29	144.20	144.19	-0.10	-0.01
MbM-8	145.20	145.10	145.09	-0.11	-0.01
MbM-9	145.51	145.41	145.41	-0.10	0.00
MbM-10	145.63	145.52	145.52	-0.11	0.00
MbM-11	146.16	146.11	146.11	-0.05	0.00
MbM-12	145.42	145.37	145.37	-0.05	0.00
MbM-13	145.00	144.99	145.00	0.00	0.01
MbM-14	144.99	144.98	144.98	-0.01	0.00
MbM-15	144.79	144.79	144.79	0.00	0.00
MbM-16	144.78	144.78	144.78	0.00	0.00
MbM-17	144.79	144.78	144.79	0.00	0.01
MbM-18	144.55	144.54	144.54	-0.01	0.00
MbM-20	145.86	145.75	145.75	-0.11	0.00

At the Egypt Fault Monitoring System (see Figures 2 and 3) and the Big Barn Fault Monitoring System (see Figures 2 and 4), SJRA hired consultants to design and contractors to build safeguards to protect the water line from potential damage caused by fault movement. At these two locations, SJRA also hired a consultant to install monitoring points to monitor changes in the elevation of the transmission pipe and casing near the faults. At the water line segment W1A Monitoring System (Figures 2 and 3), SJRA hired a consultant to design and a contractor to build safeguards to protect the water line from potential damage caused by fault movement. Additionally, at the water line segment W1A Monitoring System, SJRA hired consultants to install monitoring benchmarks to monitor changes in land elevations over time.

At the water line segment W2A Monitoring System (see Figure 5) along Research Forest Drive no safeguards similar to those installed for the Big Barn Fault and the Egypt Fault were constructed to protect the water line from possible damage caused by fault movement because the Fugro report (2012) did not show the suspected Panther Branch Fault crossing the water line. However, SJRA hired consultants to install monitoring benchmarks capable of monitoring the change in land elevation at the Segment W2A Monitoring System (see Figure 5) along Research Forest Drive in the vicinity of the suspected Panther Branch Fault.

The labeling of the downthrown and the upthrown side of the faults in Figures 3, 4, and 5 is based on the information presented by Fugro (2012) in their Plate 1. The designations of the two sides of a fault are based on the historical vertical movement of the fault. The downthrown side of the fault has historically moved downward relative to the upthrown side of the fault.

<u>Egypt Fault Monitoring System</u> - At the Egypt Fault Monitoring System (Figure 3), the changes in the elevations from March 2015 to March 2025 indicate that a greater decrease in pipe/casing elevation occurred on the downthrown side than on the upthrown side of the Egypt Fault. Over a 10-year period from 2015 to 2025, the pipe/casing elevation on the downthrown side of the Egypt Fault decreased 0.045 ft relative to the upthrown side of the Egypt Fault. The 0.045 ft decrease over an 10-year period translates into an average subsidence rate of approximately 0.0045 ft/yr.

<u>W1A Segment</u> - At the W1A segment where 18 monitoring benchmarks are located along FM 2978 (Figure 3), the changes in monitoring benchmark elevations from March 2015 to March 2025 indicate that a greater decrease in land elevation has occurred on the downthrown side than on the upthrown side of the Egypt Fault. Over the 10-year period from 2015 to 2025, the land surface on downthrown side of the Egypt Fault decreased 0.005 ft in elevation relative to the upthrown side of the Egypt Fault. The 0.005 ft decrease in land elevation over a 10-year period translates into an average subsidence rate of approximately 0.0005 ft/yr. (note: as explained in a note on page 7, benchmark 11 was not included in the analysis).

<u>Big Barn Monitoring System</u> - At the Big Barn Fault Monitoring System where four monitoring points on Research Forest Drive straddle the Big Barn Fault (Figure 4), the changes in the monitoring benchmark elevations indicate that a greater decrease in pipe/casing elevation has occurred on the downthrown side than on the upthrown side of the Big Barn Fault. Based on the change in elevations of the four monitoring benchmarks over a 10-year period from March 2015 to March 2025, the pipe/casing elevation on downthrown side of the Big Barn Fault decreased 0.030 ft relative to the upthrown side of the Big Barn Fault. The 0.030 ft decrease in pipe/casing over a 10-year period translates into average subsidence rate of approximately 0.003 ft/yr.

<u>W2A Segment</u> - Along the W2A segment where 19 monitoring benchmarks on Research Forest Drive are located near the suspected Panther Branch Fault (Figure 5), the changes in the monitoring benchmark elevations suggest that greater land subsidence has occurred on the downthrown side than on the upthrown side of the suspected Panther Branch Fault. Based on the change in elevations of the 19 monitoring benchmarks over a 10-year period from March 2015 to March 2025, the land surface on downthrown side of the suspected Panther Branch Fault decreased 0.101 ft in elevation relative to the upthrown side of the suspected Panther Branch Fault. The 0.101 ft decrease in land elevation over a 10-year period translates into an average subsidence rate of approximately 0.010 feet per year (ft /yr).

Based on the changes in monitoring benchmark elevations and benchmark points during the last 10 years, the SJRA GRP water line is not at risk of damage from land subsidence where it crosses the Egypt Fault and the Big Barn Fault for the next 50 years if land subsidence continues at its current rate and if the consultant's safeguards work as designed. For the suspected Panther Branch Fault, the amount of subsidence that has occurred since March 2015 does not pose a threat to the safety of water line based on INTERA's discussion with SJRA consultants who designed the water line. Based on a review of the LAN

(2023) report, INTERA has determined that at least 0.33 ft of differential subsidence needs to occur before there is a risk of leakage from the GRP pipeline. Differential subsidence is measured as the difference in land elevation between the upthrown and downthrown side of the suspected Panther Branch fault trace.

General Comment on the Interpretating the Re-measured Monitoring Points and Monitoring Benchmark Elevations for Evidence of Land Subsidence

Given that the measured elevations are reported to the nearest hundredth of a foot, an actual elevation difference of just one one-thousandth (0.001) of a foot (from 0.004 to 0.005) could result in a change in reported elevation of one one-hundredth (0.01) of a foot because of the impact of rounding from thousandths to hundredths of a foot. Thus, elevation changes of a few hundreds of a foot and less should be viewed with care before making conclusions regarding the changes in land elevations inferred from the measured elevations. In addition, other factors besides depressurization of the regional aquifer should be evaluated as possible contributors for changes in land elevation before making conclusions regarding the cause for the decrease in the land elevation. Among these factors is the shrinkage or swelling of clays near land surface in response to changes in soil moisture.

Analysis of the Nineteenth (19th) Re-measure of the Water Line W1A and W2A Monitoring Benchmark and Monitoring Point Elevations over a 1-year and a 10-year Period

W1A Segments

Tables 1 and 2 provide the differences in elevations for 18 monitoring benchmarks and 4 monitoring points located along the W1A Segment. The differences in the measured elevations for the last year and for the last 10 years are discussed below.

The discussion below excludes results from benchmark MbM 11. As discussed in previous analyses, the measured elevation change at benchmark MbM 11 is an outliner when compared to other measured differences in elevations along FM 2798. For instance, over a 10-year period, the elevation of benchmark MbM 11 decreased 0.20 ft whereas benchmarks on both sides of MbM 11 averaged a decrease of 0.005 ft in elevation. The significantly higher amount of elevation change at MbM 11 is attributed to the benchmark being located in a narrow zone of highly disturbed soil in the downthrown fault blocks. The higher rate of elevation change at MbM11 is likely caused by the compaction of the highly disturbed soil.

Last year: Over the last year, the 18 monitoring benchmarks that comprise the Segment W1A Monitoring System along FM2978 had the following elevation changes:

- The four monitoring benchmarks on the upthrown side of the Egypt Fault ranged from an increase in elevation of 0.01 ft to no change in elevation and averaged an increase of 0.007 ft in elevation.
- After omitting results from benchmark MbM11, the thirteen monitoring benchmarks on the downthrown side of the Egypt Fault ranged from increase of 0.02 ft in elevation to no change in elevation. The average elevation change for the thirteen benchmarks is an increase of 0.014 ft in elevation.
- From March 2024 to March 2025, the elevation data from Segment W1A Monitoring System indicates that the downthrown side of the fault increase in elevation was 0.007 ft less than the increase that occurred on the upthrown side of the fault.

Over the last year, the four monitoring points that comprise the Egypt Fault Monitoring System along Research Forest Drive had the following elevation changes:

- The two monitoring points on the upthrown side of the Egypt Fault had a decrease of 0.01 ft in elevation.
- The two monitoring on the downthrown side of the Egypt Fault ranged had a decrease of 0.01 ft in elevation
- From March 2024 to March 2025, the elevation data from the W1A Segment indicates that the upthrown side and the downthrown side of the fault has moved downward 0.01 ft in elevation.

Last 10 years: From March 2015 to March 2025, the 18 monitoring benchmarks that comprise the Segment W1A Monitoring System along FM 2978 had the following elevation changes:

- The four monitoring benchmarks on the upthrown side of the Egypt Fault ranged from a decrease of 0.01 ft to an increase of 0.01 ft in elevation. The four monitoring benchmarks averaged no change in elevation.
- After omitting results from benchmark BM11, the thirteen monitoring benchmarks on the downthrown side of the Egypt Fault ranged from a decrease of 0.02 ft in elevation to an increase 0.01 ft change in elevation. The thirteen monitoring benchmarks averaged a change of a decrease of 0.005 ft change in elevation.
- From March 2015 to March 2025, the elevation data from the W1A Monitoring System indicates that the downthrown side of the fault decreased 0.005 ft in elevation relative to the upthrown side of the fault.

From March 2015 to March 2025, the four monitoring points that comprise the Egypt Fault Monitoring System along Research Forest Drive had the following elevation changes:

- The two monitoring points on the upthrown side of the Egypt Fault had a decrease of 0.01 ft in elevation.
- The two monitoring points on the downthrown side of the Egypt Fault had a decrease of 0.05 ft in elevation and a 0.06 ft decrease in elevation and averaged 0.055 ft decrease in elevation.
- From March 2015 to March 2025, the elevation data from the Egypt Fault Monitoring System indicates that the downthrown side of the fault decreased 0.045 ft in elevation relative to the upthrown side of the fault.

During the last 10 years, the monitoring data indicates that more downward movement occurred on the downthrown side on the Egypt Fault. Along Research Forest Drive, the downthrown side of the fault averaged a decrease of 0.045 ft in elevation more than the upthrown side of the fault. This amount of elevation change indicates that the downthrown side of the Egypt Fault is subsiding at rate approximately 0.005 ft/yr relative to the upthrown side of the Egypt Fault. Along FM 2978, the downthrown side of the fault averaged a decrease 0.005 ft in elevation more than the upthrown side of the fault. These amounts of elevation change are too small to be considered conclusive evidence that land subsidence is occurring along Egypt Fault where it intersects FM 2978.

W2A Segments–

Tables 3 and 4 provide the differences in elevations for 23 monitoring benchmarks and monitoring points located along the W2A Segment. The differences in measured elevations for the last year and for the last 10 years are discussed below.

Last year: - Over the last year, the four monitoring points that comprise the Big Barn Fault Monitoring System along Research Forest Drive in Figure 4 had the following elevation changes:

- The two monitoring points on the upthrown side of the Big Barn Fault had no change in elevation and an increase of 0.01 ft in elevation. The two monitoring points averaged an increase of 0.005 ft in elevation.
- The two monitoring points on the downthrown side of the Big Barn Fault had no change in elevation and an increase of 0.01 ft in elevation. The two monitoring points averaged an increase of 0.005 ft in elevation.
- From March 2024 to March 2025, the elevation data from Big Barn Fault Monitoring System indicates that the upthrown side and the downthrown side of the fault have moved upward 0.005 ft in elevation.

Over the last year the 19 monitoring benchmarks that straddle the suspected Panther Branch Fault along Research Forest Drive at the Segment W2A Monitoring System in Figure 5 had the following elevation changes:

- The six monitoring benchmarks (MbM-13 through MbM-18) on the upthrown side of the suspected Panther Branch Fault had elevation changes that ranged from no change in elevation to an increase of 0.01 ft in elevation. The six monitoring benchmarks averaged an increase of 0.003 ft in elevation.
- The thirteen monitoring benchmarks (MbM-1 through MbM-12 and MbM-20) on the downthrown side of the suspected Panther Branch Fault had elevation changes that ranged from a decrease of 0.01 ft in elevation to no change in elevation. The thirteen monitoring benchmarks averaged a decrease of 0.006 ft in elevation.
- From March 2024 to March 2025, the downthrown side of the suspected Panther Branch Fault along Research Forest Drive moved downward less an than 0.01 ft than the upthrown side of the suspected Panther Branch Fault.

Last 10 years: –From March 2015 to March 2025, the four monitoring points along Research Forest Drive near the Big Barn Fault in Figure 4 had the following elevation changes:

- The two monitoring points on the upthrown side of the Big Barn Fault had no change in elevation. The upthrown side of the fault averaged no change in elevation.
- The two monitoring points on the downthrown side of the Big Barn Fault had a decrease of 0.03 ft in elevation. The downthrown side of the fault averaged a decrease of 0.03 ft in elevation. asdf
- From March 2024 to March 2025, the elevation data from Big Barn Fault Monitoring System indicates that the downthrown side moved downward 0.03 ft relative to the upthrown side of the fault. A 0.03 ft decrease in elevation over 10 years translates into an average subsidence rate of approximately 0.003 ft/yr.

From March 2015 to March 2025, the 19 monitoring benchmarks located along Research Forest Drive near the suspected Panther Branch Fault in Figure 5 had the following elevation changes:

- The six monitoring benchmarks (MbM-13 through MbM-18) on the upthrown side of the suspected Panther Branch Fault ranged between no change in elevation to a decrease of 0.01 ft change in elevation. The upthrown side of the fault averaged a decrease of 0.003 ft in elevation.
- The thirteen monitoring benchmarks (MbM-1 through MbM-12 and MbM-20) on the downthrown side of the suspected Panther Branch Fault had elevation changes that ranged from a decrease of 0.05 ft in elevation to a decrease of 0.15 ft in elevation. The downthrown side of the fault averaged a decrease of 0.1046 ft in elevation.
- From March 2015 to March 2025, the downthrown side of the fault moved downward 0.101 ft relative to the upthrown side of the fault. A 0.101 ft decrease in elevation over 10 years translates into an average subsidence rate of approximately 0.01 ft/yr.

Figure 6 shows graphs for the average vertical displacement calculated for the benchmarks located on the upthrown side and the downthrown side of the suspected Panther Branch Fault as a function of time since March 2015. The graphs show that the downthrown side of the fault has consistently greater decrease in elevation than does the upthrown side of the fault. Whereas the upthrown side of the fault has not subsided more than 0.015 ft over a 1-year period (beginning in the month of March(within the 10-year monitoring period, the downthrown side of the fault has exhibited a general trend of declining elevation with greater displacement rates at later times. Over the 10-year monitoring period, the downthrown side of the suspected Panther Branch Fault a maximum decline of about 0.032 ft over a 1-year period (beginning in the month of March)

Figure 7 and Table 5 show the rates of vertical displacement for the downthrown side of suspected Panther Branch Fault relative to the upthrown side of the suspected Panther Branch Fault. The relative rate is calculated by subtracting the rate of displacement of the upthrown side from the rate of displacement of the downthrown side. The temporal changes in the displacement has been divided into three periods: 1) from March 2015 to March 2019, the rate of vertical displacement averaged 0.003 ft/yr downward; 2) from March 2019 to March 2022, the vertical displacement rate averaged 0.008 ft/yr downward; and 3) from March 2022 to March 2025, the vertical displacement rate averaged 0.021 ft/yr downward.

Figure 7 illustrates the increase in annual vertical displacement over time from March 2015. The greatest amount of displacement occurs over a two-year period from March 2024 to March 2024. Later in the report potential causes for this temporal trend are discussed.

Table 5 Vertical displacement rates for the downthrown side of Suspected Panther Branch Fault relative to the upthrown side of the Suspected Panther Branch Fault for Three Time Intervals

Time Period	Time Interval (years)	Average Vertical Displacement since 2015 (ft)	Incremental Amount of Vertical Displacement (ft)	Average Rate of Vertical Movement (ft/yr)
March 2015 to March 2019	4	-0.013	-0.013	0.003
March 2019 to March 2022	3	-0.037	-0.024	0.008
March 2022 to March 2025	3	-0.101	-0.064	0.021

Evaluation of Potential Damage to the Water Line along Segments W1A and W2A from Land Subsidence

To provide information beneficial to support a risk assessment of potential damage to the water line posed by land subsidence, INTERA compiled information on the design of these safeguards through construction drawings and discussions with persons knowledgeable of the safeguards. The construction drawings prepared by Lockwood, Andrews & Newnam, Inc include the design of the casing pipe for the W1A area. The construction drawings by Binkley & Barfield Inc., include the design pipe for the W2A area. The design of the safeguards for the Big Barn Fault is based on the design used for where the Egypt Fault intersects the 48-inch water line.

W1A Segments

In the vicinity of the Egypt Fault Monitoring System along Research Forest Drive, SJRA's GRP 48-inch diameter water line is protected by a pipe casing along a 500-ft section that crosses over the Egypt Fault. The water line is constructed of steel and capable of shifting approximately 1-ft over the 500-ft interval. Because of the possibility that the water line could eventually have a differential movement of more than 1 ft, a pipe casing as a safeguard around the water line was constructed. The pipe casing safeguard is designed to protect the water line for up to 0.25 inches of vertical movement at the fault per year over a 50-year period. This amount of movement is equivalent to 12.5 inches over 50 years, which translates to an average rate of 0.021 ft/yr. The dip angle of the fault was estimated at 70 degrees. A 12.5-inch vertical movement is expected to cause the casing and pipe to bow and move horizontally up to 4 inches. The pipe and casing can deflect and "flex" with the vertical movement but a horizontal movement of 4 inches could stress the steel enough to break the joints. To protect against the horizontal movement, two expansion couplings, each of which can move up to 4 inches horizontally, were added at the pipe connections. These expansion joints allow for up to 8 inches of horizontal movement. Several methods are in place to monitor the condition of the water line. One of these methods is measuring the change in elevations in the casing and pipe at the ends of the pipe casing.

After 10 years of monitoring the change in the monitoring point elevations at the Egypt Fault Monitoring System, the downthrown side of the fault had subsided 0.045 ft relative to the upthrown side of the fault. Thus, the average rate of subsidence of the downthrown side of the fault relative to the upthrown side of the fault is approximately 0.005 ft/year. Based on the information that INTERA has reviewed, INTERA concludes the water line is not at risk of damage from land subsidence where it crosses the Egypt Fault along Research Forest Drive for the next 50 years if land subsidence continues at its current rate and if the SJRA safeguards work as designed.

Along FM 2978, the 16-inch water line extends to SJRA Woodlands Division Water Plant No. 4. Instead of using pipe casing to protect the water line, a SJRA contractor installed a series of ball connections in the vicinity of the Egypt Fault to accommodate movement of up to 0.25 inches of vertical movement per year over a 50-year period, or a total of 12.5 inches. Along a length of approximately 400 ft, six ball couplings were installed. During the 10 years of monitoring, the average changes in the monitoring benchmark elevations are no change in elevation and a decrease of 0.005 ft on the upthrown and downthrown side of the fault, respectively. Thus, the subsidence of the downthrown side of the fault relative to the upthrown side of the fault is approximately 0.005 over 10 years, which translates to 0.0005 ft/yr. Based on the information that INTERA has reviewed, INTERA concludes that the water line is not at risk of damage from land subsidence where it crosses the Egypt Fault along FM 2978 for the next 50 years if land subsidence continues at its current rate and if the SJRA safeguards work as designed.

W2A Segments

INTERA has reviewed the drawings for the safeguards that SJRA's contractor constructed for the transmission pipe at the Big Barn Fault Monitoring System. The safeguards are similar to the safeguards SJRA's contractor constructed using pipe casing for the Egypt Fault. The average change in the monitoring benchmark elevations at the Big Barn Fault over 10 years for the upthrown side and for the downthrown side of the Big Barn Fault are no change in elevation and a decrease of 0.030 ft in elevation, respectively. Thus, the decrease of the downthrown side of the fault relative to the upthrown side is 0.03 ft over 10 years, or approximately 0.003 ft/yr. The safeguards that were constructed are designed to handle 12.5 inches of vertical movement over 50 years or approximately 0.021 ft/year. Based on the information that INTERA has reviewed, INTERA concludes that the water line is not at risk of damage from land subsidence where it crosses the Big Barn Fault along Research Forest Drive for the next 50 years if land subsidence continues at its current rate and if the SJRA safeguards work as designed.

Because the Fugro report (2012) did not show that the suspected Panther Branch Fault crossing the water line, SJRA's consultant did not design nor did SJRA's contractor construct safeguards to protect the water line from differential subsidence associated with the suspected Panther Branch Fault. The average change in the monitoring benchmark elevations at the suspected Panther Branch Fault over 10 years for the upthrown side and for the downthrown side of the suspected Panther Fault are a decrease of 0.0033 ft in elevation and a decrease of 0.1046 ft in elevation, respectively. Thus, the decrease of the downthrown side of the fault relative to the upthrown side is about 0.102 ft over 10 years, or approximately 0.0101ft/yr. Figure 7 shows that since March 2022, the average rate of elevation change is a decrease of 0.021 ft/yr. As will be discussed later in this report, INTERA has determined that a subsidence rate of 0.021 ft/yr does not pose a risk to the structural integrity of the GRP pipeline.

Investigation into Temporal Variability in the Measured Elevation Change along the Suspected Panther Branch Fault

Figures 6 and 7 show a cyclic pattern in the vertical displacement that is characterized by greater subsidence occurring during the summer months than winter months. Figure 8 and Table 6 show the vertical displacements that have occurred during the 6-month interval preceding the March and September measured benchmark elevations. For the 6-month interval from March to September subsidence occurs on both sides of the fault whereas from 6-month interval from September to March rebound occurs on both sides of the fault. For both six-month intervals, the vertical offsets are much greater for the downthrown benchmarks than for the upthrown benchmarks. For both sets of benchmarks, the magnitude of the vertical displacements has generally steadily increased over time with the greatest rate of increases having occurred from 2022 to 2024.

Table 6 Vertical displacement that occurred during the 6-month intervals preceding the March and September measurements of elevations at the benchmarks associated with the Segment W2A Monitoring System along the suspected Panther Branch Fault.

Date (Month/Yr)	Vertical Displacement (feet)		Date (Month/Yr)	Vertical Displacement (feet)	
	Downthrown Side	Upthrown Side		Downthrown Side	Upthrown Side
Sep-15	-0.0108	-0.0050	**Mar-16**	0.0008	0.0050
Sep-16	0.0000	-0.0033	**Mar-17**	0.0015	0.0033
Sep-17	-0.0054	0.0000	**Mar-18**	0.0015	0.0000
Sep-18	-0.0077	-0.0050	**Mar-19**	0.0069	0.0050
Sep-19	-0.0131	-0.0050	**Mar-20**	0.0023	0.0017
Nov-20	-0.0108	-0.0033	**Mar-21**	0.0015	0.0050
Sep-21	-0.0046	-0.0017	**Mar-22**	0.0008	0.0033
Sep-22	-0.0354	-0.0100	**Mar-23**	0.0062	0.0067
Sep-23	-0.0385	-0.0100	**Mar-24**	0.0062	0.0067
TOTAL	*-0.1262*	*-0.0433*	***TOTAL***	*0.0277*	*0.0367*
			Mar-25*	-0.0061	0.0034
* Preceding time interval is 1 year instead of six months					

The cyclic pattern in the vertical displacement is consistent with the presence of expansive soils (Barthélémy and others, 2023; Charpentier and others, 2022; Kai and others., 2020; Mostafiz and others, 2021; Wang, 2022). Expansive soils contain clays that can undergo volume change in response to fluctuations in soil moisture. During periods of high moisture content, these soils swell, expanding their volume. During periods of low-moisture content, expansive soils dry, which causes a reduction in their volume. The cyclic pattern of vertical displacement occurs as a result of seasonal changes in evapotranspiration (ET). In the Gulf Coast of Texas ET is lowest from November through February (~20% of annual total over five months) and highest in other months with maximum monthly totals occurring between June and August for different locations (Scanlon and others, 2012).

As a general rule, the shrinkage that occurs as a result of the drying of soils is usually elastic. Elastic deformation means the full amount of shrinkage is fully recoverable under the right set of circumstances. In the case of shrinkage caused by desiccation, rewetting of the soil would cause the soil to expand back to its original volume. However, in a recent study of expansive soils in Harris County, Welch and others (2024) discovered that a fraction of the shrinkage that occurs during drying is inelastic deformation. Inelastic deformation refers to the permanent change in the volume or shape of the soil that does not revert back under rewetting. Welch and others (2024) conclude that during periods of prolonged drought, approximately 10% of the shrinkage in expansive soils is inelastic. The effect of inelastic soil shrinkage would results in a step-like permanent loss of land elevation over time.

A primary factor that contributes to seasonal patterns of drying and wetting of soils is evapotranspiration (ET). Figure 9 shows monthly values for evapotranspiration at the Segment W2A Monitoring System obtained from the OpenET data portal (https://etdata.org). The OpenET values presented here are an ensemble average of six different algorithms based on thermal satellite data and auxiliary data (Melton and others, 2022). The monthly values show a distinctive cyclic pattern with approximately 270% greater ET from March to September than from September to March. Besides ET, the monthly Palmer Drought Severity Index (PDSI) values in Figure 10 are consistent with the cyclic pattern in the vertical displacement and the greatest subsidence rates during the summer of 2022 and 2023. PDSI data for Montgomery County was obtained from the Western Regional Climate Center (2024).

The PDSI is used to estimate the relative dryness of the soil and is calculated from ET, rainfall, the soil water holding capacity from soil map developed by the National Cooperative Soil Survey. PSDI values range from +10 to -10 with lower number represent drier conditions. Table 7 provides additional details on the soil's classifications associated with the PSDI numbers. Among the saline features in Figure 10 are:

- before 2020 wet soil conditions occurred for both summer and winter months which is consistent with the smaller amounts of vertical displacements from 2015 to 2019 in Figure 8;
- From 2021 to 2023, the soils became gradually drier which is consistent with increasingly greater vertical displacements in Figure 8;
- during summer months from 2021 to 2023 where moderate drought conditions existed, the largest amounts of subsidence occurred.

Table 7 PDSI values classification of Soil Conditions

PDSI value	Soil Classification
4.0 or more	extremely wet
3.0 to 3.99	very wet
2.0 to 2.99	moderate wet
1.0 to 1.99	slightly wet
0.5 to 0.99	incipient wet spell
0.49 to -0.49	near normal
-0.5 to -0.99	incipient dry spell
-1.0 to -1.99	mild drought
-2.0 to -2.99	moderate drought
-3.0 to -3.99	severe drought
-4.0 or less	extremely drought

Based on our analysis of multiple lines of evidence, the shrinkage and expansion of soil during the summer months and during the winter months, respectively contributes to the seasonal changes the land elevations. The majority of the soil shrinkage is expected to occur within a few feet of the decay with depth. The impact of soil shrinkage will be considerable less at the depth of the GRP pipeline, which is buried at a depth of about 10 feet bgs, than at ground surface.

Another factor that may be contributing to the cyclic pattern between lowering and rising of the ground is the cyclic pattern in groundwater production. As shown in Figure 11, groundwater production from the SJRA wellfield is much greater during the summer months than during the winter months. During the periods of increased pumping, the hydrostatic pressure in the saturated aquifer is reduced, which in turn may cause consolidation of the aquifer matrix. If the reduction in hydrostatic pressure occurs over a sufficiently short time interval and is below a threshold called the critical drawdown, then the consolidation that occurs as a result of the reduced hydrostatic presume is elastic, meaning that the subsurface will expand if and when the hydrostatic pressure return with a rise in the water level.

The amount that the seasonal pattern in the soil moisture and groundwater production contributes to the dynamic and cyclic nature of the elevation change in the ground surface cannot be estimated without additional information. Among the data that would be needed to help to provide these estimates is the amount and nature of the expansive soils that exists near the benchmarks and the changes of hydraulic pressure that occur in the aquifer as a result of changes in pumping rates. At this time, no additional investigations are recommended except for continued monitoring of changes in the ground elevation. INTERA recommendation is based on our analysis of ten years of monitored elevation changes presented in this memo and our understanding of the conclusions from the LAN (2023) report.

The findings of the LAN(2023) report are discussed in the first few pages of this report. The LAN(2023) investigation involved drilling and geophysical logging three borings at the location of the suspected Panther Branch fault trace near the Woodlands High School. One borehole was located on the upthrown side of the suspected Panther Branch fault, and another three boreholes were located on the downthrown side of the suspected fault. The boreholes were located between the benchmark monitoring network at Research Forest Drive and The Woodlands High School. Based on the consistent elevations of four stratigraphic markers at each borehole, LAN (2023) concludes that their assessment did not identify a subsurface fault.

Continued monitoring of ground elevation change is recommended because superimposed on the cyclic pattern of the lowering and rising of ground surface at the monitoring locations along Research Forest Drive, there is a gradual albeit small trend of greater lowering of the ground surface elevation on the downthrown side of the suspected Panther Branch Fault than on the upthrown side of the suspected fault. Based on a review of the LAN (2023) report, INTERA has determined that the difference in elevation change between the two sides of the fault poses no risk to the structural integrity of the GRP pipeline until at least 0.33 ft of differential subsidence has occurred across the suspected fault. Evaluation of any potential risks to the GRP pipeline structural integrity of the GRP pipeline after 0.33 ft of differential subsidence has occurred is beyond the scope of this report but is addressed by LAN (2023).

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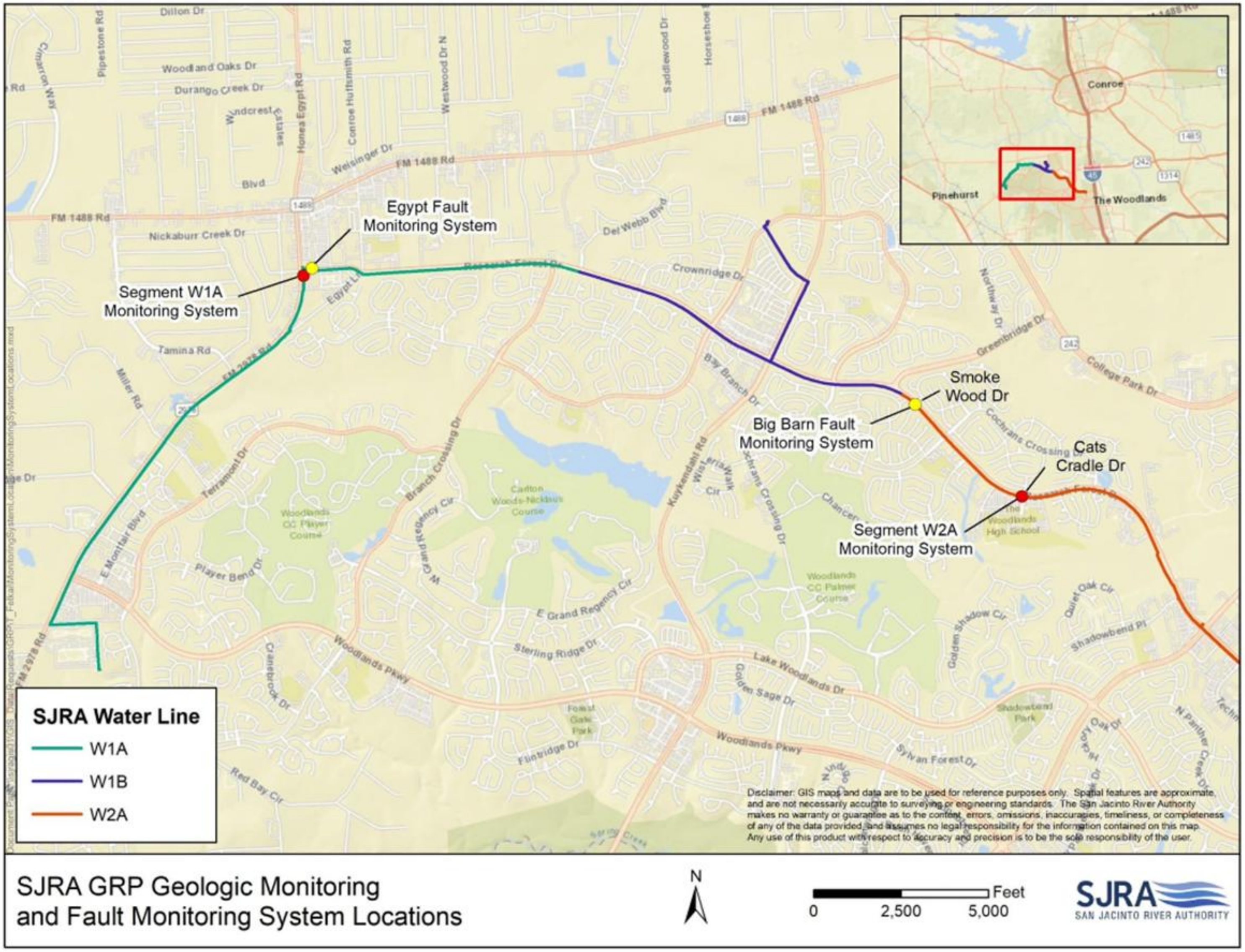

Figure 1 SJRA Groundwater Reduction Plan (GRP) Fault Monitoring System Locations (https://www.sjra.net/grp/fault-monitoring/)

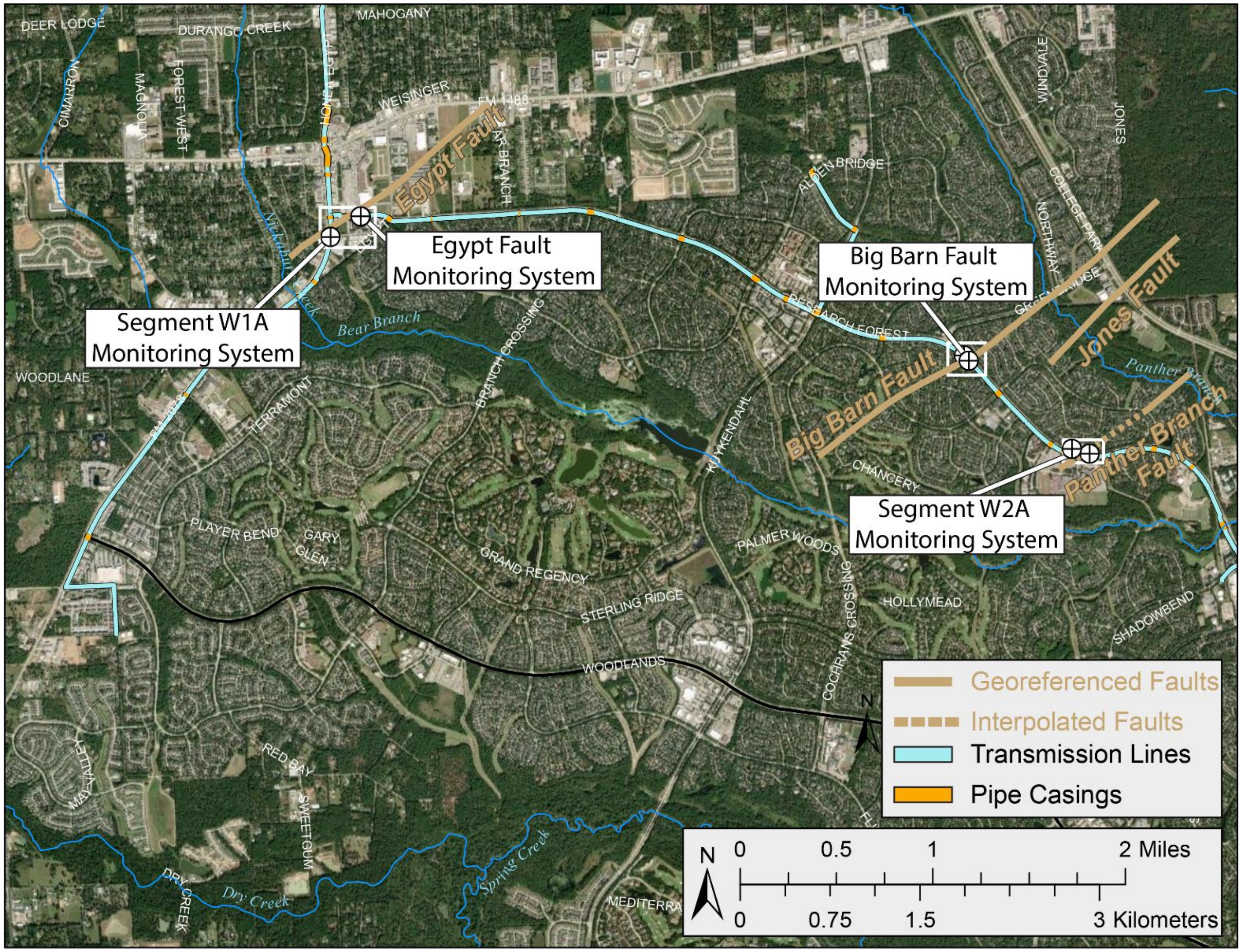

Figure 2 Satellite map showing the location of the SJRA water line, the fault locations mapped by Fugro (2012), and SJRA monitoring systems.

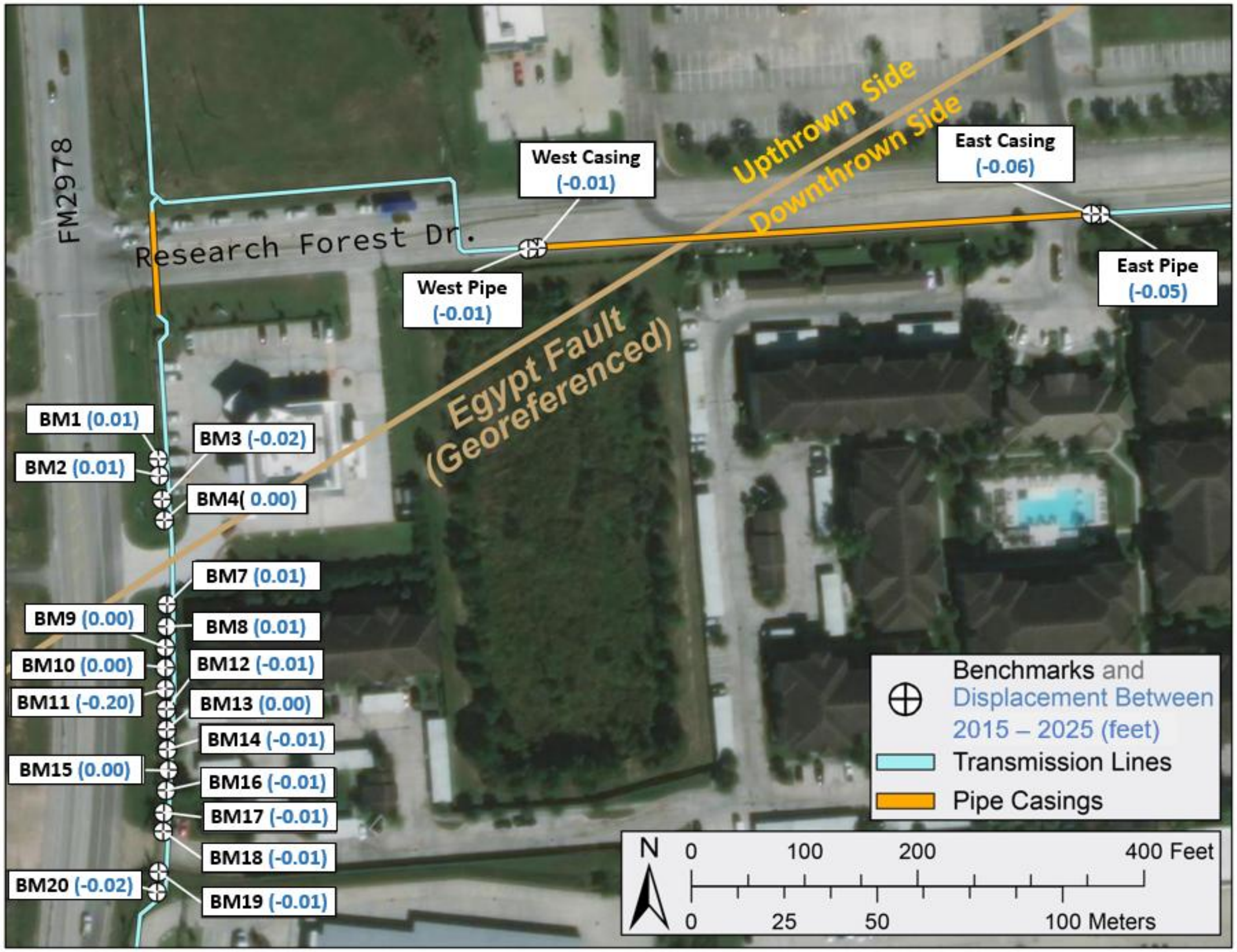

Figure 3 Satellite map showing the location of the Egypt Fault (Fugro, 2012), the W1A monitoring locations and calculated vertical displacement from March 2015 to March 2025 and the SJRA water line and pipe casing.

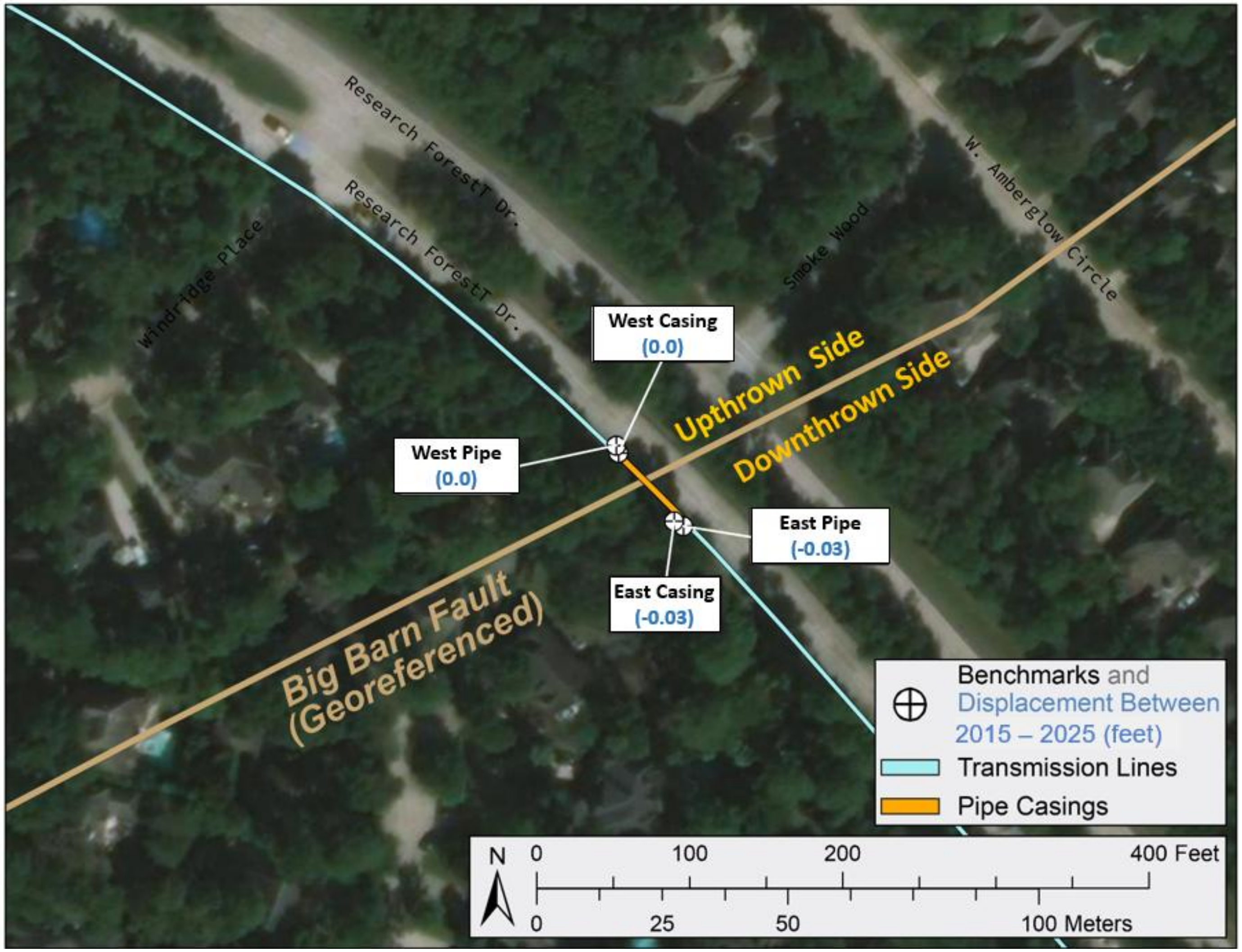

Figure 4 Satellite map showing the location of the Big Barn Fault (Fugro, 2012), the Big Barn Fault Monitoring System, calculated vertical displacement from March 2015 to March 2025, and the SJRA water line and pipe casing.

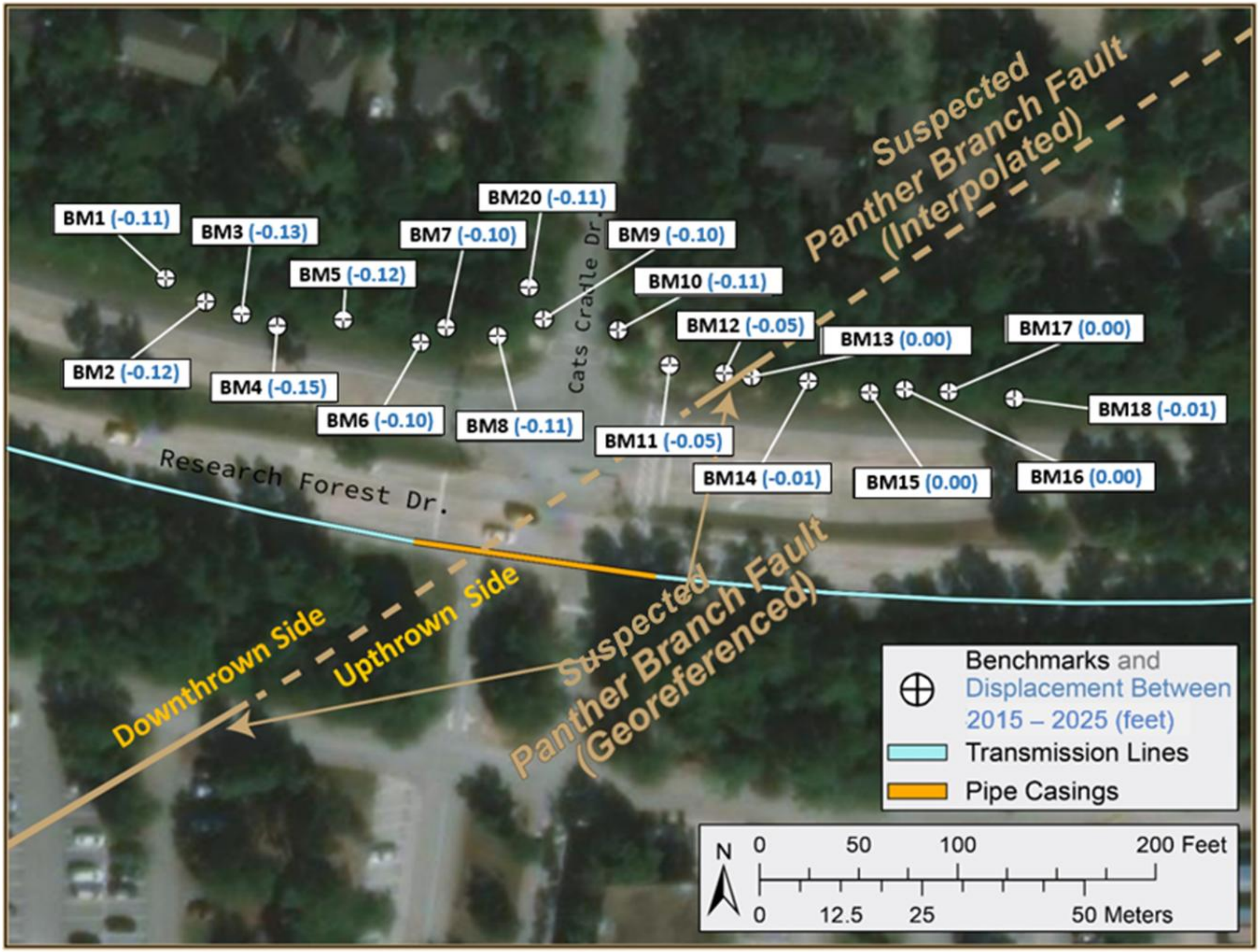

Figure 5 Satellite map showing the location of the suspected Panther Branch Fault mapped by INTERA, the Segment W2A Monitoring System, calculated vertical displacement from March 2015 to March 2025, and the SJRA water line and pipe casing.

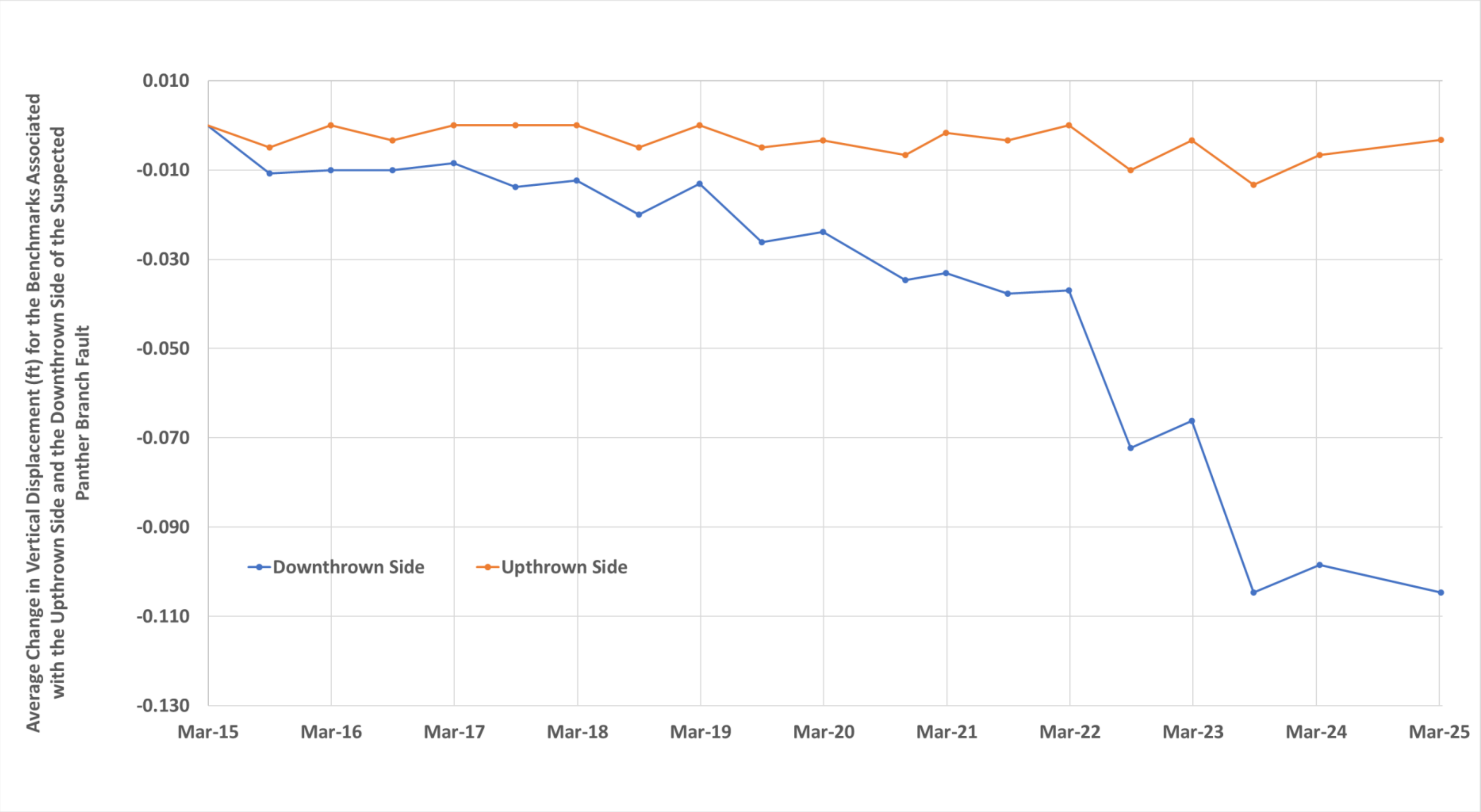

Figure 6 Comparison of average vertical displacement for the benchmarks located on the upthrown side and the downthrown side of the suspected Panther Branch Fault associated with the Segment W2A Monitoring System.

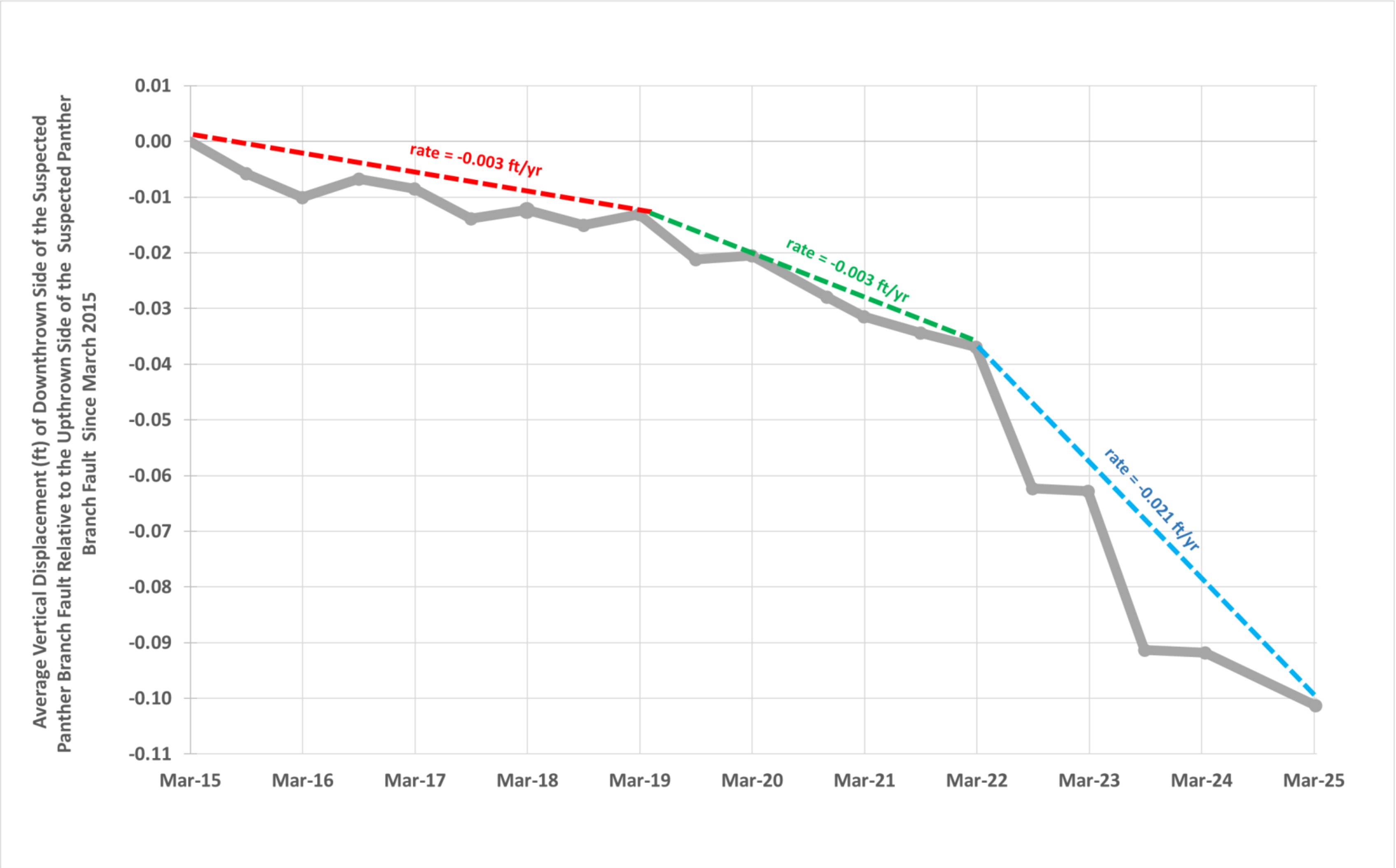

Figure 7 Relative vertical displacement and rates for relative vertical displacement for the downthrown side of the suspected Panther Branch Fault based on benchmarks associated with the Segment W2A Monitoring System

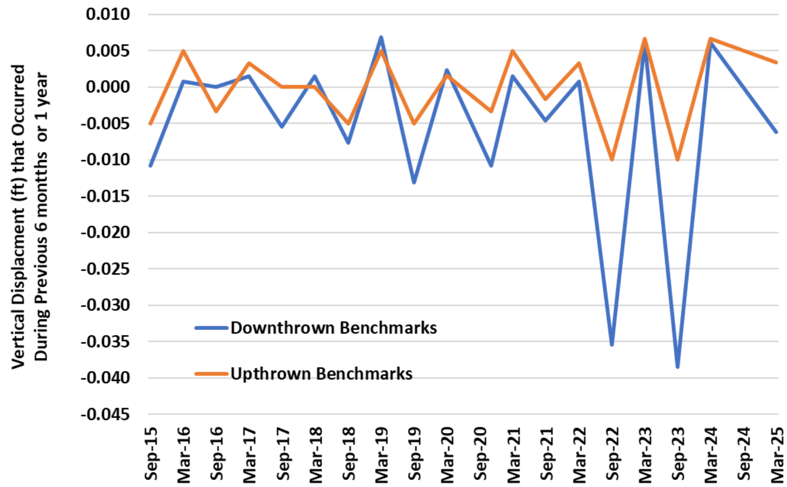

Figure 8 Vertical displacement that occurred during 6-months to 1-year intervals preceding the March and September measurements of benchmark elevations associated with Segment W2A Monitoring System along the suspected Panther Branch Fault.

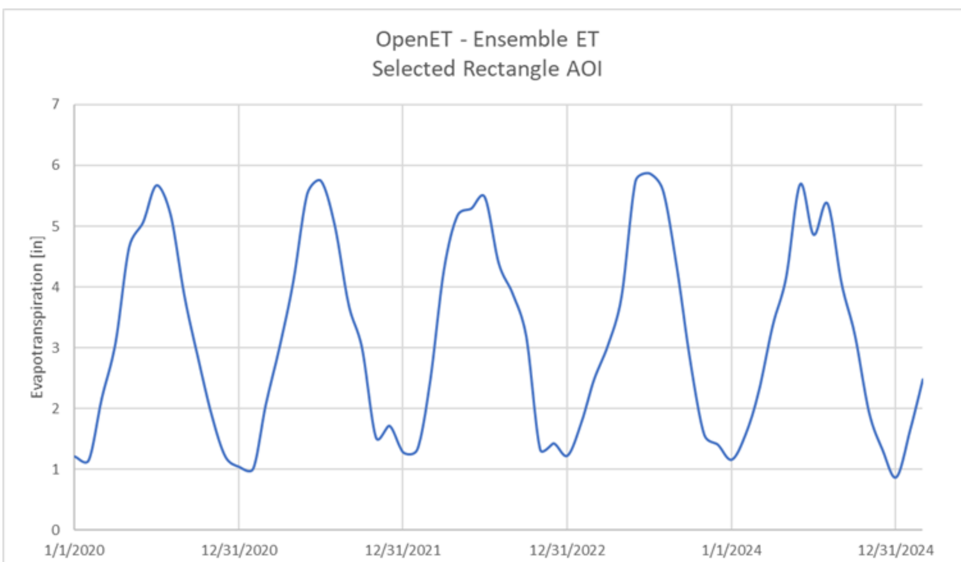

Figure 9 Monthly evapotranspiration (ET)amounts obtained for Segment W2A Monitoring System along the suspected Panther Branch Fault by OpenET (https://etdata.org/faq) Average cumulative ET amount from March to September and from September to March is about 25 inches and about 10 inches, respectively.

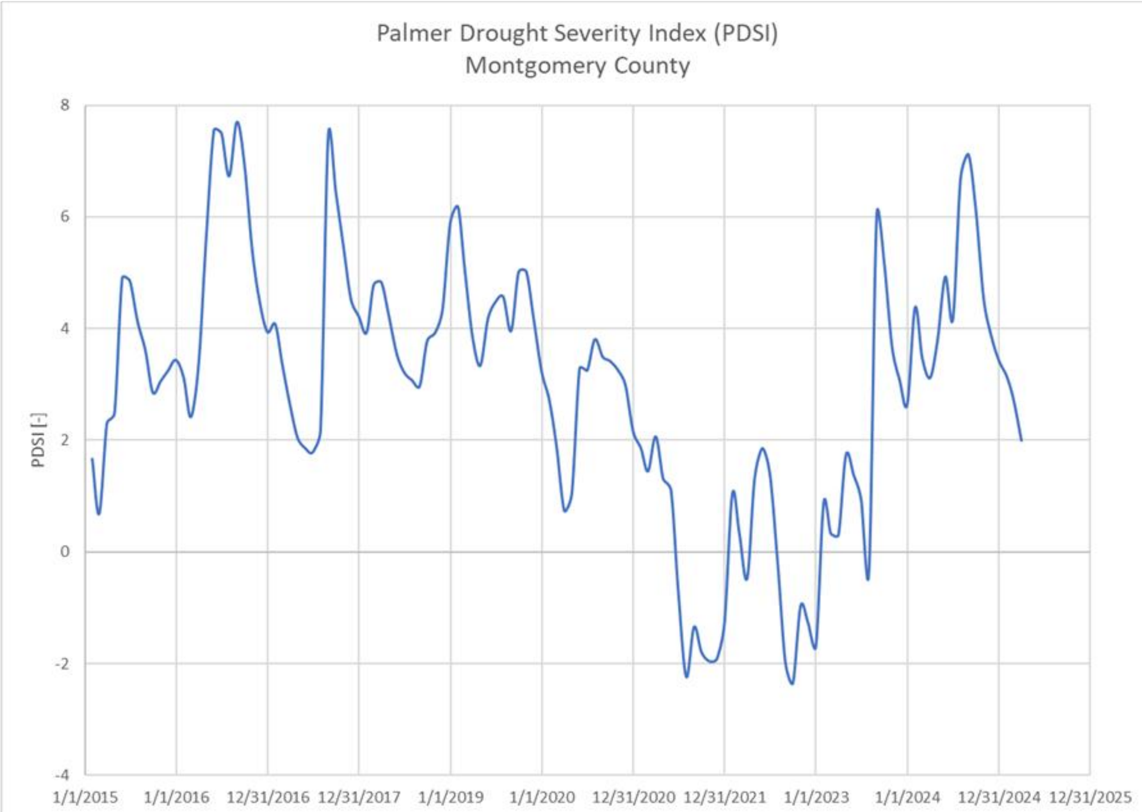

Figure 10 Monthly values for the Palmer Drought Severity Index (PSDI) form estimating relative dryness of soils.for Montgomery County (from https://wrcc.dri.edu/wwdt/time/.)

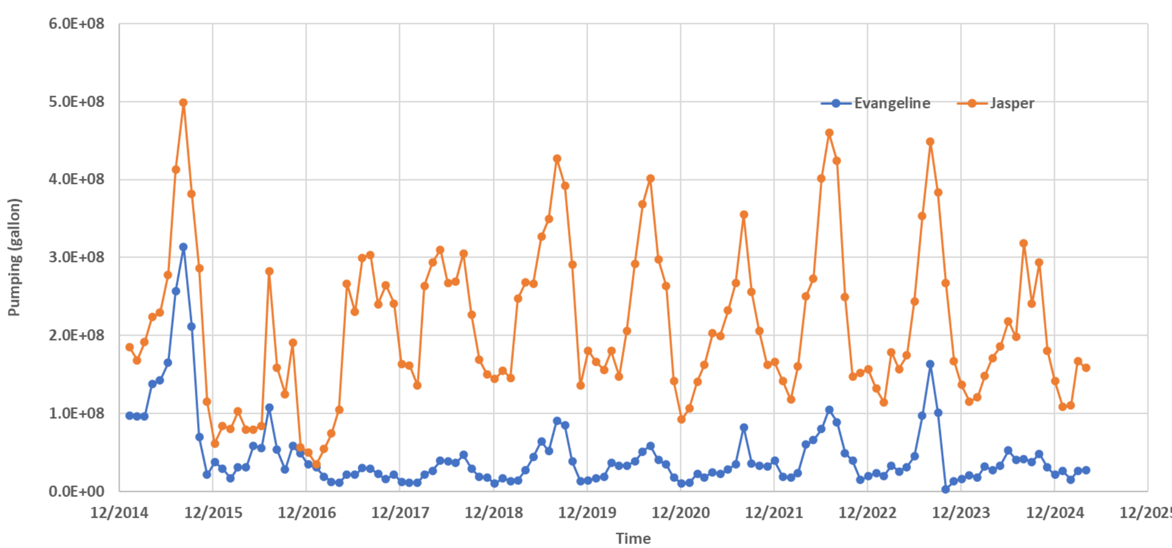

Figure 11 Monthly production from the Woodlands Wells from the Evangeline and Jasper aquifers.