

December 13, 2023

Aaron K. Schindewolf, P.E.  
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**RE: Review of Seventeenth (17th) 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 September 2023 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 2. The technical lead for this task is Dr. Steve Young.

Respectfully submitted,

A handwritten signature in black ink that reads "Steven C. Young".

Steven Young, PHD  
Professional Geologist  
INTERA Incorporated

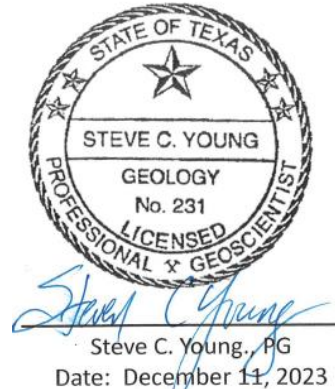
Enclosure

## ATTACHMENT A

### Review of Seventeenth (17th) 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 Seventeenth(17th) 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 remeasured the elevations of the monitoring points and monitoring benchmarks along the water line segments W1A and W2A. In September 2023, the SJRA contracted surveyor performed the seventeenth remeasurement. Starting in 2024, re-measurements will be taken once a year as confirmed at the July 24, 2023 GRP Review Committee Meeting.

**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 consists of only monitoring benchmarks.

**Figure 2** is a satellite map that shows the San Jacinto River Authority (SJRA) 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 Panther Branch Fault across the SJRA GRP water line route. INTERA mapped the suspected interpolated portion of the 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.

The September 2023 survey represents the seventeenth (17th) re-measure of the elevations since their initial measurements in March 2015. Re-measurements are made about every six months. **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 Monitoring Benchmarks along SJRA Segment W1A Monitoring Survey for March 2015, March 2023, and September 2023

Point ID	Measured Elevation			Calculated Differences	
	(a) Initial Survey March, 2015 Elev.	(b) March 2023 Elev.	(c) Sept. 2023 Elev.	Sept.2023 minus March 2015 (c) - (a)	Sept. 2023 minus March 2023 (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	189.44	189.43	-0.02	-0.01
MbM-4	189.73	189.72	189.72	-0.01	0.00
MbM-5	190.41	Destroyed	Destroyed	na	na
MbM-6	190.26	Destroyed	Destroyed	na	na
MbM-7	188.81	188.80	188.80	-0.01	0.00
MbM-8	188.28	188.28	188.27	-0.01	-0.01
MbM-9	187.93	187.92	187.91	-0.02	-0.01
MbM-10	187.76	187.75	187.75	-0.01	0.00
MbM-11	188.00	187.84	187.79	-0.21	-0.05
MbM-12	187.77	187.75	187.75	-0.02	0.00
MbM-13	187.50	187.49	187.48	-0.02	-0.01
MbM-14	187.75	187.73	187.72	-0.03	-0.01
MbM-15	188.49	188.48	188.47	-0.02	-0.01
MbM-16	187.86	187.84	187.83	-0.03	-0.01
MbM-17	189.31	189.29	189.28	-0.03	-0.01
MbM-18	189.75	189.73	189.73	-0.02	0.00
MbM-19	189.32	189.30	189.29	-0.03	-0.01
MbM-20	188.55	188.53	188.52	-0.03	-0.01

note: na= not applicable

Table 2 Elevations for Monitoring Points Along SJRA Segment W1A for March 2015, March 2023, and September 2023 at Existing Fault Protection System Egypt Fault

Station/Description	Measured Elevation			Calculated Differences	
	(a) Initial Survey March, 2015 Elev.	(b) March 2023 Elev.	(c) September 2023 Elev.	Sept. 2023 minus March 2015 (c) - (a)	Sept. 2023 minus March 2023 (c) - (b)
Sta 103 + 72 Top Square Nut on 2" Steel Cap	187.20	187.20	187.20	0.00	0.00
Sta 103 + 82 Top 2" Steel Pipe (NO CAP)	186.93	186.93	186.93	0.00	0.00
Sta 108 + 70 Top Square Nut on 2" Steel Cap	190.28	190.24	190.24	-0.04	0.00
Sta 108 + 80 Top 2" Steel Cap	190.31	190.27	190.27	-0.04	0.00

Table 3 Elevations for Monitoring Points along SJRA Segment W2A for March 2015, March 2023, and September 2023 at Existing Fault Protection System Big Barn Fault

Station/Description	Measured Elevation			Calculated Differences	
	(a) Initial Survey March, 2015 Elev. (ft, msl)	(b) March 2023 Elev. (ft, msl)	(c) September 2023 Elev. (ft, msl)	Sept. 2023 minus March 2015 (c) - (a)	Sept. 2023 minus March 2023 (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	177.73	-0.01	0.00
Sta 9 + 85 Top 2" Steel Cap	176.73	176.71	176.70	-0.03	-0.01
Sta 9 + 95 Top 2" Steel Cap	176.78	176.76	176.76	-0.02	0.00

Table 4 Elevations for Monitoring Benchmarks along SJRA Segment W2A Monitoring Survey for March 2015, March 2023, and September 2023

Point ID	Measured Elevation			Calculated Differences	
	(a) Initial Survey March, 2015 Elev. (ft, msl)	(b) March 2023 Elev. (ft, msl)	(c) Sept. 2023 Elev. (ft, msl)	Sept 2023 minus March 2015 (c) - (a)	Sept. 2023 minus March 2023 (c) - (b)
MbM-1	142.59	142.52	142.49	-0.10	-0.03
MbM-2	142.80	142.73	142.68	-0.12	-0.05
MbM-3	143.31	143.23	143.18	-0.13	-0.05
MbM-4	143.35	143.26	143.21	-0.14	-0.05
MbM-5	143.85	143.78	143.73	-0.12	-0.05
MbM-6	144.14	144.08	144.04	-0.10	-0.04
MbM-7	144.29	144.23	144.19	-0.10	-0.04
MbM-8	145.20	145.13	145.10	-0.10	-0.03
MbM-9	145.51	145.44	145.42	-0.09	-0.02
MbM-10	145.63	145.56	145.52	-0.11	-0.04
MbM-11	146.16	146.12	146.08	-0.08	-0.04
MbM-12	145.42	145.38	145.36	-0.06	-0.02
MbM-13	145.00	145.00	144.99	-0.01	-0.01
MbM-14	144.99	144.98	144.97	-0.02	-0.01
MbM-15	144.79	144.79	144.78	-0.01	-0.01
MbM-16	144.78	144.78	144.77	-0.01	-0.01
MbM-17	144.79	144.79	144.78	-0.01	-0.01
MbM-18	144.55	144.54	144.53	-0.02	-0.01
MbM-20	145.86	145.79	145.75	-0.11	-0.04

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. 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.

Egypt Fault Monitoring System - At the Egypt Fault Monitoring System (Figure 3), the changes in the elevations from March 2015 to September 2023 indicate that a greater decrease in pipe/casing elevation occurred on the downthrown side than on the upthrown side of the Egypt Fault. Over an 8.5-year period from 2015 to 2023, the pipe/casing elevation on the downthrown side of the Egypt Fault decreased 0.04 ft relative to the upthrown side of the Egypt Fault. The 0.04 ft decrease over an 8.5-year period translates into an average subsidence rate of approximately 0.0047 ft/yr.

W1A Segment - 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 September 2023 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 8.5-year period from 2015 to 2023, the land surface on downthrown side of the Egypt Fault decreased 0.019 ft in elevation relative to the upthrown side of the Egypt Fault. The 0.019 ft decrease in land elevation over an 8.5-year period translates into an average subsidence rate of approximately 0.0022 ft/yr. (note: as explained below benchmark 11 was not included in the analysis).

Big Barn Monitoring System - 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 an 8.5-year period from March 2015 to September 2023, the pipe/casing elevation on downthrown side of the Big Barn Fault decreased 0.020 ft relative to the upthrown side of the Big Barn Fault. The 0.020 ft decrease in pipe/casing over an 8.5-year period translates into average subsidence rate of approximately 0.0023 ft/yr.

W2A Segment - 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 an 8.5-year period from March 2015 to September 2023, the land surface on downthrown side of the suspected Panther Branch Fault decreased 0.084 ft in elevation relative to the upthrown side of the suspected Panther Branch Fault. The 0.084 ft decrease in land elevation over an 8.5-year period translates into an average subsidence rate of approximately 0.0099 feet per year (ft /yr).

Based on the changes in monitoring benchmark elevations and benchmark points during the last 8.5 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. However, INTERA recommends SJRA continue with studies of the suspected Panther Branch Fault study to determine if and

where the suspected Panther Branch Fault crosses the SJRA GRP water line and whether or not mitigation measures will be needed in future.

## **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 Seventeenth (17th) Re-measure of the Water Line W1A and W2A Monitoring Benchmark and Monitoring Point Elevations over a 6-month and an 8.5-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 6 months and for the last 8.5 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 outlier when compared to other measured differences in elevations along FM 2798. For instance, over an 8.5-year period, the elevation of benchmark BM11 decreased 0.21 ft whereas benchmarks on both sides of MbM 11 averaged a decrease of 0.015 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 BM11 is likely caused by the compaction of the highly disturbed soil.

Last 6 months: Over the last 6 months, 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 elevation change of 0.01 t to -0.01 ft and averaged a 0.002 ft increase in elevation.
- After omitting results from benchmark BM11, the thirteen monitoring benchmarks on the downthrown side of the Egypt Fault ranged from no change in elevation to a decrease of 0.01 ft in elevation and averaged a decrease of 0.007 ft in elevation

Over the last 6 months, 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 ranged from no change in elevation to a 0.01 ft decrease in elevation. The two values averaged 0.005 ft decrease in elevation.
- The two monitoring on the downthrown side of the Egypt Fault had a 0.04 ft decrease in elevation.

The differences in the elevation changes are viewed from two criteria. One criterion is whether there is a consistent set of data that indicates a net downward movement on the downthrown side of the Egypt Fault. The elevation data from the W1A Segment indicates that the downthrown side of the fault has moved 0.009 ft downward relative to the upthrown side of the fault. The elevation data from the Egypt Fault Monitoring System indicates that the downthrown side of the fault has moved 0.005 ft upward relative to the upthrown side of the fault. The second criterion is how large are the changes in elevations between the upthrown and downthrown side of the fault compared to the reported accuracy of 0.01 ft for the elevation measurements. For both set of measured elevation data the observed average differences of less than 0.01 ft are too small compared to the 0.01 ft reported precision of the measured elevations to make definitive statements regarding the actual amount of vertical movement on the upthrown and downthrown side the Egypt Fault. Based on these two criteria, there is no conclusive evidence to indicate that the downthrown side of the Egypt Fault subsided from March 2023 to September 2023.

Last 8.5 years: From March 2015 to September 2023, 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 0.02 ft to an increase of 0.01 ft change in elevation. The four monitoring benchmarks averaged a decrease of 0.003 ft 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 0.03 ft to a decrease of 0.01 ft change in elevation. The thirteen monitoring benchmarks averaged a change of a decrease of -0.022 ft change in elevation.

From March 2015 to September 2023, 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 no change in elevation.
- The two monitoring points on the downthrown side of the Egypt Fault each had a decrease of 0.04 ft in elevation, which is also the average change in elevation.

During the last 8.5 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 0.04 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 0.0047ft/yr relative to the upthrown side of the Egypt Fault. Along FM 2978, the downthrown side of the fault averaged a decrease 0.009 ft in elevation more than the upthrown side of the fault. These amounts of elevation change are too small to be consider 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 6 months and for the last 8.5 years are discussed below.

Last 6 months: - Over the last 6 months, 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.
- The two monitoring points on the downthrown side of the Big Barn Fault had changes of -0.01 ft in elevation and no change in elevation. The two points averaged a decrease of 0.005 ft in elevation.

Over the last 6 months the 19 monitoring benchmarks 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 all had elevation changes of a decrease of 0.01 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 to a decrease of 0.04 ft in elevation and averaged a decrease of 0.038 ft in elevation.

From March 2023 to September 2023, the downthrown side of the suspected Panther Branch Fault along Research Forest Drive averaged 0.028 ft more subsidence than the upthrown side of the suspected Panther Branch Fault.

Last 8.5 years: –From March 2015 to September 2023, 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 ranged from a 0.010 ft decrease in elevation to no change in elevation and averaged a decrease of 0.005 ft in elevation.
- The two monitoring points on the downthrown side of the Big Barn Fault ranged from -0.02 ft and -0.03 ft in elevation and averaged 0.025 ft decrease in elevation.

The changes in the elevation of monitoring points that straddle the Big Barn Fault indicate that the downthrown side of the fault has subsided approximately 0.02 ft more than the upthrown side of the fault. A 0.02 ft decrease in elevation over 8.5 years translates into an average subsidence rate of approximately 0.0002 ft/yr.

From March 2015 to September 2023, 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 a decrease of 0.01 ft and a decrease of 0.02 ft change in elevation and averaged a decrease of 0.013 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 0.06 ft in elevation to a decrease of 0.14 ft in elevation and averaged a decrease of 0.105 ft in elevation.

The changes in the elevation for the monitoring benchmarks near the suspected Panther Branch Fault indicate that the downthrown side of the fault has subsided approximately 0.091 ft more than the upthrown side of the fault. The 0.091 ft decrease in elevation over 8.5 years translates into an average subsidence rate of approximately 0.0107 ft/yr since March 2015.

**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. Whereas the upthrown side of the fault has not subsided more than 0.01 ft over a 6-month period within the 8.5-year monitoring period, the downthrown side of the fault has exhibited a general trend of declining elevation with greater displacement rates at later times.

**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 can be characterized into three periods: 1) from March 2015 to March 2019 the rate of vertical displacement averaged 0.0033 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 September 2023, the vertical displacement rate averaged 0.036 ft/yr downward.

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	Interval (years)	Average Rate of Net Vertical Displacement (ft/yr)
March 2015 to March 2019	4	-0.0033
March 2019 to March 2022	3	-0.0080
March 2022 to September 2023	1.5	-0.0360

## 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 up for 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 8.5 years of monitoring the change in the monitoring point elevations at the Egypt Fault Monitoring System, the downthrown side of the fault had subsided 0.035 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 0.0041 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 8.5 years of monitoring, the average changes in the monitoring benchmark elevations are a decrease of 0.003 ft and a decrease of 0.022 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 0.019 over 8.5 years, which translates to 0.0022 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 8.5 years for the upthrown side and for the downthrown side of the Big Barn Fault are a decrease of 0.005 ft in elevation and a decrease of 0.025 ft in elevation, respectively. Thus, the decrease of the downthrown side of the fault relative to the upthrown side is about 0.020ft over 8.5 years, or approximately 0.0023 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 8.5 years for the upthrown side and for the downthrown side of the Big Barn Fault are a decrease of 0.013 ft in elevation and a decrease of 0.105 ft in elevation, respectively. Thus, the decrease of the downthrown side of the fault relative to the upthrown side is about 0.092 ft over 8.5 years, or approximately 0.0108 ft/yr. Figure 7 shows that since March 2022, the rate is 0.036 ft/yr. Per discussion with SJRA, SJRA plans to continue to monitor subsidence using the benchmarks associated with the Segment W2A Monitoring System and to investigate what safeguards may be needed to protect the transmission line. In addition, INTERA suggests that SRJA consider investigating a possible correlation between changes in seasonal pumping rates or in weather conditions during the recent hot and dry summers in 2022 and 2023 and the accelerated subsidence rates during those two summers.

## References

Fugro Consultants, Inc., 2012. Geologic Fault Delineation Study SJRA Distribution Lines – Route W1 San Jacinto River Authority Montgomery County, Texas. Report No. 04.12110014-9 Prepared for Lockwood, Andrews & Newnam, Inc., Houston Texas.

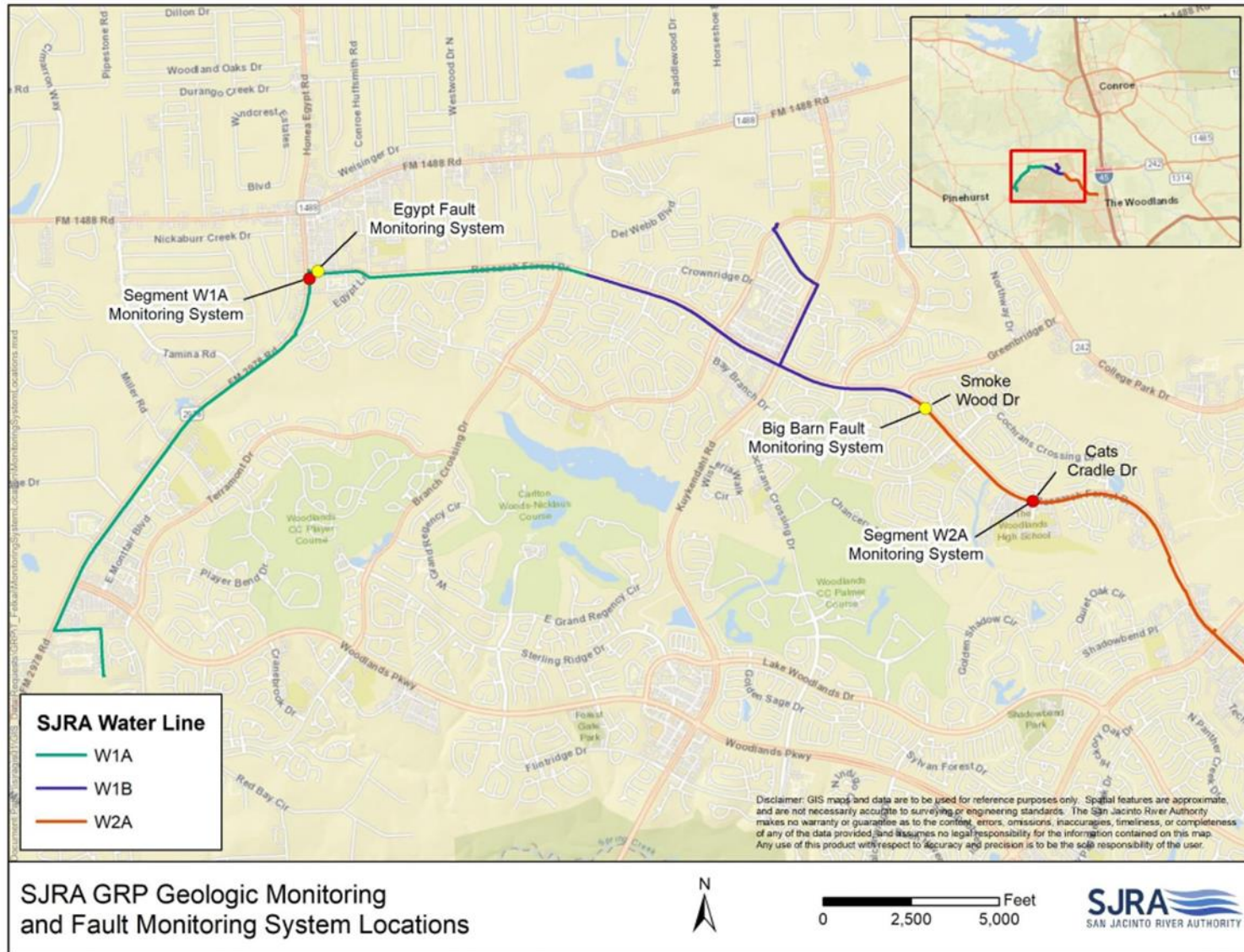


Figure 1 SJRA Groundwater Reduction Plan (GRP) Fault Monitoring System Locations (<https://www.sjra.net/grp/fault-monitoring/>)

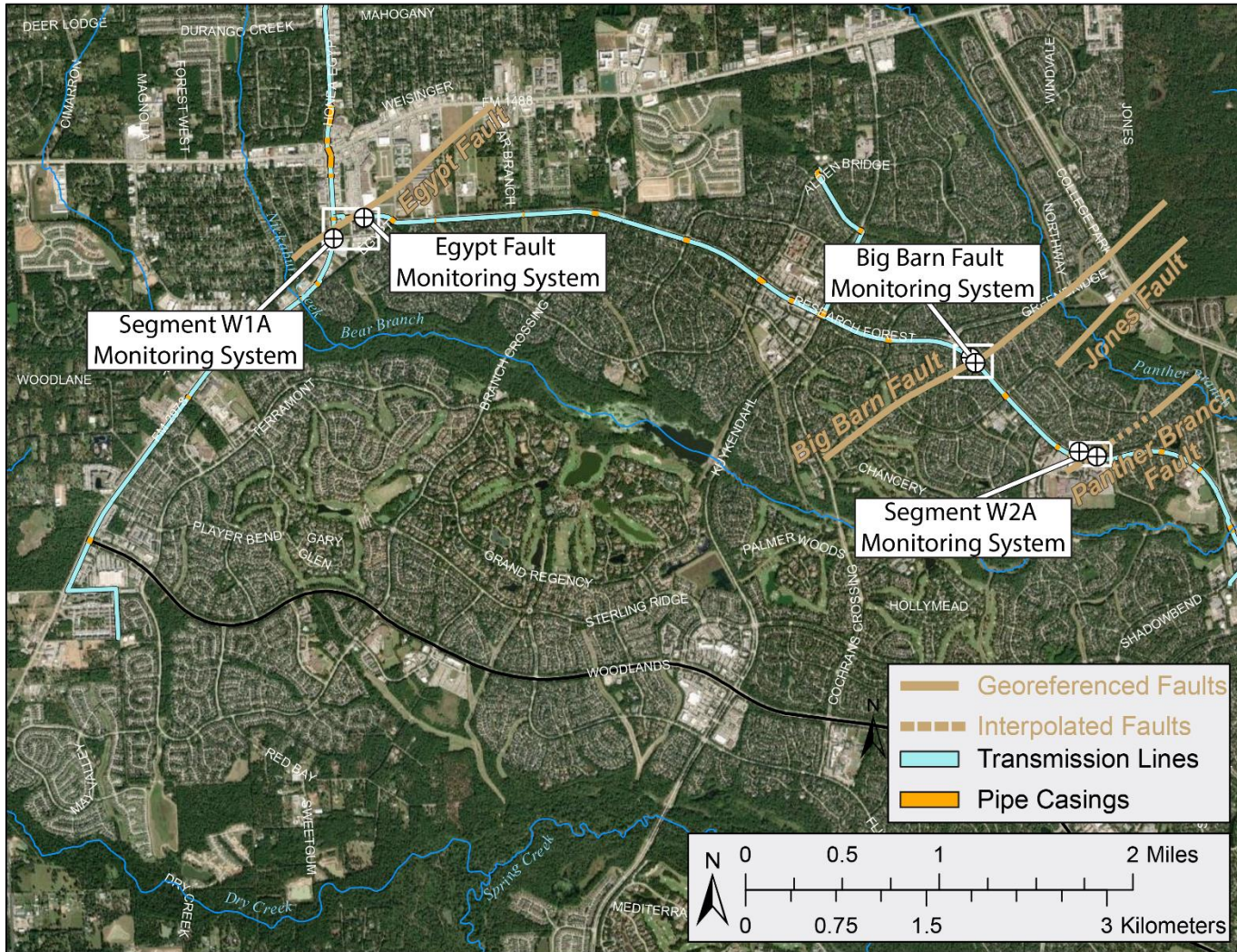


Figure 2 Satellite map showing the location of the SJRA water line, the fault locations mapped by Fugro (2012), and SJRA monitoring systems.

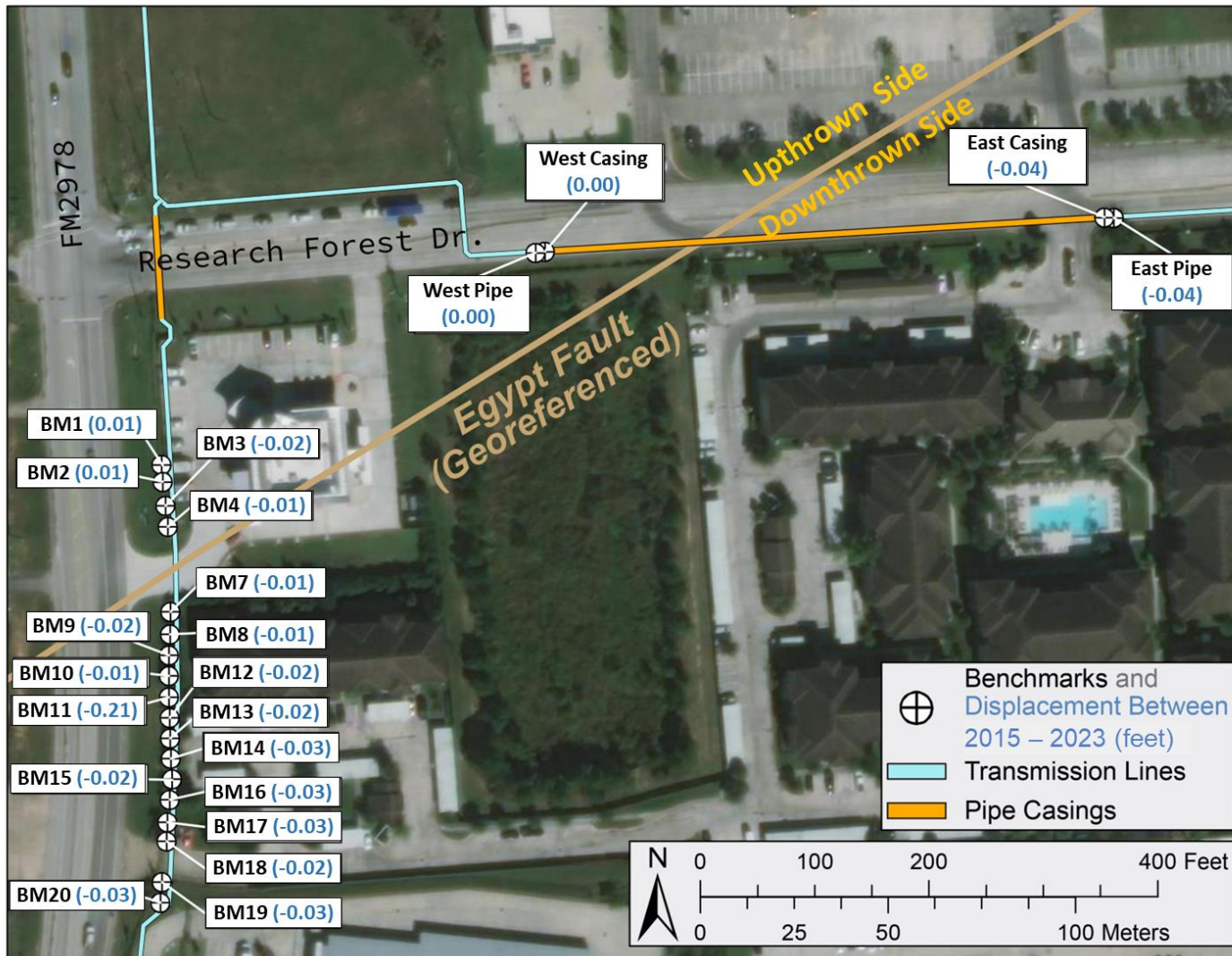


Figure 3 Satellite map showing the location of the Egypt Fault (Fugro, 2012), the W1A monitoring locations and calculated vertical displacement from March 2015 to September 2023 and the SJRA water line and pipe casing.

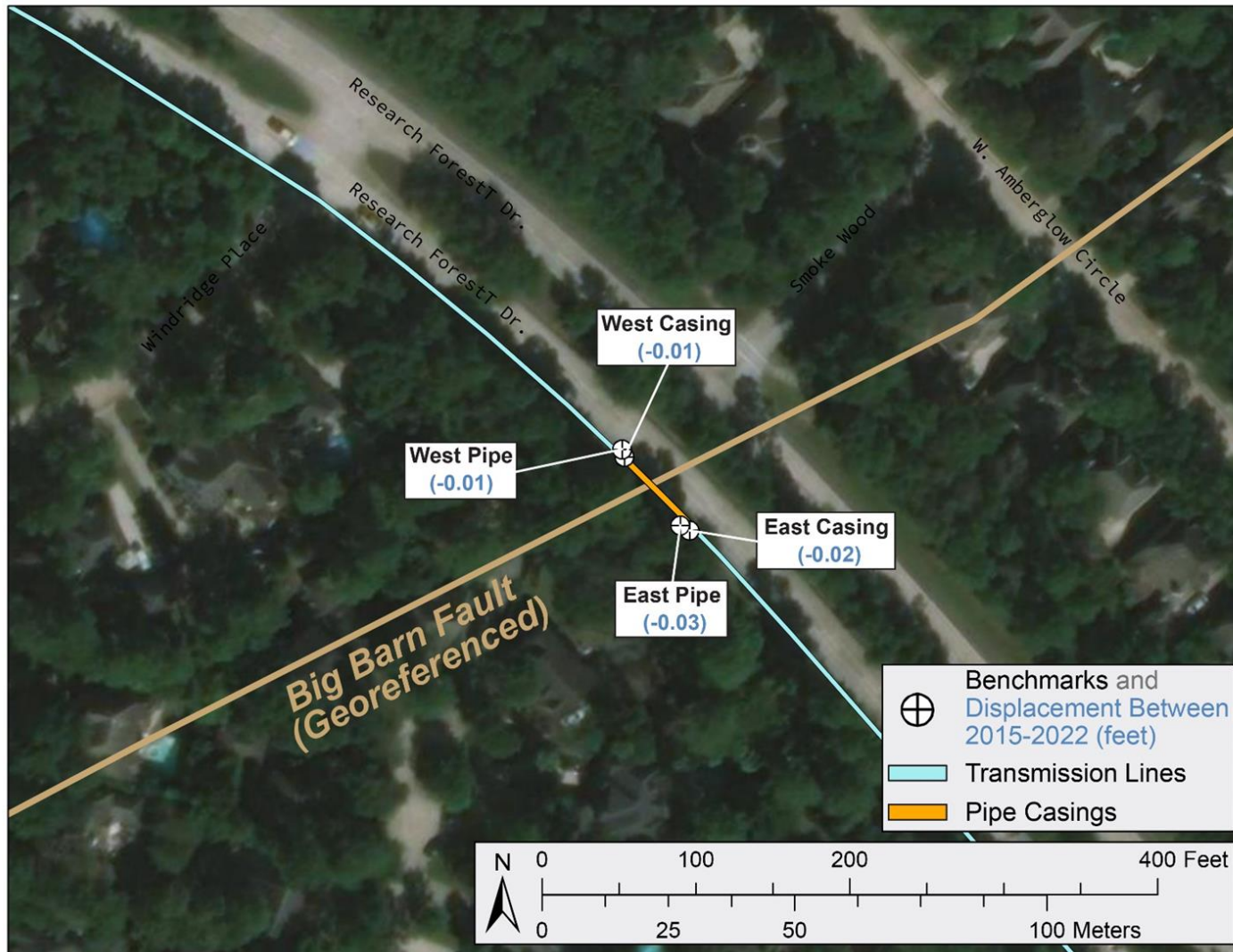


Figure 4 Satellite map showing the location the Big Barn Fault (Fugro, 2012), the Big Barn Fault Monitoring System, calculated vertical displacement from March 2015 to September 2023, and the SJRA water line and pipe casing.



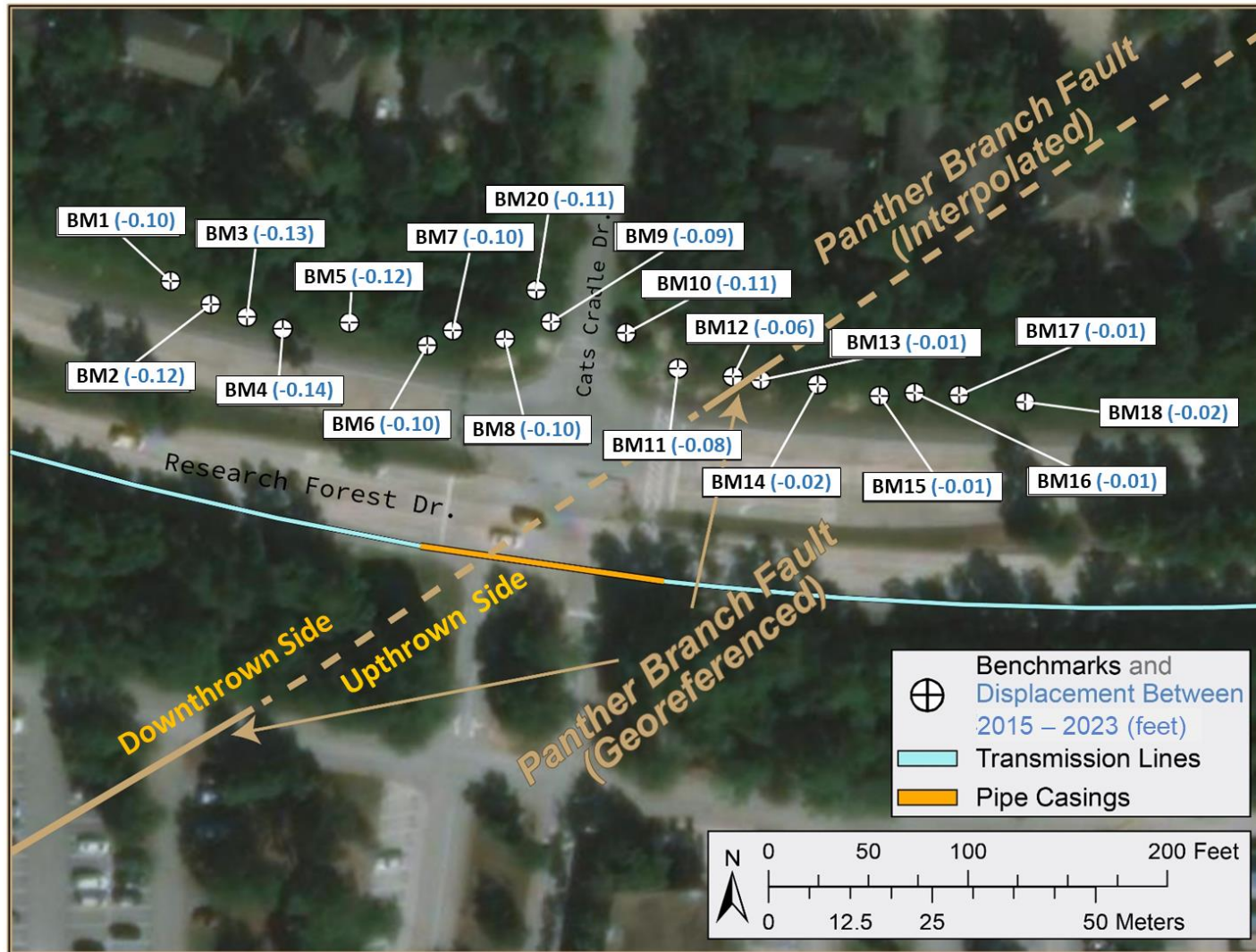


Figure 5

Satellite map showing the location the suspected Panther Branch Fault mapped by INTERA, the Segment W2A Monitoring System, calculated vertical displacement from March 2015 to September 2023, and the SJRA water line and pipe casing.

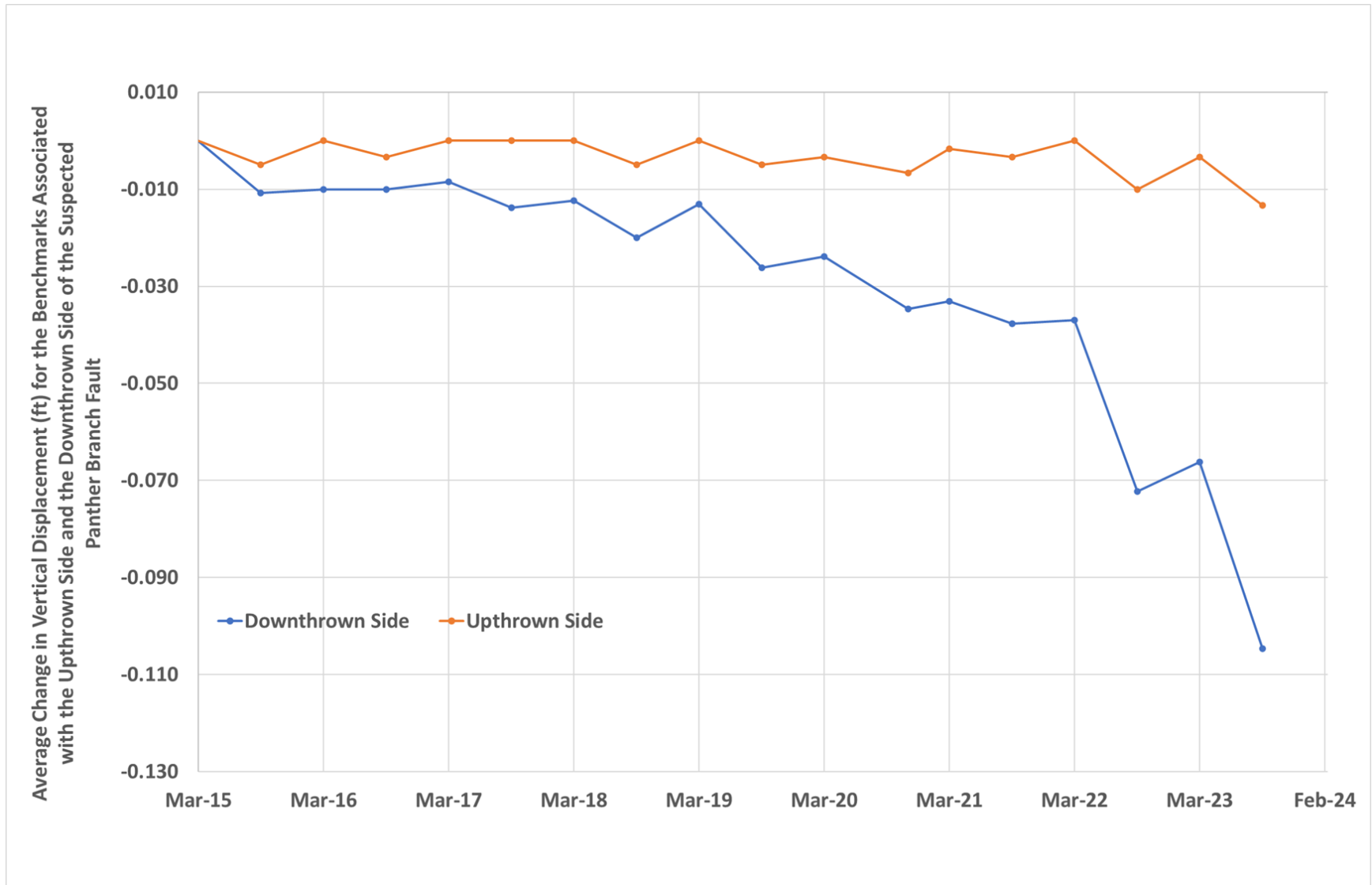


Figure 6 Comparison of average vertical displacement for the benchmarks located on the upthrown side and the downthrown side of the suspected Panther Branch Fault associated with the Segment W2A Monitoring System.

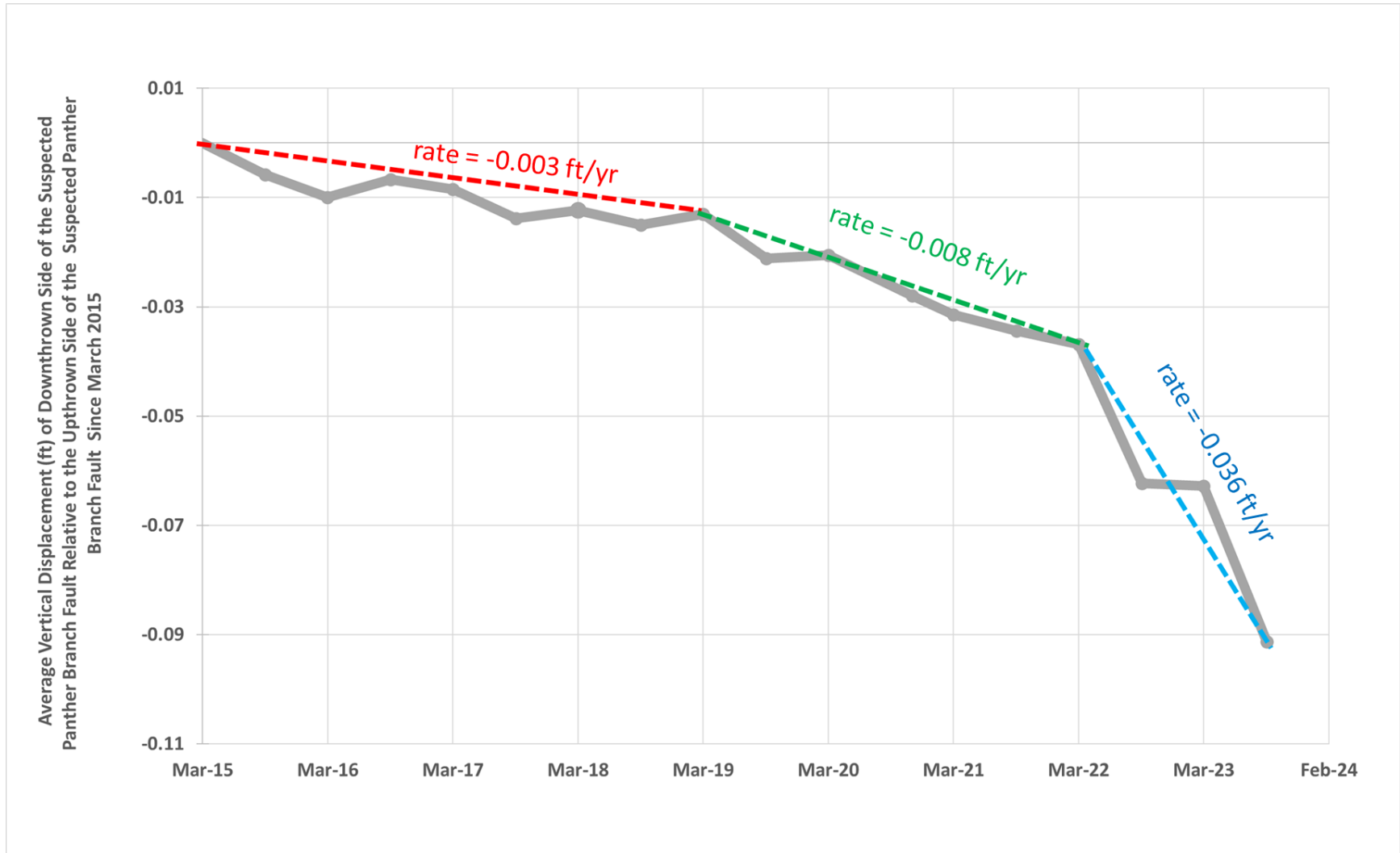


Figure 7 Relative vertical displacement and rates for relative vertical displacement for the downthrown side of the suspected Panther Branch Fault based on benchmarks associated with the Segment W2A Monitoring System