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November 10, 2022

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2436 Sawdust Road
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**RE: Review of Fifteenth (15th) 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 a September 2022 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. 20-0077 and under Work Order 8 (PO Number: 23-0007). The technical lead for this task is Dr. Steve Young.

Respectfully submitted

Steven C Young

Steven Young, PHD
Professional Geologist
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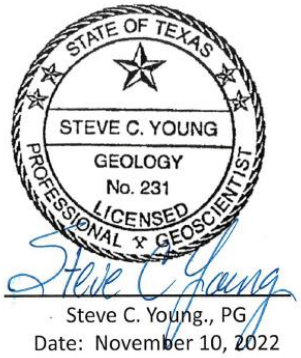
Enclosure

# ATTACHMENT A

## Review of Fifteenth (15th) 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.




Steve C. Young., PG
Date: November 10, 2022

## Overview of Fifteenth (15th) Re-measure of the Elevations at Monitoring Points and Monitoring Benchmarks along Water Line Segments W1A and W2A

The fifteenth re-measure includes measurements of elevations monitoring points and monitoring benchmarks along the water line segments W1A and W2A in September 2022. **Figure 1** shows the locations of the water line segments W1A and W2A and the four monitoring systems. Each of the monitoring systems consist 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. INTERA recommends that additional studies be performed to verify the interpolated extension of the suspected Panther Branch Fault.

The September 2022 survey represents the fifteenth (15th) re-measure of the elevations since their initial measurements in March 2015. The 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 2022, and September 2022

| Point ID | Measured Elevation | | | Calculated Differences | |
|---|---|---|---|---|---|
| | (a) Initial Survey March, 2015 Elev. (ft msl) | (b ) March 2022 Elev. | (c ) September 2022 Elev. | September 2022 minus March 2015 (c ) - (a) | September 2022 minus March 2022 (c ) - (b) |
| MbM-1 | 189.24 | 189.25 | 189.23 | -0.01 | -0.02 |
| MbM-2 | 189.27 | 189.28 | 189.26 | -0.01 | -0.02 |
| MbM-3 | 189.45 | 189.45 | 189.43 | -0.02 | -0.02 |
| MbM-4 | 189.73 | 189.73 | 189.71 | -0.02 | -0.02 |
| MbM-5 | 190.41 | Destroyed | Destroyed | na | na |
| MbM-6 | 190.26 | Destroyed | Destroyed | na | na |
| MbM-7 | 188.81 | 188.81 | 188.79 | -0.02 | -0.02 |
| MbM-8 | 188.28 | 188.29 | 188.26 | -0.02 | -0.03 |
| MbM-9 | 187.93 | 187.93 | 187.90 | -0.03 | -0.03 |
| MbM-10 | 187.76 | 187.76 | 187.74 | -0.02 | -0.02 |
| MbM-11 | 188.00 | 187.90 | 187.84 | -0.16 | -0.06 |
| MbM-12 | 187.77 | 187.76 | 187.74 | -0.03 | -0.02 |
| MbM-13 | 187.50 | 187.50 | 187.48 | -0.02 | -0.02 |
| MbM-14 | 187.75 | 187.74 | 187.72 | -0.03 | -0.02 |
| MbM-15 | 188.49 | 188.49 | 188.47 | -0.02 | -0.02 |
| MbM-16 | 187.86 | 187.85 | 187.83 | -0.03 | -0.02 |
| MbM-17 | 189.31 | 189.31 | 189.28 | -0.03 | -0.03 |
| MbM-18 | 189.75 | 189.74 | 189.72 | -0.03 | -0.02 |
| MbM-19 | 189.32 | 189.32 | 189.30 | -0.02 | -0.02 |
| MbM-20 | 188.55 | 188.54 | 188.52 | -0.03 | -0.02 |

note: na= not applicable

Table 2 Elevations for Monitoring Points Along SJRA Segment W1A for March 2015, March 2022, and September 2022 at Existing Fault Protection System Egypt Fault

| Station/Description | Measured Elevation | | | Calculated Differences | |
|---|---|---|---|---|---|
| | (a) Initial Survey March, 2015 Elev. | (b) March 2022 Elev. | (c ) September 2022 Elev. | Sept 2022 minus Mar 2015 (c ) - (a) | September2022 minus March 2022 (c ) - (b) |
| Sta 103 + 72 Top Square Nut on 2" Steel Cap | 187.20 | 187.19 | 187.19 | -0.01 | 0.00 |
| Sta 103 + 82 Top 2" Steel Pipe (NO CAP) | 186.93 | 186.92 | 186.92 | -0.01 | 0.00 |
| Sta 108 + 70 Top Square Nut on 2" Steel Cap | 190.28 | 190.25 | 190.24 | -0.04 | -0.01 |
| Sta 108 + 80 Top 2" Steel Cap | 190.31 | 190.28 | 190.28 | -0.03 | 0.00 |

Table 3 Elevations for Monitoring Points along SJRA Segment W2A for March 2015, September 2021, and March 2022 at Existing Fault Protection System Big Barn Fault

| Station/Description | Measured Elevation | | | Calculated Differences | |
|---|---|---|---|---|---|
| | (a) Initial Survey March, 2015 Elev. (ft, msl) | (b ) March 2022 Elev. (ft, msl) | (c ) September 2022 Elev. (ft, msl) | September 2022 minus March 2015 (c ) - (a) | September 2022 minus March 2022 (c ) - (b) |
| Sta 9 + 25 Top 2" Steel Cap | 177.81 | 177.81 | 177.80 | -0.01 | -0.01 |
| 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, September 2021, and March 2022

| Point ID | Measured Elevation | | | Calculated Differences | |
|---|---|---|---|---|---|
| | (a) Initial Survey March, 2015 Elev. (ft, msl) | (b ) March 2022 Elev. (ft, msl) | (c ) September 2022 Elev. (ft, msl) | September 2022 minus March 2015 (c ) - (a) | September 2022 minus March 2022 (c ) - (b) |
| MbM-1 | 142.59 | 142.55 | 142.52 | -0.07 | -0.03 |
| MbM-2 | 142.80 | 142.77 | 142.73 | -0.07 | -0.04 |
| MbM-3 | 143.31 | 143.27 | 143.23 | -0.08 | -0.04 |
| MbM-4 | 143.35 | 143.30 | 143.26 | -0.09 | -0.04 |
| MbM-5 | 143.85 | 143.81 | 143.77 | -0.08 | -0.04 |
| MbM-6 | 144.14 | 144.11 | 144.07 | -0.07 | -0.04 |
| MbM-7 | 144.29 | 144.26 | 144.23 | -0.06 | -0.03 |
| MbM-8 | 145.20 | 145.16 | 145.12 | -0.08 | -0.04 |
| MbM-9 | 145.51 | 145.48 | 145.45 | -0.06 | -0.03 |
| MbM-10 | 145.63 | 145.59 | 145.55 | -0.08 | -0.04 |
| MbM-11 | 146.16 | 146.12 | 146.09 | -0.07 | -0.03 |
| MbM-12 | 145.42 | 145.39 | 145.36 | -0.06 | -0.03 |
| MbM-13 | 145.00 | 145.00 | 144.99 | -0.01 | -0.01 |
| MbM-14 | 144.99 | 144.99 | 144.97 | -0.02 | -0.02 |
| MbM-15 | 144.79 | 144.79 | 144.79 | 0.00 | 0.00 |
| 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 | 144.55 | 144.54 | -0.01 | -0.01 |
| MbM-20 | 145.86 | 145.82 | 145.79 | -0.07 | -0.03 |

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.

At the Egypt Fault Monitoring System (Figure 3), the changes in the elevations from March 2015 to September 2022 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 7.5-year period from 2015 to 2022, the pipe/casing elevation on the downthrown side of the Egypt Fault decreased 0.025 ft relative to the upthrown side of the Egypt Fault. The 0.025 ft decrease over a 7.5-year period translates into an average subsidence rate of approximately 0.003 ft/yr.

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 2022 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 7.5-year period from 2015 to 2022, the land surface on downthrown side of the Egypt Fault decreased 0.010 ft in elevation relative to the upthrown side of the Egypt Fault. The 0.010 decrease in land elevation over a 7.5-year period translates into average subsidence rate of approximately 0.001 ft/yr.

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 7.5-year period from March 2015 to September 2022, the pipe/casing elevation on downthrown side of the Big Barn Fault decreased 0.015 ft relative to the upthrown side of the Big Barn Fault. The 0.015 ft decrease in pipe/casing over a 7.5-year period translates into average subsidence rate of approximately 0.002 ft/yr.

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 7.5-year period from March 2015 to September 2022, the land surface on downthrown side of the suspected Panther Branch Fault decreased 0.062 ft in elevation relative to the upthrown side of the suspected Panther Branch Fault. The 0.062 ft decrease in land elevation over a 7.5-year period translates into average subsidence rate of approximately 0.008 feet per year (ft /yr. However, the subsidence rate has increased over time during the 7.5-year and a significant rate increased occurred in 2022. Between March 2022 and September 2022, the downthrown side of the fault subsided at a rate of 0.051 ft/yr greater than the upthrown side of the fault.

Based on the changes in monitoring benchmark elevations and benchmark points during the last 7.5 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, based on the changes in benchmarks elevations from March 2022 to September 2022, 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. INTERA recommends SJRA continue with the suspected Panther Branch Fault study to determine if and where the suspected Panther Branch Fault crosses the SJRA GRP water line and any associated mitigation measures recommended.

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

The monitoring elevations have been remeasured at approximately 6-month intervals since March 2015. The amount of elevation change measured over a 6-month interval is typically on the order of a hundredth of a foot or less. 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 changes in soil moisture.

## Analysis of the Fifteenth (15th) Re-measure of the Water Line W1A and W2A Monitoring Benchmark and Monitoring Point Elevations over a 6-month and a 7.5-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 7.5 years are discussed below.

The discussion below excludes results from benchmark MbM 11. As discussed in previous analysis, 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 7.5-year period, the elevation of benchmark BM11 decreased 0.16 ft whereas benchmarks are both sides of MbM 11 averaged a decreased of 0.025 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 a decrease of 0.01 ft in elevation to a decrease of 0.02 ft in elevation and averaged a decrease of 0.015 ft in elevation;[1]
- 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 a decrease of 0.03 ft in elevation and averaged a decrease of 0.025 ft in elevation[1].

[1] An increase in land surface elevation can occur if a pressure head in the groundwater increases and causes the elastic storage component of the aquifer to cause a rebound at land surface

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 did not have a measured change in elevation;
- The two monitoring on the downthrown side of the Egypt Fault ranged from a decrease of 0.01 ft in elevation to a 0.00 ft in elevation change. The two values averaged a decrease of 0.005 ft 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 supports a net downward movement on the downthrown side of the Egypt Fault. Neither set of measured elevation data indicates there is more land subsidence on the downthrown side than on the upthrown side of the Egypt 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 2022 to September 2022.

*Last 7.5 years:* From March 2015 to September 2022, 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 0.01 ft decrease in elevation to a decrease of 0.02 ft in elevation. The four monitoring benchmarks averaged a decrease of 0.015 ft 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 a decrease of 0.03 ft in elevation. The thirteen monitoring benchmarks averaged a decrease of 0.025 ft in elevation;

From March 2015 to September 2022, 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 each had a decrease of 0.01 ft in elevation and averaged a decrease of 0.01 ft in elevation;
- The two monitoring points on the downthrown side of the Egypt Fault each ranged from a decrease of 0.03 ft in elevation to a decrease of 0.04 ft in elevation and averaged a decrease of 0.035 ft in elevation;

During the last 7.5 years, the monitoring data indicates that slightly more downward movement occurred on the downthrown side on the Egypt Fault. The difference is greatest along Research Forest Drive, where the downthrown side of the fault averages a decrease of about 0.025 ft in elevation 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 0.0033 ft/yr relative to the upthrown side of the Egypt Fault. Along FM 2978, the difference in the rate of subsidence is approximately 0.0013 ft/yr more for the downthrown side than the upthrown side of the Egypt Fault.

**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 7.5 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 ranged from a decrease of 0.01 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 had a decrease of Fault ranged from a decrease of 0.01 elevation to no change in elevation and 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 had elevation changes that ranged from 0.00 ft in elevation to a decrease of 0.02 ft in elevation and averaged 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 0.03 ft decrease in elevation to a decrease of 0.04 ft in elevation. The thirteen monitoring benchmarks averaged a decrease of 0.035 ft in elevation.

From September 2022 to March 2022, the downthrown side of the suspected Panther Branch Fault along Research Forest Drive averaged about 0.025 ft of subsidence more than the upthrown side of the suspected Panther Branch Fault. The 0.025 ft difference is several times greater than the 0.01 ft reported accuracy of the measurement method and the measured elevation changes are very similar for adjacent benchmarks located on the downthrown and upthrown side of the fault. The evaluation of the data suggests a greater amount of subsidence has occurred in the last six months on the downthrown side of the fault

*Last 7.5 years:* –From March 2015 to September 2022, 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 a 0.010 ft decrease in elevation and averaged a decrease of 0.010 ft in elevation;
- The two monitoring points on the downthrown side of the Big Barn Fault ranged from a decrease of 0.02 ft in elevation to a decrease of 0.03 ft in elevation and averaged a decrease of 0.025 ft 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 0.015 ft more than the upthrown side of the fault. A 0.015 ft decrease in elevation translates into an average subsidence rate of approximately 0.002 ft/yr.

From March 2015 to September 2022, 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 0.02 ft decrease in elevation and no change in elevation and averaged 0.010 decrease 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 elevation to a decrease of 0.09 elevation and averaged a decrease of 0.072 ft in elevation.

The changes in the elevation of the monitoring benchmarks that are near the suspected Panther Branch Fault indicate that the downthrown side of the fault has subsided approximately 0.062 ft more than the upthrown side of the fault. The 0.062 ft decrease in elevation translates into an average subsidence rate of approximately 0.008 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 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 at any time within the 7.5-year monitoring period, the downthrown side of the fault has exhibited a clear trend of declining elevation with higher 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. A potentially important observation is that the relative vertical displacements are increasing in magnitude over time and that a rate increase occurred between March 2022 and September 2022.

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 (months) | Average Rate of Net Vertical Displacement (ft/yr) |
|---|---|---|
| March 2015 to March 2020 | 60 | -0.004 |
| March 2020 to March 2022* | 24 | -0.008 |
| March 2022 to September 2022 | 6 | -0.051 |

## 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, and 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 7.5 years of monitoring the change in the monitoring point elevations at the Egypt Fault Monitoring System, the downthrown side of the fault had subsided 0.025 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 0.003 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. After 7.5 years of monitoring, the changes in the monitoring benchmark elevations are 0.015 ft and 0.025 ft for the upthrown and downthrown side of the fault, respectively. Thus, the rate of subsidence of the downthrown side of the fault relative to the upthrown side of the fault is approximately 0.001 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 7.5 years for the upthrown side and for the downthrown side of the Big Barn Fault are a decrease of 0.010 ft in elevation and a decrease of 0.025 ft in elevation, respectively. Thus, the decrease of downthrown side of the fault relative to the upthrown side is about 0.015 ft in 7.5 years, or approximately 0.002 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. Per discussion with SJRA, SJRA plans to continue to monitor subsidence using the benchmarks associated with the Segment W2A Monitoring System. SJRA has also commissioned a consultant to study the suspected Panther Branch Fault to determine if the fault crosses the water line and what safeguards may be needed.

## 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.

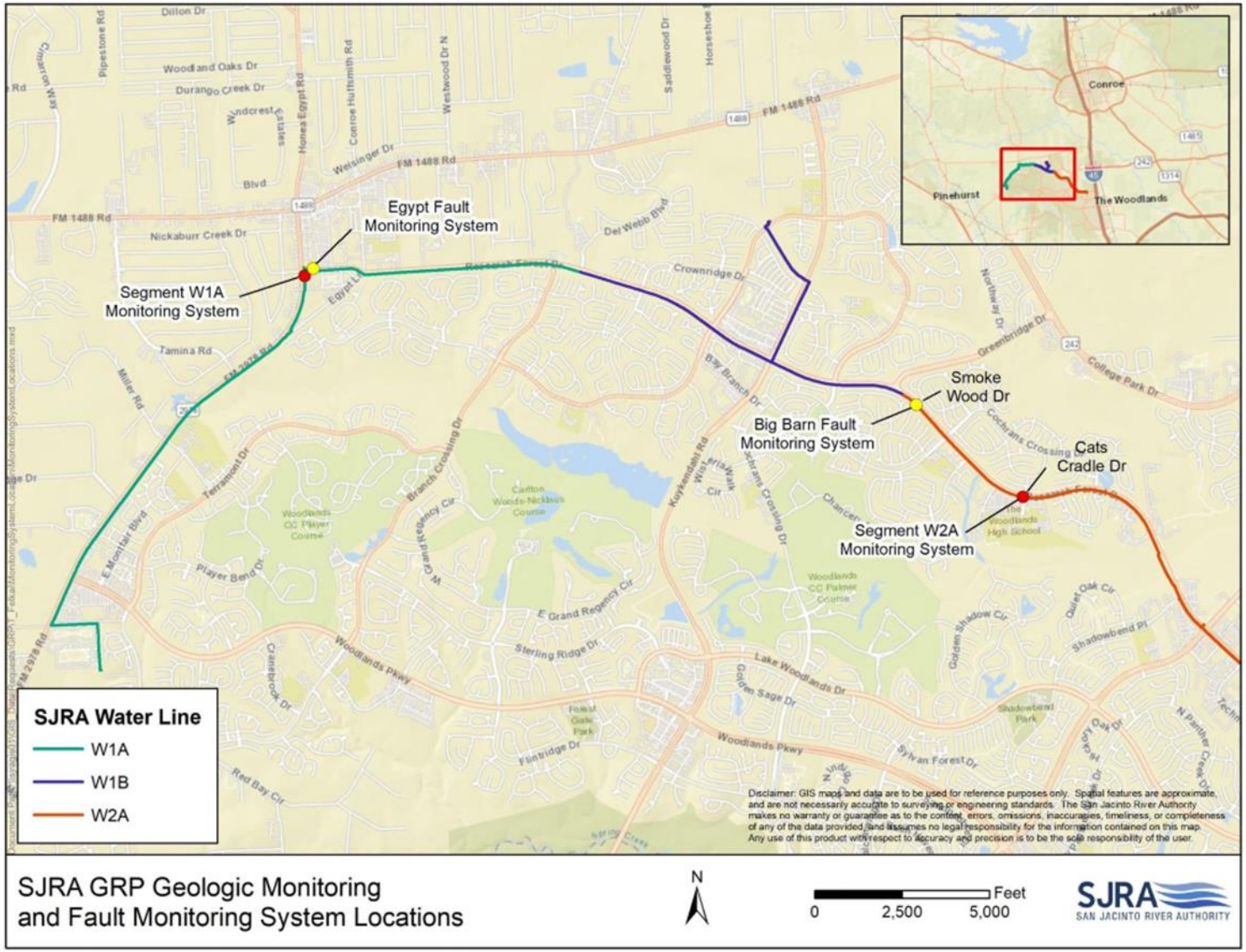



Figure 1 SJRA Groundwater Reduction Plan (GRP) Fault Monitoring System Locations (https://www.sjra.net/grp/fault-monitoring/)

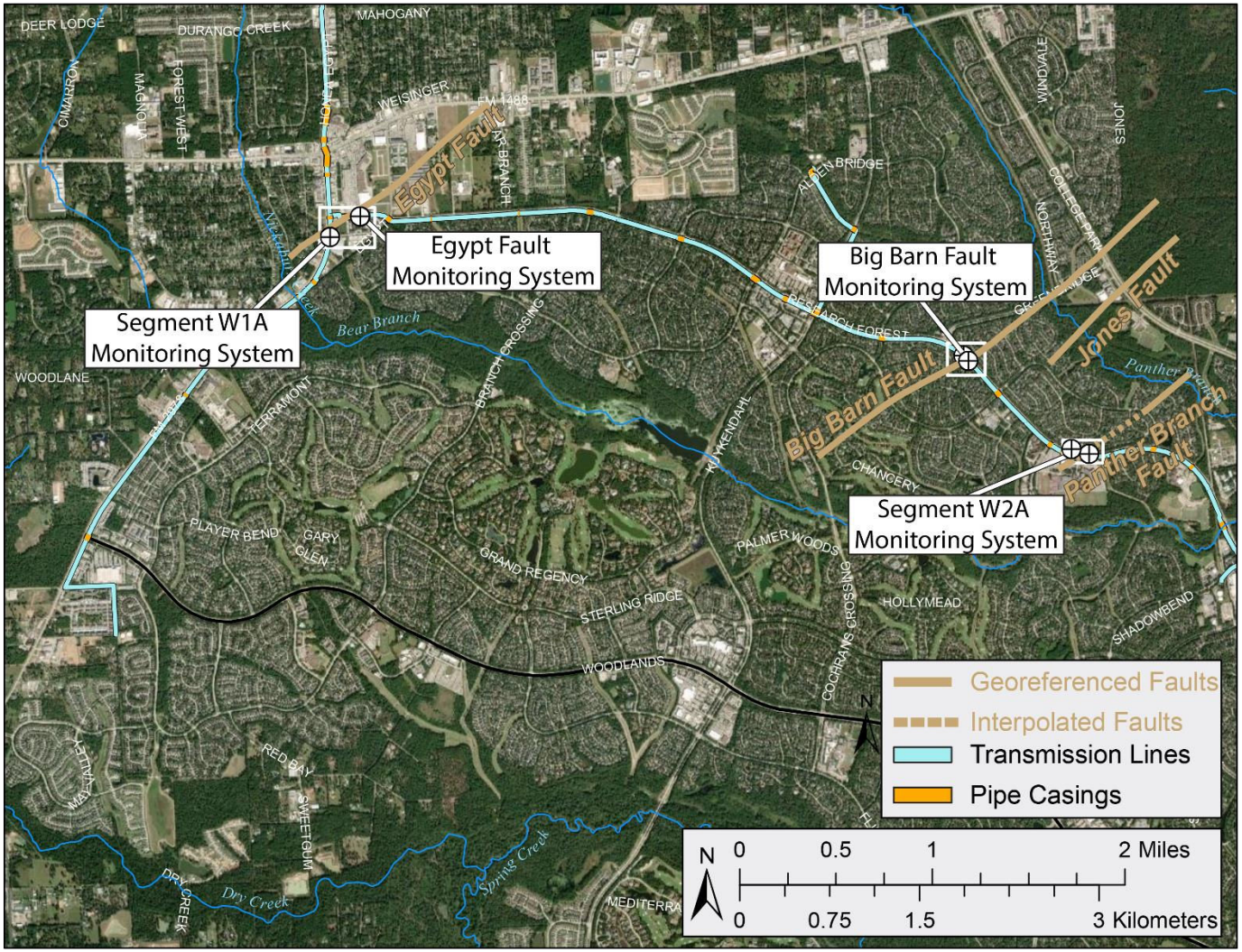



Figure 2 Satellite map showing the location of the SJRA water line, the fault locations mapped by Fugro (2012), and SJRA monitoring systems

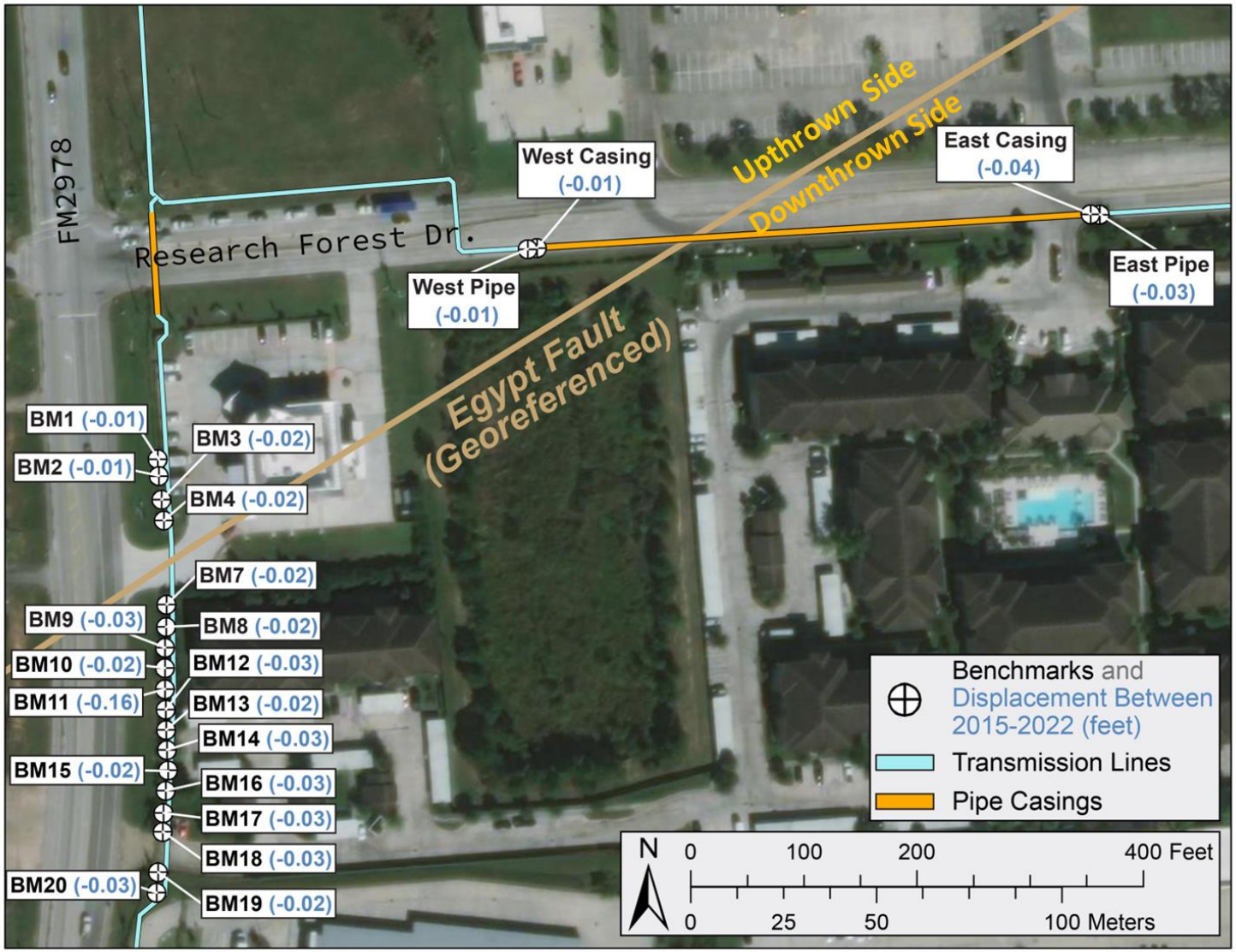



Figure 3 Satellite map showing the location of the Egypt Fault (Fugro, 2012), the W1A monitoring locations and calculated vertical displacement from March 2015 to March 2022 and the SJRA water line and pipe casing.

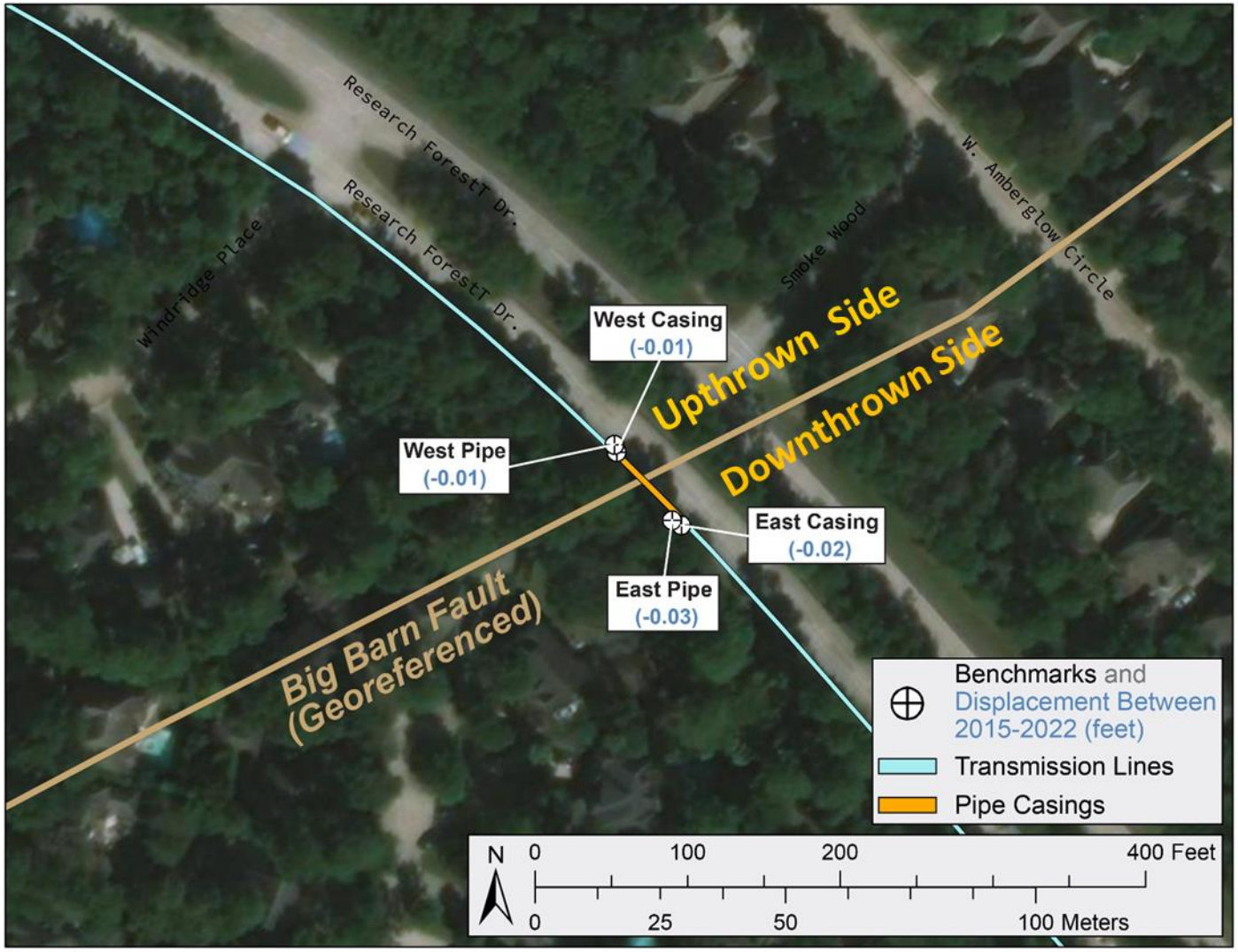



Figure 4 Satellite map showing the location the Big Barn Fault (Fugro, 2012), the Big Barn Fault Monitoring System, calculated vertical displacement from March 2015 to March 2022, and the SJRA water line and pipe casing

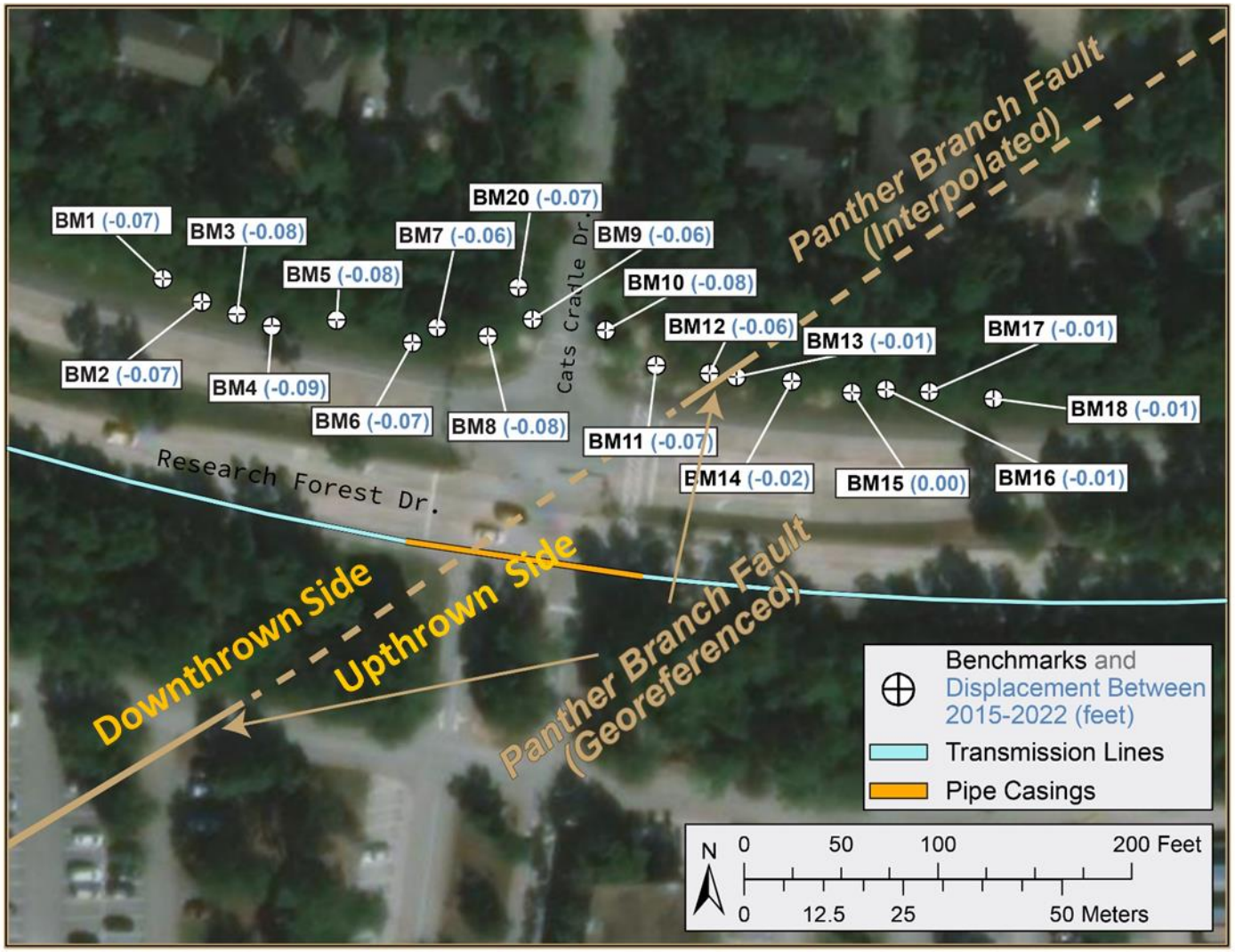



Figure 5 Satellite map showing the location the suspected Panther Branch Fault mapped by INTERA, the Segment W2A Monitoring System, calculated vertical displacement from March 2015 to March 2022, and the SJRA water line and pipe casing.

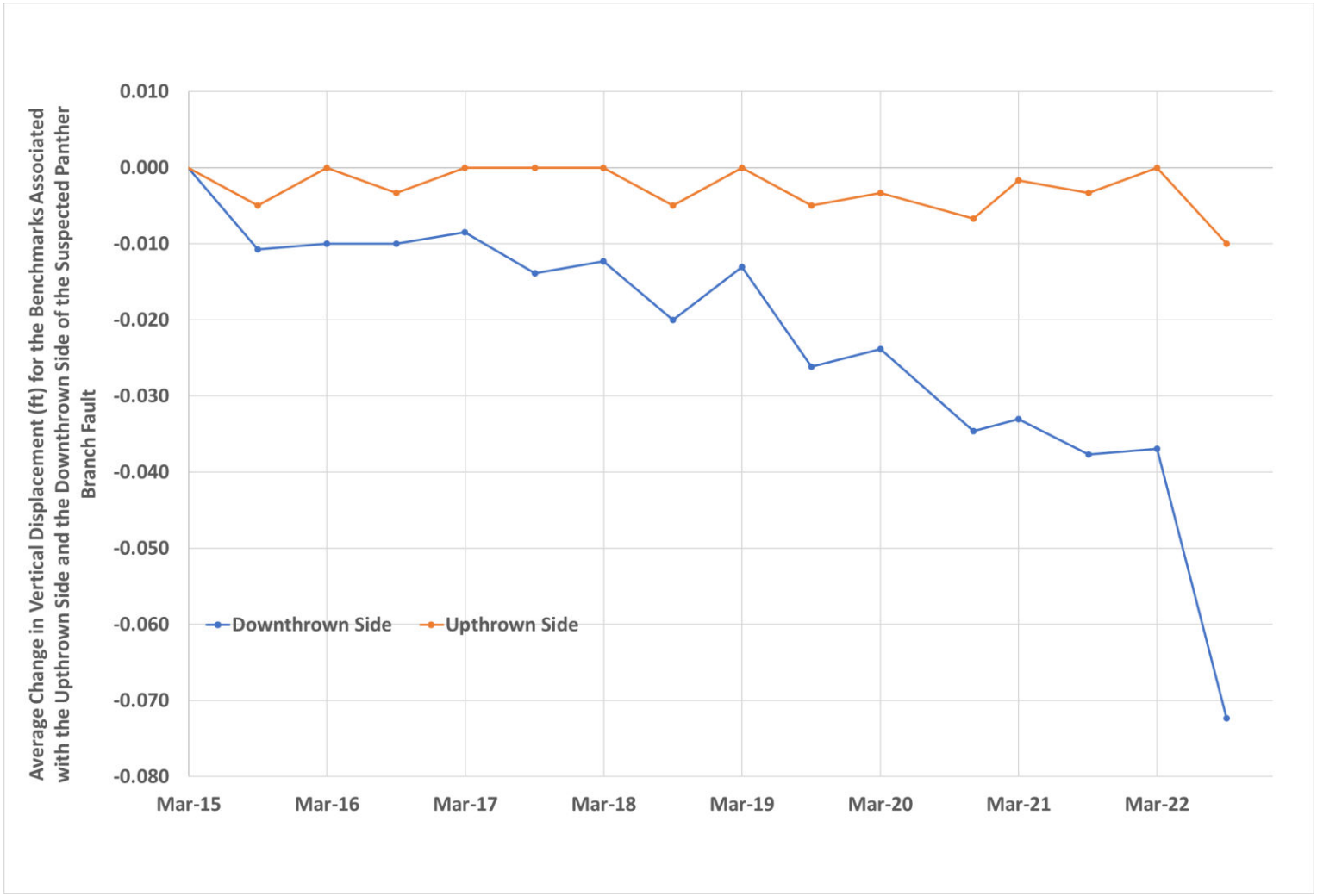



Figure 6 Comparison of average vertical displacement for the benchmarks located on the upthrown side and the downthrown side of the suspected Panther Branch Fault associated with the Segment W2A Monitoring System.

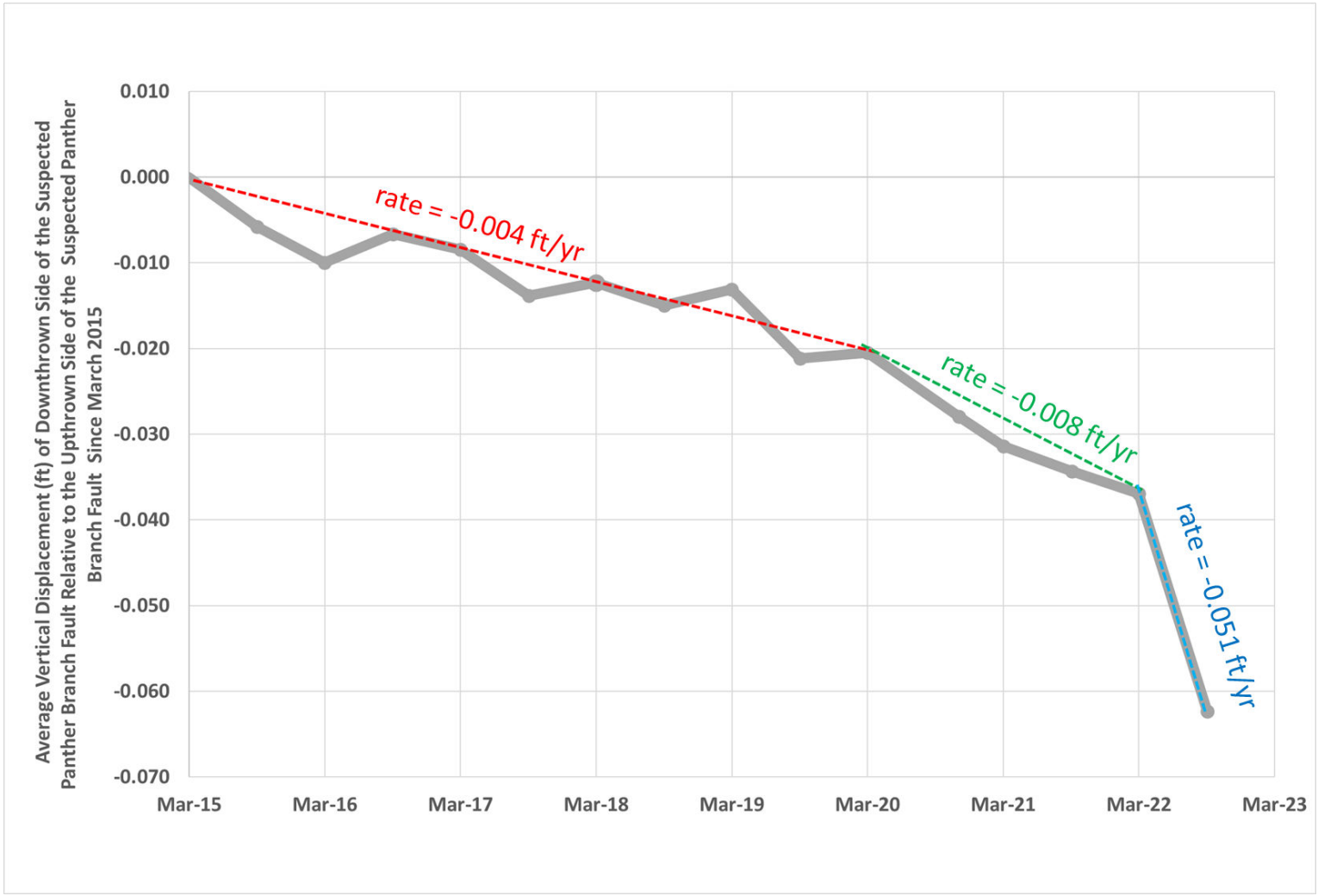



Figure 7 Relative vertical displacement and rates for relative vertical displacement for the downthrown side of the suspected Panther Branch Fault based on benchmarks associated with the Segment W2A Monitoring System