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Technical Memorandum

To: Mr. Rick DiSalvo
From: Lance Heyer, EI
Thomas A. Chapel, PE
Company: S. M. Stoller Corporation
Date: March 29, 2013
Re: Instrumentation and Monitoring, Rocky
Flats OLF
Tt Project #: 114-181750

Introduction

This technical memorandum provides a summary and evaluation of data collected from inclinometer and piezometer instrumentation at the Rocky Flats Original Landfill (OLF). Previously collected data has been updated with information collected during 2012 and the beginning of 2013. Data from piezometers located on the outside of the inclinometer casings were also reviewed and evaluated for possible correlation with the inclinometer data. Background information regarding the results of the geotechnical investigation conducted in 2008 (Tetra Tech 2008) during which the inclinometers were installed has been provided in our previous technical memorandums and is not repeated here (Tetra Tech, 2010, Tetra Tech, 2011).

Background

Minor localized surface cracking, differential settlement, slumping and subsidence has been previously documented at the site, and similar minor distress may have continued during 2012, albeit to a lesser extent. Figure 1, Plan View of OLF Site, shows the locations of the localized cracking, slumping and settling, seeps, test pits for the 2008 geotechnical investigation and the inclinometers. A summary of performance of the instruments prior to this reporting is provided in the following sections for clarity.

Instrumentation and Monitoring

Water level and inclinometer readings began on April 13, 2008. Piezometers are located near the base of each inclinometer tube and on the outside of the tube within each borehole. Piezometers were grouted in place according to standard practice for this type of instrument at the time each borehole was grouted as required to encase the inclinometer tube. The piezometers include automatic data loggers set to take readings at even intervals. The readings can be converted to water levels using the manufacturers' calibration curves. Hourly data readings were logged from April 2008 through late December 2008. On December 22, 2008 S.M. Stoller decided to switch to daily readings in order to increase the battery life of the data logger. The daily reading interval has been used since December 22, 2008.

Deflections of the inclinometers were manually read approximately monthly throughout each year, starting on April 13, 2008. Inclinometer readings are obtained by inserting a 32 inch long probe

into the inclinometer tube, and taking electronic readings of the vertical and horizontal orientation of the instrument at one foot intervals along the length of the tube. Wheels on the top and bottom of the probe align the measurement instrument in precise grooves along the length of the tube. Inclinometer readings are taken in two perpendicular directions created by the orientation of the grooves, relative to the A-axis and the B-axis of the inclinometer tube. The direction of the slope movement is indicated by the relative movement of each inclinometer tube along both the A and B-axes. A lack of movement along both axes indicates a stable slope. Due to the length and diameter of the probe, large inclinometer tube deflections and deformations can prevent the probe from being inserted over the full length of the tube. Large enough deflections can cause the tube to break, also preventing insertion of the probe beyond the point of the break. The data for the inclinometers is included in Attachment A. Coupled inclinometer and piezometer graphs are included in Attachment C.

Piezometers Tt-2, Tt-4 and Tt-5 began to show erratic readings in the summer of 2008. Piezometers Tt-3 and Tt-7 began to show erratic readings in November 2008 and January 2009, respectively. Piezometer Tt-3 has shown erratic readings from April 2010 to present. The readings were considered erratic because the fluctuations varied more than half a foot within a one hour time period. As noted by S.M. Stoller the Tt-5 and Tt-7 data loggers stopped receiving data during 2011 and the Tt-4 and Tt-6 data loggers stopped receiving data during October 2012 and November 2012, respectively. Piezometer Tt-1 is the only piezometer with readings that have remained reliable to date. Piezometers, Tt-2, Tt-3, Tt-4, Tt-6, and Tt-7 have had periods of unreliability coupled with periods of reasonable readings. It is not clear whether the lack of data logger data, or erratic and unreliable readings are the result of instrument failure, problems with response of the inclinometer to changing water levels, or other causes such as fluctuating water levels over time above and below the level of the piezometer.

Piezometer data for Tt-1, Tt-2, Tt-4, Tt-6, and Tt-7 followed logical trends during 2011 without excessive variations between readings. Similarly, logged piezometer data for Tt-1, Tt-4 and Tt-6 followed logical trends during 2012 without excessive variations between readings. Piezometer data for Tt-2 followed a logical trend from April 2012 to January 2013 before experiencing a spike in the data during February and early-March 2013. Due to large discrepancies between daily readings, piezometer data for Tt-3 is unreliable after 4/25/2010. Tt-5 data is very erratic and only a few readings appear reliable during April and May of 2011. Piezometer data for Tt-5 and Tt-7 were not available during 2012. For ease of viewing, the unreliable data are not plotted on graphs in Attachment C. For completeness, the unfiltered data are presented in Attachment D.

Little movement was observed for any of the inclinometers from April 2008 to April, 2009. Following a period of heavy precipitation in April 2009 deflections became apparent. The largest deflections were noted in inclinometers Tt-2, Tt-3 and Tt-4, on the western edge of the OLF. This was the area with the most pronounced differential settling, slumping and surface cracking observed in 2007.

Inclinometer Tt-2 was installed to a depth of 34 feet. Sometime after the August 19, 2009 reading, slope movement resulted in inclinometer tube deformation or breakage and the inclinometer could not be read below a depth of 25 feet. Therefore, subsequent readings have been taken to a depth of 25 feet.

Inclinometer Tt-3 was installed to a depth of 38 feet. Slope movement at this location also resulted in inclinometer tube deformation or breakage, and the inclinometer could not be read below a depth of 33 feet. Therefore, subsequent readings have been taken to a depth of 33 feet.

Inclinometer Tt-4 was installed to a depth of 28 feet. Slope movement at this location also resulted in inclinometer tube deformation or breakage after April 19, 2010, and the inclinometer could not be read below a depth of 14 feet. Therefore, subsequent readings have been taken to a depth of 14 feet.

The deformed or broken casing likely indicates movement of the slope at or near the location of the break/obstruction. For the inclinometer in Tt-2, the depth at which the casing deformed or broke corresponds with the depth in the boring where soft clay was found. For the inclinometer in Tt-3, the casing is deformed or broken at a depth of 33 feet, which corresponds to a location in the subsurface where the geologic materials changed from sandy gravelly clay to claystone bedrock. For inclinometer in Tt-4, the casing is deformed or broken at a depth of 14 feet, near the location in the subsurface where the geologic materials changed from sandy clay with gravel to sandy claystone bedrock with gravel at 12 feet. The 2008 geotechnical investigation concluded that the slope failures were occurring in this weak clay layer that is below the landfill deposits, on top of or in the upper portions of the bedrock. It is our opinion that monitoring of the inclinometers at the OLF should continue, in order to monitor the relative movement over time to the depths that can be measured.

Tetra Tech noted previously that in general, there is a correlation between water in the subsurface and the movement that is occurring at the OLF. Some of the change in the subsurface water condition is likely related to recharge of the upper hydrostratigraphic unit that occurs well upgradient of the OLF, and some of the change is due to an influx of water into the subsurface in the vicinity of the OLF. The relative influence of these two sources on the movement that is occurring is not known. Measures that are undertaken to decrease infiltration of surface water in the immediate vicinity of the OLF will not affect the up-gradient infiltration and therefore will not impact movement that results from up-gradient infiltration. However, the general decrease in movement recorded by the inclinometers during 2012 may be related to a gradual stabilization as a result of improvements made to the drainage features on the OLF that were constructed by S.M. Stoller in 2009.

Not each one of the boreholes/piezometers/inclinometers show correlation between water levels measured and movement that has occurred. The inclinometers were read periodically, at intervals that differed from the interval that the piezometers' data were being automatically logged. The piezometer data were recorded at a much shorter interval (either hourly or daily, as described above), so as the piezometers recorded increases and decreases in the water level over short time periods. The inclinometers were read approximately monthly during these time periods, therefore a correlation between the piezometer readings and inclinometer readings may not have been apparent.

The precipitation in the area was measured by S.M. Stoller using on-site devices during the period of record for the inclinometers and piezometers. S.M. Stoller has noted that some inaccuracy of the measurements is likely during events when significant snowfall accumulates on the devices. When significant snow accumulates some of the snow may blow or fall off the device instead of accumulating in the device. In addition, the gauges are not heated; therefore winter readings are not considered as accurate as summer readings. Graphs prepared by S.M. Stoller show monthly average precipitation values during 2012 and are included in Attachment B. In general, the graphs show that during the period of record for these piezometers and inclinometers, precipitation at the site was higher between April and September and lower between October and March.

The Location of each borehole instrumented with piezometers and inclinometers is shown on Figure 1. The specifics of each borehole/piezometer/inclinometer are discussed below when significant changes occurred during the reporting interval. A lack of comment on a particular time interval indicates that the performance of the instrumentation during the intervening period was not interpreted as being significant, or was reported during a previous interval. Graphs showing the water levels measured by piezometers and movement of each axis of the inclinometers are shown in Attachment C. In cases where unusually erratic and/or widely variable piezometer data resulted in a difficult to read graph, some of the data points were removed from the graphs to improve clarity. For completeness, data without these points removed are also presented in Attachment D.

Tt-1. Tt-1 was intentionally placed outside of the historical slide area. As was noted in the 2010 Technical Memorandum, there does not appear to be a relationship between piezometer readings and inclinometer readings for Tt-1. The inclusion of the 2012 data continues to support this conclusion. There is a very small increase in movement in the direction of the A and B-axes of the inclinometer during 2012.

Tt-2. The inclinometer readings for Tt-2 showed movements starting in May 2008 and continuing to 1.4 inches on the A-axis on July 22, 2009. This followed a spike in the high water level on 6/12/09. Readings for both A and B-axes show total movement to date of 2.7 inches on the A-axis and 1.8 inches on the B-axis. Little movement occurred between 4/26/2011 and 2/28/2013.

Tt-3. The piezometer data collected in 2010 is erroneous and indicates that the piezometer in Tt-3 is no longer functioning. The inclinometer data show that negligible movement occurred between 8/31/2011 and 2/28/2013.

Tt-4. The inclinometer readings in Tt-4 show movement in both axes starting in May 2009 and peaking in April 2010. The movement in both directions lagged behind a large increase in water level that occurred in the late spring and early summer of 2009. The movement in 2010 peaked again in June in both directions due to precipitation in April. Movement was nearly negligible from the summer of 2010 to present.

Tt-5. In 2010 the inclinometer showed an increase in movement in both directions with a peak in the summer months. The piezometer data show a sharp increase in the water level during this time period, although the magnitude of the water level increase suggests that the piezometer data are erroneous. The general correlation between a water level increase and inclinometer movement is consistent. Piezometer readings were erratic over the majority of 2011 and throughout 2012, however the movement recorded by the inclinometer follows the trend of increasing water level indicated by the piezometer from March 2009 to February 2012. Movement has been negligible along both A- and B-axes during 2012.

Tt-6. Following significant movement in the spring of 2010, subsequent movement and water level changes were small. However, an increase in recorded movement that occurred between February 2011 and August 2011 appears related to an increase in water level recorded during the same period. Movement along the A-axis displays a general increasing trend and has been negligible along the B-axis in 2012.

Tt-7. Overall, there has been a general trend for an increase in movement along the A- and B-axes. During 2011 the inclinometer indicated insignificant movement and piezometer measurements were erratic. During 2012 movement along the A-axis displays a general increasing trend and has been negligible along the B-axis.

Recommendations

The recommendations made in the original report (Tetra Tech, 2008) and our 2010, 2011 and 2012 Technical Memoranda remain valid. The instrumentation indicates that instability is caused by one or more weak layers in the shallow subsurface, and movement is exacerbated by precipitation events and elevated water levels. Slope stability modeling indicates the large scale, overall slope is stable. However, localized failures have occurred on the OLF under elevated water level conditions. A reduction in the water level alone is not considered adequate to ensure the long term stability of the slope, however it is possible that the reduced movements recorded by inclinometers during 2012 are related to drainage improvements constructed at the OLF during the same time frame. Continued monitoring and regular maintenance of distress are recommended, however it is not necessary to continue readings on piezometers that have stopped functioning.

Limitations

The above opinions and recommendations are based on a reasonable degree of certainty. This report has been prepared based upon a review of climate, weather and design documents, field investigation and testing, geotechnical engineering analyses, site visits, and our experience. The conclusions represent our best judgment based on the information available. Should additional information become available we should be allowed to review that information and modify our conclusions accordingly.

References

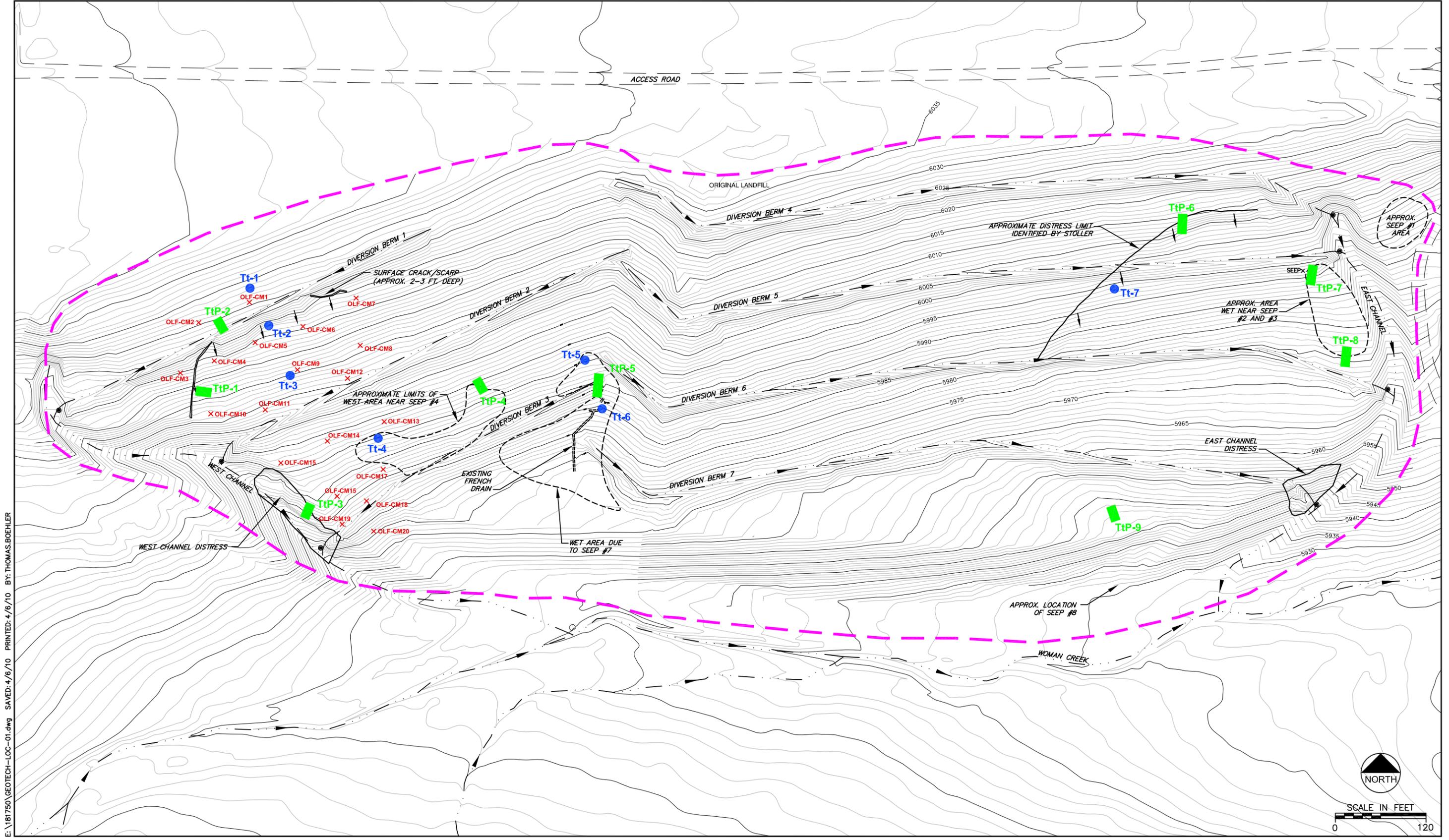
Tetra Tech, Inc. 2008. Rocky Flats Original Landfill Geotechnical Investigation Report. Jefferson County, Colorado. June.

Tetra Tech, Inc. 2010 Technical Memorandum, Instrumentation and Monitoring, Rocky Flats OLF, April.

Tetra Tech, Inc. 2011 Technical Memorandum, Instrumentation and Monitoring, Rocky Flats OLF, April.

Tetra Tech, Inc. 2012 Technical Memorandum, Instrumentation and Monitoring, Rocky Flats OLF, April.

Figure



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Project No. 181750

April 2010



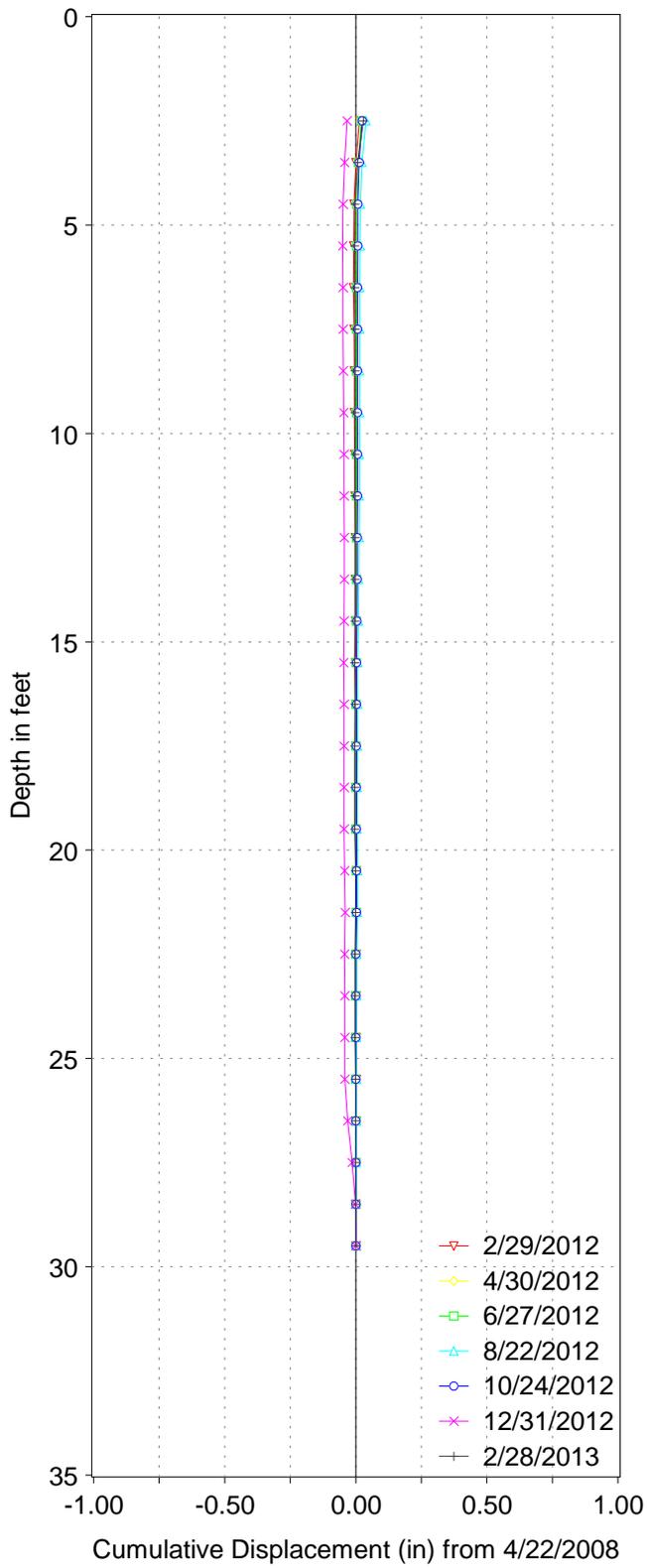
LEGEND:

- - - - -	DITCH/CHANNEL/CREEK	— — — — —	APPROXIMATE LIMITS OF GEOTECHNICAL INVESTIGATION
↓ ↓ ↓	SLUMP OR SUBSIDENCE LINE AND DIRECTION	■	TEST PIT LOCATION
== == ==	ROAD	●	TEST BORING AND INCLINOMETER LOCATION
×	SETTLEMENT MONUMENT (EXISTING)		

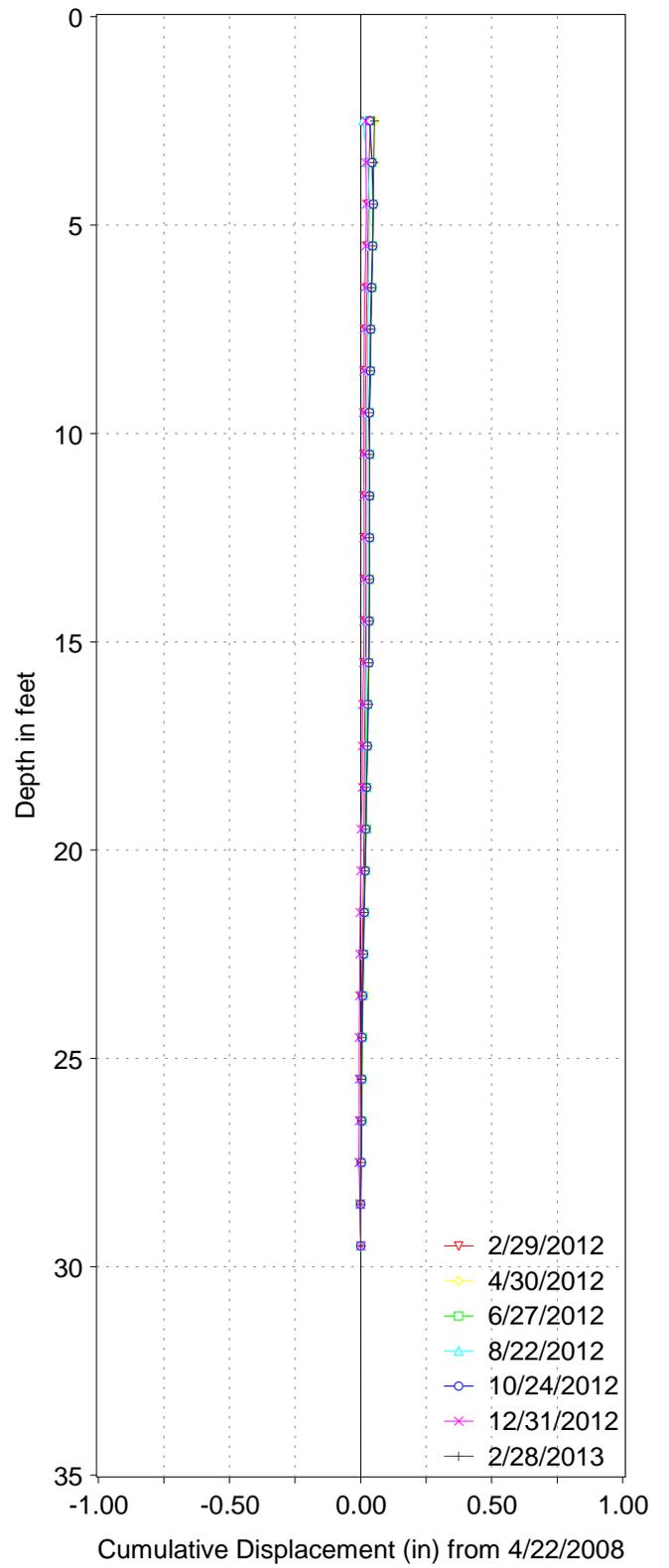
Figure 1
Plan View of OLF Site

Attachment A
Inclinometer Graphs

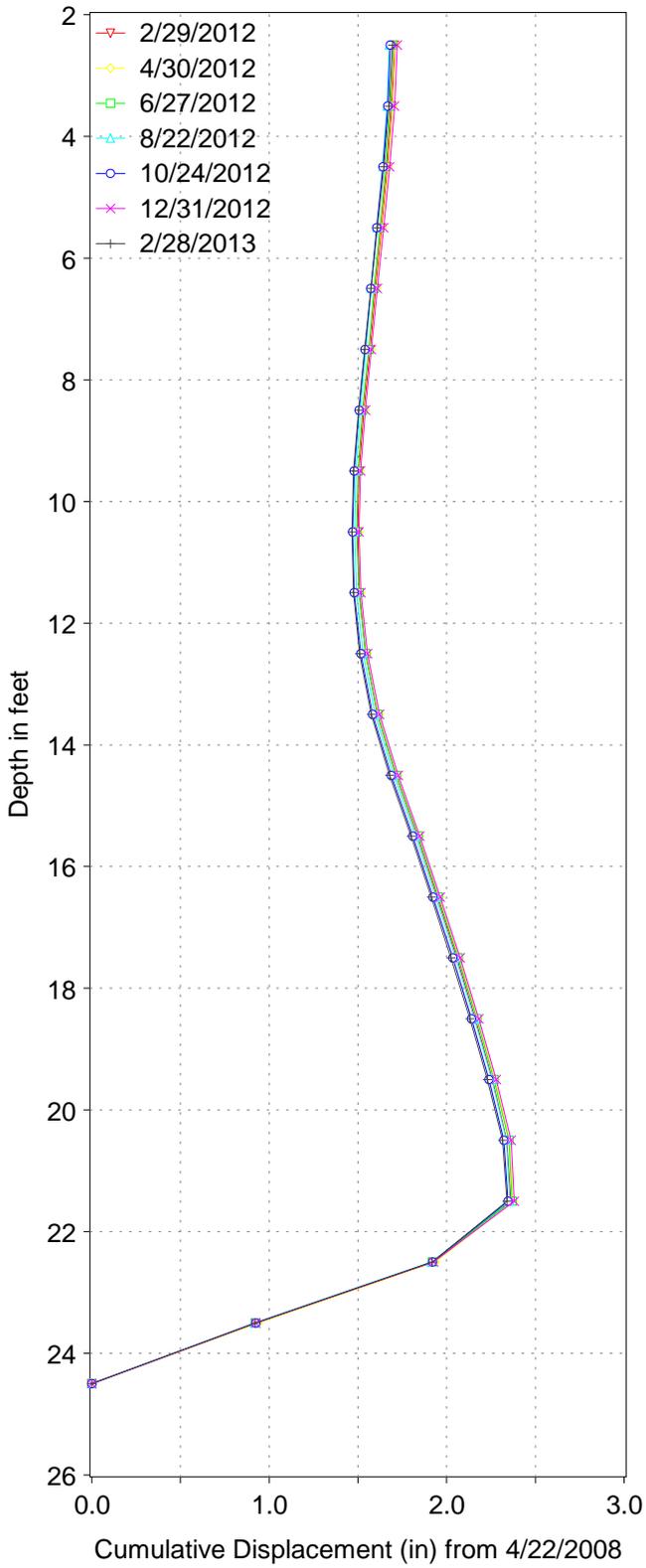
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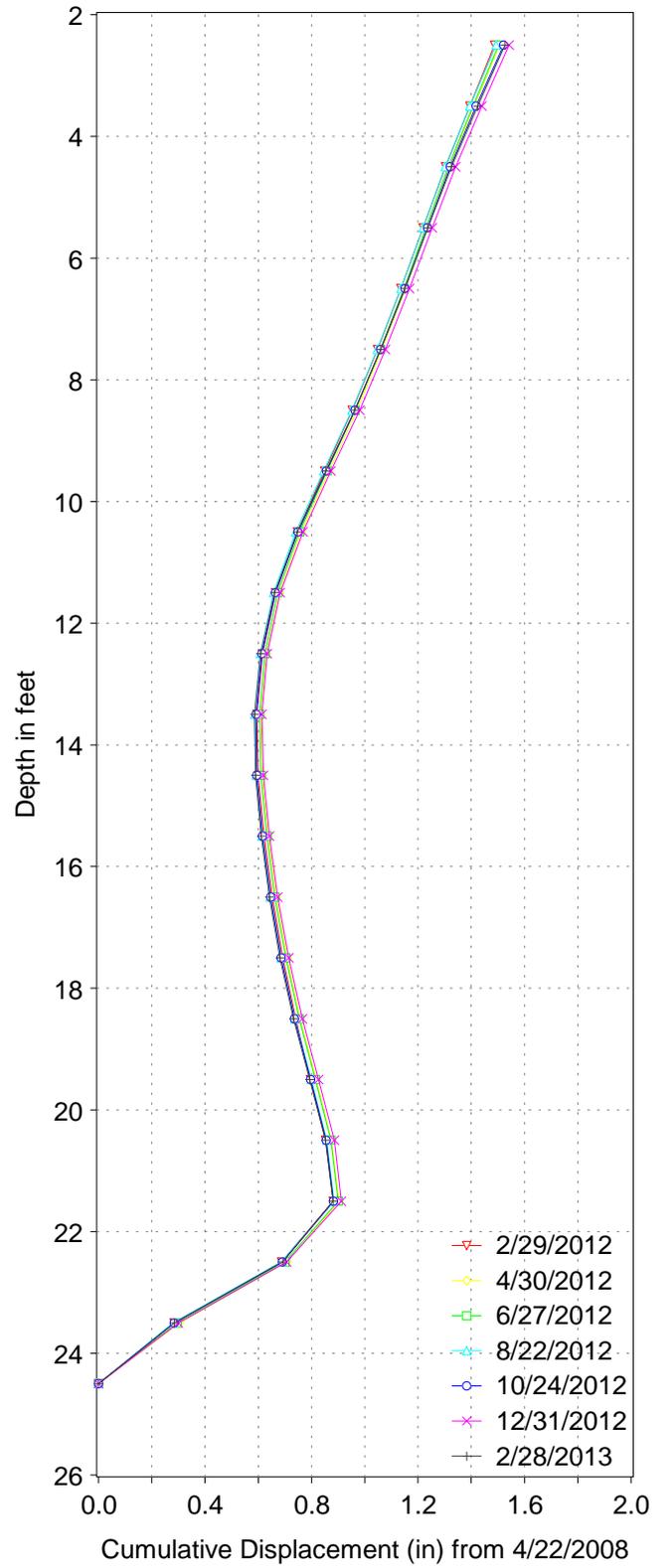
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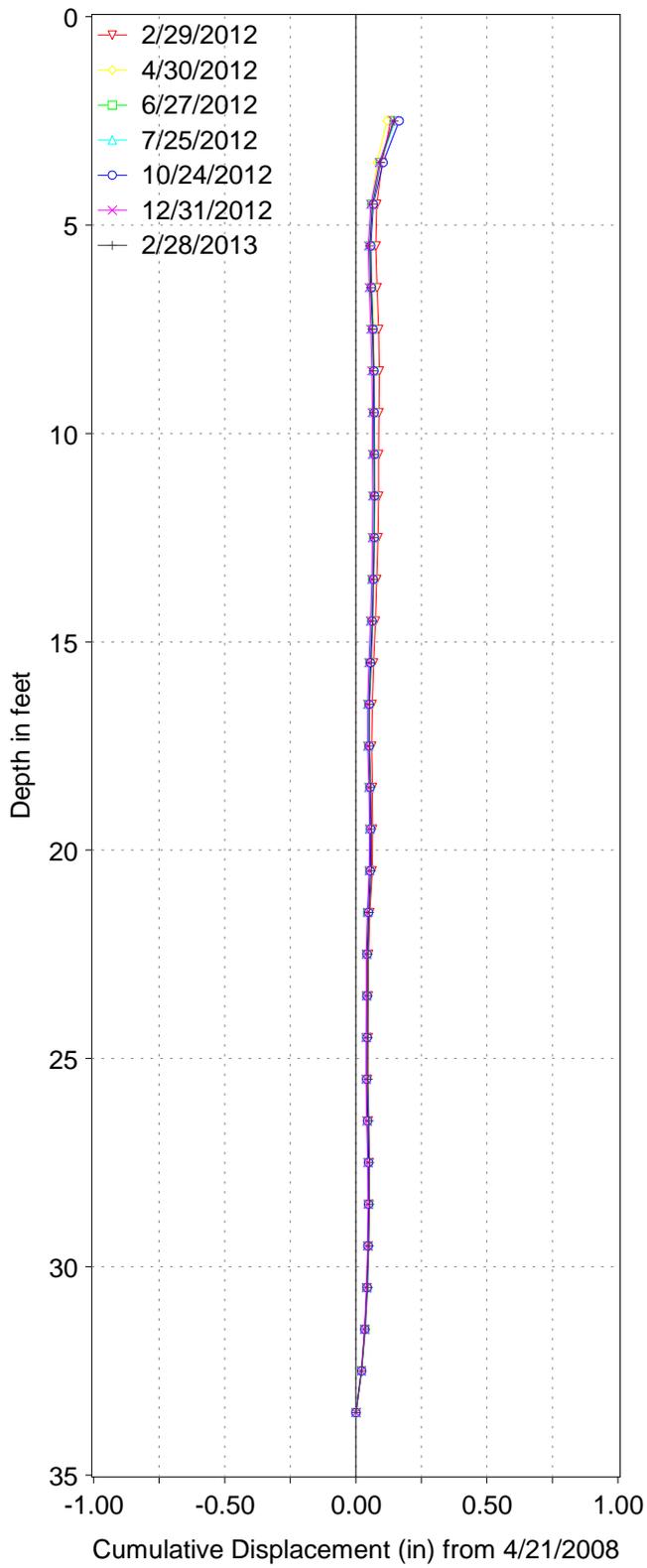
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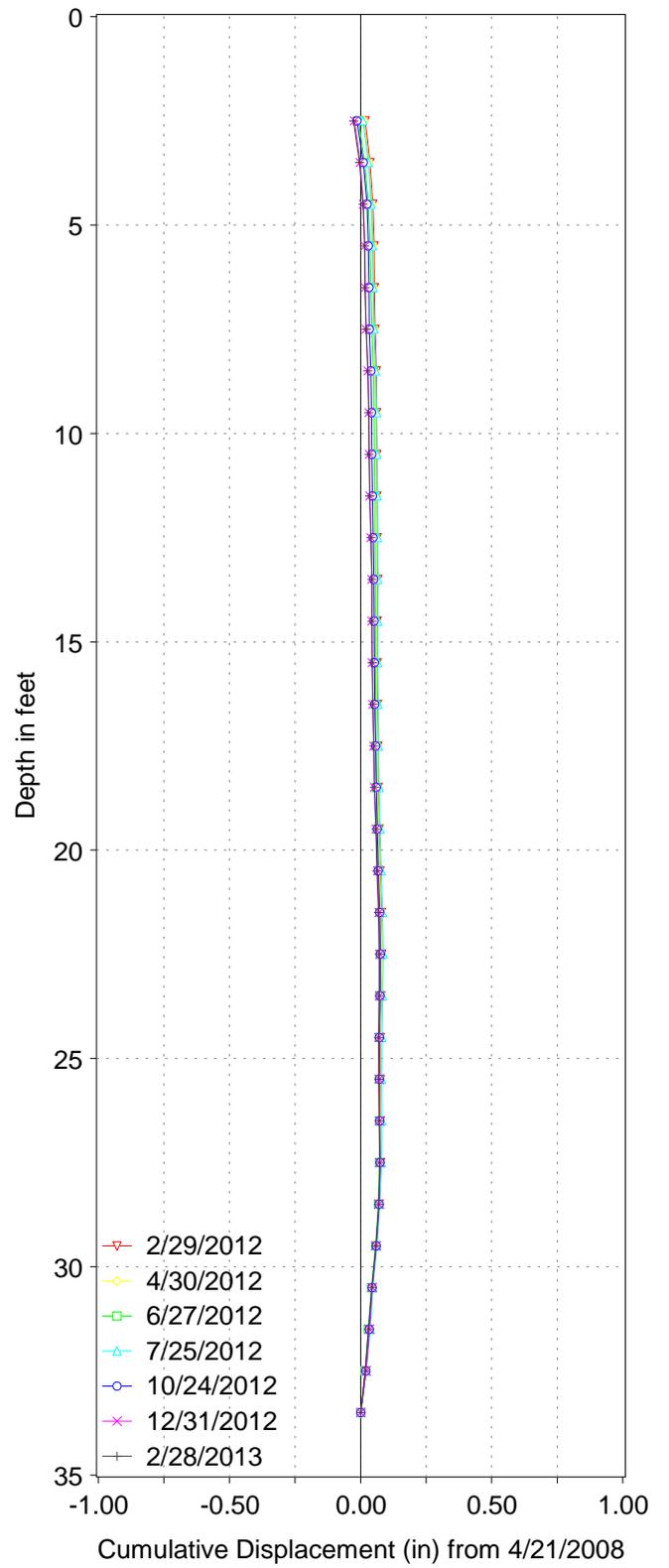
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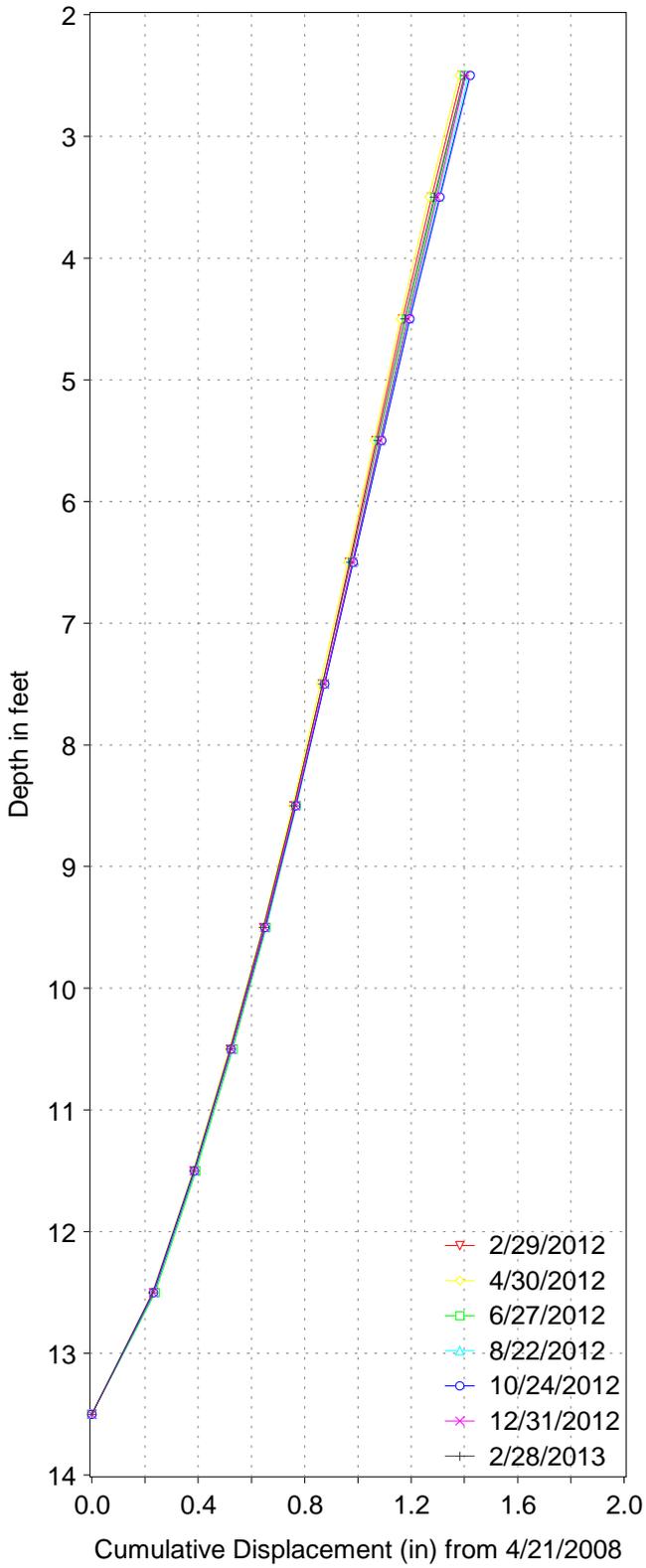
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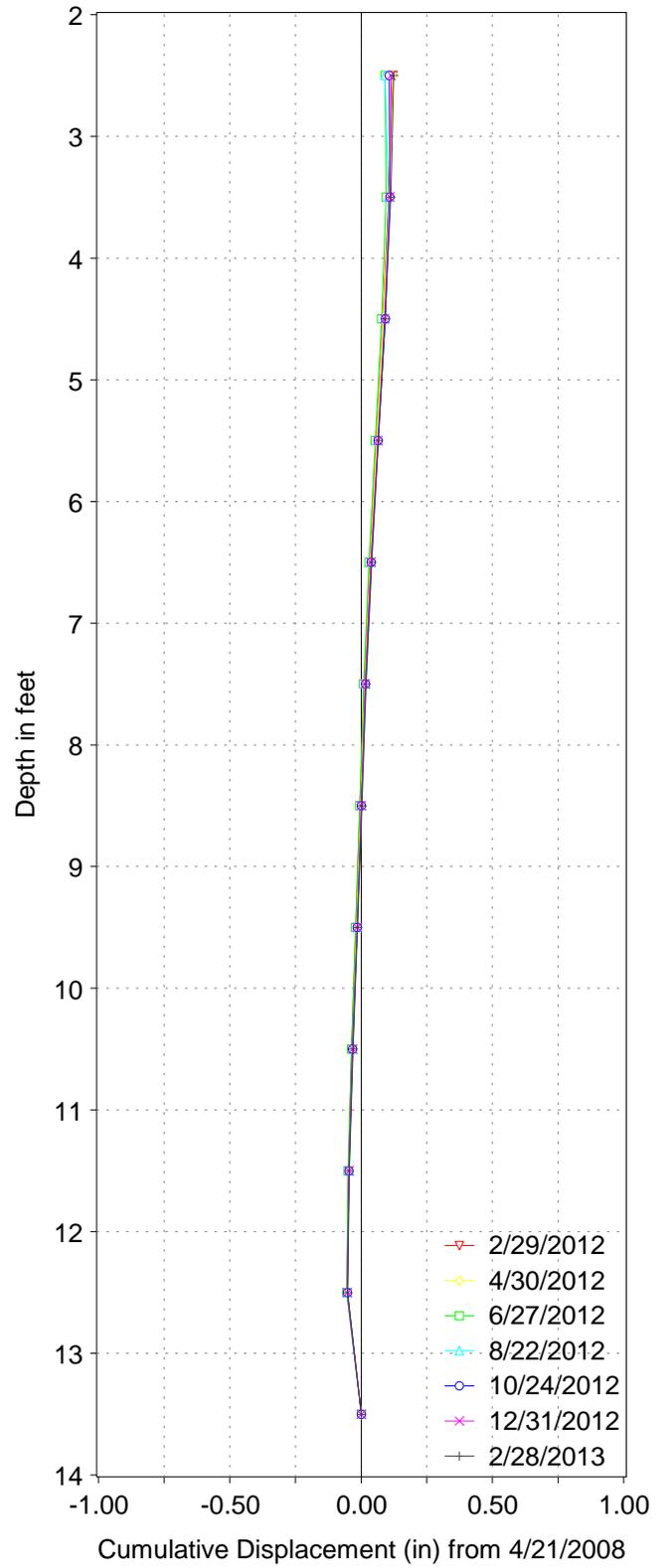
OLF 82308I, B-Axis



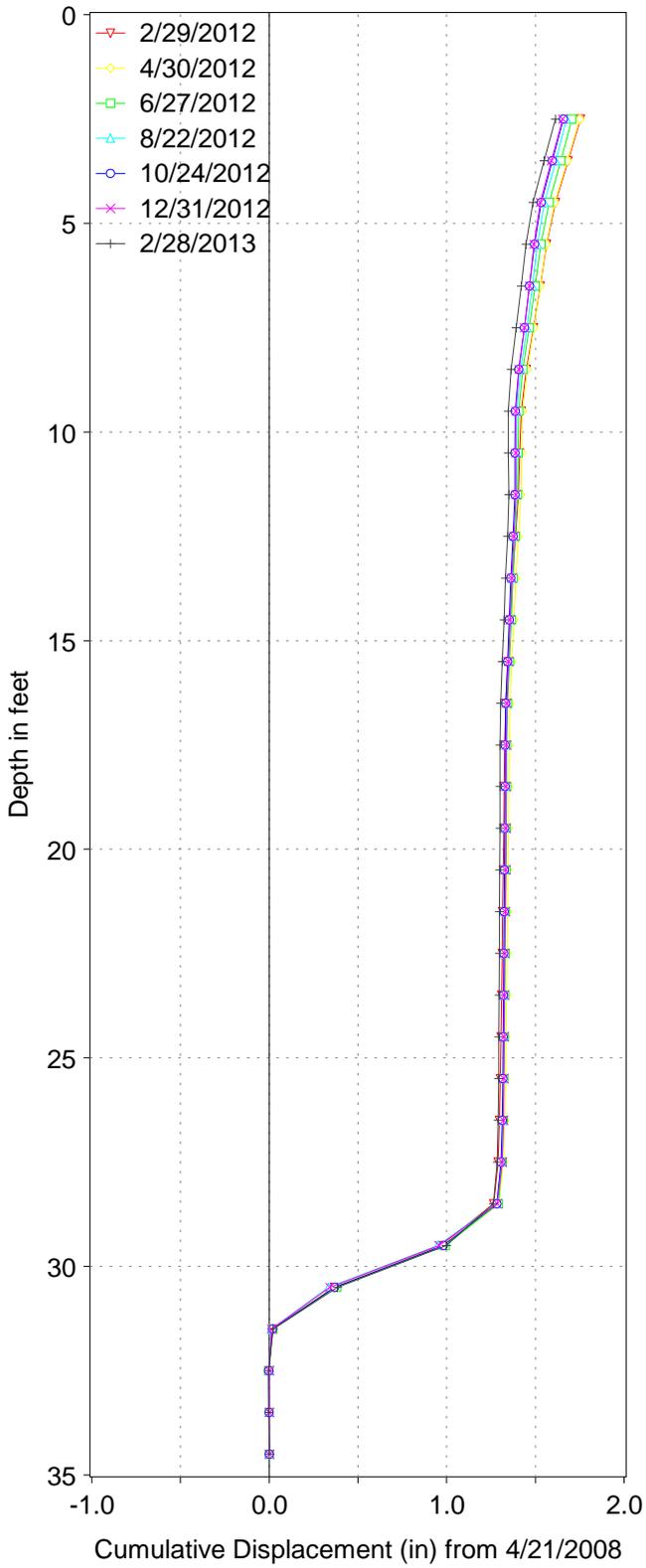
OLF 82408I, A-Axis



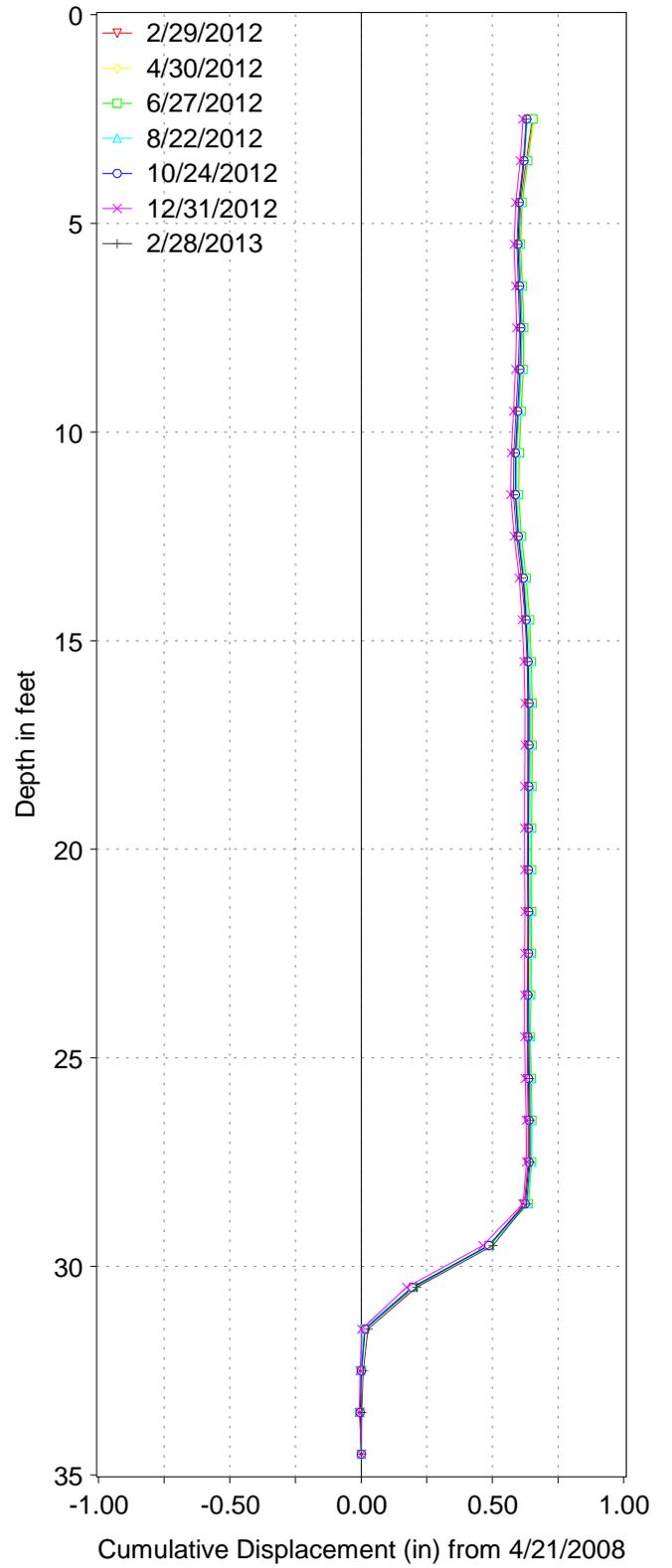
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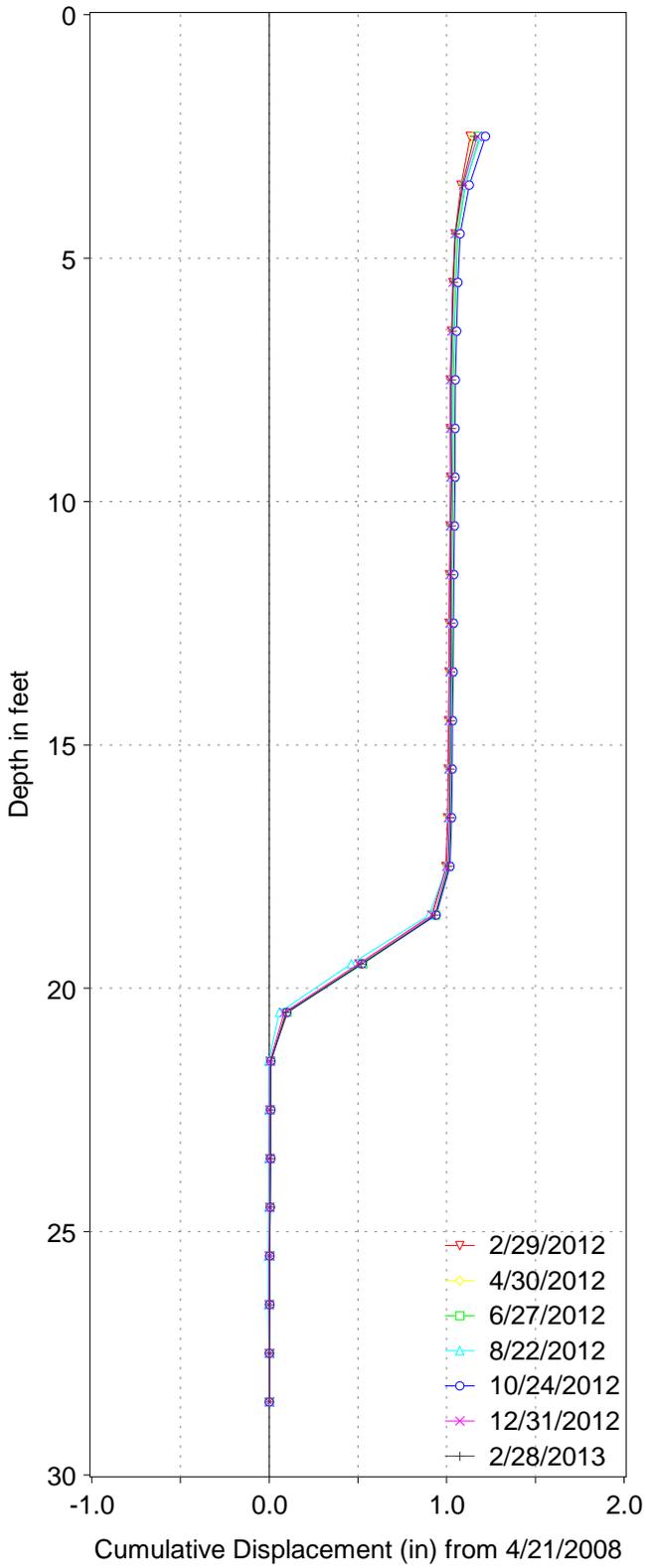
OLF 82508I, A-Axis



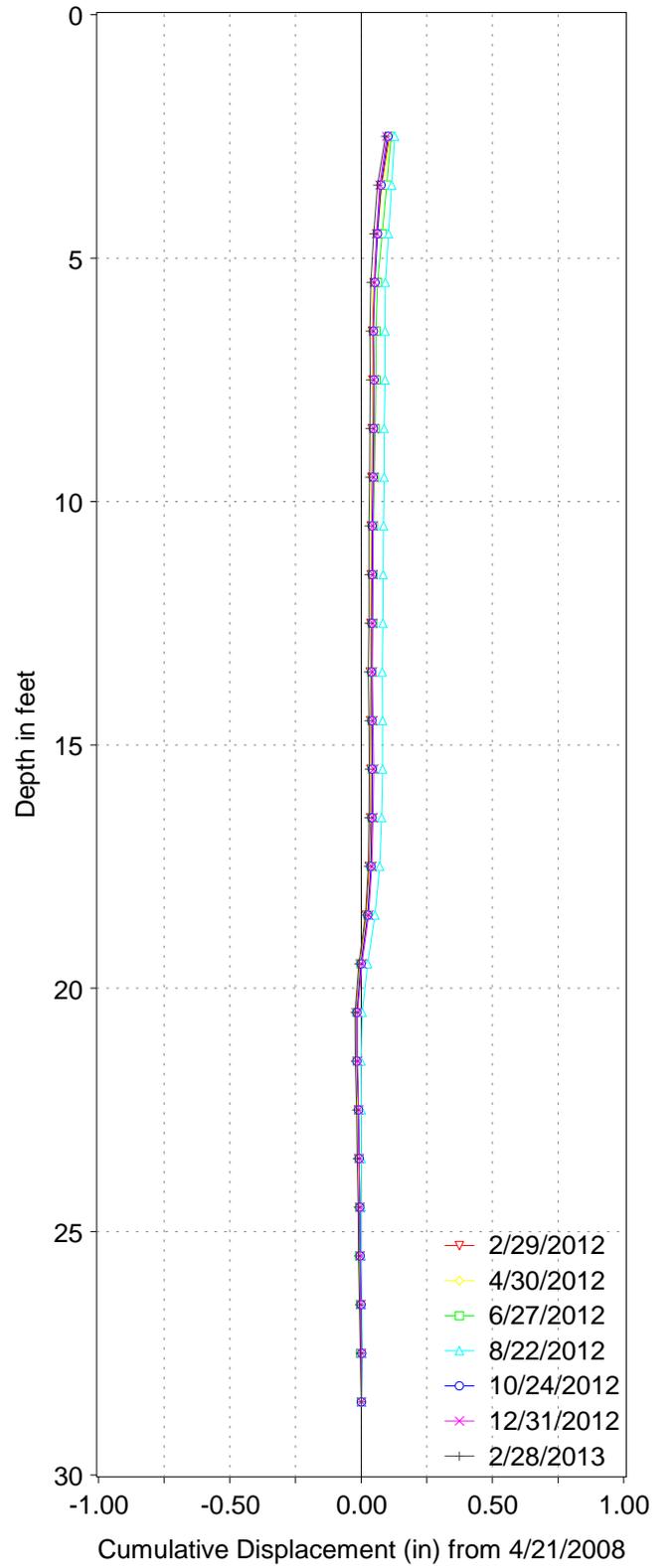
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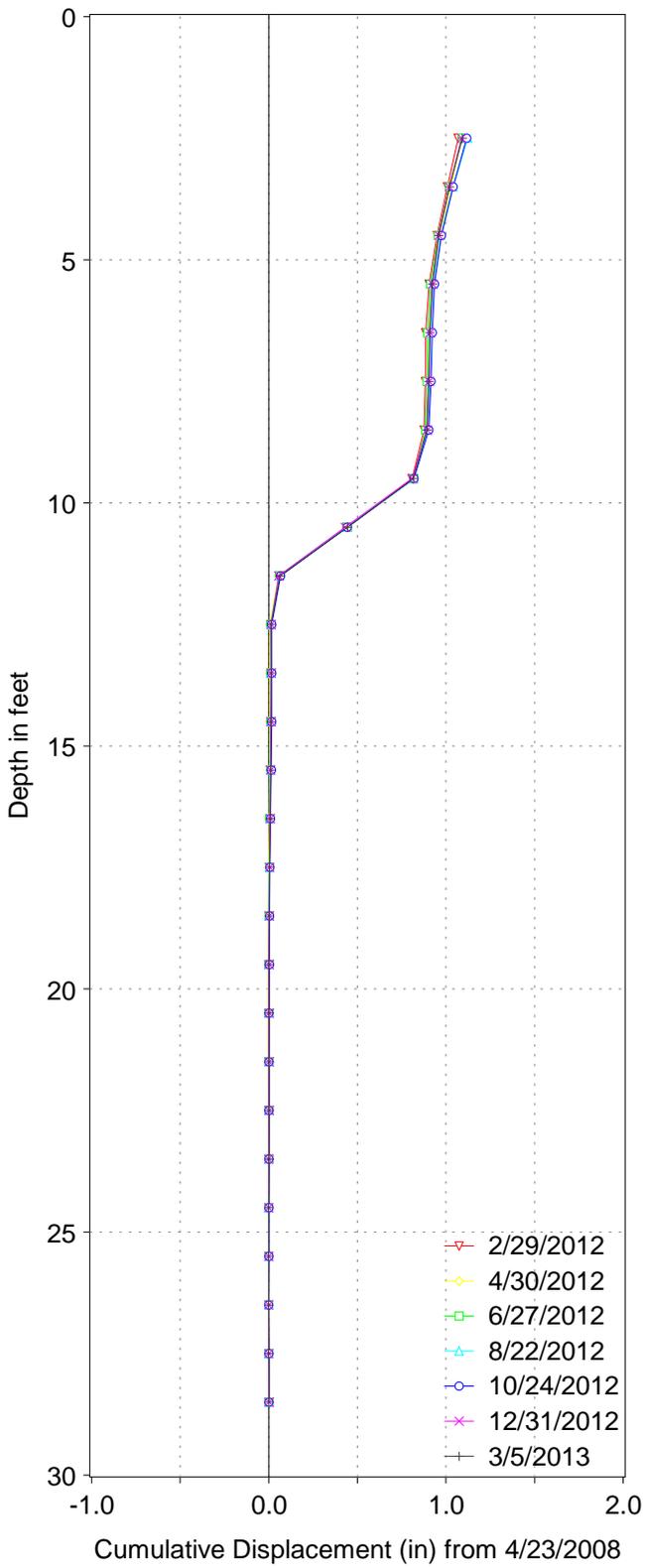
OLF 82608I, A-Axis



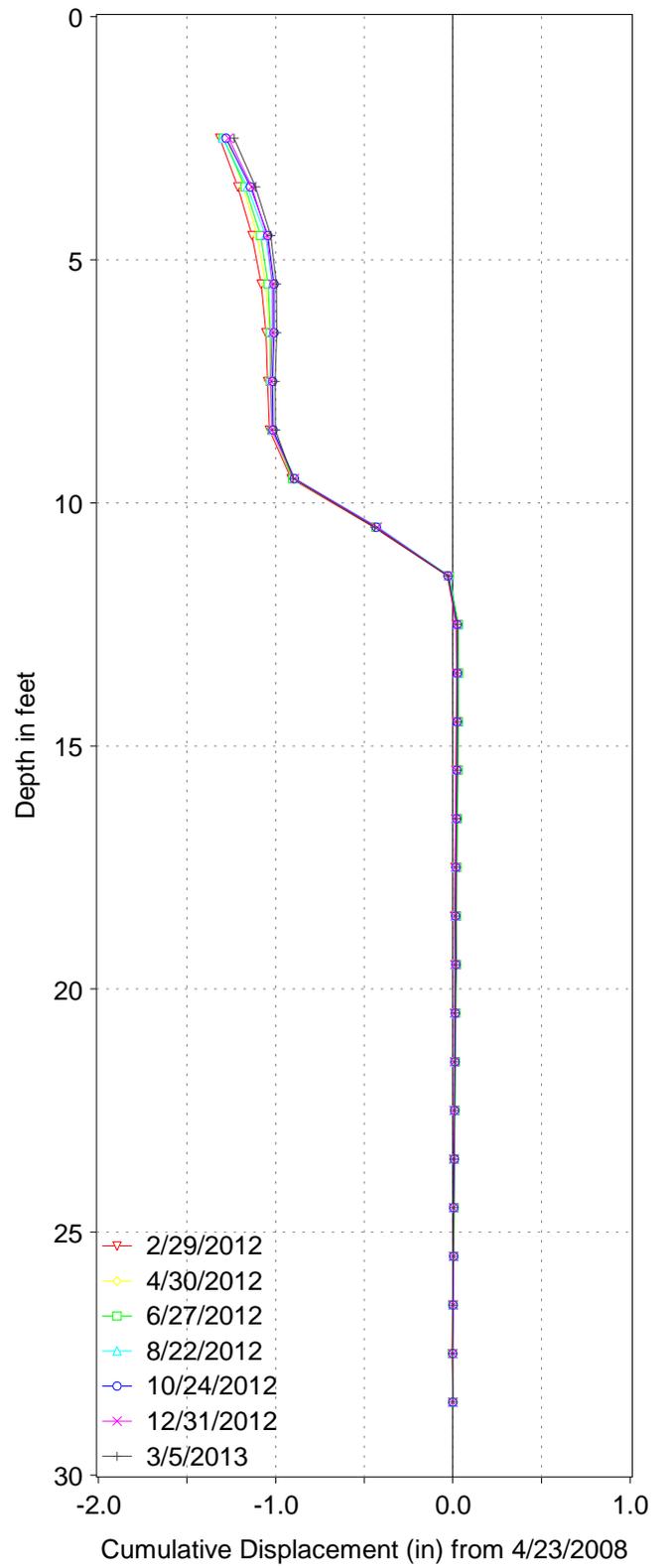
OLF 82608I, B-Axis



OLF 82708I, A-Axis



OLF 82708I, B-Axis



Attachment B
Precipitation Data

Precipitation by Month during 2012

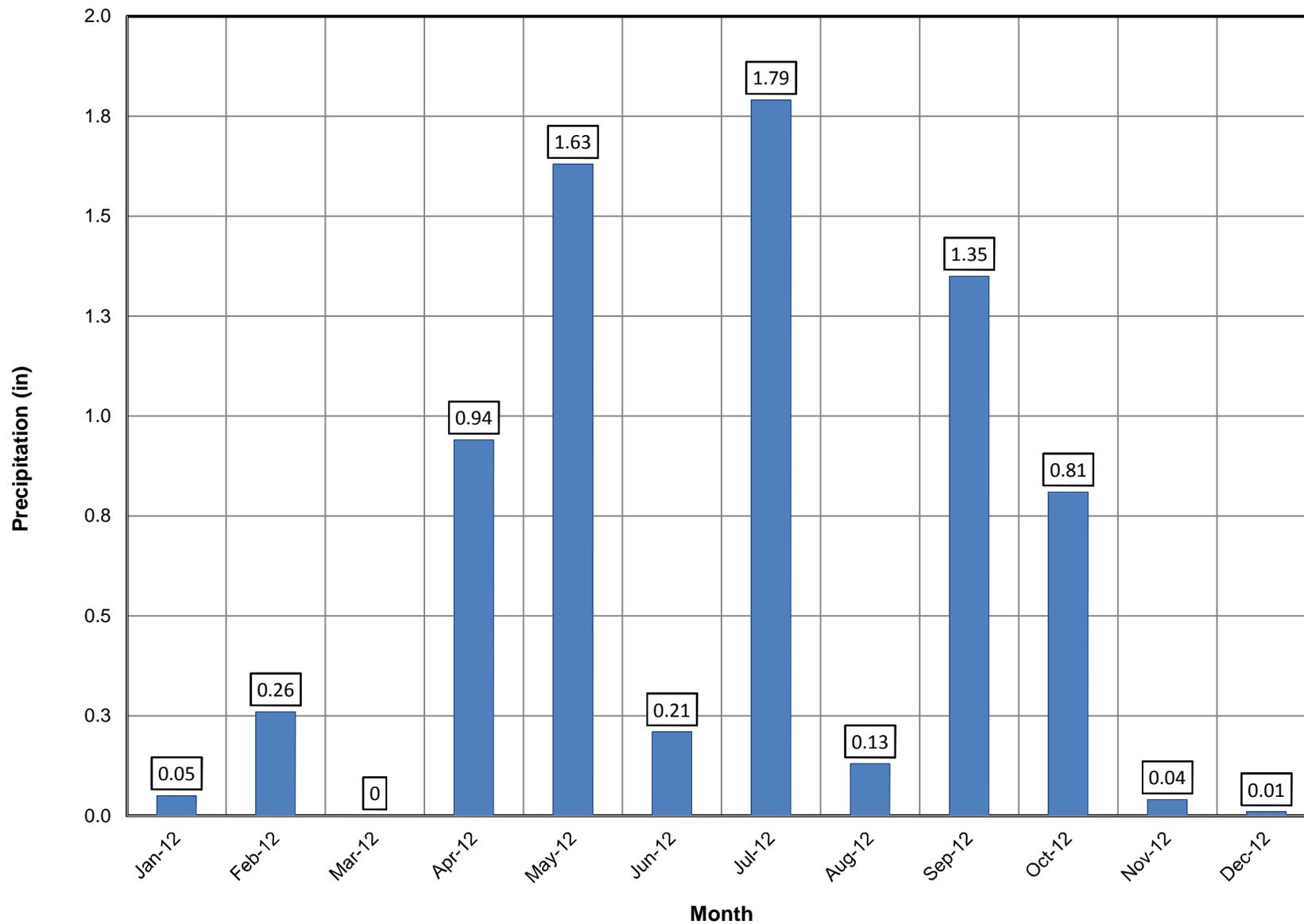


Figure B-1

Attachment C
Filtered Inclinator and Piezometer Data

Filtered Inclinometer and Piezometer Data: Tt-1

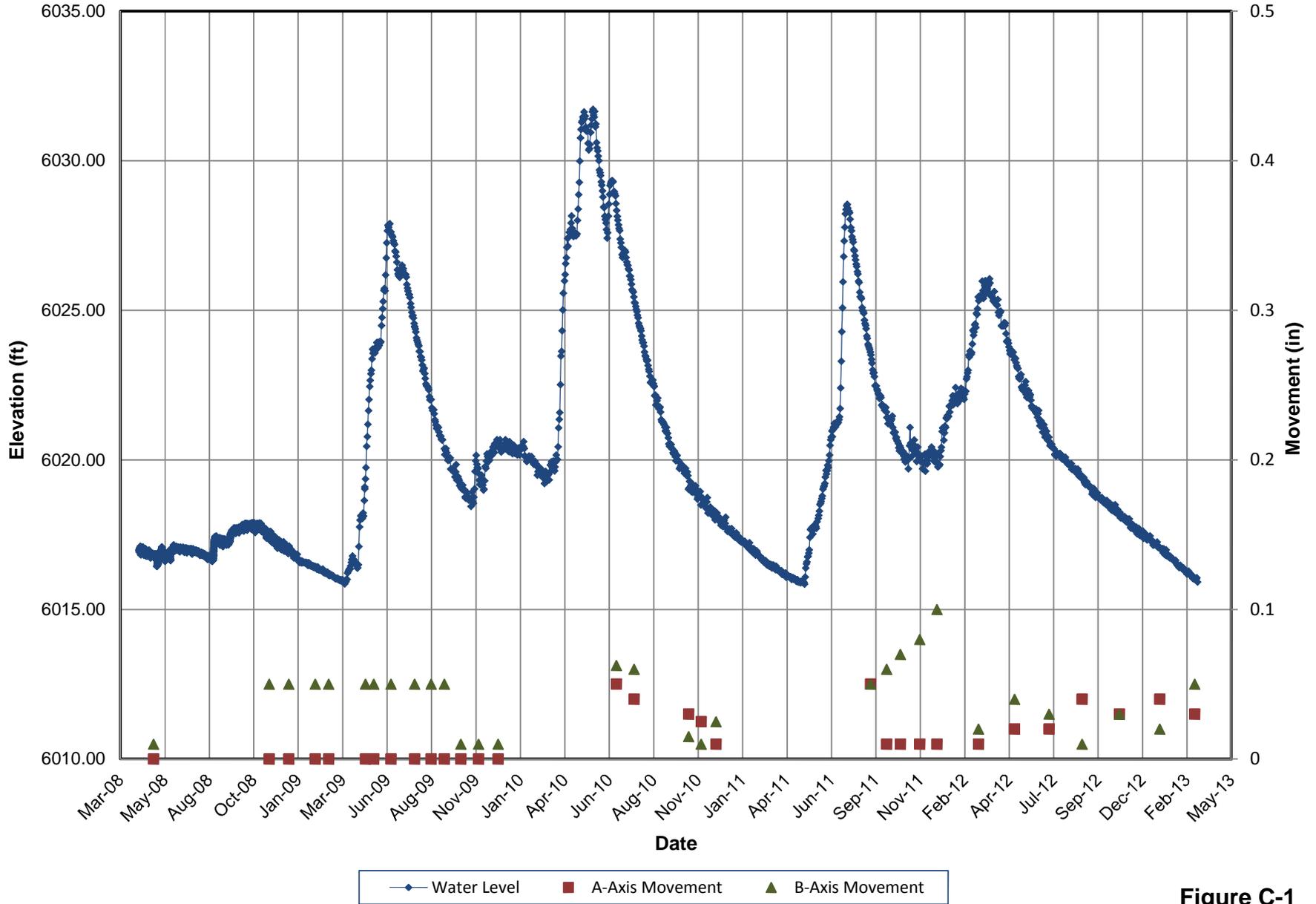


Figure C-1

Filtered Inclinometer and Piezometer Data: Tt-2

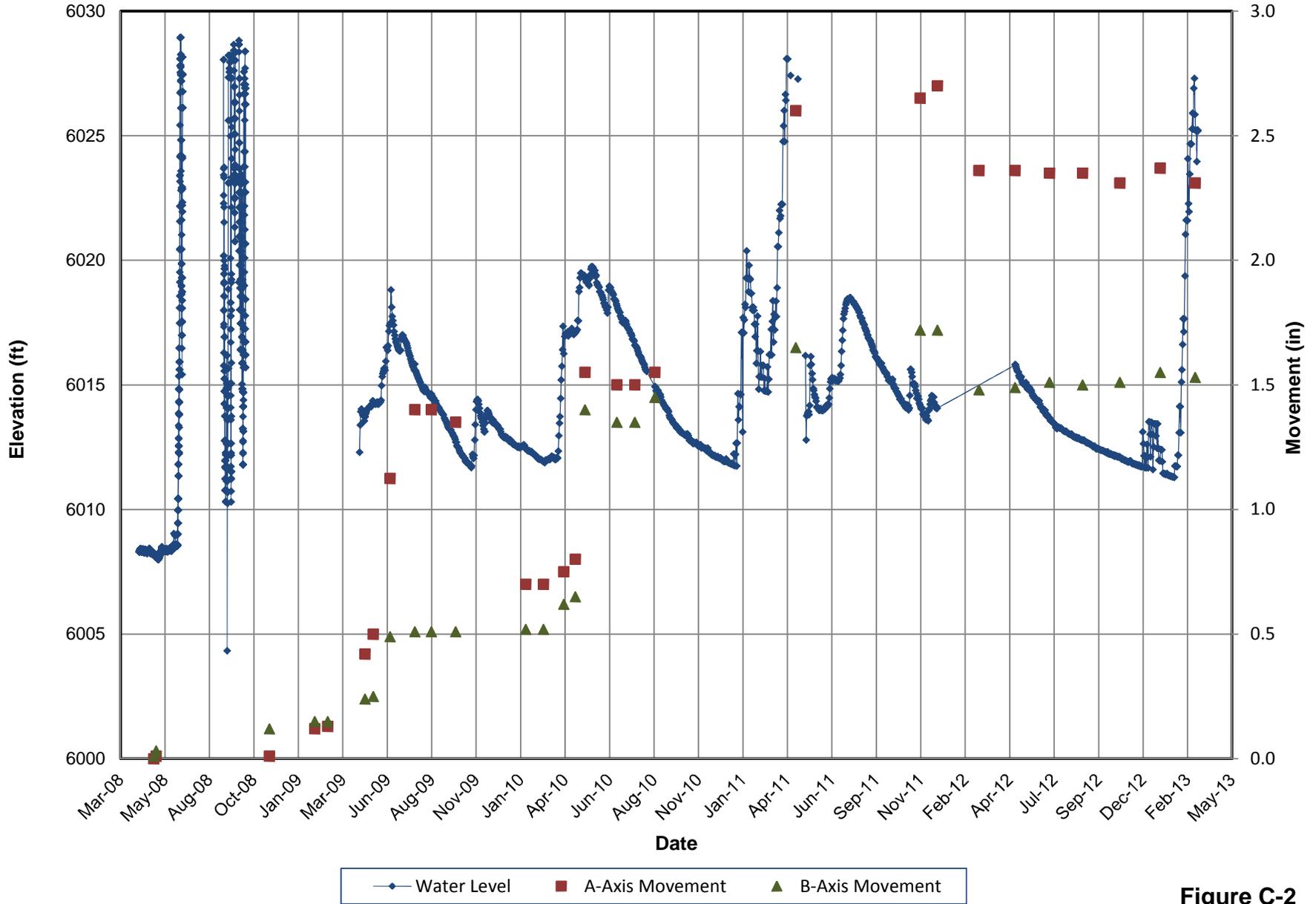


Figure C-2

Filtered Inclinometer and Piezometer Data: Tt-3

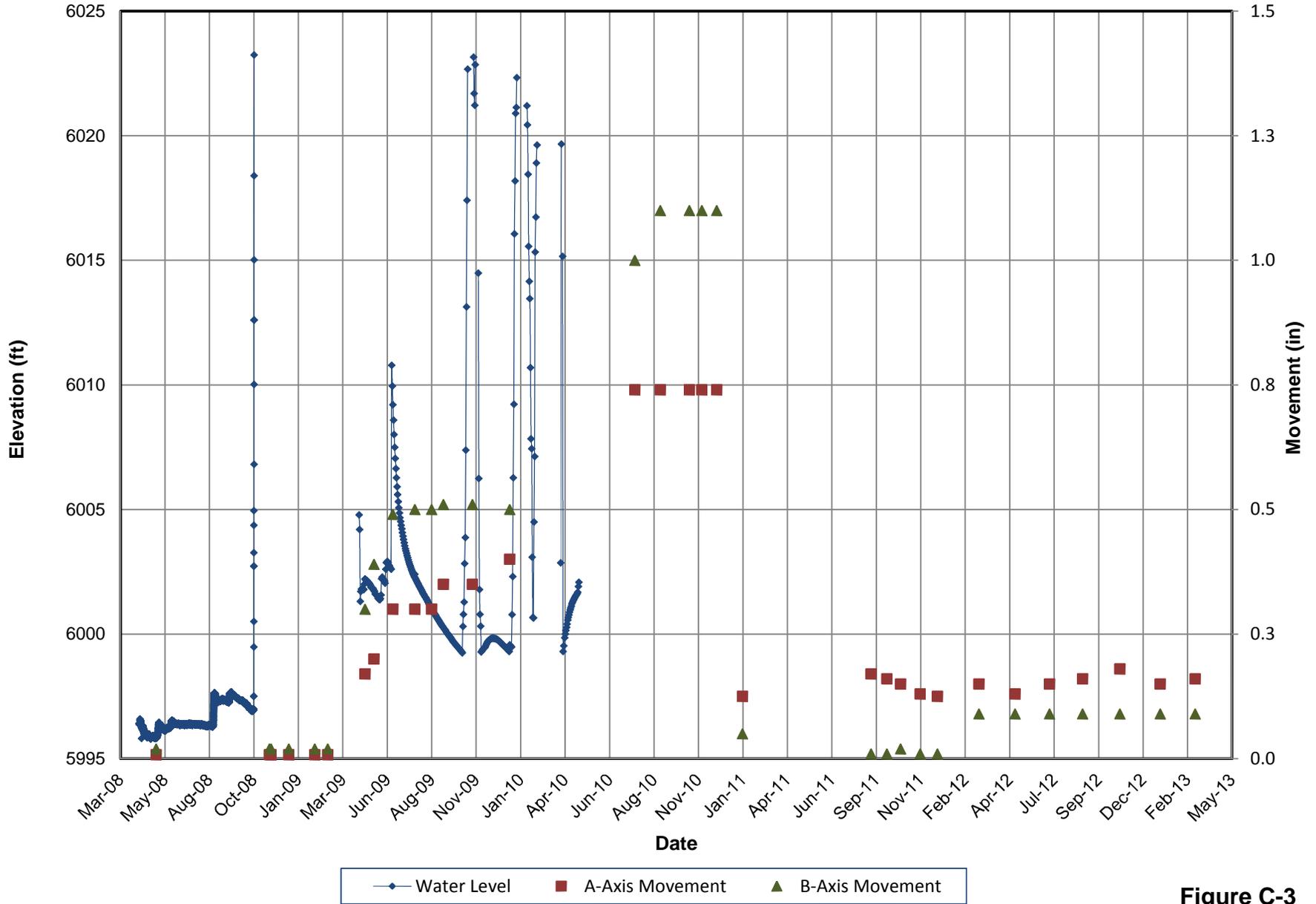


Figure C-3

Filtered Inclinometer and Piezometer Data: Tt-4

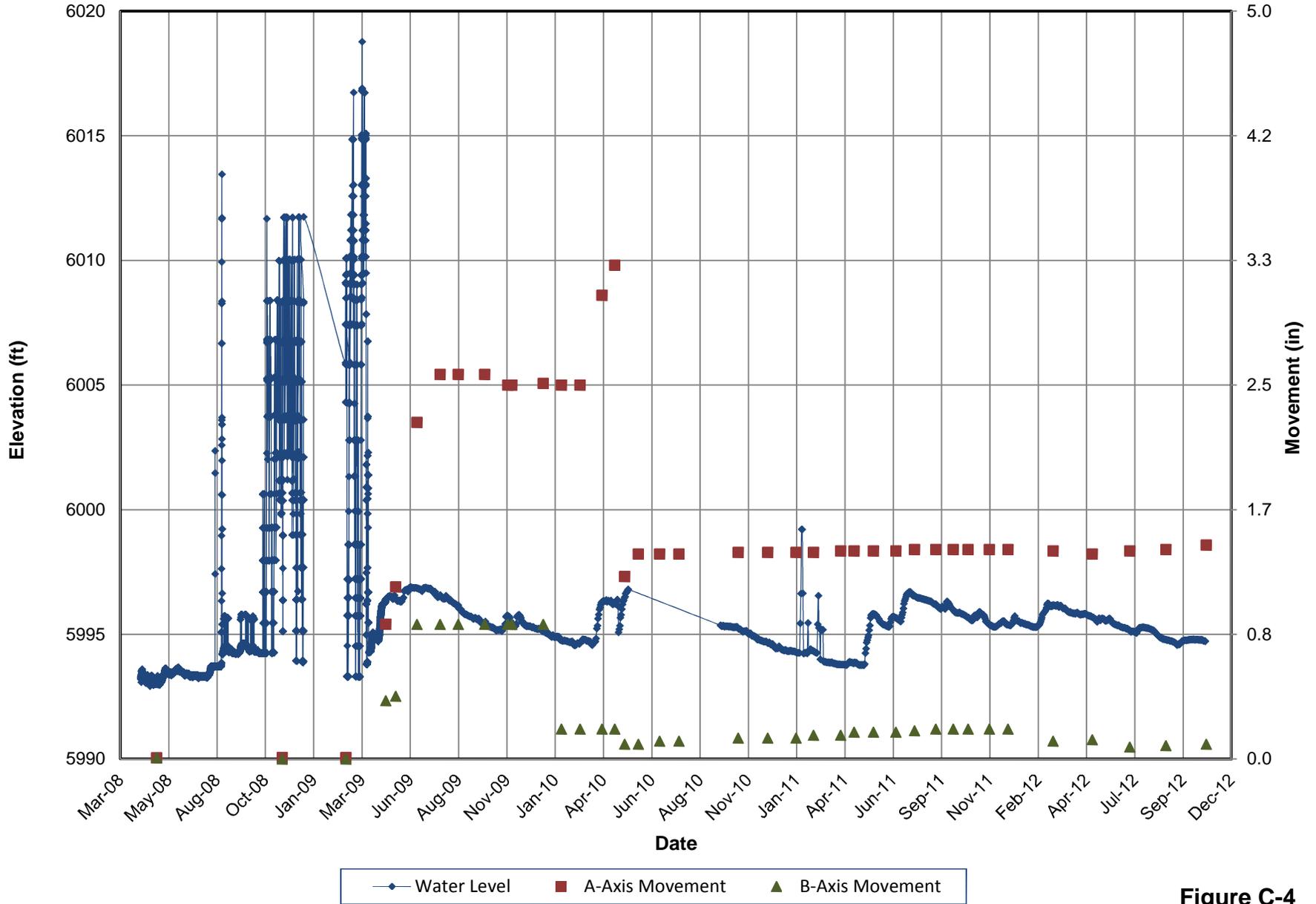
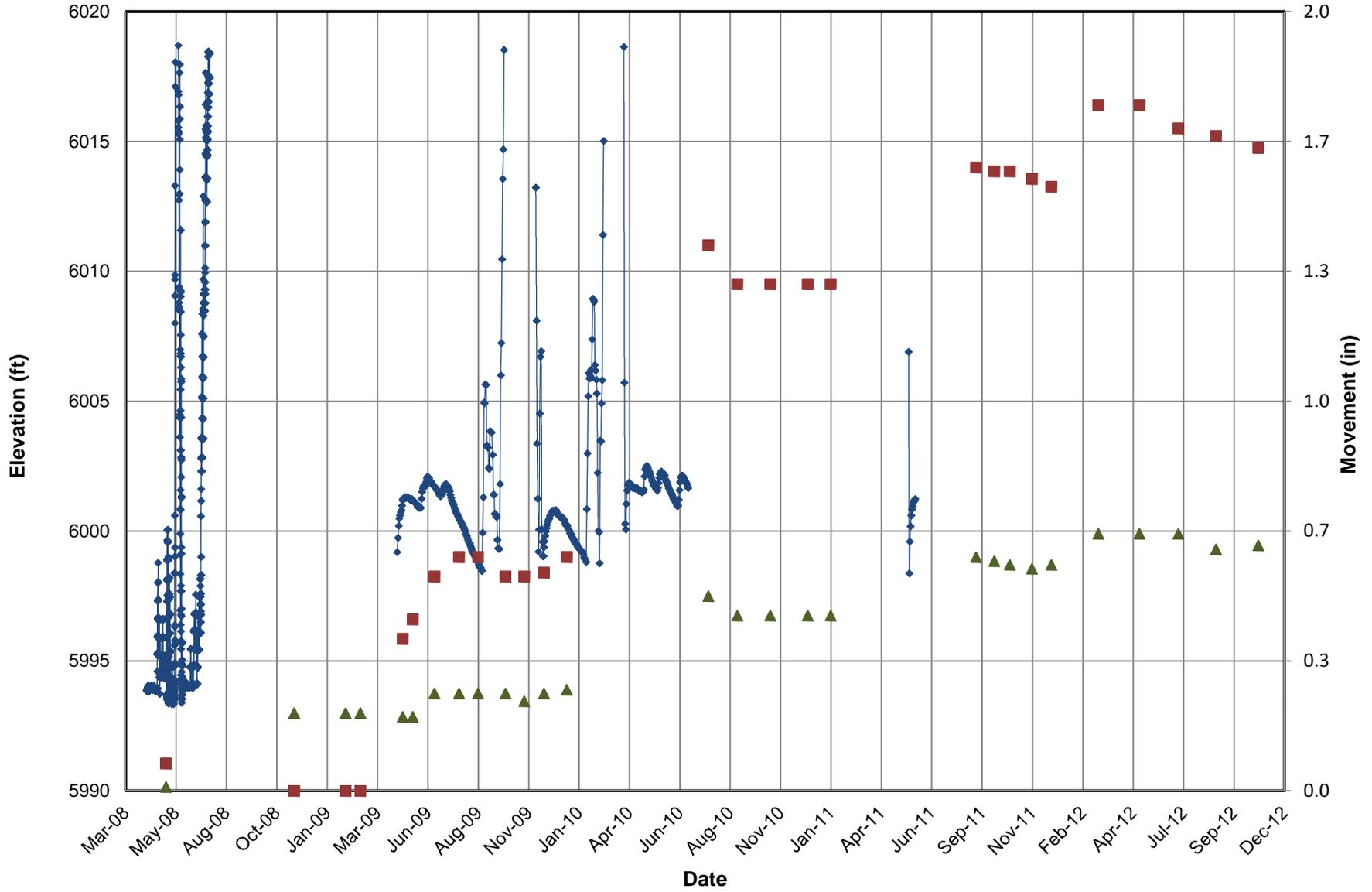


Figure C-4

Filtered Inclinometer and Piezometer Data: Tt-5



—◆— Water Level ■ A-Axis Movement ▲ B-Axis Movement

Figure C-5

Filtered Inclinometer and Piezometer Data: Tt-6

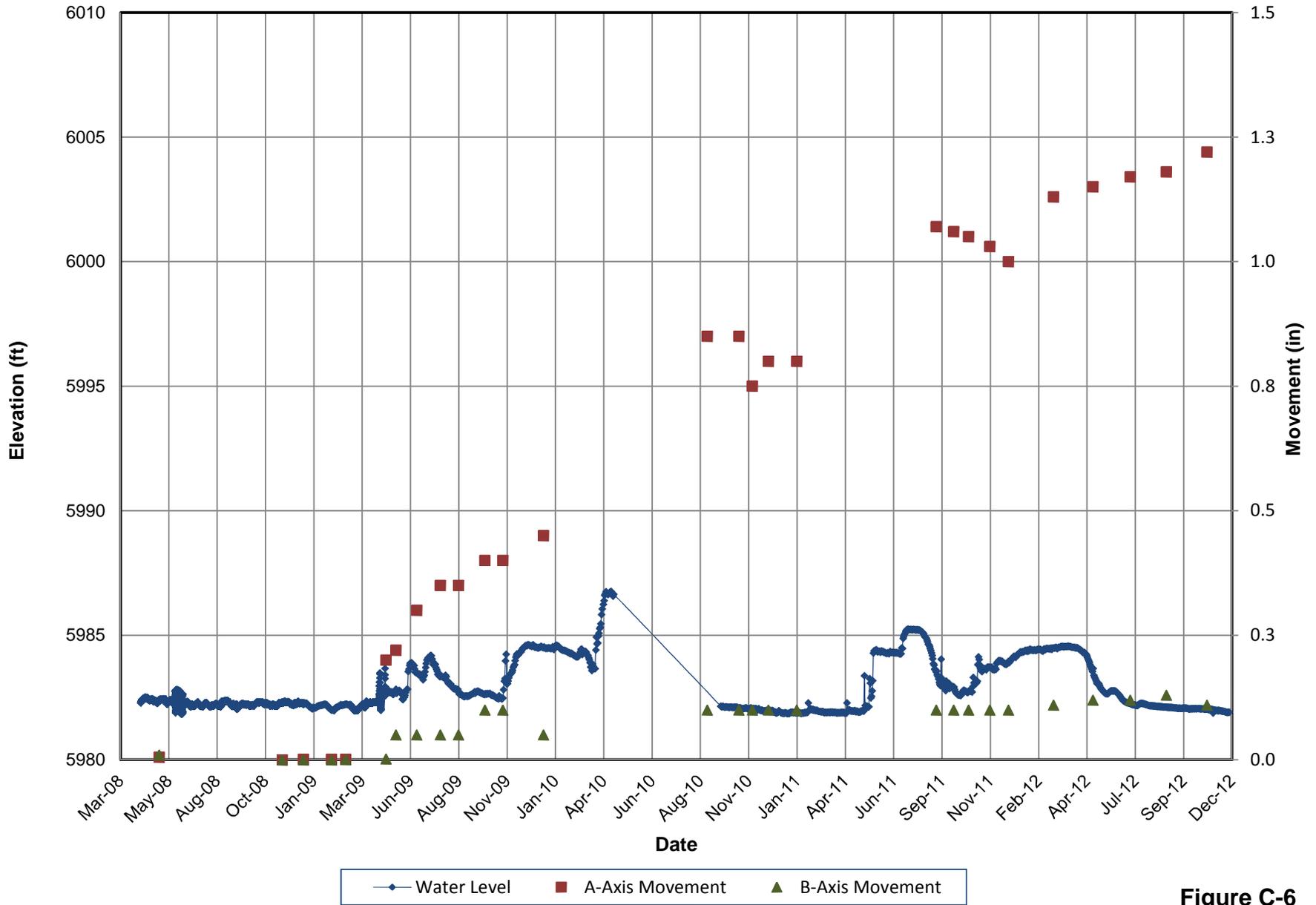


Figure C-6

Attachment D
Unfiltered Inclinator and Piezometer Data

Unfiltered Inclinometer and Piezometer Data: Tt-1

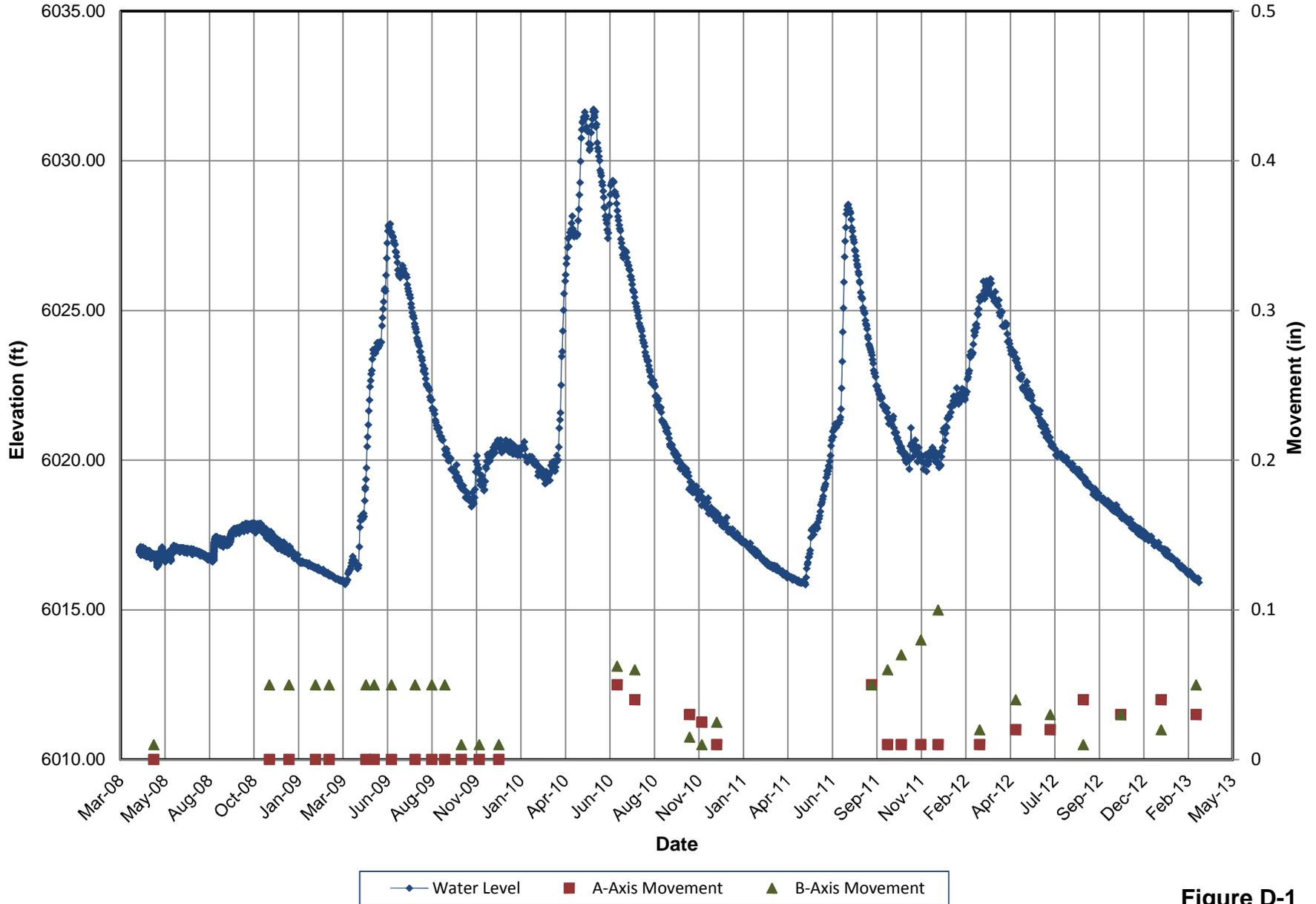


Figure D-1

Unfiltered Inclinometer and Piezometer Data: Tt-2

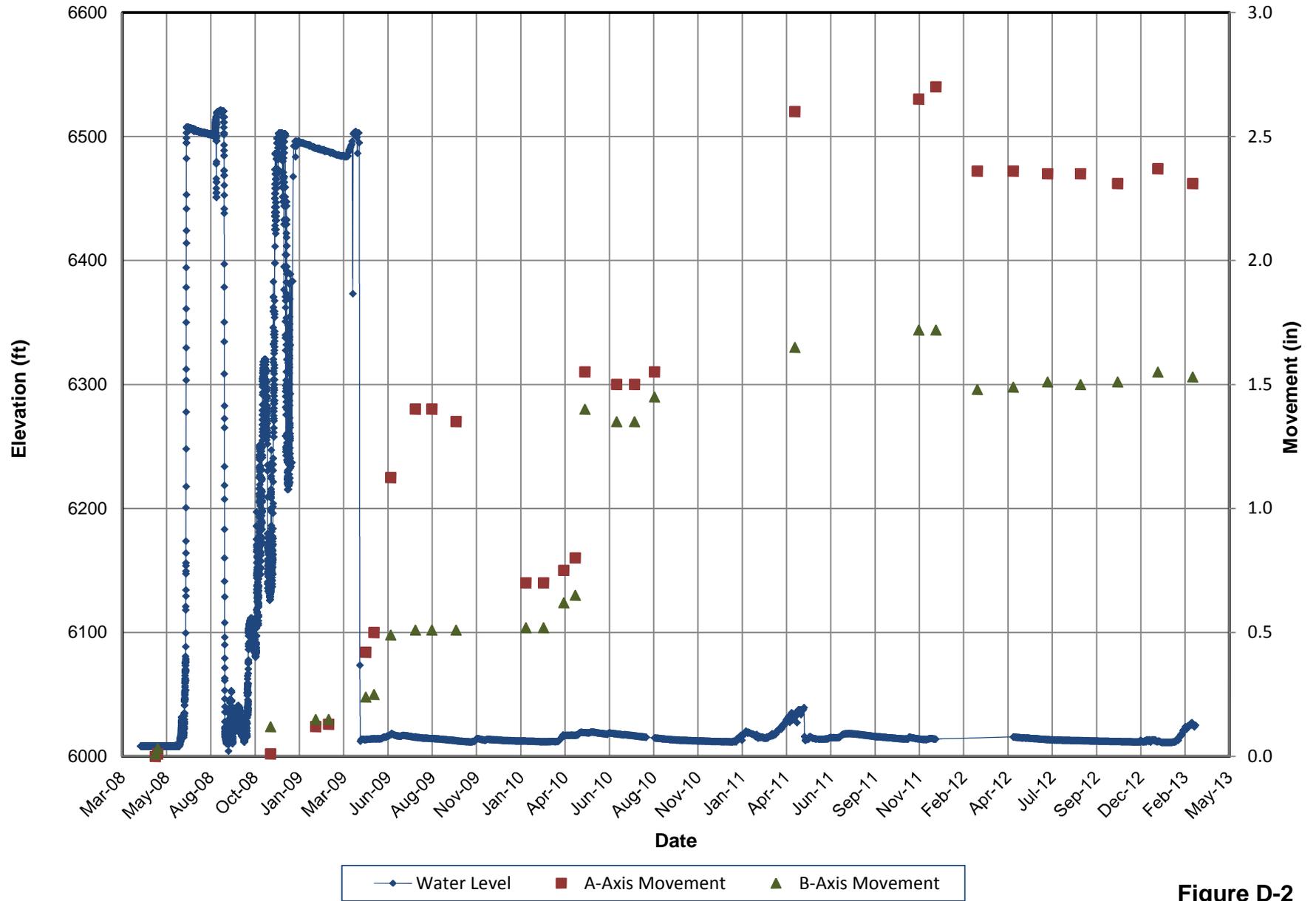


Figure D-2

Unfiltered Inclinometer and Piezometer Data: Tt-3

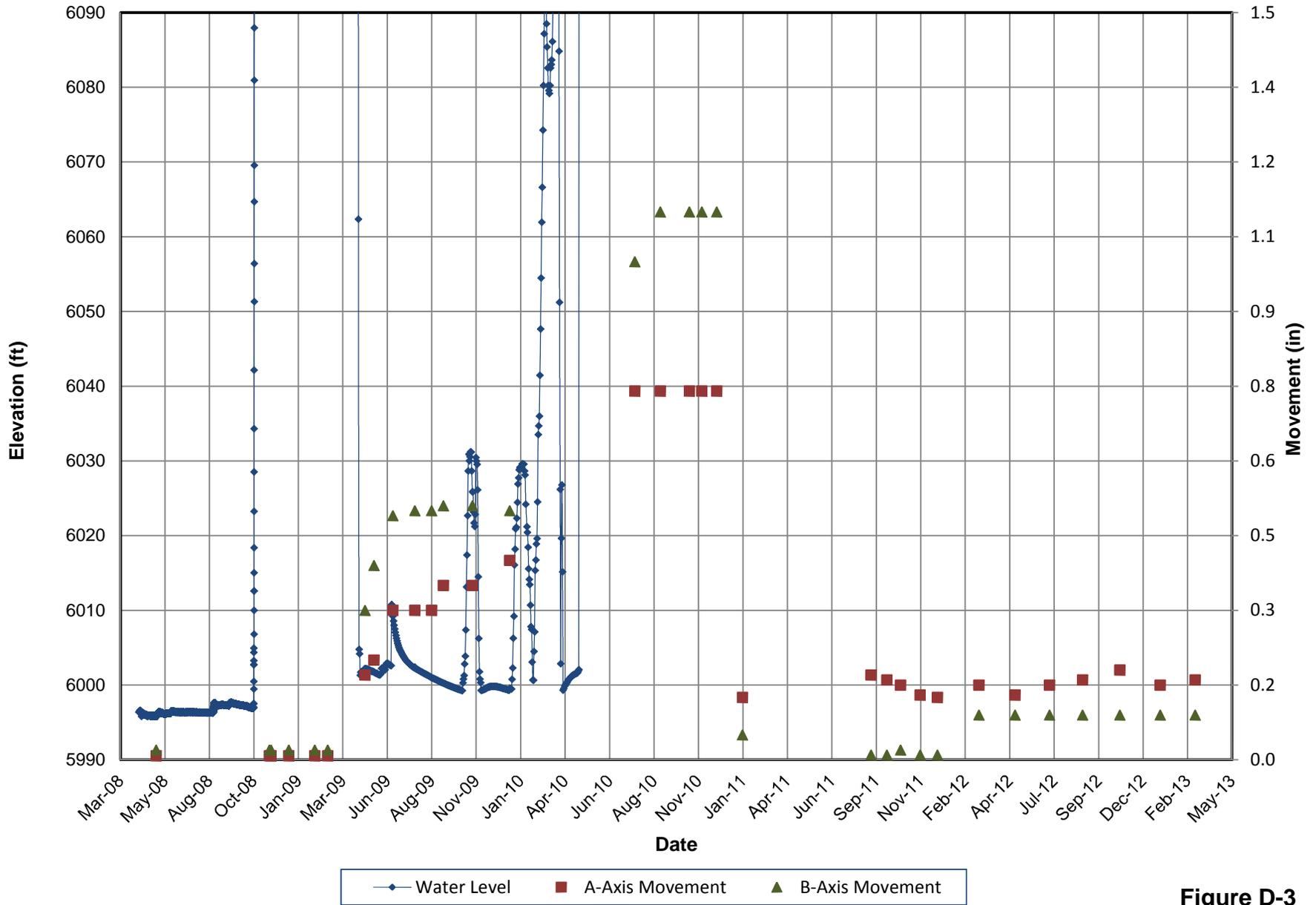


Figure D-3

Unfiltered Inclinometer and Piezometer Data: Tt-4

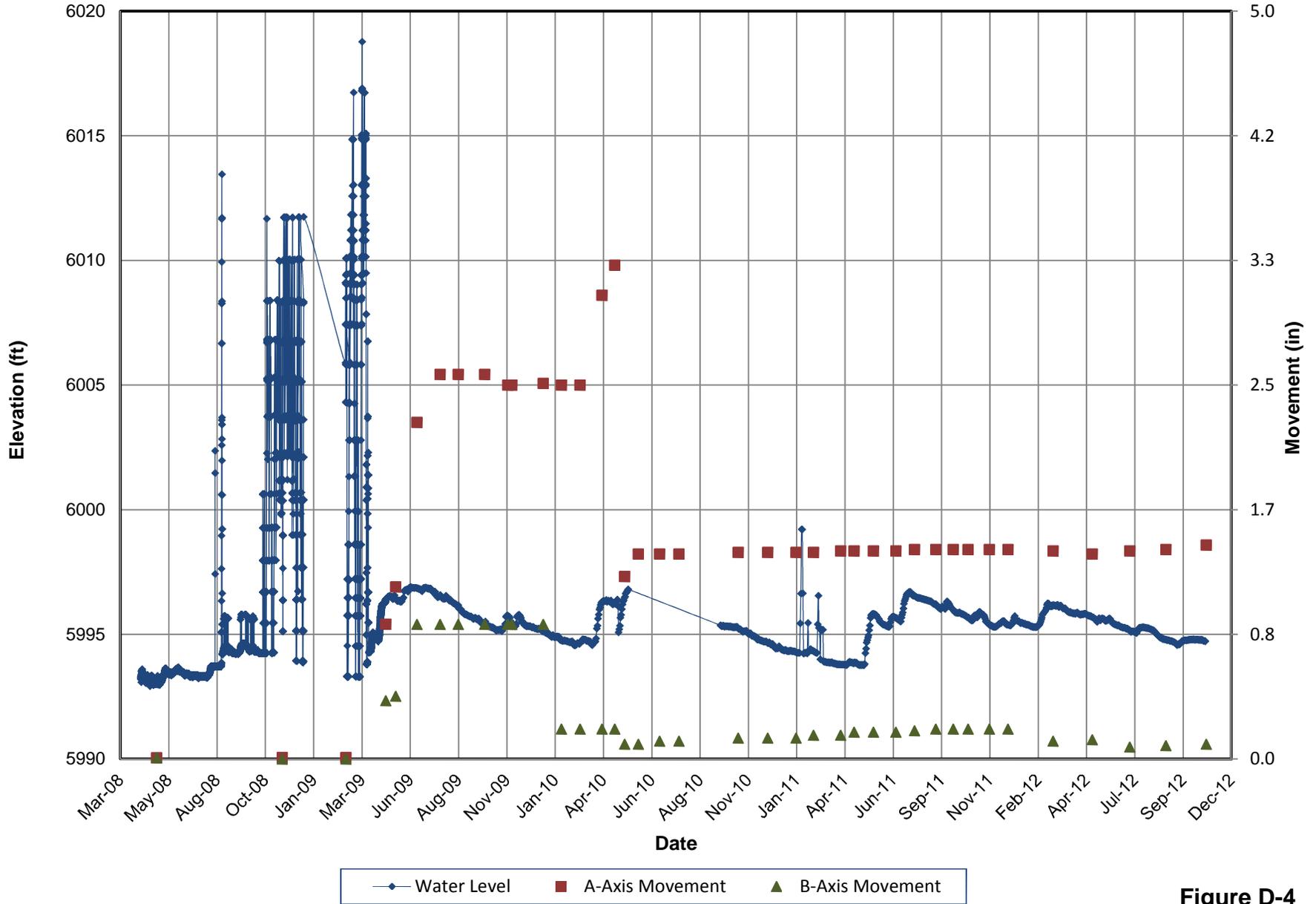


Figure D-4

Unfiltered Inclinometer and Piezometer Data: Tt-5

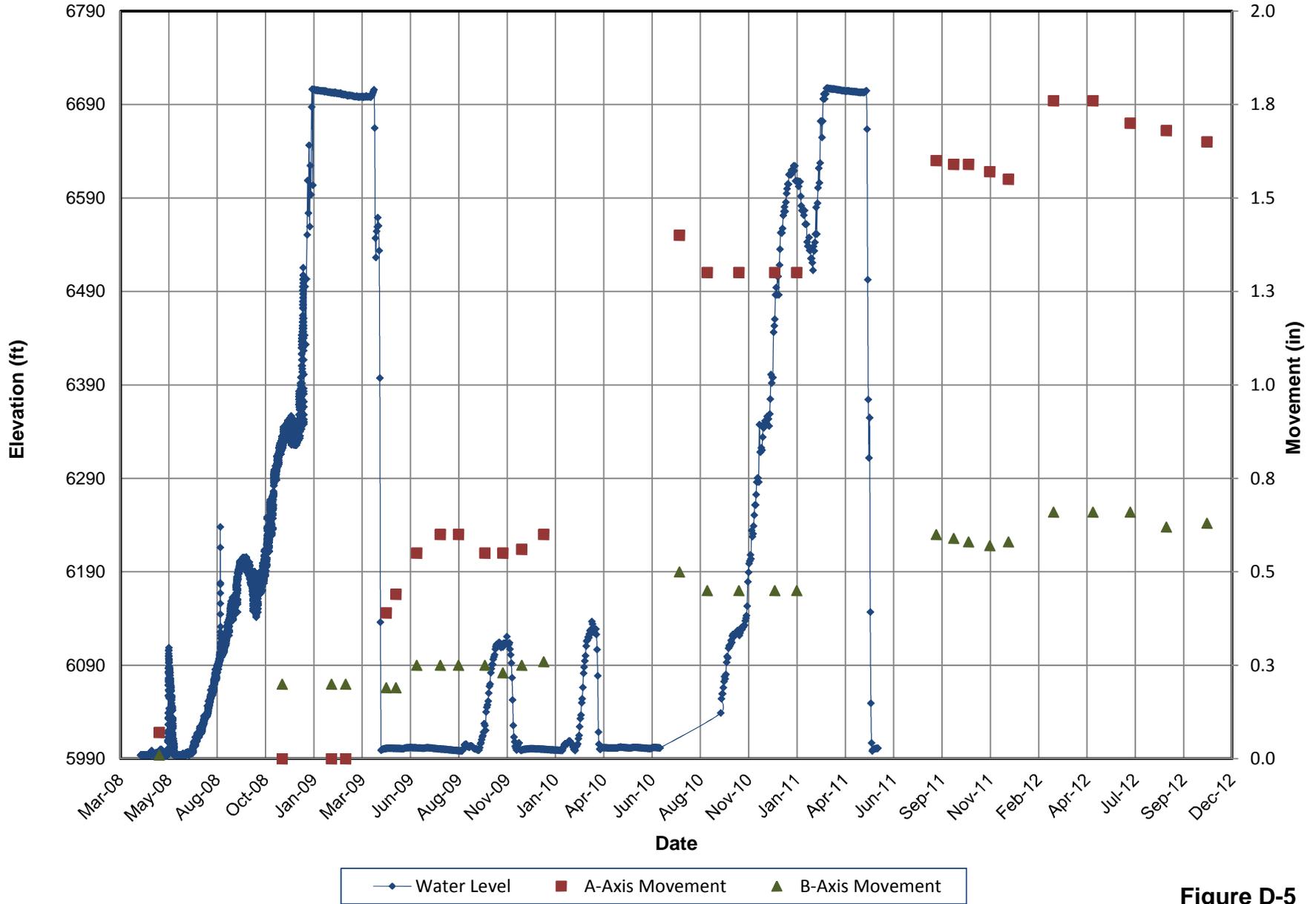


Figure D-5

Unfiltered Inclinometer and Piezometer Data: Tt-6

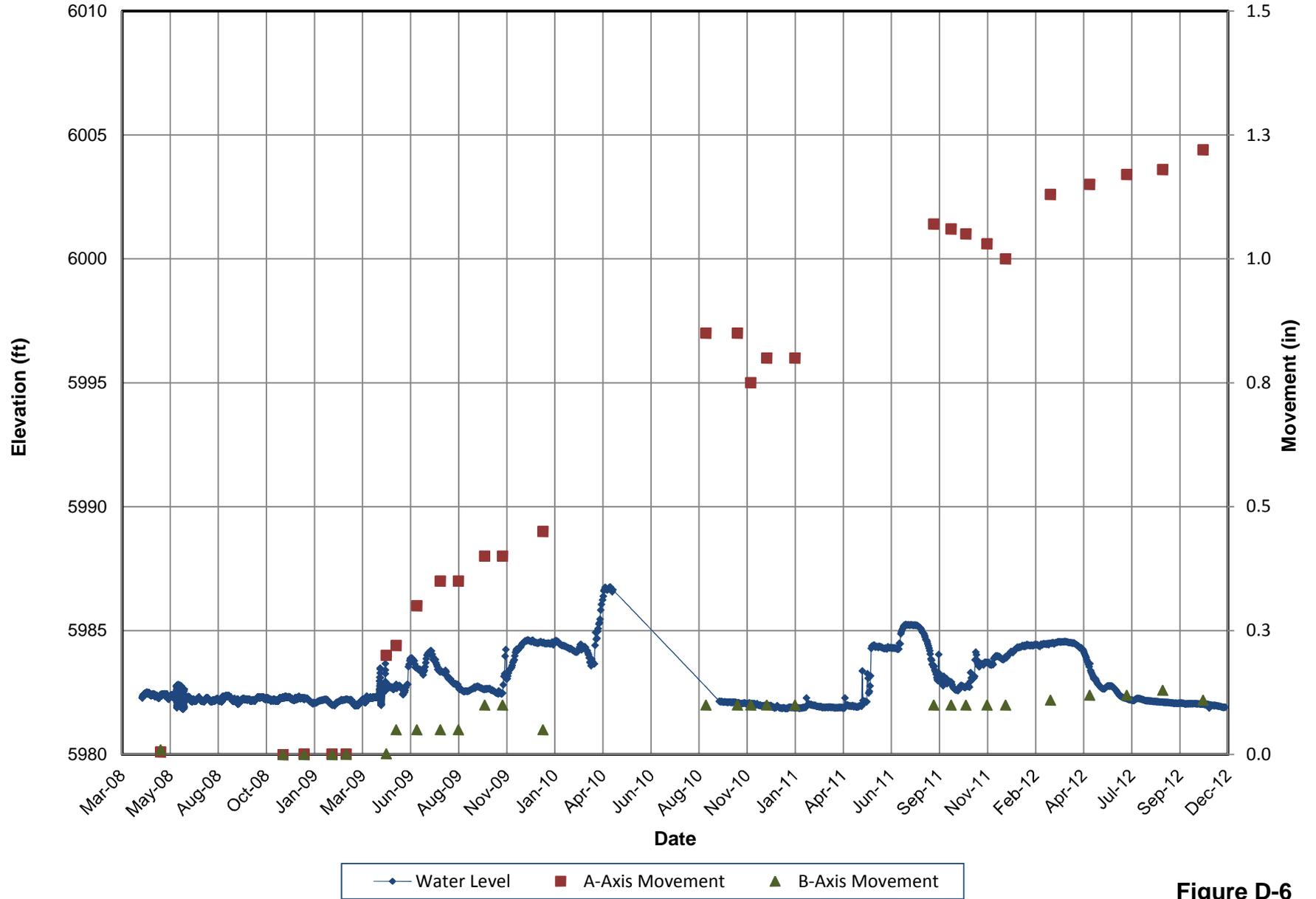


Figure D-6

Unfiltered Inclinometer and Piezometer Data: Tt-7

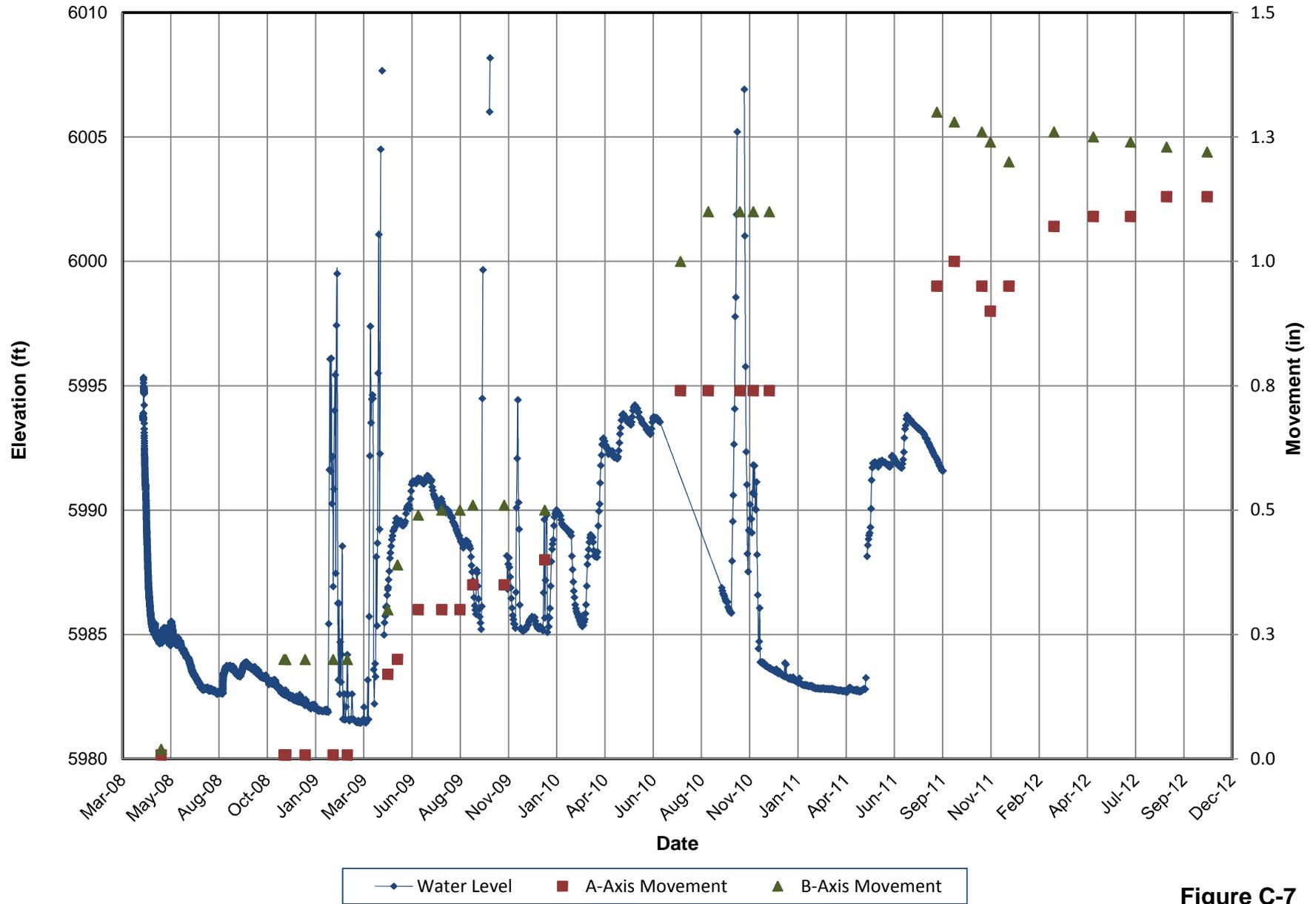


Figure C-7

Unfiltered Inclinometer and Piezometer Data: Tt-7

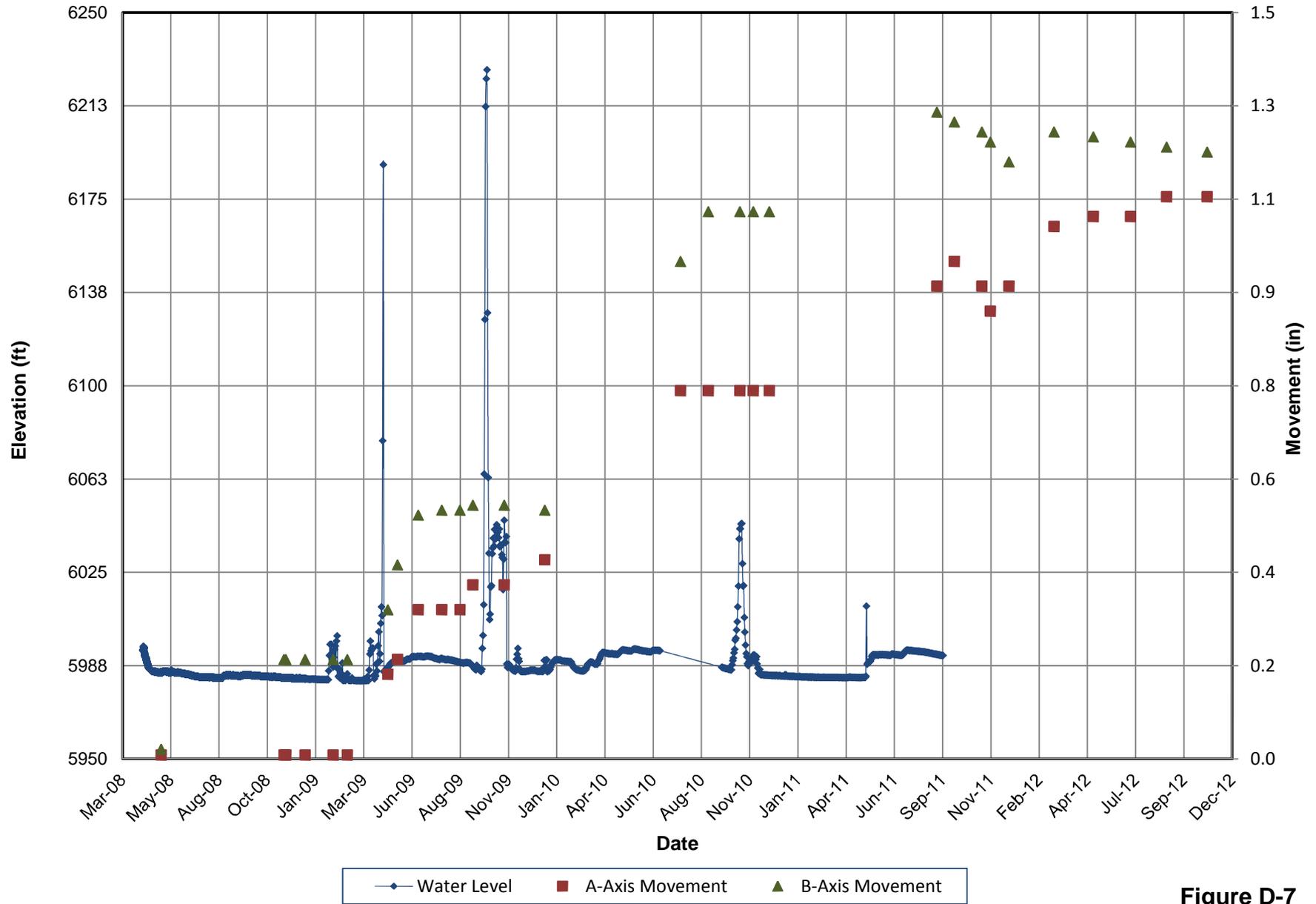


Figure D-7