Appendix E

Technical Memorandum Regarding Instrumentation and Monitoring at the Rocky Flats OLF

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Technical Memorandum

To:	Mr. Rick DiSalvo	**From:**	Heather Trantham, Ph.D. PE, Thomas A. Chapel, PE
Company:	S. M. Stoller Corporation	**Date:**	April 15, 2010
Re:	Instrumentation and Monitoring, Rocky Flats OLF	**Tt Project #:**	114-181750

Introduction

This technical memorandum provides an evaluation of data collected from inclinometers at the Rocky Flats Original Landfill (OLF) between the time they were installed in April, 2008, through December 2009. Data from piezometers located on the outside of the inclinometer casings are also reviewed and evaluated for possible correlation with the inclinometer data. Relevant background information regarding the results of the geotechnical investigation during which the inclinometers were installed is also provided.

Background

According to information provided to Tetra Tech by S.M. Stoller (2007), the OLF was used between 1952 and 1968. During this time approximately 74,000 cy of sanitary waste and construction debris were reportedly disposed in the OLF. The remedial action selected to close the OLF included construction of a 2-foot-thick soil cover. The existing slopes were regraded prior to placement of the soil cover, and a buttress fill was constructed near the toe of the landfill. The remedial action also included installation of perimeter drainage channels and diversion berms to control surface water run-on and runoff around the landfill cover. Construction was completed in September 2005, with the final regulatory walk-down occurring on September 12, 2005.

Minor localized surface cracking, differential settlement, slumping and subsidence in drainage channels, and seeps that created saturated areas or direct surface flows on the cover or near the buttress toe were observed in 2006 and 2007, and triggered the need for a geotechnical investigation which was completed in June 2008 by Tetra Tech.

The geotechnical investigation by Tetra Tech included a geophysical investigation, seven exploratory borings, nine test pits, laboratory testing, inclinometer and piezometer installation, and slope stability analyses. Figure 1, Plan View of OLF site, shows the locations of the localized cracking, slumping and settling, seeps, test pits and the inclinometers.

The June 4, 2008 TetraTech OLF Geotechnical Investigation Report (TetraTech, 2008) (TetraTech Report) concluded that the slope failures that have occurred at the site are localized failures that are a result of movement of soil over one or more weak clay and organic soil layers within the native soil and bedrock. The weak planes are believed to be responsible for historic movement and slope instability that has been recognized in the OLF area. Landsliding and slope instability has been noted in previous reports and is visible on historic aerial photography. The Tetra Tech Report concluded that the risk of deep-seated slope failure has not been increased as a result of the OLF construction. In fact, the previous mitigative design and construction have improved the stability of the slope below the OLF. However, localized movements are likely to continue in the area when surface or ground water builds up and lubricates the weak layers. Working with S.M. Stoller and the DOE to identify a range of mitigation alternatives that would work within the framework of the approved OLF Monitoring and Maintenance Plan (M&M Plan), Tetra Tech presented alternatives to reduce water infiltration from surface cracks and drainage berms, and to facilitate natural drainage to the buttress and native soils. The recommendations are summarized below.

Improving surface drainage and reducing infiltration of surface water are considered the most feasible alternatives for increasing the slope stability and reducing the frequency and severity of continued slope movement. Any improvements that increase the drainage of surface water and reduce standing water or slow-flowing water on the OLF will increase the stability of the slopes because the infiltration into the subsurface will be decreased. We recommend monitoring the existing drainage conditions to ensure that standing water does not develop. Grading using hand tools, and occasional placement of local fill materials are suitable remedies for the localized distress that is likely to continue at the site. Additional means could be implemented that would reduce infiltration seasonally, such as construction of wind breaks or snow fences to reduce snow accumulation on the OLF. The introduction of plant species that would extract more water from the soil could be investigated.

Refer to the Tetra Tech Report for further details regarding the geotechnical investigation and resulting recommendations.

To implement recommendations in the TetraTech Report, S.M. Stoller constructed a drain extension for Seep 7, and modified the drainage features on the western side of the OLF as part of the OLF west perimeter channel filling and regrading work that was designed to improve stability in the vicinity of the observed localized cracking and slumping. S.M. Stoller also constructed snow fences north of the OLF, and has performed minor grading and filling of observe localized narrow surface cracks to mitigate water infiltration.

Instrumentation and Monitoring

Water level and inclinometer readings began on April 13, 2008. The piezometers are located near the base of each inclinometer tube, on the outside of the tube within the borehole. The piezometers were grouted in place, according to standard practice for this type of instrument, when the borehole was grouted as required to encase the inclinometer tube. The piezometers include automatic data loggers that were set to take readings that are converted to water levels using the manufacturers' calibration curves. Hourly data were logged from April 2008 through late December 2008. On December 22, 2008 S.M. Stoller switched to daily readings to increase data logger battery life. Daily readings have been collected since that time. The amount of deflection of the inclinometers was manually read approximately monthly – there is no automatic data logging feature for the inclinometers. Inclinometer readings are obtained by inserting an approximately 32 inch long instrument into the inclinometer tube, and taking electronic readings of the exact orientation of the instrument at one foot intervals along the length of the tube. Wheels on the top and bottom of the instrument align the instrument in precise grooves along the length of the inside 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. Depending on the direction of the slope movement, some movement of the inclinometer tube may be seen in each axis, or all movement may be seen in one direction with no movement in the other direction. Because of the length and diameter of the instrument, inclinometer tube deflection can cause deformation that prevents the instrument from being inserted the full length of the tube. Also, deflection can reach a point causing the tube to break, also preventing insertion of the instrument beyond the point of the break. The data for the piezometers and inclinometers is included in Appendix A.

Piezometers 2, 4 and 5 began to show erratic readings in the summer of 2008. Piezometers 3 and 7 began to show erratic readings in November 2008 and January 2009, respectively. The readings were considered erratic because the fluctuations varied over half a foot or more within a one hour time period. Piezometer 1 is the only piezometer with readings that have remained reliable through 2009. Piezometer 5 has the longest stretches of unreliable readings. The other piezometers, 2, 3, 4, 6, and 7 have had periods of unreliability coupled with periods of reasonable readings. It is not clear whether the 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.

The inclinometers were read on a regular basis beginning in April, 2008. Essentially no movement was observed for any of the inclinometers until April, 2009, following a period of heavy precipitation. 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 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 on subsequent readings. 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 on subsequent readings. Subsequent readings have been taken to a depth of 33 feet.

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. 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. The Tetra Tech Report 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.

In general, there is a correlation between water in the subsurface and the movement that is occurring at the OLF. Some of the movement is likely related to recharge of the upper hydrostratigraphic unit that occurs well upgradient of the OLF, and some of the movement is due to an influx of water into the subsurface in the vicinity of the OLF. The relative influence of these two mechanisms on the movement that is occurring is not known. As a result, 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 the up-gradient infiltration.

Not each 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 and the inclinometers were read approximately monthly during these time periods, 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 these inclinometers and piezometers. S.M. Stoller has noted that some inaccuracy of the measurements is likely because during events when significant snowfall accumulates on the devices, some of the snow may blow or fall off the device instead of accumulating in the device. Graphs prepared by S.M. Stoller that show monthly and average precipitation 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 highest between April and October and lower between November and March.

The locations of each borehole that was instrumented with piezometers and inclinometers is shown on Figure 1. The specifics of each borehole/piezometer/inclinometer are discussed below when significant changes were seen to occur. 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. Graphs showing the water levels measured by piezometers and movement of each axis of the inclinometers are shown in Attachment A. 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 C.

Tt-1. There does not appear to be a relationship between piezometer readings and inclinometer readings for Tt-1. Tt-1 was intentionally placed outside of the current slide area. There is a very small increase in movement in the direction of the B-axis of the inclinometer.

Tt-2. The inclinometer readings for Tt-2 show movements starting in May 2008 and continuing until a peak of 1.4 inches on the A-axis was recorded on July 22, 2009. This followed a spike in the high water level on 6/12/09. There is a lag time between the increase in water level and the measured movement of approximately 4 to 6 weeks. This lag time is seen when analyzing the correlations for the other boreholes as well. During the same period, there was movement in the B-axis direction.

Movement in the B-axis direction that was recorded on July 22, 2009 may be related to an increase in the water level, but the data are not conclusive. It is not clear from the piezometer data if the large increase in water level shown is accurate or if it is “noise” recorded as part of the erratic behavior. After the movement occurred, a small decreasing trend can be seen in the A-axis, and no additional movement is apparent in the B-axis direction.

Tt-3. Movement in the direction of the A-axis started in November 2008, and movement in the B-axis direction started in April 2009. The maximum movement in both the A- and B- axes seems to coincide with a spike in water level that occurred on June 13, 2009. It is likely that the precipitation that caused the maximum movement occurred prior to the water level spike seen at this time. We are unable to verify this due to the erratic piezometer behavior prior to the end of April 2009. After the peak movement occurred, the movement seems to decrease in the A-axis direction even though there is a large fluctuation in the water level as measured by the piezometer in October and November, 2009. Movement in the B-axis direction did not correlate with the large fluctuation in the water table seen in October and November, 2009.

Tt-4. The inclinometer readings in Tt-4 show movement in both axes starting in May 2009 and peaking in July 2009. The movement in both directions lagged behind a large increase in water level that occurred in the late spring and early summer of 2009.

Tt-5. The movement of the inclinometer casing in both axes correlated with an increase in water level as measured by the piezometer in Tt-5 at the beginning of June, 2009. The inclinometer movement leveled off during a period when the water level decreased according to the piezometer data in the middle of August, 2009. The piezometer in Tt-5 displayed erratic behavior from September to November of 2009, and it is not possible to draw conclusions between the water level measurements and the movement measured by the inclinometer during that time.

Tt-6. The general trend of the inclinometer data in the A-axis is an increase in movement starting in April 2009 that reached a maximum of 0.45 inches. A small increase in the water level was indicated in 2008 and early 2009 as measured by the fluctuation of the piezometer. No significant movement of the inclinometers was apparent during that time. A general increase in water level started in April 2009 and continued throughout the rest of the year. There was a corresponding increase in movement measured by the inclinometer during that time. Small movements occurred along the B-axis.

Tt-7. There has been a general trend for an increase in movement along the A- and B- axes. A large movement that occurred along both axes in April, 2009 followed a gap in piezometer data which were eliminated from the graph to improve the clarity of the figure. There was precipitation during this time and it is likely that there was a rise in the water table as a result of the precipitation The local precipitation data contained in Appendix B also indicates a large increase in precipitation during April 2009.The movement in the A-axis direction increased but then did not continue after June 2009. The movement in the B-axis direction reached a plateau in the summer of 2009, and then increased slightly.

Recommendations

The recommendations made in the original report (Tetra Tech, 2008) 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. If the drainage/surface water repairs are made, localized failures will still be possible during or after large or prolonged precipitation events, or when movement results from water that is related to regional recharge of the upper hydrogeologic unit. Modeling showed that an increase in soil strength is also needed to increase the safety factor to typical long term levels. Additional instrumentation, while interesting from a scientific and engineering perspective, would likely not provide new or additional insight into opportunities to improve performance of the landfill cover. We believe that continued monitoring and maintenance provide an effective course of action so long as the on-going level of maintenance can be continued.

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.

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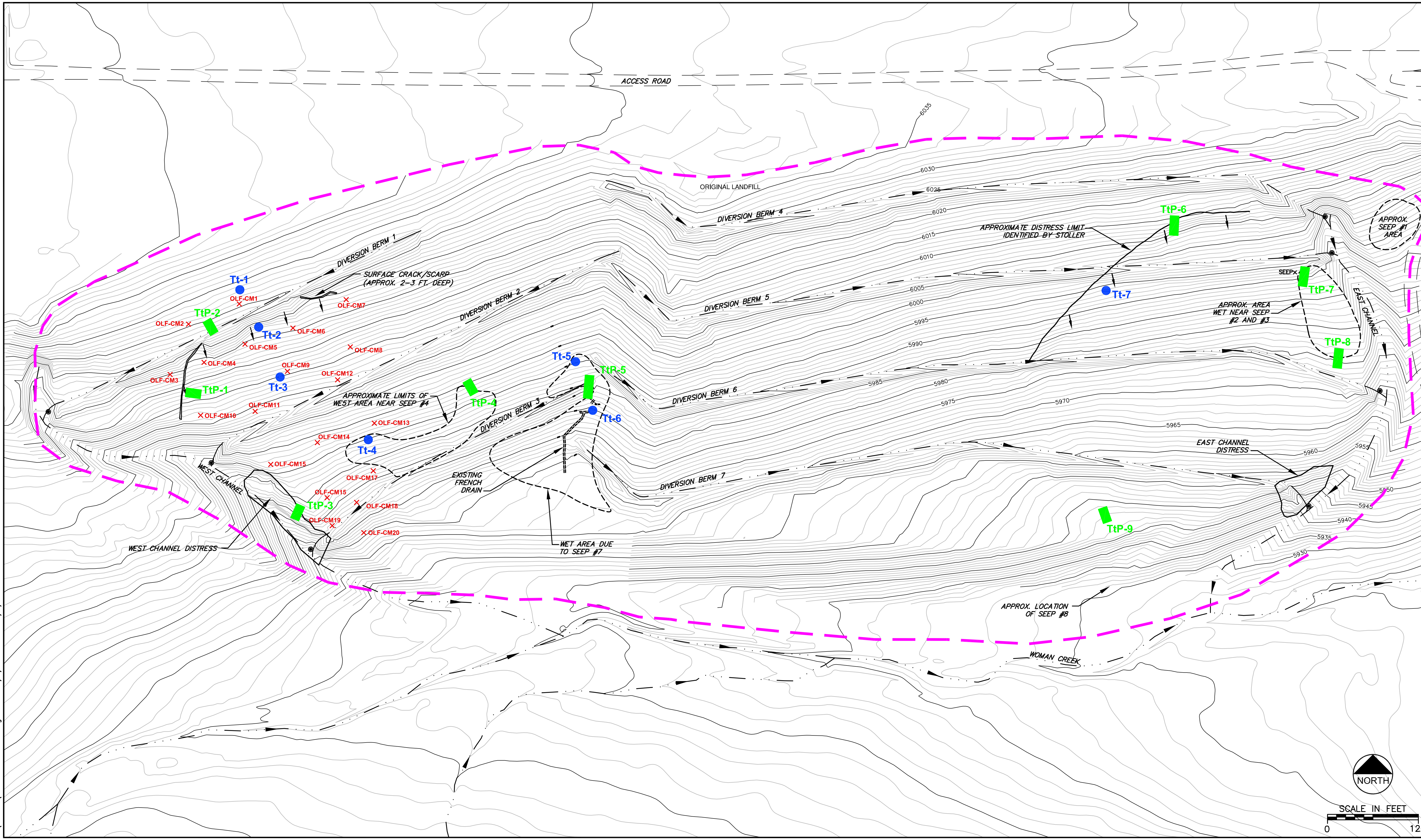

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Project No. 181750

April 2010

LEGEND:

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

Figure 1
Plan View of OLF Site

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Attachment A
Inclinometer and Piezometer Graphs

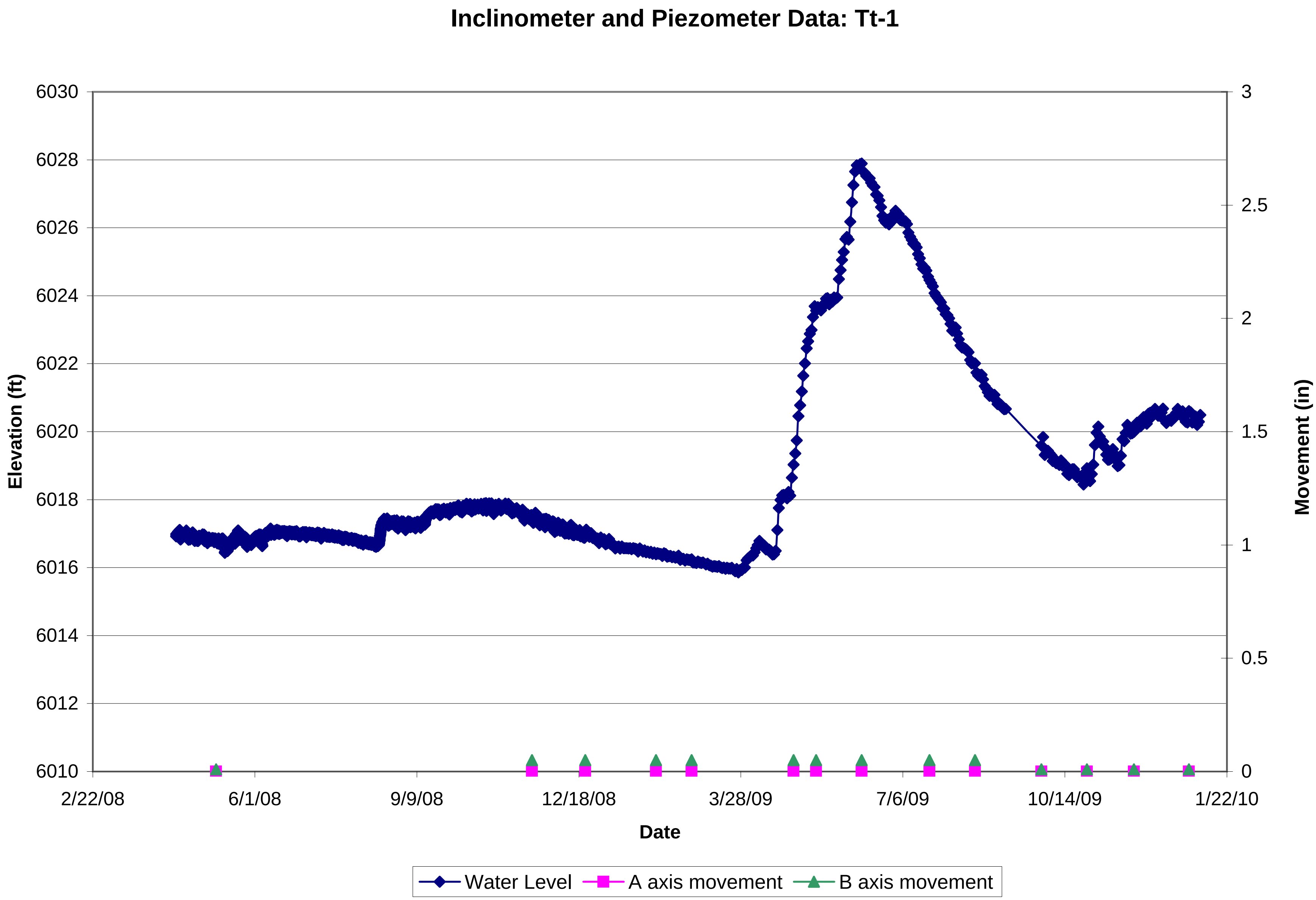

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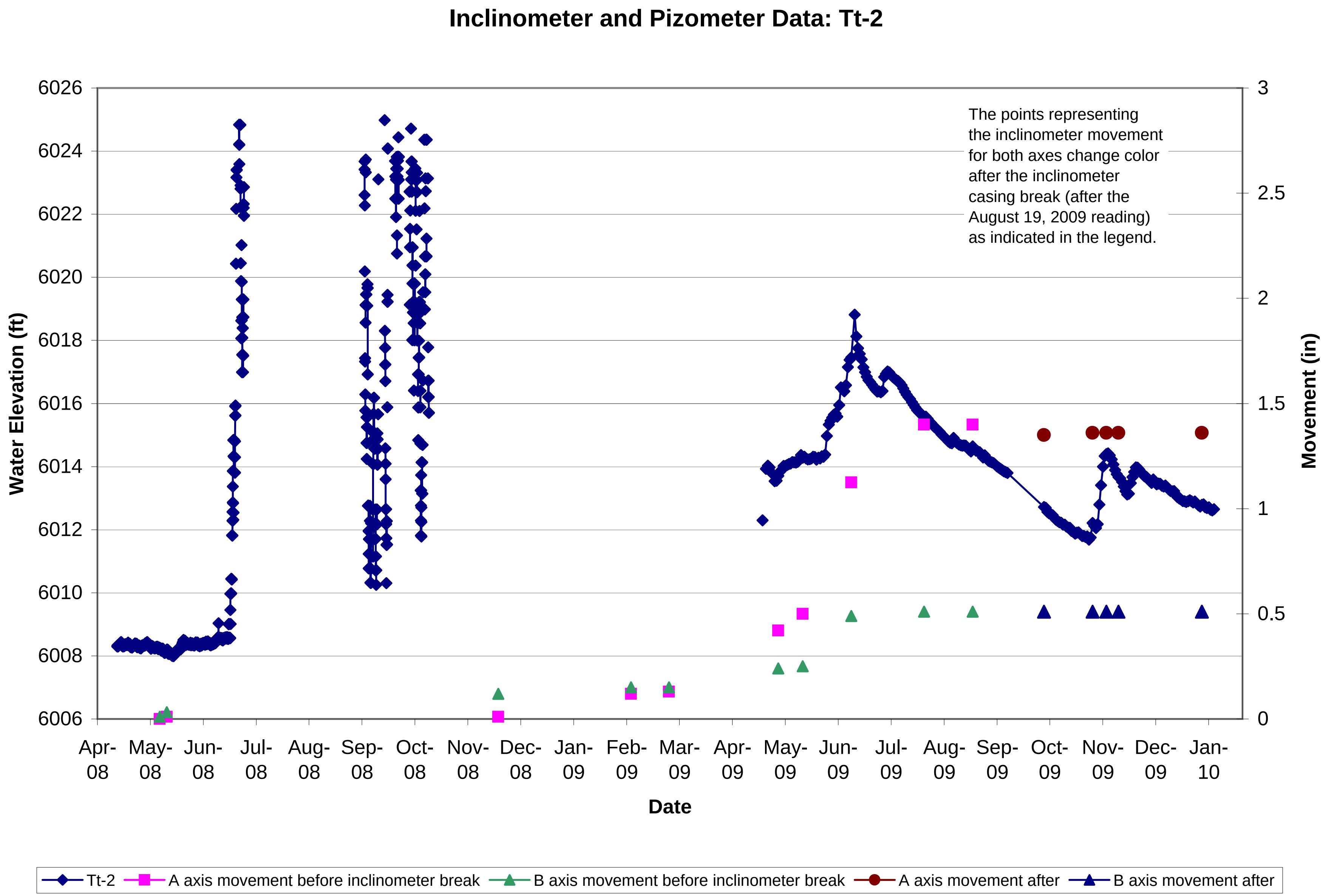
Figure A-1


Inclinometer and Pizometer Data: Tt-2
Water Elevation (ft)
6026
6024
6022
6020
6018
6016
6014
6012
6010
6008
6006
Movement (in)
3
2.5
2
1.5
1
0.5
0
Apr-08
May-08
Jun-08
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09
Jul-09
Aug-09
Sep-09
Oct-09
Nov-09
Dec-09
Jan-10
Date
The points representing the inclinometer movement for both axes change color after the inclinometer casing break (after the August 19, 2009 reading) as indicated in the legend.
Tt-2
A axis movement before inclinometer break
B axis movement before inclinometer break
A axis movement after
B axis movement after

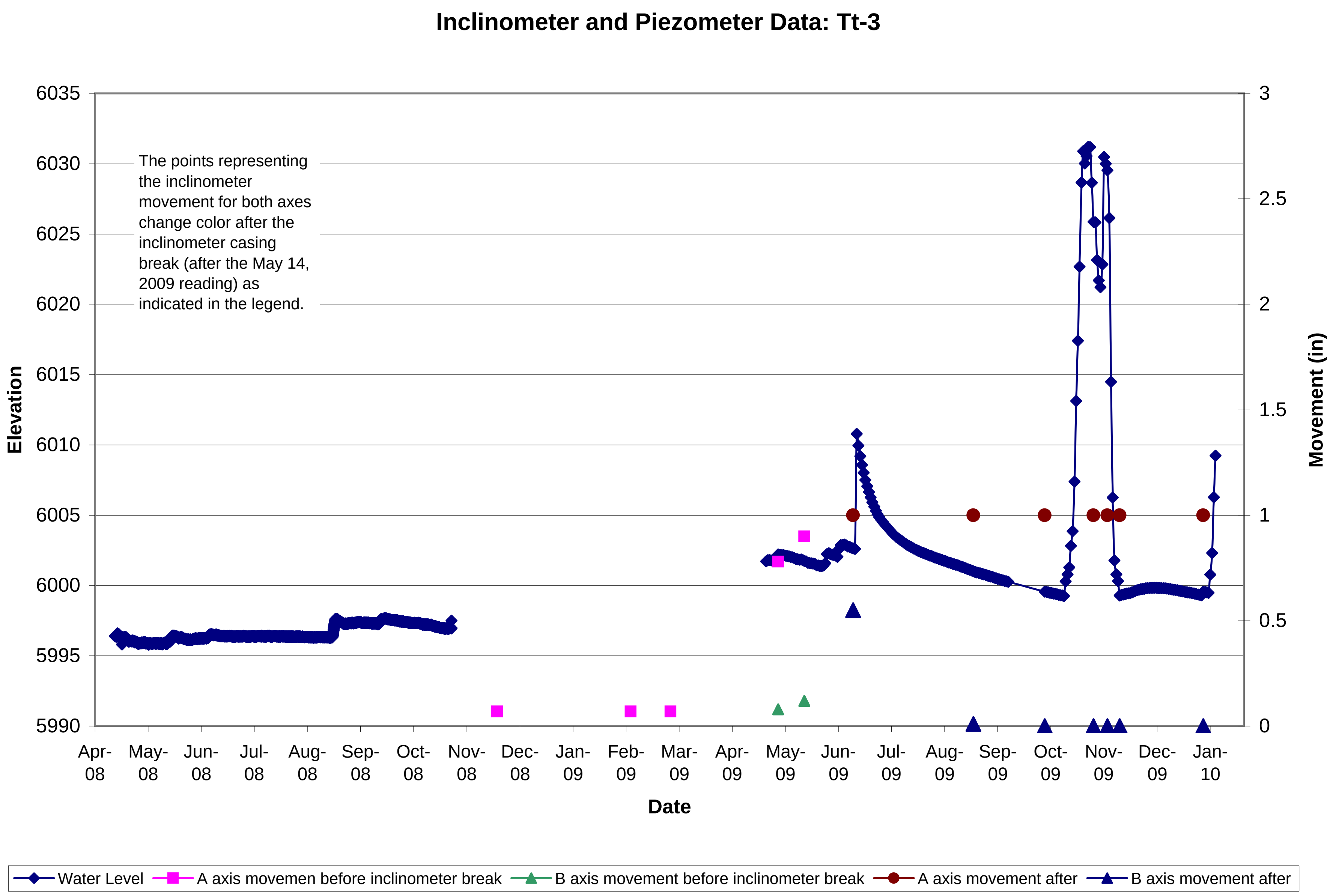

Inclinometer and Piezometer Data: Tt-3
Elevation
Movement (in)
Date
6035
6030
6025
6020
6015
6010
6005
6000
5995
5990
3
2.5
2
1.5
1
0.5
0
Apr-08
May-08
Jun-08
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09
Jul-09
Aug-09
Sep-09
Oct-09
Nov-09
Dec-09
Jan-10
The points representing the inclinometer movement for both axes change color after the inclinometer casing break (after the May 14, 2009 reading) as indicated in the legend.
Water Level
A axis movemen before inclinometer break
B axis movement before inclinometer break
A axis movement after
B axis movement after

Figure A-3

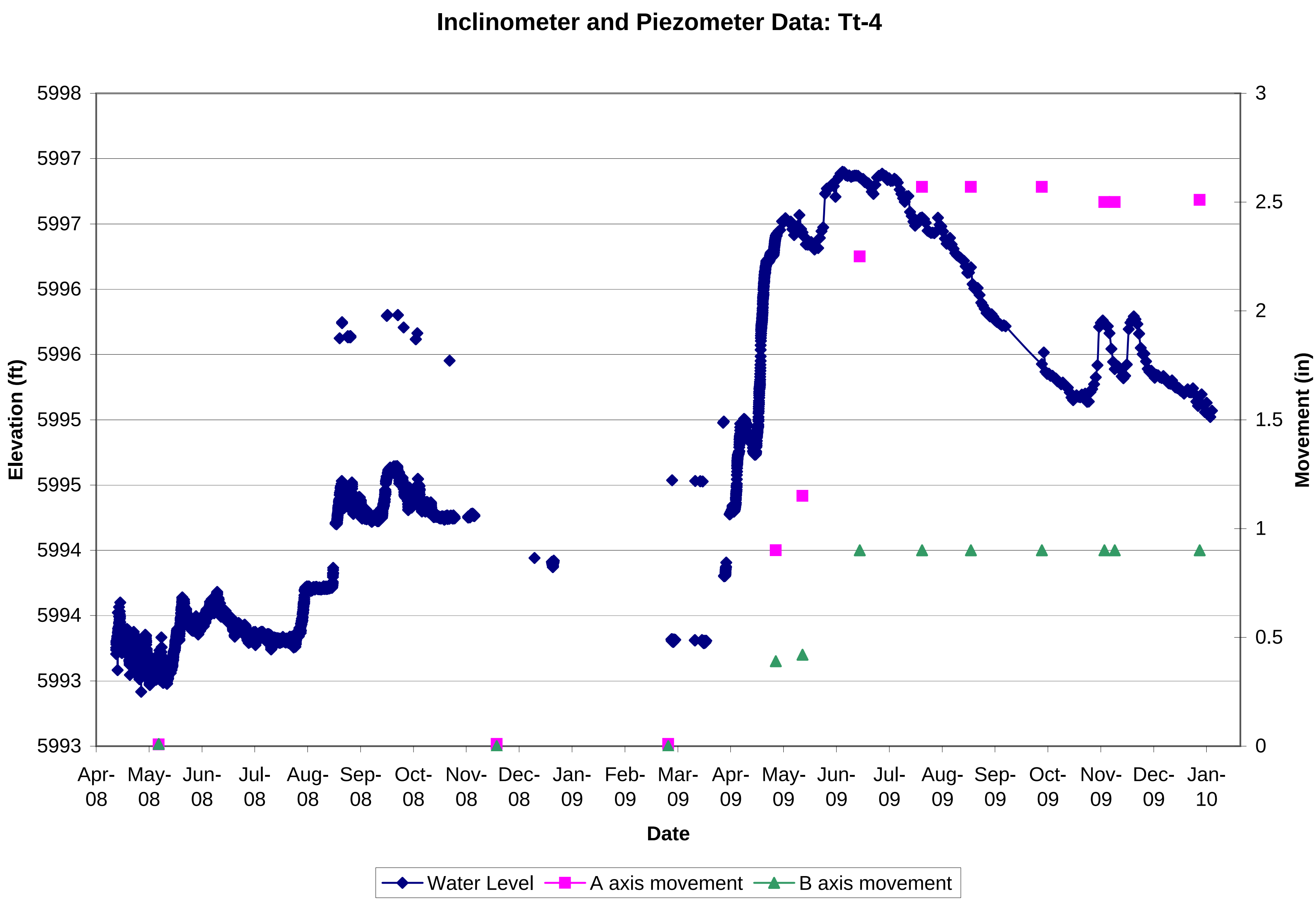


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Figure A-4

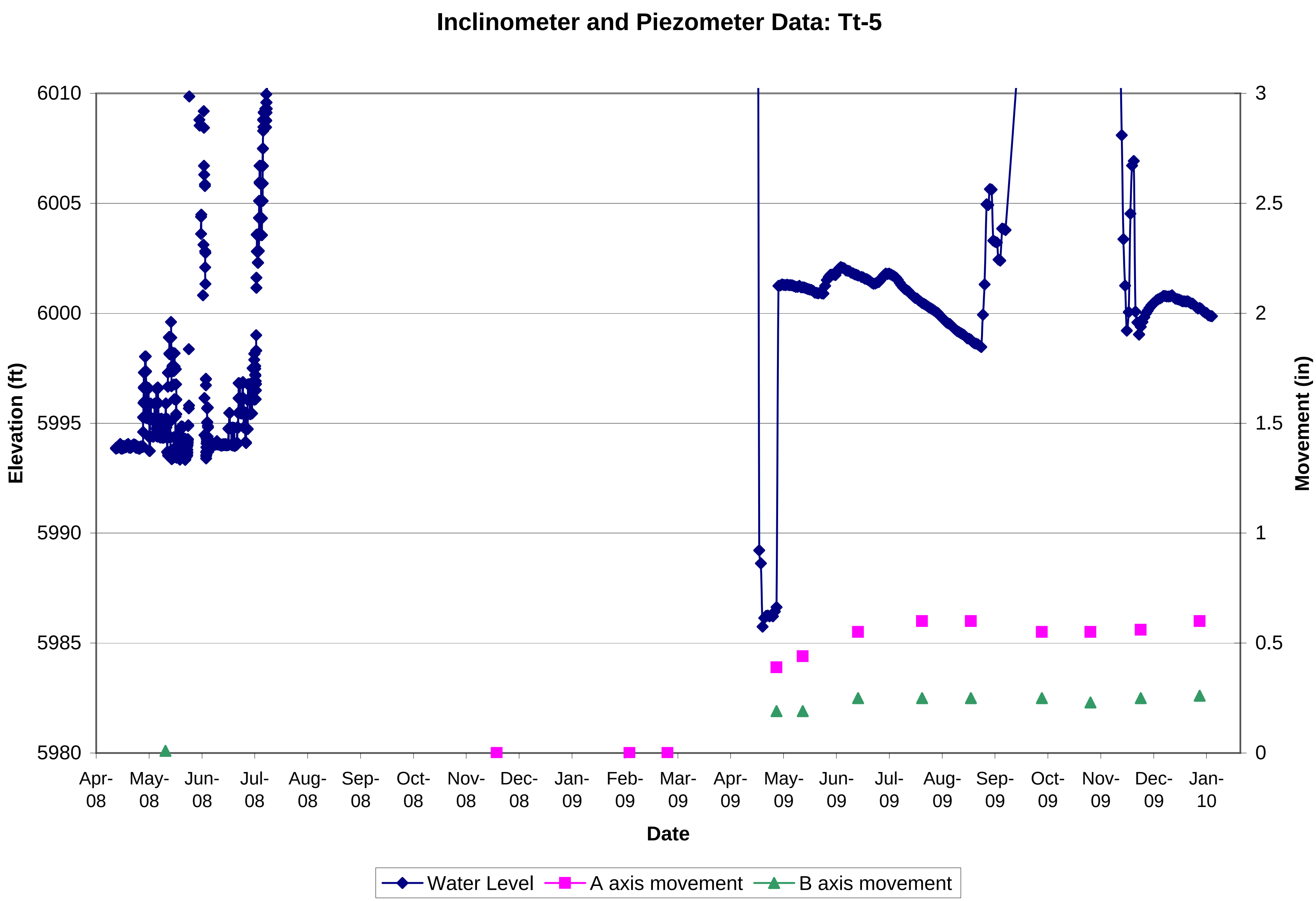

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Figure A-5

Inclinometer and Piezometer Data: Tt-6

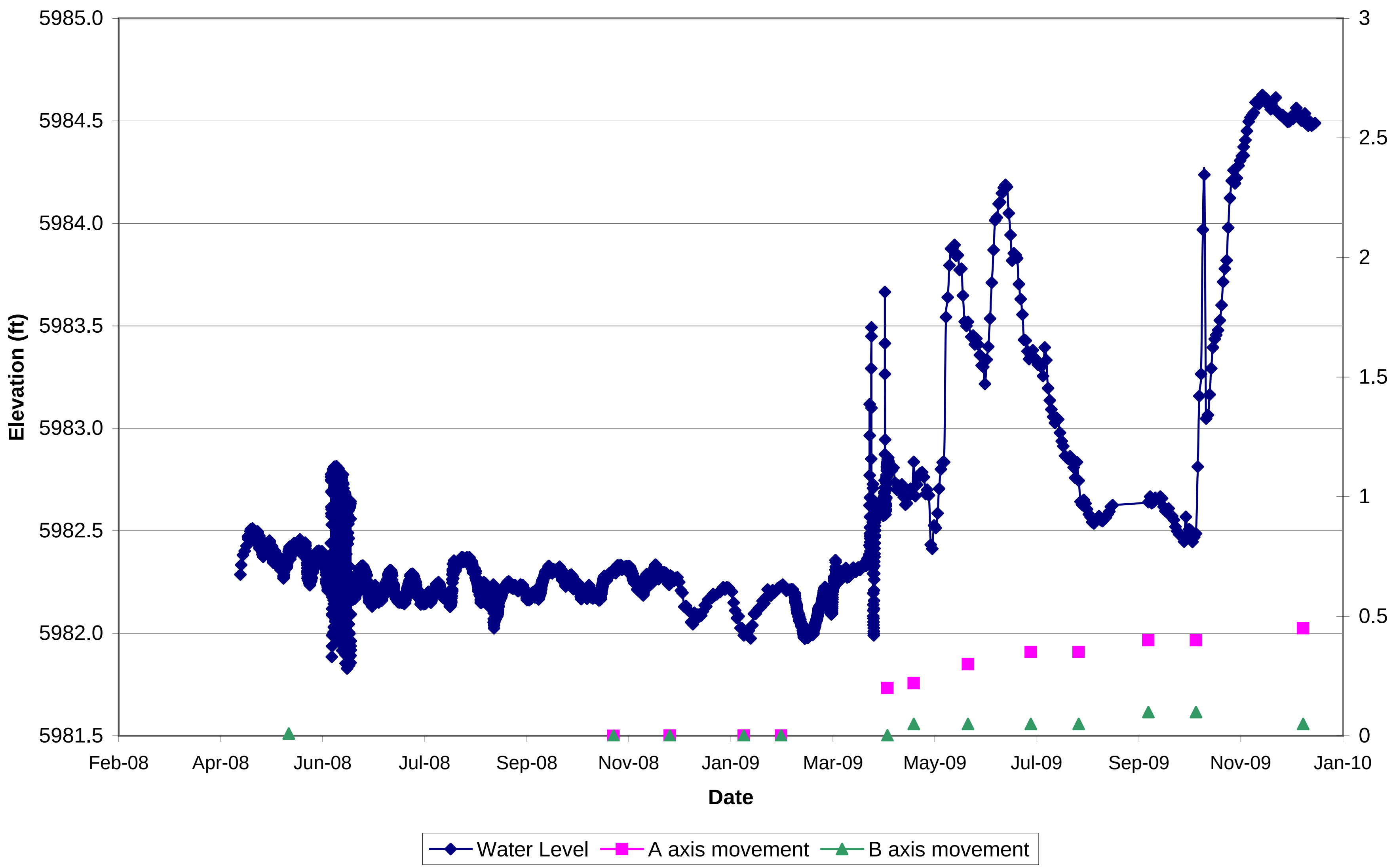

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Figure A-6

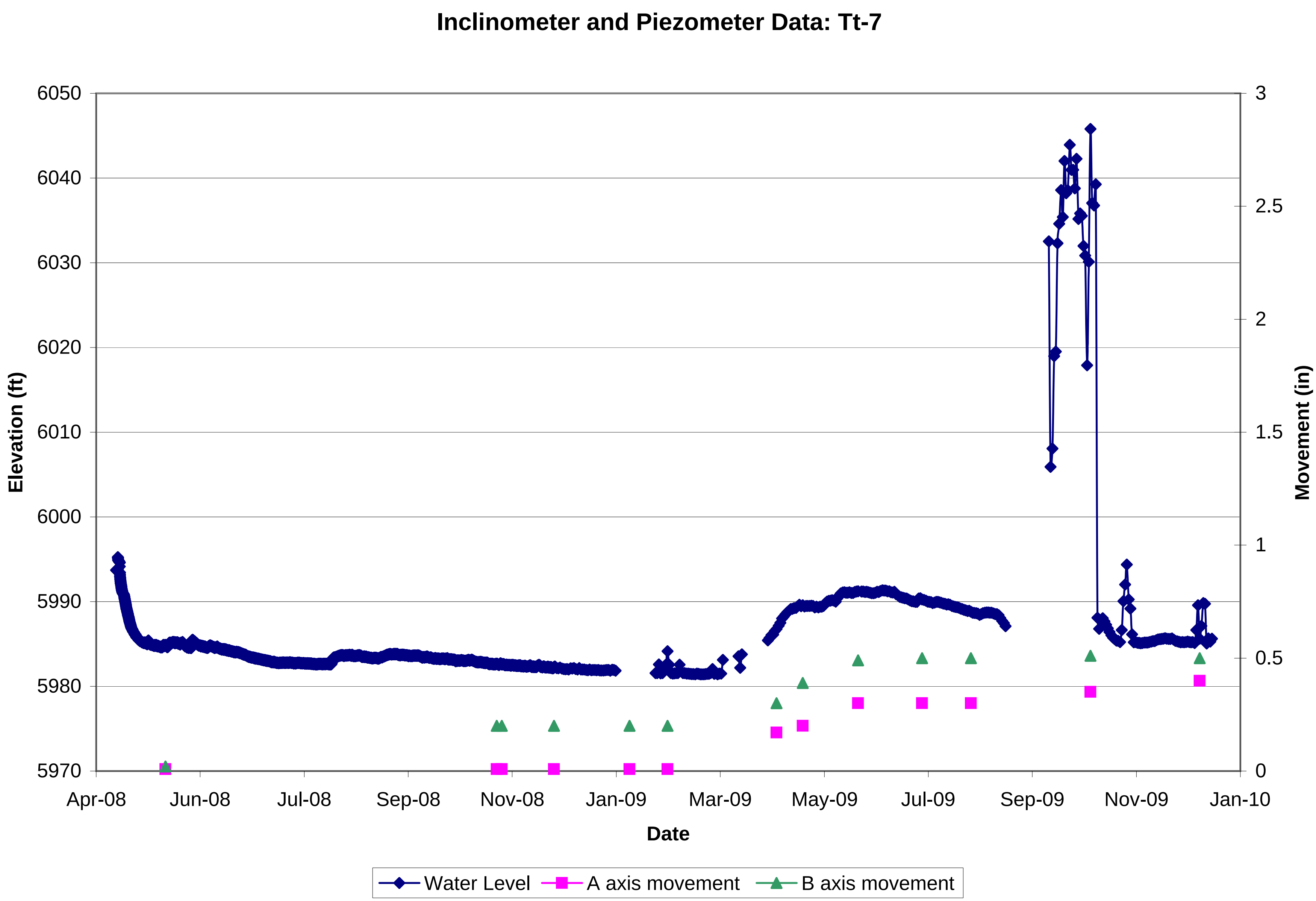

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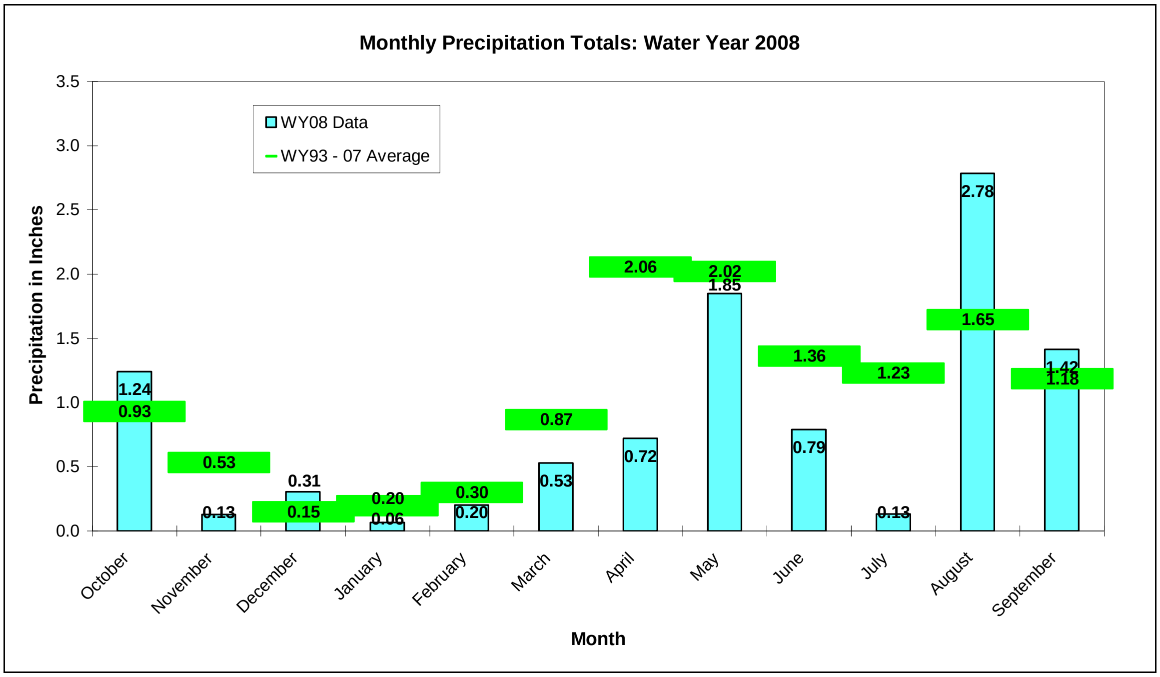
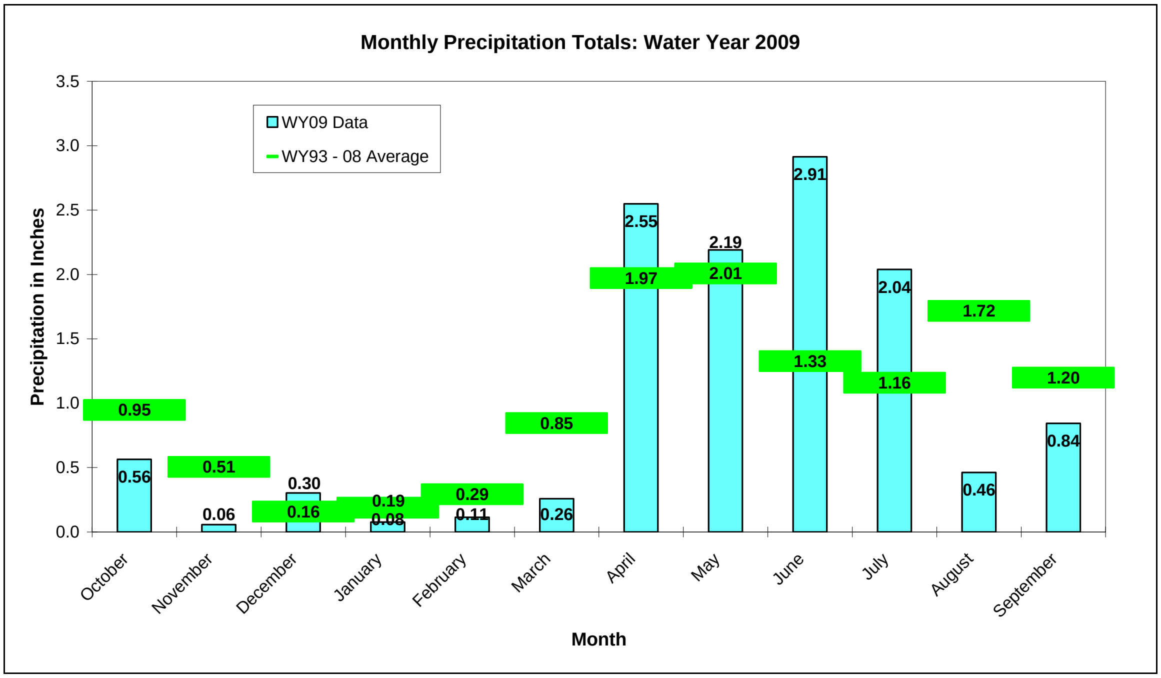
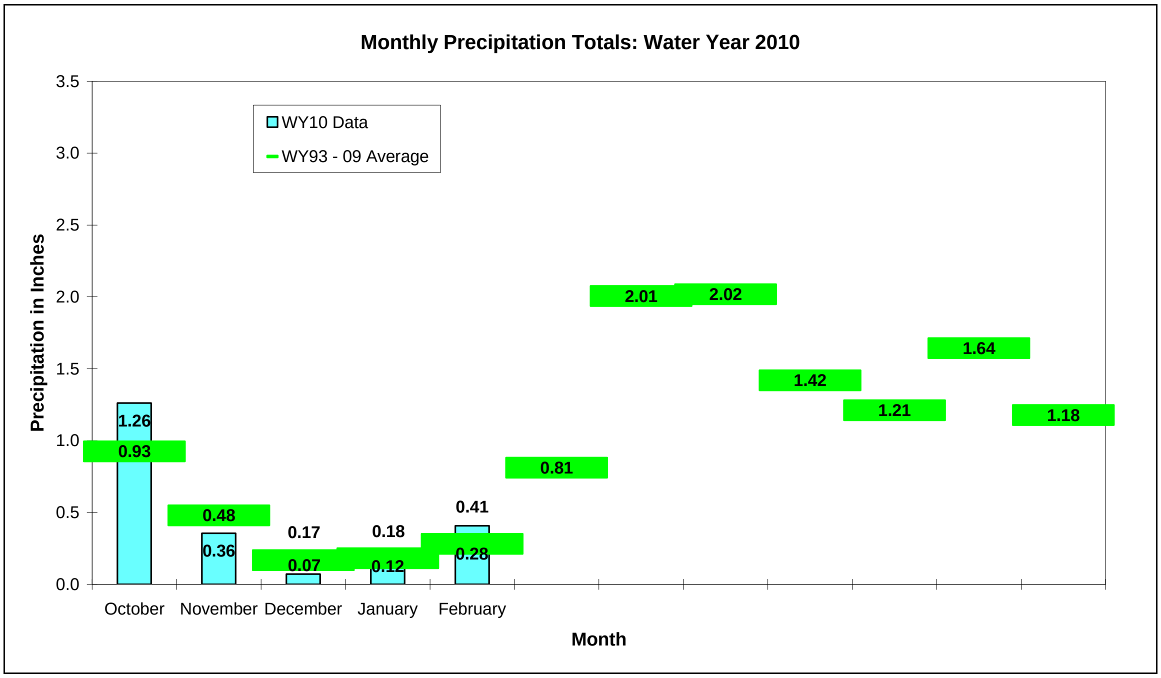
Figure A-7

Attachment B
Precipitation Data


Monthly Precipitation Totals: Water Year 2008
WY08 Data
WY93 - 07 Average
Precipitation in Inches
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1.24
0.93
0.53
0.13
0.31
0.15
0.20
0.06
0.30
0.20
0.87
0.53
2.06
0.72
2.02
1.85
1.36
0.79
1.23
0.13
1.65
2.78
1.42
1.18
October
November
December
January
February
March
April
May
June
July
August
September
Month



Monthly Precipitation Totals: Water Year 2009
WY09 Data
WY93 - 08 Average
Precipitation in Inches
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.56
0.95
0.06
0.51
0.30
0.16
0.08
0.19
0.11
0.29
0.26
0.85
2.55
1.97
2.19
2.01
2.91
1.33
2.04
1.16
0.46
1.72
0.84
1.20
October
November
December
January
February
March
April
May
June
July
August
September
Month


Monthly Precipitation Totals: Water Year 2010
WY10 Data
WY93 - 09 Average
Precipitation in Inches
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1.26
0.93
0.48
0.36
0.17
0.07
0.18
0.12
0.41
0.28
0.81
2.01
2.02
1.42
1.21
1.64
1.18
October
November
December
January
February
Month

Attachment C
Unfiltered Inclinometer
and Piezometer Data

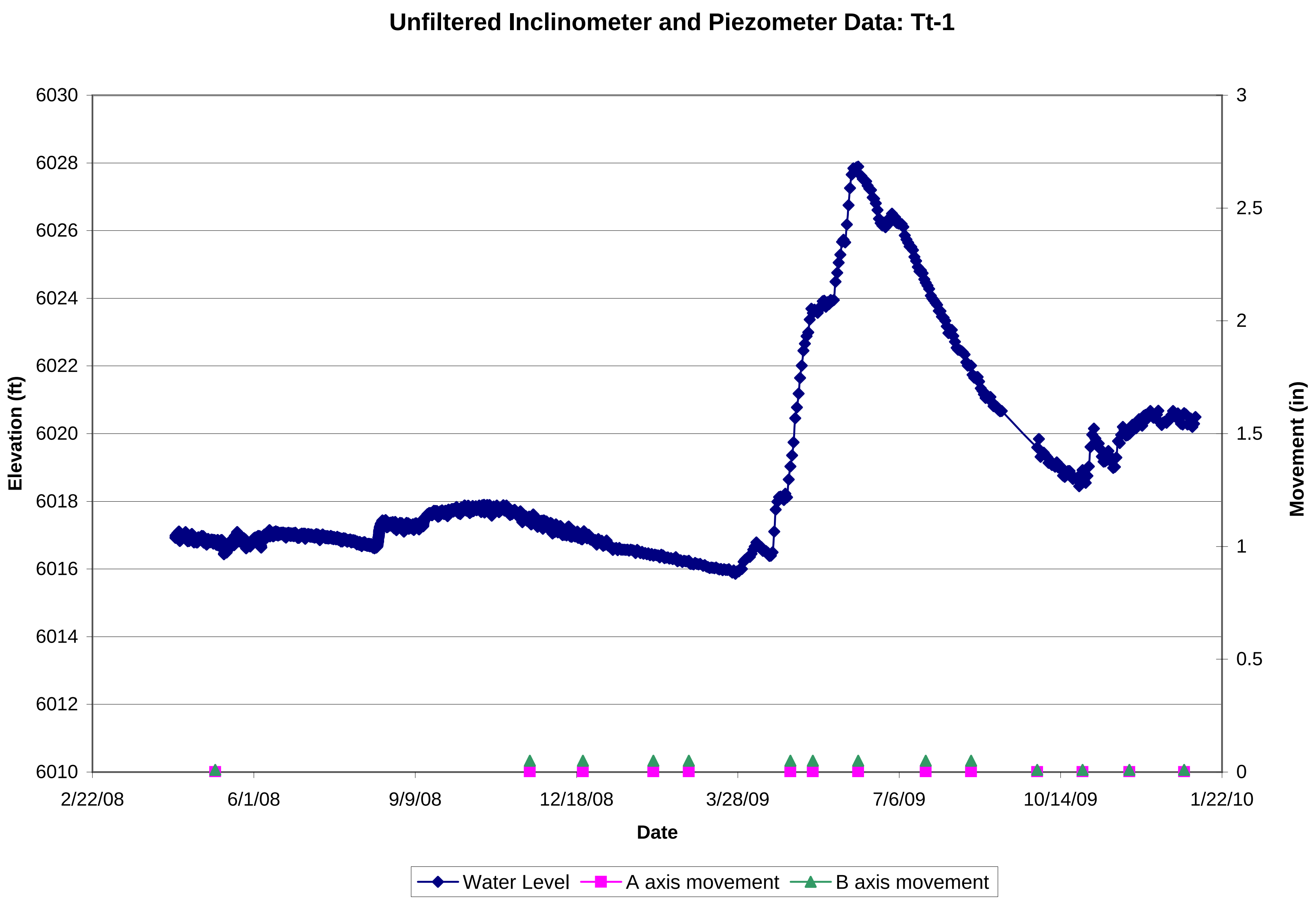


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Figure C-1

Unfiltered Inclinometer and Piezometer Data: Tt-2

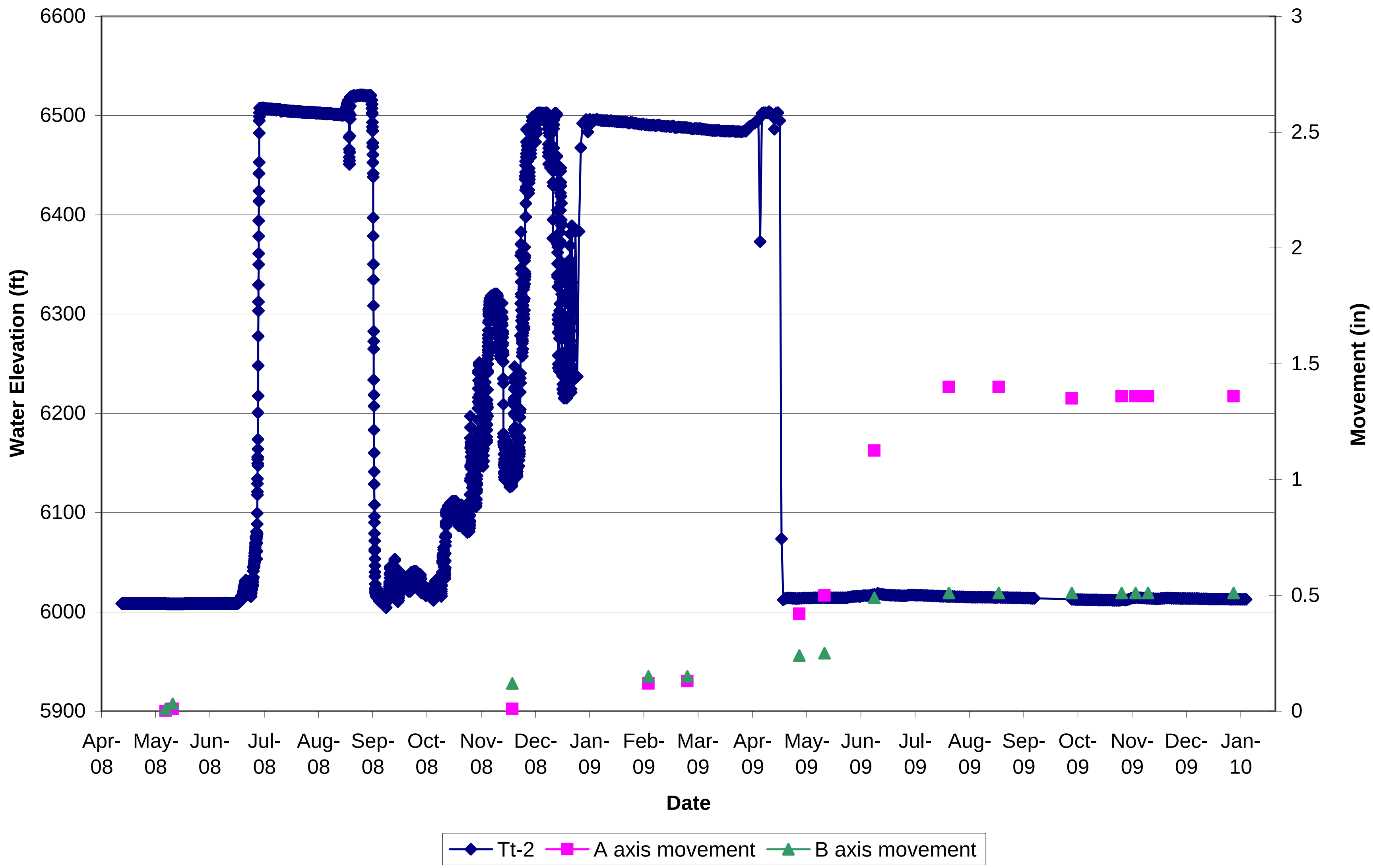

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Figure C-2

Unfiltered Inclinometer and Piezometer Data: Tt-3

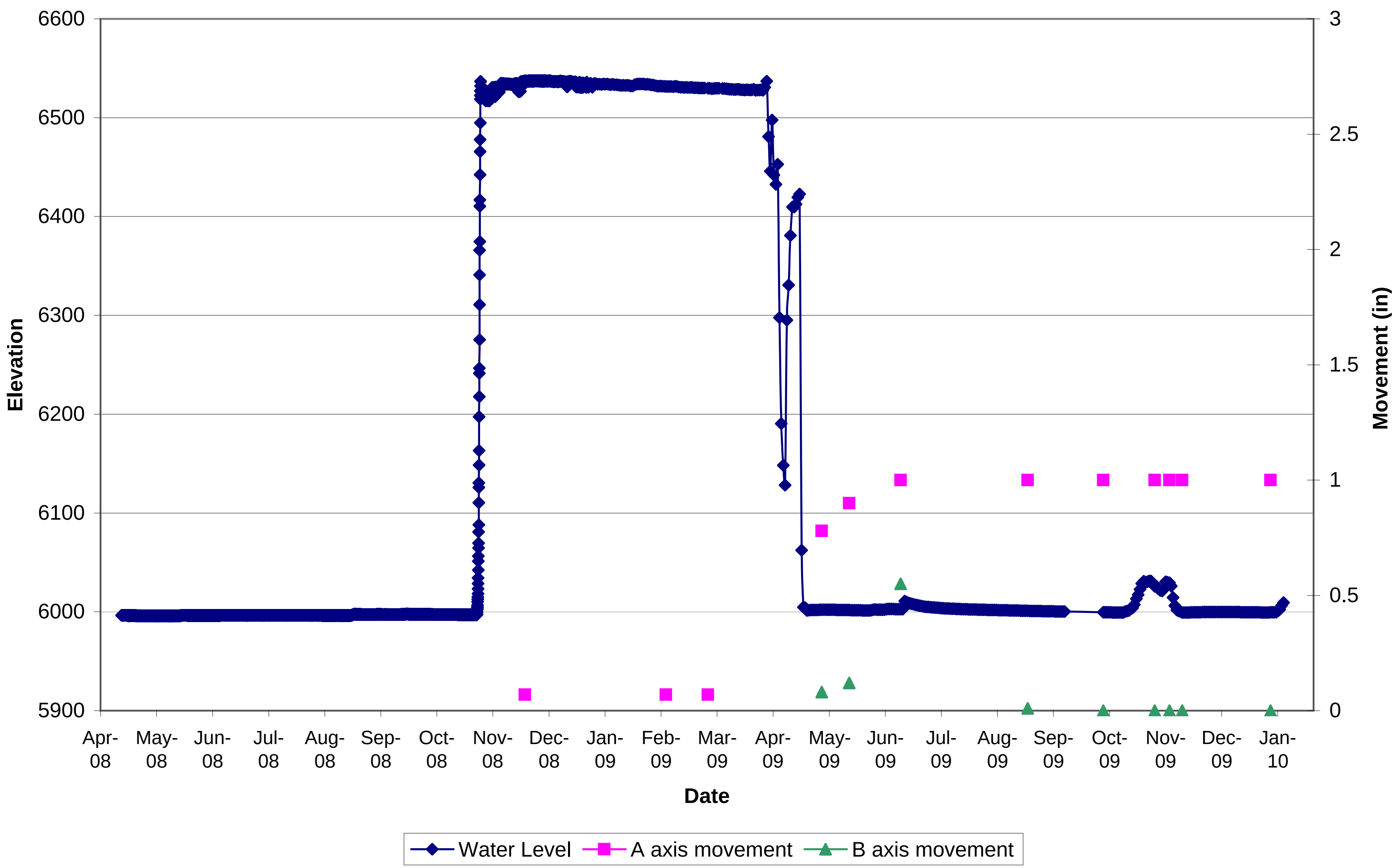

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Figure C-3

Unfiltered Inclinometer and Piezometer Data: Tt-4

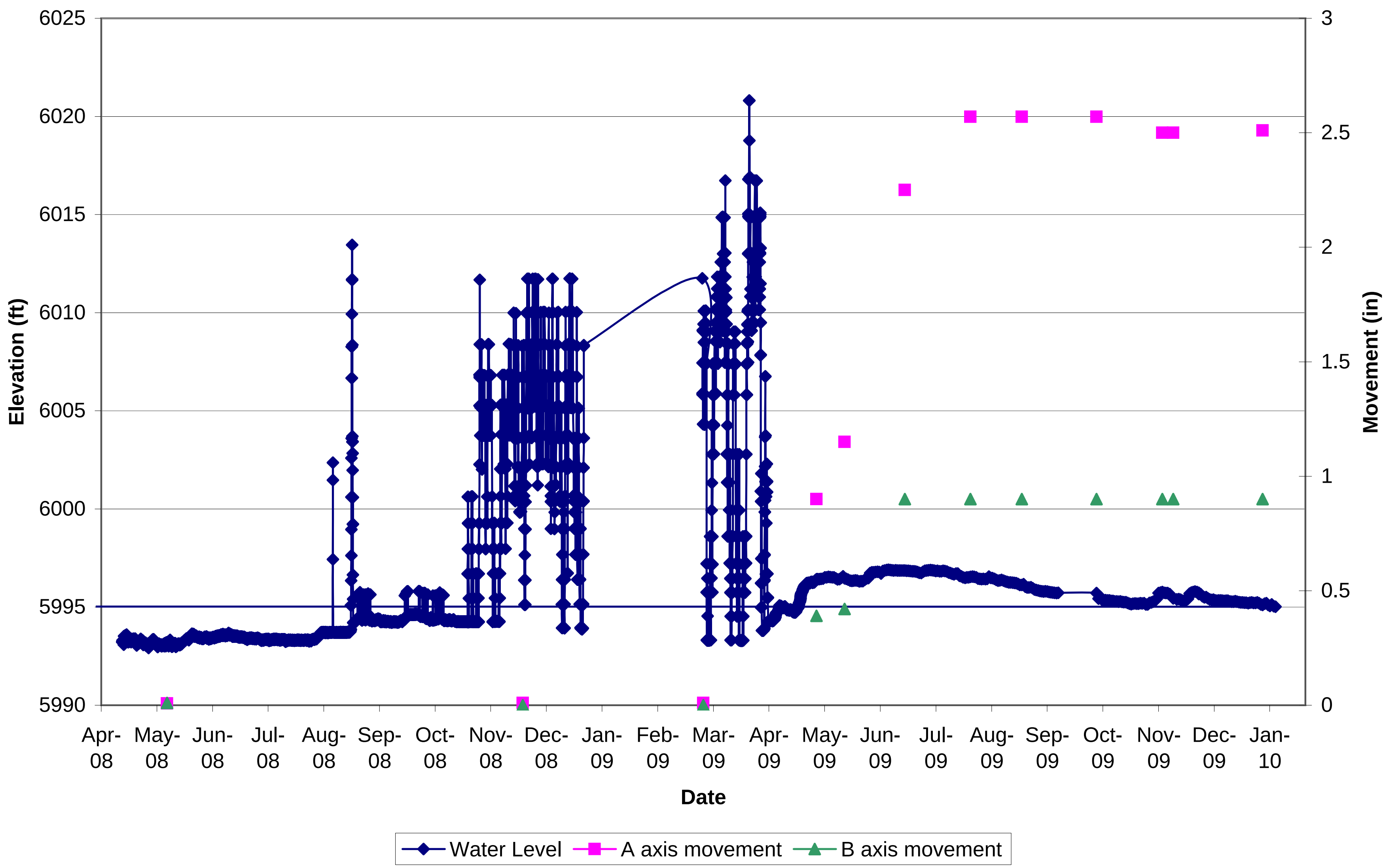

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Figure C-4

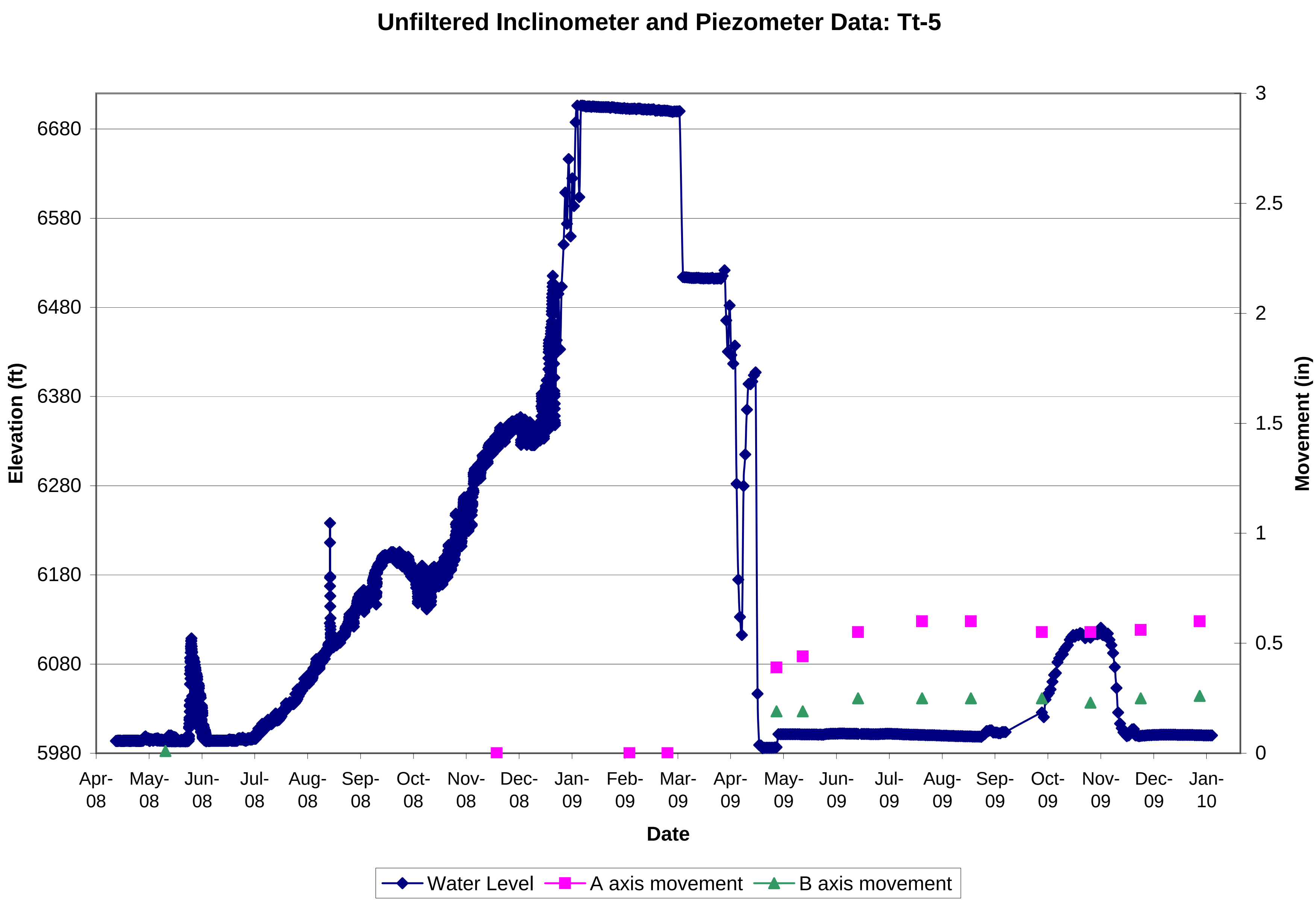

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Figure C-5

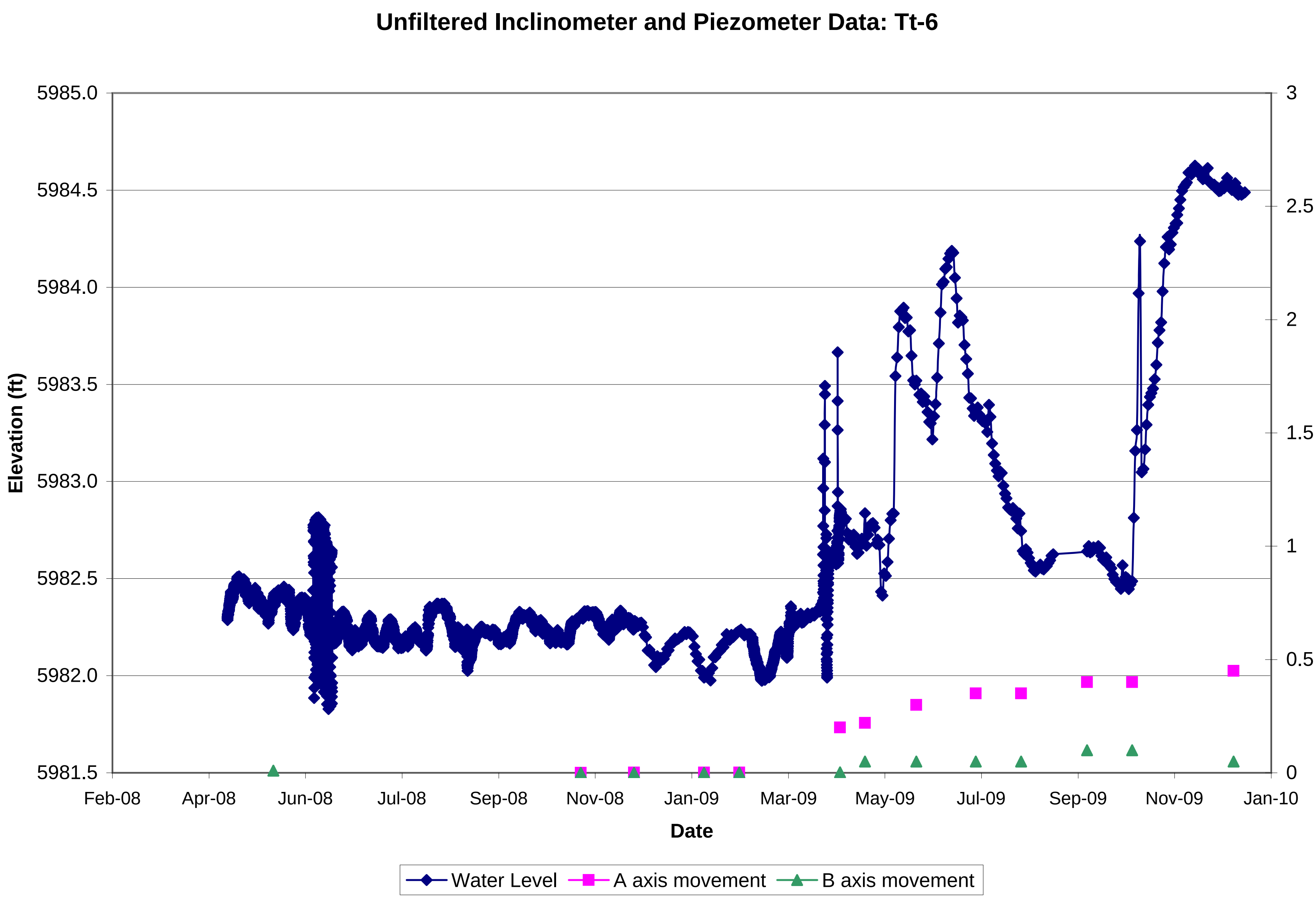

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Figure C-6

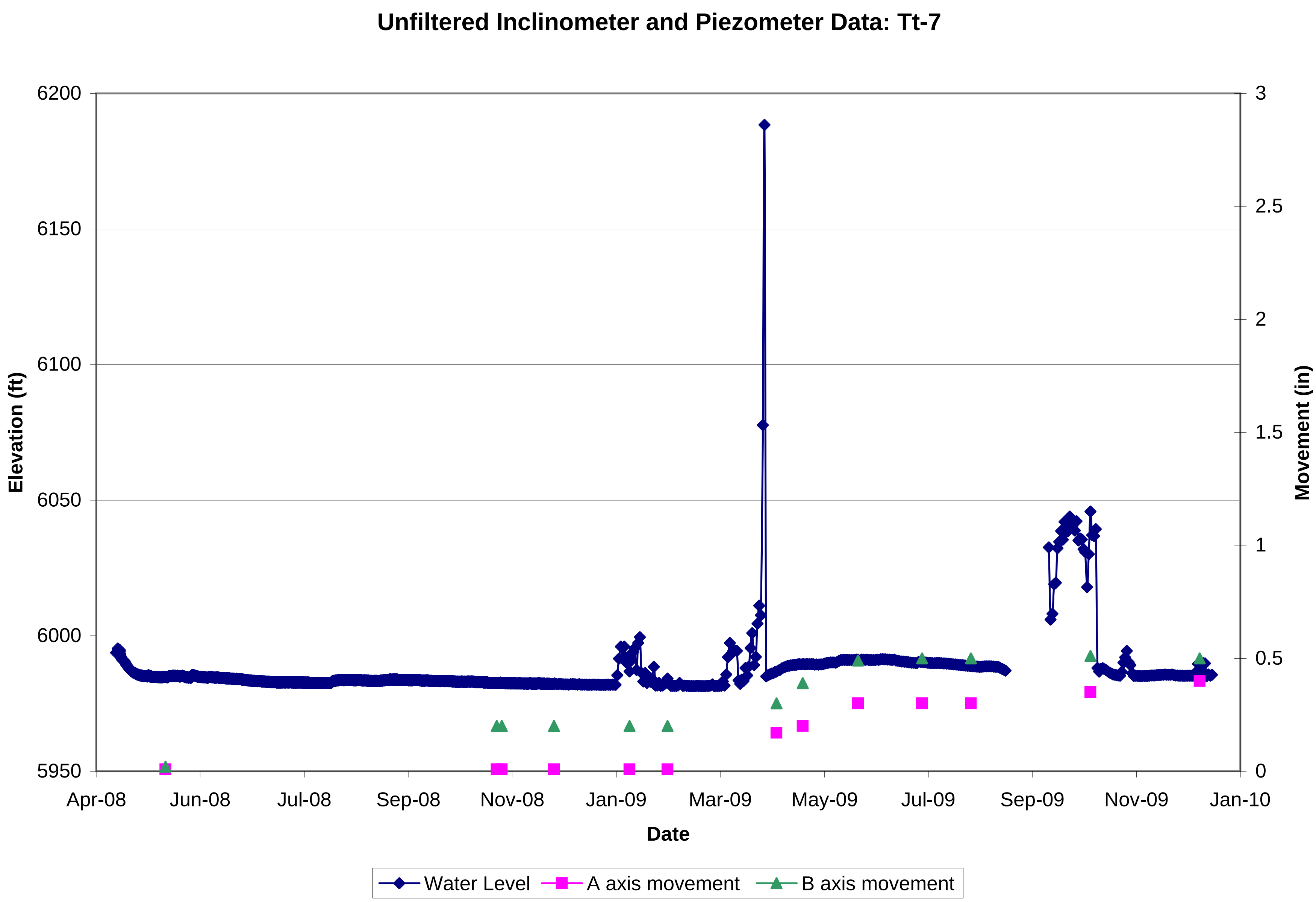

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Figure C-7