Appendix E

Technical Memorandum Regarding Instrumentation and Monitoring at the Rocky Flats OLF
Technical Memorandum

To: Mr. Rick DiSalvo

From: Heather Trantham, Ph.D. PE, Thomas A. Chapel, PE

Company: S. M. Stoller Corporation

Date: April 22, 2011

Re: Instrumentation and Monitoring, Rocky Flats OLF

Tt Project #: 114-181750

Introduction

This technical memorandum provides a summary and evaluation of data collected from instrumentation at the Rocky Flats Original Landfill (OLF). Previously collected data has been updated with information collected during 2010 and January and February, 2011. 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 during which the inclinometers were installed has been provided in our previous annual report and is not repeated here (Tetra Tech, 2008, Tetra Tech, 2010)

Background

Minor localized surface cracking, differential settlement, slumping and subsidence has been previously documented at the OLF, and similar minor distress continued during 2010. Figure 1, Plan View of OLF site, shows the locations of the localized cracking, slumping and settling, seeps, test pits and the inclinometers. A summary of performance of the instruments prior to this Technical Memorandum is provided in the following sections for clarity.

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, except as noted below. The amount of deflection of the inclinometers was manually read periodically – 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 Attachment 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 2010. 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.

During 2010, no data were collected by the data loggers for a portion of the year for five of the piezometers. The data loggers were only downloaded to a field computer infrequently, since the data loggers are designed to hold many thousands of readings. S.M. Stoller staff reports that based upon the dates the batteries were changed in the data loggers, a number of the replacement batteries probably went dead prematurely, and the data was not logged. Although switching to daily readings was intended to extend battery life, it appears that perhaps the replacement batteries may have been defective. Table 1 presents the monthly intervals in 2010 and to date in 2011 for which piezometer data were not available for this evaluation. S.M. Stoller staff plans now to download the piezometer data loggers quarterly and change batteries at the same time.

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.
Table 1. Piezometer Data not Available for 2010

<table>
<thead>
<tr>
<th>Piezometer</th>
<th>Dates for which data is not available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tt-3</td>
<td>7/16/2010 through 9/29/2010</td>
</tr>
<tr>
<td></td>
<td>11/29/2010 through 12/31/10</td>
</tr>
<tr>
<td>Tt-4</td>
<td>5/11/2010 through 9/29/2010</td>
</tr>
<tr>
<td>Tt-5</td>
<td>6/29/2010 through 9/29/2010,</td>
</tr>
<tr>
<td>Tt-6</td>
<td>4/18/2010 through 9/29/2010,</td>
</tr>
<tr>
<td>Tt-7</td>
<td>6/27/2010 through 9/29/2010</td>
</tr>
</tbody>
</table>

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 after the May 14, 2009 reading the inclinometer probe could not be lowered beyond a depth of 33 feet. Subsequent readings have been taken to a depth of 33 feet.

Inclinometer Tt-4 was installed to a depth of 29 feet. Slope movement at this location also resulted in inclinometer tube deformation or breakage, and after April 19, 2010, the inclinometer probe could not be lowered beyond the 13 foot level in Tt-4. Subsequent readings have been taken to a depth of 13 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. 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. It is our opinion that monitoring of the inclinometers should continue to whatever depth the probe can be lowered to, in order to monitor the relative movement over time to the depths that can be measured.

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.

The precipitation in the area was measured by S.M. Stoller using on-site precipitation gages during the period of record for these inclinometers and piezometers. S.M. Stoller staff have reported that some inaccuracy of the precipitation gage 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 March and July (9.25 inches, or approximately 80% of the total 11.64 inches precipitation for the year).

The specifics of each borehole/piezometer/inclinometer (see Figure 1) and any observed significant changes are discussed below. 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 the total movement, or deflection, of each axis of the inclinometers since installation 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. 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 2010 data continues to support this conclusion. 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. Another peak of 1.5 inches on the A-axis and 1.4 on the B-axis was recorded in the summer of 2010 following high rainfall in April 2010. 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.

Tt-3. The piezometer data collected in 2010 is erroneous and indicates that the piezometer in Tt-3 is no longer functioning. A small amount of movement was seen in the A-axis direction in the spring and summer months of 2010, but this movement cannot be correlated with any precipitation data. Movement in the direction of the A-axis started in November 2008, and movement in the B-axis direction started in April 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. The movement in 2010 peaked again in June in both directions due to precipitation in April.
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 correlations between the water level measurements and the movement measured by the inclinometer during that time. In 2010 the inclinometers showed an increase in movement in both directions with a peak in the summer. The piezometer data shows a sharp increase in the water level during this time period, however the magnitude of the water level increase suggests that the piezometer data are erroneous.

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. In 2010, movement increased in the A-axis direction. However, because the piezometer data is missing in the months before the movement occurred, the movement cannot be correlated with an increase in water level.

Tt-7. There has been a general trend for an increase in movement along the A- and B- axes. A 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 Attachment 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. The movement in both directions increased during 2010. Water level fluctuation is recorded before the movement, and the movement can be attributed to the rise in the water table.

Recommendations

The recommendations made in the original report (Tetra Tech, 2008) and our 2010 Technical Memorandum 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. 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.

It is our opinion that monitoring of the inclinometers should continue, in order to provide data on the relative movement over time that may be correlated to observed minor surface cracking, differential...
settlement, slumping and subsidence. Inclinometers that have deformed or broken tubes should continue to be monitored to the depths that can be measured. Although it appears the piezometer at Tt-3 is not functioning, it is recommended that data be collected at this piezometer through 2011, as other piezometers have shown periods of erratic behavior followed by stable periods. If the 2011 data confirms the Tt-3 piezometer is not functioning, then data logging at this location should cease.

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. 2010 Technical Memorandum, Instrumentation and Monitoring, Rocky Flats OLF, April.
Attachment A
Inclinometer and Piezometer Graphs
Inclinometer and Piezometer Data: Tt-1

![Graph showing water level and movement over time.]

- **Elevation (ft)**: 0, 0.5, 1, 1.5, 2, 2.5, 3
- **Movement (in)**: 0, 0.5, 1, 1.5, 2, 2.5, 3
- **Date**:
  - Jan-08, Mar-08, Jun-08, Aug-08, Oct-08, Jan-09, Mar-09, Jun-09, Aug-09, Nov-09, Jan-10, Apr-10, Jun-10, Sep-10, Nov-10, Feb-11, Apr-11

Legend:
- Water Level
- A axis movement
- B axis movement
Figure A-5

Inclinometer and Piezometer Data: Tt-5

Date

Elevation (ft)

Movement (in)

Water Level
A axis movement
B axis movement

Appendix E, Page 15
Inclinometer and Piezometer Data: Tt-7

Date

5970 5980 5990 6000 6010 6020 6030 6040 6050

Apr-08 Jun-08 Aug-08 Nov-08 Jan-09 Apr-09 Jun-09 Sep-09 Nov-09 Feb-10 Apr-10 Jul-10 Sep-10 Dec-10 Feb-11

Elevation (ft)

0 0.5 1 1.5 2 2.5 3

Movement (in)

Water Level A axis movement B axis movement

Figure A-7

Appendix E, Page 17
Attachment B
Precipitation Data
Precipitation Summary 2010

Inches of Precipitation

Month | Oct-09 | Nov-09 | Dec-09 | Jan-10 | Feb-10 | Mar-10 | Apr-10 | May-10 | Jun-10 | Jul-10 | Aug-10 | Sep-10
--- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | ---
Oct-09 | 1.26 | 0.36 | 0.07 | 0.12 | 0.41 | 1.06 | 3.24 | 1.57 | 1.83 | 1.55 | 0.68 | 0.17

Appendix E, Page 19
Precipitation Summary 2011

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<th>Month</th>
<th>Inches of Precipitation</th>
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<tr>
<td>Oct-10</td>
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<tr>
<td>Nov-10</td>
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</tr>
<tr>
<td>Dec-10</td>
<td>0.02</td>
</tr>
<tr>
<td>Jan-11</td>
<td>0.04</td>
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<tr>
<td>Feb-11</td>
<td>0.00</td>
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<tr>
<td>Mar-11</td>
<td>0.00</td>
</tr>
<tr>
<td>Apr-11</td>
<td>0.00</td>
</tr>
<tr>
<td>May-11</td>
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<tr>
<td>Jun-11</td>
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<tr>
<td>Jul-11</td>
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<tr>
<td>Aug-11</td>
<td>0.00</td>
</tr>
<tr>
<td>Sep-11</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Attachment C
Unfiltered Inclinometer
and Piezometer Data
Unfiltered Inclinometer and Piezometer Data: Tt-1

Date
Jan-08 Mar-08 Jun-08 Aug-08 Oct-08 Jan-09 Mar-09 Jun-09 Aug-09 Oct-09 Jan-10 Apr-10 Jun-10 Sep-10 Nov-10 Feb-11 Apr-11

Elevation (ft)
0
0.5
1
1.5
2
2.5
3

Movement (in)

Water Level
A axis movement
B axis movement

Appendix E, Page 22
Unfiltered Inclinometer and Piezometer Data: Tt-3

Date
- Apr-08
- Jun-08
- Aug-08
- Nov-08
- Jan-09
- Apr-09
- Jun-09
- Sep-09
- Nov-09
- Feb-10
- Apr-10
- Jul-10
- Sep-10
- Dec-10
- Feb-11

Elevation
- 6000
- 6100
- 6200
- 6300
- 6400
- 6500
- 6600

Movement (in)
- 0
- 0.5
- 1
- 1.5
- 2
- 2.5
- 3

Water Level
- A axis movement
- B axis movement

Appendix E, Page 24
Unfiltered Inclinometer and Piezometer Data: Tt-4

Date

- Apr-08
- Jun-08
- Aug-08
- Nov-08
- Jan-09
- Apr-09
- Jun-09
- Sep-09
- Nov-09
- Feb-10
- Apr-10
- Jul-10
- Sep-10
- Dec-10
- Feb-11

Elevation (ft)

- 5990
- 5995
- 6000
- 6005
- 6010
- 6015
- 6020
- 6025

Movement (in)

- 0
- 0.5
- 1
- 1.5
- 2
- 2.5
- 3
- 3.5
- 4
- 4.5
- 5

Water Level

A axis movement

B axis movement

Figure C-4

Appendix E, Page 25
Unfiltered Inclinometer and Piezometer Data: Tt-7

Date
Apr-08 Jun-08 Aug-08 Nov-08 Jan-09 Apr-09 Jun-09 Sep-09 Nov-09 Feb-10 Apr-10 Jul-10 Sep-10 Dec-10 Feb-11

Elevation (ft)
5950 6000 6050 6100 6150 6200

Movement (in)
0 0.5 1 1.5 2 2.5 3

Water Level
A axis movement
B axis movement

Figure C-7
Appendix E, Page 28