Department of Energy
Washington, DC 20585

March 31, 2017

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Deputy Director
Mail Stop T8-F5
Washington, DC 20555-0001

40-8902

Subject: Evaluation of Disposal Cell Topography Using LiDAR Surveys, Bluewater, New Mexico, Disposal Site

To Whom It May Concern:

The U.S. Department of Energy Office of Legacy Management (DOE-LM) conducted a light detection and ranging (LiDAR) topographic survey of the main tailings disposal cell at the Bluewater, New Mexico, Disposal Site in March 2016. Data from this survey were compared to LiDAR survey data collected in July 2012 as well as topography generated from aerial photography in 1997.

An evaluation of the topographic data is presented in the enclosed report *Evaluation of Disposal Cell Topography Using LiDAR Surveys, Bluewater, New Mexico, Disposal Site* (October 2016). The report provides the following conclusions:

- The entire top slope has settled since the cell was completed in 1995, with the greatest amount of settlement occurring on the north portion of the top slope.
- The top slope continues to settle, but at a decreasing rate.
- Precipitation runoff ponds in depressions on the north portion of the top slope. There is no evidence that top slope runoff has ever spilled over the north edge of the top slope as originally designed.
- The largest pond to date, calculated using LiDAR topography, has been approximately 4.3 million gallons. The largest pond that could develop before runoff spills over the north edge of the cell would hold approximately 7.1 million gallons.

The ponded runoff water is not considered to have a negative impact on the cell cover materials because most of the water dissipates through evaporation instead of percolating through the radon barrier. Pond dissipation is also accelerated by operation of a 2-inch diameter siphon that was installed in fall 2015; the siphon has to be manually started to move water from the ponds to an area along the north side of the disposal cell. The siphon has been successfully operated on two occasions, removing nearly all of the ponded water from the cover.

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Please call me at (970) 248-6550 if you have any questions. Please address any correspondence to:

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Sincerely,

Bernadette Tsosie
Site Manager

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File: BLU 0045.15 (Records)

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Evaluation of Disposal Cell Topography Using LiDAR Surveys Bluewater, New Mexico, Disposal Site

October 2016

U.S. DEPARTMENT OF ENERGY | Legacy Management

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Abbreviations

DOE	U.S. Department of Energy
LiDAR	light detection and ranging
LM	Office of Legacy Management
NRC	U.S. Nuclear Regulatory Commission
UAS	unmanned aerial system
UMTRCA	Uranium Mill Tailings Radiation Control Act

1.0 Introduction

The Bluewater, New Mexico, Uranium Mill Tailings Radiation Control Act (UMTRCA) Title II Disposal Site has two rock-covered tailings disposal cells and four other smaller cells and landfills that contain radioactively contaminated materials associated with the former uranium mill at the site. The focus of this report is on the use of the light detection and ranging (LiDAR) topographic mapping method to evaluate changes in the top slope of the main tailings disposal cell, which is currently the largest disposal cell managed by the U.S. Department of Energy (DOE) Office of Legacy Management (LM). Understanding topographic changes is necessary for evaluating performance and long-term management of the disposal cell. LiDAR mapping of this cell was conducted in 2012 and 2016.

1.1 Disposal Cell Design

During milling operations (1953 through 1982) predominantly sandy tailings, containing a component of silts and clays, were slurried from the mill to the south end of the tailings pond. Coarse sand in the slurry settled out first at the south end of the pond, then an interbedded mixture of finer sands, silts, and clays settled in the middle portion of the pond, and lastly, predominantly clay settled at the north portion of the pond (DOE 2014). The clay-rich tailings are referred to as slimes. Over time, the south end of the tailings pile grew in elevation, forcing the pond to the north end of the pile. A dike, constructed with uncontaminated material, surrounded the tailings and was periodically and differentially (highest at the south end and lowest at the north end) raised to contain the increasing amount of tailings. The resulting configuration of the top slope of the tailings pile had its highest elevation at the south end of the impoundment and sloped downward to a relatively flat surface at the north end.

Prior to final grading of the tailings pile, the former mill licensee attempted to dewater the pile according to plans concurred on by the U.S. Nuclear Regulatory Commission (NRC). Extraction wells withdrew tailings fluids from the sandy portion of the pile until production essentially ceased. To extract fluids from the slimes portion of the pile, the licensee installed band drains and covered the slimes with as much as 15 feet of sandy clay material derived from the mill site. The weight of added material squeezed fluids held by the clay into the band drains that wicked the water to the surface for removal to an evaporation pond. The addition of material and removal of tailings fluids caused the slimes to consolidate. Consolidation continued until attaining a predicted total consolidation target of 90 percent as concurred on by NRC, at which time the band drains were removed.

After tailings fluid removal activities were completed, the tailings pile cover was graded and then capped with a radon barrier protected by crushed rock. The completed main tailings disposal cell conforms to the configuration of the tailings pile and has a footprint of 354 acres with a top slope of 250 acres. According to the reclamation completion report (ARCO 1996), the final configuration of the top slope consisted of an approximate 4 percent slope beginning at the south end, flattening out to an approximate 0.5 percent slope at the north end (over the slimes). The radon barrier, consisting of a sandy clay material obtained from the mill site, ranges in thickness from 2.3 to 4.2 feet over the coarse sand tailings and 1.0 to 2.2 feet over the slimes tailings. An average 4-inch-thick layer of crushed basalt rock (median rock size of 3 inches) was placed over the radon barrier to protect it from erosion.

The disposal cell was completed in 1995 and was designed to withstand a probable maximum precipitation event in accordance with UMTRCA Title I disposal cell design requirements (NRC 1993). The top slope was designed to shed all runoff from snowmelt and rainfall evenly over the north end of the disposal cell without causing erosion to the cell. Consequently, the rock protecting the north side slope has a larger diameter than the rock covering the other side slopes and the top slope. The adequacy of the design needs to be evaluated according to NRC's current requirements for UMTRCA Title II disposal cells (NRC 2002, NRC 2003).

1.2 Observed Conditions of the Disposal Cell Top Slope

The Bluewater mill site was transitioned to DOE under the NRC general license in 1997. LM is responsible for ensuring the site remains protective of human health and the environment in accordance with the requirements of the site-specific Long-Term Surveillance Plan (DOE 1997). These requirements include annual inspections of the disposal cells and other site features, and monitoring groundwater aquifers impacted by milling operations.

At the time of site transition, the former mill licensee provided DOE with a topographic site map developed from aerial photography. The site topography was mapped at 2-foot contour intervals. At that level of resolution, the topographic map of the main tailings disposal cell confirmed that the cell configuration was in accordance with the design (Figure 1). However, an aerial photo taken in 1997 shows water-filled depressions on the north end of the main tailings disposal cell top slope (Figure 2).

A shallow pond on the north end of the main tailings disposal cell top slope was observed by DOE inspectors during the first annual site inspection in 1998 (DOE 1998). During subsequent inspections, multiple shallow ponds or areas of white evaporite minerals in depressions were noted, indicating that water had ponded and subsequently evaporated. The depressions were observed to be enlarging in area and depth. However, pond development on the top slope was not considered to be a concern because it was concluded that nearly all of the ponded water was dissipating through evaporation based on regional precipitation and evaporation rates. Minimal precipitation was assumed to be percolating through the radon barrier and into the tailings.

Occasionally a large pond develops over the area of depressions; one such pond was present during the 2015 inspection (DOE 2015). Evaporite minerals clearly define the maximum coverage of the largest pond, which occurred prior to 2012. To date, no evidence that runoff water has ever spilled over the north edge of the top slope has been observed; all runoff has collected in the depressions.

1.3 Disposal Cell Evaluation

Uranium concentrations in a point-of-compliance monitoring well in the alluvial aquifer began increasing in 1999 and eventually exceeded an approved alternate concentration limit in 2010 (DOE 2011). In consultation with NRC, LM began to evaluate the main tailings disposal cell in 2011 to determine if there was a correlation between the increasing uranium concentrations and disposal cell performance. Performance of the cell was in question because of the depressions that had developed on the cover and ponding of runoff water in the depressions. The concern was that ponded water might be percolating through the cover and the tailings, thereby recharging the alluvial groundwater with a surge of contaminated water.

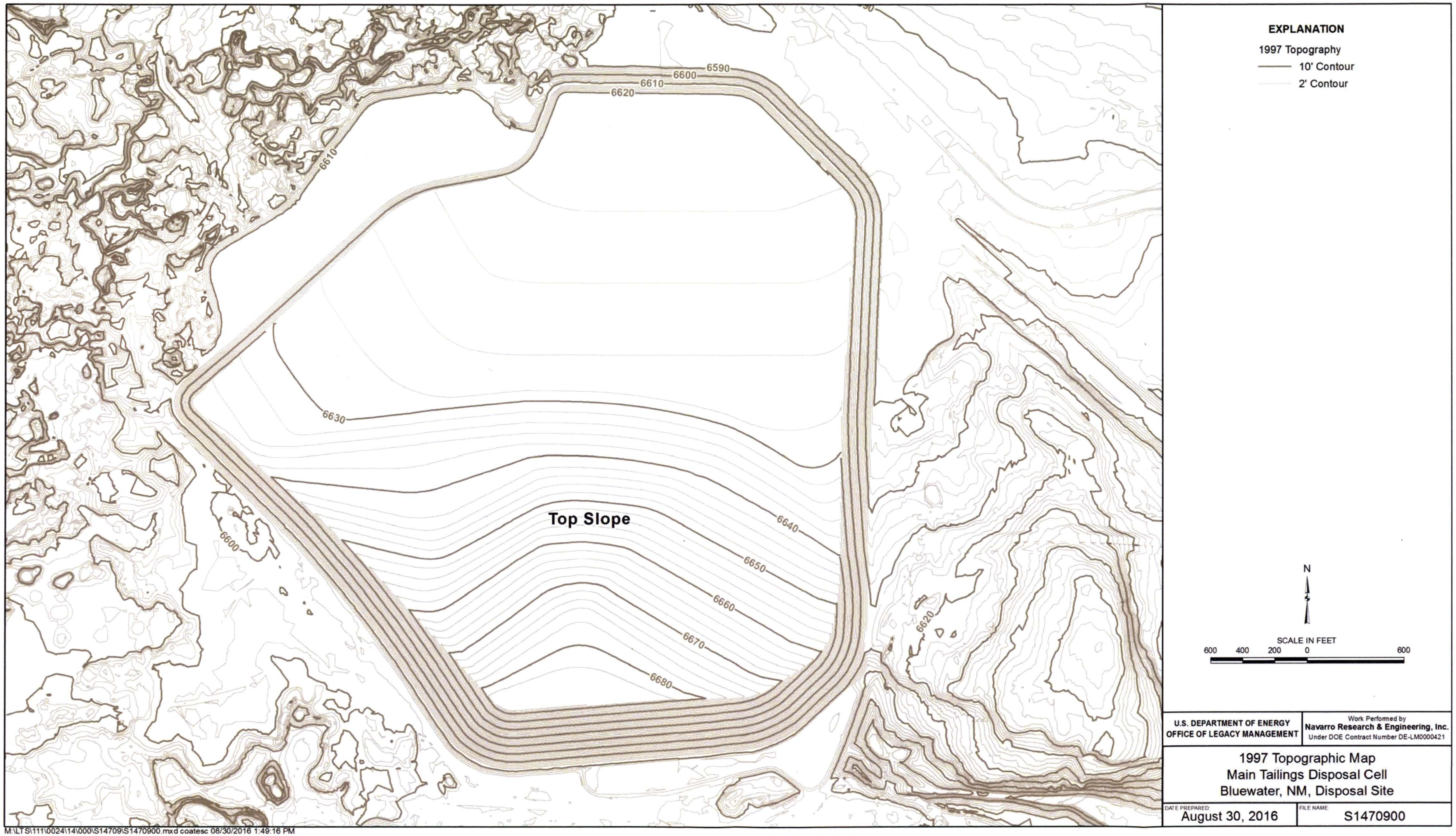

Figure 1. 1997 Aerial Photography-Generated Topographic Map of the Main Tailings Disposal Cell

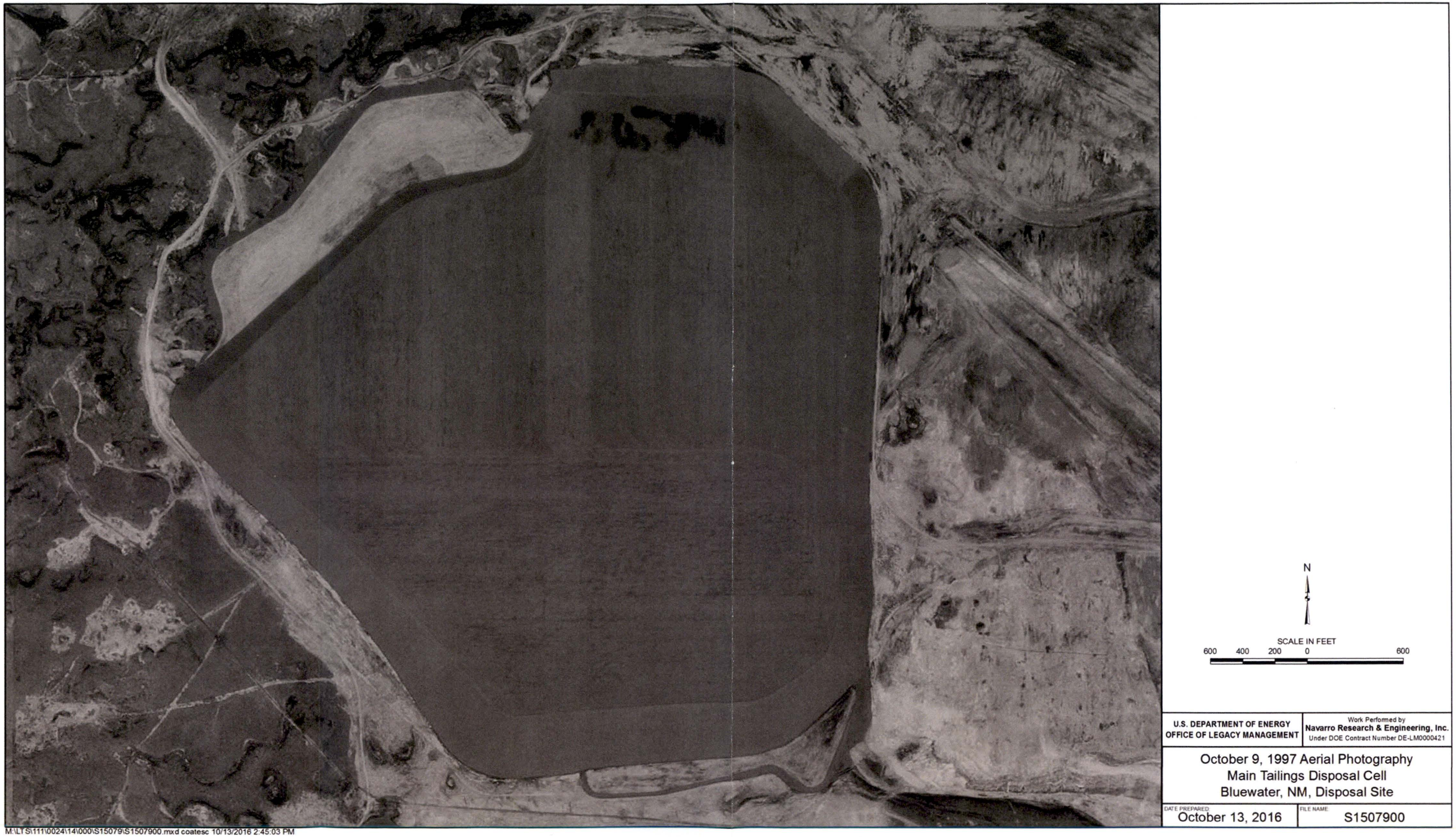

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Figure 2. 1997 Aerial Photo of the Main Tailings Disposal Cell Showing Ponded Water on the Top Slope

Evaluation of cell performance and groundwater contamination was completed and included in a site status report (DOE 2014). The report, currently being reviewed by NRC, included the following observations related to the main tailings disposal cell.

- Approximately 5.7 billion gallons of tailings fluid seeped through the bottom of the main tailings impoundment prior to construction of the disposal cell cover in 1995. Most of the seepage occurred prior to 1960, at which time the licensee began decanting processing fluids from the tailings pond and disposing the fluids into a deep injection well and later to lined evaporation ponds.
- It was concluded that tailings fluids will continue to seep from the disposal cell indefinitely. However, there have been no increasing trends in contaminant concentrations in groundwater monitoring wells next to the cell since the cell was completed. LM and an independent evaluation concluded that the increase in uranium concentrations in the alluvial well was due to well-specific issues instead of cell performance (SRNL 2014).
- The band drains were removed after 90 percent consolidation was achieved but not all of the tailings fluid was removed from the slimes. The depressions had already started to develop when the site was transitioned to DOE and are due to continued consolidation of the slimes.
- The material added by the licensee to dewater the slimes resulted in a thick, low-permeability layer that significantly reduces infiltration of precipitation and ponded water into the slimes, thereby maintaining a low seepage rate from the encapsulated tailings.
- A LiDAR survey of the cell in 2012 provided information to determine the extent and magnitude of the depressions on the cell's top slope. One survey was not sufficient, however, to determine if the cover had stabilized and additional surveys were recommended for 2015 and 2018.
- Radon measurements collected on the surface of the radon barrier in the area of depressions in 2013 indicated that the radon barrier was performing as designed. Therefore, the depressions were not degrading the effectiveness of the radon barrier.
- The persistence of ponds on the top slope and on land near the disposal cell indicates that the ponds that develop in the depressions are reduced primarily through evaporation rather than infiltration. There is no evidence, therefore, that suggests the depressions and associated ponds are causing additional seepage from the cell.

2.0 LiDAR as a Mapping Tool

LM is using LiDAR technology to create high-resolution topographic maps of radioactive-waste disposal cells. LiDAR uses laser light to map the location and elevation of surface features. Initial uses of this technology are to determine if changes are occurring to the physical configurations of disposal cells at the Bluewater and Weldon Spring, Missouri, sites. LM is investigating the use of LiDAR or high-resolution photogrammetry methods to map other disposal cells to document as-built or current conditions and to determine if slow-acting changes are occurring.

A LiDAR system is mounted on a piloted aircraft or an unmanned aerial system (UAS). The LiDAR device emits pulses of laser light. Some pulses reflect off the ground and back to a detector in the aircraft or UAS. The position of the detector is accurately recorded and the distance to an object is measured by the time it takes the pulse to reflect off the object and back to the detector. A fixed-wing piloted aircraft has been used for LiDAR surveys at the Bluewater and Weldon Spring sites, but UAS-mounted systems are being investigated by LM because the cost of a UAS survey may be considerably less than a piloted aircraft survey.

Laser light is extremely focused. A pulse can be reflected off the surface of anything—the top of a plant, a tree branch, or the land surface. Reflections off vegetation arrive sooner than reflections off the land surface. Each pulse is recorded with reflection time and location information. The data points form a three-dimensional "point cloud." A minimum of 20 elevation data points are collected per square meter of surface area.

After data are collected, they are processed to remove vegetation and other effects and then analyzed to create a digital elevation model of the disposal cell surface. The resolution of the resulting data is dependent on the roughness of the surface being mapped. Because of the multi-faceted surfaces of the 3-inch-diameter rock on the top slope of the main tailings disposal cell, the system can define elevation changes as small as 3 inches on the top slope. Data can be presented as topographic maps, three-dimensional visualizations, or in other formats. Data from different surveys can be compared to identify changes in elevation, which might indicate slow, modifying processes at work on disposal structures.

3.0 2012 LiDAR Survey

A LiDAR survey of the main tailings disposal cell was conducted on July 10, 2012, to document the current topography of the cell, particularly the aerial extent and depths of depressions on the top slope. The survey was conducted when there were no ponds on the top slope because pond surfaces would be mapped as flat surfaces. Also, there were few annual weeds on the top slope because the summer monsoon, which normally occurs July through September, had not begun (nearly half of the annual regional rainfall of 10.5 inches occurs during the monsoon season as isolated high-intensity precipitation events).

A topographic map generated from the 2012 LiDAR data is shown in Figure 3. Surface elevation is represented as 6-inch (0.5-foot) contours; contours as fine as 3 inches could be developed but would have been difficult to distinguish at the map scale. Figure 3 shows the uneven surface area on the north portion of the top slope where the depressions are present.

As previously mentioned, depressions were noted during the first annual inspection in 1998. It is assumed that they began to develop soon after the cell cover was completed in 1995. Depressions did not appear on the 1997 topographic map because the 2-foot contour interval did not provide sufficient resolution (Figure 1). At that time, even 0.5-foot contours may not have defined any of the depressions because they were so shallow.

The depressions as they existed in 2012 are more easily visualized when overlain by a representation of the largest pond that had developed to that date (Figure 4). The elevation at the edge of the largest pond was determined by collecting GPS locations at the edge of the area containing white evaporite minerals. According to the LiDAR data, the elevation of the edge of the evaporite minerals was approximately 6619.5 feet. This elevation was confirmed by overlaying the LiDAR map with satellite imagery from the same time period that clearly showed the extent of evaporite minerals.

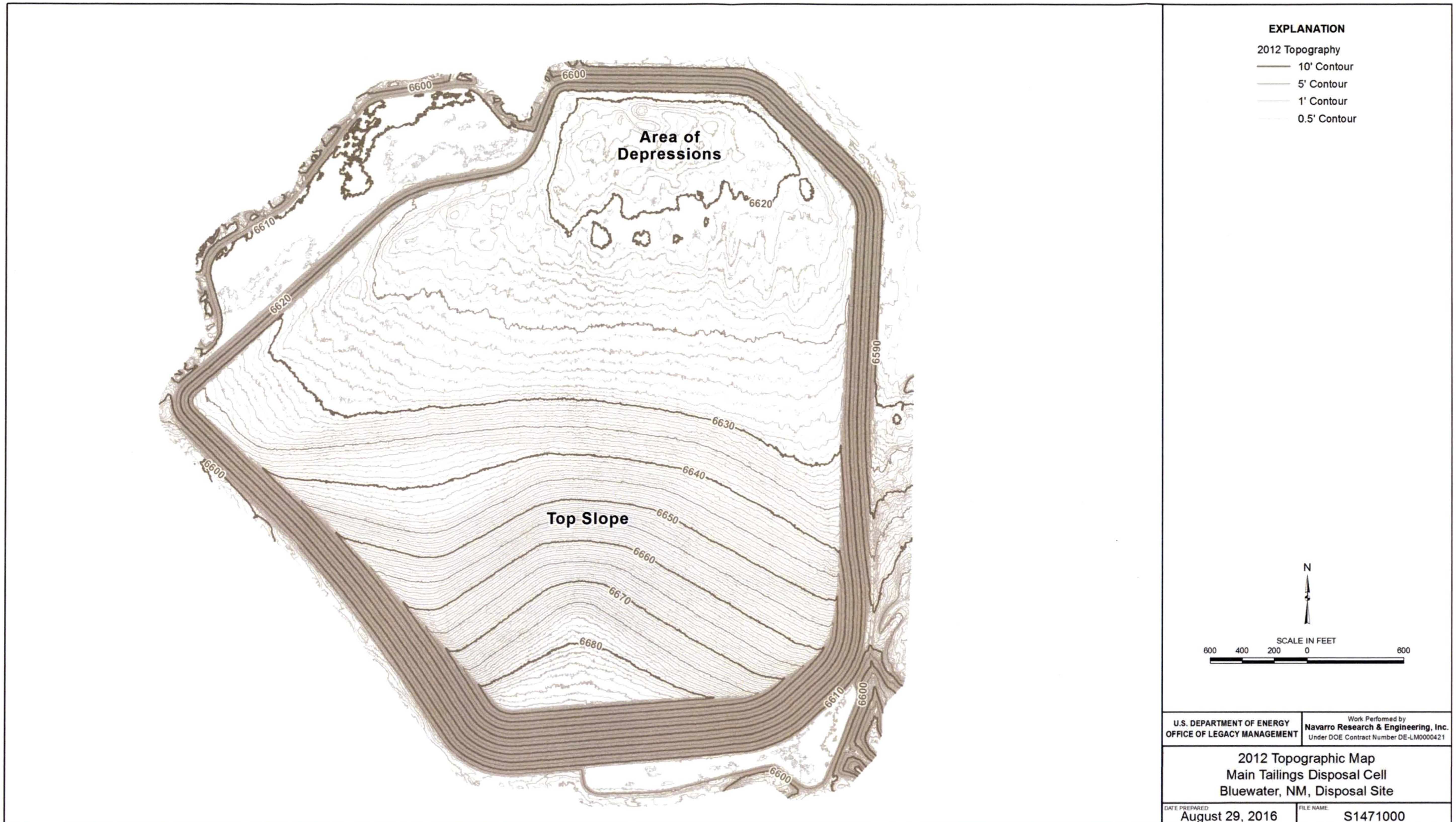

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Figure 3. 2012 LiDAR-Generated Topographic Map of the Main Tailings Disposal Cell

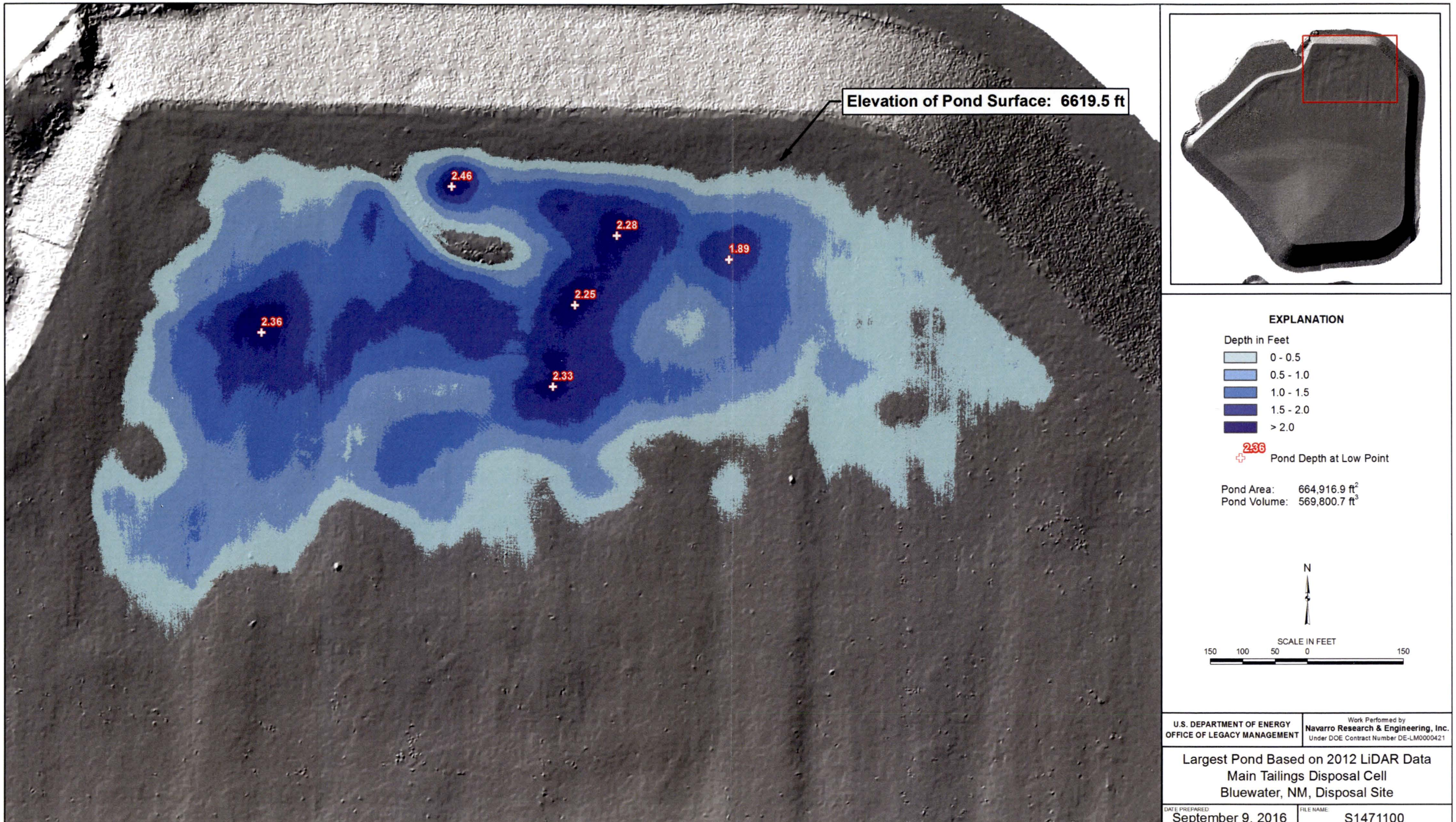

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Figure 4. Largest Pond that has Occurred on the Main Tailings Disposal Cell Based on 2012 LiDAR Topography (Surface Elevation at 6619.5 Feet)

Figure 4 can be used to show how ponds develop during periods of frequent precipitation runoff or during melting of significant snow accumulations. Ponds first develop in the darkest blue areas as runoff flows over the top slope toward the north end of the cell. Depending on the amount of runoff, they will continue to grow and eventually coalesce into one large pond as represented by the lighter shades of blue. During annual inspections and other site visits, as many as seven shallow ponds up to one large pond have been observed.

Based on the maximum pond surface elevation of 6619.5 feet, the maximum depths of water in the deepest depressions ranged from 1.89 feet (elevation of 6617.61 feet) to 2.46 feet (elevation of 6617.04 feet). The pond covered an area of approximately 15.3 acres and held approximately 4.3 million gallons of water.

4.0 2016 LiDAR Survey

A second LiDAR survey was planned in 2015 before the monsoon season commenced. The purpose of the survey was to determine if the surface of the main tailings disposal cell top slope had stabilized or was continuing to settle. The carbonate tailings disposal cell was included in the planned survey to establish a topographic baseline for that cell and because a very shallow depression had been observed on the top slope of the northwest extension of the cell.

Spring rainstorms resulted in the development of several shallow ponds on the top slope of the main tailings disposal cell that did not evaporate until mid-June. A survey was conducted in early July 2015; unfortunately a rainstorm the night before resulted in several shallow ponds on the top slope, compromising the results and forcing a resurvey. It was an unusually wet monsoon season and storms continued into the fall, resulting in one large pond on the top slope. Most of the water was discharged off the north toe of the disposal cell in November using a siphon system installed that month, but the remaining shallow ponds did not evaporate until spring 2016. The cells were finally resurveyed on March 24, 2016.

A topographic map generated from the 2016 LiDAR data is shown in Figure 5. Surface elevation is represented in 0.5-foot contours, and a visual comparison of the 6620-foot contour line on Figure 3 shows a change between the 2012 and 2016 surveys.

LiDAR data were used to evaluate the magnitude of change that occurred in the period between the two surveys (3.7 years). The light-blue colored areas shown in Figure 6 indicate areas that have subsided as much as 0.5 feet since the 2012 survey. Most of the subsidence occurred in the area of depressions (blue lines along the grade break between the top slope and side slopes are a processing artifact and do not indicate that the vertex of the side and top slopes is subsiding). A simulated pond with a surface elevation of 6619.5 feet shown in Figure 7 further demonstrates the change. The pond area has increased from approximately 15.3 acres to 17.9 acres, and the volume has increased from approximately 4.3 million gallons to 5.8 million gallons. Maximum depths of water in the deepest depressions increase from 1.89 to 2.46 feet in 2012, to 2.13 to 2.78 feet in 2016.

As mentioned previously, there is no evidence that runoff has ever spilled over the north edge of the top slope; to date, all runoff has ponded in depressions on the top slope. Although the cell was designed to allow runoff to spill evenly over the north edge of the top slope, ponded water will begin to spill when its surface elevation reaches the lowest elevation along the north edge.

Figure 8 shows the largest pond that could develop without runoff spilling over the edge of the top slope, based on the 2016 LiDAR-generated topographic map. The lowest elevation along the north edge of the top slope is 6620.08 feet. Assuming that the rock cover thickness at that location is 4 inches (0.33 feet), ponded water would begin to spill over the top surface of the underlying compacted soils at an elevation of 6619.75 feet (only 0.25 feet higher than the largest pond to date). A pond with this surface elevation would cover approximately 20.5 acres and would hold approximately 7.1 million gallons.

5.0 Changes Since Cell Construction

In addition to the pond representations shown in Figure 4 and Figure 7, and the direct digital comparison of 2012 and 2016 LiDAR-generated elevations shown in Figure 6, cross sections and grid elevations were generated to further represent changes since the main tailings disposal cell was completed. Although a topographic map with low-resolution 2-foot contours was developed from the aerial survey in 1997, a digitized version of the map allows for linear interpolation of elevations between the contour lines. The topographic maps generated using LiDAR in 2012 and 2016 were compared to the 1997 map to estimate elevation changes between the surveys.

Representative cross-section locations on the 2016 topographic map are shown in Figure 9. Cross sections A–A' and B–B' run generally north to south to represent changes over the entire top slope, cross section C–C' runs west to east through the main area of depressions to represent changes in the most affected area, and cross section D–D' runs west to east along the north edge of the top slope to represent elevations where runoff was designed to spill over the edge of the top slope.

When compared to the elevations estimated from the 1997 topographic map, cross section A–A' (Figure 10) and cross section B–B' (Figure 11) show that the south half of the top slope has experienced little change while the area at the north end (over the slimes) has experienced substantial subsidence (as much as 4 feet at the cross-section locations). Cross section C–C' (Figure 12) graphically represents how much subsidence has occurred across the north portion of the top slope between the edges of the top slope (the outside edge of the top slope was constructed as a containment dike for the tailings pond). Cross section D–D' (Figure 13) shows an uneven surface at the north edge of the top slope, which may represent uneven construction or slight differential settlement. On the latter two cross sections, the 1997 surface is below the 2016 surface in places, which implies that the cell increased in elevation at those locations. However, this is a function of mapping at 2-foot contours over a nearly flat surface and the digital interpolation between the contours; it is likely that the next lower 2-foot contour was below the edge of the top slope.

A 500-foot grid was projected over the top slope to numerically evaluate elevation changes at the grid intersections (Figure 14). Grid points M1 through M9 represent the top slope area over the slimes tailings, grid points M10 through M26 represent the area over mixed sand and slimes tailings, and grid points M27 through M43 represent the area over the sand tailings. Elevation changes between the 1997, 2012, and 2016 surveys are presented in Table 1.

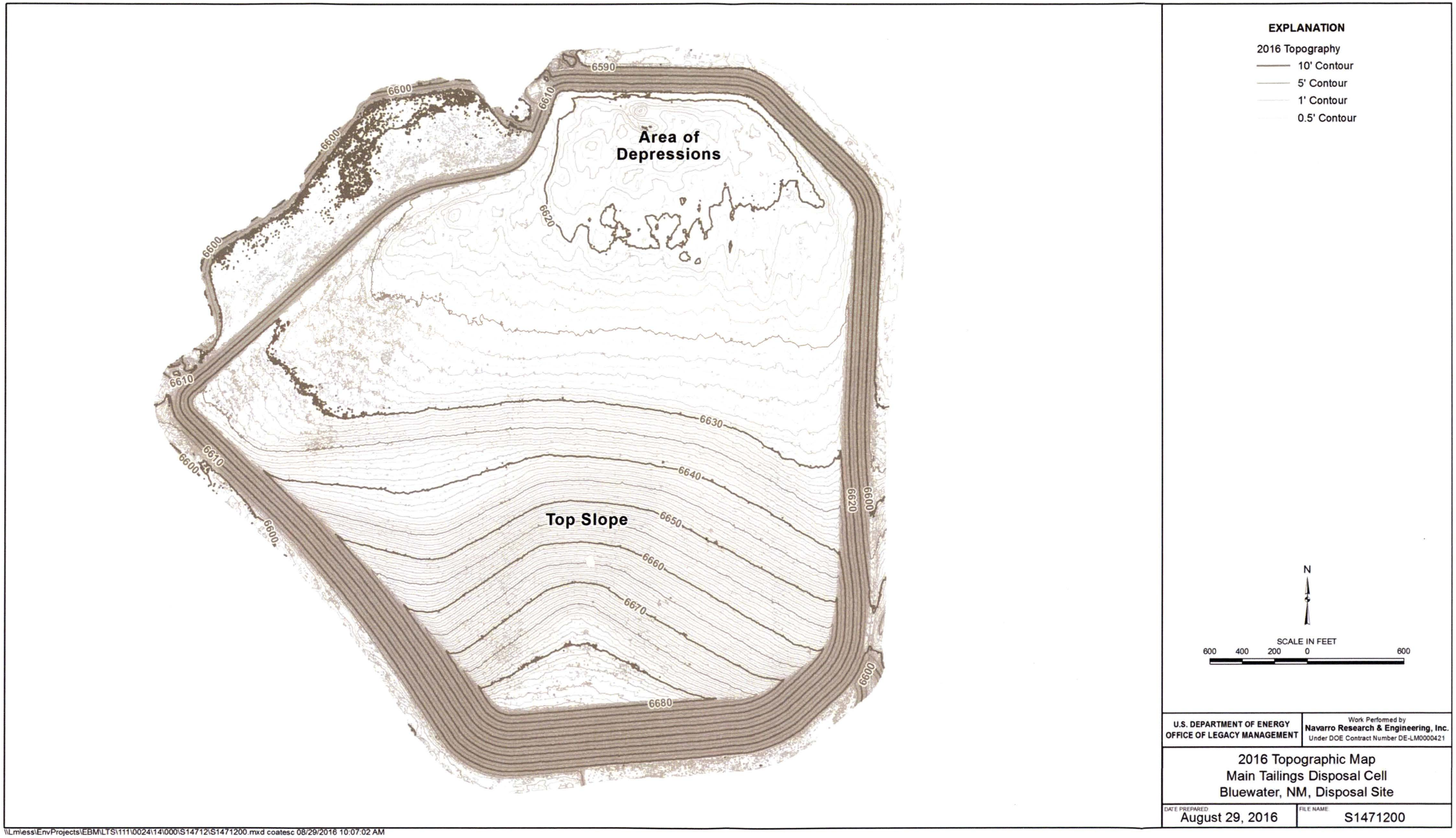


Figure 5. 2016 LiDAR-Generated Topographic Map of the Main Tailings Disposal Cell

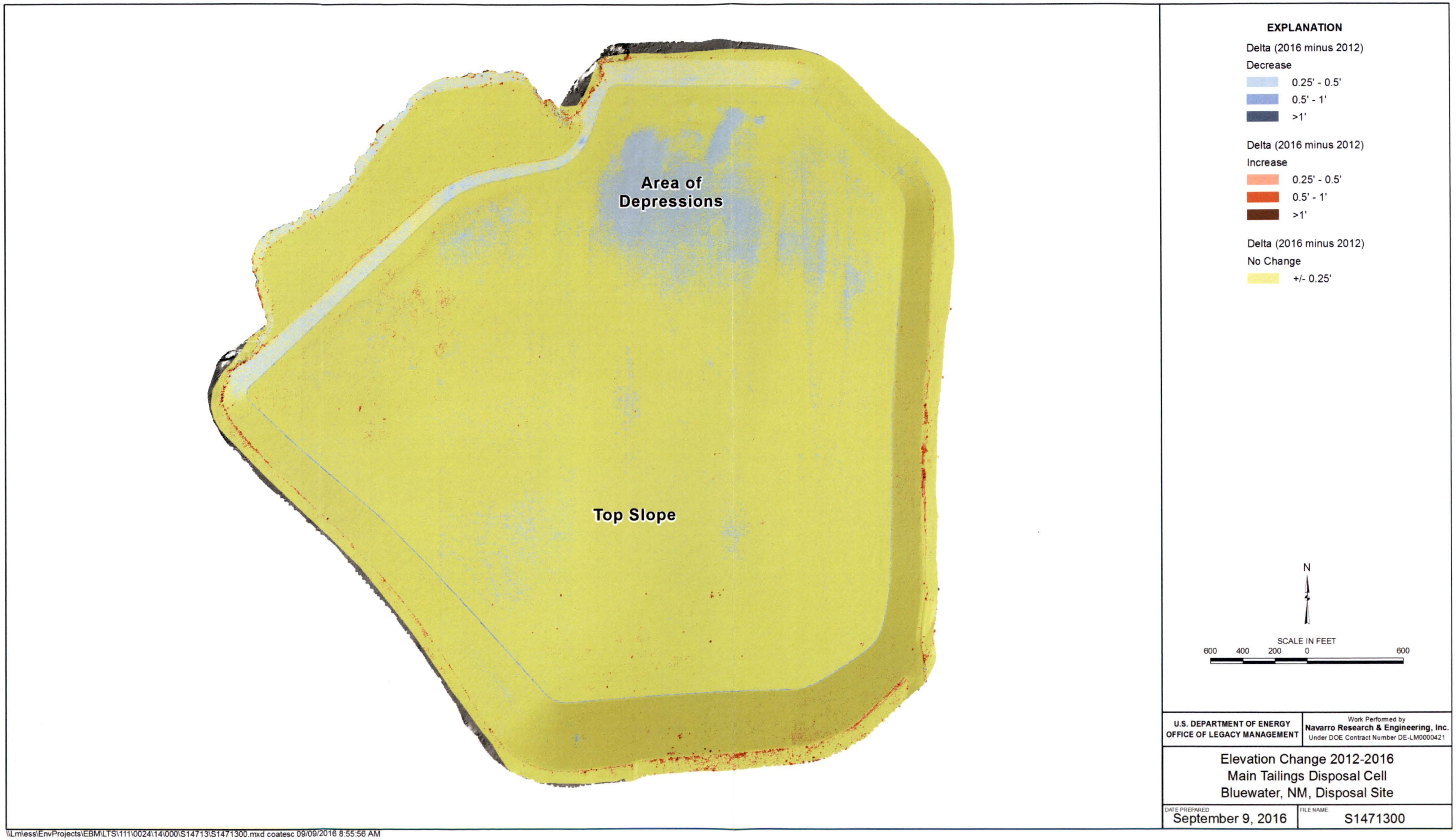


Figure 6. Elevation Changes on the Main Tailings Disposal Cell from the 2012 to the 2016 LiDAR Surveys

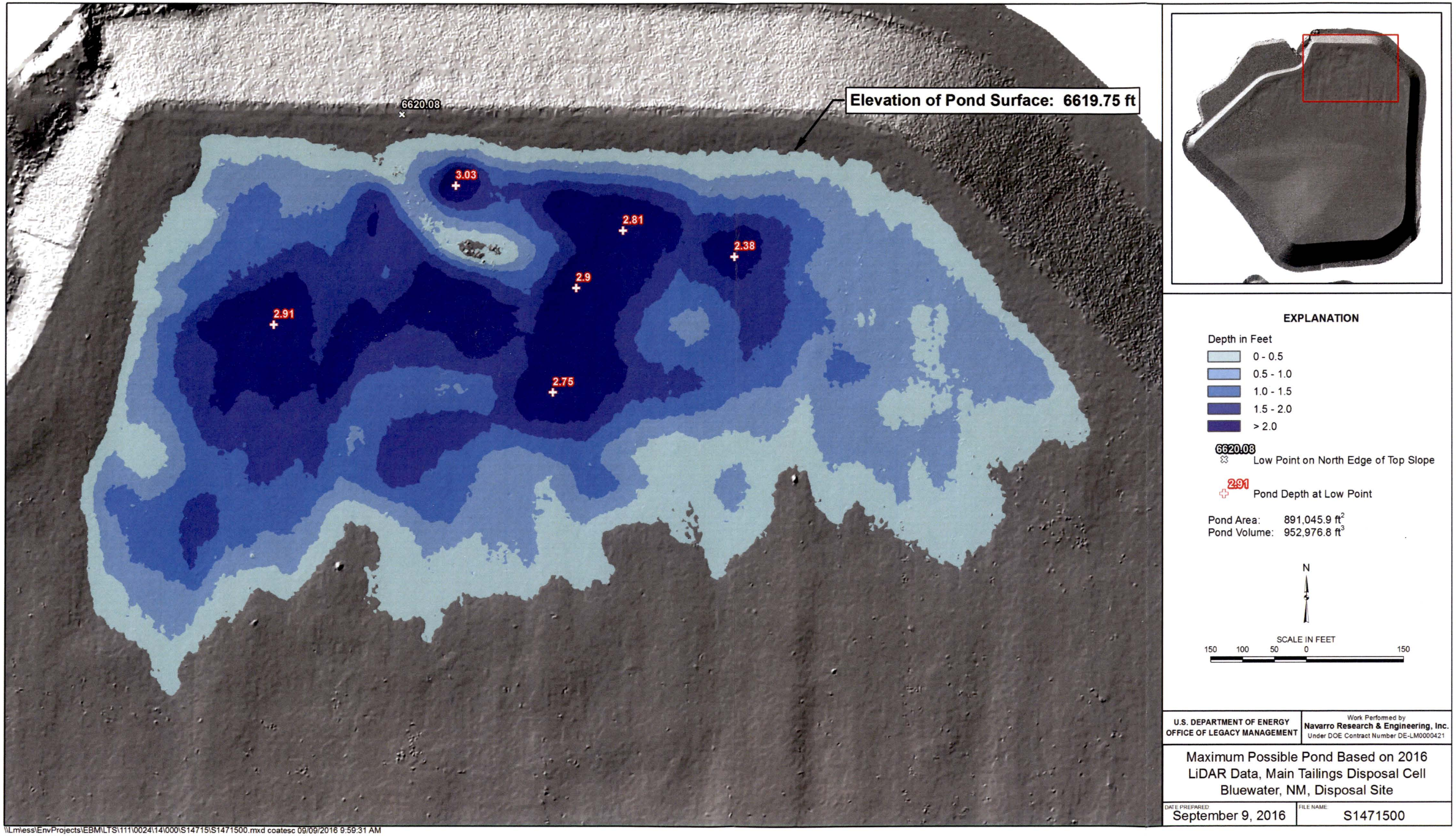


Figure 7. Simulated Pond on the Main Tailings Disposal Cell Based on 2016 LiDAR Topography (Surface Elevation at 6619.5 Feet)

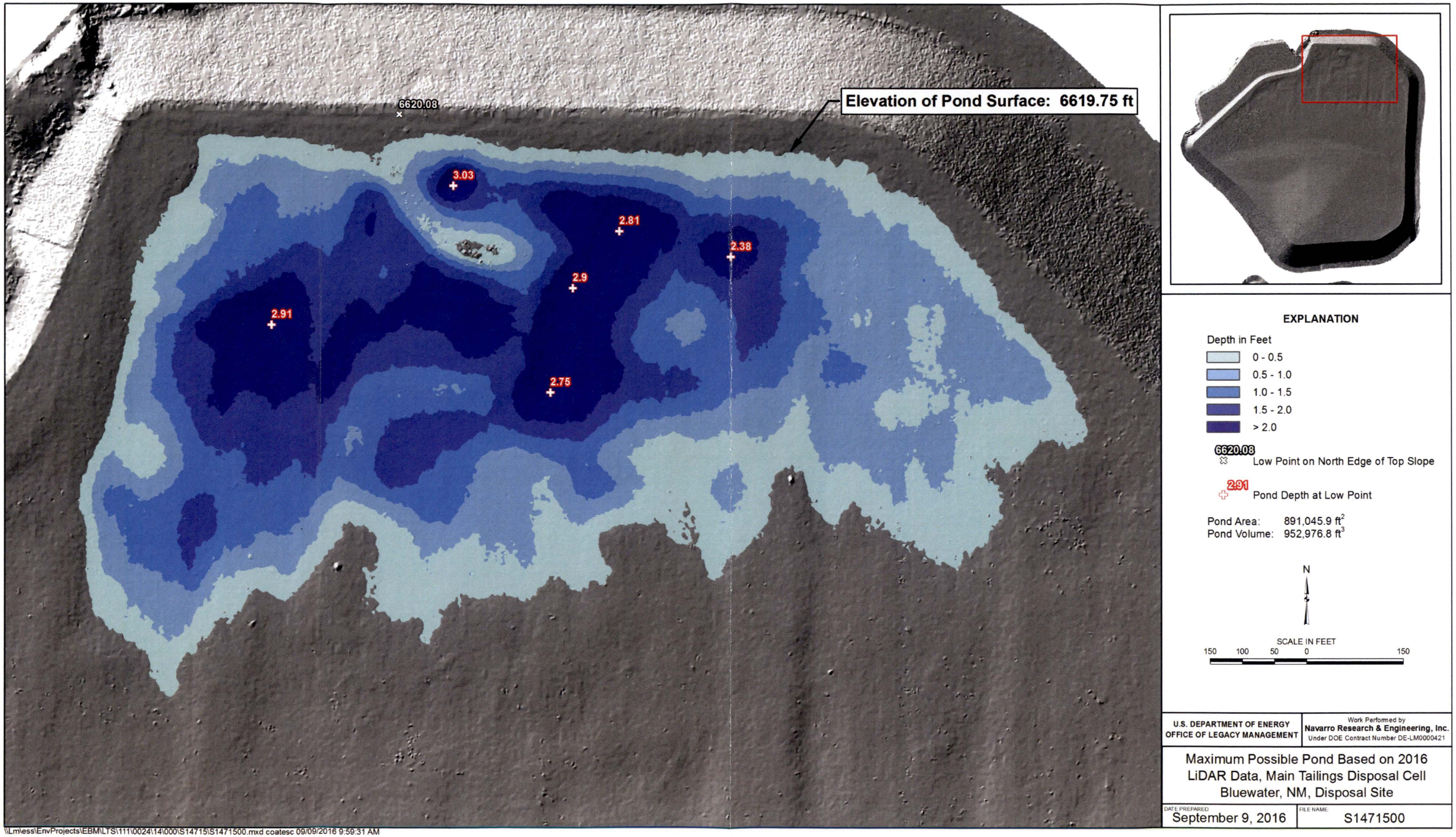


Figure 8. Largest Pond Possible Without Spillage on the Main Tailings Disposal Cell Based on 2016 LiDAR Topography (Surface Elevation at 6619.75 Feet)

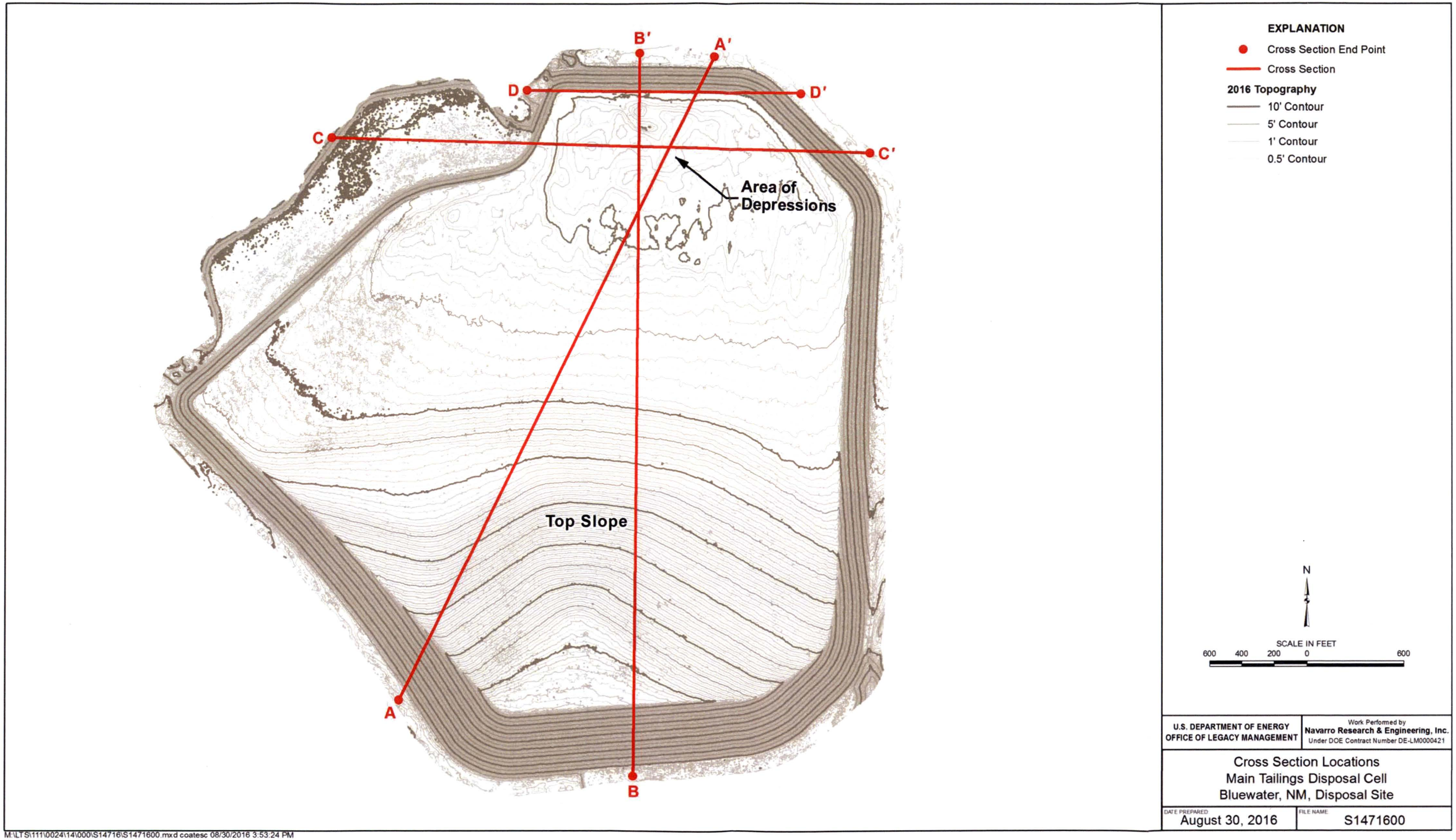


Figure 9. Cross-Section Locations on the Main Tailings Disposal Cell

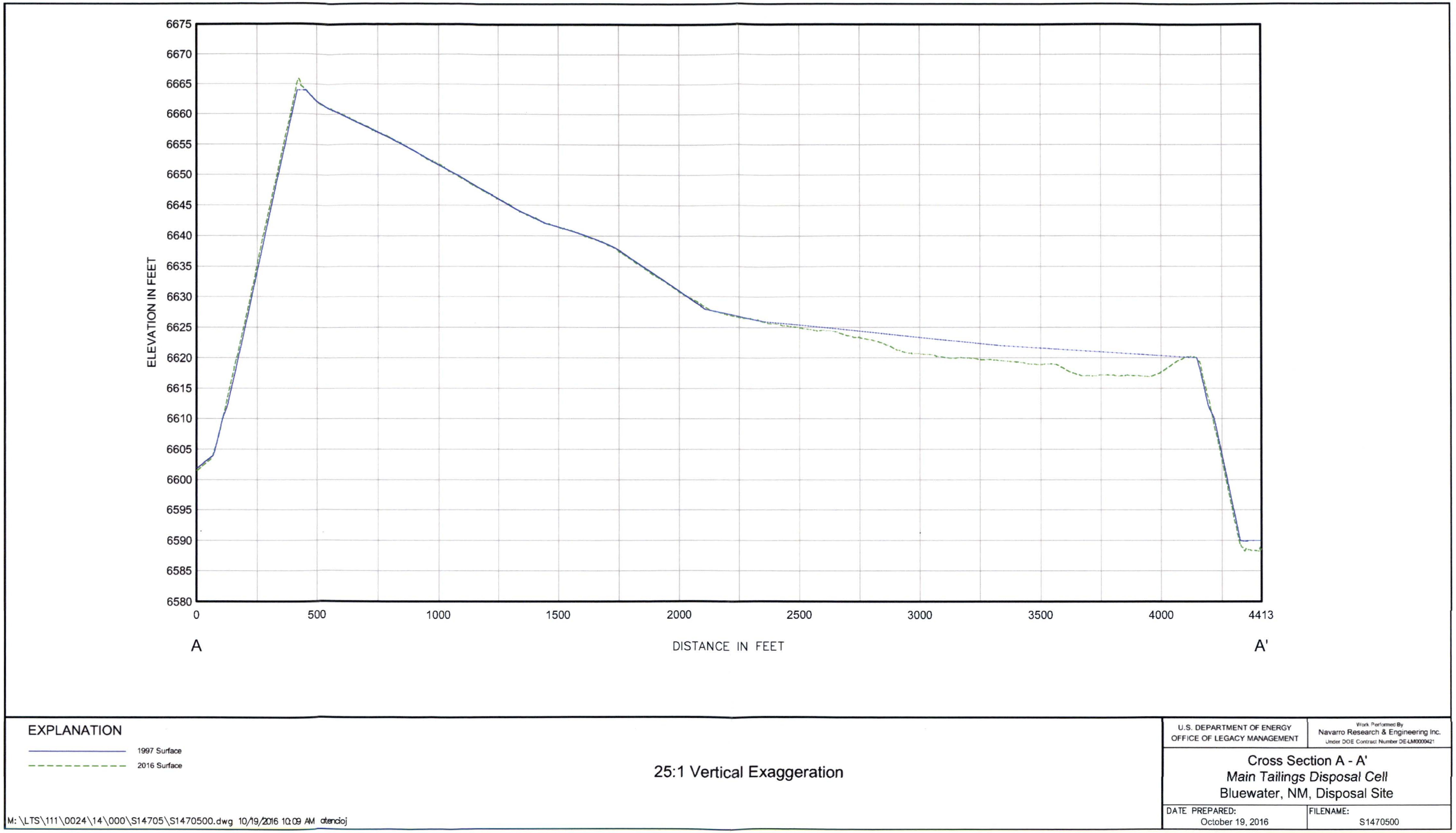


Figure 10. Cross Section A–A' of the Main Tailings Disposal Cell

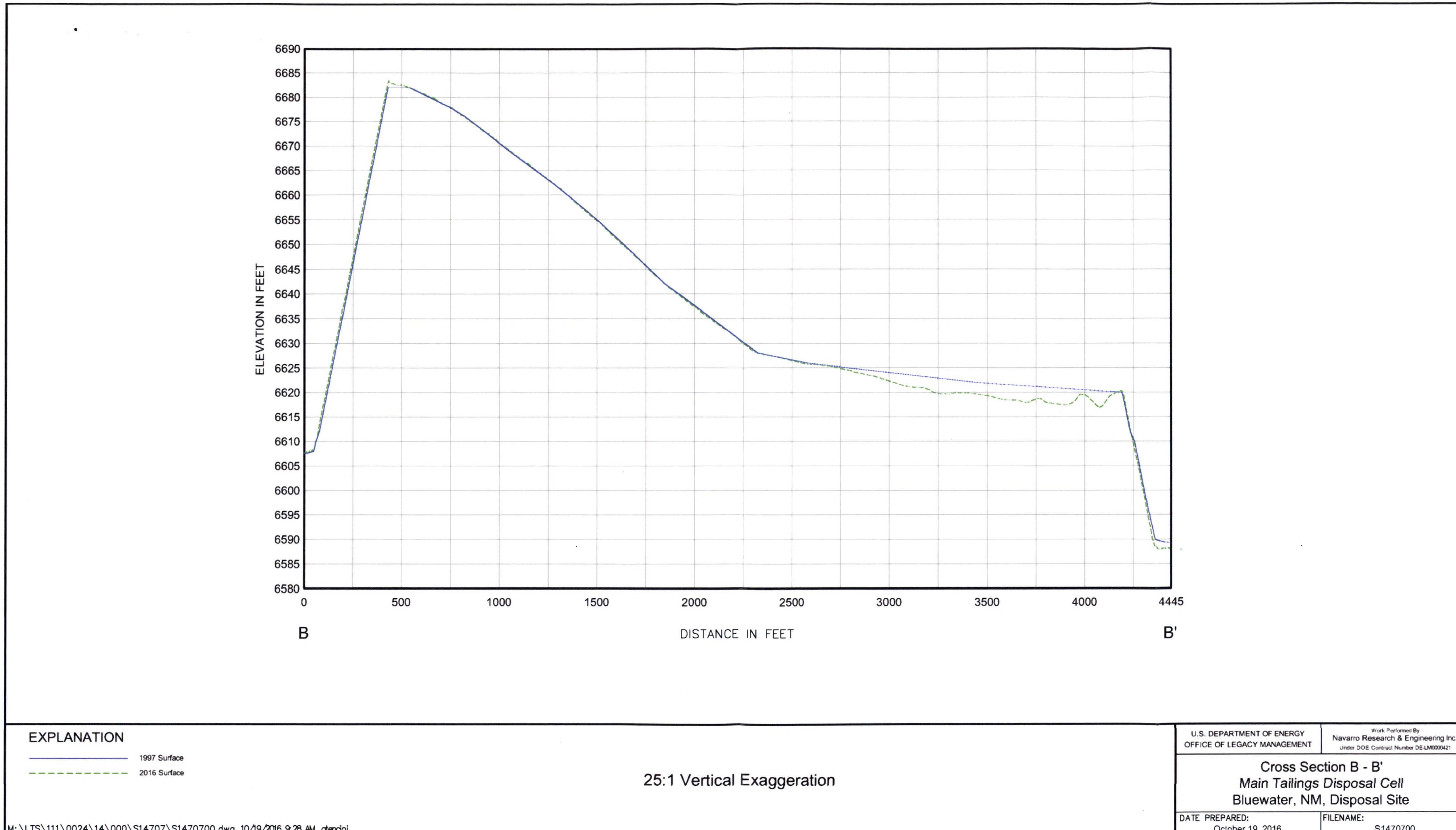
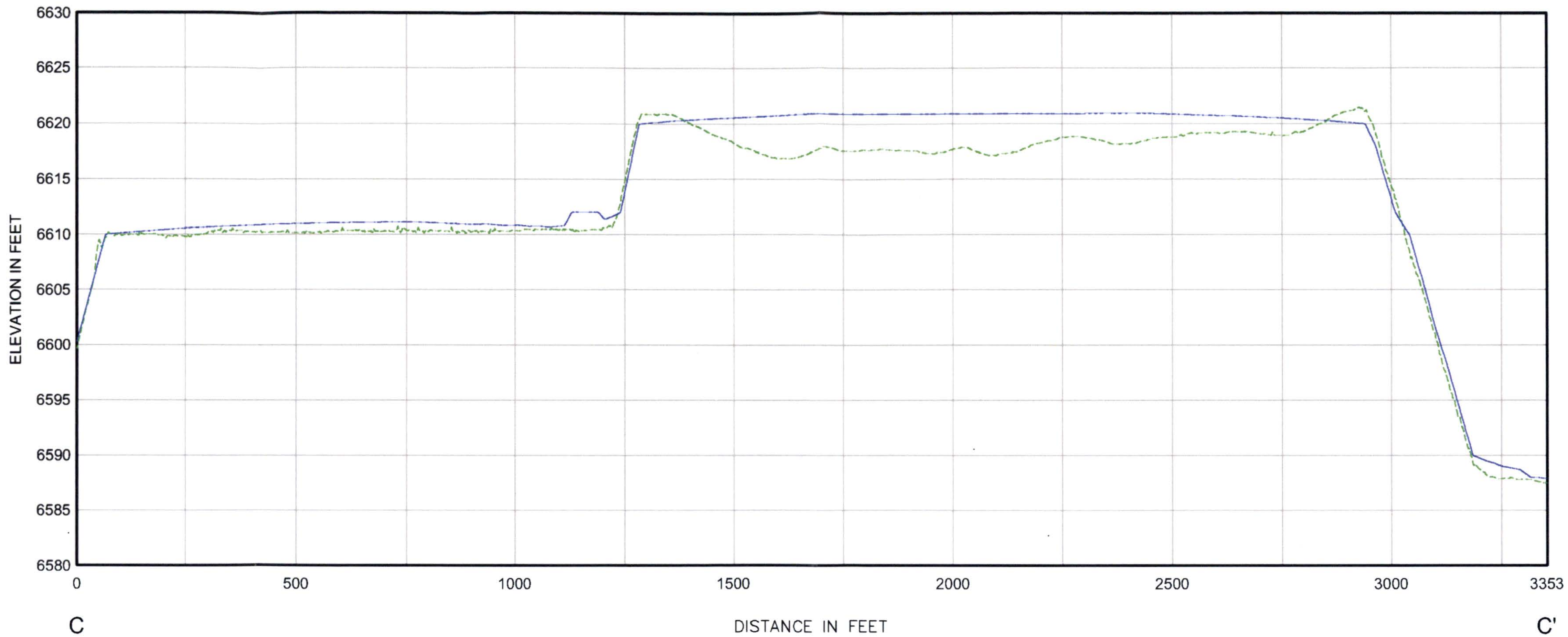


Figure 11. Cross Section B–B' of the Main Tailings Disposal Cell



EXPLANATION

1997 Surface

2016 Surface

25:1 Vertical Exaggeration

U.S. DEPARTMENT OF ENERGY OFFICE OF LEGACY MANAGEMENT	Work Performed By Navarro Research & Engineering Inc. Under DOE Contract Number DE-LM0000421
Cross Section C - C' *Main Tailings Disposal Cell* Bluewater, NM, Disposal Cell	
DATE PREPARED: October 19, 2016	FILENAME: S1470600

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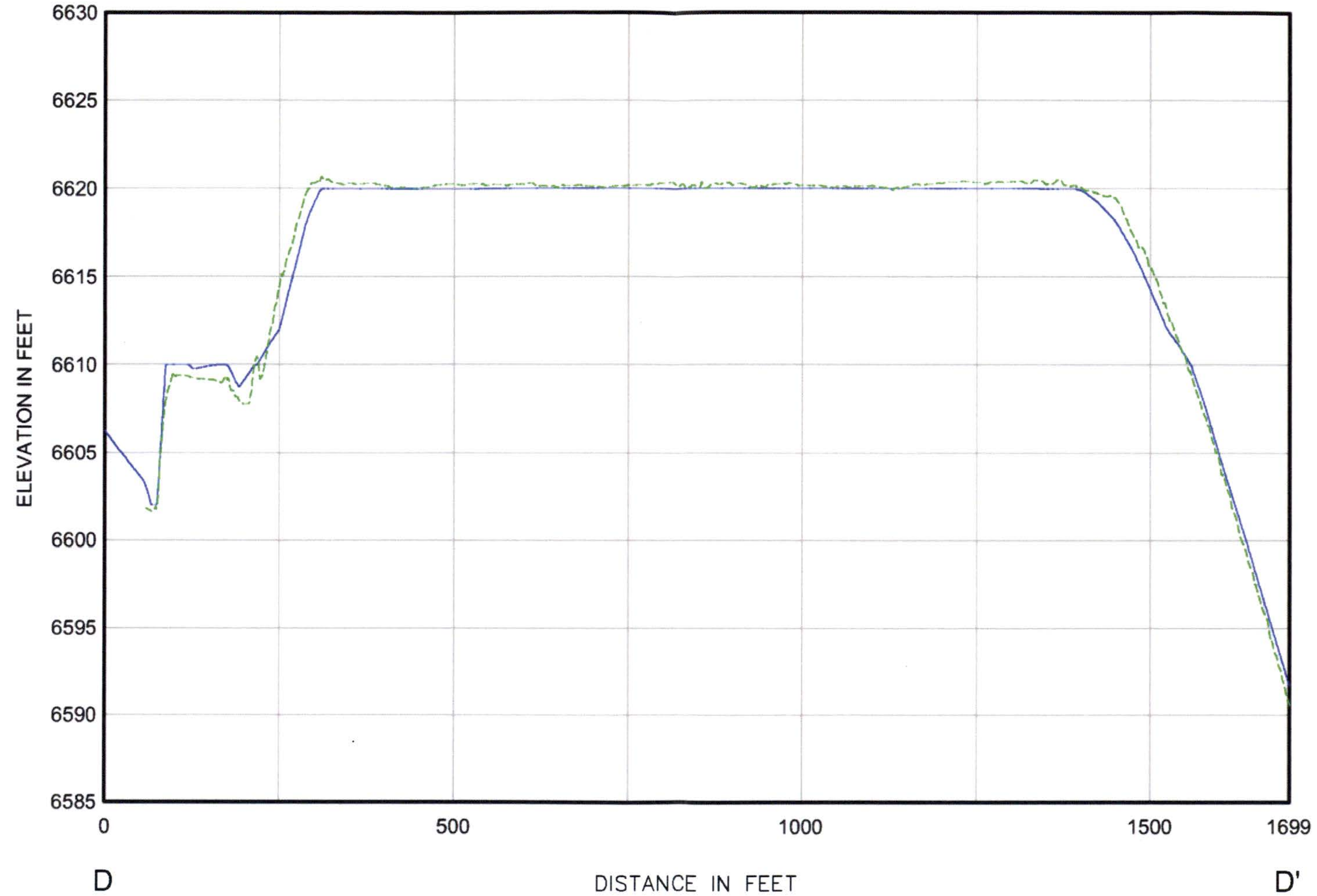
Figure 12. Cross Section C–C' of the Main Tailings Disposal Cell



EXPLANATION

1997 Surface

2016 Surface

25:1 Vertical Exaggeration

U.S. DEPARTMENT OF ENERGY OFFICE OF LEGACY MANAGEMENT	Work Performed By Navarro Research & Engineering Inc. Under DOE Contract Number DE-LM0000421
Cross Section D - D' *Main Tailings Disposal Cell* Bluewater, NM, Disposal Site	
DATE PREPARED: October 19, 2016	FILENAME: S1470800

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Figure 13. Cross Section D–D' of the Main Tailings Disposal Cell

Location	Elevation		
	1997	2012	2016
M1	6621.07	6617.69	6617.38
M2	6621.11	6617.71	6617.49
M3	6620.88	6619.43	6619.24
M4	6624.66	6622.22	6621.95
M5	6623.10	6621.65	6621.43
M6	6622.79	6619.69	6619.41
M7	6622.79	6619.91	6619.69
M8	6622.79	6620.96	6620.73
M9	6622.46	6621.99	6621.83
M10	6628.01	6629.41	6629.36
M11	6627.72	6626.66	6626.87
M12	6625.88	6625.69	6625.63
M13	6625.10	6624.95	6624.66
M14	6625.07	6624.78	6624.67
M15	6625.06	6624.64	6624.45
M16	6625.06	6624.24	6623.87
M17	6624.43	6624.74	6624.49
M18	6634.00	6635.84	6635.68
M19	6631.75	6631.79	6631.65
M20	6629.41	6629.46	6629.32
M21	6628.96	6629.29	6629.13
M22	6630.13	6630.27	6630.17
M23	6630.05	6630.33	6630.19
M24	6628.14	6628.39	6628.23
M25	6627.37	6627.42	6627.26
M26	6627.87	6627.61	6627.44
M27	6639.56	6639.82	6639.67
M28	6639.54	6639.75	6639.58
M29	6642.50	6642.63	6642.48
M30	6645.58	6645.60	6645.50
M31	6642.68	6642.75	6642.59
M32	6636.98	6637.08	6636.89
M33	6632.00	6632.30	6632.15
M34	6651.08	6651.34	6651.15
M35	6660.47	6660.75	6660.65
M36	6665.03	6665.27	6665.09
M37	6657.94	6658.15	6657.97
M38	6649.84	6649.87	6649.73
M39	6642.07	6642.49	6642.41
M40	6675.71	6676.09	6675.94
M41	6679.71	6679.95	6680.02
M42	6672.76	6672.88	6672.85
M43	6664.21	6664.38	6664.36

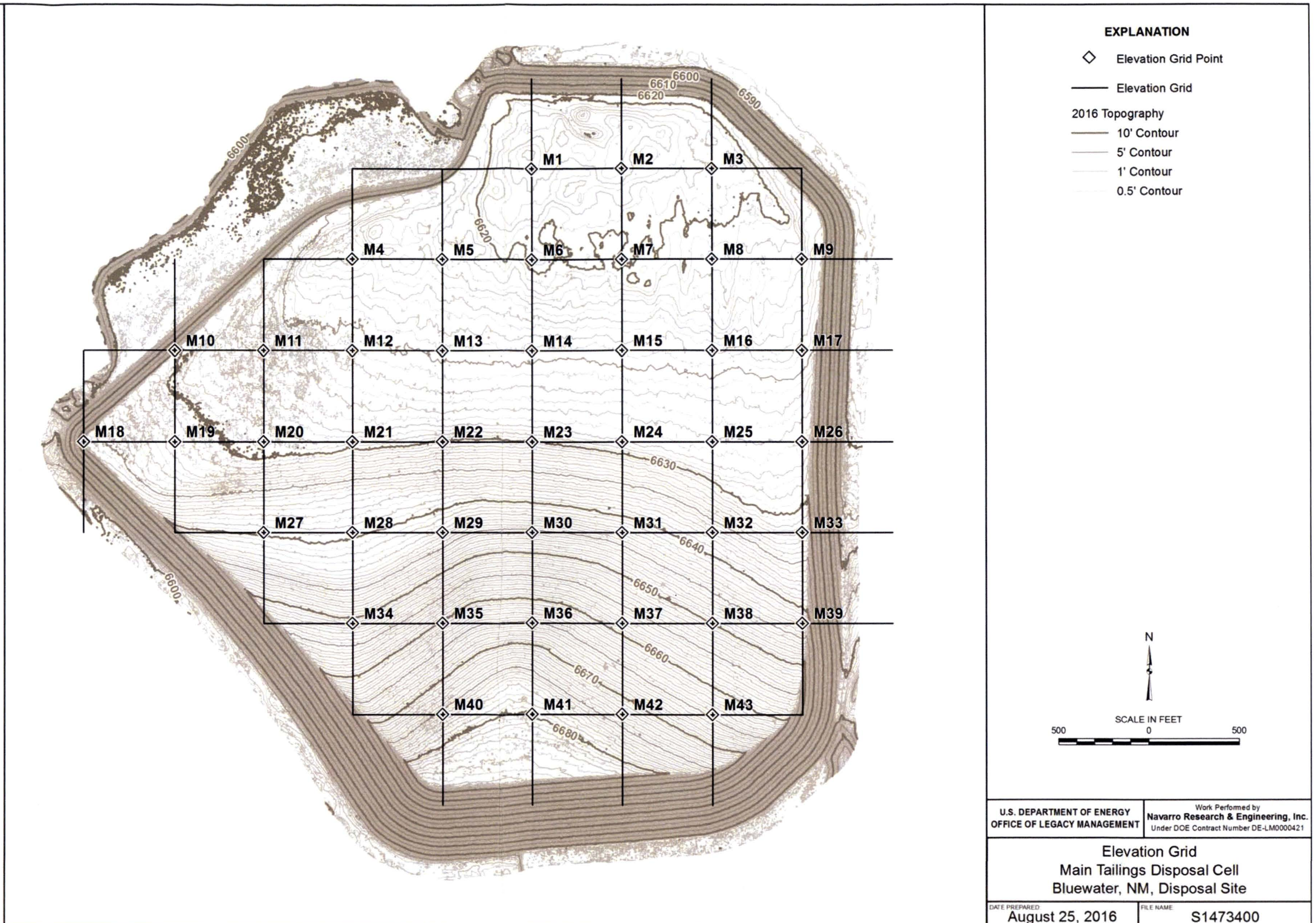

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Figure 14. 500-Foot Elevation Grid on the Main Tailings Disposal Cell

Table 1. Elevation Changes on the Top Slope of the Main Tailings Disposal Cell

Tailings Under Top Slope	Grid Location[a]	Elevation Change Between 1997 and 2012 (feet)	Elevation Change Between 2012 and 2016 (feet)
Slimes (North Portion)	M1	-3.38	-0.31
	M2	-3.40	-0.22
	M3	-1.45	-0.19
	M4	-2.44	-0.27
	M5	-1.45	-0.22
	M6	-3.10	-0.28
	M7	-2.88	-0.22
	M8	-1.83	-0.23
	M9	-0.47	-0.16
	Average Change	-2.27	-0.23
	Annual Rate[b]	0.15 feet per year	0.06 feet per year
Mixed Fine Sand, Silt, and Clay (Middle Portion)	M11	-1.06	0.21
	M12	-0.19	-0.06
	M13	-0.15	-0.29
	M14	-0.29	-0.11
	M15	-0.42	-0.19
	M16	-0.82	-0.37
	M19	0.04	-0.14
	M20	0.05	-0.14
	M21	0.33	-0.16
	M22	0.14	-0.10
	M23	0.28	-0.14
	M24	0.25	-0.16
	M25	0.05	-0.16
	Average Change	-0.14	-0.14
Coarse Sand (South Portion)	M27	0.26	-0.15
	M28	0.21	-0.17
	M29	0.13	-0.15
	M30	0.02	-0.10
	M31	0.07	-0.16
	M32	0.10	-0.19
	M34	0.26	-0.19
	M35	0.28	-0.10
	M36	0.24	-0.18
	M37	0.21	-0.18
	M38	0.03	-0.14
	M40	0.38	-0.15
	M41	0.24	0.07
	M42	0.12	-0.03
	M43	0.17	-0.02
	Average Change	0.18	-0.12

[a] Grid locations M10, M17, M18, M26, M33, and M39 are excluded because they are over the former tailings pond perimeter dike.

[b] Annual rate of subsidence calculated as average subsidence divided by the number of years (15 and 3.7 years, respectively).

Three observations are drawn from Table 1. First, positive measurements represent an increase in elevation. Because it is unlikely that the cell cover is rising, the positive change on the south portion of the top slope is due to the lower resolution of the 1997 topographic map. However, the average calculated change between 1997 and 2012 for that area is only 0.18 feet (approximately 2 inches). The actual surface of the top slope was likely several inches higher than the 1997 topographic map indicates, but the 1997 map is a reasonably close representation of the top slope elevation at that time. The 2012 and 2016 surveys indicate an average settlement of 0.12 feet (approximately 1.5 inches) on the south portion, suggesting that some degree of settlement also occurred in that area between 1997 and 2012.

Second, the amount of settlement on the top slope increases from south to north. This observation is explained by the nature of the underlying materials. The slimes underwent the greatest amount of consolidation during cell dewatering activities because clay-rich materials tend to hold fluids (they do not have pore spaces between mineral grains that easily drain like sandy materials). Therefore, the smallest amount of settlement would be expected over the predominantly sand tailings and the greatest amount of settlement would be expected over the predominantly clay tailings.

Third, the annual rate of settlement over the slimes is decreasing with time. The calculated average rate of settlement between 1997 and 2012 is 0.15 feet per year (probably greater assuming the starting elevation was higher than the 1997 map indicates), while the rate decreased to 0.06 feet per year between the 2012 and 2016 surveys. Additional surveys will be needed to estimate when settlement may cease. The next survey is scheduled for 2019.

6.0 Conclusions

LiDAR-generated topographic maps provide the necessary resolution to evaluate changes that have occurred on the top slope of the main tailings disposal cell. Evaluation of the data generated from the 1997 aerial photography and the 2012 and 2016 LiDAR surveys have led to the following conclusions.

- The entire top slope of the main tailings disposal cell has settled since the cell was completed in 1995, with the greatest amount of settlement occurring on the north portion of the top slope (as much as 4 feet in places).
- The rate of settlement is decreasing, but the expected time of stabilization cannot be predicted without conducting additional surveys because of the time period between the 1997 and 2012 surveys (the rate of settlement may have varied) and the low resolution of the 1997 survey.
- The largest pond that has developed occurred prior to the 2012 survey. Based on the 2012 LiDAR-generated topography, the pond held approximately 4.3 million gallons before dissipating primarily by evaporation.
- Based on the 2016 LiDAR-generated topography, the largest potential pond that could develop before it begins to spill over the north edge of the top slope would hold approximately 7.1 million gallons of water.

7.0 Recommendations

Evaluation of the LiDAR-generated topography is useful for determining how the top slope surface has changed since the disposal cell was completed and it is an important tool for deciding how to manage the disposal cell. The following recommendations are presented to further understand the future of top slope settlement and how the top slope topography factors into runoff control and potential mitigation of ponding.

7.1 Additional Survey Data

Although the LiDAR survey data show that settlement is still occurring on the top slope of the main tailings disposal cell, at least one more survey is needed to predict when the top slope will stabilize. This survey can be conducted using LiDAR or high-resolution photogrammetry, as long as the new data can be compared directly to existing LiDAR data for the cell. The next survey is scheduled for 2019.

The 2016 LiDAR survey included the carbonate tailings disposal cell, which is located immediately south of the main tailings disposal cell. The planned 2019 survey should include the carbonate cell to determine if changes are occurring. The results of that survey should be used to determine if additional surveys will be needed.

7.2 Other Investigations

An assumption is that most of the ponded water evaporates. Because there is a thick layer of clay-rich material under the radon barrier in the area of depressions, it is likely that very little ponded water is percolating into the underlying slimes. These assumptions need to be tested through analytical methods to determine if ponding on the top slope degrades the performance of the disposal cell cover materials. A joint DOE/NRC investigation of the engineering properties of the main tailings disposal cell cover was initiated in June 2016. Results of that investigation, in conjunction with the conclusions drawn from the LiDAR-generated topography, will be used to evaluate future management of the disposal cell.

7.3 Concerns About Restoring the Top Slope to the Design Grade

The disposal cell was designed to allow all runoff on the top slope of the disposal cell to spill evenly over the north edge of the top slope. Erosion protection of the top slope and side slopes was designed in accordance with UMTRCA Title I requirements. The adequacy of the design should be evaluated against subsequent design requirements for UMTRCA Title II disposal cells. No spillage has occurred to date because all runoff water is captured in depressions that have formed on the north portion of the top slope. Therefore, the top slope is not functioning as designed.

The top slope should not be restored to the original design grade at this time because settlement continues to occur. The added weight of cover materials necessary to bring the top slope back to design grade could cause settlement to occur at a faster rate or to a greater degree.

The greatest concern with restoring the top slope to its original design grade is the design itself. Runoff water, either as overflow of a pond or from a direct precipitation event (assuming the cover is regraded to prevent ponding), will begin to spill at the lowest point (or points) along the north edge of the top slope. As soon as this occurs, the compacted soil surface under the rock cover will likely erode at the spill point. Erosion would accelerate as all runoff spills over at that point. Assuming 7.1 million gallons of water in the largest possible pond spilled over, or assuming a probable maximum precipitation event occurs, erosion at the spill point would be expected to cut through the soil containment dike and eventually expose and transport tailings materials.

7.4 Evaluate Mitigation of Ponding and the Potential for Erosion

The following options should be considered in lieu of restoring the top slope to its design grade.

1. Further evaluate whether ponded water is degrading cell cover performance. The results of the current DOE/NRC investigation should provide the necessary information. If it is concluded that ponding is detrimental, then reduction or elimination of ponding will be required.
2. Review original runoff design criteria and evaluate top slope runoff hydraulics. Assuming the top slope is not regraded, determine the amount of rainfall necessary to fill a 7.1 million gallon pond. If it is less than the probable maximum precipitation event, then some means to reconfigure the cell's top slope or dewater the pond is necessary (otherwise, the existing depressions would store the runoff). Precipitation data from an existing on-site gauge, correlated with pond volumes, will be useful to determine the amount of rainfall.
3. A 2-inch-diameter siphon is currently in place to drain ponded water to avoid excessive accumulations of water. The siphon pipe is on the top surface and its installation did not penetrate the cover materials. It was first operated in November 2015 and drained approximately 1.4 million gallons of water in two weeks (several shallow ponds holding a total of approximately 40,000 gallons remained after the siphon stopped). Disadvantages of the siphon system are that it has to be manually started after a large pond is discovered on the top slope, and its size limits the rate of pond reduction. Siphon operations should continue and perhaps be expanded until other mitigation measures are in place.
4. Evaluate the use of gravity drains to dewater the ponds. Installation of drain pipes (designed to discharge water to the area north of the disposal cell) would require trenching through the cell cover materials that may expose tailings or other materials with elevated radioactivity, requiring appropriate handling of that material. The gradient of the pipes would need to be adjusted based on additional settlement projected for the area of the depressions. The drains would not necessarily need to be able to convey probable maximum precipitation runoff; the design would take into account the storage capacity of the largest possible pond.
5. Evaluate the construction of one or more armored spillways over the north side slope of the disposal cell. Ponding with partial draining would be designed such that erosion would not occur. The spillways should be designed to discharge runoff from a probable maximum precipitation event in case the top slope is regraded to prevent ponding at a later date.

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