ATTACHMENT 12

OVERLINER OPTIMIZATION REPORT

(CTI ASSOCIATES, INC.)

Ottawa County Farms Landfill
Over-liner Optimization
Data Review Report

Prepared for

Republic Services
Ottawa County Farms Landfill
15550 68th Ave.
Coopersville, Michigan 49404

April 2016

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OTTAWA COUNTY FARMS LANDFILL
OVER-LINER OPTIMIZATION
DATA REVIEW REPORT

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1. INTRODUCTION

CTI and Associates, Inc. (CTI), was retained by Republic Services (Republic) to provide a settlement and liner strain analysis for the proposed over-liner system included in the 2016 expansion effort at Ottawa County Farms Landfill (OCFL, Site). OCFL is a licensed Type II solid waste disposal unit located near the City of Coopersville, Ottawa County, Michigan. Republic is preparing an expansion permit application for OCFL, including a vertical expansion over older waste units that do not contain a composite base liner. In accordance with Part 115 of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended (Part 115), a vertical expansion at any Type II landfill that does not contain a composite base liner can be approved only if the over-liner system has design slopes of not less than 10%. Alternatively, the rule allows a design slope less than 10% if the slope is designed using a method acceptable to the Director of the Michigan Department of Environmental Quality (MDEQ). This data review report has been prepared to summarize the data used as input to the settlement and liner strain analysis for the proposed over-liner system at OCFL.

The Site consists of 246 acres of land located in Polkton Township, Ottawa County, Michigan. The proposed expansion permit consists of both a vertical expansion over the existing solid waste boundary and a lateral expansion west of the existing of solid waste boundary.

1.1. Scope and Purpose

In order to provide an optimal design of the over-liner system, CTI developed a probabilistic model to simulate differential settlements and their effect on the over-liner system performance. CTI used a probabilistic model because it is able to address the significant uncertainties associated with the future behavior of buried waste at OCFL as well as the inherent variability in settlement behavior across the Site due to the types of waste present and the methods used to dispose the waste originally. This model is based on the volume loss model presented by Foye and Soong (2013). The volume loss model predicts how void collapse or settlement at depth translates to the surface. The volume loss at depth is modeled as a distribution of possible values based on the available data related to the existing waste mass and data from similar sites. To gather input for this model, CTI reviewed existing data related to the Site, including reports and engineering drawings. Data useful to design includes information about types of wastes, methods of disposal, cell design, and daily cover methods.

The purpose of this data review report is to evaluate the existing data related to OCFL, including reports and engineering drawings used to characterize Site conditions. This data review report summarizes the findings that are relevant to an optimal design of the over-liner system.

1.2. Organization

This Report contains the following information:

- **Site Chronology** – Estimation of age of waste in each disposal area
- **Site Geology** – Environmental characterization, Subsurface geology, Climatic conditions, Hydrogeologic Properties
- **Waste Characterization** – Type of waste received at OCFL and general disposal practices.
- **Cell Design** – Review of the liner system and construction process
- **Landfill Gas Well Log Review** – A review of recent landfill gas borings in the proposed vertical expansion area.

2. SITE CHRONOLOGY

The site chronology as gathered during the data review is presented below. This information was taken from Attachment A of the current OCFL solid waste disposal operating license. The chronology of waste disposal was used to get an understanding of the age of waste placed in each existing Cell under the proposed vertical expansion. The active years listed for each cell may differ slightly from the actual years those cells were active at the Site. For example, a cell may not have become active until the year following its construction. Additionally, cells may have continued to be active after the date of construction listed for the next cell. However, for determining the general age of waste used in the settlement analysis for the over-liner system, the information gathered and used was tabulated as follows:

Cell Name	Year Constructed	Years Active
Cell A	1983	1983-1985
Cell B	1985	1985-1987
Cell C	1987	1987-1989
Cell D	1989	1989-1993
Cell E	1993	1993-1995
Cell A Extension	1995	1995-1997
Cell B Extension	1995	1995-1997
Phase 1A	1997	1997-1998
Phase 1B	1998	1998-1999
Phase 2	1998	1998-1999
Phase 2	1999	1999-2002
Phase 3	2002	2002-2004
Phase 4A	2004	2004-2005
Phase 4B	2005	2005-2006
Phase 5A	2006	2006-2008
Phase 5B	2008	2008-2010
Phase 6A	2010	2010-2012
Phase 6B	2012	2012-2013
Phase 7A	2013	Currently operating

3. SITE GEOLOGY

Conclusions from various hydrogeological investigation studies, including investigations by Dell Engineering, Inc. in 1995 and Engineering & Environmental Solutions, LLC in 2016, were gathered to assess the geological conditions at OCFL. The subsurface geology of the site consists of approximately 2,400 feet of consolidated sedimentary rocks of the Marshall Formation and up to 400 feet of unconsolidated glacial sediments. The consolidated sedimentary rocks are primarily shale, sandstone, and limestone. The overlying glacial sediments consist of clay, silt, sand, and gravel.

Exploratory borings drilled around the perimeter of the site and beneath the existing landfill encountered approximately 190 to 205 feet of glacial sediments above the Marshall Formation. The glacial sediments consist of interbedded silt, sand, and gravel interlayered with large beds of low-permeability clay. The clay beds restrict vertical groundwater movement. The sediments are divided into four stratigraphic units based on their hydrogeologic characteristics. From ground surface down, they include an upper clay unit, an upper sand unit, a lower discontinuous clay unit, and a lower discontinuous sand and gravel unit.

The upper clay unit consists of clay beds interstratified with discontinuous lenses of poorly-graded sand. The upper sand unit consists of poorly-graded, fine to medium-grained sand and sandy silt beds. The upper sand unit contains the site's uppermost aquifer.

The lower clay unit consists primarily of sandy clay with minor silt and sandy silt lenses. The unit is discontinuous with a maximum thickness of approximately 60 feet beneath the northern area of the site. The lower sand unit consists of poorly-graded, medium to coarse-grained sand and includes a well-graded gravel to clayey gravel at the base of the section. The basal sand and gravel lies directly above the bedrock and is hydraulically connected to the bedrock. The lower sand unit is discontinuous with a maximum thickness of approximately 25 feet beneath the eastern portion of the site.

4. WASTE CHARACTERIZATION

Historical waste disposal information was obtained from both historical waste disposal records and discussions with the Site Manager. Historical waste disposal records were reviewed for the years 2000 through 2015. Information regarding waste disposal prior to 1996 was obtained from discussions with the Site Manager.

The historical waste disposal records for 2000-2015 show the following incoming waste characterization:

9.6% sludge

12.1% fly ash and shredder fluff

16.8% contaminated soil

34% municipal solid waste

6.8% construction and demolition waste

20.1% miscellaneous/special waste

Discussions with the Site Manager were used to get an idea of specific waste disposal practices and waste characterization in each Cell. Following is a summary of the information gathered through these discussions.

Cells A and B – Mainly residential and commercial waste with some industrial waste.

Cell C – Up to 40% contaminated soil due to many remediation jobs near the City of Kalamazoo.

Cell D – Sludge was disposed of in Cell D in approximately two locations, each about 20 feet below finish grade and located approximately along the 6000N line. The first area was located approximately between 1700E and 2000E. The second area was located approximately between 2500E and 2700E.

Cell E – Sludge was placed in approximately a 10 foot thick layer over the bottom of the cell.

Cell A and B Extension – Mainly residential and commercial waste with less sludge.

Phase 1 – Typical waste mix for the Site.

Phase 2 – Approximately 10% sludge blended with waste.

Phase 3 – Typical waste mix for the Site.

Phases 4 and 5 – Approximately 20% sludge blended with waste.

Phase 6 – Less sludge than previous phase but more contaminated soil

Daily cover consists mainly of shredder fluff and occasionally foundry sand. Contaminated soil is blended with the waste as much as possible rather than being used as daily cover.

An onsite solidification process has been ongoing for approximately the past 10 years. Disposal of solidified waste began with the operation of Phase 3 or 4. Incoming liquid waste is mixed with fly ash and shredder fluff in an onsite steel tank. The solidified waste is then mixed with general waste at the active disposal face.

5. CELL DESIGN

Construction of waste disposal areas at OCFL can be generally broken into two categories – clay lined Cells A through E, A Extension, B Extension, and composite lined Phases 1-7. Cells A through E and Cells A and B extensions were constructed with a leachate collection system and a low permeability clay liner. Phases 1-7 were constructed with a leachate collection system and a composite liner. The proposed over-liner system at OCFL will be installed above the clay lined Cells A through E, A extension and B extension.

6. LANDFILL GAS WELL LOG REVIEW

CTI reviewed available landfill gas extraction well boring and construction logs in order to gather information on the waste in place in the area of the proposed vertical expansion. Based on the well logs reviewed, many wells in the proposed vertical expansion area had sections of the borehole noted as “wet” or “saturated” during installation. A greater number of well logs in the geosynthetic lined area outside of the proposed vertical expansion area had sections of the borehole noted as “wet” or “saturated” during installation.

Based on discussions with the Site Manager, many of the landfill gas collection wells contain pumps to remove liquid. It was also noted during discussions that the northern area of the Site, generally the area of the proposed vertical expansion, is typically more dry than the southern area of the Site.

The review of the well logs also noted pockets of sludge in some landfill gas well borings. Most of the wells with notations of sludge were located outside the proposed vertical expansion area. However, for many of the wells installed in 2014, BEL Environmental Engineering, LLC noted that the waste in the proposed vertical expansion area was highly decomposed. A summary of the information gathered during review of the landfill gas well logs is included in Appendix 1.

7. CONCLUSIONS

The data review conducted for the settlement and liner strain analysis of the proposed OCFL over-liner provided insight into the types of waste, methods of disposal, and general characteristics of the waste mass. Based on the site specific data, CTI performed specialized engineering analyses to determine the acceptable design slopes for the over-liner. The results of the analysis are presented in the Over-liner Settlement Analyses Calculation Sheet, dated April, 2016.

8. REFERENCES

Historical documents referenced and used in this data review report are listed below.

Allied Waste Industries, Inc., Gas System Evaluation including Wellfield Map, Historic Well Construction Logs, and Maintenance Plans, Ottawa County Farms Landfill, ongoing.

BEL Environmental Engineering, LLC, Record Documentation and Construction Report, 2014 Landfill Gas Management System, Ottawa County Farms Landfill, October 2014.

Dell Engineering, Inc., Environmental Assessment for Laidlaw Waste Systems, Inc., Ottawa County Farms Landfill, August 1995.

Dell Engineering, Inc., Hydrogeologic Site Characterization for Ottawa County Farms Landfill, Laidlaw Waste Systems, Inc., August 1995

Engineering & Environmental Solutions, LLC, Hydrogeological Investigation Cross Sections, Ottawa County Farms Landfill, 2016.

Environmental Resources Management, Inc., Environmental Monitoring Plan, Ottawa County Farms Landfill, 2001.

Field Technology Services, Site Map, Attachment A to the Solid Waste Disposal Area Operating License, Otttawa County Farms Landfill, January 2014.

Field Technology Services, Ottawa County Farms Landfill Gas Expansion 2015, Updated Site Map, September 2015.

APPENDIX 1

LANDFILL GAS WELL LOG DATA REVIEW

Ottawa County Farms Landfill
Gas Extraction Well Log Info

Well ID	Date	Surface Elevation	Upper Depth of Saturation (ft bgs)	Lower Depth of Saturation (ft bgs)	Upper Elevation of Saturated/ Wet Waste	Lower Elevation of Saturated/ Wet Waste	Noted Sludge Elevation	Waste Description	Comments	Located on map?
5	11/10/2003		50	65				Sludge		no
115A	10/24/2006		0	80				C&D, Gen Waste	Moderate Decomposition	no
22A	10/30/2006		10	70				C&D, Gen Waste	Moderate Decomposition	no
44A	10/30/2006		10	70				C&D, Gen Waste	Moderate Decomposition	no
9A	10/31/2006		30	60				Gen Waste, metal	Moderate Decomposition	no
EW 7	11/13/2003		90	100				Sludge		no
EW 7A	11/12/2003		5	20				Sludge	Drilling and hole abandoned due to sludge	no
EW 81	8/28/2007	737	30	93	707	644		C&D, Gen Waste	High Decomposition	no
EW 8A	11/14/2003		5	20				Sludge	Drilling and hole abandoned due to sludge	no
EW 9	11/13/2003		90	100				Sludge		no
EW 95	8/30/2007	716	15	76	701	640		C&D, Gen Waste	High Decomposition, * Very Wet, well settled while drilling	yes
EW 97 R	9/4/2007	724	60	83	664	641		C&D, Gen Waste	High Decomposition	yes
EW-115	6/22/2009	696	8	31	688	665		C&D, Gen Waste	High Decompostion	yes
EW-116	6/22/2009	699	13	35	686	664		C&D, Gen Waste	High Decompostion	yes
EW-117	6/16/2009	698	3	36	695	662		C&D, Gen Waste	High Decompostion	yes
EW-118	8/17/2011	747	55	55	692	692		C&D, Gen Waste		yes
EW-15R	11/5/2008		30	80				C&D, Gen Waste	High Decomposition	yes
EW-30	7/10/2014	727	40	60	687	667	687-677	C&D, Gen Waste, Sludge	Moderate Decomposition, Sludge at 40-50 ft bgs	yes
EW-32	6/18/2009	743	1	80	742	663		C&D, Gen Waste	High Decomposition	yes
EW-33	11/11/2008		5	95				C&D, Gen Waste , tire chips	High Decomposition	no
EW-34	11/12/2008		10	99				C&D, Gen Waste , tire chips	High Decomposition	yes
EW-35-R	11/13/2008		80	105				C&D, Gen Waste	High Decomposition	yes
EW-38	7/10/2014	734	30	70	704	664	694-684	C&D, Gen Waste, Sludge	Moderate Decomposition, Sludge at 40-50 ft bgs	yes
EW-39	8/30/2012	722	34	81	688	641	688-641	C&D, Gen Waste, Sludge		yes
EW-45	7/11/2014	740	10	70	730	670		C&D, Gen Waste	Moderate to Heavy Decomposition	yes
EW-46	8/30/2012	729	35	84	694	645	694-677	C&D, Gen Waste, Sludge		yes
EW-47	8/18/2011	728	62	80	666	648		C&D, Gen Waste		yes
EW-48	6/16/2009	706	40	97	666	609		Gen Waste	High Decomposition	yes
EW-49	11/10/2008		35	94				tire chips, muck	High Decomposition	yes
EW-50 R	8/31/2007	746	40	100	706	646	676-646	C&D, Gen Waste, Sludge	High Decomposition	yes
EW-50 R	11/14/2005	749	20	97	729	652		Gen Waste	High Decomposition	yes
EW-51	11/18/2005	749	15	95	734	654		Gen Waste	*Very wet waste	no
EW-62	6/10/2009	701	40	51	661	650		Gen Waste	Moderate Decomposition	no
EW-64	6/15/2009	744	30	88	714	656	684-656	Gen Waste, Sludge	Moderate Decompostion	yes
EW-65	11/6/2008		49	91				C&D, Gen Waste , tire chips	Heavy Decomposition	yes
EW-66	11/20/2005	742	15	90	727	652		Gen Waste, Sludge	*Problems drilling due to wet waste	yes
EW-67	10/31/2005	751	50	67	701	684	701-684	Gen Waste, Sludge	*Had to stop drilling due to wet waste/sludge	no
EW-69	8/19/2011	728	25	39	703	689		C&D, Gen Waste		yes
EW-79	8/22/2011	740	80	87	660	653		C&D, Gen Waste		yes
EW-7R	9/1/2007	741	80	100	661	641		C&D, Gen Waste	High Decomposition	yes
EW-80	6/12/2009	737	20	75	717	662	695-662	Gen Waste, Sludge	Moderate Decomposition	yes
EW-82	11/2/2005	736	45	95	691	641		Gen Waste		no

Ottawa County Farms Landfill
Gas Extraction Well Log Info

Well ID	Date	Surface Elevation	Upper Depth of Saturation (ft bgs)	Lower Depth of Saturation (ft bgs)	Upper Elevation of Saturated/ Wet Waste	Lower Elevation of Saturated/ Wet Waste	Noted Sludge Elevation	Waste Description	Comments	Located on map?
EW-83	10/27/2005	740	40	90	700	650	690-675	C&D, Sludge	*Had to stop drilling due to wet waste/sludge	no
EW-84-A	6/22/2009	722	40	78	682	644		C&D, Gen Waste	High Decomposition	yes
EW-88	7/11/2014	744	40	80	704	664	704-694	C&D, Gen Waste, Sludge	Moderate Decomposition, Sludge at 40-50 ft bgs	yes
EW-89	8/30/2012	733	38	86	695	647		C&D, Gen Waste		no
EW-8R2	8/28/2012	736	72	81	664	655		C&D, Gen Waste , clay		yes
EW-90	8/18/2011	736	39	52	697	684		C&D, Gen Waste		yes
EW-91	8/19/2011	733	22	43	711	690		C&D, Gen Waste		yes
EW-92	6/11/2009	728	30	73	698	655		Gen Waste	Moderate Decomposition	yes
EW-93	8/30/2007	726	45	84	681	642		C&D, Gen Waste	High Decomposition	no
EW-93R	8/28/2012	717	62	73	655	644		C&D, Gen Waste		yes
EW-94	6/10/2009	714	40	73	674	641		Gen Waste	Moderate Decomposition	yes
EW-96R	8/28/2012	718	72	75	646	643		C&D, Gen Waste		no
EW-96R	11/3/2005	727	50	89	677	638		Gen Waste	*concerns that stone will silt in with sludge	yes
EW-97	10/26/2005	727	30	75	697	652	687-652	Gen Waste, Sludge	*Had to stop drilling due to wet waste/sludge	no
EW-98	11/10/2005	715	25	50	690	665		Gen Waste	*problems making target depth	no
EW-99-R	8/19/2011	712	28	37	684	675		C&D, Gen Waste		yes
EW-99-R	11/14/2005	712	60	74	652	638		Gen Waste	*Very wet waste	yes
EW-9A	10/25/2006		0	100				C&D, Gen Waste	Moderate Decomposition	yes
GW 14	5/25/2004		47	70				Gen Waste	High Decomposition	no
GW-15	5/24/2004		52	70				Gen Waste	High Decomposition	no
PW-40	11/13/2002		24	53				Gen Waste	*Very wet waste	no
PW-47A	1/14/2003		30	50				Gen Waste	*Very wet waste, boring cave in due to water	no
PW-49A	1/15/2003		35	50				Gen Waste		no
W 106 R	8/16/2007	721	20	70	701	651		C&D, Gen Waste	High Decomposition	yes
W 108 R	8/15/2007	717	30	68	687	649	667-662	C&D, Gen Waste, Sludge	High Decomposition, * described as saturated	yes
W 110 R	8/15/2007	714	30	66	684	648		C&D, Gen Waste	High Decomposition, * described as saturated	yes
W 113 R	8/14/2007	715	35	67	680	648		C&D, Gen Waste	High Decomposition, * described as saturated	yes
W 129 R	8/13/2007	734	70	90	664	644		C&D, Gen Waste	High Decomposition	yes
W 77 R	8/27/2007	706	28	50	678	656		Gen Waste, Soil	3 ft clay layer at 670	yes
W 79 R	8/16/2007	699	40	50	659	649		C&D, Gen Waste	High Decomposition	yes
W 81 R	8/17/2007	702	40	53	662	649		C&D, Gen Waste	High Decomposition	yes
W 83 R	8/17/2007	703	40	54	663	649		C&D, Gen Waste	High Decomposition	yes
W 88 R	8/28/2007	703	50	56	653	647		,	High Decomposition	yes
W 95 R	8/16/2007	707	40	55	667	652		C&D, Gen Waste	High Decomposition	yes
W-19R	7/15/2014	715	30	40	685	675		C&D	Heavy Decomposition	yes
W-29AR	7/14/2014	723	20	50	703	673		C&D, Gen Waste	Moderate Decomposition	yes
W-33R	7/14/2014	714	0	40	714	674		C&D, Gen Waste	Moderate Decomposition	yes
W-36R	7/14/2014	715	20	40	695	675		Gen Waste	Moderate Decomposition	yes
W-55R	7/12/2014	732	20	70	712	662		C&D, Gen Waste	Moderate Decomposition	yes
W-62-R	11/5/2008		30	63				C&D, Gen Waste , tire chips	Heavy Decomposition	yes

ATTACHMENT 2

OVER-LINER SETTLEMENT ANALYSES CALCULATION SHEET

CALCULATION SHEET		Project No. :	2168070020		
Client:	Republic Services	Calculated By:	RR-MK-AS	Date:	4/11/2016
Project:	OCFL Over-liner Design	Checked By:	KCF	Date:	4/11/2016
Calculation:	Over-liner Settlement Analyses	Approved By:		Date:	

OVER-LINER SETTLEMENT ANALYSES

OBJECTIVES

- To establish acceptable probabilistic levels of performance for landfill post-settlement slopes by analyzing the existing Phase 5 cell floor at Ottawa County Farms Landfill (OCFL, site, landfill).
- To determine the minimum over-liner N-S and E-W design slopes and over-liner leachate collection pipe flowline slope for the vertical expansion over existing Cells A through E at OCFL, using the established levels of performance as the benchmark criteria.
- To estimate the distribution of computed strain values in the geomembrane resulting from modeled differential settlement for the selected design slopes.

PROJECT BACKGROUND

Ottawa County Farms Landfill, located in Polkton Township, Michigan is a municipal solid waste landfill owned by Republic Services, Inc. (Owner). The site contains 5 non-composite lined cells, Cells A through E built between 1983 and 1995, and 7 composite lined cells, Phase 1 through 7 built between 1997 and 2013. The proposed 2016 OCFL expansion permit application will include the installation of an over-liner over the existing non-composite lined landfill Cells A through E. Based on Rule 419 of the Part 115 Administrative Rules (MDEQ 2015), a vertical expansion at any Type II Landfill without composite floor liner system can be approved only if the over-liner (liner system over existing waste) has design slopes greater than 10%. Alternatively, the rule allows a design slope less than 10% if the slope is designed using a method acceptable to the director of Michigan Department of Environmental Quality. This calculation sheet discusses once such method.

THEORY

The long-term functionality of the over-liner system depends primarily on the differential settlement the system undergoes. Differential settlement occurring underneath the over-liner system may create local depressions in the over-liner system as shown in Figure 1, thereby preventing positive drainage and increasing the potential for infiltration of leachate into the existing waste. Design slope recommendations for the over-liner system considered settlement analysis of the over-liner subgrade and was aimed at limiting the negative impacts of differential settlement.

Traditionally, settlement analyses for buildings, bridges, highways and other structures are performed using the deterministic approach, where the subgrade material is assumed to be homogenous. The deterministic approach is

not adequate for the settlement evaluation of the over-liner system, since it fails to capture the highly heterogeneous nature of the waste subgrade. This heterogeneity of the waste mass gives actual landfill settlement a seemingly random pattern of variation. For a realistic assessment of the long-term performance of the proposed over-liner system, CTI adopted a probabilistic approach to settlement analyses, using random fields to model the spatial distribution of waste properties.

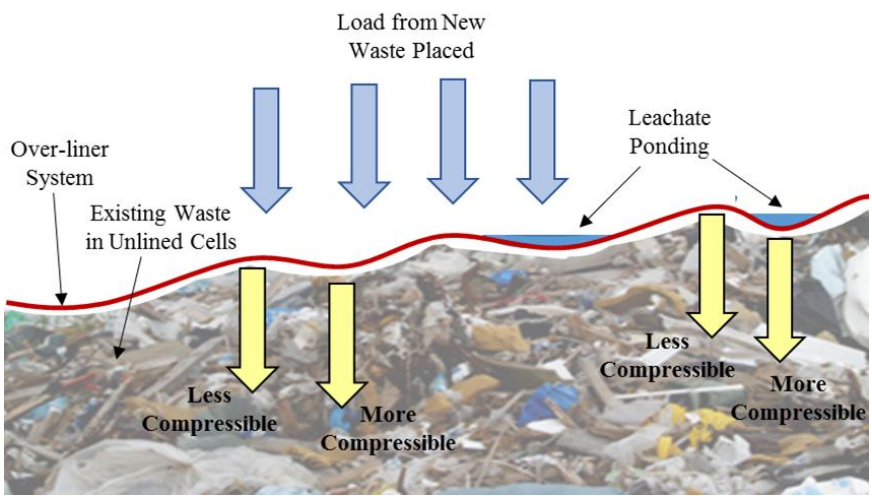

Figure 1. Differential Settlement of Over-liner System

Differential settlement within landfills is caused by inconsistent compaction, void space distribution, collapsing buried structures, variable waste material stiffness, variable compressibility of the surrounding soil matrix, uneven long-term creep settlement of the soil matrix, uneven loads and non-uniform debris, etc. The existing waste mass is highly heterogeneous and the spatial distribution of the waste properties is unknown and cannot be determined precisely. The variability observed in the behavior of the waste subgrade can be modeled using random fields. In this modeling method, different points in space are assigned random values from a given range of property values. This randomness is expected to capture the unknown variables that describe the waste behavior, while maintaining spatial correlation between the points in space. The spatial correlation is expressed mathematically using a correlation function, which can be used to govern the selection of random values in a simulated random field (Foye and Soong 2010).

A single instance of simulated random fields is known as a realization. As part of the over-liner settlement analyses, a minimum of 100 realizations were performed for each trial design slope to assess the likelihood of various possible outcomes. The use of random fields and a probabilistic approach to settlement analysis produces post-settlement profiles that seem to capture the inherent variability in materials like waste and soil.

To assess the effectiveness of the over-liner design, a set of probabilistic design criteria was needed. The design criteria for the probabilistic approach were determined based on the modeling of settlement of an existing cell floor with clay subgrade at OCFL, in conformance with the Part 115 rules. Because these cell floor designs are considered to produce acceptable post-settlement performance by the MDEQ, analysis of their performance allows

the development of design criteria that can then be considered acceptable as well.

For the settlement analyses at OCFL, the level of performance was expressed in terms of the percentage of modeled segments meeting or exceeding the desired design outcome (e.g., positive drainage, slopes greater than design minimum, etc.) over a minimum of 100 realizations. The modeled performance of the over-liner system was then compared to the design criteria established by the performance of the cell floor. The design slopes of the over-liner were refined through trial and error, until the over-liner provided, at a minimum, the same degree of confidence in post-settlement drainage as the cell floor.

To ensure completeness of the settlement analyses, each profile analyzed using the probabilistic approach was also analyzed using the deterministic approach. The following sections describe the design geometry and the scenarios considered for the settlement analyses in further detail.

DESIGN GEOMETRY

As seen in Figure 2 below, the conceptual design of the over-liner design features a cross-slope ("sheet flow") extending in the north-south direction over the non-composite lined Cells A through E. At the toe of the North slope, the design adopted a funnel-like pattern for drainage towards sumps. The over-liner limits were also divided into smaller regions, resulting in smaller watersheds draining to their respective sumps. Leachate collection pipes will be installed at areas of flow concentrations, as shown in the figure below. The leachate sheet flow across the South slope will drain to the south where it will be collected within the limits of the existing composite-lined cells.

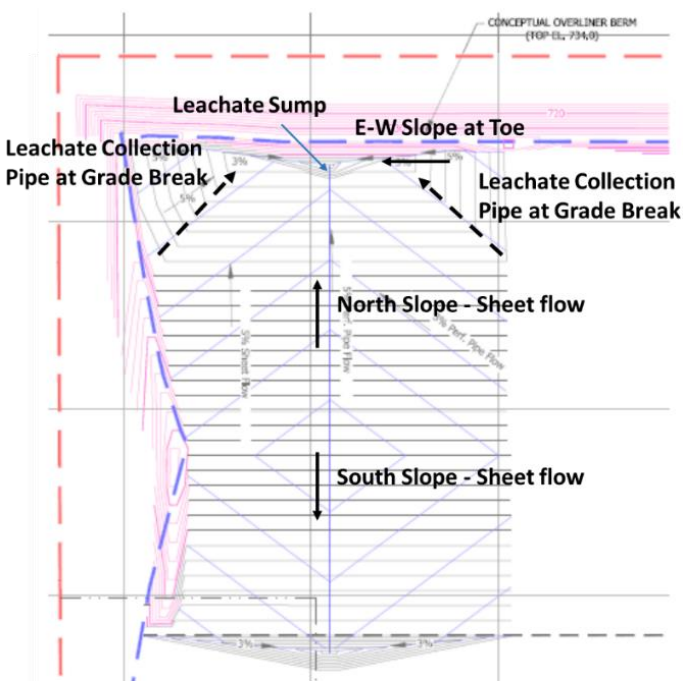

Figure 2. Conceptual Over-liner Design at OCFL

METHODOLOGY

Four different scenarios were considered for the settlement analyses of the over-liner system at OCFL. The settlement analyses were performed for at least two different design features under each scenario - (A) cross-slope or sheet flow, and (B) leachate collection pipe or concentrated flow. The general methodology followed for the settlement analyses of the over-liner is presented below in Figure 3. The multiple scenarios are also listed in Table 1 for reference and explained in greater detail in this section.

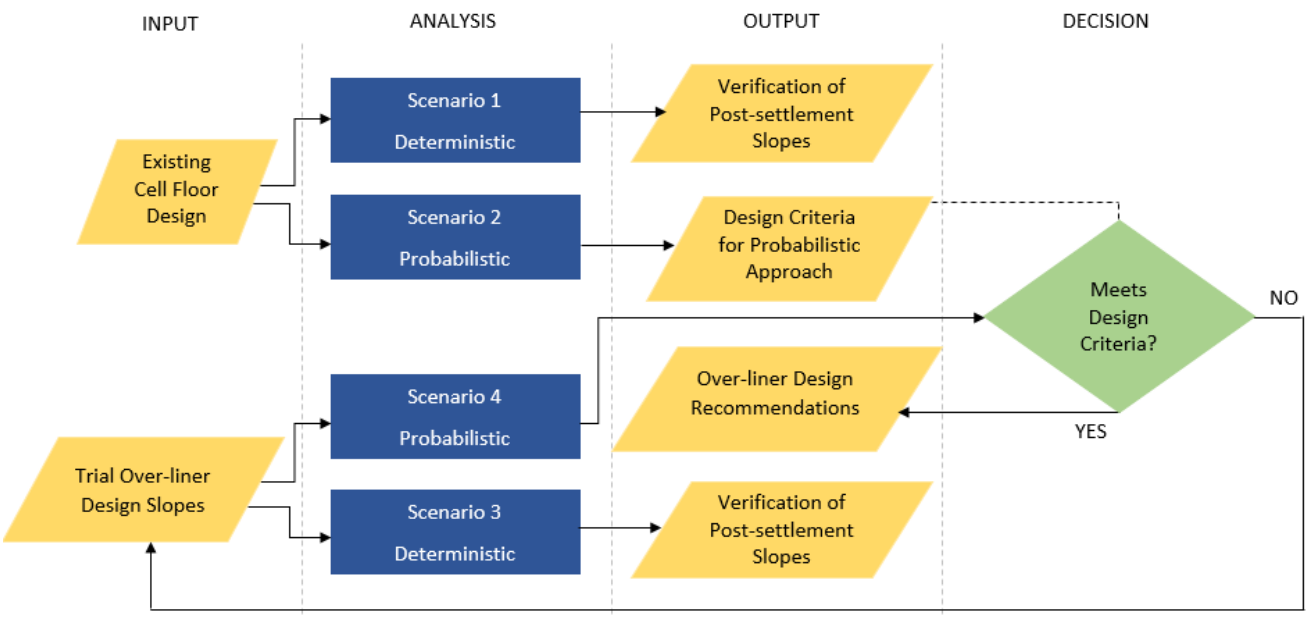

Figure 3. Flow Chart for the Over-liner Design Methodology

Scenarios 1 and 3 were considered as part of the settlement analyses to provide a comparison between the deterministic approach and the probabilistic approach. Results from Scenarios 2A and 2B were used to establish the design criteria for the probabilistic settlement analysis of the over-liner system. Scenarios 4A and 4B then used the established criteria to determine acceptable design slopes for the over-liner. Since over-liners on waste subgrades are more susceptible to differential settlement than floor liners on clay subgrades, the use of the relatively stringent probabilistic level of performance from clay liners (i.e., Scenarios 2A and 2B) in the design of over-liners is conservative. The soil and waste parameters used in the engineering analyses have been tabulated in Table 2 below.

Table 1. Over-liner Design Scenario Matrix

Scenario Number	Reference/ Design	Deterministic/ Probabilistic	Cross-slope/ Pipe Flow Line	Analysis Profile	Notes
1A	Reference	Deterministic	Cross-slope	Phase 5[1]	Verifies that reference meets rule requirements
1B	Reference	Deterministic	Pipe Flow Line	Phase 5[1]	Verifies that reference meets rule requirements
2A	Reference	Probabilistic	Cross-slope	Phase 5[1]	Establishes probabilistic criteria for cell floor cross-slope
2B	Reference	Probabilistic	Pipe Flow Line	Phase 5[1]	Establishes probabilistic criteria for cell pipe flow line
3A(N-S)	Design	Deterministic	Cross-slope	E3000[2]	Demonstrates that design slopes are conservative
3A(E-W)	Design	Deterministic	Cross-slope	N5728[2]	Demonstrates that design slopes are conservative
3B(N-S)	Design	Deterministic	Pipe Flow Line	E3000[2]	Demonstrates that design slopes are conservative
4A(N-S)	Design	Probabilistic	Cross-slope	E3000[2]	Determines minimum design slope using probabilistic criteria
4A(E-W)	Design	Probabilistic	Cross-slope	N5728[2]	Determines minimum design slope using probabilistic criteria
4B(N-S)	Design	Probabilistic	Pipe Flow Line	E3000[2]	Determines minimum design slope using probabilistic criteria

Notes:
1. Refer to Figure 4.
2. Refer to Figure 5.

Table 2. Material Properties Used in the Analyses

Material	Property	Symbol	Value	Units
Final Cover	Moist Unit weight	γ_{fcover}	120[6]	pcf
New Waste	Moist Unit weight	γ_{nwaste}	80[1]	pcf
Over-liner	Moist Unit weight	γ_{ofl}	120[6]	pcf
Existing Waste	Maximum biodegradation-induced strain potential	E_{DG}	0.193[8]	-
	Rate constant for biodegradation	d	0.002[8]	1/days
	Moist Unit weight	γ_{waste}	80[1]	pcf
	Compression Ratio	$[C_c/(1+e_0)]_w$	0.25[7]	-
Sludge	Moist Unit weight	γ_{waste}	80[1]	pcf
	Compression Ratio	$[C_c/(1+e_0)]_s$	0.40[7]	-
Cell Floor Liner	Moist Unit weight	γ_{liner}	120[6]	pcf
Clay Subgrade	Moist unit weight	γ	120[6]	pcf
	Buoyant unit weight	γ_b	75[6]	pcf
	Initial Void Ratio	e_0	0.48[5]	-
	Compression Ratio	$[C_c/(1+e_0)]_{cl}$	0.166[2],[4]	-
	Recompression Index	C_r	0.049[3],[4]	-

Notes -
1. This value is towards the high end of typical waste unit weights of 65 to 85 pcf to account for large quantities of water and sludge mixed with waste onsite and for a conservative analysis.
2. The compression index, C_c is determined from this formula (Coduto 1999) - C_c = Plasticity Index / 74
3. The recompression index, C_r is determined from this formula (Coduto 1999) - C_r = Plasticity Index / 370
4. Plasticity Index = 18.2% (OCFL Hydrogeological Report 1995)
5. From OCFL Hydrogeological Report (1995)
6. Typical industry-standard values
7. Qian et al. (2002), Reddy et al. (2009), McDougall (2011)
8. Foye et al. (2014), Foye et al. (2007)

In Scenarios 2A and 2B, the clay subgrade was assumed to be over-consolidated with an OCR of 2.0. This assumption resulted in lesser settlement within the clay subgrade and more stringent design criteria to meet, thereby adding conservativism to the analyses. In Scenarios 4A and 4B, the clay subgrade was assumed to be normally consolidated for two reasons. First, there is around 70 to 80 feet of existing waste over the non-composite lined cells of the landfill. Second, this assumption maximizes the settlement within the clay subgrade layer and makes the analyses more conservative. The following paragraphs explain how each scenario was analyzed.

Scenario 1 - Deterministic analysis of landfill cell floor with clay subgrade

Table 1. Over-liner Design Scenario Matrix

Scenario Number	Reference/ Design	Deterministic/ Probabilistic	Cross-slope/ Pipe Flow Line	Analysis Profile	Notes
1A	Reference	Deterministic	Cross-slope	Phase 5[1]	Verifies that reference meets rule requirements
1B	Reference	Deterministic	Pipe Flow Line	Phase 5[1]	Verifies that reference meets rule requirements
2A	Reference	Probabilistic	Cross-slope	Phase 5[1]	Establishes probabilistic criteria for cell floor cross-slope
2B	Reference	Probabilistic	Pipe Flow Line	Phase 5[1]	Establishes probabilistic criteria for cell pipe flow line
3A(N-S)	Design	Deterministic	Cross-slope	E3000[2]	Demonstrates that design slopes are conservative
3A(E-W)	Design	Deterministic	Cross-slope	N5728[2]	Demonstrates that design slopes are conservative
3B(N-S)	Design	Deterministic	Pipe Flow Line	E3000[2]	Demonstrates that design slopes are conservative
4A(N-S)	Design	Probabilistic	Cross-slope	E3000[2]	Determines minimum design slope using probabilistic criteria
4A(E-W)	Design	Probabilistic	Cross-slope	N5728[2]	Determines minimum design slope using probabilistic criteria
4B(N-S)	Design	Probabilistic	Pipe Flow Line	E3000[2]	Determines minimum design slope using probabilistic criteria

Notes:
1. Refer to Figure 4.
2. Refer to Figure 5.

As summarized in Table 1 earlier, Scenarios 1A and 1B (deterministic) compute the post-settlement slopes of an existing floor liner design in conformance with the Part 115 rules. The analyzed cell floor had a cross-slope of 2% and leachate pipe flowline slope of 1.25%. Figure 4 presents the cross-sections used for Scenarios 1 and 2. Following the deterministic approach for Scenarios 1A and 1B, the compressibility parameters for the subgrade clay were assumed to be constant throughout the analysis.

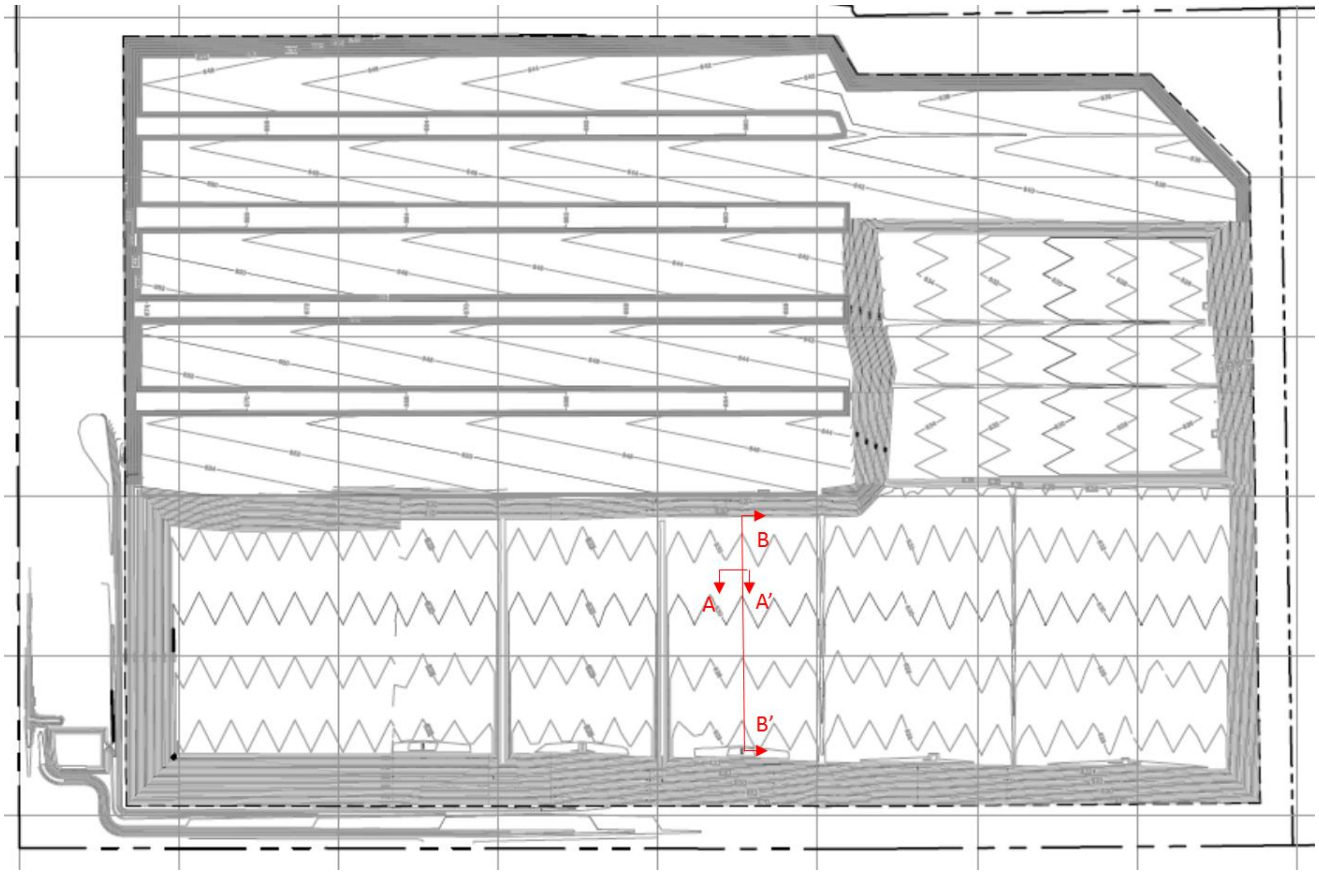

Figure 4. Cross-sections used for Scenarios 1 and 2

The deterministic analysis of the floor liner was performed according to the following methodology.

1. With the compressibility parameters assigned to the clay subgrade, the settlement within this layer was calculated using the following equation.

$$\Delta h_c = \frac{h_0}{1+e_0}\left(C_r \log\frac{\sigma_c}{\sigma_0} + C_c \log\frac{\sigma_i}{\sigma_c}\right) \qquad (1)$$

Where:

Δh_c = primary compression settlement of the compressible clay subgrade [ft]
C_c = primary compression index
C_r = Recompression index
h_0 = initial compressible layer thickness [ft]
e_0 = initial void ratio of the clay subgrade
σ_0 = initial overburden pressure acting on the compressible layer [psf]
σ_i = final overburden pressure acting on the compressible layer [psf]

σ_c = preconsolidation stress [psf]
= OCR × σ_0
OCR = overconsolidation ratio

In the case of waste, where values of compressibility are back calculated from field data and the initial void ratio is unknown, Equation 1 is modified to allow the use of C'_c:

$$\Delta h_c = h_0 C'_c \log \frac{\sigma_i}{\sigma_0} \qquad (2)$$

Where:

C'_c = Compression ratio
$C_c / (1 + e_0)$

2. The total settlement for each layer is calculated by applying either Equation 1 or Equation 2 to each of the points along the slope.

3. The differential settlement and post-settlement slopes are then calculated using the total settlement for each of the points along the slope, the distance between the points, and the original design slope.

Scenario 2 – Probabilistic analysis of landfill cell floor with clay subgrade

Table 1. Over-liner Design Scenario Matrix

Scenario Number	Reference/ Design	Deterministic/ Probabilistic	Cross-slope/ Pipe Flow Line	Analysis Profile	Notes
1A	Reference	Deterministic	Cross-slope	Phase 5[1]	Verifies that reference meets rule requirements
1B	Reference	Deterministic	Pipe Flow Line	Phase 5[1]	Verifies that reference meets rule requirements
2A	Reference	Probabilistic	Cross-slope	Phase 5[1]	Establishes probabilistic criteria for cell floor cross-slope
2B	Reference	Probabilistic	Pipe Flow Line	Phase 5[1]	Establishes probabilistic criteria for cell pipe flow line
3A(N-S)	Design	Deterministic	Cross-slope	E3000[2]	Demonstrates that design slopes are conservative
3A(E-W)	Design	Deterministic	Cross-slope	N5728[2]	Demonstrates that design slopes are conservative
3B(N-S)	Design	Deterministic	Pipe Flow Line	E3000[2]	Demonstrates that design slopes are conservative
4A(N-S)	Design	Probabilistic	Cross-slope	E3000[2]	Determines minimum design slope using probabilistic criteria
4A(E-W)	Design	Probabilistic	Cross-slope	N5728[2]	Determines minimum design slope using probabilistic criteria
4B(N-S)	Design	Probabilistic	Pipe Flow Line	E3000[2]	Determines minimum design slope using probabilistic criteria

Notes:
1. Refer to Figure 4.
2. Refer to Figure 5.

In Scenario 2, the cell floor liner and leachate pipe flowline design slopes from Scenario 1 were analyzed by probabilistic approach, devised by CTI (Foye and Soong 2010). The probabilistic analysis evaluated how frequently each segment of the post-settlement profile met or exceeded the Part 115 Rules slope requirement for the cell floor liner cross-slope (minimum 2%) and the leachate collection pipe (minimum 1%). The results from this scenario were used to establish the probabilistic level of performance for the design of the over-liner system that will serve as the design criteria. These criteria were then used to optimize the design of the over-liner slopes in Scenarios 4A and 4B.

The probabilistic analysis of the floor liner was performed according to the following methodology.

1. The subgrade was divided into discrete columns at regular simulation intervals (7 feet).

2. Each column was assigned a set of compressibility parameters according to a randomly-generated spatial field value set. This random field was generated according to stochastic rules governing the variability of the subgrade compressibility properties. These rules corresponded to the actual variability and the spatial distribution of subgrade properties measured in field-scale experiments (Foye et al. 2007, Foye and Soong

2010, Foye et al. 2014).

3. In order to ensure that the modeling correctly captures the inter-column interaction and differential settlement behavior of the subgrade, the spatial distribution rules were also tied to the geometry of the analysis (Foye and Soong 2010).

4. With the compressibility parameters and the random field values assigned, the settlement of each column was calculated using Equation 1 or Equation 2, for every realization.

5. The differential settlement and post-settlement slopes were then calculated for every modeled segment of the floor liner for each realization, using the total settlement of each column, the distance between the columns (the simulation interval), and the original design slope.

6. A cumulative distribution graph, depicting the distribution of post-settlement slopes was then generated by cumulatively summing the number of modeled segments that fall within each range of post-settlement slope values, divided by the total number of modeled segments.

Once the post-settlement slopes were calculated for Scenarios 2A and 2B, the resulting cumulative distribution graphs of post-settlement floor slopes were used as the design criteria for Scenario 4. The percentage of slopes meeting the minimum design slope criteria from Scenario 2 represents the design level of performance benchmark criteria for the probabilistic analyses.

Scenario 3 - Deterministic analysis of over-liner on existing waste subgrade

Table 1. Over-liner Design Scenario Matrix

Scenario Number	Reference/ Design	Deterministic/ Probabilistic	Cross-slope/ Pipe Flow Line	Analysis Profile	Notes
1A	Reference	Deterministic	Cross-slope	Phase 5[1]	Verifies that reference meets rule requirements
1B	Reference	Deterministic	Pipe Flow Line	Phase 5[1]	Verifies that reference meets rule requirements
2A	Reference	Probabilistic	Cross-slope	Phase 5[1]	Establishes probabilistic criteria for cell floor cross-slope
2B	Reference	Probabilistic	Pipe Flow Line	Phase 5[1]	Establishes probabilistic criteria for cell pipe flow line
3A(N-S)	Design	Deterministic	Cross-slope	E3000[2]	Demonstrates that design slopes are conservative
3A(E-W)	Design	Deterministic	Cross-slope	N5728[2]	Demonstrates that design slopes are conservative
3B(N-S)	Design	Deterministic	Pipe Flow Line	E3000[2]	Demonstrates that design slopes are conservative
4A(N-S)	Design	Probabilistic	Cross-slope	E3000[2]	Determines minimum design slope using probabilistic criteria
4A(E-W)	Design	Probabilistic	Cross-slope	N5728[2]	Determines minimum design slope using probabilistic criteria
4B(N-S)	Design	Probabilistic	Pipe Flow Line	E3000[2]	Determines minimum design slope using probabilistic criteria

Notes:
1. Refer to Figure 4.
2. Refer to Figure 5.

In Scenario 3, the selected cross-sections were analyzed using the deterministic approach for reference. Since the conceptual design of the over-liner features sheet flow in North-South (N-S) and East-West (E-W) directions, two different cross-sectional profiles were analyzed as part of Scenario 3A. The leachate collection pipe over the over-liner is expected to be installed in the Southwest-Northeast and Southeast-Northwest directions as shown in Figure 2. For ease of calculations and added conservatism, the leachate collection pipes were assumed to be installed in the N-S direction. Since the N-S cross-sectional profile was already analyzed under Scenario 3A, the results were examined to ensure the post-settlement slopes were greater than 1%, as required by the Part 115 Rules.

Figure 5 presents the N-S and E-W cross-sections used for Scenarios 3 and 4. The selected N-S cross-section included areas of the over-liner with the thickest sections of the waste mass. It was therefore considered the critical section for the settlement analyses since it will yield the greatest total and differential settlement estimates.

The deterministic analysis of the over-liner was performed according to the following methodology:

1. Settlement in each over-liner subgrade layer was calculated in the same manner and using the same equations in Scenario 1, using the compressibility parameters of waste and clay subgrade established in Table 2.

2. Additionally, mechanical and biological secondary compression of the existing waste subgrade was accounted for in Scenario 3 using the equation below (Foye et al. 2007).

$$\Delta h_B = E_{DG}\left[\left(1-e^{-dtf}\right)-\left(1-e^{-dt0}\right)\right]h_0 \qquad (3)$$

Where:

Δh_B = secondary compression due to mechanical and biological mechanisms [ft]
E_{DG} = maximum amount of strain that can occur due to biodegradation
d = rate constant for biodegradation [1/days]
tf = time of landfill lifetime [days]
$t0$ = time since existing waste placement [days]
h_0 = initial waste layer thickness [ft]

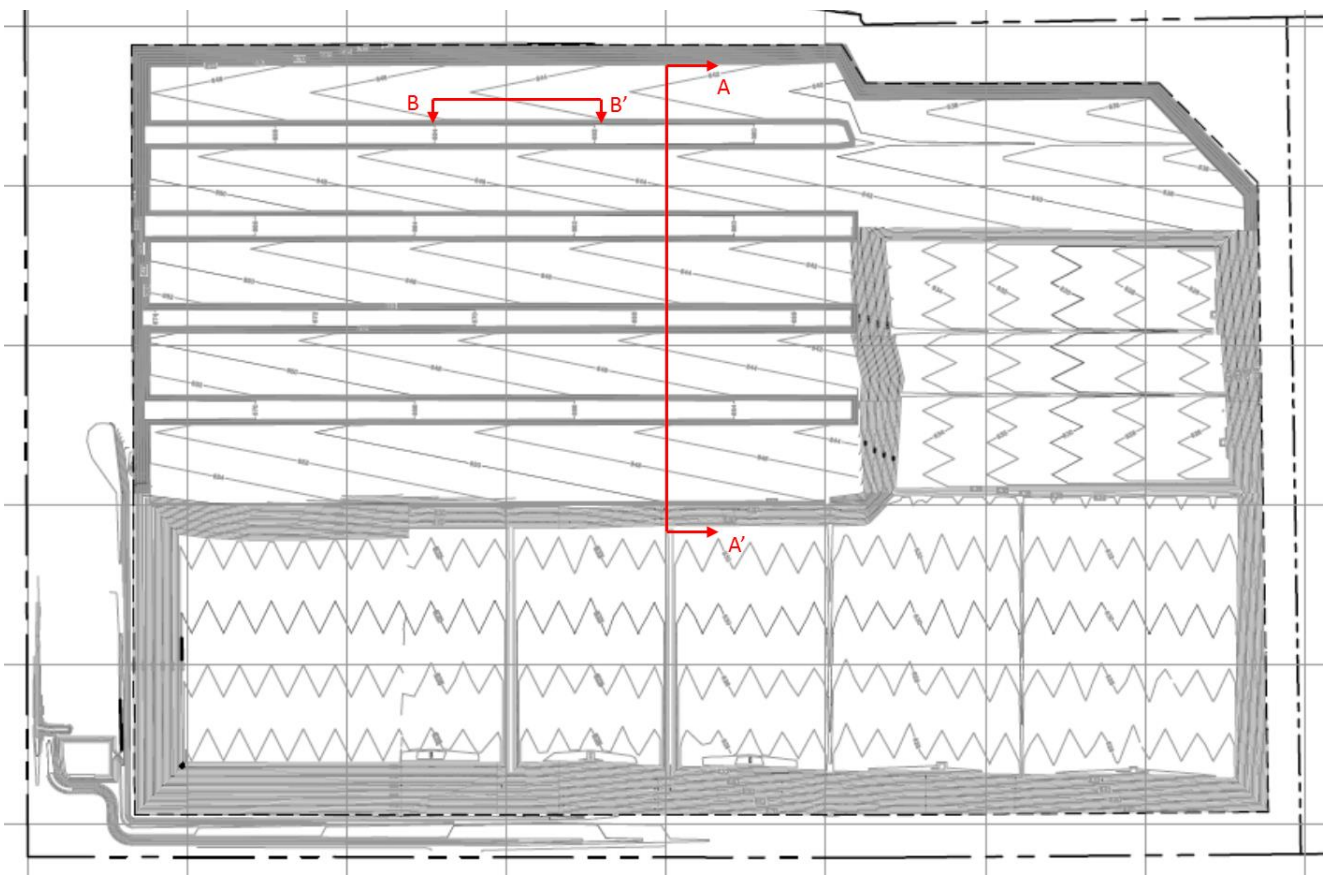

Figure 5. Cross-sections used for Scenarios 3 and 4

Scenario 4 – Probabilistic analysis of over-liner on existing waste subgrade

Table 1. Over-liner Design Scenario Matrix

Scenario Number	Reference/ Design	Deterministic/ Probabilistic	Cross-slope/ Pipe Flow Line	Analysis Profile	Notes
1A	Reference	Deterministic	Cross-slope	Phase 5[1]	Verifies that reference meets rule requirements
1B	Reference	Deterministic	Pipe Flow Line	Phase 5[1]	Verifies that reference meets rule requirements
2A	Reference	Probabilistic	Cross-slope	Phase 5[1]	Establishes probabilistic criteria for cell floor cross-slope
2B	Reference	Probabilistic	Pipe Flow Line	Phase 5[1]	Establishes probabilistic criteria for cell pipe flow line
3A(N-S)	Design	Deterministic	Cross-slope	E3000[2]	Demonstrates that design slopes are conservative
3A(E-W)	Design	Deterministic	Cross-slope	N5728[2]	Demonstrates that design slopes are conservative
3B(N-S)	Design	Deterministic	Pipe Flow Line	E3000[2]	Demonstrates that design slopes are conservative
4A(N-S)	Design	Probabilistic	Cross-slope	E3000[2]	Determines minimum design slope using probabilistic criteria
4A(E-W)	Design	Probabilistic	Cross-slope	N5728[2]	Determines minimum design slope using probabilistic criteria
4B(N-S)	Design	Probabilistic	Pipe Flow Line	E3000[2]	Determines minimum design slope using probabilistic criteria

Notes:
1. Refer to Figure 4.
2. Refer to Figure 5.

This scenario considered the same cross sections as indicated in Scenario 3. However, in this scenario, the analysis was performed by applying the probabilistic approach. A minimum of 100 realizations were performed for each trial design slope to evaluate the differential settlement in the over-liner system and to calculate the post-settlement slopes of the modeled segments in the analysis. The design slopes of the over-liner were refined through trial and error, until the post-settlement slopes of the over-liner met the established criteria.

In Scenario 4A and 4B, the cumulative distribution graphs of the post-settlement slopes were compared to that of Scenarios 2A and 2B, respectively to determine acceptability. In comparison to the established criteria, if the analyzed trial design slope produced a lower percentage of modeled segments with a post-settlement slope of less than the minimum required slope, the trial design slope was considered acceptable. For additional conservatism, another criterion was applied: the design in Scenario 4 would have fewer post-settlement slopes that are less than 0% ("slope reversal") than Scenario 2.

RESULTS

Settlement analyses were performed for all four scenarios. The following sections summarize the results for each scenario analyzed.

Scenario 1 - Deterministic analysis of landfill cell floor with clay subgrade

The analyses for Scenario 1 were performed following the methodology described in the previous section using the properties outlined in Table 2. Multiple points were selected for settlement analyses along the chosen cross-section in the existing cell, Phase 5 at OCFL. Figures 6 and 7 show the pre-settlement and the post-settlement profiles of the clay subgrade as computed by the deterministic approach.

Based on the results, a 2.0% design cross-slope slope yields a post-settlement slope equal to or greater than 1.75% for the cell floor liner. A 1.25% design slope yields a post-settlement slope greater than the minimum required post-settlement slope (1.0%) for the leachate pipe flowline.

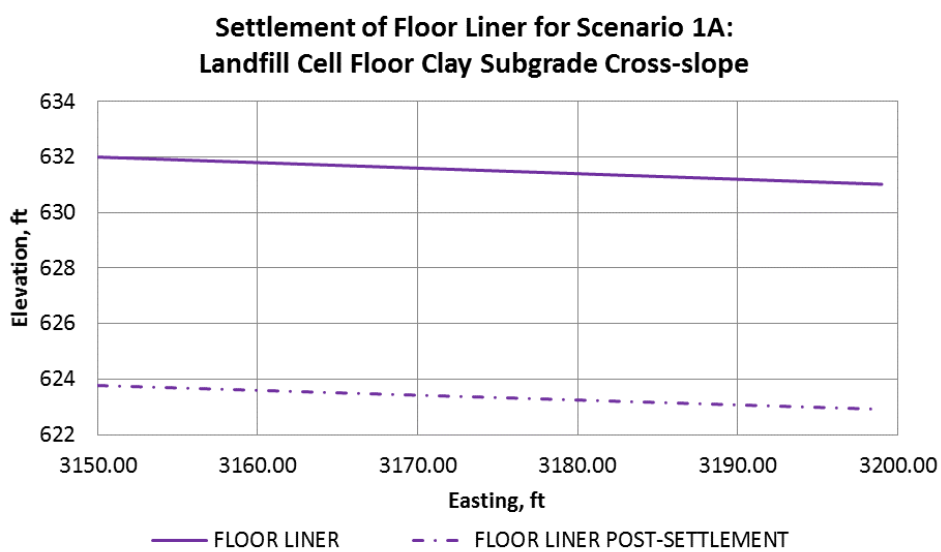

Figure 6. Scenario 1A Pre-settlement and Post-settlement Cell Floor Profiles

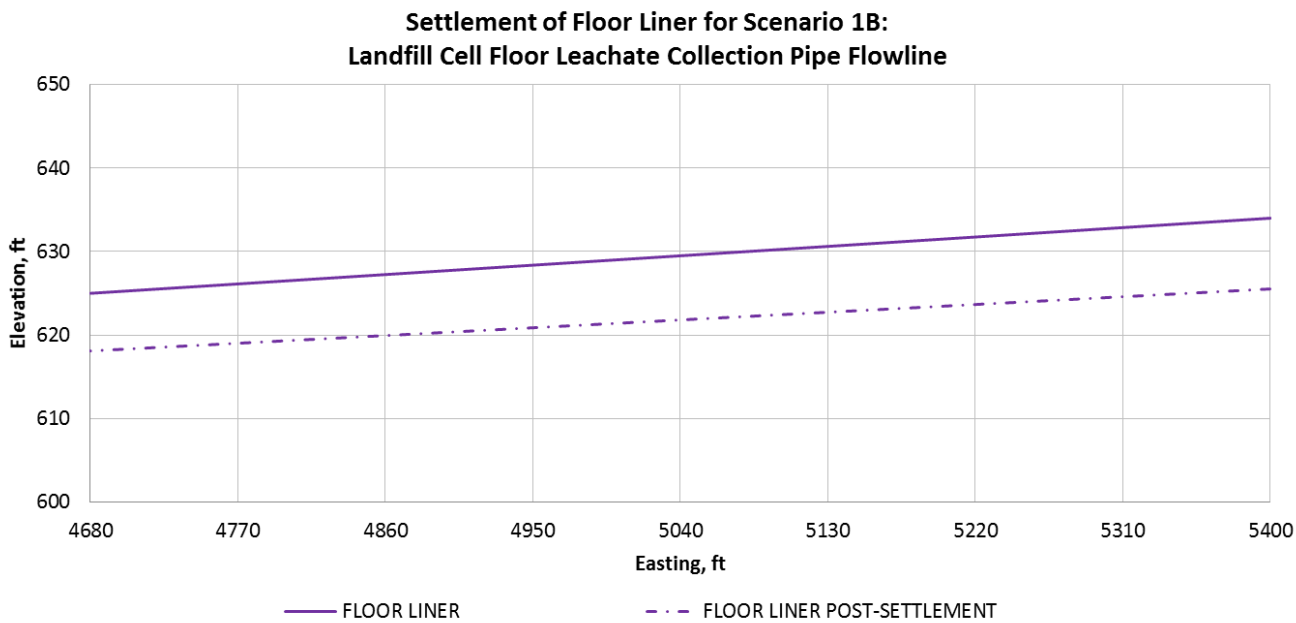

Figure 7. Scenario 1B Pre-settlement and Post-settlement Cell Floor Profiles

Scenario 2 - Probabilistic analysis of landfill cell floor with clay subgrade

Table 3 summarizes the post-settlement slopes of modeled segments for a design cross-slope of 2.0% (Scenario 2A) and 1.25% (Scenario 2B). The results presented in Table 3 are expressed in percentages of modeled segments that fall within each range of post-settlement slopes.

Table 3. Summary of Post-Settlement Slopes

Post-Settlement Slope Range	% of Modeled Segments	
	Scenario 2A	Scenario 2B
< -4%	4.65	5.52
-4% to -2%	8.52	10.97
-2% to 0%	14.81	20.29
0% to 2%	20.76	24.17
2% to 4%	21.38	20.33
4% to 6%	16.68	11.91
6% to 8%	8.76	5.04
8% to 10%	3.29	1.47
> 10%	1.14	0.30
TOTAL	99.99	100

The analyses for Scenario 2 were performed following the methodology described in the previous section using the properties outlined in Table 2. For Scenario 2A, analyses were performed to obtain the percentage of modeled cell floor liner segments with post-settlement slopes that are less than 2.0% for a simulation interval of 7 feet. At least 900 realizations were performed using random fields to generate a distribution of the post-settlement slopes for cross-slope profile. For Scenario 2B, analyses were performed to obtain the percentage of modeled segments with post-settlement slopes that are less than 1.0% for the same simulation interval of 7 feet. A minimum of 100 realizations were performed using random fields to generate a distribution of the post-settlement slopes for the leachate collection pipe flow line. Figures 8 and 9 show the typical pre-settlement and post-settlement profiles for Scenario 2A and 2B, respectively. Figures 10 and 11 show the cumulative distribution graphs generated for Scenarios 2A and 2B, respectively.

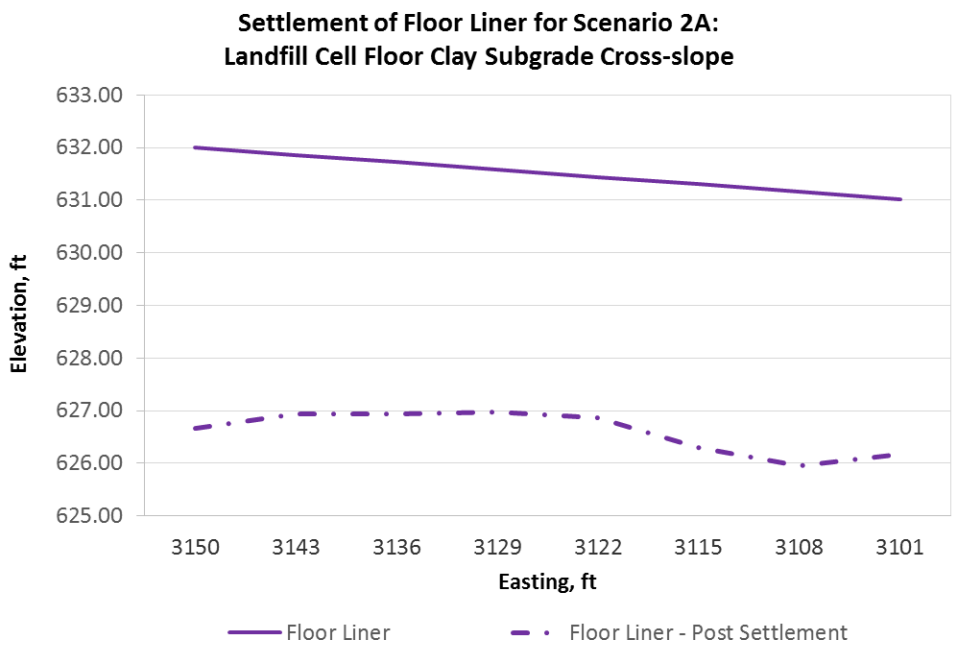

Figure 8. Example Scenario 2A Pre-settlement and Post-settlement Cell Floor Profiles

CALCULATION SHEET

Client:	Republic Services	Project No. :	2168070020		
Project:	OCFL Over-liner Design	Calculated By:	RR-MK-AS	Date:	4/11/2016
Calculation:	Over-liner Settlement Analyses	Checked By:	KCF	Date:	4/11/2016
		Approved By:		Date:	

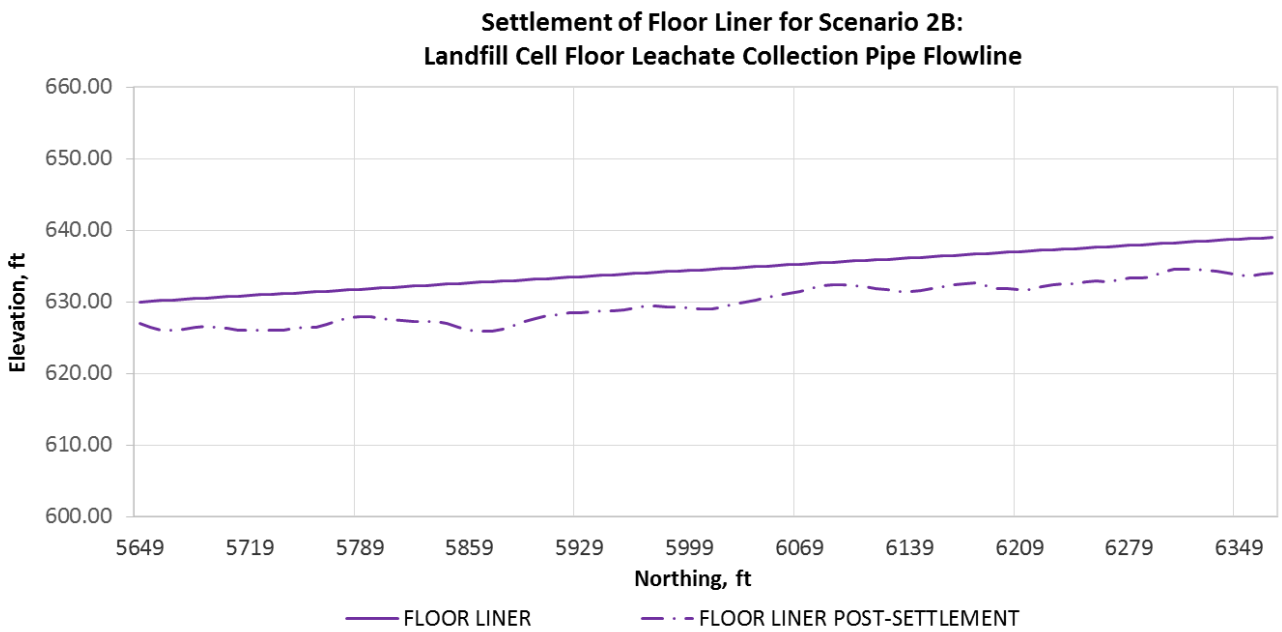

Figure 9. Example Scenario 2B Pre-settlement and Post-settlement Cell Floor Profiles

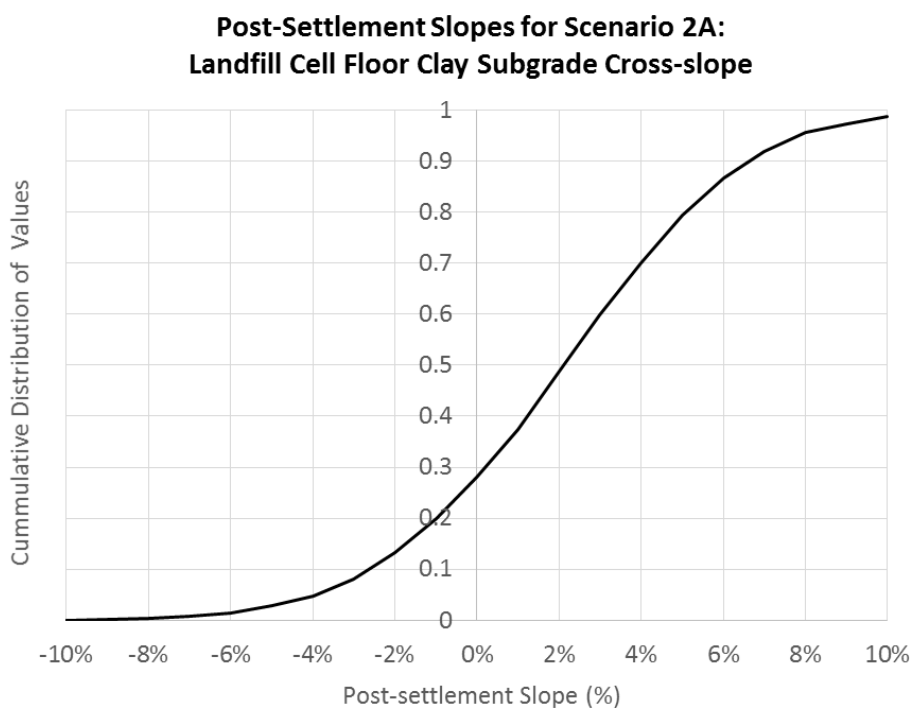

Figure 10. Cumulative Distribution Graph of Post-settlement Slopes for Scenario 2A

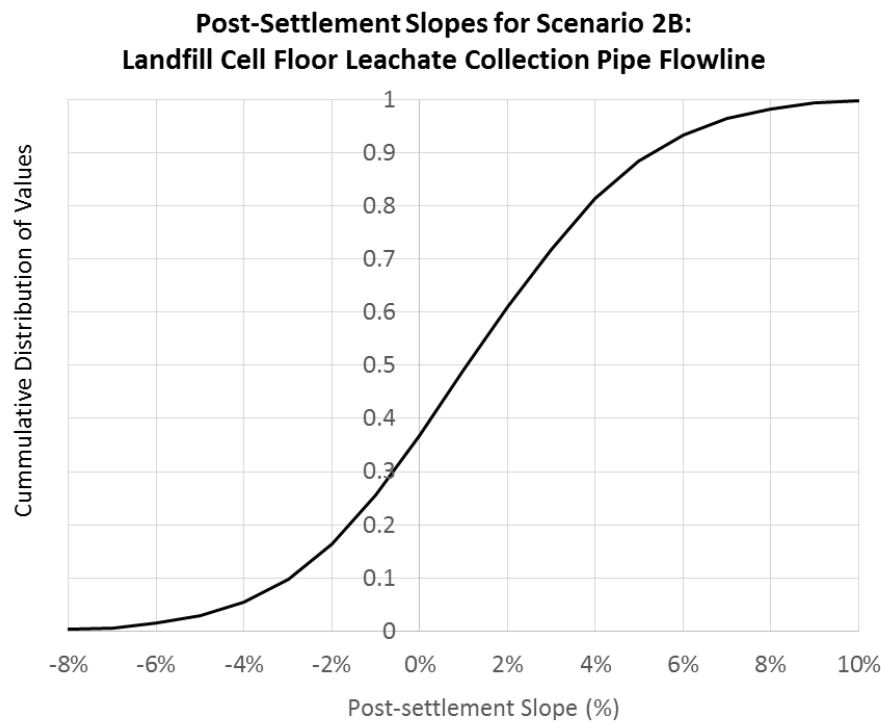

Figure 11. Cumulative Distribution Graph of Post-settlement Slopes for Scenario 2B

The results from Scenario 2 can be summarized as follows.

- For Scenario 2A -
  - 51.25% of the modeled segments maintained a post-settlement slope of at least 2.0%.
  - 72% of the modeled segments maintained a positive post-settlement slope (at least 0.0%).

- For Scenario 2B -
  - 50.8% of the modeled segments maintained a post-settlement slope of at least 1.0%.
  - 63.2% of the modeled segments maintained a positive post-settlement slope (at least 0.0%).

Based on these results, it follows that the design slopes of the over-liner system will provide the same degree of confidence in post-settlement drainage as the cell floor if the following criteria were met.

- For the over-liner cross-slopes in North-South and East-West directions -
  - At least 51.25% of the modeled segments should maintain a post-settlement slope of at least 2%, and
  - At least 72% of the modeled segments should maintain a positive post-settlement slope.

- For the over-liner leachate collection pipe flowline -
  - At least 50.8% of the modeled segments should maintain a post-settlement slope of at least 1%,

and

- At least 63.2% of the modeled segments should maintain a positive post-settlement slope.

These criteria are reasonable design criteria for a liner system to be placed on clay subgrade with properties similar to those assumed for this analyses. These criteria can be considered especially conservative for waste subgrades since the behavior of clay subgrades is expected to be more uniform than that of waste subgrades. Therefore, this calculation approach applies a very high standard to the post-settlement performance of waste subgrades. These criteria are applied to determine the acceptability of the design slopes in Scenario 4.

Scenario 4 – Probabilistic analysis of over-liner on existing waste subgrade

The analyses for this Scenario were performed following the methodology described in the previous section using the properties outlined in Table 2. As seen in Scenario 2, the results are expressed in terms of percentage of modeled segments with post-settlement slopes that are less than the minimum required slope per Part 115 Rules, for simulation intervals of 7 feet. A minimum of 100 realizations were performed for each trial design slope to calculate the distribution of the post-settlement slopes at each of the points along the over-liner (OFL). To illustrate the results of the settlement analyses, the post-settlement profiles of 100 realizations from the analysis of the 5% design slope have been attached to this calculation sheet. Since the conceptual design featured E-W sheet flow specifically at the toe of the over-liner slope where the waste layer was thinner, the E-W design slope was analyzed at shallower slopes than the N-S design slope. The results from the trial design analyses have been summarized below in Table 4. Also shown in Table 4 are summary data for each trial slope and a comparison of the design criteria with trial slope performance.

Table 5 summarizes the post-settlement slopes of modeled segments for the selected design slopes of 5.0% and 3.0% in the N-S and E-W directions, respectively. The results presented in Table 5 are expressed in percentages of modeled segments that fall within each range of post-settlement slopes. Figures 12 and 13 show example pre-settlement and post-settlement profiles for Scenario 4A (N-S) and 4A (E-W), respectively. Figures 14 and 15 show the cumulative distribution graphs generated for Scenarios 4A (N-S) and 4A (E-W), respectively. The cumulative distributive graphs demonstrate that the design slopes provide drainage performance better than the established design criteria from the probabilistic approach in Scenario 2A.

- For the over-liner cross-slopes in North-South and East-West directions -
  - At least 51.25% of the modeled segments should maintain a post-settlement slope of at least 2%, and
  - At least 72% of the modeled segments should maintain a positive post-settlement slope.

CALCULATION SHEET

Client:	Republic Services	Project No. :	2168070020		
Project:	OCFL Over-liner Design	Calculated By:	RR-MK-AS	Date:	4/11/2016
Calculation:	Over-liner Settlement Analyses	Checked By:	KCF	Date:	4/11/2016
		Approved By:		Date:	

Table 4. Summary of Trial Design Slopes - Scenario 4A[2]

#	Direction of Cross-slope	Cross-section considered[1]	Design Slope (%)	2A Design Criteria		4A Analysis Results		Criteria met? (Y/NO)	
				Percentage of Post-settlement slopes -					
				< 0%	< 2%	< 0%	< 2%	< 0%	< 2%
1	N-S	A-A'	4	28%	48.75%	27.7%	45.3%	Y	Y
2	N-S	A-A'	5			18.2%	35.5%	Y	Y
3	N-S	A-A'	6			10.4%	25.1%	Y	Y
4	N-S	A-A'	8			2.2%	8.4%	Y	Y
5	N-S	A-A'	10			0.6%	2.3%	Y	Y
6	E-W	B-B'	2			25.1%	52.4%	Y	NO
7	E-W	B-B'	3			15.2%	38.4%	Y	Y
8	E-W	B-B'	4			8.5%	23.3%	Y	Y

Notes:
1. Refer to Figure 5.
2. Results are based on a minimum of 100 realizations for each trial design slope.

Table 5. Summary of Post-Settlement Slopes - Scenario 4A

Post-Settlement Slope Range	% of Modeled Segments	
	N-S 5% slope	E-W 3% slope
< -4%	3.37	1.25
-4% to -2%	4.92	3.25
-2% to 0%	9.87	10.68
0% to 2%	17.35	23.26
2% to 4%	21.18	28.48
4% to 6%	18.51	21.67
6% to 8%	12.94	8.96
8% to 10%	6.43	2.14
> 10%	5.41	0.30
TOTAL	99.98	99.99

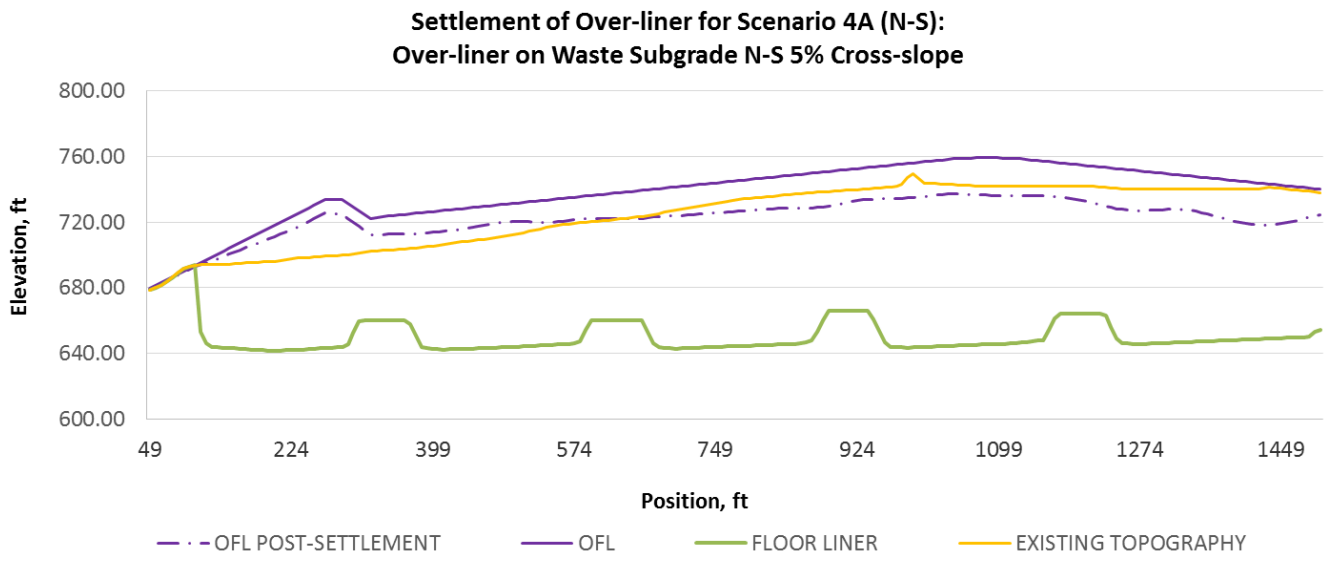

Figure 12. Example Scenario 4A Pre-settlement and Post-settlement N-S Cross-slope Profiles

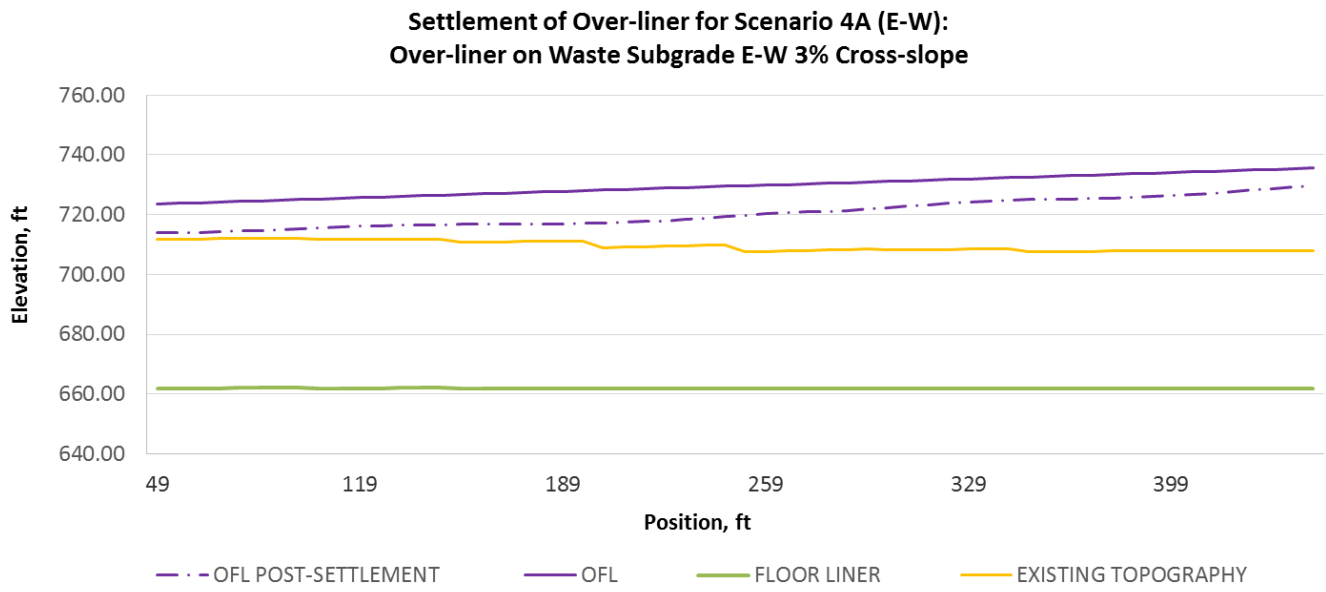

Figure 13. Example Scenario 4A Pre-settlement and Post-settlement E-W Cross-slope Profiles

CALCULATION SHEET		Project No. :	2168070020		
Client:	Republic Services	Calculated By:	RR-MK-AS	Date:	4/11/2016
Project:	OCFL Over-liner Design	Checked By:	KCF	Date:	4/11/2016
Calculation:	Over-liner Settlement Analyses	Approved By:		Date:	

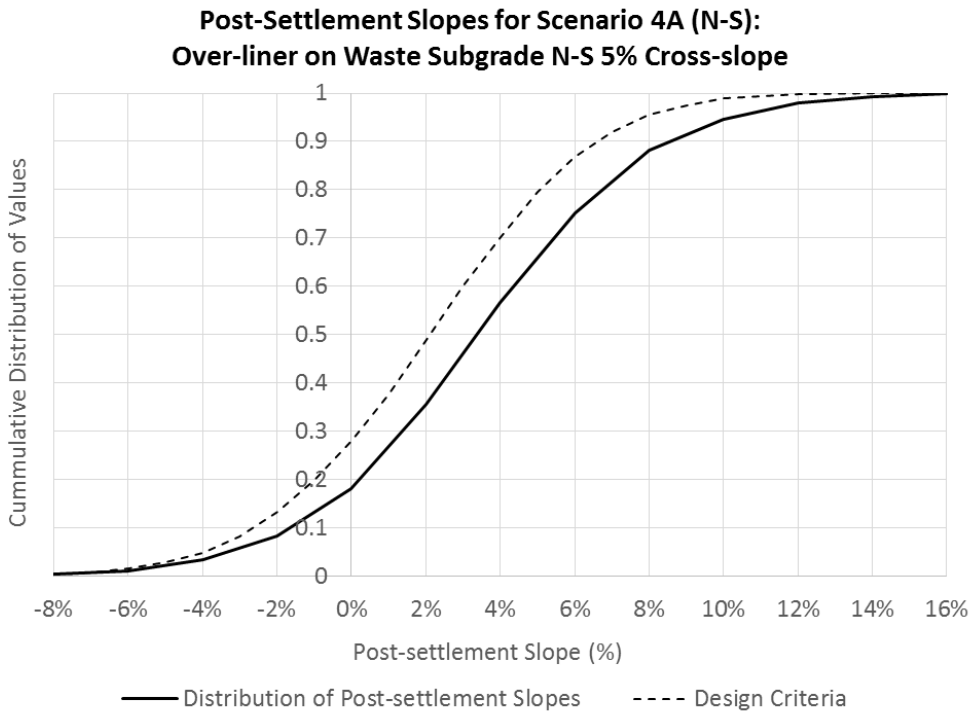

Figure 14. Cumulative Distribution Graph for Scenario 4A (N-S)

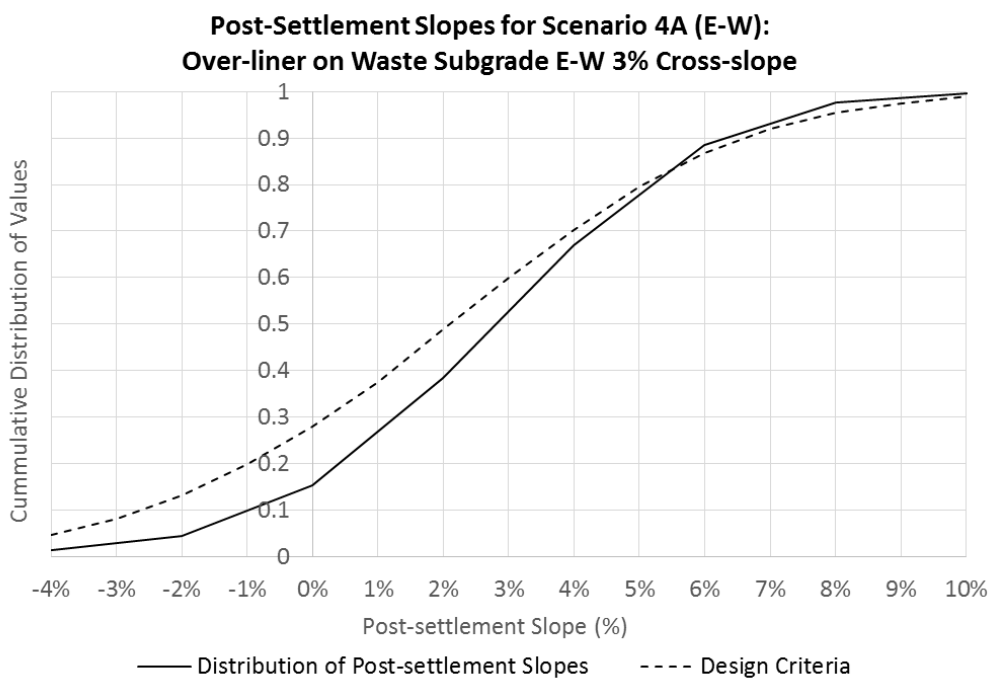

Figure 15. Cumulative Distribution Graph for Scenario 4A (E-W)

The results from the analysis of the N-S cross-sectional profile were compared to the design criteria from Scenario 2B for establishing the minimum design slope of the leachate collection pipe as shown below in Table 6.

Table 6. Summary of Trial Design Slopes - Scenario 4B[2]

#	Direction of Cross-slope	Cross-section considered[1]	Design Slope (%)	2B Design Criteria		4B Analysis Results		Criteria met? (Y/NO)	
				Percentage of Post-settlement slopes -					
				< 0%	< 1%	< 0%	< 1%	< 0%	< 1%
1	N-S	A-A'	4	36.8%	49.2%	27.7%	35.9%	Y	Y
2	N-S	A-A'	5			18.2%	25.8%	Y	Y
3	N-S	A-A'	6			10.4%	16.5%	Y	Y
4	N-S	A-A'	8			2.2%	4.3%	Y	Y

Notes:
1. Refer to Figure 5.
2. Results are based on a minimum of 100 realizations for each trial design slope.

Additionally, the uniaxial strain in the over-liner system was calculated using Equation 4 presented below for the selected over-liner design slope of 5%.

$$\varepsilon(\%) = \frac{dl}{l_0} = \frac{\sqrt{(s_1 - s_2)^2 + dx^2} - dx}{dx} * 100 \qquad (4)$$

Where:

dl = change in length [ft]
l_0 = initial length [ft]
dx = simulation interval [ft]
= 7 feet (as used in analyses)
s_1 = total settlement at K position [ft]
s_2 = total settlement at (K+1) position [ft]

The post-settlement uniaxial strain was calculated for every 7-foot segment of the geosynthetic over-liner system, for each of the 100 realizations performed during the settlement analyses. The frequency distribution of the strain calculated is presented below in Table 7 and Figure 16.

CALCULATION SHEET

Client:	Republic Services	Project No. :	2168070020		
Project:	OCFL Over-liner Design	Calculated By:	RR-MK-AS	Date:	4/11/2016
Calculation:	Over-liner Settlement Analyses	Checked By:	KCF	Date:	4/11/2016
		Approved By:		Date:	

Table 7. Summary of Post-settlement Strain Distribution

Strain (%)	Frequency	Cumulative Frequency	Cumulative Fraction of Values
0 - 0.05	6486	6486	0.395
0.05 - 0.1	2471	8957	0.546
0.1 - 0.15	1636	10593	0.646
0.15 - 0.2	1206	11799	0.719
0.2 - 0.25	877	12676	0.773
0.25 - 0.3	747	13423	0.818
0.3 - 0.35	546	13969	0.852
0.35 - 0.4	424	14393	0.878
0.4 - 0.6	1023	15416	0.940
0.6 - 0.8	495	15911	0.970
0.8 - 1.0	254	16165	0.986
1.0 - 1.2	116	16281	0.993
1.2 - 1.4	65	16346	0.997
1.4 - 1.6	33	16379	0.999
1.6 - 1.8	10	16389	0.999
1.8 - 2	11	16400	1.000
TOTAL	**16400**		

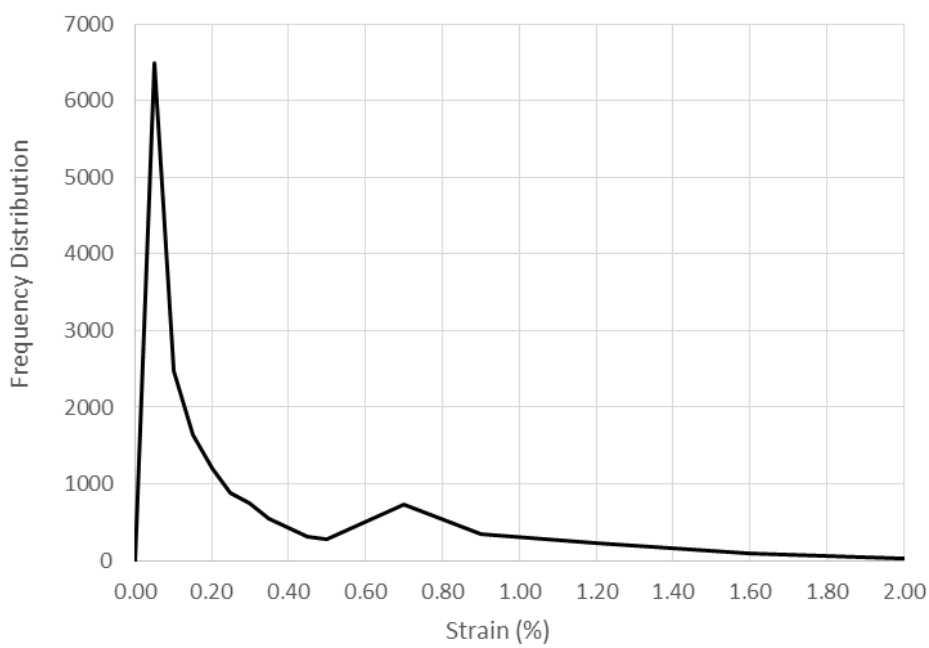

Figure 16. Frequency Distribution of Strain for Over-liner Design Slope at 5%

The cumulative distribution graph of the post-settlement strain in the over-liner system was also plotted and is presented below in Figure 17. The maximum uniaxial strain in the over-liner system was calculated as 2%.

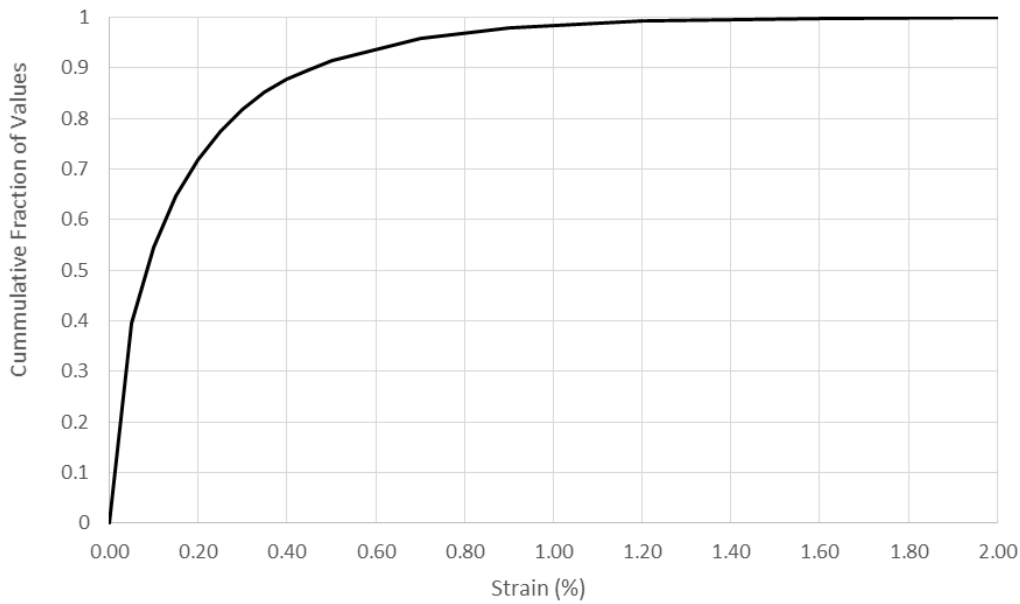

Figure 17. Cumulative Distribution Graph of Strain for Over-liner Design Slope at 5%

Scenario 3: Deterministic analysis of over-liner on existing waste subgrade

The analyses for Scenario 3A were performed to verify acceptable performance of the selected design slope, after the design slopes were established by Scenarios 4A and 4B. Scenario 3A analyses follow the methodology described in the previous section using the properties outlined in Table 2. The total settlement at each selected point of the design slope was calculated using the deterministic approach. Then, the differential settlement was evaluated by comparing the post-settlement slopes between the points. Figures 18 and 19 show the pre-settlement and post-settlement profiles generated for Scenario 3A (N-S) and 3A (E-W), respectively.

For Scenarios 3A (N-S) and 3A (E-W), the 5.0% design slope for the over-liner yields a post-settlement slope of at least 3.2% in the E-W direction and 2.5% in the N-S direction. This exceeds the minimum design value of 2.0%, required per Part 115 Rules. Since the N-S profile meets the minimum required slope of 2%, it was established that the design slope of 5% exceeds the minimum required post-settlement slope of 1% for the leachate collection pipe flowline.

CALCULATION SHEET

Client:	Republic Services	Project No. :	2168070020		
Project:	OCFL Over-liner Design	Calculated By:	RR-MK-AS	Date:	4/11/2016
Calculation:	Over-liner Settlement Analyses	Checked By:	KCF	Date:	4/11/2016
		Approved By:		Date:	

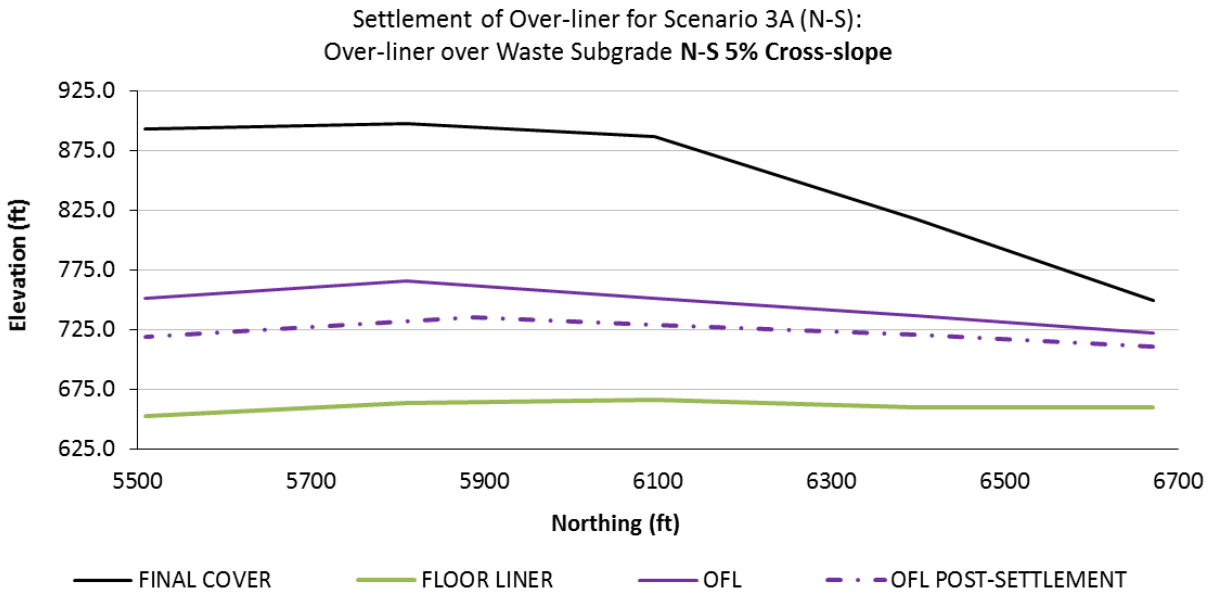

Figure 18. Pre-settlement and post-settlement over-liner profiles corresponding to Scenario 3A (N-S)

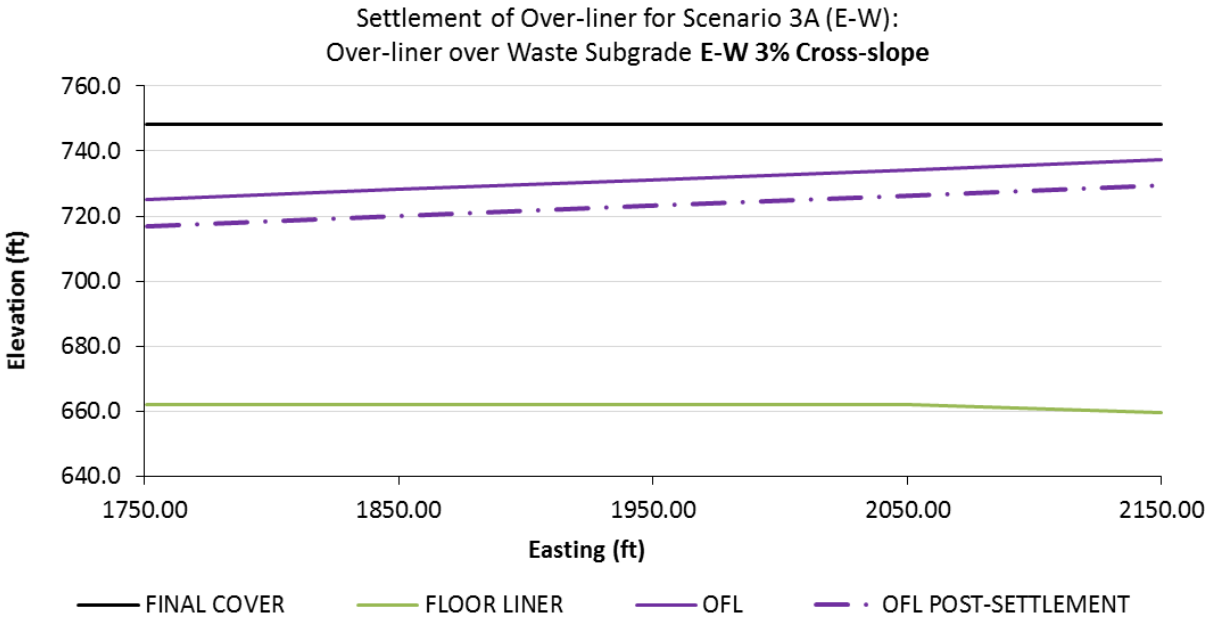

Figure 19. Pre-settlement and post-settlement over-liner profiles corresponding to Scenario 3A (E-W)

CONCLUSIONS

- The traditional, deterministic method for calculating differential settlement does not account for subgrade variability and therefore under-predicts differential settlement. The post-settlement profiles from Scenarios 2 and 4 clearly depict the subgrade variability modeled by the probabilistic approach to settlement analysis.

- The probabilistic method allows a quantitative assessment of the likelihood of post-settlement liner slopes smaller than 2.0%, 1.0% or 0%. This likelihood is expressed using cumulative distribution graphs or distribution tables illustrating the distribution of post-settlement slopes for all modeled over-liner and cell floor liner segments.

- Scenario 2A of the settlement analyses utilized a probabilistic approach to analyze an existing cell floor design on a clay subgrade at OCFL. The resulting distribution of modeled slope segments with slopes less than 2.0% and 0.0% were taken as the probabilistic design criterion for the over-liner cross-slope design (Scenario 4A). Similarly, Scenario 2B analyzed the existing leachate collection pipe flowline for the same cell at OCFL and the resulting distribution was adopted as the design criteria for Scenario 4B.

- Based on the results tabulated in Tables 4 and 6, and illustrated in Figures 14 and 15, a minimum N-S cross-slope design slope of 5%, a minimum E-W cross-slope design slope of 3% and a minimum N-S leachate collection pipe flowline slope of 5% will result in fewer segments with slopes shallower than the minimum required slopes, compared to the approved cell floor liner design. The results confirm that the proposed design is at least as conservative as the approved design at the site.

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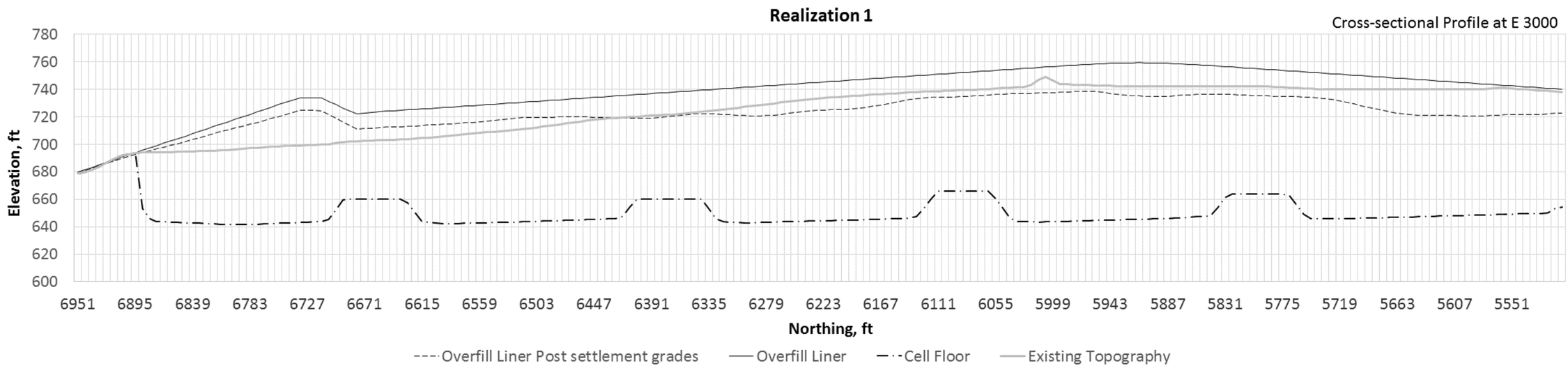
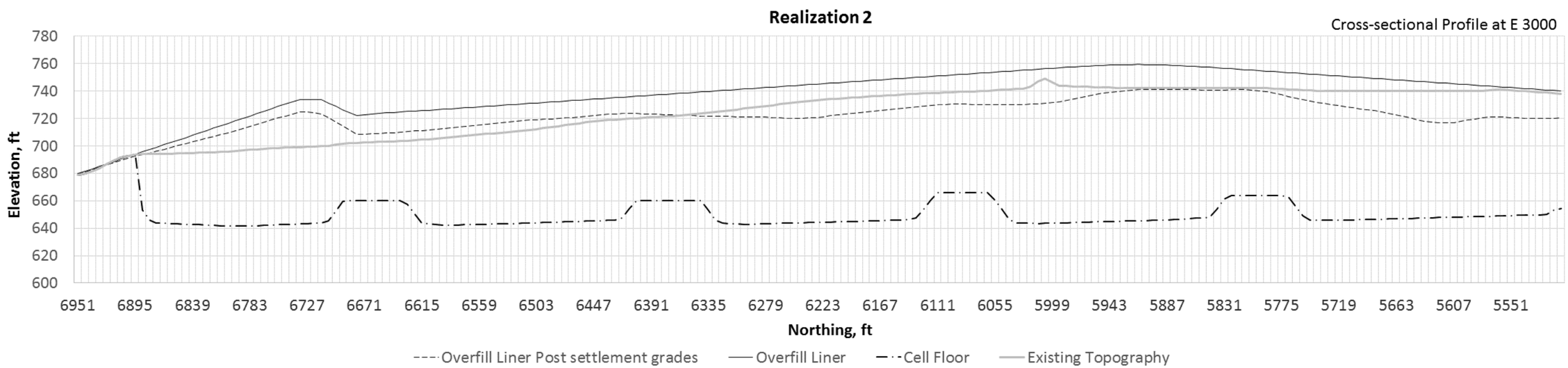
APPENDIX

REALIZATIONS FROM OVER-LINER SETTLEMENT ANALYSES: SCENARIO 4A (N-S) 5% DESIGN SLOPE


Realization 1
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography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Cross-sectional Profile at E 3000
Elevation, ft
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760
740
720
700
680
660
640
620
600
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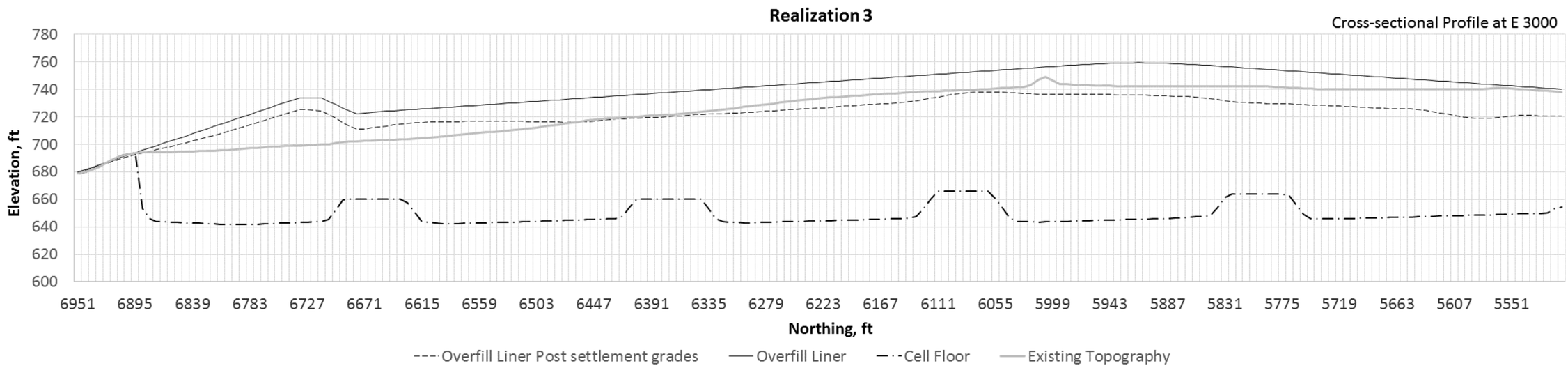
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography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Elevation, ft
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760
740
720
700
680
660
640
620
600
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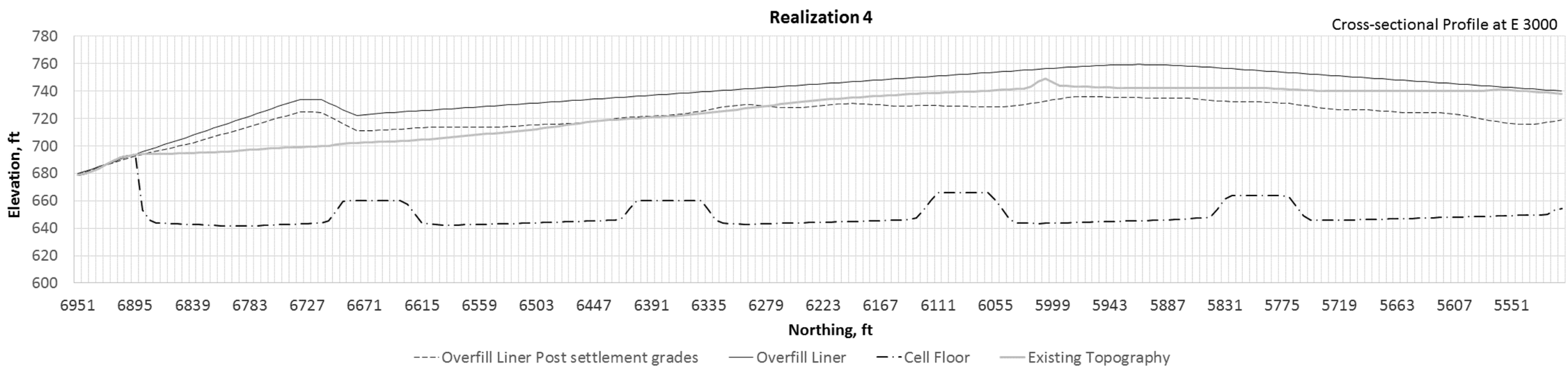
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 4
Cross-sectional Profile at E 3000
Elevation, ft
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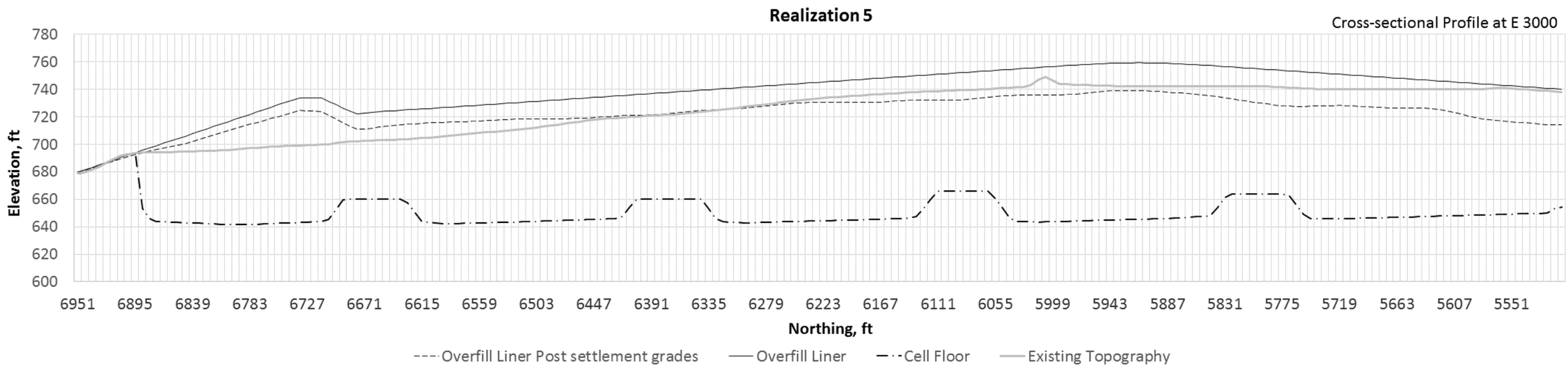
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 5
Cross-sectional Profile at E 3000
Elevation, ft
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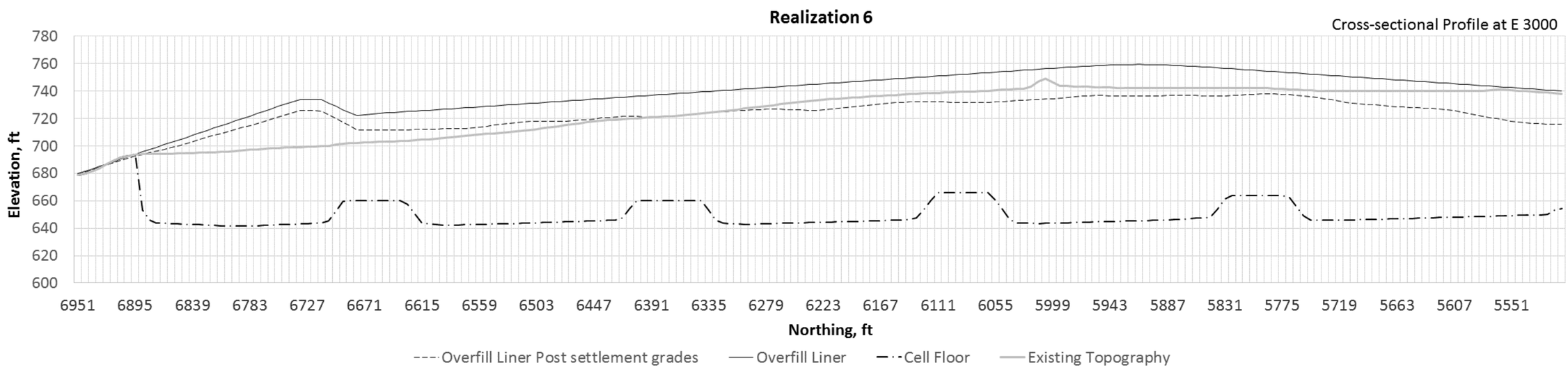
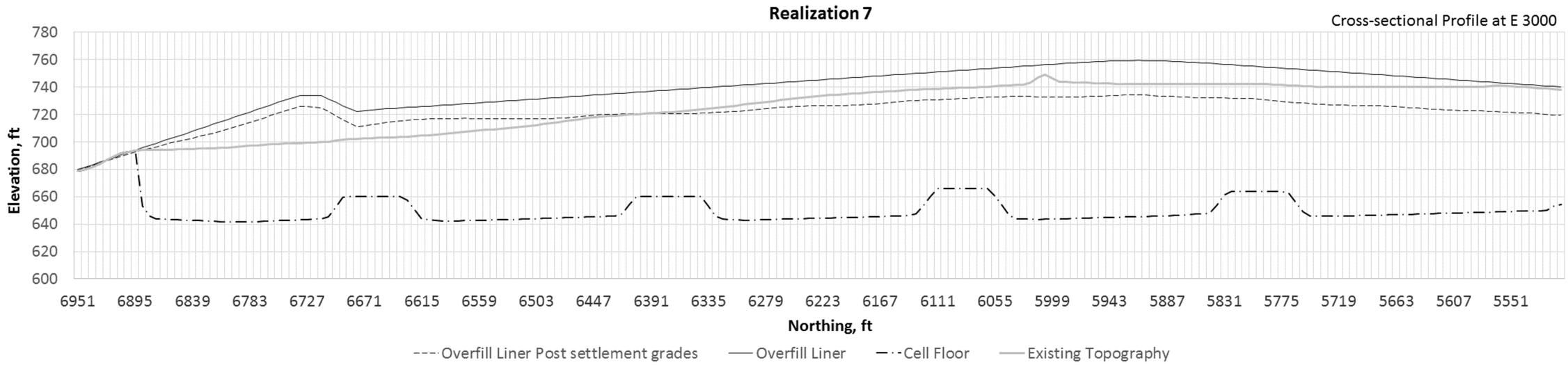
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 6
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography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Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
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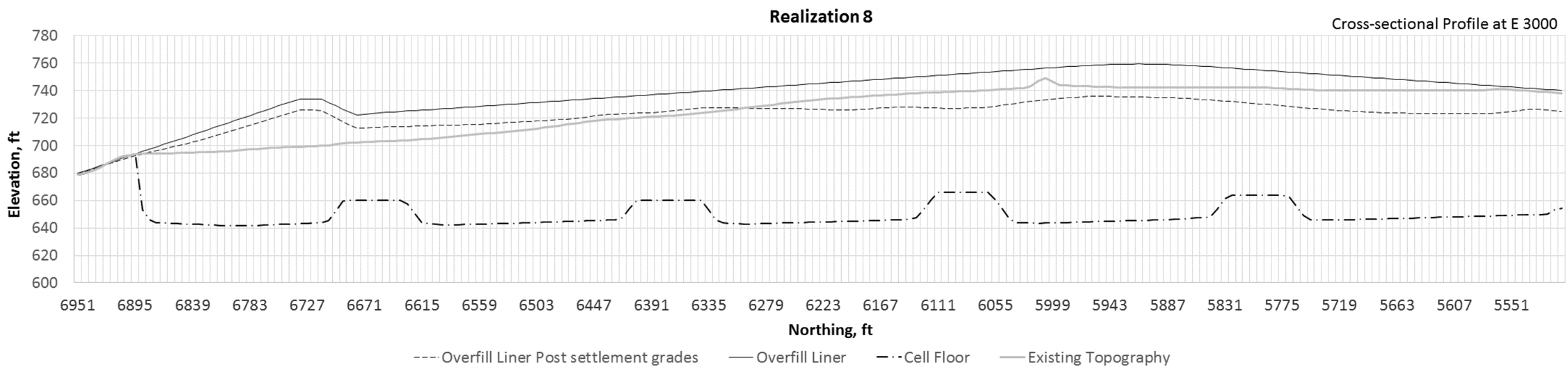
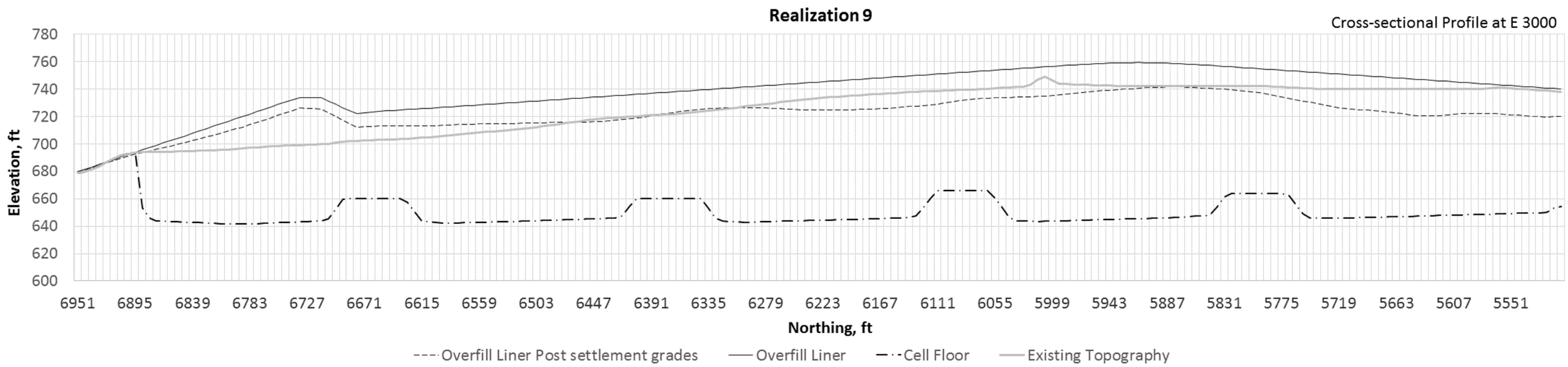
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 8
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography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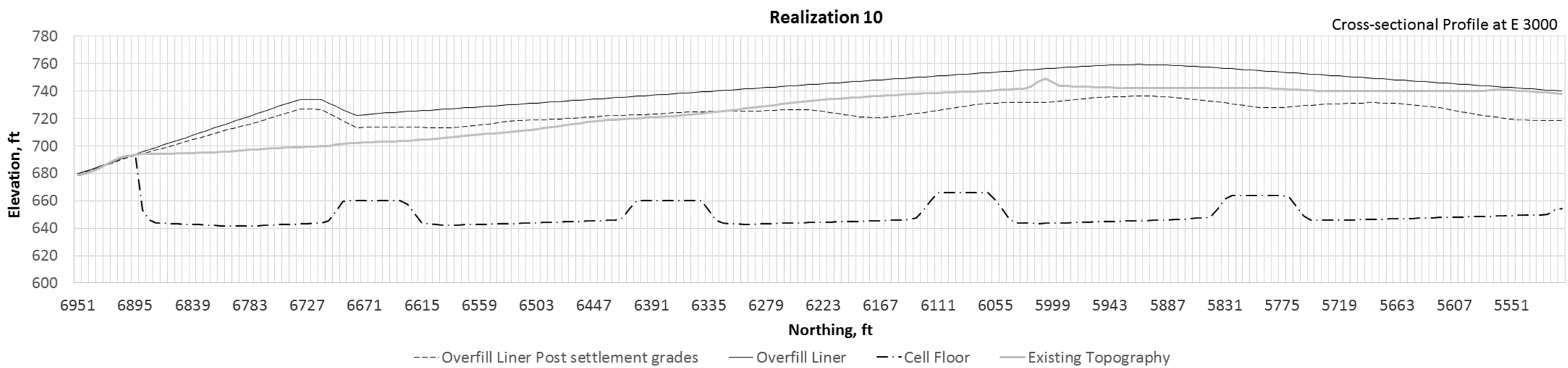
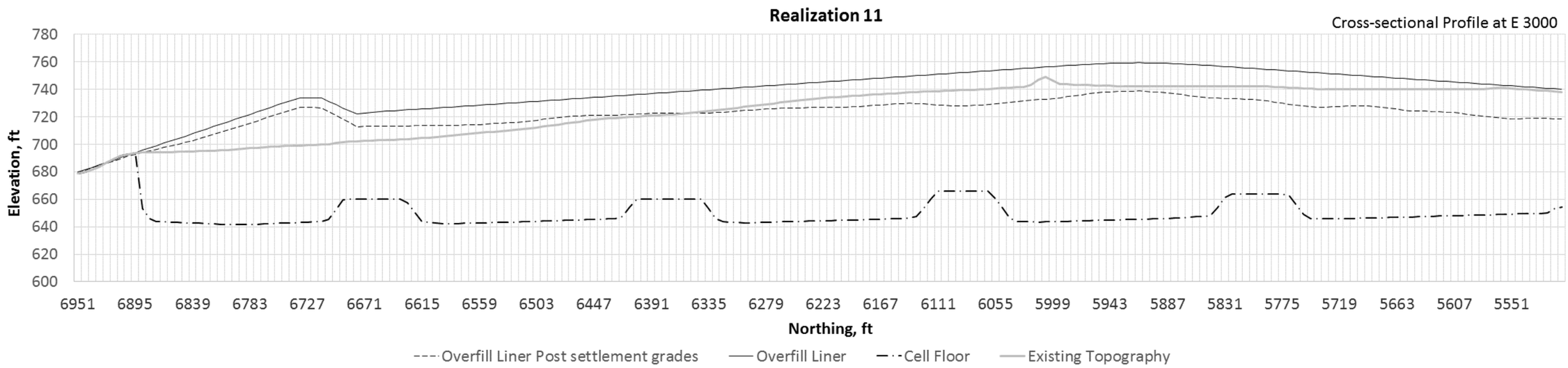
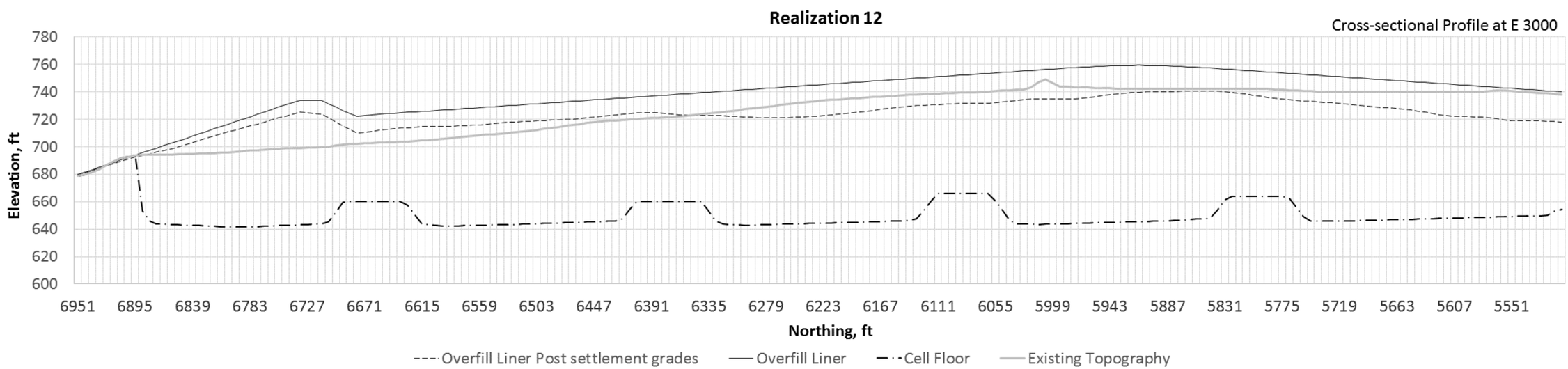
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 10
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 11
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography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Cross-sectional Profile at E 3000
Elevation, ft
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640
620
600
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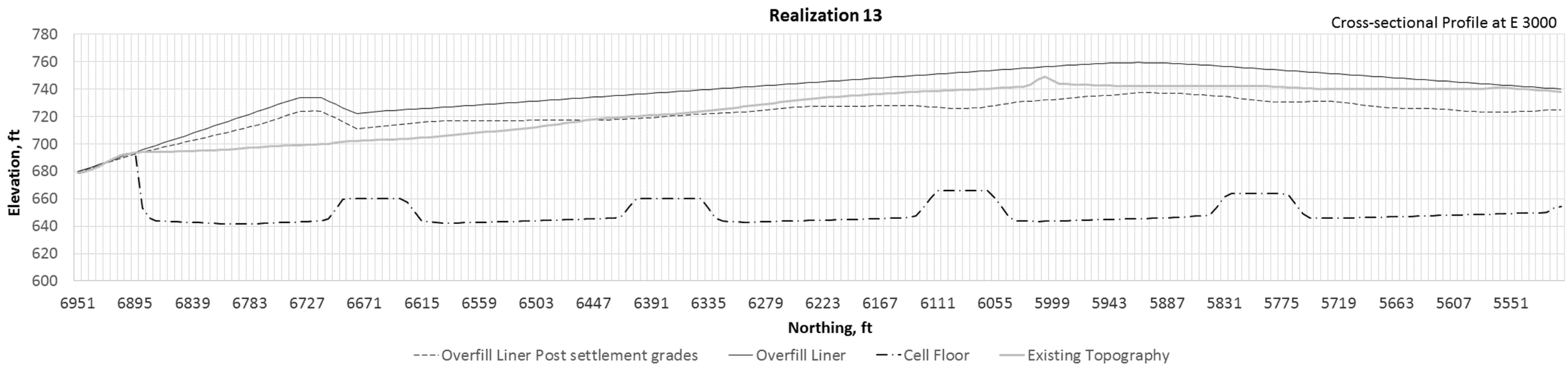
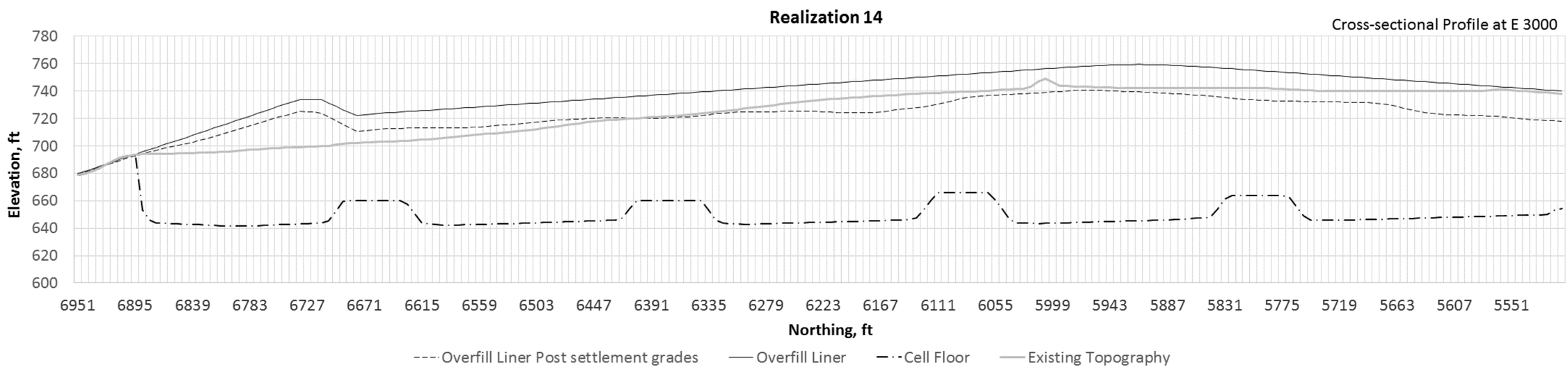
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 13
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 14
Cross-sectional Profile at E 3000
Elevation, ft
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700
680
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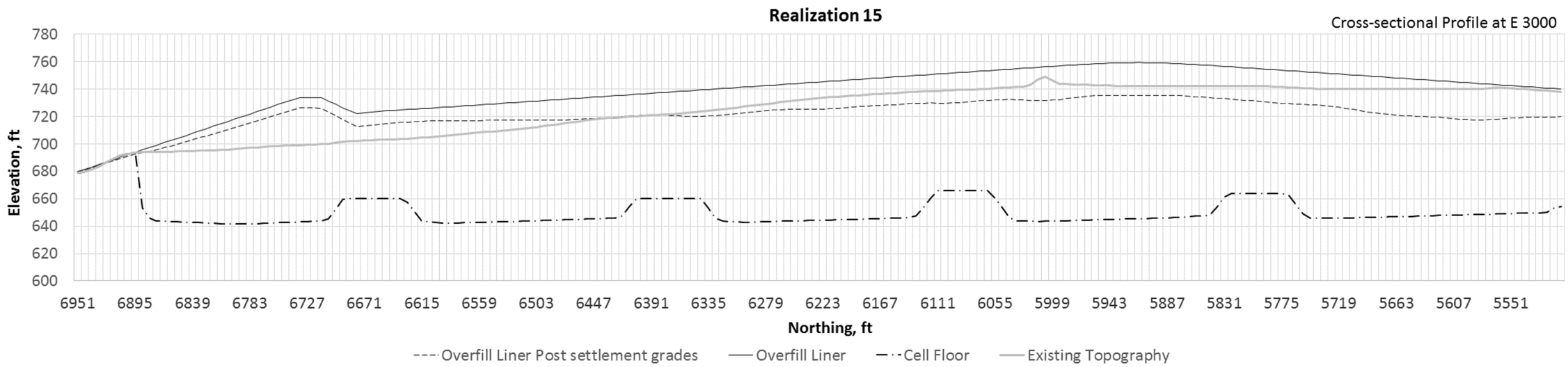
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography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Cross-sectional Profile at E 3000
Elevation, ft
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720
700
680
660
640
620
600
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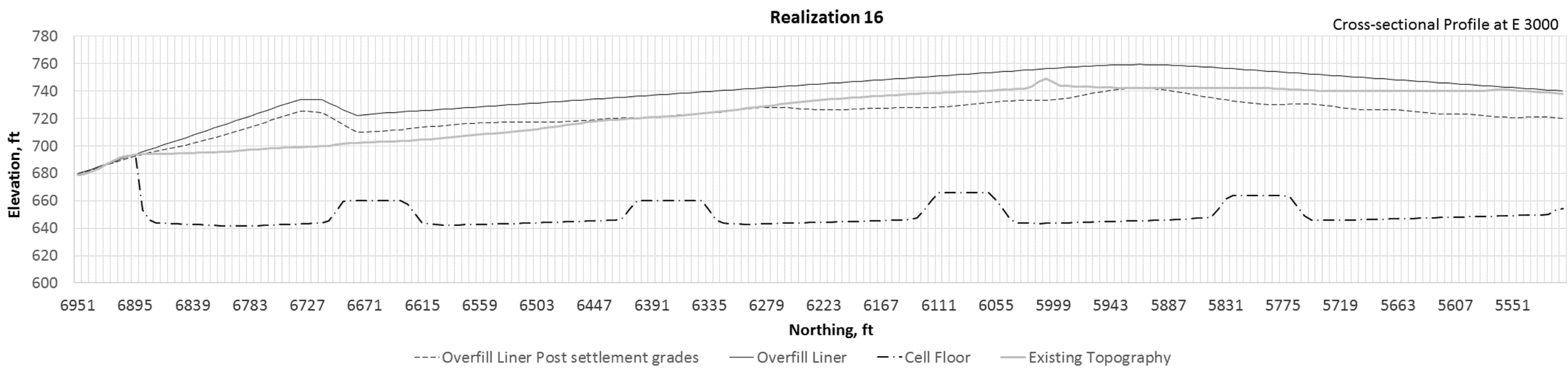
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 16
Cross-sectional Profile at E 3000
Elevation, ft
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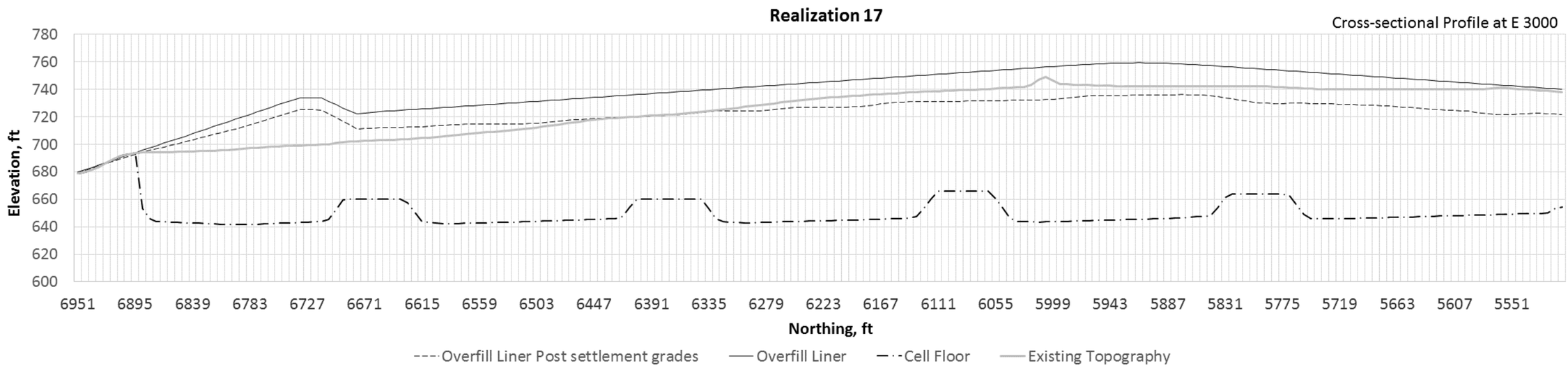
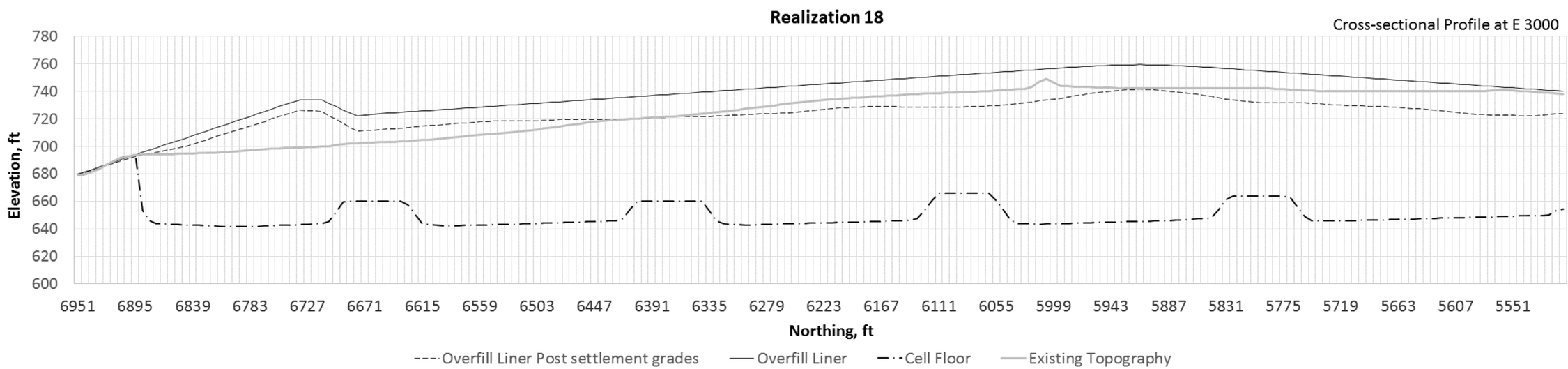
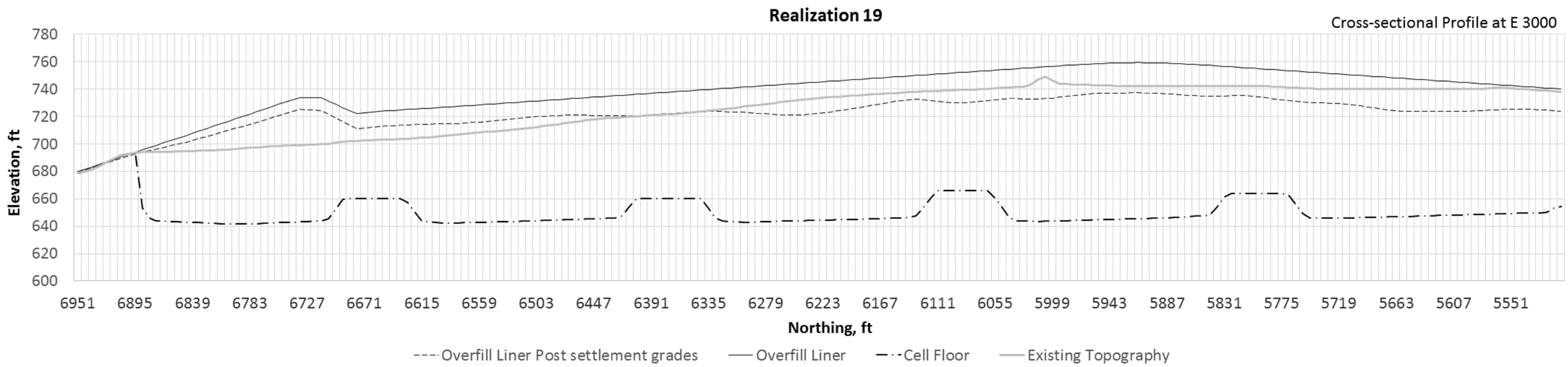
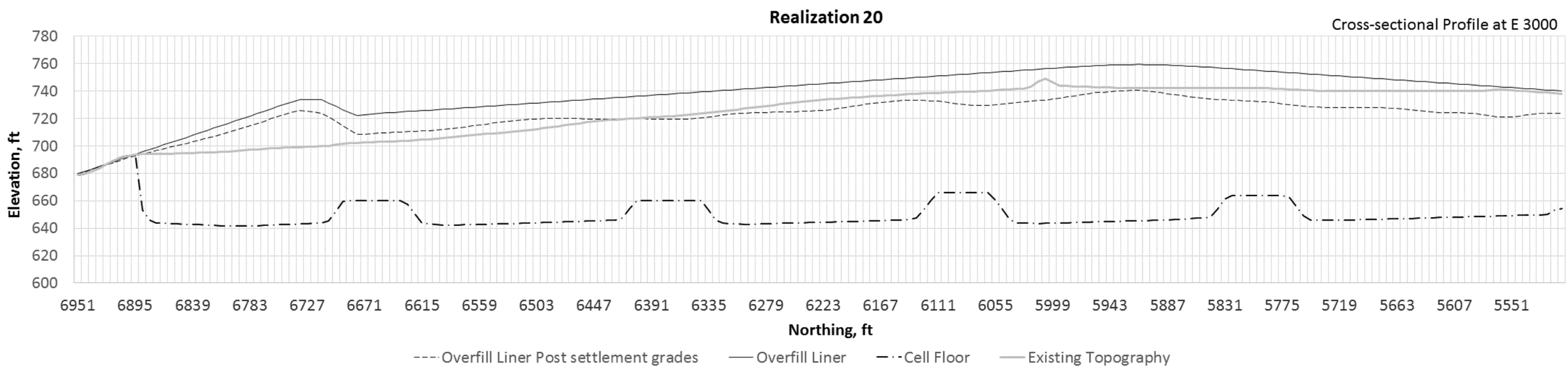
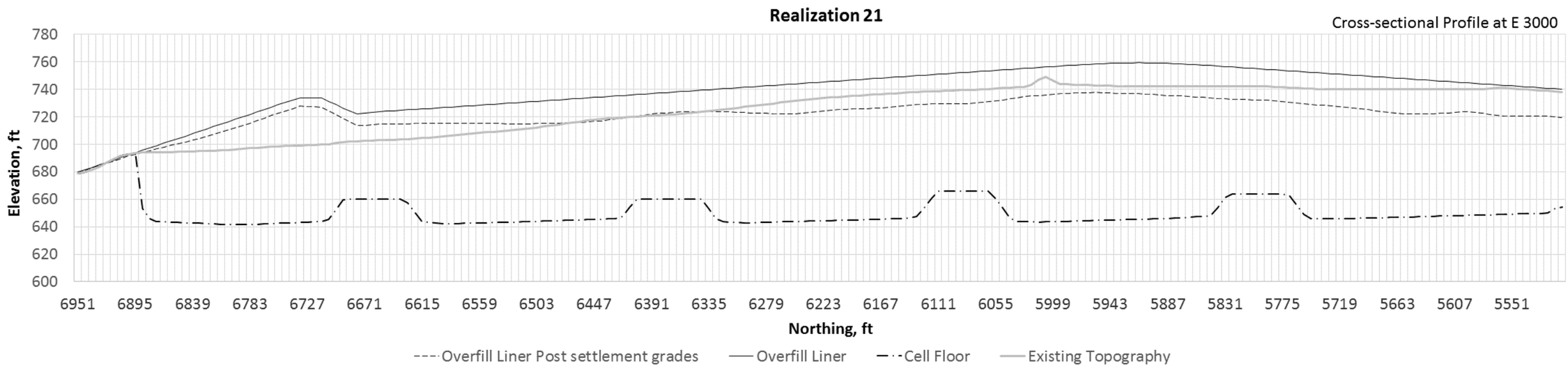
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

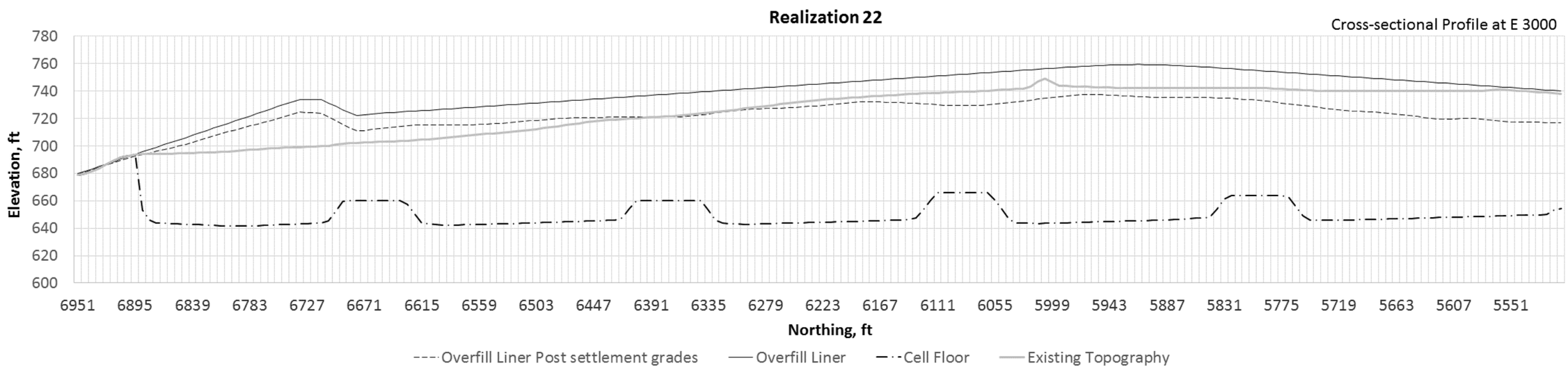

Realization 17
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

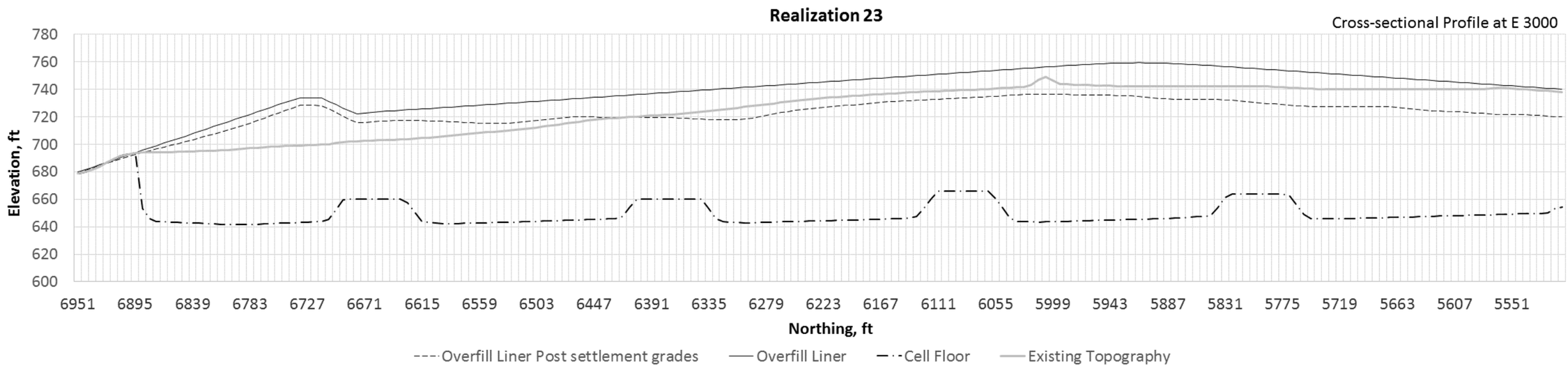

Realization 18
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

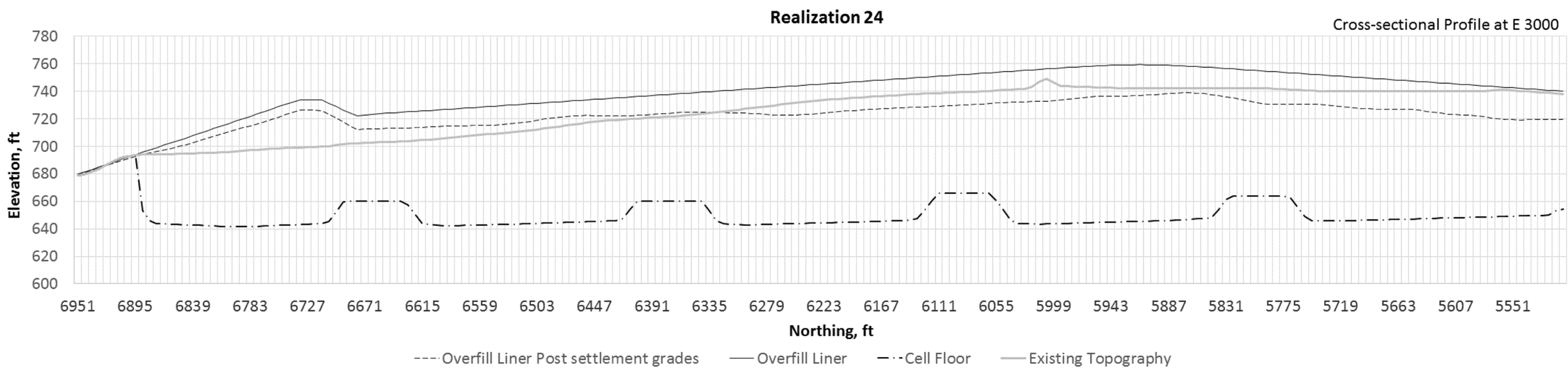

Realization 19
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

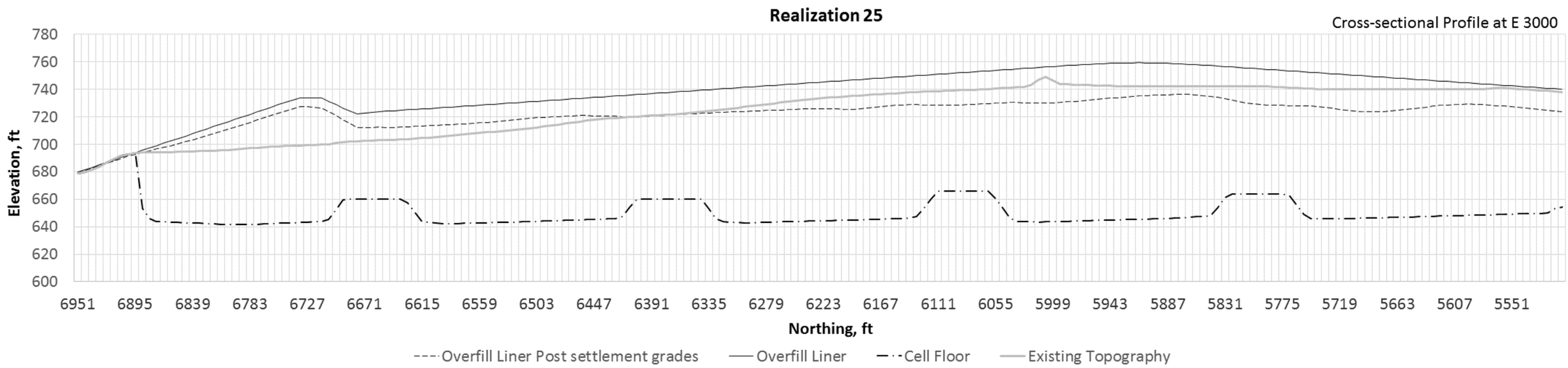

Realization 20
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

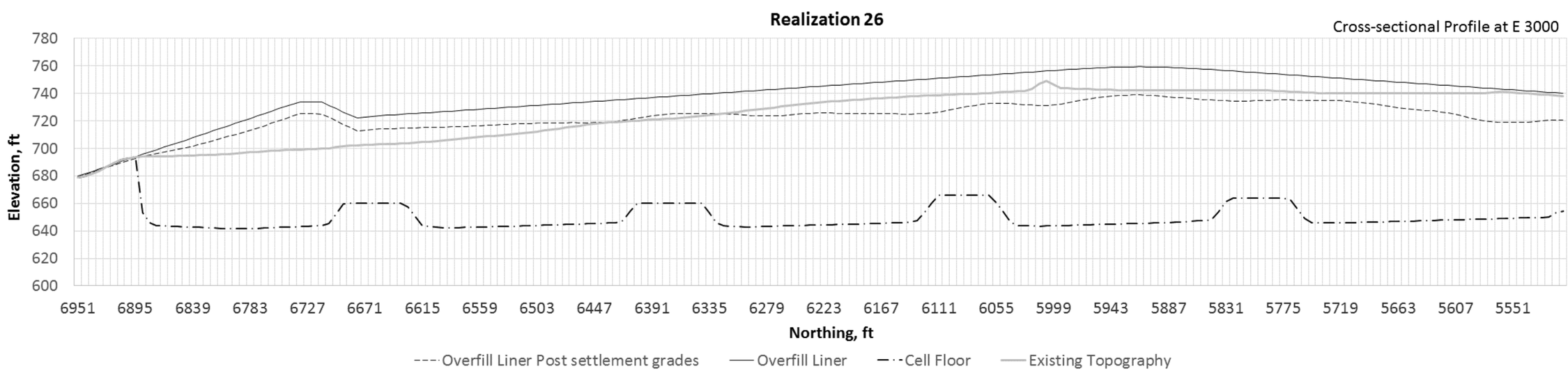

Realization 21
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

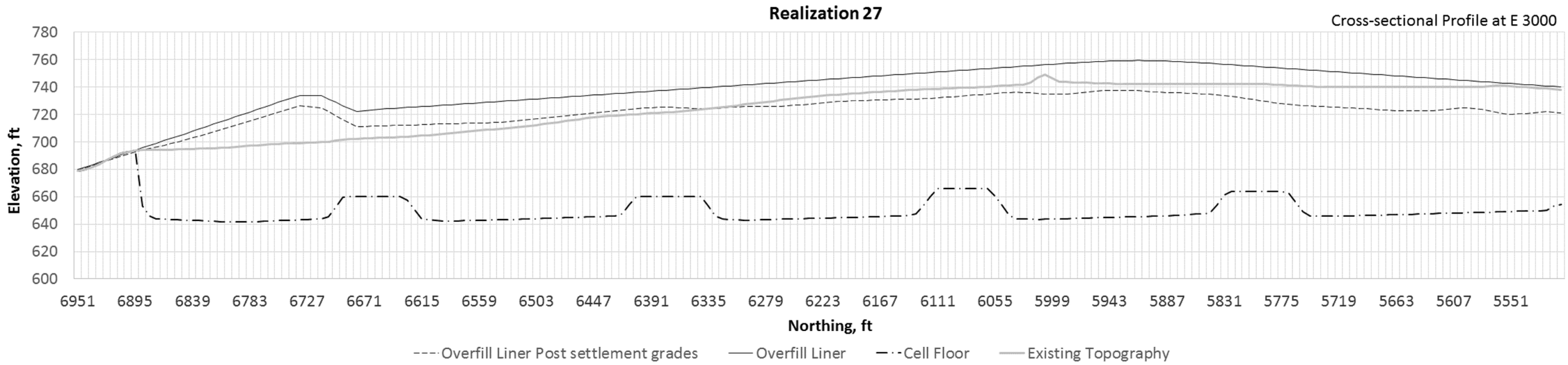

Realization 22
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

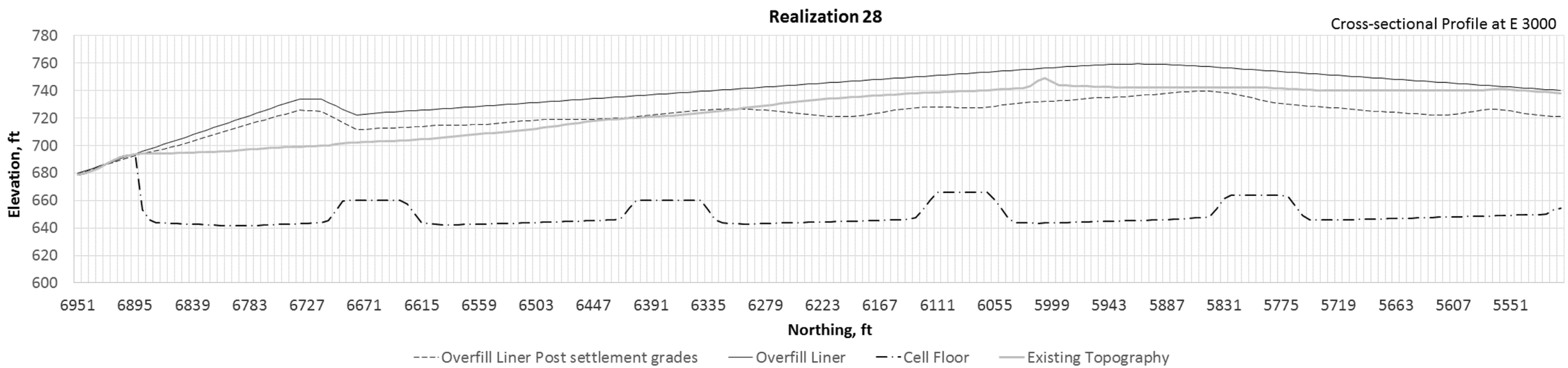

Realization 23
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

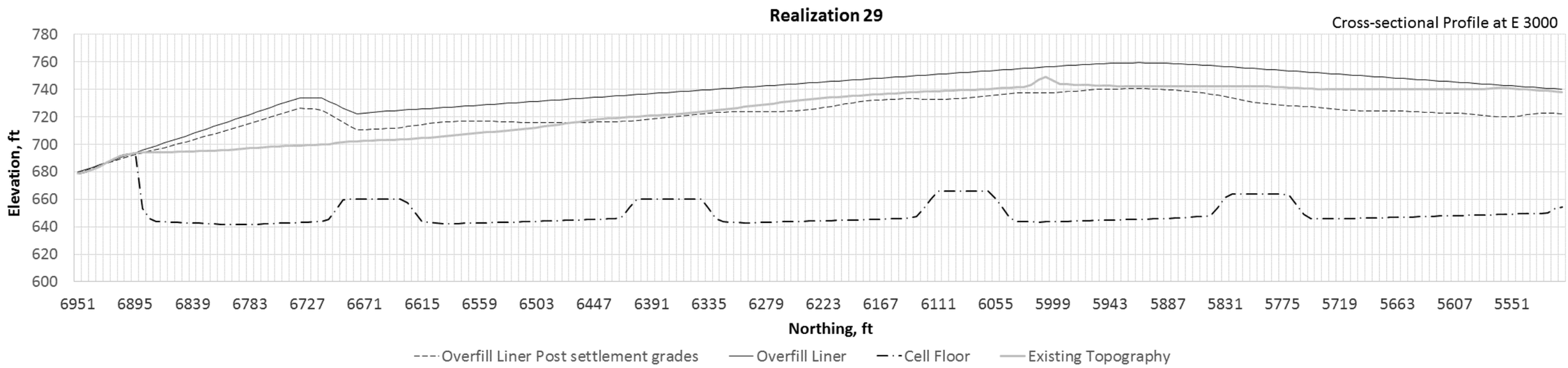

Realization 24
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

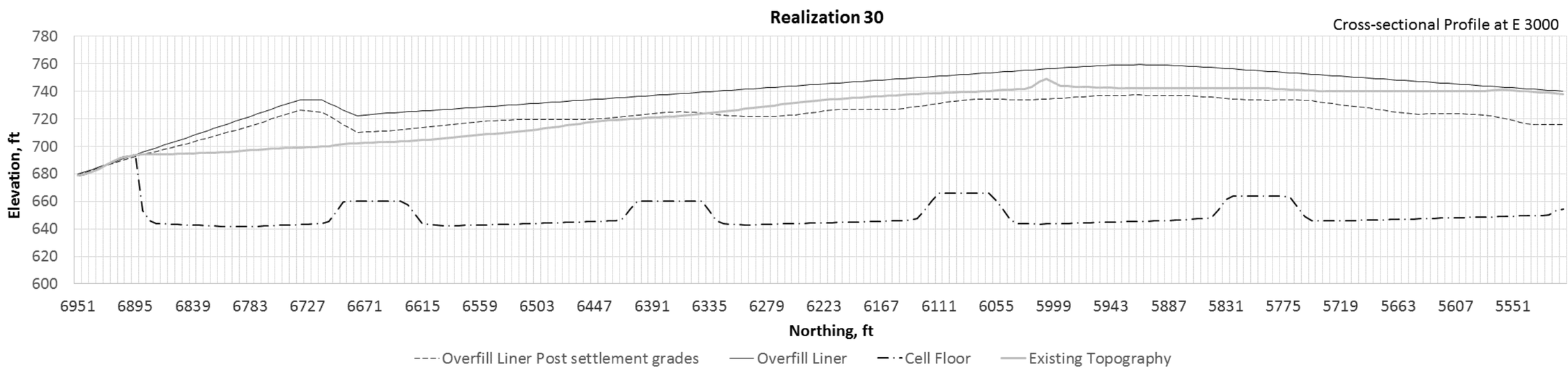

Realization 25
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

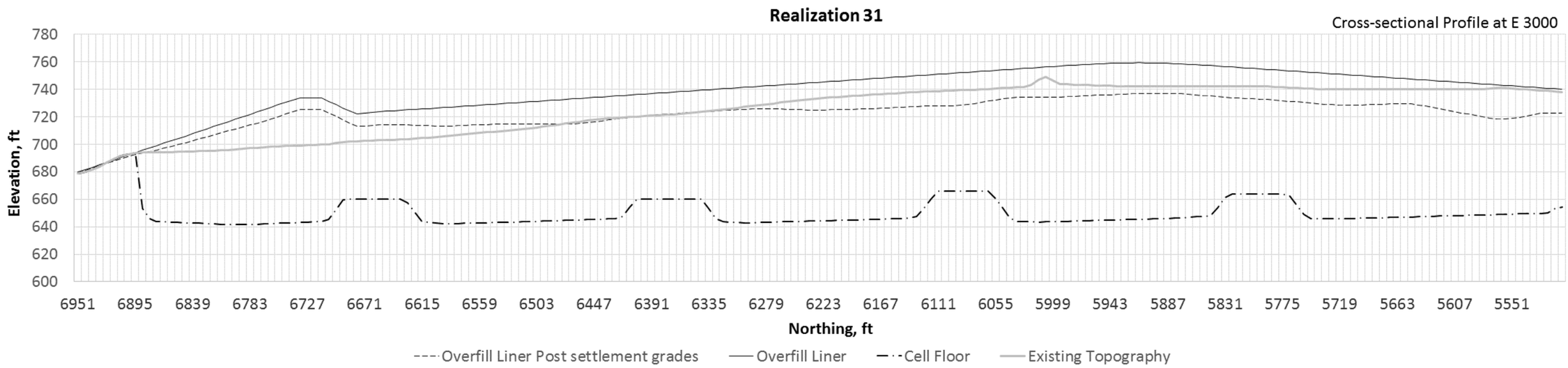

Realization 26
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

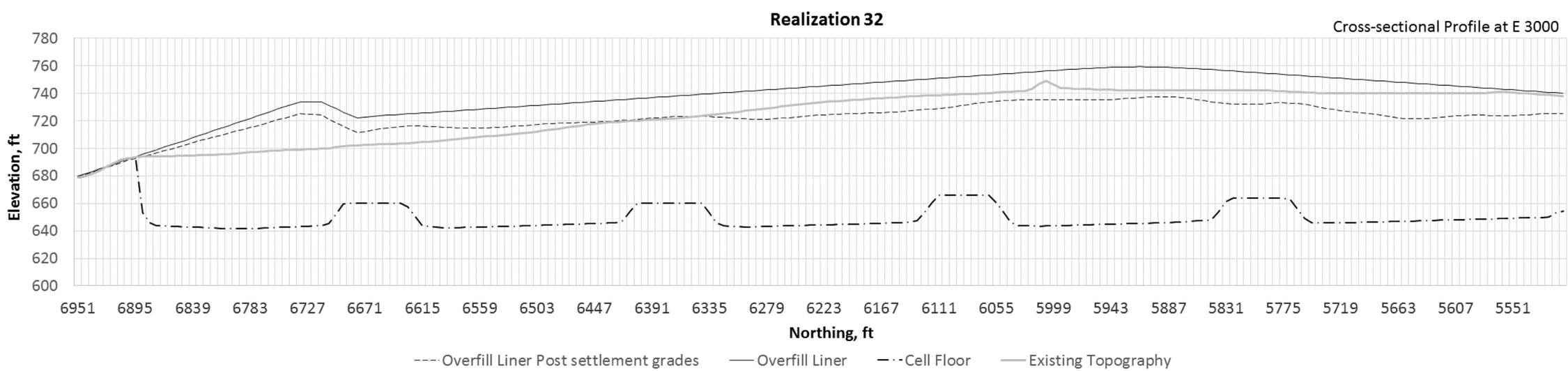

Realization 27
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

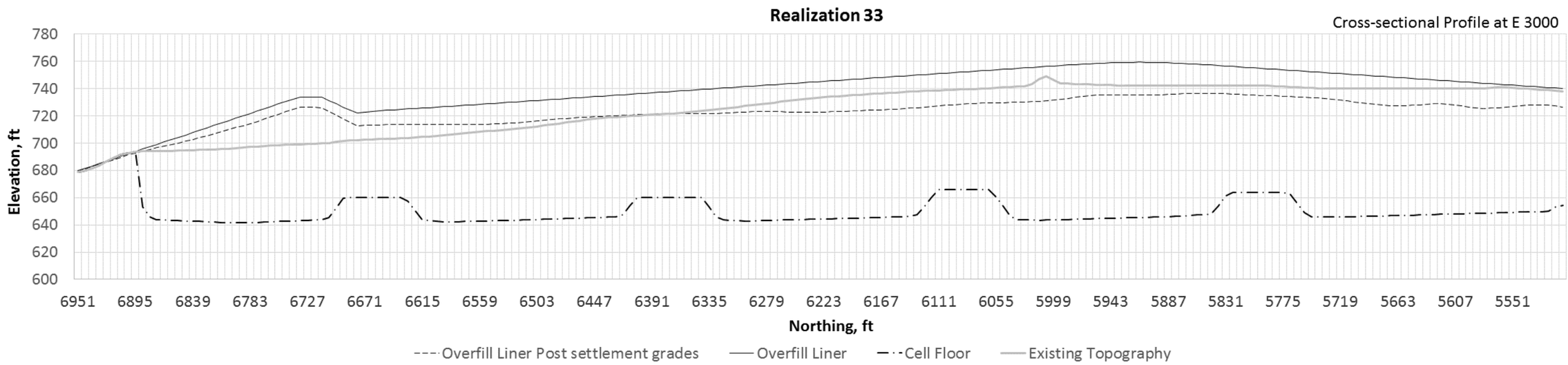

Realization 28
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

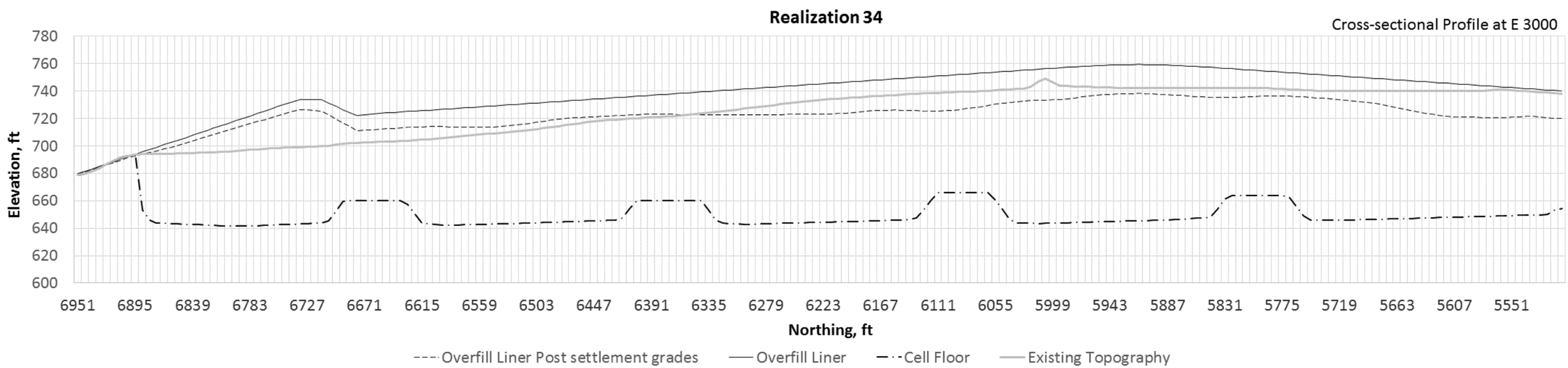

Realization 29
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

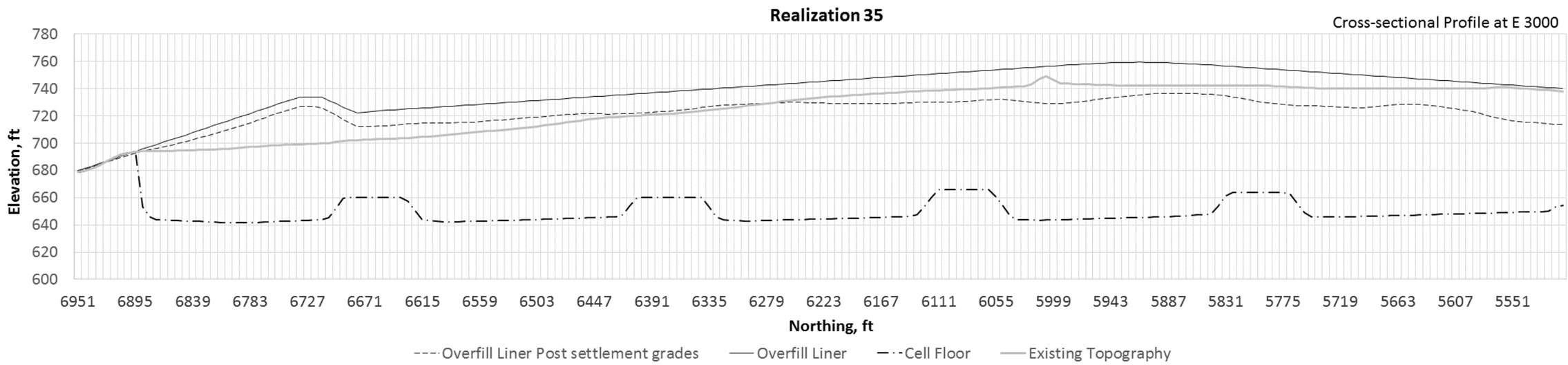

Realization 30
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

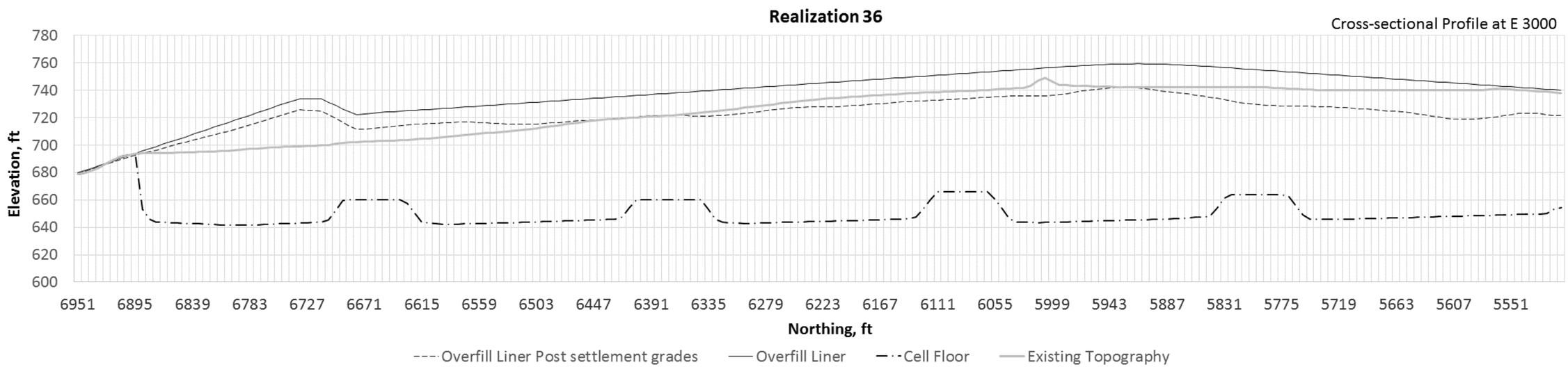

Realization 31
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

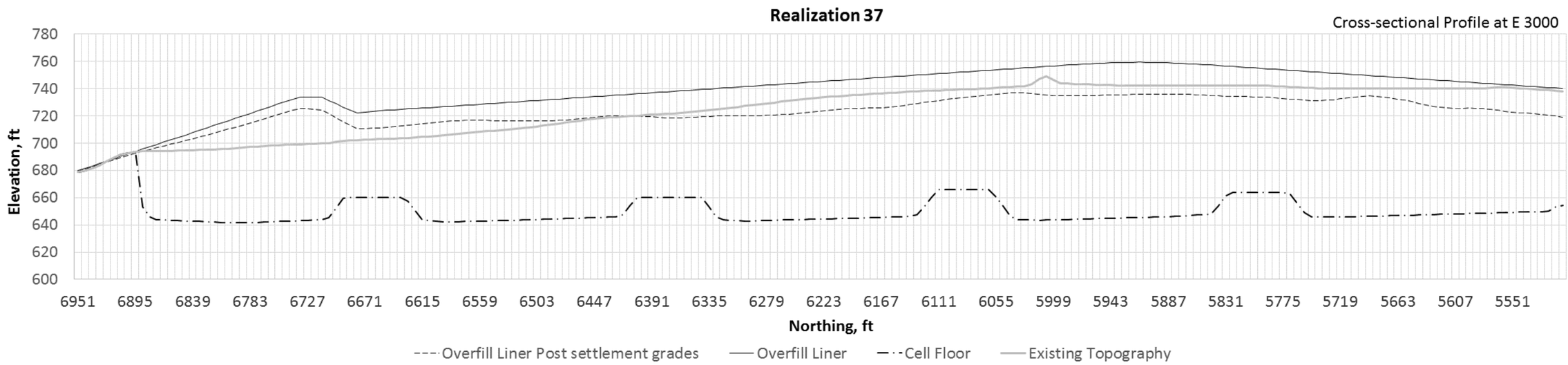

Realization 32
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

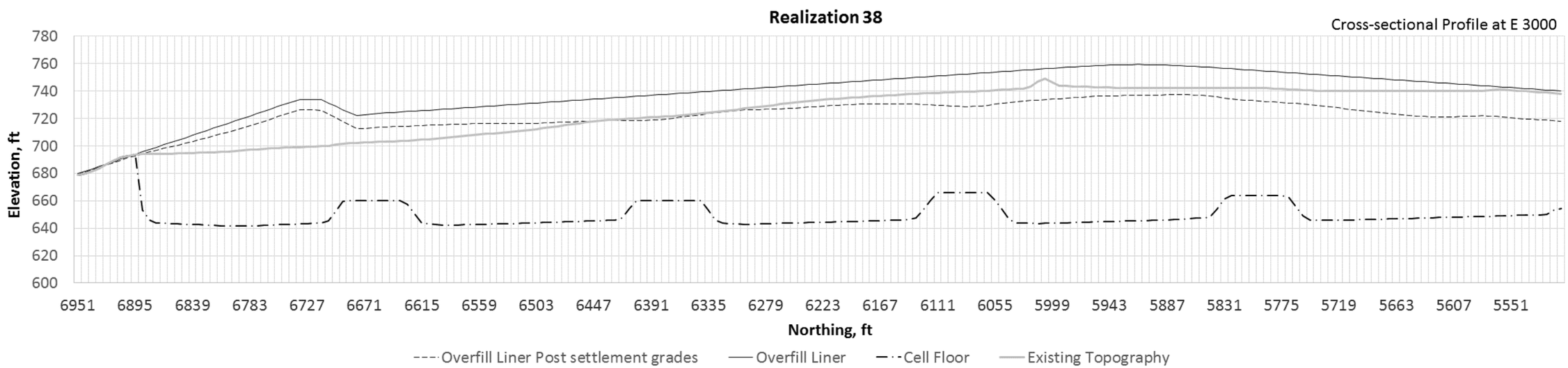

Realization 33
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

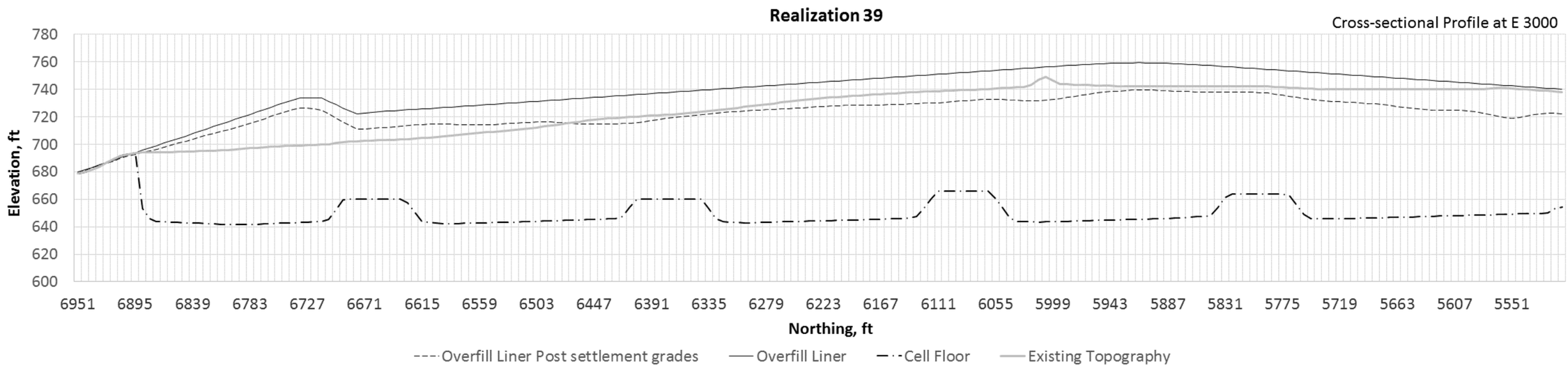

Realization 34
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

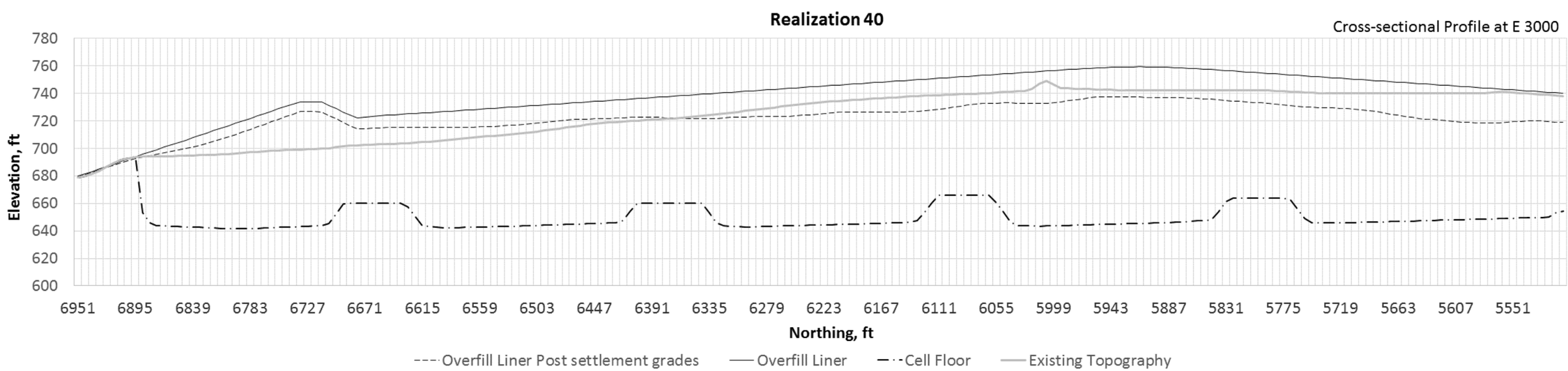

Realization 35
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

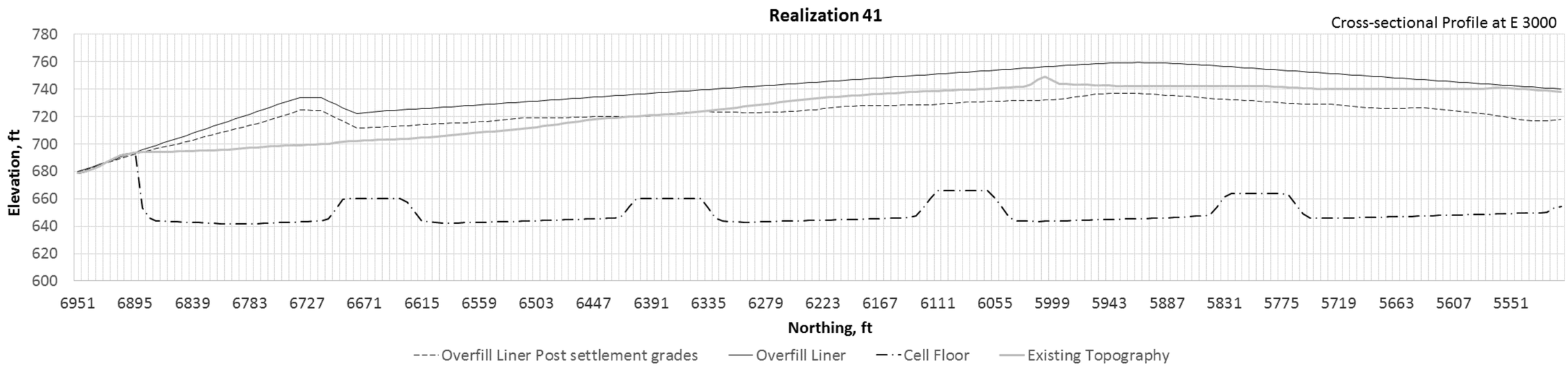

Realization 36
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

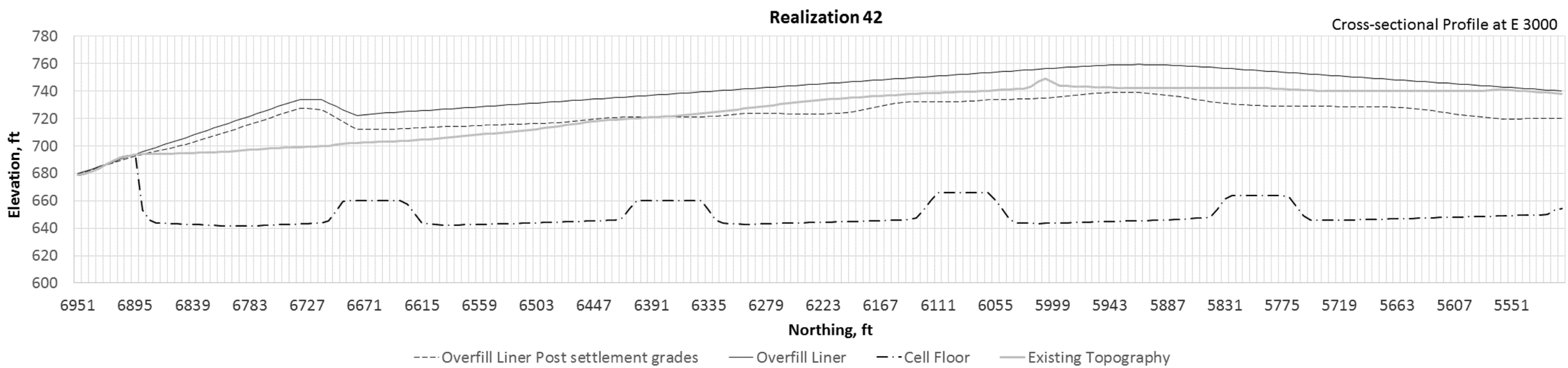

Realization 37
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

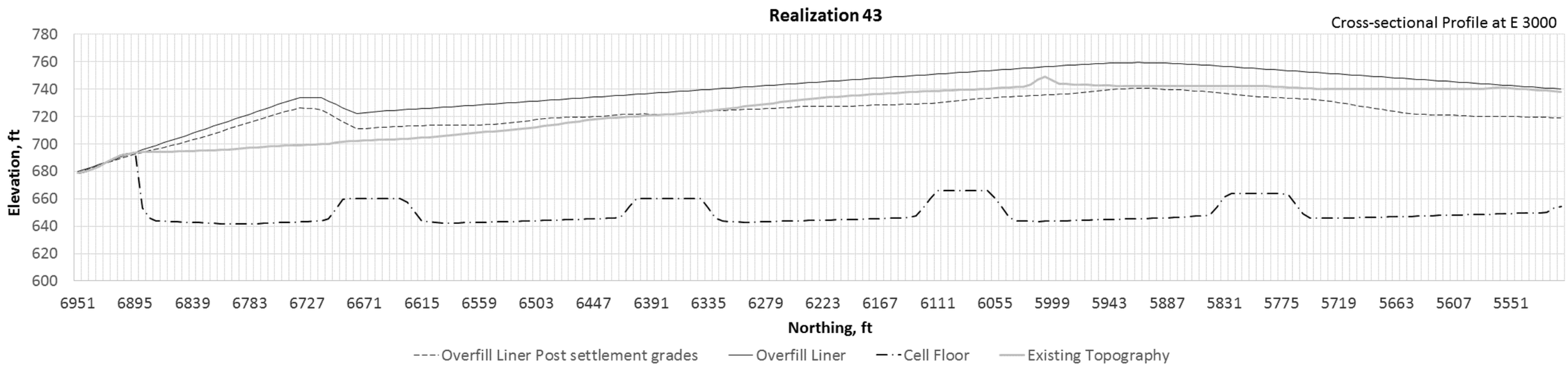

Realization 38
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

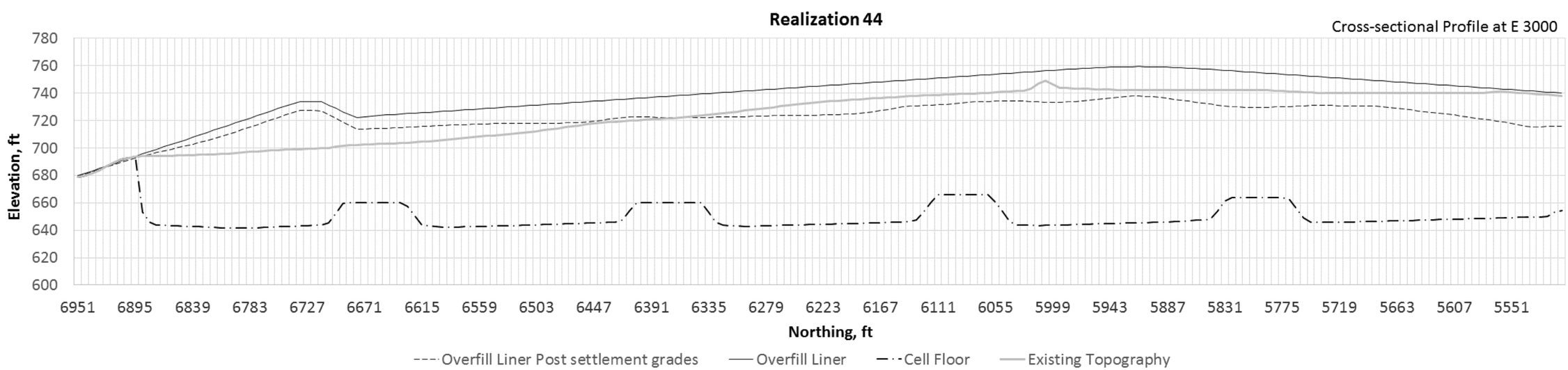

Realization 39
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

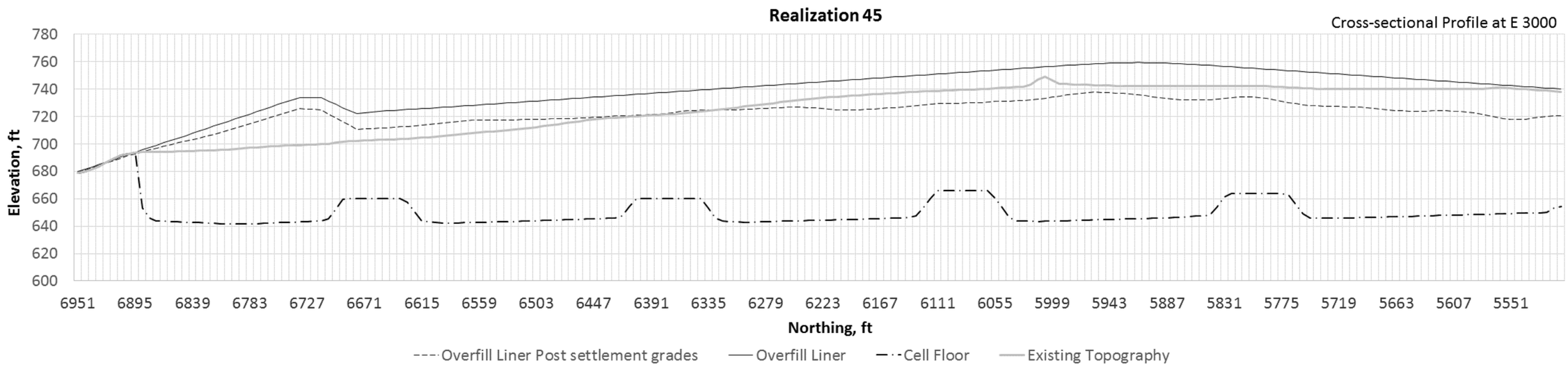

Realization 40
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

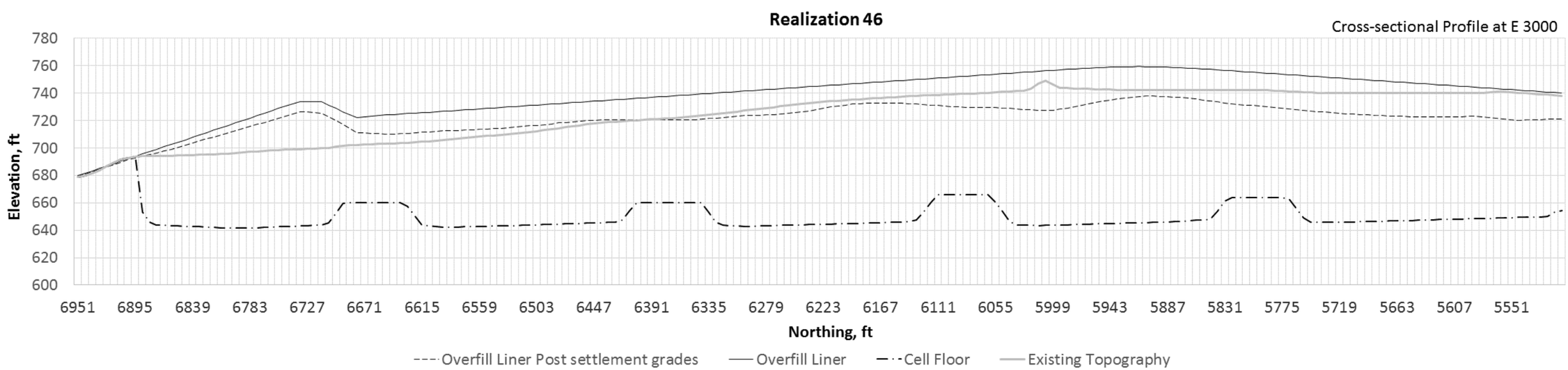

Realization 41
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

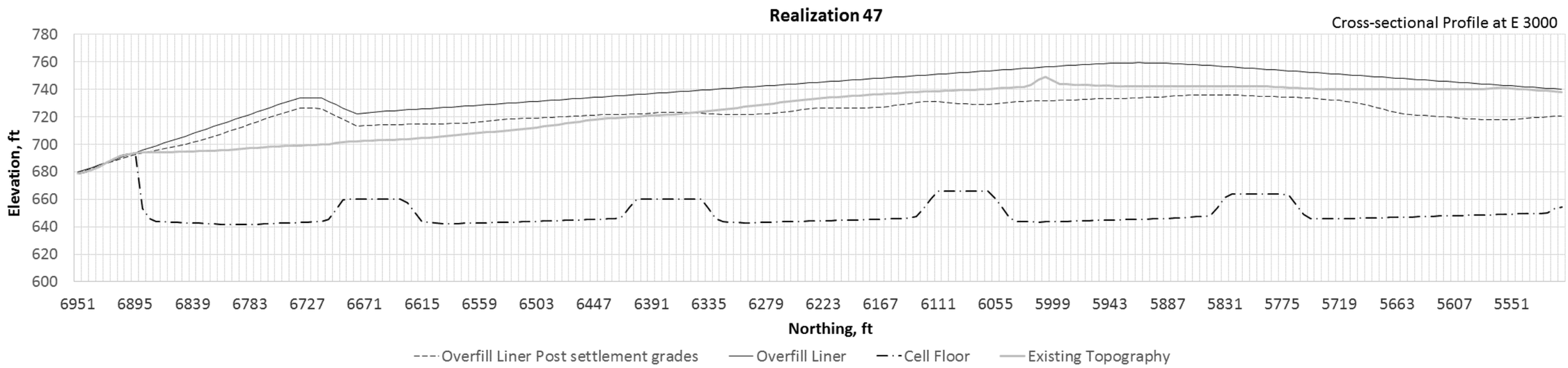

Realization 42
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

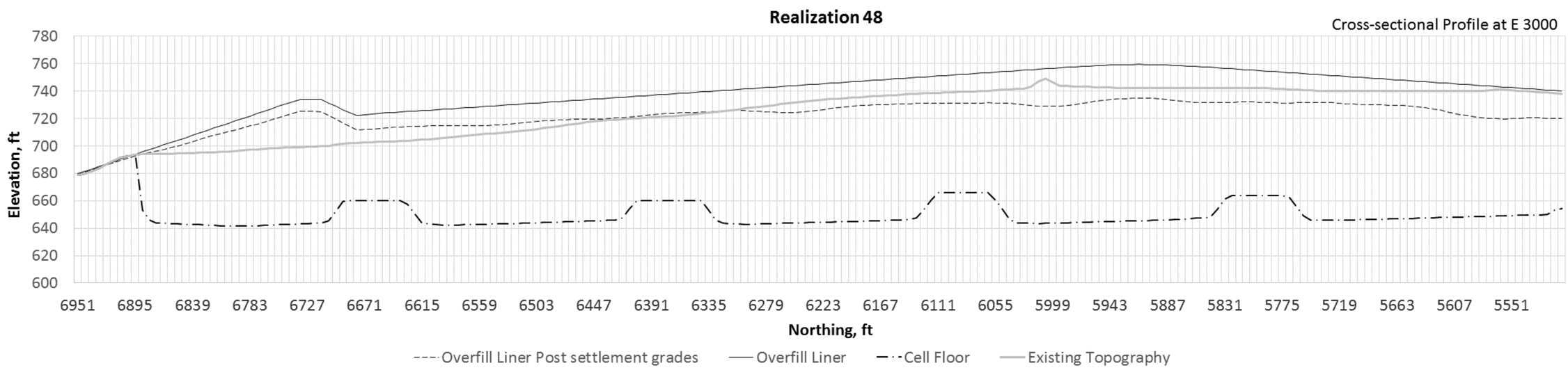

Realization 43
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

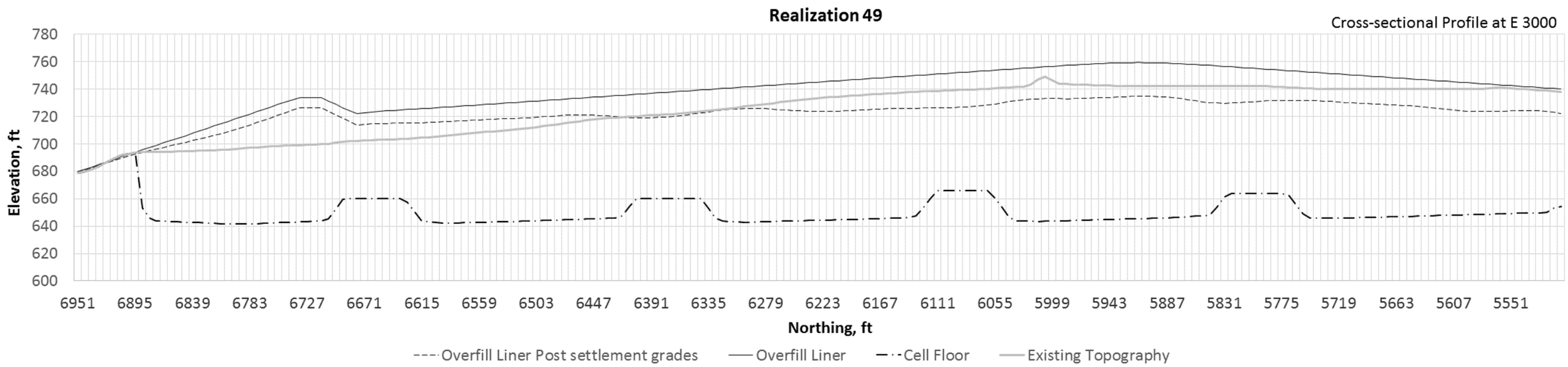

Realization 44
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

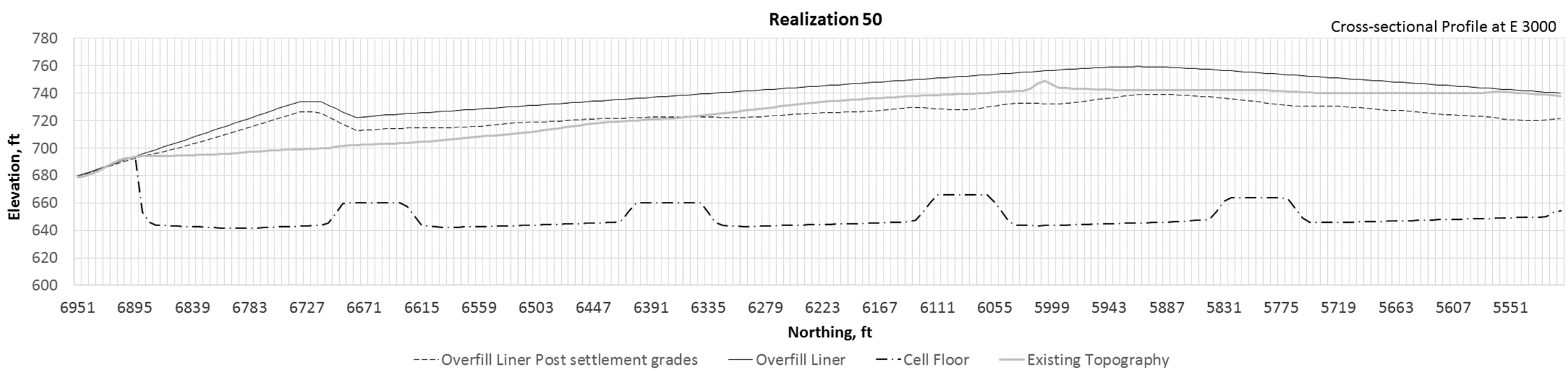

Realization 45
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

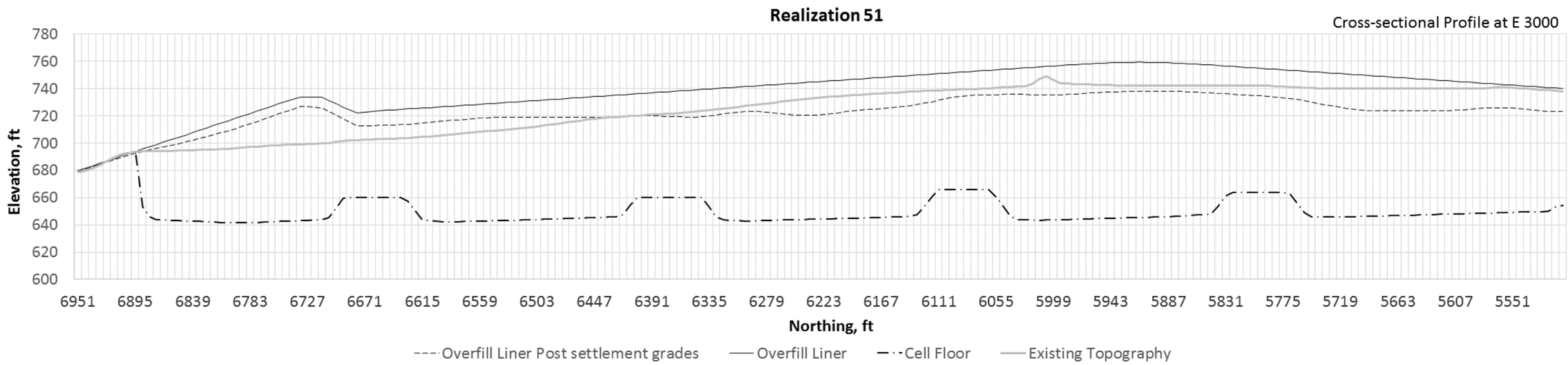

Realization 46
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

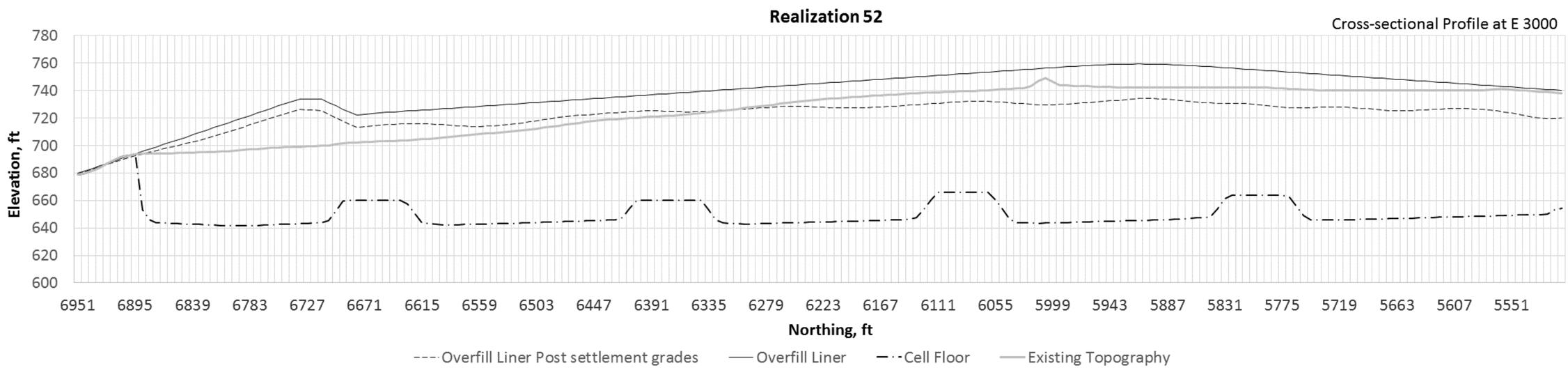

Realization 47
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography

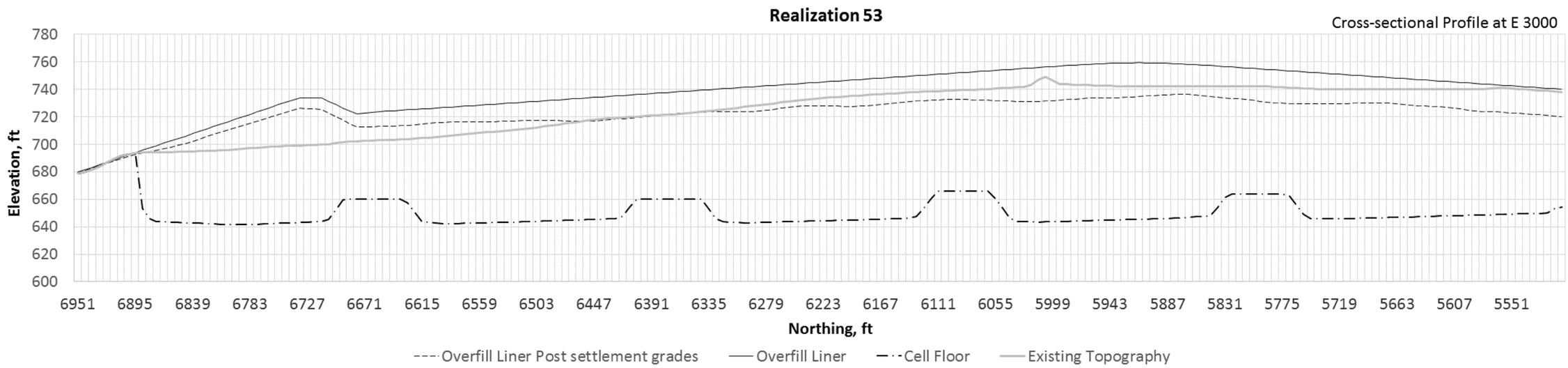

Realization 48
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 49
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 50
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 51
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 52
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
700
680
660
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 53
Cross-sectional Profile at E 3000
Elevation, ft
780
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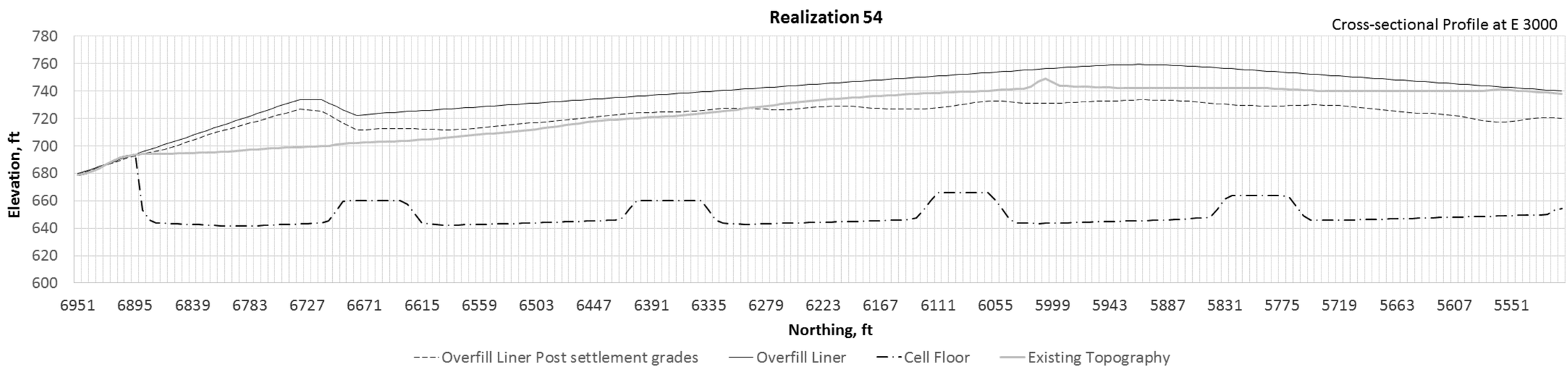
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 54
Cross-sectional Profile at E 3000
Elevation, ft
780
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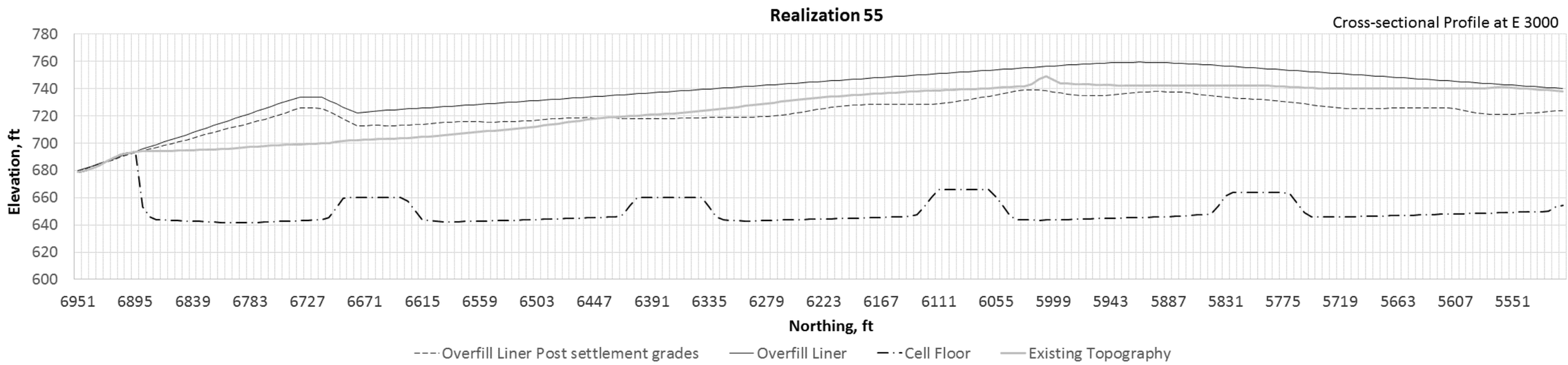
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 55
Cross-sectional Profile at E 3000
Elevation, ft
780
760
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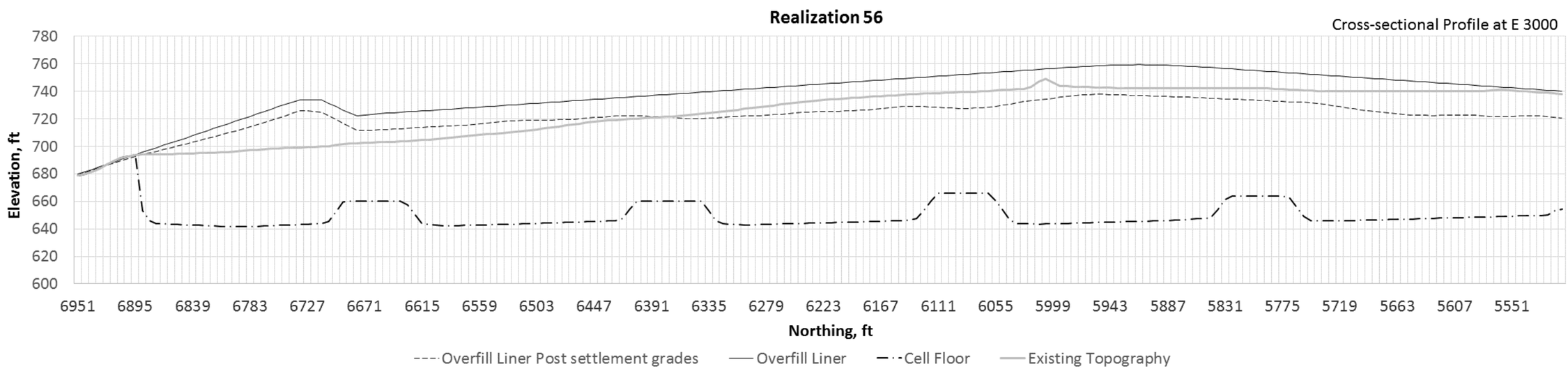
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 56
Cross-sectional Profile at E 3000
Elevation, ft
780
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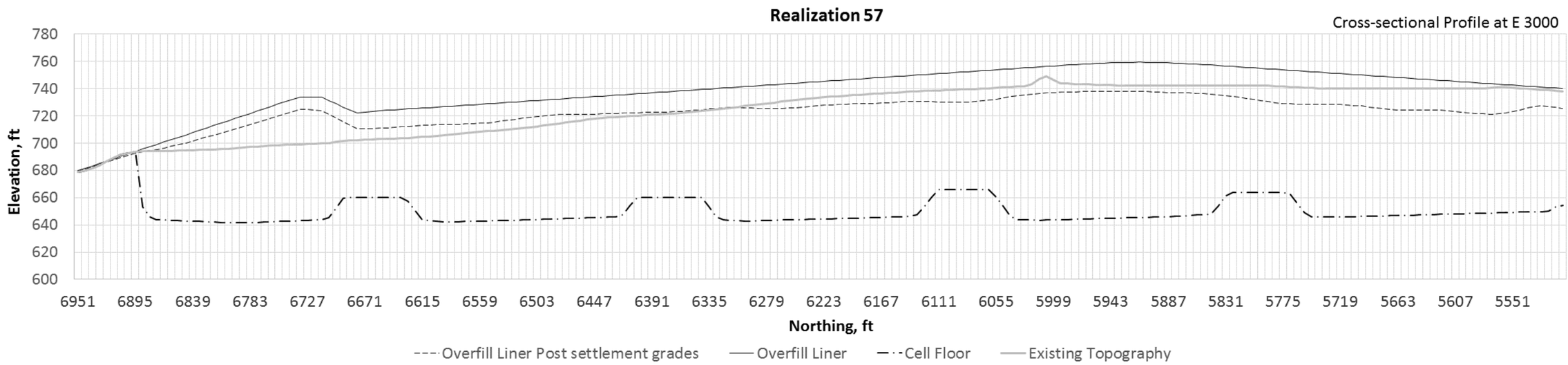
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 57
Cross-sectional Profile at E 3000
Elevation, ft
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6951
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6839
6783
6727
6671
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6391
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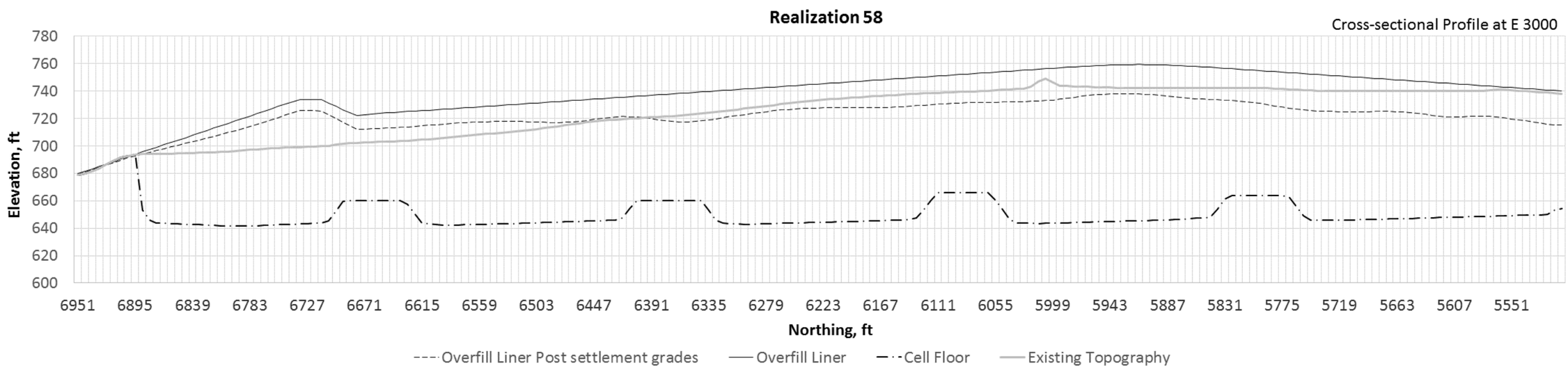
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 58
Cross-sectional Profile at E 3000
Elevation, ft
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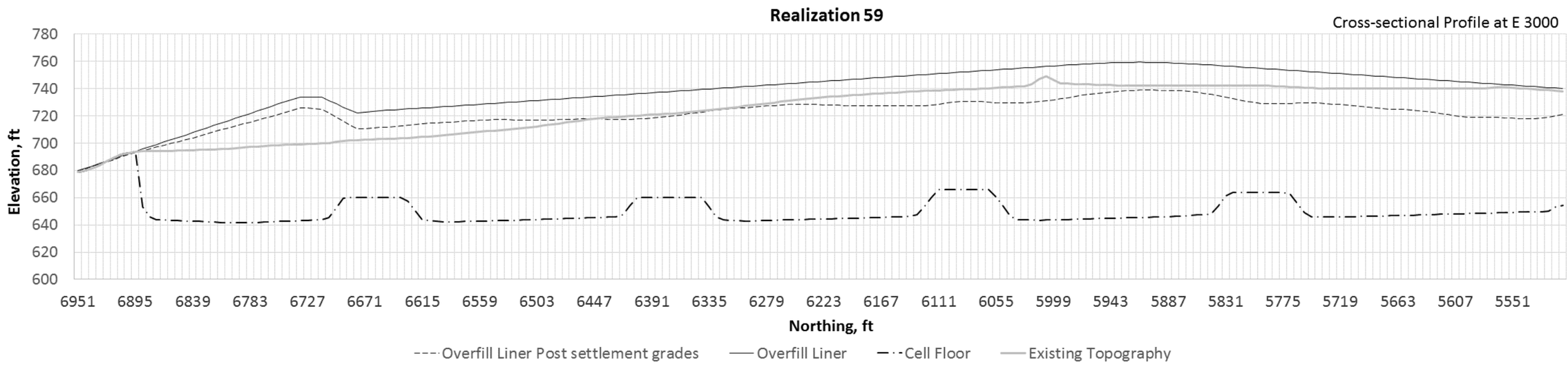
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 59
Cross-sectional Profile at E 3000
Elevation, ft
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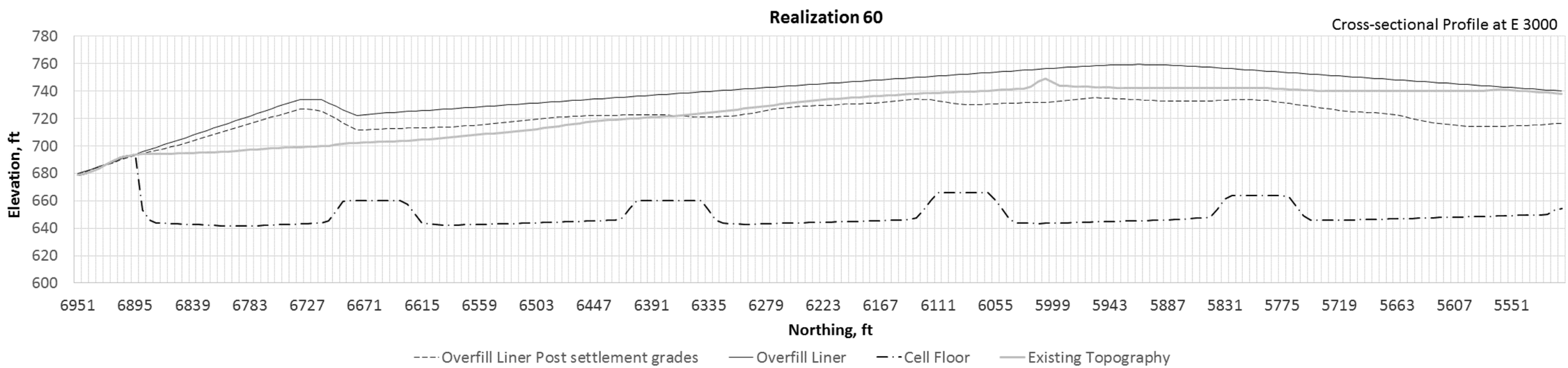
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 60
Cross-sectional Profile at E 3000
Elevation, ft
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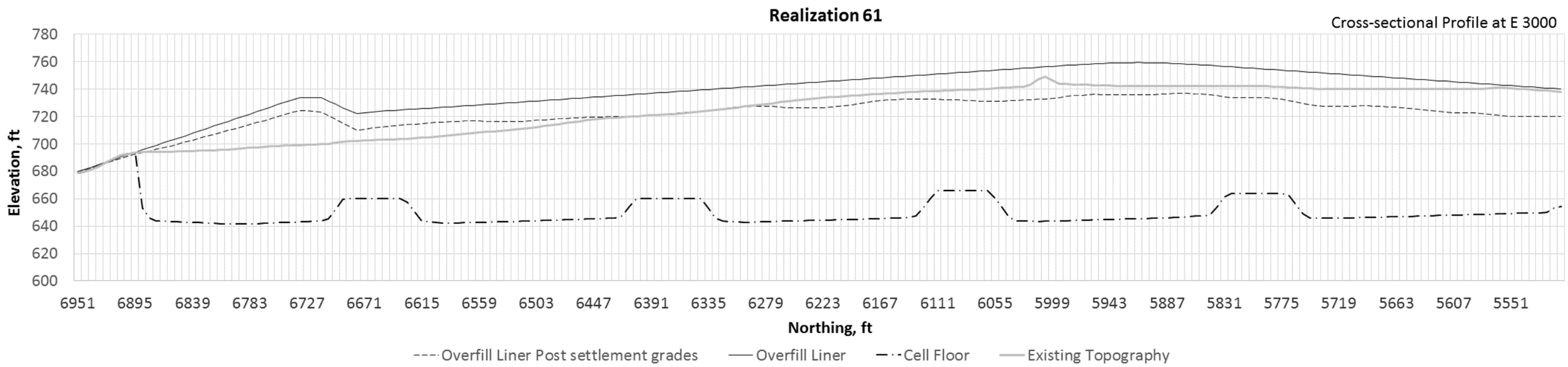
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 61
Cross-sectional Profile at E 3000
Elevation, ft
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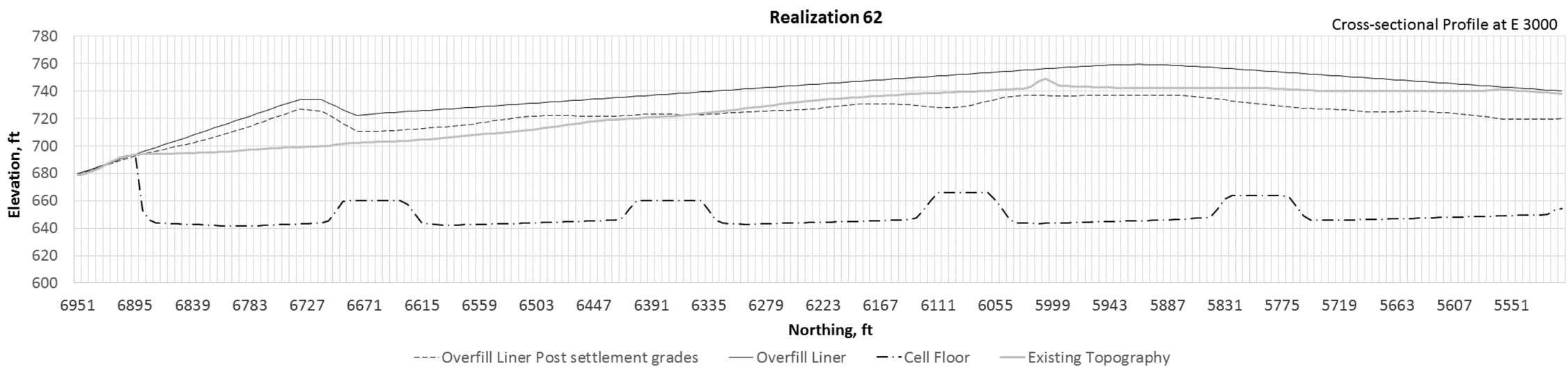
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 62
Cross-sectional Profile at E 3000
Elevation, ft
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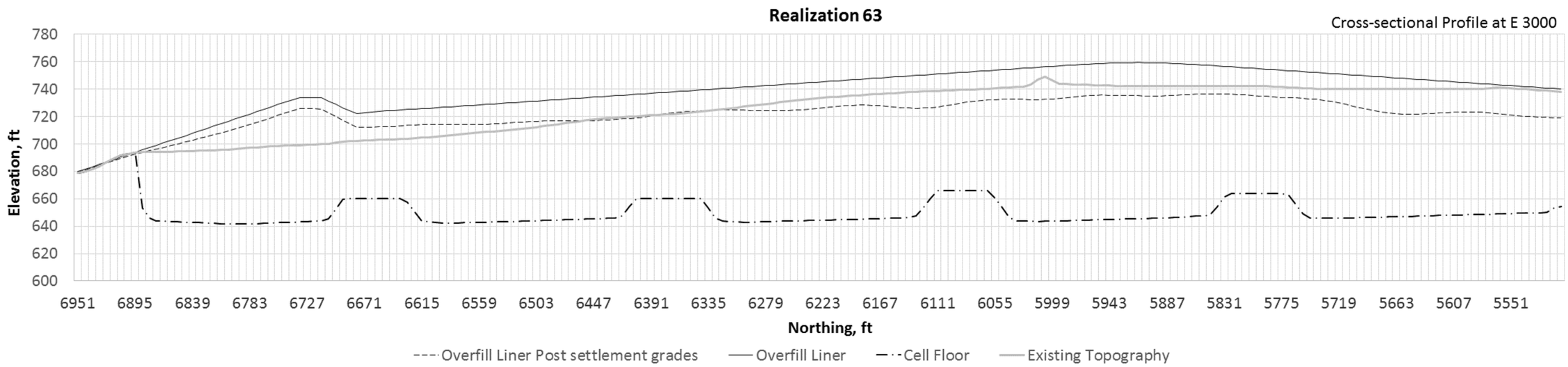
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 63
Cross-sectional Profile at E 3000
Elevation, ft
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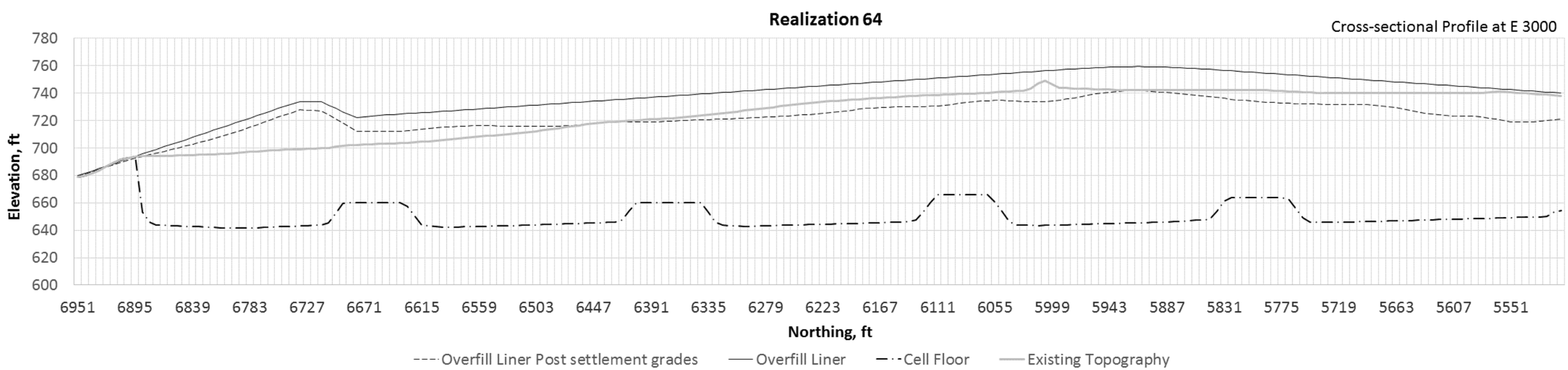
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 64
Cross-sectional Profile at E 3000
Elevation, ft
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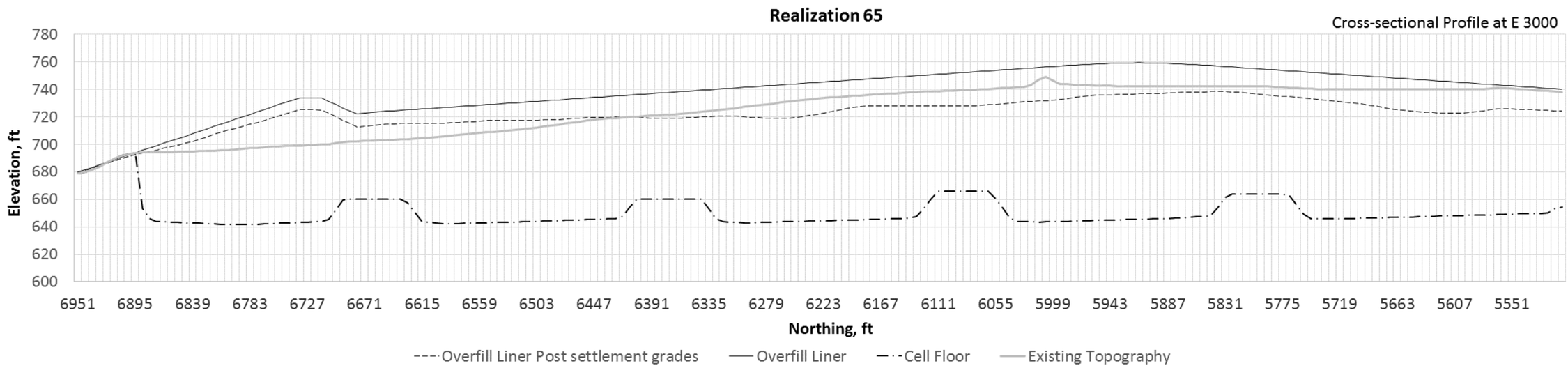
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 65
Cross-sectional Profile at E 3000
Elevation, ft
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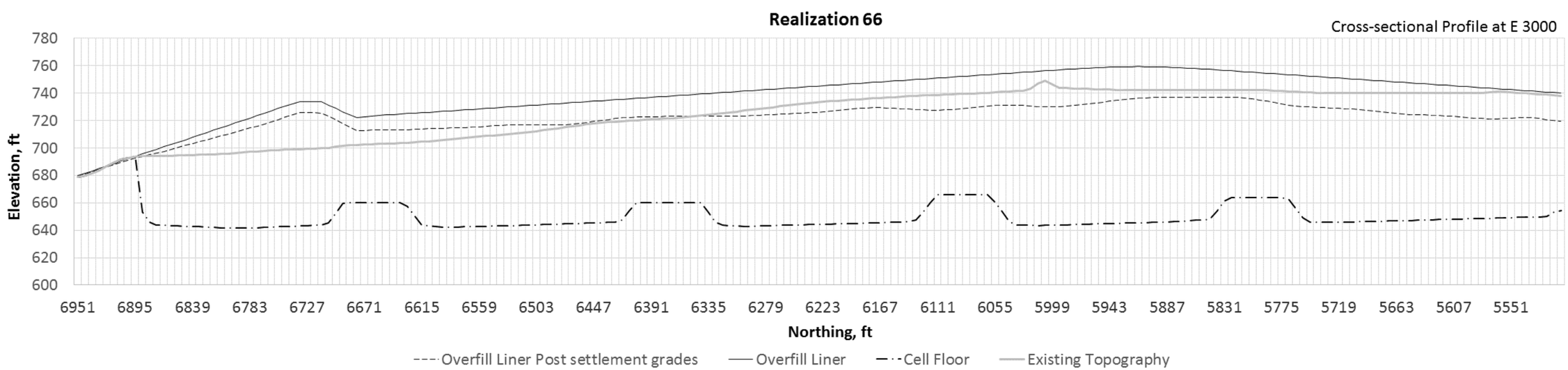
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 66
Cross-sectional Profile at E 3000
Elevation, ft
780
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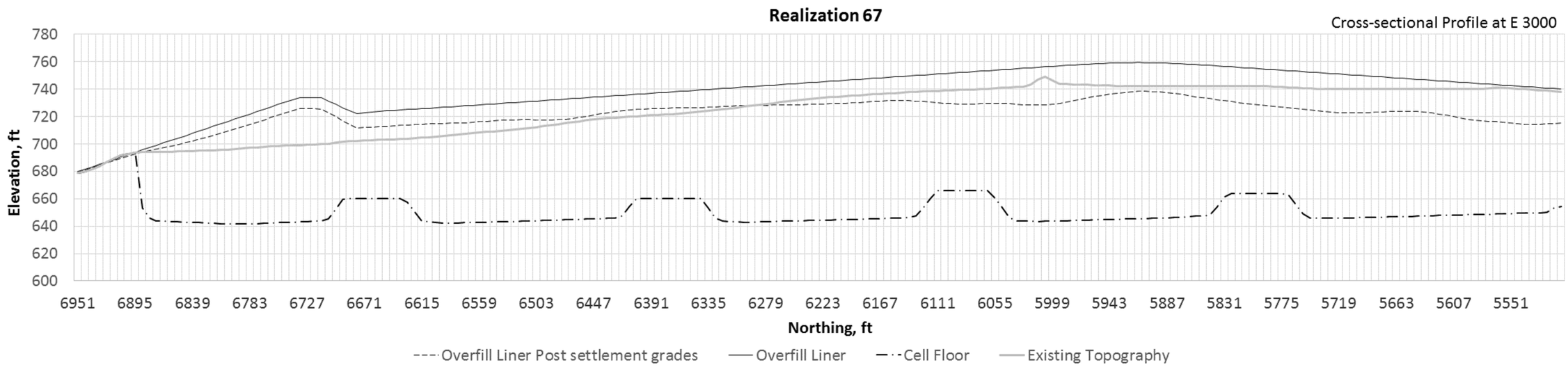
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 67
Cross-sectional Profile at E 3000
Elevation, ft
780
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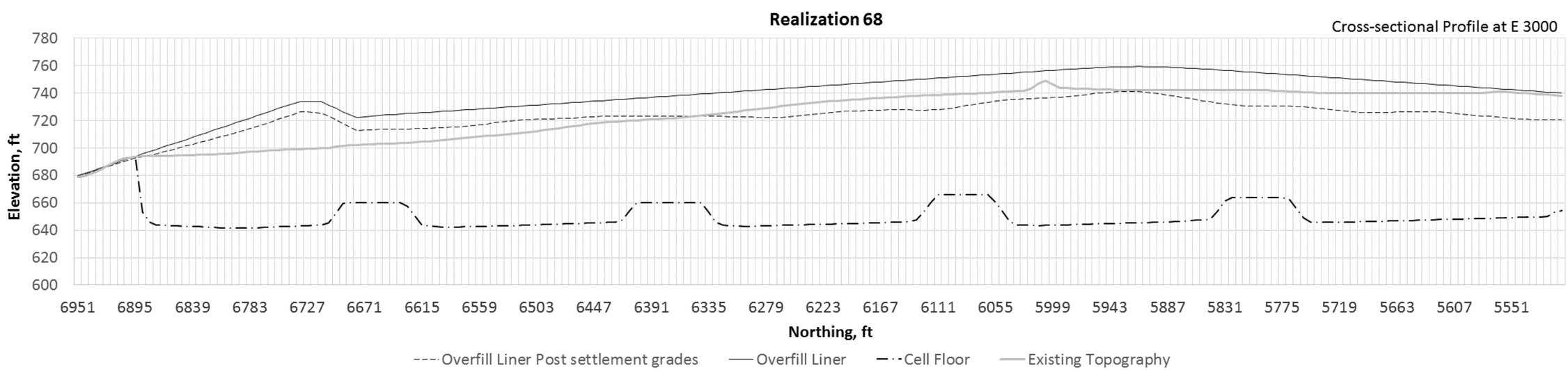
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 68
Cross-sectional Profile at E 3000
Elevation, ft
780
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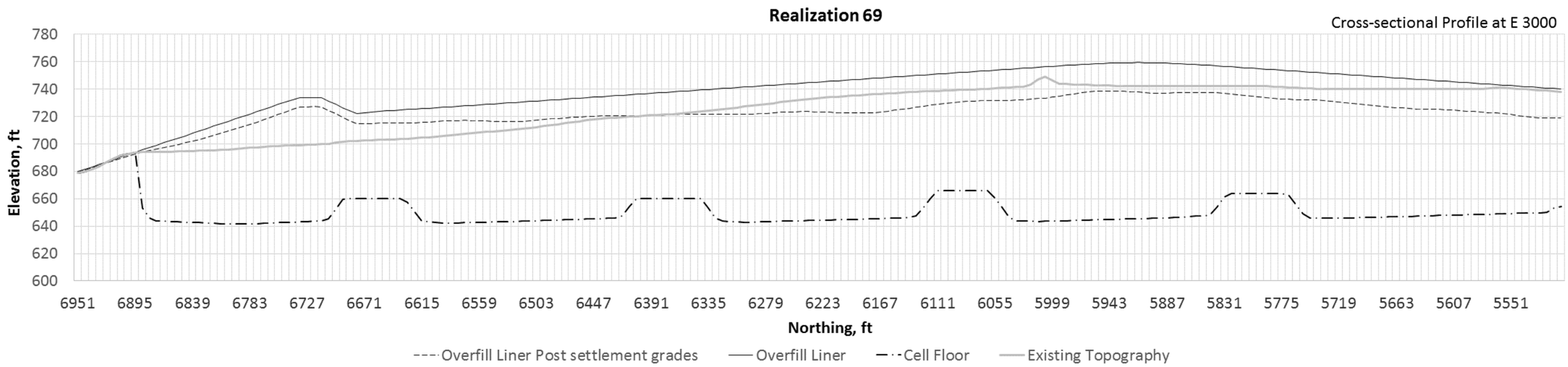
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 69
Cross-sectional Profile at E 3000
Elevation, ft
780
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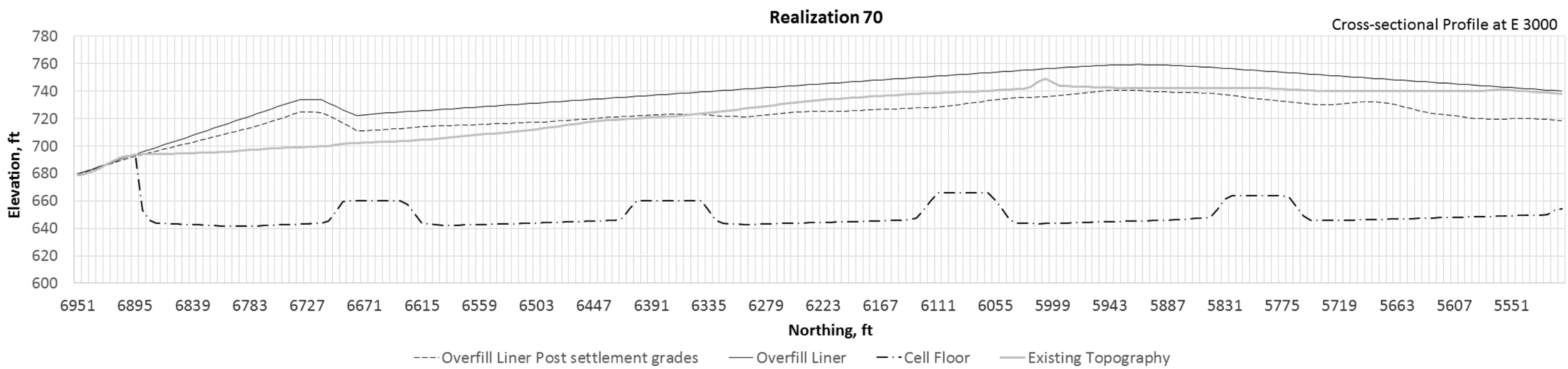
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 70
Cross-sectional Profile at E 3000
Elevation, ft
780
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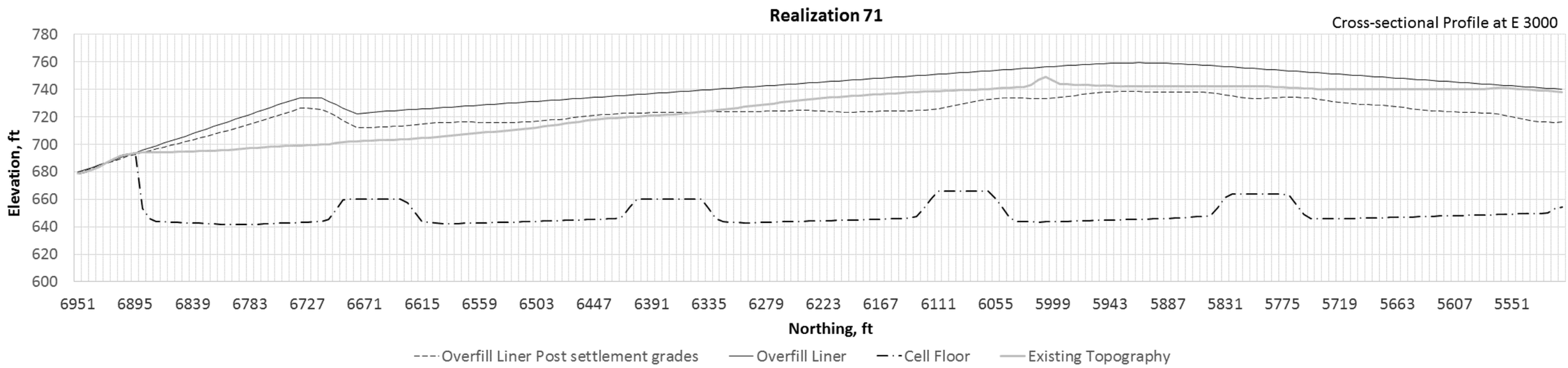
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 71
Cross-sectional Profile at E 3000
Elevation, ft
780
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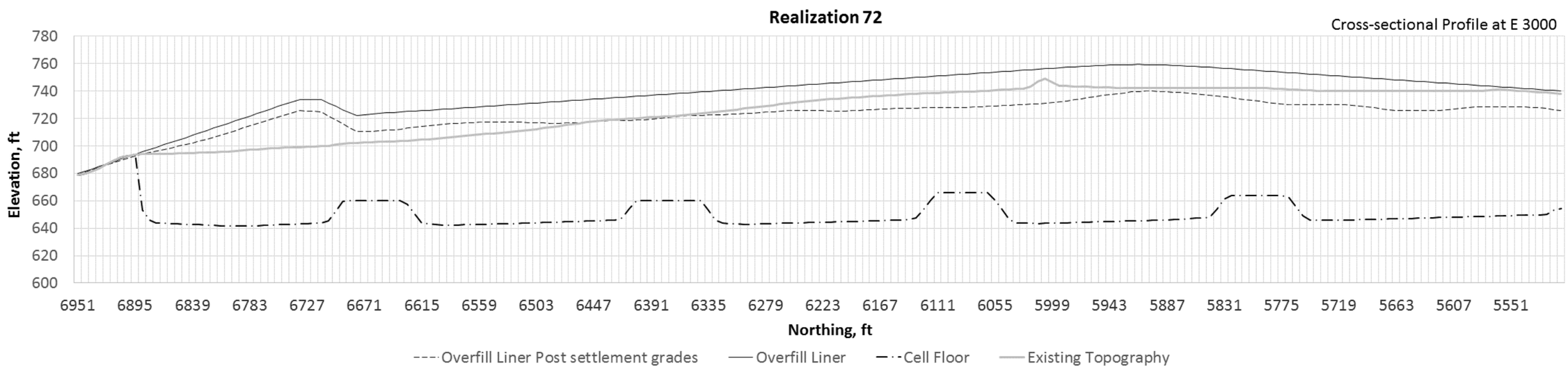
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 72
Cross-sectional Profile at E 3000
Elevation, ft
780
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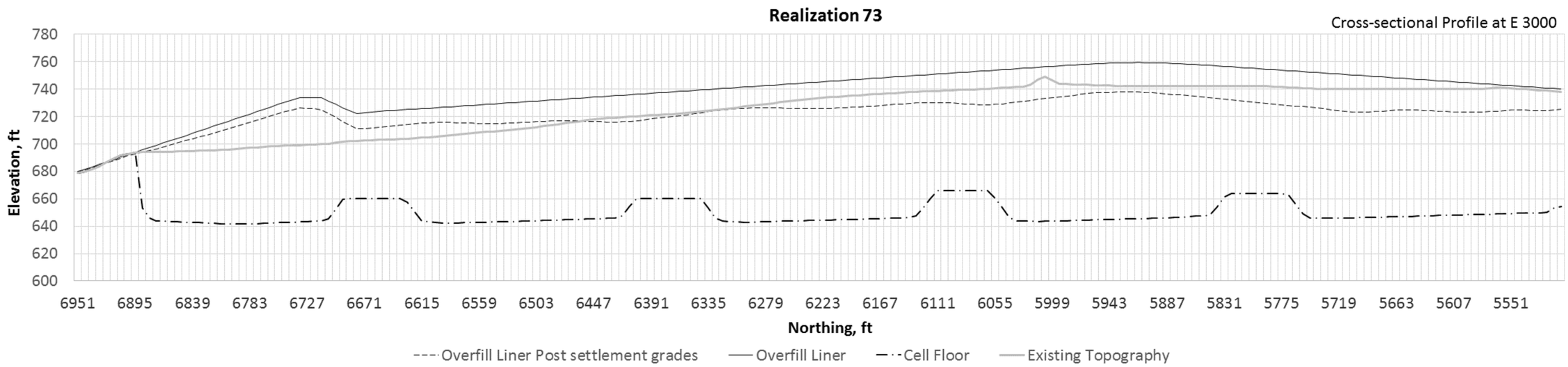
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 73
Cross-sectional Profile at E 3000
Elevation, ft
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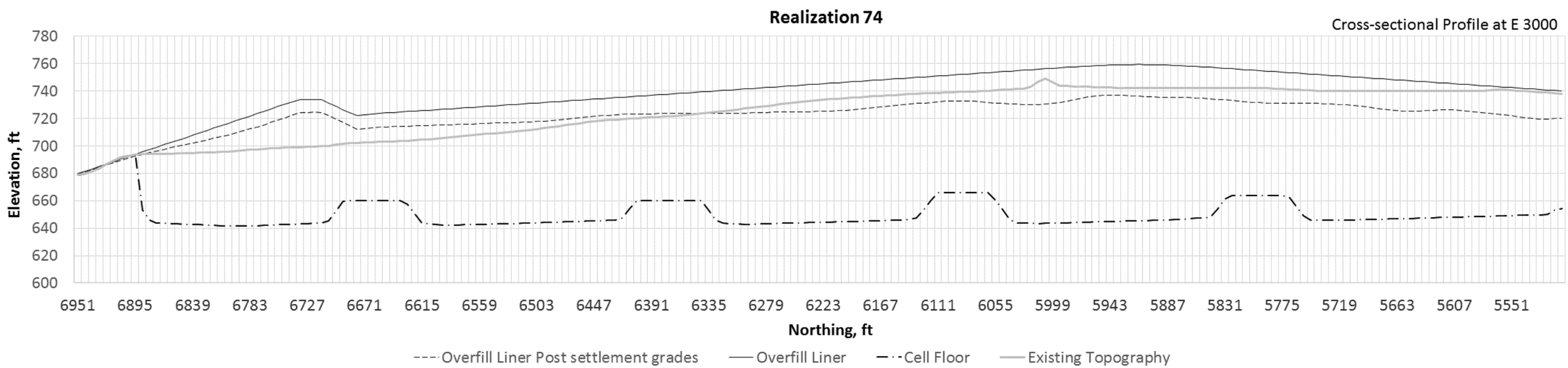
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 74
Cross-sectional Profile at E 3000
Elevation, ft
780
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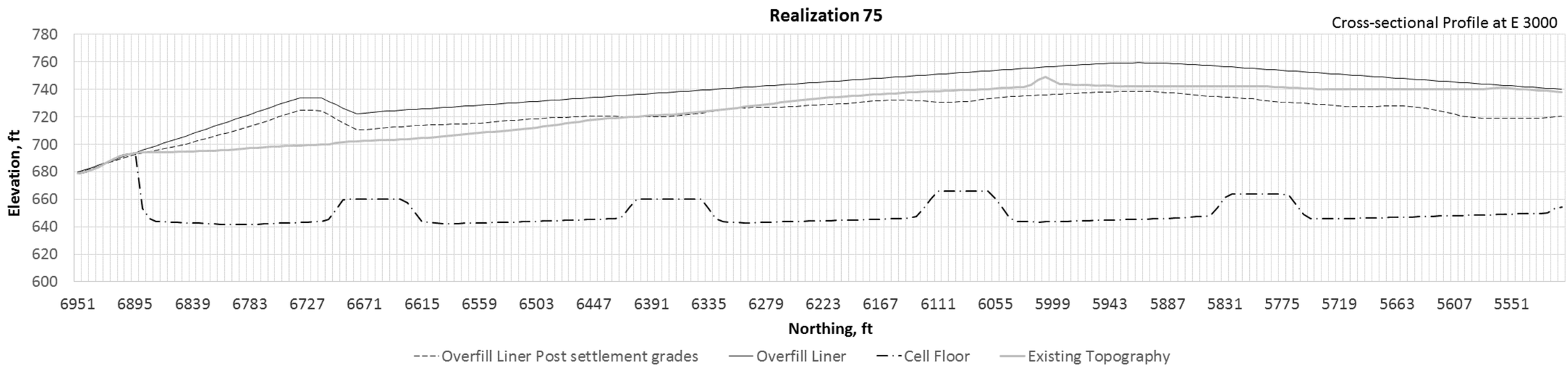
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 75
Cross-sectional Profile at E 3000
Elevation, ft
780
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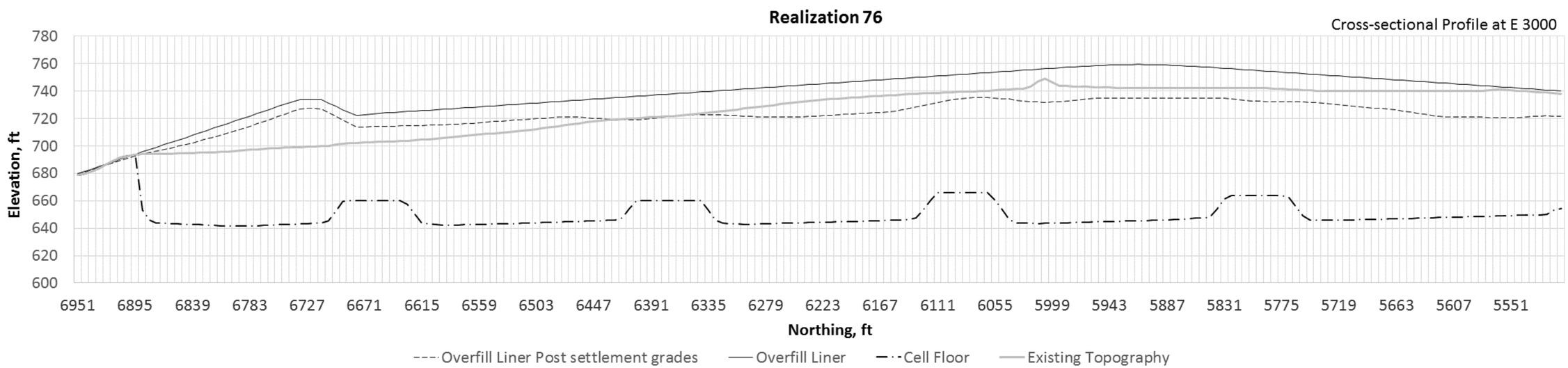
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 76
Cross-sectional Profile at E 3000
Elevation, ft
780
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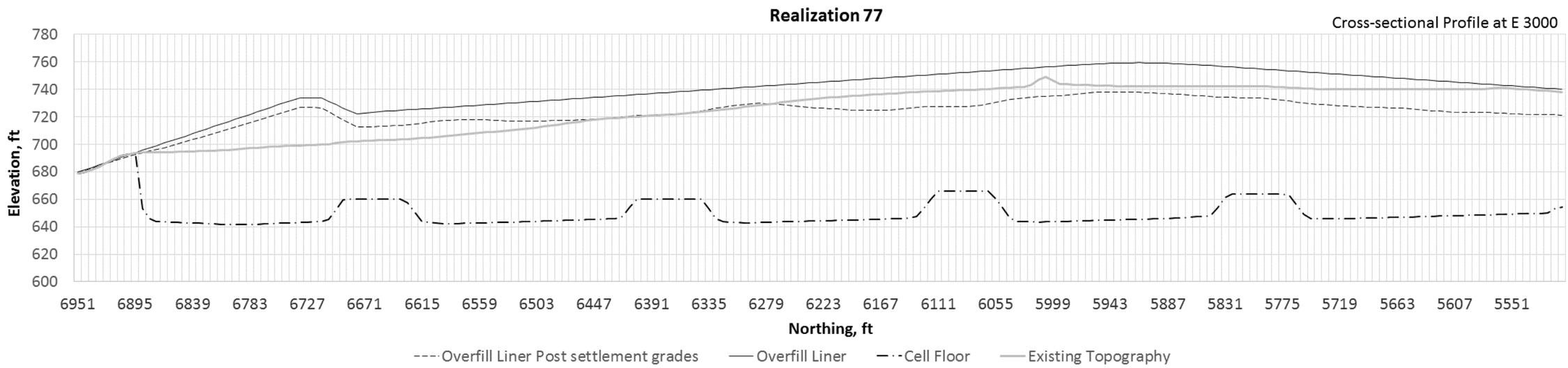
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 77
Cross-sectional Profile at E 3000
Elevation, ft
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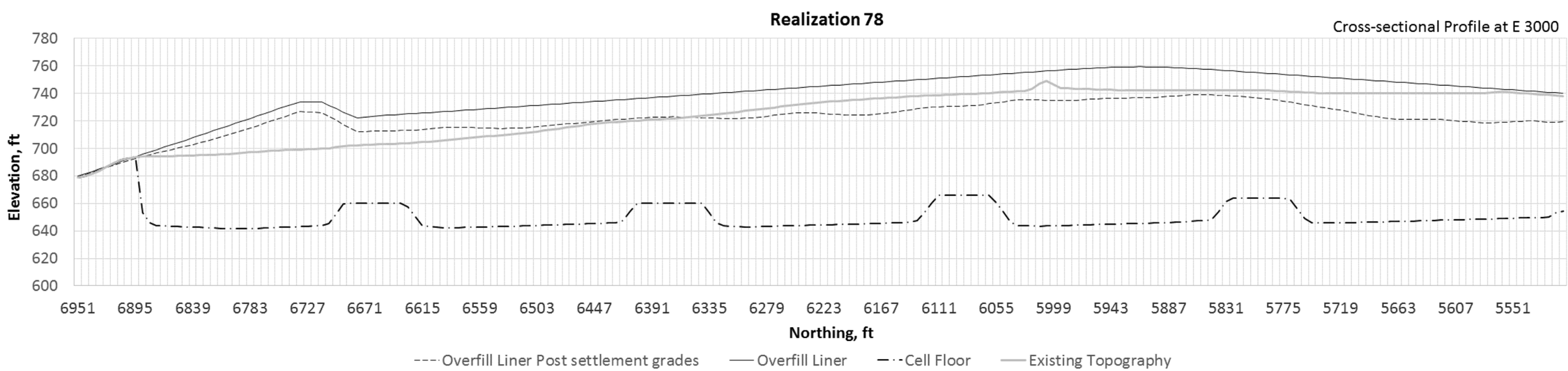
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 78
Cross-sectional Profile at E 3000
Elevation, ft
780
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740
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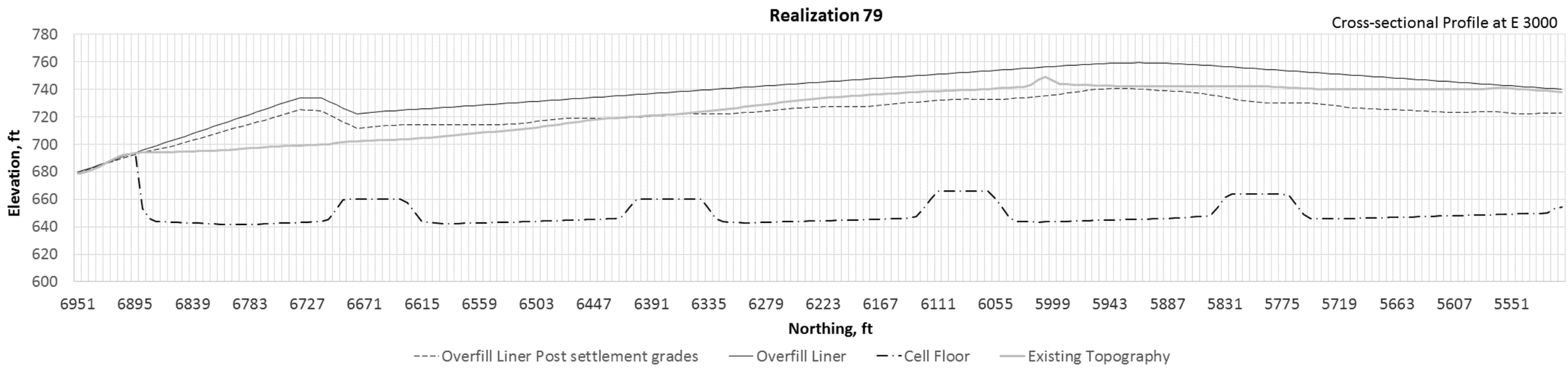
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 79
Cross-sectional Profile at E 3000
Elevation, ft
780
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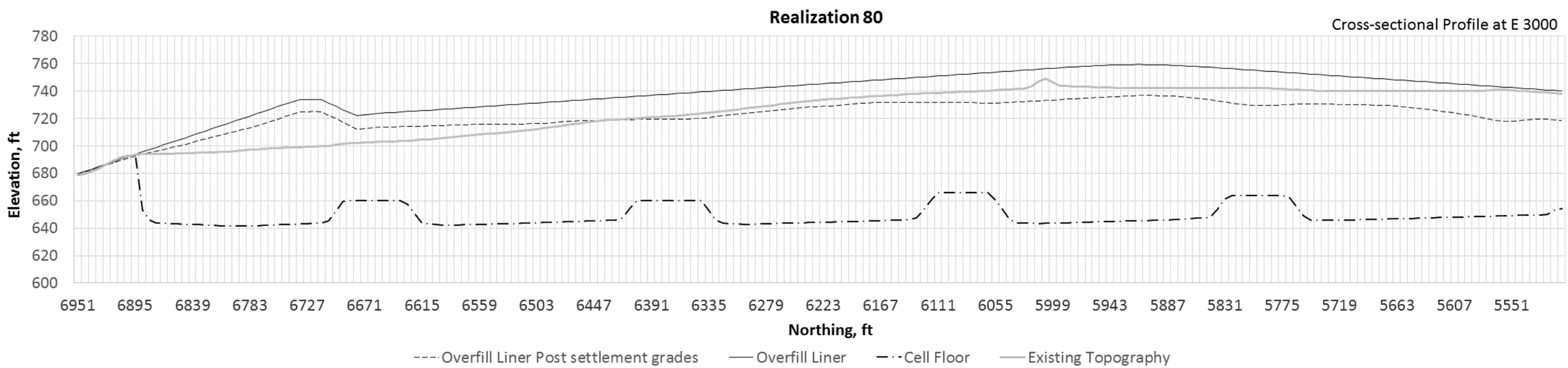
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 80
Cross-sectional Profile at E 3000
Elevation, ft
780
760
740
720
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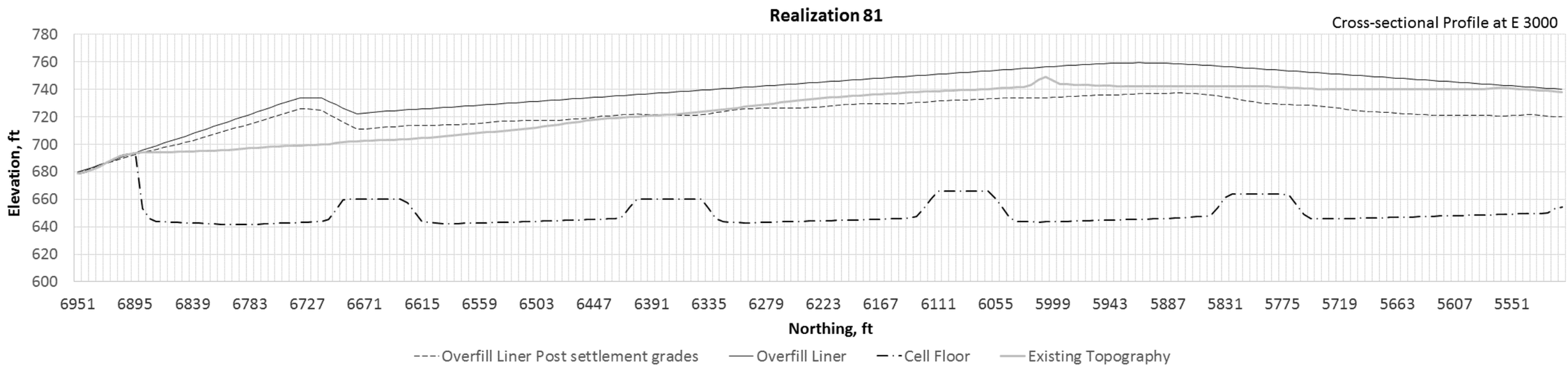
640
620
600
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 81
Cross-sectional Profile at E 3000
Elevation, ft
780
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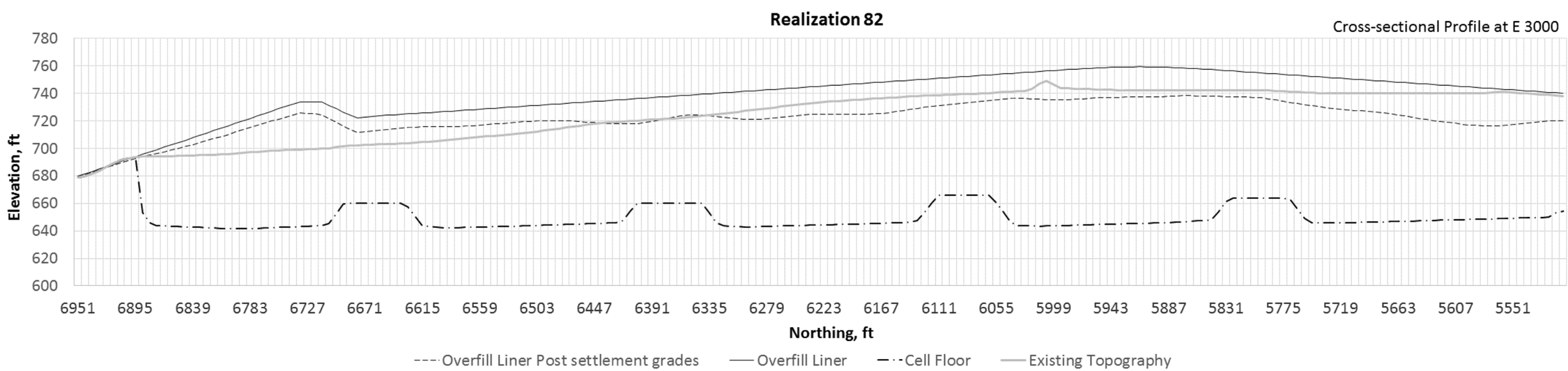
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 82
Cross-sectional Profile at E 3000
Elevation, ft
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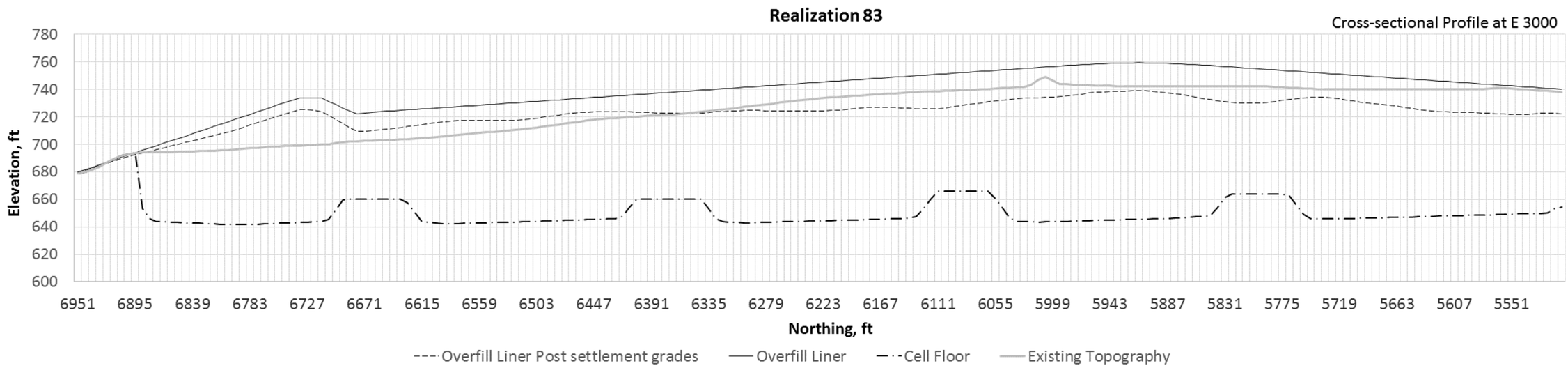
6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 83
Cross-sectional Profile at E 3000
Elevation, ft
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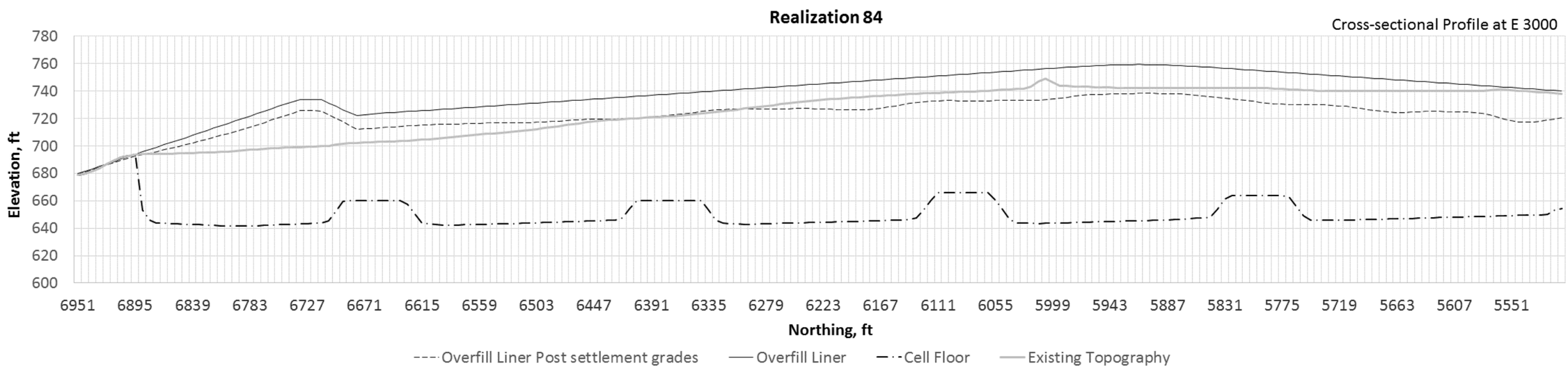
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 84
Cross-sectional Profile at E 3000
Elevation, ft
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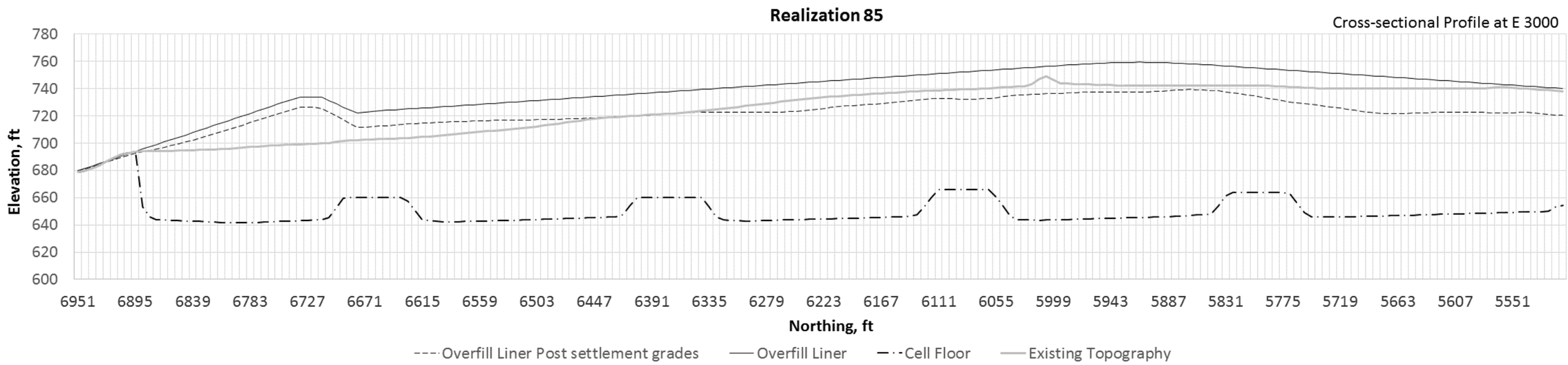
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 85
Cross-sectional Profile at E 3000
Elevation, ft
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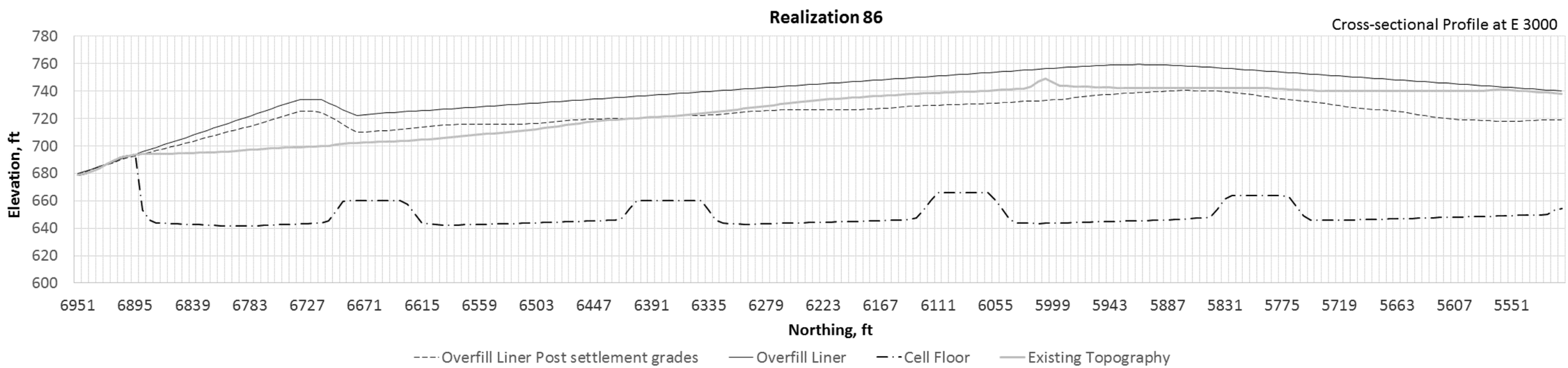
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 86
Cross-sectional Profile at E 3000
Elevation, ft
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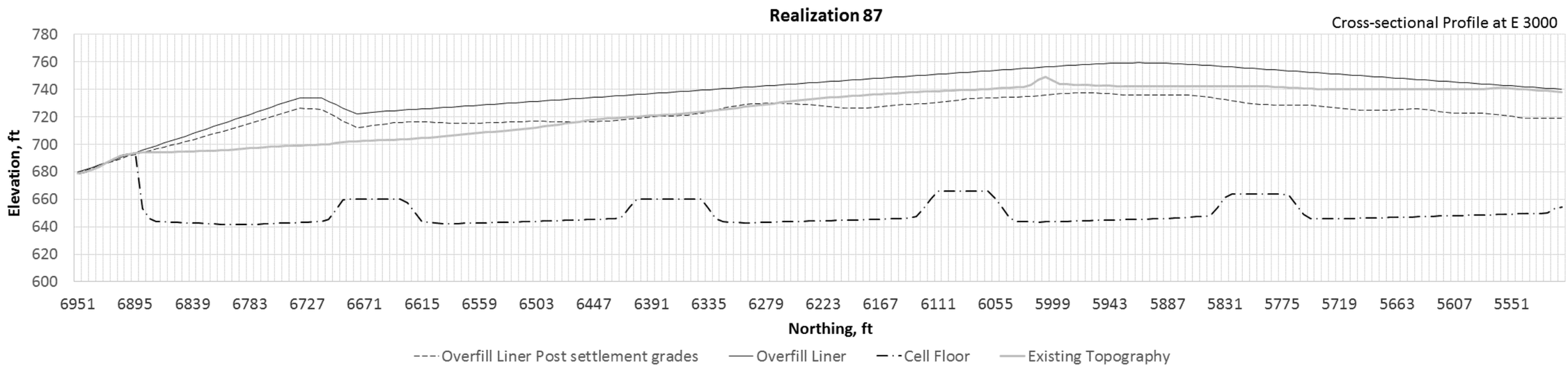
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 87
Cross-sectional Profile at E 3000
Elevation, ft
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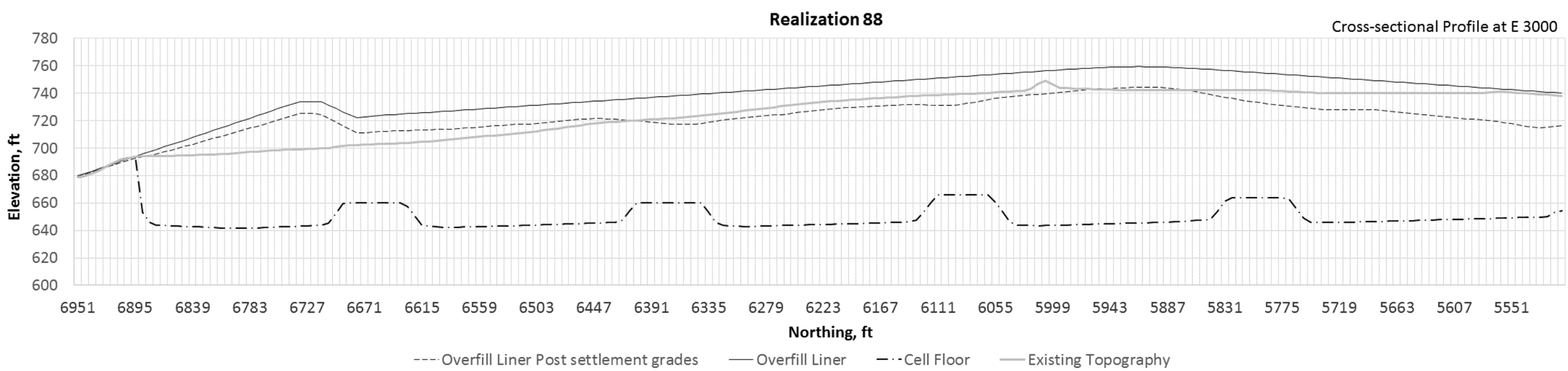
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 88
Cross-sectional Profile at E 3000
Elevation, ft
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Northing, ft
Overfill Liner Post settlement grades
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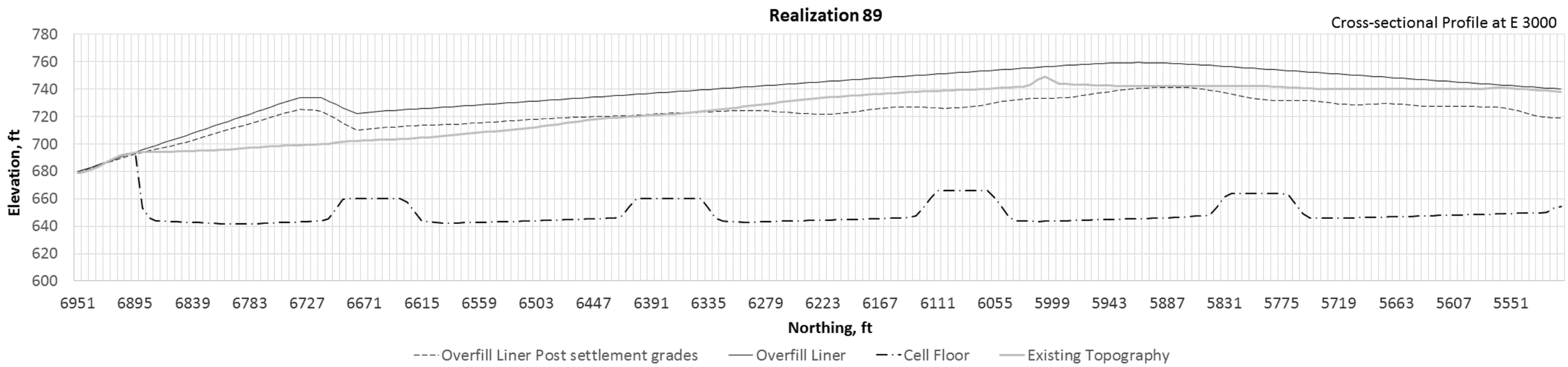
Cell Floor
Existing Topography


Realization 89
Cross-sectional Profile at E 3000
Elevation, ft
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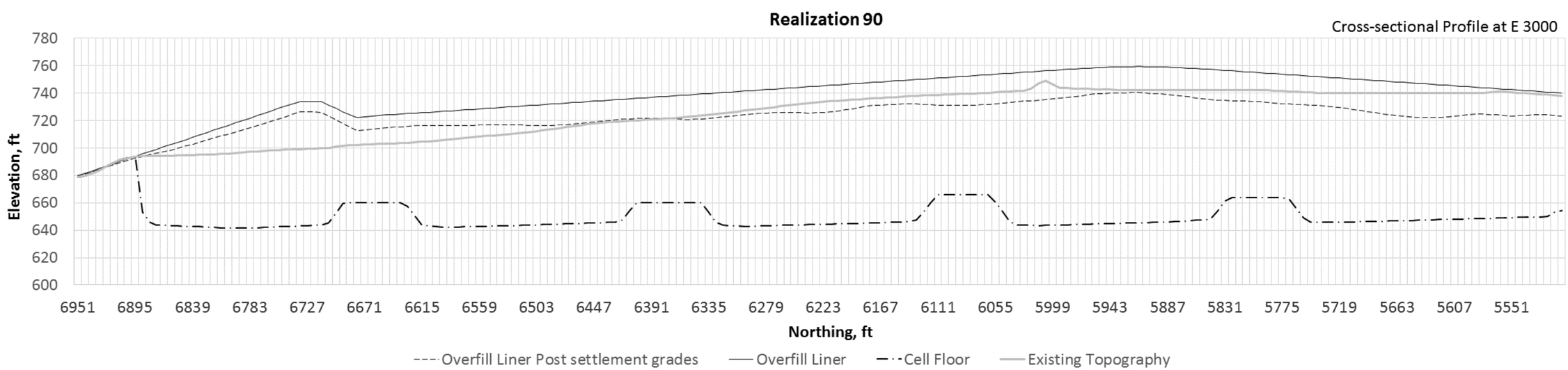
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 90
Cross-sectional Profile at E 3000
Elevation, ft
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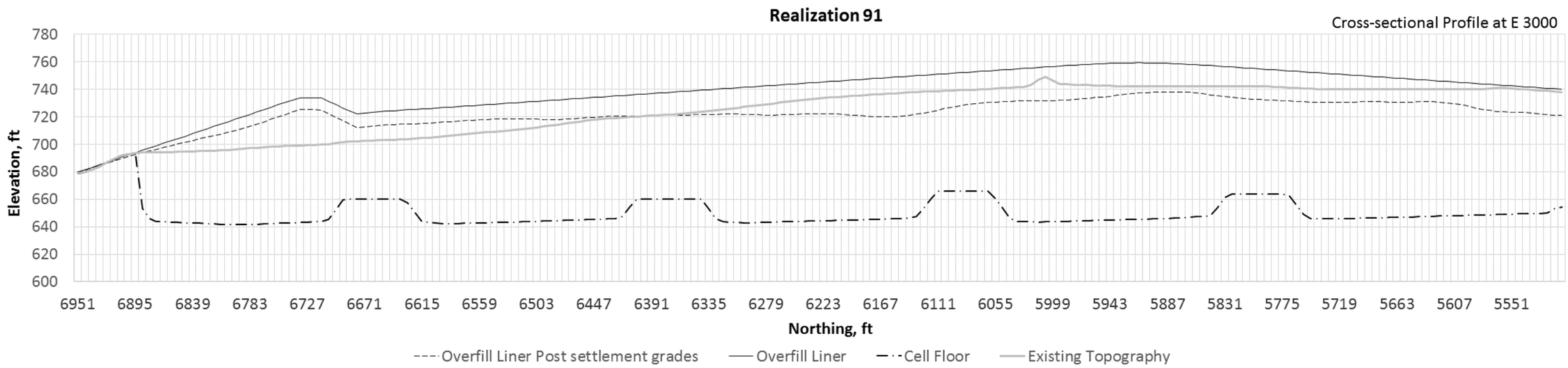
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 91
Cross-sectional Profile at E 3000
Elevation, ft
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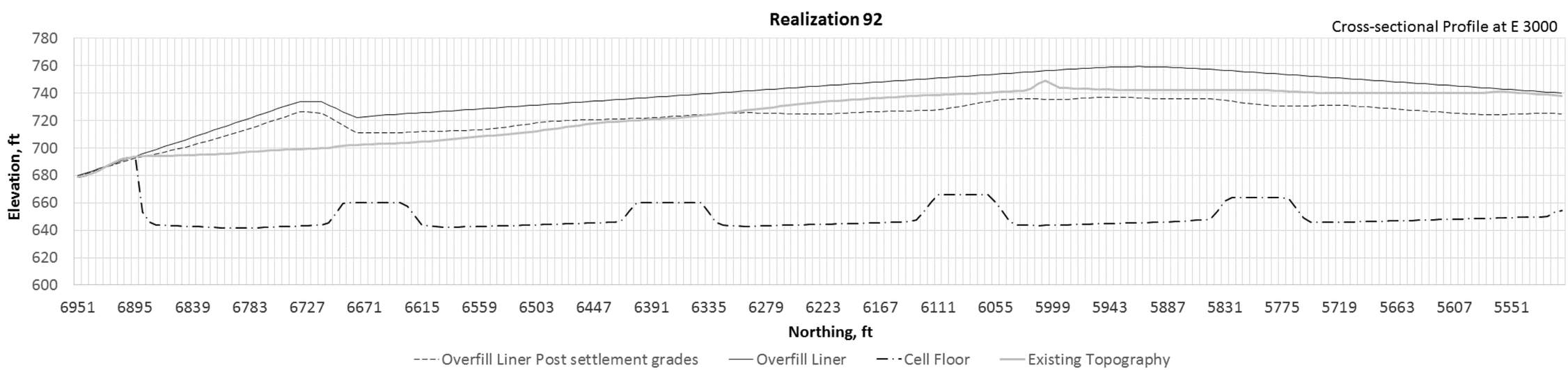
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 92
Cross-sectional Profile at E 3000
Elevation, ft
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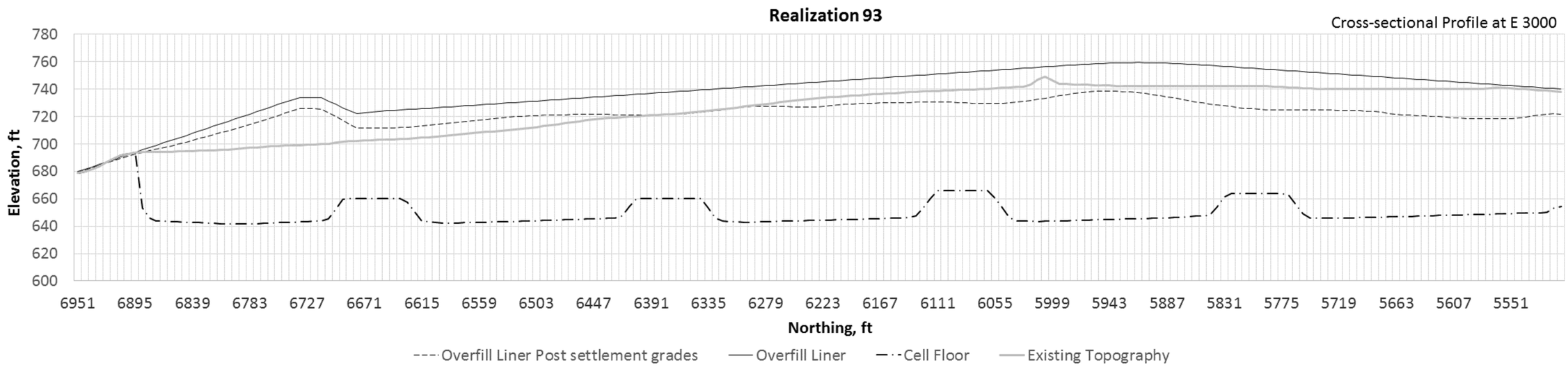
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 93
Cross-sectional Profile at E 3000
Elevation, ft
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Northing, ft
Overfill Liner Post settlement grades
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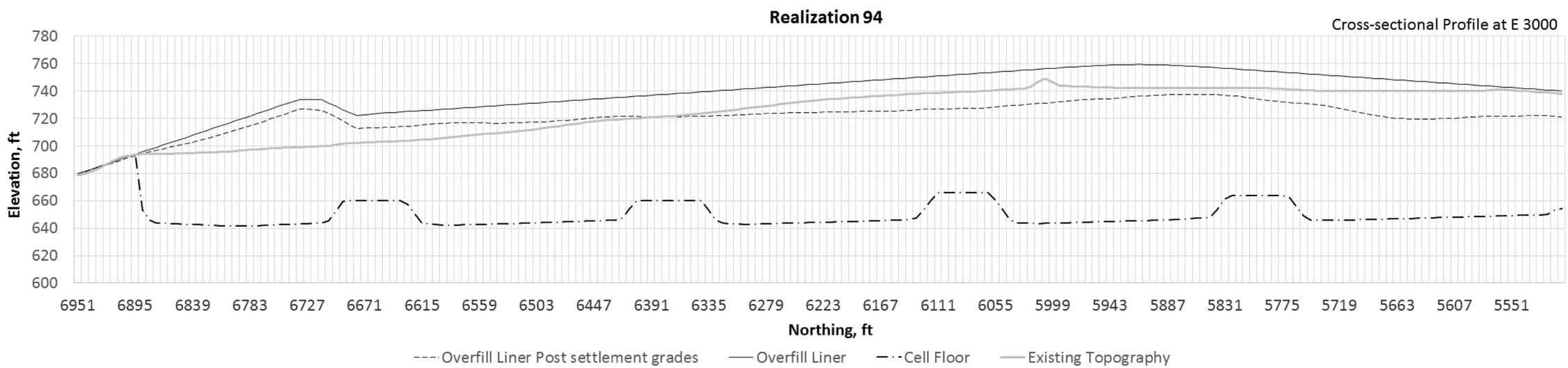
Cell Floor
Existing Topography


Realization 94
Cross-sectional Profile at E 3000
Elevation, ft
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Northing, ft
Overfill Liner Post settlement grades
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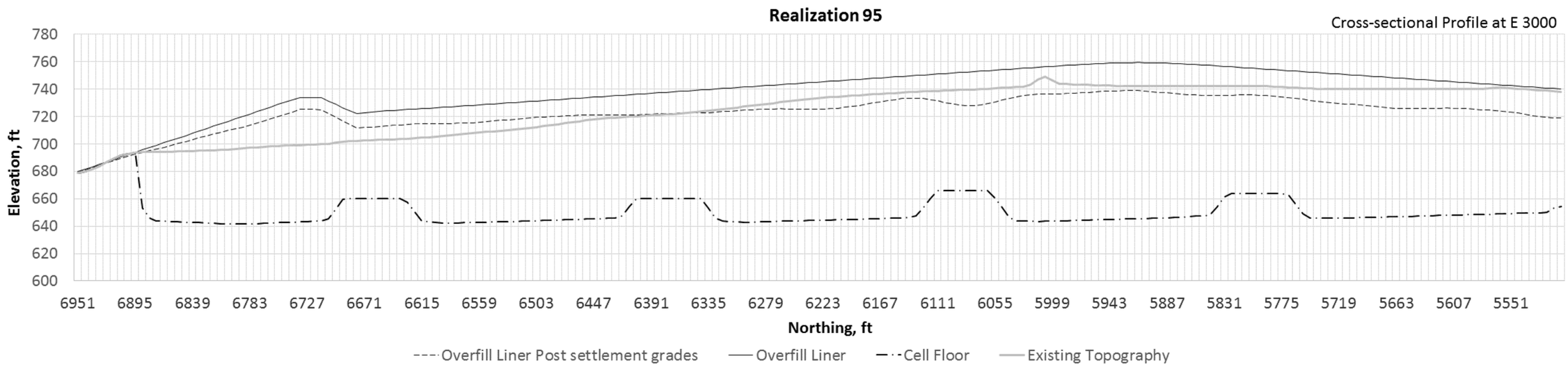
Cell Floor
Existing Topography


Realization 95
Cross-sectional Profile at E 3000
Elevation, ft
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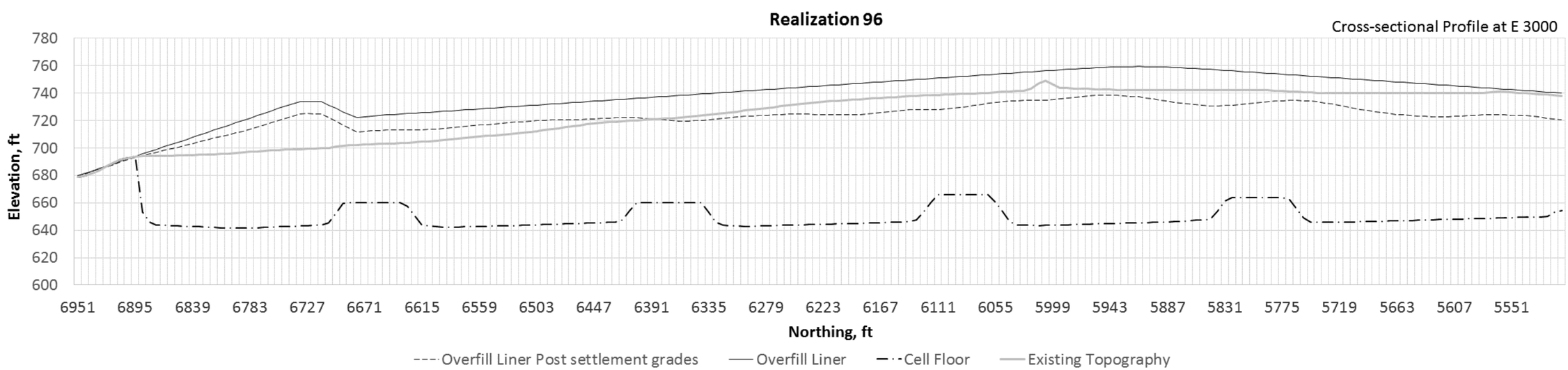
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 96
Cross-sectional Profile at E 3000
Elevation, ft
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Northing, ft
Overfill Liner Post settlement grades
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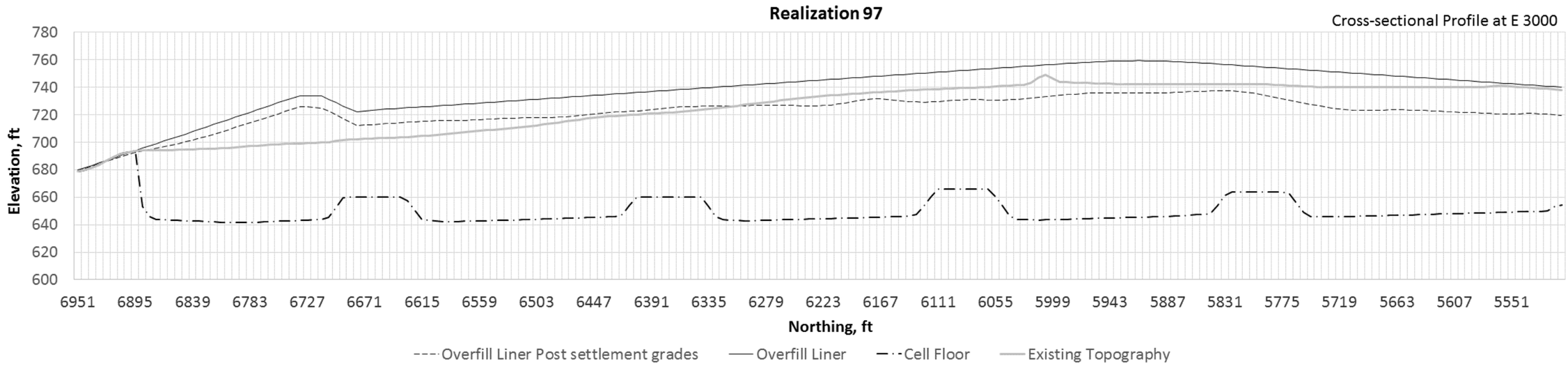
Cell Floor
Existing Topography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Cross-sectional Profile at E 3000
Elevation, ft
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Northing, ft
Overfill Liner Post settlement grades
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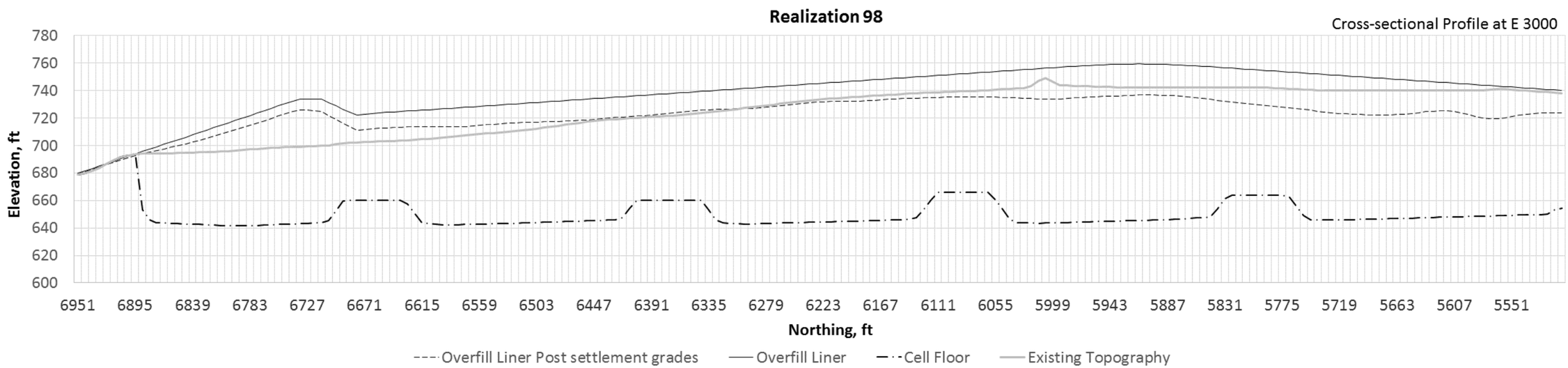
Cell Floor
Existing Topography


Realization 98
Cross-sectional Profile at E 3000
Elevation, ft
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Northing, ft
Overfill Liner Post settlement grades
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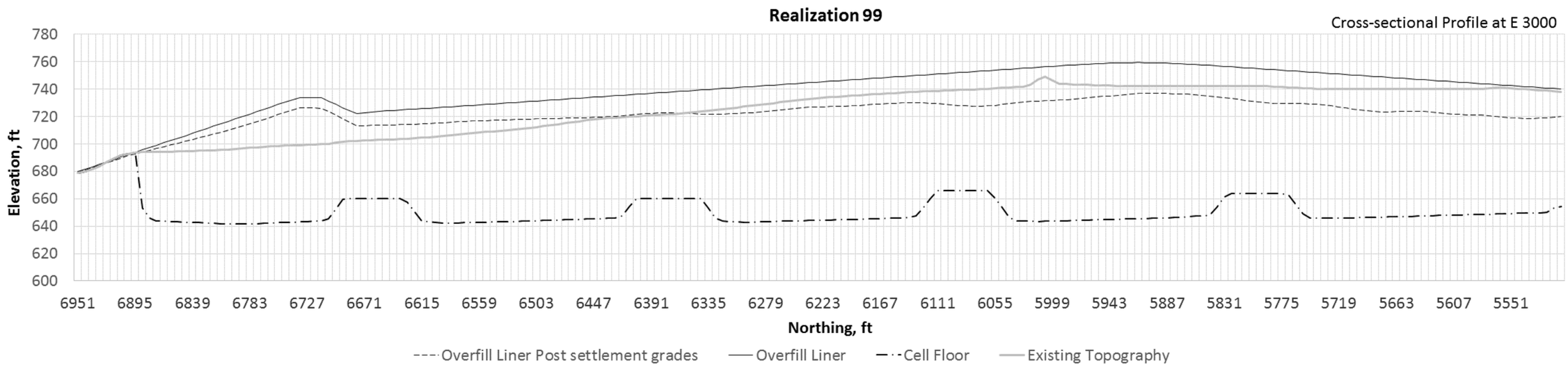
Cell Floor
Existing Topography


Realization 99
Cross-sectional Profile at E 3000
Elevation, ft
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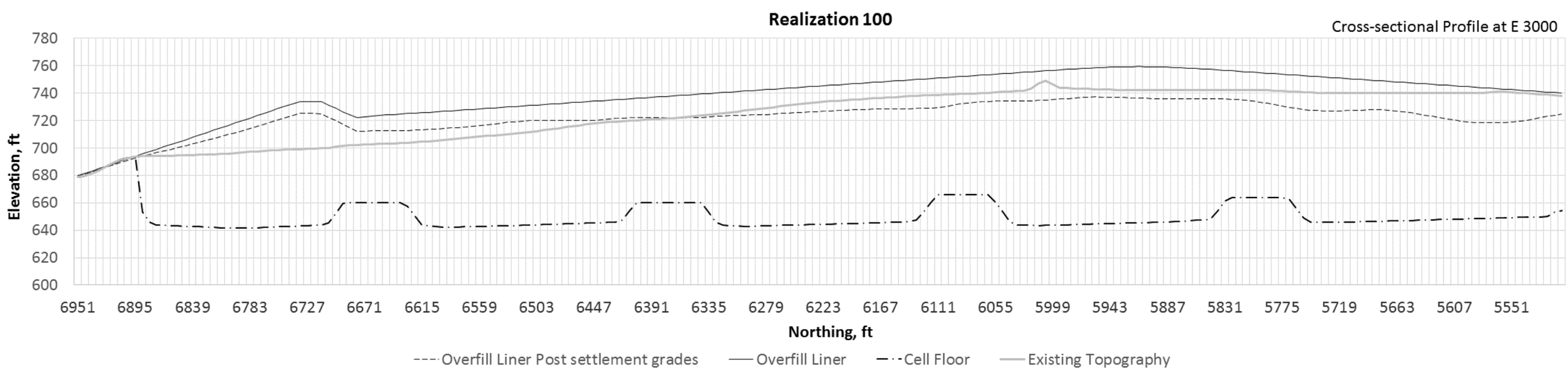
Northing, ft
Overfill Liner Post settlement grades
Overfill Liner
Cell Floor
Existing Topography


Realization 100
Cross-sectional Profile at E 3000
Elevation, ft
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6951 6895 6839 6783 6727 6671 6615 6559 6503 6447 6391 6335 6279 6223 6167 6111 6055 5999 5943 5887 5831 5775 5719 5663 5607 5551
Northing, ft
Overfill Liner Post settlement grades
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Cell Floor
Existing Topography