WIPP
Subsidence Monument
Leveling Survey
2018

December 2018

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Waste Isolation Pilot Plant

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List of Acronyms

DOE	Department of Energy
DOY	Day of year
FGCS	Federal Geodetic Control Subcommittee
M&TE	Measurement and Test Equipment
NGS	National Geodetic Survey
NWP	Nuclear Waste Partnership
WIPP	Waste Isolation Pilot Plant

References

Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys, Federal Geodetic Control Committee (now Federal Geodetic Control Subcommittee), [1975] 1980, Reprint.

FGCS Specifications and Procedures to Incorporate Electronic Digital / Bar-Code Leveling Systems, Federal Geodetic Control Subcommittee, ver. 4.1, dated May 27, 2004.

WP 09-ES4001, *Subsidence Survey Data Acquisition and Report, September* 2016, Rev. 4.

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WIPP Subsidence Monument Leveling Survey 2006, DOE / WIPP 07-2293, December 2006

WIPP Subsidence Monument Leveling Survey 2007, DOE / WIPP 08-2293, December 2007

WIPP Subsidence Monument Leveling Survey 2008, DOE / WIPP 09-2293, December 2008

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WIPP Subsidence Monument Leveling Survey 2010, DOE / WIPP 11-2293, December 2010

WIPP Subsidence Monument Leveling Survey 2011, DOE / WIPP 12-2293, December 2011

WIPP Subsidence Monument Leveling Survey 2012, DOE / WIPP 12-3497, December 2012

WIPP Subsidence Monument Leveling Survey 2013, DOE / WIPP 13-3512, November 2013

WIPP Subsidence Monument Leveling Survey 2014, DOE / WIPP 14-3541, December 2014

WIPP Subsidence Monument Leveling Survey 2015, DOE / WIPP 15-3562, December 2015

WIPP Subsidence Monument Leveling Survey 2016, DOE / WIPP 16-3577, November 2016

WIPP Subsidence Monument Leveling Survey 2017, DOE / WIPP 17-3595, November 2017

1. Introduction

Sections 2 through 7 of this report define the result of the 2018 leveling survey through the subsidence monuments at the WIPP site. Approximately 15 miles of leveling was completed through nine vertical control loops. The 2018 survey includes the determination of elevation on each of the 48 existing subsidence monuments and the WIPP baseline survey, and 14 of the National Geodetic Survey's (NGS) vertical control points. The field observations were completed during September through October 2018 by the Nuclear Waste Partnership (NWP) Mine Engineering Surveyors.

Digital leveling techniques were utilized to achieve better than Second Order Class II loop closures as outlined by the Federal Geodetic Control Subcommittee (FGCS). Because it is important to perform the subsidence survey in exactly the same manner each year, WIPP procedure (WP 09-ES4001) details each step of the survey. Starting with the 2002 survey, this procedure has been used to perform the subsidence survey. A major revision of WP 09-ES4001 was completed in mid-2014 to accommodate the use of new digital levels and new level data processing software.

Starting with the survey of the year 2001, Loop 1 and redundant survey connections among the various loops were removed from the survey and report. This resulted in a reduction of fieldwork with no loss of accuracy or precision. The redundant connections caused multiple elevations for the same stations. The differences were so slight that they were not used in elevation adjustments for the loops. The redundancy was used to spot gross errors in the field. After several years of surveying these loops, it is evident that no gross errors occur that are not also evident in the loop closures.

Finally, Section 8 contains Table F, which summarizes the elevations for all surveys from 1987 through 2018, inclusive. A detailed listing of the 1986 through 1997 surveys is contained in the report, *WIPP Subsidence Monument Leveling Surveys 1986-1997*, DOE/WIPP 98-2293. A reference to the summary reports for each year after 1997 is listed in the reference section of this document.

2. Equipment

The observations were taken with the Leica DNA03 Digital Level (WIPP M&TE ID# DM1358) and DNA03 Digital Level (WIPP M&TE ID #DM 1357) manufactured by Leica, and bar coded leveling staffs. The calibration for the DM1358 is valid from August 6, 2018 through August 6, 2020. The calibration for DM 1357 is valid from July 28, 2017 through July 28, 2019. The data was recorded on the digital level's internal memory. In addition to the electronic record, a written field log was maintained to record

information that is not stored in the electronic record. Starting with the 2014 Subsidence Survey, the Leica DNA03 Digital Level replaced the WILD NA3003 Electronic Digital Level used in prior years.

3. Office Processing

The data was transferred from the digital level's internal memory to the survey group computer. The original raw data files were maintained intact while further processing was performed on a copy of the original raw data file. The data from each of the leveling loops was processed with Leica Geo Office software. The results, as summarized below, were extracted from the Level Summary reports for each loop. The Leica Geo Office software was tested, verified, and validated in accordance with WIPP procedures and is in the WIPP controlled software list. The use of WILDSoft and DIGILEV to process the level loop data from previous years was discontinued in 2014.

4. Methodology

The weather conditions during the observations of the 2018 survey were generally mild with moderate temperatures and light to moderate breezes.

The elevations for the 2018 survey are computed from the adjusted observations based on the elevation of the subsidence monument, S-37 (3,423.874 feet). S-37, originally, was the WIPP monument furthest from the influence of the underground excavations. S-37 has been held fixed for all of the subsidence leveling surveys since 1993. The condition of the individual monuments was substantially the same as the previous subsidence survey.

In the 2004 survey, it was noted that the brass cap of monument PT-31 came loose making it unusable and monuments S-17 and S-18 no longer exist due to construction of the new salt storage/disposal pad.

As in previous years, the subsidence survey was divided into nine loops. Each loop generally takes one day to complete. This allows a loop to be completed in one surveying session and results in a lower probability of error.

For visual reference, Figure 1 is a graphic display of the individual loops, the total survey, and the relationship to the underground excavations.

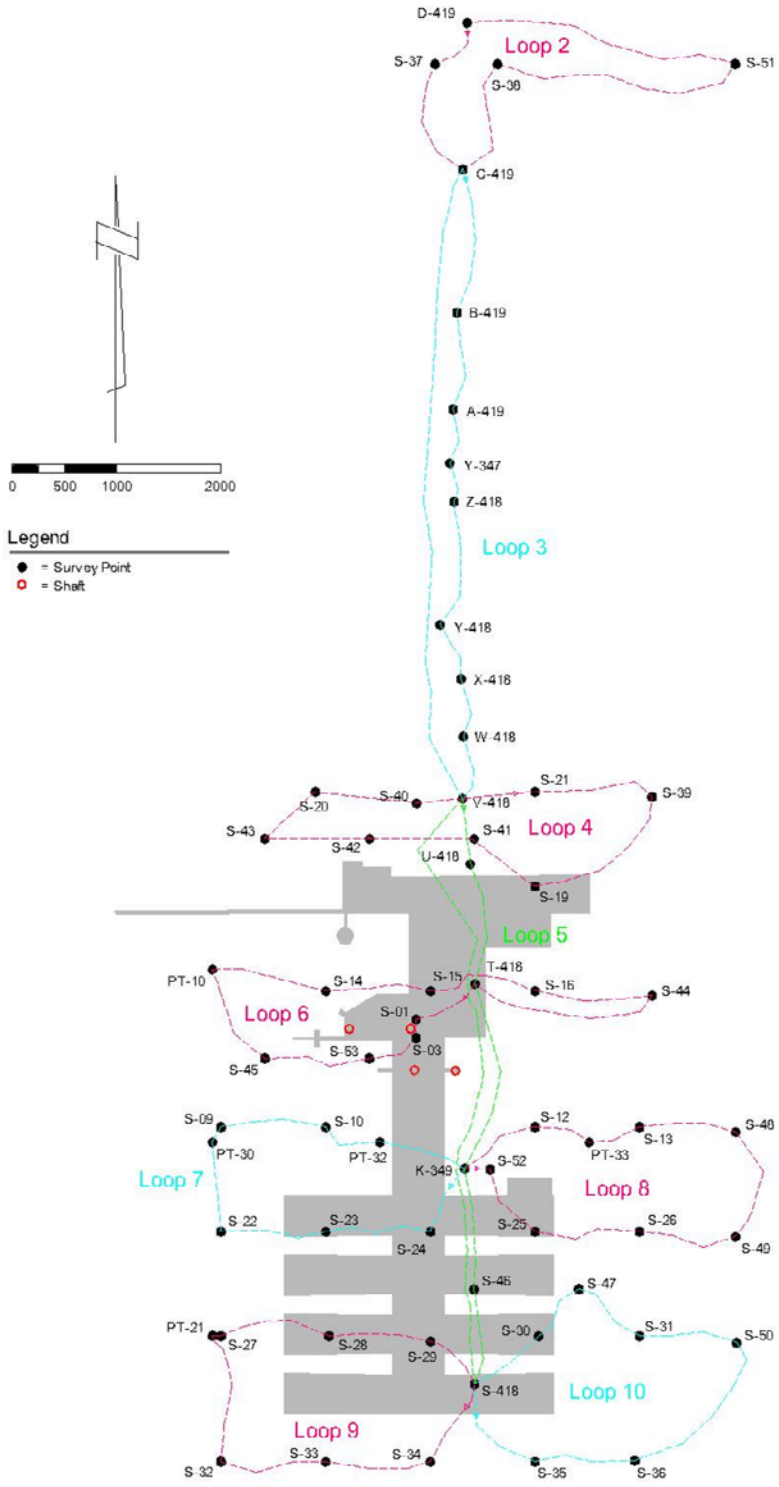


Figure 1. Individual Loops, Total Survey and Underground Excavations

5. General Summary of Results

Table A below describes the nine leveling loops that were measured to obtain the elevations of the subsidence monuments. The table contains the start date of the observations, a loop number, and the points that are contained within the loop. Due to construction east of the site, the nine loops were not surveyed in the usual order.

Table A. Description of 2018 Leveling Loops

Start Date (DOY)	Loop	Points
September 19, 2018 (262)	2	D-419, S-37, C-419, S-38, S-51, D-419
September 24, 2018 (267)	3	C-419, B-419, A-419, Y-347, Z-418, Y-418, X-418, W-418, V-418, C-419
October 25, 2018 (298)	4	V-418, S-21, S-39, S-19, S-41, S-42, S-43, S-20, S-40, V-418
September 11, 2018 (254)	5	V-418, U-418, T-418, K-349, S-46, S-418, V-418
October 30, 2018 (303)	6	T-418, S-01, S-03, S-53, S-45, PT-10, S-14, S-15, S-16, S-44, T-418
October 9, 2018 (282)	7	K-349, S-24, S-23, S-22, PT-30, S-09, S-10, PT-32, K-349
September 6, 2018 (249)	8	K-349, S-52, S-25, S-26, S-49, S-48, S-13, PT-33, S-12, K-349
October 16, 2018 (289)	9	S-418, S-34, S-33, S-32, PT-21, S-27, S-28, S-29, S-418
October 23,2018 (296)	10	S-418, S-35, S-36, S-50, S-31, S-47, S-30, S-418

Table B summarizes the results of the leveling loops in terms of vertical closure and accuracy. The requirement for Second Order Class II loop closure accuracy was achieved in all cases.

Table B. Summary of Distance and Accuracy for 2018 Leveling Loops

Loop	Cumulative Distance (ft.)	Vertical Closure (ft.)	Accuracy (ft.√mile)	Allowable Accuracy (ft.√mile)
2	7,738.42	-0.0019	0.002	0.040
3	12,578.37	0.0014	0.001	0.051
4	8281.79	-0.0088	0.007	0.041
5	13,269.15	-0.0055	0.003	0.052
6	9,954.29	0.0001	<0.001	0.045
7	6382.04	-0.0029	0.003	0.036
8	7246.41	0.0008	0.001	0.039
9	7355.29	-0.0022	0.002	0.039
10	7,020.55	-0.0059	0.005	0.038

5.1 Accuracy Summary by Loop

Table C displays a detailed summary of the observations in the leveling loops for the 2018 survey. All results are displayed in feet. The information in the table for each loop includes:

Between each benchmark in the loop:

- The distance leveled between benchmarks along the loop.
- The number of instrument setups between each of the benchmarks.
- The difference in adjusted elevation from each benchmark to the next.

For each loop as a whole:

- The cumulative, or total, distance of each loop.
- The vertical closure of the loop.
- The accuracy of leveling.
- Allowable accuracy for each loop.

The accuracy of the leveling is given in terms of feet times the square root of the length of the loop in miles. The actual accuracy of leveling is computed by hand, and is based on the actual vertical closure of the loop. The maximum allowable accuracy is based on the allowable accuracy of a loop as stated in the FGCS specification for digital leveling. The FGCS specification for Second Order Class II loop closure permits a maximum of 8mm$\sqrt{}$Km (8mm times the square root of the length of the loop in Km). This converts to 0.033 ft.$\sqrt{}$mile (0.033 feet times the square root of the length of the loop in miles) when stated in the English System. All values indicated in this summary are expressed in feet.

Inspection of the following tables displays that in every case the actual accuracy is well below the maximum allowable accuracy for each loop. The column in each table that is labeled “Difference” is the vertical difference from one point to the next. It is important to note that the vertical difference figures are calculated from the adjusted point elevations and because of rounding, the algebraic sum of the column may not be zero.

Table C. Detailed Loop Measurements

Loop 2

From	To	Distance	Setups	Difference
D-419	S-37	507.02	4	0.621
S-37	C-419	1166.02	8	13.802
C-419	S-38	1061.62	8	-7.914
S-38	S-51	2292.69	16	7.940
S-51	D-419	2711.07	18	-14.449
Cumulative Distance:		7,738.42		
Vertical Closure:				-0.0019
Accuracy of Leveling:				0.002
Allowable Accuracy:				0.040

Loop 3

From	To	Distance	Setups	Difference
C-419	B-419	1423.25	8	12.167
B-419	A-419	960.68	6	4.891
A-419	Y-347	531.29	4	0.560
Y-347	Z-418	384.30	4	5.804
Z-418	Y-418	1288.52	8	4.002
Y-418	X-418	579.81	4	-9.118
X-418	W-418	578.15	4	-6.702
W-418	V-418	608.87	4	-12.822
V-418	C-419	6223.50	42	1.217
Cumulative Distance:		12578.37		
Vertical Closure:				0.0014
Accuracy of Leveling:				0.001
Allowable Accuracy:				0.051

Loop 4

From	To	Distance	Setups	Difference
V-418	S-21	723.84	6	5.460
S-21	S-39	1127.05	8	-3.785
S-39	S-19	1415.31	8	-12.074
S-19	S-41	767.16	6	4.779
S-41	S-42	1122.48	8	-2.625
S-42	S-43	1002.96	8	-4.404
S-43	S-20	664.67	6	10.508
S-20	S-40	1013.36	8	0.099
S-40	V-418	444.96	4	2.043
Cumulative Distance:		8281.79		
Vertical Closure:				-0.0088
Accuracy of Leveling:				0.007
Allowable Accuracy:				0.041

Loop 5

From	To	Distance	Setups	Difference
V-418	U-418	669.97	6	-10.242
U-418	T-418	1203.80	8	-9.460
T-418	K-349	2675.48	18	-12.848
K-349	S-46	1163.92	8	-4.557
S-46	S-418	942.99	8	1.990
S-418	V-418	6612.99	46	35.117
Cumulative Distance:		13269.15		
Vertical Closure:				-0.0055
Accuracy of Leveling:				0.003
Allowable Accuracy:				0.052

Loop 6

From	To	Distance	Setups	Difference
T-418	S-01	768.20	6	-7.328
S-01	S-03	185.61	2	-0.804
S-03	S-53	540.41	4	-0.041
S-53	S-45	1178.19	8	-8.209
S-45	PT-10	1171.60	8	7.286
PT-10	S-14	1218.81	8	3.587
S-14	S-15	1003.88	6	1.738
S-15	S-16	1009.12	8	8.247
S-16	S-44	1136.85	8	6.859
S-44	T-418	1741.62	14	-11.334
Cumulative Distance:		9954.29		
Vertical Closure:				0.0001
Accuracy of Leveling:				<0.001
Allowable Accuracy:				0.045

Loop 7

From	To	Distance	Setups	Difference
K-349	S-24	777.26	6	-2.267
S-24	S-23	1030.99	8	-6.034
S-23	S-22	1022.70	8	-7.867
S-22	PT-30	861.72	6	4.964
PT-30	S-09	176.21	2	1.296
S-09	S-10	1096.21	8	8.277
S-10	PT-32	555.52	4	1.713
PT-32	K-349	861.43	6	-0.083
Cumulative Distance:		6382.04		
Vertical Closure:				-0.0029
Accuracy of Leveling:				0.003
Allowable Accuracy:				0.036

Loop 8

From	To	Distance	Setups	Difference
K-349	S-52	253.61	2	3.377
S-52	S-25	903.40	6	0.263
S-25	S-26	1020.73	6	12.262
S-26	S-49	977.51	6	12.789
S-49	S-48	1007.97	6	0.704
S-48	S-13	934.11	6	-11.048
S-13	PT-33	529.91	4	-2.526
PT-33	S-12	634.52	4	-8.184
S-12	K-349	984.65	6	-7.637
Cumulative Distance:		7246.41		
Vertical Closure:				0.0008
Accuracy of Leveling:				0.001
Allowable Accuracy:				0.039

Table C continued on next page…

Table C. Detailed Loop Measurements (continued)

Loop 9				
From	**To**	**Distance**	**Setups**	**Difference**
S-418	S-34	1033.57	6	-9.419
S-34	S-33	1026.58	6	-13.000
S-33	S-32	1083.05	8	-5.513
S-32	PT-21	1301.36	8	10.401
PT-21	S-27	106.47	2	3.350
S-27	S-28	1040.98	6	5.777
S-28	S-29	978.72	6	6.634
S-29	S-418	784.56	6	1.770
Cumulative Distance:		7355.29		
Vertical Closure:				-0.0022
Accuracy of Leveling:				0.002
Allowable Accuracy:				0.039

Loop 10				
From	**To**	**Distance**	**Setups**	**Difference**
S-418	S-35	1365.55	10	-0.916
S-35	S-36	988.90	6	9.097
S-36	S-50	1500.20	10	16.327
S-50	S-31	949.71	6	-13.649
S-31	S-47	744.42	6	-3.228
S-47	S-30	595.42	4	-5.318
S-30	S-418	876.35	8	-2.313
Cumulative Distance:		7020.55		
Vertical Closure:				-0.0059
Accuracy of Leveling:				0.005
Allowable Accuracy:				0.038

6. Adjusted Level Loops

Table D is a summary of the adjusted elevations for the nine loops measured in 2018. They have been extracted from the output of the Leica Geo Office software. These are adjusted elevations within each loop. These final adjusted elevations also appear in Table E.

Table D. Adjusted Elevations by Loop

Loop 2	
D-419	3423.253
S-37	3,423.874
C-419	3,437.676
S-38	3,429.762
S-51	3,437.702
D-419	3,423.253

Loop 3	
C-419	3437.676
B-419	3,449.843
A-419	3,454.734
Y-347	3,455.294
Z-418	3,461.098
Y-418	3,465.100
X-418	3,455.982
W-418	3,449.281
V-418	3,436.459
C-419	3,437.676

Loop 4	
V-418	3,436.459
S-21	3,441.919
S-39	3,438.134
S-19	3,426.059
S-41	3,430.839
S-42	3,428.213
S-43	3,423.809
S-20	3,434.317
S-40	3,434.416
V-418	3,436.459

Loop 5	
V-418	3,436.459
U-418	3,426.217
T-418	3,416.757
K-349	3,403.909
S-46	3,399.352
S-418	3,401.342
V-418	3,436.459

Loop 6	
T-418	3,416.757
S-01	3,409.429
S-03	3,408.625
S-53	3,408.583
S-45	3,400.374
PT-10	3,407.660
S-14	3,411.247
S-15	3,412.985
S-16	3,421.232
S-44	3,428.091
T-418	3,416.757

Loop 7	
K-349	3,403.909
S-24	3,401.642
S-23	3,395.609
S-22	3,387.742
S-09	3,394.002
S-10	3,402.279
PT-32	3,403.992
K-349	3,403.909

Loop 8	
K-349	3,403.909
S-52	3,407.286
S-25	3,407.549
S-26	3,419.811
S-49	3,432.600
S-48	3,433.304
S-13	3,422.256
PT-33	3,419.730
S-12	3,411.546
K-349	3,403.909

Loop 9	
S-418	3,401.342
S-34	3,391.923
S-33	3,378.923
S-32	3,373.410
PT-21	3,383.811
S-27	3,387.162
S-28	3,392.938
S-29	3,399.572
S-418	3,401.342

Loop 10	
S-418	3,401.342
S-35	3,400.426
S-36	3,409.524
S-50	3,425.850
S-31	3,412.201
S-47	3,408.973
S-30	3,403.655
S-418	3,401.342

7. Adjusted Elevations (2018)

Table E displays the adjusted elevations for the subsidence monuments and the NGS points contained within the 2018 survey. These elevations are normalized to the monument, S-37. All elevations are displayed in feet and are within the WIPP local coordinate system.

Table E. 2018 Adjusted Elevations

Point	Elevation (ft.)	Point	Elevation (ft.)
S-01	3,409.429	S-42	3,428.213
S-03	3,408.625	S-43	3,423.809
S-09	3,394.002	S-44	3,428.091
S-10	3,402.279	S-45	3,400.374
S-12	3,411.546	S-46	3,399.352
S-13	3,422.256	S-47	3,408.973
S-14	3,411.247	S-48	3,433.304
S-15	3,412.985	S-49	3,432.600
S-16	3,421.232	S-50	3,425.850
S-19	3,426.059	S-51	3,437.702
S-20	3,434.317	S-52	3407.286
S-21	3,441.919	S-53	3,408.583
S-22	3,387.742		
S-23	3,395.609	PT-10	3,407.660
S-24	3401.642	PT-21	3,383.811
S-25	3,407.549		
S-26	3,419.811		
S-27	3,387.162	PT-32	3,403.992
S-28	3,392.938	PT-33	3,419.730
S-29	3,399.572	S-418	3,401.342
S-30	3,403.655	T-418	3,416.757
S-31	3,412.201	U-418	3,426.217
S-32	3,373.410	V-418	3,436.459
S-33	3,378.923	W-418	3,449.281
S-34	3,391.923	X-418	3,455.982
S-35	3,400.426	Y-347	3,455.294
S-36	3,409.524	Y-418	3,465.100
S-37	3,423.874	Z-418	3,461.098
S-38	3,429.762	A-419	3,454.734
S-39	3,438.134	B-419	3,449.843
S-40	3,434.416	C-419	3,437.676
S-41	3,430.839	D-419	3,423.253
		K-349	3403.909

8. Comparison of Elevations*

Table F compares the elevations from all of the subsidence leveling surveys from 1987 through 2018**.** All elevations are displayed in feet.

Table F. Comparison of Elevations 1987-2018

	S-01	S-02	S-03	S-09	S-10	S-11	S-12	S-13	S-14
1987	3,409.738	3,408.219	3,408.914	3,394.056	3,402.466	3,406.437	3,411.790	3,422.428	3,411.500
1989	3,409.719	3,411.907	3,408.900	3,394.046	3,402.459	3,406.408	3,411.739	3,422.413	3,411.483
1992	3,409.695	3,411.904	3,408.875	3,394.053	3,402.440	3,406.372	3,411.727	3,422.412	3,411.439
1993	3,409.616	(1) (2)	3,408.797	3,393.969	3,402.365	(3)	3,411.630	3,422.324	3,411.382
1994	3,409.626		3,408.806	3,393.988	3,402.374		3,411.653	3,422.348	3,411.372
1995	3,409.613		3,408.795	3,393.986	3,402.373		3,411.650	3,422.345	3,411.376
1996	3,409.615		3,408.795	3,393.994	3,402.373		3,411.645	3,422.340	3,411.369
1997	3,409.610		3,408.793	3,394.002	3,402.379		3,411.656	3,422.349	3,411.368
1998	3,409.617		3,408.802	3,394.011	3,402.388		3,411.653	3,422.352	3,411.374
1999	3,409.613		3,408.798	3,394.004	3,402.385		3,411.650	3,422.358	3,411.365
2000	3,409.607		3,408.792	3,394.003	3,402.381		3,411.644	3,422.352	3,411.364
2001	3,409.599		3,408.786	3,394.006	3402.378		3,411.636	3,422.350	3,411.361
2002	3,409.595		3,408.783	3,394.012	3,402.381		3,411.637	3,422.354	3,411.357
2003	3,409.583		3,408.771	3,394.007	3,402.372		3,411.629	3,422.307	3,411.351
2004	3,409.575		3,408.762	3,394.006	3,402.373		3,411.630	3,422.310	3,411.329
2005	3,409.551		3,408.739	3,393.997	3,402.357		3,411.611	3,422.274	3,411.307
2006	3,409.539		3,408.727	3,393.992	3,402.349		3,411.603	3,422.274	3,411.301
2007	3,409.546		3,408.734	3,394.012	3,402.356		3,411.609	3,422.281	3,411.301
2008	3,409.533		3,408.722	3,394.006	3,402.350		3,411.606	3,422.284	3,411.297
2009	3,409.531		3,408.721	3,394.008	3,402.344		3,411.596	3,422.279	3,411.294
2010	3,409.513		3,408.701	3,393.999	3,402.329		3,411.586	3,422.268	3,411.287
2011	3,409.519		3,408.707	3,394.005	3,402.333		3,411.586	3,422.282	3,411.297
2012	3,409.509		3,408.699	3,393.996	3,402.319		3,411.584	3,422.273	3,411.295
2013	3,409.503		3,408.694	3,394.017	3,402.331		3,411.587	3,422.280	3,411.290
2014	3,409.481		3,408.671	3,394.012	3,402.321		3,411.577	3,422.275	3,411.279
2015	3,409.466		3,408.658	3,394.013	3,402.309		3,411.571	3,422.273	3,411.268
2016	3,409.446		3,408.639	3,394.003	3,402.295		3,411.555	3,422.262	3,411.256
2017	3,409.445		3,408.639	3,394.010	3,402.292		3,411.555	3,422.263	3,411.257
2018	3,409.429		3,408.625	3,394.002	3,402.279		3,411.546	3,422.256	3,411.247

Note: (1) The subsidence monument, S-02 was relocated in 1989.
(2) The subsidence monument, S-02, no longer exists after the 1992 survey.
(3) The subsidence monument, S-11, no longer exists after the 1992 survey.

Table F continued on next page…

Table F. Comparison of Elevations 1987-2018 (continued)

	S-15	S-16	S-17	S-18	S-19	S-20	S-21	S-22	S-23
1987	3,413.291	3,421.378	3,422.519	3,425.010	3,426.235	3,434.464	3,442.030	3,387.786	3,395.914
1989	3,413.291	3,421.341	3,422.482	3,424.974	3,426.217	3,434.452	3,442.005	3,387.795	3,395.970
1992	3,413.263	3,421.331	3,422.469	3,424.964	3,426.223	3,434.364	3,441.956	3,387.788	3,396.028
1993	3,413.185	3,421.256	3,422.404	3,424.859	3,426.136	3,434.332	3,441.919	3,387.701	3,395.853
1994	3,413.188	3,421.261	3,422.402	3,424.852	3,426.134	3,434.339	3,441.932	3,387.732	3,395.886
1995	3,413.189	3,421.261	3,422.418	3,424.864	3,426.143	3,434.342	3,441.936	3,387.727	3,395.877
1996	3,413.182	3,421.263	3,422.419	3,424.860	3,426.138	3,434.345	3,441.935	3,387.727	3,395.885
1997	3,413.178	3,421.268	3,422.431	3,424.864	3,426.141	3,434.346	3,441.937	3,387.738	3,395.889
1998	3,413.184	3,421.271	3,422.436	3,424.869	3,426.150	3,434.355	3,441.946	3,387.744	3,395.887
1999	3,413.177	3,421.275	3,422.435	3,424.865	3,426.152	3,434.362	3,441.959	3,387.729	3,395.873
2000	3,413.172	3,421.278	3,422.440	3,424.864	3,426.140	3,434.362	3,441.956	3,387.727	3,395.861
2001	3,413.167	3,421.277	3,422.434	3,424.858	3,426.138	3,434.363	3,441.956	3,387.728	3,395.857
2002	3,413.159	3,421.275	3,422.434	3,424.855	3,426.132	3,434.361	3,441.950	3,387.731	3,395.857
2003	3,413.152	3,421.279	3,422.430	3,424.849	3,426.117	3,434.350	3,441.939	3,387.728	3,395.850
2004	3,413.142	3,421.281	(4)	(5)	3,426.128	3,434.359	3,441.955	3,387.727	3,395.841
2005	3,413.118	3,421.268			3,426.107	3,434.343	3,441.941	3,387.720	3,395.826
2006	3,413.109	3,421.269			3,426.101	3,434.338	3,441.937	3,387.711	3,395.815
2007	3,413.113	3,421.280			3,426.105	3,434.346	3,441.947	3,387.730	3,395.823
2008	3,413.099	3,421.274			3,426.104	3,434.344	3,441.945	3,387.721	3,395.810
2009	3,413.093	3,421.283			3,426.107	3,434.347	3,441.950	3,387.726	3,395.802
2010	3,413.083	3,421.271			3,426.088	3,434.331	3,441.936	3,387.716	3,395.768
2011	3,413.088	3,421.280			3,426.095	3,434.345	3,441.944	3,387.724	3,395.748
2012	3,413.073	3,421.274			3,426.092	3,434.345	3,441.945	3,387.715	3,395.724
2013	3,413.065	3,421.273			3,426.085	3,434.340	3,441.935	3,387.735	3,395.727
2014	3,413.042	3,421.259			3,426.073	3,434.334	3,441.927	3,387.721	3,395.694
2015	3,413.028	3,421.252			3,426.074	3,434.333	3,441.931	3,387.730	3,395.674
2016	3,413.007	3,421.237			3,426.061	3,434.320	3,441.919	3,387.736	3,395.643
2017	3,413.005	3,421.241			3426.068	3434.325	3441.924	3387.752	3395.632
2018	3,412.985	3,421.232			3,426.059	3,434.317	3,441.919	3,387.742	3,395.609

Note: (4) The subsidence monument, S-17, no longer exists after the 2003 survey.
(5) The subsidence monument, S-18, no longer exists after the 2003 survey.

Table F continued on next page…

Table F. Comparison of Elevations 1987-2018 (continued)

	S-24	S-25	S-26	S-27	S-28	S-29	S-30	S-31	S-32
1987	3,402.201	3,408.036	3,420.010	3,387.280	3,393.414	3,400.111	3,404.082	3,412.315	3,373.513
1989	3,402.167	3,408.005	3,419.978	3,387.287	3,393.400	3,400.098	3,404.064	3,412.302	3,373.498
1992	3,402.159	3,407.974	3,419.948	3,387.310	3,393.421	3,400.113	3,404.073	3,412.303	3,373.533
1993	3,402.042	3,407.870	3,419.854	3,387.181	3,393.287	3,400.008	3,403.958	3,412.206	3,373.396
1994	3,402.072	3,407.907	3,419.883	3,387.225	3,393.312	3,400.038	3,403.984	3,412.234	3,373.427
1995	3,402.062	3,407.895	3,419.871	3,387.216	3,393.309	3,400.031	3,403.978	3,412.230	3,373.425
1996	3,402.074	3,407.897	3,419.875	3,387.213	3,393.316	3,400.037	3,403.979	3,412.221	3,373.411
1997	3,402.077	3,407.897	3,419.883	3,387.229	3,393.330	3,400.050	3,403.994	3,412.248	3,373.438
1998	3,402.076	3,407.902	3,419.883	3,387.248	3,393.338	3,400.059	3,403.998	3,412.248	3,373.452
1999	3,402.067	3,407.898	3,419.886	3,387.229	3,393.322	3,400.053	3,403.990	3,412.252	3,373.429
2000	3,402.051	3,407.876	3,419.871	3,387.226	3,393.316	3,400.045	3,403.980	3,412.252	3,373.428
2001	3,402.035	3,407.862	3,419.872	3,387.231	3,393.318	3,400.040	3,403.972	3,412.255	3,373.431
2002	3,402.029	3,407.858	3,419.877	3,387.231	3,393.316	3,400.034	3,403.968	3,412.258	3,373.433
2003	3,402.012	3,407.840	3,419.871	3,387.233	3,393.311	3,400.016	3,403.951	3,412.252	3,373.433
2004	3,401.995	3,407.822	3,419.870	3,387.231	3,393.310	3,399.996	3,403.932	3,412.254	3,373.439
2005	3,401.976	3,407.786	3,419.853	3,387.221	3,393.294	3,399.961	3,403.902	3,412.235	3,373.426
2006	3,401.956	3,407.762	3,419.857	3,387.207	3,393.278	3,399.930	3,403.870	3,412.221	3,373.413
2007	3,401.958	3,407.764	3,419.850	3,387.226	3,393.280	3,399.928	3,403.872	3,412.237	3,373.431
2008	3,401.929	3,407.739	3,419.850	3,387.217	3,393.260	3,399.910	3,403.848	3,412.222	3,373.421
2009	3,401.910	3,407.725	3,419.840	3,387.218	3,393.235	3,399.888	3,403.834	3,412.225	3,373.423
2010	3,401.868	3,407.700	3,419.832	3,387.202	3,393.190	3,399.846	3,403.811	3,412.218	3,373.413
2011	3,401.836	3,407.685	3,419.835	3,387.200	3,393.153	3,399.819	3,403.795	3,412.223	3,373.423
2012	3,401.804	3,407.663	3,419.830	3,387.191	3,393.118	3,399.780	3,403.768	3,412.215	3,373.413
2013	3,401.795	3,407.662	3,419.837	3,387.212	3,393.112	3,399.767	3,403.767	3,412.226	3,373.442
2014	3,401.752	3,407.634	3,419.828	3,387.190	3,393.068	3,399.718	3,403.735	3,412.216	3,373.432
2015	3,401.732	3,407.617	3,419.829	3,387.191	3,393.044	3,399.688	3,403.722	3,412.227	3,373.433
2016	3,401.694	3,407.586	3,419.816	3,387.174	3,393.000	3,399.639	3,403.688	3,412.200	3,373.424
2017	3,401.678	3,407.573	3,419.819	3,387.175	3,392.976	3,399.613	3,403.677	3,412.208	3,373.419
2018	3,401.642	3,407.549	3,419.811	3,387.162	3,392.938	3,399.572	3,403.655	3,412.201	3,373.410

Table F continued on next page…

Table F. Comparison of Elevations 1987-2018 (continued)

	S-33	S-34	S-35	S-36	S-37	S-38	S-39	S-40	S-41
1987	3,379.093	3,392.128	3,400.597	3,409.583					
1989	3,379.073	3,392.137	3,400.583	3,409.584	3,423.888	3,429.736			
1992	3,379.090	3,392.138	3,400.591	3,409.605	3,423.874		3,438.146	3,434.469	3,430.931
1993	3,378.975	3,392.026	3,400.478	3,409.504	3,423.874	3,429.736	3,438.110	3,434.430	3,430.888
1994	3,379.006	3,392.042	3,400.490	3,409.518	3,423.874	3,429.740	3,438.115	3,434.425	3,430.888
1995	3,379.009	3,392.042	3,400.495	3,409.520	3,423.874	3,429.739	3,438.124	3,434.437	3,430.899
1996	3,378.992	3,392.028	3,400.483	3,409.501	3,423.874	3,429.744	3,438.118	3,434.436	3,430.891
1997	3,379.019	3,392.057	3,400.516	3,409.533	3,423.874	3,429.745	3,438.127	3,434.444	3,430.894
1998	3,379.028	3,392.066	3,400.516	3,409.539	3,423.874	3,429.750	3,438.134	3,434.442	3,430.901
1999	3,379.011	3,392.056	3,400.507	3,409.539	3,423.874	3,429.751	3,438.149	3,434.445	3,430.900
2000	3,379.012	3,392.053	3,400.505	3,409.541	3,423.874	3,429.754	3,438.145	3,434.445	3,430.902
2001	3,379.014	3,392.057	3,400.509	3,409.546	3,423.874	3,429.756	3,438.145	3,434.436	3,430.898
2002	3,379.017	3,392.060	3,400.513	3,409.550	3,423.874	3,429.757	3,438.142	3,434.437	3,430.897
2003	3,379.016	3,392.057	3,400.511	3,409.546	3,423.874	3,429.760	3,438.130	3,434.425	3,430.892
2004	3,379.020	3,392.055	3,400.514	3,409.549	3,423.874	3429.761	3,438.152	3,434.449	3,430.900
2005	3,379.011	3,392.035	3,400.505	3,409.536	3,423.874	3,429.757	3,438.144	3,434.449	3,430.882
2006	3,378.994	3,392.017	3,400.484	3,409.524	3,423.874	3,429.757	3,438.145	3,434.448	3,430.881
2007	3,379.001	3,392.022	3,400.492	3,409.536	3,423.874	3,429.763	3,438.143	3,434.450	3,430.882
2008	3,378.988	3,392.006	3,400.476	3,409.530	3,423.874	3,429.759	3,438.145	3,434.442	3,430.878
2009	3,378.979	3,391.999	3,400.469	3,409.535	3,423.874	3,429.758	3,438.150	3,434.439	3,430.884
2010	3,378.961	3,391.982	3,400.464	3,409.532	3,423.874	3,429.751	3,438.135	3,434.426	3,430.864
2011	3,378.962	3,391.981	3,400.454	3,409.540	3,423.874	3,429.760	3,438.145	3,434.411	3,430.872
2012	3,378.949	3,391.967	3,400.446	3,409.532	3,423.874	3,429.760	3,438.152	3,434.416	3,430.871
2013	3,378.972	3,391.982	3,400.457	3,409.543	3,423.874	3,429.757	3,438.142	3,434.416	3,430.862
2014	3,378.959	3,391.965	3,400.451	3,409.537	3,423.874	3,429.757	3,438.148	3,434.422	3,430.859
2015	3,378.957	3,391.961	3,400.451	3,409.538	3,423.874	3,429.763	3,438.142	3,434.426	3,430.854
2016	3,378.937	3,391.939	3,400.439	3,409.522	3,423.874	3,429.761	3,438.139	3,434.426	3,430.846
2017	3,378.935	3,391.937	3,400.434	3409.527	3423.874	3429.762	3438.134	3434.424	3430.846
2018	3,378.923	3,391.923	3,400.426	3,409.524	3,423.874	3,429.762	3,438.134	3,434.416	3,430.839

Table F continued on next page…

Table F. Comparison of Elevations 1987-2018 (continued)

	S-42	S-43	S-44	S-45	S-46	S-47	S-48	S-49	S-50
1987									
1989									
1992	3,428.279	3,423.849	3,428.146	3,400.501	3,399.946	3,409.236	3,433.308	3,432.635	3,425.868
1993	3,428.230	3,423.813	3,428.070	3,400.406	3,399.837	3,409.133	3,433.238	3,432.572	3,425.809
1994	3,428.228	3,423.820	3,428.066	3,400.419	3,399.865	3,409.163	3,433.264	3,432.596	3,425.830
1995	3,428.238	3,423.826	3,428.071	3,400.424	3,399.856	3,409.158	3,433.258	3,432.588	3,425.830
1996	3,428.238	3,423.823	3,428.078	3,400.423	3,399.856	3,409.157	3,433.256	3,432.585	3,425.816
1997	3,428.249	3,423.815	3,428.084	3,400.428	3,399.877	3,409.181	3,433.274	3,432.600	3,425.846
1998	3,428.252	3,423.822	3,428.086	3,400.440	3,399.876	3,409.178	3,433.276	3,432.598	3,425.838
1999	3,428.255	3,423.825	3,428.091	3,400.435	3,399.866	3,409.176	3,433.289	3,432.611	3,425.851
2000	3,428.254	3,423.820	3,428.095	3,400.434	3,399.842	3,409.168	3,433.288	3,432.606	3,425.854
2001	3,428.247	3,423.818	3,428.094	3,400.433	3,399.824	3,409.163	3,433.290	3,432.606	3,425.858
2002	3,428.246	3,423.815	3,428.097	3,400.435	3,399.818	3,409.160	3,433.297	3,432.613	3,425.863
2003	3,428.236	3,423.805	3,428.090	3,400.430	3,399.790	3,409.147	3,433.294	3,432.610	3,425.857
2004	3,428.254	3,423.814	3,428.105	3,400.440	3,399.770	3,409.149	3,433.311	3,432.620	3,425.876
2005	3,428.243	3,423.798	3,428.093	3,400.421	3,399.745	3,409.114	3,433.297	3,432.603	3,425.855
2006	3,428.242	3,423.795	3,428.097	3,400.415	3,399.718	3,409.096	3,433.310	3,432.617	3,425.854
2007	3,428.244	3,423.802	3,428.099	3,400.417	3,399.705	3,409.095	3,433.306	3,432.612	3,425.866
2008	3,428.242	3,423.802	3,428.100	3,400.415	3,399.675	3,409.079	3,433.321	3,432.623	3,425.859
2009	3,428.245	3,423.818	3,428.099	3,400.414	3,399.643	3,409.064	3,433.306	3,432.611	3,425.856
2010	3,428.227	3,423.819	3,428.087	3,400.399	3,399.605	3,409.048	3,433.301	3,432.608	3,425.852
2011	3,428.236	3,423.832	3,428.094	3,400.412	3,399.565	3,409.041	3,433.310	3,432.616	3,425.860
2012	3,428.236	3,423.833	3,428.097	3,400.414	3,399.526	3,409.027	3,433.308	3,432.610	3425.857
2013	3,428.228	3,423.830	3,428.096	3,400.419	3,399.519	3,409.030	3,433.307	3,432.611	3,425.860
2014	3,428.229	3,423.825	3,428.098	3,400.414	3,399.485	3,409.022	3,433.314	3,432.612	3,425.864
2015	3,428.224	3,423.823	3,428.100	3,400.405	3,399.453	3,409.020	3,433.309	3,432.611	3,425.876
2016	3,428.217	3,423.811	3,428.090	3,400.381	3,399.420	3,408.993	3,433.310	3,432.604	3,425.851
2017	3428.218	3423.817	3,428.094	3,400.380	3,399.386	3,408.981	3,433.306	3,432.606	3,425.852
2018	3,428.213	3,423.809	3,428.091	3,400.374	3,399.352	3,408.973	3,433.304	3,432.600	3,425.850

Table F continued on next page…

Table F. Comparison of Elevations 1987-2018 (continued)

	S-51	S-52	S-53	S-54	PT-10	PT-21	PT-30	PT-31	PT-32
1987									
1989									
1992	3,437.765	3,407.611	3,408.775	3,411.085	3,407.722		3,392.914	3,385.117	3,404.370
1993	3,437.746	3,407.523	3,408.670	(6)	3,407.664	3,383.821	3,392.823	3,385.027	3,404.296
1994	3,437.749	3,407.542	3,408.709		3,407.672	3,383.868	3,392.843	3,385.051	3,404.311
1995	3,437.746	3,407.542	3,408.702		3,407.671	3,383.862	3,392.844	3,385.050	3,404.322
1996	3,437.729	3,407.536	3,408.704		3,407.669	3,383.858	3,392.852	3,385.053	3,404.312
1997	3,437.725	3,407.544	3,408.702		3,407.675	3,383.874	3,392.857	3,385.063	3,404.321
1998	3,437.724	3,407.549	3,408.714		3,407.687	3,383.887	(7)	3,385.067	3,404.322
1999	3,437.729	3,407.544	3,408.709		3,407.689	3,383.868		3,385.053	3,404.315
2000	3,437.729	3,407.531	3,408.704		3,407.685	3,383.868		3,385.053	3,404.306
2001	3,437.731	3,407.522	3,408.701		3,407.687	3,383.874		3,385.053	3,404.259
2002	3,437.733	3,407.521	3,408.700		3,407.688	3,383.871		3,385.057	3,404.250
2003	3,437.731	3,407.507	3,408.690		3,407.685	3,383.874		3,385.054	3,404.234
2004	3,437.730	3,407.501	3,408.686		3,407.685	3,383.874		(8)	3,404.172
2005	3,437.720	3,407.473	3,408.667		3,407.669	3,383.862			3,404.152
2006	3,437.720	3,407.461	3,408.659		3,407.667	3,383.848			3,404.138
2007	3,437.720	3,407.458	3,408.666		3,407.670	3,383.866			3,404.146
2008	3,437.720	3,407.445	3,408.659		3,407.669	3,383.857			3,404.132
2009	3,437.721	3,407.432	3,408.656		3,407.673	3,383.858			3,404.124
2010	3,437.705	3,407.408	3,408.640		3,407.665	3,383.841			3,404.101
2011	3,437.717	3,407.407	3,408.650		3,407.678	3,383.838			3,404.097
2012	3,437.715	3,407.388	3,408.645		3,407.681	3,383.834			3,404.076
2013	3,437.708	3,407.386	3,408.644		3,407.685	3,383.857			3,404.079
2014	3,437.710	3,407.367	3,408.625		3,407.677	3,383.840			3,404.058
2015	3,437.708	3,407.342	3,408.614		3,407.673	3,383.841			3,404.045
2016	3,437.700	3,407.322	3,408.597		3,407.662	3,383.825			3,404.019
2017	3437.704	3,407.307	3,408.597		3,407.668	3,383.823			3,404.013
2018	3,437.702	3,407.286	3,408.583		3,407.660	3,383.811			3,403.992

Note: (6) The subsidence monument, S-54, no longer exists after the 1992 survey.
(7) The monument, PT-30, has been physically disturbed and was removed from the 1998 survey.
(8) The monument, PT-31, has been physically disturbed and was removed from the 2004 survey.

Table F continued on next page…

Table F. Comparison of Elevations 1987-2018 (continued)

	PT-33	S-418	T-418	U-418	V-418	W-418	X-418	Y-347	Y-418
1987									
1989									
1992	3,419.939								
1993	3,419.853								
1994	3,419.884								
1995	3,419.869								
1996	3,419.865	3,401.696	3,416.902	3,426.267	3,436.481	3,449.276	3,455.969	3,455.274	3,465.080
1997	3,419.873	3,401.708	3,416.906	3,426.272	3,436.487	3,449.282	3,455.976	3,455.281	3,465.091
1998	3,419.879	3,401.715	3,416.915	3,426.279	3,436.497	3,449.292	3,455.987	3,455.291	3,465.101
1999	3,419.880	3,401.707	3,416.913	3,426.275	3,436.500	3,449.304	3,456.000	3,455.304	3,465.117
2000	3,419.872	3,401.702	3,416.911	3,426.273	3,436.502	3,449.307	3,456.005	3,455.309	3,465.123
2001	3,419.866	3,401.702	3,416.905	3,426.270	3,436.502	3,449.310	3,456.007	3,455.312	3,465.125
2002	3,419.868	3,401.701	3,416.901	3,426.269	3,436.502	3,449.311	3,456.009	3,455.314	3,465.126
2003	3,419.866	3,401.685	3,416.892	3,426.264	3,436.500	3,449.308	3,456.007	3,455.312	3,465.125
2004	3,419.855	3,401.670	3,416.887	3,426.265	3,436.499	3,449.310	3,456.009	3,455.315	3,465.126
2005	3,419.789	3,401.634	3,416.868	3,426.252	3,436.485	3,449.295	3,455.993	3,455.301	3,465.113
2006	3,419.784	3,401.605	3,416.860	3,426.247	3,436.481	3,449.290	3,455.991	3,455.300	3,465.111
2007	3,419.788	3,401.604	3,416.865	3,426.258	3,436.491	3,449.302	3,456.003	3,455.311	3,465.122
2008	3,419.785	3,401.580	3,416.857	3,426.259	3,436.490	3,449.301	3,456.000	3,455.307	3,465.120
2009	3,419.783	3,401.562	3,416.853	3,426.261	3,436.493	3,449.307	3,456.006	3,455.312	3,465.125
2010	3,419.771	3,401.531	3,416.840	3,426.246	3,436.477	3,449.293	3,455.994	3,455.301	3,465.113
2011	3,419.778	3,401.515	3,416.841	3,426.259	3,436.487	3,449.306	3,456.006	3,455.317	3,465.125
2012	3,419.765	3,401.487	3,416.828	3,426.257	3,436.488	3,449.308	3,456.009	3,455.317	3,465.129
2013	3,419.776	3,401.480	3,416.819	3,426.249	3,436.479	3,449.296	3,455.995	3,455.303	3,465.110
2014	3,419.763	3,401.446	3,416.801	3,426.240	3,436.473	3,449.294	3,455.995	3,455.305	3,465.111
2015	3,419.754	3,401.426	3,416.789	3,426.235	3,436.473	3,449.291	3,455.992	3,455.302	3,465.109
2016	3,419.736	3,401.388	3,416.770	3,426.219	3,436.459	3,449.279	3,455.982	3,455.293	3,465.100
2017	3,419.736	3,401.372	3,416.772	3,426.226	3,436.466	3,449.286	3,455.989	3,455.299	3,465.105
2018	3,419.730	3,401.342	3,416.757	3,426.217	3,436.459	3,449.281	3,455.982	3,455.294	3,465.100

Table F continued on next page…

Table F. Comparison of Elevations 1987-2018 (continued)

	Z-418	A-419	B-419	C-419	D-419	K-349			
1987									
1989									
1992									
1993									
1994									
1995									
1996	3,461.073	3,454.714	3,449.825	3,437.633	3,423.234	3,404.152			
1997	3,461.082	3,454.720	3,449.829	3,437.642	3,423.238	3,404.162			
1998	3,461.091	3,454.730	3,449.835	3,437.648	3,423.242	3,404.173			
1999	3,461.105	3,454.744	3,449.848	3,437.657	3,423.247	3,404.169			
2000	3,461.109	3,454.749	3,449.853	3,437.660	3,423.250	3,404.157			
2001	3,461.111	3,454.752	3,449.856	3,437.663	3,423.254	3,404.152			
2002	3,461.113	3,454.754	3,449.857	3,437.665	3,423.256	3,404.150			
2003	3,461.112	3,454.752	3,449.856	3,437.665	3,423.256	3,404.137			
2004	3,461.117	3,454.754	3,449.858	3,437.668	3,423.257	3,404.127			
2005	3,461.108	3,454.742	3,449.848	3,437.663	3,423.243	3,404.105			
2006	3,461.108	3,454.739	3,449.846	3,437.664	3,423.243	3,404.091			
2007	3,461.117	3,454.749	3,449.855	3,437.673	3,423.248	3,404.096			
2008	3,461.112	3,454.747	3,449.854	3,437.673	3,423.250	3,404.081			
2009	3,461.117	3,454.752	3,449.857	3,437.675	3,423.251	3,404.073			
2010	3,461.109	3,454.741	3,449.846	3,437.666	3,423.240	3,404.047			
2011	3,461.122	3,454.757	3,449.861	3,437.682	3,423.253	3,404.042			
2012	3,461.124	3,454.758	3,449.861	3,437.682	3,423.255	3,404.022			
2013	3,461.106	3,454.744	3,449.850	3,437.674	3,423.251	3,404.020			
2014	3,461.107	3,454.743	3,449.849	3,437.673	3,423.255	3,403.990			
2015	3,461.106	3,454.742	3,449.849	3,437.677	3,423.254	3,403.971			
2016	3,461.098	3,454.731	3,449.838	3,437.668	3,423.243	3,403.941			
2017	3461.104	3454.740	3449.848	3437.679	3423.253	3403.932			
2018	3,461.098	3,454.734	3,449.843	3,437.676	3,423.253	3,403.909			

* The 1986 elevations that appear in all reports prior to the 2001 report are from a report filed by Jerry Williams (3/89), Geoscience Department. Those elevations were, in turn, taken from the 1987 data, rounded to two decimal places and referenced as 1986. When this was discovered it was decided to remove the 1986 information from all subsequent reports.