JUL 9 1999

SANDIA REPORT

SAND99-1478

Unlimited Release

Printed June 1999

Analysis of Subsidence Data for the Big Hill Site, Texas

RECEIVED
JUL 21 1999
OSTI

Stephen J. Bauer

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia is a multiprogram laboratory operated by Sandia Corporation,
a Lockheed Martin Company, for the United States Department of
Energy under Contract DE-AC04-94AL85000.

Approved for public release; further dissemination unlimited.

Sandia National Laboratories

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represent that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof, or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof, or any of their contractors.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Prices available from (703) 605-6000
Web site: <http://www.ntis.gov/ordering.htm>

Available to the public from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Rd
Springfield, VA 22161

NTIS price codes
Printed copy: A03
Microfiche copy: A01

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

SAND99-1478
Unlimited Release
Printed June 1999

Analysis of Subsidence Data for the Big Hill Site, Texas

Stephen J. Bauer
Underground Storage Technology

Sandia National Laboratories
P.O.Box 5800
Albuquerque, NM 87185-0706

ABSTRACT

The elevation change data measured at the Big Hill SPR site over the last 10 years has been studied and a model utilized to project elevation changes into the future. The subsidence rate at Big Hill is low in comparison with other Strategic Petroleum Reserve sites and has decreased with time due to the maintenance of higher operating pressures and the normal decrease in creep closure rate of caverns with time. However, the subsidence at the site is projected to continue. A model was developed to project subsidence values 20 years into the future; no subsidence related issues are apparent from these projections.

TABLE OF CONTENTS

	Page
ABSTRACT	1
TABLE OF CONTENTS	2
FIGURES	3
INTRODUCTION	4
RESULTS AND ANALYSES	7
DISCUSSION AND CONCLUSIONS	13
REFERENCES	14
APPENDIX 1: Measured and Projected Elevations at Big Hill	15
APPENDIX 2: Calculated Historical Subsidence Rates at Big Hill	16
APPENDIX 3: Fitting Parameters for Long Term Subsidence Prediction	18
DISTRIBUTION	19

FIGURES

Figure	Page
1. Top of caprock contour map at Big Hill	5
2. Big Hill salt dome structure map, including top of salt contours, shear zone and salt spine locations	6
3. Big Hill site measured elevations (feet), April, 1989	7
4. Big Hill site measured elevations (feet), May, 1995	8
5. Big Hill site measured elevations (feet), January, 1999	8
6. Big Hill subsidence rate, 4/89-5/94 (ft/yr)	9
7. Big Hill subsidence rate, 5/94-1/99 (ft/yr)	9
8. Examples of exponential decay fit for stations "5" and "BH 114B"	11
9. Big Hill site projected elevations (feet) for the year 2004	12
10. Big Hill site projected elevations (feet) for the year 2009	12
11. Big Hill site projected elevations (feet) for the year 2019	13

INTRODUCTION

The subsidence monument elevations at the Big Hill Strategic Petroleum Reserve (SPR) site have been surveyed nine times beginning in April, 1989. The earlier survey data has been most recently reported on by Osnes (1995). This report provides an update which includes additional measurements completed in the past few years. The changes in elevation, the rates of subsidence, as well as projections of future elevation changes are presented. Elevation data were most recently collected at the Big Hill site in January 1999. Data are used by the cavern engineer and other site personnel in assuring certain aspects of site integrity, for example how to plan for periodic inundation.

At Big Hill and other SPR sites in general, elevation changes are measured because they document surface subsidence resulting from creep closure of caverns. General subsidence on the scale of the site or portions thereof is seen in the survey data taken. This type of subsidence will capture gross effects of creep closure of underground openings in response to the state of stress in the salt surrounding the caverns. However, the measured long term subsidence provided by the surveys is important, especially because it permits the long term extrapolation of elevation changes into the future.

Elevation data represents the raw data. The most recent data set included 32 stations. The number of data points varies from year to year because it is a function of ability to find monuments, destruction of monuments, damage to monuments, etc. The measurements have been made at various time intervals; the current time interval is about two years.

In practice, measurements of subsidence are difficult at best. At Big Hill the reference is an off-site benchmark located close to the site (to the northwest of the DOE property). This introduces some small error in traversing the distance to the site. The leveling surveys are performed to Second-Order First-Class accuracy, with allowable vertical closure not to exceed approximately $0.025 \text{ ft/mile}^{0.5}$ (Osnes, 1995).

A layout of the site with cavern locations is given in Figure 1. This together with Figure 2 allows one to understand the impact (on the order of 1000 ft) of the thick caprock at Big Hill. It is likely that the thick caprock provides stability at the surface, even in the presence of subterranean creep closure of caverns. It is unclear exactly how the caprock's presence effects subsidence; its fracture and faulted condition is difficult to analyze. However, we know that the creep closure rate is on par with those at West Hackberry (Ehgartner, 1997) where the subsidence rate is much higher. For comparable cavern ages, the subsidence rate at West Hackberry was approximately 0.25 ft/yr (Bauer, 1997), whereas this study shows the Big Hill rate to be an order of magnitude less.

Figure 2. Big Hill salt dome structure map, including top of salt contours, shear zone and salt spine locations (Magorian and Neal, 1988).

RESULTS AND ANALYSES

As evidenced by the similarity between Figures 3-5, and data listed in Appendix 1, the elevation at the Big Hill SPR facility has changed very little during the past 10 years. The ground surface at the site has subsided on the average about 0.3 feet during the past 10 years. The data control (number of stations) is sparse at Big Hill. Most stations are located on well heads, thus the elevations reported are for well head elevations, not the ground level. This location of stations on well heads is common for SPR sites, because of the convenience. These elevations are known distances above the actual ground surface; their location does not effect the elevation change from measurement to measurement.

Figure 3. Big Hill site measured elevations (feet), April 1989.

Figure 4. Big Hill site measured elevations (feet), May, 1995.

Figure 5. Big Hill site measured elevations (feet), January, 1999.

The rate of subsidence was studied to determine the uniformity of subsidence rates across the site. Local areas of greater subsidence rates may be signals of abnormal creep closure behavior, leaching of salt, and/or shifting of the caprock. The rate of subsidence is calculated by dividing the amount of elevation change in a time period by the time span of the period in years. This calculation was made for each time period between measurements and is presented in Appendix 2. The rate of subsidence has decreased during the measurement period. For the first five years of measurement the site was subsiding at about 0.02 to 0.05 feet per year (Figure 6); for the last five years the rate has decreased to 0.02 to 0.03 feet per year (Figure 7). This decrease is probably due to the operational procedure adopted of maintaining the caverns at relatively high operating pressure and the corresponding decrease in creep closure rate of the caverns with time. Transient creep effects are also diminishing with time (Ehgartner, 1992) since the earlier data reflects a time just after leaching (1990-1991).

Figure 6. Big Hill subsidence rate, 4/89-5/94 (ft/yr).

Figure 7. Big Hill subsidence rate, 5/94-1/99 (ft/yr).

It is important to develop a relationship to extrapolate changes in elevation into the future, in order to provide the DOE with important information for planning future work at the site. Such an extrapolation is possible by making use of the past history of the elevation measurements. Elevation data collected at known times at each station were fit to a first order exponential decay of the form:

$$Y = Y_0 + A_1 e^{-(x-x_0)/t_1}$$

where Y is the calculated elevation at the time of interest (x), Y_0 is the elevation at X_0 (time=0), A_1 is a constant, and t_1 is a fitting parameter.

This relationship allowed the data to be projected into the future with confidence. Examples of the data compared to the first order exponential decay relationship are given in Figure 8. Appendix 3 contains fitting parameters for equations fit to data for each measurement station allowing the reader to make projections to any time in the future.

Figure 8. Examples of exponential decay fit for stations “5” and “BH 114B”.

Projected elevations for the years 2004, 2009, and 2019 are presented in Figures 9, 10, and 11. Consistent with information already presented, it is predicted that the Big Hill site will continue to subside, but at an ever decreasing rate.

Figure 9. Big Hill site projected elevations (feet) for the year 2004. The contour interval is 2 feet.

Figure 10. Big Hill site projected elevations (feet) for the year 2009. The contour interval is 2 feet.

Figure 11. Big Hill site projected elevations (feet) for the year 2019. The contour interval is 2 feet.

DISCUSSION AND CONCLUSIONS

Big Hill is historically known for its low subsidence rates and relatively high elevations; this report echoes this historical perspective. No issues or concerns were uncovered in this analysis and review of historic and recent data.

The elevation change data at the Big Hill SPR site has been studied and a model utilized to project elevation changes 20 years into the future. This work may assist DOE in planning the construction and location of mitigative measures for operations as well as life extension.

Operationally it is prudent to continue the practice of maintaining the caverns at relatively high operating pressure. The measured subsidence rate is increased for time periods when higher cavern pressures were not maintained, and decreased for time periods when relatively high cavern pressures were maintained (this observation is more evident at older SPR sites that practiced a lower range in the operating pressure during the 1980's).

The results of analyses warrant the following conclusions:

- The subsidence rate has decreased with time due to relatively high operating pressures of caverns and the decrease in creep closure of caverns with time.
- The subsidence rate at Big Hill is low in comparison with other Strategic Petroleum Reserve sites; the subsidence at the site is projected to continue, however, if the cavern pressure is maintained at current levels, the subsidence rate can be expected to decrease.
- A model was developed to project subsidence values 20 years into the future; no subsidence related issues are apparent from these projections.

References

Bauer, S. J., 1997, "Analysis of Subsidence Data for the West Hackberry Site, Louisiana" SAND97-2036, Sandia National Laboratories, Albuquerque, NM.

Ehgartner, B., 1992, "Effects of Cavern Spacing and Pressure on Subsidence and Storage Losses for the U.S. Strategic Petroleum Reserve" SAND91-2575, Sandia National Laboratories, Albuquerque, NM.

Ehgartner, B., 1997, "SPR Ullage Study" SNL letter from Linn to Myers dated 11/25/97.

Osnes, J., 1995, "Update to subsidence analyses of SPR site for fiscal years 1993 and 1994," Re/Spec Topical Report RSI-0590 for DynMcdermott, published 3/95.

Magorian, T.R. and J. T. Neal, 1988, "Strategic Petroleum Reserve (SPR) Additional Geologic Site Characterization Studies Big Hill Salt Dome, Texas," SAND88-2267, September, 1988, Sandia National Laboratories.

Appendix 1

Measured and Projected Elevations at Big Hill

Station		SUBSIDENCE MONITORING, (ft)												
		APR 89	JAN 90 CONC	JAN 91 CONC	JAN 92	OCT 92	MAY 94	FEB 95	DEC 96	JAN 99				
RIEDEL		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0				
REF MON 2		76.78	76.78	76.78	76.78	76.78	76.78	76.78	76.78	76.78				
REF MON 4					96.82									
		Time, months	0	9	21	33	43	62	71	93	118	projected	projected	projected
	NORTH	EAST	APR 89	JAN 90	JAN 91	JAN 92	OCT 92	MAY 94	FEB 95	DEC 96	JAN 99	2004	2009	2019
5	2410.7	2154.8	94.73	94.69	94.63	94.52	94.53	94.51	94.49	94.40	94.39	94.36	94.34	94.33
6	3086.2	3516.4	96.90	96.87	96.87	96.81	96.81	96.82	96.82	96.76	96.60	96.53	96.41	96.18
7	3086.0	4486.4	94.44	94.41	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			
8	3085.1	2936.0	94.34	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			
9	1273.4	4256.3	85.30	85.26	85.20	85.04	85.02	85.01	85.01	84.91	not found	84.88	84.87	84.87
10	1273.3	3216.3	88.18	88.13	88.07	87.89	87.86	87.86	87.85	87.74	87.72	87.71	87.70	87.70
11A	2187.0	6003.5	81.65	81.64	81.61	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			
12	1790.0	4814.7	92.08	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			
13	2175.8	3242.2	92.67	92.59	92.55	#N/A	92.44	92.46	92.42	#N/A	#N/A	92.40	92.40	92.40
14	2213.9	3968.4	91.72	91.67	91.60	91.51	91.52	91.52	91.50	91.40	91.40	91.39	91.38	91.38
BH101A	2817.0	5587.6	94.24	94.25	94.22	94.13	94.16	94.17	94.16	94.11	94.13	94.12	94.12	94.11
BH101B	2817.1	5627.3	94.17	94.18	94.14	94.06	94.10	94.10	94.10	94.05	94.07	96.06	94.06	94.06
BH102A	2816.8	4837.0	95.73	95.71	95.63	95.57	95.60	95.59	95.58	95.52	95.52	95.32	95.51	95.51
BH102B	2816.8	4877.0	95.67	95.67	95.59	95.52	95.56	95.55	95.53	95.47	95.47	95.47	95.47	95.46
BH103A	2817.0	4087.0	96.15	96.11	96.04	95.97	96.00	95.98	95.96	95.89	95.89	95.87	95.86	95.86
BH103B	2817.0	4127.3	96.16	96.12	96.06	95.98	96.00	95.99	95.97	95.90	95.88	95.85	95.84	95.83
BH104A	2816.9	3337.4	97.02	96.96	96.89	96.79	96.83	96.80	96.77	96.70	96.69	96.68	96.67	96.67
BH104B	2816.4	3377.4	97.14	97.09	97.00	96.91	96.96	96.92	96.90	96.83	96.79	96.78	96.77	96.77
BH105A	2816.8	2587.4	98.66	98.60	98.53	98.44	98.45	98.45	98.42	98.35	98.35	98.34	98.34	98.93
BH105B	2816.9	2626.9	98.67	98.62	98.55	98.45	98.47	98.46	98.46	98.37	98.36	98.36	98.36	98.36
BH106A	2167.9	5211.9	91.21	91.18	91.12	91.05	91.09	91.09	91.07	91.01	91	91.02	91.02	94
BH106B	2167.9	5251.7	91.23	91.20	91.14	91.07	91.08	91.09	91.07	91.01	91.02	91.02	91.02	91
BH107A	2167.9	4461.7	97.67	97.61	97.54	97.47	97.49	97.48	97.47	#N/A	97.39	97.41	97.41	97.41
BH107B	2167.9	4501.7	97.66	97.62	97.55	97.46	97.49	97.48	97.45	97.37	97.36	97.35	97.34	97.34
BH108A	2167.9	3711.7	94.69	94.63	94.54	94.44	94.49	94.47	94.42	94.34	94.3	94.34	94.34	94.34
BH108B	2167.9	3751.7	94.68	94.66	94.57	94.46	94.47	94.48	94.47	94.36	94.4	94.34	94.33	94.33
BH109A	2167.9	2961.7	96.59	96.54	96.47	96.35	96.38	96.36	96.34	96.24	96.25	96.23	96.22	96.22
BH109B	2167.9	3001.7	96.65	96.60	96.52	96.41	96.44	96.44	96.39	96.31	96.31	96.29	96.29	96.29
BH110A	2167.9	2211.7	96.13	96.10	96.03	95.93	95.96	95.94	95.92	95.82	95.81	95.78	95.77	95.76
BH110B	2167.9	2251.7	96.16	96.10	96.02	95.90	95.94	95.92	95.88	95.80	95.79	95.78	95.78	95.78
BH111A	1518.8	4876.1	91.17	91.13	91.06	90.97	91.01	91.00	91.02	90.92	90.88	90.91	90.90	90.90
BH111B	1518.6	4835.8	91.24	91.20	91.15	91.04	91.06	91.06	91.09	90.98	90.95	90.95	90.94	90.94
BH112A	1518.6	4126.1	91.68	91.64	91.57	91.46	91.47	91.47	91.47	91.38	91.34	96.23	96.22	96.22
BH112B	1518.3	4086.0	91.70	91.64	91.58	91.47	91.48	91.48	91.49	91.39	91.35	91.35	91.34	91.34
BH113A	1518.9	3376.3	92.18	92.12	92.07	91.94	91.96	91.96	91.94	91.85	91.82	91.81	91.80	91.79
BH113B	1518.7	3335.8	92.11	92.06	92.01	91.86	91.88	91.88	91.86	91.77	91.75	91.73	91.72	91.71
BH114A	1518.9	2625.6	88.37	88.30	88.24	88.11	88.16	88.14	88.10	88.01	88.00	87.98	87.98	87.97
BH114B	1518.8	2586.3	88.53	88.47	88.42	88.30	88.35	88.33	88.28	88.20	88.19	88.16	88.14	88.14

Appendix 2

Calculated Historical Subsidence Rates at Big Hill

Elevation change (ft); Interval rate (ft/yr)

Station	NORTH	EAST	JAN 90		JAN 91		JAN 92		OCT 92		MAY 94	
			change	rate	change	rate	change	rate	change	rate	change	rate
5	2410.7	2154.8	-0.04	-0.05	-0.06	-0.06	-0.11	-0.11	0.01	0.01	-0.02	-0.01
6	3086.2	3516.4	-0.03	-0.04	0.00	0.00	-0.06	-0.06	0.00	0.00	0.01	0.01
7	3086.0	4486.4	-0.03	-0.04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
8	3085.1	2936.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
9	1273.4	4256.3	-0.05	-0.06	-0.05	-0.05	-0.16	-0.16	-0.03	-0.03	-0.01	-0.01
10	1273.3	3216.3	-0.05	-0.07	-0.06	-0.06	-0.18	-0.18	-0.04	-0.04	0.01	0.00
11A	2187.0	6003.5	-0.02	-0.02	-0.03	-0.03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
12	1790.0	4814.7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13	2175.8	3242.2	-0.08	-0.10	-0.04	-0.04	#N/A	#N/A	#N/A	#N/A	0.01	0.01
14	2213.9	3968.4	-0.05	-0.06	-0.07	-0.07	-0.09	-0.09	0.01	0.01	0.00	0.00
BH101A	2817.0	5587.6	0.01	0.01	-0.03	-0.03	-0.09	-0.09	0.03	0.04	0.01	0.00
BH101B	2817.1	5627.3	0.00	0.00	-0.03	-0.03	-0.08	-0.08	0.04	0.04	0.01	0.00
BH102A	2816.8	4837.0	-0.02	-0.03	-0.08	-0.08	0.06	0.06	0.03	0.03	-0.01	0.00
BH102B	2816.8	4877.0	-0.01	-0.01	-0.08	-0.08	-0.06	-0.06	0.03	0.04	-0.01	-0.01
BH103A	2817.0	4087.0	-0.04	-0.05	-0.07	-0.07	-0.07	-0.07	0.02	0.03	-0.02	-0.01
BH103B	2817.0	4127.3	-0.04	-0.05	-0.07	-0.07	-0.08	-0.08	0.03	0.03	-0.02	-0.01
BH104A	2816.9	3337.4	-0.06	-0.08	-0.08	-0.08	-0.09	-0.09	0.04	0.05	-0.03	-0.02
BH104B	2816.4	3377.4	-0.05	-0.07	-0.08	-0.08	-0.09	-0.09	0.05	0.06	-0.04	-0.03
BH105A	2816.8	2587.4	-0.05	-0.07	-0.07	-0.07	-0.09	-0.09	0.01	0.01	-0.01	0.00
BH105B	2816.9	2626.9	-0.05	-0.07	-0.07	-0.07	-0.10	-0.10	0.02	0.03	-0.02	-0.01
BH106A	2167.9	5211.9	-0.03	-0.04	-0.06	-0.06	-0.07	-0.07	0.04	0.04	0.01	0.00
BH106B	2167.9	5251.7	-0.02	-0.03	-0.06	-0.06	-0.07	-0.07	0.02	0.02	0.01	0.01
BH107A	2167.9	4461.7	-0.06	-0.08	-0.07	-0.07	-0.08	-0.08	0.03	0.03	-0.01	-0.01
BH107B	2167.9	4501.7	-0.04	-0.05	-0.07	-0.07	-0.09	-0.09	0.03	0.04	-0.01	-0.01
BH108A	2167.9	3711.7	-0.07	-0.09	-0.09	-0.09	-0.10	-0.10	0.05	0.06	-0.02	-0.01
BH108B	2167.9	3751.7	-0.02	-0.03	-0.09	-0.09	-0.11	-0.11	0.01	0.01	0.01	0.01
BH109A	2167.9	2961.7	-0.05	-0.07	-0.07	-0.07	-0.11	-0.11	0.02	0.03	-0.02	-0.01
BH109B	2167.9	3001.7	-0.05	-0.06	-0.08	-0.08	-0.11	-0.11	0.03	0.04	0.00	0.00
BH110A	2167.9	2211.7	-0.03	-0.04	-0.08	-0.08	-0.10	-0.10	0.03	0.04	-0.02	-0.01
BH110B	2167.9	2251.7	-0.06	-0.08	-0.08	-0.08	-0.13	-0.13	0.04	0.05	-0.02	-0.01
BH111A	1518.8	4876.1	-0.03	-0.05	-0.07	-0.07	-0.09	-0.09	0.04	0.05	-0.01	-0.01
BH111B	1518.6	4835.8	-0.04	-0.05	-0.06	-0.06	-0.11	-0.11	0.02	0.02	0.00	0.00
BH112A	1518.6	4126.1	-0.05	-0.06	-0.06	-0.06	-0.11	-0.11	0.01	0.02	-0.01	0.00
BH112B	1518.3	4086.0	-0.05	-0.07	-0.06	-0.06	-0.11	-0.11	0.01	0.01	0.00	0.00
BH113A	1518.9	3376.3	-0.06	-0.07	-0.05	-0.05	-0.13	-0.13	0.02	0.03	0.00	0.00
BH113B	1518.7	3335.8	-0.05	-0.07	-0.05	-0.05	-0.15	-0.15	0.02	0.02	0.00	0.00
BH114A	1518.9	2625.6	-0.06	-0.09	-0.06	-0.06	-0.12	-0.12	0.04	0.05	-0.02	-0.01
BH114B	1518.8	2586.3	-0.06	-0.08	-0.05	-0.05	-0.12	-0.12	0.05	0.06	-0.02	-0.01

Appendix 2 (cont.)

Calculated Historical Subsidence Rates at Big Hill

Elevation change (ft); Interval rate (ft/yr)

Station	NORTH	EAST	FEB 95 change	rate	DEC 96 change	rate	JAN 99 change	rate	Total change	rate
5	2410.7	2154.8	-0.02	-0.03	-0.09	-0.09	-0.01	-0.01	-0.33	-0.03
6	3086.2	3516.4	0.00	-0.01	-0.05	-0.05	-0.16	-0.08	-0.30	-0.03
7	3086.0	4486.4	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
8	3085.1	2936.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
9	1273.4	4256.3	0.00	0.00	-0.10	-0.10	not found	not found	-0.39	-0.04
10	1273.3	3216.3	-0.02	-0.02	-0.10	-0.10	-0.02	-0.01	-0.46	-0.05
11A	2187.0	6003.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
12	1790.0	4814.7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13	2175.8	3242.2	-0.03	-0.05	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
14	2213.9	3968.4	-0.02	-0.03	-0.10	-0.10	0.00	0.00	-0.31	-0.03
BH101A	2817.0	5587.6	-0.01	-0.01	-0.04	-0.04	0.02	0.01	-0.11	-0.01
BH101B	2817.1	5627.3	-0.01	-0.01	-0.05	-0.05	0.02	0.01	-0.11	-0.01
BH102A	2816.8	4837.0	-0.02	-0.03	-0.05	-0.05	-0.01	0.00	-0.21	-0.02
BH102B	2816.8	4877.0	-0.02	-0.03	-0.05	-0.05	0.00	0.00	-0.20	-0.02
BH103A	2817.0	4087.0	-0.02	-0.03	-0.07	-0.07	0.00	0.00	-0.27	-0.03
BH103B	2817.0	4127.3	-0.02	-0.02	-0.07	-0.07	-0.02	-0.01	-0.28	-0.03
BH104A	2816.9	3337.4	-0.03	-0.03	-0.07	-0.07	-0.01	-0.01	-0.33	-0.03
BH104B	2816.4	3377.4	-0.02	-0.03	-0.07	-0.07	-0.04	-0.02	-0.35	-0.04
BH105A	2816.8	2587.4	-0.02	-0.03	-0.08	-0.08	0.00	0.00	-0.31	-0.03
BH105B	2816.9	2626.9	0.00	0.01	-0.09	-0.09	-0.02	-0.01	-0.32	-0.03
BH106A	2167.9	5211.9	-0.02	-0.03	-0.06	-0.06	0.00	0.00	-0.20	-0.02
BH106B	2167.9	5251.7	-0.02	-0.03	-0.06	-0.06	0.02	0.01	-0.20	-0.02
BH107A	2167.9	4461.7	-0.01	-0.01	#N/A	#N/A	#N/A	#N/A	-0.28	-0.03
BH107B	2167.9	4501.7	-0.03	-0.04	-0.08	-0.08	-0.01	0.00	-0.30	-0.03
BH108A	2167.9	3711.7	-0.05	-0.06	-0.08	-0.08	0.00	0.00	-0.35	-0.036
BH108B	2167.9	3751.7	-0.02	-0.02	-0.11	-0.11	0.00	-0.32	-0.32	-0.03
BH109A	2167.9	2961.7	-0.02	-0.02	-0.10	-0.10	0.00	-0.34	-0.34	-0.03
BH109B	2167.9	3001.7	-0.05	-0.07	-0.08	-0.08	0.00	-0.35	-0.35	-0.04
BH110A	2167.9	2211.7	-0.02	-0.02	-0.10	-0.10	0.00	-0.32	-0.32	-0.03
BH110B	2167.9	2251.7	-0.04	-0.05	-0.08	-0.08	-0.01	-0.37	-0.37	-0.04
BH111A	1518.8	4876.1	0.02	0.03	-0.10	-0.10	-0.02	-0.29	-0.29	-0.03
BH111B	1518.6	4835.8	0.03	0.04	-0.11	-0.11	-0.02	-0.29	-0.29	-0.03
BH112A	1518.6	4126.1	0.01	0.01	-0.10	-0.10	-0.02	-0.34	-0.34	-0.03
BH112B	1518.3	4086.0	0.01	0.01	-0.11	-0.11	-0.02	-0.34	-0.34	-0.03
BH113A	1518.9	3376.3	-0.02	-0.02	-0.09	-0.09	-0.01	-0.36	-0.36	-0.04
BH113B	1518.7	3335.8	-0.02	-0.02	-0.09	-0.09	-0.01	-0.36	-0.36	-0.04
BH114A	1518.9	2625.6	-0.03	-0.04	-0.09	-0.09	0.00	-0.37	-0.37	-0.04
BH114B	1518.8	2586.3	-0.04	-0.06	-0.09	-0.09	0.00	-0.34	-0.34	-0.03

Appendix 3

Fitting Parameters for Long Term Subsidence Prediction

	NORTH	EAST	Y_0	A_1	t_1
5	2410.7	2154.8	94.33045	0.39613	64.21564
6	3086.2	3516.4	89.96714	6.93767	3255.28676
7	3086.0	4486.4			
8	3085.1	2936.0			
9	1273.4	4256.3	84.8699	0.44907	46.94525
10	1273.3	3216.3	87.69877	0.46422	48.52785
11A	2187.0	6003.5			
12	1790.0	4814.7			
13	2175.8	3242.2	92.40316	0.26364	29.68799
14	2213.9	3968.4	91.37891	0.33274	52.14162
BH101A	2817.0	5587.6	94.11908	0.13249	38.51311
BH101B	2817.1	5627.3	94.06028	0.12386	35.54321
BH102A	2816.8	4837.0	95.513	0.21547	42.84765
BH102B	2816.8	4877.0	95.46468	0.21469	44.26207
BH103A	2817.0	4087.0	95.85721	0.29095	53.87395
BH103B	2817.0	4127.3	95.8312	0.31899	66.44405
BH104A	2816.9	3337.4	96.66862	0.34481	48.74488
BH104B	2816.4	3377.4	96.76657	0.36303	56.19501
BH105A	2816.8	2587.4	98.33347	0.32064	43.71217
BH105B	2816.9	2626.9	98.35462	0.31593	42.37535
BH106A	2167.9	5211.9	91.01704	0.19381	36.21939
BH106B	2167.9	5251.7	91.01422	0.21704	38.58779
BH107A	2167.9	4461.7	97.41315	0.25287	33.42865
BH107B	2167.9	4501.7	97.33787	0.31462	52.84372
BH108A	2167.9	3711.7	94.3362	0.35177	41.43518
BH108B	2167.9	3751.7	94.32835	0.35544	52.81414
BH109A	2167.9	2961.7	96.22047	0.36533	48.92786
BH109B	2167.9	3001.7	96.28395	0.36491	48.62465
BH110A	2167.9	2211.7	95.75876	0.37243	65.69522
BH110B	2167.9	2251.7	95.77493	0.38158	46.3358
BH111A	1518.8	4876.1	90.90043	0.26402	46.38014
BH111B	1518.6	4835.8	90.94044	0.29334	54.13512
BH112A	1518.6	4126.1	91.32225	0.35743	54.37363
BH112B	1518.3	4086.0	91.3363	0.35225	54.14484
BH113A	1518.9	3376.3	91.78928	0.38197	57.28376
BH113B	1518.7	3335.8	91.71134	0.39437	56.10384
BH114A	1518.9	2625.6	87.97098	0.38767	52.94901
BH114B	1518.8	2586.3	88.13465	0.38448	63.792

*The fitting parameter x_0 (x_1 at time =0) is equal to zero for all predictions.

DISTRIBUTION

U.S. Department of Energy (2)
Strategic Petroleum Reserve
1000 Independence Avenue SW
Washington, D.C. 20585
Attn: D. Johnson, FE 421
D. Buck, FE 421

U.S. Department of Energy (12)
Strategic Petroleum Reserve
900 Commerce Road East
New Orleans, LA 70123
Attn: W. C. Gibson, FE 44
15102
J. C. Kilroy, FE 443
W. Poarch, FE 4432
G.B. Berndsen, FE 443.1 (5)
J. Culbert, FE 443
R. Myers, FE 4421
TDCS (2)

U.S. Department of Energy (3)
Strategic Petroleum Reserve
Attn: A. Fruge, Big Hill, FE 4421.2
900 Commerce Road East
New Orleans, LA 70123

DynMcDermott (3)
850 South Clearview Parkway
New Orleans, LA 70123
Attn: L. Eldredge, EF 20
K. Mills, EF 20
J. McHenry, EF 25

PB-KBB Inc.
11767 Katy Freeway
P O Box 19672
Houston, TX 77224
Attn: S. Raghuraman

Sandia Internal: (20)

MS 0701 L. Shephard, 6100
MS 0706 J. Linn, 6113
MS 0706 B. Ehgartner, 6113
MS 0706 T. Hinkebein, 6113
MS 0706 D. Munson, 6113
MS 0706 C. Williams, 6113
MS 0706 S. Bauer, 6113 (10)
MS 9018 Cen. Tech. Files, 8940-2
MS 0899 Tech. Library, 4916 (2)
MS 0619 Review and Approval Desk
for DOE/OSTI, 00111