SANDIA REPORT
SAND2021-13783
Printed November 2021

Sandia National Laboratories

Parametric Study of SANSMIC Input and Resulting Impact on Predicted Cavern Geometry and Leaching Efficiency

Todd R. Zeitler
Tonya S. A. Ross

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

Issued by Sandia National Laboratories, operated for the United States Department of Energy by National Technology & Engineering Solutions of Sandia, LLC.

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

Telephone:	(865) 576-8401
Facsimile:	(865) 576-5728
E-Mail:	reports@osti.gov
Online ordering:	http://www.osti.gov/scitech

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5301 Shawnee Rd
Alexandria, VA 22312

Telephone:	(800) 553-6847
Facsimile:	(703) 605-6900
E-Mail:	orders@ntis.gov
Online order:	https://classic.ntis.gov/help/order-methods/

ABSTRACT

The Sandia Solution Mining Code (SANSMIC) has been used for many years to examine the development of salt cavern geometry, both in a confirmatory manner with comparisons made to real-world sonar data and in a predictive manner when updated sonar data are not available. SANSMIC models require some modeling choices in order to incorporate real-world data. Key modeling choices include the vertical resolution of cavern geometry to implement, as well as how to incorporate daily raw water injection data into the SANSMIC model. This report documents five studies that address the impact of the modeling choices on the predicted cavern geometries and calculated leaching efficiencies. In most cases, hypothetical cylindrical initial cavern geometries are used to provide a common baseline against which to test the systematic variation of input variables including cavern radius, oil-brine-interface (OBI) depth, vertical cell size, raw water injection rate, raw water injection duration, workover time, and number of leaching stages. The use of smaller cell sizes is recommended moving forward to provide a better one-to-one relationship between sonar data and the modeled cavern. A new methodology for incorporating raw water injection data is also recommended, in order to more closely model real-world injection and workover times. Overall, the systematic studies performed here have increased our confidence in previous SANSMIC model results, as well future use of the code for predicting leaching effects on cavern geometries. Some minor changes to modeling choices are recommended, which can easily be applied with the version of SANSMIC currently under development.

ACKNOWLEDGEMENTS

This work was funded by the U.S. Department of Energy, Office of Fossil Energy, Strategic Petroleum Reserve Program. The technical reviewer was David Lord, Sandia National Laboratories.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

This page left blank

ACRONYMS AND DEFINITIONS

Abbreviation	Definition
bbl	barrel (of oil); 1 bbl = 42 gal (US) ≅ 0.158987 m3
EOT	depth of end of brine string tubing
MB	thousand barrels
MMB	million barrels
OBI	oil-brine interface
SANSMIC	Sandia solution mining code
SPR	Strategic Petroleum Reserve

1. INTRODUCTION

The U.S. Strategic Petroleum Reserve is a crude oil storage system run by the U.S. Department of Energy. The reserve consists of 60 active storage caverns spread across four sites in Louisiana and Texas, near the Gulf of Mexico. Beginning in 2016, the SPR began executing U.S. congressionally mandated oil sales. The configuration of the reserve, with a total capacity of greater than 700 MMB, requires raw water to be used instead of saturated brine for oil withdrawals such as for sales. All sales will produce leaching within the caverns used for oil delivery.

The Sandia Solution Mining Code (SANSMIC) has been used for many years to examine the development of cavern geometry, both in a confirmatory manner with comparisons made to real-world sonar data and in a predictive manner when updated sonar data are not available [1][2][3]. SANSMIC modeling results have typically been shown to be in good agreement with sonar data when available [4][5][6][7][8][9] and have also been used as a predictive tool to suggest operational changes in order to reduce the growth of disadvantageous cavern geometry features[10].

SANSMIC models require some modeling choices in order to incorporate real-world data. Key modeling choices include the vertical resolution of cavern geometry to implement, as well as how to incorporate daily raw water injection data into the SANSMIC model. Vertical resolution is implemented via the choice of cell sizes in the SANSMIC input file. Cell sizes of 10 ft have been used in recent annual leaching modeling reports despite the availability of sonar data in 1-ft vertical intervals—sonar data have been interpolated over 10-ft sections as part of the process of generating initial cavern geometries. One driver for the use of 10-ft cells has been the limitation of 500 vertical cells in the current version of the SANSMIC code. With caverns that have depths greater a thousand feet, 1-ft cells were not possible.

Real-world raw water injection data is used as input to SANSMIC models in order to provide the driver for leaching as the raw water is modeled as dissolving salt from the surrounding formation in order to reach an equilibrium with the existing brine in the cavern. In recent years, annual leaching modeling reports have used two methodologies for incorporation of daily raw water volumes into SANSMIC leaching models, which require leaching rates and durations to be defined for each leaching stage. In both cases, a leaching stage is defined over which no EOT movement is made and over which no oil filling occurs. Typically, a single leaching stage encompasses weeks or months associated with seasonal oil sales. One averaging methodology has counted individual days with injections, while the other methodology counts the number of days from the beginning until the end of the leaching stage. In both cases, leaching rates are calculated as the total raw water injected volume (the same for each methodology) divided by the number of injected days (different for each methodology). A third methodology could be imagined in which daily injection volumes are directly implemented in SANSMIC models. While this methodology may be more work intensive to set up in a SANSMIC input file, it could also be a more direct implementation of the daily injection data, including intermediate days with no water injection.

This report documents five studies that address the impact of the modeling choices described above on the predicted cavern geometries and calculated leaching efficiencies (an important output that connects modeled output to real-world leaching expectations). One of the studies also takes advantage of this undertaking using systematic variation of SANSMIC input variables to estimate the impact of repeated leaching over the same vertical cavern interval, a leach-and-fill practice that has been common in recent years and which has been shown to lead to the development of disadvantageous cavern features.

In most cases, hypothetical cylindrical initial cavern geometries are used to provide a common baseline against which to test the systematic variation of input variables including cavern radius, oil-brine-interface (OBI) depth, vertical cell size, raw water injection rate, raw water injection duration, workover time, and number of leaching stages. Although the cylindrical caverns differ from the real-world caverns of the SPR, the general trends observed may be applied (albeit with some caution) to future leaching modeling efforts using the SANSMIC code.

Finally, in a separate effort, the SANSMIC code is undergoing a major change of platform from FORTRAN to Python, which will allow for the incorporation of new process models alongside existing ones, which may have improvements as well [11]. The work described here was undertaken in part with the intention to exercise the current code over a range of inputs that could potentially uncover ways to improve the new Python version of the code.

2. MODELING APPROACH

Five studies are undertaken here to examine specific aspects of SANSMIC modeling, particularly the impact of modeling choices that must be made when incorporating real-world data into a model. The general approach is to use idealized, cylindrical cavern geometries as initial configurations and vary input parameters of interest. However, impacts to real-world cavern shapes were also investigated. Inputs tested here include cavern radius, oil-brine-interface (OBI) depth, vertical cell size, raw water injection rate, raw water injection duration, workover time, and number of leaching stages. Output results of interest include cavern geometry, cavern volume change, and leaching efficiency.

A total of 346 SANSMIC runs have been performed as part of this study (Table 2-1). While the currently validated version of the SANSMIC code has a limitation of 500 vertical cells for each model, a new version of the SANSMIC code was compiled to allow for up to 5,000 cells in order to facilitate this study. All runs were performed on the Skybridge computing platform at Sandia. Runs of the SANSMIC code are relatively short, typically taking less than one minute to complete the calculation for one model.

Details for the modeling setup are included in the first subsection for each of the five studies. A summary of the conclusions is included in the final subsection for each study. The running of a large number of SANSMIC runs has benefited from the use of various setup, run, and post-processing Python programs and shell scripts developed as part of this work.

Table 2-1. Details on Studies in this Report

Study	Description	Number of SANSMIC Runs
1	Examines the impact of reducing vertical cell dimensions on resulting cavern geometry.	240
2	Examines the impact of OBI-EOT separation on resulting cavern geometry, as well as potential impact of repeated leaching over same vertical interval.	56
3	Examines the impact of three methodologies for incorporating real-world injection volume data into SANSMIC calculations.	10
4	Examines the impact of injection volume and vertical cell size on leaching efficiency.	66
5	Examines the impact of vertical cell size on cavern geometry and leaching efficiency for two real-world caverns with real leaching histories.	4

3. RESULTS

A series of five independent studies were performed using the SANSMIC code, each study answering a specific question regarding the impact to SANSMIC results due to changing input parameters. SANSMIC results of interest vary from study to study, but include cavern geometry, cavern volume change, and leaching efficiency.

3.1. Study 1: What is the Impact of Simulation Cell Dimension on Resulting Cavern Geometry?

The version of the SANSMIC code currently qualified for running calculations has a hard-coded maximum of 500 cells used to define the vertical extent of the cavern. With caverns extending thousands of feet deep, a common practice has been to rely on 10-ft cell sizes to avoid exceeding the cell number limit. Cavern geometries from sonars are typically reported in 1-ft increments, so a Python script has been used to create initial cavern geometries for use in SANSMIC by averaging the cavern radii over 10-ft segments. As a result, some fidelity in the cavern geometry is lost during the averaging process, although cavern volume is conserved. A new version of the SANSMIC code was created to allow for up to 5,000 cells in order to facilitate this study.

The impact of reducing cell sizes on resulting cavern geometry has been tested here in order to assess what cavern geometry resolution should be used in future cavern leaching studies, to provide an estimate for the impact of the choice for 10-ft cells on previously calculated cavern geometries, and to assess the need for any changes to the SANSMIC code as development continues on a new code version.

3.1.1. Model Setup

A total of 240 SANSMIC runs were performed for this study for the cylindrical cavern tests. Study 1 began with a smaller breadth of parameter ranges, but the parameter ranges were later expanded to incorporate additional parameter combinations. Each run in this study has a name of the form CYL_E1_O*o*_R*r*_D*d*_C*c*_W*w*, where *o* refers to the oil-brine-interface (OBI) option number (1-4), *r* refers to the raw water injection rate option number (1 or 2), *d* refers to the injection duration option number (1 or 2), *c* refers to the cell size option number (1-5), and *w* refers to the workover time option number (2 or 3; note that the workover time parameter was not part of the initial study, so for some runs, there was no W*w* designation). All runs in this study were done for a hypothetical cylindrical cavern of initial radius 140 ft, with cavern floor at a depth of 3750 ft, cavern height of 800 ft, and end-of-tubing (EOT) depth of 3740 ft (height of 10 ft off of the floor) (this cavern is similar in size to WH-11) (Table 3-1).

Parameter values used in Study 1 are summarized in Table 3-2 through Table 3-6. Four OBI options were considered at depths of 3640, 3690, 3720, and 3730 ft. Two injection rates were considered at 50,000 and 100,000 bbl/day. Two injection durations were considered at 5 and 10 days. Five cell size options were considered at 0.5, 1, 2, 5, and 10 ft/cell (note that the initial study had C1 at 1 ft/cell and C2 at 10 ft/cell, but intermediate cell sizes were added later, such that cell sizes do not increase with cell size option number). Initially, the workover time was not a parameter to be varied and was set as 60 d. Later, workover times of 90 and 120 d were added as options.

Table 3-1. Cavern Properties for Hypothetical Cylindrical Cavern in Study 1

Cavern Floor (ft)	Cavern Roof (ft)	Cavern Height (ft)	Cavern Radius (ft)	Cavern Volume (ft^3)	Cavern Volume (bbl)
3750	2950	800	140	4.93E+07	8.77E+06

Table 3-2. OBI Options in Study 1

Option O	Initial OBI Depth (ft)
1	3730
2	3720
3	3690
4	3640

Table 3-3. Raw Water Injection Rate Options in Study 1

Option R	Rate (bbl/day)
1	50000
2	100000

Table 3-4. Raw Water Injection Duration Options in Study 1

Option D	Duration (days)	Volume @ R=1 (bbl)	Volume @ R=2 (bbl)
1	5	250000	500000
2	10	500000	1000000

Table 3-5. Vertical Cell Size Options in Study 1

Option C	Vertical Dimension (ft/cell)	Cells/ft
1	1	1
2	10	0.1
3	2	0.5
4	5	0.2
5	0.5	2

Table 3-6. Workover Time Options for Study 1

Option W	Workover Time (days)
<no value>	60
2	90
3	120

3.1.2. Cylindrical Test: Multiple Simulation Cell Sizes Over a Range of Other Parameters

Study 1 was the largest of the studies performed here with 240 SANSMIC calculations executed. Presenting the results of that many calculations in a meaningful way is a challenge—as a result, the results are presented here in multiple stages in order to gain the best understanding of their meaning.

3.1.2.1. Impact of Cell Size on Resulting Cavern Geometry

Figure 3-1 shows the resulting cavern geometries for 16 runs using 1-ft cells, CYL_E1_O[1-4]_R[1-2]_D[1-2]_C1, and Figure 3-2 shows the resulting cavern geometries for 16 runs using 10-ft cells, CYL_E1_O[1-4]_R[1-2]_D[1-2]_C2. In each figure, a range of cavern shapes and sizes is observed, as expected for the ranges of input parameters represented. However, there are qualitative differences in the shapes between the 1-ft cell models (Figure 3-1) and 10-ft cell models (Figure 3-2). While 1-ft cell models result in relatively smooth cavern geometries, the 10-ft cell models in many cases show odd and jagged shapes. Again, these qualitative differences are somewhat expected based on the difference in vertical resolution of the cavern geometry, but it raises the questions as to whether 1-ft cells should be used as we move forward with leaching studies, as well as the impact of the choice to use 10-ft cells in previous studies.

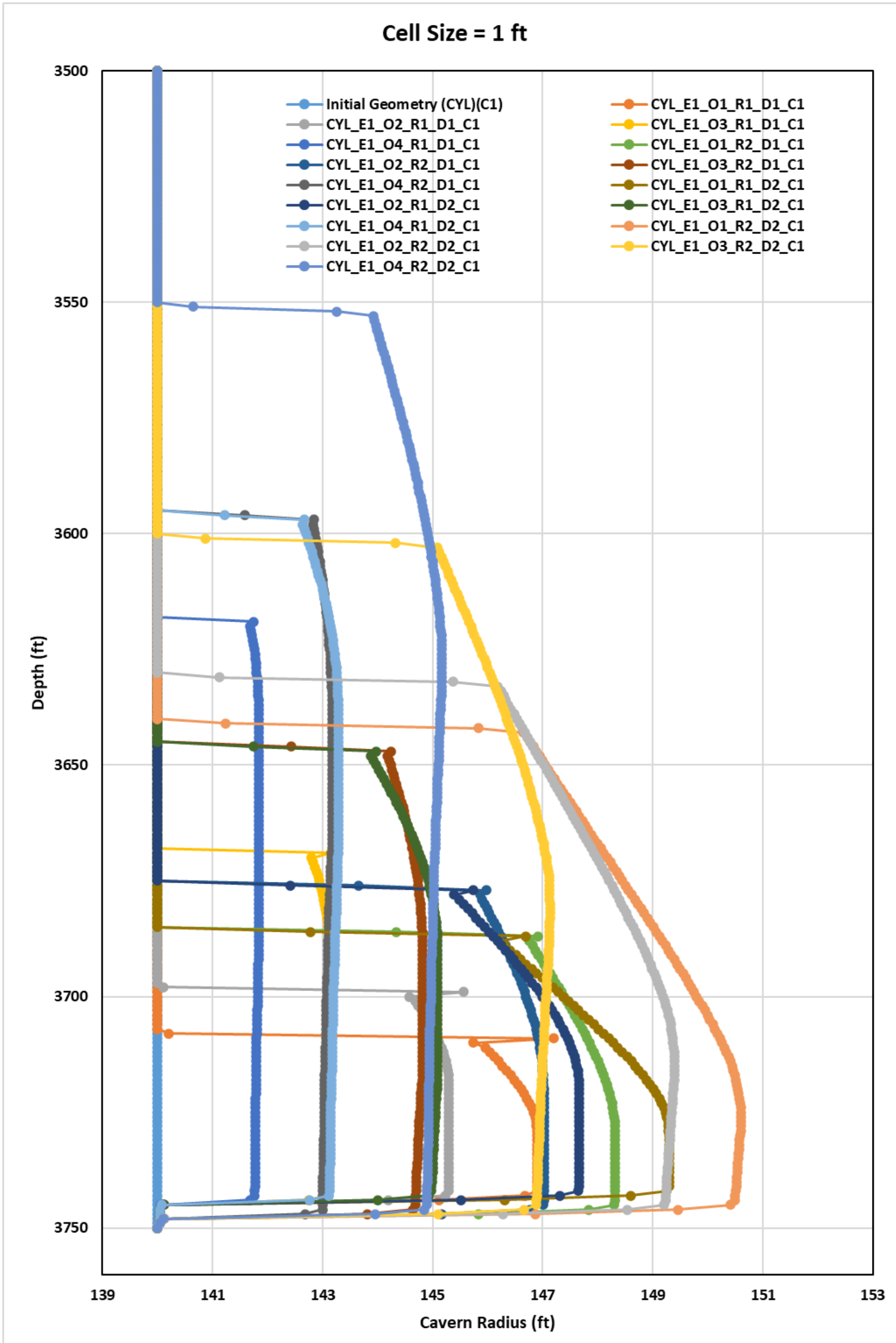

Figure 3-1. Cavern geometries for 16 runs with 1-ft cell sizes (C1)

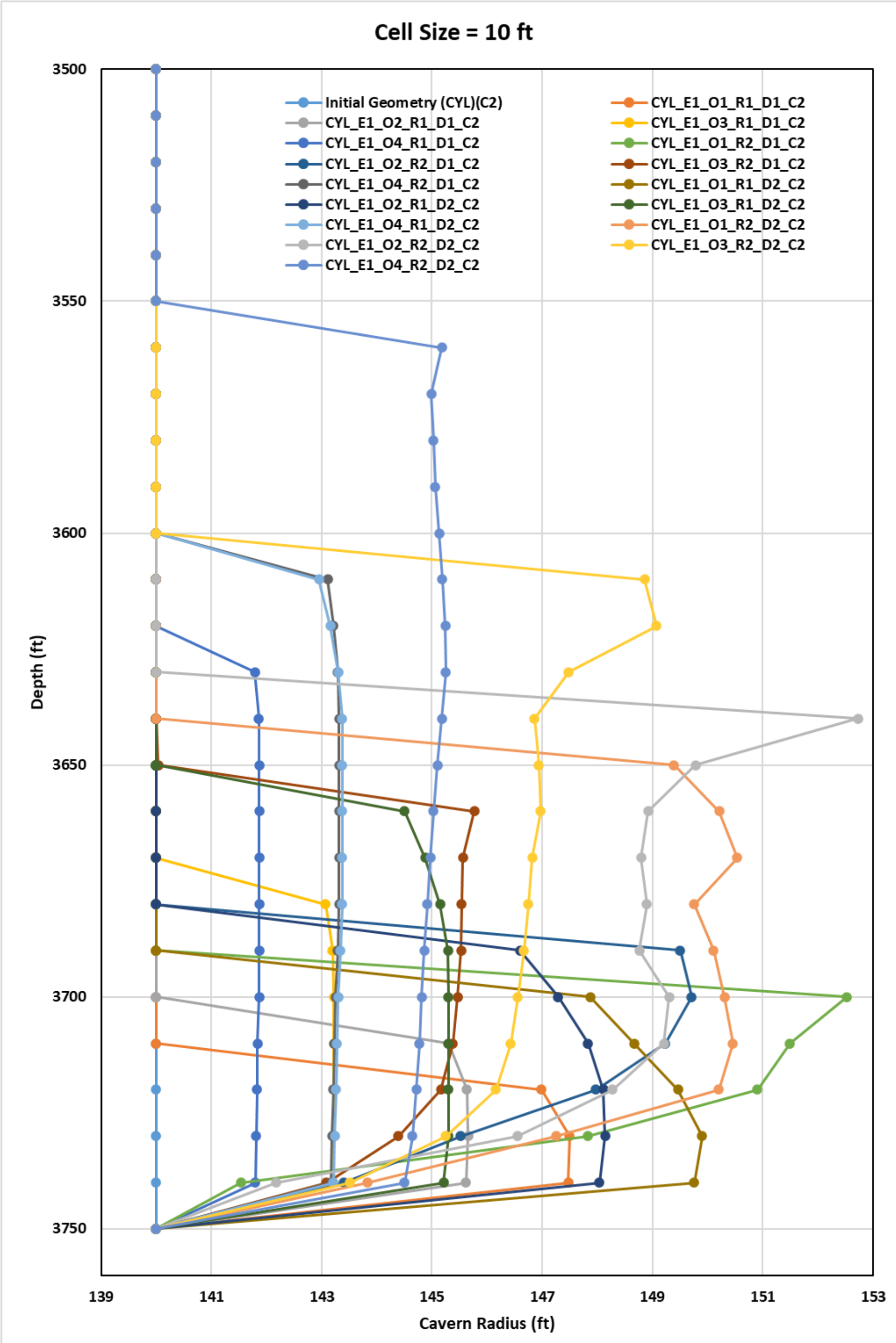

Figure 3-2. Cavern geometries for 16 runs with 10-ft cell sizes (C2)

To answer these questions, we examine more of the output data from the 240 runs. Figure 3-3 shows the results of five runs in which all parameters are kept the same (O1_R2_D1) except for cell size. The 10-ft cell geometry is substantially different in shape than those of small cell sizes, which are all very similar. Because they converge to a similar geometry as cell size decreases, we take this converged geometry to be a best representation of the final cavern geometry. The observed difference for the 10-ft cell model indicates that, since 10-ft cells have been the standard in recent leaching work, the modeled geometries for some real caverns may have been different if small cell sizes had been used. Later in this section, we examine to what extent differences may have existed. Also, the shape of the 10-ft cell run shows a maximum radial growth that is ~4-5 ft greater than the other cases, although at some depths the radius is predicted to be smaller than for the other cases. This raises the question of whether total volume change is conserved, which is also examined later in this section.

Note that the runs shown in Figure 3-3 were for cases where the initial OBI was closest to the EOT. For comparison, the results from a series of runs where the OBI is furthest from the EOT (O4_R2_D2) are shown in Figure 3-4. For these runs, there is still a qualitative difference observed for a few points in the 10-ft model, but the differences are much smaller. This can be attributed to the larger OBI-EOT separation, which allows for leaching to occur across a greater vertical distance, thus leaving relatively less impact of the vertical distance between cells. While it may be the case that most of the real-world leaching cases occur when OBI-EOT separations are relatively large, it is not always the case, and thus there appears to be an advantage to using cell sizes of 5 or fewer feet. Since there is essentially no observable difference in computational expense for different cell sizes (all runs take less than one minute), there is no reason not to proceed using 1-ft simulation cells, which also provide a one-to-one relationship with existing sonar data vertical resolution.

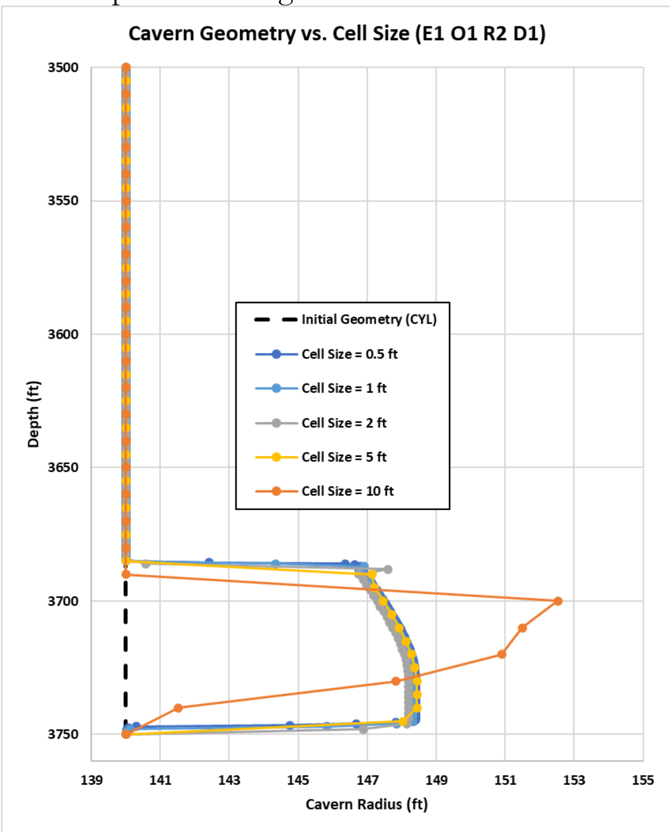

Figure 3-3. Cavern geometries for 5 runs (O1_R2_D1) with varying cell sizes

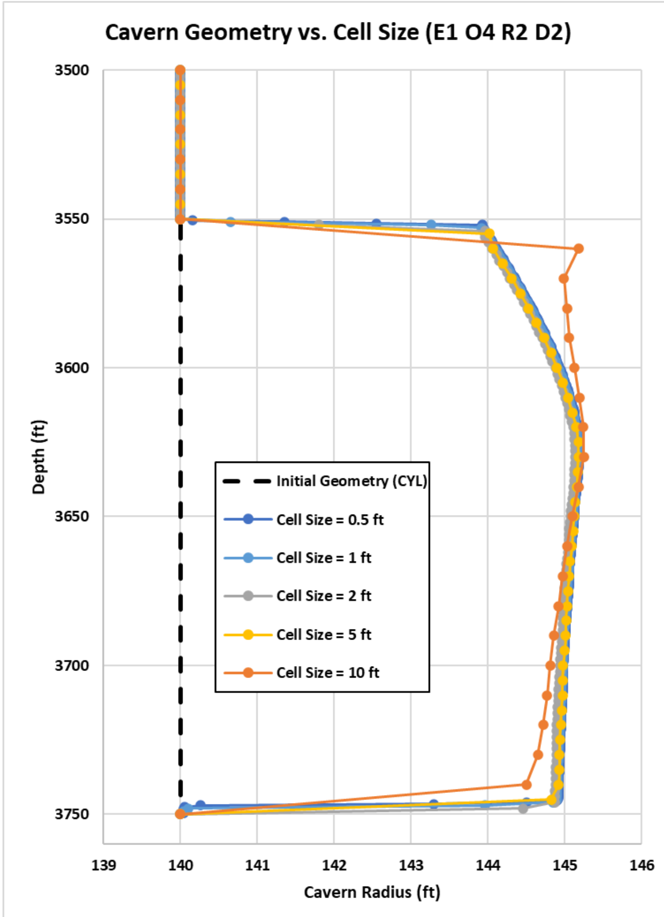

Figure 3-4. Cavern geometries for 5 runs (O4_R2_D2) with varying cell sizes

3.1.2.2. Impact of Cell Size on Maximum Cavern Radius

In order to further compare the maximum radii across the runs using different cell sizes, maximum radii for 48 pairs of runs are plotted in Figure 3-5. Each pair consists of the maximum cavern radius from a 1-ft cell model compared against the maximum cavern radius for the equivalent run with a 10-ft cell size. That figure shows that across the 96 runs, the maximum radius from the 10-ft cell model is equal to or exceeds the value from the 1-ft cell model. In other words, a model using 10-ft cells is likely to overestimate growth and is not likely to underestimate growth, although these observations appear to only be true for the largest change in radius; recall that Figure 3-3 shows that growth may also be underestimated in other regions, likely in compensation for the overestimation of growth in other areas as, presumably, leaching efficiency should be approximately the same in all cases (that assumption is examined later in this section). The relative smoothness of the cavern geometry for the 1-ft cell models is a result of the small vertical interval between cells, while the large interval for 10-ft cells may result in a more jagged shape due to over- and underestimation of growth. However, it should be noted that the differences in maximum growth are typically less than 3-4 ft. This may not be substantial in most cases in terms of impacting advice on future plans for a given cavern but could lead to greater differences when comparing leaching predictions against sonar data.

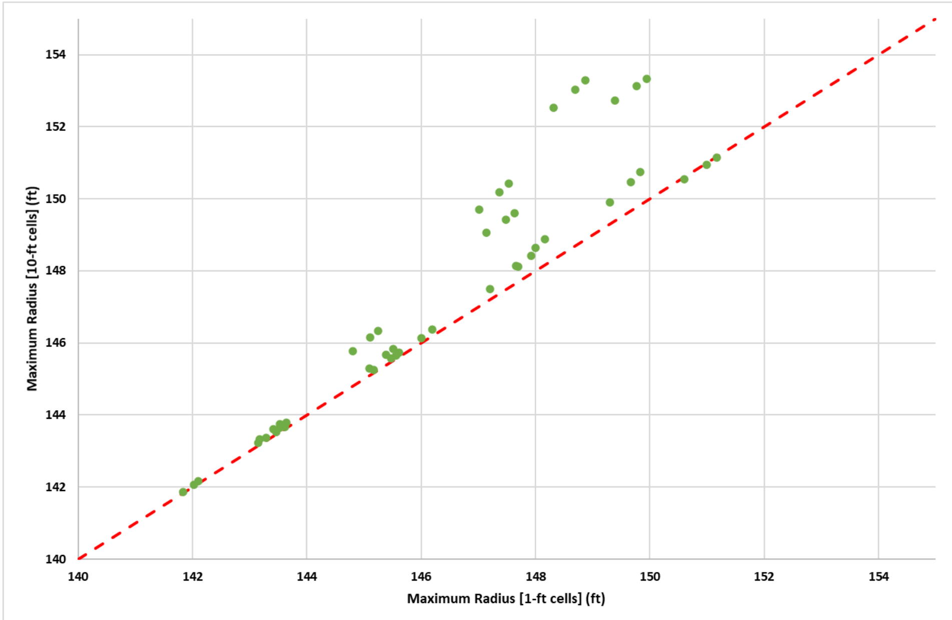

Figure 3-5. Comparison of maximum radii for 48 pairs of runs (1-ft and 10-ft cell size pairs)

3.1.2.3. Impact of Cell Size on Volume Change and Leaching Efficiency

A subset of 80 runs is examined to look beyond cavern radii to the impacts of cell size on volume change and leaching efficiency. Five series of 16 runs were chosen—each series corresponds to a different cell size (C1-C5). Within a series, the first four runs have an injected volume of 250 Mbbl (R1_D1), the next eight have 500 Mbbl (R1_D2 and R2_D1), and the final four have 1 MMbbl (R2_D2). Figure 3-6 shows that cavern volume changes tend to be greatest for 10-ft cell models and eventually converge such that 0.5-ft cells and 1-ft cells have almost the same volume changes.

Leaching efficiency, defined as the cavern volume change divided by injected volume, is a similar representation of this data and is shown in Figure 3-7 for the 80 runs. Leaching efficiency is expected to be below 20%, closer to 15-16%. The 10-ft cells show extremely high efficiencies, indicating that more cavern volume is being leached than is necessary to provide sufficient salt to the raw water to reach a specific gravity of about 1.2. For lower injection volumes, the leaching efficiency is generally higher. Anomalously high leaching efficiencies have been observed in some cases for leaching studies of real caverns with real leaching histories [4][6][9].

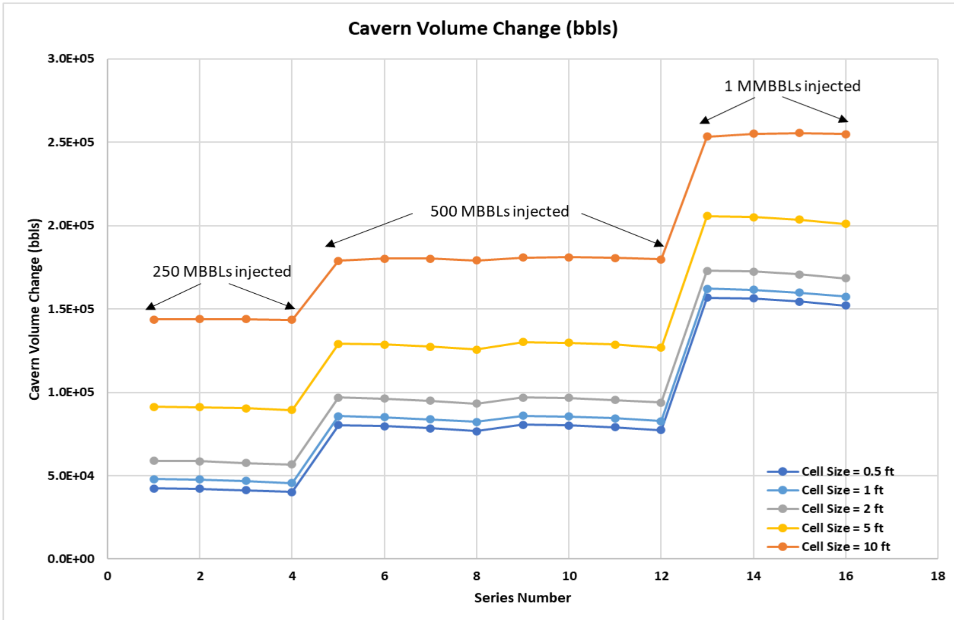

Figure 3-6. Cavern volume change for 80 runs arranged by cell size (series number described in Appendix A)

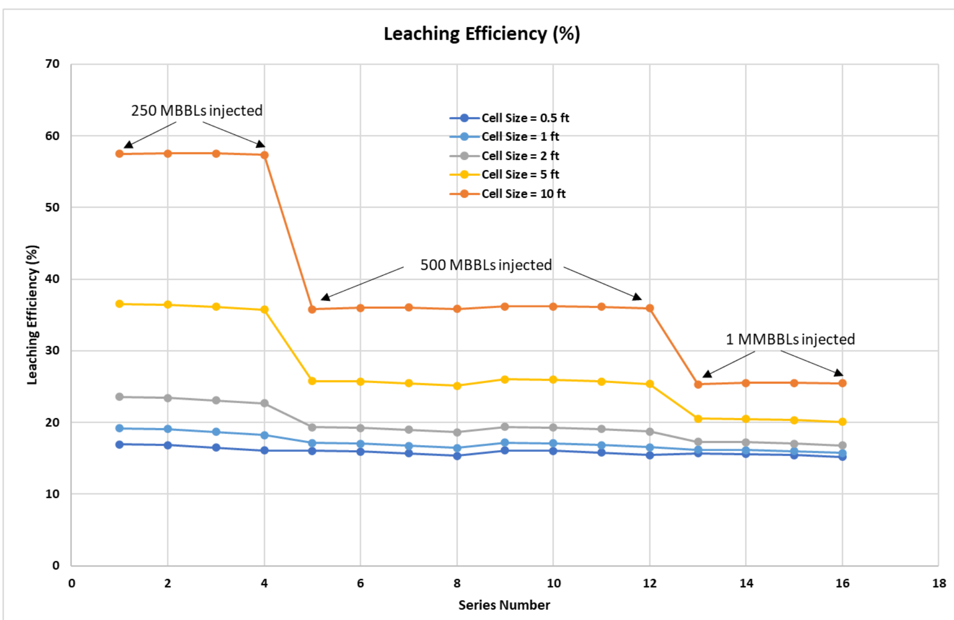

Figure 3-7. Leaching efficiency for 80 runs arranged by cell size (series number described in text)

3.1.2.4. Detailed Look at Correlations Between Leaching Efficiency and All Parameter Types

For the 240 runs in Study 1, leaching efficiencies are plotted against different parameter options in Figure 3-8 through Figure 3-14 in attempt to better understand any correlations between those parameters and the observed anomalously high leaching efficiencies. For Option O (OBI depth), there does not appear to be a correlation with leaching efficiency; each of the four OBI depth options has approximately the same range of observed leaching efficiencies (Figure 3-8).

For Option R (injection rate), there is some correlation with leaching efficiency, as the efficiencies above 40% only occur for R1 (i.e., lower injection rate) models (Figure 3-9). Similarly, there is some correlation for Option D (injection duration), as the efficiencies above 40% only occur for D1 (i.e., lower duration) models (Figure 3-10). As a result of these correlations, it is not surprising that there is a correlation between injected volume (simply the product of injection rate and duration) and leaching efficiency—leaching efficiencies above 40% only occur for the lowest injected volume (i.e., the R1_D1 cases) (Figure 3-11).

For Option W (workover time), there is a correlation with leaching efficiency, although it is somewhat difficult to observe in Figure 3-12 where the ranges are similar. Figure 3-13 shows a typical relationship for multiple runs that have the only difference due to Option W. Leaching efficiency is observed to slightly increase with workover time. This is not unexpected, as the increased time allows for further leaching of the cavern. A 60-day workover period has been used in recent leaching studies.

Finally, the impact of cell size on leaching efficiency is reexamined here for all 240 runs in Figure 3-14. Figure 3-14 shows that the range of leaching efficiencies, as well as maximum values, increases with increased cell size. Smaller cell sizes are well correlated to the lower leaching efficiencies expected (i.e., below 20%). Combining the results shown in Figure 3-11 and Figure 3-14 indicates that the R1_D1_C2 models show the highest leaching efficiency. In performing leaching studies for real world caverns, modeling low injection rates and durations may be unavoidable, but these results again show the tendency for 10-ft cell models to lead to erroneously high leaching efficiencies.

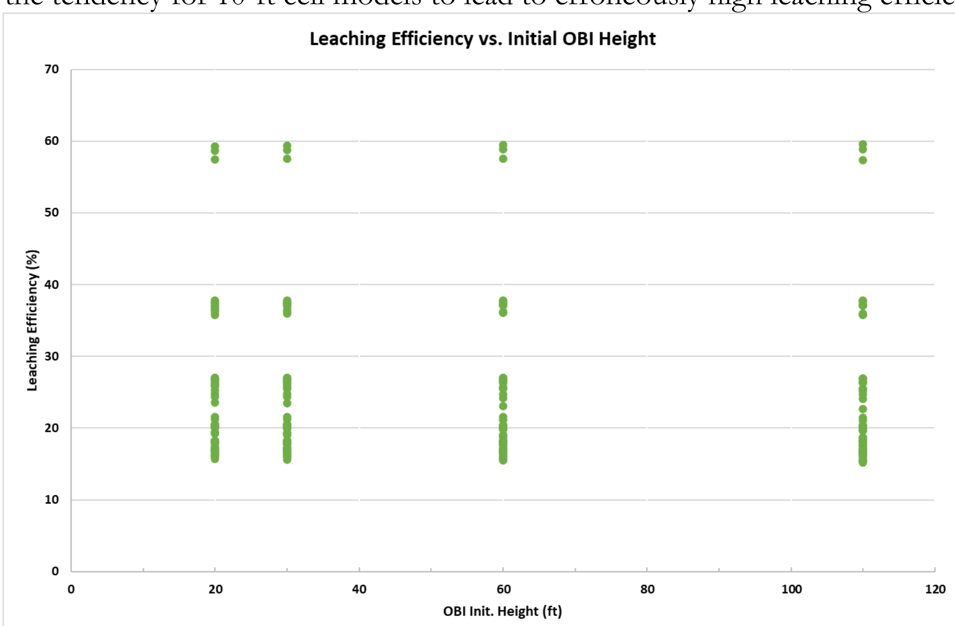

Figure 3-8. Leaching efficiency for 240 runs vs. initial OBI height

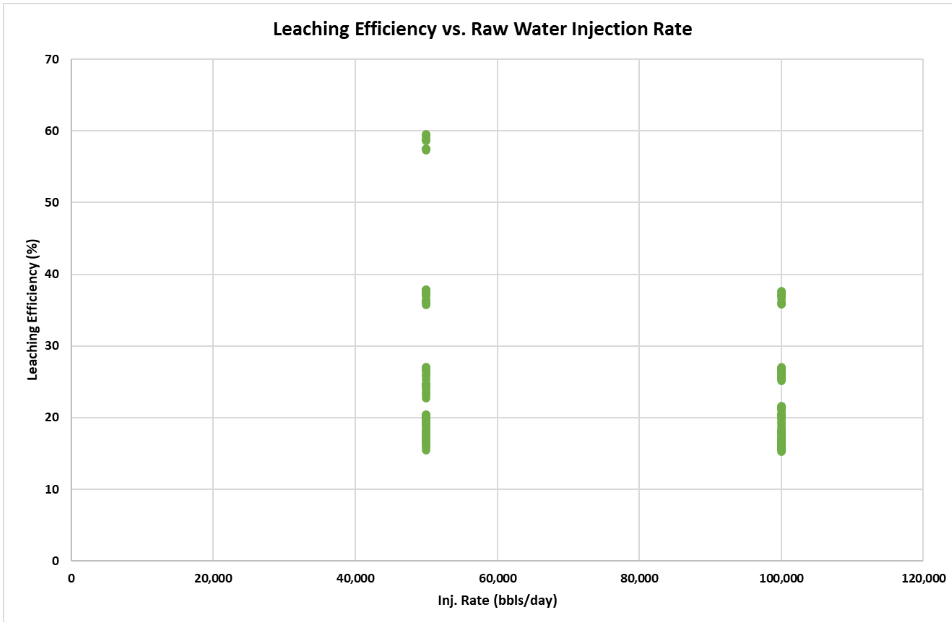

Figure 3-9. Leaching efficiency for 240 runs vs. raw water injection rate

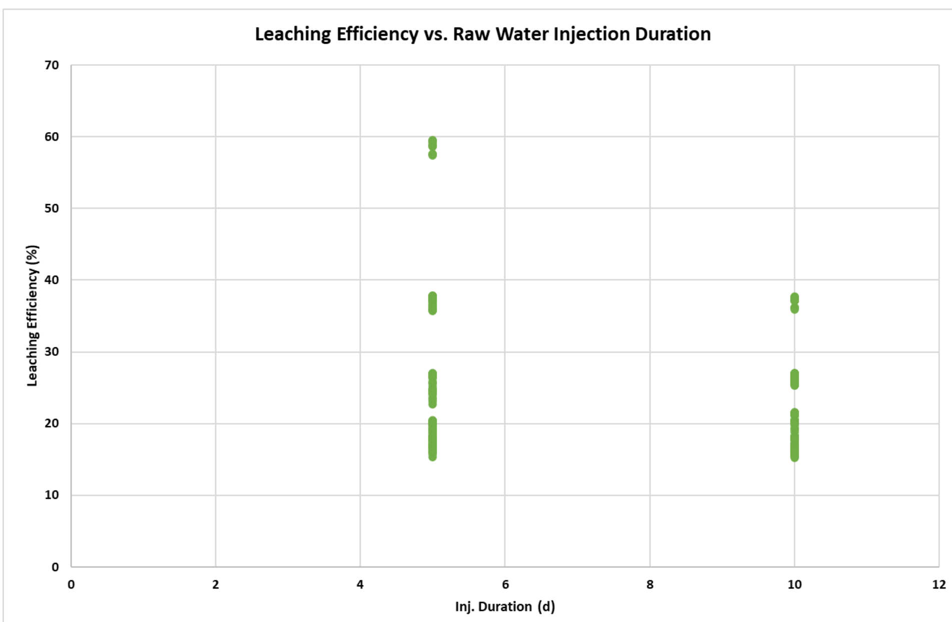

Figure 3-10. Leaching efficiency for 240 runs vs. raw water injection duration

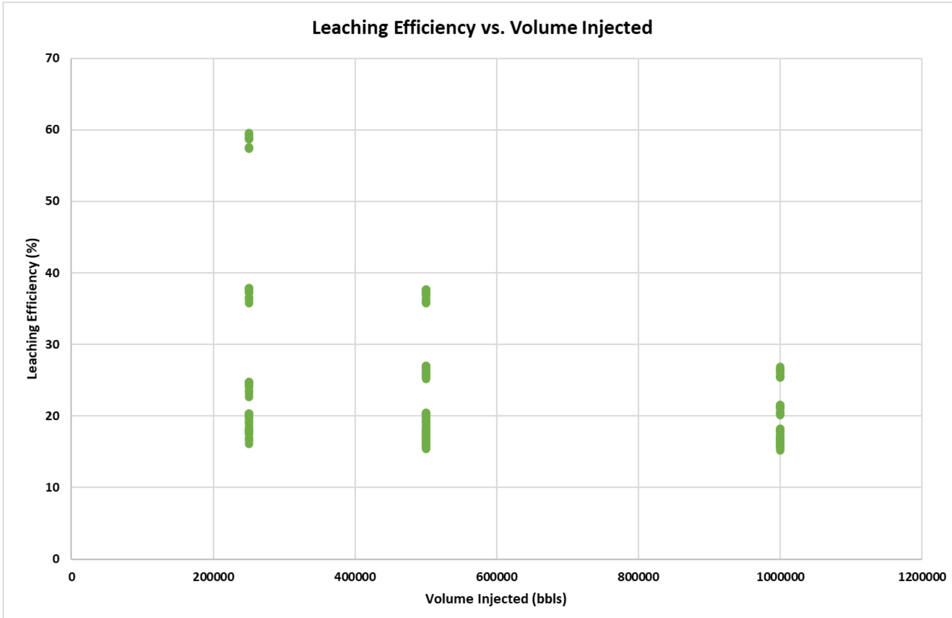

Figure 3-11. Leaching efficiency for 240 runs vs. injection volume

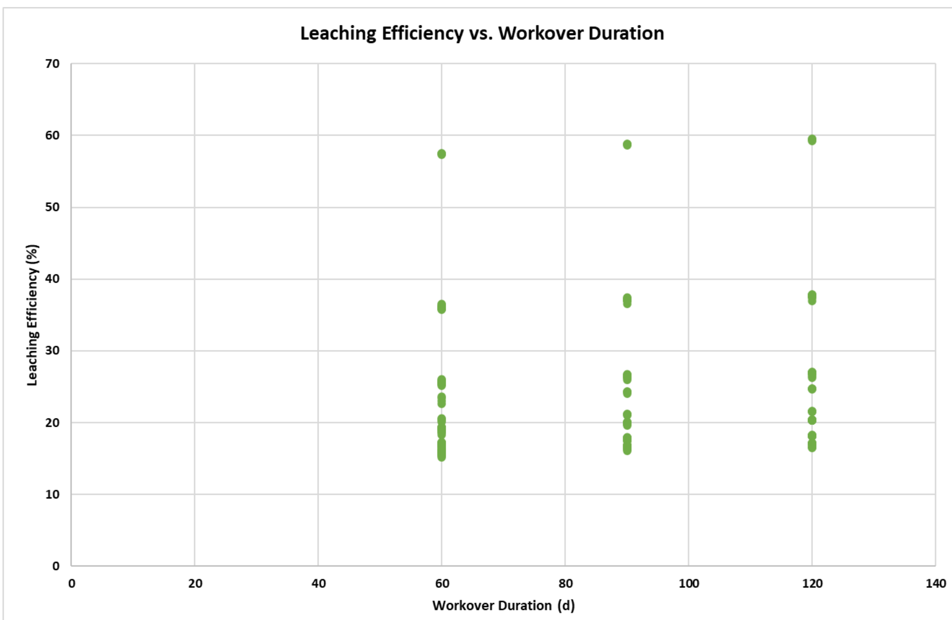

Figure 3-12. Leaching efficiency for 240 runs vs. workover duration

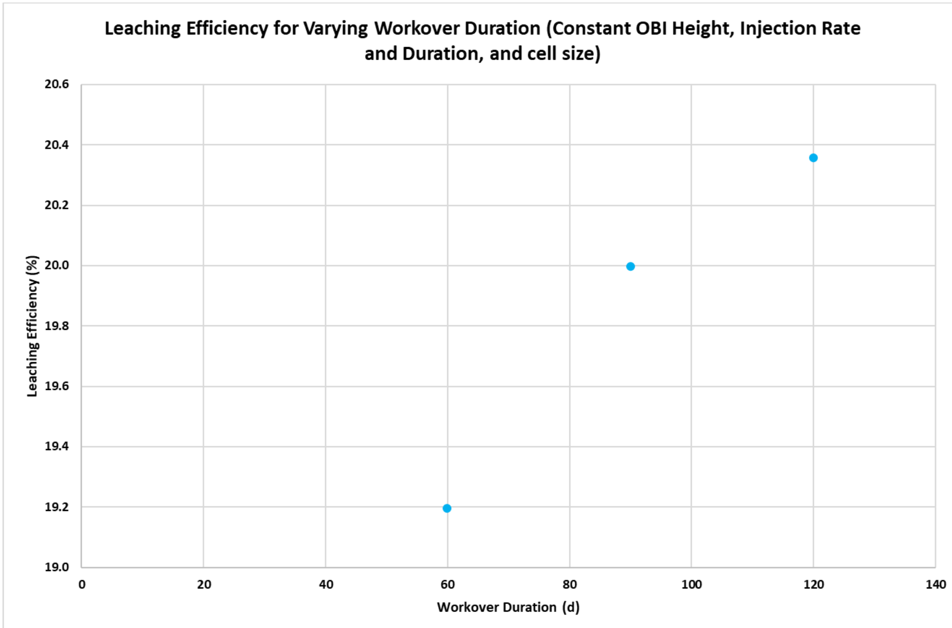

Figure 3-13. Leaching efficiency for 3 runs (O1_R1_D1_C1) vs. W option number (workover time)

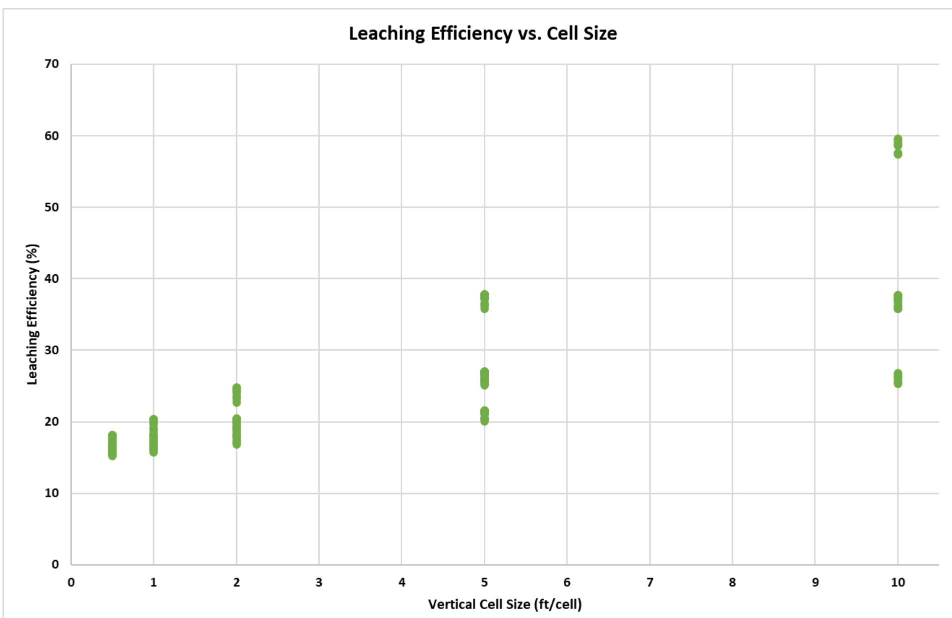

Figure 3-14. Leaching efficiency for 240 runs vs. cell size

3.1.3. Summary of Study 1

The impact of reducing cell sizes on resulting cavern geometry has been tested here for a hypothetical cylindrical cavern. Results show that reducing the cell size below 10-ft/cell (the current standard) leads to a convergence of cavern geometries that is in some cases qualitatively different from the 10-ft cell model. However, it is estimated that differences in radii (for the injection rates and cavern size used here) are limited to only a few feet. Nonetheless, it is still recommended that cell size of 1-ft be used moving forward. To accommodate this in future versions of the SANSMIC code, the limitation on number of cells should be substantially increased.

Anomalously high leaching efficiencies were observed and are generally associated with larger cell sizes, as well as lower injection rates and durations. Additional studies focusing on leaching efficiency are found in Sections 3.4 and 3.5.

3.2. Study 2: What is the Impact of OBI-EOT Separation on Resulting Cavern Geometry for Single Leaches and Multiple Leaches?

Based on years of experience, it is well-known that the majority of leaching takes place between the EOT and OBI (the OBI moves up as raw water is injected). A full cavern drawdown would have an ever-increasing OBI-EOT separation as the OBI rises in the cavern and would result in relatively uniform radial cavern growth. Due to the increased use of partial drawdowns (e.g., relatively small drawdowns and refills) by the SPR, leaching has been observed to sometimes result in disadvantageous cavern growth over small vertical distances (e.g., WH-11 [10]) when the OBI tends to be relatively close to the EOT for multiple leaching cycles. These observations have raised the questions of the impact of OBI-EOT distance (in this case, OBI refers to the initial OBI prior to raw water injection) on resulting cavern geometry, as well as the potential impact of repeated leaching over the same region of the cavern.

For example, repeated leaching over the same vertical interval could lead to increased geomechanical instability that could result in a reduced number of available drawdowns and possibly the need for remedial leaching. A previous Sandia study showed the advantages of cutting the brine string in order to avoid additional disadvantageous leaching for a cavern with an existing large radius “feature” [10]—in that case, a Sandia recommendation to cut the brine string was made and showed to positively impact later leaching in that cavern. The current study takes a more systematic approach in examining the impacts on hypothetical caverns of constant initial geometry rather than a real cavern with existing irregularities in cavern geometry.

Answering the questions on the impact of OBI-EOT distance on resulting cavern geometry, as well as the potential impact of repeated leaching over the same region of the cavern will provide insight into changing cavern geometries that will improve Sandia’s confidence in reporting leaching modeling results, as well as advising the SPR on future drawdowns and string cut recommendations.

3.2.1. Model Setup

A total of 56 SANSMIC runs were performed for this study. Each run in this study has a name of the form CYL*Name*_O*o*_R*r*_D*d*_C*c*_Ll, where *Name* refers to the cavern number (1-4), *o* refers to the oil-brine-interface (OBI) option number (1-4), *r* refers to the raw water injection rate option number (1 or 2), *d* refers to the injection duration option number (1 or 2), *c* refers to the cell size option number (1-2), and *l* refers to the number of leaching stages (1 or 5; note that the number of leaches parameter was not part of the initial study, so for some runs with a single leaching stage, there was no L*l* designation). The four cylindrical caverns of varying radii modeled in this study each had a cavern floor at a depth of 4000 ft, cavern height of 1000 ft, and end-of-tubing (EOT) depth of 3900 ft (height of 10 ft off of the floor) (Table 3-7 and Figure 3-15).

Parameter values used in Study 2 are summarized in Table 3-8 through Table 3-11. Four OBI options were considered at depths of 3800, 3850, 3750, and 3700 ft. Two injection rates were considered at 20,000 and 200,000 bbl/day and two injection durations were considered at 5 and 50 days, but these options were always combined such that the total injected volume always equal 1 MMB. Two cell size options were considered at 1 and 10 ft/cell. Half of the runs consisted of a single leaching stage, while the other half consisted of five leaching stages. For runs with five leaching stages, the duration of each stage was one-fifth of the total duration, while the injection rate stayed the same. After each leaching stage, a 60-day workover period was modeled. Input and output for the 56 runs is summarized in Appendix A. At the end of each workover, the OBI was reset to the initial OBI, reflecting a leach-and-fill approach. The purpose of these runs was to show a comparison of introducing 1 MMB of raw water via a single leach vs. repeated leaching over the same vertical cavern extent.

Table 3-7. Cavern Properties for Hypothetical Cylindrical Caverns in Study 2

Cavern Property	CYL1	CYL2	CYL3	CYL4
Cavern Top (ft)	3000	3000	3000	3000
Cavern Bottom (ft)	4000	4000	4000	4000
Cavern Height (ft)	1000	1000	1000	1000
Cavern Radius (ft)	100.00	141.42	81.65	70.71
Cavern Volume (bbl)	5.60E+06	1.12E+07	3.73E+06	2.80E+06
EOT (ft)	3900	3900	3900	3900
Volume of 1 Vertical ft (bbl/ft)	5595	11191	3730	2798

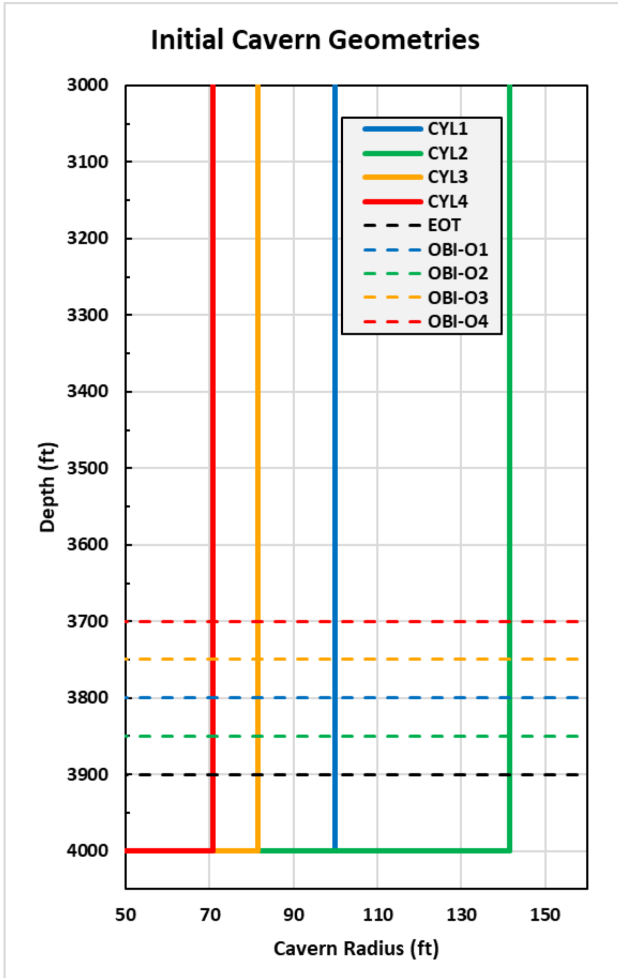

Figure 3-15. Initial cavern geometries, EOT, and initial OBI depths for Study 2

Table 3-8. OBI Options in Study 2

Option O	Initial OBI Depth (ft)
1	3800
2	3850
3	3750
4	3700

Table 3-9. Raw Water Injection Rate and Duration Options in Study 2

Option R	Option D	Combined Option	Rate (bbl/day)	Duration (days)	Total Volume Injected (MMB)
1	1	R1_D1	200000	5	1.0
2	2	R2_D2	20000	50	1.0

Table 3-10. Vertical Cell Size Options in Study 2

Option C	Vertical Dimension (ft/cell)	Cells/ft
1	1	1
2	10	0.1

Table 3-11. Number of Leach Options for Study 2

Option L	Number of Leaching Stages
<no value>	1
5	5

As described above in Section 3.1, there is an impact of the SANSMIC model cavern geometry resolution (i.e., simulation cell vertical dimension) on leaching output, so that was varied here, although little impact was observed such that only C1 (1-ft cell) results are presented here (full results are in Section A.2). Comparisons of cavern geometry changes with respect to OBI-EOT separation for the four hypothetical cylindrical caverns of varying radii have been investigated here in two primary ways: 1) constant initial volume between OBI and EOT (Section 3.2.2); and 2) constant initial vertical distance between OBI and EOT (Section 3.2.3). Total injection volumes were identical for all runs in Study 2. Finally, the impact of repeated leaching cycle over the same vertical interval have also been tested and compared (Section 3.2.4).

3.2.2. Constant Volume Between EOT and OBI for Varying Initial Cavern Radius

A series of runs were performed for the four caverns with the OBIs set to different depths (O1-O4) in order to maintain a constant initial brine volume between the OBI and EOT. Details on these runs are found in Table 3-12. This setup provided four configurations with identical initial volumes between the OBI and EOT for mixing with the incoming raw water, although the initial cavern surface areas for leaching over these regions differed. Final cavern geometries for eight runs (four for each of two injection durations with identical injection volumes) are found in Figure 3-16.

As expected, smaller caverns showed cavern growth to higher extents due to the same injection volume across all cases moving the OBI higher in the cavern (in addition to starting at higher depths). Increased radial cavern growth was observed for larger caverns for a similar same reason, due to larger radii caverns having greater volumes per vertical foot—lower surface area to volume ratios lead to increased radial growth into the salt formation in order to provide salt to increase specific gravity to equilibrium levels.

The geometry profile shapes differ qualitatively depending on duration of the raw water injection (injection volumes were identical). The shorter duration injections result in radial growth that was more uniform along the cavern axis, while longer duration injections result in larger radial growth near the starting OBI tapering to smaller radial growth near the final OBI. This behavior can be attributed to slightly increased (approximately 1-3 feet) maximum radial leaching for longer durations as result of the additional time that the OBI is at lower depths. Additionally, shorter duration injections show increased cavern growth below the EOT (approximately 15 ft compared to approximately two feet for longer durations) which may be attributed to the increased injection rate providing a driver for more leaching over a shorter period of time—leaching therefore finds a path to additional salt below the EOT.

Table 3-12. Run Properties for Study 2 (Constant Volume Between EOT and OBI)

Cavern Property	CYL1-O1	CYL2-O2	CYL3-O3	CYL4-O4
Cavern Radius (ft)	100.00	141.42	81.65	70.71
EOT (ft)	3900	3900	3900	3900
OBI (ft)	3800	3850	3750	3700
EOT - OBI (ft)	100	50	150	200
Volume Brine Between EOT and OBI (bbl)	5.60E+05	5.60E+05	5.60E+05	5.60E+05

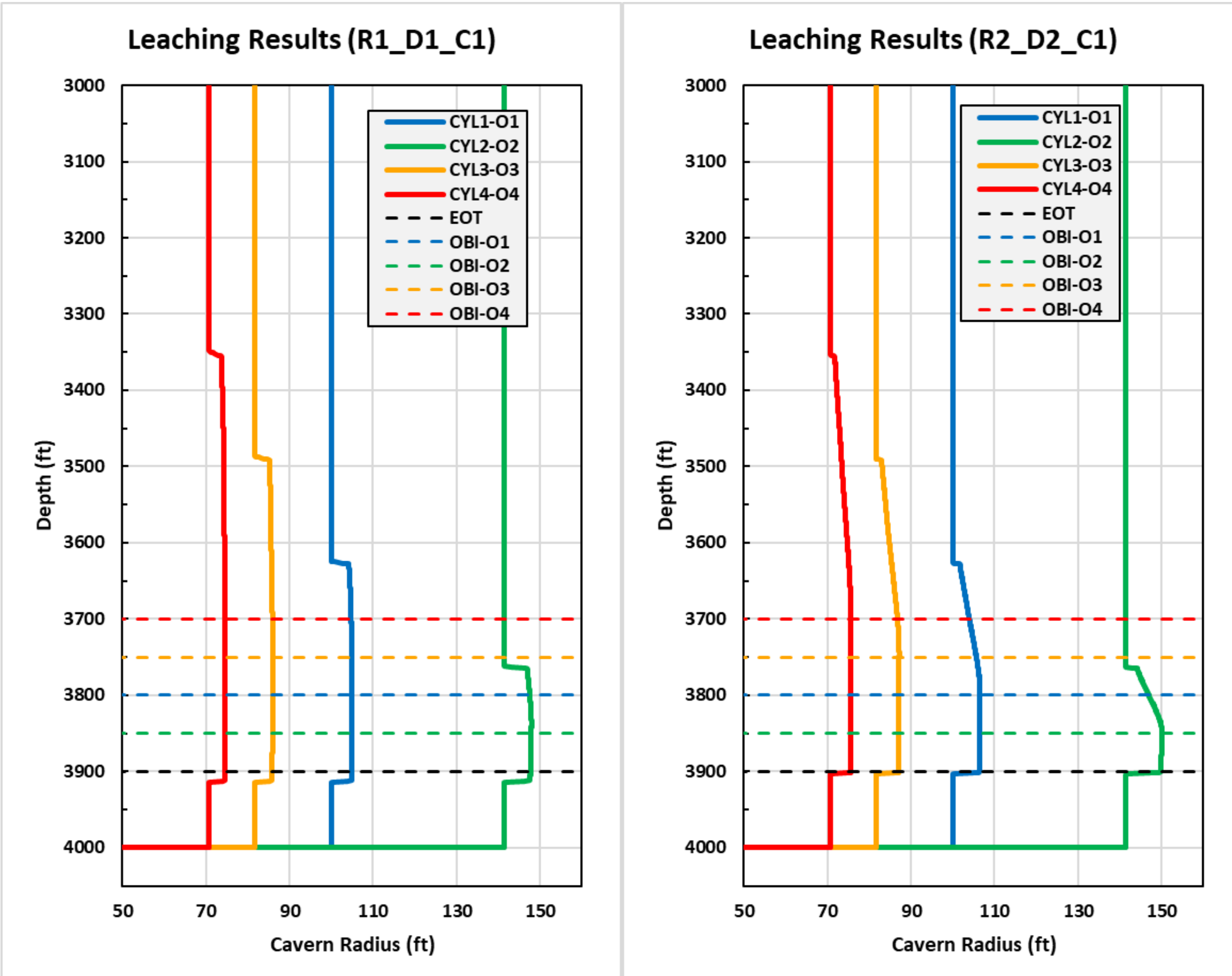

Figure 3-16. Final cavern geometries for constant initial volume between OBI and EOT, shorter injection duration (left) and longer injection duration (right)

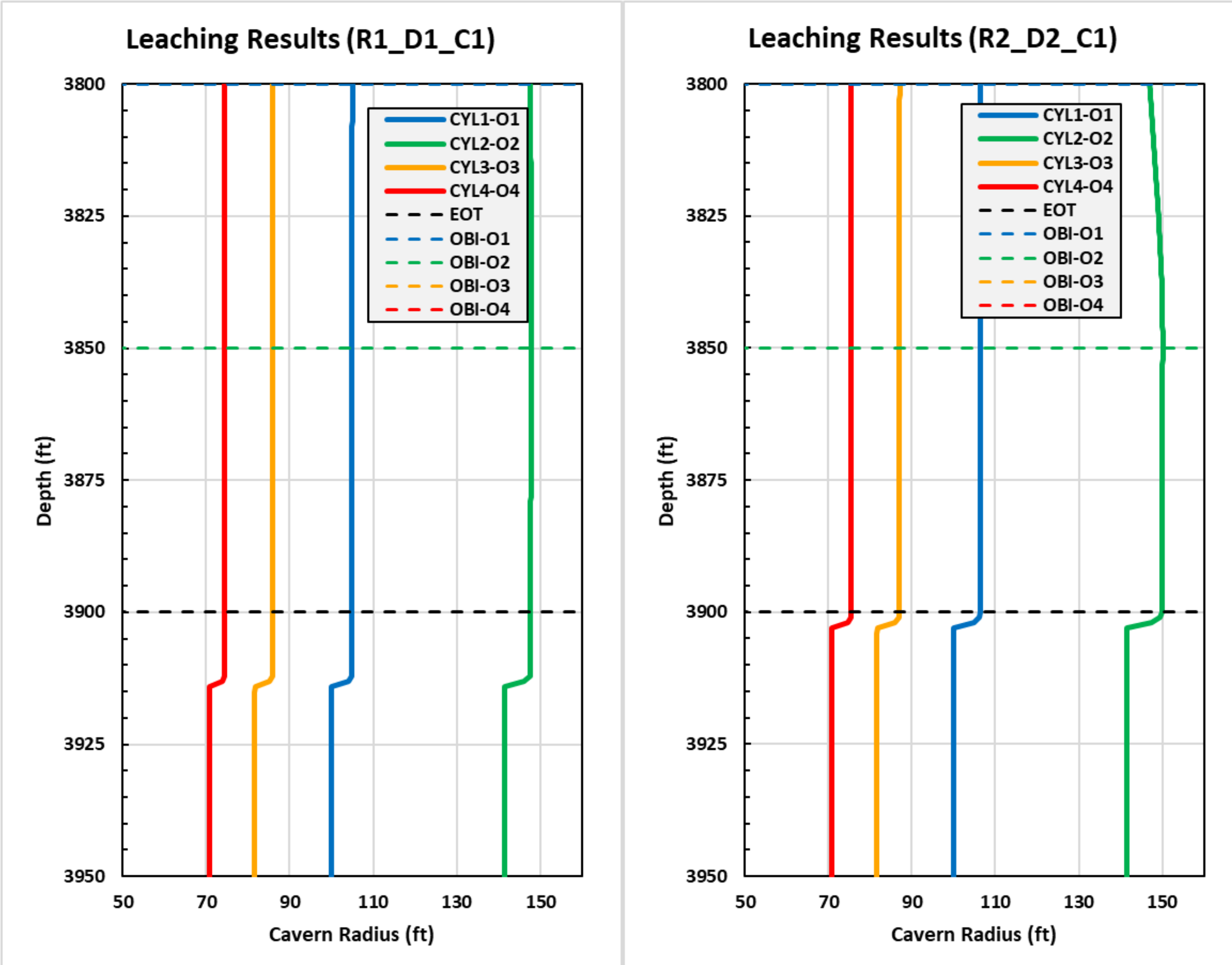

Figure 3-17. Near-EOT region for runs with constant initial volume between OBI and EOT, shorter injection duration (left) and longer injection duration (right)

3.2.3. Constant Distance Between EOT and OBI for Varying Initial Cavern Radius

A series of runs were performed for the four caverns with the OBIs set to identical depths (O1) in order to maintain a constant initial vertical distance between the OBI and EOT. Details on these runs are found in Table 3-13. This setup provided four configurations with identical initial cavern surface areas between the OBI and EOT for leaching, although the initial available mixing volumes over these regions differed. Final cavern geometries for eight runs (four for each of two injection durations with identical injection volumes) are found in Figure 3-18. Comparisons with the results from Section 3.2.2 above are plotted in Figure 3-19.

Results are generally qualitatively similar to the results discussed in Section 3.2.2 above. The results of this part of the study provide a comparison of cavern growth for caverns of different radii with the same initial OBI. For shorter injection durations, the difference in results are related directly to the difference in initial OBI position from the Section 3.2.2 results—the geometry profiles are almost identical, maintaining a constant growth profile, with a vertical shift corresponding to the vertical shift in OBI position. For longer durations, a more tapered profile is again observed.

Table 3-13. Run Properties for Study 2 (Constant Vertical Distance Between EOT and OBI)

Cavern Property	CYL1-O1	CYL2-O1	CYL3-O1	CYL4-O1
Cavern Radius (ft)	100.00	141.42	81.65	70.71
EOT (ft)	3900	3900	3900	3900
OBI (ft)	3800	3800	3800	3800
EOT - OBI (ft)	100	100	100	100
Volume Brine Between EOT and OBI (bbl)	5.60E+05	1.12E+06	3.73E+05	2.80E+05

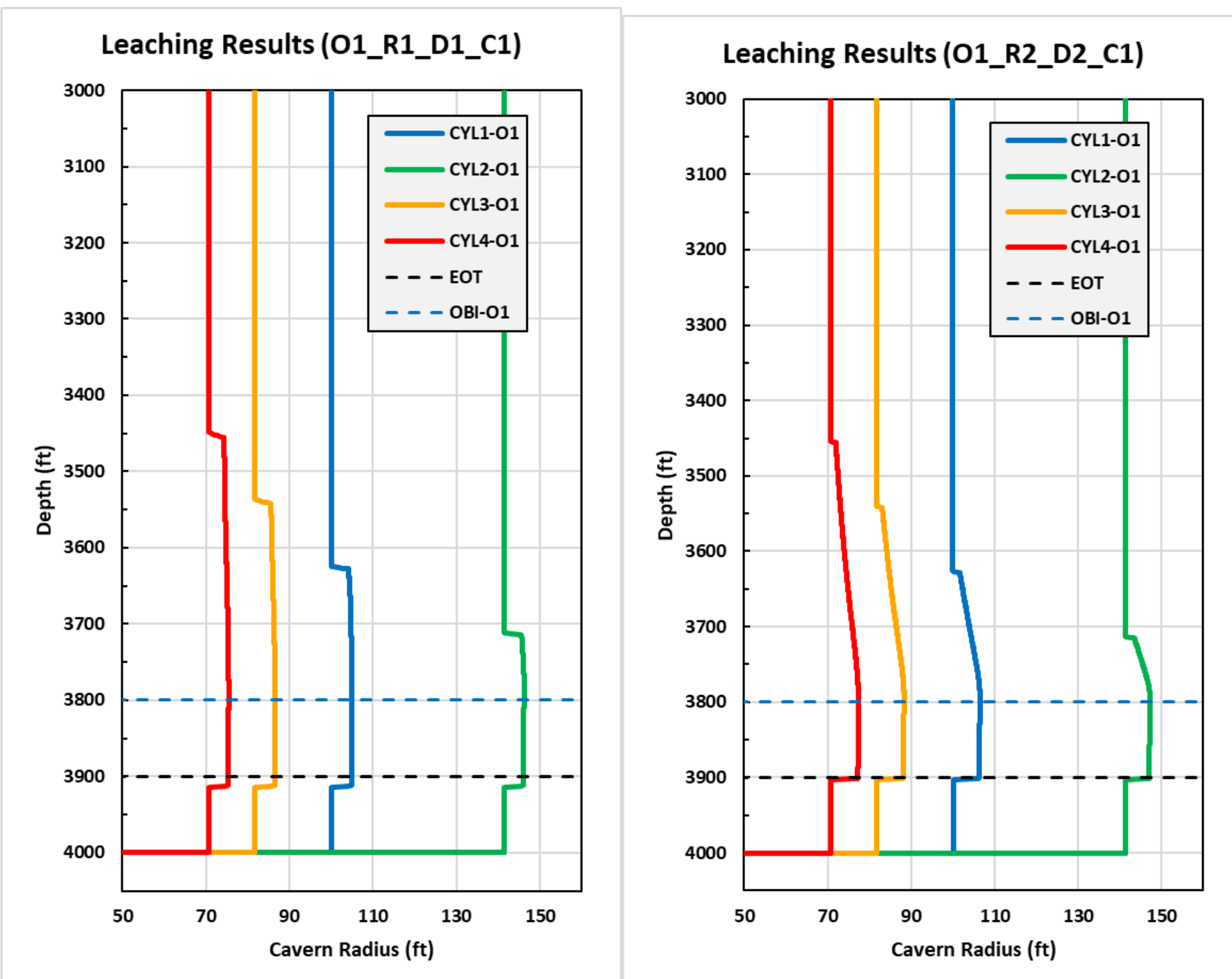

Figure 3-18. Final cavern geometries for constant initial distance between OBI and EOT, shorter injection duration (left) and longer injection duration (right)

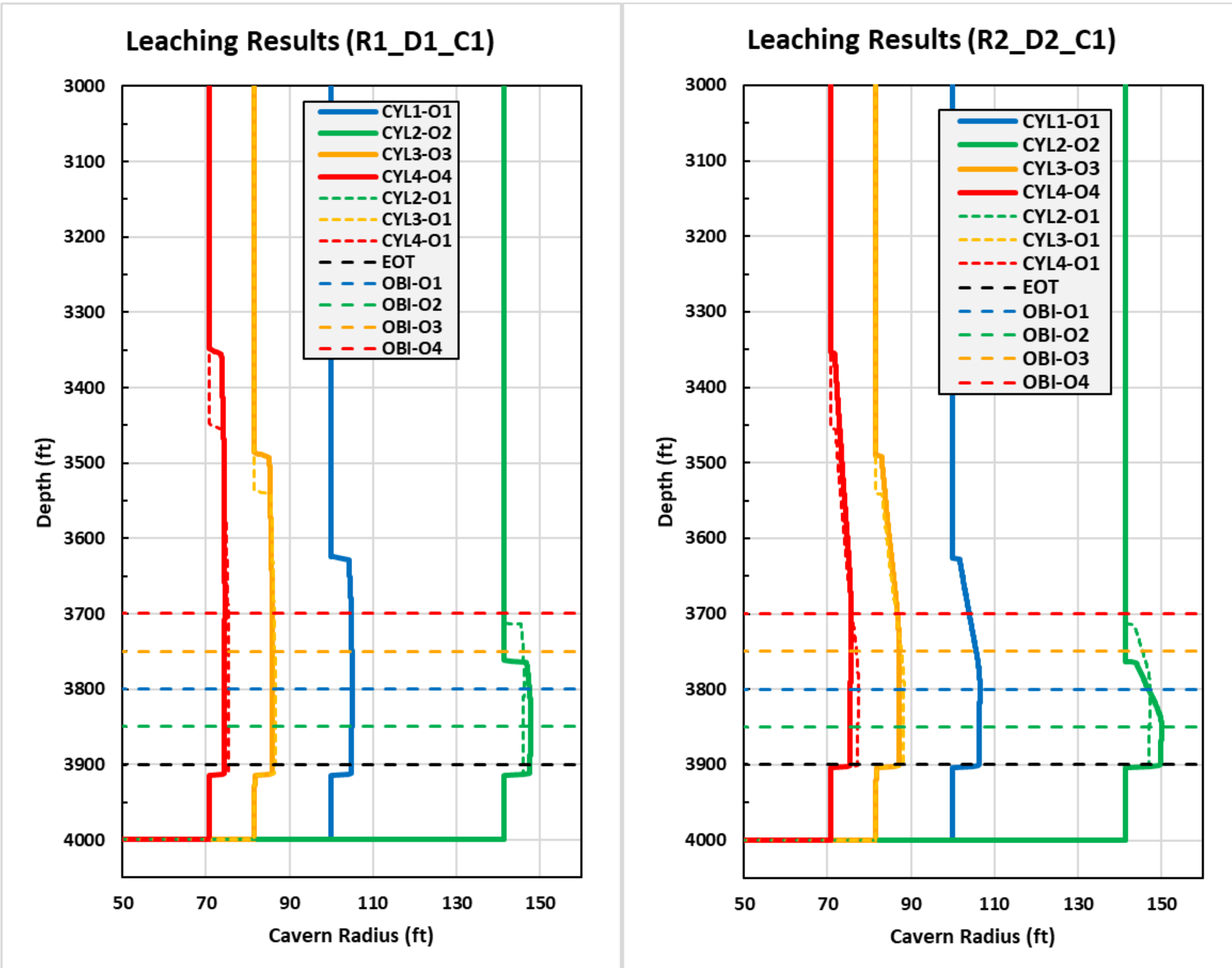

Figure 3-19. Comparison of final cavern geometries for constant initial distance and volume between OBI and EOT, shorter injection duration (left) and longer injection duration (right)

3.2.4. Constant Injection Volume for Varying Number of Leaching Cycles

The runs in Sections 3.2.2 and 3.2.3 were repeated with the number of leaching stages increased from 1 to 5 with the same total injection volume preserved. A 60-d workover period followed each stage. At the end of each workover, the OBI was reset to the initial OBI, reflecting a leach-and-fill approach. The purpose of these runs was to show a comparison of introducing 1 MMB of raw water via a single leach (Sections 3.2.2 and 3.2.3) vs. repeated leaching over the same vertical cavern extent. Results for the runs with 5 leaches are found in Figure 3-20 and Figure 3-21.

As expected, the vertical extent of leaching is much reduced and the extent of radial leaching increased for the 5-leach cases. The maximum radius reached in each case is an indicator of radial leaching growth. Maximum radii for the 1-leach and 5-leach cases are compared in Figure 3-22 and Figure 3-23 against initial OBI-EOT separations. For a given separation distance, the greater number of leaches and longer injection duration runs show greater maximum radii, consistent with the discussion above. Maximum change in radii for the 1-leach and 5-leach cases are compared in Figure 3-24 and Figure 3-25 against initial OBI-EOT separations. Five-leach runs tend to result in an additional 4-6 ft of maximal radial growth compared to single leach runs for the same injection volume.

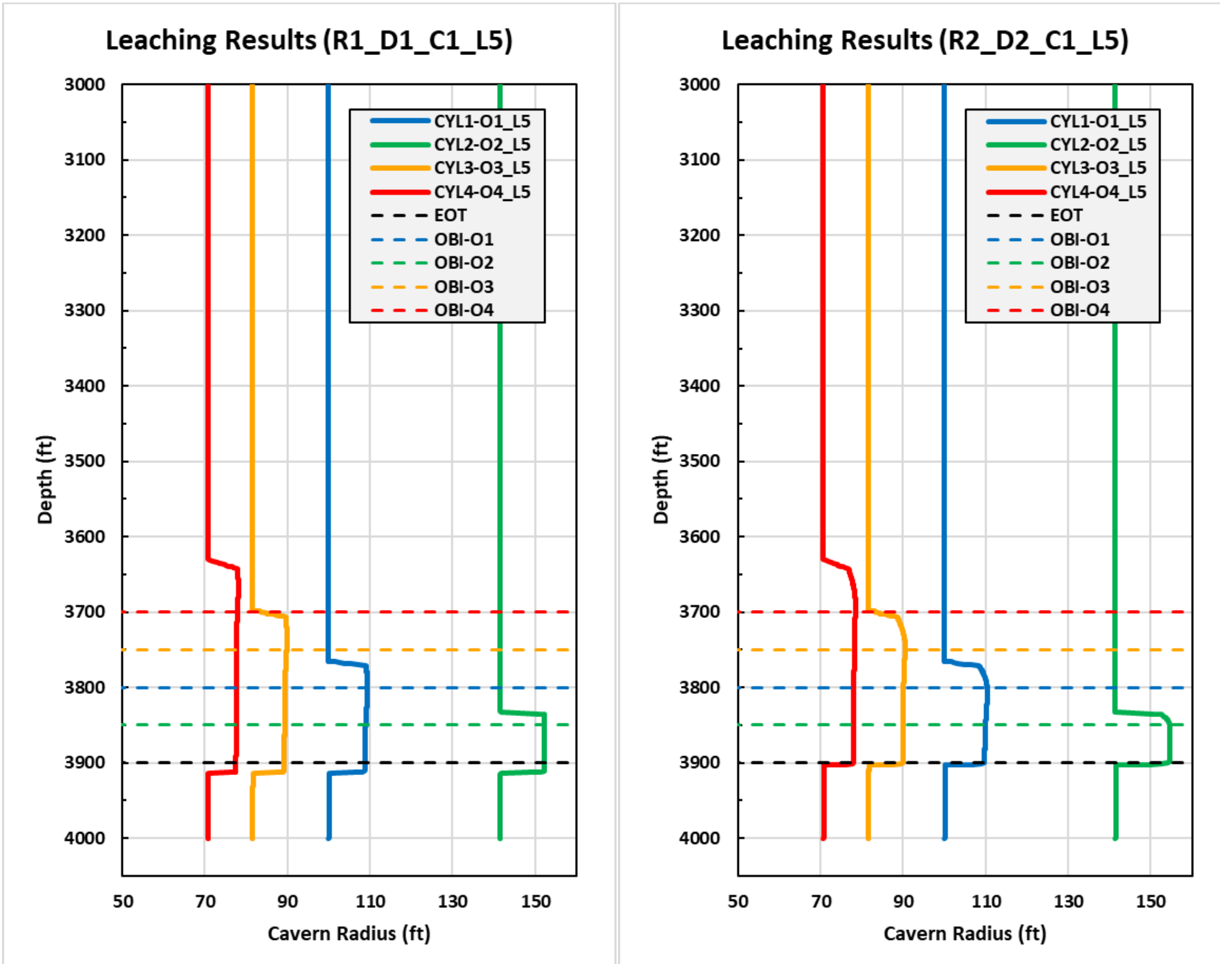

Figure 3-20. Final cavern geometries for constant initial volume between OBI and EOT, shorter injection duration (left) and longer injection duration (right), 5 consecutive leaches

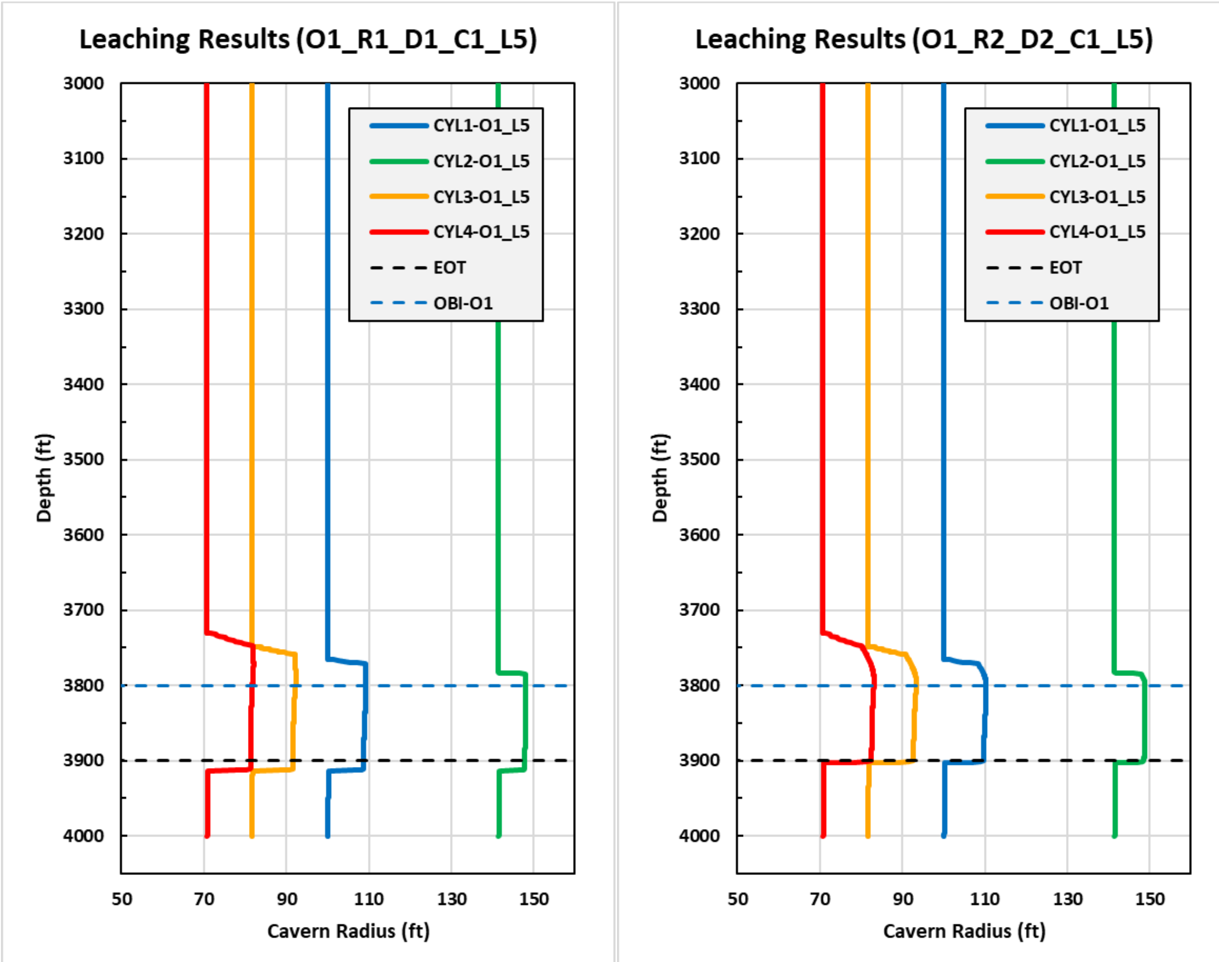

Figure 3-21. Final cavern geometries for constant initial distance between OBI and EOT, shorter injection duration (left) and longer injection duration (right), 5 consecutive leaches

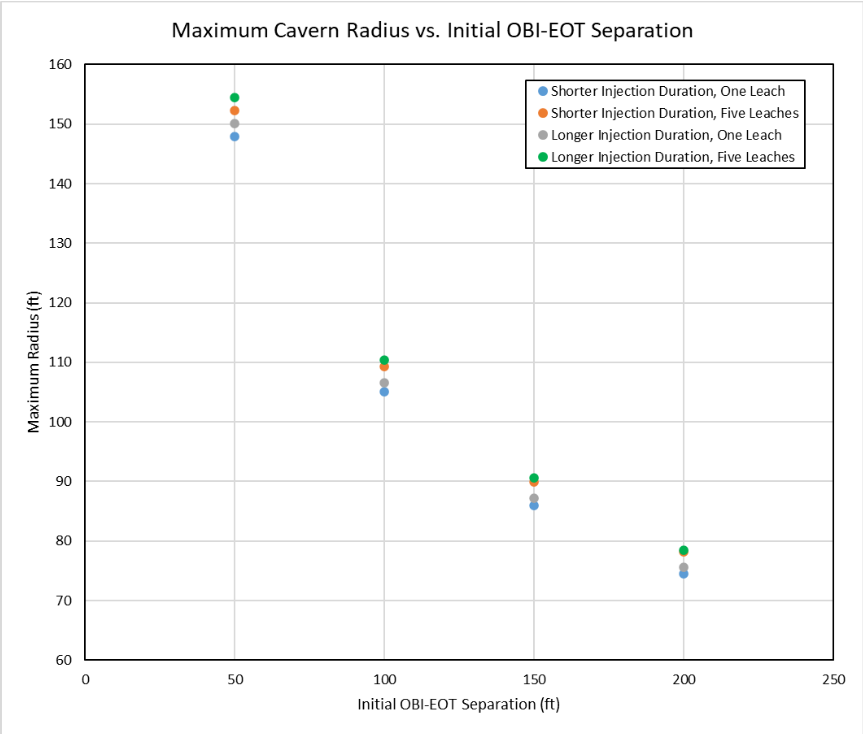

Figure 3-22. Cavern radii maxima for varying initial OBI-EOT separation distance (short/long injection duration series and 1/5 leaches series)

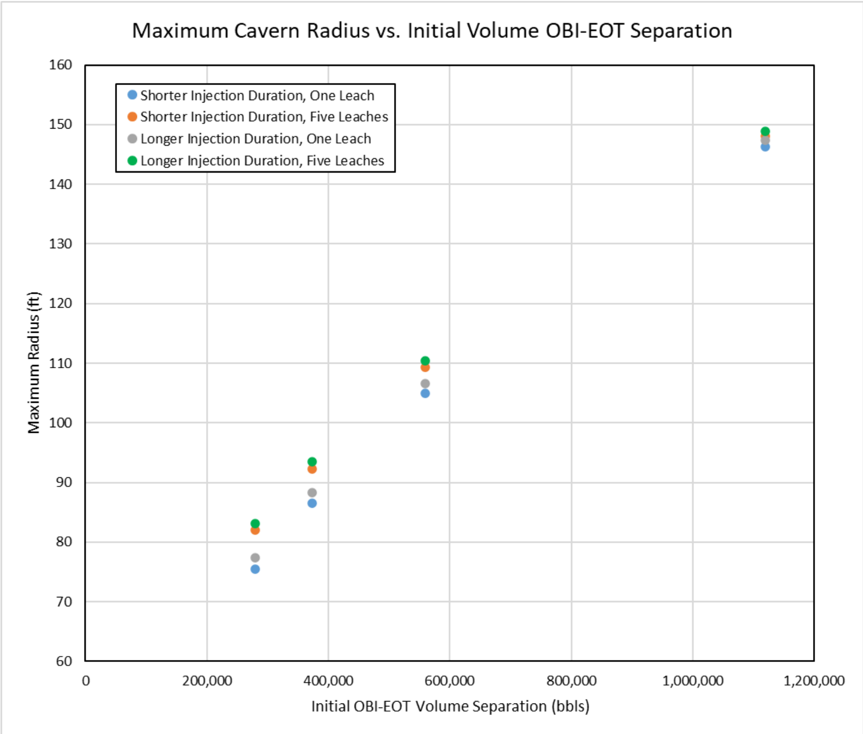

Figure 3-23. Cavern radii maxima for varying initial OBI-EOT volume separation (short/long injection duration series and 1/5 leaches series)

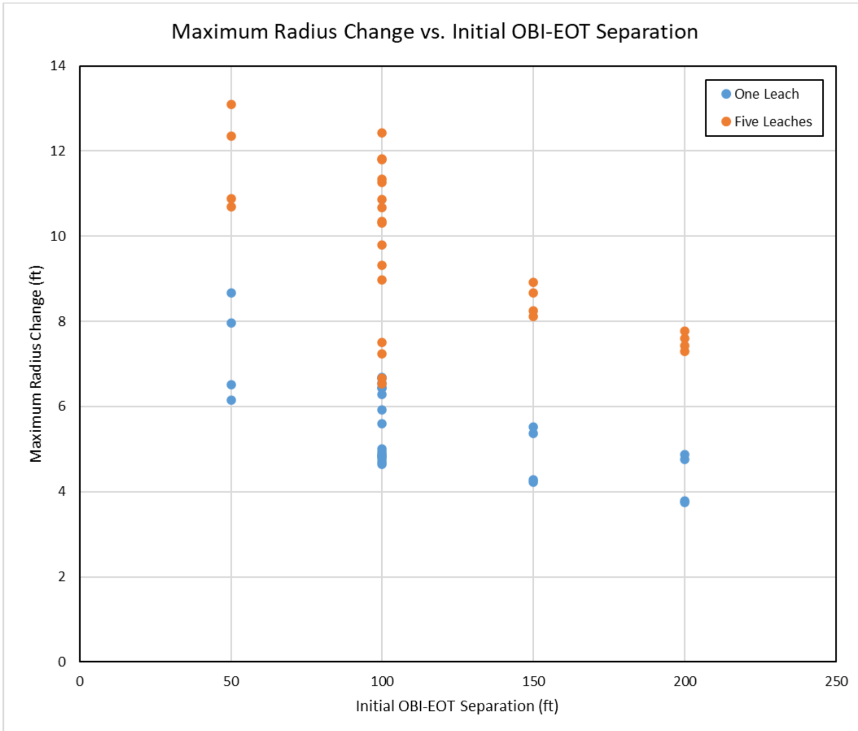

Figure 3-24. Maximum change in cavern radii for varying initial OBI-EOT separation distance (short/long injection duration series and 1/5 leaches series)

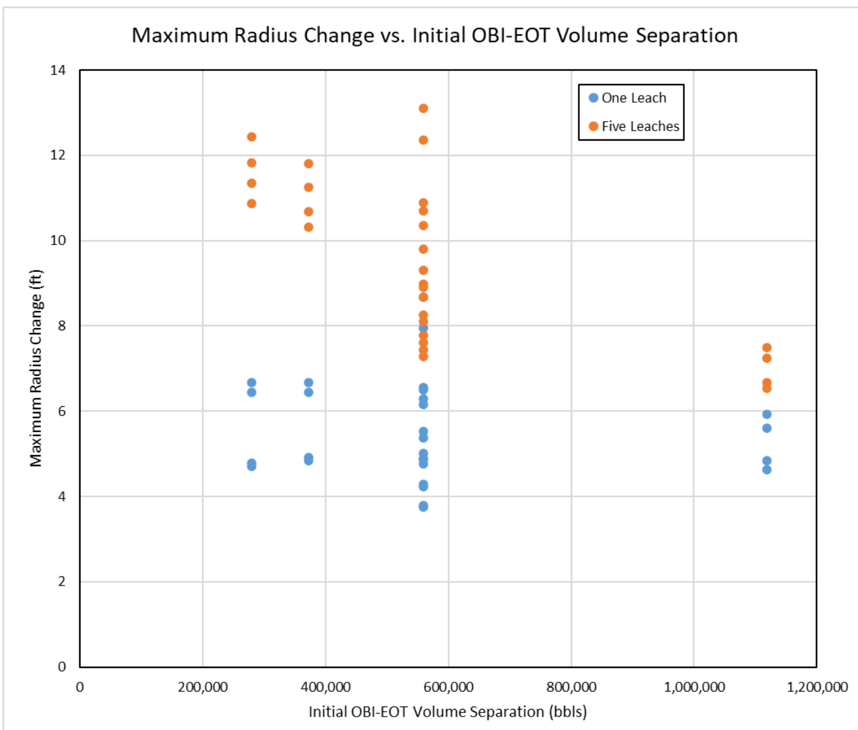

Figure 3-25. Maximum change in cavern radii for varying initial OBI-EOT volume separation (short/long injection duration series and 1/5 leaches series)

3.2.5. Summary of Study 2

Although it has been known that the majority of leaching takes place between the EOT and OBI, the recent increased use of partial drawdowns has raised the issue of repeated leaching when the OBI-EOT separation is relatively small. This study has systematically examined the impact of multiple leaching stages for hypothetical caverns of varying size and varying OBI-EOT separation. The SANSMIC runs showed results that were generally as-expected, with smaller caverns showing cavern growth to higher depths and increased radial cavern growth for larger caverns. Shorter duration injections resulted in more uniform radial growth along the cavern axis , while longer duration injections resulted in larger radial growth near the starting OBI tapering to smaller radial growth near the final OBI. Additionally, shorter duration injections show increased cavern growth below the EOT (approximately 15 ft compared to approximately two feet for longer durations). Five-leach runs tended to result in an additional 4-6 feet of maximal growth compared to single leach runs for the same injection volume.

By providing additional information for a range of potential scenarios, this study has increased our confidence in being able to report leaching modeling results, as well as in making any future recommendations for operational changes associated with remedial leaching. Finally, our ability to anticipate cavern geometry changes based on planned repeated leach-and-fill activities has been enhanced and will contribute to drawdown predictions.

3.3. Study 3: What is the Impact of Lumping Injection Data on Cavern Geometry?

Real world raw water injection data typically are documented in barrels per day. In SANSMIC, an injection rate and duration must be specified for a given calculation stage. For simplicity in setup of a SANSMIC input file (i.e., minimizing the number of specified stages), day-by-day data have typically been lumped together over longer time periods. Note that for a given real world injection period ("leaching cycle"), leaching may not occur on each calendar day.

Two different data lumping methodologies have been used recently in order to translate real-world injection data into representative injection rates and durations. In each case, the first and final days for a leaching cycle were identified, as well as the total volume of raw water injected. For the 2018-19 and 2020 annual leaching reports [6][9], the number of days on which leaching actually occurred was used as the leaching duration (Method 1). For the 2017 annual leaching report [4], the number of days between leaching start and end was used as the leaching duration (Method 2); with this methodology, the number of days is at least as large as for Method 1. In each case, the leaching rate was calculated as the total injected volume divided by the leaching duration.

For each methodology, the total injection volume was conserved. For Method 1, the duration is shorter with a higher injection rate, while Method 2 more closely matches the calendar time over which leaching occurred, but does not include workover time as part of the real world injection period. **Here, the two previously-used data lumping methodologies are compared alongside a proposed additional methodology in order to answer the question of how impactful the data lumping methodologies are to the final SANSMIC results and to provide guidance for future leaching studies.**

3.3.1. Model Setup

Three injection data lumping methodologies were tested using six tests—each test represents a different daily injection data set. The three methodologies investigated here were Methods 1 and 2 above, as well as a newly-defined Method 3: model individual daily injections with their own stages, as well as model individual workover times in between injection stages. The three methodologies tested in Study 3 are described in Table 3-14.

Table 3-14. Descriptions of Three Data Lumping Methodologies Tested in Study 3

Methodology Name	Methodology for Determining SANSMIC Injection Duration	Methodology for Determining SANSMIC Injection Rate
Method 1	Equal to number of injection days	Equal to injected volume divided by injection duration
Method 2	Equal to number of days between injection start and end	Equal to injected volume divided by injection duration
Method 3	Equal to number of injection days	Equal to daily rate; Workover stages inserted between injection stages

The baseline model for the tests in this study was chosen to be the CYL4_O1_R*r*_D*d*_C1 model from Section 3.2; i.e., a cylinder of radius 70.71 ft, EOT of 3700 ft, OBI of 3800 ft, and vertical cell dimension of 1 ft. Injection rates and durations vary by test and method as detailed in Table 3-15 and Table 3-16. Models for this study were named CYL_M*m*_T*t*, where *m* refers to the method number and *t* refers to the test number. Note that in some cases, tests from different methods have redundant input and thus were not rerun (e.g., all of the Method 2 models are identical for each of the six tests due to the averaging scheme used for that method). A total of 10 independent runs were performed.

Each test consists of a total of 500 MBBL of raw water injected over a 31-day period followed by a 60-day workover period. Each run consists of a single injection stage followed by a single 60-day workover stage. Injection volumes on a daily basis are shown for the six tests in Figure 3-26. Test 1 is a daily injection model where a constant volume is injected on each day of the 31-day test period (note that the Test 1 runs are identical for Methods 1 and 2 because the number of injection days are the same). The Test 2 injection scheme has 7 injection days of equal volume every 5 days. The Test 3 injection scheme has 4 injection days of equal volume every 10 days. The Test 4 injection scheme has 2 injection days of equal volume every 30 days. The Test 5 injection scheme consists of 3 injection days at the beginning followed by 1 injection day at the end. The Test 6 injection scheme consists of one injection day at the beginning followed by 3 injection days at the end. Injection volumes per day are shown in Figure 3-26. Note that in order to implement any user-specified change in EOT or OBI, a new stage must be defined, but these examples to not reflect any of those changes.

Table 3-15. Injection Details for Six Data Lumping Tests Using Methods 1 and 2

Test	Description	No. Injection Days	Duration from Start to Finish (d)	Injection Volume (Mbbl)	Method 1				Method 2			
					Inj. Dur. (d)	Inj. Rate (bbl/d)	Sim. Dur. (d)	Model Name	Inj. Dur. (d)	Inj. Rate (bbl/d)	Sim. Dur. (d)	Model Name
1	Daily injection	31	31	500	31	16129	91	CYL_M1_T1	31	16129	91	CYL_M2_T1
2	Injection every 5 days	7	31	500	7	71429	67	CYL_M1_T2	31	16129	91	CYL_M2_T2
3	Injection every 10 days	4	31	500	4	125000	64	CYL_M1_T3	31	16129	91	CYL_M2_T3
4	Injection every 30 days	2	31	500	2	250000	62	CYL_M1_T4	31	16129	91	CYL_M2_T4
5	Early injections	4	31	500	4	125000	64	CYL_M1_T5	31	16129	91	CYL_M2_T5
6	Late Injections	4	31	500	4	125000	64	CYL_M1_T6	31	16129	91	CYL_M2_T6

Table 3-16. Injection Details for Six Data Lumping Tests Using Method 3

Test	Description	No. Injection Days	Duration from Start to Finish (d)	Injection Volume (Mbbl)	Method 3						
					Inj. Dur. (d)	Dur. per Inj. Stage (d)	Inj. Rate (bbl/d)	Leaching Stages	Workover Stages	Sim. Dur. (d)	Model Name
1	Daily injection	31	31	500	31	31	16129	1	1	91	CYL_M3_T1
2	Injection every 5 days	7	31	500	7	1	71429	7	7	91	CYL_M3_T2
3	Injection every 10 days	4	31	500	4	1	125000	4	4	91	CYL_M3_T3
4	Injection every 30 days	2	31	500	2	1	250000	2	2	91	CYL_M3_T4
5	Early injections	4	31	500	4	3, 1	125000	2	2	91	CYL_M3_T5
6	Late Injections	4	31	500	4	1, 3	125000	2	2	91	CYL_M3_T6

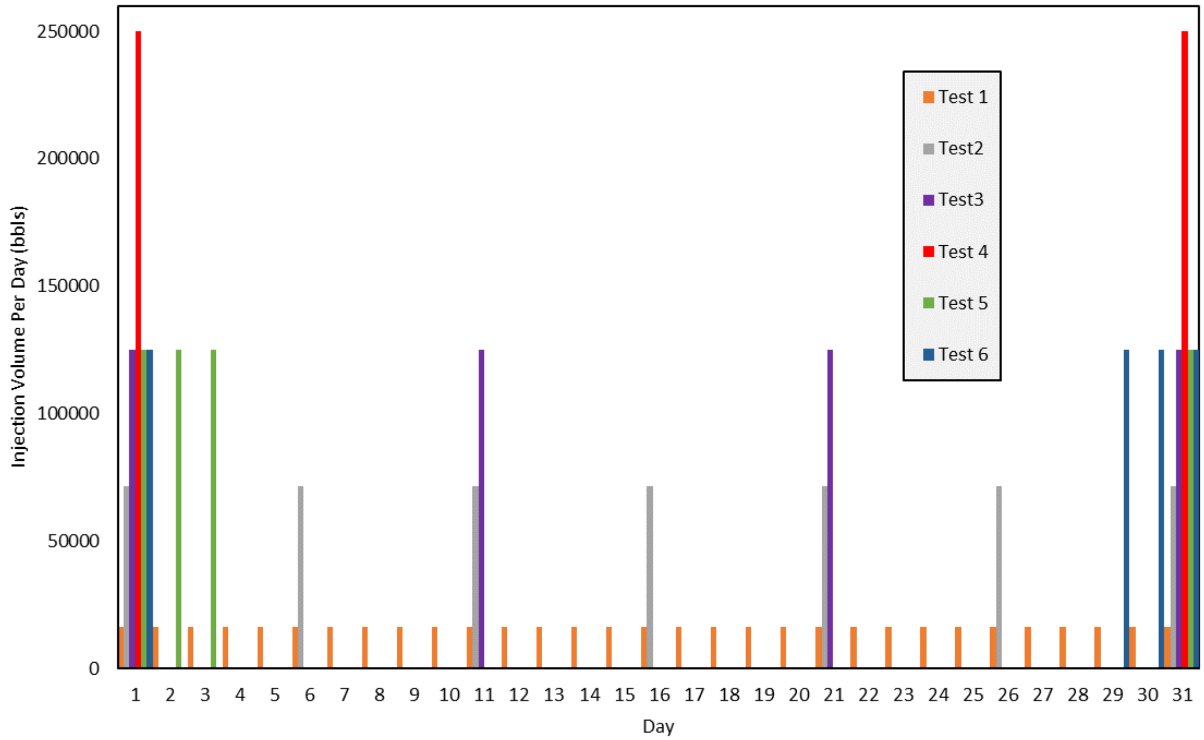

Figure 3-26. Injection volume per day for the six data lumping tests

3.3.2. Constant Injection Volume for Varying Data Lumping Strategies

Cavern geometry results for all tests are shown in Figure 3-27 through Figure 3-37. Note that in some cases, tests from different methods have redundant input and thus were not rerun or plotted. Note also that the radial dimensions in these plots are exaggerated compared to the vertical dimensions.

While the injection histories for all six tests have the same total injection volume, an array of cavern shapes develops as the OBI moves higher in the cavern, although the differences in radial growth at a given depth are limited to a few feet (Figure 3-27).

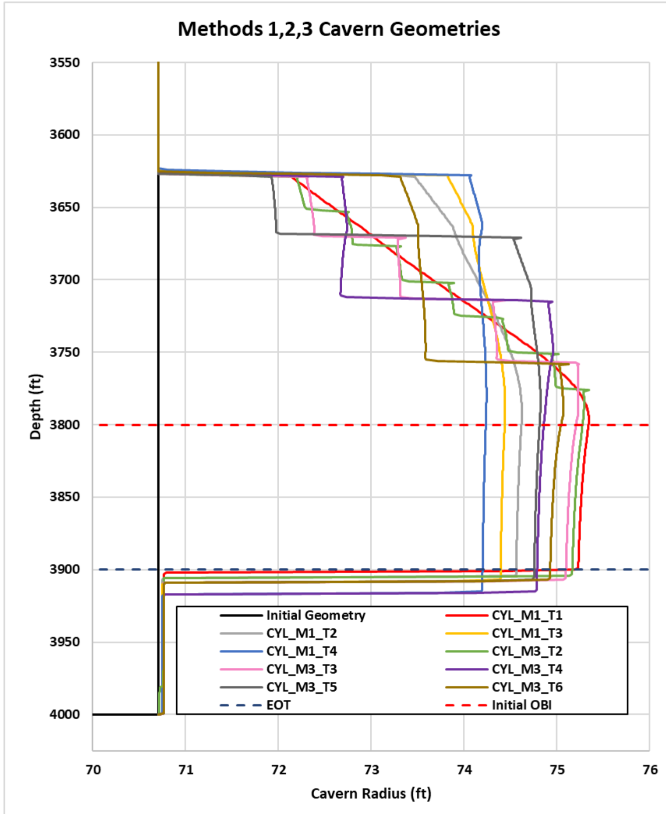

Figure 3-27. Cavern geometries for all methodologies and tests

3.3.2.1. Discussion of Results by Method

Method 1 tests show that the longer duration Test 1 results in slightly more radial growth and less vertical growth below the EOT (Figure 3-28). Also, the shorter duration injections result in more uniform radial growth along the cavern axis. These results are consistent with the results observed for Study 2. The lumping methodology in Method 2 results in identical input parameters for all tests, since all tests have the same overall injection duration of 31 days (Figure 3-29).

The Method 3 lumping methodology results in the greatest variety of cavern geometries across the six tests, since it captures the most detail from the daily injection data (Figure 3-30), although again the range of radial growth is only a few feet for a given depth and is not substantial on the scale of a typical cavern (Figure 3-31). The increased growth below the EOT ranges over about 2-17 ft with the greatest growth in this region observed for Test 4, which has the fewest number of injection days across the six tests, but also represents the greatest daily injection rate (Figure 3-31). The leaching methodology is important to predicting vertical growth when injection of large daily rates are separated by long time periods.

Overall, the observed differences in radial growth are small for the 500 MMB injection considered here. However, the differences could be compounded over time for longer and more complex leaching histories sometimes encountered in SPR caverns and result in more substantial differences in calculated geometries.

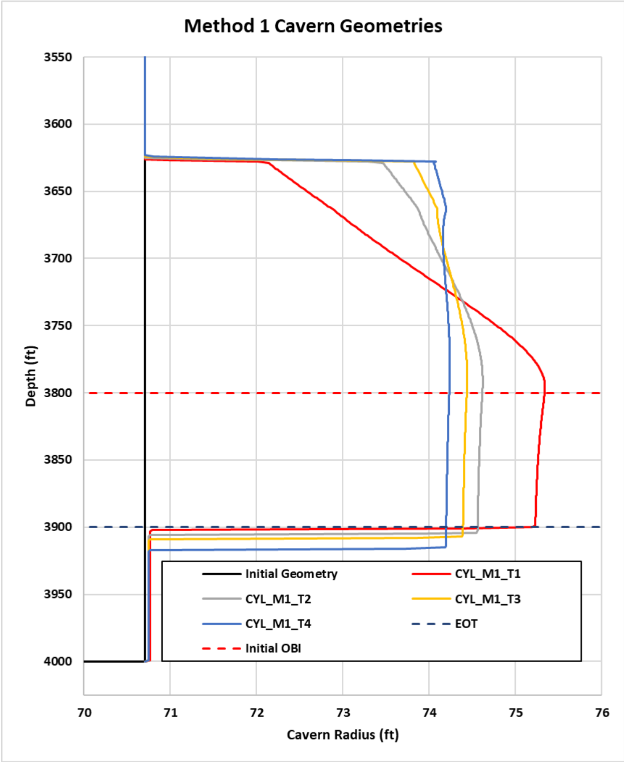

Figure 3-28. Cavern geometries for Method 1 tests (Tests 5 and 6 give same results as Test 4)

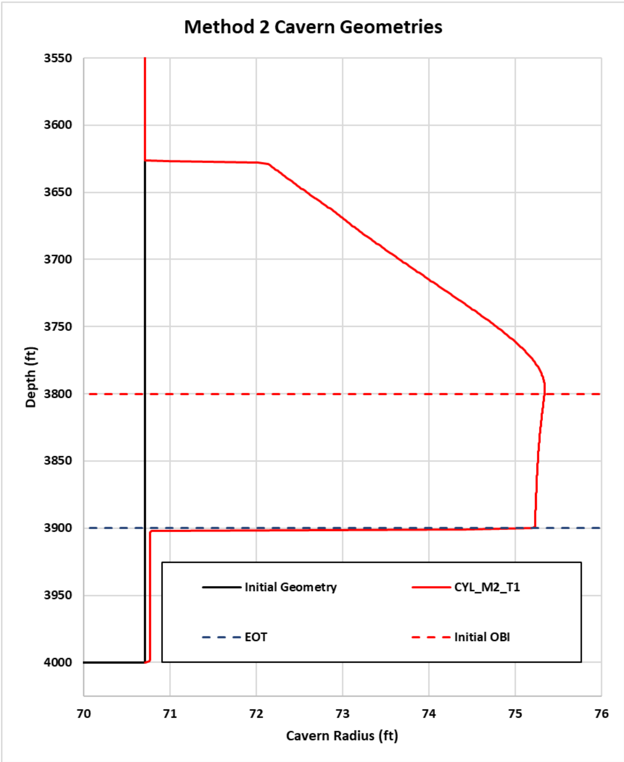

Figure 3-29. Cavern geometries for Method 2 tests (all tests have the same results as Test 1)

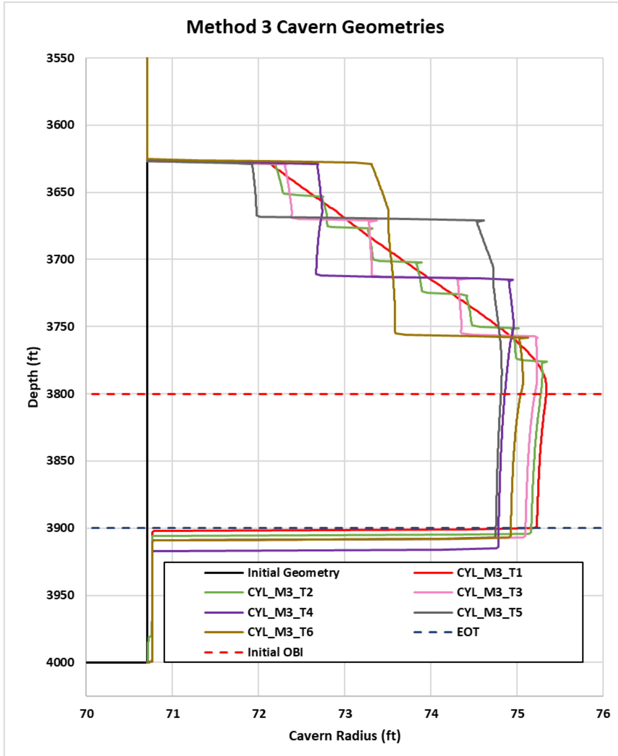

Figure 3-30. Cavern geometries for Method 3 tests

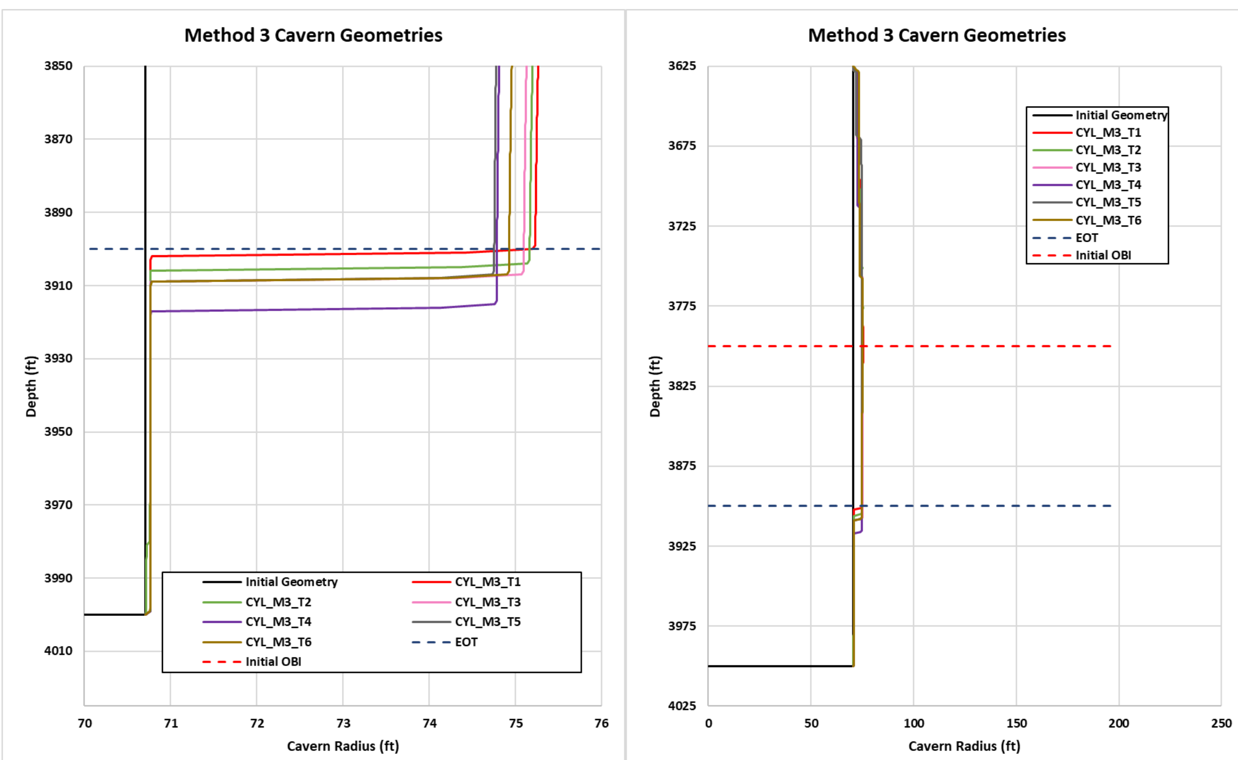

Figure 3-31. Cavern geometries for Method 3 tests on rescaled plots: focus on region below EOT (left) and close to true scale (right)

3.3.2.2. Discussion of Results by Test

Inputs for Test 1 (daily injections) are identical for all methods due to it being a case where the number of days with injection is equal to the number of days between the first and last injection, plus the injection rates are the same for each day. Therefore, the Test 1 results for all methods are redundant (Figure 3-32).

For Test 2 (injections every 5 days), Methods 1 and 2 show the typical "smooth" geometry changes (Method 2 resulting in a slightly larger radial growth due to longer injection time), while Method 3 shows a staircase pattern resulting from intermediate workover periods between leaching stages. Interestingly, small features (which may be model artefacts) are observed which show sharp edges jutting into the surrounding salt. Throughout all the tests in this study, these features only appear at the OBIs for Method 3 runs, so they may be a result of the workover periods following smaller injection volumes. They may not be realistic features expected in a real world leaching case, so care should be taken in using Method 3 for lumping injection data, unless the source of the features can be tracked to areas of the SANSMIC source code and addressed in a future code version.

Results for Test 3 (injections every 10 days) are similar to results for Test 2, with the staircase shape of the Method 3 run delineating each leaching stage. Results for Test 4 (injections every 30 days) are consistent with those from the previous two tests, with the staircase shape recurring for the two leaching stages.

Results for Test 5 (more volume injected earlier in the injection time period) are also consistent with those from the previous tests, with the Method 1 and 3 runs resulting in increased leaching below the EOT. Results for Test 6 (more volume injected later in the injection time period) are also consistent with previous tests. The difference between earlier and later injections (Tests 5 and 6) is evident for Method 3, where the greatest radial growth region extending further up in the cavern for the earlier injections.

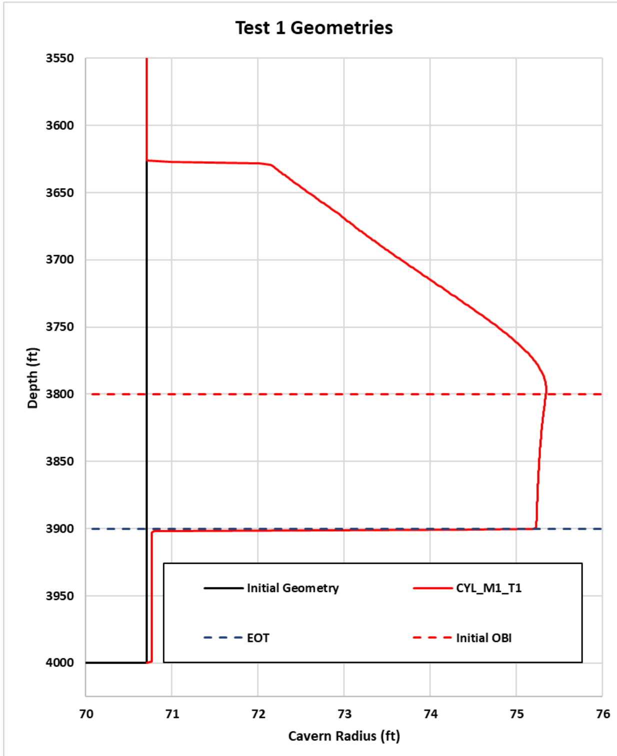

Figure 3-32. Cavern geometries for Test 1 (all Methods have the same result as Method 1)

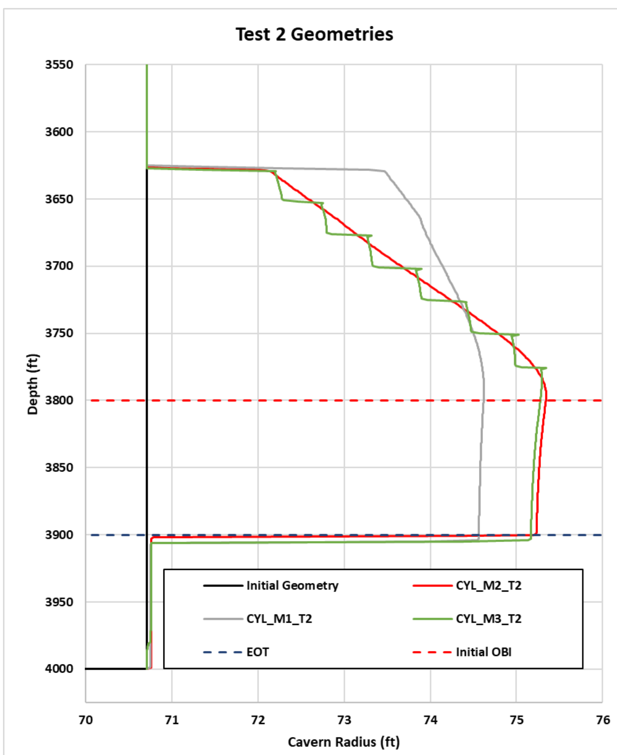

Figure 3-33. Cavern geometries for Test 2 (3 Methods)

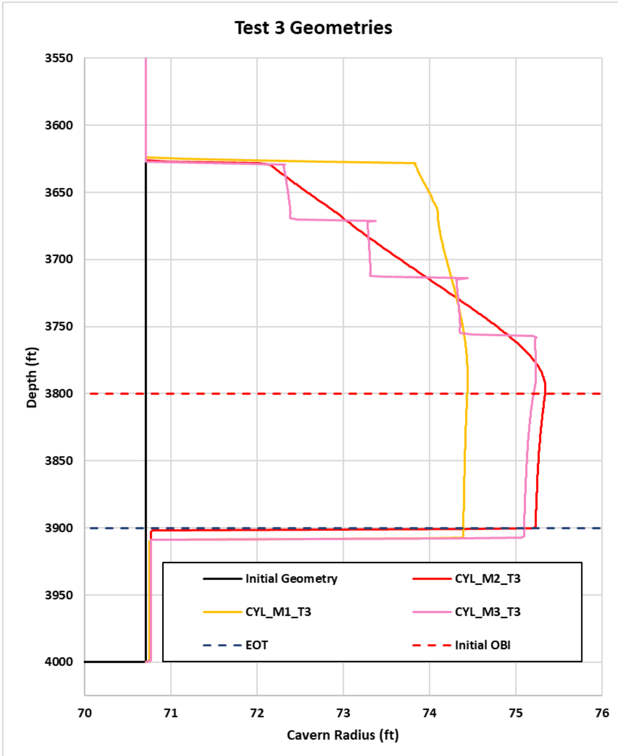

Figure 3-34. Cavern geometries for Test 3 (3 Methods)

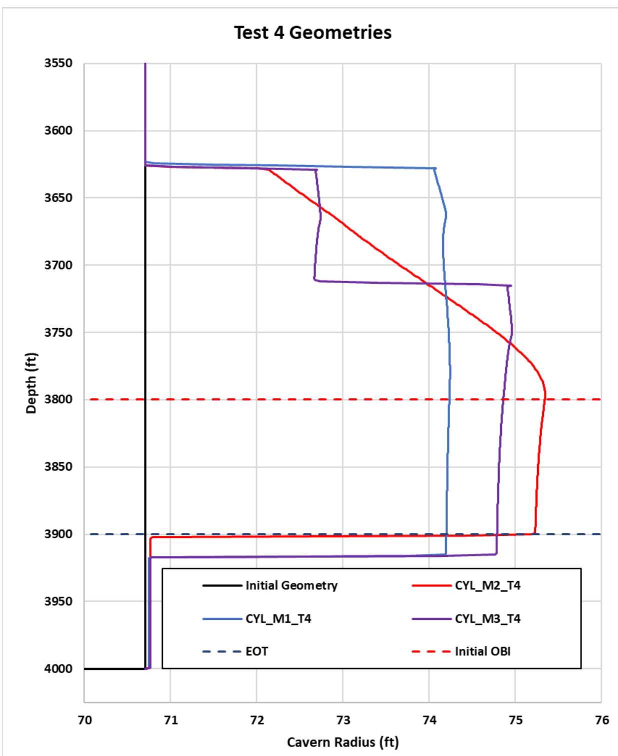

Figure 3-35. Cavern geometries for Test 4 (3 Methods)

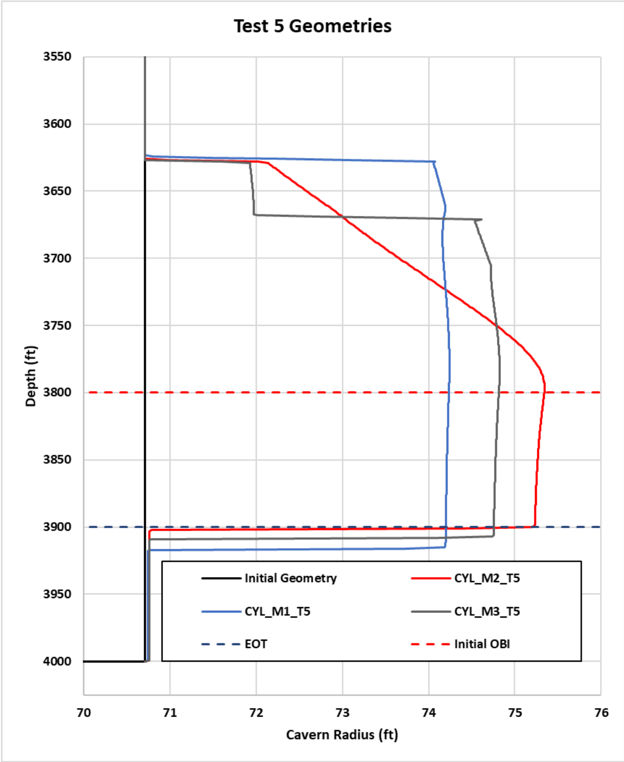

Figure 3-36. Cavern geometries for Test 5 (3 Methods)

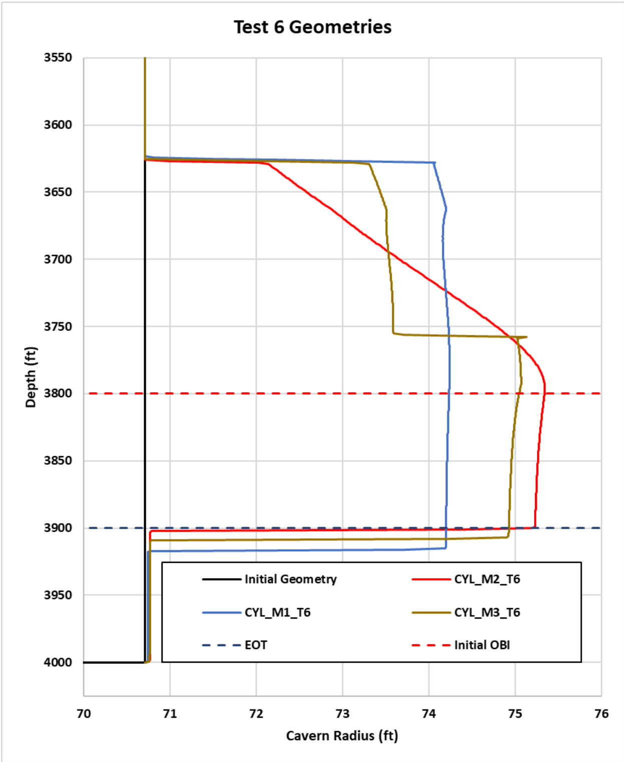

Figure 3-37. Cavern geometries for Test 6 (3 Methods)

3.3.3. *Summary of Study 3*

Three methodologies for lumping injection volume data have been tested to examine their impact on resulting cavern geometries and to provide guidance for future leaching studies. Methods 1 and 2 are different averaging methodologies used in previous Sandia leaching reports. Method 3 is a new methodology tested here for the first time, that is designed to more closely replicate daily leaching activities by including workover time for days when no raw water is injected.

A variety of cavern shapes were observed depending to the timing of leaching stages and inclusion of workover stages. In cases with a smaller number of injection days, the injection rate is higher and increased depth of leaching below the EOT is observed. Overall, the observed differences in radial growth are small (a few feet at a given depth) for the 500 MMB injection considered here. However, the differences could be compounded over time for longer and more complex leaching histories sometimes encountered in SPR caverns and result in more substantial differences in calculated geometries.

Additionally, small features (which may be model artifacts) are observed which show sharp edges jutting into the surrounding salt—these features only appear at the OBIs for Method 3 runs and may be attributed to workover periods, which do not exist for Method 1 or 2 runs. While the Method 3 methodology is designed to more closely replicate the day-to-day leaching/workover times, the presence of these features may not be expected in a real world leaching case, so care should be taken in using Method 3 for lumping injection data, unless the source of the features can be tracked to areas of the SANSMIC source code and addressed in a future code version.

3.4. Study 4: What is the Impact of SANSMIC's Internal Rounding Scheme, Injection Volume, and Cell Size on Cavern Geometry and Leaching Efficiency?

A recurring issue when analyzing leaching results for real caverns is the observation of unreasonably high leaching efficiencies (e.g., > 20%) output for some leaching stages [4][6][9]. When considering leaches of relatively larger volumes or leaches over longer time periods, the leaching efficiencies appear to result in reasonable values (~15-16 %). However, no clear study has been done to uncover the source of the high leaching efficiencies. Some hypotheses as to the reason for the observed high efficiencies have been: 1) cell sizes that are too large; 2) injection volumes that are too small; or 3) a combination of 1 and 2. A systematic approach to investigating the impact of injection volume and cell size on leaching efficiency has been performed here. **Understanding the impact of injection volume and cell size will help as the development of a new version of the SANSMIC code proceeds and may uncover the root cause for the observation of anomalously high leaching efficiencies [11].**

3.4.1. *Model Setup*

In order to test the impact of injection volume and cell size on leaching efficiency, 66 runs were set up with the following run names: CYL_O*o*_C*c*_V*v*, where *o* is the OBI option number (1-11), *c* is the cell size option number (1 or 2), and *v* is the volume option number (1-3). The CYL4 cylindrical geometry from Study 2 was used here (constant radius of 70.71 ft and floor at 4000 ft). The OBI for O1 was chosen at 3800 ft, corresponding to a height from the floor of 200 ft, and each additional OBI option number indicates an initial OBI height of 1 ft lower (e.g., O2 has a height of 199 ft). As a result, OBIs with heights of 190-200 ft were covered on 1-ft increments. Two cell sizes (C1 = 1-ft cells and C2 = 10-ft cells) were tested. Additionally, three injection volumes were tested (V1 =

2000 bbl over 1 day, V2 = 20,000 bbl over 1 day, and V3 = 1 MMBLs over 4 days). A single workover period of 60 days followed each injection period.

One of the limitations of the SANSMIC code used in recent annual leaching reports is on the number of simulation cells. A maximum of 500 cells has been allowed, which when paired with caverns with thousands of feet of depth, requires cell sizes greater than 1 ft. A standard cell size of 10 ft has been used. Sonar data are generally reported in 1-ft increments. To create a cavern geometry for use in SANSMIC, sonar data have been averaged across 10-ft increments and thus cavern widths are only specified in depth increments of 10 ft. However, OBI and EOT measurements are typically given to the nearest 1 ft. As a result, even if OBI and EOT are given as depths in between cell edges, OBI and EOT values are "rounded" by the SANSMIC code in order that they lie on a cell edge. It is not known if this internal rounding scheme (where input values for OBI and EOT depths take on new values inside the code) may also contribute to the anomalous leaching efficiencies via anomalous volumes. This is also tested here by varying the input values of OBI and noting the value at which the OBI is tracked internally to the code, as well as the impact on the final OBI and leaching efficiency.

3.4.2. Constant Injection Volume for Varying Initial OBI Depth

Results for the 66 tests under Study 4 are summarized in Table 3-17 through Table 3-22. First, we observe that, as expected, even though OBIs are specified at 1-ft intervals, the SANSMIC code only reports the OBIs at 190 or 200 ft height in the output files for simulations with 10-ft cells (Figure 3-38). For simulations with 1-ft cells, OBIs are reported on 1-ft intervals, also as expected. However, despite the bimodal distribution of OBIs for 10-ft cell simulations, final OBIs are consistent with final OBIs for 1-ft cell simulations (Figure 3-39). This result indicates that the OBI height, as input, is kept by the SANSMIC code independently of whether that height corresponds to a defined cell height. This gives confidence that OBIs have been used internally by the code in a way that has ***not*** contributed to anomalous cavern volumes or leaching efficiencies (i.e., the initial OBIs reported in output files are not necessarily the same as those being used by the code at startup). Investigation of the SANSMIC source code confirms that while the cell containing the OBI has a depth on 10-ft intervals, the value of the OBI depth that lies between cell edges is saved and used as the simulation proceeds. Thus the internal rounding scheme used in the SANSMIC code is only used for reporting output and not in actual calculations, so there is no need to alter this part of the code in the future.

The impact of injection volume was tested by comparing results from V1, V2, and V3 simulations. Results from V1 simulations show relatively high leaching efficiencies in the range of 20-30%, while leaching efficiencies tend to decrease with increasing injection volume (Figure 3-40). This is consistent with anecdotal observations that smaller injection volumes are associated with higher leaching efficiencies. One contributor to anomalous leaching efficiencies for stages involving small injection volumes may be the output resolution of volumes from the SANSMIC code. The code currently reports cavern volumes to the nearest 100 barrels. For C2_V1 simulations, volume changes were mostly 500 bbl, corresponding to a leaching efficiency of 25%; however, in two cases, volume changes were only 400 bbl, corresponding to a leaching efficiency of only 20%. Therefore, this is a relatively large difference in leaching efficiency that may be the result of only a few bbl difference (plus rounding). For reference, a 2,000 bbl injection represents less than the volume of a single cell for either C1 (2,800 bbl) or C2 (28,000 bbl) model cell; so it is possible that the time for the injected raw water volume to reach the cavern edge is not sufficient. It is recommended that a review of previous annual leaching reports be performed to correlate injection volumes with leaching efficiencies to confirm the observation.

The impact of cell size on leaching efficiency was tested by comparing results from C1 and C2 simulations. Results from C1 simulations are generally very close to C2 simulations, consistent with the observation above that initial OBIs are being used correctly by the code despite being output on a cell interval basis (Figure 3-40). The exception to this general observation is for the V1 simulations, in which there is some observed difference between C1 and C2 leaching efficiencies. However, this is likely related only to relatively small differences in cavern volume change (600 bbl vs. 500 bbl for a 2,000 bbl injection). Thus, there does not appear to be a cell-size driver for the observed differences in leaching efficiency.

In summary, injection volume, cell size, and the internal rounding scheme used in the SANSMIC code have been tested in attempt to uncover the source of anomalously high leaching efficiencies observed in previous annual leaching reports. The most notable output of these tests is that small injection volumes are more impactful to leaching efficiency than cell size. A review of recent reports may result in confirmation of the association of small injection volumes with higher leaching efficiencies. This confirmation could then help direct the further development of the SANSMIC code to address the issue (it may be as simple as updating the output resolution of volumes or could be something more substantial).

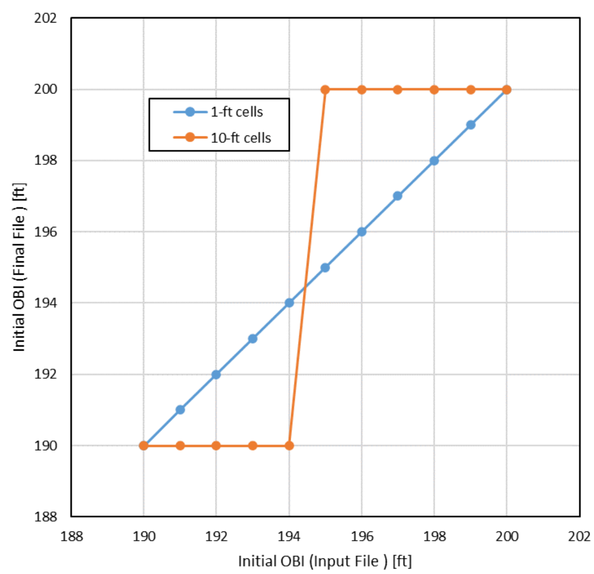

Figure 3-38. Comparison of initial OBI specified in SANSMIC input file vs. initial OBI used by SANSMIC code (results are independent of injection volume)

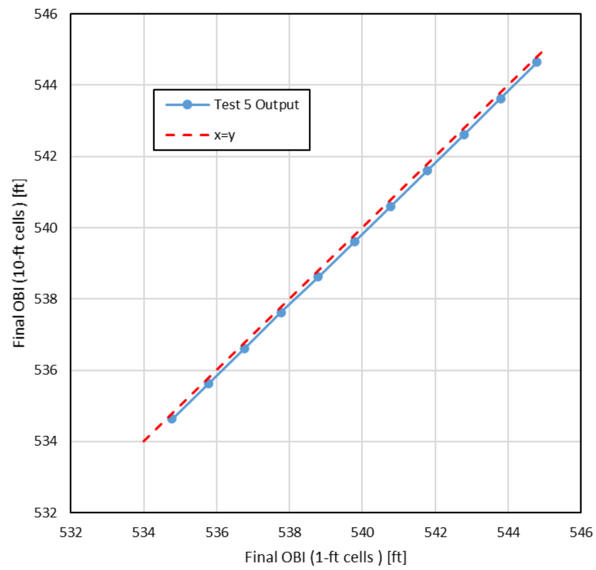

Figure 3-39. Comparison of final OBI for tests with 1-ft cells vs. tests with 10-ft cells

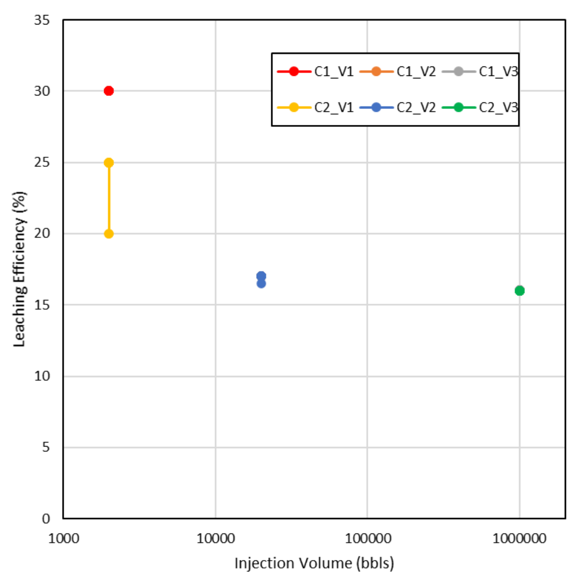

Figure 3-40. Comparison of leaching efficiencies for three injection volumes (V1, V2, V3) and 1-ft cells (C1) vs. 10-ft cells (C2)

Table 3-17. Output from Tests Using 1-ft Cells in Study 4 for V1 (2 MBLs)

Run Name	Initial OBI		Final OBI	Cavern Volume (bbl)	Volume Change (bbl)	Leaching Efficiency (%)	Specific Gravity)
	Input File	Output File					
CYL_O1_C1_V1	200	200	200.77	2798300	600	30.0	1.2019
CYL_O2_C1_V1	199	199	199.77	2798300	600	30.0	1.2019
CYL_O3_C1_V1	198	198	198.77	2798300	600	30.0	1.2019
CYL_O4_C1_V1	197	197	197.77	2798300	600	30.0	1.2019
CYL_O5_C1_V1	196	196	196.77	2798300	600	30.0	1.2019
CYL_O6_C1_V1	195	195	195.77	2798300	600	30.0	1.2019
CYL_O7_C1_V1	194	194	194.77	2798300	600	30.0	1.2019
CYL_O8_C1_V1	193	193	193.77	2798300	600	30.0	1.2019
CYL_O9_C1_V1	192	192	192.77	2798300	600	30.0	1.2019
CYL_O10_C1_V1	191	191	191.77	2798300	600	30.0	1.2019
CYL_O11_C1_V1	190	190	190.77	2798300	600	30.0	1.2019

Table 3-18. Output from Tests Using 10-ft Cells in Study 4 for V1 (2 MBLs)

Run Name	Initial OBI		Final OBI	Cavern Volume (bbl)	Volume Change (bbl)	Leaching Efficiency (%)	Specific Gravity)
	Input File	Output File					
CYL_O1_C2_V1	200	200	200.74	2798200	500	25.0	1.2019
CYL_O2_C2_V1	199	200	199.72	2798100	400	20.0	1.2019
CYL_O3_C2_V1	198	200	198.74	2798200	500	25.0	1.2019
CYL_O4_C2_V1	197	200	197.73	2798200	500	25.0	1.2019
CYL_O5_C2_V1	196	200	196.72	2798100	400	20.0	1.2019
CYL_O6_C2_V1	195	200	195.74	2798200	500	25.0	1.2019
CYL_O7_C2_V1	194	190	194.74	2798200	500	25.0	1.2019
CYL_O8_C2_V1	193	190	193.74	2798200	500	25.0	1.2019
CYL_O9_C2_V1	192	190	192.74	2798200	500	25.0	1.2019
CYL_O10_C2_V1	191	190	191.74	2798200	500	25.0	1.2019
CYL_O11_C2_V1	190	190	190.74	2798200	500	25.0	1.2019

Table 3-19. Output from Tests Using 1-ft Cells in Study 4 for V2 (20 MBLs)

Run Name	Initial OBI		Final OBI	Cavern Volume (bbl)	Volume Change (bbl)	Leaching Efficiency (%)	Specific Gravity)
	Input File	Output File					
CYL_O1_C1_V2	200	200.0	206.95	2.80E+06	3400	17.0	1.20E+00
CYL_O2_C1_V2	199	199.0	205.95	2.80E+06	3400	17.0	1.20E+00
CYL_O3_C1_V2	198	198.0	204.95	2.80E+06	3400	17.0	1.20E+00
CYL_O4_C1_V2	197	197.0	203.95	2.80E+06	3400	17.0	1.20E+00
CYL_O5_C1_V2	196	196.0	202.95	2.80E+06	3400	17.0	1.20E+00
CYL_O6_C1_V2	195	195.0	201.95	2.80E+06	3400	17.0	1.20E+00
CYL_O7_C1_V2	194	194.0	200.95	2.80E+06	3400	17.0	1.20E+00
CYL_O8_C1_V2	193	193.0	199.95	2.80E+06	3400	17.0	1.20E+00
CYL_O9_C1_V2	192	192.0	198.95	2.80E+06	3400	17.0	1.20E+00
CYL_O10_C1_V2	191	191.0	197.95	2.80E+06	3400	17.0	1.20E+00
CYL_O11_C1_V2	190	190.0	196.95	2.80E+06	3400	17.0	1.20E+00

Table 3-20. Output from Tests Using 10-ft Cells in Study 4 for V2 (20 MBLs)

Run Name	Initial OBI		Final OBI	Cavern Volume (bbl)	Volume Change (bbl)	Leaching Efficiency (%)	Specific Gravity)
	Input File	Output File					
CYL_O1_C2_V2	200	2.00E+02	206.93	2.80E+06	3400	17.0	1.20E+00
CYL_O2_C2_V2	199	2.00E+02	205.93	2.80E+06	3400	17.0	1.20E+00
CYL_O3_C2_V2	198	2.00E+02	204.94	2.80E+06	3300	16.5	1.20E+00
CYL_O4_C2_V2	197	2.00E+02	203.93	2.80E+06	3400	17.0	1.20E+00
CYL_O5_C2_V2	196	2.00E+02	202.93	2.80E+06	3400	17.0	1.20E+00
CYL_O6_C2_V2	195	2.00E+02	201.93	2.80E+06	3400	17.0	1.20E+00
CYL_O7_C2_V2	194	1.90E+02	200.93	2.80E+06	3400	17.0	1.20E+00
CYL_O8_C2_V2	193	1.90E+02	199.93	2.80E+06	3400	17.0	1.20E+00
CYL_O9_C2_V2	192	1.90E+02	198.93	2.80E+06	3400	17.0	1.20E+00
CYL_O10_C2_V2	191	1.90E+02	197.93	2.80E+06	3400	17.0	1.20E+00
CYL_O11_C2_V2	190	1.90E+02	196.93	2.80E+06	3400	17.0	1.20E+00

Table 3-21. Output from Tests Using 1-ft Cells in Study 4 for V3 (1 MMBLs)

Run Name	Initial OBI		Final OBI	Cavern Volume (bbl)	Volume Change (bbl)	Leaching Efficiency (%)	Specific Gravity)
	Input File	Output File					
CYL_O1_C1_V3	200	200	544.79	2958300	160600	16.1	1.2004
CYL_O2_C1_V3	199	199	543.79	2958300	160600	16.1	1.2004
CYL_O3_C1_V3	198	198	542.78	2958300	160600	16.1	1.2004
CYL_O4_C1_V3	197	197	541.78	2958300	160600	16.1	1.2004
CYL_O5_C1_V3	196	196	540.78	2958300	160600	16.1	1.2004
CYL_O6_C1_V3	195	195	539.78	2958300	160600	16.1	1.2004
CYL_O7_C1_V3	194	194	538.78	2958300	160600	16.1	1.2004
CYL_O8_C1_V3	193	193	537.77	2958300	160600	16.1	1.2004
CYL_O9_C1_V3	192	192	536.77	2958300	160600	16.1	1.2004
CYL_O10_C1_V3	191	191	535.77	2958300	160600	16.1	1.2004
CYL_O11_C1_V3	190	190	534.77	2958300	160600	16.1	1.2004

Table 3-22. Output from Tests Using 10-ft Cells in Study 4 for V3 (1 MMBLs)

Run Name	Initial OBI		Final OBI	Cavern Volume (bbl)	Volume Change (bbl)	Leaching Efficiency (%)	Specific Gravity)
	Input File	Output File					
CYL_O1_C2_V3	200	200	544.65	2957500	159800	16.0	1.2005
CYL_O2_C2_V3	199	200	543.63	2957600	159900	16.0	1.2004
CYL_O3_C2_V3	198	200	542.61	2957800	160100	16.0	1.2004
CYL_O4_C2_V3	197	200	541.60	2957800	160100	16.0	1.2004
CYL_O5_C2_V3	196	200	540.60	2957800	160100	16.0	1.2004
CYL_O6_C2_V3	195	200	539.61	2957800	160100	16.0	1.2004
CYL_O7_C2_V3	194	190	538.62	2957800	160100	16.0	1.2004
CYL_O8_C2_V3	193	190	537.62	2957900	160200	16.0	1.2004
CYL_O9_C2_V3	192	190	536.62	2957900	160200	16.0	1.2004
CYL_O10_C2_V3	191	190	535.62	2957900	160200	16.0	1.2004
CYL_O11_C2_V3	190	190	534.63	2957500	159800	16.0	1.2005

3.4.3. Summary of Study 4

Leaching efficiency and cavern geometry are key outputs from SANSMIC simulations. In performing leaching studies to-date, it has been noted that SANSMIC reports OBI depths to the nearest cell edge, rather than a value between cell edges. Also, anomalously high leaching efficiencies have been observed for some leaching stages. The impacts of SANSMIC's internal rounding scheme, injection volume, and vertical cell size were tested here for their impacts.

The internal rounding scheme used in the SANSMIC code is only used for reporting output and not in actual calculations, so there is no need to alter this part of the code in the future. The most notable output of the tests in this study is that small injection volumes are more impactful to leaching efficiency than cell size. A review of recent reports may result in confirmation of the association of small injection volumes with higher leaching efficiencies. This confirmation could then help direct the further development of the SANSMIC code to address the issue (it may be as simple as updating the output resolution of volumes or could be something more substantial).

3.5. Study 5: What is the Impact of Cell Size Choice on Cavern Geometries and Leaching Efficiencies for Real Caverns and Real Leaching Histories?

While the other Studies documented in this report have used hypothetical cylindrical caverns as the basis for testing the impact of input parameters, Study 5 uses two real-world cavern geometries with real leaching histories. The input parameterization tested here is only the cell size. The WH-111 and BH-101 caverns were selected for this study because they were recently studied for the latest annual leaching report [10] and each showed an instance of anomalously high leaching efficiency. **The impact to cavern geometry and leaching efficiency due to reducing cell size was tested here for real-world cavern geometries with real leaching histories**.

3.5.1. Model Setup

Multiple simulation cell sizes (1-ft geometry and 10-ft geometry) were run for WH-111 and BH-101 to study the impact of cell size on cavern geometry and leaching efficiency. Table 3-23 and Table 3-24 summarize the simulation input parameters for the West Hackberry (WH) 111 and the Big Hill (BH) 101 caverns, respectively. The simulation run for WH-111 was conducted using four phases, while the BH-101 simulation run was completed using 5 phases. The updated simulation run for WH-111 and BH-101 updated the EOT, OBI, cavern floor for cell sizes one and 10. Leaching histories were identical for each run and were based on leaching histories used in the latest annual leaching report [10].

Table 3-23. Summary of Simulation Input for WH-111

Phase	Dates	Cavern Floor Depth (ft)	EOT Rise (ft)	Mod EOT Rise (ft)	OBI Rise (ft)	Mod OBI Rise (ft)	Injection Rate (bbl/day)	Injection Duration (days)	Total Injected Water Volume (bbl)
1	2017	4527	25	20	1142	1140	75,750	5	378,750
2	2017	4527	25	20	Auto	1220	39,597	44	1,742,268
3	2017	4527	14	10	1402	1400	12,292	95	1,167,740
4	2017	4527	14	20	1551	1550	28,144	42	1,182,048
5	10/26/20-11/22/20	4527	14	20	1575	1580	4,055	4	16,220
All	N/A	N/A	N/A	N/A	N/A	N/A	N/A	190	4,487,026

Table 3-24. Summary of Simulation Input for BH-101

Phase	Dates	Cavern Floor Depth (ft)	EOT Rise (ft)	Mod EOT Rise (ft)	OBI Rise (ft)	Mod OBI Rise (ft)	Injection Rate (bbl/day)	Injection Duration (days)	Total Injected Water Volume (bbl)
1	03/05/14-08/28/14	4160	17	10	81	80	10,739	5	53,695
2	01/08/16-12/09/17	4160	18	10	48	50	13,234	3	39,702
3	05/29/18-10/15/18	4160	18	10	Auto	60	15,313	4	61,252
4	04/23/19-05/12/19	4160	18	10	Auto	70	16,730	6	100,380
5	08/01/20-09/26/20	4160	18	10	94	90	18,926	38	719,188
ALL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	56	974,217

3.5.2. *WH-111 Leaching for Varying Cell Size*

For both cell sizes, the final outlet SG for each phase was close to the value of 1.2, suggesting that leaching was near completion. The leaching efficiency was anomalously high at 49.3% for Phase 4 for 10-ft cell sizes; it was reduced for a 1-ft cell model, but still remained high at 39%. The source of the anomaly is likely the small injection volume leading to a small volume change that is close to the output resolution of volumes from the SANSMIC code (i.e., the nearest 1000 bbl). As summarized in Table 3-25, the overall leaching efficiency for the WH-111 cavern was relatively unchanged despite the relatively large change for Phase 4 (again, due to the small volume of that phase). This is consistent with results from Studies 1 and 4, which showed that small injection volumes and large cell sizes tended toward high leaching efficiencies.

Table 3-25. Summary of Simulation Output for WH-111

Phase	Final OBI Rise (ft)		Outlet SG		Change in Volume (bbl)		Leaching Efficiency (%)	
	1-ft Cell	10-ft Cell	1-ft Cell	10-ft Cell	1-ft Cell	10-ft Cell	1-ft Cell	10-ft Cell
1	1213	1213	1.2010	1.2010	57,000	56,000	15.0	14.8
2	1477	1478	1.1980	1.1979	265,000	266,000	15.2	15.3
3	1625	1626	1.2010	1.2010	282,000	281,000	16.0	15.9
4	1577	1577	1.2019	1.2019	6,000	8,000	37.0	49.3
ALL	1577	1577	1.2019	1.2019	610,000	611,000	15.4	15.3

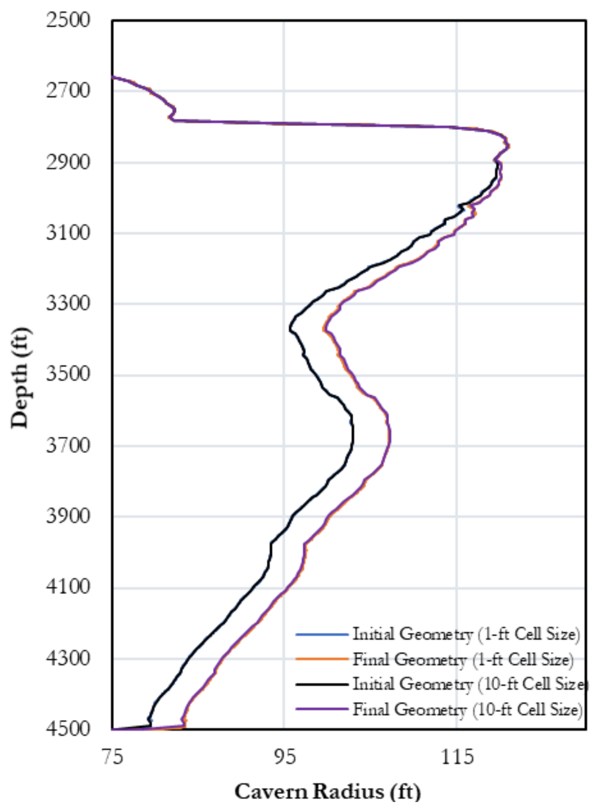

Figure 3-41. Comparison of WH-111 cavern geometries for 1-ft and 10-ft cells

As shown in Figure 3-41, differences in the final cavern radii are not substantial or even observable on the scale of the overall cavern growth. Changes are relatively small due to the overall relatively large injection volumes in the leaching history of this cavern. Again, this is consistent with previous results where larger injection volumes led to less discrepancy with the converged geometries.

3.5.3. BH-101 Leaching for Varying Cell Size

For both cell sizes, the final outlet SG for each phase was close to the value of 1.2, suggesting that leaching was near completion. The leaching efficiency was anomalously high at 25.2% for Phase 2 for 10-ft cell sizes; it was reduced to 15.1% for a 1-ft cell model, bringing it into the expected range. Although the phase had a relatively small injection volume (as did WH-111 above), the change in initial geometry due to using 1-ft cells has provided enough difference to reduce the leaching efficiency to a reasonable value. As summarized in Table 3-26, the overall leaching efficiency for the BH-101 cavern was reduced by about 1 % due to observed changes for multiple phases with small volumes. In general, this is consistent with results from Studies 1 and 4, which showed that small injection volumes and large cell sizes tended toward high leaching efficiencies, although Phase 1 showed a small increase in volume change likely due to be close to the output resolution of volumes from the code.

Table 3-26. Summary of Simulation Output for BH-101

Phase	Final OBI Rise (ft)		Outlet SG		Change in Volume (bbl)		Leaching Efficiency (%)	
	1-ft Cell	10-ft Cell	1-ft Cell	10-ft Cell	1-ft Cell	10-ft Cell	1-ft Cell	10-ft Cell
1	90	90	1.1992	1.1993	9,000	8,000	16.8	14.9
2	58	59	1.1992	1.1999	6,000	10,000	15.1	25.2
3	68	71	1.1981	1.1983	9,000	11,000	14.7	18.0
4	84	87	1.1979	1.1985	16,000	17,000	15.9	16.9
5	211	211	1.1976	1.1976	113,000	112,000	15.7	15.6
ALL	211	211	1.1976	1.1976	153,000	158,000	15.4	16.3

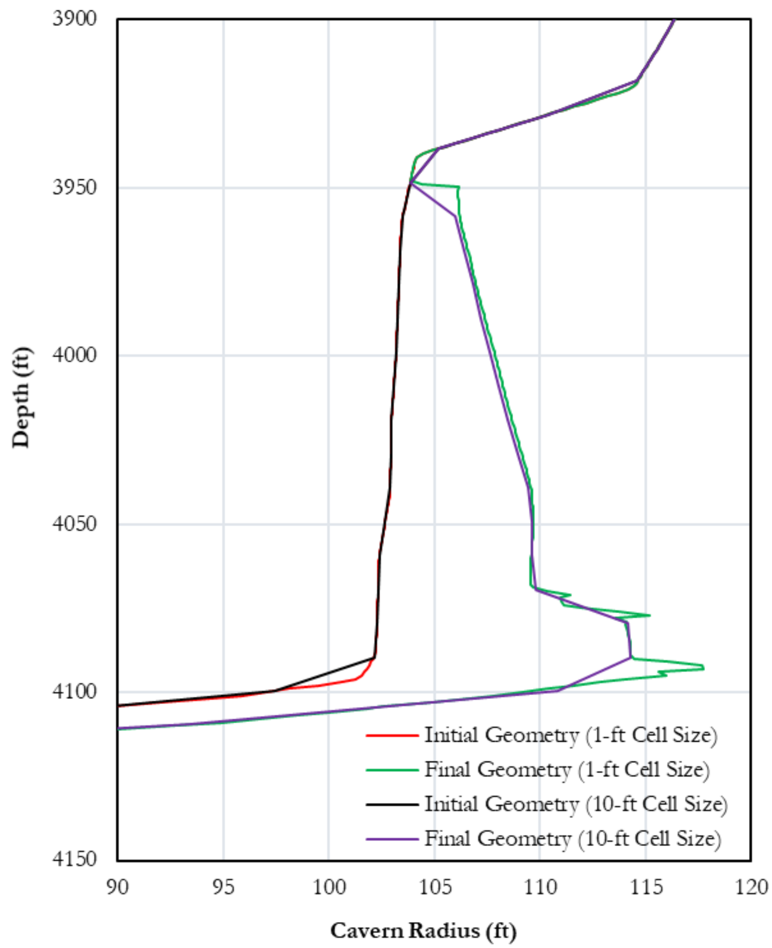

Figure 3-42. Comparison of BH-101 cavern geometries for 1-ft and 10-ft cells

As shown in Figure 3-42, there are small differences between the 1-ft cell and 10-ft cell model geometries. There are minute differences in the initial geometries due to the rounding associated with creating the initial geometry from sonar data. They are only observable on this scale due to small injections in the injection history of this cavern. By moving to a 1-ft cell model, the initial geometry moves to a greater radius, which then results in the development of small, but noticeable leached features that distinguish the final cavern geometries. In contrast to the general trend observed for the cylindrical caverns (Figure 3-5), this is a case in which the final geometry of the 1-ft cell model showed increased cavern radius compared to the 10-ft cell model. This result shows the limitation of the use of hypothetical, idealized initial cavern geometries and the need to test against real cavern geometries.

3.5.4. Summary of Study 5

The impact of vertical cell size on the output for two real-world cavern geometries has been tested here using real leaching histories for WH-111 and BH-101. These caverns were shown to have leaching stages with anomalously high leaching efficiencies in previous leaching reports. The results of this study show that reducing cell size reduced leaching efficiency.

For WH-111, the leaching efficiency remained high (39%), which may be in part due to the small injection volume associated with the problematic leaching stage. For BH-101, the leaching efficiency was reduced from 25 to 15%, considered a reasonable value. Interestingly, the reduction in cell size, while increasing the resolution of cavern geometry, was also shown to allow for the development of new, small features in the cavern geometry. Testing of cavern geometries of varying cell size resolution is recommended when sonars become available in order to better understand when the use of small cell sizes could potentially introduce spurious cavern features. When leaching efficiencies were calculated across many leaching stages, very little difference was observed with respect to runs of varying cell size, confirming that small injection volumes are a primary contributor to abnormally high leaching efficiencies observed for some single stages.

4. CONCLUSIONS

Confidence in the predictions of cavern geometries is important as they can be an early warning sign for the development of disadvantageous cavern geometry features before sonar data may be available. Confidence in leaching efficiency calculation results provides confidence in the leaching calculations themselves, so understanding the source of observed anomalous leaching efficiencies is important. The five studies performed here using the SANSMIC code have provided useful information on the relative impact of modeling choices on resulting post-leaching cavern geometries and calculated leaching efficiencies. Key outcomes from the five studies are summarized at the end of each subsection in Section 3, as well as in Table 4-1.

Key modeling choices include the vertical resolution of cavern geometry to implement, as well as how to incorporate daily raw water injection data into the SANSMIC model. Vertical resolution is implemented via cell sizes in the SANSMIC input file and have been shown in these studies to be impactful on resulting cavern geometries, but substantial impact on results found in previously leaching reports is not expected. The use of smaller cell sizes is recommended moving forward to provide a better one-to-one relationship between sonar data and the modeled cavern. A new methodology for incorporating raw water injection data is also recommended, in order to more closely model real-world injection and workover times.

The observation of anomalously high calculated leaching efficiencies in previous annual leaching reports was tested for hypothetical cylindrical caverns, as well as two real-world caverns. Results indicate that smaller cell sizes reduce leaching efficiencies, while small injection volumes may increase them—overall leaching efficiencies across many leaching stages with high injection volumes are largely unaffected. While general trends associated with the hypothetical cylindrical caverns and well-defined leaching histories are clear, some caution is encouraged when applying these general rules to cavern geometries with preexisting features and with complex leaching histories.

Overall, the systematic studies performed here have increased our confidence in previous SANSMIC model results, as well future use of the code for predicting leaching effects on cavern geometries. Some minor changes to modeling choices are recommended, which can easily be applied with the version of SANSMIC currently under development.

Table 4-1. Results of Studies in this Report

Study	Key Outcomes	
1	a.	Reducing cell size below 10-ft/cell (the current standard) leads to a convergence of cavern geometries that is in some cases qualitatively different from the 10-ft cell model. Differences in cavern radii are limited to only a few feet for the volumes tested here. Cell size of 1 ft/cell recommended moving forward.
	b.	Anomalously high leaching efficiencies were observed and are generally associated with larger cell sizes, as well as lower injection rates and durations.
2	a.	Results were generally as-expected, with smaller caverns showing cavern growth to higher depths and increased radial cavern growth for larger caverns.

Study		Key Outcomes
	b.	Shorter duration injections resulted in more uniform radial growth along the cavern axis, while longer duration injections resulted in larger radial growth near the starting OBI tapering to smaller radial growth near the final OBI.
	c.	Shorter duration injections show increased cavern growth below the EOT (approximately 15 ft compared to approximately two feet for longer durations).
	d.	Five-leach runs tended to result in an additional 4-6 ft of maximal radial growth compared to single leach runs for the same injection volume.
	e.	Increased our confidence in being able to report leaching modeling results, as well as in making any future recommendations for operational changes associated with remedial leaching.
	f.	Ability to anticipate cavern geometry changes based on planned repeated leach-and-fill activities has been enhanced and will contribute to drawdown predictions.
3	a.	New data incorporation methodology tested here for the first time, which is designed to more closely replicate daily leaching activities by including workover time for days when no raw water is injected.
	b.	A variety of cavern shapes were observed depending on the timing of leaching stages and inclusion of workover stages.
	c.	In cases with a smaller number of injection days, the injection rate is higher and increased depth of leaching below the EOT is observed.
	d.	Observed differences in radial growth are small (a few feet at a given depth) for the 500 MMB injection considered here. However, differences could be compounded over time for longer and more complex leaching histories sometimes encountered in SPR caverns and result in more substantial differences in calculated geometries.
	e.	Small features (which may be model artifacts) are observed which show sharp edges jutting into the surrounding salt—these features only appear at the OBIs for Method 3 runs and may be attributed to workover periods, which do not exist for Method 1 or 2 runs.
	f.	While the Method 3 methodology is designed to more closely replicate the day-to-day leaching/workover times, so care should be taken in using Method 3 for lumping injection data, unless the source of the small horizontal features can be tracked to areas of the SANSMIC source code and addressed in a future code version.
4	a.	The internal rounding scheme used in the SANSMIC code is only used for reporting output and not in actual calculations, so there is no need to alter this part of the code in the future.

Study		Key Outcomes
	b.	Small injection volumes are more impactful to leaching efficiency than cell size.
	c.	A review of recent reports may result in confirmation of the association of small injection volumes with higher leaching efficiencies. This confirmation could then help direct the further development of the SANSMIC code to address the issue.
5	a.	Impact of vertical cell size on the output for two real-world cavern geometries has been tested here using real leaching histories for WH-111 and BH-101.
	b.	Reducing cell size resulted in reduced leaching efficiency for leaching phases of relatively small injection volumes.
	c.	For WH-111, the leaching efficiency remained high (39%), which may be in part due to the small injection volume associated with the problematic leaching stage.
	d.	For BH-101, the leaching efficiency was reduced from 25 to 15%, considered a reasonable value.
	e.	The reduction in cell size, while increasing the resolution of cavern geometry, was also shown to allow for the development of new, small features in the cavern geometry.
	f.	When leaching efficiencies were calculated across many leaching stages, very little difference was observed with respect to runs of varying cell size, confirming that small injection volumes are a primary contributor to abnormally high leaching efficiencies observed for some single stages.

REFERENCES

[1] Lord, D. L. et al. (2012). *Solution Mining Characteristics of US Strategic Petroleum Reserve Oil Drawdown*. SMRI Spring 2012 Conference. Solution Mining Research Institute, Regina, Saskatchewan, Canada.

[2] Weber, P. D. et al. (2014). *SANSMIC Validation*. FY14-2.4(b2), S. N. Laboratories, Albuquerque, NM.

[3] Russo, A. J. (1981). *A solution mining code for studying axisymmetric salt cavern formation*. SAND81-1231.

[4] Chojnicki, K. N., (2019a) *Cavern leaching at SPR associated with 2017 oil sales and exchanges*. SAND2019-1910. S. N. Laboratories, Albuquerque, NM.

[5] Chojnicki, K. N. (2019b) *Cavern leaching at SPR associated with 2017 oil sales and exchanges*. SMRI Spring 2019 Conference. Solution Mining Research Institute, New Orleans, LA.

[6] Chojnicki, K. N., R. Valdez, and D. Hart (2020) *Cavern Leaching Monitoring CY18 and CY19*. SAND2020-3673. S. N. Laboratories, Albuquerque, NM.

[7] Eyermann, T. J. (1984) *Comparison of SANSMIC simulation results with cavern shapes on the SPR project*, Solution Mining Research Institute Meeting, Atlanta, Georgia

[8] Lord, D. L. and D. K. Rudeen (2011). *Calculations to Guide Timing of Drawdown and Remedial Leach Sonar Measurements*. Letter Report, Geotechnology & Engineering Department, Sandia National Laboratories, Albuquerque, NM. U.S. Strategic Petroleum Reserve. September 14, 2011.

[9] Zeitler, T. R., R. Valdez, and D. Hart (2021) *Cavern Leaching Monitoring CY20*. SAND2021-7278. S. N. Laboratories, Albuquerque, NM.

[10] Zeitler, T. R., K. N. Chojnicki (2020) *Hanging String Cuts in SPR Caverns: Modeling Investigation and Comparison with Sonar Data*. SAND2020-9898. S. N. Laboratories, Albuquerque, NM.

[11] Zeitler, T. R., D. B. Hart (2020) *FY2020 Progress on Upgrading SANSMIC Code from Fortran to Python*. S. N. Laboratories, Albuquerque, NM.

APPENDIX A. DETAILED DATA FOR STUDIES 1 AND 2

A.1. Study 1 Data

This section contains data from the Study 1 SANSMIC runs in Table 4-2.

Table 4-2. Summarized Input and Output for Study 1 SANSMIC Runs

Run No.	Title	E	O	R	D	C	W	OBI Init. Height (ft)	Inj. Rate (bbl/day)	Inj. Duration (d)	Workover Duration (d)	Vol. Inj. (bbl)	OBI Final Height (ft)	Spec. Grav.	Total Volume (bbl)	Cavern Volume Change (bbl)	Leaching Efficiency (%)
1	CYL_E1_O1_R1_D1_C1	1	1	1	1	1	1	20	50000	5	60	250000	42	1.19	8821600	47989	19.2
2	CYL_E1_O2_R1_D1_C1	1	2	1	1	1	1	30	50000	5	60	250000	52	1.19	8821300	47689	19.1
3	CYL_E1_O3_R1_D1_C1	1	3	1	1	1	1	60	50000	5	60	250000	82	1.20	8820400	46789	18.7
4	CYL_E1_O4_R1_D1_C1	1	4	1	1	1	1	110	50000	5	60	250000	132	1.20	8819300	45689	18.3
5	CYL_E1_O1_R2_D1_C1	1	1	2	1	1	1	20	100000	5	60	500000	64	1.19	8859300	85689	17.1
6	CYL_E1_O2_R2_D1_C1	1	2	2	1	1	1	30	100000	5	60	500000	74	1.19	8858800	85189	17.0
7	CYL_E1_O3_R2_D1_C1	1	3	2	1	1	1	60	100000	5	60	500000	104	1.19	8857500	83889	16.8
8	CYL_E1_O4_R2_D1_C1	1	4	2	1	1	1	110	100000	5	60	500000	154	1.20	8855800	82189	16.4
9	CYL_E1_O1_R1_D2_C1	1	1	1	2	1	1	20	50000	10	60	500000	64	1.19	8859600	85989	17.2
10	CYL_E1_O2_R1_D2_C1	1	2	1	2	1	1	30	50000	10	60	500000	74	1.19	8859200	85589	17.1
11	CYL_E1_O3_R1_D2_C1	1	3	1	2	1	1	60	50000	10	60	500000	104	1.19	8858000	84389	16.9
12	CYL_E1_O4_R1_D2_C1	1	4	1	2	1	1	110	50000	10	60	500000	154	1.20	8856400	82789	16.6
13	CYL_E1_O1_R2_D2_C1	1	1	2	2	1	1	20	100000	10	60	1000000	108	1.19	8935800	162189	16.2
14	CYL_E1_O2_R2_D2_C1	1	2	2	2	1	1	30	100000	10	60	1000000	118	1.19	8935200	161589	16.2
15	CYL_E1_O3_R2_D2_C1	1	3	2	2	1	1	60	100000	10	60	1000000	148	1.19	8933500	159889	16.0
16	CYL_E1_O4_R2_D2_C1	1	4	2	2	1	1	110	100000	10	60	1000000	198	1.19	8931100	157489	15.7
17	CYL_E1_O1_R1_D1_C2	1	1	1	1	2	1	20	50000	5	60	250000	42	1.19	8917300	143689	57.5
18	CYL_E1_O2_R1_D1_C2	1	2	1	1	2	1	30	50000	5	60	250000	52	1.19	8917500	143889	57.6

Run No.	Title	E	O	R	D	C	W	OBI Init. Height (ft)	Inj. Rate (bbl/day)	Inj. Duration (d)	Workover Duration (d)	Vol. Inj. (bbl)	OBI Final Height (ft)	Spec. Grav.	Total Volume (bbl)	Cavern Volume Change (bbl)	Leaching Efficiency (%)
19	CYL_E1_O3_R1_D1_C2	1	3	1	1	2	1	60	50000	5	60	250000	82	1.19	8917500	143889	57.6
20	CYL_E1_O4_R1_D1_C2	1	4	1	1	2	1	110	50000	5	60	250000	132	1.20	8917000	143389	57.4
21	CYL_E1_O1_R2_D1_C2	1	1	2	1	2	1	20	100000	5	60	500000	64	1.19	8952600	178989	35.8
22	CYL_E1_O2_R2_D1_C2	1	2	2	1	2	1	30	100000	5	60	500000	74	1.19	8953700	180089	36.0
23	CYL_E1_O3_R2_D1_C2	1	3	2	1	2	1	60	100000	5	60	500000	104	1.19	8953900	180289	36.1
24	CYL_E1_O4_R2_D1_C2	1	4	2	1	2	1	110	100000	5	60	500000	154	1.19	8952800	179189	35.8
25	CYL_E1_O1_R1_D2_C2	1	1	1	2	2	1	20	50000	10	60	500000	64	1.19	8954500	180889	36.2
26	CYL_E1_O2_R1_D2_C2	1	2	1	2	2	1	30	50000	10	60	500000	74	1.19	8954600	180989	36.2
27	CYL_E1_O3_R1_D2_C2	1	3	1	2	2	1	60	50000	10	60	500000	104	1.19	8954300	180689	36.1
28	CYL_E1_O4_R1_D2_C2	1	4	1	2	2	1	110	50000	10	60	500000	154	1.19	8953300	179689	35.9
29	CYL_E1_O1_R2_D2_C2	1	1	2	2	2	1	20	100000	10	60	1000000	108	1.19	9026900	253289	25.3
30	CYL_E1_O2_R2_D2_C2	1	2	2	2	2	1	30	100000	10	60	1000000	118	1.19	9028700	255089	25.5
31	CYL_E1_O3_R2_D2_C2	1	3	2	2	2	1	60	100000	10	60	1000000	148	1.19	9029100	255489	25.5
32	CYL_E1_O4_R2_D2_C2	1	4	2	2	2	1	110	100000	10	60	1000000	198	1.19	9028400	254789	25.5
33	CYL_E1_O1_R1_D1_C3	1	1	1	1	3	1	20	50000	5	60	250000	42	1.19	8832600	58989	23.6
34	CYL_E1_O2_R1_D1_C3	1	2	1	1	3	1	30	50000	5	60	250000	52	1.19	8832200	58589	23.4
35	CYL_E1_O3_R1_D1_C3	1	3	1	1	3	1	60	50000	5	60	250000	82	1.20	8831300	57689	23.1
36	CYL_E1_O4_R1_D1_C3	1	4	1	1	3	1	110	50000	5	60	250000	132	1.20	8830300	56689	22.7
37	CYL_E1_O1_R2_D1_C3	1	1	2	1	3	1	20	100000	5	60	500000	64	1.19	8870400	96789	19.4
38	CYL_E1_O2_R2_D1_C3	1	2	2	1	3	1	30	100000	5	60	500000	74	1.19	8869900	96289	19.3

Run No.	Title	E	O	R	D	C	W	OBI Init. Height (ft)	Inj. Rate (bbl/day)	Inj. Duration (d)	Workover Duration (d)	Vol. Inj. (bbl)	OBI Final Height (ft)	Spec. Grav.	Total Volume (bbl)	Cavern Volume Change (bbl)	Leaching Efficiency (%)
39	CYL_E1_O3_R2_D1_C3	1	3	2	1	3	1	60	100000	5	60	500000	104	1.19	8868500	94889	19.0
40	CYL_E1_O4_R2_D1_C3	1	4	2	1	3	1	110	100000	5	60	500000	154	1.20	8866800	93189	18.6
41	CYL_E1_O1_R1_D2_C3	1	1	1	2	3	1	20	50000	10	60	500000	64	1.19	8870600	96989	19.4
42	CYL_E1_O2_R1_D2_C3	1	2	1	2	3	1	30	50000	10	60	500000	74	1.19	8870200	96589	19.3
43	CYL_E1_O3_R1_D2_C3	1	3	1	2	3	1	60	50000	10	60	500000	104	1.19	8869000	95389	19.1
44	CYL_E1_O4_R1_D2_C3	1	4	1	2	3	1	110	50000	10	60	500000	154	1.20	8867400	93789	18.8
45	CYL_E1_O1_R2_D2_C3	1	1	2	2	3	1	20	100000	10	60	1000000	108	1.19	8946600	172989	17.3
46	CYL_E1_O2_R2_D2_C3	1	2	2	2	3	1	30	100000	10	60	1000000	118	1.19	8946000	172389	17.2
47	CYL_E1_O3_R2_D2_C3	1	3	2	2	3	1	60	100000	10	60	1000000	148	1.19	8944300	170689	17.1
48	CYL_E1_O4_R2_D2_C3	1	4	2	2	3	1	110	100000	10	60	1000000	198	1.19	8941900	168289	16.8
49	CYL_E1_O1_R1_D1_C4	1	1	1	1	4	1	20	50000	5	60	250000	42	1.19	8865000	91389	36.6
50	CYL_E1_O2_R1_D1_C4	1	2	1	1	4	1	30	50000	5	60	250000	52	1.19	8864700	91089	36.4
51	CYL_E1_O3_R1_D1_C4	1	3	1	1	4	1	60	50000	5	60	250000	82	1.20	8864000	90389	36.2
52	CYL_E1_O4_R1_D1_C4	1	4	1	1	4	1	110	50000	5	60	250000	132	1.20	8863000	89389	35.8
53	CYL_E1_O1_R2_D1_C4	1	1	2	1	4	1	20	100000	5	60	500000	64	1.19	8902600	128989	25.8
54	CYL_E1_O2_R2_D1_C4	1	2	2	1	4	1	30	100000	5	60	500000	74	1.19	8902200	128589	25.7
55	CYL_E1_O3_R2_D1_C4	1	3	2	1	4	1	60	100000	5	60	500000	104	1.19	8901000	127389	25.5
56	CYL_E1_O4_R2_D1_C4	1	4	2	1	4	1	110	100000	5	60	500000	154	1.19	8899300	125689	25.1
57	CYL_E1_O1_R1_D2_C4	1	1	1	2	4	1	20	50000	10	60	500000	64	1.19	8903800	130189	26.0
58	CYL_E1_O2_R1_D2_C4	1	2	1	2	4	1	30	50000	10	60	500000	74	1.19	8903400	129789	26.0

Run No.	Title	E	O	R	D	C	W	OBI Init. Height (ft)	Inj. Rate (bbl/day)	Inj. Duration (d)	Workover Duration (d)	Vol. Inj. (bbl)	OBI Final Height (ft)	Spec. Grav.	Total Volume (bbl)	Cavern Volume Change (bbl)	Leaching Efficiency (%)
59	CYL_E1_O3_R1_D2_C4	1	3	1	2	4	1	60	50000	10	60	500000	104	1.19	8902200	128589	25.7
60	CYL_E1_O4_R1_D2_C4	1	4	1	2	4	1	110	50000	10	60	500000	154	1.20	8900400	126789	25.4
61	CYL_E1_O1_R2_D2_C4	1	1	2	2	4	1	20	100000	10	60	1000000	108	1.19	8979300	205689	20.6
62	CYL_E1_O2_R2_D2_C4	1	2	2	2	4	1	30	100000	10	60	1000000	118	1.19	8978700	205089	20.5
63	CYL_E1_O3_R2_D2_C4	1	3	2	2	4	1	60	100000	10	60	1000000	148	1.19	8977100	203489	20.3
64	CYL_E1_O4_R2_D2_C4	1	4	2	2	4	1	110	100000	10	60	1000000	198	1.19	8974700	201089	20.1
65	CYL_E1_O1_R1_D1_C5	1	1	1	1	5	1	20	50000	5	60	250000	42	1.19	8816000	42389	17.0
66	CYL_E1_O2_R1_D1_C5	1	2	1	1	5	1	30	50000	5	60	250000	52	1.19	8815700	42089	16.8
67	CYL_E1_O3_R1_D1_C5	1	3	1	1	5	1	60	50000	5	60	250000	82	1.20	8814900	41289	16.5
68	CYL_E1_O4_R1_D1_C5	1	4	1	1	5	1	110	50000	5	60	250000	132	1.20	8813900	40289	16.1
69	CYL_E1_O1_R2_D1_C5	1	1	2	1	5	1	20	100000	5	60	500000	64	1.19	8853900	80289	16.1
70	CYL_E1_O2_R2_D1_C5	1	2	2	1	5	1	30	100000	5	60	500000	74	1.19	8853400	79789	16.0
71	CYL_E1_O3_R2_D1_C5	1	3	2	1	5	1	60	100000	5	60	500000	104	1.19	8852100	78489	15.7
72	CYL_E1_O4_R2_D1_C5	1	4	2	1	5	1	110	100000	5	60	500000	154	1.20	8850400	76789	15.4
73	CYL_E1_O1_R1_D2_C5	1	1	1	2	5	1	20	50000	10	60	500000	64	1.19	8854100	80489	16.1
74	CYL_E1_O2_R1_D2_C5	1	2	1	2	5	1	30	50000	10	60	500000	74	1.19	8853800	80189	16.0
75	CYL_E1_O3_R1_D2_C5	1	3	1	2	5	1	60	50000	10	60	500000	104	1.19	8852600	78989	15.8
76	CYL_E1_O4_R1_D2_C5	1	4	1	2	5	1	110	50000	10	60	500000	154	1.20	8851000	77389	15.5
77	CYL_E1_O1_R2_D2_C5	1	1	2	2	5	1	20	100000	10	60	1000000	108	1.19	8930500	156889	15.7
78	CYL_E1_O2_R2_D2_C5	1	2	2	2	5	1	30	100000	10	60	1000000	118	1.19	8929900	156289	15.6

Run No.	Title	E	O	R	D	C	W	OBI Init. Height (ft)	Inj. Rate (bbl/day)	Inj. Duration (d)	Workover Duration (d)	Vol. Inj. (bbl)	OBI Final Height (ft)	Spec. Grav.	Total Volume (bbl)	Cavern Volume Change (bbl)	Leaching Efficiency (%)
79	CYL_E1_O3_R2_D2_C5	1	3	2	2	5	1	60	100000	10	60	1000000	148	1.19	8928100	154489	15.4
80	CYL_E1_O4_R2_D2_C5	1	4	2	2	5	1	110	100000	10	60	1000000	198	1.19	8925700	152089	15.2
81	CYL_E1_O1_R1_D1_C1_W2	1	1	1	1	1	2	20	50000	5	90	250000	42	1.20	8823600	49989	20.0
82	CYL_E1_O2_R1_D1_C1_W2	1	2	1	1	1	2	30	50000	5	90	250000	52	1.20	8823500	49889	20.0
83	CYL_E1_O3_R1_D1_C1_W2	1	3	1	1	1	2	60	50000	5	90	250000	82	1.20	8823200	49589	19.8
84	CYL_E1_O4_R1_D1_C1_W2	1	4	1	1	1	2	110	50000	5	90	250000	132	1.20	8822700	49089	19.6
85	CYL_E1_O1_R2_D1_C1_W2	1	1	2	1	1	2	20	100000	5	90	500000	64	1.20	8863000	89389	17.9
86	CYL_E1_O2_R2_D1_C1_W2	1	2	2	1	1	2	30	100000	5	90	500000	74	1.20	8862800	89189	17.8
87	CYL_E1_O3_R2_D1_C1_W2	1	3	2	1	1	2	60	100000	5	90	500000	104	1.20	8862300	88689	17.7
88	CYL_E1_O4_R2_D1_C1_W2	1	4	2	1	1	2	110	100000	5	90	500000	154	1.20	8861500	87889	17.6
89	CYL_E1_O1_R1_D2_C1_W2	1	1	1	2	1	2	20	50000	10	90	500000	64	1.20	8863000	89389	17.9
90	CYL_E1_O2_R1_D2_C1_W2	1	2	1	2	1	2	30	50000	10	90	500000	74	1.20	8862900	89289	17.9
91	CYL_E1_O3_R1_D2_C1_W2	1	3	1	2	1	2	60	50000	10	90	500000	104	1.20	8862400	88789	17.8
92	CYL_E1_O4_R1_D2_C1_W2	1	4	1	2	1	2	110	50000	10	90	500000	154	1.20	8861700	88089	17.6
93	CYL_E1_O1_R2_D2_C1_W2	1	1	2	2	1	2	20	100000	10	90	1000000	108	1.20	8942400	168789	16.9
94	CYL_E1_O2_R2_D2_C1_W2	1	2	2	2	1	2	30	100000	10	90	1000000	118	1.20	8942100	168489	16.8
95	CYL_E1_O3_R2_D2_C1_W2	1	3	2	2	1	2	60	100000	10	90	1000000	148	1.20	8941200	167589	16.8
96	CYL_E1_O4_R2_D2_C1_W2	1	4	2	2	1	2	110	100000	10	90	1000000	198	1.20	8940100	166489	16.6
97	CYL_E1_O1_R1_D1_C2_W2	1	1	1	1	2	2	20	50000	5	90	250000	42	1.19	8920200	146589	58.6
98	CYL_E1_O2_R1_D1_C2_W2	1	2	1	1	2	2	30	50000	5	90	250000	52	1.20	8920500	146889	58.8

Run No.	Title	E	O	R	D	C	W	OBI Init. Height (ft)	Inj. Rate (bbl/day)	Inj. Duration (d)	Workover Duration (d)	Vol. Inj. (bbl)	OBI Final Height (ft)	Spec. Grav.	Total Volume (bbl)	Cavern Volume Change (bbl)	Leaching Efficiency (%)
99	CYL_E1_O3_R1_D1_C2_W2	1	3	1	1	2	2	60	50000	5	90	250000	82	1.20	8920700	147089	58.8
100	CYL_E1_O4_R1_D1_C2_W2	1	4	1	1	2	2	110	50000	5	90	250000	132	1.20	8920700	147089	58.8
101	CYL_E1_O1_R2_D1_C2_W2	1	1	2	1	2	2	20	100000	5	90	500000	64	1.20	8956400	182789	36.6
102	CYL_E1_O2_R2_D1_C2_W2	1	2	2	1	2	2	30	100000	5	90	500000	74	1.20	8958300	184689	36.9
103	CYL_E1_O3_R2_D1_C2_W2	1	3	2	1	2	2	60	100000	5	90	500000	104	1.20	8959100	185489	37.1
104	CYL_E1_O4_R2_D1_C2_W2	1	4	2	1	2	2	110	100000	5	90	500000	154	1.20	8959000	185389	37.1
105	CYL_E1_O1_R1_D2_C2_W2	1	1	1	2	2	2	20	50000	10	90	500000	64	1.19	8959000	185389	37.1
106	CYL_E1_O2_R1_D2_C2_W2	1	2	1	2	2	2	30	50000	10	90	500000	74	1.20	8959300	185689	37.1
107	CYL_E1_O3_R1_D2_C2_W2	1	3	1	2	2	2	60	50000	10	90	500000	104	1.20	8959500	185889	37.2
108	CYL_E1_O4_R1_D2_C2_W2	1	4	1	2	2	2	110	50000	10	90	500000	154	1.20	8959200	185589	37.1
109	CYL_E1_O1_R2_D2_C2_W2	1	1	2	2	2	2	20	100000	10	90	1000000	108	1.20	9033500	259889	26.0
110	CYL_E1_O2_R2_D2_C2_W2	1	2	2	2	2	2	30	100000	10	90	1000000	118	1.20	9035300	261689	26.2
111	CYL_E1_O3_R2_D2_C2_W2	1	3	2	2	2	2	60	100000	10	90	1000000	148	1.20	9037000	263389	26.3
112	CYL_E1_O4_R2_D2_C2_W2	1	4	2	2	2	2	110	100000	10	90	1000000	198	1.20	9037900	264289	26.4
113	CYL_E1_O1_R1_D1_C3_W2	1	1	1	1	3	2	20	50000	5	90	250000	42	1.20	8834600	60989	24.4
114	CYL_E1_O2_R1_D1_C3_W2	1	2	1	1	3	2	30	50000	5	90	250000	52	1.20	8834500	60889	24.4
115	CYL_E1_O3_R1_D1_C3_W2	1	3	1	1	3	2	60	50000	5	90	250000	82	1.20	8834100	60489	24.2
116	CYL_E1_O4_R1_D1_C3_W2	1	4	1	1	3	2	110	50000	5	90	250000	132	1.20	8833700	60089	24.0
117	CYL_E1_O1_R2_D1_C3_W2	1	1	2	1	3	2	20	100000	5	90	500000	64	1.20	8874100	100489	20.1
118	CYL_E1_O2_R2_D1_C3_W2	1	2	2	1	3	2	30	100000	5	90	500000	74	1.20	8873900	100289	20.1

Run No.	Title	E	O	R	D	C	W	OBI Init. Height (ft)	Inj. Rate (bbl/day)	Inj. Duration (d)	Workover Duration (d)	Vol. Inj. (bbl)	OBI Final Height (ft)	Spec. Grav.	Total Volume (bbl)	Cavern Volume Change (bbl)	Leaching Efficiency (%)
119	CYL_E1_O3_R2_D1_C3_W2	1	3	2	1	3	2	60	100000	5	90	500000	104	1.20	8873300	99689	19.9
120	CYL_E1_O4_R2_D1_C3_W2	1	4	2	1	3	2	110	100000	5	90	500000	154	1.20	8872500	98889	19.8
121	CYL_E1_O1_R1_D2_C3_W2	1	1	1	2	3	2	20	50000	10	90	500000	64	1.20	8874100	100489	20.1
122	CYL_E1_O2_R1_D2_C3_W2	1	2	1	2	3	2	30	50000	10	90	500000	74	1.20	8873900	100289	20.1
123	CYL_E1_O3_R1_D2_C3_W2	1	3	1	2	3	2	60	50000	10	90	500000	104	1.20	8873500	99889	20.0
124	CYL_E1_O4_R1_D2_C3_W2	1	4	1	2	3	2	110	50000	10	90	500000	154	1.20	8872700	99089	19.8
125	CYL_E1_O1_R2_D2_C3_W2	1	1	2	2	3	2	20	100000	10	90	1000000	108	1.20	8953300	179689	18.0
126	CYL_E1_O2_R2_D2_C3_W2	1	2	2	2	3	2	30	100000	10	90	1000000	118	1.20	8952900	179289	17.9
127	CYL_E1_O3_R2_D2_C3_W2	1	3	2	2	3	2	60	100000	10	90	1000000	148	1.20	8952100	178489	17.8
128	CYL_E1_O4_R2_D2_C3_W2	1	4	2	2	3	2	110	100000	10	90	1000000	198	1.20	8950900	177289	17.7
129	CYL_E1_O1_R1_D1_C4_W2	1	1	1	1	4	2	20	50000	5	90	250000	42	1.20	8867200	93589	37.4
130	CYL_E1_O2_R1_D1_C4_W2	1	2	1	1	4	2	30	50000	5	90	250000	52	1.20	8867100	93489	37.4
131	CYL_E1_O3_R1_D1_C4_W2	1	3	1	1	4	2	60	50000	5	90	250000	82	1.20	8866800	93189	37.3
132	CYL_E1_O4_R1_D1_C4_W2	1	4	1	1	4	2	110	50000	5	90	250000	132	1.20	8866500	92889	37.2
133	CYL_E1_O1_R2_D1_C4_W2	1	1	2	1	4	2	20	100000	5	90	500000	64	1.20	8906800	133189	26.6
134	CYL_E1_O2_R2_D1_C4_W2	1	2	2	1	4	2	30	100000	5	90	500000	74	1.20	8906600	132989	26.6
135	CYL_E1_O3_R2_D1_C4_W2	1	3	2	1	4	2	60	100000	5	90	500000	104	1.20	8906000	132389	26.5
136	CYL_E1_O4_R2_D1_C4_W2	1	4	2	1	4	2	110	100000	5	90	500000	154	1.20	8905200	131589	26.3
137	CYL_E1_O1_R1_D2_C4_W2	1	1	1	2	4	2	20	50000	10	90	500000	64	1.20	8907300	133689	26.7
138	CYL_E1_O2_R1_D2_C4_W2	1	2	1	2	4	2	30	50000	10	90	500000	74	1.20	8907100	133489	26.7

Run No.	Title	E	O	R	D	C	W	OBI Init. Height (ft)	Inj. Rate (bbl/day)	Inj. Duration (d)	Workover Duration (d)	Vol. Inj. (bbl)	OBI Final Height (ft)	Spec. Grav.	Total Volume (bbl)	Cavern Volume Change (bbl)	Leaching Efficiency (%)
139	CYL_E1_O3_R1_D2_C4_W2	1	3	1	2	4	2	60	50000	10	90	500000	104	1.20	8906600	132989	26.6
140	CYL_E1_O4_R1_D2_C4_W2	1	4	1	2	4	2	110	50000	10	90	500000	154	1.20	8905800	132189	26.4
141	CYL_E1_O1_R2_D2_C4_W2	1	1	2	2	4	2	20	100000	10	90	1000000	108	1.20	8986300	212689	21.3
142	CYL_E1_O2_R2_D2_C4_W2	1	2	2	2	4	2	30	100000	10	90	1000000	118	1.20	8986000	212389	21.2
143	CYL_E1_O3_R2_D2_C4_W2	1	3	2	2	4	2	60	100000	10	90	1000000	148	1.20	8985200	211589	21.2
144	CYL_E1_O4_R2_D2_C4_W2	1	4	2	2	4	2	110	100000	10	90	1000000	198	1.20	8984000	210389	21.0
145	CYL_E1_O1_R1_D1_C5_W2	1	1	1	1	5	2	20	50000	5	90	250000	42	1.20	8818100	44489	17.8
146	CYL_E1_O2_R1_D1_C5_W2	1	2	1	1	5	2	30	50000	5	90	250000	52	1.20	8818000	44389	17.8
147	CYL_E1_O3_R1_D1_C5_W2	1	3	1	1	5	2	60	50000	5	90	250000	82	1.20	8817700	44089	17.6
148	CYL_E1_O4_R1_D1_C5_W2	1	4	1	1	5	2	110	50000	5	90	250000	132	1.20	8817200	43589	17.4
149	CYL_E1_O1_R2_D1_C5_W2	1	1	2	1	5	2	20	100000	5	90	500000	64	1.20	8857600	83989	16.8
150	CYL_E1_O2_R2_D1_C5_W2	1	2	2	1	5	2	30	100000	5	90	500000	74	1.20	8857400	83789	16.8
151	CYL_E1_O3_R2_D1_C5_W2	1	3	2	1	5	2	60	100000	5	90	500000	104	1.20	8856800	83189	16.6
152	CYL_E1_O4_R2_D1_C5_W2	1	4	2	1	5	2	110	100000	5	90	500000	154	1.20	8856000	82389	16.5
153	CYL_E1_O1_R1_D2_C5_W2	1	1	1	2	5	2	20	50000	10	90	500000	64	1.20	8857600	83989	16.8
154	CYL_E1_O2_R1_D2_C5_W2	1	2	1	2	5	2	30	50000	10	90	500000	74	1.20	8857400	83789	16.8
155	CYL_E1_O3_R1_D2_C5_W2	1	3	1	2	5	2	60	50000	10	90	500000	104	1.20	8857000	83389	16.7
156	CYL_E1_O4_R1_D2_C5_W2	1	4	1	2	5	2	110	50000	10	90	500000	154	1.20	8856300	82689	16.5
157	CYL_E1_O1_R2_D2_C5_W2	1	1	2	2	5	2	20	100000	10	90	1000000	108	1.20	8937100	163489	16.3
158	CYL_E1_O2_R2_D2_C5_W2	1	2	2	2	5	2	30	100000	10	90	1000000	118	1.20	8936700	163089	16.3

Run No.	Title	E	O	R	D	C	W	OBI Init. Height (ft)	Inj. Rate (bbl/day)	Inj. Duration (d)	Workover Duration (d)	Vol. Inj. (bbl)	OBI Final Height (ft)	Spec. Grav.	Total Volume (bbl)	Cavern Volume Change (bbl)	Leaching Efficiency (%)
159	CYL_E1_O3_R2_D2_C5_W2	1	3	2	2	5	2	60	100000	10	90	1000000	148	1.20	8935900	162289	16.2
160	CYL_E1_O4_R2_D2_C5_W2	1	4	2	2	5	2	110	100000	10	90	1000000	198	1.20	8934700	161089	16.1
161	CYL_E1_O1_R1_D1_C1_W3	1	1	1	1	1	3	20	50000	5	120	250000	42	1.20	8824500	50889	20.4
162	CYL_E1_O2_R1_D1_C1_W3	1	2	1	1	1	3	30	50000	5	120	250000	52	1.20	8824500	50889	20.4
163	CYL_E1_O3_R1_D1_C1_W3	1	3	1	1	1	3	60	50000	5	120	250000	82	1.20	8824500	50889	20.4
164	CYL_E1_O4_R1_D1_C1_W3	1	4	1	1	1	3	110	50000	5	120	250000	132	1.20	8824400	50789	20.3
165	CYL_E1_O1_R2_D1_C1_W3	1	1	2	1	1	3	20	100000	5	120	500000	64	1.20	8864700	91089	18.2
166	CYL_E1_O2_R2_D1_C1_W3	1	2	2	1	1	3	30	100000	5	120	500000	74	1.20	8864600	90989	18.2
167	CYL_E1_O3_R2_D1_C1_W3	1	3	2	1	1	3	60	100000	5	120	500000	104	1.20	8864400	90789	18.2
168	CYL_E1_O4_R2_D1_C1_W3	1	4	2	1	1	3	110	100000	5	120	500000	154	1.20	8864100	90489	18.1
169	CYL_E1_O1_R1_D2_C1_W3	1	1	1	2	1	3	20	50000	10	120	500000	64	1.20	8864500	90889	18.2
170	CYL_E1_O2_R1_D2_C1_W3	1	2	1	2	1	3	30	50000	10	120	500000	74	1.20	8864600	90989	18.2
171	CYL_E1_O3_R1_D2_C1_W3	1	3	1	2	1	3	60	50000	10	120	500000	104	1.20	8864500	90889	18.2
172	CYL_E1_O4_R1_D2_C1_W3	1	4	1	2	1	3	110	50000	10	120	500000	154	1.20	8864200	90589	18.1
173	CYL_E1_O1_R2_D2_C1_W3	1	1	2	2	1	3	20	100000	10	120	1000000	108	1.20	8945400	171789	17.2
174	CYL_E1_O2_R2_D2_C1_W3	1	2	2	2	1	3	30	100000	10	120	1000000	118	1.20	8945200	171589	17.2
175	CYL_E1_O3_R2_D2_C1_W3	1	3	2	2	1	3	60	100000	10	120	1000000	148	1.20	8944800	171189	17.1
176	CYL_E1_O4_R2_D2_C1_W3	1	4	2	2	1	3	110	100000	10	120	1000000	198	1.20	8944200	170589	17.1
177	CYL_E1_O1_R1_D1_C2_W3	1	1	1	1	2	3	20	50000	5	120	250000	42	1.20	8921700	148089	59.2
178	CYL_E1_O2_R1_D1_C2_W3	1	2	1	1	2	3	30	50000	5	120	250000	52	1.20	8922000	148389	59.4

Run No.	Title	E	O	R	D	C	W	OBI Init. Height (ft)	Inj. Rate (bbl/day)	Inj. Duration (d)	Workover Duration (d)	Vol. Inj. (bbl)	OBI Final Height (ft)	Spec. Grav.	Total Volume (bbl)	Cavern Volume Change (bbl)	Leaching Efficiency (%)
179	CYL_E1_O3_R1_D1_C2_W3	1	3	1	1	2	3	60	50000	5	120	250000	82	1.20	8922400	148789	59.5
180	CYL_E1_O4_R1_D1_C2_W3	1	4	1	1	2	3	110	50000	5	120	250000	132	1.20	8922500	148889	59.6
181	CYL_E1_O1_R2_D1_C2_W3	1	1	2	1	2	3	20	100000	5	120	500000	64	1.20	8958300	184689	36.9
182	CYL_E1_O2_R2_D1_C2_W3	1	2	2	1	2	3	30	100000	5	120	500000	74	1.20	8960500	186889	37.4
183	CYL_E1_O3_R2_D1_C2_W3	1	3	2	1	2	3	60	100000	5	120	500000	104	1.20	8961700	188089	37.6
184	CYL_E1_O4_R2_D1_C2_W3	1	4	2	1	2	3	110	100000	5	120	500000	154	1.20	8962000	188389	37.7
185	CYL_E1_O1_R1_D2_C2_W3	1	1	1	2	2	3	20	50000	10	120	500000	64	1.20	8961200	187589	37.5
186	CYL_E1_O2_R1_D2_C2_W3	1	2	1	2	2	3	30	50000	10	120	500000	74	1.20	8961600	187989	37.6
187	CYL_E1_O3_R1_D2_C2_W3	1	3	1	2	2	3	60	50000	10	120	500000	104	1.20	8962000	188389	37.7
188	CYL_E1_O4_R1_D2_C2_W3	1	4	1	2	2	3	110	50000	10	120	500000	154	1.20	8962100	188489	37.7
189	CYL_E1_O1_R2_D2_C2_W3	1	1	2	2	2	3	20	100000	10	120	1000000	108	1.20	9036600	262989	26.3
190	CYL_E1_O2_R2_D2_C2_W3	1	2	2	2	2	3	30	100000	10	120	1000000	118	1.20	9038500	264889	26.5
191	CYL_E1_O3_R2_D2_C2_W3	1	3	2	2	2	3	60	100000	10	120	1000000	148	1.20	9040700	267089	26.7
192	CYL_E1_O4_R2_D2_C2_W3	1	4	2	2	2	3	110	100000	10	120	1000000	198	1.20	9042300	268689	26.9
193	CYL_E1_O1_R1_D1_C3_W3	1	1	1	1	3	3	20	50000	5	120	250000	42	1.20	8835500	61889	24.8
194	CYL_E1_O2_R1_D1_C3_W3	1	2	1	1	3	3	30	50000	5	120	250000	52	1.20	8835500	61889	24.8
195	CYL_E1_O3_R1_D1_C3_W3	1	3	1	1	3	3	60	50000	5	120	250000	82	1.20	8835400	61789	24.7
196	CYL_E1_O4_R1_D1_C3_W3	1	4	1	1	3	3	110	50000	5	120	250000	132	1.20	8835300	61689	24.7
197	CYL_E1_O1_R2_D1_C3_W3	1	1	2	1	3	3	20	100000	5	120	500000	64	1.20	8875800	102189	20.4
198	CYL_E1_O2_R2_D1_C3_W3	1	2	2	1	3	3	30	100000	5	120	500000	74	1.20	8875700	102089	20.4

Run No.	Title	E	O	R	D	C	W	OBI Init. Height (ft)	Inj. Rate (bbl/day)	Inj. Duration (d)	Workover Duration (d)	Vol. Inj. (bbl)	OBI Final Height (ft)	Spec. Grav.	Total Volume (bbl)	Cavern Volume Change (bbl)	Leaching Efficiency (%)
199	CYL_E1_O3_R2_D1_C3_W3	1	3	2	1	3	3	60	100000	5	120	500000	104	1.20	8875500	101889	20.4
200	CYL_E1_O4_R2_D1_C3_W3	1	4	2	1	3	3	110	100000	5	120	500000	154	1.20	8875100	101489	20.3
201	CYL_E1_O1_R1_D2_C3_W3	1	1	1	2	3	3	20	50000	10	120	500000	64	1.20	8875600	101989	20.4
202	CYL_E1_O2_R1_D2_C3_W3	1	2	1	2	3	3	30	50000	10	120	500000	74	1.20	8875600	101989	20.4
203	CYL_E1_O3_R1_D2_C3_W3	1	3	1	2	3	3	60	50000	10	120	500000	104	1.20	8875500	101889	20.4
204	CYL_E1_O4_R1_D2_C3_W3	1	4	1	2	3	3	110	50000	10	120	500000	154	1.20	8875200	101589	20.3
205	CYL_E1_O1_R2_D2_C3_W3	1	1	2	2	3	3	20	100000	10	120	1000000	108	1.20	8956200	182589	18.3
206	CYL_E1_O2_R2_D2_C3_W3	1	2	2	2	3	3	30	100000	10	120	1000000	118	1.20	8956100	182489	18.2
207	CYL_E1_O3_R2_D2_C3_W3	1	3	2	2	3	3	60	100000	10	120	1000000	148	1.20	8955600	181989	18.2
208	CYL_E1_O4_R2_D2_C3_W3	1	4	2	2	3	3	110	100000	10	120	1000000	198	1.20	8955100	181489	18.1
209	CYL_E1_O1_R1_D1_C4_W3	1	1	1	1	4	3	20	50000	5	120	250000	42	1.20	8868100	94489	37.8
210	CYL_E1_O2_R1_D1_C4_W3	1	2	1	1	4	3	30	50000	5	120	250000	52	1.20	8868200	94589	37.8
211	CYL_E1_O3_R1_D1_C4_W3	1	3	1	1	4	3	60	50000	5	120	250000	82	1.20	8868200	94589	37.8
212	CYL_E1_O4_R1_D1_C4_W3	1	4	1	1	4	3	110	50000	5	120	250000	132	1.20	8868100	94489	37.8
213	CYL_E1_O1_R2_D1_C4_W3	1	1	2	1	4	3	20	100000	5	120	500000	64	1.20	8908700	135089	27.0
214	CYL_E1_O2_R2_D1_C4_W3	1	2	2	1	4	3	30	100000	5	120	500000	74	1.20	8908600	134989	27.0
215	CYL_E1_O3_R2_D1_C4_W3	1	3	2	1	4	3	60	100000	5	120	500000	104	1.20	8908400	134789	27.0
216	CYL_E1_O4_R2_D1_C4_W3	1	4	2	1	4	3	110	100000	5	120	500000	154	1.20	8908000	134389	26.9
217	CYL_E1_O1_R1_D2_C4_W3	1	1	1	2	4	3	20	50000	10	120	500000	64	1.20	8908800	135189	27.0
218	CYL_E1_O2_R1_D2_C4_W3	1	2	1	2	4	3	30	50000	10	120	500000	74	1.20	8908800	135189	27.0

Run No.	Title	E	O	R	D	C	W	OBI Init. Height (ft)	Inj. Rate (bbl/day)	Inj. Duration (d)	Workover Duration (d)	Vol. Inj. (bbl)	OBI Final Height (ft)	Spec. Grav.	Total Volume (bbl)	Cavern Volume Change (bbl)	Leaching Efficiency (%)
219	CYL_E1_O3_R1_D2_C4_W3	1	3	1	2	4	3	60	50000	10	120	500000	104	1.20	8908600	134989	27.0
220	CYL_E1_O4_R1_D2_C4_W3	1	4	1	2	4	3	110	50000	10	120	500000	154	1.20	8908300	134689	26.9
221	CYL_E1_O1_R2_D2_C4_W3	1	1	2	2	4	3	20	100000	10	120	1000000	108	1.20	8989500	215889	21.6
222	CYL_E1_O2_R2_D2_C4_W3	1	2	2	2	4	3	30	100000	10	120	1000000	118	1.20	8989400	215789	21.6
223	CYL_E1_O3_R2_D2_C4_W3	1	3	2	2	4	3	60	100000	10	120	1000000	148	1.20	8989000	215389	21.5
224	CYL_E1_O4_R2_D2_C4_W3	1	4	2	2	4	3	110	100000	10	120	1000000	198	1.20	8988400	214789	21.5
225	CYL_E1_O1_R1_D1_C5_W3	1	1	1	1	5	3	20	50000	5	120	250000	42	1.20	8819000	45389	18.2
226	CYL_E1_O2_R1_D1_C5_W3	1	2	1	1	5	3	30	50000	5	120	250000	52	1.20	8819000	45389	18.2
227	CYL_E1_O3_R1_D1_C5_W3	1	3	1	1	5	3	60	50000	5	120	250000	82	1.20	8819000	45389	18.2
228	CYL_E1_O4_R1_D1_C5_W3	1	4	1	1	5	3	110	50000	5	120	250000	132	1.20	8818900	45289	18.1
229	CYL_E1_O1_R2_D1_C5_W3	1	1	2	1	5	3	20	100000	5	120	500000	64	1.20	8859300	85689	17.1
230	CYL_E1_O2_R2_D1_C5_W3	1	2	2	1	5	3	30	100000	5	120	500000	74	1.20	8859200	85589	17.1
231	CYL_E1_O3_R2_D1_C5_W3	1	3	2	1	5	3	60	100000	5	120	500000	104	1.20	8859000	85389	17.1
232	CYL_E1_O4_R2_D1_C5_W3	1	4	2	1	5	3	110	100000	5	120	500000	154	1.20	8858600	84989	17.0
233	CYL_E1_O1_R1_D2_C5_W3	1	1	1	2	5	3	20	50000	10	120	500000	64	1.20	8859100	85489	17.1
234	CYL_E1_O2_R1_D2_C5_W3	1	2	1	2	5	3	30	50000	10	120	500000	74	1.20	8859100	85489	17.1
235	CYL_E1_O3_R1_D2_C5_W3	1	3	1	2	5	3	60	50000	10	120	500000	104	1.20	8859000	85389	17.1
236	CYL_E1_O4_R1_D2_C5_W3	1	4	1	2	5	3	110	50000	10	120	500000	154	1.20	8858800	85189	17.0
237	CYL_E1_O1_R2_D2_C5_W3	1	1	2	2	5	3	20	100000	10	120	1000000	108	1.20	8940000	166389	16.6
238	CYL_E1_O2_R2_D2_C5_W3	1	2	2	2	5	3	30	100000	10	120	1000000	118	1.20	8939800	166189	16.6

Run No.	Title	E	O	R	D	C	W	OBI Init. Height (ft)	Inj. Rate (bbl/day)	Inj. Duration (d)	Workover Duration (d)	Vol. Inj. (bbl)	OBI Final Height (ft)	Spec. Grav.	Total Volume (bbl)	Cavern Volume Change (bbl)	Leaching Efficiency (%)
239	CYL_E1_O3_R2_D2_C5_W3	1	3	2	2	5	3	60	100000	10	120	1000000	148	1.20	8939400	165789	16.6
240	CYL_E1_O4_R2_D2_C5_W3	1	4	2	2	5	3	110	100000	10	120	1000000	198	1.20	8938800	165189	16.5

A.2. Study 2 Data

This section contains data from the Study 2 SANSMIC runs in Table 4-3.

Table 4-3. Summarized Input and Output for Study 2 SANSMIC Runs

Run Number	Run Name	Cavern	OBI Option	Rate Option	Duration Option	Cell Option	Leach Option	Initial Cavern Radius (ft)	Initial OBI-EOT Separation (ft)	Initial OBI-EOT Volume Separation (bbl)	Maximum Radius (ft)
1	CYL1_O1_R1_D1_C1	CYL1	1	1	1	1	-	100.0	100	5.60E+05	105.0
2	CYL1_O1_R1_D1_C2	CYL1	1	1	1	2	-	100.0	100	5.60E+05	104.9
3	CYL1_O1_R2_D2_C1	CYL1	1	2	2	1	-	100.0	100	5.60E+05	106.6
4	CYL1_O1_R2_D2_C2	CYL1	1	2	2	2	-	100.0	100	5.60E+05	106.3
5	CYL2_O2_R1_D1_C1	CYL2	2	1	1	1	-	141.4	50	5.60E+05	147.9
6	CYL2_O2_R1_D1_C2	CYL2	2	1	1	2	-	141.4	50	5.60E+05	147.6
7	CYL2_O2_R2_D2_C1	CYL2	2	2	2	1	-	141.4	50	5.60E+05	150.1
8	CYL2_O2_R2_D2_C2	CYL2	2	2	2	2	-	141.4	50	5.60E+05	149.4
9	CYL3_O3_R1_D1_C1	CYL3	3	1	1	1	-	81.6	150	5.60E+05	85.9
10	CYL3_O3_R1_D1_C2	CYL3	3	1	1	2	-	81.6	150	5.60E+05	85.9
11	CYL3_O3_R2_D2_C1	CYL3	3	2	2	1	-	81.6	150	5.60E+05	87.2
12	CYL3_O3_R2_D2_C2	CYL3	3	2	2	2	-	81.6	150	5.60E+05	87.0
13	CYL4_O4_R1_D1_C1	CYL4	4	1	1	1	-	70.7	200	5.60E+05	74.5
14	CYL4_O4_R1_D1_C2	CYL4	4	1	1	2	-	70.7	200	5.60E+05	74.5
15	CYL4_O4_R2_D2_C1	CYL4	4	2	2	1	-	70.7	200	5.60E+05	75.6

Run Number	Run Name	Cavern	OBI Option	Rate Option	Duration Option	Cell Option	Leach Option	Initial Cavern Radius (ft)	Initial OBI-EOT Separation (ft)	Initial OBI-EOT Volume Separation (bbl)	Maximum Radius (ft)
16	CYL4_O4_R2_D2_C2	CYL4	4	2	2	2	-	70.7	200	5.60E+05	75.5
17	CYL2_O1_R1_D1_C1	CYL2	1	1	1	1	-	141.4	100	1.12E+06	146.3
18	CYL2_O1_R1_D1_C2	CYL2	1	1	1	2	-	141.4	100	1.12E+06	146.1
19	CYL2_O1_R2_D2_C1	CYL2	1	2	2	1	-	141.4	100	1.12E+06	147.4
20	CYL2_O1_R2_D2_C2	CYL2	1	2	2	2	-	141.4	100	1.12E+06	147.0
21	CYL3_O1_R1_D1_C1	CYL3	1	1	1	1	-	81.6	100	3.73E+05	86.6
22	CYL3_O1_R1_D1_C2	CYL3	1	1	1	2	-	81.6	100	3.73E+05	86.5
23	CYL3_O1_R2_D2_C1	CYL3	1	2	2	1	-	81.6	100	3.73E+05	88.3
24	CYL3_O1_R2_D2_C2	CYL3	1	2	2	2	-	81.6	100	3.73E+05	88.1
25	CYL4_O1_R1_D1_C1	CYL4	1	1	1	1	-	70.7	100	2.80E+05	75.5
26	CYL4_O1_R1_D1_C2	CYL4	1	1	1	2	-	70.7	100	2.80E+05	75.4
27	CYL4_O1_R2_D2_C1	CYL4	1	2	2	1	-	70.7	100	2.80E+05	77.4
28	CYL4_O1_R2_D2_C2	CYL4	1	2	2	2	-	70.7	100	2.80E+05	77.1
29	CYL1_O1_R1_D1_C1_L5	CYL1	1	1	1	1	5	100.0	100	5.60E+05	109.3
30	CYL1_O1_R1_D1_C2_L5	CYL1	1	1	1	2	5	100.0	100	5.60E+05	109.0
31	CYL1_O1_R2_D2_C1_L5	CYL1	1	2	2	1	5	100.0	100	5.60E+05	110.4

Run Number	Run Name	Cavern	OBI Option	Rate Option	Duration Option	Cell Option	Leach Option	Initial Cavern Radius (ft)	Initial OBI-EOT Separation (ft)	Initial OBI-EOT Volume Separation (bbl)	Maximum Radius (ft)
32	CYL1_O1_R2_D2_C2_L5	CYL1	1	2	2	2	5	100.0	100	5.60E+05	109.8
33	CYL2_O2_R1_D1_C1_L5	CYL2	2	1	1	1	5	141.4	50	5.60E+05	152.3
34	CYL2_O2_R1_D1_C2_L5	CYL2	2	1	1	2	5	141.4	50	5.60E+05	152.1
35	CYL2_O2_R2_D2_C1_L5	CYL2	2	2	2	1	5	141.4	50	5.60E+05	154.5
36	CYL2_O2_R2_D2_C2_L5	CYL2	2	2	2	2	5	141.4	50	5.60E+05	153.8
37	CYL3_O3_R1_D1_C1_L5	CYL3	3	1	1	1	5	81.6	150	5.60E+05	89.9
38	CYL3_O3_R1_D1_C2_L5	CYL3	3	1	1	2	5	81.6	150	5.60E+05	89.8
39	CYL3_O3_R2_D2_C1_L5	CYL3	3	2	2	1	5	81.6	150	5.60E+05	90.6
40	CYL3_O3_R2_D2_C2_L5	CYL3	3	2	2	2	5	81.6	150	5.60E+05	90.3
41	CYL4_O4_R1_D1_C1_L5	CYL4	4	1	1	1	5	70.7	200	5.60E+05	78.1
42	CYL4_O4_R1_D1_C2_L5	CYL4	4	1	1	2	5	70.7	200	5.60E+05	78.0
43	CYL4_O4_R2_D2_C1_L5	CYL4	4	2	2	1	5	70.7	200	5.60E+05	78.5
44	CYL4_O4_R2_D2_C2_L5	CYL4	4	2	2	2	5	70.7	200	5.60E+05	78.3
45	CYL2_O1_R1_D1_C1_L5	CYL2	1	1	1	1	5	141.4	100	1.12E+06	148.1
46	CYL2_O1_R1_D1_C2_L5	CYL2	1	1	1	2	5	141.4	100	1.12E+06	148.0
47	CYL2_O1_R2_D2_C1_L5	CYL2	1	2	2	1	5	141.4	100	1.12E+06	148.9

Run Number	Run Name	Cavern	OBI Option	Rate Option	Duration Option	Cell Option	Leach Option	Initial Cavern Radius (ft)	Initial OBI-EOT Separation (ft)	Initial OBI-EOT Volume Separation (bbl)	Maximum Radius (ft)
48	CYL2_O1_R2_D2_C2_L5	CYL2	1	2	2	2	5	141.4	100	1.12E+06	148.7
49	CYL3_O1_R1_D1_C1_L5	CYL3	1	1	1	1	5	81.6	100	3.73E+05	92.3
50	CYL3_O1_R1_D1_C2_L5	CYL3	1	1	1	2	5	81.6	100	3.73E+05	92.0
51	CYL3_O1_R2_D2_C1_L5	CYL3	1	2	2	1	5	81.6	100	3.73E+05	93.5
52	CYL3_O1_R2_D2_C2_L5	CYL3	1	2	2	2	5	81.6	100	3.73E+05	92.9
53	CYL4_O1_R1_D1_C1_L5	CYL4	1	1	1	1	5	70.7	100	2.80E+05	82.1
54	CYL4_O1_R1_D1_C2_L5	CYL4	1	1	1	2	5	70.7	100	2.80E+05	81.6
55	CYL4_O1_R2_D2_C1_L5	CYL4	1	2	2	1	5	70.7	100	2.80E+05	83.1
56	CYL4_O1_R2_D2_C2_L5	CYL4	1	2	2	2	5	70.7	100	2.80E+05	82.5

DISTRIBUTION

Email—Internal

Name	Org.	Sandia Email Address
Donald Conley	08862	dconley@sandia.gov
Carolyn Kirby	08862	sprlibrary@sandia.gov
David Hart	08862	dbhart@sandia.gov
Anna Lord	08862	acsnide@sandia.gov
David Lord	08862	dllord@sandia.gov
Technical Library	01977	sanddocs@sandia.gov

Email—External [redacted]

Name	Company Email Address	Company Name
Robert Ariatti	Robert.Ariatti@SPR.DOE.GOV	DOE
Paul Malphurs	Paul.Malphurs@SPR.DOE.GOV	DOE
Diane Willard	Diane.Willard@SPR.DOE.GOV	DOE

This page left blank

This page left blank

Sandia National Laboratories