SANDIA REPORT

SAND2014-18621
Unlimited Release
Printed October 2014

CaveMan Enterprise version 1.0 Software Validation and Verification

David B. Hart

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

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia National Laboratories

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

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

Available to DOE and DOE contractors from
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@adonis.osti.gov
Online ordering:	http://www.osti.gov/bridge

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

Telephone:	(800) 553-6847
Facsimile:	(703) 605-6900
E-Mail:	orders@ntis.fedworld.gov
Online ordering:	http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online

SAND2014-18621
Unlimited Release
Printed October 2014

CaveMan Enterprise version 1.0 Software Validation and Verification

David B. Hart
Geochemistry Department
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0751
dbhart@sandia.gov

Abstract

The U.S. Department of Energy Strategic Petroleum Reserve stores crude oil in caverns solution-mined in salt domes along the Gulf Coast of Louisiana and Texas. The CaveMan software program has been used since the late 1990s as one tool to analyze pressure measurements monitored at each cavern. The purpose of this monitoring is to catch potential cavern integrity issues as soon as possible. The CaveMan software was written in Microsoft Visual Basic, and embedded in a Microsoft Excel workbook; this method of running the CaveMan software is no longer sustainable. As such, a new version called CaveMan Enterprise has been developed.

CaveMan Enterprise version 1.0 does not have any changes to the CaveMan numerical models. CaveMan Enterprise represents, instead, a change from desktop-managed workbooks to an enterprise framework, moving data management into coordinated databases and porting the numerical modeling codes into the Python programming language. This document provides a report of the code validation and verification testing.

ACKNOWLEDGMENT

Thanks to Dave Rudeen, from Gram, Inc., and Jason Dodgen and Alan Fontenot from Fluor Federal Petroleum Operations for their work in extracting and rewriting the code from the original Caveman workbooks. Thanks to Lisa Eldredge, Alan Fontenot, Carolyn Kirby, Dave Rudeen, and Paula Weber who provided peer review for this document.

This report contains references to trademarked names of certain software programs and programming languages – please see the legal notice at the beginning of this document: “[r]eference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof, or any of their contractors or subcontractors.”

“JavaScript” is a trademark or registered trademark of Sun Microsystems, Inc. or its subsidiaries in the United States and other countries.

“Microsoft”, “Excel”, and “Visual Basic” are either registered trademarks or trademarks of Microsoft Corporation in the United States and/or other countries.

“Python” and the Python logos are trademarks or registered trademarks of the Python Software Foundation.

“SQLite” is a registered trademark of Hipp, Wyrick & Company, Inc.

CONTENTS

LIST OF TABLES

LISTINGS

NOMENCLATURE

API American Petroleum Institute

DB database

DCS distributed control system

DOE U.S. Department of Energy

data historian a software tool that records data from a DCS and saves it in a database or file

Excel the Microsoft Excel spreadsheet program; files have the extensions `.xls` or `.xlsx` depending on the program version

JSON the JavaScript Object Notation string and file format; files typically have the extension `.json`

NumPy a Python library for numerical arrays

Python the Python programming language; source code files typically have the extension `.py`

SciPy a Python library for scientific computing

SNL/NM Sandia National Laboratories in New Mexico

SPR Strategic Petroleum Reserve

SPR/NO Strategic Petroleum Reserve in New Orleans

SQLite the SQLite database file format; files typically have the extension `.db`

tag a tag identifies data that came from the same source; a tag and a time stamp combine with a value to identify a unique data point

VB the Microsoft Visual Basic programming language

VBA the Microsoft Visual Basic for Applications environment

XML the Extensible Markup Language file format; files have the extension `.xml`

1 EXECUTIVE SUMMARY

This report comprises a verification and validation (V&V) review of the CaveMan Enterprise software package, version 1.0. The scope of this document covers verification of the source code port to the Python programing language, regression tests between CaveMan v4.1 and CaveMan Enterprise v1.0, and discussion and recommendations based on the results. Appendices provide a record of the current parameter sets, the new database schema, and a simple guide to running the new enterprise version.

The legacy CAVEMAN software was developed in Visual Basic for Applications (VBA) and embedded in the same Microsoft Excel workbooks that contained the raw data. This method is no longer sustainable, both in terms of data management and source code and parameter controls. The enterprise version of CaveMan was requested designed to move to both a modern programming language and an enterprise class data management system. The Python programming language was chosen for the recoding of the CaveMan models; a database solution was developed using SQLite at the deployment sites with a SQL Server database serving as the master in New Orleans.

The source code was ported to Python by staff members at Fluor Federal Petroleum Operations, and was then reviewed and slight modifications made by staff members at Sandia National Laboratories. The algorithms and functions were not changed from the previous CaveMan v4.1, with one exception: the numerical method for spline interpolation was changed to use a Python library call, as the VBA code was determined to be inappropriate for use in the enterprise version.

The regression testing process discovered numerous data integrity issues in the original CaveMan v4.1 workbooks, such as duplicated pressure and transfer records. Because historical data validation is not in the scope of this document, a single cavern's data set was cleaned up from the Bayou Choctaw site and used for testing. Once a consistent data set was available for use, the results of the v4.1 and enterprise version of CaveMan differed by less than $1 : 10^6$.

The regression test results show consistent and correct porting of the CaveMan models to an enterprise platform. The CaveMan Enterprise version 1.0 software conversion process has been verified and the results validated against previous versions, and the software is ready for use.

2 INTRODUCTION

The U.S. Department of Energy Strategic Petroleum Reserve stores crude oil in caverns solution-mined in salt domes along the Gulf Coast of Louisiana and Texas. As part of the program to monitor caverns for potential leaks, the CaveMan software program was developed. The original CaveMan software was written in Microsoft Visual Basic, and embedded in a Microsoft Excel workbook; this method of running the CaveMan software is no longer sustainable. As such, a new version called *CaveMan Enterprise* has been developed. This document provides a report of the code validation and verification (V&V) testing for version 1.0 of the new CaveMan Enterprise software.

2.1 Scope

The software V&V of CaveMan Enterprise is intended to demonstrate that the software is performing in the same manner as the CaveMan v4.1 software. As such, the tests performed are limited to acceptance testing, showing that the software is performing the same calculations as previous versions and that the results are the same to within a certain tolerance. Additionally, some limited data validation is performed to ensure that the key parameters are correct, and to document those parameters prior to installation and checkout. Of primary focus is that CaveMan Enterprise is calculating the same predicted cavern pressures as the most recent previous version.

Specifically out of the scope of this document are: detailed analysis of the software design, testing the correctness of the numerical models, and testing communications protocols that are only relevant at the installation sites. Additionally, unit testing will not be performed at this time. Certain aspects of the CaveMan v4.1 software, such as the production of graphs or certain analysis worksheets, are not reproduced in CaveMan Enterprise v1.0, and the functionality provided by those extras will now be provided by different software, not CaveMan.

2.2 System overview and key features

The CaveMan software was originally designed in 1995[5] as a tool to aid in the detection of possible leaks of oil from SPR storage caverns. The software was written in Microsoft Visual Basic (VB) and embedded within a Microsoft Excel workbook. Each of the four SPR sites maintained a separate instance of the CaveMan workbook, and keeping the data and source code synchronized between SNL/NM, SPR headquarters in New Orleans (SPR/NO), and the SPR sites involved emailing workbooks back and forth. The software was updated to version 2.0 in 1997[2], to version 3.0 in 2000[1], to version 4.0 in 2003[3], and finally to version 4.1 in 2004[4]. After nearly a decade since the last upgrade, and nearly two decades in service, it has become necessary to modernize the CaveMan software to an "enterprise" capable software system.

The key features of the upgrade from CaveMan 4.1 to CaveMan Enterprise 1.0 are divided into two classes: source language and data management. To move to an enterprise-style method of operation, and to enable better future development, maintenance, and capabilities, it was decided that the new software should be rewritten in a more modern programming language, specifically one that could run stand alone and not just embedded in some other piece of software. The Python 2.7 programming language was chosen for this task. Unlike Excel sheets, or standalone VB code, Python code does not need to be compiled into an executable. Python also has key scientific and numerical computing pacakges, NumPy and SciPy, that makes future development work on the underlying numerical models easier and consistent with other activities. Installation and testing also become easier using Python development tools.

The data management portion of the software was moved from spreadsheet files to a database system. The local sites will run off a local SQLite database that will be synchronized with a networked, enterprise-class commercial database at SPR/NO. The data will also be passed to SNL/NM to be kept in a local database. While, on the surface, this may not seem any more efficient that passing Excel workbooks, the database synchronization tasks can be automated, and databases are designed to be synchronized where spreadsheets are not. This will lead to greater data reliability and consistency between teams who use the CaveMan Enterprise software.

2.3 Test overview

There are three groups of testing that will be performed during the V&V activities for CaveMan Enterprise 1.0. The first test group will encompass visual comparison of the translated and original source code. The second test group will do data validation, comparing the historical data that is available from the CaveMan v4.1 workbooks to the test datasets that will be used in the third level. The third test group will provide acceptance testing, ensuring that the results of the new software are the same (to within a reasonable degree) as the results of the Excel version.

3 Source Code and Input Data Verification

3.1 Source code modifications

The original source code, written in Visual Basic and documented in [5, 2, 1, 3, 4], was converted to Python code by the team at Fluor Federal Petroleum Operations in New Orleans. After performing visual verification of the code port, and becoming familiar with the new structure, it was discovered that certain functions used in the VB code could not be used or distributed as Python code. This meant that the functionality would need to be replaced with new routines or with calls to commonly available Python packages. An existing function was found in the SciPy interpolate package, and the source code was modified to use the SciPy methods.

Other changes, either at Sandia or by Fluor, included:

- adding command-line options for running CaveMan,
- adding configuration file handling,
- using NumPy matrices and arrays for data storage,
- accessing data from SQLite databases instead of from a spreadsheet,
- synchronizing the database automatically with a local DCS and central database historians,
- adding logging capabilities, and
- moving related functions into classes.

The following changes were *not* attempted at this time:

- changing single-item vectors into scalars (a side effect of VB pass-by-reference requirements),
- using Python-style return statements rather than VB pass-by-reference methods, or
- changing any of the underlying models or processing.

3.2 Data storage schema

One of the fundamental reasons for moving to CaveMan Enterprise is to ensure that enterprise quality data management can be used with the CaveMan models. Storing data in spreadsheets that are being constantly opened and modified by users opens the door for data integrity issues and human error. By placing the data in a proper database, changes in values can be tracked back and identified, backups can be made automatically, and the data can be more easily used by software. The database schema is listed in Appendix B. There is not a one-to-one correspondence between the old spreadsheet worksheets and the new data tables – some worksheets have been separated into separate tables while the individual cavern worksheets have been combined. The worksheets that have been split are those that had multiple sub-tables within them, such as the "CaveMan Parameters" worksheet, which had per-cavern parameters as well as the salt density by weight table. The "Cav#" worksheets have been combined into the "daily_well" and "caveman_pressures" tables; the "daily_well" database table only contains data from 2012 forward while the "caveman_pressures" database table contains oil and brine pressure data from 1990 forward.

The "daily_well", "daily_transfer", and the 'measured' "caveman_pressure" database entries are filled by communications with the DCS at the site or the historian master database in New Orleans. These communications functions were created and tested by Fluor, and are not included in the testing done for this report; testing these functions requires CaveMan to be run on the actual deployment network and computers, which is outside the scope of the model validation, and is in line with installation testing.

3.3 Input data verification

Listing all the input data in a report would be unmanageable, as there are nearly 9000 pressure measurements alone for every cavern; however there are some data that are worth listing completely in this report: the input parameters. The input parameters are listed by site in tables in Appendix A. This ensures that there is at least a baseline reference for parameter values going forward. These parameters have been verified as being the same in both the test databases and the CaveMan v4.1 workbooks. The DCS tags are listed, but have to be verified at the sites at installation time. In addition, spreadsheet flat files (comma-separated-value formatted text files) with all the input data through May of 2014 will be stored with the source code in an initialization directory.

The tables and fields that are required to be populated for CaveMan Enterprise operation are:

- the "wells" table,
- the "caverns" table,
- the "caveman_parameters" table,
- the "caveman_transfers" table,
- the "caveman_kaufman" table, and
- the 'measured' and primary key fields of the "caveman_pressures" table.

All other tables will be populated automatically by the DCS, the historian, or the CaveMan models.

3.4 Anomalies within the datasets

During the process of testing CaveMan Enterprise, many of the data issues prompting a move to an enterprise system were encountered within CaveMan v4.1 workbooks. CaveMan was not designed to handle multiple oil transfer records – however, in each of the workbooks there are dozens of doubled transfer records. It is impossible to create duplicate transfer records within CaveMan Enterprise, due to the primary key indexing restrictions on the database tables. This means that when multiple records are listed in the workbooks, a determination must be made as to which transfer should be kept (if the transfers differ), whether the transfers should be combined, or whether only one record should be kept. Of particular difficulty are transfers where both oil and brine are listed as having been pumped into one cavern (this is a known issue in v4.1).

There are a total of four possible errors within the workbook data:

1. a transfer is entered twice,
2. a transfer is entered out of order,
3. two transfers are listed for the same day, or
4. a pressure measurement is entered twice.

Because solving these types of issues is out of scope, particularly for transfers that were entered over a decade ago, a simple approach was taken for the regression testing – all invalid entries were simply deleted from a testing copy of the workbooks, and for multiple transfers, the database was checked to ensure the remaining transfer record matched between both the database and workbook inputs. While the automation will fix most of these issues in the future, ensuring that CaveMan handles historical transfers in a robust and consistent way should be something that is addressed with any future changes to the CaveMan models.

3.5 Verification Results

The source code has been verified as faithfully porting the original CaveMan models without any more modifications to the methods than was absolutely necessary. Structural changes to the code, such as grouping functions and adding logging capabilities, are in line with the move to a modern software architecture rather than the single, large file that programming in VBA required. The database schema maintains the same data records that were contained in the CaveMan v4.1 workbooks in a logical manner. Data issues that modernization of the code is intended to fix in the future were removed from the test databases to allow for a solid comparison of the models' results.

4 Model Validation Testing

4.1 Test overview

The model validation will be accomplished through regression testing. Because the original source code did not have unit or functional tests, and because the move to CaveMan Enterprise was a language port, and not a code rewrite, regression testing makes sense as a way to validate the software's performance. Regression testing operates on the premise that if two versions of a software program produce the same results from the same input, that the two versions are operating equivalently. If one of the versions is considered 'valid,' then a different version that passes regression testing against the original is also considered valid.

There are many cases in software testing where regression testing is not an appropriate approach – fundamental changes in the underlying models or edge cases that have certain inputs which have not been explored in the original code may invalidate regression testing. For CaveMan, the only issue that could cause problems is how to handle repeated transfer records. Since repeated transfers are a problem to be fixed in the new version, CaveMan Enterprise should *not* behave the same way as CaveMan v4.1 in this case. As long as the testing input data can be duplicated exactly for both versions of the software, regression testing should adequately validate CaveMan Enterprise's performance.

Regression testing will be performed on one cavern, BC-15. The reason only a single cavern was tested is due to the data validation effort that is required to run both the CaveMan v4.1 workbooks and CaveMan Enterprise 1.0. During the testing of this cavern, five iterations were required just to find all the data that had discrepancies between the worksheet histories and the database histories; while it would be possible to re-extract the data from the workbooks and put that data into the databases, the data in the new databases has corrections which are not present in the workbooks, and loading the data into the workbooks from the databases is not as straightforward. Rather than trying to clean up or import all the data at all the sites, or even one cavern at each site, testing will only use the data from BC-15, which is among the most complete data sets, and has the fewest validation issues.

4.2 Approach details

There is one primary switch that needs to be tested. A testing copy for both settings will created, and the selected cavern will have its data cleaned up. Duplicate pressure entries on the 'CaveMan Pressures' worksheet will be removed from the workbook and the date of the entries documented. On the 'Transfers' worksheet, any transfers that are out of order will be documented and then removed in both the worksheet and from within the 'caveman_transfers' table in the test database. Any entries that do not have an input fluid temperature will be documented, and a reasonable temperature will be added to the records. On dates where there are multiple entries, if the entries are identical, one entry will be removed from the 'Transfers' worksheet – no modification of the database is necessary, as only one record was added; if the entries are not identical, but can be combined, they will be combined in the worksheet and the database record modified. If two entries on the same day are present and cannot be combined, the latter entry in the worksheet will be used, and the database will be checked to ensure that the right entry is present. The 'CaveMan Parameters' worksheet and 'caveman_parameters' table will be compared visually to ensure values are correct; that the inspection occurred will be noted in the test case details. *All data after 1/1/2013 should be removed from the testing database to ensure that calculations stop at the same place in both versions*.

The two versions – CaveMan v4.1 and CaveMan Enterprise 1.0 – are run quite differently. The approach for each is described below, after which, the approach for comparison will be discussed.

4.2.1 Running CaveMan v4.1

For the v4.1 workbooks, the 'CaveMan Temperature Worksheet' and the 'CaveMan Pressure Worksheet' are the two areas that provide the detailed results needed for regression testing. The following steps should be performed, in order:

1. Recalculate temperatures and volumes; this is the v4.1 equivalent to calling the method `CavemanModel.initialize_caveman()` in CaveMan Enterprise 1.0.

    a) Select the 'CaveMan Temperature Worksheet'

    b) Set the Cavern, cell **B1**, to the name of the cavern to be used for testing

    c) Set the Start Date, cell **B2**, to *1/1/1990*

    d) Set the End Date, cell **B3**, to *1/1/2013*

    e) Set the Time Increment, cell **B4**, to *1*

    f) Set the Time Increment Units, cell **B5**, to *days*

    g) Click on the "Caveman" button (in Excel 2010, it will be under the Add-Ins ribbon, and will have an icon like a calculator)

    h) After CaveMan runs, the data that will be used for regression testing will be in columns **D** through **H**

2. Calculate the predicted pressures and status variables; this is the v4.1 equivalent to calling the `CavemanModel.calculate_caveman()` method in CaveMan Enterprise 1.0.

    a) Select the 'CaveMan Pressure Worksheet'

    b) Set the Cavern, cell **B1**, to the name of the cavern to be used for testing

    c) Set the Start Date, cell **B2**, to *1/1/1990*

    d) Set the End Date, cell **B3**, to *1/1/2013*

    e) Leave the Window, cell **B4**, as *5*

    f) Click on the "Caveman" button (in Excel 2010, it will be under the Add-Ins ribbon, and will have an icon like a calculator – the same button used in the first step)

    g) After CaveMan runs, the data that will be used for regression testing will be in columns **D:F** and **N**

4.2.2 Running CaveMan Enterprise 1.0

CaveMan Enterprise is run from the command line. All commands should be typed on a single line. The following steps should be taken to create the regression testing data:

1. To prepare the data, use the `caveman_utils` script that comes with CaveMan; variables are expressed as starting with a dollar sign – **$AVARIABLE** – and should be replaced with the proper values.

   ```
   caveman_utils --site $SITECODE --database $TESTDATABASE
     clear-predictions 1990-01-01
   ```

   This will clear all predicted values from the database to ensure a clean calculation run.

2. To run CaveMan, use the following command:

   ```
   caveman -v --no-sync-dcs --no-sync-hist --site $SITECODE
     --database $TESTDATABASE
   ```

   This enables verbose logging outputs and disables the DCS and central historian transfers, which will simply fail otherwise

3. Once CaveMan completes, the data to be regression tested will be in the following tables. The values from these tables should be extracted using the SQLite command line:

   - The 'caveman_pressures' table can be exported using the following command:

     ```
     sqlite3 -header -csv $TESTDATABASE
      "SELECT * FROM caveman_pressures
       WHERE cavern_id = $CAVERNID
       ORDER BY ts_date ;" > test_pressures_out_$SITECODE.csv
     ```

   - The 'caveman_temp_predicted' table

     ```
     sqlite3 -header -csv $TESTDATABASE
      "SELECT * FROM caveman_temp_predicted
       WHERE cavern_id = $CAVERNID
       ORDER BY ts_date ;" > test_temperatures_out_$SITECODE.csv
     ```

   - The 'caveman_volumes' table

     ```
     sqlite3 -header -csv $TESTDATABASE
      "SELECT * FROM caveman_volumes
       WHERE cavern_id = $CAVERNID
       ORDER BY ts_date ;" > test_volumes_out_$SITECODE.csv
     ```

   These files can now be used to compare results between the two versions.

4.2.3 Data comparison techniques

Rather than extensive automated test routines that would read from the database and compare results to the Excel workbooks, it is simpler to do the comparisons in a new Excel workbook. The results will be compared by calculating the deviation of the CaveMan Enterprise results from the v4.1 results. By enabling the debug flag in both systems, a line of final and intermediate values is produced in 'Sheet1' in the workbooks and within the log file for the Enterprise program. One known issue is that the dates are off by one day between results – this is a side effect of enabling automatic reading of the DCS at the sites, and is easily accounted for by simply ensuring the new CaveMan data is shifted down by one cell. The deviations will be analyzed statistically for each of the two runs tested, looking at the minimum, maximum, average, and RMS average of the differences, and the percentage of the mean raw values the deviation represents.

4.3 Pass/fail criteria

If the deviations for all the selected measures are within acceptable limits, the test will pass. Acceptable limits are changes that can be attributed to improved precision and floating point calculations, differences in the underlying compiler architectures, or the change in the spline functions affecting brine temperatures and should be in the last significant digit or less. Given the original precision in the Excel workbooks, the changes in the spline, and the type of equations being solved, deviation dx that is less than six orders of magnitude less than the value of x can be considered equivalent:

$$|dx| < |x|10^{-6} \tag{4.1}$$

or:

$$\log_{10} \frac{|dx|}{|x|} \leq -6 \tag{4.2}$$

4.4 Test case details

4.4.1 Test execution

The BC-15 cavern was selected for testing. The 'cavern_id' is 1 for this cavern. The values removed from the *BCtesting.xls* workbook are listed in Table 4.1. In addition to the transfers below, line 4924 of the 'CaveMan Pressures,' data from 06/20/03, was removed as duplicated and out of place. Additionally, the measured pressures from 1/1/2012 – 1/3/2012 were corrected to match the values in the database. The commands used are listed in Listing 4.1. It was during the execution of the BC-15 tests that it became clear how much data cleanup had already been done to the test databases, and why trying to redo this cleanup within the Excel workbooks for all of the caverns would be out of scope for testing.

The debug data was extracted from each of the versions, and was compared using Excel. The results of the test case with the dissolution model active are shown in Table 4.2. The results of the test case with the dissolution model inactive are shown in Table 4.3.

It is worth looking at the effect the change in precision has on the dissolution model results. Looking that the details of the debug outputs, dissolution effects are truncated to zero in the v4.1 workbooks once the magnitude of the change decreases below 10^{-45}. The change to 64-bit precision within the Enterprise version means that the DR value never truncates to zero.

Listing 4.1: Commands to run CaveMan Enterprise BC test

```
caveman_utils --site BC --database caveman_bc.db clear-predictions 1990-01-01
sqlite3 caveman_bc.db "DELETE FROM caveman_pressures WHERE ts_date > '2013-01-01'"
sqlite3 caveman_bc.db "DELETE FROM caveman_volumes WHERE ts_date > '2013-01-01'"
sqlite3 caveman_bc.db "DELETE FROM caveman_temp_predicted WHERE ts_date > '2013-01-01'"
sqlite3 caveman_bc.db "DELETE FROM caveman_transfers WHERE ts_date > '2013-01-01'"
caveman -v --site BC --no-sync-dcs --no-sync-hist --database caveman_bc.db
sqlite3 -header -csv caveman_bc.db "SELECT * FROM caveman_pressures WHERE cavern_id = 1 AND ts_date <= '2013-01-01'" > test_pressures_out_BC.csv
sqlite3 -header -csv caveman_bc.db "SELECT * FROM caveman_temp_predicted WHERE cavern_id = 1 AND ts_date <= '2013-01-01'" > test_temperatures_out_BC.csv
sqlite3 -header -csv caveman_bc.db "SELECT * FROM caveman_volumes WHERE cavern_id = 1 AND ts_date <= '2013-01-01'" > test_volumes_out_BC.csv
cp caveman_bc.db caveman_bc_nodiss.db
caveman_utils --site BC --database caveman_bc_nodiss.db clear-predictions 1990-01-01
caveman -v --site BC --no-sync-dcs --no-sync-hist --magnitude-factor=0 --database caveman_bc_nodiss.db
sqlite3 -header -csv caveman_bc_nodiss.db "SELECT * FROM caveman_pressures WHERE cavern_id = 1 AND ts_date <= '2013-01-01'" > test_pressures_out_nodiss_BC.csv
sqlite3 -header -csv caveman_bc_nodiss.db "SELECT * FROM caveman_temp_predicted WHERE cavern_id = 1 AND ts_date <= '2013-01-01'" > test_temperatures_out_nodiss_BC.csv
sqlite3 -header -csv caveman_bc_nodiss.db "SELECT * FROM caveman_volumes WHERE cavern_id = 1 AND ts_date <= '2013-01-01'" > test_volumes_out_nodiss_BC.csv
cp caveman_bc.db caveman_bc_nodiss.db
```

Reason	Date	V Out (bbls)	Fulid Out	V In (bbls)	Fluid In	Temp °F
duplicated	12/28/1999	5,205	oil			
missing T	9/9/2005	48,204	oil	48,204	1	*set to 100*
missing T	9/11/2005	17,940	oil	17,940	1	*set to 100*
missing T	9/12/2005	83,650	oil	83,650	1	*set to 100*
missing T	5/27/2012	75	brine	689	oil	*set to 100*

Table 4.1: Duplicate and/or missing data values in the BC15 data sets.

	$mean(d\hat{x})$	$RMS(d\hat{x})$	$\hat{\sigma}_{d\hat{x}}$	$\min d\hat{x}$	$\max d\hat{x}$	$\log_{10} \frac{\max\lvert d\hat{x}\rvert}{\max\lvert\hat{x}\rvert}$
$T_{oil,pred}$	-2.62E-08	2.63E-08	1.28E-09	-2.83E-08	-2.43E-08	-10
$T_{brine,pred}$	-2.59E-08	2.60E-08	1.72E-09	-2.84E-08	-1.74E-08	-10
$P_{oil,pred}$	-1.70E-06	1.25E-04	1.25E-04	-8.31E-04	5.44E-04	-6
$V_{oil,pred}$	1.30E-08	2.55E-08	2.20E-08	0.00E+00	9.87E-08	-14
$V_{brine,pred}$	5.80E-01	1.05E+00	8.75E-01	0.00E+00	2.05E+00	-6

Table 4.2: Deviations between v4.1 and Enterprise CaveMan results with dissolution model active.

	$mean(d\hat{x})$	$RMS(d\hat{x})$	$\hat{\sigma}_{d\hat{x}}$	$\min d\hat{x}$	$\max d\hat{x}$	$\log_{10} \frac{\max\lvert d\hat{x}\rvert}{\max\lvert\hat{x}\rvert}$
$T_{oil,pred}$	-2.62E-08	2.63E-08	1.28E-09	-2.83E-08	-2.43E-08	-10
$T_{brine,pred}$	-2.59E-08	2.60E-08	1.72E-09	-2.84E-08	-1.74E-08	-10
$P_{oil,pred}$	8.36E-07	1.22E-04	1.22E-04	-3.65E-04	5.44E-04	-6
$V_{oil,pred}$	1.30E-08	2.55E-08	2.20E-08	0.00E+00	9.87E-08	-14
$V_{brine,pred}$	5.80E-01	1.05E+00	8.75E-01	0.00E+00	2.05E+00	-6

Table 4.3: Deviations between v4.1 and Enterprise CaveMan results with dissolution model inactive.

However, even with 10000 steps, the sum of these extra dissolution values would be less than 10^{-45}, and this change is not a cause of significant deviation in any parameter.

Another place to see the effects of the change in precision are in the $V_{oil,pred}$ output. The only input data that impacts the volume of oil in the system are transfer records. The only calculation that has to be done is addition and subtraction. Yet after a complete run, there is still an average difference of 2.55×10^{-8} barrels between v4.1 and Enterprise v1.0. If even this simple additive process can deviate at this magnitude, processes which involve exponentiation, logarithms, and trigonometry functions will all propagate faster. This is the rationale for setting the acceptance criteria based on Equation 4.2.

5 CONCLUSIONS AND RECOMMENDATIONS

The new version of CaveMan, CaveMan Enterprise 1.0, has been shown to produce the same results as CaveMan version 4.1. The new database format will provide enormous benefits to the integrity of data used by CaveMan, and helps eliminate the potential for human errors that older versions contained. The Python language allowed CaveMan to be structured in a way that will allow better future work to be tracked and integrated into the software. The CaveMan Enterprise software has passed acceptance testing V&V, and is ready for installation at the sites and to replace CaveMan v4.1 as the working version of the code.

References

[1] Ballard, S. and Ehgartner, B. L. (2000). CaveMan version 3.0: A software system for SPR cavern pressure analysis. Technical Report SAND2000-1751, Sandia National Laboratories, Albuquerque, NM and Livermore, CA.

[2] Ballard, S., Ehgartner, B. L., Berndsen, J., Myers, R., and McHenry, J. (1997). The CAVEMAN cavern pressurization model. Technical Report SAND97-2952C, Sandia National Laboratories, Albuquerque, NM.

[3] Ehgartner, B. (2003). Review of caveman – recommended upgrades. Letter report to R. E. Meyers, dated October 24.

[4] Ehgartner, B. (2004). Incorporation of compressibility model and other enhancements/upgrades into caveman. Letter report to R. E. Meyers, dated March 31.

[5] Ehgartner, B., Ballard, S., Tavares, M., Yeh, S., Hinkebein, T., and Ostensen, R. (1995). A predictive model for pressurization of SPR caverns. In *Proc. Fall Meeting, October 23-24, 1995 in San Antonio, TX*. Solution Mining Research Institute.

Appendix A Current CaveMan Parameters

The majority of the database tables defined in the schema – see Appendix B – have far too much data to be included in a printed document as tables; instead, they were validated against the original CaveMan input data and results using the tests described in the body of this document. However, certain CaveMan data values, particularly parameter values that impact the model results, are important enough, and compact enough, to be documented in this appendix. The contents of the wells tables for each site comprise Tables A.1 through A.4. The contents of the caverns tables for each site comprise Tables A.5 through A.8. The contents of the caveman_parameters tables for each site comprise Tables A.9 through A.12.

A.1 The wells database tables

The wells database table contains lookup and DCS tag information for each well at a site. Measured oil, water and annulus pressures are unique to a particular well ID, even though they are recorded on a per-cavern basis.

Table A.1: The wells table for the Bayou Choctaw site. †Cavern BC102 is newly added since CaveMan v4.1, and has not yet been fully parameterized.

well_id	cavern_id	well_name	oil_pressure	water_pressure	annulus_pressure
1	1	15	4C015PI41/PV.CV		4C015PI43/PV.CV
2	1	15A	4C015PIC30/PV.CV	4C015PI32/PV.CV	4C015PI33/PV.CV
3	2	17	4C017PI41/PV.CV		4C017PI43/PV.CV
4	2	17A	4C017PIC30/PV.CV	4C017PI32/PV.CV	4C017PI33/PV.CV
5	3	18	4C018PI41/PV.CV		4C018PI43/PV.CV
6	3	18A	4C018PIC30/PV.CV	4C018PI32/PV.CV	4C018PI33/PV.CV
7	4	19	4C019PIC30/PV.CV	4C019PI32/PV.CV	4C019PI33/PV.CV
8	4	19A	4C019PI41/PV.CV		4C019PI43/PV.CV
9	5	20	4C020PIC30/PV.CV	4C020PI32/PV.CV	4C020PI33/PV.CV
10	5	20A	4C020PI41/PV.CV		4C020PI43/PV.CV
11	6	101A	4C101PIC30/PV.CV	4C101PI32/PV.CV	4C101PI33/PV.CV
12	6	101B	4C101PI41/PV.CV		4C101PI43/PV.CV
13†	7	102A	4C102PIC30/PV.CV	4C102PI32/PV.CV	4C102PI33/PV.CV
14†	7	102B	4C102PI41/PV.CV		4C102PI43/PV.CV

Table A.2: The wells table for the Big Hill site. †Old annulus bore-hole lines that should be recorded, but that do not impact CaveMan.

well_id	cavern_id	well_name	oil_pressure	water_pressure	annulus_pressure
1	1	101A	8C101PI41/PV.CV		8C101PI43/PV.CV
2	1	101B	8C101PIC30/PV.CV	8C101PI32/PV.CV	8C101PI33/PV.CV
3	2	102A	8C102PI41/PV.CV		8C102PI43/PV.CV
4	2	102B	8C102PIC30/PV.CV	8C102PI32/PV.CV	8C102PI33/PV.CV
5	3	103A	8C103PI41/PV.CV		8C103PI43/PV.CV
6	3	103B	8C103PIC30/PV.CV	8C103PI32/PV.CV	8C103PI33/PV.CV
29†	3	103B_O			8C103PI34/PV.CV
7	4	104A	8C104PI41/PV.CV		8C104PI43/PV.CV
8	4	104B	8C104PIC30/PV.CV	8C104PI32/PV.CV	8C104PI33/PV.CV
9	5	105A	8C105PI41/PV.CV		8C105PI43/PV.CV
10	5	105B	8C105PIC30/PV.CV	8C105PI32/PV.CV	8C105PI33/PV.CV
30†	5	105B_O			8C105PI34/PV.CV
11	6	106A	8C106PI41/PV.CV		8C106PI43/PV.CV
12	6	106B	8C106PIC30/PV.CV	8C106PI32/PV.CV	8C106PI33/PV.CV
13	7	107A	8C107PI41/PV.CV		8C107PI43/PV.CV
14	7	107B	8C107PIC30/PV.CV	8C107PI32/PV.CV	8C107PI33/PV.CV
15	8	108A	8C108PI41/PV.CV		8C108PI43/PV.CV
16	8	108B	8C108PIC30/PV.CV	8C108PI32/PV.CV	8C108PI33/PV.CV
17	9	109A	8C109PI41/PV.CV		8C109PI43/PV.CV
18	9	109B	8C109PIC30/PV.CV	8C109PI32/PV.CV	8C109PI33/PV.CV
31†	9	109B_O			8C109PI34/PV.CV
19	10	110A	8C110PI41/PV.CV		8C110PI43/PV.CV
20	10	110B	8C110PIC30/PV.CV	8C110PI32/PV.CV	8C110PI33/PV.CV
21	11	111A	8C111PI41/PV.CV		8C111PI43/PV.CV
22	11	111B	8C111PIC30/PV.CV	8C111PI32/PV.CV	8C111PI33/PV.CV
23	12	112A	8C112PI41/PV.CV		8C112PI43/PV.CV
24	12	112B	8C112PIC30/PV.CV	8C112PI32/PV.CV	8C112PI33/PV.CV
25	13	113A	8C113PI41/PV.CV		8C113PI43/PV.CV
26	13	113B	8C113PIC30/PV.CV	8C113PI32/PV.CV	8C113PI33/PV.CV
27	14	114A	8C114PI41/PV.CV		8C114PI43/PV.CV
32†	14	114A_O			8C114PI40/PV.CV
28	14	114B	8C114PIC30/PV.CV	8C114PI32/PV.CV	8C114PI33/PV.CV
33†	14	114B_O			8C114PI34/PV.CV

Table A.3: The wells table for the Bryan Mound site. †Old annulus bore-hole lines that should be recorded, but that do not impact CaveMan. ‡Bore-hole has been plugged, no new measurements will be made.

well_id	cavern_id	well_name	oil_pressure	water_pressure	annulus_pressure
1	1	101A	2C101PI41/PV.CV		2C101PI43/PV.CV
2	1	101C	2C101PIC30/PV.CV	2C101PI32/PV.CV	2C101PI33/PV.CV
3	2	102B	2C102PIC30/PV.CV	2C102PI32/PV.CV	2C102PI34/PV.CV
49†	2	102B_O			2C102PI33/PV.CV
4	2	102C	2C102PI41/PV.CV		2C102PI40/PV.CV
50†	2	102C_O			2C102PI43/PV.CV
5	3	103B	2C103PI41/PV.CV		2C103PI43/PV.CV
6	3	103C	2C103PIC30/PV.CV	2C103PI32/PV.CV	2C103PI33/PV.CV
7	4	104A	2C104PI51/PV.CV		2C104PI53/PV.CV
8	4	104B	2C104PIC30/PV.CV	2C104PI32/PV.CV	2C104PI33/PV.CV
9	4	104C	2C104PI41/PV.CV		2C104PI43/PV.CV
10	5	105B	2C105PI41/PV.CV		2C105PI43/PV.CV
11	5	105C	2C105PIC30/PV.CV	2C105PI32/PV.CV	2C105PI33/PV.CV
12	6	106A	2C106PIC30/PV.CV	2C106PI32/PV.CV	2C106PI34/PV.CV
51†	6	106A_O			2C106PI33/PV.CV
13	6	106B	2C106PI41/PV.CV		2C106PI44/PV.CV
52†	6	106B_O			2C106PI43/PV.CV
14	6	106C	2C106PI51/PV.CV	2C106PI52/PV.CV	2C106PI53/PV.CV
15	7	107A	2C107PI51/PV.CV		2C107PI53/PV.CV
16	7	107B	2C107PI41/PV.CV		2C107PI43/PV.CV
17	7	107C	2C107PIC30/PV.CV	2C107PI32/PV.CV	2C107PI33/PV.CV
18	8	108A	2C108PI41/PV.CV		2C108PI43/PV.CV
19	8	108B	2C108PIC30/PV.CV	2C108PI32/PV.CV	2C108PI33/PV.CV
20	8	108C	2C108PI51/PV.CV		2C108PI54/PV.CV
21	9	109A	2C109PIC30/PV.CV	2C109PI32/PV.CV	2C109PI33/PV.CV
22	9	109B	2C109PI41/PV.CV		2C109PI43/PV.CV
23	9	109C	2C109PI51/PV.CV		2C109PI53/PV.CV
24	10	110A	2C110PIC30/PV.CV	2C110PI32/PV.CV	2C110PI33/PV.CV
25	10	110B	2C110PI41/PV.CV		2C110PI43/PV.CV
26	10	110C	2C110PI51/PV.CV		2C110PI53/PV.CV
27	11	111A	2C111PI41/PV.CV		2C111PI43/PV.CV
28	11	111B	2C111PIC30/PV.CV	2C111PI32/PV.CV	2C111PI33/PV.CV
29	12	112A	2C112PI41/PV.CV		2C112PI43/PV.CV
30	12	112C	2C112PIC30/PV.CV	2C112PI32/PV.CV	2C112PI33/PV.CV
31	13	113A	2C113PI40/PV.CV	2C113PI42/PV.CV	2C113PI43/PV.CV
32	13	113B	2C113PIC30/PV.CV	2C113PI32/PV.CV	2C113PI33/PV.CV
33	14	114A	2C114PI41/PV.CV		2C114PI43/PV.CV
34	14	114B	2C114PIC30/PV.CV	2C114PI32/PV.CV	2C114PI33/PV.CV
35	15	115A	2C115PI41/PV.CV		2C115PI43/PV.CV
36	15	115B	2C115PIC30/PV.CV	2C115PI32/PV.CV	2C115PI33/PV.CV
37	16	116A	2C116PI41/PV.CV		2C116PI43/PV.CV
38	16	116B	2C116PIC30/PV.CV	2C116PI32/PV.CV	2C116PI33/PV.CV
39	17	1	‡		‡
40	17	1A	2C001PIC30/PV.CV	2C001PI32/PV.CV	2C001PI33/PV.CV
41	18	2	2C002PI41/PV.CV		2C002PI43/PV.CV
42	18	2A	2C002PIC30/PV.CV	2C002PI32/PV.CV	2C002PI33/PV.CV
43	19	4A	2C004PI41/PV.CV		2C004PI43/PV.CV
44	19	4B	2C004PIC30/PV.CV	2C004PI32/PV.CV	2C004PI34/PV.CV
53†	19	4B_O			2C004PI33/PV.CV
45	19	4C	2C004PI51/PV.CV	2C004PI52/PV.CV	2C004PI53/PV.CV
46	20	5	2C005PI41/PV.CV	2C005PI42/PV.CV	2C005PI43/PV.CV
47	20	5A	2C005PI51/PV.CV		2C005PI53/PV.CV
48	20	5C	2C005PIC30/PV.CV	2C005PI32/PV.CV	2C005PI33/PV.CV

Table A.4: The wells table for the West Hackberry site. †Old annulus bore-hole lines that should be recorded, but that do not impact CaveMan. ‡Bore-hole has been plugged, no new measurements will be made.

well_id	cavern_id	well_name	oil_pressure	water_pressure	annulus_pressure
1	1	101	3C101PIC30/PV.CV	3C101PI32/PV.CV	3C101PI33/PV.CV
2	2	102	3C102PIC30/PV.CV	3C102PI32/PV.CV	3C102PI33/PV.CV
3	3	103	3C103PIC30/PV.CV	3C103PI32/PV.CV	3C103PI33/PV.CV
4	4	104	3C104PIC30/PV.CV	3C104PI32/PV.CV	3C104PI34/PV.CV
33†	4	104_O			3C104PI33/PV.CV
5	5	105	3C105PIC30/PV.CV	3C105PI32/PV.CV	3C105PI33/PV.CV
6	6	106	3C106PIC30/PV.CV	3C106PI32/PV.CV	3C106PI34/PV.CV
34†	6	106_O			3C106PI33/PV.CV
7	7	107	3C107PIC30/PV.CV	3C107PI32/PV.CV	3C107PI34/PV.CV
35†	7	107_O			3C107PI33/PV.CV
8	8	108	3C108PIC30/PV.CV	3C108PI32/PV.CV	3C108PI34/PV.CV
36†	8	108_O			3C108PI33/PV.CV
9	9	109	3C109PIC30/PV.CV	3C109PI32/PV.CV	3C109PI33/PV.CV
10	10	110	3C110PIC30/PV.CV	3C110PI32/PV.CV	3C110PI33/PV.CV
11	11	111	3C111PIC30/PV.CV	3C111PI32/PV.CV	3C111PI33/PV.CV
12	12	112	3C112PIC30/PV.CV	3C112PI32/PV.CV	3C112PI33/PV.CV
13	13	113	3C113PIC30/PV.CV	3C113PI32/PV.CV	3C113PI34/PV.CV
37†	13	113_O			3C113PI33/PV.CV
14	14	114	3C114PIC30/PV.CV	3C114PI32/PV.CV	3C114PI34/PV.CV
38†	14	114_O			3C114PI33/PV.CV
15	15	115	3C115PIC30/PV.CV	3C115PI32/PV.CV	3C115PI33/PV.CV
16	16	116	3C116PIC30/PV.CV	3C116PI32/PV.CV	3C116PI33/PV.CV
17	17	117A	3C117PI41/PV.CV		3C117PI43/PV.CV
18	17	117B	3C117PIC30/PV.CV	3C117PI32/PV.CV	3C117PI33/PV.CV
19	18	6S	‡		‡
20	18	6B	3C006PIC30/PV.CV	3C006PI32/PV.CV	3C006PI34/PV.CV
39†	18	6B_O			3C006PI33/PV.CV
21	18	6C	3C006PI41/PV.CV	‡	3C006PI43/PV.CV
22	19	7A	3C007PIC30/PV.CV	3C007PI32/PV.CV	3C007PI33/PV.CV
23	19	7B	3C007PI40/PV.CV		3C007PI43/PV.CV
24	20	8S	3C008PI41/PV.CV	‡	3C008PI43/PV.CV
25	20	8A	3C008PIC30/PV.CV	3C008PI32/PV.CV	3C008PI33/PV.CV
26	20	8B	3C008PI50/PV.CV		3C008PI53/PV.CV
27	21	9S	3C009PI51/PV.CV		3C009PI53/PV.CV
28	21	9A	3C009PI40/PV.CV		3C009PI43/PV.CV
29	21	9B	3C009PIC30/PV.CV	3C009PI32/PV.CV	3C009PI33/PV.CV
30	22	11S	3C011PI41/PV.CV		3C011PI43/PV.CV
31	22	11A	3C011PIC30/PV.CV	3C011PI32/PV.CV	3C011PI33/PV.CV
32	22	11B	3C011PI50/PV.CV		3C011PI53/PV.CV

A.2 The caverns database tables

The caverns tables define cavern-based parameters that are not specific to the CaveMan program. For example, the `opr_low` and `opr_high` refer to the "Operating Pressure Range - Low/High" values, which are set by cavern engineers. There are also numerous tags defined in this table which are used when parsing DCS data to be read into CaveMan. A crude type of 1 is sweet; a crude type of 2 is sour.

Table A.5: The caverns table for the Bayou Choctaw site. †The indicated instrumentation for BC-20 has been removed, as the cavern has been emptied and placed in alternate monitoring mode. ‡The BC-102 parameters will be documented elsewhere once it is fully configured.

cavern_id	cavern_name	active_well	crude_type	opr_low	opr_high	mov01	mov02	mov03	oil_temp	oil_flow_total	water_flow_total
1	15	2	2	815	990	4C015MOV01/PV.CV	4C015MOV02/PV.CV	4C015MOV03/PV.CV	4C015TI13/PV.CV	4C015FIC09/PREV_HOUR_TOTAL.CV	4C015FIC08/PREV_HOUR_TOTAL.CV
2	17	4	2	815	990	4C017MOV01/PV.CV	4C017MOV02/PV.CV	4C017MOV03/PV.CV	4C017TI13/PV.CV	4C017FIC09/PREV_HOUR_TOTAL.CV	4C017FIC08/PREV_HOUR_TOTAL.CV
3	18	6	1	690	740	4C018MOV01/PV.CV	4C018MOV02/PV.CV	4C018MOV03/PV.CV	4C018TI13/PV.CV	4C018FIC09/PREV_HOUR_TOTAL.CV	4C018FIC08/PREV_HOUR_TOTAL.CV
4	19	7	2	900	950	4C019MOV01/PV.CV	4C019MOV02/PV.CV	4C019MOV03/PV.CV	4C019TI13/PV.CV	4C019FIC09/PREV_HOUR_TOTAL.CV	4C019FIC08/PREV_HOUR_TOTAL.CV
5	20	9	1	825	875	†	†	†	†	†	†
6	101	11	2	825	1000	4C101MOV01/PV.CV	4C101MOV02/PV.CV	4C101MOV03/PV.CV	4C101TI13/PV.CV	4C101FIC09/PREV_HOUR_TOTAL.CV	4C101FIC08/PREV_HOUR_TOTAL.CV
7‡	102	13				4C102MOV01/PV.CV	4C102MOV02/PV.CV	4C102MOV03/PV.CV		4C102FIC09/PREV_HOUR_TOTAL.CV	4C102FIC08/PREV_HOUR_TOTAL.CV

Table A.6: The caverns table for the Big Hill site

cavern_id	cavern_name	active_well	crude_type	opr_low	opr_high	mov01	mov02	mov03	oil_temp	oil_flow_total	water_flow_total
1	101	2	1	850	960	8C101MOV01/PV.CV	8C101MOV02/PV.CV	8C101MOV03/PV.CV	8C101TI13/PV.CV	8C101FIC09/PREV_HOUR_TOTAL.CV	8C101FIC08/PREV_HOUR_TOTAL.CV
2	102	4	1	850	960	8C102MOV01/PV.CV	8C102MOV02/PV.CV	8C102MOV03/PV.CV	8C102TI13/PV.CV	8C102FIC09/PREV_HOUR_TOTAL.CV	8C102FIC08/PREV_HOUR_TOTAL.CV
3	103	6	1	850	960	8C103MOV01/PV.CV	8C103MOV02/PV.CV	8C103MOV03/PV.CV	8C103TI13/PV.CV	8C103FIC09/PREV_HOUR_TOTAL.CV	8C103FIC08/PREV_HOUR_TOTAL.CV
4	104	8	1	850	960	8C104MOV01/PV.CV	8C104MOV02/PV.CV	8C104MOV03/PV.CV	8C104TI13/PV.CV	8C104FIC09/PREV_HOUR_TOTAL.CV	8C104FIC08/PREV_HOUR_TOTAL.CV
5	105	10	1	850	960	8C105MOV01/PV.CV	8C105MOV02/PV.CV	8C105MOV03/PV.CV	8C105TI13/PV.CV	8C105FIC09/PREV_HOUR_TOTAL.CV	8C105FIC08/PREV_HOUR_TOTAL.CV
6	106	12	2	850	960	8C106MOV01/PV.CV	8C106MOV02/PV.CV	8C106MOV03/PV.CV	8C106TI13/PV.CV	8C106FIC09/PREV_HOUR_TOTAL.CV	8C106FIC08/PREV_HOUR_TOTAL.CV
7	107	14	2	850	960	8C107MOV01/PV.CV	8C107MOV02/PV.CV	8C107MOV03/PV.CV	8C107TI13/PV.CV	8C107FIC09/PREV_HOUR_TOTAL.CV	8C107FIC08/PREV_HOUR_TOTAL.CV
8	108	16	2	850	960	8C108MOV01/PV.CV	8C108MOV02/PV.CV	8C108MOV03/PV.CV	8C108TI13/PV.CV	8C108FIC09/PREV_HOUR_TOTAL.CV	8C108FIC08/PREV_HOUR_TOTAL.CV
9	109	18	2	850	960	8C109MOV01/PV.CV	8C109MOV02/PV.CV	8C109MOV03/PV.CV	8C109TI13/PV.CV	8C109FIC09/PREV_HOUR_TOTAL.CV	8C109FIC08/PREV_HOUR_TOTAL.CV
10	110	20	2	850	960	8C110MOV01/PV.CV	8C110MOV02/PV.CV	8C110MOV03/PV.CV	8C110TI13/PV.CV	8C110FIC09/PREV_HOUR_TOTAL.CV	8C110FIC08/PREV_HOUR_TOTAL.CV
11	111	22	2	850	960	8C111MOV01/PV.CV	8C111MOV02/PV.CV	8C111MOV03/PV.CV	8C111TI13/PV.CV	8C111FIC09/PREV_HOUR_TOTAL.CV	8C111FIC08/PREV_HOUR_TOTAL.CV
12	112	24	2	850	960	8C112MOV01/PV.CV	8C112MOV02/PV.CV	8C112MOV03/PV.CV	8C112TI13/PV.CV	8C112FIC09/PREV_HOUR_TOTAL.CV	8C112FIC08/PREV_HOUR_TOTAL.CV
13	113	26	2	850	960	8C113MOV01/PV.CV	8C113MOV02/PV.CV	8C113MOV03/PV.CV	8C113TI13/PV.CV	8C113FIC09/PREV_HOUR_TOTAL.CV	8C113FIC08/PREV_HOUR_TOTAL.CV
14	114	28	1	850	960	8C114MOV01/PV.CV	8C114MOV02/PV.CV	8C114MOV03/PV.CV	8C114TI13/PV.CV	8C114FIC09/PREV_HOUR_TOTAL.CV	8C114FIC08/PREV_HOUR_TOTAL.CV

Table A.7: The caverns table for the Bryan Mound site

cavern_id	cavern_name	active_well	crude_type	opr_low	opr_high	mov01	mov02	mov03	oil_temp	oil_flow_total	water_flow_total
1	101	2	2	645	745	2C101MOV01/PV.CV	2C101MOV02/PV.CV	2C101MOV03/PV.CV	2C101TI13/PV.CV	2C101FIC09/PREV_HOUR_TOTAL.CV	2C101FIC08/PREV_HOUR_TOTAL.CV
2	102	3	2	645	745	2C102MOV01/PV.CV	2C102MOV02/PV.CV	2C102MOV03/PV.CV	2C102TI13/PV.CV	2C102FIC09/PREV_HOUR_TOTAL.CV	2C102FIC08/PREV_HOUR_TOTAL.CV
3	103	6	2	645	745	2C103MOV01/PV.CV	2C103MOV02/PV.CV	2C103MOV03/PV.CV	2C103TI13/PV.CV	2C103FIC09/PREV_HOUR_TOTAL.CV	2C103FIC08/PREV_HOUR_TOTAL.CV
4	104	8	2	645	745	2C104MOV01/PV.CV	2C104MOV02/PV.CV	2C104MOV03/PV.CV	2C104TI13/PV.CV	2C104FIC09/PREV_HOUR_TOTAL.CV	2C104FIC08/PREV_HOUR_TOTAL.CV
5	105	11	2	645	745	2C105MOV01/PV.CV	2C105MOV02/PV.CV	2C105MOV03/PV.CV	2C105TI13/PV.CV	2C105FIC09/PREV_HOUR_TOTAL.CV	2C105FIC08/PREV_HOUR_TOTAL.CV
6	106	12	1	600	745	2C106MOV01/PV.CV	2C106MOV02/PV.CV	2C106MOV03/PV.CV	2C106TI13/PV.CV	2C106FIC09/PREV_HOUR_TOTAL.CV	2C106FIC08/PREV_HOUR_TOTAL.CV
7	107	17	2	645	745	2C107MOV01/PV.CV	2C107MOV02/PV.CV	2C107MOV03/PV.CV	2C107TI13/PV.CV	2C107FIC09/PREV_HOUR_TOTAL.CV	2C107FIC08/PREV_HOUR_TOTAL.CV
8	108	19	2	645	745	2C108MOV01/PV.CV	2C108MOV02/PV.CV	2C108MOV03/PV.CV	2C108TI13/PV.CV	2C108FIC09/PREV_HOUR_TOTAL.CV	2C108FIC08/PREV_HOUR_TOTAL.CV
9	109	21	2	645	745	2C109MOV01/PV.CV	2C109MOV02/PV.CV	2C109MOV03/PV.CV	2C109TI13/PV.CV	2C109FIC09/PREV_HOUR_TOTAL.CV	2C109FIC08/PREV_HOUR_TOTAL.CV
10	110	24	2	645	745	2C110MOV01/PV.CV	2C110MOV02/PV.CV	2C110MOV03/PV.CV	2C110TI13/PV.CV	2C110FIC09/PREV_HOUR_TOTAL.CV	2C110FIC08/PREV_HOUR_TOTAL.CV
11	111	28	2	645	745	2C111MOV01/PV.CV	2C111MOV02/PV.CV	2C111MOV03/PV.CV	2C111TI13/PV.CV	2C111FIC09/PREV_HOUR_TOTAL.CV	2C111FIC08/PREV_HOUR_TOTAL.CV
12	112	29	2	645	745	2C112MOV01/PV.CV	2C112MOV02/PV.CV	2C112MOV03/PV.CV	2C112TI13/PV.CV	2C112FIC09/PREV_HOUR_TOTAL.CV	2C112FIC08/PREV_HOUR_TOTAL.CV
13	113	32	1	605	755	2C113MOV01/PV.CV	2C113MOV02/PV.CV	2C113MOV03/PV.CV	2C113TI13/PV.CV	2C113FIC09/PREV_HOUR_TOTAL.CV	2C113FIC08/PREV_HOUR_TOTAL.CV
14	114	34	1	605	755	2C114MOV01/PV.CV	2C114MOV02/PV.CV	2C114MOV03/PV.CV	2C114TI13/PV.CV	2C114FIC09/PREV_HOUR_TOTAL.CV	2C114FIC08/PREV_HOUR_TOTAL.CV
15	115	36	1	655	755	2C115MOV01/PV.CV	2C115MOV02/PV.CV	2C115MOV03/PV.CV	2C115TI13/PV.CV	2C115FIC09/PREV_HOUR_TOTAL.CV	2C115FIC08/PREV_HOUR_TOTAL.CV
16	116	38	1	655	755	2C116MOV01/PV.CV	2C116MOV02/PV.CV	2C116MOV03/PV.CV	2C116TI13/PV.CV	2C116FIC09/PREV_HOUR_TOTAL.CV	2C116FIC08/PREV_HOUR_TOTAL.CV
17	1	40	2	545	595	2C001MOV01/PV.CV	2C001MOV02/PV.CV	2C001MOV03/PV.CV	2C001TI13/PV.CV	2C001FIC09/PREV_HOUR_TOTAL.CV	2C001FIC08/PREV_HOUR_TOTAL.CV
18	2	42	1	495	530	2C002MOV01/PV.CV	2C002MOV02/PV.CV	2C002MOV03/PV.CV	2C002TI13/PV.CV	2C002FIC09/PREV_HOUR_TOTAL.CV	2C002FIC08/PREV_HOUR_TOTAL.CV
19	4	44	1	700	745	2C004MOV01/PV.CV	2C004MOV02/PV.CV	2C004MOV03/PV.CV	2C004TI13/PV.CV	2C004FIC09/PREV_HOUR_TOTAL.CV	2C004FIC08/PREV_HOUR_TOTAL.CV
20	5	48	2	685	735	2C005MOV01/PV.CV	2C005MOV02/PV.CV	2C005MOV03/PV.CV	2C005TI13/PV.CV	2C005FIC09/PREV_HOUR_TOTAL.CV	2C005FIC08/PREV_HOUR_TOTAL.CV

Table A.8: The caverns table for the West Hackberry site

cavern_id	cavern_name	active_well	crude_type	opr_low	opr_high	mov01	mov02	mov03	oil_temp	oil_flow_total	water_flow_total
1	101	1	1	900	1040	3C101MOV01/PV.CV	3C101MOV02/PV.CV	3C101MOV03/PV.CV	3C101TI13/PV.CV	3C101FIC09/PREV_HOUR_TOTAL.CV	3C101FIC08/PREV_HOUR_TOTAL.CV
2	102	2	1	900	1040	3C102MOV01/PV.CV	3C102MOV02/PV.CV	3C102MOV03/PV.CV	3C102TI13/PV.CV	3C102FIC09/PREV_HOUR_TOTAL.CV	3C102FIC08/PREV_HOUR_TOTAL.CV
3	103	3	1	900	1040	3C103MOV01/PV.CV	3C103MOV02/PV.CV	3C103MOV03/PV.CV	3C103TI13/PV.CV	3C103FIC09/PREV_HOUR_TOTAL.CV	3C103FIC08/PREV_HOUR_TOTAL.CV
4	104	4	1	900	1040	3C104MOV01/PV.CV	3C104MOV02/PV.CV	3C104MOV03/PV.CV	3C104TI13/PV.CV	3C104FIC09/PREV_HOUR_TOTAL.CV	3C104FIC08/PREV_HOUR_TOTAL.CV
5	105	5	1	900	1040	3C105MOV01/PV.CV	3C105MOV02/PV.CV	3C105MOV03/PV.CV	3C105TI13/PV.CV	3C105FIC09/PREV_HOUR_TOTAL.CV	3C105FIC08/PREV_HOUR_TOTAL.CV
6	106	6	2	850	920	3C106MOV01/PV.CV	3C106MOV02/PV.CV	3C106MOV03/PV.CV	3C106TI13/PV.CV	3C106FIC09/PREV_HOUR_TOTAL.CV	3C106FIC08/PREV_HOUR_TOTAL.CV
7	107	7	1	900	1040	3C107MOV01/PV.CV	3C107MOV02/PV.CV	3C107MOV03/PV.CV	3C107TI13/PV.CV	3C107FIC09/PREV_HOUR_TOTAL.CV	3C107FIC08/PREV_HOUR_TOTAL.CV
8	108	8	1	900	1030	3C108MOV01/PV.CV	3C108MOV02/PV.CV	3C108MOV03/PV.CV	3C108TI13/PV.CV	3C108FIC09/PREV_HOUR_TOTAL.CV	3C108FIC08/PREV_HOUR_TOTAL.CV
9	109	9	2	900	1040	3C109MOV01/PV.CV	3C109MOV02/PV.CV	3C109MOV03/PV.CV	3C109TI13/PV.CV	3C109FIC09/PREV_HOUR_TOTAL.CV	3C109FIC08/PREV_HOUR_TOTAL.CV
10	110	10	1	900	1040	3C110MOV01/PV.CV	3C110MOV02/PV.CV	3C110MOV03/PV.CV	3C110TI13/PV.CV	3C110FIC09/PREV_HOUR_TOTAL.CV	3C110FIC08/PREV_HOUR_TOTAL.CV
11	111	11	2	900	1040	3C111MOV01/PV.CV	3C111MOV02/PV.CV	3C111MOV03/PV.CV	3C111TI13/PV.CV	3C111FIC09/PREV_HOUR_TOTAL.CV	3C111FIC08/PREV_HOUR_TOTAL.CV
12	112	12	2	900	1030	3C112MOV01/PV.CV	3C112MOV02/PV.CV	3C112MOV03/PV.CV	3C112TI13/PV.CV	3C112FIC09/PREV_HOUR_TOTAL.CV	3C112FIC08/PREV_HOUR_TOTAL.CV
13	113	13	1	900	1040	3C113MOV01/PV.CV	3C113MOV02/PV.CV	3C113MOV03/PV.CV	3C113TI13/PV.CV	3C113FIC09/PREV_HOUR_TOTAL.CV	3C113FIC08/PREV_HOUR_TOTAL.CV
14	114	14	2	900	1030	3C114MOV01/PV.CV	3C114MOV02/PV.CV	3C114MOV03/PV.CV	3C114TI13/PV.CV	3C114FIC09/PREV_HOUR_TOTAL.CV	3C114FIC08/PREV_HOUR_TOTAL.CV
15	115	15	2	900	1030	3C115MOV01/PV.CV	3C115MOV02/PV.CV	3C115MOV03/PV.CV	3C115TI13/PV.CV	3C115FIC09/PREV_HOUR_TOTAL.CV	3C115FIC08/PREV_HOUR_TOTAL.CV
16	116	16	1	900	1040	3C116MOV01/PV.CV	3C116MOV02/PV.CV	3C116MOV03/PV.CV	3C116TI13/PV.CV	3C116FIC09/PREV_HOUR_TOTAL.CV	3C116FIC08/PREV_HOUR_TOTAL.CV
17	117	18	2	900	1020	3C117MOV01/PV.CV	3C117MOV02/PV.CV	3C117MOV03/PV.CV	3C117TI13/PV.CV	3C117FIC09/PREV_HOUR_TOTAL.CV	3C117FIC08/PREV_HOUR_TOTAL.CV
18	6	20	2	850	950	3C006MOV01/PV.CV	3C006MOV02/PV.CV	3C006MOV03/PV.CV	3C006TI13/PV.CV	3C006FIC09/PREV_HOUR_TOTAL.CV	3C006FIC08/PREV_HOUR_TOTAL.CV
19	7	22	1	850	950	3C007MOV01/PV.CV	3C007MOV02/PV.CV	3C007MOV03/PV.CV	3C007TI13/PV.CV	3C007FIC09/PREV_HOUR_TOTAL.CV	3C007FIC08/PREV_HOUR_TOTAL.CV
20	8	25	2	900	950	3C008MOV01/PV.CV	3C008MOV02/PV.CV	3C008MOV03/PV.CV	3C008TI13/PV.CV	3C008FIC09/PREV_HOUR_TOTAL.CV	3C008FIC08/PREV_HOUR_TOTAL.CV
21	9	29	2	900	950	3C009MOV01/PV.CV	3C009MOV02/PV.CV	3C009MOV03/PV.CV	3C009TI13/PV.CV	3C009FIC09/PREV_HOUR_TOTAL.CV	3C009FIC08/PREV_HOUR_TOTAL.CV
22	11	31	2	900	950	3C011MOV01/PV.CV	3C011MOV02/PV.CV	3C011MOV03/PV.CV	3C011TI13/PV.CV	3C011FIC09/PREV_HOUR_TOTAL.CV	3C011FIC08/PREV_HOUR_TOTAL.CV

A.3 The caveman_parameters database tables

These parameters are used by the CaveMan models during the pressure calculations. Temperatures in this table are in degrees Fahrenheit; depths are in feet. The `api` field refers to the API gravity. The `interface_htc` is the heat transfer coefficient at the interface between oil and brine. The well identified in the `well_1` field should be the `active_well` identified in the caverns table.

Table A.9: The caveman_parameters table for the Bayou Choctaw site

cavern id	well 1	well 2	well 3	api	cavern top depth	cavern bottom depth	salt temp top	salt temp bottom	interface htc	oil salt temp	brine salt temp	salt modulus	salt structure factor	salt stress	kzero	alpha	alphar	eta0	date0	erms
1	2	1	1	32.9	2597	3304	112.206	124.225	17	112.206	118.2155	955184.247	1.44E+17	3130	628000	-17.37	-2.999835451	0.00110809	1/1/1990	5.221340656
2	4	3	3	33.8	2590	4029	112.087	136.55	2	112.087	124.3185	851702.7191	1.77E+17	3669.25	581240.7081	-9.000009	-3.443383805	0.001296291	1/1/1990	8.041099548
3	6	5	5	33.8	2100	4232	103.757	140.001	17	103.757	121.879	2424473.661	7.92E+16	3699	290390.1419	-9	-3.6	0.000906633	1/1/1990	8.818147659
4	7	8	8	32.7	2980	4231	118.717	139.984	17	118.717	129.3505	2097607.4	2.50E+17	3918.25	221226.0091	-9	-3.265091853	0.00102407	1/1/1990	7.414090157
5	9	10	10	36.1	3825	4233	133.082	140.018	2	133.082	136.55	603837.1394	2.37E+17	4131	155133.0915	-9	-3.6	0.000569981	1/1/1990	8.425942421
6	11	12	12	34.6	2550	4824	111.407	150.065	17	111.407	130.736	955184.247	8.64E+16	4255.5	637867.3143	-9.0034976	-3.469172239	0.000370064	1/1/1990	7.113911629

Table A.10: The caveman_parameters table for the Big Hill site

cavern id	well 1	well 2	well 3	api	cavern top depth	cavern bottom depth	salt temp top	salt temp bottom	interface htc	oil salt temp	brine salt temp	salt modulus	salt structure factor	salt stress	kzero	alpha	alphar	eta0	date0	erms
1	2	1	1	33	2266	4176	106.83	134.52	17	106.83	120.67	1185013.498	2.05E+18	3698.5	227401.6912	-9	-3.6	0.001001686	9/19/1990	10.43
2	4	3	3	33	2300	4087	107.32	133.23	17	107.32	120.28	1082632.54	2.04E+18	3640.25	104274.6735	-9	-3.6	0.00070405	3/23/1991	10.71
3	6	5	5	33	2200	4054	105.87	132.75	17	105.87	119.31	994536.3241	2.47E+18	3733.020557	840867.2233	-9	-3.6	0.001015593	11/29/1990	13.01
4	8	7	7	32	2278	4247	107	135.55	17	107	121.28	1675094.546	1.53E+18	3754.75	222380.8325	-9	-3.594995529	0.000927806	6/1/1991	10.37
5	10	9	9	34.6	2280	4232	107.03	135.33	17	107.03	121.18	939954.9765	1.22E+18	3744	101108.0857	-9	-3.6	0.000936231	5/14/1990	10.4
6	12	11	11	34.6	2284	4108	107.09	133.54	17	107.09	120.31	879115.9342	6.24E+17	3652	209019.2786	-9	-3.6	0.000930549	10/17/1990	11.94
7	14	13	13	32.8	2265	4118	106.81	133.68	17	106.81	120.25	902759.1207	1.91E+18	3654	432560.5919	-9	-3.595437617	0.000930858	4/25/1990	10.67
8	16	15	15	34.6	2334	4148	107.81	134.12	17	107.81	120.96	940731.7682	1.89E+18	3696	900000	-19	-2.993600186	0.0007	6/14/1991	12.06
9	18	17	17	34.6	2300	4273	107.32	135.93	17	107.32	121.62	946596.0678	1.02E+18	3780	375854.7547	-10.25203601	-3.6	0.000893347	7/25/1990	11.95
10	20	19	19	34.6	2300	4219	107.32	135.15	17	107.32	121.23	1043916.598	1.18E+18	3740	364630.9378	-10.50000764	-3.6	0.000700001	4/20/1990	11.58
11	22	21	21	34.6	2300	4243	107.32	135.49	17	107.32	121.41	1112891.299	5.56E+17	3757	377284.8425	-10.27520368	-3.6	0.000900296	7/15/1991	11.26
12	24	23	23	34.6	2300	4228	107.32	135.28	17	107.32	121.3	950810.3812	1.10E+18	3746	377285.1203	-10.27520265	-3.6	0.000900296	6/19/1991	11.02
13	26	25	25	34.6	2300	4166	107.32	134.38	17	107.32	120.85	1024713.54	1.18E+18	3700	368689.3571	-10.37040061	-3.6	0.000911032	5/2/1991	10.67
14	28	27	27	34.6	2300	4160	107.32	134.29	17	107.32	120.81	679159.9044	3.64E+18	3695	298795.4132	-19	-3.6	0.001223977	8/29/1991	9.16

Table A.11: The caveman_parameters table for the Bryan Mound site

cavern id	well 1	well 2	well 3	api	cavern top depth	cavern bottom depth	salt temp top	salt temp bottom	interface htc	oil salt temp	brine salt temp	salt modulus	salt structure factor	salt stress	kzero	alpha	alphar	eta0	date0	erms
1	2	1	1	34.1	1998	4162	120.46	153.57	17	120.46	137.02	431523.3062	1.49E+17	3621	641999.9021	-9	-3.407152897	0.001183165	1/1/1990	5.862829685
2	3	4	4	33.5	2225	4249	123.94	154.9	17	123.94	139.42	620043.5622	1.59E+17	3743	617210.8579	-9.148727472	-3.558001579	0.001218256	1/1/1990	5.640853405
3	6	5	5	34.7	2110	4138	122.18	153.21	17	122.18	137.69	602767.9512	2.82E+17	3631	605221.7885	-9	-3.599996368	0.001396251	1/1/1990	8.182245255
4	8	7	9	33	2220	4175	123.86	153.77	17	123.86	138.82	688504.7019	1.66E+17	3686	660834.4167	-9	-2	0.001280195	1/1/1990	5.794867992
5	11	10	10	33.2	2100	4206	122.03	154.25	17	122.03	138.14	481359.0217	1.00E+17	3679	794552.7981	-9	-2.784780136	0.001961761	1/1/1990	5.232748508
6	12	13	14	22.5	2097	4031	121.98	151.57	17	121.98	136.77	559406.2887	4.98E+17	3596	494432.6688	-19	-2	0.00171756	1/1/1990	9.278377533
7	17	15	16	32.9	2225	4106	123.94	152.72	17	123.94	138.33	843042.5817	1.86E+17	3635	878662.8816	-13.21019977	-3.085103267	0.001129666	1/1/1990	6.560742855
8	19	18	20	33.7	2165	4138	123.02	153.21	17	123.02	138.11	713241.1013	1.38E+17	3635	876861.7044	-13.20221295	-2.452416489	0.001036269	1/1/1990	6.885832787
9	21	22	23	33.3	2170	4185	123.1	153.93	17	123.1	138.51	729326.274	2.22E+17	3681	962020.3159	-15.4175438	-3.38426995	0.002004179	1/1/1990	6.939658642
10	24	25	26	32.8	2150	4118	122.79	152.9	17	122.79	137.85	610258.9666	1.38E+17	3626	965552.4501	-14.98345478	-2.000003732	0.00173813	1/1/1990	4.427186966
11	28	27	27	33.8	2125	4162	122.41	153.57	17	122.41	137.99	244286.5865	2.20E+17	3653	101629.1994	-9	-3.584726647	0.002004076	1/1/1990	9.587569237
12	29	30	30	33.4	2065	4152	121.49	153.42	17	121.49	137.46	411461.3436	3.00E+17	3630	500000.0938	-9.50011668	-2	0.001279731	1/1/1990	14.14809418
13	32	31	31	36.2	2159	4219	122.93	154.45	17	122.93	138.69	361526.735	3.73E+17	3704	732671.4792	-14.35486059	-3.000181495	0.001276561	1/9/1990	7.401179314
14	34	33	33	36.2	2150	4180	122.79	153.85	17	122.79	138.32	264234.6251	5.30E+17	3672	820010.3716	-16.69426539	-3.512486408	0.001774705	1/1/1990	6.789059639
15	36	35	35	36.2	2185	4137	123.33	153.19	17	123.33	138.26	373378.1932	5.42E+17	3649	818077.6103	-16.6581316	-3.405176729	0.002160906	1/1/1990	6.278347015
16	38	37	37	36.2	2100	4266	122.03	155.16	17	122.03	138.59	1002137.116	1.70E+17	3725	820791.6383	-15.25305352	-2.000000923	0.0019066	1/1/1990	6.220088005
17	40	39	39	36.3	2345	2768	125.77	132.25	17	125.77	129.01	3133395.31	4.08E+17	2835	845945.2923	-18.18413265	-3.6	0.000605703	1/1/1990	5.887854576
18	42	41	41	36.6	1450	1672	112.08	115.48	17	112.08	113.78	115508.3639	2.88E+17	2221	818261.0234	-17.0589932	-2	0.00085494	1/1/1990	5.572516918
19	44	43	45	35.8	2495	3081	128.07	137.03	2	128.07	132.55	1155356.622	2.85E+17	3415	818285.5529	-17.05560741	-2	0.000899236	1/1/1990	5.416892052
20	48	46	47	33.6	2102	3275	122.06	140	17	122.06	131.03	1800000	2.89E+17	3449	816668.8658	-17.03952295	-2.033996879	0.000996912	1/1/1990	4.138215065

Table A.12: The caveman_parameters table for the West Hackberry site

cavern id	well 1	well 2	well 3	api	cavern top depth	cavern bottom depth	salt temp top	salt temp bottom	interface htc	oil salt temp	brine salt temp	salt modulus	salt structure factor	salt stress	kzero	alpha	alphar	eta0	date0	erms
1	1	1	1	36.6	2555	4446	125.3815	142.9678	17	125.3815	134.17465	774654.3272	5.97E+17	3777.24474	472126.5346	-16.36915831	-3.646808369	0.00073086	1/1/1990	10.92560196
2	2	2	2	37.6	2628	4502	126.0604	143.4886	17	126.0604	134.7745	1264030.644	3.22E+17	3991.634638	386488.2621	-16.4850409	-3.428137817	0.000773113	1/1/1990	9.969085693
3	3	3	3	36.6	2700	4424	126.73	142.7632	17	126.73	134.7466	445712.9308	4.27E+17	4087.990251	384276.4354	-16.48652272	-3.539967469	0.000773233	1/1/1990	10.96901321
4	4	4	4	36.6	2625	4555	126.0325	143.9815	17	126.0325	135.007	1081763.852	3.90E+17	4029.50846	290670.1578	-17.09375348	-3.6	0.000667636	1/1/1990	17.24636459
5	5	5	5	37.5	2648	4612	126.2464	144.5116	17	126.2464	135.379	559975.4412	3.67E+17	4162.090408	498721.9073	-16.63540384	-3.442047268	0.000778882	1/1/1991	12.0175066
6	6	6	6	34.3	2760	4361	127.288	142.1773	17	127.288	134.73265	541173.1132	4.61E+17	4034.400042	484325.7317	-17.46588381	-3.583816812	0.000771972	1/1/1991	7.665943146
7	7	7	7	37.3	2600	4547	125.8	143.9071	17	125.8	134.85355	440286.8129	4.83E+17	4036.547258	450951.7076	-16.92513751	-3.637581691	0.000770543	1/1/1991	9.699276924
8	8	8	8	37.3	2600	4427	125.8	142.7911	17	125.8	134.29555	867121.2324	4.91E+17	3949.800895	223661.5643	-16.91282256	-2.627605732	0.000772949	1/1/1991	11.79224396
9	9	9	9	33.8	2485	4648	124.7305	144.8464	17	124.7305	134.78845	725060.8199	2.76E+17	4177.466075	263300.1984	-16.24032284	-3.601696425	0.000694729	1/1/1991	12.22137833
10	10	10	10	37.6	2650	4571	126.265	144.1303	17	126.265	135.19765	465808.2307	4.72E+17	4086.549974	116191.78	-16.404823	-3.537860958	0.000762386	1/1/1991	8.73739624
11	11	11	11	33.5	2630	4600	126.079	144.4	17	126.079	135.2395	367378.0685	4.93E+17	4111.07949	122490.6162	-16.42317325	-3.582404362	0.000764671	1/1/1990	8.255633354
12	12	12	12	34.6	2575	4532	125.5675	143.7676	17	125.5675	134.66755	950856.3784	3.49E+17	4054.682558	272112.9981	-19.00001316	-3.619999523	0.000801058	1/1/1990	9.572999001
13	13	13	13	36.8	2925	4684	128.8225	145.1812	17	128.8225	137.00185	1986493.661	3.48E+17	4189.265188	270503.7671	-18.9996699	-3.478093235	0.000802351	1/1/1990	11.60949421
14	14	14	14	34.1	2600	4548	125.8	143.9164	17	125.8	134.8582	759561.5225	3.29E+17	4056.294267	256831.2982	-19.00374848	-3.565632918	0.000803672	1/1/1990	11.95204258
15	15	15	15	34.2	2550	4631	125.335	144.6883	17	125.335	135.01165	521923.9311	3.63E+17	4086.654048	174297.7782	-15.96584876	-3.62	0.000786645	1/1/1990	13.09029007
16	16	16	16	37.2	2680	4719	126.544	145.5067	17	126.544	136.02535	528439.7562	4.47E+17	4205.173879	176915.0388	-15.9766466	-3.505605134	0.000786954	1/1/1990	9.219552994
17	17	18	18	33.8	2570	4616	125.521	144.5488	17	125.521	135.0349	1710619.397	5.10E+17	4091.684528	181426.049	-15.97212346	-3.62	0.000786992	1/8/1990	9.654985428
18	20	19	21	33.1	3225	3385	131.6125	133.1005	17	131.6125	132.3565	378678.4383	4.55E+17	4314.852046	216059.181	-16.23453604	-2.764695929	0.000280142	1/1/1990	9.582855225
19	23	22	22	37	2540	3495	125.242	134.1235	17	125.242	129.68275	855748.5238	3.32E+17	3733.587161	95481.6495	-17.15227636	-3.353725094	0.0003281	3/13/1990	7.03283453
20	25	24	26	33.2	2440	3452	124.312	133.7236	17	124.312	129.0178	1137334.667	3.22E+17	3677.76598	98244.22533	-17.52383511	-3.492819895	0.000328248	1/1/1990	6.337388515
21	28	27	29	32.9	3210	3572	131.473	134.8396	17	131.473	133.1563	322958.4639	3.48E+17	4164.640466	217705.2202	-17.45003808	-3.533893295	0.000331505	1/1/1991	6.471155167
22	31	30	32	33.2	2945	3743	129.0085	136.4299	17	129.0085	132.7192	608208.5588	3.30E+17	3824.652092	217921.8485	-17.43676666	-3.273832385	0.000328248	1/1/1990	7.413360119

APPENDIX B CAVEMAN DATABASE SCHEMA

The following SQL code describes the schema for the CaveMan Enterprise database. The types shown are generic SQL types, and specific products may declare types differently – always check the documentation. In particular, the **timestamp** type may need to be replaced with **datetime** for proper functioning, and the **float** type may have different data widths in different databases.

```
CREATE TABLE caverns (cavern_id integer, cavern_name varchar,
    active_well integer, crude_type integer, opr_low integer, opr_high
     integer, mov01 varchar, mov02 varchar, mov03 varchar, oil_temp
    varchar, oil_flow_total varchar, water_flow_total varchar, primary
     key(cavern_id));

CREATE TABLE wells (well_id integer, cavern_id integer, well_name
    varchar, oil_pressure varchar, water_pressure varchar,
    annulus_pressure varchar, primary key(well_id, cavern_id));

CREATE TABLE caveman_parameters (cavern_id integer, well_1 integer,
    well_2 integer, well_3 integer, api float, cavern_top_depth
    integer, cavern_bottom_depth integer, salt_temp_top float,
    salt_temp_bottom float, interface_htc float, oil_salt_temp float,
    brine_salt_temp float, salt_modulus float, salt_structure_factor
    float, saltstress float, kzero integer, alpha float, alphar float,
     eta0 float, date0 date, erms float, primary key(cavern_id));

CREATE TABLE caveman_pressures (cavern_id integer, ts_date date,
    pressure float, predicted_pressure float, status_variable float,
    ts_update timestamp, ts_sync timestamp, primary key(cavern_id,
    ts_date));

CREATE TABLE caveman_temp_predicted (cavern_id integer, ts_date date,
     temp_oil float, temp_brine float, ts_update timestamp, ts_sync
    timestamp, primary key(cavern_id, ts_date));

CREATE TABLE caveman_temp_radius (cavern_id integer, ts_date date,
    radius float, temp_oil float, temp_brine float, primary key(
    cavern_id, radius));

CREATE TABLE caveman_transfers (cavern_id integer, ts_date date,
    out_volume integer, out_type varchar, in_volume integer, in_type
    varchar, in_sg float, in_temp float, record_deleted integer,
    ts_update timestamp, ts_sync timestamp, primary key(cavern_id,
    ts_date));

CREATE TABLE caveman_volumes (cavern_id integer, ts_date date, cavern
     float, oil float, dissolution float, ts_update timestamp, ts_sync
     timestamp, primary key(cavern_id, ts_date));

CREATE TABLE daily_transfer (cavern_id integer, ts_date date, dsv
    integer, oil_transfer integer, oil_temp float, brine_transfer
    integer, brine_temp float, brine_sg float, accepted integer,
```

```
    processed integer, synced integer, ts_sync timestamp, primary key(
    cavern_id, ts_date));

CREATE TABLE daily_well (well_id integer, ts_date date, oil_pressure
    float, water_pressure float, annulus_pressure float, dsv integer,
    oil_status integer, water_status integer, annulus_status integer,
    accepted integer, processed integer, synced integer, ts_sync
    timestamp, primary key(well_id, ts_date));

CREATE TABLE caveman_kaufman (id integer, temperature float, salt
    float, sg float);
```

APPENDIX

C

THE *CAVEMAN* PROGRAM

The *caveman* program is used to run the CaveMan Enterprise software. The following options are all optional, though if no site is defined in the `settings` submodule, *caveman* will not run unless a site code or configuration file is provided. CaveMan Enterprise requires the following python requirements: Python 2.7, NumPy 1.7+, and SciPy 0.12+. CaveMan Enterprise v1.0 is *not* Python 3 compatible at this time.

C.1 Command-line options

C.1.1 main command-line options

`--configfile` `FILE`
: read options from a JSON formatted file; command line values will override any options in the file; must be specified last on the command line

`--site` `CODE`
: set the site to the one specified by the site CODE; using the site code is the preferred way to select the site

`--id` `IDNUM`
: set the site to the one specified by ID_NUM

`--database` `FILE/URL`
: set the local or remote database to use

`--magnitude-factor` `{0,1}`
: set the magnitude factor (turning on or off the dissolution model) for the site

`-v, --verbose`
: increase the logging level

`-q, --quiet`
: decrease the logging level

C.1.2 site deployment command-line options

Sets up local DCS reading and master database web synchronization options. By default, *caveman* will attempt to read the local data files at startup, and will attempt to synchronize with the master database both before and after running.

`--sync-dcs`
: read new data from the local SCADA DCS

`--no-sync-dcs`
: do not look for local SCADA updates

--input-xml-files GLOB
set the input file glob for the input filenames from the DCS

--processed-xml-files DIRECTORY
set the destination directory for processed files

--sync-hist
synchronize with a remote master historian database

--no-sync-hist
use only the local database

--insert-data-url URL
set the URL to insert data into the central database

--get-data-url URL
set the URL to get data from the central database

--update-data-url URL
set the URL to update data in the central database

C.1.3 configuration file help command-line options

To get a list of the currently configured defaults, please use the *–create-sample* or *–print-sample* option to get the JSON formatted configuration defaults that have been currently installed.

--create-sample FILE
create a sample JSON configuration file called FILE; any specified options will be used

--print-sample
print a sample JSON configuration string; any specified options will be used

C.2 Example configuration file

The following is an example configuration file, *config.json*, for running at the Bayou Choctaw site:

```
{
  "site": "BC",
  "name": "Bayou Choctaw",
  "database": "caveman_bc.db",
  "magnitude factor": 1,
  "sync dcs": true,
  "input xml files": "D:\\HDA\\Caveman\\CM*.xml",
  "processed xml files": "D:\\HDA\\Caveman\\processed",
  "sync hist": true,
  "get data url": "http://someserver/Caveman/get_data.php",
  "insert data url": "http://someserver/Caveman/insert_data.php",
  "update data url": "http://someserver/Caveman/update_data.php"
}
```

DISTRIBUTION:

Electronic Wayne Elias (wayne.elias@hq.doe.gov) for distribution to DOE SPR Program Office, 1000 Independence Ave. SW Washington, DC 20585

Electronic Diane Willard (diane.willard@spr.doe.gov) for distribution to DOE and Fluor FPO SPR Project Management Office, 900 Commerce Road East New Orleans, LA 70123

Sandia Distribution
Print Copies to:

1	MS	0751	David Hart, 06915
5	MS	0750	Carolyn Kirby, 06913
1	MS	0899	Technical Library, 9536 (electronic copy)

Sandia National Laboratories