

## Chapter 3

# **A Monte Carlo Simulation Method for the Assessment of Undiscovered, Conventional Oil and Gas**

By Ronald R. Charpentier and T.R. Klett



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Chapter 3 of

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# A Monte Carlo Simulation Method for the Assessment of Undiscovered, Conventional Oil and Gas

By Ronald R. Charpentier and T.R. Klett

## Abstract

The U.S. Geological Survey has developed two Monte Carlo programs for assessment of undiscovered conventional oil and gas resources. EMCEE (for Energy Monte Carlo) and Emc2 (for Energy Monte Carlo program 2) are programs that calculate probabilistic estimates of undiscovered resources based on input distributions for numbers and sizes of undiscovered fields. Emc2 uses specific types of distributions for the input, whereas EMCEE allows greater flexibility of the input distribution types.

## Introduction

EMCEE (for Energy Monte Carlo) and Emc2 (for Energy Monte Carlo program 2) are U.S. Geological Survey (USGS)-developed Monte Carlo simulation programs for assessment of undiscovered conventional oil and gas resources. EMCEE allows a variety of distribution types for input, whereas Emc2 works with a specific set of distributions. Both programs run as spreadsheet workbooks in Microsoft Excel.<sup>1</sup> EMCEE and Emc2 require Crystal Ball, a commercially available Monte Carlo simulation program from Decisioneering, Inc., that runs in Microsoft Excel.

EMCEE and Emc2 forecast undiscovered resources by simulating the sizes and numbers of undiscovered oil and gas fields. The user provides input distributions for several variables. The program samples from these distributions and calculates a forecast of undiscovered resources. This procedure is then iterated a specified number of times and the distributions of forecasts are presented in both tabular and graphical formats.

The programs EMCEE and Emc2 are contained in Microsoft Excel workbooks, copies of which are included in the folder named 21\_PROGRAMS. The files are named emcee.xls and Emc2.xls.

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<sup>1</sup>Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government. The programs were tested on a number of computers before release, but no guarantee is given or implied that they will run on other computers or with other versions of software without modification.

## Requirements

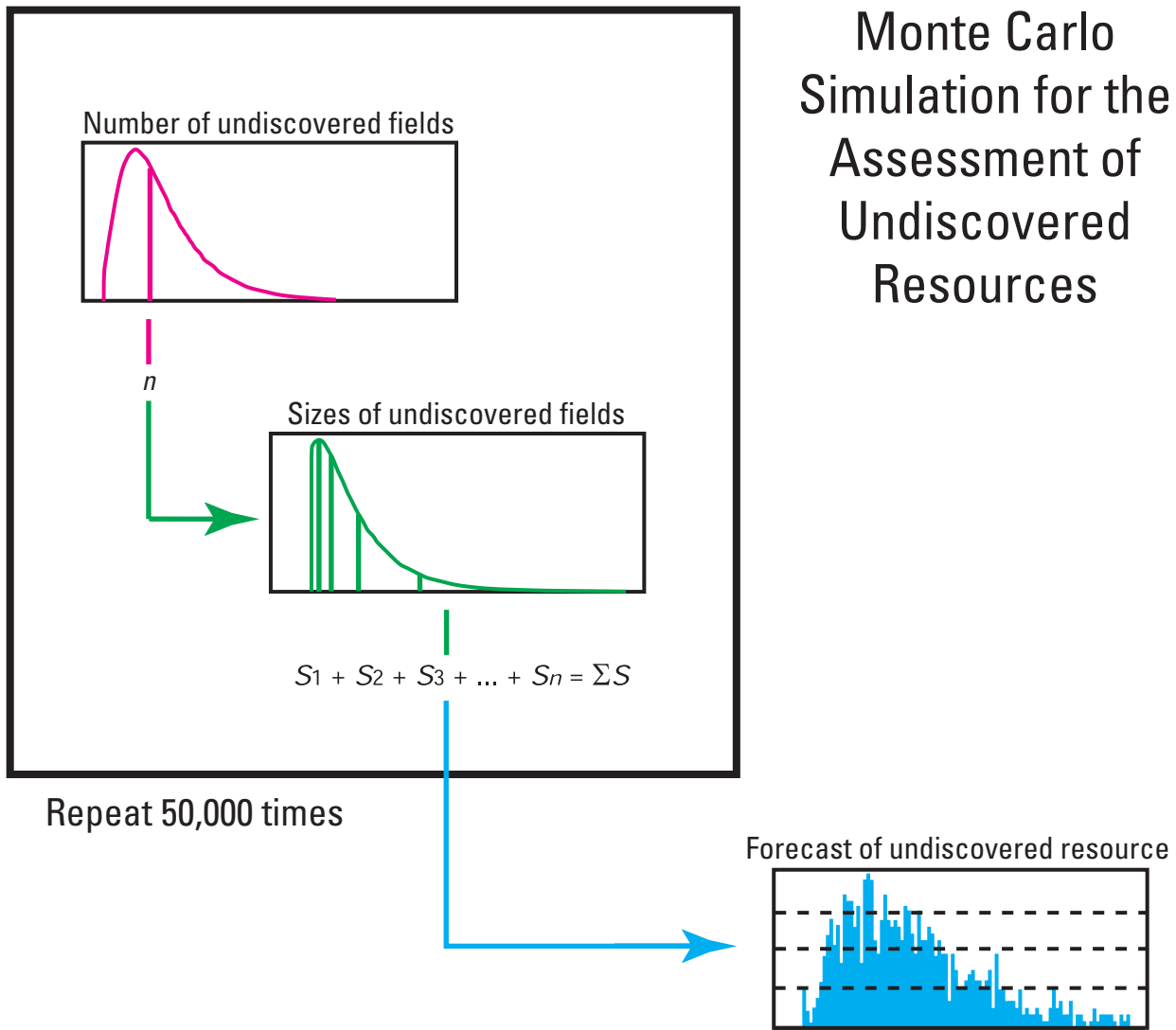
EMCEE and Emc2 require both Microsoft Excel and Decisioneering Crystal Ball, which are commercially available software packages. Familiarity with both software packages is assumed in this report. Microsoft Excel version 5.0 or higher for the Macintosh or version 7.0 or higher for Windows is required. Crystal Ball version 4.0c or higher is required. Either the Windows or the Macintosh version is acceptable. Early development of the programs was performed primarily on Crystal Ball version 4.0b and Microsoft Excel 5.0 in a Macintosh environment. Final development occurred on Crystal Ball version 4.0e and Microsoft Excel 97 in a Windows 95 environment.

## Data Model

Both EMCEE and Emc2 forecast undiscovered resources for oil fields and gas fields separately. The user provides distributions for the number and sizes of undiscovered fields. Distributions for the ratios of coproducts (gas in oil fields, oil in gas fields, or natural gas liquids (NGL) in either) to the main product (oil in oil fields, gas in gas fields) are used to calculate the coproduct volumes. Risk factors assess the probability of the presence of a field of at least a specified minimum size in the assessment unit. Results are presented in both risked and nonrisked distributions.

The calculation procedure for oil fields begins with a sample from the distribution for number ( $n$ ) of undiscovered oil fields (fig. 1). That number is rounded to a whole number and used as the number of independent samples taken from the distribution of oil field sizes. These sampled sizes are totaled to give a volume ( $\sum S$ ) of undiscovered oil in oil fields. The volume  $\sum S$  is multiplied by the gas/oil ratio (GOR) to give volume of gas in oil fields, which in turn is multiplied by the NGL/gas ratio (LGR) to give volume of NGL in oil fields. The maximum value of the sampled field sizes is also determined. Calculation of gas field resources is performed similarly from separate input distributions.

Risk calculations are performed where some chance exists for no fields of at least a specified minimum size in the assessment unit. The probabilities for fluids, rocks, and



**Figure 1.** Schematic diagram of data model used for Monte Carlo simulation for the assessment of undiscovered resources using programs EMCEE and Emc2 described in text.

timing are multiplied to give the geologic probability of the assessment unit, that is, the probability of the presence in the assessment unit of at least one field at least as large as the user-defined minimum size. Accessibility is the probability that at least part of the assessment unit will be politically and technologically open to petroleum-related activity during the assessment period. When the geologic probability is multiplied by the accessibility probability, the product is the geologic and access probability of the assessment unit. A uniform distribution from 0 to 1 (cell E11 on worksheet **Risk**) gives a number to compare to the geologic probability and to the geologic and access probability. When the sampled number is greater than the geologic probability, the geologic-risked amount of resource (column B on worksheet **Risk**) is zero for that iteration. When the sampled number is greater than the geologic and access probability, the geologic- and access-risked amount of resource (column E on worksheet **Risk**)

**Output**) is zero for that iteration.

This entire process is rerun a specified number of times. Crystal Ball provides statistics and graphs that describe the forecast distributions. Either these results can be displayed on the screen by using the forecast windows (step 15 in instructions), or a report on a separate Microsoft Excel worksheet can be generated (step 16 in instructions).

## Differences between EMCEE and Emc2

The EMCEE (for Energy Monte Carlo) program is meant to be a generalized program for performing Monte Carlo simulations according to the data model described in the previous section. Experimentation using EMCEE led to a more specific model for use in certain USGS assessments (including the

USGS National Assessments), using shifted, truncated lognormal distributions for the field size and triangular distributions for numbers of undiscovered fields and for coproduct ratios. The Emc2 (for Energy Monte Carlo program 2) program was built to fit this constrained model. Because of the constraints, more features could be automated and more data checks could be included in Emc2.

## Before You Begin

A reference to the Crystal Ball library must be established in Microsoft Excel. Without the appropriate reference, the macros cannot execute Crystal Ball commands. To establish this reference, do the following before running EMCEE or Emc2 for the first time.

1. Start Microsoft Excel and open Crystal Ball, if it is not opened automatically.
2. Open either EMCEE or Emc2.
3. Depending on your version of Excel, either go to the Macro worksheet or, from the **Tools** menu on the menu bar, choose **Macro** and then **Visual Basic Editor**.
4. Choose **References...** from the **Tools** menu on the menu bar.
5. Make sure that **CB.xls** is checked and that **Missing: CB.xls** is not checked.
6. Close the Visual Basic editor, if it is open.

This procedure need only be done once. Subsequent runs should not require reestablishing the reference.

## Directions for Use of EMCEE

This program allows input distribution types to be defined by the user.

1. Make a copy of the emcee.xls workbook and rename it with the .xls suffix.
2. Start Microsoft Excel.
3. Open Crystal Ball, if it is not opened automatically.
4. Close any open workbooks, such as **Sheet1**.
5. Open the workbook copied in step 1.
6. Open the worksheet labeled **Identification** and fill in the identification information (optional). On this worksheet and others, input cells are colored yellow.
7. Open the worksheet labeled **Risk** and modify the risk factors if necessary.
8. Open the worksheet labeled **Oil Calculations** and, either using the **Define Assumption** button on the Crystal Ball toolbar or choosing **Define Assumption...** from the **Cell** menu, fill in the assumption information on the worksheet as necessary:
  - a. The number of fields distribution in cell B1. If either no oil or no gas fields are to be simulated, the number of fields should be set to exactly one

(using the custom distribution).

- b. The coproduct ratios in cells B3 and B5. If either no oil or no gas fields are to be simulated, the coproduct ratios should be set to exactly zero (using the custom distribution).
  - c. The size of fields distribution in cell D1. If either no oil or no gas fields are to be simulated, the size of fields should be set to exactly zero (using the custom distribution).  
Follow the same procedure for the **Gas Calculations** worksheet.
9. Click on the **Run Preferences** button on the Crystal Ball toolbar or choose **Run Preferences...** from the **Run** menu.
  10. Set the number of iterations to the desired number in the **Trials** section of the dialog box.
  11. Set the windows to be minimized, if desired, in the **Speed** section of the dialog box.
  12. In the **Macros** section of the dialog box, set the **Eachstep\_VBA** macro to run before each iteration. Do this by typing the macro name in the **Before Recalculations** area using the format **'Emc2.xls'!Macros.Eachstep\_VBA** (with the appropriate filename from step 1 used in place of **Emc2.xls**).
  13. Depending on your version of Microsoft Excel, run the **Setup\_VBA** macro by one of the following two methods:
    - a. First choose **Macro...** from the **Tools** menu. Then choose **Setup\_VBA** from the list and click the **Run** button.
    - b. Select the **Macros** worksheet. Place the pointer anywhere in the **Setup\_VBA** macro and then press the green arrow (**Run Macro**) button on the Visual Basic toolbar.
  14. Run the simulation by one or the other of the following:
    - a. Click on the green **Start Simulation** button on the Crystal Ball toolbar.
    - b. Choose **Run** from the **Run** menu.
  15. After the simulations have finished running, open the forecast windows by one or the other of the following:
    - a. Click on the **Forecast Windows** button on the Crystal Ball toolbar and either click on **Open All Forecasts** or select some forecasts from the list and then click on **Open Selected Forecasts**.
    - b. Choose **Forecast Windows...** from the **Run** menu and either click on **Open All Forecasts** or select some forecasts from the list and then click on **Open Selected Forecasts**.
  16. Create a report (optional) by one or the other of the following:
    - a. Click on the **Create Report** button on the Crystal Ball toolbar.
    - b. Choose **Create Report...** from the **Run** menu.

## Notes

1. After any changes to either the maximum number of fields or to the field size distribution, the **Setup\_VBA** macro must be rerun.
2. Cell calculation should be set to automatic. This setting can be reached by choosing **Options...** from the **Tools** menu and then choosing the **Calculation** page.
3. No other workbooks should be open in Excel when either **Setup\_VBA** or the simulations are running; otherwise, Excel may not locate the correct macro.

## Directions for Use of Emc2

This program uses pre-set input distribution types.

1. Make a copy of the Emc2.xls workbook and rename it with the .xls suffix.
2. Start Microsoft Excel.
3. Open Crystal Ball, if it is not opened automatically.
4. Close any open workbooks, such as **Sheet1**.
5. Open the workbook copied in step 1.
6. Open the worksheet labeled **Identification** and fill in the identification information (optional). On this worksheet and others, input cells are colored yellow.
7. Open the worksheet labeled **Risk** and modify the risk factors if necessary.
8. Open the worksheet labeled **Input** and fill in the information on the oil and gas worksheets as necessary. Do not leave any of the input fields blank. The Emc2 program requires numbers in those fields, and the numbers must be ordered such that the median is not less than the minimum and the maximum is not less than the median. Fill in the following:
  - a. The minimum, median, and maximum numbers of oil and gas fields in rows 5 and 6. (If either no oil or no gas fields are to be simulated, place zeros for the minimum, median, and maximum numbers of fields of that type.)
  - b. The minimum, median, and maximum sizes of oil and gas fields in rows 11 and 12.
  - c. The minimum, median, and maximum values of the coproduct ratios in rows 18, 19, 22, and 23.
9. Click on the **Run Preferences** button on the Crystal Ball toolbar or choose **Run Preferences...** from the **Run** menu.
10. Set the number of iterations to the desired number in the **Trials** section of the dialog box.
11. Set the windows to be minimized, if desired, in the **Speed** section of the dialog box.
12. In the **Macros** section of the dialog box, set the

**Eachstep\_VBA** macro to run before each iteration. Do this by typing the macro name in the **Before Recalculations** area using the format '**Emc2.xls**'!**Macros.Eachstep\_VBA** (with the appropriate filename from step 1 used in place of **Emc2.xls**).

13. Run the **Setup\_VBA** macro by one or the other of the following:
  - a. Click on the **Run Setup** button on the **Input** worksheet.
  - b. Choose **Macro...** from the **Tools** menu. Choose **Setup\_VBA** from the list and click the **Run** button.
14. Run the simulation by one or the other of the following:
  - a. Click on the green **Start Simulation** button on the Crystal Ball toolbar.
  - b. Choose **Run** from the **Run** menu.
15. After the simulations have finished running, open the forecast windows by one or the other of the following:
  - a. Click on the **Forecast Windows** button on the Crystal Ball toolbar and either click on **Open All Forecasts** or select some forecasts from the list and then click on **Open Selected Forecasts**.
  - b. Choose **Forecast Windows...** from the **Run** menu and either click on **Open All Forecasts** or select some forecasts from the list and then click on **Open Selected Forecasts**.
16. Create a report (optional) by one or the other of the following:
  - a. Click on the **Create Report** button on the Crystal Ball toolbar.
  - b. Choose **Create Report...** from the **Run** menu.

## Notes

1. To rerun the simulation with different input, rerun the **Setup\_VBA** macro after making changes in the **Input** worksheet.
2. Cell calculation should be set to automatic. This setting can be reached by choosing **Options...** from the **Tools** menu and then choosing the **Calculation** page.
3. No other workbooks should be open in Excel when either **Setup\_VBA** or the simulations are running, otherwise Excel may not locate the correct macro.
4. If the minimum, median, and maximum values in a row are all the same, a point estimate is used for that variable.

## Software Availability

Crystal Ball is available from Decisioneering, Inc. of Denver, Colo.; phone 303-534-1515 or 1-800-289-2550; www.decisioneering.com.

Microsoft Excel is available from Microsoft Corporation of Redmond, Wash.; www.microsoft.com.



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