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A Primer On Computer Simulation of Hydrocarbon Reservoirs

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Powerful computers with the capacity to simultaneously solve vast numbers of equations have made possible many new analytic tools. One such tool is the computer simulator. A computer simulator is a complex mathematical model of an event or phenomenon that utilizes both data (observed facts) and opinion (where the facts are not known).[1]

With computer simulation, the modeler must identify a real-world reference system. He then constructs a mathematical model, which describes such reference system in terms of equations or relationships. Often, theoretical simplifications and assumptions must be used.[2] Once constructed, the model is run on a computer, and the results of the run are tested against observed facts. If the computed results conflict with, or do not account for, observed facts, the model is manipulated and rerun.[3] This process of running the model, comparing the results with observed facts, and then manipulating the model, is repeated until the modeler is satisfied that the model accounts for the observed facts with an acceptable degree of accuracy.[4] Once this is accomplished, the model may be used with a degree of confidence in drawing inferences about, and making predictions with respect to, the real-world reference system.[5]

While computer simulations can perform many functions, two are especially important. First, simulations can give an overview of a com-

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1. R. WEHMHOEFER, STATISTICS IN LITIGATION 142 (1985).
2. Note, *Computer Simulation and Gaming: An Interdisciplinary Survey with a View Toward Legal Application*, 24 STAN. L. REV. 712 (1972).
3. *See* Eastin, *The Use of Models in Litigation: Concise or Contrived?* 52 CHI.-KENT L. REV. 610, 612-15 (1976).
4. 2 D. BENDER, COMPUTER LAW § 4B.06, at 4B-30 (1984).
5. *See* Perma Research & Dev. v. Singer Co., 542 F.2d 111, 122 (2d Cir.) (Van Graafeiland, Cir. J., dissenting), *cert. denied*, 429 U.S. 987 (1976).

plex set of data. Put simply, a mass of data can be organized, synthesized and presented in a coherent fashion. Second, simulations can demonstrate possible relationships between variables.[6]

Given the important functions which computer simulations can perform, it is not surprising that expert testimony based upon simulations has been used in a wide variety of cases. Four cases illustrate this variety. First, in *Southern Pacific Communications Co. v. American Telephone & Telegraph Co.*,[7] plaintiff's expert witnesses presented a damages model based upon an imaginary company that might have been "but for" defendant's alleged antitrust violations. The modeled company, which provided extensive telecommunication services, came complete with a market share, the ability to begin construction with the correct lead time, and perfect knowledge about future demand and costs. Second, a much less complicated computer model was relied upon by an expert witness in *Ideker, Inc., v. Missouri State Highway Commission*,[8] in which plaintiff sought to recover costs incurred in hauling excess dirt from a construction project. The expert utilized a simulation to calculate haul cycles for different types of equipment. Third, in a number of cases accidents have been reconstructed by the use of models.[9] Finally, in *Sorensen v. Lower Niobrara Natural Resources District*,[10] expert witnesses based opinions upon computer simulations of aquifer properties in testifying about the effect of proposed water wells upon existing wells.

With use there is also the potential for abuse. As with other scientific evidence,[11] there is considerable potential for misleading a jury with computer simulations. An expert witness, armed with computer printouts and the concomitant explanatory charts and graphs, can give the appearance of scientific acceptability to his position even though the model underlying his testimony is fraught with incomplete data and unreasonable assumptions. For the lawyer, it is a formidable task to understand what it is this witness is purporting to do and cross-examine such witnesses in a manner intelligible to a jury.

This article considers the use in litigation of one type of model: computer simulations of hydrocarbon-bearing reservoirs. Such models can be

6. Eastin, *supra* note 3, at 612.

7. 556 F. Supp. 825, 1073-93 (D.D.C. 1983), *aff'd*, 740 F.2d 980 (D.C. Cir. 1984), *cert. denied*, 105 S. Ct. 1359 (1985).

8. 654 S.W.2d 617, 625 (Mo. Ct. App. 1983).

9. *See, e.g.*, Starr v. Campos, 134 Ariz. 254, 655 P.2d 794, 796-98 (Ct. App. 1982); Schaeffer v. General Motors Corp., 372 Mass. 171, 360 N.E.2d 1062, 1066-67 (1977). In each of these cases, the court expressed reservations as to the admissibility of expert testimony based upon computer simulations which purport to present models reconstructing accidents. It should be noted that these cases involve an unusual application of simulations; simulations are typically used to predict the future, not reconstruct the past.

10. 221 Neb. 180, 184, 376 N.W.2d 539, 543-44 (1985). With respect to water allocation problems, see Schaab, *Prior Appropriation, Impairment, Replacements, Models and Markets*, 23 NAT. RES. J. 25, 45-46 (1983), where the author states that "an accurate [computer] model can be substituted for the physical reality for all relevant judicial and administrative purposes."

11. 22 C. WRIGHT & K. GRAHAM, FEDERAL PRACTICE AND PROCEDURE: EVIDENCE § 5217, at 295 (1978 & Supp. 1986).

used in various types of oil and gas cases. For example, simulations can be used in cases concerning whether certain areas are in communication[12] or in disputes between operators as to the proper development of a field.[13]

In the first part of this article, reservoir simulation is described in detail. Specifically, the conceptual basis for the computer simulation of hydrocarbon reservoirs and the manner in which a model is constructed will be examined. The manipulation of the model, that is the "history matching process," is described. The first part of this article concludes with a general discussion of certain abuses of computer simulation.

The use of computer simulations in litigation raises many issues, a number of which are addressed in the second part of this article. Included is a discussion of the admissibility of expert testimony which is based upon a simulation of a reservoir. Also considered are discovery-related issues. The author hopes that the reader will gain a basic understanding as to what an expert witness is attempting to do when using a computer simulation of a hydrocarbon reservoir.

COMPUTER SIMULATION OF HYDROCARBON RESERVOIRS

Conceptual Basis

A hydrocarbon reservoir can be produced just once. If the optimal production method is not used, hydrocarbons which otherwise might be produced may remain forever in the ground. A computer simulation allows an operator to "produce" a field more than once.[14] After developing a sufficiently accurate model of a reservoir, the modeler can test various production methods. For example, the production rates, well spacing or the timing of drilling development wells can be varied. By testing a number of possible methods, the operator is better able to choose the production plan which will increase hydrocarbon recovery.[15]

Models have been used for quite some time. Indeed, the basic building block of computer simulation of hydrocarbon reservoirs, the "tank" model, has been used for decades.[16] As suggested by the name, the tank model views a reservoir as a container or tank. Graphically, the reservoir is shown as a cube or block. The tank is assumed to be homogeneous, or have uniform properties throughout. For example, the porosity[17] and permeability[18]

12. United States v. Standard Oil Co., 545 F.2d 624, 630 (9th Cir. 1976).

13. Majority of Working Interest Owners in Buck Draw Field Area v. Wyoming Oil & Gas Conservation Comm'n, 721 P.2d 1070 (Wyo. 1986).

14. H. CRICHLOW, MODERN RESERVOIR ENGINEERING—A SIMULATION APPROACH 18 (1977).

15. For an excellent case study, see C. Van Kirk, *Jormar-Reservoir Performance and Numerical Simulation of a Classic Denver-Julesburg Basin Oil Field*, a paper prepared for the Rocky Mountain Regional Meeting of the Society of Petroleum Engineers of AIME held in May 1976, Paper No. SPE 5890 (1976) (on file at the Land & Water Law Review office).

16. Odeh, *Reservoir Simulation—What Is It?* J. PETROLEUM TECH. 1383 (Nov. 1969); G. THOMAS, PRINCIPLES OF HYDROCARBON RESERVOIR SIMULATION 3 (2d ed. 1982).

17. Porosity is the total volume of open spaces, pores or voids in a rock or sediment. It is expressed as a percentage. H. LEVIN, CONTEMPORARY PHYSICAL GEOLOGY 345 (2d ed. 1986).

18. Permeability refers to the relative ease with which a fluid moves through porous media. *Id.* at 347.

values do not vary from point to point in the reservoir. Furthermore, pressure is the same throughout the reservoir, and a change in pressure in one point of the reservoir is instantaneously reflected at all other points in the reservoir. Finally, the reservoir is said to have sealed boundaries which do not allow fluids to naturally flow in or out of it.[19]

Once the reservoir is so described, the volumes of oil, gas, and water in-place can be calculated. Also, the cumulative effect of production can be calculated by use of the Material Balance Equation, commonly referred to as the "MBE." A simple expression of the MBE for oil is cumulative net oil withdrawal equals the oil originally in-place minus the oil remaining in-place.[20]

The tank model, while sometimes useful, has serious drawbacks. First, reservoirs typically are not homogeneous. There can be considerable variation in the rock and fluid properties. Second, a reservoir's boundaries are rarely sealed. A reservoir, for example, may be connected to a regional aquifer. As the reservoir is produced, its pressure will decrease relative to the aquifer. This will create a pressure differential which could cause water to enter the reservoir. Third, the tank model also assumes that any change in reservoir pressure will be reflected instantaneously throughout the reservoir. In reality, if a reservoir covers a square mile, production from a well in the north end of the reservoir will create a pressure drop there that will not be immediately apparent at the south end. By failing to recognize pressure differentials, the tank model does not take into account fluid flow in the reservoir.[21]

To overcome these deficiencies, the modeler can divide the reservoir into two or more tanks or cells and allow fluids to flow between the cells. Each cell can be given different rock and fluid properties. In this manner, the heterogeneous nature of the reservoir can be more accurately reflected in the model. The use of multiple cells also allows one to discard the simple tank model concept of pressure uniformity throughout the reservoir. By allowing for multiple pressure levels, fluid flow within a reservoir can be evaluated.[22]

Fluid flow within the reservoir is calculated by the use of Darcy's law, which was formulated in 1856.[23] Darcy's law provides that the velocity of a fluid in a porous medium, for example, reservoir rock, is directly proportional to the pressure gradient and inversely proportional to the fluid viscosity.[24]

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19. Odeh, *supra* note 16.
20. *Id.*
21. G. THOMAS, *supra* note 16, 3-4.
22. Odeh, *supra* note 16, at 1383-84.
23. B. CRAFT & M. HAWKINS, APPLIED PETROLEUM RESERVOIR ENGINEERING 259 (1959).
24. Permeability of rock is expressed in darcy units. A rock of one darcy permeability is one in which a fluid of one centipoise viscosity will move at a velocity of one centimeter per second under a pressure gradient of one atmosphere per centimeter. Reservoir rocks with one darcy permeability are above average. Thus, permeabilities are commonly expressed in units one-thousandth as large, the millidarcy or 0.001 darcy. *Id.* at 260.

The simple tank model, as described above, is a zero-dimensional model because reservoir properties and pressure are uniform throughout. If the reservoir is broken down into two or more cells in a single row and fluids are permitted to flow from one cell to another, a one-dimensional model is created. By breaking down the reservoir into numerous cells in a single plane and permitting horizontal flow through all common faces, a two-dimensional model is created. A three-dimensional model is created when cells are also stacked on top of a two-dimensional model and vertical fluid flow is added to the model.[25]

Even if the model has only a handful of cells, it can be a most time-consuming task to compute the MBE within each cell and the fluid flow among the cells. Computers can perform this task with great speed. As Odeh has observed:

> Since a simulator can consist of hundreds of cells, keeping account of the MBE for each cell is a formidable bookkeeping operation ideally suited to digital computation. But we emphasize once again that the principles and equations used in reservoir simulation are not new. They only appear so because of the complexity of the bookkeeping.[26]

Setting Up the Simulation

In setting up a model, the first consideration is the type of physical system, that is, a reservoir, with which one is dealing.[27] Reservoirs are typically classified by the phase or phases (oil, gas, or oil and gas) present in the reservoir at the time of discovery and then by the energy systems which contribute to production.[28] An example of a simple reservoir is a volumetric gas reservoir. Such a reservoir is a gas accumulation that experiences no water influx and the gas does not change phases (from gas to liquid) as production decreases the reservoir's pressure. Slightly more complex is an oil accumulation in contact with an aquifer. Production of such fields often leads to water encroachment. A more complex reservoir is one with a gas cap and an oil ring which is in communication with a regional aquifer. By producing such a field and thereby reducing its pressure, one must contend with gas coming out of solution from the oil (solution gas) and water encroaching into the reservoir.[29] Retrograde condensate gas reservoirs are among the most difficult to operate. These reservoirs can experience significant changes from the gas to the liquid phase as they are produced.[30]

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25. H. CRICHLOW, *supra* note 14, at 239-45; *see also* Staggs & Herbeck, *Reservoir Simulation Models—An Engineering Overview*, J. PETROLEUM TECH. 1428, 1429-30 (Dec. 1971).
26. Odeh, *supra* note 16, at 1384.
27. H. CRICHLOW, *supra* note 14, at 238.
28. Bass, *Reservoir Engineering* in ROCKY MTN. MIN. L. FOUND., BASIC OIL AND GAS TECHNOLOGY FOR LAWYERS AND LANDMEN 4-7 to 4-9 (1979) (Paper No. 4).
29. A gas cap is the portion of a reservoir occupied by free gas rather than solution gas. Because it is less dense than oil, gas occupies the highest portion of the reservoir. Oil is less dense than water. Thus, the oil will lie on top of the water. *See* 8 H. WILLIAMS & C. MEYERS, OIL AND GAS LAW 355 (1984).
30. Bass, *supra* note 28, at 4-8.

A number of different computer simulators have been developed for the various types of reservoirs. Gas simulators are available to handle gas volumetric reservoirs. The most commonly used and basic type of simulator is the "black oil simulator." This type is used to simulate reservoirs in which oil (regardless of its color), gas and water are present. Perhaps the most complex simulator is the compositional model, which is used in simulating the natural depletion of either a volatile oil or a retrograde gas condensate reservoir. These less-commonly used compositional models, which are expensive to develop and run, can account for changes in the hydrocarbon components, for example, methane, ethane, butane, propane, and the heavier ends. In addition, simulators have been developed to handle special production situations such as water flooding.[31]

Once the appropriate type of simulator is selected, the modeler chooses the dimensions and grid size. The number of dimensions is largely dependent upon practical considerations such as the degree of accuracy required, the level of data available, the particular facet of the reservoir which is being studied, and the money and time available.[32] Set forth below are examples of one-dimensional, two-dimensional or three-dimensional models and their appropriate uses.

A one-dimensional model is appropriate when studying a simple linear segment of a reservoir. Such a model can be constructed by stacking the cells vertically, horizontally or in a curvilinear manner. A one-dimensional model can be most helpful in studying gross fluid movement and pressure distribution in a reservoir. In addition, a radial one-dimensional model is used to study wellbore effects. A two-dimensional model can be best applied to problems concerning areal changes. Because such models can accommodate variations in reservoir properties, they can be used to simulate an entire reservoir system with many wells. These models can handle areal effects of water flooding and gas injection. The areal coverage of two-dimensional models also makes them a potential tool in analyzing lease line drainage problems.[33] Smaller two-dimensional models with radial grid patterns can be used to model production rates in analyzing the deliverability of gas wells.[34]

Three-dimensional models are used when more accuracy concerning both the horizontal and vertical behavior of the reservoir must be studied. For example, if a reservoir contains a gas cap and an oil ring and the trap-

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31. G. THOMAS, *supra* note 16, at 6-7. Water flooding is a secondary recovery method "in which water is injected into an oil reservoir for the purpose of washing the oil out of the reservoir rock and into the base of the producing well." 8 H. WILLIAMS & C. MEYERS, *supra* note 29, at 959.

32. Staggs & Herbeck, *supra* note 25, at 1430.

33. H. CRICHLOW, *supra* note 14, at 291-94; *see also* Coats, *Use and Misuse of Reservoir Simulation Models*, J. PETROLEUM TECH. 1391, 1395-96 (Nov. 1969). Coats' article is often referred to in technical papers concerning reservoir simulations.

34. Staggs & Herbeck, *supra* note 25, at 1430; *see also* H. CRICHLOW, *supra* note 14, at 239-43.

ping mechanism is an anticline[35] with great structural relief, such a model could be used to study the possible movement of oil up-structure, where it may not be recoverable, with the production of the gas cap. A three-dimensional model may be useful if there are significant variations in rock or fluid properties. For example, because of the manner in which the rocks were deposited, the rock may be more (or less) permeable at the top than at the bottom of the structure. A three-dimensional model can also be employed to simulate a reservoir which contains impermeable beds interspersed throughout the reservoir rock. Such beds, if large enough, can restrict fluid flow.[36]

The same considerations which determine a model's dimensions also determine the grid size. The grid's areal extent varies from model to model.[37] Moreover, more than one cell size is typically used in a grid. The grid is smaller or more refined at the areas of interest (such as around wells) to allow for better definition. Also, areas of increased heterogeneity may require a more refined grid.[38] Larger cells can be used in those portions of the model less important to the study. Because grid size can influence the accuracy of the model, it is sometimes necessary to run sensitivity studies to determine the effect the cell sizes have on the results. Sensitivity studies are commonly used in cross-sectional problems to determine the number of layers to use in a model.[39]

The next step in constructing the model is to ascribe data to each cell. This is one of the most critical steps in the model's development. As discussed previously, the purpose of a reservoir simulation is to develop a model which accurately accounts for observed data so it may be used to predict the reservoir's behavior. If the model is based upon incomplete or inconsistent data, the results will be meaningless, and the model will have no validity in predicting the performance of the reservoir.

The following types of data are typically ascribed to each cell within a model: (a) rock properties; (b) fluid properties; (c) production data; (d) flow data; and (e) mechanical or operational data.[40] The rock properties, which include permeability, relative permeabilities,[41] porosity, formation

35. An anticline is "an upfold or arch of stratified rock in which the beds or layers bend downward in opposite directions from the crest or axis of the fold." United States v. Standard Oil Co., 618 F.2d 511, 514 n.3 (9th Cir. 1980) (citing WEBSTER'S NEW INTERNATIONAL DICTIONARY 94 (3d ed. 1971)).

36. H. CRICHLOW, *supra* note 14, at 243-44.

37. For example, Van Kirk, *supra* note 15, used cells that ranged in size from as little as four acres up to 80 acres, while Staggs and Herbeck, *supra* note 25, at 1431, reported good results with 160-acre grid cells.

38. H. CRICHLOW, *supra* note 14, at 79.

39. K. AZIZ & A. SETTARI, PETROLEUM RESERVOIR SIMULATION 417 (1979). This text is highly respected. *See* Aronofsky, Cull, Cox & Gaffney, *Use and Abuse of Reservoir Simulation - 1: Pressure Often Exists to Perform Expensive Reservoir Simulation,* OIL & GAS J. 79, 81 (Nov. 5, 1984) [hereinafter Aronofsky, *Part I*].

40. H. CRICHLOW, *supra* note 14, at 160.

41. Relative permeability is the ratio of effective permeability to absolute permeability. Absolute permeability is the permeability of a fluid when the pore space is at 100 percent saturation. The effective permeability is the permeability of a rock to a particular fluid when such fluid has a pore saturation of less than 100 percent. B. CRAFT & M. HAWKINS, *supra* note 23, at 355-56.

elevations, and formation thickness, are usually based upon a geological study of the reservoir, which study precedes the simulation work.[42] Formation elevations are derived from structure contour maps which show, through the use of contours connecting points of equal elevation, the elevation of either the top or the bottom of a given formation relative to sea level. Such elevations are commonly "picked" from electric logs[43] or determined by viewing cores. The rock thicknesses are determined by reference to isopach maps. These maps use lines connecting points in a reservoir with equal rock thickness. Similarly, isopermeability and isoporosity maps are prepared.

The value for each rock property is specified for each cell. This may be accomplished by placing a mylar copy of the grid over the contour map. The appropriate value for a cell is determined by looking at the corresponding area on the contour map and writing the value in the cell on the grid. If more than one contour line crosses through a cell, an average value must be used because the simulator treats each value as being uniformly distributed throughout a given cell.[44] From the mylar grid, the values can be easily read and entered into the computer.

Fluid saturations must be specified for each cell. Fluid saturation is that percentage of the rock pore space occupied by a particular fluid.[45] These values can be determined by reference to net oil or net gas isopach maps or the fluid contacts (gas-oil, gas-water or oil-water). Fluid contacts are determined in turn by using wireline logs, drill-stem tests or cores. Pressure and reservoir temperature data are also included in the cells.

A second broad category of data included in each cell is fluid data or properties. Such data are commonly referred to as "pressure-volume-temperature" or "PVT" data because these properties are determined in a laboratory as a function of pressure and temperature by testing a fluid sample taken from the reservoir. This data includes specific gravity and viscosity.[46] Another type of PVT data is the formation volume factor which is based upon the relationship between surface volumes and reservoir volumes of fluids.[47] For example, the gas formation volume factor relates a volume of gas in the reservoir to the volume of such gas at the surface under standard conditions.[48] Another important type of PVT data is the

42. Harris, *The Role of Geology in Reservoir Simulation Studies*, J. PETROLEUM TECH. 625 (May 1975); *see also* Poston & Gross, *Numerical Simulation of Sandsone Reservoir Models*, SPE RESERVOIR ENGINEERING 423 (July 1986) (on file at the Land & Water Law Review Office).

43. For a useful discussion of electric logs, see Hilchie, *Well Logging*, in ROCKY MTN. MIN. L. FOUND., BASIC OIL AND GAS TECHNOLOGY FOR LAWYERS AND LANDMEN (1979) (Paper No. 3).

44. H. CRICHLOW, *supra* note 14, at 193-95.

45. F. COLE, RESERVOIR ENGINEERING MANUAL 5 (2d ed. 1969).

46. Specific gravity is defined as the ratio of the density of a gas at a given temperature and pressure to the density of air at the same temperature and pressure. B. CRAFT & M. HAWKINS, *supra* note 23, at 16. Viscosity refers to the ability of a fluid to flow. 8 H. WILLIAMS & C. MEYERS, *supra* note 29, at 949.

47. Bass, *supra* note 28, at 4-9 to 4-10.

48. B. CRAFT & M. HAWKINS, *supra* note 23, at 101-05.

solution gas-oil ratio. This ratio expresses the volume of gas released from the oil as the pressure in the reservoir decreases.

The third general category included in a model is historical oil, gas, and water production data. Problems may arise with the accuracy of the gas and water production figures. With respect to gas, there may be difficulties with the field meters. For example, because of poor maintenance, the meter may not accurately measure the gas produced. Also, gas may be unaccounted for because the gas used to fuel surface equipment or to satisfy "free gas" clauses often is not metered. Finally, with respect to older fields developed before rules governing the flaring of gas became more strict, it may be difficult to ascertain the volume of gas which has been flared. With respect to water, production records are normally not maintained in the same manner as oil production records. On production reports, water production is usually estimated by referring to oil production. For example, for every barrel of oil produced a certain number of barrels of water are also produced.

The fourth general type of data included in the cells which contain wells is the productivity data. This is required by the simulator to compute the production capability of the wells.[49] One type of flow data is the productivity index, which is the ratio of the rate of production (in stock-tank barrels per day) to the pressure drawdown at the midpoint of the formation.[50]

The final type of data includes mechanical or operational data of the wells. Included here are the casing size, tubing size, location of wellbore perforations, and lift capability of the wells.[51] This type of data is especially important in models which examine a single well.

A final point must be noted in constructing a model. Specifically, the cells on the model's perimeter, the boundary cells, require special consideration. If there is little or no interest in the outside limits of the reservoir, the permeability values for the outside edges of the boundary cells can be set at zero, thus precluding flow into and out of the model.[52] However, if there are conditions of interest outside the principal reservoir under study, such as an aquifer or other fields which may be in communication with the principal reservoir, the model must account for flow across the boundary cells. This may be accomplished by adding a "source term" to the boundary cells or by increasing the size of the model to include the additional area.[53] It is not uncommon to use mixed boundary conditions in models. For example, if there is water influx on the east side of the reservoir and a sealing fault on the west side, flow cells will be used on the former side and no-flow cells will be used on the latter.[54]

49. H. CRICHLOW, *supra* note 14, at 204.

50. B. CRAFT & M. HAWKINS, *supra* note 23, at 289-90.

51. See Bergeson, *Basic Operational Engineering* in ROCKY MTN. MIN. L. FOUND., BASIC OIL AND GAS TECHNOLOGY FOR LAWYERS AND LANDMEN (1979) (Paper No. 2), for a general discussion of wellbore mechanics.

52. D. PEACEMAN, FUNDAMENTALS OF NUMERICAL RESERVOIR SIMULATION 8-9 (1977).

53. H. CRICHLOW, *supra* note 14, at 78-9.

54. G. THOMAS, *supra* note 16, at 82.

The reservoir as described above is combined with differential equations describing the physical processes forming a mathematical model of the reservoir. These computer programs constitute computer models which are referred to as reservoir simulators.[55]

History Matching

Once a computer model is constructed, it is run and the computed results are compared against observed facts. The model is modified and rerun if the computed results are not sufficiently close to the observed facts, the model is modified and rerun. This process, by which the validity of the simulation is established, is repeated until there is satisfactory agreement between the model's computed results and the observed facts. This is referred to as "history matching."[56]

In the history matching process, the computer is programmed to calculate or solve for a "match parameter" over a series of "time steps." The match parameter is usually one of the following: (a) observed average pressures; (b) observed flow rates; (c) observed water-oil ratios; or (d) observed gas-oil ratios.[57] A match parameter must be selected for which one has sufficient observed data. For example, assume that the North field (a hypothetical field), an oil field with a weak water drive, was discovered in 1970. When the discovery well and each of the seven development wells (drilled between 1971 and 1974) were completed, bottom-hole pressures were obtained. However, from 1974 through early 1986 pressures were not obtained on a field-wide basis; rather, sometimes when a well was worked over, a bottom-hole pressure was obtained. In 1986, the operator conducted a field-wide pressure survey as part of its data gathering for a proposed water flood simulation study. In this simulation, average pressure is a poor match parameter because of the twelve-year gap in the field-wide pressure data. It would be far more sensible to use the water-oil ratio as the match parameter because it is likely that monthly production data is available.

The various points in time at which the match parameters are calculated are called time steps. Using the North field example, if the operator selects the water-oil ratio as the match parameter and uses time steps covering a calendar-year, the simulator will calculate the water-oil ratio as of the end of each year. In other words, with calendar-year time steps the operator will not be able to obtain the water-oil ratio on any given day within a particular year other than December 31.

There is considerable flexibility in selecting the time steps to be used in simulation.[58] If short time steps are used, however, computing time is

55. *Id.* at 4-5; K. AZIZ & A. SETTARI, *supra* note 39, at 2-3.

56. *Id.* at 8-9.

57. K. AZIZ & A. SETTARI, *supra* note 39, at 418-19. The water-oil ratio is the quotient of all of the water produced from the reservoir and all of the oil produced therefrom. Similarly, the gas-oil ratio is the quotient of all of the gas produced from the reservoir and of all of the oil produced. B. CRAFT & M. HAWKINS, *supra* note 23, at 112.

58. Most computer programs which may be purchased include instructions concerning the selection of time steps. H. CRICHLOW, *supra* note 14, at 286.

increased. On the other hand, if the time steps are too long, there may be undesirable oscillations in the fluid saturations and pressures within cells containing wells.[59]

Given the lack of complete data for any reservoir, it is highly unlikely that a satisfactory history match will be obtained with initial runs of the model. Therefore, the model must be modified. Because each reservoir is unique, there are no specific rules to be followed in adjusting reservoir parameters to obtain a history match. Adjustments are simply made on a trial-and-error basis.[60] Moreover, the modeler must rely on experience and intuition in determining the limit to which a given parameter can be properly adjusted.

While there are no specific rules, there is a general rule which is followed in history matching: the modeler should manipulate the parameters which have the largest uncertainty and the largest influence on the solution.[61] Clearly, it defeats the purpose of history matching if the modeler were to modify known, reliable data originally entered into the reservoir simulator simply to force a history match.[62] Likewise, it is inefficient if continual modifications are made to a reservoir parameter which, after substantial variation in the initial runs, is shown to have little or no bearing on the computed results.

Using the North field example again, the following illustrates some steps that might obtain an acceptable history match. Assume the simulator stopped running in the 1983 time step because it had produced all of the recoverable oil-in-place by that point. Obviously, the simulator is defective because it does not account for the field's production of oil through 1986. For the modeler to obtain a history match, the volume of oil originally in-place in 1970 (the initial condition of the field) might be increased. Such an increase may be obtained by increasing the pore space in the reservoir. Also, the oil saturation may be increased, the water saturation decreased, or both. Consideration may also be given to lowering the water-oil contact. All of these steps, taken individually or collectively, increases the original oil-in-place in the model. In making such changes, however, the modeler must avoid adversely affecting the model in other ways.[63]

Conversely, if the North field model produces too much oil, the modeler should take steps opposite to those suggested above. In addition, the

59. *Id.*
60. K. AZIZ & A. SETTARI, *supra* note 39, at 419.
61. *Id.*
62. Staggs & Herbeck, *supra* note 25, at 1428.
63. H. CRICHLOW, *supra* note 14, at 251. If, after numerous runs, the observed production rates remain higher than the production rates calculated by the simulator, this would indicate there may be an outside energy source influencing the productive area of the reservoir defined in the model. Such energy source could be either a previously unrecognized water drive or the presence of additional productive zones. In this situation, Crichlow suggests that "the presence of communicating zones should be looked into as the last resort and the engineer should not flagrantly increase the productive acreage unless the evidence is overpowering." *Id.* at 260.

modeler might also decrease the model's permeability values to slow the flow of oil. It may also be necessary to manipulate the productivity data for the wells.

Manipulations, such as those discussed above, will be made and the model rerun until an acceptable history match is achieved. Unfortunately, it is quite difficult to objectively define what constitutes an "acceptable history match."[64] Indeed, determining what is an acceptable history match is somewhat subjective. One author, for example, defines a good history match as "that set of rock, fluid, and relative permeability data which acting together produce the *most reasonable results* at a given point in time."[65] Other authors simply state that a history match is acceptable if the calculated results are "close" to the observed data;[66] they do not, however, indicate how "close" the match must be.

Ultimately, the acceptability of a history match depends on the modeler's goal. If, for example, the modeler intends to use a coarse model simply to gain insight into a problem, it is not necessary for the calculated match parameter to exactly equal the observed data. A plot of the calculated match parameters which generally parallel the observed data may constitute an acceptable history match. On the other hand, a modeler who uses a large three-dimensional model to determine the optimum method of producing a large oil field may not be satisfied with the history match until the calculated results and observed data substantially agree.

Once the history match is acceptable, the modeler has validated the model and may use it to make predictions. The modeler can predict simply by allowing the model to run a number of time steps beyond the end of the historical period used in the history matching process without modifying the manner in which the reservoir is produced. The modeler could also experiment with different means of producing the reservoir. As mentioned earlier, these experiments may entail varying production rates, well spacing, or the number and location of additional developmental wells. For specialized problems, such as water flood models, different injection and withdrawal schemes may be tried. The goal of these experiments is to determine which production method optimizes hydrocarbon recoveries.[67]

It should be noted that the validity of the predictions made by a simulator decreases as one runs the model farther beyond the historical period.[68] To reduce this problem, it is sometimes advisable to update a model study and attempt a new history match.

64. Aronofsky, Cull, Cox & Gaffney, *Use and Abuse of Reservoir Simulation - 2: Why Simulation Studies Can Be Good or Bad*, OIL & GAS J. 109, 110 (Nov. 19, 1984) [hereinafter Aronofsky, *Part II*].
65. H. CRICHLOW, *supra* note 14, at 249 (emphasis supplied).
66. K. AZIZ & A. SETTARI, *supra* note 39, at 418.
67. G. THOMAS, *supra* note 16, at 9.
68. K. AZIZ & A. SETTARI, *supra* note 39, at 420.

Misuse of Reservoir Simulation

A reservoir simulator is simply a tool.[69] Like all other tools, it can be misused. Crichlow has noted:

> Some people's concept of simulation borders on the incredible: the simulator is a black box of unknowns which miraculously produces results that are in some way sacred, numbers that are infallible to all their significant digits. This is the blue-sky approach to simulation.[70]

Three of the more prevalent misuses of reservoir simulation are noted below.

Perhaps the greatest misuse of reservoir simulation is "overkill," that is, using a model that is too sophisticated and complex for the problem under consideration.[71] As a general rule, a modeler should select the least complicated model and grossest reservoir description that will allow the desired estimation of reservoir performance.[72] Indeed, at the outset the engineer must consider whether a simulation of a reservoir is even necessary. If it is determined that a model, rather than conventional reservior studies, is needed, the fewest dimensions and cells possible should be used.[73]

A second misuse of reservoir simulation, closely related to the first, is construction of a model without regard to cost. The development of a model can be expensive in terms of both time and money. One may simulate all possible field development plans in connection with the entire range of assumptions concerning the description of the reservoir if one has the wherewithall to do so.[74] The efficacy of such testing is doubtful at best.

The third prevalent misuse of reservoir simulation is the construction of models without adequate data.[75] The quality of the history match is a function of the quality of the ascribed in-put data. A history match (using the term rather loosely) may always be forced by simply "faking-in" critical, unknown data.[76] By doing so, all the modeler will have accomplished is to demonstrate that, with enough patience, one can force a computer to calculate the desired results. However, as to developing a tool which can be used with confidence to predict the performance of a reservoir, the modeler will have completely failed.

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69. Aronofsky, Cull, Cox & Gaffney, *Use and Abuse of Reservoir Simulation - 3: Common Pitfalls in Reservoir Simulation*, OIL & GAS J. 116, 118 (Dec. 3, 1984).

70. H. CRICHLOW, *supra* note 14, at 1-2.

71. Aronofsky, *Part I*, *supra* note 39, at 81; Coats, *supra* note 44, at 1396; H. CRICHLOW, *supra* note 14, at 237; Staggs & Herbeck, *supra* note 25, at 1429.

72. Coats, *supra* note 33, at 1396; Staggs & Herbeck, *supra* note 25, at 1436.

73. K. AZIZ & A. SETTARI, *supra* note 39, at 4.

74. Aronofsky, *Part I*, *supra* note 39, at 81.

75. Coats, *supra* note 33, at 1396-97; Staggs & Herbeck, *supra* note 25, at 1436.

76. Staggs & Herbeck, *supra* note 25, at 1434. See also Aronofsky, *Part I*, *supra* note 39, at 82, where reference is made to modelers who flog simulators to achieve history matches by the "brutal adaption" of data.

SELECTED LEGAL PROBLEMS

This part of the article discusses two subjects arising from the use of reservoir simulators as the basis for expert testimony. The first subject involves the admissibility of such testimony when based upon a properly constructed model. The second subject concerns discovery and the types of documentation that one would expect to discover.

Admissibility of Testimony

It is common practice for experts outside of the courtroom to rely upon the reports, notes, observations, data or computer printouts prepared by others in formulating an opinion. However, at trial such documents may be inadmissible as hearsay. Formerly, expert testimony had to rely exclusively upon the evidence in the case. If no testimony was presented at trial, reflecting the substance of such documents, it could have been argued that expert testimony based solely upon a review of the documents was inadmissible.[77]

Rule 703 of the Federal Rules of Evidence removes this argument.[78] It provides:

> The facts or data in the particular case upon which an expert bases an opinion or inference may be those perceived by or made known to him at or before the hearing. If of a type reasonably relied upon by experts in the particular field in forming opinions or inferences upon the subject, the facts or data need not be admissible in evidence.[79]

The proper focus, thus, is upon whether the data underlying the expert's opinion are of a type reasonably relied upon in his field of expertise.[80] To focus upon the admissibility of the underlying data itself would miss the point.[81] Rule 703 brings judicial practice in line with the common practice of experts outside the courtroom.[82]

The word "reasonable" in Rule 703 is interpreted by two leading commentors as being synonymous with "customarily."[83] Accordingly, the legal issue becomes whether experts in the field customarily rely upon the material in performing their work.[84] The court must determine whether this test has been met. However, if the witness is qualified and a technical field is involved, the court should give considerable weight to the testimony of the expert as to whether the data underlying the opinion is adequate.[85]

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77. Younger, *Computer Printouts in Evidence: Ten Objections and How to Overcome Them*, 2 LITIGATION 28, 30 (Fall 1975) (erroneously referring to FED. R. EVID. 704).
78. 3 J. WEINSTEIN & M. BERGER, WEINSTEIN'S EVIDENCE ¶ 703[03] (1985).
79. FED. R. EVID. 703.
80. J. WEINSTEIN & M. BERGER, *supra* note 78, at 703-17.
81. D. LOUISELL & C. MUELLER, FEDERAL EVIDENCE § 389, at 661 (2d ed. 1979).
82. M. GRAHAM, HANDBOOK OF FEDERAL EVIDENCE § 703.1, at 622 (1986).
83. J. WEINSTEIN & M. BERGER, *supra* note 78, at 703-16; Younger, *supra* note 77, at 30.
84. J. WEINSTEIN & M. BERGER, *supra* note 78, at 703-16 to -17.
85. *Id.* at 703-16; *see also* D. LOUISELL & C. MUELLER, *supra* note 80, at 661-63.

There can be no doubt that expert testimony based upon the specific type of computer simulation under consideration here, reservoir simulation, is admissible under Rule 703.[86] Reservoir simulators have been in use since 1955.[87] One of the leading experts in the field wrote in 1977 that "[o]ver the past decade, numerical reservoir simulation has gained wide acceptance throughout the petroleum industry."[88] Two others noted as early as 1971 that reservoir simulation was then passing into "everyday use" by reservoir engineers.[89] Clearly, reservoir simulators are customarily used in the petroleum industry as a tool to assist in making reservoir management decisions.

However, it could be argued under Rule 703 that, if the reservoir simulation underlying the expert's proposed testimony is not properly conducted, such testimony should not be admitted. This argument presumes that an expert in petroleum engineering would not reasonably rely upon an invalid or improper simulator in formulating an opinion. Case law supports this argument.[90]

Given that the modeler has wide latitude in constructing the simulator and in manipulating the data and because there is no defined standard as to what constitutes an acceptable history match, it will be difficult for a court to conclude that a model is so unreliable that an expert may not base his opinion on it, except in blatant cases. In the typical case, the issue thus becomes not whether this expert testimony is admissible, but how much weight the trier of fact should give to expert testimony based upon a reservoir simulator. This, in turn, requires effective cross-examination to demonstrate any improper actions in the construction or manipulation of the underlying simulator.

Discovery Matters

Because expert testimony based upon a properly conducted reservoir simulation is admissible, discovery relating to reservoir simulation must be considered.[91] Preliminarily two points must be addressed. First, as indicated above, there is considerable potential for misuse in reservoir simulation.[92] A modeler so inclined may slant or tilt the simulator in such

86. Those commentators who have generally addressed the issue have concluded that Rule 703 allows for the admission of expert testimony based upon a computer simulation. *See* Bernacchi & Johnston, *Trial Objections to Computer-Based Evidence and Methods of Overcoming Them*, in THE USE OF COMPUTERS IN LITIGATION 341, 367-68 (J. Young, M. Kris & H. Trainor eds. 1979); Jenkins, *Computer-Generated Evidence Specially Prepared for Use at Trial*, 52 CHI.-KENT L. REV. 600, 607-08 (1976).

87. Aronofsky, Cox & Lane, *Reservoir Simulation Moves into Third Generation*, OIL & GAS J. 75 (Nov. 5, 1985).

88. D. PEACEMAN, *supra* note 52, at 2.

89. Staggs & Herbeck, *supra* note 25, at 1428.

90. *See, e.g.*, Soden v. Freightliner Corp., 714 F.2d 498, 502-07 (5th Cir. 1983); Zenith Radio Corp. v. Matsushita Elec. Indus. Co., Ltd., 505 F. Supp 1313, 1329-30 (E.D. Pa. 1981). Neither case involved a computer simulation or petroleum engineering.

91. *See generally* Note, *Computer Discovery in Federal Litigation: Playing By the Rules*, 69 GEO. L.J. 1465 (1981).

92. Indeed, the potential for misuse exists with respect to all forms of computer simulation. See Sprowl, *Evaluating the Credibility of Computer-Generated Evidence*, 52 CHI.-KENT

a manner that the simulator will produce only the results desired by the modeler. The simulator may be infected by the manner in which the underlying programs are written, by the data used, by model manipulation, or by a combination of these. In turn, expert testimony based upon a misuse of a reservoir simulation will mislead the trier of fact, rather than assist as required by the Federal Rules of Evidence.[93] Only through complete discovery of all aspects of a party's simulation work can the potential for misuse be avoided.

Those authorities which have considered the issue generally agree that complete discovery is permissible against the proponent of expert testimony based upon a computer simulation. In *City of Cleveland v. Cleveland Electric Illuminating Co.*,[94] plaintiffs delivered written reports by expert witnesses which were based on computer simulations. By a motion to compel, defendant requested discovery of the experts' data and programs which were utilized in formulating their opinions. Defendant argued that the input data and assumptions used in the simulations could not be deduced from the reports, thus making it impossible for defendant to adequately prepare for cross-examination of the experts or to determine even if cross-examination was warranted.[95] After reviewing the precedents, most of which were criminal cases, the court granted the defendant's motion. It held:

> where, as here, the expert reports are predicated upon complex data, calculations and computer simulations which are neither discernible nor deducible from the written reports themselves, disclosure thereof is essential to the facilitation of "effective and efficient examination of these experts at trial . . . ."[96]

Similarly, in *Pearl Brewing Co. v. Jos. Schlitz Brewing Co.*,[97] one party proposed to use expert testimony based upon an econometric model, dubbed the "Texas Beer Market Model," constructed to simulate various market conditions. In response to a motion to compel,[98] the court ordered the proponent of the Model to make available the documentation relating to the model's programming for the other party's inspection and copying. The court also allowed the movant to depose the computer experts who wrote the program even though these experts were not expected to be called as witnesses at trial.[99]

L. Rev. 547, 565 (1976), where the author notes that "simulations or models are almost always simplified representations, and they can prejudice either party by making the other party's position appear more favorable than it actually is."

93. FED. R. EVID. 702.
94. 538 F. Supp. 1257 (N.D. Ohio 1981).
95. *Id.* at 1266.
96. *Id.* at 1267.
97. 415 F. Supp. 1122, 1134-41 (S.D. Tex. 1976).
98. In addition to arguments similar to those made by the defendant in *City of Cleveland*, the discovering party contended that denial of access to all of the documentation it requested would subject it "to expend needlessly many hours trying to resolve the meaning" of the codes used in the Model's programs. *Id.* at 1134.
99. *Id.* at 1140-41. This case also contains a thorough analysis of the circumstances under which discovery can be obtained from "non-trial" experts. *Id.* at 1135-41.

Finally, Professors Wright and Miller have recommended the following:

> In order to prepare to defend against the conclusions that are said to flow from these efforts [computer studies or simulations], the discovering party not only must be given access to the data that represents the computer's "work product," but he also must see the data put into the computer, the programs used to manipulate the data and produce the conclusions, and the theory or logic employed by those who planned and executed the experiment. This often will have to be accomplished under the provision in Rule 26(b)(4) [of the Federal Rules of Civil Procedure] relating to experts.[100]

The second preliminary consideration follows from the first. Not only must complete access be afforded to the proponent's documents and expert witnesses regarding the reservoir simulation, such access must be at an early stage.[101] To discover how the expert prepared his simulator and to prepare for cross examination, an attorney requires ample time. This has been recognized by the authorities. In a case concerning expert testimony based upon a computer simulation, Justice Clark wrote that it was better practice for the proponent of this testimony to deliver to his opponent all of the underlying data and theorems employed in the simulation in advance of trial.[102] Similarly, in the *Manual for Complex Litigation* it is recommended that discovery of computer-generated evidence be undertaken "well in advance of trial."[103]

Assuming the court allows complete discovery into the data underlying computer simulation, consideration should first be given to Rule 34 of the Federal Rules of Civil Procedure which covers in part the production of documents. Although the framers of the Federal Rules may not have foreseen the computer age,[104] the Rules were brought into the computer age with a 1970 amendment to Rule 34(a).[105] The amendment expands the definition of "documents" to include "other data compilations from which information can be obtained, translated, if necessary, by the respondent through detection devices into reasonably usable form. . . ."[106]

100. 8 C. WRIGHT & A. MILLER, FEDERAL PRACTICE AND PROCEDURE: CIVIL § 2218, at 660 (1970) (footnotes omitted).

101. Jenkins, *supra* note 86, at 608.

102. Perma Research & Dev. v. The Singer Co., 542 F.2d 111, 115 (2d Cir.), *cert. denied*, 429 U.S. 987 (1976). While the appellate court stated that disclosure of the simulation materials in advance of trial was the better practice, it nonetheless upheld the trial judge's ruling on the nondisclosure of the expert's computer program in view of the facts of the case. Judge Van Graafeiland wrote a strong dissent. He argued that the computer simulation must be made available sufficiently in advance of the trial so that the adverse party will have an opportunity to examine and test the inputs, program and outputs prior to trial. *Perma*, 542 F.2d at 125.

103. MANUAL FOR COMPLEX LITIGATION 2D § 21.446, at 61 (1986).

104. Nat'l Union Elec. Corp. v. Matsushita Elec. Indus. Co., Ltd., 494 F. Supp. 1257, 1262 (E.D. Pa. 1980).

105. 8 C. WRIGHT & A. MILLER, *supra* note 100, § 2218, at 657-58.

106. FED. R. CIV. P. 34.

The Advisory Committee Notes indicate that, pursuant to this definition, the party responding to a discovery request may, at its own expense, be required to furnish the other party with printouts of the data stored in the respondent's computer.[107] If the requirement poses an "undue burden or expense," the respondent may seek relief by asking for restricted discovery or requiring the discovering party to pay the costs pursuant to Rule 26(c).[108] The Advisory Committee also state that the discovering party may also obtain access to the "electronic source itself."[109] In other words, the programming and system design can be discoverable.[110] Again, the responding party may seek relief from the court pursuant to Rule 26(c).[111]

A hypothetical request for production pursuant to Rule 34 served by a plaintiff upon a defendant sponsoring simulation-based testimony might call for the production of the following:

> All documents and files referring or relating to or used in any manner in any computer simulator, reservoir simulation or computer modeling study relating to the North field or any part thereof which has been performed, conducted or undertaken by defendant or its expert witness.

If the defendant responds to such data request, plaintiff might expect to find the following types of documents. First, one would expect the program and all related subprograms.[112] Purchased, leased or licensed programs normally include instruction manuals. These instructions may be of great use to the plaintiff. For instance, the manual could be used to determine whether the defendant or its experts used the programmer's recommended time steps. On the other hand, if the program was specially developed to simulate the reservoir concerned in the litigation, one would find documents relating to the program's design, writing and "debugging."[113]

However, the respondent may claim the program is confidential. For example, if the respondent to the above document request is a major oil company which has developed at considerable expense its own computer program for reservoir simulation, it may be most reluctant to turn over such program to the discovering party. The respondent cannot unilaterally refuse to make the program available for inspection as "there is no absolute privilege for trade secrets and similar confidential informa-

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107. FED. R. CIV. P. 34 advisory committee's note, *reprinted in* U.S.C.S. RULES OF CIVIL PROCEDURE, Rule 34, at 12-13 (Law. Co-op. 1974).

108. *Id.; see also* FED. R. CIV. P. 26(c); R. HAYDOCK & D. HERR, DISCOVERY PRACTICE § 5.16 (1982 & Supp. 1986).

109. FED. R. CIV. P. 34 advisory committee's note, *reprinted in* U.S.C.S. RULES OF CIVIL PROCEDURE, Rule 34, at 12-13 (Law. Co-op. 1974).

110. 8 C. WRIGHT & A. MILLER, *supra* note 100, § 2218, at 659.

111. *Id.*

112. For a general discussion of computer programming, see Roberts, *A Practitioner's Primer on Computer-Generated Evidence*, 41 U. CHI. L. REV. 254, 259-261 (1974).

113. *See* Pearl Brewing Co. v. Jos. Schlitz Brewing Co., 415 F. Supp. 1122, 1134-35 (S.D. Tex. 1976).

tion. . . ."[114] Instead, the party may move for a protective order and seek the court's permission to withhold the program from the discovering party's inspection.[115] However, it is highly unlikely that the court would grant such a motion.[116] It is far more likely that a court would order production of the program under the terms of a protective order which would limit access to the program.[117] In entering such a protective order, the court will need to balance the need for the discovering party to review the program and the need of the respondent for confidentiality.[118]

Second, the response to the discovery request would include documents or computer tapes setting forth the data used in constructing the simulation. Clearly, access to such data is essential to determine the validity of the model. If erroneous or incomplete data are used, the results calculated by the simulator will likewise be in error.[119]

The data would include the maps[120] which formed the geologic model for the simulator. The discovering party may use the maps to compare closely the geologic model reflected by the maps with the geology used in the simulator. For example, did the modeler modify the geology simply to force a history match? It should also include the production, pressure and PVT data. The data placed in the simulator may be compared with the actual data which was originally provided to the modeler. Likewise, the discoveror should be attentive to the data which the modeler rejected.

The last general type of document which should be produced are those documents generated in connection with the history matching process. According to Crichlow, the "engineer must endeavor to keep clearly identifiable records of each run; by comparing the results from these runs, he can make new changes to the data."[121] Such data are usually maintained on magnetic tape in sequential order; but, as discussed above, such tapes constitute discoverable documents under Rule 34(a). In addition, computer printouts for the various runs of the simulator should be produced. Careful review of the various simulation runs is warranted. It is always possible that the modeler may have obtained calculated results in a run which favored the opposition's case.[122]

114. 8 C. WRIGHT & A. MILLER, *supra* note 100, § 2043, at 300.

115. FED. R. CIV. P. 26(c)(7).

116. The United States Supreme Court has stated that "orders forbidding any disclosure of trade secrets or confidential commercial information are rare." Federal Open Mkt. Comm. v. Merrill, 443 U.S. 340, 362 n.24 (1979).

117. *Id.*

118. *See* 8 C. WRIGHT & A. MILLER, *supra* note 100, § 2043, at 301-03.

119. *See generally* Roberts, *supra* note 112, at 263.

120. One textbook author specifically recommends that the modeler retain a copy of each digitized map so that the modeler can refer to them while doing the history matching. H. CRICHLOW, *supra* note 14, at 195.

121. *Id.* at 222-23.

122. It has been argued that fairness may require discovery of the comparable information relating to each of the experiments that preceded the one to be used at trial, many of which may have been "failures" in the sense of yielding results that are more favorable to the discovering party than to the party presenting the study. 8 C. WRIGHT & A. MILLER, *supra* note 100, § 2218, at 660.

Also, documents reflecting analyses of computer runs made during the history matching process should be produced. Included here would be the modeler's notes reflecting manipulations of the model and commentary on the quality of the history match. The modeler often prepares graphs plotting the observed data and the data calculated by the simulator. Similarly, tables may be prepared which set forth the observed data at various points in time with calculated results at the same points. These graphs and tables assist in simplifying the task of comparing computer runs against one another and against observed data.

As indicated in the above discussion, three possible subjects to be developed in discovery are the programming of the computer, the data and the history matching process. Two additional subjects may warrant development in discovery. First, counsel should inquire into the decision to conduct a reservoir simulation in the first instance. Secondly, counsel should inquire whether the model was too complex.

One final issue with respect to computer simulation discovery should be noted. History matching can be a drawn-out process. If such work is performed over a protracted period, certain discovery timing problems can arise. For example, assume that, on June 1, the proponent of a computer simulation makes a complete response to the discovering party's document request. Assume also that, on June 10, the proponent modifies the reservoir simulator and, on June 11, runs the simulator, resulting in a new computer printout. The question thus arises whether the discovering party is entitled to the June 11 computer printout. Some often argue that discovery requests are "continuing" (usually a reference to the instructions accompanying the discovery request is made), and thus the discovering party should receive the June 11 printout. This argument, however, is not supported by the Federal Rules of Civil Procedure.

Rule 26(e) provides that, if a discovery response is complete at the time it is made, there is no duty to supplement, except in those instances where Rule 26(e) imposes a duty to supplement. In other words, there is no absolute duty to supplement, and the instances in which a party must supplement are limited.[123] Accordingly, under the facts above, the discovering party would not be entitled to the June 11 printout. To obtain access to it, the discovering party will have to make a new discovery request. By not periodically renewing its discovery requests, this party may find itself at trial prepared to cross-examine an expert on one model when the expert is in fact basing his testimony on a later version. A possible solution to this problem would be to request a court order pursuant to Rule

123. Johnson v. H.K. Webster, Inc., 775 F.2d 1, 7 (1st Cir. 1985). Another issue on appeal in *Johnson* was whether expert testimony on certain matters should be excluded because such matters were not disclosed in the original or in supplemental discovery responses. After being deposed, plaintiff's expert learned that his analysis was flawed, and he then modified his position. The First Circuit held that Rule 26(e) did not require the exclusion of testimony based upon the modified portion.

26(e)(3) which would impose a duty to supplement discovery responses upon the proponent of the reservoir simulation.[124]

CONCLUSION

The use of reservoir simulators has increased as computers have become more powerful and computing costs have decreased. This trend will continue as simulators are developed for use on personal computers. Undoubtedly, this will lead to more and more expert testimony based upon the results of a reservoir simulation study. By this article, it is hoped the reader has gained a basic understanding as to what an expert witness is attempting to do when using a reservoir simulation.

124. FED. R. CIV. P. 26(e) advisory committee's note, *reprinted in* U.S.C.S. RULES OF CIVIL PROCEDURE, Rule 26, at 253 (Law. Co-op. 1982).