

COMMENTS ON THE USE OF NUMERICAL MODEL BY KERR-McGEE CORPORATION  
IN APPRAISING EFFECTS OF SUBSURFACE LIQUID WASTE DISPOSAL

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Numerical Modeling of Ground-Water Flow

The movement and storage of underground water in porous rock is described by complex mathematical equations. In order to quantitatively analyze or understand the movement of ground water in any particular geologic reservoir, one must solve the flow equations for that particular system. Most such systems are too complex to allow simple or exact solutions to the equations; therefore, some means of approximating the solution must be applied. One of the best methods is the use of digital computer models which use the mathematical technique of finite differences to approximate the solution to the equations.

This technique was first adapted to the analysis of underground oil and gas reservoirs and in recent years has been adapted to the evaluation of ground water reservoirs. If properly used, the models are valid, accurate tools for these studies. Their usefulness has been proven on many different ground water and petroleum field problems. Such models can be used to predict changes in the pressure distribution in an aquifer (ground-water reservoir) due to injection or withdrawal of water. They can also be used to evaluate the long-term aquifer response to pumping or injection wells. Furthermore, the models can predict rates and direction of ground water movement within the reservoir. In some cases models can be used to help define aquifer boundary locations and to quantify hydraulic properties of the aquifer.

However, all models are limited in their application. Any model is only as good as the information upon which it is based. An accurate, valid predictive model requires detailed, quantitative knowledge of the aquifer boundaries, and spacial distribution of its hydraulic properties. In addition, several simplifying assumptions must be made to apply a numerical model. The investigator must therefore be cognizant of limitations associated with the assumptions and whether or not his system meets the required conditions necessary to apply the assumptions.

Generally the physical properties of an aquifer are measured or estimated by means of tests conducted on several wells spaced over the aquifer or area of interest. This information together with other geologic and laboratory data are integrated into a digital model which is nothing more than a simplified conceptual model of the system. If data is available from only one well in the aquifer, the model may be quite unrealistic. Such a condition is analogous to the old story of the blind men describing an elephant by touching only one part of it.

Although models have multiple uses, perhaps their principle value is in estimating the performance of a complex system under various assumed stresses. Models can arbitrarily be force-fitted to generate well-performance data that is similar to that of a well or wells in a poorly understood aquifer. When this is done, there may be a tendency to assume that the aquifer has the properties of the model which is not necessarily so. This is improper, circular reasoning and can lead to many false assumptions. Hundreds of greatly different models might be contrived that yield results similar to those of one well. However, they may all be unrepresentative of the true total aquifer.

#### Kerr-McGee Model

Kerr-McGee Corporation has constructed a disposal well into the Arbuckle formation in Sequoyah County, Oklahoma. In their application for a license

to use the well for liquid waste disposal, they based much of their argument on the results of a numerical model of the local Arbuckle formation. The physical well tests and mathematical modeling procedures used by Kerr-McGee consultants are valid, accepted techniques. The methods are widely used in both petroleum and ground water industry. However, the interpretation, application, and extrapolation of the results are subject to question.

The principal shortcoming is that the applicant's model is based almost entirely on test results from only one well. The model was manipulated to yield results comparable to the test results of the well, then the formation was assumed to be similar to the model. This is the faulty logic problem mentioned above. Limestone-dolomite reservoirs are generally quite heterogeneous, and data from only one well cannot be considered representative of the whole reservoir. Results of pumping tests or (pressure fall-off tests) like the ones used for the Kerr-McGee well are much more meaningful if one or more observation wells are used in addition to the injection well. For one numerical model in a heterogeneous basalt aquifer, data from more than 100 wells were used and limitations still remained. In a heterogeneous aquifer it is not feasible to base a model on one <sup>well</sup>.

The porosity and permeabilities used in the applicant's model are based on in-hole measurements in only one well. Such measurements represent an area of only a few inches to a few feet around the well. Thus, they cannot be considered representative of an entire reservoir, extending hundreds or thousands of feet from the injection well. In a limestone aquifer, it is not uncommon for permeability to vary by several orders of magnitude in a short distance. Similarly, it is common for porosity to vary by factors of 2 to 5 in a small area. It is therefore, unrealistic to assume a homogeneous distribution of these properties in each layer of the aquifer. If the permeability were highly anisotropic (direction-oriented) or heterogeneous, it is possible that the waste would move along a preferred direction further than the 900 ft indicated by Kerr-McGee's model results.

The well-test data is suspect because in each injection test, the permeability properties of the well seemed to change. It is difficult, if not impossible, to assess what values are correct and how much additional change there might be when the well is used for waste injection. For instance, injection of acidic effluent into a carbonate aquifer would drastically change the permeability distribution, particularly near the well.

Another questionable area involves the mathematical equations used by Gruy and Associates (Kerr-McGee's consultant) for the model. Gruy's report states that one side of the equation solved by the model is  $\partial/\partial t (\frac{\phi}{B})$  which I presume was meant to be  $\partial P/\partial t (\frac{\phi}{B})$  (P was mistakenly left out in the applicant's equation). In the standard ground-water equation used by most hydrologic modelers, the analogous term is  $\partial h/\partial t (S)$ , where S is called the storage coefficient. It is not clear how S relates to  $(\phi/B)$  nor how S was varied in the Gruy model. S (or  $\phi/B$ ) is one of the most sensitive variables in a model of this kind, yet there is no mention of how it was measured or varied in the model of the Arbuckle reservoir. Normally S and permeability are both adjusted to obtain good data fits. The Gruy study apparently ignores this. They do not discuss what factor "B" is nor how it was determined.

The distance waste will migrate from a well is closely related to the porosity of the formation. If the porosity were a factor of four lower than assumed, the waste would migrate two times farther away from the well. A large error in estimated storage coefficient (or the factor  $\frac{\phi}{B}$ ) could yield drastically different long-term pressure build-ups in the formation.

The Gruy model tests indicate that the inferred boundaries do not have to be impermeable to obtain acceptable results. It appears quite possible that a narrow zone of high permeability along one of the fault boundaries could allow significant vertical leakage of brine or other reservoir fluid with the increased pressure of injection. Their results also indicate that such leakage may not be detectable by monitoring well-head pressure (see figure 14 of Gruy's report). Figure 13 of the Gruy modeling report indicates

that a small zone of high vertical permeability could exist beyond 1,200 ft from the injection well, thus allowing the possibility for upward brine leakage.

When reservoir boundaries are determined from a pressure fall-off test, it is generally assumed that the reservoir is a one-layer homogeneous system. This is not the case for the Arbuckle reservoir, so the boundary interpretation may be erroneous. This problem could be partially eliminated by running separate pressure fall-off tests on each layer of the reservoir, using packers.

It appears that the actual pressure fall-off curve used to calibrate the model deviates further from the simulated model curve as time increases. Therefore, it also appears that there might be a significant difference in the two curves over a much longer injection time of perhaps 5 years. Longer pre-injection tests (perhaps 2 or 3 weeks) could provide more meaningful data. It is dangerous to extrapolate a 150-hour injection test to the five-year performance of the well.

It took at least 32 computer trials to obtain only a fair curve-match on the Gruy model, indicating difficulty in making the proper model adjustments to obtain desirable results. In this type of modeling, it is possible to fabricate many different combinations of model properties to obtain equally good curve-fits. Therefore, the Gruy model is not the **only** method by which the real system can be simulated to produce the observed well performance.

A minor criticism of the Gruy model is the false precision reported in their results (4 or 5 significant figures). The poor degree of quantitative understanding of the reservoir and the coarseness of their finite grid system calls for only two significant figures of precision.

In summary, the Gruy model uses accepted mathematical techniques but the interpretation and application of its results are questionable.