Assessment Of Environmental Implications Of Abandoned Oil And Gas Wells

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Summary

A detailed study was made of the potential for abandoned oil and gas wells in the Lower Tuscaloosa sand of Mississippi and Louisiana to act as conduits for movement of saline water from the Lower Tuscaloosa into underground sources of drinking water (USDW's). Finite-difference numerical modeling determined the extent that water might be forced from the Lower Tuscaloosa sand into a USDW as a result of injection into the Lower Tuscaloosa. Within the range of conditions modeled, water from the Lower Tuscaloosa never traveled into a USDW. On the basis of the modeling, we concluded that it is unlikely that abandoned oil and gas wells in the Lower Tuscaloosa would serve as conduits for water movement from the trend into a USDW. The procedures developed in this study should be readily applicable to analysis of the potential for abandoned wells to act as pathways for contaminant flow into USDW's in other oil and gas producing areas of the country.


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Introduction

Purpose and Scope of Study. Because of the increasing focus by U.S. regulatory agencies on abandoned oil and gas wells, the U. of Missouri-Rolla conducted research to assess the potential for abandoned oil and gas wells in the Lower Tuscaloosa sand oil-producing trend of Mississippi and Louisiana to act as conduits for flow of saline water from the Lower Tuscaloosa into USDW's.

Fig. 1 shows locations of selected wells from oil fields in the Lower Tuscaloosa sand. The Lower Tuscaloosa sand trend extends for about 135 miles from south-central Mississippi northwest into eastern Louisiana and for about 100 miles from north to south.[1]

The study included assembly of geologic and engineering data to formulate numerical models to simulate the range of flow conditions through abandoned wells in the Lower Tuscaloosa trend. The final step in the study was the actual numerical simulation of flow conditions for these abandoned wells. The simulations performed are believed to represent conditions throughout the Lower Tuscaloosa sand and the conclusions should be applicable to all abandoned Lower Tuscaloosa sand wells. The study is intended as an example that can be replicated in other oil- and gas-producing areas with similar conditions. To conduct such a study, sufficient information concerning the subsurface geology and hydrology, oil production history, and historic well construction and abandonment practices must exist or be possible to obtain to develop a realistic computer model. Also, geologic and hydrologic conditions that are sufficiently consistent over some area or distance are needed for the model to be represent enough cases to make modeling worthwhile. One would not be likely to conduct such modeling where every injection well required formulation of a new model.

Previous Work. Ward *et al.*[2] performed the first numerical modeling work on the movement of fluids through an abandoned well. Ward *et al.* modeled the leakage of injected contaminants through an abandoned unplugged borehole. The work demonstrated the capability of the SWIFT III[3] model for such investigations, but has no direct application to the problem studied here. Ward *et al.*'s investigation involved tracking wastes moving from an injection well to and up through an abandoned well. The problem here involves tracking the movement of native saline water from a saline-water-bearing aquifer in response to the pressure created by an injection well. Although significant differences exist in the details of the two problems, most procedures in setting up the models and data input are the same. In the modeling of injected waste movement, the injected fluid was tagged and tracked and no attention was given to the native saline water residing in the injection reservoir. In this problem, the injection fluid was assumed to the same as the native saline water and all the water that moved up the borehole was considered a potential contaminant to USDW.

Warner[4] modeled the response of a specific existing abandoned well in the West Mallalieu oil field to injection through a nearby water-injection well.

Javendel *et al.*[5] developed an analytical model of the abandoned well problem. While this model cannot be used to determine the effect of an abandoned well on the quality of groundwater in a USDW, it allows calculation of the gross amount of water that can flow into an abandoned well and thus provides a means to compare the results of numerical modeling of the flow into an abandoned well with a much simpler analytical calculation. The Javendel analytical model was used to verify the accuracy of flow results obtained from the numerical model during calibration.

Abandoned Well Problem

Thousands of wells have been drilled and abandoned during the 130-year history of the U.S. petroleum industry. Regulations for plugging these wells, nonexistent in the early days of the industry, have evolved over the years to their present effective level. Thus, an unknown but large number of abandoned wells exist that may be unplugged or inadequately plugged by today's standards.

As a result of incidents in which abandoned wells were implicated as sources of groundwater contamination, such wells are often considered indiscriminately to be potential pathways for contamination of a USDW. Contamination can result from interaquifer flow of natural formation water or by transmission of injected fluids from the injection reservoir to a USDW.

The relative contamination potential of such wells actually ranges from highly likely

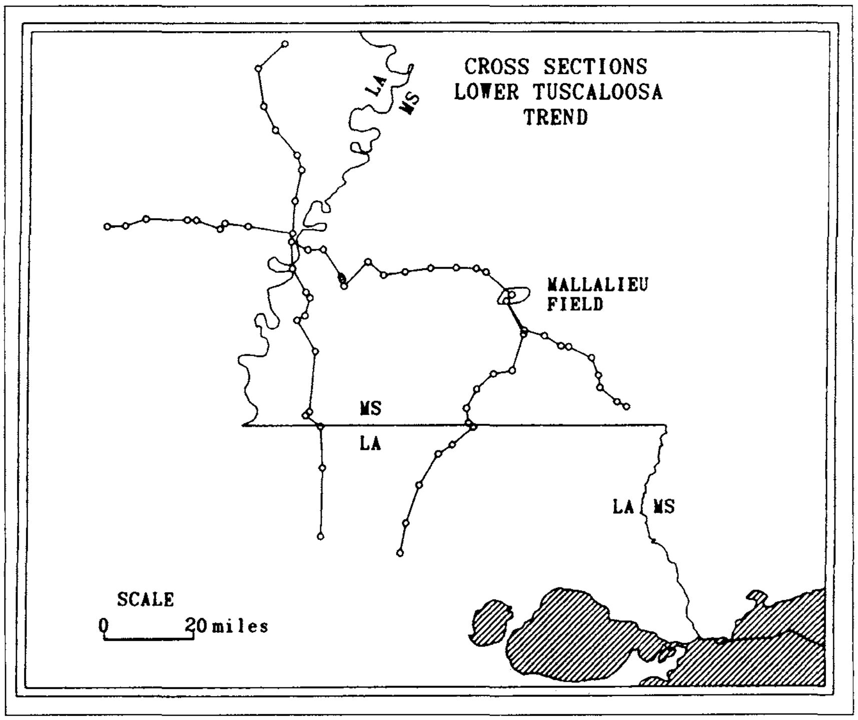

Fig. 1—Map showing locations of wells used in Lower Tuscaloosa trend study.

"Thus, an unknown but large number of abandoned wells exist that may be unplugged or inadequately plugged by today's standards."

to impossible, depending on a complex set of well factors and geologic and hydrologic circumstances. The relative contamination potential of an abandoned well or wells in a particular geologic and hydrologic setting can be analyzed qualitatively by understanding the factors involved. Warner[6] listed and discussed these factors, which include well age, depth, type, and construction; well plugging and abandonment history; and the hydrogeologic conditions at the wellsite.

Review of these general well characteristics often can establish that a well has no contamination potential because its physical condition, hydrogeology, or perhaps both, prevent migration of saline water or other liquids from aquifers containing waters with >10,000 mg/L of dissolved solids into USDW's. In such cases, no further investigation of the well is necessary.

In instances where an abandoned well does have possible pathways for natural brines or injected fluids to migrate into USDW's and where the hydrogeology is amenable to interaquifer flow, quantitative analysis with numerical computer models may predict whether such interaquifer flow is likely. This paper documents both qualitative and quantitative evaluation of abandoned oil and gas wells in the Lower Tuscaloosa trend of Mississippi and Louisiana.

General Description of Numerical Model

Modeling for this research project was carried out with the SWIFT III numerical code. SWIFT III,[3] the result of more than 10 years of model evolution, is a revised and improved version of a code originally developed for the U.S. Geological Survey specifically for injection-well modeling. Predecessor codes include SWIP,[7] SWIPR,[8] SWIFT,[9] and SWIFT II,[10,11] all publicly available through the Natl. Technical Information Service, Arlington, VA, and the Natl. Energy Software Center, Argonne, IL.

The SWIFT III code is a fully transient, 3D, finite-difference numerical code that solves the coupled equations for fluid flow, transport of chemicals that do not decay radioactively, transport of radionuclides, and heat transport. According to Prickett *et al.*[12] the SWIP (or SWIFT) type models are the latest and most comprehensive models available. No comparable numerical model is known to exist today for the type of modeling carried out in this research project.

Geology and Petroleum Production in the Lower Tuscaloosa Trend

Fig. 2 depicts a generalized stratigraphic column of the Mallalieu field, Lincoln County, MS. Strata shown in Fig. 2 range in age from the Cretaceous Lower Tuscaloosa sand at the base to the Eocene Cook Mountain and Sparta sand units at the top of the column. At the Mallalieu field and elsewhere in southern Mississippi and in southeastern Louisiana, Strata of Oligocene through Holocene Age overlie the Cook Mountain and Sparta.

The only geologic unit that has produced oil or gas in the study area is the Lower Tuscaloosa sand. This fact is of practical importance, because there are no younger and shallower or deeper and older producing units in the many Lower Tuscaloosa fields into which oil- or gas-producing wells have been drilled and abandoned. The possibilities for interaquifer flow through abandoned wells that must be considered are limited because it is not necessary to be concerned about significant number of wells other than those drilled to the Lower Tuscaloosa sand.

The fact that the Lower Tuscaloosa is the only producing formation also restricts the manner in which wells have been drilled, completed, and abandoned. Lower Tuscaloosa oil production began in the early 1940's, and fields are now in the very late stages of petroleum recovery. For example, The Mallalieu and Little Creek fields are undergoing tertiary oil recovery by CO_2 injection. By the 1940's, when drilling in the Lower Tuscaloosa trend began, the technology and regulation of well construction and abandonment had already advanced considerably over practices in the early 1900's. The actual practices used are covered in the next section.

Cross sections developed for the study[1] show correlation of the strata throughout the Lower Tuscaloosa oil-producing trend. The cross sections show the remarkable continuity of the overall geologic units within the study area. Very rapid changes in stratigraphy occur within major geologic units, even between wells in the individual oil fields, but the major units remain present throughout the trend. The cross sections show that, while all the geologic units of interest differ in thickness and lithologic detail in any one of the oil fields for which a log is shown, the section in the Mallalieu field is as representative as any that could be selected. Therefore, the stratigraphic section for the Mallalieu field (Fig. 2) was selected for modeling purposes.

Uncased Well Scenario. Fig. 3 shows the conditions of the uncased well scenario. This scenario is very straightforward in that sur-

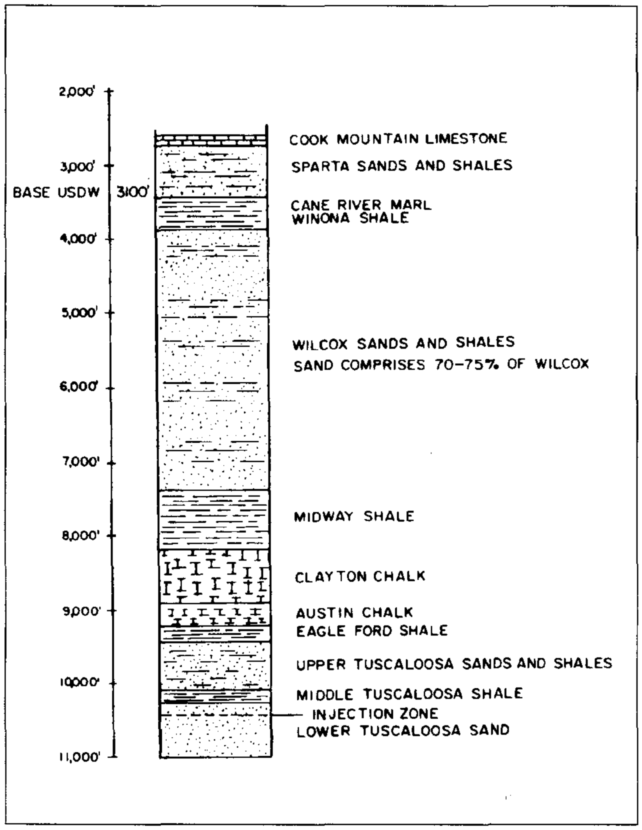

Fig. 2—Generalized stratigraphic column, Mallalieu field, Lincoln County, MS.

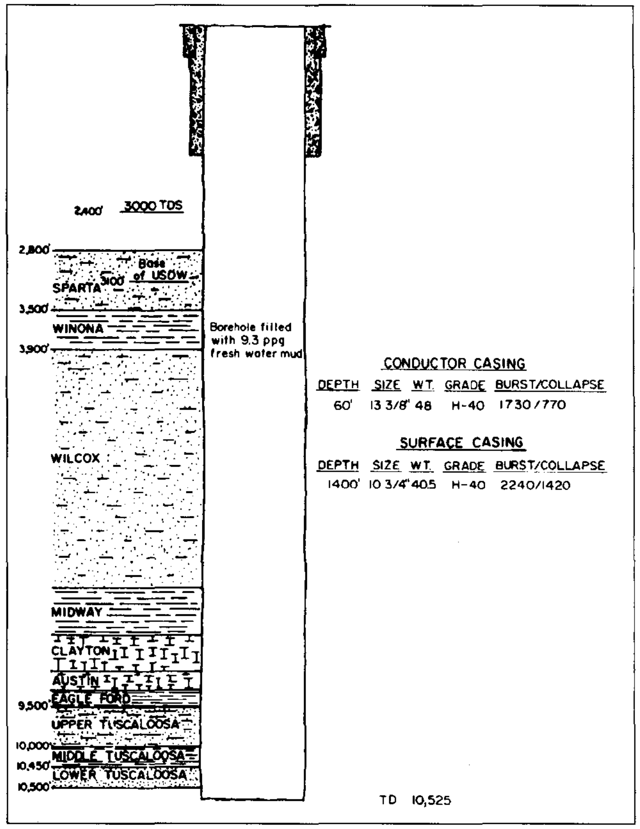

Fig. 3—Illustration of uncased abandoned well scenario, Lower Tuscaloosa trend.

face casing typically was set to about 1,400 to 1,500 ft and cemented to the surface. The remainder of the hole needed to reach the Lower Tuscaloosa sand was left open until the Lower Tuscaloosa was reached and its thickness and production capability assessed. If the Lower Tuscaloosa sand was present and sufficiently thick and promising, the well was cased. If the Lower Tuscaloosa sand was missing, thin, or otherwise unlikely to be economically productive, the well was plugged and abandoned with the drilling mud in the hole and no casing other than the surface casing. Many such abandoned wells contain cement plugs. However, in the worst case, a well might not contain anything other than drilling mud upon abandonment. This worst case scenario was selected for modeling.

Cased Well Scenario. When a Lower Tuscaloosa sand well was drilled and the sand found to be present and likely to be sufficiently productive, the well was cased with production casing through the Lower Tuscaloosa (**Fig. 4**). The production casing was cemented at the bottom with about 2,000 ft of cement. The remainder of the annulus behind the production casing was left mud filled.

Of course, if the casing remained intact, no possible threat to groundwater resources existed. However, the casing could have corroded to the extent that it breached, creating a pathway to formations behind the casing. According to Michie,* the incidence of casing corrosion in the Lower Tuscaloosa sand is very low. If corrosion were to occur, however, Michie* judged it would most

*Personal communication with T.W. Michie, Michie and Assocs., New Orleans (1988).

"...abandoned oil and gas wells in the Lower Tuscaloosa trend of Mississippi and Louisiana are unlikely to serve as conduits for movement of water from the Lower Tuscaloosa into a USDW."

TABLE 1—MODEL PARAMETERS, UNCASED ABANDONED WELL SCENARIO

Model Layer	Permeability, k_x and k_y, $k_z = k_x \times 10^{-1}$ (darcies)	Porosity (%)
1	1	35
2	2.5×10^{-8}	3
3	1	30
4	1	30
5	1	30
6	2.5×10^{-8}	3
7	0.1	23
8	2.5×10^{-8}	3
9	2.5×10^{-8}	3
10	2×10^{-3} or 3×10^{-2}	25
Drilling mud	1×10^{-3}	84
Sloughed shale	1×10^{-4}	3
Empty borehole	3.7×10^{8} (10^{9} ft/D)	100
Other Parameters		
Water compressibility, psi^{-1}	3×10^{-6}	
Rock compressibility, psi^{-1}	5.5×10^{-1}	
Fluid specific weight, lbm/ft^3	67.3	
Viscosity, cp	1	

TABLE 2—PRESSURE BUILDUPS AND FLOWS WITH TIME FOR A 20-B/D INJECTION RATE AND LOWER TUSCALOOSA SAND PERMEABILITY OF 2 md, UNCASED ABANDONED WELL SCENARIO					
Time Since Injection Began (days)	Δp of BHP, Injection Well (psi)	Δp at Bottom of Abandoned Well (psi)	q Into USDW (B/D)	q Into Abandoned Well (B/D)	q Into Upper Tuscaloosa (B/D)
0.01	80.2	0	0	0	0
0.1	122.2	0	0	0	0
1.0	159.7	0	0	4.89×10^{-11}	6.7×10^{-12}
10.0	201.4	2.8	0	3.01×10^{-8}	5.0×10^{-10}
100.0	239.1	26.9	0	7.40×10^{-7}	3.6×10^{-8}
1,000.0	277.2	63.2	0	2.47×10^{-6}	1.7×10^{-7}
2,000.0	288.5	74.4	0	3.26×10^{-6}	2.5×10^{-7}
3,650.0	298.1	84.0	0	4.19×10^{-6}	3.4×10^{-7}

likely be in the lower portion of the Wilcox sand where brine injection could render the water more corrosive. An arbitrary depth of 6,000 ft within the lower Wilcox was selected as the possible location of such a corroded casing interval.

Wellbore Properties of Settled Mud Solids and Formation Materials

Procedures described in Ref. 1 were used to calculate that, in the uncased well scenario, a 154.5-ft-thick column of sloughed shale would be present at the bottom of the hole overlain by a 4,620-ft column of settled mud solids (**Fig. 5**). The porosity of the sloughed shale column was assumed to be that of the in-place material (3%). The permeability of the sloughed shale was assumed to be 0.1 md. The porosity and permeability of the settled mud solids column was assumed to be 84% and 1.0 md, respectively.[1] The 84% settled mud solids porosity is high compared with values normally associated with sedimentary materials. This value is believed to be reasonable, however, for the settled drilling mud including hydratable clays known to be used in the area.

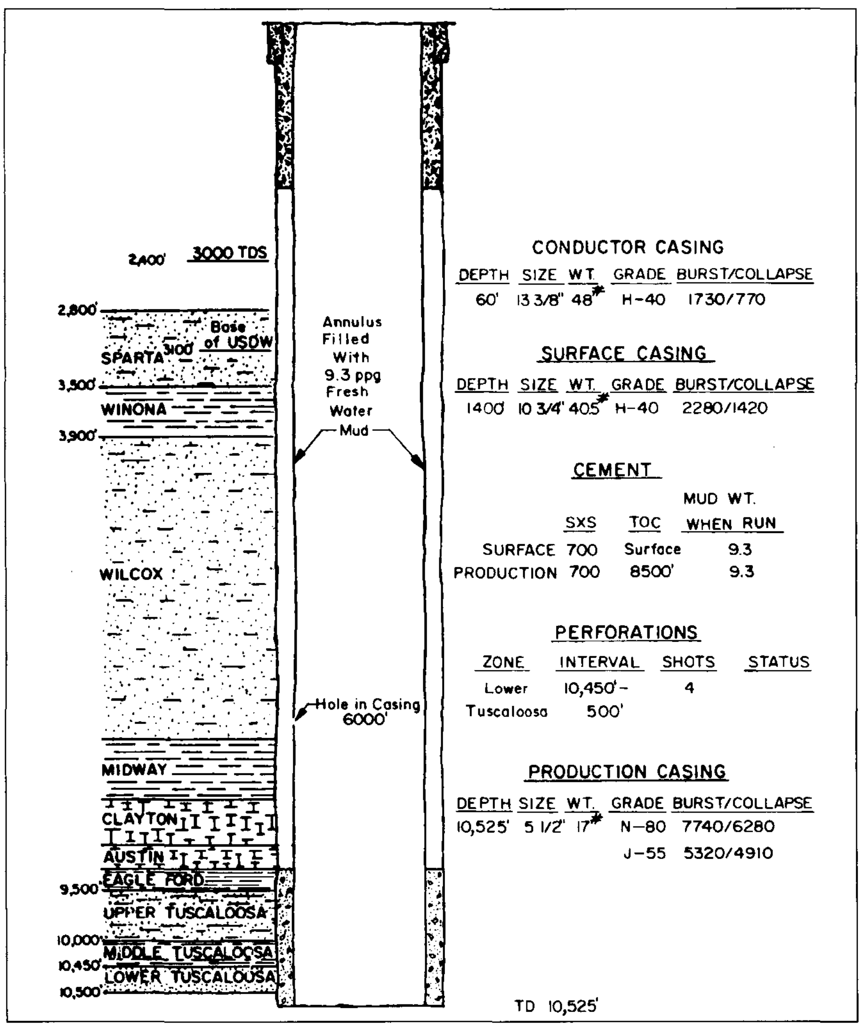

Fig. 4—Illustration of cased abandoned well scenario, Lower Tuscaloosa trend.

In the cased well scenario, a cement sheath extended from bottomhole to 8,500 ft. A 200-ft-thick sloughed shale column was calculated to be present on top of the cement and a 3,740-ft-thick settled mud column on top of the sloughed shale (**Fig. 6**). The sloughed shale and mud solids were assumed to have the porosity and permeability values given for the uncased well scenario.

Modeling of Two Regional Scenarios

Uncased Well Scenario. A 3D 47×20-node×10-layer model grid was designed for simulation of the uncased well scenario. The x-y grid nodes were spaced logarithmically to provide an efficient gridding system. Because the geologic units were treated as if they were homogeneous and areally infinite, the flow field was symmetric and only half of the grid was present in the y dimension. The injection and abandoned wells were located 500 ft apart and roughly centered along the x boundary. The x-y extent of the grid was 10×10^5 by 9×10^5 ft and was established by trial and error to be large enough to avoid significant boundary effects during the 10-year modeling period.

Fig. 5 shows the 10 model layers used in the vertical, or z, dimension. The layers were selected to discriminate both the major hydrogeologic units and the sloughed shale and settled mud layers in the borehole. For example, the Lower Tuscaloosa sand, Layer 10, is one 50-ft-thick layer, while the Middle Tuscaloosa is divided into Layers 8 and 9 to reflect the top boundary of the sloughed shale. Similarly, the top of Layer 5, in the Wilcox sand, identifies the top of the column of settled mud solids. **Table 1** lists the model parameter values used in simulation runs for the uncased abandoned well scenario. Two permeability values (2 and 30 md) were used as the likely lower and upper permeability limits for the Lower Tuscaloosa sand.

More than 20 calibration runs were performed for the uncased well scenario simulations. Each simulation required 9 megabytes of core storage and about 4 hours of CPU time. Although no exact analytical solution exists for the scenario modeled here, the modeling results were compared with the fully confined, infinite in horizontal extent, homogeneous, and isotropic case for verification. The actual model results should be

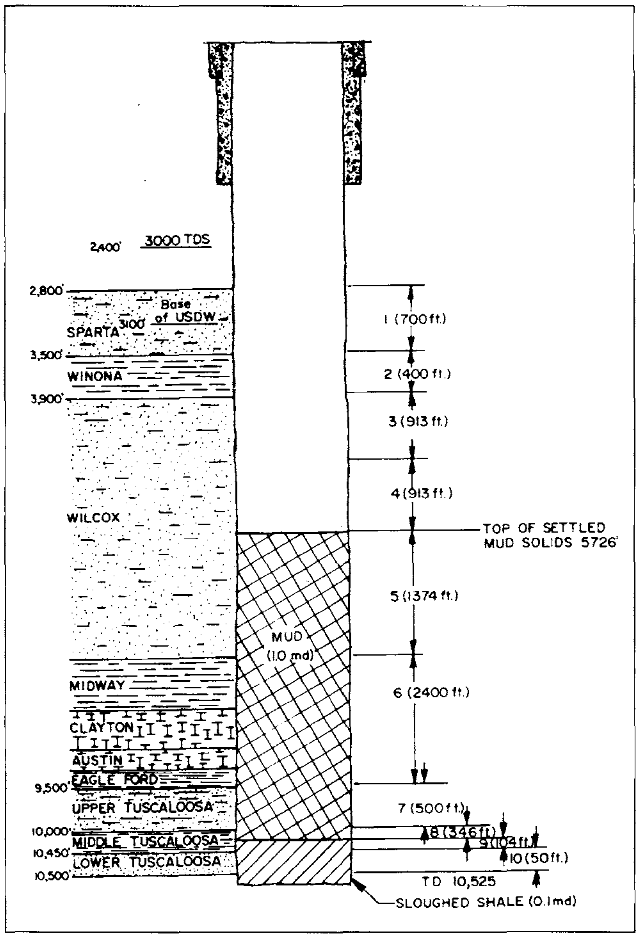

Fig. 5—Illustration of uncased abandoned well scenario, Lower Tuscaloosa trend, showing finite-difference model layers.

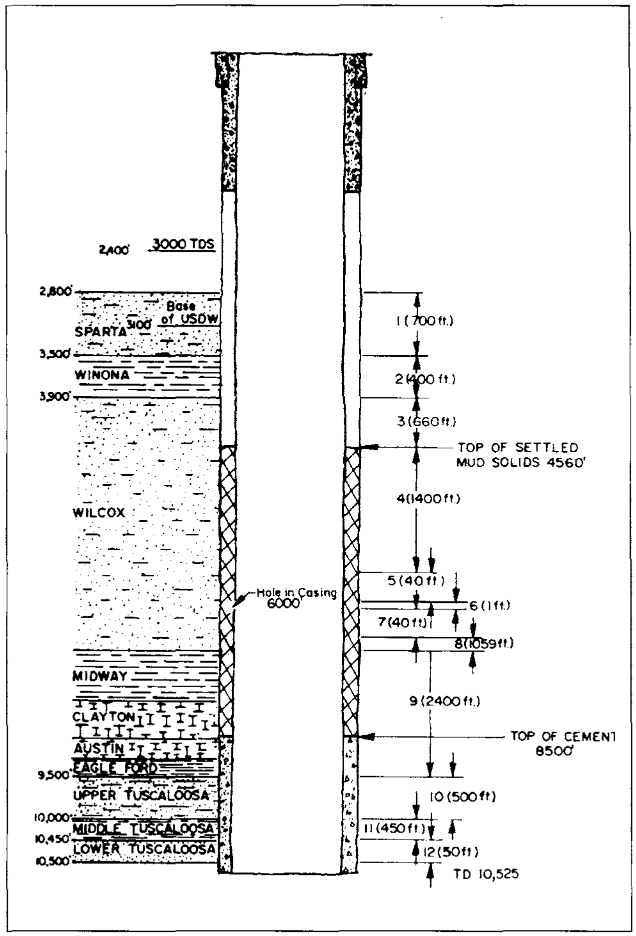

Fig. 6—Illustration of cased abandoned well scenario, Lower Tuscaloosa trend, showing finite-difference model layers.

TABLE 3—PRESSURE BUILDUPS AND FLOWS WITH TIME FOR A 200-B/D INJECTION RATE AND LOWER TUSCALOOSA SAND PERMEABILITY OF 30 md, UNCASED ABANDONED WELL SCENARIO

Time Since Injection Began (days)	Δp of BHP, Injection Well (psi)	Δp at Bottom of Abandoned Well (psi)	q Into USDW (B/D)	q Into Abandoned Well (B/D)	q Into Upper Tuscaloosa (B/D)
0.01	84.0	0	0	0	0
0.1	110.8	0	0	0	0
1.0	133.1	2.3	0	7.13×10^{-9}	0
10.0	162.8	21.0	0	2.82×10^{-7}	5.0×10^{-9}
100.0	186.4	43.4	0	1.26×10^{-6}	6.6×10^{-8}
1,000.0	13.1	70.3	0	2.81×10^{-6}	2.0×10^{-7}
2,000.0	221.0	78.2	0	3.53×10^{-6}	2.7×10^{-7}
3,650.0	227.6	84.8	0	4.38×10^{-6}	3.5×10^{-7}

TABLE 4—PRESSURE BUILDUPS AND FLOWS WITH TIME FOR A 600-B/D INJECTION RATE AND LOWER TUSCALOOSA SAND PERMEABILITY OF 30 md, UNCASED ABANDONED WELL SCENARIO

Time Since Injection Began (days)	Δp of BHP, Injection Well (psi)	Δp at Bottom of Abandoned Well (psi)	q Into USDW (B/D)	q Into Abandoned Well (B/D)	q Into Upper Tuscaloosa (B/D)
0.01	252	0	0	0	0
0.1	332.6	0.1	0	0	0
1.0	399.5	6.9	0	1.67×10^{-7}	9.9×10^{-11}
10.0	488.7	63.2	0	6.6×10^{-6}	1.6×10^{-8}
100.0	559.5	130.3	0	3.0×10^{-5}	2.0×10^{-7}
1,000.0	640.1	211.5	0	6.6×10^{-5}	6.0×10^{-7}
2,000.0	664.4	235.8	0	8.3×10^{-5}	8.1×10^{-7}
3,650.0	684.9	256.3	0	1.0×10^{-4}	1.1×10^{-6}

the same as those calculated with the analytical equation during early response time. Then, the pressure buildup should be less than or equal to the confined analytical solution, depending on the amount of leakage into the abandoned well. The close agreement between modeled and analytical solution results indicated that the model was correctly assembled and the results were valid.

Tables 2 and 3 show the simulation results for the uncased well scenario. Tables 2 and 3 list the Δp at the bottom of the injection well [bottomhole pressure (BHP)], the Δp at the bottom of the abandoned well, the flow rate, q, of saline water into the groundwater zone (USDW), the flow rate through the sloughed shale, and the flow rate into the Upper Tuscaloosa. Tables 2 and 3 differ with regard to the Lower Tuscaloosa permeability values (2 and 30 md) and injection rates (20 and 200 B/D). These values represent the range of likely permeabilities and injection rates.

To study the effect of increasing the injection rate on flow up the abandoned well and into the Upper Tuscaloosa, a simulation was performed with an injection rate of 600 B/D and an injection-zone permeability of 30 md. The 600 B/D injection rate was selected because it was the maximum that could be used in the simulation without computing a BHP that would be above the anticipated fracture pressure of the Lower Tuscaloosa sand. **Table 4** shows the results. The simulation showed no flow into the USDW zone at the 600-B/D injection rate. Flow rates less than 10^{-2} B/D should be considered too small to be meaningful. For practical purposes, such rates indicate that no measurable flow is occurring.

The highest flow rate shown in Tables 2 through 4 is 1×10^{-4} B/D into the abandoned well. Most likely, none of this negligible amount of saline water will enter the USDW because it will be diverted into other formations before reaching that level.

Cased Well Scenario. A 3D 48×22-node×12-layer model grid was designed for simulation of the cased well scenario. Because the geologic units were treated as if they were homogeneous, isotropic, and areally infinite, the flow field was symmetric and only the upper half of the grid was present in the Y dimension. The injection well and the abandoned well were 500 ft apart and roughly centered along the x boundary. The x-y extent of the grid was 3.4×10^5 by 2.1×10^5 ft and was established by trial and error to be large enough to prevent significant boundary effects during the 10-year modeling period.

Fig. 6 shows the 12 model layers used in the z dimension. The layers were selected to discriminate the hydrogeologic units; the cement, sloughed shale, and settled mud layers behind the casing; and the corroded casing interval. **Table 5** lists the values for the model parameters used in simulation runs for the abandoned cased well scenario.

TABLE 5—MODEL PARAMETERS, CASED ABANDONED WELL SCENARIO, LOWER TUSCALOOSA TREND

Model Layer	Permeability, $k_x = k_y = k_z$ (darcies)	Porosity (%)
1	1	35
2	2.5×10^{-8}	3
3	1	30
4	1	30
5	1	30
6	1	30
7	1	30
8	1	20
9	2.5×10^{-8}	3
10	0.1	23
11	2.5×10^{-8}	3
12	2 or 30×10^{-3}	25
Drilling mud	1×10^{-3}	84
Empty borehole	3.7×10^{8} (10^{9} ft/D)	100
Other Parameters		
Water compressibility, psi^{-1}	3.6×10^{-6}	
Rock compressibility, psi^{-1}	5.5×10^{-6}	
Fluid specific weight, lbm/ft^3	67.3	
Viscosity, cp	1	

More than 10 calibration runs were performed for the cased well scenario simulation. Each simulation required 14 megabytes of core storage and about 4 hours CPU time. Although no exact analytical solution exists for the scenario modeled here, the modeling results were compared with the fully confined, infinite in horizontal extent, homogeneous, and isotropic case for calibration. The actual model results should equal the analytical solution through the early transient phase. Then, the pressure buildup should be less than or equal to the confined analytical solution, depending on the amount of leaking into the abandoned well. The close agreement between modeled and analytical solution results indicated that the model was valid.

Tables 6 and 7 show the simulation results for the cased well scenario. The tables differ with regard to the Lower Tuscaloosa permeability values (2 and 30 md) and the injection rates (20 and 200 B/D). These values represent the range of likely permeabilities and injection rates. Tables 6 and 7 list the Δp of the BHP at the injection well and the flow rate into the abandoned well. The flow of saline water vertically from the Wilcox formation through the Winona shale and Cane River Marl and into the USDW was zero for all these simulations.

As in the uncased well scenario, flow rates of less than 10^{-2} B/D should be considered highly inaccurate. For practical purposes, such rates indicate that no measurable flow is occurring.

Conclusions

On the basis of the modeling performed, we concluded that abandoned oil and gas wells in the Lower Tuscaloosa trend of Mississippi and Louisiana are unlikely to serve as conduits for movement of water from the Lower Tuscaloosa into a USDW. In the scenario of the uncased well, essentially no water was found to move vertically through the sloughed shale/settled mud column and no measurable amount of water that did penetrate the settled mud column reached the Sparta, which is the USDW in the Mallalieu field area. In the cased well scenario, essentially no water moved through the settled mud sheath into the Wilcox formation and none of the water that did flow into the Wilcox moved vertically through the Wilcox and the Winona-Cane River into the Sparta.

The procedures developed in this study should be readily applicable to the analysis

TABLE 6—PRESSURE BUILDUPS AND FLOWS WITH TIME FOR A 200-B/D INJECTION RATE AND LOWER TUSCALOOSA SAND PERMEABILITY OF 30 md, CASED ABANDONED WELL SCENARIO

Time Since Injection Began (days)	Δp of BHP, Injection Well (psi)	q Into Abandoned Well (B/D)
0.01	44.7	0
0.1	70.4	0
1.0	84.5	1.6×10^{-5}
10.0	115.8	3.7×10^{-4}
100.0	132.9	7.8×10^{-4}
1,000.0	149.5	1.2×10^{-3}
2,000.0	154.6	1.4×10^{-3}
3,650.0	158.4	1.5×10^{-3}

TABLE 7—PRESSURE BUILDUPS AND FLOWS WITH TIME FOR A 20-B/D INJECTION RATE AND LOWER TUSCALOOSA SAND PERMEABILITY OF 2 md, CASED ABANDONED WELL SCENARIO

Time Since Injection Began (days)	Δp of BHP, Injection Well (psi)	q Into Abandoned Well (B/D)
0.01	23.5	0
0.1	61.9	0
1.0	98.1	1.1×10^{-6}
10.0	145.1	8.7×10^{-6}
100.0	177.3	5.6×10^{-5}
1,000.0	207.8	1.2×10^{-4}
2,000.0	215.4	1.4×10^{-4}
3,650.0	221.3	1.6×10^{-4}

of the potential for abandoned wells to act as pathways for contaminant flow into USDW's in other oil- and gas-producing areas. Modeling such as that described here is a very powerful tool for classification of abandoned wells. While this type of modeling is not a trivial exercise, and the necessary data are not routinely available, the information produced can return the necessary investment many fold by diverting concern from unwarranted areas and thus avoiding unnecessary regulatory effort.

Acknowledgments

We thank the American Petroleum Inst. for financial support for the research documented in this paper. Shell Oil Co. commissioned the stratigraphic study of the Lower Tuscaloosa trend as a separate but essential part of the project. B.E. Esquinance, Shell Offshore Inc., developed the well scenarios described. Nina K. Springer, Exxon Production Research Co., developed the method for estimating the characteristics of settled mud and sloughed shale in abandoned wells, used in the study. Bill Freeman, Shell Oil Co., chaired the API Issues Group overseeing this study. We express our appreciation to that group for its helpful suggestions and input to the study.

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SI Metric Conversion Factors

bbl	×	1.589 873	E−01	=	m^3
cp	×	1.0*	E−03	=	Pa·s
ft	×	3.048*	E−01	=	m
ft^3	×	2.831 685	E−02	=	m^3
lbm	×	4.535 924	E−01	=	kg
mile	×	1.609 344*	E+00	=	km
psi	×	6.894 757	E+00	=	kPa

*Conversion factor is exact.

Provenance

Original SPE manuscript, **A Quantitative Assessment of the Environmental Implications of Abandoned Oil and Gas Industry Wells: Lower Tuscaloosa Trend, Mississippi and Louisiana,** received for review Sept. 2, 1990. Revised manuscript received Dec. 8, 1992. Paper accepted for publication Feb. 24, 1993. Paper (SPE 20692) first presented at the 1990 SPE Annual Technical Conference and Exhibition held in New Orleans, Sept. 23–26.

JPT