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Chapter 18

GIS: The Exploration and Exploitation Tool

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ABSTRACT

In recent years, the significant increase in performance and decrease of prices of the personal computer (PC) platform have accelerated the growth of geographic information system (GIS) usage. GIS is a very dynamic technology enabling the user to display a map of any location in the world and rescale that map instantaneously. The key to the success of any exploration or exploitation team is the integration of the members, the database, and the multiple software functions. GIS is a particularly effective means of providing functionality for all of the disciplines represented on the team. GIS cannot replace all existing software applications, but it can be used to integrate and link other programs. Although GIS can be effectively applied in various petroleum industry settings, its use in exploration and exploitation is of particular interest. One specific exploration application involves the creation of reconnaissance maps. Uses of GIS in exploitation projects are perhaps more varied because exploitation evaluation typically deals with more extensive data sets than those typically used in exploration settings. Exploitation approaches are generally applied to mature producing areas where well control is dense, whereas exploration projects may not involve any wells at all. GIS is a particularly effective technology that enables exploration and exploitation teams to share information, analyze data in new ways, and integrate the evaluation process.

INTRODUCTION: THE BENEFITS OF GIS

A geographic information system (GIS) is a powerful technological tool that can be used in the problem-solving process facing any exploration and exploitation team. A GIS can provide the team with a whole new way of analyzing, visualizing, and integrating data. GIS technology is now available across all computer platforms, including the Internet. In recent years, its cost has decreased significantly, whereas functionality has been dramatically enhanced. GIS can specifically benefit exploration and exploitation teams in the following ways:

- Integration of the contributions of various team members through cross-discipline interpretation and software functionality
- Provision of new methods for visualizing data sets through the use of symbology
- Dynamic mapping of digital databases
- Presentation of data in various forms, such as maps, charts, data tables, and query results
- Sharing of, integration of, and access to centralized databases via computer networks or the Internet
- Linkage of multiple software applications
- Technology use across multiple computer platforms

- Enhanced portability of technology and data via laptop and handheld computers
- Proliferation of new tools, which are affordable and easy to use

In recent years, the significant increase in performance and decrease in prices of the personal computer (PC) platform has accelerated the growth of GIS usage. GIS technology has become very affordable and easy to use. The true power of GIS is that it presents a new way to analyze databases. GIS enables the analyst to visualize the data as they are represented spatially. Analysis of the spatial relationships of digital databases can present new pictures of the data that never could be assembled by analyzing tabular representation of data sets.

GIS is a very dynamic technology, and it enables the user to display a map of any location in the world and to rescale that map instantaneously. Interpreters can zoom into a specific area of interest by simply defining the four geographic coordinate boundaries of the map. GIS and digital map data sets create a dynamic combination whose functionality is unlimited in their combined capabilities.

Symbology is a classification method used in GIS to represent data or individual map features as varying sizes, thicknesses, colors, or styles. In any GIS, there are three types of data: points, lines, and polygons. Each type of data can be represented by different types of symbology. Color, size, and style can represent point data, such as well locations. Color, thickness, and style can represent line data, such as pipeline locations. Polygon-fill color or style can represent polygonal data, such as offshore block boundaries.

Symbology on a map presents three types of results: trends or patterns, anomalies, or a random representation. One of the most vivid results of a GIS map is when the symbolized data present a recognizable trend or pattern. The explorationist then must search for an explanation for the trend or pattern. In many cases, the trend or pattern is a result of the underlying geology. Anomalies become very apparent on symbolized maps.

Either due to color, size, thickness, or style symbology, a feature or features on the map clearly represent themselves as anomalies. Anomalies must then be further investigated to establish explanations for their occurrences. If a trend, pattern, or anomaly is not represented, then the data will exhibit a random pattern with no new pictures or ideas being presented; however, even random data patterns can be informative.

A common GIS technique is to filter data to restrict an analysis or presentation to only the information that satisfies some specific criterion. Filtering data is very effective in areas with dense data control, enabling some of the data to be removed from consideration, if only temporarily. Filtering is an excellent tool to be used, for example, in field exploitation settings, especially when many wells have been drilled. As an example, a filter could be applied to "total depth drilled" to remove all of the shallow wells from a map.

The key to the success in any multidisciplinary effort is the integration of the members, the databases, and the multiple software functions. GIS is a particularly effective means of providing functionality for all of the disciplines on the team. Most GIS systems can present data via maps, as well as in charts and tabular database tables. Multiple databases can be integrated via the GIS; and once they are integrated and centralized, every member of the team can share the same database and data sets across networks or the Internet.

GIS cannot replace the capabilities of all existing software, but it can be used to integrate and link various programs. A GIS can also access databases that are being used in other applications, and individual features in the GIS database can be linked to files from other software packages.

Today's multidisciplinary teams use various computer platforms such as UNIX workstations and PCs operating under Windows. Cross-platform GIS functionality enables the team members to continue to use their individual machines. Also, with the significant increase in speed and power of laptop PCs, GIS functionality is even more portable. The multidisciplinary team can now take a GIS on the road to the well site, lease sale, or out-of-town meeting without fear of losing access to data or established geocomputing routines. In addition, Internet-based GIS now enables spatial databases to be accessible from anywhere in the world.

USER GROUP

The implementation of multidisciplinary teams to solve exploration and production problems has become a recent trend in the petroleum industry. A multidisciplinary or synergistic team consists of two or more individuals of diverse technical expertise working toward solving common problems. The team shares a common leader, goals, workspace, technology, and databases. The multidisciplinary or synergistic team concept is based on the premise that individuals of varying technical backgrounds working closely together will produce a significantly better final product over a shorter cycle time (Sneider, 1986).

A typical petroleum exploration or exploitation team might consist of one or more geologists, geophysicists, engineers, petrophysicists, landmen, and geotechnicians. Each discipline approaches the problem-solving process in different ways. In addition to the diversity of disciplines and problem-solving approaches, petroleum industry teams, particularly those involved in exploration and development, have historically used and relied on a wide variety of computer software, hardware, and databases, which has added to the need to seek common ground and synergy. Because of the very nature of the problems involved, multidisciplinary teams have been especially effective in the exploitation arena where the skills of individuals from many disciplines are used to piece together complex geological and reservoir solutions.

APPLICATIONS OF GIS

As previously noted, GIS can be used in both the exploration and exploitation environments. The specific

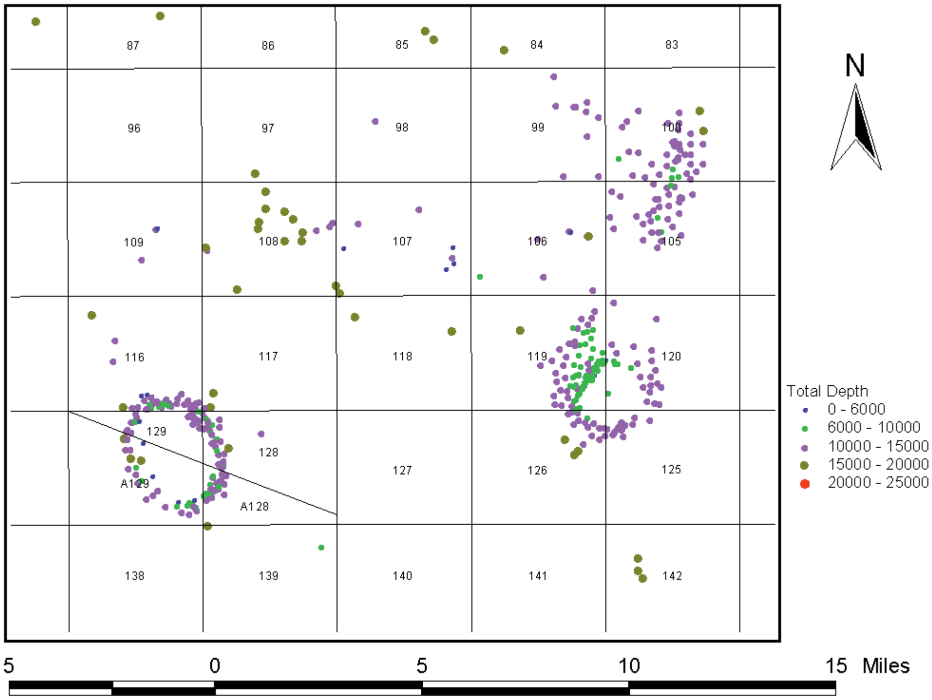

Figure 1—A Gulf of Mexico base map of wells classified by total depth drilled (includes data supplied by Petroleum Information/Dwights and Whitestar Corporation).

processes and applications of the technology will vary depending on the task or project and on the type and size of the databases involved. Although GIS can be effectively applied throughout petroleum industry settings, its implementation in exploration and exploitation is of particular interest.

Exploration Applications

GIS is a powerful tool for petroleum exploration, particularly with regard to exploration mapping. Such mapping is usually performed across large geographic areas, where many data sets or map layers are used in the analysis of hydrocarbon potential. Raster data, such as aerial photos or satellite imagery, can be incorporated with vector data, and surface culture, such as hydrography, elevation contours, and topographic landmarks or points of interest, can be presented. Where appropriate, coordinates from land surveys, such as section, township, and range, can be integrated with well data.

In exploration applications, one of the first steps taken is the creation of reconnaissance maps. Such maps are typically produced relative to the available well or well layers, with the sizes of the well data sets being dependent on the maturity of the area or basin of interest. Reconnaissance maps of mature exploration areas can present distinct trends, patterns, and anomalies.

Maps of the following features and characteristics should be included in the first phase of any exploration reconnaissance mapping program:

- Total depth
- Spud or completion date
- Well operator identification
- Producing formation
- Cumulative production
- Initial potential
- Well classification

Such maps are discussed in more detail in following paragraphs. A map of total depth can quickly identify where shallow and deep drilling has occurred over a basin, trend, or field, and apparent trends, patterns, and anomalies can be identified. Figure 1 is a total depth map for an area in the Gulf of Mexico for which well layers have been classified according to driller's total depth of the well. In this example, the symbology creates circular patterns in which the deeper wells are indicated on the flank of the salt dome structures. Deeper drilling potential can be identified in between salt dome structures.

Spud date maps represent a chronological history. Figure 2 is a spud date map for an area in northern Louisiana. Using this map, it can be determined when and where drilling has taken place. Such a map is useful when an interpreter has just started evaluating a new trend or basin because it represents a chronological history of the area. Figure 3 shows a similar map filtered in such a way that only wells drilled in the 1990s are represented. This type of map is very effective for evaluating recent activity in an area of interest because remote drilling locations and areas of dense drilling are apparent.

Operator maps contain symbology that identifies and denotes various well operators. Figure 4 is an operator map for an area in the Gulf of Mexico showing the location of wells operated by Shell Oil, Mobil

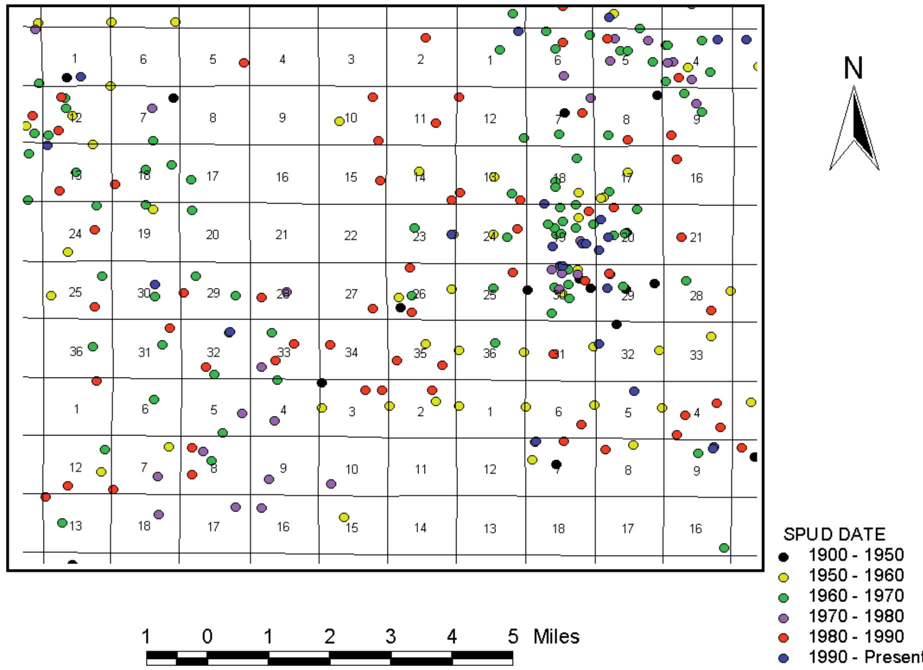

Figure 2—A northern Louisiana base map of wells classified by spud date drilled (includes data supplied by Petroleum Information/Dwights and Whitestar Corporation).

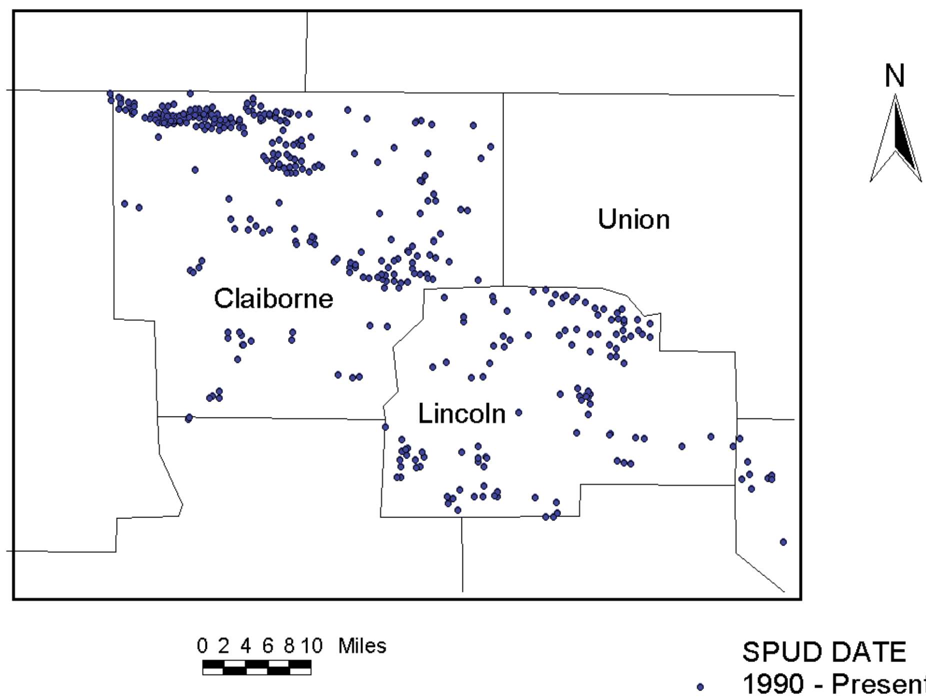

Figure 3—A northern Louisiana base map of wells filtered by spud date to display only wells drilled after 1990 (includes data supplied by Petroleum Information/Dwights).

Oil (now ExxonMobil), and Phillips Petroleum. These maps can be used to locate where competing companies are drilling wells. They can also be used to support the process of evaluating producing properties for acquisition purposes. The map in Figure 4 has been filtered to show only the wells drilled by the three specific operators.

When evaluating a new trend or basin, one of the first steps necessary is to determine which geologic formations produce hydrocarbons and where the production is located. If the production has been assigned to a formation name or code in the database, the production can then be mapped or symbolized according to its producing formation. Figure 5 is a production map of the Cotton Valley, Hosston, and Smackover horizons in northern Louisiana. A strike-trending pattern following deep, strike-trending fault blocks in the

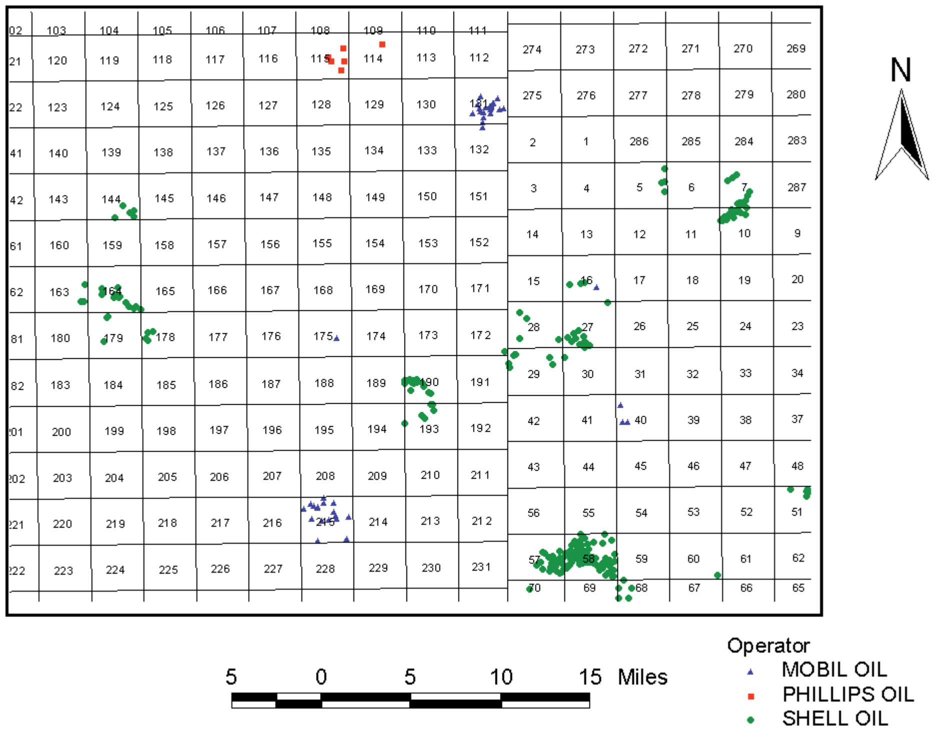

Figure 4—A Gulf of Mexico base map of wells restricted to three well operators (includes data supplied by Petroleum Information/Dwights and Whitestar Corporation).

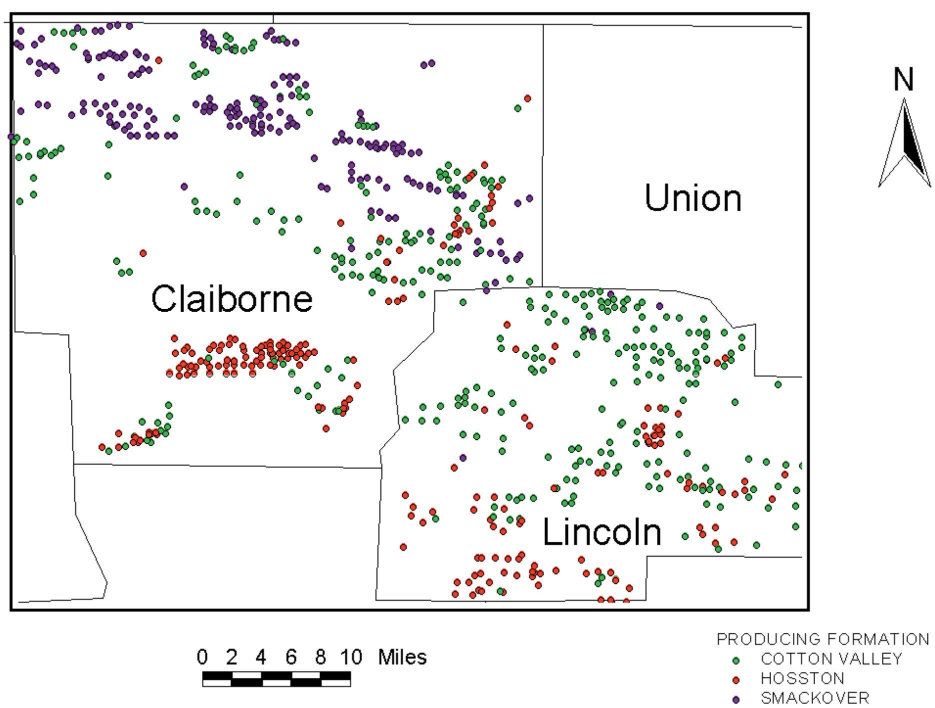

Figure 5—A northern Louisiana base map of wells restricted to three producing formations (includes data supplied by Petroleum Information/ Dwights).

Smackover Formation is represented by the symbology. As the map shows, the production from the Hosston Formation occurs in dense well patterns or clusters, and production from the Cotton Valley Formation occurs randomly across the map without any clear trend or pattern.

Once production has been identified, it can be integrated with a geological structure map (Figure 6). When the geological structure and production are integrated, the structural positions of individual wells can be evaluated. Figure 6 shows that the Hosston production typically occurs within a structural closure,

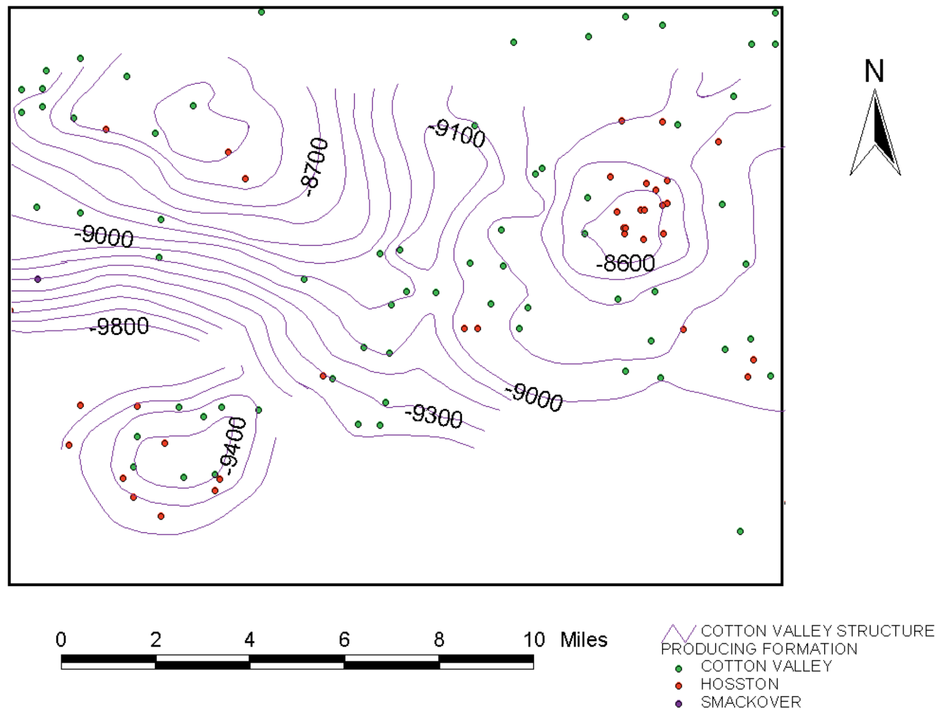

Figure 6—A northern Louisiana Cotton Valley structure map integrated with wells restricted to three producing formations (includes data supplied by Petroleum Information/ Dwights).

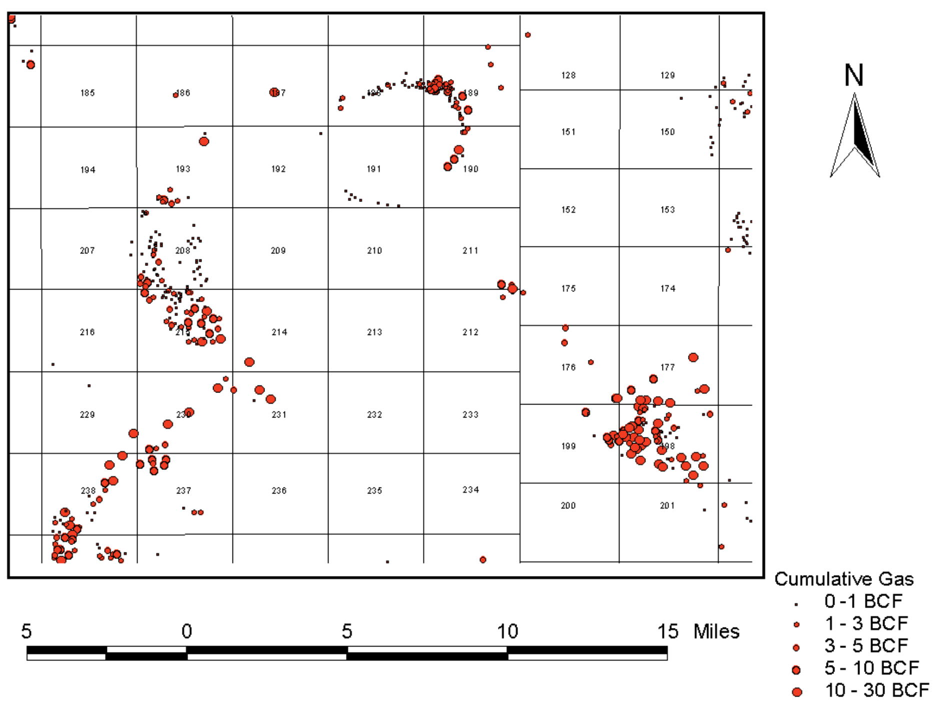

Figure 7—A Gulf of Mexico well base map of wells classified by cumulative gas production (includes data supplied by Petroleum Information/Dwights and by Whitestar Corporation).

whereas the Cotton Valley production also occurs within closures but somewhat randomly across the structure. Such a map can be used to quickly identify undrilled or untested areas.

A second step in evaluating production is to assess the cumulative total production in various wells. Spatial representation of cumulative well production can be very revealing, and trends, patterns, and anomalies can become apparent. Figure 7, a map of cumulative gas production in Gulf of Mexico wells, exhibits both unique patterns and anomalies. The most apparent pattern is a circular one representing

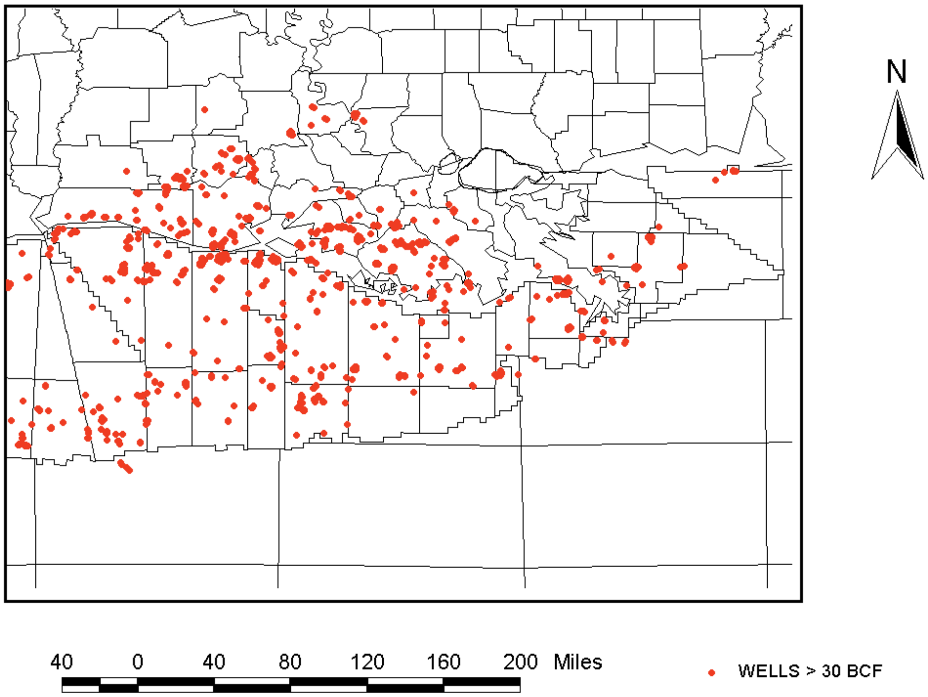

Figure 8—A Gulf of Mexico well base map restricted to wells whose cumulative gas production exceeds 30 billion ft^3 (includes data supplied by Petroleum Information/Dwights and by Whitestar Corporation).

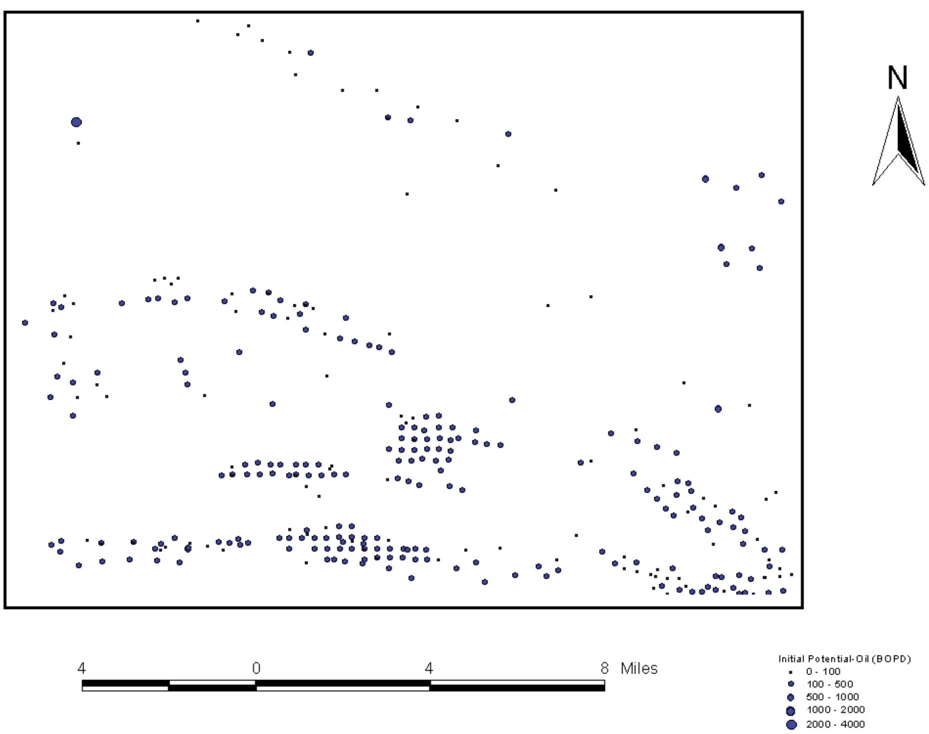

Figure 9—A southern Louisiana base map showing wells classified according to initial oil potential (includes data supplied by Petroleum Information/Dwights).

production on the flank of a salt dome in blocks 188, 189, 190, and 191. Most interesting is the fact that the amount of production around the salt dome varies significantly. For example, the southwestern flank of the dome is much less productive than the northeastern flank.

Because of the variation in production, the map in Figure 7 warrants further investigation. Blocks 187 and 193 each contain two wells that are apparently anomalous. These wells are prolific producers but are not offset by many wells. In contrast, the southeastern corner of block 211 has significant production over a

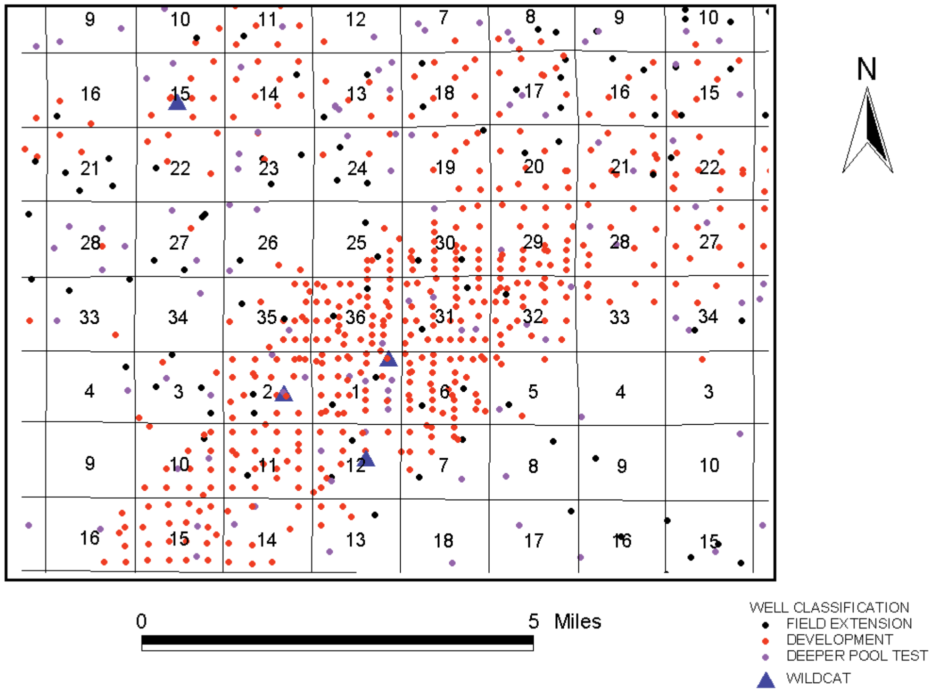

Figure 10—A northern Louisiana base map of wells by classification (includes data supplied by Petroleum Information/ Dwights).

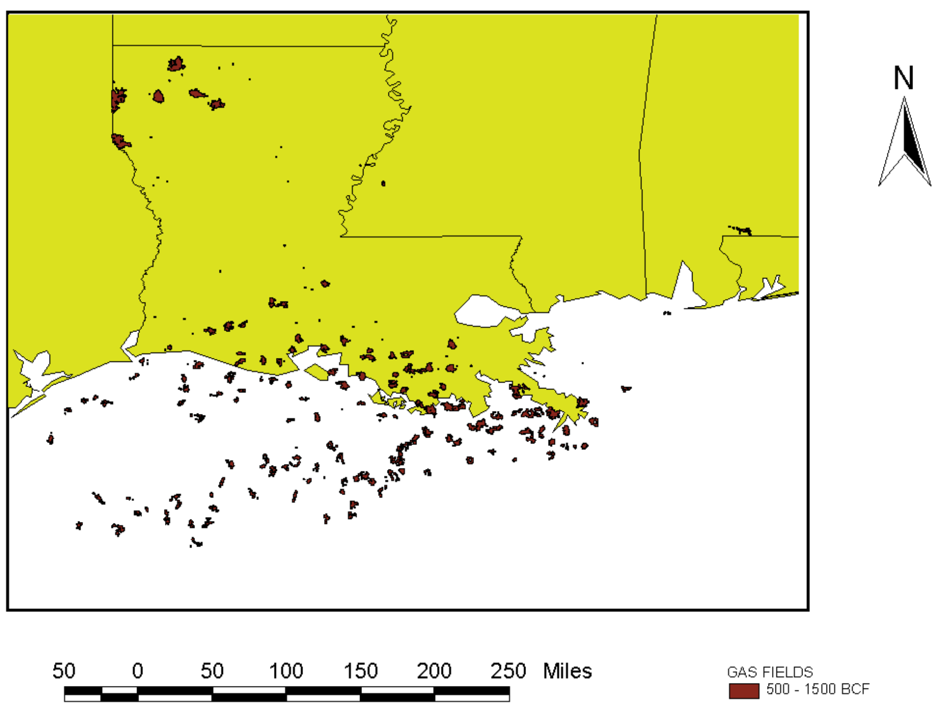

Figure 11—A Louisiana and Gulf of Mexico field map showing fields that have produced over 500 billion ft^3 of gas (includes data supplied by Petroleum Information/Dwights).

small geographic area, possibly suggesting that there may be more potential reservoirs such as these.

Cumulative production can also be evaluated over an entire basin. The map in Figure 8 shows all wells that have produced over 30 billion ft^3 of gas in southern Louisiana and the offshore Louisiana shelf. The symbology reveals clusters of prolific producing wells, along with wells exhibiting anomalous production levels in remote areas. Large geographic areas, which are void of any significant well production, are also evident. Consequently, a map produced at the basin or trend scale can be extremely informative and can reveal new areas for exploration or data acquisition.

Once cumulative production has been evaluated, well rates or initial potentials should be analyzed. Figure 9, an oil initial potential map for an area in southern Louisiana, shows both consistent patterns and a significant anomaly. The pattern is a west-to-southeast strike trend likely resulting from down-to-the-basin expansion faulting. The wells in the southern one-half of the map are more closely spaced than those in the northern one-half. However, a significant anomaly is indicated in the northwestern corner of the map, where there is a well with high initial potential offset by only one other well. This area warrants further investigation. Initial potentials in the southern portion are fairly consistent.

When evaluating a new trend or basin, it is informative to know how wells were classified when they were drilled. Typical classifications might be wildcat, development, deeper pool test, or field extension (Figure 10). A well classification map can illustrate where the wildcats have been drilled and how fields have been extended and developed through time. Figure 10 indicates that four wildcats were drilled in this area and significant development of the field followed. Many deeper pool tests were attempted across the entire area.

GIS can be an effective exploration tool at either the basin, trend, or field level because it is not limited to a specific geographic area or map scale. Figure 11 is an example of a map created to evaluate the gas field sizes in the southeastern Gulf Coast Basin. This map is filtered on cumulative gas production, and only fields that have produced over 500 billion ft^3 are presented. Such a map would illustrate a basin-scale evaluation. The location of producing fields can additionally be integrated with regional geological features to present a basin-level picture (Figure 12). The impact of geological features can then be evaluated relative to the size and location of existing fields.

Raster data, such as aerial photographs and satellite imagery, can provide powerful backdrops to cartographic map layers consisting of field outlines and well locations. The integration of a raster backdrop enables the interpreter to compare surface expression with the subsurface. For example, digital aerial photographs can be very useful for the design of 3-D seismic surveys when superimposed on a conventional map. Figure 13 illustrates the integration of LandSat imagery and well data for the design of a 3-D seismic survey. In this instance, the hydrography, or water bodies, can be evaluated for their impact on seismic acquisition, and future well locations can be sited based on the proximity to such entities.

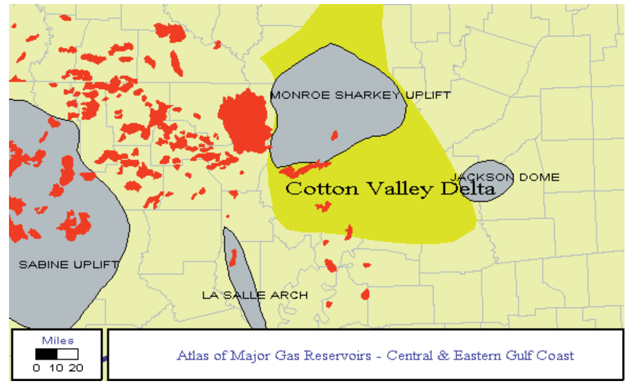

Figure 12—A northern Louisiana basin map presenting major gas fields and regional geology (after Gas Research Institute, 1998).

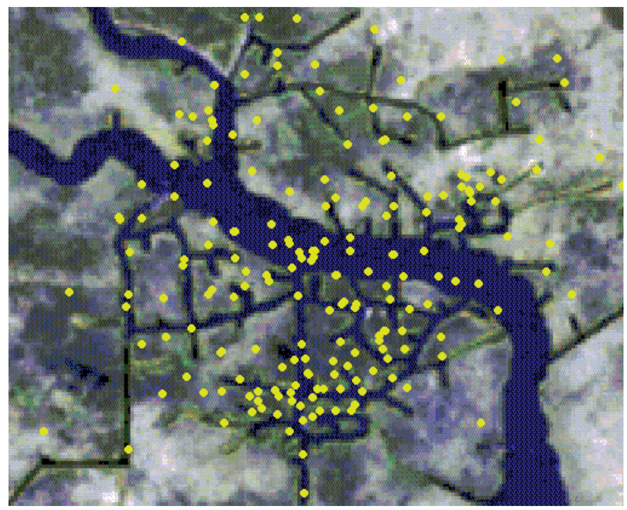

Figure 13—LandSat image superimposed on a southern Louisiana base map of wells (includes data supplied by Petroleum Information/Dwights).

Exploitation Applications

Exploitation evaluation typically deals with much larger datasets than those used in exploration settings. Exploitation approaches are generally applied to mature producing areas where well control is dense. As previously noted, the filtering capability of GIS can be useful in this environment because multiple types of maps on multiple horizons are generally required, and information from many diverse databases must be incorporated. In this situation, GIS technology can be more than just a mapping tool—it can be a powerful database management tool.

In field exploitation settings, integrating and overlaying multiple types of maps is essential. Figure 14 is a map from an area in southern Louisiana that incorporates three different map (data) layers: well locations, structure on top of the Oligocene Camerina sand, and fault locations. Note how database attributes, such as fault names or subsea formation tops, can be easily displayed as labels on the map. GIS functionality is a powerful technological tool that greatly extends the geoscientist's analysis capabilities beyond a conventional paper-based geologic map.

Another type of map frequently used in exploitation is the sand isopach map. Figure 15 is a typical map that has been constructed using GIS that integrates three

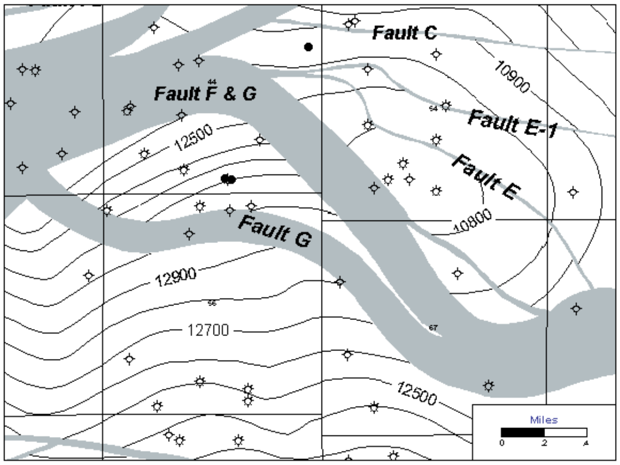

Figure 14—A southern Louisiana structure map on the Oligocene Camerina sand (includes data supplied by Petroleum Information/Dwights).

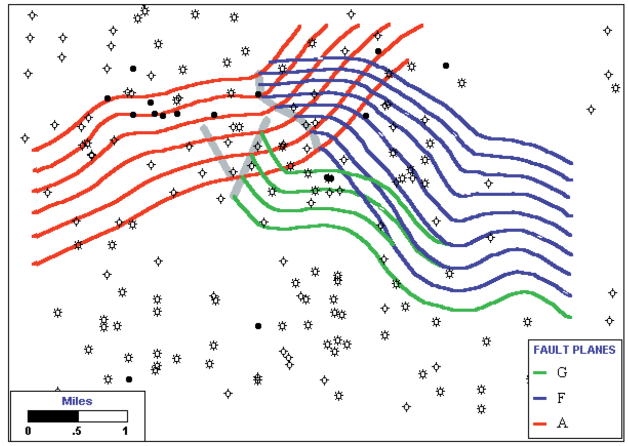

Figure 16—A southern Louisiana map of fault planes classified by fault name (includes data supplied by Petroleum Information/Dwights).

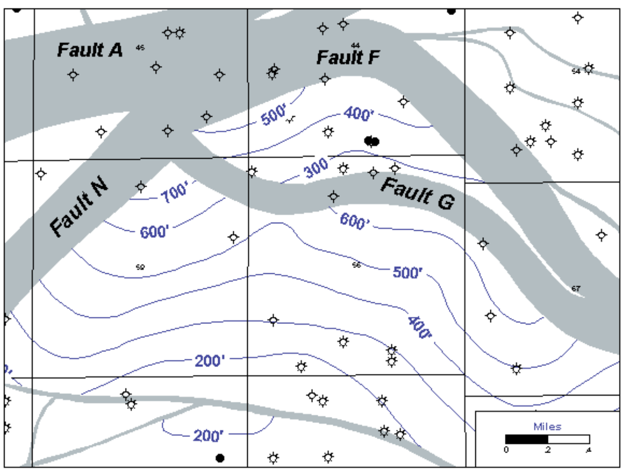

Figure 15—A southern Louisiana Oligocene Camerina sand, isopach map (includes data supplied by Petroleum Information/Dwights).

different map layers: well locations, sand isopach contours, and fault locations. Using such a map, spatial relationships between wells and sand thickness can be evaluated. The direct integration of the three data layers is nearly instantaneous using GIS; and more important, it is repeatable, leading to more productive use of the analyst's time than does conventional mapping.

Fault plane maps are also frequently generated in the exploitation process. These maps are typically very complex and again require the integration of several data layers. Figure 16 illustrates the results of having created a fault plane map using GIS where the symbology distinguishes individual fault plane contours. Note how the color symbology creates a much clearer picture of the intertwined fault contours. In the past, fault plane maps were created by overlaying multiple hardcopy maps on a light table; but with GIS, this exercise is performed dynamically on the computer. Using additional computational techniques, the resulting fault plane map is subsequently intersected with the structure contours to create the faults.

Assessment of reservoir volume and drainage area is an important part of the exploitation process. Figure 17 is a map of a gas field developed on 40-ac spacing in which the tools of GIS have been used to create buffers, or circular rings, around individual wells. Buffers are circles calculated around a point that create a visual tool for clearly identifying possibly undrained or overdrilled reservoir acreage. Having created such a map, the well spacing can be evaluated to determine whether the reservoir has been efficiently produced.

Calculating reservoir volumetric size can be achieved using GIS functionality by dynamically integrating and overlaying structure and net sand maps to produce a net pay contour map (Figure 18). The net pay contours are created as polygonal features so that the area of the polygon can be automatically calculated by the GIS. Such maps can be edited on-screen, which leads to dynamic calculation and what-if analysis of new net pay contour areas.

CONCLUSION

GIS is a particularly effective technology that enables petroleum exploration and exploitation teams to share information, analyze data in new ways, and integrate the evaluation process. Multidisciplinary teams are now present in most exploration and exploitation departments. Technological tools, such as GIS, play a vital role in the team-based approach to upstream problem solving. In particular, the application of map symbology enables geoscientists from various disciplines to more productively visualize data, examine spatial relationships, and compare and integrate interpretations. Such an approach enhances the overall problem-solving process.

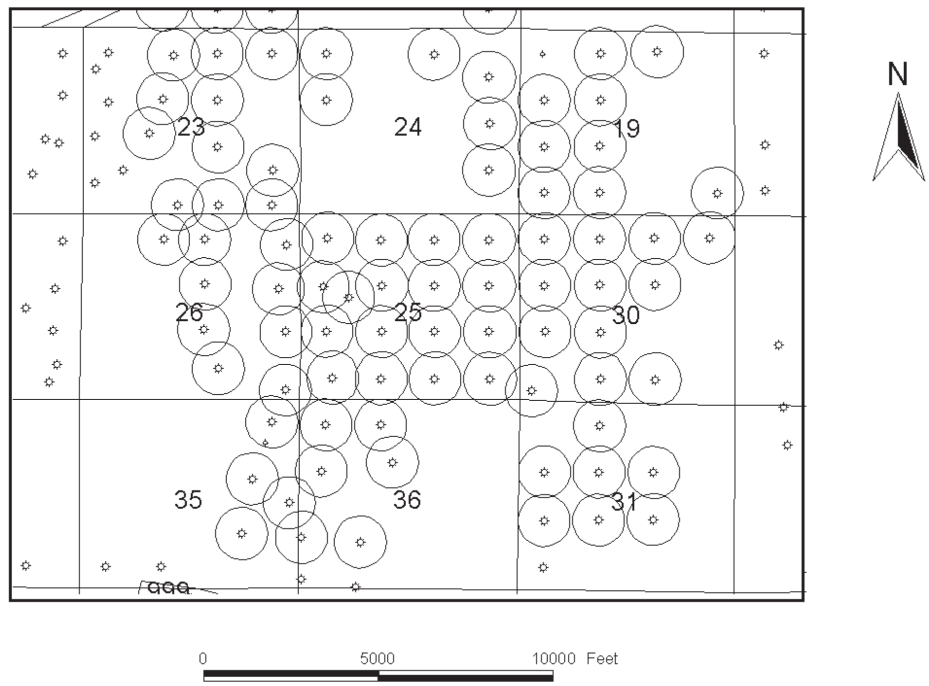

Figure 17—A northern Louisiana base map of wells showing 40 ac drainage buffers (includes data supplied by Petroleum Information/Dwights).

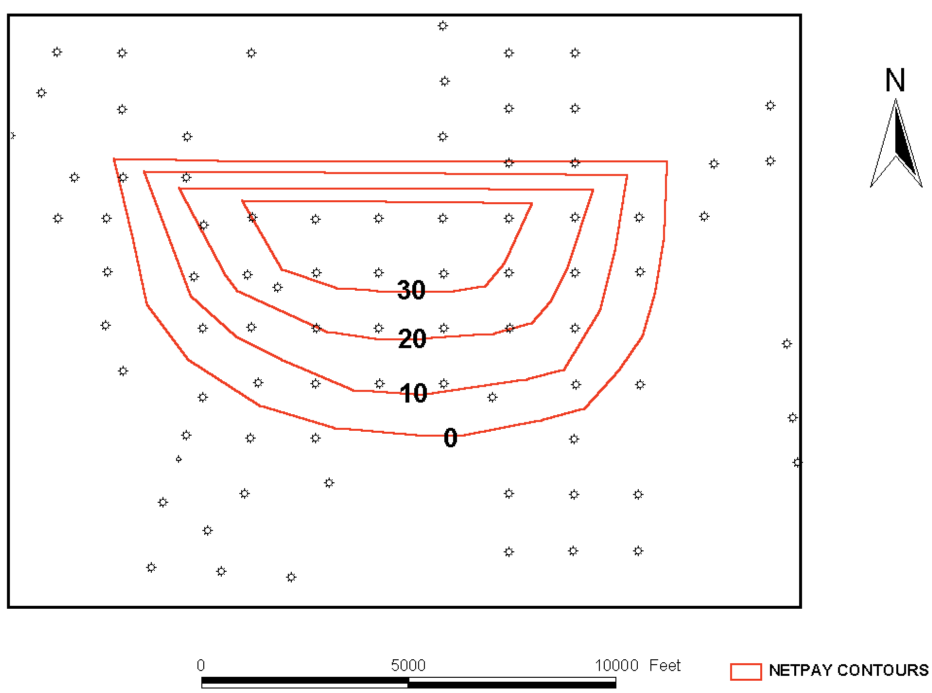

Figure 18—A northern Louisiana net pay contour map (includes data supplied by Petroleum Information/Dwights).

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