RESERVOIR CHARACTERIZATION OF THE LOWER GREEN RIVER FORMATION, SOUTHWEST UINTA BASIN, UTAH

Biannual Technical Progress Report

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TABLE OF CONTENTS

ILLUSTRATIONS

ABSTRACT

Oil productive beds in the Green River Formation in the southwest Uinta Basin have been grouped into reservoirs based on similar reservoir properties and paleodepositional history. We are currently mapping the reservoir trends and properties which will define the limits of reservoirs and identify possible new play areas. The reservoirs in stratigraphically ascending order are: (1) Uteland Butte, (2) Castle Peak, (3) lower Douglas Creek, (4) upper Douglas Creek, and (5) lower Garden Gulch.

Numerous reservoir simulation models were run to determine the impact of hydraulic fractures on the hydrocarbon recovery from the C and D sands in the upper Douglas Creek reservoir in the Monument Butte Northeast unit. Hydraulic fractures must be included in the model to obtain a reasonable match between the simulated production and the actual production. The hydraulic fractures definitely improve the reservoir performance during primary production, but are of questionable value during the secondary recovery (waterflood) phase of production. Additional simulations are needed to determine if not hydraulically fracturing the wells could actually result in increased total hydrocarbon recovery (primary + secondary).

EXECUTIVE SUMMARY

The objectives of the study are to increase both primary and secondary hydrocarbon recovery through improved characterization (at the regional, unit, interwell, well, and microscopic scale) and numerical simulation modeling of fluvial-deltaic lacustrine reservoirs, thereby preventing premature abandonment of producing wells. The study will encourage exploration and establishment of additional waterflood units throughout the southwest region of the Uinta Basin, and other basins with production from fluvial-deltaic reservoirs.

Accomplishments that were discussed in previous reports (Morgan, Chidsey, and others, 1999a; 1999b; Morgan, McClure, and others, 2000a; 2000b; 2001; Morgan, 2001) are:

1. established log-based correlation scheme and nomenclature,
2. correlated more than 1,300 wells,
3. entered the correlations into the well database (available to the public on the project web page),
4. constructed preliminary regional maps,
5. completed the geologic characterization of three fields,
6. measured, described, and gathered spectral gamma-ray data from numerous stratigraphic sections in Willow Creek Canyon, Nine Mile Canyon, and Desolation Canyon,
7. correlated the stratigraphic sections to neighboring well logs,
8. developed a detailed two-dimensional geologic model (Nutter's Ranch study site) from surface exposures,
9. described the lithology and interpreted the depositional environments in cores from 32 wells,
10. completed the numerical simulation modeling of the Monument Butte Northeast waterflood unit, and
11. continued the activities of the technology transfer program.

Accomplishments for the period October 1, 2001 through March 31, 2002 are listed below.

1. Constructing and interpreting regional structure and isochore maps, defining major reservoirs and associated systems tracts.
2. Began numerical simulation modeling of the Uteland Butte field.
3. Developed an Acrobat file on CD-ROM containing all of the descriptions of the well core that was studied. Each well has a sheet with graphical and written descriptions of the well core, with corresponding porosity, permeability, gamma-ray, neutron-porosity, and density-porosity curves. The core descriptions have hyperlinks to photographs of the core and thin sections.
4. Digitized published fault traces and faults mapped as part of this project, and entered digital traces into the GIS project file.
5. Technology transfer activities consisted of: (1) publications by Morgan and others (2002) and Bon (2002), (2) displaying project material at the American Association of Petroleum

Geologists (AAPG) National Convention in Houston, Texas, (3) submission of two abstracts to the AAPG for presentation at the Rocky Mountain Section meeting in Laramie, Wyoming, and (4) participation in the Uinta Basin Oil and Gas Collaborative Group quarterly meeting in Vernal, Utah.

INTRODUCTION

Geologic Setting

The Uinta Basin is a topographic and structural trough encompassing an area of more than 9,300 square miles (14,900 km^2) in northeast Utah (figure 1). The basin is sharply asymmetrical, with a steep north flank bounded by the east-west-trending Uinta Mountains, and a gently dipping south flank.

The Uinta Basin formed in Paleocene to Eocene time, creating a large area of internal drainage which was filled by ancestral Lake Uinta. Deposition in and around Lake Uinta consisted of open- to marginal-lacustrine sediments that make up the Green River Formation. Alluvial red-bed deposits that are laterally equivalent to, and intertongue with, the Green River make up the Colton (Wasatch) Formation.

More than 450 million barrels of oil (million BO) (72 million m^3) have been produced from the Green River and Colton Formations in the Uinta Basin. The Cedar Rim, Altamont, Bluebell, and Red Wash fields produce oil from the northern shoreline deposits of Lake Uinta, while the fields in the Monument Butte area produce from southern deltaic shoreline deposits as preserved in the middle and lower members of the Green River. The southern shore of Lake Uinta was often very broad and flat, which allowed large transgressive and regressive shifts in the shoreline in response to climatic and tectonic-induced rise and fall of the lake. The cyclic nature of Green River deposition in the Monument Butte area resulted in numerous stacked deltaic deposits. Distributary-mouth bars, distributary channels, and nearshore bars are the primary producing sandstone reservoirs in the area.

Project Status

Most of the technical investigation has been completed. The majority of the current effort is now spent on finalizing cross sections, maps, and figures, and interpretation of the data and writing up the results. Reservoir simulation modeling of the Uteland Butte and Brundage Canyon fields is continuing as well as the research on the effects of hydraulic fractures on reservoir performance.

Log cycles have been combined into reservoirs, and regional maps of reservoir and sandstone thickness have been constructed. The maps are being used for interpretation of depositional trends that can be used to identify potential new play areas.

Editing of the core descriptions is complete and a draft of the final report has been reviewed. We developed an Acrobat file on CD-ROM containing all of the descriptions of the

well core. This file will be a part of the digital GIS final report of the southwest Uinta Basin.
Each well has a sheet with graphical and written descriptions of the well core, with
corresponding porosity, permeability, gamma-ray, neutron-porosity, and density-porosity curves.
The core descriptions have hyperlinks to photographs of the core and thin sections.

Geological characterization of three oil fields, (1) Monument Butte Northeast, (2)
Uteland Butte, and (3) Brundage Canyon, has been completed. These data were used to construct
a numerical simulation model of the Monument Butte Northeast waterflood unit and will be used
to construct models for the Uteland Butte and Brundage Canyon oil fields. Production history
curves for the three fields studied and most of the other waterflood units in the area, have been
updated and will be included in the final report.

A study site was selected to better understand the interwell-scale reservoir heterogeneity
of one depositional cycle. The site, referred to as the Nutter's Ranch study site, lies along Nine
Mile Canyon from Petes Canyon to Gate Canyon, both tributaries to Nine Mile Canyon (Morgan
and others, 1999b). A two-dimensional interpretation of the strata studied was developed
(Morgan and others, 2000b) and was presented to the Technical Advisory Board during a fall
field review and later published in *Survey Notes* (Morgan and others, 2002). The photomontages
and measured sections in Petes Canyon and Gate Canyon are completed and a three-dimensional
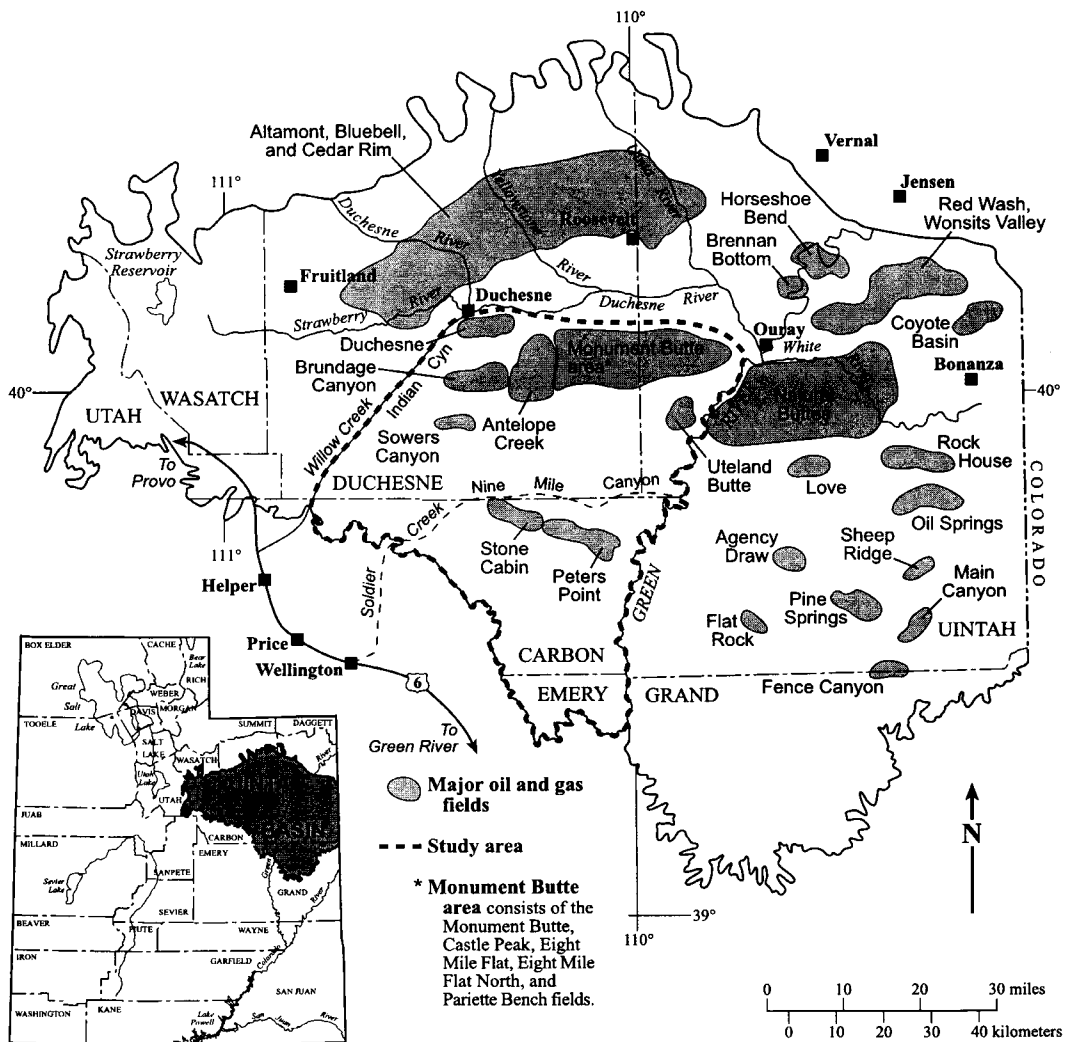geologic model is being constructed.

Figure 1. Index map of the Uinta Basin, Utah, showing study area and major oil and gas fields.

DEFINITION OF OIL RESERVOIRS IN THE SOUTHWEST UINTA BASIN

The primary oil-productive beds in the lower and middle members of the Green River Formation can be grouped into five reservoirs based on depositional environment, porosity, permeability, lithology, and other producing characteristics. The reservoirs in ascending stratigraphic order are: (1) Uteland Butte, (2) Castle Peak, (3) lower Douglas Creek, (4) upper Douglas Creek, and (5) lower Garden Gulch.

The lower member consists of the Uteland Butte and Castle Peak reservoirs. The Uteland Butte reservoir is named after the Uteland Butte field, and is a carbonate sequence interbedded with thin shale and sandstone beds. The Castle Peak reservoir is named after the Castle Peak field, and overlies the Uteland Butte reservoir. The Castle Peak produces from channel sandstone beds that are interbedded with limestone and shale.

The middle member is equivalent to the Douglas Creek and Garden Gulch Members of the Green River Formation of the eastern Uinta Basin. The Douglas Creek is divided into a lower Douglas Creek reservoir of thick (often 100+ feet [30+ m]), but narrow, cut-and-fill sandstone beds, and an upper Douglas Creek reservoir of amalgamated, lower delta plain, channel sandstone beds. The lower Garden Gulch reservoir consists of isolated individual channel to shallow bar sandstone deposits.

The Uteland Butte is the most widely distributed reservoir, but generally only produces 30 to 60 thousand barrels of oil (MBO) (4,800 – 9,500 m^3) per well. The sandstone in the Castle Peak reservoir typically has low porosity/permeability and is dependant on fractures for good production. The sandstone in the lower Douglas Creek reservoir has complex internal heterogeneity causing low productivity. The upper Douglas Creek is the most widespread oil-producing reservoir in the southwest Uinta Basin. The lower Garden Gulch reservoir consists of a few isolated beds, resulting in low oil recovery.

INCORPORATION OF HYDRAULIC FRACTURES IN THE MONUMENT BUTTE NORTHEAST RESERVOIR SIMULATION MODEL

Simulations in the C and D sands (upper Douglas Creek reservoir) of the Monument Butte Northeast waterflood unit were reported in Morgan and others (2001). One section in the Monument Butte Northeast unit was chosen for simulation. The domain is a 5,200-foot (1,580 m) by 5,200-foot (1,580-m) grid with 20 grid blocks each in the x and y directions. The reservoir was divided into 13 vertical layers with varying thicknesses. The reservoir description was provided in Morgan and others (2001). There are 16 wells located on a 5-spot pattern. Initially, all the wells act as producers before water injection begins. Reservoir simulation studies yielded a good history match of oil production in the D sands.

All of the wells in this unit and in most of the greater Monument Butte area are hydraulically fractured. The objective of this part of the study was to examine the impact of the presence of hydraulic fractures in the reservoir. The hydraulic fractures were inserted in blocks containing the wells. Even though all the wells are fractured, in this study, fractures were added to wells which later were converted to injectors. This was for the computational and total grid blocks limitation of the simulator. Based on simulations of reservoir stimulations and rock

mechanics, we know that the hydraulic fractures are vertical, disc shaped, and extend about 200 feet (60 m) beyond the well bore on either side.

The following procedure was used to incorporate hydraulic fractures in the reservoir model. There are a total of 16 wells in the section. The general practice is to produce the wells for a period of time and convert every other well to an injector. Thus, when waterflood begins there are eight injectors and eight producers in a five-spot pattern. All of the wells are hydraulically fractured. Hydraulic fractures were incorporated in the wells that acted as producers and injectors. The number of grid blocks would have exceeded the limits of the simulator, had all 16 hydraulic fractures been incorporated in the model. This will be examined with a bigger version of the simulator in the next report. The hydraulic fracture was approximately 158.5 feet (48.3 m) in length and its height spanned the perforated sand thickness. The fracture block was about 0.45 feet (0.14 m) in width. This was the smallest refinement that the simulator would allow. The width of the hydraulic fracture cannot be set to a finite value and is based upon the local grid refinement of a grid block approximately 264 feet (80.5 m) in length and width. The block was refined into five blocks each in the x and y direction (figure 2).   The 2nd, 3rd, and 4th blocks in the middle row in the x direction were further refined to five blocks in the x direction. The middle row of the resulting blocks was further refined and this procedure was carried out until the smallest refinement was slightly greater than the diameter of the well. This procedure and the final dimensions are shown in figure 3. With this refinement there were a total of 8,700 grid blocks.

The smallest refinement thus obtained was nearly 0.45 feet (0.14 m) in width. All the layers in which the wells were completed were refined to the dimensions stated above. Thus, the fracture was represented by the smallest refined block containing the well and one refined block on either side of the block containing the well. The fracture was represented by a high permeability zone and a permeability of 1,000 millidarcies (md) was assigned to each of the refined blocks representing the fracture. It should be noted that the matrix permeability varied over a range of about 0.1 to 50 md. The porosity was the same as the original refined block. All other properties were identical to the original simulation file.

Based on the simulation runs the cumulative oil production from the D sands during the primary recovery was 59.209 thousand stock tank barrels (MSTB) (9,414.2 m^3) while that from the model incorporating hydraulic fractures was 73.390 MSTB (11,669.0 m^3). Similarly the gas production increased from 33.50 to 58.33 million standard cubic feet (MMSCF) (938,000 - 1,633,000 m^3). This was a sizeable increase in production and reiterates the hypothesis that the inclusion of hydraulic fractures has significant impact on the oil and gas production.

Backflow problems were encountered during secondary recovery; for example, when water injection begins, the water starts flowing into the injector. One of the reasons why this happens may be the small size of the refined block, which is preventing the injector well from injecting large amounts of water or building sufficiently high pressures.

The next strategy was to operate it under a bottom-hole pressure constraint rather than a flow constraint. A bottom-hole pressure of 6,000 pounds per square inch (psi) (41,000 kPa) was used as the upper limit. The cumulative oil production is shown in figure 4. The simulation results with hydraulic fractures are better during primary production. These results will continue to be better when fractures are added to the remainder of the wells. After water injection, the oil production increases to a greater extent compared to the simulation without fractures.

Unfortunately, a better comparison would have been when the fracture simulations could be performed at conditions identical to the nonfractured case, but this was not possible because of the backflow problems. The cumulative injection was about 150 MSTB (24,000 m^3) higher in this case, since it was controlled by the bottom-hole pressure constraint.

Another simulation was performed with 4,000 psi (28,000 kPa) bottom-hole pressure requirement on all injectors. This would require surface pressures of about 2,000 psi (14,000 kPa), which is realistic. The cumulative water injection in this case falls short by about 300 MSTB (48,000 m^3). It can be assumed that this water moves into other sands or outside of the pay zones. The oil production is better matched by in this simulation (figure 5). Again, we assumed that the rest of the sands make up the shortfall in oil production (figure 5). The gas production predicted by this simulation is off by about 50 percent. However, in comparison to simulations without fractures, there is an improvement of about 25 percent. By incorporating fractures in all of the wells, the gas production numbers are likely to increase significantly, providing a better overall match with all of the field numbers.

In the previous set of simulations, the field history match was attempted without making any adjustments to field input parameters. There is no significant latitude in these simulations to make adjustments. It was shown that by adjusting the amount of water that moves into the D sands, oil production history could be reasonably well matched. It was difficult to match the oil and gas production during primary production in these simulations. These simulations clearly show that inclusion of hydraulic fractures is phenomenologically essential in reproducing all of the field numbers.

It is also observed that hydraulic fractures definitely help during primary production. Comparison with simulations without fractures clearly shows that fractures are not that helpful in the secondary recovery phase. More analyses and simulations will be necessary to show if not fracturing the wells would actually help total recovery from the reservoir, if injectivity can be ensured in injection wells.
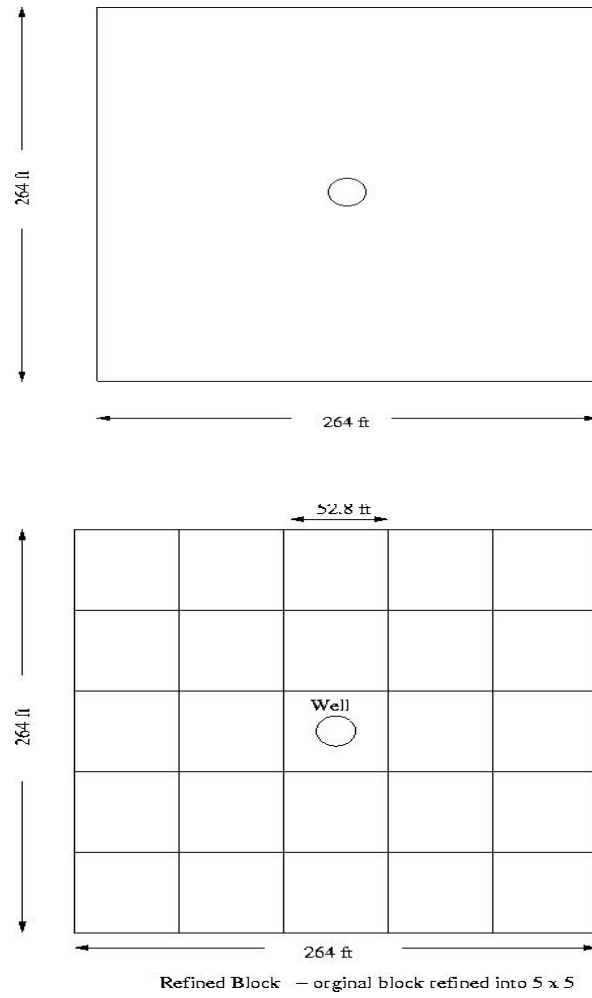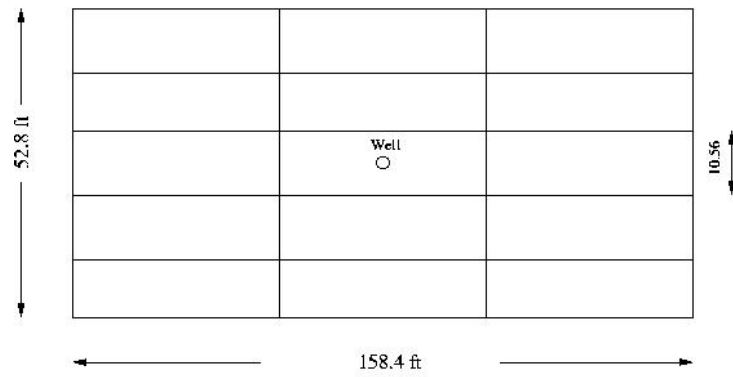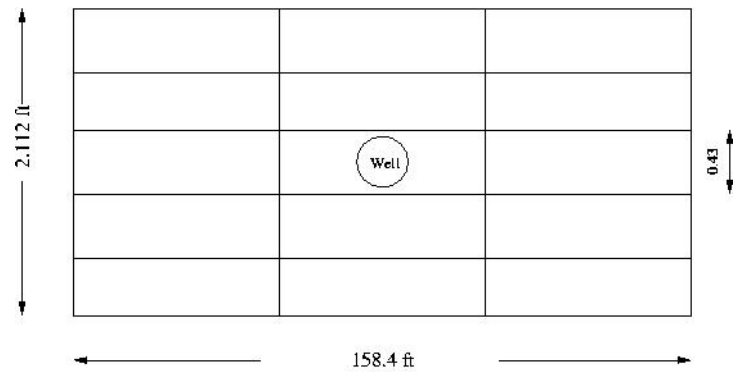
Figure 2. The parent block and the first level of refinement into a 5X5 grid are shown.

Refined Block – further refined into 1 x 5 blocks

Final level of refinement

Figure 3. Middle rows at the previous refinement level are further refined into more blocks in the y direction. The final level of refinement yields a 158.4-foot-long fracture block that is 0.43 foot wide.
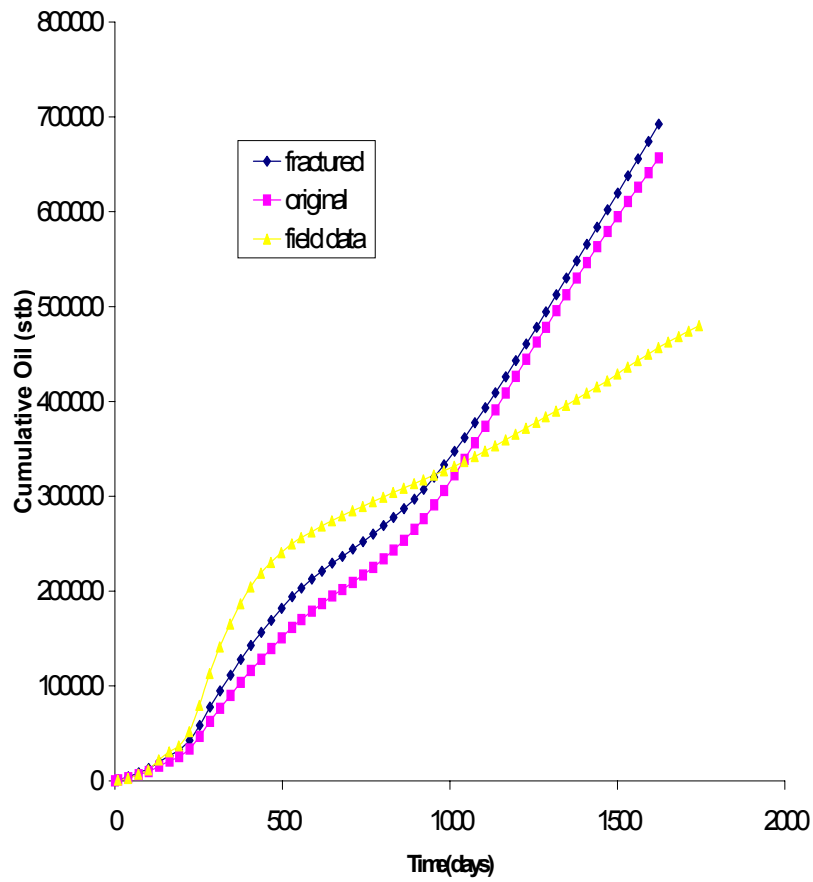
Figure 4. Comparison of cumulative oil production to the field data with and without hydraulic fractures in the injectors (bottom-hole pressure constraint 6,000 psi).
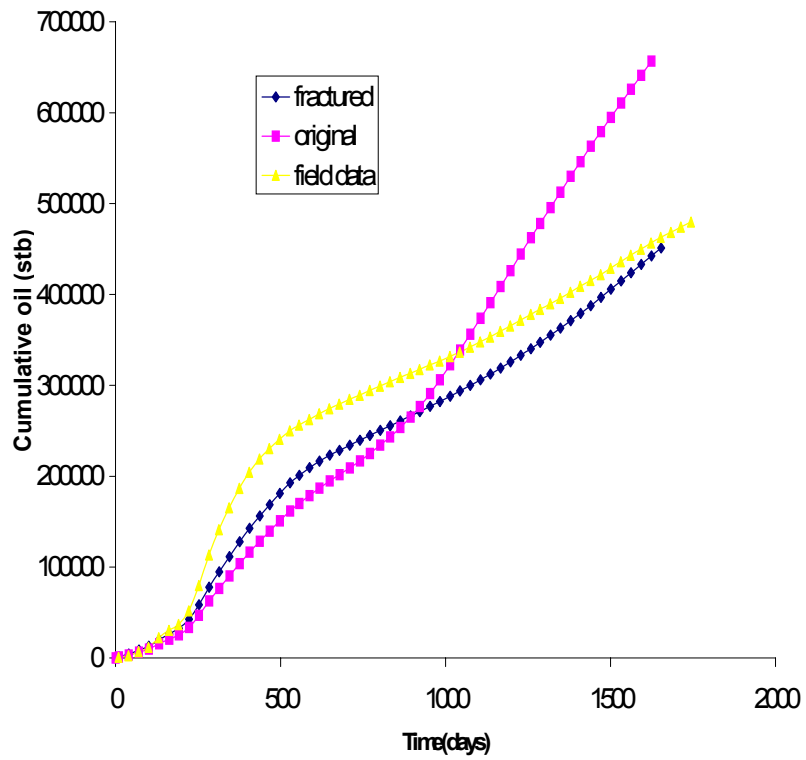
Figure 5. Comparison of cumulative oil production to the field data with and without hydraulic fractures in the injectors (bottom-hole pressure constraint 4,000 psi).

TECHNOLOGY TRANSFER

A copy of the Biannual Technical Progress Report for the period from April 1, 2001, to September 31, 2001, was sent to everyone on the project mailing list and then posted on the Utah Geological Survey (UGS) Green River Study website.

A project overview was displayed at the UGS exhibit booth during the AAPG Annual Convention, March 10 through March 13, in Houston, Texas.

A paper by Morgan and others (2002) describing the work at the Nutter's Ranch study site was published in the UGS *Survey Notes*. A paper by Bon (2002) discussed technology transfer activities and provided a general update of the project in the UGS *Petroleum News*.

Two abstracts were submitted to the AAPG for presentation at the Rocky Mountain Section meeting in Laramie, Wyoming, September 8 through September 11, 2002. One paper will discuss the definition and characterization of the reservoirs and the second paper will discuss fault styles. Both papers are a result of the work performed as part of this study.

The UGS maintains a Green River Study home page on its web site containing the following information: (1) an index map of the study area, (2) a copy of the proposal and statement of work, (3) each of the Biannual Technical Progress Reports, (4) an extensive selected reference list for the Uinta Basin and lacustrine deposits worldwide, and (5) the poster presented at the 2001 AAPG Annual Convention, in Denver, Colorado. The home page address is <***http://www.ugs.state.ut.us/greenriver/greenriv.htm*>** or <http://www.geology.utah.gov/emp/greenriver/index.html>.

FUTURE ACTIVITIES

The following work is planned for the period of April 1, 2002, through September 31, 2002:

(1) This will be the final two quarters (biannual period) of the contract; therefore, all remaining deliverables and required DOE reports will be submitted.
(2) The Biannual Technical Progress Report will be sent to all interested parties and posted on the project web site.
(3) The two-dimensional Nutter's Ranch geologic model will be expanded to three dimensions.
(4) The petrophysical report will be completed and submitted to the DOE.
(8) The geological characterization of the Uteland Butte and Brundage Canyon fields will be incorporated into the numerical reservoir simulation models for each of the fields.

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