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

Biannual Technical Progress Report

04/01/01 - 09/31/01

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ABSTRACT

The well database, consisting of more than 1,300 wells that penetrated the Green River Formation, was distributed to all members of the Technical Advisory Board for review and is now available at the project web page. Maps will be constructed using the well database. Maps of sandstone thickness and porosity trends of each log cycle defined in the database will be used to interpret paleodepositional environments and regional structural patterns. The interpretation of structure and depositional trends will increase our knowledge of the producing petroleum system, and hopefully identify new areas with exploration potential.

The D marker was mapped in Nine Mile Canyon. The sea-level elevations of the D marker have been entered into the well database and will be used in constructing the structure contour map of log-cycle MGR 3, the subsurface equivalent to the D marker. Additional work in the Nutter's Ranch area has extended the study site northward. The expansion will allow us to develop a three-dimensional geologic model that covers about 160 acres (64.8 ha), equal to a four-well producing area in Monument Butte field.

The primary producing beds (D-sands) in the Monument Butte field were numerically modeled using the Implicit-Explicit Black Oil Simulator®. We assume that about 82 percent of the oil production in the modeled area is from the D-sands. Modeling shows that only 49 percent of the injected water is going into, or flooding, the D-sands. The majority of the injected water is going into sandstone beds that contribute less than 20 percent to the total oil produced.

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 water-flood 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 and others, 1999a; 1999b; 2000a; 2000b; and 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, and
10. continued the activities of the technology transfer program.

Accomplishments for the period 04/01/01 through 09/31/01 are:

1. Additions and corrections are continuously being made to the well database. The locations and elevations of key beds exposed on the surface that have been correlated to well logs have been added to the well database. Construction and interpretation of structure and isochore maps using the current well database has started.
2. Numerical simulation modeling of the Monument Butte Northeast waterflood unit was completed and modeling of the Uteland Butte field has begun.
3. Additional stratigraphic sections have been measured and described in tributaries of Nine Mile Canyon and Desolation Canyon to improve the interpretation of facies changes in the south-to-north (proximal-to-distal) direction.
4. Stratigraphic sections at the Nutter's Ranch study site were photographed, measured, and described in Petes Canyon and Gate Canyon, both south-to-north tributaries to Nine Mile Canyon. The data from Petes Canyon and Gate Canyon will be used to expand the Nutter's Ranch two-dimensional geologic model to three dimensions. The Nutter's Ranch three-dimensional model will cover about 160 acres (64.8 ha) and will be used as an analog for fluid-flow modeling of Green River reservoirs.
5. Technology transfer activities consisted of an eight-day working field review in Desolation Canyon. The field trip reviewed work completed in 2000 and also resulted in additional stratigraphic sections being studied. The trip included representatives from the

U.S. Department of Energy (DOE) and industry geologists from the Technical Advisory Board. A meeting of the Technical Advisory Board was hosted by Inland Resources, in Denver, Colorado. S. Robert Bereskin and Craig Morgan presented a poster with core at the American Association of Petroleum Geologists Annual Convention in Denver, Colorado. A home page for the project is maintained on the UGS web site.

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

We are studying the Green River Formation on outcrop and in the subsurface to increase our knowledge of its reservoir characteristics, and to improve our ability to identify new play areas. We established a log-based correlation scheme and nomenclature that reflect, as near as possible, time-correlative depositional cycles of the middle and lower members of the Green River Formation (Morgan and others, 1999a). The regional correlation nomenclature will help identify which intervals are productive in the southwest Uinta Basin. The cycles are at a scale that is easily recognizable on geophysical well logs and can be correlated throughout most of the southwest Uinta Basin. More than 1,300 wells have been correlated and entered into the geographic information system (GIS) database and preliminary maps have been constructed. New wells have been added to the database and some correlations have been revised after consultation with some of the Technical Advisory Board members.

Cores from 32 wells in the project study area have been described and depositional environments interpreted. Porosity and permeability data were analyzed for facies and individual beds (Morgan and others, 2000a). Editing of the core descriptions is complete and a final report is being prepared.

Geological characterization of three oil fields, (1) Monument Butte Northeast, (2) Uteland Butte, and (3) Brundage Canyon, has been completed. Sandstone thickness, total feet of porous sandstone, and structural elevation of every productive bed in each of the three fields were determined and entered into the GIS database. We also determined porosity and fluid saturation from the geophysical logs at a 1-foot (0.3 m) scale for each bed. 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.

Previously, several stratigraphic sections in Willow Creek and Nine Mile Canyons were measured, described, and profiled with a spectral gamma-ray (GR) scintillometer. We generated curves from the outcrop GR data and correlated these to the geophysical logs of nearby wells. We also measured and described additional sections in Desolation Canyon and Trail Canyon, a tributary to Nine Mile Canyon. The Desolation Canyon section is the easternmost exposure studied. Detailed correlations between the various surface stratigraphic sections, and between the surface stratigraphic sections and the subsurface well logs, were made during the spring 2001 field season. We mapped the D marker (Remy, 1992), a prominent bed exposed in Nine Mile Canyon that correlates with the top of log cycle MGR 3, using a hand-held global positioning satellite (GPS) unit. The Universal Transverse Mercator (UTM) coordinates at the top of the bed were recorded and brought into ArcView along with graphic files of the 7.5-minute topographic maps; elevations were then determined from the topographic map. The coordinates and elevations from the D marker were entered into the well database and will be used in constructing a regional structure map of the MGR 3. We are gathering similar data on other beds that have been correlated to the well logs.

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 depositional interpretation of the strata studied was developed (Morgan and others, 2000b) and was presented to the Technical Advisory Board during a fall field review. The stratigraphic section has been photographed, and additional sections have been measured and described in both Petes Canyon and Gate Canyon. The data from Petes and Gate Canyons will be used to expand the Nutter's Ranch two-dimensional geologic model into a three-dimensional model. The three-dimensional model will cover about 160 acres (64.8 ha) and will be used as a reservoir analogue of the Monument Butte field for fluid-flow modeling.

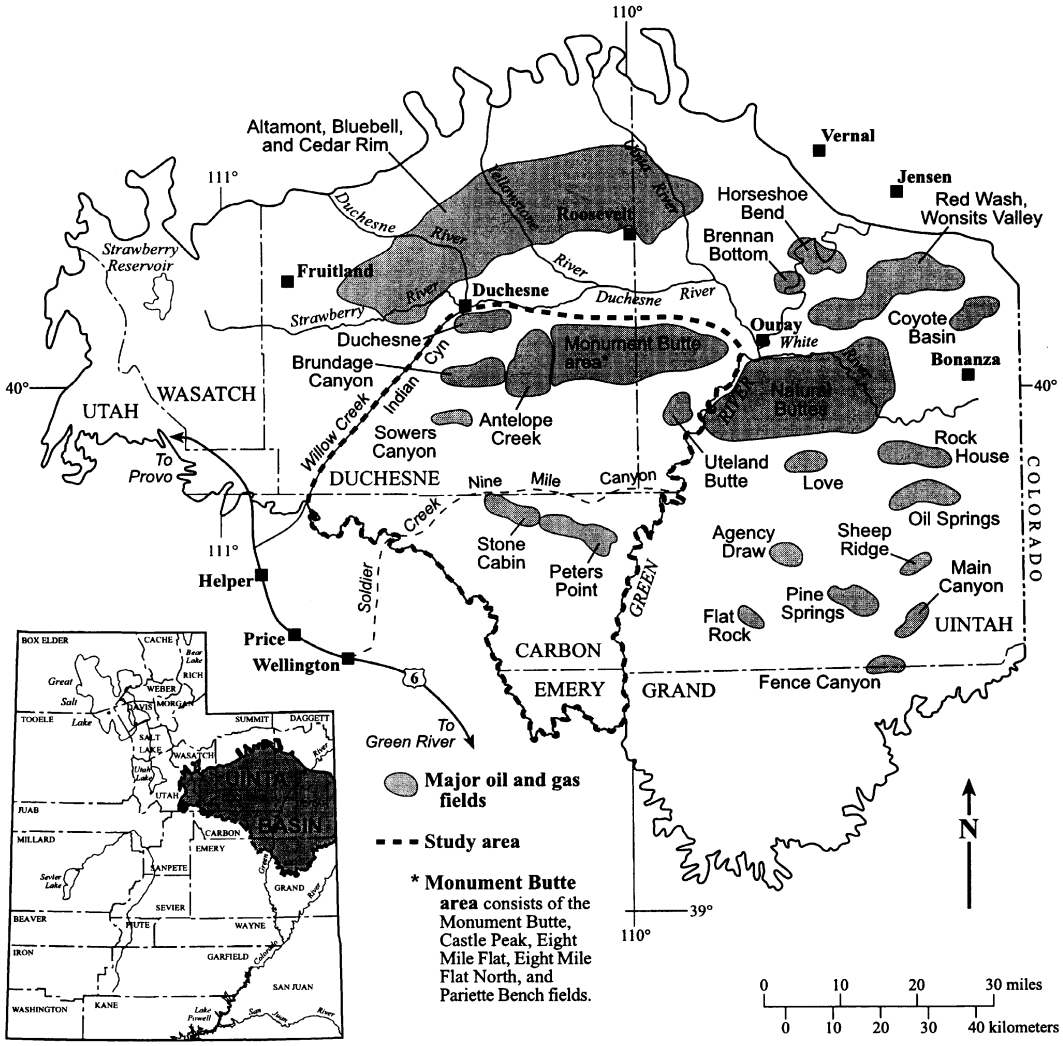

Figure 1. Index map of the Uinta Basin, Utah, showing study area and major oil and gas fields.

GEOLOGIC INVESTIGATION OF THE GREEN RIVER FORMATION IN THE SUBSURFACE

The well database consists of more than 1,300 wells and contains API numbers, location descriptions, UTM coordinates, well names and numbers, as well as elevation, interval thickness, and sandstone thickness, and feet of porosity per interval for the 22 log cycles being studied (Morgan and others, 1999a). The database was copied onto CD-ROMs in "xls" and "dbf" formats and given to members of the Technical Advisory Board for their review. The database is now available to the public and can be downloaded from the project web site.

Preliminary structure and isochore maps were constructed and sent to the DOE (deliverable 4.2, 2000). Since then, numerous edits have been made to the data and several new wells have been added to the database. Elevations of key marker beds that were mapped on the surface and correlated to well logs, are being added to the database and will be used in preparing structure contour maps. A final set of structure and isochore maps will be constructed using the revised database. The final product will be an interactive GIS product in which the user can view maps within the GIS product, or use the data files to construct their own maps.

GEOLOGIC INVESTIGATION OF THE OUTCROP OF THE GREEN RIVER FORMATION

Desolation Canyon and its Tributaries

The primary objectives of the Desolation Canyon field work are: (1) identify north-to-south (distal-to-proximal) facies changes in the lower and middle members of the Green River Formation and, (2) correlate our work in the western Uinta Basin with published work on the Green River facies in the eastern Uinta Basin.

In May 2000, UGS geologists measured and described 1,669 feet (508.7 m) of stratigraphic section in the middle member of the Green River Formation in Jacks Creek Canyon, a tributary to Desolation Canyon. UGS geologists measured and described 492 feet (149.4 m) of stratigraphic section in the lower member at two locations near Fret Rapids in Desolation Canyon.

In May 2001, UGS geologists, along with representatives from the Technical Advisory Board and the DOE, made a second trip down Desolation Canyon. We had hoped to measure and describe two sections on the east side of Desolation Canyon at the same locations as Cashion's (1967) published sections, but were unable to obtain the necessary permits. Working on the west side of Desolation Canyon we were able to measure and describe 672 feet (204.8 m) of stratigraphic section of the middle member of the Green River Formation at Rock House Canyon, a tributary to Desolation Canyon north of Jacks Creek Canyon. We also measured and described 411 feet (125.3 m) of stratigraphic section in the lower member at two locations in Cedar Ridge Canyon, a tributary to Desolation Canyon south of Jacks Creek Canyon and Fret Rapids. Unfortunately, faulting in Cedar Ridge Canyon made it difficult to correlate the stratigraphic section because we were unable to determine the stratigraphic throw on several of the faults.

In August 2001, UGS geologists hiked down the upper reaches of Cedar Ridge Canyon from above Desolation Canyon. They measured and described a short stratigraphic section in the middle member of the Green River Formation. However, several faults trend parallel to Cedar Ridge Canyon for possibly the entire length of the canyon, making it unlikely that we will be able to measure and describe enough of the stratigraphic section in the middle member at this location to be useful.

Nine Mile Canyon and its Tributaries

Petes and Gate Canyons trend south to north, and are the west and east boundaries of the Nutter's Ranch study site, respectively (Morgan and others, 1999b). These canyons were photographed from their intersection with Nine Mile Canyon northward to where the stratigraphic interval being studied intersects the canyon floor. The photographs are being digitally joined to create continuous montages of each canyon. Stratigraphic sections will be measured and described at the northernmost location in both Petes and Gate Canyons. A detailed three-dimensional model of the Nutter's Ranch study site will be constructed and serve as an

analogue for reservoirs in the middle member of the Green River Formation.

A structure contour map of the D marker, equivalent to the top of the subsurface MGR 3, was constructed for Nine Mile Canyon. We mapped the bed using a hand-held GPS unit, reading coordinates about every 0.3 miles (0.5 km) while standing on or near the D marker. The coordinates were imported into ArcView® and elevations for each point were read from the 7.5-minute topographical quadrangle maps. The wells in the Nine Mile Canyon area and the elevations for the MGR 3 bed were clipped from the well database. The structure map (figure 2) shows a general northeast dip from the north flank of the Peters Point - Stone Cabin anticline into the basin. The D marker coordinates and elevations have been entered into the well database and will be used in construction of the regional MGR 3 structure contour map.

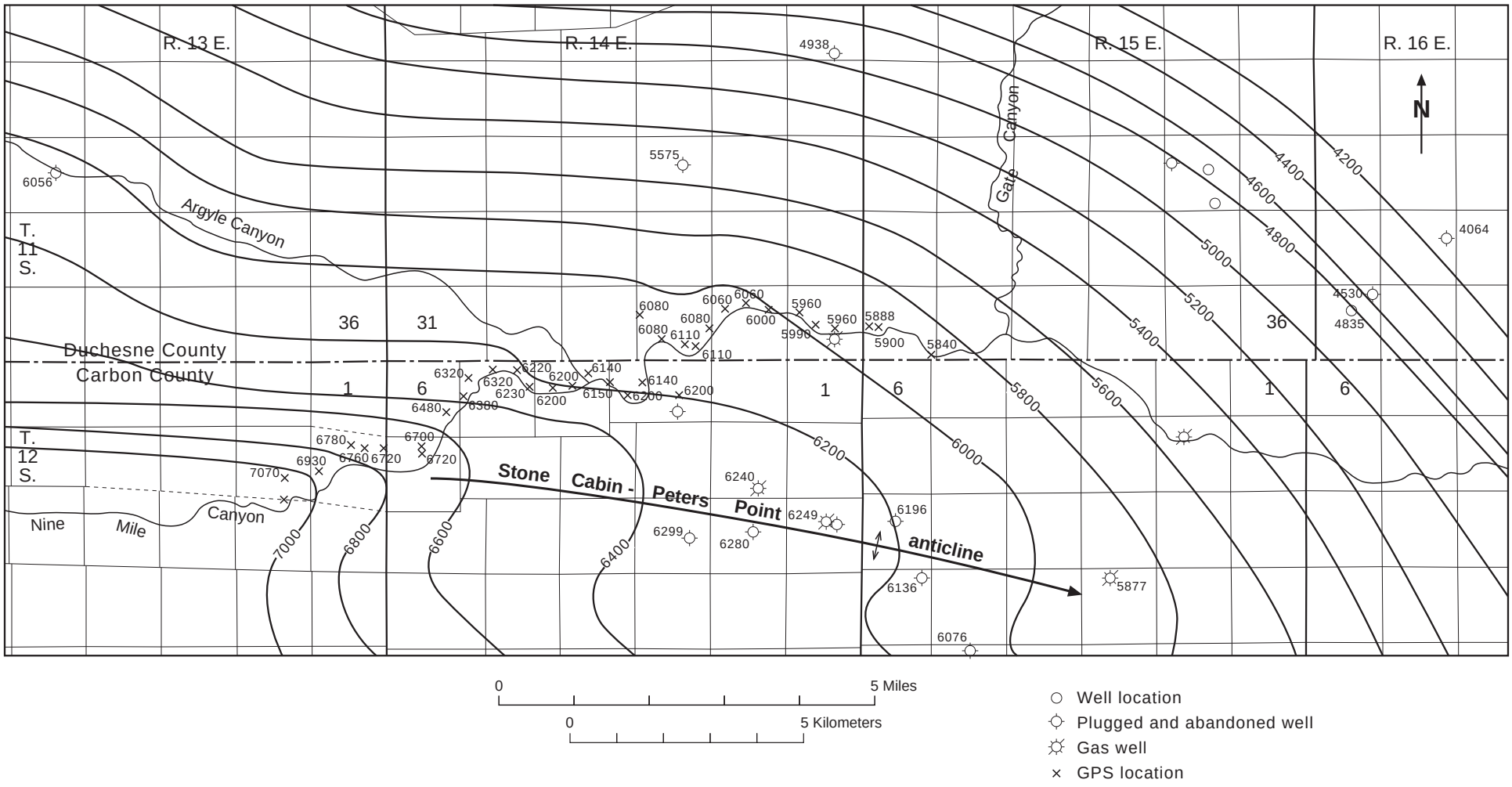

Figure 2. Structure contour map on the top of the D marker (surface exposures) and MGR 3 (well-log correlation), in Nine Mile Canyon. Contour elevations in feet, relative to mean sea level.

GENERATION OF RESERVOIR MODELS

The systematic generation of reservoir parameters was discussed in previous biannual reports (Morgan and others, 2000a; 2000b). This current report discusses the reservoir simulations of the most productive beds in the Monument Butte Northeast waterflood unit (section 25, T. 8 S., R. 18 E., Uinta Base Line and Meridian), the D-sands which are equivalent to the MGR 7 sandstones.

The simulations were carried out using the Implicit-Explicit Black Oil Simulator® (IMEX) developed by the Computer Modeling Group Limited® (CMG) with a grid generated in HERESIM® (Heterogeneities of Reservoir Simulations) as described in Morgan and others (1999b). The model consisted of a Cartesian grid with 20 X 20 X 13 blocks in the x, y, and z, directions, respectively. The block dimensions in the x and the y directions did not vary significantly. The x and the y dimensions of the blocks were approximately 264 feet (80.5 m). The thicknesses of the blocks (z dimension) varied significantly. A variable thickness, variable-depth grid was used. The porosities, permeabilities, and water saturations were generated in HERESIM® using log data on all the wells in the section. The pressure-volume-temperature relationships and fluid properties are summarized in table 1. The relative permeabilities are shown in figure 3. The relative permeabilities for water are very low even at high water saturation.

Table 1. Pressure-volume-temperature (PVT) data used in the simulation model.

Pressure psia	**GOR scf/stb**	**OVF rb/stb**	**GVF scf/rcf**	**Oil Viscosity cp**	**Gas Viscosity cp**
14.7	0	1.0018	4.730	14.100	0.0055
500	115.128	1.0625	168.80	12.248	0.0057
1000	230.256	1.1250	350.803	7.245	0.0061
1200	276.307	1.1500	426.603	6.210	0.0062
1500	345.383	1.1875	541.800	5.348	0.0065
2000	450.511	1.2500	850.991	4.140	0.0071
2500	575.639	1.3125	950.000	3.450	0.0077
3000	690.767	1.3750	1140.000	3.105	0.0842
4000	921.022	1.5000	1500.000	2.415	0.0907
6000	1370.000	1.7500	2200.000	1.500	0.0920
9000	2025.000	2.1000	3200.000	1.000	0.0930

GOR = gas to oil ratio
OVF = oil formation volume factor
GVF = gas formation volume factor
cp = centipoise
psia = pounds per square inch absolute
rb = reservoir barrel
rcf = reservoir cubic feet
scf = standard cubic feet
stb = stock-tank barrel

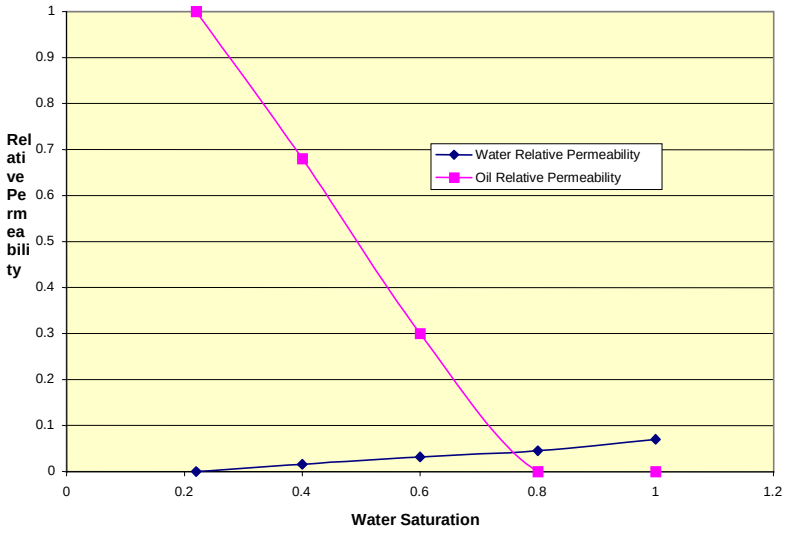

Figure 3. Water and oil relative permeabilities (millidarcies) used in the simulations.

Most of these properties were measured in an earlier U.S. DOE-sponsored project (Deo and others, 1994). The well production/injection timetable was incorporated as accurately as possible. The exact amount of water injection in D-sands was not known; We assumed that 60 percent of all of the injected water entered the D-sands. The initial reservoir conditions are summarized below in table 2.

Table 2. Initial reservoir statistics.

Total pore volume	12.28 MMstb
Initial oil in place at surface	7.525 MMstb
Initial oil in place at reservoir pressure	9.588 MMrb
Initial oil formation volume factor	1.27
Average oil saturation	78 percent
Initial gas in place	3.767 BCF
Initial gas to oil ratio	500 scf/stb
Initial reservoir pressure	2300 psia
Initial bubble point pressure	2200 psia

BCF = billion cubic feet
MM = million
psia = pounds per square inch absolute
scf = standard cubic feet
stb = stock-tank barrel
rb = reservoir barrel

Waterflood operations were begun approximately 300 days after the first well was opened for primary production. At the time of water injection, about 60,000 BO (9,500 m^3) had been produced at a cumulative GOR of 555 standard cubic feet per stock tank barrel (scf/stb). Waterflood performance was analyzed from 1995 to March of 2000. The cumulative oil production comparison is shown in figure 4. In this figure, D-sand production is assumed to be 60 percent of the total production. The data show a good match between the simulation and primary production (first 300 days). However, the model shows significantly more oil is produced during the waterflood portion of the simulation than actually occurred in the field. Two other simulations were performed assuming 100 percent of the water entered the D-sands during the water-injection phase and that only 40 percent of the water entered the D-sands (figure 5). The plot shows that the simulated oil production and the actual oil produced will not converge if we assume the water injected and the oil produced from the D-sands is an equal percentage of total water injected and the total oil produced, respectively. Assuming about 40 percent of the water was injected into D-sands, the production can be matched if we also assume that about 82 percent of the production came from the D-sands (figure 6). This discrepancy

shows that about 49 percent (0.4/0.82) of the total water injected is going into, or flooding, the D-sands. Thus, if the percentage of production from D-sands is known, the water injection analysis can be used to estimate the percentage of water injected being effective in the flood operation.

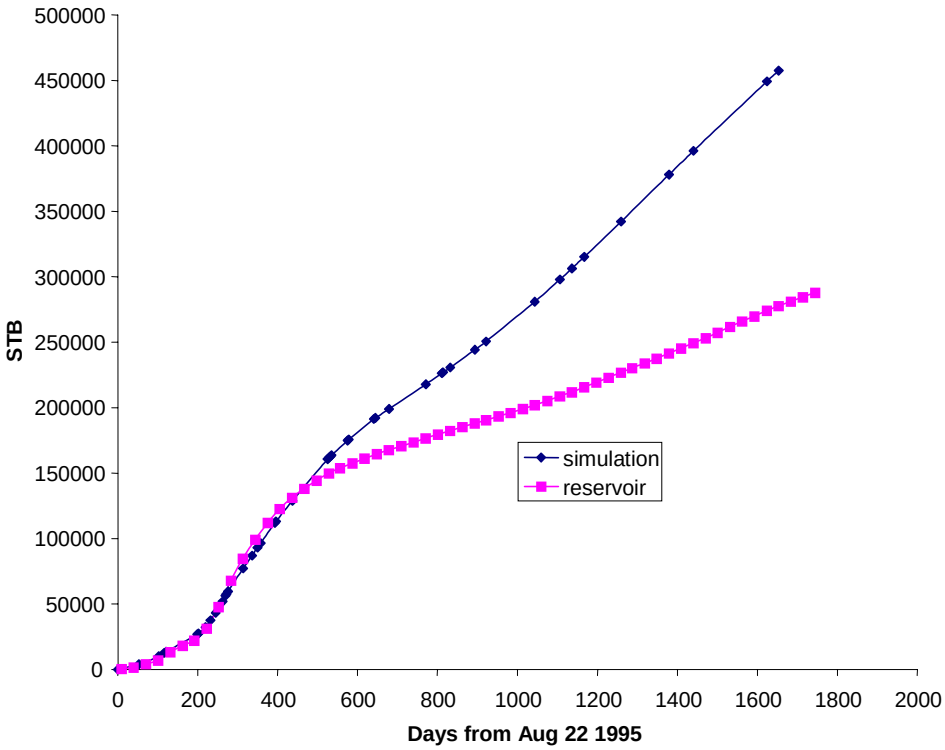

Figure 4. Production comparison from D-sands assuming that D-sands account for 60 percent of the oil production and that 60 percent of the water injected enters the D-sands. Production in stock-tank barrels (STB).

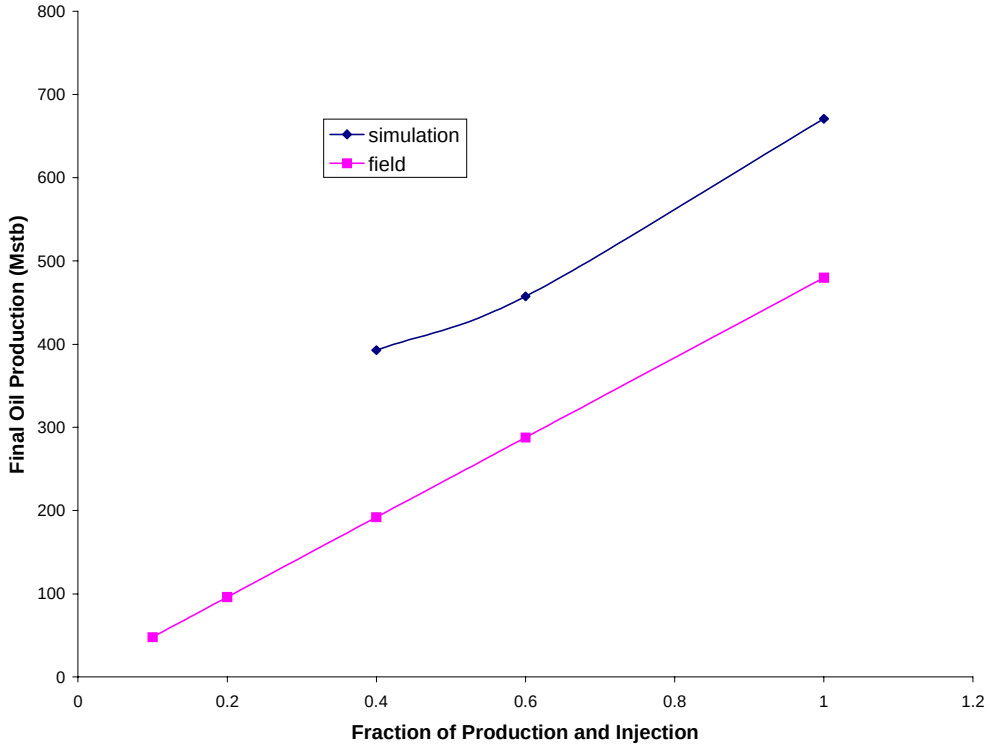

Figure 5. Comparison of the fractionated field production with identical fraction of water injected into D-sands. Oil production in thousand stock-tank barrels (Mstb).

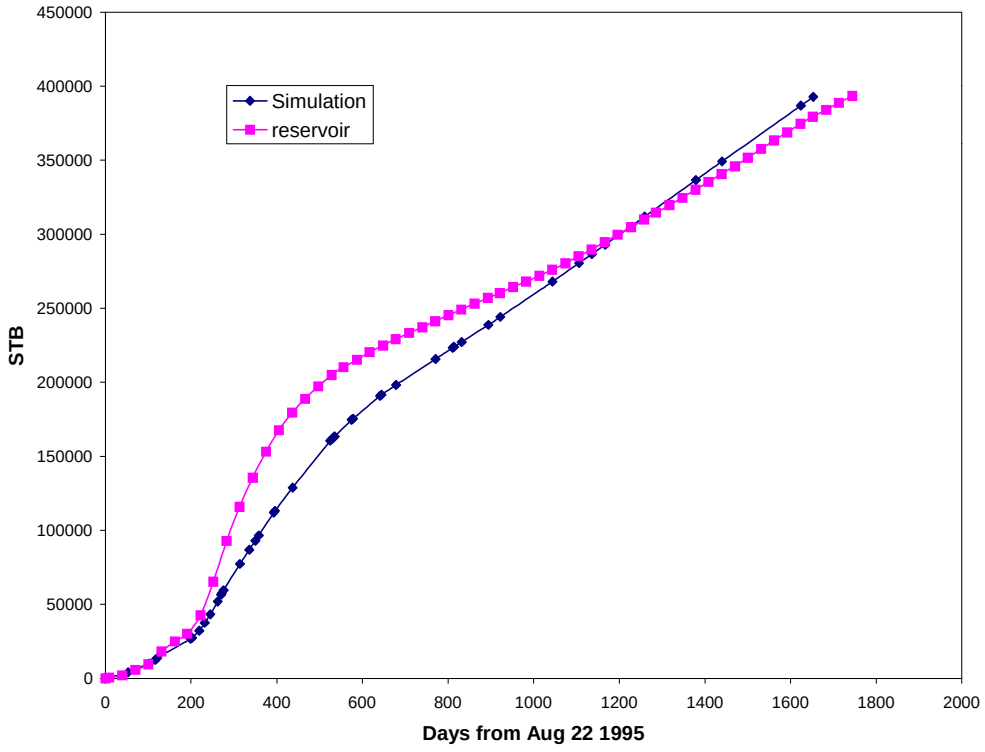

Figure 6. Comparison of field production with simulations after assuming that 40 percent of water injected enters the D-sands and that 82 percent of the total oil production is from D-sands. Oil production in stock-tank barrels (STB).

TECHNOLOGY TRANSFER

A copy of the Biannual Technical Report for the period from October 1, 2000, to March 30, 2001, was sent to everyone on the project mailing list and then posted on the Green River Study home page where it can be downloaded.

A poster with core was presented by S. Robert Bereskin and Craig D. Morgan (2001), at the 2001 American Association of Petroleum Geologists National Convention in Denver, Colorado. The accompanying abstract was entitled *Fluvial-lacustrine oil reservoirs in the middle member of the Eocene Green River Formation, south-central, Uinta Basin, Utah.* The poster can be viewed or downloaded from the project web page. A project overview was also displayed at the UGS exhibit booth during the convention.

An eight-day working field review in Desolation Canyon was held May 2001, to show the Technical Advisory Board and DOE representatives the work that was done in 2000, as well as conduct additional field work with input from everyone.

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, and (4) an extensive selected reference list for the Uinta Basin and lacustrine deposits worldwide. The home page address is <***http://www.ugs.state.ut.us/greenriv.htm***>.

FUTURE ACTIVITIES

The following work is planned for the period of October 1, 2001, through March 30, 2002:

(1) A field review in Willow Creek Canyon and Nine Mile Canyon will be conducted October 2001. This will be the second time the field trip has been run.

(2) The biannual technical report will be sent to all interested parties and posted on the project web site.

(3) Additional stratigraphic sections will be measured and described north of Nine Mile Canyon.

(4) New maps will be constructed using the revised well database.

(5) The two-dimensional Nutter's Ranch geologic model will be expanded to three dimensions.

(6) The petrophysical report will be completed and submitted to the DOE.

(7) Paleoflow and fracture data were gathered from the Nutter's Ranch study site. These data will be mapped and interpreted.

(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.

(9) Published fault traces and faults mapped as part of the project will be digitized and entered into the project file.

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