Results of Reservoir Simulation – Horizontal Infill well, Ness City North field, Ness County, Kansas

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Objective & study area

Ness City North field is located in Ness County, Kansas. The study area is spread over sections 23, 24 and 25 of 18s-24w. The producing horizon is Mississippian carbonate. The area has been under production since early 1963. The objective of this study was to characterize the reservoir in the study area and generate the data necessary to simulate the field by CMG-IMEX (black-oil) reservoir simulator. The simulation study would be used to predict the performance of an infill horizontal well that the field-operator was planning to drill. Real-life production results from the horizontal well were used to cross check and fine tune the reservoir model and the assumptions made in the simulation study.

Wells included in the study area are: Ummel #1 (Mull Drilling), Ummel #2 (Mull Drilling), Ummel #3 (Mull Drilling), Ummel #4 (Mull Drilling), Ummel #1-24 (Mull Drilling), Pfannenstiel #2 (Sun Oil Co.), Pfannenstiel #1 (Associate Oil & Gas), Pfannenstiel #1 (Sun Oil Co.), A Pember #5 (Mineral Exploration), Ummel #1 (Hembree) and Pfannenstiel #1 (Sun Oil Co.).

KGS Open File Report 99-58 describes in detail the geological and petrophysical models developed for this reservoir and also the pressure and production data analysis that was carried to develop input data for this simulation study.

Reservoir Simulation

The Ness City North field, Ness County, Kansas, was simulated using the CMG-IMEX simulator. The simulation exercise was based on the reservoir geomodel developed by integrating log, core, petrophysical, and production data. Wells that were included in this study were Ummel #1 (Mull Drilling), Ummel #2 (Mull Drilling), Ummel #3 (Mull Drilling), Ummel #1-24 (Mull Drilling), Pfannenstiel #2 (Sun Oil Co.), Pfannenstiel #1 (Associate Oil & Gas). Oil and water production data were available for the Mull Ummel wells (#1, #2, and #3). In absence of recorded production data, the oil production for the Pfannenstiel wells and for Mull Ummel #1-24 was assumed to be equal to the volume of oil sold from their respective leases as each of these wells were the only producing wells in their leases. The water production for the Pfannenstiel and Ummel #1-24 wells was calculated by using the WOR profile (against cumulative production) of Mull Ummel #2 – the mediocre performer amongst the Ummel #1, #2, and #3 wells.

The reservoir model used in this study was a 5-layer model with the layers (from the top) being named as LP1, LP2, LP3, HP1 and HP2. LP stands for low permeability while HP stands for high permeability. Figure 1 shows the structure on the Mississippian that was input into the simulator. It also shows the location and the spread of the 5 layers that comprise the reservoir rock. Figure 2 shows the storativity (product of porosity and thickness, feet) distribution in the each of the 5 layers.

The simulator output was fine-tuned to match the production and pressure (if available) histories, at each well in the study area. Good matches were obtained in some of the wells (Figure 3). Limited data was available to build the geo-model and this resulted in modest matches for some of the wells (Figures 4 to 7). Also, it is difficult to evaluate the effectiveness of history matching for wells that do not have any water production records. The production history of Mull Ummel #2 was used to calculate the water production at these wells.

Porosity logs were not available for any of the wells in the study area except for Mull Ummel #1-24. Thus, the initial reservoir model was simplified by assuming constant porosity and permeability values (Table 1) for each of 5 layers. In most wells, the bottom two layers, namely HP1 and HP2, were together found to be less or around 10 feet thick. The corresponding capillary pressure curves for these layers show that at 10 feet above the OWC (oil-water-contact) hydrocarbons saturation was negligible, i.e., in these regions only one fluid, water, flows through the reservoir. However, the simulator uses the product of relative permeability of the fluid and total matrix permeability to calculate the effective permeability for mass transfer of that fluid. At heights less than 10 feet from the OWC, water is the only fluid that flows and thus the concept of relative permeability do not apply. Initially, the matrix permeability of HP1 and HP2 were assumed to be 60 md and 40 md while the K_{rw} at S_{oir} for these layers was calculated to be close to 0.35. For the simulator to employ an effective permeability of 60 md to water-flow, matrix permeability has to be set between 160 to 170 md (as 165.0*0.35 = 58 md). During the process of history matching, it was observed that for wells where the thickness of HP1 and HP2 layers were less than 10 feet, setting the matrix permeabilities close to 180 md resulted in improving the match between the simulation output and the well production history.

The simulation output displayed the residual oil saturation, as of December 1999, in each of the reservoir layers. Figure 8 shows the oil saturation in layer 2 at the beginning of 1999. Figure 9 shows the distribution of oil saturation-feet (S_o-feet) in layer 2 (the primary producer for most of the wells in the field). Mull Ummel #4 was found to be unproductive when drilled. It however is located right within the area that the simulation study predicted to have the best remaining potential of residual reserves. The field operator decided to use Mull Ummel #4 well bore as the re-entry well to drill the infill horizontal well.

Horizontal Infill well – performance prediction

The horizontal well is located on the boundary of drainage areas of two adjacent wells, i.e., Mull Ummel #1 and Mull Ummel #2. Figure 10 overlays the gamma ray log along the length of the horizontal well. The gamma ray log demonstrates the presence of significant karst-controlled reservoir heterogeneity in the lateral direction within the

Mississippian reservoir. Such heterogeneity is expected to severely restrict the lateral drainage of vertical wells at certain locations. The uneconomic production from Mull Ummel #4 may be caused by its location at a spot where the lateral drainage from the reservoir rock is severely restrained by solution enlarged tubes that have created compartmentalized reservoirs in the Mississippian.

The total length of the horizontal well (Mull Ummel #4-H) drilled within the Mississippian formation is 533 feet. Streaks of shale are evident along the lateral length of the well from the gamma log and it effectively reduces the productive (clean) length to about 440 feet. Average fluid levels recorded in the well over a period of one month show an average bottom hole pressure (P_{wf}) of about 650 psi. The horizontal well is located on the boundary of drainage areas of two adjacent wells, i.e., Mull Ummel #1 and Mull Ummel #2. Mull Ummel #1 is the best producer in the field and no other well comes even close to its production output. It is the only well still in operation at the time of the infill drilling. Two different scenarios were simulated. In once case the drainage area of the horizontal well were attributed with flow-properties that were close to that of prevalent around Mull Ummel #1 and this was termed as the “best case” scenario. In the second set of simulation runs, the flow-properties around the infill well took on values prevalent around Mull Ummel #2 and this was called the “expected case”.

The simulation output summarized in Figure 11 was based on an effective horizontal well length of 400 feet, a uniform skin of 4.5 across the producing length, and a P_{wf} of 675 psi. Production-envelops, of oil and water, in Figure 11 are bound by the continuous and broken lines, and these highlight the expected and the best-case simulation outputs respectively. The average monthly oil and water production recorded at the horizontal well over the first 2 months is also shown (by red symbols) and it appears on the lower boundary of both the oil and water envelops. Figure 12 shows the cumulative oil and water production from the horizontal infill well during the first 10 years.

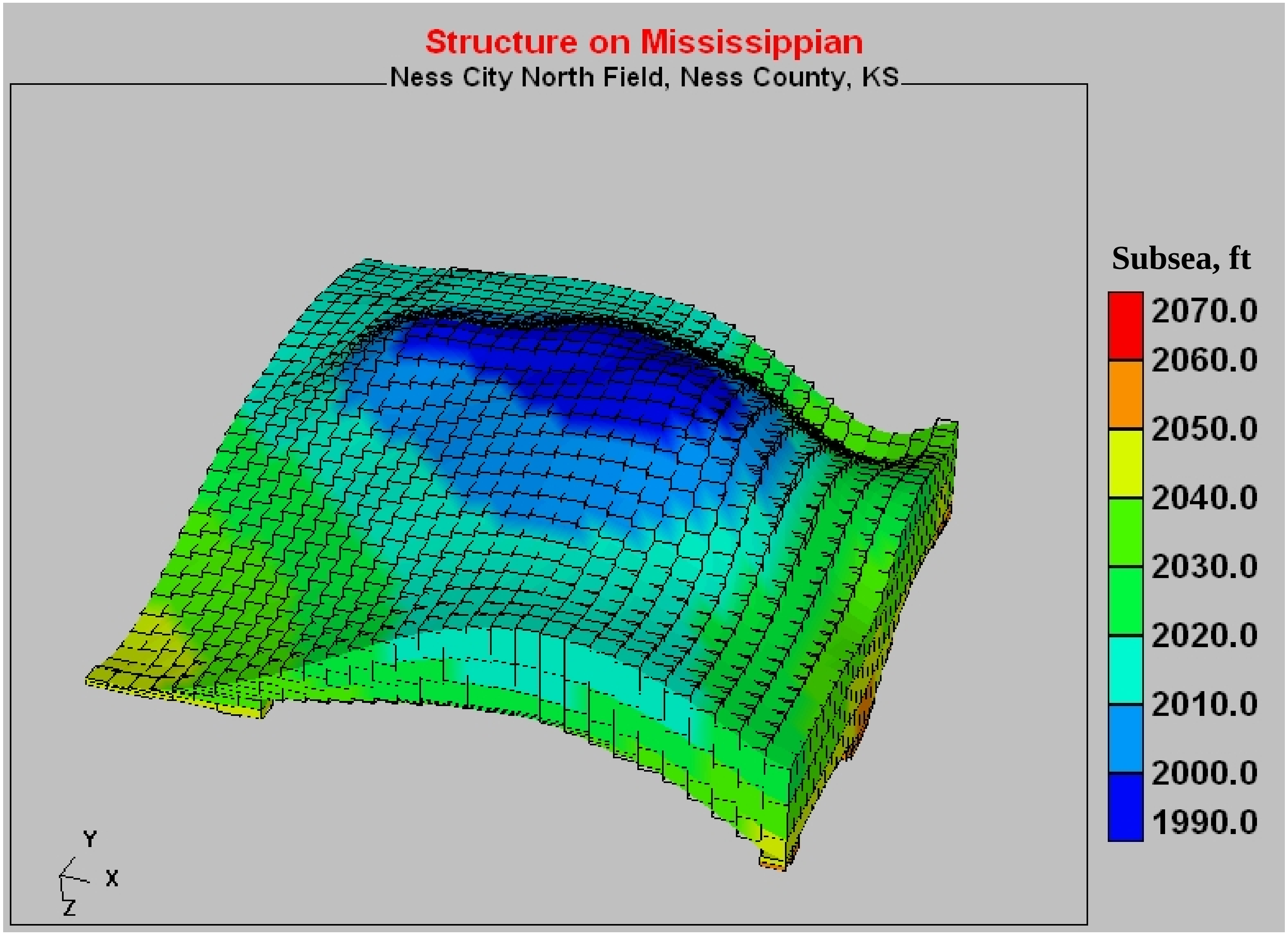
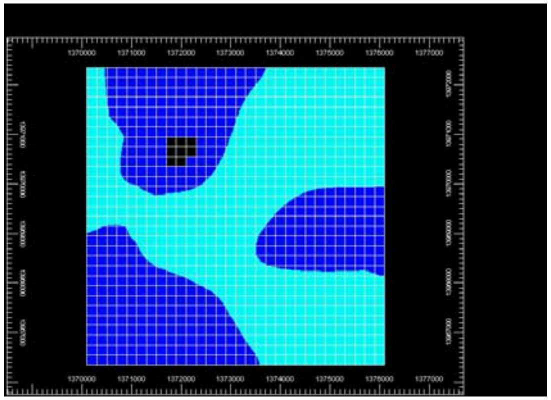
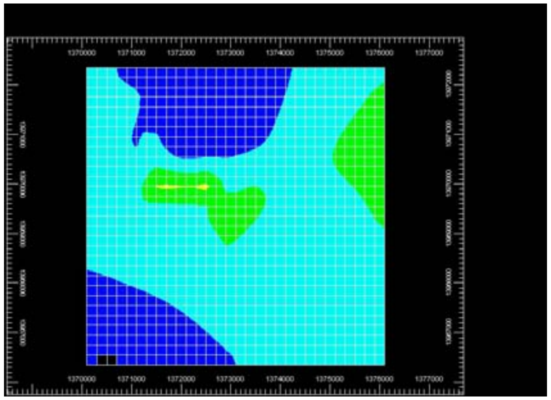
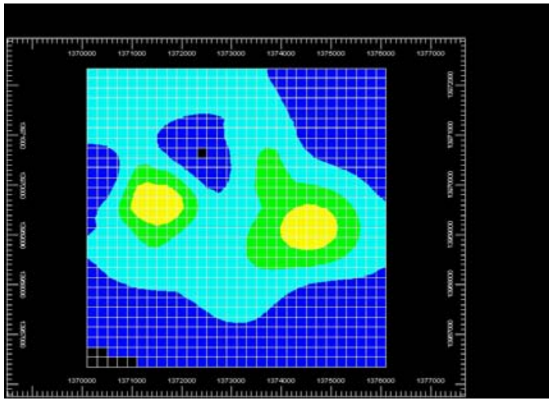

Structure on Mississippian
Ness City North Field, Ness County, KS
Subsea, ft
2070.0
2060.0
2050.0
2040.0
2030.0
2020.0
2010.0
2000.0
1990.0
Y
X
Z

Figure: 1





Layer LP3

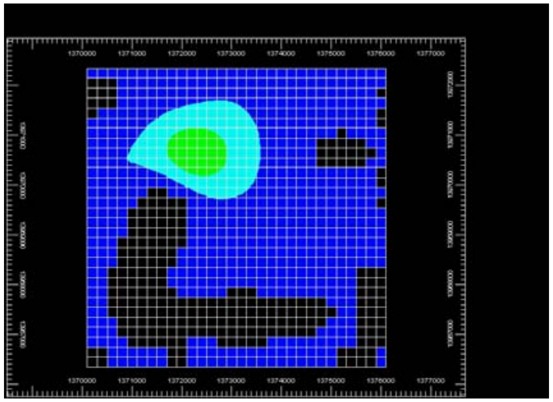


Layer
LP1

Layer LP2

Layer HP2

Layer HP1



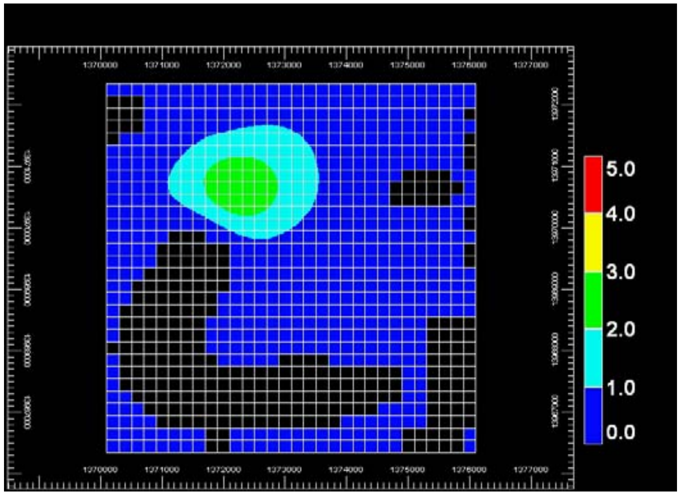


Figure: 2

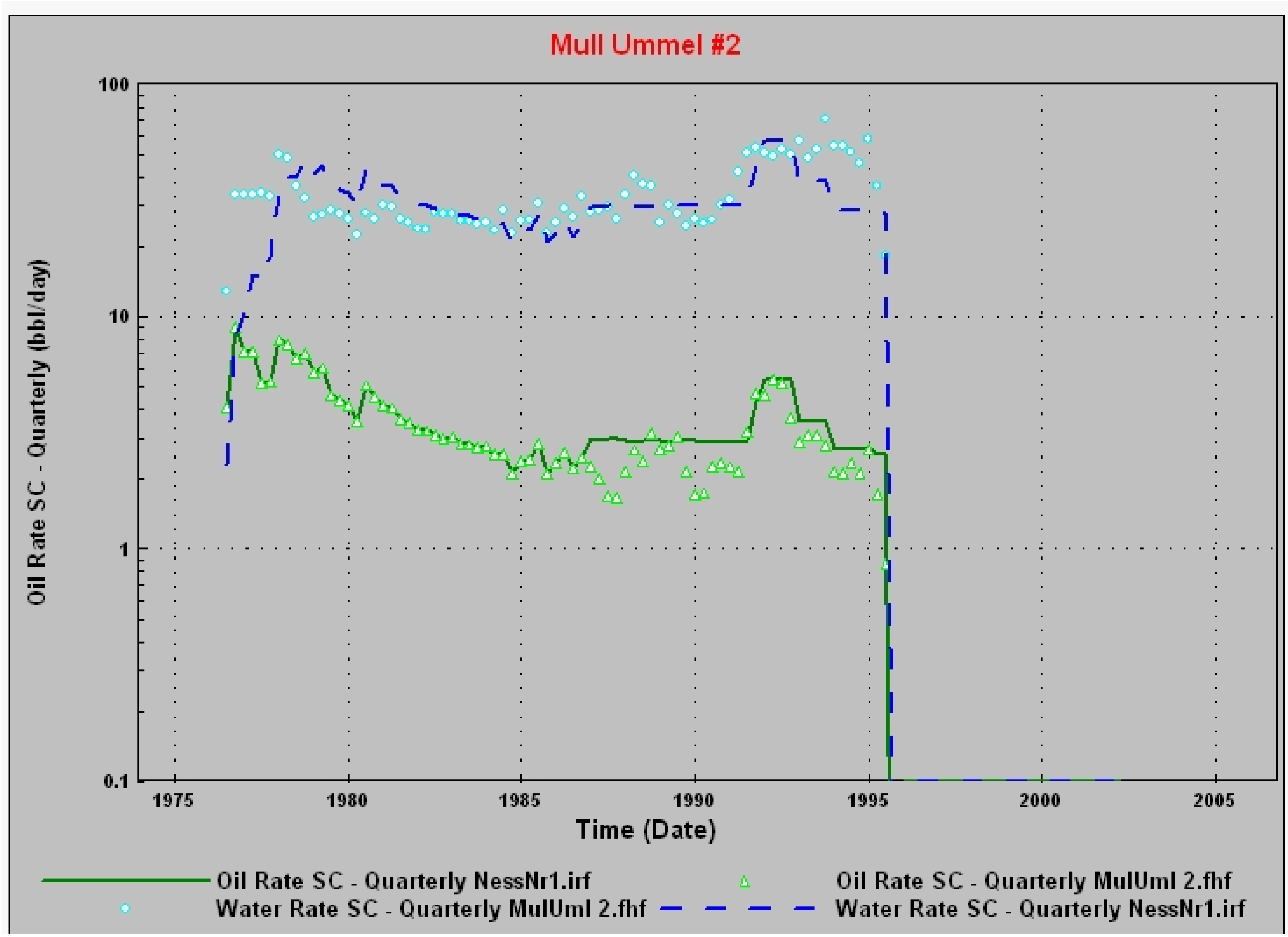

Mull Ummel #2
Oil Rate SC - Quarterly (bbl/day)
100
10
1
0.1
1975
1980
1985
1990
1995
2000
2005
Time (Date)
Oil Rate SC - Quarterly NessNr1.irf
Oil Rate SC - Quarterly MulUml 2.fhf
Water Rate SC - Quarterly MulUml 2.fhf
Water Rate SC - Quarterly NessNr1.irf

Figure: 3

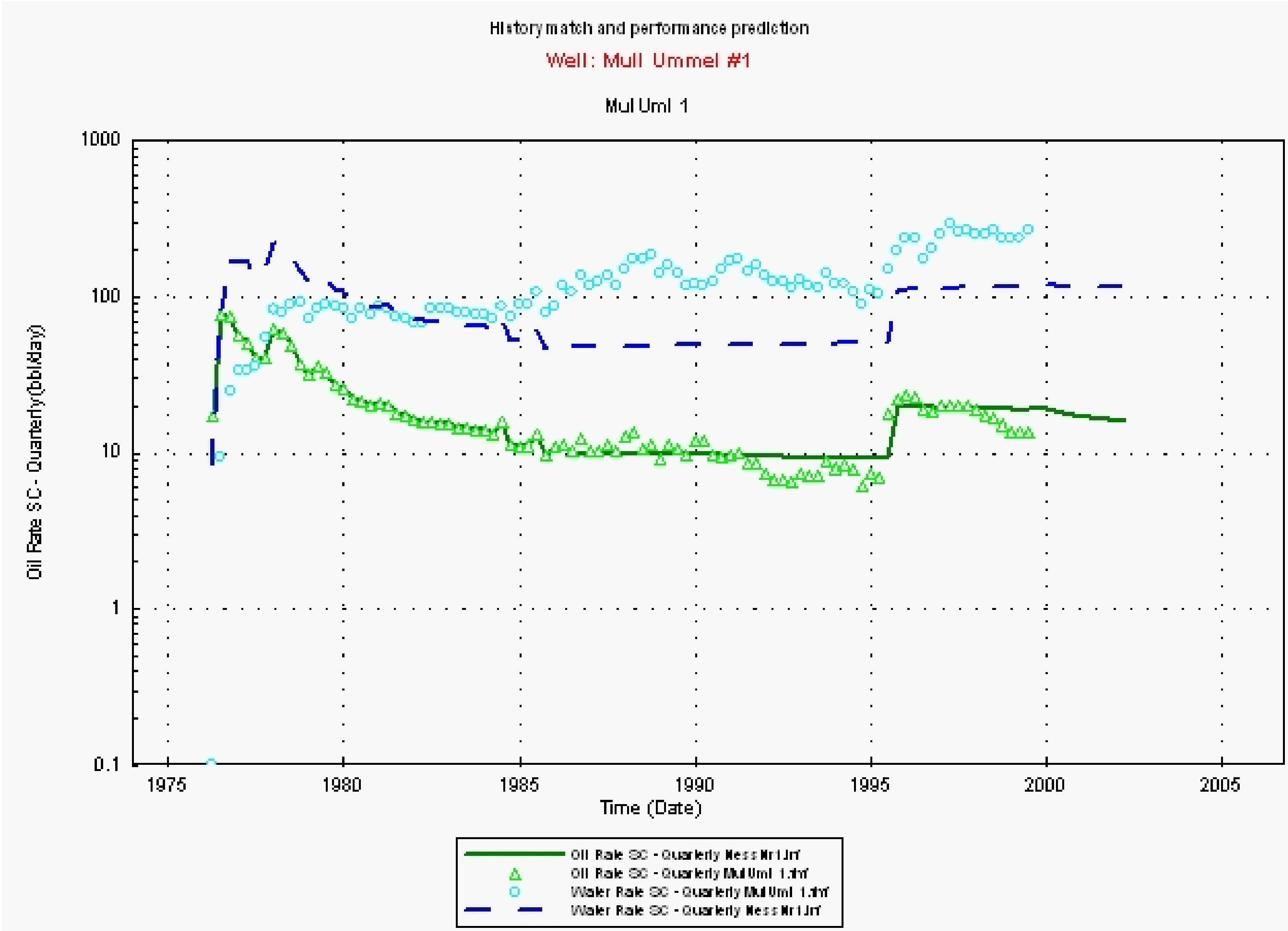

History match and performance prediction
Well : Mull Ummel #1
Mul Uml 1
1000
100
10
1
0.1
Oil Rate SC - Quarterly(bbl/day)
1975
1980
1985
1990
1995
2000
2005
Time (Date)
Oil Rate SC - Quarterly
Oil Rate SC - Quarterly Mul Uml 1
Water Rate SC - Quarterly Mul Uml 1
Water Rate SC - Quarterly

Figure: 4

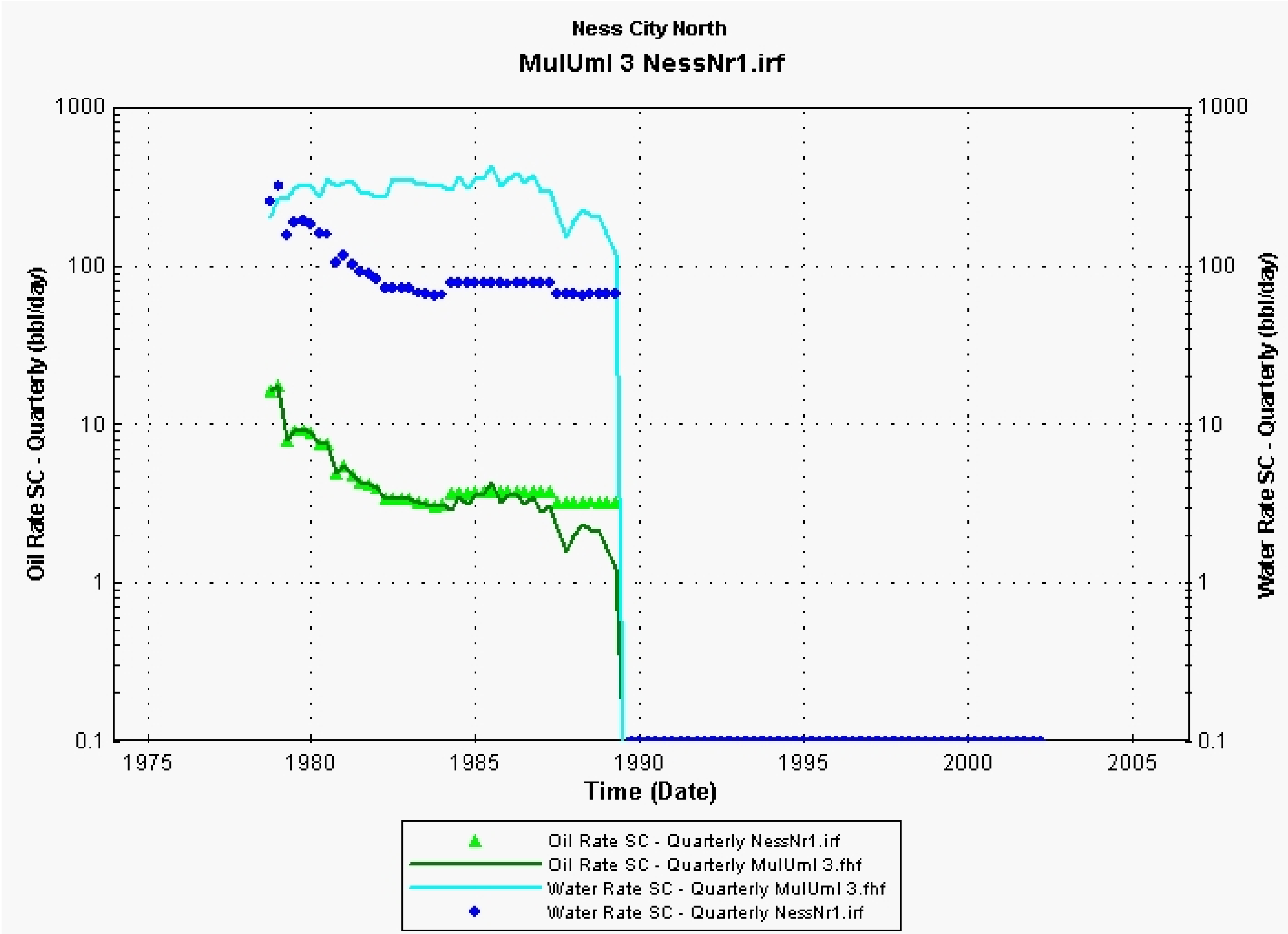

Ness City North
MulUml 3 NessNr1.irf
1000
100
10
1
0.1
Oil Rate SC - Quarterly (bbl/day)
Water Rate SC - Quarterly (bbl/day)
1975
1980
1985
1990
1995
2000
2005
Time (Date)
Oil Rate SC - Quarterly NessNr1.irf
Oil Rate SC - Quarterly MulUml 3.fhf
Water Rate SC - Quarterly MulUml 3.fhf
Water Rate SC - Quarterly NessNr1.irf

Figure: 5

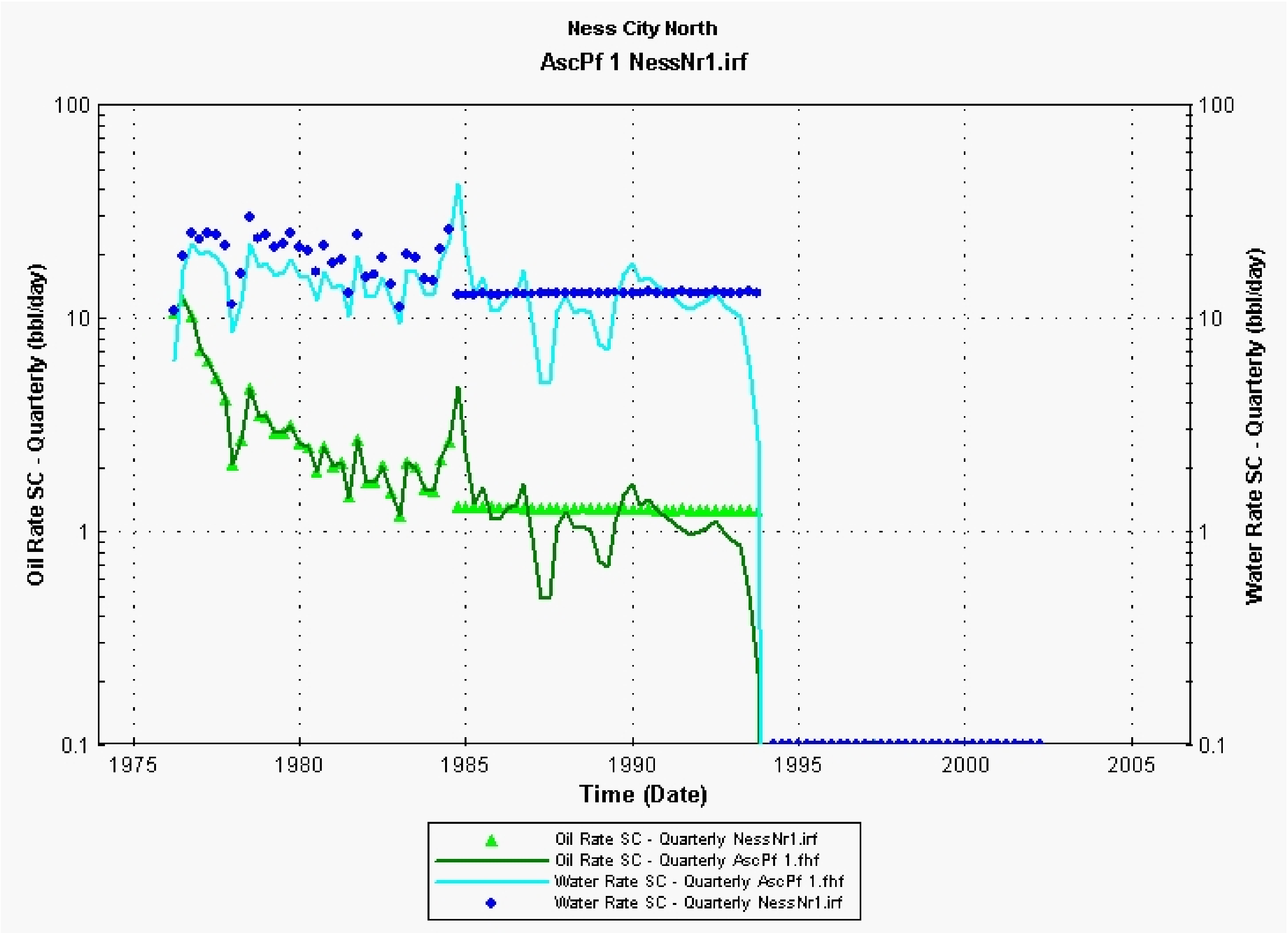

Ness City North
AscPf 1 NessNr1.irf
100
10
1
0.1
Oil Rate SC - Quarterly (bbl/day)
Water Rate SC - Quarterly (bbl/day)
1975
1980
1985
1990
1995
2000
2005
Time (Date)
Oil Rate SC - Quarterly NessNr1.irf
Oil Rate SC - Quarterly AscPf 1.fhf
Water Rate SC - Quarterly AscPf 1.fhf
Water Rate SC - Quarterly NessNr1.irf

Figure: 6

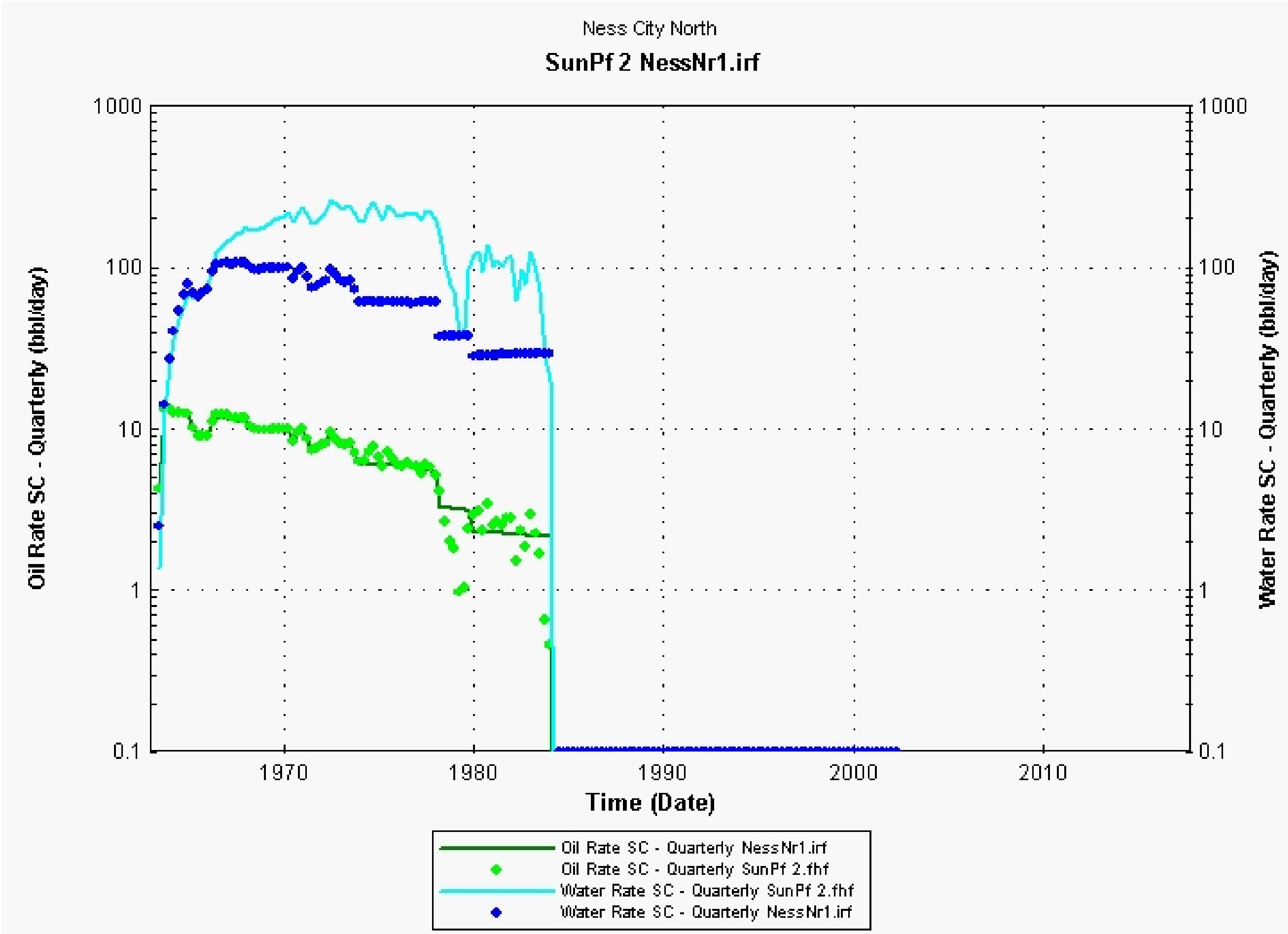

Ness City North
SunPf 2 NessNr1.irf
1000
100
10
1
0.1
Oil Rate SC - Quarterly (bbl/day)
Water Rate SC - Quarterly (bbl/day)
1970
1980
1990
2000
2010
Time (Date)
Oil Rate SC - Quarterly NessNr1.irf
Oil Rate SC - Quarterly SunPf 2.fhf
Water Rate SC - Quarterly SunPf 2.fhf
Water Rate SC - Quarterly NessNr1.irf

Figure: 7

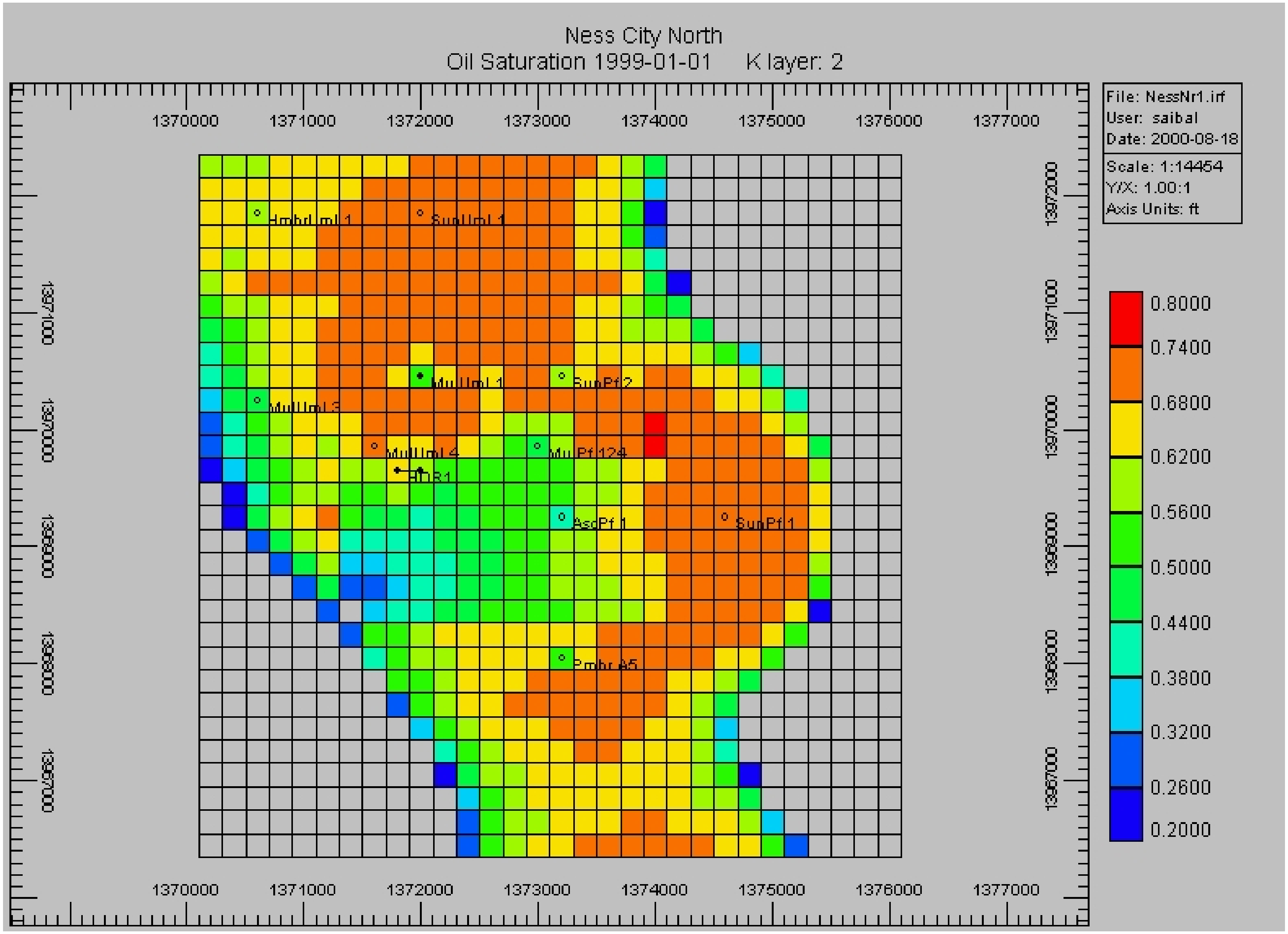
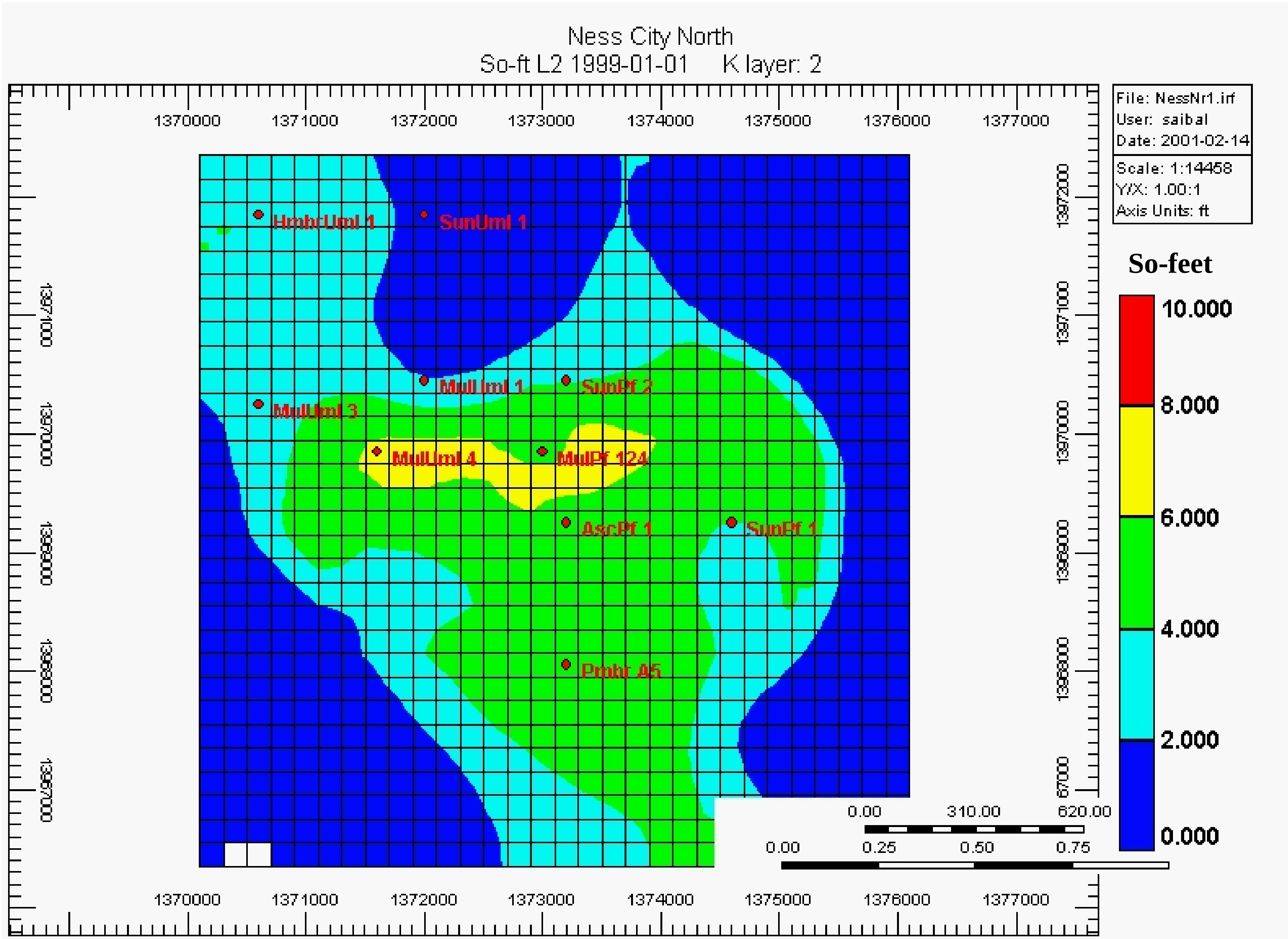

Ness City North
Oil Saturation 1999-01-01 K layer: 2
File: NessNr1.irf
User: saibal
Date: 2000-08-18
Scale: 1:14454
Y/X: 1.00:1
Axis Units: ft
1370000
1371000
1372000
1373000
1374000
1375000
1376000
1377000
1367000
1368000
1369000
1370000
1371000
1372000
0.8000
0.7400
0.6800
0.6200
0.5600
0.5000
0.4400
0.3800
0.3200
0.2600
0.2000
SunUml 1
MuUml 1
SunPf 2
MuUml 3
MuUml 4
MuPf 124
SunPf 1
AscPf 1
HUR1

Figure: 8



Ness City North
So-ft L2 1999-01-01 K layer: 2
File: NessNr1.irf
User: saibal
Date: 2001-02-14
Scale: 1:14458
Y/X: 1.00:1
Axis Units: ft
So-feet
10.000
8.000
6.000
4.000
2.000
0.000
1370000
1371000
1372000
1373000
1374000
1375000
1376000
1377000
HmbcUml 1
SunUml 1
MulUml 1
SunPf 2
MulUml 3
MulUml 4
MulPf 124
AscPf 1
SunPf 1
Prnbr A5
0.00
310.00
620.00
0.00
0.25
0.50
0.75

Figure: 9

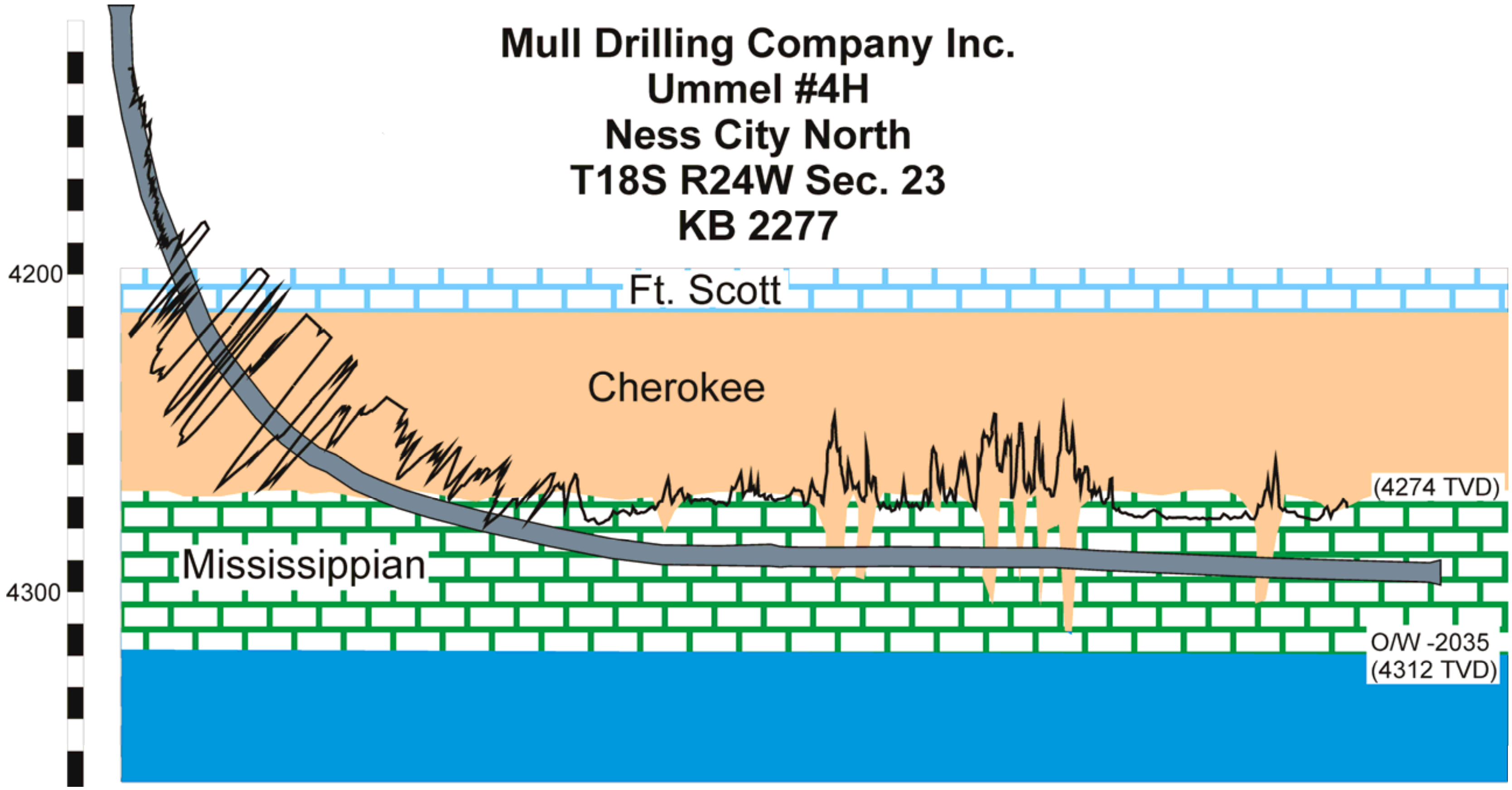
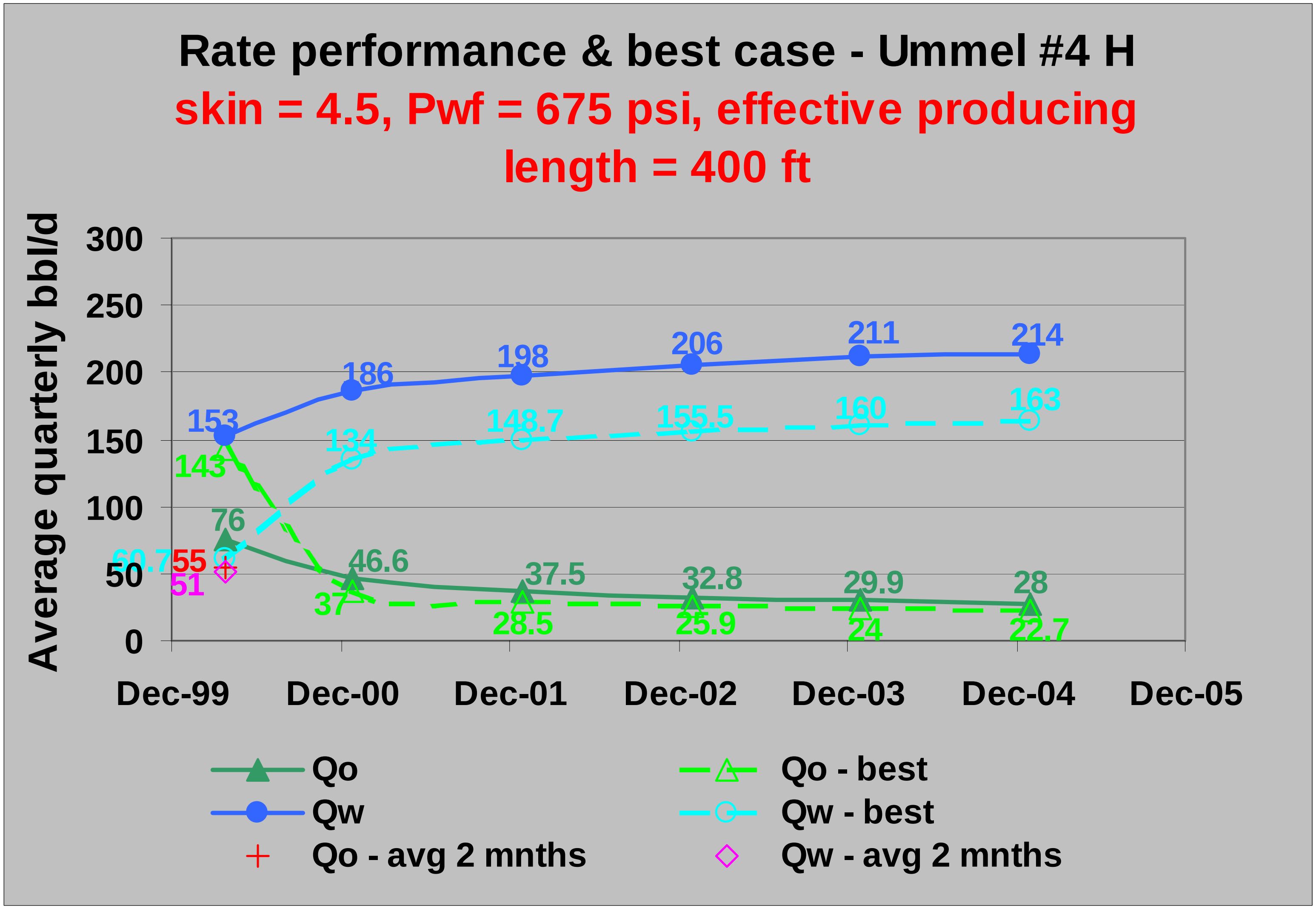


Figure: 10 Gamma ray log from Mull Ummel # 4H shows presence of significant karst-controlled horizontal herterogenity (10'-100' intervals) resulting in poor lateral draininage.



	Oil	Oil (b)	Wtr	Wtr (b)
1st yr	*18803*	*23526*	*59208*	*37232*
2nd yr	*32128*	*33560*	*126069*	*86816*

Figure: 11

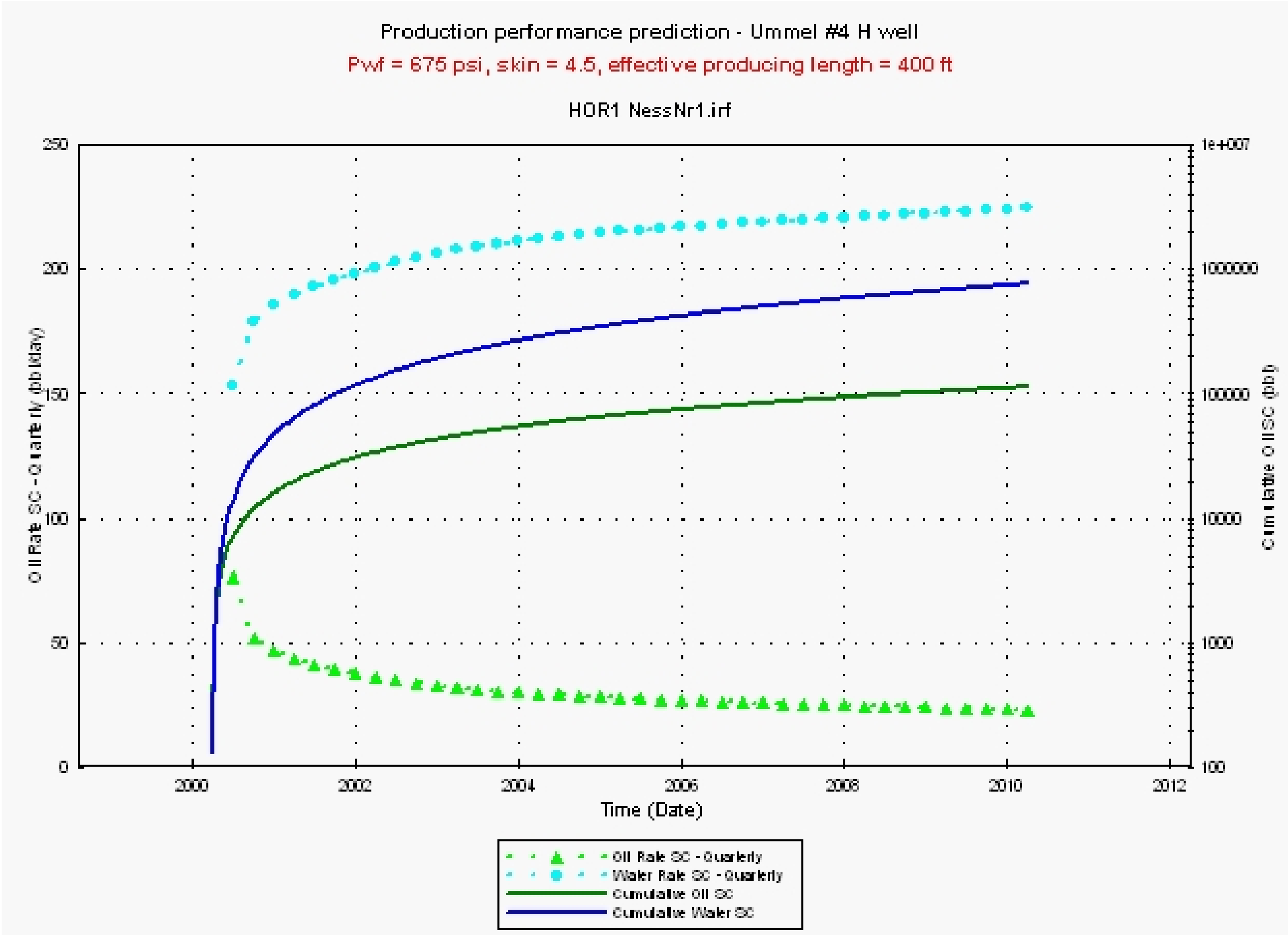

Production performance prediction - Ummel #4 H well
Pwf = 675 psi, skin = 4.5, effective producing length = 400 ft
HOR1 NessNr1.irf
Oil Rate SC - Quarterly (bbl/day)
Cumulative Oil SC (bbl)
Time (Date)
Oil Rate SC - Quarterly
Water Rate SC - Quarterly
Cumulative Oil SC
Cumulative Water SC

Figure: 12