A Review of Selected Michigan Niagaran Reef Waterfloods to Estimate the Fractional Flow Behavior During Flooding and Hysteresis Effects After Flooding*

Timothy J. Brock[1]

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[1]Brock Engineering, LLC (brock.engineering@yahoo.com)

Abstract

Michigan has many oil reservoirs that have been found since the 1960's in the Silurian-aged Niagaran Series. A number of these reservoirs were waterflooded between the 1970's and 1990's. By using some of the reservoir properties submitted for the waterflood hearings and production data submitted after the commencement of the project, it is possible to estimate the fractional flow behavior of the fields on a reservoir basis. Additionally, some of the reservoirs were produced after flooding with water diverted to a disposal well (not in the reef reservoir). This should produce data that can be used to examine the hysteresis behavior of the reservoirs. This presentation will consider a sampling of reservoirs in the Northern and Southern Niagaran Reef Trends of Michigan and present the results obtained by analyzing the available data.

References Cited

Kleppe, J., 2012, TPG4150 Reservoir Recovery Techniques: Hand-out note 4: Buckley-Leverett Analysis, Department of Petroleum Engineering and Applied Geophysics, Norwegian University of Science and Technology, 9 p. http://www.ipt.ntnu.no/~kleppe/TPG4150/BL.pdf

Macary, S., and W.A. Hamid, 1999, Creation of the Fractional Flow Curve from Purely Production Data: SPE Paper #56830, 6 p. Website accessed 23 September 2013. http://www.onepetro.org/mslib/app/Preview.do?paperNumber=00056830&societyCode=SPE

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A REVIEW OF SELECTED MICHIGAN NIAGARAN REEF WATERFLOODS TO ESTIMATE THE FRACTIONAL FLOW BEHAVIOR DURING FLOODING AND HYSTERESIS EFFECTS AFTER FLOODING

TIMOTHY J BROCK, PE
BROCK ENGINEERING, LLC

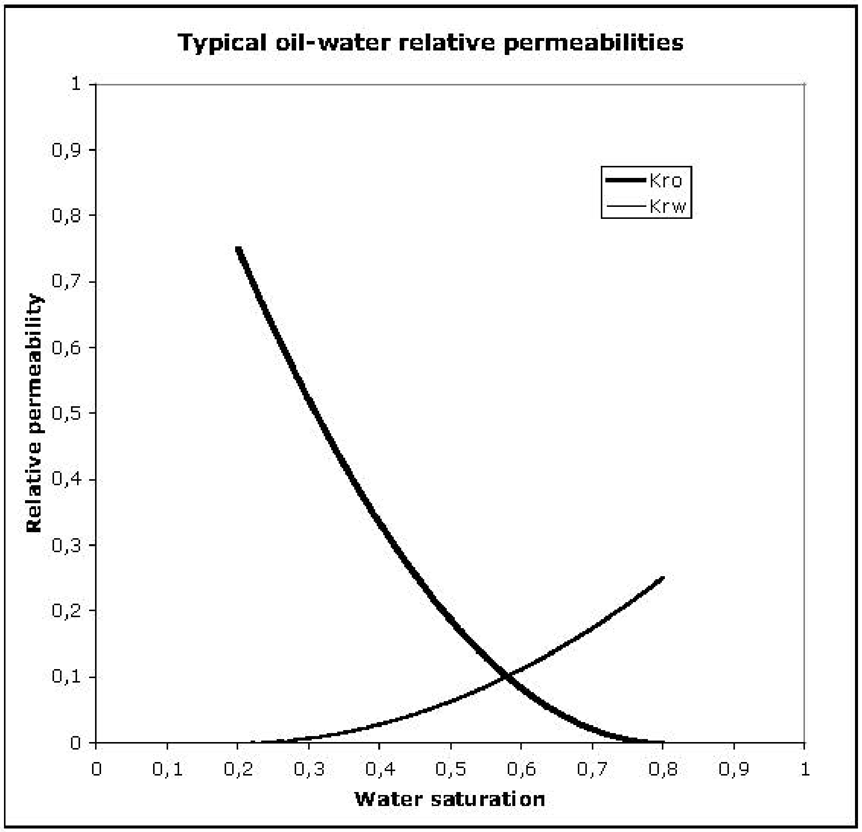
AAPG Annual Convention and
Exhibition 2013

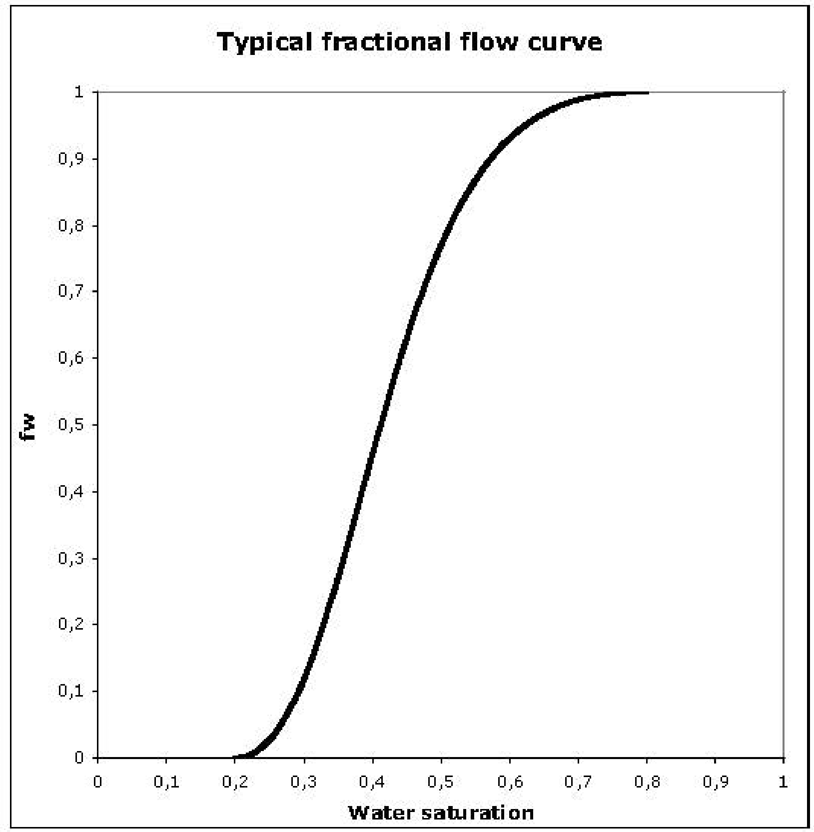
WHAT IS FRACTIONAL FLOW?

- Similar to a 'leaky piston' to describe the movement of one fluid in a reservoir displacing the original fluid, resulting in additional recovery.
- On a pore-volume basis, it incorporates viscosities of oil and water as well as the relative permeability of each.
- The result is an s-shaped curve (fractional flow curve) that is used to assist in recovery predictions for waterflood designs.

HOW IS A FRACTIONAL FLOW CURVE NORMALLY GENERATED?

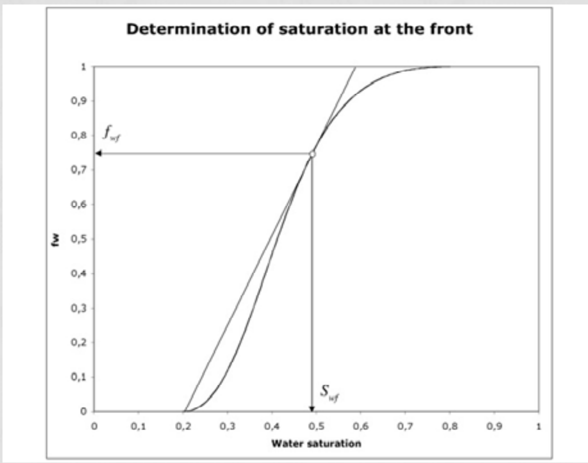
- $f_w = 1/\{1+[(k_{ro}/\mu_o)*(\mu_w/k_{rw})]\}$

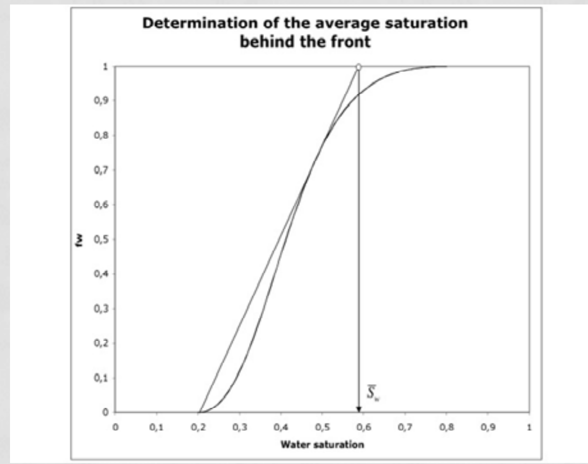


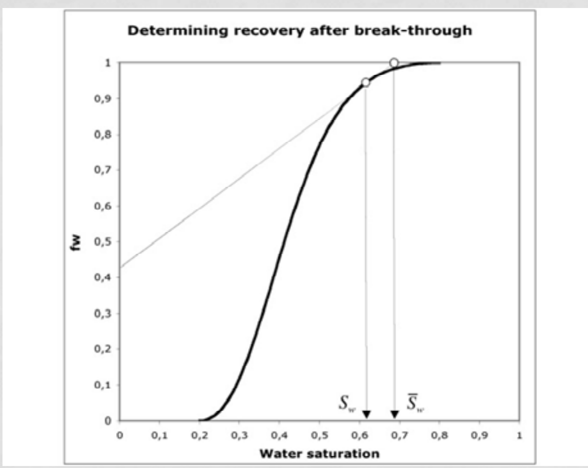


From Kleppe, 2012

SO, WHAT CAN WE USE THESE FRACTIONAL FLOW CURVES FOR?







It is important to estimate the amount of recovery a waterflood will achieve for booking of reserves, valuations, budgeting and many other reasons.

BUT, IF THIS WAS DONE ON A UNIT PORE VOLUME BASIS, WOULDN'T THAT MAKE EXTRAPOLATION TO THE ENTIRE RESERVOIR A STRETCH?

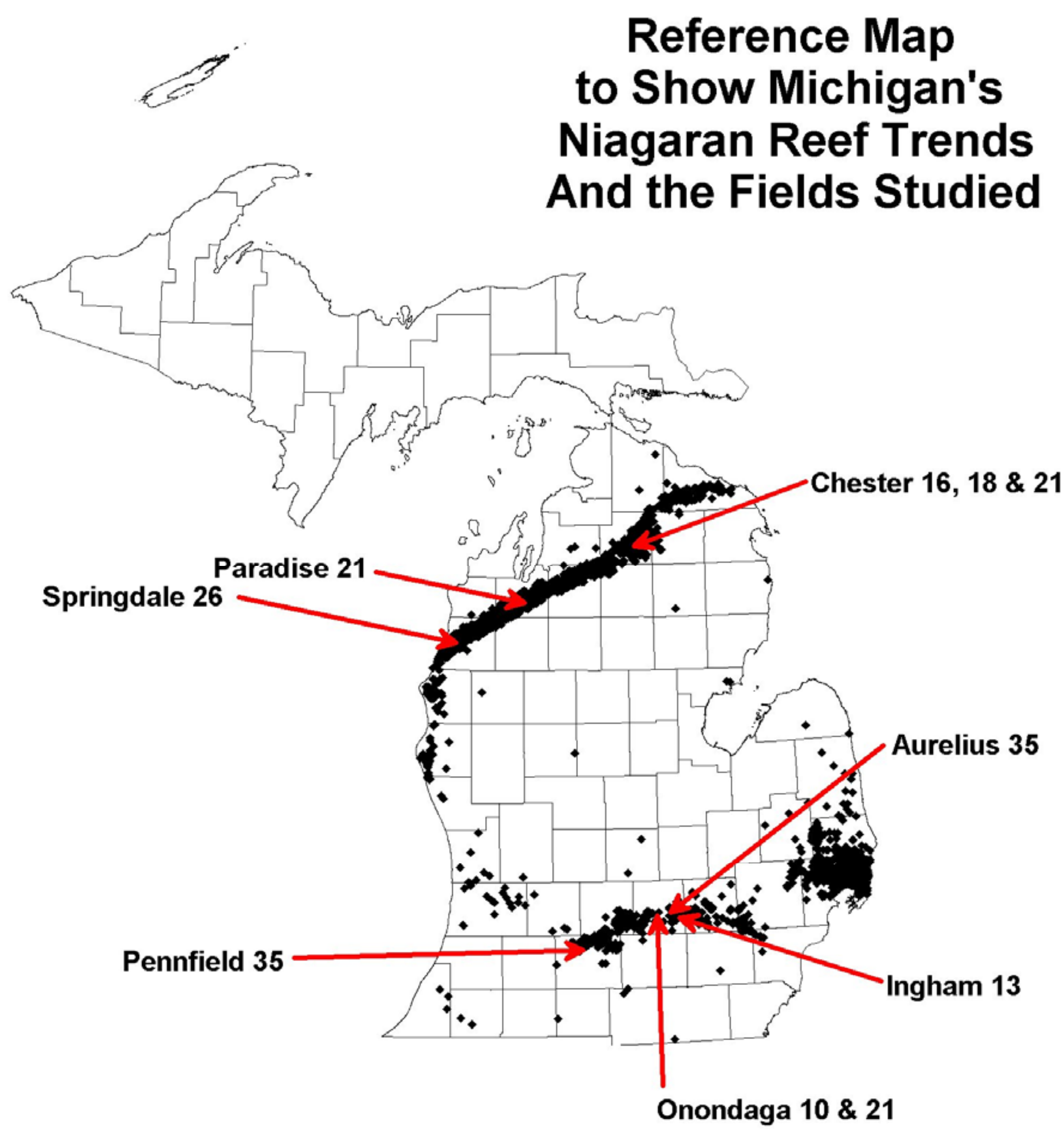
- Simply put, yes.
- However in a pattern-based flood with multiple wells and patterns, this type of analysis is very useful in determining which patterns are under (or over) performing.
- One solution (particularly on small floods) might be to look at the entire reservoir and see if there is a characteristic fractional flow behavior.

HAS THIS BEEN DONE BEFORE?

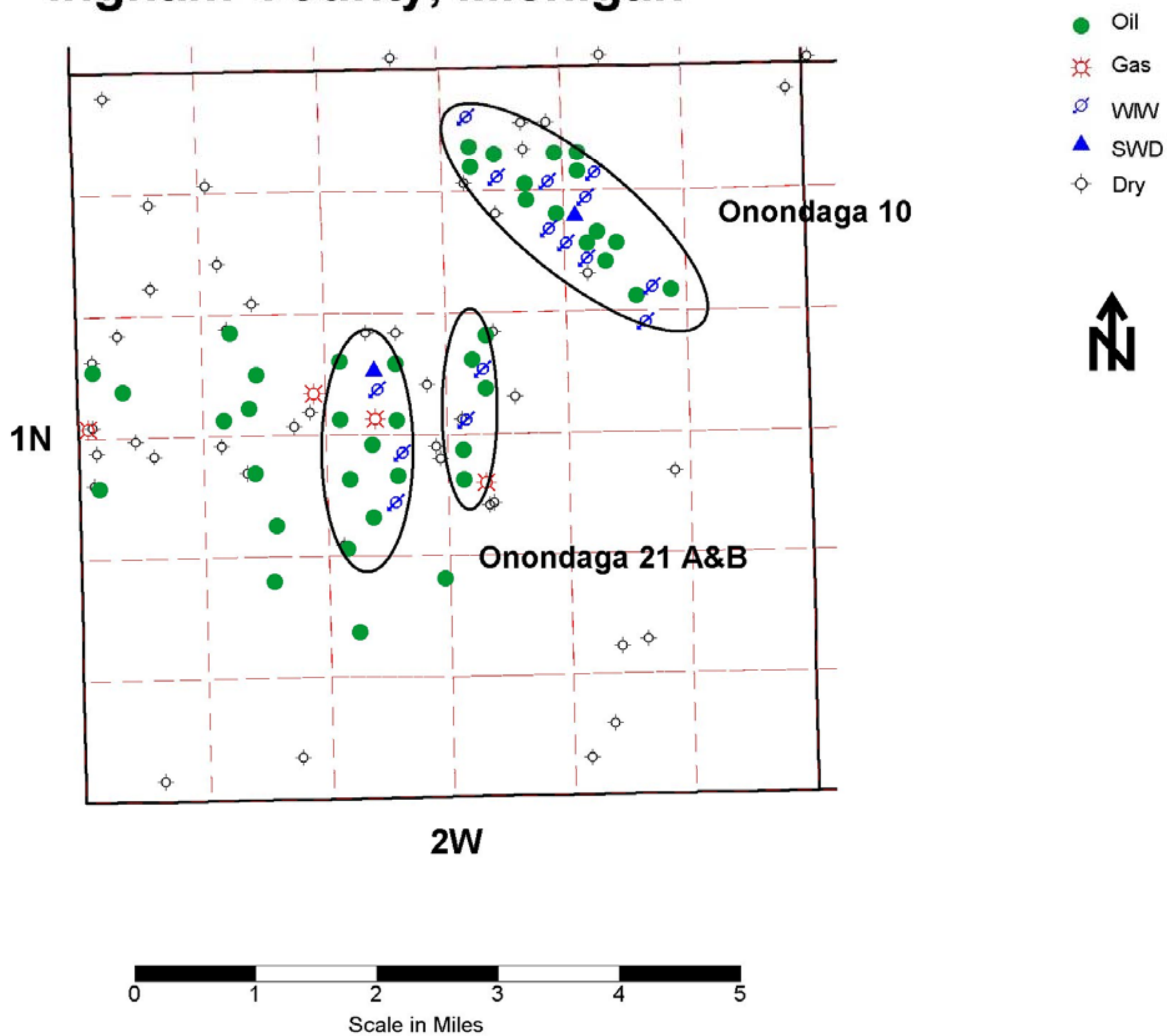
- It has been…
  - In 1999, Macary et. al. presented a paper at SPE ATC on creation of fractional flow curves from purely production data in the El Morgan and Kareem Fields operated by Gupco
  - In 2006, Sitorus et. al. presented a paper to the SPE Asia Pacific Oil and Gas Conference in which they used production data to construct fractional flow curves for the prediction of new horizontal wells in Indonesia

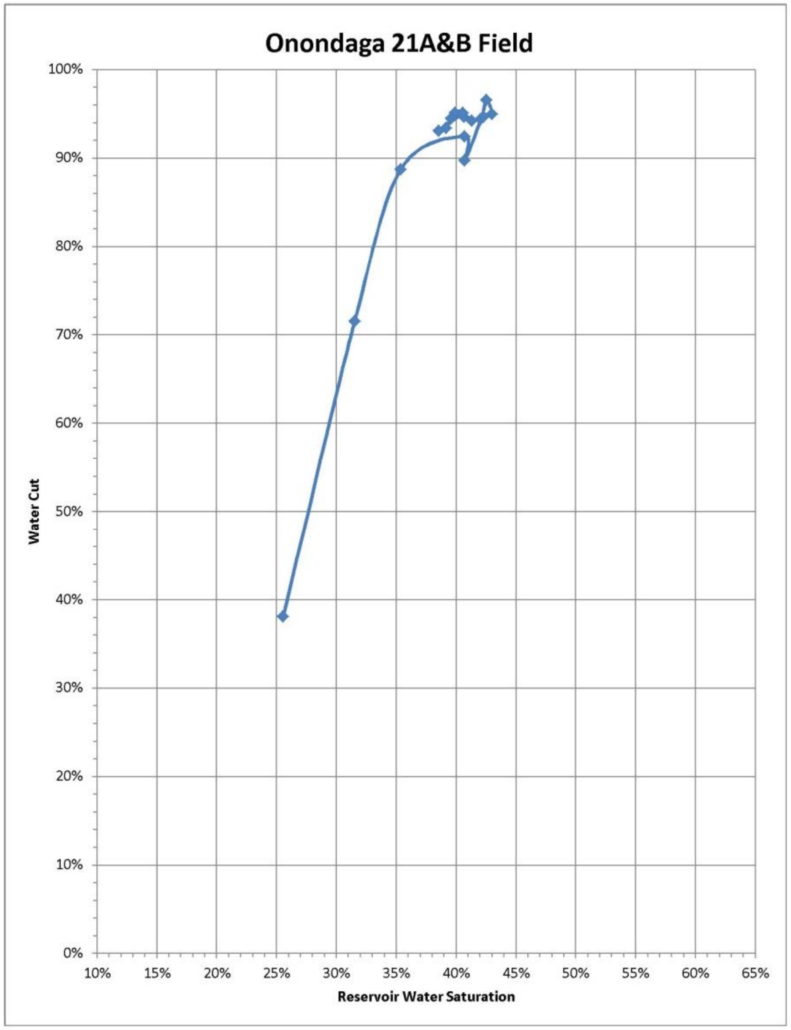
HOW CAN THIS BE DONE FOR THE MICHIGAN WATERFLOODS?

- Obtain oil, gas and water production data, as well as water injection data for the fields from discovery.
- Obtain reservoir parameters, such as water saturation, bottom hole pressure at conversion, fluid properties, etc. from State hearing records, or assume as needed based on nearby control.
- Compute, based on net injection, the effective water saturation in the reservoir and plot against the % water cut in the production, noting when injection ceases and if there is a change in water cut performance.

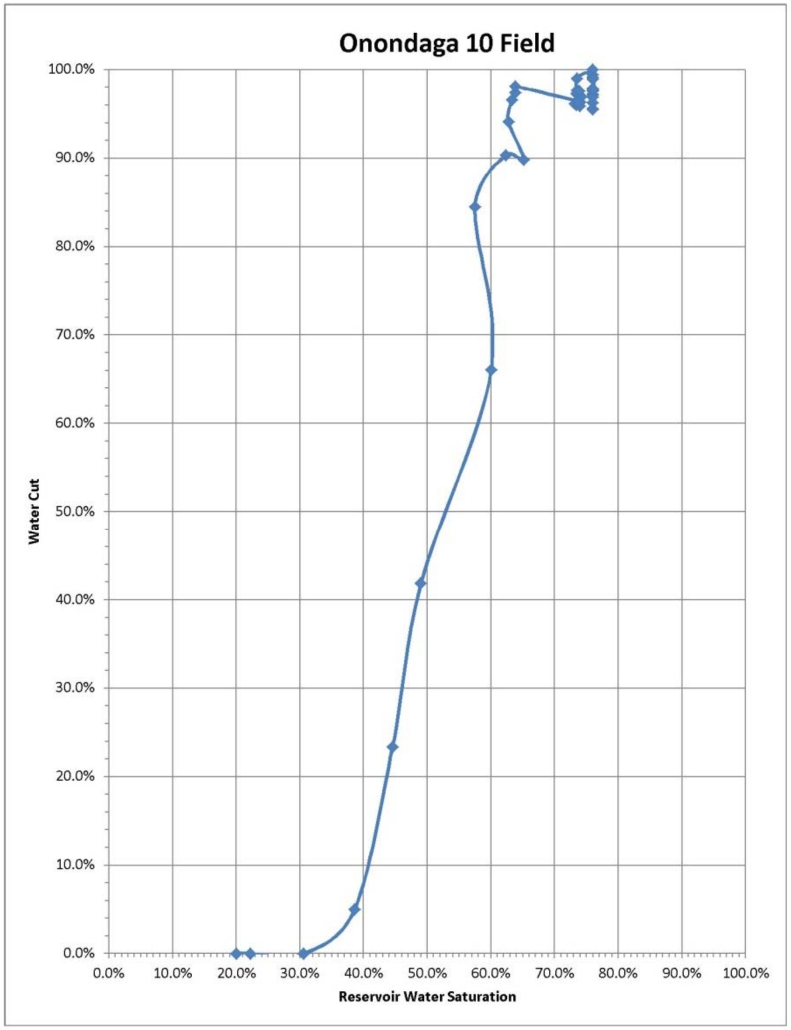

Reference Map
to Show Michigan's
Niagaran Reef Trends
And the Fields Studied
Chester 16, 18 & 21
Paradise 21
Springdale 26
Aurelius 35
Pennfield 35
Ingham 13
Onondaga 10 & 21

Onondaga 10 and 21 Fields
Ingham County, Michigan



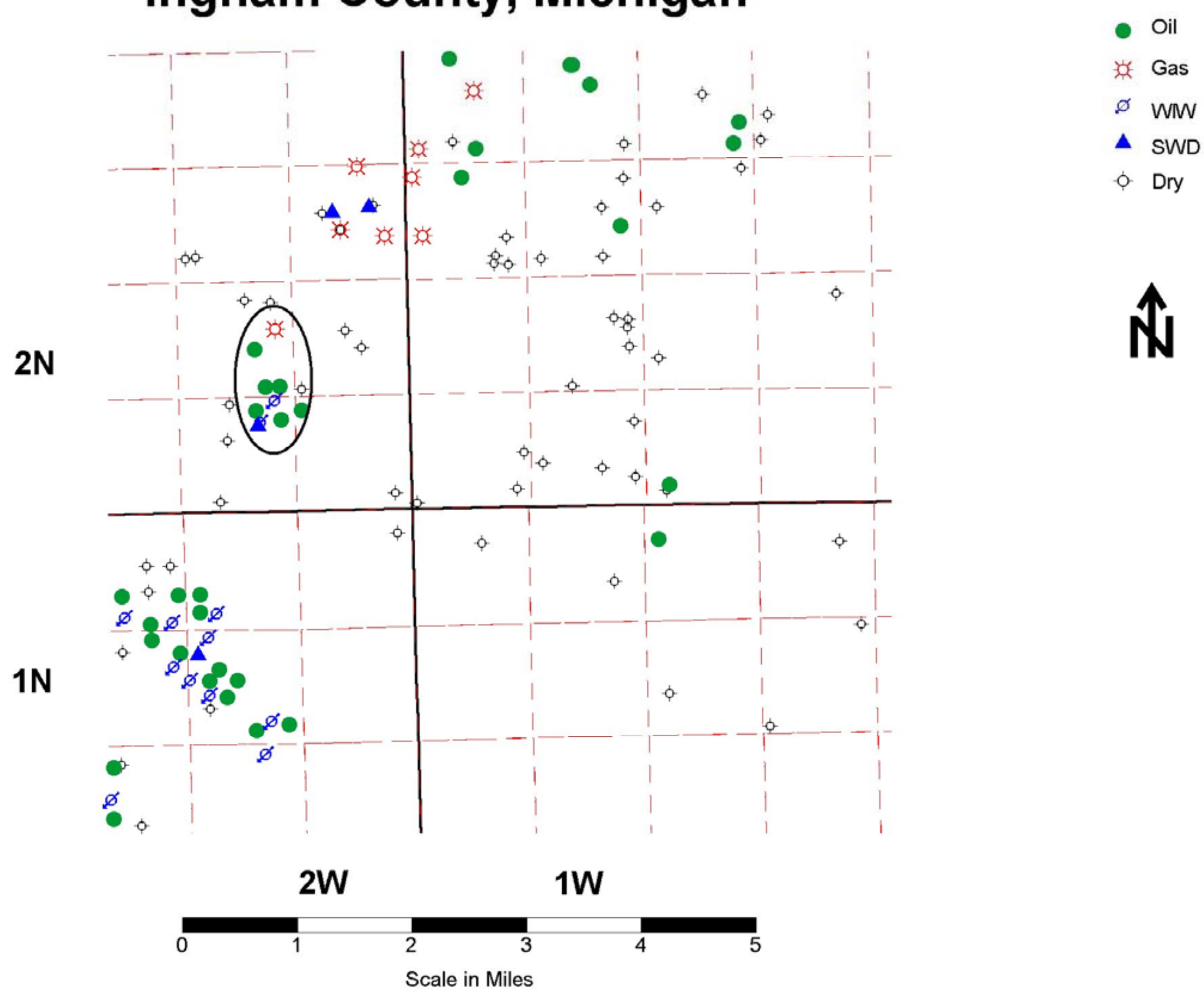


- Chart is constructed with all annual data for produced oil, produced water and injected water.
- It shows typical waterflood behavior in the early years, followed by what appears to be a hysteresis effect as more water is withdrawn than was injected.
- As expected, the imbibition curve shows a lower water cut than the drainage curve.

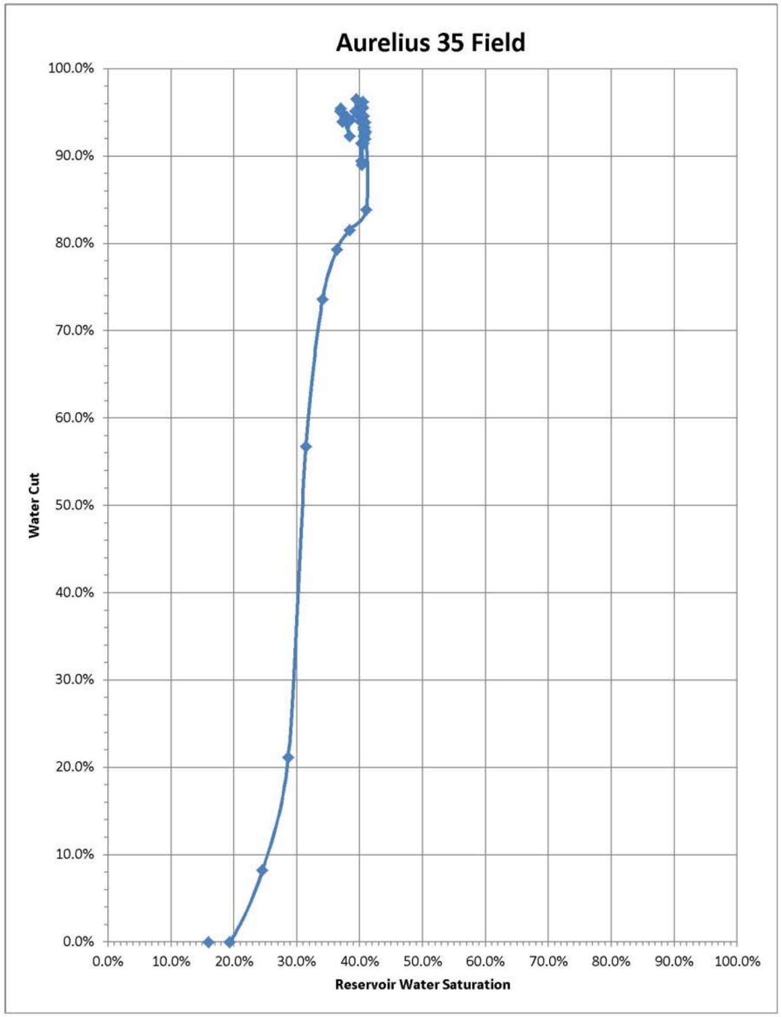


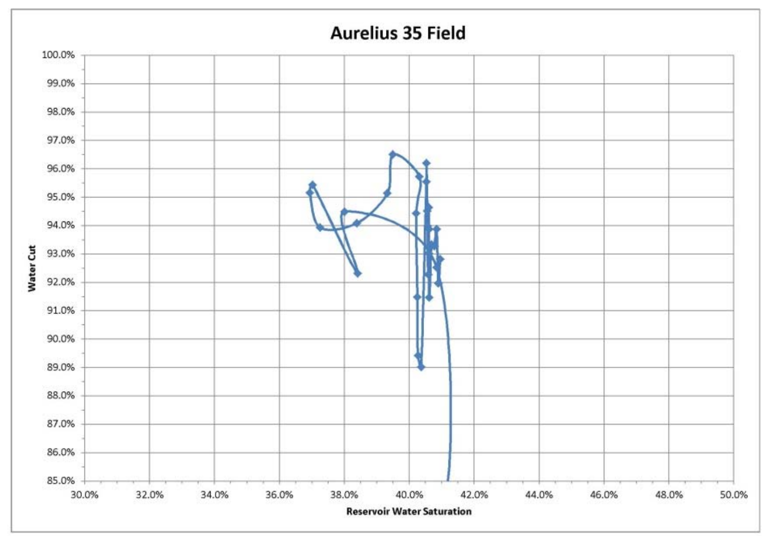
- Constructed same as Onondaga 21
- Shows early years of low water cut, then very rapid breakthrough
- Anomalies possibly due to variation in injection rates one year followed by production response the following year.
- 75% +/- reservoir water saturation seems high – was OOIP estimated too low?
- Last many years have seen injection equal to production of water and water cut has fallen somewhat, but still at very high percentages.

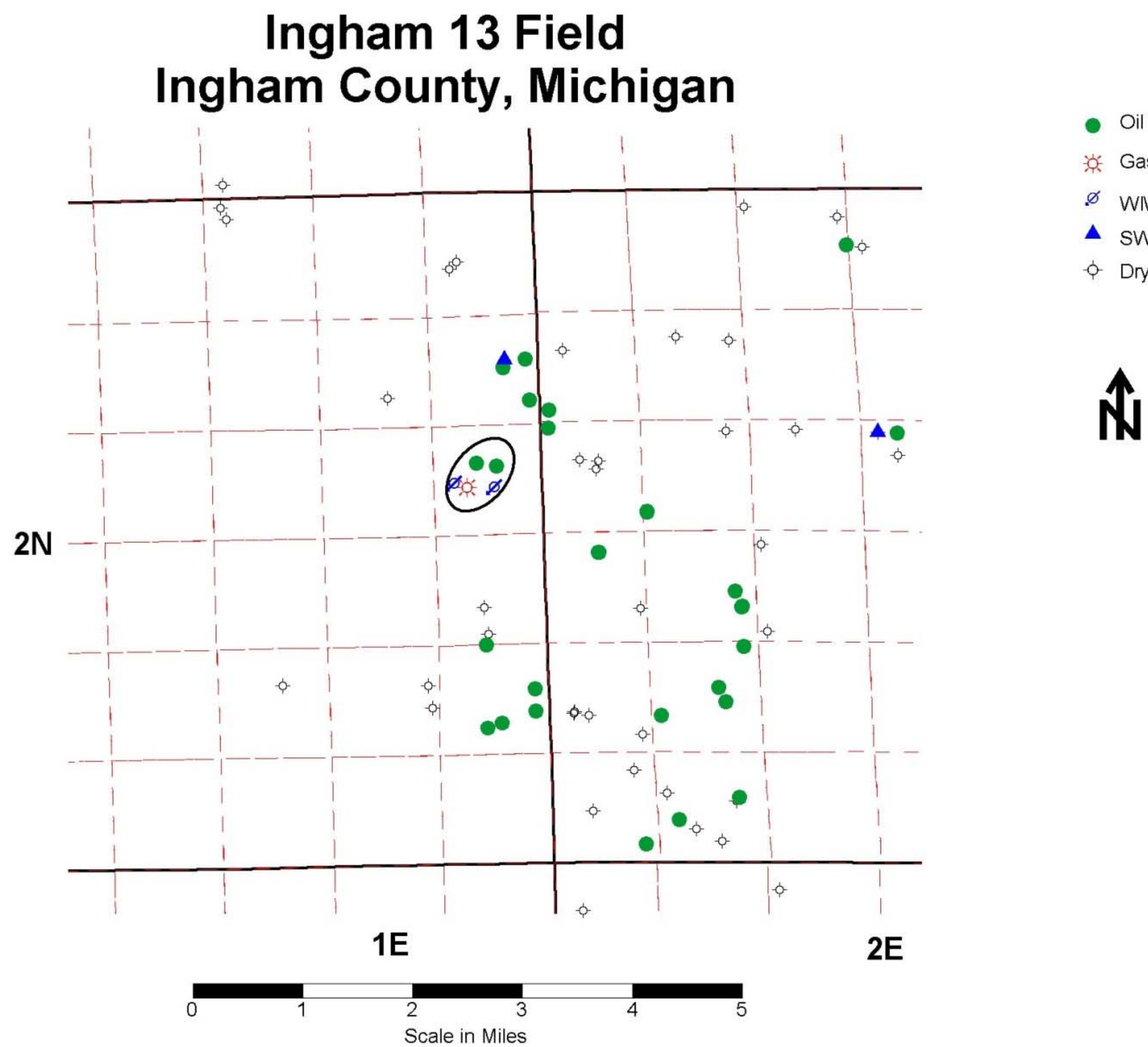
Aurelius 35 Field
Ingham County, Michigan

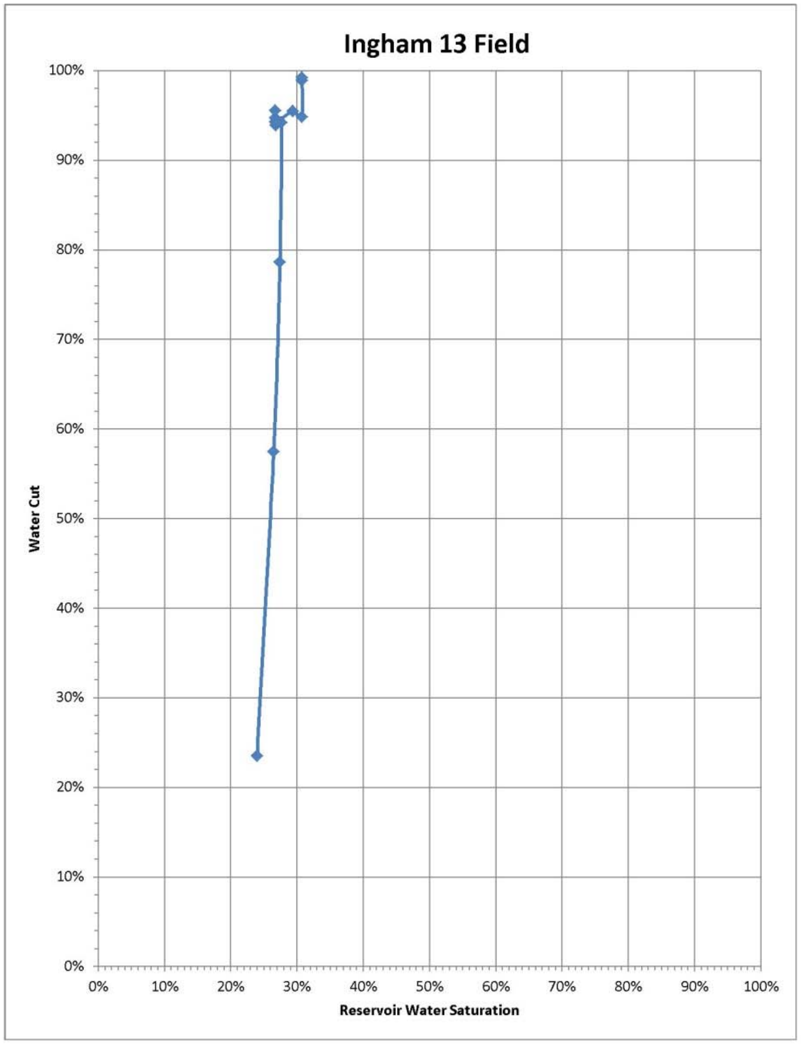


- Shows typical behavior until about 84% water cut then rapid increase.
- Possibly due to high volume lift and coning that followed.
- Late behavior very erratic



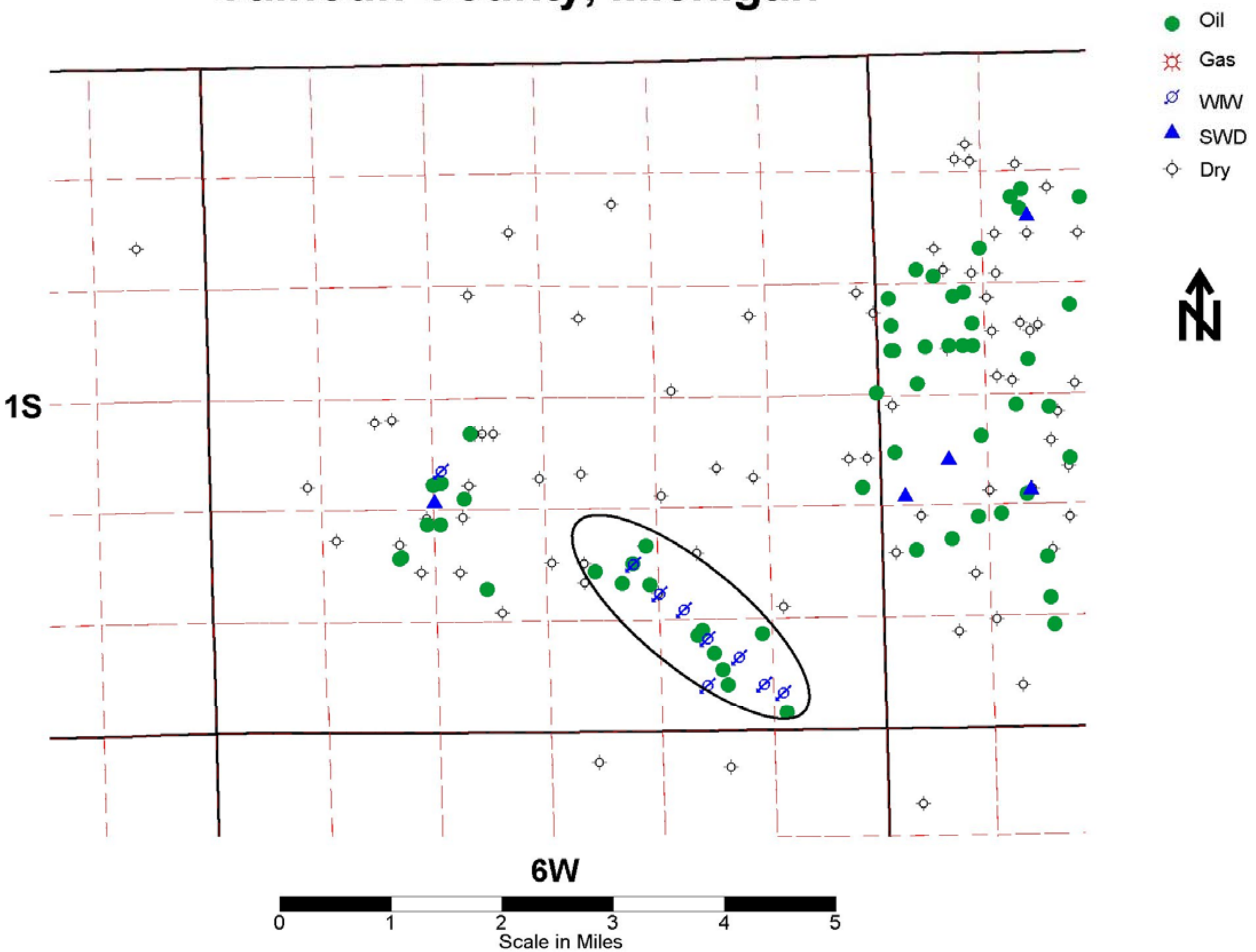


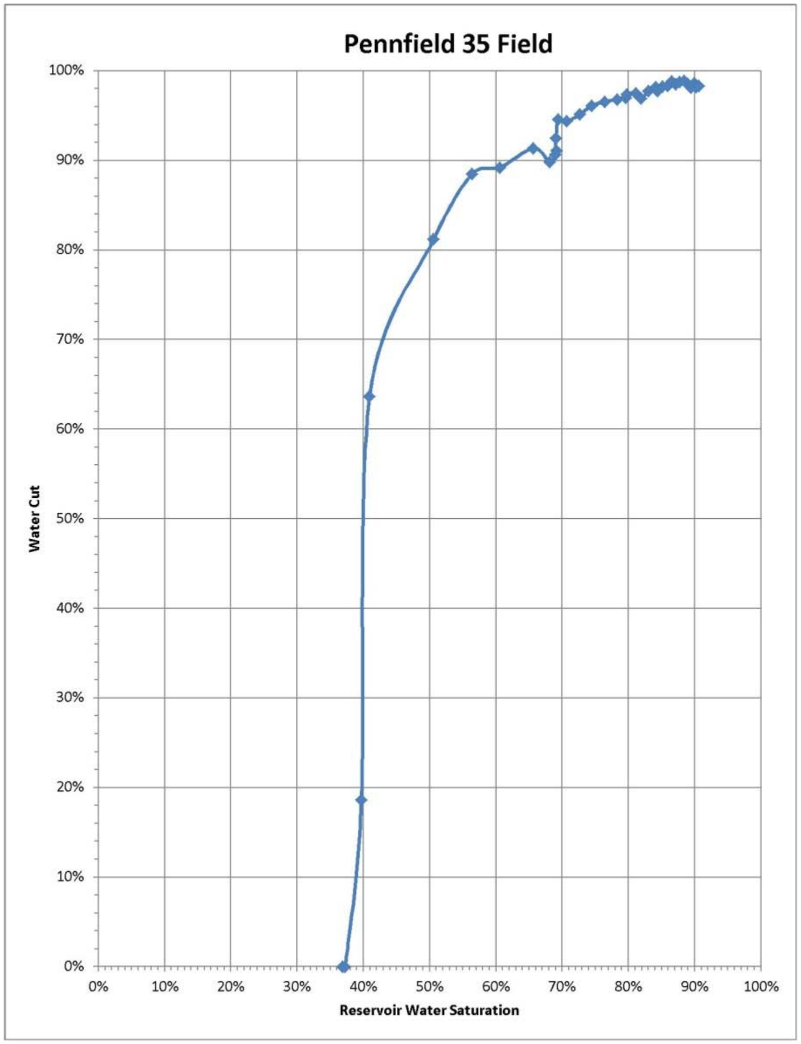

Ingham 13 Field
Ingham County, Michigan
Oil
Gas
WIW
SWD
Dry
N
2N
1E
2E
0
1
2
3
4
5
Scale in Miles



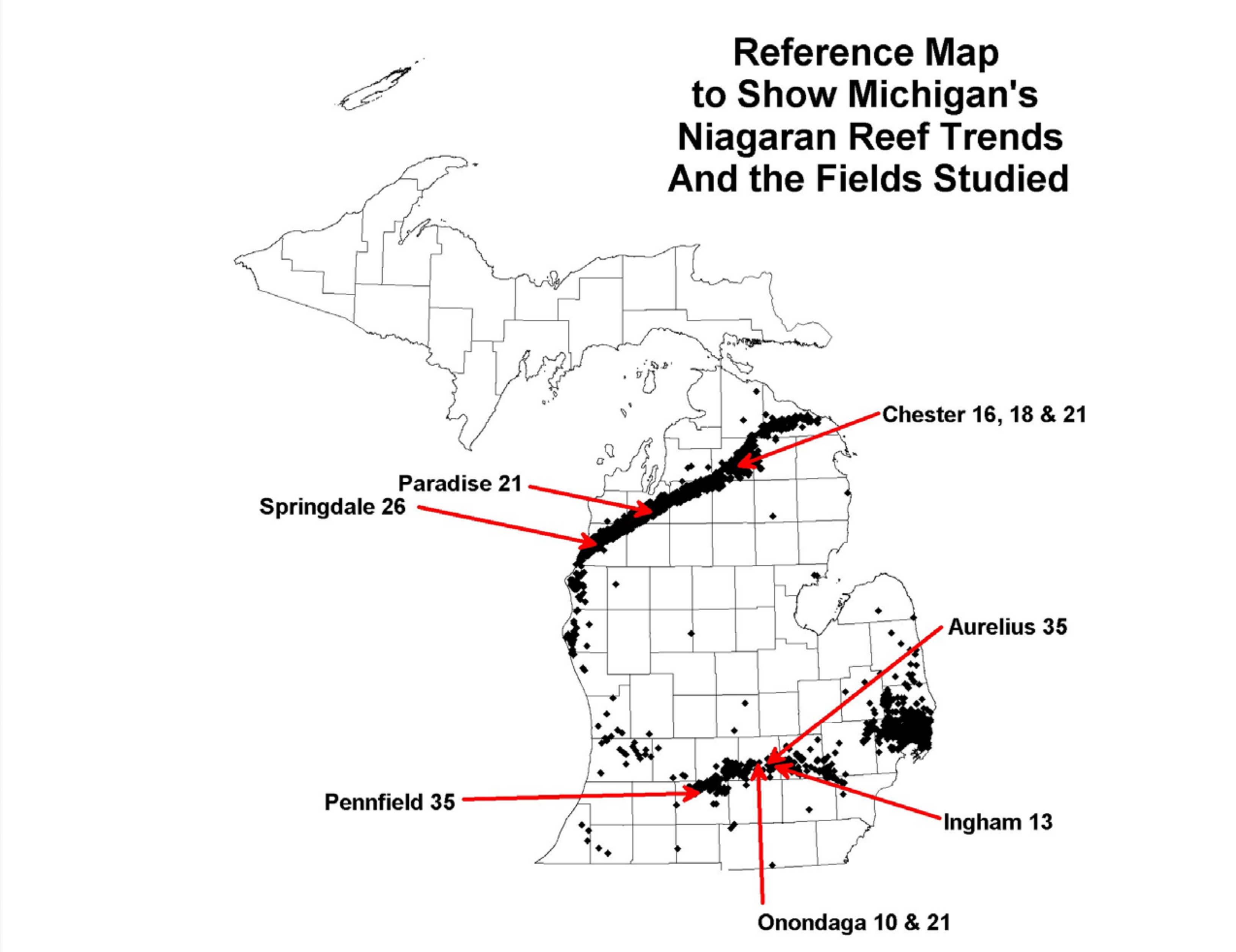
- Incredibly rapid breakthrough with virtually no incremental recovery.
- BHP at time of conversion was 25% of original.
- It is suspected that there was a significant gas saturation in the reservoir and that the water travelled through the gas saturated pore space from the injectors to the producers resulting in no incremental recovery.

Pennfield 35 Field
Calhoun County, Michigan





- Field shows nearly typical fractional flow behavior except for rapid rise in water cut and long 'tail' to curve, extending to 90% Sw in the reservoir
- Low API oil (23.6) is very viscous and can explain some of this.
- A few of the area reefs may be partial or entire bottom water drive.
- By not being a closed container, it is possible that injection after fillup may have caused water to migrate out the bottom of the reservoir.
- It is suspected that there was significant out-of-zone injection in this reservoir.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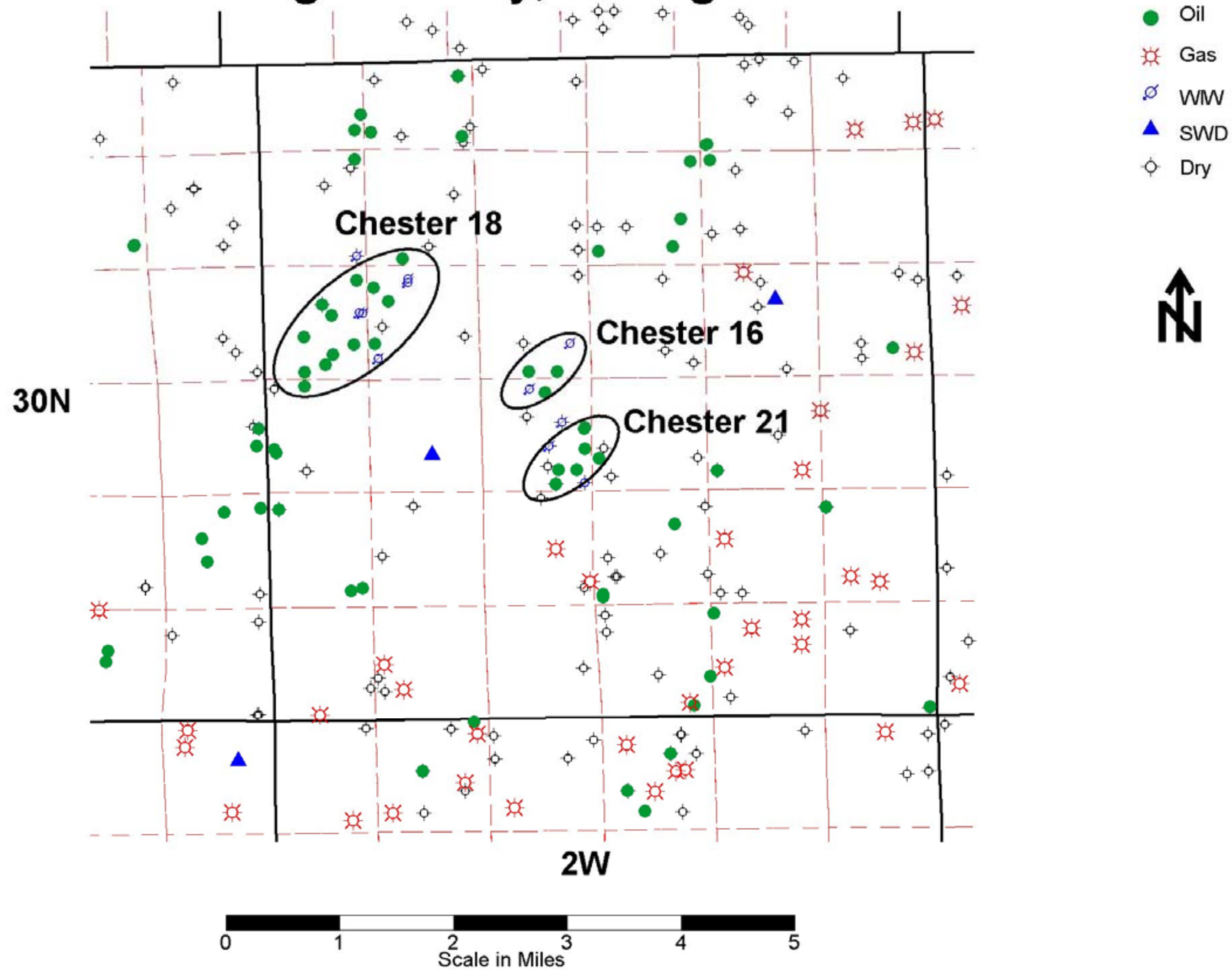
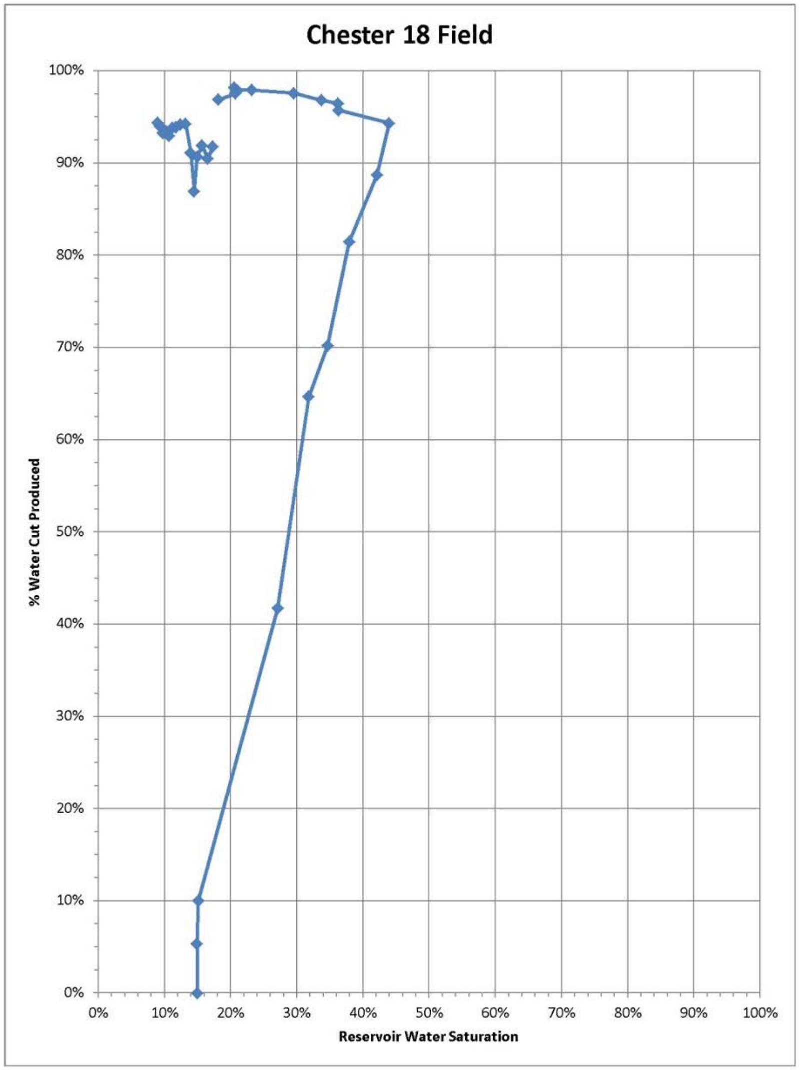
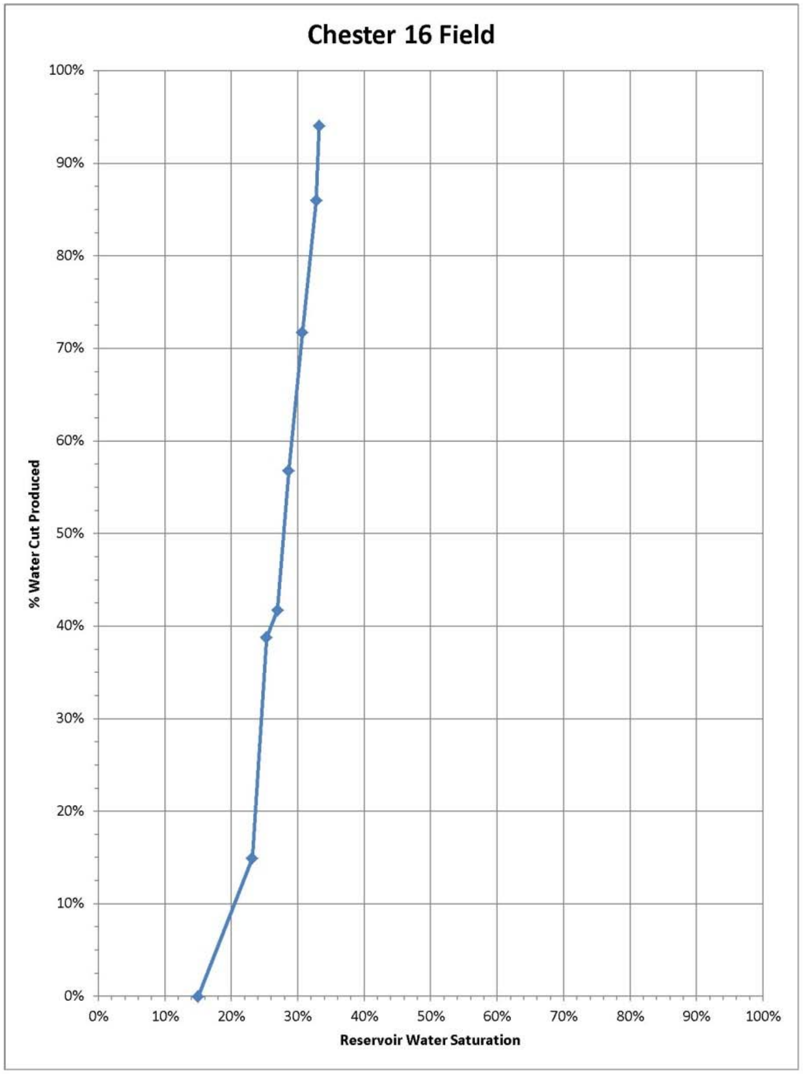
Chester 16, 18 and 21 Fields
Otsego County, Michigan

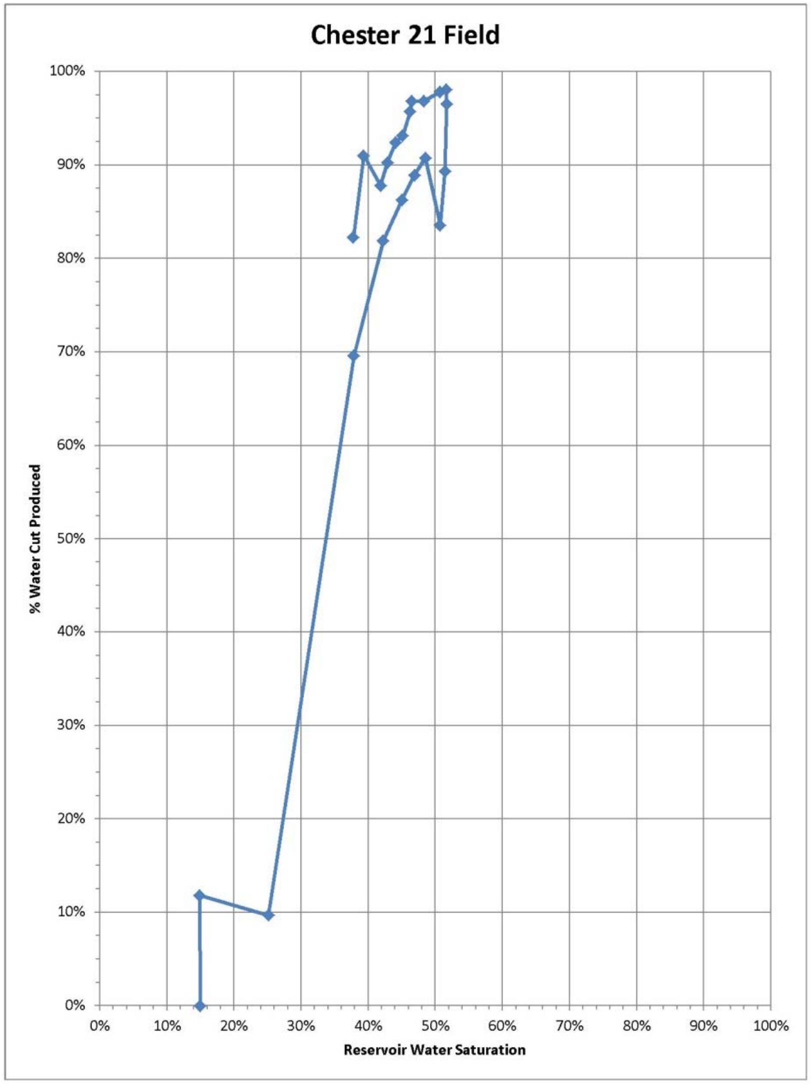




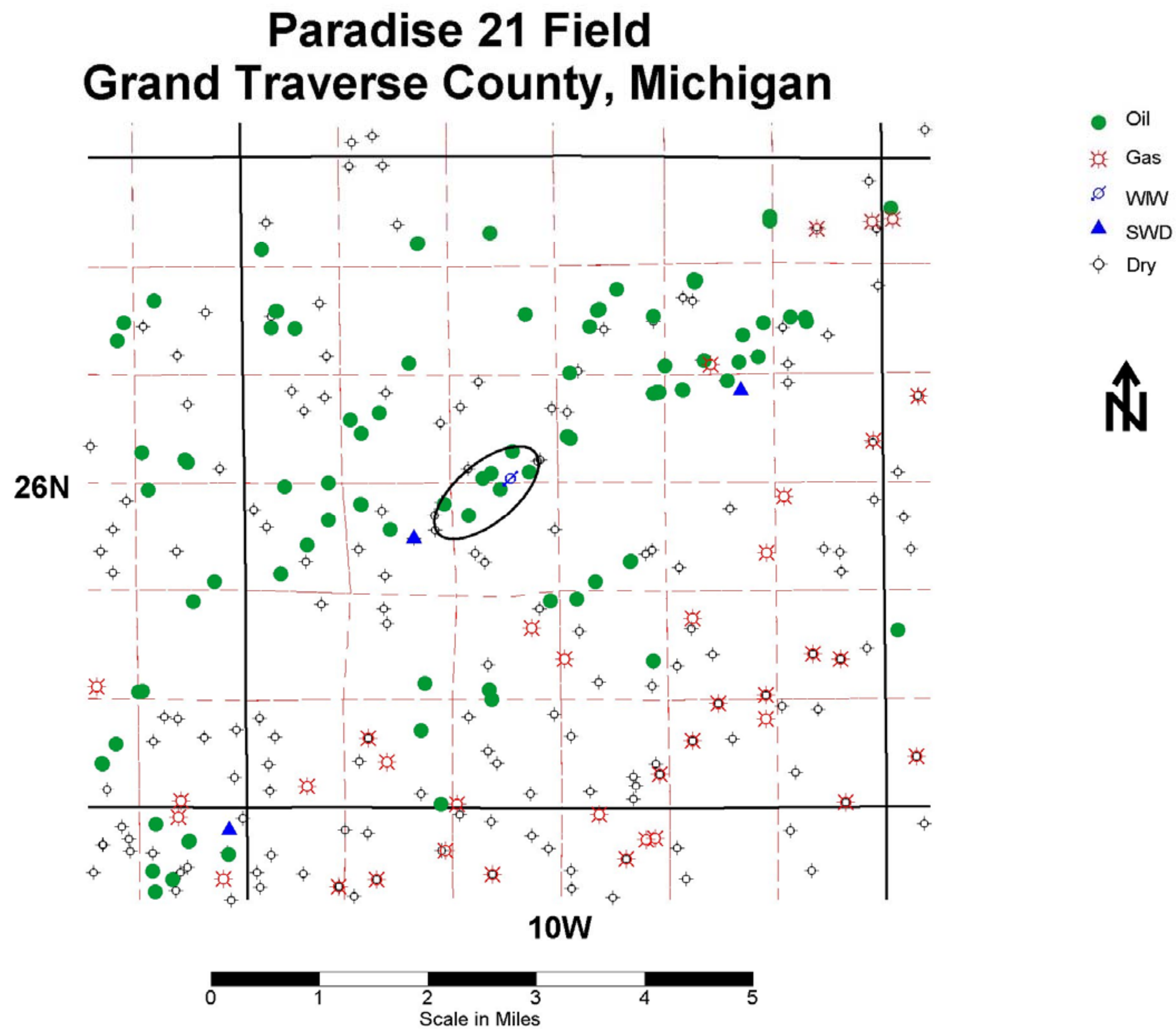
- The first and largest Northern Michigan Reef flood.
- Originally installed by Shell and commenced injection in 1977.
- Showed rapid breakthrough without typical S-shaped fractional flow curve, cut back injection to less than water production (used SWD for excess water) in 1985.
- Ceased injection in 1992.
- Plot is missing water production from 1994-1996, due to lack of reported data.
- Starting in 1997, must have shut in or plugged high water cut wells, but WC continued to increase – no hysteresis apparent.
- Concerning that calculated current S_w is less than original.

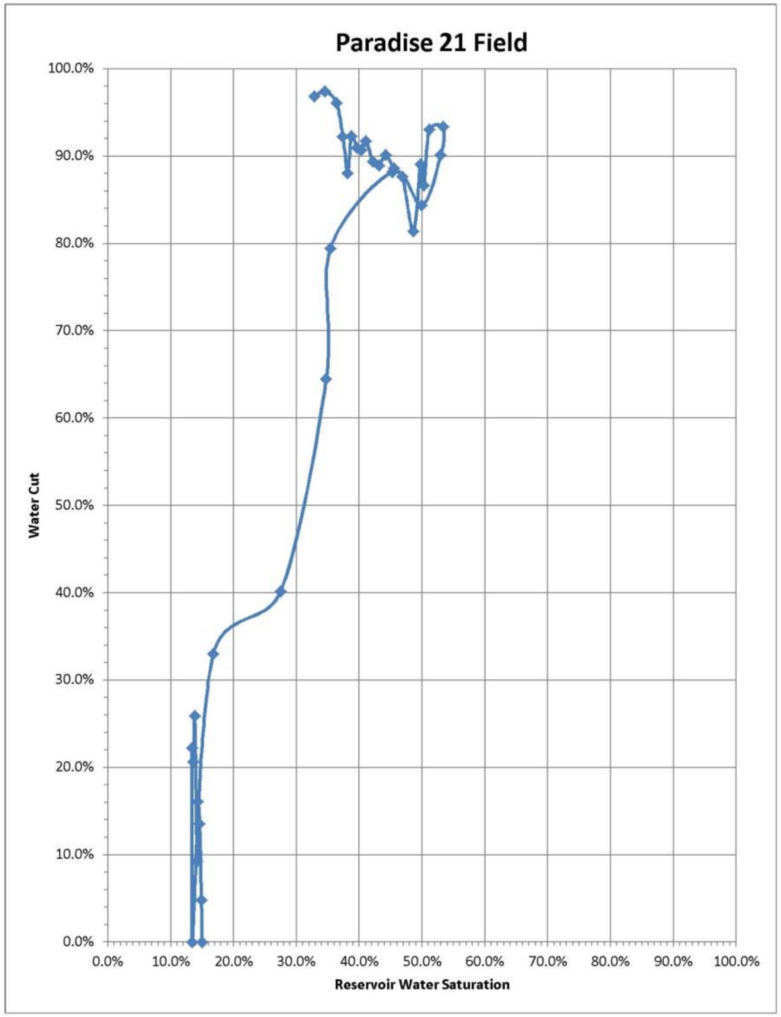


- Smaller field with 2 producers and 2 injectors.
- Flood was installed after 13 years of production, when BHP was significantly below discovery.
- It is suspected that there was a significant gas saturation present and the injectant bypassed oil by travelling through gas-saturated pore space.

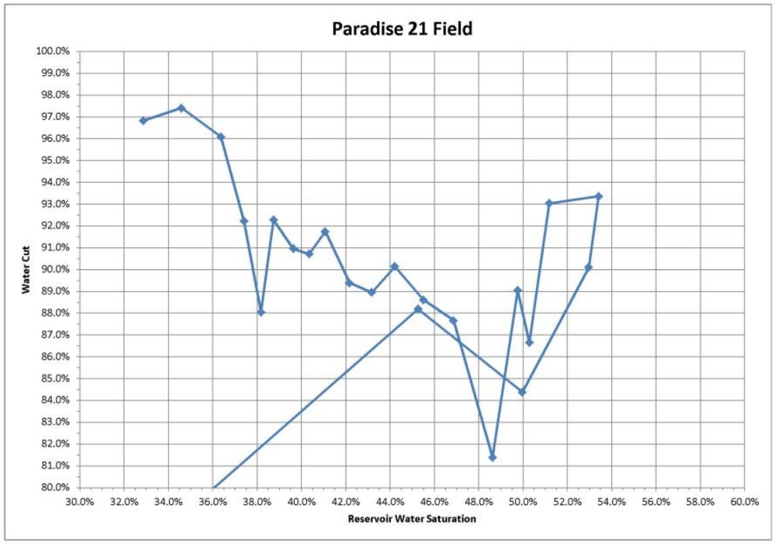


- Field shows generally good fractional flow behavior early-on, and as the injection volume became less than the produced water volume, the water cut dropped significantly.
- Good example of hysteresis.
- Interpretation may be clouded by the drilling of an infill well that has produced quite well.
- Results may point to the old axiom "The last thing you do to a waterflood is drill an infill well."

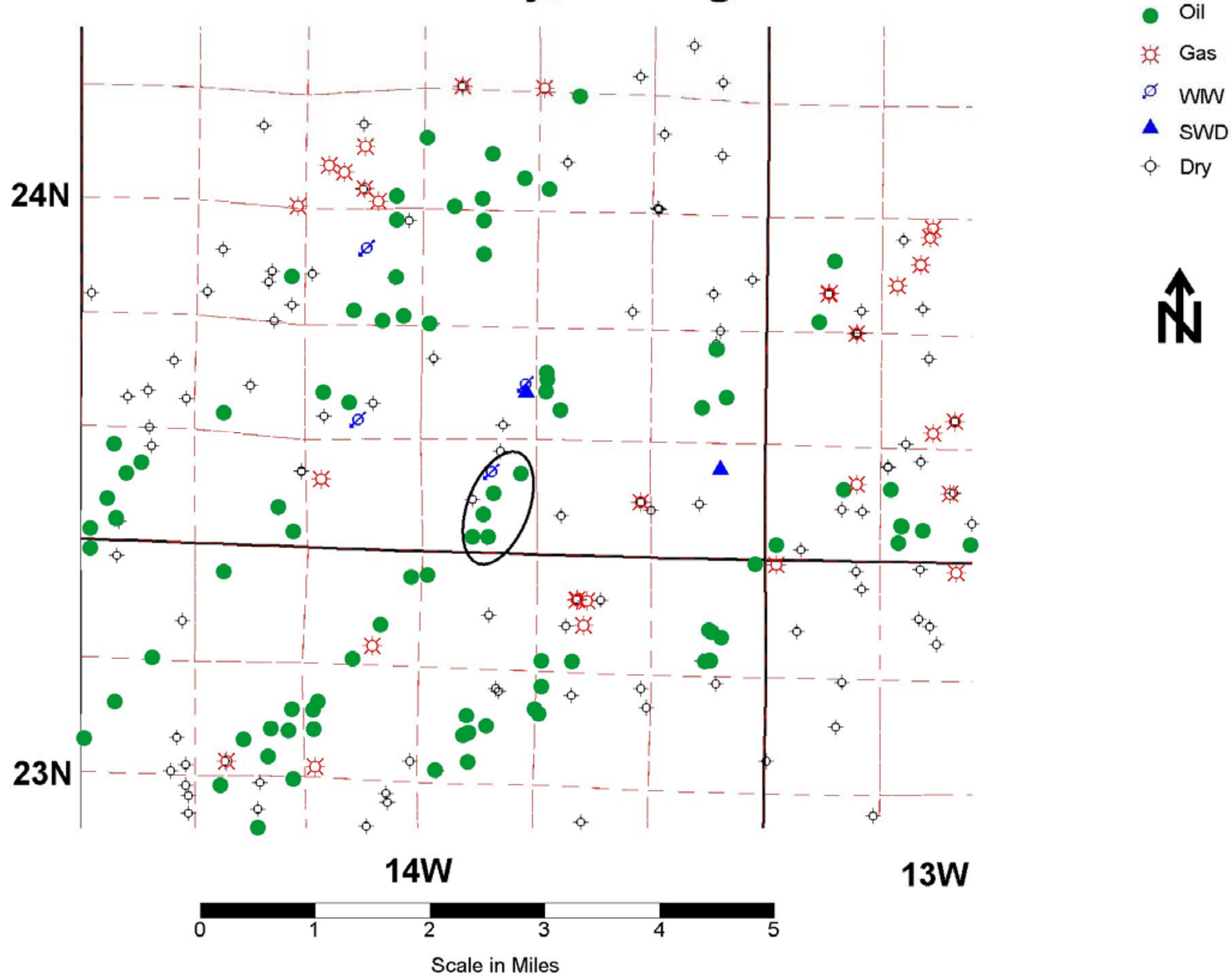

Paradise 21 Field
Grand Traverse County, Michigan
Oil
Gas
WIW
SWD
Dry
N
26N
10W
0
1
2
3
4
5
Scale in Miles

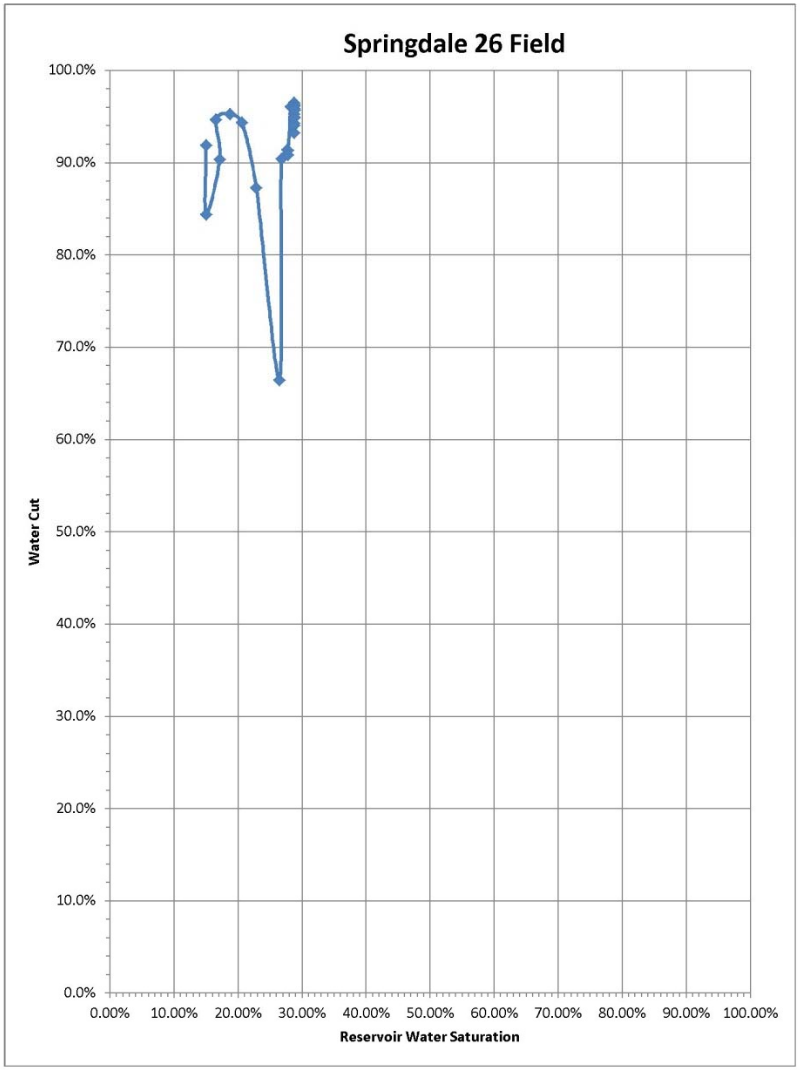


- Field was converted to injection at about 1,000 psi (1/3 of discovery pressure.
- Surprised by lack of early breakthrough.
- ‘Noisy’ FF curve, but rather predictable.
- Initial hysteresis, followed by continual increase in water cut.



Springdale 26 Field
Manistee County, Michigan





- Field was originally a gas injection project that was converted to waterflood.
- This field was previously studied and showed classic flood front movement, but that data is not publicly available.
- The publicly available data appears to be erroneous, leading to dubious results.

CONCLUSIONS

- Fractional flow curves can be used to evaluate the efficiency with which Niagaran reefs have been flooded.
- It is important to know as much of the background pertaining to each flood as possible.
- Errors in OOIP or in understanding the primary drive mechanism can lead to erroneous results.
- Floods with high gas saturation at the time of flooding experienced very rapid breakthrough and limited incremental recovery.
- Accuracy of input data is invaluable.
- Late infill wells can lead to dramatically improved results.

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