Gambit Consulting Ltd
Presentation for
Calgary SAS Users Group
08 Nov. 2013

Analyzing Enhanced Oil Recovery using SAS

Multi-Dimensional Analytics and Visualization of Fluid Communication

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GOAL

Develop an analytical tool for waterflooded fields which will assist in:

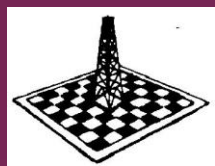
- monitoring,
- analyzing,
- understanding, and
- predicting
  - » fluid communication (RESPONSES) and
  - » fluid production.
- Optimizing water usage and oil production
- Plan new waterflood activity
- Discover unknown communication between different pools

New applications (environmental)

New Tool

Characteristics

- Simple
- Uses only public domain data (Injection/Production)
- No assumptions
- No streamlines, no tubes, no grid blocks, etc.
- Captures ‘actual’ different fluid responses in specific time window
- Estimates come with ‘significance level’
- Shows no communication or detrimental responses
- Can detect communication between different pools/fields
- Detects communication prior to waterfloods
- FAST
- Good for new players without experience
- Good for studies before acquisitions
- Brings unbiased view and differences between what is good, bad, and maybe
- Enables VISUAL EXPLORATION of many dimensions

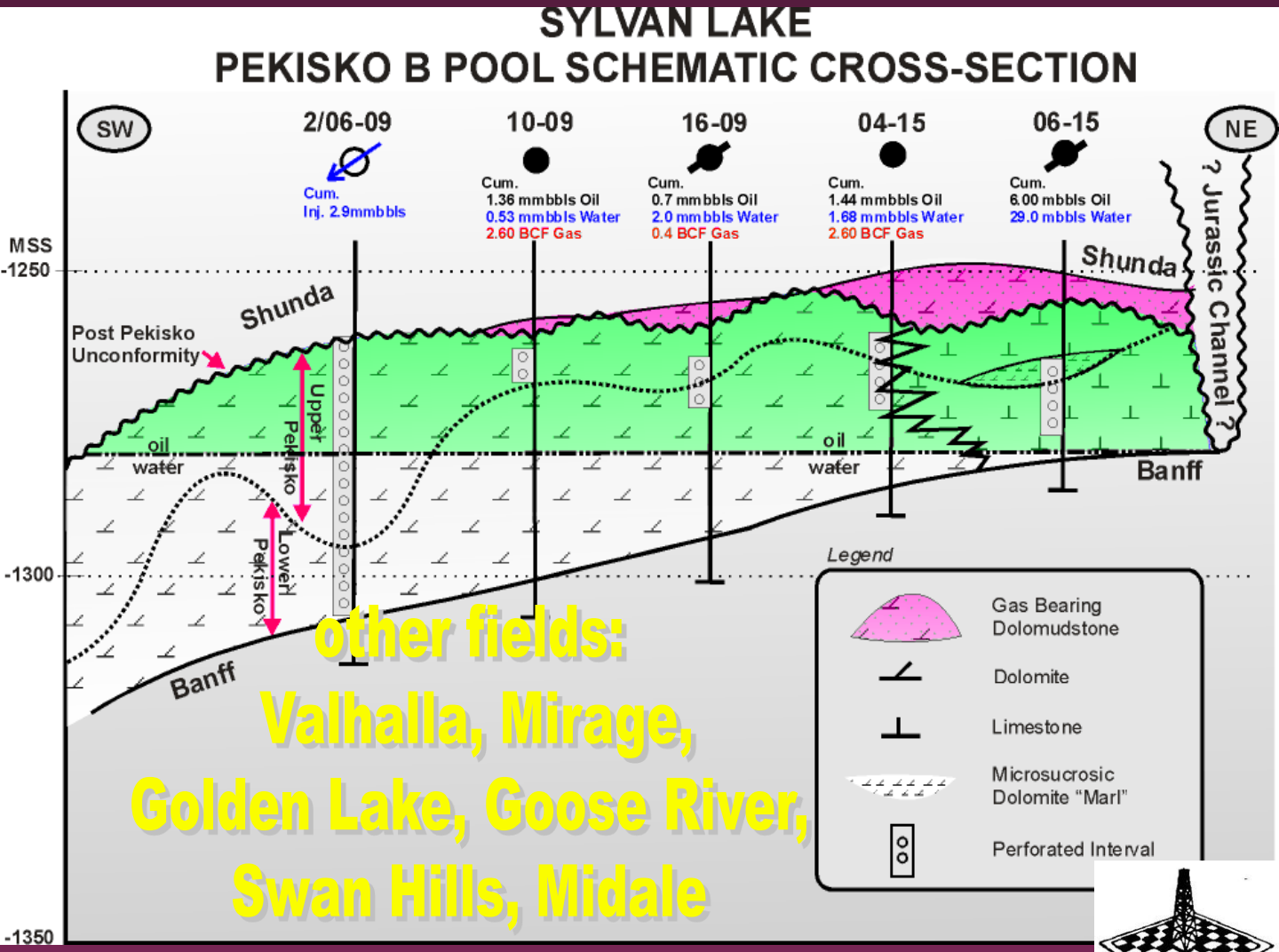


STEPS in Studies

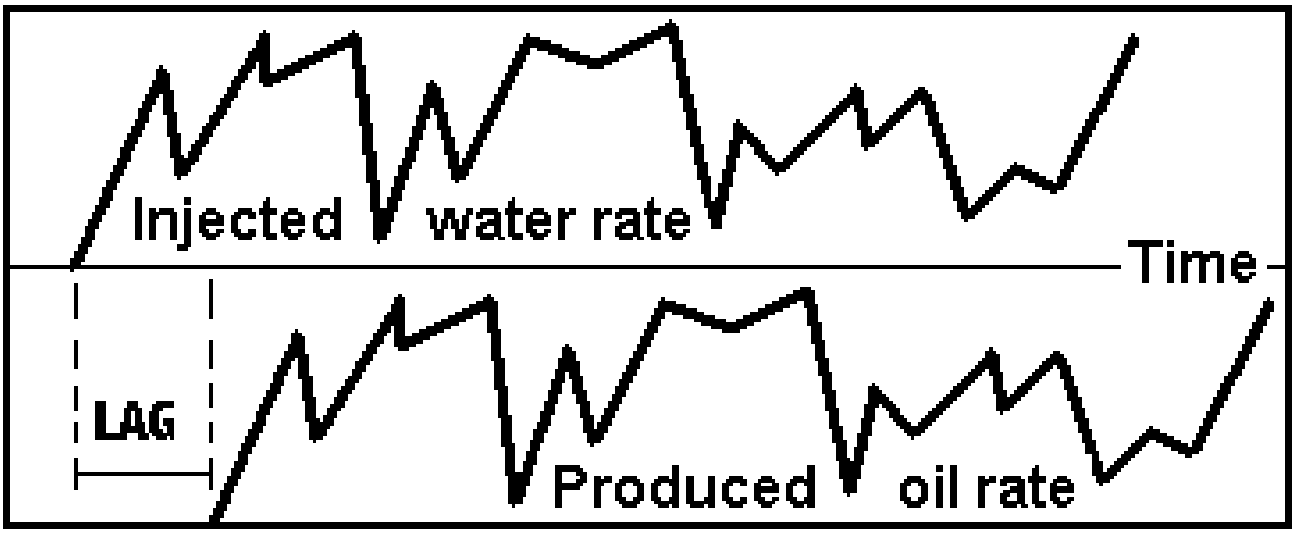
- Detect and measure waterflood responses
- Visualize them in time
- Integrate responses with geological, completion, treatment,…, data sets
- Predict future responses and production
- Optimize resources (Minimize water, solvents, etc.) and Maximize oil production

Published

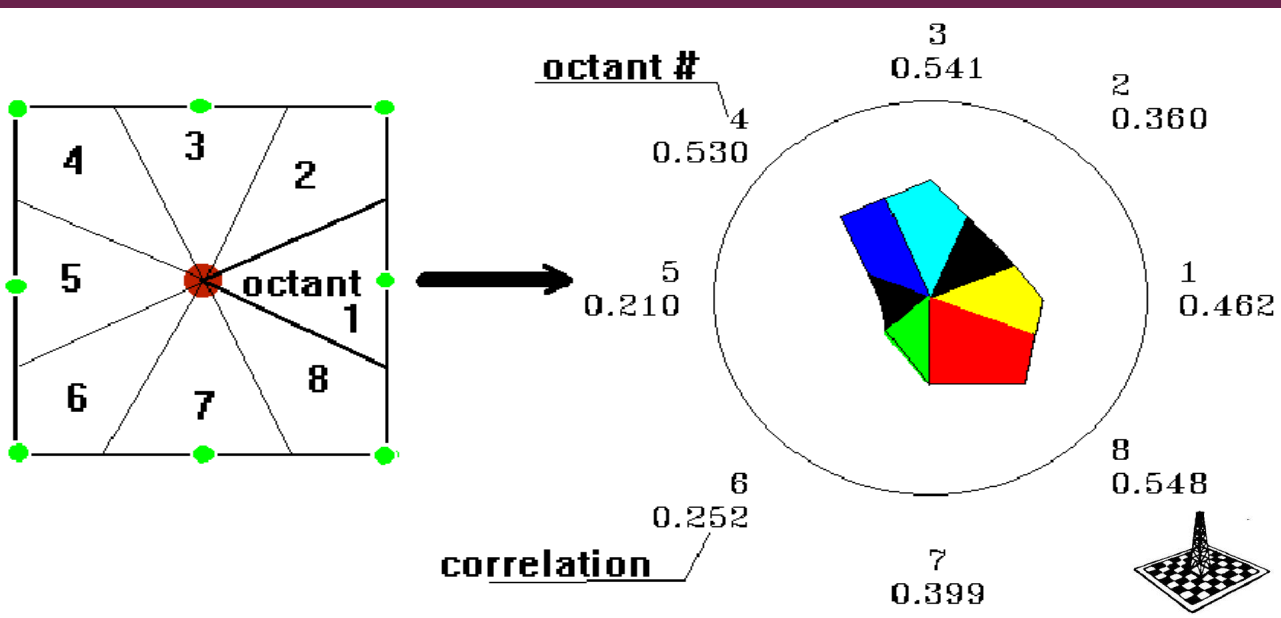
Journal of Canadian Petroleum Technology, vol. 40, No. 6
Journal of Canadian Petroleum Technology, No.5, Vol.46
SPE 50430
and more



Oil Response - Definition Visualization - Star Diagram



Response=Correlation between series



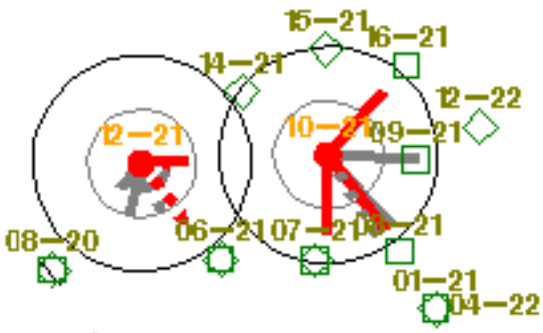
Waterflood Response Parameters

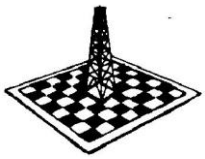
- Oil/gas/water/total fluid responses at lag=0
- Oil/gas/water/total fluid lagged responses
- Time lags corresponding to the lagged responses
- Combination of two responses defined as: Response Type
  - » oil-water
  - » oil-gas
  - » oil-total fluid

  Can be associated with flow units and geological units

Estimates come with confidence level

Multi-dimension Visualization Spine Diagram





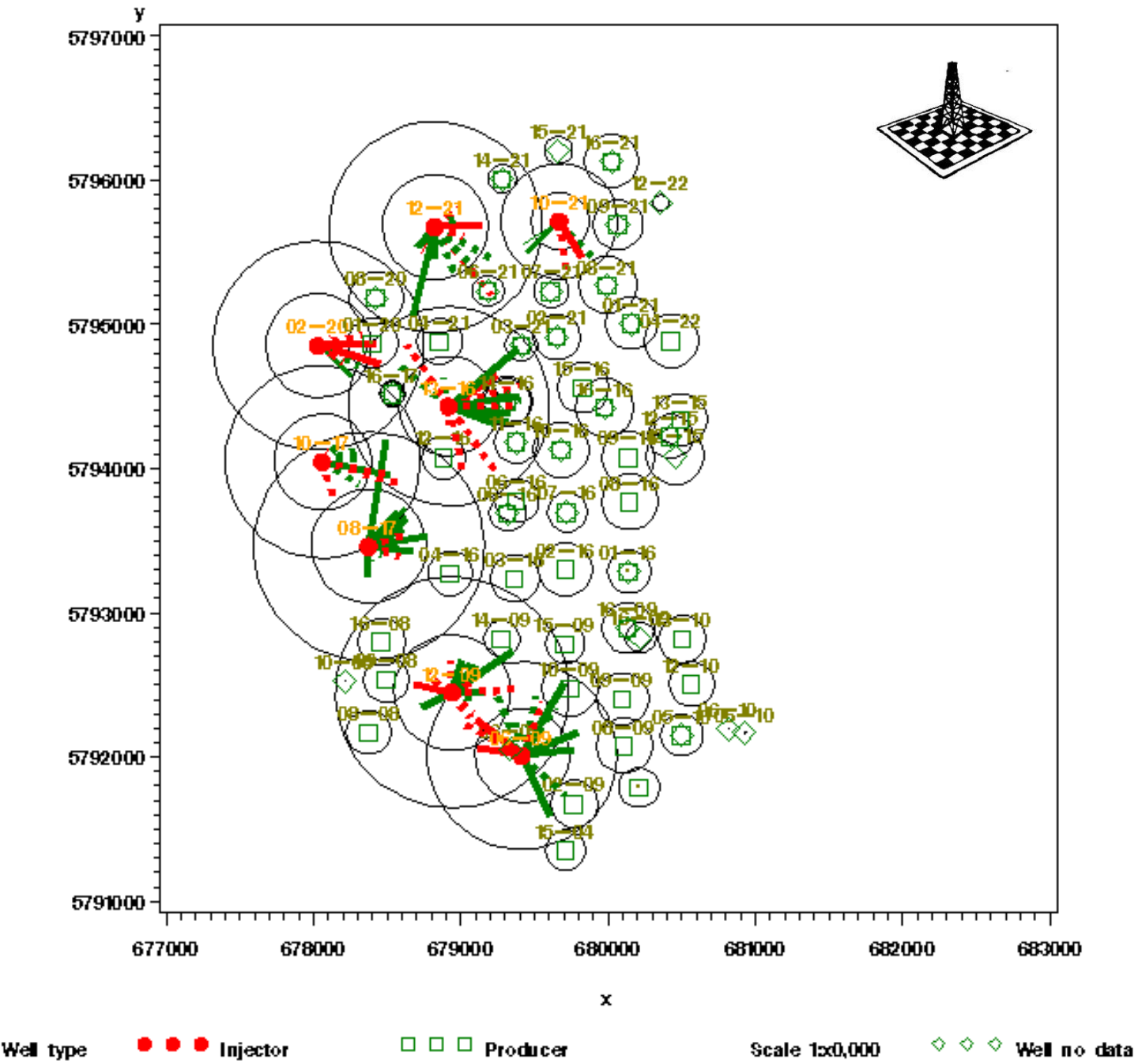
- Injector
- Producer
- Missing Data
- Positive Response
- Negative Response

Scale=0-1
(centre-outer circle)

- Response Time Lag < 6 months
- otherwise

Radius=function of
(Well's injection/Field's Injection
or
Well's Production/Field's Production)

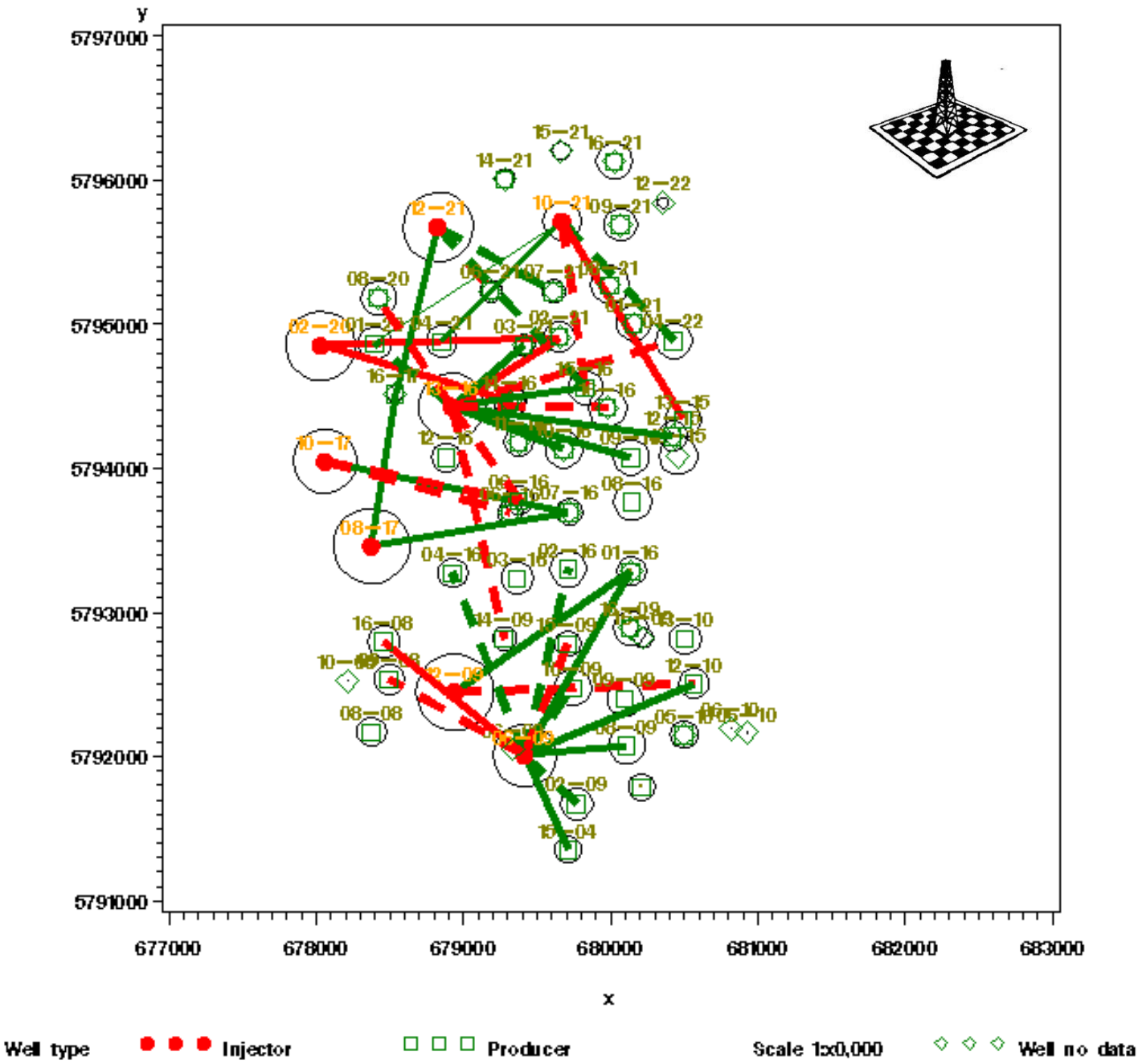
Composite Spine Diagram Large Scale - Oil Responses



Radius=f(normalized injection or production)

Composite Spider Diagram

e.g. Oil Responses >=0.5 or/and Distance <2500m



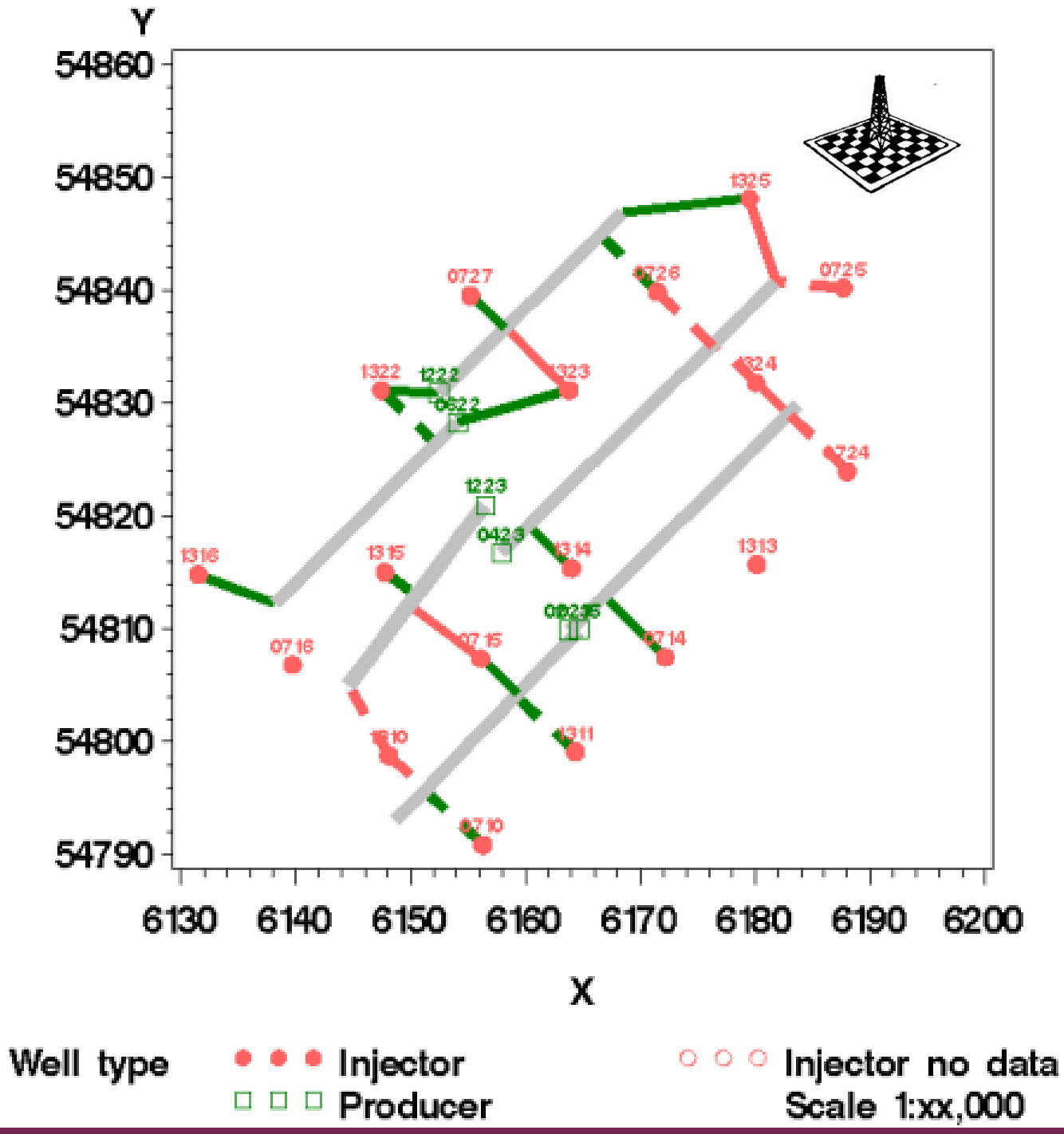
Radius=f(normalized injection or production)

Composite Spider Diagram

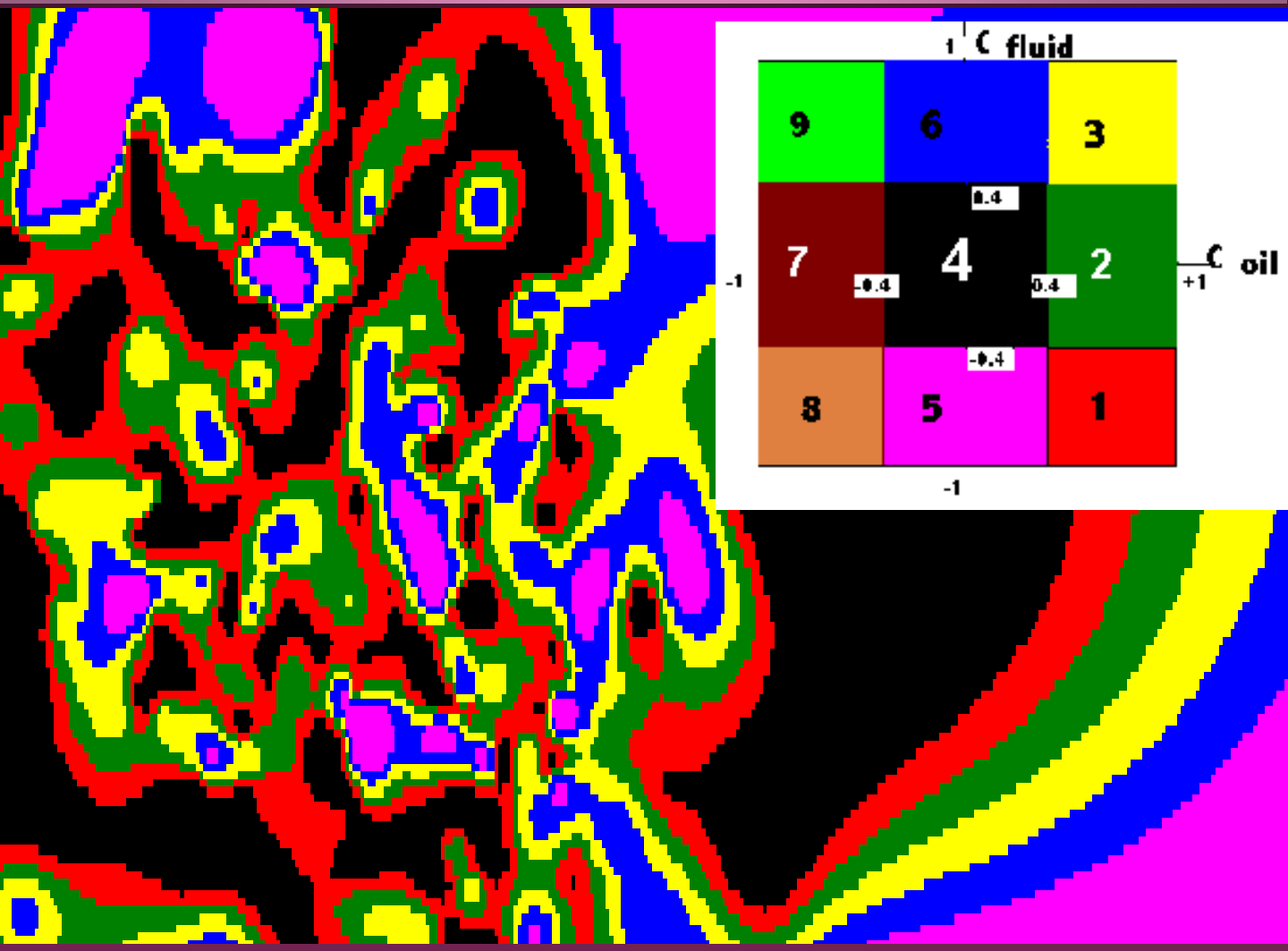
with horizontal wells

Oil Responses >=0.5

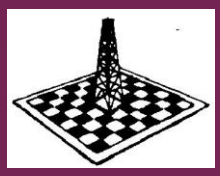
MIDALE example; paper No. SPE 50430



Combination of Responses Response Type (oil & fluid) =>Flow Units



Response type= f (oil response and fluid/water/gas response)



Application of Responses

- Finding communication paths and boundaries
- Mapping flow units
- Identifying ineffective injectors
- Identifying producers without support
- Improving production allocation estimates
- Identifying areas with fluid loses
- Predicting future responses
- Developing infill programs
- Generating correction maps for reservoir simulation.

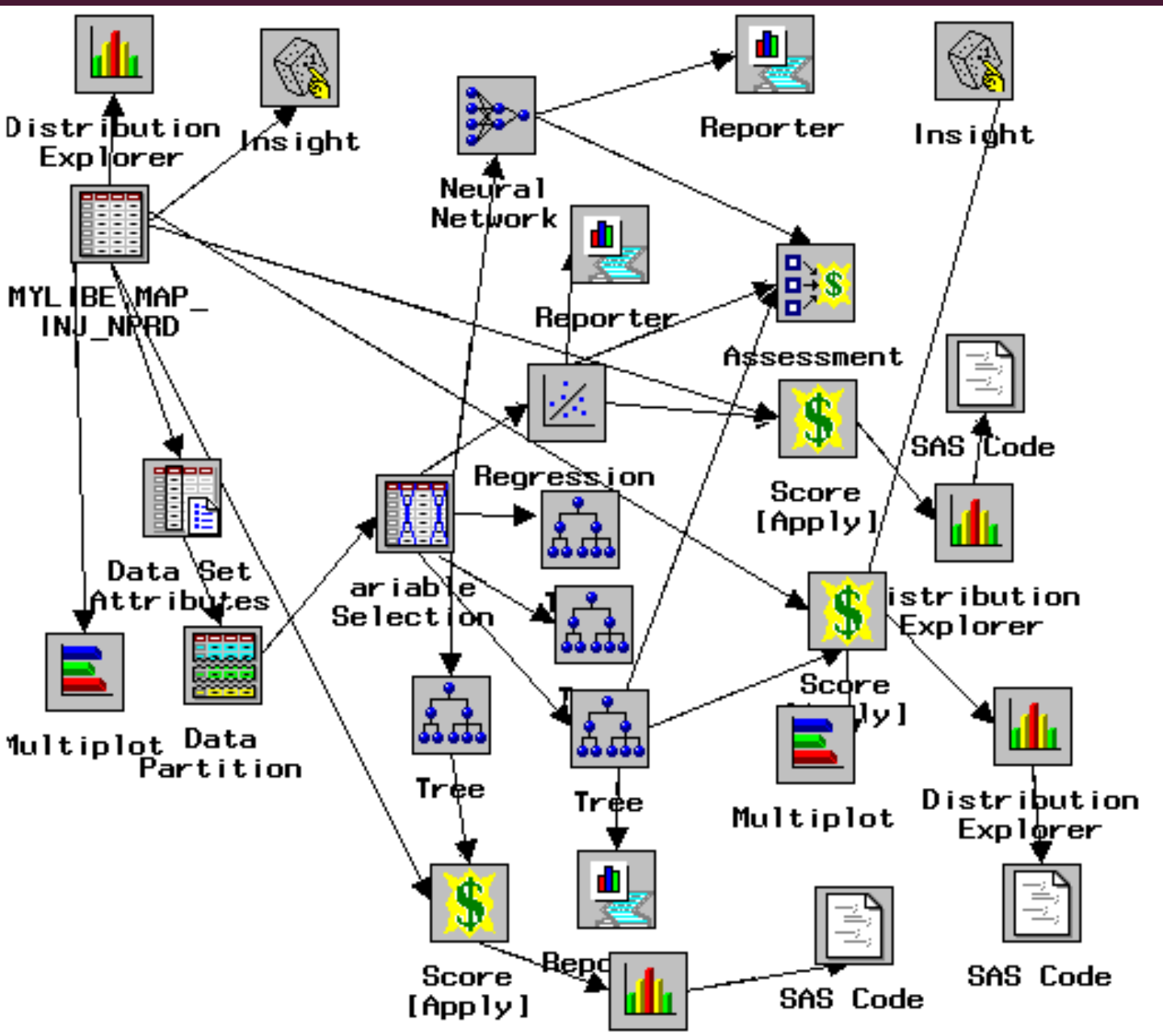
NEXT
Numerical Integration and Visualization

- **Data Sets:**
  - » **Geological (all possible)**
  - » **Completion**
  - » **Treatment**
  - » **Waterflood Responses**
- **Predictive modeling**
- **Target (Predicted variable):**
  - » **PRODUCTION Rate**
  - » **High Rate PRODUCTION PROBABILITY (top 25 percentile)**
    ===> Rank = Good or Poor.
- **Advanced Visualization**

Modeling Example

- **Data:**
  - » Lagged and non-lagged responses, time lags, and response types
  - » Pekisko B top subsea
  - » Pekisko B subsea of oil-water contact
  - » Pekisko B netpay
- **Target:** Probability of oil production in the highest 25 percentile
- **Three model types:**
  - » Logistic regression
  - » Decision tree
  - » Neural network
- **Decision tree can be the best performer**

SAS/EM PROJECT DIAGRAM



Decision Tree = Set of English Rules

IF 16.0 <= P_NET_OIL and C_OIL_0 < -0.045 THEN

N : 25

0 : 20.0%

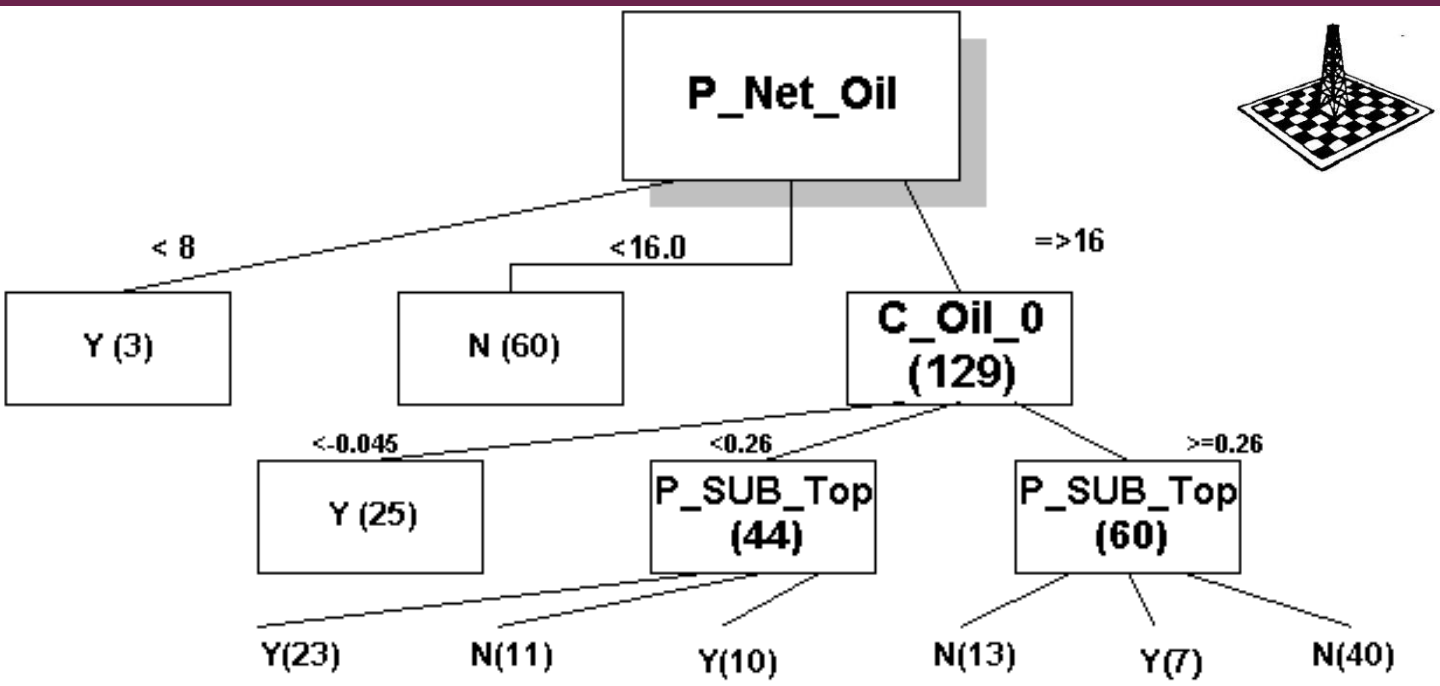
1 : 80.0%

IF 16.0 <= P_NET_OIL and -0.045 <= C_OIL_0 < 0.26 and P_SUB_TOP < -1252.21 THEN

N : 23

1 : 65.2%

0 : 34.8%



Modeling Outcome

- Integrated geological and waterflood response parameters.
- Developed predictive models for the oil production rates during waterflood.
- Models predicted the probability of a GOOD well.
- Developed and tested Regression, NN, and Decision Tree models.
- Decision trees provided the best predictive models.
- Model based on decision tree had <u>two to four</u> times better success rate than the observed rate.
- Profit and fixed cost matrices helped in predicting: Return=costs/return(fixed, true positive, false positive, true negative, and false negative predictions).

ADVANTAGES

- Scientific
- Consistent (no bias)
- Fast
- Based on public data
- Low cost
- 200 patterns and 500+ wells NO PROBLEM
- Links responses to other data sets
- Leads to better understanding
- Helps to:
  - » monitor performance
  - » make production decisions
  - » predict/optimize return.

SAS as
Development and Implementation Tools

- **DEVELOPMENT**
  - » Data Integration
  - » Data Cleansing
  - » Data Transformation
  - » Normalization
  - » Log Transformation
  - » Simple Stats
  - » Time Series Correlation
  - » Custom Ranking
  - » Graphics/Visualization
  - » Regression, Neural Net, and Decision Tree Models
- **IMPLEMENTATION**
  - » SAS Programs Data Steps
  - » SAS Programs Macros
  - » SAS Procedures
  - » SAS/EM Exported Model Code
  - » SAS Visual Explorer

Comment: Development Prototype becomes Implementation Code Version 1