PERFORMANCE PREDICTION OF WATER FLOODED RESERVOIR USING ECLIPSE SIMULATOR

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CERTIFICATE

This is to certify that the work contained in this dissertation titled **"Performance Prediction of Water Flooded Reservoir Using Eclipse Simulator"** has been carried out by **Naman Wadhwa (R0404205039)** under my supervision and has not been submitted elsewhere for a degree.

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ABSTRACT

Water flooding is a EOR technique in which water is injected in to the reservoir formation to displace residual oil. The water from injection wells physically sweeps the displaced oil to adjacent production wells. It is dominant among the fluid injection methods and unquestionably responsible for higher recoveries and production rates from the reservoir.

Reservoir engineering is one of the few applied sciences that deal with the system that cannot in its totality be seen, weighed, measured or tested. Even in fields where every drilled well is cored, less than one millionth of the reservoir rock is ever sampled and seen by man. Fluid samples on which detailed laboratory measurements are made are limited. In such a situation it has always been experienced that we are able to simulate the reservoir performance than to describe the reservoir itself.

Reservoir simulation is a sophisticated mathematical tool which allows the engineer to apply classical reservoir engineering principles to reservoir analysis in the context of realistic reservoir description which display variations in reservoir rock and fluid parameters in space and time. Reservoir simulation divides the reservoir into number of small blocks or cells in two dimensional or three dimensional network of rock and applies the fundamental equations of fluid flow through porous media (Darcy's Law), phase behavior (Equation of State) and conservation of mass (Material Balance) to each book. Once a model is prepared which satisfies the history match then it can be used to predict almost anything in the reservoir.

With high speed, high capacity digital computers, the perfect water flood prediction can be closely approached. Long reservoir performance can be predicted with adequate degree of accuracy within a few minutes or hours and thus future course of action can be accordingly decided.

Using ECLIPSE-100 which is a fully-implicit, three phase, three dimensional, general purpose black oil simulator with gas condensate option, simulation is done. ECLIPSE can be used to simulate 1, 2 or 3 phase systems. Two phase options (oil/water, oil/gas, gas/water) are solved as two component systems saving both computer storage and computer time. In addition to gas

dissolving in oil (variable bubble point pressure or gas/oil ratio), ECLIPSE may also be used to model oil vaporizing in gas (variable dew point pressure or oil/gas ratio).

OBJECTIVES ACHIEVED

- Building of the simulation model
- Undertaken a literature survey to find out the various models that are applicable for predicting water flood performance
- Running the simulation model and getting results
- History matching
- Adding 2 prediction wells
- Adding 3 prediction wells
- Applying water flooding technique with irregular pattern with 3 injection wells and 2 prediction wells
- Applying water flooding technique with irregular pattern with 3 injection wells and 3 prediction wells
- Comparing the performance

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(UNIVERSITY OF PETROLEUM AND ENERGY STUDIES, Dehradun)

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CHAPTER- 1

INTRODUCTION

1.1 RESERVOIR SIMULATION

Reservoir simulation is a geo scientific and mathematical attempt to replicate the reservoir and happenings in the subsurface reservoir. In other words reservoir simulation is an area of reservoir engineering in which computer models are used to predict the flow of fluids (typically, oil, water and gas) through porous media. The geo scientific and mathematical computations provide pressure- production information, GOR vs. time/pressure, water cut, spatial distribution of oil saturations at different time frames.

It can also be defined as the reservoir simulation is the numerical study of multiple phase flow in porous media. Simulation is in many practical cases the only way one can describe quantitatively suck multi phase flow, and is today an important tool which is used daily by many reservoir engineers.

Reservoir simulation models are predominantly used by major oil and gas companies in the development of new oil fields. As building and maintaining robust, reliable models of field is often time- consuming and expensive, models are typically only constructed when large investment decisions are at stake. A computer run of a reservoir model is made over time to examine the flow of fluid within the reservoir and from the reservoir. Reservoir simulators are built on reservoir models that include the petro physical characteristics required to understand the behavior of the fluids over time. Usually, the simulator has been successfully calibrated, it is used to predict future reservoir production under a series of potential scenarios; such as drilling new wells, injecting various fluids or stimulation.

1.1.1 SIMULATION

1. Reservoir simulation is geo scientific and mathematical attempt to replicate the reservoir and happenings in the subsurface reservoir.

2. Reservoir/Numerical simulation is based on Material Balance Equation, taking into account reservoir rock characteristics and properties of fluids.

3. It considers position of wells and their operating environment to work out the reservoir fluid dynamics.

4. Reservoir is divided into small cells or blocks to take care of rock-fluid-pressure characteristics.

5. Computations are carried out using material balance and fluid flow equations for oil, gas and water phases for each cell at discrete time steps, starting with the initial.

1.2 RESERVOIR SIMULATOR

The basic tool for conducting a reservoir simulation study is a *simulator.* A reservoir simulator is a mathematical model of a system that is simply an equation which relates the behavior of the system, expressed in terms of observable variables, to some parameters which describe the system. These equations are frequently described as physical laws. Examples of mathematical models applied to petroleum reservoirs are material balance equations and decline curve analysis. These models are very useful in conducting analytical reservoir performance evaluation but because of the simplifying assumptions, they are of less use for detailed reservoir description purposes.

As a result more detailed mathematical model are constructed by subdividing the reservoir in to small volume elements, referred to as grid, and applying the laws of mass conservation and fluid flow to each grid. By letting the elements tend to zero volume, the equation for movement of fluid in a porous medium can be constructed. The resulting equations are non linear differential equations which are almost always too difficult to solve analytically. As a result, approximations are made in order to solve the equations at discrete points in space and time and it is this discretization which leads to the requirement to solve large linear matrix systems. The discretized partial differential equation is referred to as numerical model, which is easier to solve.

A simulator or numerical model can be described as a series of numerical operations whose results represent the reservoir behavior. A simulator can be referred to as a tool for integrating all of the factors that influence reservoir production and it is basically solution to conservation equations that represent physical loss.

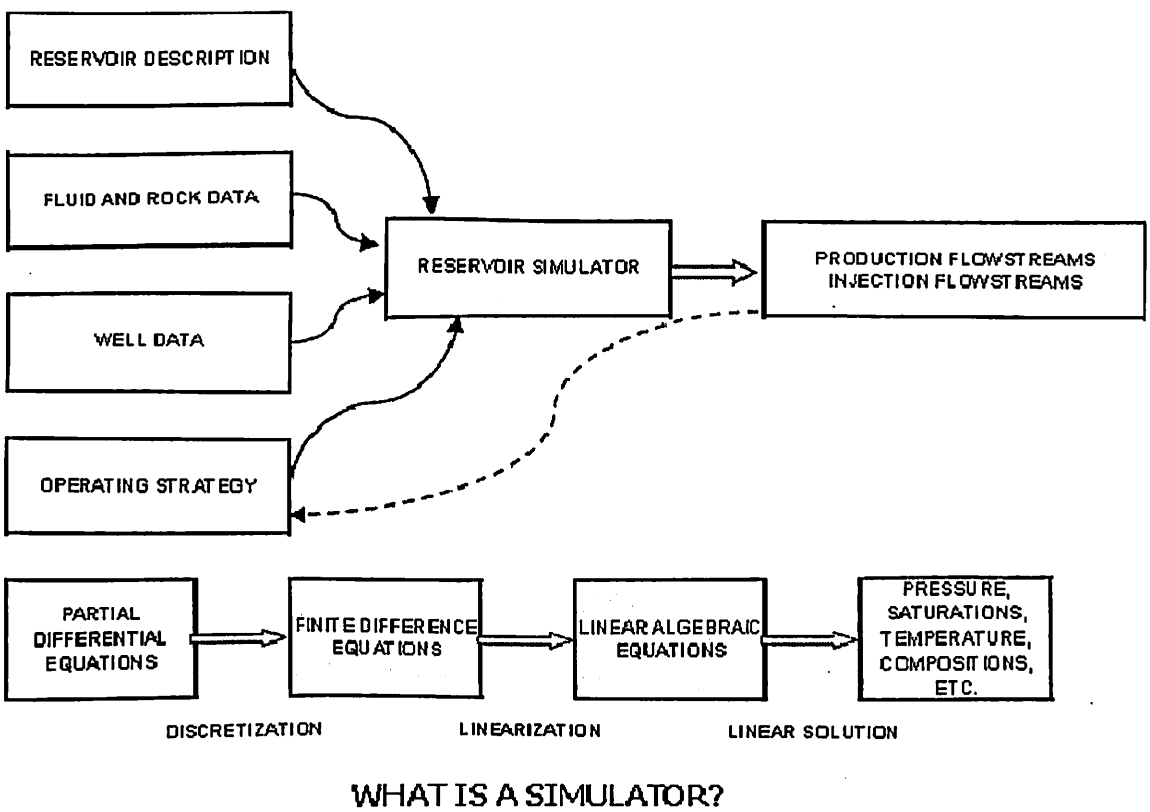

Figure-1, Simulation data book, IRS, ONGC

According to Lake, 1989, the equations that comprise a simulator can be divided in to two groups:

1. Conservation of

   a) Mass
   b) Energy

2. Empirical laws

a) Darcy
b) Capillary
c) Phase behavior
d) Reaction rates

It is not technically possible to have a single simulator that can represent all possible cases of flow. As a result, Lake, 1989, classified simulators as follows:

1. Dimensionality (1-D, 2-D and 3-D)
2. Numerical algorithm
    a) Finite difference
    b) Implicit
    c) Direct solvers
3. Vectorization
4. Physical properties
    a) Single phase (Gas or Oil)
    b) Black oil
    c) Compositional
    d) Thermal

1.2.1 PHYSICAL PROPERTIES

Black Oil or Single Phase Simulators

- Basic fluid flow
- Oil and gas represented as single components
- Gas can be soluble in oil
- Oil can vaporize in gas
- Used for dead oil or dry gas

Compositional Simulators

- Oil and gas represented as multi component fluids
- Used for volatile oils or gas condensates
- Model changes in oil or gas compositions
- Gas cycling
- Computationally expensive

Miscible Simulators

- Can model solvent injection
- Injectant can have CO2 and/or enriched gas
- Requires a history match for credible results
- Computationally expensive

Chemical Simulators

- For modeling polymer injection
- For modeling surfactant injection

Thermal Simulators

- For hot waters and/or steam fluids
- Huff and puff steam injection
- Air injection
- In-situ combustion

Dual Porosity Simulators

- Naturally fractured reservoirs

1.2.2 MODEL GEOMETRY

Cartesian

- Most often used
- Suitable for all model dimensions
- Used for pattern models and full fields

Radial

- Used for single well studies
- Suitable for coning studies
- Suitable for near well studies
- For matching well tests

Unstructured

- Used to accurately capture reservoir geometry
- Can represent various well geometries
- Difficult to construct
- May add to computational costs
- Requires a precursor for modifying model

1.2.3 MODEL CHARACTERISTICS

Phase and Dimensions

1. Single phase when oil or gas flows
2. Two phase when oil and gas or water flows
3. Three phase when oil, gas and water flows

Models are also named as

1. 1- Dimensional linear/ radial in case of one directional flow
2. 2- Dimensional areal or cross-sectional when flows is in x-y, x-z or y-z directions

3. 3- Dimensional when flow occurs in x-y-z directions

1.2.4 OBJECTIVES OF SIMULATION

- Optimize the economics of petroleum recovery – optimize recovery while minimizing cost.
- Predict reservoir performance under various exploitation schemes – select an optimal field development plan.

1.3 Why Reservoir Simulation

- **Business Reasons**
  - Economics and Timing of Investments
  - Credibility and reliability
  - Arbitration, Unitization and regulation
  - Decision making
- **Technical Reasons**
  - Evaluating different exploitation strategies
  - Performance monitoring
  - Trouble shooting

1.3.1 RESERVOIR SIMULATION GIVES AN OPORTUNITY TO:

- Predict and evaluate future production
- Evaluate different development scenarios

- Do several sensitivities to evaluate the best strategy
- Find optimal methods of field development and production schemes
- Identify location of remaining reserves
- Identify swept zones
- Establish best completion strategies for wells
- Assess possible EOR schemes and their implementation
- As a result – maximize hydrocarbon recovery

1.4 MODEL VALIDATION

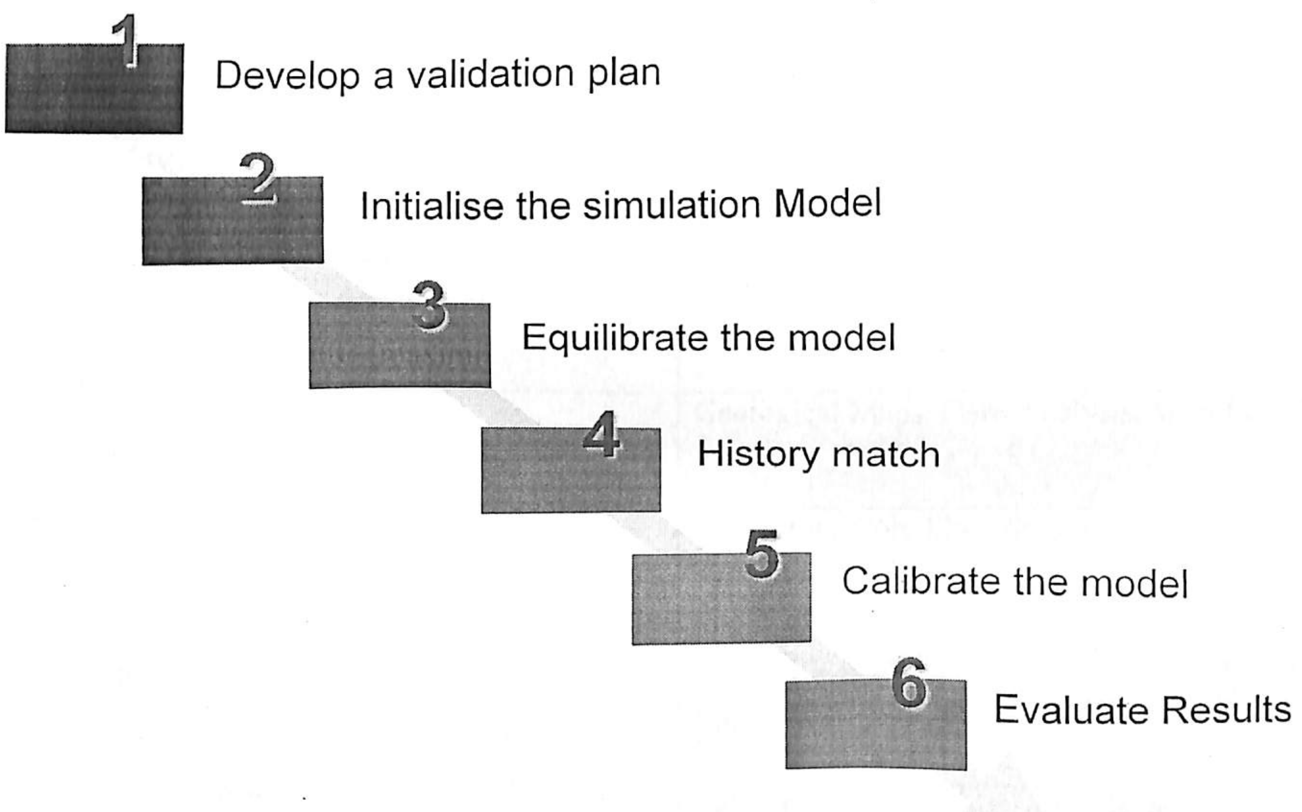

Figure-2, ECLIPSE Manual, Schlumberger

1.4.1 RESERVOIR SIMULATION PLAN

There are four steps in Reservoir Simulation which are as follows:

1. Initialization (INPUT DATA)
2. History Matching
3. Performance Prediction
4. Techno-Economic Analysis

1.4.1.1 Initialization:- The input data requirements for generating a digital dynamic picture of the reservoir are:

Table 1: Reservoir Properties and their Sources

PROPERTY	SOURCES
Permeability	Pressure Transient Testing, Core Analysis, Correlations
Porosity	Core Analysis, Well log Data
Structure, Thickness	Geological Maps, Core Analysis, Well Log Data
Relative Permeability and Capillary Pressure	Laboratory Core Flow Studies
Saturations	Well Log Data, Core Analysis, Pressure Cores, Single Well Tracer Tests
PVT Data	Laboratory Analysis of Reservoir Fluids, Samples Correlations

1.4.1.2 Input Data

General data for the entire reservoir-

1. Dimensions, grid definition, number of layer, original reservoir pressure, initial water-oil and gas-oil contacts, these data are obtained from log and core analysis well pressure tests.
2. Rock and fluid data relative permeability, capillary pressure, rock compressibility and PVT data from laboratory test and correlation.
3. Grid data geological data including elevation, gross and net thickness, permeability-porosity and initial fluid saturation from well log, core analysis, well pressure and well producibility.
4. Production/Injection and well data- oil water and gas production history or injection history and future production and injection history for each well, well location, productivity index, skin factor and perforation interval for each well.

1.5 HISTORY MATCHING

The goal of reservoir simulation is to build a reservoir model that is capable of predicting the actual reservoir performance (water cut, reservoir pressure and gas-oil ratio, and ect.) for different production scenarios by minimizing associated uncertainties/errors. Minimization of the simulator error is achieved by performing reservoir history matching. History match process involves comparing the simulator dynamic output with observed field production performance

The petroleum industry conventional approach to minimize the difference between observed history data and simulation model result is to vary the model input parameters until a match with the history data is achieved. This optimization process is conducted using least square objective function algorithm. On the other hand, a more recent approach involves constructing multiple reservoir simulation models and conduct history matching of simulated and observed data. When a match is obtained, the matched model is used to forecast future reservoir performance and to quantify associated uncertainty. The major problem with this multiple realization technique is an increase in the computation cost. While this technique was developed to minimize the nonuniqueness of traditional history matching since a match with a single simulation model may have resulted from compensation errors of the various interacting parameters/factors. The fact is that more than one model can reproduce the real reservoir observed history data.

History matching is required since accuracy of prediction depend on the accuracy of history match. History matching of past production and pressure performance is done by calibrating the reservoir parameter of a model until the simulated performance matches the observed or historical behavior.

A step wise history matching procedure is given below:

- Verifying input data
- Pressure matching by specifying production/injection for the wells and adjusting parameters affecting original hydrocarbons in place.
- Saturation matching by adjusting relative permeability curves, vertical permeability, water-oil and gas gas-oil contact.
- Well pressure matching by modifying productivity index.

1.6 PERFORMANCE PREDICTION

Performance prediction is essential for management decision to understand withdrawal rate, well spacing strategy. For knowing performance predictions, company applies following approaches:

1. The reserves are planned to exploit at a certain rate.
2. Resultant pressure- production with time is worked out using reservoir simulation techniques.
3. This is called performance of the reservoir. It includes rate of oil, gas and water production behavior with time and resultant pressure.
4. More than one withdrawal rate is considered.
5. The numbers of wells are worked out to produce the required amount of oil depending on productivity of the wells.
6. The various options of withdrawal rates, number of wells and capital investment are subjected to economic evaluation.

CHAPTER- 2

LITERATURE SURVEY

2.1 WATER FLOODING

Water flooding is a technique of enhanced oil recovery from a depleted oil reservoir. Water being much closer in viscosity compared to gas is an effective agent to drive out oil from the reservoir. Water is injected from the injector well and the oil comes out from the producer. Secondary oil recovery refers to the additional recovery that comes from the conventional methods of water injection and immiscible gas injection. Water flooding is perhaps the most common method of secondary recovery. However, before undertaking a secondary recovery project, it should be clearly proven that the natural recovery processes are insufficient; otherwise there is a risk that the substantial capital investment required for a secondary recovery project may be wasted. Experience teaches us that the gas space in the reservoir must be replaced or filled up by water before production wells fully respond to water injection.

2.1.1 FACTORS TO CONSIDER IN WATER FLOODING

In determining the suitability of a candidate reservoir for water flooding, the following reservoir characteristics must be considered:

- Reservoir geometry
- Fluid properties
- Reservoir depth
- Lithology and rock properties
- Fluid saturations
- Reservoir uniformity and pay continuity
- Primary reservoir driving mechanisms

2.1.1.1 Reservoir Geometry

The areal geometry of the reservoir will influence the location of wells and, if offshore, will influence the location and number of platforms required. The reservoir's geometry will essentially dictate the methods by which a reservoir can be produced through water-injection practices. An analysis of reservoir geometry and past reservoir performance is often important when defining the presence and strength of a natural water drive and, thus, when defining the need to supplement the natural injection. If a water-drive reservoir is classified as an active water drive, injection may be unnecessary.

2.1.1.2 Fluid Properties

The physical properties of the reservoir fluids have pronounced effects on the suitability of a given reservoir for further development by water flooding. The viscosity of the crude oil is considered the most important fluid property that affects the degree of success of a water flooding project. The oil viscosity has the important effect of determining the mobility ratio that, in turn, controls the sweep efficiency.

2.1.1.3 Reservoir Depth

Reservoir depth has an important influence on both the technical and economic aspects of a secondary or tertiary recovery project. Maximum injection pressure will increase with depth. The costs of lifting oil from very deep wells will limit the maximum economic water–oil ratios that can be tolerated, thereby reducing the ultimate recovery factor and increasing the total project operating costs. On the other hand, a shallow reservoir imposes a restraint on the injection pressure that can be used, because this must be less than fracture pressure. In water flood operations, here is a critical pressure (approximately 1 psi/ft of depth) that, if exceeded, permits the injecting water to expand openings along fractures or to create fractures. This results in the channeling of the injected water or the bypassing of large portions of the reservoir matrix. Consequently, an operational pressure gradient of 0.75 psi/ft of depth normally is allowed to provide a sufficient margin of safety to prevent pressure parting.

2.1.1.4 Lithology and Rock Properties

Reservoir lithology and rock properties that affect flood ability and success are:

- Porosity
- Permeability
- Clay content
- Net thickness

In some complex reservoir systems, only a small portion of the total porosity, such as fracture porosity, will have sufficient permeability to be effective in water-injection operations. In these cases, a water-injection program will have only a minor impact on the matrix porosity, which might be crystalline, granular, or vugular in nature. Although evidence suggests that the clay minerals present in some sands may clog the pores by swelling and deflocculating when water flooding is used, no exact data are available as to the extent to which this may occur. Tight (low-permeability) reservoirs or reservoirs with thin net thickness possess water-injection problems in terms of the desired water injection rate or pressure.

2.1.1.5 Fluid Saturations

In determining the suitability of a reservoir for water flooding, a high oil saturation that provides a sufficient supply of recoverable oil is the primary criterion for successful flooding operations. Note that higher oil saturation at the beginning of flood operations increases the oil mobility that, in turn, gives higher recovery efficiency.

2.1.1.6 Reservoir Uniformity and Pay Continuity

Substantial resérvoir uniformity is one of the major physical criterions for successful water flooding. For example, if the formation contains a stratum of limited thickness with a very high permeability (i.e., **thief zone**), rapid channeling and bypassing will develop. Unless this zone can be located and shut off, the producing water–oil ratios will soon become too high for the flooding operation to be considered profitable.

The lower depletion pressure that may exist in the highly permeable zones will also aggravate the water-channeling tendency due to the high permeability variations. Moreover, these thief zones will contain less residual oil than the other layers, and their flooding will lead to relatively lower oil recoveries than other layers.

Areal continuity of the pay zone is also a prerequisite for a successful water flooding project. Isolated lenses may be effectively depleted by a single well completion, but a flood mechanism requires that both the injector and producer be present in the lens. Breaks in pay continuity and reservoir anisotropy caused by depositional conditions, fractures, or faulting need to be identified and described before determining the proper well spanning and the suitable flood pattern orientation.

2.1.2 OPTIMUM TIME TO WATERFLOOD

The most common procedure for determining the optimum time to start waterflooding is to calculate:

- Anticipated oil recovery
- Fluid production rates
- Monetary investment
- Availability and quality of the water supply
- Cost of water treatment and pumping equipment
- Cost of maintenance and operation of the water installation facilities
- Cost of drilling new injection wells or converting existing production to injectors

These calculations should be performed for several assumed times and the net income for each case determined. The scenario that maximizes the profit and perhaps meets the operator's desirable goal is selected.

2.1.3 SELECTION OF FLOODING PATTERNS

One of the first steps in designing a water flooding project is flood pattern selection. The objective is to select the proper pattern that will provide the injection fluid with the maximum possible contact with the crude oil system. This selection can be achieved by (1) converting existing production wells into injectors or (2) drilling infill injection wells. When making the selection, the following factors must be considered:

- Reservoir heterogeneity and directional permeability
- Direction of formation fractures

• Availability of the injection fluid (gas or water)
• Desired and anticipated flood life
• Maximum oil recovery
• Well spacing, productivity, and injectivity

Essentially four types of well arrangements are used in fluid injection projects:
• Irregular injection patterns
• Peripheral injection patterns
• Regular injection patterns
• Crestal and basal injection patterns

2.1.3.1 Irregular Injection Patterns

Willhite (1986) points out that surface or subsurface topology and/or the use of slant-hole drilling techniques may result in production or injection wells that are not uniformly located. In these situations, the region affected by the injection well could be different for every injection well. Some small reservoirs are developed for primary production with a limited number of wells and when the economics are marginal, perhaps only few production wells are converted into injectors in a non uniform pattern. Faulting and localized variations in porosity or permeability may also lead to irregular patterns.

2.1.3.2 Peripheral Injection Patterns

In peripheral flooding, the injection wells are located at the external boundary of the reservoir and the oil is displaced toward the interior of the reservoir, in an excellent review of the peripheral flood, points out the following main characteristics of the flood:

- The peripheral flood generally yields a maximum oil recovery with a minimum of produced water.
- The production of significant quantities of water can be delayed until only the last row of producer's remains.
- Because of the unusually small number of injectors compared with the number of producers, it takes a long time for the injected water to fill up the reservoir gas space. The result is a delay in the field response to the flood.

- For a successful peripheral flood, the formation permeability must be large enough to permit the movement of the injected water at the desired rate over the distance of several well spacing's from injection wells to the last line of producers.
- To keep injection wells as close as possible to the water flood front without bypassing any movable oil, watered-out producers may be converted into injectors. However, moving the location of injection wells frequently requires laying longer surface water lines and adding costs.
- Results from peripheral flooding are more difficult to predict. The displacing fluid tends to displace the oil bank past the inside producers, which are thus difficult to produce.
- Injection rates are generally a problem because the injection wells continue to push the water greater distances.

2.1.3.3 Regular Injection Patterns

Due to the fact that oil leases are divided into square miles and quarter square miles, fields are developed in a very regular pattern. A wide variety of injection-production well arrangements have been used in injection projects. The most common patterns, are the following:

2.1.3.4 Direct line drive. The lines of injection and production are directly opposed to each other. The pattern is characterized by two parameters: a = distance between wells of the same type, and d = distance between lines of injectors and producers.

2.1.3.5 Staggered line drive. The wells are in lines as in the direct line, but the injectors and producers are no longer directly opposed but laterally displaced by a distance of a/2.

2.1.3.6 Five spot. This is a special case of the staggered line drive in which the distance between all like wells is constant, i.e., a = 2d. Any four injection wells thus form a square with a production well at the center.

2.1.3.7 Seven spot. The injection wells are located at the corner of a hexagon with a production well at its center.

2.1.3.8 Nine spot. This pattern is similar to that of the five spot but with an extra injection well drilled at the middle of each side of the square. The pattern essentially contains eight injectors surrounding one producer.

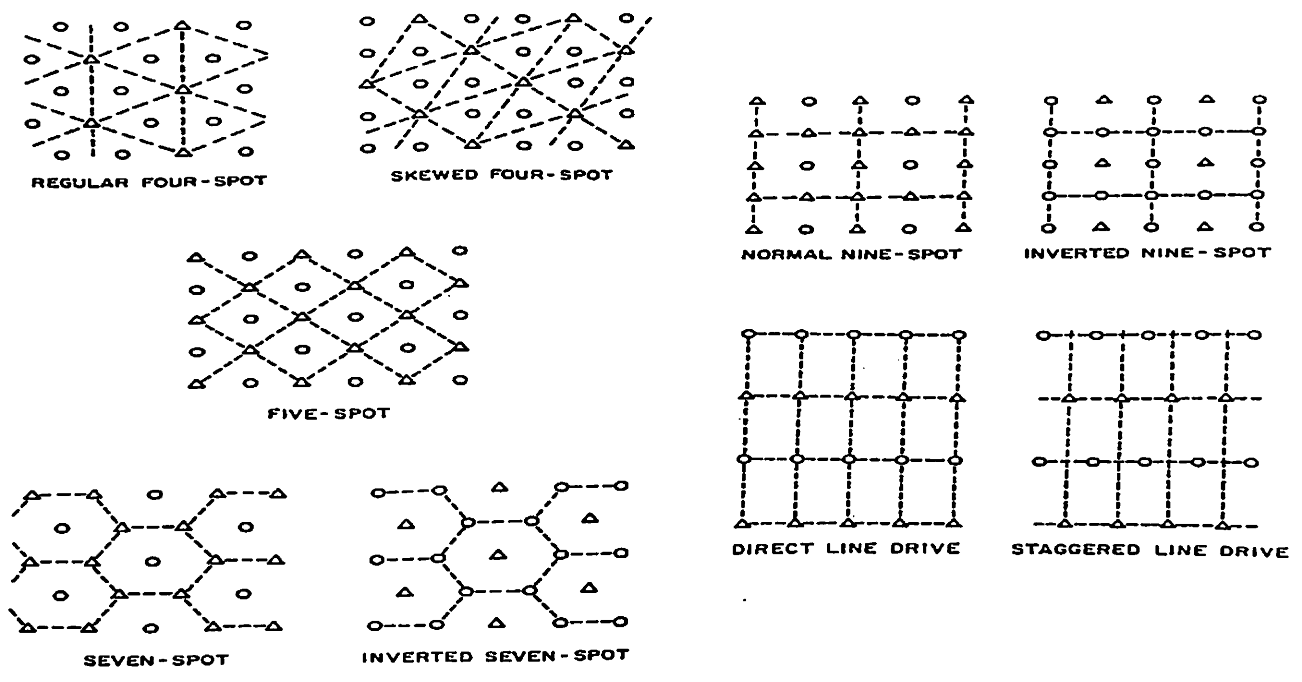

Figure-3, Regular Flood Patterns, Reservoir Engineering Handbook, Tarek Ahmed

The patterns termed **inverted** have only one injection well per pattern. This is the difference between **normal** and **inverted** well arrangements. Note that the four-spot and inverted seven-spot patterns are identical.

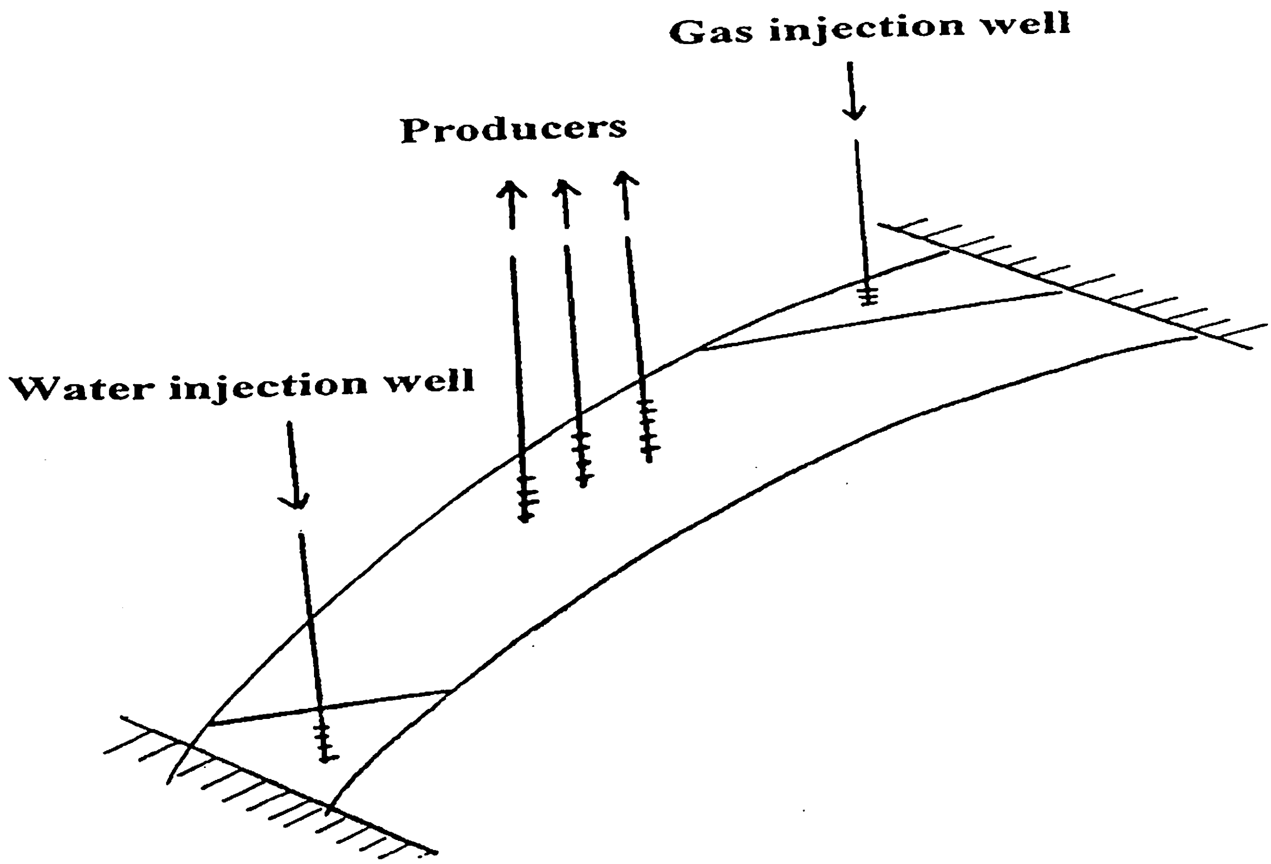

Figure-4, Well arrangements for dipping reservoirs, Reservoir Engineering Handbook, Tarek Ahmed

2.1.3.9 Crestal and Basal Injection Patterns

In crestal injection, as the name implies, the injection is through wells located at the top of the structure. Gas injection projects typically use a crestal injection pattern. In basal injection, the fluid is injected at the bottom of the structure. Many water-injection projects use basal injection patterns with additional benefits being gained from gravity segregation.

2.2 ABOUT ECLIPSE

ECLIPSE-100 is a fully-implicit, three phase, three dimensional, general purpose black oil simulator with gas condensate option. Program is written in FORTRAN77 and operates on any computer with an ANSI-standard FORTRAN77 compiler and with sufficient memory.

ECLIPSE can be used to simulate 1, 2 or 3 phase systems. Two phase options (oil/water, oil/gas, gas/water) are solved as two component systems saving both computer storage and computer time. In addition to gas dissolving in oil (variable bubble point pressure or gas/oil ratio), ECLIPSE may also be used to model oil vaporizing in gas (variable dew point pressure or oil/gas ratio). Both corner-point and conventional block-center geometry options are available in ECLIPSE. Radial and Cartesian block-center options are available in 1, 2 or 3 dimensions. A 3D radial option completes the circle allowing flow to take place across the 0/360 degree interface

2.2.1 THE ECLIPSE SIMULATOR SUITE

The ECLIPSE simulator suite consists of two separate simulators: ECLIPSE 100 specializing in black oil modeling, and ECLIPSE 300 specializing in compositional modeling.

ECLIPSE 100 is a fully-implicit, three phases, three dimensional, general purpose black oil simulator with gas condensate options. ECLIPSE 300 is a compositional simulator with cubic equation of state, pressure dependent K-value and black oil fluid treatments.

ECLIPSE 300 can be run in fully implicit, IMPES and adaptive implicit (AIM) modes.

Both programs are written in FORTRAN and operate on any computer with an ANSI-standard FORTRAN90 compiler and with sufficient memory. For large simulations the simulators can be run in parallel mode. The Parallel option is based on a distributed memory architecture implemented using MPI (message passing interface).

2.2.2 OPEN-ECLIPSE

Open-ECLIPSE enables ECLIPSE 100 and ECLIPSE 300 to be controlled by, and communicate interactively with, other applications. Although ECLIPSE is primarily used in a batch stand-alone mode, controlled solely by the contents of the input data file, there are many situations in which it would be advantageous to have ECLIPSE controlled by another software application. Examples include the requirement to have ECLIPSE tightly coupled to a surface gathering system model or a specialized production optimization application. It could also be useful to couple ECLIPSE to an interactive controller, to allow you to view the current status of the simulation and make well management decisions during the course of the run.

Open-ECLIPSE was developed to address these requirements. It consists of a set of subroutines in the code that communicates with an external application. Activation of Open-ECLIPSE puts ECLIPSE into 'listening mode', awaiting commands from a suitably configured controlling program. The controlling program may set well and group operating constraints, interrogate well and group flows, control the advancement of the simulation run and control the output of reports and RESTART files. Communication between ECLIPSE and the controlling program is handled by PVM (Parallel Virtual Machine), which must be present on your system.

Those wishing to develop their own applications to control ECLIPSE may obtain the Open-ECLIPSE Developer's Kit. This consists of full documentation of the communications dialog, a copy of the message passing systems annex with which to link their application, and a simple demonstration controller for testing the Open-ECLIPSE interface.

2.2.3 GRID

GRID is an interactive program used to build reservoir models, design simulation rids and produce input data for ECLIPSE. The basic geological model consisting of contours, faults, map features and well locations may be digitized or input directly from industry standard map files. The geological model is used as a background display to aid the construction of the simulation grid.

Features include color graphics, corner-point or conventional geometry, sloping or vertical faults, areal, cross sectional or three dimensional displays, contouring back of grid properties to compare with original input data, flexible easy to use editing and comprehensive help facilities. Locally refined and coarsened grids can be prepared and displayed, for use with the Local Grid Refinement option.

The ECLMAP options in GRID provide facilities for handling seismic shot line data, volumetric calculations and depth conversion of seismic horizons or map grids.

2.2.4 FLOGRID

FloGrid is an interactive 3D product that constructs fluid flow simulation grids and properties. FloGrid imports geological data in most popular map and 3D geological model formats, including the POSC Rescue format. Simulation grids can be exported in ECLIPSE and other formats. FloGrid provides full 3D visualization of the data - wells, maps, geocellular models, faults and simulation grids.

FloGrid supports the generation of both structured and unstructured grids. Structured (Cartesian) grids are optimized to fit to selected faults and the boundary, with remaining grid nodes placed to minimize orthogonality errors. Faults that are not explicitly gridded may be automatically zig-zagged. For 3D geological models, simulation layering can, optionally, be determined using algebraic and flow based techniques to automatically identify simulation layers that best capture the flow characteristics of the fine scale models. Unstructured PEBI and tetrahedral (Petra Grid) grids can be tailored to honor all boundaries, wells and faults. They support rectangular and radial refinements around wells, and general refinements consisting of a rectangular, triangular or hexagonal grid within a specified polygonal region.

FloGrid also provides a suite of algebraic and flow based single phase upscaling tools that calculate appropriate simulation block properties from the fine scale geologic or stochastic property grids.

2.2.5 PVTi

PVT*i* is an interactive Equation of State (EoS) package used for the analysis of laboratory measurements performed to determine the phase behavior of reservoir fluids. The quality of the laboratory measurements can be tested through material balance checks. Laboratory experiments can be simulated using a variety of cubic EoS, and any discrepancies between calculated and measured data can be minimized by regression of one or more EoS parameters. The EoS model can then be used to generate data suitable for use in ECLIPSE 100 or 300 and VFP*i*.

2.2.6 SCAL

SCAL is a tool to help you effectively use laboratory derived relative permeability and capillary pressure measurements in reservoir simulation. The program has facilities to read in laboratory data, perform quality control such as curve smoothing, group data according to lithological parameters and end-point values, transform the laboratory data into rock curves suitable for

ECLIPSE, and automatically assign these curves to grid cells on the basis of rules which you set up (for example, as a function of porosity / permeability / lithological parameters). The output consists of a series of INCLUDE files, for both the PROPS and REGIONS sections. The program has facilities for 3D visualization of simulation grids and 3-phase relative permeability's, and for experimenting with ECLIPSE end point scaling options. The behavior of SCAL can be extended or modified by the use of user-programmable command scripts to, for example, implement a company confidential algorithm.

2.2.7 SCHEDULE

Schedule imports production data from a variety of common sources including PA, Oilfield Manager and Finder, and generates the corresponding ECLIPSE production control keywords. Production data can also be extracted from existing ECLIPSE models. The program has advanced graphic display features, which simplify the editing, validating and averaging of production data. Time steps on which rates are averaged are based on a user defined combination of calendar periods and reservoir events such as well completions, shut-ins and simulations.

All the main categories of production data necessary for simulation can be handled by Schedule. These typically take the form of well deviation surveys, historical production and injection volumes and completion data. A key feature of Schedule is the capability to generate accurate and representative COMPDAT keywords with time-varying connection factors calculated from perforation data specified in terms of measured depths and formations. Corrections are made for deviated wells, partial penetrations and multiple completions within a single cell.

Schedule has comprehensive facilities for creating prediction run controls for ECLIPSE. Controls can be set for wells, groups and the field. Wells can be created by defining IJK locations or by digitizing in the 3D Viewer, where simulation results can be used as a backdrop to aid placement.

Schedule can also prepare data for input to the Multi-segment Well model. It can read data describing casing, liner and tubing characteristics and locations of chokes, packers and inflow control valves. This information can be used, with perforation data, to generate WELSEGS and COMPSEGS/COMPSEGL keywords describing the multi-segment well.

2.2.8 FloViz

FloViz is an interactive 3D visualization system for the display and analysis of reservoir simulation results. It replaces RTView as the product of choice for reservoir visualization. FloViz has a simple to operate graphical user interface and provides faster 3D interaction and animation of simulation results. It runs on both PCs and workstations.

FloViz incorporates most of the RTView functionality with some key new features. The program allows multiple views (which can be tailored), through the use of slave viewers, of the reservoir with independent slicing, property, and time animation. Model rotation can be shared across the views. FloViz can display both structured and unstructured grids, and, also, streamlines. The program contains a host of new options to allow easier visual interpretation of the grid and its results.

2.2.8.1 3D visualization facilities

Master / slave viewers allow you to have as many 3D views as you require. In each view, you can choose whether you want to have independent control of one or more of time, property and geometry. For example you can have three viewer windows open, with windows 1 and 2 sharing the same IJK slicing but different properties and windows 1 and 3 sharing the same property but having different time control. You can restrict the cells displayed by using the Thresholding facility. This facility allows you to select multiple threshold properties.

The Cell Probe facility may be used to display properties for the 'picked' cell. Grids may be artificially thickened, or flattened to a datum plane, to assist visual understanding of very thin or highly dipping reservoirs.

A comprehensive and flexible IJK Slicer panel is available with direct control over slicing the global cells or LGR domains. Cell selection is further enhanced by the 2D Editor, which allows digitizing of a boundary on the surface of the model. The view may then be restricted to cells that fall within or outside of this boundary.

An auto normalize feature makes the model automatically fit the viewport. Perspective can be turned on or off. Directional lighting can be turned on or off. A seek to point option zooms the viewer to a selected point on the model. A color legend can be displayed. This automatically changes to a ternary legend if the ternary property is selected. Color maps are drawn as integer or floating point legends depending on the type of data. They can also be set to display continuous, discrete or logarithmic mappings. Full color map and legend editing facilities are provided. The display background color can be toggled between black and white, useful for hardcopy output. Label and line colors invert accordingly. Inactive cells can optionally be displayed in a user-defined color. This can be useful for viewing shale breaks or pinch outs that you would not normally see. A Rubber Band Zoom allows key areas to be rapidly selected and visualized.

A View Statistics option allows immediate investigation of Grid, Property and Well statistics for either the currently selected or whole model. The axes display can be fully tailored, with display of tick marks and values. Axes may be switched to encompass the whole model or just the currently selected parts.

The model can be exaggerated in any of XY or Z. Toolbar icons give quick access to vertical (Z) exaggeration. The model can be flipped in X or Y to cater for situations where the origin is not defined, as for ECLIPSE. The appearance of the model can be changed to a wireframe or bounding box when rotating, translating, scaling. Images may be captured using PostScript, TIFF, JPEG or PBM formats. Models may be viewed in full 3D Stereo on both PCs and UNIX machines, where hardware allows.

2.2.8.2 Property editing

Initial and recurrent simulation properties may be edited and new ones created with the Simulation Property Editor. New properties may be created or existing ones edited by three methods:

1. The Expression Editor allows you to define simple expressions involving constants and/or initial and recurrent properties acted upon by simple arithmetic operators. You can

also use two special operators T+1-T and T-T0 on recurrent properties to generate time difference properties.

2. You can use a Calculator script to evaluate more complex expressions.
3. You can calculate the difference between properties generated by different simulation runs using the Run Differencing option.

2.2.8.3 Dual porosity

Dual porosity grids have been specially catered for so that we display the model reservoir correctly and make the matrix and fracture properties available for viewing. Slave viewers can be used to view matrix and fracture properties simultaneously.

2.2.8.4 Animation

You can control the time animation of the model using toolbar buttons (similar to the controls on a video recorder). FloViz is significantly faster at animating report steps than RTView (irrespective of the size of the model).

The camera angle can be altered horizontally or vertically by a given angle, and a full 360 degree rotation can be animated. This is provided for purposes of demonstrations and production of movies.

2.2.8.5 Well appearance

You can customize the appearance of wells by turning the following options on or off:

- well labels
- well status (producer or specific type of injector)
- well connections

The width of the well tube and the height it rises above the model can also be set. The display may be toggled between showing all wells in the model and just those completed in the currently selected cells. ECLIPSE multi-lateral wells are supported. Well display may be switched between high and low resolution to compromise between speed and detail.

2.2.9 ECLIPSE OFFICE

ECLIPSE Office provides an interactive environment for the creation and modification of Black Oil and Compositional models, the submission and control of runs, the analysis of results and report generation. Data sets may be created using a PEBI gridding module, correlations for PVT and SCAL data, keyword panels, or input from other pre-processors. Panels exist for all ECLIPSE keywords. Tools are provided for the management of cases within a project. Run management is provided for submitting, monitoring and controlling simulator execution. New interactive graphics are used to view results.

ECLIPSE Office is a tool to help manage reservoir simulations. It provides a convenient user Interface for:

- Launching and managing any of the ECLIPSE applications
- Running a rapid quick-look simulation from start to finish
- Allowing you check your results during simulation runs
- Editing and reviewing simulation results and generates reports.

ECLIPSE Office offers an integrated desktop for launching all the applications in the ECLIPSE product line, which includes the pre- and post-processing applications and the ECLIPSE simulators.

ECLIPSE Office also features modules that greatly improve your control of the simulation workflow: Case Manager, Data Manager, Run Manager, Result Viewer, Report Generator and Templates.

2.2.9.1 Case manager

The Case Manager helps to capture the relationship between runs and graphically display them. Runs are shown as children to Cases from which they were derived by simply modifying some data.

2.2.9.2 Data manager

The Data Manager provides user-friendly access to the keywords for all the simulators, and to some basic features of FloGrid, Schedule, SCAL and PVTi.

2.2.9.3 Run manager

The Run Manager offers an environment for launching, monitoring and controlling simulation runs. Runs may be started locally or over the network on a server. Multiple realizations generated for well control options and multiple cases may be run simultaneously. With the Run Manager, it is possible to monitor the progress of runs on line plots and solution displays, and if they are not delivering the required results, the runs can be stopped.

2.2.9.4 Result viewer

The Result Viewer can display simulation results in both two and three dimensions. It can also be used to create and view solution displays and line plots of production data as a replacement for GRAF. Results from multiple runs can also be displayed simultaneously for comparative purposes and as an aid to quick decision making.

2.2.9.5 Report generator

The Report Generator is used to create reports from the extraction of relevant information from the SUMMARY files or from the .PRT file, and put them in a form required for the creation of written reports.

2.2.10 FRONTSIM

FrontSim is a three-dimensional, two-phase fluid flow simulator based on a state-of-the-art streamline concept. FrontSim can perform simulations on large and complex reservoir models several orders of magnitude faster than standard finite difference simulators, and can achieve this without grid orientation effects or numerical dispersion.

The streamline concept is based on an IMPES (Implicit Pressure Explicit Saturation) solution. First the pressure is solved with an implicit numerical method and then the saturation equation is solved using an explicit method. The pressure is used to compute a velocity field which is, in turn, used to compute streamlines. The saturation equations are solved on the streamlines using a front tracking method.

In addition, GridSim is available as a grid and simulation data processor for FrontSim. It can be used to edit and visualize 3D solid graphics, and to visualize streamlines and line graphics. GridSim can also be used as a pre/post processor for ECLIPSE.

2.2.11 SECTION HEADER KEYWORDS

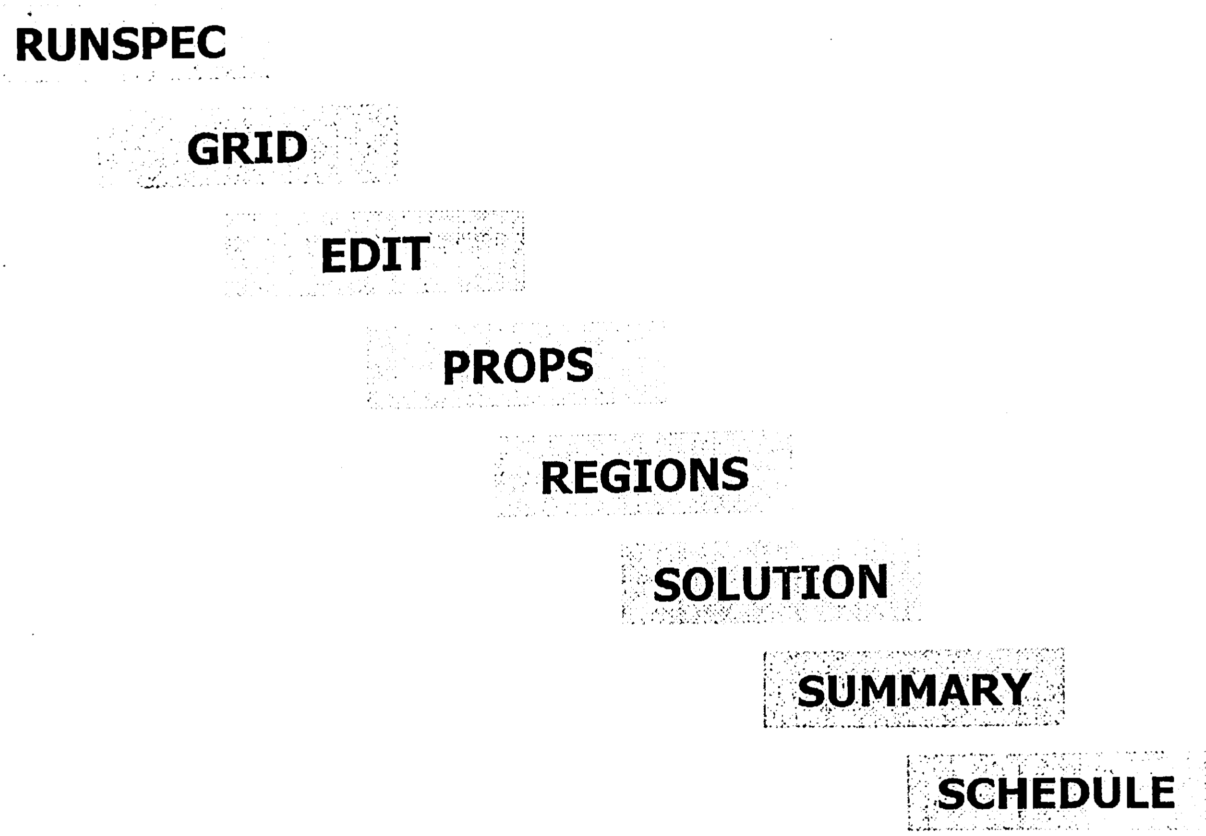

Figure-5, ECLIPSE Manual, Schlumberger

2.2.11.1 RUNSPEC Section

The RUNSPEC section is the first section of an ECLIPSE data input file. It contains the run title, start date, units, various problem dimensions (numbers of blocks, wells, tables etc.), flags for phases or components present and option switches. It may be preceded only by comments, global keywords and LOAD. The RUNSPEC section must always be present, unless the LOAD keyword is used to restart a run from a SAVE file that contains the RUNSPEC data.

The RUNSPEC section consists of a series of keywords, which turn on the various modeling options, or contain data (for example problem dimensions). For keywords that have associated data, the data record must be terminated by a slash (/). If a data record is terminated early with a slash, the remaining data items are set to their default values. Similarly, if a keyword is omitted all its associated data items are set to their default values. For most runs, the majority of the data items can be defaulted.

2.2.11.2 GRID Section

The GRID section determines the basic geometry of the simulation grid and various rock properties (porosity, absolute permeability, net-to-gross ratios) in each grid cell. From this information, the program calculates the grid block pore volumes, mid-point depths and interblock transmissibility's.

The actual keywords used depend upon the use of the radial or Cartesian geometry options. The program accepts the radial form in a Cartesian run and vice versa, but issues a warning.

2.2.11.3 EDIT Section

The EDIT section contains instructions for modifying the pore volumes, block center depths, transmissibility's, diffusivities (for the Molecular Diffusion option), and non-neighbor connections (NNCs) computed by the program from the data entered in the GRID section.

2.2.11.4 PROPS Section

The PROPS section of the input data contains pressure and saturation dependent properties of the reservoir fluids and rocks.

2.2.11.5 REGIONS Section

The REGIONS section divides the computational grid into regions for:

- Calculation of saturation functions (relative permeability and capillary pressure)
- Calculation of PVT properties (fluid densities, FVFs, viscosities)
- Equilibration (setting initial pressures and saturations)
- Reporting of fluids in place and inter-region flows
- Calculation of directional relative permeability's
- Calculation of saturation functions for imbibitions (Hysteresis option)
- Calculation of ROCKTAB properties for the Rock Compaction option
- Calculation of initial tracer concentrations (Tracer Tracking option)
- Calculation of the saturation table end points from depth tables
- Calculation of mixture properties (Miscible Flood option)
- Specifying pressure maintenance regions.

If there is no REGIONS section, ECLIPSE puts all grid blocks into a single region for all the above operations.

2.2.11.6 SOLUTION Section

The SOLUTION section contains sufficient data to define the initial state (pressure, saturations, (compositions) of every grid block in the reservoir.

The keywords in the SOLUTION section may be specified in any order. All keywords must start in column 1. All characters up to column 8 are significant.

2.2.11.7 SUMMARY Section

The SUMMARY section specifies a number of variables that are to be written to Summary files after each time step of the simulation. The graphics post-processor may be used to display the variation of variables in the Summary files with time and with each other. If there is no SUMMARY section, ECLIPSE does not create any Summary files.

2.2.11.8 SCHEDULE Section

The SCHEDULE section specifies the operations to be simulated (production and injection controls and constraints) and the times at which output reports are required. Vertical flow performance curves and simulator tuning parameters may also be specified in the SCHEDULE section.

All keywords in this section are optional, except for those necessary to define the status of the wells, and the END keyword, which should mark the end of the scheduling data.

CHAPTER- 3

EXPERIMENTATION AND RESULTS

3.1 THE BASIC MODEL

The main objective of this project is to predict the change in the production performance by simulating the water flooded reservoir. This helps to find the optimum condition for maximum recovery from the reservoir.

The model is made with grid pattern of 42x56x1with cell dimension 100mx100m.

The reservoir model consists of a single mathematical layer. The structure, gross thickness, effective thickness, iso-porosity and iso-oil saturation maps were digitized and values were assigned to the grids.

3.1.1 DATA

The data available is of an XYZ field. This field is surrounded by faults from both the sides (it can be seen clearly from the isopach maps). This field started producing on 28 Feb 2000 and now this field is producing with 3 wells Y-12, Y-22 and Y-26. The data which is available for this field are:

1. Isopach maps
2. Production data
3. PVT data
4. Porosity data
5. Permeability data
6. Thickness
7. Structure tops
8. Relative permeability data
9. Density
10. Oil water and gas saturations

11. Solution GOR
12. Oil and gas gravity
13. Formation volume factor
14. Water salinity
15. Oil, gas, water saturations
16. Bubble point and viscosity

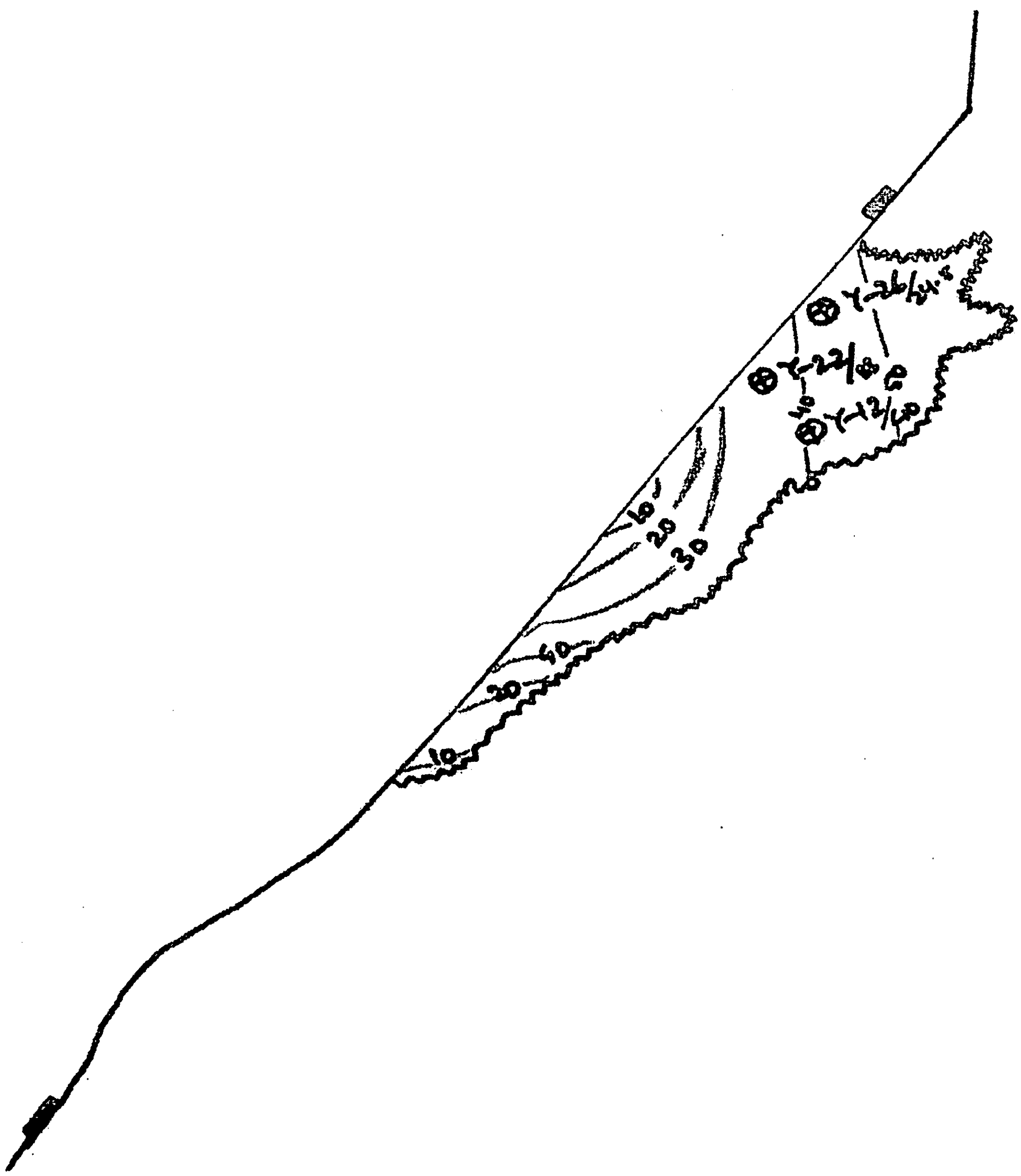

Figure-6, IRS, ONGC

This figure is the effective thickness map for the XYZ field.

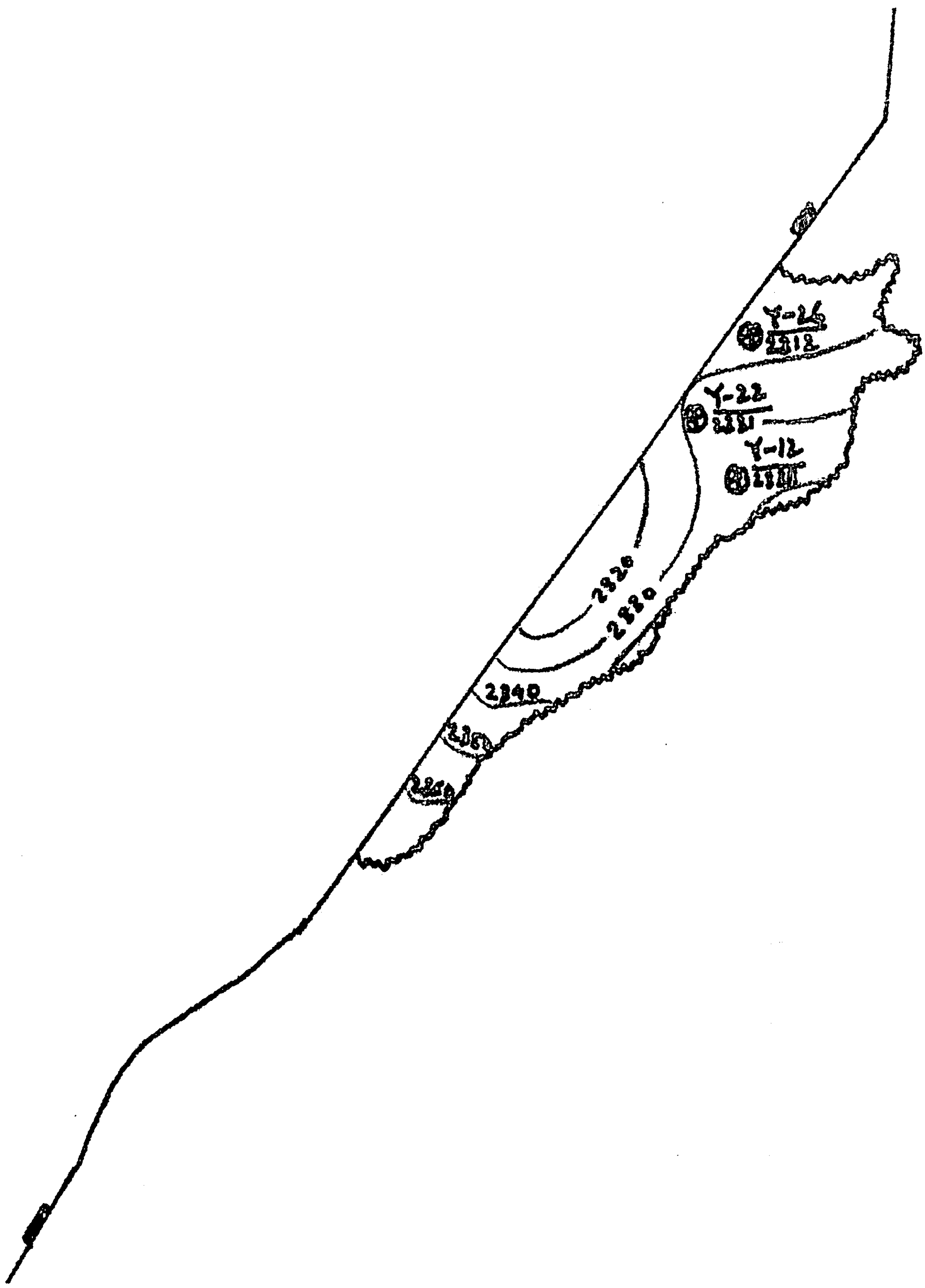

Figure-7, IRS, ONGC

This figure is the structure contour map of the XYZ field.

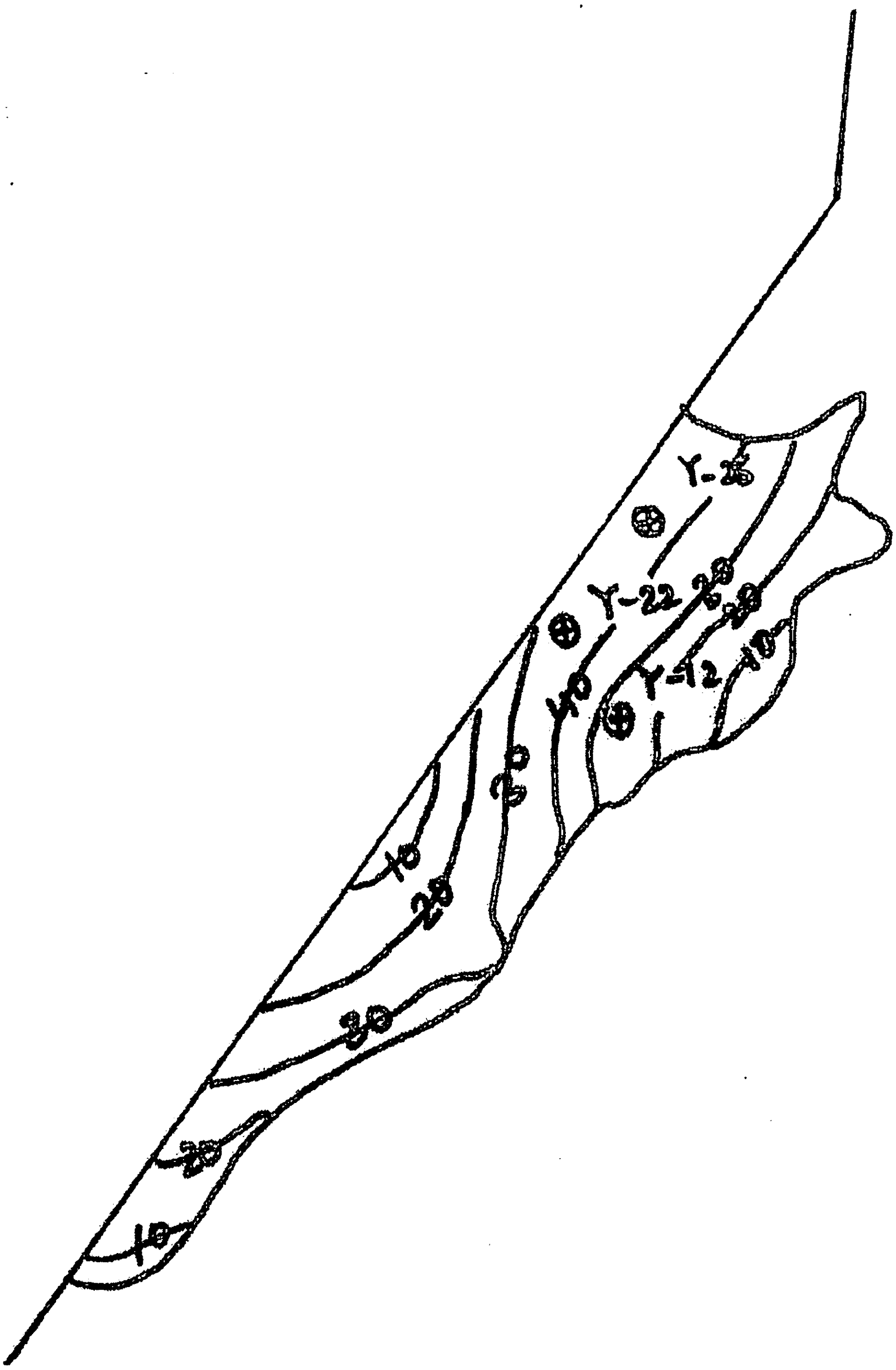

Figure-8, IRS, ONGC

This is the Oil Isopach map of the XYZ field.

3.2 INITIAL OBSERVATIONS

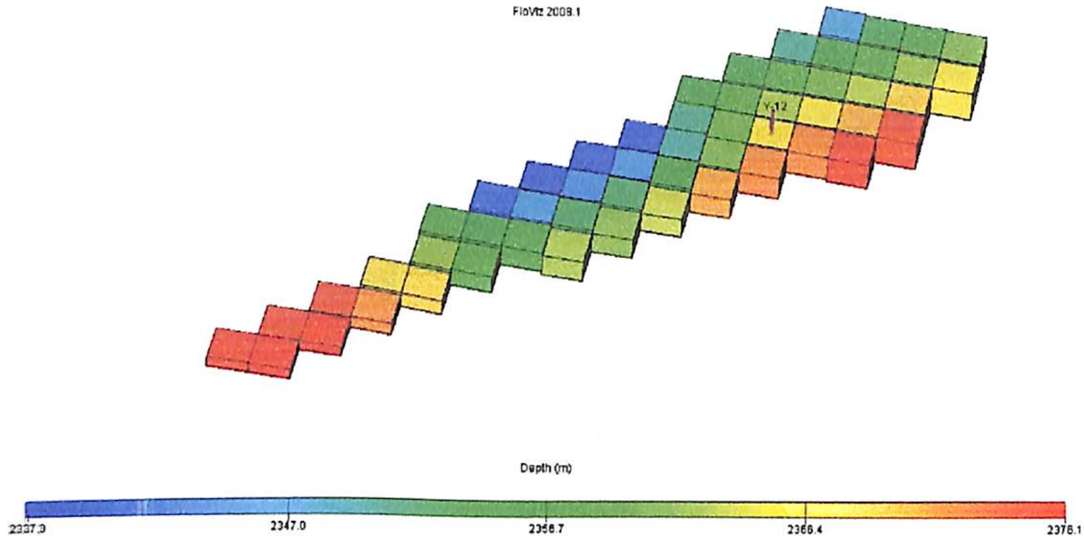

Figure-9, ECLIPSE, Schlumberger

This figure gives the overall depth of the reservoir in meters. The maximum depth being 2377m and the minimum 2337m.

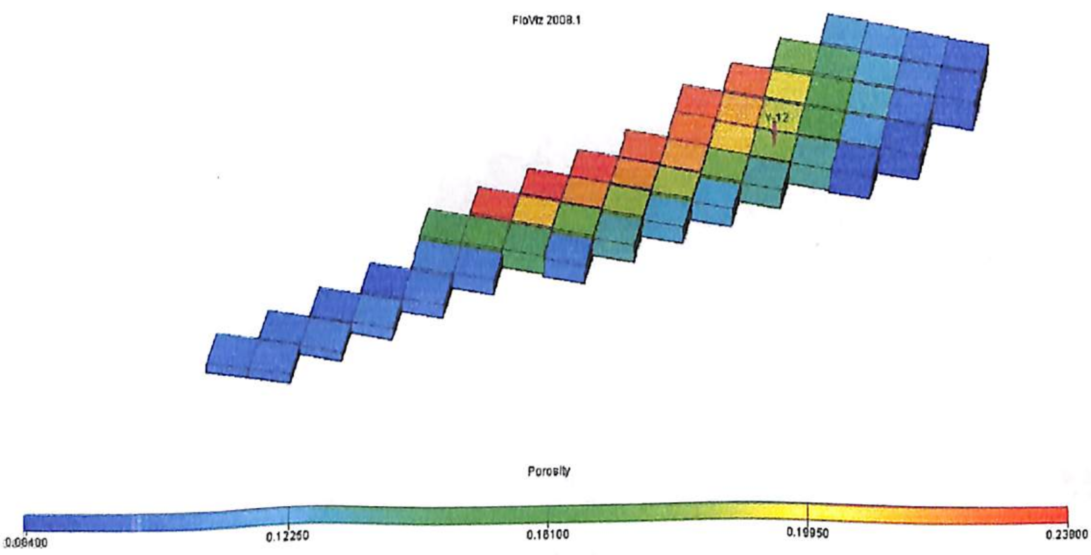

Figure-10, ECLIPSE, Schlumberger

This figure gives the overall porosity of the reservoir. The maximum porosity being 23.8%.

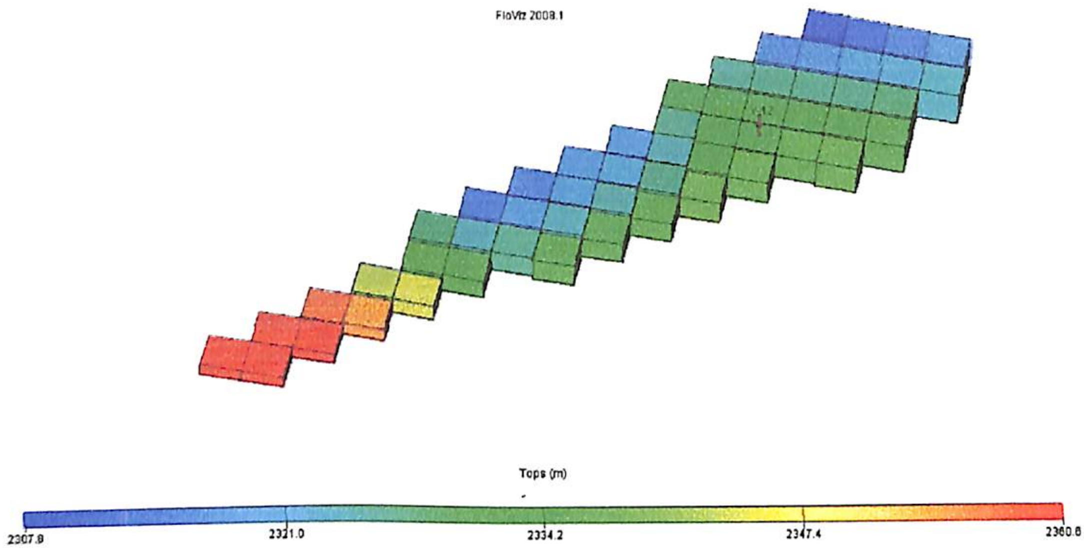

Figure-11, ECLIPSE, Schlumberger

This figure depicts the structure tops of the reservoir.

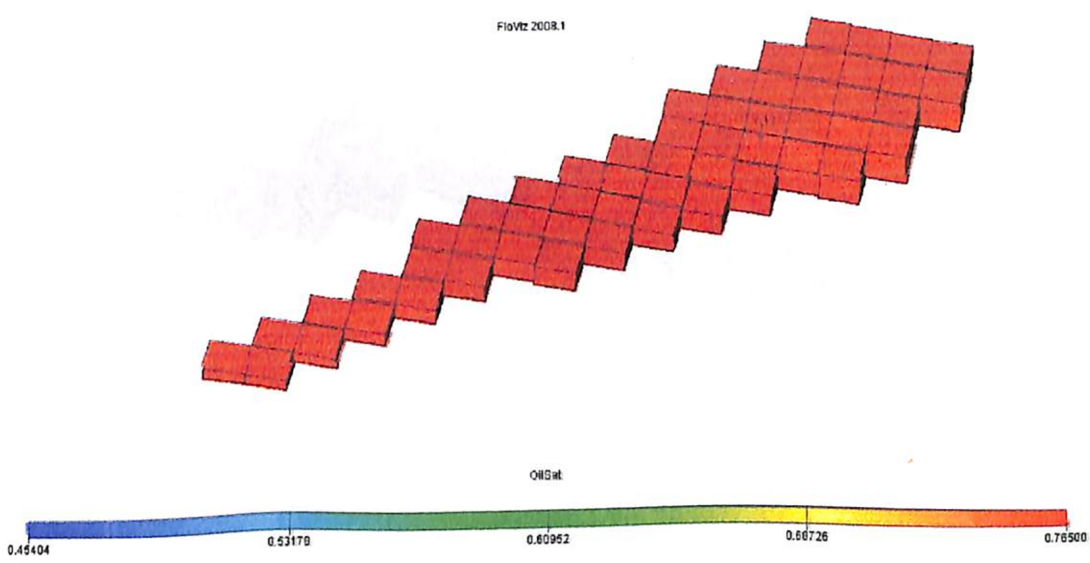

Figure-12, ECLIPSE, Schlumberger

This figure shows the initial oil saturation of the reservoir. The maximum oil saturation is 76.5%.

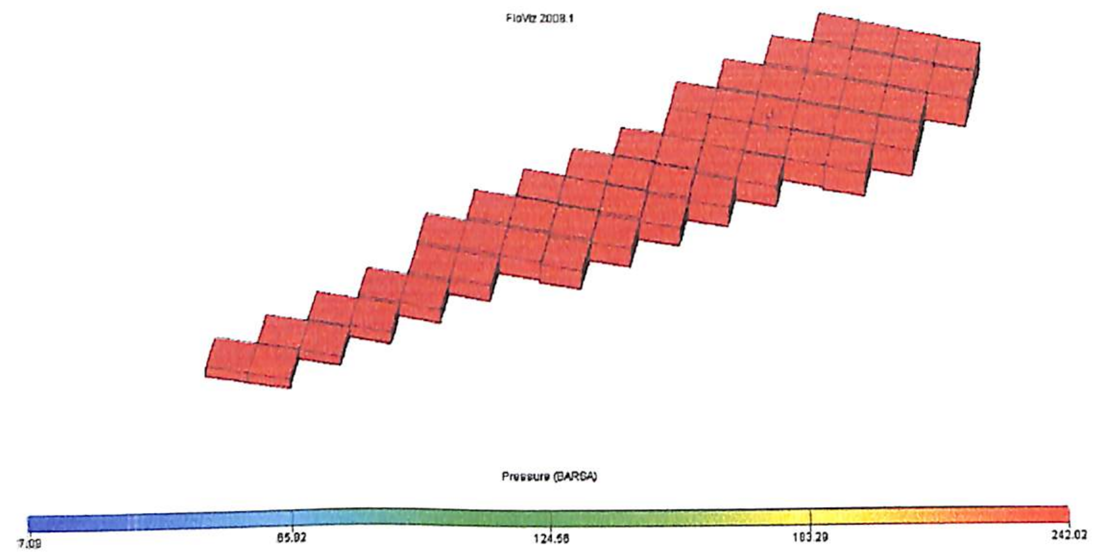

Figure-13, ECLIPSE, Schlumberger

The figure denotes the initial pressure of the reservoir. The maximum pressure being 242 Bar.

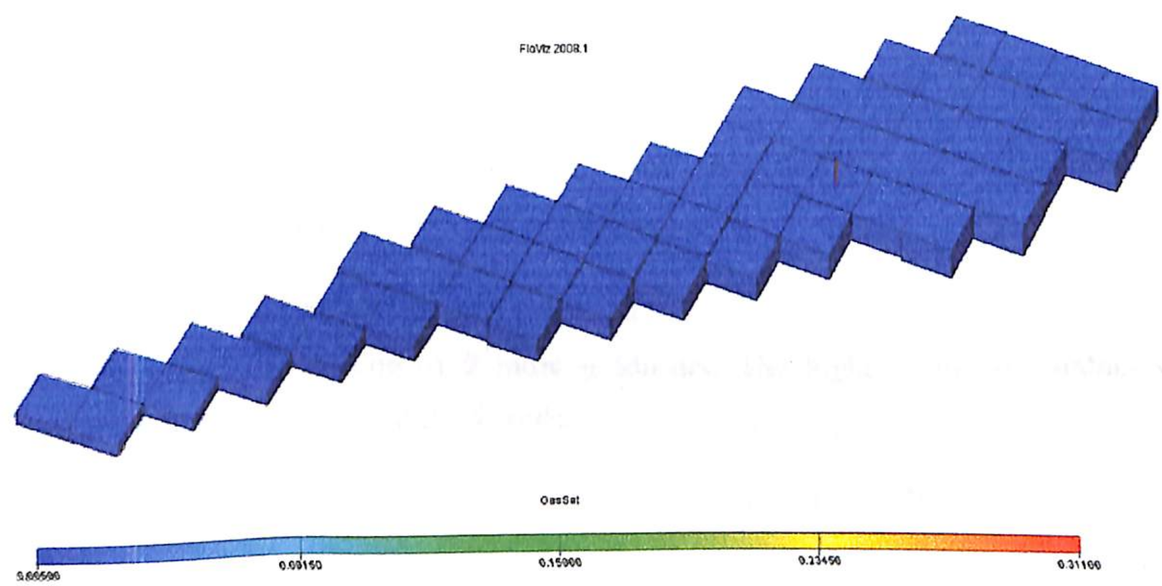

Figure-14, ECLIPSE, Schlumberger

The figure shows the initial gas saturation of the reservoir. The maximum gas saturation being 31.1%.

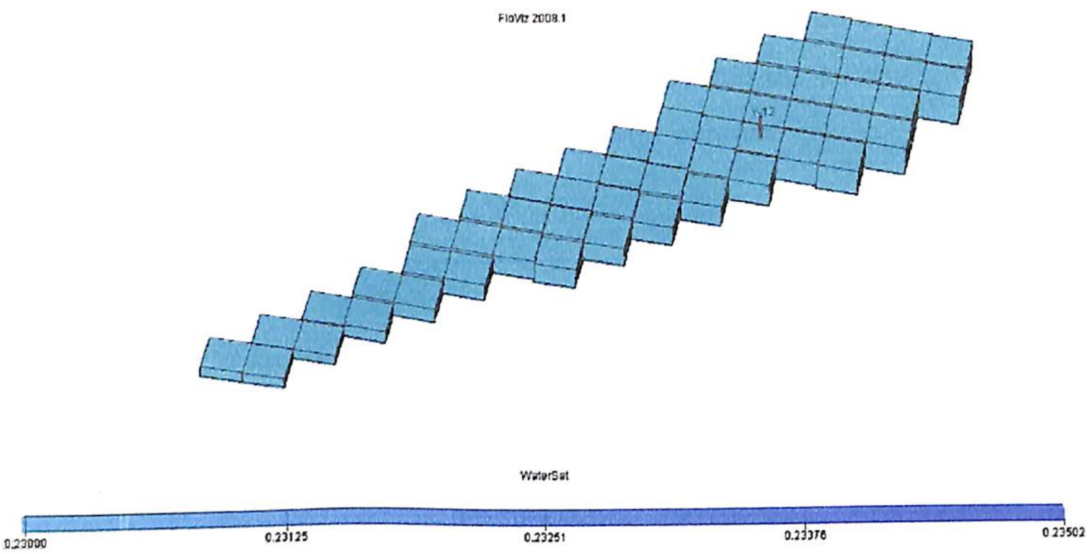

Figure-15, ECLIPSE, Schlumberger

This figure shows the initial water saturation of the reservoir.

3.3 BASE CASE

The field was put on production through well Y-12 on 28 FEB'2000. Till then 3 wells have been completed in the field which have contributed to the production.

The production of the field started with well Y-12 at a rate of 688m3 per month. The production of the field increased with drilling of 2 more producers. The highest rate of 5460m3 was achieved during Feb'2004 through all the 3 wells.

The highest water cut of 42 % was reached on 31 Mar 2007 with the production of all the three wells.

Water cut in the wells and the gradual decline in the pressure shows some support from the aquifer. The average GOR of the field is around 210 v/v.

Material balance calculations were carried out and suggest good aquifer support.

Y-12:

This well on production since Feb 2000. Initially the well produced about 54m3/d. Initial pressure measured in this well was 242 bar. The peak rate was observed during Oct 2001 at the rate of 86 m3/d. Since then the production rate is on decline and the current production rate is about 25m3/d. This decline is due to the decline in reservoir pressure.

Y-22:

This well was put on production on 31 Aug 2002. This well has produced at an average rate of 18 m3/day. Initial pressure measured in this well was 232 bar. The well was closed from Dec 2003 to Jan 2004 for Work over Job due to high water cut as well ceased to flow. In the period from Feb 2005 to Apr 2005, the well ,on repeated activation produced water with traces of oil, so it had to be closed for repeated Work Over Job due to high water cut problem. From Jul 2006 to Aug 2006 the well was put on artificial lift (Sucker Rod Pump) , and since then it is in production on SRP.

Y-26:

This well was put on production on 31 Oct 2003. This well has produced at an average rate of 36 m3/day. Initial pressure measured in this well was 223Bar. The well has been encountering sand cut and water cut problems. Well was ceasing to flow due to sand cut which finally led to water loading and so the well had to be taken for Water Shutoff Jobs.

When the model for the base case has been run the following results were obtained for the oil, gas and water saturations and the reservoir pressure. Graphs have been plotted to see the overall behavior of the reservoir.

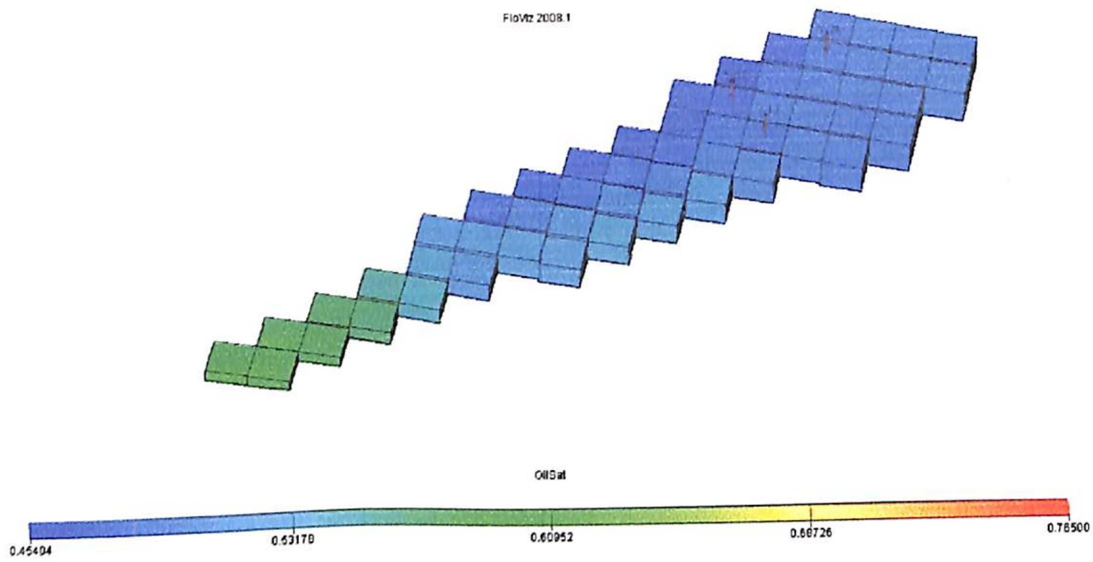

Figure-16, ECLIPSE, Schlumberger

This is the final oil saturation of the reservoir. Now the maximum oil saturation became 57%.

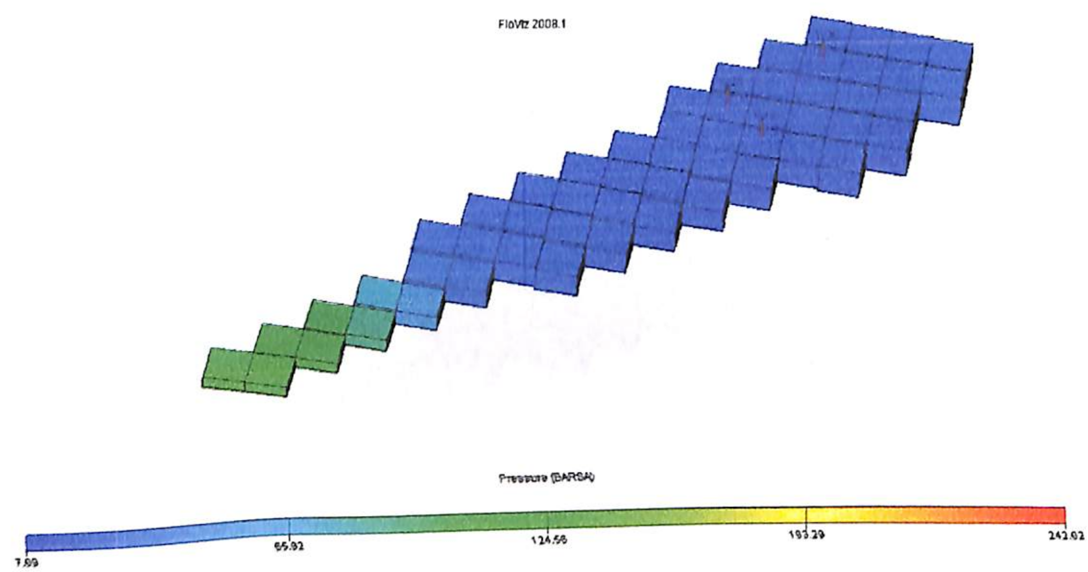

Figure-17, ECLIPSE, Schlumberger

The figure shows the final pressure after the simulation run which has dropped to 7 Bar.

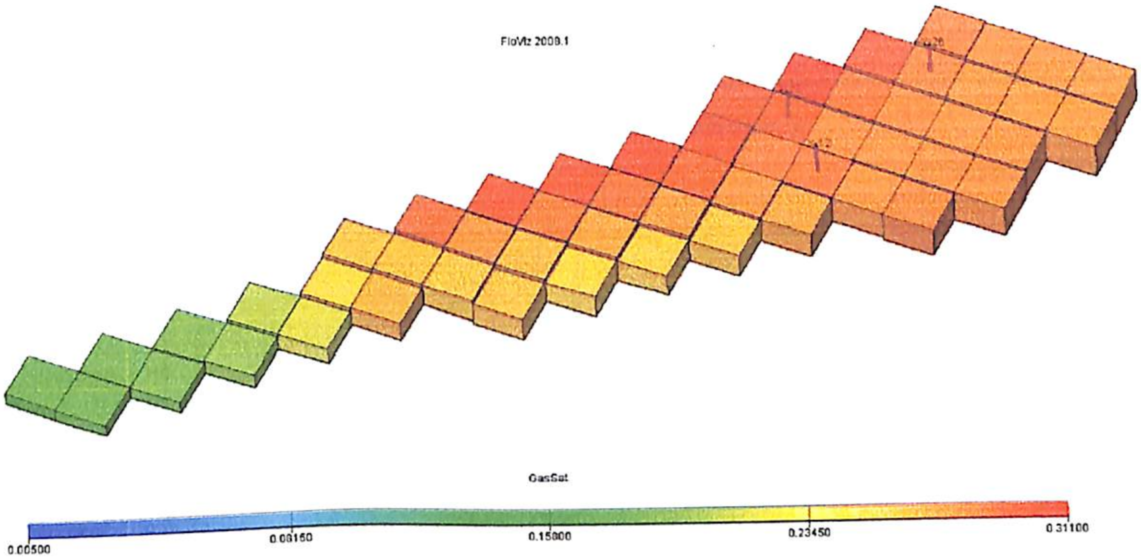

Figure-18, ECLIPSE, Schlumberger

The figure shows the final gas saturations after the simulation run. The maximum gas saturations is 31%.

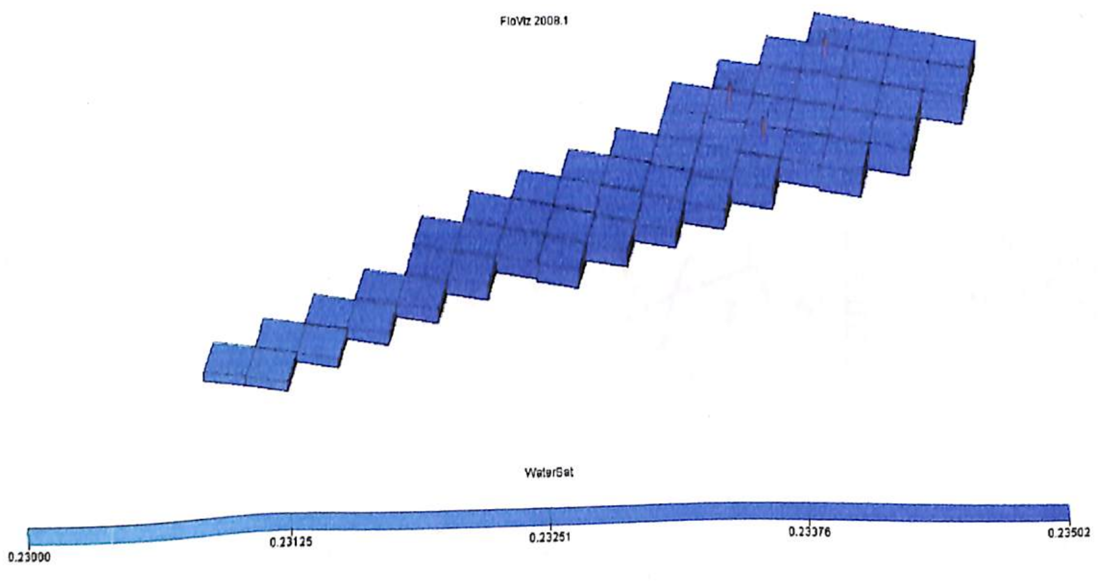

Figure-19, ECLIPSE, Schlumberger

The figure shows the final water saturations after the run. The maximum saturation have increased to 23.5%.

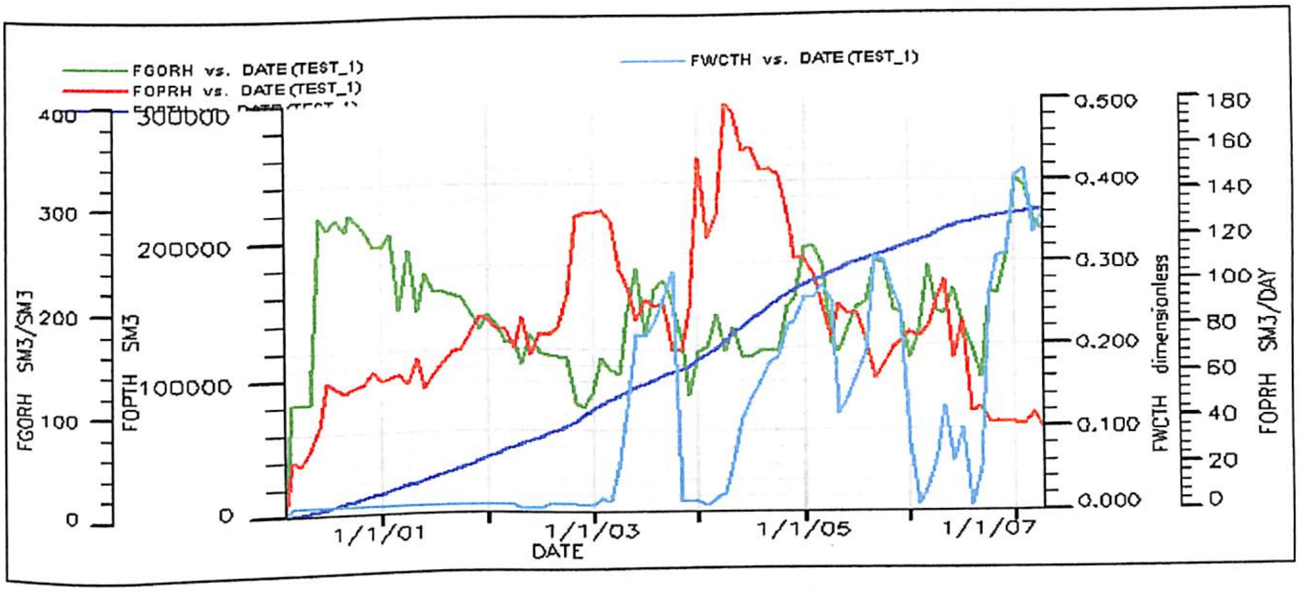

Figure-20, ECLIPSE, Schlumberger

This figure shows the change of the field oil production rate history, field oil production total history, field water cut history, field GOR history with respect to time.

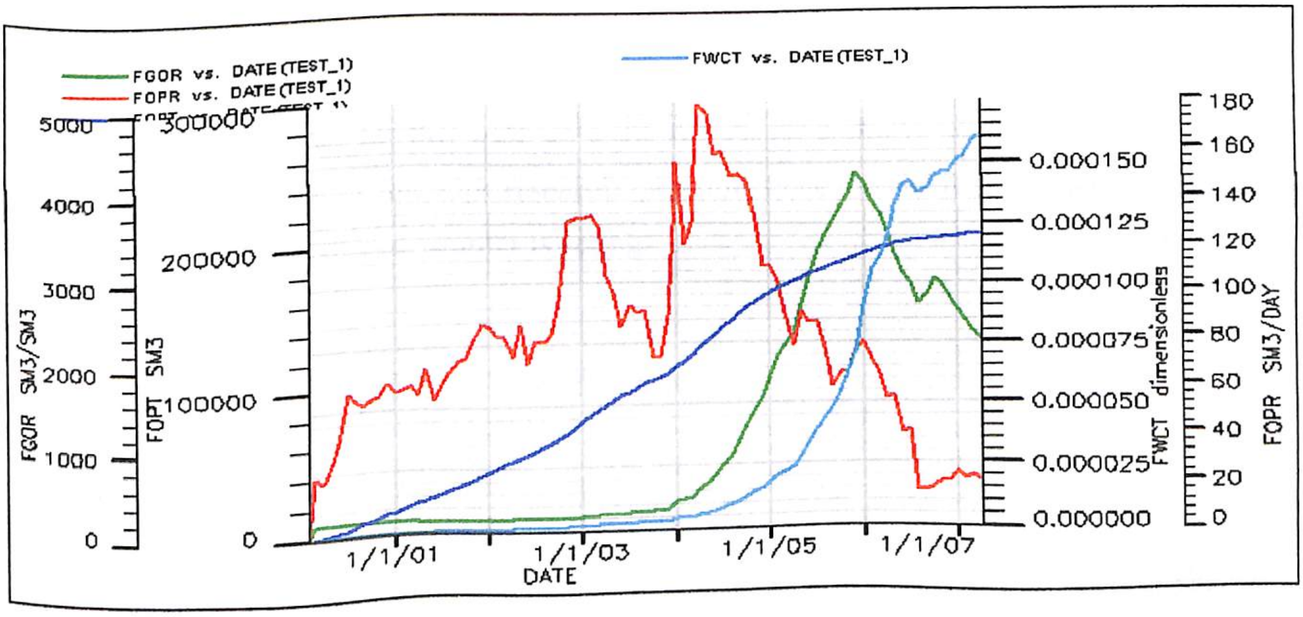

Figure-21, ECLIPSE, Schlumberger

This figure shows the change of the field oil production rate history, field oil production total, field water cut, field GOR with respect to time after the simulation run.

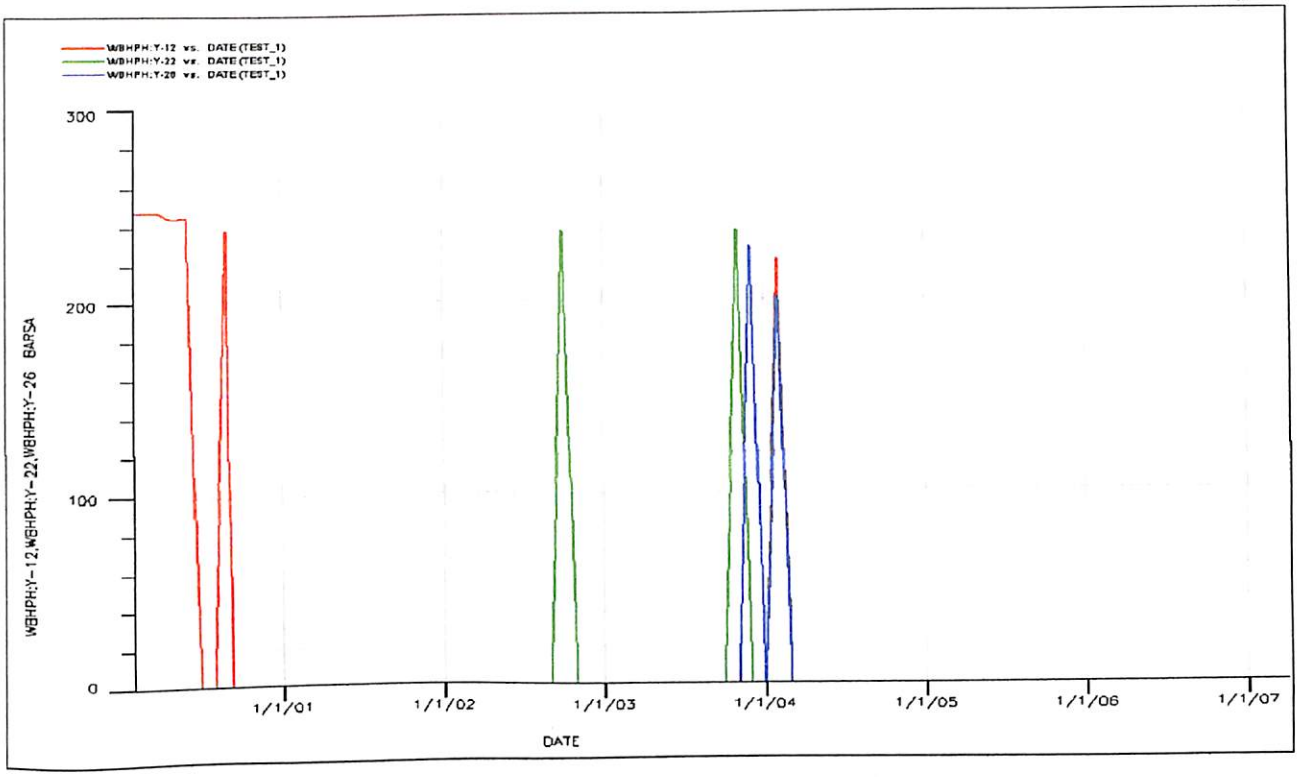

Figure-22, ECLIPSE, Schlumberger

This graph is showing the change in bottom hole pressure of Well Y-12, Y-22, Y-26 with time. The bottom hole pressure of all the three wells is decreasing drastically.

BASE CASE CONCLUSION

After the simulation run for this base case the results have shown that the production rate is declining very drastically and the reservoir pressure have declined to 7 Bar, which is not possible, so it shows that some aquifer is acting.

3.4 AQUIFER ADDITION CASE

From the base case it has been concluded that there is some aquifer acting in the reservoir which is maintaining the reservoir pressure and the production rate. So a Carter Tracy aquifer is added. The maximum number of analytic aquifer added in the model is 1. The maximum number of grid blocks connected to the aquifer is 10000. The maximum numbers of rows in this Carter Tracy aquifer influence table is 0. The angle of influence of the aquifer is 180°. The depth at which the aquifer is acting is 2437m.

After the addition of the aquifer again the simulation run has been done and the run has given the following results:

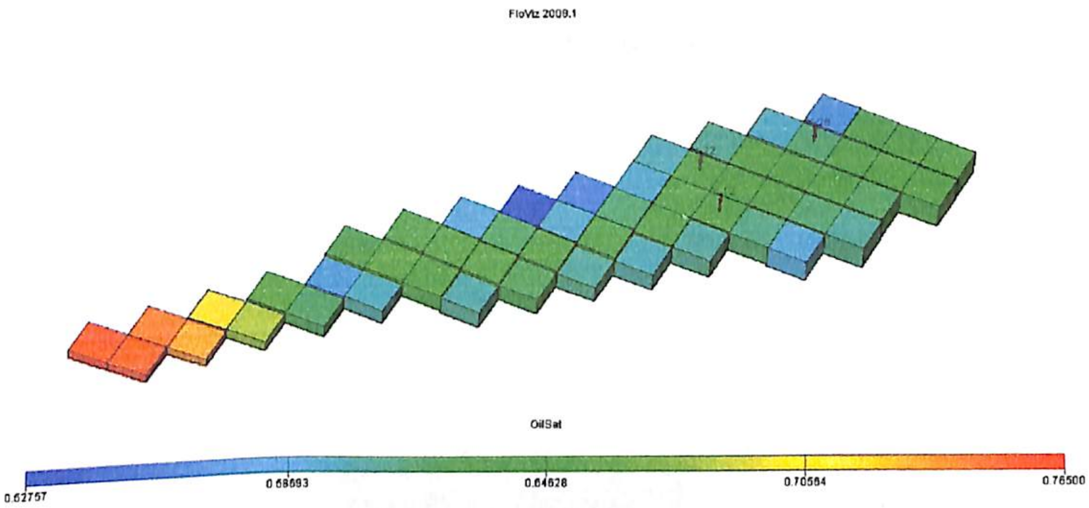

Figure-23, ECLIPSE, Schlumberger

This figure shows the total oil saturation across the reservoir which has now increased and the production has also increased substantially.

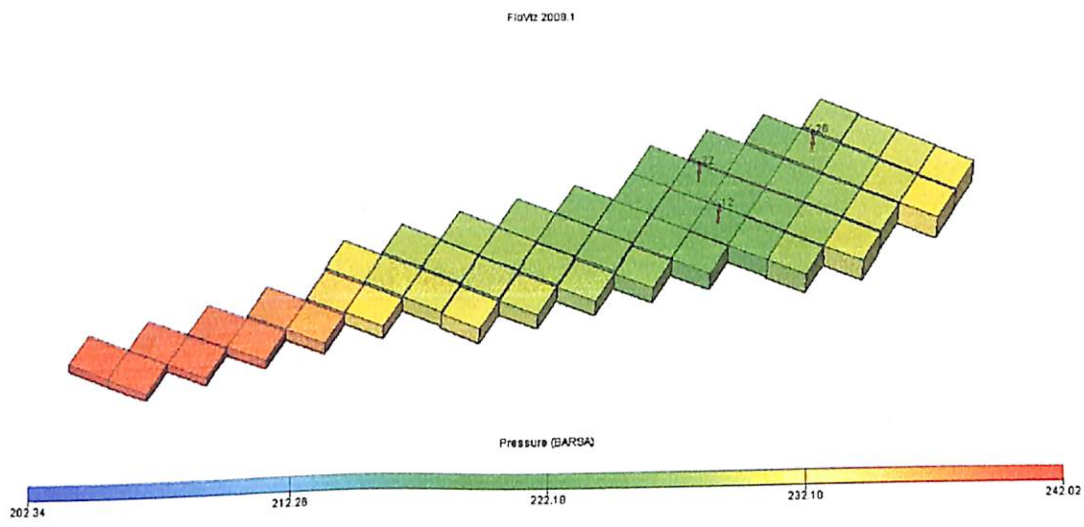

Figure-24, ECLIPSE, Schlumberger

This figure shows the reservoir pressure across the reservoir. The minimum pressure is now 220Bar.

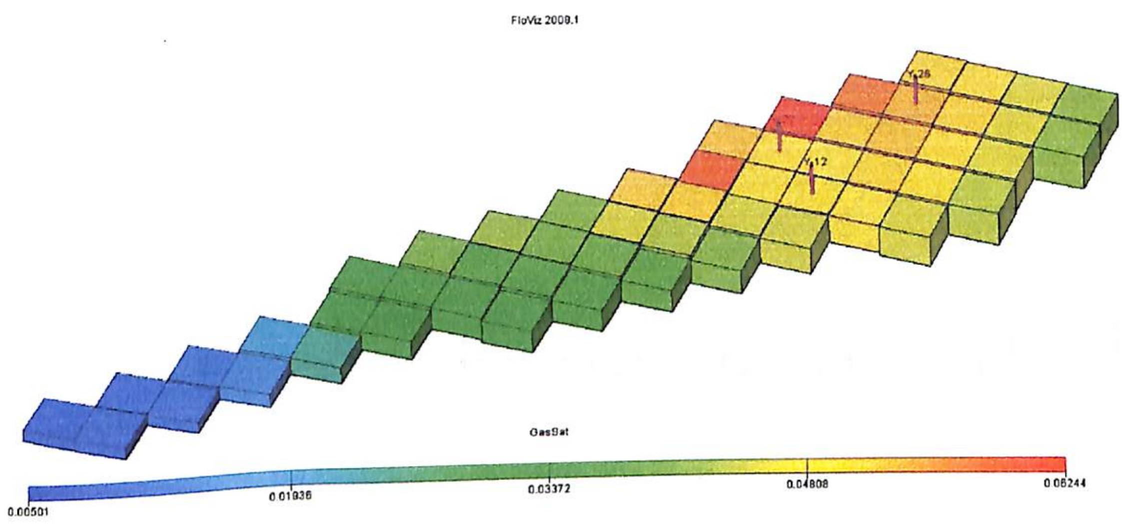

Figure-25, ECLIPSE, Schlumberger

This figure shows the total gas saturation across the reservoir.

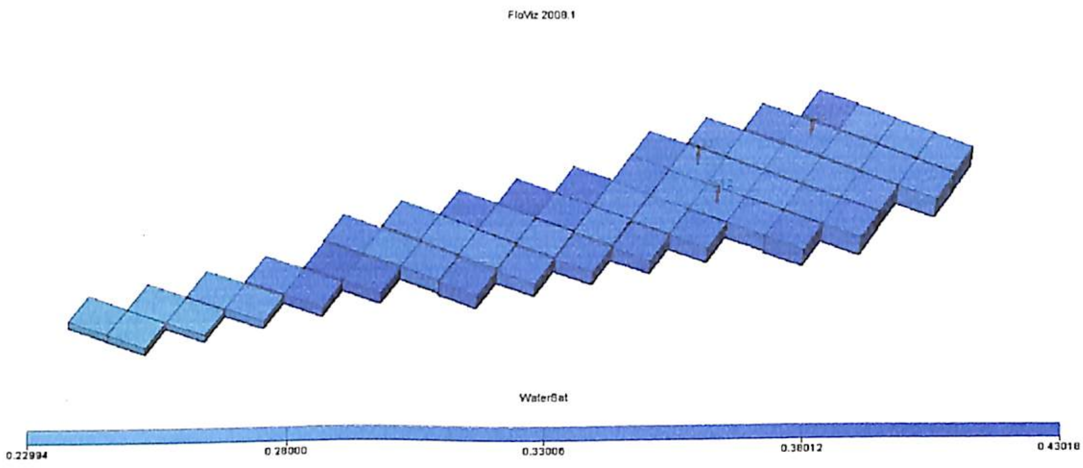

Figure-26, ECLIPSE, Schlumberger

This figure shows the total water saturation across the reservoir.

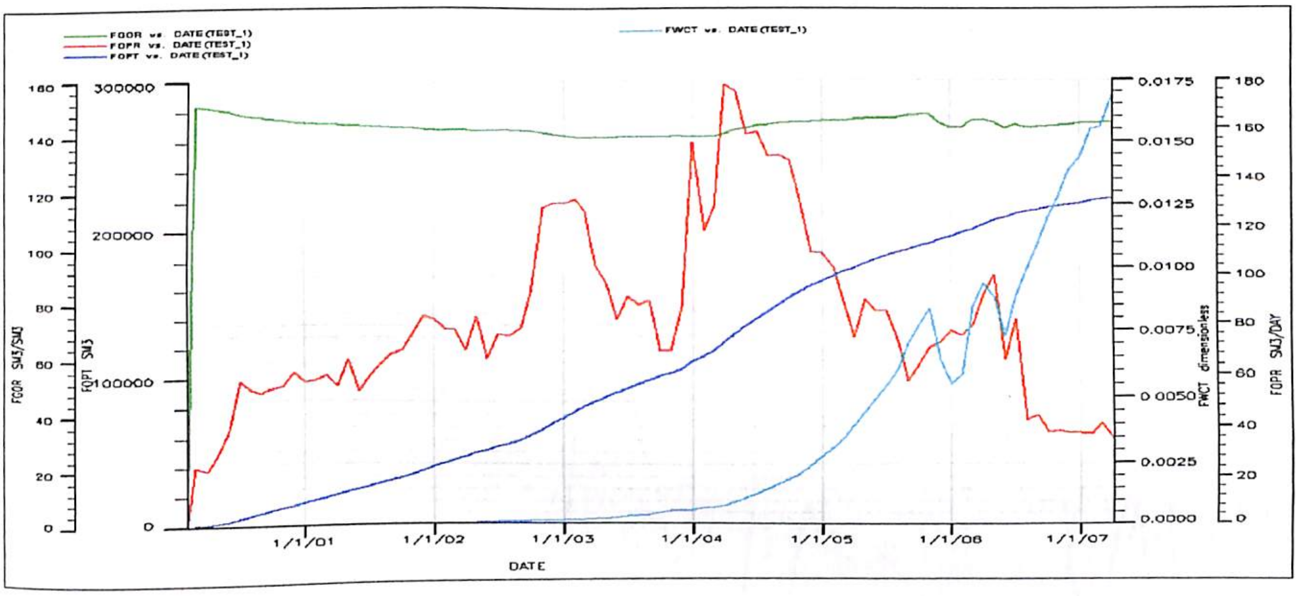

Figure-27, ECLIPSE, Schlumberger

This graph is depicting the increase in field oil production rate, field's total oil production, field's GOR and field's water cut with time.

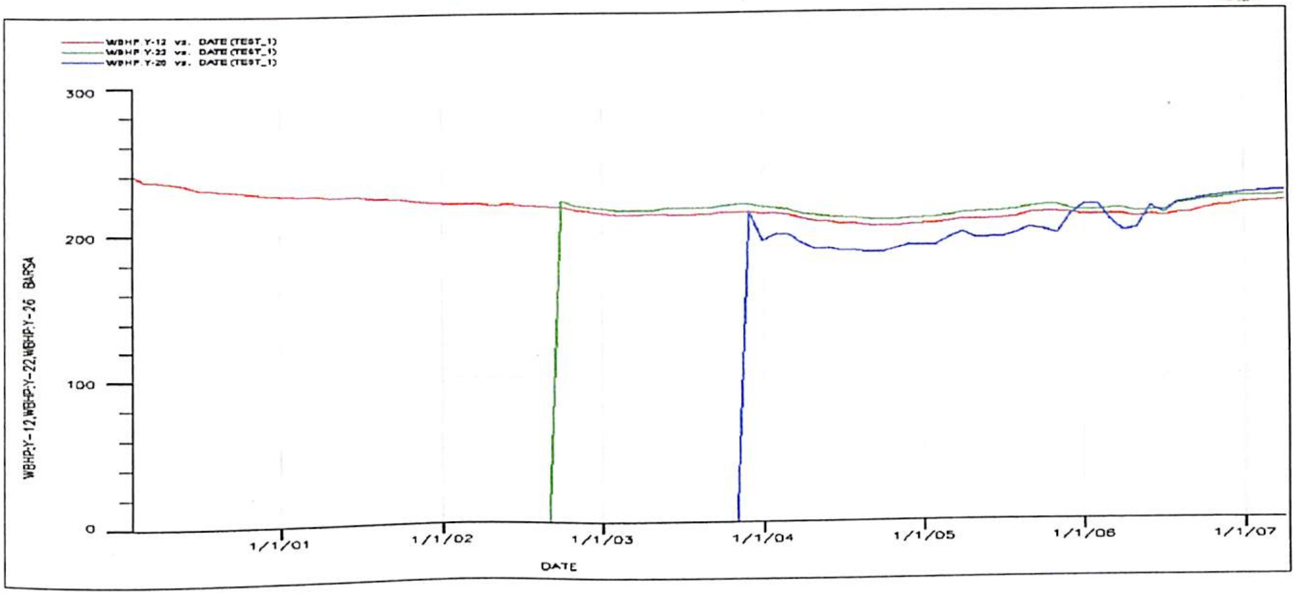

Figure-28, ECLIPSE, Schlumberger

This graph is showing a substantial increase in the bottom hole pressure of Well Y-12, Y-22, Y-26 with time with the addition of the aquifer.

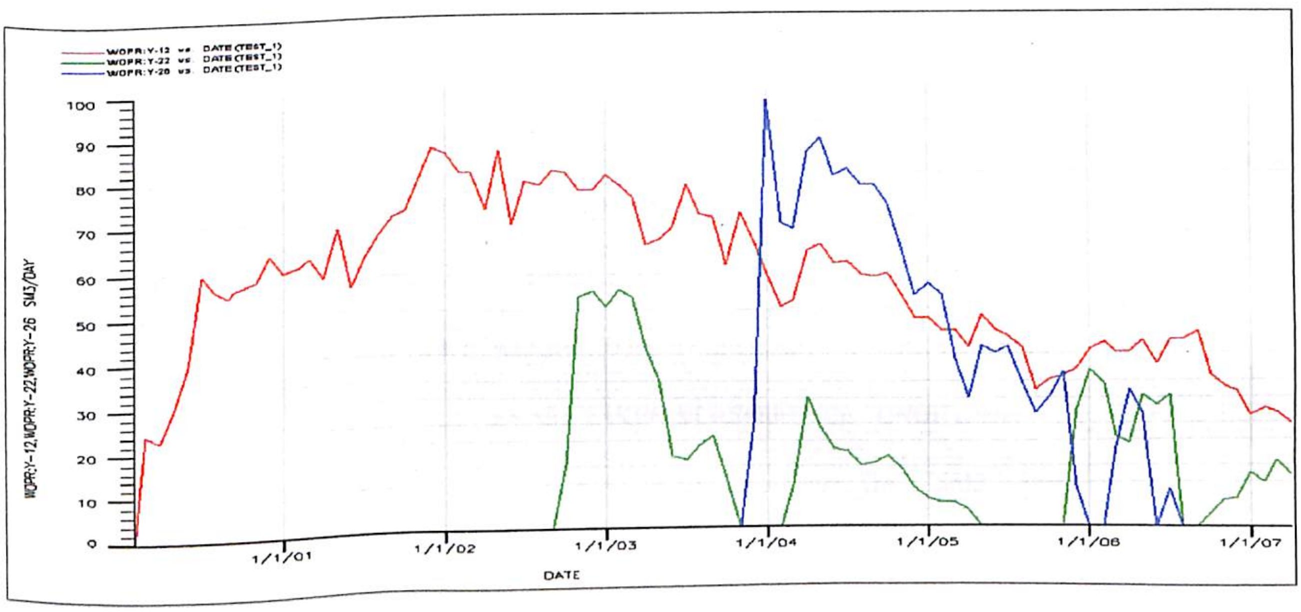

Figure-29, ECLIPSE, Schlumberger

This graph is showing increase of oil production rate well wise for all three wells with time on the addition of aquifer.

AQUIFER ADDITION CASE CONCLUSION

After the successful addition of the Carter Tracy aquifer, there is a substantial increase in the oil production rate of the field and the field's bottom hole pressure. So now to match these results with the history data, history matching has to be done by which further prediction of the field can be done.

3.5 HISTORY MATCH CASE

After addition of the Carter Tracy aquifer, history matching of the simulation model is done to match the results with the history data, so that the further prediction of the reservoir can be done. History matching is done by adding the history production data to the model. The results obtained for the history match are:

Output File: PRT(Production Report)

: FIELD TOTALS :

: PAV = 225.36 BARSA :

: PORV= 2046998. RM3 :

:(PRESSURE IS WEIGHTED BY HYDROCARBON PORE VOLUME:

: PORE VOLUMES ARE TAKEN AT REFERENCE CONDITIONS):

	OIL SM3 LIQUID	OIL SM3 VAPOUR	OIL SM3 TOTAL	WAT SM3 TOTAL	GAS SM3 FREE	GAS SM3 DISSOLVED	GAS SM3 TOTAL
:CURRENTLY IN PLACE	877103.		877103.	732408.	21102159.	116108190.	137210350.
:OUTFLOW THROUGH WELLS			218938.	18800.			31905598.
:ANALYTIC AQUIFER INFLUX				288539.			

:WELL MATERIAL BAL. ERROR: 0.: 0. : 0.:

:FIELD MATERIAL BAL. ERROR: 0.: 0. : 319.:

:------------------------:--:---------------:---:

:ORIGINALLY IN PLACE : 1096040. 1096040.: 462669. : 2319878. 166796389. 169116267.:

==

==

The previously model result is nearly matching with the history matching result

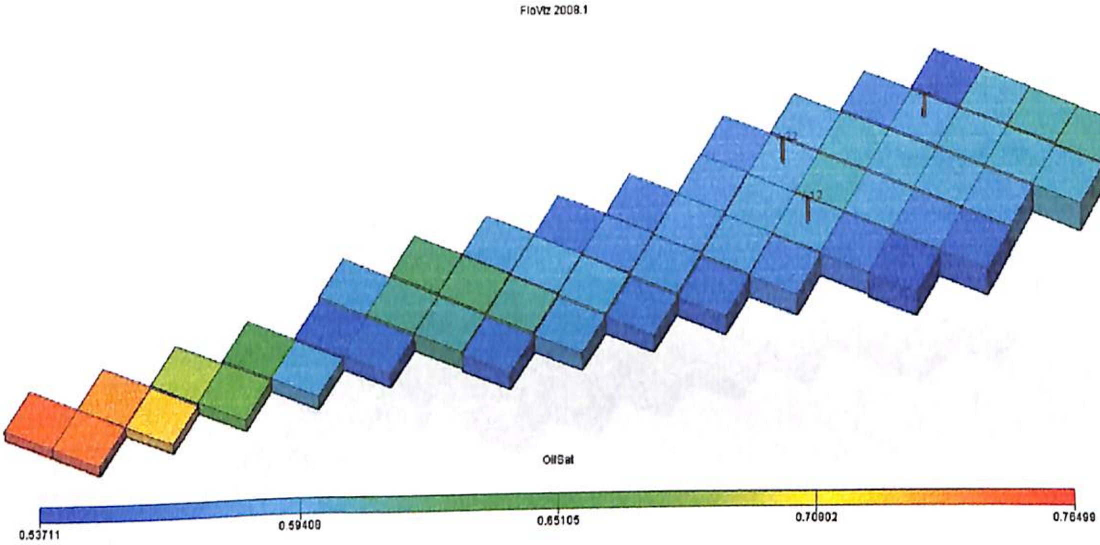

Figure-30, ECLIPSE, Schlumberger

This figure shows the total oil saturation of the reservoir after doing the history match.

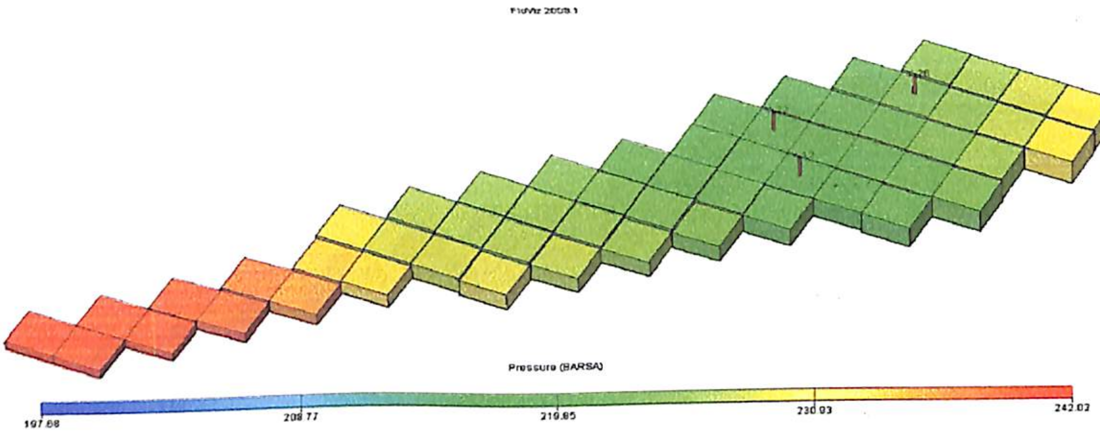

Figure-31, ECLIPSE, Schlumberger

This figure shows the reservoir pressure after doing the history match.

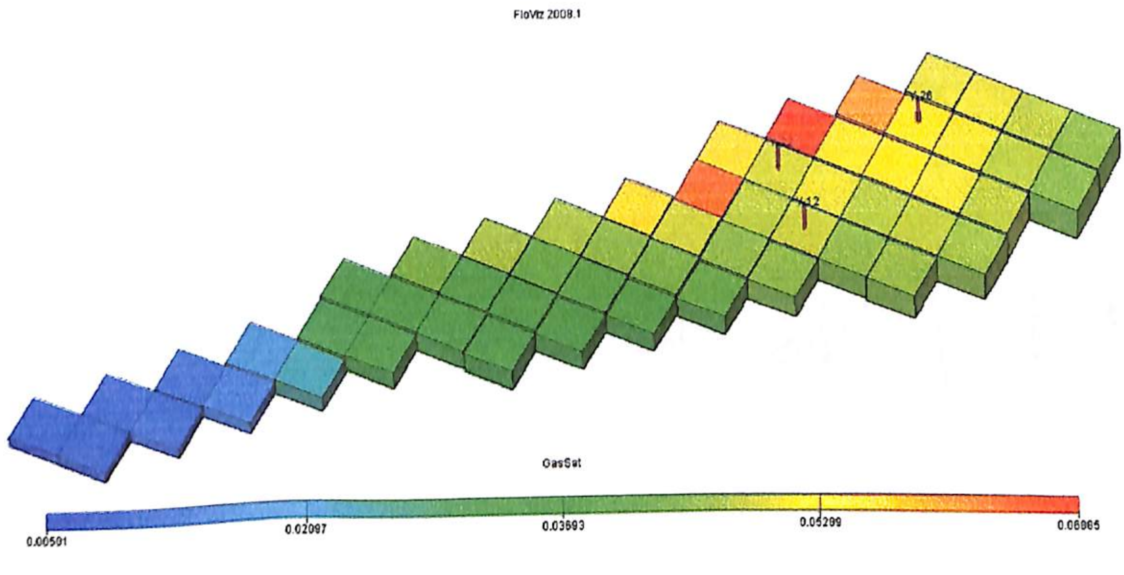

Figure-32, ECLIPSE, Schlumberger

This figure shows the total gas saturation of the field after doing the history match.

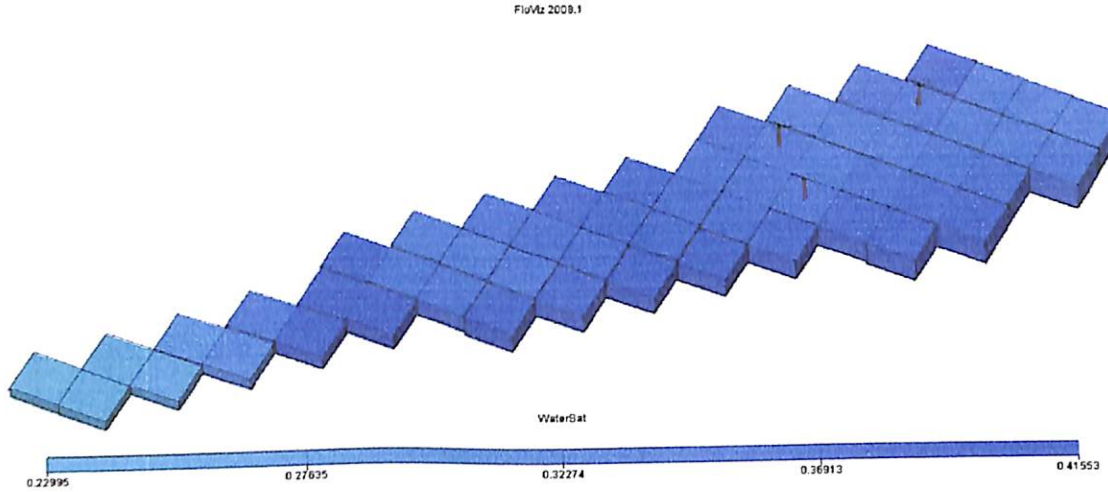

Figure-33, ECLIPSE, Schlumberger

This figure is depicting the total water saturation after doing the history match.

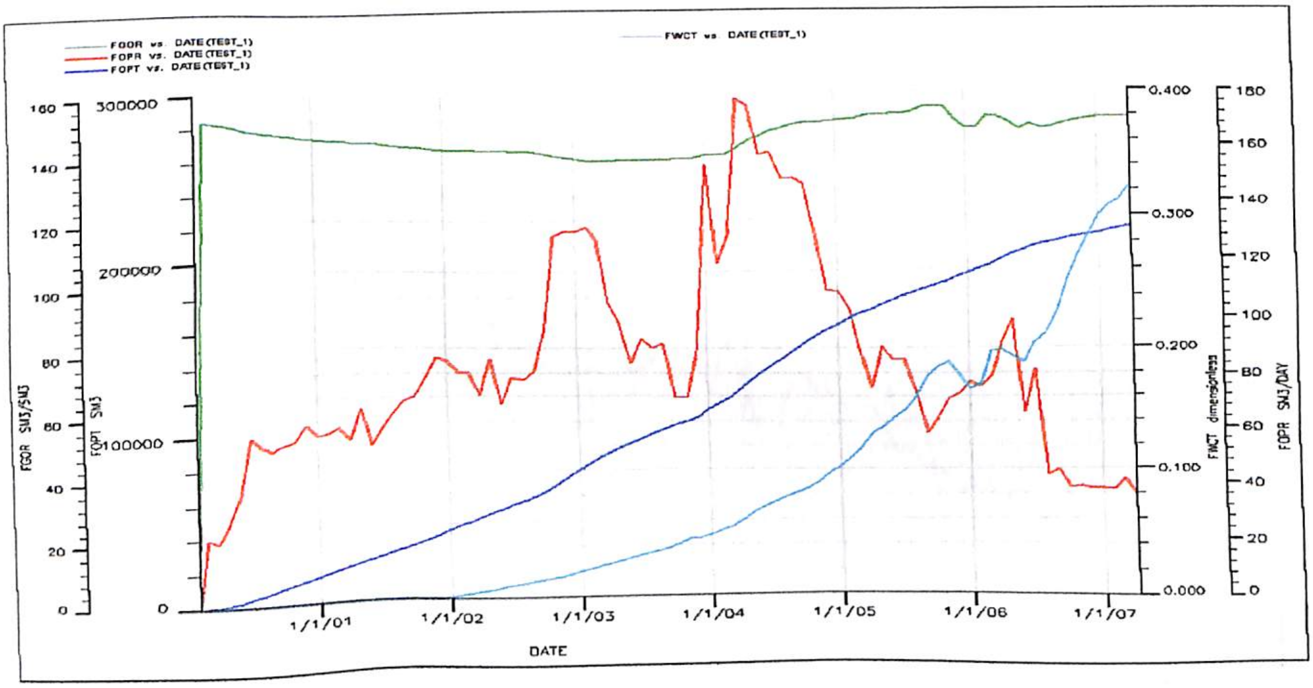

Figure-34, ECLIPSE, Schlumberger

This graph is showing field's oil production rate, field's total oil production, field's GOR and field's water cut with time after doing the history match.

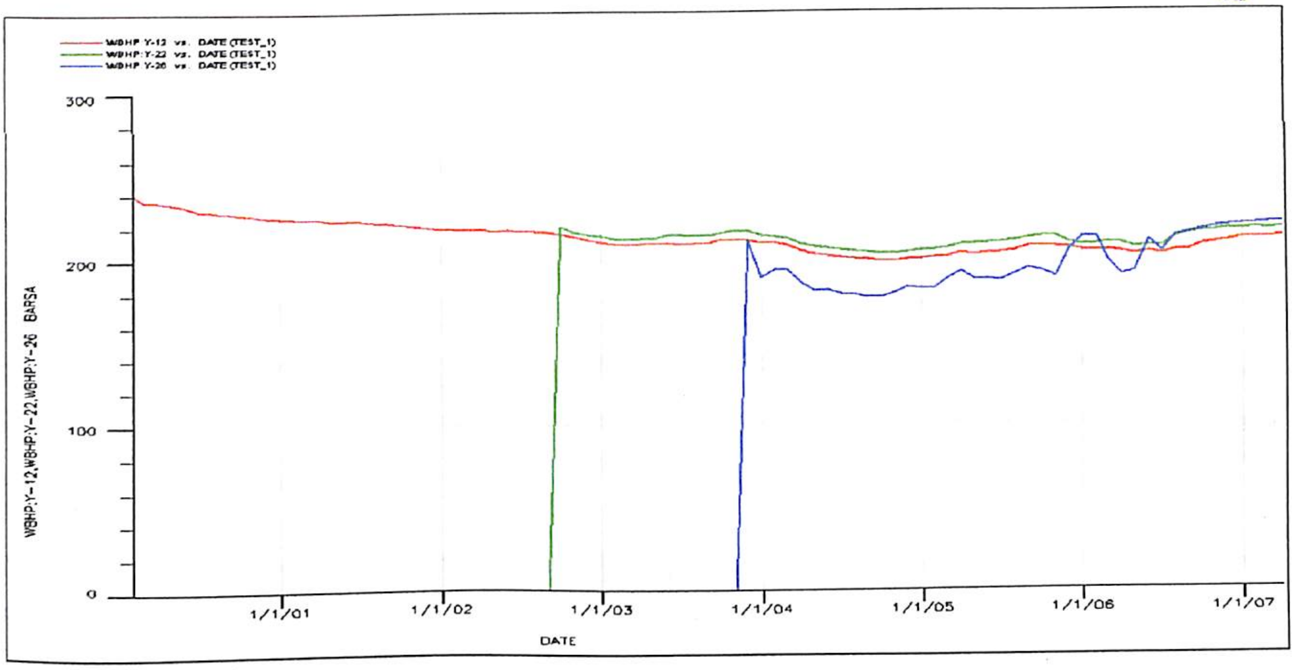

Figure-35, ECLIPSE, Schlumberger

This graph is showing the well wise bottom hole pressure for the wells Y-12, Y-22, Y-26 with time after the history match has been done.

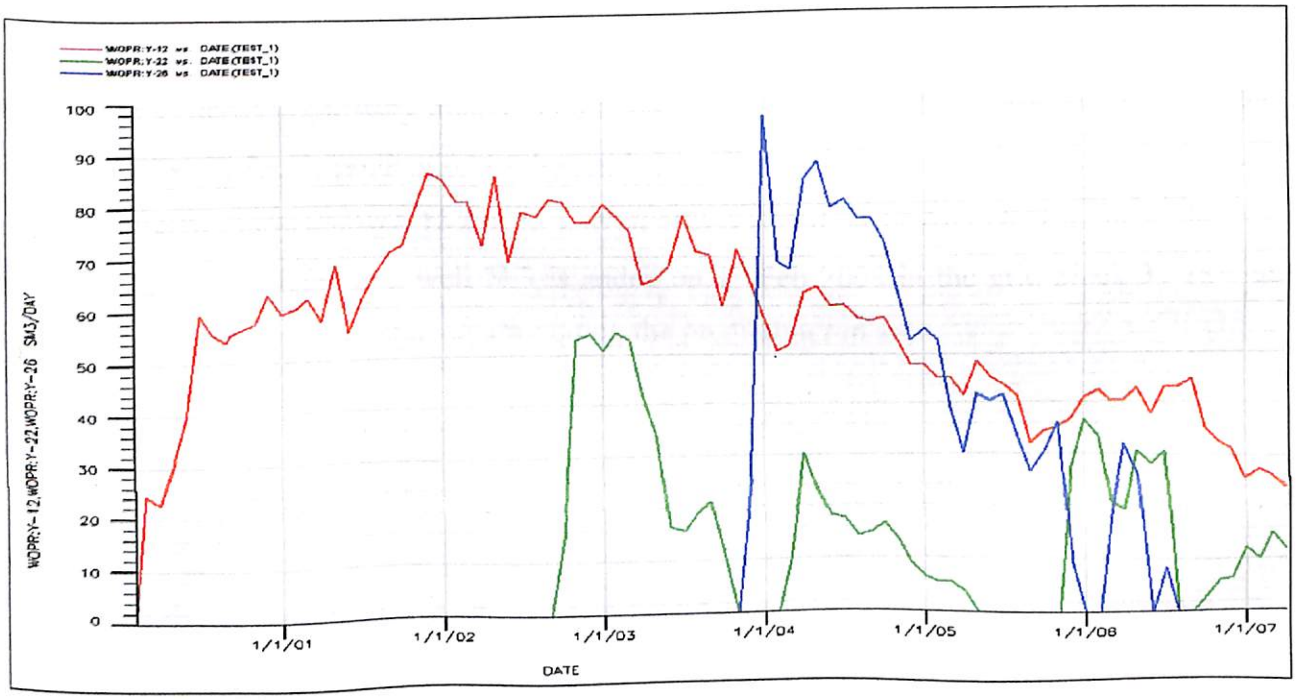

Figure-36, ECLIPSE, Schlumberger

This graph is depicting the change in oil production rate for all the three wells with respect to time after the history match.

HISTORY MATCH CONCLUSION

On doing the history match results showed that the field's water cut and GOR were not matching with that of the models. There was just a slight increase in the water cut in the model as compared to higher water cut of the production history data. GOR of the model were very high. So to match all these parameters certain variations were made in thickness of the aquifer, angle of influence of the aquifer.

After all these variations were done, satisfactory history match was achieved and it was found that the model data such as cumulative oil production, bottom hole pressures, water cut and GOR were near about matching with the production history data.

3.6 PREDICTION ADDING 2 WELLS

After doing a successful history match, prediction of the field is done to know the future of the field. To know the future production of the field, 2 prediction wells were added along with the 3 producing wells. These are well N-2 & N-3. Well N-2 is added on 1st Aug 2007 in the grid block 26-25-1 at 2337.3m depth and well N-3 is added on 1st Feb 2008 in the grid block 34-18-1 at 2357.3m depth. The results obtained after doing the prediction run are:

Output File: PRT (Production Report)

```
:                 FIELD TOTALS                  :
:         PAV =      205.59  BARSA              :
:         PORV=      2046998.   RM3             :
:(PRESSURE IS WEIGHTED BY HYDROCARBON PORE VOLUME:
: PORE VOLUMES ARE TAKEN AT REFERENCE CONDITIONS):
```

	OIL SM3			WAT SM3	GAS SM3		
	LIQUID	VAPOUR	TOTAL	TOTAL	FREE	DISSOLVED	TOTAL
CURRENTLY IN PLACE	622631.		760630.	1091547.	16319281.	80175092.	96494373.
OUTFLOW THROUGH WELLS			335410.	532747.			72621609.
ANALYTIC AQUIFER INFLUX				1161626.			
WELL MATERIAL BAL. ERROR:			0.	0.			1.
FIELD MATERIAL BAL. ERROR:			-1.	0.			284.
ORIGINALLY IN PLACE	1096040.		1096040.	462669.	2319878.	166796389.	169116267.

With adding of these two prediction wells N-2 and N-3 and with wells Y-12, Y-22, and Y-26 the production in the prediction run has increased to 335410m^3 of oil and 72621609m^3 of gas.

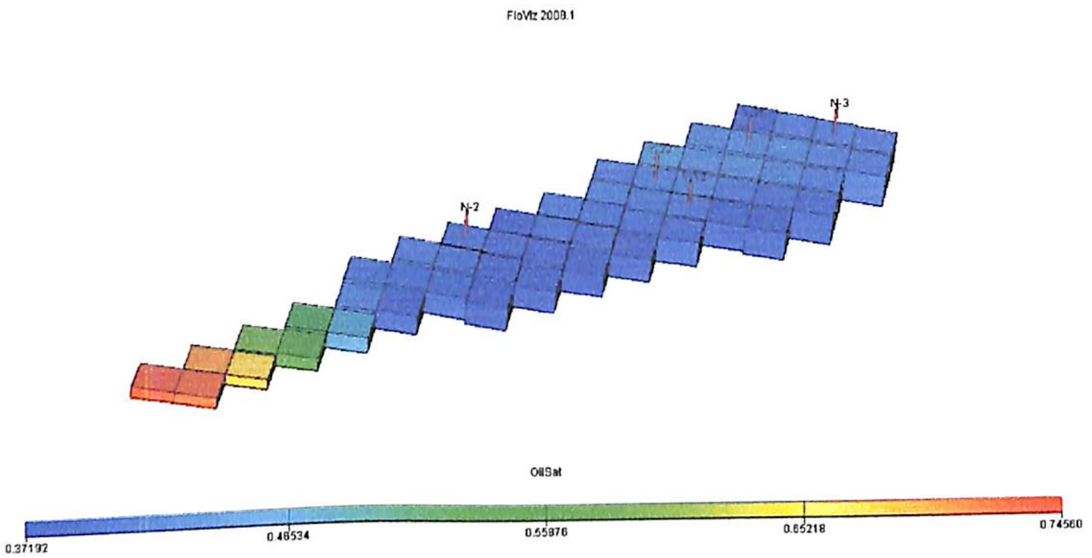

Figure-37, ECLIPSE, Schlumberger

This figure shows the total oil saturation of the field after two predictions wells have been added.

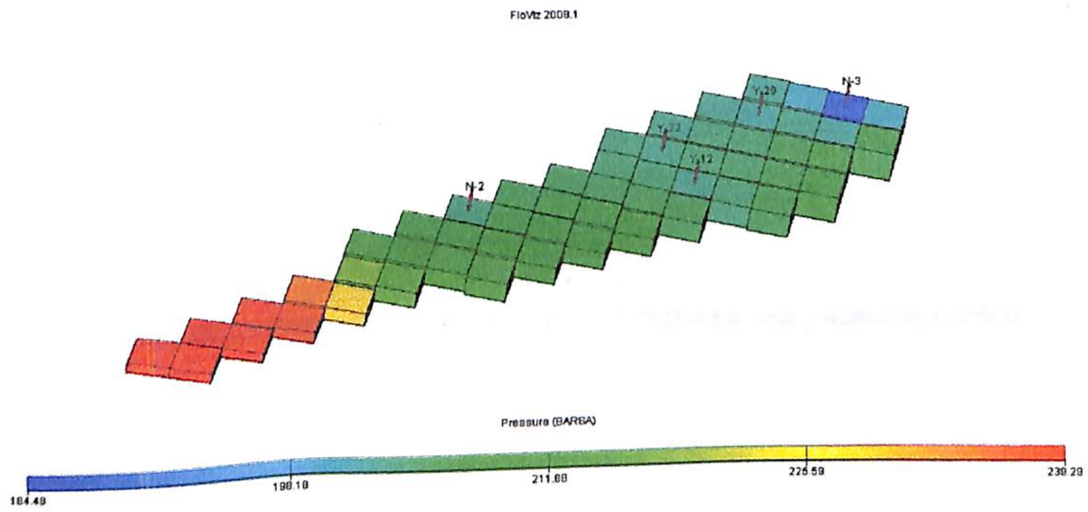

Figure-38, ECLIPSE, Schlumberger

This figure is depicting the decrease in the reservoir pressure after adding two prediction wells.

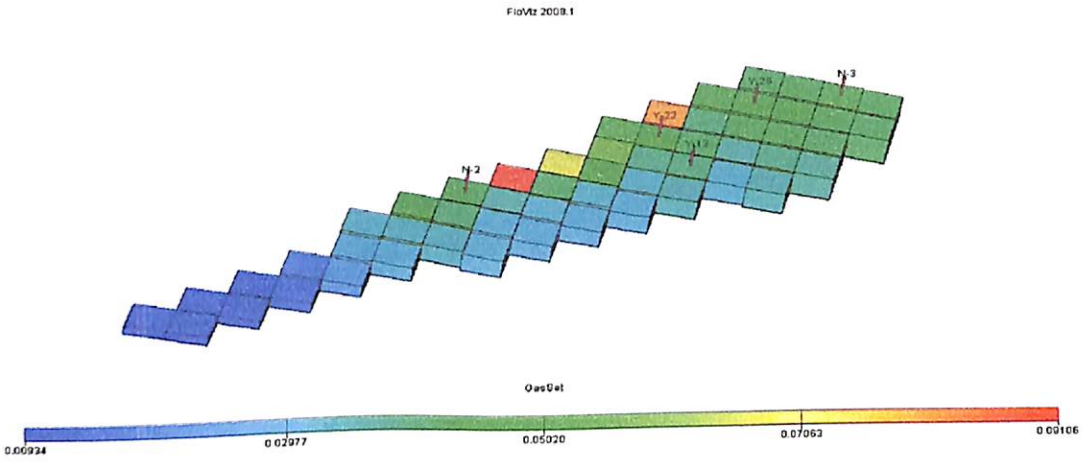

Figure-39, ECLIPSE, Schlumberger

This figure shows the field's total gas saturation after adding two prediction wells.

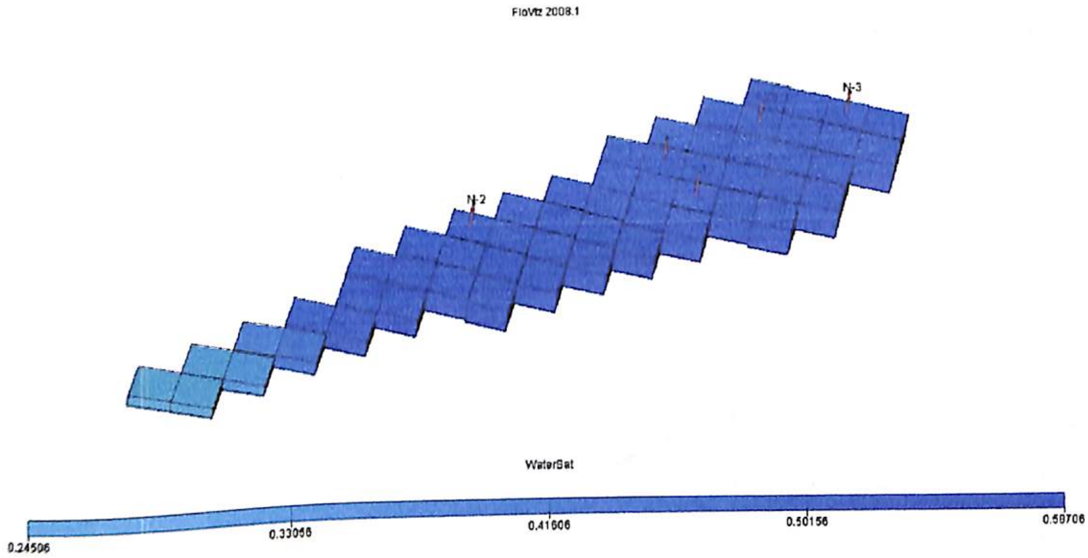

Figure-40, ECLIPSE, Schlumberger

This figure shows field's total water saturation after adding two prediction wells.

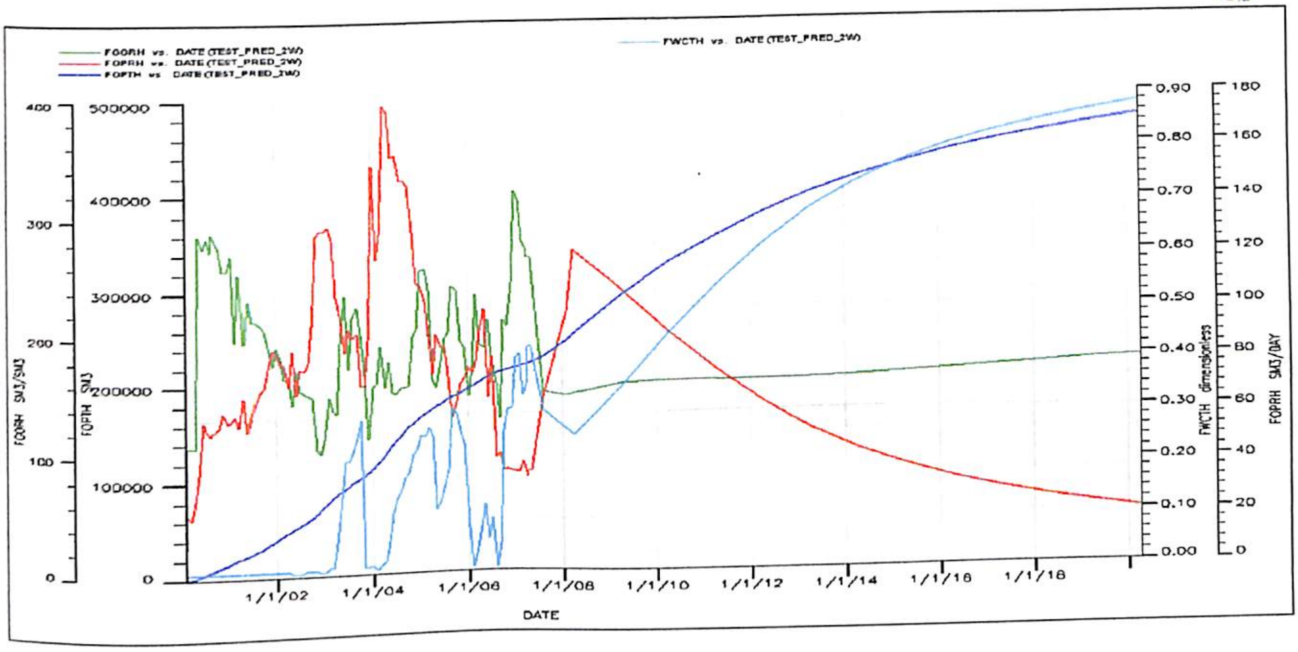

Figure-41, ECLIPSE, Schlumberger

This graph shows the change in field oil production rate history, field total oil production history, and field water cut history and field GOR history with time on addition of the two prediction well.

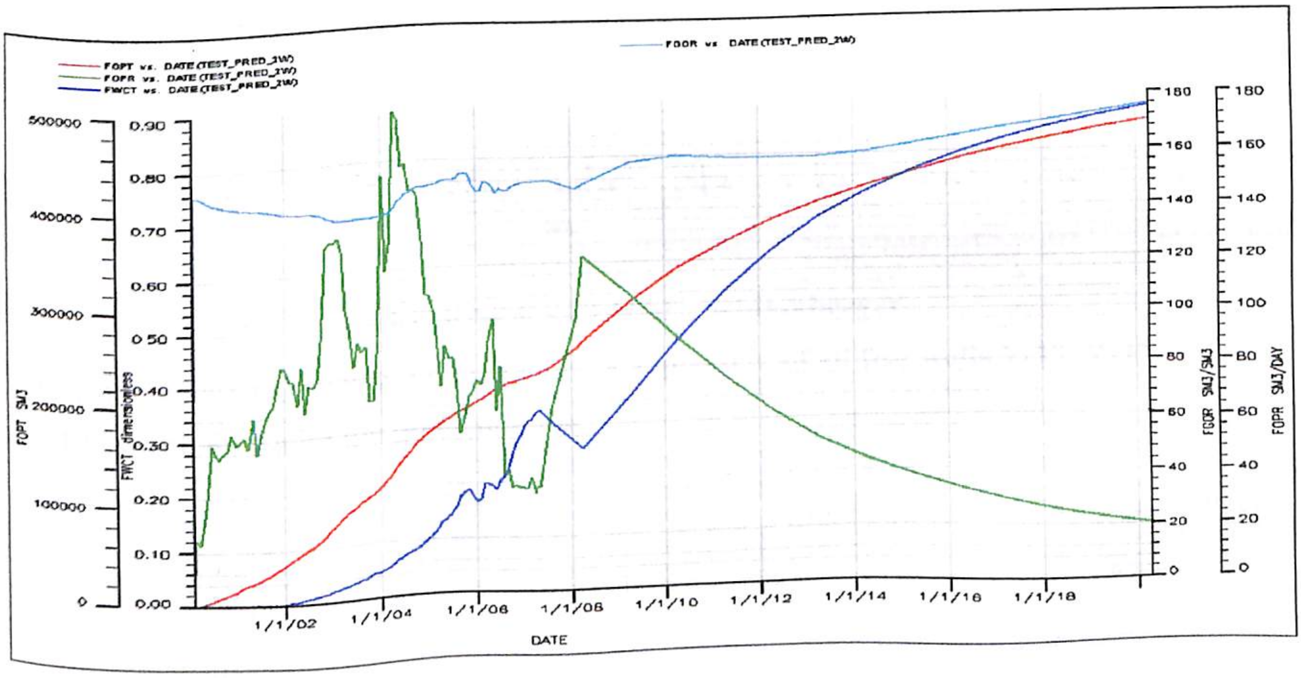

Figure-42, ECLIPSE, Schlumberger

This graph is showing the change in field's oil production rate, field's total oil production, field's GOR and field's water cut with respect to time. There is an increase in the oil production rate and total oil production of the field.

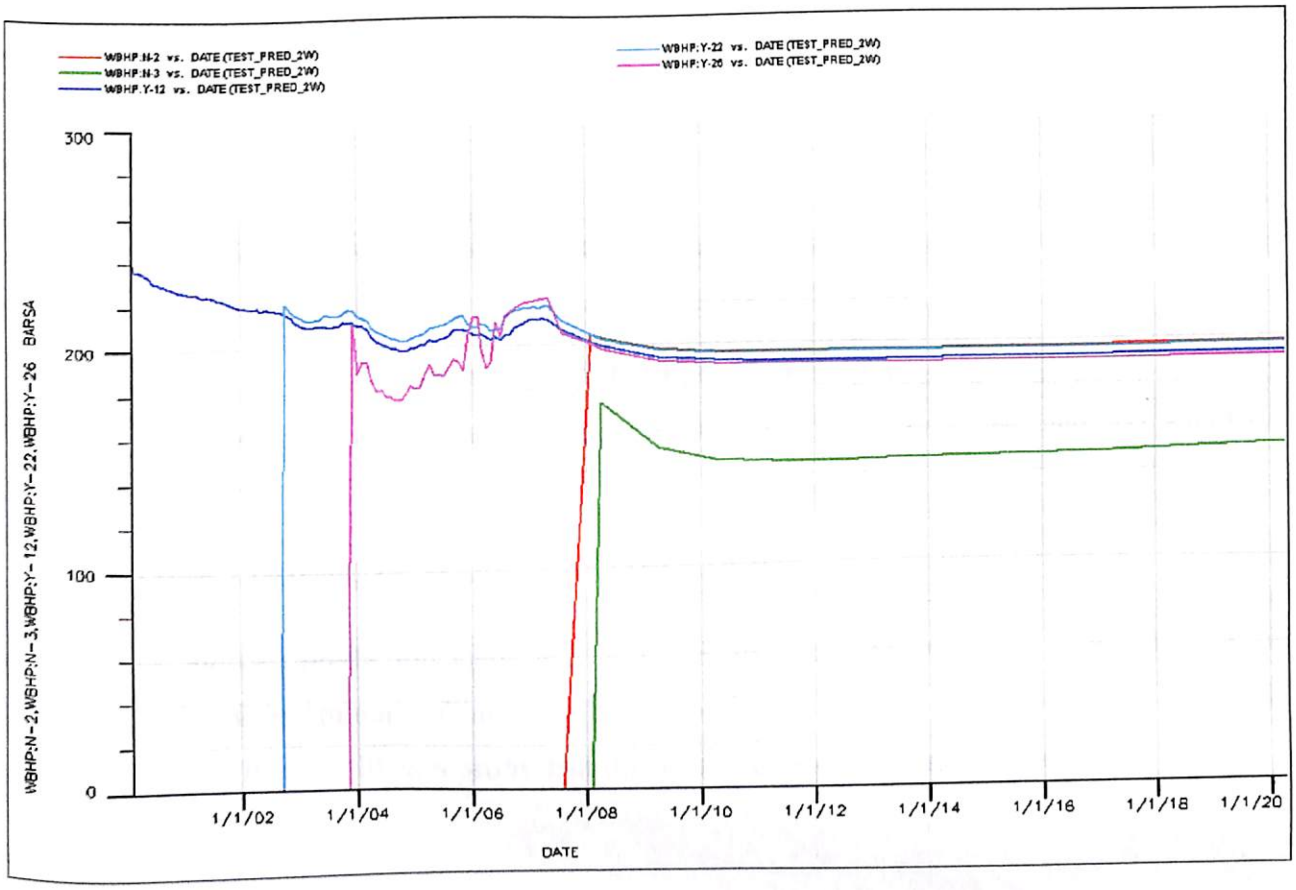

Figure-43, ECLIPSE, Schlumberger

This graph is showing change in the bottom hole pressure of all five wells Y-12, Y-22, Y-26, N-2 and N-3 with time after the prediction run.

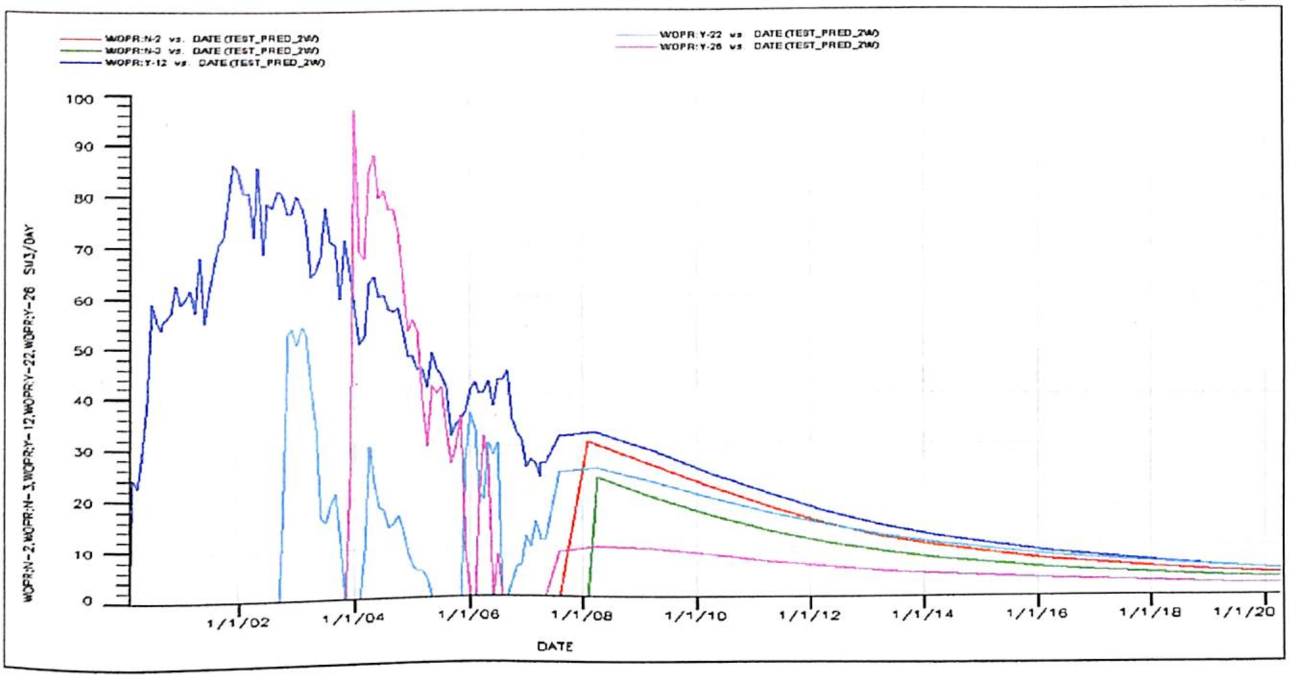

Figure-44, ECLIPSE, Schlumberger

This graph is showing the oil production rate of wells Y-12, Y-22, Y-26, N-2 and N-3 with time after the prediction run.

PREDICTION ADDING TWO WELLS CONCLUSION

After adding the two prediction wells N-2 and N-3 the prediction run was done till 1st April 2020, a considerable amount of increase in production of oil and gas is obtained which is economically viable and will earn profit. But this increase can be further increased.

3.7 PREDICTION ADDING 3 WELLS

After adding two prediction wells it has been concluded that it is economically viable to add one more prediction well to further increase the production of the field and thereby increasing the profits. So one more prediction well N-1 has been added to the model to increase the production. The well N-1 has been added on 1st Aug 2008 in the grid block 23-30-1 at a depth of 2337.3m. The results obtained after adding N-1 to the model are:

Output File: PRT (Production Report)

: FIELD TOTALS :

: PAV = 203.63 BARSA :

: PORV= 2046998. RM3 :

:(PRESSURE IS WEIGHTED BY HYDROCARBON PORE VOLUME:

: PORE VOLUMES ARE TAKEN AT REFERENCE CONDITIONS):

	OIL SM3			WAT SM3	GAS SM3		
	LIQUID	VAPOUR	TOTAL	TOTAL	FREE	DISSOLVED	TOTAL
CURRENTLY IN PLACE	612223.		712222.	1106031.	16495555.	78077043.	94572598.
OUTFLOW THROUGH WELLS			383818.	627080.			74543424.
ANALYTIC AQUIFER INFLUX				1270443.			
WELL MATERIAL BAL. ERROR			0.	0.			3.
FIELD MATERIAL BAL. ERROR			0.	0.			243.
ORIGINALLY IN PLACE	1096040.		1096040.	462669.	2319878.	166796389.	169116267.

With adding of this prediction well N-1 and with wells N-2, N-3, Y-12, Y-22, and Y-26 the total oil production in the prediction run has increased to 383818m^3 of oil and 74543424m^3 of gas.

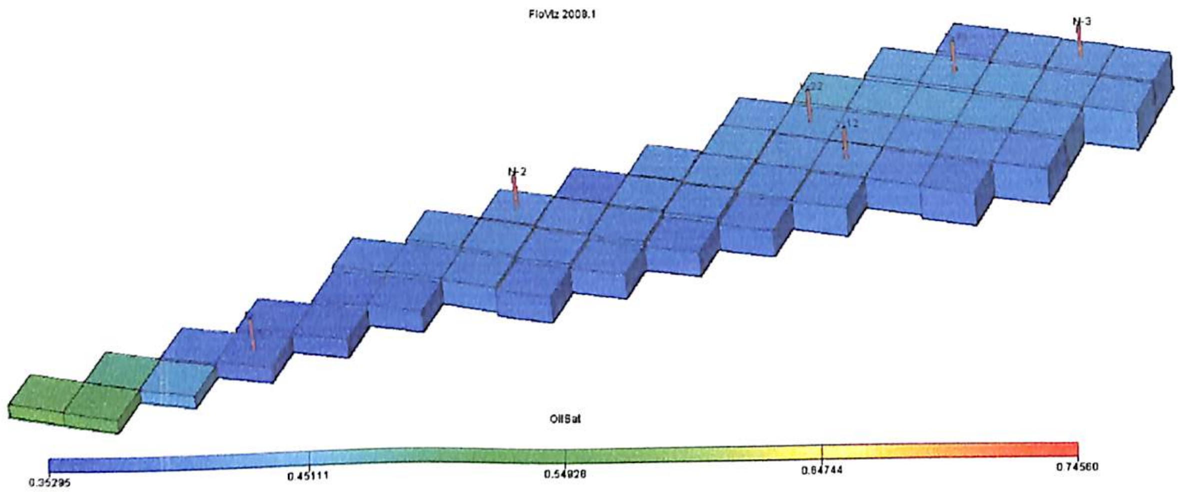

Figure-45, ECLIPSE, Schlumberger

This figure shows the total oil saturation of the field after prediction run after adding the third prediction well.

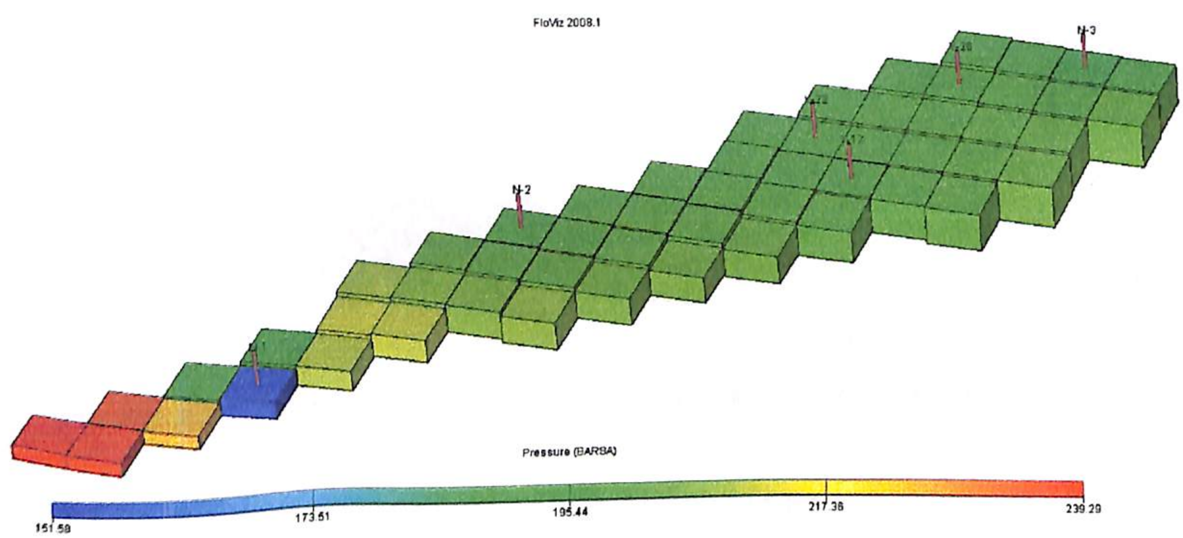

Figure-46, ECLIPSE, Schlumberger

This figure is showing the decrease in the overall reservoir pressure of the field after adding the third prediction well.

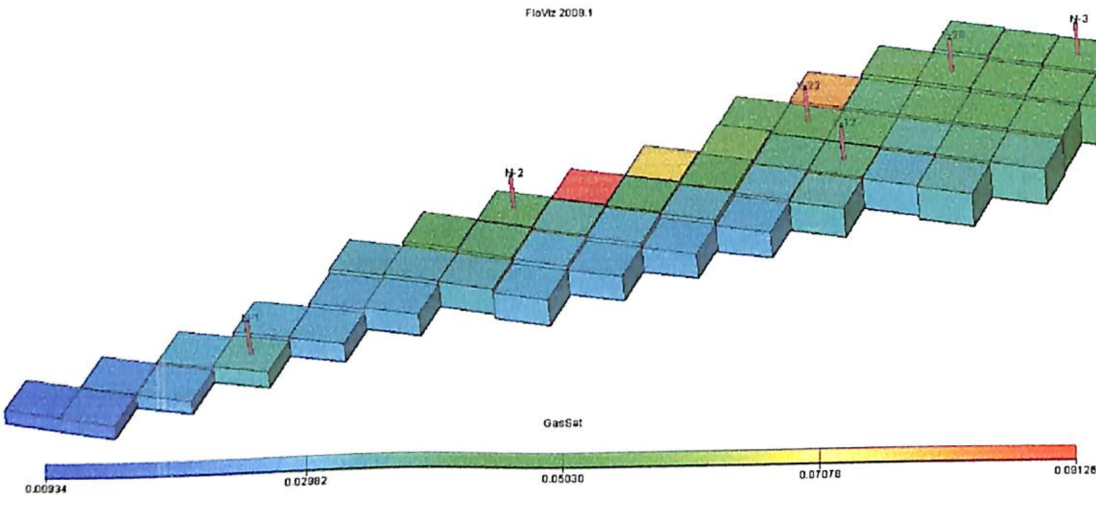

Figure-47, ECLIPSE, Schlumberger

This figure is showing the total gas saturation after adding the third prediction well.

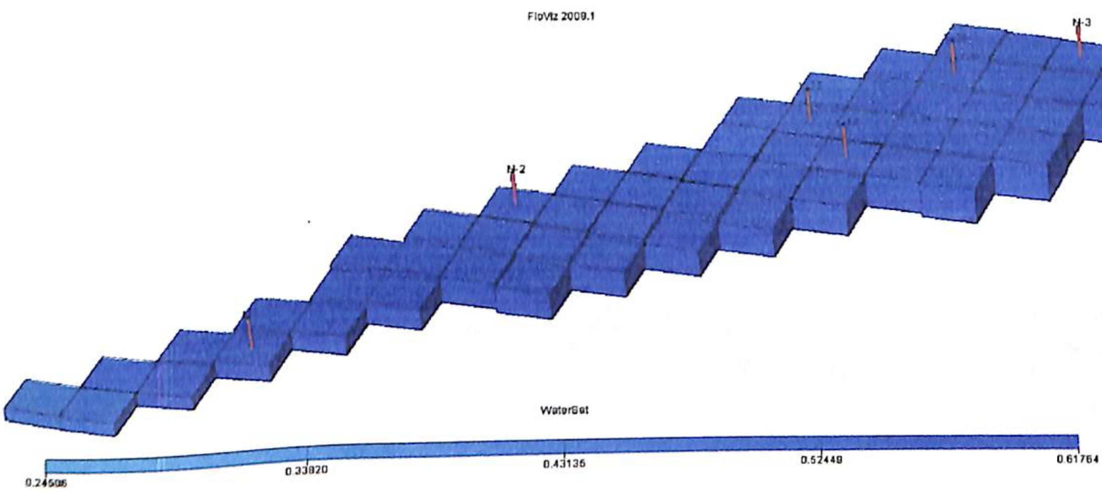

Figure-48, ECLIPSE, Schlumberger

This figure is showing the total water saturation across the field after adding the third well.

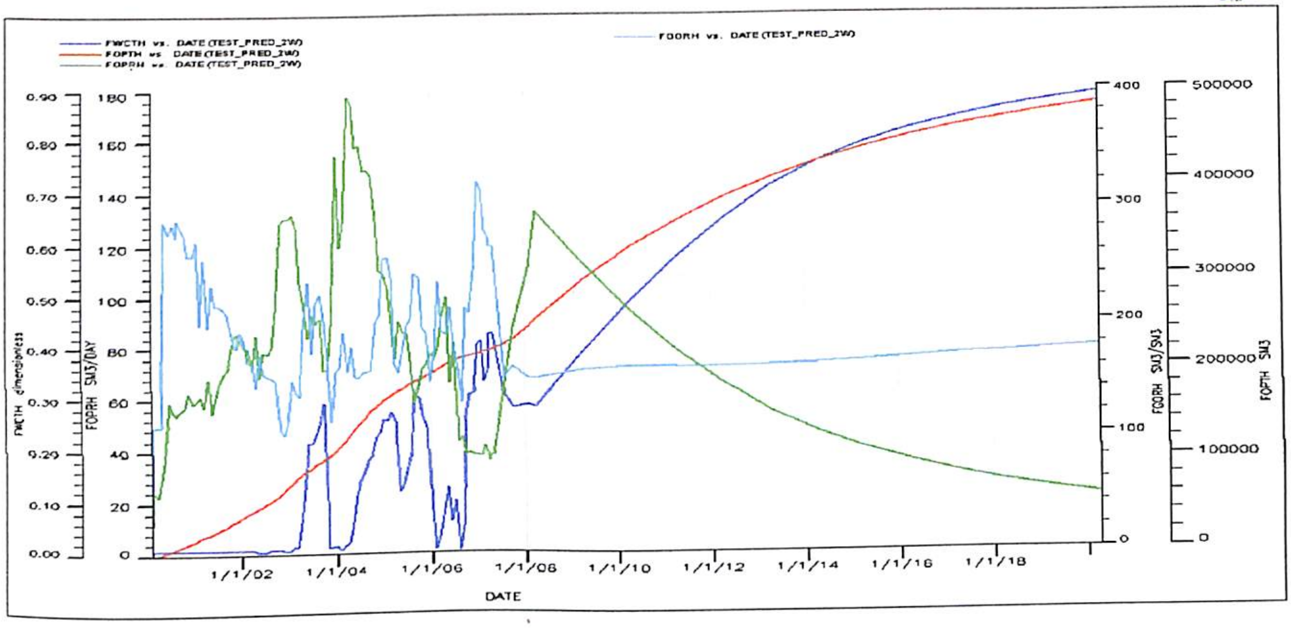

Figure-49, ECLIPSE, Schlumberger

This graph is showing the change in the field's oil production rate history, field's total oil production history, field's water cut history, field's GOR history with respect to time after adding the third prediction well.

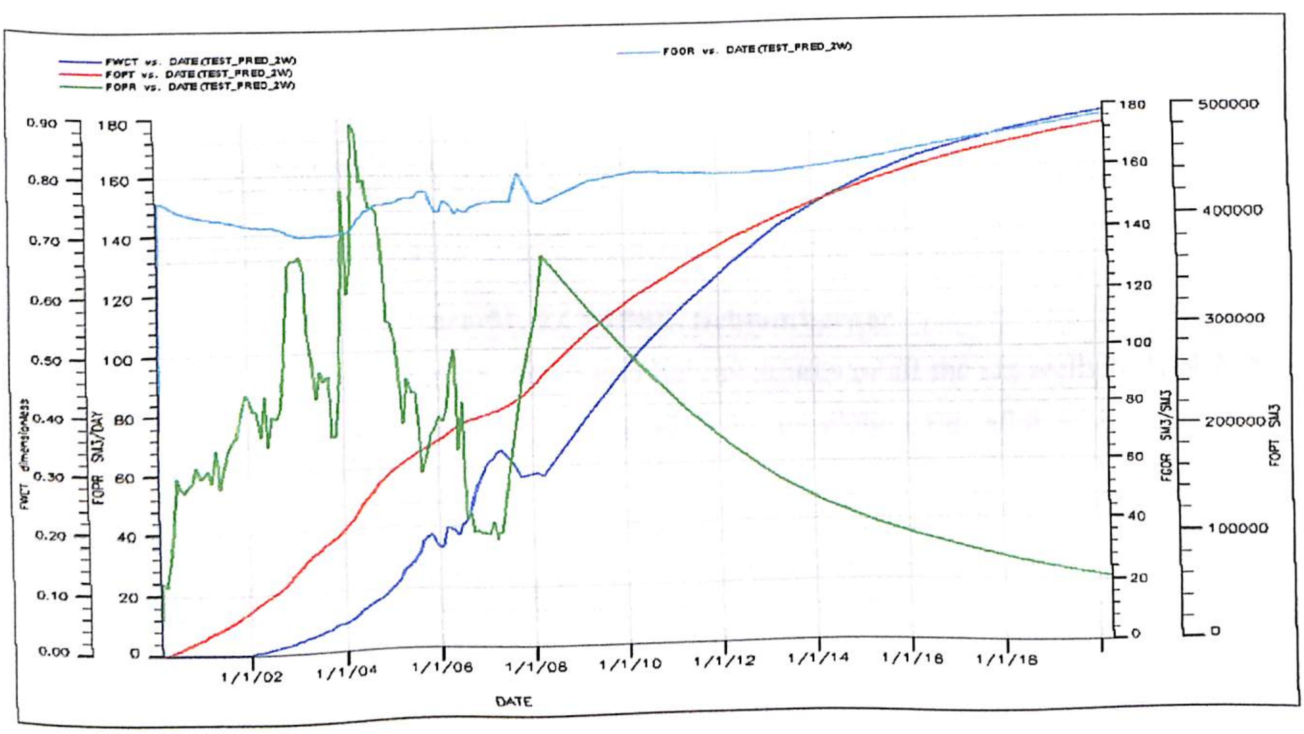

Figure-50, ECLIPSE, Schlumberger

This graph shows the change in field's oil production rate, total oil production, water cut and GOR with respect to time after the prediction run after adding the third prediction well.

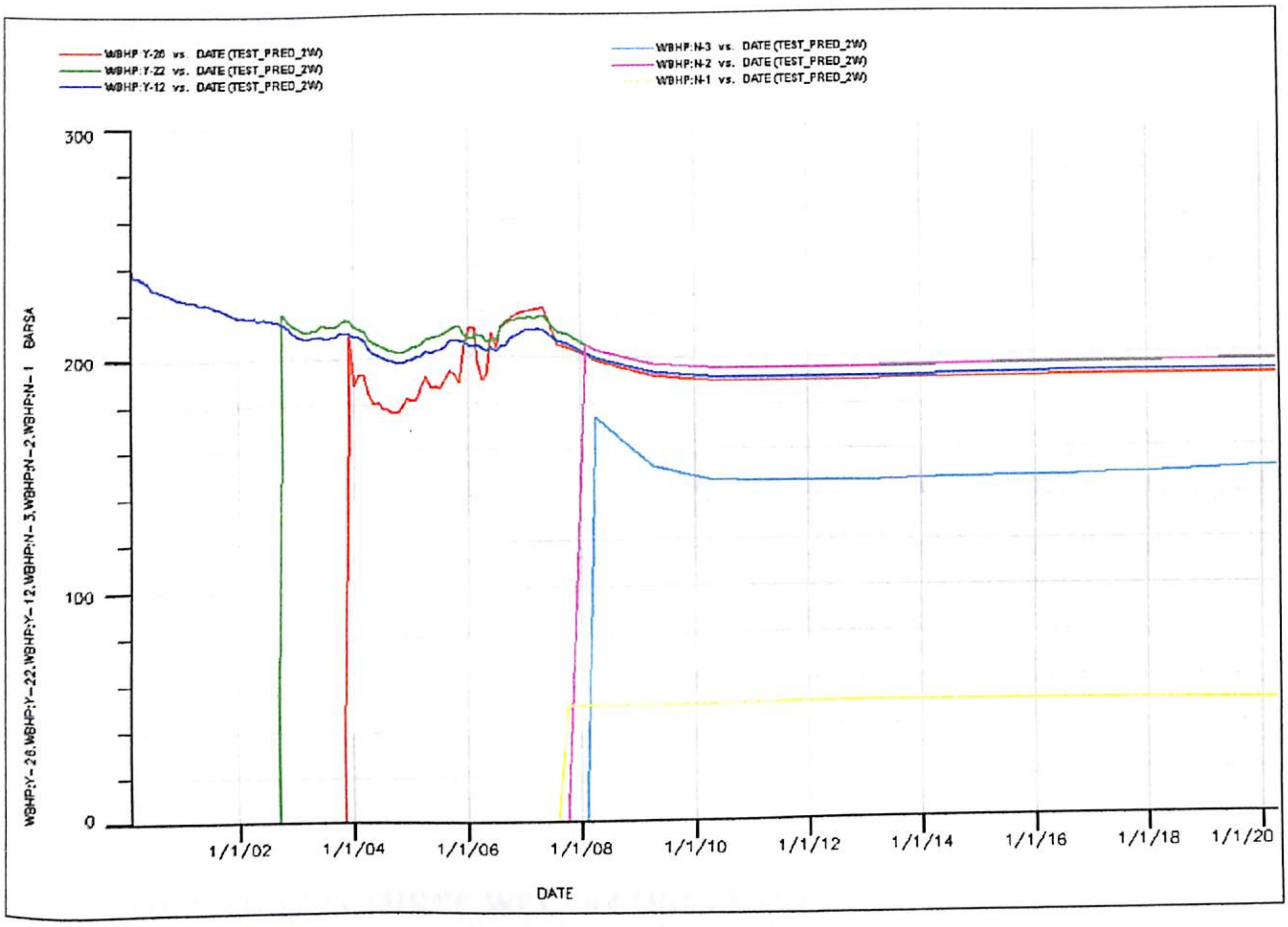

Figure-51, ECLIPSE, Schlumberger

This graph is depicting the change in the bottom hole pressures of all the six wells N-1, N-2, N-3, Y-12, Y-22 and Y-26 with respect to time after the prediction run after adding the third prediction well.

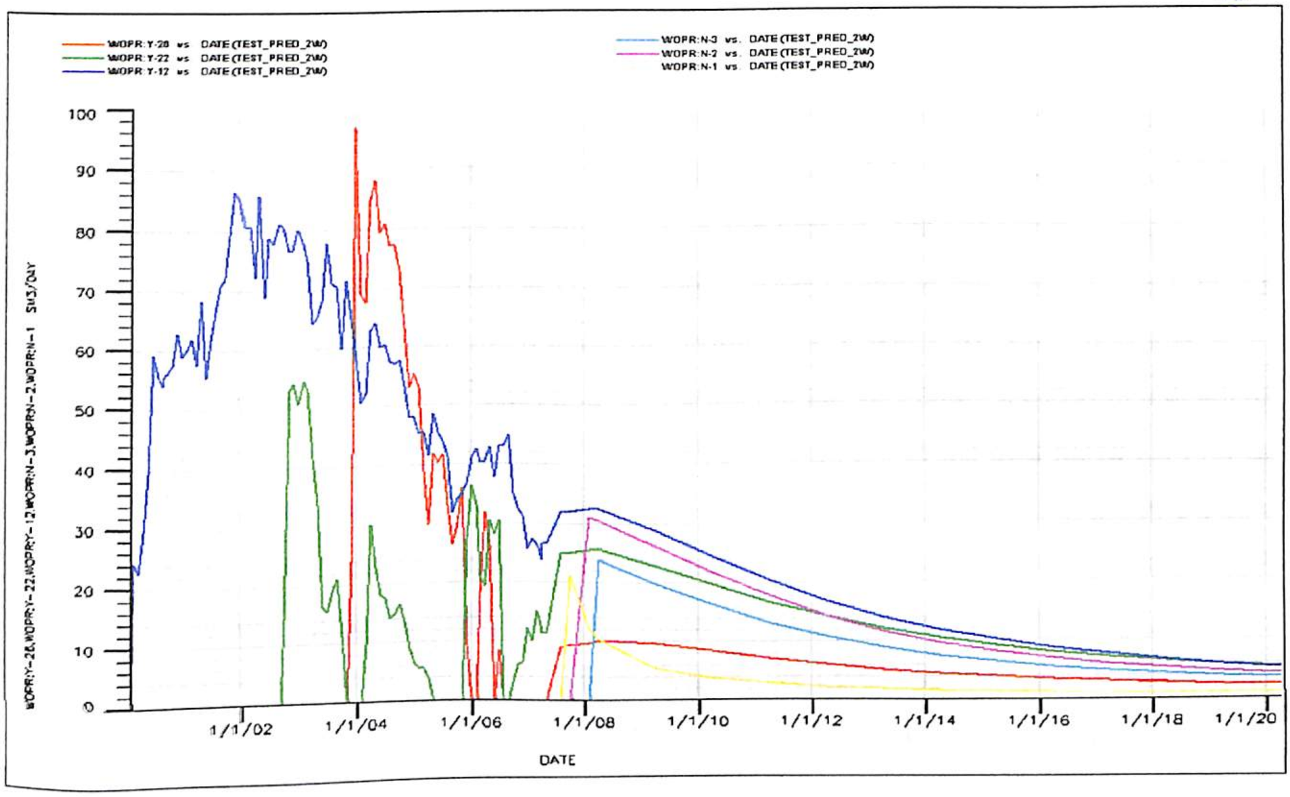

Figure-52, ECLIPSE, Schlumberger

This graph is showing the change in the oil production rate of all the six wells with respect to time after the prediction run has been done after adding the third well.

PREDICTION ADDING THREE WELLS CONCLUSION

After adding the third prediction well N-1 the prediction run was done till 1st April 2020, a considerable amount of increase in production of oil and gas is obtained which is economically viable and will earn profit. But this increase can further be increased.

3.8 WATER FLOODING WITH 2 PREDICTION WELLS

As seen production increased after adding 2 prediction wells and then further increased after adding 3 prediction wells. Production can be further increased by applying water flooding technique and it will also deplete the reservoir fast as compared to the natural reservoir energy. So to apply the water flooding technique in the field 3 water injection wells were added in the field with 2 production well to see the production profile. These wells are W-4, W-5 and W-6. The well W-4 started injecting on 1st Oct 2008. It is drilled in the grid block 25-28-1 at a depth of 1332m. The well W-5 started injecting on 1st Nov 2008. It is drilled in the grid block 33-19-1 at the depth of 1332m. The well W-6 started injecting on 1st Dec 2008. It is drilled in the grid block 28-24-1 at a depth of 1332m. The positions of the prediction wells were also changed to see the change in production. These injection wells are placed in an irregular water flooding pattern to apply the water flooding technique due to the topology of the field. The surface flow rate for the injector wells W-4, W-5 and W-6 were kept varying between 2-10 stb/day, to get the maximum production from the field. The model with these water flooding technique and prediction wells is run till 1st April 2020. The results obtained from this water flooding model with two prediction wells are:

Output File: PRT (Production Report)

```
=====================================================
        :        FIELD TOTALS          :
        :    PAV =     215.29  BARSA   :
        :    PORV=     2046998.  RM3   :
        :(PRESSURE IS WEIGHTED BY HYDROCARBON PORE VOLUME:
        : PORE VOLUMES ARE TAKEN AT REFERENCE CONDITIONS):
:--------------- OIL   SM3 ---------------:-- WAT   SM3 -:--------------- GAS   SM3 ---------------:
      :  LIQUID       VAPOUR       TOTAL  :    TOTAL  :    FREE    DISSOLVED        TOTAL
:
:------------------------:-------------------------------------------:----------------:--------------------------------------------:
```

:CURRENTLY IN PLACE	: 644379.	654379.:	1063666. :	16522792.	84354290.	100877082.:
:---------------------:----------	----------	----------:	----------:	----------	----------:	
:OUTFLOW THROUGH WELLS :		441662.:	395821. :			68238865.:
:ANALYTIC AQUIFER INFLUX :		:	996818. :			:
:WELL MATERIAL BAL. ERROR:		0.:	0. :			0.:
:FIELD MATERIAL BAL. ERROR:		-1.:	0. :			320.:
:---------------------:----------	----------	----------:	----------:	----------	----------:	
:ORIGINALLY IN PLACE	: 1096040.	1096040.:	462669. :	2319878.	166796389.	169116267.:

===

==================================

With applying the water flooding technique with 3 injection wells W-4, W-5 and W-6 and 2 prediction wells N-2 and N-3with wells Y-12, Y-22, and Y-26 the total oil production in the prediction run has increased to 441662m^3 of oil and 68238865m^3 of gas.

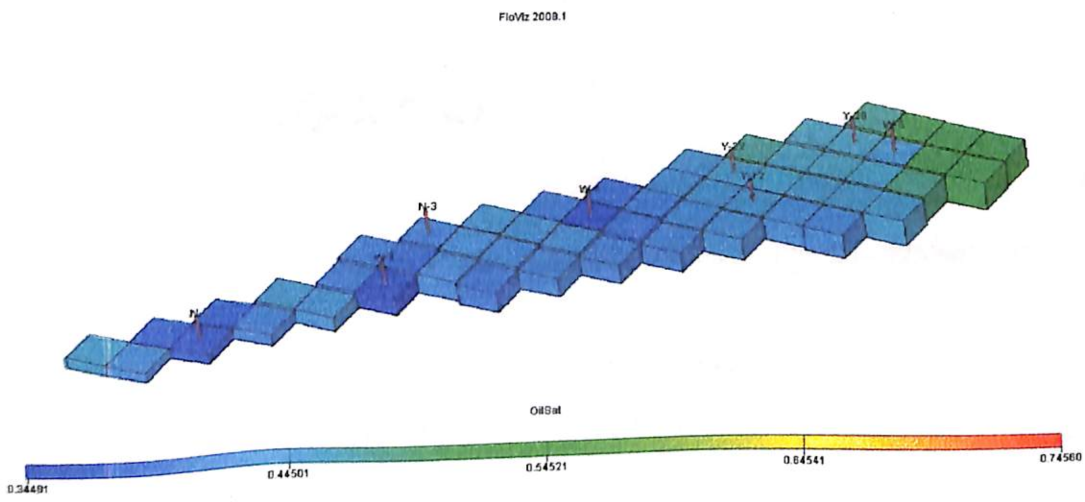

Figure-53, ECLIPSE, Schlumberger

This figure is showing the total oil saturation across the field for the water flooding case with two prediction wells.

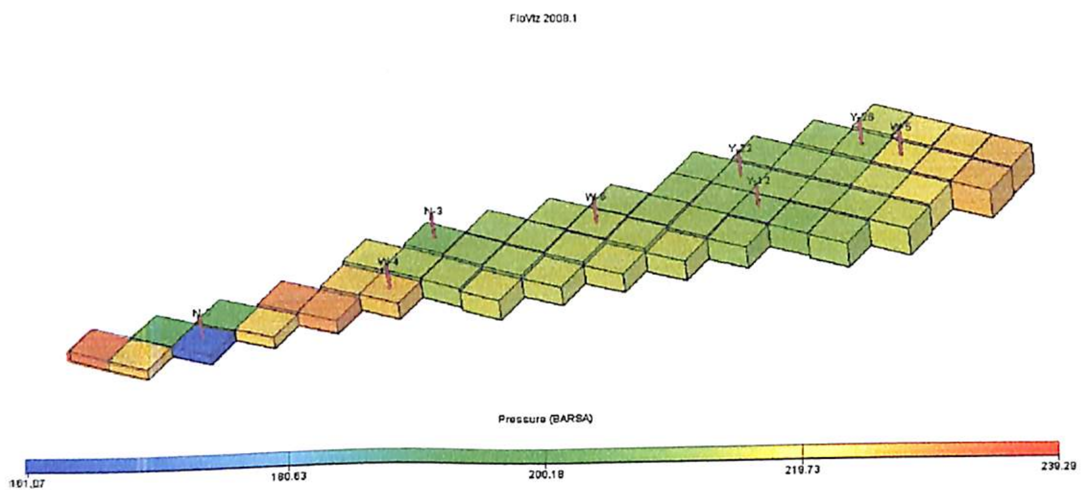

Figure-54, ECLIPSE, Schlumberger

This figure is depicting the reservoir pressure after running the model with water flooding pattern with 2 prediction wells.

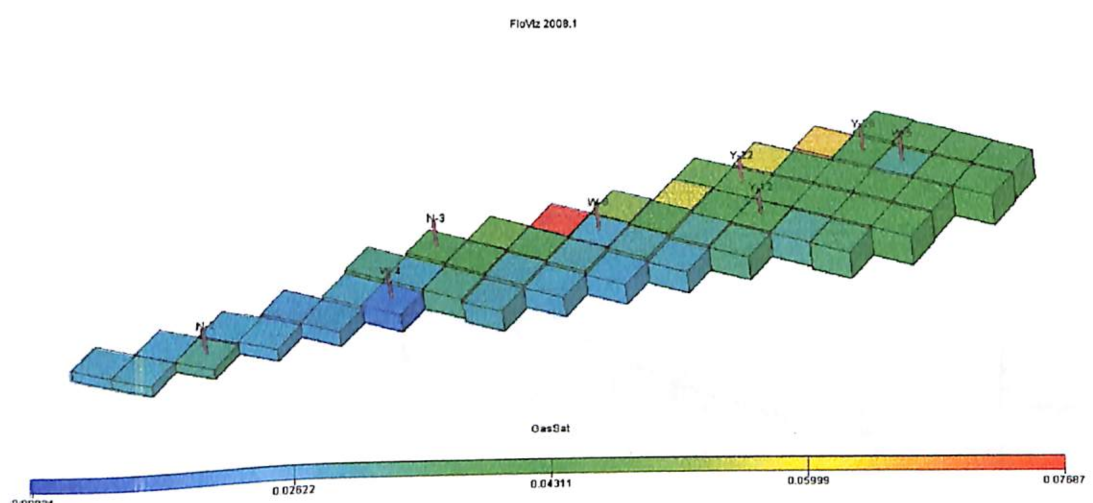

Figure-55, ECLIPSE, Schlumberger

This figure is showing the total gas saturation across the field after running the model with water flooding pattern with 2 prediction wells.

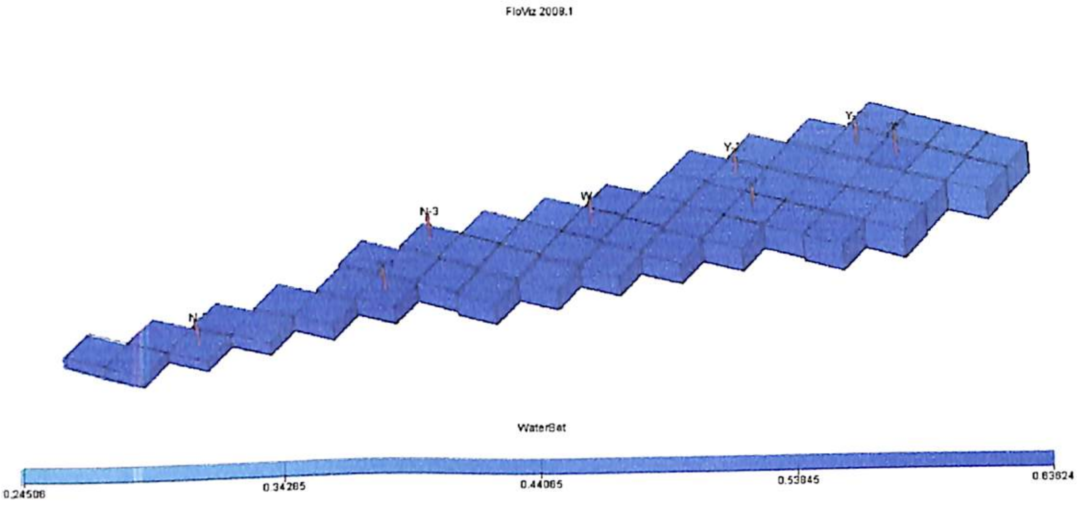

Figure-56, ECLIPSE, Schlumberger

This figure is depicting the total water saturation across the field.

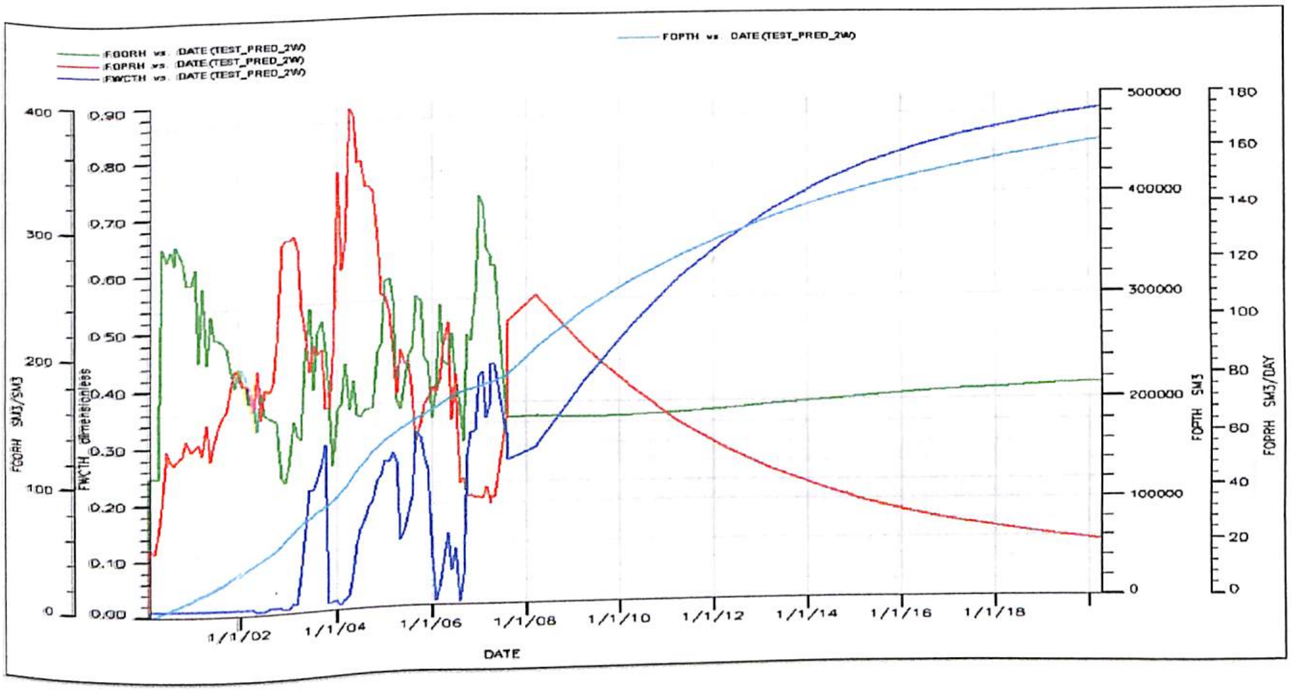

Figure-57, ECLIPSE, Schlumberger

This graph is showing the change of field's oil production rate history, total oil production history, GOR history, water cut history with respect to time.

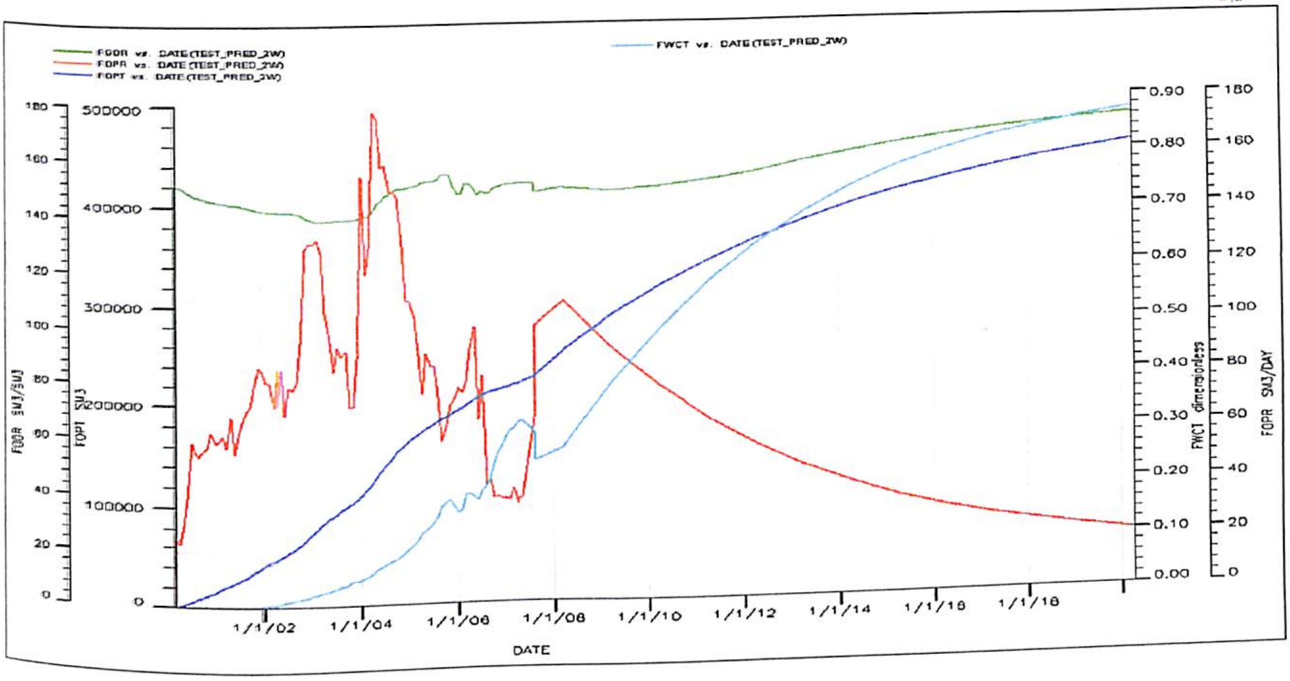

Figure-58, ECLIPSE, Schlumberger

This graph is depicting the change of the field's oil production rate, total oil production, water cut and GOR with respect to time after running the model with the water flooding pattern and 2 prediction wells.

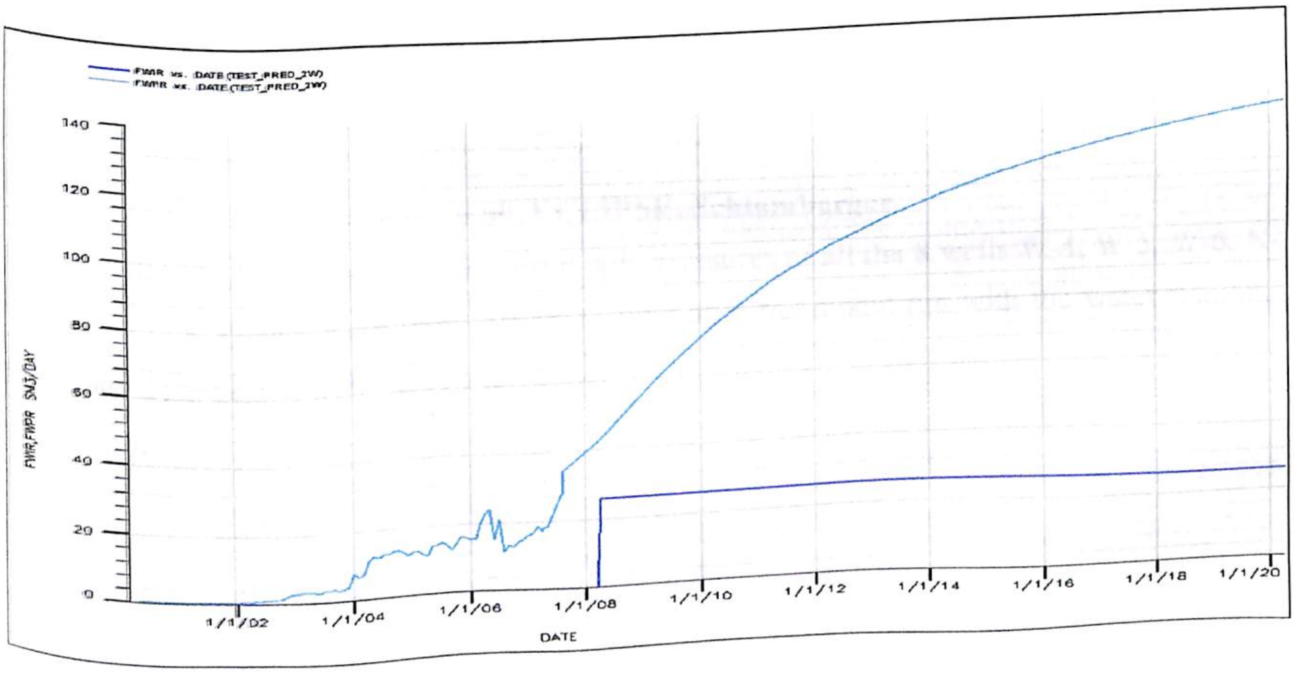

Figure-59, ECLIPSE, Schlumberger

This graph is showing the change of field's water injection rate and water production rate with respect to time.

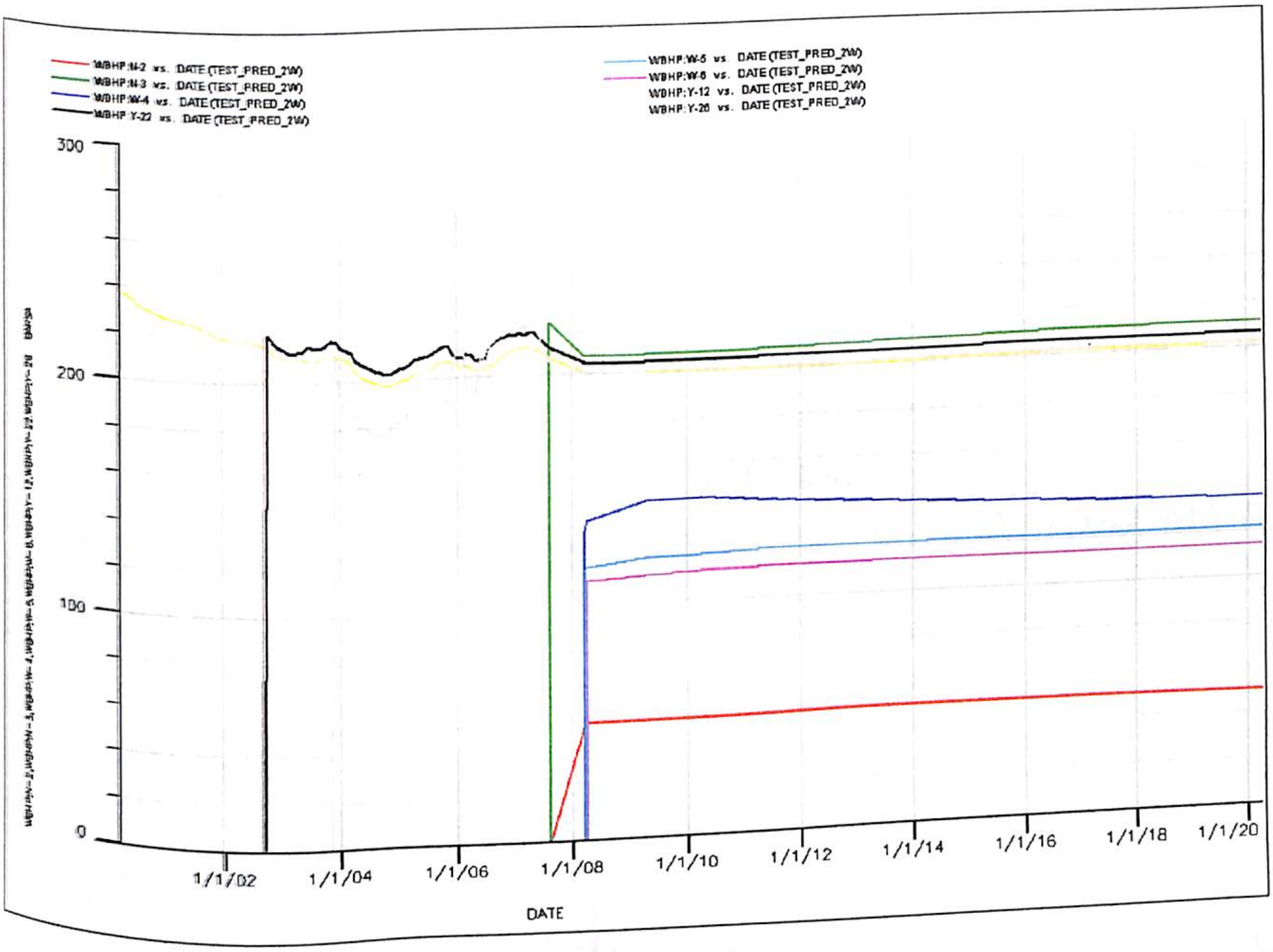

Figure-60, ECLIPSE, Schlumberger

This graph is showing the change in bottom hole pressures of all the 8 wells W-4, W-5, W-6, N-2, N-3, Y-12, Y-22 and Y-26 with respect to time after the model run with the water flooding pattern and 2 prediction wells have been done.

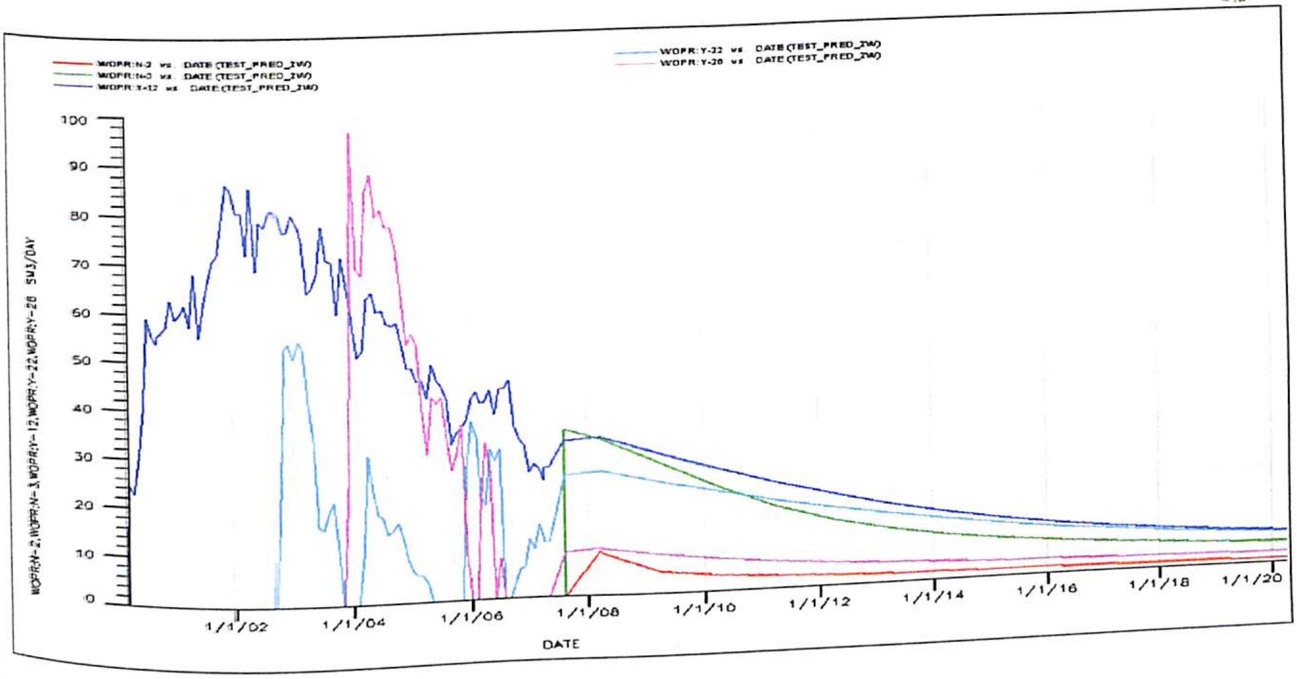

Figure-61, ECLIPSE, Schlumberger

This graph is showing the change in oil production rates of wells N-2, N-3, Y-12, Y-22 and Y-26 with respect to time.

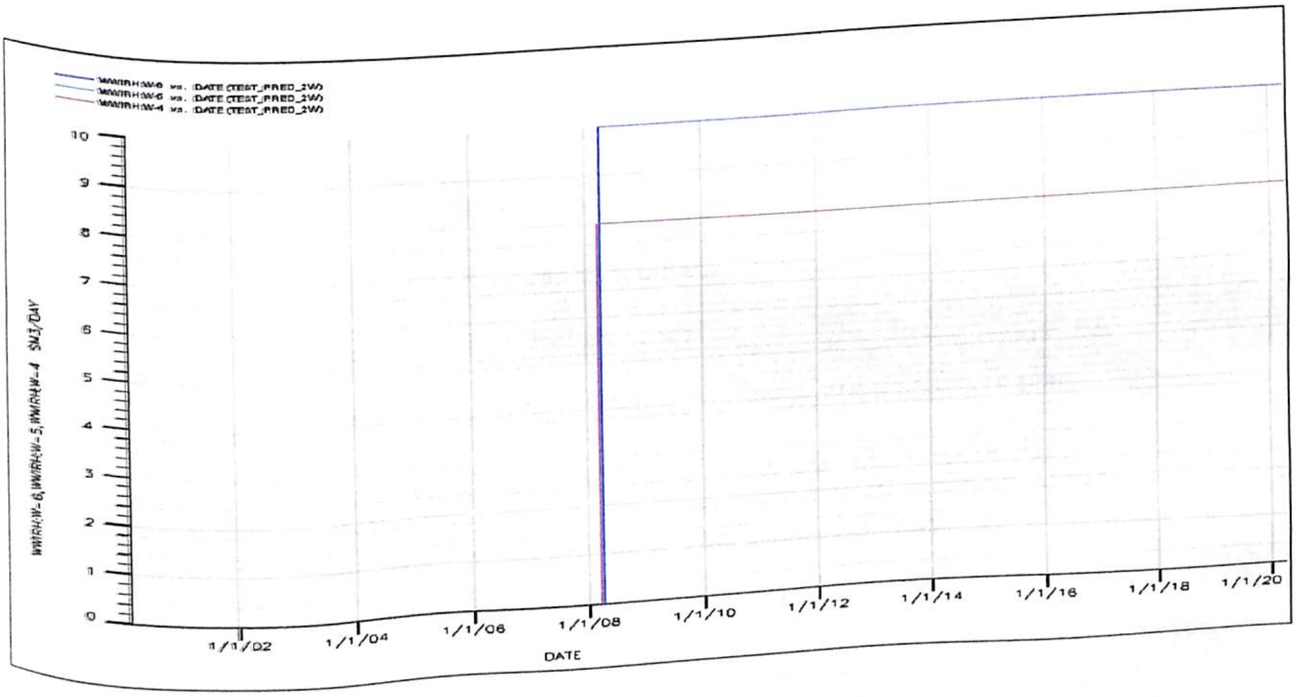

Figure-62, ECLIPSE, Schlumberger

This graph is showing the change in well wise water injection rate for each injection well with respect to time.

WATER FLOODING WITH 2 PREDICTION WELLS CONCLUSION

After applying the water flooding technique with two prediction wells the total oil and gas production has increased substantially which is economically viable and giving profits, but this production can further be increased by adding more prediction wells.

3.9 WATER FLOODING WITH 3 PREDICTION WELLS

After the substantial increase in production with 2 prediction wells with the water flooding technique with 3 water injection wells, this production can be further increased by adding one more prediction well. A prediction well N-4 is added in the grid 34-18-1 at a depth of2337.3m. The positions of the other prediction wells and injection wells were also altered to see the change in the production rate thus getting the maximum production from the field. The prediction run was done till 1st April 2020. The results obtained from the model and 3 prediction wells are:

Output File: PRT (Production Report)

```
:        FIELD TOTALS              :
:     PAV =     206.83  BARSA    :
:     PORV=     2046998.  RM3    :
:(PRESSURE IS WEIGHTED BY HYDROCARBON PORE VOLUME:
: PORE VOLUMES ARE TAKEN AT REFERENCE CONDITIONS):
:--------------- OIL  SM3 ---------------:-- WAT  SM3 -:--------------- GAS  SM3 ---------------:
         : LIQUID    VAPOUR    TOTAL :   TOTAL :   FREE    DISSOLVED    TOTAL :
:-----------------------:-------------------------------------------:---------------:-----------------------------------------:
:CURRENTLY IN PLACE    : 605037.              605037.:   1118779.:   15905105.   77713884.   93618989.:
:-----------------------:-------------------------------------------:---------------:-----------------------------------------:
```

:OUTFLOW THROUGH WELLS :		491004.:	540503. :			75496975.:
:ANALYTIC AQUIFER INFLUX :		:	1196613. :			:
:WELL MATERIAL BAL. ERROR:		0.:	0. :			-1.:
:FIELD MATERIAL BAL. ERROR:		-1.:	0. :			303.:
:ORIGINALLY IN PLACE	: 1096040.	1096040.:	462669. :	2319878.	166796389.	169116267.:

With *applying the water flooding technique with* 3 *injection* wells W-4, W-5 *and* W-6 *and* 3 prediction wells N-2, N-3 and N-4 with wells Y-12, Y-22, and Y-26 the total oil production in the prediction run has increased to 491004.m^3 of oil and 75496975m^3 of gas.

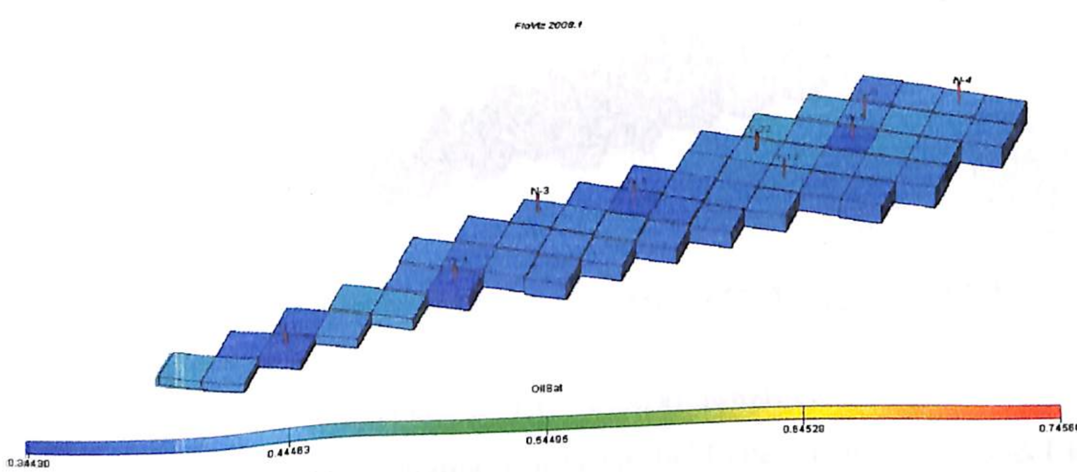

Figure-63, ECLIPSE, Schlumberger

This figure is showing the total oil production of the reservoir after running the model with water flooding pattern and 3 prediction wells.

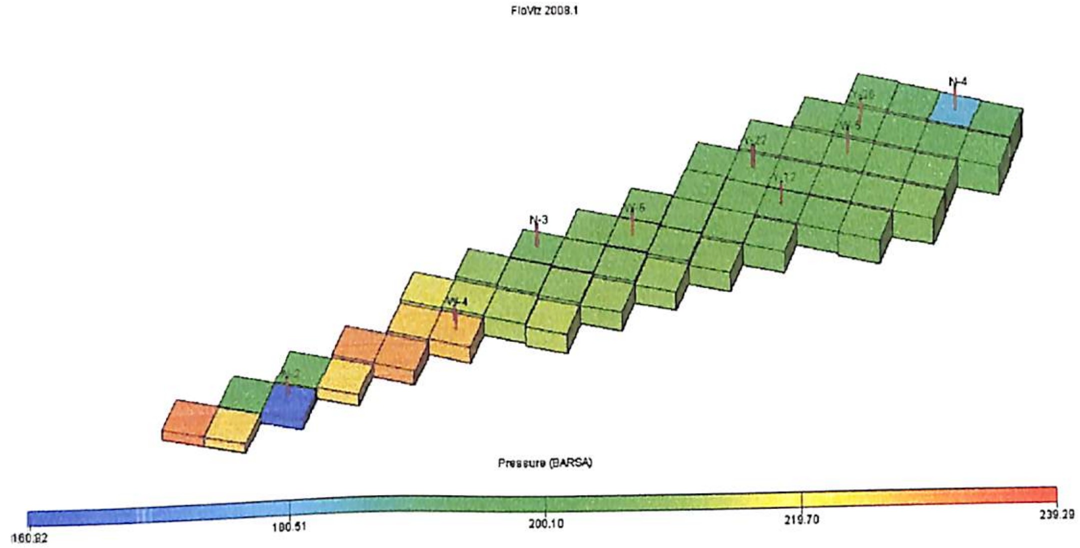

Figure-64, ECLIPSE, Schlumberger

The figure shows the reservoir pressure across the field after running the model with water flooding pattern and 3 prediction wells.

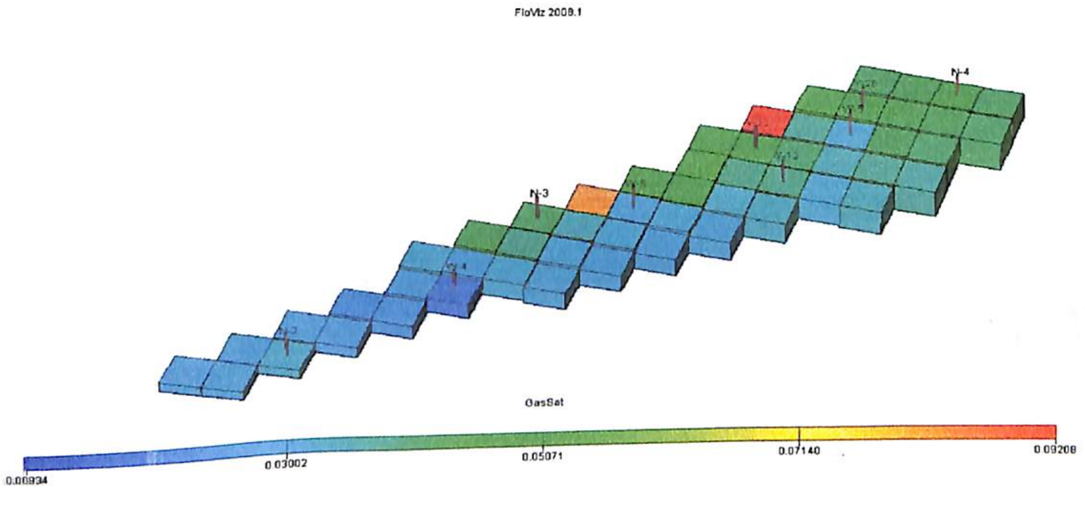

Figure-65, ECLIPSE, Schlumberger

The figure shows the total gas saturation across the field after running the model with water flooding pattern and 3 prediction wells.

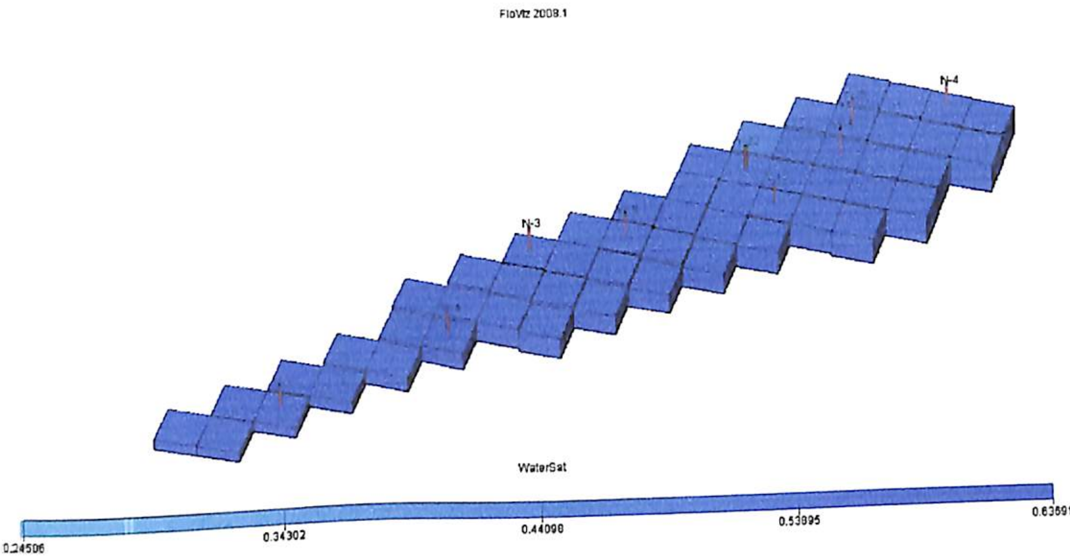

Figure-66, ECLIPSE, Schlumberger

The figure shows the total water saturation across the field after running the model with water flooding pattern and 3 prediction wells.

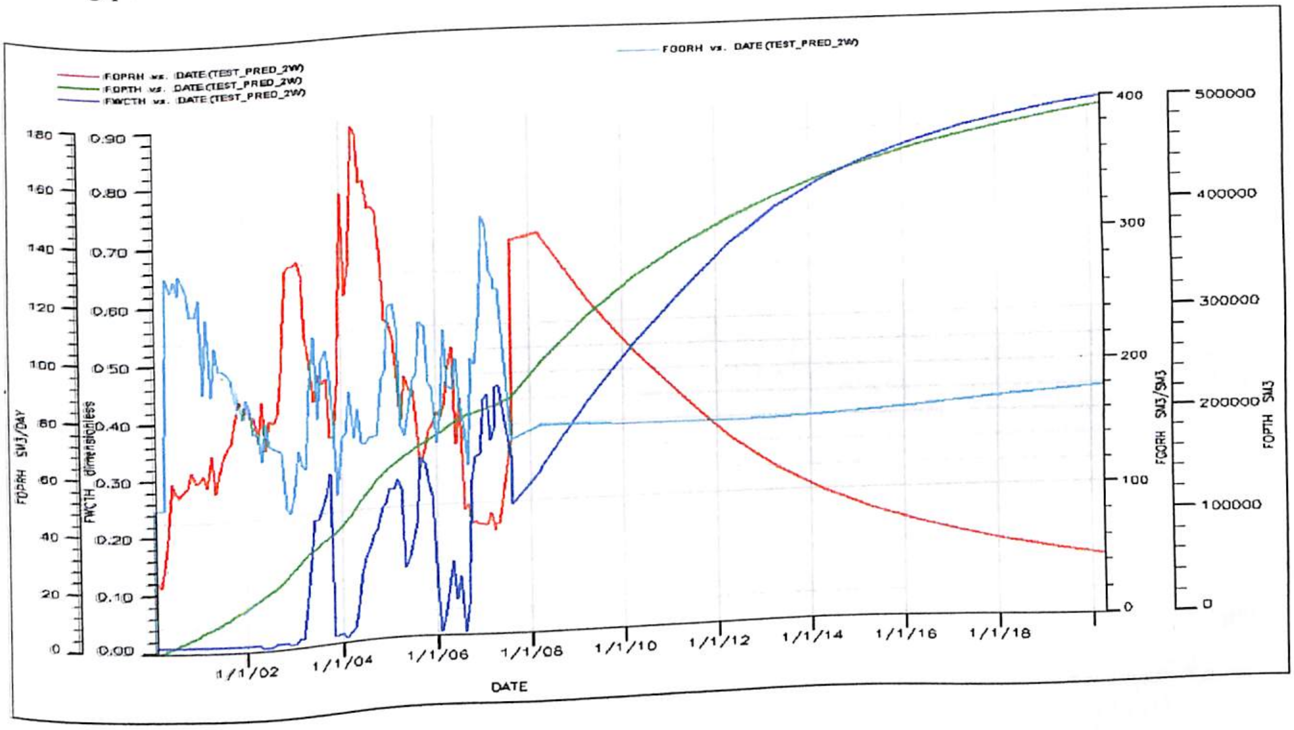

Figure-67, ECLIPSE, Schlumberger

The graph shows the change of field's oil production rate history, total oil production history, water cut history, GOR history with respect to time.

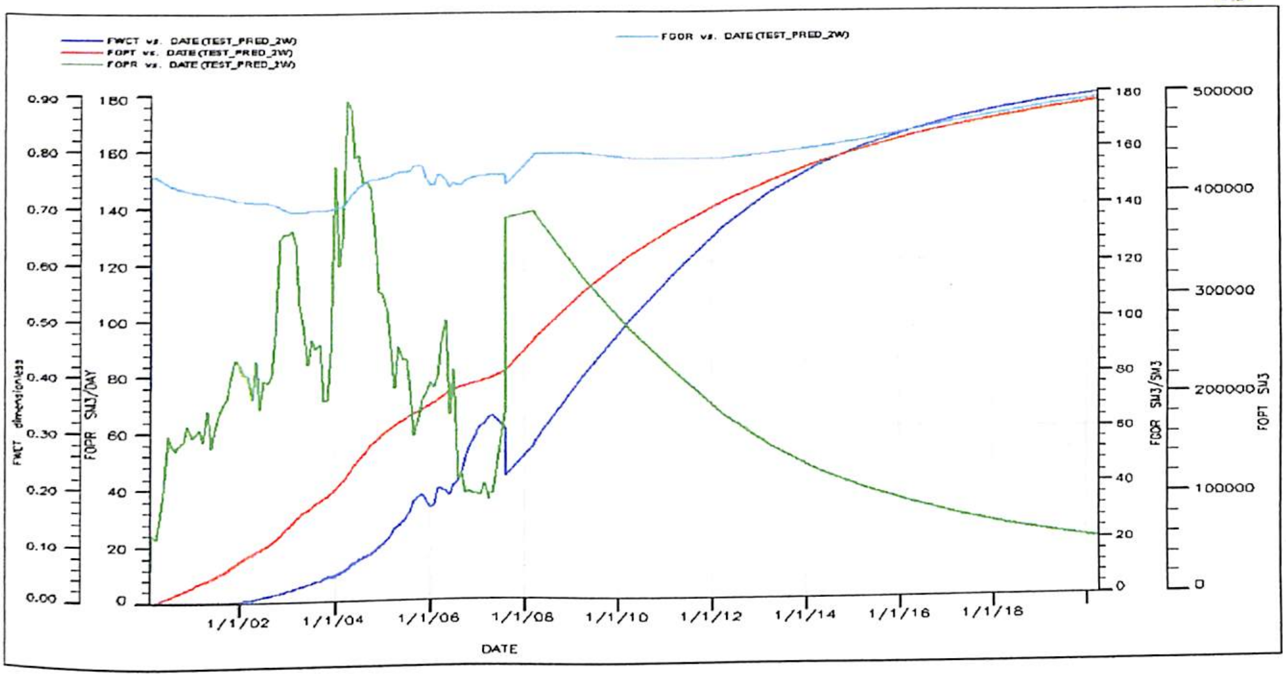

Figure-68, ECLIPSE, Schlumberger

The graph shows the change of field's oil production rate, total oil production, water cut, GOR with respect to time after the model has been run.

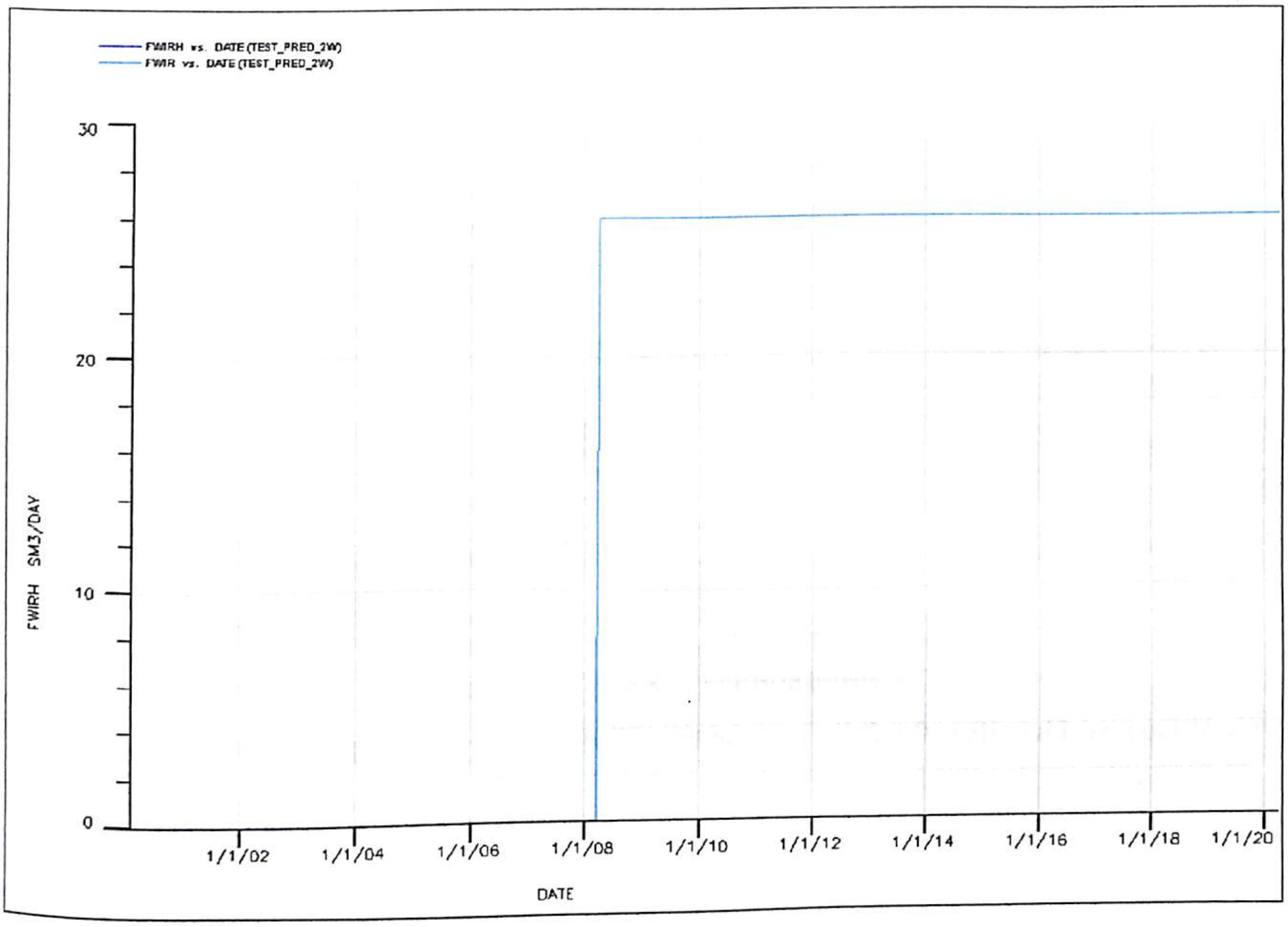

Figure-69, ECLIPSE, Schlumberger

The graph depicts the change in the field's water injection rate history and field's water injection rate with respect to time after the model has been run.

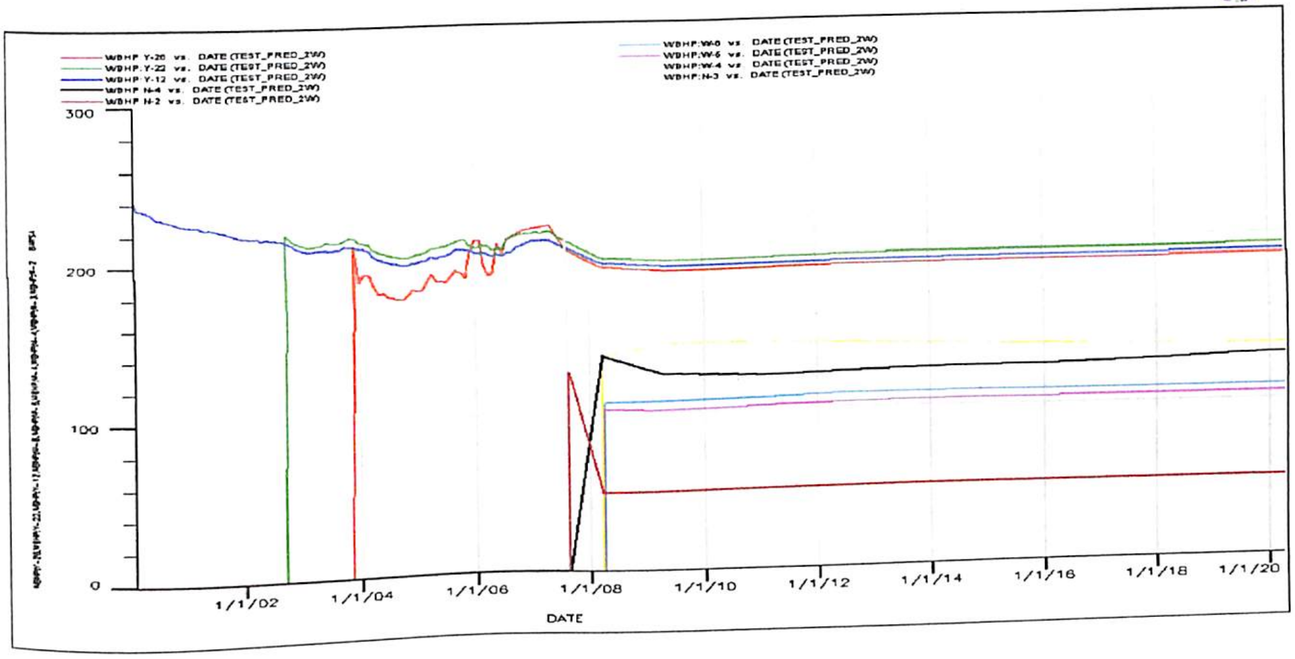

Figure-70, ECLIPSE, Schlumberger

The graph shows the change in the bottom hole pressures of all the 9 wells with respect to time after the model has been run.

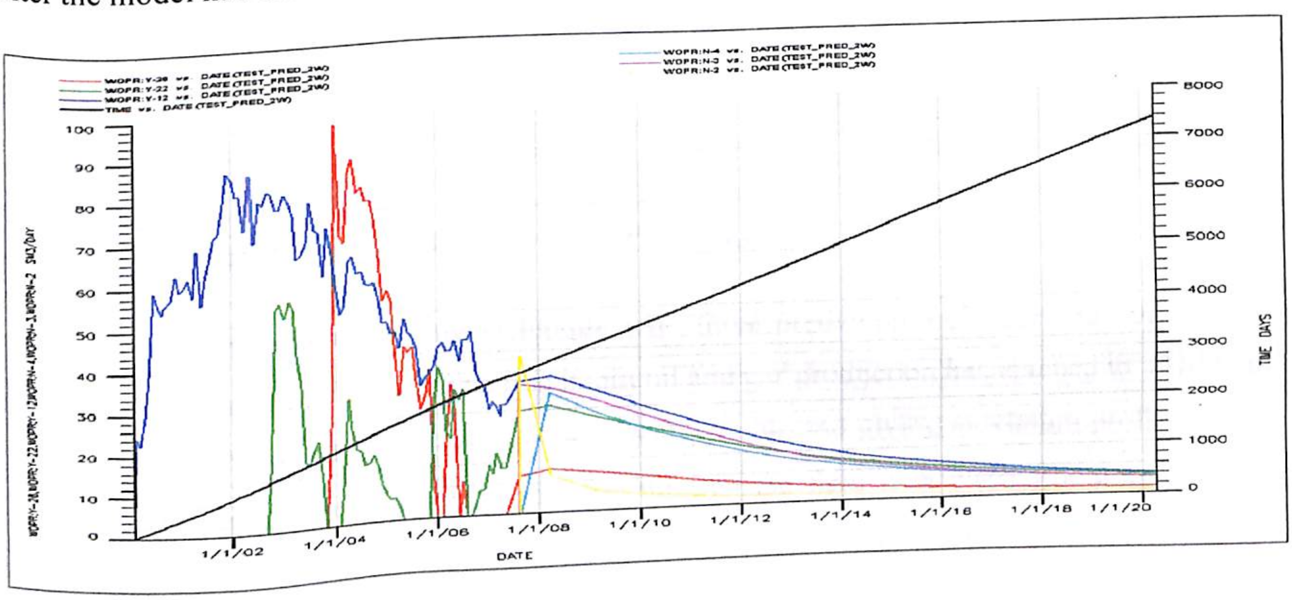

Figure-71, ECLIPSE, Schlumberger

This graph shows the change in oil production rate of each well N-2, N-3, N-4, Y-12, Y-22 and Y-26 with respect to time after the model has been run.

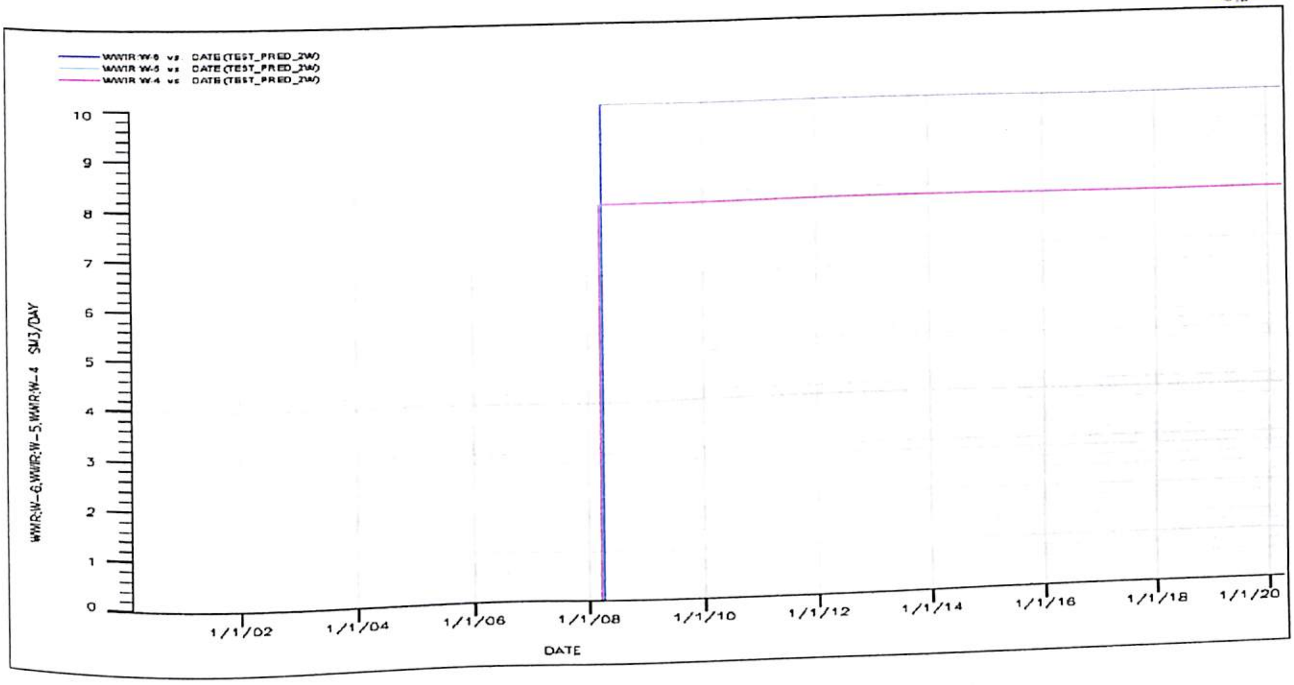

Figure-72, ECLIPSE, Schlumberger

This graph shows the change in water injection rate of all the injection wells W-4, W-5 and W-6 with respect to time after the model has been run.

WATER FLOODING WITH 3 PREDICTION WELLS CONCLUSION

After applying the water flooding technique with three prediction wells the total oil and gas production has increased a large. The maximum oil and gas production has reached to 491004.m^3 of oil and 75496975m^3 of gas which is economically viable and giving maximum profits. This is the maximum economically viable production through the field with water flooding technique which has been achieved. The results given shows the best position of the wells for the maximum production achieved.

CONCLUSION

The project on Performance Prediction of Water Flooded Reservoir using Eclipse Simulator helped me to understand the Schlumberger's ECLIPSE-100 simulator.

The project helped me understand how to simulate water flooded reservoir project and similarly how we can get results from simulation of any other project. Simulation does not mean varying any parameter any time but the change made must be justifiable. The project helped me to understand the various parameters that can be varied to optimize the results. It also helped to have a better understanding of the Reservoir Engineering as we could observe the effects of modified reservoir or operational parameters. These operational parameters were combined and used simultaneously to get better results.

The recovery of oil and gas has been achieved to approximately 50% from 20% by using the water flooding technique and the prediction wells. After the base case it was observed that the pressure and production rate was declining drastically and water cut was very less and GOR was very high. Material balance calculations suggested good aquifer support. So a Carter Tracy aquifer was added after which the cumulative oil production rates increased substantially and they nearly matched with the production history data. Then the history match was done after which future prediction can be done. After the history match it was observed that there was just a slight increase in the water cut in the model as compared to higher water cut of the production history data. GOR of the model were very high because it is very obvious as the pressure decreases, the GOR will rise. So to match all these parameters certain variations were made in thickness of the aquifer, angle of influence of the aquifer. After all these variations were done, satisfactory history match was achieved and it was found that the model data such as cumulative oil production, bottom hole pressures, water cut and GOR were near about matching with the production history data. Then two prediction wells were added and there was increase in the production rate but it can be further increased, so then one more prediction well was added making three prediction wells. After this the production further increased and was economically viable. Then for the further increased in production water flooding technique was applied to the reservoir. Firstly it was added with two prediction wells and the production increased drastically and it was economically viable this increase can be further increased by adding one more prediction well. By adding these three prediction wells with the water flooding pattern maximum production was achieved which was economically viable.

The injection rates and the position of the prediction wells was so selected after trials so that the maximum production is achieved and maximum profit was made which was economically viable.

ANNEXURE-1

INPUT DATA FILE

```
------------------------------------------------------------
--       SIMULATION DATA FILE
--          APRIL 2009
--
------------------------------------------------------------
RUNSPEC
--'HERE WE GIVE 'TITLE' 'PROBLEM DIMENSIONS' 'PHASES PRESENT' 'COMPONENTS' ETC'
TITLE
Reservoir simulation of Pool-A of XYZ field
SAVE
/
NOECHO
--'NO ECHO MAY BE USED TO REDUCE THE AMOUNT OF PRINTOUT FROM A RUN, OR TO AVOID
THE OUTPUT FROM LARGE FILES'
--NOSIM
--'TURN OFF SIMULATION'
DIMENS
--'SPECIFIES THE DIMENSIONS OF THE GRID'
 42 56 1 /
OIL
WATER
DISGAS
GAS
METRIC
UNIFOUT
--'INSTEAD OF PRODUCING SEPERATE RESTART AND SUMMARY FILES, THESE FILES ARE
AMALGAMATED INTO SINGLE FILE OF EACH TYPE'
UNIFIN
--'INPUT FILES ARE UNIFIED'

--SATOPTS
-- 'HYSTER'  /
```

```
EQLDIMS
--'DIMENSIONS OF EQUILIBRATION TABLES'
--'NO OF EQUILIBRATION REGIONS, NO.OF DEPTH NODES IN ANY TABLE OF PRESSURE V/S DEPTH,
MAX NO OF DEPTH NODES'
-- 2 100  10 /
  1 1  1 /
TABDIMS
--'TABLE DIMENSIONS'
--'NO OF SATURATION TABLES, NO OF PVT TABLES, MAX NO OF SATURATION NODES IN ANY
SATURATION TABLE, MAX NO OF PRESSURE NODES IN ANY PVT TABLE'
--'MAX NO OF FIP REGIONS, MAX NO OF RS NODES IN A LIVE OIL PVT TABLE'
--12  1  50 100  4  50 /
  1  1  35  20  1  20 /
REGDIMS
--'REGIONS DIMENSION DATA'
--'MAX NO OF FLUID IN PLACE TABLES, NO OF SETS OF FLUID IN PLACE REGIONS'
 --4  1  0  0  /
  1  1 /
WELLDIMS
--'WELL DIMENSION DATA'
--'MAX NO OF WELLS IN MODEL, MAX NO OF CONNECTIONS PER WELL, MAX NO OF GROUPS IN
THE MODEL, MAX NO OF WELLS IN ANY ONE GROUP'
 --50  10  10  20  /
  3 1 1 3 /
--LGR
--'SET OPTIONS FOR LOCAL GRID REFINEMENT'
--MAXLGR MAXCLS
--'MAX NO OF LGR IN THE MODEL, MAX NO OF CELLS IN EACH LGR'
-- 3 20000 /

--FAULTDIM
--'DIMENSIONS FOR FAULT DATA'
--77 /

AQUDIMS
--'DIMENSIONS FOR AQUIFER'
```

--'MAX NO OF LINES OF NUMERICAL AQUIFER DATA ENTERED IN KEYWORD AQUNUM IN GRID SECTION (MXNAQN),
-- THE MAX NO OF LINES OF CONNECTION DATA FOR NUMERICAL AQUIFER ENTERED IN KEYWORD AQUCON IN THE GRID SECTION (MXNAQC),
-- MAX NO OF INFLUENCE TABLES FOR CARTER TRACY AQUIFERS (NIFTBL),
-- MAX NO OF ROWS IN A CARTER TRACY AQUIFER INFLUENCE TABLES (NRIFTB),
-- MAX NO OF ANALYTIC AQUIFERS IN MODEL (NANAQU),
-- MAX NO GRID BLOCKS CONNECTED TO ANY SINGLE ANALYTIC AQUIFER (NCAMAX)'

```
 --0   0  2  50  2   1000 /
  0   0  1  36  1      10000 /
--EQLOPTS
--'OPTIONS FOR EQUILIBRATION'
--'QUIESC'  'THPRES'  'IRREVERS' /
--'ENABLES PRESSURE MODIFICATIONS TO ACHIEVE INITIAL QUIESCENCE', 'ENABLES THE THRESHOLD PRESSURE OPTION',
--'THRESHOLD PRESSURES MUST BE SPECIFIED FOR EACH DIRECTION'
--/
--AUTOREF
--'SET OPTIONS FOR AUTO REFINEMENT'
--'REFINEMENT FACTOR IN X-DIR (NX SHOULD BE AN ODD NO),
-- REFINEMENT FACTOR IN Y-DIR (NY SHOULD BE AN ODD NO),
-- REFINEMENT FACTOR IN Z-DIR (NZ SHOULD BE AN ODD NO)'
--1 1 5 /

NUPCOL
--'NO.OF ITERATIONS TO UPDATE WELL TARGETS'
 10 /

SMRYDIMS
--'MAX NO OF SUMMARY QUANTITIES'
 50000 /

START
 1 'FEB' 2000  /

NSTACK
--'LINEAR SOLVER STACK SIZE'
```

30 /

MESSAGES

--'RESETS MESSAGE PRINT AND STOP LIMITS'

--'IST NINE COMMANDS ARE SET TO DEFAULT, STOP LIMIT FOR SEVERITY 4 MESSAGES, STOP LIMIT FOR SEVERITY 5 MESSAGES'

9* 3000 10 /

--FMTOUT

--'INDICATES THAT OUTPUT FILES ARE FORMATTED'

--FMTIN

--'THIS INDICATES THAT INPUT FILES WHICH MAY EITHER BE FORMATTED OR UNFORMATTED, SUCH AS REASTART FILES ARE TO BE FORMATTED'

GRID ==

--'THIS DETERMINES THE BASIC GEOMETRY OF THE SIMULATION GRID AND VARIOUS ROCK PROPERTIES

--(POROSITY, ABSOLUTE PERMEABILITY, NET TO GROSS RATIO) IN EACH GRID CELL. FROM THIS INFORMATION THE PROGRAM CALCULATES THE

--GRID BLOCK PORE VOLUMES, MID POINT DEPTHS, AND INTER BLOCK TRANSMISSIBILITIES'

--INIT

--'REQUESTS OUTPUT OF AN INIT FILE'

--DXV

--'X-DIR GRID BLOCK SIZES'

```
--  100.000  100.000  100.000  100.000  100.000  100.000  100.000  100.000
--  100.000  100.000  100.000  100.000  100.000  100.000  100.000  100.000
--  100.000  100.000  100.000  100.000  100.000  100.000  100.000  100.000
--  100.000  100.000  100.000  100.000
--/
```

--DYV

--'Y-DIR GRID BLOCK SIZES'

```
--  100.000  100.000  100.000  100.000  100.000  100.000  100.000  100.000
--  100.000  100.000  100.000  100.000  100.000  100.000  100.000  100.000
```

```
--  100.000  100.000  100.000  100.000  100.000  100.000  100.000  100.000
--  100.000  100.000  100.000  100.000
--/

INCLUDE
TOP1_SAND_Y.INC
/

INCLUDE
GROSS_SAND_Y.INC
/

INCLUDE
NET_SAND_Y.INC
/

--ACTNUM
--'ACTIVE GRID BLOCK IDENTIFICATION'
INCLUDE
 NULL_SAND_Y.INC
/

--EQUALS
--'NAME OF ARRAY TO BE MODIFIED, CONSTT TO BE ASSIGNED TO THE ARRAY, IST BLOCK TO BE
MODIFIED ON X-AXIS (IX1), LAST BLOCK TO BE MODIFIED ON X-AXIS (IX2),
--SIMILARLY FOR Y AND Z (JY1  JY2  KZ1  KZ2)'
--'ACTNUM' 0 1 18 1 1 1 3 /

INCLUDE
 PHI_SAND_Y.INC
/

--EQUALS
-- 'PORO' 0.20 7 7 15 15 1 125 /
-- /
```

```
-- MULTIPLY
--'PORO' 0.97  1  23   1   22   1   125 /
-- /

--CARFIN
--'SPECIFIES A CARTESIAN LOCAL GRID REFINEMENT'
--NAME    I1 I2  J1 J2  K1 K2 NX NY NZ NWMAX--
--'NAME OF LOCAL GRID REFINEMENT, LOWER AND UPPER CO-ORDINATE OF BOX IN PARENT
GRID (I1 I2 J1 J2 K1 K2),
-- NO OF REFINED CELLS ALONG X,Y,Z DIRECTION (NX NY NZ), MAX NO OF WELLS THIS LOCAL
REFINED GRID WILL CONTAIN'
--'LBS' 1 28 1 28 1 3 28 28 15 20 /

--EQUALS

--  'PERMZ' 0.01     1 28  1 28  7 7 /
--  'PERMX' 20.0     1 28  1 28  6 6 /
--  'PERMY' 20.0     1 28  1 28  6 6 /


--ENDFIN
--'TERMINATES DATA FOR A LOCAL GRID REFINEMENT'

EQUALS
   'DX'   100.000   /
   'DY'   100.000   /
/
INCLUDE
 PERMX_SAND_Y.INC
/

--MULTFLT
--'MODIFIES THE TRANSMISSIBILITY ACROSS A NAMED FAULT'
--'FLT-1' 1.0


INIT
```

```
--'REQUESTS OUTPUT OF AN INIT FILE'
COPY
   'PERMX' 'PERMY' 1 42 1 56 1 1 /
   'PERMX' 'PERMZ' 1 42 1 56 1 1 /
/
--Changes in Permeabilities
MULTIPLY
'PERMZ' 0.10 1  42   1   56   1   1 /

/

--MINPV
--'SETS A MIN PORE VOL A CELL MUST HAVE TO BE ACTIVE'
-- 1500.0 /

--FLUXNUM
--'IDENTIFIES EXTENT OF EACH FLUX REGION'

--MULTIREG
--'MULTIPLIES AN ARRAY BY A CONSTT IN A GIVEN FLUX REGION'

--OLDTRAN
--'SPECIFIES BLOCK CENTRE TRANSMISSIBILITIES'

-- OUTPUT OF DX, DY, DZ, PERMX, PERMY, PERMZ, MULTZ, PORO AND TOPS DATA
-- IS REQUESTED, AND OF THE CALCULATED PORE VOLUMES AND X, Y AND Z
-- TRANSMISSIBILITIES
--RPTGRID
--'DX'  'DY'  'DZ'  'PERMX'  'PERMY'  'PERMZ'  'MULTZ'
--'PORO'  'TOPS'  'PORV'  'TRANX'  'TRANY'  'TRANZ'  /
--'TRANX'    'TRANY'  /
--/

EDIT  ==================================================
--'MODIFICATIONS TO CALCULATED PORE VALUES, GRID BLOCK CENTRE DEPTHS AND
TRANSMISSIBILITIES'
--EQUALS
```

--'TRANX' 0.0 2 2 19 19 1 125 /

--'TRANX' 'TRANY'
--/
--MULTIPLY
--'TRANZ' 0.01 19 21 4 6 12 25 / --G-27

--/
PROPS ==
--'TABLES OF PROPERTIES OF RESERVOIR ROCKS AND FLUIDS AS FUNCTIONS OF FLUID PRESSURES, SATURATIONS AND COMPOSITIONS
--(DENSITY, VISCOSITY, RELATIVE PERMEABILITY, CAPILLARY PRESSURE ETC.) CONTAINS THE EQUATION OF STATE DESCRIPTION IN COMPOSITIONAL RUNS'

--STONE2
--INCLUDE
-- relk2.inc /
-- relk_mod.inc /
--relk3.inc /

--SWOF
--'WATER/OIL SATURATION FUNCTIONS V/S WATER SATURATION'
-- Drainage Curve (swi=0.40) RT=1

--Sw	Krw	Krow	Pcow
--0.40	0.00	1.00	0.00
--0.44	0.01	0.69	0.00
--0.47	0.02	0.50	0.00
--0.51	0.03	0.34	0.00
--0.55	0.05	0.23	0.00
--0.59	0.07	0.13	0.00
--0.62	0.10	0.06	0.00
--0.66	0.160	0.03	0.00
--0.70	0.220	0.02	0.00
--0.73	0.290	0.01	0.00
--0.77	0.350	0.00	0.00
--1.00	1.000	0.00	0.00 /

--SLGOF

--'GAS/OIL SATURATION FUNCTIONS VERSUS LIQUID SATURATION'

-- Drainage Curve (swi=0.40) RT=1

--Sl	Krg	Krog	Pcow
--0.63	0.52	0.00	0.00
--0.70	0.38	0.007	0.00
--0.75	0.29	0.01	0.00
--0.80	0.20	0.04	0.00
--0.85	0.13	0.11	0.00
--0.90	0.07	0.25	0.00
--0.93	0.04	0.39	0.00
--0.95	0.02	0.52	0.00
--0.96	0.02	0.59	0.00
--0.97	0.01	0.68	0.00
--0.98	0.00	0.77	0.00
--1.00	0.00	1.00	0.00 /

SWOF

-- Sw	krw	krow	Pcow
0.230000	0.00000	0.800000	0.00
0.246061	8.344519E-06	0.729452	0.00
0.262121	6.676158E-05	0.663178	0.00
0.278182	2.253311E-04	0.601045	0.00
0.294242	5.341361E-04	0.542920	0.00
0.310303	1.043262E-03	0.488668	0.00
0.326364	1.802795E-03	0.438156	0.00
0.342424	2.862823E-03	0.391252	0.00
0.358485	4.273436E-03	0.347820	0.00
0.374545	6.084722E-03	0.307727	0.00
0.390606	8.346773E-03	0.270840	0.00
0.406667	1.110968E-02	0.237026	0.00
0.422727	1.442353E-02	0.206150	0.00
0.438788	1.833843E-02	0.178079	0.00
0.454848	2.290445E-02	0.152680	0.00
0.470909	2.817170E-02	0.129818	0.00
0.486970	3.419027E-02	0.109361	0.00
0.503030	4.101025E-02	9.117402E-02	0.00

0.519091	4.868174E-02	7.512451E-02	0.00
0.535152	5.725483E-02	6.107851E-02	0.00
0.551212	6.677962E-02	4.890245E-02	0.00
0.567273	7.730619E-02	3.846274E-02	0.00
0.583333	8.888466E-02	2.962580E-02	0.00
0.599394	0.101565	2.225805E-02	0.00
0.615455	0.115398	1.622592E-02	0.00
0.631515	0.130432	1.139582E-02	0.00
0.647576	0.146719	7.634191E-03	0.00
0.663636	0.164309	4.807450E-03	0.00
0.679697	0.183250	2.782030E-03	0.00
0.695758	0.203595	1.424362E-03	0.00
0.711818	0.225392	6.008823E-04	0.00
0.727879	0.248692	1.780307E-04	0.00
0.743939	0.273544	2.225202E-05	0.00
0.760000	0.300000	0.00000	0.00 /

SLGOF

-- Sl	krg	krog	Pcog
0.47	0.8	0	0.00
0.502188	0.65918	0.000184363	0.00
0.534375	0.535938	0.0014749	0.00
0.566562	0.429102	0.0049778	0.00
0.59875	0.3375	0.0117992	0.00
0.630937	0.259961	0.0230454	0.00
0.663125	0.195313	0.0398224	0.00
0.695313	0.142383	0.0632365	0.00
0.7275	0.1	0.0943939	0.00
0.759688	0.0669922	0.134401	0.00
0.791875	0.0421875	0.184363	0.00
0.824062	0.0244141	0.245387	0.00
0.85625	0.0125	0.318579	0.00
0.888437	0.00527344	0.405046	0.00
0.920625	0.0015625	0.505892	0.00
0.952812	0.000195313	0.622225	0.00
0.985	0	0.755151	0.00
0.99	0	0.77736	0.00

```
0.995        0        0.8    0.00 /

INCLUDE
 SOIL_SAND_Y.INC
/

--      PVT Properties of Water
--      Ref. Press  Ref FVF  Comp. Water  Ref. Visc        Viscosibility
PVTW
     242.0     1.0175    4.41e-05    0.5341     0
/
--      Rock Compressibility
--      Ref. Press   Compressibility
ROCK
--      Effect of Rock compressibility on Performance
     241.9      4.8E-05    /

--      Surface densities of Reservoir fluid
--      Oil      Water    Gas
DENSITY
    920.0    1030    0.001844   /

PVDG

--      PVT properties of Dry Gas (No Vapourised Oil)
--      Press.      Bg          Visc. Gas
        45.08      0.025554     0.01327
        64.69      0.01700      0.01400
        84.31      0.012499     0.01494
       103.92      0.009782     0.01610
       123.54      0.008020     0.01747
       143.15      0.006827     0.01901
       162.77      0.005993     0.02066
       182.38      0.005392     0.02236
       202.00      0.004945     0.02407
       221.62      0.004605     0.02575
       241.62      0.004405     0.02675 /
```

```
--PVT properties of Live Oil (With dissolved gas)

PVTO
--- Rs   Poil   Bo   Uo
  20.86   45.08   1.1018   1.7621/
  32.33   64.69   1.1276   1.5400/
  44.53   84.31   1.1559   1.3523/
  57.31   103.92   1.1862   1.1950/
  70.59   123.54   1.2185   1.0632/
  84.30   143.15   1.2526   0.9526/
  98.40   162.77   1.2882   0.8593/
  112.85   182.38   1.3254   0.7801/
  127.62   202.00   1.3641   0.7124/
  140.00   221.62   1.3959   0.6675
           241.23   1.3901   1.6893/

/

-- OUTPUT CONTROLS FOR PROPS DATA
RPTPROPS
'PVDG' 'PVTO' /

--/

-------------- Finite aquifer with bounded exterior boundary -----------
--AQUTAB
-- 0.001   0.0352
-- 0.004   0.0694
-- 0.006   0.0845
-- 0.009   0.1028
-- 0.01    0.1081
-- 0.02    0.1503
-- 0.05    0.2301
-- 0.10    0.3144
-- 0.20    0.4241
```

```
-- 0.40    0.5645
-- 0.52    0.6270
-- 0.60    0.6620
-- 0.70    0.703
-- 0.80    0.740
-- 0.90    0.776
-- 1.00    0.806
-- 1.40    0.920
-- 2.00    1.076
-- 3.00    1.328
-- 4.00    1.578
-- 5.00    1.828
--/


----------------------------------------------------------
REGIONS
----------------------------------------------------------
--'SPLITS COMPUTATIONAL GRIDS INTO REGIONS FOR CALCULATION OF PVT PROPERTIES,
SATURATION PROPERTIES INITIAL CONDNS, FLUIDS IN PLACE ETC.)
--INCLUDE
--SATNUM.INC
--EQUALS
--'SATNUM' 1 15 15 11 11 2 2 /
--/

EQLNUM
--'EQUILIBRATION REGION NUMBERS'
 2352*1 /

FIPNUM
--'FLUID IN PLACE REGION NUMBERS'
 2352*1 /


--RPTREGS
--'CONTROLS ON OUTPUT FROM REGIONS SECTION'
```

```
-- 'PVTNUM' 'SATNUM' 'EQLNUM' 'FIPNUM' /
--/
---------------------------------------------------------------------------
SOLUTION ==================================================================
-------- THE SOLUTION SECTION DEFINES THE INITIAL STATE OF THE SOLUTION
---------------------------------------------------------------------------

-- VARIATION OF INITIAL RS WITH DEPTH
--  DEPTH   RS
RSVD
--'RS V/S DEPTH TABLES FOR EQUILIBRATION'
 1500   140
 2420   140 /

--RPTSOL
--'CONTROLS ON OUTPUT FROM SOLUTION SECTION'
--'PRES'  'RS' /
-- 410.24  93.69 /
--'SOIL' /
--/
--SOLUTION

--Equilibrium data

INCLUDE
 EQUIL_SAND_Y.INC

--RESTART
-- SAFRAILGR2 57 /
/

---------------------------------------------------------------------------
-- aquifer definition
--AQUCT
--'SPECIFIES THE PROPERTY DATA FOR CARTER TRACY AQUIFERS'
--1 2726.5 440.0 150.0 0.20 0.00005 2400.0 6.0 180.0 1 2 /
--1  3886.0  430.4  10.0 0.11 0.00005 1177.0 5.0 180.0 1 1 /
```

```
--1 3973.0 270.5 10.0 0.10 0.00005 1646.0 38.0 180.0 1 1 /
--1 4060.5 398.2 10.0 0.11 0.00005 1400.0 3.0 180.0 1 1 /

---AQUANCON
--'SPECIFIES CONNECTION DATA FOR ANALYTIC AQUIFERS'
---1 8 18 1 2 1 4 'J-' 1.0 /
---1 32 32 10 16 2 4 'I+' 1.0 /

SUMMARY ==============================================================
-------- THIS SECTION SPECIFIES DATA TO BE WRITTEN TO THE SUMMARY FILES
-------- AND WHICH MAY LATER BE USED WITH THE ECLIPSE GRAPHICS PACKAGE
------------------------------------------------------------------------
--RUNSUM
--SUMMARY
SEPARATE
RPTONLY
--FIELD OIL PRODUCTION
FOPR
FOPRH
FWIT
FWITH
FWIR
FWIRH
FGOR
FGORH
FLPR
FLPT
FLPRH
FLPTH
FOPT
FOPTH
FWPR
FWPRH
FGPR
FGPRH
FWPT
FWPTH
```

FGPT
FGPTH
FWCT
FWCTH
FPR
FOE
FMWPR
FMWIN

WOPR
/
WOPRH
/
WBP9
/
WBHPH
/
WGOR
/
WGORH
/
WWCT
/
WWCTH
/
WWIR
/
WWIRH
/
WBHP
/
WLPR
/
WLPT
/
WLPRH
/

WLPTH
/
WOPT
/
WOPTH
/
WWIR
/
WWIRH
/
WWIT
/
WWITH
/
ROPR
/
ROPT
/
ROP
/
ROE
/
ROEW
/
RRS
/
RPR
/
RWIT
/
RWIR
/
RWPR
/
RWPT
/

```
SCHEDULE ==============================================================
-------- THE SCHEDULE SECTION DEFINES THE OPERATIONS TO BE SIMULATED
--------------------------------------------------------------------
RPTSCHED
--'CONTROLS ON OUTPUT FROM SCHEDULE SECTION'
--- 'PRES' 'SOIL' 'SWAT'
-- 'PB' 'SGAS' 'RS'
 'WELLS' '=' 5  'FIP' '=' 3 /

RPTRST
--'CONTROLS ON OUTPUT FROM RESTART FILE'
 'BASIC=3' 'FREQ=1' /

DRSDT
--'MAX RATE OF INCREASE OF SOLUTION GOR'
0.0
/
--GRUPTREE

-------------schedule file -------------------
INCLUDE
SAND_Y.SCH
/
---------------------------------
END
```

This is the basic input data file which is used for all the cases with certain changes for each case.

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2. Craft, B.C Hawkins, M.F; " Petroleum Reservoir Engineering", London: Constable and Company Limited, Copyright 1959.
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4. Franchi, John R; Principles of "Applied Reservoir Simulation", Second Edition, Huston: Gulf Professional Publishing, 2001.
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