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RWE Dea AG

Master Thesis

Usage of Streamline Simulation to Improve Prediction and Water Flood of Dogger Beta Reservoir

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Affidavit

I declare in Lieu of oath, that I wrote this thesis and performed the associated research myself, using only literature cited in this volume.

Ahmed Swedan

March 2008

Abstract

Oil field development strategies are progressively changing by introducing new concepts, tools and technology. In the field of reservoir simulation the *Streamline simulation* has made significant progress in recent years, which increases demand to implement the streamline-based flow simulators in reservoir management workflow. The technique is based on the concept of transporting fluids along natural paths, which are defined by streamlines, rather than between explicit grid blocks.

Streamline simulation provides new engineering information which is very useful for making better development and prediction plans. This thesis presents streamline simulation optimization of the existing prediction plan based on Mittelplate-Dogger Beta reservoir. Mittelplate is the largest German oil reservoir to date and produces the most oil within the country.

In this study using the new information from streamline simulation, a concise water flood plan for Mittelplate-Dogger Beta reservoir was provided. This plan provides methods to improve injection efficiency and increase oil production. The process nicely integrates into the current simulation methodology as well as provides an additional tool for the reservoir engineer.

Kurzfassung

Ölfelderentwicklungsstrategien ändern sich zunehmend durch die Einführung von neuen Konzepten, Werkzeugen und Technologien. In den letzten Jahren hat die Streamline Simulation in der Lagerstättensimulation große Fortschritte gemacht. Dies erweitert die Anwendung der Streamline Simulation im Lagerstätten-Management enorm. Das Verfahren basiert auf dem Konzept des Flüssigkeitstransportes entlang natürlicher Pfade, die von Streamlines definiert werden, und nicht wie bisher zwischen Gitterblöcken.

Streamline Simulation ermöglicht den Zugriff auf neue Informationen und verbessert die Entwicklung von Voraussageplänen. Diese Arbeit behandelt Sreamline Simulations-Optimierung von existierenden Voraussagenpläne der Mittelplatte-Dogger Beta Lagerstätte. Mittelplatte ist heute die größte deutsche Öllagerstätte.

In dieser Studie wurden die neuesten Informationen für die Streamline Simulation verwendet, um einen präzisen Wasserflutplan für die Mittelplatte-Dogger Beta Lagerstätte zu erstellen. Sie zeigt Möglichkeiten zur Verbesserung der Erdölproduktion auf. Die angewandten Methoden integrieren sich problemlos in die vorhandenen Simulationsmethoden und liefern ein zusätzliches Werkzeug für Lagerstätteningenieure.

Dedication

This work is dedicated with love to

My beloved parents my adored mother *Nabela* and dear father *Zayed*
For their care, support, and sustained prayers

My forever love, *Enas* for her continuous patience, encouragement, and prayers
My lovely daughter *Asmah* who had born when I started my thesis work

My precious brothers and sisters, *Amal, Kassem, Osama, Akrem, Eman, and Enas*
My family in-law *Dr. Musa* and my mother *Easha*
My Uncle *Monsef Swedan*
My aunt *Kefaya*
All dear Friends

Above all, this work is offered to Allah for His greater glory.

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Further, I would like to thank my sponsor company, NOC in associated with Enioil, for giving me the opportunity to pursue my master's degree.

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Nomenclature

u_t = The total phase velocity.

D = The depth below datum.

λ_t = Total mobility

λ_g =Total gravity mobility

k_{rj} =The relative permeability of Phase j,

μ_j = Phase viscosity,

ρ_j = Phase density,

g = Gravity acceleration constant,

n_p = Number of phases present.

$\vec{u}_t$ = The total velocity

v_{xo} = The x velocity at the origin location $x=x_o$

g_x = Velocity gradient in the x direction:

x_i = the inlet position

x_e = The exit x coordinate

Δt= Time step

v_i = The inlet velocity

v_0 = The velocity at the origin.

τ = Time of flight

G_j = Gravity

∂t_c = Convective step

∂t_c = Gravity step

CFL =Courant-Freidrichs-Lewy, stability requirement

$f_w^{'}$ = The Buckley-Leverett speed of the saturation S_w

IE = Injection Efficiency

WAF= Well allocation factor

e_{wp} = Injection/production pairs

e_i = Injection Efficiency for well i

$\bar{e}$ = Average Field Injection Efficiency

w_i = Increase or decrease in weight

$w_{\max}$ = Maximum weight at $e_{\max}$

$e_{\max}$ = Upper limit of Injection Efficiency

$w_{\min}$ = Minimum weight at $e_{\min}$

$e_{\min}$ = Lower limit of Injection Efficiency

α = Exponent

Chapter One

1 Introduction

1.1 Streamlines Technology

The use of streamlines technology as a complementary tool to finite difference is receiving renewed attention in the reservoir simulation over the past few years.

Reservoir simulation using streamlines is not a minor modification of current finite difference approaches, but is a radical shift in methodology. The fundamental difference is in how fluid transport is modelled. In finite-difference, fluid move between explicit grid blocks, whereas in the streamline method, fluids are moved along streamline grid that may be dynamically changing at each time step, and is decoupled from the underlying grid on which the pressure solution is obtained. By decoupling transport from the underlying grid, we have noted large speed-up factors, minimization of numerical diffusion, and reduced grid orientation effect.

The approach is based on the usage of pressure solution to calculate the pressure gradients and streamlines, then calculate the saturation along the streamlines either by Buckley-Leverett approach or by a series of one-dimensional model. The governing equations are discretized and solved on separate structures, pressure by grid-blocks and saturation by streamline. As long as the flow path does not change dramatically in time, longer timestep can be taken. Therefore, it leads the model to contain a finer resolution and more cells can be solved in shorter timeframe and longer timestep without the restriction caused by CFL (Courant-Fredrich-Levy) condition. This allows decisions to be made on a daily basis, impossible for conventional simulation.

One of the key strengths of streamline simulation, from a fluid flow perspective, is its ability to represent more accurately the transport phenomena taking place within the reservoir. From a computational perspective, the technique allows much larger timestep than finite difference models, thus speeding up the calculations. The benefits of a decoupled solution and the solution of several 1D problems rather than one large 3D problem, ensures that the simulation always scales linearly with the size of model making it highly suitable for flow simulations on geological scale grids. Streamlines and their properties, particularly the time-of-flight, have many useful applications unique to streamline simulation.

Recent advantages of streamline-based flow simulator have overcome the many of the limitation of previous streamline and streamtube method, allows the detailed tracking of fluid movements as well as enhanced visualisation and analysis of fluid flows.

Modern streamline-based simulation can now properly account for true 3D (Three Dimension) displacements, multi-phase gravity effects, and changing well conditions. Streamline simulation can routinely generate multi-million grid block flow, and rank multiple earth models in an efficient way and acceptable runtimes. Streamline simulation now can be implant in a wild range of reservoir engineering application. Particularly effective in solving fine scale, geologically complex and heterogeneous systems, and recent water flooding studies are frequently carried out using streamline simulation.

Not only the efficiency and the shorter runtime make the technology as a new way of thinking, but also the new information that can be obtained. For instance, well conductivity, derange volume, and well allocation factor, at any instant time, SL offer a snapshot of how reservoir is connected and how much fluid is allocated between injection/producer pairs. This additional information is clearly quantifying the relationship of the injector to producer. Moreover, allows an easy identification of wells or regions that required modification to achieve the optimum case of production, things that can not be provided from conventional simulation model. Conversely, the streamline simulation is not the best option for all cases. It is not well suited to complex physics displacements such as high compressibility, capillary effects, complicated phase behaviour.

1.2 Objective of the Study

Field development strategy has been increasingly dependent on the results of reservoir simulation models, which are providing the basis for reservoir management decisions. Reservoir studies demand fast and efficient results to make rapid investment strategy with an adequate performance of accuracy and elapsed time. Streamline simulation substantially has made a significant progress over the last decade, which allows streamline-based flow simulators to be applied in the reservoir engineering workflow, and achieved the proposed requirements.

The primary objective of the thesis project was to perform streamline-based simulation for Mittelplate-Dogger Beta reservoir using ForntSim reservoir simulator. The target of using such a simulator was to highlight the advantages and disadvantages of the streamline approach compared to a traditional finite-difference simulation. In addition, figure out the limitations of both model approaches in term of production/injection optimization and reservoir management.

In term of water injection management prospective, the main objective was provided and obtain waterflood prediction plan for Mittelplate-Dogger Beta reservoir. Specifically, improve the Injection Efficiency of Mittelplate-Dogger Beta in order to maintaining or even increasing oil production target by best utilization of water injection. Finally, set up a methodology for waterflooding management using the streamline simulation approach.

1.3 Introduction of Mittelplate oil field

Mittelplate oil field is located in the national park called Wattenmeer off the coast of the German state of Schleswig-Holstein. The field was discovered in 1955, and considered as the largest German reserves and most productive oil field. Mittelplate has been developed by RWE Dea AG as an operator and Wintershall AG, each with 50% ownership. The field has been producing since October 1987 from four geological horizons of Jurassic and Cretaceous age. The horizons are primarily deltaic sand deposits. The rock and fluid properties of the Mittelplate reservoirs are shown below in table1.1.

Reservoir properties	**Dogger Beta**	**Dogger Gamma**	**Dogger Delta**	**Dogger Epsilon**
Porosity [%]	15 - 24	22 - 25	17 - 27	22 - 25
Permeability [md]	200 - 3000	50 - 500	2000 - 10000	2000 - 10000
Depth [m]	2400 - 2975	1900 - 2222	1900 - 2222	1900 - 2222
Net reservoir thickness [m]	5-17	30 - 50	40 - 60	20 - 30
Oil Density [kg/m^3]	--	--	913	913
Water Density [kg/m^3]	1049	1049	1049	1049
Oil Water Contact @ TVD [m]	2975	2222	2222	2222

Table 1-1: Reservoir properties of Mittelplate oil field

The reservoir is associated with a large salt dome, and classified as a structural trap. The estimated total recoverable reserves are about 53 million metric tons (mt). Mittelplate oil field was producing from an offshore platform until May 2000. By extended-reach technology, well drilled over distances of 8000 and up to more than 9000 meters (among the world's longest extended-reach wells) have enabled additional onshore operation of the field and increased the annual production to over two million mt.[1-2]

This study was conducted for RWE Dea on Dogger Beta reservoir of Mittelplate oil field, which is currently producing from 12 wells, three of which are water injectors. Injectors are playing an important role of the pressure support and improve the sweeping efficacy. The reservoir has an edge water drive aquifer which provides an additional pressure support. The high productivity is enhanced by injection wells to maintain the reservoir pressure. Electrical submersible pumps (ESP's) have been installed to increase well production capacity.

Figure 1.1 is the structural map of Dogger Beta reservoir-Mittelplate oil field. Recent reservoir simulation study has been done; carried out with a history match using commercial finite difference simulator ECLIPSE, to improve the understanding of fluid flow.

Our purpose is to model the 13 wells with the same data set using streamline based flow simulator; FrontSim, and compare the result of both models approach. Moreover, run the predication case with more emphasis on the optimization of production profile and waterflood management.

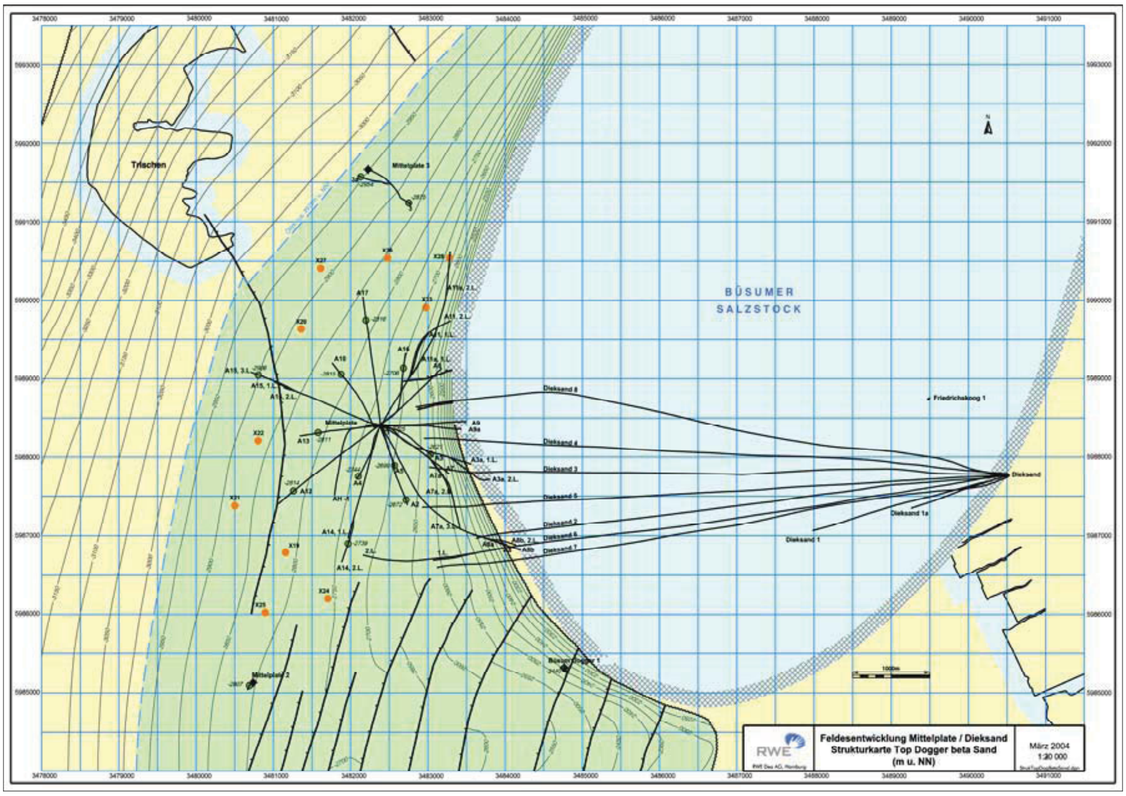


Figure 1.1: Structural map of Dogger Beta reservoir-Mittelplate oil field

Currently, a new 70 meter high drilling rig is being built on the island. It is one of the most modern rigs in operation in Europe and is capable of sinking bore holes within a radius of up to 6000 meters. The previous radius was up to 2000 meters. This way the oil fields of Mittelplate Island can be better explored.

1.4 Project Methodology

In order to achieve the objectives of the study, we have implemented two main steps that will declare the workflow of the study.

1- Compare the streamline result with the conventional finite difference simulation

First step is set up the streamline simulation model for production history, which has been beginning in 10th October 1987 and end up in 1st July 2007, using FrontSim simulator. The purpose of build up such a model is compared the result of the streamline approach with the finite difference simulation. RWE Dea had already completed a history-matched model using a commercial finite difference simulator Eclipse. The comparison will include the field oil production rate, field cumulative oil production rate, the field pressure decline, field water production rate, field water cut in term of water breakthrough. Nevertheless, the comparison will include also the individual production and the injection wells parameters. However, this investigation will be a clear guidance to extend the knowledge of the advantage and disadvantage of different approach. Additionally, defined the most important factors, which affecting the result of both models approach.

2- Prediction Optimization

Streamline based flow simulation is a unique application, in terms of provided new engineering information. Streamline simulation allow to quantify the amount of injected and produced fluids between well pairs via dynamic well allocation factor (WAF).

WAF is not a guessing quantity. It is calculated from the streamline, which contain all the geological information and the historical data. In addition, WAF provides the information of haw the injection/producer pairs are connected up. Armed with these unique data, it is possible to define the injection efficiency for each injector and/or for injection/producer pairs in a simulation model. Injection Efficiency can be defined as the ratio of injected water to the oil produced at offset wells. With injection efficiencies known across the field for each injector, water can be reallocated from low-efficiency to high efficiency wells, thereby optimizing production for each metric cube of water injected.

The basic idea behind the proposed water flood management can be implemented by promote water in the connections that have high efficiency and demote the connections that have low efficiency.

Chapter Two

2 Literature Review

2.1 Brief Historical Review

Using streamlines for modelling subsurface flow has been in the literature for a number of decades, dating back to Muskat and Wyckoff's paper[3], 1934. The main motivation for using streamlines to solve for the fluid flow is the computational speed, but it is also attractive that the streamlines forms a natural grid for the transport equation where a choice of numerical method can be applied. In the 1990's, there were a number of new developments for streamline simulation that brought it back into the limelight. Modern streamline simulators now include 3D irregular and faulted grids, changing well controls, compressibility, and gravity segregation as well as multi-component, multiphase flow.

As matter of fact, the current 3D streamline simulation technology originated from four previous methods to model convection-dominated flow in the reservoir:

1. Line Source/Sink Solutions: These methods have been widely used by the petroleum industry. An analytic solution has been used to solve the pressure and velocity distribution in the reservoir. The primary limitation of these methods is the requirement for homogeneous properties and constant reservoir thickness.

2. Streamtubes: Requires tracking of tube geometry. These methods are more general and have been applied successfully for field-scale modelling of waterflooding and miscible flooding[5]. The flow domain is divided into a number of streamtubes and fluid-saturation calculations are performed along these streamtubes. However, the need to keep track of the streamtube geometries can become quite cumbersome in three dimensions. Thus, the application of streamtubes is just for 2D problems or some hybrid approach. In fact, it is difficult to extend the solution to 3D.

3. Particle Tracking: These methods have been used by the oil industry to model tracer transport in hydrocarbon reservoirs and also for groundwater applications. These methods track the movement of a statistically significant collection of particles along appropriate path lines; while they generally work fine near steep fronts, they do not work as well for smooth profiles. Another drawback is the loss of resolution of the front with the progression of time and the statistical variance in the concentration response.

4. Front Tracking Methods: These methods involve complications arising from the topology of the fronts, difficult to extend to 3-D and introduce fluid fronts as a degree of freedom in computation.

Later, streamline method's evolution has involved several improvements and advances mentioned below:

1. Fully Three-Dimensional Heterogeneous Media (Pollock, 1988). Pollock[6] proposed a linear interpolation of the velocity field within a grid block which significantly improved the original Runge-Kutta streamline tracing technique used by Shafer[6]. Pollock tracing was successfully used in a number of streamline simulators where appropriate flow modelling along the streamlines allowed for simulation of first contact miscible displacements and evaluation of the effects of reservoir heterogeneity. Martin et al.[6] showed streamtube models failed predicting waterflood performance for an isolated five-spot pattern under favourable mobility ratio which highlighted the need to update the streamlines to accurately account for non-linear viscous effects. Muskat[6] gave an early description to the governing analytical equations that define the stream function and potential function in simple two-dimensional domains for incompressible flow. A notable work with these definitions was by Fay and Pratts[6], who developed a numerical model to predict tracer and two-phase flow on a two-well homogenous 2D system.

2. Time of Flight Formulation (Datta-Gupta & King, 1995). Datta-Gupta & King[7] introduced the concept of "time of flight" along a streamline. This idea shall be used in this research quite extensively. Datta-Gupta & King[7] also presented a streamline model for 2D heterogeneous areal displacements of two well-tracer and waterflooding problems. Most of the current streamline based flow simulators use this concept of time of flight, because of its simplicity and its decoupling effects, which splits a 3D problem into a series of 1D problem. This has been the most significant contribution in streamline simulation. The present research work also builds on this concept of ‘time of flight’.

3. Gravity Effects and Changing Field Conditions (Bratvedt et al[6]., 1996, Thiele et al[7]. 1996-1997, and Batycky et al[6]., 1997). Blunt et al[6], extended the streamline method to three dimensional systems, accounting for longitudinal and transverse diffusion. Bratvedt[7] introduced an operator splitting technique similar to that used in front tracking methods, allowing him to account for multiphase gravity effects.

With advances in SL methods, the technique has become a common tool to assist in the modelling and forecasting of field cases. This technology is now available to a large group of engineers. Because of the increasing interest in this technology, the main objective in this study is to apply the advantages of streamline simulation. In order to extract new information that leads to interpret the fluid flow behaviour and optimise the field development plan of Dogger Beta reservoir.

2.2 Streamline Method

A streamline is a line that is tangent to the velocity vector at a given instant in time. In a streamline simulator, there is constant flux in each streamline.

Streamline method is based on a sequential approach where the governing equations for pressure and saturations are solved sequentially. The IMPES (Implicit Pressure Explicit Saturations) method is based on a sequential approach as well, but suffers severely from the timestep length-limiting CFL (Courant-Friedrich-Levy) condition that occurs as fluid can not move more than one cell during one timestep. One of the advantages of the sequential approach over the fully implicit approach is the opportunity it gives to use a fit for purpose numerical method for each of the equations to be solved. Nevertheless, the notable disadvantages of streamline approach is ignored the capillary and dispersion effects.

Conceptually, IMPES type simulation: Solving for pressure first and then saturation and occasional updating of pressure field. Its difference from a conventional numerical type simulation lies on the way fluid transport is modeled. Streamline method decouples the transport from the physical underlying grid on which pressure field is obtained. Saturation is moved along streamlines characterized by time of flight coordinate. Due to the decoupling and infrequent pressure updating, streamline method can have large time steps for saturation computation without suffering from numerical instability or dispersion and consequently have a superior simulation speed (Can be orders of magnitude faster than conventional finite difference simulators).[8]

The governing equation for fluid flow in porous media is based on the fundamental laws of physics. Conventional reservoir simulators solve the governing differential equations that are based on the following three equations:

1. Conservation of Mass (Continuity Equation).

2. Conservation of Momentum (Darcy Equation: empirical solution of Motion Equation).

3. Equation of State.

The computations required within one single timestep with user-defined boundary conditions including well flow targets are:

Step 1: Solving for Pressure

Given the petrophysical properties and the boundary conditions, the pressure field is computed on a physical grid in the same way as in the finite difference simulator calculation.

Step 2: Streamline Tracing and Time of Flight Computation

Based on the pressure potentials, a Darcy velocity field is generated and streamline is traced. Then particle travel time along the streamline is computed.

Step 3: Saturation Advancing Along Streamlines

Using coordinate transformation, the 3D spatial coordinate is transformed into 1D travel time coordinate along streamline. Then, fluid saturation is advanced along the streamlines by solving the 1D saturation equations analytically or numerically. The saturation along streamlines is mapped onto the underlying grid and the gravity is solved for segregation. Finally, accumulate all the solution variables on each individual streamline or gravity line to form the solution on the global grid at the end of the timestep.

Step 4: Pressure Updating

Occasionally, pressure updating is necessary to take into account total mobility changes due to saturation changes over times or well condition changes such as rate changes and infill drilling. For this updated pressure field, the streamlines are retraced and saturation remapped onto the new streamlines.

These steps are illustrated in figure 2.1 below and will be described in more detail.

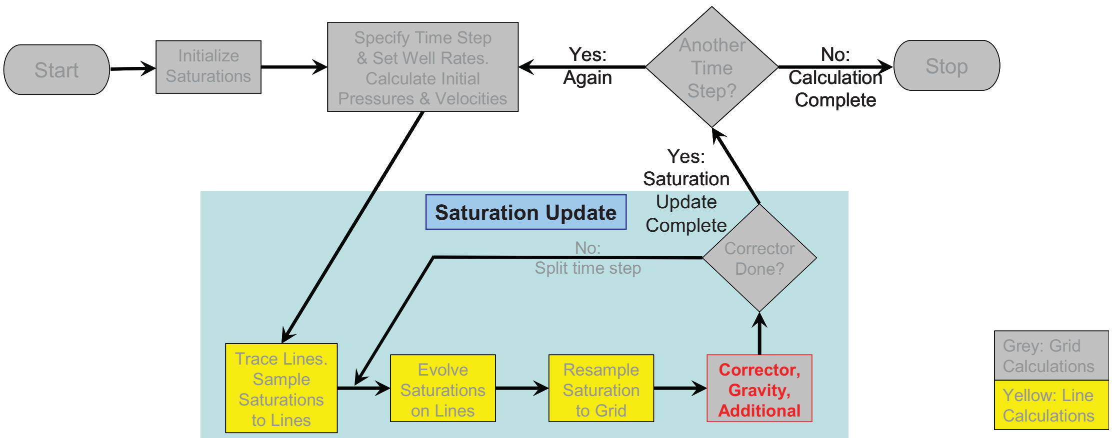


Figure 2.1: Steps in streamline simulation: yellow boxes represent calculations along streamlines whereas the grey boxes represent calculations on the grid[4]

2.2.1 Governing Implicit-Pressure Explicit-Saturation (IMPES) Equations

The streamline method is an IMPES solution (Implicit Pressure Explicit Saturation). That is, we solve a pressure equation in which all the terms that depend on saturation are evaluated at the initial saturation and where the spatial derivatives of the pressure are evaluated using the pressure at the end of the time step. The implicit pressure is a non-linear equation and is solved using a Newton Raphson method. The Newton Raphson itself results in a system of linear equations which are solved using an Algebraic Multi-Grid equation solver. The continuity equation for incompressible, multiphase flow is given by, $\nabla.u_t = 0$ where; u_t is the total phase velocity.

By applying the Darcy's equation, including gravitational effects and away from source or sink, we can rewrite this equation $\nabla.u_t = 0$ in terms of pressure distribution as

$$\nabla.\vec{\vec{K}}.(\lambda_t.\nabla P + \lambda_g.D) = 0 \quad \text{………………} \; (1)$$

Where, D is the depth below datum. Total mobility, λ_t, and total gravity mobility, λ_g, are defined as:

$$\lambda_t = \sum_{j=1}^{n_p} \frac{k_{rj}}{\mu_j} \qquad \lambda_g = \sum_{j=1}^{n_p} \frac{k_{rj}.\rho_j.g}{\mu_j} \quad \text{……... (2)}$$

Where, k_{rj} is relative permeability of Phase j, μ_j is phase viscosity, ρ_j is phase density, g is gravity acceleration constant, and n_p is number of phases present. We also require a material balance equation for each Phase j:

$$\phi \frac{\partial S_j}{\partial t} + \vec{u}_t.\nabla f_j + \nabla.G_j = 0 \quad \text{………………} \; (3)$$

The total velocity, $\vec{u}_t$, is derived from the 3D solution to the pressure field (Eq. 1) and application of Darcy's law. The phase fractional flow is given by

$$f_j = \frac{k_{rj}/\mu_j}{\sum_{i=1}^{n_p} k_{rj}/\mu_j} \quad \text{……………………….…} \; (4)$$

The phase velocity resulting from gravity effects is given by

$$\vec{G}_j = \vec{\vec{K}}.g.\nabla D.f_j.\sum_{i=1}^{n_p}\frac{k_{ri}}{\mu_j(\rho_i - \rho_j)} \quad \ldots\ldots\ldots\ldots (5)$$

Eqs. 1 and 3 form the IMPES set of equations in the formulation of the streamline simulator. We confine our discussion to the solution of these equations for two-phase flow.

2.2.2 Tracing Streamlines in Three Dimension

Tracing the streamline is the process whereby we create the unique streamline passing through a specified point in 3D space. From this starting point the streamline is traced backward and forward to create the complete streamline. The algorithm is iterative and rests on calculating the exit point in a grid cell given an entry point, repeated until a stop criterion is reached[9].

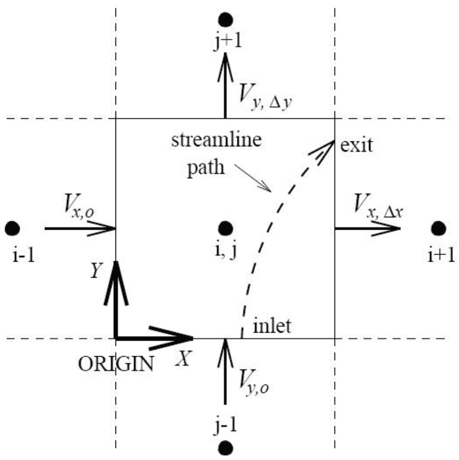


Figure 2.2: Schematic of streamline path through a 2D gridblock of dimensions dx by dy[9]

The method was first developed by the environmental literature by Pollock (1988) for Cartesian cells and assumes that the velocity varies linearly in each direction.

Pollock's formulation is consistent with the standard five points in two dimensions (Seven points in 3D) stencil for computing pressure as illustrated in figure 2.2.

In the following equations, v is the total interstitial velocity ($v=u/\phi$). The linear velocity description in the x direction is:

$$v_x = v_{xo} + g_x(x - x_o) \qquad (12)$$

Where, v_{xo} is the x velocity at the origin location x=x_o, and
g_x is velocity gradient in the x direction:

$$g_x = \frac{v_{x\Delta x} - v_{xo}}{\Delta x} \qquad (13)$$

Since v_x =dx/dt, we can integrate Eq. (12) to find the time to exit from the x exit face:

$$\Delta t_x = \frac{1}{g_x} \ln\left[\frac{v_{xo} + g_x(x_e - x_o)}{v_{xo} + g_x(x_i - x_o)}\right] \qquad (14)$$

Where x_i is the inlet position and x_e is the exit x coordinate.
Similarly, the times to exit the y and z faces are given by:

$$\Delta t_y = \frac{1}{g_y} \ln\left[\frac{v_{yo} + g_y(y_e - y_o)}{v_{yo} + g_y(y_i - y_o)}\right] \qquad (15)$$

$$\Delta t_z = \frac{1}{g_z} \ln\left[\frac{v_{zo} + g_z(z_e - z_o)}{v_{zo} + g_z(z_i - z_o)}\right] \qquad (16)$$

The streamline will exit from the face with the smallest value of Δt

$$\Delta t = MIN(\Delta t_x, \Delta t_y, \Delta t_z) \qquad (17)$$

Once this time is known, the exit locations are calculated by re-solving Eqs. (14, 15 and 16.) for x_e, y_e, and z_e:

$$x_e = \frac{1}{g_x}\left[v_{xi}.\exp(g_x.\Delta t) - v_{xo}\right] + x_o \qquad (18)$$

$$y_e = \frac{1}{g_y}\left[v_{xi}.\exp(g_y.\Delta t) - v_{yo}\right] + y_o \qquad (19)$$

$$z_e = \frac{1}{g_z}\left[v_{zi}.\exp(g_z.\Delta t) - v_{zo}\right] + z_o \qquad (20)$$

Where v_i is the inlet velocity and v_0 is the velocity at the origin.

Tracing equations has used in order to determine the time of flight through a single gridblock using the Excel-spreadsheet. Figure (2.3) shows the result of streamline path in two-dimension grid block. Figures (2.4) extended to the next neighbouring cells showing how the exit coordinate from one block is used as the entry coordinate for the next cell. This simple illustration leads to better understanding how the streamline chose its direction in three-dimensional underlying gridblock.

dx	Vx_0	Vx_dx	gx
1	10	210	200
dy	**Vy_0**	**Vy_dy**	**gy**
1	50	120	70

Inlet		Outlet
xi	Δtx	xe
0	0.015223	**0.560**
yi	Δty	ye
0	0.012507	**1.000**

Min Δt
0.012507

TOF	X	Y
0.0000	0.00	0.00
0.0006	0.01	0.03
0.0013	0.01	0.07
0.0019	0.02	0.10
0.0025	0.03	0.14
0.0031	0.04	0.17
0.0038	0.06	0.21
0.0044	0.07	0.26
0.0050	0.09	0.30
0.0056	0.10	0.34
0.0063	0.12	0.39
0.0069	0.15	0.44
0.0075	0.17	0.49
0.0081	0.20	0.55
0.0088	0.24	0.60
0.0094	0.28	0.66
0.0100	0.32	0.72
0.0106	0.37	0.79
0.0113	0.42	0.86
0.0119	0.49	0.93
0.0125	0.56	1.00

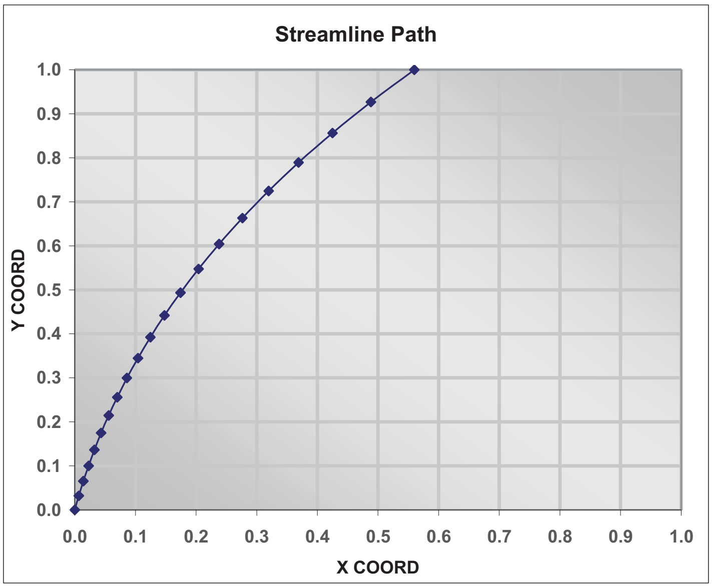


Figure 2.3: Time of flight through a single gridblock

dx	Vx_0	Vx_dx	gx
2	10	210	200
dy	**Vy_0**	**Vy_dy**	**gy**
2	50	120	70

Inlet		Outlet
xi	Δtx	xe
0.560	0.006061	**0.678**
yi	Δty	ye
1.000	0.006565	**1.377**

Min Δt
0.006061

TOF	X	Y
0.0000	0.56	1.00
0.0003	0.60	1.04
0.0006	0.64	1.07
0.0009	0.68	1.11
0.0012	0.73	1.15
0.0015	0.78	1.19
0.0018	0.83	1.23
0.0021	0.88	1.27
0.0024	0.94	1.32
0.0027	1.00	1.36
0.0030	1.07	1.41
0.0033	1.14	1.45
0.0036	1.21	1.50
0.0039	1.29	1.54
0.0042	1.37	1.59
0.0045	1.46	1.64
0.0048	1.56	1.69
0.0052	1.66	1.74
0.0055	1.77	1.80
0.0058	1.88	1.85
0.0061	2.00	1.91

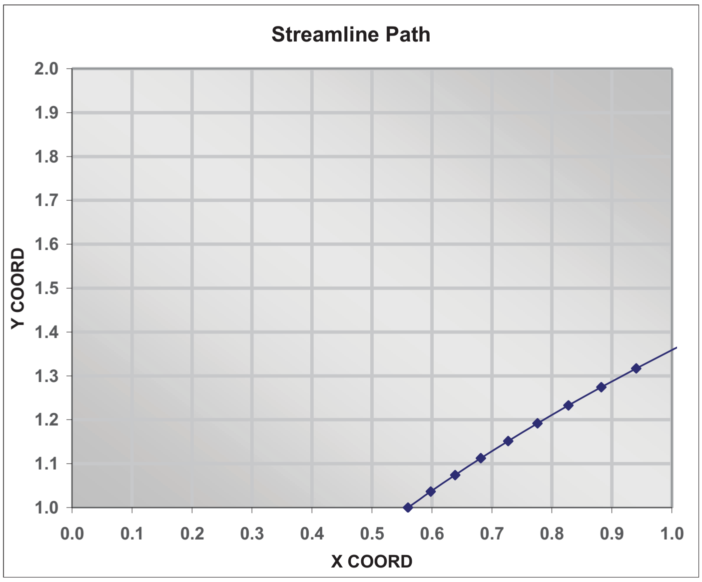


Figure 2.4: Time of flight through the next gridblock

TOF	X	Y
0.0000	0.00	0.00
0.0006	0.01	0.03
0.0013	0.01	0.07
0.0019	0.02	0.10
0.0025	0.03	0.14
0.0031	0.04	0.17
0.0038	0.06	0.21
0.0044	0.07	0.26
0.0050	0.09	0.30
0.0056	0.10	0.34
0.0063	0.12	0.39
0.0069	0.15	0.44
0.0075	0.17	0.49
0.0081	0.20	0.55
0.0088	0.24	0.60
0.0094	0.28	0.66
0.0100	0.32	0.72
0.0106	0.37	0.79
0.0113	0.42	0.86
0.0119	0.49	0.93
0.0125	0.56	1.00
0.0000	0.56	1.00
0.0003	0.60	1.04
0.0006	0.64	1.07
0.0009	0.68	1.11
0.0012	0.73	1.15
0.0015	0.78	1.19
0.0018	0.83	1.23
0.0021	0.88	1.27
0.0024	0.94	1.32
0.0027	1.00	1.36
0.0030	1.07	1.41
0.0033	1.14	1.45
0.0036	1.21	1.50
0.0039	1.29	1.54
0.0042	1.37	1.59
0.0045	1.46	1.64
0.0048	1.56	1.69
0.0052	1.66	1.74
0.0055	1.77	1.80
0.0058	1.88	1.85
0.0061	2.00	1.91

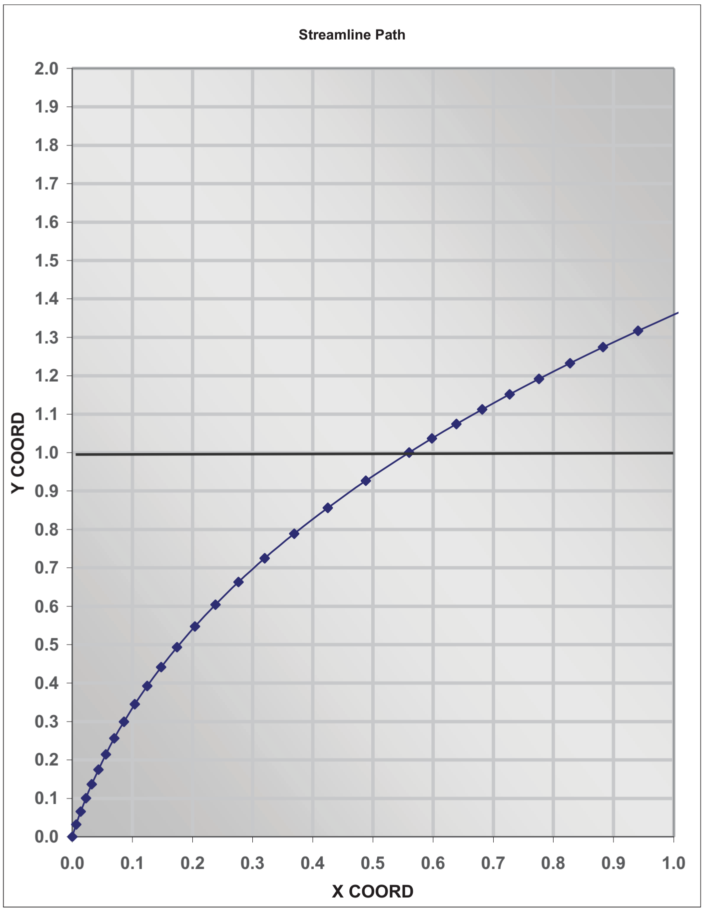


Figure 2.5: **Time of flight through two neighbouring gridblock**

2.2.3 Coordinate Transform.

In a conventional IMPES finite-difference simulator, Eq. 3 is solved in its full 3D form with the previously calculated pressure field. In the streamline method, we transform the 3D equation into multiple 1D equations that are solved along streamlines.

Streamlines are launched from gridblock faces containing injectors. As the streamlines are traced from injectors to producers, we determine *the time of flight* along the streamline, which is defined as the following:

$$\tau = \int_0^s \frac{\phi}{u_t.(\zeta)} d\zeta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

It gives the time required to reach a point s on the streamline based on the total velocity $u_t.(\zeta)$ along the streamline. The permeability, porosity, and total mobility effects of the 3D Cartesian domain are incorporated along a streamline by means of the τ coordinate.

To determine the coordinate transform, we rewrite Eq. 6 as

$$\frac{\partial \tau}{\partial s} = \frac{\phi}{|\, u_t \,|} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(7)}$$

This can further be rewritten as the following:

$$|\, u_t \,| \frac{\partial}{\partial s} \equiv \vec{u}_t . \nabla = \phi \frac{\partial}{\partial \tau} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(8)}$$

Substituting Eq. 8 into Eq.3 gives:

$$\frac{\partial S_j}{\partial t} + \frac{\partial f_j}{\partial \tau} + \frac{1}{\phi} . \nabla . \vec{G}_j = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(9)}$$

Equation (9) is the governing pseudo-1D material-balance equation for Phase *j* along a streamline coordinate. The equation is pseudo-1D because the gravity term is typically not aligned along the direction of a streamline. To solve Eq. 9, we split the equation into two parts using operator splitting as outlined by Glimm et al.,[6] Colella et al.,[6] and Bratvedt et al.[6] First, a convective step along streamlines is taken governed by

$$\frac{\partial S_j^c}{\partial t} + \frac{\partial f_i}{\partial \tau} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(10)}$$

In order to construct an intermediate saturation distribution, S_j^c. Then, the gravity steps is taken along gravity lines governed by

$$\frac{\partial S_j}{\partial t} + \frac{g}{\phi} \frac{\partial \vec{G}_j}{\partial z} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(11)}$$

With S_j^c as the initial condition to construct S_j and $\vec{G}_j = \left| \vec{G}_j \right|$. For simplicity, we have assumed that the z-coordinate direction is aligned with the gravity lines.

2.2.4 One Dimension Numerical Solvers

One-dimensional numerical solvers are used to solve Eq. 10 and Eq. 11. Each solver is completely decoupled from the rest of the simulator. Here, we have chosen to solve Eq. 9, but any equation with the desired physics written in 1D can be used. For example, this method has been extended to composition-al displacements.[10]

For cases presented here, Eq. 10 is solved numerically with a single-point-upstream (SPU) weighting scheme explicit in time. By discrediting in t space, this leads to a natural refinement in 1D where flow velocities are high and reduced resolution where flow velocities are low. To retain accuracy within the numerical solver, the irregularly spaced t grid is converted to a regularly spaced t grid. Time stepping for the SPU scheme is controlled within the solver by use of the optimal local CFL constraint particular to a given streamline so that the fastest front is always moved one t node per local time interval (Dt_1D). The ability to honour the local CFL constraint minimizes numerical diffusion.

For the gravity solver, Eq. 11 is discredited in space limited to the same vertical resolution of the underlying grid on which the pres-sure field is defined. Eq. 11 is solved with an explicit upstream weighting method outlined by Sammon.[36] An additional advantage of decoupling the gravity step in this way is that Eq. 11 is solved only in flow regions where gravity effects are important.

2.2.5 Time Stepping

Modelling field scale displacements considers that the streamline paths change with time due to the changing mobility field and/or changing boundary conditions. Thus, the pressure field is updated periodically in accordance with these changes. By using numerical solutions along the recalculated streamline paths the method accounts for the non-uniform initial conditions now present along the recalculated paths.

To move the 3D solution forward in time from t_n to $t_{n+1}=t_n+ .t_{n+1}$ the following algorithm is used:

1. At the start of a new time step, t_{n+1}, solve for the pressure field P using equation (1) in the IMPES formulation. This equation may be solved using a standard seven-point finite difference scheme, with no-flow boundary conditions over the surface of the domain and specified pressure or rate at the wells.
2. Apply Darcy's law to determine the total velocity at gridblock faces.
3. Trace streamlines from injectors to producers. For each streamline the following is performed:

- While tracing a streamline, the current saturation information from each grid block that the streamline passes through is remembered. In this manner, a profile of saturation versus (τ) is generated for the new streamline.

- Move the saturations forward by .t_{n+1} by solving equation (10) numerically in 1D. Map the new saturation profile back to the original streamline path.

4. Average all the streamline properties within each grid block of the 3D domain to determine the saturation distribution at t_{n+1}
5. If $G_j \neq 0$ include gravity step that traces gravity lines from the top of the domain to the bottom of the domain along $\vec{g}$. For each gravity line the following is done:

- While tracing a gravity line, the saturation distribution calculated in the convective step as a function of z is remembered
- The saturations are moved forward by .t_{n+1} using equation (11). The new saturation profile is mapped back to the original gravity line.

6. If $G_j \neq 0$ average all gravity line properties within each grid block of the 3D domain to determine the final saturation distribution at t_{n+1}.
7. Return to step 1.

2.3 Factors Affecting Streamline Simulation

2.3.1 Gravity Effect

Clearly if we have two or three phases flowing along the streamlines we have to take account of gravity segregation of the phase. The effect of gravity is incorporated by operator splitting and the use of "vertical" gravity streamlines. In fact the gravity lines are made up of columns of cells in the Z direction of the model. These "vertical" streamlines are then solved using the same method as the original streamlines.

Gravity effect is another fundamental factor that can be accounted during streamline method. Streamlines follow the total velocity field rather than individual phase velocities; modeling gravity effects when mapping analytical solutions to the streamlines has been a discussion in earliest technical investigations. Blunt et al.[7] comment that the method works best for cases where the principal flow directions are dominated more by heterogeneity than by gravity.

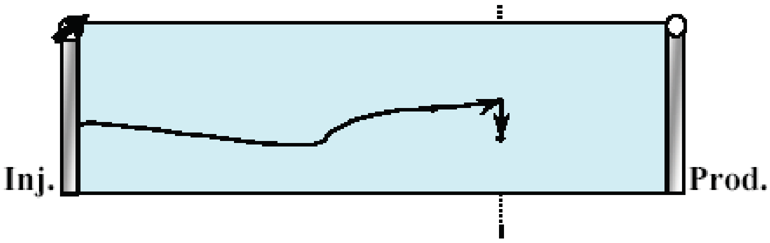


Figure 2.6: Gravity effect for streamline model

Figure 2.6 shows how streamlines can be affected by gravity effect, this effect is an additional nonlinearity that alters the pressure field through time, and hence the streamline paths. The presence of gravity does require additional pressure solves over a given time interval to reach a converged solution. Also, as it was mentioned before, during multiphase flow, individual phase velocities may not be aligned with the total fluid velocity as show in figure 2.7.

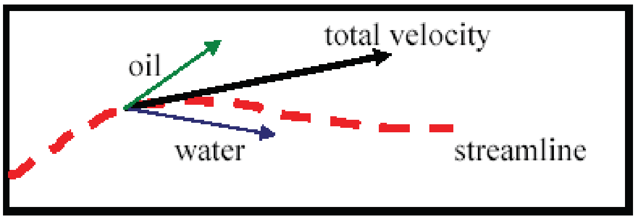


Figure 2.7: Phase velocities of multiphase flow in streamline model

Gravity effects in first-contact miscible displacements could successfully be modeled over a large range of gravity numbers. Two-phase gravity problems are more difficult to model with the streamline method. However, by separating the governing equation into a convective step and a gravity step (operator-splitting) the streamline method now accounts for gravity effects in multiphase flow[10].

In comparisons with conventional simulation methods, the streamline method still retains significant speedups and reasonable accuracy. The magnitude of the speedup depends on the size of the gravity number, the model size, and the type of displacement process.

Gravity effects in the streamline method are modeled using an operator splitting technique, which corrects fluid positions in the vertical direction after they have been moved convectively along streamlines. Conceivably, any other mechanism that is deemed important at the field scale simulators could be accounted using a similar operator splitting approach and viewed as a corrective step. Operator splitting relies on the consistency of treating the convective flux independently from the gravity flux within a given time step of the simulation. For small time steps the operator splitting approximation is fairly accurate whereas large time steps may lead to significant errors in the approximation[11].

Bratvedt et al[6]. Presented a similar front tracking method as that of Glimm[12], but extended the method to full 3D systems with multiple wells. Their ideas were implemented in the commercial code FRONTSIM[12].

Gravity effects are accounted for by operator splitting such that fluids are moved convectively along streamlines then vertically due to gravity effects.

Then, this equation is solved with a two-step approach (operator-splitting):

$$\frac{\partial S_j}{\partial t} + \frac{\partial f_j}{\partial \tau} + \frac{1}{\phi}.\nabla.\vec{G}_j = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(12)}$$

First, saturations are transported along streamlines, ignoring any gravity effects. Next, saturations are then allowed to segregate because of density differences. Recently, this technology has been extended to compressible and compositional flows[10].

Gravity and capillary forces are often important in the description of the dynamics of flow and must be included in the reservoir model. For this purpose, operator splitting algorithms represents an efficient numerical method to solve the reservoir model equations.

After the streamlines are computed, the equation for saturation is then solved. For this purpose the convective and gravity effects have to be treated differently.

Thus the mentioned equation is divided into two parts and solved using the operator splitting technique. The first part is a one dimensional, non-linear, hyperbolic equation which includes the convective term and is solved along the streamlines. The second part is a non linear parabolic equation which includes the gravity effect and it is solved using finite differences over the three dimensional grid. See figures 2.6 and 2.7.

$$\frac{\partial S_w}{\partial t} = \frac{\partial S_w}{\partial t_c} + \frac{\partial S_w}{\partial t_G} \quad \text{(13)}$$

∂t_c: Convective step

∂t_c: Gravity step

2.3.2 Compressibility Effect

All streamtube and streamline theory has been developed around the assumption of in-compressible flow. The reason, of course, is that incompressible flow introduces simplifying assumptions that are particularly suitable for SL simulation, the two most important assumptions:

1. All streamlines must start in a source (injector and/or aquifer) and end in a sink (producer and/or aquifer).
2. The flow rate along each streamline (or streamtube) is constant.

The second assumption is particularly important and implies that for incompressible flow transport along a streamline only involves solving for the component wave speeds. Incompressibility also allows calculating the volume associated with a streamline simply as the product of the time-of-flight times the flow rate along the streamline.

For compressible flow, on the other hand, streamlines can start or end in any grid blocks that act as a volume source or sink because of the compressible nature of the model. Any gridblock that sees its density decrease with decreasing pressure (expansion) is a source and thus a potential starting point for a streamline. Conversely, any grid block that sees its total density increase with increasing pressure (compression) is a potential sink. [9]

There are six main extensions of the incompressible theory required to accommodate compressible flow along streamlines:

1. A compressible pressure equation has to be solved to determine the velocity field.
2. Streamlines no longer begin at injectors and end at producers. Streamlines can now begin and/or end in the far field.
3. A conservation equation must be solved along each streamline accounting for compressibility.
4. The volumetric flow rate (q) along a streamline is no longer constant.
5. Global time step size is now also restricted by pressure changes.
6. Translations of well boundary conditions (such as surface oil rate) to individual streamline boundary conditions.

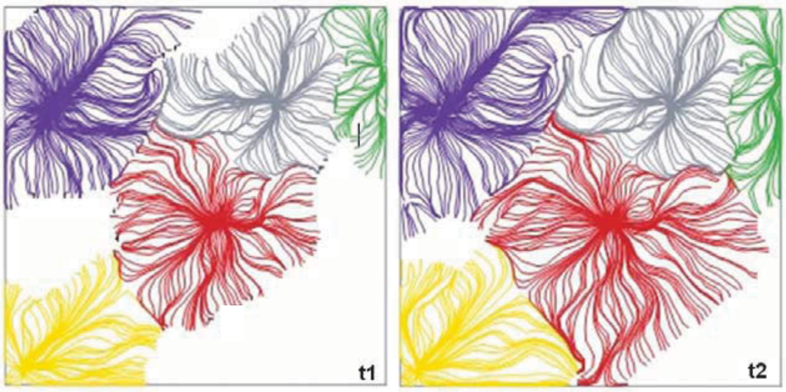


Figure 2.8: Compressible flow[9]

In compressible flow, gridblocks that can act as sources even though without injection wells (see figure 2.8). In the case of primary depletion, a streamline will start in the far field and end in a producer and produce some volume from each gridblock it crosses.

2.4 Streamline Application

Streamline simulators are particularly effective for modelling large, heterogeneous, multi-well systems. Nevertheless, water-flooding studies are frequently carried out using streamline simulation. Conversely, the streamline method is not well suited for modelling processes that rely on diffusive physics such as high compressibility (gas systems), strong capillary effects, or complicated phase behaviour. Most importantly, streamline simulation is best applied in cases where the voidage replacement ratio (volume in at reservoir conditions/volume out at reservoir conditions) is close to one[9].

The following is a partial list of problems and application for which streamlines are particularly exploited.

2.4.1 Water Flooding Management

One area in which streamlines simulation play a major role is water flood management. The use of well allocation factor accurately describes waterflood patterns. Presumably, by quantifying the injector to producer relationship, well injection efficiency easily estimated and the benefits of reallocation injection rate will be applied. Individual waterflood injection rate can be then assigned for each injector in order to maximize oil production and reduce water cycling in the field.

2.4.2 Associated History match

History matching traditionally requires many forward simulations. Therefore, assuming a streamline model can capture the first order physics influencing a simulation model, the speed and efficiency of streamline simulation will reduce the turn-around time of a history-matching project. Speed and efficiency can also be used to history-match with a finer grid that might otherwise be used if one were to use less efficient finite-differencing modelling. Additionally, streamlines allow a new approach to history matching since the time-of-flight (TOF) can be shown to be proportional to permeability and inversely proportional to porosity. Thus, mismatches in simulated well production responses can be related back to specific areas of the reservoir (volumes associated with particular streamlines) that in turn can be modified (in-crease/decrease permeability or porosity) in a geologically consistent way.

2.4.3 Compare Different Upscaling Methodologies

For upscaling, streamlines offer the opportunity to generate the fine scale solution, which generally is difficult and computationally expensive. Streamline simulation allows going beyond checking fine-scale and upscaled field/well responses by additionally looking at drainage/irrigation zones. This can be particularly powerful complimentary information, as it maintains that volumes associated with wells should be similar between fine scale and upscaled models. Finally, because upscaling should ideally be process independent, the simple physics approach of streamline simulation fits wells into this type of approach.

2.4.4 Ranking Geological Model

Ranking is generally done on green fields, with the main purpose being to quantify the uncertainty associated with the sparse geological information and its impact on potential development scenarios. Here the speed of streamline simulation is particularly useful, allowing a more exhaustive search of the solution space. Combined with experimental design techniques, streamline simulation can be very effective and possibly the only possibility for an acceptable estimation of uncertainty. The key of using streamlines for ranking is to use just enough flow physics to capture first order effects without however sacrificing the speed and efficiency inherent in streamline simulation.

2.4.5 Optimal Infill Drilling

The optimal location of infill well(s) is dependent on a number of factors, including reservoir heterogeneity, other well locations, and displacement mechanism. Finding the optimal location requires the minimization of some objective function and therefore multiple forward simulations, which can be run efficiently using streamlines.

2.4.6 Fractured System

Dual porosity models (fractured systems) are particularly difficult to model for traditional finite difference simulators because of the locally high flow velocities that can happen as a result of the fracture network. The streamline-based dual porosity models can efficiently model the quick flow of water in the fractures while accounting for the imbibitions process into the matrix. The efficiency of streamlines allows using much finer grids and therefore a much higher resolution of the flow through fractured systems.

2.4.7 Miscible Gas injection

Interaction of heterogeneity and low-viscosity miscible gas injection makes this a difficult problem for finite difference. Even using simplified PVT models, streamlines can give excellent insight on preferential flow paths and impacts on recovery due to miscible tuning parameters. Modern streamline simulation includes all the necessary physics to model miscible gas injection:

a) Gravity to ensure possible segregation of the phases.

b) Miscibility to properly model changing density and viscosity of the resident phases as a function of composition.

c) Changing streamlines to account for changing well conditions over time.

d) The ability to include fine scale grids for better resolution of injected gas fronts and improved description of geological feature.

Chapter Three

3 Project Workflow

3.1 Production History Simulation

In this section, we will demonstrate the advantages and disadvantages of the streamline approach compared to finite-difference simulation. Mittelplate- Dogger Beta reservoir model will be used in order to illustrate the primary difference of both approaches.

This study was conducted for RWE Dea. Mittelplate oil field is located in the North Sea coast. It is considered Germany's largest and most productive oil field. Reserves far in excess of 100 million metric tons (mt) of crude oil are located in several oil-bearing strata5-17m deep in the Dogger Beta, 40-60m deep in the Delta and 20-30m deep in the Epsilon zones, at true vertical depths between 2000 and 3000 meters. However, for physical, technical and economic reasons, these reserves can only be exploited to a limited extent. The deployment of new technologies in drilling and production operations resulted in steady increases in production volumes over recent years. The initial production rates of around 200,000 mt of crude annually have increased more than tenfold.

The focus of the study will be only for Mittelplate – Dogger Beta reservoir, which is apart of four other horizon in Mittelplate oil field. The reservoir has produced intermittently for 20 years. Water injection was initiated at the early stage of production. In order to re-pressurize the reservoir. A finite difference simulation model including history match modifications was constructed and maintained for the reservoir by RWE Dea AG staff.

The target was to perform streamline simulation using FrontSim™ and predict the reservoir performance under water flooding by employed new engineering data provided from the streamline approach. Streamline simulation was used to formulate a methodology that could improve injection efficiency under realistic field conditions. Specifically, the simulation results were used to improve rate allocations, determine optimum placement of injectors, and visualize flow patterns.

3.1.1 Streamline Model Description

Mittelplate- Dogger Beta reservoir model is constructed by (93 x 244) cells in X, Y directions combined with 14 layers. The reservoir has developed up to date with three injector and seven producers. In fact, two wells are excluded out of injection due to the lack of their efficiencies.

- The presented phases in the model are oil and water.
- Vertical reservoir depth varies from 2400m to 2975 m.
- Average gross reservoir thickness in the range of 5-17 m.
- Average reservoir porosity in the range of 15-24 %.
- Average Reservoir Permeability 200-300 md.
- Total grid block: (93 x 244) combined with 14 layers**.** Leads to (*317688)* total grids.
- Active edge water drive was modelled using an infinite Fetkovich Aquifer.
- Simulation started at 01 October 1987
- History matching period is simulated until 30 of July 2007 using conventional finite difference simulator, Eclipse.
- The prediction case starts 01 Aug 2007
- The end of the prediction is 01 Jan 2027
- Three injectors and Seven Producers, presented at Current Status.
- **FrontSim** streamline Simulator and **Eclipse100** are applied.
- Metric Units are used.

3.1.2 Compare Streamlines Simulation with Finite Difference

The streamline simulation is not a minor modification of the current finite difference approaches, but is a radical shift in methodology. The fundamental difference is how the fluid transport is modelled. In finite-differences, fluid movement is between explicit grid blocks, whereas in the streamline method, fluids are moved along a streamline grid that may be dynamically changing at each time step, and is decoupled from the underlying grid on which the pressure solution is obtained. By decoupling transport from the underlying grid, we have noted *large speed-up factors*, *reduced grid orientation effects*, and *minimization of numerical diffusion*. the inherent simplicity of the approach offers unique opportunities for integration with modern reservoir characterization methods.

3.1.2.1 Large Speed-Up Factors

The fundamental reason for large speedup factors in the streamline method is the fact that the time step size for a convective can be larger than the time step size in conventional simulators. This is a result of eliminating the global CFL (Courant-Freidrichs-Lewy) condition by decoupling fluid movement from the underlying grid. Streamline methods are not restricted by the global CFL condition, but rather local CFL along each streamline. As a result they have an advantage over conventional finite difference IMPES simulators, allowing less frequent pressure updates.

The CFL construction for one-dimensional Buckley-Leverett waterflood is well known as the following:

$$CFL = \frac{u}{\phi}.\frac{\Delta t}{\Delta x}.f_w' \quad \text{.................................... 3.1}$$

The IMPES CFL stability requirement is $CFL \leq 1$. There is a simple interpretation for this stability requirement. The fastest wave must not pass across an entire cell during timestep. The interstitial fluid speed is (u/ϕ) and Δx is the distance to be covered. The factor f_w' is the Buckley-Leverett speed of the saturation S_w.

One advantage of streamline simulation over more traditional approaches is its inherent efficiency, both in terms of memory and computational speed. Memory efficiency is a result of two key aspects of the formulation:

- streamline-based simulation is an IMPES-type method and therefore involves only the implicit solution of pressure;
- Tracing of streamlines and solution of the relevant transport problem along each streamline is done sequentially. Only one streamline needs to be kept in memory at any given time.

Computational speed is achieved because:

- The transport problem along each streamline is 1D and can be solved efficiently.
- The number of streamlines increases linearly with the number of active cells (see figure 3.1).

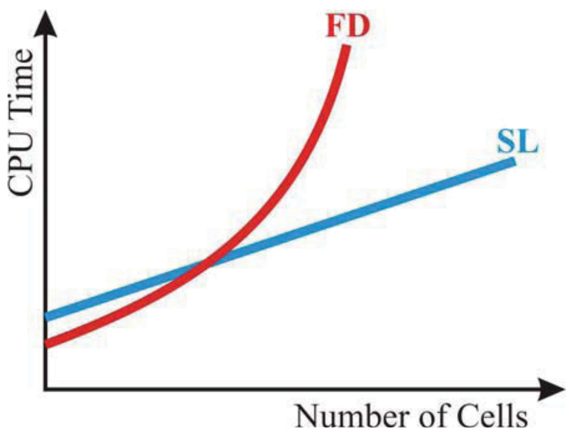


Figure 3.1: CPU efficiency verses model size

- Streamlines only need to be updated infrequently.

While streamlines change over time due to mobility changes, gravity, and changing boundary conditions, for many practical problems, grouping well events into yearly or semi-yearly intervals and assuming that the streamlines remain unchanged over that period is reasonable. Field simulations with 30 to 40 year histories are successfully and routinely simulated with 1-year time steps (*Baker et al. 2001*).

In contrast to other simulation techniques, the size and number of the global time steps (frequency of streamline updates) is only a function of the physical process modeled and completely independent from the size and heterogeneity of the 3D model. A good example to demonstrate the efficiency of streamline simulation is Model 2 of the 10th SPE comparative solution project (*Christie and Blunt, 2001*).

The linear behavior with model size is the main reason why streamline simulation is so useful in modeling large systems. In finite difference, finer models not only cause smaller timesteps due to smaller gridblocks but usually face problems because of increased heterogeneity as finer models tend to have wider permeability and porosity distributions. The usual workaround is to use an implicit or adaptive-implicit formulation, but for large problems these solutions can become prohibitively expensive, both in terms of CPU time and memory.

Large timestep can be taken without numerical instability giving streamline simulation method a near-linear Scaling in term of CPU efficiency verses model size.

Streamline approach differs from regular finite difference models in that it first determines the direction of flow everywhere in the field (by solving the pressure problem on regular grid and finding flow directions in each grid block based on this solution for pressure) and then it solves for flow along the streamlines. Besides eliminating the numerical diffusion, this method makes it possible to more accurately trace the water/gas fronts during flooding. As a result, time steps can be increased and run-times substantially diminished.

In general, accelerated calculation times are achieved in the streamline simulation approach by taking advantage of the following shortcuts:

1. <u>Streamlines are not recalculated at every time step</u>. This cannot be done if production rates are varying often and if pressure patterns are changing rapidly.
2. <u>The model assumes an incompressible flow</u>. As the active developers of streamline simulation method themselves underline, ". . . while streamlines can model truly compressible systems, the inherent speed advantage over finite difference methods can diminish significantly. ----- This is due simply to the constraint that if absolute pressure needs to be properly resolved to capture the transients, then limits on the global time-step size are very similar between finite difference and streamline simulation methods"

Current conventional finite difference simulation has two-segment solution, a pressure solver segment and a transporting (saturation) solver. For IMPES (Implicit Pressure Explicit Saturation solution), the oil pressure is solved implicitly first as required for stability at each point then solved explicitly the saturation. The method is frequently subject to stability problem, however, which restrict the allowable timestep. A common restriction on IMPES resulting from saturation being handled explicitly is that no more than one grid block pore volume throughput is allowed per timestep. This restriction can be severe when grid block are very small. IMPES methods can be useful in finite difference approach because of their relatively small computing requirement per timestep. Nevertheless, it has their stability limitation and grid block orientation effect. In fact, this method continuous to be used widely, despite the recent advance presented by streamlines simulation that uses the same approach with an overcome of its Limitations.

Because the transport problem is non-linear, the finite difference solution method can be very sensitive to grid block size and grid block orientation. As a result of non-linearity, timestep control also strongly affects the result of finite difference simulations.

In a streamline simulation, the pressure equation is solved on an underlying grid as in the same method as a conventional simulation. In fact, streamlines are computed orthogonal to pressure contours. Therefore, a "natural" transport network is constructed and fluid is transported along each streamline to track oil/water movement within the reservoir. Streamlines have an inherent advantage because the fluid is transported in the direction of the pressure gradient along the streamlines and not between grid blocks as shown in Figure 3.1. Because of this greater stability, larger time-steps with less sensitivity to grid block size and orientation effect can be used.

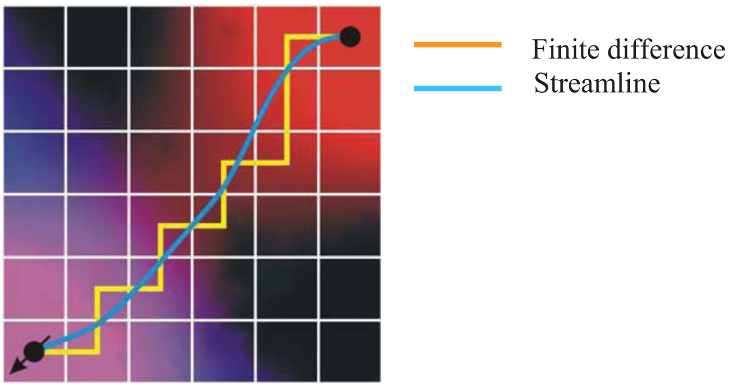


Figure 3.2: Fluid transporting in finite difference compared with streamline

3.1.2.2 Grid Orientation Effects

Problems in which finite-differences fail in practise due to grid orientation are good candidates for streamline-based simulation. This is because streamline-based fluid transport does not exhibit grid orientation effects. Figure 3.2 shows how finite difference approach transport fluid between gridblocks for different grid orientations. Presumably, the injected fluid takes longer travel time to cross the gridblock in figure 3.2B than 3.2A due to the different grid orientation. This illustration shows that with different grid orientation, finite difference model would have different result.

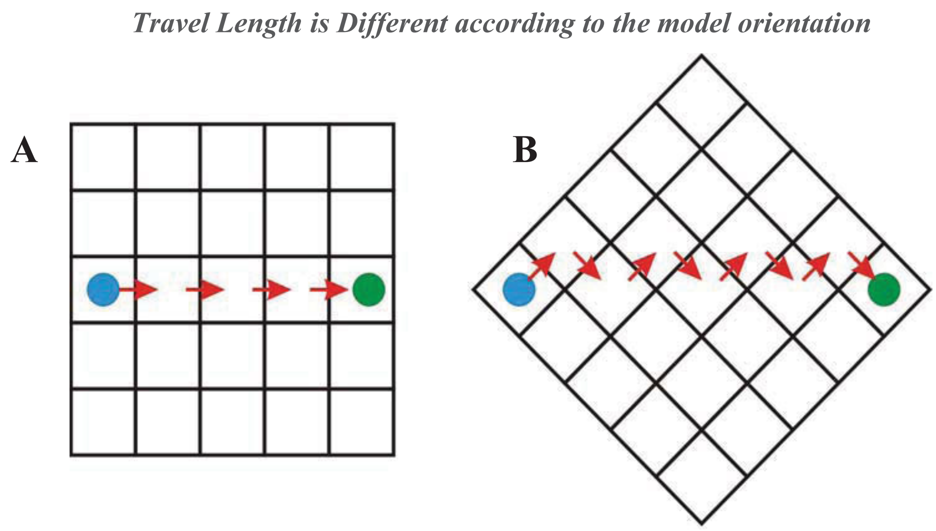


Figure 3.3: Finite Difference Orientation Effect

3.1.2.3 Numerical Diffusion

The second major artefact of finite difference simulation is numerical diffusion. Numerical diffusion can become a problem when simulating strongly heterogeneous systems that might force a small time step in finite-difference models; Whereas Streamline simulation is ideally suited for modelling such a large heterogeneous multi-well systems dominated by convection.

To properly classify the above-mentioned approaches, it is important to remember that streamline technology emerged as an attempt to overcome some of drawbacks of regular finite difference models. Streamline simulation is, in fact, a modification of the approach. Regular finite difference simulators work in such a way that they solve two problems at each time step: they solve for pressure distribution and then for fluxes of fluids between the modelling cells. This second step has an intrinsic problem, i.e. when the grid blocks are not aligned directly along the flow direction, it does not represent the flow correctly. This phenomenon is called dispersion or numerical diffusion. To overcome this problem within a finite difference model, one has to decrease cell sizes and even adjust their orientation, which leads to substantial runtime growth and some degree of numerical distortion. This is true to the point that, depending upon the parameters of each particular case; many big fields cannot be modelled using finite difference methods without sacrificing considerable accuracy and time.

On the other hand, streamline method is not well suited to complex physics displacements (high compressibility, capillary effects, complicated phase behaviour). Another problem inherent with streamline simulation technology is modelling a singularity. This is because vertical wells are usually hidden within the grid block in which they are completed and are therefore never modelled directly. Similar difficulties and inaccuracies are encountered with most fractured wells, where pressures and flow along the fracture face can only be estimated. The following graph illustrates the typical method in which both approach should be used dependent on the reservoir description.

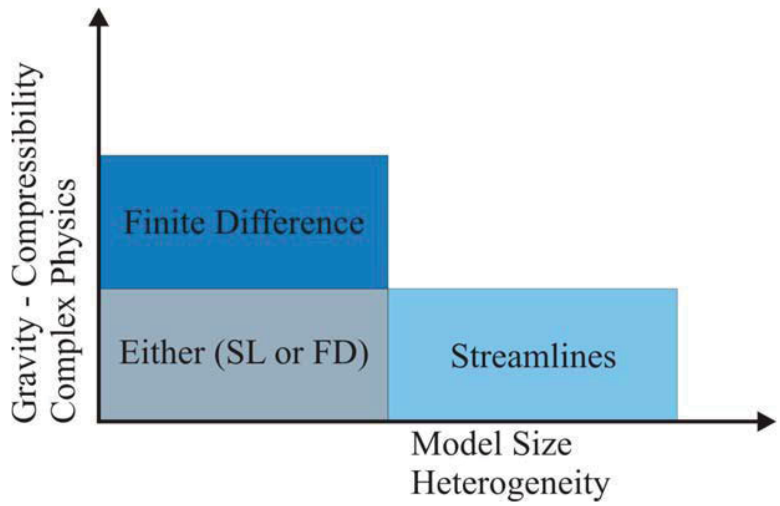


Figure 3.4: Applicability of streamline vs. finite difference simulation.[4.]

From a time, data and process standpoint, setting up a case for streamline simulation modelling is quite similar to doing it for regular finite difference model. For example, Schlumberger GeoQuest has a streamline simulation module “FrontSim” that works with “Eclipse” and shares standards for setting up cases. The claims that streamline simulation models are faster then regular finite difference model simulators are valid only under certain, limited conditions.

If heterogeneity is believed to have a first-order affect on field performance, (i.e. convection term dominates) then multiple fine scale realizations are required. In this instance streamline based simulation is the simulation method of choice because it is fast, can simulate fine scale models, and can capture effects due to heterogeneity.

Feature	FD	SL
Two-phase flow	Yes	Yes
Three-phase flow	Yes	Yes
Setting up a grid	Yes	Yes
Setting up a case	Substantial time	Substantial time
Models singularities (including fractured and horizontal wells)	Approximately, with difficulty; not accurately	Approximately, with difficulty; not accurately
3D flow	Implemented	Implemented
Waterflood	**Difficulty in tracking fronts**	**Good at tracking water fronts**
Tracking pressure transients	Increases runtimes	Increases runtimes
Modeling big fields	**Often results in unacceptable run-times & numerical distortion/errors**	**Moderate run-times achieved using some general assumptions (quasi-steady flow, incompressible flow)**
Visualisation of flow patterns	Can be added	Intrinsically implemented
Visualisation of pressure distribution	Implemented	No

Table 3-1: Application of SL (Streamline) simulation compared with FD (finite difference) approach

In order to recap what was discussed, the fundamental difference between streamline method and finite-difference method is the way fluid transport is modeled. In finite difference models, fluid movement is between explicit blocks, whereas in the streamline method, fluids are moved along a streamline grid. The streamline method decouples the underlying pressure grid from the saturation grid. This decoupling allows large time step sizes and increases the speed with which a simulation can be conducted. Because streamline simulators

Neglect compressibility and capillary effects, they typically can be run using more grid blocks than finite-difference simulators. A number of field studies have shown that streamline methods are well suited for honoring fine-scale heterogeneity effects.[6]

Ultimately, there is no one numerical method, which can solve the governing equation for all cases efficiently. Depending on which terms dominated, different techniques should be use and applied. Although reservoir simulation is mature technique, there are always common problems either an incorrect application representation or lack of clearly defined objectives. Once those issues precisely specified, the best approach would be directly chosen and the delineate objective quickly achieved.

3.1.2.4 Streamline Visualization

Streamline images provide a unique glimpse of the flow patterns that relate to injector/producer pairs. The movement of fluids in a reservoir are often more complex than anticipated. Geophysical and Geological models provides a static model illustrates the reservoir property without any hence of fluid movement and situation change (figure 3.6-A). Conventional reservoir simulation qualifies pressure and saturation distribution reference to the time as in figure 3.6-B.therefore provide additional information than the static mode. Streamline simulation yield further information that leads to better understanding and management of the reservoir. For instance it easy to illustrate the flow path by water saturation bundles as in figure 3.6-C. on the other way around, the illustration of the fluid flow by introduce the oil saturation bundles are also possible and have a lot to comment

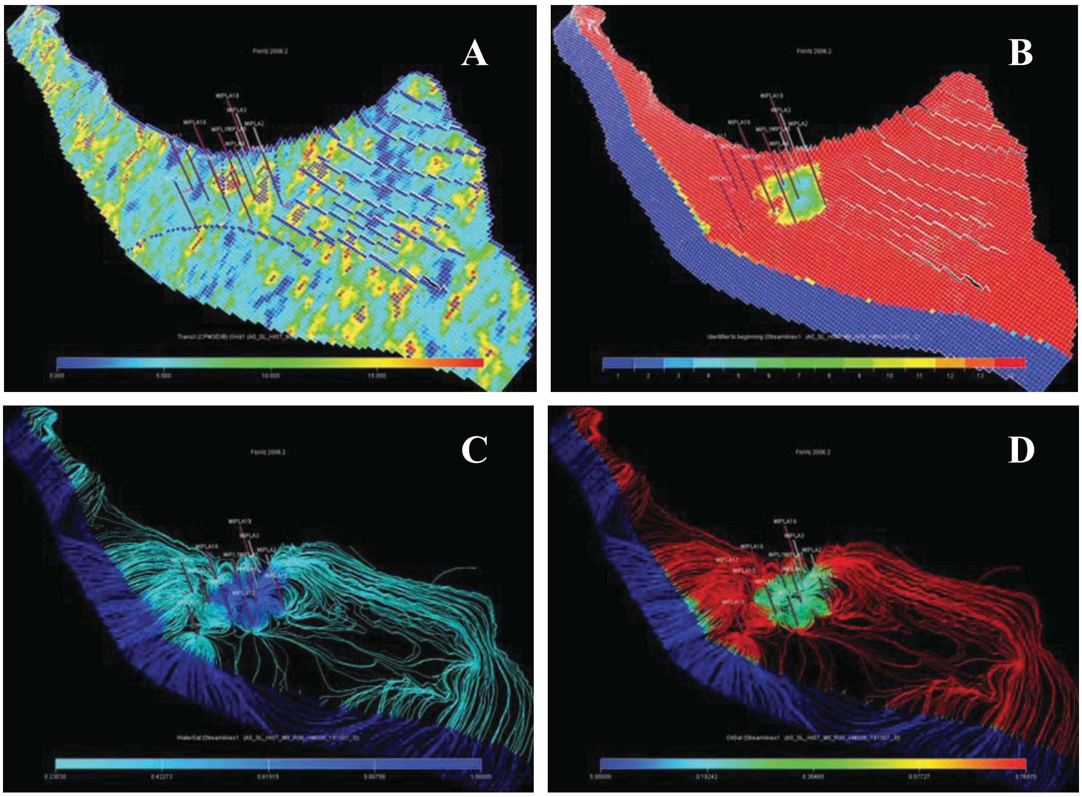


Figure 3.5: Streamline Visualization

Nevertheless, streamline image can also display allocation factors that illustrate the allocation for a given producer relative to the injectors in the field and vice versa. Figure 3.6-A-B, is a good example for this kind of reservoir visualization. The streamline plot coupled with the saturation plots give the user a good indication regarding infill well placement.

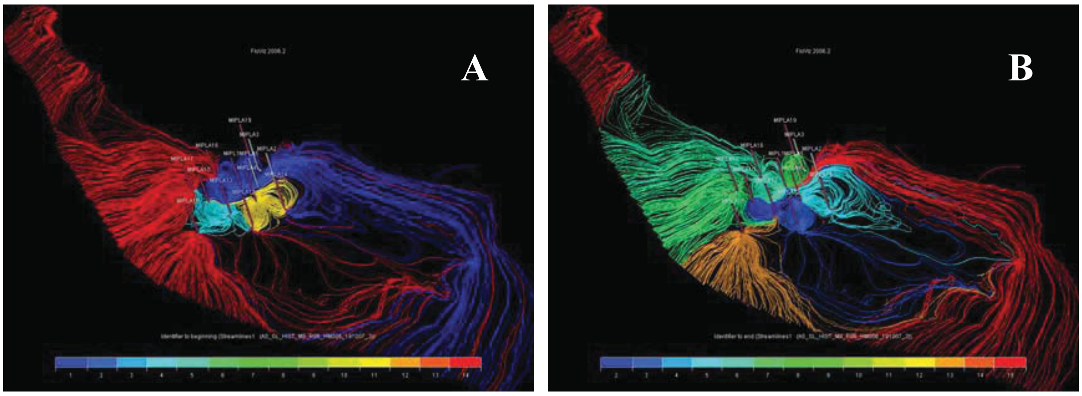


Figure 3.6: Streamline bundles introduced by injectors (A) and producers (B)

Figure 3.6-A introduce the streamline bundles that start from the injectors (Source) and end up in the producers (Sink) whereas, Figure 3.6-B introduces the streamline bundles start from the producers (Sink) and end up in the supported injectors (Source). Streamlines makes it easy to place new injector and producer infill wells into an existing model. The yellow wells shown are new injectors and producers that were inserted into the model forecast. FrontSim generates saturation and streamlines image that include these new wells.

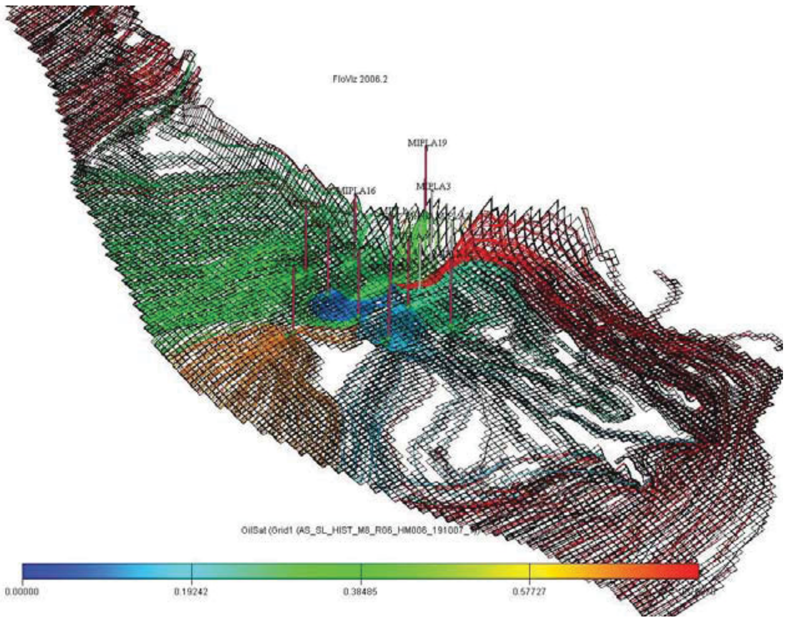


Figure 3.7: Streamline colored by producers across associated gridblocks

The optimal location of infill wells is dependent on a number of factors, including reservoir heterogeneity, other well locations, and displacement mechanism. In all cases, finding the optimal location requires the minimization of some objective function based on dynamic response data and therefore multiple forward simulations. These forward simulations can be run efficiently using streamlines and its fluid flow visualization.

3.1.2.5 Time Step Sensitivity

As it was discussed in the last section, finite-difference method based on an IMPES approach suffers from the time-step length limiting (CFL condition). As the number of cells grows higher, the maximum time-step length gets shorter for a given model. For a very large number of cells, the shortness of the time step can render the total CPU time impractical for a simulation.

It is worth noting that upscaling historical data also would benefit run times for finite difference simulations. Where possible, both streamline simulation and finite difference methods would then require similar simulation times. As the gridblocks becomes finer in finite difference methods, CFL limitations begin to dictate the timestep size, which is much smaller than is necessary to honour nonlinearities. This is why streamline methods exhibit larger speed-up factors over finite difference methods as the number of grid cells increases. Figure 3.8 demonstrate the advantage of the streamline simulation to speed up the runtime for Dogger Beta reservoir model. Implement streamline simulation will significantly reduce the model runtime by three hours and forty minutes, resulted in the way of limited the workflow consuming time.

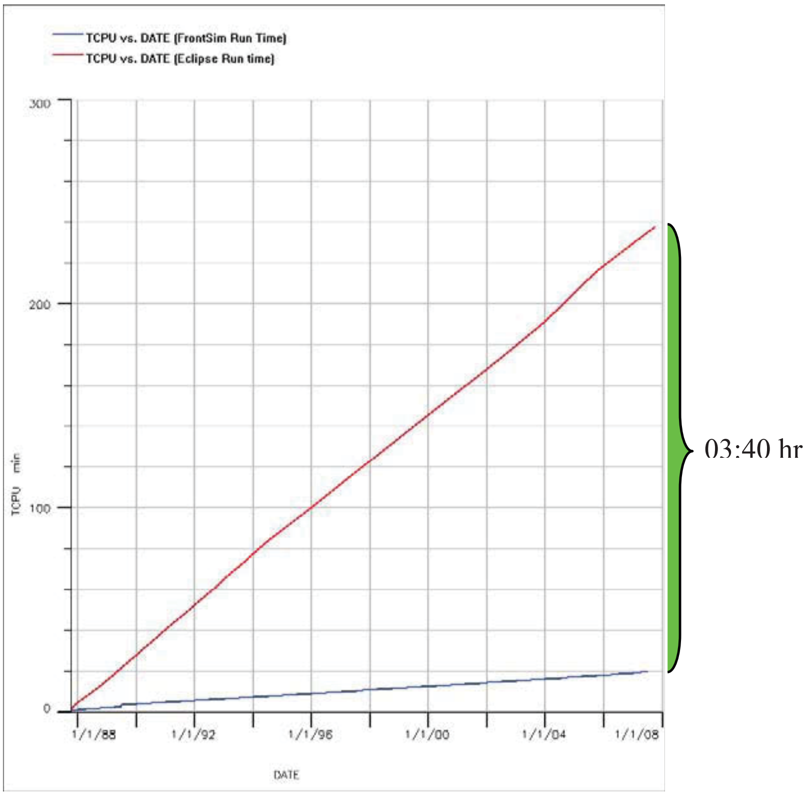


Figure 3.8: Comparison Total CPU time for streamline with finite different approach for the historical data of Dogger Beta reservoir

The timestep duration in streamline methods is not limited by a classic grid throughput CFL condition but by how far fluids can be transported along the current streamline grid before the streamlines need to be updated. Factors that influence this limit include nonlinear effects like mobility, gravity, and well rate changes. In real field displacements, historical well effects have a far greater impact on streamline-pattern changes than do mobility and gravity.

The speed of FrontSim is partly dependent on time step lengths. This is because if any time well conditions are changed, FrontSim has to re-solve the pressure equation. Therefore, FrontSim is forced to take a time step each time a new historical well data is given. By averaging the production rates over longer time steps, such as quarterly or half year time steps, some speed advantage can be obtained.

Streamlines simulation may need to be updated only infrequently and the transport equations along streamlines can often be solved analytically. Even though, the 1-D numerical solutions along streamlines are not constrained by the underlying grid stability criteria, thus allowing for larger timesteps to rum the model, and radically decrease the CPU time. By averaging the production rates over longer time steps, such as quarterly, half year, or even five years time steps, the speed up of the run time advantage can be obtained.

If the displacement is mainly convective dominated, sensitivity studies are best done using streamlines due to the speed of the method. The first concern is the timestep duration that honours the accuracy of the model.

According to Dogger-Beta reservoir model, we have implemented different timesteps in order to define adequate timestep duration. The result of this sensitivity is demonstrated in the following graph (figure 3.9).

Timestep, day	1	30	91	180	365	1825	2737.5
Timestep, year	0.0027	0.083	0.25	0.5	1	5	7.5
CPU Time, min	1200	55	24	13.5	9	5.5	5

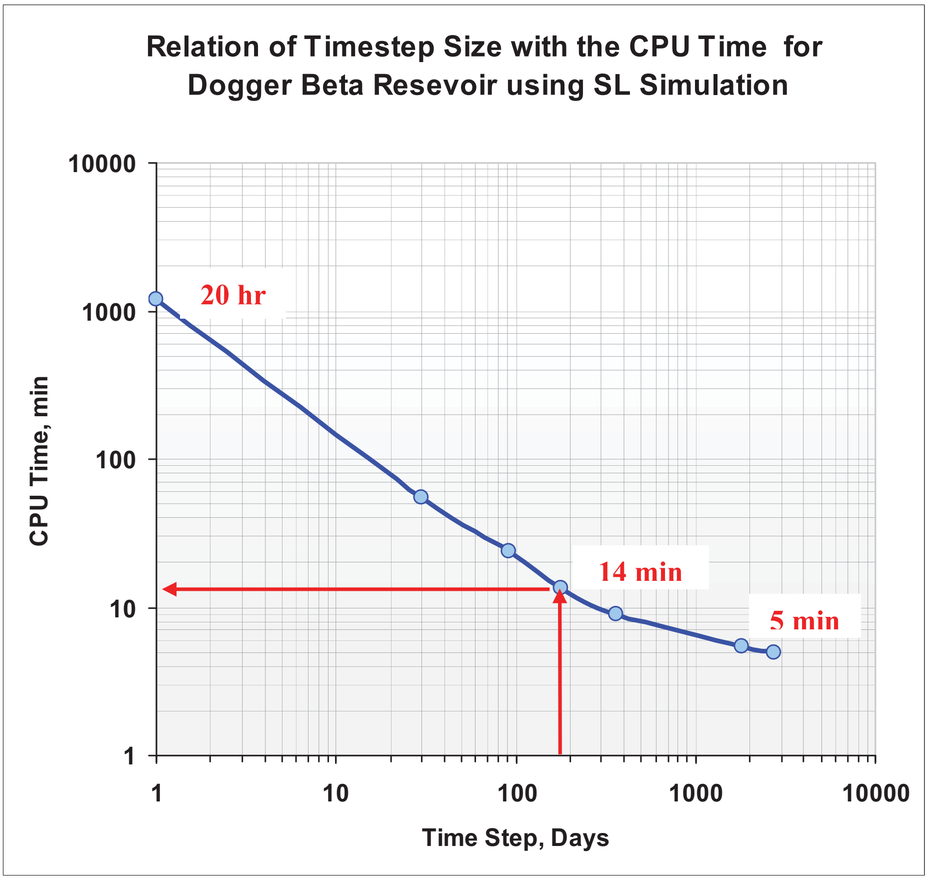


Figure 3.9: Timestep Sensitivity for Dogger Beta Reservoir

Time step duration is one of the most influences parameters, which should be controlled in order to get the advantage of the speed up rum time model in streamline simulation. The speed of streamline simulation is partly dependent on time step lengths. This is because if any time well conditions are changed, the streamlines have to re-solve the pressure equation. Therefore, simulation is forced to take a time step each time a wells condition is given. Thus, the key is determining how much historical data can be upscaled without significantly impacting simulation results. For all cases considered here, 3 months timestep sizes were more than adequate to capture changes in historical data, gravity, and mobility effects.

In fact, five and seven year's time steps show a sharp differential from the actual trend of the cumulative oil production. That is why we exclude them from the consideration, and upscale the production history up to 90 days time step duration.

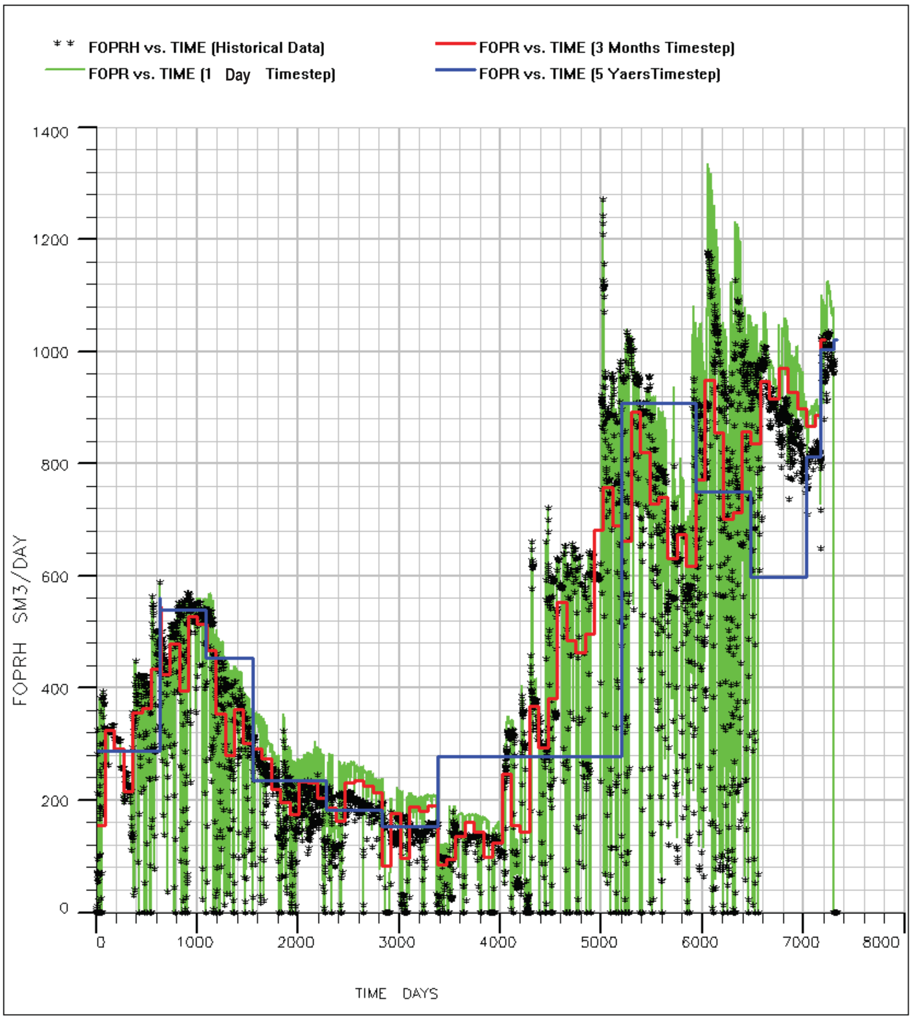


Figure 3.10: Dogger beta oil production rate with different timestep compared with historical data

Figure 3.10 shows historical field oil production rate compared to different streamline simulation results, which conducted with different time step duration (1 day, 3 months and 5 years). It is important to recognize that five years time step behave out of the historical trend.

Before predicting future performance, it was essential to match the historical production performance under primary depletion.. RWE Dea had already completed a history-matched model using a commercial finite difference simulator, Eclipse. The streamline FrontSim simulator was used to reproduce the history match results with the same time step. Figure 3.12 illustrate the history match results for both models approach.

It is important to mention here that streamline simulation does not exhibit large speed up factor when timestep is relatively small. It takes more than 12 hour to run Dogger-Beta model with one-day timestep. Conversely, it is worth nothing that upscaling the historical data also would benefit rum time for finite difference simulator.

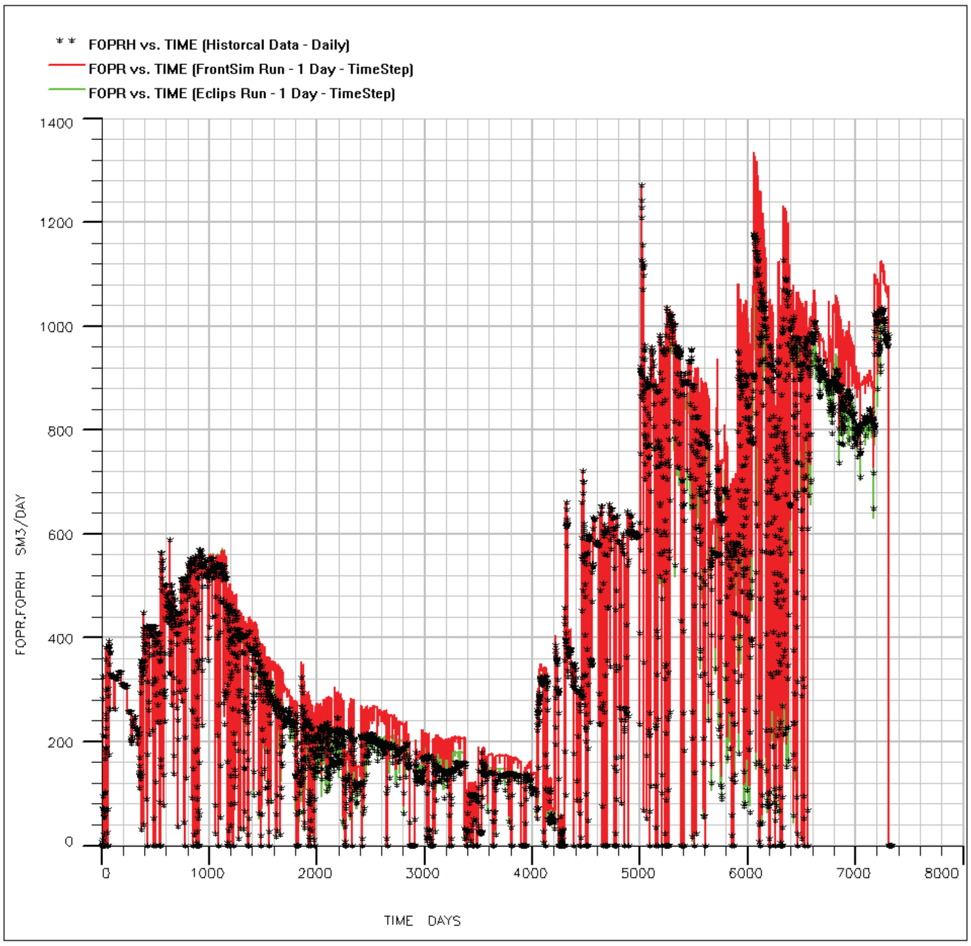


Figure 3.11: Historical Field Oil Production compared with streamline and finite different result

Presumably, Finite different result in figure 3.12 shows better mach to the historical data than streamline simulation result. The minor variation between both models is due to the differences in the computational technique. More over, FrontSim does not honour individual well targets along with the field/group control. Practically, It is recommended to use total reservoir rates as target if it possible. In general, the modification and the adjustment for history mach were performed with respect to the result of finite difference.

Because of our target is to demonstrate waterflooding management using streamline, this mach was accepted to initiate the predication case. In order to do so, three months time step model has been conducted as illustrated in figure 3.12.

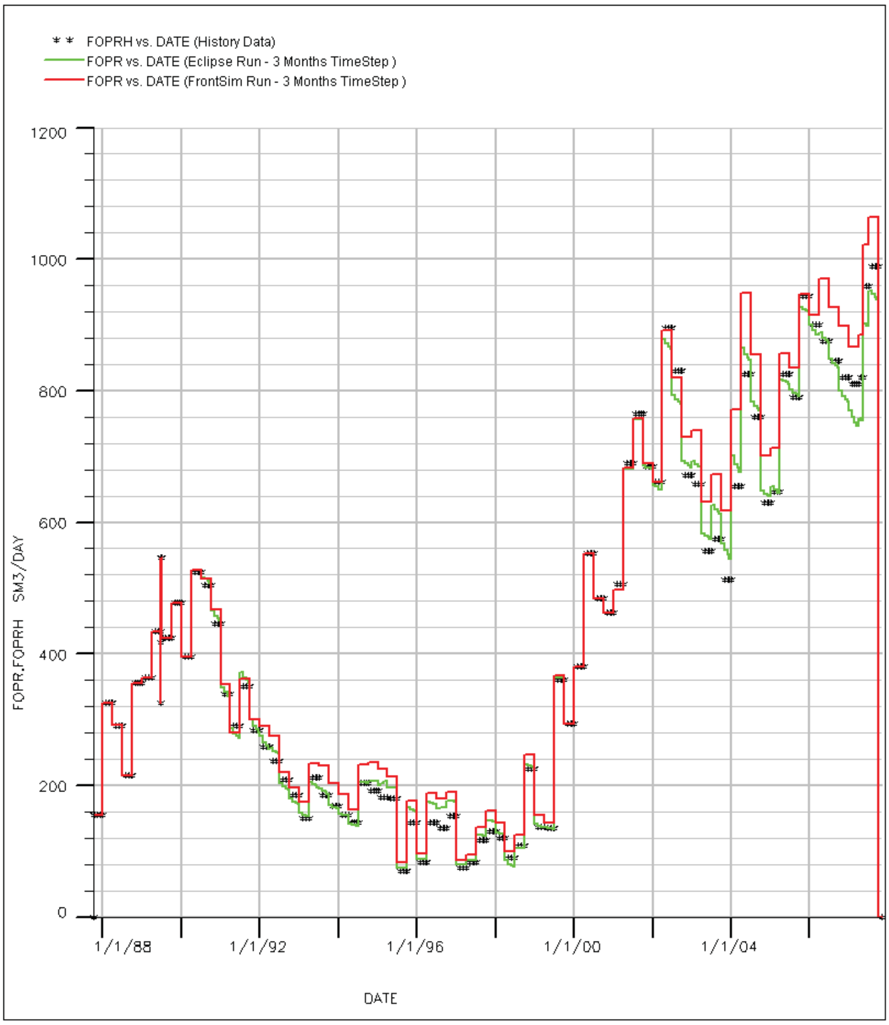


Figure 3.12: Historical Field Oil Production compared with streamline and finite different results

Eventually, the result of streamline simulation is not vary too mach comparing with finite difference approach as it shows in the following figures. The well pressure, field pressure, and historical rates are in an accepted agreement for the purpose of waterflood management. The well water cut was, in general, a little higher than in the Eclipse results.

The forward comparison between finite difference approach and streamline simulation is illustrated in the following figures. Notably, SL refers to the Streamline simulation and FD to finite difference approach. Streamline simulation model shows higher cumulative oil production, lower reservoir pressure and early water breakthrough.

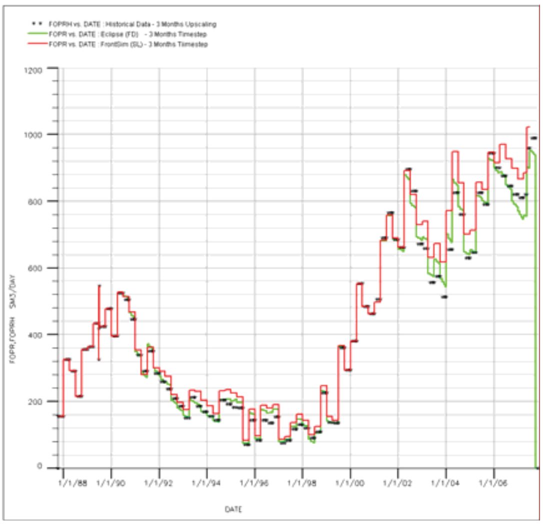


Figure 3.13: Historical Field Oil Production Rate compared with SL and FD results

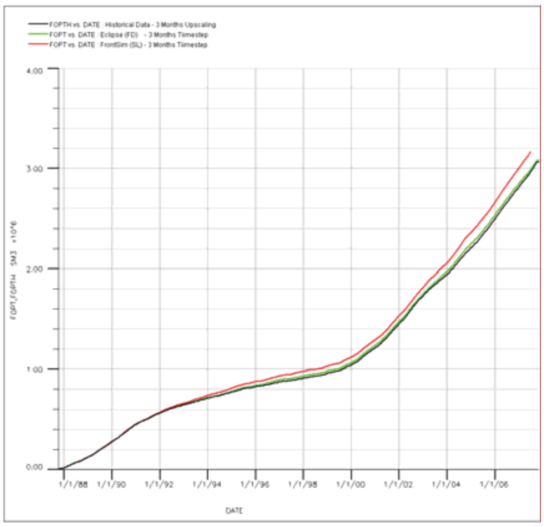


Figure 3.14: Historical Cumulative Field Oil Production compared with SL and FD results

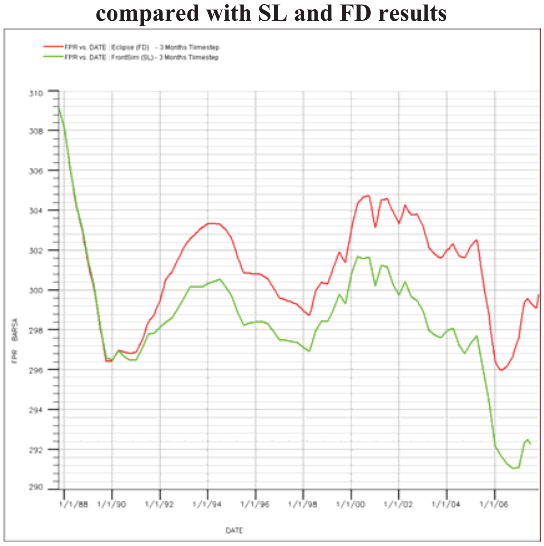


Figure 3.15: Field Reservoir Pressure Result of SL compared with FD Simulation

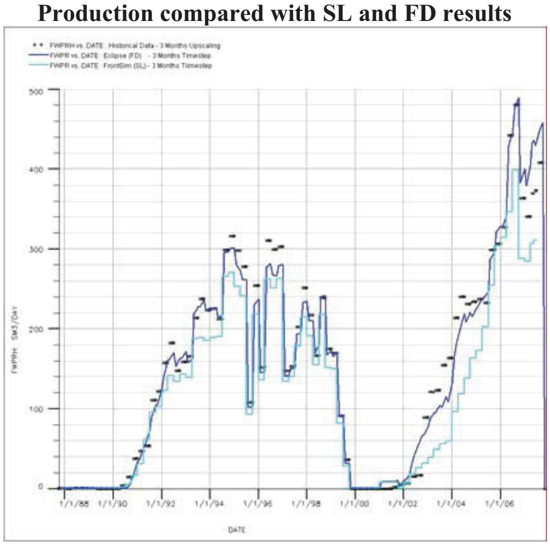


Figure 3.16: Historical Field Water Production Rate compared with SL and FD results

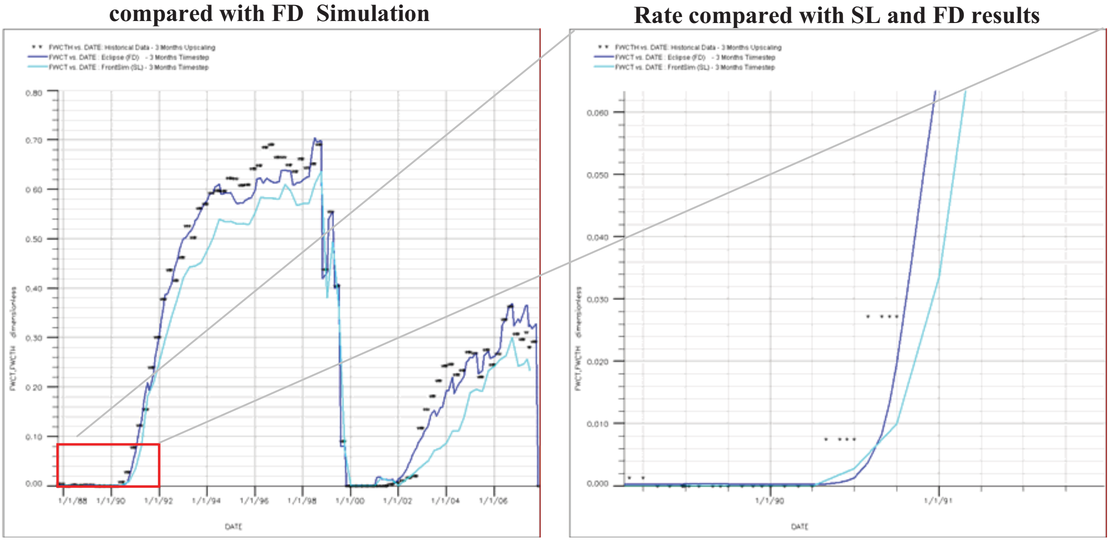


Figure 3.17: Historical Cumulative Field Water Production compared with SL and FD results

3.1.2.6 Historical Well Data Effect

There are an important practical issue that is worth mentioning here. Changing field conditions such as infill drilling and rate changes are accounted for by streamline updating.[12]

Streamlines will change over time because of changes in well rates, well locations, and distribution of fluid mobility's. Changing streamlines also means that the initial conditions for the transport problem will generally not be uniform and require a numerical solution. In general, the most dramatic changes in streamline geometry are given by changing well rates and/or wells coming on or going off line. The more wells and the higher the well rates, the more the streamline paths are pinned down by the location of injector/producer pairs. Streamline paths will only undergo major shifts when well rates change significantly or new well configurations occur.

As observed in figure 3.19, MIPL1 is supported four producers in July 2004. As soon as MIPLA13 converted to injector in July 2005, the streamline path is changed with different direction. The same when MIPLA19 was put on production in July 2006, different result would be obtained. Finally, in July 2007 MIPLA5 was shut down and as the result of that, we have got new streamline directed to the south part of the reservoir.

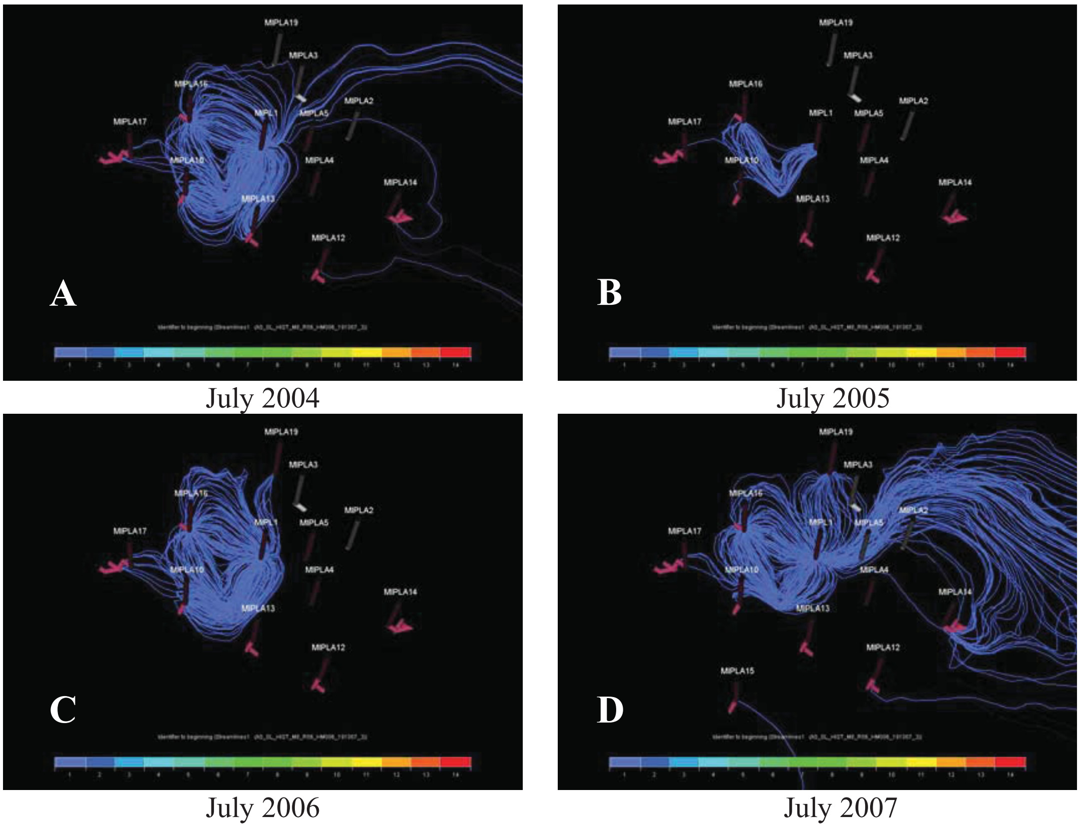


Figure 3.18: Changing streamline with changing well rates and locations

3.1.2.7 Time of Flight (TOF)

The time-of-flight, τ, introduced by Pollock (1988) and used by King et al. (1993) and Datta-Gupta and King (1995), is the time taken for a neutral tracer particle to move a distance x along a streamline starting from a source (i.e. injector).

The time-of-flight (left) can be painted on streamlines showing areas that will be swept over time as illustrated in figure 3.19. Observed TOF after 1825 days shows the propagation of water break through into the producers. In addition, after 14 600 days the aquifer support show a high contribution to the MIPLA15 and 17. This will leads to better understanding to the flow behaviour in time scale. Not only swept area could be identified over time but also it is also possible to plot drainage time showing the areas drained over time by producers

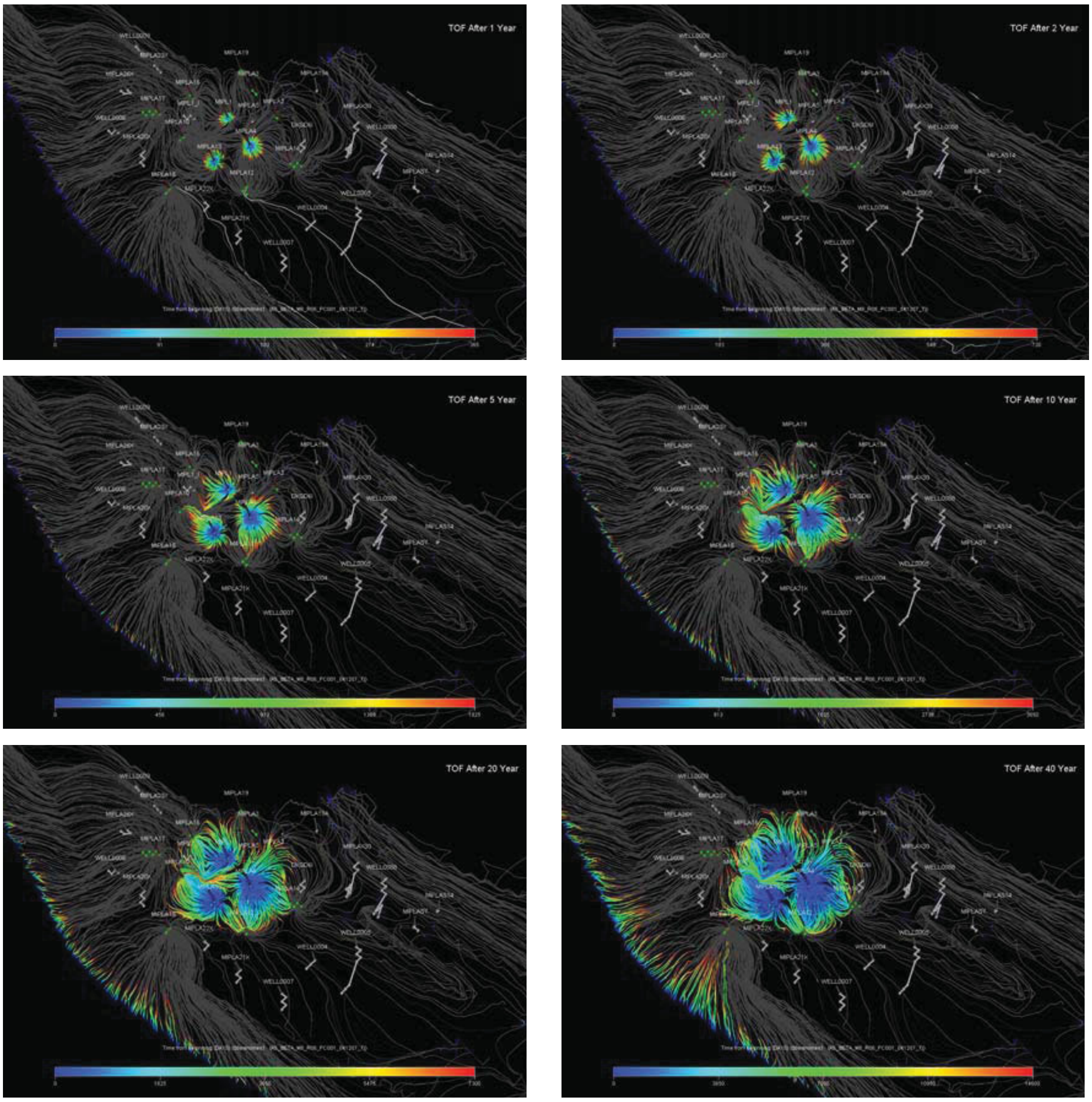


Figure 3.19: Field Status in July 2007with Different Time of flight (from 1 year, up to 40 year)

3.2 Current status of the reservoir conditions

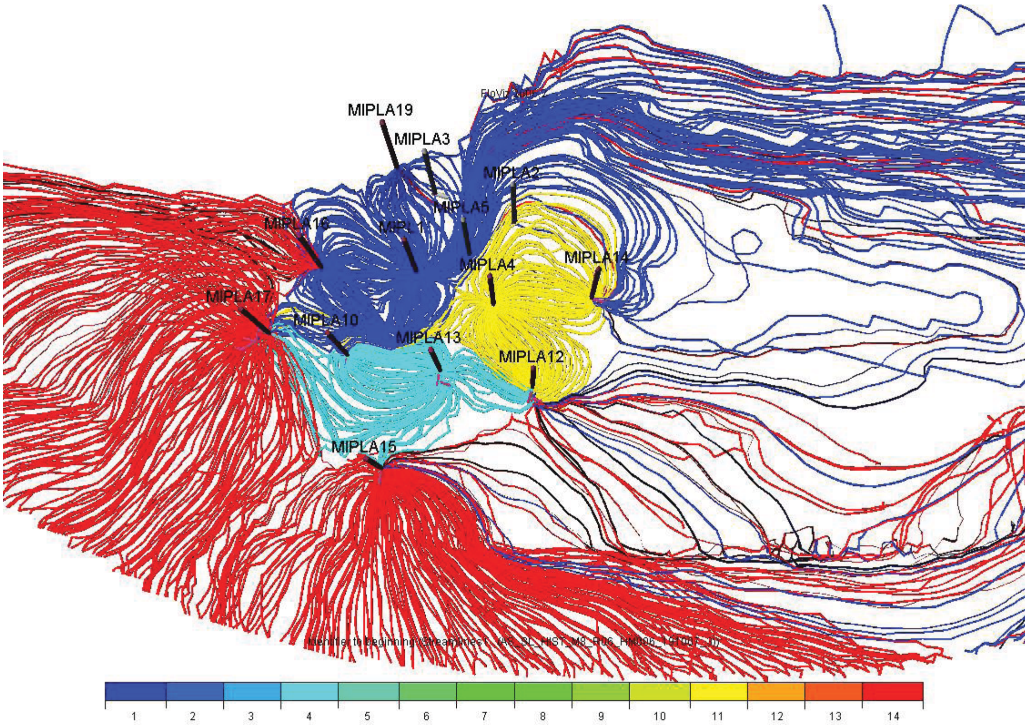


Figure 3.20: streamline colored by injectors for Dogger Beta reservoir at July 2007

As shown in Figure 17, there are areas of intense flux (dense streamlines) and areas of relative inactivity. Additionally, Figure 17 shows the relationship between the injectors and producers. The streamlines are coloured by injector or producer to show the regions that each well is influenced by which are clearly defined. Alternatively, each streamline could have been be coloured by saturation, injector, time-of-flight to or from well. All of this information can be output and visualized as a grid array and used for waterflood management and history matching. Also the allocation of fluids to or from each well can be output as a table which is useful to compare with production analysis values. There is a wealth of information associated with streamlines, which goes far beyond the saturation tracking and the dynamic visual display.

Streamline Simulation goes beyond their visual appeal by producing new engineering data, which is not available from a classical reservoir approach such as Finite difference. By construction, streamlines allow one to gather data that is not possible to extract from finite-difference simulators. The following section a simple illustration of each injector and its performance at the current status of Dogger Beta reservoir (July 2007).

3.2.1.1 Injector MIPL1

Source	Sink	Rate(m^3/D)	Fraction	PoreVolume(m^3)
MIPL1		-379.08	1.00	4.302E+07
MIPL1	MIPLA16	-242.96	0.64	2.798E+06
MIPL1	MIPLA19	-79.61	0.21	1.387E+06
MIPL1	MIPLA10	-22.65	0.06	1.715E+05
MIPL1	MIPLA14	-19.62	0.05	7.731E+06
MIPL1	MIPLA17	-11.60	0.03	3.007E+05
MIPL1	P-edge	-2.46	0.01	2.633E+07
MIPL1	MIPLA12	-0.16	0.00	3.922E+06
MIPL1	MIPLA15	0.00	0.00	3.752E+05

Table 3-2: Pattern Allocation Report for Well MIPL1

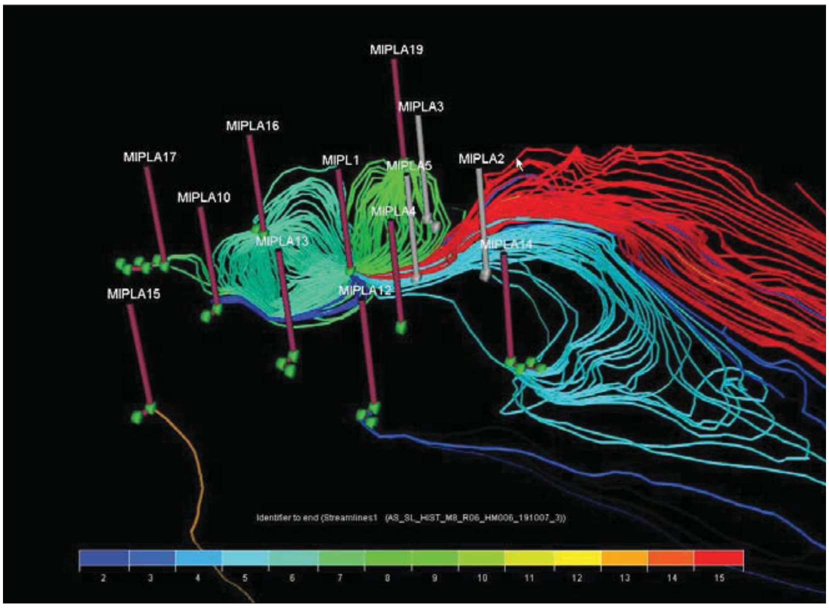


Figure 3.21: Flow visualization of the injector MIPL1

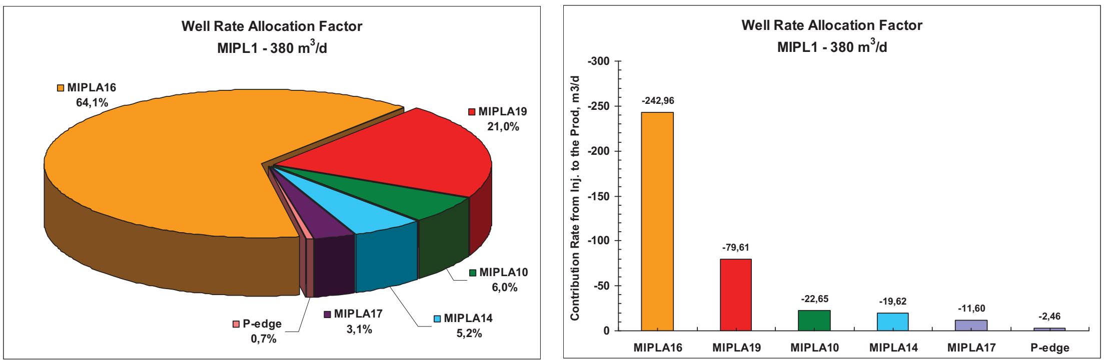


Figure 3.22: Well allocation factor for the injector MIPL1

According to the well allocation factor, the most injected water of MIPL1 contributed to MIPLA16. The term P-edge is referred to the water lost to the aquifer.

3.2.1.2 Injector MIPLA13

Source	Sink	Rate(m^3/D)	Fraction	PoreVolume(m^3)
MIPLA13		-290.09	1.01	3.219E+06
MIPLA13	MIPLA10	-193.73	0.67	9.312E+05
MIPLA13	MIPLA12	-46.16	0.16	4.996E+05
MIPLA13	MIPLA17	-39.19	0.14	1.217E+06
MIPLA13	MIPLA15	-11.01	0.04	5.708E+05

Table 3-3: : Pattern Allocation Report for Well MIPLA13

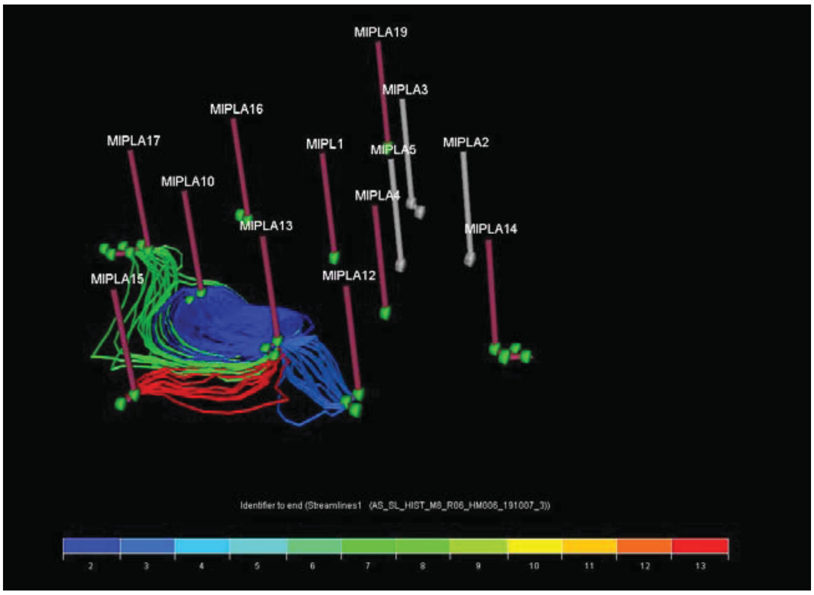


Figure 3.23: Flow visualization of the injector MIPLA13

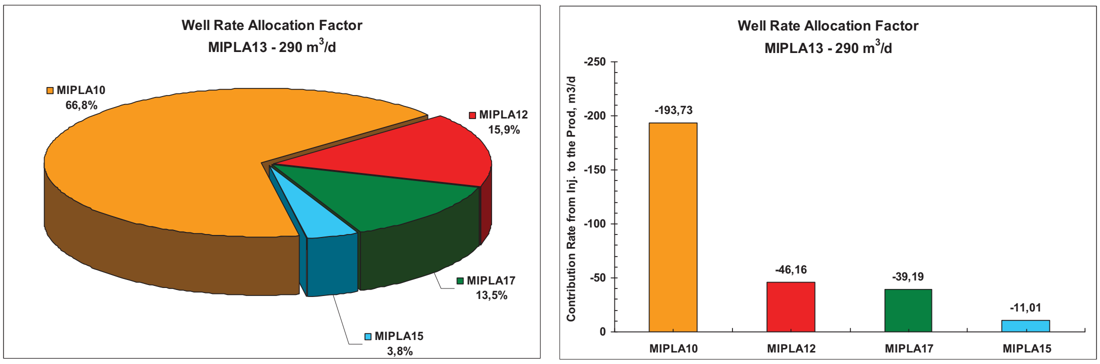


Figure 3.24: Well allocation factor for the injector MIPLA13

According to the well allocation factor, the most of the water that injected in MIPLA13 contributed to MIPLA10.MIPLA12, MIPLA17 and MIPLA15 relatively have less water support by MIPLA13.

3.2.1.3 Injector MIPLA4

Source	Sink	Rate(m^3/D)	Fraction	PoreVolume(m^3)
MIPLA4		-367.42	1.00	3.714E+06
MIPLA4	MIPLA12	-197.63	0.54	1.748E+06
MIPLA4	MIPLA14	-142.72	0.39	1.577E+06
MIPLA4	MIPLA10	-24.15	0.07	2.313E+05
MIPLA4	MIPLA17	-2.10	0.01	1.331E+05
MIPLA4	P-edge	-0.82	0.00	2.442E+04

Table 3-4: Pattern Allocation Report for Well MIPLA4

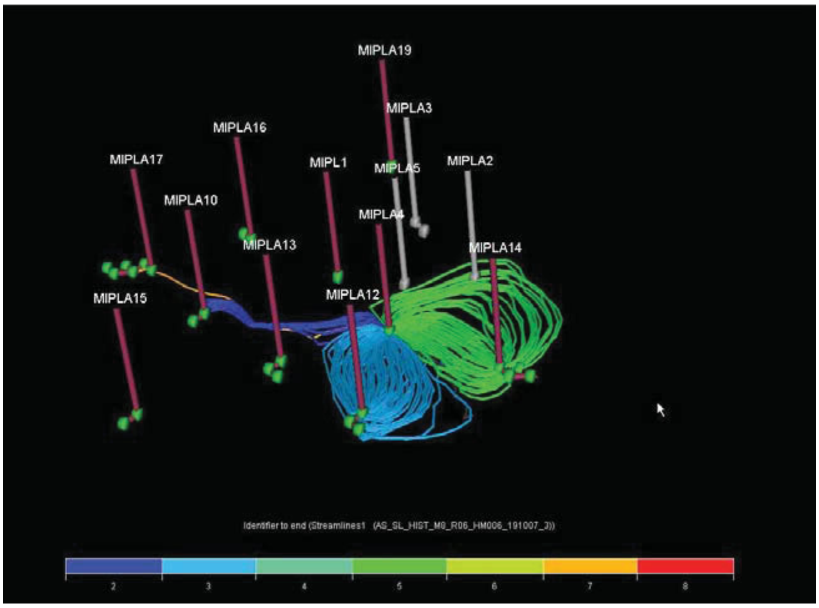


Figure 3.25: Flow visualization of the injector MIPLA4

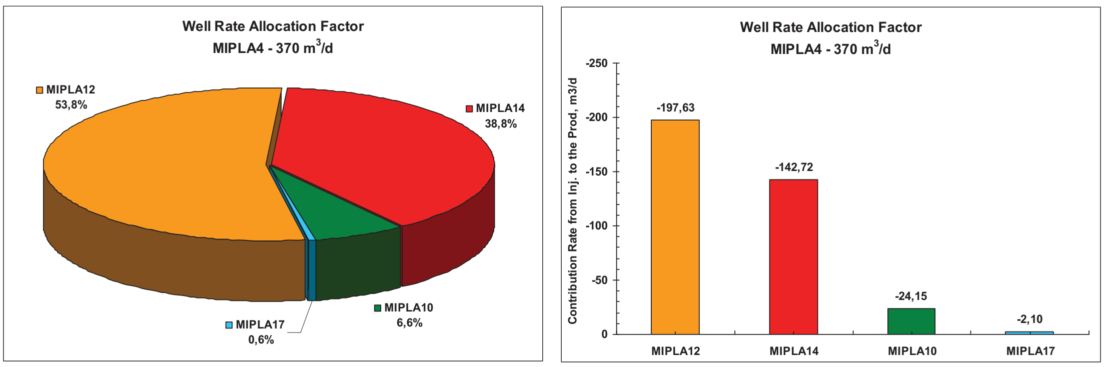


Figure 3.26: Well allocation factor for the injector MIPLA4

MIPLA12 and MIPLA14 receiving most of its flow from the injector MIPLA4, whereas supporting MIPLA 10 by only 6.6%

3.2.1.4 Dogger beta Injection Efficiency

Injection efficiency is simply defined as the total offset oil production that produced by water injection divided by the total amount of injected water.

$$IE = \frac{offset\ oil\ production\ \ rate}{Injected\ water\ rate}$$

Well Name	Injected Water	Offset Oil Produced	Injection Efficiency
	Sm^3	Sm^3	%
MIPL1	384	350	91%
MIPLA13	294	184	63%
MIPLA4	372	175	47%

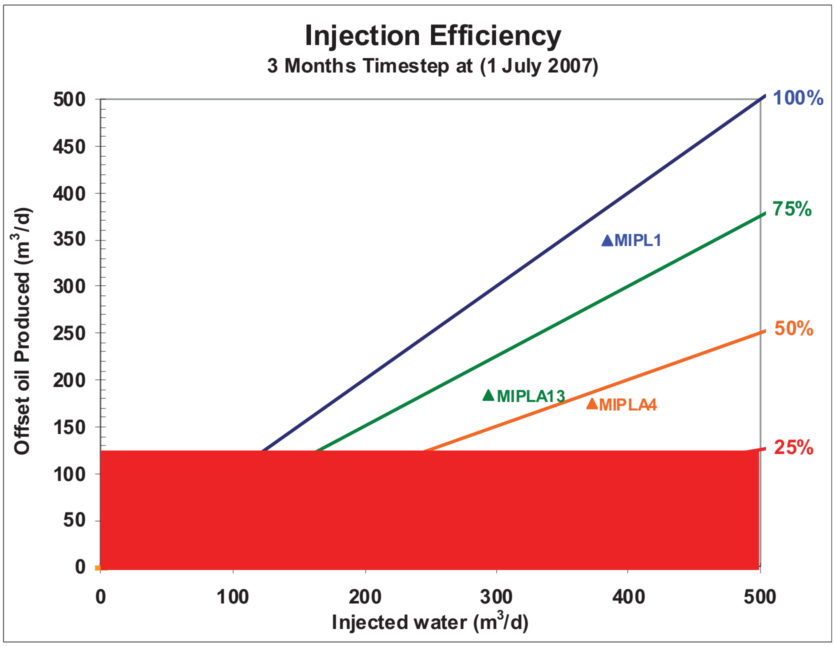


Figure 3.27: injection Efficiency at 1 July 2007

Each point in the pervious plot represents an injector. The injectors are plotted according to their efficiency concerning oil production. It can also calculate and plot injection efficiency for a reservoir. In this case, the blue injectors affect far more oil to be produced per unit of water injected than the green injector does.

The efficiency plot can be mapped aerially to provide an indication of where the injection is most effective (above the orange line) or where areas have been well swept (below the red line). Any injector located in the red region would be the prim candidate for optimization.

3.3 Prediction Optimization

3.3.1 Methodology

Because streamlines quantify the connectivity of injectors and producers as a function of reservoir geology, well placement and rates, PVT properties, etc., it is possible to optimally distribute injected volumes to minimize injected and produced water while maximizing oil production.

The first use of proposed methodology introduced by Macro R. Thiele and Rod P. Batycky, StreamSim Technology at 2006 (*SPE paper 80084*).[12]

The methodology focuses on the unique ability of streamline simulation to define the dynamic well allocation factors (WAF) between injection and production wells. The quantification of WAF will lead to estimate the Injection efficiency (IE) for each injector and for injection/production pairs (e_{wp}).

The criteria is to reduce the injected water rate in the low efficiency wells and increase the injection rates in the efficient wells based on the average field efficiency and by using sort of weighting function.

Injector with bad efficiency and high injection rate are the best candidate for reduction of water injection. Conversely, the high efficient wells with low water injection have to be more promoted by increasing the water injection. The proposed methodology is mainly focus on reallocate water injection rather than changing well location for best optimization.

3.3.2 Injection Efficiency (IE)

IE quantifies how mach oil can be recovered at producing well for every unit of water injected by an offset injector that connected to it.[12]

$$IE = \frac{offset - oil\ production\ \ rate}{Injected\ water} = \frac{\sum_{P=1} q_o^{p-i}}{Q_w^i} \quad \text{…..... 3.2}$$

Once IE known, improved water flood management can be implemented by relocation injected water from low-efficient to high-efficient injector. The main target is to mange injection well rate by reduced cycling of injected fluid while increasing or even maintaining the oil rate.

In order to improve the injector efficiency, well allocation factors (WAF) will be utilized to construct IE plot. Following is the systematic procedure:

1. Generate allocations file (*.ALLOC) using FrontSim simulator.
2. Select an interested injector for the evaluation.
3. Obtain the total injection rate from allocation file; this value is the X-Axis on the 2D plot.
4. Select each corresponding producer that connected to this injector. Then obtain the production rate corresponding to the selected injector.
5. Repeat the last step for all corresponding producers that connected to the selected injector.
6. Sum up the entire production rate from all corresponding producers; this value is Y-Axis on the plot and represents the offset oil production.
7. Repeat these steps for each individual injector and plot them in the same plot.

The efficiency plot is divided into percentage lines. The 100% efficiency line lies along the 45 degree. Injectors that laying a long this line, are the most efficient injectors, since every injected cubic meter produces an equal volume of oil. Similarly, the 75% efficiency line lies along 33.75 degree line and so on. The injection wells under the 25% efficiency line (11.25 degree), on the other hand, represent the most inefficient well; wells that inject high volume of water and produce a little in term of offset oil production. These wells are a prime candidate for shut-in or reallocation the injection rate. Particularly in case where the amount of water is limited by surface facilities, it is more effective to inject the water elsewhere in the field where the efficiency is demented better.

IE is changed with time dependent on the updated well conditions and reservoir depletion. The injection efficiency cross-plot was constructed at the end of production history, 1st July 2007, as shown in figure 3.24. Each point on the plot represents an individual injector well.

Well Name	Injected Water	Offset Oil Production	Injection Efficiency
	Sm^3	Sm^3	%
MIPL1	384	350	91%
MIPLA13	294	184	63%
MIPLA4	372	175	47%
Field	**1050**	**709**	**68%**

Table 3-5: Injection Efficiency for each injector combined with Average field efficiency

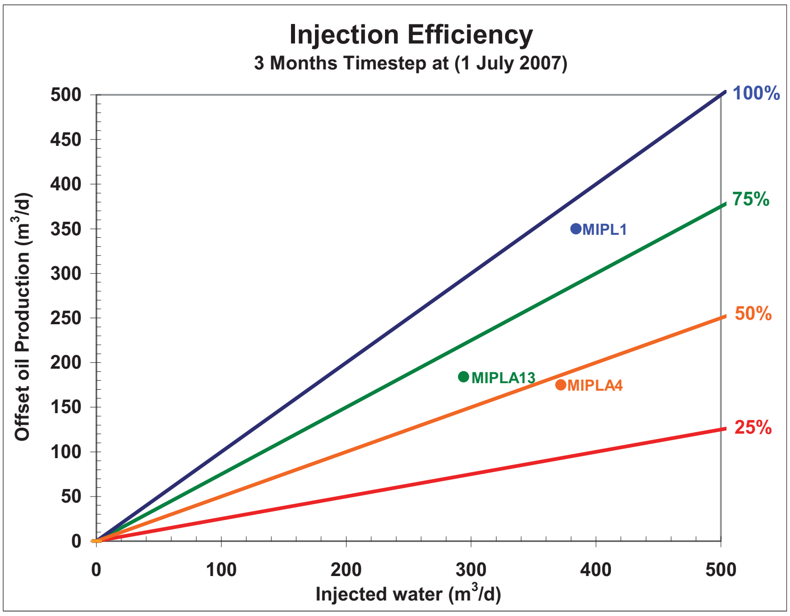


Figure 3.28: Injection Efficiency at 1 July 2007

It could be also calculate and plot injection efficiency for a reservoir. The injectors are plotted according to their efficiency with regards to oil production. In this example, the green injectors affect far more oil to be produced per unit of water injected than the red injector.

Average field efficiency is not the average value among the offset oil production rate and the total injected rate, it calculated using the sum of oil produced divided the water injected.

The efficiency plot can be mapped aerially to provide an indication of where the injection is most effective (above the green line) or where would be chosen for reallocation the injection rate or even shut-in (below the red line).

3.3.3 Well Pair Efficiency

It is another term to illustrate the efficiency. The well pair efficiency (e_{wp}) is calculated in the same way as IE of injectors, except that in this case injection water associated with each bundle of streamline must be extracted.

The well pair efficiency is the value to be used in order to reallocate the water injection for the individual injector. Nevertheless, it is another way to express the oil cut between well pairs.

Field Condition		
Water m^3/d	Oil m^3/d	IE %
1050	**709**	**68%**

Total Injection Rate for		**MIPL1**	**is**	**384**	**m^3/d**

Source (Injector)	Sink (Producer)	Water in m^3/d	Oil Out m^3/d	e_{wp} %
MIPL1	MIPLA10	23	9	39%
MIPL1	MIPLA12	0	1	-
MIPL1	MIPLA14	20	32	-
MIPL1	MIPLA15	0	1	-
MIPL1	MIPLA16	246	220	89%
MIPL1	MIPLA17	12	9	80%
MIPL1	MIPLA19	81	78	97%
MIPL1	P-edge	3	0	0%

Total Injection Rate for		**MIPLA13**	**is**	**294**	**m3/d**

Source (Injector)	Sink (Producer)	Water in m^3/d	Oil Out m^3/d	e_{wp} %
MIPLA13	MIPLA10	196	103	53%
MIPLA13	MIPLA12	47	27	57%
MIPLA13	MIPLA15	11	25	-
MIPLA13	MIPLA17	40	30	75%

Total Injection Rate for		**MIPLA4**	**is**	**372**	**m3/d**

Source (Injector)	Sink (Producer)	Water in m^3/d	Oil Out m^3/d	e_{wp} %
MIPLA4	MIPLA10	25	9	36%
MIPLA4	MIPLA12	200	84	42%
MIPLA4	MIPLA14	145	80	55%
MIPLA4	MIPLA17	2	2	84%
MIPLA4	P-edge	1	0	0%

Table 3-6: Well Pair Efficiency at 1 July 2007

3.3.4 Flux-Pattern Map

Flux-Pattern Map (FPmap) breaks down all the streamlines into a single straight-line segment between each source (injector) and associated sinks (Producers), where thickness is used to represent the contribution strength of the flow rate between the pairs.

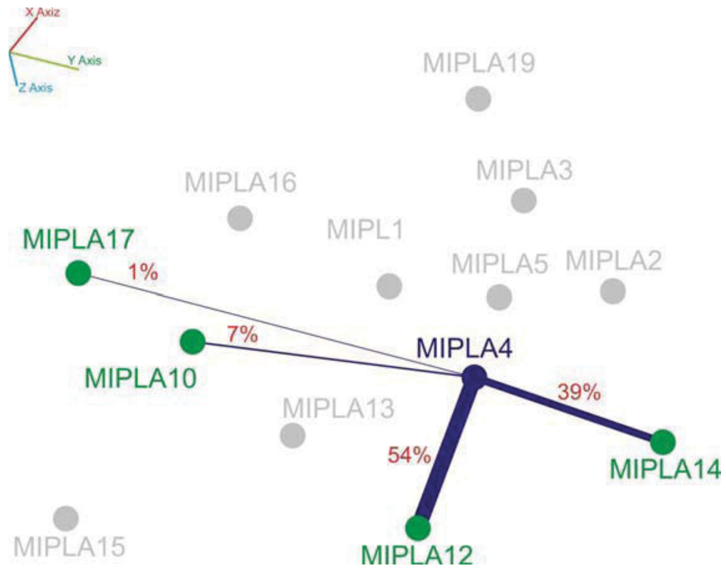


Figure 3.29: Injection Efficiency for injector MIPLA4 at 1 July 2007

By applying the same role of MIPLA4 for the entire reservoir, the Flux-Pattern map for Dogger Beta reservoir at 1 July 2007 will looks as following:

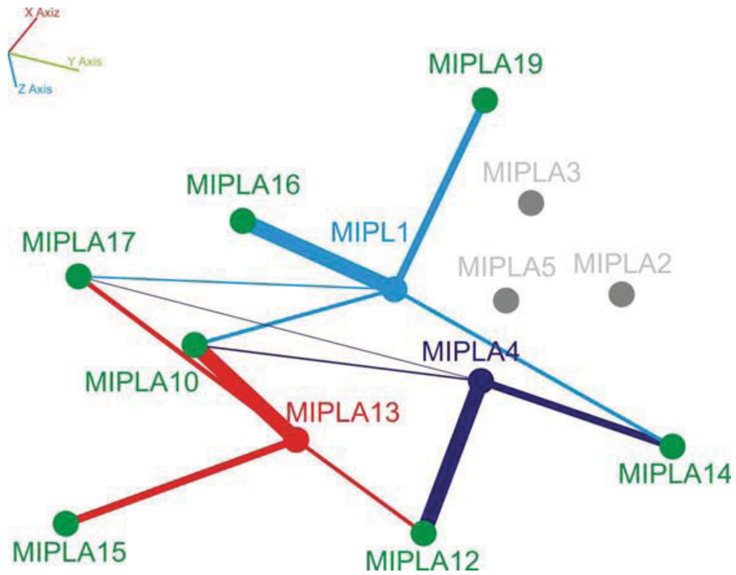


Figure 3.30: Injection Efficiency at 1 July 2007

3.3.5 Well Rate Weight Function

The way of reallocate the rate is dependent on the injection rate associated with each injection/producer pair. The idea is to multiply the old injection rate by a factor of (1+ w_i) where (w_i) is a function of well pair efficiency of that connection and (i) refer to the injector/producer pair. The function would be as the following:

$$q_i^{new} = (1 + w_i) \times q_i^{old} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

Average field efficiency is chosen to be used as a reference point to decide wither the weight should be larger or less than zero.

For instance, the average injection efficiency at 1st of July 2007 is 68%. An injector such as MIPL1 is supporting five producers (MIPLA10, MIPLA16, MIPLA17, MIPLA19, and MIPLA14), each of those producers has individual well pair efficiency, which leads to decide to increase or decrease the injection rate of associated pair. The goal is to have a weight value grater than zero for the connections such as MIPL1-MIPL10, as the result of the well pair efficiency of this connection is larger than the average field efficiency, (39%). Whereas the weight should be less than zero for the connection MIPL1-MIPLA16, which has well pair efficiency larger than the average field efficiency, (89%).

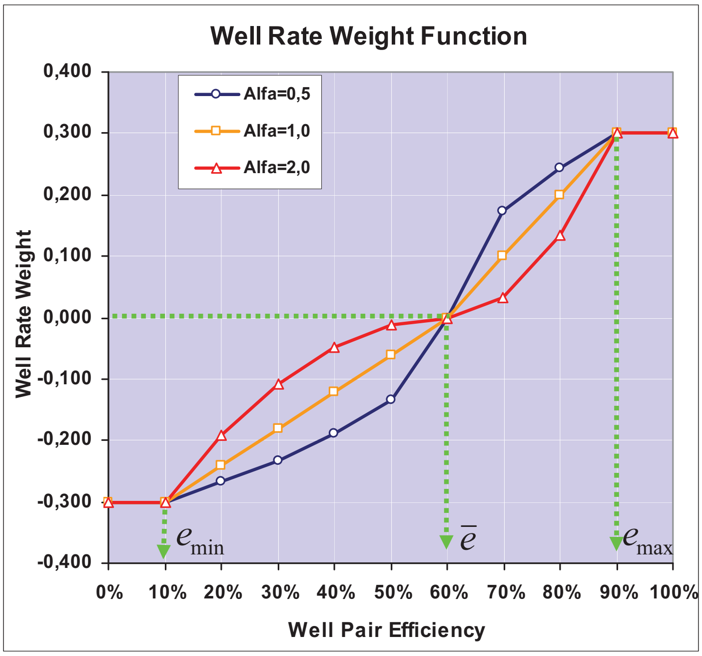


Figure 3.31: Well Weight Function at Average with field efficiency 60%

3.3.6 Optimization

The steps by step for optimize water injection management are summarised as follows:

- Determine Injection Efficiency IE for each injector at current statues.
- Determine Average Injection Efficiency IE for Field at current statues.
- Construct and corresponding Flux Pattern map FPmap for each injector.
- Reallocate injected water using well pair injection efficiency (e_{wp}).
- In order to determine how much reallocate injection from low efficient well pair to height efficient pair, the following function is used:

$$\begin{aligned} &if \quad e_i > \bar{e} \qquad w_i = \min\left[w_{\max},\ w_{\max} \cdot \left(\frac{e_i - \bar{e}}{e_{\max} - \bar{e}} \right)^{\alpha} \right] \\ &if \quad e_i < \bar{e} \qquad w_i = \max\left[w_{\min},\ w_{\min} \cdot \left(\frac{\bar{e} - e_i}{\bar{e} - e_{\min}} \right)^{\alpha} \right] \end{aligned} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3.4)$$

Where:

e_i : Injection Efficiency for well *i*
$\bar{e}$: Average Field IE
w_i : Increase or decrease in weight
$w_{\max}$: Maximum weight at $e_{\max}$
$e_{\max}$: Upper limit of Injection Efficiency
$w_{\min}$: Minimum weight at $e_{\min}$
$e_{\min}$: Lower limit of Injection Efficiency
α: Exponent

3.3.7 Optimization Workflow

In this section describes a novel approach to optimize injection and production well rates in a waterflood using streamline-based (STREAMLINE SIMULATION) flow simulation. The method provides engineers with an approach that is well beyond the traditional field management workflows offered by standard surveillance and finite difference (FD) simulation. The method is automated and therefore applicable to very large fields with many wells.

Streamline based flow simulation is unique in that it allows to quantify the amount of injected and produced fluids between well pairs via well allocation factors (WAF's). WAF's allows calculating the efficiency of injection wells as the ratio of injected water to the oil produced at offset wells. With injection efficiencies known across the field for each injector, water can be reallocated from low-efficiency to high efficiency wells, thereby optimizing production for each barrel of water injected.

6 Optimization step has been established, at the following dates:

- 01 July 2007
- 07 April 2009
- 29 January 2011
- 07 May 2012
- 13 August 2014
- 09 October 2015

For each date of optimization the following step will applied:

- Flow pattern visualization evaluation supported by countrified dynamic *WAF*.
- Calculate *IE's* of injectors
- Calculate Average Field *IE*
- Reallocate the water injection using (e_{wp} function)
- Optimize Production for each (m3) of Water injected
- Camper the result of the reallocation with the initial

The first values that could be extracted from streamline simulation and considered to be quite powerful are dynamic well allocation factor (WAF) for injectors and producers wells. WAF is described how the wells in the reservoir are connected up. It is not a guess; WAF containing all the geological information and historical well rate.

An outline of the proposed procedure is given in a flow chart in figure 3.31

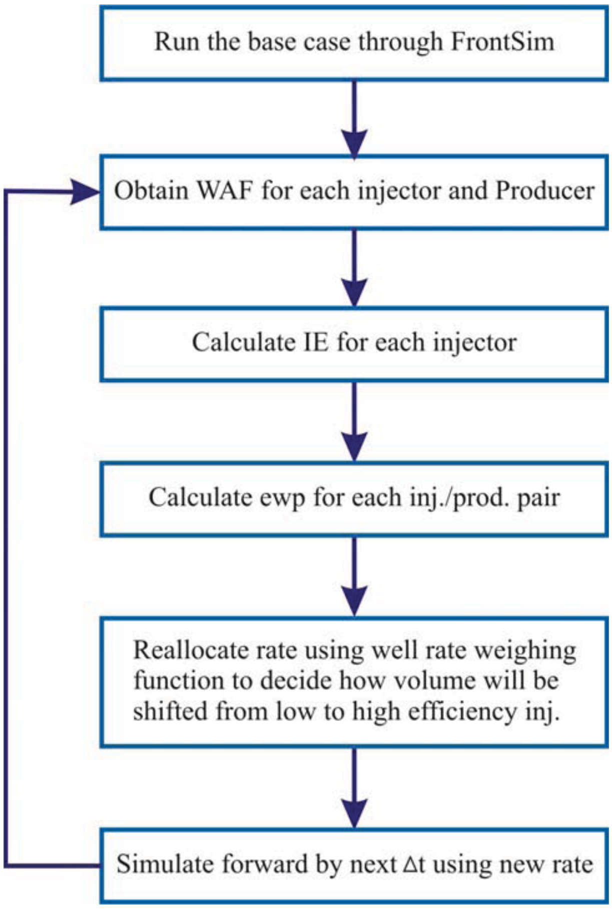


Figure 3.32: Water Injection optimization workflow

3.3.8 Result and Discussion

This section is divided to six subsections independent on the results, which collected each evaluated timestep. The ultimate target is to increase or even maintain oil production and reduce injected ad production water. On other word, decrease cycling water resulted in the way of receded the operating cost.

3.3.8.1 Evaluation at 01 Jul 2007

Injectors Name	Water Injection	Offset Oil	IE
	m3/d	m3/d	%
MIPL1	384	350	91%
MIPLA13	294	184	63%
MIPLA4	372	175	47%
Field	1050	709	68%

Table 3-7: Well allocation report at 1 July 2007

The average field injection efficiency is 68%, which is fairly good. This means 1050 m^3 injected water is responsible to produce 709 m^3 of oil. Figure (3.33) shows the Injection efficiency of each injection posted cross the main four efficiency lines.

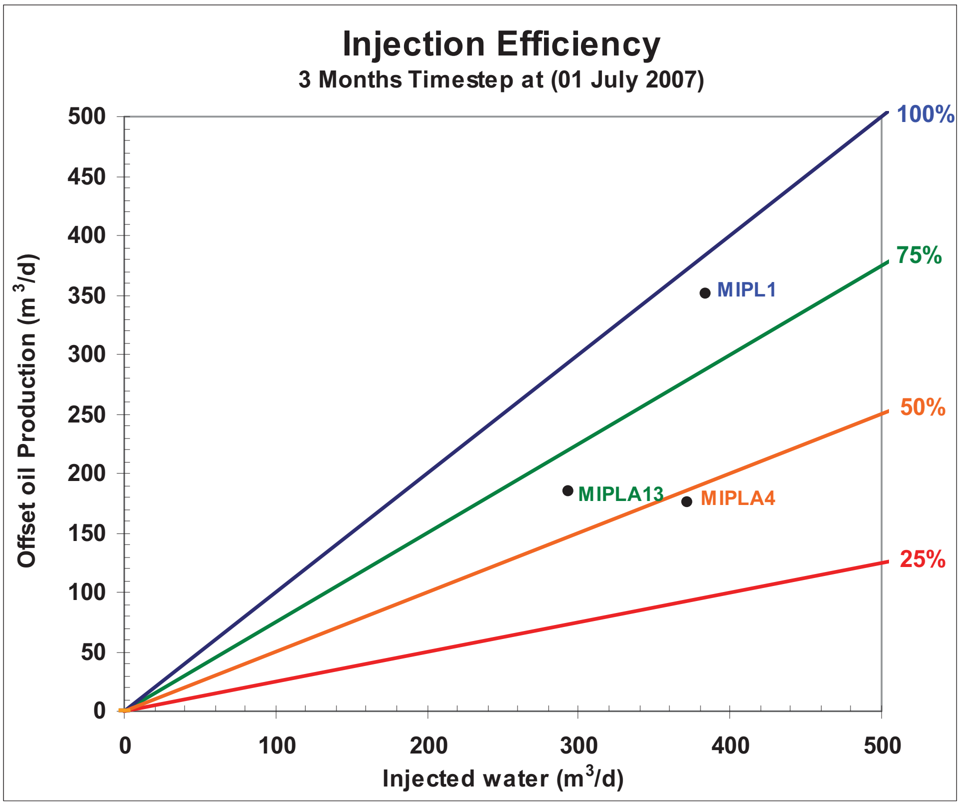
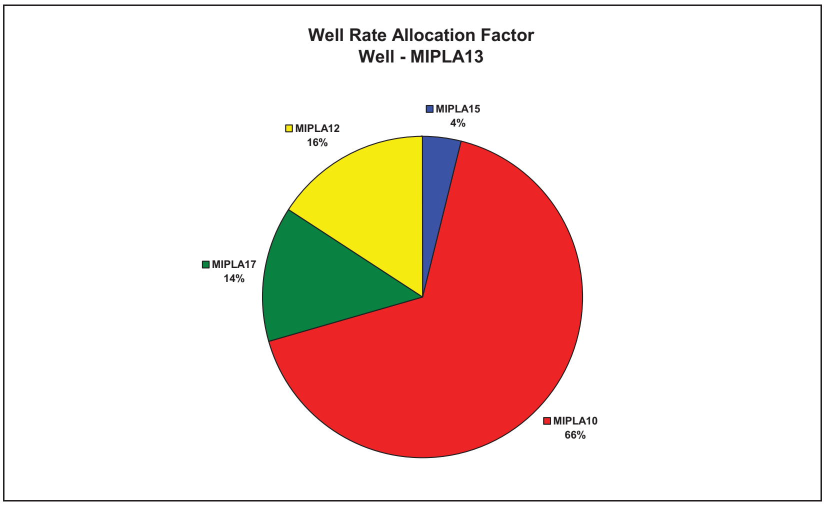
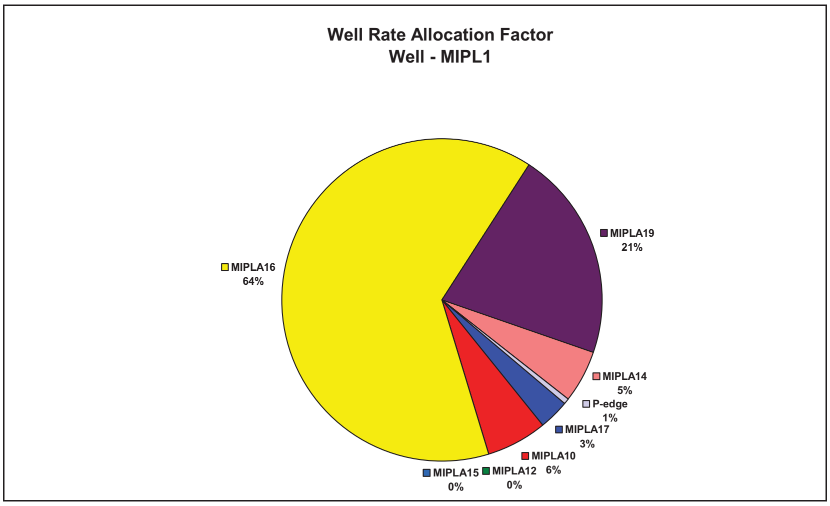


Figure 3.33: Injection efficiency at 1 July 2007





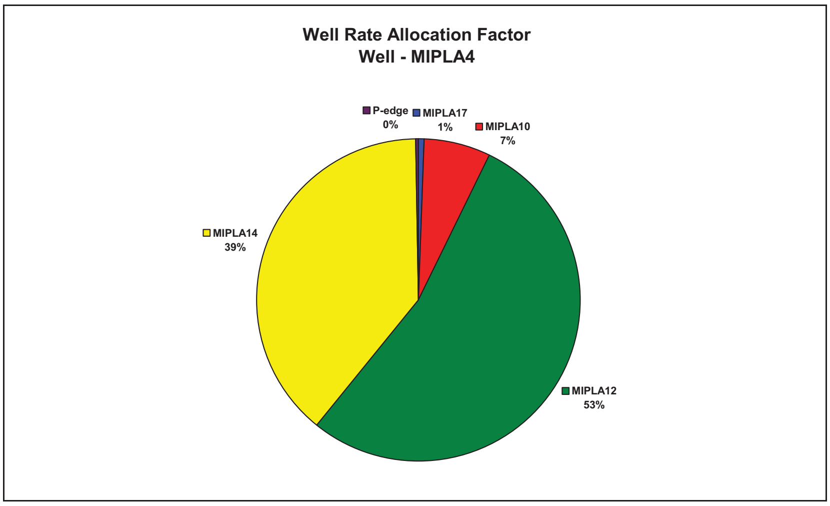


Figure 3.34: Well allocation factor for MIPLA4 at 1 July 2007

The next step is to calculate the well pair injection efficiency. Injectors organized the well pair efficiencies are summarized as following:

Total Injection Rate for		MIPL1	381,57	m^3/d
Source (Injector)	**Sink (Producer)**	**Water in** m^3/d	**Oil Out** m^3/d	e_{wp} %
MIPL1	MIPLA10	23,00	9,06	39%
MIPL1	MIPLA12	0,17	0,77	-
MIPL1	MIPLA14	19,90	31,80	-
MIPL1	MIPLA15	0,00	0,91	-
MIPL1	MIPLA16	246,00	220,00	89%
MIPL1	MIPLA17	11,80	9,45	80%
MIPL1	MIPLA19	80,70	78,10	97%

Table 3-8: Well pair injection efficiency for MIPL1

Total Injection Rate for		MIPLA13	293,70	m3/d
Source (Injector)	**Sink (Producer)**	**Water in** m^3/d	**Oil Out** m^3/d	e_{wp} %
MIPLA13	MIPLA10	196,00	103,00	53%
MIPLA13	MIPLA12	46,80	26,50	57%
MIPLA13	MIPLA15	11,20	25,00	-
MIPLA13	MIPLA17	39,70	29,70	75%

Table 3-9: Well pair injection efficiency for MIPLA13

Total Injection Rate for		MIPLA4	371,63	m3/d
Source (Injector)	**Sink (Producer)**	**Water in** m^3/d	**Oil Out** m^3/d	e_{wp} %
MIPLA4	MIPLA10	24,50	8,81	36%
MIPLA4	**MIPLA12**	**200,00**	**84,40**	**42%**
MIPLA4	MIPLA14	145,00	80,20	55%
MIPLA4	**MIPLA17**	**2,13**	**1,79**	**84%**

Table 3-10: Well pair injection efficiency for MIPLA4

Notably that the connection MIPLA4-MIPLA12 has 200 m^3/d as an injected water and 84 m^3/d of offset oil production, leading to an well pair efficiency of 42%. The size of volumetric rate associated with the well pair clearly makes this connection an important pair for the modification. On the other hand, consider the connection MIPLA4-MIPLA17. Although it has high efficiency leads to 84%, the total injected rate is only 2 m^3/d and offset oil production is1.79, making this connection inefficient connection.

Note: e_{wp} comparing with Fpmap water could be less but with high efficiency. Such an example MIPLA4 communicated with MIPLA17. The following input has been used in order to produce the well weight function, which is illustrated in figure (3.35)

Input	
Avrage Field IEs	67,6%
Afa	2
e_{max}	90,0%
e_{min}	40,0%
w_{max}	0,300
w_{min}	-0,300

Table 3-11: Well Rate Weight Function Input

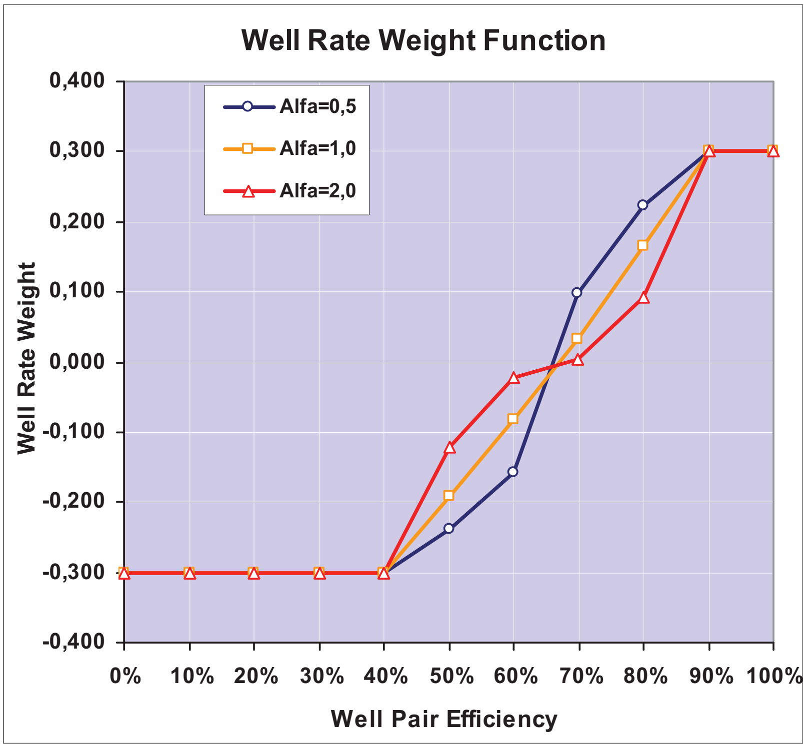


Figure 3.35: Well rate function at 1 July 2007

The next step is to apply weigh function in order to obtain new allocation water injection, which is mainly dependent on the average field efficiency. If the calculated well pair efficiency is less than the average field efficiency, the optimized injection rate will be decreased. If the well pair efficiency grater than average field efficiency the optimized injection rate will be increased by corresponding weight. Presumably, by summing up the new optimized rate for each injector, the new injection rate for each connected injector will be assigned to FrontSim simulator. The results of the spreadsheet that established to calculate and arrange these result in formatted way are presented as following:

Well Name	MIPL1

Output									
Source	Sink	Water in	Oil Out	ewp	Max w	Min w	wi	Q old	Q new
MIPL1	MIPLA10	23,0	9,1	39,4%	0,0000	-0,3134	-0,3000	23,0	16,1
MIPL1	MIPLA16	246,0	220,0	89,4%	0,2850	1,0000	0,2850	246,0	316,1
MIPL1	MIPLA17	11,8	9,5	80,1%	0,0934	1,0000	0,0934	11,8	12,9
MIPL1	MIPLA19	80,7	78,1	96,8%	0,5087	1,0000	0,3000	80,7	104,9
							Cum	362	450
							Reallcotion %.		124,5%

Well Name	MIPLA13

Output									
Source	Sink	Water in	Oil Out	ewp	Max w	Min w	wi	Q old	Q new
MIPLA13	MIPLA10	196,0	103,0	52,6%	0,0000	-0,0890	-0,0890	196,0	178,6
MIPLA13	MIPLA12	46,8	26,5	56,6%	0,0000	-0,0473	-0,0473	46,8	44,6
MIPLA13	MIPLA17	39,7	29,7	74,8%	0,0313	1,0000	0,0313	39,7	40,9
							Cum	283	264
							Reallcotion %.		93,5%

Well Name	MIPLA4

Output									
Source	Sink	Water in	Oil Out	ewp	Max w	Min w	wi	Q old	Q new
MIPLA4	MIPLA10	24,50	8,81	36%	0,0000	-0,3944	-0,3000	24,5	17,2
MIPLA4	MIPLA12	200,00	84,40	42%	0,0000	-0,2540	-0,2540	200,0	149,2
MIPLA4	MIPLA14	145,00	80,20	55%	0,0000	-0,0593	-0,0593	145,0	136,4
MIPLA4	MIPLA17	2,1	1,8	84,0%	0,1617	1,0000	0,1617	2,1	2,5
							Cum	372	305
							Reallcotion %.		82,1%

Table 3-12: Result of realloction optimization at 01 July 2007

Average field efficiency has been chosen to be used as the reference point to decide wither to the increase the weight or decreased.

According to the result from table (3-11) and (3-12), Injection rate should be increased in MIPL1 by 124.5 %. This incremental of injection rate resulted as the effective well efficiency 91%, which is grater than the average field efficiency 68%. Never

3.3.8.2 Evaluation at 07 Apr. 2009

Well Allocation Factor

Injectors Name	Water Injection	Offset Oil	IE
	m3/d	m3/d	%
MIPLA13	109	60	55%
MIPLA4	258	169	66%
MIPL1_I	385	225	59%
Field	**752**	**454**	**60%**

Table 3-13: Well allocation reported at 7 April 2009

The main objective of such a modification is to move injectors up to the left on this plot. This means that increase the offset oil production by less utilization of water injection. As observed in figure 3.50, offset oil production of MIPLA4 increased (moved up) and water injection of MIPLA13 decreased (moved left).

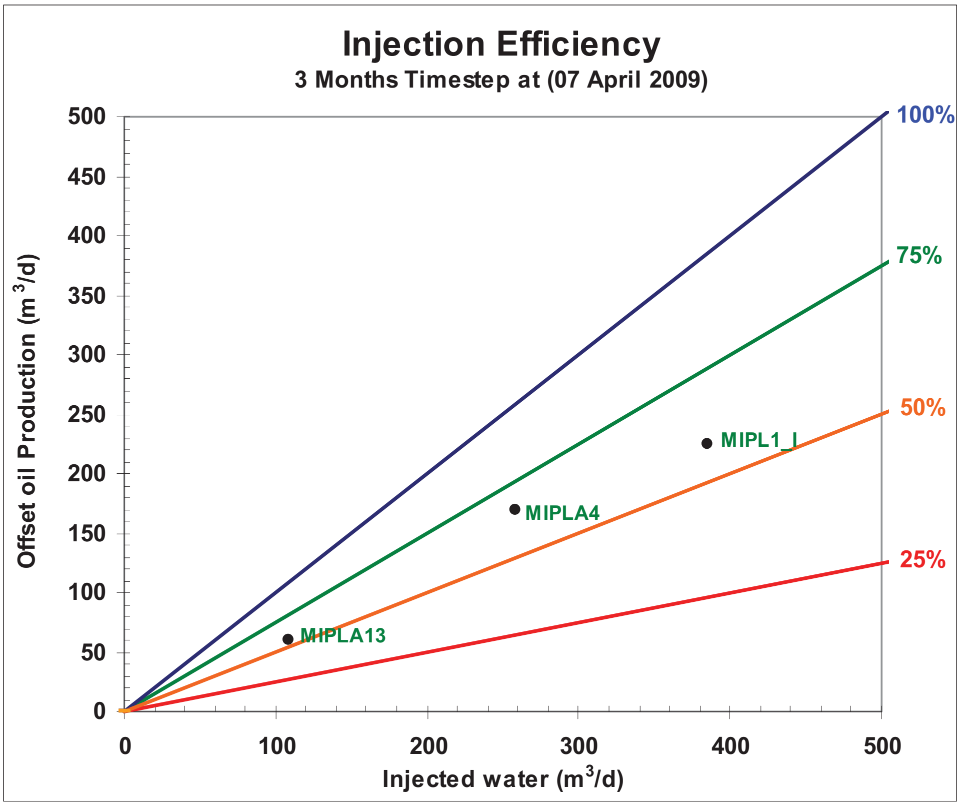


Figure 3.36: Injection efficiency at 1 07 April 2009

Nevertheless, sort of balanced sweep pattern was obtained (see figure 3.51) by applying this methodology. Thus it will be more effective by continue reallocated flow rate in the future predication.

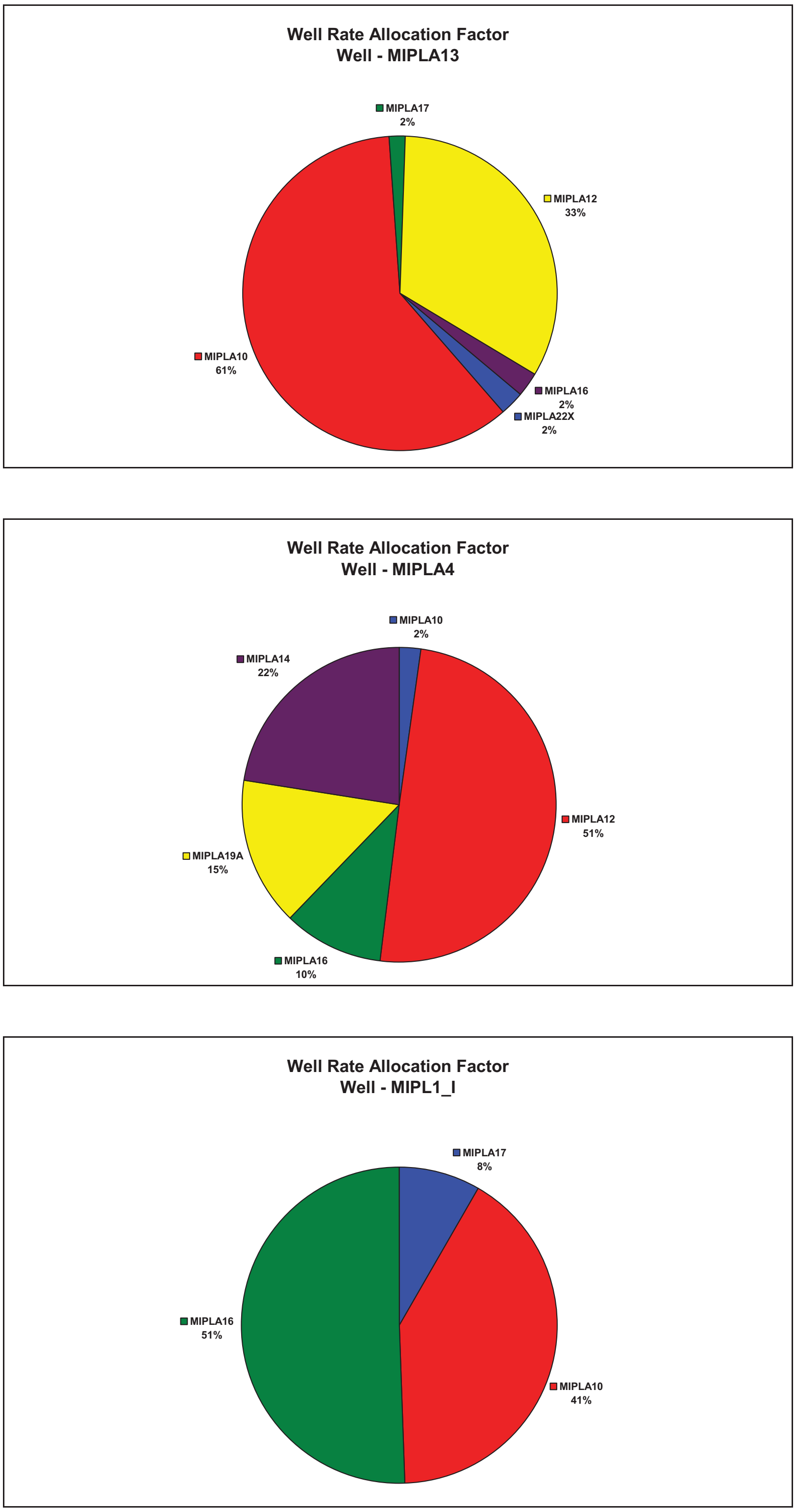


Figure 3.37: Well allocation factor for the injectors at 07 April 2009

Injection flow visualization

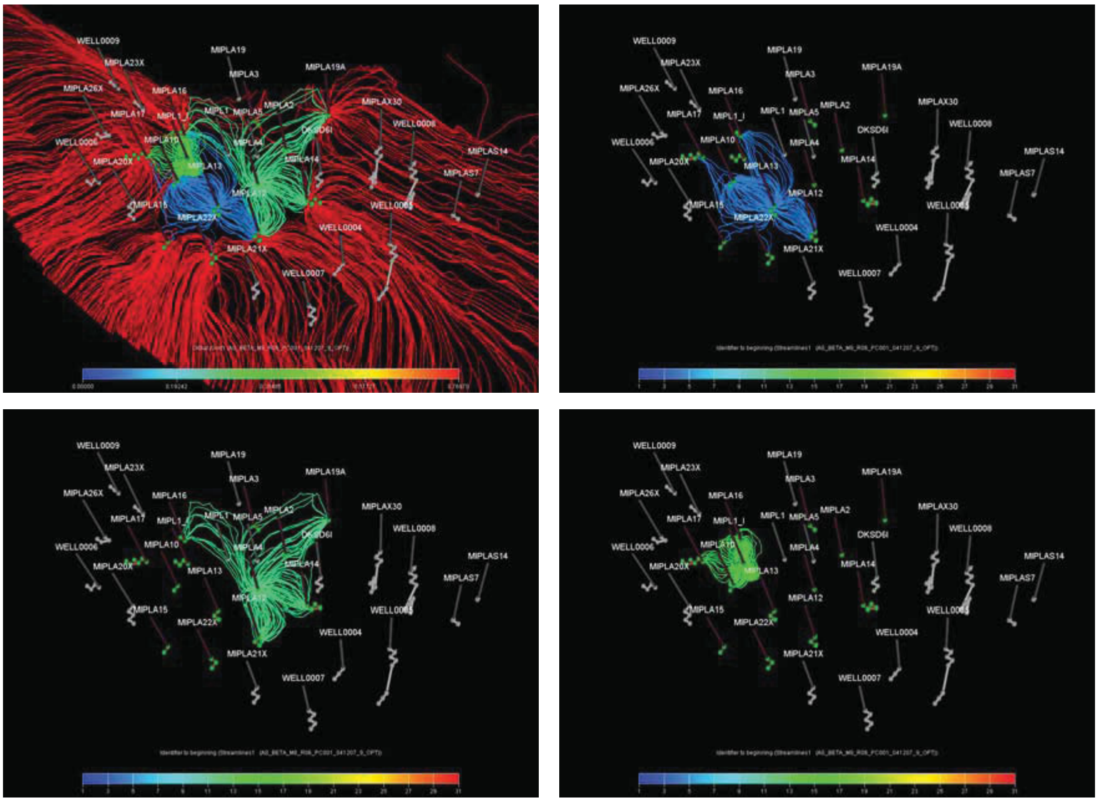


Figure 3.38: Flow Visualization colored by injectors at 07 Apr. 2009

The next step is to calculate the well pair injection efficiency. These values will lead to reallocate new injection rate for injection wells.

Total Injection Rate for		MIPLA13	108,74	m^3/d
Source (Injector)	**Sink (Producer)**	**Water in** m^3/d	**Oil Out** m^3/d	e_{wp} %
MIPLA13	MIPLA10	65,60	33,40	51%
MIPLA13	MIPLA12	36,10	20,50	57%
MIPLA13	MIPLA16	2,59	2,08	80%
MIPLA13	MIPLA17	1,87	1,20	64%
MIPLA13	MIPLA22X	2,58	2,40	93%

Table 3-14: Well pair injection efficiency for MIPLA13

Total Injection Rate for		MIPLA4	218,57	m3/d
Source (Injector)	**Sink (Producer)**	**Water in** m^3/d	**Oil Out** m^3/d	e_{wp} %
MIPLA4	MIPLA10	5,97	4,51	76%
MIPLA4	MIPLA12	128,00	53,10	41%
MIPLA4	MIPLA14	58,00	37,40	64%
MIPLA4	MIPLA16	26,60	28,30	-
MIPLA4	MIPLA19A	39,20	45,80	-

Table 3-15: Well pair injection efficiency for MIPLA4

Total Injection Rate for		MIPL1_I	385,20	m3/d
Source (Injector)	**Sink (Producer)**	**Water in** m^3/d	**Oil Out** m^3/d	e_{wp} %
MIPL1_I	MIPLA10	158,00	46,50	29%
MIPL1_I	MIPLA16	195,00	152,00	78%
MIPL1_I	MIPLA17	32,20	26,80	83%

Table 3-16: Well pair injection efficiency for MIPLA1_I

The following input has been used in order to produce the well weight function, which is the base function for reallocate the injection rate.

Input	
Avrage Field IEs	60,4%
Afa	1,2
e_{max}	90,0%
e_{min}	30,0%
w_{max}	0,300
w_{min}	-0,300

Table 3-17: Well Rate Weight Function Input

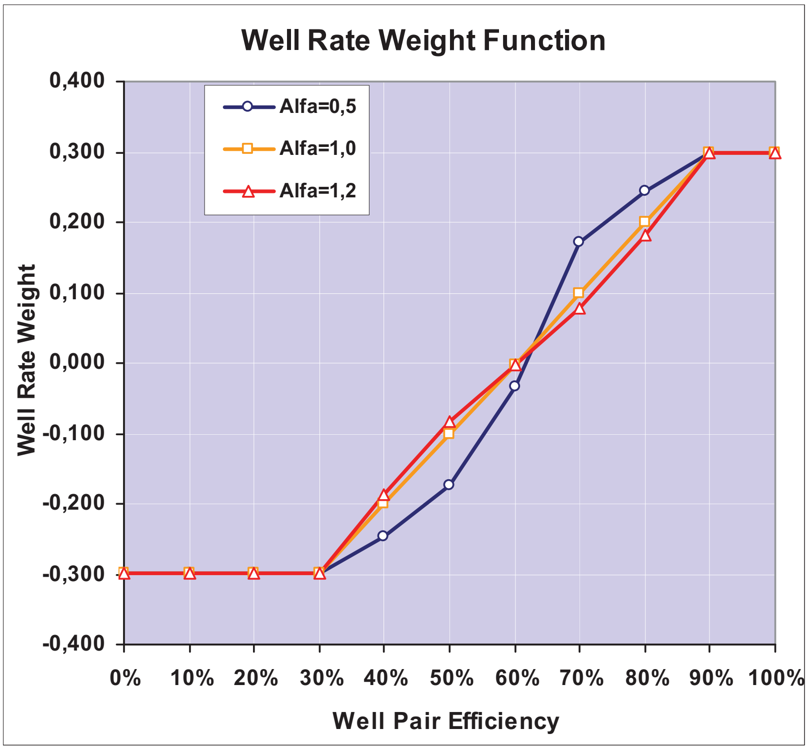


Figure 3.39: Well rate function at 1 July 2009

The next step is to apply weigh function in order to obtain new allocation water injection, which is mainly dependent on the average field efficiency. If the calculated well pair efficiency is less than the average field efficiency, the optimized injection rate will be decreased. If the well pair efficiency grater than average field efficiency the optimized injection rate will be increased by corresponding weight. Presumably, by summing up the new optimized rate for each injector, the new injection rate for each connected injector will be assigned to FrontSim simulator. The results of the spreadsheet that established to calculate and arrange these result in formatted way are showed in following table.

Well Name	MIPLA13

Output									
Source	Sink	Water in	Oil Out	ewp	Max w	Min w	wi	Q old	Q new
MIPLA13	MIPLA10	65,6	33,4	39,4%	0,0000	-0,1925	-0,1925	65,6	53,0
MIPLA13	MIPLA12	36,1	20,5	89,4%	0,2931	1,0000	0,2931	36,1	46,7
MIPLA13	MIPLA16	2,6	2,1	80,1%	0,1840	1,0000	0,1840	2,6	3,1
MIPLA13	MIPLA17	1,9	1,2	96,8%	0,3841	1,0000	0,3000	1,9	2,4
MIPLA13	MIPLA22X	2,6	2,4	196,8%	1,8745	1,0000	0,3000	2,6	3,4
							Cum	109	109
							Reallcotion %.		99,8%

Well Name	MIPLA4

Output									
Source	Sink	Water in	Oil Out	ewp	Max w	Min w	wi	Q old	Q new
MIPLA4	MIPLA10	6,0	4,5	52,6%	0,0000	-0,0589	-0,0589	6,0	5,6
MIPLA4	MIPLA12	128,0	53,1	56,6%	0,0000	-0,0244	-0,0244	128,0	124,9
MIPLA4	MIPLA14	58,0	37,4	74,8%	0,1266	1,0000	0,1266	58,0	65,3
MIPLA4	MIPLA16	26,6	28,3	174,8%	1,5184	1,0000	0,3000	26,6	34,6
MIPLA4	MIPLA19A	39,2	45,8	274,8%	3,2259	1,0000	0,3000	39,2	51,0
							Cum	258	281
							Reallcotion %.		109,2%

Well Name	MIPL1_I

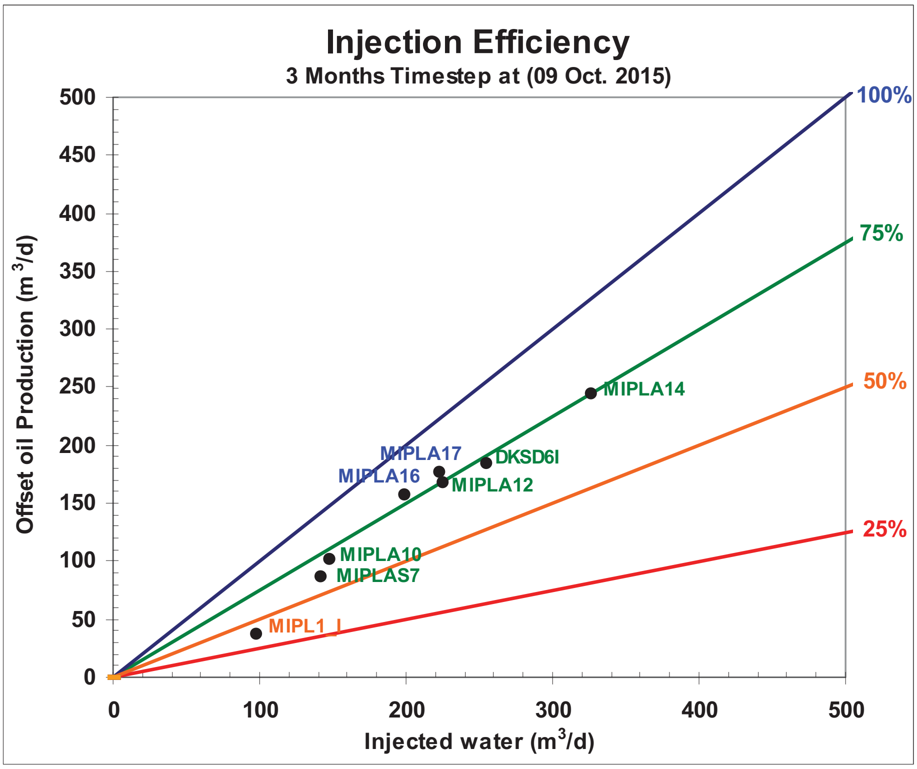
Output									
Source	Sink	Water in	Oil Out	ewp	Max w	Min w	wi	Q old	Q new
MIPL1_I	MIPLA10	158,00	46,50	36%	0,0000	-0,2308	-0,2308	158,0	121,5
MIPL1_I	MIPLA16	195,00	152,00	42%	0,0000	-0,1620	-0,1620	195,0	163,4
MIPL1_I	MIPLA17	32,20	26,80	55%	0,0000	-0,0349	-0,0349	32,2	31,1
							Cum	385	316
							Reallcotion %.		82,0%

Table 3-18: Result of reallocation optimization at 07 Apr. 2009

The results in table 3-18 showed old injection rate and new optimized rate, which will be singed to the model for the next optimization stage.

The same calculation is repeated for each associated injector dated in the next optimization step (07 May 2012). Then, carrying out this summation result, the main target is efficient well pairs should exhibit an increase in injection volume, while inefficient well pairs should exhibit a decrease.

3.3.8.3 Evaluation at 09 Oct. 2015



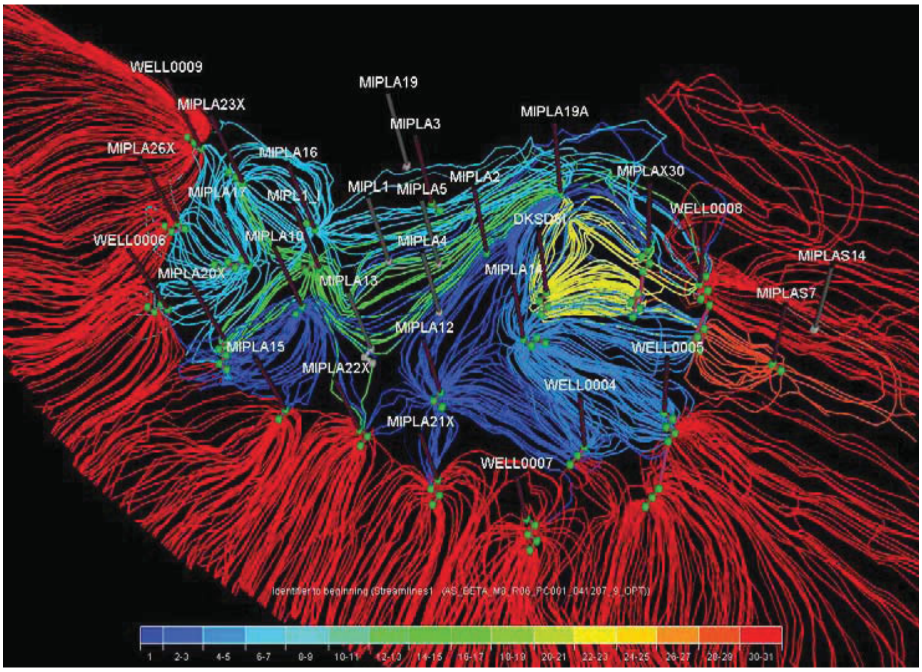
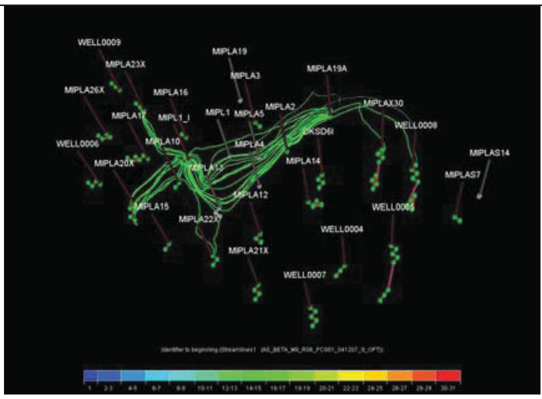
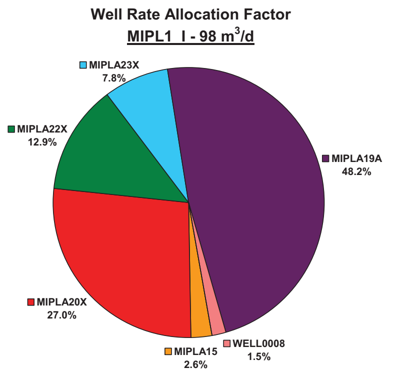


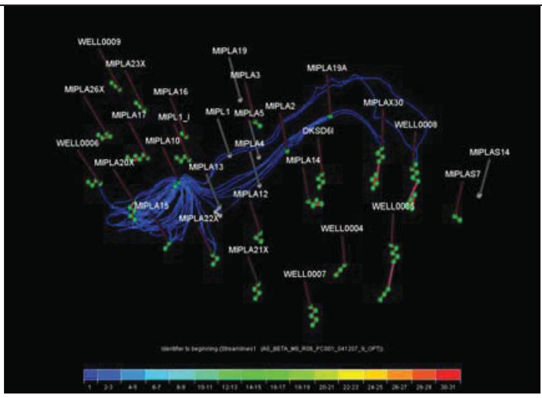
Figure 3.40: flow pattern visualization at 09 Oct 2015

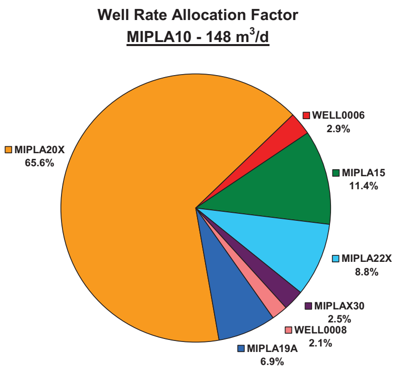
With the aid of streamline simulation, it is easy to define the well communicating with other wells far outside the expected pattern, as it was demonstrated in figure 3.40.

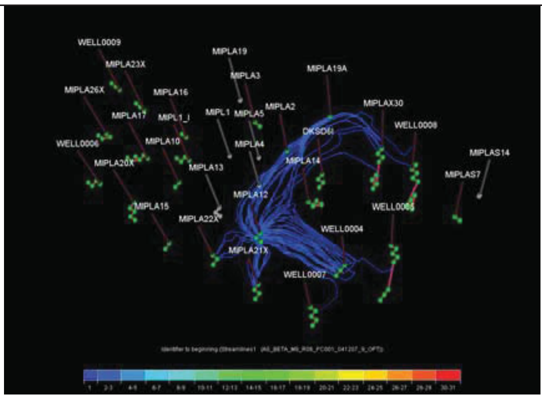
Well Allocation Factor associated with flow pattern visualization for each injector at last optimization stage (09 Oct. 2015).

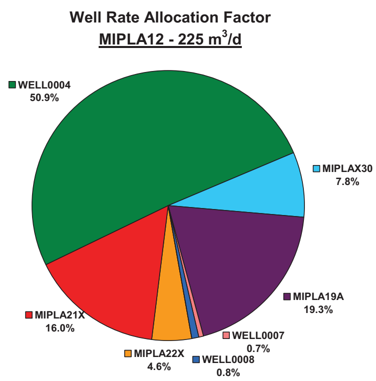


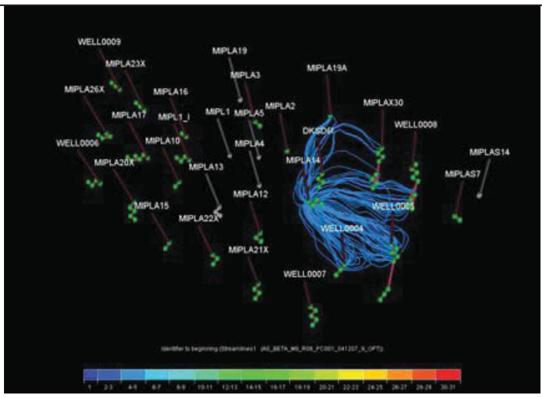


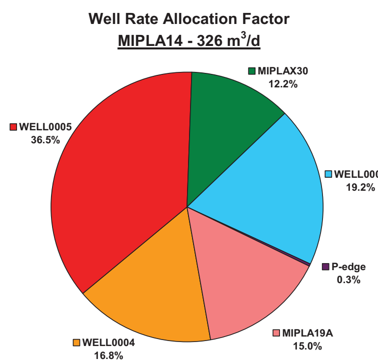












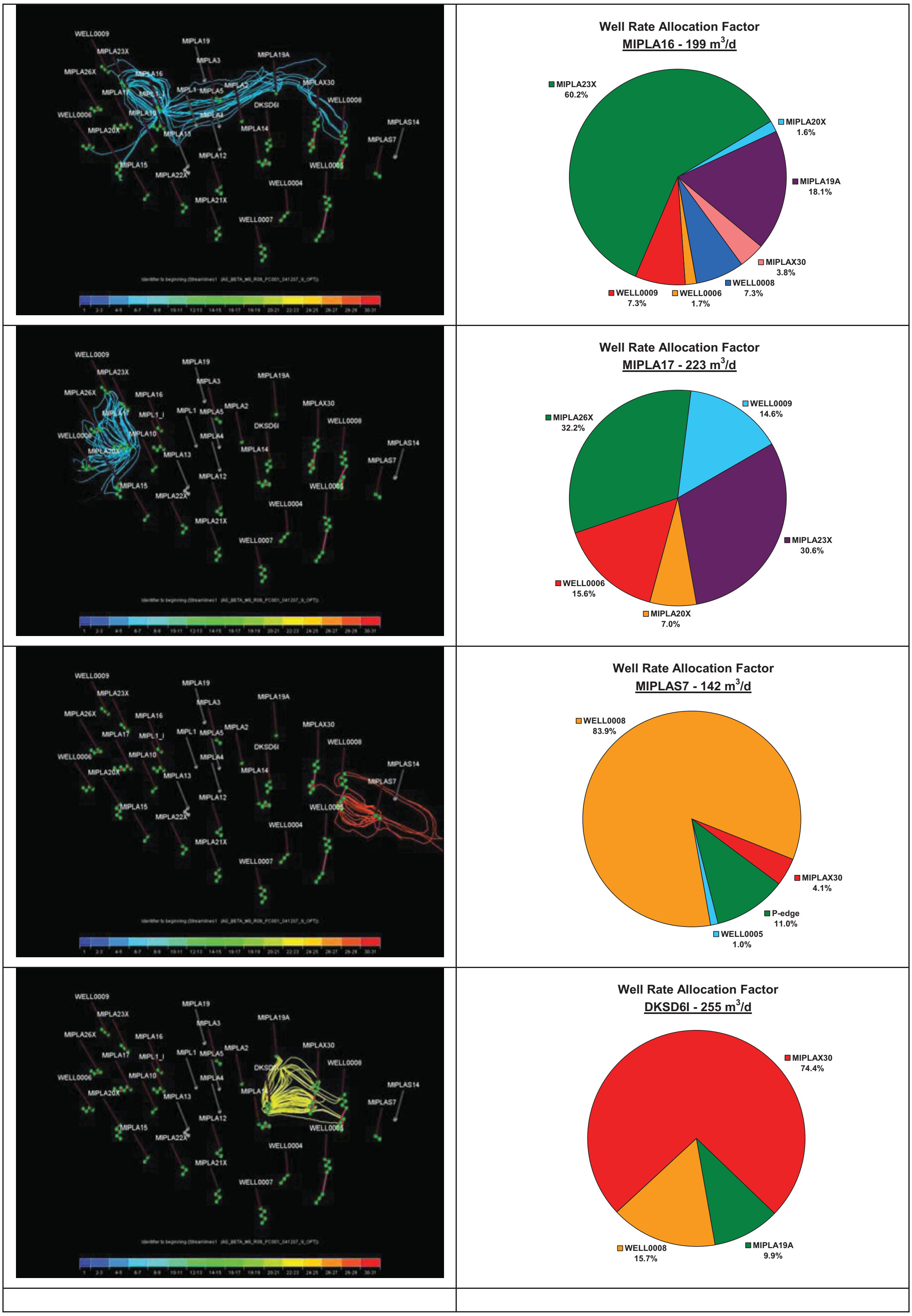


Figure 3.41: Individual flow pattern visualization for each injector at 09 Oct 2015

The objective is to move the efficiencies of the injectors up to the left side of the plot, either to increase the offset production or decrease water injection. The stage of the optimization shows this improvement in wells MIPLA4 and MIPLA13.

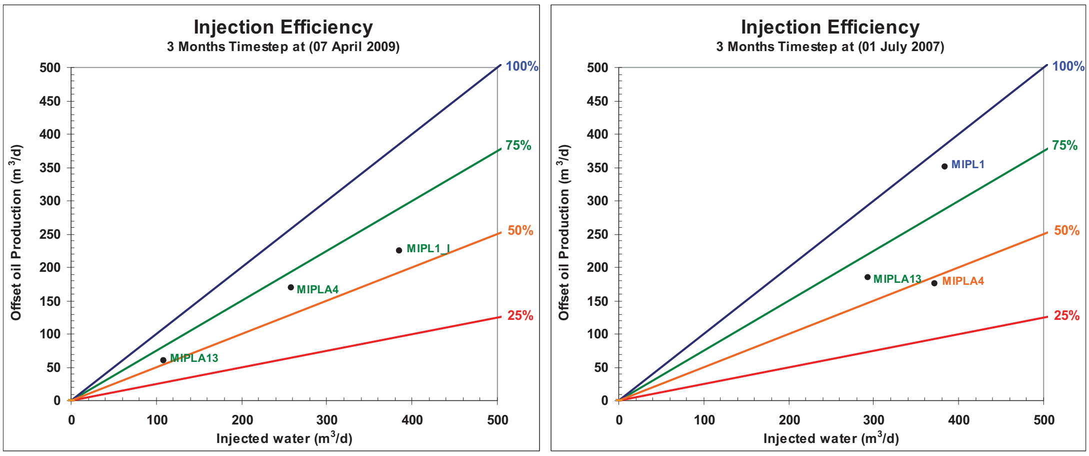


Figure 3.42: 2007-2009 Injection Efficiency Evaluation

Well Name	Injected Water	Offset Oil Production	Injection Efficiency
	Sm^3	Sm^3	%
MIPLA10	148	102	69%
MIPLA12	225	168	75%
MIPLA14	326	245	75%
MIPLA16	199	158	79%
MIPLA17	223	177	79%
MIPL1_I	98	37	38%
DKSD6I	255	185	73%
MIPLAS7	142	87	61%
Field	1616	1159	72%

Table 3-19: Injection Efficiency at Oct. 2015

As demonstrated in table 3-19 the overall field efficiency has been increased from 68% up to 72%. By best utilization of water injection and reallocate the injection rate according to the purposed methodology, Injection efficiency has been increased by 7%.

According to the low efficiency that well MIPL1_I showed, the well location should be taken in account in order to achieve better result.

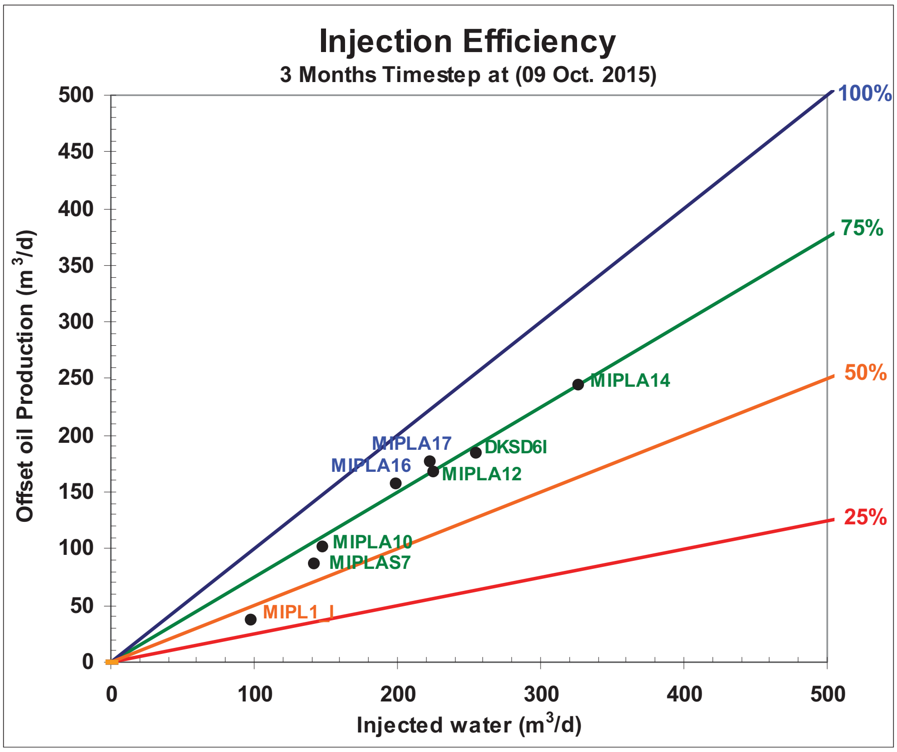


Figure 3.43: Injection Efficiency at 09 Oct. 2015

Figure 3.43 shows that most of the injector efficiencies at Oct. 2015 leys on the line of 75%, which lead conclude the improvement of overall efficiency of Dogger Beta in this range. However, Well MPL1_I presents an inefficient performance compared with other wells. Notably, the location of this injector is not approved yet. Thus, the impropriate location could be a reason for bad performance for this injector.

Compare the result of optimized case with the base case

The following is the result of the optimization started at Jan 2008 and end up at Oct. 2005.

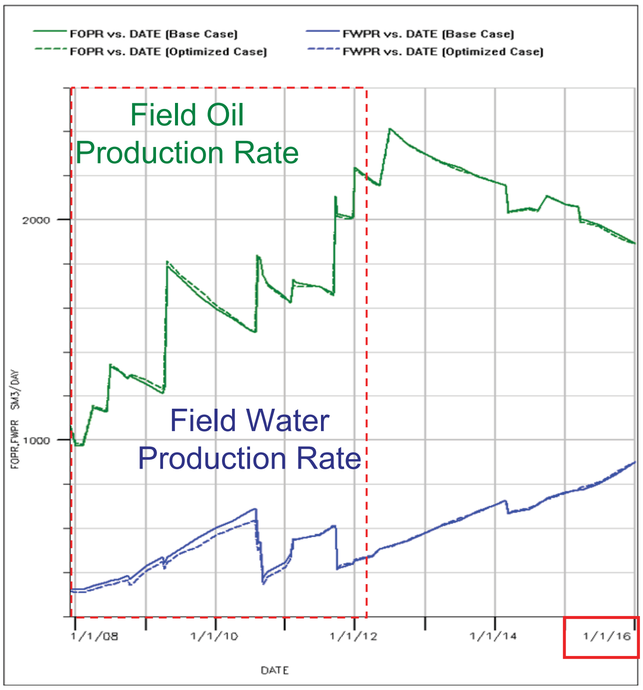


Figure 3.44: Optimized field oil and water production rate compared with base case

Reallocate injection rate leads to promising results in term of increased oil flow rate. However, the improvement of these results is not exhibited after Jan 2012 as in figure 3.44.

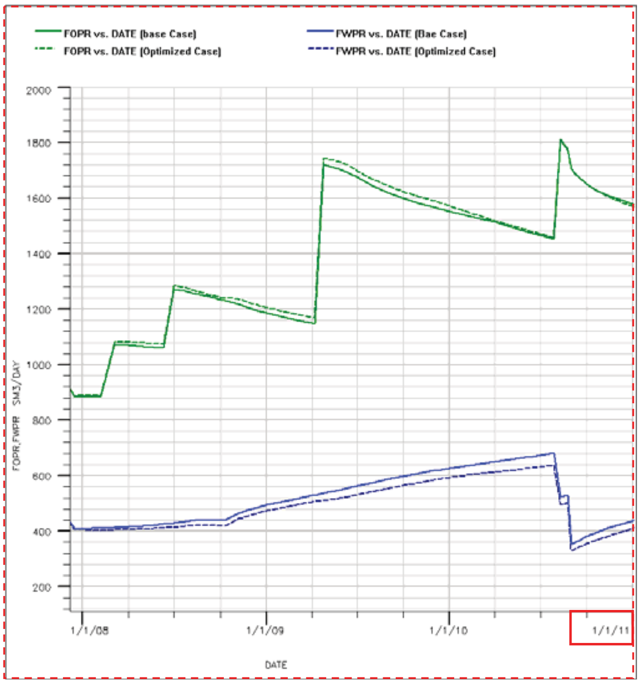


Figure 3.45: Optimized field oil and water production rate compared with base case up to 1 Jan 2011

Not only the cumulative oil production has been increased slightly, but also the cumulative water production was decreased, effect on the operating cost.

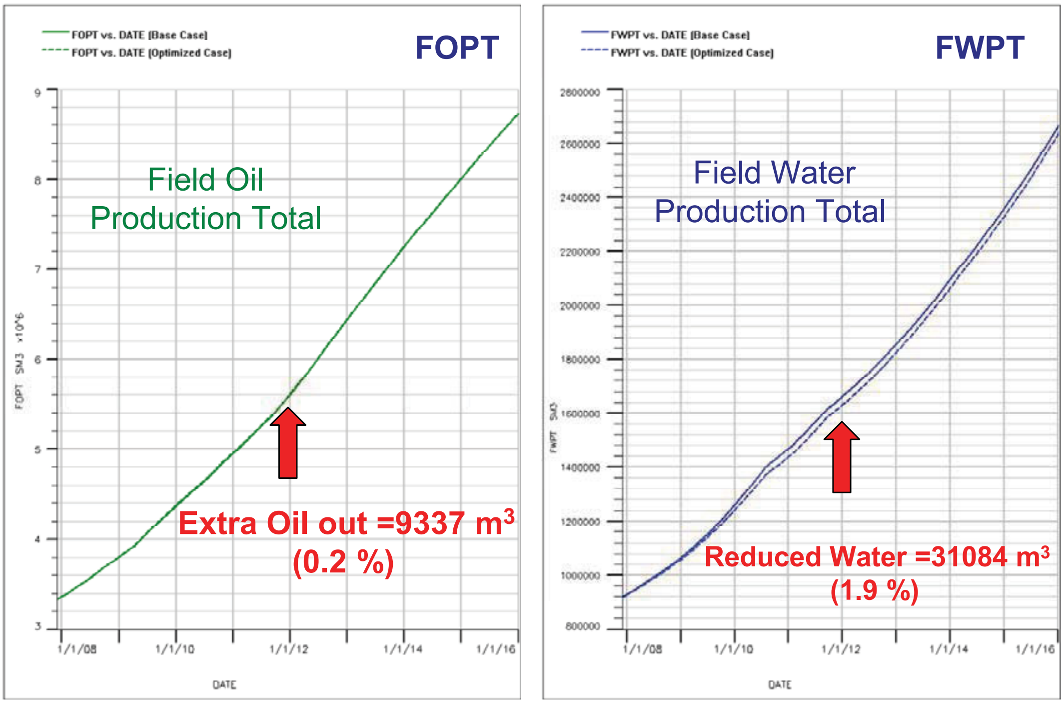


Figure 3.46: Optimized cumulative oil and water production compared with base case

On the other hand, the total field injection rate decreased also with a minor reduction of the field presser rate (almost 2 bars).

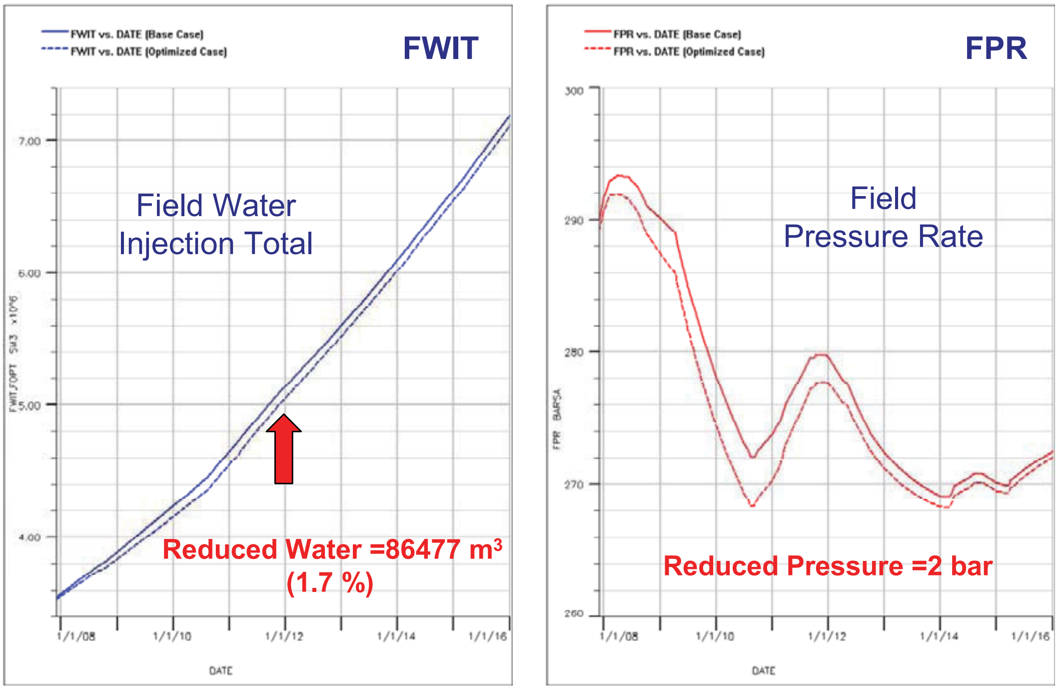


Figure 3.47: Optimized water injection rate and field pressure compared with base case

Chapter 4

4 Conclusion and Recommendations

4.1 Summary and Conclusion

As already discussed by previous application streamline technology is more efficient of modeling water floods management and it is considered as an effective and practical tool for reservoir engineering workflow.

In this study, we have demonstrated how streamline simulation offered a fast and efficient workflow for characterizing and optimizing Mittelplatte-Dogger Beta reservoir.

Streamline simulation has many advantages, compared to conventional finite difference simulation, in terms of commotional speed, flow pattern visualization, generating of well allocation factor and easy identification of flow, or grange area, or pattern.

Not only the run time speed makes the SL best alternative to FD, but also the extra data that could be obtained are really enormous information in term of reservoir management and improve the injection efficiency.

Eventually, the results of streamline simulation is not too mach different comparing with finite difference approach. Large timestep that streamline could be performed without applying the stability restriction is unique. Thus, Streamline simulation has the ability of to run large field/many wells. However, Streamline simulation is a powerful Complementary tool for finite difference simulation. Streamline simulation provides trustworthy answer.

For Mittelplate-Dogger Beta Reservoir perspective, Injection efficiency allows a powerful approach to improve reservoir management.

The conducted study showed that the proposed methodology is beneficial. It is increase the overall injection efficiency by 7% and defining the adequate injection targets for each individual injector. Moreover, we have achieved more balanced pattern in terms of better sweep efficiency.

By best utilization of injected water volume using proposed methodology, we are able to slightly increase total oil production by 0.2% (Not significant).On the other hand, the method leads to reduce cycling water. This means that the production water was decreased by 1.9% and water injection was decreased also by 1.7%. This result will be directly affected to reduce the operating cost of the reservoir.

Finally, the new data and information provided by streamline simulation will be an influential guide to confirm optimized prediction plan for Dogger Beta reservoir.

4.2 Recommendations

For further future work we are recommended the following points that we believe that will leads to better result and best improvements

- Improving history mach by FrontSim with assisted history match, will leads to better result and better confident of prediction optimization.
- Conduct a Short Scale range for prediction period, Three or five year for instant, associated with proposed optimization for each updated timestep, will direct leads to better optimization result.
- Well location and configuration (perforation intervals for instance) should be given more emphasis in the proposed methodology in order to improve the production oil optimization, especially after 2011.
- I recommended evaluating 3DSL streamline Simulator because I find out that this simulator have many useful features for waterflood management than FrontSim.

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