

Norwegian Continental Shelf Petroleum Pipe-It Integrator & Production Forecaster



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Master of Science (MSc)

2012 June

Preface

This project is a part of the Master of Science Program, Petroleum Engineering. The author acknowledges with thanks the assistance given by Curtis H. Whitson, Professor at Norwegian University of Science and Technology (NTNU) and all of the author's colleagues at Petrostreamz A/S for the help provided. Special thanks goes to M. Faizul Hoda for his help creating the model, and to Oleksandr Iakovliev and Hans Jørgen Grimstad for their assistance in teaching me basic C++. The duration of this assignment has been the spring semester 2012.

I herewith declare that I have produced this paper without the prohibited assistance of third parties and without making use of aids other than those specified; notions taken over directly or indirectly from other sources have been identified as such. This paper has not previously been presented in identical or similar form.

Signature

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June 10, 2012

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Abstract

This thesis summarizes and concludes my master thesis research work. My work and dedication to this work will continue as part of my employment in Petrostreamz. The main objective of this research was to develop a rigorous and generic forecast model for all the fields on the Norwegian Continental Shelf based on publicly available data.

Pipe-It Norwegian Continental Shelf Integrator and Forecaster solution provides the opportunity to forecast oil and gas production rate and economics for all assets on the Norwegian Continental Shelf. The solution is automatically synchronized with an on line database, that is maintained by the Norwegian Petroleum Department. The solution currently contains 87 fields and handles thousands of application launches in parallel. The results can be filtered and aggregated for multiple engineering purposes, like the impact of new discoveries on future production rates and economics.

As part of my work a presentation was given by Curtis H. Whitson at the SPE Bergen One Day Seminar April 18, 2012⁽¹⁾. A video which gives an overview of the use of the model, and shows some example applications has been created, and can be viewed on Youtube⁽²⁾.

Sammendrag

Denne oppgaven oppsummerer og avslutter mitt MSc. forskningsarbeid. Mitt arbeid og dedikasjon til dette arbeidet vil fortsette som en del av sysselsettingen i Petrostreamz. Hovedmålet med denne forskningen var å utvikle en solid og generisk prognose modell for alle feltene på Den Norske Kontinentalsokkel basert på offentlig tilgjengelige data og stort sett gratis tilgjengelig programvare.

Pipe-It Norwegian Continental Shelf Integrator and Forecaster løsningen gir muligheten til å forutsi raten til olje-og gassproduksjon og økonomi for alle feltene på den Norske kontinentalsokkel. Løsningen blir automatisk synkronisert med en online database, som driftes av Oljedirektorated. Løsningen inneholder for tiden 87 felt og håndterer tusenvis av programmer som kan startes parralelt eller sekvensielt. Resultatene kan filtreres og aggregeres for flere formål, som virkningen av nye funn på fremtidig produksjon, priser og økonomi.

Som en del av arbeidet mitt ble en presentasjon gitt av Curtis H. Whitson ved SPE Bergen One Day Seminar 18. april 2012⁽¹⁾. En video som gir en oversikt over bruken av modellen, og viser noen eksempler har blitt opprettet, og kan sees på Youtube⁽²⁾.

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1 Introduction

The idea behind this master thesis is to build an integrated model that incorporates all the fields on the Norwegian Continental Shelf(NCS) in one model. The integrated model should build on a foundation of publicly available data and mainly free software. It should be flexible and configurable. The idea is that the model should work as a framework, and be easy for any individual engineer or organization to customize the integrated model for their particular need. Petrostreamz A/S⁽³⁾ recently released a commercial software called Pipe-It⁽⁴⁾ which is used to integrate all the different components of the integrated model and provide the means that allow the different components to communicate. An intuitive graphical user interface will display plots and other output, and easily allows modifications for custom purposes. Pipe-It's runner engine will handle the execution order, in sequence or parallel.

This thesis will describe the different features and engineering possibilities within the model, however the best way to understand how it works is to download it and test it on your own computer. To do this you need to download Pipe-It from the website www.petrostreamz.com. To get a trial license you have to register, and a license will be sent via email. In the future the Integrated model will also be available on the website, but if it is not when you are reading this, you can contact the author at kjetil@petrostreamz.com. See **Appendix A** for a step-by-step procedure of how to proceed with the installation of Pipe-It and running the mode.

The model consist of several different components:

1. **Data Acquisition** - The first time you run the integrated model and whenever you want it updated, the integrated model will gather all the data that it requires. The main source for information will be the website called factpages⁽⁵⁾, a website that is maintained by the Norwegian Petroleum Directorate⁽⁶⁾(NPD).
2. **Data Processing** - The downloaded data will be processed and analyzed. The field structure data is provided by several different comma separated files, and the Data Processing model will read and create a structure output file based on this. All the input data files are converted to a file format called Streamz⁽⁷⁾, which will facilitate cross-application communication and stream management.

3. **Generic Integrated Model Builder** - A very important aspect of the integrated model is its ability to generate itself. Infrastructure changes, new production data and reserve estimations, and new fields being discovered forces the model to be flexible and continuously updated and modified. Petrostreamz Project Builder will do just that using the data acquisition and the data processing modules it will generate the integrated model.
4. **Decline Curve Analysis for Individual Fields** - Fetkovich based Decline Curve Analysis is used to predict the production rates of individual fields. The prediction is based on reserve approximations, current initial production rate and the Arps exponent b . This is investigated in a brief literature study described in Section 2.
5. **Economic History and Prediction** - To put some familiar numbers to the model, a simple economic calculation is included. The model includes historical oil and gas spot prices, and multiplies these numbers with the production rate. For production forecasting no attempt at future petroleum price prediction has been made, and the current oil and gas price is used. This model gives an estimation of income, and does not include expenses.
6. **Aggregation** - As a default, the NCS Petroleum Pipe-It Integrator & Production Forecaster aggregates all the production rates and cumulative production, and economic value flow from all the fields on the NCS. However, it can also be interesting to look at the aggregated production rates and predictions in specific regions.
7. **Enhanced Oil Recovery Impact Estimation** - Efforts are made to simulate Enhanced Oil Recovery (EOR) procedures, for individual fields or model wide. The estimation is generic and not dependent of the EOR procedure itself. The resulting petroleum reserve increase and production rate potential increase are used as EOR model input.
8. **New field Developments** - A field template is included in the integrated model, and can be copy-pasted to quickly create new fields for field development or tie-in evaluation.

While reading this thesis, keep in mind that *any* decision made in model, whether it is structure, engineering solutions, or the model output - can be replaced, modified, or extended based on user requirements.

This MSc. thesis played a role in the continued development of Pipe-It. A project this big had at the time of implementation not yet been developed. The generality needed had never been required before. The engineers at Petrostreamz involved themselves with the project, and developed solutions for the problems the author faced. As a consequence of this, for this project to work, you need at least Pipe-It version 1.1, scheduled to be released the 15th of June. At the time of writing this thesis, the author was not yet satisfied with how the Project Builder works. It is a very good tool, but not very easy to use, and is somewhat limited to certain projects. Currently efforts are being made to improve this function of Pipe-It, and in the future this part will be much better.

The current key feature of the model developed in this thesis is the ability to forecast future production based on limited field data. The production forecast is done by Fetkovich based decline curve analysis (DCA), and in the next section a brief introduction to the development history of DCA is given. The implementation of DCA in the model is covered in **section 3.5**.

2 Decline Curve Analysis

In order to predict the future production rate for numerous fields generically, decline curve analysis has proven to be a very suitable solution. This section will describe how decline curve analysis was developed, and how it should be used. In 1944 Arps⁽⁸⁾ published a review of previous efforts and his work provided the exponential, hyperbolic and harmonic rate decline relations.

$$\text{Exponential, } (b = 0) : q(t) = q_i e^{-D_i t} \quad (1)$$

$$\text{Hyperbolic, } (0 < b < 1) : q(t) = \frac{q_i}{(1 + b D_i t)^{1/b}} \quad (2)$$

$$\text{Harmonic, } (b = 1) : q(t) = \frac{q_i}{(1 + D_i t)} \quad (3)$$

Arps DCA Nomenclature

D_i	Arps decline time constant	$1/day$
b	Arps decline exponent	
q_i	Initial pseudosteady rate at start of decline	$sm^3/month$
t	Time	$months$

The most significant development of DCA was introduced by Fetkovich⁽⁹⁾ in 1980. He created an analytical solution for a well producing with constant bottomhole pressure during boundary dominated flow with exponential decline. Fetkovich also developed type curves, which enabled engineers to do 1st order correct production forecast with the help of a calculator and graph papers. Fetkovich defined the Arps decline time constant as

$$D_i = \frac{1}{1 - b} \frac{q_i}{N_i} \quad (4)$$

For oil, Fetkovich obtained the following expressions for q_i and N_{pi} in field units.

$$q_i = \frac{kh(p_i - p_{wf})}{141.2\mu B[\ln(r_e/r_{wa}) - 0.5]} \quad (5)$$

$$N_i(t = 0) = \frac{\pi(r_e^2 - r_{wa}^2)\phi c_t h p_i}{5.615B} \quad (6)$$

Combining **Eq. 4**, **Eq. 5**, and **Eq. 6** Fetkovich obtain an expression for D_i , which can be used if no production data is available.

$$D_i = \frac{kh(p_i - p_{wf})5.615B}{\pi(r_e^2 - r_{wa}^2)\phi c_t h p_i 141.2\mu B [\ln(r_e/r_{wa}) - 0.5]} \quad (7)$$

$$D_i[day^{-1}] = \frac{k[md](p_i[psia] - p_{wf}[psia])}{25.15\pi\phi\mu[cp]c_t[psia^{-1}]p_i[psia](r_e^2[ft] - r_{wa}^2[ft])[\ln(r_e/r_{wa}) - 0.5]} \quad (8)$$

In pseudo SI units this equation would be:

$$D_i = \frac{k(p_i - p_{wf})}{18.66\pi\phi\mu c_t p_i (r_e^2 - r_{wa}^2)[\ln(r_e/r_{wa}) - 0.5]} \quad (9)$$

Fetkovich DCA Nomenclature using pseudo SI units

D_i	Decline time constant	1/day
k	Permeability	md
p_i	Initial reservoir pressure	bara
p_{wf}	Bottomhole flowing pressure	bara
ϕ	Porosity	
μ	Dynamic Viscosity	cp
c_t	Total Compressibility	1/bara
r_e	External Boundary Radius	m
r_{wa}	Apparent Wellbore Radius	m

The Arps exponent b is used to account for different producing mechanisms. It should be history matched with respect to declining production history. It varies from 0 to 0.9, but it is usually lower than 0.5. Fetkovich also developed procedures to deal with layered no cross flow reservoirs, fractured reservoirs, change in backpressure and infinite acting behavior, however this is not used in this thesis and is not covered.

3 NCS Petroleum Integrator & Production Forecaster

Petroleumz Pipe-It provides the framework for building this model, and it is the most important component of the integrated model. Pipe-It provides the flexibility we need. It was released in December 2011, and is not yet widely in use. Therefore a brief explanation of how Pipe-It works, and it's basic concepts will be provided in the following section.

3.1 Pipe-It

Pipe-It's simplicity is what makes it powerful. A Pipe-It model consists of 3 basic building blocks - the Resource, the Process and the Connectors. From these 3 simple bricks you can build huge complex models. In addition to the 3 basic building blocks Pipe-It provide a variety of other functions to augment the functionality of these.

3.1.1 The Resource

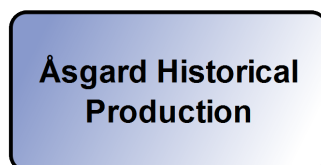


Fig. 1: A Pipe-It resource - a graphical representation of a file on the disc

A resource represents a file on the hard disk or network. It can be any file, and Pipe-It does not have to know or understand anything else than that it is a file and where it is located.

3.1.2 The Process

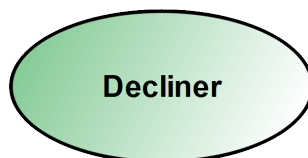


Fig. 2: A Pipe-It process - a graphical representation of an application launch

A process represents a launched application. It can be an integrated Pipe-It application, or any 3rd-party application which can be launched from the console.

3.1.3 The Connectors

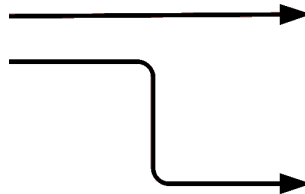


Fig. 3: A Pipe-It connector - a graphical representation of a connector

The connector defines the flow of information and process dependencies. The Pipe-It Runner creates the application launching based on how the connectors are configured, and provides a visual connectivity for the user. The connector can also be used as a convenient way of quickly setting up input and output files for applications.

3.1.4 The Composite



Fig. 4: A Pipe-It Composite - Composites are used to keep the canvas clean, and visually gather resources and process together in logical groups.

Composites are used to group together resources and processes in logical groups. It keeps the canvas clean and provides abstraction to the project.

3.1.5 The Sockets

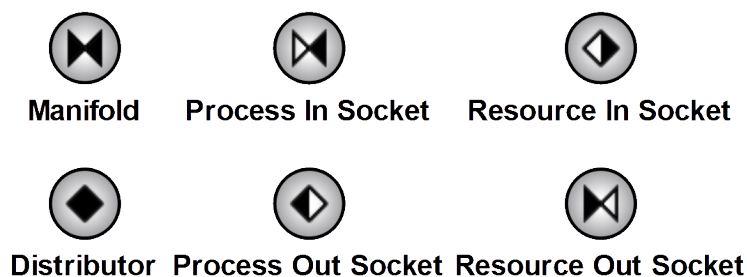


Fig. 5: Pipe-It Sockets - Sockets provide connections between different composites

The manifold gathers multiple connectors into one, while the distributor splits one connector into multiple. Sockets provide connections between different composites.

3.1.6 The Collection

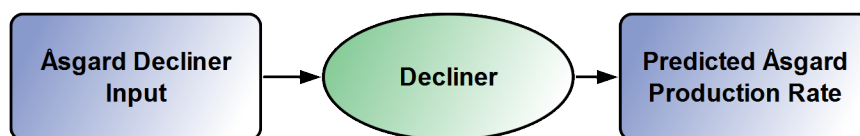


Fig. 6: A Pipe-It Project - The collection of the three basic elements forms a simple Pipe-It Project

The resulting collection of these 3 building blocks is almost limitless, see the Pet-rostreamz case-studies⁽¹⁰⁾ for examples.

3.2 Data Acquisition

To access the up-to-date data provided by the factpages an open source program called curl⁽¹¹⁾ is utilized. It is a console application for transferring data using URL syntax. The Data Acquisition plays an important part in the Integrated model, as it seamlessly updates the input data. In addition to the NCS specific data from the factpages, his-

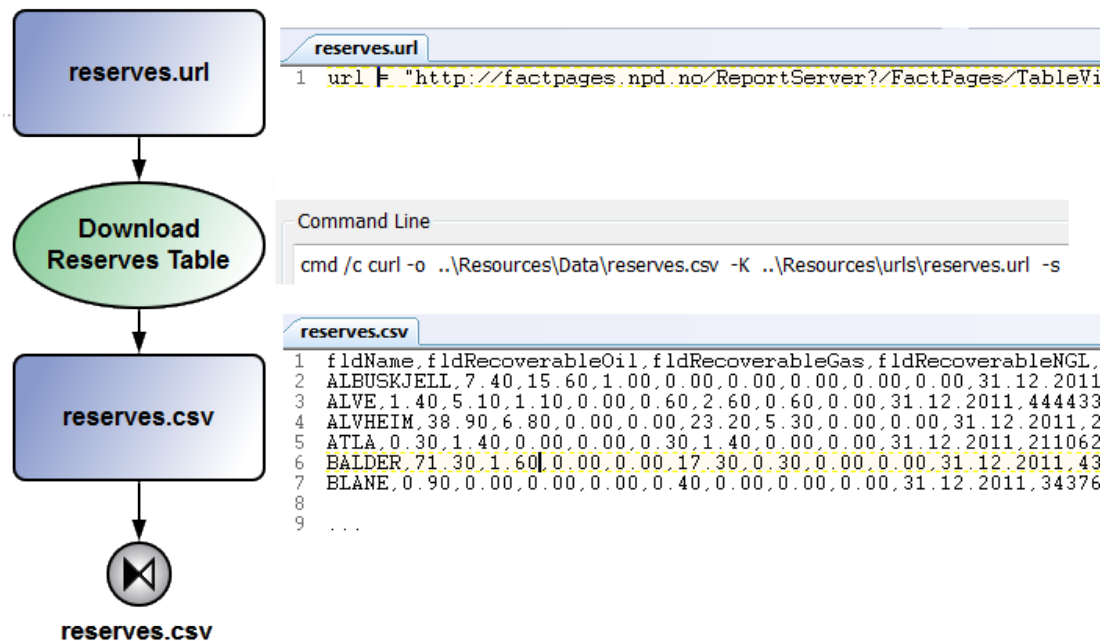


Fig. 7: Example usage of the open source program curl - Curl will download the file specified by the file reserves.url and put the data in the file reserves.csv

torical oil prices are downloaded from the U.S. Energy Information Administration⁽¹²⁾. Gas prices proved harder to come by, as they vary greatly by location, however the International Monetary Fund⁽¹³⁾ provides historical commodity prices for various commodities. The price of Russian Natural gas at the German border is used. The accuracy of this is unknown to the author, and efforts should be put in to obtaining better historical gas prices for the NCS .

3.3 Data Processing

3rd party programs from different vendors seldom use the same syntax and file format for input and output files. To build an integrated model communication between the different sub-models is of paramount importance. To facilitate the communication manually is cumbersome at best, and often impossible in any reliable time frame. To accomplish the cross program communication the author of this thesis wrote a program called `txt2Str`. It's function is simple, it will convert a delimited text file, for instance a comma separated file, into a streamz file. Streamz, as mentioned earlier, is a program designed to facilitate communication between different applications. It can translate one fluid stream from one characterization to another. Streamz also has some other very useful features, like aggregation, filtering, splitting, accumulation. Although it was time consuming to write this program, especially for someone with limited programming experience, this only has to be done once, and it can be reused.

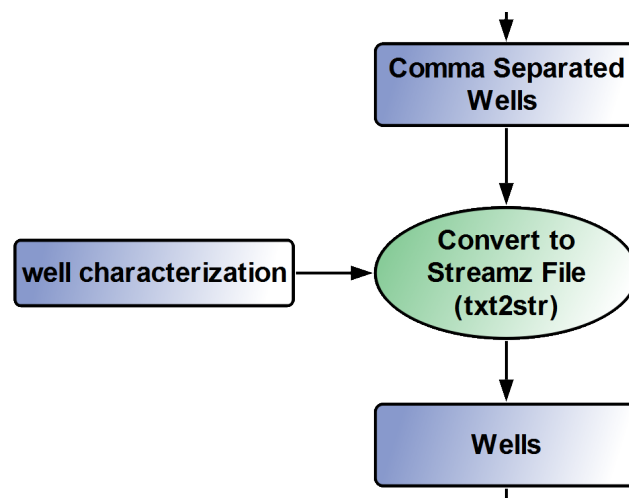


Fig. 8: `txt2Str` converts a text file to a Streamz file - The process requires a characterization file which specifies the number of components.

3.4 Generic Integrated Model Builder

A compressed and unbuilt version of the entire model occupies 1.5 MB of disk space. This stripped down version potentially contains all the functionality of the full built model. The stripped down version is basically a template, and the template is combined with an instruction file and Petrostreamz' Project Builder. The project builder will follow the instructions from the instruction file, and prompt the user for case specific data, like where you would like to locate the new project and what you want to name it. The Project Builder user interaction is done through a wizard type user interface. The project builder is still undergoing important development, and will be improved significantly in the near future. The integrated solution will be updated to support the new options that will be available in the future. Further the Project

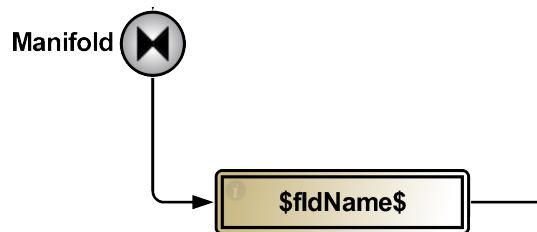


Fig. 9: Project Template - The composites to be duplicated are specified with the variable name in-capsuled dollar signs.

Builder will copy all the basic files from the template to the new directory, and launch composites inside the template, first the Data Acquisition and Data Processing module. This will keep the model up to date. Secondly it will launch a special composite designed specifically for the purpose of generating a structure file for the NCS. This composite will use the NPD-reader (see **section 3.5.1**) to parse all the downloaded data and build a structure tree based on this. The project builder will use the structure data to create all the current active fields and connect discoveries, wells, and facilities to their corresponding fields. See **Appendix A** for a step-by-step guide of how to build the model.

3.5 Decline Curve Analysis for individual fields

In 2006 Arent Arntzen wrote an application called Decliner. The program was written under the guidance of Curtis H. Whitson and based on Fetkovich decline curve analysis. The goal was to create a reservoir simulator based on Decline Curve Analysis described in Section 2, which honored rate constraints, multiple wells and groups. The program was altered by the author of this thesis to improve it's functionality. The decliner discretize time by user selected time steps, and calculates maximum potential production at every time step. The discretization serves a powerful function, time is "reset" every time step and the fields reserves and potential production at day 1 does not have to be known. Changes can also be made to reserves and production rate at different times.

$$Q_{i,new} = Q_i - Q_p \quad (10)$$

$$D = \frac{1}{1-b} \frac{q_i}{Q_{i,new}} \quad (11)$$

$$\Delta Q_p = Q_{i,new} \left[1 - (1 + bDdt)^{1-\frac{1}{b}} \right] \quad (12)$$

ΔQ_p represents the maximum potential production, if this is larger than a specified production rate constraint, the production rate constraint is used instead.

Similar to other reservoir simulators the decliner requires an input text file as its driver file. Due to the genericness of our integrated model, we require that this driver file has to be written automatically, based on a few field specific variables. See appendix C for an example input file. The decliner input file is created by a tailor made program called the NPD-reader.

3.5.1 NPD-reader

NPD-reader is written in the object oriented programming language C++. This makes it highly customizable, and the user of the integrated model can easily add new features to the generation of the decliner file. Enhanced Oil Recovery procedure estimation (see section 3.7), in-phasing production rate (see section 4.7) have already been implemented. Future implementations could include, but not limited to, wells and facilities being added to the model in the future at different times, individual constraints for wells and facilities etc. The NPD reader creates the input file for the Decliner based on:

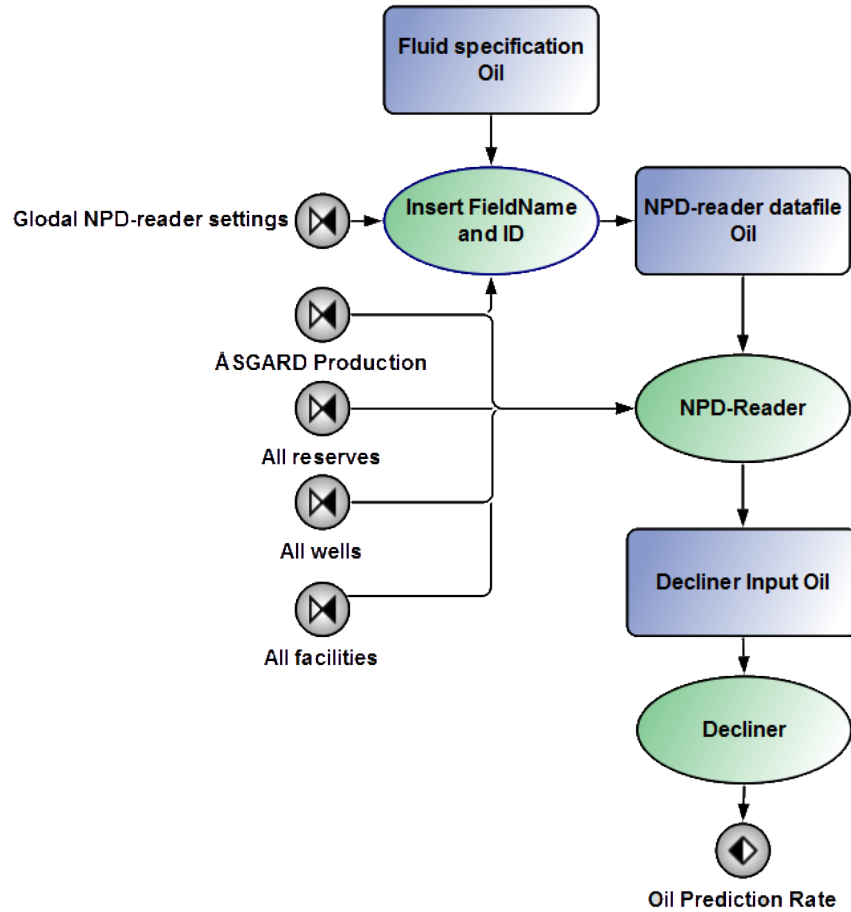


Fig. 10: Field specific Decline Curve Analysis - Screenshot of the Decliner model for Åsgard

1. NPD-reader driver file, where the user or the automatic generation must specify field name, Arps decliner constant b , characterization files, fluid characterization, prediction time and time step and a few more options. The fluid characterization and field name are automatically inserted by Pipe-It.
2. Data files, such as remaining reserves, historical production, wells, and facilities. The historical production rates from the NPD database are on a per field basis, as a consequence of this we are unable to implement any rate constraint or deliverabilities for individual wells. Until this data becomes available, the NPD-reader will distribute the current production rate evenly among the member wells.

An engineering application of this model could be to modify the number of wells, and individual well constraints to see how this will influence the predicted oil and gas rate production. If you bring in the economics model (**section 3.6**) and a economic model to describe the cost of new wells, the Pipe-It Optimizer can be used to find the optimum number of wells for a given field.

3.6 Historical and Predicted Economics

The economics model is simple, income is equal to cumulative fluid production during a period multiplied with fluid spot price during that period. Historical oil prices is fetched from the US Energy Information Administration, and Europe Brent Spot data is available from May 1987 to present time. Gas prices are provided by the International Monetary fund, where data is available from 1985. No price for NCS gas was found, and the price of Russian gas on the German border was used. Given the later results, the author is skeptic concerning the accuracy of these gas prices, but has been unable to find any calculation mistakes. The historical oil and gas prices are combined with the historical oil and gas production and predicted oil and gas production for each field, to provide data and plots of income rate and cumulative income for each field. The economic model described above is weak, but if it was to be combined with a cost model, time value of money, a more accurate and extensive model of historic prices, and a price forecast model this could prove to be a very powerful tool.

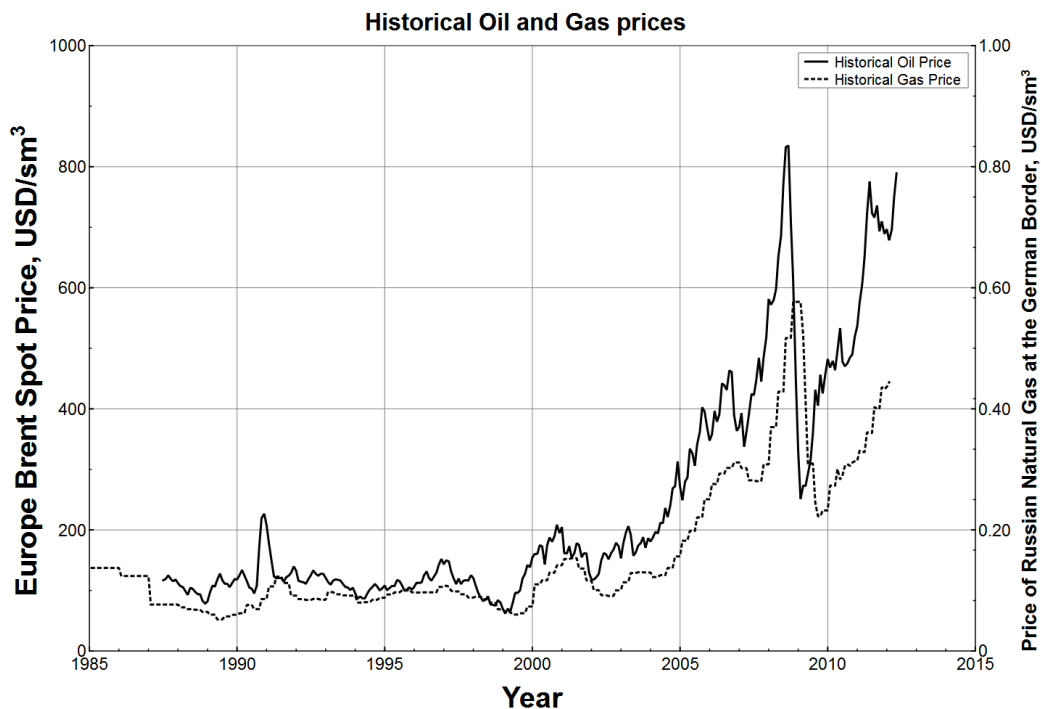


Fig. 11: Historical oil and gas prices - Europe Brent spot price in solid lines, plotted on the primary y-axis. Price of Russian Natural Gas at the German border plotted at the secondary y-axis.

3.7 EOR impact estimation

Secondary and tertiary recovery techniques aims to increase a field's reserves. There are several different techniques, and a lot of research effort is put into this area. The task of modeling of all the different techniques is a lot larger than the scope of this master thesis, so the author has chosen a simplistic method of modeling EOR procedures, by simply modeling the expected resulting reserve increase of an EOR procedure. It is left to the engineer using the model to input the estimated reserve increase and the effect this will have on the production rate. To make this work generically for the NCS model the age of the fields has to be taken into account. Some field has been producing for decades and has produced most of it's reserves, while others are brand new. If we want to be able to increase the reserves of the entire NCS by say, 5%, we have to take both remaining reserves and produced reserves into account to get reasonable results.

$$N_i(t=0)_{eor} = N_i(t=0) \times f_{eor} \quad (13)$$

The initial recoverable reserves is equal to the current remaining reserves added to the current cumulative oil produced $N_i(t=0) = N_i + N_p$.

$$N_i(t=0)_{eor} = (N_i + N_p) \times f_{eor} \quad (14)$$

Subtract the current cumulative oil produced at both sides.

$$N_i(t=0)_{eor} - N_p = (N_i + N_p) \times f_{eor} - N_p \quad (15)$$

$N_i(t=0)_{eor} - N_p$ is equal to the current remaining reserves after the EOR increase, $N_{i,eor}$. Simplify the right side of the equation.

$$N_{i,eor} = N_p \times (f_{eor} - 1) + N_i \times f_{eor} \quad (16)$$

Here f_{eor} is the remaining reserve EOR factor. If f_{eor} is equal to 1 then $N_{i,eor} = N_i$.

3.8 New field developments

Performing new field development assessments are readily available in the integrated model, which is broken down to individual composites for each field. By making a copy of a template field and manually inserting the initial reserves and initial production rates, a forecast is created in less than 2 minutes. This forecast can be evaluated stand-alone, or in combination with a local cluster, or all the fields on the NCS. Optional inputs for the new field can be:

1. Well and group structure
2. Rate build up period
3. Process capacity limited production

The input of the data is readily available through the Linkz interface, see **Fig.12**.

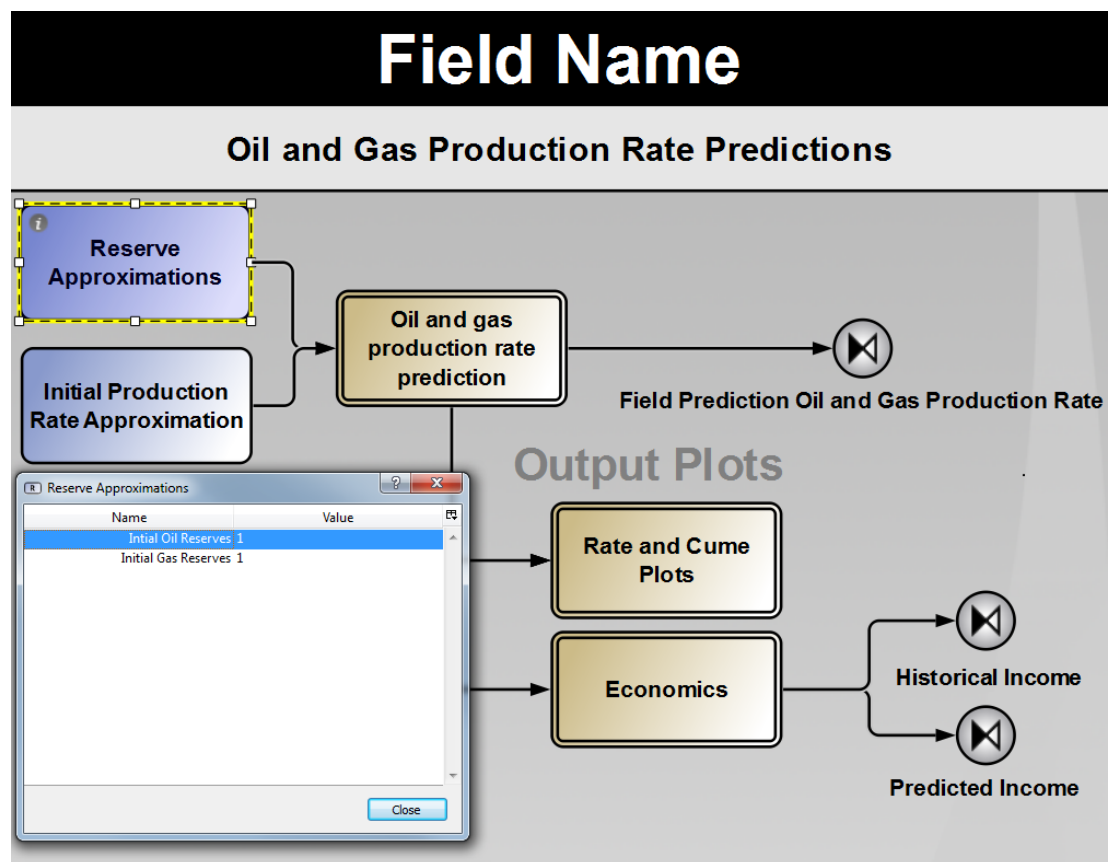


Fig. 12: A field template - Make a copy, insert initial oil & gas reserves and initial oil and gas production rates.

4 Example Applications of the Integrated Model

4.1 Historical Oil and Gas Production for all fields on the NCS

The most import part of any modeling work is to control the quality of your input data. Although it would be easy to trust data provided by the Norwegian Petroleum Directorate, it is important to spend time to control this. A part of this QC work turns out to provide us some useful information, the plot in **Fig. 13** and **Fig. 14** shows the total historical production rate for all the fields combined. The data is taken as is from the factpages. The Norwegian Historical Oil Production has often been compared to Hubbert's Idealized Peak Oil Curve. Even though it is a very skeptic approach, it is a very quick forecast and it gives decent fit to historical production data in just a few minutes. A plot of the historical monthly NCS production oil rate overlaid Hubbert's Peak Oil curve can be seen in **Fig. 15**. Subsequently we will see other and perhaps more realistic approaches of forecasting the NCS oil production.

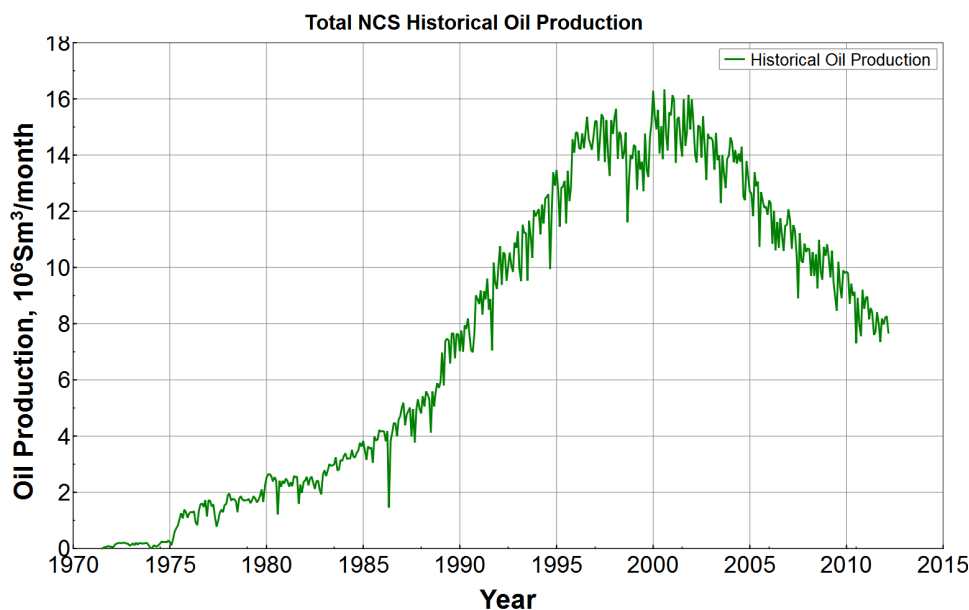


Fig. 13: Historical oil production rate - for all fields on the NCS combined.

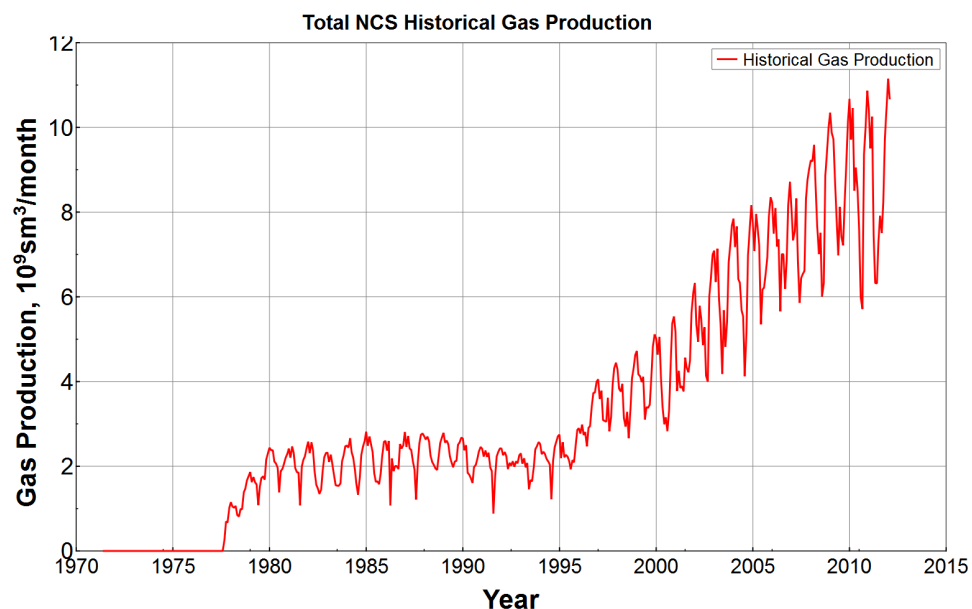


Fig. 14: Historical gas production rate - for all fields on the NCS combined. The plot shows seasonal cycles of the gas production rate.

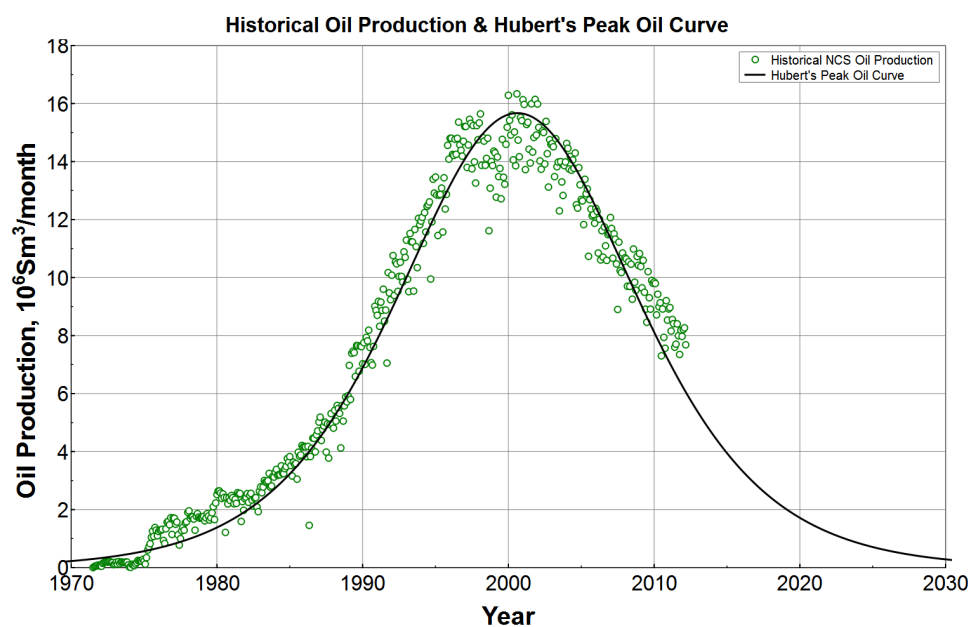


Fig. 15: Hubbert's Peak Oil Curve - overlaid the NCS monthly oil production rates.

4.2 Historical and Predicted Oil and Gas Production for Åsgard

To perform a oil and gas production forecast we use the decline method described in **section 2** and **section 3.5**. A schematic of the data flow can be seen in **Fig. 16**. The NPD-reader will read all the input files and perform the follow operations:

1. Read the remaining reserve file to acquire the remaining reserves for the field of interest.
2. Read the i newest historical production entries from the Historical production file. The NPD-reader will insert the average production rate as the initial forecast production rate.
3. Read the Arps Decline Constant b from the Global model constants file.
4. Read the contents of the well- and facility file and generate the well and facility connectivity structure.
5. Write the Decliner driver file.

When the decliner input is generated, the decliner program will launch and forecast the oil or gas production. This procedure has to run twice, once for oil and once for gas. The Åsgard historical production & predicted oil production rate can be seen in **Fig. 17**

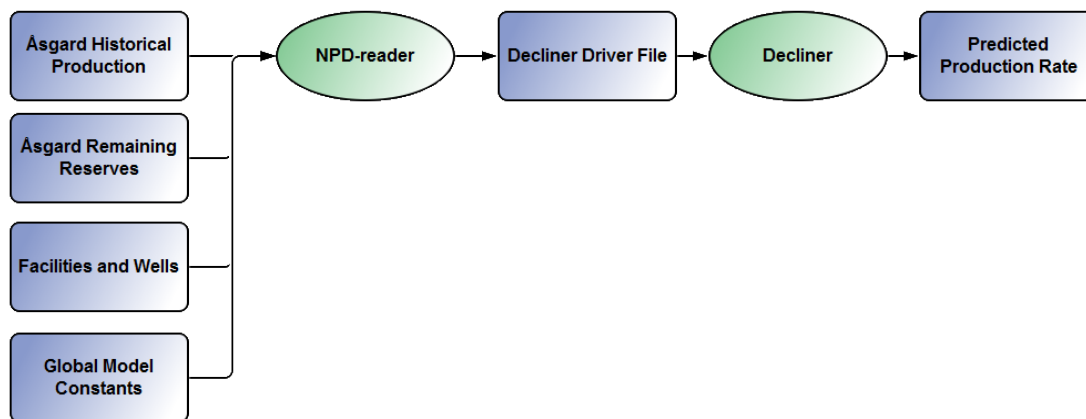


Fig. 16: Schematic layout of the decline curve forecast data flow - for Åsgard.

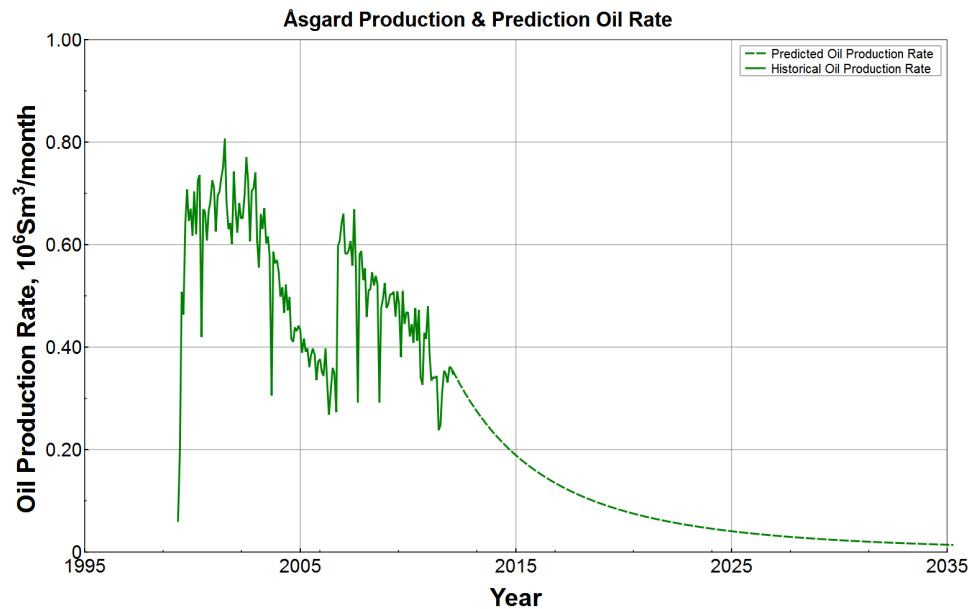


Fig. 17: Historical & Predicted Production Oil Rate for Åsgard - Predicted Oil Production Rate in dashed line.

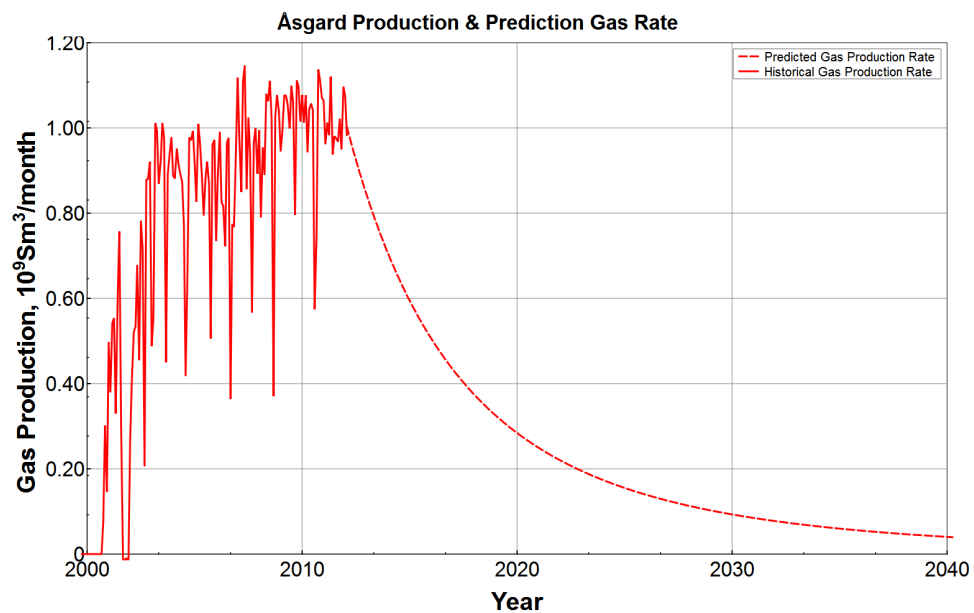


Fig. 18: Historical & Predicted Production Gas Rate for Åsgard - Predicted Gas Production Rate in dashed line. Åsgard's gas production is clearly not on decline, and the prediction is not correct. Predicted gas production rate will mostly be excluded from subsequent plots and calculations.

4.3 Historical and Prediction Economic Income for Åsgard

Historical and predicted income can be seen in **Fig. 19** and cumulatives in **Fig. 20**.

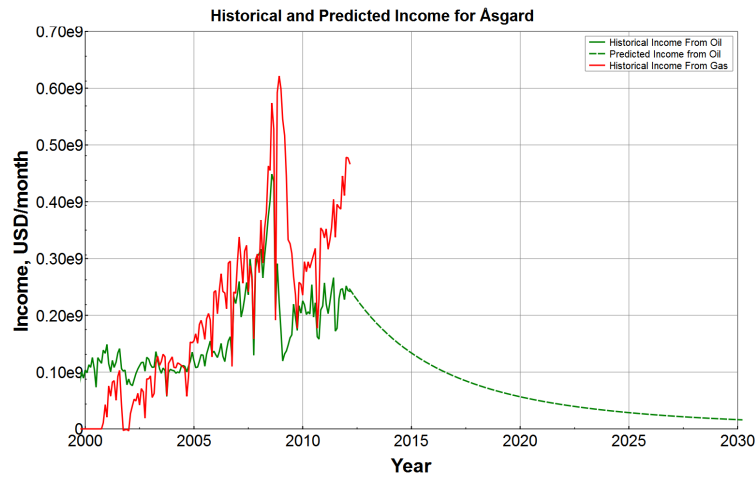


Fig. 19: Historical & Predicted Income for Åsgard - Predicted gas income is not included, as Åsgards gas production has not yet gone on decline.

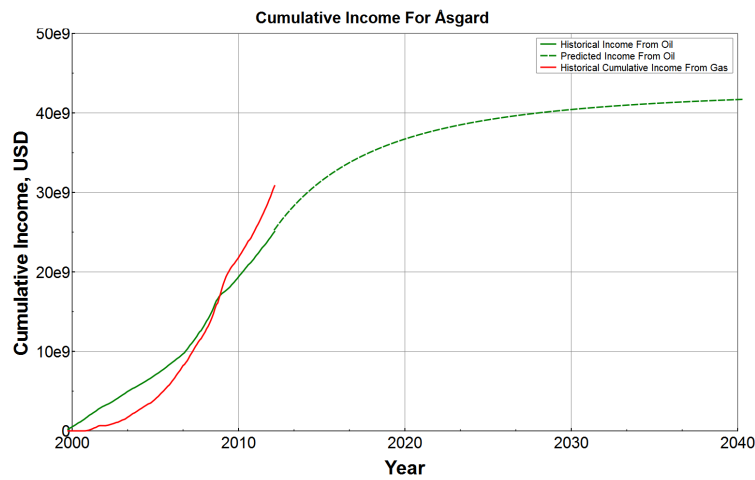


Fig. 20: Historical & Predicted Cumulative Income for Åsgard -

4.4 Oil and Gas Production for all the Fields on the NCS

Oil and gas production forecast is done by individual fields, and aggregated together to form the prediction for the entire NCS. This can be seen in **Fig. 21**. Other interesting aggregations could be fields grouped and aggregated per operator, geographic region, or maturity of the fields.

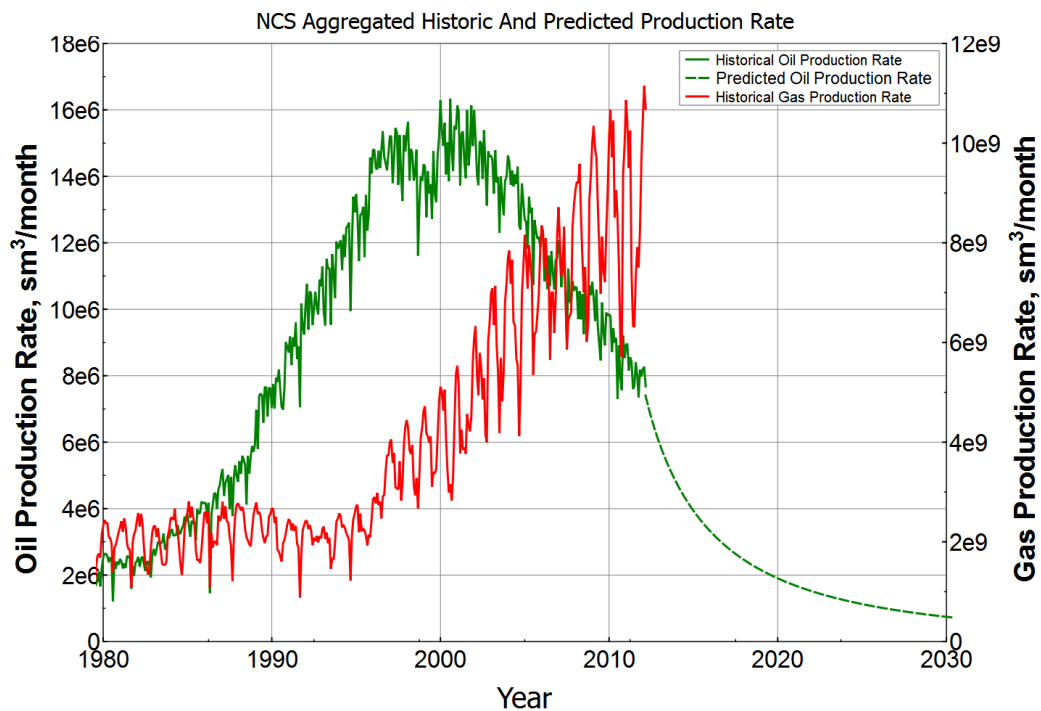


Fig. 21: Aggregated Historical & Predicted Production Rate for all the fields on the NCS - Historical Oil Production is plotted as the green solid line, and predicted Oil Production Rate in the green dashed line. Historical gas production is included on the secondary axis as the red solid line. Predicted Gas Production is calculated, but not included in the plot, as most gas production on the NCS has not yet gone on decline.

4.5 Income for all the Fields on the NCS

All the individual economic income rates are aggregated in the same manner as the production rate predications.

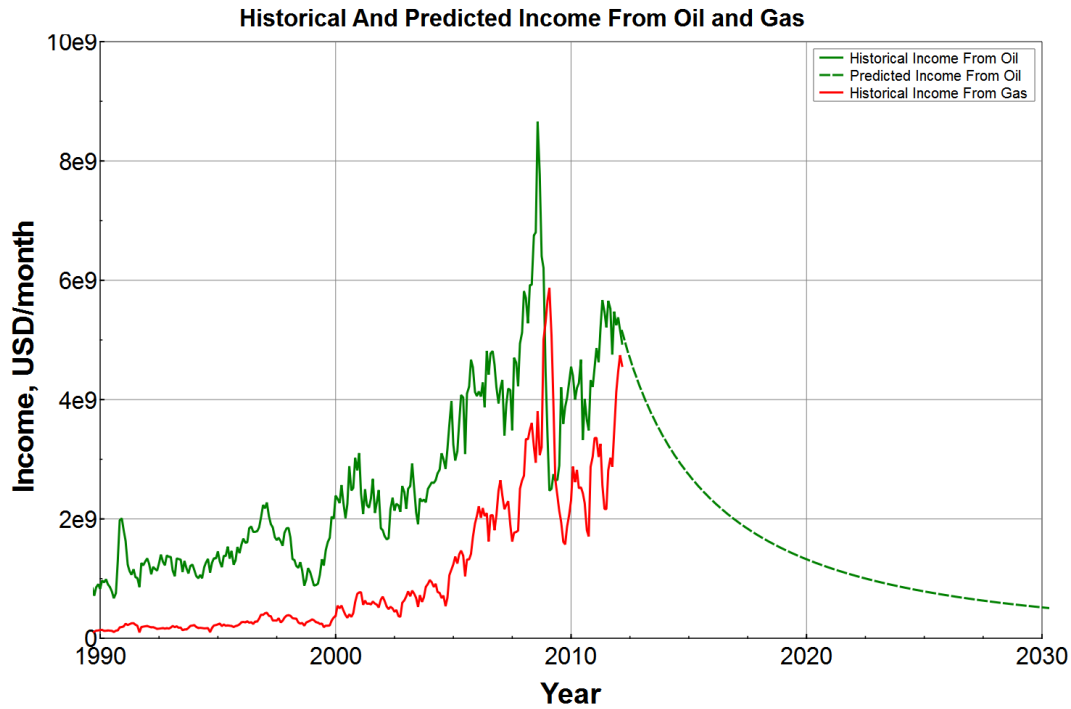


Fig. 22: Total Historical and Predicted Income for all the fields on the NCS
 - The prediction is based on all the current fields in production. New fields not yet in production and future discoveries is not included. The oil price stays constant throughout the prediction, at 696 USD/sm^3

4.6 Enhanced Oil Recovery Simulation

Enhanced Oil Recovery is estimated by increasing the initial reserves by a factor at the start of production. What the actual cause of the increase is, is disregarded.

4.6.1 The impact of a simulated EOR procedure on one individual field

The resulting increasing productivity of a reserve increase is modeled for Troll. A before and after EOR procedure comparison can be seen in **Fig. 23**. The reserves at the start of production is increased by 50%. This means if the ultimate recovery was expected to be 40%, the ultimate recovery is increased to 60%. This number is chose for illustration purposes only.

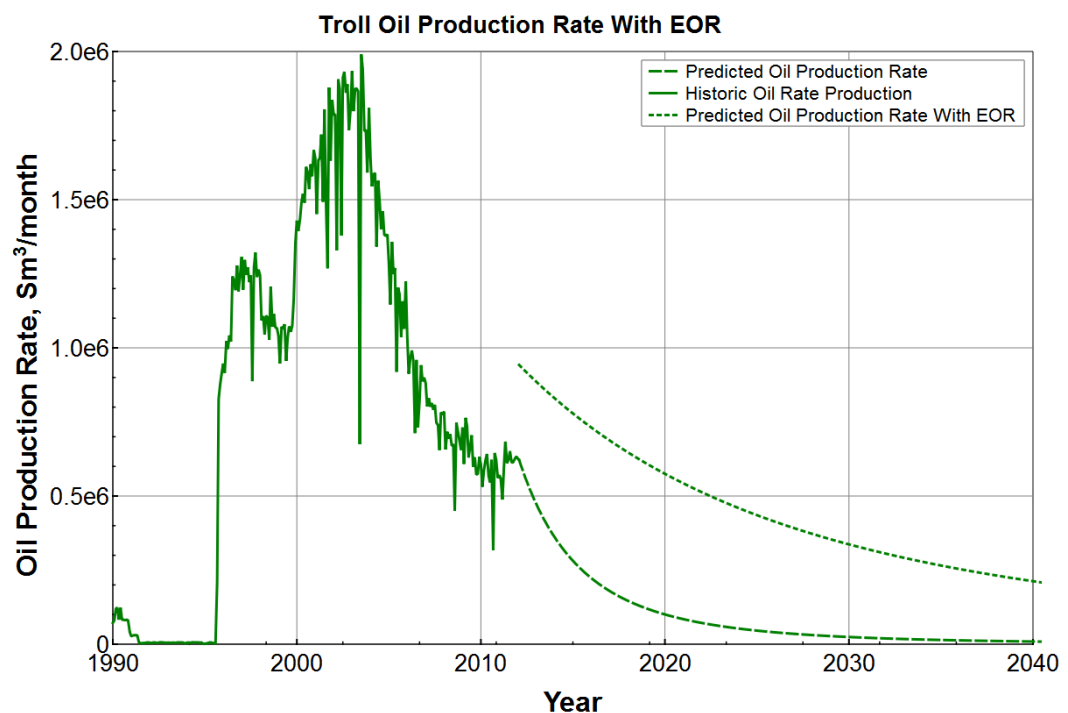


Fig. 23: Troll Historical Oil Production and two predictions - 1. Predicted Oil Production Rate on normal decline. 2. Predicted Oil Rate Production with 50% increased initial reserves

4.6.2 The impact a simulated EOR procedure on three fields has on the total production for the entire NCS

Troll, Ekofisk and Åsgards initial reserves at the start of production are all increased by 50%. The resulting impact on the entire NCS production is plotted in **Fig. 24**.

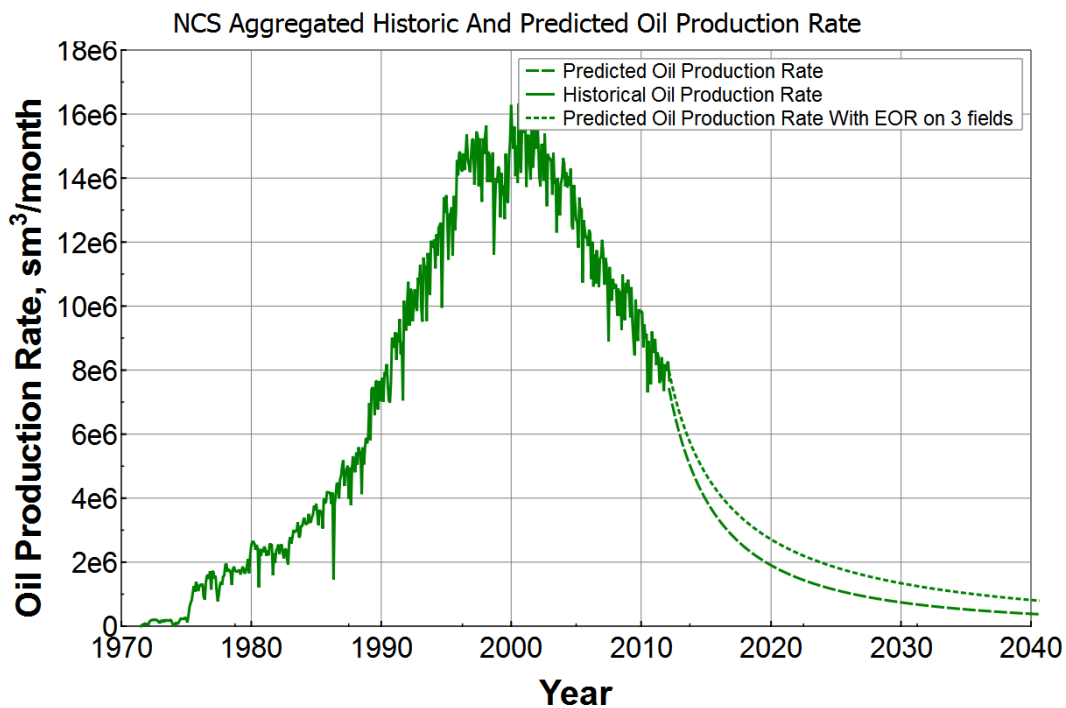


Fig. 24: Total Historical NCS Oil Production and two predictions - 1. Predicted Oil Production Rate on normal decline. 2. Predicted Oil Rate Production with 50% increased initial reserves for Ekofisk, Troll and Åsgard.

4.7 New Discoveries - Sverdrup Oil Production Prediction

In September 2010 Lundin Petroleum discovered a a giant field on the Avaldsnes prospect. Another large discovery was made by Statoil on the same structure on the Aldous Major South prospect. In early 2012 the Avaldsnes/Aldous discovery was re-named to Johan Sverdrup Prospect. With more appraisal wells to drill, the current reserve approximation ranges from 1,700 *MMbo* to 3,300 *MMbo*. It is difficult to say what Sverdrups initial production rate will be. The reservoir is described to be of "Excellent reservoir quality" with high porosity & permeability sands ⁽¹⁴⁾. Statfjord is also described to have excellent reservoir quality⁽⁵⁾. In order to estimate an initial production rate for Sverdrup we pick the maximum production rate ever achieved by Statfjord and use that. We keep in mind that technology has evolved, and assume this is pessimistic approximation. To do the production rate forecast, we use the procedure

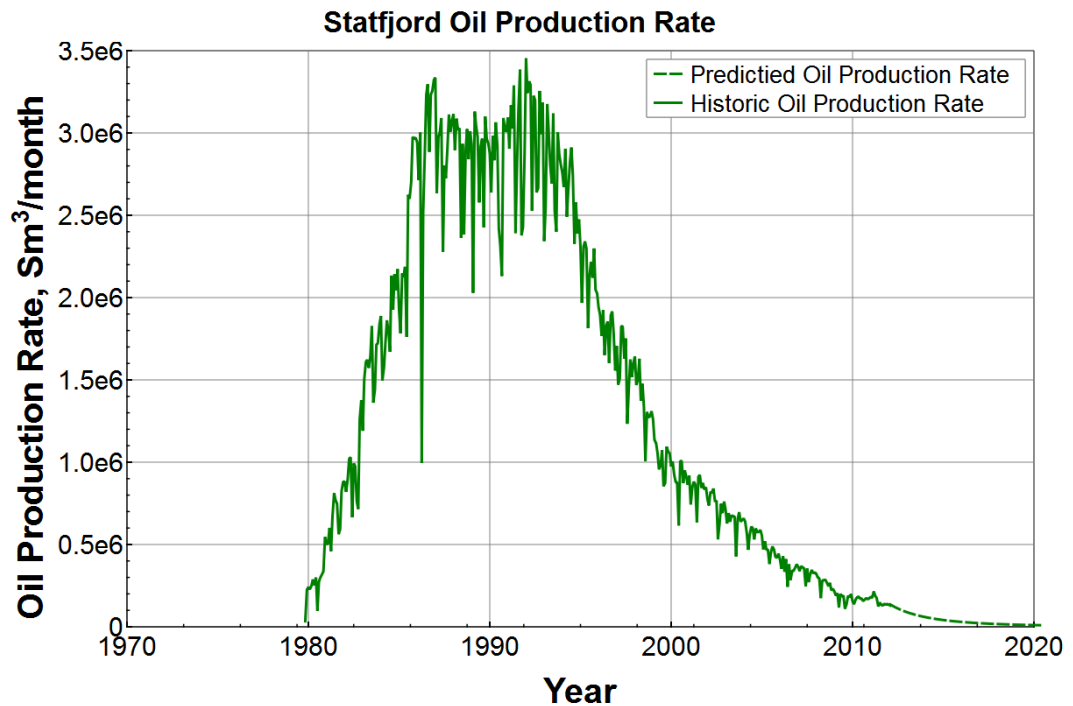


Fig. 25: Statfjord Historical and Predicted Oil Production Rate - The maximum oil rate ever achieved at Statfjord was 3,453,530 *sm³/month*

described in section 3.8. The initial production rate is set to 3,453,530 *sm³/month*, see **Fig. 25**. The reserves are set to 3.98×10^8 *sm³*, the average of the upper and

lower bounds of Lundins and Statoils reserve approximations⁽¹⁴⁾. The Arps exponent b is set to 0.3, however this is uncertain. To simulate the implementation of an actual

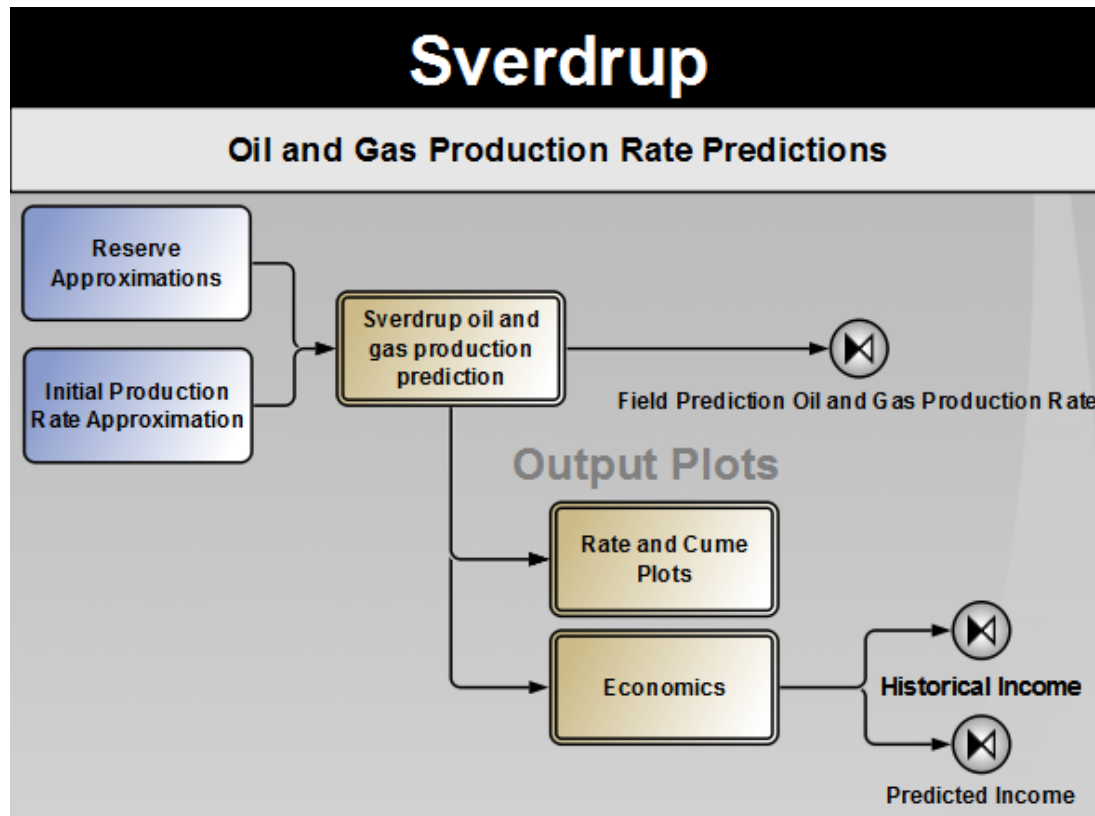


Fig. 26: Sverdrup Oil and Gas Prediction Rate Model - Input: Reserve estimation, Initial Rate Production Rate estimation, and Arps decline exponent b . Output: Economic and Production Rate predictions.

oil field more realistically than what we have done previously, we are going to utilize some of the features of the decliner. A linear build up period of 3 years is added, and a maximum production of $2,000,000 \text{ sm}^3/\text{month}$ is added like this:

```

;-----
;Decliner input file
;Field      'Sverdrup'
;Rate Type:  oil
;-----
Unit Sverdrup 398000000 0.3
Well SuperWellSverdrup Sverdrup 3500000

```

```
Group Main_Sverdrup SuperWellSverdrup
Main Main_Sverdrup
```

```
Outfile oil.str
```

```
Rate Main_Sverdrup 58824
Time 1 1
Rate Main_Sverdrup 117647.0588
Time 2 1
Rate Main_Sverdrup 176470.5882
Time 3 1
Rate Main_Sverdrup 235294.1176
Time 4 1
```

```
[...]
```

```
Rate Main_Sverdrup 1882352.941
Time 32 1
Rate Main_Sverdrup 1941176.471
Time 33 1
Rate Main_Sverdrup 2000000
Time 600 1
```

```
chr_OutFile ..\chr\declinerOil.chr
StreamzReport Main_Sverdrup
```

The NCS production predicted is compared with and without Sverdrup, see **Fig. 28**

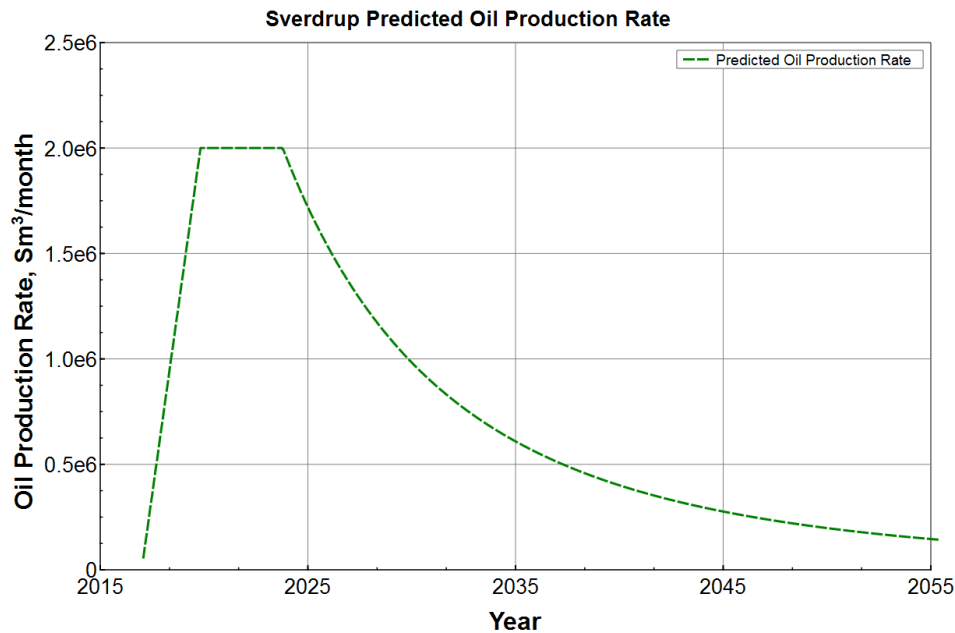


Fig. 27: Predicted production rate profile for Sverdrup - Predicted Production rate profile contains a three year long linear build up period and a production threshold of $2 \times 10^6 \text{ sm}^3/\text{month}$. The following decline is predicted using DCA.

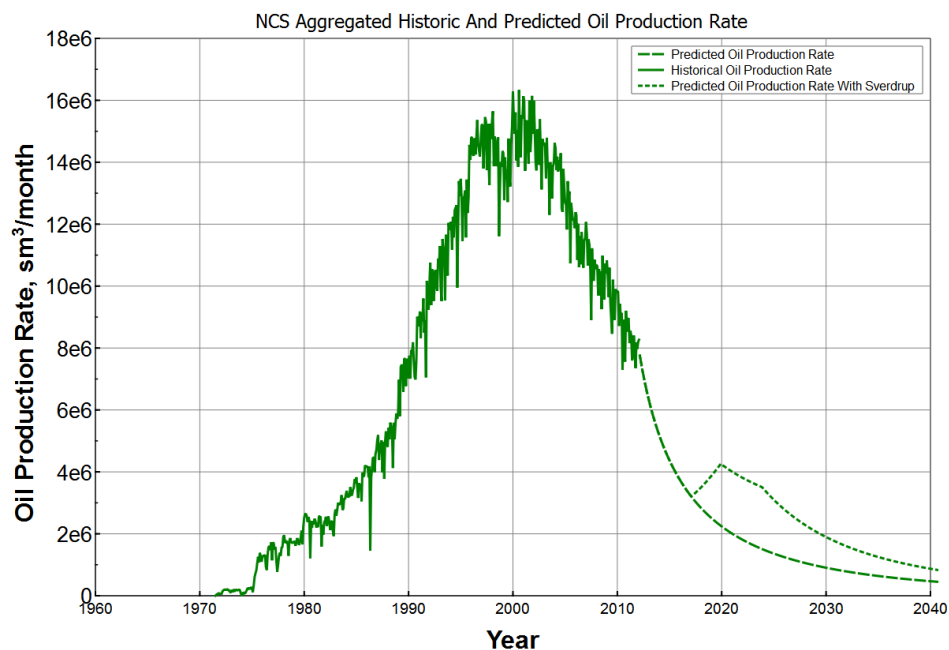


Fig. 28: Tabulated oil production rate for the entire NCS - Short dashed lines includes the prediction from the Sverdrup Field.

5 Discussion

The fantastic one of a kind database provided by the Norwegian Petroleum department has in the authors opinion has been underutilized and this MSc. thesis tries to remedy that. The examples provided previously shows some applications possible by the data available, but it is not limited by them.

Another aspect of the thesis is model integration, and the work done shows it is possible to integrate different sub-models in an integrated model. The Integrated Asset Modeling(IAM) tool Pipe-It has been extensively tested, and has proved suitable for building huge models. A common concern when building large models has been execution time. This model, consisting of about 90 fields, and performing about 3,000 application launches, runs in about 10 minutes on personal laptop. No verifications or testing of accuracy and rigorousness of the models has been done, and none of the results should be used without extensive quality control first. The economic income from gas, both historical and predicted, is likely highly inaccurate - and it should be interpreted with great care. The historic gas prices is not necessarily accurate at the NCS, and gas is often not yet on decline due to process capabilities.

6 Further Work

The author is very interested in input from the readers of thesis of how to further develop the Integrated Model. As a recent graduate the author does not know what the industry currently needs, but the generic nature of the Integrated Model allows it solve a wide variety of engineering problems. The intuitive graphical user interface makes it suitable for quickly getting an orientation of an unknown field or region.

The author plans to extend the model for Petrostreamsz A/S in the following ways:

- Grouping by region
- Grouping by operator
- Historic and predicted economic income and petroleum production rates based on operators license ownership.
- Create an on line version of the project.
- Quality control and verification of model results.
- Implement automatic quality control of input data
- Geographically correct layout overlaying a map of the NCS.
- Implement logic in the Project Builder to make the layout of the field duplication more user friendly. Manifolds should also be added at suitable places to make the model run more smoothly.

The author is very interest in industry or governmental involvement to continue the development of the model.

7 Summary

An integrated model for the entire Norwegian Continental Shelf(NCS) has been developed. The model currently does production rate and economic rate forecast, Enhanced Oil Recovery assessments, and new field development modeling. The model is based on publicly available data provided by the Norwegian Petroleum Directorate(NPD). The model is built and run mostly on publicly available software, with the exception of Petrostreamz' Pipe-It which is an Integrated Asset Modeling(IAM) software. In the authors opinion the model shows great potential for engineering use in the Norwegian oil industry, to be used for quickly doing broad spectered engineering assessments, and provide sufficiently accurate results where limited data is available. Pipe-It provides an intuitive graphical user interface, which provides the user of the integrated model a graphical representation, and is an effective tool for acquiring an overview of the NCS or a subgroup of the NCS. The integrated model is highly customizable, and can be tailor fit to any specific purpose, the examples provided in this thesis, are just that, example application limited by time and the authors limited petroleum experience. An innovative industry user can, and is encouraged to participate in the further development.

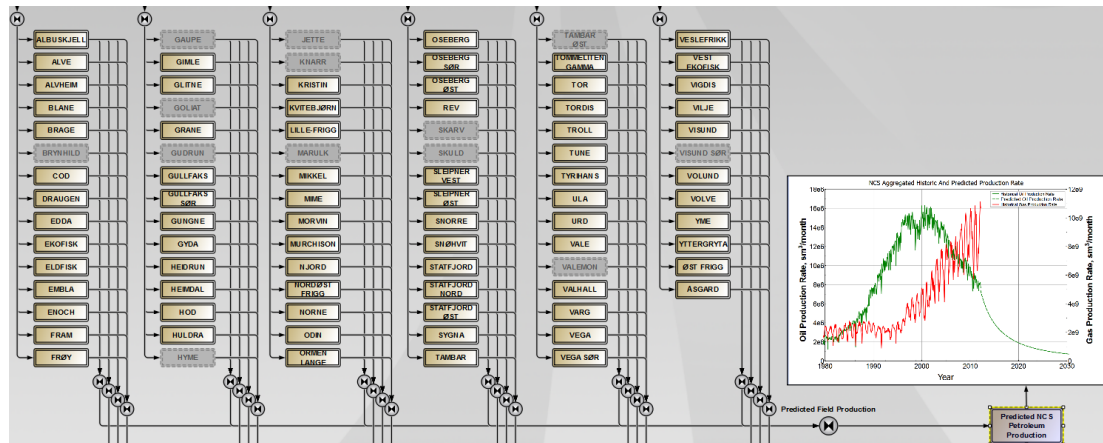


Fig. 29: Snippet of the production rate forecast model - The brown composites contain one field each. The predicted production rate from each field is aggregated in the predicted NCS petroleum production composite. The grayed out fields are not yet in production.

Nomenclature

Roman Symbols

B	Formation Volume Factor, m^3/sm^3
b	Arps decline exponent
c	Compressibility, $1/bar$
c_t	Total Compressibility, $1/bar$
D_i	Arps decline time constant, $1/day$
f_{eor}	EOR: Reserve increase factor, $f_{eor} \geq 1$
h	Thickness, m
k	Permeability, md
N_i	Cumulative oil productive, sm^3
N_p	Cumulative oil produced, sm^3
$N_{i,eor}$	Cumulative oil productive after EOR procedure, sm^3
p	Pressure, bar
p_i	Initial Reservoir Pressure, bar
p_{wf}	Well Flowing Pressure, bar
Q_i	Initial producible hydrocarbon from start of decline, sm^3
q_i	Initial pseudosteady rate at start of decline, $sm^3/month$
q_i	Initial Oil Production rate, $sm^3/month$
r	Radius, m
r_e	External Boundary Radius, m
r_w	Wellbore Radius, m

r_{wa} Apparent Wellbore Radius, m

t Time, usually in months

Greek Symbols

μ Dynamic Viscosity, cp

ϕ Porosity

Subscripts

i Initial from start of decline

Acronyms

DCA Decline Curve Analysis

EOR Enhanced Oil Recovery

IAM Integrated Asset Modeling

NCS Norwegian Continental Shelf

NPD Norwegian Petroleum Department

References

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A Model Execution

To run this model you need the following.

A.1 Installing Pipe-It

1. Go to www.petrostreamz.com
2. Click Download
3. Select "No, I'd like to register" and click "Go to registration"
4. Fill in the registration form.
5. When the account is approved, you will receive an activation email. After the activation go back to the download pages at petrostreamz.com and log in.
6. Download the most recent version of Pipe-It and install it.

A.2 Download the NPD-project

If the project is available in the download section at petrostreamz.com, download it there. If not, contact me at kjetil@petrostreamz.com. The download should be a zip file containing 2 folders, unzip it to a suitable location.

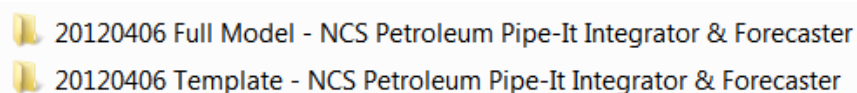


Fig. 30: Top level folder in the NPD-zip file. - The Full Model contains a built model, which is run and updated at the time of submission. The Template contains a template which can be run by project builder to create an up to date full model.

A.3 Build the project using the project builder.

This section will describe how to use the project builder to build the integrated model.

1. Open the ProjectBuilder.exe, it's located in your Pipe-It installation folder, or under Pipe-It in your start menu.

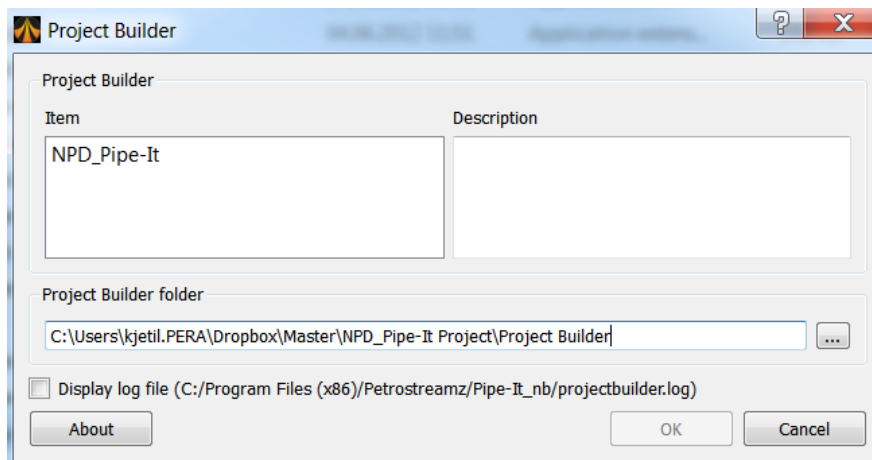


Fig. 31: Project Builder Main window - Browse to the location parent directory of your template, and select the NPD_Pipe-it

2. Browse to the location parent directory of your template, and select the NPD_Pipe-it. Click OK.
3. Specify what name you want to give the project, and where you want it located. Click next.
4. The Download NPD Factbook data window will connect to the factpages and other websites and download all the data needed. Make sure you are connected to the Internet. Click next.
5. The Generate Structure window will use the downloaded information to build a structure file. This might take a few minutes. Click next.
6. In the Map Variables window you have to help the project builder a little bit for it to understand the parent child relationship. Set it up as indicated by **Fig. 32**. Click next.
7. Check "Launch destination project" , and wait for the build to complete.
8. When the project is loaded, run the model once to update all data.

The screenshot shows the 'Map Variables' window of the 'Pipe-It Project Builder - NPD_Pipe-It'. The window has a title bar with a back arrow, a help icon, and a close button. The main content area is titled 'Map Variables' and contains the following sections:

- Source files:** A text box containing 'Project builder na' and 'Data file', with a 'working model' label and 'grouping_structure.str' value.
- Project variable, Data variable, Child variable:** A table with three columns and four rows of dropdown menus.
- Reset:** A button below the table.
- Page indicator:** 'NPD_Pipe-It - Page 4 of 5' at the bottom right.
- Navigation:** 'Next' and 'Cancel' buttons at the bottom right.

Project variable	Data variable	Child variable
fIdName	fIdName	dscName
dscName	dscName	fclName
fclName	fclName	wlbWellboreName
wlbWellboreName	wlbWellboreName	None

Fig. 32: Map variables window. - The parent child relationship.

B Project Builder Backup Solution

During the final days of the authors work on the integrated model it became apparent that the Project Builder would not be finished in time for the deadline of the MSc. Thesis delivery. In the files submitted with this project a project built by a backup solution is included. The work on the Project Builder is still being done at Petrostreamz, and the solution described in the previous section should work in the future. But for now, the solution in the folder "20120408 Backup Solution - NCS Petroleum Pipe-It Integrator & Forecaster" has to be used. Inside this folder there's 2 Pipe-It projects. NPD-Gen, and NPD-All. The NPD-Gen can be used to build the solution. For this to work you have to open NPD-Gen and run the project. Pipe-It will "freeze" for a few minutes, and the model will be built. This requires Pipe-It version 1.1. After the model is built, save the project with a new name and close the project. You have to enter the fields folder, and execute copyFolders.bat. Reopen the solution, and delete the process "Duplicate fields" and execute the model. After the model has finished running, you have to disable all the fields that are not yet in production, they will be flagged as red as they failed during the build. The solution is not as generic as the project builder version and harder to understand how to use it. It will not include new fields, or contain the field structure for individual fields. NPD-All contains a version of the model that has already been built, by following the procedure above. I suggest you use that one.

C Decliner Input File

Example of the decliner input file Tyrihans. All the input variables are tab-delimited. Consistent units for remaining reserves, production rate, and time is require. In this example sm^3 is used for volume, and *month* is used for time.

Unit [reservoir nane] [remaining reserves] [Arps decline factor *b*]

```
;
; Decliner input file created by npd-reader.exe
; Field      'TYRIHANS'
; Rate Type: oil
;
Unit  'TYRIHANS'  2.11e+07  0.3
```

Code 1: Reservoir declarations

Well declarations, syntax: Well [well name] [rate constraint]

```
Well  6407/1-B-3_H      'TYRIHANS'  15860.5
Well  6407/1-B-1_H      'TYRIHANS'  15860.5
Well  6407/1-B-1_AH     'TYRIHANS'  15860.5
Well  6407/1-A-4_H      'TYRIHANS'  15860.5
Well  6407/1-A-4_AY1H    'TYRIHANS'  15860.5
Well  6407/1-A-4_AY2H    'TYRIHANS'  15860.5
Well  6407/1-C-2_H      'TYRIHANS'  15860.5
Well  6407/1-C-2_AY1H    'TYRIHANS'  15860.5
Well  6407/1-C-2_AY2H    'TYRIHANS'  15860.5
Well  6407/1-C-3_Y1H     'TYRIHANS'  15860.5
Well  6407/1-C-3_AY1H    'TYRIHANS'  15860.5
Well  6407/1-C-3_AY2H    'TYRIHANS'  15860.5
Well  6407/1-A-1_H      'TYRIHANS'  15860.5
Well  6407/1-A-1_AY1H    'TYRIHANS'  15860.5
Well  6407/1-A-1_AY2H    'TYRIHANS'  15860.5
Well  6407/1-A-1_AY3H    'TYRIHANS'  15860.5
Well  6406/3-D-2_H      'TYRIHANS'  15860.5
Well  6407/1-W-2_H      'TYRIHANS'  15860.5
Well  6406/3-D-4_H      'TYRIHANS'  15860.5
Well  6406/3-D-4_AY1H    'TYRIHANS'  15860.5
Well  6406/3-D-4_AY2H    'TYRIHANS'  15860.5
...

```

Code 2: Well declarations

Group Declarations, syntax: Group [group name] [list of connected wells]

```
Group TYRIHANS_A 6407/1-A-1_H 6407/1-A-1_AY1 ...
Group TYRIHANS_B 6407/1-B-1_H 6407/1-B-1_AH ...
Group TYRIHANS_C 6407/1-C-2_H 6407/1-C-2_AY1 ...
Group TYRIHANS_D 6406/3-D-1_H 6406/3-D-1_AY1 ...
Group TYRIHANS_W 6407/1-W-2_H
```

Code 3: Group declarations

Super group declaration, syntax Group [super group name] [list of connected groups]

```
Group Field_ 'TYRIHANS' TYRIHANS_A TYRIHANS_B ...
```

Code 4: Super group declaration

Main group declaration, it is included to account for the cases of more than 1 reservoir. Syntax: Group [main group name] [connected super groups]

```
Group Main_ 'TYRIHANS' Field_ 'TYRIHANS'
```

Code 5: Main group declarations

Main group specification, syntax: Main [main group name]

```
Main Main_ 'TYRIHANS'
```

Code 6: Main group specification

Outfile and outfile chracteriztion declaration.

```
Outfile str\oil.str
chr_OutFile ..\..\chr\declinerOil.chr
```

Code 7: Outfile and outfile chracteriztion declaration.

Rate constraint group specification, syntax: Rate [well, group or unit name which the constraint applies to.] [max rate]

```
Rate Main_ 'TYRIHANS' 428233
```

Code 8: Rate constraint group specification

Simulation time, syntax: Time [simulate to] [time step size]

```
Time 400 1
```

Code 9: Simulation time declaration

Output type specification, syntax: StreamzReport [list of prediction rate to output]

```
StreamzReport  Main_ 'TYRIHANS'
```

Code 10: Output type specification