Material Balance Analysis of Multiple Reservoirs Sharing a Common Aquifer: The Gannet Cluster

By
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DECLARATION OF OWN WORK

I declare that this thesis: Regional Aquifer Study in the Gannet Area: A Material Balance Approach is entirely my own work and that where any material could be construed as the work of others, it is fully cited and referenced, and/or with appropriate acknowledgement given.

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ABSTRACT

It is crucial to identify key factors in a field that will affect production before developing it. When several fields are sharing a common aquifer, hydrodynamic communications can occur between them. In this case, the pressure depletion in one field is not only influenced by its own production, but also by the production of the surrounding fields. It is crucial to capture these pressure effects as it will have an impact on the future development of the fields.

Different tools and methods such as analytical computation, material balance analysis and full 3D simulation models exist to create an understanding of how fields are connected through a regional aquifer and how they are influencing each other. Indeed when fields are in hydrodynamic communication through an aquifer they are initially in pressure equilibrium so if a field starts producing, in the absence of pressure maintenance technology, the pressure depletion due to this production will impact the surrounding fields. This can have a dramatic impact, especially in the presence of both oil and gas fields. The great production from a gas field can indeed involve a depletion in the surrounding oil fields that can lead to a pressure drop below the bubble point. This unwanted scenario can be avoided if the impact of the fields on each other is known and the development strategy can be changed accordingly. To reach these conclusions, it is necessary to define the extent of the aquifer to determine the fields that are possibly in communication. This can be achieved using a material balance approach incorporating the geological data to validate the boundaries and aquifer connectivity.

This paper demonstrates the application of a material balance analysis to the Gannet cluster of fields to obtain a better understanding of how these fields are interconnected through the regional aquifer, and how they are influencing each other. A model using a material balance approach was chosen because of its simplicity, and speed. It also allows some of the uncertainties to be reduced prior running a 3D numerical simulation study. Several material balance models were built using the Software MBAL™, to capture the geological and hydrodynamic interferences that exist between the fields in the Gannet area. This paper first studies the extent of the aquifers in the gannet area and how the fields are connected through these aquifers. Then the influence of fields on each other is investigated. Finally a prediction using the production forecast for the future years is run and the results can then be integrated into the future development strategy.
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Table A 1: Milestones in Material Balance Analysis for Complex Reservoirs

Table A 2: Milestones in Determination of pressure interferences between fields
Regional Aquifer Study in the Gannet Area: A Material Balance Approach

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Abstract

It is crucial to identify key factors in a field that will affect production before developing it. When several fields are sharing a common aquifer, hydrodynamic communications can occur between them. In this case, the pressure depletion in one field is not only influenced by its own production, but also by the production of the surrounding fields. It is crucial to capture these pressure effects as it will have an impact on the future development of the fields.

Different tools and methods such as analytical computation, material balance analysis and full 3D simulation models exist to create an understanding of how fields are connected through a regional aquifer and how they are influencing each other. Indeed when fields are in hydrodynamic communication through an aquifer they are initially in pressure equilibrium so if a field starts producing, in the absence of pressure maintenance technology, the pressure depletion due to this production will impact the surrounding fields. This can have a dramatic impact, especially in the presence of both oil and gas fields. The great production from a gas field can indeed involve a depletion in the surrounding oil fields that can lead to a pressure drop below the bubble point. This unwanted scenario can be avoided if the impact of the fields on each other is known and the development strategy can be changed accordingly. To reach these conclusions, it is necessary to define the extent of the aquifer to determine the fields that are possibly in communication. This can be achieved using a material balance approach incorporating the geological data to validate the boundaries and aquifer connectivity.

This paper demonstrates the application of a material balance analysis to the Gannet cluster of fields to obtain a better understanding of how these fields are interconnected through the regional aquifer, and how they are influencing each other. A model using a material balance approach was chosen because of its simplicity, and speed. It also allows some of the uncertainties to be reduced prior running a 3D numerical simulation study. Several material balance models were built using the Software MBAL™, to capture the geological and hydrodynamic interferences that exist between the fields in the Gannet area. This paper first studies the extent of the aquifers in the gannet area and how the fields are connected through these aquifers. Then the influence of fields on each other is investigated. Finally a prediction using the production forecast for the future years is run and the results can then be integrated into the future development strategy.

Introduction

The Gannet cluster (Appendix B. 1) contains seven fields ranging from undersaturated oil to oil rims to gas fields that are connected by regional aquifers. The fields operated by Shell UK EP are located in the North Sea and lie 180 km East of Aberdeen in a water depth of 95 m. The cluster is developed through a single platform at Gannet A, with subsea tie-back from the other six fields. Three of the fields are saturated oil rims with a free gas cap (Gannet A, B and C). The remainders of the fields are undersaturated oil fields (Gannet D, E, F and G). The first development phase consisted of the development of Gannet A to Gannet D in 1992. The three other fields were developed in the late 90’s.

The Gannet fields include Palaeocene and Eocene aged deep marine sandstones. The two primary reservoirs across the Gannet fields are the Forties Sandstone members and The Tay Sandstone member. These sands were deposited in a deep marine environment and were strongly influenced by the pre-existing topography and halokinesis. During the late Palaeocene and Eocene, these deep marine sediment flows have lead to a number of sand packages being found in the Gannet Cluster fields including Andrew, Bittern, Cromarty, Odin and Gannet Sandstone members. The support of the regional aquifer that connects the field is important as it has eliminated the requirement for water injection facilities. Thus it is necessary to capture the uncertainty in the behaviour and extent of aquifers and the pressure communication between the fields as it will have an impact on the future development of the cluster.

The seven fields are producing independently from each other, however, it seems that the fields are in hydrodynamic continuity through the aquifer. This has been inferred from pre-production depletion observed in Gannet E, F and G fields. Therefore, production from each field probably results in an interference, or pressure drop, with respect to the other fields transmitted through the aquifer. That is why a study to investigate pressure communication between the fields in the Gannet area is necessary.

After considering carefully all the data required, we analyse the geological description of the fields in term of hydraulic units and producing intervals, then the extent of the aquifers through the Gannet area. These information are then integrated into several material balance models to determine the characteristics of the aquifers and to evaluate the impact of the fields on
each other. The general adopted workflow is shown in Appendix B. 2 and consists of the understanding of the subject with a literature review, the preparation of the model, the integration of the results into a MBAL™ model and the analysis of the results.

**Literature Review**

In this section, all the relevant literature used for this study is reviewed. This can be divided into two groups. The first one includes all the papers describing methodology used to analyse and describe complex reservoirs using a material balance model, often illustrated by field cases. The second group presents different studies and methodologies to determine pressure interferences between reservoirs sharing a common aquifer from an analytical to a simulation point of view.

**Material balance analysis for complex reservoirs.** Material balance analysis is a simple tool that is mainly used to narrow down uncertainties before running a full 3D simulation model. However, a single tank material balance model does not enable to capture the heterogeneity/geometry of the reservoir, so it is necessary sometimes to describe a reservoir using a multi tank model. This can allow to describe the different compartments/ hydraulic units, which is necessary when pressure depletion is not the same in the whole reservoir. Several examples of material balance analysis for complex reservoirs can be found in the literature. For instance the modeling of the Samarang field (Bui, T., Bandal, M., Hutamin, N. And Gajraj, A.,2006) is a good application that highlights complex reservoir modeling using a material balance approach. Indeed this field consists of several stacked sands and is highly compartmentalized. This study also shows the importance of a proper integration of the reservoir data (Pressure, PVT data, Heterogeneity…)

Other relevant papers also describe the advantages of a multi tank model over a single tank model. In their study, J. Malzoom, M. Tosdevin, D.Frizzell, B.Foley and M.Sibley (IPCT-11489, 2007) compare the results given by a single and multi tank model in the case of a highly heterogeneous reservoir with the results obtained with a 3D model. Then, they outline the importance of the model description on the final results. Finally other field cases given in the references were used to realize this study.

**Determination of pressure interferences between fields.** In this study the pressure interferences are captured using a material balance approach, however the problem can also be solved using other tools and methods. For instance, various techniques have been established to evaluate the extent of aquifers and pressure interferences between fields sharing a common aquifer. One of the first studies realised was the evaluation of the pressure performance of five fields sharing a common aquifer in West Texas with an electrical analyser (Moore and Truby, Jr, 1952). This study highlights the major impact that neighbour fields can have on one another when they are sharing a common aquifer. 3D simulations were also used to determine the extent of pressure communications between fields and pressure drawdowns on surrounding fields (S.D Coutts, 1997). Although few analytical models have been developed for characterizing reservoirs sharing a common aquifer, models were presented by Mortada (1955), Hurst (1960), Sageev and Horne (1985), Rodriguez et al. (1996) and Shimada and Yildiz (2009). For the first four models, the main limitation is because they can be applied only to an edgewater drive mechanism. Indeed, the assumptions made infer that the water influx can come in the horizontal direction only. The last model developed by Shimada and Yildiz (2009) is a three dimensional analytical model, which can also describe bottomwater drive mechanisms.

**Data preparation**

To build the most accurate material balance model, the preparation of data and the verification of the consistency of these data are of high importance. Material balance requires valid pressure, production data and PVT data.

**PVT data.** The PVT data where gathered for the seven fields and were validated afterwards. When basic PVT data only were available, traditional black oil correlation were used. Though, when both basic fluid data and some PVT laboratory measurements were available, a matching method available in MBAL was applied to modify the existed correlations and fit better the measured data using a non-linear regression technique.

**Pressure data.** Both Repeat Formation Tester and pressure build-up data are available from production logs and permanent downhole gauges. Pressure data for every appraisal/exploration and production wells were investigated and allow to highlight signs of pre-production depletion. Indeed these comparisons show difference in the reservoir pressure between the appraisal phase and the beginning of production phase. Finally the pressure were converted to datum and were then used for the history matching and the determination of different compartments.

**Production and injection data.** Historical production data are available for all the Gannet fields. The monthly production and injection data were exported for each producing well from the Gannet area.

**Reservoir data.** Reservoir data such as porosity, permeability, connate water/oil or gas saturation were obtained using available information such as existing MBAL or Petrel models. Discussion with the field reservoir engineers and petrophysicists was necessary to validate these data.
**Geological data.** The geological data such as depth maps of the main formations or reservoir fault system maps were gathered to detect elements that could give a better understanding of how fields are compartmentalized and how they could communicate between them. The geological data acquisition was an essential step, and a good collaboration with the field geologists was necessary to investigate all these data. However, some assumptions had to be made, especially concerning the transmissibility of the faults, and will be validated during the history matching phase.

**Aquifer data.** Some aquifer data were gathered to determine the extent of the aquifer and the possible connection between the fields. However, the aquifer properties are rarely available and correlation with the formation within the reservoir had to be done to infer these properties. Moreover, all the data that could help us to limit the extent of the aquifer or to justify some connections were gathered. For example porosity of permeability in the area between the fields or formation water analysis. However because of the lack of data, especially between the fields, a large amount of uncertainties remains concerning the aquifer parameters.

**Investigation of Signs of Pre-Production Depletion**

Investigation of the signs of pre-production depletion in non-producing fields is the first step in deciding to investigate the possibility of pressure interferences between fields. Indeed, within the Gannet area, all fields have not started producing at the same time. For instance, Gannet A, B, C and D have been put in production in 1992 whereas Gannet G, E and F have started producing in the late 90’s. To highlight signs of pre-production depletion, it is necessary to compare the appraisal/exploration and first production pressure data for these three fields. The pressure data show clear evidence of pre-production depletion. The results are presented for Gannet E in Figure 1 and in Appendix C. 1 and Appendix C. 2 for Gannet G and F. From these plots, we reach the conclusion that the influence of producing fields is non-negligible as the amount of pre-production depletion for Gannet E, F and G are respectively 150, 100 and 30 psia.

These results clearly highlight that the direct production itself will not be the only cause of the depletion in the fields and it is necessary to investigate the origin of this indirect depletion as it will impact the future development plan of the Gannet fields.

![Figure 1: Evidence of pre-production depletion in Gannet E. The pressure from the appraisal wells and the pressure obtained just before the beginning of the production show a depletion of around 150 psia.](image)
Description of the Geology, Fault System and Compartmentalization

To build a material balance model, an accurate description of the different hydraulic units for each reservoir has to be made. Indeed a single tank model will assume that all wells contact all hydrocarbons and so presence of faults and compartments is not a factor in recovery. This approach is not compatible with this study as fields can produce from different compartments or producing intervals which will not necessarily share the same aquifer system. This is done by studying the reservoir intervals and the fault systems in the fields to define the different compartments. These results can also be assumed or confirmed by comparing the depletion behaviour in each of these compartments. Finally, when uncertainties concerning the presence and transmissibility of the faults remained, assumptions were made and then validated using the material balance model. This process consists of describing compartments in the MBAL model that are compatible with the geological data, and then attempts to match the pressure data with this description.

The Gannet fields contain both Palaeocene and Eocene aged deep marine sandstones. The four main reservoirs interval across the Gannet fields are the Tay, the Forties, the Rogaland and the Andrew formations. These intervals are isolated from each other by major, regional or semi regional shales. Moreover a number of other sand packages such as the Balder and the Cromarty can also be found. As shown in the geological cross section given in Figure 2, the Forties is a reservoir interval for all the Gannet fields except Gannet D, and the Tay is a reservoir interval for Gannet A, B, G and is really thin in Gannet D. Moreover the Tay is subdivided into the lower, middle and upper Tay by shale barriers (not shown in Figure 2).

Then, depth maps at Forties and Tay levels were gathered for each field and collaboration with geologists allowed to describe the fault system. A summary of the results is given below:

Gannet A. It was put on production in November 1993. The field consists of two separate formations, the Upper Tay and the Forties. Currently the wells are producing from the Tay interval only. The Tay formation can be divided into seven different facies as shown on Figure 3:

Facies 1, 2 and 6 are considered to be channels, facies 3 a levee of channels 1 and 6 and facies 4, 5 and 7 are considered lobes. The locations of the facies are based on seismic data, turbidite analogues and geological environment. According to the 4D seismic results, it can be inferred that there is a barrier to flow between lobe 4 and channel 6 and lobe 7. All the data described above are taken into account by dividing the Gannet A into three hydraulic units 1) facies 1-2-6, 2) facies 4, 3) facies 3-5-7

This description of Gannet A is also validated by the different pressure depletion trends observed and shown in Appendix D. 1.

Gannet B. Gannet B was put on production in November 1992. It is a gas field with an initial thin oil rim and it consists of four formations: the Tay, the Balder, the Forties and the Cromarty. Four wells are currently producing. Three from the Forties and four from the Middle Tay/Balder. This allows us to describe the field in terms of two producing intervals without the necessity of splitting the production.

Moreover, according to the top Forties structure map shown in Appendix D. 2, faults are present. However, none of them are considered to be a barrier to flow.

Gannet C. Gannet C was put on production in December 1992, and consists of one main producing interval: the Forties. A geological study of this formation allows us to conclude that the reservoir is highly faulted as shown in the map in Appendix D. 3. Then an individual analysis of the faults was carried out with geologists to determine their transmissibility. Finally a compartment model was established by separating the field into three tanks in the North-West, the South-East and the East.
The three mains faults shown in Appendix D. 3 are the limits of the tanks. However, large uncertainties remained concerning the transmissibility of these faults and this will have to be investigated during the history matching phase.

These hydraulic units are also confirmed by the different trend of depletion observed over the reservoir (Appendix D. 4). However, the pressure data in the northern tank seems erroneous. Indeed, according to the production data, it is unlikely that such depletion (250 psia in less than two years) happened whereas almost no production occurred in the tank and because no fields around had such a depletion in the same time. Moreover a surveillance RST survey run in 2007 demonstrated that the pressure should be 200 psia more than the last pressure point observed in 2003. In conclusion we can consider that the downhole gauge has been giving wrong data since 2002 and these points will not be taken into account for the history matching (these points are shown in Appendix D. 4).

Gannet D. Gannet D was discovered in 1988. The dip closed structure consists of two hydrocarbon accumulations, the Tay/Rogaland and the Andrew/Lista formations separated by the Lista shales. Gannet D is currently producing from these two formations but it is unlikely that they are in communication because of the presence of an impermeable shale barrier in between.

The upper accumulation is contained in two Tay sand units, the Balder and Cromatry. These two sand units are separated by a thick shale barrier although it is known that they share a common OWC. There is a high level of uncertainty concerning the connection between these two sand units. However, wells are producing from both of these sand units and no PLT is available to split the production so a single tank to describe this part of the reservoir needs to be chosen even though this presents some uncertainty. A second tank will be used to describe the Andrew formation.

These formations are not divided by any major faults, so a description in terms of two tanks will be modeled for Gannet D.

Gannet E. Gannet E started producing in January 1998. The field consists of one producing interval, the Forties. At the Top Forties level, the structure is cut by an East-North East/West-South West trending set of normal faults. A series of minor parallel faults (30 to 60 ft throw) are also present in the field. In view of the generally thin shale layers, medium to relatively high Net to Gross encountered in the Forties Formation and small fault throws, none of the faults are believed to be sealing. This is also validated by the similar OWC found in the two appraisal wells 21/30-19 and 21/30-11, which were drilled on opposite sides of the main ENE/WSW fault. The top Forties structure map is shown in Appendix D. 5. This assumption will be investigated during the modeling by comparing the results obtained with a single and a two tank model.

Gannet F. Gannet F started producing in June 1997. The field is a dome shaped structure consisting of the Forties formation. A base case top Forties structure map is shown in Appendix D. 6. At top Forties level, the area of the main field is divided by a series of faults trending West/East. These faults reveal small displacements suggesting they are unlikely to be sealing. So a single tank model is adequate to describe the reservoir.

Gannet G. Gannet G started producing in June 1999. This field is similar to Gannet A and consists of two separate formations but the Upper Tay only is producing. Moreover, the top Tay structure map does not highlight any faults in the reservoir, so a description in term of a single hydraulic unit can be used in the model.

Other Fields around the Gannet area: It is also essential to consider the fields around the Gannet area because they can also be in hydrodynamic communication. For instance, fields that are also producing from the Tay and the Forties interval, such as the Guillelmoit fields, may be in communication with the Gannet fields. First of all, the Guillelmoit A field is producing from the Forties however it is not the main hydrocarbon interval, and wells producing from this formation also produce from other formations. It is therefore necessary to split the production from these wells. As no PLT split was conducted on production, the oil split had to be based on the geochemical fingerprinting samples whilst the water allocation which is more uncertain, had been split according to the water chemistry samples. Moreover, three pressure data points only are available in the Forties and that will lead to a high level of uncertainty during the history matching. Furthermore two other fields in the Guillelmoit area are producing from the Tay interval, however these fields are operated by PetroCanada, so limited information are available. Two pressure points only are given and the production history was taken from the DECC website (Department of Energy and Climate Change). In other words, the modeling of the influence of these fields is highly uncertain and a good history match for these data is therefore not expected.
Extent and Properties of the Gannet Aquifer

When reservoirs are sharing a common aquifer, the source of pressure interference between the fields is through the aquifer. Therefore, the pressure depletion in one field is influenced not only by its own production, but also by the production of the neighbour fields. In that way, it is necessary to determine the extent and the behaviour of the aquifer(s) within the Gannet area to determine fields in hydrodynamic communication.

This has been completed with the review and the analyse of all the available data around the fields to reach a good understanding of the aquifers. These data could either be the presence of faulting and displacement, porosity and permeability pinchout in areas between the fields or thickness changes in the main intervals. However, one of the main problems raised in this study was the dearth of data in the region between the fields as few or no appraisal wells were drilled in these areas. To overcome the lack of data, the estimated boundaries of pressure communication were determined with the available data and then the assumptions were tested using the material balance model.

Aquifer Mapping. The mapping of the aquifers was started by analyzing the different geological formations in the Gannet area. As said before, it consists of four separated formations and it was determined in accordance with geologists that the aquifers in all of these formations are not likely to be in communication, as they are separated by impermeable shale barriers. In conclusion it seems that at least four aquifers models have to be built to describe the four formations. However, because two only are reservoirs interval in most of the Gannet fields we will focus on the modeling of the aquifers in the Tay and the Forties intervals.

The Tay Aquifer. The Tay is a reservoir interval in Gannet A, B, D, G and Guillemtot fields, however this interval is subdivided into three layers, the upper, middle and lower Tay, isolated from each other. Gannet A, G and the Guillemtot fields only are producing from the Upper Tay and can therefore have an influence on each other. Gannet D is producing from the middle Tay and is unlikely to be influenced by the other. Concerning Gannet B and C, because they are not producing from the Tay interval, they will not have an impact on the Tay aquifer.

A thickness map of the Upper Tay that includes the position of Gannet A, B, C and G is given in Figure 4. It shows the boundaries of the Upper Tay interval. This map will be used as a basis to build the aquifer model. The low thickness area shown in Figure 4 denotes possible boundaries of the Upper Tay aquifer. This highlights a probable strong communication between Gannet A and G as no deterioration is observed in the thickness of the formation. The upper Tay also extends to the Guillemtot fields (not shown in the map).

The seismic data in the area does not demonstrate the presence of major faulting that would impact the communication between the fields.

Finally concerning Gannet A, a description in term of three tanks had been chosen and the aquifer does not seem to be connected to the South West tank. This is supported by the fact that this part was deposited later than the others lobes and the base of the south west part of the field is higher than the other lobes.

The Forties Aquifer. Limited information about the Forties fan system is available in comparison to the Tay fan system because detailed seismic mapping of the Forties is restricted to the area around highly drilled oil and gas fields, and no wells were drilled in between. This lack of data will therefore require to make assumptions and to validate them during the history matching phase. The Forties is a reservoir interval in Gannet A, B, C, G, E, F and Guillemtot A, however it is not a producing interval for Gannet A and G, so these fields will not be taken into account when building the model. As for the information available, the seismic data does not indicate the presence of faults between the fields, and the quality of the reservoirs does not seem to be altered either. Finally, according to the deep marine sediment flows it seems to appear that the field are not all linked with each other but rather linked from the South to the North. However, different aquifer networks will be modeled and compare to allow to narrow down the level of uncertainty.

Aquifer Water Analysis. Formation water was also analysed to outline changes in the water composition. Indeed, significant differences in water composition would suggest that fields belong to different aquifer systems. To characterize the different aquifers, the key ions were analysed (Chlorine, Magnesium, Sodium, Potassium and Salinity). However, from this analysis,
few results could be drawn. This can either be explained by the fact that the aquifers are linked, or because the water properties of the aquifers are similar. The results are shown in Appendix E. 1.

**Associated uncertainty.** During this study the main problem encountered was the lack of data and this has led to a high level of uncertainty during the building of the model. For instance concerning the aquifer properties, most of them had to be extrapolated from reservoir parameters. Moreover, the lack of exploration wells in the area between the fields has also led to a high level of uncertainties in the behaviour of the aquifer between the fields. Finally, in the case of the Tay aquifer, it is necessary to include the impact of the Guillemonf fields, however as they are not operated by shell, limited data are available. That is why it was necessary to investigate a wide range of data in to obtain a description which is the less uncertain possible. However uncertainties still remain and will have to be narrow done during the history matching phase.

**Integration into a Material Balance Model**

The modeling was done to evaluate the aquifer parameters and investigate the behaviour of the pressure in the Gannet area. The models were built based on the elements and the data presented previously. The fields were described in term of one or several tanks and two different models were done to represent the Forties and the Tay aquifer. Several models and simulations were required to analyse all the assumptions made. In this section, the results for the Forties only are presented. The Tay aquifer is explained in Appendix F. 3. The history match was then done by varying the uncertain parameters such as the aquifer properties (size, water in place) and the transmissibility between the different tanks. The main criterion used to assess the quality of the matches is to obtain a satisfactory pressure matches for all the tanks. In this study the influence of the original oil and gas in place on the history matching was not analysed as it would have led to a number of parameters to analyse. Moreover these parameters are less uncertain in comparison to the aquifers properties and networks.

**Choice of the aquifer model.** The choice of the aquifer model is an important step in the modeling process. Indeed, several aquifer models are available in MBAL™. Then it is necessary to investigate the benefits and drawbacks for each of them to choose the one that best fit for the model. The most important criterion is the necessity to describe the water influx as time dependent. Indeed, the response of the aquifer to a pressure change cannot be assumed as instantaneous.

The description of the different aquifers models and the reasons for not using them is described in Table 1.

<table>
<thead>
<tr>
<th>Aquifer Model</th>
<th>Description</th>
<th>Reason for not using the model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Plot</td>
<td>Assumes aquifer of fixed volume and water influx is time independent.</td>
<td>Applicable only for very small aquifer For large aquifer a mathematical model is required which includes time dependence (Take infinite time for the aquifer to respond fully to pressure change in the reservoir)</td>
</tr>
<tr>
<td>Schilthuis Steady State</td>
<td>Assumess that the flow is time dependent but is in a steady state process.</td>
<td>Pressure disturbance travels instantaneously throughout the aquifer and reservoir system</td>
</tr>
<tr>
<td>Hurst Steady State</td>
<td>It is a steady state model</td>
<td>It is a steady State model</td>
</tr>
<tr>
<td>Hurst – van Everdingen – Dake</td>
<td>This model does not assume that the pressure disturbance travels instantaneously throughout the aquifer and reservoir system. Pressure decline is approximated as a series of time steps with constant pressure</td>
<td></td>
</tr>
<tr>
<td>Hurst – van Everdingen – Odeh</td>
<td>It is essentially the same model than the previous one. The difference only comes from the input data.</td>
<td>Need to enter the aquifer constant and dimensionless time constant instead of inputting the aquifer parameters (thickness, radius, permeability) These data are not available</td>
</tr>
<tr>
<td>Hurst – van Everdingen – Modified</td>
<td>The method is similar to the Hurst – van Everdingen Dake model. The main difference comes from the way the pressure decline is approximated Pressure decline approximated as a linear decline for each time step and allows to have varying rate within a step time rather than it being constant</td>
<td>Need to know the aquifer productivity index.</td>
</tr>
<tr>
<td>Fetkovich Semi Steady State</td>
<td>With this model the aquifer pressure in not kept constant.</td>
<td></td>
</tr>
<tr>
<td>Model</td>
<td>Description</td>
<td>Used for</td>
</tr>
<tr>
<td>---------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>----------------------------------------------</td>
</tr>
<tr>
<td>Fetkovich Steady</td>
<td>Water influx is calculated using productivity index</td>
<td>Steady State model</td>
</tr>
<tr>
<td>State</td>
<td>Required the aquifer productivity index</td>
<td>Required the aquifer productivity index</td>
</tr>
<tr>
<td>Vogt – Wang</td>
<td>Similar model as the Hurst – van Everdingen – Dake.</td>
<td>However this model cannot be used in MBAL for</td>
</tr>
<tr>
<td></td>
<td></td>
<td>production prediction in comparison to the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hurst - van Everdingen – Dake model.</td>
</tr>
<tr>
<td>Carter – Tracy</td>
<td>Expresses the aquifer influx in term of a series of constant terminal rate</td>
<td>Used for radial geometry only</td>
</tr>
<tr>
<td></td>
<td>solution</td>
<td></td>
</tr>
</tbody>
</table>

Finally, three aquifer models only can fit for the model and the Hurst-van Everdingen-Modified model was chosen rather than the Hurst-van Everdingen-Dake or the Vogt-Wang model because of the way the pressure decline is approximated. Indeed as we are trying to match the pressure data it is more accurate to approximate the pressure decline with a linear decline instead of constant time steps.

**Individual modeling.** The modeling part was achieved in two steps. In the first one, individual models were built for every field and history matched. This approach was chosen because of the amount of data to integrate. Indeed a direct input of all these data in a global model would lead to difficulty of history matching. Actually it would lead to a high number of parameters to analyse and post-treat in the same time. One of the advantage of starting by an individual approach is that we can obtain a first idea of the value of the uncertain parameters such as the aquifers properties. Moreover individual models are necessary to compare the obtained results with the results coming from the global model as it can help to investigate solutions for pressure interference integration into individual dynamic models. During the process of pressure matching, all the assumptions described in the sections above were modeled and evaluated. For example, models were run to investigate the influence of a description of Gannet C in term of one, two, three or four tank models. The same was performed to determine the presence of a sealing fault in Gannet E. For this model, the description with two tanks gives the best match when a high transmissibility between the tanks (10-20 times higher than transmissibility obtained between the tanks in Gannet C) is added confirming this fault cannot be considered as sealing. As shown in Appendix F.1 it is difficult to obtain satisfactory matches and it is not possible to match the pre production depletion using this approach which highlights that the models are incomplete. A comparison between the results observed in the individual and the global model for Gannet E is shown in Figure 5 to emphasise this.

**Global modeling.** In the second step the connection between the fields were added according to the results obtained during the previous studies. Three different scenarios were built to investigate different possible aquifer networks. In a first model, the assumptions of the connection were based on geographical consideration and fields were linked according to their distance in respect with each other. However in this model, Gannet C and E were not linked resulting in a difficulty to match the pre-production depletion, therefore this model will not be presented as it does not bring relevant results for the study. It however shows the importance of a good description of the aquifer network. A second model was realised and is shown in Figure 6. Its particularity is that only one tank was used to describe the aquifer network. Satisfactory matches can be obtained as it can be seen in Appendix F. 2 with this description however this model presents some drawbacks. First it is not able to highlight the aquifer network and preferential connection between the fields. This representation also assumes that the properties of the aquifers (porosity, permeability, thickness...) over the area are the same. Finally this model is not able to provide the individual aquifer parameters that can be necessary for an integration.
into a dynamic model. In conclusion, even though the results obtain with this model are satisfactory, this approach cannot be considered as valid as the level of uncertainties is too important.

Finally a third model was built based on the data gathered during the study of behaviour of the aquifer and is presented in Error! Reference source not found.. This modeling allows to narrow done the level of uncertainties in comparison to the ther two models. It describes an aquifer network extending from the fields in North to the one in South which is supported by the deep marine sediment deposition. Moreover it allows to capture the different changes in porosity, permeability or thickness that occur over the area which is necessary as all aquifer tanks may not have the same properties. In conclusion the main difference between the two models is that this one is a more accurate representation of the behaviour of the aquifers and it is the one with the lowest level of uncertainty. In the figure below, the green and yellow rectangles represent the different reservoir or compartments and the blue ones represent the aquifers tanks. Using several different tanks for the aquifer model allow to model the variation of the properties of the aquifer in the area. Then light blue diamonds represent the connexion between the fields and the aquifers. They allow to define the value of the transmissibility between two tanks. Between the aquifers tanks these values are high as this is supposed to represent one aquifer. Between the reservoirs tanks (Gannet C) the values are low (around ten times less) as they represent the transmissibility of the faults.

Concerning the different aquifers parameters, in the model with only one aquifer, average values were used to define the properties such as porosity, permeability and thickness. In terms of size and total aquifer volume the summation of all the values used in the model with several aquifers tanks was chosen at the beginning for the model with one aquifer tank then these parameters were refine in order to obtain good pressures matches in all the tank.

**Figure 6:** Model obtained for the Forties aquifer with only one aquifer tank.

**Figure 7:** Model obtained for the Forties aquifer, based on the work done during the first part of the study.
Pressure matches obtained (Figure 8) are satisfactory for all the tanks and allow to validate the model above. However, one should keep in mind that a large part of uncertainties remains concerning the different parameters and aquifer networks as it is possible to obtain similar matches with a description using one aquifer tank. Finally the model with several aquifer tanks will be chosen to evaluate the pressure interference effects as it is the one with the lowest level of uncertainty.

![Graphs of pressure matches for Gannet B, Gannet C North, Gannet C East, Gannet C West, Gannet E, and Gannet F.](image)

Figure 8: Pressure matches obtained for the Forties Aquifer.

It can be seen from these results that in Gannet E and F, the pre-production depletions caused by the surrounding fields are well estimated. It can now be interesting to evaluate individual influences of Gannet B and C on the depletion in Gannet E and F, as it can have an impact on the individual development strategy of the fields.
Analysis of the Simulation Results
In this section the results obtained are detailed and analysed. Once again the results for the Forties aquifer only are displayed in this section, the Tay aquifer being explained in Appendix G. 1. One of the goals of this study is to evaluate the pressure interferences between the fields. Also, consequences from these communications on the development strategy of the fields should be investigated. Indeed it is important to highlight the various effects of pressure communications between the fields that are not always apparent to engineers studying individual fields in isolation. This could lead to fail to match performance predictions with field behaviour. These interferences are quantified in the first part, then using the Business Plan 2010 made by the reservoirs engineers, the forecasted production is integrated into the model and the depletion is analysed. Finally a comparison between the results obtained for the individual and global models is conducted. A way of integrating the pressure interferences into an individual dynamic model is then investigated.

Evaluation of the pressure interferences. In this section the pressure interferences between the fields are examined. This is achieved for Gannet E and F as they are the fields that can be the most impacted by these interferences. After obtaining the pressure matches, the interference effects were evaluated by withdrawing the production of one field and by observing the results on the others. Indeed the pressure interference of fields on another is additive so by applying the principle of superposition the interference effect of a field A on a field B is equal to the depletion observed when both fields are producing less the depletion observed when the field A is not producing. The depletion in Gannet E and F decomposed according to the impact of the different neighbour fields are shown in Figure 9.

![Gannet E - Cumulative depletion](image1)
![Gannet F - Cumulative depletion](image2)

Figure 9: Causes of the depletion in Gannet E and F. On figure 9.a the decomposition of the depletion in Gannet E is presented and in figure 9.b the same result is shown for Gannet F

The conclusions withdrawn for Gannet E and F are in the same range. The depletion in these two fields is mostly influenced by the neighbour fields. For instance the production from Gannet E has reduced the pressure in Gannet E by 100 psi only so 30 % of the current total depletion. In other words, if the fields around were not being put in production, the depletion in Gannet E would have been of 100 psi only. Thus the production from Gannet B and C is responsible of 70% of the depletion in Gannet E. This confirms the great impact that neighbour fields can have and the importance to take into account these results in the development strategy. We can also notice that Gannet E and F have few impacts on each other.

Evaluation of the future depletion in the fields. The necessity to take into account neighbour fields has been demonstrated. Their impacts on each other make the investigation of the interference consequences on the future pressure depletion essential. Indeed, knowing the future depletion trend is of primary importance as it can impact the development strategy of the fields. For instance Gannet E and F are both oil fields currently producing above the bubble point and it should stay like that. The pressure forecast were realised by integrating the production forecast from the business plan 2010 made by reservoir engineers into the model. The pressure predictions are shown in Figure 10 for Gannet E and F. It appears from these results that the interferences effect will not have a major impact on the future depletion, and therefore these results will not have important consequences on the development strategy.

Finally a last question has to be investigated. Indeed currently there is no existing dynamic model for Gannet E but it will have to be done. Therefore the question of the integration of these pressure interference need to be raised as we saw that they are non negligible in this field. A first answer may be found when comparing individual and global modeling as satisfactory matches can be achieved (except for the pre-production depletion in Gannet E and F) for both models.
Impact on the current 3D models: Aquifers parameters and influx. Individual models were done and history matched for all the fields. Then the global modeling had been built starting from the individual models and by adding connections. History matches had been obtained by varying both the transmissibility and the aquifer parameters and the quality of these matches was assessed by comparing the results obtain in all the tanks. Thus the main difference between the two descriptions came from the value of the aquifer influx in the different fields. It is interesting to compare these different models as it can bring a solution to integrate the effect of the pressure communication in individual full numerical simulation models. The values of the aquifer influx in the two models are given in Figure 11 for Gannet C and E.

The results are consistent with what can be expected. For Gannet C, the aquifer influx is greater in the individual model than in the global model. This difference allows to model the pressure support that should come from the neighbour fields and which cannot be captured in the individual approach. Conversely, the aquifer influx in Gannet E is lower in the individual model than it is in the global one. It can be viewed as a way of compensating the pressure depletion in the individual approach that should have been caused by the neighbour fields. Finally it seems to appears that the pressure interference effects might be modeled when building an individual model by adding or withdrawing a pseudo aquifer influx.

However, this simple way to model the impact of pressure interference in an individual model is not sufficient. Indeed, if we compare the forecast depletion trend we can obtain with the individual and global model we can notice difference in the depletion. These results are shown in Figure 12. The green curve shows the pressure depletion we can forecast using an individual model and in blue the depletion obtained with the global model. This shows that it is not accurate to try to model the impact of neighbour fields by just adding or withdrawing a pseudo aquifer influx, therefore the integration of the interference effects in a dynamic model still need to do investigate.
Discussion

Considering that fields are sharing a common aquifer, communication and pressure interferences between them will occur. It is therefore necessary to capture these interferences of fields on each other as it can have an impact on the development strategy.

As it can be found in the literature review section, the material balance approach is not the only solution that can be used to solve the problem of pressure interference in reservoir sharing a common aquifer. Analytical method using mathematical models (Yildiz and Shimada, 2009) and other solutions (Moore and Truby, Jr, 1952) can also give good results. However it can be concluded from this study that a material balance approach using a MBAL™ modeling is satisfactory to describe the problem and to obtain valid solutions able to evaluate the impact on the development strategy.

The main objectives of this study were to create an understanding of how fields are connected through the regional aquifer, and to model the consequences of these results. These objectives were achieved. The communications between the fields were realised by two separate aquifers and a various range of data has enable to identify the aquifer behaviour between the fields. However, during these studies, a main problem was raised concerning the dearth of data in the region of the aquifer leading to a high level of uncertainty. Indeed, the interest on behalf of oil companies concerning data in between fields or in the aquifers intervals is less important, which explains this lack of data. Moreover, in one case, the aquifer extends over several licences block, resulting in a limited amount of data. This problem has been partially overcome by extrapolating the reservoir data to describe the aquifer, but also by gathering and investigating data from various sources. From this study the following conclusion were drawn:

- In the presence of several reservoirs sharing a common aquifer, pressure interferences must occur and are not necessarily negligible. These results highlight the various effect of pressure communication between fields not always apparent to engineers studying individual fields in isolation.
- The forecast of the pressure depletion can be achieved by integrating the forecast production data and allows to have an idea of the future depletion that will occur in the reservoir. Also these last results can be interesting to plan further development for the fields.
- Finally this paper also describes the method applied to evaluate the impact fields can have on each other. Similar study can be realised for other fields displaying the same problem.

Finally a question can be raised from this study concerning the integration of these results into a 3D simulation model. Indeed, because of cost and time concerns to run simulation, 3D simulation model cannot be done to describe several fields and their impact on each other. Therefore it is necessary to investigate a solution that will allow to describe the pressure interferences in the dynamic model. A possible answer was investigated by evaluating the impact of adding a pseudo aquifer influx, although this solution is limited as it cannot be used to accurately give proper forecasts. It is therefore necessary to investigate the range of uncertainty brought by this approach. Other concerns can also be raised with that solution. Indeed it is possible that a modeling with a pseudo aquifer can then lead to a wrong estimation of other parameters such as the position of the OWC and conning effects that can occur in producing wells. Therefore it is necessary to keep in mind that the pressure interferences cannot be ignored as they represent around 70% of the total depletion in Gannet E and F.

Conclusion

Through this work, it has been shown that considering the neighbour fields when several reservoirs are sharing a common aquifer can be essential to more accurately forecast the pressure depletion. It also presents a way to characterize these interferences. This study was divided into several steps. First the pressure depletions were highlighted when investigating the signs of pre production depletion. Then the model was carefully prepared by gathering all the necessary data. The model was then built to be the best representative of the geological data. This essential step can also be justified by obtaining good history matches with different models. Then the integration of a various range of data has allowed to determine the boundaries of the aquifers. The fields that are in communication were also determined and the results finally enabled us to explain the interactions between the fields and to quantify them.

This study has also shown that in the case of several fields ranging from undersaturated oil to oil rims and gas fields, the pressure interferences phenomenon can be really important as the depletion in gas fields is greater than in oil fields. This should be taken into account as it can have critical consequences on the development strategy of the fields. It has also been noticed that an individual study of a field can be in some situations insufficient.

Finally a question remains concerning the integration of these results into dynamics models as they should definitively be incorporated when preparing for the development strategy of a field.
Nomenclature

3D = Three Dimension
EP = Exploration and Production
PVT = Pressure, Volume and Temperature
RFT = Repeat Formation Tester
PLT = Production logging Tool
OWC = Oil Water Contact
DECC = Department of Energy and Climate Change

References

Evans, R. A Tectono-Stratigraphic study of the Tay Fan in the Gannet Area, UK North Sea: Implication for Reservoir Architecture and Field Development Planning. Imperial College of London, Msc Thesis
Hurst, W and Aime, M. 1960. Interference Between Oil Fields. Vol. 219, SPE 1335-
Yildiz, T. and Shimada, M. 2009. Predicting Water Influx From a Common Shared Aquifer. SPE-120897
APPENDIX A

CRITICAL LITERATURE REVIEW

<table>
<thead>
<tr>
<th>PAPER SOURCE</th>
<th>YEAR</th>
<th>TITLE</th>
<th>AUTHORS</th>
<th>CONTRIBUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPE 90362</td>
<td>2004</td>
<td>“Use of Material Balance to Enhance 3D Reservoir Simulation: A Case Study”</td>
<td>Eugene Esor, Stefano Dresda, Carlo Monico</td>
<td>How to narrow down uncertainty using a material balance evaluation before running a full 3D numerical simulation study Integration into the work process of a full 3D reservoir simulation study</td>
</tr>
<tr>
<td>SPE 101138</td>
<td>2006</td>
<td>“Material Balance Analysis in Complex Mature Reservoirs – Experience in Samarang Field, Malaysia”</td>
<td>T. Bui, M. Bandal, N. Hutamin, A. Gajraj</td>
<td>Results of a material balance study for a mature field in East Malaysia General Workflow for building a Material Balance model using MBAL Two new techniques were used for the modeling: - Moving linear regression for generating the input pressure for the Material Balance model - Production derived relative permeability data for Material Balance prediction</td>
</tr>
<tr>
<td>IPTC 11489</td>
<td>2007</td>
<td>“Capturing Complex Dynamic Behaviour in a Material Balance Model”</td>
<td>Jalal Mazloom, Mike Tosdevin, Dominique Frizell, Bill Foley, Mike Sibley</td>
<td>Comparisons between 3D simulation and material balance model for complex reservoirs: - Effect of reservoir heterogeneity and aquifer influx on final recovery factor can be captured with material balance model - Explain how multi tank model can capture the effect of aquifer and condensate drop out on reservoir performance if the model is tuned properly</td>
</tr>
</tbody>
</table>

Table A 1: Milestones in Material Balance Analysis for Complex Reservoirs

<table>
<thead>
<tr>
<th>PAPER SOURCE</th>
<th>YEAR</th>
<th>TITLE</th>
<th>AUTHORS</th>
<th>CONTRIBUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPE 238-G</td>
<td>1952</td>
<td>“The Pressure Performance Of Five Fields Completed in a Common Aquifer”</td>
<td>W.D. Moore, L.G. Truby, Jr.</td>
<td>First to study and calculate the pressure interference between fields using an electrical analyzer</td>
</tr>
<tr>
<td>SPE 38470</td>
<td>1997</td>
<td>“Aquifer Behaviour During Brent Depressurisation and the Impact on Neighbouring”</td>
<td>S.D Coutts</td>
<td>Example of 3D simulation model used to predict pressure response to both pressure maintenance and depressurisation of the Brent field Study of the pressure interferences of fields sharing a common aquifer Example of regional aquifer modeling</td>
</tr>
<tr>
<td>SPE 120897</td>
<td>2009</td>
<td>“Predicting Water Influx From Common Shared Aquifer”</td>
<td>Munenori Shimada, Thurhan Yildiz</td>
<td>Present an analytical model to forecast water influx in producing reservoirs sharing a common aquifer First analytical model for the case of multiple reservoirs sharing a bottom water drive aquifer</td>
</tr>
</tbody>
</table>

Table A 2: Milestones in Determination of pressure interferences between fields
Material Balance Analysis of Multiple Reservoirs Sharing a Common Aquifer: The Gannet Cluster

SPE 90362 (2004)
Use of Material Balance to Enhance 3D Reservoir Simulation: A Case Study

✓ Authors:
Eugene Esor, SPE, Nigerian Agip Oil Co., Stefano Dresda, SPE, and Carlo Monico, ENI E&P Division, Italy

✓ Contribution to the material balance analysis for complex reservoir:
This paper demonstrates the advantages of using a material balance analysis to determine important parameters and to narrow down uncertainty before building a 3D simulation model.
Also this model is a good application of a Material balance analysis for a complex reservoirs using MBAL.

✓ Objectives of the paper:
This study aims at narrowing down uncertainty on some parameters using a material balance approach. These main parameters are:
- The connected hydrocarbon volumes,
- The presence of different compartments,
- The initial hydrocarbon in place
- The main drive mechanisms.

Moreover it also presents a material balance analysis workflow to model a reservoir using MBAL.

✓ Methodology used:
The Material balance models are built using the software MBAL. The Methodology use is the common workflow of the material balance evaluation:
First the geological and geophysical data were gathered and validated. These data were then integrated into the material balance model. Finally the data were matched using both the analytical and a graphical method available in MBAL.

✓ Conclusion reached:
The conclusion reach are that a material balance analysis is a powerful tool to define reservoir drive mechanism, hydrocarbon in place and compartmentalization of the reservoir.
The paper also provides a good workflow for the modeling of a complex reservoir using MBAL.
Material Balance Analysis of Multiple Reservoirs Sharing a Common Aquifer: The Gannet Cluster

Material Balance Analysis in Complex Mature Reservoirs – Experience in Samarang Field, Malaysia

✓ Authors:
T.Bui, SPE, Schlumberger; M.Bandal, SPE, and N.Hutamin, SPE, Petronas; and A. Gajraj, SPE, Golden Eagle Int.

✓ Contribution to the material balance analysis for complex reservoir:
This paper presents the results of a material balance analysis for a complex reservoir. Moreover this study introduces two new techniques concerning the building of a material balance model:
- A moving linear regression for generating the input pressure for model
- A production derived relative permeability data for material balance prediction

✓ Objectives of the paper:
The objective of the paper is to model the Samarang field using a material balance approach. This study shows the importance of proper integration of all the data and the description of the compartmentalization in the reservoir. Finally it also aims at experimenting two new techniques described above.

✓ Methodology used:
The methodology used to realise this analysis is the classical workflow used for material balance analysis. The geological and geophysical data were gathered and then integrated into MBAL. The main difference is the improvement of the data using the two methods described above.

✓ Conclusion reached:
Necessity of using accurate reservoir data (pressure, production, PVT ...) when building a model is critical.
A moving linear regression technique shows clear advantages in case of significant variation in the pressure data at well level. It provides smoother data than an averaging method and it should be considered when preparing the pressure input data. It is important to identify the primary matching parameters and incorporated other type of data to get a representative material balance model.

✓ Comment:
The application of the moving linear regression techniques will not be necessary in our case as few pressure data points only are available.
Capturing Complex Dynamic Behaviour in a Material Balance Model

Authors:
Jalal Mazloom and Mike Tosdevin, SPE, Sasol Petroleum International, and Dominic Frizell, Bill Foley and Mike Sibley, SPE, Chevron

Contribution to the material balance analysis for complex reservoir:
This paper intends to highlight the difference between a single and a multi tank description for a complex reservoir. The results obtained with these two models are compared to the results given by a 3D simulations model.

Objectives of the paper:
The objective of the paper is to illustrate the importance of considering the geological data when building a material balance model, particularly the integration of the heterogeneity using a multi tank description is evaluated.

Methodology used:
To compare the results given by a single and a multi tanks model, a 3D simulation model was built and used as reference. The results given by the material balance models were then compared to the ones given by the 3D model.

Conclusion reached:
Because of its inability to capture the heterogeneity, the single tank model overestimates gas recovery factor. Wrong estimation of the production of condensate due to the single grid block used to describe the reservoir in the single tank model.
The effect of heterogeneity is captured in a reasonable range when using a multi tank model.
SPE 238-G (1952)

The pressure performance of five fields completed in a common aquifer

✔ Authors:
W.D. Moore, Humble Oil and Refining Co., Midland, Tex., and L.G. Truby, JR., Humble Oil and Refining Co., Corpus Christi, Tex., Junior Members AIME

✔ Contribution to the determination of pressure interference between fields:
First paper that characterize and calculate pressure interferences between fields using an electrical analyzer

✔ Objectives of the paper:
The objective of the paper is to presents the results of the evaluation of the pressure interference for five fields completed in a common aquifer.

✔ Methodology used:
The method use an electrical analyzer to calculate simultaneously matches of the observed pressure performance of the five fields.
First a survey of all available geological information of the fields was made to identify possible communications between them and the boundaries of the aquifer. Then the electrical analyzer was used for evaluating reservoir pressure performance. This tool is well suited for evaluation of reservoir pressure performance where more than one reservoir is producing from a common aquifer. It also provides a method for simultaneously calculating the magnitude of the pressure drawdown in reservoirs where interferences exists.

✔ Conclusion reached:
The conclusion reach were that it is not possible to obtain a good pressure match with the electrical analyzer when considering each field individually, highlighting the possible communication between the fields through the aquifer. Then the impact of the influence of fields on each other was calculated.
The conclusion reaches was that in the case of limited aquifer shared by several fields, the pressure communication between them can be really important. So an individual approach becomes inadequate for predicting the pressure depletion. It is therefore necessary to consider the impact of surrounding fields when preparing the development strategy, as their impact can be high.

✔ Comment:
The use of the electrical analyzer was proved being adapted for this study.
SPE 38470 (1997)
Aquifer Behaviour During Brent Depressurisation and the Impact on Neighbouring Fields

✓ Authors:
S. D. Coutts, SPE, Shell U.K Exploration Production.

✓ Contribution to the determination of pressure interference between fields:
Characterization of the aquifer behaviour and the impact of neighbouring fields during the Brent depletion

✓ Objectives of the paper:
This paper describes the model used to predict the pressure response in the aquifer and neighbouring fields, to both pressure maintenance and depressurization of the Brent Field.
It also details the approach used to determine the properties and extent of the regional aquifer present around the Brent field

✓ Methodology used:
The methodology used is the following:
• Using all the geological and geophysical data, the extent and properties of the aquifer around the Brent field was determined. Then a depth map of the regional aquifer was built.
• All these data were integrated into a 3D model
• The pressure and production data were history matched and the conclusions on the study were evaluated

✓ Conclusion reached:
The integration of the data has allowed to describe the extent and properties of the aquifer and the interaction between fields was captured. The communication between the fields through the aquifer has allowed to explain some aspects of the fields performance.
The impact of the Brent depletion on other fields was found being limited
Finally an investigation concerning a possible leakage of the fault separating the Brent and the Statfjord fields was evaluated.
The conclusion highlighted that the impact would be minor because of the presence of low permeability in this area.

✓ Comment:
This example shows the application of a 3D numerical model to calculate the impact of fields on each other when they are sharing a common aquifer. This study also gives an interesting methodology to describe the extent of the aquifer.
SPE 120897 (2009)

Predicting Water Influx From Common Shared Aquifers

✓ Authors:
Munenori Shimada, Norwest Corporation, and Turhan Yildiz, SPE

✓ Contribution to the material balance analysis of reservoirs sharing a common aquifer:
This paper presents a 3D analytical model to forecast water influx from an aquifer shared by several producing reservoirs. This is the first 3D analytical model. Before 2D models only were available

✓ Objectives of the paper:
The objective of this paper is to present an analytical demonstration of the model. Then the model is validated with simple configurations by comparing the results with other aquifers models present in the literature.

✓ Methodology used:
The three dimensional diffusivity equation is used, and initially the assumption of a known and time dependent flow rate at all the reservoir aquifer interfaces is made. Then the general aquifer solution is solved in the Laplace domain and three specific solutions were developed:
• For a constant water influx rate at the aquifer-reservoir interface
• For a constant pressure drop at the aquifer-reservoir interface
• For a variable pressure drop at the aquifer-reservoir interface

Then the validation of the model is done by solving simple case (already described by existing models) and by comparing the results obtained with models present in the literature

✓ Conclusion reached:
The initial objective was reached and the water influx solutions were obtained for three conditions at the aquifer-reservoir interface.
The final solutions are given in the Laplace domain, however it is possible to convert them in the real time domain using Stehfest (1970) or Iseger (2006) algorithms.
This new model can be applied for reservoirs with irregular shape.

✓ Comments:
This new approach is an interesting step to model reservoirs sharing a common aquifer and could be implemented into a material balance software, such as MBAL, to solve the problem of pressure communication between fields.
Appendix B. Map of the Gannet Area

Figure B 1: Map of the Gannet area, showing the position of the different fields
Appendix B. 2 Workflow adopted for the internship

Figure B 2: Workflow adopted for the study
APPENDIX C

Investigation of Signs of Pre-Production Depletion

Appendix C. 1 Gannet G

Figure C 1: Evidence of pre-production depletion in Gannet G. The pressure obtained from the appraisal wells and the pressure obtained just before the beginning of the production show a depletion of around 30 psia.

Appendix C. 2 Gannet F

Figure C 2: Evidence of pre-production depletion in Gannet F. The pressure obtained from the appraisal wells and the pressure obtained just before the beginning of the production show a depletion of around 100 psia.
APPENDIX D

Description of the Geology, Faults System and Compartmentalization

Appendix D. 1 Pressure depletion in Gannet A

Figure D 1: Depletion observed in Gannet A. As it can be seen, the depletion trend is not the same in the three parts of the reservoir, confirming the description in term of three tanks.
Appendix D. 2 Gannet B - Top Forties Structure Map

Figure D 2: Top Forties structure Map that exhibits the fault system.
Appendix D. 3 Gannet C - Top Forties Structure Map

Figure D 3: Top Forties structure Map that exhibits a complex fault system. An analysis carried out with geologists has allowed to highlight three compartments in the North, the West and the East. Uncertainties still remain concerning the transmissibility of the faults and will be evaluated during the history matching part.
Appendix D. 4 Pressure depletion in Gannet C

Figure D 4: Depletion observed in Gannet C. The depletion observed in the Gannet C seems to indicate the presence of distinct compartments. However wrong pressure data in the North tank were demonstrated and therefore these points (surrounded in black) will not be integrated in the model.
Appendix D. 5 Gannet E - Top Forties Structure Map

Figure D 5: Top Forties structure Map that exhibits a complex fault system in Gannet E. One fault is separating the field into two parts. Moreover a series of minor parallel faults are also present in the field. However in view of the generally thin shale layers, medium to relatively high Net to Gross encountered in the Forties formation and small fault throws, none of the faults are believed to be sealing. These assumptions were validated during the modeling.
Appendix D. 6 Gannet F - Top Forties Structure Map

Figure D 6: Top Forties structure Map that exhibits a complex fault system in Gannet F. The area of the main field is divided by a series of faults trending West/East. These faults exhibit small displacements suggesting they are unlikely to be sealing.
APPENDIX E

Extent and Properties of the Gannet Aquifers

Appendix E.1 Aquifer Water Analysis

Figure E 1: Results of the water formation analysis for the main producing intervals. Only differences in water composition can be conclusive. Only few differences are observed and can be explained by similar water composition in the different aquifers. However, the results concerning the concentration in magnesium and potassium seem to validate the assumption of non-communication between the Tay and the Forties aquifers.
APPENDIX F
Integration into a Material Balance Model

Appendix F. 1 Individual models for the fields in the Forties area

![Graphs of individual models for Gannet B, Gannet C North, Gannet C West, Gannet C East, Gannet E, and Gannet F.]

Figure F 1: Results of the history matching for the individual models. It can be noticed that it is difficult to obtain acceptable matches highlighting that the individual approach is an incomplete description. Moreover this approach does not allow to capture the pre-production depletion.
Appendix F. 2 Forties aquifer using a single aquifer tank model

Figure F 2: Model for the Forties aquifer with one aquifer tank.
Material Balance Analysis of Multiple Reservoirs Sharing a Common Aquifer: The Gannet Cluster

Figure F 3: History matches obtained for the second model. The matches obtained are satisfactory, however this approach does not represent the understanding of the Gannet area. This shows the importance of the preparation of the model, as it allows to justify the choices realised.

Appendix F.3 Results of the Tay Modeling

Figure F 4: Final model for the Tay Aquifer.
Figure F 5: Pressure Matches obtained for the Tay Aquifer. The pressure matches are satisfactory enough to validate the model. The difficulty to match the last pressure point in Gannet A South-East is due to the high uncertainty concerning this value. Indeed it had been measured using a temporary downhole gauge 200 m above datum and the gradient used to convert this point to datum is highly uncertain.
APPENDIX G

Analysis of Simulation Results

The conclusion drawn for the Tay aquifer are the same than the one we have obtained for the Forties aquifer. The different conclusions are presented below.

Appendix G. 1 Influence of the production of Gannet A on Gannet G

Figure G 1: Pressure interference in Gannet G. It shows that the neighbour fields are responsible for a large part in the depletion in Gannet G.

Appendix G. 2 Prediction forecast and Impact of the Gannet A blow down on Gannet G

Figure G 2: Pressure depletion forecast in Gannet G. It allows to conclude that the pressure will not drop below the bubble point (2200 Psia) and therefore the development strategy will not be affected.