



Peterhead CCS Project

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Executive summary

The objective of this report is to document the range of Initially-In-Place (IIP) hydrocarbon volumes indicated by the suite of static models created to investigate the suitability of the Goldeneye field for CO₂ sequestration for the Peterhead CCS Project. A second objective is to demonstrate the robustness of the upscaling process from the static model suite to the dynamic Full Field Simulation Model suite by comparing the IIP volumes in both. The volumes provide input to the derivation of CO₂ storage capacity for the Goldeneye site. The storage capacity is documented for the project in the Dynamic Modelling (Full Field Modelling) report. There has been no change from the Longannet CCS Project version of this report save for a refocusing and minor improvements to its clarity.

Initially in-place hydrocarbon volumes were calculated for the entire suite of Static Reservoir Models (SRMs). The Gas Initially In-Place (GIIP) volumes derived from the model suite have a range between 706 and 792 Bscf, [$19.99 \times 10^9 \text{ m}^3$ and $22.43 \times 10^9 \text{ m}^3$] which all fall within the probabilistic P15 to P85 expectation range from the field calculated in the late stage of field life by the Goldeneye asset production team (705 and 799 Bscf, respectively [$19.96 \times 10^9 \text{ m}^3$ and $22.63 \times 10^9 \text{ m}^3$]). They additionally compare with the in-place volume indicated by production data gathered from the field to end of field life. From this it is possible to say that the range of scenarios created for exploring CCS potential are representative of the field.

Three sensitivities expected to have an impact on the behaviour of CO₂ in the Full Field Simulation Model (FFSM) were investigated with the SRM suite of models. Of the three, the internal reservoir zonation has the greatest volumetric impact (-9.6% to +4.8%, when compared to the production team's base case model – SRM1), the position of the northern stratigraphic pinchout has the next largest impact (-5.3% to +1.2%), and the angle of dip of the western flank of the field has the least effect, leading to a maximum in-place volume reduction of only 1.5%.

As a quality assurance/quality control step, one of the SRMs has been upscaled into the dynamic simulator and IIP volumes from this FFSM have been compared with the source SRM. A comparison of these showed only small variations in hydrocarbon volumes in the two realisations of the model (3.25%), due to differences in resolution between the two. The models are, therefore, deemed suitable for dynamic simulation and history matching to observed production data.

Note: none of the figures included in this report should be interpreted, in any way, as statements pertaining to SEC (Securities and Exchange Commission) compliant proved or expectation reserves or scope for recovery.



1. Introduction

A suite of SRMs has been built to allow the investigation of CO₂ injection and sequestration performance of the Goldeneye reservoir¹. Using the hydrocarbon saturation model designed for the field, IIP hydrocarbon volumes have been calculated for each realisation of the field. This allows for the assessment of each scenario against the same volume calculations derived from the previous production team realisations of the field (which includes a stochastic distribution) as well as the in-place volume indicated by the production data gathered from the field. Finally, an estimate of in-place volumes, combined with the volume of recovered hydrocarbons, will contribute to the estimation of pore space voidage and, hence, to the storage capacity calculation and the volume of hydrocarbon that remains present in the structure post-cessation of production. It is key to note that this is storage in a depleted hydrocarbon field. As such, the storage volume is more defined and determined by the accurately known produced hydrocarbon volume than by the rock volume uncertainty. Where the original volumes do play a part, however, assessment of the volume of remaining, unproduced hydrocarbons will allow for fluid mixing to be taken into account when modelling refill efficiency.

Reference to third party software in this document is solely for informational purposes to assist in understanding how the work was completed, and does not amount to an endorsement of that software nor is any warranty as to its suitability given or implied.

There has been no change from the Longannet CCS Project version of this report save for a refocusing and minor improvements to its clarity with an addition of an expanded Executive Summary.

2. Objectives

The objective of this report is to document the range of IIP hydrocarbon volumes indicated by the suite of static models created to investigate the performance of CO₂ sequestration in the Goldeneye field and to demonstrate the robustness of the upscaling process from the SRM to the FFSM by comparing the IIP volumes in both.

This report is not intended to be an estimate for the ultimate storage capacity of the Goldeneye field with respect to CO₂. This estimate will only be done when the FFSM has been calibrated and has been operated in prediction mode. Similarly, the agreement between IIP volumes measured from the static (and derived dynamic) reservoir models with IIP volumes indicated by historical production data will only be assessed once the dynamic model is successfully 'history matched'. This analysis will be reported out in the storage development plan².

Also, this report is not intended to be used for determination of proved or expected reserves, or scope for recovery.

¹ PCCS-05-ZG-0580-00004 - Static Model Field Report, Key Knowledge Deliverable 11.108.

² Shell 2013, Peterhead CCS Project Storage Development Plan, PCCS-00-PT-AA-5726-00001, Key Knowledge Deliverable 11.128



3. Static Volumes

Seven SRMs have been created as initial input to the FFSM of CO₂ sequestration performance within the Goldeneye field. These are labelled SRM1, SRM2.0, SRM2.1, SRM2.2, SRM2.25, SRM3.0 and SRM3.1. The specific inputs to each model and the specific uncertainties they are intended to address are fully reported in a previous document³. **Note:** Volumes reported in 109 standard cubic feet (scf) except where noted. shows the calculated GIIP volumes for each of the models produced. The oil rim has been excluded from this calculation.

Table 3-1—GIIP calculated from each of the suite of SRMs generated for the Goldeneye carbon capture and storage (CCS) project, classified by zone.

	SRM1	SRM2.0	SRM2.1	SRM2.2	SRM2.2 5	SRM3	SRM3.1
GIIP (Captain)	765	706	797	768	792	728	773
GIIP (10⁹ standard m³)	21.7	20	22.6	21.8	22.4	20.6	21.9
Captain E	93	88	95	121	94	109	118
Captain D	621	551	652	562	648	564	580
Captain C	45	61	44	50	51	55	71
Captain A	6	5	6	35	0	0	4
Captain D & E	714	640	747	683	742	673	698
Captain C, D & E	759	700	791	733	792	728	769

Note: Volumes reported in 109 standard cubic feet (scf) except where noted.

3.1. Static in-place volume calculation

Calculation of in-place hydrocarbon volumes follows a stepwise process, which is advanced by the progressive application of new interpretation products:

1. **Gross Rock Volume (GRV):** Structural model + fluid contact(s)
2. **Net Rock Volume (NRV):** GRV combined with net to gross model
3. **Net Pore Volume (NPV):** NRV combined with porosity model
4. **Hydrocarbon Pore Volume (HCPV):** NPV combined with hydrocarbon saturation model
5. **Initially In-Place Volume (IIP):** HCPV combined with formation volume factor (commonly abbreviated to B_o for oil or B_g for gas)

For this project, all models have been built, and all volumetrics calculated, using Schlumberger's Petrel™ software. The method of constructing each piece of data has been described at length in the static model (field) report⁴ and will not be re-described here.

³ PCCS-05-PT-ZG-0580-00004_Static Model Field, Key Knowledge Deliverable 11.108

⁴ PCCS-05-PT-ZG-0580-00004_Static Model Field, Key Knowledge Deliverable 11.108



3.2. Factors controlling in-place volumes

For the current project, understanding the distribution of likely in-place hydrocarbon volumes outcomes has not been the primary focus. Instead, the focus of the work done has been to assess the geological uncertainties that are likely to affect the migration of sequestered CO₂ within the Goldeneye structure. However, it is recognised that these uncertainties (reservoir zonation, the position of the northern stratigraphic pinchout and the steepness of the western flank of the field) do have an impact on the hydrocarbon volume IIP in the field, as calculated from the various different SRMs, and so this is reported here.

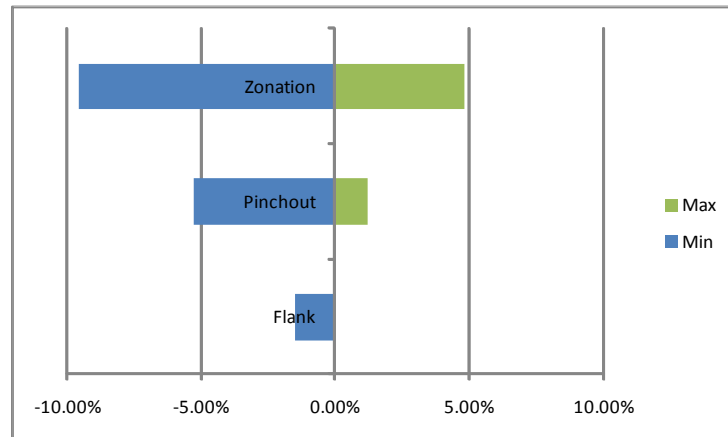


Fig. 3-1—Tornado plot showing impact of three key uncertainties addressed by the suite of SRMs created for the Goldeneye CCS project

Note: X-axis shows change in in-place hydrocarbon volume with reference to the SRM1.

Of the uncertainties investigated, the one with the largest impact on the size of the in-place hydrocarbon volumes is the internal zonation of the reservoir. Reallocating volume between the high net to gross D unit and the low net to gross C unit can change the in-place volume between -9.6% and +4.8% (Fig. 3-1). The lowest volume is generated when using constant isochores to create the reservoir zones (the SRM3.1 approach) whilst the largest volume is associated with the approach taken in SRM2.25, where well tops are used without isochores or seismically interpreted surfaces to divide the reservoir. As well as changing the size of the reservoir from which gas is being produced, this reallocation of rock volume will affect the full field simulation, swapping volumes between an easily accessible, high quality container and a less easily accessed, low quality one. Fig. 3-2 shows the minimum (shallow) and maximum (deep) extents for each zone. Second in terms of its impact on in-place hydrocarbon volume is the position of the northerly pinch-out, which can produce a maximum reduction in GIIP of -5.3% and a maximum increase in volume of +1.2%. The position of the pinch-out has been picked, in the base case model, on the pre-stack depth migration (PreSDM) seismic data, with the extreme positions being controlled by the locations of the 14/29a-2 well (which saw no Captain Sandstone Member) and GYA03 and GYA02 (the most northerly of the producing wells, both of which encountered Captain Sandstone Member stratigraphy). Fig. 3-3 shows the most northerly and most southerly ranges of the pinch-out as modelled in the suite of SRMs considered here. Finally, a slight change in the velocity model (due to the lateral translation of the Supra-Beauy wedge, detailed in the Static Model report⁵) produced a very small difference (-1.5%) in in-place volume (Fig. 3-3).

⁵ Shell 2013, Static Model Field Report, PCCS-05-PT-ZG-0580-00004, Key Knowledge Deliverable 11.108



3.3. Stochastic IIP volume assessment

As described in a previous report⁶, the model SRM1.0 is our attempt to reproduce the existing production team’s SRM, used as the basis for history matching and production forecasting for the Goldeneye field. During the construction of the original version of this model, the production team’s geologist investigated the range of volumetric outcomes based on the key subsurface uncertainties identified on the field, principally the exact nature of the top reservoir map and the internal reservoir zonation. 381 realisations were created and the resultant GIIP values calculated so that P10, P50 and P90 expectation cases could be extracted (Fig. 3-4).

Table 3-2—GIIP & STOIP probability for the Captain Sandstone reservoir based on 381 runs of the production team model.

Probability	GIIP (10 ⁹ scf)	STOIP (10 ⁶ bbl)
P10	695	27.7
P15	705	28.5
P50	753	31.5
P85	799	34.5
P90	816	35.5

Note: Workflow uses new seeds for facies and property modelling, with stochastic reservoir horizons generated for each run using the standard deviation of the top reservoir well residuals after depth conversion.

Comparing the SRM models with the range from the production team’s stochastic modelling, shows that the suite of realisations that have been created for this study are representative of the mid-two thirds of the production team’s expectation range. This is to be expected for a number of reasons. Firstly, the capacity of Goldeneye to contain CO₂ is mainly dependent on produced rather than in-place volumes; therefore, there is no requirement to model the entire probabilistic range of volumes. Secondly, the uncertainties that the suite of models created for this project represent are relevant to the potential migration of CO₂ through the storage container. These uncertainties do not necessarily have any impact on the IIP volumes of hydrocarbon in the Goldeneye field. Finally, the objective of this study is to model downside. The reason for this is that there is confidence, based upon the estimated ultimate recovery figures for the field (nearly 550 Bscf [15.57 10⁹ m³] of which has already been produced) that the Goldeneye field has sufficient capacity to contain the proposed volume of CO₂.

⁶ Shell 2013, Static Model Field Report, PCCS-05-PT-ZG-0580-00004, Key Knowledge Deliverable 11.108

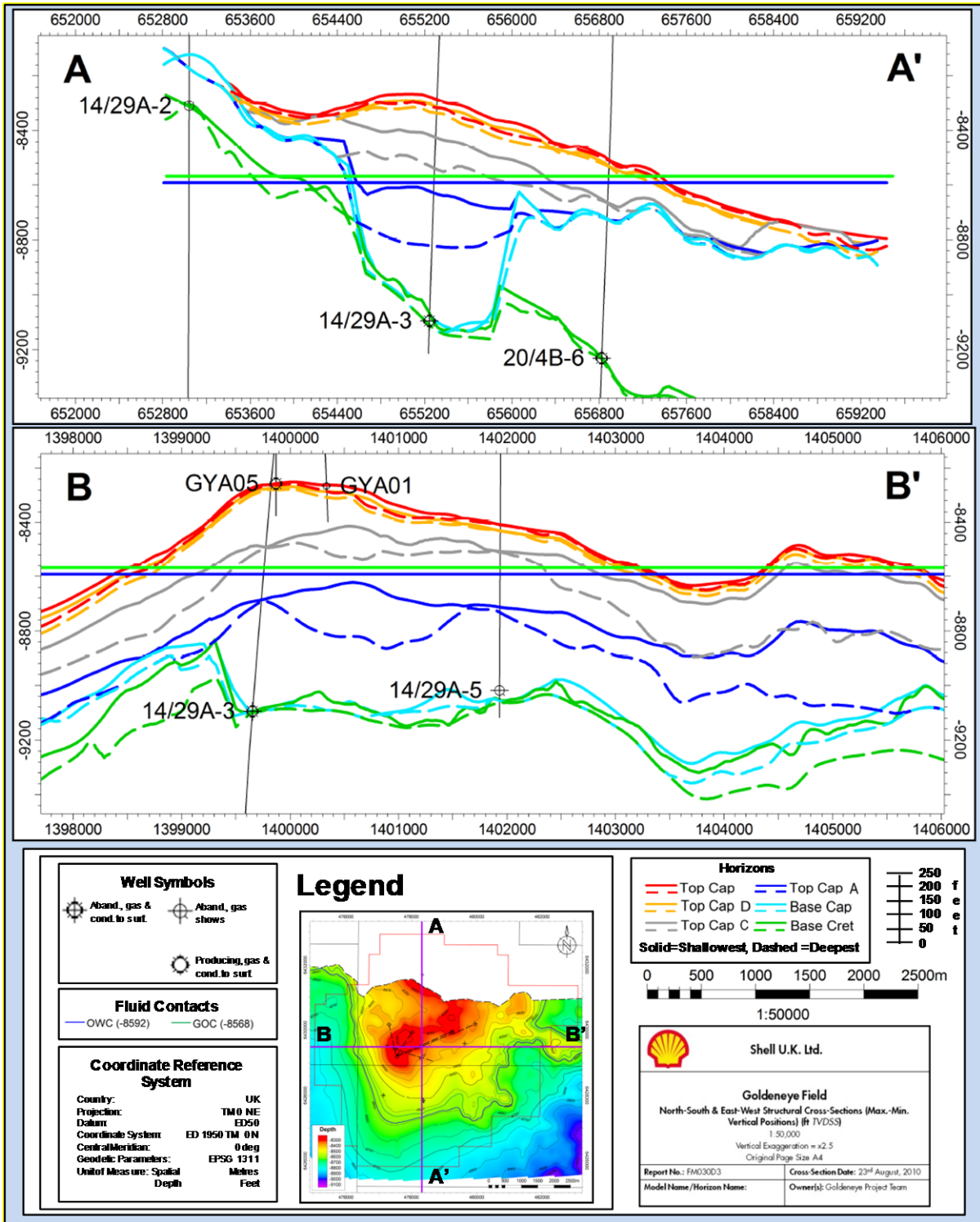


Fig. 3-2—Reservoir zonation uncertainties. Well paths projected onto lines of section. Fluid contacts extended for clarity.

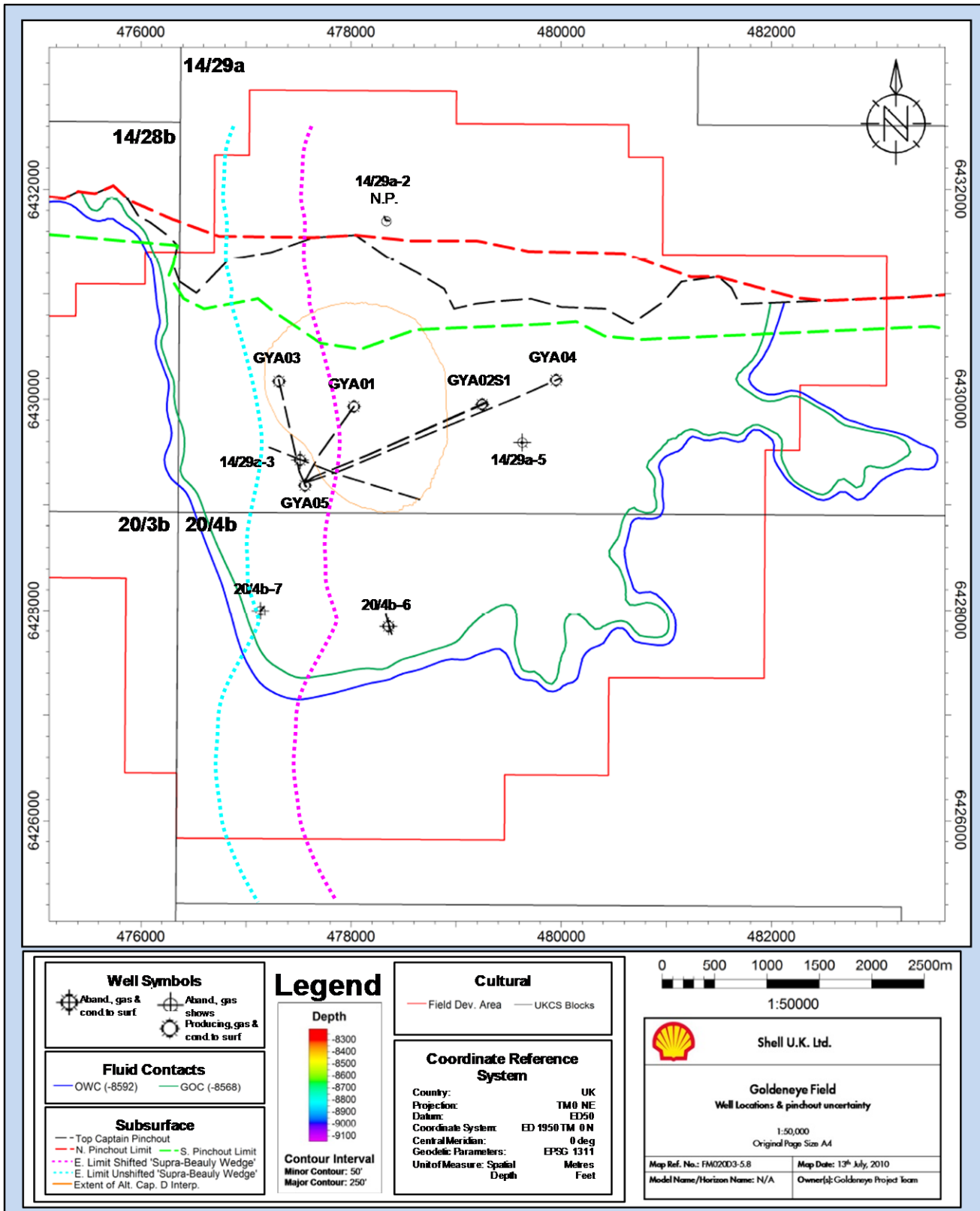


Fig. 3-3—Well locations and uncertainties.

Note: N.P. is not penetrated

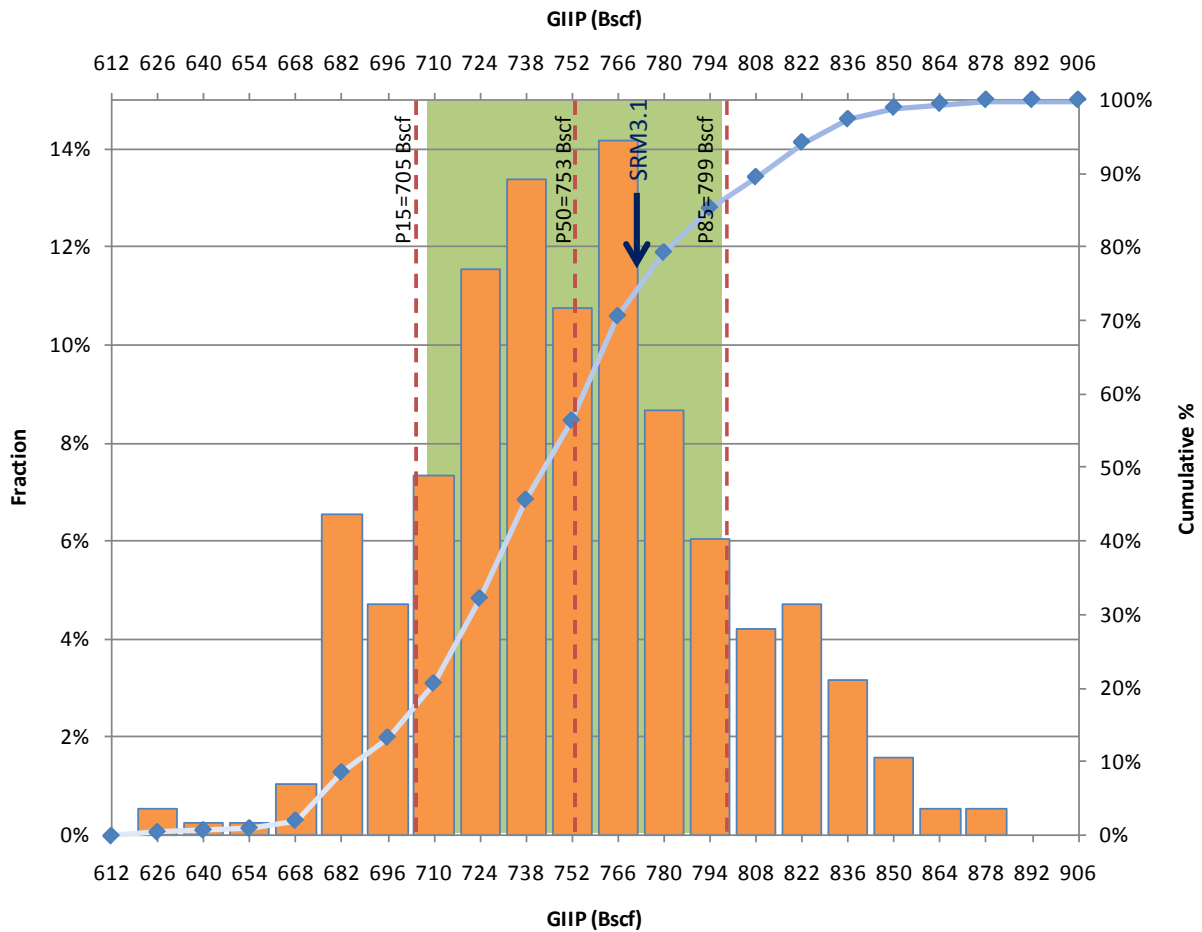


Fig. 3-4—GIIP probability distribution based on 381 runs of the production team model

Note: Workflow uses new seeds for facies and property modelling with stochastic reservoir horizons generated for each run using the standard deviation of the top reservoir well residuals after depth conversion. Green shading indicates volume range of SRMs generated for this study.

It follows that there is no benefit from generating models to represent the high in-place volume cases. Additionally, the current recovery from the field, when compared to the lowest in-place volume reported from our SRM scenarios, implies a recovery factor of 77%, a high efficiency that would be difficult to justify for a water invaded gas reservoir given the heterogeneity seen in the field.



4. Dynamic volumes

To create the FFSM, the SRM was exported in Rescue format from the Petrel software application and imported into Shell’s dynamic simulator (MoReS), via an upscaling application, also software developed within Shell, called ‘Reduce++’. The upscaling process converts a fine scale geological model into a coarser model which can be used for history matching or forecasting with acceptable runtimes. The coarse grid block properties are derived from the properties of the underlying geological model such that their behaviour closely reflects that of the geological model. Different upscaling methods are used for different properties.

4.1. In-place volumes from upscaled SRM

Table 4-1 shows the equivalent volumetric measurements in the SRM and the FFSM. Fluid saturations in the FFSM are not imported from the SRM. Instead a capillary pressure curve is used (for the SRM, saturations are derived using a saturation height function derived to match the S_w curves calculated from petrophysical analysis). The B_g used in the SRM is the one used by the production team and is not the same as the one derived from the latest pressure, volume, temperature (PVT) model⁷ - which is used in the FFSM.

Table 4-1—Equivalent quantities in SRM and FFSM. Gross Bulk Volume (GBV)

SRM	FFSM
Bulk volume	Not available
Net volume	GBV : Net reservoir (rock) volume
Pore volume	GBV * porosity = Net pore volume
HCPV gas	Net pore volume * saturation of gas
GIIP	HCPV gas / B_g

Fig. 4-1 shows comparison of net, pore and HCPV volumes and in Fig. 4-2 GIIP volumes from the SRM3.1 scenario calculated in the static reservoir modelling software (Petrel) and in the dynamic simulator, MoReS. The differences in volumes between SRM and FFSM reported for this scenario are similar to those seen in other models and their causes are also believed to be the same, so the individual volumes from the other scenarios which were imported into the dynamic simulator will not be reported here. As noted in the previous chapter, the SRM hydrocarbon volume was calculated with the production team’s value for B_g . For this project, a review of the available PVT information has led us to calculate a different value ($B_g = 0.783 \text{ RB/Mscf [0.004396 Sm}^3/\text{Sm}^3]$). To allow for a meaningful comparison, however, the value used in the SRM ($0.766 \text{ RB/Mscf [0.004301 Sm}^3/\text{Sm}^3]$) was used to calculate GIIP in MoReS. Despite using the same B_g value, there is not an exact match between the static and dynamic versions of the model. This is probably due to the greater resolution of the Petrel version of the model. Using the production team’s B_g figure, the Petrel model reports approximately 2.8% larger GIIP from the main reservoir zone (Captain D) than the equivalent MoReS model. Using the B_g calculated from the updated PVT analysis subtracts a further 2.2% from the GIIP in MoReS, compared to that calculated in Petrel.

⁷ Shell 2010. PVT Modelling Report for CO₂ in Goldeneye Project, UKCCS-KT-S7.21-Shell-001

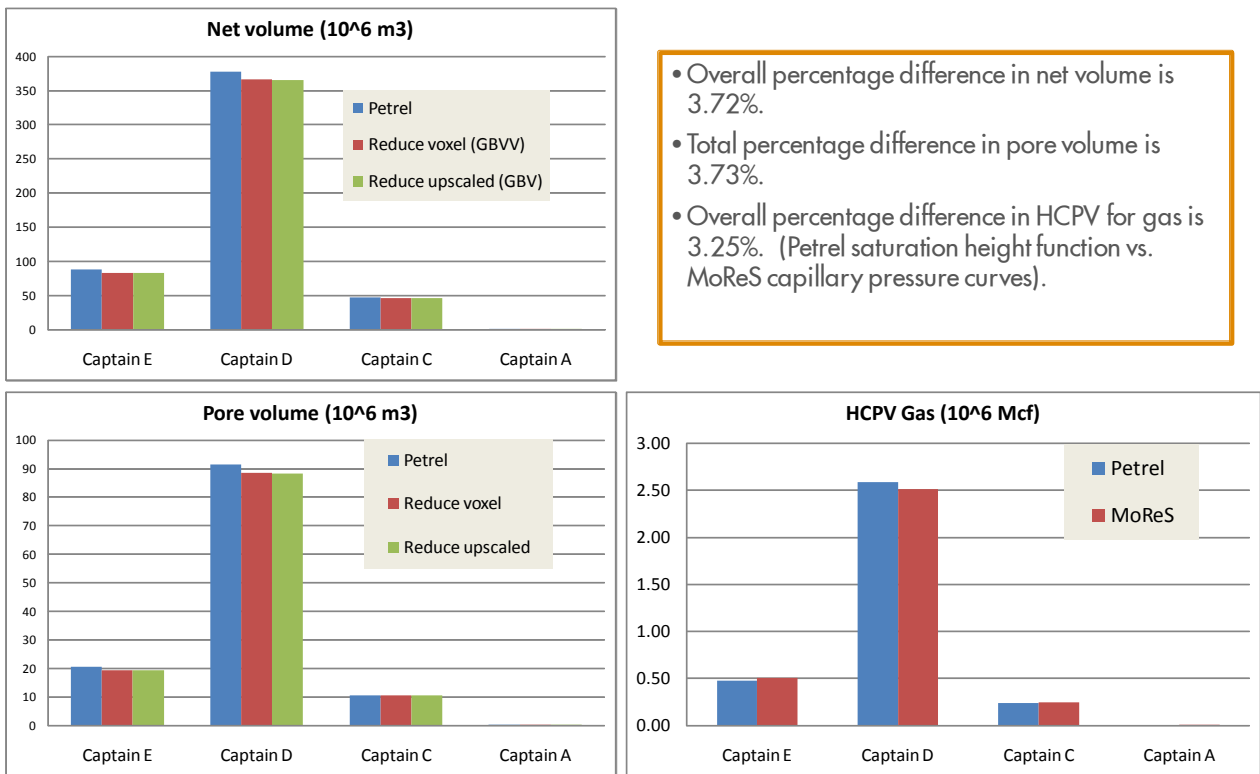


Fig. 4-1—Comparison of different volumes calculated from SRM3.1 in (Petrel), during initial import into dynamic simulator and after upscaling (Reduce upscaled/MoReS).

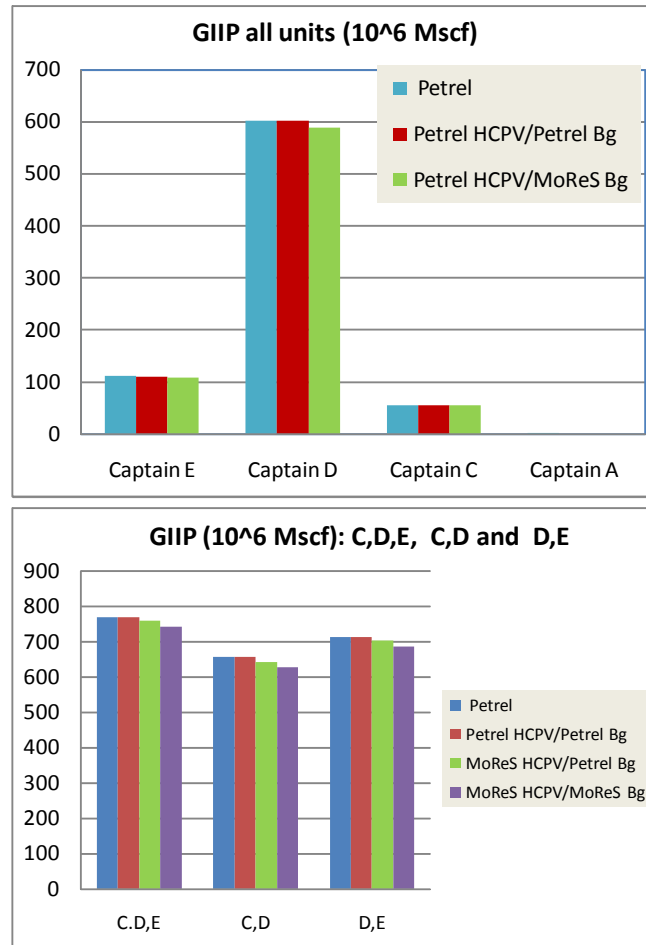


Fig. 4-2—Comparison of GIIP calculated from SRM3.1 in (Petrel) and FFSM (MoReS)

The detailed comparison of the fine scale, static model volumes and those in the coarser simulation model is only shown here for the SRM3.1 model. However, the same consistency has been demonstrated for the other models which have been exported to the dynamic realm, specifically SRM1.0, SRM2.0, SRM2.1 and SRM3.0.



5. Conclusions

The suite of SRMs in use to investigate Goldeneye's suitability for CCS has a range of IIP volumes of between 706 and 792 Bscf, [$19.99 \times 10^9 \text{ m}^3$ and $22.43 \times 10^9 \text{ m}^3$] giving a spread of 86 Bscf [$2.44 \times 10^9 \text{ m}^3$]. All of these models, therefore, have GIIP volumes that lie between the P15 and P85 expectation volumes as calculated by the Goldeneye production team (705 and 799 Bscf, respectively [$19.96 \times 10^9 \text{ m}^3$ and $22.63 \times 10^9 \text{ m}^3$]). As described in the static model (field) report⁸, the objective of the modelling exercise was not to evaluate the range of in-place volumes but to generate a series of scenarios that allowed the review of the impact of key subsurface uncertainties on the injection and sequestration performance of CO₂ within the Goldeneye reservoir. However, it is possible to say that the scenarios created are representative of the field.

The upscaling procedure that generates a full field model from the SRM input honours the IIP hydrocarbon volumes to within acceptable tolerance (3.25%). The small differences are consistent with the differences expected during upscaling. The models are, therefore, deemed suitable for dynamic simulation and history matching to observed production data.

⁸ Shell 2013, Static Model Field Report, PCCS-05-PT-ZG-0580-00004, KKD no. 11.108.



6. Glossary of terms

bbbl	Barrels of oil at standard conditions
B_g	Formation Volume Factor (Gas)
B_o	Formation Volume Factor (Oil)
Bscf	Billion (10^9) cubic feet of gas at standard conditions
CCS	Carbon Capture & Storage
CO ₂	Carbon Dioxide
EUR	Estimated Ultimate Recovery
FEED	Front End Engineering Design
FFSM	Full Field Simulation Model
GBV	Gross Bulk Volume
GIIP	Gas Initially In-Place
GRV	Gross Rock Volume
HCPV	Hydrocarbon Pore Volume
IIP	Initially In-Place (volumes)
Mcf	Thousand cubic feet at reservoir conditions
Mscf	Thousand cubic feet at standard conditions
Mscf	Thousand cubic feet of gas at standard conditions
NPV	Net Pore Volume
NRV	Net Rock Volume
PreSDM	Pre-Stack Depth Migration
PVT	Pressure, Volume, Temperature
RB	Barrels of oil at reservoir conditions
scf	Cubic feet of gas at standard conditions
SEC	Securities and Exchange Commission
SRM	Static Reservoir Model
STOIIP	Stock Tank of Oil Initially In-Place

7. Glossary of Unit Conversions & Well Naming

For the provision of the SI metric conversion factor as applicable to all imperial units in the Key Knowledge Deliverable.

Table 7-1: Unit Conversion Table

Function	Unit - Imperial to SI Metric conversion Factor
Length	1 Foot = 0.3048m Metres
	1 Inch = 2.54cm Centimetres
	1 Inch = 25.4mm millimetres
Pressure	1 Psia = 0.0690 Bara
Temperature	1°F Fahrenheit = -17.22°C Centigrade
Weight	1lb Pound = 0.45kg Kilogram



In the text well names have been abbreviated to their operational form. The full well names are given in Table 7-2.

All volumes in this report quoted at ‘standard conditions’ assume temperature of 60°F and pressure of 14.7 psia [101.35 KPa]. A conversion factors of 1 m : 3.28048 ft and 1 scf : 0.028317 m³ have been assumed.

Table 7-2—Well name abbreviations

Full well name	Abbreviated well name
DTI 14/29a-A3	GYA01
DTI 14/29a-A4Z	GYA02S1
DTI 14/29a-A4	GYA02
DTI 14/29a-A5	GYA03
DTI 14/29a-A1	GYA04
DTI 14/29a-A2	GYA05