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OCS Study BOEM 2014-772

FINAL REPORT

Loss of Well Control Occurrence and Size Estimators for Alaska OCS

BOEM Contract Number M12PC00004

October 2014

By

BERCHA GROUP

Bercha International Inc.
Calgary, Alberta, Canada

BOEM Bureau of Ocean Energy Management

U.S. Department of the Interior
Alaska Outer Continental Shelf Region
Environmental Sciences Management

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Principal Investigator: Dr. Frank G. Bercha, P.Eng.

BERCHA GROUP

Bercha International Inc.
2926 Parkdale Boulevard N.W.
Calgary, Alberta, T2N 3S9, Canada
Email: berchaf@berchagroup.com

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EXECUTIVE SUMMARY

A. Introduction

Probabilistic estimates of oil spill occurrences are used by the United States Department of the Interior, Bureau of Ocean Energy Management (BOEM), to support the development of environmental impact assessments for hypothetical and proposed developments in the U.S. Chukchi and Beaufort seas. Due to the limited offshore oil development in this region, it was not feasible to base these oil spill probability estimates on empirical data from that region alone. Rather, statistically significant non-Arctic empirical data from the U.S. Outer Continental Shelf (OCS) – including the Gulf of Mexico (GOM) and Pacific OCS – and world-wide sources, together with their variance, are used as a starting point, to be adjusted using fault and event tree methodologies to emulate Arctic conditions. One of the sources of oil spills, and likely the largest spill volume potential, is the Loss of Well Control (LOWC) leading to a blowout during drilling, production, workover or abandonment. Accordingly, BOEM has retained Bercha International Inc. (Bercha) to conduct a study of world-wide data on LOWC incidents, and generate statistics and information characterizing regional, incident type, causal, and other characteristic variations of LOWC frequencies and associated consequences including hydrocarbon spill volumes. LOWC events include both blowouts and well releases.

B. Summary of Report

The present report deals with the scope of work in successive chapters as follows:

- Chapter 2 – Databases and Exposure
- Chapter 3 – U.S. GOM and PAC Statistics
- Chapter 4 – UK, Norway, and North Sea Statistics
- Chapter 5 – U.S. GOM and North Sea Statistics
- Chapter 6 – Australia, Holland, and Canada Statistics
- Chapter 7 – Temporal and Regional Comparisons
- Chapter 8 – LOWC Spills
- Chapter 9 – Conclusions and Recommendations

Chapter 8 deals with LOWC hydrocarbon (HC) spills and their characteristics, including volume distributions. The value and variability of specific spill volume LOWC frequencies for a specified development can be more accurately derived using quantitative risk analysis (QRA) approaches including fault trees. Accordingly, an algorithm to assess LOWC spill frequencies and characteristics for specified developments using the regional frequencies presented in this report as a starting point, and incorporating the principal development characteristics and risk factors is described and illustrated with an example.

In its entirety the work provides a perspective on world wide and U.S. OCS LOWC spill characteristics, as well as statistics and methodology to facilitate BOEM's LOWC spill potential evaluations in support of its environmental impact assessments of hypothetical and proposed specific U.S. OCS projects.

C. Summary of Conclusions

General conclusions of the work can be summarized as follows:

- Generally adequate data on LOWC occurrences and their characteristics in western waters such as the North Sea and the U.S. GOM, are available from the SINTEF database for a sufficiently large exposure for the period from 1980 to 2011.
- More detailed data, on LOWC occurrences and their characteristics, including spill volumes, for the U.S. OCS are available from the BOEM/BSEE database for a sufficiently large exposure for the period from 1980 to 2011.
- The above data are of sufficient quantity and quality to permit the generation of statistics, including occurrence rates for different operational phases and products spilled, associated confidence intervals, and other statistical measures.
- Certain data, however, were not available, including spill volumes for locations other than the U.S. OCS, well exposure populations by water depth intervals for all locations, or detailed characterization of the products spilled from LOWC incidents.

Table 1 summarizes the key high level LOWC parameters for the principal regions studied. These are only the high level results; far more details are in the report.

Table 1: Summary of Principal LOWC Parameters for Key Regions

REGION	EXPOSURE		LOWC FREQUENCY			LOWC DURATION	
	Drilling	Production	Drilling	Production	Interventions	50 % stopped	90 % stopped
	wells drilled	well-years	per 1000 wells drilled	per 1000 well-years	per 1000 well-years	minutes	days
U.S. GOM	31,574	197,721	3.45	0.106	0.314	200	8
North Sea	13,727	59,141	2.99	0.051	0.355	3	20
Holland	1,143	2,948	0	0.339	0.339	n/d*	n/d
Australia	2,559	9,589	1.56	0.104	0	n/d	n/d
Canada East Coast	679	3,955	2.95	0	0	n/d	n/d

* n/d = no data

It should be noted that the LOWC DURATION values give the % chance that an LOWC incident will cease within the time given in each case.

D. Summary of Recommendations

The following recommendations based on the work summarized here:

- Reconcile any minor differences between the SINTEF and BOEM/BSEE data for the U.S. OCS.
- Explain the main differences among the regional LOWC parameters displayed in Table 1, by further review of associated conditions having an effect on LOWC frequencies.
- The depth interval well exposure data are not available for the GOM and other regions, resulting in a less meaningful assessment of LOWC occurrence variation with depth. Obtain the number of wells by depth interval and evaluate the variation of LOWC frequency and its characteristics with depth.
- LOWC duration data for many incidents indicates a 0 duration. The significance of this datum should be investigated and durations adjusted.
- Full exposure data for Australia, Holland, and Canada were not available, and accordingly were estimated for the number of production well-years. Obtain exposure data from the stated regional administrations and re-evaluate LOWC frequencies.
- In earlier editions of SINTEF documentation (pre 2000) spill volumes were included, but are not included in current data. SINTEF has been advised and are considering options.
- Surface and subsea LOWC data in SINTEF are not adequately documented to assess likelihood of releases into the marine environment as opposed to underground releases. Determine which of the subsea incidents release into the sea and which stay underground.
- Review of the Chapter 9 LOWC algorithm which gives frequency as a function of various regulatory, operational, and reservoir parameters, with experts, and by specific application to known regions. As appropriate, modify aspects of the algorithm following such review and application.

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- Dr Frank G Bercha, Project Manager and Principal Engineer
- Milan Cerovšek, Reliability Engineering Specialist
- Wesley Abel, Offshore Operations Advisor
- Dr. Ove Tobias Gudmestad, Norwegian and SINTEF liaison
- Dr. Philip Laird, Australian liaison
- Susan Bercha, Editorial and Word Processing Manager
- Scientific Advisory Panel:
  - Dr. Richard Prentki, Oceanographer and Alaska OCS expert
  - Wesley Abel, P.Eng. , Retired OIM and VP of multinational oil company
  - Dr. Elliott Taylor, Oil Spill Specialist

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GLOSSARY OF TERMS AND ACRONYMS

bbl	Barrel. A volumetric unit used in the petroleum industry; equivalent to 42 U.S. gallons or 158.99 liters.
Blowout	A blowout is an incident where formation fluid flows out of the well or between formation layers after all the predefined technical well barriers or the activation of the same have failed.
BOEM	**B**ureau of **O**cean **E**nergy **M**anagement, U.S. Department of the Interior
BSEE	**B**ureau of **S**afety and **E**nvironmental **E**nforcement, U.S. Department of the Interior
Consequence	The direct effect of an accidental event.
Delineation well	A well drilled specifically to determine the boundary of a discovered reservoir.
Development well	A well drilled for the extraction of reservoir hydrocarbons.
Exploration well	A well drilled to test a potential, but unproven hydrocarbon trap. Also called a "wildcat" well.
FT	**F**ault **T**ree
FTA	**F**ault **T**ree **A**nalysis
GOM	**G**ulf **o**f **M**exico OCS
GOR	**G**as to **O**il **R**atio is the ratio of volumetric flow of produced gas to the volumetric flow of crude oil for a specific crude oil and gas mixture sample.
Hazard	A condition with a potential to create risks such as accidental leakage of hydrocarbons from a pressurized vessel.
LOWC	**L**oss **o**f **W**ell **C**ontrol
MMbbl	Million Barrels
MMS	**M**inerals **M**anagement **S**ervice. On October 1, 2011, the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE), formerly the Minerals Management Service (MMS), was replaced by the Bureau of Ocean Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE) as part of a major reorganization
NPS	**N**ominal **P**ipe **S**ize or diameter
OCS	**O**uter **C**ontinental **S**helf
PAC	**P**acific OCS

Risk	A compound measure of the probability and magnitude of adverse effect.
SINTEF	The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology
Spill frequency	The number of spills of a given spill size range per year. Usually expressed as spills per 1,000 years (and so indicated).
Spill frequency per barrel produced	The number of spills of a given spill size range per barrel produced. Usually expressed as spills per billion barrels produced (and so indicated).
Spill index	The product of spill frequency for a given spill size range and the mean spill size for that spill size range.
Spill occurrence	Characterization of an oil spill as an annual frequency and associated spill size or spill size range.
Spill occurrence indicator	Any of the oil spill occurrence characteristics; namely, spill frequency, spill frequency per barrel produced, or spill index (defined above).
Spill sizes	Small (S): 50 - 99 bbl Medium (M): 100 - 999 bbl Large (L): 1,000 - 9,999 bbl Huge (H): 10,000 - 149,999 bbl Enormous: >=150,000 bbl
TIMS	**T**echnical **I**nformation **M**anagement **S**ystem (of BSEE)
Well	One or more wellbores into the earth for the purpose of either finding or producing underground resources or providing services related to the production of underground resources, specifically hydrocarbons in this document.
Wellbore	Also called “borehole,” means a unique oriented hole from the bottom of a drilled interval to the surface. If more than one path exists from a surface location to a bottom hole point then more than one wellbore exists.
Well interventions	Activities to remediate an existing well, such as workovers.
Well release	The reported incident is a well release if oil or gas flowed from the well from some point where flow was not intended and the flow was stopped by use of the barrier system that was available on the well at the time the incident started.

CHAPTER 1

INTRODUCTION

1.1 General Introduction

1.1.1 Background

In order to provide context for the present report, background and details of the project are provided. The project is entitled, "Loss of Well Control Occurrence and Size Estimators Alaska OCS" and identified as Project Number M12PS00020. It was awarded to Bercha International Inc. (Bercha) by the Bureau of Offshore Energy Management (BOEM). Its completion is estimated in March of 2016.

BOEM uses the historical blowout record for the U.S. Outer Continental Shelf (OCS) and the North Sea as an input to the fault tree model to develop oil spill occurrence rates for oil-and-gas-lease sales and any development projects in the Chukchi and Beaufort Sea OCS Planning Areas proposed under BOEM and industry planning [12, 13, 14]*. In recent years, the Alaska OCS Region has frequently been tasked to provide frequency estimates and analysis of potential loss of well control (LOWC) occurrence during lease sale, exploration and development in National Environmental Policy Act (NEPA) assessments. The largest spill from a single well control incident in the history of the U.S. offshore oil industry, the Macondo blowout in the U.S. Gulf of Mexico (GOM) OCS [23, 51], has further focused interest in consideration of very large spills from well control incidents in NEPA analyses.

Under the Bureau of Safety and Environmental Enforcement regulations 30 CFR § 250.188 (3) [52] industry must report all losses of well control.

"Loss of well control" means:

(i) Uncontrolled flow of formation or other fluids. The flow may be to an exposed formation (an underground blowout) or at the surface (a surface blowout);

(ii) Flow through a diverter; or

(iii) Uncontrolled flow resulting from a failure of surface equipment or procedures.

In general, well control incidents can be separated into two categories: (i) loss of well control without release to the environment, and (ii) loss of well control with release to the environment. An additional categorization of the latter is made in this work; namely, distinguishing between principally gaseous releases and principally hydrocarbon (HC) liquid releases or spills.

* Numbers in square brackets refer to publications and documents listed in the "References" section of this report.

Although the offshore LOWC has received attention over the last few decades [3, 4, 9, 11, 32, 33, 40], *Offshore Blowouts, Causes and Control* by Holand [35], has the most comprehensive analysis of worldwide blowout data published to date, but those data are in need of updating. The primary world database for this information has been compiled by and is held by SINTEF (http://www.sintef.no/Home/Technology-and-Society/Safety-Research!Projects/SINTEF-Offshore-Blowout-Database/) [46], with SINTEF and members of SINTEF (including Bercha) with access to the data and various statistical analyses based on the database [34, 38, 39, 43, 44]. The current work has included continued membership and acquisition, analysis, and reporting on the SINTEF database in the context of the present contract by Bercha.

1.1.2 Objectives

The general objectives of the project reported herein are to:

- Update offshore loss of well control frequency information through 2011 for the U.S., Canadian and Australian offshore regions, the North Sea, and other areas with a comparable regulatory regime. Collate exposure variable information.
- Apply statistical procedures to develop loss of well control occurrence rates for different operational phases and product spilled (e.g., gas, crude and condensate, drilling mud).
- Estimate confidence intervals for occurrence rates.
- Provide statistical measures such as mean and median spill sizes including appropriate methods for statistical outliers such as the Macondo blowout.
- Provide professional support to BOEM in regard to statistical issues of occurrence rates, size estimator(s) and confidence intervals related to this study and study results.
- The products should be suitable for use in BOEM NEPA documents and in BOEM Fault Tree analyses of Oil Spill Occurrence Estimators.

1.2 Scope of Work

The technical scope of work for the study may be summarized as follows:

- **Task 1: Post Award Meeting with BOEM and Identify a Scientific Review Panel**
  - *Task 1a* – Post Award Meeting
  - *Task 1b* – Scientific Review Panel candidates -- *3 total*
- **Task 2: Update and Collate Offshore Loss of Well Control Records**
  - *Task 2a* – Update and collate offshore loss of well control records for the U.S., Canadian, and Australian offshore regions, the North Sea, and other areas with a comparable regulatory regime.
  - *Task 2b* – Collate exposure variable information
  - *Task 2c* – Coordinate with the study “Updates to the Fault Tree for Oil Spill Occurrence Estimators”

- **Task 3: Develop Information and Occurrence Rates for Well Control Incidents from Compiled Databases**
  - *Task 3a* – Develop general information about well control incidents.
  - *Task 3b* – Develop statistical approach for handling small sample size.
  - *Task 3c* – Provide occurrence estimators for well control incidents by operational phase and product spilled based on the historical record.
  - *Task 3d* – Provide occurrence estimators for well control incidents in the Gulf of Mexico and Pacific OCS by geographical area based on water depth and reservoir properties.

Additional management and consulting tasks are also included, and will be completed in the project timeframe.

1.2.1 Task 3 Detailed Scope of Work

Task 3: Develop Information and Occurrence Rates for Well Control Incidents from Compiled Databases

- **Task 3a – Develop general information about well control incidents.**
  - The Contractor shall develop general information about loss of well control that can be used to estimate small, large and very large spill impact producing factors. Some examples include:
  - U.S. OCS versus other regions.
  - Loss of well control by product spilled (gas, crude and condensate, and drilling mud).
  - Loss of well control by spill size.
  - Loss of well control by spill duration.
  - Statistical measures of loss of well control such as mean and median spill sizes and durations, and confidence intervals.
- **Task 3b – Develop statistical approach for handling small sample size.**
  - The Contractor shall develop methodology/statistical approach to deal with the inherent challenges associated with a small population size. This may include development of a methodology that addresses phenomena such as temporal and spatial autocorrelation, ensuring that the sample population consists of independent observations, and other such issues. It was found that in fact the populations sampled were large, with ample statistical significance.
  - In progress meetings it was agreed that the primary approach will be to identify LOWCs with spill occurrences for the GOM and worldwide, and among these to isolate the probability of occurrence of spills such as Macondo, and to comment on the principal factors leading to such spills possibly using fault trees to illustrate the key causal factors.

- **Task 3c – Provide occurrence estimators for well control incidents by operational phase and product spilled based on the historical record.**
  - The Contractor shall develop occurrence estimators as the number of well control incidents per number of wells drilled for the following categories: all operations (production, workover, completion, drilling), drilling operations (exploration and development), exploration drilling, and development drilling.
  - Provide additional occurrence estimators within each category based on volume and type of product spilled (gas, crude and condensate, and drilling mud).
  - Use statistical measures to identify any spatial and temporal trends in well control incident rates, volume spilled, and confidence intervals by region, phase of operation, type of product spilled.
- **Task 3d – Provide occurrence estimators for well control incidents in the Gulf of Mexico and Pacific OCS by geographical area based on water depth and reservoir properties.**
  - The Contractor shall develop well control incident occurrence estimators for the Gulf of Mexico and Pacific OCS for very shallow (0-200 feet), shallow (201-500 feet), deep (501-5000 feet), and ultra-deep (> 5000 feet) water depth ranges, and reservoir properties such as differences with high-temperature, high-pressure wells or other such variables.

1.3 Organization and Cross-reference of this Report with Task 3

In order to logically address Task 3 and additional work, this report – following this introductory chapter – has been organized into 8 chapters, intended to cover the above Task 3 Scope of Work, as follows:

- Chapter 2: Databases and Exposure – Task 3a
- Chapter 3: U.S. GOM and PAC Statistics – Tasks 3a and 3d
- Chapter 4: UK, Norway, and North Sea Statistics Task 3a
- Chapter 5: U.S. GOM and North Sea Statistics – Tasks 3a and 3d
- Chapter 6: Australia, Holland, and Canada Statistics – Task 3a
- Chapter 7: Temporal and Regional Comparisons – Tasks 3a and 3d
- Chapter 8: LOWC Spills – Task 3b

1.4 Principal Definitions

In 2006, the Minerals Management Service (MMS) [40] published the following definition of a Loss of Well Control (LOWC) event:

- A blowout is an uncontrolled flow of formation or other fluids either to an exposed formation (underground blowout) or to the surface or sea floor (surface blowout).

- Flow through a diverter.
- Uncontrolled flow from the well resulting from a failure of surface equipment or procedures.

In the SINTEF analysis [34], these LOWC events have generally been subdivided into two principal categories; namely, Blowouts as described above in the first bullet, and Well Releases, as described in the second and third bullets above. The following definitions are used for these terms by SINTEF:

- A blowout is an incident in which formation fluids continue to flow out of the well to the surface or sea floor or between formation layers after all existing technical well barriers have failed to stop the flow.
- A well release is an incident in which formation fluids flow out of the well or between formation layers but the flow is stopped using existing technical well barriers.

Detailed descriptions of other technical terms and acronyms used are given in the Glossary of Terms and Acronyms on page *viii* at the front of this report. Other related terms and acronyms are given in [34, 50].

CHAPTER 2

DATABASES AND EXPOSURE

2.1 Principal Databases Used

The principal databases reviewed for this worldwide LOWC study were the SINTEF worldwide database [46], U.S. GOM and PAC data [22, 24, 41], and several other databases and publications relating to offshore LOWC statistics [2, 25, 36, 42].

Of these, the principal database is that generated by SINTEF. SINTEF is the Norwegian acronym for *Stiftelsen for Industriell og Teknisk Forskning*, meaning "The Foundation for Scientific and Industrial Research". It was established at the Norwegian Institute of Technology in Trondheim, Norway, in 1950, and has expanded rapidly to its current configuration with over 2,000 employees (most of whom are located in Trondheim, Norway). Details of the SINTEF organization are available from their website (www.sintef.no) [46].

One of the activities in which the SINTEF organization has engaged is in the collection of databases to support risk analyses of various industrial activities, including offshore drilling. Thus, the SINTEF offshore blowout database is used as the foundation for most of the blowout characteristic and statistical results generated under the present project.
In addition to providing the database (once membership status has been acquired, as has been done by Bercha), not only can one access the raw data, but also receive publications by one of its affiliated companies, ExproSoft headed by Per Holand [34], as well as other publications indicating various analyses of the database [38, 43, 44, 45, 46].

Information sources utilized under the present project include the SINTEF [46] database, the BOEM/BSEE database [22, 24] and several anecdotal sources of information, including the National Energy Board and the Transportation Safety Board of Canada [9], the Australian Offshore Regulator, and direct review of reports by agencies such as the U.S. Coast Guard (U.S.CG) [51], BOEM [23], and TransOcean [49].

2.2 SINTEF Database

2.2.1 Characteristics of SINTEF Database

An initial description of the SINTEF database is provided below.

The database fields for LOWCs are summarized in Table 2.1.

Table 2.1: SINTEF Database Fields

BlowoutID	BlowoutDate	MainCategory	SubCategory	CountryName	Field
WaterDepth	Operator	InstallationName	InstallationType	WellDepth	WellStatusType
CasingSize	CasingDepth	MudWeight	BH_Pressure	MaxMeasuredShutIn Pressure	MaxTheoreticShutInWH _Pressure
API_grade	GasVolume	OilVolume	WaterVolume	GasOilRatio	RockType
FormationAge	FormationName	LossOfBarrier1	LossOfBarrier1Desc	LossOfBarrier2	LossOfBarrier2Desc
NorthSeaStandards	ExternalCause	HumanError	PhaseType	Activity	OperationType
FlowPath	FlowPathDesc	ReleasePoint	ReleasePointDesc	FlowMediumType	Flowrate
PollutionType	LostProduction	Duration	Fatalitie	IgnitionTime	IgnitionType
ConsequenceClass	MaterialLoss	ControlMethod	ControlMethodDesc	RevisionDate	
DataQuality	ActivityDesc	OperationDesc	InstallationTypeDesc	ExternalReference	Remarks

In addition to providing tabular results for each of the database fields as available, SINTEF also contains detailed incident reports. A typical (but somewhat more detailed than most) incident report is shown in Table 2.2, in this case for the Macondo blowout.

The regions covered by the SINTEF database include the offshore drilling jurisdictions of Australia, Canada, Holland, Norway, UK, and of course the U.S.A, and are shown in Table 2.3. Norway and the UK comprise the North Sea.

Unfortunately, other drilling regions such as the Java Sea, the Indian Ocean, the Gulf of Bohai, the Sea of Okhotsk, as well as off the coast of Nigeria – which have extensive offshore drilling and production activity – are not covered by the SINTEF database. To some degree, the drilling standards in these regions are not the same as those of the regions covered by SINTEF, so that statistical data would be biased to lower standards if drawn from these regions.

Table 2.2: SINTEF Incident Details (typical but more detailed than most)

Category and location			Field	: Mississippi Canyon Block 252, Macondo, lease G32306	X
Blowout ID	: 611	X	Water depth	: 1521	[m] X
Date	: 20.04.2010	X	Operator	: BP Exploration & Production Inc.	X
Category	: Blowout (surface flow)		Installation name	: Deepwater Horizon	X
Sub category	: Totally uncontrolled flow, from a deep zone		Installation type	: SEMISUBMERSIBLE	
Country name	: U.S./GOM OCS		Remark		
Well description			API grade	: 0	X
Well depth	: 5579	[m] X	Gas volume	: 0	[1.000 m^3/day] X
Well status	: KILLED		Oil volume	: 0	[m^3/day] X
Casing size	: 9,625	[inch] X	Water volume	: 0	[m^3/day] X
Casing depth	: 5579	[m] X	Gas/oil ratio	: 0	[Sm^3/Sm^3] X
Mud weight	: 0	[kg/m^3] X	Rock type	: A.SANDSTONE	
B.H. Pressure	: 817	[bar] X	Formation age	: B.MIOCENE	
MMSIP	: 0	[bar] X	Formation name		X
MTSIP	: 0	[bar] X			
Blowout causes			Loss of barrier 2	: B1.FAILED TO CLOSE BOP	
Loss of barrier 1	: C14.CASING PLUG FAILURE		Remark		
Remark	: Cement in casing failed		External causes	: NO	
	: No, acoustic backup BOP control system		Human error	: Failed to observe kick before well was flowing	X
Present operation			Activity	: B1.CIRCULATING	
Phase	: EXPL.DRLG WILDCAT		Remark		
Operation	: W9.ABANDON WELL				
Op Remark		X			
Blowout characteristics			Release point	: DRILLFLOOR - THROUGH ROTARY SUBSEA BOP	
Flowpath	: A.THROUGH DRILL STRING/TUBING B.THROUGH ANNULU.S.		Remark		
Remark			Flowrate	: 8000	[m^3/day] X
Flow medium	: Oil, Gas (deep)		Ignition time	: 0	[hrs] X
Pollution	: LARGE		Ignition type	: EXPLOSION	
Lost production		X	Consequence Class	: TOTAL LOSS	
Fatalities	: 11	X	Material loss	: 0	[mil U.S.$] X
Duration	: 85	[days] X			
Other					
Control method	: CAPPED				
Remark					
Revision date	: 06.10.2010	X			
Data quality	: VERY GOOD				
Reference	: www.bp.com	X			

Table 2.2: SINTEF Incident Details ~ *Continued* ~

Remarks	: From BP Investigation published September 2010. (http://www.bp.com/sectiongenericarticle.do?categoryId=9034902&contentId=7064891) A sequence of failures involving a number of different parties led to the explosion and fire which killed 11 people and caused widespread pollution in the Gulf of Mexico earlier this year. Decisions made by "multiple companies and work teams" contributed to the accident which it says arose from "a complex and interlinked series of mechanical failures, human judgments, engineering design, operational implementation and team interfaces."
	The report found that: • The cement and shoe track barriers – and in particular the cement slurry that was used – at the bottom of the Macondo well failed to contain hydrocarbons within the reservoir, as they were designed to do, and allowed gas and liquids to flow up the production casing; • The results of the negative pressure test were incorrectly accepted by BP and Transocean, although well integrity had not been established; • Over a 40-minute period, the Transocean rig crew failed to recognise and act on the influx of hydrocarbons into the well until the hydrocarbons were in the riser and rapidly flowing to the surface; • After the well-flow reached the rig it was routed to a mud-gas separator, causing gas to be vented directly on to the rig rather than being diverted overboard; • The flow of gas into the engine rooms through the ventilation system created a potential for ignition which the rig's fire and gas system did not prevent; • Even after explosion and fire had disabled its crew-operated controls, the rig's blow-out preventer on the sea-bed should have activated automatically to seal the well. But it failed to operate, probably because critical components were not working. "To put it simply, there was a bad cement job and a failure of the shoe track barrier at the bottom of the well, which let hydrocarbons from the reservoir into the production casing. The negative pressure test was accepted when it should not have been, there were failures in well control procedures and in the blow-out preventer; and the rig's fire and gas system did not prevent ignition. "We have said from the beginning that the explosion on the Deepwater Horizon was a shared responsibility among many entities. This report makes that conclusion even clearer, presenting a detailed analysis of the facts and recommendations for improvement both for BP and the other parties involved. We have accepted all the recommendations and are examining how best to implement them across our drilling operations worldwide. BP said the report was based on information available to the investigating team. It noted that additional relevant information may be forthcoming, for example, when Halliburton's samples of the cement used in the well are released for testing and when the rig's blow-out preventer is fully examined now that it has been recovered from the sea-bed.
	Other recommended reports: Chief Counsel's Report, http://www.oilspillcommission.gov/chief-counsels-report (Published February 17th, 2011) Report to the President, http://www.oilspillcommission.gov/final-report (Published January 11 2011) DNV report on the BOP, http://www.deepwaterinvestigation.com/go/site/3043/ (Published March 23 2011)
	The DNV report related to failed to close shear rams concluded: The primary cause of failure was identified as the BSRs failing to fully close and seal due to a portion of drill pipe trapped between the blocks.
	Contributing causes to the primary cause included: • The BSRs were not able to move the entire pipe cross section into the shearing surfaces of the blades. • Drill pipe in process of shearing was deformed outside the shearing blade surfaces. • The drill pipe elastically buckled within the wellbore due to forces induced on the drill pipe during loss of well control. • The position of the tool joint at or below the closed Upper Annular prevented upward movement of the drill pipe. • The Upper VBRs were closed and sealed on the drill pipe. • The flow of well fluids was uncontrolled from downhole of the Upper VBRs
	The blowout was capped. A relief well was drilled to finally control the well.

Table 2.3: SINTEF Regions

Nationality	Region	Well Type	Well Subtype
Australia	All	Drilling	As available
Canada	Canada	Drilling	As available
Holland	All	Drilling	As available
Norway	All	Drilling	Wildcat, appraisal, development
		Production	Oil, gas, condensate, injection, suspended/abandoned
UK	All	Drilling	Wildcat, appraisal, development
		Production	Oil, gas, condensate, injection, suspended/abandoned
U.S.	GOM	Drilling	Wildcat, appraisal, development
		Production	Oil, gas, condensate, injection, suspended/abandoned
	Pacific	Drilling	Wildcat, appraisal, development
		Production	Oil, gas, condensate, injection, suspended/abandoned

2.2.2 SINTEF Database Exposure

Tables 2.4 and 2.5 summarize the regional totals for drilling and production wells, respectively.

As will be discussed later, data on production well-years is not available for certain regions. Accordingly, to estimate production well-years and volumes of oil to gas producers, ratios from available regional data, as shown in Table 2.6, are used here as a rough estimate.

Table 2.4: Total Wells Drilled Exposure (1980-2011)

Region	Exploration	Development	Drilling Total
U.S. GOM OCS	12,299	19,275	31,574
U.S. PACIFIC OCS	130	745	875
UK	3,302	5,807	9,109
Norway	1,251	3,367	4,618
Holland	703	440	1,143
Australia	1,628	931	2,559
Denmark	214	455	669
Canada East Coast	295	384	679
TOTAL	19,822	31,404	51,226

Table 2.5: Production Well-Years Exposure (1980-2011)

Region	Oil Producers	Gas/-Cond Producers	Total Producers	Injection Wells
U.S. GOM	101,262	96,459	197,721	9,045
UK	23,301	15,807	39,108	10,800
Norway	16,703	3,330	20,033	5,365
Total:	141,266	115,596	256,862	25,210

Table 2.6: Ratios of Production well-years to Development Wells Drilled and Oil to Gas Producers (1980-2011)

Region	Oil Producers	Gas/-Cond Producers	Total Producers	Development Wells Drilled	Ratio Producers / DevDrill	Ratio Oil/Gas Producers
U.S. GOM	101,262	96,459	197,721	19,275	10.3	1.0
UK	23,301	15,807	39,108	5,807	6.7	1.5
Norway	16,703	3,330	20,033	3,367	5.9	5.0
TOTAL	141,266	115,596	256,862	33,442	7.7	1.2

2.2.3 SINTEF Database Confidentiality

SINTEF database is proprietary, with access subject to membership and annual update participation based on fees. Bercha is both a member and has access for the years 2013 and 2014.

In accordance with ExproSoft AS, the agents of SINTEF, on June 21, 2012, Bercha received the following advice from them in an email from Dr. Per Holand:

"Use of data extracted from the Blowout database externally.

One of the participants requested a clarification related to use of data extracted from the database for external clients. This is regulated in § 8.3 in the agreement as follows:

§8.3 During the confidentiality period specified in Annex C, each Party has the right to divulge data from the Project to Affiliates, clients, consultants, contractors, members of production groups for which it is operator or technical assistant, relevant regulatory authorities and certifying agencies to the extent that their participation in a specific project would so necessitate. Any Party making use of this right shall require the recipient to sign a confidentiality agreement limiting the use and divulging of Project data to such specific and named project only.

It was agreed that our interpretation of this is:

- The main goal is that the data shall not be released in such a way that they may be used to establish a competing database
- Raw data shall not be presented, i.e. a large number of unedited blowout descriptions should not be included, only cases
- Divulged data, i.e. frequencies and distributions can be presented

This means that you cannot dump all the information in the database but make reasonable extracts."

Bercha as the Contractor, interprets this to mean that BOEM as "relevant regulatory agency" can view and receive the data we assimilate from the SINTEF database under a confidentiality agreement, and that there exist no restrictions on publication of statistics and summaries from those data, as is done in the present report.

2.3 BOEM and BSEE Data

LOWC data from the U.S. GOM and Pacific (PAC) regions is provided. These data, however – just as the SINTEF data – have limited information on oil spills. More recent analysis of LOWC spill volumes provided by BOEM [22] provides detailed information on those from 1964 to 2010. Data for the period of focus, 1980-2010, from BOEM [22], are given in Table 2.7. The data show 9 spills exceeding or equal to 50 bbl.

Table 2.7: U.S. OCS LOWC Crude and Condensate Spill Volume Data (1980-2010) [22]

#	Blowout Date	Water Depth	Well Type*	Duration (days)	Operation**	Spillage (bbl)	Product Spilled	OCS Region
26	18-Sep-1980	105	D	4	PR	1.00	crude oil	GOM
27	12-Jan-1981	36	E	1	DR	0.90 [1]	condensate	GOM
28	27-Feb-1981	48	D	1	WO	0.90 [1]	crude oil	GOM
29	26-Jul-1981	48	D	6	CO	0.90 [1]	crude oil	GOM
30	19-Oct-1981	44	D	1	CO	0.90 [1]	crude oil	GOM
31	28-Nov-1981	340	D	1	WO	64.00	crude oil	GOM
32	7-Feb-1982	141	D	0.50	WO	0.90 [1]	crude oil	GOM
33	14-Jul-1982	38	D	57	WO	0.90 [1]	crude oil	GOM
34	20-Jul-1983	68	E	1	DR	2.00	crude oil	GOM
35	23-Feb-1985	190	D	0.33	WO	50.00	crude oil	GOM
36	20-Mar-1987	126	D	3	CO	60.00	condensate	GOM
37	6-Sep-1987	104	D	1	WO	1.00	Unknown	GOM
38	9-Apr-1988	48	D	0.08	PR	4.50	crude oil	GOM
39	9-Sep-1990	214	D	4	WO	8.00	condensate	GOM
40	9-Oct-1990	186	D	0.04	WO	0.50	crude oil	GOM
41	11-Nov-1991	80	E	1	DR	0.80	condensate	GOM
42	26-Dec-1992	186	E	3	DR	100.00	condensate	GOM
43	22-Feb-1998	87	D		PR	1.10	crude oil	GOM
44	8-Jul-1998	51	D	2.2	PA	1.50	condensate	GOM
45	9-Sep-1999	463	D	11	WO	125.00	condensate	GOM
46	12-Jan-2000	309	E	7	DR	0.50	crude oil	GOM
47	28-Feb-2000	2,223	E	0.17	DR	200.00	crude oil	GOM
48	19-Nov-2000	739	D	0.001	WO	0.02	crude oil	PAC
49	6-Jul-2001	169	D		WO	1.00	crude oil	GOM
50	12-Jan-2002	153	D	0.0003	WO	0.01	crude oil	GOM
51	3-Oct-2002	50	D		PRH	350.00	crude oil	GOM
52	6-Dec-2002	133	D	0.5	PR	0.50	crude oil	GOM
53	8-Mar-2003	30	D	0.17	WO	10.00	condensate	GOM
54	12-Apr-2003	198	D	1	PR	0.02	condensate	GOM
55	9-Feb-2004	23	E	0.25	DR	5.40	condensate	GOM
56	22-Feb-2004	419	D		CO	2.50	crude oil	GOM
57	21-Oct-2004	3,855	E	0.21	DR	11.00	crude oil	GOM
58	20-Feb-2006	189	D		PA	10.00	condensate	GOM
59	26-Aug-2009	169	D	4	PA	2.44	condensate	GOM
60	29-Dec-2009	6,100	E		PA	62.00	crude oil	GOM
61	20-Apr-2010	4,992	E	87	DR-TA	4,900,000.00 [2]	crude oil	GOM

* Well Type
E = Exploration
D = Development

** Operation
CO = Completion
DR = Drilling
PA = Permanent Abandonment or Leaking PA
PR = Production
PRH = Production - Hurricane
SIH = Shut-In - Hurricane
TA = Temporary Abandonment or Leaking TA
WO = Workover

Notes:

1. A volume of 0.9 bbl signifies that the historical records state “minimal oil pollution”.
2. Spill #61 spillage is a preliminary volume estimate, not a final volume determined by BOEM.

CHAPTER 3

U.S. GOM AND PAC STATISTICS

3.1 General Description of U.S. GOM and PAC LOWC Statistics

This chapter is intended to provide a comprehensive set of statistics and characteristic descriptions for LOWC events in the U.S. GOM and PAC Regions. The results are based on the SINTEF data covering the period from 1980 to 2011 [46], except when specified otherwise.

This chapter covers the following principal areas:

- U.S. GOM exposure
- U.S. GOM LOWC frequency characteristics
- U.S. GOM LOWC durations
- U.S. GOM LOWC water depth distribution
- Available statistics for U.S. PAC LOWC events

The SINTEF data [46] are for the OCS only, and exclude state waters.

3.2 U.S. GOM LOWC Exposure

The exposure for U.S. GOM and other regions was briefly summarized in Section 2.2.2. In the period from 1980 to 2011, a total of 12,299 exploration wells and 19,275 development wells were drilled in the U.S. GOM, and a total of 197,721 production well-years occurred [46]. Figure 3.1 graphically illustrates the variation in the number of wells of each type drilled annually for the subject period, while Figure 3.2 graphically illustrates the number of wells in production annually for the same period. Statistics generated in the balance of this chapter are based on the above exposure values, and are reproduced in relevant tables. Exposure for production and well interventions has been assumed to be the same, as most interventions occur during production.

3.3 U.S. GOM LOWC Frequency Characteristics

The characteristics considered in this section include general drilling and production LOWC frequencies, details of drilling LOWC frequency characteristics, and the statistical variability of the frequency statistics developed; all based on SINTEF data.

Table 3.1 summarizes the general statistics associated with the general U.S. GOM LOWC frequencies based on SINTEF [46] data. As can be seen, the events considered are surface blowouts and underground blowouts, and well releases characterized by equipment failure release or flow through a diverter – in accordance with the definition provided in Section 1.4. Wells are principal exposure variables; one well is counted as one exposure unit – whether or not it contains one or more boreholes. These occurrences are considered for production wells and well drilling. Statistics for production wells are given per well-year. These production well statistics are provided for both oil producers and gas and/or condensate producers. A separate category of LOWCs for event categories is given for well intervention. Drilling, again for the same event categories, is given for exploration drilling and development drilling as well as their summary. All well drilling statistics are based on a frequency per well drilled.

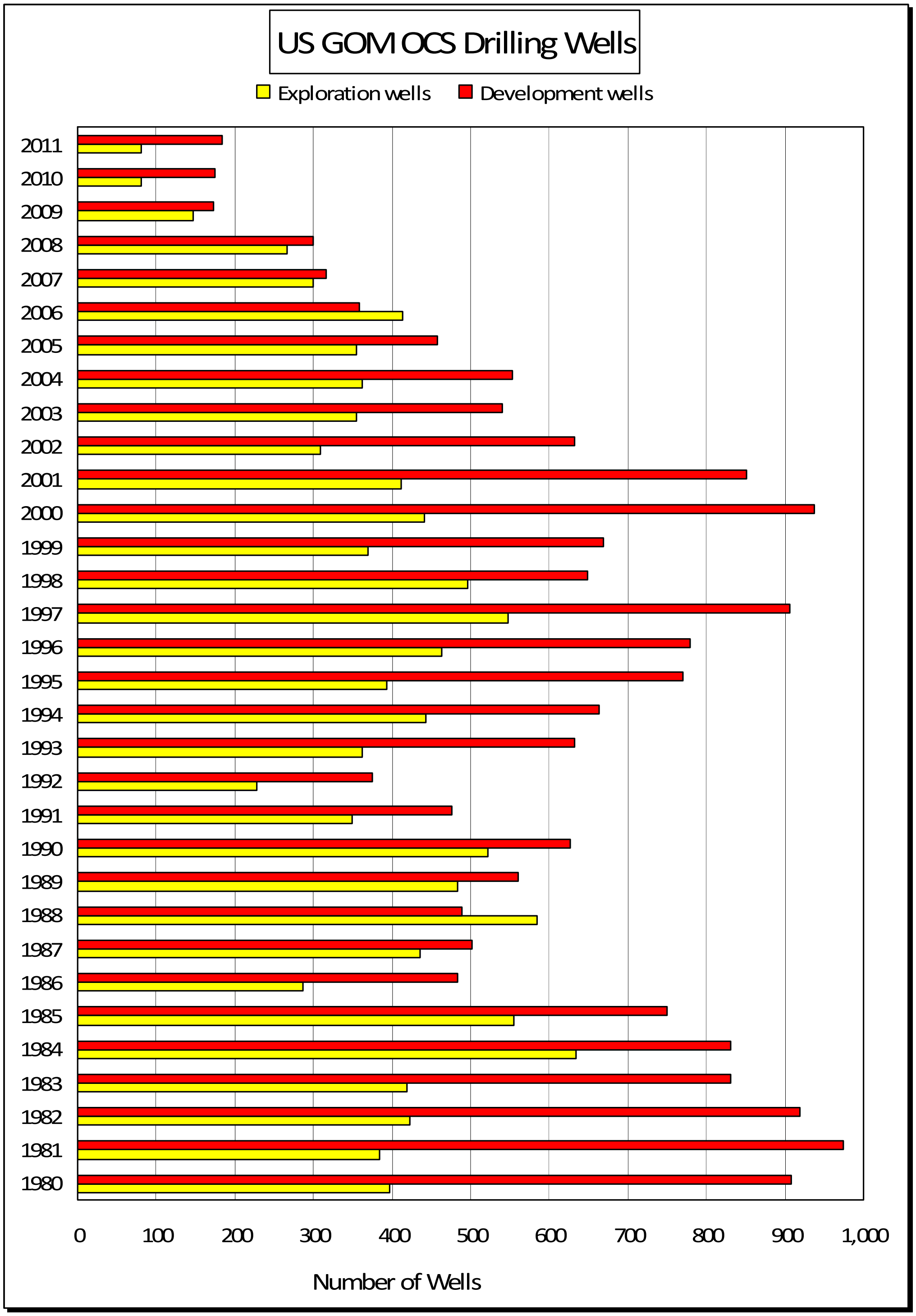


Figure 3.1: U.S. GOM Annual Well Drilling Exposure

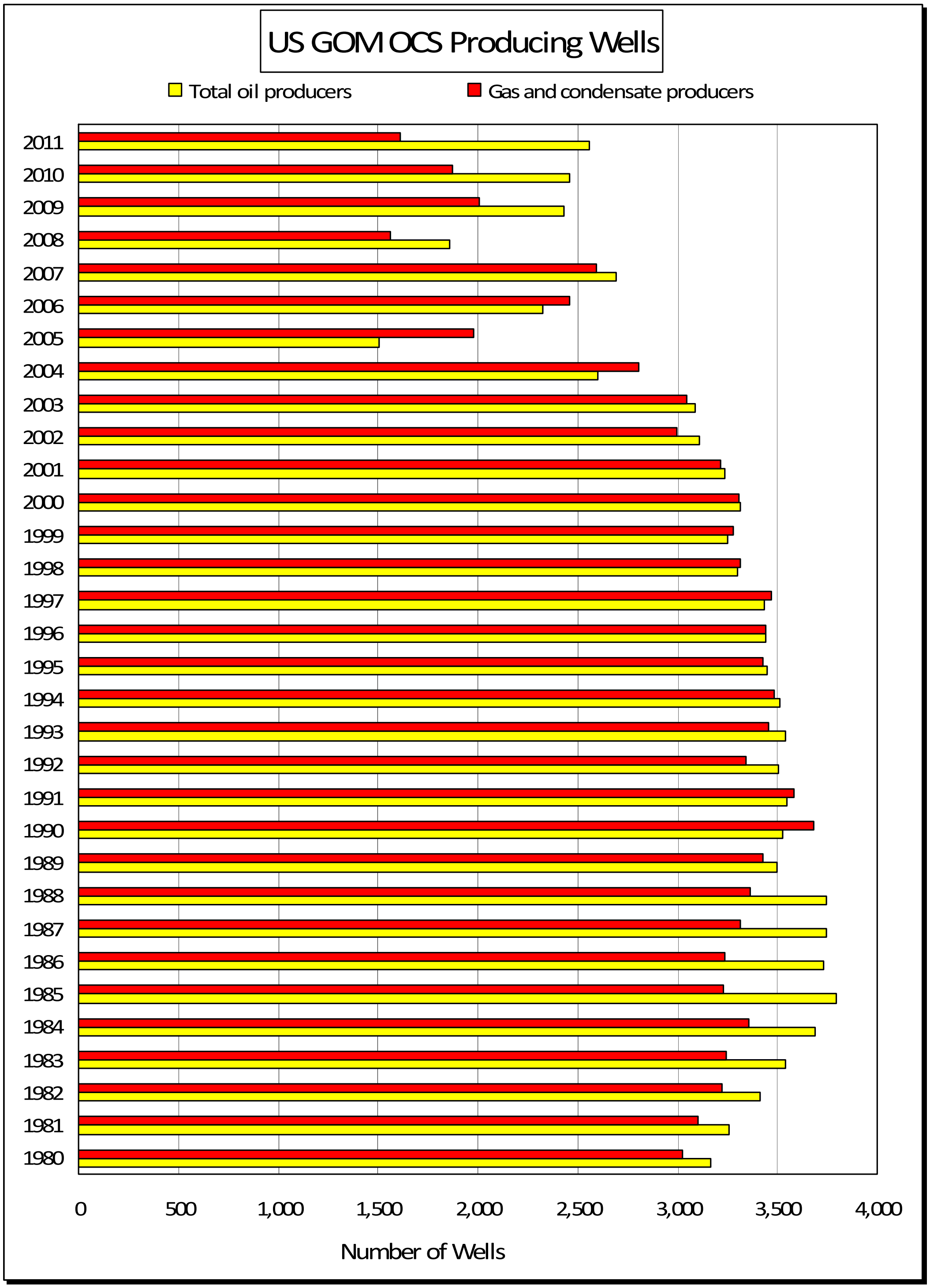


Figure 3.2: U.S. GOM Annual Producing Well Exposure

Table 3.1: U.S. GOM LOWC Frequency Summary

U.S. GOM OCS Wells 1980-2011	Oil Production		Gas/Condensate Production		All Production		Well Interventions		Exploration Drilling		Development Drilling		All Drilling	
	101,262		96,459		197,721		197,721		12,299		19,275		31,574	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	9	8.89E-05	7	7.26E-05	16	8.09E-05	34	1.72E-04	40	3.25E-03	28	1.45E-03	68	2.15E-03
Blowout (underground flow)	1	9.88E-06			1	5.06E-06	1	5.06E-06	4	3.25E-04	5	2.59E-04	9	2.85E-04
Blowout Total	10	9.88E-05	7	7.26E-05	17	8.60E-05	35	1.77E-04	44	3.58E-03	33	1.71E-03	77	2.44E-03
Well Release	1	9.88E-06	3	3.11E-05	4	2.02E-05	26	1.31E-04	1	8.13E-05	3	1.56E-04	4	1.27E-04
Diverted Well Release							1	5.06E-06	9	7.32E-04	19	9.86E-04	28	8.87E-04
Well Release Total	1	9.88E-06	3	3.11E-05	4	2.02E-05	27	1.37E-04	10	8.13E-04	22	1.14E-03	32	1.01E-03
TOTAL	11	1.09E-04	10	1.04E-04	21	1.06E-04	62	3.14E-04	54	4.39E-03	55	2.85E-03	109	3.45E-03

Table 3.2 gives further details of the well drilling statistics. It is important to separate out shallow gas LOWCs from other or deep well drilling LOWCs. The reason for this is that by definition, under SINTEF, shallow gas drilling occurs when the surface hole is drilled without a blowout preventer (BOP). The exposure for shallow gas drilling is the same as that for all drilling, because all offshore wells are initiated by shallow drilling prior to the installation of a BOP. One can see that shallow gas drilling frequencies tend to be somewhat higher than well drilling with BOP in place.

Table 3.2: U.S. GOM Drilling LOWC Frequency Details

U.S. GOM OCS Wells 1980-2011	Exploration Drilling						Development Drilling						All Drilling					
	Shallow Gas		Other		All		Shallow Gas		Other		All		Shallow Gas		Other		All	
	12,299		12,299		12,299		19,275		19,275		19,275		31,574		31,574		31,574	
	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	17	1.38E-03	23	1.87E-03	40	3.25E-03	17	8.82E-04	11	5.71E-04	28	1.45E-03	34	1.08E-03	34	1.08E-03	68	2.15E-03
Blowout (underground flow)			4	3.25E-04	4	3.25E-04	1	5.19E-05	4	2.08E-04	5	2.59E-04	1	3.17E-05	8	2.53E-04	9	2.85E-04
Blowout Total	17	1.38E-03	27	2.20E-03	44	3.58E-03	18	9.34E-04	15	7.78E-04	33	1.71E-03	35	1.11E-03	42	1.33E-03	77	2.44E-03
Well Release			1	8.13E-05	1	8.13E-05	1	5.19E-05	2	1.04E-04	3	1.56E-04	1	3.17E-05	3	9.50E-05	4	1.27E-04
Diverted Well Release	8	6.50E-04	1	8.13E-05	9	7.32E-04	19	9.86E-04			19	9.86E-04	27	8.55E-04	1	3.17E-05	28	8.87E-04
Well Release Total	8	6.50E-04	2	1.63E-04	10	8.13E-04	20	1.04E-03	2	1.04E-04	22	1.14E-03	28	8.87E-04	4	1.27E-04	32	1.01E-03
TOTAL	25	2.03E-03	29	2.36E-03	54	4.39E-03	38	1.97E-03	17	8.82E-04	55	2.85E-03	63	2.00E-03	46	1.46E-03	109	3.45E-03

Finally, Table 3.3 gives the variability for blowout and well release frequencies which were given as average values in Table 3.1. The variability calculations are based on those presented by Holand [35], indicating the upper and lower 90% confidence intervals for the value based on a Chi Square distribution [47]. Thus, for example, for exploration drilling, the expected or mean value is 3.58E-03, with an upper 90% confidence interval value of 4.51E-03 and a lower 90% confidence interval of 2.74E-03. The same applies to the other values indicating the variability of the statistics presented. Figures 3.3 and 3.4 graphically show this variability for production and drilling blowouts, respectively. These figures also present the tabular values for convenience.

Table 3.3: U.S. GOM LOWC Frequency Variability

U.S. GOM OCS Wells Production 1980-2011	Blowout Frequency per Well-Year			Well Release Frequency per Well-Year		
	High	Low	Expected	High	Low	Expected
Oil Production	1.55E-04	5.36E-05	9.88E-05	2.96E-05	5.07E-07	9.88E-06
Gas/Condensate Production	1.23E-04	3.41E-05	7.26E-05	6.53E-05	8.48E-06	3.11E-05
All Production	1.23E-04	5.48E-05	8.60E-05	3.92E-05	6.91E-06	2.02E-05
Well Interventions	2.29E-04	1.31E-04	1.77E-04	1.71E-04	9.64E-05	1.37E-04
U.S. GOM OCS Wells Drilling 1980-2011	**Blowout Frequency per Well**			**Well Release Frequency per Well**		
	High	Low	Expected	High	Low	Expected
Exploration Drilling	4.51E-03	2.74E-03	3.58E-03	1.28E-03	4.41E-04	8.13E-04
Development Drilling	2.23E-03	1.25E-03	1.71E-03	1.57E-03	7.73E-04	1.14E-03
All Drilling	2.91E-03	2.00E-03	2.44E-03	1.33E-03	7.38E-04	1.01E-03

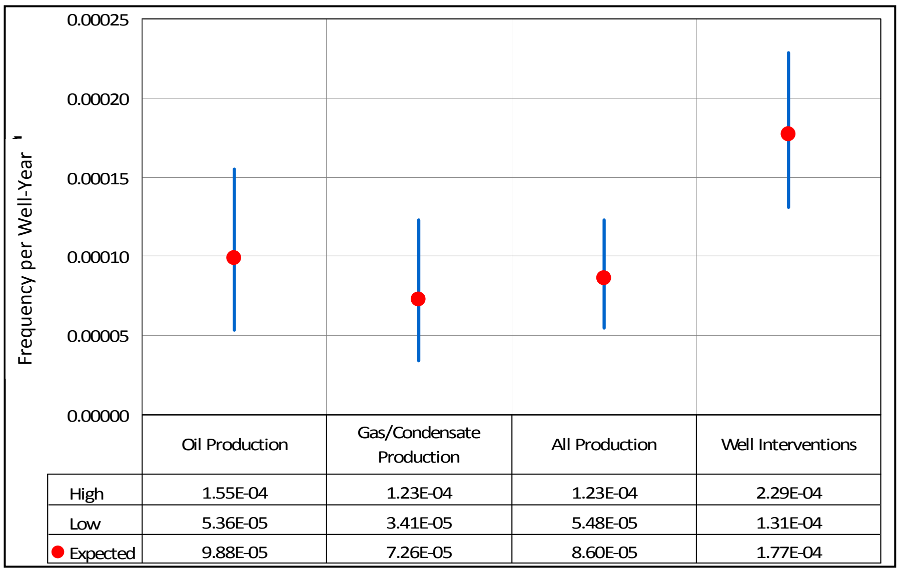


Figure 3.3: Blowout Frequency – U.S. GOM OCS Production Variability (1980-2011)

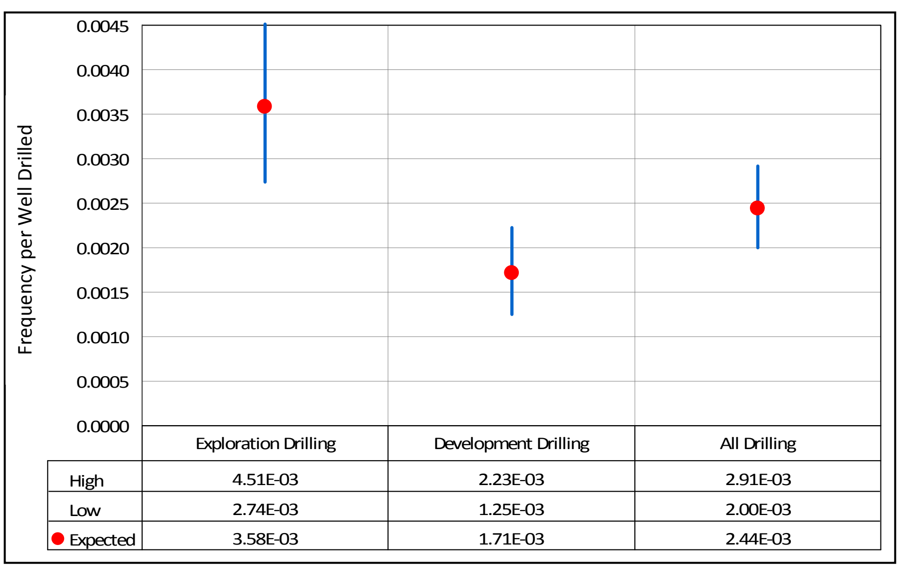


Figure 3.4: Blowout Frequency – U.S. GOM OCS Drilling Variability (1980-2011)

3.4 U.S. GOM LOWC Duration

Duration of LOWC incidents based on the SINTEF data from 1980 to 2011 can be determined from the SINTEF database. The expected duration is displayed both over the initial hours (in Figure 3.5 by the minute, up to 5 hours) and in Figure 3.6 by the hour up to roughly 8 days. As can be seen, durations up to 200 minutes account for roughly 50% of LOWC incidents. The longer view, displayed in Figure 3.6 for up to 8 days, indicates that roughly 90% of LOWCs stop within 8 days. Longer duration blowouts, such as Macondo, will be discussed in Chapter 8.

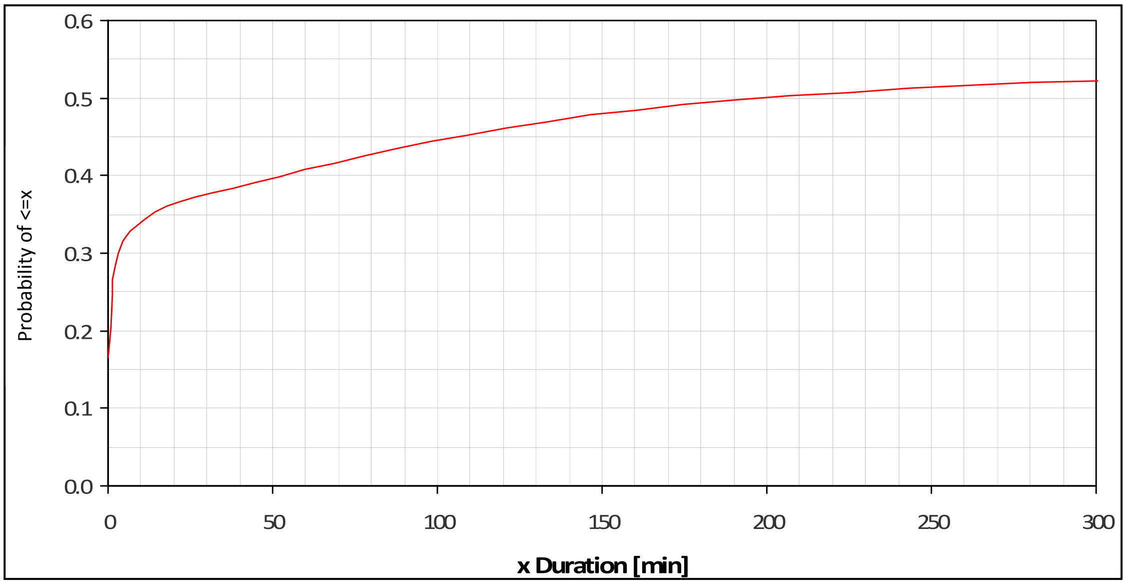


Figure 3.5: U.S. GOM OCS Loss of Well Control – Duration by Minutes

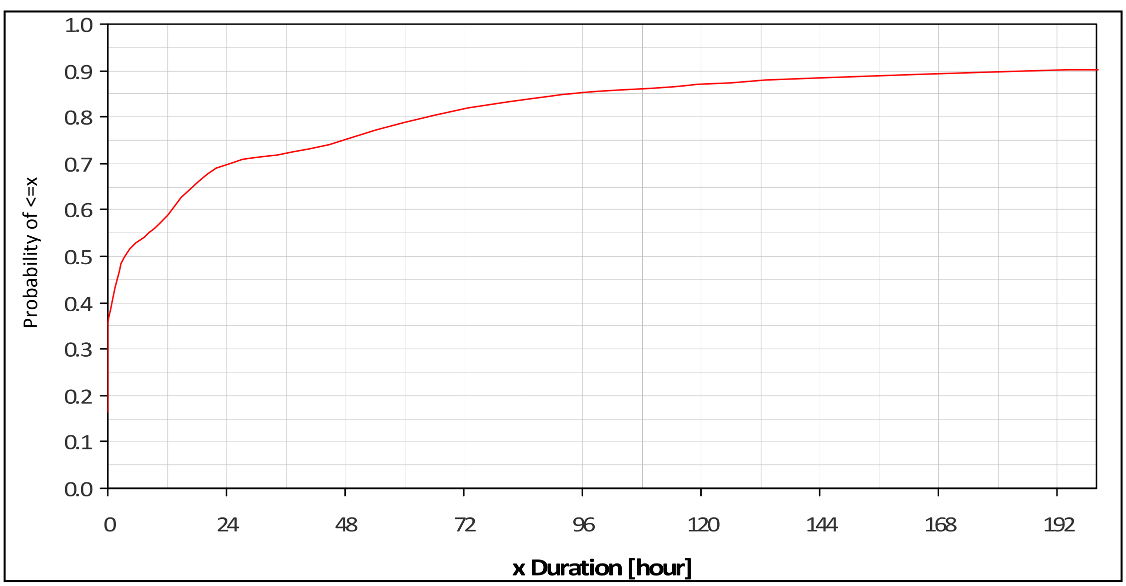


Figure 3.6: U.S. GOM OCS Loss of Well Control – Duration by Hours to 8 Days

3.5 U.S. GOM LOWC Depth Variation

3.5.1 Approach and Water Depth Ranges

The variation of the number of LOWC incidents with water depth for the U.S. GOM was extracted from the SINTEF database. It should be noted that only the number of LOWCs, rather than their rate per exposure unit, was available from the data which only gives the LOWC incidents by water depth without an exposure variable such as number of wells drilled in the subject water depth range; thus, the variable presented in this section is not directly comparable to any of the spill occurrence indicators.

Two water depth ranges were used; namely, the Shelf Range and the Offshore Range.
The Shelf Range corresponds to water depths used in general data updates [12] specific OCS development studies for BOEM [14, 16] and may be summarized as follows:

- Shallow Shelf: <10 m (<33ft)
- Inner Shelf: 10 to 29m (33 to 95ft)
- Middle Shelf: 30 to 60m (95 to 197ft)
- Outer Shelf and Basin: >60m (>197ft)

The Offshore Range corresponds to water depths more representative of operations in the GOM and North Sea and may be summarized as follows:

- Very Shallow: <61 m (<200ft)
- Shallow: 61 to 152m (201 to 500ft)
- Deep: 153 to 1524m (501 to 5000ft)
- Outer Shelf and Basin: >1524m (>5000ft)

Although the individual range intervals are different, the entire range from 0 to an open unlimited interval results in the coverage of the same water depth, with just a different subdivision of the initial intervals. That is, as will be seen the total number of LOWCs is the same for both ranges, but the depth intervals below the maximum open interval are different.

3.5.2 U.S. GOM Shelf Water Depth Range

Table 3.4 gives the distribution of number of LOWC incidents in each of the four Shelf water depth ranges. Clearly the maximum number of incidents occurs in the deepest range, over 60m. This trend may indicate either that many more wells are drilled in this range or that the incident rate is higher in this range or both. Figure 3.7 gives a bar graph and a pie chart graphically illustrating these incident number distributions in this range.

3.5.3 U.S. GOM Offshore Water Depth Range

Table 3.5 gives the distribution of number of LOWC incidents in each of the four Offshore water depth ranges. Clearly the maximum number of incidents occurs in the Very Shallow range, under 61m. This trend may indicate either that many more wells are drilled in this range or that the incident rate is higher in this range or both. Figure 3.8 gives a bar graph and a pie chart graphically illustrating these incident number distributions in this range.

Table 3.4: U.S. GOM Shelf Water Depth Range LOWC Incident Distribution

U.S. GOM OCS 1980-2011				
Shallow Shelf	Inner Shelf	Middle Shelf	Outer Shelf and Basin	Total
< 10 m (< 33 ft)	10 to 29 m (33 to 95 ft)	30 to 60 m (95 to 197 ft)	> 60 m (>197 ft)	All
7	53	51	82	193

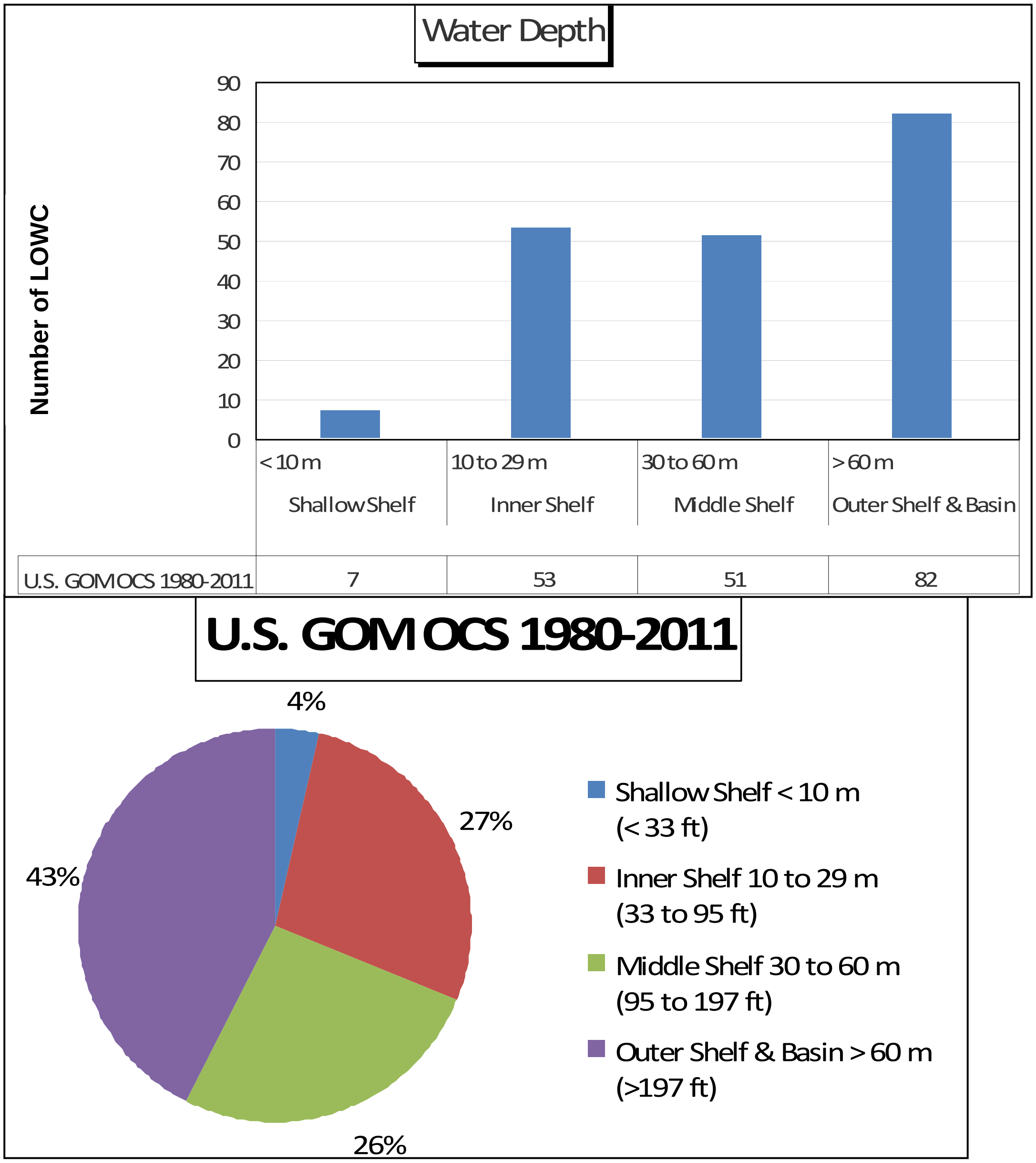


Figure 3.7: U.S. GOM Shelf Water Depth Range LOWC Incident Distribution Graphs

Table 3.5: U.S. GOM Offshore Water Depth Range LOWC Incident Distribution

U.S. GOM OCS 1980-2011				
Very Shallow	Shallow	Deep	Ultra Deep	Total
≤ 61 m (≤ 200 ft)	61 to 152 m (201 to 500 ft)	153 to 1524 m (501 to 5,000 ft)	> 1524 m (> 5,000 ft)	All
112	57	23	1	193

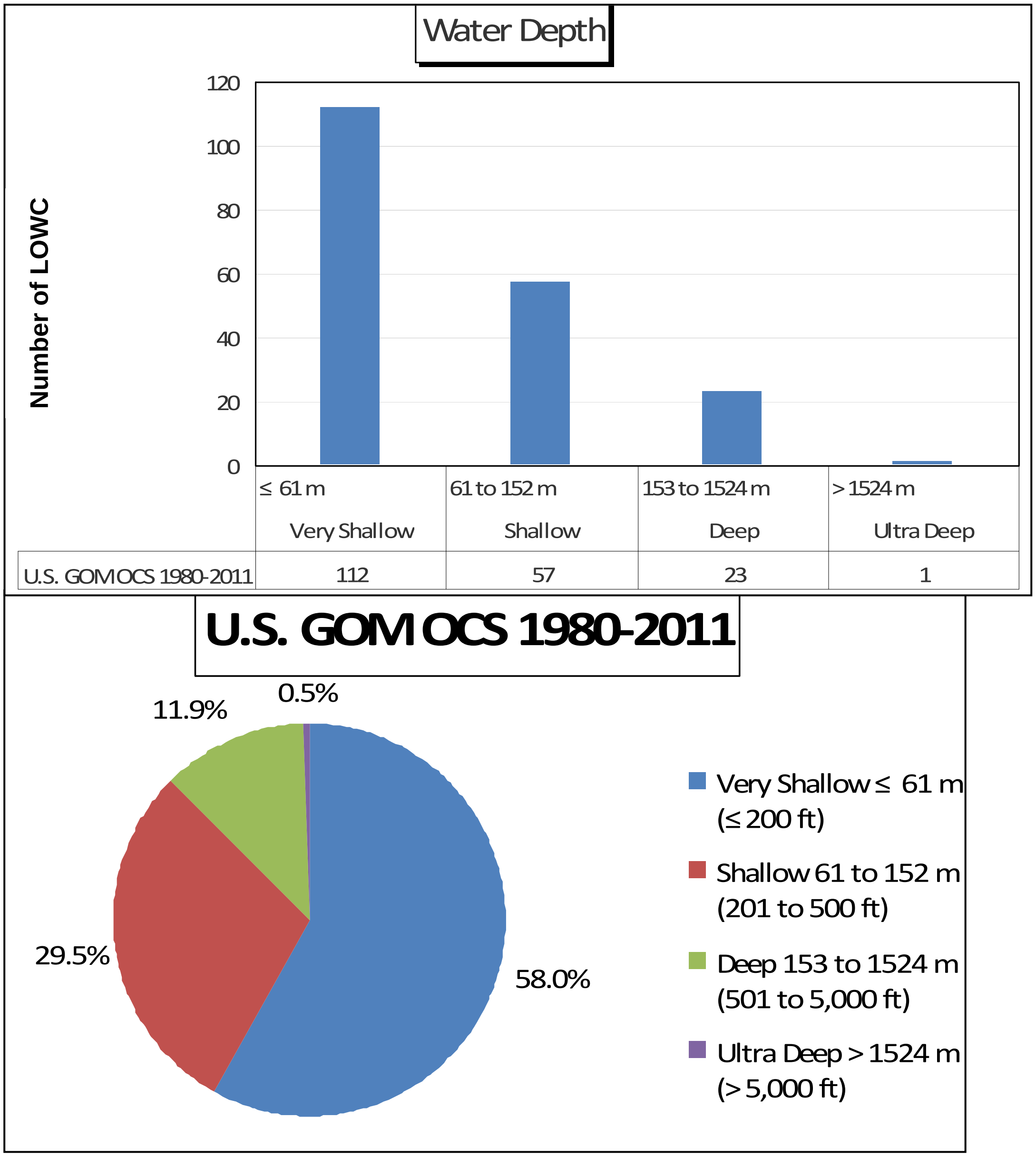


Figure 3.8: U.S. GOM Offshore Water Depth Range LOWC Incident Distribution Graphs

3.6 U.S. Pacific OCS (PAC) LOWC Characteristics

A paucity of data, both in BOEM and SINTEF for LOWC incidents exists for the U.S. Pacific OCS (PAC). Only well drilling information is available from SINTEF. This drilling exposure, for exploration wells and development wells is summarized in Table 3.6.

Table 3.6: OCS 1980-2011 Exposure - Drilling

Year	Exploration Wells	Development Wells	All Drilling Wells
1980	10	40	50
1981	14	50	64
1982	27	58	85
1983	38	44	82
1984	19	45	64
1985	6	39	45
1986	5	34	39
1987	4	39	43
1988	3	29	32
1989	4	15	19
1990		17	17
1991		8	8
1992		5	5
1993		21	21
1994		25	25
1995		19	19
1996		31	31
1997		29	29
1998		19	19
1999		11	11
2000		13	13
2001		16	16
2002		21	21
2003		18	18
2004		20	20
2005		23	23
2006		17	17
2007		12	12
2008		5	5
2009		7	7
2010		8	8
2011		7	7
Total 1980-2011	130	745	875

Offshore drilling and hydrocarbon production off the U.S. Pacific coast has occurred predominantly off the coast of the County of Santa Barbara. The Santa Barbara oil spill created by a blowout on January 28, 1969 on Union Oil Platform A is estimated to have released 80,000 to 100,000 bbl of crude oil at a location 10 km from the coast. Although there were many regulatory and legal consequences for this and other spills [57], on the Pacific OCS, the data in Table 3.7 reflects the moratorium on new leases established in 1981, showing a rapid decrease in exploration drilling to zero wells in 1990.

Table 3.7: PAC Region LOWC Frequencies Summary

California OCS Wells 1980-2011	Oil Production		Gas/Condensate Production		All Production		Well Interventions		Exploration Drilling		Development Drilling		All Drilling	
	Estimated 3,837		Estimated 3,837		Estimated 7,674		Estimated 7,674		130		745		875	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)							1	1.34E-04						
Blowout (underground flow)														
Blowout Total							1	1.34E-04						
Well Release							3	4.03E-04						
Diverted Well Release											1	1.34E-03	1	1.14E-03
Well Release Total							3	4.03E-04			1	1.34E-03	1	1.14E-03
TOTAL							4	5.37E-04			1	1.34E-03	1	1.14E-03

SINTEF does not report on the number of wells in production in the PAC region. However, the ratios of development drilling to producing well-years evaluated in Table 2.6 can be used to give an approximate exposure and frequencies are shown in Table 3.7. Basically, from Table 2.6, the total number of production well-years is equal to 10.3 times the number of development wells drilled; and the number of oil versus gas producers is 50% of the production well years. As can be seen, the largest number of LOWCs occurred during well interventions, but because of the large number of well-years of exposure, LOWC frequencies result in a relatively low value per year.

CHAPTER 4

NORTH SEA STATISTICS

4.1 General Description of North Sea LOWC Statistics

This chapter is intended to provide a comprehensive set of statistics and characteristic descriptions for LOWC events in the North Sea, which consists of the United Kingdom (UK) and Norwegian sectors. Following production of North Sea results, some details on the UK and Norwegian sectors *per se* are also given. The results are based on the SINTEF data [46] covering the period from 1980 to 2011.

This chapter covers the following principal areas:

- North Sea exposure
- North Sea LOWC frequency characteristics
- North Sea LOWC durations
- North Sea LOWC water depth distribution
- Selected statistics for UK and Norwegian sectors

4.2 North Sea LOWC Exposure

The exposure for the North Sea and other regions was briefly summarized in Section 2.2.2. In the period from 1980 to 2011, a total of 4,553 exploration wells and 9,174 development wells were drilled in the North Sea, with a total of 59,141 production well-years for the period. Figure 4.1 graphically illustrates the variation in the number of wells of each type drilled annually for the subject period, while Figure 4.2 graphically illustrates the number of wells in production annually for the subject period. Statistics generated in the balance of this chapter are based on the above exposure.

4.3 North Sea LOWC Frequency Characteristics

The characteristics considered in this section include general drilling and production LOWC frequencies, details of drilling LOWC frequency characteristics, and the statistical variability of the frequency statistics developed.

Table 4.1 summarizes the general statistics associated with the general North Sea LOWC frequencies. As can be seen, the events considered are surface blowouts and underground blowouts, and other well releases – in accordance with the definition provided in Chapter 1, Section 1.4. These occurrences are considered for production wells and well drilling. Statistics for production wells are given per well-year, for both oil producers and gas and/or condensate producers. A separate category of LOWCs is given for well interventions. Drilling is given for exploration drilling and development drilling, as well as their summary. All well drilling statistics are based on a frequency per well drilled.

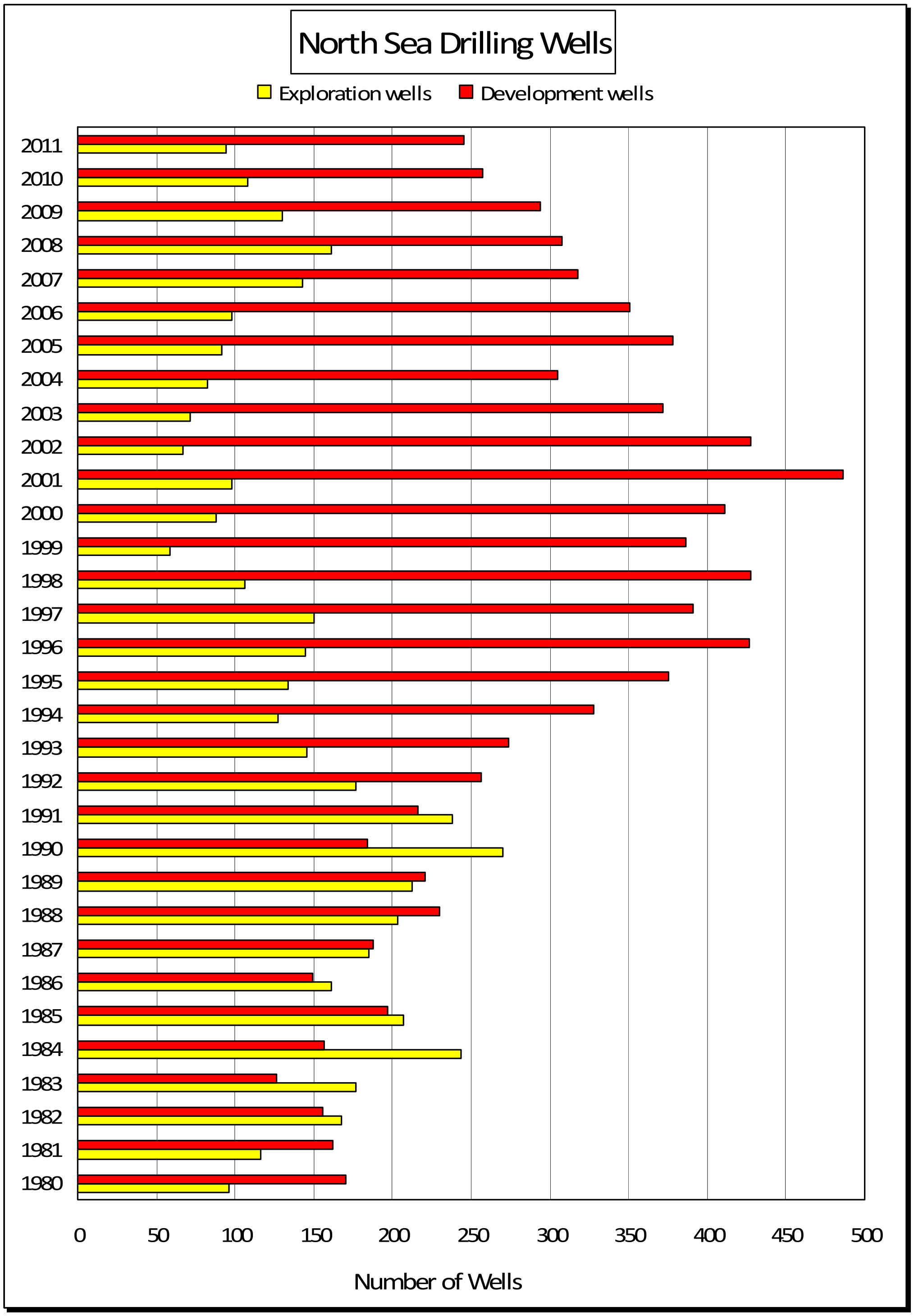


Figure 4.1: North Sea Annual Well Drilling Exposure

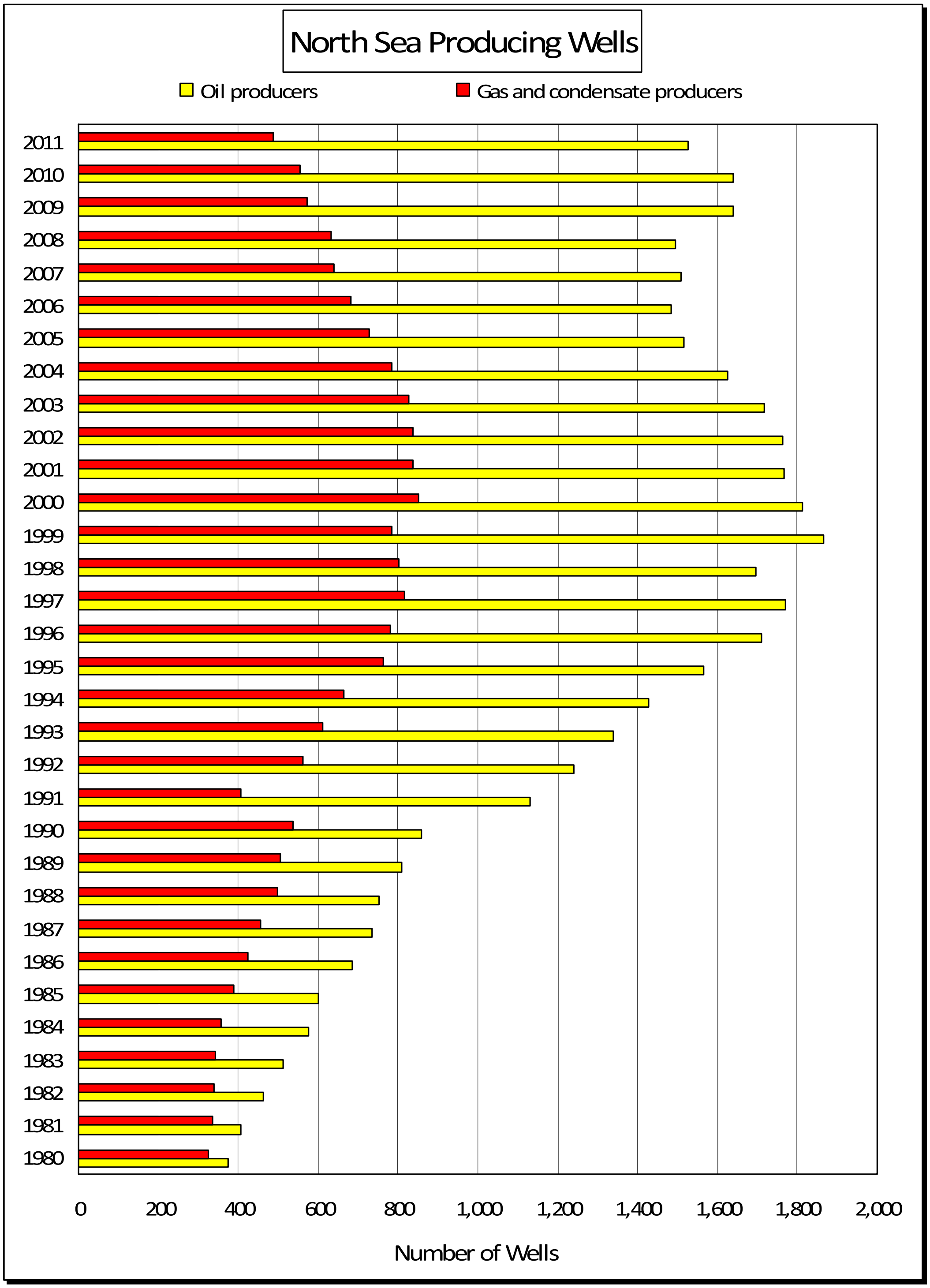


Figure 4.2: North Sea Annual Producing Well Exposure

Table 4.1: North Sea LOWC Frequency Summary (1980 - 2011)

North Sea Wells 1980-2011	Oil Production		Gas/Condensate Production		All Production		Well Interventions		Exploration Drilling		Development Drilling		All Drilling	
	40,004		19,137		59,141		59,141		4,553		9,174		13,727	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	1	2.50E-05	1	5.23E-05	2	3.38E-05	4	6.76E-05	16	3.51E-03	4	4.36E-04	20	1.46E-03
Blowout (underground flow)									4	8.79E-04			4	2.91E-04
Blowout Total	1	2.50E-05	1	5.23E-05	2	3.38E-05	4	6.76E-05	20	4.39E-03	4	4.36E-04	24	1.75E-03
Well Release			1	5.23E-05	1	1.69E-05	17	2.87E-04	8	1.76E-03	5	5.45E-04	13	9.47E-04
Diverted Well Release									4	8.79E-04			4	2.91E-04
Well Release Total			1	5.23E-05	1	1.69E-05	17	2.87E-04	12	2.64E-03	5	5.45E-04	17	1.24E-03
TOTAL	1	2.50E-05	2	1.05E-04	3	5.07E-05	21	3.55E-04	32	7.03E-03	9	9.81E-04	41	2.99E-03

Table 4.2 gives further details of the well drilling statistics. It is important to separate out shallow gas LOWCs from other or deep well drilling LOWCs. The reason for this is that by definition, under SINTEF, shallow gas drilling occurs when the surface hole is drilled without a BOP. The exposure for shallow gas drilling is the same as that for all drilling, because all offshore wells are initiated by shallow drilling prior to the surface completion and installation of a BOP. One can see that shallow gas drilling frequencies tend to be somewhat higher than other or deeper well drilling with BOP activities.

Table 4.2: North Sea LOWC Drilling Frequency Details (1980 - 2011)

North Sea Wells 1980-2011	Exploration Drilling						Development Drilling						All Drilling					
	Shallow Gas		Other		All		Shallow Gas		Other		All		Shallow Gas		Other		All	
	4,553		4,553		4,553		9,174		9,174		9,174		13,727		13,727		13,727	
	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	15	3.29E-03	1	2.20E-04	16	3.51E-03	4	4.36E-04			4	4.36E-04	19	1.38E-03	1	7.28E-05	20	1.46E-03
Blowout (underground flow)			4	8.79E-04	4	8.79E-04									4	2.91E-04	4	2.91E-04
Blowout Total	15	3.29E-03	5	1.10E-03	20	4.39E-03	4	4.36E-04			4	4.36E-04	19	1.38E-03	5	3.64E-04	24	1.75E-03
Well Release	2	4.39E-04	6	1.32E-03	8	1.76E-03	1	1.09E-04	4	4.36E-04	5	5.45E-04	3	2.19E-04	10	7.28E-04	13	9.47E-04
Diverted Well Release	4	8.79E-04			4	8.79E-04							4	2.91E-04			4	2.91E-04
Well Release Total	6	1.32E-03	6	1.32E-03	12	2.64E-03	1	1.09E-04	4	4.36E-04	5	5.45E-04	7	5.10E-04	10	7.28E-04	17	1.24E-03
TOTAL	21	4.61E-03	11	2.42E-03	32	7.03E-03	5	5.45E-04	4	4.36E-04	9	9.81E-04	26	1.89E-03	15	1.09E-03	41	2.99E-03

Finally, Table 4.3 gives the variability for the blowout and well release frequencies which were given as average values in Table 4.1. The variability calculations are based on those presented by Holand [35], indicating the upper and lower 90% confidence intervals for the value based on a Chi Square distribution [47]. Thus, for example, for exploration drilling, the expected or mean value is 4.39E-03, with an upper 90% confidence interval of 6.12E-03 and a lower 90% confidence interval of 2.91E-03. The same applies to the other values indicating the variability of the statistics presented. Figures 4.3 and 4.4 graphically show this variability for production and drilling blowouts, respectively. These figures also present the tabular values for convenience.

Table 4.3: North Sea LOWC Frequency Variability

North Sea Wells 1980-2011	Blowout Frequency per Well-Year			Well Release Frequency per Well-Year		
	High	Low	Expected	High	Low	Expected
Oil Production	7.49E-05	1.28E-06	2.50E-05	0	0	0
Gas/Condensate Production	1.57E-04	2.68E-06	5.23E-05	1.57E-04	2.68E-06	5.23E-05
All Production	8.02E-05	6.01E-06	3.38E-05	5.07E-05	8.67E-07	1.69E-05
Well Interventions	1.31E-04	2.31E-05	6.76E-05	4.11E-04	1.83E-04	2.87E-04
North Sea Wells 1980-2011	**Blowout Frequency per Well**			**Well Release Frequency per Well**		
	High	Low	Expected	High	Low	Expected
Exploration Drilling	6.12E-03	2.91E-03	4.39E-03	4.00E-03	1.52E-03	2.64E-03
Development Drilling	8.45E-04	1.49E-04	4.36E-04	9.98E-04	2.15E-04	5.45E-04
All Drilling	2.37E-03	1.21E-03	1.75E-03	1.77E-03	7.89E-04	1.24E-03

Note: 90% confidence that Frequency is in the Low-High Interval
Reference: Offshore Blowouts, Per Holand (page 132)

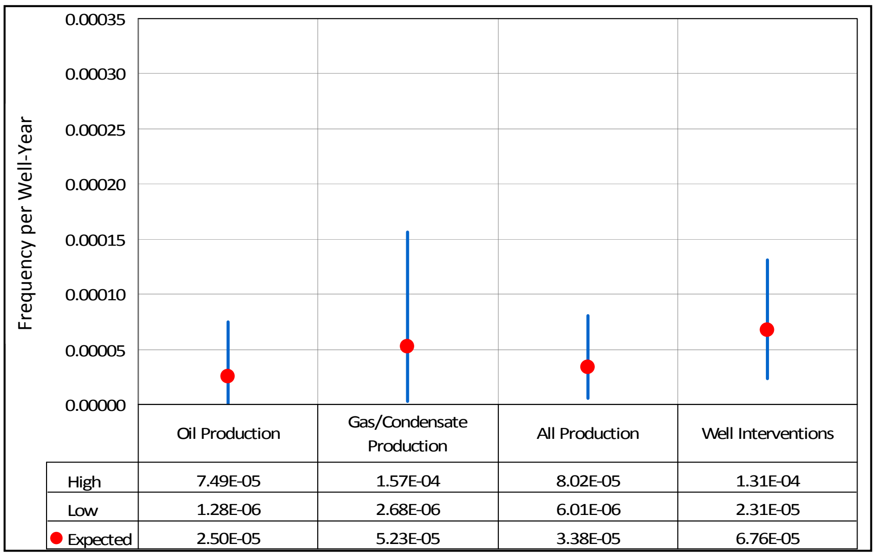


Figure 4.3: Blowout – North Sea Production Variability (1980-2011)

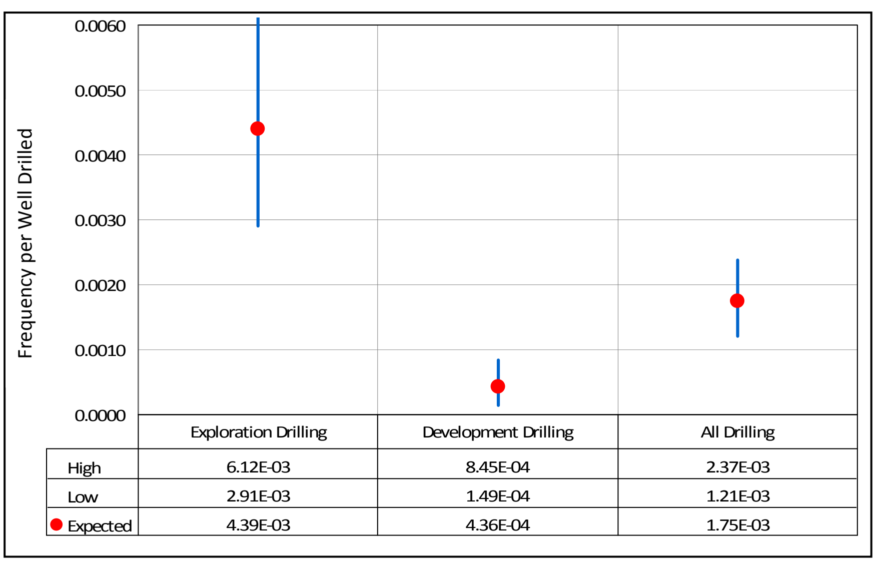


Figure 4.4: Blowout – North Sea Drilling Variability (1980-2011)

4.4 North Sea LOWC Duration

Duration of well control incidents based on the SINTEF data from 1980 to 2011 can be determined. The expected duration is displayed both over the initial period (by minutes, up to 20 minutes) and by the hour up to roughly 20 days. Figure 4.5 shows the initial blowout duration for up to 20 minutes. As can be seen, durations up to 3 minutes account for roughly 50% of LOWC incidents. The longer view, displayed in Figure 4.6 for up to 20 days, indicates that roughly 90% of LOWCs stop within 20 days. Longer duration blowouts, such as Macondo, will be discussed in Chapter 8.

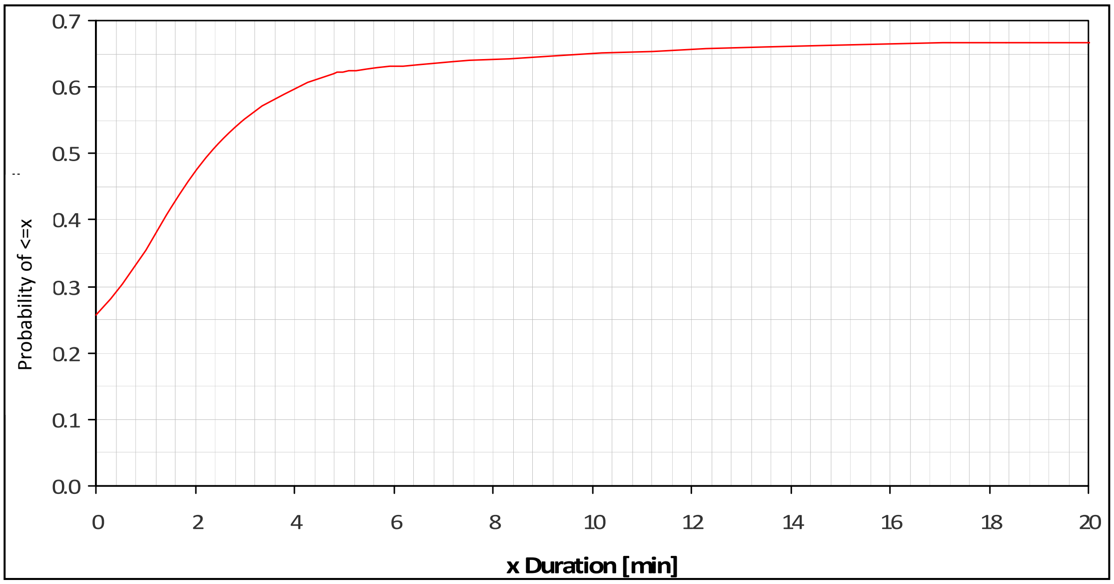


Figure 4.5: North Sea Loss of Well Control – Duration by Minutes

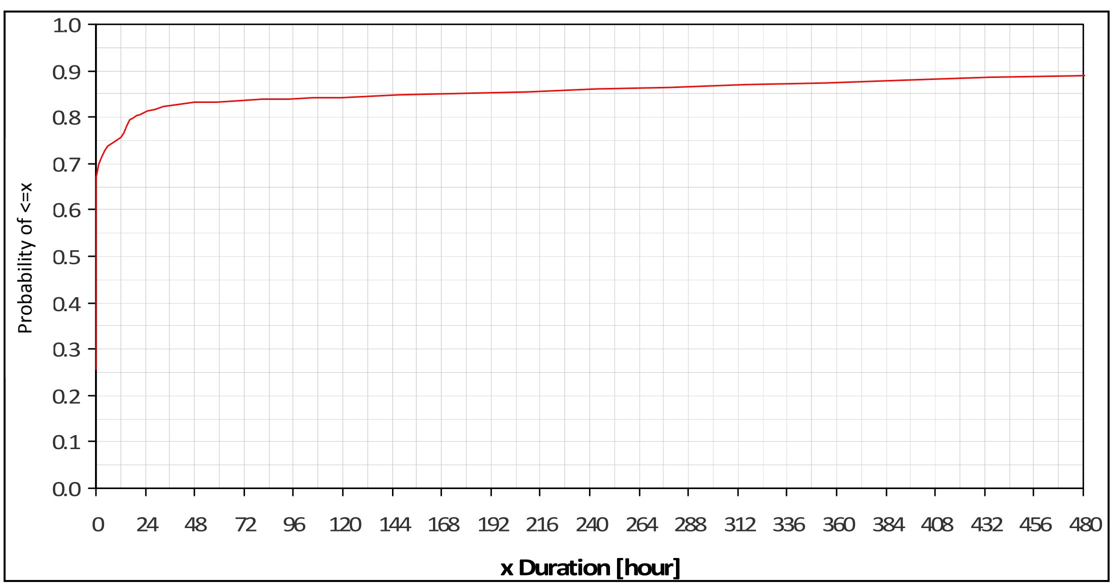


Figure 4.6: North Sea Loss of Well Control – Duration by Hours to 20 Days

4.5 North Sea LOWC Depth Variation

4.5.1 Approach and Water Depth Ranges

The variation of the number of LOWC incidents with water depth in the North Sea was extracted from the SINTEF database. It should be noted that only the number of LOWCs, rather than their rate per exposure unit, was available from the data which only gives the LOWC incidents by water depth without an exposure variable such as number of wells drilled in the subject water depth range; thus, the variable presented in this section is not directly comparable to any of the spill occurrence indicators.

Two water depth ranges were used as described in Section 3.5; namely, the Shelf Range and the Offshore Range.

4.5.2 North Sea Shelf Water Depth Range

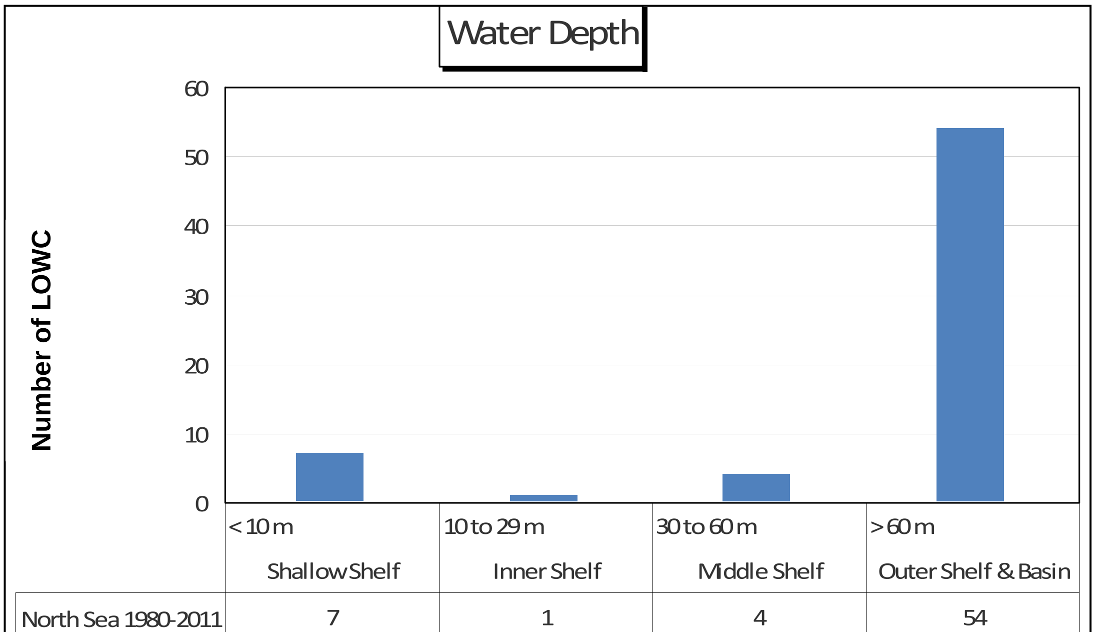
Table 4.4 gives the distribution of number of LOWC incidents in each of the four Shelf water depth ranges. Clearly the maximum number of incidents occurs in the deepest range, over 60m. This trend may indicate either that many more wells are drilled in this range or that the incident rate is higher in this range or both. Figure 4.7 gives a bar graph and a pie chart graphically illustrating these incident number distributions in this range.

4.5.3 North Sea Offshore Water Depth Range

Table 4.5 gives the distribution of number of LOWC incidents in each of the four Offshore water depth ranges. Clearly the maximum number of incidents occurs in the Very Shallow range, under 61m. This trend may indicate either that many more wells are drilled in this range or that the incident rate is higher in this range or both. Figure 4.8 gives a bar graph and a pie chart graphically illustrating these incident number distributions in this range.

Table 4.4: North Sea Shelf Water Depth Range LOWC Incident Distribution

North Sea 1980-2011				
Shallow Shelf	Inner Shelf	Middle Shelf	Outer Shelf and Basin	Total
< 10 m (< 33 ft)	10 to 29 m (33 to 95 ft)	30 to 60 m (95 to 197 ft)	> 60 m (>197 ft)	All
7	1	4	54	66



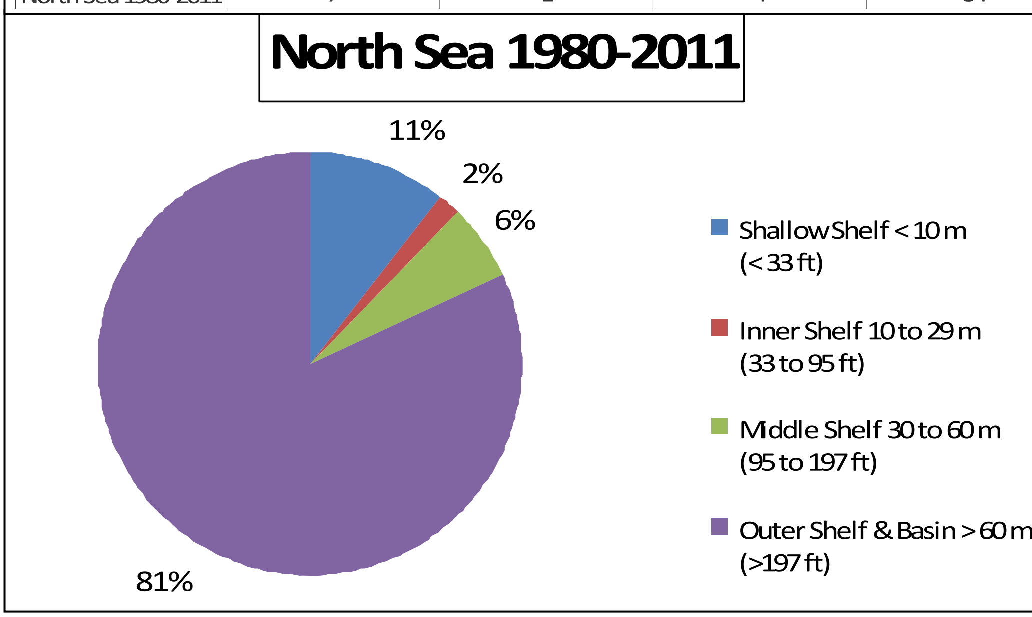
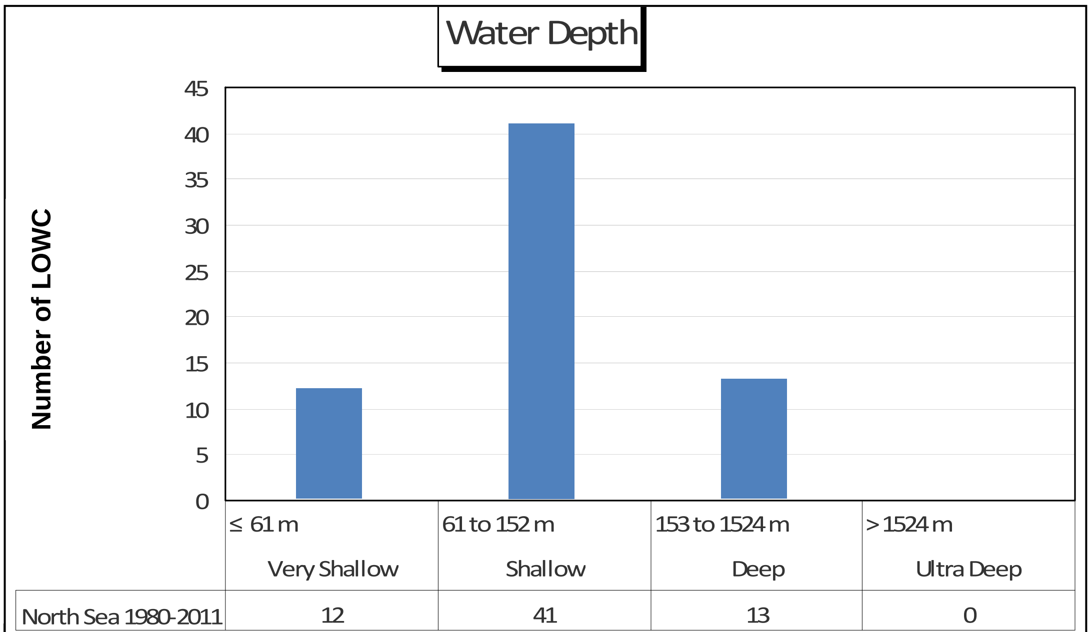


Figure 4.7: North Sea Shelf Water Depth Range LOWC Incident Distribution Graphs

Table 4.5: North Sea Offshore Water Depth Range LOWC Incident Distribution

North Sea 1980-2011				
Very Shallow	Shallow	Deep	Ultra Deep	Total
≤ 61 m (≤ 200 ft)	61 to 152 m (201 to 500 ft)	153 to 1524 m (501 to 5,000 ft)	> 1524 m (> 5,000 ft)	All
12	41	13	0	66



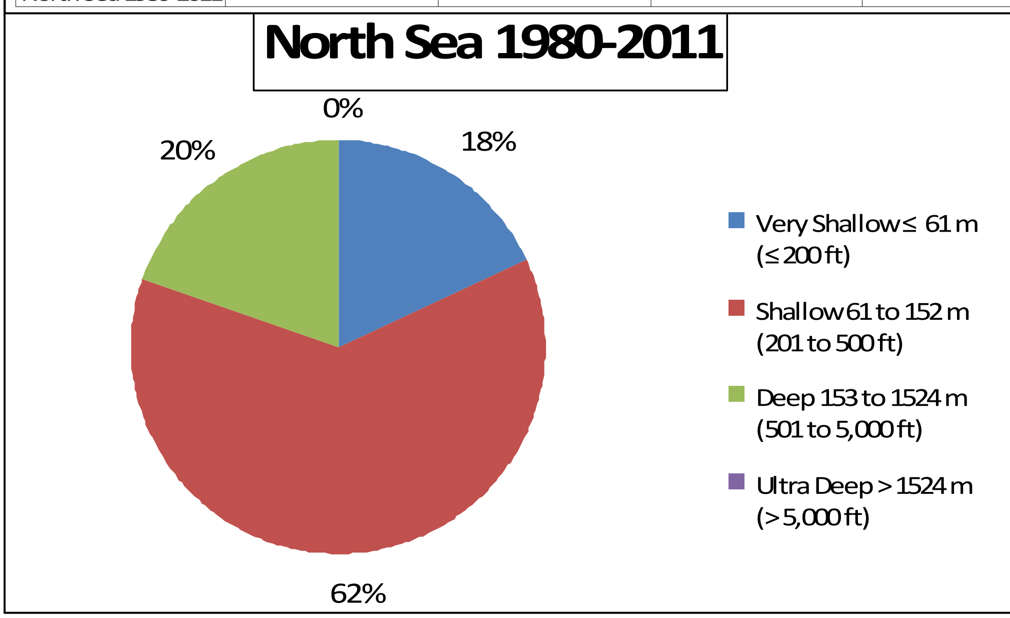


Figure 4.8: North Sea Offshore Water Depth Range LOWC Incident Distribution Graphs

4.6 North Sea UK Sector LOWC Characteristics

Table 4.6 summarizes the UK Sector LOWC statistics, and also provides the measures of exposure.

Table 4.6: UK Sector LOWC Statistics Summary

UK Wells 1980-2011	Oil Production		Gas/Condensate Production		All Production		Well Interventions		Exploration Drilling		Development Drilling		All Drilling	
	23,301		15,807		39,108		39,108		3,302		5,807		9,109	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	1	4.29E-05	1	6.33E-05	2	5.11E-05	3	7.67E-05	6	1.82E-03	3	5.17E-04	9	9.88E-04
Blowout (underground flow)														
Blowout Total	1	4.29E-05	1	6.33E-05	2	5.11E-05	3	7.67E-05	6	1.82E-03	3	5.17E-04	9	9.88E-04
Well Release			1	6.33E-05	1	2.56E-05	14	3.58E-04	1	3.03E-04	3	5.17E-04	4	4.39E-04
Diverted Well Release														
Well Release Total			1	6.33E-05	1	2.56E-05	14	3.58E-04	1	3.03E-04	3	5.17E-04	4	4.39E-04
TOTAL	1	4.29E-05	2	1.27E-04	3	7.67E-05	17	4.35E-04	7	2.12E-03	6	1.03E-03	13	1.43E-03

4.7 North Sea Norwegian Sector LOWC Characteristics

Table 4.7 summarizes the Norwegian Sector LOWC statistics, and also provides the measures of exposure.

Table 4.7: Norwegian Sector LOWC Statistics Summary

Norway Wells 1980-2011	Oil Production		Gas/Condensate Production		All Production		Well Interventions		Exploration Drilling		Development Drilling		All Drilling	
	16,703		3,330		20,033		20,033		1,251		3,367		4,618	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)							1	4.99E-05	10	7.99E-03	1	2.97E-04	11	2.38E-03
Blowout (underground flow)									4	3.20E-03			4	8.66E-04
Blowout Total							1	4.99E-05	14	1.12E-02	1	2.97E-04	15	3.25E-03
Well Release							3	1.50E-04	7	5.60E-03	2	5.94E-04	9	1.95E-03
Diverted Well Release									4	3.20E-03			4	8.66E-04
Well Release Total							3	1.50E-04	11	8.79E-03	2	5.94E-04	13	2.82E-03
TOTAL							4	2.00E-04	25	2.00E-02	3	8.91E-04	28	6.06E-03

CHAPTER 5

U.S. GOM AND NORTH SEA STATISTICS

5.1 General Description of U.S. GOM and North Sea LOWC Statistics

This chapter is intended to provide a comprehensive set of statistics and characteristic descriptions for LOWC events in the U.S. GOM and North Sea. The results are based primarily on the SINTEF data covering the period from 1980 to 2011 [46].

This chapter covers the following principal areas:

- U.S. GOM and North Sea exposure
- U.S. GOM and North Sea LOWC frequency characteristics
- U.S. GOM and North Sea LOWC durations
- U.S. GOM and North Sea LOWC water depth

5.2 U.S. GOM and North Sea LOWC Exposure

The exposure for U.S. GOM and North Sea was briefly summarized in Section 2.2.2. In the period from 1980 to 2011, a total of 16,852 exploration wells and 28,449 development wells were drilled, and a total of 256,862 production well-years accrued in the period. Figure 5.1 graphically illustrates the variation in the number of wells of each type drilled annually for the subject period, while Figure 5.2 graphically illustrates the number of wells in production annually for the subject period. Statistics generated in the balance of this chapter are based on the above exposure.

5.3 U.S. GOM and North Sea LOWC Frequency Characteristics

The characteristics considered in this section include general drilling and production LOWC frequencies, details of drilling LOWC frequency characteristics, and the statistical variability of the frequency statistics developed.

Table 5.1 summarizes the general statistics associated with the general U.S. GOM LOWC frequencies. As can be seen, the events considered are surface blowouts and underground blowouts, and other well releases – in accordance with the definition provided in Section 1.4. These occurrences are considered for production wells and well drilling. Statistics for production wells are given per well-year, for both oil producers and gas and/or condensate producers. A separate category of LOWCs for event categories is given for well intervention. Drilling, again for the same event categories, is given for exploration drilling and development drilling, as well as their summary. All well drilling statistics are based on a frequency per well drilled.

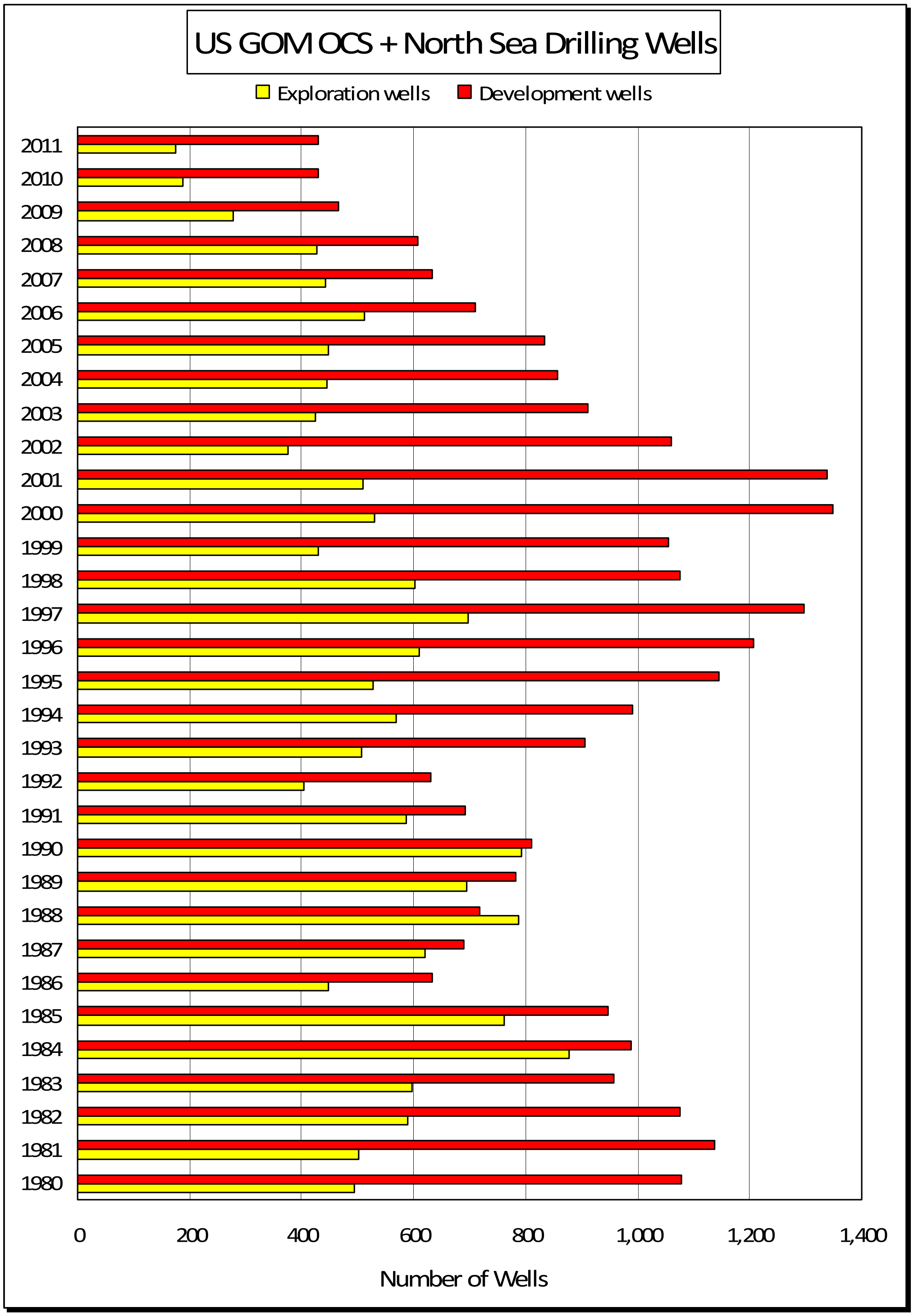


Figure 5.1: U.S. GOM and North Sea Annual Well Drilling Exposure

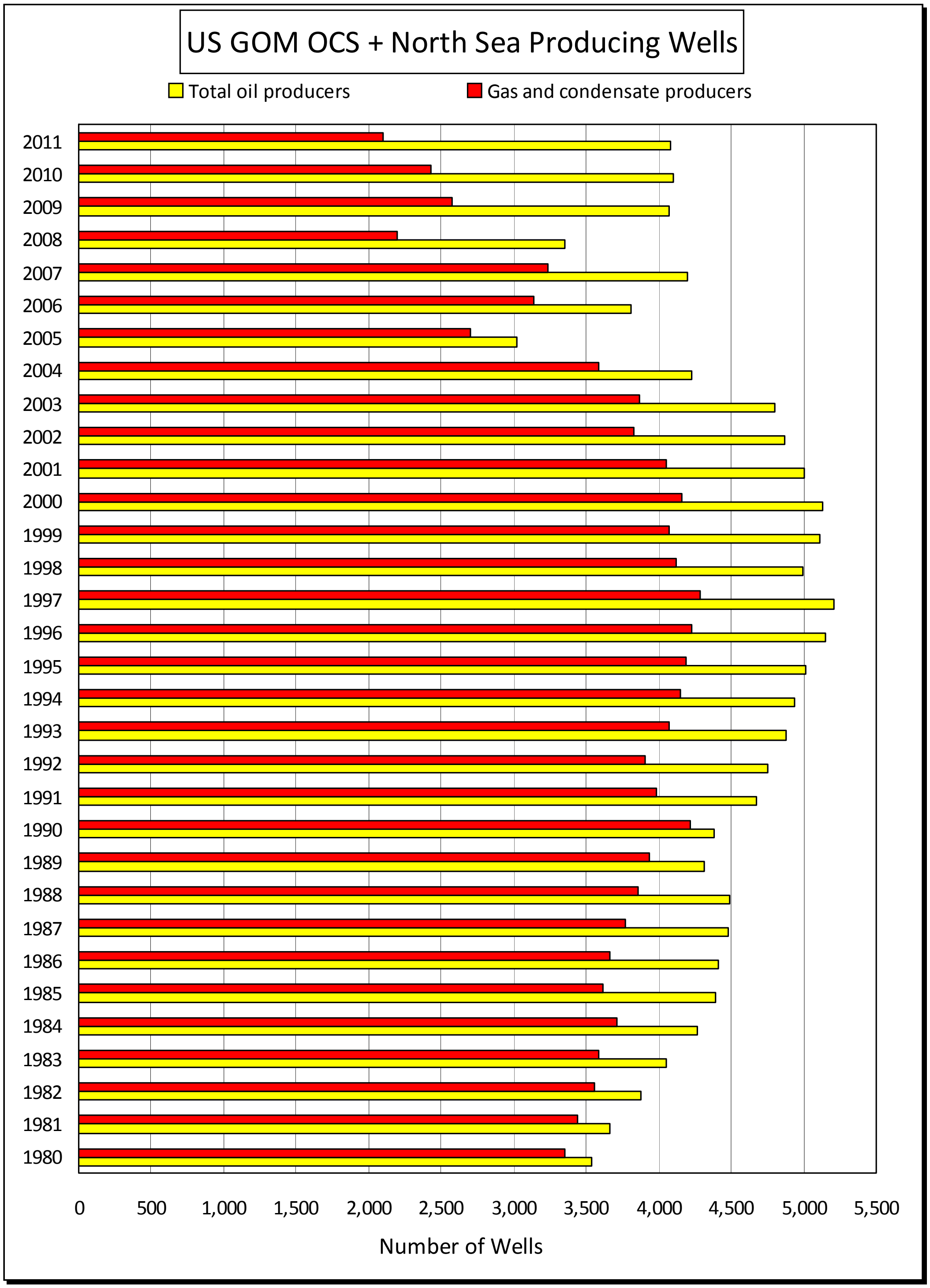


Figure 5.2: U.S. GOM and North Sea Annual Producing Well Exposure

Table 5.1: U.S. GOM and North Sea LOWC Frequency Summary

U.S. GOM OCS + North Sea Wells 1980-2011	Oil Production		Gas/Condensate Production		All Production		Well Interventions		Exploration Drilling		Development Drilling		All Drilling	
	141,266		115,596		256,862		256,862		16,852		28,449		45,301	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	10	7.08E-05	8	6.92E-05	18	7.01E-05	38	1.48E-04	56	3.32E-03	32	1.12E-03	88	1.94E-03
Blowout (underground flow)	1	7.08E-06			1	3.89E-06	1	3.89E-06	8	4.75E-04	5	1.76E-04	13	2.87E-04
Blowout Total	11	7.79E-05	8	6.92E-05	19	7.40E-05	39	1.52E-04	64	3.80E-03	37	1.30E-03	101	2.23E-03
Well Release	1	7.08E-06	4	3.46E-05	5	1.95E-05	43	1.67E-04	9	5.34E-04	8	2.81E-04	17	3.75E-04
Diverted Well Release							1	3.89E-06	13	7.71E-04	19	6.68E-04	32	7.06E-04
Well Release Total	1	7.08E-06	4	3.46E-05	5	1.95E-05	44	1.71E-04	22	1.31E-03	27	9.49E-04	49	1.08E-03
TOTAL	12	8.49E-05	12	1.04E-04	24	9.34E-05	83	3.23E-04	86	5.10E-03	64	2.25E-03	150	3.31E-03

Table 5.2 gives further details of the LOWC statistics. It is important to separate out shallow gas LOWCs from other or deep well drilling LOWCs. The reason for this is that by definition, under SINTEF, shallow gas drilling occurs when the surface hole is drilled without a BOP. The exposure for shallow gas drilling is the same as that for all drilling, because all offshore wells are initiated by shallow drilling prior to the surface completion and installation of a BOP. One can see that shallow gas drilling frequencies tend to be somewhat higher than other or deeper well drilling with BOP activities.

Table 5.2: U.S. GOM and North Sea LOWC Drilling Frequency Details

U.S. GOM OCS + North Sea Wells 1980-2011	Exploration Drilling						Development Drilling						All Drilling					
	Shallow Gas		Other		All		Shallow Gas		Other		All		Shallow Gas		Other		All	
	16,852		16,852		16,852		28,449		28,449		28,449		45,301		45,301		45,301	
	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	32	1.90E-03	24	1.42E-03	56	3.32E-03	21	7.38E-04	11	3.87E-04	32	1.12E-03	53	1.17E-03	35	7.73E-04	88	1.94E-03
Blowout (underground flow)			8	4.75E-04	8	4.75E-04	1	3.52E-05	4	1.41E-04	5	1.76E-04	1	2.21E-05	12	2.65E-04	13	2.87E-04
Blowout Total	32	1.90E-03	32	1.90E-03	64	3.80E-03	22	7.73E-04	15	5.27E-04	37	1.30E-03	54	1.19E-03	47	1.04E-03	101	2.23E-03
Well Release	2	1.19E-04	7	4.15E-04	9	5.34E-04	2	7.03E-05	6	2.11E-04	8	2.81E-04	4	8.83E-05	13	2.87E-04	17	3.75E-04
Diverted Well Release	12	7.12E-04	1	5.93E-05	13	7.71E-04	19	6.68E-04			19	6.68E-04	31	6.84E-04	1	2.21E-05	32	7.06E-04
Well Release Total	14	8.31E-04	8	4.75E-04	22	1.31E-03	21	7.38E-04	6	2.11E-04	27	9.49E-04	35	7.73E-04	14	3.09E-04	49	1.08E-03
TOTAL	46	2.73E-03	40	2.37E-03	86	5.10E-03	43	1.51E-03	21	7.38E-04	64	2.25E-03	89	1.96E-03	61	1.35E-03	150	3.31E-03

Finally, Table 5.3 gives the variability for the blowout and well release frequencies which were given as average values in Table 5.1. The variability calculations are based on those presented by Holand [35], indicating the upper and lower 90% confidence intervals for the value based on a Chi Square distribution [47]. Thus, for example, for exploration drilling, the expected or mean value is 1.31E-03, with an upper 90% confidence interval of 1.79E-03 and a lower 90% confidence interval of 8.84E-03. The same applies to the other values indicating the variability of the statistics presented. Figures 5.3 and 5.4 graphically show this variability for production and drilling blowouts, respectively. These figures also present the tabular values for convenience.

Table 5.3: U.S. GOM and North Sea Blowout Frequency Variability

U.S. GOM OCS + North Sea Wells 1980-2011	Blowout Frequency per Well-Year High	Blowout Frequency per Well-Year Low	Blowout Frequency per Well-Year Expected	Well Release Frequency per Well-Year High	Well Release Frequency per Well-Year Low	Well Release Frequency per Well-Year Expected
Oil Production	1.20E-04	4.37E-05	7.79E-05	2.12E-05	3.63E-07	7.08E-06
Gas/Condensate Production	1.14E-04	3.44E-05	6.92E-05	6.71E-05	1.18E-05	3.46E-05
All Production	1.04E-04	4.84E-05	7.40E-05	3.56E-05	7.67E-06	1.95E-05
Well Interventions	1.94E-04	1.14E-04	1.52E-04	2.05E-04	1.31E-04	1.71E-04
U.S. GOM OCS + North Sea Wells 1980-2011	**Blowout Frequency per Well High**	**Blowout Frequency per Well Low**	**Blowout Frequency per Well Expected**	**Well Release Frequency per Well High**	**Well Release Frequency per Well Low**	**Well Release Frequency per Well Expected**
Exploration Drilling	4.61E-03	3.05E-03	3.80E-03	1.79E-03	8.84E-04	1.31E-03
Development Drilling	1.67E-03	9.70E-04	1.30E-03	1.27E-03	6.70E-04	9.49E-04
All Drilling	2.61E-03	1.88E-03	2.23E-03	1.35E-03	8.41E-04	1.08E-03

Note: 90% confidence that Frequency is in the Low-High Interval
Reference: Offshore Blowouts, Per Holand (page 132).

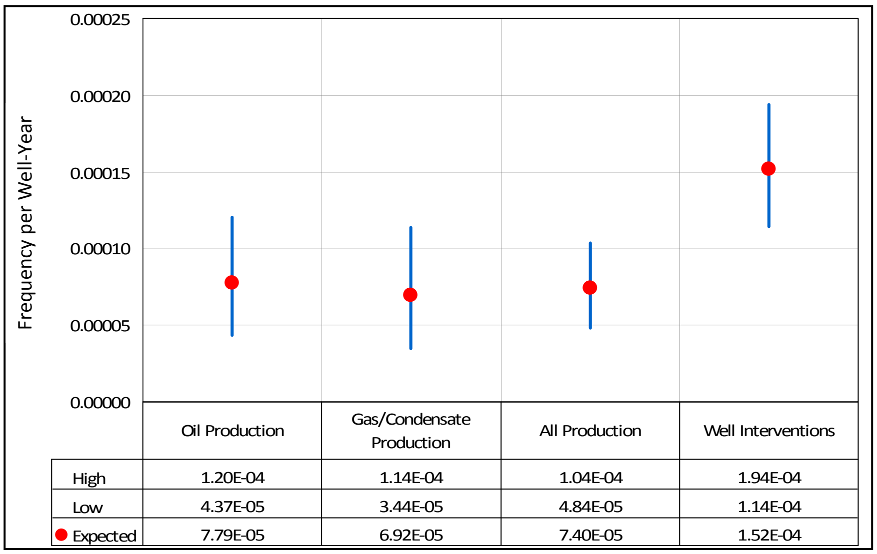


Figure 5.3: Blowout – U.S. GOM OCS and North Sea Production Variability (1980-2011)

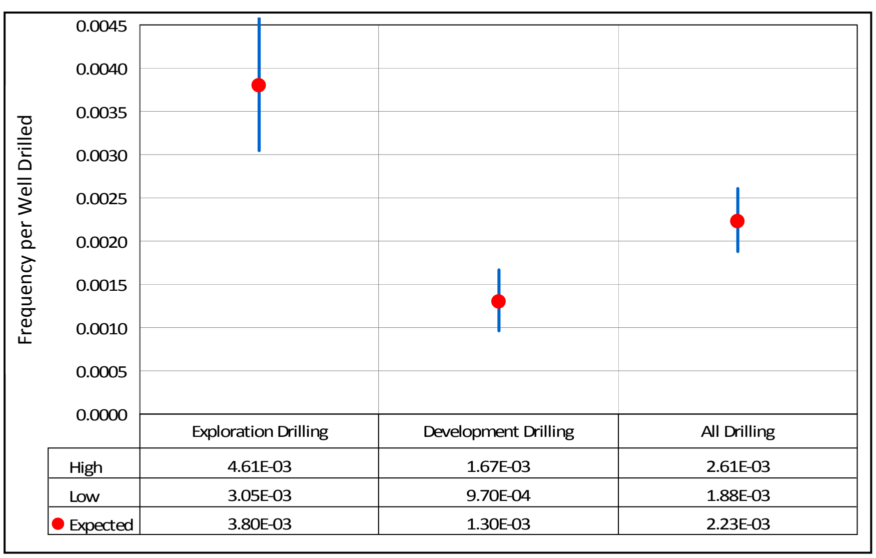


Figure 5.4: Blowout – U.S. GOM OCS and North Sea Drilling Variability (1980-2011)

5.4 U.S. GOM and North Sea LOWC Duration

Duration of well control incidents based on the SINTEF data from 1980 to 2011 can be determined from the SINTEF database. The expected duration is displayed both over the initial hours (by the minute, up to 5 hours) and by the hour up to 20 days (480 hours). Figure 5.5 shows the initial blowout duration for up to 5 hours. As can be seen, durations up to 1.5 hours account for roughly 50% of LOWC incidents. The longer view, displayed in Figure 5.6 for up to 20 days, indicates that roughly 90% of LOWCs stop within 9 days. Longer duration blowouts, such as Macondo, will be discussed in Chapter 8.

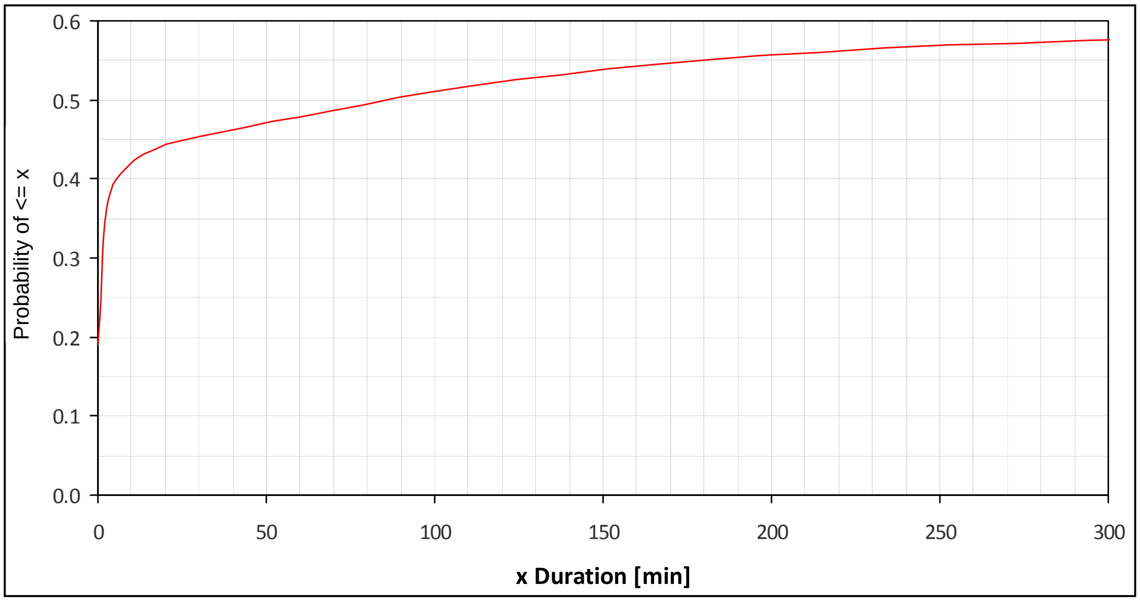


Figure 5.5: U.S. GOM and North Sea Loss of Well Control – Duration by Minutes

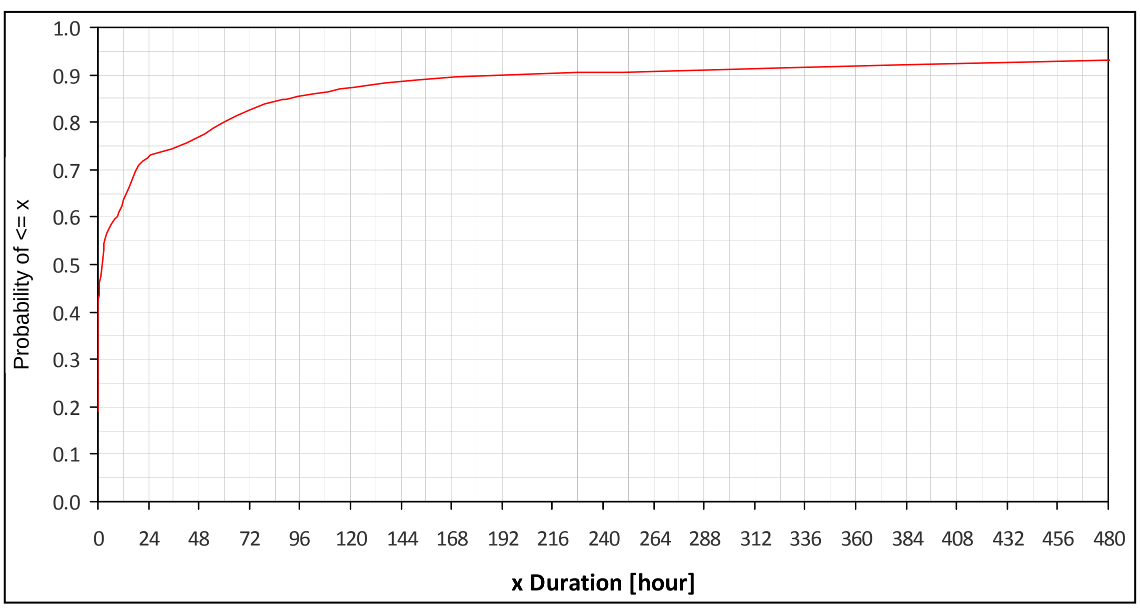


Figure 5.6: U.S. GOM and North Sea Loss of Well Control – Duration by Hours to 20 Days

5.5 U.S. GOM and North Sea LOWC Depth Variation

5.5.1 Approach and Water Depth Ranges

The variation of the number of LOWC incidents with water depth in the U.S. GOM and North Sea was extracted from the SINTEF database. It should be noted that only the number of LOWCs, rather than their rate per exposure unit, was available from the data which only gives the LOWC incidents by water depth without an exposure variable such as number of wells drilled in the subject water depth range; thus, the variable presented in this section is not directly comparable to any of the spill occurrence indicators.

Two water depth ranges were used as described in Section 3.5; namely, the Shelf Range and the Offshore Range.

5.5.2 U.S. GOM and North Sea Shelf Water Depth Range

Table 5.4 gives the distribution of number of LOWC incidents in each of the four Shelf water depth ranges. Clearly the maximum number of incidents occurs in the deepest range, over 60m. This trend may indicate either that many more wells are drilled in this range or that the incident rate is higher in this range or both. Figure 5.7 gives a bar graph and a pie chart graphically illustrating these incident number distributions in this range.

5.5.3 U.S. GOM and North Sea Offshore Water Depth Range

Table 5.5 gives the distribution of number of LOWC incidents in each of the four Offshore water depth ranges. Clearly the maximum number of incidents occurs in the Very Shallow range, under 61m. This trend may indicate either that many more wells are drilled in this range or that the incident rate is higher in this range or both. Figure 5.8 gives a bar graph and a pie chart graphically illustrating these incident number distributions in this range.

Table 5.4: U.S. GOM and North Sea Shelf Water Depth Range LOWC Incident Distribution

U.S. GOM OCS and North Sea 1980-2011				
Shallow Shelf	Inner Shelf	Middle Shelf	Outer Shelf and Basin	Total
< 10 m (< 33 ft)	10 to 29 m (33 to 95 ft)	30 to 60 m (95 to 197 ft)	> 60 m (>197 ft)	All
14	54	55	136	259

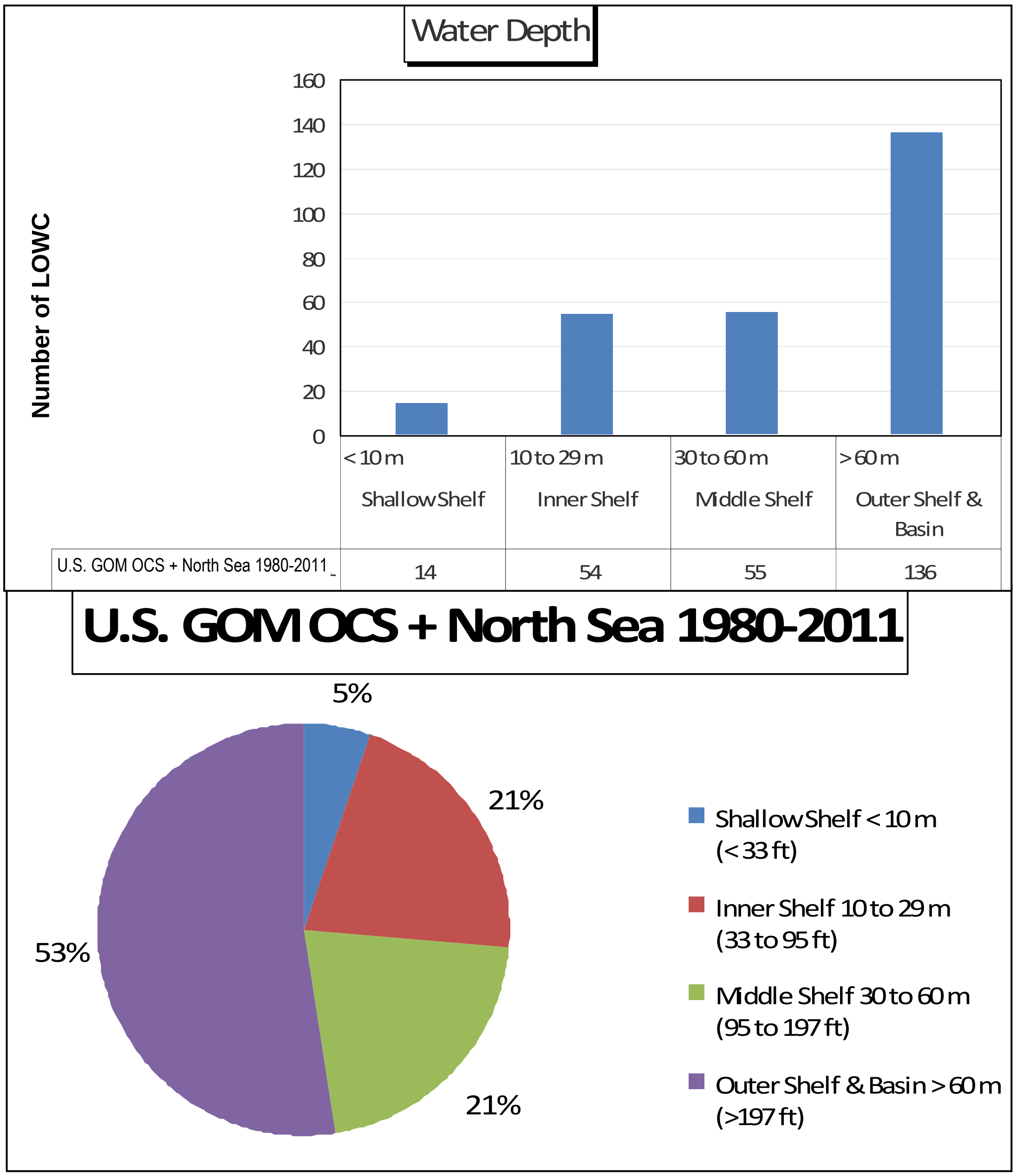
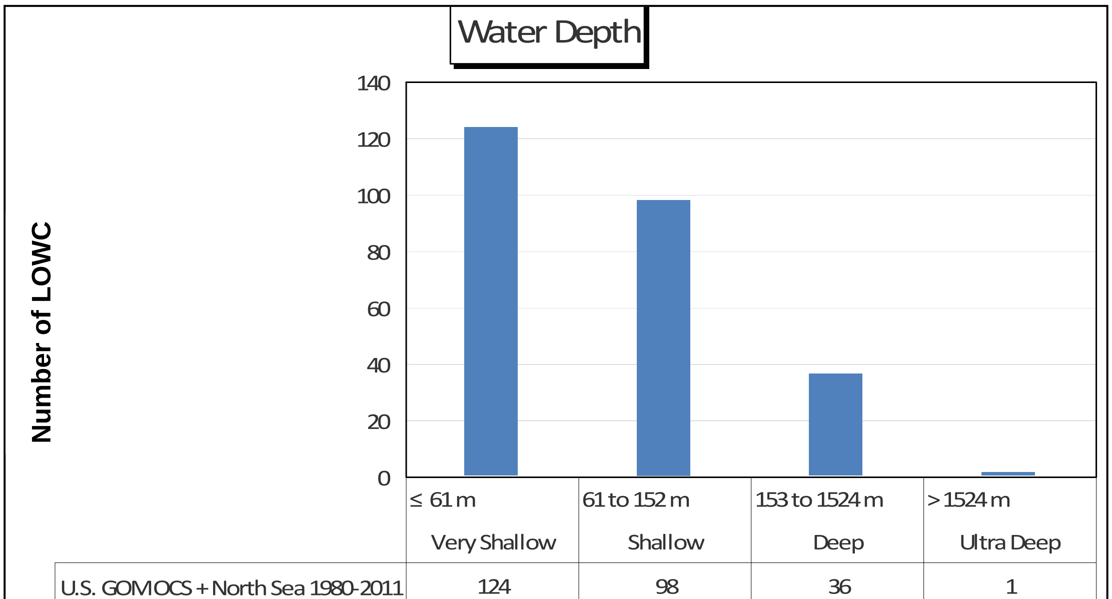


Figure 5.7: U.S. GOM and North Sea Shelf Water Depth Range LOWC Incident Distribution Graphs

Table 5.5: U.S. GOM and North Sea Offshore Water Depth Range LOWC Incident Distribution

U.S. GOM OCS and North Sea 1980-2011				
Very Shallow	Shallow	Deep	Ultra Deep	Total
≤ 61 m (≤ 200 ft)	61 to 152 m (201 to 500 ft)	153 to 1524 m (501 to 5,000 ft)	> 1524 m (> 5,000 ft)	All
124	98	36	1	259



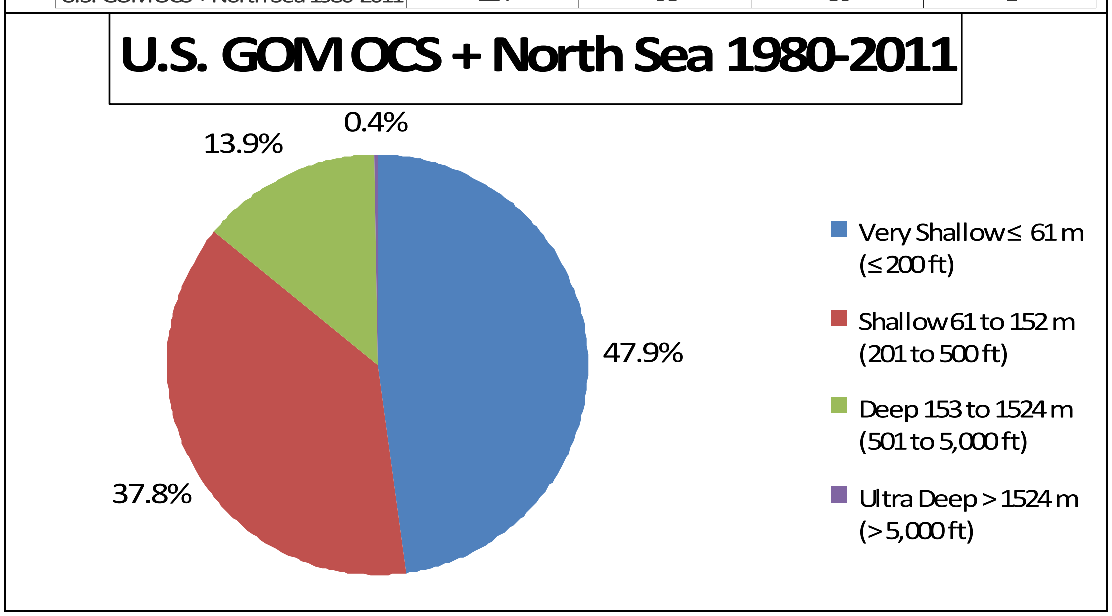


Figure 5.8: U.S. GOM and North Sea Offshore Water Depth Range LOWC Incident Distribution Graphs

CHAPTER 6

AUSTRALIA, HOLLAND AND CANADA STATISTICS

6.1 General Description of Australia, Holland, and Canada Statistics

This chapter is intended to provide an outline of statistics and characteristic descriptions for LOWC events in the Australian, Dutch, and Canadian offshore production regions. The results are based on the SINTEF data covering the period from 1980 to 2011 [46].

SINTEF and other sources only provided the exposure as exploratory and development wells drilled in each year over the period 1980-2011. No production well-years were explicitly given. However, from inspection of other regional data, it was found for this period that the total production well-years are 6 to 10 times the total number of development wells drilled. Also, oil to gas or condensate producers ratios run between 5 and 1.0. Table 6.1 gives details of these ratios for regions with available data.

Table 6.1: Ratios of Production Well-Years to Development Wells Drilled and Oil and Gas Producers (1980-2011)

Region	Oil Producers	Gas/-Cond Producers	Total Producers	Development Wells Drilled	Ratio Producers / Dev Drill	Ratio Oil/Gas Producers	Analogous Regions
U.S. GOM	101,262	96,459	197,721	19,275	10.3	1.0	U.S. PAC, Australia, Canada
UK	23,301	15,807	39,108	5,807	6.7	1.5	Holland, Denmark
Norway	16,703	3,330	20,033	3,367	5.9	5.0	~
TOTAL	141,266	115,596	256,862	33,442	9.0	1.2	~

6.2 Australian LOWC Statistics

Table 6.2 summarizes the general statistics associated with the Australian LOWC frequencies. As can be seen, the events considered are surface blowouts and underground blowouts, and well releases and diverted well releases. These occurrences are considered for production wells and well drilling. Statistics for production wells are given per well-year. These production well statistics are provided for both oil producers and gas and/or condensate producers. A separate category of LOWCs for event categories is given for well intervention. Drilling, again for the same event categories, is given for exploration drilling and development drilling, as well of course, as their summary. All well drilling statistics are based on a frequency per well drilled. Production and well intervention exposures were calculated on the basis of the U.S. GOM data in Table 6.1.

Table 6.2: Australian LOWC General Frequency (1980-2011)

Australian Wells 1980-2011	Oil Production*		Gas / Condensate Production*		All Production*		Well Interventions*		Exploration Drilling		Development Drilling		All Drilling	
	4,795		4,795		9,589		9,589		1,628		931		2,559	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	1	2.09E-04							1	6.14E-04	1	1.07E-03	2	7.82E-04
Blowout (underground flow)									2	1.23E-03			2	7.82E-04
Blowout Total	1	2.09E-04							3	1.84E-03	1	1.07E-03	4	1.56E-03
Well Release														
Diverted Well Release														
Well Release Total														
TOTAL	1	2.09E-04				1.04E-04			3	1.84E-03	1	1.07E-03	4	1.56E-03

* Estimated from U.S. GOM, Table 6.1

6.3 Dutch LOWC Statistics

Table 6.3 summarizes the general statistics associated with the Dutch LOWC frequencies. As can be seen, the events considered are surface blowouts and underground blowouts, and well releases and diverted well releases. These occurrences are considered for production wells and well drilling. Statistics for production wells are given per well-year. These production well statistics are provided for both oil producers and gas and/or condensate producers. A separate category of LOWCs for event categories is given for well intervention. Drilling, again for the same event categories, is given for exploration drilling and development drilling, as well of course, as their summary. All well drilling statistics are based on a frequency per well drilled. Production and well intervention exposures were calculated based on the UK data in Table 6.1.

Table 6.3: Dutch LOWC General Frequency (1980-2011)

Dutch Wells 1980-2011	Oil Production*		Gas / Condensate Production*		All Production*		Well Interventions*		Exploration Drilling		Development Drilling		All Drilling	
	1,769		1,179		2,948		2,948		703		440		1,143	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)			1	8.48E-04										
Blowout (underground flow)														
Blowout Total			1	8.48E-04										
Well Release							1	3.39E-04						
Diverted Well Release														
Well Release Total							1	3.39E-04						
TOTAL			1	8.48E-04		3.39E-04	1	3.39E-04						

* Estimated from UK, Table 6.1

6.4 Canadian East Coast LOWC Statistics

Table 6.4 summarizes the general statistics associated with the Canadian LOWC frequencies. As can be seen, the events considered are surface blowouts and underground blowouts, and well releases and diverted well releases. These occurrences are considered for production wells and well drilling. Statistics for production wells are given per well-year. These production well statistics are provided for both oil producers and gas and/or condensate producers. A separate category of LOWCs for event categories is given for well intervention. Drilling, again for the same event categories, is given for exploration drilling and development drilling, as well of course, as their summary. All well drilling statistics are based on a frequency per well drilled. Production and well intervention exposures were calculated based on the GOM data in Table 6.1.

Table 6.4: Canadian East Coast LOWC General Frequency (1980-2011)

Canada East Coast Wells 1980-2011	Oil Production*		Gas / Condensate Production*		All Production*		Well Interventions*		Exploration Drilling		Development Drilling		All Drilling	
	1,978		1,978		3,955		3,955		295		384		679	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)									1	3.39E-03			1	1.47E-03
Blowout (underground flow)									1	3.39E-03			1	1.47E-03
Blowout Total									2	6.78E-03			2	2.95E-03
Well Release														
Diverted Well Release														
Well Release Total														
TOTAL									2	6.78E-03			2	2.95E-03

* Estimated from U.S. GOM, Table 6.1

CHAPTER 7

LOWC FREQUENCY REGIONAL AND TEMPORAL COMPARISONS

7.1 Approach to Comparisons

Having presented the LOWC frequency characteristics for several different regions from the SINTEF database [46], primarily for the same period from 1980 to 2010 or 2011, the logical questions that arise are: How do the LOWC characteristics vary from region to region? *and* How do they vary for different periods or epochs during the data gathering period? Accordingly, the following areas are discussed in successive sections in this chapter:

- Regional exposure.
- LOWC principal characteristic variation for U.S. GOM and North Sea regions.
- Regional and temporal LOWC detailed comparisons.
- Shallow and deep drilling LOWC characteristic comparisons.

7.2 Regional Exposure

The SINTEF database contains a variety of quantitative characterizations of LOWC events for a variety of regions. Table 7.1 summarizes the regions for which LOWC characteristics, at different levels of detail, are provided in SINTEF. Note that the quantities in bold italics were derived utilizing the ratios of development wells drilled to producing well years (described earlier in Table 6.1), together with the corresponding ratios of oil to gas producers. Ratios chosen were those from the U.S. GOM for all but the Dutch and Danish regions, which were based on the UK. As can be seen, only the first three regions are fully characterized by data. Essentially, this comes down to the U.S. GOM OCS and the UK and Norway regions, which together constitute the North Sea region. Accordingly, in the balance of this chapter, it is the U.S. GOM and the North Sea regions that are used in the comparisons provided.

7.3 LOWC Principal Characteristic Variation for U.S. and North Sea Regions

Table 7.2 gives the principal LOWC frequency comparisons for the principal categories of well operations, including oil production, gas or condensate production, and exploration and development drilling. It should be noted that well interventions, which apply to both drilling and production, have not been included – although well interventions are considered in the subsequent chapter, which provides quantitative estimates of hydrocarbon spill characteristics.

As can be seen, in Table 7.2 and the accompanying bar chart (Figure 7.1), there is notable variation between U.S. GOM LOWC characteristics and North Sea LOWC characteristics. Generally speaking, for oil production, the LOWC frequencies for the GOM are roughly four times as high as those for the North Sea LOWC. For gas production, however, the frequencies are roughly the same. For drilling, a somewhat different trend is apparent, the exploratory drilling LOWC frequencies in the GOM are somewhat lower than those in the North Sea, while the development drilling LOWC frequencies for the GOM are higher than those in the North Sea. The resultant for all drilling is that LOWC frequencies for the GOM and North Sea are roughly the same.

Table 7.1: LOWC and Exposure Information (1980-2011)

Region	Blowouts and Well Releases (LOWC)	LOWC and Exposure Data available in SINTEF and *estimated* (1980-2011)					
		Oil Producing Wells	Gas / Condensate Producing Wells	Total Producing Wells	Exploration Drilling Wells	Development Drilling Wells	Total Drilling Wells
U.S. GOM OCS	193	101,262	96,459	197,721	12,299	19,275	31,574
Norway – North Sea	32	16,703	3,330	20,033	1,251	3,367	4,618
UK – North Sea	34	23,301	15,807	39,108	3,302	5,807	9,109
Australia	5	*4,795*	*4,795*	*9,589*	1,628	931	2,559
U.S. Pacific OCS	4	*3,837*	*3,837*	*7,674*	130	745	875
Canada East Coast	2	*1,978*	*1,978*	*3,955*	295	384	679
Holland	2	*1,769*	*1,179*	*2,948*	703	440	1,143
Denmark	0	*1,829*	*1,219*	*3,049*	214	455	669
U.S. GOM not OCS	28						
U.S. Alaska State	4						
U.S. California State	2						
Indonesia	18						
Mexico	11						
Nigeria	4						
India	8						
U.S.SR	6						
Egypt	7						
Trinidad	4						
Brazil	6						
Azerbaijan	5						
Venezuela	4						
Saudi Arabia	4						
Brunei	2						
China	3						
Dubai	1						
Congo	2						
Other in SINTEF	31						
Total SINTEF and *estimated*	422	155,473	128,604	284,077	19,822	31,404	51,226

Table 7.2: LOWC Frequencies for U.S. GOM and North Sea Regions (1980-2011)

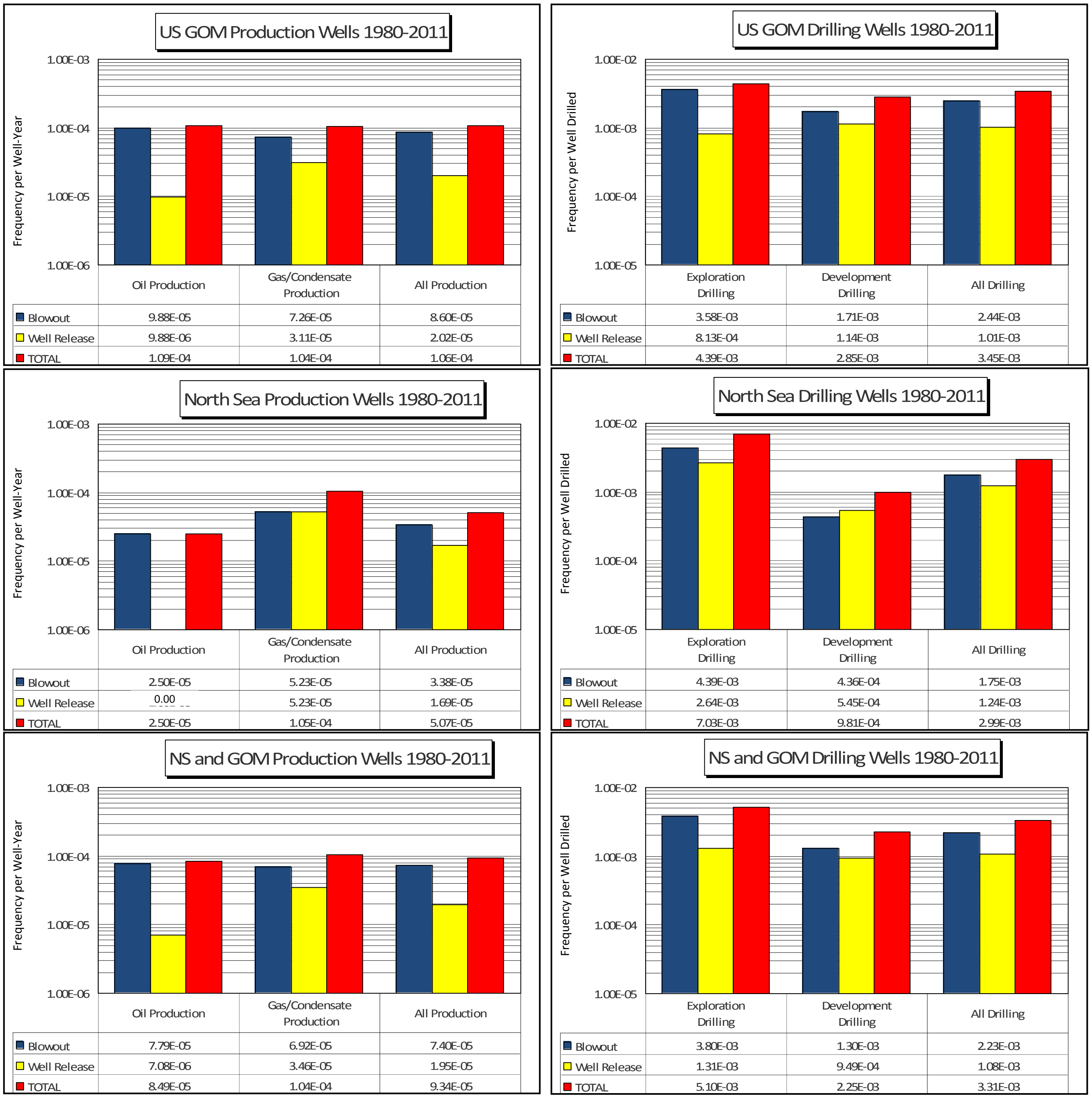
U.S. GOM OCS 1980-2011	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	101,262		96,459		197,721		12,299		19,275		31,574	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout	10	9.88E-05	7	7.26E-05	17	8.60E-05	44	3.58E-03	33	1.71E-03	77	2.44E-03
Well Release	1	9.88E-06	3	3.11E-05	4	2.02E-05	10	8.13E-04	22	1.14E-03	32	1.01E-03
TOTAL	11	1.09E-04	10	1.04E-04	21	1.06E-04	54	4.39E-03	55	2.85E-03	109	3.45E-03

UK 1980-2011	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	23,301		15,807		39,108		3,302		5,807		9,109	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout	1	4.29E-05	1	6.33E-05	2	5.11E-05	6	1.82E-03	3	5.17E-04	9	9.88E-04
Well Release		1.10E-06	1	6.33E-05	1	2.56E-05	1	3.03E-04	3	5.17E-04	4	4.39E-04
TOTAL	1	4.29E-05	2	1.27E-04	3	7.67E-05	7	2.12E-03	6	1.03E-03	13	1.43E-03

Norway 1980-2011	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	16,703		3,330		20,033		1,251		3,367		4,618	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout							14	1.12E-02	1	2.97E-04	15	3.25E-03
Well Release							11	8.79E-03	2	5.94E-04	13	2.82E-03
TOTAL		0.00		0.00		0.00	25	2.00E-02	3	8.91E-04	28	6.06E-03

North Sea (Norway, UK) 1980-2011	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	40,004		19,137		59,141		4,553		9,174		13,727	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout	1	2.50E-05	1	5.23E-05	2	3.38E-05	20	4.39E-03	4	4.36E-04	24	1.75E-03
Well Release			1	5.23E-05	1	1.69E-05	12	2.64E-03	5	5.45E-04	17	1.24E-03
TOTAL	1	2.50E-05	2	1.05E-04	3	5.07E-05	32	7.03E-03	9	9.81E-04	41	2.99E-03

All U.S. GOM OCS + North Sea 1980-2011	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	141,266		115,596		256,862		16,852		28,449		45,301	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout	11	7.79E-05	8	6.92E-05	19	7.40E-05	64	3.80E-03	37	1.30E-03	101	2.23E-03
Well Release	1	7.08E-06	4	3.46E-05	5	1.95E-05	22	1.31E-03	27	9.49E-04	49	1.08E-03
TOTAL	12	8.49E-05	12	1.04E-04	24	9.34E-05	86	5.10E-03	64	2.25E-03	150	3.31E-03



US GOM Production Wells 1980-2011

	Oil Production	Gas/Condensate Production	All Production
Blowout	9.88E-05	7.26E-05	8.60E-05
Well Release	9.88E-06	3.11E-05	2.02E-05
TOTAL	1.09E-04	1.04E-04	1.06E-04

US GOM Drilling Wells 1980-2011

	Exploration Drilling	Development Drilling	All Drilling
Blowout	3.58E-03	1.71E-03	2.44E-03
Well Release	8.13E-04	1.14E-03	1.01E-03
TOTAL	4.39E-03	2.85E-03	3.45E-03

North Sea Production Wells 1980-2011

	Oil Production	Gas/Condensate Production	All Production
Blowout	2.50E-05	5.23E-05	3.38E-05
Well Release	0.00	5.23E-05	1.69E-05
TOTAL	2.50E-05	1.05E-04	5.07E-05

North Sea Drilling Wells 1980-2011

	Exploration Drilling	Development Drilling	All Drilling
Blowout	4.39E-03	4.36E-04	1.75E-03
Well Release	2.64E-03	5.45E-04	1.24E-03
TOTAL	7.03E-03	9.81E-04	2.99E-03

NS and GOM Production Wells 1980-2011

	Oil Production	Gas/Condensate Production	All Production
Blowout	7.79E-05	6.92E-05	7.40E-05
Well Release	7.08E-06	3.46E-05	1.95E-05
TOTAL	8.49E-05	1.04E-04	9.34E-05

NS and GOM Drilling Wells 1980-2011

	Exploration Drilling	Development Drilling	All Drilling
Blowout	3.80E-03	1.30E-03	2.23E-03
Well Release	1.31E-03	9.49E-04	1.08E-03
TOTAL	5.10E-03	2.25E-03	3.31E-03

Figure 7.1: Frequency Graphs: GOM and North Sea (1980-2011)

7.4 Regional and Temporal LOWC Detailed Comparisons

For each of the two principal regions discussed in Section 7.3, the U.S. GOM and the North Sea, the LOWC characteristics over three principal periods were considered; namely, 1980 to 2011, 2001 to 2011, and 1980 to 2000. These three epochs can be considered to roughly represent the entire data collection period (1980-2011), the most recent 10 years (2001 to 2011), and the earlier two decades (1980 to 2000).

Table 7.3 provides LOWC frequency characteristics for the entire data period from 1980 to 2011, Table 7.4 provides these for the most recent 10 years, from 2001 to 2011, and Table 7.5 provides these for the earlier decade from 1980 to 2000.

What is interesting, rather than the regional comparison, is the temporal variation for each of the two principal regions considered, the U.S. GOM and the North Sea. Figure 7.2 shows the three characteristic periods for the U.S. GOM. It is interesting to note, in fact, that in the U.S. GOM, gas/condensate production operations in the most recent decade have higher LOWC rates than those in the earlier two decades from 1980 to 2000, while oil production LOWCs are lower. In the case of U.S. GOM drilling operations, again a similar but much less notable difference is evident between these two epochs. For the North Sea, in case of production, the opposite trend is evident, with zero LOWC events over the recent decade, and a distribution roughly similar to that of the GOM in the earlier two decades. Again, in terms of drilling, the North Sea shows a distinct reduction in LOWC frequencies in the most recent decade over that during the earlier two decades (Figure 7.3).

Finally, Figure 7.4 shows the variation in LOWC frequencies for both regions, the U.S. GOM and the North Sea. Many of the distinct trends that were associated with each region described above, have now been compensated to make the overall regional trend temporal variations closer together, but still distinct. In terms of production, one can see that the more recent gas production has had a higher rate of LOWCs than that of the earlier two decades, while the oil producers show the opposite trend. All production, however, tends to be lower in LOWC frequency for the most recent decade. In the case of drilling, LOWC frequencies are similar for all three epochs, with a slight decrease in the most recent decade.

Table 7.3: Regional LOWC Frequency (1980-2011)

U.S. GOM OCS 1980-2011	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	101,262		96,459		197,721		12,299		19,275		31,574	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	9	8.89E-05	7	7.26E-05	16	8.09E-05	40	3.25E-03	28	1.45E-03	68	2.15E-03
Blowout (underground flow)	1	9.88E-06			1	5.06E-06	4	3.25E-04	5	2.59E-04	9	2.85E-04
Well Release	1	9.88E-06	3	3.11E-05	4	2.02E-05	1	8.13E-05	3	1.56E-04	4	1.27E-04
Diverted Well Release							9	7.32E-04	19	9.86E-04	28	8.87E-04
TOTAL	11	1.09E-04	10	1.04E-04	21	1.06E-04	54	4.39E-03	55	2.85E-03	109	3.45E-03
UK 1980-2011	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	23,301		15,807		39,108		3,302		5,807		9,109	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	1	4.29E-05	1	6.33E-05	2	5.11E-05	6	1.82E-03	3	5.17E-04	9	9.88E-04
Blowout (underground flow)												
Well Release			1	6.33E-05	1	2.56E-05	1	3.03E-04	3	5.17E-04	4	4.39E-04
Diverted Well Release												
TOTAL	1	4.29E-05	2	1.27E-04	3	7.67E-05	7	2.12E-03	6	1.03E-03	13	1.43E-03
Norway 1980-2011	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	16,703		3,330		20,033		1,251		3,367		4,618	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)							10	7.99E-03	1	2.97E-04	11	2.38E-03
Blowout (underground flow)							4	3.20E-03			4	8.66E-04
Well Release							7	5.60E-03	2	5.94E-04	9	1.95E-03
Diverted Well Release							4	3.20E-03			4	8.66E-04
TOTAL		0.00		0.00		0.00	25	2.00E-02	3	8.91E-04	28	6.06E-03
North Sea (Norway, UK) 1980-2011	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	40,004		19,137		59,141		4,553		9,174		13,727	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	1	2.50E-05	1	5.23E-05	2	3.38E-05	16	3.51E-03	4	4.36E-04	20	1.46E-03
Blowout (underground flow)							4	8.79E-04			4	2.91E-04
Well Release			1	5.23E-05	1	1.69E-05	8	1.76E-03	5	5.45E-04	13	9.47E-04
Diverted Well Release							4	8.79E-04			4	2.91E-04
TOTAL	1	2.50E-05	2	1.05E-04	3	5.07E-05	32	7.03E-03	9	9.81E-04	41	2.99E-03
All U.S. GOM OCS + North Sea 1980-2011	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	141,266		115,596		256,862		16,852		28,449		45,301	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	10	7.08E-05	8	6.92E-05	18	7.01E-05	56	3.32E-03	32	1.12E-03	88	1.94E-03
Blowout (underground flow)	1	7.08E-06			1	3.89E-06	8	4.75E-04	5	1.76E-04	13	2.87E-04
Well Release	1	7.08E-06	4	3.46E-05	5	1.95E-05	9	5.34E-04	8	2.81E-04	17	3.75E-04
Diverted Well Release							13	7.71E-04	19	6.68E-04	32	7.06E-04
TOTAL	12	8.49E-05	12	1.04E-04	24	9.34E-05	86	5.10E-03	64	2.25E-03	150	3.31E-03

Table 7.4: Regional LOWC Frequency (2001-2011)

U.S. GOM OCS 2001-2011	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	27,863		26,142		54,005		3,080		4,539		7,619	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	1	3.59E-05	4	1.53E-04	5	9.26E-05	9	2.92E-03	6	1.32E-03	15	1.97E-03
Blowout (underground flow)					1	1.85E-05	3	9.74E-04	4	8.81E-04	7	9.19E-04
Well Release	1	3.59E-05	3	1.15E-04					2	4.41E-04	2	2.63E-04
Diverted Well Release							7	2.27E-03	15	3.30E-03	22	2.89E-03
TOTAL	2	7.18E-05	7	2.68E-04	6	1.11E-04	19	6.17E-03	27	5.95E-03	46	6.04E-03

UK 2001-2011	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	7,559		6,019		13,578		745		2,068		2,813	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)									1	4.84E-04	1	3.55E-04
Blowout (underground flow)												
Well Release									2	9.67E-04	2	7.11E-04
Diverted Well Release												
TOTAL		0.00		0.00		0.00		0.00	3	1.45E-03	3	1.07E-03

Norway 2001-2011	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	10,120		1,565		11,685		399		1,674		2,073	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)							1	2.51E-03			1	4.82E-04
Blowout (underground flow)												
Well Release												
Diverted Well Release												
TOTAL		0.00		0.00		0.00	1	2.51E-03			1	4.82E-04

North Sea (Norway, UK) 2001-2011	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	17,679		7,584		25,263		1,144		3,742		4,886	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)							1	8.74E-04	1	2.67E-04	2	4.09E-04
Blowout (underground flow)												
Well Release									2	5.34E-04	2	4.09E-04
Diverted Well Release												
TOTAL		0.00		0.00		0.00	1	8.74E-04	3	8.02E-04	4	8.19E-04

All U.S. GOM OCS + North Sea 2001-2011	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	45,542		33,726		79,268		4,224		8,281		12,505	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	1	2.20E-05	4	1.19E-04	5	6.31E-05	10	2.37E-03	7	8.45E-04	17	1.36E-03
Blowout (underground flow)					1	1.26E-05	3	7.10E-04	4	4.83E-04	7	5.60E-04
Well Release	1	2.20E-05	3	8.90E-05					4	4.83E-04	4	3.20E-04
Diverted Well Release							7	1.66E-03	15	1.81E-03	22	1.76E-03
TOTAL	2	4.39E-05	7	2.08E-04	6	7.57E-05	20	4.73E-03	30	3.62E-03	50	4.00E-03

Table 7.5: Regional LOWC Frequency (1980-2000)

U.S. GOM OCS 1980-2000	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	73,399		70,317		143,716		9,219		14,736		23,955	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	8	1.09E-04	3	4.27E-05	11	7.65E-05	31	3.36E-03	22	1.49E-03	53	2.21E-03
Blowout (underground flow)	1	1.36E-05			1	6.96E-06	3	3.25E-04	4	2.71E-04	7	2.92E-04
Well Release									2	1.36E-04	2	8.35E-05
Diverted Well Release							7	7.59E-04	15	1.02E-03	22	9.18E-04
TOTAL	9	1.23E-04	3	4.27E-05	12	8.35E-05	41	4.45E-03	43	2.92E-03	84	3.51E-03

UK 1980-2000	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	15,742		9,788		25,530		2,557		3,739		6,296	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	1	6.35E-05	1	1.02E-04	2	7.83E-05	6	2.35E-03	2	5.35E-04	8	1.27E-03
Blowout (underground flow)												
Well Release									2	5.35E-04	2	3.18E-04
Diverted Well Release												
TOTAL	1	6.35E-05	1	1.02E-04	2	7.83E-05	6	2.35E-03	4	1.07E-03	10	1.59E-03

Norway 1980-2000	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	6,583		1,765		8,348		852		1,693		2,545	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)							9	1.06E-02	1	5.91E-04	10	3.93E-03
Blowout (underground flow)							4	4.69E-03			4	1.57E-03
Well Release							7	8.22E-03	2	1.18E-03	9	3.54E-03
Diverted Well Release							3	3.52E-03			3	1.18E-03
TOTAL		0.00		0.00		0.00	23	2.70E-02	3	1.77E-03	26	1.02E-02

North Sea (Norway, UK) 1980-2000	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	22,325		11,553		33,878		3,409		5,432		8,841	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	1	4.48E-05	1	8.66E-05	2	5.90E-05	15	4.40E-03	3	5.52E-04	18	2.04E-03
Blowout (underground flow)							4	1.17E-03			4	4.52E-04
Well Release							7	2.05E-03	4	7.36E-04	11	1.24E-03
Diverted Well Release							3	8.80E-04			3	3.39E-04
TOTAL	1	4.48E-05	1	8.66E-05	2	5.90E-05	29	8.51E-03	7	1.29E-03	36	4.07E-03

All U.S. GOM OCS + North Sea 1980-2000	Oil Production		Gas/Condensate Production		All Production		Exploration Drilling		Development Drilling		All Drilling	
	95,724		81,870		177,594		12,628		20,168		32,796	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	9	9.40E-05	4	4.89E-05	13	7.32E-05	46	3.64E-03	25	1.24E-03	71	2.16E-03
Blowout (underground flow)	1	1.04E-05			1	5.63E-06	7	5.54E-04	4	1.98E-04	11	3.35E-04
Well Release							7	5.54E-04	6	2.98E-04	13	3.96E-04
Diverted Well Release							10	7.92E-04	15	7.44E-04	25	7.62E-04
TOTAL	10	1.04E-04	4	4.89E-05	14	7.88E-05	70	5.54E-03	50	2.48E-03	120	3.66E-03

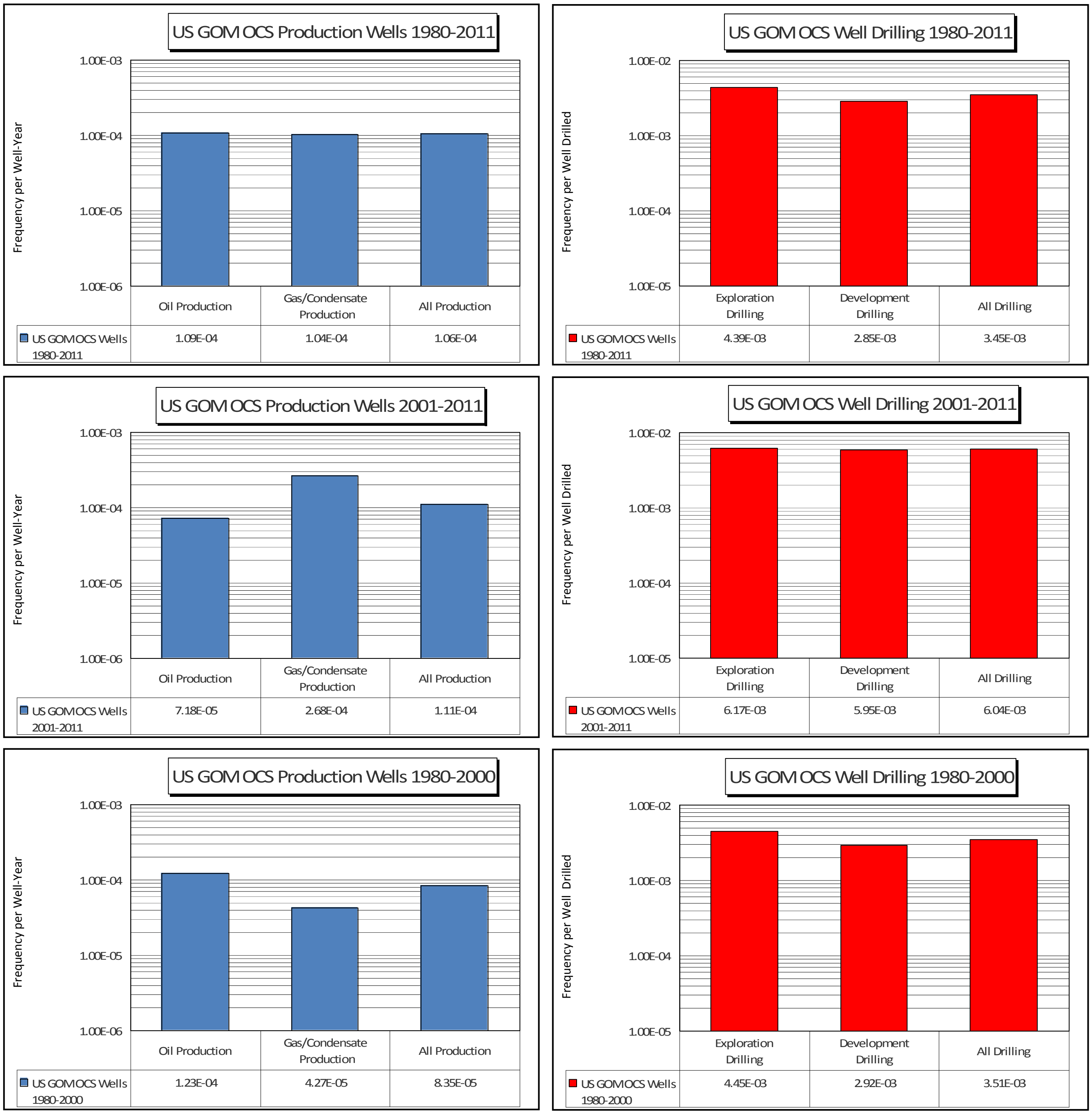


Figure 7.2: U.S. GOM Temporal LOWC Frequency Comparisons

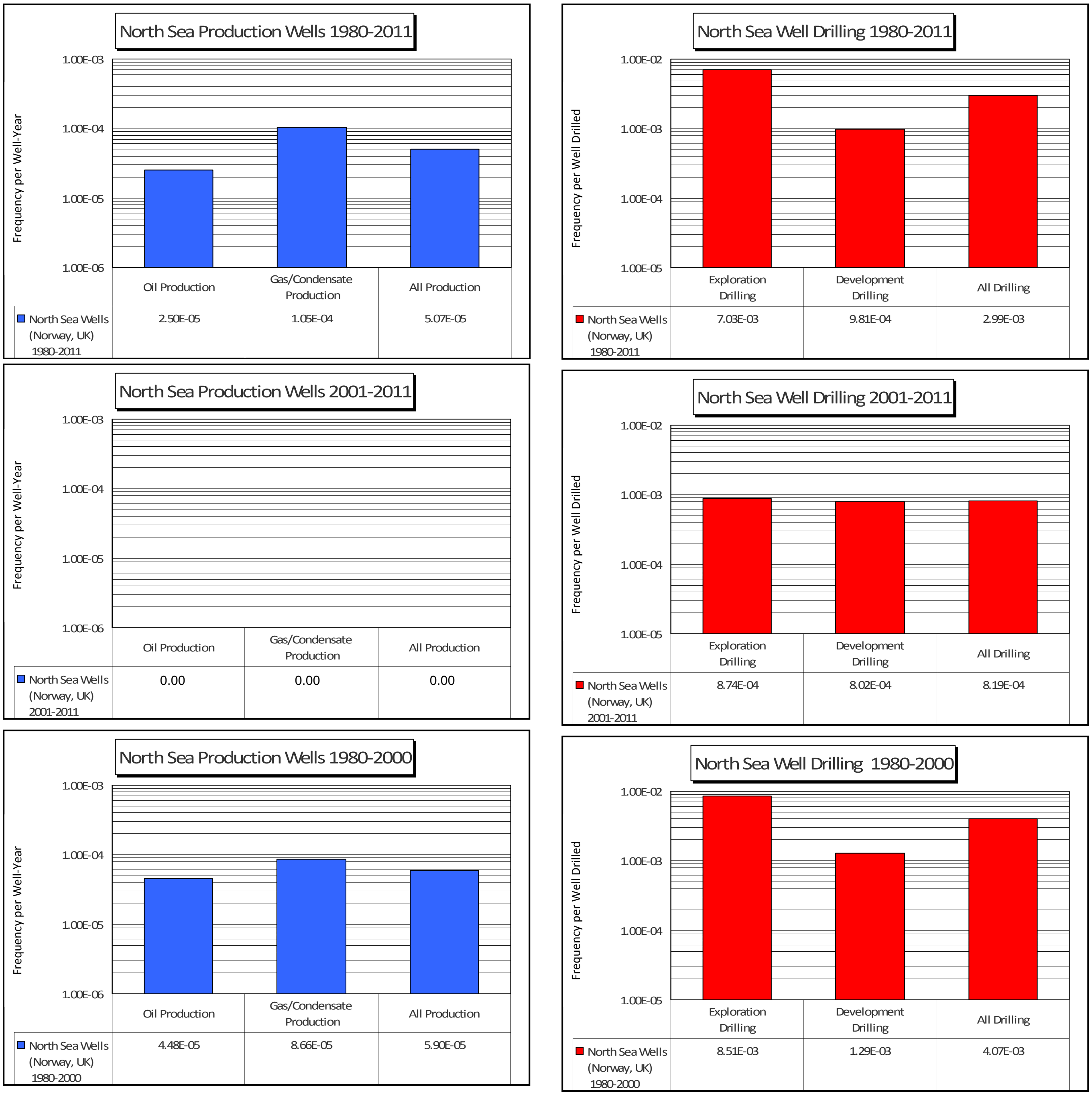


Figure 7.3: North Sea Temporal LOWC Frequency Comparisons

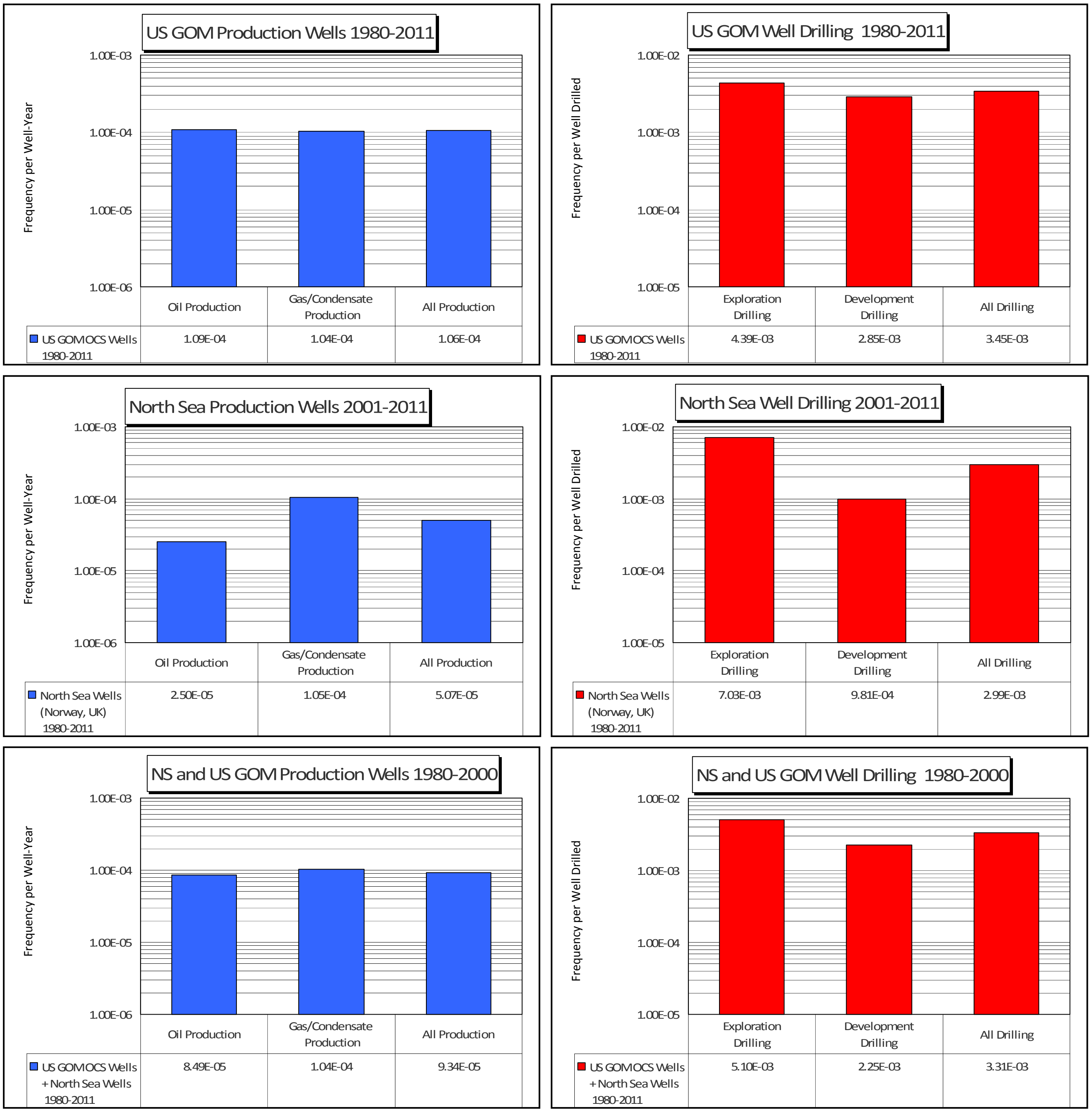


Figure 7.4: All Well (North Sea and U.S. GOM) Temporal LOWC Frequency Comparisons

7.5 Shallow and Deep Drilling LOWC Characteristic Comparisons

For the North Sea, the definition of shallow gas according to Holand [34], is unambiguous. Specifically, the definition put forward by Holand and accordingly SINTEF [34] is as follows: "Shallow gas release. The release from any gas zone penetrated before the BOP has been installed. Any zone penetrated after the BOP is installed is not shallow gas."

King, in her MSc Thesis of 2009 [36], defines a shallow gas blowout in a similar fashion, as follows: "A shallow gas blowout will be defined as a blowout before the blowout preventer (BOP) is set."

There is some ambiguity, however, for shallow gas LOWC releases in the U.S. GOM. According to Holand [34], the following qualifications need to be used in the context of GOM incidents:

- U.S. GOM OCS reservoirs vary greatly in depth. Some reservoirs are as shallow as 200 metres. In some LOWC incidents, a full BOP stack had been set, but cannot be used because it would likely cause a blowout outside the casing and a possible crater.
- For some incidents, very deep drilling has occurred without running an extra casing string and setting a BOP.
- For some LOWC incidents, a combination of a BOP and diverter is used to control flow.

In the present section, shallow gas LOWC incidents are taken to be those defined by SINTEF, which in the North Sea are relatively unambiguous, meaning drilling without a BOP. Those for the GOM are interpreted similarly by SINTEF, and so reported in the database.

Tables 7.6, 7.7, and 7.8 report LOWC incidents and associated frequencies for drilling in the U.S. GOM, the North Sea, and both the North Sea and GOM, respectively. As can be seen from Table 7.6, each of the drilling categories, exploration, development, and oil drilling, is subdivided into shallow gas and other, with "Other" generally meaning deeper drilling with a BOP. From an inspection of the bottom line, which summarizes blowouts and well releases, one can see that the shallow gas incident frequency is generally higher than the deep or other frequency for all of the regions, the U.S. GOM, the North Sea, and the combined U.S. GOM and North Sea. Finally, Figure 7.5 shows the comparative shallow gas and deep drilling blowout (not LOWC) frequencies. While this is true for the North Sea, the frequencies for All drilling blowouts are similar but somewhat higher for deep drilling in GOM, and similar (but somewhat lower) in the combined region.

Table 7.6: U.S. GOM Shallow Gas and Other Drilling LOWC Frequencies

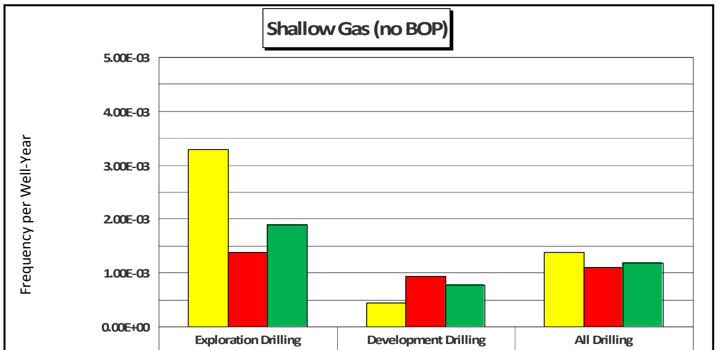
U.S. GOM OCS Wells 1980-2011	Exploration Drilling						Development Drilling						All Drilling					
	Shallow Gas		Other		All		Shallow Gas		Other		All		Shallow Gas		Other		All	
	12,299		12,299		12,299		19,275		19,275		19,275		31,574		31,574		31,574	
	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	17	1.38E-03	23	1.87E-03	40	3.25E-03	17	8.82E-04	11	5.71E-04	28	1.45E-03	34	1.08E-03	34	1.08E-03	68	2.15E-03
Blowout (underground flow)			4	3.25E-04	4	3.25E-04	1	5.19E-05	4	2.08E-04	5	2.59E-04	1	3.17E-05	8	2.53E-04	9	2.85E-04
Blowout Total	17	1.38E-03	27	2.20E-03	44	3.58E-03	18	9.34E-04	15	7.78E-04	33	1.71E-03	35	1.11E-03	42	1.33E-03	77	2.44E-03
Well Release			1	8.13E-05	1	8.13E-05	1	5.19E-05	2	1.04E-04	3	1.56E-04	1	3.17E-05	3	9.50E-05	4	1.27E-04
Diverted Well Release	8	6.50E-04	1	8.13E-05	9	7.32E-04	19	9.86E-04			19	9.86E-04	27	8.55E-04	1	3.17E-05	28	8.87E-04
Well Release Total	8	6.50E-04	2	1.63E-04	10	8.13E-04	20	1.04E-03	2	1.04E-04	22	1.14E-03	28	8.87E-04	4	1.27E-04	32	1.01E-03
LOWC TOTAL	25	2.03E-03	29	2.36E-03	54	4.39E-03	38	1.97E-03	17	8.82E-04	55	2.85E-03	63	2.00E-03	46	1.46E-03	109	3.45E-03

Table 7.7: North Sea Shallow Gas and Other Drilling LOWC Frequencies

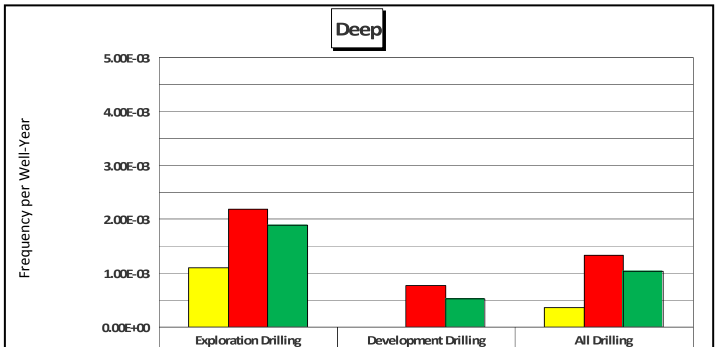
North Sea Wells 1980-2011	Exploration Drilling						Development Drilling						All Drilling					
	Shallow Gas		Other		All		Shallow Gas		Other		All		Shallow Gas		Other		All	
	4,553		4,553		4,553		9,174		9,174		9,174		13,727		13,727		13,727	
	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	15	3.29E-03	1	2.20E-04	16	3.51E-03	4	4.36E-04			4	4.36E-04	19	1.38E-03	1	7.28E-05	20	1.46E-03
Blowout (underground flow)			4	8.79E-04	4	8.79E-04									4	2.91E-04	4	2.91E-04
Blowout Total	15	3.29E-03	5	1.10E-03	20	4.39E-03	4	4.36E-04			4	4.36E-04	19	1.38E-03	5	3.64E-04	24	1.75E-03
Well Release	2	4.39E-04	6	1.32E-03	8	1.76E-03	1	1.09E-04	4	4.36E-04	5	5.45E-04	3	2.19E-04	10	7.28E-04	13	9.47E-04
Diverted Well Release	4	8.79E-04			4	8.79E-04							4	2.91E-04			4	2.91E-04
Well Release Total	6	1.32E-03	6	1.32E-03	12	2.64E-03	1	1.09E-04	4	4.36E-04	5	5.45E-04	7	5.10E-04	10	7.28E-04	17	1.24E-03
LOWC TOTAL	21	4.61E-03	11	2.42E-03	32	7.03E-03	5	5.45E-04	4	4.36E-04	9	9.81E-04	26	1.89E-03	15	1.09E-03	41	2.99E-03

Table 7.8: U.S. GOM and North Sea Shallow Gas and Other Drilling LOWC Frequencies

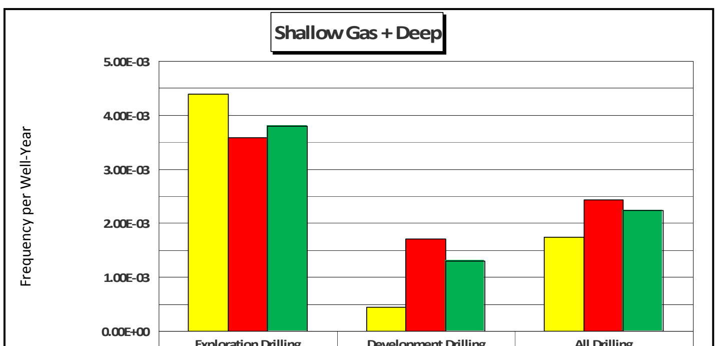
North Sea Wells +U.S. GOM OCS Wells 1980-2011	Exploration Drilling						Development Drilling						All Drilling					
	Shallow Gas		Other		All		Shallow Gas		Other		All		Shallow Gas		Other		All	
	16,852		16,852		16,852		28,449		28,449		28,449		45,301		45,301		45,301	
	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout (surface flow)	32	1.90E-03	24	1.42E-03	56	3.32E-03	21	7.38E-04	11	3.87E-04	32	1.12E-03	53	1.17E-03	35	7.73E-04	88	1.94E-03
Blowout (underground flow)			8	4.75E-04	8	4.75E-04	1	3.52E-05	4	1.41E-04	5	1.76E-04	1	2.21E-05	12	2.65E-04	13	2.87E-04
Blowout Total	32	1.90E-03	32	1.90E-03	64	3.80E-03	22	7.73E-04	15	5.27E-04	37	1.30E-03	54	1.19E-03	47	1.04E-03	101	2.23E-03
Well Release	2	1.19E-04	7	4.15E-04	9	5.34E-04	2	7.03E-05	6	2.11E-04	8	2.81E-04	4	8.83E-05	13	2.87E-04	17	3.75E-04
Diverted Well Release	12	7.12E-04	1	5.93E-05	13	7.71E-04	19	6.68E-04			19	6.68E-04	31	6.84E-04	1	2.21E-05	32	7.06E-04
Well Release Total	14	8.31E-04	8	4.75E-04	22	1.31E-03	21	7.38E-04	6	2.11E-04	27	9.49E-04	35	7.73E-04	14	3.09E-04	49	1.08E-03
LOWC TOTAL	46	2.73E-03	40	2.37E-03	86	5.10E-03	43	1.51E-03	21	7.38E-04	64	2.25E-03	89	1.96E-03	61	1.35E-03	150	3.31E-03



	Exploration Drilling	Development Drilling	All Drilling
North Sea Wells 1980-2011	3.29E-03	4.36E-04	1.38E-03
US GOM OCS Wells 1980-2011	1.38E-03	9.34E-04	1.11E-03
North Sea Wells +US GOM OCS Wells 1980-2011	1.90E-03	7.73E-04	1.19E-03



	Exploration Drilling	Development Drilling	All Drilling
North Sea Wells 1980-2011	1.10E-03	0.00E+00	3.64E-04
US GOM OCS Wells 1980-2011	2.20E-03	7.78E-04	1.33E-03
North Sea Wells +US GOM OCS Wells 1980-2011	1.90E-03	5.27E-04	1.04E-03



	Exploration Drilling	Development Drilling	All Drilling
North Sea Wells 1980-2011	4.39E-03	4.36E-04	1.75E-03
US GOM OCS Wells 1980-2011	3.58E-03	1.71E-03	2.44E-03
North Sea Wells +US GOM OCS Wells 1980-2011	3.80E-03	1.30E-03	2.23E-03

Figure 7.5: Comparative Regional Shallow Gas and Other Drilling Blowout Frequencies (1980-2011)

CHAPTER 8

LOWC HYDROCARBON SPILLS

8.1 Introduction on LOWC Hydrocarbon Spills

A critical area of LOWC information, both qualitative and quantitative, is that of the hydrocarbon (HC) spill characteristics associated with LOWC incidents. Clearly, this is important because of the concern over the impact of oil and other hydrocarbon fluid releases into the marine environment. Unfortunately, SINTEF [46] does not provide any quantitative information on the volumes of spills associated with LOWC incidents, restricting its characterization to a qualitative one indicating the degree (no, low, medium, large, unknown) of "pollution" associated with each specific incident. Pollution in SINTEF means a release into the marine environment. A more recent analysis by BOEM [22], however, does provide quantitative data and analysis of U.S. OCS LOWC spills dating back to 1964. In the balance of this chapter, characterization of spill frequencies will be based primarily on the BOEM [22] data and analysis, supplemented as appropriate by the SINTEF [46] data.

The following areas relating to LOWC HC spill volumes and characterization of LOWC spill frequencies are discussed herein:

- Spill Data Sources
- General Spill Frequency Characteristics and Exposure for U.S. GOM
- U.S. OCS Spill Size Distributions
- U.S. GOM Spill Volume Frequencies
- Risk Analysis Approaches to Predicting LOWC Spill Frequencies and Volumes

8.2 Spill Data Sources

8.2.1 SINTEF GOM LOWC Release Data

As indicated above, SINTEF [46] does not provide quantitative estimates of the volumes of HC liquids released, restricting itself only to a qualitative description of the degree of pollution as defined above and the severity of consequences. Table 8.1 summarizes the U.S. GOM HC spill data as characterized by SINTEF, including the qualitative level of pollution and severity of consequences, as well as the phase or operation associated with the spills. SINTEF defines HC liquids as a Flow Medium which is oil or condensate, and oil is defined as an HC liquid with a Gas to Oil Ratio (GOR) less than 1000 Sm^3/Sm^3. Thus, the first entry, Oil, represents oil with GOR less than 1000, while the next two entries represent HC liquids with GOR higher than 1000.

Table 8.2 gives data for HC liquid spills which cause pollution or enter into the marine environment. It excludes the "unknown" pollution spills. Clearly polluting incidents are less in number than those in Table 8.1, as all LOWC HC spills do not enter into the ocean.

Table 8.1: SINTEF General LOWC HC Spill Data - U.S. GOM (1980-2011)

U.S. GOM OCS 1980-2011 SINTEF Data	Flow Medium Type Only HC Liquids	Total	Pollution Type					Consequence Class						Phase Type						
			No	Small	Medium	Large	Unknown	No	Small	Damage	Severe	Total Loss	Unknown	Oil Production	Gas/Cond Production	Production Total	Exploration Drilling	Development Drilling	All Drilling	Well Interventions
Blowout (surface flow)	Oil	4			4				1				3	4		4				
	Oil, Gas (deep)	20	10	7	1	1	1	4	12	1	1	2		5		5	4	3	7	8
	Condensate, Gas(deep)	8	1	7				4	3	1					1	1		2	2	5
	Total	32	11	14	5	1	1	8	16	2	1	2	3	9	1	10	4	5	9	13
Blowout (underground flow)	Oil																			
	Oil, Gas (deep)	1	1										1	1		1				
	Condensate, Gas(deep)																			
	Total	1	1										1	1		1				
Well Release	Oil	3		2			1	3						1		1				2
	Oil, Gas (deep)	10	6	3			1	1	8				1				1		1	9
	Condensate, Gas(deep)	2		2				2							2	2				
	Total	15	6	7			2	6	8				1	1	2	3	1		1	11
Diverted Well Release	Oil																			
	Oil, Gas (deep)																			
	Condensate, Gas(deep)																			
	Total																			
TOTAL	Oil	7		2	4		1	3	1				3	5		5				2
	Oil, Gas (deep)	31	17	10	1	1	2	5	20	1	1	2	2	6		6	5	3	8	17
	Condensate, Gas(deep)	10	1	9				6	3	1						3		2	2	5
	TOTAL	48	18	21	5	1	3	14	24	2	1	2	5	11	3	14	5	5	10	24

8.2

Table 8.2: SINTEF LOWC HC Spill Data With Pollution - U.S. GOM (1980-2011)

U.S. GOM OCS 1980-2011 SINTEF Data - General	Spill Type HC Liquids with Pollution	Total	Phase Type				
			Production	Exploration Drilling	Development Drilling	All Drilling	Well Interventions
Blowout (surface flow)	Oil	4	4				
	Oil, Gas (deep)	9	1	4		4	4
	Condensate, Gas(deep)	7			2	2	5
	Total	20	5	4	2	6	9
Blowout (underground flow)	Oil						
	Oil, Gas (deep)						
	Condensate, Gas(deep)						
	Total						
Well Release	Oil	2	1				2
	Oil, Gas (deep)	3		1		1	2
	Condensate, Gas(deep)	2	2				
	Total	7	3	1		1	4
Diverted Well Release	Oil						
	Oil, Gas (deep)						
	Condensate, Gas(deep)						
	Total						
TOTAL	Oil	6	5				2
	Oil, Gas (deep)	12	1	5		5	6
	Condensate, Gas(deep)	9	2		2	2	5
	TOTAL	27	8	5	2	7	13

8.2.2 BOEM GOM LOWC Spill Data

BOEM data provides a level of detail necessary for the quantification of spill volumes. For this analysis, spills equal to or greater than 50 barrels (bbl) are considered. These are given in Table 8.3, with their subdivision among oil and condensate hydrocarbon liquids. The median LOWC spill size in the GOM, when a spill of hydrocarbon liquids does occur (1964 to 2010), is 2 bbl [22]. BOEM data also include spills down to 1 bbl, which is the reportable quantity. Between the SINTEF and GOM data reported here, the analysis includes all spill sizes down to 1 bbl.

Table 8.3: BOEM GOM Spill (>= 50 bbl) Data

U.S. GOM OCS 1980-2011 BOEM Data	Spill Type	Total	Phase Type				
			Production	Exploration Drilling	Development Drilling	All Drilling	Well Interventions
Spill >= 50 bbl LOWC	Oil	6	1	3		3	2
	Condensate	3			1	1	2
	Total	9	1	3	1	4	4

8.3 General U.S. GOM LOWC Incident Characteristics and Exposure

8.3.1 SINTEF GOM Spill Frequency Characteristics

To be consistent with the previous chapters in this report, exposure from 1980 to 2011, for the categories of producing wells, well interventions, and exploration and development well drilling, has been based on the SINTEF [46] data. Table 8.4, using the incident qualification as hydrocarbon liquid releases of 1 bbl or more with pollution from SINTEF, gives the general frequency distribution for the principal well operation categories, subdivided into blowouts and well releases. Utilizing the Chi Square 90% confidence interval assessment [47], Table 8.5 gives the associated distributions.

Table 8.4: SINTEF GOM LOWC General Spill Frequency Characteristics

U.S. GOM OCS HC Liquids With Pollution SINTEF 1980-2011	Production		Well Interventions		Exploration Drilling		Development Drilling		All Drilling	
	197,721		197,721		12,299		19,275		31,574	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
Blowout	5	2.53E-05	9	4.55E-05	4	3.25E-04	2	1.04E-04	6	1.90E-04
Well Release	3	1.52E-05	4	2.02E-05	1	8.13E-05			1	3.17E-05

Table 8.5: SINTEF U.S. GOM OCS 1980-2011 Blowout Spill Frequency Variability

U.S. GOM OCS HC Liquids With Pollution SINTEF 1980-2011	Blowout Frequency per Well-Year		
	High	Low	Expected
Production	4.63E-05	9.96E-06	2.53E-05
	Blowout Frequency per Well		
	High	Low	Expected
Exploration Drilling	6.30E-04	1.11E-04	3.25E-04
Development Drilling	2.46E-04	1.84E-05	1.04E-04
All Drilling	3.33E-04	8.28E-05	1.90E-04

Note: 90% confidence that Frequency is in the Low-High Interval
REF: Offshore Blowouts -Per Holand /page 132

8.3.2 BOEM GOM LOWC Spills

As indicated above, spills have been considered as those with spills of hydrocarbon liquids equal to or in excess of 50 bbl. Table 8.6 gives the general frequency characteristics associated with these releases based on the BOEM data from 1980 to 2011 [22]. Although the category of release incidents is described as LOWC, all of these incidents were in fact blowouts, rather than diverted well releases or other well control incidents. Next, Table 8.7 gives the statistical distribution again based on the Chi Square statistical algorithm [47]. Comparing the results in Tables 8.5 and 8.7, although they are for distinctly different ranges of spill sizes, with SINTEF covering all spills and BOEM data limited to HC spills greater than or equal to 50 bbl, one can see that the drilling LOWC frequencies are quite similar, while the production well LOWC frequencies are lower for the BOEM data, since spills less than 50 bbl have not been considered.

Table 8.6: BOEM GOM LOWC General Spill >= 50 bbl Frequency Characteristics

U.S. GOM OCS BOEM >=50 bbl 1980-2011	Production		Well Interventions		Exploration Drilling		Development Drilling		All Drilling	
	197,721		197,721		12,299		19,275		31,574	
	#	Frequency per well-year	#	Frequency per well-year	#	Frequency per well	#	Frequency per well	#	Frequency per well
LOWC	1	5.06E-06	4	2.02E-05	3	2.44E-04	1	5.19E-05	4	1.27E-04

Table 8.7: BOEM U.S. GOM OCS 1980-2011 LOWC Spill >= 50 bbl Frequency Variability

U.S. GOM OCS BOEM – Spills >= 50 bbl 1980-2011	Blowout Frequency per Well-Year		
	High	Low	Expected
Production	1.52E-05	2.59E-07	5.06E-06
	Blowout Frequency per Well		
	High	Low	Expected
Exploration Drilling	5.12E-04	6.65E-05	2.44E-04
Development Drilling	1.55E-04	2.66E-06	5.19E-05
All Drilling	2.46E-04	4.33E-05	1.27E-04

Note: 90% confidence that Frequency is in the Low-High Interval
REF: Offshore Blowouts -Per Holand /page 132

8.4 U.S. OCS LOWC Spill Volume Distributions (1964-2010)

The information on U.S. OCS LOWC spill sizes and its analysis utilizing a least squares regression [22, Figure 4.3.3-1], forms a reasonable estimate for the relative distribution of spill sizes, which can then be applied to the overall frequencies given in Section 8.3. Based on the analysis provided in [22], Figure 8.1 provides the cumulative spill size exceedance frequency in the top portion, and exceedence percentage in the bottom portion. As can be seen, the full range of spill sizes, from less than 1 bbl to almost 10 million bbl, has been plotted on the horizontal axis. Table 8.8 summarizes the percentage distributions based on the figure. Under the column "Full Distribution", together with the normalized partial distribution for spills greater than or equal to 50 bbl on the left hand side. Because of the current interest in the largest spills, such as those that have occurred with Macondo [23] and earlier in the Mexican portion of the Gulf of Mexico with the Ixtox [56] spill, the tabulation of spill sizes has been extended to include the greater than 1 million size. Although not shown in Table 8.8, the Enormous spill size category has further been subdivided into Class A (150,000 to 999,999 bbl) and Class B (>= 1 million bbl). The extended percentage distribution is shown in Table 8.9.

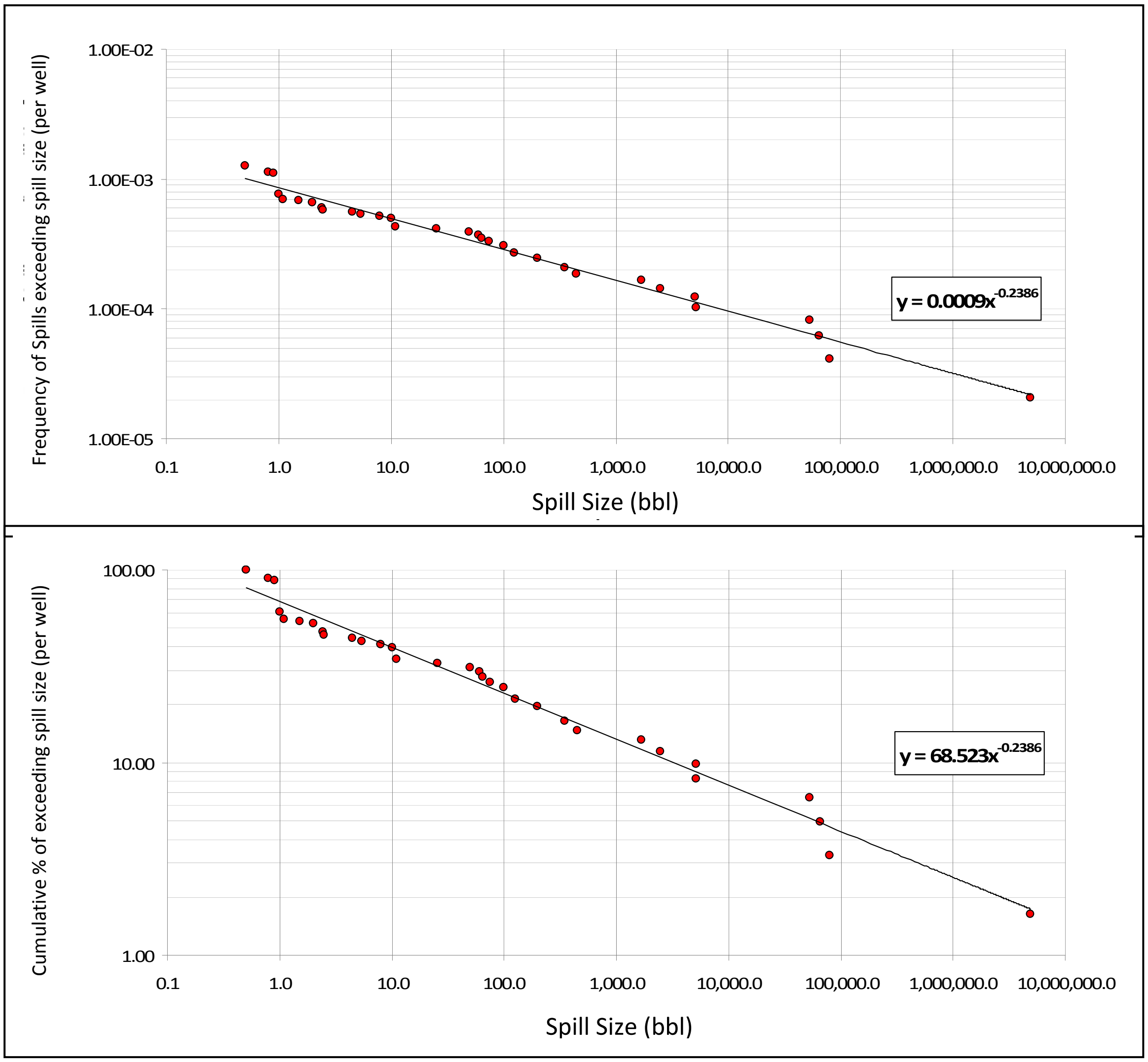


Figure 8.1: Cumulative Frequency and Percentage Spill Size Exceedance

Table 8.8: U.S. OCS LOWC Spill Distribution Summary (1964-2010)

Category	Spill Range	>= 50 bbl Distribution	Full Distribution
	bbl	Small - Catastrophic	0 bbl - Catastrophic
		%	%
Very Small	0-49	n/a	74.82
Small	50-99	16.31	4.11
Medium	100-999	38.32	9.65
Large	1,000-9,999	22.10	5.56
Huge	10,000-149,999	14.35	3.61
Enormous	>= 150,000	8.91	2.24
	ALL	100.00	100.00

Table 8.9: U.S. OCS LOWC Spill Distribution Summary Including 10^6 bbl Spills

Category	Spill Range (bbl)	Distribution Small – Enormous (%)
Small	50-99	16.31
Medium	100-999	38.32
Large	1,000-9,999	22.10
Huge	10,000-149,999	14.35
Enormous – Class A	150,000-999,999	5.75
Enormous – Class B	>= 1,000,000	3.17
	ALL	100.00

8.5 U.S. GOM Drilling Spill Volume Frequencies

Application of the spill size distributions identified in the above section to the LOWC with spills greater than or equal to 50 bbl frequencies identified in Table 8.9, leads to the spill size frequency distribution, ranging from small to enormous spills, shown in Table 8.10, together with the statistical upper and lower 90% confidence intervals. Figure 8.2 shows a graphical display of the associated full size frequency confidence limits.

Table 8.10: U.S. OCS LOWC Spill Size Frequency Distribution

U.S. GOM OCS BOEM DATA - SPILLS >=50 bbl (1980-2011)			All Drilling Frequency per Well Drilled High	Low	Expected
		Loss of Well Control	2.46E-04	4.33E-05	1.27E-04
Spill Category	bbl	Distribution %			
Small	50-99	16.31	4.01E-05	7.06E-06	2.07E-05
Medium	100-999	38.32	9.41E-05	1.66E-05	4.85E-05
Large	1,000-9,999	22.10	5.43E-05	9.56E-06	2.80E-05
Huge	10,000-149,999	14.35	3.52E-05	6.21E-06	1.82E-05
Enormous – Class A	150,000-999,999	5.75	1.41E-05	2.49E-06	7.28E-06
Enormous – Class B	>= 1,000,000	3.17	7.78E-06	1.37E-06	4.01E-06
	All	100.00	2.46E-04	4.33E-05	1.27E-04

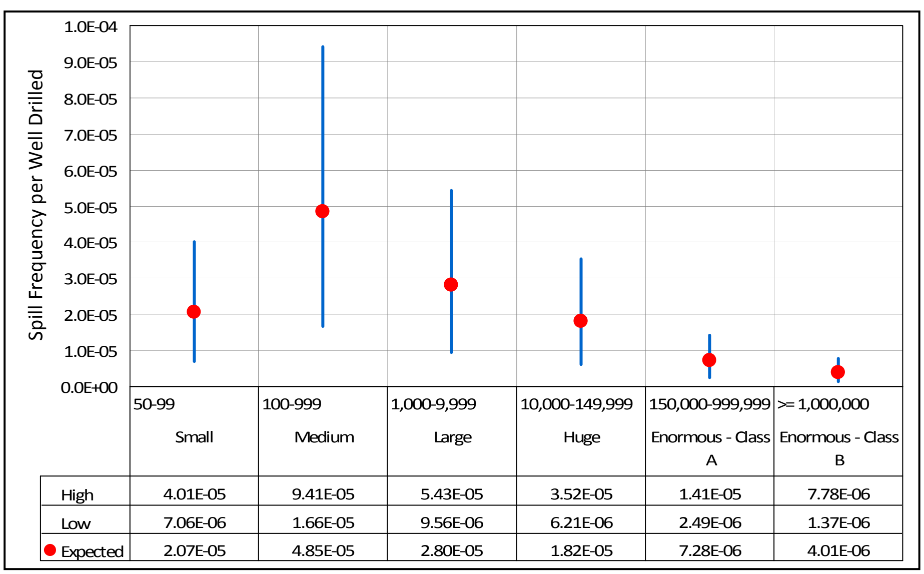


Figure 8.2: U.S. OCS (1980-2011) Spills Blowout Frequency Variability >= 50 bbl

From another point of view, it is interesting to simply take a direct large sample statistical approach to the occurrence of Enormous Class B spills. Over the period from 1980 to 2011 (and for that matter, in the entire offshore drilling history in the U.S. GOM), only one spill exceeding 1 million bbl of oil has occurred; namely, Macondo [23]. Dividing this by the total number of wells drilled (31,574), focusing on the 1980-2011 period, one obtains an expected value of 3.17 x 10^{-5} per well drilled. Although this value is roughly one order of magnitude higher than the Enormous Class B spill expected spill value of 4.01 x 10^{-6} given in Table 8.10 (obtained as described above), its low 90% confidence interval value of 1.62 x 10^{-6} is higher than the low 90% confidence interval of 1.37 x 10^{-6} in the distribution in Table 8.10, while its high value of 9.49 x 10^{-5} (as one could anticipate) remains over one order of magnitude higher than the higher 90% confidence interval of 7.78 x 10^{-5} of the value in Table 8.10. Combining the two sets of results, averaging the expected value and using upper and lower extremes, one can postulate the following ranges of Enormous Class B LOWC occurrence frequencies for U.S. GOM well drilling:

- Expected value: 1.78 x 10^{-5}
- Upper 90% value: 9.49 x 10^{-5}
- Lower 90% value: 1.37 x 10^{-6}

The variability of the large or Enormous Class B spill frequency in Table 8.11 and Figure 8.3 was assessed on the basis of the single event statistic from a very large population or sample size; that presented earlier in Table 8.10 was assessed using a least squares best fit method reflecting the influence of smaller spill sizes, and likely represents a better historical hindsight evaluation. Further approaches to a better understanding of the Enormous Class B and other specific LOWC spill potentials can be generated on the basis of risk analysis methods, as described in the next section.

Table 8.11: Enormous Class B Blowout Frequency and Its Variability

All Wells Drilled 1980-2011 U.S. OCS GOM			
31,574			
Number of Enormous Class B Blowouts	Frequency per well drilled		
	High	Low	Expected
1	9.49E-05	1.62E-06	3.17E-05

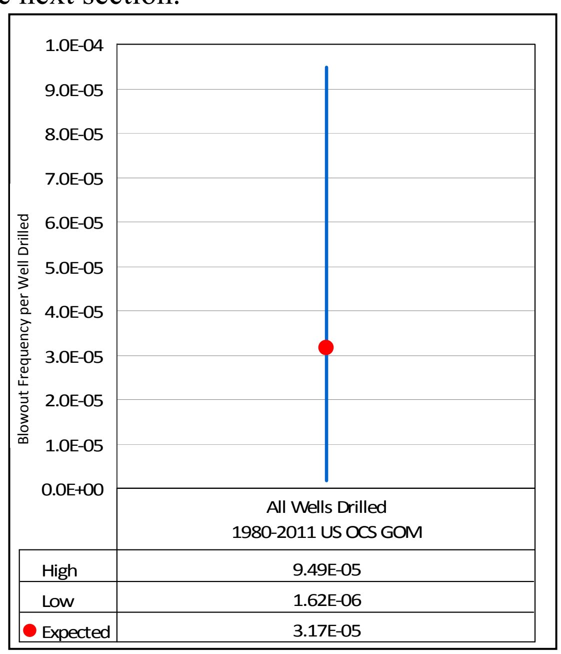


Figure 8.3: U.S. OCS GOM (1980-2011) Enormous Class B Spill Frequency Variability

8.6 General Description of Largest Gulf of Mexico LOWC Spills

The largest recorded Gulf of Mexico LOWC spills are the Ixtox blowout [56] which commenced on June 3, 1979 in the Mexican portion of the Gulf, and the Macondo blowout [23, 27, 30, 49, 51, 55] which commenced on April 20, 2010 in the GOM.

Ixtox I [56] was an exploratory oil well in the Mexican Gulf drilled by the Sedco I35-F semisubmersible in 1979 for Pemex, the Mexican government oil company. The location was approximately 50m deep, approximately 100km NW of Ciudad del Carmen. During drilling at approximately 3600m below the seafloor, the drill entered a soft stratum and mud circulation was lost as it flowed into the formation. Rather than shutting in the well using the BOP, Pemex ordered removal of the bit by pulling the drill pipe and running the pipe back to the formation to enable pumping cement and material to seal the surrounding soft formation. During the drill string pulling, or well swabbing, a kick occurred and when shear rams were activated to shut in the well, drill collars were at the shear ram elevation, so the drill pipe was not sheared, and the well could not be shut in, resulting in the blowout [32, 40]. Formation fluids, oil and gas, continued to flow, ignited, and the rig sank. Initial flow rates were estimated at 30,000 bbl per day, and over the 10 month period until capping of the well on March 23, 1980 it is estimated a total of over 3.5 million barrels were spilled into the Gulf. The principal cause of the blowout is improper and unsafe procedure used in an attempt to save the well for production.

The main references used here in outlining the Macondo blowout are those by BOEMRE [23] and the U.S.CG [51], while additional views are given in [27, 30, 49, 55]. On April 20, 2010 the Deepwater Horizon, a Transocean dynamically positioned semisubmersible, with BP as the designated operator, was in the process of completing and abandoning the Macondo exploration well in a water depth of approximately 1500m, drilled to approximately 5600m below the ocean floor. At approximately 10 pm an undetected kick occurred, shortly thereafter escalating to a blowout as none of the existing well barriers could be used to stop it. The flammable gas component of the blowout resulted in an explosion and fire on the rig, killing 11 men, and continuing to burn until the rig sunk, likely from firewater overburden on April 22. It is estimated that nearly 5 million barrels of oil were spilled into the Gulf during the 87 days it took to cap the well, resulting in the largest oil spill in the history of the GOM. The investigations by BOEMRE [23] and the U.S.CG [51] concluded that the accident and its aftermath occurred as a result of a complex combination of the operator decision to take additional risks to accelerate task completion schedules and resultant inadequate and unsafe procedures, failure to follow even its own emergency procedures, inadequate operator personnel emergency training and emergency drills, numerous incorrect tactical acts and omissions, inadequate equipment configurations and inadequate equipment maintenance, and various command and control communication failures and procedural deficiencies. It appears the principal causes can be summarized as those stemming from deficient safety procedures and culture.

8.7 Risk Analytic Approaches to Predicting LOWC Spill Frequencies and Volumes

8.7.1 Introduction on Risk Analysis Approaches to Specific LOWC Characteristics

The value and variability of specific spill volume LOWC frequencies for a specified development can be more accurately derived using quantitative risk analysis (QRA) approaches including fault and event trees [5]. Accordingly, following a brief review of QRA approaches by the author [6, 7, 8] and others [30, 31, 53], an algorithm to assess LOWC spill frequencies and characteristics for specified developments using the regional frequencies reported in this report as a starting point, and incorporating the principal development risk factors is described and illustrated with an example.

8.7.2 Review of Risk Analysis Approaches to Evaluating Specific LOWC Characteristics

Application of fault tree analysis (FTA) to evaluate frequencies of systems without history (which is adequate to generate failure statistics) such as Arctic offshore oil and gas developments, has been extensively developed and applied by the author for BOEM (formerly MMS) [13, 14, 15, 16, 17, 18, 19, 20, 21], and others [10, 11]. Essentially, historical data such as those generated in the earlier chapters of this report and their statistical properties are used as a starting point for fault tree application to oil spill indicator quantification for the Alaska OCS, the location without history. In the initial fault tree analysis in 2002 [21], data from the GOM OCS were analyzed for the period from 1972 to 1999 [2], as well as for earlier periods using world wide data [11]. Subsequently, a more refined publication of the data characteristics by the Bureau of Safety and Environmental Enforcement (BSEE) [24] has made it possible to conduct a more thorough statistical analysis as well as an update of the data and its analysis to 2010 [22]. As described in the following section a similar approach using FTA is taken here to the characterization of LOWC properties for specific developments based on regional statistics. Some of the methodologies described in Section 8.7.3 are partially adapted from the FT applications described and referenced above.

More LOWC specific QRA studies have recently been published by Norwegian investigators, Espen *et al* [30] and Vandenbussche *et al* [53].

The paper by Espen [30] correctly states that the North Sea blowout frequency studies are simply based on average frequencies obtained by dividing the number of blowouts by the relevant number of well operations. To provide a better perspective, Espen introduces two sets of factors which impact blowout occurrence frequencies; namely Human and Organizational Factors (HOF) and Risk Influence Factors (RIF). The factors given are described qualitatively and there appears to be some overlap in their definitions – HOFs refer to human performance and operations while RIFs deal primarily with the physical configuration of the operation including environment, reservoir, and equipment but also with operations which are covered by the HOF definition. In any case, Espen's qualitative conclusion that the Macondo blowout and its aftermath were largely due to HOF impact is consistent with the BOEMRE [23] conclusions.

Vandenbussche *et al* [53] follow a conceptually similar approach to that of Espen [30], defining a set of factors which exacerbate individual well blowout probability, more or less covering the same areas as [30], but go a step further by setting up a quantitative ranking method which they than use to generate quantitative effects on a base blowout probability. Although what they call "risk factors" do not entail risk effects, rather only probability effects independent of any volume of spills or other consequences, the exercise is useful enough to comment further. A weighing is assigned to the principal factors contributing to blowout proclivity as follows:

- Reservoir and underground conditions: 60%.
- Rig, riser, and well: 32%.
- Operational aspects: 8%.

The authors hereof do not agree with the low weighing given to operational aspects which include human performance but do agree that the reservoir should be an important contributor (although lower than Espen ranks it) as indeed if the reservoir lacks pressure and capacity, a blowout would not occur in the first place. Next, Espen uses the weighted result or "score" to multiply a base blowout frequency to obtain one for the specific well drilling. Repeating this process for various wells, a graph of frequency versus score is plotted with score incorrectly labeled as "well risk level", when in fact it is merely frequency score as no spill volume or other consequence parameter needed to constitute risk is given. However, in applying the methodology to specific scenarios, Espen does include approximate consideration of both flow duration and rate, providing a tool for blowout risk estimation for specific scenarios. In general, the Espen methodology is a promising one for the evaluation of LOWC risk from specific developments, but lacks the capability to integrate a set of wells as generally used in a production development.

8.7.3 Fault Tree Analysis Algorithm for Specific Development LOWC Characteristics

The FTA basic approach to the quantitative characterization of LOWC's is similar to that used for the characterization of oil spill indicators for the Alaskan OCS [12, 14], and incorporates some of the concepts proposed by Espen [30] and Vandenbussche [53]. Basically, a fault tree is constructed for a set of historically known regional spill frequency and volume characteristics and then modified to more accurately depict the characteristics associated with a specific development, including the production and drilling well configuration in a specified year.

The main building blocks of the algorithm are as follows:

- Regional LOWC frequency and its variation with different LOWC events.
- LOWC spill volume distribution (based on the U.S. OCS) and assumed valid for any other locations.
- Specific development characteristics including location, water depth, reservoir characteristics, operator, regulatory regime, and the annual numbers of each type of well and well operation.

We will next describe the algorithm generally, to be followed by a numerical example for a specific hypothetical development.

Figure 8.4 shows the fault tree (FT) conceptually (without values). As can be seen the base events are simply the annual frequencies of LOWC resulting from each well operation category for a specified volume spill range (such as <50bbl); namely exploration well drilling, development well drilling, production (including oil and condensate), and well interventions. These frequencies calculated for the entire numbers of wells in each year, are joined through an OR gate or summed, to give the resultant #2, which is simply the regional LOWC average resultant for the specified well configuration. This regional resultant is then multiplied by the specific development factor (analogous to the factors used by Espen) to give resultant #2 the Specific LOWC Spill annual frequency for the specified development and spill volume range.

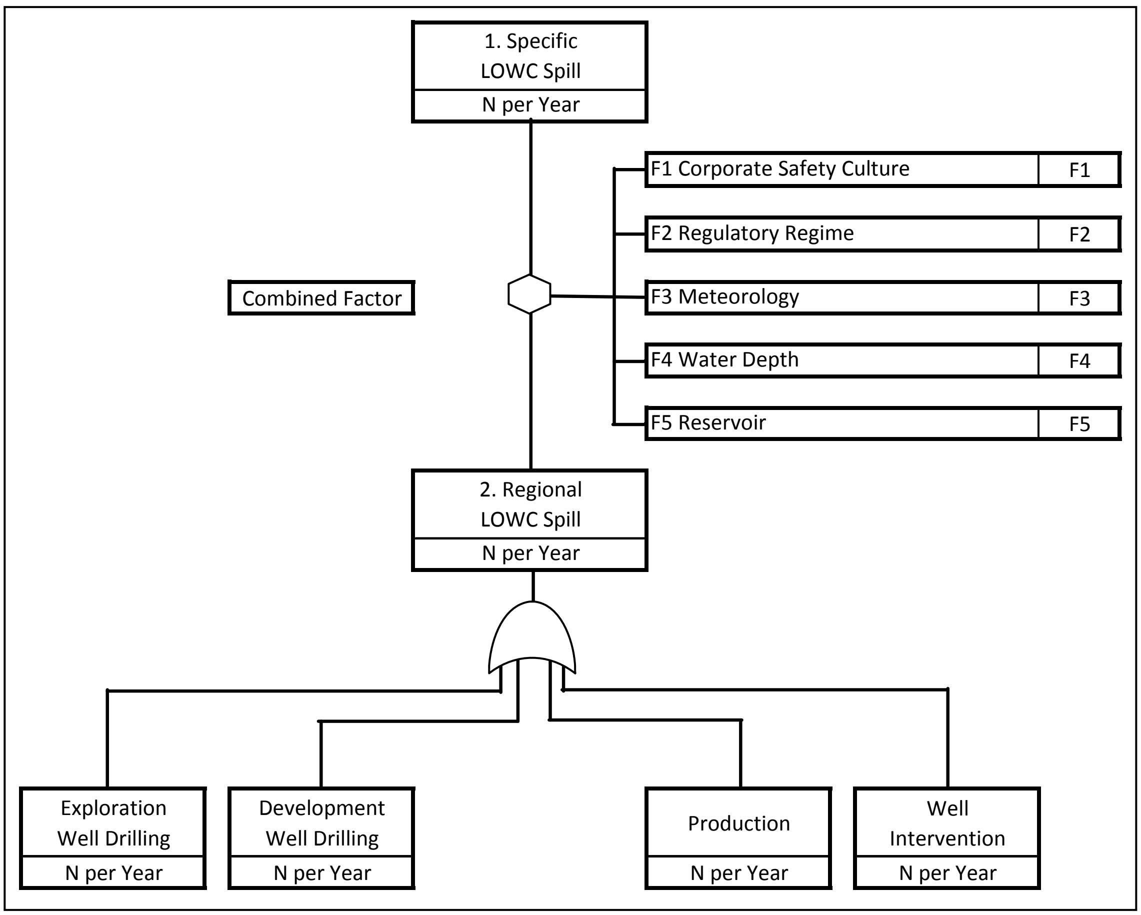


Figure 8.4: Specific Development LOWC Characteristic Evaluation Conceptual Fault Tree

Table 8.12 shows the well input table, in this case giving the U.S. GOM >=50bbl LOWC spill frequencies, as given earlier in Table 8.6. These are the "Regional Frequencies." The right hand column heading "Year TBA" refers to a generic year only.

Table 8.12: Annual Regional Frequency Input Table

Region		U.S. GOM - Regional LOWC Spills >=50 bbl			Year TBA	
#	Description	LOWC Spill Frequency Unit	LOWC Spill Frequency	Unit	# of Units	LOWC Spills per Year
1	Exploration Well Drilling	per Well	2.44E-04	Wells per Year	1	2.44E-04
2	Development Well Drilling	per Well	5.19E-05	Wells per Year	1	5.19E-05
3	Production	per Well-Year	5.06E-06	Well-Years per Year	1	5.06E-06
4	Well Intervention	per Well-Year	2.02E-05	Well-Years per Year	1	2.02E-05
Total Annual LOWC Frequency						3.21E-04

Table 8.13 then defines the factors, the "Specific Frequency Factors," used to adjust the regional volume frequencies to the specific development. The input values for each factor are 1, 3, or 3, with 3 being the worst case. These factors and their weights are as follows:

- Corporate Safety Culture: 20%
- Regulatory Regime: 10%
- Meteorology (eg, hurricanes at specific location): 10%
- Water Depth (Shelf Range Section 3.5): 10%
- Reservoir: 50%

Table 8.13: LOWC Frequency Factor Input Table

SPECIFIC FREQUENCY FACTORS			RANGE:	1	10
No.	Factor	Description	Weight %	Input	Factor Weight Value
F1	Corporate Safety Culture	1 -Average for Region 2 -More Stringent 3 -Very Stringent	20	1.0	20
F2	Regulatory Regime	1 -Regional Prevailing 2 -Less Stringent 3 -Lax	10	1.0	10
F3	Meteorology	1 -Regional Prevailing 2 - Some extreme 3 - Frequent extreme	10	1.0	10
F4	Water Depth	1 - Regional Average 2 - Deep (60m<=600m) 3 - Very Deep (>600m)	10	1.0	10
F5	Reservoir	1 - Normal 2 - Unknown 3 - HTHP	50	1.0	50
Combined values		For Given Region	100	1	100

The algorithm calculates the resultant factor so that given the weightings if all inputs are 1 (same as regional average), the resultant factor is also 1. In this methodology description case, both the specific and regional resultants are the same value as shown in Table 8.14.

Table 8.14: Regional Frequency Resultants Output

RESULTANTS		
No.	Description	Value
1	Specific LOWC Spills per Year	3.21E-04
2	Regional LOWC Spills per Year	3.21E-04

Now consider a hypothetical development, say for year 2010, with the annual numbers of wells shown in Table 8.15. To rank the development LOWC proclivity (>= 50bbl) consider Table 8.16. Then, if the development is in the GOM OCS, the same regulatory regime will apply, and we can assume the operator is of a regional average safety culture, giving a value of 1 for F1 and F2. Meteorology can also be assumed to be of base value so F3 is also 1. Assume water depth is 120 m, F4 is given a value of 2. Now, also assume the reservoir is known to be HTHP so F5 is given a value of 3. The fault tree and principal resultants for this specific hypothetical but realistic development for year 2010 are shown in Figure 8.5. The resultants #1 and #2 are shown again in Table 8.17. Basically we glean from this that the LOWC spill >=50bbl frequency for this development is 5.95 times higher than the average frequency in the GOM OCS. Of course we could input frequencies for any spill volume category, and any other region and generate analogous information. Also, one can apply the variations of frequencies and recalculate, or, to be rigorous, input frequency distributions and run the FT through a Monte Carlo simulation as was done by the authors in previous studies for BOEM [14, 15].

Table 8.15: Specific Development Annual Regional Frequency Input Table

Region		U.S. GOM - Regional LOWC Spills >=50 bbl			Year 2010	
#	Description	LOWC Spill Frequency Unit	LOWC Spill Frequency	Unit	# of Units	LOWC Spills per Year
1	Exploration Well Drilling	per Well	2.44E-04	Wells per Year	2	4.88E-04
2	Development Well Drilling	per Well	5.19E-05	Wells per Year	4	2.08E-04
3	Production	per Well-Year	5.06E-06	Well-Years per Year	20	1.01E-04
4	Well Intervention	per Well-Year	2.02E-05	Well-Years per Year	20	4.05E-04
Total Annual LOWC Frequency						1.20E-03

Table 8.16: Specific Development LOWC Frequency Factor Input Table

Specific Frequency Factors			Range	1	10
No.	Factor	Description	Weight %	Input	Factor Weight Value
F1	Corporate Safety Culture	1 -Average for Region 2 -More Stringent 3 -Very Stringent	20	1.0	20
F2	Regulatory Regime	1 -Regional Prevailing 2 -Less Stringent 3 -Lax	10	1.0	10
F3	Meteorology	1 -Regional Prevailing 2 - Some extreme 3 - Frequent extreme	10	1.0	10
F4	Water Depth	1 - Regional Average 2 - Deep (60m<=600m) 3 - Very Deep (>600m)	10	2.0	20
F5	Reservoir	1 - Normal 2 - Unknown 3 - HTHP	50	3.0	150
Combined		For Given Region	100	5.95	210

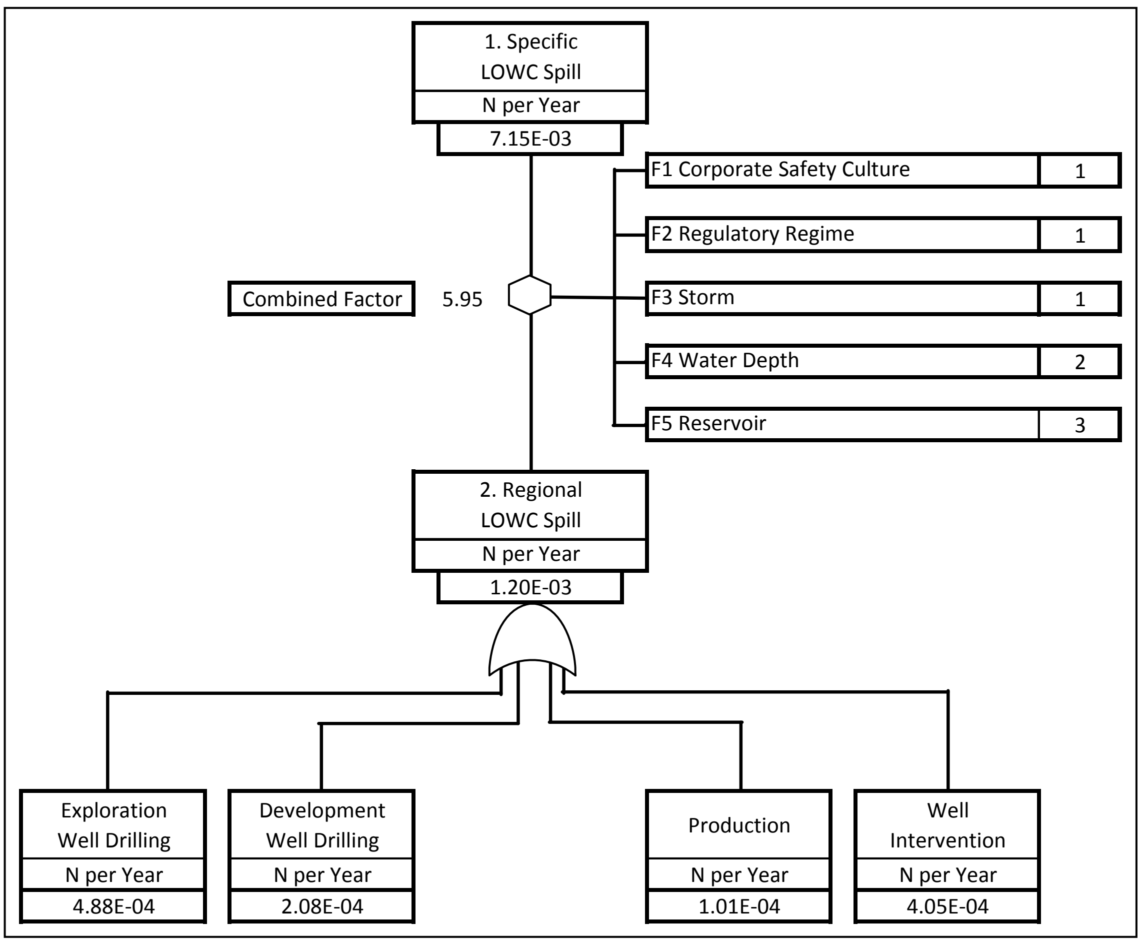


Figure 8.5: Quantified Specific Development LOWC Characteristic Evaluation Fault Tree

Table 8.17: Specific Development Frequency Resultants Output

RESULTANTS		
No.	Description	LOWC/YR
1	Specific LOWC Spills per Year	7.15E-03
2	Regional LOWC Spills per Year	1.20E-03

Finally, it is prudent to provide a note of caution. The algorithm presented, although correct mathematically, has not had its frequency factors or weighing factors and their significance subjected to rigorous review by other experts, nor has it been applied to specific proposed or existing developments. Also, if applied to the largest spill category, the Enormous Class B spills, only well drilling should be considered, as production wells have to date not produced LOWC spills exceeding 1 million bbl. Accordingly, the authors reserve the option to modify aspects of the algorithm following further review and application. It is our opinion however that the algorithm promises to fulfill a significant BOEM need for assessing LOWC spill frequencies and volumes for specific OCS developments, both proposed and existing.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 General Summary

An extensive study of world wide loss of well control (LOWC) incidents has been carried out to support BOEM's use of the results from the fault tree model generating oil spill occurrence rates for oil and gas lease sales and any development projects in the Chukchi and Beaufort Sea OCS Planning Areas proposed under BOEM and industry planning.

Specifically, this study included the following principal activities:

- Update of offshore LOWC frequency information through 2011 for the U.S., Canadian and Australian offshore regions, the North Sea, and other areas with a comparable regulatory regime, and collation of associated exposure variable information that was readily available.
- Application of statistical procedures to develop LOWC occurrence rates for different operational phases and products spilled
- Evaluation of confidence intervals for LOWC occurrence rates.
- Provision of statistical measures such as mean and median spill sizes, spill size distributions, and as well as provision of methods for possible statistical outliers such as the Macondo blowout.

The principal data sources used were the BOEM/BSEE data and the SINTEF offshore blowout database. As access to the full SINTEF database is on a proprietary membership basis, the contractor, acquired such membership as part of the work for years 2013 to 2015. The methods utilized, including data analysis, statistical, probabilistic, and risk analysis techniques used, produce results compatible with and applicable to the fault tree evaluations of oil spill occurrence estimators used by BOEM. Such an application is currently underway and the results generated herein have been found to be compatible with the application.

9.2 General Conclusions

General conclusions of the work can be summarized as follows:

- Generally adequate data on LOWC occurrences and their characteristics in western waters such as the North Sea and the U.S. GOM, are available from the SINTEF database for a sufficiently large exposure for the period from 1980 to 2011.
- More detailed data, on LOWC occurrences and their characteristics, including spill volumes, for the U.S. OCS are available from the BOEM/BSEE database for a sufficiently large exposure for the period from 1980 to 2011.

- The above data are of sufficient quantity and quality to permit the generation of statistics, including occurrence rates for different operational phases and products spilled, associated confidence intervals, and other statistical measures.
- Certain data, however, were not available, including spill volumes for locations other than the U.S. OCS, well exposure populations by water depth intervals for all locations, or detailed characterization of the products spilled from LOWC incidents.

9.3 Specific Conclusions

Table 9.1 summarizes the key high level LOWC parameters for the principal regions studied. Details on these and other results follow in the forthcoming sections.

Table 9.1: Summary of Principal LOWC Parameters for Key Regions

REGION	EXPOSURE		LOWC FREQUENCY			LOWC DURATION	
	Drilling	Production	Drilling	Production	Interventions	50 % stopped	90 % stopped
	wells drilled	well-years	per 1000 wells drilled	per 1000 well-years	per 1000 well-years	minutes	days
U.S. GOM	31,574	197,721	3.45	0.106	0.314	200	8
North Sea	13,727	59,141	2.99	0.051	0.355	3	20
Holland	1,143	2,948	0	0.339	0.339	n/d*	n/d
Australia	2,559	9,589	1.56	0.104	0	n/d	n/d
Canada E Coast	679	3,955	2.95	0	0	n/d	n/d

* n/d = no data

9.3.1 U.S. GOM OCS

The following specific conclusions can be summarized from the work detailed in Chapter 3 for the U.S. GOM OCS:

- From 1980 to 2011, a total of 31,574 wells were drilled in the U.S. GOM, and a total of 197,721 production well-years occurred
- LOWC frequencies for production wells in the subject period total 1.06 x 10^{-4} per well year, consisting of 81% blowouts and 19% well releases, while frequencies for well intervention LOWC's were 3.14 x 10^{-4} per well year
- LOWC frequencies for all well drilling in the subject period total 3.45 x 10^{-3} per well drilled, consisting of 71% blowouts and 29% well releases
- LOWC durations show that there is approximately a 50% probability that an incident will stop within 200 minutes and 90% probability, it will stop within 8 days
- LOWC incident occurrences by depth indicate that the majority of incidents (58%) occur in the shallower <60m water depth range. It should be noted that this value is only the number of incidents and not a frequency or rate as the exposure for the water depth intervals was not available.

9.3.2 North Sea

The following specific conclusions can be summarized from the work detailed in Chapter 4 for the North Sea:

- From 1980 to 2011, a total of 13,727 wells were drilled in the North Sea and a total of 59,141 production well-years occurred
- LOWC frequencies for production wells in the subject period total 5.07 x 10^{-5} per well year, consisting of 67% blowouts and 33% well releases, while frequencies for well intervention LOWCs were 3.55 x 10^{-4} per well year
- LOWC frequencies for all well drilling in the subject period total 2.99 x 10^{-3} per well drilled, consisting of 58% blowouts and 42% well releases
- LOWC durations show that there is approximately a 50% probability that an incident will stop within 3 minutes and 90% stop within 23 days
- LOWC incident occurrences by depth indicate that the majority of incidents (62%) occur in the shallower 61 to 152m water depth range. It should be noted that this value is only the number of incidents and not a frequency or rate as the exposure for the water depth intervals was not available.

9.3.3 North Sea and GOM

The following specific conclusions can be summarized from the work detailed in Chapter 5 for the combined North Sea and U.S. GOM:

- From 1980 to 2011, a total of 45,301 wells were drilled and a total of 256,862 production well-years occurred
- LOWC frequencies for production wells in the subject period total 9.34 x 10^{-5} per well year, consisting of 79% blowouts and 21% well releases, while frequencies for well intervention LOWC's were 3.23 x 10^{-4} per well year
- LOWC frequencies for all well drilling in the subject period total 3.31 x 10^{-3} per well drilled, consisting of 67% blowouts and 33% well releases
- LOWC durations show that there is approximately a 50% probability that an incident will stop within 1.5 hours and 90% probability, within 9 days
- LOWC incident occurrences by depth indicate that a large proportion of incidents (48%) occur in the shallower <60m water depth range. It should be noted that this value is only the number of incidents and not a frequency or rate as the exposure for the water depth intervals was not available.

9.3.4 Australia, Holland, and Canada

The following specific conclusions can be summarized from the work detailed in Chapter 6:

- Australia
    - From 1980 to 2011, a total of 2,559 wells were drilled and an estimated total of 9,589 production well-years occurred.

  - LOWC frequencies for production wells in the subject period total 1.04 x 10^{-4} per well year, and for interventions, 0 per well year.
  - LOWC frequencies for well drilling in the subject period total 1.56 x 10^{-3} per well drilled.

- Holland
  - From 1980 to 2011, a total of 1,143 wells were drilled and an estimated total of 2,948 production well-years occurred.
  - LOWC frequencies for production wells in the subject period total 3.39 x 10^{-4} per well year, and the same for interventions, 3.39 x 10^{-4} per well year.
  - LOWC frequencies for well drilling in the subject period total 0 as no LOWC's were recorded during drilling.

- Canada East Coast
  - From 1980 to 2011, a total of 679 wells were drilled and an estimated total of 3,955 production well-years occurred
  - LOWC frequencies for production wells and well interventions in the subject period are 0 as none were recorded
  - LOWC frequencies for well drilling in the subject period total 2.95 x 10^{-3} per well drilled

9.3.5 Regional and Temporal Comparisons

The following specific conclusions can be summarized from the regional and temporal comparison work detailed in Chapter 7:

- LOWC frequencies from 1980 to 2011 were generated for the North Sea and its principal sectors and U.S.GOM for the following principal periods:
  - 1980-2000
  - 2001-2011
  - 1980-2011
- LOWC frequencies for U.S.GOM showed the following qualitative distributions:
  - 1980-2000-lower production and well drilling LOWC frequencies than later
  - 2001-2011- higher production and well drilling LOWC frequencies than earlier, but this may be attributable to the requirement for more stringent reporting enacted in 2006.
- LOWC frequencies for North Sea showed the following qualitative distributions:
  - 1980-2000-higher production and well drilling LOWC frequencies than later
  - 2001-2011- lower production and well drilling LOWC frequencies than in the earlier period
- The distribution of LOWC frequencies between shallow gas (no BOP) drilling and BOP installed drilling were developed and assessed

9.3.6 LOWC Hydrocarbon Spill Characteristics

The following specific conclusions can be summarized from the regional and temporal comparison work detailed in Chapter 8:

- SINTEF data provides information on the type of hydrocarbon released form LOWC incidents and only qualitative information on the degree of pollution and consequences thereof
- BOEM/BSEE data provides detailed LOWC release volume information for 1960-2011 for the U.S. OCS, which was used to develop a spill size distribution for the more recent period of 1980-2011
- Comparing LOWC frequencies for spills >=50 bbl and LOWC frequencies for all LOWC incidents, it was found that LOWC frequencies for spills >=50 were approximately 17 times lower than all LOWC frequencies for production and well intervention, and approximately 27 times lower for well drilling.
- Enormous spills of Class B, equal to or exceeding 1 million barrels were considered both with a statistical spill volume distribution and as a single valued occurrence. An expected frequency of such spills for the GOM was estimated to range from 4 in 1 million to 3 in 100 thousand wells drilled.
- An algorithm based on fault tree analysis for more refined estimates of LOWC frequencies considering reservoir, water depth, meteorology, regulatory regime, and operator safety culture and illustration of its application was provided

9.3.7 Other Information Generated

In addition to the principal results summarized above, additional information generated and reported herein on LOWC characteristics includes the subdivision and quantification of LOWC frequencies among the following categories:

- Exploration and Development well drilling
- LOWC flow path subsea or to surface
- Shallow gas release or drilling without BOP LOWC frequencies
- Type of product released
- HC spill volume size distribution for GOM only

Finally, conclusions were summarized and recommendations for further work were provided in this Chapter 9

9.4 Recommendations for Further Work

The following recommendations based on the work are provided:

- There appear to be some minor differences between the SINTEF and BOEM/BSEE data for the U.S. OCS. It is recommended that these differences be reconciled. The authors have made SINTEF aware of this issue and SINTEF may agree to address it jointly.
- There are considerable differences among the regional LOWC parameters displayed in Table 9.1. It would be useful to develop a better understanding of the reasons for these differences through further review of associated conditions such as those postulated as having an effect on LOWC frequencies in Chapter 9 thereof.
- LOWC duration data for many incidents indicates 0 duration. The significance of this datum should be investigated and durations adjusted as it is unlikely that an LOWC incident would stop in less than 1 minute. Similarly, the cause of the large differences in durations of GOM and North Sea LOWCs should be investigated.
- The depth interval exposure data are not available for the GOM, resulting in a less meaningful assessment of LOWC occurrence variation with depth. As it is, the noted variation of LOWC occurrences associated with different depth intervals could be a result of simply a variable number of wells in the intervals, a change in LOWC frequency, or a combination of the two. Clearly, the variation of LOWC frequency and its characteristics with depth would be more instructive.
- Full exposure data for Australia, Holland, and Canada were not available, and accordingly were estimated on the basis of what were assumed to be similar regions for which full exposure data were available. It is recommended to obtain exposure data from the stated regional administrations, if possible.
- In earlier editions of SINTEF documentation (pre 2000) spill volumes were included. SINTEF has been advised of the usefulness of such information, particularly for regions outside the GOM where this information is lacking, and are considering options.
- Surface and subsea LOWC data in SINTEF are not adequately documented to assess likelihood of releases into the marine environment. Subsea is defined as a release point either at the sea bottom or into another formation beneath the sea bottom. Clearly, it is desirable to know which of the subsea incidents release into the sea, and this is recommended to be assessed.
- As indicated in Chapter 9, the algorithm presented, although correct mathematically, has not had its frequency factors or weighing factors and their significance subjected to rigorous review by other experts, nor has it been applied to specific proposed or existing developments. Also, if applied to the largest spill category, the Enormous Class B spills, only well drilling should be considered, as production wells have to date not produced LOWC spills exceeding 1 million bbl. Accordingly, the authors recommend further review of the algorithm with experts, and by application. As appropriate, modify aspects of the algorithm following such review and application.

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