Advanced Drilling and Well Technology

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Book Editors:

Bernt S. Aadnoy
University of Stavanger

Iain Cooper
Schlumberger

Stefan Z. Miska
University of Tulsa

Robert F. Mitchell
Halliburton

Michael L. Payne
BP

Society of Petroleum Engineers

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Society of Petroleum Engineers
222 Palisades Creek Drive
Richardson, TX 75080-2040 USA

http://store.spe.org/
books@spe.org
1.972.952.9393

Foreword

For years, the prerequisite textbook for understanding fundamental drilling engineering principles has been *Applied Drilling Engineering* (Bourgoyne et al. 1986), better known to many readers as "The Big Red Drilling Book." This new drilling volume, *Advanced Drilling and Well Technology,* is meant to complement that classic textbook, and its genesis is twofold.

First, it was felt that there were many topics more advanced than the basic concepts covered in the original textbook, which very much focuses on the fundamentals of drilling engineering. To have included all aspects of drilling, particularly those that have appeared in the last 15 years, would have led to a single volume that would be both unfocused and unwieldy. Second, the drilling industry is at a turning point. With the average age of the current workforce in their late 40s, the next 10 years will see much of today's drilling expertise retired (although, we hope, still contributing to the growing body of knowledge!). Therefore, it was felt that we must develop a mechanism to capture some of that knowledge in a form that can be passed down to the younger community who will be drilling the wells of tomorrow. To this end, we have expanded upon *Applied Drilling Engineering* to provide more detail in certain areas (i.e., casing design, wellbore hydraulics, foam dynamics), and we have elaborated on the latest thinking that has taken advantage of developments in computer processing. For example, the sections on well-control modeling, geomechanics, and heat transfer all describe the fundamental science and governing equations behind many of the sophisticated simulators that are used to plan today's wells.

Major technology breakthroughs take a significant time to incubate before they are readily accepted as appropriate techniques. The first horizontal well was drilled in the 1920s (although some would say that it was actually *dug* in the previous century) but, as a technique, directional drilling only achieved economic viability in the 1980s. Indeed, directional drilling has been one of the most significant developments in the industry, and many of the sections within this book describe developments that have been enabled by directional drilling (such as geosteering) or that have led to refinements and improvements to the technique; the discussions on drillstring design and vibration highlight the issues associated with deviated and extended-reach wells, as well as the loads and shocks such trajectories place on the drilling equipment.

The most recent evolution (some would say revolution) of drilling has been the development of rotary steerable systems. These have led to higher rates of penetration, improved borehole quality, and access to previously unobtainable reserves. This is very much a technology that is still in its infancy, and there is no doubt that eventually we will see it overtaking motors, in a range of sizes and at a reduced cost, so that it becomes the ubiquitous system for both vertical and deviated wells. We do not include an explicit description of the variety of rotary steerable mechanisms and tools, but many of the advanced techniques that we describe are facilitated by this breakthrough technology and have implications for trajectory and the corresponding drillstring design.

We also discuss some of the newer drilling procedures that have appeared over the last few years and that have steadily gained a degree of acceptance that will only increase in the future. Indeed, this text is the first that has gathered together formal descriptions of the tools and techniques associated with coiled-tubing drilling, underbalanced and managed-pressure drilling, and casing drilling. There are other techniques that we have chosen not to include for the sake of space or because of the immaturity of the technology. To this end, we do not describe the parallel well design and drilling techniques of steam-assisted gravity drainage (SAGD) or other dedicated heavy-oil-recovery techniques. Nevertheless, as unconventional reservoirs become a more significant component of total hydrocarbon production, these techniques will be addressed in future texts.

It is often said that the “easy” oil has been drilled. This is only partially true, and many of the techniques we describe in this book address methodologies for increasing the recovery factor from existing reservoirs. Nevertheless, we have seen a shift toward more complex reservoirs, and the chapters on high-pressure/high-temperature applications and deepwater operations highlight some of the difficulties we face in drilling in such environments. We will continue to face ever more harsh conditions and will have to continually adapt both the processes and the equipment used to drill efficiently and to produce safely from these wells. We feel that the material in this book provides the necessary background for understanding the pertinent issues when designing a well for ever-increasing water depths or when encountering significantly overpressured zones.

There have been enough significant drilling technology developments in the last 15 years to fill two or three new textbooks. Detailed discussions of some of these developments will no doubt appear in a future volume. The reliability and accuracy of well surveying has undergone significant improvements over the last 10 years. The increasing precision of sensors and the plurality of these sensors in the drillstring has led to a whole suite of new uncertainty models and analyses that mean more-complex trajectories in multiwell programs can be drilled to significantly increase reservoir contact. Space dictates that the discussion of those uncertainty models and their role and implementation in well planning and real-time well redesign will have to wait for another day.

Similarly, many new logging-while-drilling technologies have appeared in the last few years and continue to increase both the speed and the precision of drilling. Seismic while-drilling technology has enabled the drillbit to be placed on the seismic map with an accuracy that can enable significant course corrections to be made and hazards to be avoided. Similarly, refined electromagnetic, nuclear, and acoustic measurements and the complementary improvements in telemetry rates have illuminated the borehole around and behind the bit to the degree that simple geometric steering has been ubiquitously replaced by geology-based steering for the complex wellbore trajectories necessitated by the more challenging environments faced by today’s driller.

Now is a time more than any other where we in the drilling community have benefitted from the rapid progress in other industries. The developments in signal processing in the telecommunications world have been applied to the logging- and measurement-while-drilling environment to extend the application of the triple and quad combo (and more) from mere formation evaluation to enable not only the reservoir engineer but also the drilling engineer to make decisions in real time that will have a material benefit to both the quality of the borehole and the ultimate production from the reservoir. We have included detailed descriptions of some, but not all, of these measurements in the chapter on Wellbore Measurements: Tools, Techniques, and Interpretation, focusing on those that we feel have added the most significant value to the driller and that have had the most exposure in the literature in terms of helping maximize reservoir contact and ultimate production while also assisting in minimizing drilling trouble time.

Pore pressure while drilling was often seen to be the “holy grail” of drilling measurements. The recent development of real-time formation pressure while-drilling tools has led to a whole new area of interpretation that allows a much deeper understanding of the nature of drilling fluid behavior and well response during drilling, in addition to giving us that most fundamental of values. A variety of tools and techniques exist, and we attempt to cover all of the currently employed tools as well as a detailed analysis of the supercharging phenomenon, which has the most significant impact on a reliable interpretation of the measurements.

This would not be an “advanced” textbook unless we were allowed to try and speculate on some of the drilling systems (or should we say rock destruction mechanisms?) that may be used in the future. Therefore, in Chapter 9 we take the liberty of describing some of the techniques that appear in the literature and in conferences periodically that have yet to obtain wide acceptance in the field (such as laser and electropulse drilling), but that could provide the next significant breakthrough in terms of rate of penetration when we are able to fully deploy their effects downhole.

This book would not have been possible without many people sacrificing significant amounts of time during one of the busiest periods the drilling industry has ever seen. The editors would like to personally

thank all of the authors, illustrators, and reviewers (and their families) for their patience, dedication, quality of work, and passion that they continually brought through the 6 years it has taken to develop the volume you now have in your hands. Finally, we must acknowledge John Thorogood, who had the initial vision of a textbook that covered the more recent breakthroughs in drilling technology and processes, and who assembled the editorial team and indeed many of the original authors in a conference room in Amsterdam some 6 years ago. We believe that we have compiled a book that lives up to that vision and can now take its place on your shelf alongside "The Big Red Drilling Book" (currently in revision).

Bernt S. Aadnoy
Iain Cooper
Stefan Z. Miska
Robert F. Mitchell
Michael L. Payne

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Contents

Chapter 1

The Well-Construction Process

Claire Davy, EITICAT, and **Bernt S. Aadnoy,** University of Stavanger

This book has been compiled principally to lead well engineers through advanced drilling and well-design technology. The well-construction process provides the fundamental backbone to support such well design and completion design. We also will introduce the new technology that is applied in the design of wells and in the drilling process.

Advanced Drilling and Well Technology is aimed at the application of fundamental well-design techniques, but it also addresses far more complex challenges; the SPE textbook *Fundamentals of Drilling Engineering* (Mitchell 2009) holds a wealth of information on the fundamentals. The objective of this book is to capture the vast development that has taken place in drilling during the past decade to address meeting the requirements of designing more-challenging wells and completions. Significant advances have been seen in deepwater drilling, underbalanced drilling, logging while drilling, and pressure and temperature measurements during drilling, as a few examples. These two SPE books are closely tied together and will be considered complementary.

In short, this book will link theory to practical applications and includes detailed case studies where appropriate. Although some derivations of fundamentals are required, the idea is to refer to *Fundamentals of Drilling Engineering* to a large extent.

This chapter sets out the framework of the well-construction process into which, in practice, the design techniques are drawn one at a time at the appropriate points. Often, several alternative ways to design a well will be reviewed at the outset. Once the selection has narrowed the choice to a limited number of designs, thorough checks will be made on each design to assess viability and determine the value each design offers in terms of both direct outcomes and opportunities (particularly to address long-term life-cycle issues); the risks will also be assessed.

1.1 This Chapter in the Context of This Book

We will begin by describing the steps that are normally carried out in well design—working on the principle of designing geared to the well objectives, which usually requires bottom-up design. The reader is then systematically walked through each step. As the steps are recounted, the text points to example topics that the designer should investigate more deeply by referring to particular parts of the book. Toward the end of the chapter are examples of how to address a variety of different challenges facing well designers. Some examples point to how the topics set out in this book can be used.

This first chapter links the reader into the various topics covered in this book, giving instructions for locating pertinent information. It also points to the interplay between topics, guiding well designers to areas in the book on related issues, possible allied effects, and technologies that can be used during various processes.

These introductions are performed using the basis of a typical high-level holistic well-engineering management system, which is intended to provide support to the well-design and completion-design processes.

1.2 Overview of a Well Project

The elements of well construction are considered in the larger perspective, which includes project management, opportunity and risk assessment, and economic evaluation.

The overview of a well project includes all the high-level processes of well design, implementation, reporting, and feedback. These processes form part of the well-delivery process and the decisions made therein, [more fully described in Okstad (2006)], which are the outcome of sound project management.

The well-delivery process encompasses all the activities required to get from start to finish and is the responsibility of the drilling team. The process spans from the first concept of need for a well through developing that concept into a detailed design, constructing the well, maintaining it during its life, and, finally, abandoning it. The process noted here provides an extremely simplified version for the purpose of guiding engineers new to advanced well design. Experienced engineers will know that many of the components of the process as noted here are in fact carried out in an iterative manner and that the results of one calculation or inference often affect others. A highly skilled well-design engineer is able to determine when the outcome of one finding will impact other aspects of advanced well design and can take appropriate follow-up action. Responsibilities within the drilling team for carrying out design and planning, approving this work, and overseeing the implementation on-site are normally defined in the well-engineering management system, as are the responsibilities at the interfaces of external information input (e.g., by geologist or reservoir engineer), and at the interfaces for reporting to external parties such as regulatory bodies.

The well-delivery process has been viewed and defined from many perspectives—especially in the late 1990s—in order to fine tune and highlight the effectiveness of the parts of the process that were significantly impacting the key performance indicators (Kelly 1994; Robins and Roberts 1996; Dudouet and DeGuillaume 1995; Dupuis 1997; Morgan et al. 1999). However, in practice, the detail needed in almost every case of well design and completion design is different from one well to another. The main uses of the descriptions of business processes, at whatever level of detail is needed, are to ensure that matters requiring follow-up are properly flagged, that input (at the required accuracy) is provided by all necessary parties, and that an audit trail exists to support the process and enable tracking of decisions made.

The framework that guides the reader through this chapter refers to a management system that supports this well-delivery process and the subprocesses of well and completion design, well construction, and completion placement, right through to a responsible handover of the well for production, and all processes underpinned throughout by well integrity-assurance processes.

1.2.1 Advanced Well Design. Excellent advanced well design is the thread that sustains a successful well-delivery process. The process of advanced well design is similar to that used at a basic level; however, there are two principal differences as the design proceeds:

- Alternative ways of fulfilling the needs are constantly considered.
- The designer has to push out of the conventional *box* and sometimes beyond the comfort zone of both the designer and his or her peers. Design *rules* that may have been set previously must be challenged consistently. We must always revert to the objectives we are trying to achieve and not remain bound by traditional design methodology.

To be skilled in advanced well design, the designer must first become conversant with the technologies that are available and not be put off by perceived risk. Every risk that is presented can be minimized. As designers investigate further into experiences with certain technologies of interest, they will become more able to state for their management what real risks still exist with that technology and what opportunities others have realized.

1.3 Objectives, Needs, Assurance, and Resources

The first step in advanced well design is establishing the boundary conditions: What are we aiming to do? What is the arena in which we will work? How can we be sure to achieve the objectives? And what tools, equipment, and skilled people do we have at our disposal?

The well will be requested to fulfill specific corporate objectives. It will also have to meet design constraints, or *needs,* such as conveying fluids of a particular composition or accessing a reservoir at a point displaced from the well's surface location. Assurance that the well design meets these objectives and needs must be established to enable release of finances for the project. To estimate the authorization for expenditure (AFE), the specific resources required to carry out the work program must also be established.

To commence the journey along the well-delivery process, we begin with what is normal, good practice at the start: to define the objectives of the well. The objectives will depend on the purpose of the well that is to be constructed, and the environment within which it is set.

A well may be needed to fulfill a number of objectives depending on its purpose—it may need to meet the requirements of wildcat exploration, field appraisal, development, or even redevelopment:

- For data only or for injection, production, or observation
- To fulfill license commitment requirements

The well activity could be envisaged in several varying environments:

- Onshore or offshore
- New basin or known geology
- Sweet crude, sour crude, gas, water, or steam
- Situated in hot desert conditions, in temperate climate, or in arctic conditions
- Located in an area of strict environmental compliance or under various regulatory regimes including those that are not yet fully matured
- The well may be for a major oil company or for a much smaller independent

All of these varying requirements place different demands on the well. However, the processes of well design can still follow a similar path.

1.3.1 Objectives. ***The Starting Point.*** The best practice is to focus on the target objective. This includes repeat sessions with the client to clarify well objectives. Often, the client's link for a well's purpose to corporate strategies is not fully annotated initially, and as the well engineer seeks answers to questions, there is a firming up of strategies and objectives by the client's team, which often consists of members of several different functions (e.g., reservoir engineers and geologists). Specific objectives for the drilling program and for the completion program will become evident as this questioning process proceeds.

The well engineer must establish from these corporate objectives any specific requirements or limitations to well design:

- Final wellbore size
- Completion intervals
- Formation evaluation requirements
- Perforation strategies and sand control

Approved corporate objectives should be documented with sign-off by all relevant parties. This provides well designers with their proper remit and a good starting point.

Examples that will be more fully explained in the book will tend to hone in on wells using advanced well design and new technologies to meet the objectives of the well within the constraints imposed.

Final Wellbore Size. Today, many more options can be considered for final wellbore size. Traditionally, final casing or liner sizes were set between 4.5 and 7 in.; these sizes permitted tubing strings to be contained within the casing or liner and to have a packer set therein, isolating the annulus between the tubing and the casing or liner. Production technologists could specify the ideal tubing size to suit all the anticipated production fluids and capacities throughout the well's life. The casing or liner size was established from the required tubing size, but the tubing string size was often restricted by a non-optional final well-bore size. Exploration wells aiming to log only the borehole could even run out of workable hole size when casings had to be set to close off troublesome zones.

Advancements to provide more options recently have been demonstrated. These have been driven by many significant needs, including the requirement for bigger-bore completions [e.g., for tubing with an outside diameter of 9⅝ in. (244 mm) for high-rate wells].

The requirement for too many casing seats traditionally has forced the designer into a smaller-than-practicable final wellbore size, or into having very large surface casing sizes. Several technologies have recently come to the forefront to address these challenges: expandable casings, managed-pressure drilling, and casing drilling.

Expandable casings have the potential to offer an entirely different way of setting out casing configurations within the well, enabling the reservoir wellbore size that is ideal for production to be realized. Expandable casings can even enable focus on optimizing the hole size without compromising reservoir wellbore size (e.g., where as extended-reach wells require an ideal hole size in the high-angle portion, or require having a trouble zone cased off early).

Being able to push casing seats down farther is one of the many positive attributes of the managed-pressure drilling technique, which is described in Chapter 9.3. In some cases, this technique is combined with casing drilling to ensure the attainment of the casing-seat depth. The technique of casing drilling is also described in Chapter 9.2, and it has been used in innovative ways to overcome loss of final wellbore size caused by hole problems.

Several well examples have revolutionized completion design, with the production packer now being seated in production casing above a sealed liner top, together with production-well kill philosophies that do not require kill fluid in the annulus close to the reservoir. These examples in turn reduce the casing or liner size needed across the reservoir and are well illustrated in the over-pressured gas wells of the southern North Sea.

Monobore completions are now accepted practice in some areas where corrosion of the casings is unlikely to occur during the production life of the well. The principle of desiring the ideal tubing-size specification thus becomes even more important because it is now possible to obtain this.

Completion Intervals. Are the zones to be produced all to be open from the outset? Is there a likelihood of differing pressure regimes from one zone to another? Is the reservoir pressure predictable before the zones are penetrated by drilling? Will the pore pressure be detectable at the time of drilling?

The answers to these questions and the certainty of each will lead well designers to ensure that they have contingent plans in place to avoid wasting time (and money) in responding to a possible outcome for which there is no established plan.

Formation Evaluation Requirements. The biggest advance in this respect is the use of underbalanced-drilling techniques, which can offer not only the benefit of reducing impairment but also the allowance of well testing while drilling (see Chapter 9.1).

There is considerable reward for designers in minimizing he critical path time for rig operations. As these are heightened further, innovation is creeping in to remove activities from the critical path, including formation evaluation activities. Openhole logging tools have become crammed into shorter units to enable combination runs to replace several runs of logging tools and to become a norm. Likewise, longer coring runs are achievable in one attempt. More focus is placed on enlightening the customer with the cost of information gained in these ways to enable compromises to be settled upon. Logging results derived from measurement-while-drilling techniques are now widely accepted as definitive surveys for formation evaluation purposes by oil companies and regulatory bodies, although there is controversy over the outcome readings. Unfortunately, it is still necessary to spend time on a gyro survey to define directional paths of wells that may later have other wells nearby or are to be sidetracked in or near a reservoir.

Perforation Strategies and Sand Control. The first design choice would be to perforate or to have an openhole completion of sorts. Perforation technology has moved ahead, and the choice for selection now spans a wide range.

Once the well designer has information about pore pressures and reservoir characterization, including the extent and thickness of interbeds and the nature of the reservoir rock and its permeability mechanisms, agreement can be reached on how perforation intervals will be chosen—what log they may need to be based upon, the intensity of perforation (shots per foot), and the phasing. From mud types and prediction of formation-invasion characteristics and perforation-channel constraints on production, the desired depth of penetration and type of perforation charges can be selected. These must be compatible with the technique by which they will be introduced and discharged.

The whole completion sequence will have to be considered in detail at this point and *what if* scenarios worked through to ensure that the well can be used in the way required.

Openhole completions can have screens or slotted pipe set across them, or simply can have raw sandface exposed. The use of expandable sand screens and sandpacks have changed the options for completion extensively.

1.3.2 Define the Needs of the Well. Differentiating the needs of a well at an early stage can simplify much of the planning. If the final product to be conducted through the well is to be gas, then this immediately calls for a requirement for gas integrity of the well. This also can lead to constraints on well configurations, tubular connections, and kick tolerances permitted by some oil companies' in-house well-design policies.

If the fluids that are to be conveyed will have significant carbon dioxide or sour gas content, then this normally implies further metallurgy constraints to the materials that will be used.

The production magnitude, lifetime production profile, and changes of fluids must be established. Often, this will be linked closely to the economics of the project that this well supports.

For example, if the well is to be an exploration well to collect geological samples and log data only and no fluid is to be flowed, then the size of the final conduit could well be quite small (6 in., or 152 mm). However, if the well must produce at a high flow rate, a maximum-size reservoir conduit will be most favored. When considering if this is the requirement, it also needs to be established whether a high off-take will be sustainable by the reservoir over a considerable period. Related facts to be established are the viability (both practical and economic) of re-entering the well to change tubing size or completion configuration as the well life proceeds and the supply from the reservoir changes in pressure and, perhaps, rate.

Similarly, the shape of the well must be understood by all in light of the forecasts of hydrocarbon deliverability (e.g., with a lengthy horizontal well) and the susceptibility of wells to water ingress over time.

The key to good well design at this stage is having already thought through remedial plans to cope with the changes of fluids flowing into the well during the well's predicted life cycle. The key to success for a company is having all the stakeholders agree on such plans, and the likelihood of their being needed at this stage. Several iterations made on such points at this stage will provide huge gains for the advanced well-design engineer (and the company), both in the subsequent design process and in the longer term.

A similar set of discussions is needed to establish the completion design and to challenge it. It must be established whether any form of smart technology is to operate or be resident in this well at any time in the well's life. Will downhole monitoring systems be required? Are downhole flow-control devices envisaged? Would the field development benefit from special adaptations or special configurations of wells? Could the well be expected to have a junction in it?

A basis of design for both the completion and the well is normally drafted at this stage to capture the assumptions thus far and to provide a repository for more detail as further data on the materials or formation properties are collected.

The basis of design can be used as the first formal statement showing that well integrity is to be established for the life of the well. The document will name the conditions likely to be encountered and point out how each is to be met in a way that shows that basic philosophies supporting well integrity are maintained. For example, most oil companies adopt a two-barrier policy, and demonstration of the intent of meeting this policy can guide the development of designs and will certainly influence material and equipment selections and operational sequencing.

Data Sourcing, Collation, and Analysis. Once the basic requirements for the well have been established, as many data as possible are assembled to define the environment within which this well must be constructed. Data sought are typically:

- Likely and available surface location, including note of restrictions
- Weather, water depth (if any), and any constraints implied thereby
- Subsurface data including
  - A geological prognosis
  - Geological information showing regional stresses
  - Pore pressure/depth profiles, reservoir fluid type
  - Fracture pressure/depth profiles
  - Temperature/depth profiles
  - Nearby well paths

- ○ The nature of each of the geological formations and their drill ability, well-bore stability performance at various hole angles and azimuths
- ○ Mud programs from past wells and their success

For each of the components of work in data collation and analysis, the advanced methodologies in this book can be considered. Guidance on when these advanced methodologies may be used appropriately is indicated in **Table 1.1.**

First Pass: Planning the Well. The interpretation of these data with a view to meeting well objectives (established earlier) is used to define (ideally), in the following order:

1. Completion details
2. Well paths
3. Formation characteristics that will impact well design
4. Casing-seat placements in certain formations or at or below specific depths
5. Casing configurations: sizes, weights, and connections

The overall well design is thereby generated, incorporating

- Completion design
- Well profile and direction
- Casing design: production casing or liner and intermediate and surface strings

For each of the components of work in planning the well, the advanced technologies can be considered. Guidance on when these advanced technologies may be used appropriately is given in **Table 1.2.** The pore pressure and fracture pressure plot with depth are the keys to determining which enabling technology could add value by reference to **Table 1.3.**

TABLE 1.1— DATA COLLATION AND ANALYSIS TOPICS IN THIS BOOK

Data Collation and Analysis Topic		Chapter for Reference
Wellbore stability	Chap. 5.1	Geomechanics and Wellbore Stability
	Chap. 6.1	Images While Drilling
	Chap. 6.2	Geosteering
Pore pressure	Chap. 5.2	Normalization and Inversion Methods

TABLE 1.2—ESSENTIAL WELL-PLANNING TOPICS IN THIS BOOK

Well-Planning Topic		Chapter for Reference
Casing seat placements Casing configurations Tubing selection	Chap. 2	Advanced Casing and Tubing Design
Completion details	Chap. 3.4	Loads, Friction and Buckling
Well paths—trajectory design	Chap. 3.1	Advanced Drillstring Design
Well-control modeling	Chap. 4.2	Well-Control Modeling

TABLE 1.3—ENABLING-TECHNOLOGIES TOPICS IN THIS BOOK

Enabling-Technologies Topic		Chapter for Reference
Using underbalanced-drilling fluid hydrostatics	Chap. 9.1	Underbalanced-Drilling Operations
Using at-balanced-drilling fluid hydrostatics	Chap. 9.3	Managed-Pressure Drilling
Using foam as drilling fluid	Chap. 4.3	Foam Drilling
Casing while drilling	Chap. 9.2	Casing While Drilling

1.3.3 Assurance to Achieve the Design. Once the well design is outlined, it will be important to ensure that the complete drilling program can support the requirements to fulfill the objectives of the well. Assurance that the well can have continued integrity will become progressively more of a concern to satisfy the regulatory authorities.

Management will need to be presented with several ways to design the well, with the cost for each set out and a list of the strengths, weaknesses, opportunities, and threats presented by each. Assurance that the designed well can be put in the ground will need to be justified. The more non-standard and the more deviations from traditional technology that are proposed, the greater the depth of study to prove the project viable. Identification of the opportunities that the design offers is highly valuable at this stage. The reservoir engineers should be encouraged to share their vision of how the well will continue to drain the field during its life, including production rates, fluid types, and whether water influx or sand production will likely occur after a specific number of years.

Certain parts of this book provide guidance on how this can be addressed within an advanced design approach. **Table 1.4** points to the following components:

- Directional program
- Drilling, workover, and completion fluids
- Drilling practices

Considerations for Special Environmental Conditions. When data are initially collated, it will become evident whether special environmental conditions exist. Examples that will require a complete additional set of considerations are deepwater or high-pressure/high-temperature subsurface conditions.

For each of these special environments, there are complete chapters in this book to guide the engineer as to extra considerations and different approaches that must be made for such advanced well design as per **Table 1.5**.

TABLE 1.4—FURTHER WELL-PLANNING TOPICS IN THIS BOOK

Well-Planning Topic		Chapter for Reference
Drillpipe	Chap. 3.1	Advanced Drillstring Design
	Chap. 3.2	Drillstring Dynamics
Mud and completion-fluids program	Chap. 4.1	Wellbore Hydraulics
Directional program—geosteering wellbore measurements: tools, techniques and interpretation	Chap. 6.2	Geosteering
	Chap. 6.5	Drilling Vibration
Formation evaluation program	Chap. 6.4	Formation Pressure While Drilling

TABLE 1.5—SPECIALIST ENVIRONMENTAL CONDITION TOPICS IN THIS BOOK		
Specialist Environmental Condition Topic		Chapter for Reference
Deepwater wells	Chap. 7	Deepwater Drilling
High-pressure/high-temperature wells	Chap. 8	High-Pressure/High-Temperature Well Design and Drilling

1.3.4 Resources to Meet These Requirements. Resources to enable the designed well to be put in place are next determined by the advanced well-design engineer. In particular, it is determined what is available and what is appropriate with respect to

- Drilling rigs or workover units
- Service equipment
- Access routes to supply the drilling rig and their limitations
- Local assistance, support, and any constraints
- Expert personnel to deliver the required objectives

New technologies have emerged within the provision of many services required for constructing and servicing wells. Examples are set out in Chapter 9.4, "Coiled Tubing Drilling" and Chapter 9.5, "Novel Drilling Techniques."

The complete well design and the resources to be used are normally documented in a drilling program. Appendices of this program provide the outline of how special components of the program such as the mud or the directional program will be executed. For operations on the United Kingdom Continental Shelf (UKCS), the drilling program is referred to as the Health and Safety Executive (HSE) Submission. As in many countries, it must be submitted to the regulatory authority for approval or acceptance prior to permission being granted for the oil company to construct the well.

The detailed procedures for all the planned activities then are compiled in a detailed drilling program. The well engineer performs significant planning with all of the required parties and also organizes formal risk assessments that address the additional risks created by the interactivity of the various contributors (which are over and above the risk assessments that each service provider performs in-house on the activities for which each is wholly responsible). It is important not to miss the risks presented by bringing together different teams of service providers: No two well designs are identical; thus, a myriad of risks are presented for which minimization, mitigation, and responses need to be thought through formally before activity on-site.

A typical management system for companies operating on the UKCS formalizes what in fact tends to work well anywhere. Excerpts of flow charts from this management system are provided in **Figs. 1.1 through 1.4** to show how the design process is rigorously integrated; the charts include definite steps and checks by the well examiner for well integrity, and risk assessment activities are injected as the design develops right from the basis of design through the well-drilling program and on through the development of detailed procedures. Well design and completion design are addressed in the same rigorous manner.

The management system goes on to point out in particular the steps in which well-integrity concerns would be identified as the well is constructed (or as the completion is put in the ground), as reporting and handover of the product well to the customer is achieved, and as review occurs.

1.4 Implementation

1.4.1 Delivery of the Advanced Well Design. Enabling on-site delivery of the design requires several key systems to be in place. The size of the project to which this well contributes can vary greatly. Where the well