Preface

About a dozen years ago, after my first SPE Distinguished Lecturer circuit on a related subject, I realized from my visits to various SPE sections that there was a gap and a perceived need to provide balanced, yet comprehensive, information on Reservoir Surveillance that was both practical and didactic. During those visits, I interacted with engineers and scientists around the world who were interested in the subject. They were keen on the application side, but most of them had working knowledge in only one or two of the functional disciplines that comprise the whole field.

At the same time, the industry was just beginning to develop a structured framework for evaluating, planning, and executing surveillance programs in an integrated fashion with a focus on the bottom line. The disciplines of Options Value and Decision Analysis were coming into vogue in the oil industry, and tremendous improvements in instrumentation and surveillance systems were occurring. But the justifications for large expenditures in monitoring were getting difficult owing to low oil prices. Unfortunately, the industry was simultaneously undertaking substantially increased risk with leaner appraisal programs while entering even harsher environments and addressing complex reservoir systems.

The need for guidance on addressing these issues in a structured way could not have been greater. Yet the struggle for what a book such as this would address was vexing. Surveillance can be applied exclusively to any single functional discipline within our business, but a study on surveillance is incomplete without a consolidated view of its value to our assets in a global sense. It was also critical to inculcate the view that surveillance is an ongoing process that generates new opportunities and, hence, the inclusion of the concept of aggregation of reservoir intelligence over the asset life.

Having struck a balance on that, the next question was, who would the book's audience be? This was partly easy because the focus had to be on the application of surveillance methods for our practicing engineers and tied to business objectives. Nonetheless, there is a rich literature in other industries, including foundational information from industrial engineering on reliability, goal-based decision analysis frameworks, and abstraction methodologies from data analytics and data mining techniques that we can learn from. I am a firm believer that in the not-so-distant future, surveillance will be a discipline on its own and we will be graduating surveillance engineers with a background in reservoir engineering, production engineering, hardware technologies, formation evaluation, and deeper understanding of surface facilities. These budding engineers need exposure at the university level.

Today, a few companies are taking bold steps in making surveillance a mainstream activity. I believe they are being visionary, as the whole construct of reservoir development in the future may revolve around risk and uncertainty management, in which surveillance plays a central role. I anticipate that universities will institute classes dedicated to surveillance in short order, and books such as this one will assist in developing our next generation of surveillance engineers with practical backgrounds in software, hardware, data management, interpretation, design, and optimization techniques.

I have tried to address these conflicting yet important requirements in this book. This has required, at times, not going into detail in some areas while exposing enough for understanding, clarity, and follow-up. To some, this may leave something to be desired, but a thick tome with a handbook-like feel was also not worthwhile because in this business, practice and experience will be irreplaceable in the end.

I hope that this book will be useful to university students as well as early to mid-career practicing engineers in production, reservoir, and operations alike. Charts, tools, and tables with practical guidance will hopefully assist in putting the book to early and good use.

Happy Surveilling!
Jitendra Kikani
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Chapter 1

Introduction

In Webster's dictionary, *surveillance* is defined as "close observation of a person or group especially of one under suspicion." The literal definition is confined to the act of passive observation, which in itself has little value in our business. Monitoring and reconnaissance are other terms that are used interchangeably. Reconnaissance is defined as a mission that requires active participation rather than simple passive observations. In military parlance, surveillance and reconnaissance are clearly distinguished. Both involve observations using similar sensors, platforms, and communications but differ from each other in that surveillance is systematic and continuous but reconnaissance is not.

The word *monitoring* is interchangeably used with surveillance, and to some it implies more than the act of observing (i.e., it includes the analysis and prediction components). For purists, surveillance has the connotation of passive activity while monitoring implies somewhat active participation. Canonically speaking, we use these terms under a broader umbrella of activities underlying the processes. Both of these terms are used interchangeably in this book.

Surveillance has been used in the oil industry since the early days; however, until recently it has been mostly episodic and reactive in nature. As production from wells in producing fields declines, measurements are made to understand the cause and appropriate remedial measures are taken. With the increased availability of hardened military electronic hardware technologies and improvements in indirect measurements, the industry has embraced surveillance. The practice is now at a point where most projects are required to have proactive surveillance not only to monitor the health and safety of the systems but also to ensure active reservoir management decision making. This has been possible because of improved correlation of direct and indirect measurements with uncertain parameters of interest.

Surveillance techniques were first discussed in the SPE literature in the early 1960s (Kunkel and Bagley 1965). Since then, reference to surveillance has been made, but mostly in the context of episodic data gathering to monitor performance, primarily in flooding situations (Talash 1988; Bucaram and Sullivan 1972; Moore 1986). As enhanced oil recovery (EOR) techniques got used more extensively and piloting became common, integrated plans for surveillance started to occur in the literature. Talash (1988) contends that the desire to understand chemical recovery process applications led to a significant increase in surveillance activities. Discussions relating not only to data gathering but also to documentation, automated systems, data integration, and other process elements started to appear (Thakur 1991; Terrado et al. 2006; Grose 2007).

A common failure of field development plans is to underemphasize that effective reservoir management requires ongoing investment and an evergreen surveillance plan.

There is now an extensive body of literature. This spans from data acquisition, measurement and interpretation techniques to surveillance planning, system integration, real-time monitoring, data management, as well as a multitude of case studies. While the citations provide insight into possible permutations and industry experiences, it is difficult to find common process, design, and implementation of surveillance programs that link to value drivers for active decision making.

Substantial synergy can be realized when surveillance is coupled with data assimilation, active analysis, correlation, and prediction. These activities set the stage for the success of active reservoir management plan that uses knowledge intelligence to maximize field value.

The four stages of value creation using measurements, in order of increasing benefits, are

- Data[*]
- Information
- Knowledge
- Intelligence

Fig. 1.1 shows these stages along with the characteristics pertaining to each stage. Significant increase in effort is required for large gains in value as the information is converted to knowledge and then into intelligence. Intelligence is gained when we possess the ability to predict the future for a parameter, property, or system. The rapidity with which companies gain system intelligence differentiates and distinguishes them from their competitors (Apgar 2006).

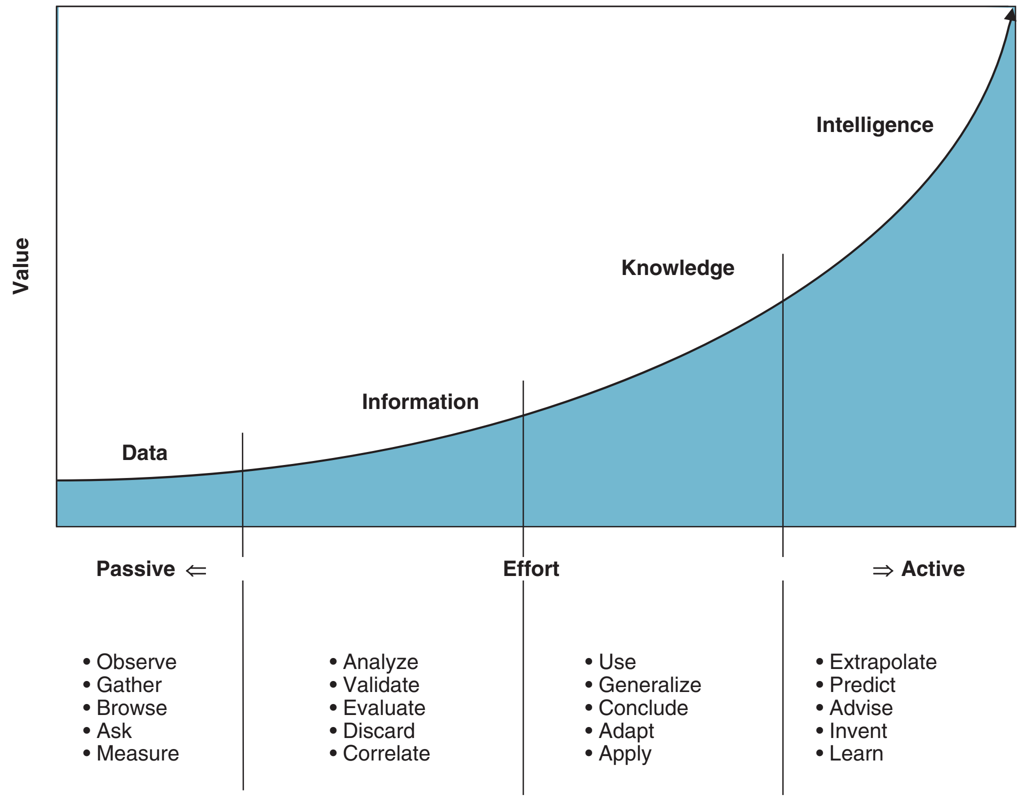

Fig. 1.1—Value is created by active surveillance.

[*]Data refers to a collection of an organized set, usually the result of experience, observation or experiment, or a set of premises.

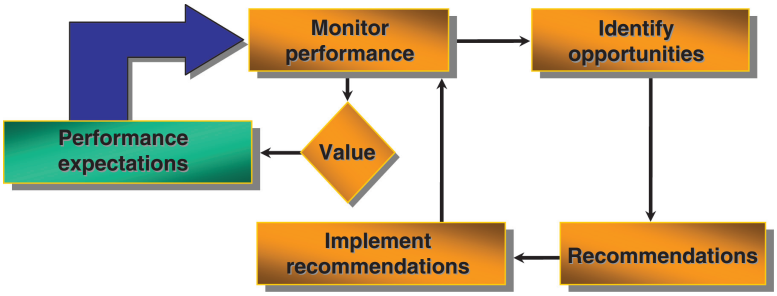

Fig. 1.2—Role of surveillance in asset management.

A definition of surveillance that is more suitable for managing hydrocarbon assets is *the continuous process of generating opportunities for improving reservoir performance* (Kikani 2005). In this book, surveillance is used within this context. **Fig. 1.2** illustrates this concept. Asset teams set performance expectations based on the current state of knowledge. Key uncertainties are defined and relating parameters are monitored. This leads to identification of gaps in understanding and meeting performance expectations; the correction of which results in the generation of further opportunities. As the opportunities are seized or realized, further surveillance is conducted, leading to modified performance expectations from the reservoir. This closed-loop interface between opportunity creation and expectation is driven by surveillance. The end result is to drive the asset toward optimality (Thakur and Satter 1994).

1.1 Monitoring in Industrial Systems

The monitoring process for any industrial system is implemented at a number of levels depending on the mission critical nature of such systems. From a process control perspective, the following steps are taken:

- Sense
- Monitor
- Measure and feedback

Each step has its place depending on the parameters it influences and actions that may be necessary. In fail-safe and safety systems, for example, the sensing of equipment condition and health that influence long-term actions and compliance would qualify as the lowest common denominator. *Monitoring* would imply the need for alarm or an alert to indicate exceedance of certain specified tolerance levels in say pressure, temperature, fluid level, etc. The actual values are not important; however, a relative level based on set-level indicator is needed. *Measurement* on the other hand assumes a more active participation. The quantification of the parameter becomes important in these conditions. Generally, this is needed in situations where we not only want to be aware of levels exceeding a certain value but also want to find out how much (absolute value) and how fast (gradients), so that corrective actions can be designed in current and future systems. Quantification also allows the ability to predict future occurrence. This concept is discussed in terms of level of monitoring by Sengul and Bekkousha (2002).

1.2 Military Surveillance

In military surveillance, if a threat or tension is ever present over a defined area, surveillance needs are defined by our ability to react (i.e., they are objective driven). If a critical event starts and develops into a conflict within a certain time, it is imperative that the surveillance be continuous if time to develop a tactical picture is of similar scale as the time it takes for the event to develop into an armed conflict (Ince et al. 1998) (i.e., timeliness and frequency of surveillance activity are critical design parameters).

The degree of continuity or intermittence permitted in a surveillance system is related to the threat perception in the area. It is determined by the condition that the time interval during which the area is not observed or the tactical picture is not available is not larger than the duration of the development of the undesirable situation.

For systems design, with a given or specified performance in terms of decision parameters, it is necessary to know how these parameters relate to the functions of the operational system.

1.3 Reservoir Surveillance

Surveillance programs are part and parcel of initiatives aimed at reservoir characterization, development, and management. These programs result in different actions being taken depending on the stage of field development.

Surveillance programs are not merely data-gathering exercises but impact routine and long-term decisions. In other words, if a specific set of measurements do not reduce the uncertainty in some parameter estimate and/or do not directly assist in determining and/or changing a decision, the value of the acquisition of that piece of data is questionable.

The function of reservoir surveillance is to provide facts, information, knowledge, and intelligence necessary to

- Chronicle reservoir performance
- Provide information on performance parameters to improve ability for prediction
- Identify or anticipate barriers to meeting or exceeding forecast performance and provide methodologies to mitigate the impact

1.4 Global Perspective

In the past, attention was focused mainly on monitoring the production and injection side well and reservoir performance mainly to understand drive mechanisms, sweep behavior, and recovery issues. With the modern reservoir management approach, however, a more holistic approach is taken to get an integrated assessment of system-wide performance including bottlenecks and impact of constraints. **Fig. 1.3** shows a block diagram of the significant components of an oil/gas field. A quick review of the schematic illustrates the opportunity and complexity of surveillance

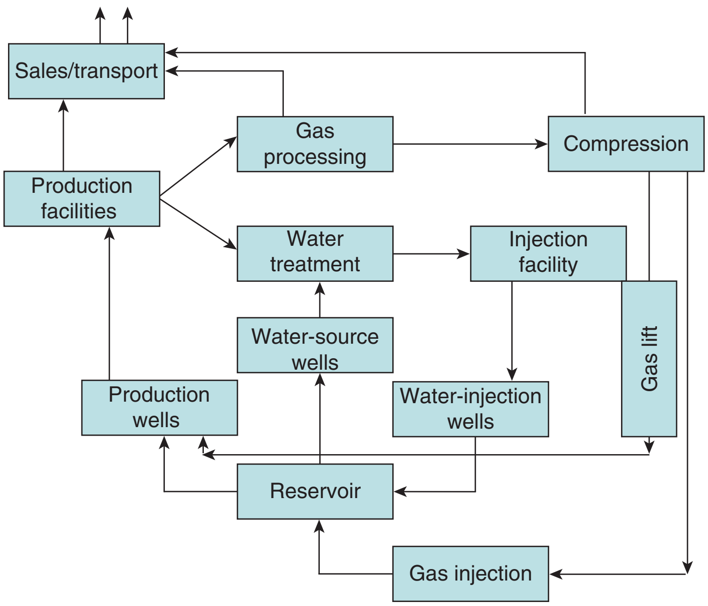

Fig. 1.3—Simplified facilities block flow diagram.

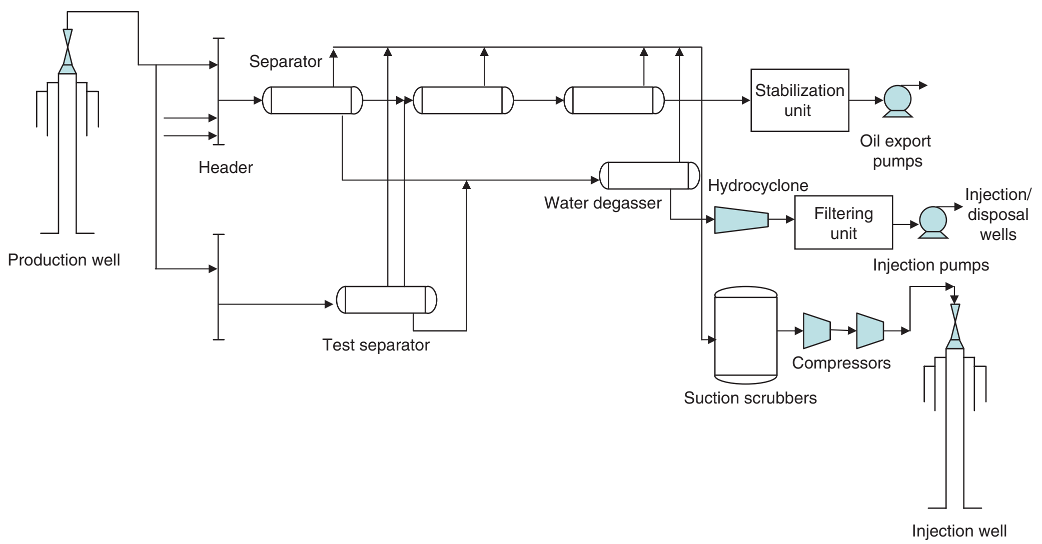

Fig. 1.4—Simplified process flow diagram of a typical injection/production facility.

and monitoring if an oil field is to be operated as a modern day factory or a plant with high reliability and optimal control.

Experience in many industries has shown that simple collection and monitoring of data at many different points in a process system has increased uptime and production efficiency by allowing operators to spot and correct trends before conditions occur that would lead to a process upset. **Fig. 1.4** shows a schematic process flow diagram of a typical facility. Note the multitude of available monitoring points. Ample choices exist for measurement and monitoring in an oil field. The key is to optimize the monitoring system by making it cost effective such that it facilitates decision making.

1.5 Surveillance and Decision Making

A large number of parameters can be measured in a modern day oilfield. With advances made in instrumentation and sensing technologies, one can measure until the utility of an additional piece of data is practically zero (in economic terms *marginal utility* is defined as the incremental utility of one additional unit of measurement). More formally, it is the slope of the utility vs. commodity curve (in our case a specific additional measurement) that matches the supply and demand.

The decision to measure a certain parameter at a given point in the system at a given time is invariably linked to its value. The value can be looked at as a quantification of benefit over cost (Sengul and Bekkousha 2002; Holstein and Berger 1997; Raghuraman et al. 2003).

There are measurements necessary for maintaining the health and process safety for any oilfield operation. These need to be considered separately with an eye for more global, political, and socioeconomic implications.

1.6 Objectives of Surveillance

Each asset has different overall surveillance objectives. These are driven by the strategic alignment of business drivers with the specific asset objective. A case in point would be a company's involvement in, say mining of Athabasca tar sands. Their stated business driver could be *"to be the company of choice in heavy oil operation around the world*." This specific business driver could lead to the setting up of surveillance objectives for the tar sands operation. An example of setting an objective for a surveillance plan for a gas-injection project could be *"to provide computer applications, processes and procedures to capture and deliver information on reservoir*