The Value of the Risk Assessment Process (Part 2 of DHM Series)

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Abstract

Nothing is without risk in drilling and completion operations. Risk cannot be eliminated, but it can be managed. Drilling Hazards Management means using mitigating practices and technologies to deliver the best risk management methods and tools.

Drilling Hazards Management is the practice of managing the mechanical and efficiency risk (This paper does not deal with HES risks) of all drilling operations. Managing risks requires applying the best practices and mitigating technologies to successfully reduce the risk profile while improving the risk adjusted cost of applying such mitigants successfully.

On occasion, hazards do not just occur; rather the industry can be guilty of inducing hazards. DHM requires understanding the totality of drilling data to avoid inducing risks and applying best practices and technologies to mitigate risk. Good drilling practices revolve around interpretation of the totality of the data to make the correct pro-active decision while drilling.

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1 The Value of the Risk Assessment Process

Attaining success with DHM depends on a cognizant and deliberate recognition of the project's risks. If executed effectively, the process yields a comprehensive awareness that provides a foundation to not only mitigate risk but optimize operations. Nothing is without risk in drilling and completion operations. Risk cannot be eliminated, but it can be managed. Complex wells especially require multi-disciplinary alignment to ensure and sustain performance and marginalize risk.

The basic premise of DHM is to eliminate, reduce, or prepare for risks and hazards by following a distinct process. Aligning objectives is a multi-disciplinary responsibility necessary to manage drilling hazards and associated mechanical risk. Drilling Hazards Management means using mitigating practices and technologies to deliver the best risk management methods and tools.

The risk assessment process can be conducted for any operation. With an evergreen, iterative process planned mitigations that create further risks can be evaluated. There is not a correct or incorrect way to identify and assess risk; however, there is a distinct process to follow. This process implemented should be used to critically challenge each facet of the well design.

Risk assessment should be applied at the following stages of the previously defined well planning process World Oil article entitled "Drilling Hazards Management: Excellence in Drilling Performance Begins with Planning."

- Phase 2: Analysis – design alternatives evaluated for potential risks, possible hazards, and probable benefits facilitate selection of the best approach.
- Phase 3: Design –the Basis of Design (BoD) provides specifics of the selected alternative and requires more focused evaluation.
- Phase 4: Execution –risk assessments of all procedures, logistics, communications, etc. should be conducted to ensure that all risks are managed, help minimize non-productive time and sustain performance.
- For any change in scope of the operation, a Management of Change (MoC) should be accompanied by a risk assessment of any new procedures, practices, or technologies.

Three determinants succinctly sum up how risk can be managed risk—accept, mitigate, or avoid.

Accepting a risk means that the likelihood and consequence of the risk event actually happening ranks so low that it is an acceptable risk to undertake. This likelihood is commonly referred to as low as reasonably practical (ALARP). Mitigating means that the risk, as currently understood, is not acceptable and requires new or additional intervention. These new mitigations can come in the form of best practices, polices, procedures, techniques, and technologies that better manage the risk. Avoiding usually requires revising the well design or mitigant-in-place or eliminating a step or task.

Using a risk matrix as a guidance tool enables the team to select any action they determine reasonable and appropriate for the operation. A matrix provides a vehicle for documenting and organizing what is important to better understand the risk profiles of the operations and manage accordingly. Decisions are guided by company policies, rules or regulations, as well as any regulatory authority.

Factual information, a clear scope, and well-defined objectives are needed to keep the assessment focused to accomplish a successful risk assessment session. The first step of the process is to perform due diligence and collect all pertinent data available.

Obtain the information

Data gathering is fundamental to the risk assessment process. Adequate data collection should include the most current information from all sources and stakeholders. Data can come from multiple sources including, but not limited to, local, regional, and global well histories, reports, studies, and personal experiences supported by facts.

2 Assemble the Right People

Risk assessment success depends on the quality and range of the participants' knowledge and experience. A broad knowledge base and wide range of expertise produce better results. Drilling engineering peers and other disciplinary personnel, such as geoscientists and reservoir and production engineers, should be integral sources of input during discussion and planning. Service providers are key contributors and those deemed critical should also be included in the process.

3 Plan the Risk Assessment: Scope and Risk Register

The degree of rigor applied to the risk-assessment process should be commensurate with the complexity of the well. Although the process can be tedious, it begins by defining the scope of any given risk-assessment session. All stakeholders involved need to provide their expertise. It is important for the disciplines as stakeholders to fully understand the impact of their own objectives, procedures, and requirements. The participants must know and understand the scope prior to the risk-assessment session and be prepared to brainstorm on any given operational task. Understanding the scope of any session affords the stakeholders the opportunity to gather and present their own experiences and data to discern possible, potential, and probable risks and hazards. Asking "what if" opens the session to speculate scenarios. If, for example, the session scope is risk assessment of tripping the drillstring, the "what-ifs" would include such issues as the risk of stuck pipe, loss of circulation, and swabbing. Participants prepared to bring their experiences and knowledge to identify risks and hazards help maintain efficient use of time, stay within scope, and compile a comprehensive assessment.

4 Conducting the Risk Assessment Sessions

The initial risk assessment session should be conducted in a multi-disciplinary environment to collect risks and associated consequences from the stakeholders. All participants should be given an opportunity to identify their risks and consequences, which can be accomplished through simple brainstorming.

Identification of potential risks constitutes the risk register—the "what-if" of any given operation. Once the "what-if's" are identified, consequences can be gathered by asking "so-what".

Effective rules of thumb for conducting a session include:

- Appoint an unbiased facilitator and an excellent scribe.
- Review the risk assessment tool and capabilities.
- Define and communicate the scope prior to the session.

- Keep the time limits reasonable. Experience suggests anything over two hours can be counterproductive.
- The idea of a brainstorming session is to record, simply and concisely, the risks and associated consequences, which constitutes the risk register.
- Complete the risk register offline by the engineer or other person responsible for the project or well.
- Do not debate or "word smith" the brainstorming session. Simply allow each person to offer their ideas and record them in the register.
- Work out granularity and details offline.

5 The Risk Assessment Process

The risk assessment process is evergreen and dynamic and should be continually reviewed and updated with the most current information.

Because a consequence can also become a new risk, the assessment process can be somewhat circular in nature. For example, if the risk is fluid loss and the consequence becomes stuck pipe, this new risk generates a new consequence, such as the pipe lost is irretrievably stuck. The key to addressing circular issues is managing the worst-case risk event first. This approach usually resolves circular issues and the original risk itself. The risk then eventually becomes mitigated and thus managed.

Sometimes risk can be superfluous, or deemed so by some of the stakeholders. Notwithstanding, these risks should always be recorded. The process, particularly if the worst-case risk events are evaluated first, often removes the superfluous issues by default.

Another issue that sometimes arises focuses on the costs used to determine the risk-adjusted value of a new mitigant. The assessment process at this stage should be with high-level discussion, and should cost enter into the dialogue, use rough numbers. Dwelling on absolutes at this point leads to getting caught up in the minutia and losing sight of the scope. If more granularity is required, a subsequent risk-assessment session can be scoped, communicated to all stakeholders, and conducted on that singular focus. Over time, granularity and objectivity improves. Establishing an initial base line is important, and the multi-disciplinary brainstorming sessions should be kept at a high level. If the process is kept evergreen and dynamic, details can be added later. First-time risk assessments conducted at a high level exemplify the old adage, the simpler the better.

The risk-assessment process should also determine and justify trade-offs between the geosciences, reservoir engineers, production engineers, and drilling engineers. Accommodating the disciplines is fundamental to the process and one of the reasons why it is necessary to assess any risk mitigant. Total cost of ownership means that the multi-disciplines understand the trade-offs that occur in well planning designs and, ultimately, the execution of the well. For example, directional well targets in slim hole profiles have specific risks associated with hole cleaning. The geosciences need to understand this issue and how the associated risks impact the cost of the well. Risk assessments become a decision quality tool and therefore assist in evaluating alternative well models.

6 The Risk Matrix

Acceptable forms of a risk matrix can range from the very simple high, medium, and low risk of occurrence to the more granular tabular matrix for probability on one axis and consequences on the other. In general, the more granular the matrix, the more valuable it becomes in terms of defining, ranking, and managing risks. Table depicts a typical industry risk matrix.

The risk matrix can be adjusted for levels of likelihood or probability and costs. Identifying costs associated with consequences are important to evaluate the added value and risk-adjusted costs of any new mitigant. The only exception is for health, safety, and environment (HSE) because it is not possible to monetize the value of human life. Adjustments to the matrix axis should be based on relevant best fits for any given project. For example, if an operation is in deepwater, costs should reflect those that are relevant to the operations itself. Probabilities are more subjective, but percentages of occurrence should be based on and agreed to by the team conducting the risk assessment. For a given project or well, the same matrix should be utilized. Over time, if the relative values of the project or well changes, exceptions can be made. In general, if the values are representative of the project or well, then unless they significantly change over time, the same matrix should be used to provide continuity for the well or project. Objectivity improves with better input data and experience.

Table 6.1 - Typical industry risk assessment matrix (Risk of Success, not HES)

Risk Matrix									
Probability (likelihood) Percentages & Index				**Notes:**					
Probability Percentages	**Likelihood Indices**								
>40 %	**1**	**Likely**	**Decreasing Likelihood**	**6**	**5**	**4**	**3**	**2**	**1**
20 – 40 %	**2**	**Occasional**		**7**	**6**	**5**	**4**	**3**	**2**
10 – 20 %	**3**	**Seldom**		**8**	**7**	**6**	**5**	**4**	**3**
5 – 10 %	**4**	**Unlikely**		**9**	**8**	**7**	**6**	**5**	**4**
<5 %	**5**	**Remote**		**10**	**9**	**8**	**7**	**6**	**5**
<1 %	**6**	**Rare**		**10**	**10**	**9**	**8**	**7**	**6**
Consequence Descriptions or Cost & Index	**Consequence Indices: Examples (can be adjusted for local costs)**			**← ← Decreasing Consequence/Impact ← ←**					
				6	**5**	**4**	**3**	**2**	**1**
				Incidental	**Minor**	**Moderate**	**Major**	**Severe**	**Catastrophic**
	Consequence Description	Wells and Subsurface*		**½ Day lost, Costs: <$100,000**	**1 Day lost, Costs: $100,000 - $250,000**	**Loss of Hole section, Costs: $250,000 - $1,000,000**	**Loss of >1 Hole section, Costs: $1,000,000 - $5,000,000**	**Loss of Well, Costs: $5,000,000 - $20,000,000**	**Loss of Rig, Costs: > $20,000,000**
		***rig / equipment damage / downtime and mechanical damage / downtime**							

7 The Risk Assessment Process Tool

It is important to capture risks in a tool that can be used to conduct and record the entire risk assessment process. The process must be auditable and sustainable. Table represents a typical industry risk assessment tool populated with step-wise aspects of the process that uses actual examples to illustrate key points.

Table 7.1 – The risk assessment tool.

	Risk	Consequences	Existing Mitigations in place	Likelihood (% Probability) of Occurrence with Existing Mitigations (IN PLACE)	Likelihood Ranking (1-6)	Consequence Ranking (1-6)	Risk Ranking Factor	Risk Response Choice: Accept, Mitigate, aVoid	Mitigations	Cost of Mitigations	Likelihood (Probability, %) of Occurrence with Mitigants needed in place.	Likelihood Ranking (1-6)	Consequence Ranking (1-6)	Risk Ranking Factor (w/ Mitigations Needed in Place)	Extra Time if event occurs (hrs)	Extra cost if the event occurs	Risked Time (hrs)	Risked Cost	Benefit Cost Ratio	Comments
1.00	**Hole Section 1**																			
1.01	Fluid loss in hole	Non productive time	Mud program, loss circulation procedures and materials, Blowout prevention equipment, pit drills	100 %	1	6	6	M												
1.02		Slight losses	Mud program, loss circulation procedures and materials, Blowout prevention equipment, pit drills	100 %	1	6	6	M												
1.03		Whole mud losses	Mud program, loss circulation procedures and materials, Blowout prevention equipment, pit drills	30 %	2	3	4	V	Mitigate this risk as the occurrence of the risk has resulted in lost hole sections with high costs. The new mitigant will be to add PWD for proactive ECD management	$500,000	5 %	5	3	7	72.00	$3,000,000	3.60	$150,000	150 %	This indicates that not only is the risk profile improved, but in a risk adjusted basis, the cost of the new mitigant adds value to the operation.
1.04		Well Control	Mud program, loss circulation procedures and materials, Blowout prevention equipment, pit drills	10 %	4	2	5	M	Mitigate this risk as the occurrence of the risk has resulted in lost hole sections with high costs. The new mitigant will be to add PWD for proactive ECD management	$500,000	1 %	6	2	7	73.00	$3,000,000	0.73	$30,000	54 %	The above further mitigates and justifies the new mitigant.
1.05		Blowout	Mud program, loss circulation procedures and materials, Blowout prevention equipment, pit drills	5 %	5	1	5	M	Mitigate this risk as the occurrence of the risk has resulted in lost hole sections with high costs. The new mitigant will be to add PWD for proactive ECD management	$500,000	1 %	6	1	6	74.00	$3,000,000	0.74	$30,000	24 %	The above further mitigates and justifies the new mitigant.
2.00	**Hole Section 2**																			

•These columns represent the **risk register**. The combination of a risk by a single consequence is a risk event. •First, identify the risk – the "what if?" •Migitants in place recognize exiting practices. •Each risk can have different consequences – the "so what?" •Probability of occurrence is based on data or experience. •Ranking from the matrix, **A**ccept, **M**itigate, or a**V**oid is suggested by color (red, green, yellow). Action is determined by the team. •The new mitigant is described with the intent to reduce the probability of the risk occurring. •The discrete cost of the new mitigant is indicated. •The new ranking is based on the lower probability of the risk occurring. The Consequence, in general, remains the same. Note the improvement of the risk profile. •Risk adjusted lost time and cost if the event still occurs. Normally the total non-productive time off the critical path to the time on the critical path. Associated costs are the total daily cost of operations. •This is the added value of the new mitigant represented by the *discrete cost of the new mitigant as a function of the reduced risk exposure.* This value for the worst ranked risk indicates that the mitigant has added value. •Thus the overall risk is managed by the new mitigant.

8 The Execution Phase and Well "Listening"

In the execution phase of well operations, DHM begins with understanding and making the correct proactive decisions regarding the totality of the drilling dynamics as illustrated in Table.

The industry has become so dependent on real-time data that a singular focus can result in a misinterpretation of issues. The commonplace issue of background gas, for example, can result in the quick tendency to weight up drilling systems arbitrarily. This reaction is counterproductive to performance and can also induce dangerous drilling conditions. Good drilling practices revolve around interpretation of the totality of the data to make the correct proactive decision while drilling.

Listening to the well is simply recognizing, integrating, and correctly interpreting all drilling dynamics—weight-on-bit (WOB), revolutions per minute (RPM), equivalent circulating density (ECD), and shale shaker cuttings—to assist in making the correct decision while executing drilling operations. The advent of real-time technologies facilitates accurate decisions and best practices for any operation.

Table 8.1 – Well listening techniques.

Indicators ECD Too Low	Comments
Unexpected high rate of penetration (ROP)	Mud weight too low can have the net effect of removing the force at the bit, allowing the formation being drilled to fail more easily, thus increasing ROP.
Torque/drag increase	Removal of mud weight force can cause the formation to collapse inward, thereby creating lateral forces on the bit, BHA, and drillstring.
Cavings (particularly "concave" or "splintered")	Recognizing types of cuttings over the shaker is critical to drilling data interpretation. Cuttings from a shale section where the wellbore is trying to fail will characteristically appear concave (the shape of the hole) or splintered.
Flow rate increase	Lessened force of the mud weight can create underbalanced conditions, allowing fluid influx into the wellbore.
Shut-in drilling pipe pressure +/– well control	An obvious condition of well control events or formations trying to feed into the wellbore.
Drilling break gas failing to "fallout" after circulating	Indicative of in-situ gas feeding into the wellbore from a permeable gas horizon.
BHA drift (principles stress vectors)	Pseudo-induced stress can be caused by tectonics, salt diapers, faults, etc. Stress can be quite different from pore pressure in magnitude and is a vector. This phenomenon can have the net effect of trying to force the BHA in a principle direction if not correctly balanced with mud weight. Recognizing the difference between stress and pore pressure while drilling is crucial to interpreting dynamic drilling data.
Hole fill-up (sloughing or collapsing hole)	Hole collapse can result in fill when off bottom and is quite common in softer formations.
Indicators ECD Too High	**Comments**
Unexpected low ROP	Mud weight too high can have the net effect of adding confining force at the bit, making the formation being drilled more difficult to fail, thus the ROP decreases with poor performance.

High bit wear	Extraordinary mud weight force creates more confining stress on the rock, effectively increasing the confined stress on the rock and making the rock more difficult to fail.
"Over-wet" shale	Mud weight too high increases the instability of the shale section. Shale is not permeable but does respond to wetting through ionic exchange, much the same as clay on the ground that cracks when dry then swells when hydrated. Over-wet shale reduces the net effect of inhibition, regardless of the drilling fluid. Even oil based systems are never 100% water free.
Mud weight too high creates unnecessary fluid losses, differential sticking, and exacerbates the risk of fracturing softer formations	Mud weight too high can create fluid loss events leading to stuck pipe or formation fracturing.
Mud weight and ECD too high will Increase opportunities for "ballooning," possibly creating unsafe drilling conditions.	This phenomenon is primarily associated with "ballooning", one of the most commonly misinterpreted drilling dynamics. Responding to a ballooning event by increasing mud weight exacerbates the problem in the best case and can result in dangerous well control situation in the worst case if inducing a fracture occurs.
Other Hazard Indicators	**Comments**
"D"exponents: Changing drillability trends (analogue of mud weight, ROP, and WOB)	"D"exponents represent real-time drilling analogues of specific energy applied to the bit or formation drillability. This data is normally and routinely compiled in the mud log and can represent shifts in drilling trends from a normal to a stressed environment. Trend shifts are very reliable predicators of changes in the drilling environment. This data compiled with other interpretations can be a clear indictor of the need to increase mud weight; especially in light of other interpreted data. "D"exponents are independent of bit type. A common misunderstanding in the industry is that "D"exponents have no value with fixed cutters, when quite the opposite is true. This engineering, specific energy algorithm has nothing to do with bit type. Another value of these as trend predictors is that they can help forecast changes in wellbore stresses, which PWD tools cannot. PWD tools measure only the net balance in the static and dynamic states.
Elliptical hole (principle stress vectors)	An elliptical hole is normally an after-the-fact indicator, but recognizing this stress-induced hazard can help plan the next well to identify wellbore stability issues and assist in directional planning. This data can also be used to compare conventional pore pressure predictions to stress both in direction and magnitude and to better deliver a reliable mud weight schedule and help improve predictions.
Fluffy, wetted shales (Chemical instability)	Chemical instability is common in shale. Cutting characteristics can be exhibited as "fluffy", or in the worst case, gumbo. This phenomenon can happen in any mud balance condition and is exacerbated if the mud weight is too high. If wetting occurs with mud weight too high, reducing the mud weight can create further instability because wetted shale will stress relive. New exposed shales undergo ionic exchanged and re-wetted. Once the applied mud weight is too high, it can be nearly impossible to correct this condition as the hazard will compound itself.

9 Potential Hazards

Misinterpreting any of the previous well listening techniques can result in inducing hazards ranging from simple fluid losses to catastrophic failure. Singular interpretation of conditions from any of these dynamics can be counterproductive to maintaining a safe and stable wellbore.

9.1 Ballooning (Wellbore Breathing)

"Ballooning" is a phenomenon and consequence often associated with an ECD that is too high. Resultant flowback when pumps are shut down can often be confused with influx from pore pressure greater than mud balance. This interpretation is often further complicated by gas entrained in shale, common especially in mottled shale. "Weighting up" the mud to counter the shale gas can further complicate ballooning. Arbitrarily increasing mud weight in the presence of shale gas alone can result in extending natural fractures or fracturing the formation below or at the shoe. The consequence can be catastrophic.

Failure to recognize ballooning versus well control is a common mistake made in drilling operations. It is also one of the leading causes of unnecessarily expending casing strings in narrow margin drilling operations such as High Pressure, High Temperature Operations (HPHT) and deepwater environments.

Table represents an actual example where high ECD resulted in ballooning, and subsequent raising of the mud weight resulted in extenuating fractures. The higher ECD further exacerbated wellbore instability conditions by increasing the cyclic bleed offs. Ultimately, the mud weight increase fractured the formation and massive and unsafe losses were sustained before regaining control of the well. The misinterpretation of ballooning required setting a liner before planned and losing a casing point.

Table 9.1 – The common misinterpretation of ballooning.

Condition	Actions Taken
Prior casing depth of 3,465m.	The casing was set with 1.7 SG mud weight, which was arbitrarily increased in the shoe track to 1.9 SG before drilling ahead. ECD management became difficult with frequent events of ballooning. Frequent flow checks conducted showed no flow. All other drilling dynamics were normal: no torque or drag and normal cuttings.
Background gas increasing in shale.	Several incidents of weighting up occurred without conducting any flow checks. Gas alone is not a reason to increase mud weight. Since shale does not have transmissibility but does have porosity, entrained gas is common and cannot be "weighted-out", especially in highly mottled shale. Entrained gas **always** arrives with the cuttings and expands according to Boyle's law, no matter the mud weight.
Continued drilling in shale from 4,055-4,268m, with increasing background gas.	Circulated and conditioned with no fill. Closed BOP, no flow, no pressure, and control circulated through the choke. No torque spikes, no drag, no fill with normal cuttings. Increased mud weight to 2.0 SG while circulating on the choke.

Condition	Actions Taken
Shut in drill pipe pressure, 340 psi, bled back with no further flow or pressure.	Closed BOP with 340 psi. Opened. The well briefly had slight initial flow and then shut in with no pressure. Well opened and was stable with no flow. Shut-in pressure was not measurable. Circulated and conditioned and further increased the mud weight to 2.3 SG. **Further increased mud weight to 2.45 SG with immediate and massive fluid loses. Ballooning-induced fracturing occurred after increasing the mud weight**. Three days of circulating and conditioning back to 2.1 SG was necessary to stabilize the well.
Severe losses as a result of inordinate and arbitrary high mud weight.	A decision to run liner once stable. The pore pressure/fracture gradient curves were normal. Other than background and connection gas, which bled off, there was no reason to increase the mud weight initially.

The conclusion from this well was that managing ECD and recognizing ballooning as a consequence of high ECD could have resulted in drilling this section deeper. Instead, a drilling liner was required before planned. Ballooning and then fracturing the well created an unsafe condition with massive fluid losses. This condition could have resulted in wellbore collapse, or worse, a shallower formation influx from an underbalanced formation.

When ballooning is recognized, care must be taken to avoid unnecessarily weighting up. Bleeding back trapped pressure as a result of ballooning is critical.

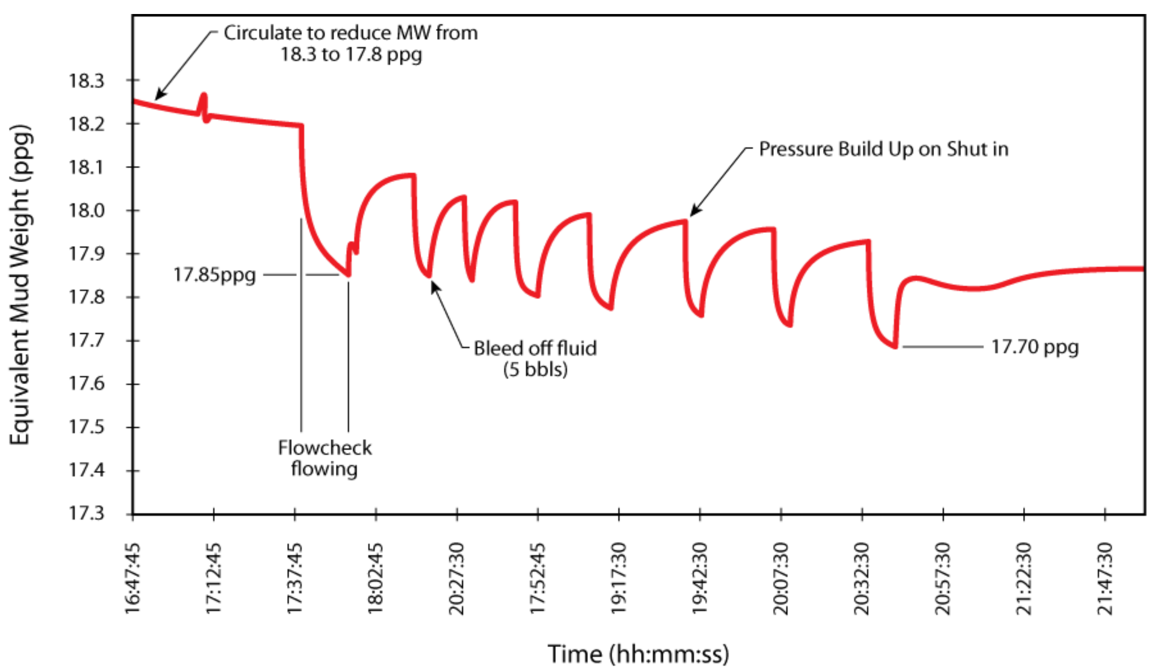

Figure 9.1 – Downhole pressure during fluid feedback from the formation.[ii]

[ii] SPE 38480 1997 Aberdeen Scotland: Measurement of Hydrostatic and Hydraulic Pressure Changes…., Swanson, Elliot et al. al.

9.2 Fluid Loss

Fluid losses can range from slight to catastrophic and result in wellbore failure or well-control events. The primary cause of fluid loss is exceeding the boundaries of the drilling margins, that is, exceeding the overburden fracture gradient, or the insitu pore pressures and stress of the formations. Exceeding these boundaries can be a result of ballooning, or in porous formations, merely the result of applying an unnecessarily high mud weight and resultant ECDs. Maintaining the ECD low enough to ensure fluid volume integrity yet high enough to exceed the lower boundary necessary for wellbore integrity is critical. Applying "well listening" techniques is a predecessor to making correct decisions driven by drilling conditions.

Sometimes losses can be acceptable and sustained. In these cases, recognizing the types, relative volumes, classes of lithology, and placement of proper fluids loss material is critical to the success of managing fluid losses.

9.2.1 Best Practice

The best practice and first line of defense is to avoid overweighting the hole and prevent ballooning events. Typical fluid loss decision tree processes can and should be created. Table is an example of the foundation of a fluids loss control applications process.

Table 9.2 – Defining fluid losses, lithology, and the application of loss control materials.

Generic Loss Circulation Control Methodology								
	Type of Formation							
			Sandstone				Coal	
Type of Loss	Conglom-erate	Shale /Silty Shale	Low Porosity	Medium Porosity	High Porosity	Fractured	Small Fissured	Fractured
Seepage Only	1, 2	1, 2	1, 3	1, 3	1, 3	1, 3	1, 8	1, 8
Small Losses	1, 2	1, 2	1, 3	1, 3	1, 3, 2	1, 3, 2	1, 8, 2	1, 8, 2
Medium Losses	1, 4	1, 4	1, 3, 6	1, 3, 2, 5	1, 3, 2, 5	1, 3, 2, 4, 5	1, 2, 4	1, 2, 4, 5
High Losses	1, 4, 5	1, 4, 5	*	1, 3, 5, 6	1, 3, 5, 6	1, 4, 5, 6	1, 4, 5	1, 4, 5
Uncontrolled Losses	1, 7, 4, 5, 6	1, 7, 4, 5, 6	*	*	1, 7, 4, 5, 6	1, 7, 4, 5, 6	1, 4, 5, 6	1, 4, 5, 6

Recommended Solutions and Applications

1. Avoid applying too much mud weight, improve hydraulics, overall ECD including improve hole cleaning and control drilling.
2. Flush or spot 1 to 3 % fibrous and/or flaked type LCM pill, or add 1 to 3 % fibrous and/or flaked type LCM to circulation mud.
3. Flush or spot 1 to 3 % sized calcium carbonate pill, or add 1 to 3 % sized calcium carbonate to circulation mud.
4. Spot and/or squeeze 8 to 12 % LCM pill (mixture of fibrous, flaked, and granular type LCM).
5. Apply cement spot and/or squeeze.
6. Specialty techniques such as chemical plug or gunk squeeze
7. Blind drilling.
8. Improve mud cake with adding asphaltic material.

9.3 Stuck Pipe

Stuck pipe is a drilling hazard that can be associated with ballooning and fluid losses. Recognizing and avoiding stuck pipe requires some of the same "well listening' techniques.

Generally, stuck pipe is avoidable if drilling margins are honored, with the exception of the following causes:

- Geometry or volume of shaker cuttings, trends in mud properties, or drilling parameters
- Out-of-balance mud weight or high ECD
- Hole caving
- Splintered cuttings
- Concave-shaped cuttings
- Sloughing shale, chemical shale wetting, and instability
- Tectonic or pseudo-induced stresses

9.3.1 Best Practice

The best practices to avoid stuck pipe are much the same as ballooning and fluids loss recognizing the conditions within the drilling margins and events and reacting correctly (e.g. drilling hazard understanding). In addition, other factors such as BHA, drill string configuration, and the inhibitive characteristics of the formations being drilled should be considered.