REVISED APPENDIX C:
MUDLOGGING ON THE DEEPWATER HORIZON GENERALLY AND ON APRIL 20, 2011

EXECUTIVE SUMMARY OF HALLIBURTON'S SPERRY MUDLOGGING

Sperry Drilling's ("Sperry") mudloggers acted reasonably in light of the convoluted, non-standard rig activities on the Deepwater Horizon on the night of the Macondo disaster. Unfortunately, BP and Transocean's decision to conduct multiple, simultaneous operations during the final hours before the blowout—in an effort to accelerate the completion of the well—blinded the on-duty mudlogger to his primary kick indicators—pit volume and flow-out from the well. The displacement procedure designed by M-I SWACO, executed by Transocean, and authorized by BP, put the Sperry mudlogger at a distinct disadvantage to other members of the drilling crew who could not only monitor primary kick-indicators that the mudlogger could not (such as flow-out), but also had full knowledge of the rig operations (such as staggering the pumps), as well as the ability to shut in the well (by activating the blowout preventer) in the event of a kick. In addition, these other members of the drilling crew and the BP company man were required by regulation to be certified every two years in kick detection, while the mudlogger is not, which reflects the prevailing understanding that the mudlogger is, at best, a "second set of eyes" for the drilling crew. Therefore, the 200 psi rise in standpipe pressure during the sheen test, while possibly significant in hindsight, would not necessary have stood out as a classic kick indicator to a reasonable mudlogger viewing the data in real time. Under the circumstances, Joe Keith's failure to detect the kick was not unreasonable.

Mudloggers perform a variety of tasks, but the primary task of a mudlogger is to set up, configure, maintain, and monitor a host of drilling-related parameters. These parameters are measured by sensors (such as flow sensors) positioned at various locations around the rig. As part of maintaining this system, the mudlogger monitors the sensors' output for anomalies. The main parameters monitored by the mudlogger for kick detection are pit volumes, which can be analyzed to indicate potential fluid gains or fluid losses. Anomalies in pit volumes, or other parameters available to the mudlogger, can be caused by a number of different activities such as fluid transfers between pits, rig movement, crane activity, and, of course, an influx into the well. Significant anomalies which the mudlogger cannot reconcile are communicated to the driller, assistant driller, company man, toolpusher, and/or mud engineer so those individuals may determine whether the anomaly is an expected response, or a sign of a potential problem, such as a pipe washout, fluid influx into the well, or a faulty sensor.

On the Deepwater Horizon, the driller, assistant driller, toolpusher, company man, and OIM all had the ability to monitor the well using both the data from the Sperry mudlogger as well as data from the Transocean flow-out sensor not available to the mudlogger. Further, the driller, assistant driller, toolpusher, company man, and OIM all have the ability to shut in the well by activating the blowout preventer ("BOP")—something the mudlogger cannot do. For this and other reasons, the driller, assistant driller, toolpusher, company man, and OIM all have primary responsibility for kick detection, as compared to the mudlogger who has secondary responsibility for kick detection and well control issues. MMS regulations in effect on April 20, 2010 reflect this allocation of responsibility.[1]

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[1] A mudlogger is not required to have the same advanced training and certification as the drilling crew. *See* 30 CFR 250.401(c) ("You must take necessary precautions to keep wells under control at all times. You must: . . . (c) Ensure that the toolpusher, operator's representative, or a member of the drilling crew maintains continuous surveillance on the rig floor from the beginning of drilling operations until the well is completed or abandoned, unless you have secured the well with blowout preventers (BOPs), bridge plugs, cement plugs, or packers; (d) Use personnel trained according to the provisions of subpart O." (emphasis added)). As drafted, a mudlogger does not clearly fit within Subpart O, which applies to contract personnel "performing well control, deepwater well control, or production safety duties for the lessee." 30 CFR 250.1501. The mudlogger's duties do not fit within the statutory definition of "well control." 30 CFR 250.1500 ("*Well control* means drilling, well completion, well workover, and well servicing operations. For purposes of this subpart, well completion/well workover means

On April 20, 2010, the Deepwater Horizon was preparing to abandon the Macondo well. To do so, BP's plan called for underbalancing the well by replacing heavy drilling fluid with lighter seawater prior to setting a cement plug. All parties knew a kick could occur during this process, yet in their haste to move to a new drill site, BP, Transocean, and M-I SWACO elected to perform multiple simultaneous and non-standard actions without regard for safety or even their own standard operating procedures. These actions included:

- Diverting M-I SWACO's LCM spacer overboard in a manner that bypassed the mudlogger's flow-out sensor, preventing the mudlogger from monitoring the amount of fluid flowing out of the well;
- Transferring mud to the Damon Bankston and failing to notify the mudlogger when this transfer ceased;
- Pumping seawater into the well from an unmonitored sea chest;
- Cleaning and emptying several mud pits;
- Repeatedly draining the trip tanks without notification;
- Draining the unmonitored sand traps;
- Conducting disruptive crane activities during critical well operations;
- Staggering pump speed; and
- Changing the pit that received well returns without notifying the mudlogger so that he could change the designated active pit.

Each of these actions frustrated the mudloggers' ability to completely monitor the well for anomalies. Nevertheless, the Sperry mudlogger accurately and continuously monitored the well under the circumstances. In so doing, the Sperry mudlogger noticed and communicated several

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those operations following the drilling of a well that are intended to establish or restore production to a well."

anomalies, including abnormal pit gains, a brief pressure spike, and strange pumping actions.[2]

Indeed, analysis of the surviving Sperry well data shows that due to simultaneous rig operations, the kick that resulted in the Macondo blowout would have been difficult for the mudlogger to detect in real time until the final minutes leading up to the disaster—when the Transocean drilling crew had already recognized a problem.[3] Had the mudlogger had access to the additional Transocean data available to the driller, the assistant driller, the toolpusher, the company man, and the OIM, the mudlogger could have potentially detected the influx before it reached a critical volume. However, BP decided the mudlogger did not need this additional sensor information.[4] Having blinded the Sperry mudlogger to his primary kick indicators, the responsibility for missing the kick rests squarely on BP's and Transocean's shoulders.

I. MUDLOGGING ON THE *DEEPWATER HORIZON*

Halliburton provided several services on the Macondo well, including cementing, logging while drilling, directional drilling, and mudlogging services.[5] BP (among others) contends that Halliburton's Sperry mudlogging service was inadequate, if not outright negligent, by failing to detect the kick following the negative pressure test.[6] I disagree.

On April 20, 2010, BP's, Transocean's, and M-I SWACO's decisions to conduct simultaneous and non-standard operations during temporary abandonment procedure impaired Joe Keith's ability to detect the kick.

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[2] J. Keith Depo., 3/28/2011 at 74:9-75:5, 170:15-171, 231:22-233:18, 235:2-236:9, 237:8-14, 237:22-239:1, and 317:1-318:1.

[3] *See, e.g.*, Expert Report of Calvin Barnhill report at 40 and 41.

[4] J. Keith Depo., 3/28/2011 at 180:7-22 ("A. We don't get their -- we don't get their flow-out. Q. Could you ask for it? A. We did at one time, but they didn't want us to use it. . .").

[5] S. Clark Depo., 7/29/2011 at 21:23-24:10.

[6] *See* BP cross-complaint against Halliburton.

These decisions were an ill-fated attempt to accelerate completion of the well. These simultaneous and non-standard operations masked any influx into the well. Nevertheless, Mr. Keith continuously and accurately performed his duties, which included monitoring the well using the data available to him. As evidenced by the numerous and varied expert interpretations of the available well data in the days since the blowout—the very same data Mr. Keith was monitoring—the kick that resulted in the Macondo blowout was not easily detectable in real time. Neither Mr. Keith nor Halliburton acted in an unreasonable or reckless manner.

Traditional kick indicators include an increase in mud pit volume, increase in flow-out, increase in gas content, continuous flow during a flow check, and a decrease in standpipe pressure.[7] Due to decisions made by BP, Transocean, and M-I SWACO regarding operations on April 20, 2010, the mudlogger's ability to monitor these key parameters for early indications of a kick was critically undermined. The decisions include permitting simultaneous and non-standard operations, permitting the extraordinary and unusually excessive movement of fluids between pits on the rig during displacement, and diverting fluids overboard. The impact of each of the simultaneous and non-standard operations on traditional kick indicators is explained in greater detail below.

A. Well monitoring and kick detection

Mudlogging, or more accurately Surface Data Logging (SDL), encompasses much more than staring at one screen watching for signs of a kick, as some have suggested. Mudloggers analyze cuttings from the well, set up and maintain a rig and well monitoring system, calibrate sensors, ensure data from the monitoring system is being correctly streamed throughout the rig and to onshore installations, generate multiple reports, monitor fluid and gas movement on the rig and in the well, and continually update a log book detailing rig activity and the mudlogger's observations/actions.

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[7] *See, e.g.*, IADC Deepwater Well Control Guidelines, 2002, §2.1.1, TRN-I NV-00800307; and API RP 59 §6, OSE126-004133.

The mudlogger does not have primary responsibility for kick detection.[8] Indeed, if a kick is detected, the mudlogger does not even have the ability to shut in the well; this is reserved for parties with more training and access to additional well data, as is explained in a later section.

To facilitate monitoring the rig and the well, the *Deepwater Horizon* used several sensors to monitor various drilling-related parameters. Nearly all of these sensors were Transocean's sensors which fed into Transocean's Hitec monitoring system before being transmitted to the Sperry mudlogger—notably, the Transocean flow-out sensor was not transmitted to the mudlogger, although he did have access to a separate Sperry flow-out sensor. Signals from these sensors were passed into Sperry's InSite software program that visually displayed the sensor measurements to the mudlogger. The InSite program is also able to display additional traces containing information derived from the sensor data. This information is not directly measured by the sensors, but is calculated by InSite using data from a sensor (*e.g.*, pump stroke counter) along with certain static data (*e.g.*, pump volume per stroke) that is provided by the rig crew and input by the mudlogger into the InSite program.

The mudlogger was able to monitor: the volume of fluid in twenty different mud and fluid pits, pressures on multiple standpipes, pressures on two choke/kill lines, stroke count/rate of four pumps, gas units coming from the well, fluid flow-out of the well,[9] mud weight, hookload, block position, weight on bit, rate of bit penetration, drill string torque, drill string RPM, cement pump pressure, fluid flow down the drill string, fluid flow to the riser, volumes pumped, and cement flow.[10]

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[8] P. Lee Depo., 6/2/2011, 459:20-460:22 ("Q. The driller, the AD, the drilling crew are the -- have the primary responsibility for monitoring downhole conditions; would you agree with that? A. I think so, yes, sir." (objection omitted)). Mr. Lee was a BP well site leader on the Deepwater Horizon.

[9] The Deepwater Horizon actually had 2 flow out sensors, one maintained by Transocean, and one maintained by Sperry. The mudlogger did not have access to the data from the Transocean flow out sensor. Transocean and BP personnel had access to both the Sperry and the Transocean sensors.

[10] *See* Exhibit 606.

The mudlogger uses InSite to display both the sensed and derived data in real time. Below is a screen capture from InSite illustrating the standard template used by Mr. Keith. For context, an image of the mudlogger's station onboard the *Deepwater Horizon* in 2003 is also below. Additionally, a real time recreation of the mudlogging data available to Mr. Keith during the final Macondo displacement is provided in Appendix D.

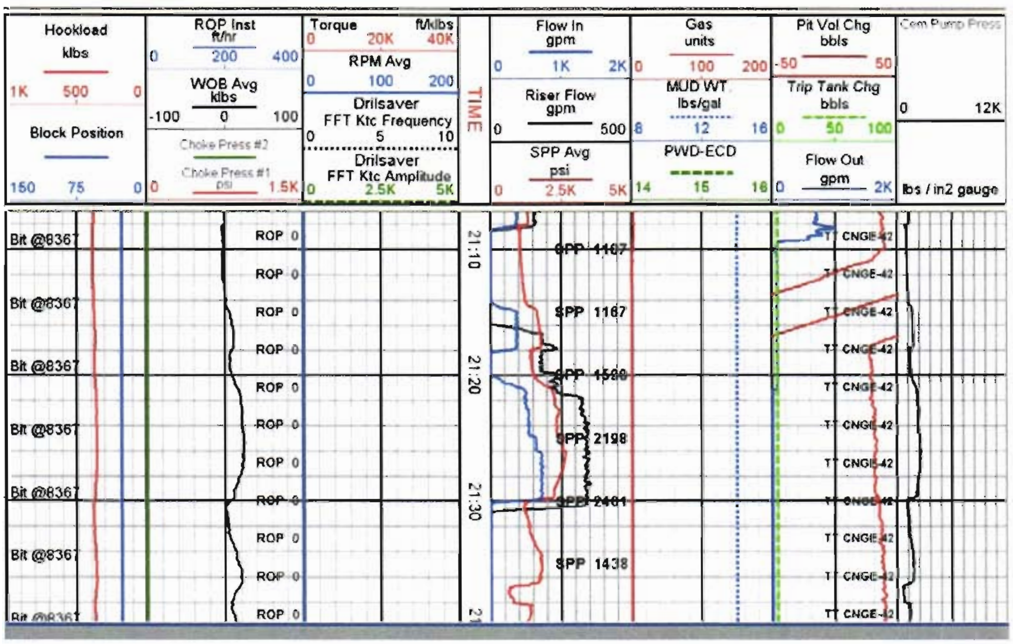

Figure 1: Screen capture from InSite

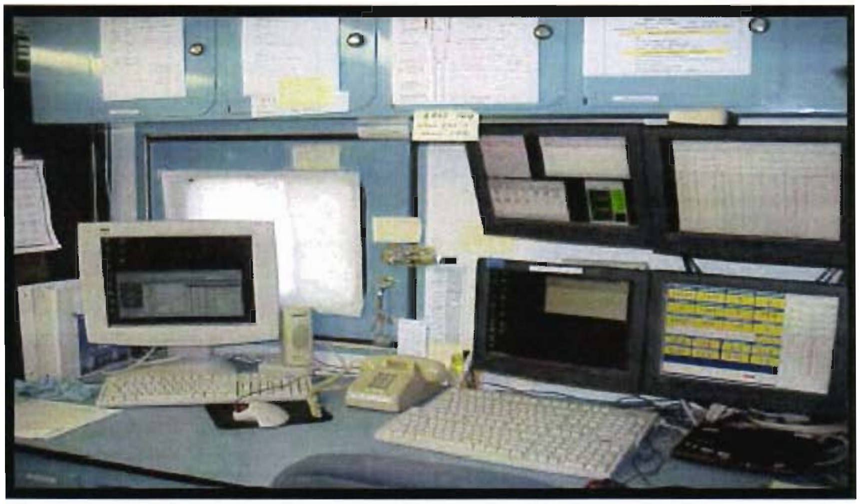

Figure 2: Mudlogger's station on the Deepwater Horizon circa 2003[11]

On the *Deepwater Horizon*, like most drilling operations, monitoring by the mudlogger via the InSite system was in addition to the monitoring done by the Transocean drilling crew and the BP company man, who all had access to both Sperry's InSite program as well as Transocean's separate Hitec monitoring system, as shown in the below image. Testimony indicates the drilling crew preferred the Transocean system over the Sperry system,[12] however the Sperry mudlogger was only permitted access to the information in the Sperry system.[13]

[11] HAL_0073878.

[12] W. Wheeler Depo., 8/25/2011 at 95:22-96:1 ("Q. Okay. Did you rely on the Sperry-Sun mudloggers, or did you rely more on the -- your own data that the drill crew would get? A. I relied on mine"); M. Burgess Depo., 4/20/2011 at 327:12-328:5 ("My primary ones I watched was the HiTech. That's the primary ones I watched. Sperry was a backup, in my book.").

[13] J. Keith Depo., 3/28/2011 at 180:7-22.

Figure 3: The Driller and Assistant Driller had access to both the InSite and Hitec Systems[14]

One likely reason the drilling crew preferred the Hitec system was because it displayed the flow-out of the well even when fluid was being diverted overboard. In contrast, the Sperry flow-out sensor did not register flow when fluids were diverted overboard, rendering the mudlogger blind to flow from the well.[15]

While the mudloggers on the *Deepwater Horizon* monitored all the above parameters, they paid the closest attention to the volumes of the twenty pits where drilling fluids were stored. The location of these pits, and the mudlogger's shack, can be seen in Figure 4 below.

[14] Transocean Investigation Report, Volume I, p. 119.

[15] *See*, *e.g.*, Figure 15 and Exhibit 607.

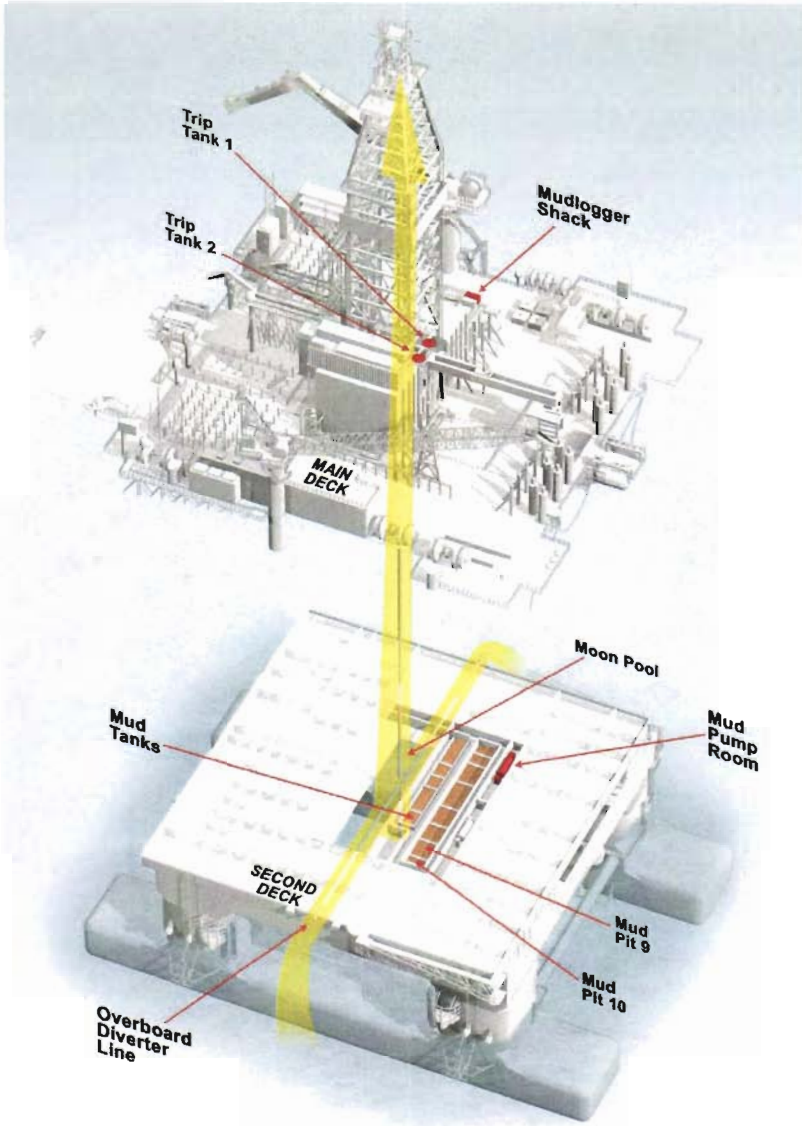

Figure 4: Mud pits on the Deepwater Horizon

At the end of his shift, a mudlogger would typically meet with the mud engineer to discuss and calculate which fluids were used during the mudlogger's shift, and where they ended up.[16] This is a necessary step so that a mud supplier may appropriately bill the operator for fluids consumed during operations. The mudlogger must therefore keep accurate account of all drilling fluid on the rig—not just fluids going into and coming out of the well—in real time. In instances like the Macondo displacement, where

[16] L. Lindner Depo., 9/15/11 at 481:16-2.

fluids are frequently and continuously moved around the rig in preparation for detaching from the well, a mudlogger can spend a considerable amount of time tracking fluid transfers unrelated to primary well operations—this is an understood component of the mudlogger's duties.

A mudlogger is also trained to watch pit volume because an increase in pit volume is a primary kick indicator.[17] Sperry mudloggers use a computerized active pit system, a feature of the InSite well monitoring program that totals the volumes in (a) the pits selected as sources for fluids pumped into the well and (b) the pits selected to receive returns from the well. InSite's active pit feature allows the mudlogger to select any combination of the *Deepwater Horizon*'s twenty monitored pits for inclusion into the total active pit volume—essentially displaying all active pits as one large pit that is easier to monitor.

The graphic below illustrates the "active pit" system concept as implemented by the InSite system.

[17] *See*, *e.g.*, IADC Deepwater Well Control Guidelines, 2002, §2.1.1, TRN-I NV-00800307; and API RP 59 §6, OSE126-004133.

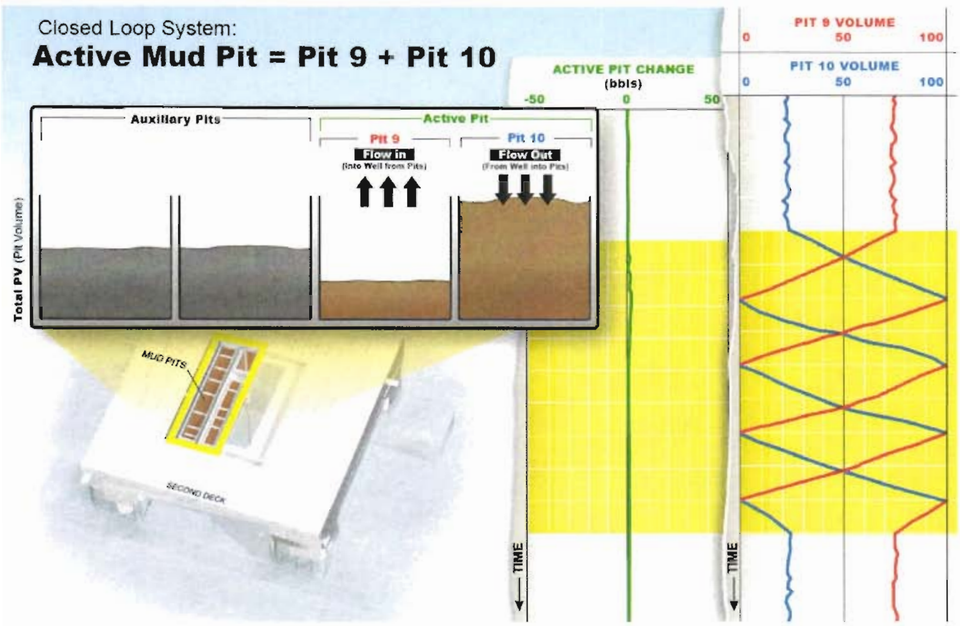

Figure 5: Active Pit System Explained

In this sense, the InSite "active pit" can be thought of as a single pit, as shown below:

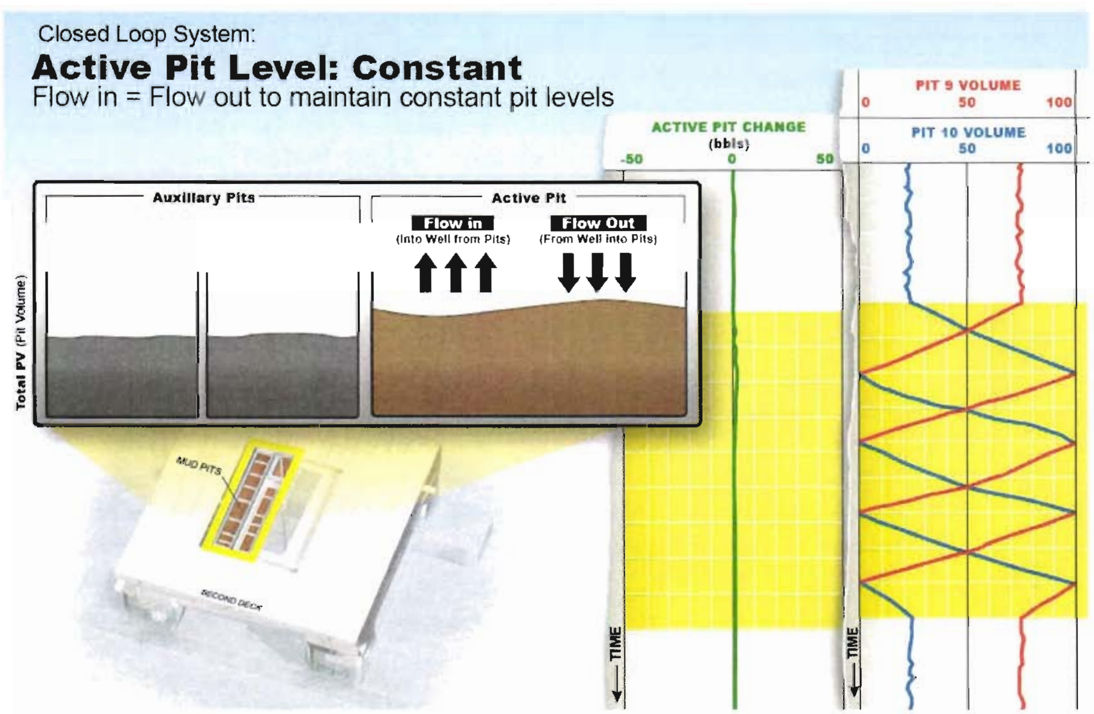

Figure 6: Active Pit System Explained

Most well operations, such as drilling or flushing the well, are conducted while the well is configured as a closed system. In a closed system, depicted below in Figure 7, fluid from the well is returned to the same active pit system that is the source for fluid pumped into the well. In such a system, in the absence of fluid losses or gains, fluid volume pumped into the well should be equal to the volume returned to the pits and the active pit total volume should remain constant.[18] A constant level in the active pit system is illustrated by an essentially flat line in the InSite monitoring software, as shown above in Figure 6 by the green vertical line.

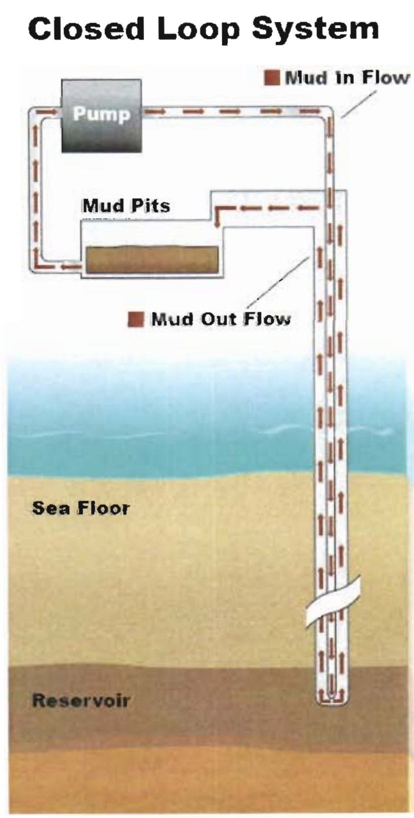

Figure 7: Normal closed loop well configuration

[18] In some instances, flow out of the well may lag a few seconds or minutes behind flow into the well, but the mudlogger is able to account for this time shift.

In a closed system, when the well is taking an influx, the addition of fluid volume from the flowing well will cause an increase in the fluid volume in the active pits. Figure 8 below illustrates such an influx. As illustrated, the hydrocarbons from the wellbore (shown in red) become entrained in the mud pumped out of the well. The flow out from the well is then deposited in the active pits. Because the flow out of the well is greater than the flow into the well, the InSite data shows a positive change in the "Active Pit Change" display. When the change exceeds 50 bbls, in this case, the data wraps around and continues in this manner as long as the influx continues.

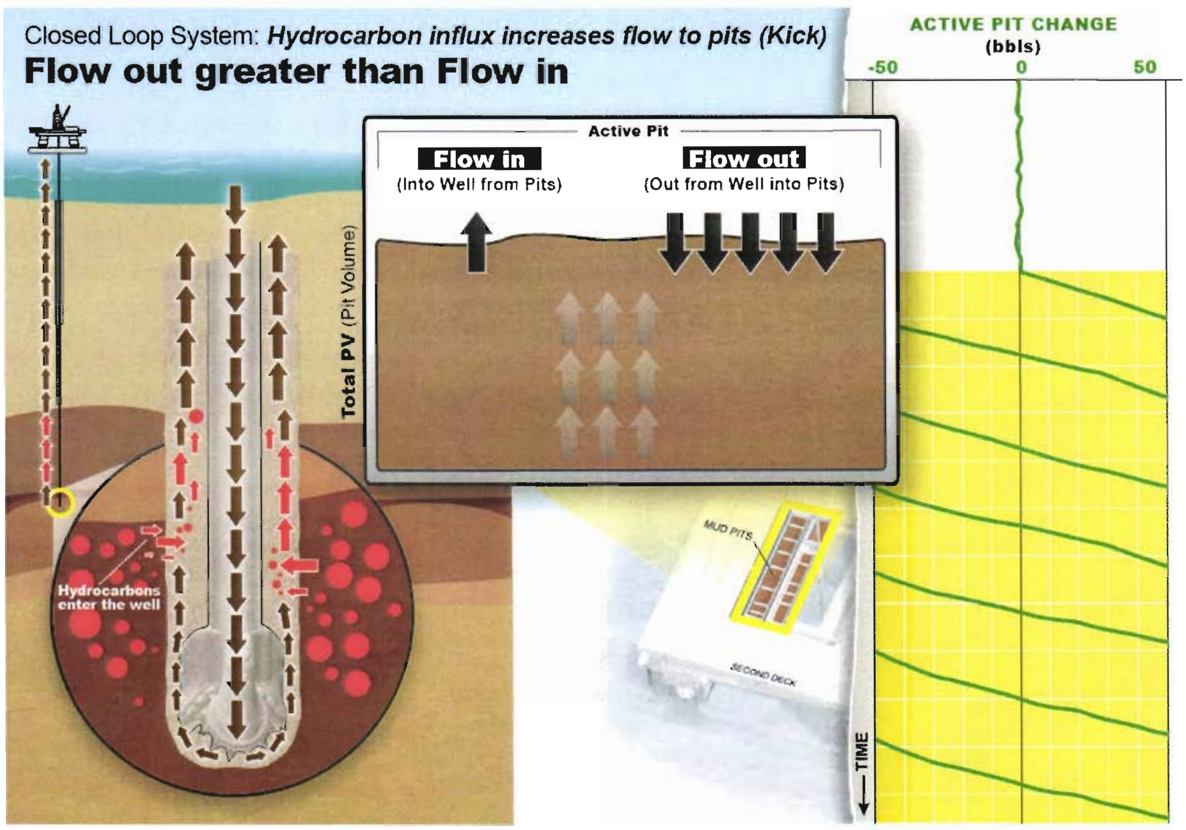

Figure 8: Detection of a kick in a closed loop system

Similarly, when the well is taking losses into the formation, the fluid volume in the active pits will decrease. As illustrated below, the mud pumped into the well is lost into the formation. As a result, less volume is pumped out of the well than into the well, resulting in a net loss in the active pits. This is displayed in InSite as a negative change in the "Active Pit Change" display.

Because of its simplicity, monitoring active pit volume in a closed system is the mudlogger's primary method of detecting kicks.

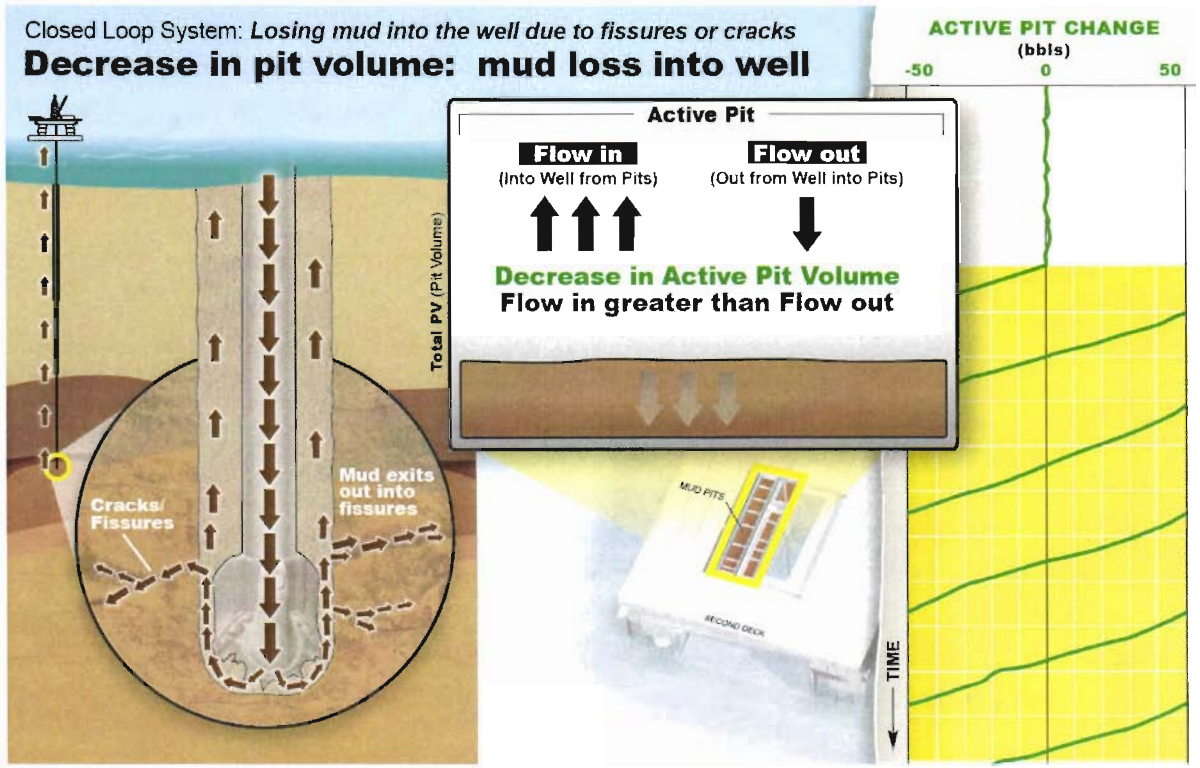

Figure 9: Detection of losses in a closed loop system

Despite the ease with which pit volumes can be monitored in a closed system configuration, the *Deepwater Horizon*'s kick detection resolution was at times as high as 30 barrels, meaning that, under some conditions, until a kick reached about 30 bbls it is doubtful a reasonable mudlogger could detect the kick.[19] The cause for this resolution is, in part, because the fluid in the pits can be disturbed when the rig moves due to crane

[19] *See, e.g.*, R. Sepulvado Depo., 3/10/2011 at 32:25-34:10 and 533:22-534:8 ("The flow shows will change, the crane operations make them change, swing the crane with a load over the side, you may get a 30-barrel increase in volume pretty quick. . . And that's the same thing you see when you get a kick out of the well, in the well.").

movement, fluid transfers, or ballasting, all of which change the rig's equilibrium in the sea.[20] This phenomena is illustrated below.

As shown in Figure 10, rig movement causes the fluid level to be disturbed. This change in level is interpreted as a change in pit volume by InSite because the Transocean pit sensors are calibrated such that a change in distance from the sensor to the top of the fluid translates into a corresponding change in pit volume. That change in pit level reading produces a corresponding change on the display, as shown below. The more significant the rig movement, the greater the deviation displayed on the computer screen.

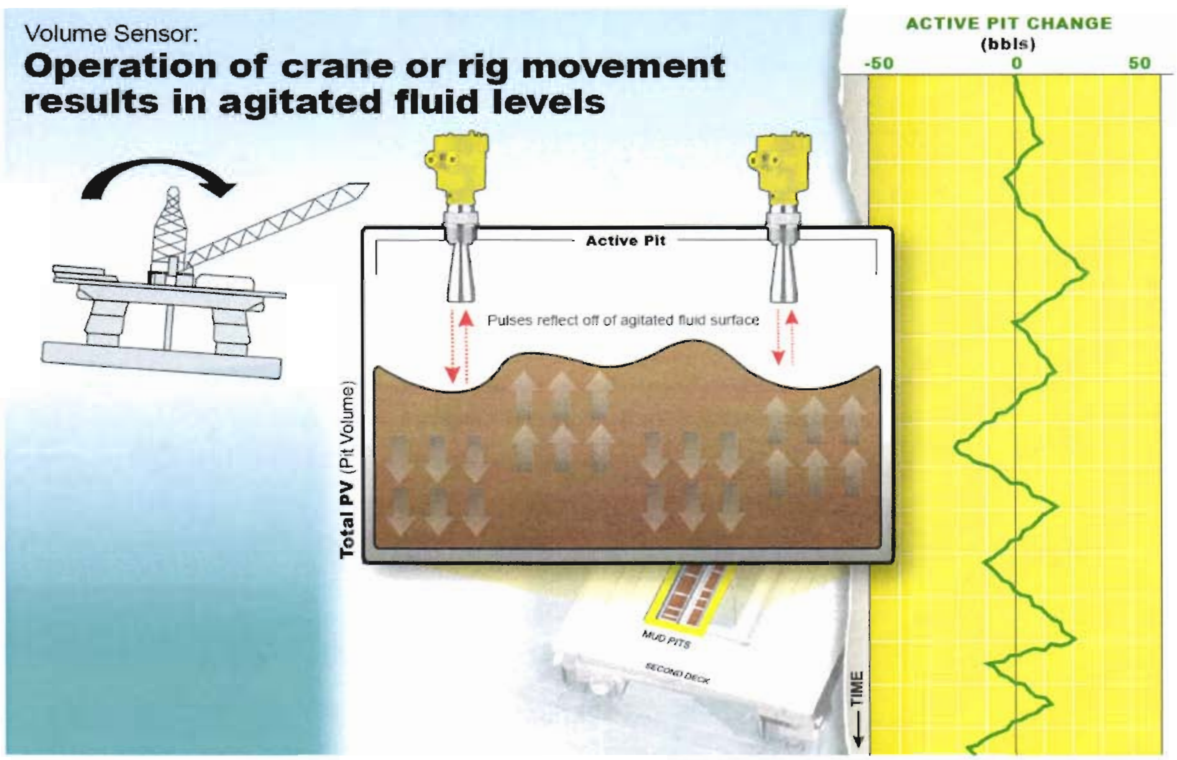

Figure 10: Crane movement complicates pit volume monitoring

[20] *Id.*; *see also* P. Lee Depo., 6/2/2011, 455:14-457:18; M. Sepulvado Depo., 5/11/2011 at 374:3-11; J. Keith Depo., 3/28/2011 at 67:3-13, 67:19-682, 163:3-22, and 170:9-171:11; C. Breland Depo., 5/18/11 at 68:9-70:19; J. Bellow Depo., 5/3/2011 at 487:2-488:2.

Also, because the fluid in the well compresses various amounts depending on pressure in the well, changing pump speed can also affect pit volume. For example, increasing pump speed compresses fluid in the well, requiring more fluid from the pits to keep the well full.

As mentioned above, the primary kick detection method of monitoring pit volumes was not available during the Macondo displacement due to decisions made by BP, Transocean, and M-I SWACO about how the displacement should be conducted.

If the rig is using an open system configuration, where the fluid from the well is returned into a different location than the source of fluids pumped into the well, a kick is considerably more difficult to detect. This situation is rare, because the InSite program allows the mudlogger to add or remove pits to the active system—simulating a closed system even when returns are placed in a pit that is not the source of fluid for the well. However, if fluid is pumped into the well from an unmonitored pit, or fluid is pumped out of the well and not returned to one of the *Deepwater Horizon*'s twenty monitored pits, the active pit system cannot be configured to track all fluid movement. Such an open loop rig configuration is illustrated below.

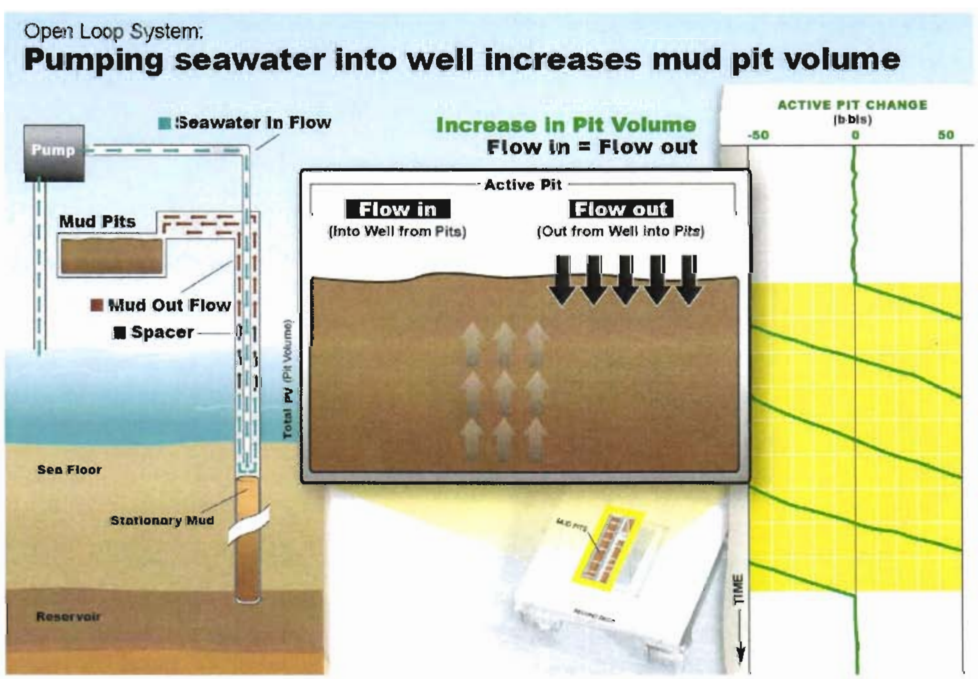

Figure 11: Well monitoring in an open loop system, such as when displacing with seawater

In this example, sea water is pumped into the well from an unmonitored sea chest rather than the active pit system. Because the fluid flowing into the well is not from the active pit, but rather an unmonitored source, the volume pumped out of the well appears to exceed the volume pumped into the well in the active pit system. This results in the active pit volume constantly increasing, as shown above. On the InSite display, this increase appears similar to a hydrocarbon influx. When pumping into the well from an unmonitored pit or sea chest, the traditional alarms built into the InSite program that alert the mudlogger of excessive pit gain are rendered useless—a fact known by the Transocean drilling crew and the BP company man, since they also have access to InSite.

When the well is configured as an open system, the mudlogger must perform additional steps to calculate flow into the well and then subtract that from gains in the active system. The extra steps required to calculate gains/losses can be time consuming, and would have to be performed repeatedly while the fluid being pumped into the well is not coming from the active system.

When pumping from an unmonitored pit, such as the sea chest, the mudlogger can determine fluid volume pumped into the well by multiplying: the volume per stroke, pump efficiency, and the number of strokes pumped (*i.e.*, $V_{in} = V_{stroke} \times PumpEfficiency \times StrokeCount$). The drilling crew or operator will provide the mudlogger with both the volume per stroke and the efficiency values to use in this calculation. Alternatively, InSite allows the mudlogger to store the volume per stroke and efficiency values in the system and will keep a calculated running total of volume pumped in since the parameter was last reset. Even with this functionality, to determine whether the well is flowing the mudlogger must subtract the calculated volume flow into the well from increases in the active pits during the same time interval to determine whether there is an influx. When fluid not used in primary well activities is transferred into and/or removed from the active pit system during this time (as in the case of the Macondo displacement), the mudlogger must also subtract or add these transfers into his calculation in order to reach a final determination of well flow. Since these calculations will need to be repeated as long as the displacement continues, it is not difficult to understand how a mudlogger trying to maintain accurate volumetric totals during a displacement fraught with multiple simultaneous operations can quickly have his attention fully occupied trying to monitor for fluid influx from a kick.

Another open pit configuration that frustrates a mudlogger's ability to monitor for kicks occurs when fluid from the well is being diverted overboard, such as occurred on the Macondo well beginning around 9:08 PM on April 20, 2010. When fluid is diverted overboard, the mudlogger cannot even compare pit gain to flow into the well, as described above, because the mud bypasses the pits entirely. When the well is configured in this manner, the mudlogger is blind to all flow from the well—a fact known to both the Transocean drilling crew and the BP company man.[21] This configuration is illustrated below.

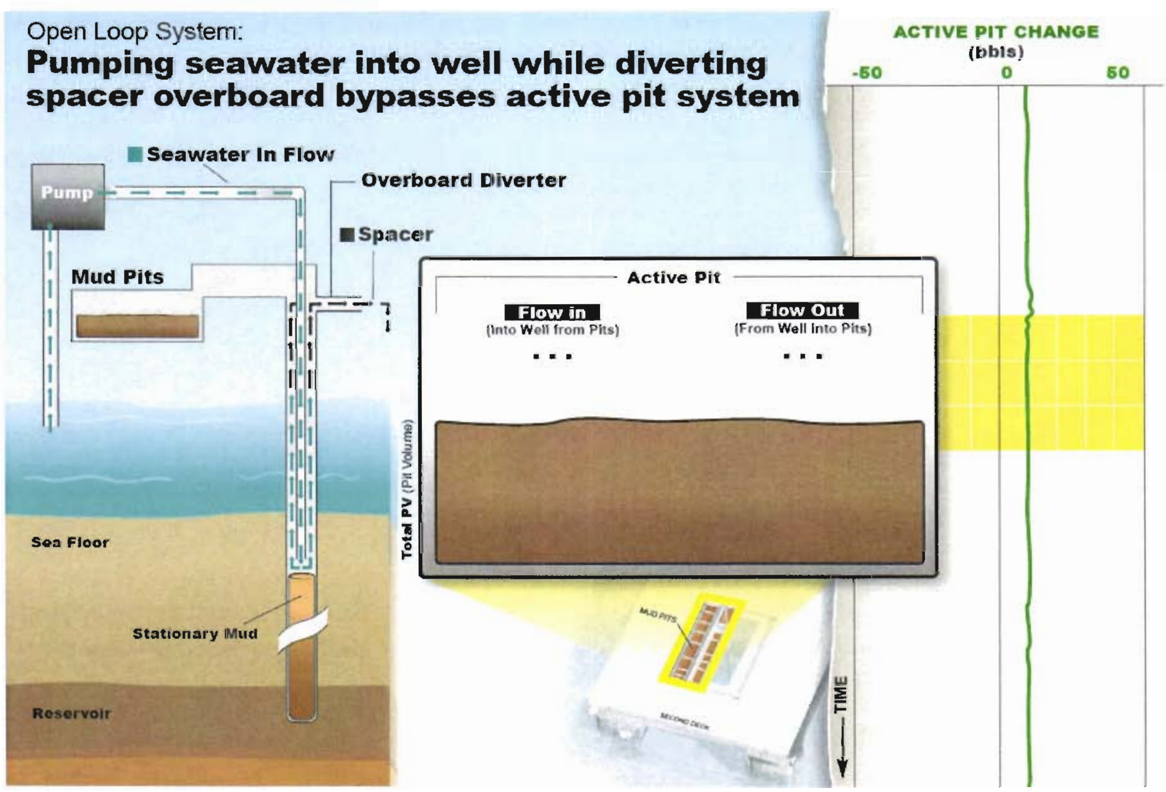

Figure 11: Pumping seawater in and diverting spacer overboard bypasses the pit system

[21] *See* R. Sepulvado Depo., 3/10/2011 at 125:11-25; M. Sepulvado Depo., 5/11/2011 at 374:24-376:20 ("[W]henever that dump valve is open, it isolates their flowmeter.").

Due to the difficulty of comparing rate of flow-in to changes in pit volumes, individuals unfamiliar with mudlogging may be tempted to ignore pit totals, and instead rely on measurements by the flow-out sensor which is theoretically an easier comparison. Unfortunately, this approach is inaccurate because flow-out sensors lack the accuracy to effectively quantify minor influxes. When a Sperry flow-out sensor is accurately calibrated, it can still have at least 10% error.[22]

The flow-out sensor measures the rate of fluid flow coming out of the well. Like measured pit volume, the accuracy of this measurement can be influenced by a variety of factors, including (a) rig movement due to waves, ballasting, fluid transfers, or crane movement (illustrated below); (b) sending excess fluid from the trip tank down the flow line; and (c) changes in density or composition of the flowing fluid. For this reason, flow-out sensors are primarily used to gauge trends in flow from the well (whether flow is increasing, decreasing, or constant), rather than precise volumetric calculations.[23]

[22] Tr. of J. Gisclair testimony before the Joint USCG Investigation, 10/8/2010 at 100:7-15.

[23] *See*, *e.g.*, Exhibit 526A at BP-HZN-BLY00061694 ("Ronnie noted that it was his belief that the flow meters had inherent variability and were not completely accurate; he said they can show flow trends but they are not completely accurate flow measures.").

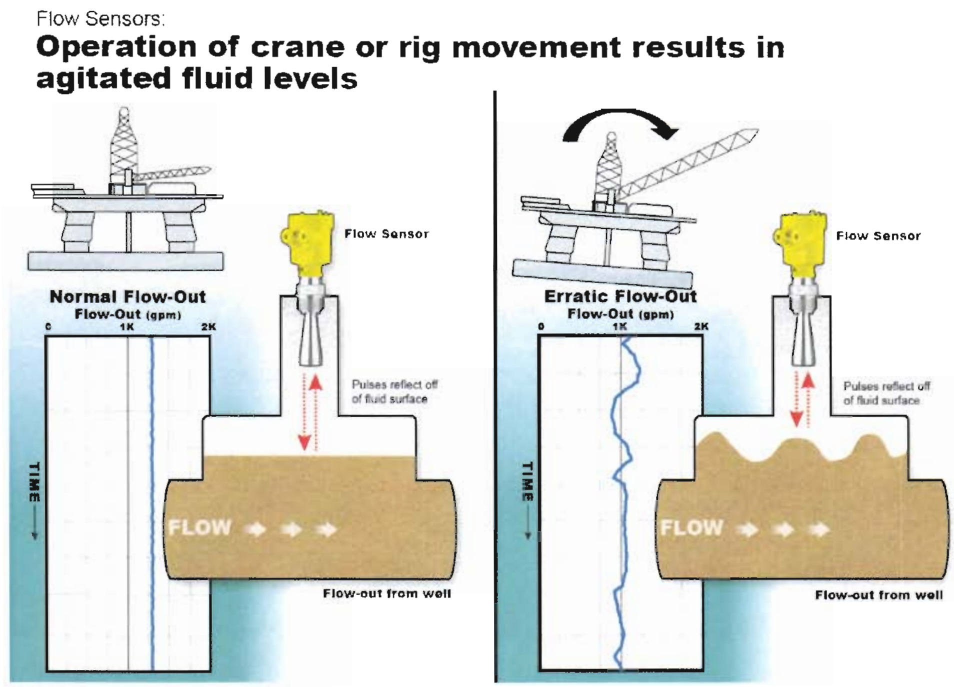

Figure 12: Rig movement introduces noise in flow out data

To minimize this error, flow-out sensors also require periodic recalibration, which is accomplished by comparing the flow-out to flow-in while the active pits remain at a constant level and the well is configured as a closed system. In situations like the Macondo displacement, where flow-in was from an unmonitored sea chest, the mudlogger was never provided an opportunity to update the flow-out sensor calibration, and the flow-out data available to the mudlogger was likely inaccurate. This inaccurate data is the same data that was sent to shore and is currently being used by several other parties to interpret flow from the well.

On the Deepwater Horizon, there were two flow-out sensors: (a) one sensor maintained by Sperry that was available to the mudlogger, the Transocean drilling crew, and the BP company man (shown below); and (b) a second flow-out sensor maintained by Transocean that was available to all but the mudlogger. Technically, the mudlogger could have accessed the Transocean sensor flow-out data through a system called PROFIBUS that allowed the mudlogger to tap into Transocean sensors,[24] but Sperry personnel had been told by BP that the Sperry sensor was preferred, and the mudlogger should not access the output from the Transocean sensor.[25]

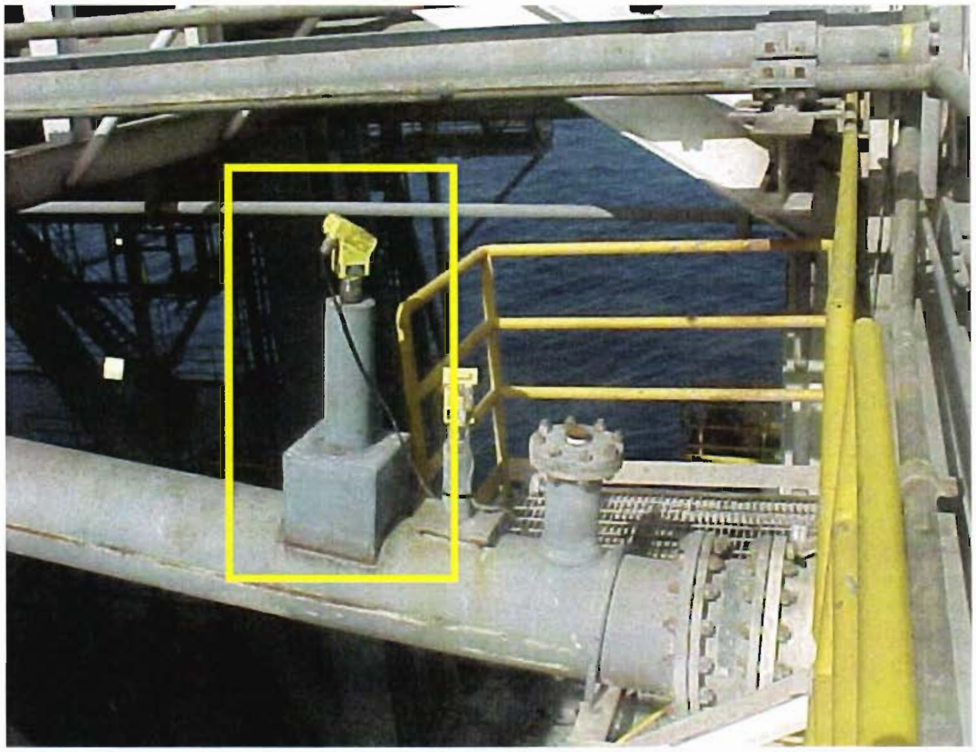

Figure 13: Sperry flow-out sensor installed on a flow line[26]

The Sperry flow-out sensor was a sonic sensor housed in a column attached to the flow-out line of the rig. When fluid flows down the flow-out line, some of this fluid enters the column. The sonic sensor is able to measure the height of fluid in the column, and that measurement can be correlated to a flow rate. Because the position of fluid in the column is affected by movement of the column (similar to jostling a glass of water, or holding it at an angle), rig movement can create distortions in the flow-out

[24] In fact, most of the sensor data obtained by InSite during the final hours of the Macondo displacement were from Transocean sensors shared via PROFIBUS. The flow-out and gas unit sensors were the primary Sperry sensors transmitting during the final Macondo displacement.

[25] J. Keith Depo., 3/28/2011 at 310:19-313:1.

[26] *See* HAL_0309944.

sensor's output, and the Sperry sensor is a course indicator of fluid flow, let alone fluid volume, as depicted above in Figure 12 above.

The Transocean flow-out sensor was a paddle sensor that stuck down into the flow line of the rig. When fluid flows through the line, it pushes the paddle. The faster the fluid flows, the greater the displacement of the paddle. The value returned is a percentage of total paddle travel, and not a precise measurement of flow from the well. Because the position of both the paddle and the fluid level can be affected by movement of the rig, and because the sensor response is in percentages and not volume, the Transocean sensor also is not a precise indicator of volume. Its best use, like the Sperry sensor, is to indicate trends in fluid flow. Because the data from the Transocean flow-out sensor was not transmitted to shore, any Transocean flow-out data recorded during the Macondo incident was lost with the rig. An example of a paddle sensor can be seen in Figure 14.

Figure 14: Typical paddle flow sensor, likely similar to Transocean's flow-out sensor

As illustrated below, Transocean's flow-out sensor was upstream of the overboard diverter valve, and returned well flow measurements even when the *Deepwater Horizon* was diverting overboard.[27] The Sperry flow-out sensor, on the other hand, was downstream of the overboard diverter valve in the flow path. Thus, when returns were diverted overboard, such as after the sheen test, the Sperry sensor was bypassed and the mudlogger's display would show zero flow-out while TO's HITEC display would continue to display flow-out.

[27] *See, e.g.*, R. Sepulvado Depo., 3/10/2011 at 269:19-270:1.

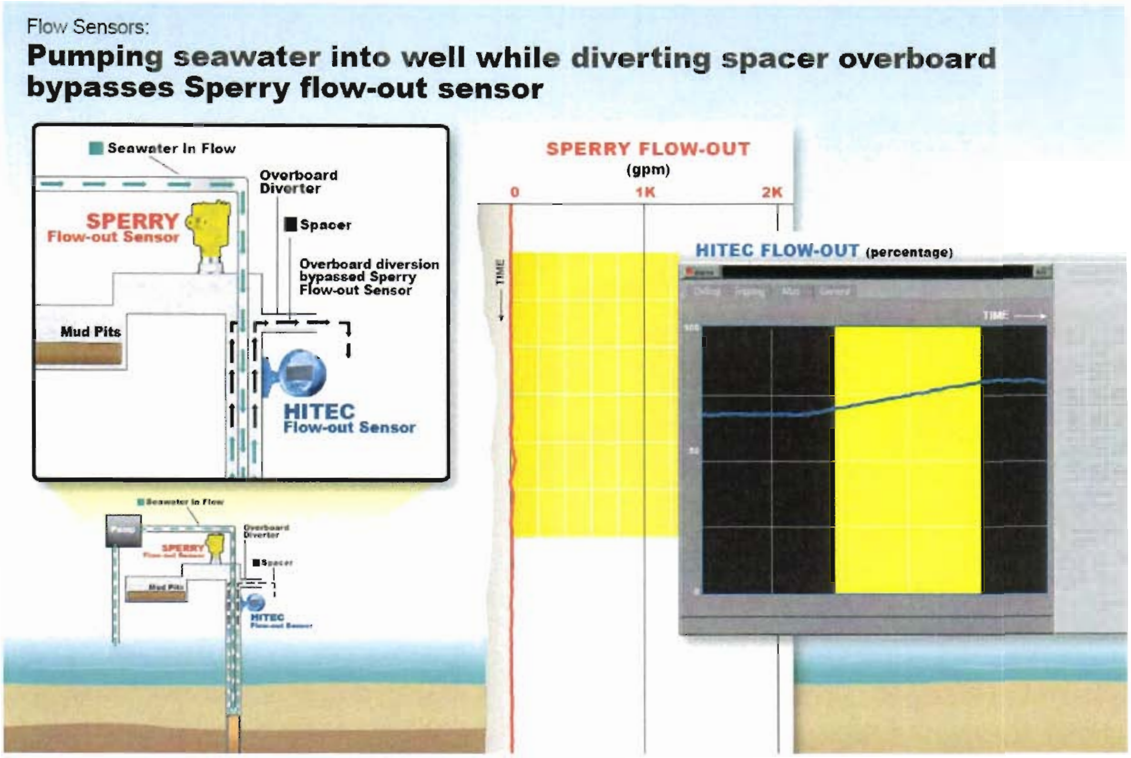

Figure 15: When diverting overboard, Sperry's flow sensor was bypassed; TO's was not[28]

This means that after about 9:08 on April 20, 2011, when all returns bypassed the pits and were sent overboard, the mudlogger was essentially blind to all flow from the well. The mudlogger could not use pit volume totals or rate of flow from the well as a means for detecting a kick. This is when the majority—if not all—of the kick that caused the Macondo blowout occurred. Because the Transocean flow-out sensor was not bypassed, the drilling personnel and company man had access to the Transocean flow-out data that should have indicated flow from the well was increasing while flow-in remained constant. BP and Transocean were well aware that while they had access to flow-out information while diverting overboard, the mudlogger did not.[29]

[28] *See also* Exhibit 607.

[29] *See* R. Sepulvado Depo., 3/10/2011 at 125:11-25; M. Sepulvado Depo., 5/11/2011 at 374:24-376:20 ("[W]henever that dump valve is open, it isolates their [Sperry's] flowmeter.")

Despite the flow-out sensors' susceptibility to error, when other more reliable sources of kick detection are obscured, rate of fluid flow from the well can be used to monitor for kicks. If total flow-out and flow-in remain steady and close in value, the well is likely stable. However, due to the inaccuracies of the flow-out sensor, the mudlogger typically monitors flow-out for trends. If a decreasing trend in flow-out is observed, the well may be taking losses to the formation, as illustrated below.

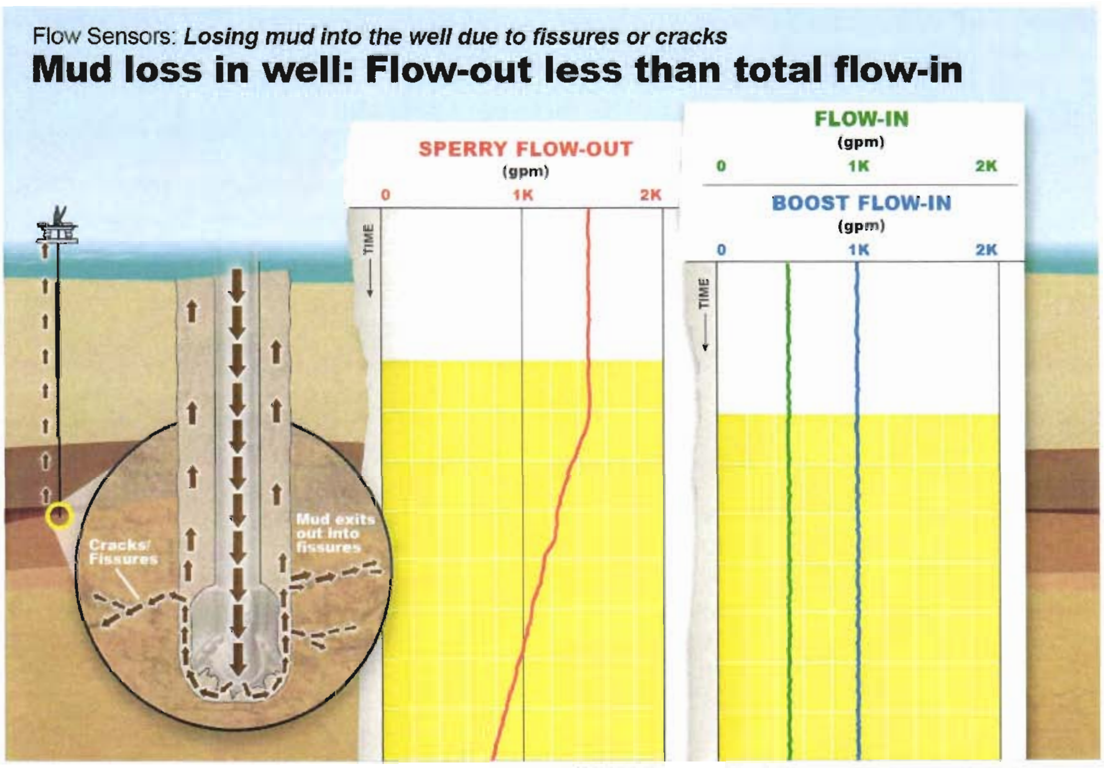

Figure 16: Impact of losses on flow-out

If, on the other hand, an increasing trend in flow-out is observed, the well may be taking a kick, as illustrated below.

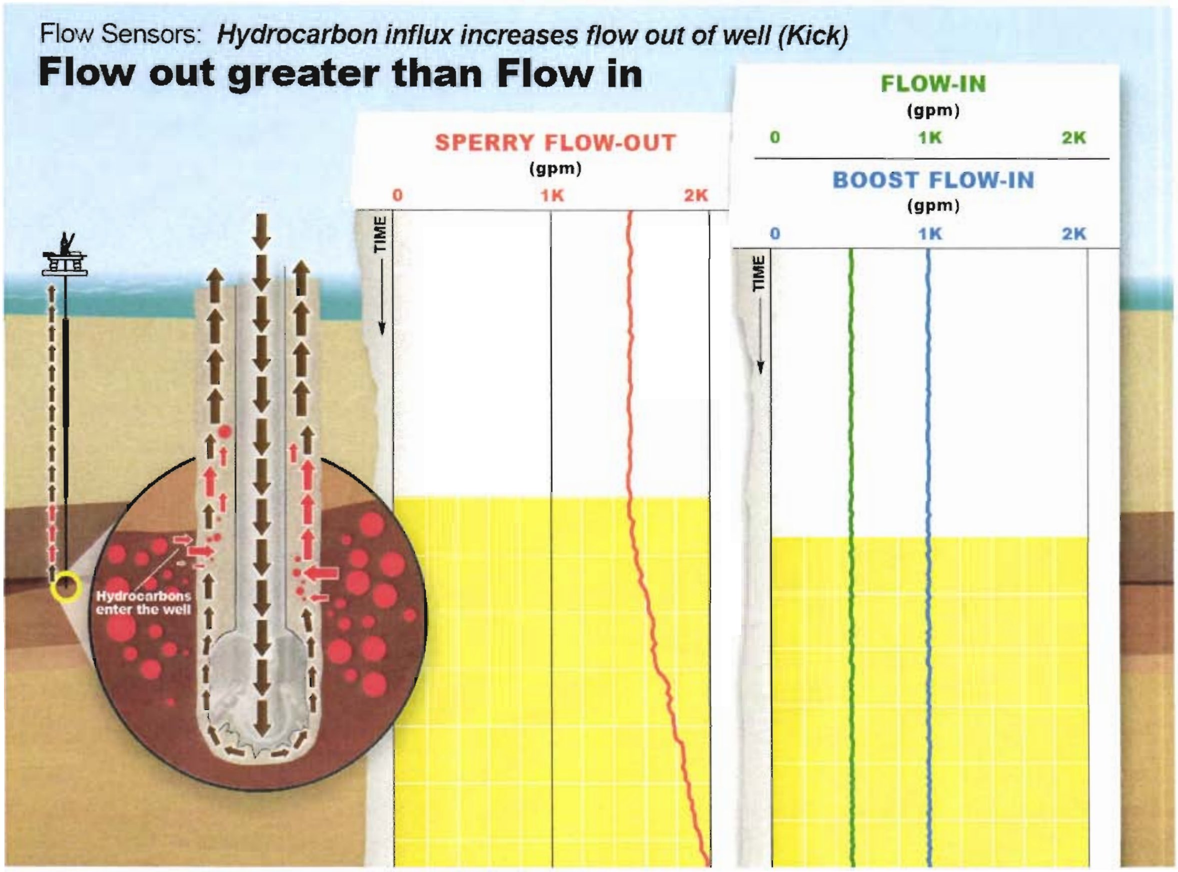

Figure 17: Impact of a kick on flow out

Perhaps the clearest indication of a flowing well is literally to check for flow. This is the test done by the drill crew when a kick indicator is detected. To perform a flow check, all pumps and sources of fluid into the well are shut down and the well is left open to atmospheric pressure at the surface. If the well is not flowing, fluid should stop coming out of the well shortly after the pumps are turned off. If the well is flowing, fluid will continuously stream from the well. When the rig pumps were shut down at 9:08 PM for the sheen test, the monitored flow from the well ceased after about a minute, and Joe Keith confirmed visually that there was no flow either on his sensor or through the Gumbo box.[30] Because the flow sensor showed

[30] Exhibit 620, Sperry mudlogging data and J. Keith Depo., 3/28/2011 at 151:17-152:17 and 236:16-22.

"no flow," one can reasonably make one of two conclusions: (1) the well was not flowing at this time, or (2) the Transocean drilling crew inappropriately diverted fluids overboard—and out of the mudlogger's monitoring capability—before verifying that the well was indeed not flowing.

An additional kick indicator is the presence of gas in fluid coming out the well. On the *Deepwater Horizon*, gas concentration in the drilling fluid was measured by a Sperry sensor placed in the rig's "possum belly." During the final Macondo displacement, the fluid pumped from the well exhibited no significant increase in gas concentration. However, like the Sperry flow-out sensor, the Sperry gas concentration sensor was bypassed when returns were diverted overboard. Thus, after 9:08 PM, the Sperry mudlogger was unable to monitor gas concentration as a potential kick indicator.

Figure 18 shows an example of a significant gas concentration coming from the Macondo well on February 17, 2010.

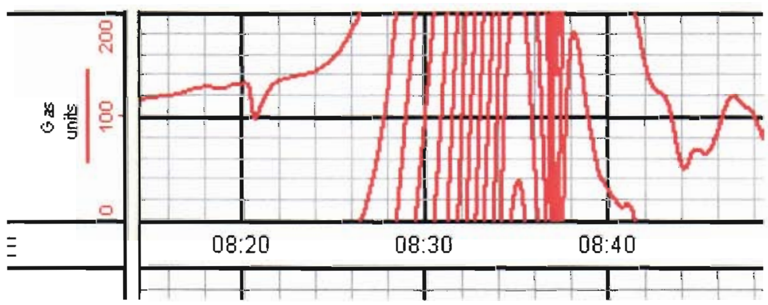

Figure 18: Gas increase of about 2900 units on the Deepwater Horizon on February 17, 2010

Another, albeit less reliable, kick indicator is changing standpipe pressure (also called "drill pipe pressure" or "pump pressure").[31] Standpipe pressure can be influenced by a number of factors—such as changing pump speed, variable fluid densities in the well, mud viscosity, mud weight, and wellbore geometry—and is therefore a less accurate metric for determining potential well flow. In fact, it took a team of investigators combing through the final 20 minutes of Macondo standpipe pressure data to explain what could

[31] Standpipe pressure is at best an "ambiguous kick indicator." President's Report at 110. *See also* HAL0051030 at §5.5.4 ("Pump pressure changes can be caused by several different things").

cause the pressures that were seen in the well; this is certainly not something that is or should be expected of a mudlogger in real time.[32]

Traditionally, if a well is flowing, any pressure change will manifest as a decrease in standpipe pressure.[33] As illustrated below, this is due to lighter fluid entering the well from the formation, which causes a reduction in hydrostatic pressure at the point of influx. This reduction in pressure at the bottom of the well causes a corresponding drop in pressure throughout the well which can be measured at the standpipe on the rig.

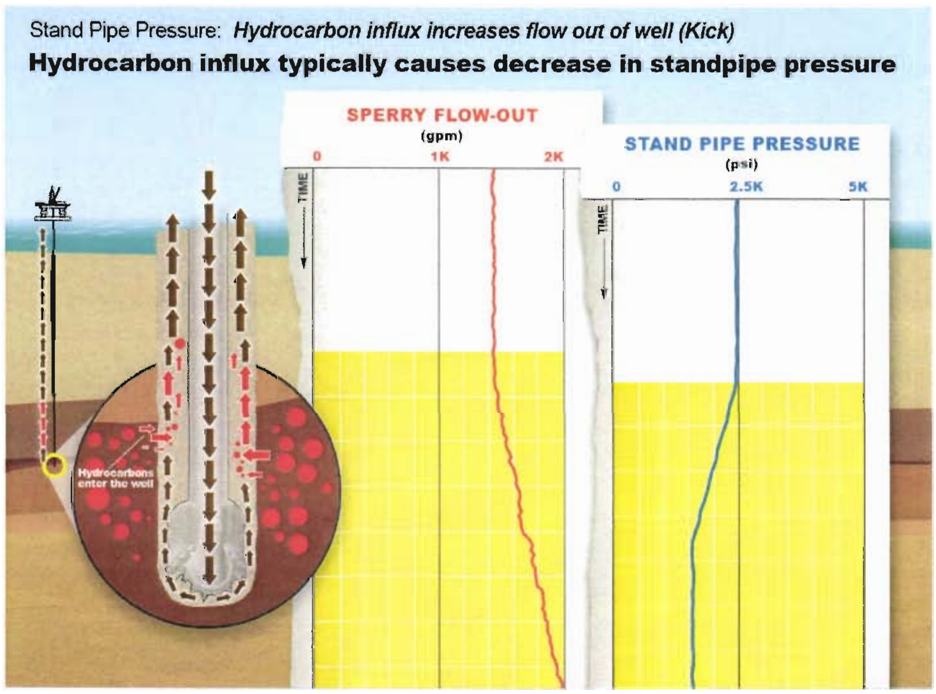

Figure 18: Standpipe pressure typically decreases in response to a kick.

While several parties have concluded the slight increase in standpipe pressure seen during the sheen test from 9:08 PM through 9:14 PM (below in Figure 20) was indicative of a kick, mudloggers are not specifically trained to associate a slight standpipe pressure increase with indication of

[32] F. Abbassian Depo, 05/03/2011 at 334:20-335:23.

[33] *See*, *e.g.*, IADC Deepwater Well Control Guidelines, 2002, §2.1.1, TRN-I NV-00800307. *See also*, API RP 59 §6.6 noting that a kick can cause a momentary, typically undetected, pressure spike "followed by a gradual decrease in pump pressure." OSE126-004133.

a kick. Rather, mudloggers would have monitored standpipe pressure for an unexpected decrease.

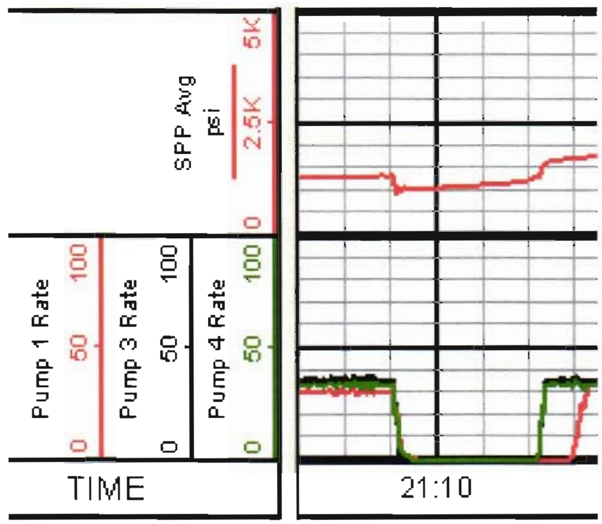

Figure 20: Pressure increase during the Macondo sheen test

Standpipe pressure is also affected by drilling operations. Because of this, standpipe pressure as a kick indicator typically falls within the domain of the driller, the assistant driller, and the toolpusher. These individuals are on the drill floor and have a better context for what activities are occurring and how those activities could influence pressure measurements from the well. The mudlogger, by contrast, sits in a container separated from the drill floor by a firewall.[34] Unless the mudlogger can determine what operations are occurring by decoding the monitored signals, the driller, assistant driller, or toolpusher must call the mudlogger and keep him apprised of well operations. It is likely that if he noticed the slight pressure increase between 9:08 PM and 9:14 PM, Joe Keith would have considered the increase in drill pipe pressure to be an artifact of something other than a kick, such as the weighted spacer that remained in the well, or trapped pressure, which was common ton the *Deepwater Horizon*. In fact, Mr. Keith indicated that the *Deepwater Horizon* drilling crew frequently trapped

[34] Tr. of J. Keith testimony before the Joint USCG Investigation, 12/7/2010 at 50:17-20.

pressure on the well, and that it was not uncommon for pressure to rise and then level out.[35]

Figure 21: A Mudlogging "shack" on the Deepwater Horizon circa 2003[36]

B. Mudlogger is a "second set" of eyes

It is important to reiterate that all the measurable parameters discussed above, as well as operational data, were available to the drilling crew and the BP company man. While the Sperry mudlogger only had access to data being monitored in the InSite program, the Transocean drilling crew and the BP company man could access InSite as well as Transocean's Hitec monitoring system. The Sperry system and mudlogger were seen as a backup to Transocean's Hitec system and drilling crew.[37]

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[35] J. Keith Depo., 3/28/2011 at 103:16-25 (". . . 90 percent of the time, when they [Transocean drill crew] do shut the pumps off they do not bleed the stand pipe pressure off, and sometimes the pressure will come up a little bit and then level out.").

[36] HAL_0073878.

[37] *See*, *e.g.*, M. Sepulvado Depo., 5/12/2011 at 733:13-734:5; I. Little Depo., 6/11/2011 at 346:24-347:13; P. Lee Depo., 6/2/2011, 459:20-460:23 ("Q. The driller, the AD, the drilling crew are the -- have the primary responsibility for monitoring downhole

Because the drilling crew directs well operations, it is in a better position to know which monitored data is expected and which is anomalous. For this reason, the drilling crew is supposed to notify the mudlogger whenever it performs an operation which will impact the monitored data. Unfortunately, on April 20, 2010 this did not occur,[38] and the Sperry mudlogger's task was further complicated because he had to do his best to infer rig activities based on the data he was viewing—data which was complicated by simultaneous operations.

C. On April 20, leading up to the explosion, Joe Keith was continuously and accurately monitoring the well under the circumstances

During the Macondo displacement, Joe Keith was presented with a challenging, but manageable situation. The *Deepwater Horizon* was preparing to abandon the Macondo well, and rather than wait for displacement operations to finish, BP and Transocean decided to begin preparing the rig for future drilling operations while Macondo operations were ongoing. This necessitated the movement of hundreds of barrels of fluid between the pits and the nearby *Damon Bankston*. In addition to monitoring returns from the well, Mr. Keith had to monitor this additional fluid movement. Mr. Keith appears to have continuously and accurately monitored the well data available to him. Mr. Keith diligently recorded information regarding mud transfers (time and volumes) in his logbook to ensure an accurate accounting of volume.[39]

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conditions; would you agree with that? A. I think so, yes, sir." (objection omitted)); T. Probert Depo., 5/10/2011 at 537:15-538:2; and J. Gisclair Depo., 5/14-15/2011 at 354:14-22 and 388:1-6; W. Wheeler Depo., 8/25/2011 at 95:22-96:1 ("Q. Okay. Did you rely on the Sperry-Sun mudloggers, or did you rely more on the -- your own data that the drill crew would get? A. I relied on mine"); M. Burgess Depo., 4/20/2011 at 327:12-328:5 ("My primary ones I watched was the HiTech. That's the primary ones I watched. Sperry was a backup, in my book.").

[38] Tr. of USCG/MMS Investigation, 12/7/2010 at 193:11-15; *see also* J. Bellow Depo., 5/3/2011 at 610:4-9 (BP's 30(b)(6) witness agreeing that "there is an expectation that the wellsite leadership will inform mudloggers of information that will affect their ability to do their job.").

[39] J. Keith Depo., 3/28/2011 at 139:16-21.

Evidence of Mr. Keith's diligence can be seen in the phone calls he made during the displacement. For example, at one point Mr. Keith noticed a slight steady increase in the volume of the active pits at a time when no such increase was expected. To investigate, Mr. Keith called someone in the mud lab, who informed Mr. Keith that mud was being transferred from the sand traps—an unmonitored pit—into the active pit system.[40] Although the gain was not a kick, it looked like it could have been, and Joseph Keith responded by calling the mud lab to investigate. Similarly, when Mr. Keith noticed an increase in the Sperry flow-out sensor around 8:28 PM, he called the assistant driller to confirm the increase was due to dumping of the trip tank and not well flow.[41] Further, after the sheen test ended at 9:14 PM, Mr. Keith noticed an anomaly in the way the pumps were being ramped up. He called the Transocean assistant driller to investigate, and was informed "[w]e are just doing it like that."[42] The Transocean assistant driller "roughly hung up" on Mr. Keith before he could inquire further. Mr. Keith called back minutes later regarding a pressure spike on one of the standpipes.[43] The assistant driller again confirmed this was the result of turning on a pump which was connected to an improperly configured line.

While Mr. Keith accurately monitored the available data, key information used to detect kicks was not available to Mr. Keith. Once the spacer had supposedly reached surface and the Transocean drilling crew had diverted flow overboard around 9:08 PM, returns from the well bypassed Mr. Keith's flow-out sensor, gas concentration sensor, and the rig's pits. Mr. Keith was blind to three traditional kick indicators—increased flow from the well, increased pit volumes, and increased gas content in the fluid pumped from the well. The Transocean crew knew these parameters were unavailable to Mr. Keith while they were diverting overboard.[44]

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[40] J. Keith Depo., 3/28/2011 at 317:1-318:1.

[41] J. Keith Depo., 3/28/2011 at 170:15-171:2 and 231:22-233:18.

[42] J. Keith Depo., 3/28/2011 at 235:2-236:9.

[43] J. Keith Depo., 3/28/2011 at 237:8-14, 237:22-239:1.

[44] *See* R. Sepulvado Depo., 3/10/2011 at 125:11-25; M. Sepulvado Depo., 5/11/2011 at 374:24-376:20 ("[W]henever that dump valve is open, it isolates their flowmeter.").

D. Simultaneous and non-standard operations complicated detection of subtle secondary kick indicators in real time.

Although Mr. Keith accurately monitored the available data during the Macondo displacement, it is possible that simultaneous rig operations planned and executed by BP, Transocean, and M-I SWACO masked any early indicators that the well was flowing. As a general matter, both BP and Transocean understood the dangers of conducting multiple operations simultaneously.

Transocean's own Well Control Handbook states that individuals involved in rig activity should "[k]eep all mud treatment and pit transfers to the absolute minimum during critical sections of the well. The Mud Engineer and the Derrickman must keep the Driller and Mud Loggers informed of any transfers or treatments of mud."[45] By allowing multiple fluid transfers—including transfers into the active system—during a critical displacement without notifying the Sperry mudlogger, Transocean violated its own well control policies.

Similarly, in BP's Drilling and Well Operations Practice Manual, BP instructs its employees that "Major Accident Hazards as a result of Simultaneous Operations shall be identified so that controls and mitigations can be put in place before the activity takes place."[46] There is no indication that BP identified the simultaneous operations during displacement to assess whether they posed a "Major Accident Hazard," nor did BP attempt to mitigate any potential harm due to the simultaneous operation.

As discussed above, and in the body of my report, traditional kick indicators include (1) flow when pumps are off, (2) increased gas concentration in returns from the well, (3) change in active pit volume, (4) change in rate of fluid flow from the well, and, to a lesser degree, (5) decrease in standpipe

[45] Transocean Well Control Handbook, Section 4, Subsection 1.1, Exhibit 590 at TRN-MDL-00286819.

[46] BP's Drilling and Well Operations Practice Manual, Section 28, Exhibit 93 at BP-HZN-2179MDL00057356. *See also* BP's Engineering Technical Practice GP 10-75 - Simultaneous Operations, Exhibit 1575.

pressure. The non-standard procedures and simultaneous operations during the final displacement specified by Transocean and BP could have impacted each of these kick indicators.

1. Pumping from an unmonitored sea chest

After pumping the LCM spacer into the well following the positive pressure test, BP and Transocean commenced the initial displacement by pumping seawater into the well from the sea chest. The sea chest is an unmonitored pit that cannot be added to InSite's active pit system, and sea water may be simultaneously pumped into and out of the sea chest during displacement. As explained above, when pumping from the sea chest, the mudlogger is unable to rely on his primary kick detection indicator—the fluid volumes in the active pits. Rather, to determine whether an influx has occurred, the mudlogger must manually subtract the total volume of sea water pumped in from the pit increase at a given time.[47] This time consuming process must be repeated periodically as long as pumping from the sea chest continues, yet the mudlogger cannot focus on this single parameter; he must also continue to engage in other tasks and monitor other parameters.

2. Trip tanks were emptied at critical times, sending additional flow past the Sperry flow-out sensor and into the pits – obscuring returns from the well.

The *Deepwater Horizon* contained at least two trip tanks, designated pits 17 and 18. These are monitored pits shown on the mudlogger's InSite display. A trip tank is a small pit typically used to receive fluid equivalent to the volume of the drill string when lowering the drill string into the well ("tripping into the hole"). This fluid is put back into the well when removing the drill string from the well.

During the final Macondo displacement, the trip tanks were repeatedly filled and drained (or "dumped"), around 8:28 PM and 8:59 PM.[48] Both times,

[47] J. Keith Depo., 3/28/2011 at 134:19-135:25 and 144:14-24.

[48] Tr. of J. Keith testimony before the Joint USCG Investigation, 12/7/2010 at 39:23-40:18.

the fluid was transferred from the trip tanks into the active pits, causing an increase in active pit volume. Additionally, the fluid was drained through the well's flow-out line, causing a perceived increase in well flow, as illustrated below. During the initial trip tank dump at 8:28, Joe Keith noticed this flow increase and called the rig floor to verify that the increase was due to the trip tank dump and not an anomaly, like a kick.[49] The assistant driller confirmed. If the well began flowing during one of the trip tank dumps, as some have suggested, the mudlogger may have logically attributed the entire increase in flow to the trip tank, rather than a combination of the trip tank and a flowing well.

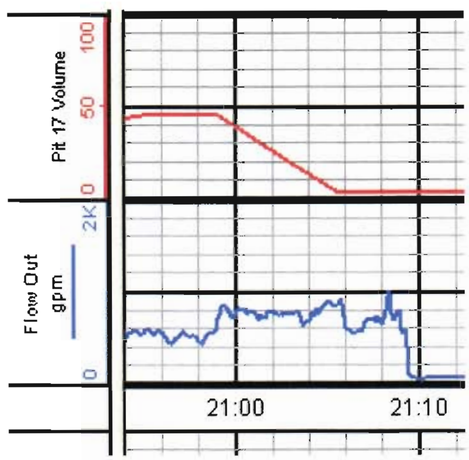

Figure 22: The trip tank, pit 17, was dumped in the minutes leading up to the sheen test

Several parties to this litigation have attempted to analyze the Macondo InSite data after the fact, and assess well flow. An error in several of these analyses is the failure to account for the increased flow due to dumping the trip tanks.[50] This error could substantially impact important conclusions, such as assessments of when the well began to flow and how much excess fluid was present.

[49] J. Keith Depo., 3/28/2011 at 170:15-171:2 and 231:22-233:18.

[50] *See*, *e.g.*, Richard Heenan Report for the United States at 22.

3. Crane activity disturbed levels of fluid in the pits and the flow-out sensor

Concurrent with the Macondo displacement, at least one of the *Deepwater Horizon*'s two cranes was active. Movement by the *Deepwater Horizon*'s cranes caused fluid in the mud pits, and fluid in the flow-out sensor's measurement column, to move and slosh around.[51] Because the flow-out sensor and the pit sensors operate by measuring the height of fluid, any fluid movement induced by crane movement creates a corresponding change in the sensors' output. This phenomenon affects the measured pit volumes and the Sperry flow-out sensor. Testimony from members of the *Deepwater Horizon* drilling crew indicated that crane movement could induce perceived pit changes of 15 to 30 barrels.[52] Because a kick of that order is significant, crane movement can potentially mask an influx and significantly impact the mudlogger's ability to accurately monitor the well. Perhaps because of this, Joe Keith indicated that during his 18 years in the gulf, he had never seen a situation where cranes were needed during a displacement procedure.[53]

4. Mud was moved out of the sand traps and emptied into the pits

As mentioned briefly above, during the displacement Joe Keith noticed an unexpected increase in the active pit volume. To investigate, he called the M-I SWACO office on board the *Deepwater Horizon*.[54] The person who

[51] Tr. of J. Keith testimony before the Joint USCG Investigation, 12/7/2010 at 25:13-21, 146:1-146:5, 197:20-198:14.

[52] *See, e.g.*, R. Sepulvado Depo., 3/10/2011 at 32:25-34:10 and 533:22-534:8 ("The flow shows will change, the crane operations make them change, swing the crane with a load over the side, you may get a 30-barrel increase in volume pretty quick. . . And that's the same thing you see when you get a kick out of the well, in the well."); P. Lee Depo., 6/2/2011, 455:14-457:18; M. Sepulvado Depo., 5/11/2011 at 374:3-11; J. Keith Depo., 3/28/2011 at 67:3-13, 67:19-682, 163:3-22, and 170:9-171:11; C. Breland Depo., 5/18/11 at 68:9-70:19; J. Bellow Depo., 5/3/2011 at 487:2-488:2.

[53] J. Keith Depo., 3/28/2011 at 68:13-69:1.

[54] J. Keith Depo., 3/28/2011 at 317:1-318:1; Tr. of J. Keith testimony before the Joint USCG Investigation, 12/7/2010 at 178:24-181:9.

answered informed Mr. Keith that the unmonitored sand traps were being emptied into the active pits. On the *Deepwater Horizon*, the sand traps were unmonitored pits. Over time, the sand traps fill up with fluid and need to be emptied. On April 20, 2010, the sand traps were being emptied so they could be cleaned before the *Deepwater Horizon* moved to its next site.[55] During the Macondo displacement, the sand traps were bypassed, so all mud transferred from the sand traps was in excess of the expected well returns.[56] While Mr. Keith noticed the increase in the active pits during the displacement, he had no way of accurately differentiating between active pit increase due to mud from the sand traps and active pit increases due to well flow. Mud flow from the sand traps was slow, but still impeded Mr. Keith's ability to accurately measure returns from the well in real time.

Several parties to this litigation have attempted to analyze the Macondo InSite data after the fact. A common error in most of these analyses is the failure to account for the increase the active pits due to the sand traps.[57] This error could substantially impact important conclusions, such as assessments of when the well began to flow.

5. Mud was being offloaded to the *Damon Bankston* during the day

One example of potential error caused by simultaneous operations involved offloading excess drilling mud to the *Deepwater Horizon*'s support ship, the *Damon Bankston*. During the pre-job meeting on April 20, 2010, Leo Lindner presented the displacement procedure that specified many of the displacement activities.[58] Included in this displacement procedure was an instruction to offload excess mud to the *Damon Bankston* during the displacement.[59] Cathleenia Willis, the Sperry mudlogger on shift before Joe Keith, understood that because she did not have access to any

[55] L. Lindner Depo., 9/15/2011 at 468:8-469:11.

[56] Exhibit 967, Macondo Final Displacement Procedure.

[57] *See, e.g.*, Appendix S to BP's Bly Report.

[58] L. Lindner Depo., 9/14/2011 at 299:9-300:1.

[59] *See* Appendix P to BP's Bly Report; and Exhibit 967.

information about the rate or volume of fluid being transferred from the *Deepwater Horizon*'s pit system, she would be unable to accurately measure pit volumes until the transfer to the *Damon Bankston* ceased.[60] After the meeting, Ms. Willis informed the assistant driller—likely Transocean's Donald Clark—of her concerns about pit volume monitoring. Mr. Clark told Ms. Willis he would inform her when the transfer ceased.

At 5:12 PM, after learning there were irregularities with the negative pressure test, M-I SWACO's Leo Lindner ordered that the transfer of mud to the Bankston cease.[61] In case a well control situation developed, Mr. Lindner wanted to have mud available on the rig that could be quickly pumped into the well.[62]

Unfortunately, at this time, neither Mr. Clark nor any other member of the Transocean drilling crew remembered to inform Ms. Willis that the transfer to the *Damon Bankston* had ceased.[63] When Mr. Keith replaced Ms. Willis as the mudlogger on duty, Ms. Willis informed Mr. Keith about the transfer to the *Damon Bankston* and that the Transocean drilling crew would contact the mudlogger on duty when the transfer to the *Damon Bankston* ceased. Accordingly, Mr. Keith believed his ability to monitor the active pits was compromised.[64] Despite this belief, Mr. Keith did his best to monitor pit volumes, understanding that the volume could be affected by mud transfers to the *Damon Bankston*. Because the Transocean drilling crew never notified the mudloggers that transferring mud to the *Damon Bankston* had ceased, Mr. Keith believed that mud was being transferred off the

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[60] *See*, *e.g.*, Exhibit 3203A.

[61] Tr. of L. Lindner testimony before the Joint USCG Investigation, 7/19/2010 at 345:18-347:2.

[62] *Id.*

[63] Tr. of J. Keith testimony before the Joint USCG Investigation, 12/7/2010 at 181:17 - 182:3.

[64] *Id.*

Deepwater Horizon, obscuring Mr. Keith's pit monitoring, the entire evening leading up to the well blowout.[65]

6. Joe Keith was not informed of changes in the active pits or other transfers

As described above, the Sperry InSite monitoring software allows the mudlogger to specify which pits make-up the active system. Traditionally on the Macondo well, pits 9 and 10 were configured as the active pits. During displacement, however, the Sperry data indicates the majority of flow into pits 9 and 10 ceased at 8:34 PM, and the volume in pit 7 began to rapidly increase. A few minutes later, at 8:59 PM, pit 7 stopped increasing and the volume of fluid in pit 6 began to rapidly increase. Then, around 9:10 PM, the volume in pits 9 and 10 begin to rapidly decrease. The rapid changes in pits 6 and 7, while pits 9 and 10 remained relatively constant indicate that the Transocean drilling crew likely switched to using first pit 7 and then pit 6 as the active pits in the minutes leading up to the sheen test at 9:14 PM.[66] At about 9:10, flow into pit 6 increased, likely because pits 9 and 10 appear to have also been emptied into pit 6. When the drilling crew or the mud engineer switch active pits or transfer fluids, they are supposed to notify the mudlogger so he can configure InSite accordingly.[67] During the Macondo displacement, despite switches in the active pits and a myriad of fluid transfers, Joe Keith was never once contacted by the Transocean drilling crew or the M-I SWACO mud engineer.[68]

Joe Keith was in the dark as to rig activities. While he accurately monitored the data available to him, his ability to precisely monitor well conditions was impacted by poor communication and simultaneous operations.

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[65] *Id.*

[66] Exhibit 620, Sperry mudlogging data.

[67] Transocean Well Control Handbook, Section 4, Subsection 1.1, Exhibit 590 at TRN-MDL-00286819.

[68] Tr. of J. Keith testimony before the Joint USCG Investigation, 12/7/2010 at 193:11-15. *See also* J. Bellow Depo., 5/3/2011 at 610:4-9 (BP's 30(b)(6) witness agreeing that "there is an expectation that the wellsite leadership will inform mudloggers of information that will affect their ability to do their job.").

Transocean and BP set Mr. Keith up to fail. Had BP and Transocean (1) offloaded to the *Damon Bankston* only the minimum amount of mud needed to free up space for the riser displacement, (2) effectively communicated with Mr. Keith during rig operations, (3) provided Mr. Keith an opportunity to recalibrate Sperry's flow-out sensor, (4) waited to conduct rig cleaning activities until after the displacement was complete and the cement plug in place, (5) pumped sea water through the active pit system, instead of through the sea chest, and (6) waited until the completion of rig activities before sending fluid overboard, Mr. Keith and the numerous other individuals monitoring the well would have had a more accurate view of the well conditions, and likely could have detected the kick before it led to a catastrophic blowout.

7. Irregular pump activity

An additional factor which complicated Mr. Keith's ability to effectively monitor the well was the manner the rig pumps were staggered up to speed following the sheen test. Rather than increasing the rig pumps to the speed at once, as was typical in this scenario, the Transocean drilling crew brought the pumps on sequentially and then gradually increased pumping speed.[69] In and of itself, this is not an inherently dangerous activity. However, pump speed has a significant impact on well pressure. As shown below, the changing pump speeds created a pressure response that could have masked pressure changes indicative of a kick. Because this procedure is non-standard, Mr. Keith called the Transocean drilling crew to question what was going on. Mr. Keith was told "[w]e are just doing it like that."[70] The assistant driller hung up on Mr. Keith before he could inquire further. Because the pump rates were continuously changing, any pressure response in the well indicative of a kick was masked.

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[69] J. Keith Depo., 3/28/2011 at 235:2-236:9.

[70] *Id.*

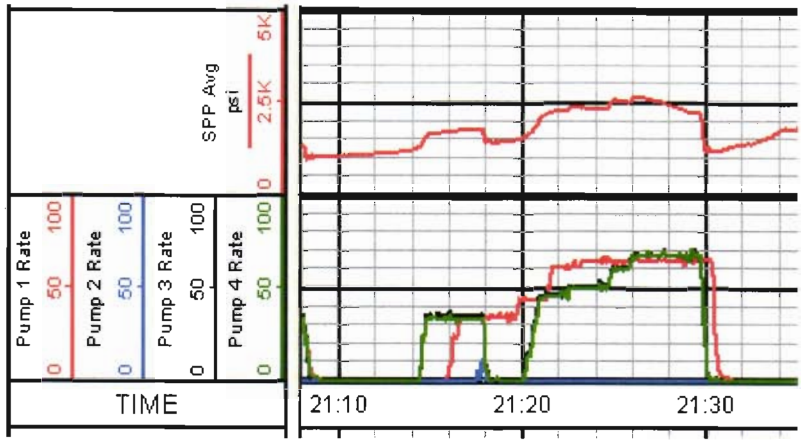

Figure 23: Ramping up the pumps after the sheen test and the pressure response

E. What in hindsight may have been a kick indicator was difficult to detect by the mudlogger in real time

As described above, changing standpipe pressure, while less reliable than traditional kick indicators, could be an indication a well is flowing. Standpipe pressure changes are, at best, an ambiguous kick indicator, and are not a direct indicator of hydrocarbons flowing into the wellbore. Because traditional indicators of a kick were obscured in the Sperry data due to BP's, Transocean's, and M-I's decision to permit simultaneous rig activities during displacement, several parties to this action have focused on a slight increase in standpipe pressure when the pumps were stopped for the sheen test beginning around 9:08 PM. While the pumps were shut down, the standpipe pressure rose about 200 psi. In hindsight, this increase may have been an early indication of a kick, but real time in the midst of a complicated displacement, a reasonable mudlogger could have logically attributed this increase to the effects of the weighted spacer remaining in the annulus, particularly in the absence of a positive flow-out indication.

After the sheen test, pressure generally tracked pump speed, as one would anticipate for the next several minutes. This may explain why Mr. Keith did not see anything anomalous about the standpipe pressure upon his return from break. While there is no indication that Mr. Keith notified the driller of the anomalous pressure response at 9:30 PM, it is evident from the data and the cessation of pumping that the TO drilling crew had already identified this anomaly and was investigating, as described in the Barnhill report.[71]

On April 20, 2010, Joe Keith was monitoring the well using all of the various sensors available to him, including standpipe pressure. A large part of monitoring the well that evening involved tracking each of the multiple fluid transfers that occurred during the displacement. At this time, Mr. Keith was using a standpipe pressure scale that went from 0 to 5000 psi.[72]

When analyzed in real time, using the same 0 to 5000 psi scale Mr. Keith used, a pressure increase of 200 psi would be slight. Indeed, when watched in real time, this slight increase is barely detectible, as can be seen in the real time video in Appendix D.

F. Hookload is not a standard kick indicator, and no anomalies were seen in hookload on April 20, 2010

At least one party has suggested that Joseph Keith should have focused on hookload to detect a kick on April 20, 2010.[73] Hookload is not a traditional kick indicator. API RP 59 §6 identifies several "Well Control Warning Signals," including many which are not typical—hookload is not even mentioned. A reasonable mudlogger exercising ordinary care would not have recognized the negligible fluctuations in hookload from 9:06 PM to 9:15 PM as an indicator that the well was flowing. Many factors can influence hookload, including slight changes in block position and pumping down the drillstring. Indeed, hookload fluctuations during the Macondo displacement appear closely related to pressure and whether the rig was pumping.

[71] *See*, *e.g.*, Expert Report of Calvin Barnhill report at 40 and 41.

[72] *See* J. Gisclair Depo., 3/14/2011 at 69:1-12.

[73] *See* Expert Report of David M. Pritchard at 22, 368; and Republic of the Marshall Islands Investigative Report, 51.

II. Timeline of displacement:

A detailed timeline of the Macondo displacement, including plots similar to those monitored by the Sperry mudlogger, helps put the impact of the simultaneous and non-standard operations specified by Transocean and BP into context.[74] All times are approximate.

April 20, 2010 AM – During a pre-tower meeting, Cathleenia Willis informs the Transocean assistant driller that offloading mud to the *Damon Bankston* during displacement will frustrate her ability to accurately monitor pit volumes.[75] The assistant driller informs Ms. Willis he will contact her once the transfer has stopped.

[74] The data used to create this timeline is the surviving Sperry mudlogging data. *See*, *e.g.*, Exhibit 604.

[75] *See*, *e.g.*, Exhibit 3203A.

1:38 PM – Transocean and the mud engineer begin offloading mud to the *Damon Bankston*, as indicated by rapid decreases in pits 7, 9, and 10 that are not accounted for by equivalent increases in other pits.

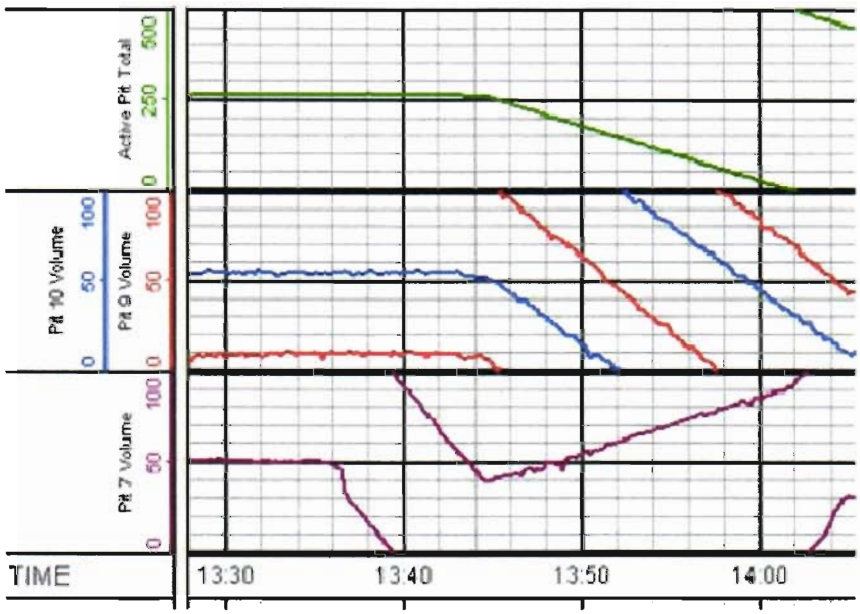

Figure 25

3:04 PM - 3:15 PM – The boost line is filled with seawater in preparation for the negative pressure test.

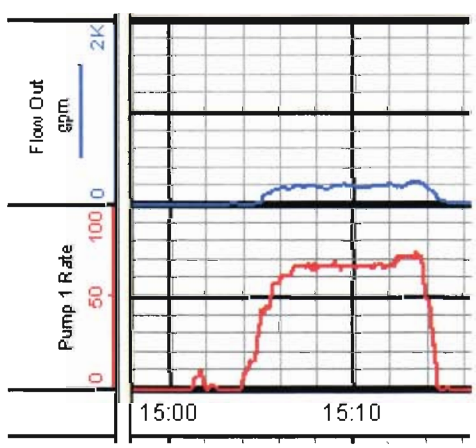

Figure 26

3:22 PM - 3:56 PM – The choke and kill lines are filled with seawater in preparation for the negative pressure test.

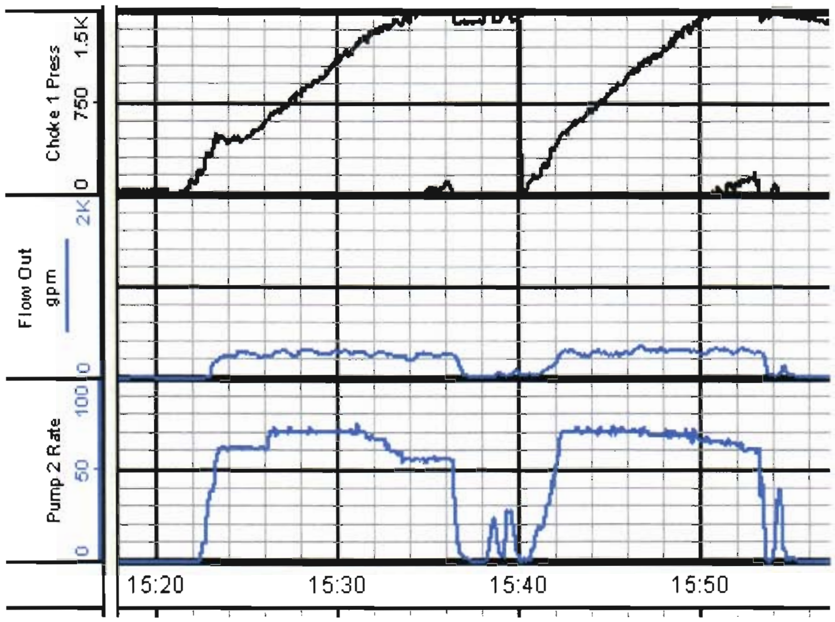

Figure 27

3:56 PM - 4:26 PM – The LCM spacer is pumped from pit 5 into the well at 8,367 ft. The transfer to the *Damon Bankston* continues during this time, as shown by the decreases in pits 6, 9, and 10.

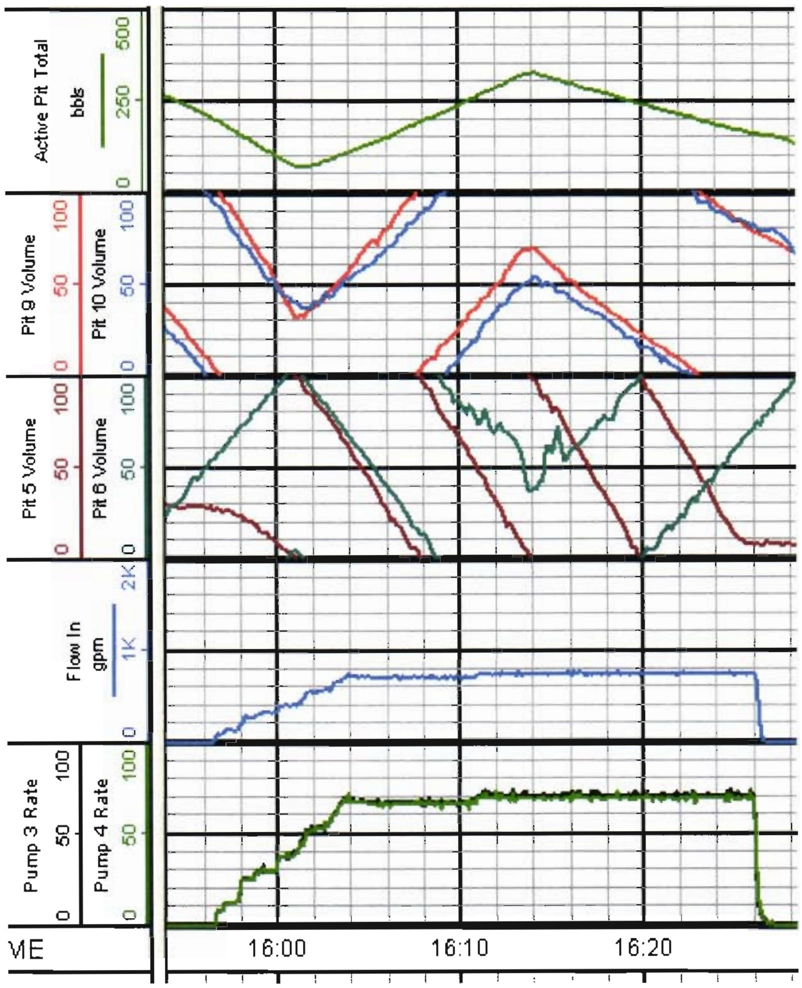

Figure 28

4:29 PM - 4:53 PM – The spacer is chased by seawater from the sea chest intended to raise the mud and spacer above the BOP, as indicated by an increase in the active pits. The transfer to the *Damon Bankston* continues, as indicated by the decreasing level of pit 6.

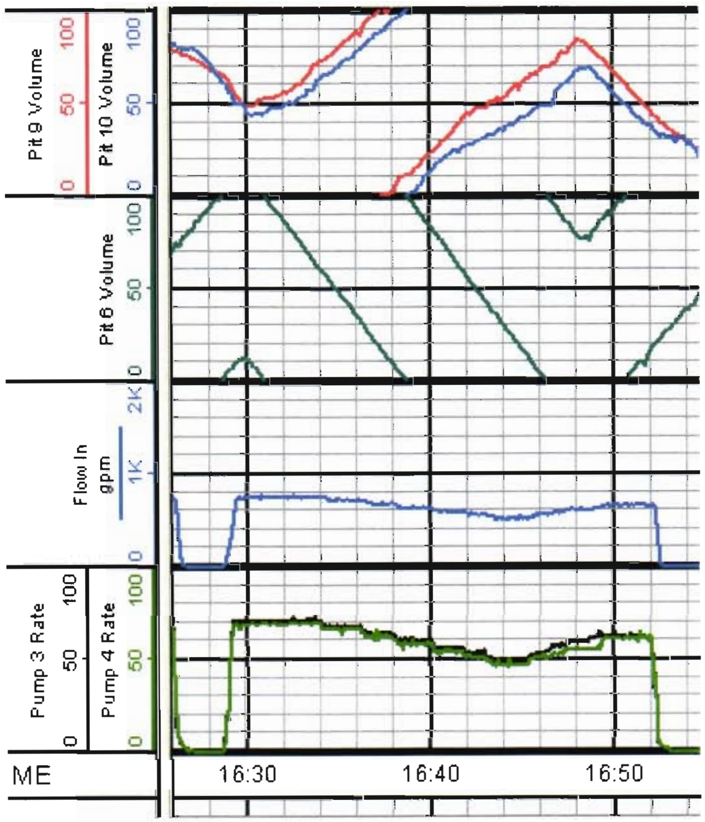

Figure 29

4:54 PM – The negative pressure test begins.

5:00 PM - 5:30 PM – Somewhere in this time window Joe Keith comes on tower. He meets with Cathleenia Willis to discuss the status of operations and go over anticipated upcoming activity, including the negative test and displacement procedure.[76] Mr. Keith retains all alarm settings for the

[76] J. Keith Depo., 3/28/2011 at 53:22-54:4.

surface data parameters he was monitoring; he does not modify or delete the alarms.[77]

5:12 PM – Leo Lindner orders that offloading mud to the *Damon Bankston* cease due in part to anomalies in the negative pressure test.[78] Joe Keith and Cathleenia Willis are not notified.[79]

7:55 PM – The negative pressure test ends after several attempts. During these attempts, several barrels of excess fluid were bled from the well in an attempt to normalize well pressure. The mudlogger had no role in interpreting the negative pressure test.

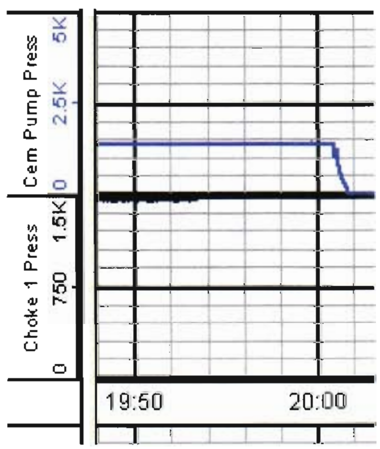

Figure 30

[77] J. Keith Depo., 3/28/2011 at 331:19-24.

[78] Tr. of L. Lindner testimony before the Joint USCG Investigation, 7/19/2010 at 345:18-347:2.

[79] Tr. of J. Keith testimony before the Joint USCG Investigation, 12/7/2010 at 181:17 - 182:3.

8:03 PM – Pumping of seawater down the drill pipe resumes after BP and Transocean declare the negative pressure test was a success, as indicated by increasing pump rates and gains in pits 9 and 10.

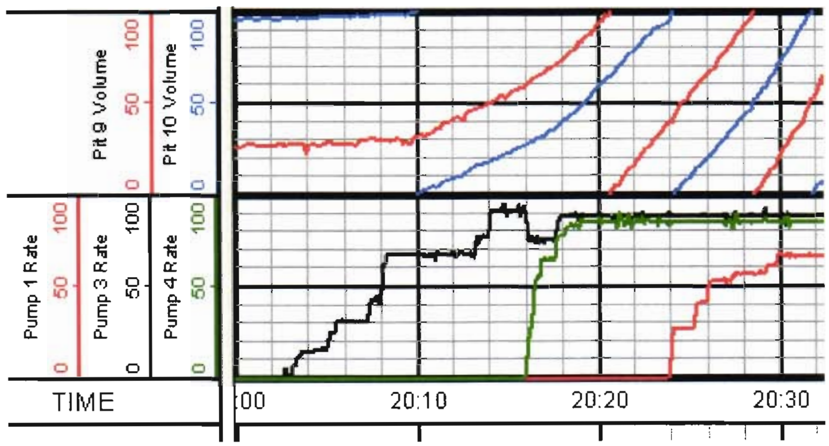

Figure 31

8:24 PM – Riser boost pump turns on to increase flow and speed up displacement, as can be seen in Figure 31 above.

8:28 PM – Pits 17 and 18, the trip tanks, are emptied. At this time, the slope of the lines indicating flow into pits 9 and 10 slightly increase, indicating the trip tanks were emptied into the active pits. At this same time, flow from the well increases. Mr. Keith catches this increase in flow and calls the drill floor to verify it was due to the trip tanks being dumped across the flow-out sensor.[80]

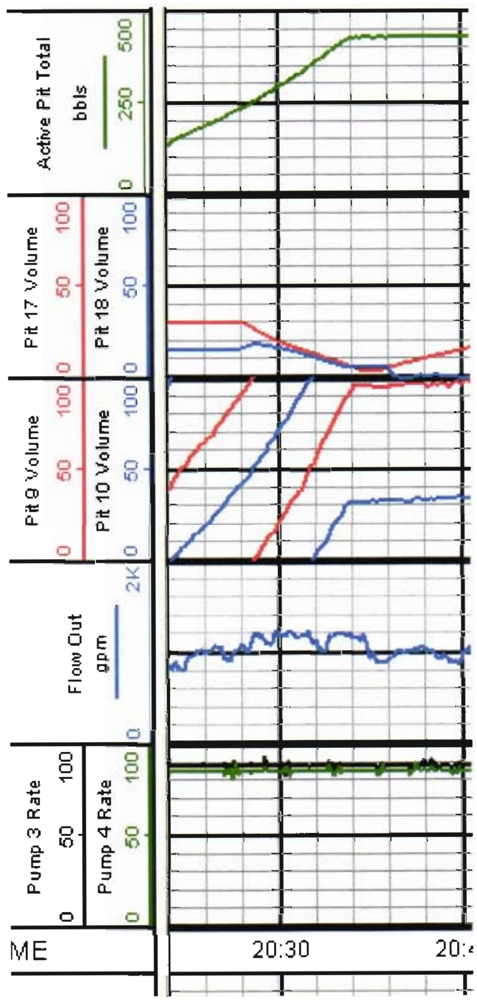

Figure 32

8:30 PM - 9:00 PM – Somewhere in this time window, Joe Keith leaves the mudlogger's shack to use the restroom, grab coffee, and smoke half of a

[80] J. Keith Depo., 3/28/2011 at 231:22-232:23.

cigarette. Before leaving his unit, Mr. Keith calls the assistant driller to notify him that Mr. Keith would be briefly stepping away from his post for a break. Mr. Keith was gone for about 8-10 minutes and returns in time to visually confirm there was no flow from the flow line at 9:08 PM.[81] There is nothing unusual or inappropriate about a mudlogger taking a brief break during a 12 hour shift, provided the mudlogger contacts the drilling crew prior to doing so.

8:35 PM – Returns are switched from pits 9 and 10 to pit 7. The mudlogger is not informed of this switch, so he does not change the specified active pits in the InSite monitoring program. At the same time, the trip tank (pit 17) begins taking returns from the well.

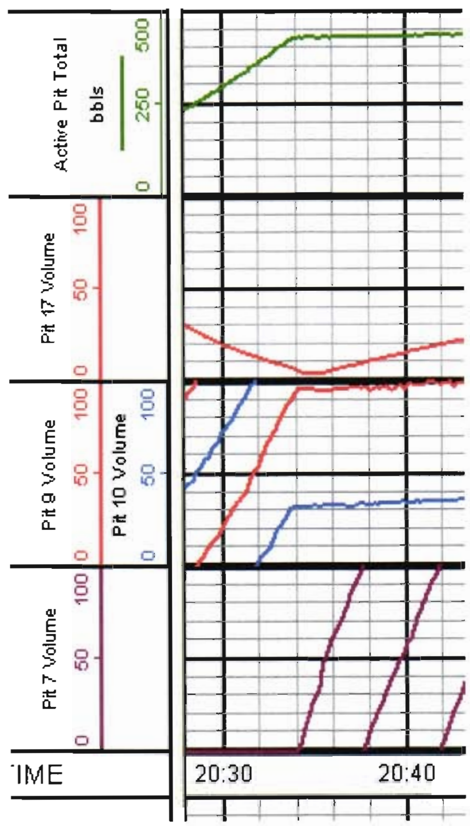

Figure 33

[81] J. Keith Depo., 3/28/2011 at 151:17-152:17 and 236:16-22.

8:40 PM – Returns are switched from pit 7 to pit 6. The mudlogger is not informed of this switch, so he does not change the specified active pits in the InSite monitoring program.

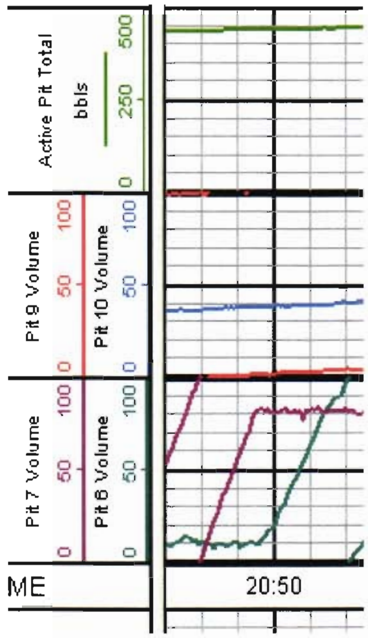

Figure 34

8:50 PM – The rig pumps are stepped down in anticipation of the arrival of the LCM spacer at the surface. Flow out increases due to the trip tank dump at 8:58 PM, described below.

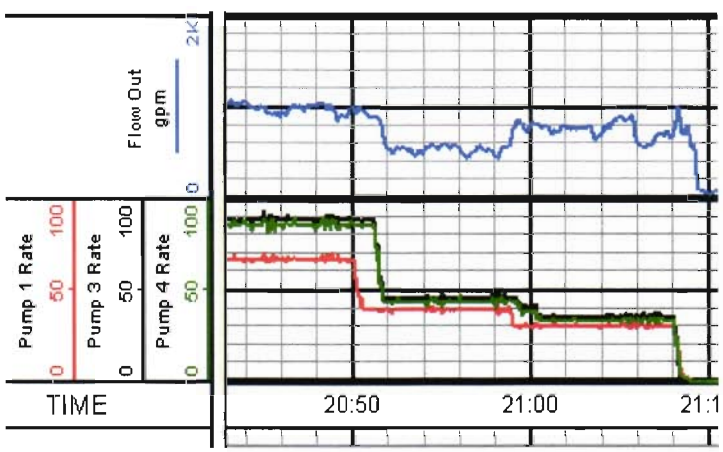

Figure 35

8:58 PM – The trip tank begins emptying past the flow-out sensor into the active pits, causing an increase in perceived flow from the well.

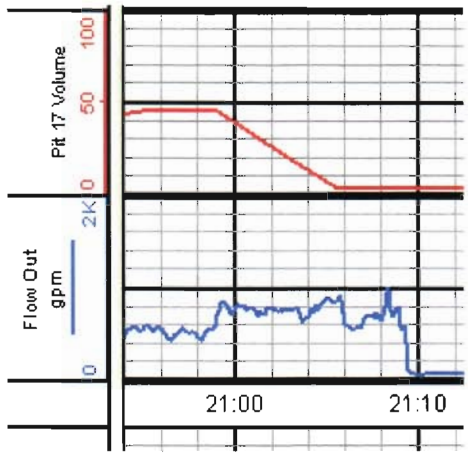

Figure 36

9:08 PM – The rig pumps are stopped for the sheen test, as shown above in Figure 35. This stoppage for the sheen test is performed like a flow check, the test used by the drilling crew to determine whether a well is flowing: all pumps are stopped, the well is left open, and flow from the well appears to stop on its own. Joseph Keith monitors a video of the flow line and visually confirms there is no flow from the well.[82] On his video feed, Mr. Keith witnesses the cessation of flow from the flow line, and then the gate that seals off the gumbo box from the flow line is lowered.[83] Because Mr. Keith witnessed first-hand the stoppage of flow from the well, he could feel reasonably secure the well was not kicking. Either the well was not flowing at this point, or someone on the drilling crew inappropriately diverted the fluid overboard too soon, a change the mudlogger was not made aware of.

[82] J. Keith Depo., 3/28/2011 at 151:17-152:17.

[83] J. Keith Depo., 3/28/2011 at 90:14-23 and 152:12-17.

9:10 PM – Mud from pits 9 and 10 (still designated the active system) are transferred to pit 6. The mudlogger is not notified.

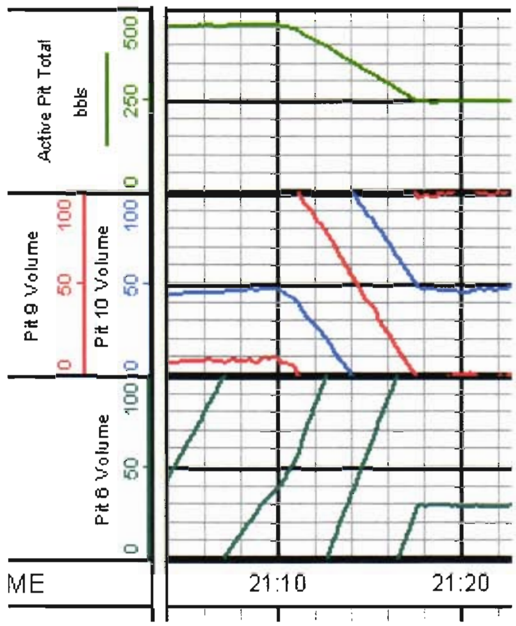

Figure 37

9:10 PM - 9:14 PM – While the sheen test is being conducted to determine whether returns may be diverted overboard, pressure slightly builds up in the well. Much has been made of this slight pressure increase in other reports, as addressed above. Also, a transfer from the active pits (pits 9 and 10) to pit 6 occurs during the sheen test. Mr. Keith likely monitors this fluid transfer that occurred simultaneously with the sheen test so he can properly account for all fluid volumes in his ledger.

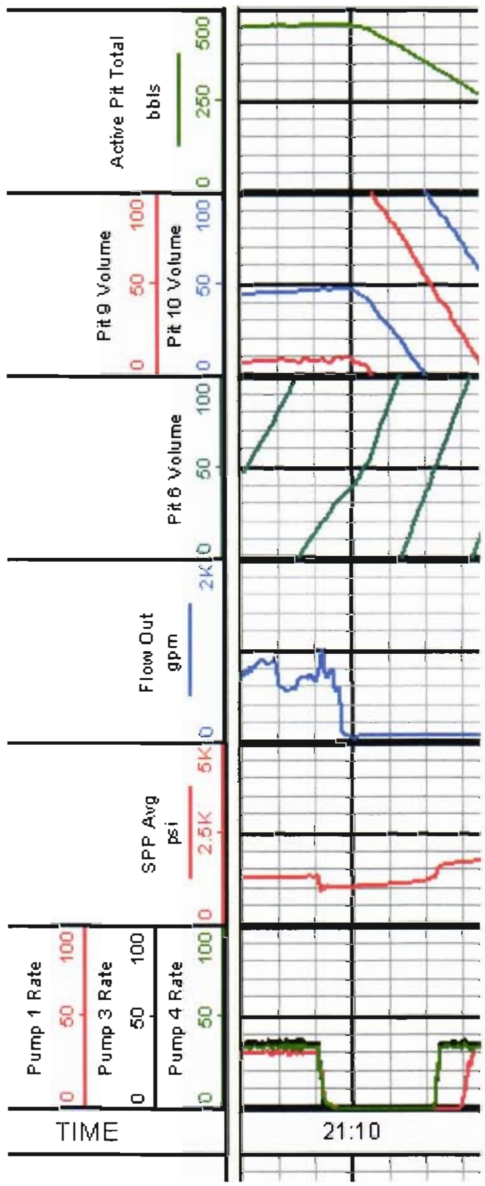

Figure 38

9:14 PM – Returns are diverted overboard and the mudlogger is unable to monitor flow from the well by either pit volume, or the less accurate flow-out sensor that is bypassed. The driller gradually steps up the pump speeds, instead of immediately increasing them to the required rate, causing pressure changes in the well that potentially mask signs of a kick. Joe Keith identifies this anomaly and calls the rig floor to determine why the pumps are being slowly stepped up, to which the assistant driller replies: "[w]e are just doing it like that."[84]

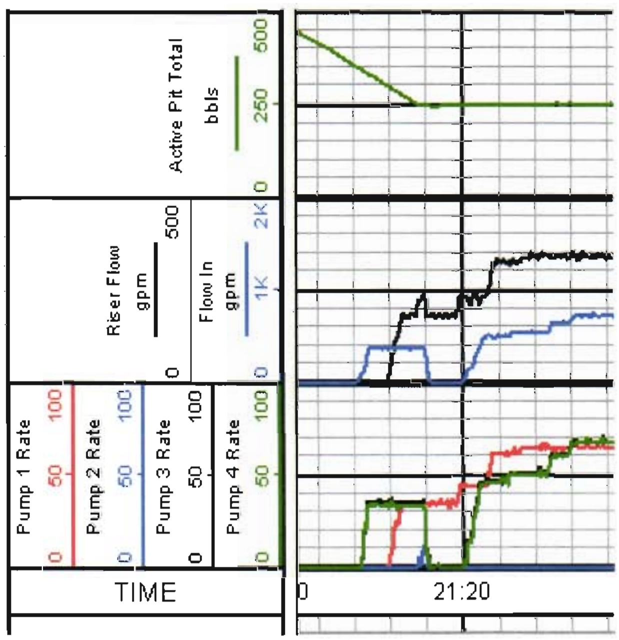

Figure 39

[84] J. Keith Depo., 3/28/2011 at 235:2-236:9.

9:18 PM – Mr. Keith notices a spike in one of the standpipe pressure measurements. He calls the rig floor again and is informed the crew blew a pop-off valve while pumping on an improperly configured line.[85]

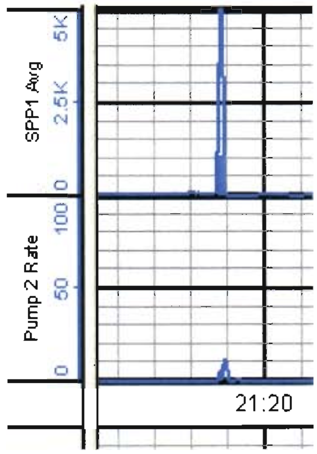

Figure 40

9:30 PM – The driller ceases displacement operations to investigate an anomaly in the standpipe and kill choke line pressures.

In addition to the above timeline, to help the Court better understand what the mudlogger was able to do and see during the Macondo displacement, Appendix D to this report includes a video reproduction of the data viewed by the mudlogger from 8:40 PM through the end of the available data, the time period when other parties allege the well began to flow. For a similar experience to the monitoring undertaken by Joe Keith during the Macondo final displacement, one should view this video in real time, trying to spot anomalies while keeping track of fluid transfers and not focusing on the known data anomalies that have been identified in post incident analyses. This process will aid in understanding why subtle increases in standpipe pressure—not traditionally believed to be a kick indicator—were not identified by Mr. Keith as data anomalies.

[85] J. Keith Depo., 3/28/2011 at 237:8-14, 237:22-239:1.