Det Norske Veritas
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abdel.ghoneim@dnv.com
May 18, 2006

Re: Contract No. 1435-01-05-CT-39236
Report No. 440 38570
"Pipeline Damage Assessment from Hurricane Ivan in the Gulf of Mexico"

U.S. Department of the Interior
Minerals Management Service
Engineering and Research Branch
381 Elden Street, Mail Stop 40
Herndon, VA 20170-4817

Attention: Mr. Michael (Mik) Else
Contracting Officer's Technical Representative

Dear Mr. Else:

Please find enclosed five (5) copies and one (1) digital copy of the above referenced final report. This completes the deliverables as per the terms of the contract.

If you have any questions, please do not hesitate to contact me via telephone at (281) 721-6642 or via electronic mail. We appreciate the opportunity to be of service to the MMS and thank you for your advice and direction throughout the project.

Yours truly,

Abdel Ghoneim, Ph.D, P.E.
Project Manager

Enclosures: 6

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Re: Contract No. 1435-01-05-CT-39236
Report No. 440 38570
"Pipeline Damage Assessment from Hurricane Ivan in the Gulf of Mexico"

U.S. Department of the Interior
Minerals Management Service
Procurement Operations Branch
381 Elden Street, Mail Stop 2100
Herndon, VA 20170-4817

Attention: Ms. Debbie Bridge
Contracting Officer

Dear Ms. Bridge:

Please find enclosed one (1) hard copy and one (1) digital copy of the above referenced final report. This completes the deliverables as per the terms of the contract.

If you have any questions, please do not hesitate to contact me via telephone at (281) 721-6642 or via electronic mail. DNV appreciates the opportunity to be of service to the MMS.

Yours truly,

Abdel Ghoneim, Ph.D, P.E.
Project Manager

Enclosures: 2

TECHNICAL REPORT

MINERALS MANAGEMENT SERVICE

PIPELINE DAMAGE ASSESSMENT FROM HURRICANE IVAN IN THE GULF OF MEXICO

REPORT NO. 440 38570

REVISION NO. 2

DET NORSKE VERITAS

DET NORSKE VERITAS

TECHNICAL REPORT

Date of first issue: 2006-05-08	Project No.: 440 38570
Approved by: Santhosh Kumar, Head of Section	Organizational unit: Pipeline Services
Client: Minerals Management Service	Client ref.: Mik Else

Summary:

DNV performed an assessment of the damage to the Gulf of Mexico (GOM) offshore pipelines resulting from the passage of Hurricane Ivan in September 2004, under contract with the Department of Interior's Mineral Management Service (MMS). The objective was to determine what happened to pipelines during Hurricane Ivan, and how to minimize the damage to pipelines, and the disruption of the U. S. oil and gas supplies originating in the GOM, as a result of hurricanes.

Study deliverables include a web-based damage mapping system concept, and report on damage effects, potential root causes, industry practices, and data collection methods assessment.

Report No.: 440 38570	Subject Group: Pipeline Damage	
Report title: Pipeline Damage Assessment from Hurricane Ivan in the Gulf of Mexico		
Work carried out by: Molly Atkins, Saadat Mirza, John Skinner, Abie Mathew, Bridge Solutions – Tim Edward		
Work verified by: G. Abdel Ghoneim		
Date of this revision: 05/15/2006	Rev. No.: 1	Number of pages: 64

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TECHNICAL REPORT

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TECHNICAL REPORT

1 EXECUTIVE SUMMARY

DNV performed an assessment of the damage to the GOM offshore pipelines resulting from the passage of Hurricane Ivan in September, 2004, upon request from the Department of Interior's Minerals Management Service (MMS). The objective was to determine what happened to pipelines during Hurricane Ivan, and how to minimize the damage to pipelines and the disruption of the U. S. oil and gas supply originating in the Gulf of Mexico, as a result of hurricanes.

DNV evaluated the available failure reports and industry practices and has concluded that the vast majority of GOM offshore pipelines performed well during the passage of Hurricane Ivan. Public and personnel safety experience has been excellent. Evacuations of non-essential personnel, and other operational precautions taken prior to hurricane events, including training, planning, spill response exercises, and industry alliances provided results that have protected life as the first priority. The impact to the environment has been minimal in hurricane events, primarily due to the design features, and similar industry practices intended for protection of life that are also focused on minimizing releases to the environment through planning, preparedness and response. The most significant impacts appear to have been disruption of the oil and gas supply, and financial losses from the oil and gas infrastructure damage. While these are not desirable outcomes, the overall goal of prioritizing protection of life and the environment is clear in the demonstrated performance of the industry, meeting two of the major goals of the MMS for personal and environmental safety.

The majority of pipeline damages occurred at or near platform interfaces, in areas of mudflows, or as a result of impact by an outside force other than the hurricane, such as platform failure or anchor dragging. Pipelines that may have exceeded their design limits from pure hurricane forces were studied as a specialized subset of the reported damages. However, the ability to determine the actual root cause of the failures is limited by the incomplete data that we have about the pipeline's in-situ condition and the actual sequence of events that occurred during the hurricane with respect to failure or loadings imposed by movement of interconnected facilities at platforms and tie-ins.

Localized failures at pipeline crossings and excessive movements in shallow water depths suggest that more hurricane resistant design considerations might be needed, but they appear to be site specific, and do not warrant industry wide design code revisions. The continued occurrences of excessive pipeline movement in shallow waters does indicate a need to evaluate the assumptions associated with burial, cover and stability analyses that may be performed for these pipelines. DNV is not suggesting that a cover maintenance program should be initiated, as this is not practical from a maintenance standpoint for constantly shifting sediments in the shallow Gulf waters. However, DNV is suggesting that the assumptions used in the design of shallow water pipelines may need to be carefully evaluated in areas of silty weak soils, particularly where self-burial is intended as the method of installation.

The data collection and damage reporting is an area that could be improved through report automation, consistent methodology and format and industry wide definitions of the failure categories for the purposes of data analysis. DNV believes that the identification of the critical data, and reporting through an automated process would benefit both the industry and MMS in the information management related to pipeline damage reporting. DNV recommends that

Graphical tools and mapping can provide improved data management for quicker assessments of hurricane impacted areas, development of NTLs that are technically based, and visual data management. Simple, cost effective, yet powerful mapping tools have been developed as part of this study. These geospatial tools can support the continued analyses by MMS and enhance the automation of the pipeline damage reporting without cost or specialized software acquisition by pipeline operators. These web-based mapping developments are discussed in greater detail in the body of this report.

Significant numbers of the pipeline damages occurred outside of the path identified in the Hurricane Ivan NTLs. The criterion for such post-hurricane damage surveys are typically tied to wind speeds, and while this is appropriate for surface structures, it appears that better criteria for pipelines may be based upon reverse current areas that result from the hurricane passage, and water depths. Development of specific criteria for pipeline damage surveys are recommended to focus on the most likely undetected damage (excessive movement without failure), and minimize the drain on already over-utilized recovery and inspection resources.

With the increased reliance on the GOM oil and gas supplies, disruption of production has greater economic and social impacts, increasing the need for expeditious, yet safe return to service of hurricane damaged or destroyed facilities. Planning for decision criteria to assess integrity, and developing alliances prior to events proved valuable in expediting the assessment and review and approval process for returning to service, and is recommended as a best practice for pipeline operators. It is recommended that MMS provide guidance to pipeline operators and encourage them to develop integrity assessment plans in advance of hurricanes, particularly for those pipelines that are critical energy infrastructure and without alternate routes to production.

2 INTRODUCTION

2.1 Objective

On behalf of the Department of the Interior, Minerals Management Service (MMS), DNV carried out a damage assessment of the pipelines in the Gulf of Mexico, resulting from the passage of Hurricane Ivan in September, 2004. The objective of the assessment was to determine the performance of offshore pipelines during Hurricane Ivan, and to develop recommendations to minimize damage to the pipelines and disruption of the U.S. oil and gas supply originating in the Gulf of Mexico resulting from hurricanes.

2.2 Scope

The project scope included an assessment of the pipeline infrastructure damage caused by Hurricane Ivan, with an attempt to identify the root causes of the damage through analyses of the damage reports, interviews of pipeline operators and participation in industry hurricane-related workshops. The scope also included investigation of current design, operations, maintenance and hurricane preparedness and response practices by Gulf of Mexico pipeline operators. The results were collected and evaluated through technical and graphical analyses to determine possible revisions to codes and practices with the intent of better protecting pipelines during subsequent major hurricane events.

This report describes the GOM OCS pipeline system in Sec. 3 and gives background on the hurricane environment in Sec. 4 including the latest 2005 hurricane season. Hurricane impacts and trends are discussed in Sec. 5. The work related pipeline response to Hurricane Ivan is covered in Sections 6 to 11. Section 12 is dedicated to the damage mapping development while Sec. 13 lists the DNV conclusions and recommendations made as a result of this study.

3 GULF OF MEXICO OUTER CONTINENTAL SHELF PIPELINE SYSTEM DESCRIPTION

The MMS Gulf of Mexico Regional Office (GOMR) conducts all leasing and resource management functions on the GOM Outer Continental Shelf (OCS). The OCS consists of submerged Federal lands off the United States coasts. MMS leases these Federal offshore areas for exploration and production and closely monitors OCS operations to protect coastal environments and ensure proper royalty collection. As well as meeting major energy needs through management of the production of roughly 30% of the US oil supply at roughly 1.5 Million barrels per day, and 22% of the US natural gas supply totaling over 10 billion cubic feet per day, MMS provides about $6 billion in annual revenue benefits to the Nation. The GOMR's three planning areas include 43 million acres under lease, with nearly 4,000 platforms and 33,000 miles of pipeline, represented by the map in Figure 1.

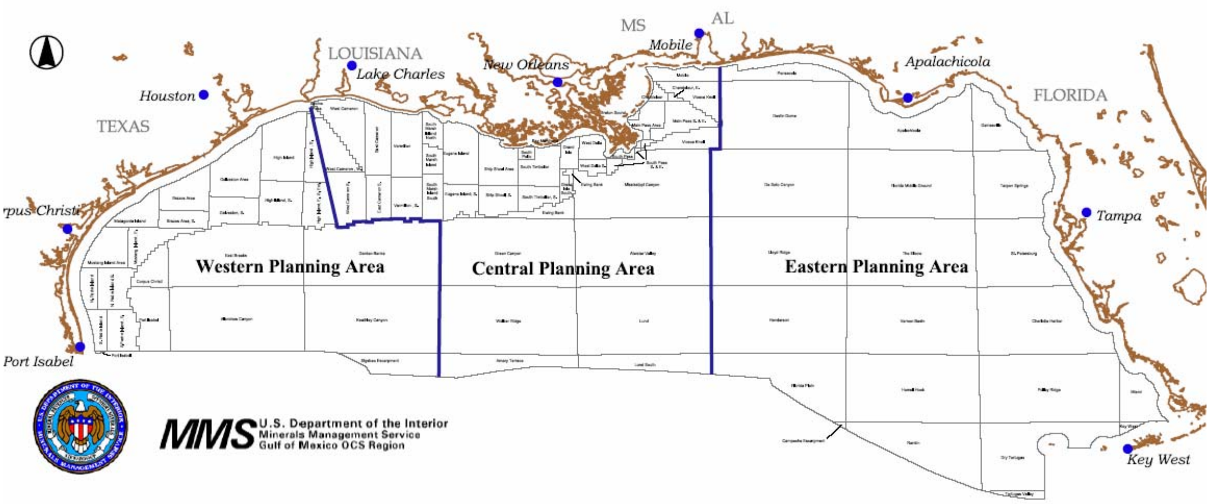


Figure 1 GOMR Area Map

4 GOM HURRICANE HISTORICAL STUDIES AND EXPERIENCE

4.1 Hurricanes in Perspective

Hurricane Season:

The official Atlantic hurricane season takes place each year between June 1 and November 30, with peak hurricane activity generally occurring between mid-August and mid-October.

In an average year, ten tropical storms develop in the Gulf of Mexico, Caribbean Sea, or Atlantic Ocean; six of these storms become hurricanes. In a typical three-year span, five hurricanes hit the United States mainland; two are designated major (Category 3 – 5) hurricanes. The southeastern United States is the region most vulnerable to a hurricane strike. The States most likely to be hit by a major hurricane are Florida, Texas, and Louisiana.

--National Oceanic and Atmospheric Administration, Hurricanes: Unleashing Nature's Fury and U.S. Mainland Hurricane Strikes by State

The 2004 Hurricane Season produced 15 named events with 7 tropical storms and 9 which reached hurricane force winds, characterized as wind speeds above 74 mph, using the U.S. 1-minute average. With ten being the average number of systems normally occurring annually in the Atlantic Basin, the 2004 hurricane season was characterized as *extremely active*. The 2004 storms are represented in Figure 2.

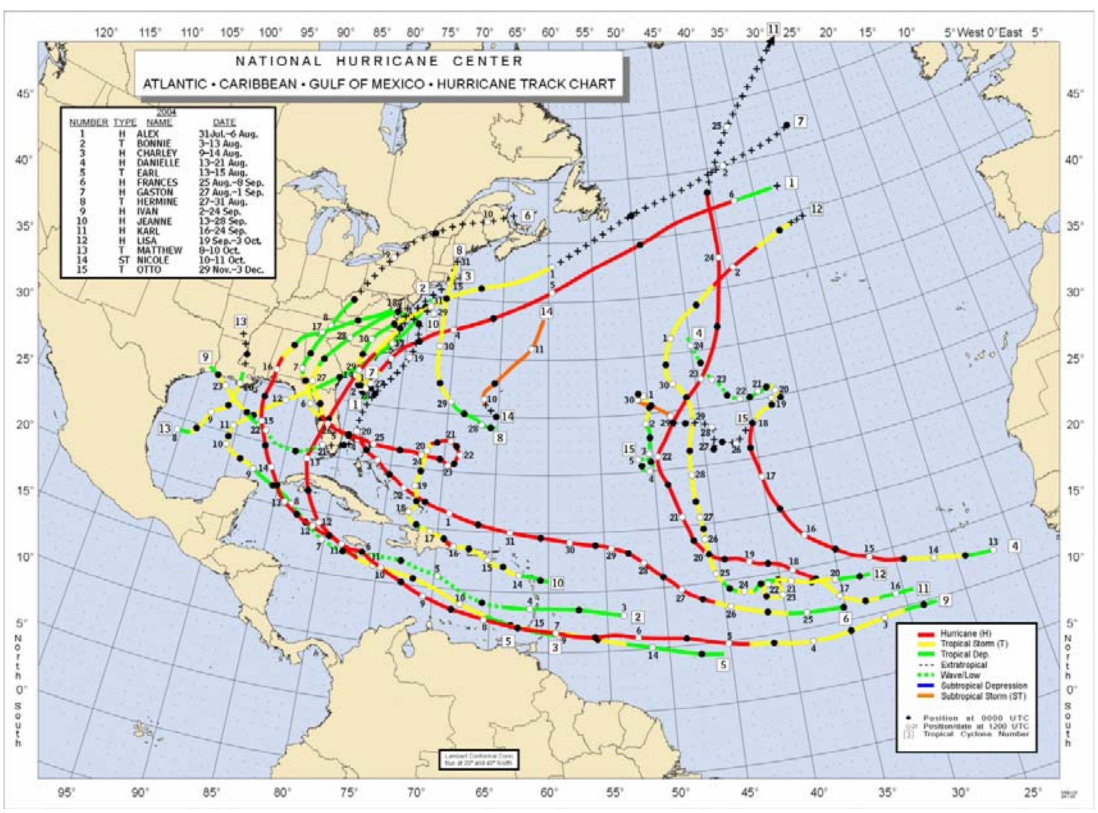


Figure 2 – 2004 Storm Events & Hurricane Track Chart

Hurricanes are rated on the Saffir-Simpson Hurricane Scale. The Saffir-Simpson Hurricane Scale is a 1-5 rating based on the hurricane's intensity. This is used to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. Wind speed is the determining factor in the scale, as storm surge values are highly dependent on the slope of the continental shelf and the shape of the coastline, in the landfall region. Note that all winds are using the U.S. 1-minute average.

Saffir-Simpson Hurricane Scale

Category	Storm Surge	Winds
1	4 -5 feet	74 – 95 mph
2	6-8 feet	96 – 110 mph
3	9-12 feet	111 – 130 mph
4	13-18 feet	131 – 155 mph
5	More than 18 feet above normal	Greater than 155 mph

* To be a Tropical Storm, winds must be between 39-73 mph.

The timing of the hurricane events and typical experience are represented in the NOAA chart shown in Figure 2-1.

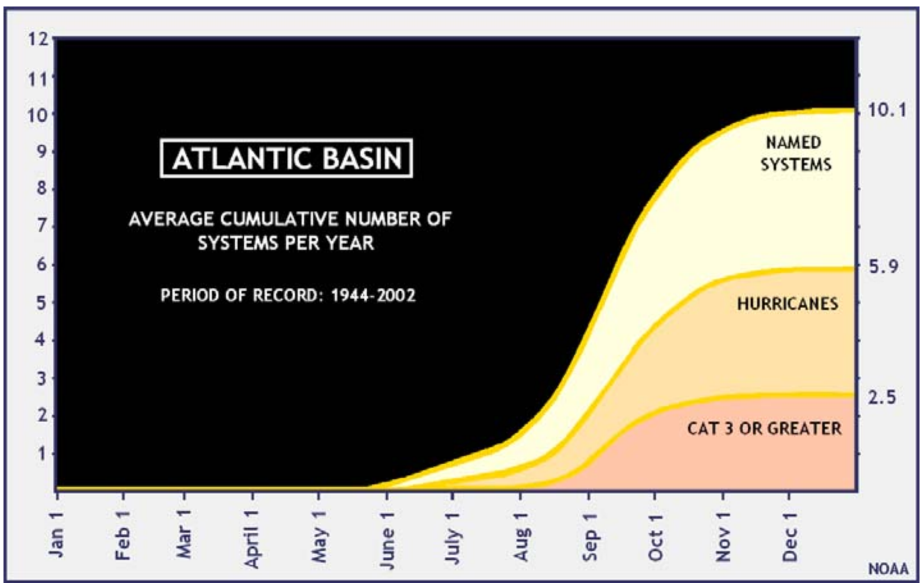


Figure 2-1 Average cumulative number of Atlantic systems per year

In Figure 2-1, curves represent the average cumulative production of all named tropical systems, all hurricanes, and those hurricanes which were Category 3 or stronger.

For example, by the beginning of September in an average year we would expect to have had four named systems, two of which would be hurricanes and one of which would be of category 3 or greater in strength.

The following is a summary of the historical hurricanes studied for comparison to the Hurricane Ivan damage, and a preview of the damage experienced during Hurricanes Katrina and Rita.

4.2 Hurricane Andrew

Hurricane Andrew damage to offshore pipelines was studied by Southwest Research Institute, and a Final Report was produced under MMS Contract No. 14-35-0001-30748 for the MMS Technical Assessment and Research Branch in March of 1995. Hurricane Andrew passed through the Gulf of Mexico in August 1992, following the path shown in Figure 3. About 36 major platforms and 145 satellite well jackets and caissons were damaged and more than 480 pipelines and flow lines were damaged by the passage of Hurricane Andrew. Hurricane Andrew was a category-4 level storm with sustained winds up to 140 miles per hour and significant wave heights estimated to be at 35-40 feet. Hurricane Andrew passed to the west of the Mississippi Delta, with its path overlaying some 700 structures, felling 22, and damaging to some degree about 65 others. Consequently, the westward path of Hurricane Andrew, shown in Figure 3, resulted in few pipelines being damaged by mudslides in this hurricane event.

Figure 3 – Path of Hurricane Andrew

Prior to Hurricane Andrew, minimal damage to pipelines had been experienced as a result of passing hurricanes. Pipeline failures from hurricanes for the period of 1971 through 1988 resulted in about 100 damage reports compared to Andrew's 485 damage reports. This dramatic increase in damages prompted the MMS to commission the study in an attempt to understand why when compared to the historical experience, the pipeline damages from Hurricane Andrew were so excessive. The results of the Hurricane Andrew study stated that most of the failures (87%) occurred in small diameter pipelines in the range of 2" to 6" diameter and that most of the failures were in depths less than 100 feet of water. The majority of the remaining damages were primarily attributed to riser and platform damage. No correlation was found to the age of the pipelines that sustained damage.

The study further concluded that the design standards appeared to be adequate, and the overall procedures followed by operators with regard to planning and recovery for hurricanes were also deemed to be adequate. Overall pollution from pipeline damages during all storms was low and was deemed not to be a major concern in the study report.

The summary recommendations from this study were:

- Efforts should be made to improve safety of platforms and jackets to withstand 100 year events to minimize pipeline damage
- Efforts should be made to improve anchoring and stationkeeping of mobile rigs
- Improvements for protection of small sized lines in shallow water depths
- Improvements for self burial installation stability for storm conditions

- Riser supporting clamps and adjacent pipeline sections should be carefully analyzed to verify integrity for the 100 year storm conditions
- Periodic inspection and maintenance of risers and supporting clamps are key in ensuring satisfactory performance to the intended design stress level.

4.3 Hurricane Lili

Hurricane Lili damage to offshore pipelines was evaluated and compared to prior hurricanes by Stress Engineering Services, Inc. in a study commissioned by MMS, and a Final Report was issued under contract 1435-01-03-RP-70926 in August 2005. Hurricane Lili was a category-4 level storm offshore, and was downgraded to a category-2 level at landfall, it passed through the GOM in late September 2002, making landfall on October 4, 2002. There were 120 pipeline damages reported to the MMS as a result of Hurricane Lili. Additionally, Hurricane Lili passed over approximately 800 platform structures resulting in the complete collapse of two platforms and serious damage to 17 others.

The primary focus of the Hurricane Lili pipeline damage assessment was on the comparison of the pipeline damage experience during Hurricane Lili with that of Hurricane Andrew. The study picked up where the Hurricane Andrew study left off, and evaluated the overall damage in much the same manner as the Hurricane Andrew report, focusing its attention on the area of pipeline riser damage, as recommended by the Hurricane Andrew study. As a result, the primary recommendations that resulted from the Hurricane Lili study were focused on recommended improvements in clamp design and maintenance for platform risers and their clamps.

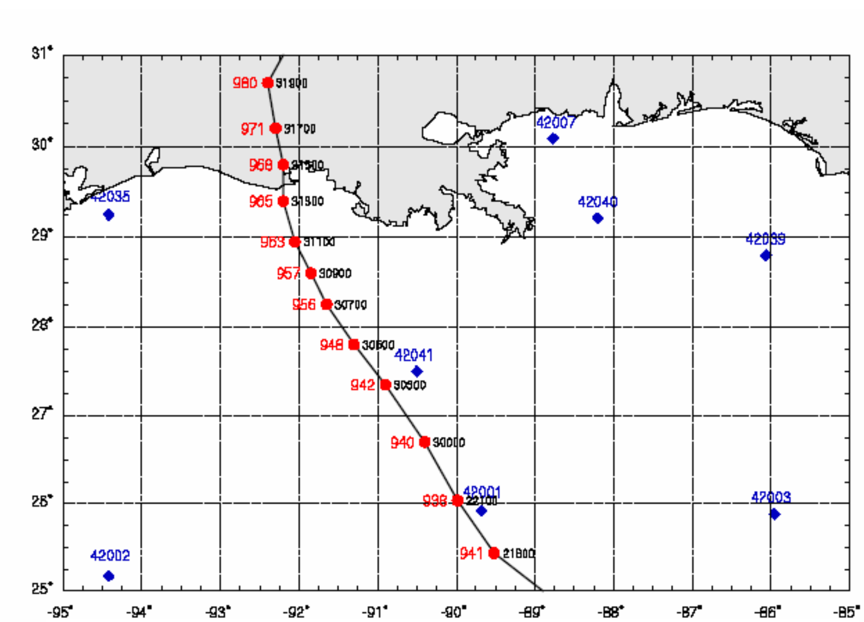


Figure 4 – Path of Hurricane Lili

The damage statistics from Hurricane Lili were contrasted to those of Hurricane Andrew, with similar statistical findings. As was true in Hurricane Andrew, the majority of the pipeline failures in Lili occurred in small pipeline diameter sizes (85%), and there was no apparent correlation by age. Again, the path of this hurricane, was as shown in Figure 4, was to the west of the Mississippi delta, and as a result, the pipeline damage from mudflows was minimal.

The summary recommendations from the Hurricane Lili study were:

- Improvements in the questions asked of operators in the damage reporting process to better elicit root causes and improve data collection

- A simple check of riser clamp spacing by pipeline operators
- Evaluate improvements of riser inspection processes by operators in their maintenance programs
- Development of an in-situ riser integrity test for discovery and replacement of weak risers prior to storm events

4.4 Hurricane Ivan

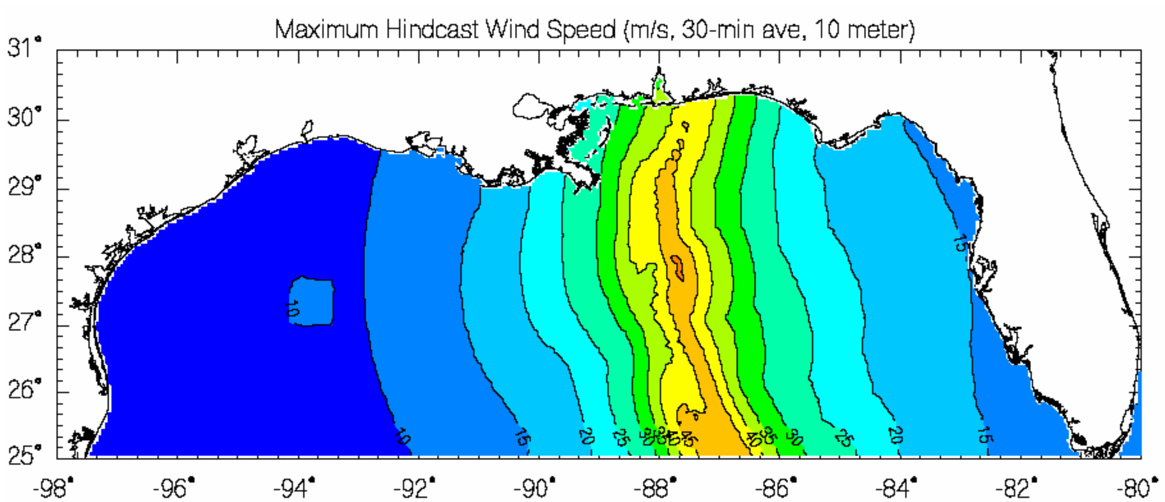
Hurricane Ivan, the subject of this study report, was a classic, long-lived Cape Verde hurricane that reached Category 5 strength three times, and was a category 3 hurricane at landfall. For the period of 1851 - 2004, Hurricane Ivan was 27^{th} out of approximately 1325 storm systems, ranked by Saffir-Simpson category at landfall and the measured minimum barometric pressure.

4.4.1 Synoptic History

(Source: Excerpted from the Tropical Cyclone Report, Hurricane Ivan, 2-24 September 2004, Stacy R. Stewart, National Hurricane Center, Updated 27 May 2005)

Ivan developed from a large tropical wave that moved off the west coast of Africa on 31 August. On 13 September, Ivan approached a weakness in the subtropical ridge over the central Gulf of Mexico and turned northwestward at a speed of 8-10 kt. As Ivan moved over the northwestern Caribbean Sea, the combination of the impressive upper-tropospheric outflow that was being enhanced by the south-southwesterly upper-level flow ahead of an approaching trough and the very warm water in that region probably helped the hurricane maintain category 5 strength for an unusually long 30 h. Once again major land areas were spared the full force of the hurricane because the 20 n mi diameter eye and strongest winds passed through the Yucatan channel just off the extreme western tip of Cuba.

Shortly after emerging over the southern Gulf of Mexico early on 14 September, Ivan turned north-northwestward and then northward. A steady weakening trend also ensued as moderate southwesterly flow on the east side of a large mid- to upper-level trough over the central United States and northeastern Mexico gradually caused the vertical shear to increase across the hurricane. As Ivan neared the northern U.S. Gulf coast, the upper-level wind flow ahead of the trough became more westerly and strengthened to more than 30 kt, which helped to increase the shear even more and advect dry air into the inner core region. Despite the unfavorable environmental conditions, the presence of cooler shelf water just offshore and eyewall replacement cycles, Ivan weakened only slowly and made landfall as a 105 kt, category 3 hurricane at approximately 0650 UTC 16 September, just west of Gulf Shores, Alabama. By this time, the eye diameter had increased to 40-50 nautical miles, which resulted in some of the strongest winds occurring over a narrow area near the southern Alabama-western Florida panhandle border.



After Ivan moved across the barrier islands of Alabama, the hurricane turned north-northeastward across eastern Mobile Bay and weakened into a tropical storm 12 hours later over central Alabama. A gradual turn to the northeast occurred shortly thereafter and Ivan became a tropical depression by 0000 UTC 17 September over northeast Alabama. A northeastward motion at 10-14 kt continued for the next 36 h before Ivan merged with a frontal system and became an extratropical low over the Delmarva Peninsula around 1800 UTC 18 September. However, even as a weak tropical depression, Ivan was a prodigious rain and tornado producer causing flash floods and tornado damage across much of the southeastern United States.

Even as an extratropical low, the remnant circulation of Ivan was identifiable in both surface and upper-air data. Over the next 3 days, the low moved south and southwestward and eventually crossed the southern Florida peninsula from the Atlantic the morning of 21 September and emerged over the southeastern Gulf of Mexico later that afternoon. As Ivan moved westward across the warm water of the Gulf, the low began to re-acquire warm core, tropical characteristics as showers and thunderstorms started developing near the well-defined low-level circulation center. During the morning of 22 September, Ivan completed a large anticyclonic loop and by 1800 UTC reconnaissance aircraft reports indicated that it had become a tropical depression again over the central Gulf of Mexico.

Ivan regained tropical strength 6 h later when it was located about 120 n mi south of the mouth of the Mississippi River. Tropical Storm Ivan turned northwestward and made landfall as a tropical depression in extreme southwestern Louisiana around 0200 UTC 24 September. After landfall, Ivan quickly dissipated later that morning over the upper Texas coastal area about 20 n mi northwest of Beaumont. Including its extratropical phase, Ivan existed for 22.5 days and produced a track more than 5600 n mi long.

4.4.2 Hurricane Ivan Impacts to Offshore Oil and Gas

Hurricane Ivan produced record level wave heights and wind speeds that exceeded the 100 year design criteria for surface structures, and produced high levels of pipeline damage, many resulting from mudslides and excessive movement in the Mississippi Delta region.

The mapping of the pipeline damage with respect to the path of Hurricane Ivan is shown in Figure 4-1. Hurricane Ivan resulted in approximately 168 pipeline damage reports, 7 platforms were destroyed while 31 were seriously damaged, with an estimated 10,000 of the 33,000 miles of OCS pipelines, and 150 of the 4,000 platforms in the direct path of Hurricane Ivan. The damage to offshore pipelines will be described in greater detail in the damage assessment portion of this report.

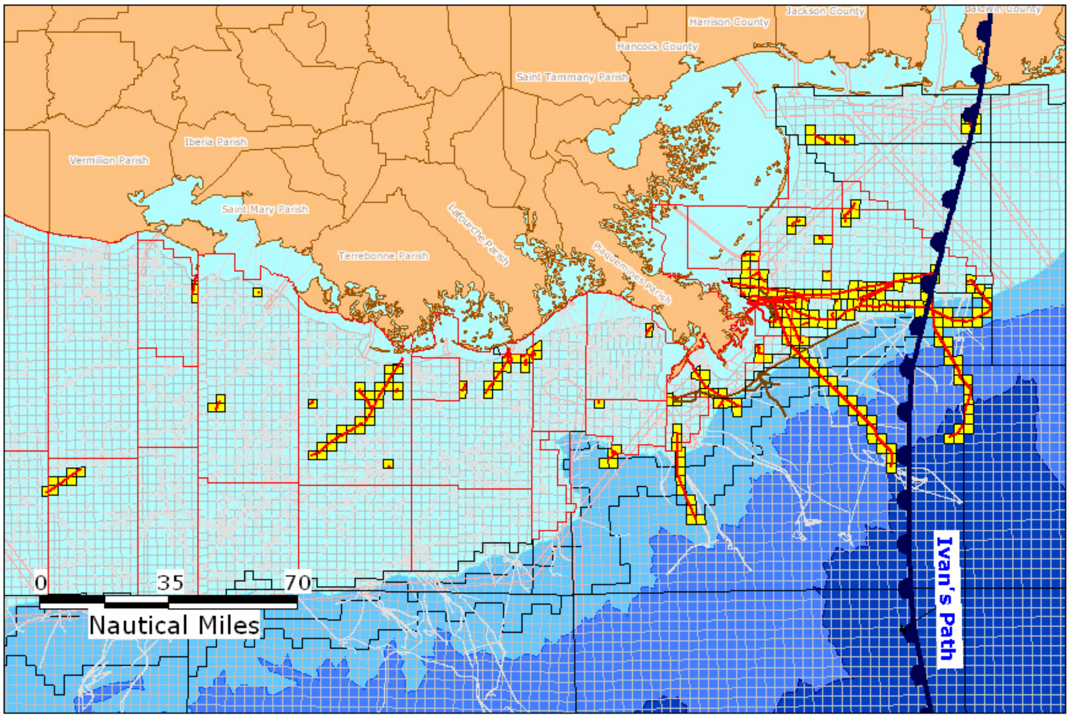


Figure 4-1 Study Map Showing Location of Reported Hurricane Ivan Pipeline Damage

4.5 Hurricanes Katrina and Rita

The 2005 Hurricane season was one of the most active on record, with a record level of named storm activity, and two particularly devastating hurricanes hitting the southern U.S. gulf coast. As a result of the tremendous impact and losses sustained in the first event, President Bush ordered a comprehensive review of the Federal response to Hurricane Katrina. The following is an excerpt from the February 23, 2006 White House Report, *Federal Response to Hurricane Katrina, Lessons Learned*, which was prepared by a team led by Frances Fragos Townsend, Assistant to the President for Homeland Security and Counterterrorism describing the 2005 Atlantic hurricane season prediction.

On May 16, 2005, Brigadier General David L. Johnson (ret.), Director of the National Oceanic & Atmospheric Administration (NOAA), National Weather Service (NWS), released the 2005 Atlantic hurricane outlook to kick off National Hurricane Preparedness Week. In its report, NOAA assessed a 70 percent chance of an above-average hurricane season, predicting twelve to fifteen Atlantic tropical storms, with seven to nine becoming hurricanes and three to five of those becoming major hurricanes (equivalent to Categories 3, 4, and 5 on the Saffir-Simpson scale). NOAA also noted that the previous year had been "extremely active," with fifteen Atlantic tropical storms, including nine that developed into hurricanes. That same day, Max Mayfield, Director of the National Hurricane Center (NHC), cautioned, *"[l]ast year's hurricane season provided a reminder that planning and preparation for a hurricane do make a difference. Residents in hurricane vulnerable areas who had a plan, and took individual responsibility for acting on those plans, faired [sic] far better than those who did not."*

On August 2, 2005, NOAA released an updated 2005 Atlantic hurricane season outlook that projected the formation of an additional eleven to fourteen tropical storms, with seven to nine becoming hurricanes, including three to five major hurricanes. Based on the developments in June and July, NOAA revised its assessment to a "95 to 100 percent" chance of an above-normal 2005 Atlantic Hurricane season. It reported that "the atmospheric and oceanic conditions favoring hurricane formation that were predicted in May are now in place. These conditions, combined with the high levels of activity already seen, make an above-normal season nearly certain. "Moreover, while there already had been "considerable early season activity," NOAA emphasized that the next three months constituted the peak of hurricane season. NHC Director Mayfield explained, "Knowing precisely where a hurricane will strike and at what intensity cannot be determined even a few days in advance. "He urged that "residents and government agencies of coastal and near-coastal regions should embrace hurricane preparedness efforts and should be ready well before a tropical storm or hurricane watch is posted." With four more months remaining in hurricane season, the NOAA outlook proved an ominous forecast.

Hurricanes Katrina and Rita caused significant damage to the oil and gas production structures in the GOM, with estimates by MMS stating that roughly 3050 of the 4000 platforms and about 22,000 of the 33,000 miles of offshore pipelines were in the path of these two hurricanes. Additionally, the onshore damage caused a significant impact in the ability of the oil and gas industry to respond due to the lack of resources, personnel, and infrastructure. These needs were competing with the impacts caused by the devastation of New Orleans and western Louisiana/eastern Texas shore communities that normally provide the services and supplies for the industry. This included the temporary relocation of the MMS GOMR staff and functions to Houston, Texas.

Preliminary reports of pipeline damage to MMS number approximately 450 at the time of this report. These two hurricanes produced a higher percentage of impact to larger diameter lines than historical experience. These damages will be evaluated in future MMS funded research studies.

Hurricane Katrina was a category 5 hurricane when it entered the OCS, destroying 46 platforms and damaging 20 others, making landfall on August 29, 2005. Katrina's path is the easterly one in Figure 5. There were about 211 minor pollution incidents reported to the MMS. Minor pollution incidents are categorized as incidents involving less than 500 barrels of oil that do not reach the coast line.

Hurricane Rita was a category 4 hurricane when it entered the OCS and destroyed 69 platforms and damaged 32 others making landfall on September 24, 2005. Rita's path is the westerly one shown Figure 5.

These two storms caused major disruption to the oil and gas facilities in the GOM. Among other impacts, Hurricane Katrina resulted in the immediate 8.8 MMscf/day reduction in natural gas supply. Less than a month later, with 44% of the offshore production not yet returned to operations, Hurricane Rita struck. The impacts of Hurricane Rita hit the already damaged GOM gas industry, losing almost 3.5% of the annual US natural gas as a result of the lost production abilities resulting from the damages to the GOM gas infrastructure and associated facilities.

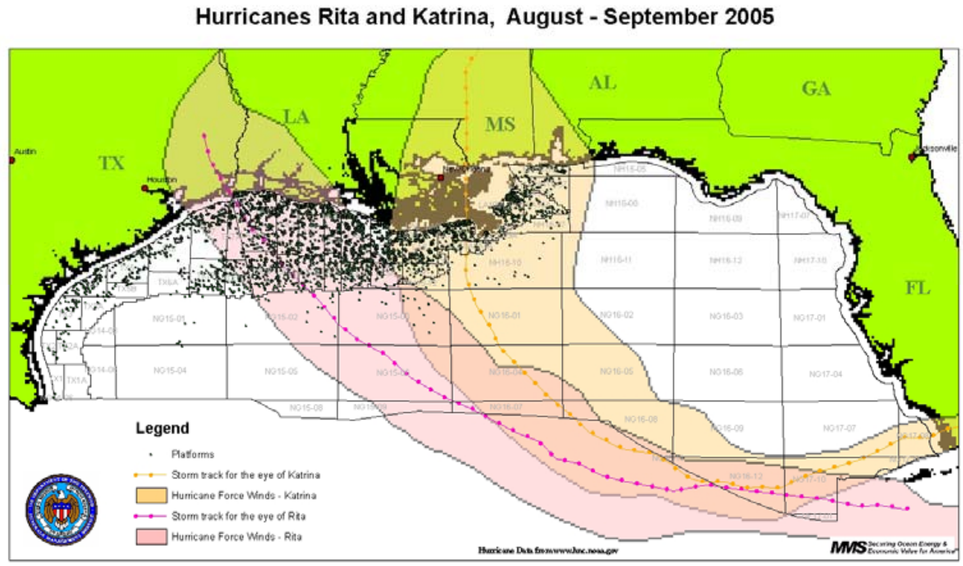


Figure 5 – Storm Tracks for Hurricanes Katrina and Rita

5 HURRICANE ACTIVITY AND ECONOMIC FACTORS

Two factors are present in the GOM oil and gas production environment that have not been as visible in past studies. The first factor is the much higher than average hurricane activity in the GOM has caused speculation that hurricanes are increasing in both severity and frequency, and that this trend will continue and/or worsen. The two recent hurricanes, Katrina and Rita hit in rapid succession and impacted the oil and gas production more significantly than Hurricane Ivan, as shown in Figure 6.

	Oil Production Shut-In			Gas Production Shut-In		
	Ivan	Katrina	Rita	Ivan	Katrina	Rita
Max Shut-In	82.9%	95.2%	100.0%	53.0%	88.0%	80.5%
1 Day After	72.5%	91.5%	100.0%	41.6%	83.5%	78.4%
2 Days After	64.7%	90.4%	100.0%	34.1%	78.7%	78.6%
3 Days After	51.5%	88.5%	100.0%	27.6%	72.5%	80.3%
4 Days After	41.1%	79.0%	98.6%	23.5%	57.8%	79.8%
5 Days After	39.2%	73.3%	97.8%	22.7%	55.0%	79.4%
6 Days After	34.0%	69.6%	94.7%	19.5%	52.3%	76.8%
7 Days After	27.7%	58.0%	92.8%	18.9%	41.6%	75.0%
14 Days After	28.5%	56.4%	77.5%	18.9%	37.2%	64.2%

Source: MMS/rigzone

Figure 6 - Short Term OCS GOM Shut–In comparison for Hurricanes Ivan, Katrina, Rita

This leads into the second factor; the economic criticality of the oil and gas supplied by the production facilities of the GOM. With more than 30% of the US oil consumption and nearly one quarter of the country's natural gas supply coming from the production in the GOM, the hurricane impacts have a direct affect on the US economy with respect to oil and gas commodities, and pressure is intense to return facilities to production as soon as safely possible. The Department of Energy's short term energy outlook, presented by the Energy Information Administration (EIA), is developed from information including the MMS shut-in statistics to depict the economic and production forecasts for offshore oil and gas production.

Figures 6a and 6b represent the current projections, as of March 2006, for the oil and gas price forecasts from the EIA. The charts show the amount of offshore oil and gas production remaining shut-in as a result of Hurricanes Katrina and Rita.

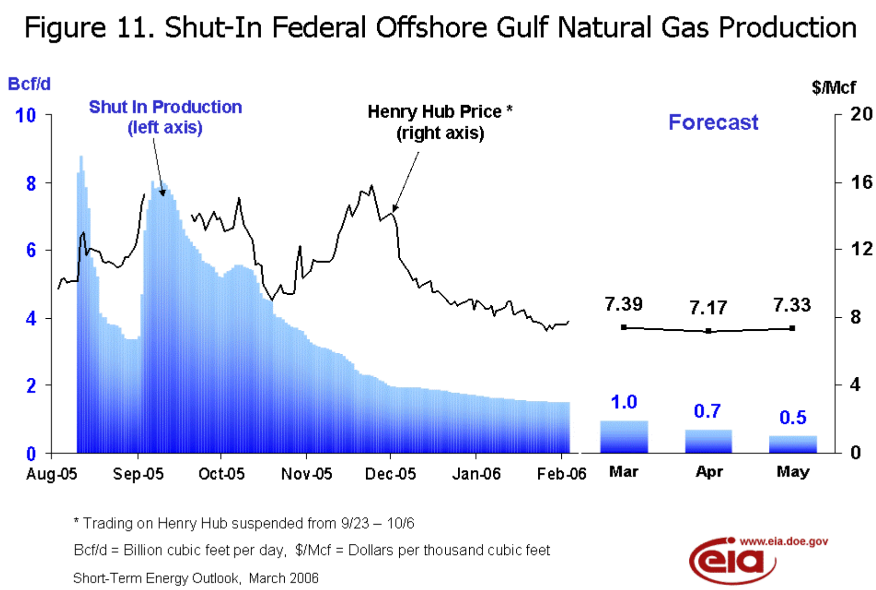


Figure 6a – Offshore Gulf Natural Gas Production

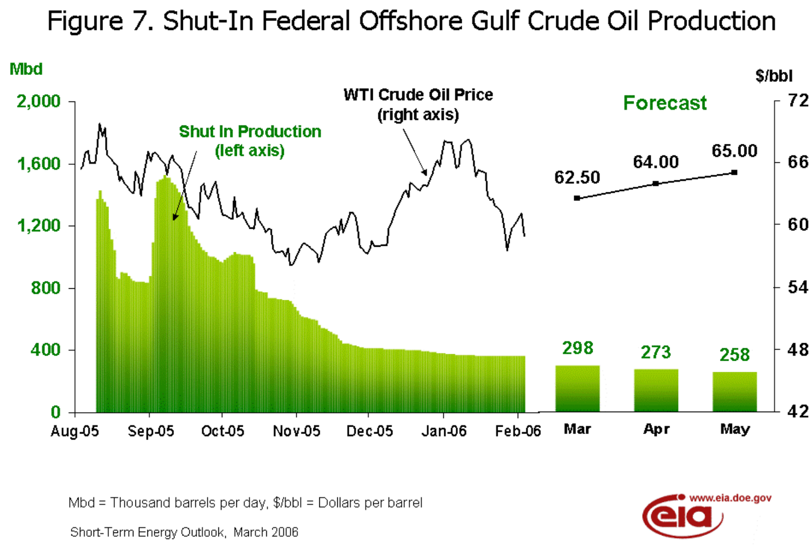


Figure 6b – Offshore Gulf Crude Oil Production

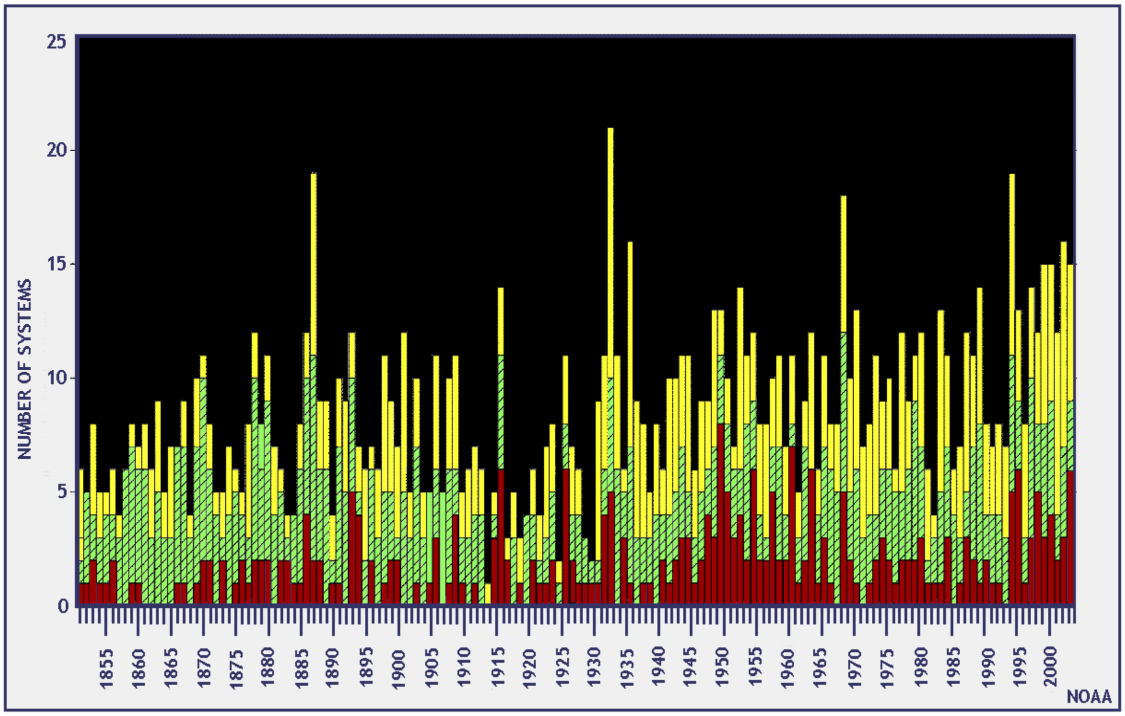
5.1 Relaxation of Regulatory Requirements by Federal Agencies

The unprecedented high levels of shut-in production after Hurricanes Katrina and Rita prompted temporary relief from Federal Energy Regulatory Commission (FERC) in the gas market, as well as temporary relaxation of rules, and expedited permitting processes under blanket authority to construct, repair, and provide alternate routes for onshore pipelines and processing facilities.

Petroleum production and transportation is not regulated by FERC, but sectors of the refined products industry received temporary waivers from EPA for specific standards in some regions to ease supply and production issues. Oil spill reporting and clean-up requirements were not relaxed. However, the minimal release of oil that was experienced was largely based upon the industry practices and timely and efficient evacuation of platforms and production facilities. Even with significant damages to infrastructure, there were only 13 reports of significant pollution reported. Of these reports, 7 reports were attributed to pipeline failures, and all but one was associated with a platform failure. Worst case scenario was an approximate volume of 4700 barrels of product spilled, based upon estimates of capacity and shut-in production at the time of failures. Additional recovery efforts reduced this spilled volume significantly.

5.2 Hurricane Trends

There is widespread agreement that 2004 and 2005 were higher than average years for the number of named storms in the Atlantic Basin. However, general debate exists as to whether this timeframe marks an upward trend in hurricane activity, or if it is part of a normal cyclical variation. The historic hurricane activity level has been tracked by the National Hurricane Center as shown in Figure 7.



Bars depict number of named systems (open/yellow), hurricanes (hatched/green), and category 3 or greater (solid/red), 1886-2004

Figure 7 – Number of Named Systems, Category 3 or Greater 1886 - 2004

This question on hurricane trends has been studied by various agencies including the USGS who published the following news release on March 15, 2006, summarizing one such study.

Century of Data Shows Water Cycle Intensifying But No Increase in Storms or Floods

A review of the findings from more than 100 peer-reviewed studies shows that although many aspects of the global water cycle have intensified, including precipitation and evaporation, this trend has not consistently resulted in an increase in the frequency or intensity of tropical storms or floods over the past century. The USGS findings, which have implications on the effect of global climate change, are published today in the Journal of Hydrology.

"A key question in the global climate debate is if the climate warms in the future, will the water cycle intensify and what will be the nature of that intensification," said USGS scientist Thomas Huntington, who authored the study. "This is important because intensification of the water cycle could change water availability and increase the frequency of tropical storms, floods, and droughts, and increased water vapor in the atmosphere could amplify climate warming."

For the report, Huntington reviewed data presented in more than 100 scientific studies. Although data are not complete, and sometimes contradictory, the weight of evidence from past studies shows on a global scale that precipitation, runoff, atmospheric water vapor, soil moisture, evapotranspiration, growing season length, and wintertime mountain glacier mass are all increasing. The key point with the glaciers is that there is more snowfall resulting in more wintertime mass accumulation – another indication of intensification.

"This intensification has been proposed and would logically seem to result in more flooding and more intense tropical storm seasons. But over the observational period, those effects are just not borne out by the data in a consistent way," said Huntington.

Huntington notes that the long term and global scale of this study could accommodate significant variability, for example, the last two Atlantic hurricane seasons.

"We are talking about two possible overall responses to global climate warming: first an intensification of the water cycle being manifested by more moisture in the air, more precipitation, more runoff, more evapotranspiration, which we do see in this study; and second, the potential effects of the intensification that would include more flooding and more tropical storms which we don´t see in this study," said Huntington.

DNV does not intend to study this issue further, but has premised its basis for the observations and recommendations in this study on the same conclusion. DNV contends that current hurricane trends are part of cyclical variations in the hurricanes experienced in the GOM.

5.3 Criticality of the Oil and Gas Infrastructure

The U.S. dependence upon the supply of oil and gas from the GOM, and the affects to the economy when supplies are curtailed has increased visibility of the MMS Daily Production Shut In Statistics that are published after hurricane events. The pipeline damage reporting process, Notice to Leaseholders and Right of Way Holders (NTLs) to survey pipeline facilities and the permitting, repair, replacement or abandonment of facilities are all oversight activities that MMS must perform in the process of returning to operations.

While the majority of the damage to pipelines is discovered within the first weeks after the hurricane passing, damage is also discovered during return to service testing and commissioning, and in subsequent surveys directed by the NTLs issued after passage of a hurricane. In September 2004, it was estimated that the consequence of Hurricane Ivan to GOM annual production equated to 7.2% or 43.8 million barrels of oil and 3.87% or 172.3 billion standard cubic feet of natural gas between September 11, 2004 and February 14, 2005. The transient shut in statistics immediately prior to and days after a hurricane are significantly higher as noted in the GOM Daily Production Shut-In statistics presented by the MMS graph shown in Figure 8.

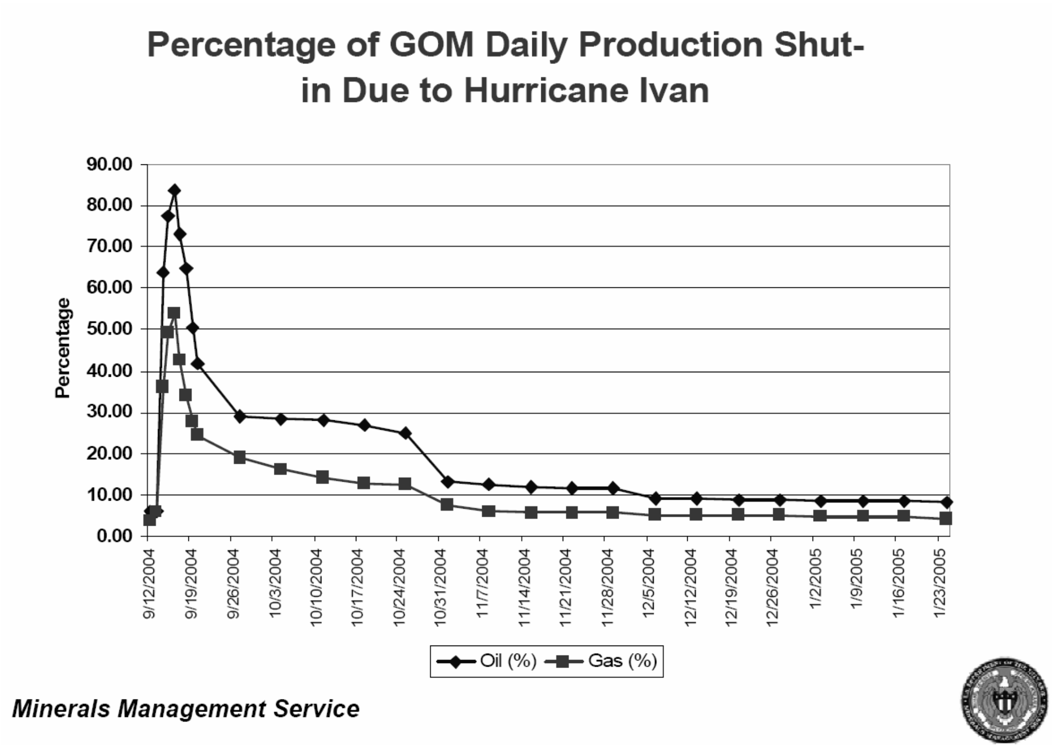


Figure 8 - Hurricane Ivan Production Shut-In Statistics

The MMS oversight activities have received heightened visibility as production shut-in and supply curtailments have a sharper economic and energy supply impact with the growing share of the oil and gas supplies coming from the GOM. The MMS post hurricane activities provide oversight on the conditions of the permits held by leaseholders, while updating and managing the information about the facilities for which MMS has jurisdiction. The activities and are intended to facilitate the safe return to service of oil and gas facilities, in the most expeditious manner possible, without compromising the safety of the public, environment or operating personnel.

However, the role that MMS GOMR plays in this effort is often overlooked, as was noted in the recent White House Study Report conducted after the critical accounting of the federal response to Hurricane Katrina. This is also reflected by some of the difficulties in obtaining reports from pipeline operators that may not see the permit conditions as requirements to report or seek approval from the MMS prior to performing repairs. The study report *Federal Response to Hurricane Katrina*, *Lessons Learned* failed to acknowledge the role of the MMS, and did not list it as one of the Department of Interior's agencies having a response role. It was noted that primary credit for things that went well was given to FERC for waiving rules and working to grant temporary relaxation of rules for the gas industry with respect to the ability to restore service and mitigate supply curtailments. Additionally, the Department of Interior is not formally considered as one of the Federal Agencies having a role in the National Response Plan (NRP) Energy Emergency Support Function (ESF-12), in conjunction with the lead agency, Department of Energy. This sets up a lack of formal coordination and resource sharing in the event of activation of the NRP.

RECOMMENDATION 1 Evaluate the possible benefits of integrating DOI, MMS into National Response Plan for ESF-12.

The prioritization of permitting repairs is primarily based upon the timing of the receipt of the permit applications, and reviews and approvals are processed in the order received. It does not appear that identification of criticality to energy infrastructure is formally defined as a factor for prioritization of the review process. If critical links to the offshore energy infrastructure are identified, this should be a factor in the evaluation process as a result of the increased economic considerations relevant to the return to production capacity. This could be enhanced by the online reporting and mapping of the pipeline damage locations proposed later in this report.

RECOMMENDATION 2 Evaluate whether a formal process should be defined to identify and prioritize critical energy infrastructure repairs, permitting and approvals.

The GOMR office was relocated to Houston after Hurricane Katrina, while maintaining oversight activities relevant to the repair of the offshore pipelines under the GOM Continuity of Operations Plan (COOP). Almost all MMS GOMR functions were carried out from Houston, with the exception of suspending some reporting and notification requirements in the interim. While FERC may be able to utilize blanket certificates to avoid performing NEPA required activities in response to such natural disaster events, as noted in the White House Report, there is no relaxation of the OPA requirements for the pipeline operators when responding to oil spills resulting from hurricanes. While the cooperation was reported to be very good between the USCG, MMS and pipeline operators, there was no relaxation of environmental permitting or clean-up requirements allowed. The oil spill prevention, response and recovery efforts by industry were effective and the offshore industry should be commended for the minimal releases that occurred in Hurricane Ivan and historical hurricane events.

RECOMMENDATION 3 Evaluate if any relaxation of MMS permit or regulatory requirements are warranted, and if so – through what mechanism, for expedited return to service of pipelines, without compromising safety or environmental protection.

5.4 Hurricane Damage Statistics Summary and Graphical Representation

The primary factor for the damage experience correlation is the path of the storm, with respect to the facilities that are in the storm's path. While this may seem like a simple concept, it is useful to compare damage statistics on a relative or comparative basis when looking for anomalies or common factors in the damage statistics with respect to the storm's path.

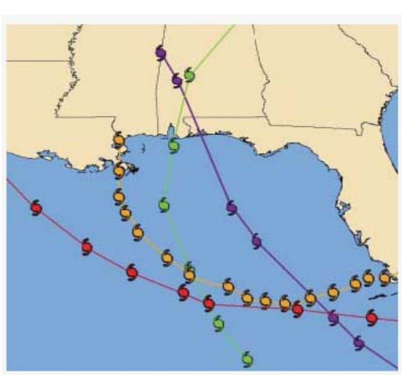


Figure 9 – MMS Map

DNV developed visual tools and mapping applications as part of the study scope that allowed quicker assessment through graphical representation of the storm hindcast data, water depth, damage reports, and hurricane path for use as overlays on the pipeline facilities maps. Maps used by MMS for communicating with the public, such as the one shown to the left are useful for the same purpose - simple, rapid information transfer. In the MMS map shown in Figure 9, the GOM hurricane tracks are shown for Rita in red, yellow for Katrina, green for Ivan, and purple for Dennis.

By mapping and overlaying the hurricane data, it was much easier to manage and analyze the data visually to make correlations, develop categorical hypotheses, and make initial assessments of the factors that influenced the pipeline damage. Much of the affects of the hurricanes are geospatially dependent, and these factors are not clearly represented in tables such as those characteristically used to represent the damage sustained in a hurricane event. Much of the historical analysis of pipeline damage caused by hurricanes has been largely statistical in nature, grouping the damage reports by pipeline attributes such as age, outer diameter, water depth, and failure causes.

The limitation of non-geospatial data presentation is the inability to represent the significance of the data, or the proximity to the storm path, the environmental conditions, and characteristics that can be quickly assessed and understood when represented in a geospatial format. While there appear to have been a very high number of pipeline damage reports in Hurricane Andrew, it is unclear if they were all in one location, or water depth. The Hurricane Ivan pipeline damage report numbers are less than half of the total of Hurricane Andrew, yet these damages had far greater impact on production due to the criticality of the damages. Inconsistencies in reporting and changes in reporting methodology make damage trending less meaningful. For example, Hurricane Andrew pipeline damage reports included lost anodes as part of the pipeline damages that are not included in later hurricane damage reports.

For example, when mapping the damage data for the impacts of Hurricane Ivan, it became clear that many of the damages reported did not mention mudflow as a cause, yet when mapped, the damages were clearly in areas of mud globes and gullies. The statistics are only as accurate of the reported causes of the damages, and it appears that for Hurricane Ivan, the damage attributed to mud flows would be significantly under-reported if one relied solely upon the information provided in the damage reports.

Table 1 provides a summary comparison of the reported damage categories for recent hurricane events. Categories of pipeline failure that have been studied individually are those in mudflow areas and riser locations. These two specific failure modes have been addressed by other studies commissioned by the MMS.

Table 1 Hurricane Pipeline Damage Summary

Hurricane	Year	Total PL Damage Reports	Platform Damage	Mudflow PL Damage	Riser Damage	Pipe & Excessive Movement Damage	Outside Force Damage	Other and Unknown
Andrew	1992	485	253	10	103	44	18	57
Lili	2002	120	16	NR*	78	NR*	NR*	6
Ivan	2004	168	20	16	67	38	9	18

* NR = Not Reported

While platforms were not in the scope of this study report, the damage statistics in Table 2 are provided for relative performance in the same hurricane events. On the average, platforms have suffered a relatively constant low 3% *destroyed* loss rate and an extremely variable *damage* rate that averages to about 10.5%.

Table 2 Hurricane Platform Damage Summary

Hurricane	Year	Platforms Exposed to Hurricane Forces	Platforms Destroyed	Platforms Damaged	Percentage Exposed Platforms Destroyed	Percentage Exposed Platforms Damage
Andrew	1992	700	22	65	3.1%	9.3%
Lili	2002	800	2	17	¼%	2.1%
Ivan	2004	150	7	31	4.7%	20.1%
Total		1650	31	113	---	---
Average		550	10	36	2.7%	10.5%

5.5 Data Quality and Damage Reporting Limitations

The pipeline damage data collected by MMS has been submitted by pipeline operators or their authorized representatives in various written formats, and without consistent content or definitions of the failure causes. This data is manually entered into an Excel spreadsheet that is maintained by MMS GOMR Pipeline Section. The hurricane pipeline damage reports are typically submitted to MMS by the pipeline operator, or their authorized representative, with a primary cause of “Natural Hazard,” secondary causes typically identified as “Storm/Hurricane” or “Mudflow” and the damage described in terms of type and location.

Difficulty in the hurricane pipeline damage assessment review is that root causes of the failures were indeterminate due to limited or incomplete reporting or availability. These uncertainties were previously characterized by Southwest Research Institute as *random variables* and *random processes*. Additionally, damages can have multiple cause categories, and may be categorized as riser failure in a mudflow area, or a pipeline movement that is created by the platform being destroyed. Thus, all characterization of damage should be viewed as categorical, only, and not formally determined by scientific root cause methodologies for the purposes of the discussions in this study report.

6 STUDY APPROACH

The study approach undertaken by DNV followed these steps:

1) Damage Analysis and Mapping
   - Identify commonalities or exceptions in past hurricane experiences with Ivan experiences
   - Categorize damages by primary failure descriptions
   - Map pipeline damage and metaocean data
   - Identify commonalities or exceptions in damage experiences by pipeline
   - “Hypothesize” the root causes of failures for pipeline damages that were not associated with mudflows, risers, or platform failure to identify pure pipeline failure modes

2) Risk Assessment and Analysis
   - Conduct "What-If" type scenario analysis to identify possible preventive measures or additional risk control measures for hypothesized root causes
   - Evaluate risk control activities for prevention and mitigation of hurricane impacts to identify best practices and any potential gaps in current industry codes or practices
3) Detailed Technical Analysis
   - Gather additional data from operators for detailed technical analyses
   - Perform on-bottom stability calculations

The preliminary assessment results were discussed with representatives from industry in a DNV sponsored workshop on January 5, 2006, prior to undertaking detailed technical analyses, to confirm the data analysis, study findings and initial conclusions by DNV. During this workshop, the "What-If" type scenario was used to identify any gaps in the current risk control strategies employed in the GOM oil and gas industry.

6.1 Damage Analysis

DNV conducted analysis of the MMS pipeline damage spreadsheet summary, the available operator damage reports, and interviewed pipeline operators for additional data needed to conduct the damage analyses.

The damage analysis was the first step for determination of possible root causes of the pipeline failures that occurred in Hurricane Ivan. Categorization of failures was carried out in various formats to identify commonalities or anomalies in the types of failure events that occurred.

6.1.1 Damage Statistics

MMS GOMR received 168 pipeline damage reports for 160 unique pipeline segments. The pipeline damage, categorized as reported, is represented in the following breakdown, with a chart showing the distribution immediately after the list:

- Dents on Pipelines/Risers -5
- Kinks on Pipelines/Risers - 7
- Separations Pipelines/Risers - 59
- Risers Pulled Up - 2
- Ruptures on Pipelines/Risers - 4
- Twisted/Bent Pipelines/Risers - 7
- Splits in pipelines - 1
- Cracks in Welds - 1
- Exposed pipelines - 2
- Pipeline Crossing Damage - 10
- Pipeline Movements - 9
- Riser Clamp Damage - 2
- Leaking Flange - 1
- Safety Joint Separation - 1
- Umbilical Damage - 2
- Pipeline Leak - 2
- Bent Risers - 24
- Unknown - 25
- Unclassified – 4

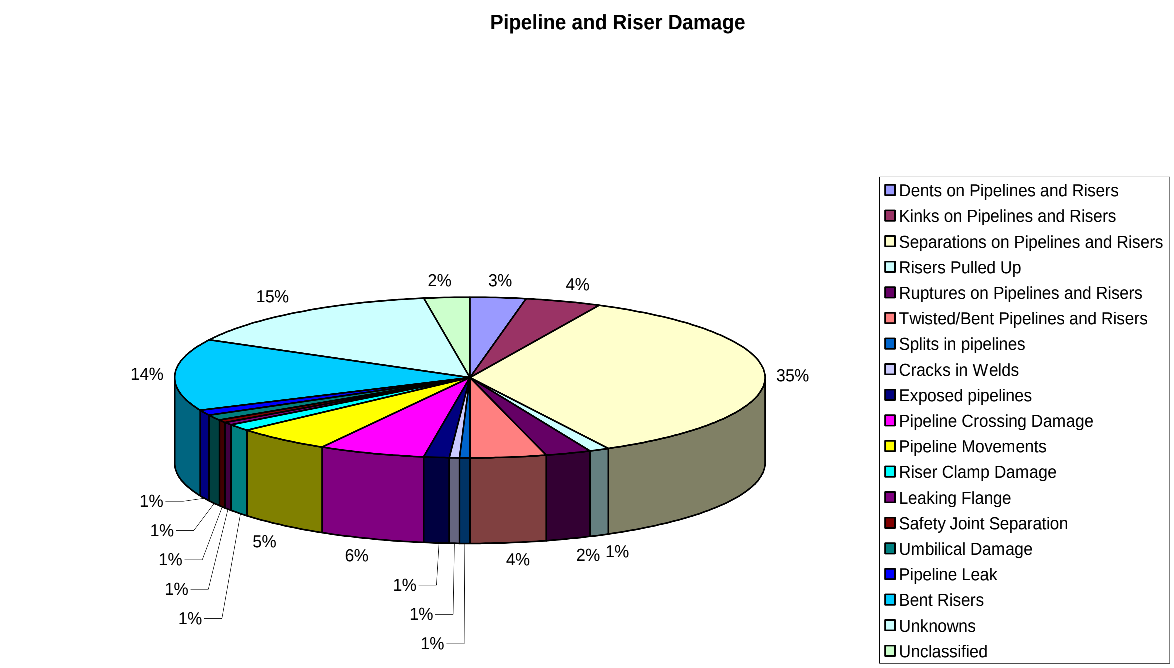


Figure 10 - Breakdown of damage to the pipeline and risers reported due to Hurricane Ivan

The description of the damage locations represented above did not serve as an useful method for categorization of damage necessary to perform causal analyses. With this in mind, DNV took the damage information spreadsheets provided by MMS, and the original damage reports submitted by the pipeline operators, and evaluated them to assess where pipeline failures may have occurred that were not a result of any of the following causes:

- Mudflows
- Platform Failures
- Riser Failures
- Tie-In Failures
- Impact by Outside Force/Structure

The application of this criterion to the pipeline damage reports yielded approximately 31 of the 168 reports that appear to be primarily as a result of the loading applied by the hurricane induced subsea forces. Of the 31 damage reports, 9 pipelines moved significantly from their right of way locations. These pipeline damage reports were then studied for their relevance to on-bottom stability design and pipeline response to hurricane forces. Three pipelines were selected as representative samples for further technical analysis.

Hurricane Ivan pipeline damage experience indicated that pipeline crossings are an area that may merit special attention for greater hurricane resistant design. Hurricane Andrew and Hurricane Ivan damages were similar in the fact that the there was damage to pipelines in shallow water that would not be expected to move, if they were buried, or had adequate cover. The number of pipeline damages that were unrelated to risers, mudflows, platforms, and subsea tie-ins that were damaged resulted in 53 segments. The majority of the 53 pipeline damage occurred in shallow water, less than 200 feet in depth, as shown in Figure 10-1.

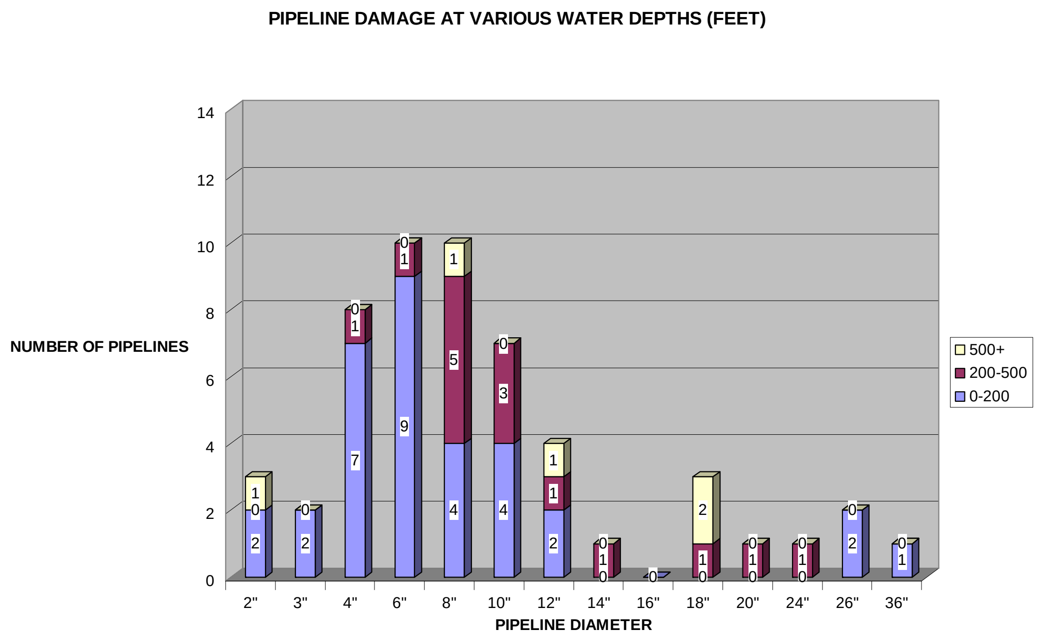


Figure 10-1– Number of Pipeline Damages by Diameter and Water Depth

RECOMMENDATION 4 Focus evaluation of study report technical analyses on crossing and burial design practices, particularly in pipelines in water depths less than 200 feet, and areas of low strength soils.

6.1.2 Root Cause Analysis

Observations about the lack of reporting consistency and data quality have been made in other hurricane pipeline damage studies and by pipeline operators and industry teams trying to perform root cause analyses. The manner in which the data is collected and analyzed is an area where possible improvements and increased efficiencies can be realized. This subject will be dealt with in more detail later in this report.

Proper root cause analysis identifies the basic source or origin of the failure. Root cause analysis is a step by step approach that leads to the identification of the first or *root* cause. Every system, equipment, or component failure happens for a reason. There is a specific sequence of events that leads to the failure. A root cause analysis investigation follows the cause and effect path from the final failure back to the root cause.

To prevent the failure from recurring, it is not always necessary to identify the root cause, and it is not always necessary to prevent the first, or root cause, from happening. It is merely necessary to break the chain of events at any point and the final failure will not occur. Frequently the root cause analysis identifies an initial design problem. Then a redesign is commonly enacted. Where the root cause analysis leads back to a failure of procedures it is necessary to either address the procedural weakness or to develop an approach to prevent the damage caused by the procedural failure.

Generally accepted principles of root cause analysis include the following:

- **Do all reasoning from solid evidence**. When reviewing the damage reports, DNV was faced with observations that lacked solid evidence about the cause of damage, and the in-situ condition of the structures at the time of failure. Additionally, the actual loading conditions were unknown, because all of the metaocean data readings were taken at the surface, not subsea.

- **Determine what influenced the consequences, i.e., determine the necessary and sufficient influences that explain the nature and the magnitude of the consequences.** The influences were clear in almost all cases; however, they could not be ranked in significance when there were multiple influences. For example, was lack of on bottom stability the primary cause of the failure, or was it at the platform riser interface?

- **Establish tightly linked chains of influence**. It was possible to establish the influences, but not possible to link them sequentially, or in order of importance.

- **At every level of analysis determine the necessary and sufficient influences.** With many of the damage reports it was possible to determine the influences. However, with lack of specific gravity information, and general on-bottom conditions, it was almost always not possible to determine the actual loading variables and seafloor conditions.

- **Whenever feasible drill down to root causes.** Data is not available to perform the drill down without actual in-situ condition and environmental loading applied to the pipelines.

- **There are always multiple root causes**. Platform failures, mud slides, outside forces, hurricane forces, installation location and practices, are all examples of primary causes, and can also be root causes.

DNV’s analysis of the damage reports and data analysis quickly concluded that the information was not detailed enough to perform scientific root cause analyses or other failure mode type criticality studies that could definitively identify design code inadequacies. While the variations in reporting definitions could be easily addressed, the inability to assess the in-situ condition of the offshore pipeline structures at the time of failure, or the actual sequence of the failures made the analyses at best, educated guesses as to what had occurred, or the sequence in which the events occurred.

With this conclusion before us, the DNV team also questioned the value of collecting the data in future hurricane events, for such detailed failure analyses, particularly in light of the generally good performance of the pipelines. Collection of the data would require increased inspection, monitoring, and reporting requirements for operators, and data management for the regulator. The estimated costs and technical feasibility of instrumenting pipeline systems to measure actual hurricane loading conditions, performing subsea inspections prior to hurricane events to determine in-situ conditions, and monitoring storm events to evaluate the cause and effects related to the timing of failure events, and attempting to determine the random variables far outweighs the value of the collected data.

The pipeline industry has historically taken actions and enacted solutions through consensus standards, and the regulatory authorities have addressed similar issues through regulatory requirements. DNV has evaluated where additional practical recommendations may be offered, but has concluded that by and large, the design practices and operating procedures are adequate. It appears that there may be benefits from applying some risk based approaches for zones or locations that may pose higher threats to pipeline damage from hurricanes. However, industry wide design code or regulatory revisions do not appear to be required.

7 RISK ASSESSMENT AND ANALYSIS

7.1 Risk Control Fundamentals

The concept of risk management allows that all risk cannot be eliminated. Exposure to risk is unavoidable. This is particularly true for the GOM and the risks posed by hurricanes to the oil and gas infrastructure. One recurrent finding in various investigations of catastrophic events in recent years has continued to identify the lack of adequate attention to a systematic approach to risk assessment. The goal of risk management is to reduce the risk to achieve an acceptable level of residual risk. The acceptable level is usually defined by criteria found in industry standards or corporate policies, in absence of defined criteria from authorities having jurisdiction. Let us first define the following:

- Risk = Probability x Consequence
- Probability = The frequency or likelihood of an event occurring
- Consequence = The severity of impacts to life, property, or the environment
- Risk Management is the logical identification, assessment and control of hazards with the intended purpose of protecting life, property and the environment from harm.
- Risk Assessment is the identification and assessment of the hazards (the first two steps in risk management).

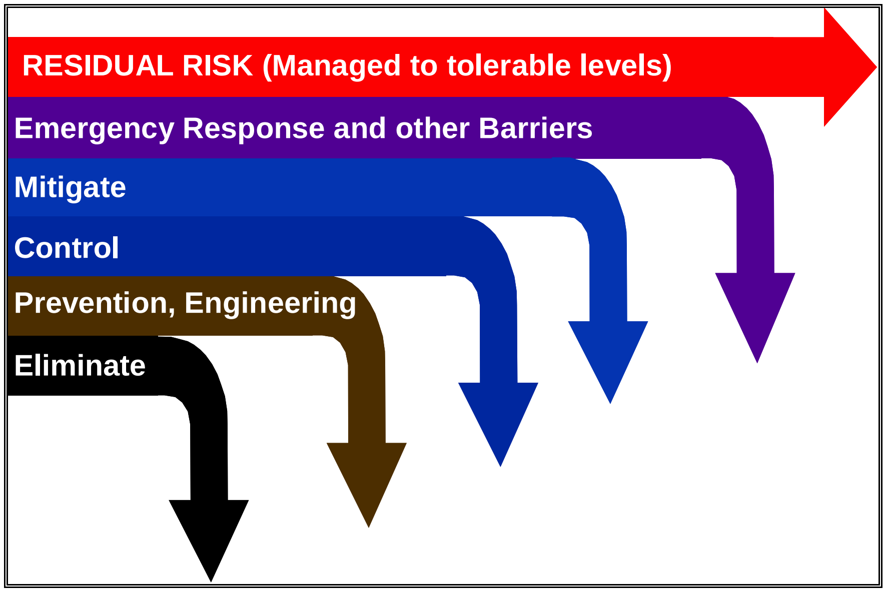


Figure 11 – Risk Control Strategy Model – Managing Risk to Tolerable Levels

The risk control strategies that are utilized by the MMS and industry for management of the GOM offshore oil and gas pipeline facilities follow the principles represented in the risk model shown in Figure 11. These are shown in order of priority of 1) eliminating the risk, if possible, 2) prevention of failure/release through engineered controls, 3) controlling the consequences of the failure if it occurs, and 4) mitigating the impacts through emergency response practices and barriers to the environmental receptors in the event of a failure/release. In the case of hurricanes, the risk cannot be eliminated unless the facilities are not constructed, or the hurricanes can be prevented. However, the likelihood of hurricanes occurring could be considered in an effort to address the site specific conditions that exist for each facility.

7.2 Risk Control Strategies

The review of the Hurricane Ivan pipeline damage reports identified three primary categories of failures Shown in Figure 12. These failure categories were characterized as those that were design sensitive, location sensitive, or those resulting from impacts from outside forces such as platform failure, anchor drags, or debris. All of these items were grouped together under the heading of Damage Prevention, to look at the preventive measures that could be employed for the reduction of the probability side of the risk equation, primarily through engineered controls.

The next category of risk control strategies was titled Planning and Preparedness. These activities are those steps that were intended to reduce the consequence side of the risk equation, primarily through operational controls, in the event of a failure or release.

The third category, Recovery and Response, are the risk controls that are intended primarily to address the reduction of the consequences of release/failure and facilitate the safe return to service, with minimal interruption to service.

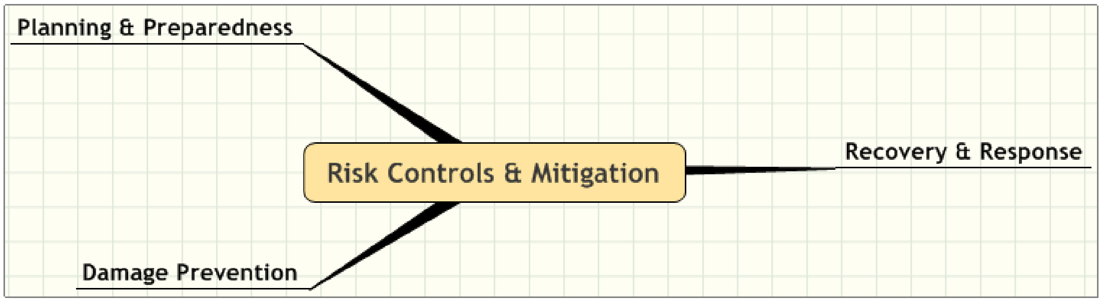


Figure 12 - Risk Control Categories

Identification of risk control measures was completed through a structured "What-If" process. This activity listed the risks that are controlled through design/damage prevention, planning & preparedness, and recovery and response to identify any potential gaps in current practices. The results of this activity are used in the description of the best practices that are employed to manage the risks of hurricanes with respect to pipelines in the GOM. For each risk control category, hurricane pipeline damages were reviewed to identify either 1) actual failure modes that did not have proper controls identified, or 2) potential failure modes that may not have been anticipated by current industry practices.

8 DAMAGE PREVENTION

The prevention of damage to GOM pipeline facilities is primarily managed through design practices aimed at hurricane resistant design, and the location or orientation of facilities to minimize impacts from mudflows and other outside forces. The prevention of impacts to people or the environment are primarily dealt with through design practices and operating procedures that include provisions for pressure management and shut-in, or other loss prevention devices such as shut-off valves, where effective and appropriate.

The diagram shown in Figure 13 represents the results of the "What-If" brainstorming session for identification of methods for prevention of damage to life, environment or property resulting from pipeline damage in the event of a hurricane. The chart shows all of the ideas, practices or methodologies that were identified. These are listed without regard to their effectiveness or cost/benefit for the purposes of completeness of the list of potential risk control measures identified in the exercise. The three categories of Mudflows, Hurricane Forces, and Physical Impacts were selected based upon the historical performance and primary failure modes of the pipelines studied in hurricanes Andrew, Lili and Ivan. Additionally, these three categories are grouped because of common risk control strategies that are location sensitive for mudflows, design sensitive for hurricane forces, and barrier resistant sensitive for physical impacts.

Figure 13 represents a high level view of the hurricane damage prevention risk control categories that are employed in pipeline design, and operations. Each category was discussed in greater detail than is represented to identify any emerging technologies or innovative practices that may have been successful in responding to the recent hurricane events.

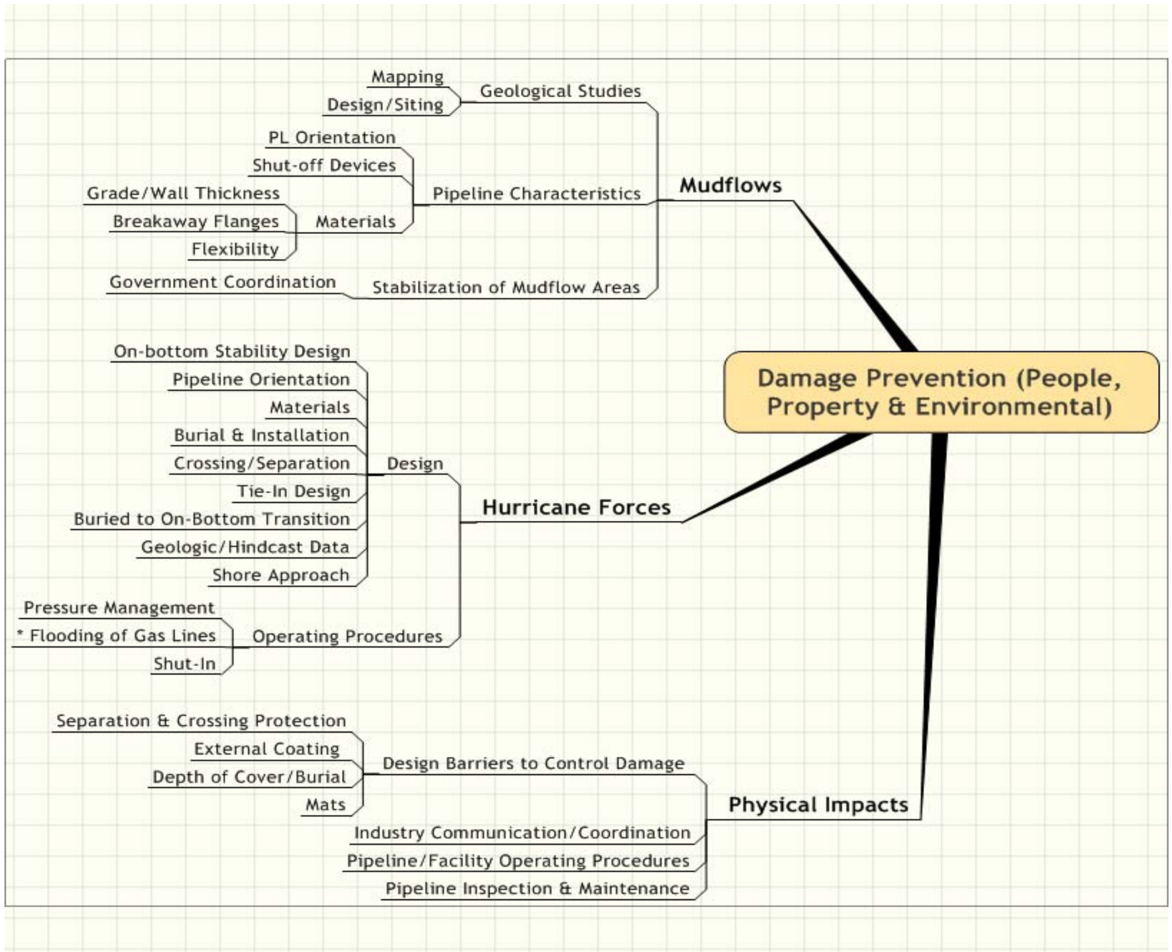


Figure 13 – Damage Prevention Risk Control Measures

After completing this diagram, discussions were held regarding the relative practicality of the various potential risk controls identified. It was recognized that each design should be site specific and the risk control measures evaluated through appropriate cost benefit analyses that ensure compliance with the minimum Federal pipeline safety standards and permit requirements, while offering the best allocation of resources for the risk that is being mitigated. An example is the practice of flooding a gas line to increase its on bottom stability by increasing its specific gravity. The decision to carry out such a risk control measure has significant impacts to the return to operations as a result of the need to dewater and dry the line, and poses significant operational risks to forming hydrates in the line. Considering that a gas line would have minimal environmental impact if a failure occurred, it appears to be highly impractical to select this mitigation for an operating pipeline. However, an operator with a newly constructed line that had not yet been hydrotested or placed in service may wish to employ this method for protection of the pipeline. Albeit a rare occurrence, it is a viable option for reducing the risk of excessive movement. This example is intended to illustrate that not all options are valid for all situations, and that risk control measures are not prescriptive in nature, nor are they "one size fits all."

The discussion of the mitigation activities did not identify any new hazards that were previously unknown, and confirmed that appropriate risk controls are in place for the prevention of hurricane damage. The next step was the assessment of the effectiveness of the various mitigation activities. This assessment was based upon the historical performance of the pipelines in hurricane events, and a subjective analysis of the results of the pipeline damage relative to the three categories of damage. The damage categories were further broken down into eight categories, as represented in Figure 13-1. These categories were useful in looking for common failure modes, locations or factors relative to the pipeline characteristics to evaluate the hypothetical root causes.

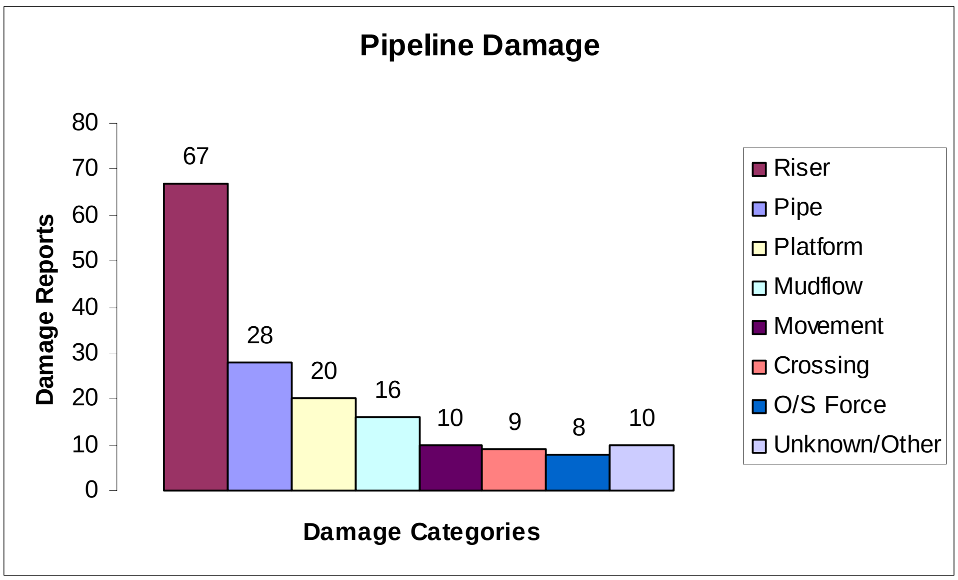


Figure 13-1 - Categorized Pipeline Damage Reports

The findings of this study are consistent with the identified failure mode experience of previous Hurricane Andrew and Lili studies, relative to the general types of failures experienced. The primary distinction between the other two studies and the Hurricane Ivan damage is the high damage incidence rate near the Delta area, outside of the direct hurricane path. However, just as in Hurricane Andrew, the majority of the failures were in water depths less than 200 feet.

As with Hurricanes Andrew and Lili, no correlation was found for the age of pipe. The pipelines that were damaged ranged in age and date of installation, with no pattern indicated in the damage modes. The only correlations identified were relative to the following factors:

Platform failures with common lines at the platform
Parallel pipelines in mudflow areas perpendicular to the maximum current
Water depths less than 200 feet

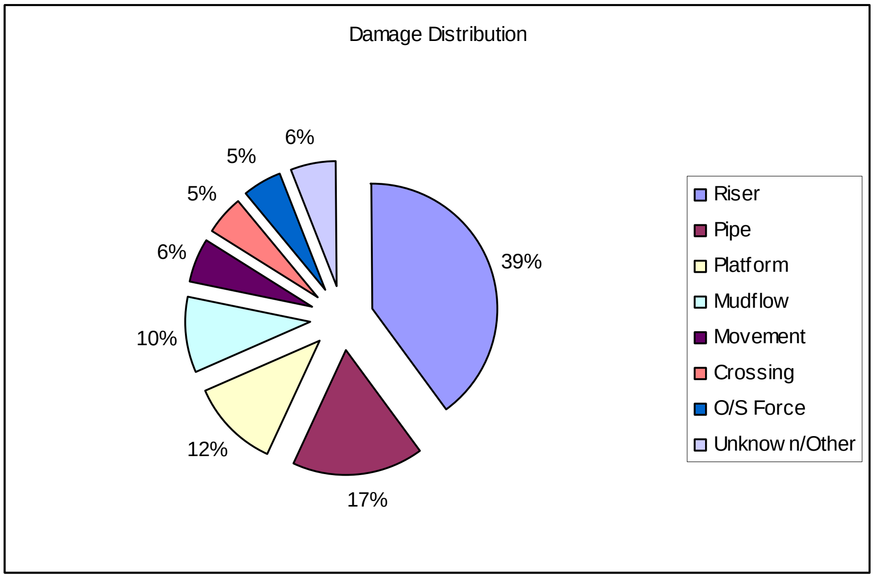


Figure 13-2 Pipeline Damage Distribution by Study Category

The highest incidence of failure, or 39% of the damage reports, was related to riser damage. Roughly 17% of the damages were attributed to pipe failure or damage, 12% were a result of platform failure or damage, 10% were reported as resulting from mudflows, 6% related to excessive movement 5% to crossing damage, 5% resulted from outside force, and the remaining 6% were unknown, or related to subsea tie-in damage.

8.1 Platform Damage and Failures

Platforms are being studied by others to assess the adequacy of current design practices. Any recommendations should be incorporated into pipeline structural interface design practices. The performance of the pipelines after failure, and the minimal release of hydrocarbons indicate that the offshore industry operations and planning efforts in advance of hurricanes are by and large meeting the expectations of the environmental protection goals of the MMS.

DNV made one observation with respect to platform damage. The design and pressure test factors used in platform riser design is different for facilities subject to the requirements of 49 CFR 192, and ASME B31.3, which are more stringent than those of 30 CFR 250 or 49 CFR 195. The performance of the risers is discussed in Section 7.5. It appears that those risers that are designed with a 0.5 design factor and 1.5 x MAOP test pressure may have survived the hurricane forces at a better rate than those that were designed to lesser test pressures and higher design factors. Increased hurricane resistant performance of risers at platforms may be realized if the more stringent criteria

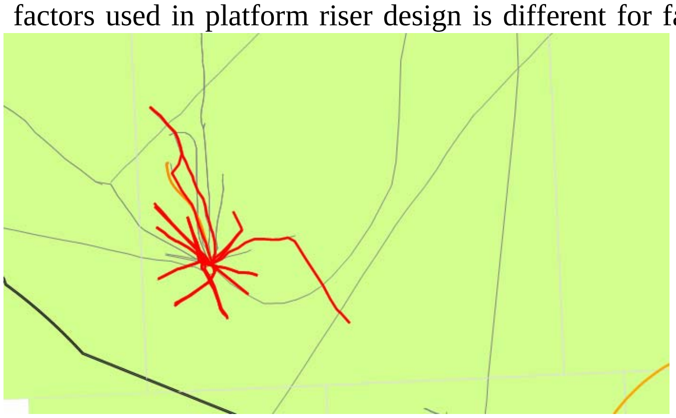


Figure 14 - Risers Damaged in MP 64

were to be applied in the design. However, the data is not conclusive, and therefore does not support a formal recommendation to revise the current design practices. However, the observation is relevant with respect to the historically good performance of gas risers at platforms and DNV would recommend study of this factor in riser and platform design

8.2 Mudflows

Figure 15a - Aerial Photo of Delta Area Mudflows

The study of mudflows, or mud slides, and mapping of those areas in the Mississippi River Delta region are covered in two other research projects. The mechanics of the failure modes for the pipelines associated with mudflow forces were excessive movement, or burial in up to 30 – 40 feet of mud, as a result of the movement caused by the weakening of the silt deposits, and resultant loss of support to the pipeline structures. The delta region has formed gullies (primarily in the 100 to 300 foot water depths) where mud flows into areas called lobes (typically mudlobe failures occurred in the 200 to 400 foot depth ranges). The mud gully and mud lobe regions occur in the Mississippi Delta waters from about two to five miles from the delta, as shown in Figure 15a. The deposits of weak silty soils build up until they fail either through forces from currents or hurricanes, or general weakening of the soils. Particularly strong hurricanes, such as Ivan cause larger forces on the seafloor, and cause larger mudflow movements, resulting in greater platform and pipeline losses. Figure 15b, depicting a well-recognized, and widely accepted theory, was presented at the 2005 API Hurricane Preparedness and Recovery Conference represents the forces on the seafloor that cause the movement, and ultimately failure of the offshore oil and gas structures.

During Hurricane Ivan, much of the movement and failure was also seen in this area where the currents were at their maximum, as a result of the geometry of the delta, and the current flows. The combination of the mudflows, weak silty deposits and maximum currents produced by Hurricane Ivan resulted in the majority of the pipeline and platform damage that fell outside of the direct path of the hurricane force winds.

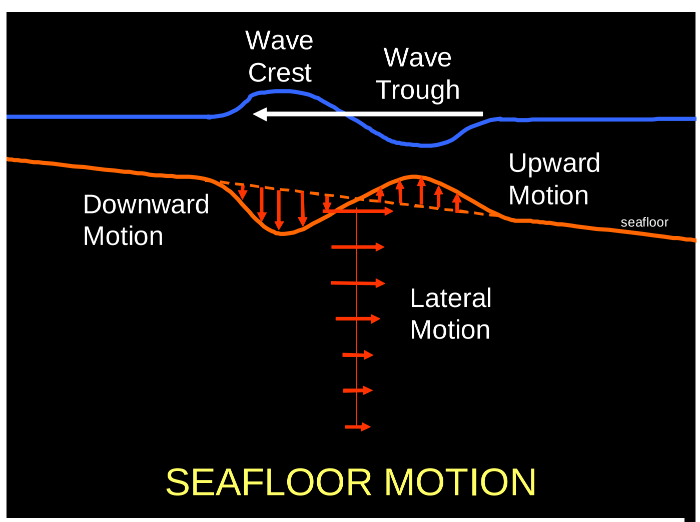


Figure 15b – Wave Forces on the Seafloor

The primary risk control mitigation for this threat is to not locate facilities in mudflow areas. However, that not always being a practical solution, and with the fact that the mudflow lobes advance with time, pipelines will exist in GOM mudflow zones. DNV recommends that pipelines in mudflow areas be treated as being at higher risk for mudflow and hurricane force damages, with MMS requiring more stringent design criteria developed from geotechnical investigations and their resultant recommendations.

Operators should perform a risk-based analysis and demonstrate that mitigation measures to control risk to an acceptable level have been adequately applied to their structures. Increased burial depth is not a practical solution for this failure mode.

RECOMMENDATION 5 MMS GOMR should treat pipelines in mudflow areas as higher risk facilities and require mitigation measure to manage risk to an acceptable level. DNV suggests creating risk zone maps of mudflow areas for use with a risk-based approach to the design and oversight of pipelines in mudflow areas.

8.3 Riser Damage

The IVAN pipeline damages reported as having riser damage were analyzed. The riser damages resulting from platforms failing, mud flows, or outside force were excluded, leaving 67 hurricane induced riser damage reports. Another seven (7) reports identified subsea tie-in damage. The damages were grouped by product, and location of riser damage as tabulated below:

Above Waterline (Wave Action)	24
Below Waterline (Near Surface)	10
Unidentified (No Location)	14
Near Mudline (Bottom Conditions)	9
At Clamp (Failed)	7
Pipeline (Near Riser)	3

Product Code	No.
BLKO	24
LIFT	19
BLKG	13
SPLY	5
COND	2
OIL	2
GAS	2

Damage Location	No.
Receiving Riser	28
Departing Riser	32
Both Risers	7
Sub Sea Tie-In	7
SCR (W/O Platform Dmg)	0

The majority of riser damage not related to platform damage, or reported as mudflows, was as a result of wave and wind forces at or near the surface.

The recommendations that are developed as part of the platform failure studies should be evaluated for possible incorporation in platform riser design for structures above the waterline.

The study carried out in response to Lili addressed the subject of riser failures in great detail and provided recommendations to address this failure mode. In evaluating the damage experience in Hurricane Ivan, there were no new findings to contradict those of the Hurricane Lili Study. The relatively minimal release of hydrocarbons, and ease of inspection and repair of these facilities makes them a lower risk item in the pipeline facilities. However, their continued integrity is important to the overall infrastructure, and the recommendations of the Lili report appear to be appropriate to the level of risk being addressed. One observation made under the platform section was the fact that gas lines subject to 49 CFR 192 have performed very well in hurricanes and are designed to a more stringent code.

8.4 Excessive Movement

The damage of pipelines in shallow water, where pipelines are expected to be buried has been an area of consistent damage experience and pipeline movement in the hurricane studies of Andrew, Lili and Ivan.

It is hypothesized that lines intended for self-burial do not achieve the burial, or are uncovered over time, and are therefore unrestrained and the on-bottom stability of these lines are not adequate to resist the hurricane forces imposed upon them. Additionally, those pipelines that are buried may be in weak silty soils that fail under the hurricane forces on the seafloor, causing a weakening of the surrounding soil, and failing under the reverse currents generated by the hurricane ocean patterns.

Crossing damage was a subset of this category of damage. Movement of the crossings created lost separation, mats, or cover as a result of pipelines being displaced. If crossings are located in water depths of 200 feet and less, they appear to be more susceptible to hurricane forces and should include provisions to maintain separation after installation. Mats and rock appear to be inadequate in areas of seafloor movement, and mudflows. Lessons learned and improved designs utilized as a result of a significant crossing damage location, as presented in the API Hurricane Conference should be incorporated into future designs in shallow water or mudflow areas.

RECOMMENDATION 6 Utilize improved designs and installation methods to maintain pipeline crossing minimum separation in shallow water less then 200 feet of depth, and mudflow areas.

It appears that for the majority of the pipelines installed in the GOM, pipelines designed to existing codes and standards have fared well under hurricane forces. However, the shallow water installations appear to have consistently been impacted by hurricane forces, to a greater degree than those pipelines in waters exceeding depths of 200 feet, as shown in Figure 16.

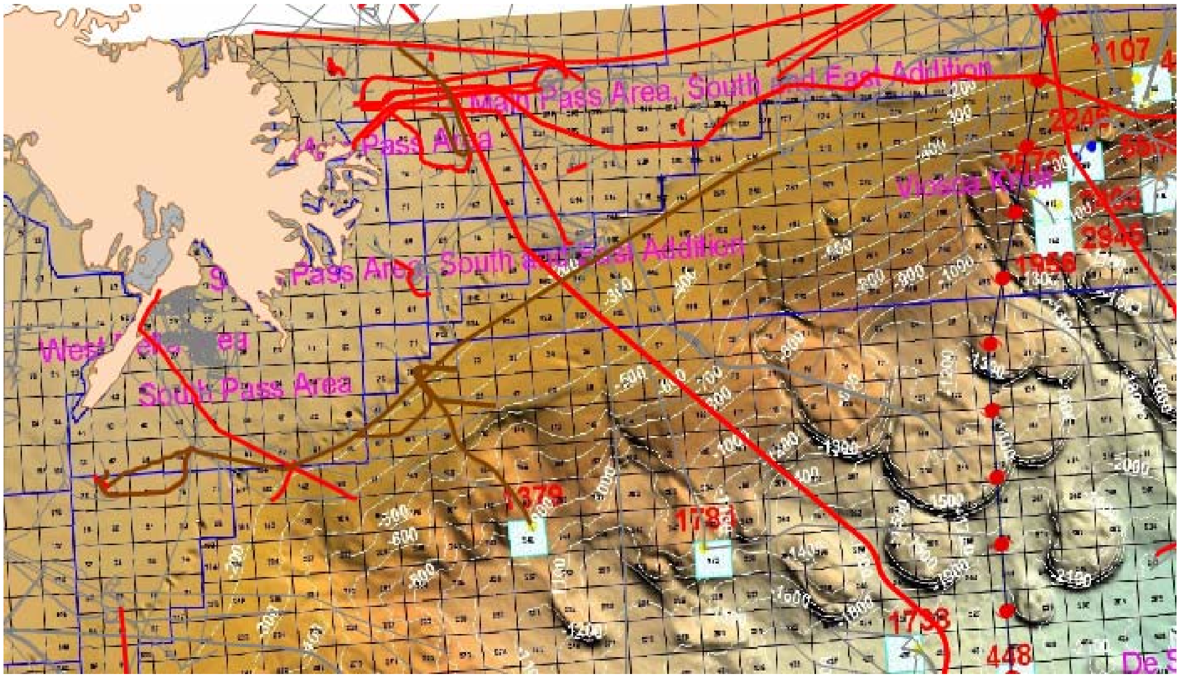


Figure 16 – Pipeline Damage in Mudflow Areas and Shallow Water

Figure 16 illustrated damage reports that indicated mud slide as the secondary cause of failure are noted in brown, and all remaining damages, regardless of cause or location, in this region are noted in red. It appears that there may be far more damage related to mud slides and seafloor movement than has been reported in the pipeline damage reports.

The path of Hurricane Ivan is shown on the right side of Figure 16, represented by the track with the red dots. Hurricanes that occur to the east of the Mississippi Delta appear to have far more mud slide damage than has been historically reported or experienced for paths to the west of the Delta. The base map shows contours of the approximate water depth, with damages to pipelines in water depths greater than 200 feet mainly occurring where facilities were connected to pipelines that had damage in the shallower waters. DNV would recommend evaluation of the design criteria for pipelines in the area of the eastern Delta, and in waters shallower than 200 feet as having a higher risk to hurricane damage, particularly with respect to on bottom stability. This is analyzed further in the technical analysis section.

8.5 Outside Forces

Outside forces that are not related to platforms, mudslides or natural forces have been grouped together as a failure category. The primary protection is through the management of the structures applying the forces, such as MODU dragging anchors, and such studies were undertaken by others to analyze these events occurring during Hurricane Ivan. In some cases of the damages that were studied, barriers could have reduced damage to pipelines at crossings or localized dents, and consideration of these risk control strategies could be part of a threat assessment performed in design. Coatings, mats, burial, crossing design and other barrier methods are practical and should continue to be considered in the design, or installation of new crossings, particularly in shallow water, or areas of active production and congested structures.

Major pipeline crossings with minimal separation, in shallow waters, might be an additional inspection point to consider in post hurricane NTLs.

8.6 Remaining Damage Categories

The remaining damage reports that have not been covered in 8.2 through 8.6 are difficult to address from a root cause approach due to the lack of detailed failure information about the pipelines. Without detailed metallurgical analyses, loading conditions, and specific gravity at the time of failure, it is not possible to identify the cause of failure. However, the four failure categories discussed in the previous sections appear to address the hypothetical root causes of the remaining reports. Ultimately, overstressing or impact - from movement or outside forces, have caused pipeline damages in the form of leaks, kinks, bends, ruptures and movement that have failed the subsea tie-ins, or body of pipe. Only one failed weld was noted as the site of failure in the remaining damage reports.

9 PLANNING & PREPAREDNESS

The MMS has three overriding principles in dealing with tropical storms or hurricanes:

- Evacuate workers so there is no loss of life or injury
- Protect the Nation's supply of oil and gas from long-term disruption of production
- Protect the environment from oil spills

The MMS works on each of these goals in close cooperation with partners in the USCG and with the regulated oil and gas industry.

The oil and gas industry has very similar principles in dealing with tropical storms and hurricanes:

- Evacuate the workers so there is no loss of life or injury
- Protect company assets
- Protect the environment from oil spills
- Return to operations as soon as safely possible

The planning and preparedness begins long before a tropical storm develops. Policies, procedures and practices are developed, tested, refined and put into action, typically at the beginning of the official hurricane season.

As a standard practice, oil and gas operators shut in production when they evacuate the platform. In some cases, natural gas production is monitored remotely from onshore through Supervisory Control and Data Acquisition or SCADA systems. This allows the production to be stopped remotely if necessary.

MMS has mandatory requirements for the use of downhole safety valves to shut off the flow of oil and gas in the event of a well failure, for the prevention of oil release in a catastrophic failure. Hurricane Ivan had 7 platforms that were completely destroyed. These 7 platforms had a total of 75 oil wells. All 75 of the downhole safety valves held and no significant pollution occurred from them. Two of the wells had very minor gas leaks but nothing of any significance.

An example of hurricane preparation that is typical of the industry is illustrated by Apache Oil's three phased hurricane planning levels described in the following excerpt from the website www.ApacheCorporation.com.

> *"Apache has a three-stage process for dealing with hurricanes," says* ***Kenny McMinn****, district production manager for Apache's offshore properties. "At the beginning of hurricane season, we automatically go into Stage One, where we have a minimal amount of equipment on the decks and all equipment not being used is tied down securely. Stage Two begins with the evacuation of non-essential personnel first, the securing of equipment and, if necessary, the ultimate evacuation of all but a skeleton crew. In Stage Three, we evacuate the last of the crew, activate automatic shut-in timers and commence a remote monitoring process. Simultaneously, we update our marketing group continuously on the date and time each producing property is shut in."*
>
> *Apache goes to Stage Two whenever a named tropical storm or hurricane enters the Gulf of Mexico (or earlier if the predicted path warrants). Outside contractors and summer roustabouts are the first to evacuate. Second-round evacuations begin either when the tropical storm is upgraded to hurricane status or is deemed to be only two days away.*

Consistently throughout the industry workshops and interviews in which DNV participated, the value of planning and preparedness could not be emphasized enough by operators that had planned, and those that will improve their planning efforts as a result of their experiences with recent hurricanes. The ability to safely restore operations as quickly as possible was dependent upon the available resources and the appropriate planning completed prior to the hurricane event.

Having just experienced Hurricane Katrina and Rita, the pipeline industry as a whole had experienced the most difficult recovery and response situations that had yet been presented as a result of Hurricanes, and the experiences and lessons learned were fresh in the minds of the industry participants during the completion of interviews and workshops. The most significant single factor that was identified was the onshore planning reassessments that were intended to address the immense devastation to the personnel and facilities that are key elements in the restoration of operations. The industry placed appropriate emphasis on the safety of employees and lives of their families while balancing the restoration needs for the activities that were necessary to return to operations. Communications and basic water and power supplies were on the critical list, and the ability to respond was tied to the Federal response that was occurring onshore. Previously, the industry had to compete among themselves for the prioritization of resources. The shift that occurred in the aftermath of Hurricanes Katrina and Rita was a shift to being in a prioritization queue, and competing with a much larger response need, and significantly fewer available resources.

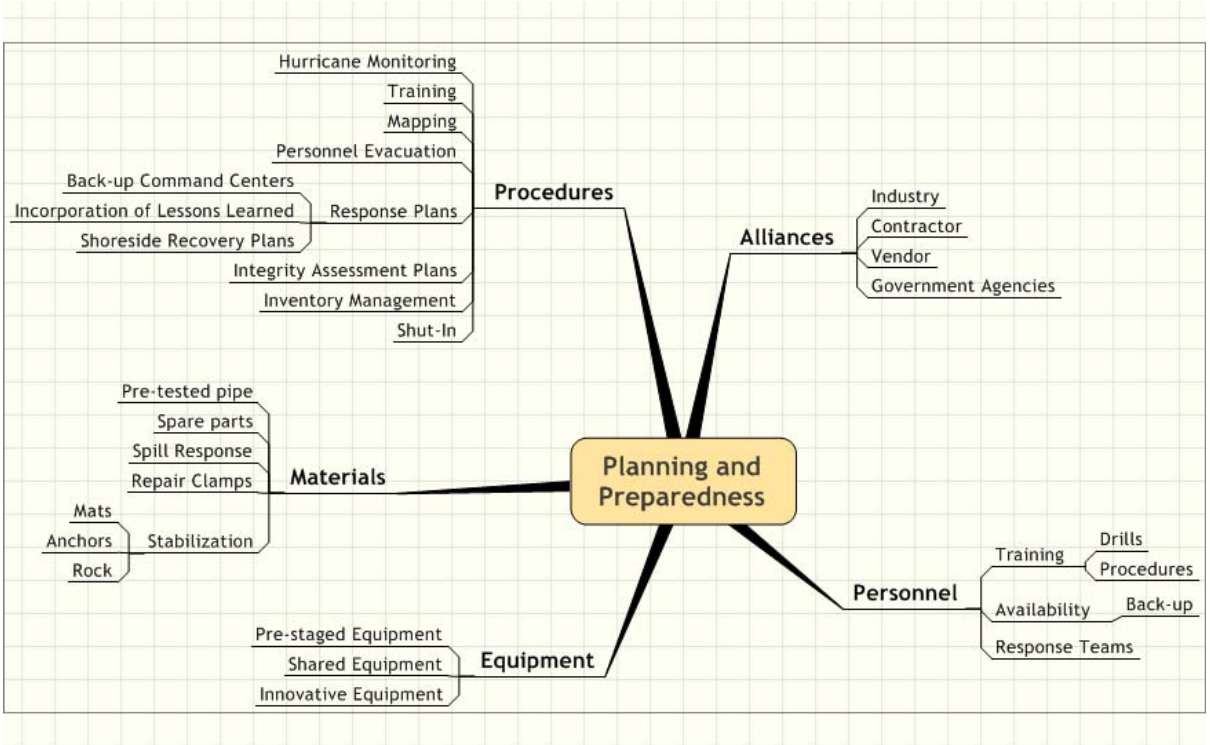


Figure 17 - Planning and Preparedness Risk Control Categories

The primary planning and preparedness practices were broken down into the categories of Procedures, Alliances, Materials, Equipment and most importantly, Personnel. Having adequate trained and qualified back-up personnel could not be emphasized enough.

Planning and preparedness is intended to address the minimum pipeline safety and environmental standards with supplemental actions that are determined relevant to the system specific risks that each operator must address. Many of the best practices were developed around the lessons learned from the opportunities to improve response times and decision making processes. One of many of the best practices shared in the API 2005 Offshore Hurricane Readiness and Recovery Conference was the development of an Integrity Assessment Decision Flow Chart Procedure to assist with the assessment and decision process when returning facilities to service after inspection, repair or replacement. Development of a process and vetting the process with the regulator prior to the hurricane event provides an expedited recovery and return to service approval process. In preparing the flow chart, gaps in organizational resources or processes can be identified prior to it becoming a critical gap, such as during the performance of a response or recovery activity, minimize cost and schedule impacts as well as potential safety or environmental issues. BP presented the following flowchart as an example of their Post Storm Integrity Plan.

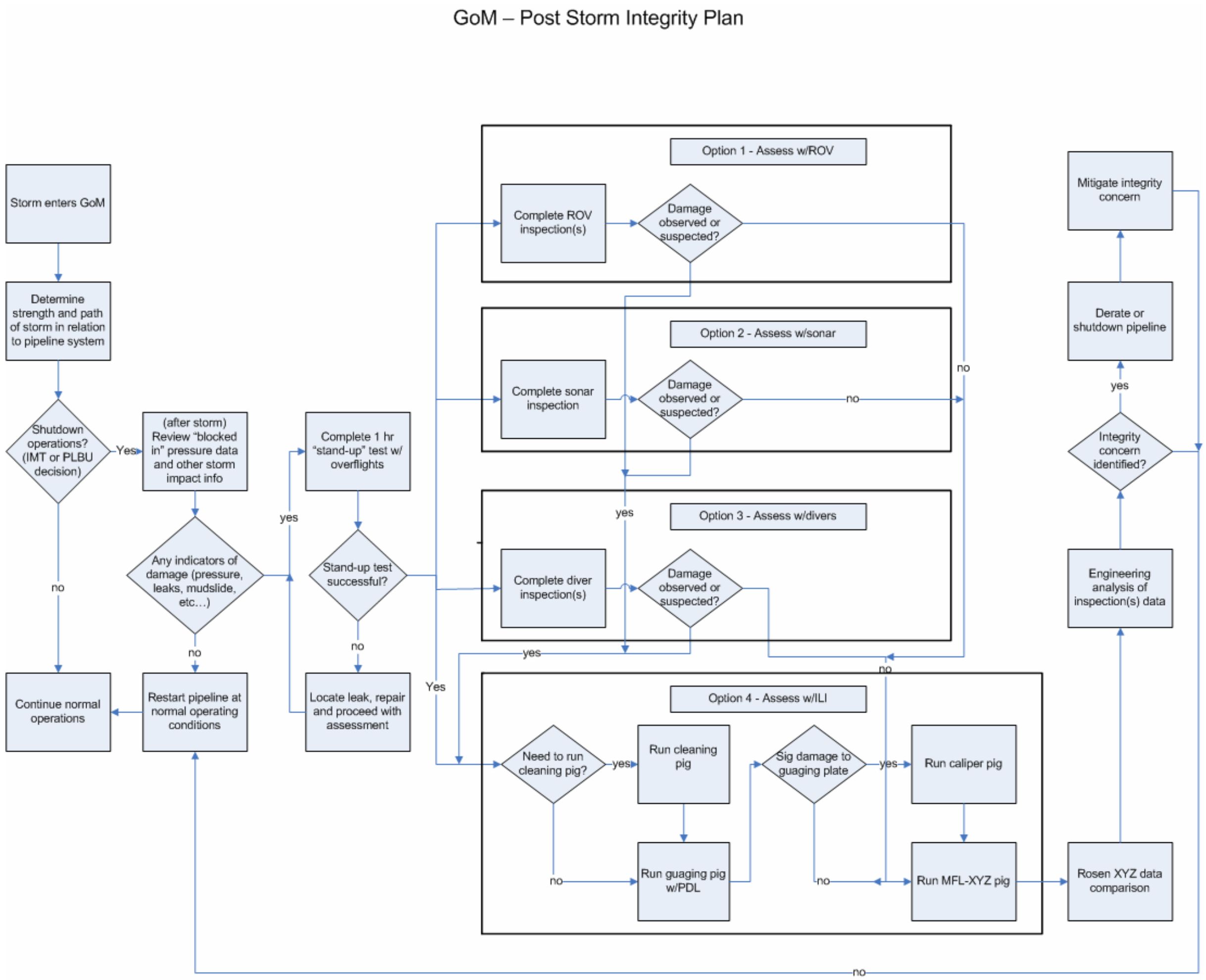


Figure 18 – BP GOM Post Storm Integrity Plan

The topic of preparedness was covered in the White House Report on the *Federal Response to Hurricane Katrina: Lessons Learned* as illustrated in the following Preparedness Flow Chart. The model in Figure 19 serves well for many industries, incorporating the process of feedback and continuous improvement to incorporate lessons learned. With the substitution of several industry terms and practices, the same model could be easily adapted to the offshore pipeline industry as a best practice for hurricane planning and preparedness.

RECOMMENDATION 7 Develop templates or flowchart samples to be issued as guidance to leaseholders to communicate lessons learned for hurricane planning and preparedness, and recommend formalization of hurricane plans by pipeline operators. Recommend review of operating procedures by MMS for inclusion of hurricane plans and review of records of hurricane drills having been conducted.

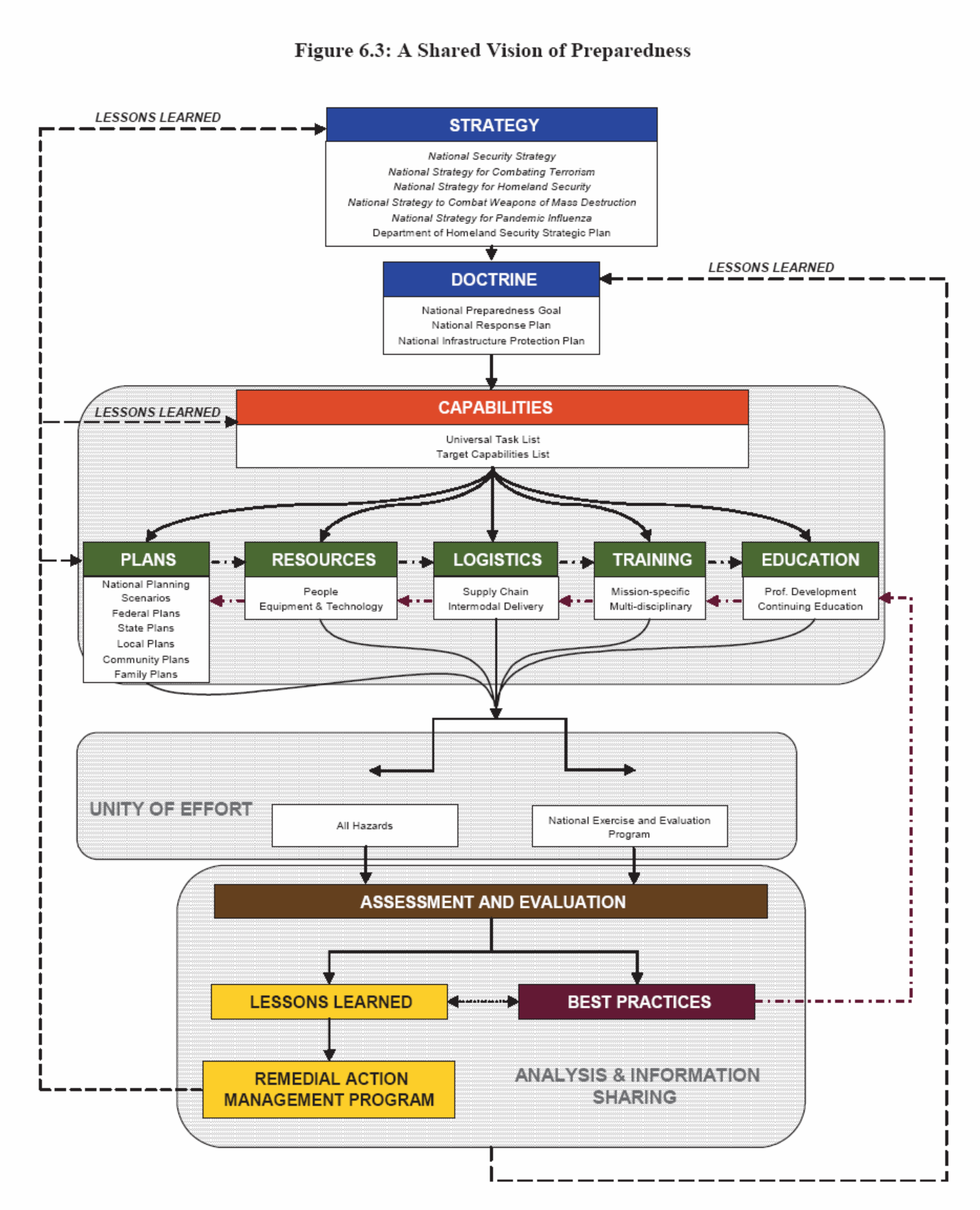


Figure 19 – Katrina White House Report – Shared Vision of Preparedness

10 RESPONSE & RECOVERY

10.1 MMS GOMR Required Inspections, Post Hurricane

After the passage of a hurricane, the MMS issues an NTL to direct pipeline operators to undertake certain activities to inspect, assess and restore their pipeline facilities, within a specified area relative to the hurricane's path, and a specified timeframe. All activities are subject to the review and approval of the GOMR Pipeline Section. The MMS works closely with operators in the reporting, review and permitting processes that are necessary to provide the oversight of the pipeline repairs and other activities intended to ensure the integrity of the facilities, within the permit conditions. The primary steps are:

1. Report failures to the Pipeline Office, MMS GOMR
2. Identify the permitting procedure type (Construct, repair, abandon, replace, etc.)
3. Submit permit request
4. Make pipeline repairs
5. Submit completion report

The balance that must be achieved in expediting the return to operations, without harm to people or the environment is the role that the oversight by MMS GOMR Pipeline Section provides. There have been many issues in returning to operations that have prompted both the industry and the GOMR to evaluate their current practices and incorporate lessons learned. The primary issues facing the MMS and industry with respect to pipelines returning to operations are:

- Identification and detection of damages
- Protection of life, property and environment
- Assessment of damage of pipelines
- Permitting activities and approvals
- Testing prior to return to operations
- Restoration of supply

The first three bullets have been addressed in previous sections of this report. By and large, the damages are being located, the releases to the environment and safety of people are being managed, and processes for the assessment of the facilities are available to pipeline operators. The remaining activities that are required by the GOMR as conditions of the permits are generally dealt with through Notice to Leaseholders and Right of Way Holders (NTLs) issued after the hurricane events, instructing the leaseholders to perform activities to ensure protection of people, assets and environmental resources.

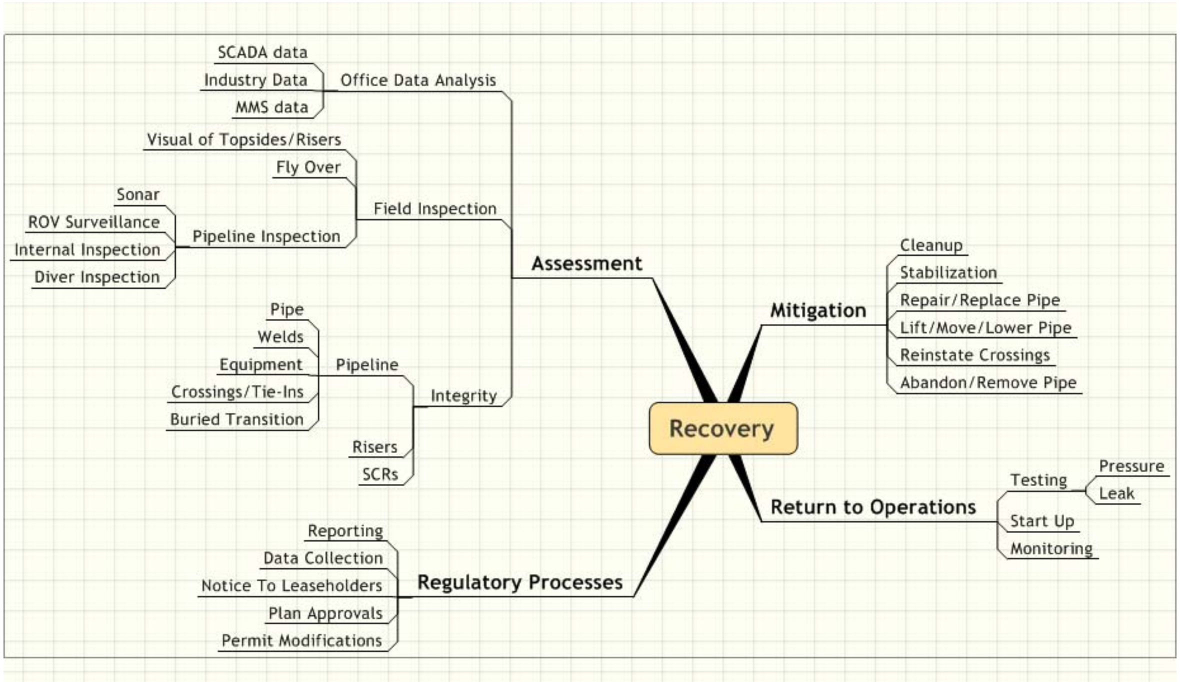


Figure 20 - Recovery Risk Control Categories

The recovery risk control categories that were identified in the risk analysis activity are shown in Figure 20. The primary recovery practices were broken down into the categories of Assessment, Mitigation, Regulatory Processes, and Return to Operations.

The MMS GOMR issued NTL No. 2004-G18 with an effective date of October 4, 2004, to describe the inspections that pipeline operators needed to conduct because of the known and potential damage to OCS facilities caused by Hurricane Ivan when it struck land September 16, 2004. The NTL contained the following requirements:

OCS Pipelines

Pursuant to 30 CFR 250.1005(a), you must conduct inspections of pipeline routes at intervals and using methods prescribed by the MMS. Under this authority, and because of the numerous reports of severe damage to OCS pipelines along the path of Hurricane Ivan, the MMS GOMR hereby directs you to conduct the following inspections by May 1, 2005:

1. Pipeline Tie-in Inspections - Conduct an underwater visual inspection using divers or ROV, a scanning sonar processor, or a 500-kHz sidescan sonar in combination with a magnetometer to inspect each of your OCS pipeline tie-ins located within the corridor between 89º 30’ W longitude and 87º 30’ W longitude (see Attachment B of this NTL for a map of the described area). Design each inspection to determine whether any valves or fittings became exposed and to determine the extent of any damage, including damage to protective devices, mats, and sandbags.

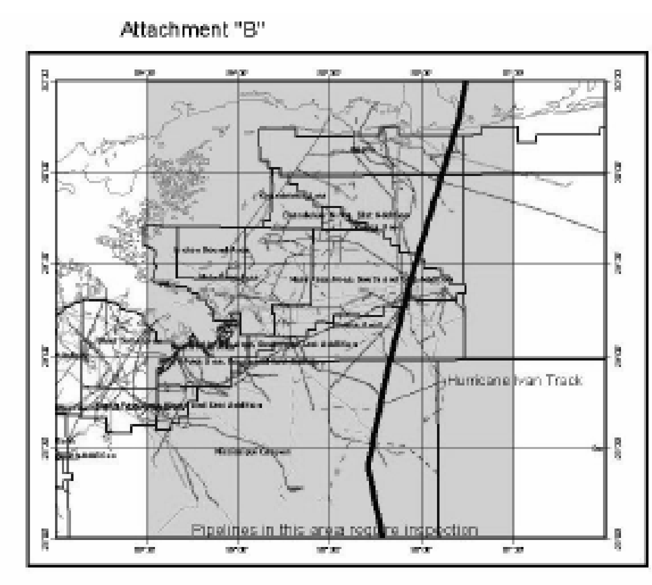
2. Pipeline Riser Inspections - Conduct a visual inspection of the above-water portion of each pipeline riser located within the corridor between 89º 30’ W longitude and 87º 30’ W longitude (see Attachment B of this NTL for a map of the described area). If applicable, conduct

this riser inspection in conjunction with the required platform Level I survey described above. Inspect the riser and riser clamps for damage. If this inspection indicates that damage may have occurred, conduct an underwater riser and pipeline inspection described in Item No. 4 below (if you are not already required to do so) to determine if the pipeline has been displaced or exposed.

3. Pipeline Steel Catenary Riser Inspections - Conduct an inspection using divers or ROV of the underwater portions of each of your OCS pipeline steel catenary risers located within the corridor between 89º 30’ W longitude and 87º 30’ W longitude (see Attachment B of this NTL for a map of the described area). Inspect the riser, vortex-induced vibration (VIV) suppression devices, and the connection point (flexible element, titanium stress joint, etc.) to the structure for damage.

4. Underwater Riser and Pipeline Inspections - Conduct a visual inspection using divers or ROV, a scanning sonar processor, or a 500-kHz sidescan sonar in combination with a magnetometer to inspect the underwater portions of each of your OCS pipeline risers and adjacent pipelines located in water depths between 200 feet and 500 feet within the corridor between 89º 30’ W longitude and 87º 30’ W longitude (see Attachment B of this NTL for a map of the described area). If applicable, conduct this riser and pipeline inspection in conjunction with the required platform Level II surveys described above. Inspect the riser and riser clamps for damage. Inspect the pipeline for evidence of displacement or exposure from the base of the riser along the entire length of the pipeline.

5. Remedial Action - If an inspection indicates (a) factors that could detrimentally affect the performance or integrity of pipeline valves and fittings at a tie-in, (b) conditions that could cause interference with navigation or other uses of the OCS, (c) riser or riser clamp damage, or (d) that a pipeline has been displaced, exposed, or damaged, submit a plan of corrective action, pursuant to the requirements of 30 CFR 250.1008(g), by mail to the GOMR Pipeline Section (MS 5232) for approval within 30 days after completing the inspection. Within 30 days after you complete the work, submit a written report indicating that the repairs were performed as proposed, confirming the type and/or cause of damage, and including the results of any pressure tests by mail to the GOMR Pipeline Section (MS 5232). Complete all work requiring corrective action before June 1, 2005.



6. Additional inspections. If you suspect that Hurricane Ivan may have damaged a pipeline or related structure that is located outside the corridor between 89º 30’ W longitude and 87º 30’ W longitude (see Attachment B of this NTL for a map of the described area), conduct the appropriate inspections described in Items Nos. 1,

2, and 4 above and, as appropriate, submit a plan of corrective action as described in Item No. 5 above.

If you haven't already done so, perform a leak test before you return to service any pipeline located within the corridor between 89º 30' W longitude and 87º 30' W longitude (see Attachment B of this NTL for a map of the described area). Make sure that the leak test successfully tests the integrity of the pipeline. A successful leak test means no observable leakage during the test period. When you conduct a leak test, make sure that you use a stabilized pressure that is capable of detecting all leaks; use pressure gauges and recorders that are sufficiently accurate to determine whether the pipeline is leaking during the test; and conduct the test for at least two hours during daylight hours. For major oil pipelines, provide aerial surveillance of the pipeline route while you perform the test.

On November 15, 2005 NTL No. 2004-G20 supplemented the previous NTL to provide clarification on the inspections to be performed on OCS pipelines and related facilities at various water depth ranges that were along the path of Hurricane Ivan.

The following chart summarized the clarifications issued under NTL No. 2004-G20 for the portions of a pipeline to be inspected, according to water depth range.

If the water depth range is	**then inspect all**
0 to 199 feet	risers, subsea tie-ins, and foreign pipeline crossings.
200 to 499 feet	risers, subsea tie-ins, foreign line crossings, and the entire pipeline route
500 feet or greater	risers, including steel catenary risers

By the time the supplemental NTL was issued, more than 40% of the pipeline damage reports had already been submitted to the MMS GOMR Pipeline Section. In reviewing the damage reports submittal dates, nearly 30% were submitted prior to the issuance of the first NTL. Within 90 days of the hurricane event, roughly 45% of the damage reports had been received. Only ten more reports were submitted in January and February, eleven in March and April, with the remaining reports constituting nearly 50% of the total reports submitted in May, prior to the May 31, 2005 deadline. In evaluating the damage reports, it was noted that the most obvious damage was identified quickly as a result of surface indications or other detection methods. The less obvious damage was often detected when testing and returning to service, and the final damage reports were those that identified exposed pipe and minor damage that was not detected until an underwater inspection was conducted, or repairs were made to connected facilities.

Based upon these observations, it could be noted that approximately 30% of reported damages were immediate or identified very soon after the passage of the hurricane, 20% were delayed, and 50% were detected through inspections conducted later, or that half of the reports lagged the discovery of the damage, significantly. The damage that is found later through inspection, or that is far outside of the expected zone of hurricane impacts is difficult to conclusively attribute to hurricane forces. However, DNV made no attempt to distinguish whether the causes were plausible, and relied upon the industry data submitted by the pipeline operators.

The statistics described in the preceding paragraph have not been reported in prior hurricane studies, but may be useful for the assessment of the proportion of obvious damage to that damage which is identified through inspection. If this data is statistically accurate, about half of the damage was made evident without inspection, and half was identified through inspection, a very sound basis for the continuation of the practice of MMS issuing NTLs for post hurricane inspection of pipeline facilities. There are many factors influencing the timing of post hurricane inspections, from resources to winter weather, to other operational priorities, and DNV makes no judgment as to the timeliness of the performance of the inspections by pipeline operators when it is within the guidance provided by the regulator.

RECOMMENDATION 8 MMS GOMR should continue to issue NTLs to survey pipeline facilities, but may wish to refine the criteria for the limits of the surveys, as soon as possible in the recovery process, or based upon the guidelines recommended by historical hurricane parameters and damage correlation presented in this report.

The inspection criteria were clearly amended after roughly half of the damage information was reported. The damage reports and processing of the data contained within the reports helped MMS in making the clarifications based upon the early industry findings. It is suggested that automating this reporting process and data assessment through the mapping techniques used in this study could simplify this process and reduce the manual entry and manipulation of the data and damage reports by MMS, allowing the technical staff performing these activities to focus on higher value tasks.

RECOMMENDATION 9 Automate and simplify the damage reporting process for pipeline operators to expedite the damage information received from the operators, as well as provide easy online access for report submittals, and a consistent format and definition for data collected.

10.2 Testing

One of the practices that received much attention during the evaluation of post hurricane events was the type of testing that should be required of pipelines prior to returning them to operations. Two methods of testing: leak testing and hydrotesting, are the primary manner of integrity confirmation being used by the MMS and industry. If a line has not suffered a failure requiring replacement or new construction, generally a leak test is sufficient to demonstrate integrity of the pipeline. If a pipeline has been replaced or new construction has been installed, the hydrotesting of the line is typically the requirement that must be met.

During the return to service of some pipelines, the leak/return to service test was the manner in which the damage was initially identified. This was identified in the comments in a handful of the damage reports submitted to the GOMR.

The question has been raised as to the benefit of requiring hydrotesting of all pipelines prior to return to operations. DNV would recommend against a blanket hydrotesting requirement for pipelines after hurricanes. However, DNV would recommend a risk-based approach to when hydrotesting that is required by code might be waived, as appropriate for the post hurricane return to operations. Where an operator was able to adequately address the confirmation of the pipeline's integrity, such as the assessment process demonstrated by the flow chart in Figure 18, a hydrotest appears not to be necessary. The GOMR and industry confirmed that leak tests were adequate, and successful for integrity confirmation of the pipelines, If the product is not harmful to the environment, the risk of release is primarily a safety and asset integrity issue, and should be adequately addressed through an operator's practices. In light of the need to restore supply from production, and the growing criticality of the GOMR role in the U.S. oil and gas supply, it appears that requiring a hydrotest would conflict with the timeliness of return to service, and competing demands on resources.

It is clear that there is not a single answer, and that the best approach is a risk based approach that evaluates the following factors:

- Inspections that have been carried out and adequacy of assessment by operator
- Risk of release/failure to people and environment
- Criticality of supply to infrastructure
- Risk to operational quality of pipeline (gas versus liquid lines)

RECOMMENDATION 10 DNV recommends a risk-based approach to the return to service testing requirements for GOM pipelines. Where an operator can adequately demonstrate that the risks have been mitigated to the MMS, waiver of hydrotests for all permit application types should be considered if the pipeline is impacting critical infrastructure supply.

10.3 Lessons Learned

It is evident in the interviews, conferences and research activities that industry and MMS alike work diligently to incorporate lessons learned to continuously improve the planning, preparedness, and response into design, procedures and regulatory requirements. The lessons learned by MMS were summarized in testimony to the Senate in a statement given by Rebecca Watson, Assistant Secretary for Land and Minerals Management, U. S. Department of the Interior before the Committee on Energy and Natural Resources on September 6, 2005.

> *"Following major hurricanes, we make a systematic effort to identify lessons learned and take steps to prepare for future hurricane seasons. Following Hurricane Ivan, we focused on five principal areas:*
>
> *First, MMS concluded that the basic design standards for deep water floating production systems seem adequate. We had no floating production facility failures.*
>
> *Second, MMS saw that some drilling units installed on the floating production platforms moved on their supports and caused damage. In consultation with MMS, industry has tightened the bolting mechanism and strengthened the clamps that secure these drilling packages on the floating platforms.*

Third, MMS issued a new reporting requirement for the 2005 hurricane season – NTL 2005 G-6. This requires industry to submit statistics to the MMS Gulf of Mexico Region (GOMR) regarding evacuation of personnel and curtailment of production because of hurricanes, tropical storms, or other natural disasters. Operators must include both those platforms and drilling rigs that are evacuated and those that they anticipate will be evacuated. Evacuation is defined as the removal of any personnel (both essential and non-essential) from a platform or drilling rig. In addition, operators submit a report regarding facilities remaining shut-in. This report includes basic platform information, prior production information, estimated time to resumption of operations and the reason for shut-in (facility damage or transportation system damage). Operators must notify the MMS GOMR when production is resumed.

Fourth, MMS issued contracts for six new engineering and technical studies to look closely at the damage caused by Hurricane Ivan and what design or operational changes may need to be made.

Fifth, MMS consulted heavily with industry experts and in July jointly sponsored with the American Petroleum Institute (API) a conference in Houston, Texas, on offshore hurricane readiness and recovery to more fully discuss these issues.

We will conduct similar reviews and assessments of facility performance and impacts from Hurricane Katrina to identify any additional steps that need to be taken."

During the API conference, operators shared their lessons learned with the attendees and offered insights into things that went well, and things that they will be addressing in the future to improve their planning and response.

11 DETAILED TECHNICAL ANALYSIS

11.1 Environmental Forces and Their Impact on Pipelines

The environmental forces that occurred during Hurricane Ivan were reviewed, and their impact on pipeline stability was investigated. Movement of pipelines contributed to a large number of the pipeline damages reported as a result of Hurricane Ivan. Nine of these reported damages had significant movement of pipelines out of their original right of ways. The majority of these pipeline movements were in the Main Pass Area and to the west of the path of Hurricane Ivan. The map in Figure 21 represents all of the pipeline damages reported as a result of Hurricane Ivan. The reports citing mudflow as the secondary cause of damage are identified by brown lines, all other secondary damage causes reported are represented by red lines, and all remaining pipelines that did not have any damage reported are represented by gray lines.

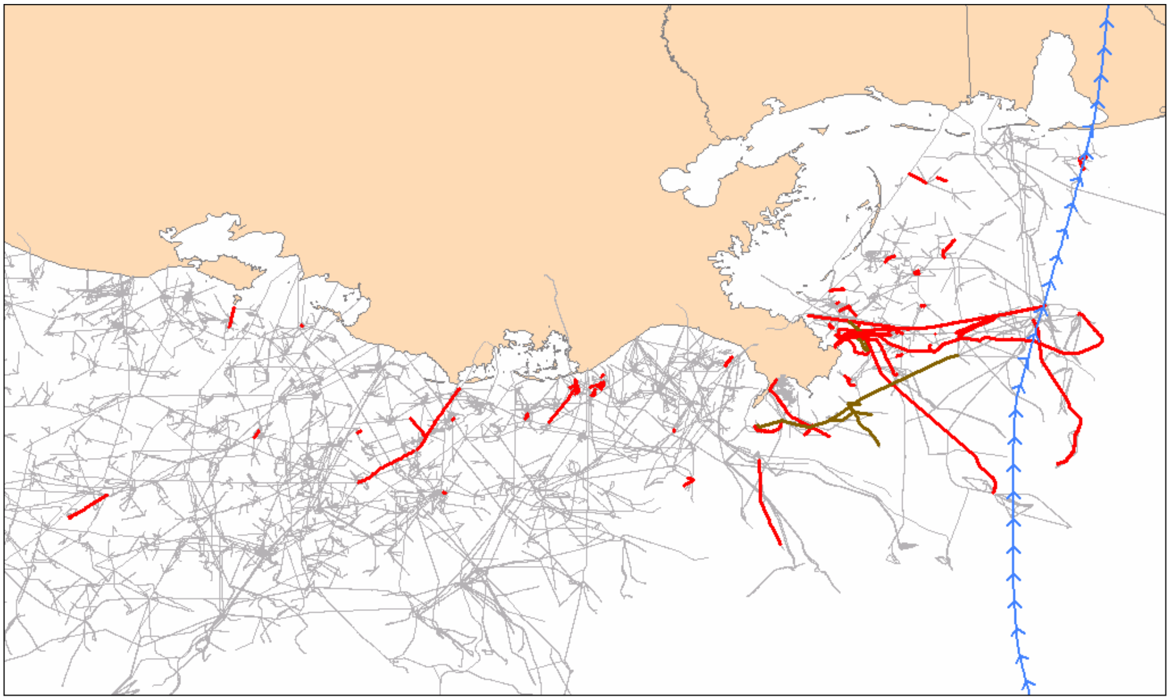


Figure 21 - Map of GOMR Pipelines and Damage Reports Relative to Hurricane Ivan Path

The first step in attempting to understand the stresses on the pipelines is to assess the environmental forces due to waves and current. Hurricane Ivan was analyzed to have a significant wave height with a return period of 2500 years, and the peak wave height exceeded the 100 year significant wave over a 150 mile swath.

The Ivan peak wind and current had a 700 year return period. The maximum current was a 700 year return period in a water depth of 50 meters. The current speed exceeded the 100 year return period over roughly a 20 mile swath. The maximum current obtained by the Hindcast model correlates very closely to the location where most of the pipelines moved, as shown below.

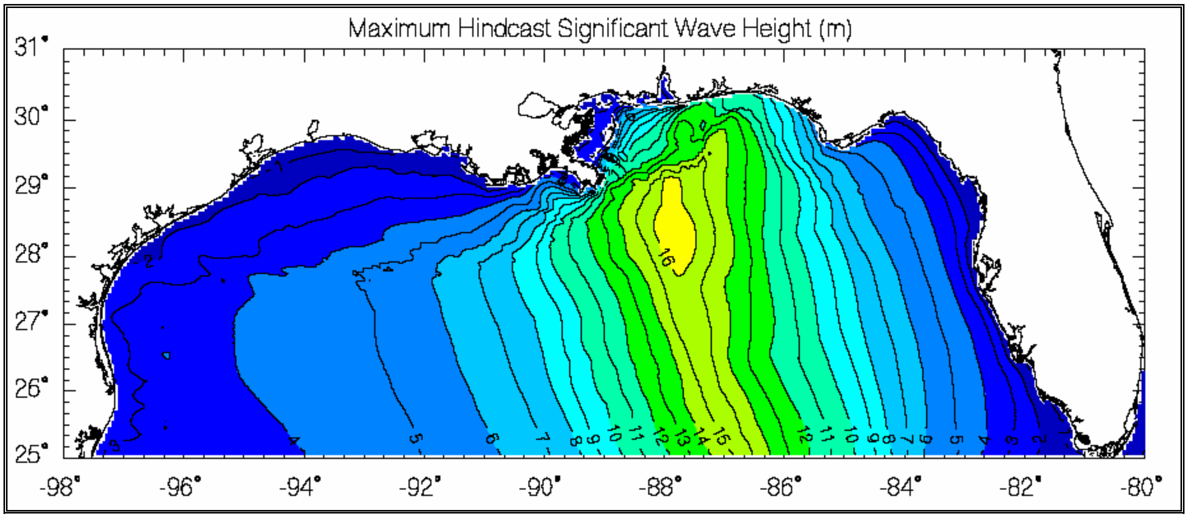


Figure 22 – Maximum Wave Height From Hurricane Ivan Hindcast Report

The hindcast methods for currents are not as developed as those for the winds and the waves. There is also little recorded data against which the hindcast methods can be compared. This is one reason that the stability analysis can only be done using estimated values for current. The Oceanweather, Inc. (OWI) hindcast report mathematically calculates the current speeds at the surface. The ability to correlate this to the subsurface current velocities is hindered by the inability to validate the model with actual data, and the ability to account for the subsea surface gradient in the shallow water depths.

Commercial hindcast models are available such as the HYCOM model, which were presented in the API Hurricane Conference by Curtis Cooper. A snapshot of the Ivan HYCOM currents is given in Figure 23, representing the intensity of the current in the delta region of the GOM as a result of Hurricane Ivan.

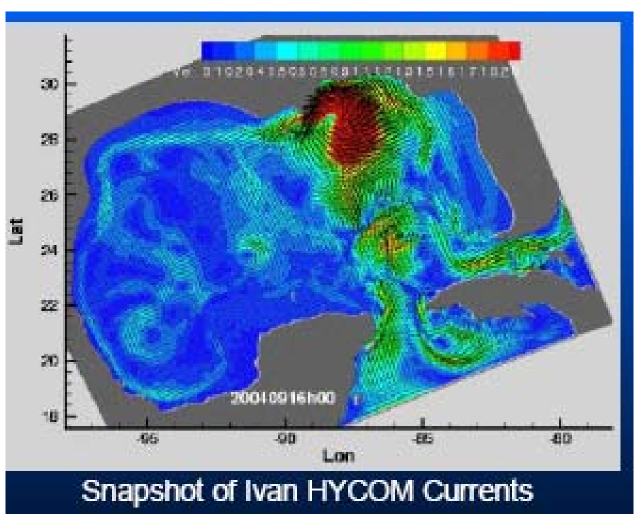
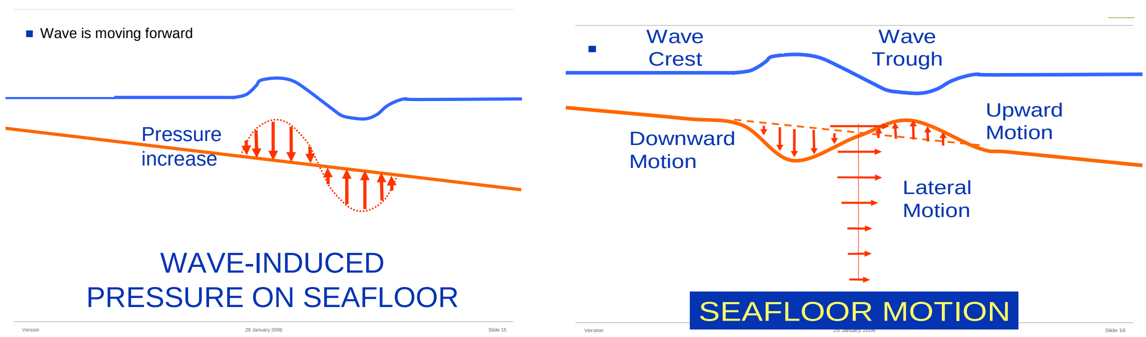


Figure 23 – HYCOM Currents - Hurricane Ivan

Since the HYCOM model was not validated for the shallow water (in terms of comparison with recorded data), the DNV project team focused on using the OWI wave and current data to assess the stability of the pipelines. OWI's standard UNIWAVE high-resolution full spectral wave hindcast model was used for evaluating the hydrodynamic load cases.

11.2 Why Pipelines Move

There are theories that abound, as to why the pipelines moved. There are no particular answers at the moment. But one possibility is that the sea-bottom is stirred, changes the specific gravity of the mud and the pipe floats in the mud due to the current action. Hooper has provided a possible explanation about the stirring of the sea-bed. When a wave passes over shallow water, it causes a pressure change on the sea-bed. This causes a movement of the sea-bed as illustrated below in Figures 23a and 23b, causing the pipeline to "float."



Figures 23a and 23b

There is no current knowledge with regard to the relationship between the height of passing waves, the pressure fluctuation on sea-bed and the amount of liquefaction of the sea-bed. DNV would recommend further study of this phenomenon as a future effort to increase the understanding of these forces as they apply to GOM pipeline facilities.

For one particular case of pipeline movement, scouring marks were observed from the NE to the SW direction on a 55 foot section of the displaced pipe. This suggested that the pipe moved south, which was opposite to the direction of the Hurricane wind and wave forces, but consistent with the direction of the OWI hindcast current. In Figure 24 the OWI Hurricane Ivan hindcast report shows that there is a "reverse current "from the coast of Alabama (Mobile Bay area) towards the Mississippi Delta.

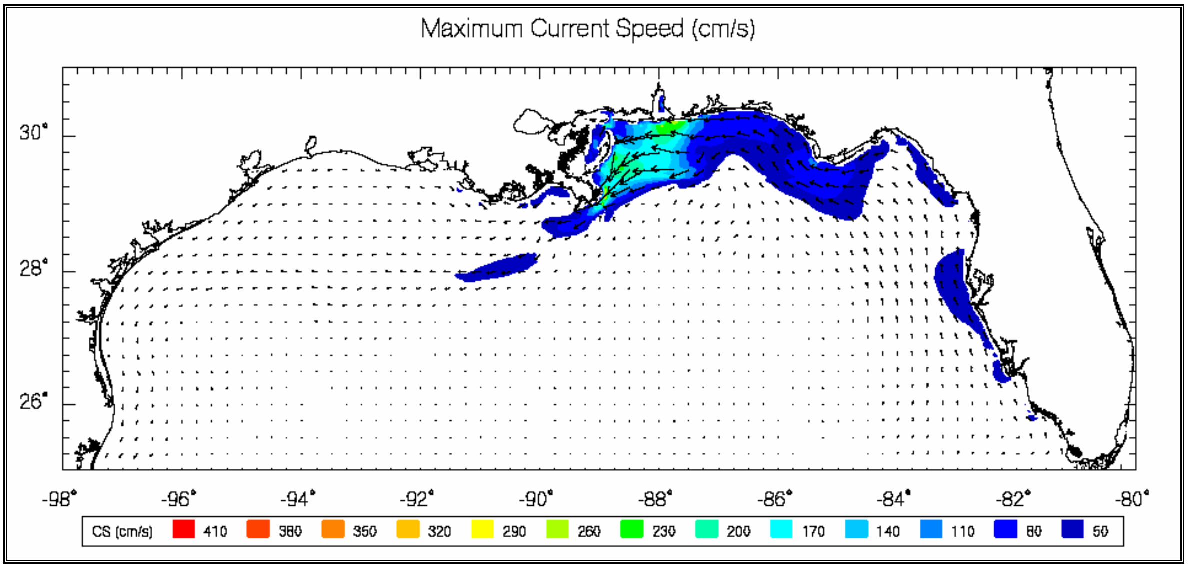


Figure 24 – Maximum Current Speed From Hurricane Ivan Hindcast Report

11.3 Comparison of Codes and Industry Stability Software

The industry accepted or practiced guidelines for evaluation of on-bottom stability is found in the three most commonly used pipeline design codes. These codes are API RP 1111, British Standard PD 8010-2 and DNV-OS- F101.

All these codes stipulate that the pipelines must be stable under the effect of wave and current loadings. In addition, it is indicated that design must take into account any special considerations with respect to soil stability such as slides and liquefied seabed conditions. None of the codes gives any detailed design guidelines to address these issues which occur primarily in shallow water. It must be mentioned that API RP 1111 specifically addresses hurricanes and the possible liquefaction or weakening of sea bottom sediments with resulting pipeline sinkage, flotation or lateral movement. However, there are no recommended methodologies for mitigating these risks.

The current industry software for calculation and analysis of on-bottom stability is a suite of software developed by the American Gas Association (AGA) Pipeline Research Committee, and was used for analysis of a major oil line that experienced significant movement during Hurricane Ivan. The results of these analyses were provided to MMS GOMR outside of this study work.

11.4 Stability Analysis by PONDUS

The stability analysis of three typical pipelines representing actual conditions and facilities in the GOM shallow water areas was carried out by the DNV study team.

As a result of inconsistent conclusions resulting from the previously mentioned stability analysis reports, DNV selected the pipeline studied in that report as one of the cases for the on-bottom stability analyses to be carried out as part of this study.

The first analysis of the three DNV cases was the subject of a study carried out by two different parties on behalf of MMS. This effort resulted in analyses that indicated that for the calculations and modeling performed, the pipeline in question should not have experienced movement as a result of the applied current loadings. The line was deemed stable by two independent studies, when in fact the pipeline moved excessively during Hurricane Ivan.

Two cases of displaced pipeline (one of them being the one in the preceding paragraph) and one of a static pipeline were analyzed using PONDUS. The three pipelines were in the general area of Main Pass, where much of the pipeline movement occurred during Hurricane Ivan. These pipelines were oriented generally perpendicular to the path of Hurricane Ivan. In each case assumptions were made regarding the submerged weight, the undrained shear strength of the soil, the nature of contents at the time of displacement, and the density of the coatings.

The values used in the simulations were based on the assumption that the specific gravity of the pipelines was 1.3 or less. The pipeline damage reports and interviews with the operators provided the wave spectra and current fields were derived from OWI hindcast models and applied appropriately to the sites under investigation. The pipeline parameters and actual displacement are summarized in Table 3.

Table 3 – Pipeline Parameters & Actual Displacement

Pipeline Parameters	Case 1	Case 2	Case 3
OD (inches)	18	14	12
Product	Oil	Gas	Oil
Displaced by (ft)	3000	1700	0
Displaced over a length of (miles)	27	2.1	0

The results of the PONDUS simulations are shown in Table 4. Case 1 was shown not to have moved, by other methods, as described above.

Table 4

Pipeline Attributes & Environmental Conditions	Case 1	Case 2	Case 3
Significant Wave Height (Hs) (m)	11.7	11.7	11.7
Peak Period (Tp) (s)	15	15	15
Depth (m)	63.7	95	100
OD (mm)	465.4	406.4	355.6
OD steel (mm)	457.2	355.6	304.8
WT (mm)	9.53	12.7	9.53
Coating (mm)	4.1 (FBE)	25.4 (concrete)	25.4 (concrete)
Coating density (kg/m^3)	950	2240	2240
Current Velocity @ sea-bed (m/s)	0.758	0.703	0.684
Submerged Weight Wsub (N/m)	892 (waterfilled)	372 (empty)	871 (waterfilled)
Soil Undrained shear strength (N/m^2)	50000	1467	50000
Lateral Displacement (m) 3 hour storm			
PONDUS Calculated movement (mean of 5 seeds)	1446 m	628 m	254 m
Reported movement from MMS damage report	914 m	518 m	0 m

11.5 Conclusions

The PONDUS analysis predicts that the pipelines will move given the environmental and hydrodynamic loading conditions which the pipeline experienced during the passage of the hurricane. Case 3 is predicted to move, while in reality, this particular pipeline did not move at all. These results are based upon assumed conditions and are largely dependent on the following variables, (among others)

- Pipeline burial and soil parameters
- Direction and time dependent variation of the hydrodynamic loading conditions
- The Specific Gravity of the pipeline at the time of displacement.

The modeling of the on-bottom stability is highly dependent upon the assumptions used in the analyses. However, the available data and information used in this study is based upon that which has been provided to DNV, and it is assumed to be factual and accurate because of its submittal to MMS in damage reports, and verification by the operator of the pipeline.

The results from the PONDUS analysis correlate fairly well with the observed movements of the pipelines, and appear to be a valid tool for such studies. However, as with all of the evaluations carried out by DNV, the results of analyses carried out are severely hindered by the actual data that is available about the environmental and pipeline conditions.

RECOMMENDATION 11 DNV recommends the further study of the methods for modeling on-bottom stability. These studies should include collection of data and validation of the models for improvements in the reliability of the results predicted through current industry tools.

12 DAMAGE MAPPING

12.1 Geographical Information System Basics

A Geographical Information System (GIS) allows us to:

- **Import existing maps.** A good GIS will let us import existing maps from many different file formats, including those used by competitive software.
- **Create new maps, and edit existing maps**. This includes adding new items to a blank map, or to change the shape and position of items already in the map or to delete items from a map.
- **Change the appearance of items in a map by changing their formatting**

A GIS is therefore very different from static, purely visual applications like AutoCAD or Photoshop in that it is both a visual representation as well as a data representation, and it is at once both a presentation and visualization tool. It can perform as being a control console and an analytical device, a limitless calculator of appearance, location, shape and data content.

A GIS can work with many different maps. Just as we can use Microsoft Word to open any document in a file format understood by Word (such as Word Perfect or other word processors), we can use our GIS to open maps saved in any file format understood by the GIS.

When we use the word "map" we mean a digital document that is a drawing in some GIS format that may or may not also include database information. The phrase "GIS format" means some file format that is useful for saving maps in a way that is useful to a GIS. A real GIS, for example, will save its files using a file format that allows saving database information, projection information and other necessary details.

Because maps used with GIS can be so complex and such a hassle to create from the ground up, sometimes our ability to accomplish a specific project will depend on whether or not we can find the right pre-built maps or data sets to use.

It is important to keep clear in one's mind the difference between the GIS program's function and any effects caused by the particular data set with which one works. For example, if one is working with a drawing that is made of lines only and has no area objects in it, then one cannot color the regions between the lines. That's not a limitation of the GIS. It is simply a reflection of the structure of the drawing that one has chosen to use.

If we import text into a Microsoft Word **.doc** it might first appear in **Courier New** font. We can format the text to change the appearance. Changing the font size, style and color can result in dramatic changes in the appearance of the text but the actual words stay the same. Just so, changing the formatting of objects in drawings can change dramatically their appearance even though the actual objects within the drawing stay the same.

We often import complex maps from formats that do not retain information about visual appearance. In such cases, the GIS will initially show the drawing using default formatting.

In their visual appearance and diagram / map editing capabilities, GIS systems are similar to a CAD editor such as AutoCAD. AutoCAD can also be used to create and edit maps. GIS adds another important capability: it incorporates database capability within the program. That database capability is used to link objects in the map with one or more database tables. The GIS links each object in the map to a record in the table.

This is probably the single most powerful idea in GIS, the idea that a map can have the objects it shows linked to a database table. This linkage makes it possible to use the map as a visual interface to fetch and manipulate data in the database. In many important GIS applications the visual appearance of the map is a secondary consideration. What is most important is the ability to use the map as a visual interface to deal with the data "behind" the map.

The linkage also enables us to use the map as a presentation tool to make sense of otherwise incomprehensible data. For example, we might click open a map's table and sort the table by a column such as "population" or "sales" or some other field of interest. We could then select the top ten records in the table and see them highlighted in the map. Right away, we can use the map to display data that otherwise might be buried within endless database records.

In the case of a few modern formats, we can usually quite effortlessly import the core data for the map. However, even with modern formats it is very rare that we can duplicate the formatting and stylistic appearance (line style and color, for example) from one mapping program to the next. In GIS work, therefore, the main focus is to import the raw data of a map and then to apply whatever appearance is desired after the map is imported.

There are often very many different maps of the same subject matter that have been prepared by different agencies. So, for example, there are often hundreds (if not thousands) of digital maps of the United States that may be downloaded via the Internet to show the same subject in different ways. If one is interested in a map of US shorelines there are many, many different maps that show the shorelines at various levels of detail with varying accuracy. Such maps have been created by different agencies at different times using different data sets for different purposes.

It is not at all difficult to create and publish a simple web site with Microsoft IIS.

The system includes the ability to publish a map for viewing on Internet through ordinary browsers. The system can publish maps, drawings, images or surfaces from **.map** files to Internet in conjunction with Microsoft's Internet Information Server (IIS).

In addition to providing web sites that can be viewed with a browser, the system can also provide an **Open GIS Consortium (OGC) WMS** server. A WMS server synthesizes images to deliver upon request to OGC WMS clients. The system is both a WMS server and a WMS client.

With the system map server anyone with a Windows server and a DSL connection, cable modem or other full-time Internet connection can publish dynamic map projects to the web for the entire world to see. Organizational users can publish projects on their Intranets to provide convenient viewing of data through browsers.

There are four steps to using the system IMS to publish to the Internet:

- Use the system to create a project containing the map or other component to be published.
- Create the files required for a map server web page using **File - Export - Web Page**. This topic describes this step in detail.
- Use the created files within a web site. If the files are created directly within a folder in your IIS directory tree (such as **C:\InetPub\wwwroot**\) the result of the **File - Export - Web Page** dialog will be an immediately "live" web site.
- Check to make sure the **IUSR_** account for the IIS machine has access permissions to the web site you have created. Use Windows Explorer to view the security settings on all files involved in your web site.

The system can create a linked drawing from data stored in an external geocoded table or query that contains latitude and longitude values for each record. Manifold can also create dynamic drawings, a more advanced form of linked drawings, from tables or queries that provide geometry for the drawing. When using simple geocoded tables, linked drawings by default consist of points, one point for each record, but may optionally be configured to create lines as well. Dynamic drawings can include areas, lines or points.

When the data in the geocoded table changes, such as when records are added, deleted, or their latitude and longitude values changed, the corresponding points in the drawing will automatically be added, deleted or move. Linked drawings are read-only because their content is controlled entirely by the external table. To make a change in a linked drawing, change the data in the external table or returned by the query.

Linked drawings are therefore perfect for a wide class of system IMS applications where drawings must be dynamically updated based on changing position data stored in database management systems. For example, a vehicle tracking application might show the current positions of trucks in a system IMS display based upon a table containing truck positions and other truck data that is stored in a SQL Server database.

Linked drawings can be created from geocoded tables using any of the data access methods provided by the system, such as connection to an ADO.NET, ODBC or OLE DB data source.

The system can store geometry in tables. **Geometry** is the information that defines objects in drawings, such as points, lines and areas. The **metric** of an object is the geometric data that defines that object. In regular drawings in the system, the geometry of objects is stored within the drawing and the data attributes are stored in the drawing's table. It is also possible to take the geometric information for each object and save it into a special geometry column in a table. Tables storing geometry can be tables within a project or they can be tables in some external database system such as a SQL Server database.

Besides the obvious benefit of creating dynamic drawings on the fly as desired, there are many practical gains from storing geometry data in tables. To name just a few examples:

We can store metric data in geometry columns in order to centralize all data within a database, perhaps a central DBMS using SQL Server.

We can store metric data in geometry columns to have more than one metric for a drawing object. For example, we could associate one object with another object without using any intermediate columns such as IDs, thus avoiding any risks of broken associations. Or perhaps we might want to store different versions of an object's metric for different projections or for different users.

We can use geometry values to store temporary results of geometric computations within queries.

We can edit the **Geom (I) intrinsic field** in tables associated with drawings to edit the objects in the drawing.

12.2 How Does this Apply to Pipeline Damage Reporting?

While all of this information is interesting, what does it mean to the MMS GOMR? The initial benefit is a GIS interface to facilitate the automation of the damage reporting for hurricanes, using much of the existing data within MMS, but organizing it in an efficient and powerful, yet very simple manner to quickly produce results from the information provided by pipeline operators.

Centralized storage allows multi-user use of common components so different users can simultaneously use the same component within their projects. This provides the ability to share a single copy of a component within many different projects.

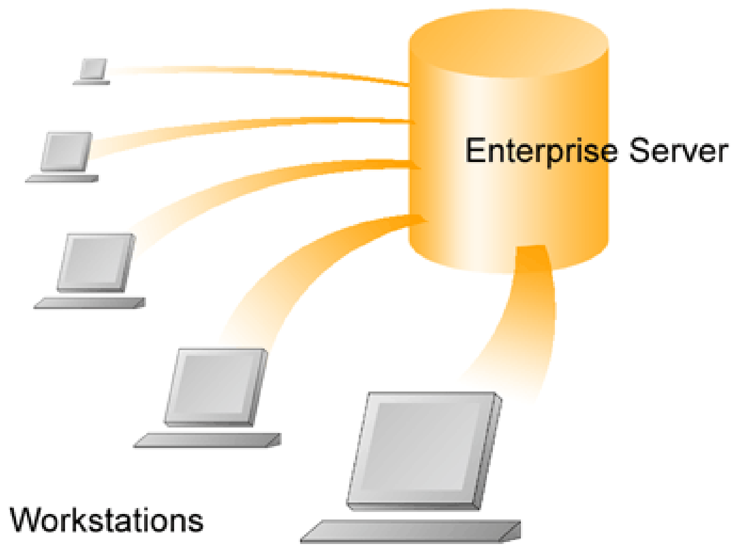


Figure 26 - Centralized Storage and Common Access to Data

The system can establish a relation between an ordinary table and a linked table, between two linked tables, between two shared tables located on the same Enterprise server, but **not** between an ordinary table and a shared table, or between two shared tables located on different Enterprise servers.

DNV, in partnership with Bridge Solutions, Inc. has developed initial components of this mapping approach, and applied it in the analysis and assessment of the pipeline damages from Hurricane Ivan.

Additionally, the damage reporting template presented by BP Pipelines at the API Hurricane Conference has been formatted as a conceptual template for an example of an online damage reporting input screen that could be used as part of the mapping information developed in this study.

A screen print of this conceptual data input template is shown in Figure 27, developed from the API industry data team's recommendation on data gathering and reporting. The mapping demonstration piloted in this study provides for improved data collection and visual representation of the damage reports that would be submitted and viewed in this geospatial format.

Figure 27 - Pipeline Failure Data Sheet – Input Screen

» Home » Pipeline Failure Data Sheet

Please complete the pipeline failure data sheet with as much detail as possible.

Pipeline Failure Data Sheet

*Segment ID:

*Company:

*P/L Name:

*Export or E&P:

*GoM Block Location:

*Water Depth:

*Pipeline Diameter:

*Wall Thickness:

*Pipe Grade:

*Year Installed:

*Design Basis (psig):

*Pipeline Orientation (relative to shore):

*Pipeline Contents:

*Failure Mode:

*S.G. w/contents:

*Burial Depth:

*Horizontal Displacement Distance:

*Horizontal Displacement Length:

Notes:

*Weight Coat: Type Amount

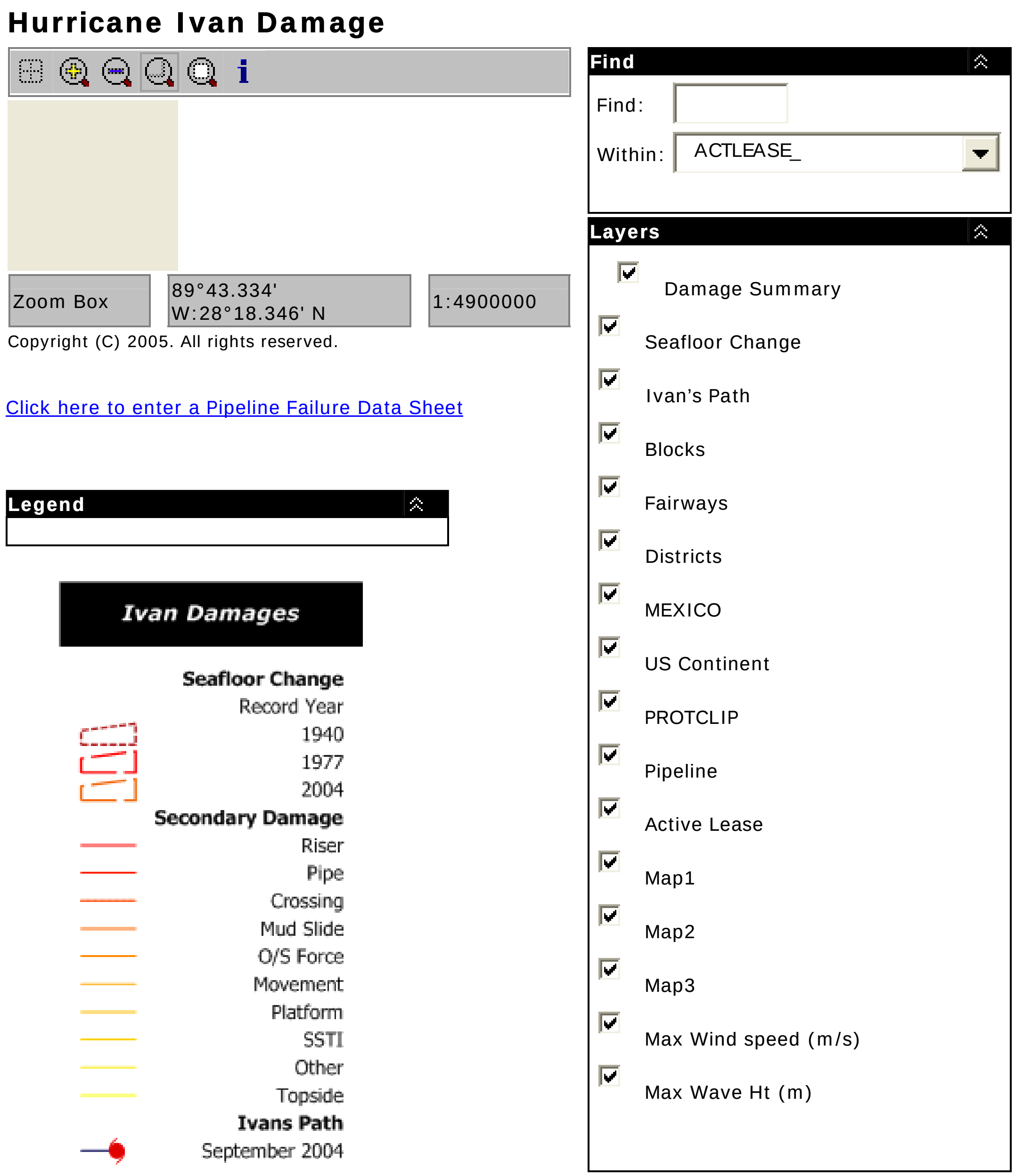
*Mud Flow Area: Yes No

*Third Party Impact: Yes No

*Pipeline Crossing: Yes No

Submit Reset

Mapping Layer and Online Map and Data Generator Developed for Hurricane Damage Analysis



The GIS is used to link all of the information that MMS presently has in its current GIS system, as long as it can be linked to a geographic location. Upon doing that, queries, assessments, reports and status can be utilized to evaluate the damages and reporting that might not have been completed.

For example, the following map shown in Figure 28 contains pipeline damage report information received for MP 64, as shown in red. The grey pipelines are those lines that have indicated no damage, or for which a report has not been submitted. Additionally, none of these damage

Figure 28 - Reported Damages in MP 64

reports indicated a platform failure, yet all of the reported damages were to the risers. It would appear that there may be significant damage to the facilities in this area. And while it was outside of the hurricane's direct path, it appears that MMS may want to communicate with other leaseholders in this area, when viewing the map, and the fact that there were more than 20 of the 168 damage reports submitted for this block. However, without the visual information provided by the mapping, this data is nearly impossible to correlate quickly or easily, by the GOMR Pipeline Section. This map was generated by the GIS used for this study project.

Many maps can be used to quickly evaluate parameters such as those found in the mudflow study, and the pipeline damage reports to see if the changing seafloor has influenced the pipeline damages in that area. Figure 29 information from the map developed by Lettis and Associates study work (dashed lines), overlayed with the pipeline damages reported for that area (solid lines).

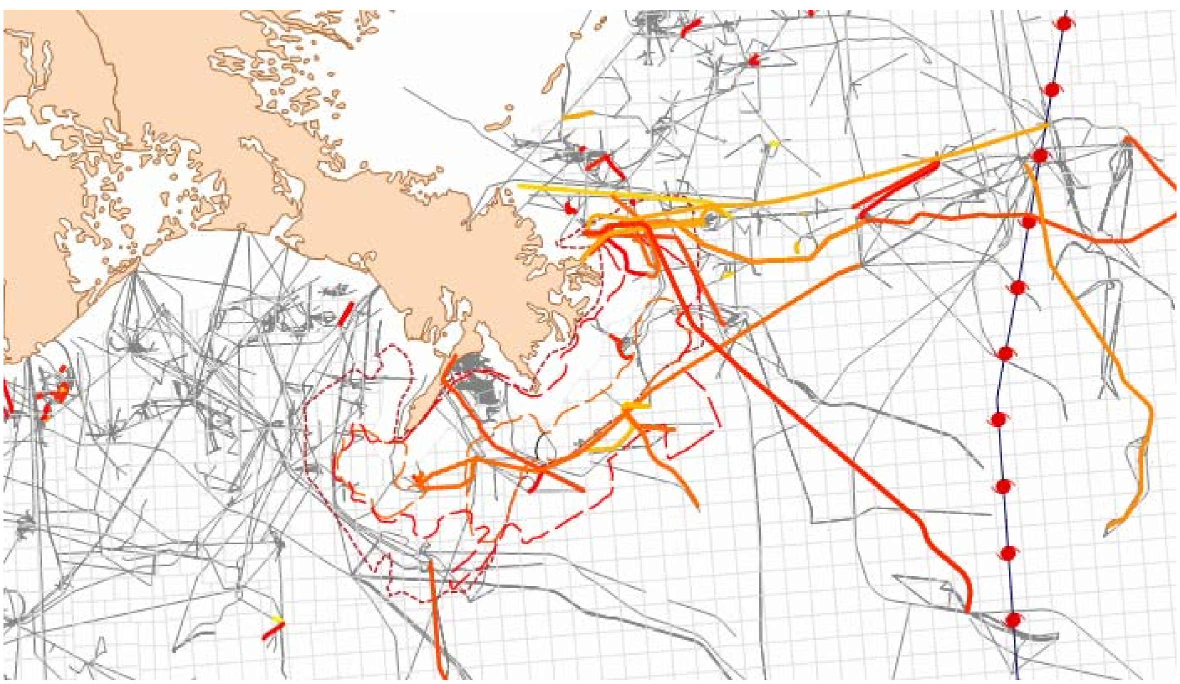


Figure 29 – Map of Sea Floor Changes Overlayed by Damage Reports for Hurricane Ivan

Additionally, the conditions such as maximum wave height and maximum wind can be represented quickly to show the lack of correlation of the damages to pipelines as shown in Figures 30a and 30b.

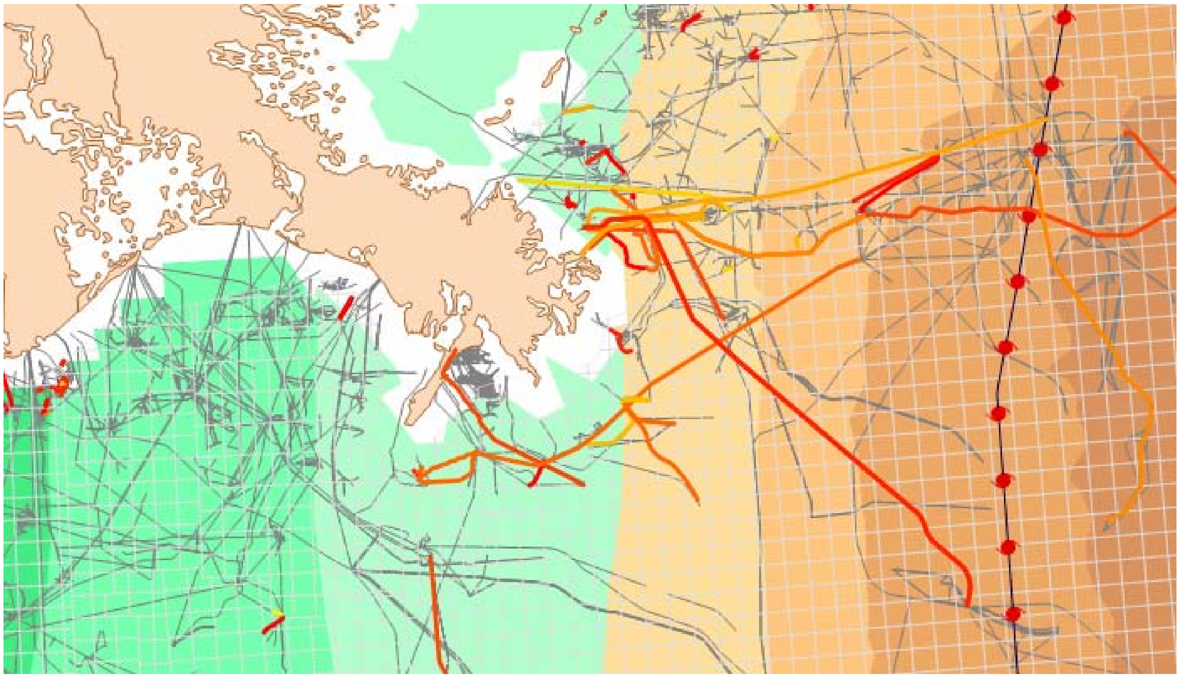


Figure 30a – Maximum Wind Speeds and Pipeline Damages – Hurricane Ivan

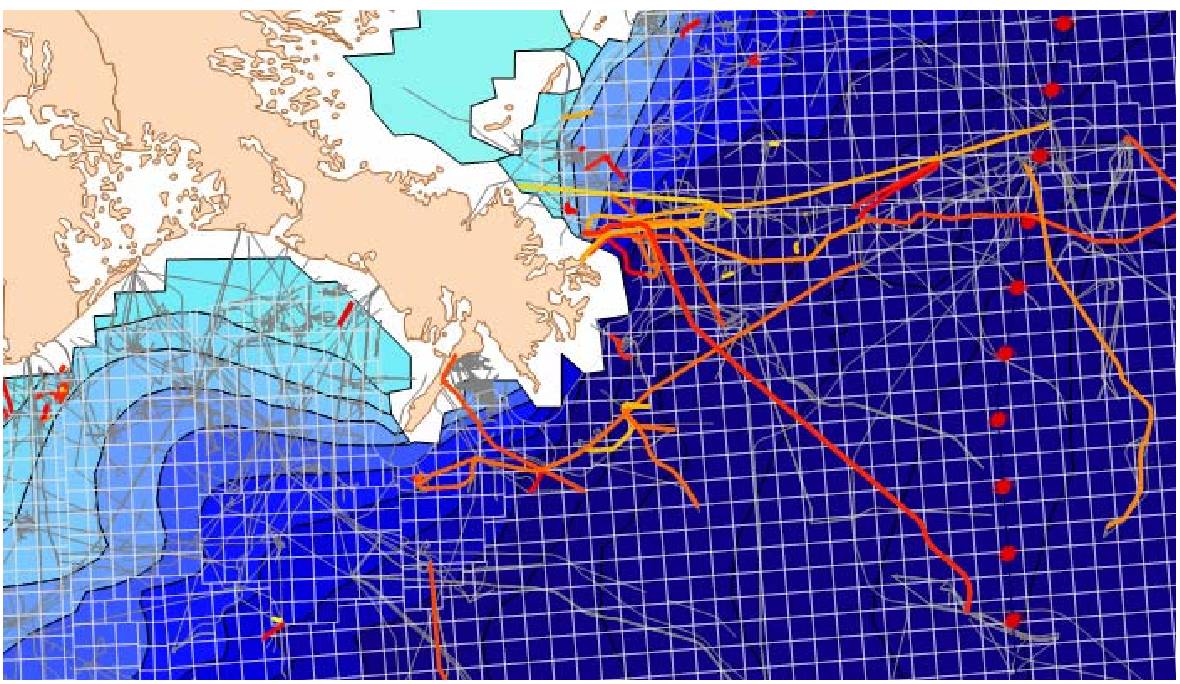


Figure 30b – Maximum Wave Heights and Pipeline Damages – Hurricane Ivan

Various colors can be used to represent parameters, and functionalities can be developed for queries and data representation. Presently, the model allows "mouse-over" information to identify the value of the colored visual layers, and zoom and database capabilities that can be demonstrated more comprehensively in a live presentation to the MMS.

The power of the visual representation of the data is quickly evident with the mapping of the information that has previously been dealt with in a paper or spreadsheet format. DNV utilized maps such as the ones shown in Figures 28 through 30 to hypothesize, evaluate, compare and correlate data. The benefit was the reduction of information clutter, and the clear and concise representation of information in a manageable format that was simple, yet powerfully effective for correlating many parameters.

There is a very large amount of information contained within the MMS data systems that does not correlate well. However, through the use of this mapping tool, DNV was able to pull together information from many sources to develop mapping representations. One example is the ability to quickly support the import of other study results with maps from MMS found online at http://www.gomr.mms.gov/homepg/offshore/safety/wtrflow.html, and geo-referenced to allow overlay for additional analysis by the DNV team. Figure 31 shows a portion of that map and the pipeline damage information overlayed onto the base map. This information was in PDF format, and added in less than an hour's time for the DNV team's use.

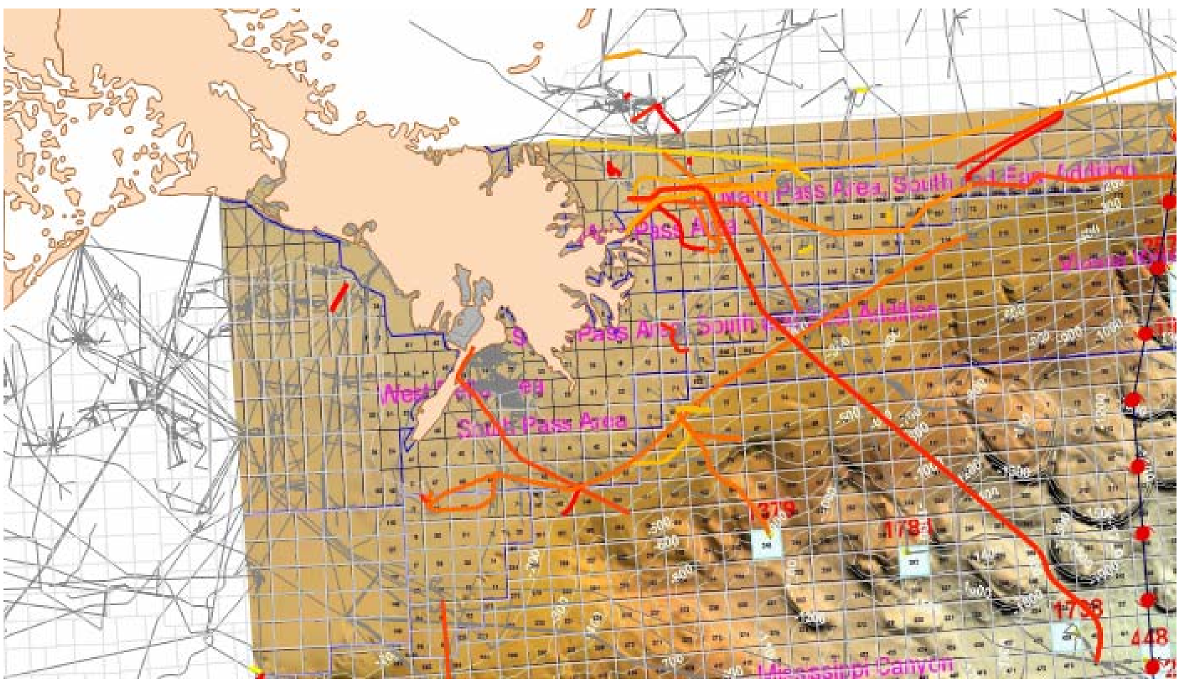


Figure 31 – Map 1 from MMS SWF Study Added as a Layer to the Pipeline Damage Maps

RECOMMENDATION 12 DNV recommends the further development and information sharing that has been accomplished on an informal basis with publicly available information. Utilize web based tools to provide additional GIS resources to the MMS for its use in pipeline information management, including the assessment of damages from hurricane passage in the GOM. Include automated online damage reporting process in this GIS system. This system will complement the existing MMS GIS system utilized by GOMR and provide data links to the various information sources within the MMS GOMR.

13 CONCLUSIONS AND RECOMMENDATIONS

The major conclusions and recommendations drawn from the work carried out in this study are listed in the following two subsections.

13.1 Conclusions

The conclusions reached from the study are presented below.

1. DNV evaluated the available failure reports and industry practices and has concluded that the vast majority of GOM offshore pipelines performed well during the passage of Hurricane Ivan and that public and personnel safety experience has been excellent.
2. The most significant Ivan impacts appear to have been the disruption of the oil and gas supply, and financial losses from the oil and gas infrastructure damage. While these are not desirable outcomes, the overall goal of prioritizing protection of life and the environment is clearly met as demonstrated by the performance of the industry.
3. The majority of pipeline damages occurred at or near platform interfaces, in areas of mudflows, or as a result of impact by an outside force other than the hurricane, such as platform failures or dragged anchors.
4. The ability to determine the actual root cause of the pipeline failures is limited by the incomplete data that we have about the pipeline's in-situ condition and the actual sequence of events that occurred during the hurricane with respect to failure or loadings imposed by movement of interconnected facilities at platforms and tie-ins.
5. Localized failures at pipeline crossings and excessive movements in shallow water depths suggest that more hurricane resistant design considerations might be needed, but they appear to be site specific, and do not warrant industry wide design code revisions.
6. The continued occurrences of excessive pipeline movement in shallow waters does indicate a need to evaluate the assumptions associated with burial, cover and stability analyses that may be performed for these pipelines.
7. Graphical tools and mapping are demonstrated to provide improved data management for quicker assessments of hurricane impacted areas. Simple, cost effective, yet powerful mapping tools have been developed as part of this study.
8. Significant numbers of the pipeline damages occurred outside of the path identified in the Hurricane Ivan NTLs. The criterion for such post-hurricane damage surveys are typically tied to wind speeds, and while this is appropriate for surface structures, it appears that better criteria for pipelines may be based upon reverse current areas that result from the hurricane passage, and water depths.
9. Planning for decision criteria to assess integrity, and developing alliances prior to events proved valuable in expediting the assessment and review and approval process for returning to service.

13.2 Recommendations

The recommendations listed below are also given in the body of the report where supporting details are provided.

RECOMMENDATION 1 Evaluate the possible benefits of integrating DOI, MMS into National Response Plan for ESF-12.

RECOMMENDATION 2 Evaluate whether a formal process should be defined to identify and prioritize critical energy infrastructure repairs, permitting and approvals.

RECOMMENDATION 3 Evaluate if any relaxation of MMS permit or regulatory requirements are warranted, and if so – through what mechanism, for expedited return to service of pipelines, without compromising safety or environmental protection.

RECOMMENDATION 4 Focus evaluation of study report technical analyses on crossing and burial design practices, particularly in pipelines in water depths less than 200 feet, and areas of low strength soils.

RECOMMENDATION 5 MMS GOMR should treat pipelines in mudflow areas as higher risk facilities and require mitigation measure to manage risk to an acceptable level. DNV suggests creating risk zone maps of mudflow areas for use with a risk-based approach to the design and oversight of pipelines in mudflow areas.

RECOMMENDATION 6 Utilize improved designs and installation methods to maintain pipeline crossing minimum separation in shallow water less then 200 feet of depth, and mudflow areas.

RECOMMENDATION 7 Develop templates or flowchart samples to be issued as guidance to leaseholders to communicate lessons learned for hurricane planning and preparedness, and recommend formalization of hurricane plans by pipeline operators. Recommend review of operating procedures by MMS for inclusion of hurricane plans and review of records of hurricane drills having been conducted.

RECOMMENDATION 8 MMS GOMR should continue to issue NTLs to survey pipeline facilities, but may wish to refine the criteria for the limits of the surveys, as soon as possible in the recovery process, or based upon the guidelines recommended by historical hurricane parameters and damage correlation presented in this report.

RECOMMENDATION 9 Automate and simplify the damage reporting process for pipeline operators to expedite the damage information received from the operators, as well as provide easy online access for report submittals, and a consistent format and definition for data collected.

RECOMMENDATION 10 DNV recommends a risk-based approach to the return to service testing requirements for GOM pipelines. Where an operator can adequately demonstrate that the risks have been mitigated to the MMS, waiver of hydrotests for **all** permit application types should be considered if the pipeline is impacting critical infrastructure supply.

RECOMMENDATION 11 DNV recommends the further study of the methods for modeling on-bottom stability. These studies should include collection of data and validation of the models for improvements in the reliability of the results predicted through current industry tools.

RECOMMENDATION 12 DNV recommends the further development and information sharing that has been accomplished on an informal basis with publicly available information. Utilize web based tools to provide additional GIS resources to the MMS for its use in pipeline information management, including the assessment of damages from hurricane passage in the GOM. Include automated online damage reporting process in this GIS system. This system will complement the existing MMS GIS system utilized by GOMR and provide data links to the various information sources within the MMS GOMR.