

Exponent[®]

Failure Analysis Associates

**Pipeline Integrity Analysis of
the Camisea Transportation
System**

May 2007



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Prepared for

Inter-American Development Bank
1300 New York Avenue N.W.
Washington, DC 20577

Prepared by

Exponent
320 Goddard, Suite 200
Irvine, CA 92618

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Limitations

At the request of the Inter-American Development Bank, Exponent has prepared this report on the integrity of the pipeline components in the Camisea Transportation System, which experienced five spill incidents between December 2004 and March of 2006. This report also provides a site-specific technical evaluation of the geotechnical and mechanical aspects of each incident, using the currently available information to identify the most probable contributing factors. The scope of services performed during this investigation may not adequately address the needs of other interested parties, and any reuse of this report or the findings or conclusions presented herein is at the sole risk of the user.

Our investigation included visual inspection of the pipeline right-of-way and adjacent areas, document review, interviews of key personnel involved in the design and construction, limited visual inspection of some failed pipe sections, and engineering analysis. Accordingly, Exponent has no direct knowledge of, and offers no warranty regarding subsurface conditions, ground stability, or the condition of concealed construction, beyond what was specifically revealed during the site visits and our document review. Comments regarding concealed construction or subsurface conditions are our professional opinion, based on engineering and geological experience and judgment, and are derived in accordance with current standards of professional practice. Changes in the conditions of the right-of-way may occur with time due to natural processes or events like rains and landslides or human activities. In addition, Exponent has used and relied upon certain information provided by sources that it believes to be reliable for the purpose of this report. Accordingly, the findings of this report may be invalidated, wholly or in part, by changes that are beyond our control.

Executive Summary

Background and Scope of Work

Exponent[®] Failure Analysis Associates (Exponent) was retained by the Inter-American Development Bank (IDB) to perform a pipeline integrity analysis of the Camisea Transportation System (the system). Exponent's retention followed the occurrence of five spill incidents, during the first 19 months of operation, each of which resulted in the release of hydrocarbons. The intent of our investigation was to develop a risk profile for the two component pipelines and identify the factors that contributed to the incidents. During our investigation of causal factors in the five incidents and assessing pipeline integrity, Exponent made recommendations to Transportadora de Gas del Peru S.A. (TgP) in order to improve future pipeline integrity by mitigating and controlling identified risks to the system. TgP has implemented many of these interim recommendations and has undertaken other additional activities based on its experience and knowledge. This report summarizes these efforts and provides a risk-based evaluation of the system that incorporates extensive sources of information and field investigations by Exponent commencing in April 2006.

The Camisea Transportation System is owned and operated by TgP. TgP contracted with Compañía Operadora de Gas del Amazonas (COGA) for the operation and maintenance of the pipeline. The system consists of two buried pipelines: 1) a natural gas (NG) pipeline, which runs from the upstream facilities at Malvinas to a terminal station at Lurin, at the southern edge of Lima; and 2) a natural gas liquid (NGL) pipeline, which transports the liquid condensates from Malvinas to a fractionation plant near Pisco, on the coast of Peru south of Lima. The two pipelines share a common right-of-way (ROW) that traverses the Peruvian jungle, climbs over the Andes Mountains at an elevation of approximately 4,800 m, and descends steeply toward the coast along the Pacific Ocean. The alignment of the ROW is shown on Figure 1. The NGL pipeline is approximately 561 km long, and the NG pipeline is approximately 734 km long.¹ Along this route, the NGL pipeline telescopes from a nominal pipe diameter of 14 to 10¾

¹ True length of pipeline.

inches, and the larger NG pipeline telescopes from a nominal pipe diameter of 32 to 24 to 18 inches. Construction of the pipelines started in 2002, and commercial operation began in August 2004.

All of the spill incidents occurred in the first 222 km of the NGL pipeline—four of the spills occurred in the selva sector, one in the transition zone between the selva and the sierra sectors, and one in the sierra sector. In contrast, no leaks have occurred on the larger diameter NG pipeline or on either pipeline in the costa sector. The locations and dates of the first five spill incidents are shown on Figure 1. Specifics of the first five individual spill incidents are presented later in this summary. Recently, TgP identified² a sixth incident on April 2, 2007, where a small amount of NGL was reported to have been released. TgP subsequently repaired the NGL pipeline and is currently investigating the root cause of this incident. The location of this spill incident is also shown on Figure 1.

Exponent's pipeline integrity analysis was conducted in two integrated phases. The objective of the first phase was to provide a forward looking, overall assessment of the integrity of the pipelines, primarily the NGL. The following components were included in our evaluation of risk in the first phase: pipe material, pipeline design, pipeline construction, geologic and geotechnical hazard mitigation, pipeline maintenance, and ongoing operation. Exponent prioritized the identified hazards and evaluated the efficacy of currently used mitigation and control measures. The first phase included an evaluation of the suitability of the seismic design, mechanical design, and design of river crossings (scour analysis). As part of that study, we established a baseline risk level for the system and performed a technical review of the five spill incidents that occurred in the system between December 2004 and March 2006.

² Exponent was informed that TgP detected this minor leak during planned activities of its pipeline integrity program.

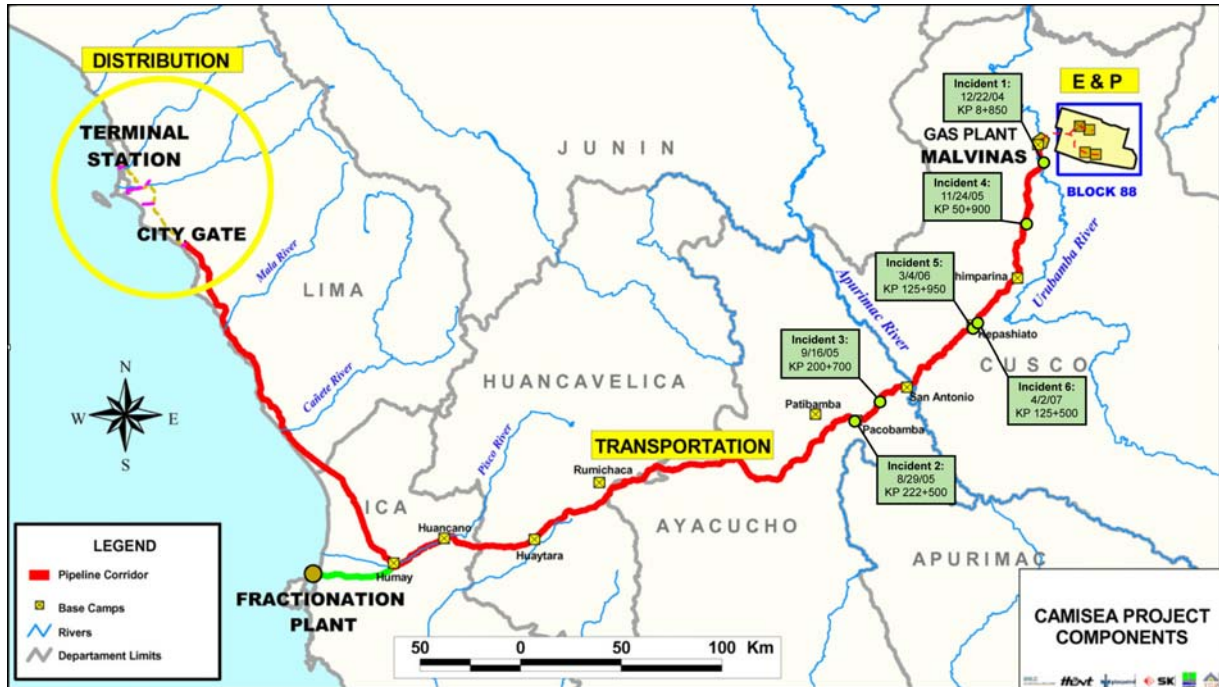


Figure 1: Right-of-way of the Camisea Transportation System in Peru, with extraction and production (E&P) center in Malvinas, NGL fractionation plant in Pesco, and NG distribution in Lurin.

The objectives of the second phase were to further evaluate key risks and to evaluate the progress made by TgP and COGA in reducing risks to the pipeline. The risk was evaluated following the implementation of various mitigation measures constructed in 2006, which was compared to the baseline risk established during the first phase of our investigation. Specifically, the second phase included: 1) developing and assisting in the implementation of a hybrid risk-based system to evaluate potential geotechnical and geologic hazards to the pipeline system, 2) evaluating the effectiveness of the geotechnical stabilization measures constructed in 2006 to mitigate external soil pressures acting on the pipelines, and 3) evaluating the efficacy of the current pipe integrity program.

In order to accomplish the pipeline integrity analysis, Exponent reviewed more than 400 sets of documents related to the design, construction, operation, and maintenance of the Camisea Transportation System. These documents included engineering specifications, construction specifications, pipe material data, pipeline design drawings and calculations, geotechnical and geological studies, seismic studies, hydrological studies, river-crossing studies, construction progress surveys, various internal and external pipeline inspection reports, and operational data.

In some cases, Exponent performed its own engineering analysis to quantify certain risks to the integrity of the pipeline.

In addition to the document review and engineering analysis activities, a multi-disciplinary team of Exponent engineers and scientists performed inspections along the pipeline ROW in June and September 2006. These inspections occurred at more than 50 sites along the ROW where geotechnical stabilization measures were proposed, under construction, or had been completed. Exponent personnel also interviewed key personnel involved with design, construction, operations, and maintenance of the system. These interviews were supplemented with numerous teleconference calls that included the designers, operators, service providers, and independent consultants hired during the construction and maintenance of the pipeline by TgP. Finally, Exponent participated in the metallurgical investigation of samples of pipe that were involved in two of the incidents, and reviewed the metallurgical examination reports and evidence from the five spill incidents that we investigated.

Spill Incidents

Exponent reviewed information related to the first five NGL pipeline spill incidents as a means of evaluating risk, and to consider the potential for systemic problems. Exponent was not retained to perform a root-cause analysis of any of the spill incidents.³

Our evaluation identified similarities in fracture surfaces in the NGL pipe from the first and fifth incidents, which occurred at KP 8+850 and KP 125+950, respectively. In both cases, Exponent identified unstable geotechnical conditions as a significant contributor to the rupture of the pipe. At both of these locations, progressive soil loading likely propagated an initial crack and induced the rupture of the NGL pipeline. In the incident at KP 8+850, the crack resulted in a through-wall leak of about 10 inches in extent. In the incident at KP 125+950, the crack resulted in complete severance of the NGL pipe. The NG pipeline was not damaged at either location.

³ A root cause analysis is the integrated evaluation of all facts pertaining to the investigated failure to uniquely identify the cause or causes of failure.

The second incident, located at KP 222+500, appears to have been primarily the result of a time-delayed, hydrogen-induced crack in the weld. The hydrogen crack escaped detection by the post-welding radiography because of the inherent incubation time associated with hydrogen-induced crack initiation. It is currently Exponent's opinion that the high toughness of the pipe material allowed the pipe to pass subsequent hydrostatic testing (performed five months after the welding), even though the crack had extended to approximately 90% of the wall thickness⁴ by the time the hydrostatic test was performed. Our current understanding is that the combination of hydrostatic load cycles and subsequent operational pressure fluctuations caused the hydrogen crack to be further destabilized, ultimately rupturing the pipe and releasing the NGL at a very slow rate.

The third incident occurred in an area that was well studied from a geologic perspective and was known to be an area of very high risk of ground failure. While some measures were taken during construction to mitigate this geologic risk, a sizable landslide ultimately overwhelmed these measures, both undermining and overtopping the ROW and the road next to the ROW. Hence, the rupture of the NGL pipe at this location is attributed to overload caused by a substantial landslide. The NG pipe at this location was not damaged.

For the fourth incident, located at KP 50+900, current information suggests that the rupture of the NGL pipe was induced by mechanical damage to the exterior concrete coating and a dent in the exterior wall of the NGL pipeline. Analysis performed to date indicates that the dent was not made by a boulder washed downstream during the flash flooding that immediately preceded the spill. Indeed, the pipe wall at this location was apparently capable of containing the NGL fluid until some unknown external loading event caused the already weakened pipe wall to fail in ductile overload at the damaged area. This triggering loading event could have been associated with riverbed scouring caused by the flash flooding. Again, the NG pipe at this location was not damaged.

⁴ This is a rather deep crack, and subsequent crack growth due to normal operational pressure fluctuations need be only minimal to reach a critical crack depth that causes the remaining ligament ahead of the crack to fail.

Finally, it is important to note that, for all five incidents, the metallurgical testing confirmed that none of them were related to pipe material quality.

Risk Identification

The pipeline integrity analysis evaluated the risk categories that influence the likelihood and severity of potential pipeline failures. For purposes of this report, we define risk as the likelihood that a given chain of events will occur and result in a consequence that has a defined severity. The aggregate of the likelihood of failure and the severity of failure is risk. In this report, risk was ranked to be minimal if the risk is currently not a concern and effectively consistent with other pipelines.

The objective of risk management as part of a pipeline integrity management program is to identify, eliminate if appropriate, and then prioritize the remaining sources of risk so they can be mitigated, controlled, and/or monitored. In this context, during our study, we identified four primary categories of risk affecting the integrity of the pipeline: geotechnical and geological,⁵ mechanical pipe integrity, seismic events, and river scouring. Each of these areas of integrity risk is discussed separately below. In summary, we found that the risk associated with geotechnical and geological conditions is currently more significant than risks associated with pipe integrity, seismic events, and scour, although pipe integrity related risks typically increase with the age of the pipeline. The higher risk level associated with geotechnical hazards is a direct consequence of the steep topography, poor foundation (ground) conditions, and abundance of water along the pipeline ROW in the selva sector. Exponent's review identified that TgP implemented various actions in 2006 to substantially reduce the risk of future incidents to the pipeline. Furthermore, our communication with TgP to date indicates that they are committed to continue identifying and reducing the geotechnical risks to the pipeline.

⁵ For purposes of this report, geotechnical and geological hazards are defined as external pressures resulting from ground movement. Geotechnical hazards are defined as movement in soil, typically when saturated, whereas geological hazards are defined as movement in rock.

Risk Evaluation

The four primary categories of risk identified above are discussed in more detail in the paragraphs that follow. However, we also recognize that the above identified four risk categories depend to varying degrees on decisions made during the design and construction of the pipeline. Due to their importance, we first provide a brief summary of our investigation into potential systemic risks resulting from the design and construction of the system.

Design-Related Risks

The system was designed to comply with the engineering code requirements of the American Society of Mechanical Engineers (ASME).⁶ Code compliance is established if the designer demonstrates that all specific code requirements and all reasonably foreseeable load conditions are addressed by the design. Foreseeable load conditions apply to internal pressures and to external loads imposed by soil pressures or ground movement.

Our review indicates that the pipe wall thickness is sufficient to contain the internal pressures of the transported hydrocarbon products along the entire length of the pipeline (i.e., hydraulic risk). We have independently verified that the computed design pressures are code compliant and in good agreement with the measured operational pressures along the whole length of both pipelines. Therefore, any risks associated with the internal pressure aspects of the design are minimal and consistent with other pipelines.

Given the demanding route of these pipelines through the jungle and up the mountains, external loads were an important element for the design and construction of the system. Our design review revealed that the pipeline designers assumed that external soil loading would be entirely mitigated by geotechnical mitigation measures implemented during construction at sites deemed to pose a geotechnical or geological hazard.

⁶ ASME B31.4 [*Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids*] is the applicable Code for the NGL pipeline and ASME B31.8 [*Gas Transmission and Distribution Piping Systems*] is the applicable code for the larger NG pipeline.

Construction-Related Risks

The system was constructed simultaneously at several so called “mini-spreads” along the ROW, using more than 100,000 individual pipes, each of which is up to 12 meters long. A review of the pipe book⁷ and the pipe manufacturing and coating records indicates that the pipe material used was purpose built for the system at two pipe mills during 2002 and 2003. The pipe manufacturer’s records indicate that these mills are located in Pindamonhangaba, SP, Brazil, and Buenos Aires, Argentina. These electric-resistance-welded tubular pipes are manufactured per the American Petroleum Institute’s API 5L standard, such that steel plates are rolled and longitudinally welded at the mill. Subsequently, all pipes were coated with an outer high-density polyethylene (HDPE) layer to protect them from external corrosion.

The pipes were transported to the individual construction sites, where the ROW itself was commonly the only available route for transportation. This ROW had to be contained in a 3 km wide, government mandated corridor, and deviations from this pre-approved corridor had to be granted by the Peruvian government. Within the 3 km wide corridor, the cleared section of the ROW was typically restricted to 25 meters.

To minimize environmental impact, the constructor decided to preferentially build the pipeline along mountain ridges. The ROW was cleared and cut, and the work was inspected by outside consultants. Exponent’s review indicates that this approach was appropriate and preferred, in that placing the ROW near the base of the mountains, and along rivers and drainages would have likely resulted in substantially more construction-related damage to the environment.

Due to limitations imposed by the narrow lane of clearing, grading along the ROW consisted of cutting into the hillside and placing the excavated material as “side-cast” or “spill” fill on the downhill side of the clearing. Although these side-cast fills were generally placed outside the limits of the pipe trenches, they ultimately became a source of concern related to the potential to exert external soil pressures on the pipes. The ground conditions encountered during installation of the pipe were reportedly assessed by geotechnical engineers and some mitigation measures were constructed at that time. Geotechnical engineers also supervised the

⁷ The pipe book lists relevant pipe data.

geotechnical mitigation measures to control surface water runoff and stabilize the ROW following installation of the pipelines.

Next, the pipe was strung out, and girth welds were used to join individual pipes. A completed pipe section that may be several hundred meters long was then lowered into the trench and welded together to form an even longer pipe section. This standard construction methodology was replaced by special construction methods in very steep terrain, at river crossings, and at locations where the pipeline was laid along an existing road. Overall, the construction methods are consistent with general pipeline construction practice, where potential risks to pipeline integrity arise primarily from the girth welds, trench conditions, and potential damage to the pipe exterior.

The more than 100,000 girth welds of both pipelines were to be welded per approved procedures and to be x-rayed 24 hours later.⁸ This process was generally effective at minimizing and detecting weld defects that needed to be repaired, where weld quality was to be evaluated per the American Petroleum Institute's API 1104 standard. To further reduce the likelihood of failure, long individual sections of the pipeline were hydrostatically tested. Hydrostatic testing involves filling each pipe section with water and pressurizing the water to a predefined level that exceeds the maximum allowable operating pressure. Next, the water-tightness of the pipeline was verified by maintaining a constant water pressure for at least 24 hours. This hydrostatic test was performed for both pipelines along the entire length of the system.

During the hydrostatic testing, eight leaks were identified, of which seven occurred in the NGL pipeline and one in the NG pipeline. The causes of the leaks were determined to be a faulty girth weld in three cases, a faulty longitudinal weld in two other cases, external damage during construction in two cases, and a foreign object being introduced during rolling of the steel plate used to manufacture a pipe in one case. All these failures were subsequently repaired and the pipeline section was successfully re-tested. Eight failures in more than 1,250 km of pipeline is a low number, especially considering the challenging terrain. The test results are more an

indication of the test's ability to detect preexisting faults. Despite the above described actions, some minimal risk exists because defects may be aligned or sized such that the hydrostatic test would not rupture the pipe and the defect could go undetected, which may be similar to other pipelines in the world. This situation arose with the second spill incident, in which a hydrogen induced crack survived the hydrostatic test initiating the subsequent spill incident. This incident is currently not considered to be indicative of any systemic problems for the more than 100,000 girth welds. Overall, the radiography of all girth welds and hydrostatic testing of the Camisea Transportation System provides a level of risk mitigation consistent with general pipeline engineering practice.

Geotechnical and Geology-Related Risks

The spill incidents and observed performance of the system as of early 2006 caused TgP to set into motion an aggressive geotechnical remediation program that began in earnest in April 2006. Geotechnical instability caused or substantially contributed to two of the five spill incidents (#1 and #5), and geologic instability caused one of the five spill incidents (#3). In this program, more than 100 sites along the ROW were evaluated and mitigated in 2006 by implementing geotechnical mitigation measures using more robust construction techniques. At the end of 2006, following extraordinary efforts to stabilize geotechnical and geologic conditions along the ROW, TgP believed that geotechnical hazards due to soil movement were more effectively documented, addressed, and controlled in this ongoing process.

Exponent observed over 50 sites, some on both occasions, during our field inspections in June and September 2006. Based on our review, observations, and engineering experience, we concluded that geotechnical and geologic conditions initially posed a substantial risk to the pipeline. Construction of geotechnical mitigation measures in 2006 significantly reduced this risk by improving the geotechnical and geological stability at specific sites of greatest hazard. While the route of the system traverses a challenging and dynamic area, our initial inspection in June 2006 indicated that some of the original stabilization measures implemented during

⁸ Exponent's scope of work did not include reviewing these x-rays; it is our understanding the government of Peru commissioned pipeline audit is performing this task.

construction were not completely effective. As early as April 2006, TgP and COGA had begun to implement a system of identifying those sites with the highest priority for mitigation based on the perceived likelihood of failure and the potential consequence of failure. TgP and COGA had also contracted additional external geotechnical and geological specialists to help assess the hazards and evaluate the likelihood of failure.

Based on our second round of inspections in September 2006 and subsequent documentation review, Exponent concluded that geotechnical stabilization measures constructed during 2006 are generally reliable and robust. Further, we determined that these measures were being applied in a consistent and effective manner. As a result of these efforts, the risk of future failure of the system from external geotechnical forces has been substantially reduced. In more critical areas, instrumentation (e.g., strain gauge, piezometer, slope inclinometer, survey control, and rainfall monitoring) is being used or is recommended to provide additional interpretation and warning of ground instability, and data on movement characteristics, to permit more expeditious, reliable repairs.

During the second phase of our project, Exponent worked collaboratively with TgP to develop a hybrid risk matrix to adequately assess the likelihood of future failure resulting from geotechnical and geologic conditions. This system was validated using information from our field inspections. To date, the sites identified are listed in the hybrid risk matrix, representing locations that have exhibited manifestations of ground instability, and the vast majority of these stations are located in the selva sector. The risk at each station was then evaluated at three different points in time, reflecting the risk prior to and after construction of the new geotechnical mitigation measures, and after implementation of the additional monitoring programs discussed below.

Exponent also reviewed a monitoring program initiated by TgP and COGA to help reduce the risk of future failure resulting from external geotechnical forces by detecting and quantifying early signs of slope instability. This program allows for the early detection and correction of potential problem areas. The core of this program involves regular visual inspections, including during the rainy season, between KP 0 and KP 220. The multi-disciplinary team of inspectors is trained by COGA's technical consultants and is intimately familiar with the project and

conditions along the alignment. This program appears to be comprehensive and is integral to reducing the risk of future failure resulting from geotechnical conditions.

The results of the geotechnical risk assessment are consistent with our field observations that TgP and COGA have made substantial progress in reducing the overall risk. Thus, while we initially ranked 45 of 94 sites as having “high” to “very high” risk (along the initial 455 Km of the ROW), the construction of the geotechnical mitigation measures in 2006 reduced this number to 12 sites. The addition of monitoring provided a further reduction to 5 sites having a “high” to “very high risk,” with solely the site at KP 108, adjacent to the second pump station, being now ranked as “very high.” TgP has stated that construction of new geotechnical stabilization measures is ongoing or completed at these sites. It is our understanding that TgP is updating the hybrid risk matrix and is committed to implementing additional geotechnical measures in 2007.

We expect that the continuous, ongoing implementation of the risk matrix process will identify additional sites that are not included in the current hybrid risk matrix due to the absence of surface manifestations of ground movement. Some of these sites may even be ranked with a high to very high risk and will need to be mitigated quickly. Therefore, we recommended that TgP adopt a proactive approach of continually assessing geotechnical hazards along the ROW. In this regard, TgP has committed to implementing the recommended Risk Management Plan (RMP) that should govern the use of all risk assessment methods and guide TgP’s actions, decision process, and manner of execution. At this time, Exponent believes that a successful implementation of the above, and the construction of additional geotechnical mitigation measures in 2007, will identify further sites and reduce the geotechnical related risks further.

Pipe Integrity–Related Risks

Pipe integrity related hazards are associated with pipe material, weld quality, and the quality of protection the pipe is afforded against environmental conditions. As discussed above, the most significant risks to the system arise from external loading caused by soil movement. Soil movement imposes lateral loading upon the pipe, which can induce axial pipe stresses in addition to those induced by the internal pressure of the transported hydrocarbons. These axial

stresses are known to affect the girth welds in the pipe. Exponent's analysis of this loading condition has shown that the as designed NG pipeline has a significantly larger external load capacity and flaw tolerance than the NGL pipeline, such that the NG pipeline generally has a low risk of failure from external loads. Load capacity estimates for the NGL pipeline show that, while sufficient for internal pressures, it is susceptible to this external failure mode, which is consistent with four of the first five spill incidents.

Several approaches have been adopted by TgP to reduce this risk. First, during construction all the welds were x-rayed, and the entire pipeline was hydrostatically tested, reducing the potential number of potential weld related and pipeline material defects. Second, any growth of such defects that would lead to the rupture of the pipe requires the presence of external loading. Removal of the loading is a good way to further mitigate the risk, and TgP's ongoing and prior geotechnical construction program reduces the likelihood of soil movement. Thus, the residual risk is now mostly confined to areas that may become geologically unstable and that may contain potential weld anomalies.

To mitigate the residual risk, TgP performed an inline inspection of the NGL pipeline in 2006 using the Magnetic Flux Leakage (MFL) inspection tool and a geometric inline inspection tool, where the MFL inspection tool has the capability to detect metal loss and other potential anomalies and the geometric tool measures the pipe's geometry along its length. TgP has reported that the inspection of the NGL pipeline identified 30 reportable defects per requirements by API 1160 and DOT⁹ 195. TgP is currently excavating these sites to perform a more detailed evaluation and initiate the appropriate repair measures if so required. In this regard, TgP has voluntarily identified additional sites to further quantify the accuracy of the inline inspection tools. Results of the MFL inspection tool and evaluation of metal loss per ASME 31G has shown that currently no severe external and internal corrosion damage exists along the NGL pipeline. However, it is Exponent's opinion that some sections of the NGL pipeline more than others may be subject to a potential long term corrosion risk that will need to be addressed in the long term planning stages of TgP's pipeline integrity program.

⁹ Department of Transportation of the United States of America

In an effort to quantify the MFL tool's ability to detect crack-like features, TgP and its contractors conducted a research program to quantify the crack detection limit of the MFL tool. In addition, Exponent performed a pipeline integrity study to determine the MFL inspection tool's utility in detecting circumferential cracks.¹⁰ Our analysis indicates that a potential circumferential crack would need to be subjected to a significant external load to be detectable at high certainty by the currently employed MFL inspection tool.

The MFL inspection tool has proven to be an excellent tool to detect internal and external corrosion damage to the pipe in this project. Overall in 2006, TgP significantly reduced pipe integrity related risks and is currently engaged in additional efforts to reduce the risk profile under technically and logistically difficult conditions. Specific resources have been committed in 2007 to further improve TgP's ability to detect potential circumferential cracks. A root cause analysis of spill incidents 1 and 5 and the origin and nucleation of the potential circumferential cracks will be performed by TgP, which will assist in assessing the implications of this concern related to pipeline integrity.

Presently no pipeline inspection company is readily able to provide a commercially available inspection tool to detect potential circumferential cracks, even though the technology to do so appears to be available. Despite the fact that the use of in-line inspection tools to detect small circumferential cracks is currently not a common practice among pipeline operators due to the relatively low risk to pipeline integrity posed by circumferential cracks under normal operating loads, TgP will evaluate potential options.

Seismic-Related Risks

The system lies within regions having the potential for very large and frequent earthquakes. The earthquake hazard appears to be the greatest in the costa sector and least near the selva sector. Recognizing the potential seismic hazard, the pipeline fabricator commissioned several seismic hazard studies during the design process. The first study characterized the

¹⁰ The service provider of the currently used MFL inspection tool has determined that only circumferential cracks

regional seismic hazard for each of the three sectors (selva, sierra, and costa) and provided more specific evaluations of ground motions for the pump stations, pressure control stations, and pressure reducing stations. Another investigation identified active fault crossings along the pipeline and evaluated the pipeline capacity for predicted fault displacements. Additional studies consisted of evaluating the potential for wave propagation damage for straight sections of buried pipe and 12 surface facilities.

Although several seismic hazard studies were performed as part of the design of the system, our review suggests that the potential for permanent ground displacements (e.g., landslides, slope instability, liquefaction, and lateral spread) should be evaluated more comprehensively to reduce uncertainty. Additionally, seismic risk management would benefit from an update of the design ground motions with up to date scientific information. Exponent currently understands that TgP is engaged in a review, as part of the pipeline integrity management plan of seismic risks, to determine whether these potential seismic risks are acceptable for this system or whether mitigation measures should be considered.

Scour-Related Risks

Scour is defined as the erosion of streambed or bank material due to flowing water. In addition, naturally occurring lateral migration of the mainstream channel within its floodplain may affect the stability of the buried pipeline crossings. Flood-induced scour can occur over short periods of time, with little warning and serious consequences. Therefore, pipeline crossings should be designed and constructed to withstand floods of relatively extreme magnitude.

Exponent's review of the scour analyses performed during the design of the project indicates that some assessments were performed to determine the minimal depth to bury the pipeline. These design studies included field investigations of stream crossings. In addition to the mentioned studies, Exponent recommends evaluation of additional potential scour processes, as described in the Federal Highway Administration's Hydraulic Engineering Circular 18 (HEC-

with a crack mouth opening of more than 0.1mm can be detected with a probability of better than 90 percent. For cracks with a smaller crack opening, the probability of detection decreases rapidly.

18), which is considered the industry standard to evaluate stream scour. However, HEC-18 is not a design standard required under Peruvian law. Despite not being required, the HEC-18 scour design approach was partially utilized along with other procedures that were deemed to be appropriate by the designer. Given the potential uncertainty and the objective to minimize this risk, additional scour studies and investigation of potential scour mitigation measures are warranted and currently being evaluated by TgP.

Future Activities

Exponent performed a pipeline integrity analysis of the pipeline components of the Camisea Transportation System. The analysis identified four primary categories of risk to the integrity of the pipeline: geotechnical, considered to be the most significant, and mechanical pipe integrity, seismic events, and river scouring as secondary risks. The higher risk level associated with geotechnical hazards is a direct consequence of the steep topography, poor foundation (soil) conditions, and the abundance of water along the pipeline ROW in the selva sector. TgP has implemented various actions to help reduce these risks, including various interim recommendations made by Exponent during our investigation. However, in the opinion of Exponent, additional actions are still recommended in order to continue the minimization of any existing pipeline integrity risks.

In this context, a technical action plan has been established with TgP and the IDB. This plan includes: 1) implementation of geotechnical mitigation and monitoring actions in 2007; continued geotechnical risk assessment; 2) re-evaluation of potential scour risk at river crossings and, based upon the results, implement actions to reduce such risks; 3) re-consideration of seismic risk, in particular wave propagation, permanent ground deformations, excluding fault rupture, resulting from strong ground shaking; 4) experimental evaluation of potential circumferential cracks and their impact upon pipe integrity; 5) spill root cause analysis of the spill incidents 1, 4 and 5.

Exponent has been retained to provide continued technical assistance to the IDB related to the Camisea Transportation System, which includes review of these actions and additional site visits

in 2007. Based upon available information obtained during Exponent's investigation and the proposed actions, it presently appears to Exponent that TgP is performing adequate pipeline integrity actions, and that these actions have significantly reduced the risk to the system.

However, Exponent also notes that pipeline integrity management is a continuous process and thus future information and risks need to be continually and properly evaluated. If and when ongoing pipeline integrity management efforts identify additional issues, risk management actions above and beyond those currently being taken may be required.