GEOTECHNICAL PIPELINE RISK MANAGEMENT IN THE CHALLENGING ANDEAN AREA

A CASE STUDY OF THE KM 235 IN OCENSA PIPELINE, COLOMBIA

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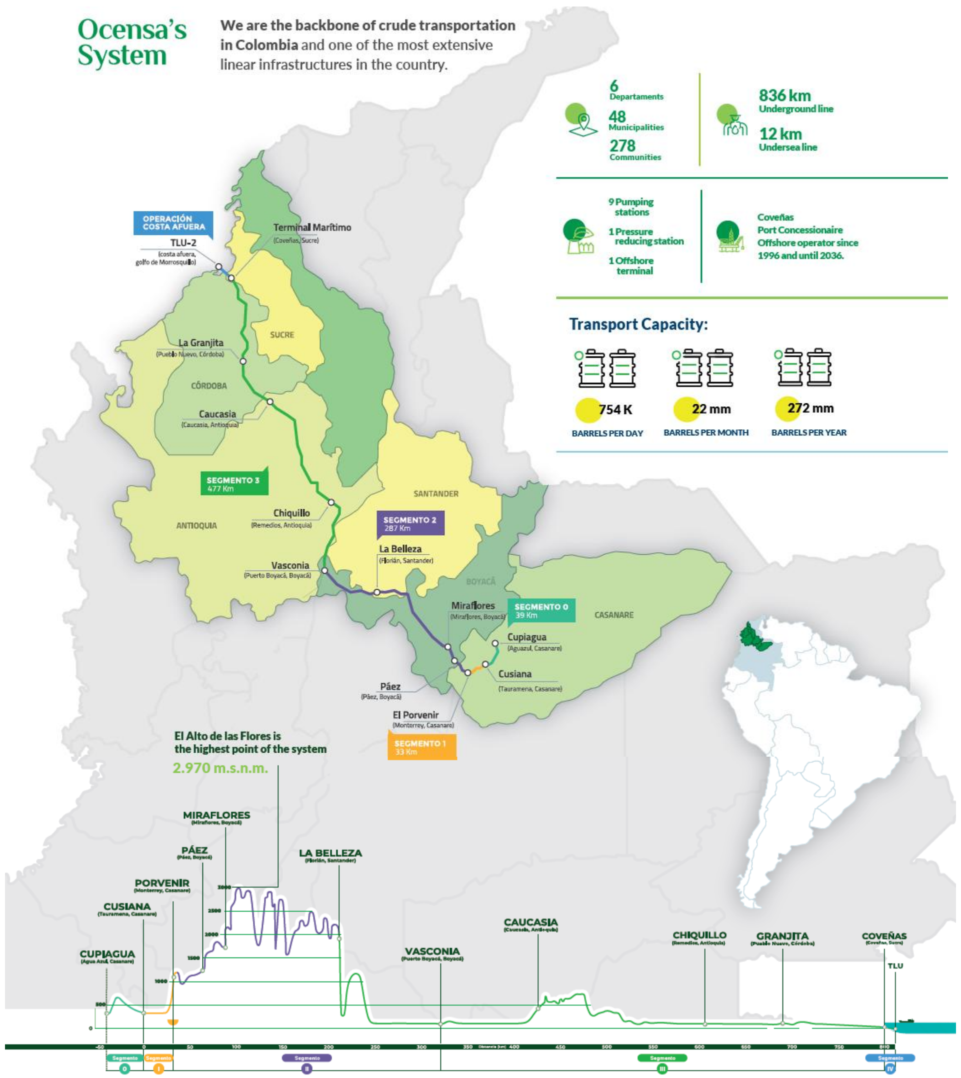
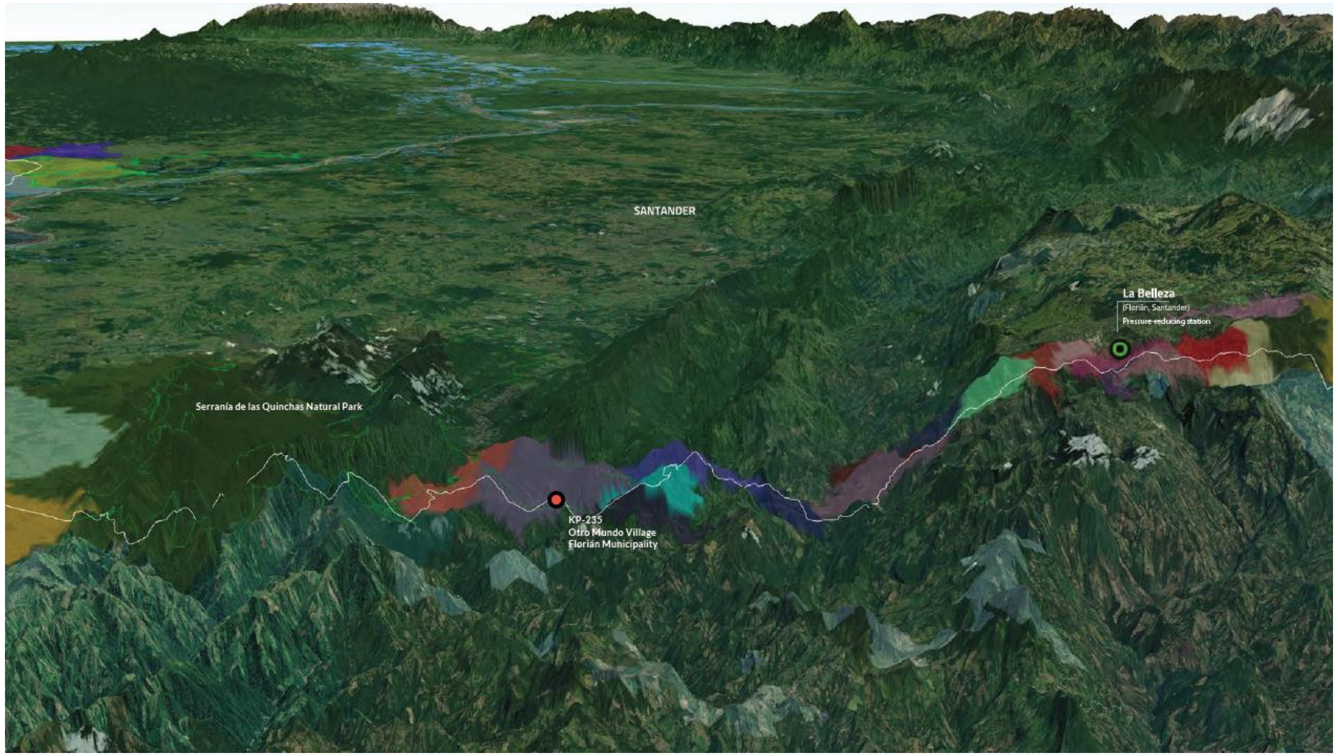
Km 235 is located in the descent of the cordillera oriental with an altitude difference of ~1300 m from the nearest upstream valve





Colombia has legislation to manage risk in high populated areas

Disaster Risk Management Plan (D.2157 de 2017)

Identify Scenarios with potential to cause a Disaster

Execute a Plan describing 3 processes

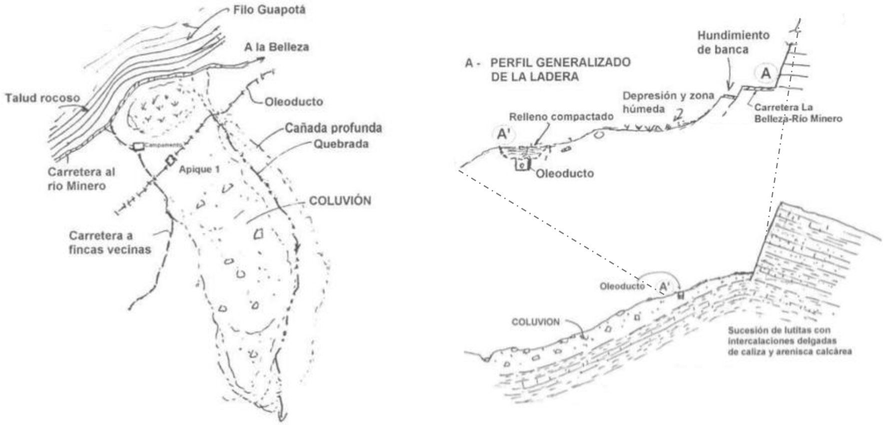
Share the plan annually

Risk Knowledge

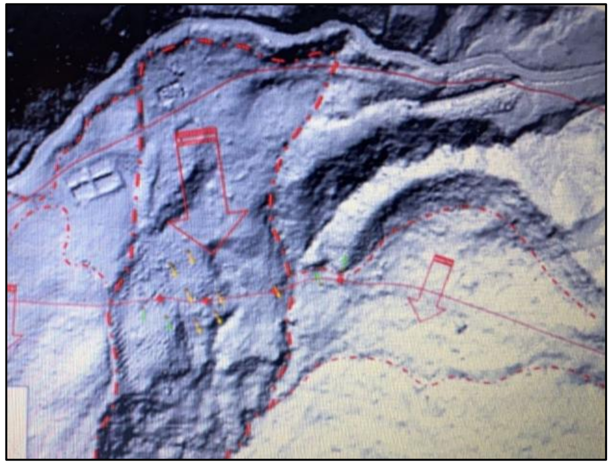
Risk Reduction

Contingency Management

The pipeline runs through a geologically and geomorphologically intricate terrain. The slope experiences a creeping movement that exerts loads on the pipeline.



Left. Plan view of the instability process affecting the oil pipeline. Rigth. Profile view of the instability process affecting the oil pipeline.



Plan view of the instability process in a lidar survey.

The pipeline needed 3 stress relief activities and 1 replacement in the last 18 years due to the external load exerted by the soil

1st Caliper + IMU ILI

2nd Caliper + IMU ILI

3rd Caliper + IMU ILI

Feb 2005 | **Oct 2005** | **Oct 2010** | **May 2011** | **Oct 2023** | **Apr 2014** | **May 2014** | **Jul – Oct 2015**

1st Stress Relief (length : 135 m)

2nd Stress Relief (length : 65 m)

3rd Stress Relief (length : 172 m)

Replacement and Reroute (length:170 m)

A **stress relief activity** was proposed for **2023** based on projections of **risk changes** anticipated **by the end of 2022**.

5th Caliper
+ IMU ILI

6th Caliper
+ IMU ILI

To be continued…

Mar-2019

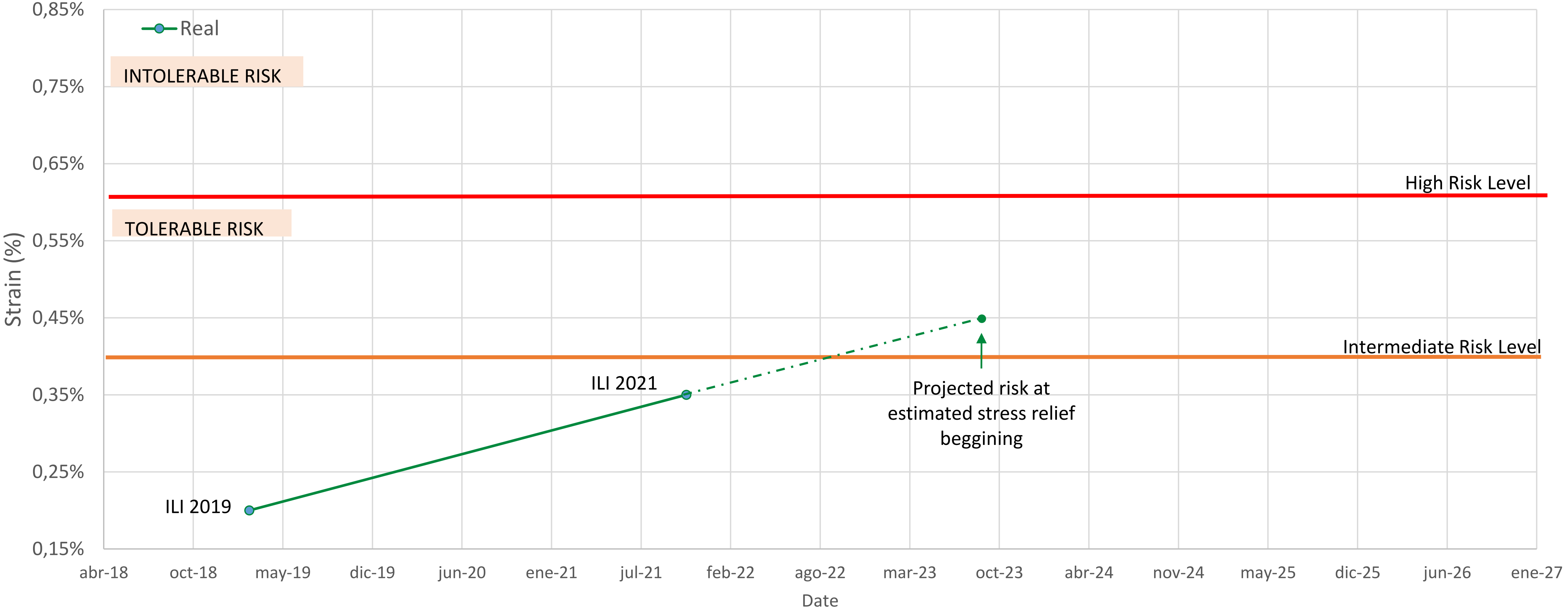
Nov-2021

Jul-2022

Stress Relief Required at Km 235
Integrity Management Plan 2023

A stress relief activity was proposed for 2023 based on projections of risk changes anticipated by the end of 2022.

Risk behaviour between 2019 and 2024 and projections to 2025



Increased rainfall linked to the ENSO weather phenomenon triggered risk monitoring efforts

Mar-2019 – 5th Caliper + IMU ILI

Nov-2021 – 6th Caliper + IMU ILI

Jul-2022 – **Stress Relief Required at Km 235**
Integrity Management Plan 2023

Feb-2023 – 7th Caliper + IMU ILI

Jun to Oct 2023 – Social Management for the Start of Relief at Km 235

Nov 7, 2023 – **Parallel pipeline failure (another operator)**

OCENSA Actions:

1. Aerial Inspection
2. Preventive Pipeline Shutdown
3. On-site Geotechnical Inspection
4. Activation of Contingency Group
5. Participation in CMGRD
6. Evaluation and Resumption of Operation

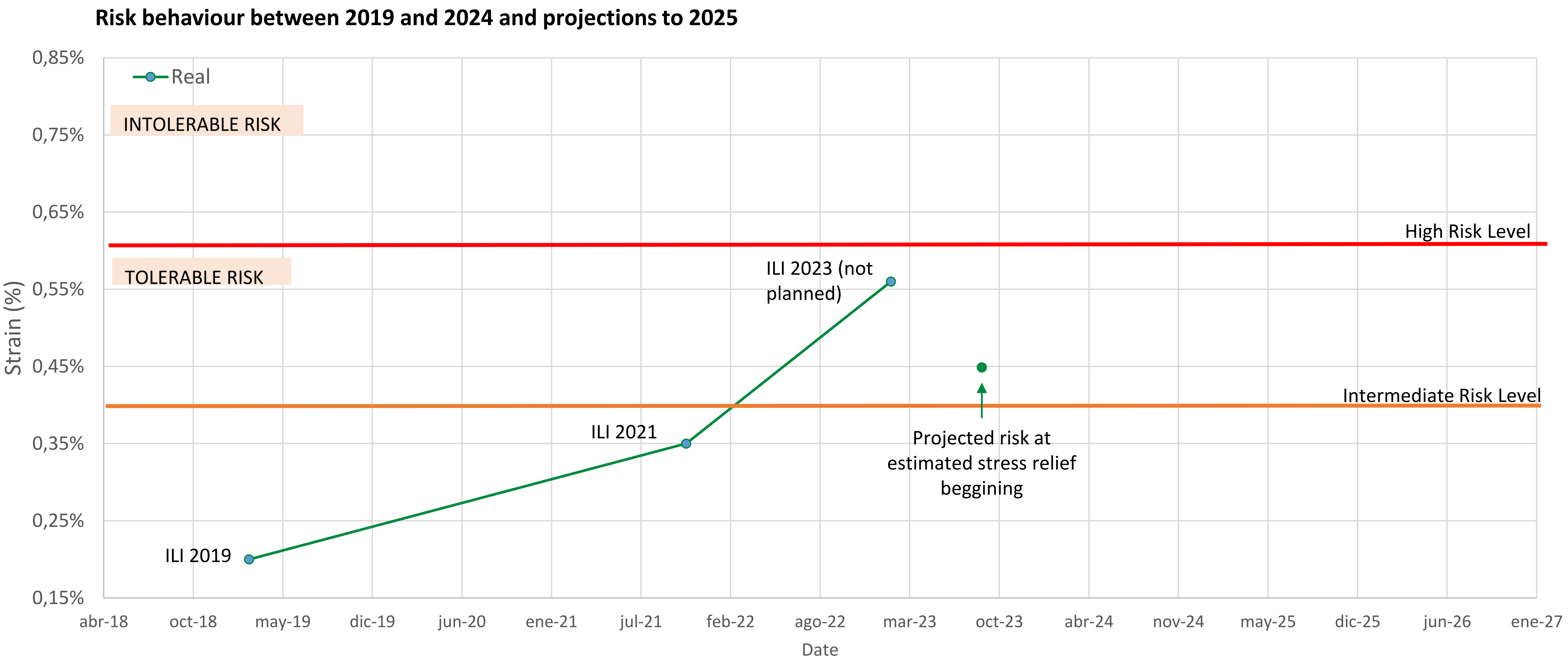
Nov 8, 2023 – **Declaration of Emergency by OCENSA**

Nov 12 2023

1. Mobilization of equipment/tools to the site.
2. Report of blockade in the communities of Florian and La Belleza.

CMGRD: Municipal Committee of Disaster Risk Management

By the end of the third quarter of 2023, strain exceeded projections by 36%, making stress relief a key priority.



Given social limitations at the location, it became essential to increase the frequency of monitoring pipeline bending strain.

5th Caliper + IMU ILI

6th Caliper + IMU ILI

7th Caliper + IMU ILI

Parallel pipeline failure (another operator)

OCENSA Actions:

1. Aerial Inspection
2. Preventive Pipeline Shutdown
3. On-site Geotechnical Inspection
4. Activation of Contingency Group
5. Participation in CMGRD
6. Evaluation and Resumption of Operation

8th IMU in lightweight tool

Mar-2019

Nov-2021

Jul-2022

Feb-2023

Jun to Oct 2023

Nov 7, 2023

Nov 8, 2023

Nov 12 2023

Jan-2024

Stress Relief Required at Km 235
Integrity Management Plan 2023

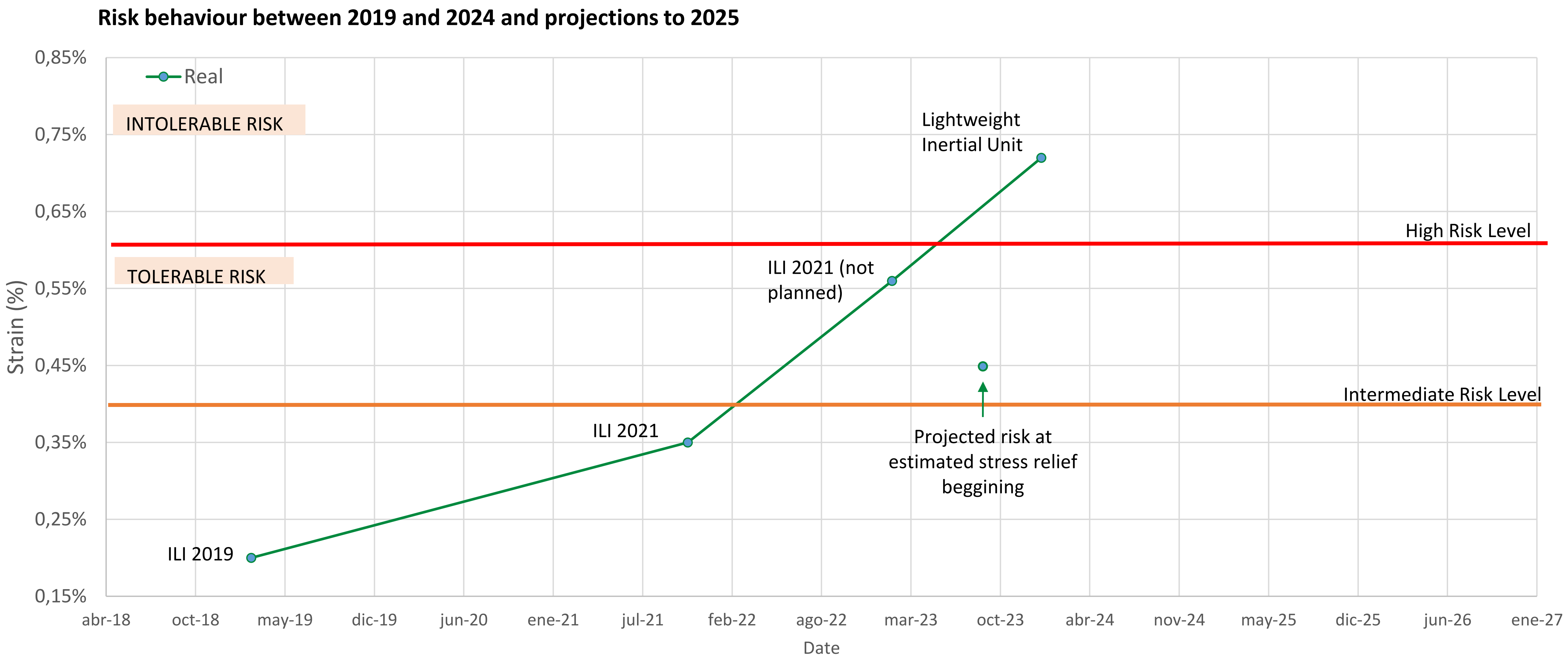
Social Management for the Start of Relief at Km 235

Declaration of Emergency by OCENSA

1. Mobilization of equipment/tools to the site.
2. Report of blockade in the communities of Florian and La Belleza.

CMGRD: Municipal Committee of Disaster Risk Management

Lightweight Inertial Unit confirmed strain continued to increase at the same rate and was close to the Very High risk zone by the beginning of 2024



Stress relief started by the mid of the first quarter of 2024

Mar-2019 – 5th Caliper + IMU ILI

Nov-2021 – 6th Caliper + IMU ILI

Jul-2022

Stress Relief Required at Km 235
Integrity Management Plan 2023

Feb-2023 – 7th Caliper + IMU ILI

Jun to Oct 2023

Social Management for the Start of Relief at Km 235

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Nov 8, 2023

Declaration of Emergency by OCENSA

Nov 12 2023

1. Mobilization of equipment/tools to the site.
2. Report of blockade in the communities of Florian and La Belleza.

Jan-2024 – 8th IMU in Cleaning Pig ILI

Feb 1, 2024

START OF EXCAVATION FOR STRESS RELIEF

CMGRD: Municipal Committee of Disaster Risk Management

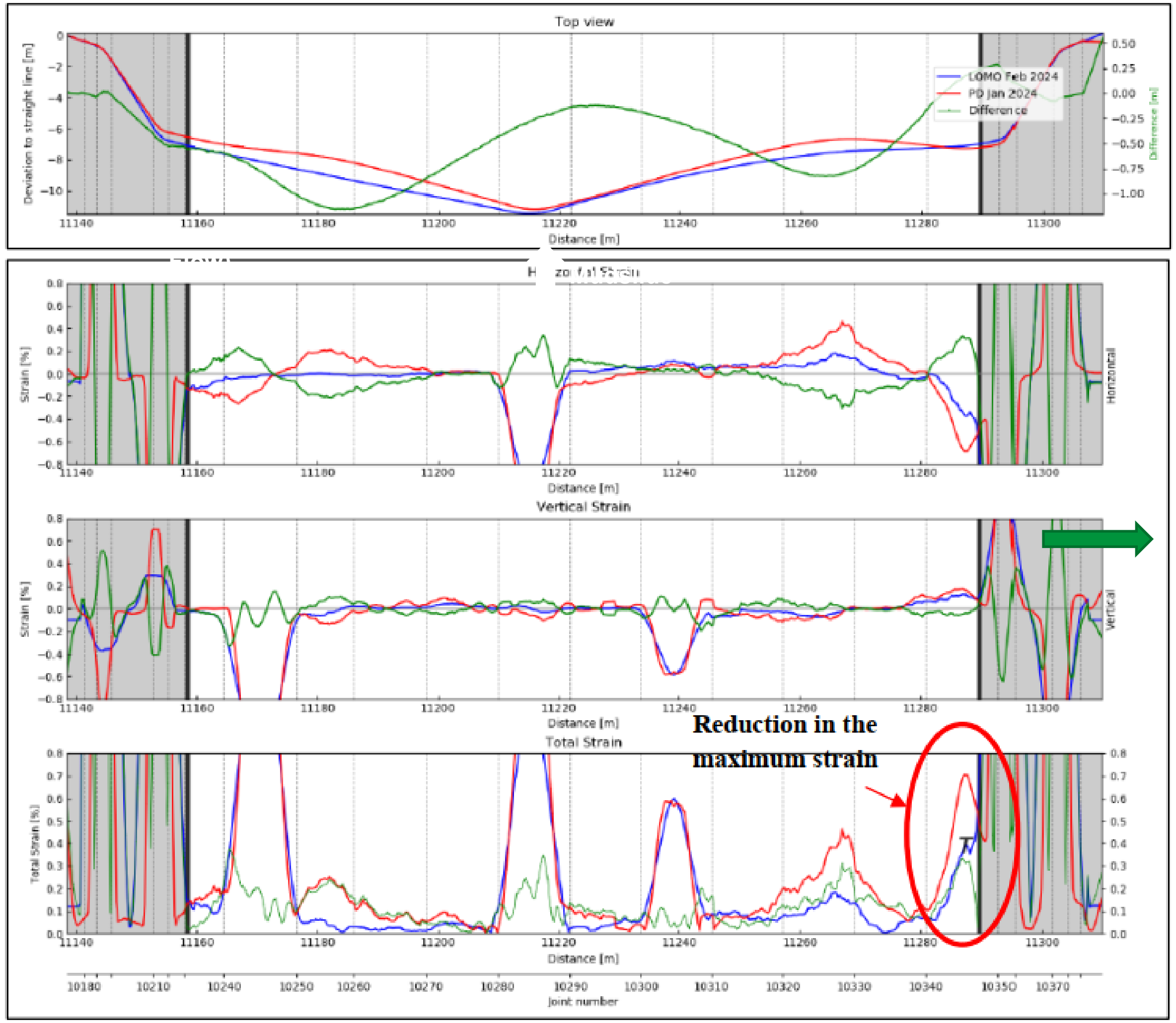
Stress relief started by the mid of the first quarter of 2024

35 days

180 meters

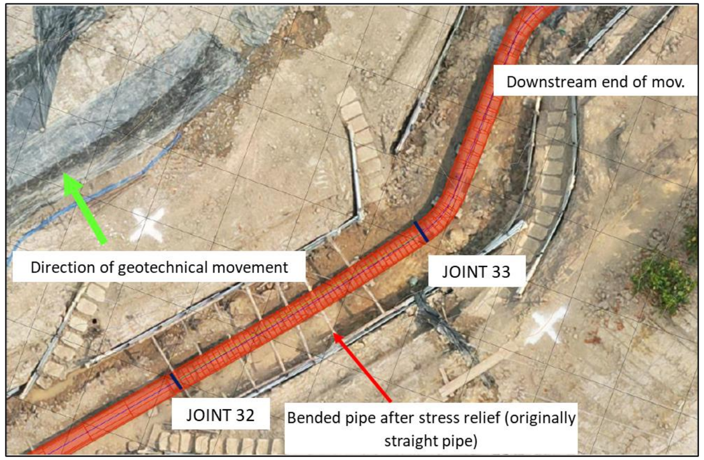
5000 m^3 of soil

Bending strain decreased throughout the entire section, with section 3 showing a partial recovery attributed to plastic deformation.



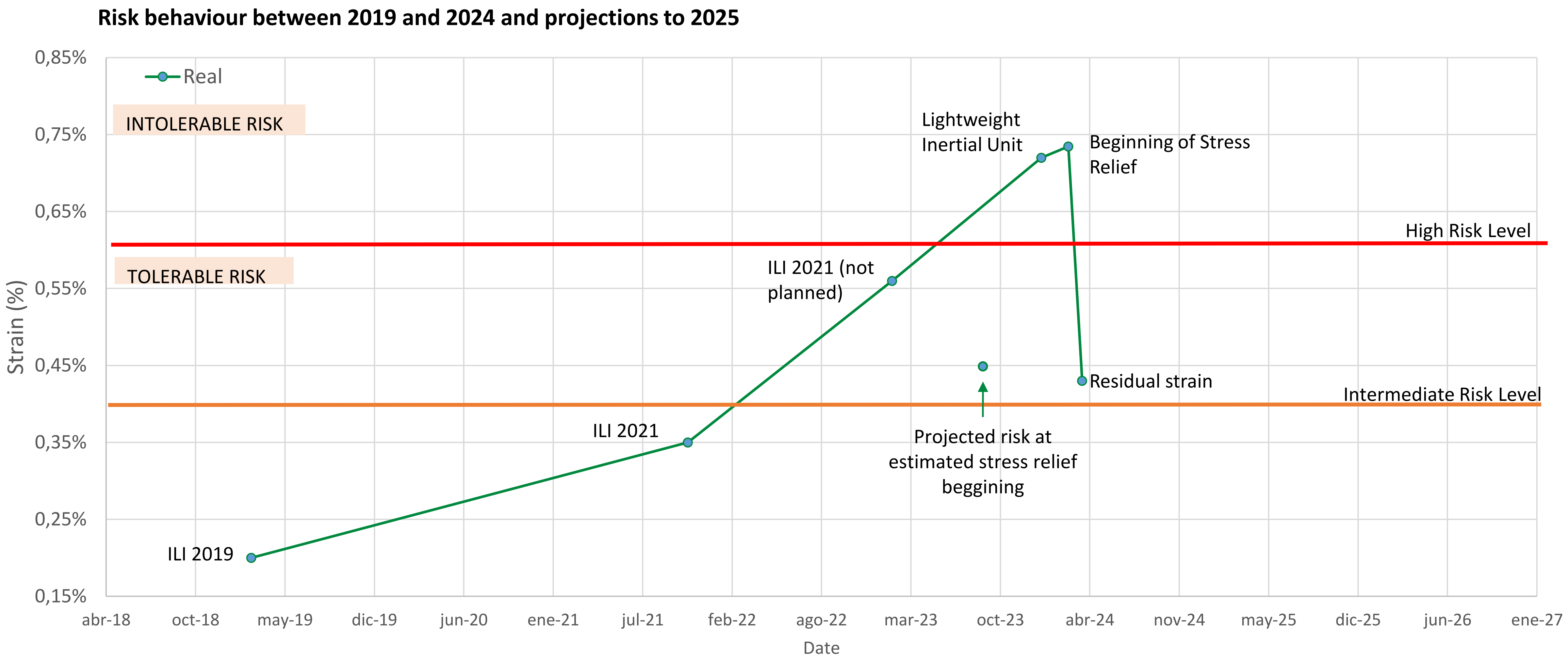
March 2024

Previous of Relief (ILI 2024)	After Relief (Topographic Survey 2024)
0.26 %	0.08 %
0.48 %	0.20 %
0.72 %	0.43 %

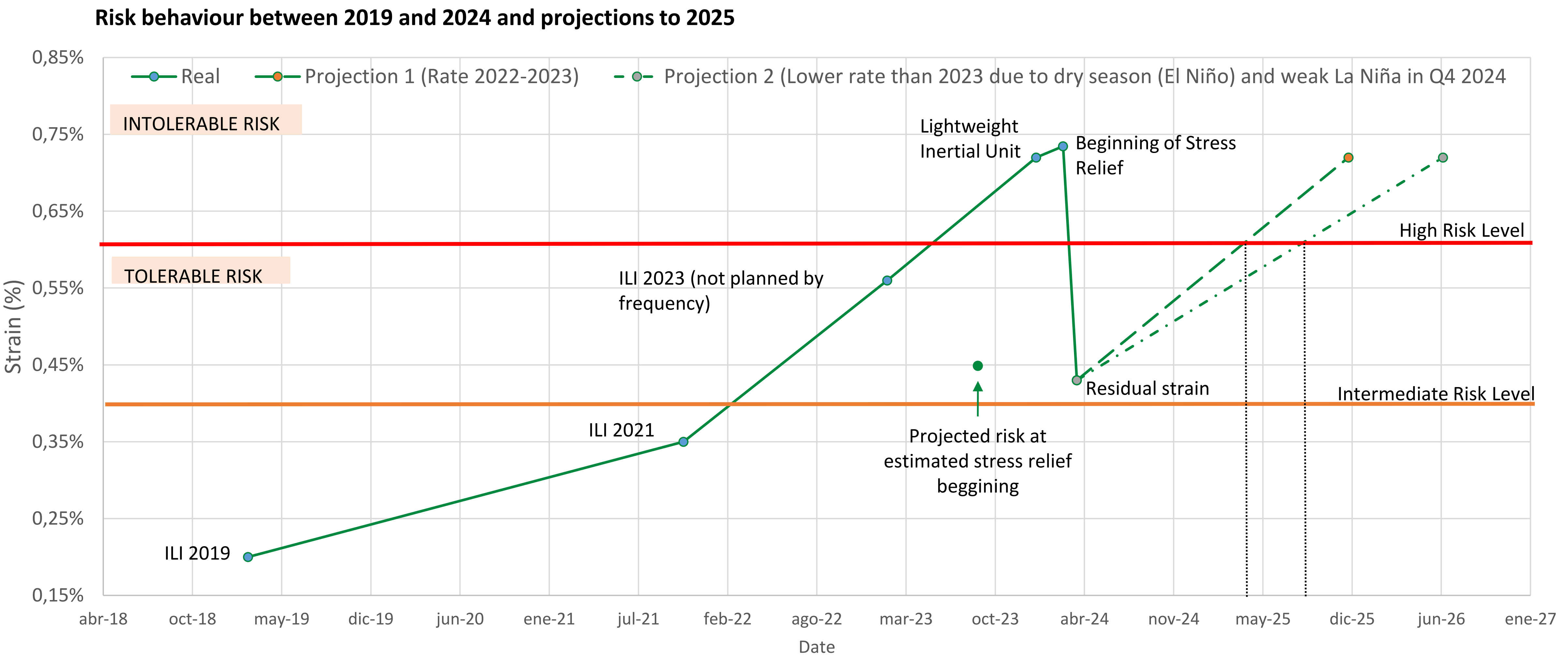


Topographic Mapping along the Pipeline

Bending strain decreased throughout the entire section, with section 3 showing a partial recovery attributed to plastic deformation.



The projected risk at a residual strain of 0.43% was expected to return to the High Risk zone between the first and third quarter of 2025



Ocensa opted to **replace and reroute** in response to **mid-term risk forecasts** and anticipated **social challenges**

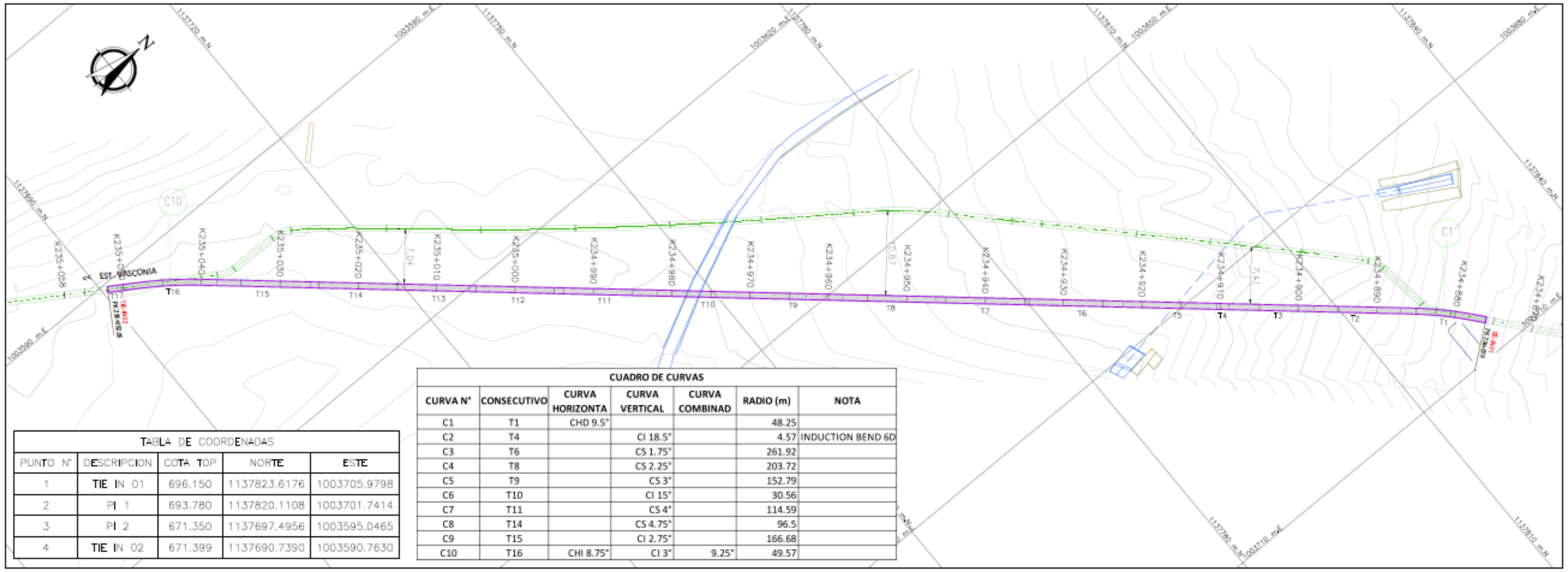
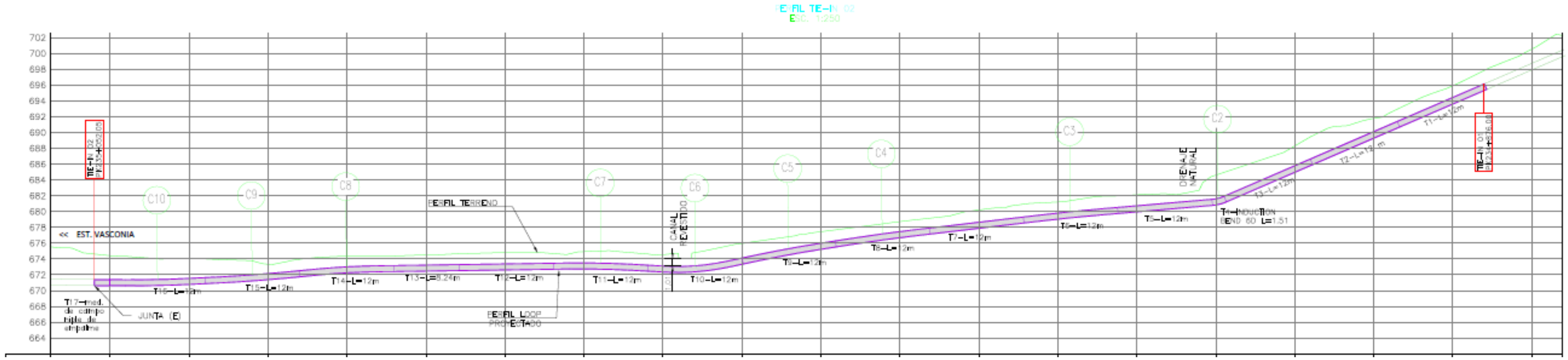


TABLA DE COORDENADAS				
PUNTO N°	DESCRIPCION	COTA TOP	NORTE	ESTE
1	TIE IN 01	696.150	1137823.6176	1003705.9798
2	PI 1	693.780	1137820.1108	1003701.7414
3	PI 2	671.350	1137697.4956	1003595.0465
4	TIE IN 02	671.399	1137690.7390	1003590.7630

CUADRO DE CURVAS						
CURVA N°	CONSECUTIVO	CURVA HORIZONTA	CURVA VERTICAL	CURVA COMBINAD	RADIO (m)	NOTA
C1	T1	CHD 9.5°			48.25	
C2	T4		CI 18.5°		4.57	INDUCTION BEND 6D
C3	T6		CS 1.75°		261.92	
C4	T8		CS 2.25°		203.72	
C5	T9		CS 3°		152.79	
C6	T10		CI 15°		30.56	
C7	T11		CS 4°		114.59	
C8	T14		CS 4.75°		96.5	
C9	T15		CI 2.75°		166.68	
C10	T16	CHI 8.75°	CI 3°	9.25°	49.57	



Ocensa opted to replace and reroute in response to mid-term risk forecasts and anticipated social challenges

5
months of planning

48
hours

174
meters

Ocensa opted to replace and reroute in response to mid-term risk forecasts and anticipated social challenges

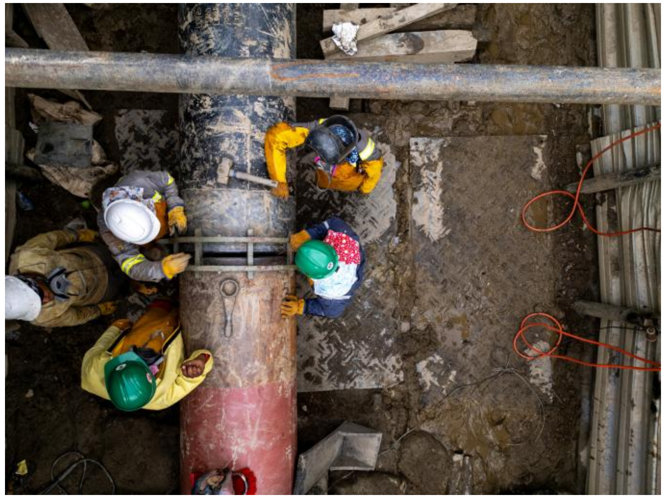
10k

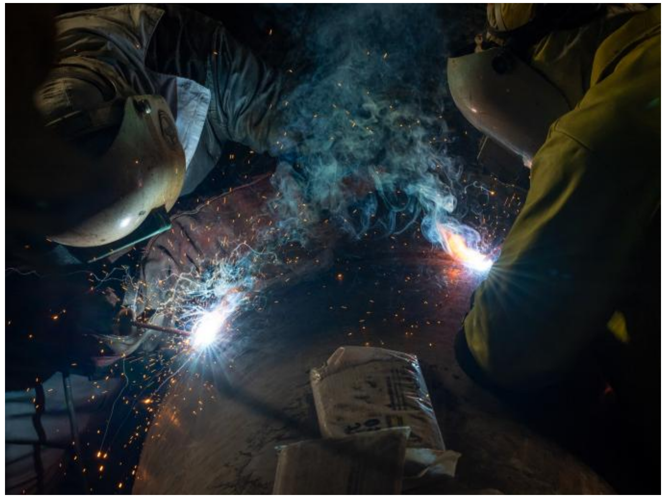
Barrels drained

~150

people

Ocensa opted to replace and reroute in response to mid-term risk forecasts and anticipated social challenges

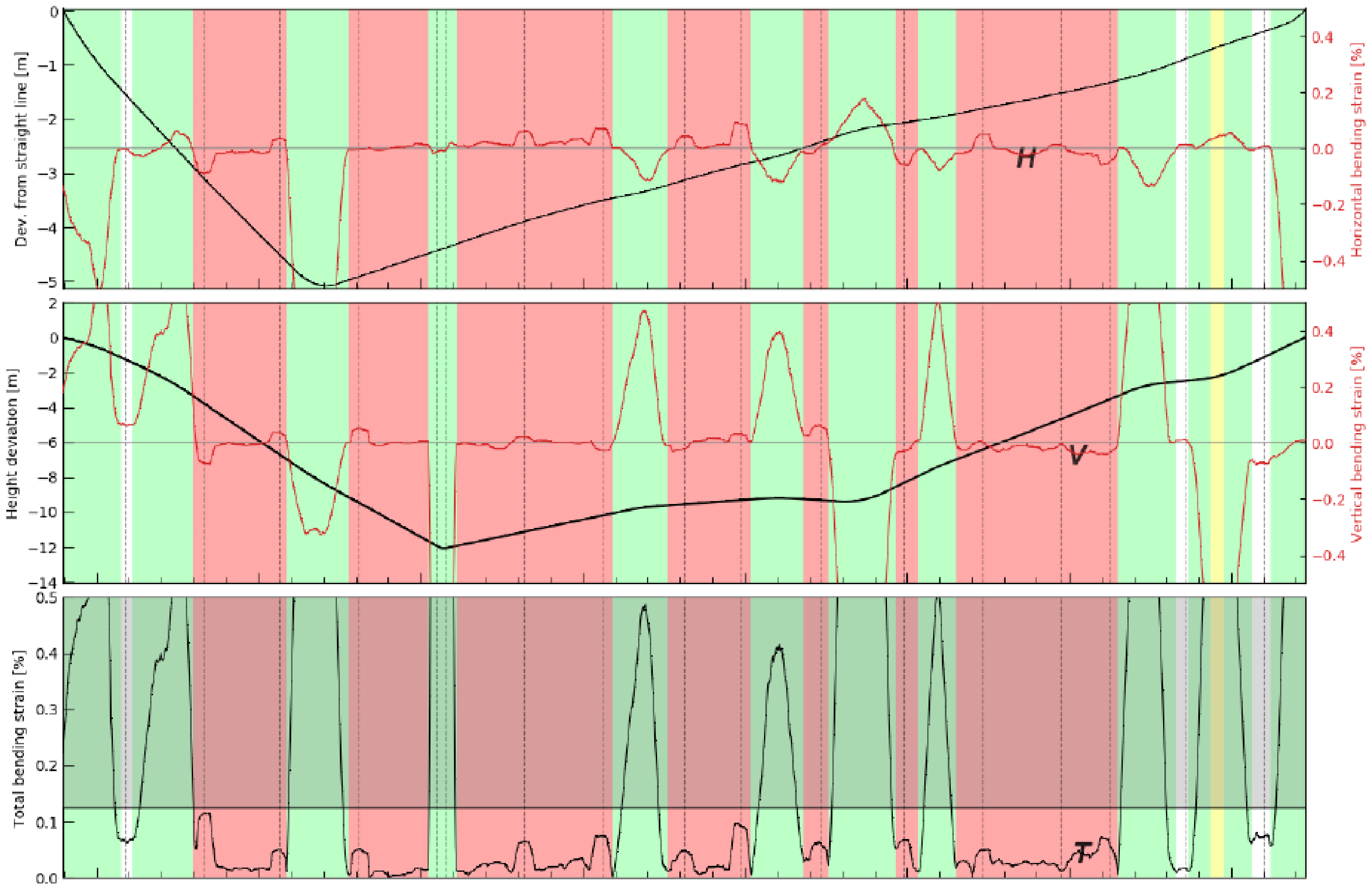




ACIEM

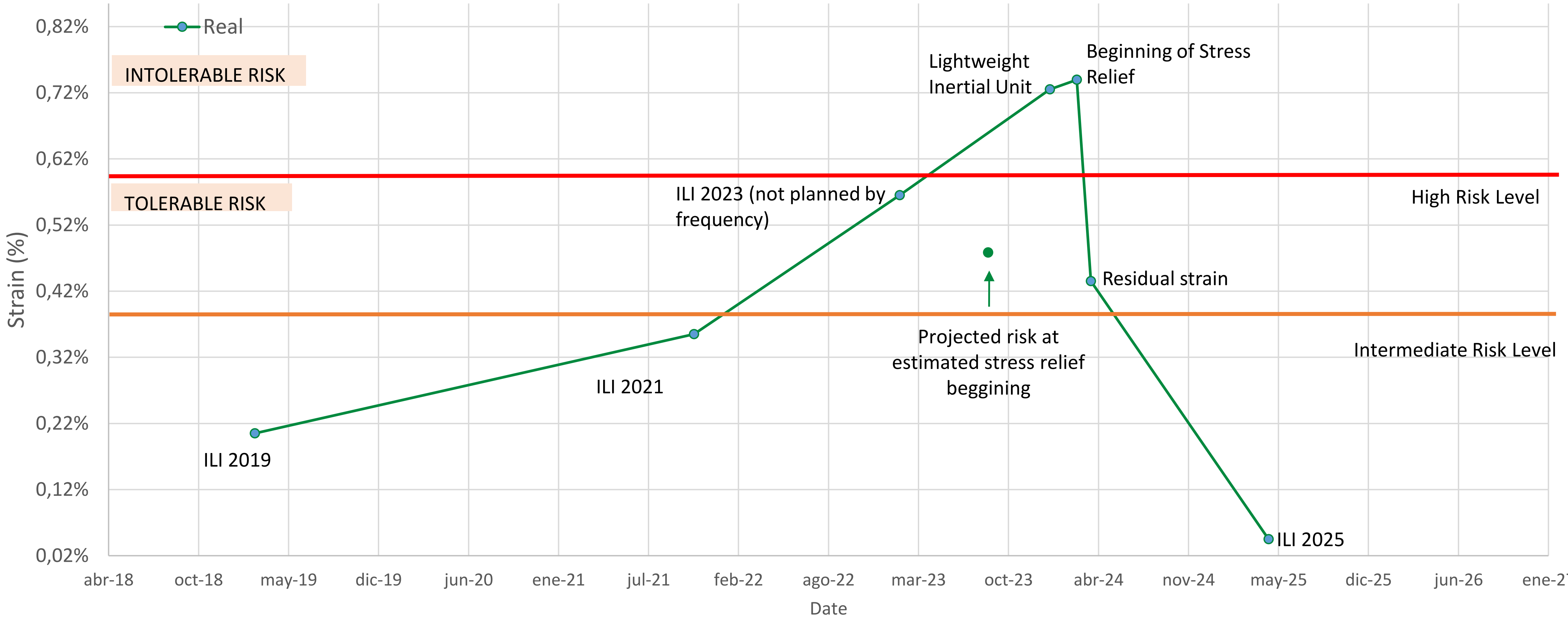
Ocensa opted to replace and reroute in response to mid-term risk forecasts and anticipated social challenges

Ocensa opted to replace and reroute in response to mid-term risk forecasts and anticipated social challenges



The intervention **reduced risk** to pre-2019 levels, with **no further measures** expected **for 10 years** due to **complementary geotechnical works**

Risk behaviour between 2019 and 2024 and projections to 2025



¡Thanks!

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ABSTRACT

Colombia is a diverse country both culturally and geographically, traversed by three mountain ranges and experiencing rainfall that can exceed 5000 mm per year. In this context, Ocensa serves as the backbone of crude oil transportation, facing the challenges of the country's geography and social diversity along its 836 km onshore and 12 km offshore route, making geo-hazards one of the most significant threats to process safety.

The KM235 is an example of such challenges due to the interaction between a large-scale landslide and the pipeline route. To manage the risk of product loss of containment due to this and other threats, Ocensa has a plan in accordance with Colombian legislation (Disaster Risk Management Plan) which includes three main processes: 1) Risk Knowledge, 2) Risk Reduction, and 3) Contingency Management.

This case study demonstrates the effectiveness of Ocensa's Risk Knowledge process in monitoring and revising loss of containment risk levels at previously identified locations. Quantitative results from internal models indicated landslide probabilities exceeded 80% following periods of rainfall, suggesting strain levels greater than projected. This information was confirmed after a light IMU tool run, which showed a twofold increase in strain rate.

This information was subsequently utilized in the Risk Reduction process, enabling timely interventions to mitigate stress on the pipeline, while accounting for the associated community challenges. The case study further details the current site conditions and outlines new risk reduction actions following the analysis of stress relief effects on the pipeline.

Keywords: Risk knowledge, pipeline strain, landslides

1. INTRODUCTION

Ocensa is the backbone of the crude oil transportation in Colombia. The pipeline spans 836 km onshore and 12 km offshore, and it transports approximately 70% of the crude oil production in the country, from the Llanos Orientales fields near Venezuela to the Coveñas Terminal in the Caribbean Sea. Along its route, Ocensa traverses two of the three mountain ranges that cross the country: the Cordillera Oriental and the Cordillera Central. Furthermore, the country can experience substantial rainfall, with annual precipitations surpassing 5000 mm, making geohazards one of the most significant threats to pipeline safety.

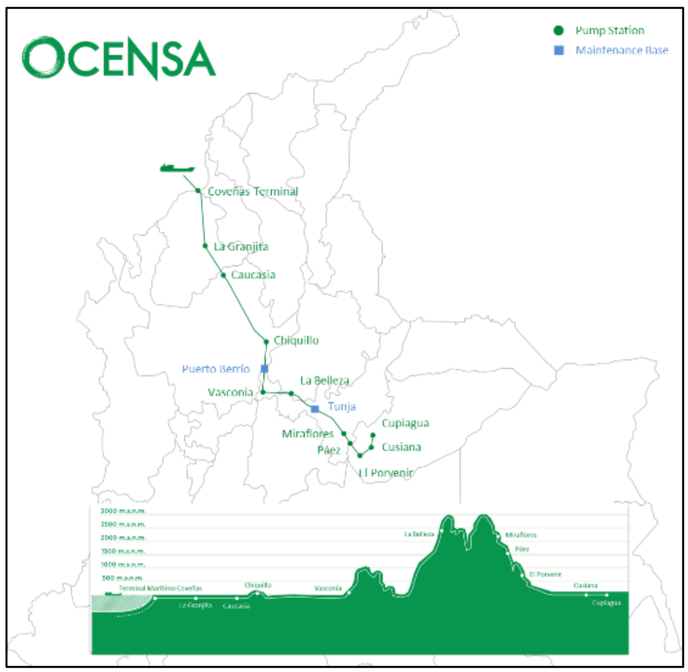

FIGURE 1. OCENSA PIPELINE LOCATION

Recent standard development such as API RP 1187 (2024) highlights the growing importance of integrated geohazard management in pipelines including proactive threat identification, monitoring, and mitigation. On the other hand, advances in monitoring technologies, including IMU-based in-line inspections and ground movement surveys, have proven effective in quantifying pipeline strain and informing risk reduction strategies [1]. In this context, the KM 235 section of the Ocensa pipeline presents a complex case of pipeline-soil interaction, where large-scale landslides and rainfall-driven instability pose ongoing risks to pipeline integrity. This work demonstrates how a risk-based integrity management system, supported by quantitative strain monitoring and proactive interventions, can effectively maintain pipeline safety in highly geohazardous Andean terrain, even under challenging community and environmental conditions.

The following sections detail the regulatory framework, the specific geotechnical challenges at KM 235, and the implementation of advanced risk knowledge and reduction processes, contextualized within the latest developments in pipeline geohazard management.

1.1 Pipeline Risk Management

Colombian legislation [2] mandates that public and private companies engaged in activities that may generate risks develop a Disaster Risk Management Plan. This plan serves as a planning and a strategic tool for managing risks that could adversely affect the environment, human populations, livelihoods, or the provision of public services.

The Disaster Risk Management Plan encompasses three principal processes:

1. Risk Knowledge: This process involves the identification, analysis, and evaluation of risks based on the results of activities that monitor different threats to pipeline safety.

2. Risk Reduction: This process entails defining technical specifications and executing interventions to mitigate identified and assessed risks (in the Risk Knowledge process). The assessment and projection of these risks may indicate the progression over time to levels that are considered intolerable for the organization.

3. Disaster Management: This process involves preparing for the occurrence of potential scenarios (based on the Risk Knowledge process) and establishing coordination mechanisms that allow for effective emergency response if the identified events materialize. This is accomplished through the formulation of an Emergency and Contingency Plan.

The legislation also requires the identification of high-consequence sites and mandates that the plan specifically addresses risk at these locations. Nevertheless, the three processes are replicated throughout the entire pipeline system, with differentiated performance standards applied to the most critical points.

In this manner, all the threats that could compromise the integrity of the Ocensa pipeline are assessed allowing prompt identification and treatment of risks that can progress over time and due to external triggering factors as in the case of the KM 235 of the pipeline.

1.2 Context of KM 235

The KM 235 of the Ocensa pipeline is located on the descent from the Cordillera Oriental towards the Magdalena River in the department of Santander. This site is situated 12 km from the La Belleza pressure reduction station, which is one of the highest points along the pipeline, at an elevation of 2000 m above mean sea level, with a height difference of 1800 m between the station and the KM 235. Due to this elevation difference and the absence of segmentation valves between these two points, the KM 235 operates under a mean pressure of 1940 psi.

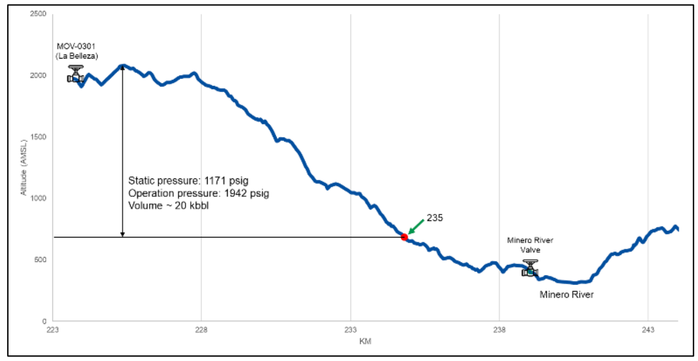

FIGURE 2. PIPELINE ELEVATION PROFILE

The KM 235 area is notably affected by geotechnical activity, primarily due to the gradual and slow movement (creep) of colluvial material. This movement exerts increasing loads on the pipeline, leading to processes of deformation and the buildup of stress along the structure. Rainfall acts as the main trigger for this instability, intensifying the effects of other existing factors such as the steepness of the terrain and the weak mechanical properties of the colluvial soil that surrounds and supports the pipeline.

2. RISK KNOWLEDGE PROCESS

This sub-process involves the identification, analysis, evaluation and monitoring of the risk of loss of process containment in the pipeline due to all threats to its integrity. This is achieved through a series of activities allowing the collection and analysis of information of the condition of the right-of-way, triggering factors and pipeline integrity to determine a probability of pipeline failure. This probability is then combined with the potential consequences of the pipeline failure to obtain the risk level, which is monitored by updating the information gathered through new risk knowledge activities. This risk is evaluated using a 6x6 risk matrix. The matrix thresholds for tolerable, acceptable, and intolerable risk were defined based on company policy and regulatory requirements, ensuring alignment with best practices in pipeline integrity management.

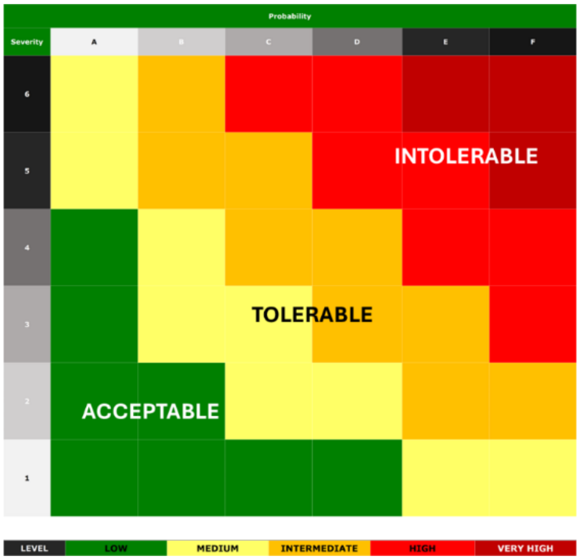

FIGURE 3. RISK MATRIX AND TOLERABILITY CRITERIA

2.1 Evaluation of potential consequences

The evaluation of potential consequences of a pipeline loss of containment in the KM 235 considered the impact on the environment and people, as well as the associated costs. This evaluation started with the calculation of the available spill volume, which was determined to be approximately 20 kbbl, based on pipeline hydraulics and the response time to shut down the pumping stations (see FIGURE 2)

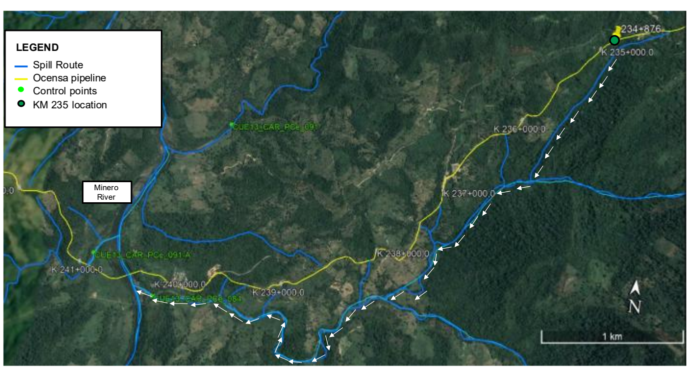

FIGURE 4. SPILL ROUTES ON THE KM 235 SECTION

Based on a hydrodynamic analysis of the various drainage systems and water bodies in proximity to the site, it was determined that in the event of a product loss of containment, it would take an average of 2 hours for the fluid to reach the nearest control point. This control point is located just before the confluence with the Minero River, which is traversed by the pipeline at KM 239, four kilometers downstream of the point of interest.

The consequence level associated with such a spill was evaluated as level 4 on the severity scale of the risk matrix. Given that this consequence could not be mitigated in the short term, the only variable that could affect the risk level was the probability of failure.

2.2 Pipeline condition and probability of failure

To evaluate the asset condition due to the threat of weather and external forces, Ocensa carries out a series of Risk Knowledge activities at defined intervals. These activities aim to assess the progression of instability processes, the status of triggering agents (rainfall), and the structural condition of the pipeline in response to soil interaction. These activities may include the following:

- Topographic survey
- Geotechnical monitoring using inclinometers
- Rainfall threshold modelling
- Right-of-way inspections (both terrestrial and aerial)
- Surveying with manned aerial photography and LiDAR
- In-line inspections with Inertial Mapping Unit (IMU) tools (every 3 years)
- Numerical modelling
- Soil-pipeline interaction abacuses

The implementation of these activities allows for the assessment and projection of the pipeline's bending strain, which is then compared against established criteria to determine pipeline failure probability. These criteria are grounded in a study conducted by Kiefner & Associates [4] as showed in the Table 1.

Table 1. Established failure probabilities based on strain levels.

Failure Probability	Description (unit bending strain)
$1x10^{-1}$	Bending Strain equal to or greater than 0.7%
$1x10^{-2}$	Bending Strain equal to or greater than 0.6% and less than 0.7%
$1x10^{-3}$	Bending Strain equal to or greater than 0.5% and less than 0.6%
$1x10^{-4}$	Bending Strain equal to or greater than 0.4% and less than 0.5%
$1x10^{-5}$	Bending Strain less than 0.4%

In the specific case of KM 235, with the objective of monitoring strain levels and associated risks, three in line inspections with Inertial Mapping Units (IMU) were conducted following the last pipeline alignment in 2014 (replacement). These runs, executed in 2015, 2019, and 2021, identified three critical points of pipeline movement and bending strain with varying strain rates (see Table 2). Notably, the strain rate increased significantly at point 3 during the second period (2019-2021), coinciding with the La Niña phenomenon and increased rainfall.

Table 2 Bending strain at three points over a 180 m pipeline segment

Date	Total strain point 1 (%)	Total strain point 2 (%)	Total strain point 3 (%)
09-2015	0,1	0,1	0,1
03-2019	0,14	0,16	0,2
11-2021	0,19	0,23	0,35

Considering this scenario, the deformation level projections indicated a gradual progression in risk by August 2022, although these levels were expected to remain within the company's tolerable range up to 2024, provided the deformation rate stayed the same. Analysis integrating findings from Risk Knowledge activities, such as topographic monitoring and rainfall pattern studies, led to a July 2022 decision to implement risk reduction strategies for 2023. This proactive approach was taken to ensure that risk would not reach an intolerable level and was further justified by the recognition—based on experience—that accessing the site could take more than six months.

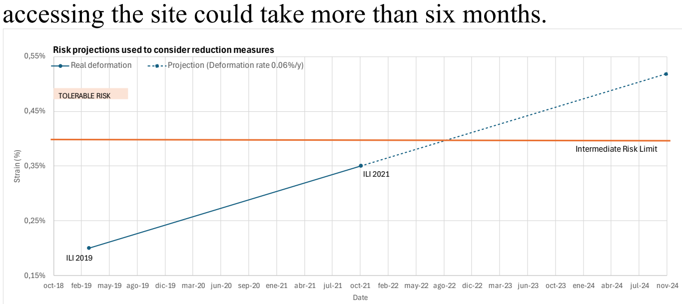

FIGURE 5. RISK PROJECTIONS USED TO CONSIDER REDUCTION MEASURES IN 2023

3. RESULTS AND RISK REDUCTION PROCESS

3.1 Risk Monitoring an Execution of first risk reduction measures

From June to October 2023, environmental and community processes were executed to enable the planned stress relief intervention, as outlined in the 2022 Pipeline Integrity Plan. However, in November 2023, a rupture occurred in a parallel pipeline operated by another entity, located at the crest of the slope where Ocensa's pipeline is situated. This event led to community challenges, hindering the execution of the stress relief activities in 2023.

Faced with these challenges and the weather conditions that ended in the parallel pipeline rupture, an Inline Inspection (ILI) run equipped with an Inertial Mapping Unit (IMU) was performed outside the routine monitoring schedule in February 2023. The findings indicated a total strain at point 3 of 0.535%, representing more than a twofold increase in the deformation rate, a result that was also confirmed by topographic monitoring. This escalation brought the site closer to an intolerable level of risk, prompting a preventive emergency declaration to facilitate the necessary stress relief activities. Projections based on the new deformation rates suggested that the risk level would soon exceed the pipeline's plastic deformation threshold, reaching up to 0.72% bending strain. This trend was confirmed in January through a PipeDrift run, where the IMU tool was attached to a cleaning pig, providing essential data for ongoing strain monitoring and timely decision-making in this complex situation (see FIGURE 7.)

The preventive emergency declaration mobilized both territorial and national authorities to address the community constraints obstructing the stress relief operations. Consequently, risk reduction activities commenced in February 2024. This operation spanned 35 days, during which 180 meters of pipeline were relieved, necessitating the removal of 5,000 cubic meters of soil (see FIGURE 6)

FIGURE 6 AERIAL PICTURE AFTER THE STRESS RELIEF

Following the pipeline stress relief activities, residual bending strain was assessed by performing topographic measurements as a Risk Knowledge activity seeking to confirm that tolerable or acceptable risk were achieved with this intervention. This analysis indicated a reduction in bending strain across the entire section, with varying residual strains observed at the three critical points detailed in Table 2. The point 3, located downstream of the section, exhibit only a partial recovery that was linked to plastic deformation, as confirmed by simulating the loading conditions by finite element analysis. The estimated residual strain at this location was approximately 0.43%, indicating that risk was effectively reduced but not reaching the 2019 or even 2021 levels (see FIGURE 7.)

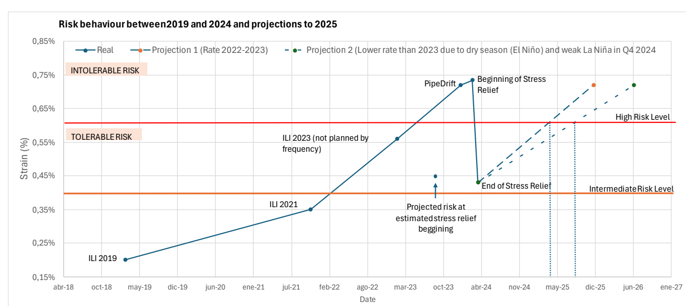

FIGURE 7. RISK PROGRESSION BETWEEN 2019 AND APRIL 2024 AND RISK PROJECTIONS TO 2025

3.3. Final Risk Reduction Activities

As a result of the updated risk estimation following the stress relief, new projections were conducted to ascertain whether additional measures were required to maintain risk at tolerable levels. Considering conservative projections that accounted for the likelihood of landslides resulting from rainfall patterns between July and December 2024, it was determined that there could be a progression in slope creep and pipeline bending strain, potentially raising the risk to intolerable levels by 2025. Therefore, Ocensa decided to undertake the replacement of a 180-meter pipeline section. The new design aimed to:

- Ensure a shallower depth-of-cover, thereby reducing lateral forces exerted by the soil;
- Avoid the construction of horizontal field bends, improving the structural integrity of the pipeline at the ends of the creeping soil mass;
- Reset the pipeline bending strain, positioning the risk at acceptable levels and postponing the need for further interventions in the short and medium term.

The new pipeline section to be replaced was redefined through topographic analyses to adapt the pipe geometry to the terrain conditions. Finite element analysis were conducted to evaluate the optimal geometric configuration of the new alignment, ensuring appropriate performance under soil-induced movements in the area. Additionally, the use of cold-formed bends within the terrain movement zone was minimized, replacing them with induced bends in sections requiring complex directional changes along the vertical axis (see Figures 8 and 9). As a result, the maximum bend angles were defined as follows:

- Lower vertical bend of 17.5° using induced bending (stream crossing)
- Left horizontal bend of 10.25° using cold bending, located outside the terrain movement zone

FIGURE 8. NEW PIPELINE LAYOUT ON HORIZONTAL AXIS

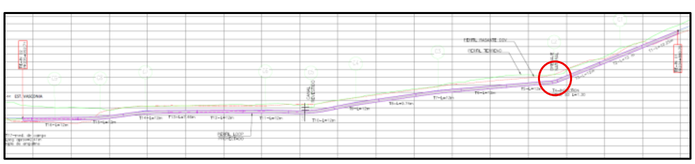

FIGURE 9. NEW PIPELINE LAYOUT ON VERTICAL AXIS

Qualified procedures and certified welders were employed for the Ocensa pipeline materials, and Non-Destructive Testing (NDT) methods—including Radiographic Testing (RT), Ultrasonic Phased Array Testing (UTPA), and Magnetic Particle Testing (MT)—were performed on each girth weld. Additionally, a hydrostatic test was carried out on the entire new pipeline section at 100% of SMYS for a sustained period of 4 hours, in order to ensure the segment's resistance to internal pressure and accumulated external loads up to 70,000 psi.

This approach is particularly important for Ocensa, given the significant challenges posed by site access, community concerns, and complex topography. As a result, further geotechnical investigations and the implementation of stabilization and drainage solutions are underway to support the long-term integrity of the pipeline system.

4. CONCLUSION

This study demonstrated how Ocensa's risk-based integrity management system enables ongoing tracking and updating of containment risks, especially from weather and external forces, by integrating Risk Knowledge activities into an inspection and monitoring strategy and using additional measures during events like heavy rainfall.

The paper also showed how collected data supports a Risk Reduction process that allows for timely pipeline interventions and addresses Colombia's community complexities. This approach is key for shifting from reactive to preventive management in the country's challenging terrain.

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