# AN INTEGRATED DECISION-MAKING PROCESS IN EMERGENCY CONDITIONS DUE TO GEOHAZARDS – A STUDY CASE

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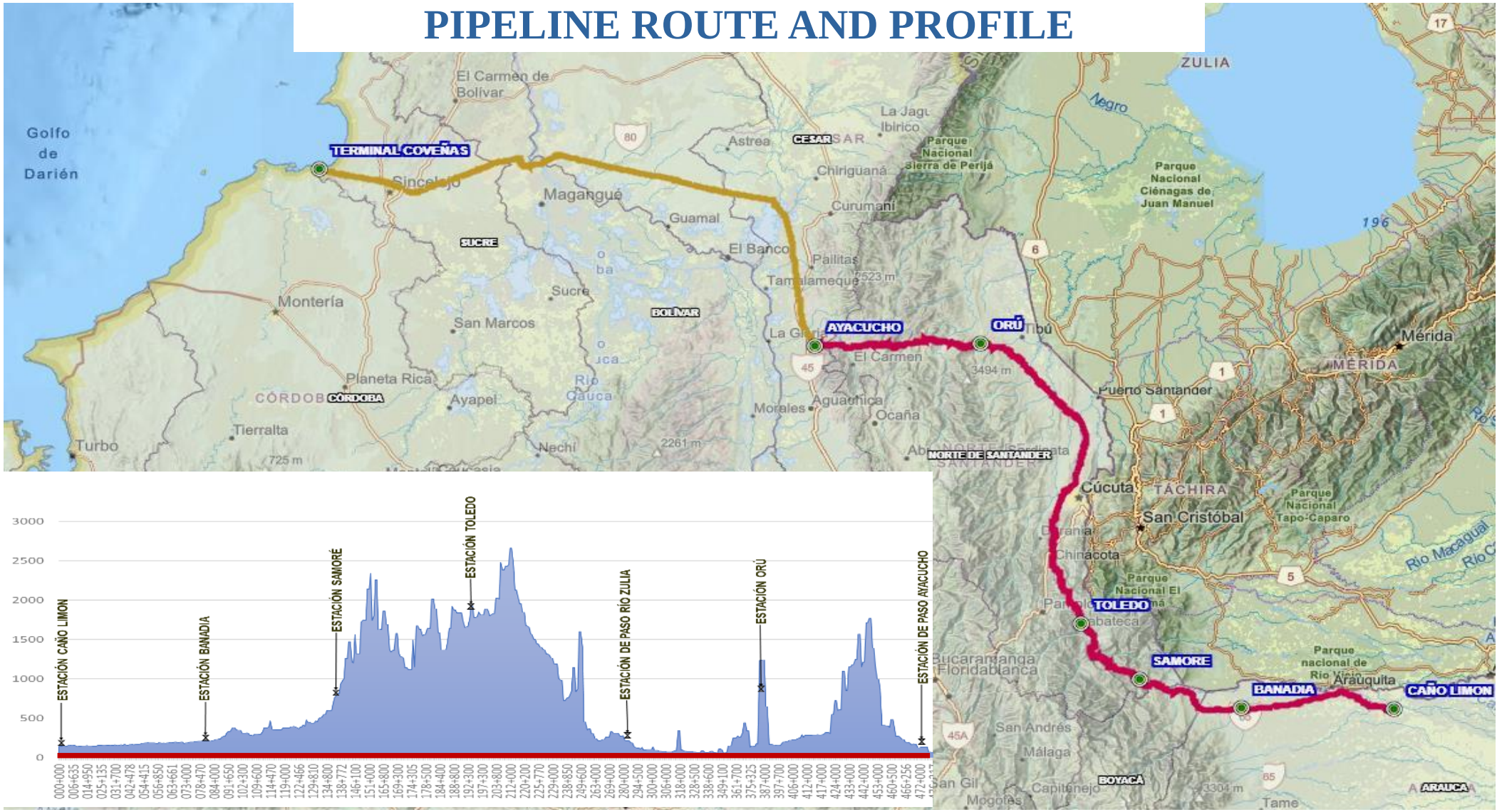
cenit
TRANSPORTE Y LOGÍSTICA DE HIDROCARBUROS

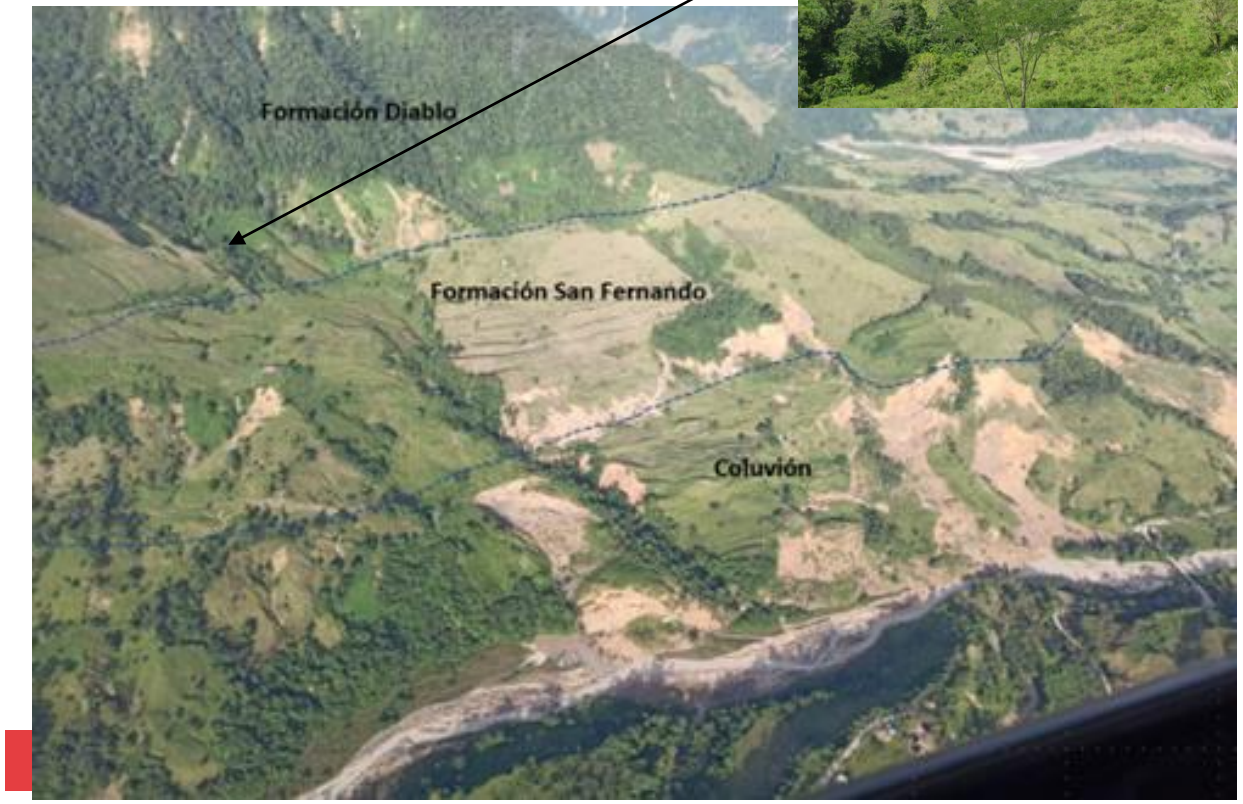
"We naturally connect the energy opportunities of Colombia towards the future"

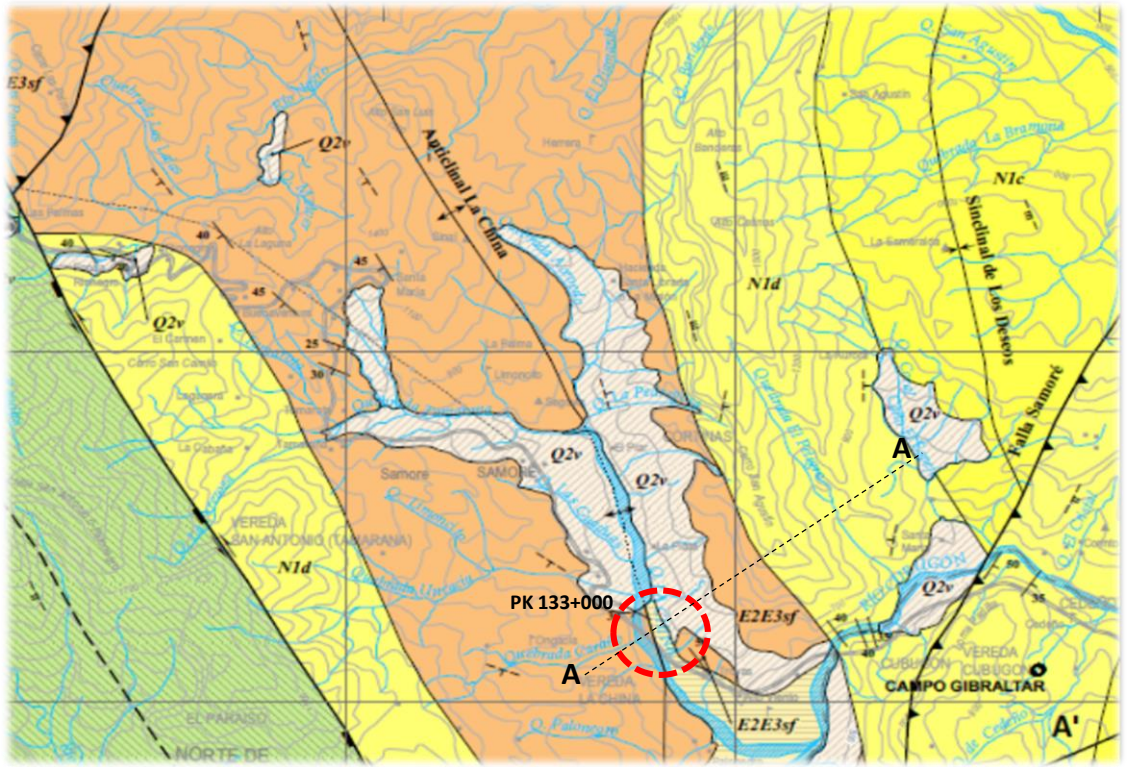
# PIPELINE ROUTE AND PROFILE

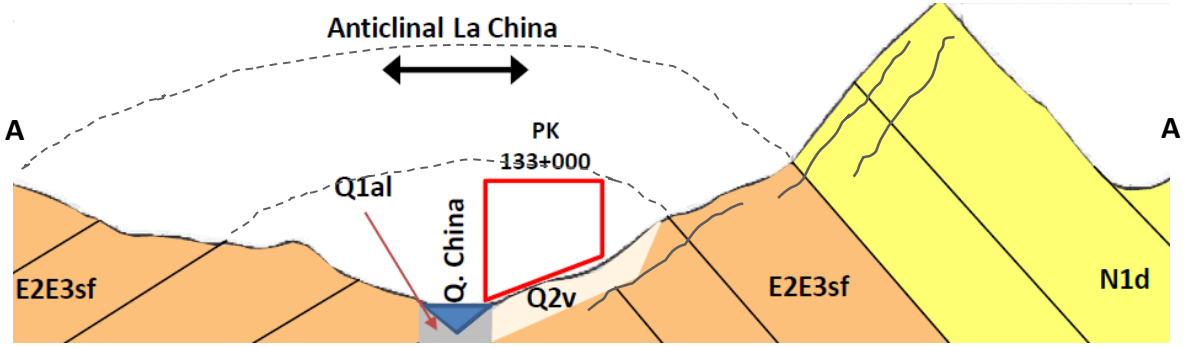


# GEOLOGICAL ENVIRONMENT OF THE AREA

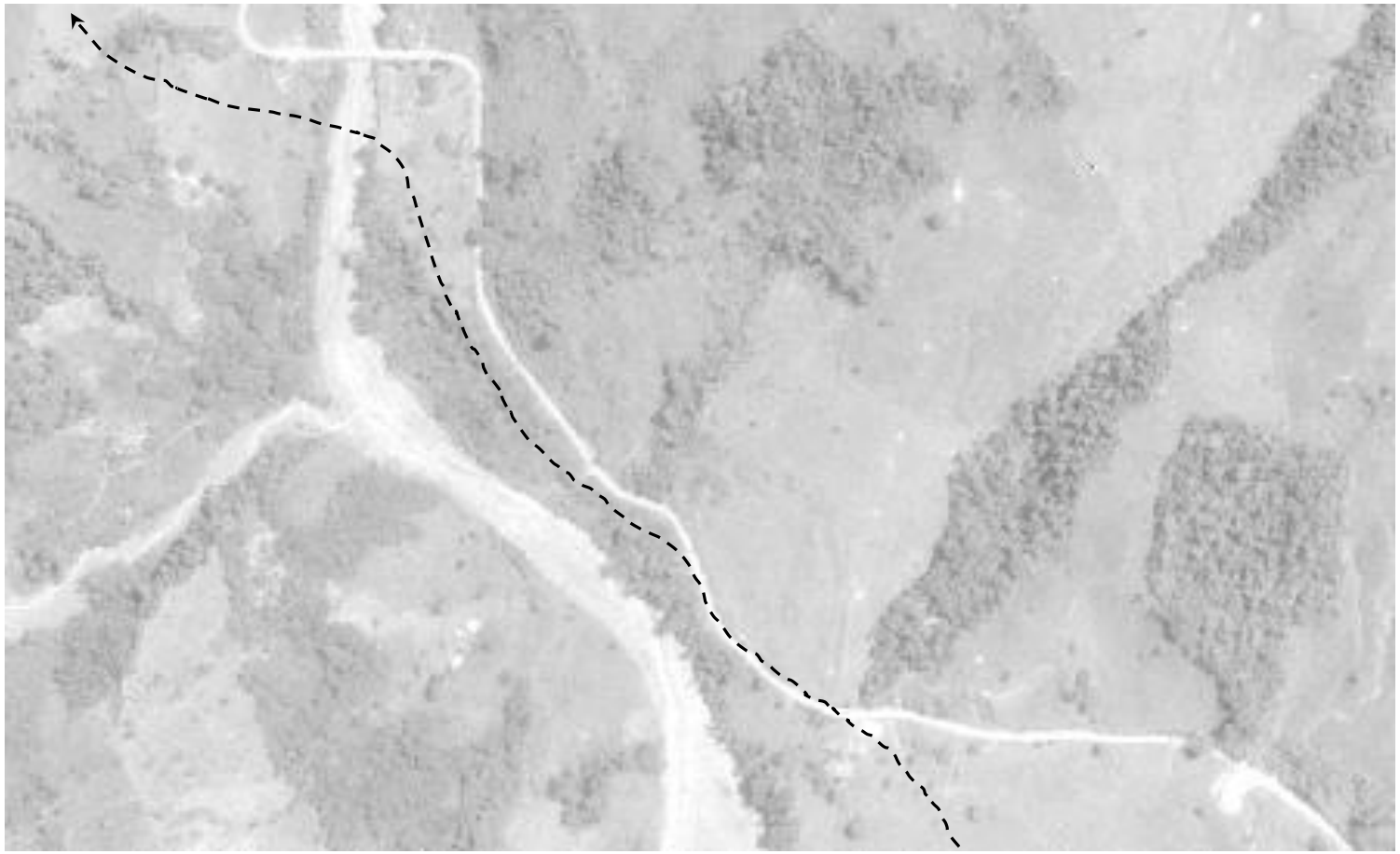
Scarp slope is formed in the upper part by hard white sandstone quartz that are part of "El Diablo" Formation and give rise to "Cortinas de Samoré", and in the lower zone by gray clay trees of "San Fernando" Formation covered by colluvium.



# BACKGROUND



1982 Aerial photography prior to the pipeline construction. Note changes in land cover on the slopes. The black dashed line represents the pipeline location.

September 14, 1986. Landslide rupture

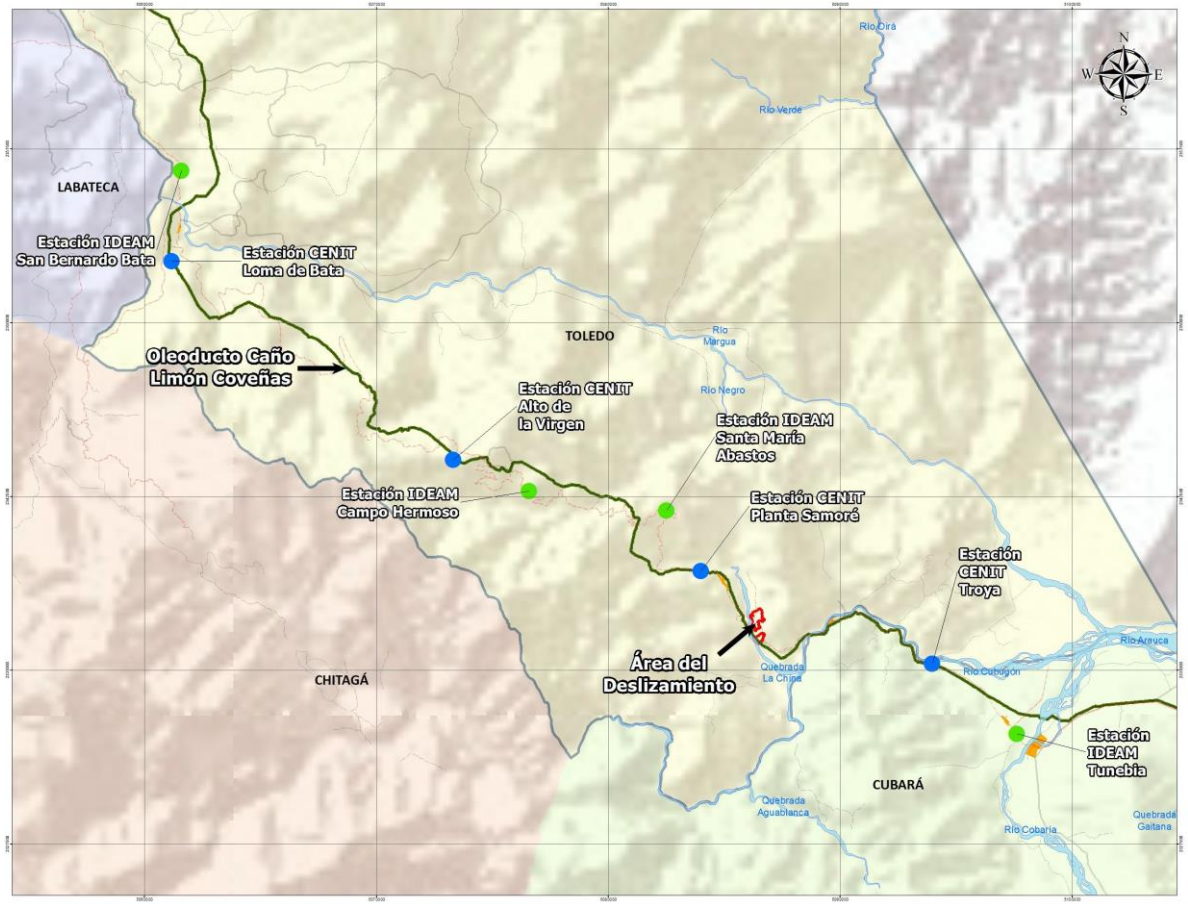
New pipeline centerline after the 1986 landslide.

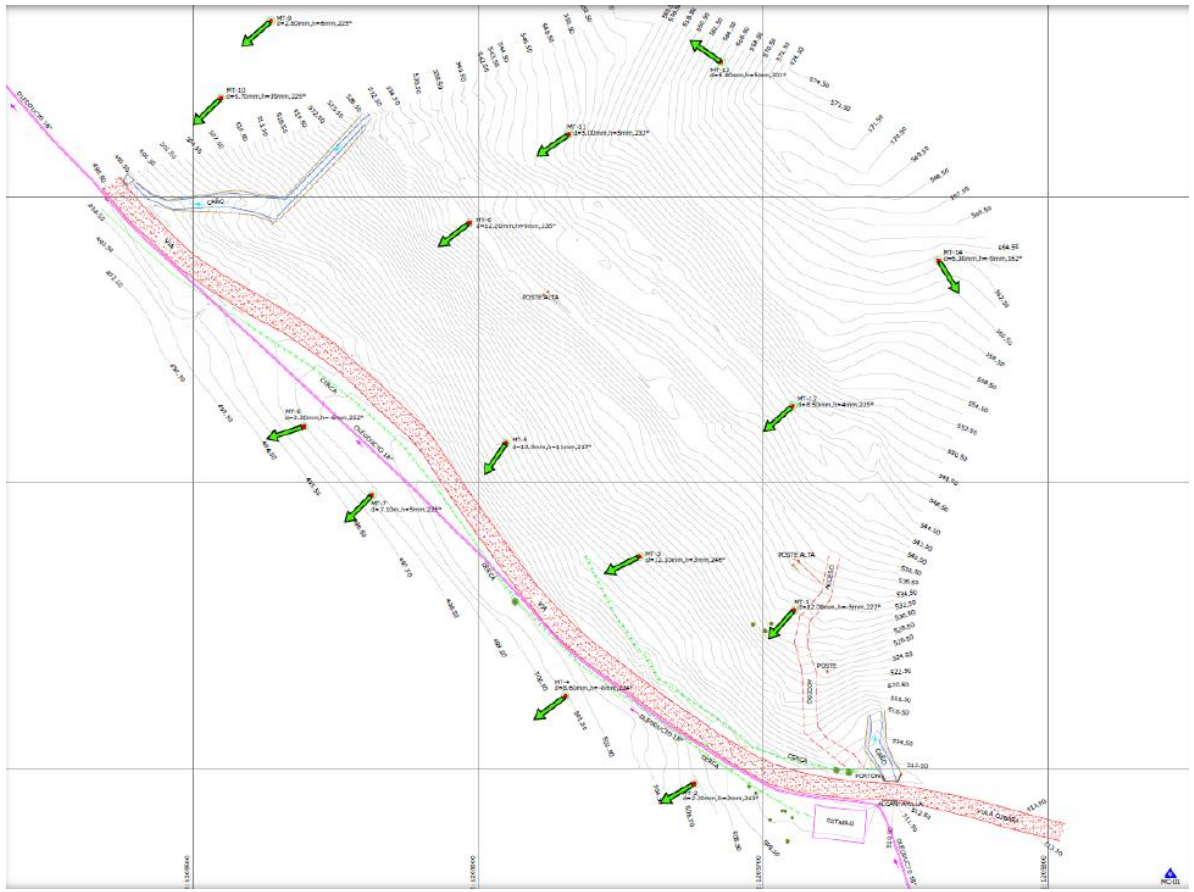
April 25, 1993. New Landslide rupture.

1998 Aerial photography, new pipeline centerline after the event of 1993.

Geotechnical protection works to stabilize the left bank of the La China stream where the pipeline was relocated after 1993.

# MONITORING PLAN



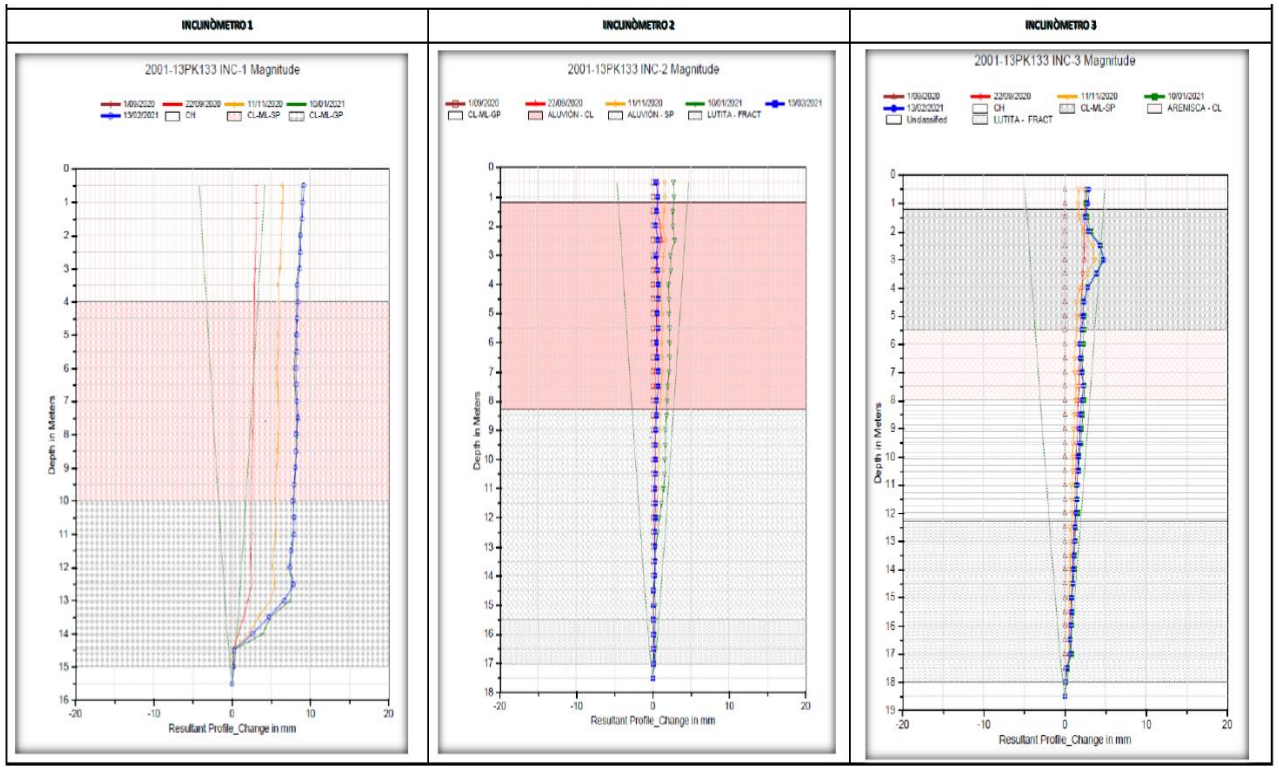
Geotechnical instrumentation consisting of 3 slope indicators and 14 topographic milestones were installed

To monitor rainfall in the area, two rainfall stations located near to the event site that capture and transmit data in real time has installed.


**INCLINÓMETRO 1**
**Dirección:** 230 Grad.
**Desplazamiento Acum:** 9.03 mm
**Velocidad Total Acum:** 0.055 mm/día
**Clasificación Velocidad Relativa:** Muy lenta
**Superficie de falla:** 12.0 m a 14.0 m

**INCLINÓMETRO 2**
**Dirección:** 259 Grad.
**Desplazamiento Acum:** 0.63 mm
**Velocidad Total Acum:** 0.004 mm/día
**Clasificación Velocidad Relativa:** Extremadamente lenta
**Superficie de falla:** N.A.

**INCLINÓMETRO 3**
**Dirección:** 252 Grad.
**Desplazamiento Acum:** 4.82 mm
**Velocidad Total Acum:** 0.029 mm/día
**Clasificación Velocidad Relativa:** Extremadamente lenta
**Superficie de falla:** N.A.

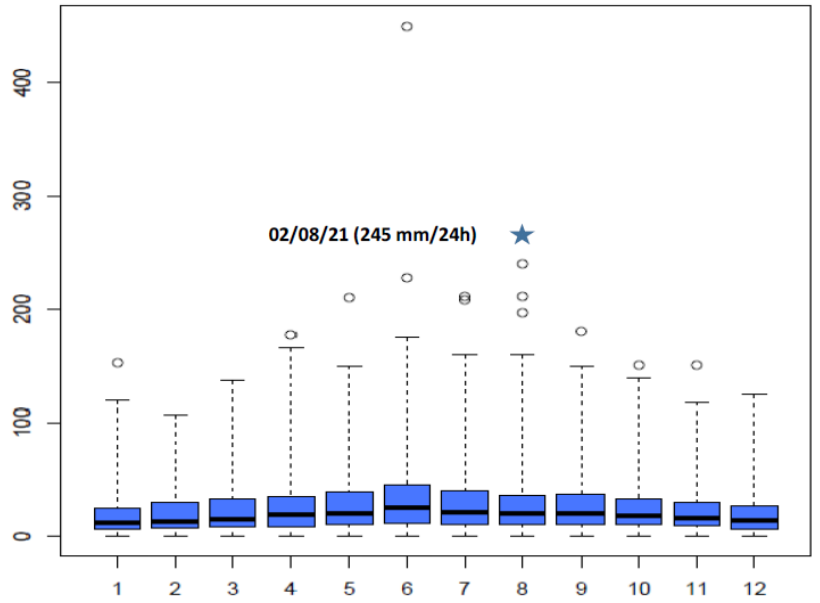



Prior to the event a slope indicator located upslope of the ROW had shown displacements of about 9 mm in the last six months with a failure surface located at 13 m depth. The slope indicators located on the ROW showed no activity.

# LANDSLIDE EVENT

| Meteorological Station | May | June | July |
|---|---|---|---|
| Troya | 111.4% | 140.1% | 133.1% |
| Samoré | 88.3% | 108.2% | 130.9% |
| Alto de La Virgen | 118.4% | 107.6% | 151.6% |

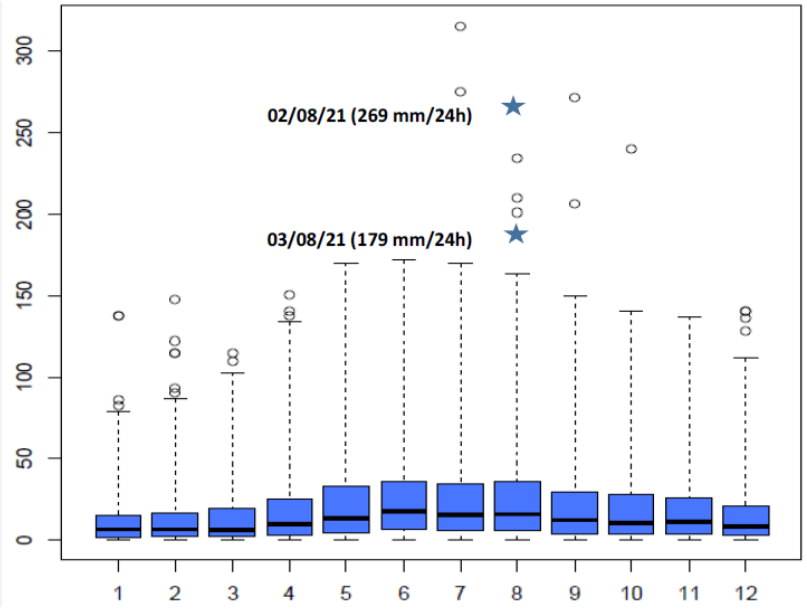
Percentage of rainfall with respect to average historical value



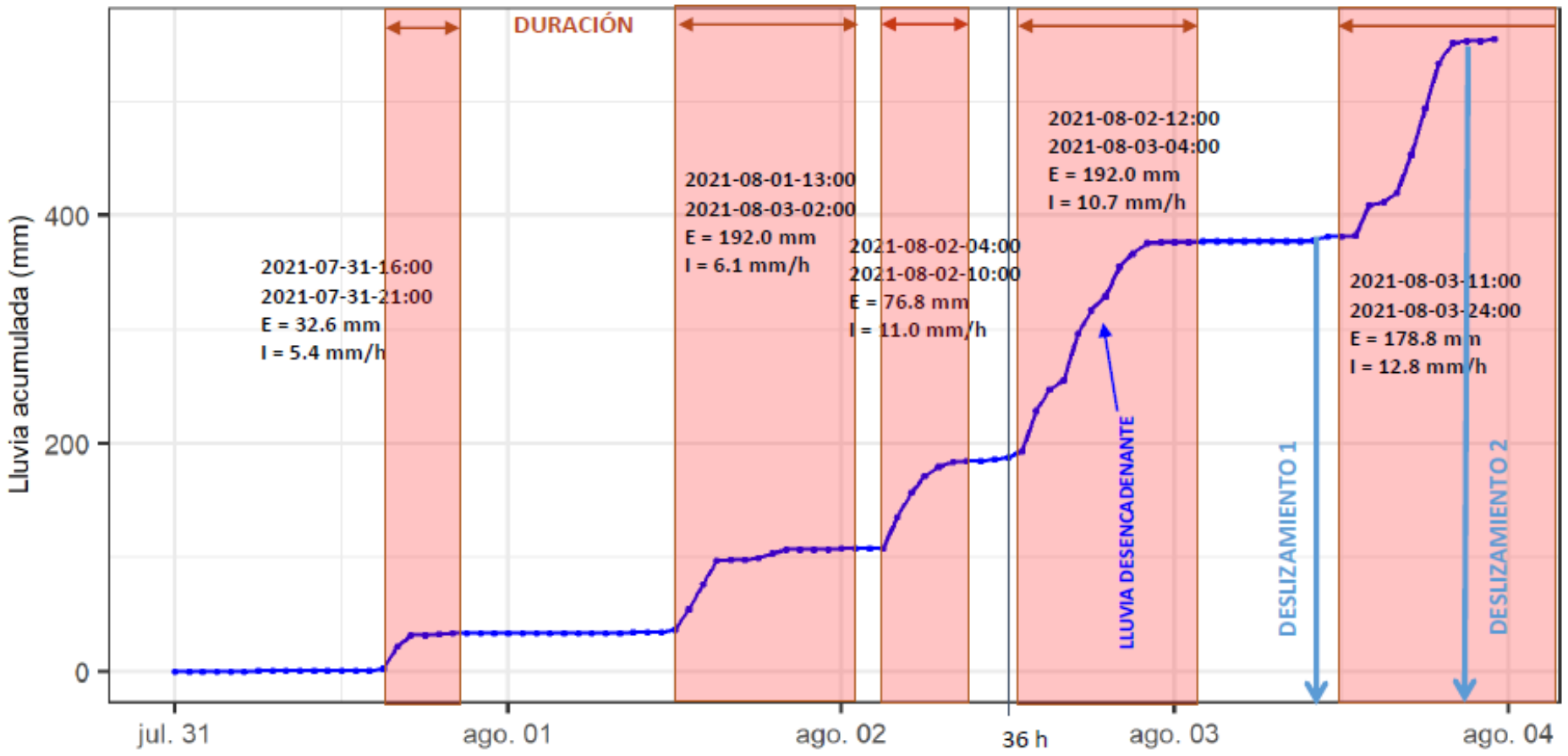

Box plot for extreme daily atypical precipitation Santa María Abastos station (compared with Samoré station).

| IDEAM Station | May | June | July |
|---|---|---|---|
| Santa María de Los Ángeles | 605,2 | 793,7 | 699,4 |
| Tunebia | 554,2 | 651,2 | 643,9 |

Historical monthly average rainfall from nearest IDEAM reference stations (mm).




Box plot for extreme daily atypical precipitation Tunebia station (compared with Troya station).




Rain episodes in the 96 hours prior to landslide event

The event affected:

- Several towers of the 230-kWpower line
- 8 points in La Soberanía road with total or partial closure
- Gibraltar –Bucaramanga gas pipeline affected in about 4 km.
- Landslides and debris flows in the afferent basins, with avalanches; for example, in La China and El Caraño streams.


## IMPACT OF THE EVENT ON THE LA SOBERANIA ROAD

- Sites blocked without passage in a short time.
- Sites with restricted access.
- Sites with slides, but enabled

# IMPACT OF THE EVENT ON PIPELINE



Pk 149+500 La Piazzola

Pk 130+380 Carbonera stream

# LANDSLIDE EVOLUTION

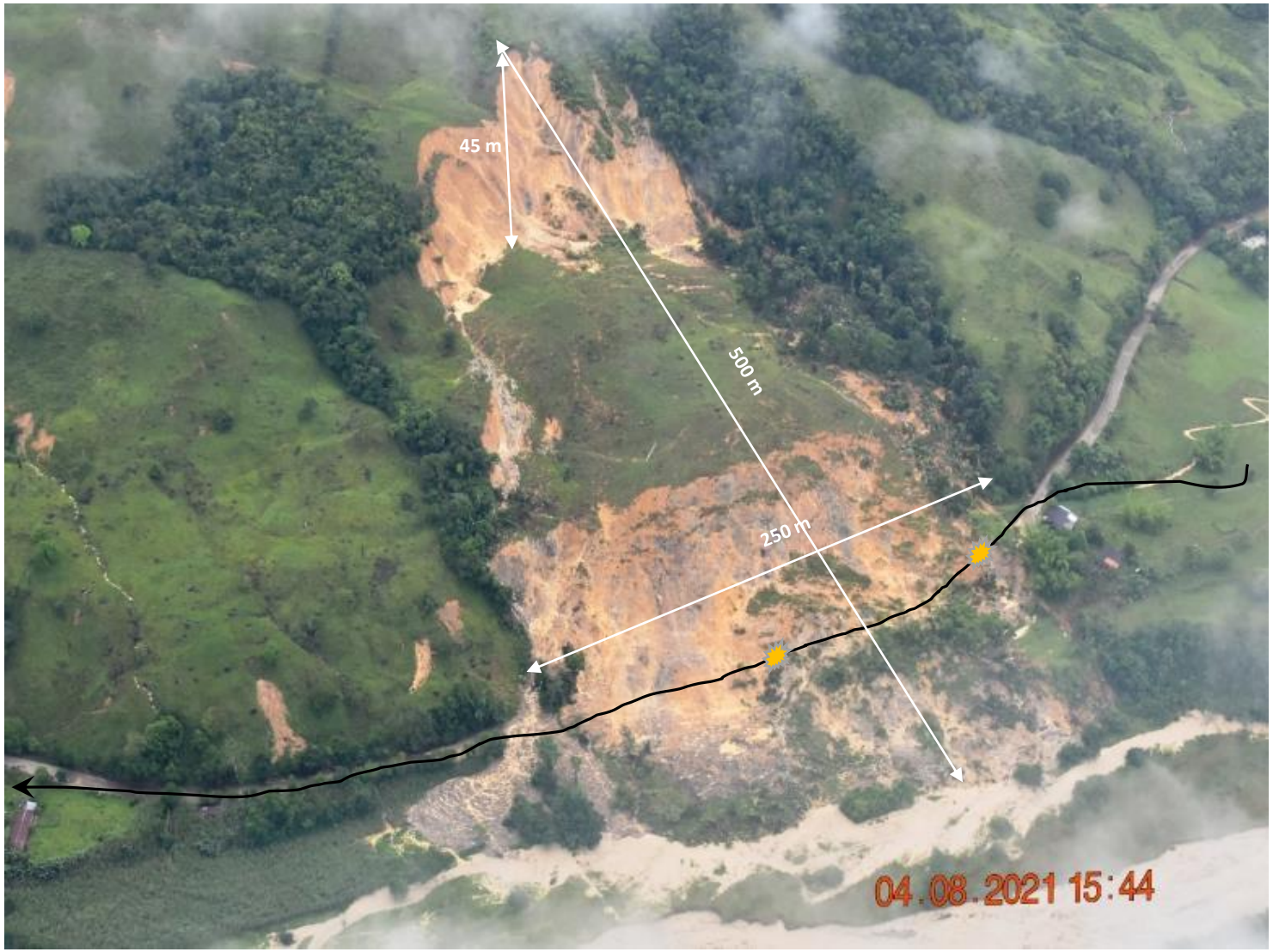




2021 08 03


2021 08 04


04.08.2021 15:44

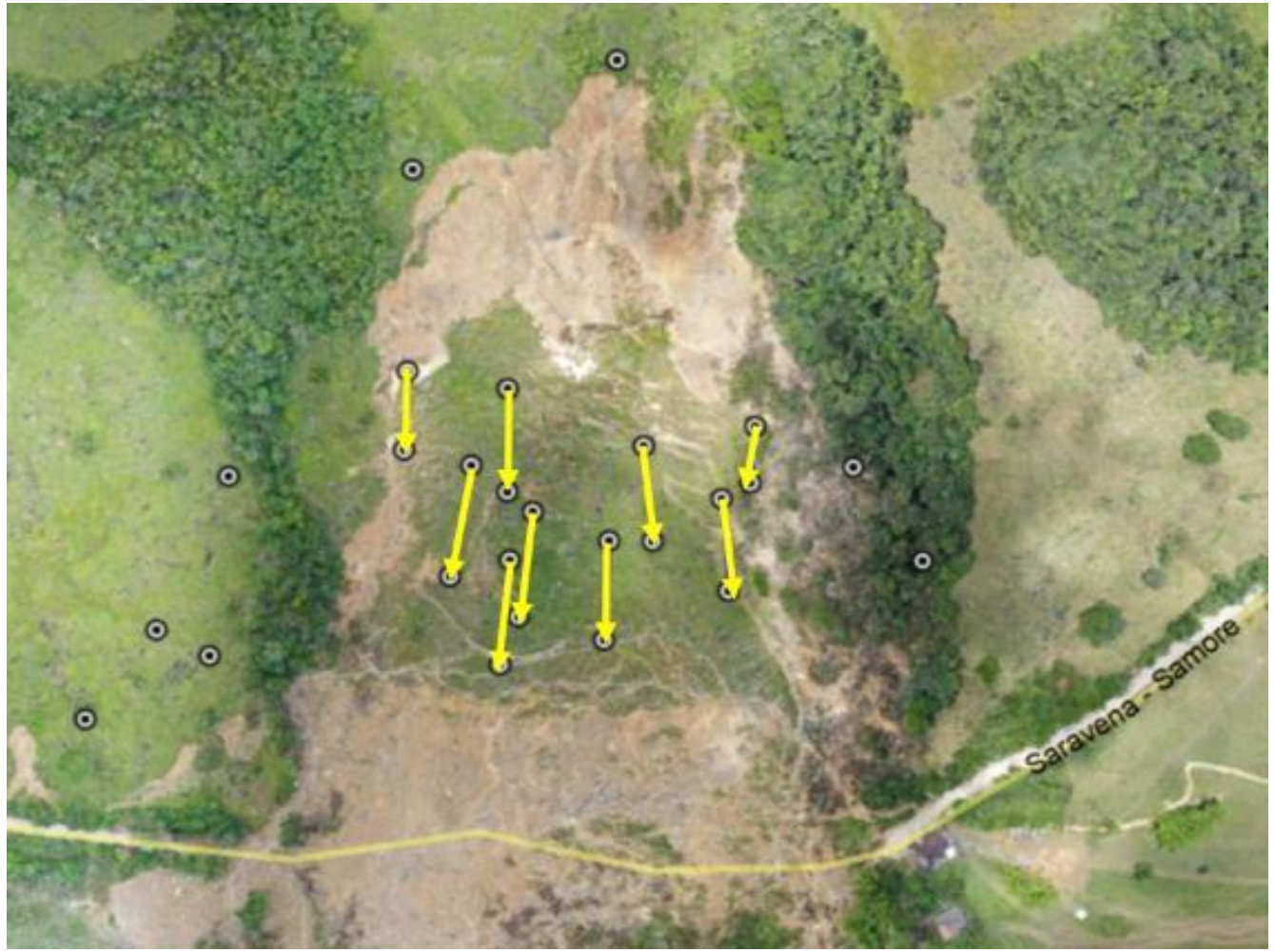



Landslide Geometry:

- width of 250 m
- an approximate length of 500 m
- main scarp reaches 45 m

So, the volume exceeds 3 million cubic meters, according to the classification of Fell (1994) is considered as very large.






Landslide displacement vectors obtained from multitemporal analysis of orthophotos. it was determined that middle and upper parts of the landslide largely retain their shape, despite the displacements evidenced of about 45 m.


Landslide toe was completely saturated and had a very soft consistency that prevented transit of people and/or equipment.

It was necessary to build a palisade to allow pipeline detection and identify section affected;

It was determined that pipeline presented a double break leaving a central section of 173 m that moved about 45 m, confirming the magnitude of the displacement vector.

# MITIGATION PLAN

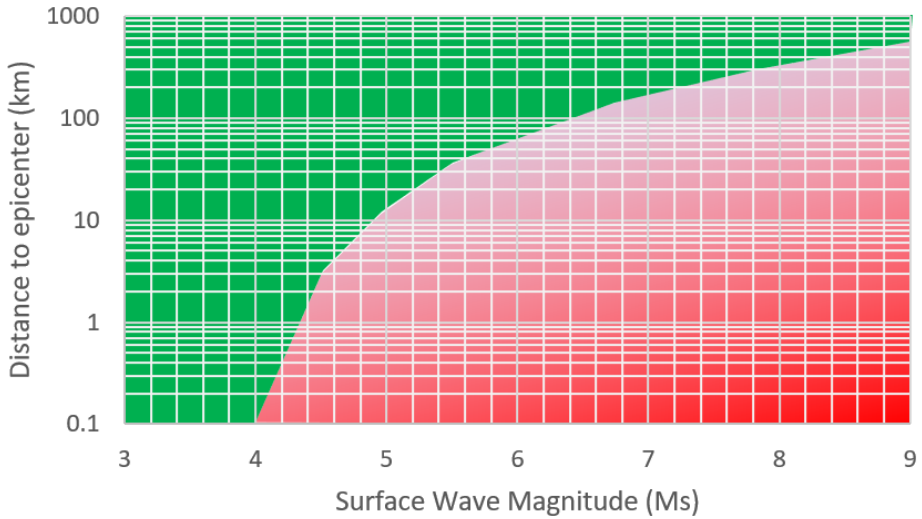
Given the impossibility of building a variant that would avoid landslide due to environmental and social restrictions, precarious stability conditions of the slope located on the right flank and consistency of material slid on ROW, it was necessary to implement a system of flexible pipes, located on the ROW, that would allow to comply with the minimum operating flow of the system.


A drainage network was built through channels on land, covered with geomembrane. Additionally, an interrupted drainage was identified, which had to be continued by means of concrete and stone channel that delivers to the stream that descends on the left flank of the landslide. In this way, the contribution of water that emerges in the transition rock-soil located on the main scarp was reduced.

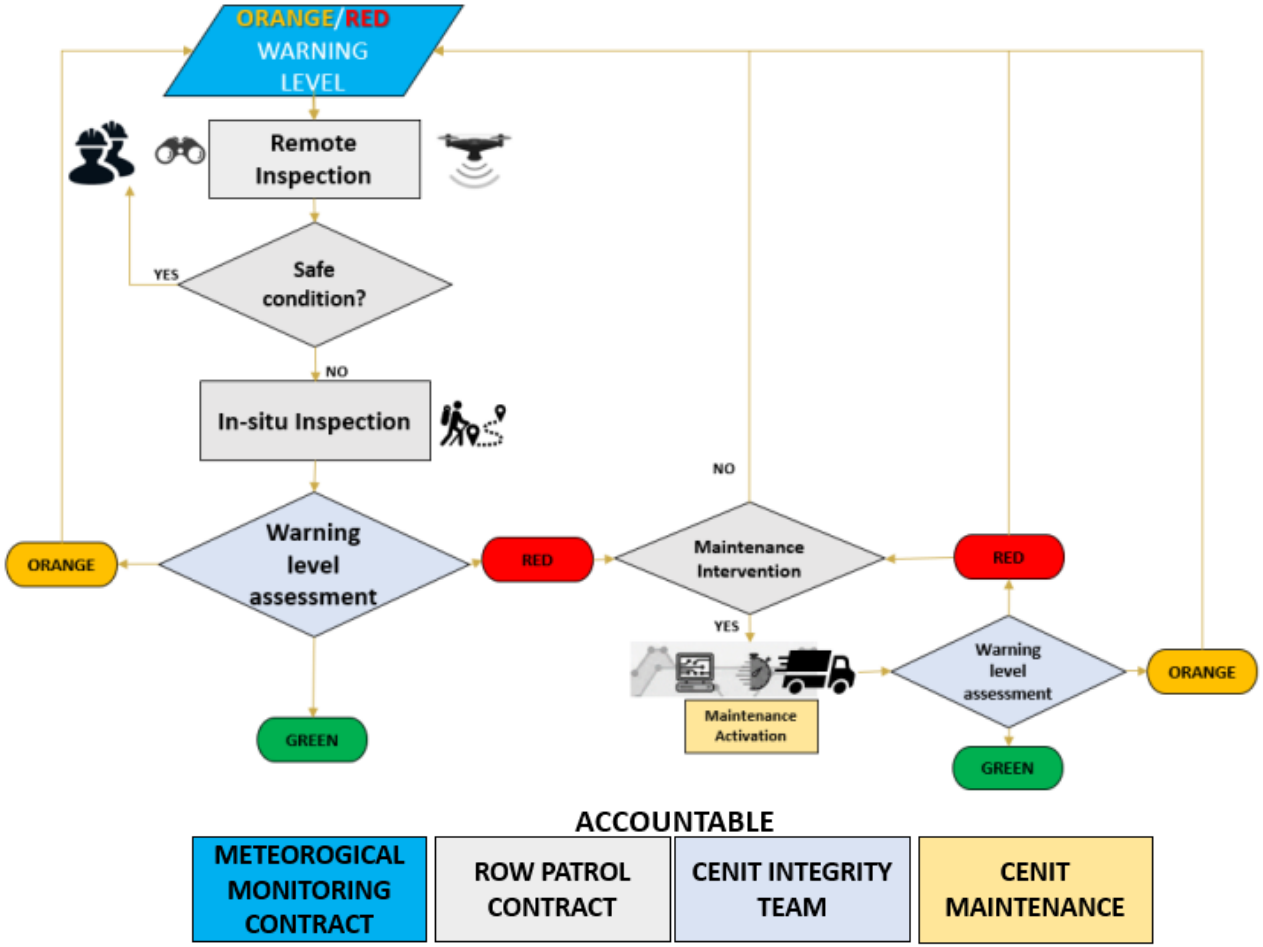
# MONITORING DURING OPERATION

| CONDITION | VALUE | WARNING LEVEL |
|---|---|---|
| If during the day the extraordinary rain threshold is exceeded. | 0 1 | If = 1 RED |
| Rainfall exceeds daily total threshold. | 0 1 | If Σ < = 1 GREEN |
| If during 4 or more hours accumulated rainfall exceeds total hourly threshold. | 0 1 | If Σ = 2 ORANGE |
| If prior rainfall (24 hr) exceeds total daily threshold. | 0 1 | If Σ = 3 RED |
| | Σ | |

Decision tree to define rainfall alert level




Earthquake induced landslide alert threshold




Alert level assessment flowchart

# CONCLUSIONS

- Although there are multiple intrinsic and extrinsic factors that generate instability processes, monitoring rainfall condition in real time is easy and economical, which allows to identify in a timely manner the occurrence of landslides and their impact along linear infrastructures, to propose preventive or corrective actions.

- Having an inspection plan that depends on rainfall conditions that occur in ROWs where linear infrastructure is installed generates great efficiency in use of resources.

- The use of orthophotos taken with drone is an economical scheme and of great help to monitor processes of instability. It also allows to obtain data on displacements and evolution of processes in a fast and timely manner.

- Flexible pipes have great versatility to meet instability processes that, due to their magnitude and/or location, do not allow traditional maintenance actions to be carried out.

# ACKNOWLEDGMENT

To José Vicente Amórtegui and Manuel Garcia for historical photographs and their teachings in classroom and in professional life.
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## THANK YOU