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MANAGEMENT RISK IN BLANCO RIVER

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ABSTRACT

Erosion in rivers is a natural process that evolves through time. In the case of OCP ECUADOR, several of them are monitored with known methodologies, however, understanding why erosion occurs and how to live with it is a task that requires investigation, this is Blanco River case KP 378+200 site that was approved as an ideal crossing in which a potential future problem was never noticed. Since the monitoring began, and after the oil pipeline operation, the monitoring did not report significant changes and it was considered in the fact that the pipeline was not leaking clogged. In 2012, the erosion became intense, losing several meters on the left bank. This event motivated the technicians to devise several works that would stop the erosion and even recover the lost section. For this purpose, breakwaters were built at an excessive cost, whose effectiveness was a solution that was called into question when they began to affect other sectors of the river. As the years passed, it was decided to change these devices with more friendly works such as the rock-casting, which despite their apparent effectiveness and easy replacement also succumb to the river's power, showing us its power and aggressiveness, transposing itself to these works, which makes us reconsider what to do, what we do it is investment or expense, how long will we be able to maintain ourselves and finally why didn't we see it?

Keywords: Pipeline; Probability of failure.

1. INTRODUCTION

This article has been selected as a topic of interest to OCP and other operators due to the incidence that the Rio Blanco activity has on the integrity of the pipeline. If we speak in the sense of risk, this value started very low, so much that it was considered negligible in 2003 when it began operations, the selection of the pipeline route followed the technical guidelines that sought to avoid rivers active meandering when its route is through pseudo-horizontal terrain, whose riverbed is covered with susceptible materials to erosion. The clog monitoring on the pipeline was the only follow-up mechanism that was proposed as an activity to ensure the integrity of the pipeline. For 5 years, the bathymetries did not present significant changes in the river. After this period until 2011 the river talweg transfer towards the left bank was recorded, causing the current to crash against the slope, losing a margin of 20m. This fact gave the indication that the river entered a change process which at first was speculated that would be temporary, in order to mitigate the margin erosion it was planned to build 4 breakwaters to allow more than diverting the current to enable the margin recovery with the material accumulation in a natural way, although the work was built in 35% its initial effects were successful in mitigating the advance erosion, this apparent success did not allow us to notice the changes that a single breakwater was going to cause both in the channel and on the opposite bank and that later affected the pipeline exposing it to the current, hence the premise of whether it is appropriate to fight against the current or we should understand what it is trying to communicate to us.

Table A: Chronology of events.

#	IDENTIFIED THREAT	PERIOD	#	IDENTIFIED THREAT	PERIOD
1	Channel erosion, coverage reduction, (4.22m)	2003-2010	7	Erosion in subfluvial crossing. Uncovered oil pipeline.	2019
2	Left bank erosion, cover reduction, (20 m)	2011-2012	8	Erosion in subfluvial crossing. Uncovered oil pipeline.	2020
3	Left bank erosion upstream of the crossing, (14 m).	2012-2015	8	Erosion in subfluvial crossing.	2021
4	Erosion at the base of groyne n.° 1, (3 m).	2015-2017	9	Erosion in subfluvial crossing.	2022
5	Erosion in the channel generates loss of cover on the oil pipeline, optical fiber breakage, (3.5 m).	2017	10	Erosion in subfluvial crossing.	2023
6	Erosion in subfluvial crossing.	2018			

2. MATERIALS AND METHODS

To determine that the Blanco River has a migration process without return, OCP carried out the following activities in 17 years, which were technically analyzed in the following order:

- DDV routine and extraordinary inspections.
- Linear bathymetric survey at annual frequency, using conventional topography.
- Spatial bathymetric survey under conditions, using instrumentation.
- Specialized studies.
- Works design, construction, and reconstruction.
- Probability of failure, (PoF), consequence of failure, (CoF) and the risk of failure, (RoF) establishment.
- Photogrammetric studies with drone.

3. RESULTS AND DISCUSSION

3.1 DDV routine and extraordinary inspections.

These inspections comply with a methodology that allows early warning changes in the environment that may affect the pipeline. Routine inspections have an established frequency that varies between 7, 14, and 21 days. In the Blanco River case, inspections are conducted every 14 days. Extraordinary inspections are guided exclusively when due to intense rains or strong earthquakes the hydraulic regime of the river may be affected with maximum floods or liquefaction phenomena.

The 2011, 2017 and 2023 inspections noted changes in the river configuration, especially on banks where important sections were lost or there were coverage losses due to flooding.

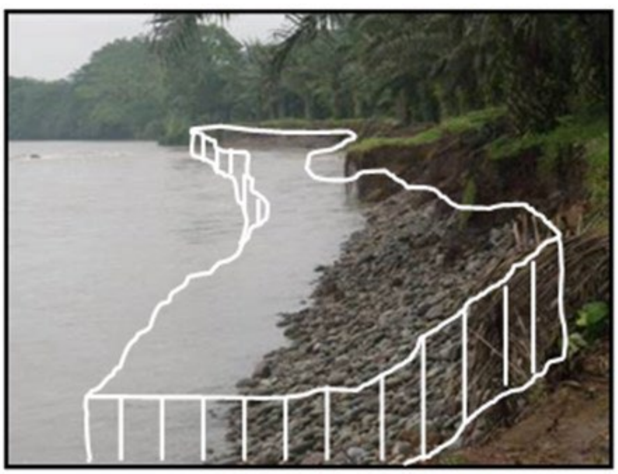

Figure 1: Magnitude of erosion with a loss of the left bank in 20m.

3.2 Linear bathymetric survey at annual frequency, using conventional topography.

The bathymetric survey with conventional topography is carried out after the winter, this limitation means that for 6 months there is no information on how the river has changed, with the possibility that the pipe is slightly uncovered or without bottom support. In 2017, this limitation allowed the fiber optic to break, giving a warning of a possible push on the pipeline as this device ran over the pipeline.

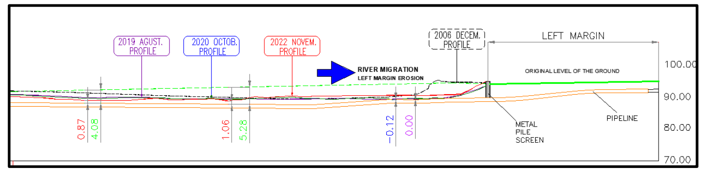

Figure 2: Bathymetric profile between the years 2018 and 2022.

3.3 Spatial bathymetric survey, using instrumentation.

The river bathymetry using instrumentation varied within these 17 years due to the type of equipment used, varying between single beam, multibeam and lateral scan, for each of these techniques it was necessary that the river depth to be high enough to avoid the instruments' damage and ensure a riverbed comprehensive scan.

The survey results were analyzed through the bathymetric/topographic integrated point clouds studies in June 2022 and March 2023 using Geographic Information System software for the generation and management of raster files to observe the changes that may have occurred in the riverbed.

The Figure shows on the left side the bathymetric survey results in June 2022, while on the right side the bathymetric survey results get in March 2023 are shown. In March 2023, it was not possible to collect data on the pipeline axis near the left bank due to river conditions. A greater distance can be observed between the contour lines in the central zone, explicitly, a lesser slope which could initially indicate sediments accumulation or rather the erosion extension zone without any deepening, it can also be observed a lower upstream elevation and close to the river left bank, which could indicate erosion or sediment transfer.

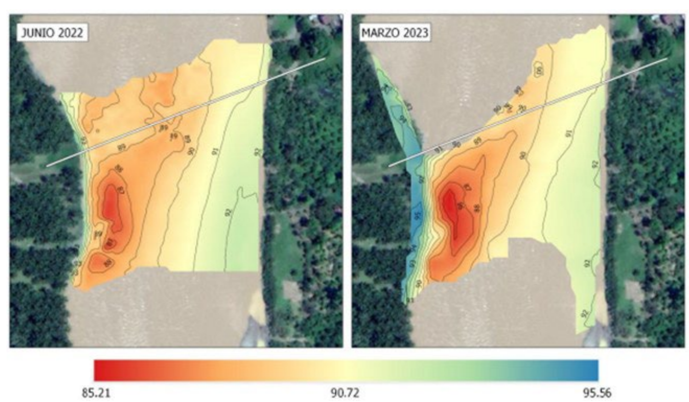

Figure 3: Spatial bathymetry between the years 2022 and 2023.

3.4 Bathymetry / topography multitemporal analysis.

By integrating all the information described in the bathymetry profiles obtained from previous years, the result is shown in the Figure.

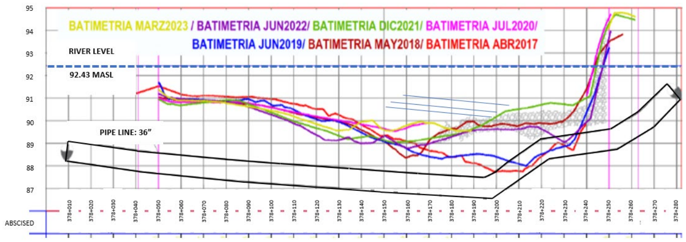

Figure 4: Illustration of the evolution of the erosion of riverbed over pipeline between the years 2017 and 2023.

Because there is a continuous replacement of stone material on the west side of the river to reduce the loss of cover, maneuvering over the affected area is difficult, however, if the water level rises and allows lifting, this it would not tell us if the pipe was exposed prior to the replacement of material. According to previous studies, the pipeline area exposure has been determined periodically, Figure 21 shows the burial depth of the pipeline from 2017 to the present, from KP 378+050 to KP 378+250.

Erosion changes were identified in the profiles on the pipeline from May 2017 to May 2018, where an erosion process of approximately 212 m3 was observed on the river west bank. It could be said that part of the material that was on the river west bank had moved towards the deep channel. Considering the pipe position delivered by OCP and the results obtained in the bathymetry in May 2018, the pipe was not discovered.

The erosion changes in the pipeline profiles were identified between May 2018 and June 2019, where an erosion process was observed on the river west bank of +22,201 m3 approximately. It was also determined in June 2019 bathymetry that the pipeline was partially uncovered between KP 378+206 and KP 378+238 for a length of 32 meters approximately.

The deposit of stone material, recommended in 2019, contributed to protecting the pipeline, therefore, in 2020 the pipeline was buried more than 2 [m] deep.

Similarly, using the information on the pipeline position provided by OCP and the topographic survey in section 8.1, it concluded that the deposit of stone material placed on the crossing of the pipeline in November 2021 by OCP Ecuador S.A, has contributed to protect the pipeline, therefore, at the time of data collection, it was buried more than (02) two meters deep, it means unsupported pipeline sectors (free spans) are not identified.

In June 2022, abrupt changes in erosion and sedimentation were observed on the west bank between KP 378+190 and KP 378+240, while on the east bank, the pipeline remains protected by an approximate burial level of three (3.0) meters between KP 378+050 and KP 378+090.

Currently, sedimentation changes are identified in the pipeline profiles between June 2022 and March 2023, where a sedimentation process was observed on the east bank of the river, between KP 378+090 and KP 378+190. It is also determined that from KP 378+050 to KP 378+190 the pipe is buried an average of 2.26 meters.

3.5 The longitudinal pipeline profiles comparison in June 2022 and March 2023.

Below are the longitudinal pipeline profiles corresponding to the surveys applied in June 2022 and March 2023.

From the graph profiles, we can identify an increase in height between approximately 2 cm - 99 cm between the KP 378+090 and KP 378+190. The bathymetries directed in 2022 and 2023, it is observed that there is little erosion and a greater tendency of sedimentation in the channel tending towards the river right bank.

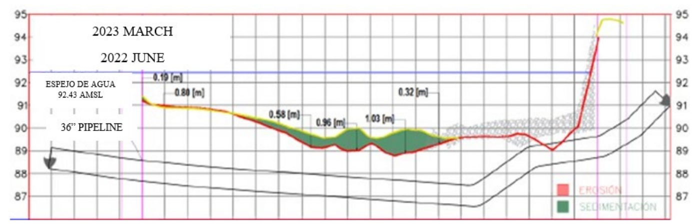

Figure 5: Illustration of the evolution of the erosion of riverbed over pipeline between the years 2022 and 2023.

3.6 Specialized third-party studies.

Location

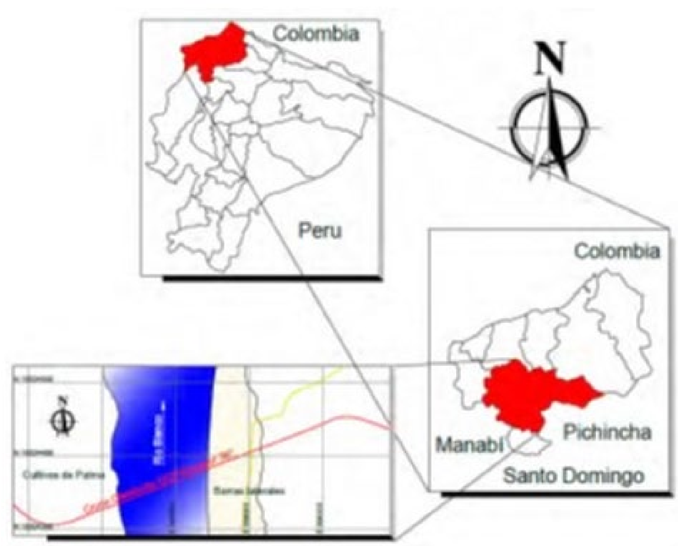

Figure 6: Blanco´s river location sub fluvial crossing in Ecuador.

The crossing under study is in the Blanco River to the southeast of Quinindé municipality, approximately 18 kilometers upstream of the river in the Esmeraldas province, Ecuador.

The analyzed site is located at approximately 94 meters above sea level, on a flat to semi-flat surface, humid surface soil; the presence evidence of gravel and river boulders on the surface of the shore, of erosion evidence and/or formation of gullies due to the lateral scour of the river are observed. Superficial drainage is acceptable, there are anthropic drainages built for palm cultivation. Subsurface soils have a moderate infiltration capacity.

Regional geology

The available geological information determines that in the Esmeraldas province there are lithological units Viche formations, Angostura, Borbón, Cayo, Canoa, Balzar, Piñón, Ostiones, Onzole, San Tadeo, Playa Rica, Zapallo Formations, among others.

The lithological types that emerge on the surface and the intervention in the vegetation cover determine strong erosive processes that contribute materials that originate alluvial fans in the lower part and cause plugging and flooding consequent to material accumulations.

Viche formations are found mainly in Tonsupa, Atacames, Tonchigue, Súa, San Francisco and Bilsa rivers, pass through the tropical humid forest.

As the rivers approach their mouths, the terrain texture is maintained, finding tuffaceous sandstones from the Bourbon Formation. Muisne, Sálima and Cojimíes rivers, on the northwestern coast branch of the Mountain range, cross humid tropical forests, and drain over medium to fine-textured terrain, defined by the Viche Formation sandstones and Playa Rica Formation. Quinindé River, fed by the Dógola, Arenanga and Cupa rivers, flows over fine-textured soils, from the Ónzole Formation sediments.

In the soil study executed, the following types are present at the crossing site:

- Well-graded, humid, gray sand, zero tenacity, zero dry resistance of the SW type.
- Poorly graded gravel with sand, grey, wet, zero toughness, zero dry strength GP type.
- Poorly graded sand with silt, brown and gray colors, humid, zero tenacity, zero dry resistance of the SP/SM type.
- Sand well graded with silt, brown and gray, moist, zero tenacity, zero dry strength, SW/SM type.
- Poorly graded sand, grey, humid, of the SP type.

Table B: Drilling record of the P1 survey on the left bank of the Blanco River.

GEOSUELOS CIA. LTDA.

PERFORATION REGISTER
RIO BLANCO KP 378+200
OLEDUCTO DE CRUDOS PESADOS
ESMERALDAS

HOJA 1 DE 1

SONDEO No.: P-1
UBICACIÓN: KP 378+201.54
DIAMETRO: NW = 76.2 mm
COORDENADAS: N10024348.103 / E683624.334
COTA: 92.27 msnm
REVESTIMIENTO NW: 14.00m
DIÁMETRO SONDEO: 3"
DIÁMETRO NÚCLEO: 2"
FECHA DE INICIO: 29 de Julio de 2011
FECHA DE FINAL: 30 de Julio de 2011

PROF COTA (m)	N.F	DESCRIPCIÓN	Recup (m)	SPT N = GOL 30cm	RQD	W (%)	L.L. (%)	I.P.	G	S	F	SUCS
0.00 – 1.00 (91.27)	0.10	ALUVIAL Arena, de colores café claro y gris, muy hýmeda, tenacidad nula, resistencia seca nula. Presencia de limo. 1.20m	50	-								
2.00 (90.27)		ALUVIAL Arena pobremente gradada con limo, colores café claro y gris, tenacidad nula, resistencia seca nula. 2.60m	50	-	-	27	-	NP	0	92	8	SP/S
		ALUVIAL 2.70m	9	-								
3.00 (89.27)		ALUVIAL 2.90m	10									
4.00 (88.27)		ALUVIAL Arena pobremente gradada, colores café claro y gris, tenacidad nula, resistencia seca nula. 3.90m	30	-								
5.00 (87.27)		ALUVIAL Arena bien gradada con limo, húmeda, colores café claro y gris, tenacidad nula, resistencia seca nula.	30	-		13	-	NP	0	94	6	SW/S
		FIN DEL SONDEO										

Blanco River Hydrology

The Blanco River, with a drainage area equivalent to 6,000 km2, is made up of multiple tributaries, including Sábalo, Inga, Silanche, Cabuyales, Caoní, Achiote, Abundancia, Bravo, Las Juntas, Mulaute, Nené, Memé Chico, Toachi, Pilatón and Santa Ana, a sub-basin that finally forms part of the Esmeraldas River hydrographic basin.

Table C: Decadal flow rates measured instrumentally.

STATION		HISTORICAL DECADAL FLOWS FEB/11-20 (m^3/s)	AVERAGE DECADAL FLOW (m^3/s)			
CODE	NAME	PERIOD	MID	MINI	MAX	(07- Feb 11-20)
H-138	Blanco DJ Toachi	82-05	536.1	163.9	970.6	430.2

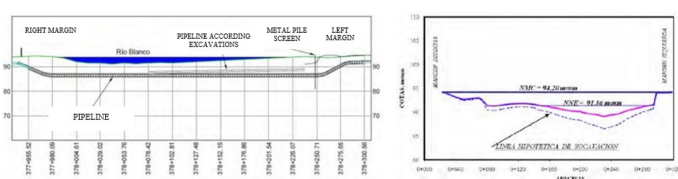

Figure 7: Blanco River´s profiles comparative between the years 2003 and 2017.

Blanco River Geomorphology

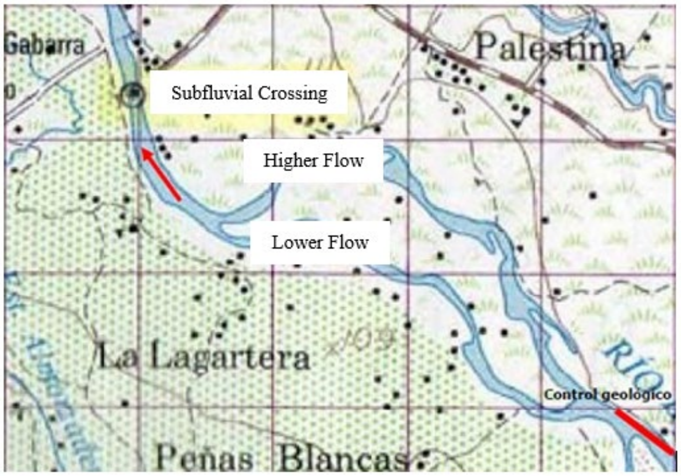

Figure 8: Configuration of the Blanco River with two branches before the sub fluvial crossing.

The Blanco River in the crossing sector is a winding and branching river. The crossing upstream is an island in the center of the river with two lateral channels. Upstream of the island on the right bank, there is a rock outcrop which acts as a geological control and directs flow towards the right side. The right channel currently handles a higher flow than the left channel. For this reason, the channel downstream of the confluence is mainly controlled by the right channel.

As a result of channel control through the right channel, a curve with extrados is formed towards the right bank towards the OCP crossing area.

Effects of erosion on the ROW and the crossing at KP 378+200.

The current location towards the left bank at the crossing site generates lateral erosion and a movement of the riverbank to the left, threatening the ROW. The construction of the jetty has prevented the direct impact of the current on the ROW, and in this way has guaranteed the left bank stability of the crossing.

Lateral erosion on the site causes.

- Lateral erosion on the left bank of the Blanco River at KP 378+200 is related to the following factors.
- The geological control upstream of the island directs the river towards the right channel of the branched channel.
- River morphology with the presence of two channels upstream of the crossing site, with higher flows in the right channel directing the river towards the left bank next to the OCP crossing.
- The gallery forest that formerly protected the left bank of the Blanco River has completely disappeared in the sector upstream of the crossing.
- The main channel or current directly impacts the crossing site. The construction of a breakwater close to the current impact site has protected the crossing site.

The evolution of the problem in prospects

In accordance with the site geomorphological and geotechnical characteristics, the following process should be in the future:

I. *Continued erosion of the river left bank and movement of the river towards the left bank upstream of the crossing site.*

If the current river morphology is maintained, the channel will try to move to the left.

II. *Problems related to the El Niño phenomenon.*

The El Niño phenomenon can generate large increases in flow at the site, with the following scenarios being possible:

Scenario 1:

Extraordinary increase in flow in the right channel of the branched channel upstream of the crossing site. In this case, an intense erosion event could occur on the left bank, which could generate a significant impact on the ROW. The jetty could fail, and a channel river forms to the left of the jetty along the ROW.

Scenario 2:

Extraordinary increase in flow in the left channel. In this case, the current would move towards the center of the river and the stability situation at the crossing would improve. With the existing information, it is not possible to predict the occurrence of the two previous scenarios. It is recommended to implement mitigation measures for the possibility of occurrence of scenario 1.

III. *Problems related to the possible pipeline exposure to the current in the center of the river.*

Currently, it is not observed that the pipeline is exposed at the bottom of the river. However, in the case of extraordinary events of large flows, the pipeline could eventually be partially or totally exposed. The occurrence of this phenomenon, although possible, is not considered very probable.

Ultimate long-term solution

The definitive long-term solution is the construction of a directed sub fluvial crossing long and deep enough to circumvent all the geomorphological problems at the crossing site.

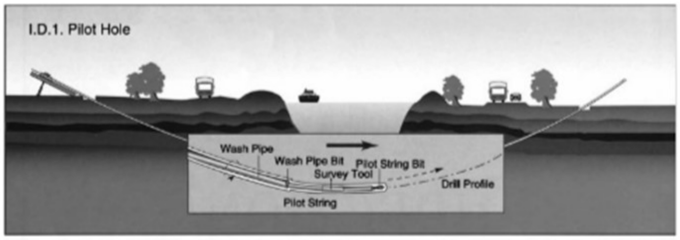

Figure 9: Pilot tunnel drilling. This method is executed regardless of the river level.

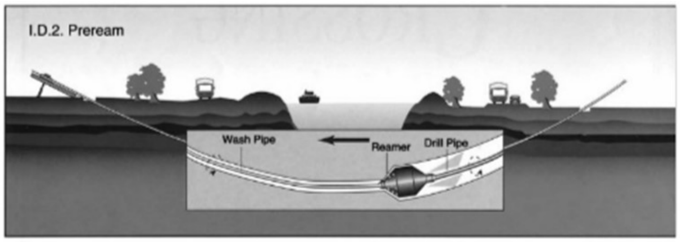

Figure 10: Reaming of the pilot tunnel with a device that widens the section.

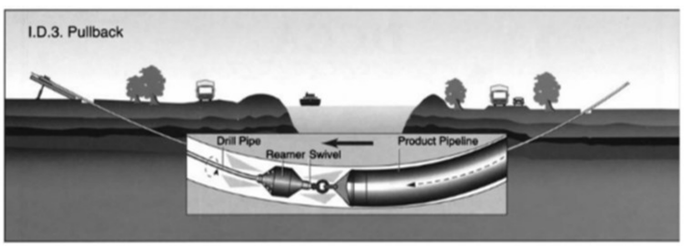

Figure 11: Dragging the pipeline with the help of the reaming device.

Short- and medium-term solutions:

In the short and medium term, it is recommended to build the following works:

- The existing groyne Reinforcement:

It is recommended to reinforce the existing breakwater by expanding its width and protecting its embedment against the shore. It is recommended to do this work using metric stone.

- A lateral protection upstream of the groyne construction:

It is recommended to build a lateral protection upstream of the breakwater using metric stone.

- Armoring the bottom of the river at the crossing:

It is recommended to place RIP-RAP from 6.0 meters upstream to 10 meters downstream on the ROW along the entire length of the crossing. This armoring generates bottom control, decreasing the depth of the channel and improving the stability of the pipeline at the crossing site.

3.7 Works design, construction, and reconstruction.

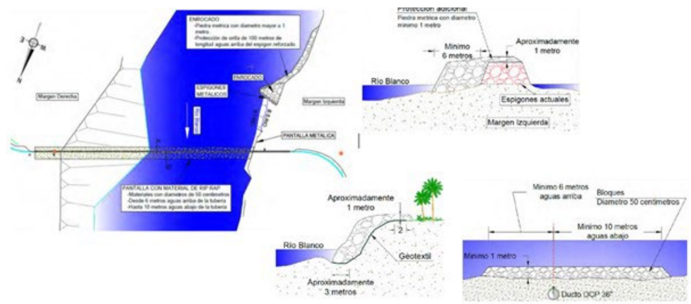

Figure 12: Recommended works to control erosion in the channel and left bank.

Figure 13: Sequence of implemented erosion control works.

3.8 Photogrammetry and satellite photos analysis.

Images of the changes registered in the interest area during the periods January 2023 – 2015.

The multitemporal analysis focuses on 3 critical points (of the 2 polygons surveyed): KP 379, KP 381 - 382 and KP 389. To carry out this analysis, the orthophotos generated by Drone & Gis in September 2022, January 2023, and April 2023, as well as Planet satellite images from January 2022, November 2020, December 2019, December 2018, December 2017, December 2016, and December 2015. In the case of satellite images, a combination of bands 1, 4, 3 to give more prominence to the water. Below are the images of the points mentioned for the different dates analyzed:

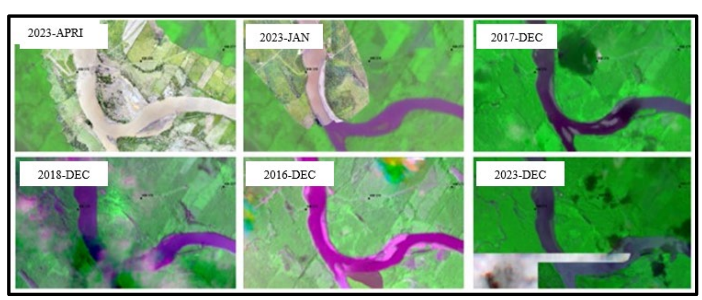

Figure 14: Multitemporal analysis satellite images.

Flooded zone in KP 378 – 379 identifications.

In the April 2023 survey, it has been identified that in the sector of the Blanco River crossing, (KP 378 -379) an area of about 23 hectares has been affected by floods and because of this there is evidence of a loss of vegetation on this surface. The following images show the comparison between the last 3 monitoring carried out in this sector:

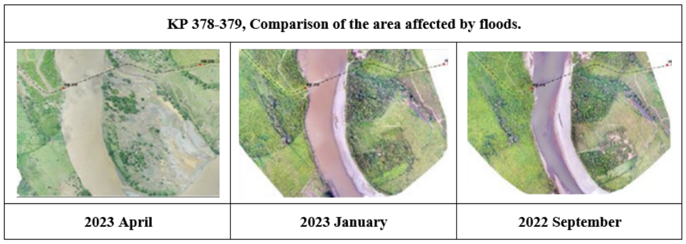

Figure 15: Analysis of orthophotos between the years 2022 and 2023.

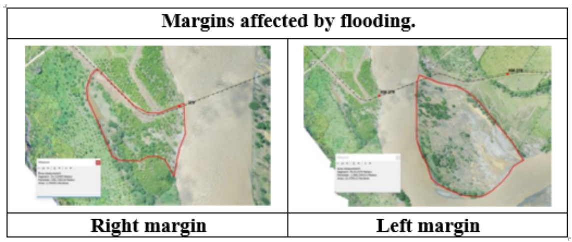

Figure 16: Evidence of the dragging of material on the banks of the Blanco River caused by flooding.

3.9 The probability of failure (PoF), consequence of failure (CoF) and the risk of failure (RoF) establishment.

The general bathymetry of the crossing as of August 2023 is presented below, in which erosion can be seen with loss of cover on the right bank, also loss of cover in the channel in the middle zone and erosion with uncovering of the pipeline in the channel near the left bank.

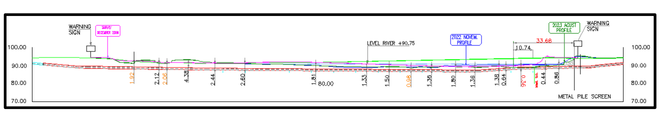

Figure 17: Complete bathymetric profile of the Blanco River (August 2023).

The following graph shows the two erosion areas on the right bank of the Blanco River, as a consequence of the extraordinary floods that occurred in the first four months of the year 2023, the erosion areas are produced by water currents that were washing the sandy silt material of which it is composed lithologically, the margin, although there is erosion, the integrity of the pipeline is not in danger. The possibility that a similar event occurring in 2024 is quite probable since the flooding was caused by the overflow of a dam that the mining activity built several years ago, and which was insufficient.

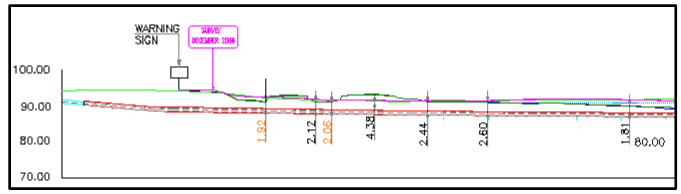

Figure 18: Enlargement of the right section of the bathymetric profile, (August 2023).

The graph below shows two important erosion areas, the first located in the middle zone of the river, where the cover is 0.98m, slightly like the cover in November 2022. The most important finding is located close to the left bank, where the loss of cover of the pipe is evident, which includes the uncovering of a third of the structure, in a length of 10.74m. There is no possibility of a no-support condition as an immediate event.

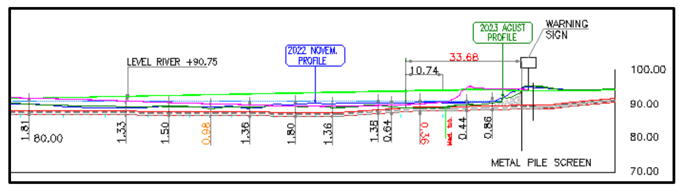

Figure 19: Enlargement of the left section of the bathymetric profile, (August 2023).

The following table reflects the probability of failure values in December 2021, December 2022, July 2022, July 2023, and August 2023. In general, it can be determined that over two and a half years of monitoring the riverbed has eroded twice, managing to uncover the pipe. The failure probability reached the value of 1e-01, a significant value that indicates the need for intervention. Talking about the Blanco River, the possibility of implementing works in its channel is only admitted in the months of October and November, which are those where the water level low being able to cross heavy machinery with the help of cofferdams and temporary embankments.

Table D: Multitemporal failure probability in riverbed.

GENERAL DATA		RIVER BED							
DATE	(Φ)	DISIGN COVER	CONST. COVER	CURRENT COVER	CURRENT COVER + (Φ)	0.5 (Φ) + Φ	0.5 (Φ) PIPE ABOVE (12) AND (12)	CUALIT. PoF	NUMERIC PoF
2021/DEC	0.91	2.67	1.94	1.22	2.13	1.37	0.91	D	1.E-02
2022/DEC	0.91	2.67	4.08	0.87	1.78	1.37	0.91	D	1.E-02
2022/JUL	0.91	2.67	1.94	-0.25	0.66	1.37	0.91	E	1.E-01
2023/APR	0.91	2.67	4.08	0.87	1.78	1.37	0.91	C	1.E-03
2023/JUL	0.91	2.67	5.11	-0.36	0.55	1.37	0.91	E	1.E-01

In the case of the riverbanks, it can be seen that there have not had a significant change except in August 2023 (right bank), which does not mean that the river floods have not caused erosion, but simply do not coincide with the crossing that the pipeline makes through the river.

Table E: Multitemporal failure probability in right margin.

GENERAL DATA		RIGHT MARGIN				
KP	(Φ)	CONST. COVER	CURRENT COVER	0.5 (Φ) + Φ	CUALIT. PoF	NUMERIC PoF
2021/DEC	0.91	2.47	2.47	1.37	A	1.00E-05
2022/DEC	0.91	2.84	3.29	1.37	A	1.00E-05
2022/JUL	0.91	2.47	2.47	1.37	A	1.00E-05
2023/APR	0.91	2.84	2.13	1.37	A	1.00E-05
2023/JUL	0.91	2.92	1.92	1.37	B	1.00E-03

Table F: Multitemporal failure probability in left margin and PoF total.

GENERAL DATA		LEFT MARGIN					TOTAL POF = BED RIVER PoF + RIGHT M. PoF + LEFT M. PoF
KP	(Φ)	CONST. COVER	CURRENT COVER	0.5 (Φ) + Φ	CUALIT. PoF	NUMERIC PoF	
2021/DEC	0.91	5.14	5.14	1.37	A	1.00E-05	1.0E-02
2022/DEC	0.91	4.69	2.76	1.37	B	1.00E-04	1.0E-02
2022/JUL	0.91	5.14	5.14	1.37	A	1.00E-05	**1.0E-01**
2023/APR	0.91	4.29	4.64	1.37	A	1.00E-05	1.0E-03
2023/JUL	0.91	4.29	4.64	1.37	A	1.00E-05	**1.0E-01**

Table G: Risk factors determination.

RISK FACTORS	VALUES	UNITS	LEVEL
PoF (Probability of Failure):	1.00E-01		(Very Likely)
CoF (Consequence of Failure):	5300000	USD	(High)
RoF (Risk of Failure):	530000	USD/YEAR	(Medium)

Table H: Costs invested in KP 378+200, period: 2011-2023.

#	IDENTIFIED THREAT	CAUSES	PERIOD	ACTION	MONITORING COST (BATHYMETRY)	COST WORKS (EROSION CONTROL)
1	Channel erosion, coverage reduction, (4.22m)	Ideal cover configuration.	2003-2010	(1) Bathymetric monitoring.	$6,000.00	
2	Left bank erosion, cover reduction, (20 m)	River migration towards the left bank, flow of the right arm significant, curve of the river makes erosion possible.	2011-2012	(1) Bathymetric monitoring. (2) Erosion control consulting. (3) Groynes design. (4) Construction four groynes.	$1,600.00	$422,637.00
3	Left bank erosion upstream of the crossing, (14 m).	Migration phenomenon in development, the groynes not build cause erosion.	2012-2015	(1) Groyne #1 reinforcement. (2) Groynes n.° 2, 3 and 4 skeleton removal. (3) Bathymetric monitoring.	$3,000.00	$103,570.00
4	Erosion at the base of groyne n.° 1, (3 m).	The river current causes erosion at the groyne base n.° 1, scour in the direction to subfluvial crossing.	2015-2017	(1) Bathymetric monitoring.	$1,800.00	
5	Erosion in the channel generates loss of cover on the oil pipeline, optical fiber breakage, (3.5 m).	The river current causes erosion at the groyne base n.° 1, scour in channel reaches the position of the pipeline.	2017	(1) Bathymetric monitoring. (2) Monitoring with echo sounder. (3) Reconformation works in channel. (4) Removal of groyne n.° 1.	$1,000.00	$213,303.00
6	Erosion in subfluvial crossing.	The scour at the position of groyne n.°1 reappears.	2018	(1) Bathymetric monitoring. (2) Reconformation works in channel.	$368.88	$17,001.00

#	IDENTIFIED THREAT	CAUSES	PERIOD	ACTION	MONITORING COST (BATHYMETRY)	COST WORKS (EROSION CONTROL)
7	Erosion in subfluvial crossing. Uncovered oil pipeline.	Continues migration to the left bank.	2019	(1) Bathymetric monitoring, 0.00 m. (2) Reconformation works in channel.	$2,624.20	$39,327.48
8	Erosion in subfluvial crossing. Uncovered oil pipeline.	Continues migration to the left bank . Old erosion in the channel has incidence.	2020	(1) Bathymetric monitoring. (2) Reconformation works in channel.	$1,885.44	$10,600.00
8	Erosion in subfluvial crossing.	Continues migration to the left bank . Old erosion in the channel has incidence.	2021	(1) Bathymetric monitoring. (2) Monitoring with echo sounder. (3) Reconformation works in channel.	$995.44	$33,596.26
9	Erosion in subfluvial crossing.	Continues migration to the left bank . Old erosion in the channel has incidence.	2022	(1) Bathymetric monitoring. (2) Monitoring with echo sounder. (3) Reconformation works in channel.	$496.48	$59,154.48
10	Erosion in subfluvial crossing.	Continues migration to the left bank . Old erosion in the channel has incidence.	2023	(1) Bathymetric monitoring. (2) Monitoring with echo sounder. (3) Reconformation works in channel. (4) Photogrametric survey. (5) Satellital images multitemporal analysis.	$1,261.60	$114,355.31
				TOTAL (USD):	**$21,032.04**	**$1,013,544.53**

Table I: Risks matrix identified KP 378+200, Blanco River.

		IMPACT				
		INSIGNIFICANT	MINOR	MODERATE	MAYOR	CATASTROPHIC
FREQUENCY		1	2	3	4	5
FREQUENT	5	5	6	7	8	9
LIKELY	4	4	5	6	7	8
OCCASIONAL	3	3	EVENT N.°1 4	5	6	7
POSSIBLE	2	2	3	EVENT N.°2 4	5	EVENT N.°3 6
UNLIKELY	1	1	2	EVENT N.°4 3	4	5

RISK LEVEL	COLOR
ACCEPTABLE	
TOLERABLE	
HIGH	
EXTREME	

Table J: Risk assessment summary.

EVENT	FREQUENCY	IMPACT	LEVEL RISK	QUALIFICATION
PIPELINE INCOVERED	OCCASIONAL	MINOR	TOLERABLE RISK	4
PIPELINE IN SPAN	POSSIBLE	MODERATE	TOLERABLE RISK	4
PIPELINE IN FAILURE	POSSIBLE	CATASTROPHIC	HIGH RISK	6
LEFT BANK EROSION DUE TO MIGRATION RIVER	UNLIKELY	MODERATE	ACCEPTABLE RISK	3

Table K: Determination of Inherent Risk and Residual Risk.

CODE	RISK NAME	INHERENT RISK	RESIDUAL RISK
ORM-6	Left bank erosion due to migration river.	LOWER	LOWER
ORM-5	Pipeline falilure	HIGH	HIGH
ORM-4	Pipeline in span	MEDIUM	MEDIUM
ORM-3	Pipeline uncovered	MEDIUM	MEDIUM

Table L: Qualification of controls adopted to mitigate risk.

CODE	CONTROL NAME	QUALIFICATION	
ORM-3	Maintenance of screen with metalic pipe, dispositive that limits erosion advanc	77.5%	REGULAR
ORM-2	Reconformation works in channel.	42.5%	REGULAR
ORM-1	Bathymetric monitoring	73.5%	REGULAR

Table M: Mitigation risk and decision making.

MITIGATION RISK AND DECISION MAKING.			
APPROVAL LINE	ACTIVITIES	PROPOSED WORKS	COST (USD)
OPERATIONS AND MAINTENANCE MANAGEMENT	(1) Authorizes the construction of major works based on risk	(1) Construction of variant. (2) New subfluvial crossing. (3) Expansion of subfluvial crossing.	>300000
OIL PIPELINE SUPERINTENDENT	(1) Authorizes the construction of minor works based on risk.	(1) Reconformation of margins and channels.	<300000
SECTION SUPERVISOR	(1) Reviews and recommends improvements to the design. (2) Build the works.		
NATURAL FORCES SUPERVISOR	(1) Request and approve the risk analysis. (2) Request and approve mitigation work. (3) Approve special studies.		
GEOTECHNICAL /GEOLOGIST SPECIAL	(1) Preparates the risk analysis. (2) Preparates or contracts the design of works. (3) Requests special studies.		

4. CONCLUSION

The monitoring of the crossing of the Blanco River with topographic bathymetry, instrumental bathymetry and photogrammetry with a drone determine the transfer of the river towards the left bank, which will cause future damage to the pipeline, this because than the rise curve "channel river - margin" is close.

In the geotechnical and hydraulic studies of the river before the construction of the oil pipeline, the probable transfer of the river is not mentioned as a totally certain fact.

The expenses incurred to keep the site safe reach approximately USD 1,013,544.53 since 2011 without much detail. This total amount would currently make it possible to run the ascent curve on the left bank, including the one located on the right side which was affected in April 2023 by a flood.

The design cover in the channel to avoid damage to the pipeline was established at an average of 2.67m, the bathymetries from 5 years ago show lower values with considerable losses, in the future it is established that cover in the channel will also be lost. OCP must consider as safer options the deeper passage or propose a new route without problems of meanders and ramifications of the river.

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