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RIVER CROSSINGS: RIVER DIVERSION THROUGH THE RIGHT OF WAY

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ABSTRACT

River diversion is one of the less common hydrotechnical hazards. It means that a river leaves its original course to divert its waters towards a different path, usually within a wide flooding valley. Water now doesn´t flow across pre-designed water crossings, which comprises a greater pipeline wall thickness and counterweights proving additional resistance to stresses induced by water in case of exposure. When diversion takes place along the right-of-way (ROW), consequences are immediate, because it offers a preferential route for the river to flow, whenever the main course is blocked by sediments and debris. Initially, vertical scour takes place since the ROW is not prepared to accommodate high flows. Then buoyancy affects the pipeline after topsoil is removed. As erosion keeps evolving vertically, long segments of pipelines are subject to free-span conditions. Still, successive hydrological wet and dry seasons occur, affecting these exposed segments to buoyancy during floods and downward forces under its own weight during dry season. In the following paragraphs, two filed cases will be presented with their evolution and history of remediation works.

1. INTRODUCTION

River crossings are designed to account for high flows associated with high return periods (50 to 100 years) and their related hydrotechnical hazards. If they became exposed by erosive processes, still pipelines can resist (up to a certain point) typical stresses such as buoyancy and drag forces since they are constructed with a greater wall thickness and weights. This scheme is totally disrupted whenever the river diverts its course and starts flowing through another route, since it affects segments of a pipeline that were not previously designed as being affected by water flows. Among the most common examples are meander cuts. However, in this paper, a particular case of diversion through the right-of-way will be treated. Although this is not a common case, it is particularly dangerous because it affects long segments of pipelines subject to buoyancy, and are originated mainly by anthropic causes.

2. DIVERSION THROUGH THE ROW

During pipeline construction, a ROW is necessary to ease access, ditch digging and pipeline lay down. In spite considering of environmentally friendly practices an impact on vegetation is made. Revegetation may take place, but in a longer period of time. Thus, in case of flooding, ROW becomes a preferential path for water. Along this way, the pipeline is usually buried at an average of 1 m depth. This topsoil is easily eroded as soon as high river flows are diverted. Furthermore, when wide flood valleys are present, erosion comes associated with lack of counterweighting, especially for vintage pipelines which did not have a comprehensive natural hazards risk analysis during its conception.

2.1 Diversion through Medina River floodplain

Medina River has a watershed of 2300 km2, having its headwaters at an elevation of 5100 m at the Aconquija Sierras, part of the Cordillera Oriental, at the province of Tucumán, Northern Argentina. Two natural gas lines are placed at an elevation of approximately 290 m. The river travels 120 km to descend 4810 meters.

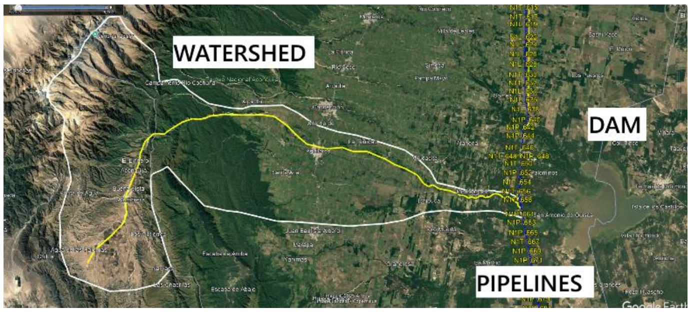

FIGURE 1: MEDINA RIVER WATERSEHD

This river is a tributary of the Salí River which drains the entire province of Tucumán. Hydrological studies performed at the basin scale yielded a discharge for a return period of 50 years of 1268 m3/sec. The river width 3 km upstream of the pipelines (before bifurcation) varies between 60 and 80 m. It is rather shallow with both banks being less than 2 m. Sediment at the crossings are made of fine silty sand.

An average hydrological year can be described as wet summer and dry winter. Rainy season usually begins in September through May, but unfortunately, high flows and floods were registered as early as October.

CITY	MEAN MONTHLY PRECIPITATION [MM]												
	Set.	Oct.	Nov.	Dic.	Ene.	Feb.	Mar.	Abr.	May.	Jun.	Jul.	Ago.	Anual
Concepción	21	65	107	139	198	177	176	81	36	21	10	9	1045
Monteagudo	8	42	67	83	120	118	110	41	14	8	4	4	620

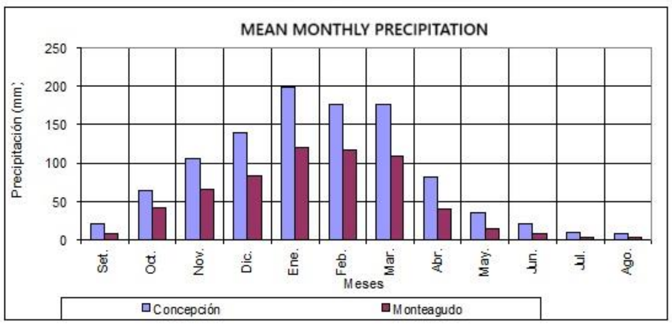

FIGURE 2: MEAN MONTHLY PRECIPITATION

In the year 1967, the Río Hondo Dam was built for multiple purposes such as irrigation, electricity generation and flood control. The presence of the dam, changed the discharge of many tributaries in the Salí river, lowering its slope and creating a delta.

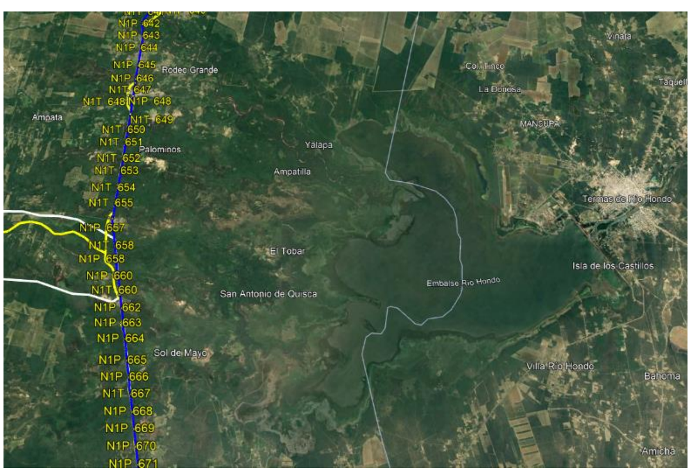

FIGURE 3: TRIBUTARIES DISCHARGE INTO THE DAM LAKE

FIGURE 4: CROSS SECTION OF A RIVER BRANCH NEAR THE CROSSINGS

Putting together the high discharge, small dimensions of the river and mild slope, flooding of a huge area becomes apparent. The river responds to this combination of factors by dividing its course into many branches which after a while are blocked with debris and sediments, before opening a new branch. Also, every rural road within the flood valley becomes a water course, changing the flow pattern and, thus, the amount of water and the location where water enters the ROW.

FIGURE 5: BLOCKED RIVER BRANCH WITH DEBRIS AND FINE SEDIMENTS

Water, year after year, flows in a different pattern and reaches the ROW at one or many points of entrance.

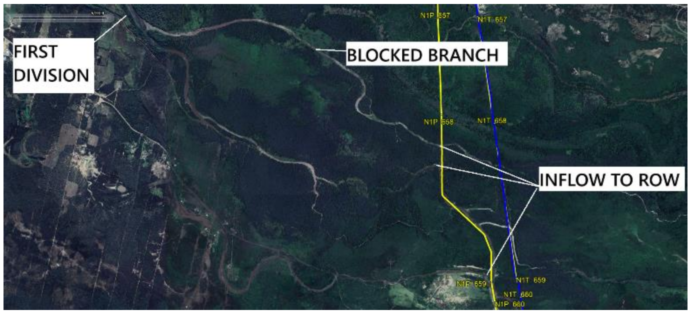

FIGURE 6: POINTS OF ENTRANCE INTO THE ROW

In successive years after construction water entered the ROW first at the main river course, then after it was blocked, using old meanders and low zones to other three points of entrance.

This process took place on both lines ending in the exposition of pipelines after extreme flood events; one in 2000 and the other in the summer of 2016. As seen in Figures 7 and 8, two long segments (of approximately 80 meters) of pipeline without counterweights were exposed, that coincide at locations where the ditch raised slightly its elevation.

FIGURE 7: BUOYANCY OF 24" LINE AFTER YEAR 2000 FLOODING

FIGURE 8: BUOYANCY OF 30" LINE AFTER YEAR 2016

For the 30" line, preliminary remediation was implemented whenever access was possible after water recede. Given the massive flood that occurred throughout the entire flood valley, access became a problem. The nearest paved road is 10 km west, while dirt roads, which are privately owned, are between 10 and 17 km long. Upgrade and maintenance of access roads involve a considerable amount of time and money. Given the fact that rain could end in May and floods can begin in October, the time window of dry weather and access that allows to implement a major scale remediation work limited to four months (June through September).

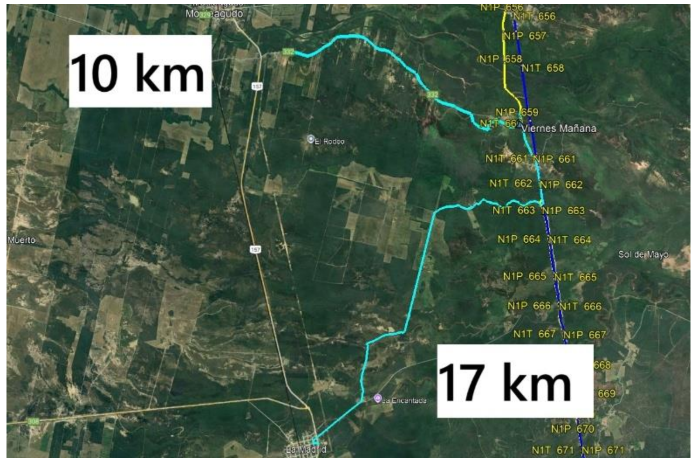

FIGURE 9: ACCESS ROADS

Temporary remediation works were undertaken consisting of sandbags placed over the pipeline. Originally, they overcame buoyancy forces. However, since water kept flowing along the ROW, its foundation was eroded. Thus, an instable situation developed in which the pipeline was ok with the counterweights while flooded but then tensioned downwards when not. This was solved by avoiding free spans by supporting the bottom of the pipeline.

FIGURE 10: SANDBAGS PLACED FOR PRELIMINARY REMEDIATION

Final remediation was reached for de 24” line by horizontal directional drilling a new crossing that is approximately 1,100 meter long and 20 m deep. The same alternative was chosen for the 30” line nowadays.

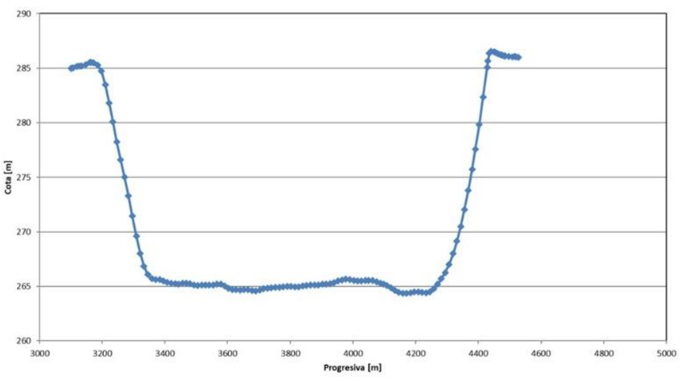

FIGURE 11: NEW HDD CROSSING FOR THE 24” LINE

2.2 Diversion through Bajo del Añelo Creek´s floodplain

This crossing is located at the desert of northern Patagonia, where mean annual precipitation is around 300 mm, with the rainy season happening during autumn (March-June). While walking around the area back in 2004, it appeared as a minor creek in terms of width (22 m) and low banks (1.5 m). After a flood, this water course experienced a lateral migration that showed minimum soil cover at its left bank and an exposed segment of pipeline at the end of the flood plain, as water moved back to the main creek through the ROW after the discharge peaked. However, water kept flowing through the main course as a general pattern. Remediation works were oriented to two localized areas: protecting the river´s original left bank and covering the exposed segment while blocking and diverting water at the edge of the flood plain out of the ROW.

FIGURE 12: RIVER COURSE IN 2004

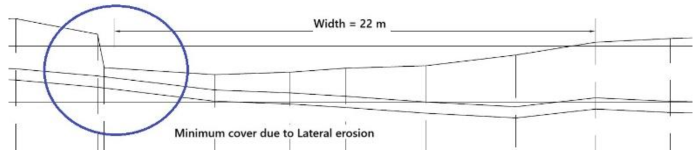

FIGURE 13: RIVER CROSSING IN 2004 AFTER FLOOD

FIGURE 14: PIPELINE EXPOSED AT THE EDGE OF FOODPLAIN AFTER 2004 FLOOD

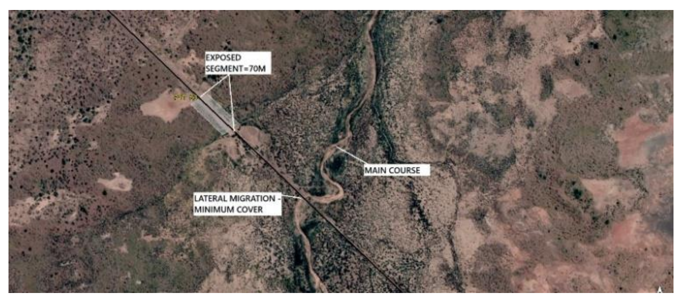

FIGURE 15: RIVER CONFIGURATION IN 2004

Although at that time it did not appear to be an extraordinary problem, a comprehensive study was carried out, including hydrologic and hydraulic modeling. The size of the watershed yielded a value of 1,500 km2, which was in contrast with a 20 m wide creek but explained why the floodplain comprised a greater width of 2.000 m.

FIGURE 16: LIMITS OF THE 1,500 KM2 WATERSHED

This situation didn´t experience any substantial change until approximately 2014. During that year, the river changed its course and started to flow through the ROW for approximately 500 meters. Among the possible reasons for this change are the lack of significant floods from 2004 to 2014, which may cause the deposition of sediments on the original river, plus the fact that the ROW offered a preferential path during high flows.

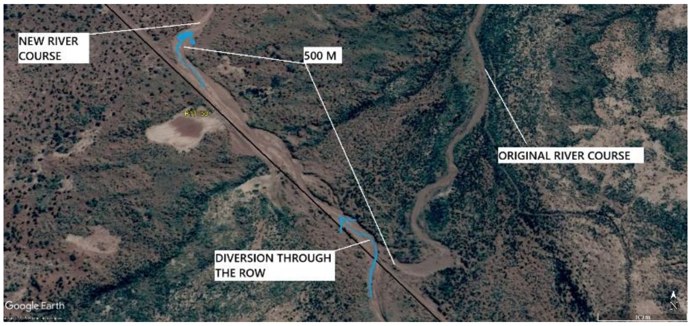

FIGURE 17: DIVERSION THROUGH THE ROW

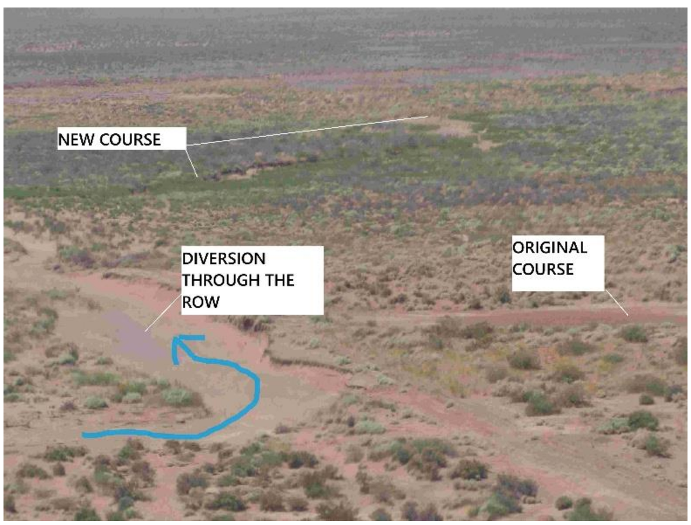

FIGURE 18: AERIAL PICTURE OF 2014 SITUATION

The new situation presented a completely different hydrotechnical threat to pipeline integrity since instead of localized exposures, a 500-meters stretch of pipeline was affected on its left new bank. As stated earlier, the original pipeline design contemplated a concrete coating of only 24 m long, located at the original crossing. Thus, the pipeline was not prepared to account for buoyancy or stresses induced by water flows in case of exposure. This was the case after the 2014 flood where new segments along the river had minimum lateral soil cover, which was now the focus of further monitoring surveys. At the beginning, temporary remediation works were implemented to restore flow through the original river course and the lateral soil cover by soil movement works. Given the fact that floods are not common due to the annual precipitation regime, this scheme proved suitable for a while. In January 2022, a new storm took place, exposing approximately 35 m of pipeline.

FIGURE 19: EXPOSED PIPELINE ALONG LEFT BANK

FIGURE 20: DETAILED PICTURE FROM THE SAME AREA

Temporary remedial measures were implemented immediately in the field. A typical solution was constructed to avoid further damage consisting in placing counterweights and a building left bank protection with geotubes that performed well in other locations with similar erosive processes. Geotubes are common in isolated places in the desert since stones for gabions and rip-rap protections are harder to get within a reasonable distance. They are filled with local soil and covered in their exposed surface with a thin layer of cement mortar to protect them from scratches from debris, especially bushes and thorns. An additional flexible protection at their foot was placed to avoid scour and sliding of the geotubes pile, made out of flexible concrete mats. Soon after construction, a flood took place verifying a suitable performance of temporary works.

FIGURE 21: COUNTERWEIGHTS OVER THE EXPOSED SEGMENTS

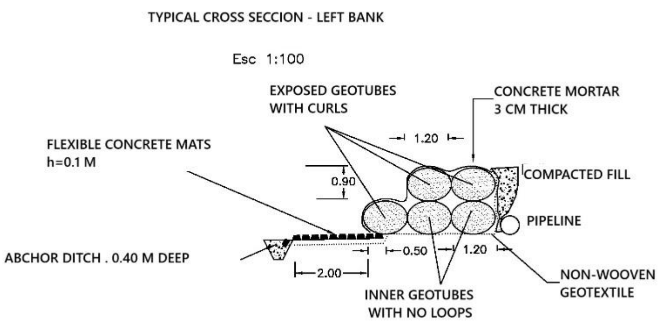

FIGURE 22: TYPICAL CROSS SECTION OF TEMPORARY REMEDIAL WORKS

FIGURE 23: BANK PROTECTION WITH GEOTUBES

FIGURE 24: PERFORMANCE AFTER A FLOOD IN 2022

In spite of having the situation under control, a parallel process started to give a more comprehensive and definite solution to this problem, given the history of remediation works performed along the years. A full integrity study was carried out to fulfil local regulations imposed by the local water authority as well as natural gas transport regulations. The study included hydrological studies and modelling to compute the design discharge, topography of the affected area to obtain the digital terrain model of the floodplain, soil studies, hydraulic modeling to obtain the water surface elevation, depth of flow, velocities along the river and the extent of the flooded area. In the following paragraphs a brief description of these main components will be provided.

As it is usual in Argentina, rain (even less discharge) information is available in such isolated areas. Thus, to compute the discharge, an effective rain-discharge model was employed. Then, the next step is to assume the areal extent of the design storm, which is set by regulations as the one that corresponds to a return period of 100 years. Two scenarios were modeled: one in which the storm is located at three different locations within the watershed, and another one used to verify the solution consisting in computing a higher discharge with rain falling over the entire watershed.

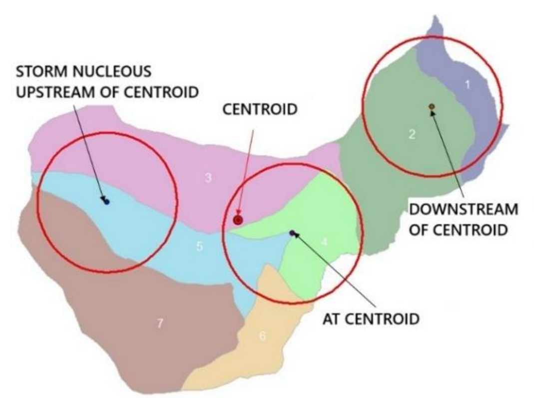

FIGURE 25: DESIGN STORM LOCATION FOR FLOW CALCULATIONS

Once the discharge was obtained, then a hydraulic model was run. In the following figures, the extent of the flooded area, water depth and the velocity maps are presented.

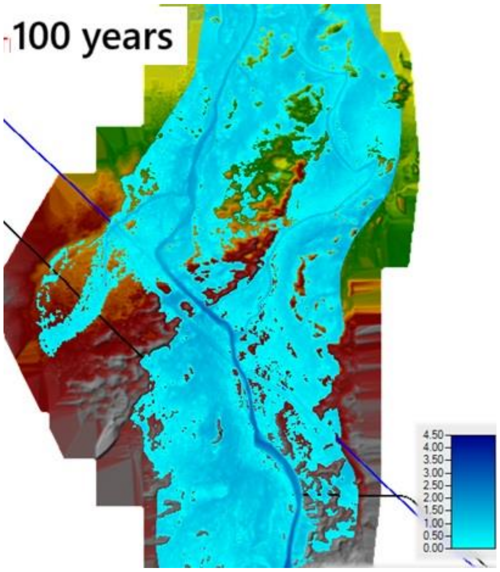

FIGURE 26: EXTENT OF THE FLOODED AREA AND WATER DEPTH

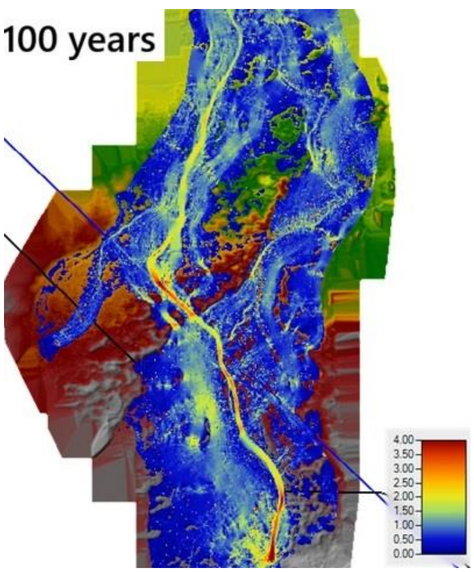

FIGURE 27: VELOCITY RANGE THROUGHOUT THE FLOOD PLAIN

Interested conclusions can be reached after these results:

- The extent of the flooded area is massive. As shown in Figure xx, the dimensions of the cross section of the original river course (22 m wide and banks of 1.5 m) could only cope with minor flows. Flood conditions will develop as soon as a strong storm takes place, a fact that was corroborated by a filed visit after a flood in April 2004.

FIGURE 28: FIELD SURVEY AFTER A FLOOD

- After diversion through the ROW, exposed segments of pipelines are congruent with zones of highest velocities, as values reached in that area were in the order of 3 to 4 m/sec.

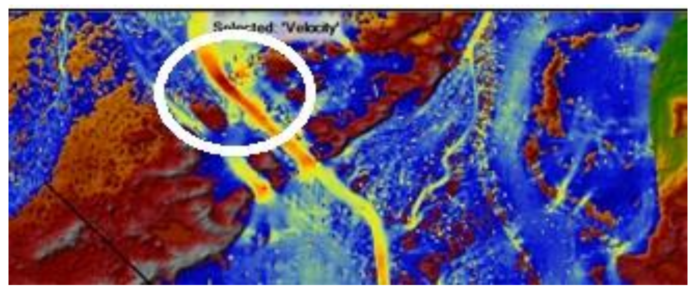

FIGURE 29: DETAILED VELOCITY MAP AT THE ROW

- The flood plain still shows a significant flow along the original river course (right side of the maps) although with lesser values of velocity.

Two mail alternatives were considered for a more comprehensive solution:

- In-service lowering of the pipeline by natural flexion for 400 meters,

- Restoring the river to its original course, avoiding water running through the ROW. This alternative was finally selected and is now on the stage of detailed engineering. It comprises a long wall of geotubes along the left bank and the construction of a riverbed protection with a flexible solution of concrete blocks placed over a woven geotextile with loops. The main dimensions for the components of the project at the crossing are:

    - Geotube wall at left bank: 700 m long and 3.6 m

- River revetment with flexible concrete mats: 32 m wide horizontal, plus 12 m inclined at right bank.

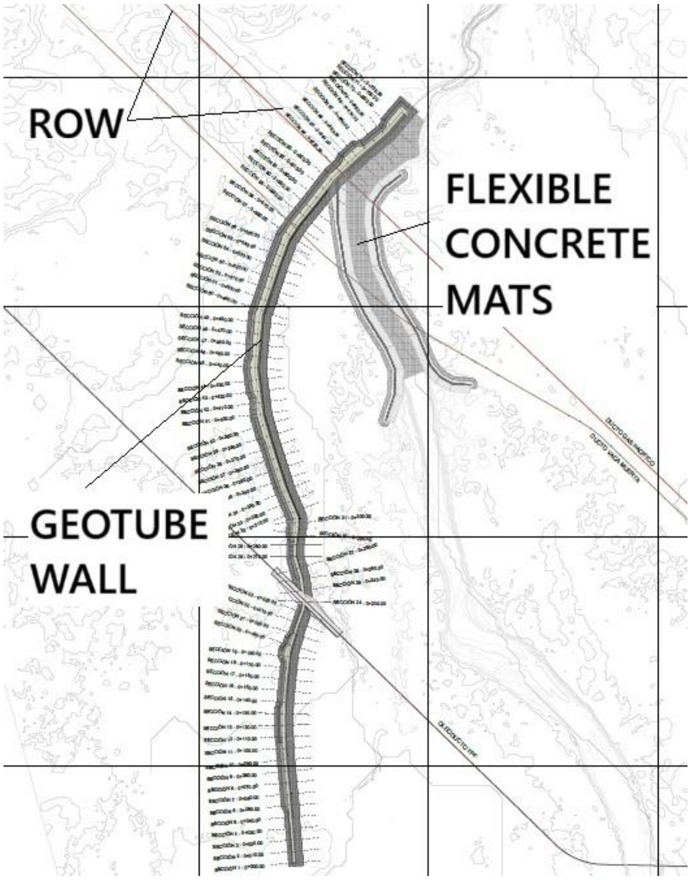

FIGURE 30: GENERAL LAYOUT OF FINAL REMEDIATION PROJECT

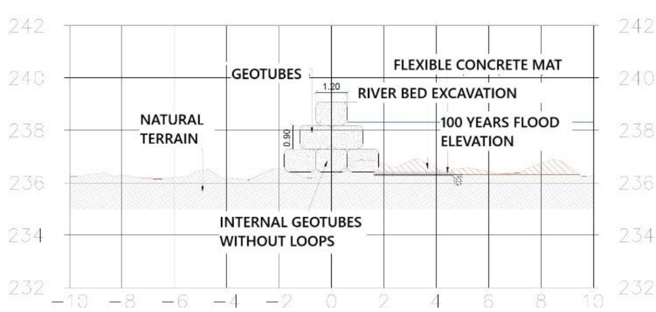

FIGURE 31: LEFT BANK GEOTUBE WALL

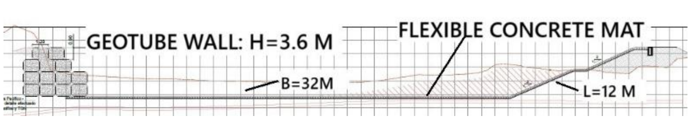

FIGURE 32: TYPICAL CROSS SECTION AT CROSSING

3 RESULTS AND DISCUSSION

As shown in the previous paragraphs, the solution to river diversion through the ROW involves expensive remediation works, since it affects the integrity of significant lengths of an operating pipeline. The two examples addressed by this paper are located at different environments. However, they share many aspects in common:

- The field situation is often misleading. River width and bank heights are rather small and do not correspond to a huge watershed, that usually has an area of thousands of square kilometers.
- During design and construction, the fact that they are built inside a floodplain is overlooked.
- Thus, common design characteristics such a lower design factor, a greater wall thickness and buoyancy control are missing.
- Once river diversion takes place, erosion (vertical and lateral) takes place easily, becoming a problem because pipeline loses support at its bottom.
- Then if weights are added, during dry conditions the pipeline´s own weight plus the added weight translate into downward flexion if unsupported. Under flooded conditions, the pipeline experiences an upward lift and drag forces. This combination becomes problematic if it is not controlled.
- Cracks in welds should be x-rayed after a flood, to evaluate their integrity.
- In flooded areas, access becomes a big part of the overall remediation works.
- Finally, solutions such a horizontal direction drilling or a massive erosion control structure that block the diversion run at a cost of several million dollars.

4 CONCLUSION

It is recommended to assess this type of hydrotechnical hazards, early at the design stage, mainly by taking a broader look at the extent of floodplain and by including in the design precautions normal at a river crossing such as lower design factor, greater wall thickness, placing the pipeline at a lower elevation due scour and controlling potential buoyancy.

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