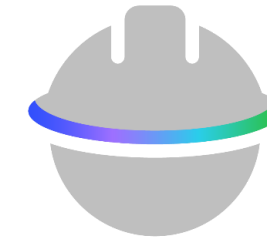
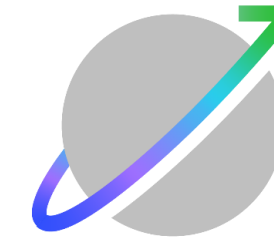


Chivor II Penstock Life Extension Project



Safety first

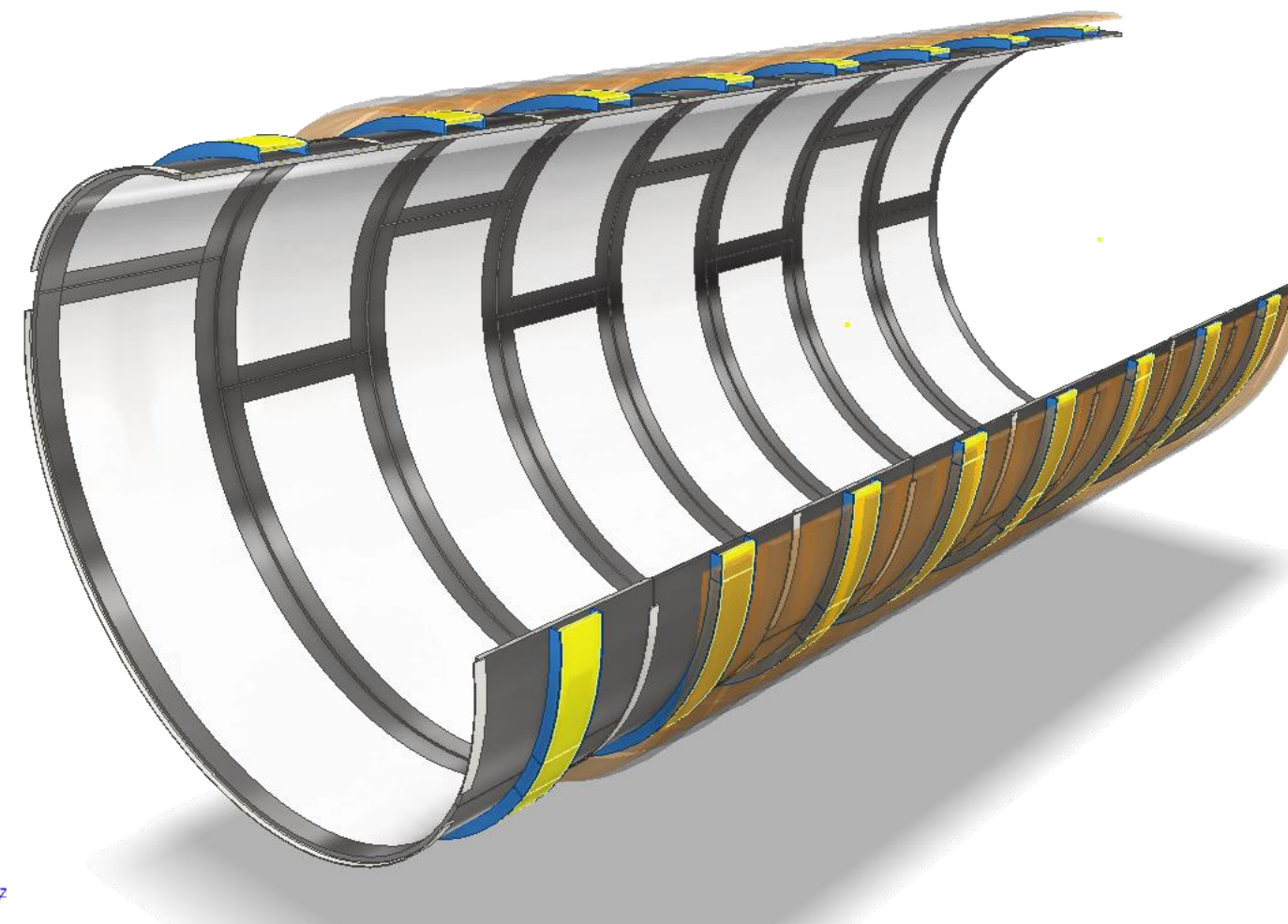
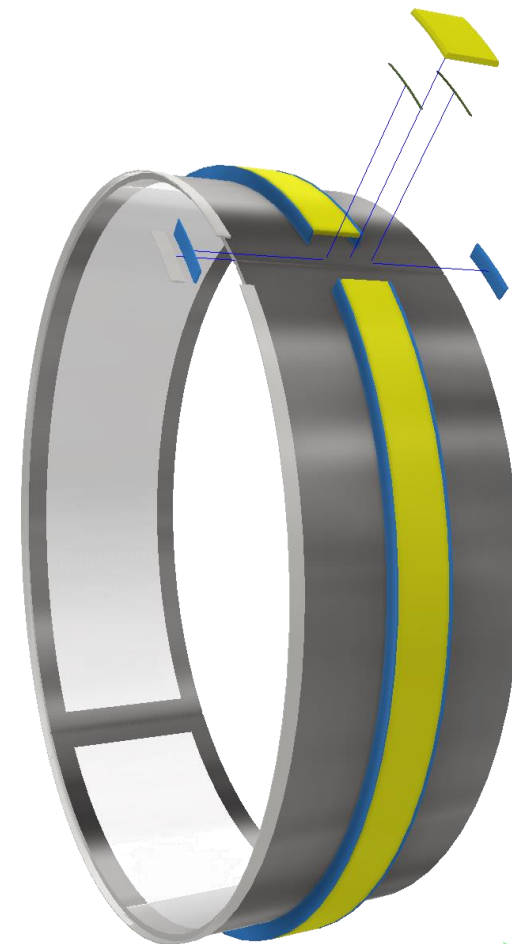
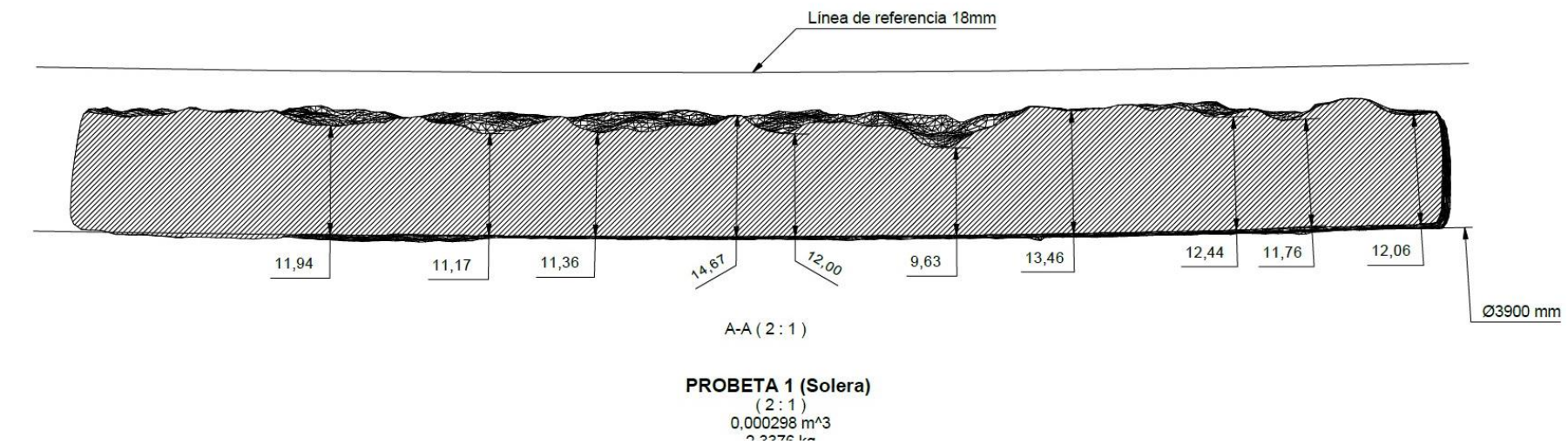


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1



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Extensión de vida útil de la
conducción Chivor II

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Agenda

- Chivor Power Plant Description
- Chivor II – Technical Description
- Background
- Problem Analysis - Summary of research studies
- Problem Analysis – Principal studies
- Problem Analysis - Conceptual Alternatives
- Alternative selected – Self-support steel lining
- Construction Methodology
- Construction Work Plan





Introduction

Ensuring sustainable energy for Colombia requires not only the development of new renewable power generation projects, but adapting and renovating existing hydropower facilities. Several large-scale hydropower projects within the country are in the ageing stage, and several companies are facing challenges to keep them operating to support the increasing energy demand within the region.

The Chivor hydropower plant has a capacity of 1000 MW (eight 125-MW Pelton turbines) divided into two stages: Chivor I started operation in 1977 and Chivor II in 1982. This plant is located at Santa María, Boyacá, 160 km from Bogotá (northeast). The plant uses water contained in a main reservoir “La Esmeralda” and two additional small reservoirs, Río Negro and Tunjita. It was built to take advantage of the potential of Batá river. Chivor has a 237 m height crest, located at 1288 m.a.s.l. and the maximum level of the reservoir is 1277 m.a.s.l. (to mitigate potential rising of the rivers, the maximum level is 1278 m.a.s.l.).

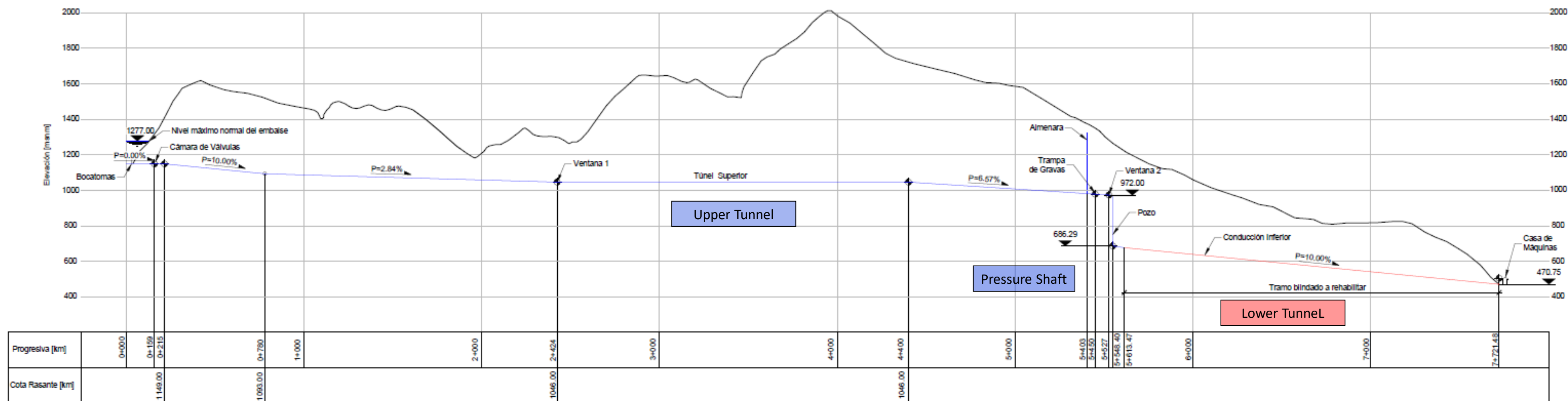
The flow is conducted to the valve chamber in the left abutment and from there in two tunnels. Chivor I conveyance system comprises three horizontal tunnels, two shafts and a surge system to feed units 1 to 4. Chivor II comprises an upper tunnel, shaft, lower tunnel, surge shaft and feeds units 5 to 8. The stage I tunnels were designed for a flow capacity of 80 m³/sec corresponding to 500 MW. The stage II tunnels have a flow capacity of 120 m³/sec corresponding to 750 MW.





Chivor II – Technical Description

- The Upper Tunnel is 5,578.12 m long, excavated in horseshoe section, 6.60 m wide by 6.40 m high, with slopes starting at 10% from the valve chamber to 2.84% to the access tunnel at K2+424.20, then horizontal to steepen incrementally to 6.59% until the surge shaft at K5+404.19. Approximately 24% of its length is lined with cast in place concrete.
- The Pressure Shaft is 284 m deep, and vertical, at K5+548.40 . The upper shaft had an excavated diameter of 5.60 m, which was completely lined in nominal 500 mm thick conventional concrete. The shaft and first 90 m of the lower tunnel are lined with conventional concrete, transitioning to the 3.9m diameter steel lined lower tunnel.
- The lower tunnel is a concrete section, 65 m in length followed by a 2 km long section composed of 616 steel pipes of 3,9 m of diameter, with a thickness between 17 mm to 41 mm.





Background

- Since the year 2000, AES has been assessing the state of the pipelines and the Buckling II zone in order to ensure the stability of the conduction tunnels. In the year 2000 Chivor II was emptied during a scheduled maintenance, and all butterfly valves were replaced or repaired, the gravel trap of the tunnel was cleaned, and a new steel pipe was installed as a liner in a 19.8-m section within a zone surrounded by limestone.
- The headrace tunnel was emptied again in 2014 and the intervention was centered on replacing relief valves and measuring the thickness of shield plates using ultrasound, which evidenced a 50% loss in thickness for 24 of the plates; hence, A36-steel 6-mm sacrificial plates were installed on plates 1 to 53, equivalent to 329.9 m².
- By 2015, thickness-loss evaluation continued and plates 54 to 129 were replaced; this is equivalent to 602.8 m² of sacrificial material to keep the tunnel operating. In the same year, an Insulated Component Test (InCoTest), that uses the pulse eddy current method, and that is considered one of the most reliable corrosion detection method, was performed to eight of the plates allowing determining the percentage of volumetric material loss in the inspection area (6-inch grids in this case).



PANDEO II – CHIVOR II (25 m)



FINAL REPAIR IN PANDEO II –



SELF-SUPPORTING



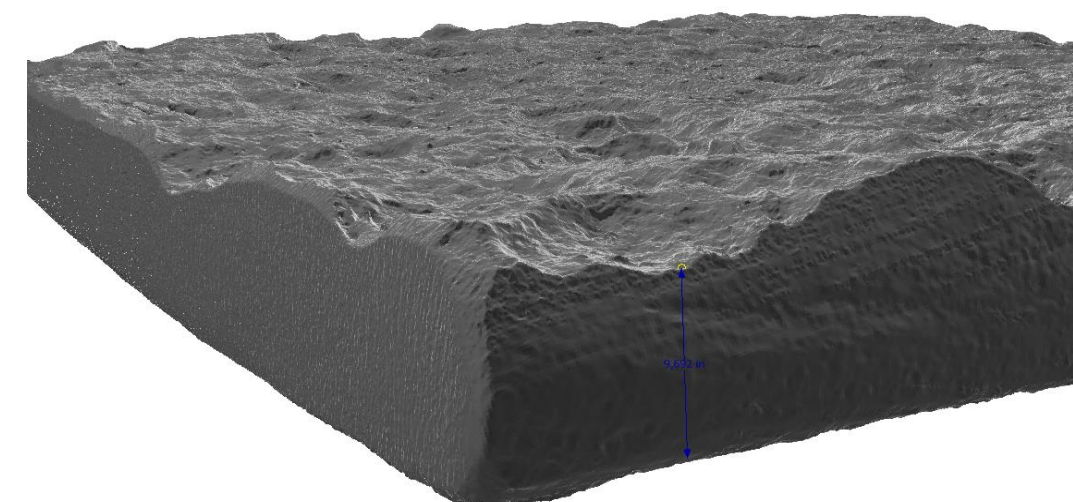
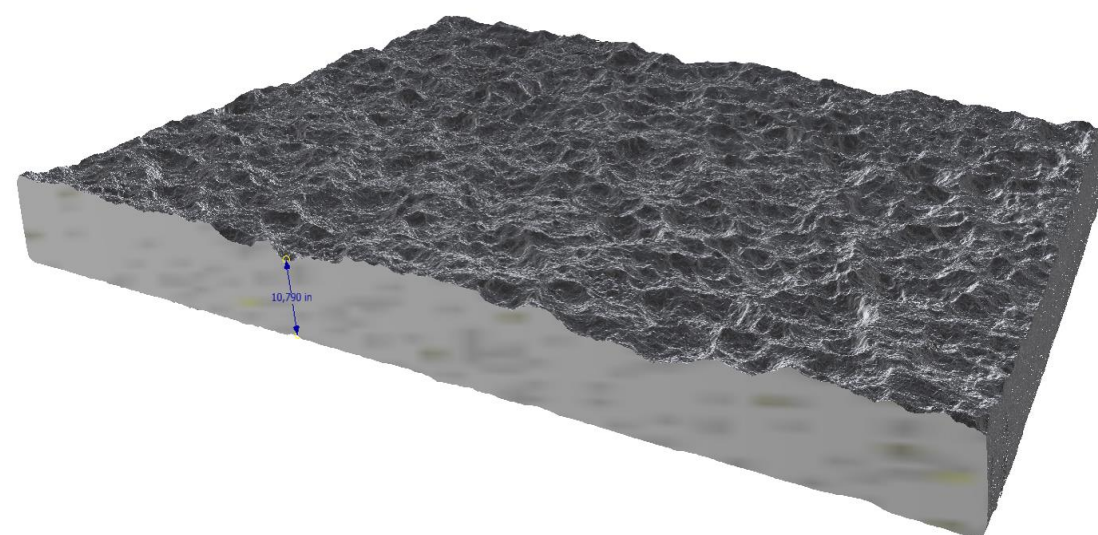
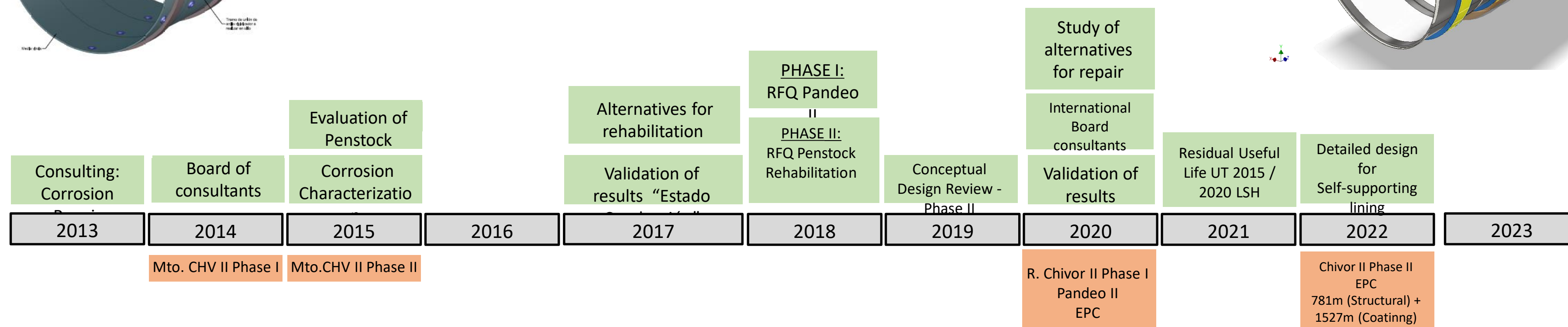
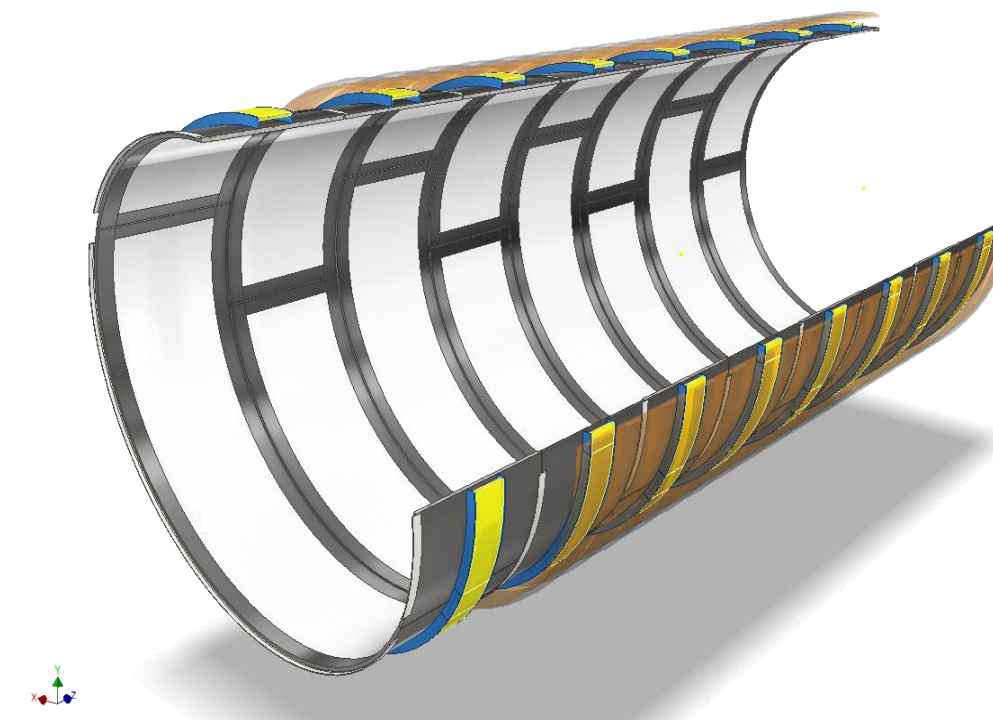
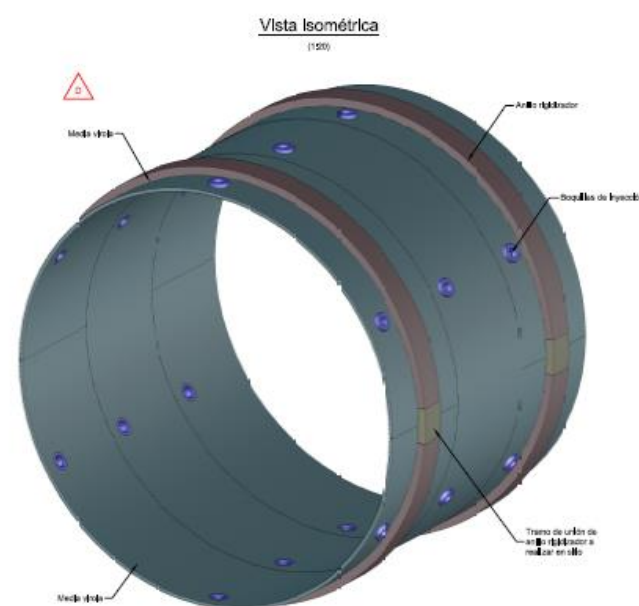
INCOTEST MEASUREMENTS



VERIFICATION BY UT



Problem Analysis - Summary of research studies

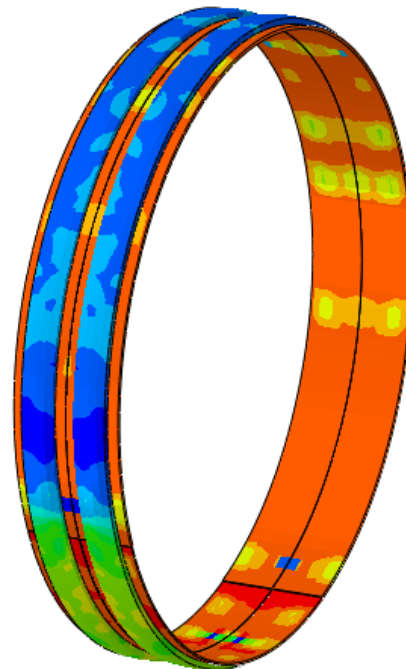




Problem Analysis – Principal studies

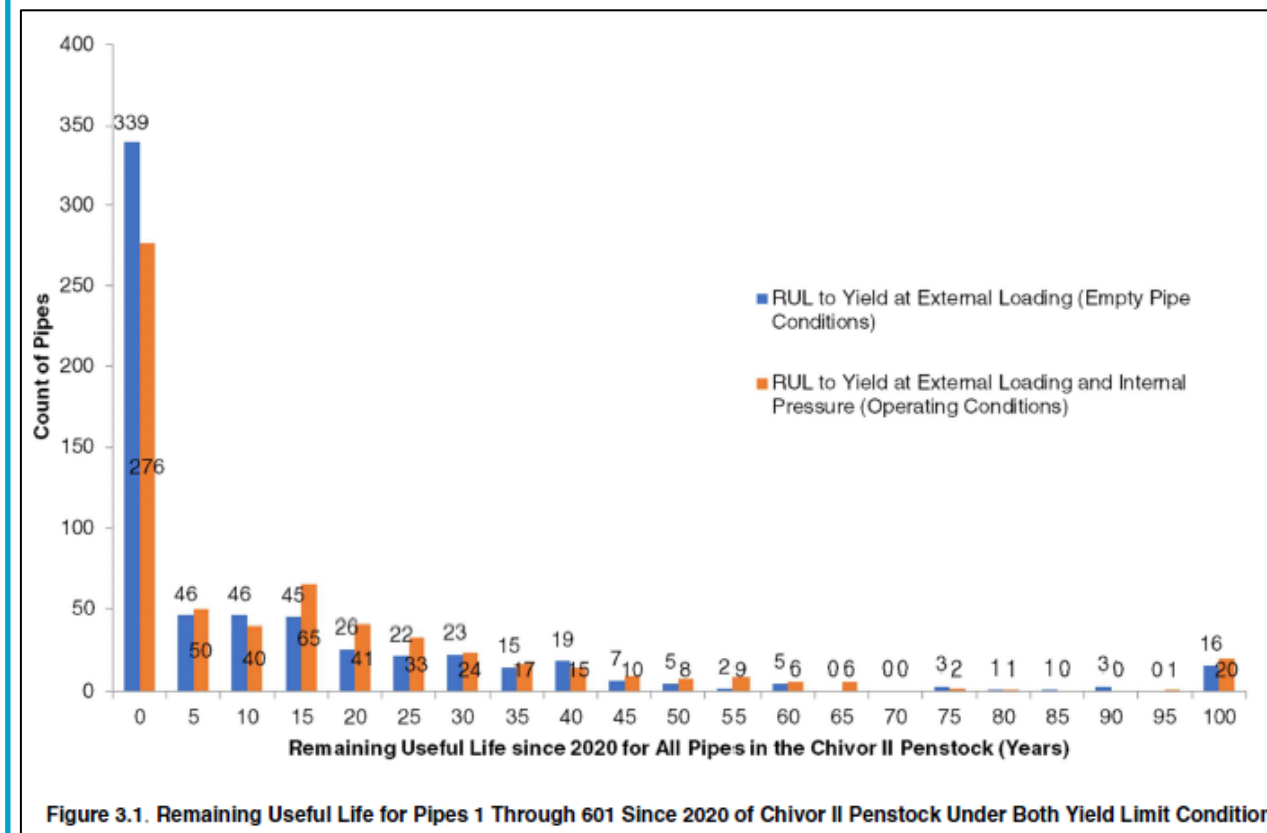
2015: Penstock Evaluation – PURE TECHNOLOGIES

- Ultrasound Log Data 2015.
- 59% of the pipe sections are exposed to stresses exceeding the yield point.
- More than 50% of the pipe sections have as projected useful life of less than 20 years.
- 367 Sections (3m) for change.



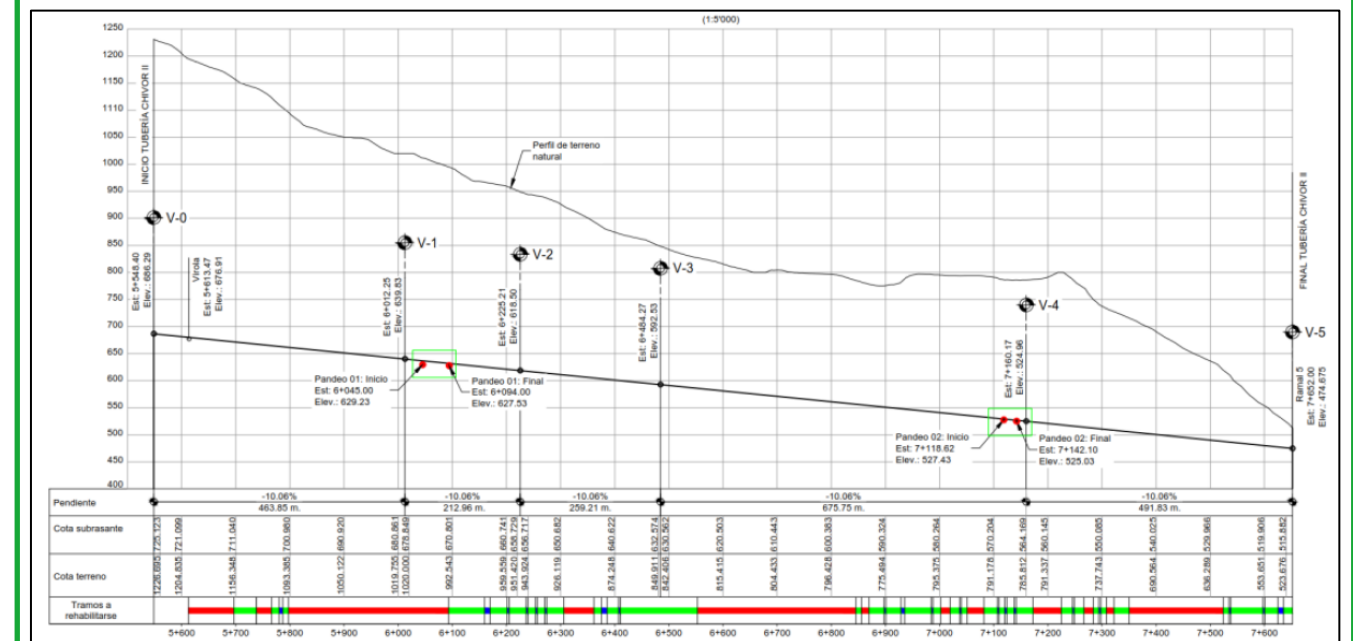
2020: RLA – PURE TECHNOLOGIES

- Ultrasound Log Data 2020.
- Deterioration Rate = 1,35 mm/y
- 381 Sections (3m) with less than 5 years of residual life (73%)
- 146 Sections (3m) with less than 20 years of residual life (27%).



2021: RLA – LSH CONSULTING ENGINEERS

- Ultrasound Log Data 2015 / 2020.
- Deterioration Rate = 1,35 mm/y
- 155 Sections (3m) with less than 7,2 years of residual life (26%).
- 67 Sections (3m) with less than 9,1 years of residual life (11%).
- 379 Sections (3m) with less than 40,1 years of residual life (63%).





Problem Analysis - Conceptual Alternatives

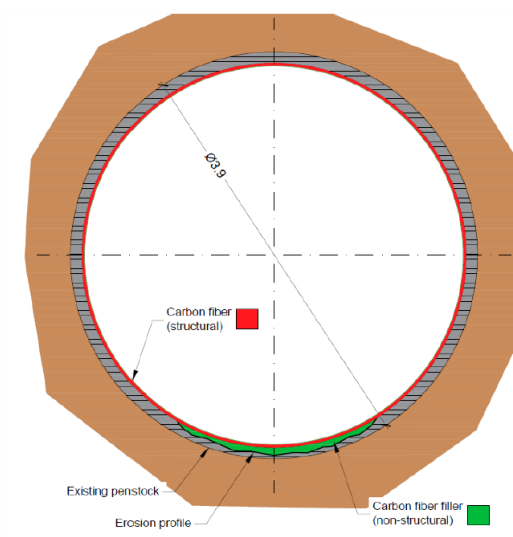
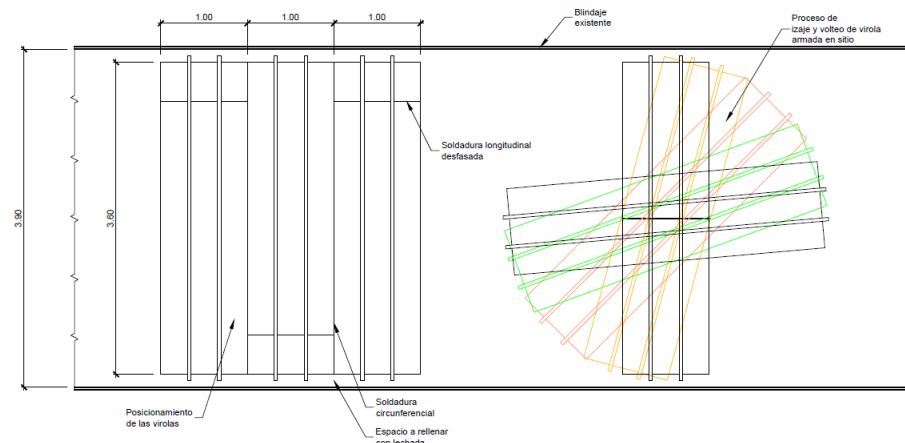
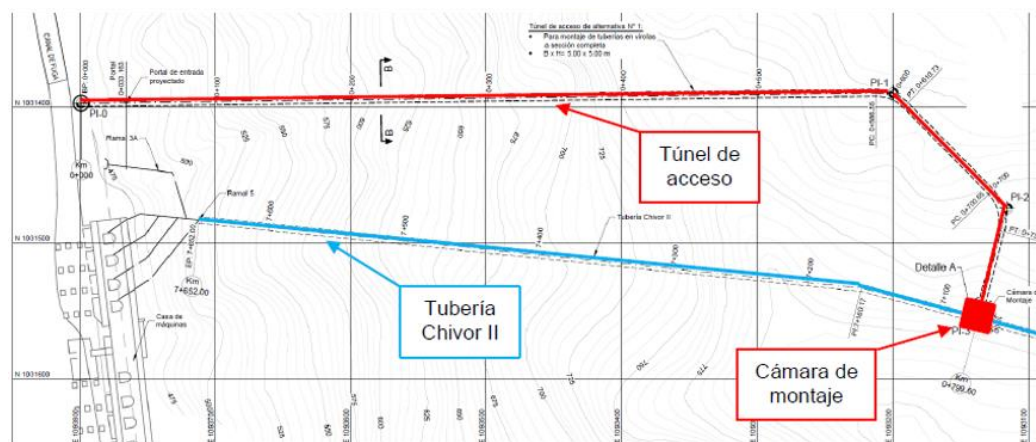
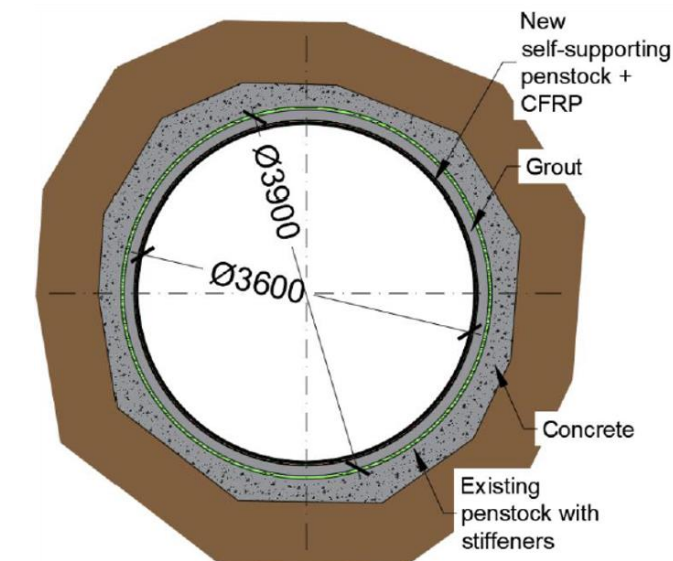


Figura 29. Esquema de reparación con fibra de carbono autoportante.



1. Full Self-Supporting

- Considered a self-supporting pipe with a diameter of 3.6 m, which would be installed using full-circumference plates in sections between 3–6 m in length. This alternative would need the construction of an access gallery and an assembly chamber for the installation of complete plates that would require only circumferential.
- To install such plates, Buckling I would need to be demolished, and a provisional lining that allows passing the plates upstream would be required, to later reestablish the Buckling 1 area with a 3.6 m pipe. For the Buckling II zone, complete plates are impossible to install because of this section's diameter, hence, the diameter of the lining in this section would be 3.4 m.
- In the assembly chamber or cavern, the sections coming from the access gallery would be received and aligned with the axis of the existing pipe.
- Inside the cavern, the pipe must be cut, replacing the eliminated section with a self-supporting section to allow the system to be reassembled once the plant needs to resume its normal operation.

The main advantages of this option are the reduction of construction times due to the simplification of the installation tasks inside the existing lining, and the reduction of welding work by applying only circumferential welds.

2. Sections Self-Supporting

- The second alternative for the lining renovation considered a self-supporting pipe, which would be divided in section plates of 1 m in length
- This alternative would use the access gallery 3A, Figure 2, which has a diameter of 2.55 m, to enter the sections in order to be welded inside. Unlike Alternative 1, the construction of the lining would require longitudinal welded joints in both sides of the plate, which increases the risk of defects along the direction of the joint.
- In this type of joint, the circumferential stresses are perpendicular to the direction of microcracks,. Therefore, complete longitudinal welded joints with full penetration from both sides of the plate would be required allowing appropriate inspection.

When plate sections are considered, the rehabilitation upstream Buckling I and downstream Buckling II presents no major restrictions since this alternative does not require demolishing Buckling I, and a 3.6-m diameter is considered downstream Buckling II.

3. Carbon Fiber Coating

- Alternative number 3 was considered due to access and logistics restrictions that appear in a more traditional structural rehabilitation process. In this case, carbon fiber would be considered either as a structural reinforcement of the existing lining or as a standalone system that acts in conjunction with the existing pipe, provided that the existing lining was structurally viable for this purpose.
- Latest interventions inside Chivor II headrace tunnel have shown no deficiencies or structural problems, however, it was assumed that the existing lining had not exceeded the yield stress; load and deformation tests would be required to verify such hypothesis.

This alternative would not be considered feasible.

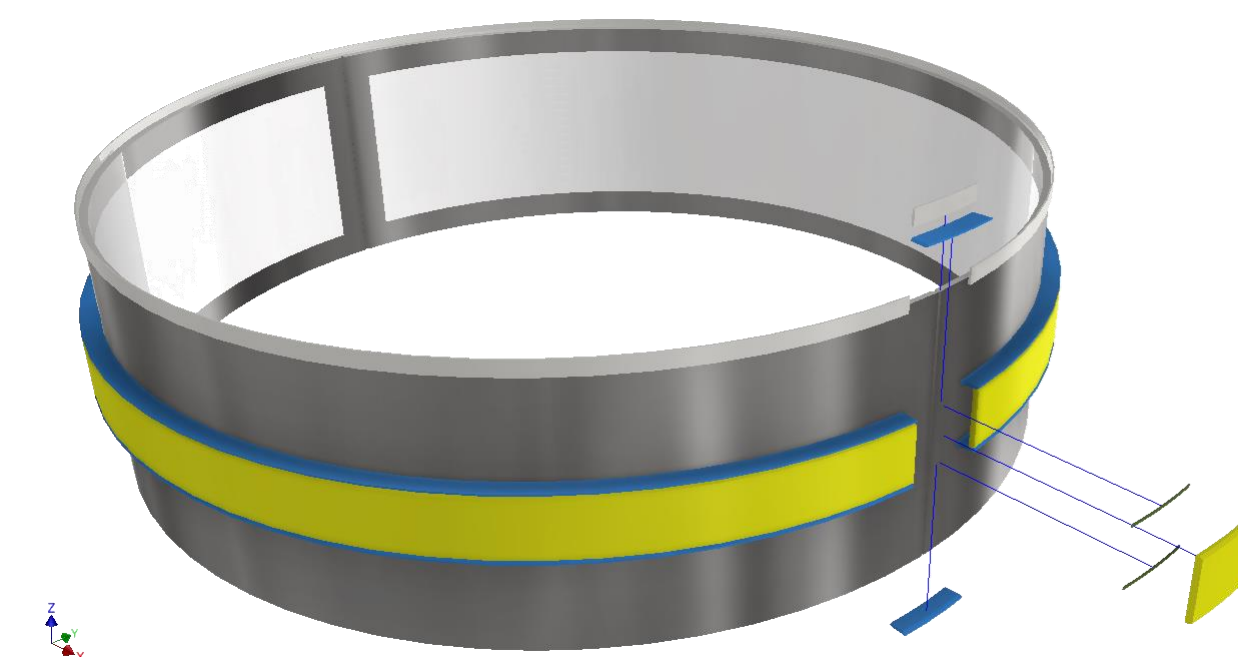
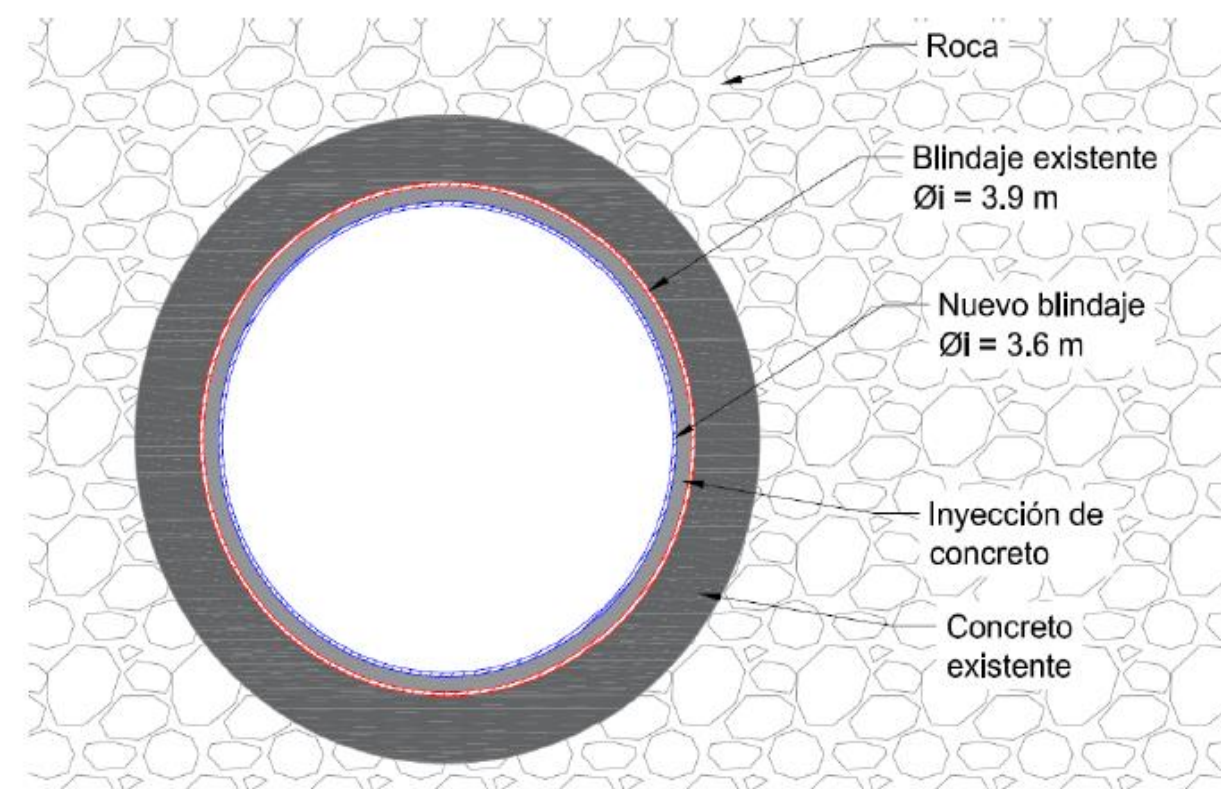
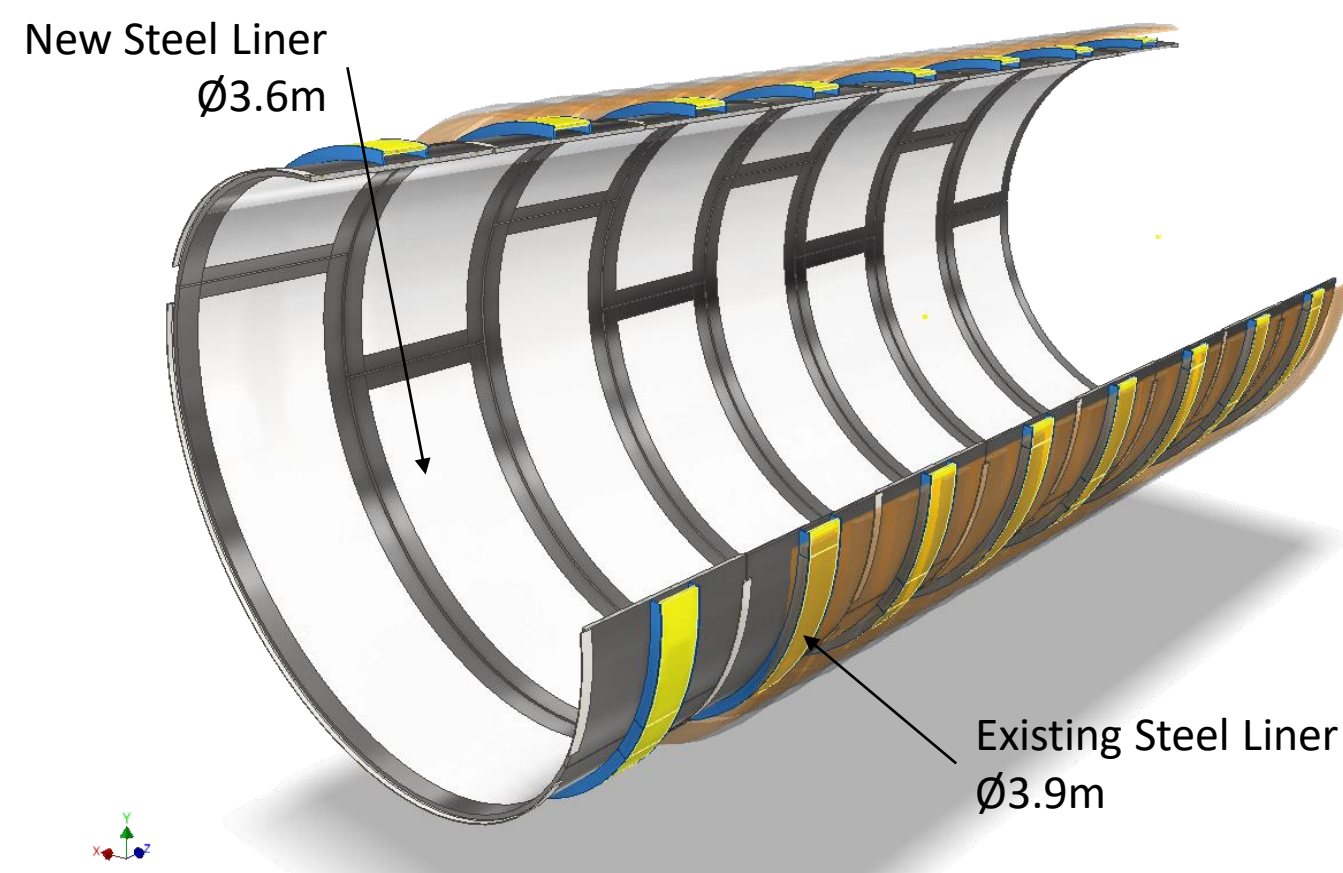
4 . Carbon Fiber Coating + Carbon Steel Plates

- Considered a self-supporting lining and that the existing steel structure and the structural carbon-fiber reinforcement would work together, due to the fact that carbon fiber layers would structurally reinforce the tunnel.
- Reinforcement has the objective of lowering the requirement on steel plates since thickness could be reduced and more commercial non-high-strength steels could be chosen in order to decrease costs and increase weldability properties.
- It has been estimated that 10 carbon-fiber-reinforced plastic (CFRP) layers would be required to reduce the amount of steel by approximately 75%, yielding to steel sheets with an estimated thickness of 25 mm

The detailed design of this alternative would require analyzing the interaction between the carbon fiber and the steel.



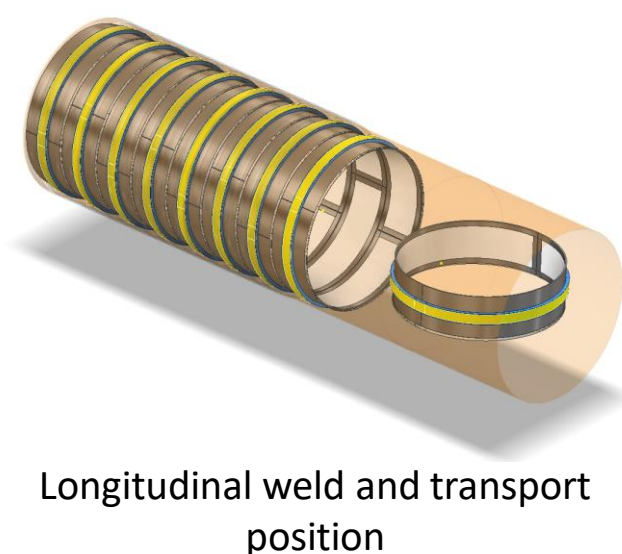
Self-Supporting lining (3,4 m)



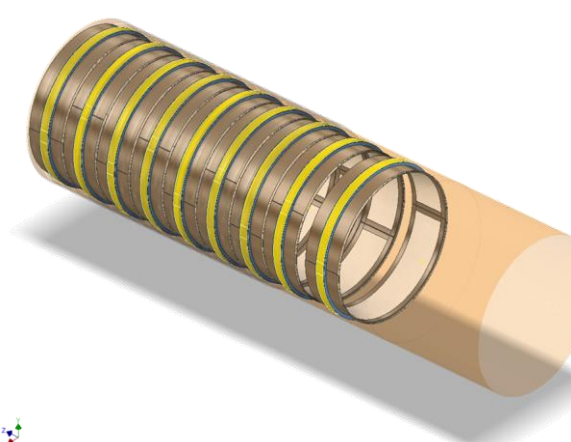
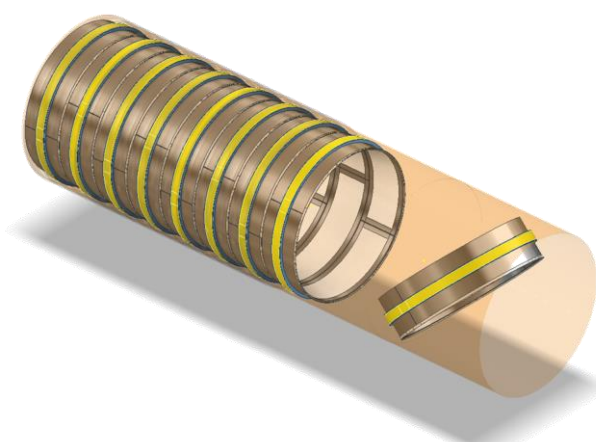
Field Longitudinal Weld

Design and Construction Considerations

- * The pipe must withstand 100% of the internal-pressure-associated loads, without contributions from the concrete or the rock behind the existing lining.
- The existing lining will not be used to increase the resistance of the new pipe.
- The pipe will be embedded in concrete filler.
- Added thickness for corrosion phenomena will be 2 mm.
- Joint efficiency will be defined as 100% for complete longitudinal welded joints with full penetration from both sides of the plate, with 100% visual and UT examination.
- Circumferential joints will be made inside the pipe once the plates have been aligned. For circumferential welds in the field, the use of a backing plate is expected since there is no access from the outside.



Longitudinal weld and transport position



Circumferential weld and erection position



Construction Methodology

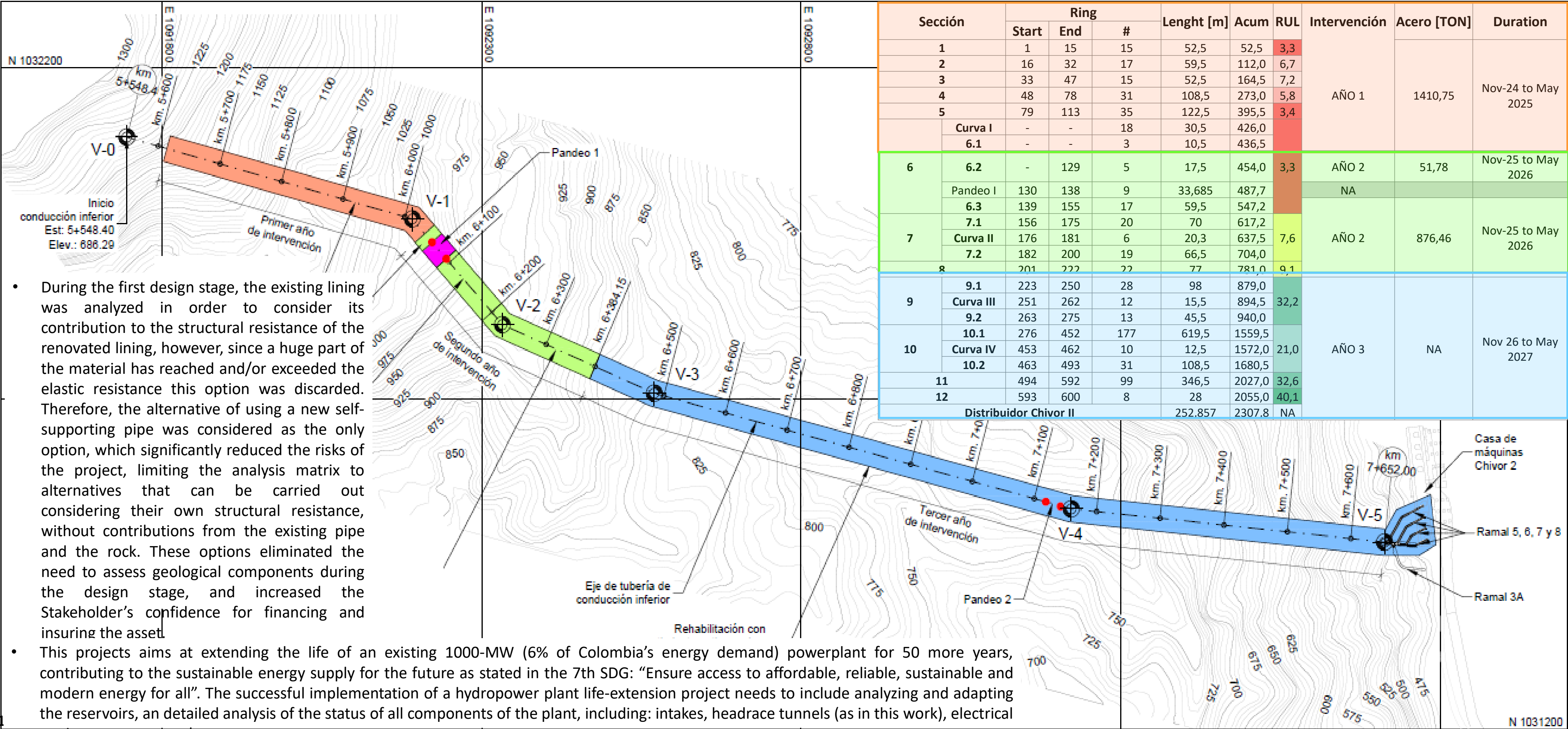


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Construction Work Plan





Schedule

ITEM	ACTIVITY	DURATION	START	END	2021				2022				2023				2024				2025				2026				2027			
					1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	Environmental Permit	390	2-Jan-22	26-Jan-23																												
2	Bidding Engineering	358	11-Dec-21	3-Dec-22																												
3	Bidding Process (First Phase)	262	14-Mar-22	30-Nov-22																												
4	Optimization of Design and Construction Methodology	93	1-Dec-22	3-Mar-23																												
5	Bidding Process (Second Phase)	137	4-Mar-23	18-Jul-23																												
6	Contract award and sign	53	19-Jul-23	9-Sep-23																												
7	Purchase of material and fabrication for First Intervention	418	10-Sep-23	31-Oct-24																												
8	Dewatering of Chivor II	15	1-Nov-24	15-Nov-24																												
9	First Intervention	187	16-Nov-24	21-May-25																												
10	Filling of Chivor II	10	22-May-25	31-May-25																												
11	Fabrication for Second Intervention	153	1-Jun-25	31-Oct-25																												
12	Dewatering of Chivor II	15	1-Nov-25	15-Nov-25																												
13	Second Intervention	187	16-Nov-25	21-May-26																												
14	Filling of Chivor II	10	22-May-26	31-May-26																												
15	Purchasing for Third Intervention	153	1-Jun-26	31-Oct-26																												
16	Dewatering of Chivor II	15	1-Nov-26	15-Nov-26																												
17	Third Intervention	187	16-Nov-26	21-May-27																												
18	Dewatering of Chivor II	15	22-May-27	31-May-27																												