

**Independent Advisory Panel to IDB Invest**

**IAP Report N°3, October 2019**

**Ituango Hydropower Project**

**Colombia**



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**IAP composition:** Mr. Ciampitti and Mr. Marinos represented the IAP during the September 2019 mission. Mr. Palmieri could not attend the visit, but he was kept informed on the findings by the other members and reviewed the present IAP report, which he fully endorses.

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## ACRONYMS

ADT	Auxiliary Diversion Tunnel (GAD or SAD in Spanish)
BID	Banco Interamericano de Desarrollo
CAP	Reservoir capacity
EPM	Empresas Públicas de Medellín
FEM	Finite Element Analysis
IAP	Independent Advisory Panel to IDB Invest
IDG	Intermediate Discharge Gallery (DI in Spanish)
MAF	Mean annual flow
MAS	Mean annual sediment yield
MLO	Middle Level Outlet
ANLA	National Authority of Environmental Licenses (ANLA in Spanish)
PH	Power House
TD2	Diversion Tunnel 2 (right)
EBIA	EPMs Board of Independent Advisors
M a.s.l.	Meters above sea level

## EXECUTIVE SUMMARY AND RECOMMENDATIONS

Safety conditions of underground works are being assessed in almost the entire underground works; this was a critical task because it controls project schedule and the possibility of definitively plugging GAD and DT2 to remove alert conditions to downstream population.

Underground investigations and works require constant attention to health and safety of workers.

Dam performance is as good as observed in March 2019.

POYRY was appointed by EPM for carrying out a stability analysis of the entire project to be submitted to the ANLA, the National Authority of Environmental Licenses, as part of the process to lift the sanction imposed by ANLA's Resolution 820 of June 2018. Their assignment includes a first phase of risk assessment and a second phase of risk follow up.

The IAP contributed, with EPM's Board of Independent Advisors (EBIA) and EPM, to clarify POYRY's doubts in terms of understanding of the technical details of the project.

All parties clearly stated and recognized that POYRY's due diligence shall be completely independent, direct and self-contained as to provide the ANLA with enough technical background to support a decision regarding Resolution 820; at the end of the section POYRY stated that they had clarified all items of their interest for the meeting.

The whole rock mass and area of the underground works is not in danger. There is an overall stability. Damages and collapses can be rehabilitated to safe geotechnical conditions.

A final assessment of the damages to most of the electromechanical equipment is already available. The situation is relatively simple to describe because, apart some mechanical parts embedded in concrete, all other equipment already installed are considered unsuitable for future operation.

EPM is still evaluating different options for the design of the IDG's intake and final decision shall be taken shortly. The option of completing the tunnel stretch between the existing plug and the inlet portal, as well as the portal itself, was the first option considered. The use of steel lining for the tunnel is recommendable.

A major design change was recently put forward. It foresees the abandonment of the original portal and the placement of the IDG intake at higher elevation, with inlet at the power intake 3 and 4, upstream of the gates but downstream of the plugs, through a vertical shaft designed for 450 m<sup>3</sup>/s and connected to the IDG downstream of its current plug.

This option is less risky in terms of schedule and methodology and less costly. However, it would definitively forego the possibility of controlling the reservoir level below 370, possibly 350, m a.s.l. The only means to lower reservoir level would be through the turbines, which cannot be relied on, in the long term, and in the occurrence of emergency situations (e.g. strong earthquake).

The IAP confirms that the availability of hydraulic works to lower the level of the reservoir, under exceptional circumstances when turbine operation cannot be relied on, is fundamental for the safe performance of the project over the long term. Project operation is not going to be reliable, and safety cannot be guaranteed, without a system for lowering levels below the power intake level, being a temporary cofferdam at the intake platform only a proxy.

IAP restates the need for additional discharge, the MLO, not necessarily before the commissioning of the units, and the importance of evaluating carefully the consequences of the new solution for the IDG intake that would limit its maximum flow and would reduce its operational range.

The IAP fully realizes that the solution is very complex to execute (be that an increase of capacity of the IDG, which would be a minimum, or the construction of a mid-level outlet, which the IAP has advocated since the beginning), but this essential feature cannot be foregone on technological complexities only.

The subject of long-term reservoir control is too important and requires detailed examination. To this end, the IAP proposes to conduct a PFMA (Potential Failure Mode Analysis) session, on site or in Medellin, to analyze potential scenarios of project operation, or failure to operate, under different waterways configurations. The session should involve all key stakeholders, and the EBIA in particular, possibly POYRY too. A decision has to be made and it must be an informed decision.

The IAP reiterates its advice to extend the slope protection measures as far upstream as the destabilized area above the two diversion tunnels and the IDG intake where major mass movements have taken place.

The value of the details of the current schedule is limited because the recent findings and assessment caused important changes in the planning of the project.

EPM will be able to issue the update project schedule in the next few months; for most of the project, except the southeast part, it should be a final schedule. It will reflect, in addition to a better-defined sequence of all activities, key decisions that need to be taken in the next few months, among other the sequence of the units to be erected and commissioned. Indeed, the two phases approach corresponding to the North and South powerhouse is likely to be abandoned.

Key drivers of the new schedule will be the assessment of existing concrete at units 3 and 4 (retain or remove) and the risk profile of the different intakes.

An element seems to be sure: Unit 7 and 8 will be the last to be commissioned due to lack of discharge tunnel and extent of the damages to the southeast part of the project. A couple of other elements seems quite probable: unit 5 and 6 shall be among the first to be commissioned, north and south shaft chamber should be divided in two halves to allow a quicker schedule.

Cost estimates is currently less uncertain than six months ago; however, for the time being, an updated cost estimate was not communicated to IAP by EPM and too few elements are available to reliably update the estimates which were made in September 2018.

Based on current knowledge, it is safe to keep the September estimates for financial purposes. The “discovers” affecting civil works should be broadly balanced by the interventions of the Insurers for the electromechanical equipment.

# 1. CURRENT PROJECT SITUATION

## 1.1. General

The Ituango Hydroelectric Project is under construction at the northwest of Colombia since 2009. The Independent Advisory Panel (IAP) to IDB Invest visited the Project for the first time, in August 2018 (IAP's Phase I) and a second time in March 2019 (IAP's Phase II). The objective of this IAP's Phase III involvement is to advise the IDB Invest on:

- Progress achieved with project implementation since March 2019;
- Assessing the Project's current situation with focus on: i) dam abutments' stability; ii) slope stability; iii) on-going works in the intermediate discharge; iv) sealing of the diversion tunnels; v) stability of powerhouse and cavern complex; vi) rehabilitation of the penstocks; and overall condition of the powerhouse intakes;
- Assessing the overall safety of the infrastructure;

Exchange views and discussion on technical opinions with EPM's Board of Independent Advisors and with other subcontractors (POYRY, Integral, etc.) took also place.

The present Report contains the IAP's findings and recommendations, following the IAP's third site visit to Ituango Hydropower Project (HPP) in September 2019. Mission started on September 23 with a full day of briefing by Integral and EPM in EPM's headquarters in Medellin, followed by a site visits on Tuesday September 24, and a subsequent section of technical questions by POYRY and a de-brief meeting with EPM's Board of Independent Advisors (EBIA) and EPM in EPM's headquarters in Medellin on the 25th. IAP members wish to acknowledge the outstanding commitment, cooperation and transparency of EPM and other parties.

At the time of the visit, the reservoir level was 403.52 m a.s.l., the spillway discharge 438 m<sup>3</sup>/s, and dam crest had reached elevation 435.

## 1.2. Comparison with March 2019

During the IAP's September 2019 visit, the situation of the Project has considerably evolved in comparison to March 2019:

- The dewatering activities are completed.
- The assessment of conditions of the underground works through which the emergency discharge took place for nine months are almost completed.
- The reestablishment of safety and security conditions are completed in several areas and advanced in several others.
- The consolidation-filling-strengthening of the rock mass in several areas is ongoing including the large cavity, between pressure shafts 1 and 2 and of the collapsed rock diaphragm among the powerhouse and the shaft chamber in correspondence of Unit 1, 2 and 3.
- A new cavity in correspondence to the transition among the north shaft chamber and the Discharge Tunnel 2 was an unpleasant finding, though one of the last.
- The most satisfying finding of last missions i.e. the undamaged roof of the machine hall is definitely confirmed and extended to the transformer gallery and shaft chambers.
- While full appraisal of rock mass conditions is not completed, the balance seems to be definitely on the positive side.
- Design and methodology for plugging RDT and GAD are advanced as well as first activities by specialized contractors.

- The contract with ATB for the penstocks is in advanced phase of negotiation.
- A design change, placing the intake of the IDG at higher elevation using a vertical shaft connected to power intake 3 and 4 has the preference of the designer, abandoning the current unfinished IDG portal at elevation 260 m a.s.l.
- The partition of each shaft chamber in two halves may be adopted to optimize the sequence of erection and commissioning of the units.

Despite the extreme challenges encountered, and those expected ahead, Project staff, of all parties involved, continue to demonstrate outstanding commitment. The IAP wishes to acknowledge the cooperation and the proactive attitude of Project’s stakeholders.

The following table updates the IAP assessment of the “Options for Project Completion” which were put forward during the August visit.

<b>Options</b>	<b>August 2018 assessment</b>	<b>March 2019 assessment</b>	<b>October 2019 assessment</b>
Full Rehabilitation	Preferable option; final confirmation after assessment of damages in the powerhouse complex	Confirmed preferable option	Substantially confirmed
Revise Project’s Outputs	Not envisaged at this stage	Power output unmodified. Schedule of second stage power supply (units 5-8) to be assessed.	Power output unmodified. Sequence for putting in operation the Unit shall be independent from the original two stages power supply.
Revise Project’s Purposes	Not realistic		
Project re-engineering	Addition of Middle Level Outlet essential		Future decision to be supported by a Potential Failure Modes Analysis (see below)
Partial/ total retirement	Very unlikely, unless cavern location must be abandoned for excessive damages.	Partial retirement can be excluded.	Partial retirement excluded.
Long-term vision	Project will have to be decommissioned at the end of its useful life, when coarse sediment management, to sustain run-of-river operation, will no longer be economical.	Bathymetric surveys should be initiated to assess sedimentation trends.	Long-term reservoir management retains its importance.

Finding the underground works in safe conditions means that the project can be completed according to original design, although with significant remedial works. The latter are being assessed.

### 1.3. Safety Assessment

Since last mission hydrological safety is no longer an issue while dam embankment progressed to its final elevation.

Safety conditions of underground works are being assessed in almost the entire underground works; this was a critical task because it controls project schedule and the possibility of definitively plugging GAD and DT2 to remove alert conditions to downstream population.

Underground investigations and works require constant attention to health and safety of workers.

Dam performance is as good as observed in March 2019.

### 1.4. POYRY/Environmental Agency Due Diligence

POYRY was appointed by EPM for carrying out a stability analysis of the entire project to be submitted to the ANLA, the National Authority of Environmental Licenses, as part of the process to lift the sanction imposed by ANLA's Resolution 820 of June 2018. Their assignment includes a first phase of risk assessment and a second phase of risk follow up.

On September 25<sup>th</sup> at EPM's headquarters in Medellin POYRY stated that they were preliminary evaluating five areas of the project as deserving the maximum attention. They are:

- Modification of dam design (priority embankment and impermeable diaphragm), long term stability and inspections (as per ICOLD).
- Modified operation of the spillway (unforeseen long continuous operation), its original design and overall stability.
- [Modified] Intermediate Discharge.
- Method statements for recovering the project components affected by the events.
- Overall rock mass stability.

The IAP contributed, with EPM's Board of Independent Advisors (EBIA) and EPM, to clarify POYRY's doubts in terms of understanding of the technical details of the project.

IAP stated that its official position is always represented by its official collegial report that are currently widely distributed.

All parties clearly stated and recognized that POYRY's due diligence shall be completely independent, direct and self-contained as to provide the ANLA with enough technical background to support a decision regarding Resolution 820; at the end of the section POYRY stated that they had clarified all items of their interest for the meeting.

### 1.5. Emergency Discharge – Essential Chronology

For readers convenience, the following table summarizes the sequence of the key events; the most critical dates subsequent to August 2018 (first IAP's visit) are shown in red, emergency response measures are highlighted in yellow.

<b>Day</b>	<b>Key Events</b>
April 28, 2018	April 28, 2018: Rock mass failure in the GAD started the sequence of events.

May 10, 2018	To avoid dam overtopping EPM let open Intake Tunnel 1 and 2 as well as 7 and 8; reservoir starts flowing through the Power House. Control of the reservoir level regained.
May 12, 2018	An abrupt washout of Right Diversion Tunnel obstruction caused a flow in excess of 4,000 m <sup>3</sup> /s which lasted about 4 hours, causing serious consequences downstream.
May 17, 2018	Tailrace Tunnel 3 reduces its flow that subsequently will stop.
May 20, 2018	EPM closed Intake Gates 7 and 8.
June 5, 2018	Dam crest level reached elevation 410 m a.s.l. allowing operation of the surface spillway. Risk of dam overtopping averted.
November 2018	The level of the reservoir remained constantly at elevation 408 m a.s.l. without causing additional damages to the dam.
December 2018	Signs of deterioration of the fixed part of the Intake gates appeared, raising concerns of the future possibility of closing the Intake Tunnel using the Intake Gates. Such event could have had severe consequences for the power house.
December 2018 / Early January 2019	<p>The acknowledgement that the activities on the intermediate discharge would not be completed before October / November 2019, the positive result of the monitoring of the dam and of the underground works jointly with the risk of facing problem in closing the Intake Tunnel recommended to reconsider the conditions previously identified as essential for closing the gates i.e. (i) final plug of GAD and RDT, (ii) completion of the plastic diagram of the dam (iii) completion of intermediate discharge.</p> <p>Careful preparations for closing of the first gate started, including installation of additional temporary instrumentation of the gate and extensive re-evaluation of the operating conditions of the Intake Gates involving Experts and Manufacturers.</p>
January 16, 2019	Closing of the first Intake Gate (n. 2)
January 2019, days subsequent to the first Intake Gate closure	During the closing of first Intake Gate a direct physical connection between Intake Tunnel 1 and 2 is unequivocally evidenced by various phenomena. First investigations revealed that shafts 1 and 2 were severely affected by collapses of their walls that generated big cavities. Rock collapse was threatening the upper elbows, with a tiny pillar left of less than 20 m.
February 5, 2019	Closing of the second Intake Gate (n. 1)
February 2019, onward	Start of underground works' dewatering; activities were anticipated partially because the volume of debris at the lowest elevations of the underground works was higher than expected.

March 4, 2019	Independent Advisory Panel visit
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Integral stated that the sequence of May 12, May 17 and May 20 events are responsible for the current situation of the area around penstock 5, 6, 7 and 8 (see below).

## 2. UNDERGROUND WORKS AND COMPLEXES

The El Romerito zone, over the intake structures, collapsed in May 2018 after the main event and a chimney failure is reported. A concern was raised thereafter. Where did the collapsed material go inside the underground works and through which trajectory? This zone potentially unstable concern the shafts in the intake area. The formation and presence of voids having affected the area of shafts 5 to 8, presented by the Designer, is hypothesized. Disturbance is found however in the boreholes drilled but there are not clearly reported voids. The IAP had not the opportunity to inspect the boreholes. This zone was commented by the IAP in the April 2019 report. Those waterways were exposed to emergency discharge and had to be closed as per the chronology above (intense vibrations were registered in the intake area at the time of closing the gates).

Reinforcement with grouting is at present undertaken in this area. Although not clear that the ground is overall destabilized and weak, the IAP is in agreement with this reinforcement, due to many uncertainties. These uncertainties are on the quality of the rock mass as investigated by the boreholes, whether is due to a disturbance caused by the event. Any disturbance cannot however be connected with the powerhouse.

The IAP has no further comments on the cavity between shaft 1 and 2 since the report of April 2019.

The panel visited a big number of the underground works and the caverns of transformers and the machines.

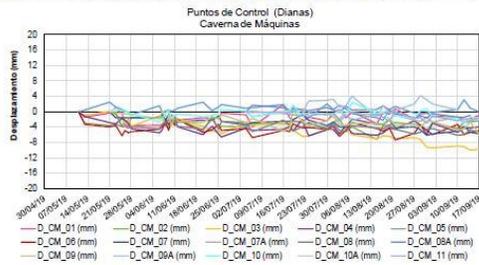
The caverns have an overall stability. There is not a disorganization of the rock mass. The monitoring (extensometers) before the event showed a stable condition. No changes are now measured regarding deformations. The rock mass is thus not distressed, no disturbed, no loosened, showing no indications of an overall stability problem. The geodetic measurements do not show any closure of the opening. No seepages from above is observed, having already an important head of reservoir water. Rock detachments certainly exist in places and reinforcement is necessary. Already rehabilitation is ongoing. With the completion, an additional monitoring net has to be installed. With the completion, an additional monitoring net has to be installed.



Figure 1 – PH cavern seen from the loading bar. Overall stability of the rock mass is recognized.

## COMPLEJO SUBTERRÁNEO

### 0.2.6 Instrumentación adicional – Caverna de transformadores



**Dianas reflectivas Caverna de Máquinas:** Desde el 13 de mayo/2019 se están monitoreando las deformaciones en la casa de máquinas mediante dianas reflectivas localizadas a la altura de los hastiales. Las lecturas obtenidas se encuentran dentro del rango de precisión del método de medición.



Figure 2 – Underground complex, transformer cavern.

# COMPLEJO SUBTERRANEO

## 0.2.2 Caverna de Transformadores Sur – GML024

El monitoreo de la caverna de transformadores se inicia el 17/05/2019, a la fecha se mantiene estable.

Debido a trabajos que se ejecutan en el sector, a partir del 27 de agosto se crea una nueva pared de monitoreo. A la fecha, la tendencia de deformación muestra un comportamiento estable con magnitudes y dispersiones dentro de la precisión del instrumento.

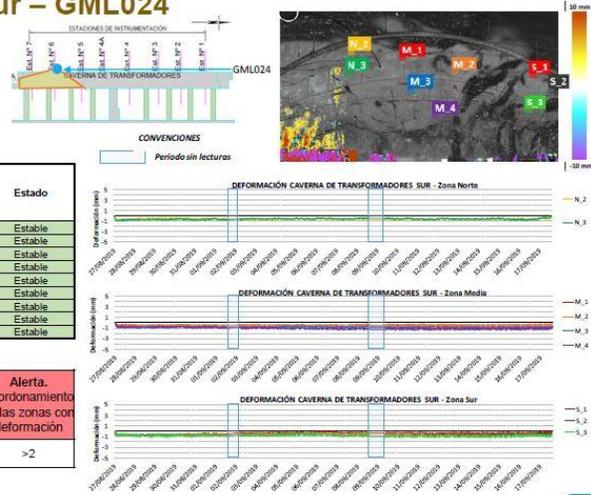


Figure 3 – Underground complex, southern transformation cavern.

# COMPLEJO SUBTERRANEO

## 0.2.5 Transformadores – Extensómetros de posición múltiple

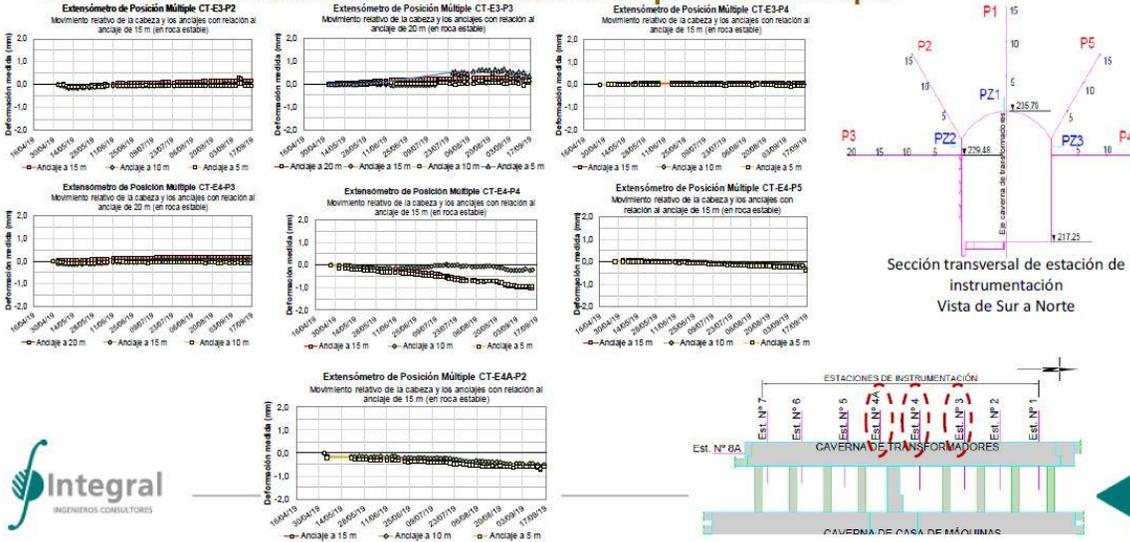


Figure 4 – Underground complex, multiple position extensometer.

## COMPLEJO SUBTERRÁNEO

### 0.2.3 Casa de Máquinas – Entre unidades 2 y 3 – GML025

El monitoreo del hastial aguas debajo de la caverna de casa de máquinas entre unidades 2 y 3 se inicia el 25/05/2019. Debido a trabajos de demolición cercanos al instrumento, se retira el 27/07/2019 y se reubica sobre la viga-riel del puente grúa el 17/08/2019 hasta el 26/08/2019 fecha en la cual se retira nuevamente el instrumento debido a trabajos sobre el riel. El 1/09/2019 se reinician las lecturas con una nueva pared de monitoreo, permaneciendo a la fecha estables.

Punto	Deformación Acumulada (mm)				Tasa (mm/día)	Estado
	14-sep-19	15-sep-19	16-sep-19	17-sep-19	Entre 14/09 y 17/09/2019	
N_1	0.97	0.83	1.47	1.61	0.21	Estable
N_2	-0.09	-0.35	-0.18	-0.15	-0.02	Estable
N_3	-0.85	-0.63	-0.49	-0.52	0.04	Estable
M_1	-0.13	-0.30	-0.11	0.09	0.07	Estable
M_2	0.42	0.33	0.55	0.64	0.07	Estable
M_3	-0.55	-0.71	-0.38	-0.09	0.15	Estable
S_1	-0.17	-0.31	-0.18	-0.01	0.05	Estable
S_2	0.26	0.18	0.53	0.68	0.14	Estable
S_3	0.20	0.02	0.21	0.30	0.04	Estable

UMBRALES DE TASAS DE DEFORMACIÓN (mm/día)	Condición	Estable.	En Observación.	Alerta.
		Sin restricción para trabajos	Se continúan trabajos y se realiza verificación en el frente de obra.	Acordonamiento de las zonas con deformación
Desde		0,00	0,50	>2
Hasta		0,50	2,00	

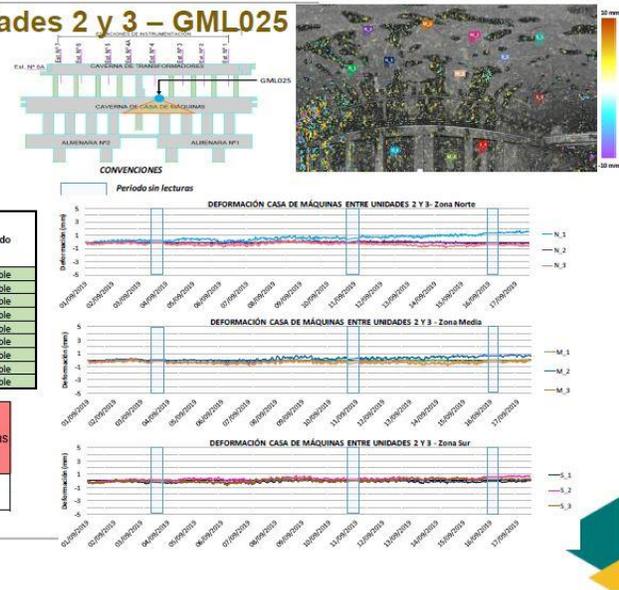


Figure 5 – Underground complex, engine room between units 2 and 3.

Figures 3-6 showed above, selected from the monitoring of the caverns since May 2019 and September 2019, no deformations are measured, or those are in the frame of the accuracy of the instrument of measurement. The rock mass is not overall distressed, no loosened, showing no indications of an overall stability problem. The geodetic measurements do not show any closure of the opening. This does not mean that the additional reinforcement of the caverns has to be neglected (rf. IAP report of March 2019).

The failures and collapses in tunnels and openings are in the majority of cases structurally, gravity dependent. They are controlled by the structural features of the gneissic rock mass (joints, schistosity planes, and the faults that cross the area). The collapsed openings are bridged soon and a new equilibrium has been achieved, but in some cases, they are large (Almenara). In many cases there is no need to fill the void of the overbreak to the old shape of the tunnel. Just the new geometry has to be reinforced (shotcrete and bolts/anchors).

Conclusion: the whole rock mass and area of the underground works is not in danger. There is an overall stability. Damages and collapses can be rehabilitated to safe geotechnical conditions.

For plugging TDD and GAD, the principles were presented; they are reasonable.

## 3. DAMAGE ASSESSMENT TO ELECTRO AND HYDROMECHANICAL EQUIPMENT

### 3.1. Electromechanical Equipment

Complying with safety provisions currently established in most of the underground works, the IAP had the possibility to visit the area of the north and south shaft chambers, the powerhouse cavern, the transformer gallery and the cable gallery that occupies its upper part.

A final assessment of the damages to most of the electromechanical equipment is already available.

The situation is relatively simple to describe because, apart some mechanical parts embedded in concrete, all other equipment already installed are considered unsuitable for future operation.

This unsuitability applies also to the transformers and HV cables, the only equipment for which a possible recover was not ruled out in principle.

Their physical and functional damages were not drastic and in line with the forecast expressed in the previous reports. However, a joint survey EPM / Insurers decided for a complete replacement, mostly at Insurers cost (details are under discussion). Such decision appears cost and risk effective for EPM and, at the above conditions, is fully supported by IAP. Moreover, this decision also seems supported by the fact that the transformers' manufacturer (SIEMENS) will not extend a guarantee for any equipment that is not replaced.

The first visual investigation by EPM, as reported to the panel, did not remark any sign of losses of oil from the transformers (the transformer tanks were unaffected). Oil was subsequently removed from the transformer tanks and properly disposed.

At the time of the site visit the transformer cavern was fully accessible: very limited damages to the civil structures were except for the presence of thin debris and all the transformers were in place.



**Figure 6** – One of the single-phase step-up transformers.

EPM has in the warehouse only 6 out of the 25 single phase transformers of the original supply; they are enough for the first two units but, having long-delivery items the other ones shall be timely procured.



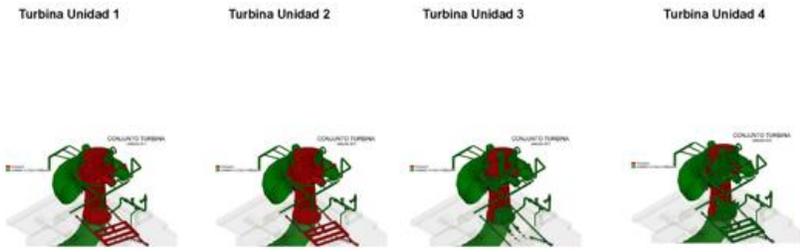
**Figure 7** – One of the HV single phase cables.

At the time of the Power House flooding, the progress of the installation of the lowest part of the units was as shown in the Figure 9 (green color shows installed equipment).

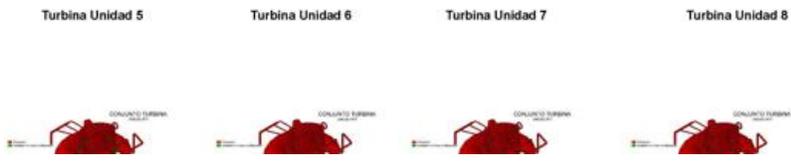
Installation of the north side turbines was well advanced, especially Unit 4 and 3 that were to be commissioned first.

The need of replacing the draft tube(s) may have consequence on the schedule as detailed in the relevant paragraph.

***Progress of installation at the time of flooding the north power house***



***Progress of installation at the time of flooding the south power house***



**Figure 8** – Progress of installation at the time of flooding the north and south power houses.

The lowest part of units 1 and 2 as well as the corresponding first and second phase concretes with their embedded parts are completely lost and their erection will start from the beginning. They were not available for a visual inspection as included in a temporary bank.



**Figure 9** – Units 1 and 2. Pictures by EPM.



**Figure 10** – Units 1 and 2. Pictures by EPM.



**Figure 11** – Unit 2, stay ring displaced by water flood undercutting and removing.



**Figure 12** – Damaged Unit 3 draft tube.



**Figure 13** – Remaining of Unit 4 draft tube.

Units 3 and 4 were partially available for visual inspection. Part of the lowest part are damaged, draft tube cone and draft tube of unit 4 are not in place anymore and the one of unit 3 are damaged. The question mark is the status of their first and second phase concretes and their embedded parts. EPM expects to complete the assessment by November 2019.



**Figure 14** – Massive wall at draft tube cone level with exposed steel bars and signs of erosion in the lower left part.

The result of EPM assessment will represent one of the key elements for deciding within the end of the year the sequence of the units to be put in commercial operation.

The two overhead cranes that were soundly fixed with cable to the two rotors in the loading bay are still in place but hopes to obtain a crane suitable for temporary activity (by cannibalizing the two cranes and replacing all electrical components) failed.



**Figure 15** – One on the cranes.

The pit where generator No.3 was in advanced status of assembly was clear of debris while stator of generator No.4 was still partially covered by debris (the two rotors were instead completely assembled in the loading bay).



**Figure 16** – Unit 3 rotor on the loading bay.



**Figure 17** – Stator of Unit 3 clean and ready to be removed.



**Figure 18** – The flange of turbine shaft emerging from the debris inside Unit 4 stator.



**Figure 19** – Unit 3 runner seen from below.

The isolated phase bus ducts of unit 3 and 4, which are mechanically fragile are lost, as anticipated.



**Figure 20** – Damaged and cut section of isolated phases bus duct of Unit 3.

Three out of four draft tube gates in the north shaft chamber are no more in place, collapsed together with the portion of shaft chamber where they were installed. They were identified in the discharge channels.



**Figure 21** – Relatively well-preserved slot for Unit 5 draft tube gate in the south shaft chamber.

The highest level of the control building at the north end of the cavern doesn't exist anymore. The control system was almost completely installed before the incident; all movable computerized equipment was removed before the start of emergency discharge.

### 3.2. Update on hydromechanical equipment

A new hydromechanical component became part of the project, the steel lining to vertical shafts.

The original design foresaw steel lining only on in the horizontal section between the lower elbow and the spiral case of the Units. Given the severe damages to the rock mass in the area of the pressure shafts, it must be assumed that the ground has lost its capacity to collaborate with the lining in withstanding internal pressures. The adoption of a self-standing, ductile, steel lining seemed inevitable and was recommended by the IAP. EPM adopted the recommendation and the relevant contract with ATB Brescia was scheduled to be signed few days after the completion of the IAP mission. The decision had to be rapid to avoid delays in commissioning the first unit.



**Figure 22** – Upper elbow of penstock n 1 “open” for facilitating installation of steel lining with on the background the downstream face of intake gate.

The following table summarizes the IAP’s brief remarks on the Spillway’s and IDG’s gates (only spillway gates were visually inspected during the site visit).

Hydro Mechanical Equipment	Progress of installation and testing	Remarks
<p><b>Spillway Gates</b>            Four Radial Gates (two with flap for debris) 15 m x 19,50 m            Discharge capacity: 22.600 m<sup>3</sup>/s (PMF)            Operation: oleodynamic servomotors, single control and oleodynamic stations for each gate + common control</p>	<p>Already in operation, testing and common control completed.            Currently still operated separately.</p>	<p>The position of the diesel generator building. In case of earthquake, rocks may fall from the slope and hit the. Risk assessment is recommended.</p>
<p><b>Gates to intermediate Discharge Gallery</b>            Two Radial Gates + two Emergency Sliding Gates            Size: 3 m x 3.90 m (Radial Gates)            Setting capacity: 750 m<sup>3</sup>/s with both gates in operation for all reservoir elevation higher than 350 m a.s.l.</p>	<p>Already in operation conditions, testing and control completed. Steel lining installation duly completed</p>	<p>None</p>

Operation: oleodynamic servomotors, single control and oleodynamic stations for each gate.		
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The following table summarizes the IAP's remarks on the Intake and Diversion gates.

<b>Hydro Mechanical Equipment</b>	<b>Progress of installation and testing</b>	<b>Remarks</b>
<p><b><i>Intake Gates</i></b>            Height Sliding Gates, 5.03 x 6.87 m, with stoplogs            Operation: oleo dynamic servomotors.</p>	<p>The area is now accessible. A physical protection was installed above pit and control box of Unit 1 and 2.</p>	<p>Gates close under balanced pressure conditions and, in emergency, under the maximum hydraulic head and the rated flow of the Unit. However, it was demonstrated their capability to close under flow higher than the rated one.</p>
<p><b><i>Diversion Gates</i></b>            Two-wheel gates, 9 m x 18 m</p>	<p>EPM is working to lower the gates lifted back to the gate chamber and damaged during the hydraulic transient of ADT the gates were. through a temporary fixed crane.</p>	<p>EPM already closed the left gate while they are working to the right one and to rehabilitate the civil works structure</p>
<p><b><i>Bottom Outlet Gates</i></b></p>	<p>They are blocked and plugged</p>	<p>without having been utilized</p>

Activities on the Intake gates and their operating systems are mostly on hold because they are not in the critical path and EPM's attention in these areas is concentrated on reinforcement works underground and slope stabilization.

The area of the IDG will be utilized for the controlled release systems of the piezometric pressure upstream of the DT2 temporary plug and GAD Diversion Gates; the aim is to increase safety at the time of permanent plugging works.

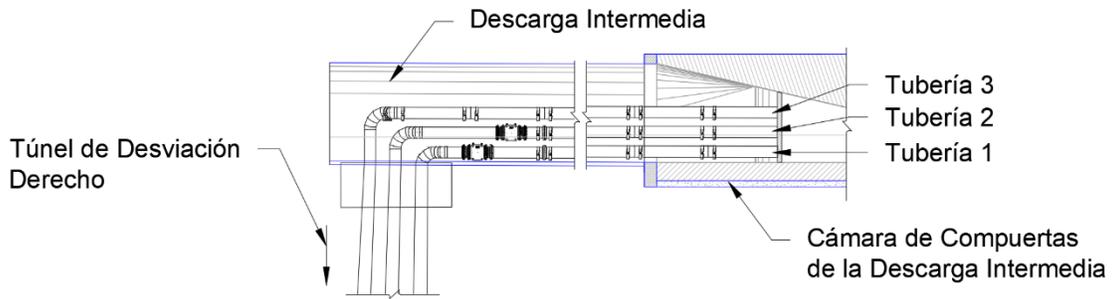


Figure 23 – Pipes of the piezometric pressure control release system for DT2.

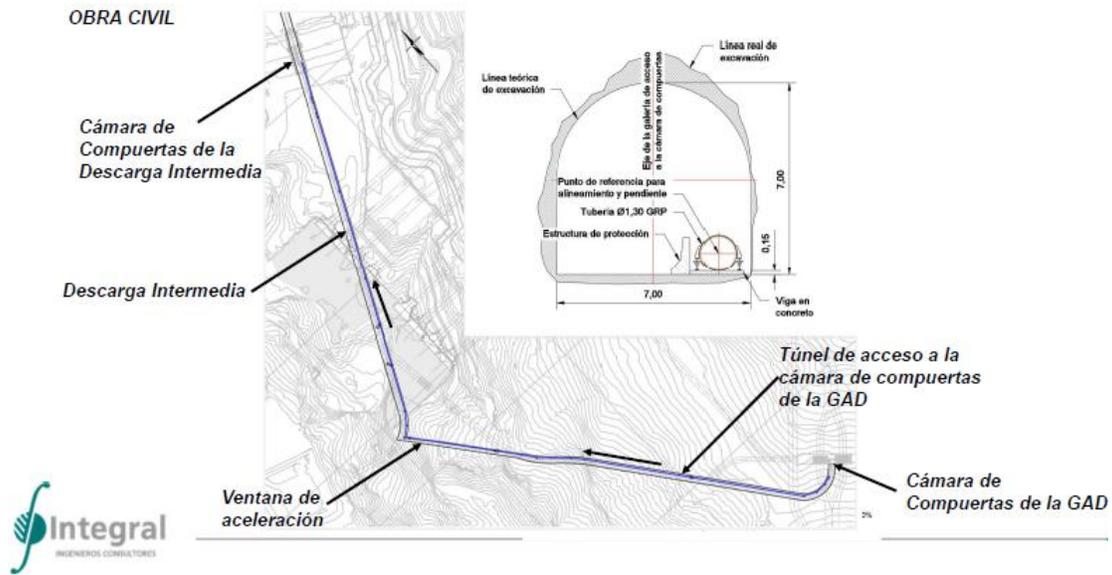


Figure 24 – Piezometric pressure control release system of GAD.

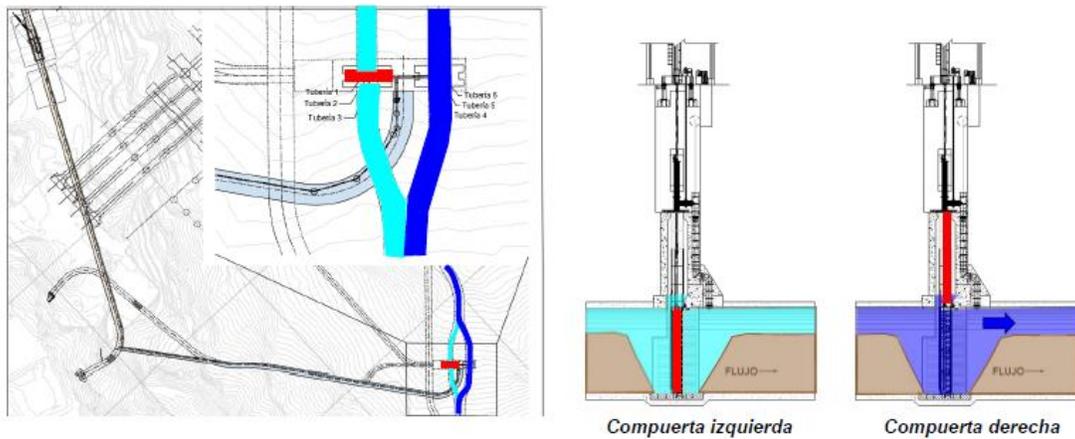


Figure 25 – Current situation of the GAD gates.

### 3.3. Update on 500 kV GIS switchyard

The 500 kV switchyard is already completed though the HV power cable as well as all other cables coming from the power plant will need to be reinstalled. The cable gallery including their connections with the 500 kV GIS switchyard. Minor stabilization works were carried out by EPM in the slope above the switchyard area.

## 4. CONTROL OF RESERVOIR LEVELS

### 4.1. Intermediate Discharge Gallery at el. 260

The possibility of controlling the level of Ituango's reservoir is extremely limited, in the current configuration. Only the Intermediate Discharge Gallery (IDG), with design sill at 260 m a.s.l., would offer partial capability in that regard. After verifying safety conditions of the plug and of the entire portion of tunnel upstream of the gates of the IDG, EPM reinforced the concrete lining, completed contact grouting behind the still lining upstream of the emergency gates, increased and strengthened the two vertical walls of the downstream channel.

### 4.2. Design options currently under evaluation

EPM is still evaluating different options for the design of the IDG's intake and final decision shall be taken shortly. The option of completing the tunnel stretch between the existing plug and the inlet portal, as well as portal itself, was the first option considered. The use of steel lining for the tunnel is conservative and recommendable.

A major design change was recently put forward. It foresees the abandonment of the original portal and the placement of the IDG intake at higher elevation, feed by the power intake 3 and 4, upstream of the gates but downstream of the plugs, through a vertical shaft designed for 450 m<sup>3</sup>/s and connected to the IDG downstream of its current plug.

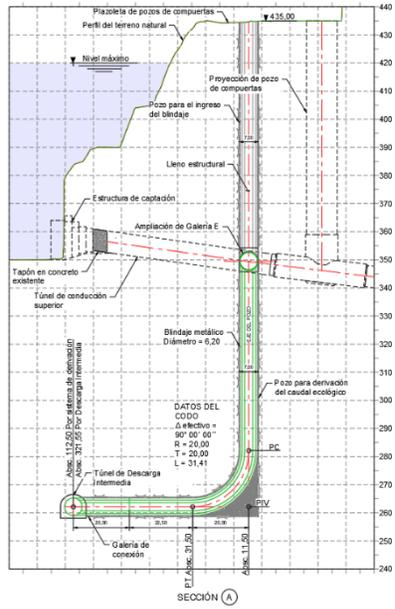


Figure 26 – Section of the alternative design.

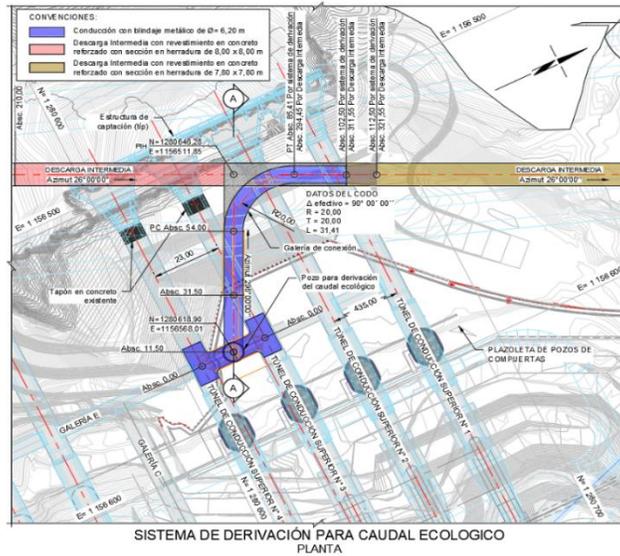


Figure 27 – Plan of the alternative design.

This option is less risky in terms of schedule and methodology and less costly.

However, it would definitively forego the possibility of controlling the reservoir level below, say, 370 / 350 m a.s.l. The only means to lower reservoir level would be through the turbines, which cannot be relied on, in the long term, and in the occurrence of emergency situations (e.g. strong earthquake).

### 4.3. Additional Middle Level Outlet

If completed, with intake at el. 260 m a.s.l., the IDG would be a positive design feature that will improve the operation of the Project. At the same time, such measure is insufficient to ensure adequate control of reservoir levels in all conditions foreseeable during the life of the scheme.

The IAP reiterated its recommendation to endow Ituango with an additional Middle Level Outlet (MLO) for, at least, two reasons:

- Safety: the upper part of the reservoir must be lowered in emergency conditions (e.g. post-earthquake, or for internal erosion manifestations), when discharge through the turbines cannot be relied on.
- Operational: to access the intake gate areas for extraordinary maintenance or repairs.

### 4.4. Importance of control reservoir levels/Potential Failure Mode Analysis

The IAP understands that EBIA is raising legitimate concerns associated with the difficulties of completing the original design of the IDG and realizing additional discharge capacity (Middle Level Outlet) in a rock mass that sees local disturbed areas and already houses several tunnels. Moreover, the project EBIA's seems still convinced that hydraulic works to control, lowering, reservoir levels, are not needed. EBIA still substantially confirming the original design foreseen at the beginning of the project; the only discharge capacity, apart obviously the spillway, is the one to ensure the 450 m<sup>3</sup>/s of the mandatory environmental release. It shall be recorded that such approach is already implemented in other hydropower project in Colombia.

The IAP confirms a different view. The availability of hydraulic works to lower the level of the reservoir, under exceptional circumstances when turbine operation cannot be relied on, is fundamental for the safe performance of the project over the long term. Project operation is not going to be reliable, and safety cannot be guaranteed, without a system for lowering levels below the power intake level, being a temporary cofferdam at the intake platform only a proxy.

IAP restates the need for additional discharge, the MLO, not necessarily before the commissioning of the units, and the importance of evaluating carefully the consequences of the new solution for the IDG intake that would limit for the future its maximum flow and would reduce its operational range.

The statement above would have been valid since the very beginning of the project, as such representing a different professional opinion compared with the one of the projects EBIA but became more stringent after the events affecting the project.

The IAP fully realizes that the solution is very complex to execute (be that an increase of capacity of the IDG, which would be a minimum, or the construction of a mid-level outlet, which the IAP has advocated since the beginning), but this essential feature cannot be foregone on technological complexities only.

The IAP received a brief documentation, prepared by Integral, with the aim to demonstrate the unsuitability of the IDG to control the reservoir level. However, such documentation is of limited interest because it considers, without demonstration and against normal practices, the lowest operating level of the units corresponding to the Minimum Operating Level 390.00 m.a.s.l. even in emergency situation and the maximum flow of IDG at its original value of 450 m<sup>3</sup>/s without considering the uprating obtained.

The subject of long-term reservoir control is too important and requires detailed examination. To this end, the IAP proposes to conduct a PFMA (Potential Failure Mode Analysis) session, on site or in Medellín, to analyze potential scenarios of project operation, or failure to operate, under different waterways configurations. The session should involve all key stakeholders, and the EBIA in particular, possibly POYRY

too. A decision has to be made and it must be an informed decision. The IAP believes that a PFMA workshop is the appropriate tool for that purpose.

## 5. DAM

### 5.1. Settlements-deformations

The dam has been completed and behaves satisfactory. The embankment shows normal settlement in crest. The deformations measured since October 2018, are associated with both the rise of the dam and the reservoir. The values measured are confident, considering that they count also the deformations from the whole high dam.

The magnetic extensometers settled from the crest of the dam, show minor variations, at the limits of the accuracy of the measurements, since the completion of the dam from July 2019, showing a stable behavior.

The control and monitoring of the deformations of the face of the dam is recorded by SAR-X interferometer radar. There is a slight increase of deformation at the upper part, explained by the rise of the dam and reservoir level. Their size is as could be expected.

### 5.2. Piezometers gradients and leakages

The piezometers located downstream of the plastic diaphragm wall towards the filter zones have been kept dry since their installation.

The piezometers installed in the core of the dam showed a behavior as expected by analysis. They have currently a stable behavior.

The readings of the main piezometers are satisfactory in all sections of the dam. There is a clear drop of the piezometric heads downstream of the axis, denoting a low hydraulic gradient and a good operation of the grout curtain. The behavior has been stable so far.

## PRESA

### 0.3.24 Deformaciones al 15/09/2019

Los PCS 29, PCS 30 y PCS 35 registran deformaciones asociadas tanto al incremento del nivel del embalse y de los llenos de la presa. En las gráficas se observa un aumento en las deformaciones, atribuido al inicio de la conformación de los llenos de la presa por encima de la cota 418, el 07 de abril de 2019. Y culminando el 19 de julio de 2019.

En el PCS\_30 el rango de valores entre umbrales es menor al error de precisión de los equipos, generando una oscilación entre umbrales.

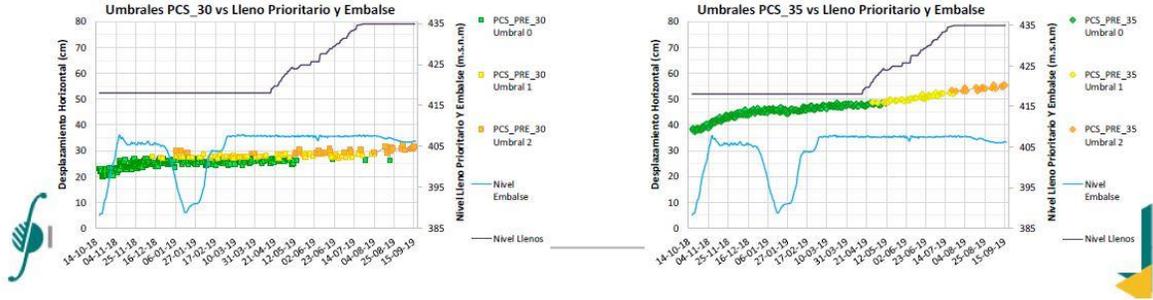


Figure 28 – Deformations of the dam, since October 2018, following the rise of the dam and the reservoir level. The values are in line with the values that could be expected.

## PRESA

### 0.3.20 Piezometría Abs 480 al 15/09/2019

Los piezómetros instalados la abscisa 480 presentaron un comportamiento de acuerdo con lo esperado bajo condiciones ideales regidas por la modelación numérica para la etapa de llenado del embalse. El comportamiento ha sido estable sin cambios significativos luego de la entrada a la etapa de operación de la presa

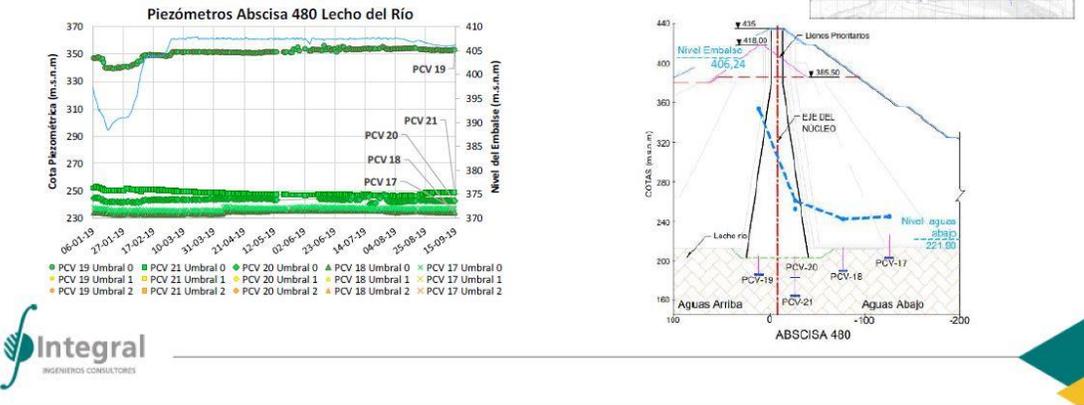


Figure 29 – Piezometric profile at the left side of the dam and its foundation, and its evolution with time. Good behavior of the core of the dam. Piezometric heads downstream of the grout curtain, higher than expected. Leakages are recorded in the inspection gallery, left side. Although no high (170 l/sec), additional grouting in this area is foreseen.

Water seepage associated with the diaphragm wall is very low. As of August 18, 2019, with the reservoir level at + 407.08, infiltrations register a flow of 7.8 l/s.

Leakages in the inspection-grouting galleries are low to very low. The need of additional grouting works in the left bank was discussed in the IAP's report of March 2019, although the extent of leakage was not excessive. Additional grouting was executed. However overall seepage is not substantially decreased. With the present reservoir level, in this abutment total seepage is reported having reached 170 l/s. Additional multidirectional grouting was recommended and is to be performed after having the grouting gallery lined. All seepage water is reported clean.

Water seepage associated with the diaphragm wall is very low. As of August 18, 2019, with the reservoir level at + 407.08, infiltrations register a flow of 7.8 l/s.

## 6. LEFT ABUTMENT

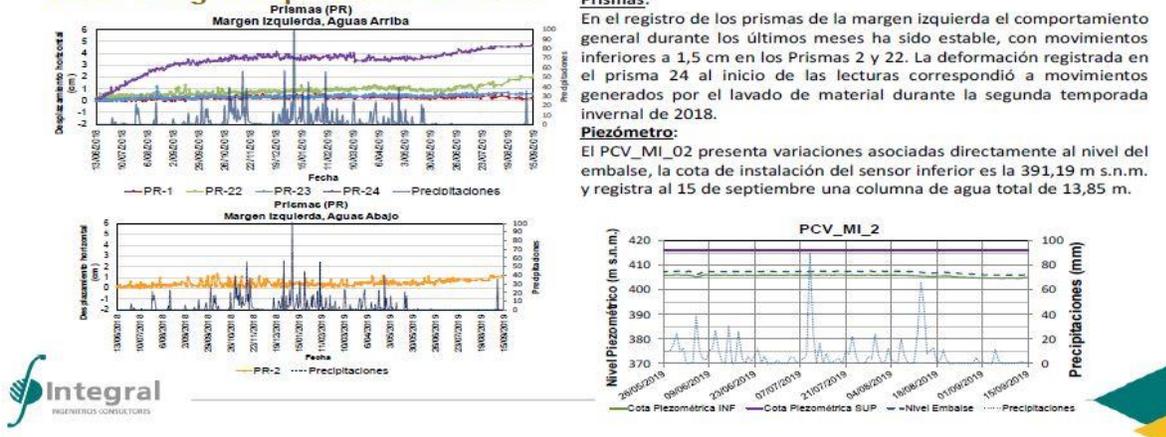
The left abutment does not show forms that could correspond to unstable ground or old slides. Skin slides could occur as the one at the upstream side of the abutment. The geodetic monitoring since June 2018 shows stable conditions. No displacement trend is recorded.



**Figure 30** – Aerial view of left abutment. Geomorphology exposing no unstable forms. Skin slides only.

## PRESA

### 0.3.27 Margen Izquierda de la Presa



**Figure 31** – Left abutment. Geodetic monitoring since June 2018 stability. No signs of deformation to be considered, no trend.

The monitoring of the lower slopes by the SAR-X radar shows a process of slow and active surface erosion, treated with geogrid and revegetalization. The tendency of deformation has decreased in recent weeks.

Monitoring of the left abutment has to be permanent.

## 7. RIGHT ABUTMENT AND EL ROMERITO

The slopes at the higher part of the right abutment are already reshaped, benched and anchored. The stabilization is proceeding downhill with another bench to the area of El Romerito sens strict. During the mission the panel visited the works in progress at the slope. Both design and implementation are considered satisfactory. This treatment will contribute to the stability of the abutment and unload the El Romerito part of the slope over and behind the intake structures.



**Figure 32** – Right abutment and “El Romerito.”

## ROMERITO

### 0.5.2 Piezómetros / Inclínómetros



**Figure 33** – Right abutment and zone over “El Romerito.” Position of inclinometers. Monitoring results are satisfactory. Only the IN-GAP-05, nevertheless over the terminal part of the natural slope, shows a displacement of about 1cm at a depth of 18m.



**Figure 34** – Structural protection above the power intake gates 2, 3 and 4 to be enhanced.

Monitoring results are satisfactory. Only the inclinometer IN-GAP-05 over the terminal part shows a displacement of about 1cm at a depth of 18m; monitoring has to follow for verification.

Cracks were observed in the shotcrete layers on the slope above the platform of the power intakes. The stability of those slopes should be revisited and monitoring continued.

The IAP reiterates its advice to extend the slope protection measures as far upstream as the destabilized area above the two diversion tunnels and the IDG intake where major mass movements have taken place.

A slope in those conditions cannot be left behind untreated in any case. It is too close to the dam, and we cannot preclude the possibility of completing the IDG or even adding a MLO. The IAP expressed this need since the first visit.

## 8. THE SPILLWAY SLOPES

The IAP has already commented on the spillway safe operation. The monitoring of the spillway slopes shows a satisfactory behavior. Load cells and the multi-position extensometers show a stable behavior. The inclinometers installed do not show displacements to be considered for instability, measurements do not define precise depth and are in the range of error of the measurements. Monitoring has to be permanent. In the zone of the substation over the spillway where a deformation was measured in November 2018 at a depth of 10 m of 4 cm, no further movement was recorded to present.

## 9. SEDIMENT MANAGEMENT/SEDIMENT TRENDS

As a follow up of the discourse initiated during its first visits, the IAP reiterates to plan reservoir surveys aimed at providing early elements for sedimentation management purposes and to consider since the very first stage of operation all possible measures to ensure sediment management.

Two types of surveys are recommended:

- Bathymetric surveys of the reservoir, and
- Grain size distribution of the delta deposits that are starting to accumulate in the upstream limit of the lake.

## 10. PROJECT COMPLETION

### 10.1. Schedule

The last project schedule was provided by EPM in August 2019 and it is dated June 29, 2019. It is a refined version of the previous ones reflecting the completion strategy with the same two phases planned in September 2018, (i) Units 1-4 (North Power House), completion by end of 2021 and (ii) Units 5-8 (South Power House), completion by end of 2023. However, this latest schedule postpones the commissioning of the first unit at the end of 2021 and dates the ones of the other first three units in 2022.

The current value of the details of this schedule is limited because the recent findings and assessment caused important changes in the planning of the project.

The new schedule will be ready within the end of the year, beginning of 2020. It will reflect, in addition to a better defined sequence of all activities, key decisions that need to be taken in the next few months, among other the sequence of the units to be erected and commissioned. Indeed, the two phases approach corresponding to the North and South powerhouse is expected to be abandoned.

Key drivers of the new schedule will be the assessment of existing concrete of the Unit 3 and 4 (retain or remove) and the risk profile of the different intakes.

An element seems to be sure: Unit 7 and 8 will be the last to be commissioned due to lack of discharge tunnel and extent of the damages to the southeast part of the project. A couple of other elements seems quite probable: unit 5 and 6 shall be among the first to be commissioned, north and south shaft chamber should be divided into two halves to support a quicker schedule.

EPM had been confident to achieve the 2021 milestone (that in IAP understanding refers to just one unit) and submitted the relevant financial guarantee to the Regulator to get market access rights (such financial guarantee was already forfeited once at the end of 2018).

Based on the current status of the assessment of the damages to the underground works, it is clear that the repairs works are the schedule-controlling factor. This is also due to the fact that an entire set of electromechanical equipment, originally assigned to Unit 5-8 (South Powerhouse), is already available in the warehouse of EPM. However according the information in the hands of IAP only single-phase transformers for two units and one draft tube are available in EPM warehouses.

Time for design, manufacturing, transportation, installation and testing of the lining should be detailed in the revised schedule.

An element on the critical path should be the availability of civil works structure (first phase concretes) of the powerhouse within the end of June 2020. Indeed, EPM esteems a delay of 18 months for the installation of electromechanical component of a unit.

Despite the significant improvement in the assessment of conditions of the underground civil works and installed electromechanical equipment, Adaptive Management will remain the guiding principle for the implementation of the project. Having said that, EPM's decision to maintain the previous schedule for the first unit appears reasonably sound.

EPM will be able to issue the update schedule in the next few months and at that time its soundness will be better substantiated; for most of the project, except the southeast part it should be a final schedule.

## 10.2. Costs

Cost estimates is currently less uncertain than six months ago; however, for the time being, an updated cost estimate was not communicated to IAP by EPM and too few elements are available to reliably update the estimates which were made in September 2018.

Based on current knowledge, it is safe to keep the September estimates for financial purposes. The "discovers" affecting civil works should be broadly balanced by the interventions of the Insurers for the electromechanical equipment.

## ANNEX: LIST OF DOCUMENTS MADE AVAILABLE TO THE IAP

- [1] Temario de la vigésima segunda reunión septiembre 23 al 28 de 2019 - Túneles de desviación, GAD y descarga intermedia, Integral.
- [2] Temario de la vigésima segunda reunión septiembre 23 al 28 de 2019 - Obras de generación, Integral.
- [3] Recuperación de las condiciones originales del lecho del Río Cauca, Integral 2019.
- [4] Instrumentación, Integral, 2019.
- [5] Otros [geotecnia], Integral, 2019.
- Equipos en inventario / equipos a reponer / equipos electromecánicos – estado, epm.
- Justificación técnica de por qué la actual descarga intermedia de la forma como está no sería una solución viable para desembalsar el reservorio + simulación desembalse sin di habilitada / simulación desembalse con di habilitada, Integral (?).
- Pánel de asesores de EPM vigésima segunda visita. Epm integral. Septiembre, 2019.