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5. The Report was prepared to provide IDB Invest and IDB Invest’s B Lenders with qualified Project status information at August 2018 and not after this date.

Independent Advisory Panel to IDB Invest
IAP Report N° 1, September 2018

Ituango Hydropower Project
Colombia

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Table of Contents

Executive summary.....	i
1 Introduction.....	1
2 Spring-2018 events.....	2
2.1 Chronology of events	2
2.2 Geotechnical considerations	3
2.3 Emergency handling.....	6
2.4 Stock-taking of the spring 2018 events	8
2.5 Strengthening the Designer Team	8
3 Engineering assessment	9
3.1 Engineering geology conditions of the Project site.....	9
3.2 Geotechnical assessment.....	12
3.2.1 Dam site.....	12
3.2.2 Slope protection measures.....	14
3.2.3 Power House Cavern complex.....	17
3.2.4 Potential landslides in the reservoir	20
3.3 Dam conditions.....	21
3.4 Hydro, Mechanical & Electric Equipment	23
3.4.1 3.4.1 Gates.....	23
3.4.2 Powerhouse Equipment.....	24
3.5 Dam Safety Management.....	30
4 Plans for Project continuation.....	31
4.1 Potential Failure Mode Analyses	31
4.2 Safety-related structural measures	32
4.3 Cost and schedule implications.....	33
4.3.1 Cost estimates	33
4.3.2 Schedule considerations	34
5 Project sustainability	35
5.1 Middle Level Outlet.....	35
5.2 Sedimentation management	37
5.3 Options assessment for Project completion.....	40

6	IAP's conclusions and recommendations	41
6.1	IAP's Main Conclusions	41
6.2	IAP's Recommendations	45

Annexes

1. *Atendencia reuniones en Medellin, Julio 30 y 31*
2. *List of documents made available to the IAP*
3. *Detailed reconstruction of the spring 2018 events*
4. *Response Level Matrix*
5. *Detalle Costo Ituango BID 36 meses (EPM agosto 2108)*
6. *Cronograma de recuperacion y puesta en servicio (EPM septiembre 2018)*

Glossary of acronyms

ADT: Auxiliary Diversion Tunnel (GAD or SAD in Spanish)
BID: Banco Interamericano de Desarrollo
CAP: reservoir capacity
EPM: Empresa Publica Medellin
FEM: Finite Element Analysis
GAD: Galeria Auxiliar de Desviacion, or SAD: Sistema Alterno de Desviacion
GSI: Geological Strength Index
IAP: Independent Advisory Panel to IDB Invest
IDG: Intermediate Discharge Gallery
MAF: mean annual flow
MAS: mean annual sediment yield
MLO: Middle Level Outlet
PFMA: Potential Failure Mode Analysis
RESCON: Reservoir Conservation
TD2: Diversion Tunnel No.2
XLPE HV: cross-linked polyethylene High Voltage (cables)

Executive Summary

The Ituango hydroelectric project is under construction at the northwest of Colombia since 2009. In the spring of 2018, when more than 84% of the works had been completed, a series of events seriously endangered Ituango Dam, during the final phases of embankment construction.

The present Report contains the findings and recommendations of the Independent Advisory Panel that IDB Invest appointed to review the situation and inform the Institution on lessons learned and viable options for the continuation and completion of the Project.

The emergency-originating event was a collapse of the tunnel with a sinkhole that obstructed the river diversion tunnel (GAD). The collapse was caused by the interaction of water with the rock mass. It is most likely that local unevenness of the lining, due to the rock mass structure and, possibly, very weak rock in the area over the tunnel, which went undetected during excavation, may have favored rapid propagation of localized erosion and, consequently, progressive failure. The subsequent mass movements, that took place in different parts of the waterways, were a consequence of the uncontrolled flow of water through interconnected galleries, some of which were never intended for conducting water.

The emergency was faced with extreme measures, involving the use of the underground powerhouse complex for water discharge purposes, an unavoidable measure, since the dam, under construction, had not reached the spillway level. The measures proved successful, at the expense of significant additional costs and schedule overrun for the Project. Timely warning of downstream communities averted casualties and allowed containing economic damages.

The IAP has no major comments on the design of the Dam. Based on the data provided, clay core, zoning, filter design, materials, static and dynamic analysis, and instrumentation of Ituango Dam, respond to engineering best practice in dam design. Dam zoning was modified, above elevation 385 meters above sea level (masl), to speed up embankment rising during emergency response. A plastic diaphragm is being constructed to improve water tightness of the zone. The Designer is investigating the global stability of that part of the dam. Results are reasonable and indicate the marginally acceptable stability conditions of the additional fill, which are generally satisfactory for the emergency state.

The Powerhouse Cavern Complex showed satisfactory rock mass behavior, with maximum deformation, localized only, in the order of 100 mm. Infiltrations were monitored and consolidation routing was done. FEM analyses showed that any extended collapse is not likely to affect the stability of the parietal slope and adjacent access tunnel. After-flooding conditions will be assessed when the area is accessible. Cavern abandonment is unlikely, but significant reinforcement and reconstruction works could be necessary.

During reservoir operation, small landslides will locally occur, in the weathered and

distressed zone of the slopes, along the rim of the lake. Such mass movements are not deemed to generate dangerous impact waves, but rather slowly contributing to reservoir silting. The Designer has carried out an impact wave analysis to check the adequacy of the available dam crest freeboard (15m) to contain wave run-ups. Results indicate that such freeboard is adequate.

Visual inspection of the Spillway and IDG Gates did not evidence reasons of concern. The gates are operational and tested. At the time of IAP's visit, finishing works and the implementation of the control system were ongoing.

River diversion through the powerhouse complex has certainly caused damage to the underground works and the already installed equipment. Level of such damage cannot be predicted before visual inspection of the underground works. Recently (September 2018) drilled boreholes have revealed that the rock mass above the cavern roof is in good conditions. Date of access can be estimated, at the earliest, in March 2019 (very optimistic), more realistically in December 2019.

Though not very common, the flooding of Ituango Power House is not unprecedented. The post-flooding, rehabilitated equipment should not be subject to significant residual risks during plant operation. The overall schedule of the project, with significant civil works rehabilitation, the availability in stock of at least an entire set of electromechanical equipment to install the first two units, are elements that can reduce residual risks during operation.

The Designer operates a satisfactory dam safety system on site. Measures implemented to date, as well as ongoing safety-related and maintenance works, allow expressing a positive assessment on project' safety in its current configuration.

Plugging works at TD2 and GAD represent the most urgent activity for Project's continuation. Grouting treatments are quite an unpredictable operation and are likely to require significant trial and error, as well as adaptive management; as such, their duration is very hard to predict.

For the time being, it should be prudently assumed that plant commissioning can be delayed 3 to 4 years from the planned date of December 2018.

It is to be expected that, after some 50 to 60 years, the plant will have to be operated as run-of-river, and coarse sediment will have to be handled. Hydro- suction, or tactical dredging in front of the intakes may prolong the life of the plant further. Decommissioning will be necessary when coarse sediment management is no longer economical. It is too premature to discuss possible decommissioning scenarios at this stage, but it will be necessary for EPM to set aside a decommissioning fund during the life of the plant.

In addition to several non-structural measures, the main IAP's recommendations are:

- Extend the same treatment and protection upstream of the spillway slopes, as far as

the intake of the Intermediate Discharge Gallery (IDG) and the destabilized area over the two diversion tunnels, as well as over the power intake shafts.

- Add a Middle Level Outlet (MLO) between the IDG and the Intake level, for safety and operational reasons.
- Steel line upper and lower elbows of the penstock shaft; extend steel lining above lower elbow. Consider the opportunity of extending the steel lining further to prevent leakage from the pressure waterways that would impair the operation of the Power Intake Gates (designed to operate under balanced pressure).
- Complete contact injections between steel lining and rock in the upstream part of the IDG; seal injection holes; strengthen existing lining by mesh- reinforced shotcrete.
- Consider the opportunity of installing embedded parts or creating adequate contact surfaces for allowing the future installation of a temporary device for emergency maintenance of the IDG emergency sliding gates.

INDEPENDENT ADVISORY PANEL (IAP) TO IDB INVEST

Report N° 1, September 2018 Ituango Hydropower Project – Colombia

1 Introduction

The Ituango hydroelectric project is under construction in the Cauca River Basin at the northwest region of Colombia since 2009. In April 2018, during the reservoir filling phase, mass movements caused the obstruction of the river diversion tunnel. That event determined reservoir level to rise uncontrolled, threatening to overtop the dam under construction. Emergency actions were activated for both reducing the probability of overtopping and minimizing potential consequences to the downstream communities should an uncontrolled release of water from the reservoir occur. Events and implemented actions are described in Annex 3. The situation is currently under control and the emergency is being adequately managed. Nonetheless, many challenges remain in order to resume project completion and the impacts of the incident, on implementation schedule and costs, will be significant.

Given its involvement in the Project, IDB Invest, member of the Inter-American Development Bank Group decided to appoint an Independent Advisory Panel (IAP) to review the situation and inform the Institution on lessons learned and viable options for the continuation and completion of the Project.

The objective of the IAP is to advise IDB Invest on:

- Fact-based understanding of what has happened;
- Lessons learned from the incident;
- Critically evaluate options for project's completion, including re- engineering, revised schedule, and potential risks for successful project completion.
- Assess the overall safety of the infrastructure;
- Evaluate the likelihood of a potential abandonment of the project including risk of eventual dam failure.

The present Report is articulated in 6 chapters covering:

- Introduction,
- Spring 2018 events
- Engineering assessment
- Plans for Project continuation
- Project Sustainability
- IAP's conclusions and recommendations.

Six annexes complement the Report.

IAP's members visited Colombia from July 30th to August 4th. Meetings with EPM (Owner),

the Designer (Integral), the Engineer (Ingetec), and the Contractor (Carmago Correa, and Constructora Conconcreto) were held in Medellin on July 30th and 31st. Site visit took place from August 1st to 3rd.

The IAP debriefed IDB Invest and EPM on its preliminary findings and recommendations on August 4th and departed from Colombia on August 5th (Mr. Ciampitti) and 6th (Messer's Palmieri and Marinos). The IAP submitted a site visit debriefing in the form of ppt on August 15th.

IAP's members wish to acknowledge the open and frank interaction with the above-mentioned parties, their professional input, and the kind hospitality provided on site.

2 Spring-2018 events

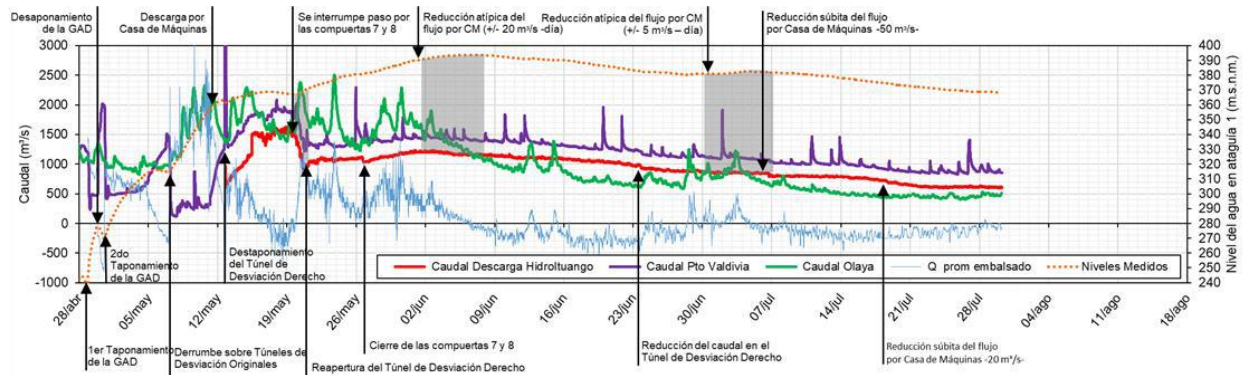
2.1 Chronology of events

Annex 3 contains a detailed reconstruction of the events.

The following table summarizes the sequence of the key events; the most critical dates are shown in red, emergency response measures are highlighted in yellow.

Day	Key Events
April 28	Rock mass failure in the Galeria Auxiliar de Desviacion (GAD) stopped water flow.
April 29	Reservoir pressure removed the plug
April 30	Second massive rock mass and soil failure blocked the GAD and a sinkhole appeared at the surface above the tunnel. At this point, there was no control on reservoir level and dam top had not yet reached the level of spillway engagement (410). Risk of dam overtopping and consequent breach.
May 7	A third rock mass failure affected the gallery through which the water was flowing into de ADT, and caused the flow to stop again.
May 9	Partial failure of the Right Diversion Tunnel's plug started water flow in the tunnel, reduced after few hours; a second sink hole and a land slide appeared on the surface above the tunnel entrance
May 10	To avoid dam overtopping EPM let open Intake Tunnel 1 and 2 as well as 7 and 8; reservoir started flowing through the Power House. Control on reservoir level regained.
May 12	An abrupt and wash-out of Right Diversion Tunnel's obstruction caused a flow in excess of 4,000 m ³ /s, which lasted about 4 hours, causing serious consequences downstream; a significant land slide in the area of the tunnel portal reduced flow to approximately 100 m ³ /s.
May 17	Tailrace Tunnel 3 reduced its flow that subsequently will stop.
May 20	EPM closed Intake Tunnel 7 and 8; few hours later a land slide in the area above these tunnel occurred.
June 1	Irregular reduction of the flow through the Power House
June 5	Dam crest level reached elevation 410 m a.s.l. allowing operation of the surface spillway. Risk of dam overtopping averted.
June 24	Reduction of the flow through Right Diversion Tunnel
July 1 to 18	Irregular reduction of the flow through the Power House
August 2	IAP visit: situation under control, reservoir 370 masl, river discharge 600 m ³ /s

The following plate shows graphically river discharge at the dam and other relevant locations, along with reservoir levels. The main events are also represented to highlight their effect on the hydraulic parameters.



2.2 Geotechnical considerations

The Auxiliary Diversion Tunnel (ADT or GAD in Spanish) was put in operation in August 2017; initially together with the right diversion tunnel, having the left one already been plugged. From March 2018 GAD operated alone.

GAD is located at the same elevation of the two diversion tunnels and has got the same 14m size. Diversion Tunnels and GAD were designed in the same way, both in terms of geometry and support measures.

The two diversion tunnels had operated satisfactorily over 3 years, under lower hydraulic heads; GAD was expected to operate over a much shorter period.

The tunnel was excavated through the gneissic formation of the area. From the data reported, and reviewed by the IAP, the rock mass was of good geotechnical quality, with moderate jointing. Crossing of two main faults encountered weak zones but, reportedly, they were not problematic. The steep inclination of the faults was favorable, and the thickness of the sheared zones limited. No stress dependent instability could develop and only structural, gravity-controlled, wedges failures could occur. Excavation was effectively stabilized by rock anchors and shotcrete. This support proved appropriate for tunnel excavation and was retained for tunnel operation.

The distressed, highly jointed, loose and weathered zone that is developed in the part of the slope close to the surface, affected the portal areas, but is not deemed to have reached the GAD alignment. However, it cannot be excluded that the depth of the distressed zone could have locally approached the sound rock above the tunnel.

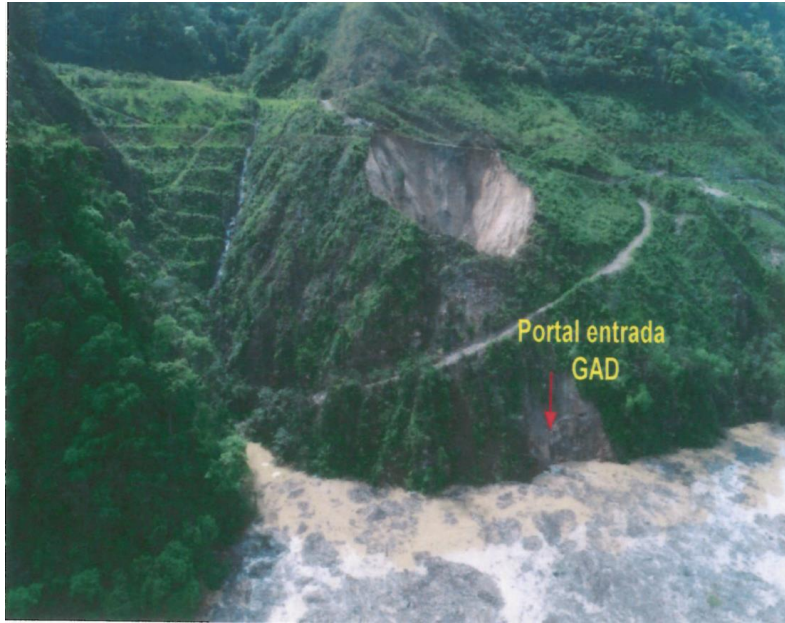


Figure No. 1: 30 April 2018. The sinkhole from the chimney collapse in front of the portal area of GAD (Photo from the files of the project)

The zone where the collapse and the sinkhole occurred (figure No.1) consists of slightly to weathered gneiss, moderately to highly jointed, with some shears and sub horizontal foliation (type IIB in figure No.2). No weak ground was present at the alignment (IC, IIA soil-rock transition zone).

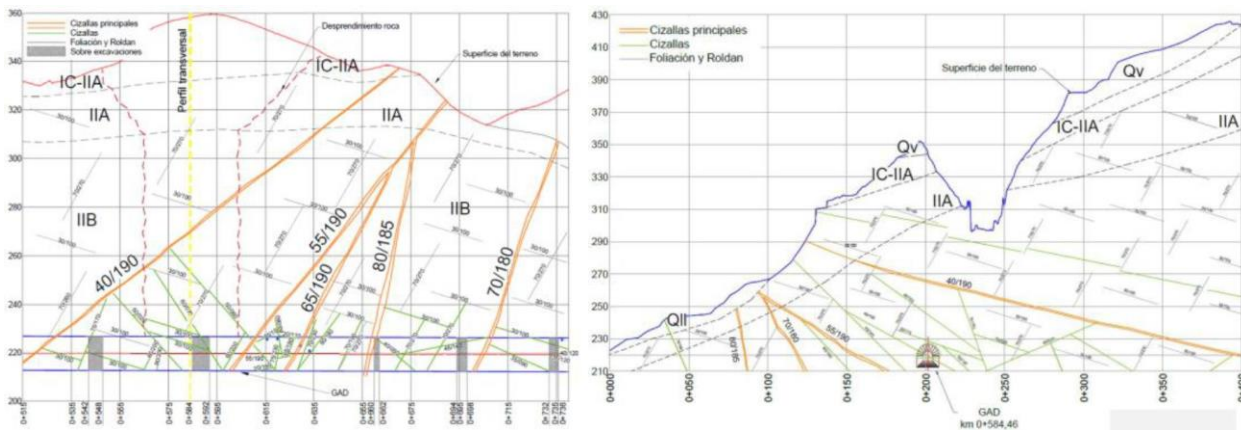


Figure No.2: Longitudinal and transversal section of GAD at the area of the collapse. From construction data (from “Analysis de taponamiento Galeria Auxiliar de Desviación”, May 2018)

GAD was constructed by drill and blast and the applied support followed the “Q” method’s recommendations: 2 layers of 5 cm each of fiber shotcrete, and rock bolts of 6m length with a spacing of 1,5m and 2m in the vault or the sides of the tunnel (type III support). In some points, important over break was treated to re-establish, as much as possible, the design section (see Figures No.3 and No.4).



Figure No.3: Top heading and bench during construction of GAD. Small over breaks present (photo from the report of the Board of Advisors #12, February 2017)



Figure No.4: Portal of GAD. The roughness that forms the good quality gneissic rock mass (photo from the report of the board of Advisors # 13, July 2017)

The Designer performed wedge-type stability analysis (structurally controlled) and found ample factors of safety (“Análisis de taponamiento Galeria Auxiliar de Desviación”, May 2018). The Designer considered that the installed support was able to hold up the unstable blocks also during operation.

The failure that took place suggest that other elements came into play, such as the occasional occurrence of over breaks, which could have caused highly turbulent flow conditions. The rise and fall of the reservoir level must have also worsened stability conditions underground.

The flow likely triggered pulsating pressures and probably penetrated trough the joints inside the rock mass and destabilized wedges. The roughness of the periphery of the tunnel and anomalies from over breaks, can indeed, induce sub- pressures. After the first smaller collapse on April 28th, the main one on April 30th was an unavoidable development in an already disturbed zone. The presence of a possibly thick distressed zone over the tunnel, possibly associated with a particularly weak rock zone at this location could be an unforeseen factor and the reason of the propagation of the sink hole to the ground surface. Figure No. 5 shows the localization of the events on the right side of the project. The slide over the intake shafts of May 26, 2018 had not yet developed, but cracks are already present in that zone.



Figure No.5: Photo from a ppt of Prof. G. Fernandez, June 2018

The Board of Advisors discussed the need for a concrete lining in their 12th report of February 2017, after an important collapse (large wedges) that took place during construction, at the portal of the tunnel. Besides the strengthening of this zone, the Board pointed out the need of a “hydraulic concrete lining to a prudent distance to the entrance of the tunnel”.

2.3 Emergency handling

From the very beginning of the emergency situation, a set of activities and tasks was devised by EPM, the Designer, the Contractor and the Construction Supervisor, in a permanent Crisis

Committee that has been appointed by EPM to assess and deal with the situation. Downstream warning had to be issued because of the uncontrolled releases from diversion tunnel 2. Timely warning averted casualties and allowed containing economic damages.

The following table illustrates five plans that were considered, the reasons for which some were rejected, and the final choice of the preferred course of action that featured parallel implementation of plans C and D.

Plan	Description	Remarks
A	Drilling and blasting of the provisional concrete plug on the Right Diversion Tunnel, in order to use this tunnel for lowering the reservoir.	Plans A and A' started to be implemented, but shortly a series of difficulties related with the amount of infiltrations through the concrete plugs, made difficult to blast the provisional concrete plug on the Right diversion tunnel. The drilling and blasting of the main concrete plug on the Left tunnel was advancing at a pace of a few meters per day, but at this time and due to both landslides at the entrance, these two plans were abandoned.
A'	Drilling and blasting of the main concrete plug and provisional concrete plug on the Left Diversion Tunnel, in order to use this tunnel for lowering the reservoir.	
B	Activities on the Intermediate Gallery to make it operational, in order to use this tunnel for lowering the reservoir.	The intermediate gallery has a rated discharge capacity of 450 m ³ /s, which is not enough to control reservoir level.
C	Activities on the spillway and the dam to make them operational and able to handle, at first stage, a flow discharge corresponding to a return period of 2,33 years, and in a second stage to discharge a flow corresponding to a return period of 50 years.	At the moment of the emergency, the spillway sill level was at 401 masl, and the dam was at 385 masl, being necessary to rise it at a fast track. To do this, a Priority Embankment (see ch. 3) was designed and its construction started from May 1st. Once constructed, to elevation 418 masl, the spillway can handle a discharge of about 500 years (return period).
D	Divert the flow through the power house.	Plan D, featuring the flooding of the power house complex, was the most appropriate, and inevitable course of action, which permitted to regain control on the reservoir levels. Dam crest elevation of 410 masl was reached on June 5th allowing operation of the surface spillway and averting risk of embankment overtopping.

On August 2nd, during the IAP's visit, the situation was in full control, with reservoir level at 370 masl, and river discharge at 600 m³/s.

The following table synthesizes the response measures during and after the emergency. Return to normal is expected around the end of the year, with successful tapping of Diversion Tunnel #2 and the GAD.

Emergency phase	Dates	Emergency response
During	30 April to May 10	Reservoir allowed to flow through the Power House. Control on reservoir level regained.
After	May 10 to June 5	Dam crest level reached elevation 410 m <u>a.s.l.</u> , allowing operation of the surface spillway. Risk of dam overtopping averted.
Return to normal	December 2018	Essential tasks: safely plug Diversion Tunnel 2 and GAD.

2.4 Stock-taking of the spring 2018 events

Based on the facts that occurred in April-May 2018, the IAP can make the following observations.

- i. The two diversion tunnels, and the GAD were designed in the same way, both in terms of geometry and support measures.
- ii. The two diversion tunnels had operated satisfactorily over 3 years; GAD was expected to operate over a much shorter period.
- iii. In view of that, switching river control to GAD was a calculated risk.
- iv. GAD closure (sinkhole) was the consequence of water flow that provoked sub pressures and likely penetrated inside the rock mass and destabilized wedges. Thus, water energy interacted directly with the rock mass and caused progressive failure of the same.
- v. Very weak rock in the sinkhole area can have initiated progressive failure.
- vi. The subsequent mass movements, that took place in different parts of the waterways, were a consequence of the uncontrolled flow of water through interconnected galleries, some of which were never intended for conducting water.

2.5 Strengthening the Designer Team

During and after the emergencies, the Designer Team has been undertaking the dual task of elaborating project design and responding to emergency conditions. While the Designer Team has satisfactorily undertaken both tasks, the double duty has stressed the Team.

The IAP recommends that Integral is supported by a firm that takes over the engineering part of the emergency management.

Integral should designate a liaison staff to ensure coordination between the Designer and

the Support Firm.

3 Engineering assessment

3.1 Engineering geology conditions of the Project site

A gneissic formation dominates the area of the dam and its appurtenant structures, passages of amphibolitic gneiss and schistose gneiss are also present. These rocks, when free from weathering, constitute moderately jointed, good quality rock masses. GSI values are fair to very good, ranging from 50 to 70. Weak passages with shears exist but are they not frequent. The following table¹ reports the rock mass quality as assessed in a number of different parts of the Project; only type IV rock corresponds to a weak rock mass.

Tabla 5-26 Porcentajes de ocurrencia para los diferentes tipos de soporte

Túnel		TIPO I	TIPO II	TIPO III	TIPO IV	
		%	%	%	%	
Sistema desviación del río	Galería acceso a descarga intermedia	50%	25%	20%	5%	
	Galería acceso a descarga de fondo					
	Descarga intermedia	50%	20%	22%	8%	
	Desviación Oeste (14x14)					
	Desviación Este (14x14)					
	Desviación No 1 (7x14) (Portal Norte)					
	Fuentes de materiales, zonas de depósito y obras de infraestructura	Desviación No 2 (7x14)	65%	20%	15%	0%
		Desviación No 3(7x14)				
Desviación No 4(7x14) (Portal Sur)						
Túnel vial a margen izquierda, subestación, acceso a casa de maquinas y a Puerto Valdivia.		40%				
Sistema de Captación y conducción	Galería de pozos de compuertas	0%	100%	0%	0%	
	Pozo de compuerta No 1. (Extremo Norte.	60%	24%	16%	0%	
	Pozo de compuerta No 2.					
	Pozo de compuerta No 3.					
	Pozo de compuerta No 4.					
	Pozo de compuerta No 5.					
Sistema de Captación y conducción	Pozo de compuerta No 6.	60%	20%	20%	0%	
	Pozo de compuerta No 7.					
	Pozo de compuerta No 8. (Extremo Sur).					
	Conducción superior No 1.					

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The few main faults are steeply dipping, and their disturbed, sheared zone is limited (scale of tens of cm). Such general conditions do not favor large scale instabilities of slopes and abutments and are generally favorable for the foundation of gravity dams. Increased support measures are needed when underground works crosses such geological structures.

However, the rock mass is distressed on the slopes, often at an important degree. This is due

¹ Excerpt from report "Caracterización Geológica y Geotécnica", 2010

to the decompression and stress release in slopes of a relatively young character in their geological history. This highly fractured zone, together with the weathering from the surface, may exhibit thickness of few to some tens of meters. In several places, colluvia and poor-quality overburden on the slopes have not yet found equilibrium and, as such, they are subject to raveling and landslides. The slope instabilities and landslides are local and are triggered by cuts or excavations.

This weak distressed zone demands treatment or removal in important foundations, construction cuts, and slopes over intakes. These zones may host perched aquifers. The following pictures (No.6, 7, and 8) provide examples of distressed rock zones.



Figure No.6: Distressed gneissic mass, heavily fractured. Photo on the 2nd of August 2018



Figure No.7: Distressed rock mass and weathered zone. Landslide over the 2 diversion tunnels area. Photo on the 3rd August from the helicopter.



Figure No.8 The site of the project at the beginning of the construction, 2014. Skin slide on steep slope, behind the spillway cuts. In this area instability events occurred in spring 2018. Photo from Google.

The good quality of the gneissic rock mass can be observed, at both small and large scale, on the spillway's cuts as modeled and exposed after the removal of the distressed zone and the

colluvia, which was not particularly thick here (Figure No.9).



Figure No.9: Sound and good rock mass under the distressed zone on slope. Cuts for the spillway. Photo on the 3rd of August from the helicopter.

3.2 Geotechnical assessment

3.2.1 Dam site

The dam is founded on the gneissic formation. The updated geological profile at a cross section of the dam site (figure No.10), indicates that the zone of cover material, colluvia, alluvia and loose rock, has been removed in the core foundation zone. Only a weak zone, with sheared and fragmented rock mass and clayey infilling, is present in part of left abutment.

3.2.2 Slope protection measures

Slope conditions upstream of the spillway are unstable, as highlighted by the recent mass movements. Part of them was destabilized by the events in the zone above the diversion tunnels, which followed the main GAD's collapse. These instabilities affect the cover and the overstressed zone of the rock, not removed or modeled. Such movements would be enhanced by the fluctuation of the reservoir during its operation, or in case of a drawdown.

The IAP recommends extending the same treatment and protection upstream of the spillway slopes, as far as the intake of the Intermediate Discharge Gallery and the destabilized area over the two diversion tunnels.

The upstream extension of the slope protection measures is also necessary to safeguard the intake to the powerhouse ("El Romerito" zone) as well as the intake of the scheduled new Intermediate Discharge Gallery. Parts of these slopes are already in a metastable condition and are evolving retrogressively. The slide that occurred on May 26th, over the intake gates is a case in point.



Figure No.12: "El Romerito" landslide. Photo 28/05/2018 (from ppt Prof. G. Fernandez, June 2018)

The protection works should aim to remove as much as possible of the distressed zone and proceed by benching. Cable anchoring could be used mainly at the lower part, as appropriate. Fortunately, the morphology of the slope is terminating soon uphill where geomorphology exhibits a concavity that can be probably associated to an old landslide (see Figures No. 12 and 13).

A catch water drain is an essential measure to limit surface water access to the slopes. Monitoring should be extended in the area, as for other slopes around the dam.



Figure No.13: The landslide over the intake structure is developed on the 26th of May. A concave form of the terrain uphill may denote the presence of an old slide (photo from helicopter August 3,2018)

To investigate possible failure modes and associated volumes, the Designer undertook two types of analyses for the “El Romerito” landslide zone: deterministic and probabilistic. Figure No. 14 illustrates the sliding surface scenarios considered.

The first group of analyses modeled two groups of sliding surface:

- shallow surfaces, practically within the superficial soil mantle (scenarios 1 to 3), and
- deeper surfaces passing through the underlying weathered and distressed rock mass (scenarios 4 to 6).

Although not familiar with this type of analysis, the IAP understand that it is a crude estimation of the potential extent of landslide movements, which are qualitatively compared to field evidence. Based on this comparison, the Designer considers that the possibility of a deeper failure, involving significant part of the weathered bedrock, is negligible. This conclusion has to be validated considering the current equilibrium state and future slope movements (if any). Involvement of a larger mass could manifest at a later stage, due to creep movements and gradual transition to residual shear strength of materials.

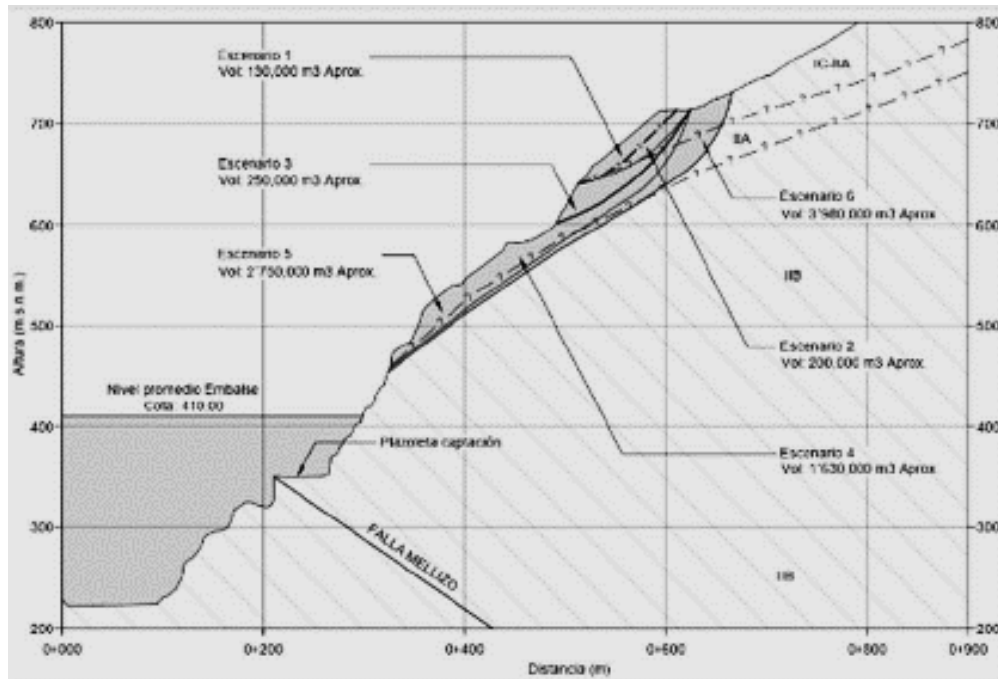


Figure No.14: Section from the analyses of the “El Romerito” landslide (June 2018 Designer Report “Diagnostico Geológico Geotécnico de la Contingencia”)

The Designer also carried out a series of probabilistic slope stability analyses, to evaluate the probability of failure of shallow slides, i.e. scenarios 1 to 3. The IAP has the following observations/suggestions:

- The sensitivity analysis examines three main cases: dry conditions, wet conditions with groundwater elevation at 700 masl, and seismic conditions without water.
- The sensitivity of results to the position of the contact surface between soil and rock should be investigated, as the current safety factors are not particularly comfortable.
- Materials above the water table elevation may also be partly saturated, which can be modeled assuming a pore pressure ratio (R_u). This is particularly important when checking the stability under seismic loading dry conditions only. It is expected that, during an earthquake, it is quite likely that the geomaterials contain water, either in the form of a water table or not. Similarly, a smaller magnitude earthquake with full water load is also possible.
- The methodology for defining and examining failure surfaces per scenario is not clear in the report. The available images illustrate one representative failure surface for each scenario, together with some sets of very different failure surfaces. The IAP suggests focusing the sensitivity analyses on surfaces similar to the representative one. This can be done either by drawing more surfaces or by using the optimization tool of the software. The particular tool makes geometrical

adjustments to the critical surfaces, in search of a potential more critical surface.

- The IAP regards too large the difference between failure probabilities of scenario 1 and scenarios 2 - 3. The Designer should check whether in scenarios 2 and 3 the lower and outer part of the considered failure surface is in weathered rock, which would drastically improve the safety factor in case the software does not have the “freedom” to adjust surfaces as mentioned above.
- Combined surfaces extending within both soil and rock should also be considered. It is not clear why wedge-type failure has been checked for only one specific slope.

Finally, the IAP recommends the execution of a couple of boreholes, in the “El Romerito” area, in places where access is possible, to reduce uncertainties and inform the design of the protection measures.

3.2.3 Power House Cavern complex

Cavern excavation encountered only wedge failure, sometime significant, from the cavern roof, which required strengthening of reinforcement (Figure No.15).



Figure No.15: Desprendiment bòveda Casa de Maquinas – Costado norte

Convergence and extensometer readings showed satisfactory rock mass behavior, before the April-May 2018 events. Stress-controlled failure mechanism was not an issue.

Deformations were insignificant or minimal and, in almost all cases, controlled effectively by the applied support. Only in the transformer’s cavern, in the stress concentration areas at the intersection with the bus-bars galleries, small deformations caused shotcrete flaking. Local reinforcement was reportedly applied.

In the machine cavern, the maximum deformation was about 100mm as measured only in a

couple of points, including the crossing of Mellizo Fault zone. Infiltrations were monitored, and consolidation grouting done.

The Designer performed some analysis to assess the possible stability conditions of the underground works in presence of water flooding of the powerhouse. The specific FEM analyses, with static internal water pressures in the underground opening, cannot be expected to produce results showing any deterioration effect. The main destabilizing factors are the erosion due to water rushing and the hydrodynamic transients (water hammer type). In addition, analyses with reduced rock modulus and rock strength to indirectly model fatigue effects due to the dynamic effects should not be expected to produce different results, because the software needs a modification of the stress state to produce new results. In the IAP view, the analyses are not reliable, under the current conditions, to assess the stability of the underground works.

Based on experience, and given the quality of the gneissic rock mass, the IAP reckons that damage to the cavern, caused by the water flows and pressure oscillations, can be in the form of block and wedge detachments of different sizes. This was also recognized by the Designer (Diagnóstico Geológico Geotécnico de la contingencia, Junio 2018) and reported by the advisors (Prof. Gabriel Fernández, June 2018, ppt, 2018).

The FEM analyses (see Figure No.16) show that any extended collapse is not likely to affect the stability of the parietal slope and adjacent access tunnel.

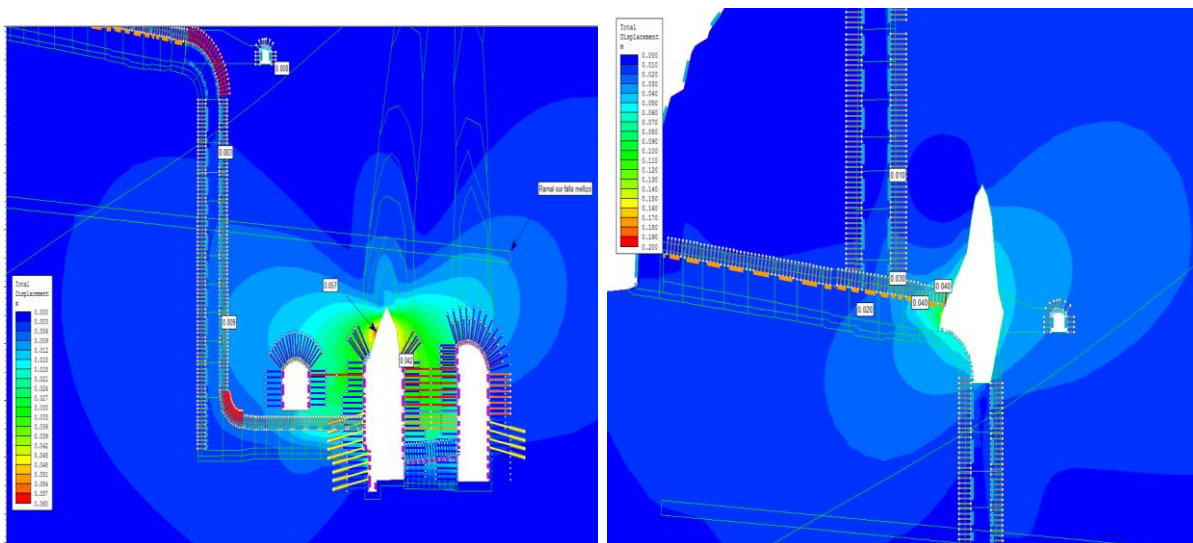


Figure No.16: Global stability of the caverns and possible influence to the parietal slope (from the Designer report, “Diagnóstico Geológico Geotécnico de la Contingencia” June 2018)

In September 2018, EPM drilled three boreholes from Galeria A with the objective of crossing a sizeable area of rock mass above the crown of the powerhouse cavern. The following figure shows the location of the three boreholes which were fully core recovered.

PERFORACIONES EXPLORATORIAS Gal A – CM

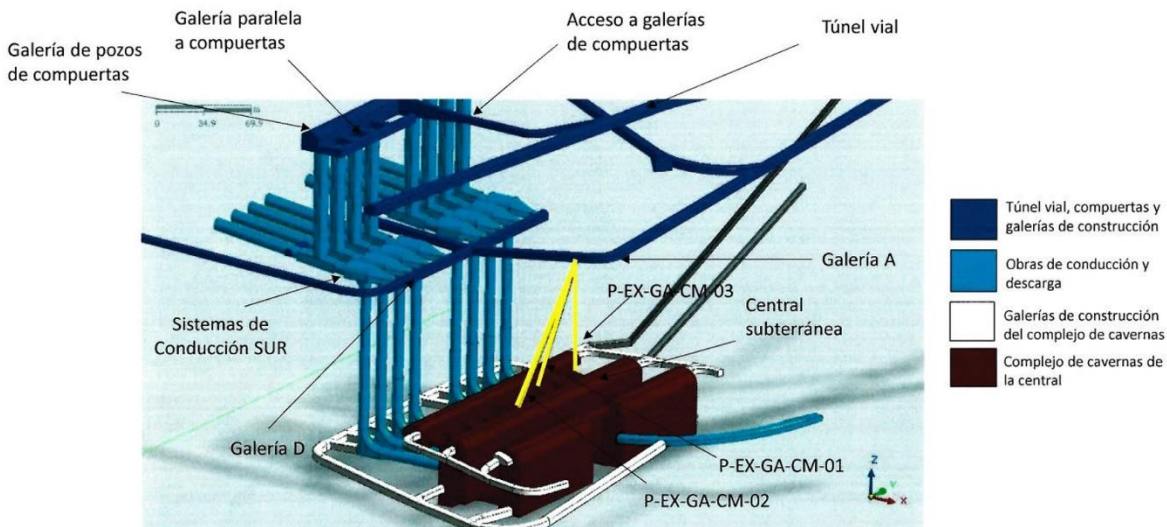


Figure No.17: Exploratory boreholes in the powerhouse roof area

In all three holes, core recovery was 100%; RQD was generally between 60 and 70%, with values of 80% in proximity of the cavern roof; no water losses occurred any time during drilling. Such observations indicate that the rock mass has not been disturbed, over the cavern, in the investigated location. Not even in the zone crossed by the Mellizo Fault (borehole 03). Borehole 02 pierced the cavern roof and was able to sample 20 cm of shotcrete lining to the cavern roof (see Figure No.18).

P-EX-GA-CM-02 (Gal A – CM – Sistema de conducción 5)

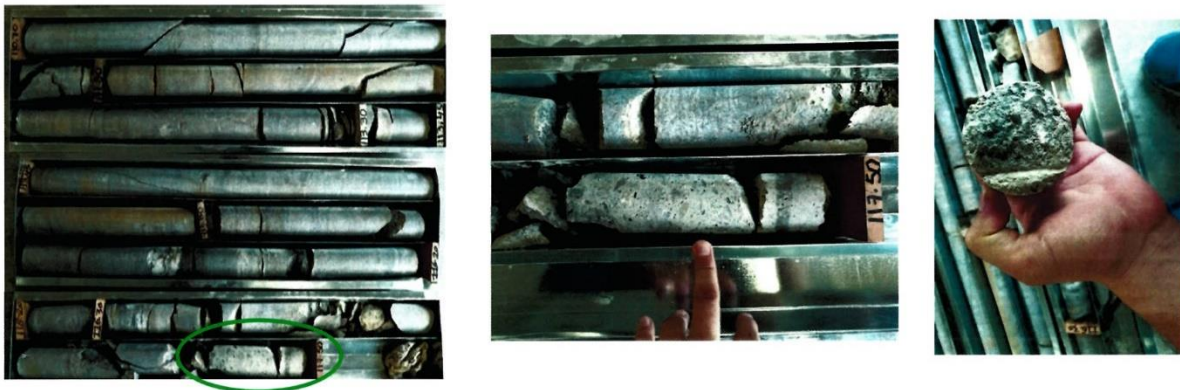


Figure No.18: Borehole 02 recovering shotcrete sample for roof lining

Information provided by the three holes is positive but, as normal with boreholes, is localized. However, given the good quality of the rock mass and the size of structures, it is very unlikely that extended or general collapse took place in the cavern of the Powerhouse. EPM is continuing exploratory drilling, which will add valuable information before direct inspection of the cavern will allow to draw a final assessment of the underground conditions.

It remains to be seen what is the extend of local block/slabs detachments (gravity controlled) that may have been triggered by the rushing water, sub-pressures, vortexes, etc. No mathematical model can predict such effects.

The fact that borehole CM-02, at entering the cavern cavity, experienced air and water inflow means that, as expectable, the cavern is affected by mixed air-water flow, which renders any behavioral forecasts even more challenging, most likely impossible.

In conclusion, cavern abandonment is unlikely, but significant reinforcement and reconstruction works could be necessary.

3.2.4 Potential landslides in the reservoir

It is certain that, during reservoir operation, small landslides will locally occur, in the weathered and distressed zone of the slopes, along the rim of the lake. Such events are already taking place, as observed from the helicopter on August 3th (see Figure No. 19).

Such mass movements are not deemed to generate dangerous impact waves, but rather slowly contributing to reservoir silting.



Figure No.19: Small landslides at the margin of the reservoir.

The question of large landslides, at the whole slope scale, has still to be settled. Old megaslides are reported to exist (probably thousand years old) and are being monitored by satellite. The Designer has carried out an impact wave analysis to check the adequacy of the available dam crest freeboard (15m) to contain wave run-ups. Results indicate that such freeboard is adequate. The issue of such landslides was included in the 2010 report “Caracterización Geológica y Geotécnica”.

In the course of the August 2018 visit, during the helicopter trip back to Medellin, the IAP did not observe major geomorphological features that could be associated with massive

slope movements and a potentially related major threat. The IAP would like to make a dedicated helicopter flight, during its next site visit, to review the assumptions used in the study in consultation with the Designer. Key assumptions for the analysis are landslide volume, distance from the dam, blocky (brittle) or massive (ductile) nature and expected speed of movement.

3.3 Dam conditions

The IAP has no major comments on the design of the dam. Based on the data provided, clay core, zoning, filter design, materials, static and dynamic analysis, and instrumentation of Ituango Dam, respond to engineering best practice in dam design².

The characteristics of the materials, as ascertained by laboratory and field tests, are adequate. Filter and transition zones meet grading specifications.

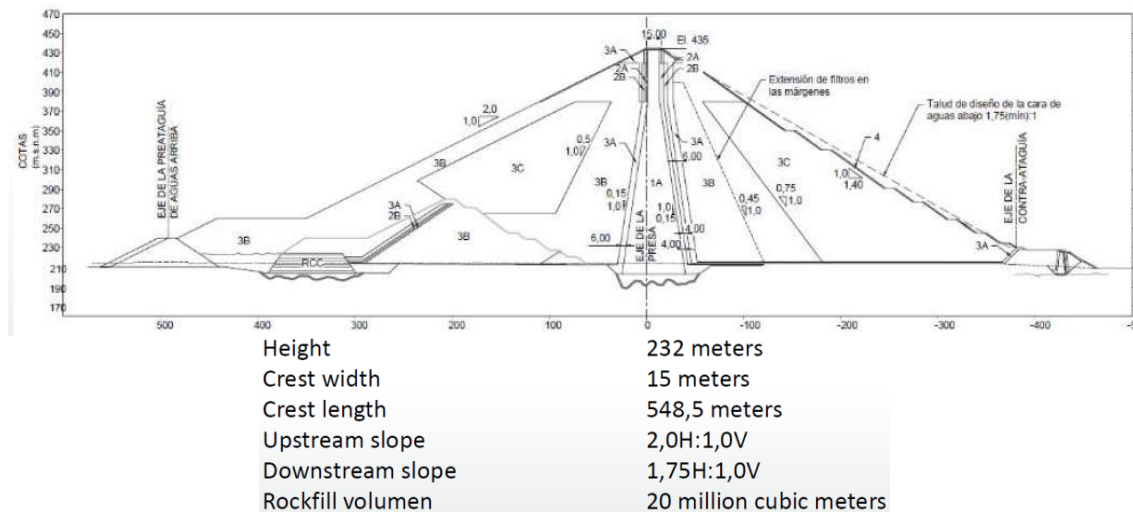


Figure No.20: Ituango Core-Rockfill Dam - Typical section and parameters

The IAP understands that the comments made about the right foundation of the core were properly addressed (“Control de elaboración, revisión, verificación, aprobación y distribución de informes”, 18/8/16). The IAP also concurs with the suggestions of the Board of Advisors (report #12, February 2017) on the plasticity of the base of the core, the width of filters and the upstream extension of the filters.

Under the reservoir head experienced to date³, the grout curtain seems to operate satisfactorily. Notably, piezometers show a clear decrease of the levels downstream of the dam. The seepage in the right abutment is about 30 l/sec. On the other hand, in the left abutment total seepage reached 80 l/s. Although not excessive, remedial measures have

² Geotechnical Behavior of Ituango Earth Core Rockfill Dam, Herrera J.D., Sierra M.C., Velazquez M.- May 2017)

³ Reservoir level 394, corresponding to 87% of maximum design head, was reached on June 6; performance to date is satisfactory.

been identified and planned. The origin of such seepage is the left drainage gallery at level +250, where grouting holes of u/s curtain were not oriented to intercept sub vertical joints; additional grouting is planned. All seepage water is reported clean.

The maximum settlement of the embankment, at almost its final height, is reported as 1.2m, a normal value for such a high dam. No deformations were observed, or reported, on the downstream face.

When the intake tunnels to the power house were opened, a short time uncontrolled outflow occurred from the ventilation gallery 283. The event did not produce any erosion at the toe of the dam.

Spillway slopes behaved satisfactorily to date. Benches are neatly defined, slopes are anchored and fully shotcreted where appropriate. Inclinometer readings, as reported, indicate satisfactory performance; overall conditions look good.

Dam zoning was modified, above el. 385 m asl, to speed up embankment rising during emergency response. A plastic diaphragm is being constructed to improve water tightness of the zone (see Figure No.21).

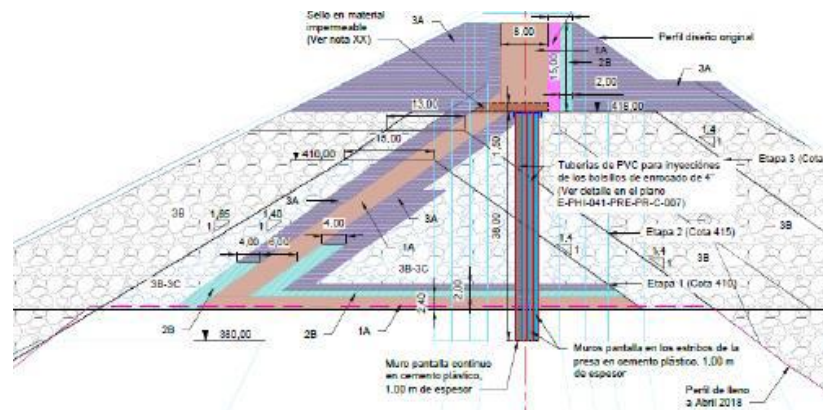


Figure No.21: Priority Embankment design

The Designer is investigating the global stability of that part of the dam (Diagnóstico Geológico Geotécnico de la Contingencia, June 2018).

The IAP has the following comments on the result of the analyses carried out so far:

- Numerical investigation regarding the hydraulic gradient and the evaluation of risk associated with internal erosion, indicate that the decision for the construction of the diaphragm wall is appropriate.
- The material parameters assumed for the impermeable and the granular body part of the priority fill are reasonable.
- Results are reasonable and indicate the marginally acceptable stability conditions of

the additional fill, which are generally satisfactory for this emergency case.

- The IAP suggests conducting stability analyses also for the final configuration (crest el. 435 masl), which may be less favorable for the downstream slope of the dam.
- Due to the orientation of different materials, prismatic surfaces should also be examined, to make sure that these do not produce lower safety factors.

3.4 Hydro, Mechanical & Electric Equipment

3.4.1 3.4.1 Gates

A detailed visual inspection was done on the accessible equipment not currently underwater.

Visual inspection of the Spillway Gates did not evidence reasons of concern for this main hydro mechanical equipment. The gates are operational and tested. At the time of IAP's visit finishing works, and the implementation of the control system was ongoing.

The situation of the Intermediate Discharge Gallery (IDG) deserved more attention. EPM and the Contractor (ATB Riva Calzoni S.p.A.) were working to complete the erection and testing of the radial gates and of the emergency sliding gates. The visual inspection of the gates and of their control systems did not evidence reasons of concern. However, the IAP has some concerns regarding the design and the completion of the IDG system. In particular, the absence of bulkheads or stoplogs at the intake can complicate future maintenance of the gates. At the time of removing the debris and the plug from the IDG's portal and intake, the Designer should reconsider the opportunity of installing embedded parts or creating adequate contact surfaces for allowing the future installation of a temporary device for emergency sliding gates maintenance. Should that device be provided or not, a relevant procedure for intake closure should be included in the O&M manual of the plant.

The following table summarizes the IAP's remarks on the Spillway's and IDG's gates.

Hydro Mechanical Equipment	Progress of installation and testing	Remarks
Spillway Gates Four Radial Gates (two with flap for debris) 15 m x 19,50 m Discharge capacity: 22.600 m ³ /s (PMF) Operation: oleodynamic servomotors, single control and oleodynamic stations for each gate + common control	Already in operation (August 1), finishing and common control ongoing	No reasons of concern from visual inspection
Gates to Intermediate Discharge Gallery Two Radial Gates + two Emergency Sliding Gates Size: 3 m x 3.90 m (Radial gates) Design capacity: 450 m ³ /s with both gates in operation Operation: oleodynamic servomotors, single control and oleodynamic stations for each gate.	Erection under completion (August 1); commissioning expected within the end of August. Contact injections at the upstream steel transition (15m long) remain to be done, including sealing of the associated 400 plugs.	No reasons of concern from visual inspection. Absence of bulkheads or stoplogs at the intake can complicate future gate maintenance.

The Intake Gates and service stoplogs were not accessible due to the incumbent landslide. Gates and stoplogs were put in place or lifted using mobile cranes and maintained in their position using dogging devices.

The Intake Gates are designed to operate under balanced pressure. Closing the turbine's ring gates allow balancing pressures but, in case of large leakages from the waterways, it would be impossible to achieve hydrostatic conditions. Therefore, in case of collapse in any part of the intake system causing an uncontrolled flow of water, it will not be possible to stop such flow. Considering the plant's head, and the fact that most of the penstocks are not steel lined, the risk exists that rock mass weaknesses, possibly tampered by the emergency discharge, could initiate potential failure mechanisms. The IAP recommends that such event is examined in the proposed PFMA workshop (see paragraph 4.1), and the extension of the steel lining of the waterways reconsidered as appropriate. In any case, the Project's Emergency Preparedness Plan should include a procedure to face the above described situation.

Diversion Gates and Bottom Outlet Gates are of limited interest because most probably they will not be utilized in the future.

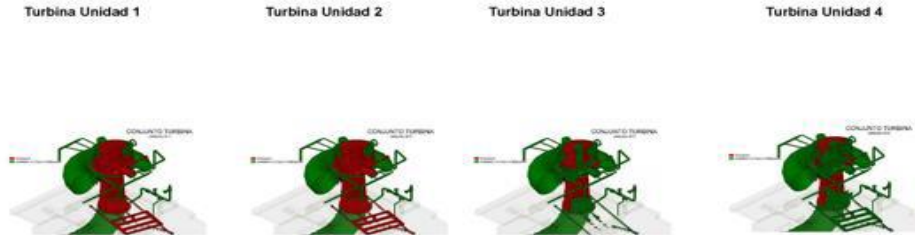
The following table summarizes the IAP's remarks on the Intake Gates.

Hydro Mechanical Equipment	Progress of installation and testing	Remarks
<i>Intake Gates</i> Height Sliding Gates, 5.03 x 6.87 m, with stoplogs Operation: oleodynamic servomotors	The area had limited access due to incumbent landslide. Gates were lowered using mobile crane. Installation of servomotors and rods.	Gates close under balanced pressure conditions
<i>Diversion gates</i> Two wheel gates, 9 m x 18 m	Currently not accessible and most probably not utilized in the future	
<i>Bottom Outlet gates</i>	Currently not accessible and most probably not utilized in the future	

3.4.2 Powerhouse Equipment

At the time of the Power House flooding the progress of the installation of the electromechanical equipment was as shown in figure No.22 (green color shows installed equipment).

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



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

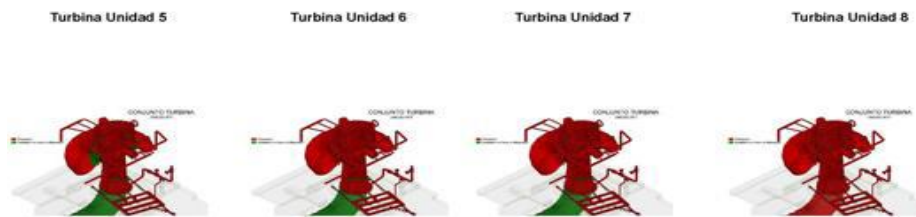
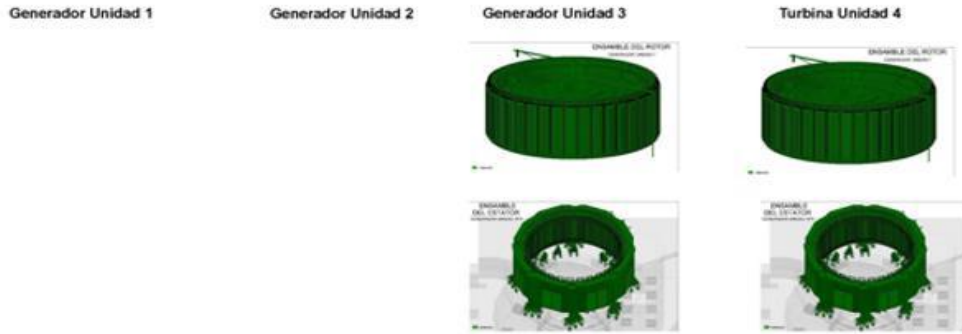


Figure No.22: Progress of installation of Turbines in the powerhouse

Installation of the north side turbines was well advanced, especially Unit 3 and Unit 4 that were to be commissioned first. On the south side (units from 5 to 8) only three draft tube had been installed.

Erection of generators, entirely assembled at site, and of Isolated Phase Bus Ducts was, consequently, limited to those of units 3 and 4. Figure No.23 shows installation progress of generators and bus bars; again, green color designated installed parts.

Progress of installation at the time of flooding the north powerhouse



Progress of installation at the time of flooding the north powerhouse



Figure No.23: Progress of installation of Generators in the powerhouse

The installation of the single-phase transformers was more advanced.

The 12 single-phase transformers of the north powerhouse, and the spare, were completely erected including auxiliaries and dielectric oil flushing (see figure No.24).

Progress of installation at the time of flooding the north powerhouse



Figure No.24: Progress of installation of Transformers

Two single-phase transformers of the south powerhouse were in similar conditions, 4 were in transport condition (with nitrogen) while 6 are currently in standby in a Colombian port.

The 13 XLPE HV cables corresponding to the transformer of the north powerhouse were already installed.

Though not very common, the flooding of Ituango Power House is not unprecedented. Information sometimes kept confidential, on similar incidents may give some insights on the expected damages. The following box illustrates four case histories.

Powerhouse flooding incidents - Case histories

On February 1998 heavy El Niño-driven rains in Machu Picchu area (Perú) caused the collapse of a hydroelectric dam: the main hydroelectric plant in Cuzco was under 60 meters of water and remained flooded for several months.

In 2007, combined effect of Tropical Storm Noel and of the stoppage of Emergency Diesel Generator caused the flooding, through the access gallery, of the 52 MW Aguacate Hydropower Plant (Rep. Dominicana) owned by National utility Corporación Dominicana de Empresas Eléctricas Estatales and its hydro generator subsidiary Empresa de Generación Hidroeléctrica (Egehid) for approximately 4 months. The power plant was out of service for five years and rehabilitated by World Bank's assistance.

Gibe 2 HPP in Ethiopia was briefly and partially flooded while in operation few years after his commissioning due to the malfunctioning of a draft tube gate.

Construction of the Rogun HPP (Tajikistan) began in 1982 but halted with the break-up of the Soviet Union in 1991 and the ensuing civil disturbances in Tajikistan (1992-97). The majority of the Machine Hall had been completed by 1992, and convergence of up to 600mm were measured in the cavern walls. No equipment had been installed. In 1993 the existing cofferdam was washed away, and the tunnels constructed in the 1980s were damaged. The underground powerhouse was flooded and remained in hydrostatic conditions for 15 years, until the Government of Tajikistan began rehabilitation of the existing tunnels and underground civil works in 2008. A technical assessment of the Project (World Bank 2014) concluded that the powerhouse cavern's conditions had not been significantly affected by the long permanence under water and that the opening could be salvaged with the installation of additional rock reinforcement. The geology of the Machine Hall comprises Good to Fair quality Sandstone and Fair quality siltstone, certainly of overall lower quality than Ituango's cavern.

The following considerations reflect direct experience and lessons learned from such incidents.

Apart for their duration, (short-term flooding cases are more common) each flooding has its own characteristics and experience shall be contextualized.

The flooding of Ituango Power House has several peculiar aspects. Indeed, EPM operators were aware several hours in advance of the possibility to expose the power plant to such a dramatic event.

Protective measures were adopted before the emergency flooding of the power house at the best of operator capability and time available. It is worth mentioning that none of the case histories in the box featured protective measures.

In the Ituango case, all transformers were sealed by EPM staff with special care of the sensitive leaking point, oil tank taps above all, and, to a lower extent, Buchholz relays to avoid / reduce water infiltration. One transformer was mechanically anchored.

Movable control system, high value, equipment was removed from the power house.

The two cranes were welded together, fixed at the rails and with cables to a rotor.

Another peculiar aspect is that the units were not in operation i.e. not rotating, when the powerhouse was flooded by debris-loaded water (large quantities of mud and, probably, rock pieces). Consequently, the contamination of water in the lubricating oil should not have caused mechanical damages to the contact surfaces of the bearings.

Physical damages due to rock hits or displacements can only be assessed by inspection.

Rotating and embedded mechanical component of the turbines should be fine with the exception of unit's bearings. White metal should also be fine due to its chemical composition, however its extremely sensitive components and some elements could have undergone corrosion or could result too complex to clean.

Generators are expected to be completely replaced and their time-consuming assembling on the critical path. However, there is some hope that they may be partially recovered. Any such attempt should be coordinated in the overall schedule of plant's completion and commissioning. The availability of equipment to replace the ones flooded may suggest replacing them when they are not on the critical path. Theoretically they may even be rehabilitated and reinstalled in a different unit. Stator lamination steel material may be tentatively submitted to cryogenic treatment and bars or even windings may be tentatively cleaned, dried and retested.

Electrical auxiliaries should be totally replaced.

Isolated Phase Bus Duct may give positive surprise, provided that they are not physically damaged, which cannot be ruled out.

Transformers are a question mark because, if the oil tank, which is most exposed to infiltration, goes underwater that often results in contamination or damage. The fact that countermeasures were adopted, gives some hope in this case.

There are cases of transformers fallen into the sea when they were unloaded from ships; in two cases attempts of recovering their performance through extensive flushing were unsuccessful. River water should be easier to cleanse, but the maximum hydrostatic pressure to which they were subject was quite high. In any case, single phase transformers, being simpler machines, are intrinsically easier to recover than more common three-phases. If On-Load or Off-Load Tap Changers are in place (they are not explicitly mentioned in the technical data) they shall be certainly replaced.

One high voltage cable was already physically damaged by a rock fall during a preliminary partial inspection and other may have faced the same fate. Unless physically damaged and after replacing the terminals at their two ends, XLPE HV cables shall be the equipment less affected by prolonged flooding.

The mechanical parts of the cranes are also a question mark: if cranes fell down, mechanical parts are most probably lost; electrical and control components are certainly lost as those of any other equipment.

The salvage of the project may benefit from the availability of all components needed to reassemble at least the first two units originally expected to be commissioned at the end of this year. Figure No.25 shows that such components constitute the majority of the equipment.

Equipment already delivered to EPM (August 1st 2018)

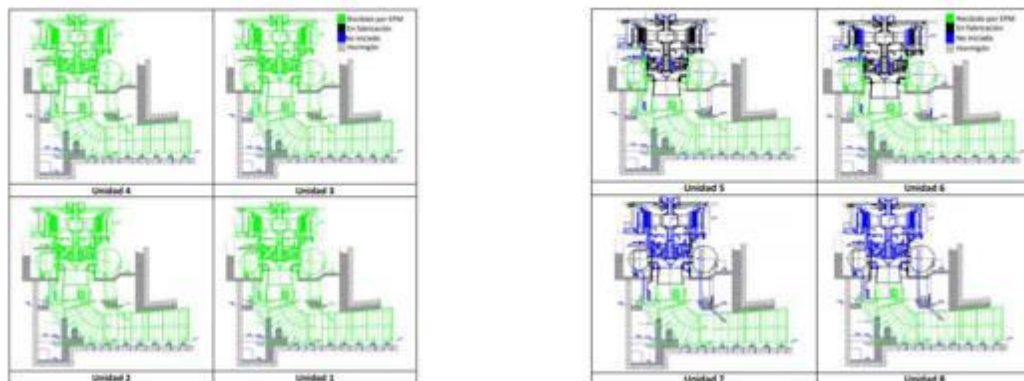


Figure No.25: Turbine components available to EPM

The post-flooding, rehabilitated equipment should not be subject to significant residual risks during plant operation.

General deformations of the cavern walls are not expected to be significant, which should limit damage to embedded parts; rock detachments cannot be excluded.

Test procedures for evaluating the reliability of the flooded equipment are available and should be applied.

EPM has the possibility to replace, even temporarily, by external maintenance, any equipment without the stress of further postponing the milestone of the first two units.

The overall schedule of the project, with significant civil works rehabilitation, the availability in stock of at least an entire set of electromechanical equipment to install the first two units, are elements that can significantly reduce residual risks during operation.

A conservative estimate of equipment repair/ replacement cost should not exceed 100 million USD, including scrap value of the equipment, but excluding EPM internal cost and contractual modification / extension of the existing guarantees.

3.5 Dam Safety Management

The Designer, Integral, operates a satisfactory dam safety system on site. Instrument readings are regularly taken and interpreted. The Instrumentation Manual [6] is available and used, on site, by competent staff.

Flow diagrams to respond to different emergency conditions are available [8]. Threshold values signaling levels of alert (reporte de alertas) are provided for key instruments; an example is shown in the figure No.26.

Alertas Proyecto Ituango								
Reporte CMT:	7/06/2018	Hora de Corte:	8:00	Valores de Referencia para alertas			Observaciones	
RIESGOS	Medida	Variable	Estado	Normal	Amarilla	Roja		
Caudal	Descarga Ituango	(m3/s)	1154,24	<1700	>1700	>3000	Registro tomado a las 7:15	
	Puerto Valdivia	(m3/s)	1401,63	<2400	>2400	>3400	Registro tomado a las 7:15	
Presa	Piezómetros	Estado	Estable	Estable	En observación	Inestable	No se presentan novedades	
	Inclinómetros	Estado	Estable	Estable	En observación	Inestable	No se presentan novedades	
	Asentamientos	Estado	Estable	Estable	En observación	Inestable	No se presentan novedades	
	Nivel de Embalse	(msnm)	393,59	<409 *	>409 *	>410 *	Se están presentando un descenso de 5cm en las últimas 6 horas	
	Infiltraciones en área total	(l/s)	32,60	<200	>200	>400	Sin evidencia de degradación de lleno	
Deslizamientos	Volumen de desplazamiento taludes captación	(m3)	0	< 250.000 m3	>250.000 m3	>400.000 m3	Deformaciones no significativas	
	Volumen de desplazamiento vertedero	(m3)	0	< 250.000 m3	>250.000 m3	>400.000 m3	Deformaciones no significativas	
	Volumen de desplazamiento portal desviación	(m3)	0	<250.000 m3	>250.000 m3	>400.000 m3	Deformaciones no significativas	

* Valores válidos para altura de la presa en la cota 412

Figure No.26: Levels of alert (sample)

The IAP believes that preparing a Response Level Matrix will be of significant assistance during Project operation. Annex 4 shows a typical template.

Figure No. 27 shows the framework used to inform and alert downstream communities, as appropriate.

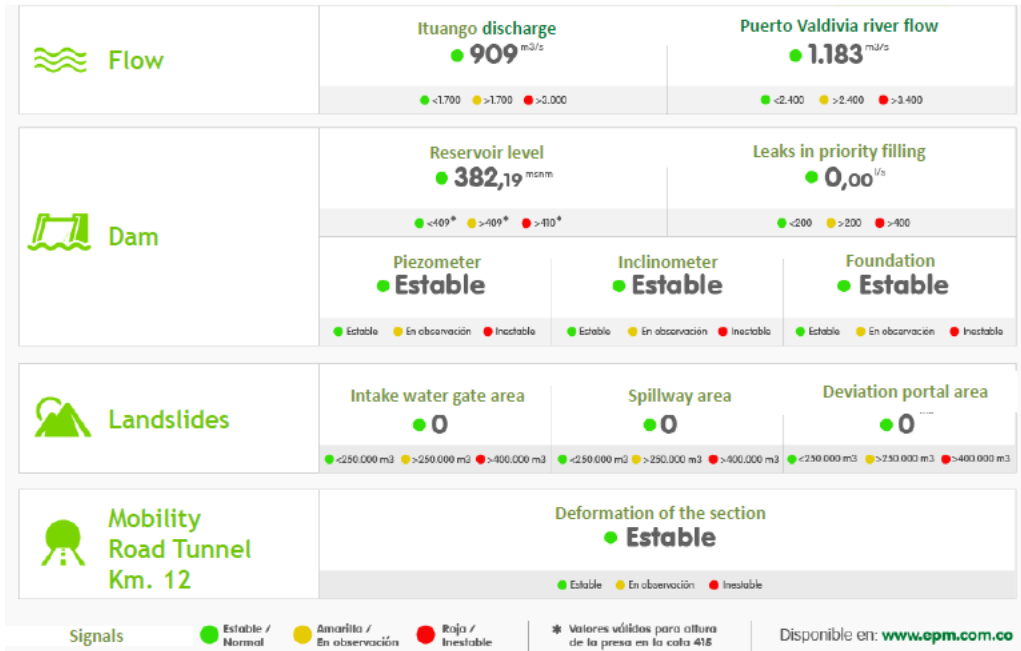


Figure No.27: Information and alert framework for downstream communities

The early warning’s alert level can be reduced when the both Diversion Tunnel #2 (TD2) and the GAD will be safely plugged.

Measures implemented to date, as well as ongoing safety-related and maintenance works, allow expressing a positive assessment on project’ safety in its current configuration.

4 Plans for Project continuation

4.1 Potential Failure Mode Analyses

Since 2002, Potential Failure Modes Analysis (PFMA) has been introduced as part of 5-year inspections under FERC (US) regulations⁴ for non-federal hydropower dams in the US. This method requires dam owners to perform a qualitative risk assessment to identify potential failure modes and to assess required remedial works, monitoring instrumentation system, etc. The PFMA has established a basis for dam safety performance assessment and provides an opportunity for comprehensive dam safety enhancements that might be overlooked by traditional standards-based approach. The FERC Guidelines, Chapter 14 provides detailed description of the PFMA process⁵ including key goals and typical outcomes, background

⁴ Code of Federal Regulations - Title 18: Conservation of Power and Water Resources - Chapter I: Federal Energy Regulatory Commission, Department of Energy - Subchapter B: Regulations Under the Federal Power Act - Part 12: Safety of Water Power Projects and Project Works - Subpart D: Inspection by Independent Consultant

⁵ www.ferc.gov/industries/hydropower/safety/guidelines/eng-guide/chap14.pdf

information review, site inspection, facilitated workshops involving “brainstorming” sessions to identify/evaluate potential failure modes, consequences, and mitigation measures.

The PFMA is intended to provide understanding of how and why dams fail by understanding how dams behave normally, learning to identify early signs that something is wrong, understanding the hazards and risks imposed by the dam, and being prepared for the unexpected behavior that leads to failure.

The IAP considers very important that the Designer, and other relevant parties, conduct a PFMA workshop taking into account experience and lessons learned from the Project’s performance to date. The following table anticipates some PFMs for the Designer’s consideration and integration as appropriate.

Potential Failure Mode Analysis	Rationale/ Scope
Sustainable outflow through power hose waterways	Tailrace 1 or 2 may experience collapses; outflow would reduce; leakage through TD2 and/ or GAD might increase challenging the existing plugs.
High leakage from penstock lining	In case of collapses in any part of the intake system causing an uncontrolled flow of water, it will not be possible to stop such flow because the intake gates can only operate under balanced pressure.
Erosion resistance of lining to Intermediate Discharge Gallery (IDG)	Upstream of control gates, 400 m of IDG are reinforced with rock bolts and shotcrete lined and are at potential risk of erosion during IDG operation; concrete lining cannot be installed because of the existing gates.
Dam crest structure above el. 418	Post-earthquake stability of the “composite structure”.
Landslide above intake gate shafts	Evaluate slope stabilization measures to mitigate long time risk level.
Potential landslides in the reservoir and associated impact waves	Geotechnical assessment. Impact wave analysis. Wave run-up. Dam overtopping.

4.2 Safety-related structural measures

The PFMA workshop is expected to identify safety-related measures of both structural and non-structural nature. Discussions with professional on site, and review of available documentation has allowed the IAP to identify the following structural measures:

- i. Intermediate Discharge Gallery (IDG): complete contact injections between steel lining and rock; seal injection holes; strengthen existing lining.
- ii. Penstocks (when accessible): steel line upper and lower elbows; extend steel lining above lower elbow.
- iii. Extension of slope profiling and stabilization measures, upstream of the spillway

and over the intake area of power intake shafts.

Chapter 6 summarizes and provides details on IAP's recommendations.

4.3 Cost and schedule implications

4.3.1 Cost estimates

Annex 5 contains the current EPM's estimate of costs associated with Project completion (36 months scenario). The IAP has concentrated on costs associated with contingency measure (detalle inversion contingencia), and on items highlighted in red.

The following table compares EPM estimates with those of the IAP for the relevant items. Item 3. "Obligaciones Adicionales Licencia Ambiental" in EPM estimate is not considered because outside the IAP's knowledge. In the absence of a conceptual design, and associated quantities, the IAP can only base the estimate on experience of other hydro projects featuring similar items of work. IAP's estimate is therefore presented as ranges, with the caution that figures can vary, even substantially, when actual quantities and methods of work will be defined.

Colombian pesos are converted to US \$ at a rate of 2989 (CO/\$).

DETALLE INVERSIONES CONTINGENCIA	Col Pesos	USD
1. Obra civil	369,000.00	123.00
2. Equipos (recuperación y reemplazos)	332,750.00	111.00
3. Taponamiento túnel derecho y SAD	100,000.00	33.00
4. Pantalla impermeable en la presa	150,000.00	50.00
5. Desembalse	300,000.00	100.00
TOTAL ESTIMADO EPM	1,251,750.00	417.00

ITEM	min	max
Civil works		
Taponamiento tunel derecho y SAD	30.00	40.00
Pantalla impermeable en la presa	50.00	50.00
Extension of spillway slopes' treatment	25.00	50.00
Repairs and reinforcement to power house cavern	30.00	50.00
Reservoir landslide risk mitigation	10.00	15.00
Intermediate Discharge Gallery	3.00	5.00
Steel lining to penstock elbows	10.00	15.00
Middle level outlet (Desembalse)	100.00	100.00
Subtotal Civil Works in USD Million	258.00	325.00

Equipment		
Generation Equipment	80.00	100.00
Balance of plant	10.00	20.00
Gates and valves	5.00	10.00
Subtotal Equipment in USD Million	95.00	130.00
TOTAL EQUIPMENT + CIVIL WORKS IN US MILLION	353.00	455.00

The EPM estimate, 419 M\$ equivalent, is close enough to the upper bound of the IAP's range (455 M\$).

The following observations are made.

- IAP estimate includes additional works, with respect to EPM's, they are:
 - Extension of spillway slopes' treatment,
 - Repairs and reinforcement to powerhouse cavern,
 - Reservoir landslide risk mitigation,
 - Intermediate Discharge Gallery (lining strengthening),
 - Steel lining to penstock elbows
- The cost of such additional works is 78 to 135 M\$; if these items are actually not included in EPM's estimate (IAP is not sure about it), the latter is considered conservative.
- The item "Desembalse" refers to the provision of a Middle Level Outlet
- ("Sistema Alternativo de Desviación, Desembalse cota 340"); the IAP is pleased to acknowledge that this essential item, discussed in chapter 5 below, is being contemplated by EPM.

4.3.2 Schedule considerations

During the IAP visit, Owner and Designer were working at an integrated plan for the implementation of remedial works and completion of the Project. A preliminary version of that plan has been made available to the IAP on September 8th, and the relative Gantt diagram is shown in annex 6. Based on that Plan, and on the verbal presentations received during the site visit, the IAP offers the following comments.

- i. Plugging works at TD2 and GAD represent the most urgent activity. Only after effective grouting treatment of the debris-obstructed area, the final concrete plugs can be built. Grouting treatments are quite an unpredictable operation and are likely to require significant trial and error, as well as adaptive management. The estimated duration is 17.2 months (523 days), with an intermediate assessment of risk level in downstream areas in early November 2018. The IAP appreciates that duration of the activities is very difficult to predict, at the same time 17 months appear a reasonable guess. Risk re-assessment in early November seems

- a bit optimistic.
- ii. Plugging works would significantly benefit from lower reservoir levels. Presently that can only be affected after completion of the IDG, and only to a limited extent, due to the limited discharge capacity of the IDG, essentially in the dry months.
 - iii. The current Plan features the construction of a Middle Level Outlet (“Sistema Alterno de Desviacion, Desembalse cota 340”). Implementation time of 20 months (625 days) seems short, unless detailed design has already been prepared, and construction equipment is available on site.
 - iv. River diversion through the power house complex has certainly caused damage to the underground works, however the level of such damage cannot be predicted before visual inspection of the underground works. Accessing the cavern area by late February 2019 is a very optimistic estimate; more realistically, that could require several more months, possibly until December 2019.
 - v. For the time being, it should be prudently assumed that plant commissioning can be delayed 3 to 4 years from the planned date of December 2018.

5 Project sustainability

5.1 Middle Level Outlet

The possibility of controlling the level of Ituango’s reservoir is extremely limited, in the current configuration. Only the IDG, with sill at 260 m a.s.l., offers partial capability in that regard, and has still to be completed. Its rated capacity, 450 m³/s is lower than the incoming flow in the dry season and it has been designed only to fulfill the duty of Environmental Water Release device.

The IAP believes that an additional Middle Level Outlet (MLO) is essential at Ituango 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).
- Operational: to access the intake gate areas for extraordinary maintenance or repairs.

The MLO should be located between the IDG and the Intake level, probably around 320 masl. Its discharge capacity should complement that of the IDG (450 m³/s, maximum) to allow effective reservoir lowering also in the wet months; preferably, the MLO should have a discharge capacity to do that on its own. According to the USBR⁶, the selected frequency flood should have a return period of five times the duration of the filling period with a minimum return period of 5 years. In general, low-level outlet works in conjunction with other release facilities should be located and sized to draw down the reservoir, within a period of 1 to 4

⁶ USBR 1990 “Criteria and guidelines for evacuating storage reservoirs and sizing low-level outlet works”

months, to the lower of the following levels:

- a) A reservoir level commensurate with a storage capacity that is 10 percent of that at the initial reservoir level.
- b) A reservoir level which is less than 50 percent of the hydraulic height of the dam.

Condition a) is not practical for Ituango. Some level near condition b) appears meaningful.

Preliminary design will likely reveal that a single waterway would have an impracticable diameter for the required construction technique. It is therefore probable that two discharge tunnels will be required.

MLO's construction will inevitably involve some major underwater activity, e.g. lake tapping technique, or bulkhead-protected outing of the waterway. Either of the two entails high design and construction challenges, therefore design and procurement should be initiated as soon as possible.

Figures No. 27 and 28 show, respectively, a notional outline of the lake tapping technique, and a recent bulkhead-protected intake in Lake Mead (Nevada, USA)⁷.

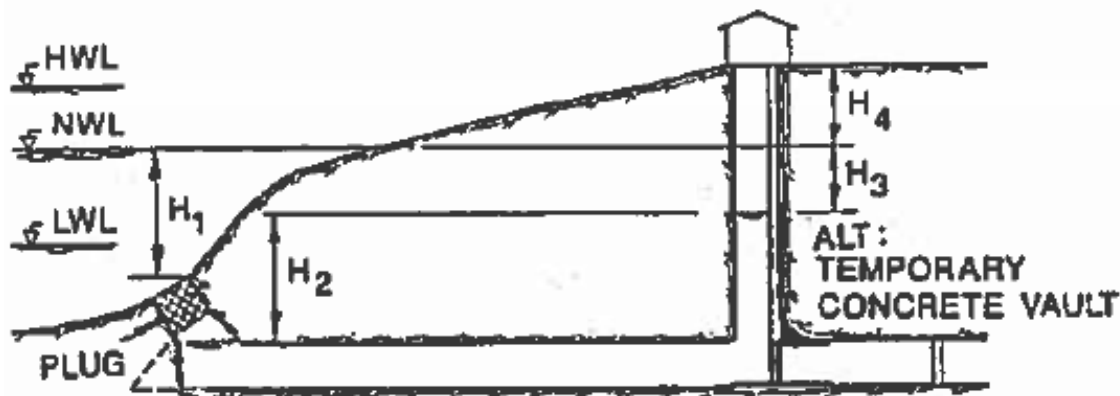


Figure No.27: Norwegian Lake Tapping technique

⁷ North American Tunneling Journal (2015) "The Legacy of Lake Mead- making tunneling history in southern Nevada" www.tunnelingjournal.com Feb/ March 2015

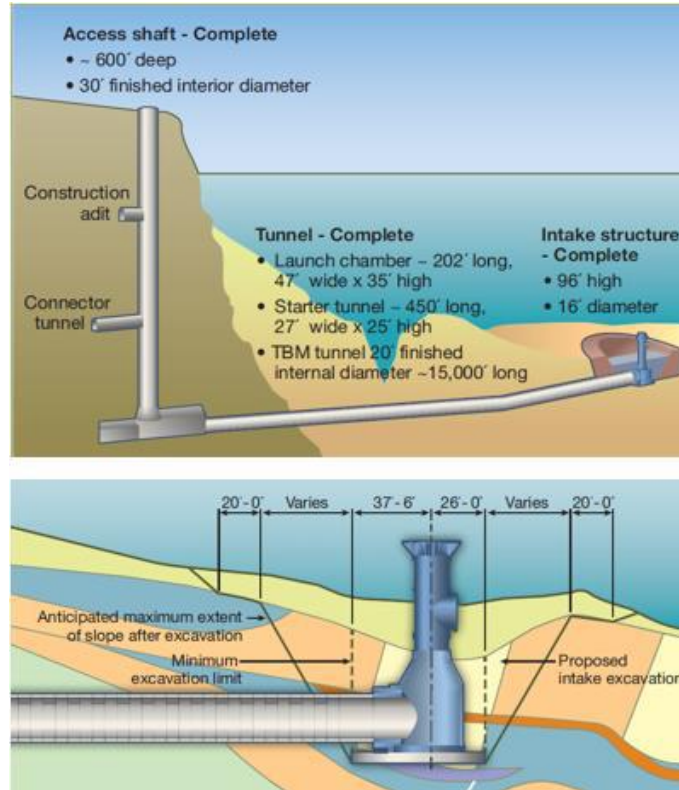


Figure No.28: Bulkhead-protected draw-off waterway at Lake Mead

5.2 Sedimentation management

The IAP acknowledges that the current concerns and efforts in defining a suitable course of actions to complete the Project and put it operation represent the priority for EPM and its consultants. At the same time, because of its relevance to Project sustainability, the IAP feels the need to discuss the subject of reservoir sedimentation.

Consideration of sediment management is a significant issue for hydropower projects in many parts of the world and has a significant bearing on the design of each project. An important reference work on the subject is the RESCON approach⁸ in which the authors consider the full life cycle of a reservoir examining both operational sustainability and safety issues. Such issues are of direct relevance to the Ituango reservoir.

The Ituango project can deliver large near-term benefits, but power production may be constrained by sediment accumulation in as little as 50 years. The sediment management approach used will determine whether Ituango transition into a long-term power generation asset to Colombia, or transition into very large and costly long-term liabilities with potential for intractable dam safety problems.

⁸ Palmieri A. et al (2003) "Reservoir Conservation- the RESCON Approach - economic and engineering evaluation of alternative strategies for managing sedimentation in storage reservoirs" World Bank , Washington DC, June 2003

The Designer has examined the subject⁹ and figure No. 29 shows the advance of the sediment delta during the operational life of Ituango's reservoir.

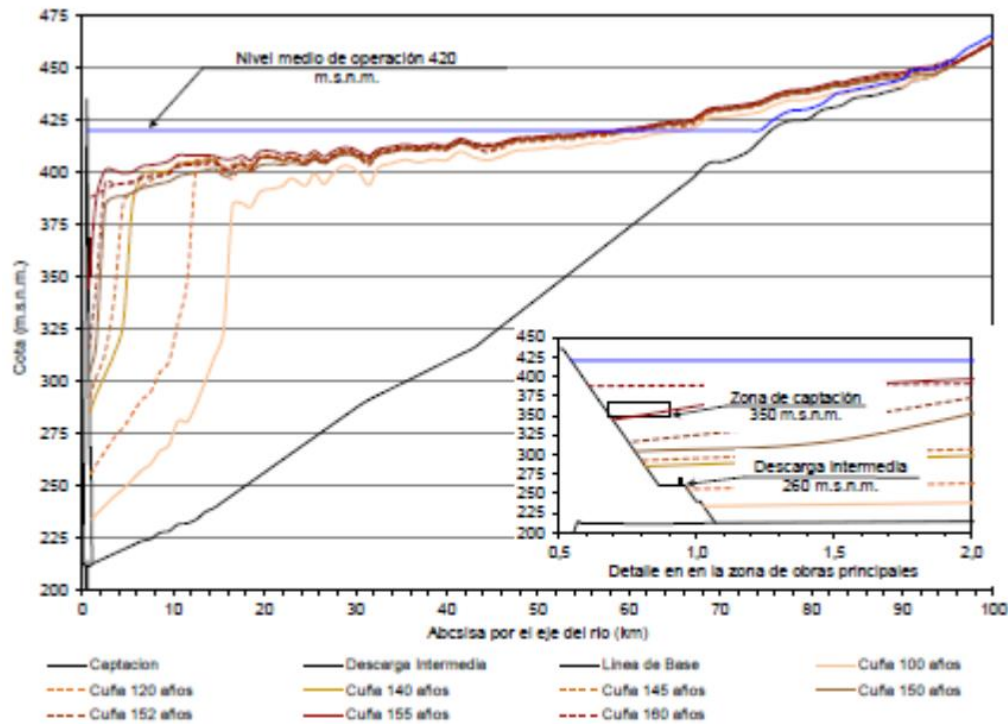


Figure No.29: Perfil del Delta de Sedimentos para periodos de 25, 50 y 100 años de Operacion del Embalse

The Designer conclusions are that the delta's coarse sediments could reach the power intakes after 150 years of plant operation, or 75 years in case sediment yield doubles.

The IAP would like to discuss the sediment yield assumptions with the Designer and offers, on the subject, the following reflections.

The feasibility of, and the most appropriated method(s) for managing reservoir sediments depends on many factors, the first of which is the "hydrological size" of the reservoir. A hydrologically small reservoir has a small capacity compared to the river's mean annual flow, and vice versa.

In the Ituango case:

MAF= 31,850 Mm³/year (mean annual flow)
CAP= 2,720 Mm³ (reservoir capacity)

⁹ Integral (2016) "Atención a Conclusiones y Recomendaciones del Documento – Evaluación Técnica del Proyecto Hidroeléctrico Ituango – Informe Final" 18 agosto 2016.

MAS= 40 Mm³/year (mean annual sediment yield¹⁰)
 Hence: CAP/MAF= 0.09; and CAP/MAS= 68

The representative point of Ituango is plotted in figure No.30¹¹

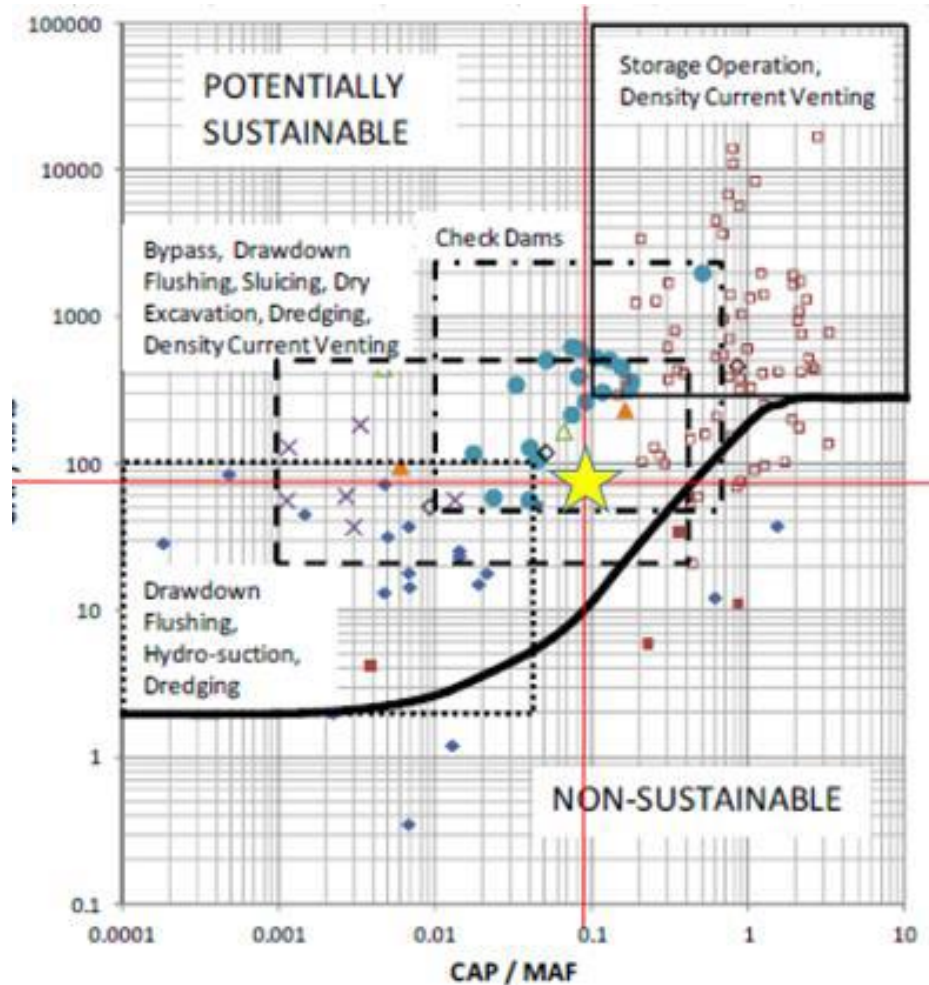


Figure No.30: Reservoir sedimentation – Ituango case

A CAP/MAF ratio lower than 0.2 indicates a hydrologically small reservoir. The CAP/MAS ratio provides a rough estimate of the reservoir life, without consideration of the reservoir trap efficiency. Taking trap efficiency into account, reservoir half-life could be in the order of 50 to 60 years.

Before that, passage of fine sediments through the turbines is to be expected, and associated effects should be properly managed.

After some 50 to 60 years, when the delta approaches the power intakes, the plant will have

¹⁰ 46 Mton/year, average sediment density 1.15 t/m³

¹¹ Annandale (2013) "Quenching the Thirst - ch. 6 Preserving Space" Create Space Independent Publishing Platform, North Charleston, SC.

to be operated as run-of-river, and coarse sediment managed accordingly. Hydro-suction, or tactical dredging in front of the intakes may prolong the life of the plant further, but retirement will be necessary when coarse sediment management is no longer economical.

The Designer has outlined some possible long-term scenarios and the IAP would like to discuss with the Designer on the subject. In any case, it will be necessary for EPM to set aside a decommissioning fund to be accrued during the life of the plant.

5.3 Options assessment for Project completion

Options and issues relevant to Project completion are summarized in the following table. For each item, the IAP presents findings and recommendations based on its August visit to the Project.

Some elements are still preliminary because factual evidence is not yet available (e.g. powerhouse cavern and flooded waterways). In those cases, the IAP has offered educated assessments based on case histories and past experience.

Options and Issues	August 2018 findings and recommendations
Review of EPM's project – continuation plans	The preliminary design solutions for Project continuation are satisfactory. EPM is progressing with detailed design.
Analysis of the convenience or necessity of dewatering the reservoir.	The IAP regards the possibility of controlling reservoir level, and of lowering it when necessary, an essential feature of Ituango HPP. For this purpose, the IAP strongly recommends adding a Middle Level Outlet of adequate hydraulic capacity.
Evaluate potential damages and options to clean up and other necessary works to complete the powerhouse.	Options will be reviewed when access to the powerhouse cavern is possible. Sections 3.2.3 and 3.4 contain some reflections on the subject, largely based on experience and case histories. Three boreholes drilled in September revealed good conditions of the rock mass above cavern's crown.
Main implications (financial/cost, technical, environmental-social) of the associated implementation schedule.	In the absence of a conceptual design, and associated quantities, the IAP can only base the estimate on experience of other hydro projects featuring similar items of work. IAP's estimate is therefore presented as ranges, with the caution that figures can vary, even substantially, when actual quantities and methods of work will be defined.
Full rehabilitation	Currently the preferable option; final confirmation after assessment of damages in the powerhouse complex.
Structural and non-structural measures	Project rehabilitation and completion will include both structural and non- structural measures, as summarized in chapter 6.

Options and Issues	August 2018 findings and recommendations
Revise project's output	Not envisaged at this stage
Revise project's purposes	Not realistic
Project re-engineering	Addition of Middle Level Outlet, and extension of slope treatment works upstream of the spillway area are essential re-engineering measures.
Partial/ total retirement	Very unlikely, unless cavern location has to be abandoned for excessive damage. Project will have to be decommissioned at the end of its useful life, when management of coarse sediments, to sustain run-of-river operation, will no longer be economical.

6 IAP's conclusions and recommendations

For convenience of the reader, the present chapter summarizes the main conclusions of the IAP that are scattered in the previous chapters.

The IAP's recommendations are also summarized and elaborated as necessary.

6.1 IAP's Main Conclusions

Lessons learned from the spring 2018 events

- GAD closure (sinkhole) was the consequence of water flow, which provoked sub pressures and likely penetrated inside the rock mass and destabilized wedges. Thus, water energy interacted directly with the rock mass and caused progressive failure of the same.
- Very weak rock in the sinkhole area can have initiated progressive failure.
- The subsequent mass movements, that took place in different parts of the waterways, were a consequence of the uncontrolled flow of water through interconnected galleries, some of which were never intended for conducting water.

Emergency Handling

- Downstream warning had to be issued because of the uncontrolled releases from diversion tunnel 2. Timely warning averted casualties and allowed containing economic damages.
- Flooding of the powerhouse complex was the most appropriate, and inevitable course of action, which permitted to re gain control on the reservoir levels.
- Dam crest elevation of 410 masl was reached on June 5th, which made the surface spillway operable, and averted the risk of embankment overtopping.

Dam

- When free from weathering, the gneiss formation, which dominates the dam site, is moderately jointed, with GSI values ranging from 50 to 70.
- Weak passages with shears exist but they are localized.
- Slope conditions upstream of the spillway are unstable. Instabilities affect the cover and the overstressed zone of the rock, not removed or modeled. Such movements will be enhanced by the fluctuation of the reservoir, or in case of a drawdown.
- The IAP has no major comments on the geotechnical design of the dam.
- Based on the data provided, clay core, zoning, filter design, materials, static and dynamic analysis, and instrumentation of Ituango Dam, respond to engineering best practice in dam design.
- The characteristics of the materials, as ascertained by laboratory and field tests, are adequate. Filter and transition zones meet grading specifications.
- Under the reservoir head experienced to date¹², the grout curtain seems to operate satisfactorily. All seepage water is reported clean.
- The maximum settlement of the embankment, at almost its final height, is reported as 1.2m, a normal value for such a high dam. No deformations were observed, or reported, on the downstream face.
- Spillway slopes behaved satisfactorily to date. Benches are neatly defined, slopes are anchored and fully shotcreted where appropriate. Inclinator readings, as reported, indicate satisfactory performance; overall conditions look good.
- Dam zoning was modified, above el. 385 masl, to speed up embankment rising during emergency response. A plastic diaphragm is being constructed to improve water tightness of the zone. The Designer is investigating the global stability of that part of the dam. Results are reasonable and indicate the marginally acceptable stability conditions of the additional fill, which are generally satisfactory for this emergency case.

Powerhouse Cavern Complex

- Excavation encountered only wedge failure, sometime significant, from the cavern's roof, which required strengthening of reinforcement.
- Convergence and extensometer readings showed satisfactory rock mass behavior, before the April-May 2018 events. Stress-controlled failure mechanism was not an issue.
- Deformations were insignificant or minimal and, in all cases, controlled effectively by the applied support.

¹² Reservoir level 394, corresponding to 87% of maximum design head, was reached on June 6; performance to date is satisfactory.

- Infiltrations were monitored, and consolidation routing was done.
- The FEM analyses show that any extended collapse is not likely to affect the stability of the parietal slope and adjacent access tunnel.
- Cavern abandonment is unlikely, but significant reinforcement and reconstruction works could be necessary.

Reservoir landslides

- During reservoir operation, small landslides will locally occur, in the weathered and distressed zone of the slopes, along the rim of the lake.
- Such mass movements are not deemed to generate dangerous impact waves, but rather slowly contributing to reservoir silting.
- The Designer has carried out an impact wave analysis to check the adequacy of the available dam crest freeboard (15m) to contain wave run-ups. Results indicate that such freeboard is adequate.
- The IAP would like to make a dedicated helicopter flight, during its next site visit, to review the assumptions used in the study in consultation with the Designer.

Hydro, Mechanical & Electric Equipment

Gates

- Visual inspection of the Spillway Gates did not evidence reasons of concern. The gates are operational and tested. At the time of IAP's visit finishing works, and the implementation of the control system was ongoing.
- The situation of the Intermediate Discharge Gallery (IDG) deserved more attention (see Recommendations). EPM and the Contractor were working to complete the erection and testing of the radial gates and of the emergency sliding gates. The visual inspection of the gates and of their control systems did not evidence reasons of concern.

Powerhouse equipment

- Though not very common, the flooding of Ituango Power House is not unprecedented. In general, short-term flooding cases are more common, and each flooding has its own characteristics and experience has to be contextualized.
- The post-flooding, rehabilitated equipment should not be subject to significant residual risks during plant operation.
- The overall schedule of the project, with significant civil works rehabilitation, the availability in stock of at least an entire set of electromechanical equipment to install the first two units, are elements that can significantly reduce residual risks during operation.

Dam Safety management

- The Designer, Integral, runs a satisfactory dam safety system on site.
- Instrument readings are regularly taken and interpreted. The Instrumentation Manual is available and used, on site, by competent staff.
- Flow diagrams to respond to different emergency conditions are available. Threshold values signaling levels of alert are provided for key instruments.
- Measures implemented to date, as well as ongoing safety-related and maintenance works, allow expressing a positive assessment on project' safety in its current configuration.

Cost and Schedule implications

- Plugging works at TD2 and GAD represent the most urgent activity. Only after effective grouting treatment of the debris-obstructed area, the final concrete plugs can be built. Grouting treatments are quite an unpredictable operation and are likely to require significant trial and error, as well as adaptive management; as such, their duration is very hard to predict.
- Plugging works would significantly benefit from lower reservoir levels.
- Presently that can only be affected after completion of the IDG, and only to a limited extent, due to the limited discharge capacity of the IDG, essentially in the dry months.
- River diversion through the powerhouse complex has certainly caused damage to the underground works, however level of such damage cannot be predicted before visual inspection of the underground works. Date of access can be estimated, at the earliest, in March 2019 (very optimistic), more realistically in December 2019.
- For the time being, it should be prudently assumed that plant commissioning can be delayed 3 to 4 years from the planned date of December 2018.

Reservoir sustainability

- Considering sediment yield, mean annual river flow, reservoir capacity, and its trapping efficiency, reservoir half-life could be in the order of 50 to 60 years.
- Before that, fine sediments through the turbines are to be expected and associated effects properly managed.
- After some 50 to 60 years, the plant will have to be operated as run-of- river, and coarse sediment will have to be managed. Hydro-suction, or tactical dredging in front of the intakes may prolong the life of the plant further.
- Decommissioning will be necessary when coarse sediment management is no longer economical.
- It is too premature to discuss possible decommissioning scenarios at this stage, but it will be necessary for EPM to set aside a decommissioning fund during the life of the plant.

6.2 IAP's Recommendations

The IAP's recommendations are recapped in the following. Non-structural, and structural measures are presented separately.

Non-structural measures	
Topic	Recommendation
Emergency management	The Designer should be supported by a firm, which takes over the engineering part of the emergency management
Slope stability analysis	See detailed recommendations in paragraph 3.2.2.
Priority embankment design	The IAP suggests conducting stability analyses also for the final configuration (crest el. 435 masl), which may be less favorable for the downstream slope of the dam. Due to the orientation of different materials, prismatic surfaces should also be examined.
Dam Safety management	Preparation of a Response Level Matrix will be of significant assistance during Project operation. Annex 4 shows a typical template
Potential Failure Mode Analysis (PFMA) workshop.	The Designer, and other relevant parties should conduct a PFMA workshop considering experience and lessons learned from the Project's performance to date.

Structural measures	
Topic	Recommendation
Slope protection and stabilization	Extend the same treatment and protection upstream of the spillway slopes, as far as the intake of the Intermediate Discharge Gallery and the destabilized area over the two diversion tunnels. Also uphill of the area of the intake shafts ("El Romerito"). Execute a couple of boreholes, in the "El Romerito" area, to reduce uncertainties and inform the design of the protection measures.
Intermediate Discharge Gallery (IDG)	<ul style="list-style-type: none"> Complete contact injections between steel lining and rock; seal injection holes; strengthen existing lining by mesh-reinforced shotcrete. Works will have to be conducted under the protection of a temporary plug; therefore, safety management of the crews will be an essential feature. Absence of bulkheads or stoplogs at the IDG intake can complicate future maintenance of the emergency sliding gates. The Designer should reconsider the opportunity of installing embedded parts or creating adequate contact surfaces for allowing the future installation of a temporary device for emergency maintenance of the gates. Should that device be provided or not, a relevant procedure for intake closure should be included in the O&M manual of the plant.
Penstocks (when accessible)	Steel line upper and lower elbows; extend steel lining above lower elbow.
Middle Level Outlet (MLO)	The IAP believes that an additional outlet is essential at Ituango for, at least, two reasons: <ul style="list-style-type: none"> Safety: the upper part of the reservoir must be lowered in emergency conditions (e.g. post-earthquake, or due to signs of internal erosion). Operational: to access the intake gate areas for extraordinary maintenance or repairs.

Structural measures	
Topic	Recommendation
Power Intake gates	The Intake Gates are designed to operate under balanced pressure. Closing the turbine's ring gates allow balancing pressures but, in case of large leakages from the waterways, it would be impossible to achieve hydrostatic conditions. The IAP recommends that such event is examined in the proposed PFMA workshop, and the extension of the steel lining of the waterways reconsidered as appropriate. In any case, the Project's Emergency Preparedness Plan should include a procedure to face the above described situation.

Annex 1: Atendencia reuniones con BID Panel, Julio 30 y 31

Debida Diligencia BID - Financiación proyecto Ituango - Reuniones con Asesores Técnicos del BID
Julio 30 de 2018 A.M.

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Debita Diligencia BID - Financiación proyecto Itango - Reuniones con Asesores Técnicos del BID
 Julio 30 de 2018 p.m.

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Debida Diligencia BID - Financiación proyecto Itzango - Reuniones con Asesores Técnicos del BID
 Julio 31 de 2018 A.M.

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Debida Diligencia BID - Financiación proyecto Itzango - Reuniones con Asesores Técnicos del BID
 julio 31 de 2018 P.M.

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Annex 2: List of documents made available to the IAP

- [1] Junta de Asesores a EPM: “Informes 1 a 14” febrero 2012 a enero 2018
- [2] Aqualogus and Artelia (2016) “Evaluacion Tecnica del Proyecto Hidroelectrico Ituango- Informe Final”, marzo 2016.
- [3] Integral (2016) “Atencion a Conclusiones y Recomendaciones del Documento – Evaluacion Tecnica del Proyecto Hidroelectrico Ituango – Informe Final” 18 agosto 2016.
- [4] Integral (2017) “Proyecto Hidroelectrico Ituango- Caracteristicas”
- [5] Herrera J.D. et al. (2017) “Geotechnical behavior of Ituango Earth Core Rockfill Dam” IV International Symposium on Rockfill Dams, May 17-18, 2017.
- [6] Integral (2018) “Monitoreo Geotecnico para el llenado del Embalse, Conduccion y Descargas” 06-03-2018
- [7] Integral (2018) “Analysis de Taponamiento Galeria Auxiliar de Desviacion” mayo 2018.
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Annex 3 – Detailed reconstruction of the Spring 2018 events

The original river diversion system of the project envisaged two gated diversion tunnels with a diameter of 14 m each, respectively Left Diversion Tunnel and Right Diversion Tunnel. Their construction was awarded as a preliminary-works contract (to the JV Ferrovial Agroman, the civil engineering construction company of Ferrovial, and local engineering firm Sainc), with a separate contract for the two diversion gates.

In 2013, unsatisfactory progress of the contract and the complex geotechnical situation at the portal area, where the two gates should have been installed, suggested EPM to change plans. Activities concentrated on the dam, which was on the critical path of the project, utilizing the two diversion tunnels as ungated tunnels (starting February 2014). The main contract was awarded to the JV CCC, led by Brazil's Carmago Correa (55%), Colombian firms Constructora Concreto (35%) and Coninsa Ramon H (10%). An acceleration plan in the main contract envisaged the construction of a gated Auxiliary Diversion Tunnel (ADT or GAD in Spanish) with portal located upstream of the two diversion tunnels.

The diversion gates, originally designed to be installed at the diversion tunnels, and the bottom outlet gates, were relocated to the GAD (bottom outlet was designed to operate just for few days during the filling of the reservoir for ensuring the mandatory Environmental Water Release Flow of 450 m³).

The two Diversion Tunnels, the Auxiliary Diversion Tunnel and the four Tailrace Tunnel are identical in terms of design and finishing, though the four Tailrace Tunnels operate at free surface.

The design of the Intermediate Discharge Gallery, conceived to guarantee the mandatory Environmental Water Release Flow of 450 m³/s when the power house and the spillway are not simultaneously in operation, remained unchanged (8 m diameter for 57,6 m² hydraulic section).

The GAD entered in operation in August 2017, in parallel to Right and Left Diversion Tunnels. Soon after, both Diversion Tunnels were plugged.

The hydrological season at Ituango alternates three dry and three wet months, the first wet month is January.

The protocol for reservoir filling envisaged the closure of the gates of the Auxiliary Diversion Tunnel in the last dry season (originally scheduled for July 2018) before the operation of the first two units (3 and 4) of the power plant (scheduled for December 2018 / January 2019). The Right and Left Diversion Tunnels were to be closed during the two previous dry seasons i.e. respectively July / September 2017 and January / March 2018. Closure of the Right and Left Diversion Tunnels was achieved as scheduled.

After the closure of Right Diversion Tunnel, for the first time, only one tunnel – GAD - was in operation. At the beginning of the wet season the reservoir raised above the levels previously

recorded with two tunnels in operations (255 masl versus 277 masl).

At the time of the first collapse, the main diversion tunnels were in the final process of being sealed by concrete plugs: in the left tunnel, a pre-seal and a seal were completed while in the right tunnel only a pre-seal was placed.

One of the two access of the construction gallery was also sealed while the second one, at higher elevation, remained open.

On the night of April 28th, 2018 at about 21:00, with a reservoir elevation around 240 masl, the water suddenly stopped flowing through the GAD. According to previously established procedures, EPM activated a plan to analyze the situation, and a team of experts from EPM and the Designer flew to the site to join other experts from the Designer, the Contractor and the Construction Supervisor, that are part of the permanent staff on site.

Preliminary evaluation of the situation suggested that an unexpected collapse near the GAD's portal had occurred. Immediately several tasks were undertaken to handle the situation, such as review of the local geology; review of the support design of the tunnel; analysis of the operational conditions, activation of emergency plans according to protocols.

This situation remained the same until April 29th at night, when the pressure generated by the reservoir (278 ma.s.l.) suddenly removed the natural plug in the ADT, causing a gradual recovery in the level of normal discharge on the tunnel.

On April 30th at 14:30, a new decrease in the flow through the GAD occurred, and a sinkhole (with a diameter of approximately 12 m at its narrowest bottom, and up to 100 m at the outer rim) appeared at the surface of the mountain immediately over the tunnel (see Picture No.1). About 220,000 m³ of soil and rock definitely blocked the GAD.



Picture No.1: Sinkhole above the ADT

The level of the reservoir kept increasing until May 5th, when the flow at the GAD outlet (namely tailrace tunnel # 4) showed evidence that water was flowing from the construction gallery into the GAD downstream of the blockage; in parallel the reservoir level decreased.

However, this situation did not last long and on May 7th a third failure affected the gallery through which the water was flowing into the GAD and caused the flow to stop and the reservoir level to increase again.

On May 9th, a partial wash-out of the Right Diversion Tunnel's plug re-started flow in the tunnel, which albeit reduced after few hours.

With the continuous increase of the water level, some fines and rocks were washed out and once again, the water flowed shortly through the right diversion tunnel, until a new sinkhole formed above it, stopping the water flow again (see Picture 2).



Picture No.2: Landslide and sinkhole at the diversion tunnel portals

At that point, the three river diversion tunnels (left main tunnel sealed and pre- sealed; right tunnel partially blocked, and GAD completely blocked) were out of service. The crest of the dam was still below the spillway level and the spill structure not ready yet. EPM took the decision of diverting the flow through the powerhouse complex of tunnels and caverns, to prevent dam's overtopping, and to protect the population and infrastructure downstream of the project.

On May 10th, to avoid dam overtopping, EPM opened Intake Tunnel 1 and 2 as well as 7 and 8; that night water started to flow through the Power House.

During the morning of May 12th, the right diversion tunnel suddenly started to operate

again, with a peak discharge of 4000 to 5000 m³/s, causing some damages at the Puerto Valdivia town. Nonetheless, this situation did not last long because after approximately 4 hours a new landslide at the diversion portal blocked the inlet again.

On May 16th, before noon, a significant amount of water, carrying pieces of rocks, came out the power house access tunnel. The same day some water came out from another constructions tunnel (#284) located at the toe of the dam.

On May 17th Tailrace Tunnel 3 reduced its flow that subsequently stopped. Elbows of Intake System 7 and 8, upstream and downstream of the reinforced concrete penstocks, were not completed.

On May 20th, the flow of water through Intake Tunnel 7 and 8 stopped; on May 26th EPM closed Intake Tunnel 7 and 8; few hours later a land slide occurred above these tunnels reducing access to the area.

On June 1st, an irregular reduction of the flow through the Power House was observed.

In early June, dam crest level reached elevation 410 m a.s.l., allowing operation of the surface spillway. At that time intensive efforts were placed in rising the dam crest level to elevation 410 m a.s.l., to allow excess inflows to evacuate through the surface spillway. That goal was achieved in early June 2018, and thanks to that, the hydrological emergency ended.

On June 24th reduction of the flow through Right Diversion Tunnel was recorded. On July 1st, July 6th and July 18th, irregular reductions of the flow through the Power House were recorded.

Annex 4. Response Level Matrix

The Response Level Matrix is a key tool for emergency handling, which provides clear guidance to:

- Identify an emergency,
- Classify it in terms of response level,
- Initiate the required response actions.

A typical template is shown below.

RESPONSE LEVEL	TYPE OF EVENT						
	Hydrological event/ Flooding	Emergency releases at upstream reservoirs	Earthquake	Excessive leakage/ internal erosion/ piping	Abnormal instrument readings	Gate failure/ power loss/ equipment failure/ fire	Sabotage/ accident
Internal Alert Situation can be managed internally. Outside notification NOT required	Reservoir level approaching design flood level. Outflows approaching channel capacity.	Upstream dam warns of imminent spill.	Earthquake less than DBE recorded	Excessive seepage		Failure of spillway gates	Any incident of threat of attack
Response Level I Conditions might lead to downstream flooding. Outside notification required	Reservoir level above design flood level, but below crest level.	Release in excess of channel capacity	Earthquake greater than DBE	Increasing rate of excessive seepage. Heavy seepage carrying fines.		-	Attack that threatens the integrity of the dam or spillway
Response Level II Prepare for evacuation	Reservoir level predicted to exceed dam crest level	Controlled releases likely to flood inhabited areas	Instability of dam resulting from earthquake	Seepage develops a major uncontrolled outflow		-	As above
Response Level III Evacuation is necessary	Overtopping imminent	As above	Integrity of dam jeopardized by earthquake	Dam collapse through piping imminent		-	As above

Annex 5: Detalle Costo Ituango BID 36 meses (EPM agosto 2108)

Cuenta HFS	Proyecto Ituango		
315.00.506	CAPEX - INV M.EXT EN M. LOC/Ituango	\$ Millones	
315.00.508	CAPEX- INVERSION M.LOC/Ituango	\$ Millones	
315.00.700	CAPEX- TOTAL INVERSIONES/Ituango	\$ Millones	
DETALLE INVERSIONES DIRECTAS			
	Ingeniería y administración	\$ Millones	1.629.056
	Infraestructura	\$ Millones	1.794.812
	Obras principales	\$ Millones	3.397.196
	Equipos	\$ Millones	1.263.087
	Gestión ambiental y social	\$ Millones	890.942
	Conexión al STN	\$ Millones	60.375
	Tierras y servidumbres	\$ Millones	78.929
	Reajustes e Imprevistos	\$ Millones	275.000
	Inversiones post contingencia	\$ Millones	1.389.000
	Total Inversiones	\$ Millones	10.778.398
DETALLE INVERSIONES CONTINGENCIA			
	1. Obra civil	\$ Millones	369.000
	2. Equipos (recuperación y reemplazos)	\$ Millones	332.750
	3. Obligaciones Adicionales Licencia Ambiental	\$ Millones	13 7.250
	4. Taponamiento túnel derecho y SAD	\$ Millones	100.000
	5. Pantalla impermeable en la presa	\$ Millones	150.000
	6. Desembalse	\$ Millones	300.000
	Total Inversiones Contingencia	\$ Millones	1.389.000

NOTAS:

* Se incluye inversión adicional por contingencia por valor \$1,39 Billones

* Las inversiones antes de contingencia se distribuyeron a los diferentes lotes de forma proporcional con la inversión por lote de la versión del costo V144

Annex 6: Cronograma de recuperación y puesta en servicio (EPM septiembre 2018)

