Seminário “Avanços Technólogicos Para a Gestão de Barragens de Mineração” - Práticas Samarco x Práticas do Mundo

Sean Ennis, P.Eng
Vice President Mining

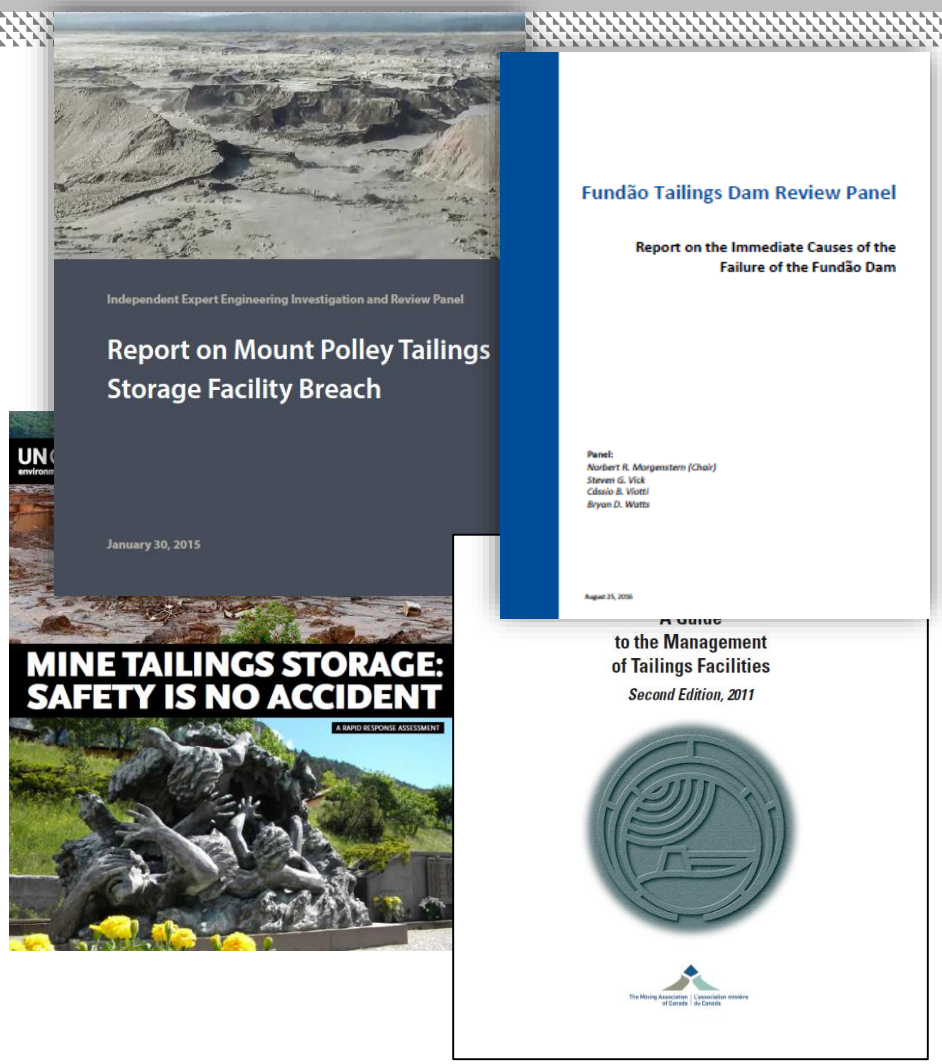
Richard Dawson, PhD, P.Eng.
Executive Vice President

December 13, 2017

NORWEST CORPORATION

“the dam safety system applied to the oil sands industry is the best in the world” (Morgenstern, 2011)

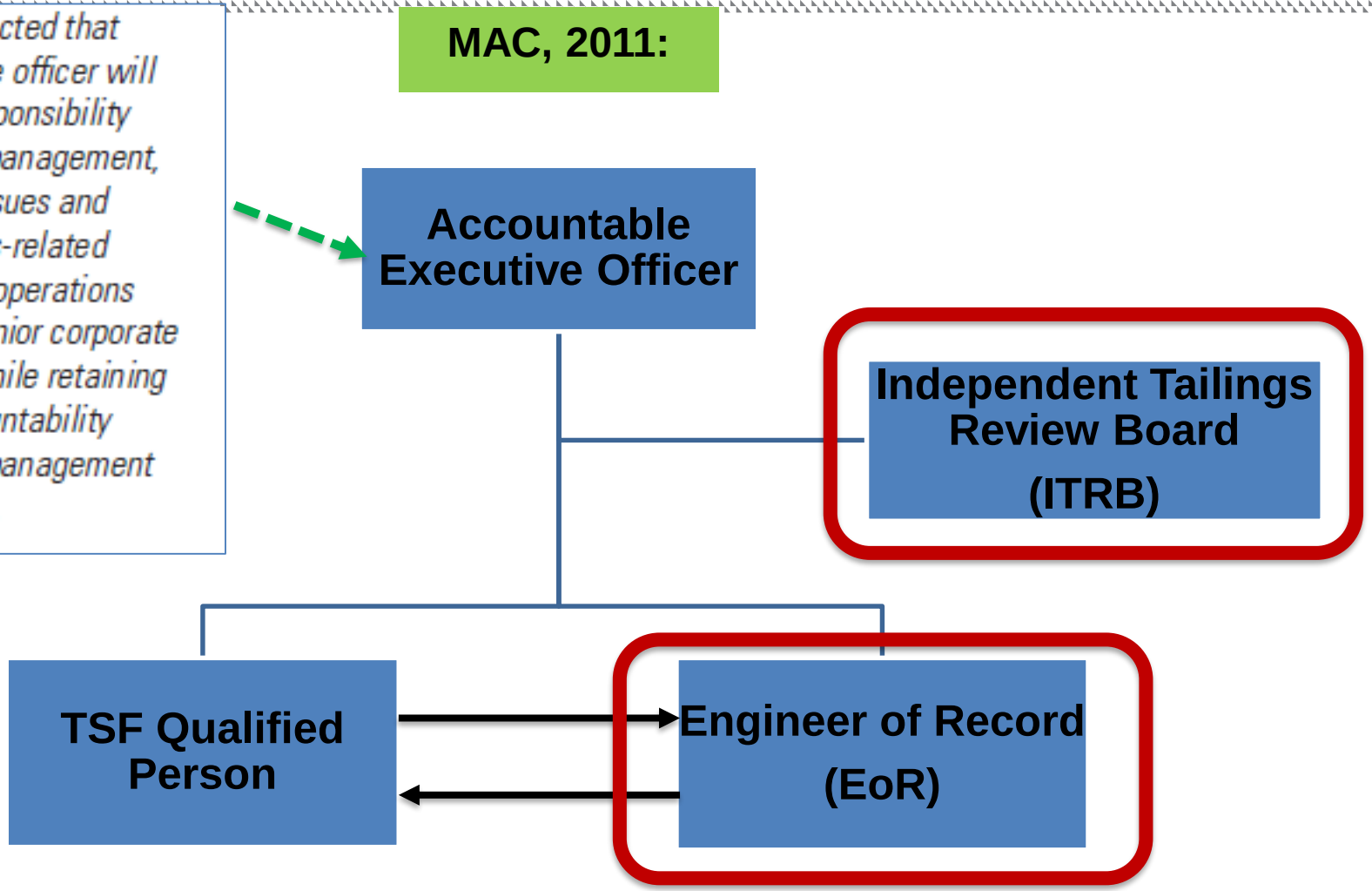
Outline



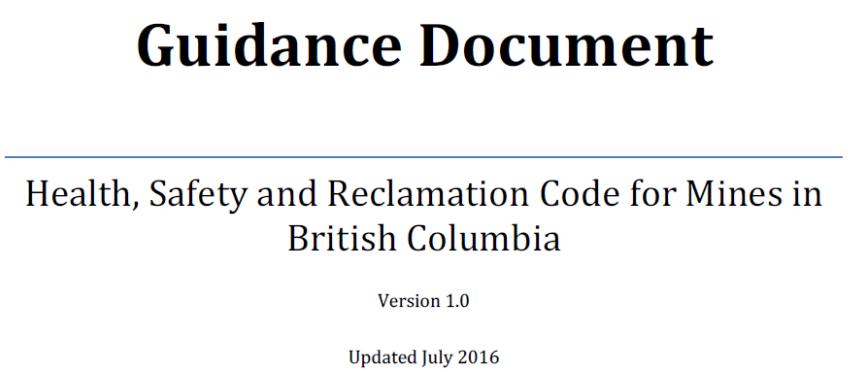
- Roles and Responsibilities
- Design Standards
- Technology Development
- Risk Management
- Dam Safety Reviews

Roles and Responsibilities

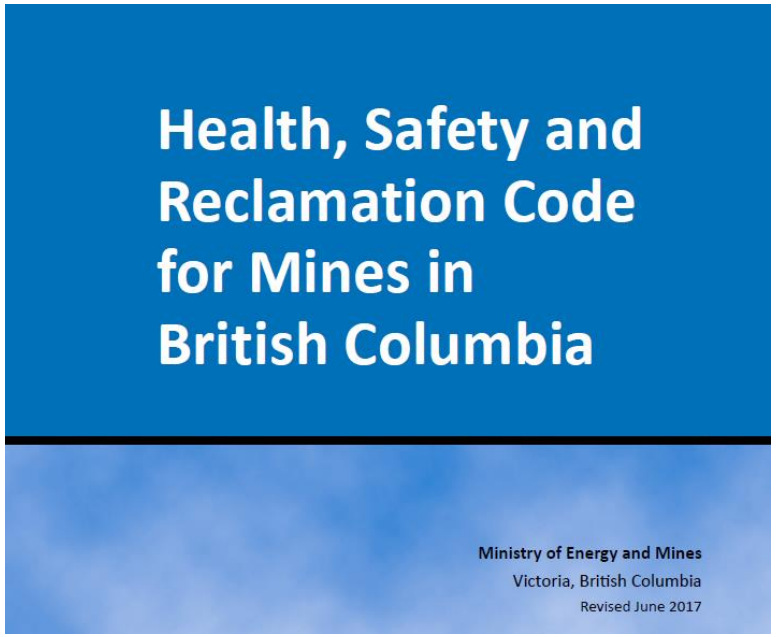
- *It is expected that the executive officer will delegate responsibility for tailings management, budgetary issues and other tailings-related functions to operations and other senior corporate personnel while retaining overall accountability for tailings management performance.*



Engineer of Record (EOR)



- “Is a qualified and competent engineer with experience commensurate with the consequence classification and complexity ”
- “Holds the professional responsibility for the facility design and is responsible for evaluating the adequacy of the as-built facility relative to the design as well as applicable standards, criteria, and guidelines”



The 2017 HSRC update integrates the EoR into the design, inspection and review of a tailings facility.

Independent Tailings Review Board (ITRB)

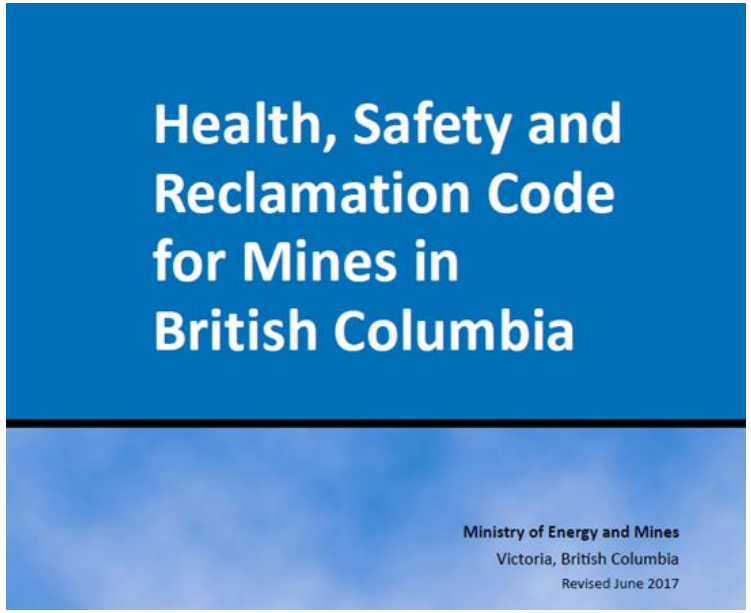
Guidance Document

Health, Safety and Reclamation Code for Mines in British Columbia

Version 1.0

Updated July 2016

- "Made up of independent subject matters experts not currently involved in or responsible for the design, operation or construction of the facility"
- "Provides non-binding advice and guidance, but does not direct the work or perform the role of the Engineer of Record"



The composition of an Independent Tailings Review Board… shall be commensurate with the complexity of the tailings storage facility"

Design Standards – Factor of Safety Criteria Comparison

Phase	Condition	Brazil (ABNT) 2006	Canada (CDA)	Australia (ANCOLD)
Short Term (EOC)	Potential Loss of Containment	**1.3**	➢ **1.3**	**1.5**
	No Potential Loss of Containment			**1.3**
Long Term (Steady State)		**1.5**	**1.5**	**1.5**
Rapid Drawdown		**1.1**	**1.2 - 1.3**	
Critical Phreatic Level		**1.3**		
Seismic	Pseudo-Static	**?**	**1.0**	
	Post Earthquake	**?**	**1.2**	**1.0 – 1.2**

Samarco Stability Design Criteria

Phase	Condition	Brazil (ABNT) 2006	Comment
Short Term (EOC)	Potential Loss of Containment	**1.3**	**Existing Brazil regulatory standard**
	No Potential Loss of Containment		
Long Term (Steady State)		**1.5**	
Rapid Drawdown		**1.1**	
Critical Phreatic Level		**1.3**	
Seismic	Pseudo-Static	**1.0**	**Adopt CDA guideline**
	Post Earthquake/**Post liquefaction***	**1.2***	

*** Include static liquefaction**

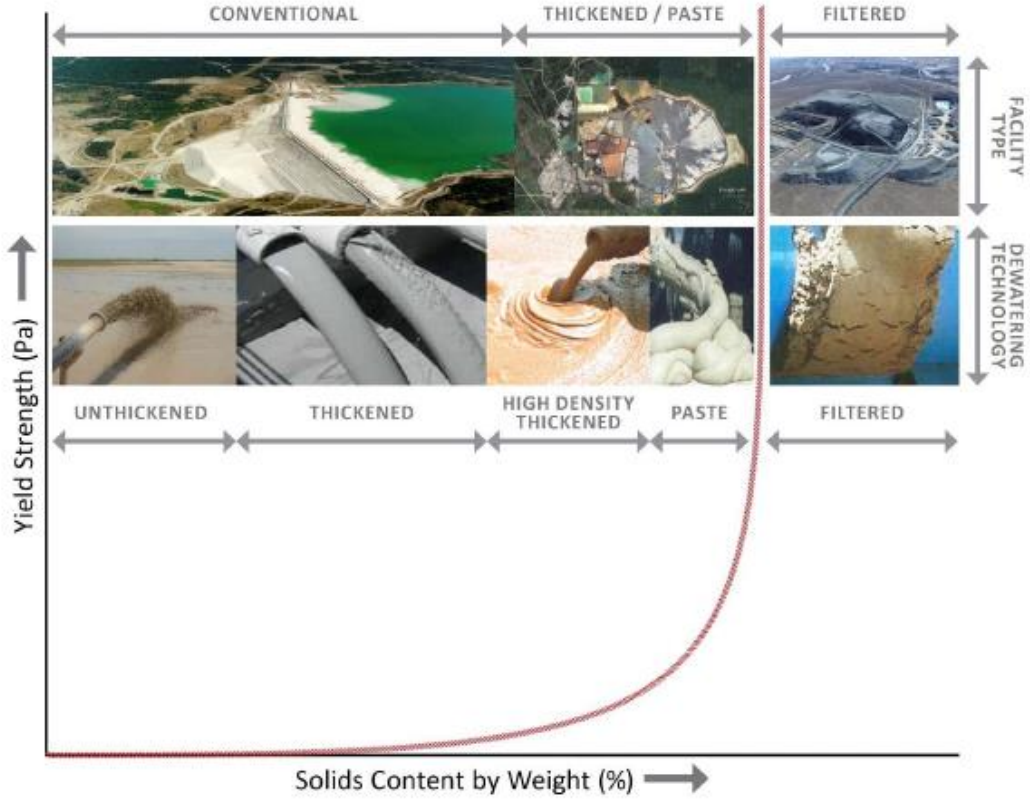
Best Technologies and Practices

- **Best Applicable Technology Economically Achievable – BATEA** - combination of technologies and techniques that most effectively reduce the economic, physical, geochemical, ecological and social risks associated with tailings during all stages of operation and closure.
- **Best Available/Applicable Practice – BAP** - management systems and operational procedures to ensure that tailings storage facilities are designed, constructed, operated, maintained, monitored and closed to support sustainable mining practices.

EXAMPLES:

- Tailings Dewatering Technologies
- Cone Penetration Testing for Site Investigation
- Real-Time and Remote Monitoring

Tailings Dewatering Technologies



Samarco planning for start-up:

Thickened Tailings

(slimes stream)

Filtered Tailings

(sand stream)

Source: Study of Tailings Management Technologies

MEND Report 2.50.1

BATEA – Tailings Technology Alternatives Evaluation

AREA:	TECHNICAL		ENVIRONMENTAL/SOCIAL								ECONOMIC		PROJECT RISK	
Tailings Disposal Method [2]	Dewatering of Tailings [3]	Tailings Deposition [4]	Process Make-Up Water (m^3/hour)	Disturbed Surface Area (ha) Total	Disturbed Surface Area (ha) Tailings Surface Area	Risk of Breach Failure [5]	Dust Potential	Seepage	Visual Impact [8, 9]	Reclamation	CAPEX	OPEX	Proven Technology at 65,000 tonnes/day	Regulatory Concern
Conventional Un-thickened (32% solids) Un-buttressed Facility	Most Favorable	Most Favorable	1.087	700	589 (326 beach, 263 pond)	Least Favorable	Less Favorable	Least Favorable	More Favorable (1,060m)	Less Favorable			Most Favorable	Less Favorable
Conventional Un-thickened (32% solids) Buttressed Facility [7]	Most Favorable	Most Favorable	1.087	700	589 (326 beach, 263 pond)	Less Favorable	Less Favorable	Least Favorable	More Favorable (1,060m)	Less Favorable			Most Favorable	Less Favorable
Thickened (60% solids) Buttressed Facility [7]	More Favorable	More Favorable	764	690	550 (450 beach, 100 pond)	More Favorable	More Favorable	Less Favorable	Most Favorable (1,056m)	More Favorable			Most Favorable	More Favorable
Paste (75% solids) Buttressed Facility [7]	Less Favorable	Less Favorable	730	603	461 (411 beach, 50 pond)	More Favorable	Most Favorable	More Favorable	Least Favorable (1,095m)	Least Favorable			Least Favorable	Least Favorable
Dry Stack (85% solids) Buttressed Facility [7]	Least Favorable	Least Favorable	400	429	362	Most Favorable	Least Favorable	Most Favorable	Least Favorable (1,055)	Most Favorable			Least Favorable	Most Favorable

Notes:
1. Qualitative ranking in order of preferred option is: Most Favorable -> More Favorable -> Less Favorable -> Least Favorable

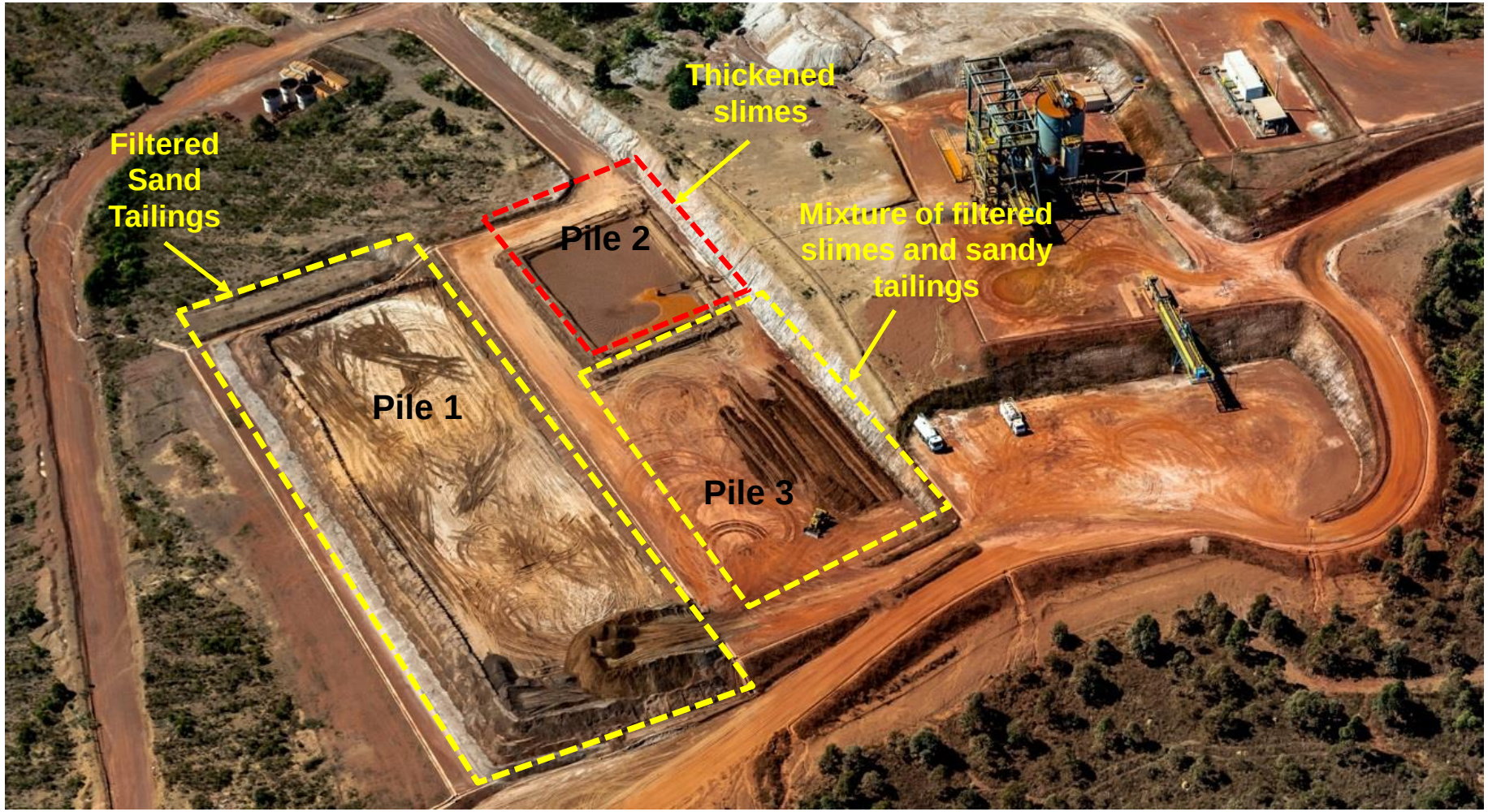
Trade off study to determine BATEA for a site in British Columbia, Canada

Operational Filtered Tailings Stack

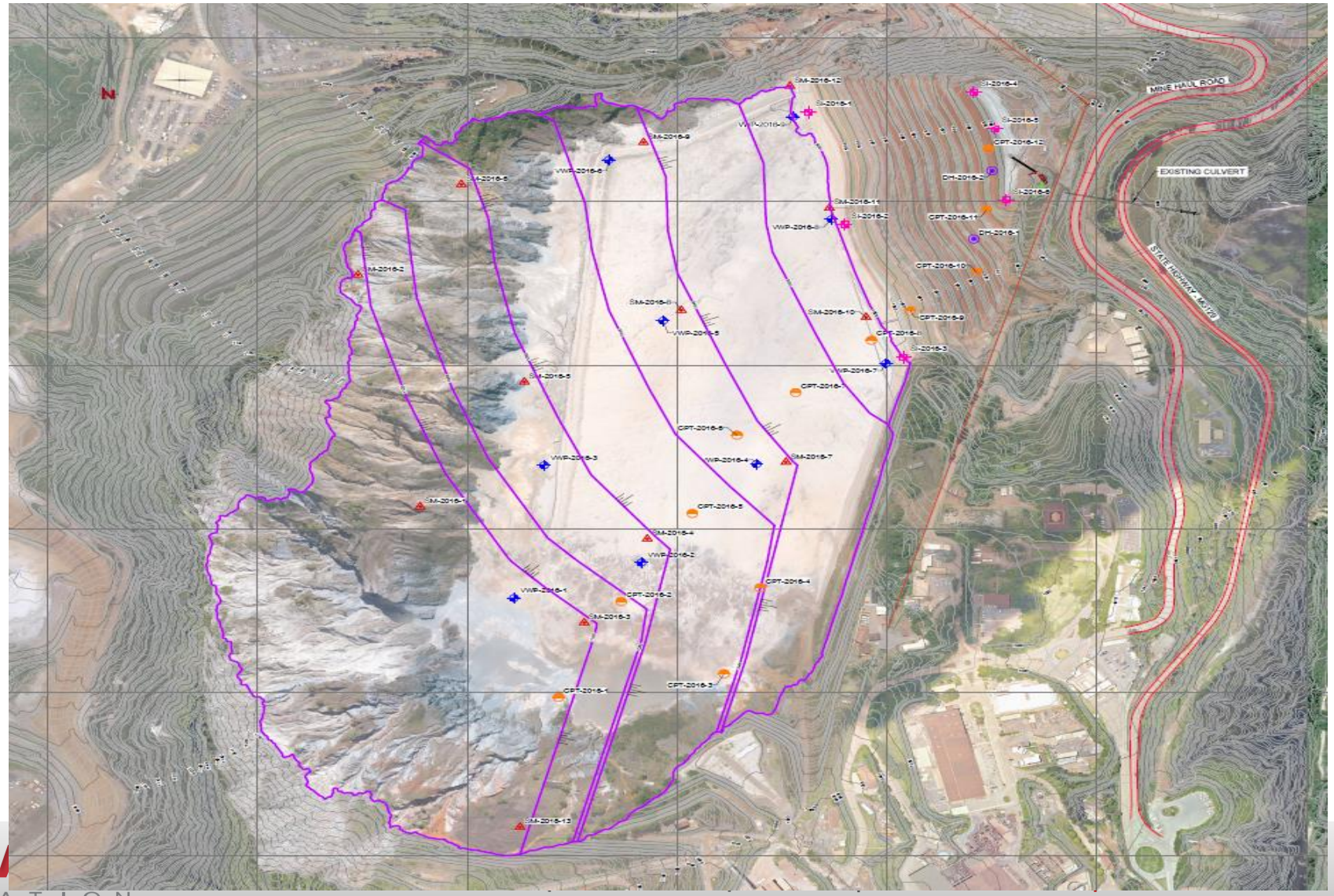
Eldorado Gold Efemcukuru Mine, Turkey

Controlled Material Placement		
Transportation	Spreading	Compaction

Brasil Filtered Tailings Pilot Plant and Test Plots



Samarco Germano Pit Filtered Tailings Design



BAP – Site Investigation
Cone Penetration Test (CPT)

ADVANTAGES:

- Fast and continuous profiling
- Repeatable and reliable data
- Economical and productive
- Strong theoretical basis for interpretation
- Additional sensors

LIMITATIONS:

- High capital investment
- Skilled operators
- No soil sample
- Penetration restricted in gravels/cemented layers

CONVENTIONAL DRILLING & SAMPLING

DIRECT-PUSH TECHNOLOGY

After Mayne, 2010

BAP – Monitoring

Automated Instrumentation Systems

Sensors
(Vibrating Wire Piezometer, Shape Accelerometer Array (SAA), In-Place Inclinometer (IPI), Transducer, Tiltmeter, Strain Gauge, GPS, Radar, inSAR)

Datalogging and Telemetry
(Storage and transmission of data via networked radios, cellular or satellite communication)

Acquisition and Analysis
(Web/Server based monitoring software, near real-time readings, alarm criteria and alert systems, Factor of Safety (FOS) analysis)

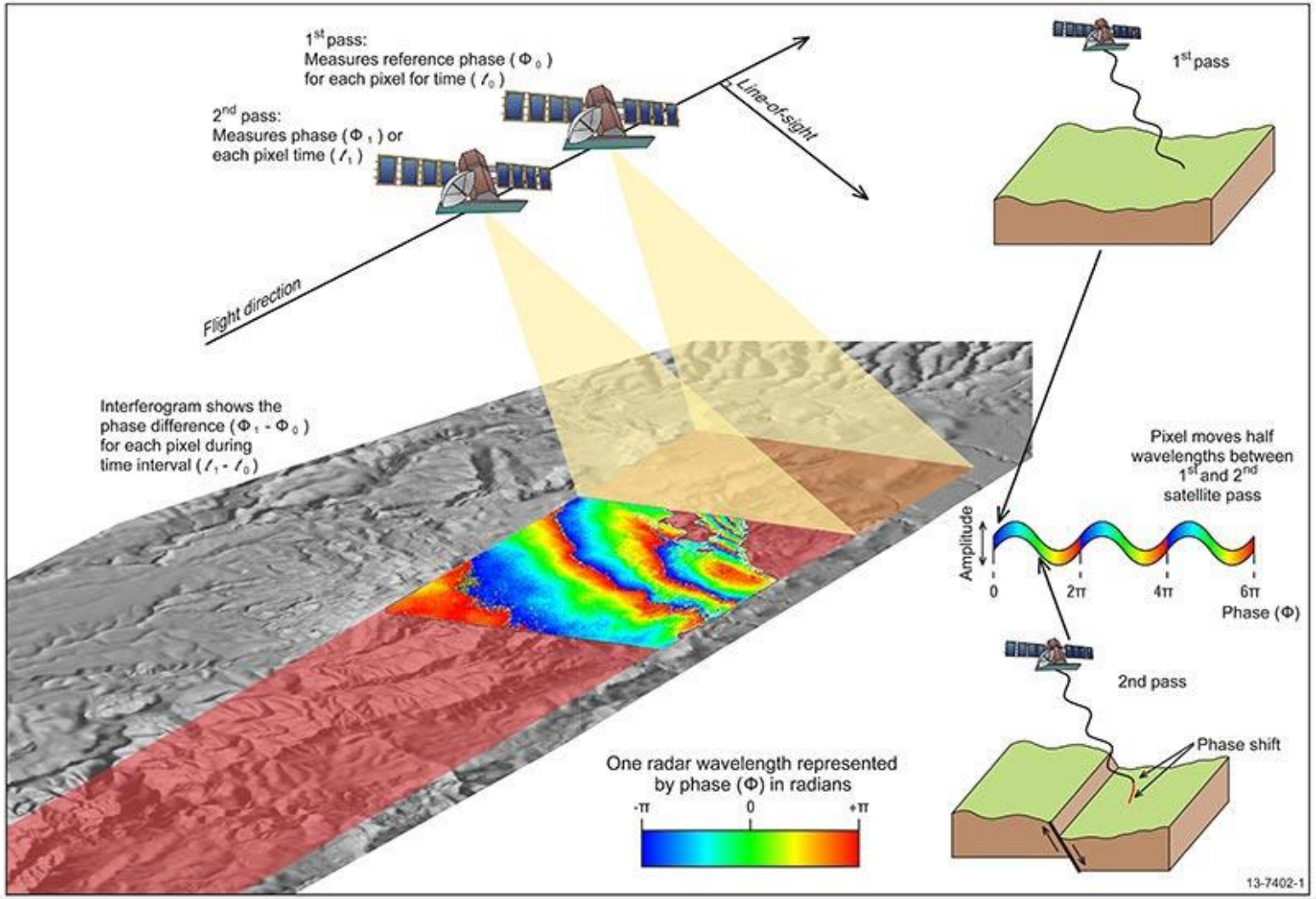
Design and Operational Decisions
(Performance based decisions, construction sequencing)

BAP - Samarco Monitoring System

Samarco monitoring control room

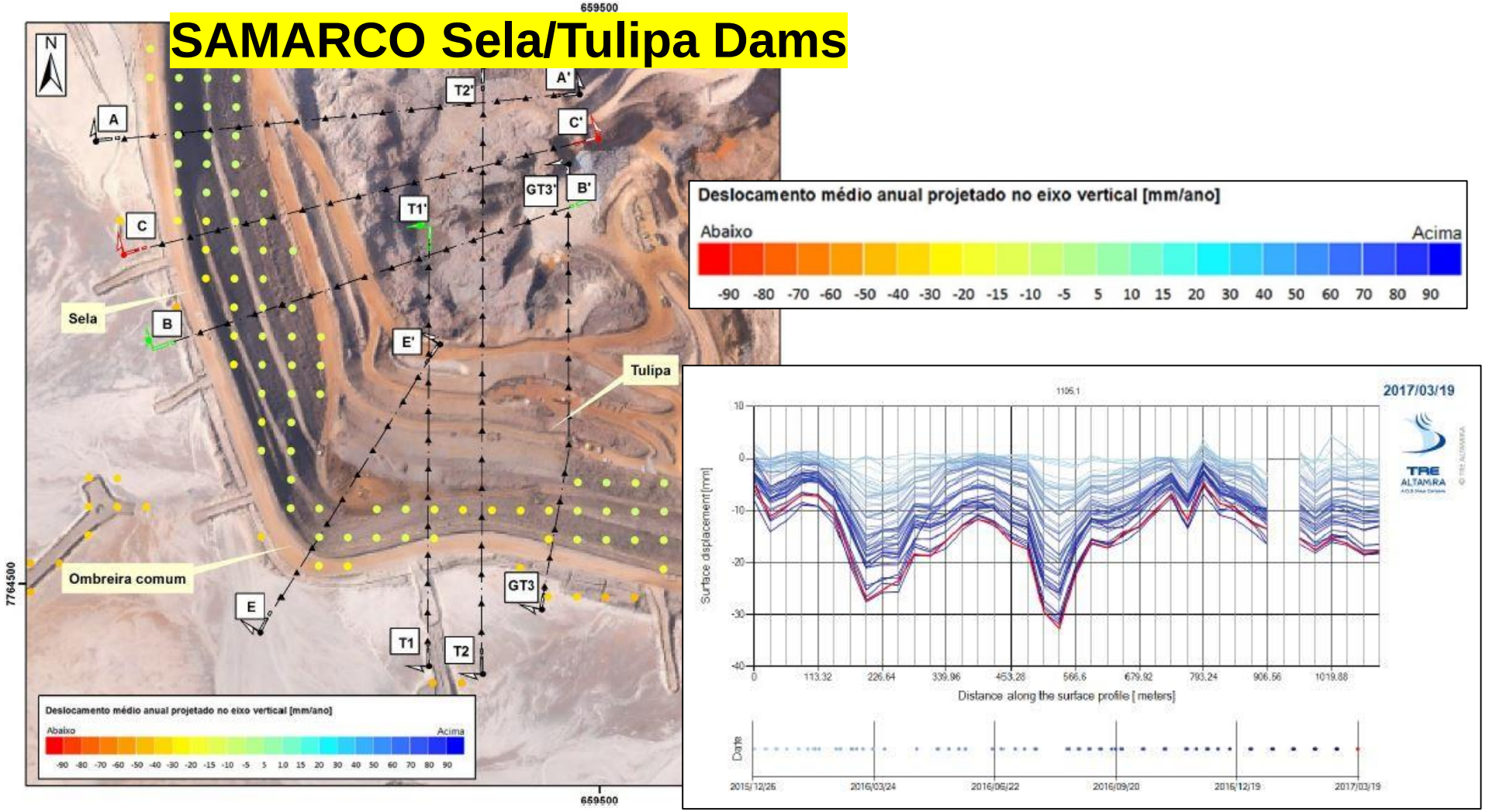
Ground-based monitoring radar station

BAP- Interferometric Synthetic Aperture Radar (InSAR)



Interferometric Synthetic Aperture Radar (InSAR)

SAMARCO Sela/Tulipa Dams

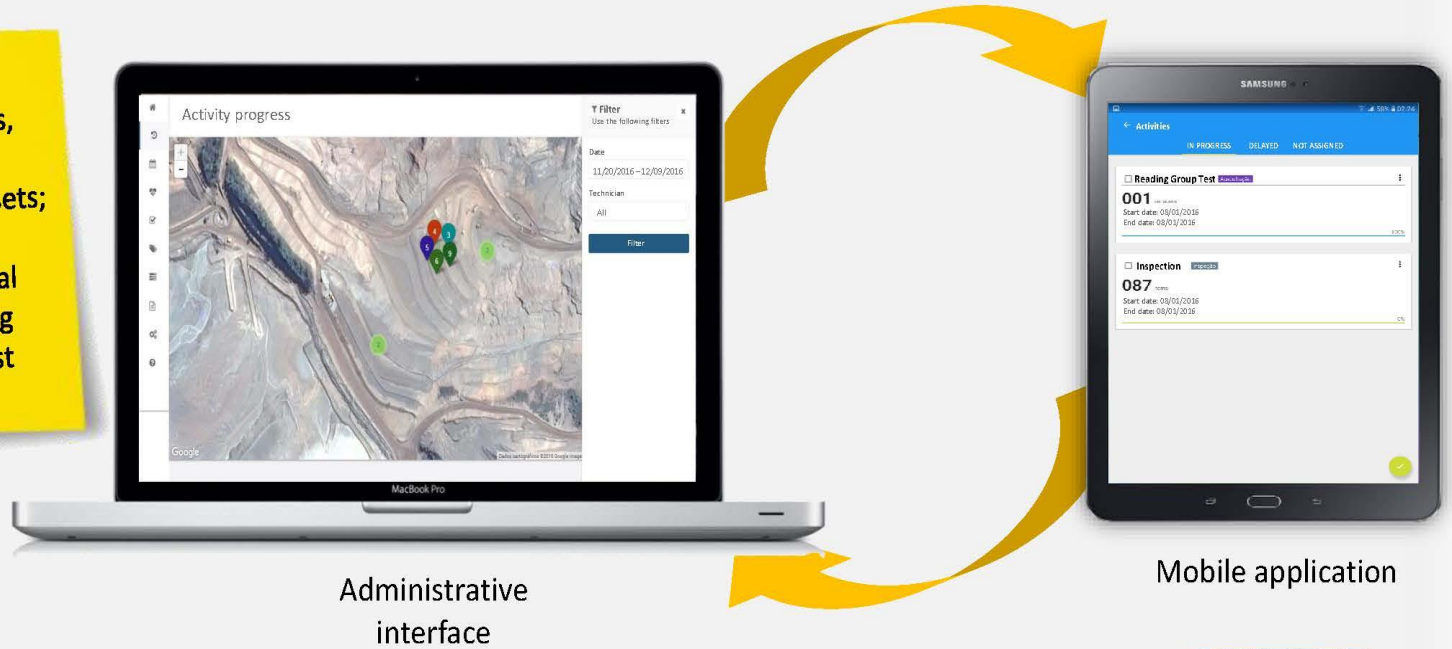


BAP – Mobile Data Collection

GEO INSPECTOR

Geo Inspector is a mobile solution with an administrative interface that allows real-time and safe management of monitoring and inspection activities.

Allows integrated management of activities, shifts and scales of technicians; anomalies; assets; and the generation of managerial and statistical reports aimed at making decisions in the shortest possible time.

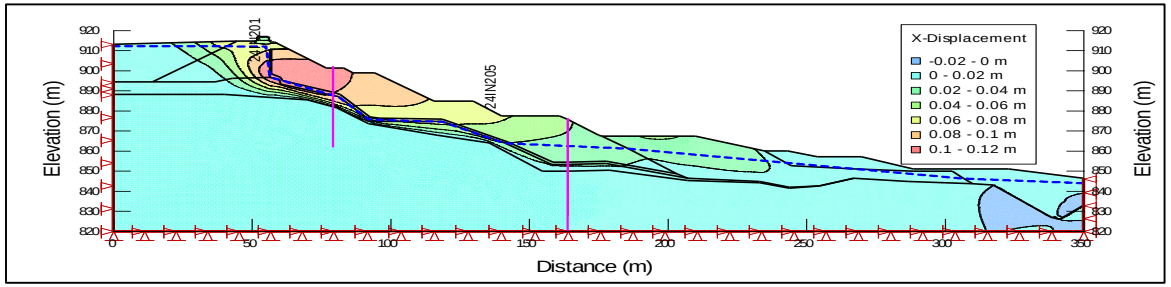


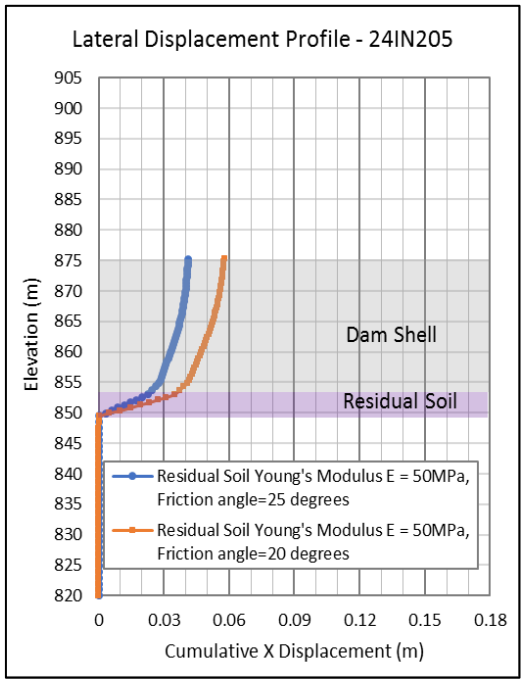
Administrative interface

Mobile application

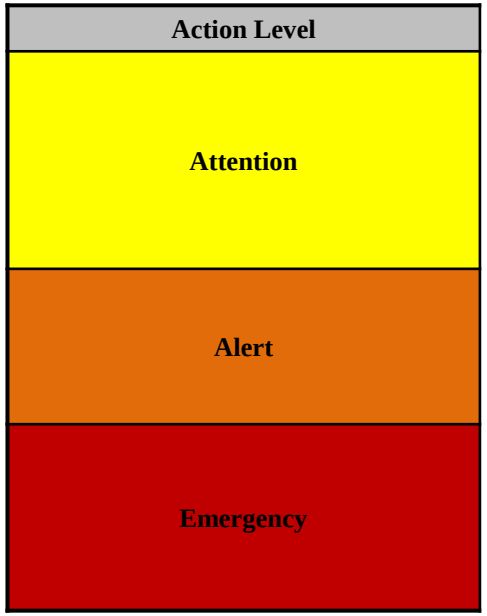
Intelltech is a Brazilian technology company

BAP - Monitoring Data Trigger Levels

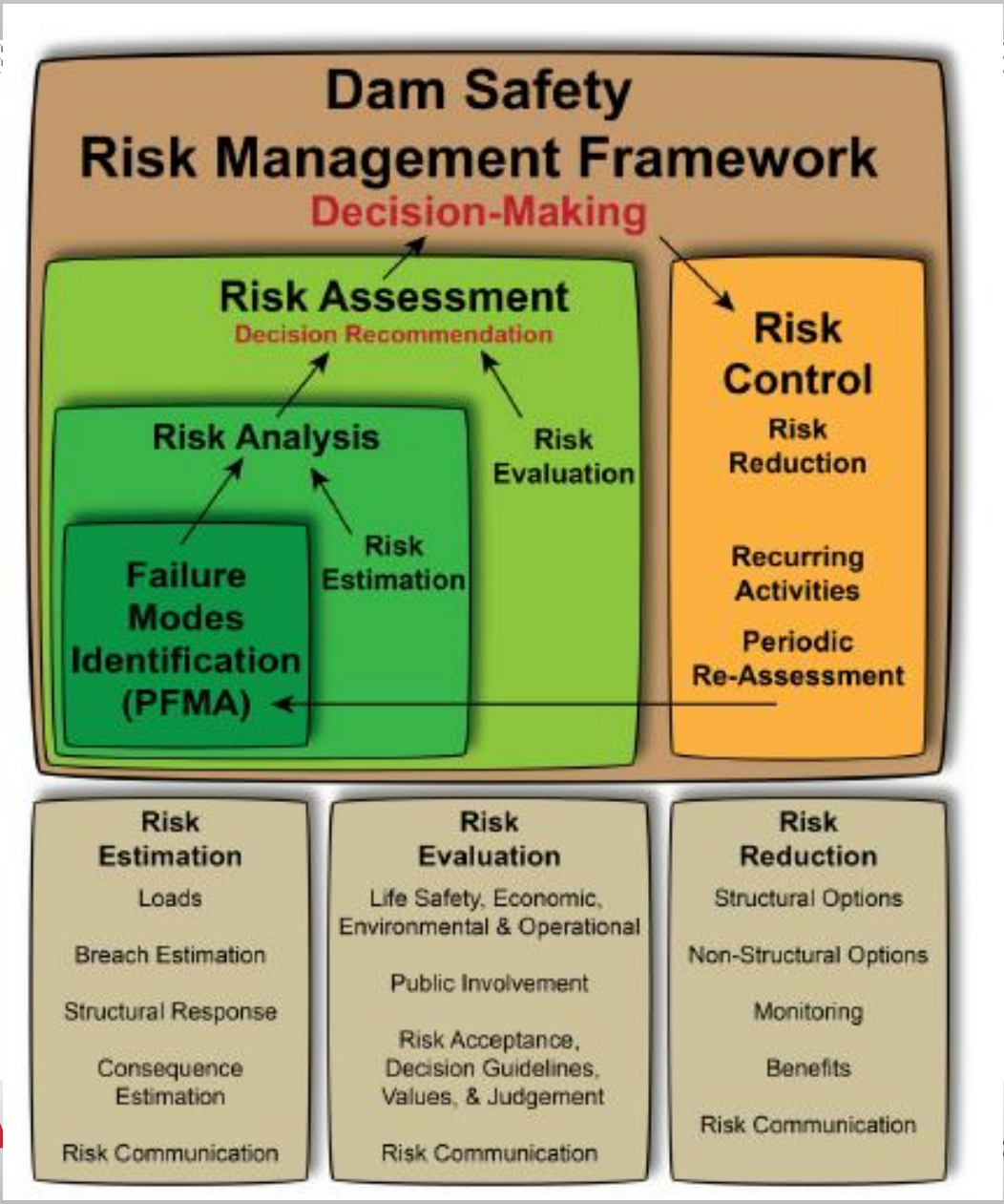


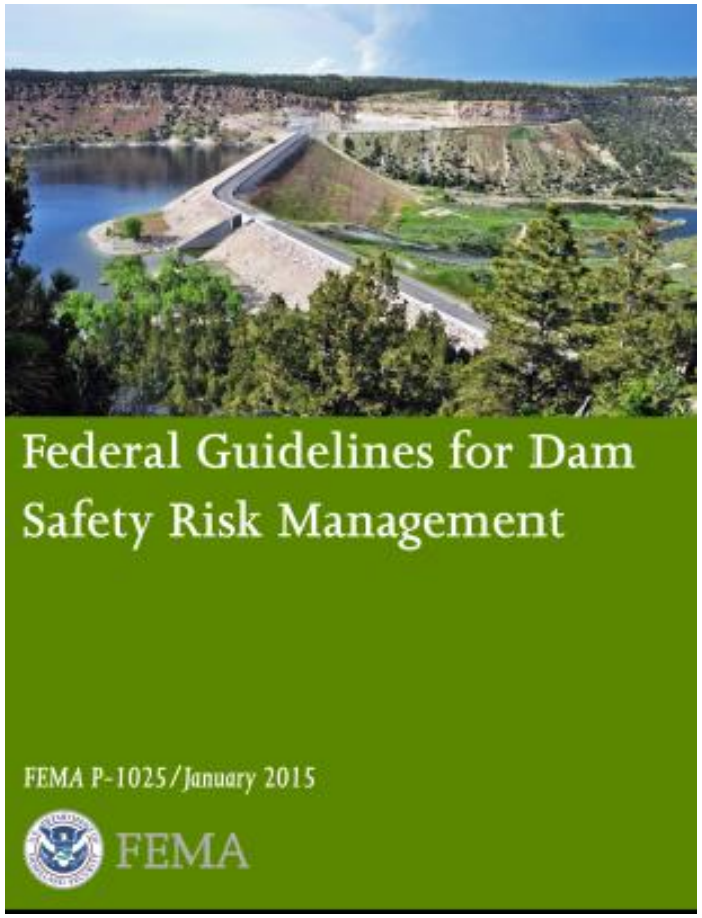


Samarco/Norwest using stress-strain modeling and stability analysis to define trigger level conditions for key failure modes

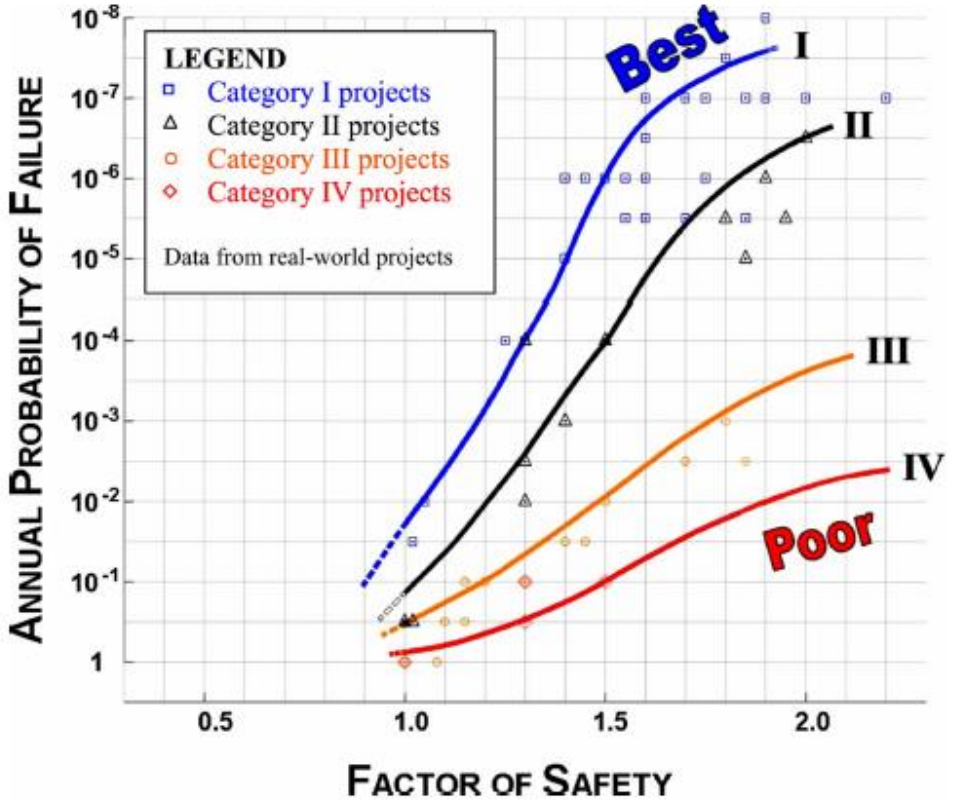


Risk Management





Risk Analysis Techniques



Probability and Risk of Slope Failure

Francisco Silva, M.ASCE[1]; T. William Lambe, Hon.M.ASCE[2]; and W. Allen Marr, F.ASCE[3]
1692 / JOURNAL OF GEOTECHNICAL AND GEOENVIRONMENTAL ENGINEERING © ASCE / DECEMBER 2008

Some examples:

- Failure Modes and Effects Analysis (FMEA)
- Bow Tie Analysis
- Event Trees
- Fault Trees
- Reliability Analysis
- Consequential Risk Analysis
- Subjective methods
- Vulnerability Index

Potential Failure Modes Analysis

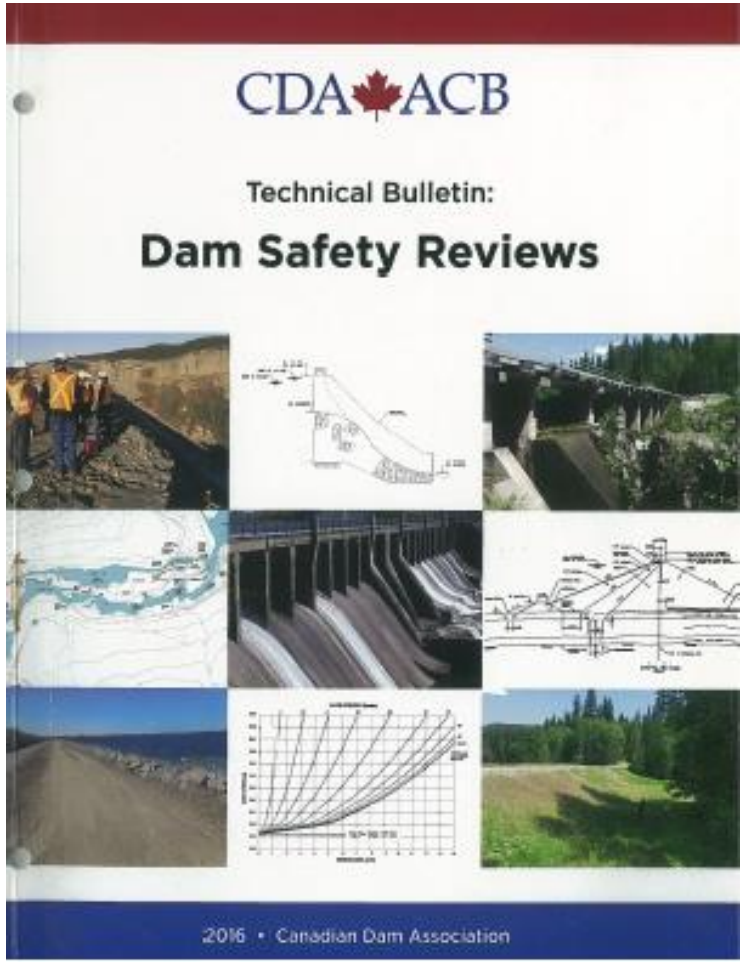
Failure Category	Potential Failure Mode Description	Controlling Areas	Positive Factors	Adverse Factor	Warning Time (hours, days, weeks)	Barriers/Controls	Hazard Category	Recommendations and Comments
Dyke Fails by Overtopping (Reservoir Goes Up)	Large storm exasperated by a pumping failure leading to a rising pond level and a subsequent breach of the dyke. Unplanned operational rise in the pond water leading to a rising pond level and a subsequent breach of the dyke.	All areas.	• Freeboard exceeds the incident PMP by a factor of 5. • Recycle water barges are in place. • Very slow increase with sufficient time to implement mitigations. • Control of the fresh water intake.	• Closed water management system. • Ultimate containment for all site water.	Weeks	• Containment structure with generous freeboard. • Specific procedures are in place to manage a rising pond condition (OMS).	IV	• There are no recommendations or comments at this time.
	Failure of the TT containment dykes leading to a wave or flow event which subsequently overtops the perimeter dyke.	EETA	• TT containment is hundreds of meters away from the perimeter dyke. • The EETA is planned as a "dry" facility. • Deposit characteristics limit the mobility. • Beaching from the perimeter dykes means that any TT released from the TT containment dykes will have to overcome a positive beach slope for some distance, as well as the perimeter dyke freeboard.	• TT dykes will be higher than the surrounding perimeter structure for a period of time. • Characteristics are not well known. • Tailings plans are subject to change.	Hours	• Continuous monitoring.	IV	• Per the CP16 plan CST beach is built in advance of the TSRU deposit, and therefore, this scenario is unlikely given the current plan. • Evaluate critical failure mechanisms.
	Failure of the BBW leading to a wave or flow event which subsequently overtops the perimeter dyke.	WETA	• BBW has slumped without consequence. • TSRU is strong (30 degrees) and compressible. • Freeboard of 3 m. • TSRU feed goes in-pit when storage space is available. • Current beach above water widths are greater than the minimum. 50 m of beach above water is added to the structural zone by Operations as a form of contingency.	• Steep (30 degrees)TSRU BBW slopes. • Removal of FFT supporting the TSRU BBW from the pond for use in TT.	Hours	• Continuous monitoring.	IV	• Operational risks (non-breach) for TSRU BBW need to be assessed. • Although this failure mode could develop quickly, the potential risk for an overtopping event is considered negligible.
			• CPT programs demonstrate BAW is dilative for the rate of	• Liquefaction occurs very rapidly and cannot be managed		• Beach surveillance program is in place		• Liquefaction potential of the BAW relies on the

- Identify "**credible**" failure modes
- Provide complete descriptions of each failure mode including the initiating event and sequence of steps leading to an uncontrolled release from the impoundment
- Describe the magnitude of the breach

Dam Safety Risk Controls

- Dam Safety Management System (MAC Guidelines in Portuguese)
- Operating Plans and Procedures
- Maintenance and Testing of Critical Equipment
- Surveillance Plans
- Performance Evaluation/Observational Method
- Mitigation/Repair
- Emergency Management

Dam Safety Reviews

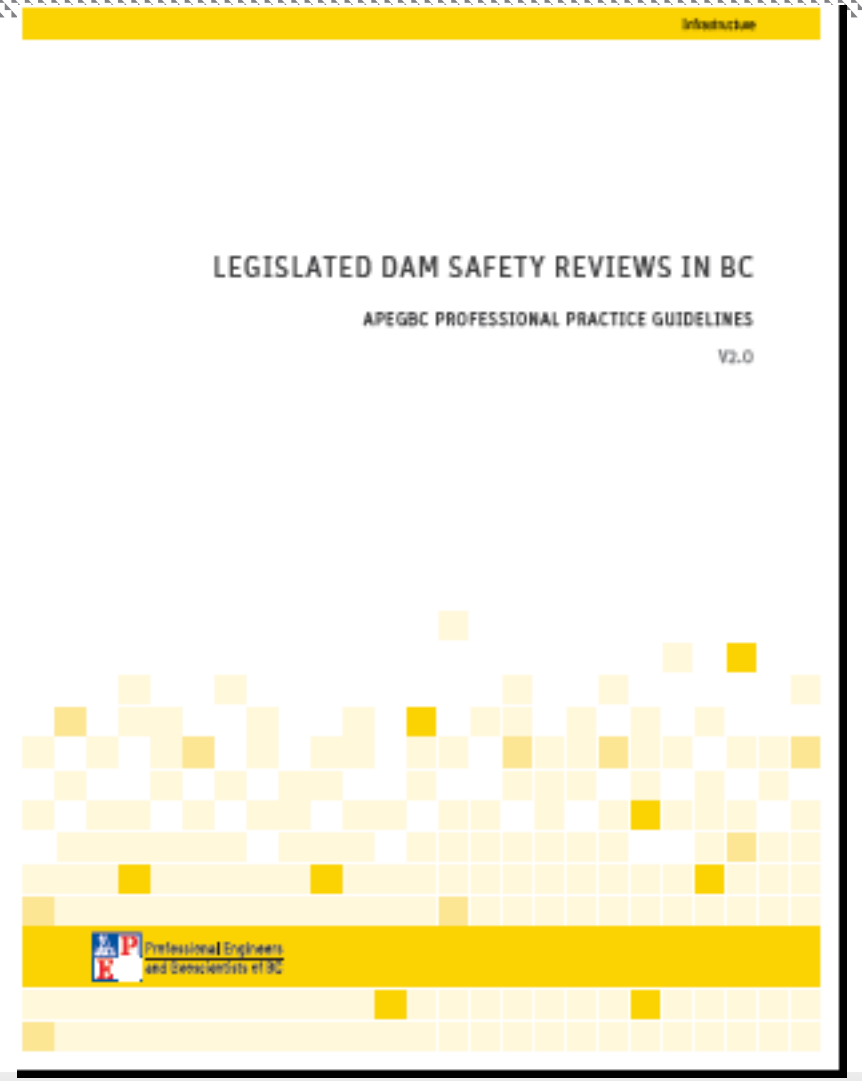


"A dam safety review is part of the dam safety management system that has the overall goal to protect people, property and the environment from harmful effects of misoperation or failure of dams and reservoirs."

Companion CDA references:

- CDA (2007, 2013); Dam Safety Guidelines
- CDA (2014) Technical Bulletin – Guidelines to Mining Dams

Types of Dam Safety Reviews



- Audit type
- Comprehensive
- Detailed Design-based Multi-disciplinary
- Comprehensive and Detailed Design and Performance Review

Tailings Structures Reviews/Audits at Samarco

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Vancouver, BC V6E 3X2
Tel: (604) 602-8992
www.norwestcorp.com

OQM | Organizational Quality Management Program

September 9, 2016

Project #: 919-2

SAMARCO MINERAÇÃO S. A.
Mariana, Brazil

Attn: Reuber Luiz Neves Koury
Jose Bernardo V Rodrigues De Oliveria

Dear Reuber and Jose:

Subject: Germano Main Dam Stability Review

Figure 3. Eroded Toe at Germano Main Dam (March 15, 2016)

Norwest and other international consultants have recently performed extensive stability reviews and audits for tailings structures at Samarco

Key Messages – Governance

- ✓ Well-defined roles, responsibilities and accountabilities for key positions (ex. Engineer of Record)
- ✓ Independent peer review with international consultants
- ✓ Formal independent review requirements with Independent Tailings Review Boards (ITRB) reporting to senior management

Key Messages – Best Practices

BAT (Best Available Technology)

- ✓ Rapid development of tailings dewatering processes. Samarco plans to adopt thickened tailings and filtered tailings technologies

BAP (Best Available Practices)

- ✓ Performance management and the observational method
- ✓ CPTU is the “standard” for evaluating tailings deposits
- ✓ Remote monitoring technologies and systems
- ✓ Mining Association of Canada (MAC) tailings guides

Key Messages – Process

- ✓ Systems based approach ….. Mining Association of Canada (MAC) Guidelines….Portuguese translation
- ✓ Risk Management:
  - Failure Modes Identification and Risk Control are critical to the process. Need to get it right… experience required
  - Quantitative Risk Assessment is not exact…. serves to calibrate judgement
  - Very High and Catastrophic failure modes dominated by the consequence of failure - unless the mechanism can be virtually eliminated as non-credible
- ✓ Monitoring methods with trigger level criteria tied to failure modes and appropriate response

Obrigado – Thank You

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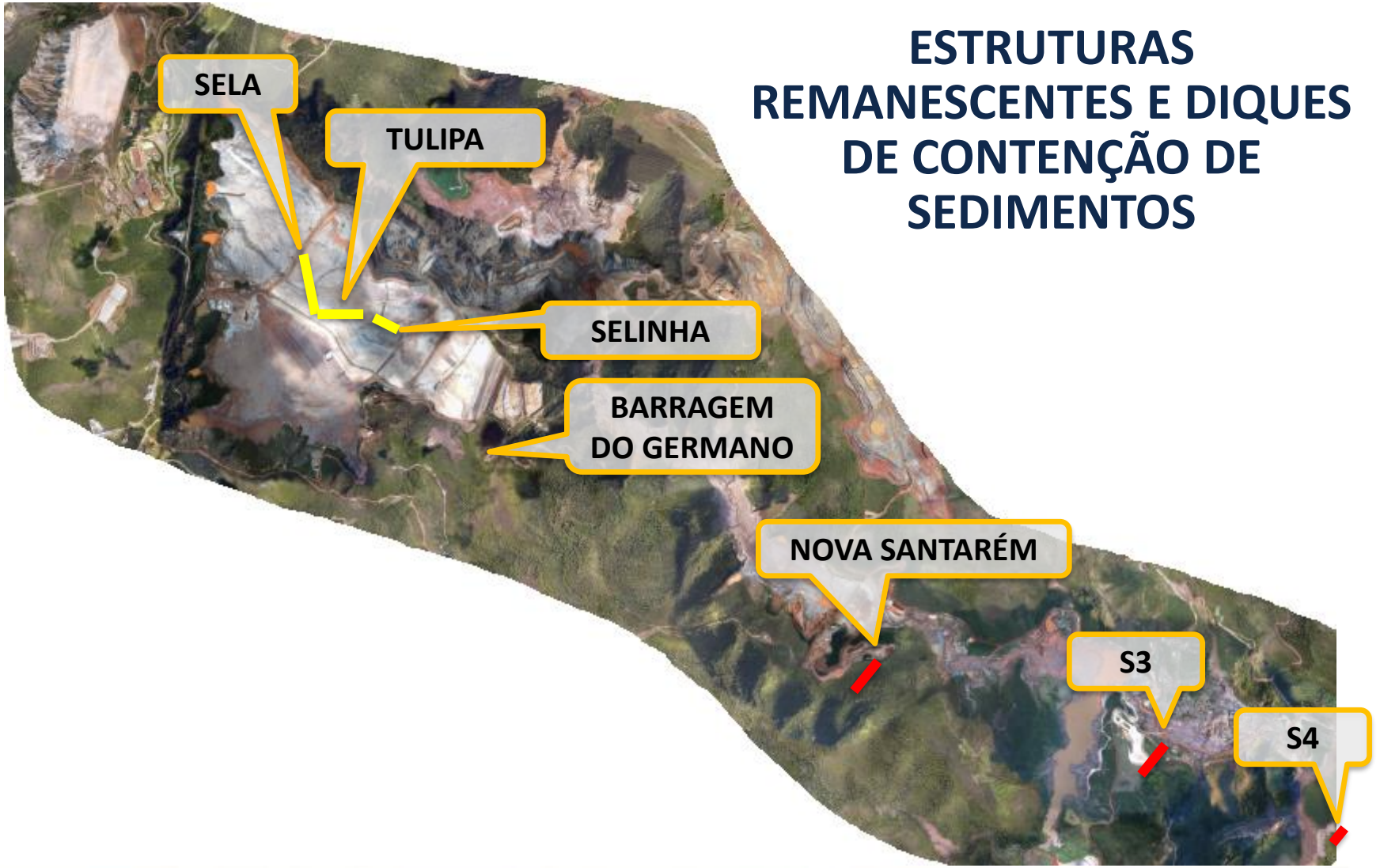
AS BUILT DAS ESTRUTURAS E FATOR DE SEGURANÇA PÓS-LIQUEFAÇÃO

Paulo Cella
Diretor
BVP Engenharia

ESTRUTURAS REMANESCENTES E DIQUES DE CONTENÇÃO DE SEDIMENTOS



BVP ENGENHARIA

ESTRATÉGIA DE PRIORIZAÇÃO DOS SERVIÇOS

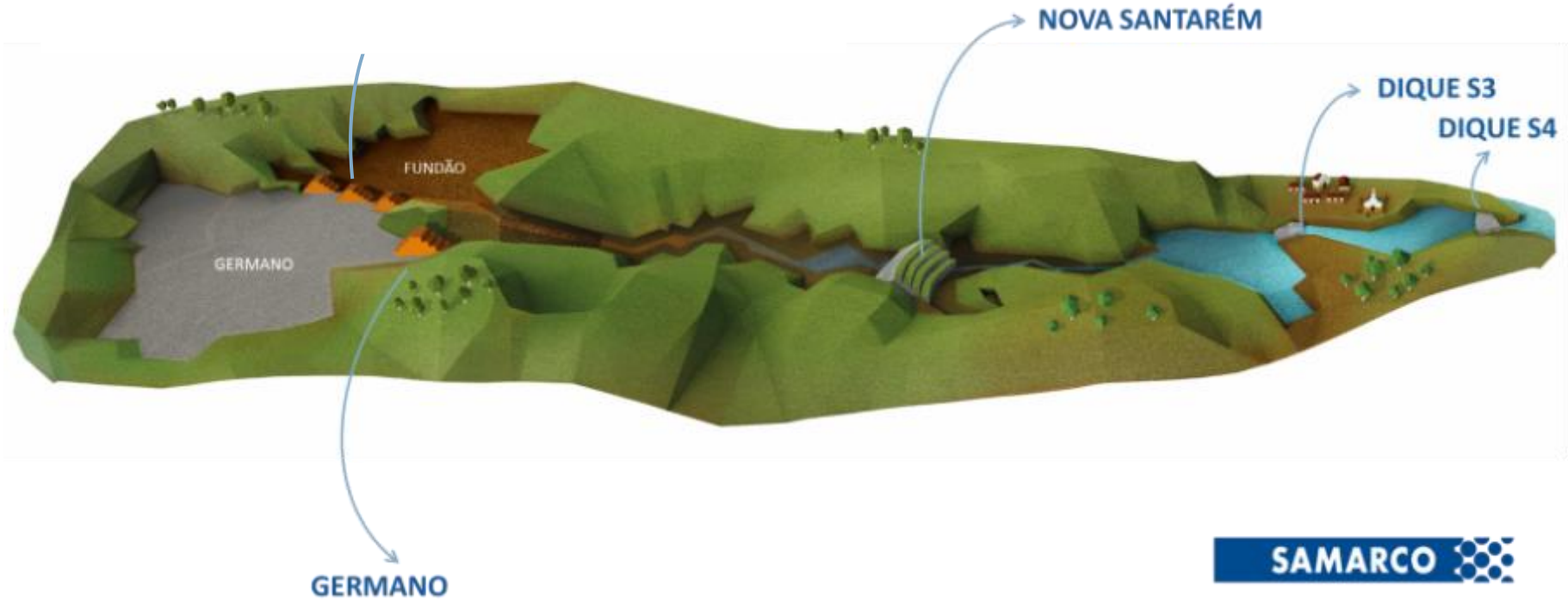
SEGURANÇA DAS ESTRUTURAS REMANESCENTES:

Sela, Tulipa e Selinha, Barragem do Germano e Santarém

CONTENÇÃO DOS SEDIMENTOS:

Nova Santarém

Diques de contenção: S3 e S4



SAMARCO

BVP ENGENHARIA

GOVERNANÇA DE PROJETOS E OPERAÇÕES

	ESTRUTURA / ATIVIDADE	PROJETISTA / RESPONSÁVEL	DESIGN REVIEW	AUDITORIAS
PROJETO	Reforço de Selinha, Sela e Tulipa Nova Santarém	BVP	Norwest	
	Reforço Barragem Germano	Norwest	SEA .	Auditoria Externa Independente
	Dique S3	BVP	NHC	Painel de Consultores Independentes Internacionais
	Dique S4	Walm	NHC	
OPERAÇÃO	Monitoramento dos Instrumentos Inspeção das Estruturas Relatório Técnico	Geotecnia Samarco	Norwest	DAM DF Consult.

AECOM (Auditoria para o MPMG)

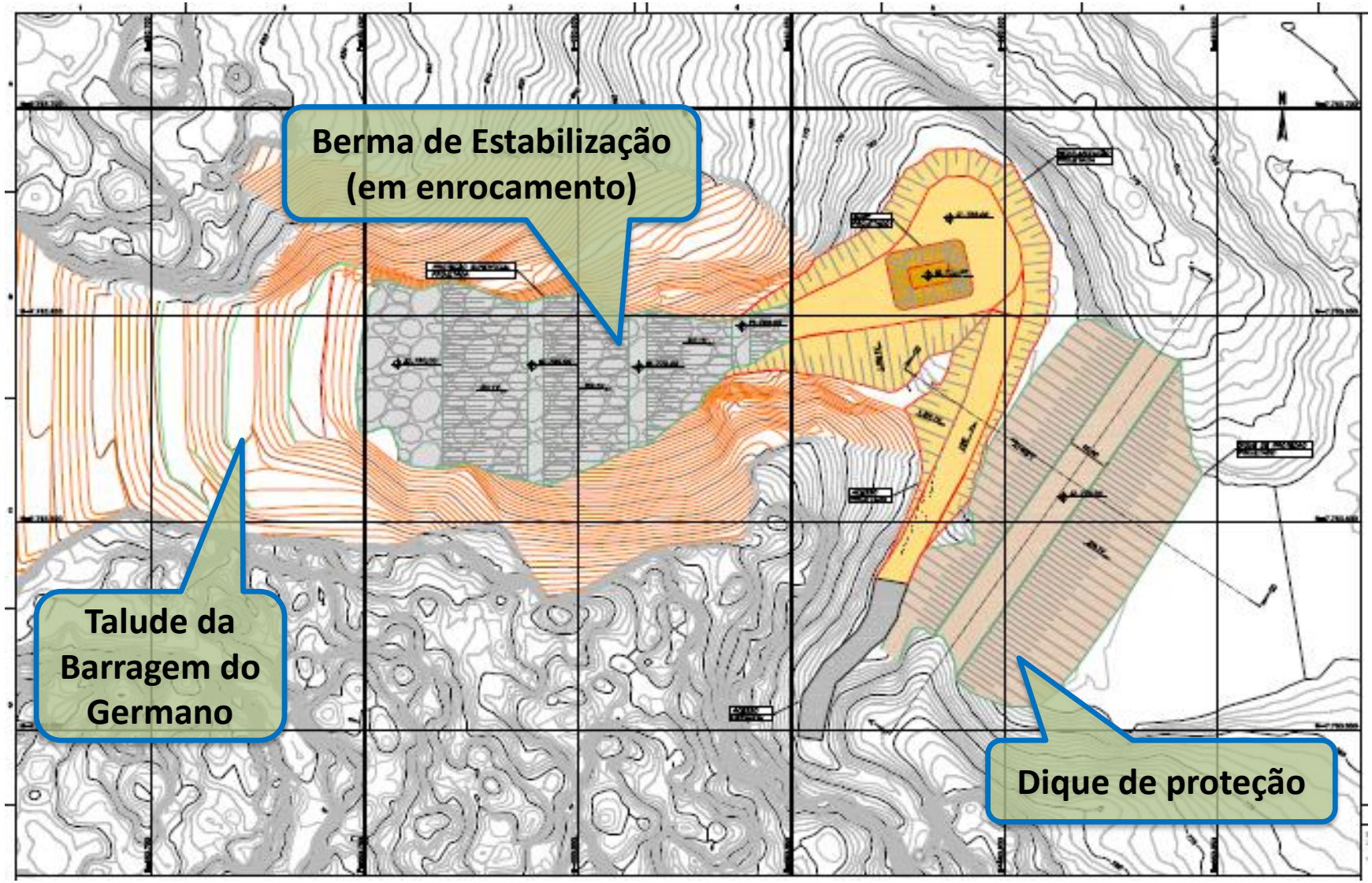
BVP ENGENHARIA

BARRAGEM DO GERMANO

BVP ENGENHARIA

BARRAGEM DO GERMANO
NOVEMBRO 2015

BARRAGEM DO GERMANO
PROJETO DE RECUPERAÇÃO DO PÉ DA BARRAGEM



BARRAGEM DO GERMANO
OBRAS DE REFORÇO (JAN A JUN/2016)

BARRAGEM DO GERMANO
SITUAÇÃO EM OUTUBRO 2017

Obra concluída em JUNHO DE 2016

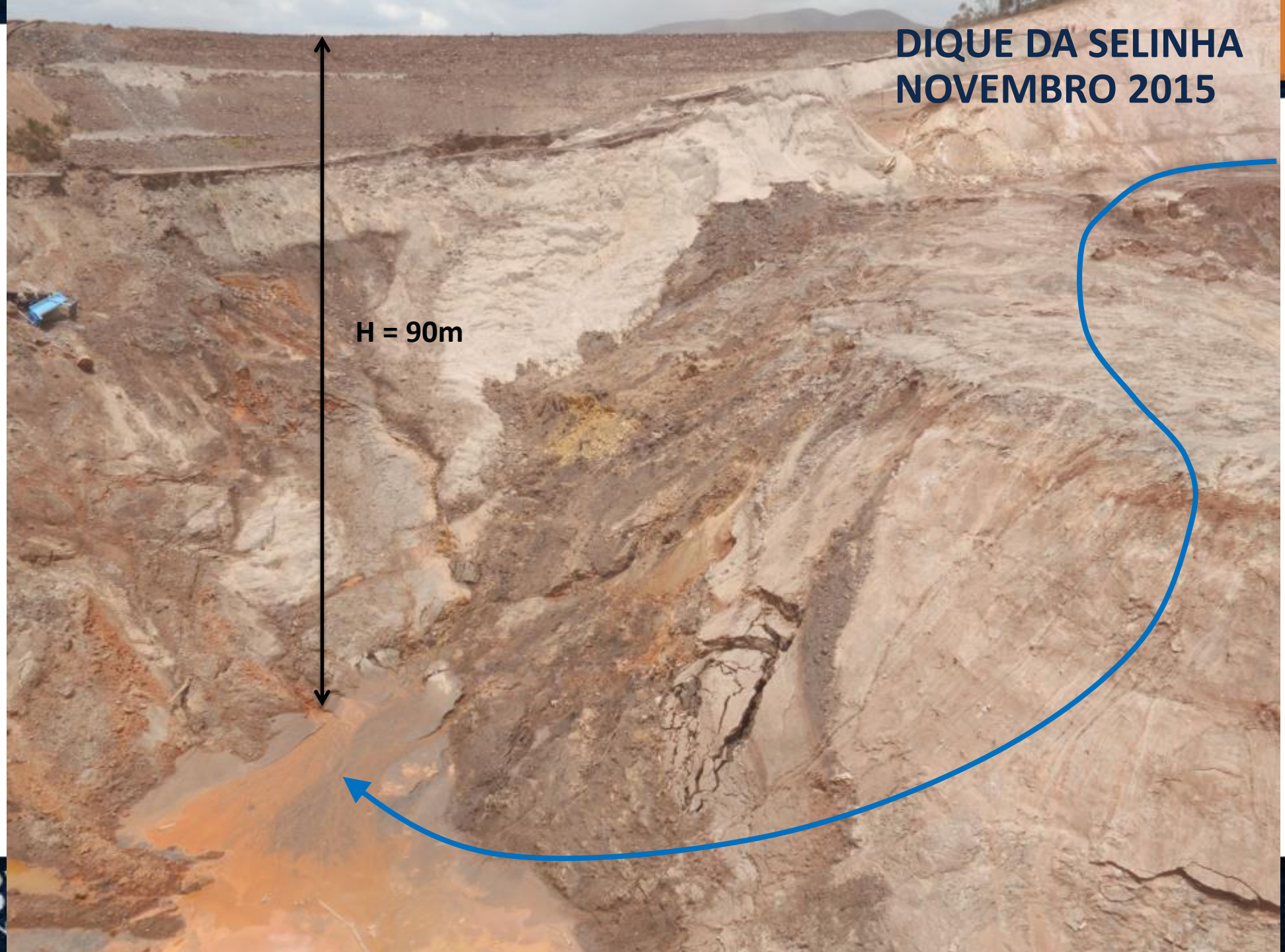
ITEM	UNIT	QUANTIDADES
ENROCAMENTO, TRANSIÇÕES, AREIA	m^3	40,482
LIMPEZA	m^3	8,150

DIQUE DA SELINHA

BVP ENGENHARIA

DIQUE DA SELINHA
NOVEMBRO 2015

DIQUE DA SELINHA
NOVEMBRO 2015



DIQUE DA SELINHA
DESENVOLVIMENTO DO ACESSO

DIQUE DA SELINHA
OBRAS DE REFORÇO (NOV A DEZ 2015)

DIQUE DA SELINHA
REFORÇO EXECUTADO

Item	Unit	Quantidades
ATERRO EM BLOCOS COM FINOS	m^3	83,000
ATERRO COM ENROCAMENTO	m^3	12,894

Obra concluída em 28 de Dezembro de 2015

DIQUES DA SELA E DA TULIPA

DIQUES DA SELA E TULIPA
SITUAÇÃO EM NOVEMBRO 2015

DIQUES DA SELA E TULIPA

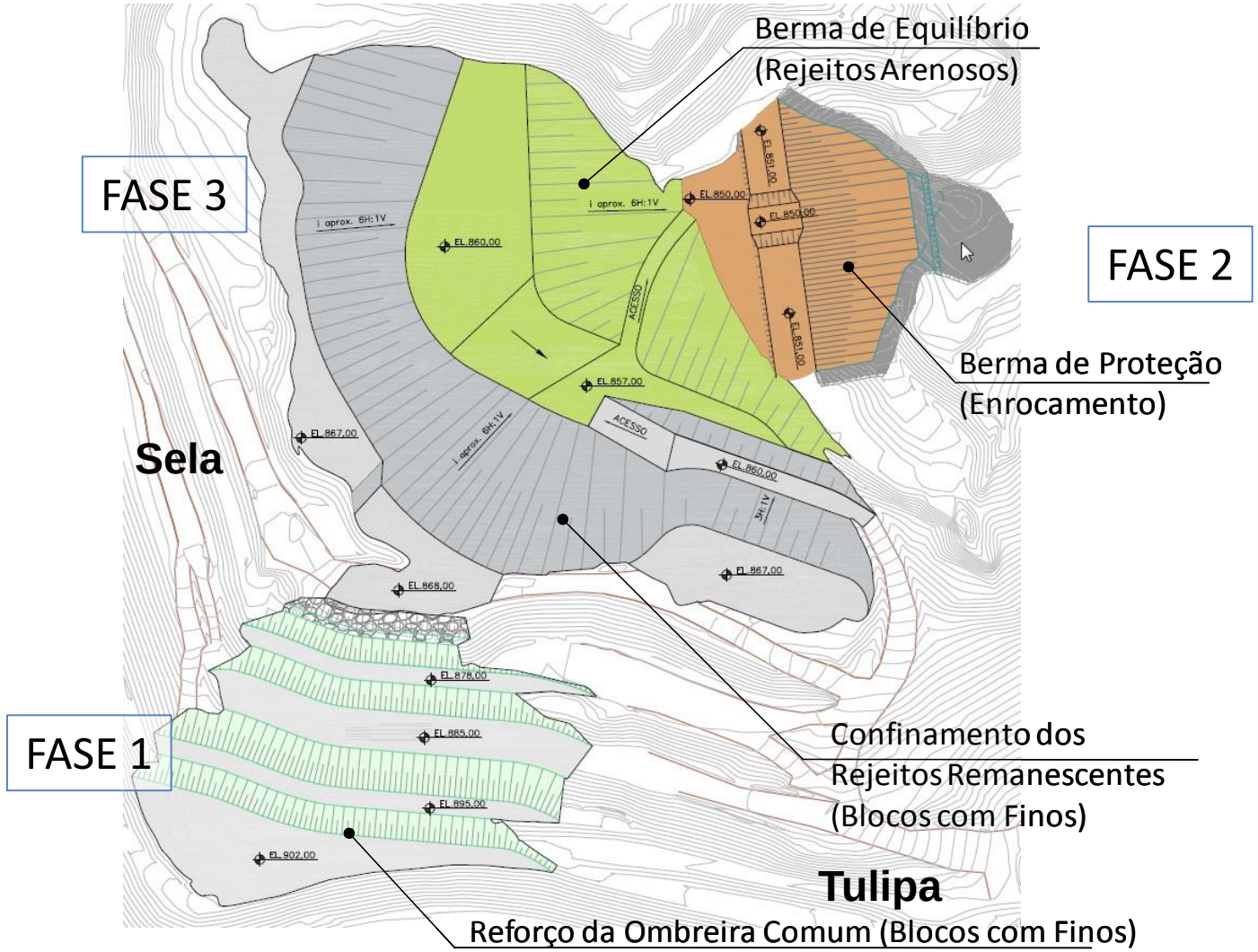
INÍCIO DE 2016

DIQUES DA SELA E TULIPA

OMBREIRA COMUM - INÍCIO DE 2016

DIQUE DA SELA E TULIPA

SOLUÇÃO PROPOSTA - PLANTA



BVP ENGENHARIA

OMBREIRA COMUM

OBRAS - FASE 1 (ABR/SET 2016)

DIQUE DA SELA

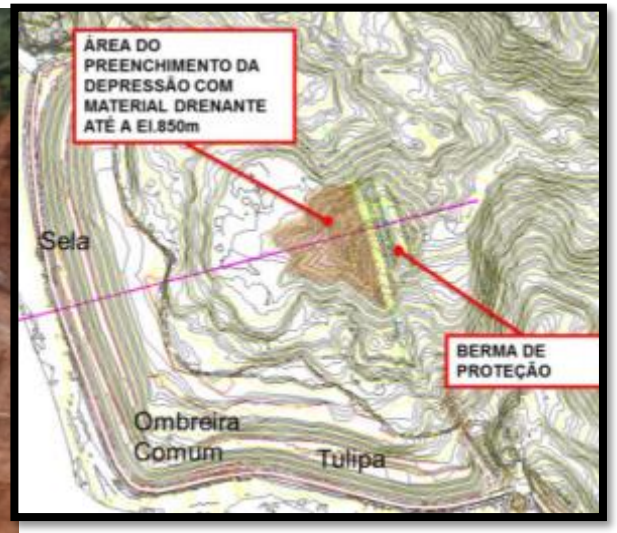
OBRAS - FASES 2 e 3 (SET/2016 a FEV/2017)

OMBREIRA COMUM
REFORÇO EXECUTADO

Obra concluída em SETEMBRO DE 2016		
Item	**Unit**	**Quantidades**
LIMPEZA DE FUNDAÇÃO	m^3	57,595
ATERRO EM BLOCOS COM FINOS	m^3	50,100

DIQUES DA SELA E TULIPA

FASE 2 EXECUTADA



Obra concluída em NOVEMBRO DE 2016

Item	Unit	Quantidades
LIMPEZA	m^3	71,391
ATERRO EM ENROCAMENTO	m^3	63,165
ATERRO EM REJEITO ARENOSO COMPACTADO	m^3	38,340

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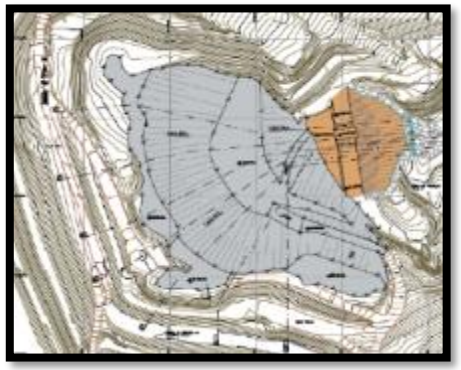
SELA E TULIPA

FASE 3 EXECUTADA



Obra concluída em FEVEREIRO DE 2017

Item	Unit	Quantities
ATERRO EM BLOCOS COM FINOS	m^3	115,400
ATERRO EM REJEITO COMPACTADO	m^3	124,184

DIQUE DA TULIPA

ADEQUAÇÃO DO SISTEMA EXTRAVASOR

DIQUE DA TULIPA

NOVO EXTRAVASOR EXECUTADO

DIQUE DA TULIPA

VISTA DO NOVO SISTEMA EXTRAVASOR

BARRAGEM NOVA SANTARÉM

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BARRAGEM SANTARÉM
SITUAÇÃO EM NOVEMBRO 2015

BARRAGEM SANTARÉM

REFORÇO IMPLANTADO

Obra concluída em Fevereiro de 2016

Item	Unit	Quantidades
ATERRO EM BLOCOS COM FINOS E TRANSIÇÕES	m3	67,000

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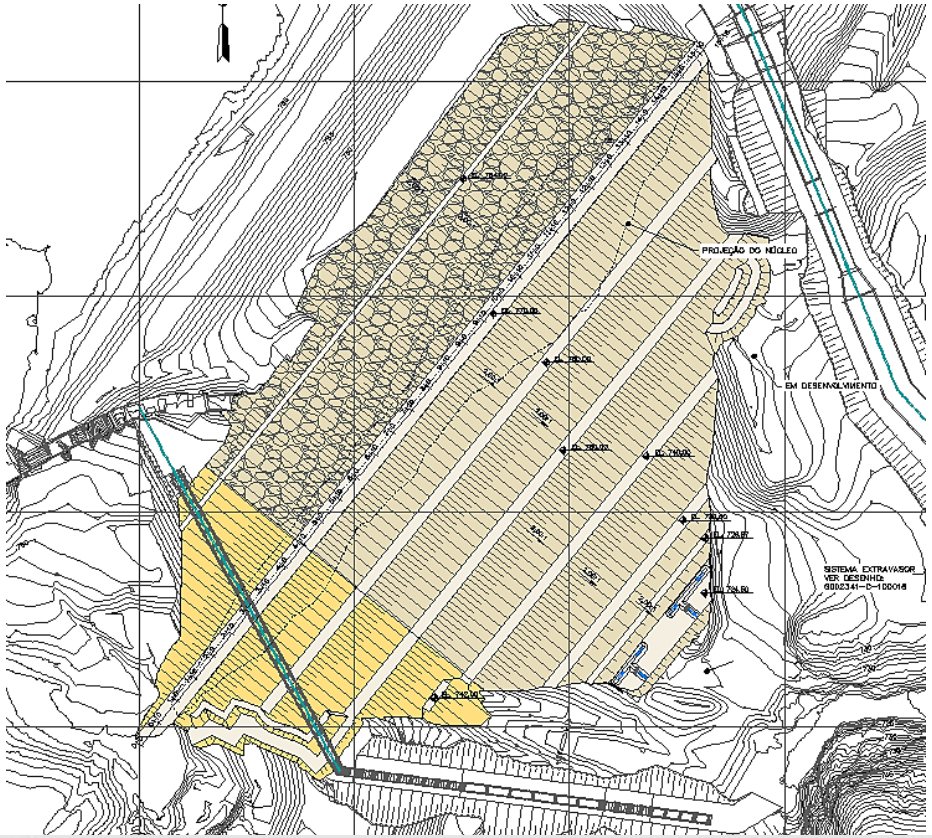
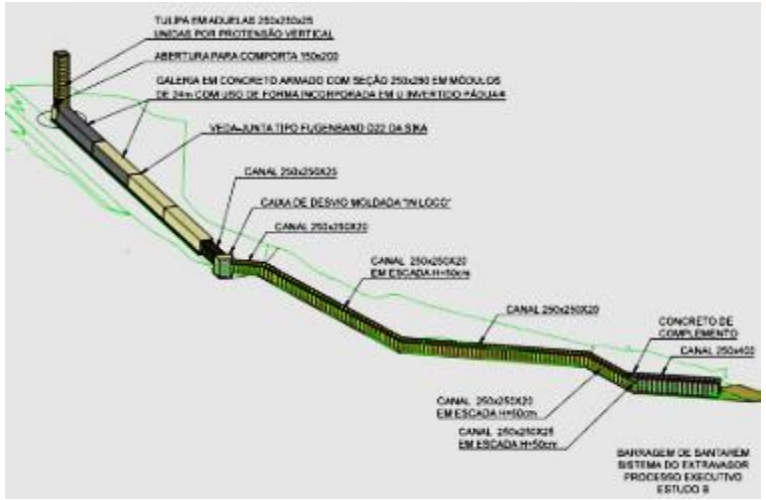
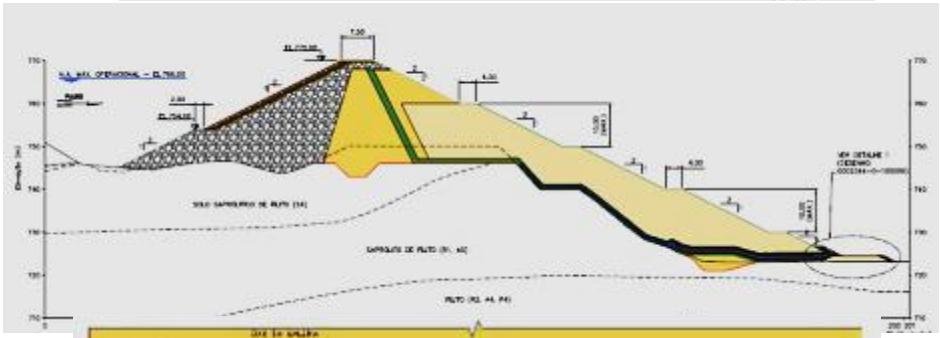
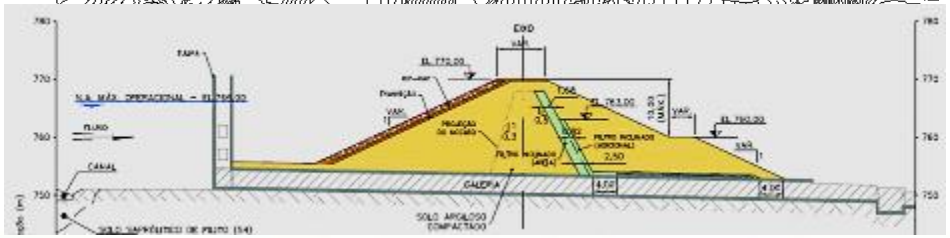
BARRAGEM NOVA SANTARÉM

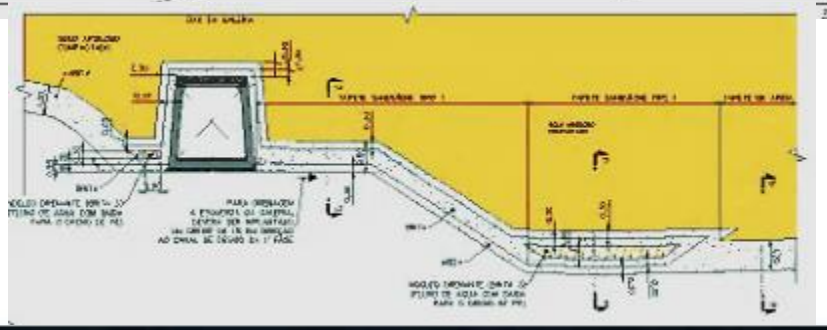
PROJETO











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BARRAGEM NOVA SANTARÉM

OBRAS (CONCLUSÃO EM JUL/2017)

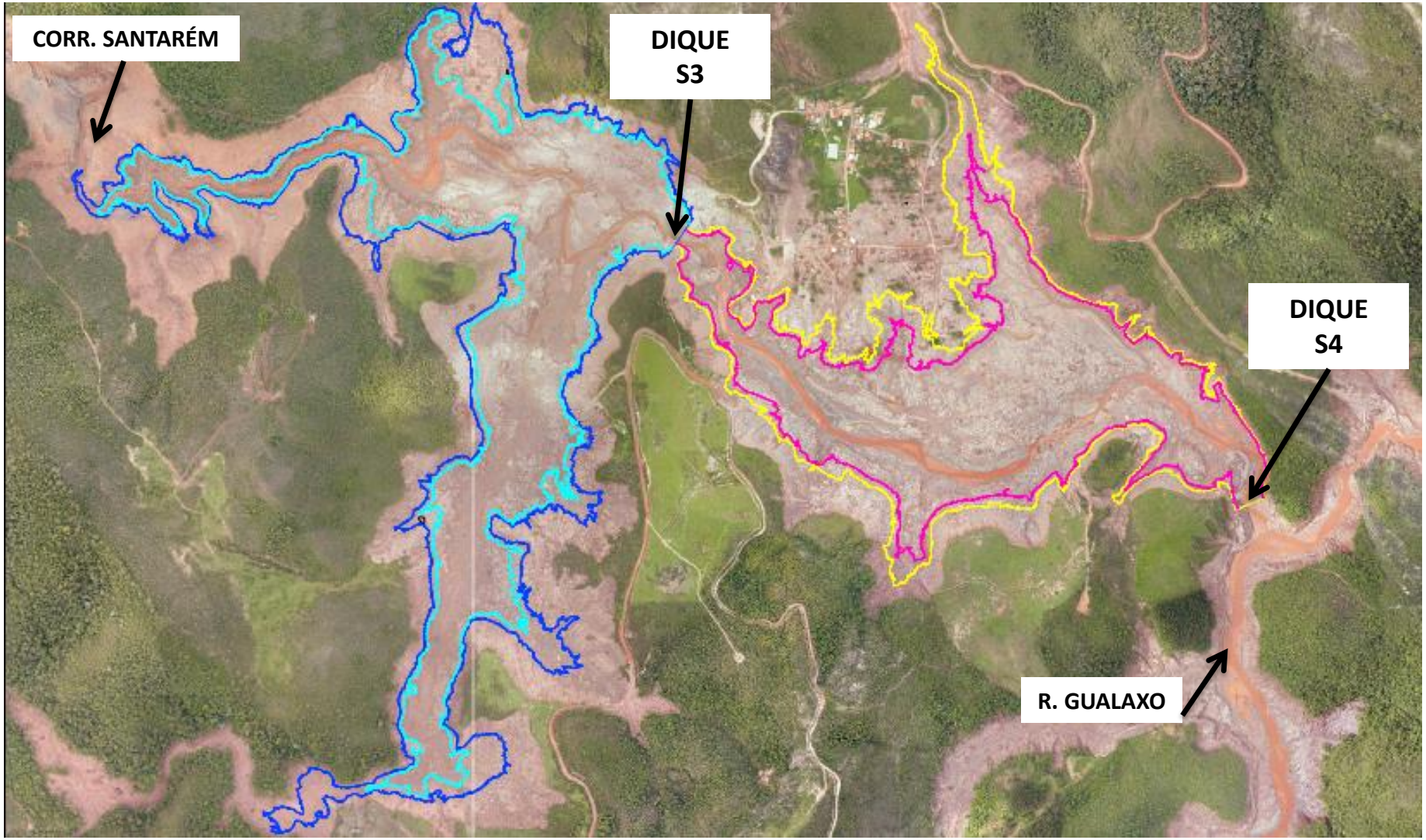
NOVA SANTARÉM
OUTUBRO 2017

NOVA SANTARÉM
OUTUBRO 2017

DIQUES S3 e S4

DIQUES S3 e S4

LOCALIZAÇÃO



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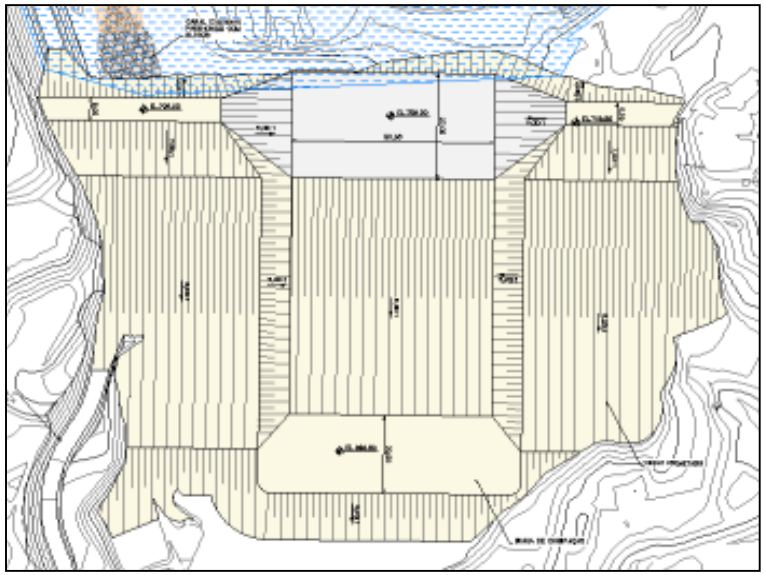
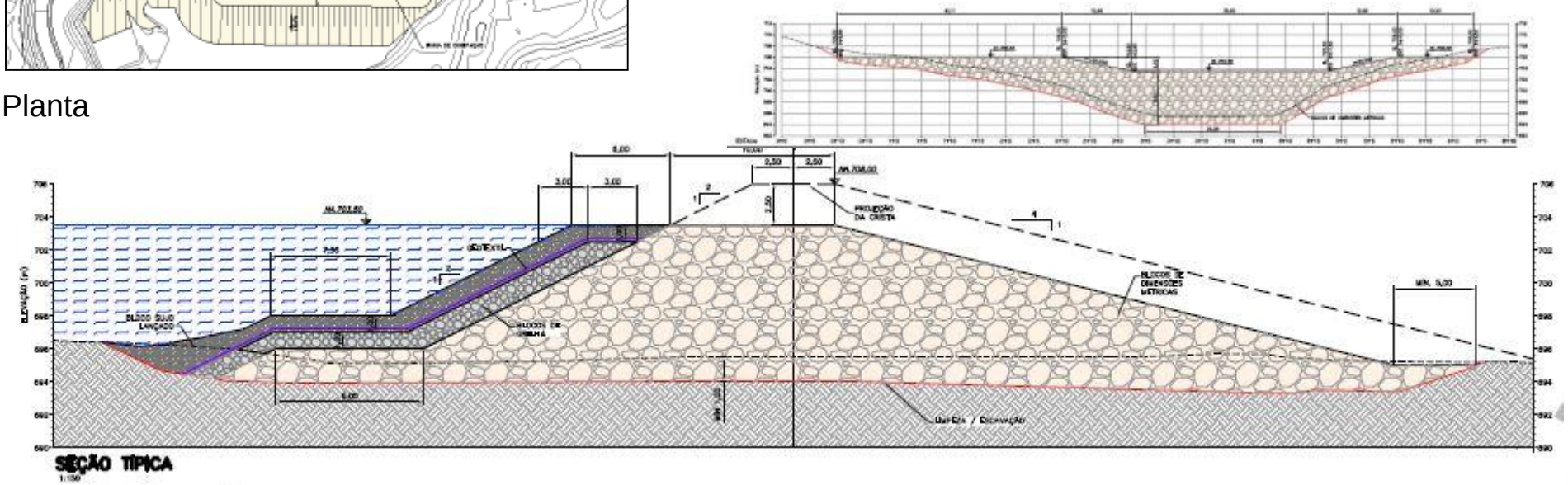
DIQUE S3

PROJETO E CONSTRUÇÃO 2 FASES

Geometria	
Altura Total	**14,5m**
Elevação da Crista	709,50m
Volume do Maciço	± 70.000m³
Elevação da Soleira do Vertedouro	706,00m
Altura do Vertedouro	3,5m
Largura do Vertedouro (PMP)	50,0m
Volume do Reservatório	**2,95Mm³**



Planta



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DIQUE S3

OBRAS (DEZ/2016 A MAR/2017)

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DIQUE S3

OUTUBRO 2017

Alteamento final concluído em Novembro de 2016

DIQUE S4

DIQUE S4
LOCALIZAÇÃO

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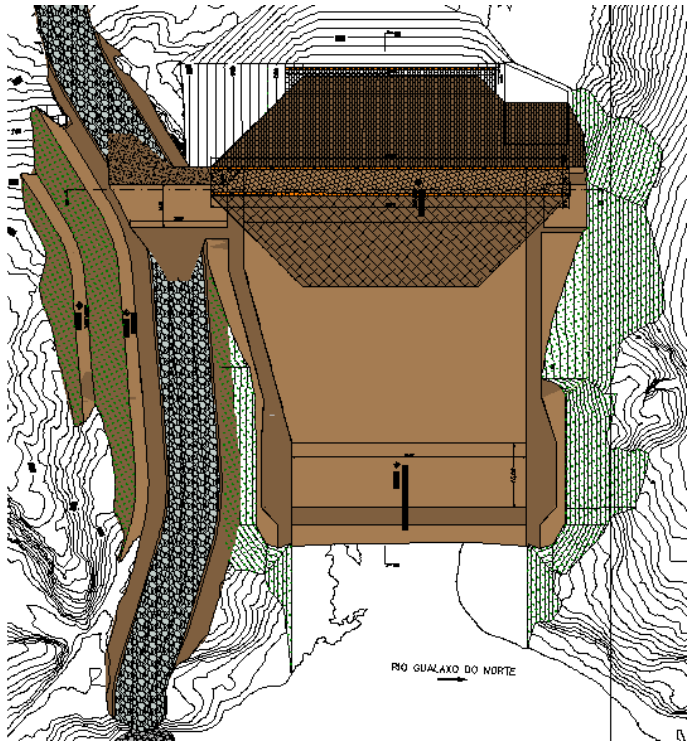
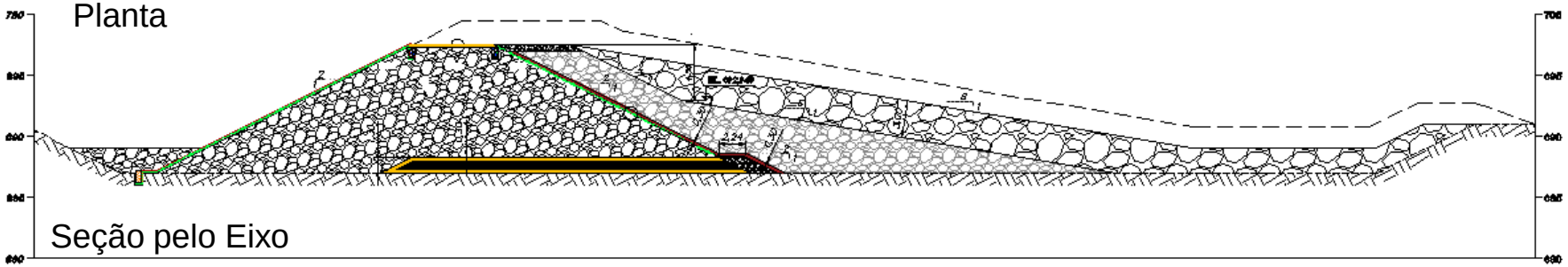
DIQUE S4

PROJETO



Planta

GEOMETRIA	
Altura Total	**10,5m**
Elevação da Crista	699,50m
Volume do Maciço	± 45.000m³
Elevação da Soleira do Vertedouro	697,50m
Altura do Vertedouro	2,00m
Largura do Vertedouro (PMP)	65,0m
Volume do Reservatório	**1,05Mm³**



Seção pelo Eixo

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DIQUE S4

OBRAS (OUT/2016 A JAN/2017)

DIQUE S4

Concluído em Janeiro de 2017

Quantidades		
Item	**Unit**	**Volumes**
LIMPEZA DE FUNDAÇÃO	m^3	75,545
BLOCOS DE ENROCAMENTO E BLOCOS COM FINOS	m^3	52,535

DIQUE S4

OUTUBRO 2017

DIQUE S4

OUTUBRO 2017

DIQUE S4

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VERIFICAÇÕES DE ESTABILIDADE

CRITÉRIOS DE PROJETO

FATORES DE SEGURANÇA ADMISSÍVEIS

Análise	Condição	Brasil (ABNT) 2006	Brasil (ABNT) 2017	Canada (CDA)	Austrália (Ancold)
Final de Construção	Antes do enchimento do reservatório	1,3	1,3	1,3	1,3
Longo Prazo	Condição permanente de fluxo	1,5	1,5	1,5	1,5
Rebaixamento Rápido	Carregamento e descarregamento rápidos	1,1	1,1	1,2-1,3	-
Nível freático crítico	Considera PMP	1,3	1,3	-	-
Sísmica	Pseudo-estática	-	1,1	1,0	
	Pós Terremoto/Pós liquefação	-	-	1,2	1,0-1,2

CRITÉRIOS ADOTADOS PELA SAMARCO

FATORES DE SEGURANÇA ADMISSÍVEIS

Análise	Condição	Brasil (ABNT) 2006	Brasil (ABNT) 2017	Canada (CDA)	Austrália (Ancold)
Final de Construção	Antes do enchimento do reservatório	1,3	1,3	1,3	1,3
Longo Prazo	Condição permanente de fluxo	1,5	1,5	1,5	1,5
Rebaixamento Rápido	Carregamento e descarregamento rápidos	1,1	1,1	1,2-1,3	-
Nível freático crítico	Considera PMP	1,3	1,3	-	-
Sísmica	Pseudo-estática	-	1,1	1,0	
	Pós Terremoto/Pós liquefação	-	-	1,2	1,0-1,2

AVALIAÇÃO DA ESTABILIDADE
FRENTE À LIQUEFAÇÃO

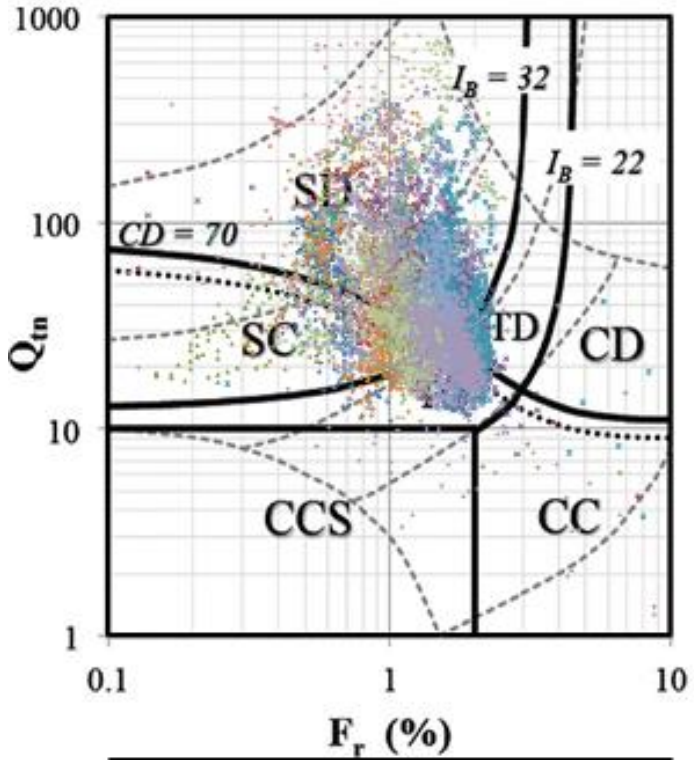
Etapas de Avaliação:

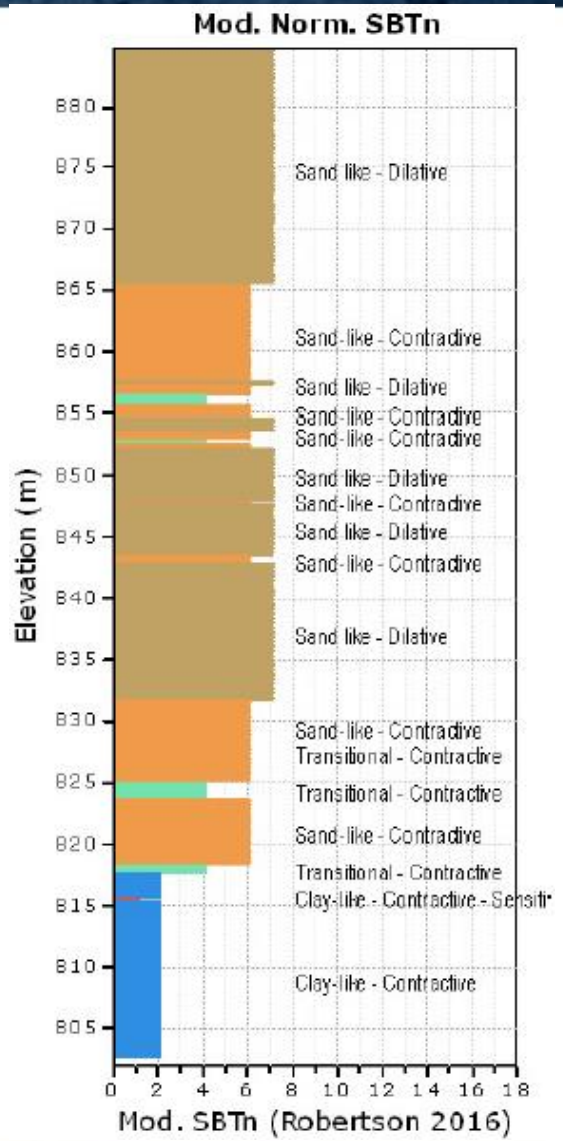
1. **Análise da susceptibilidade ou potencial do solo à falha por liquefação** – Determinação das zonas com potencial de liquefação mediante a caracterização do comportamento dos materiais sob cisalhamento (contrátil ou dilatante), através da execução de CPTUs e/ou SPTs.
2. **Análise do gatilho da liquefação** – Avaliar a possibilidade das tensões cisalhantes atuantes excederem ou não a resistência ao cisalhamento de pico dos solos suscetíveis à liquefação (durante um abalo sísmico, carregamento, subida do nível de água).
3. **Análise de estabilidade liquefeita ou pós gatilho** – Análise de estabilidade por equilíbrio de limite convencional considerando a resistência liquefeita do material contrátil.

Como critério de projeto a Samarco definiu avaliar sempre as etapas 1 e 3.

SUSCEPTIBILIDADE - ROBERTSON

A suscetibilidade à liquefação é avaliada com base no tipo de comportamento e sistema de classificação atualizados de Robertson 2016 (SBTn).





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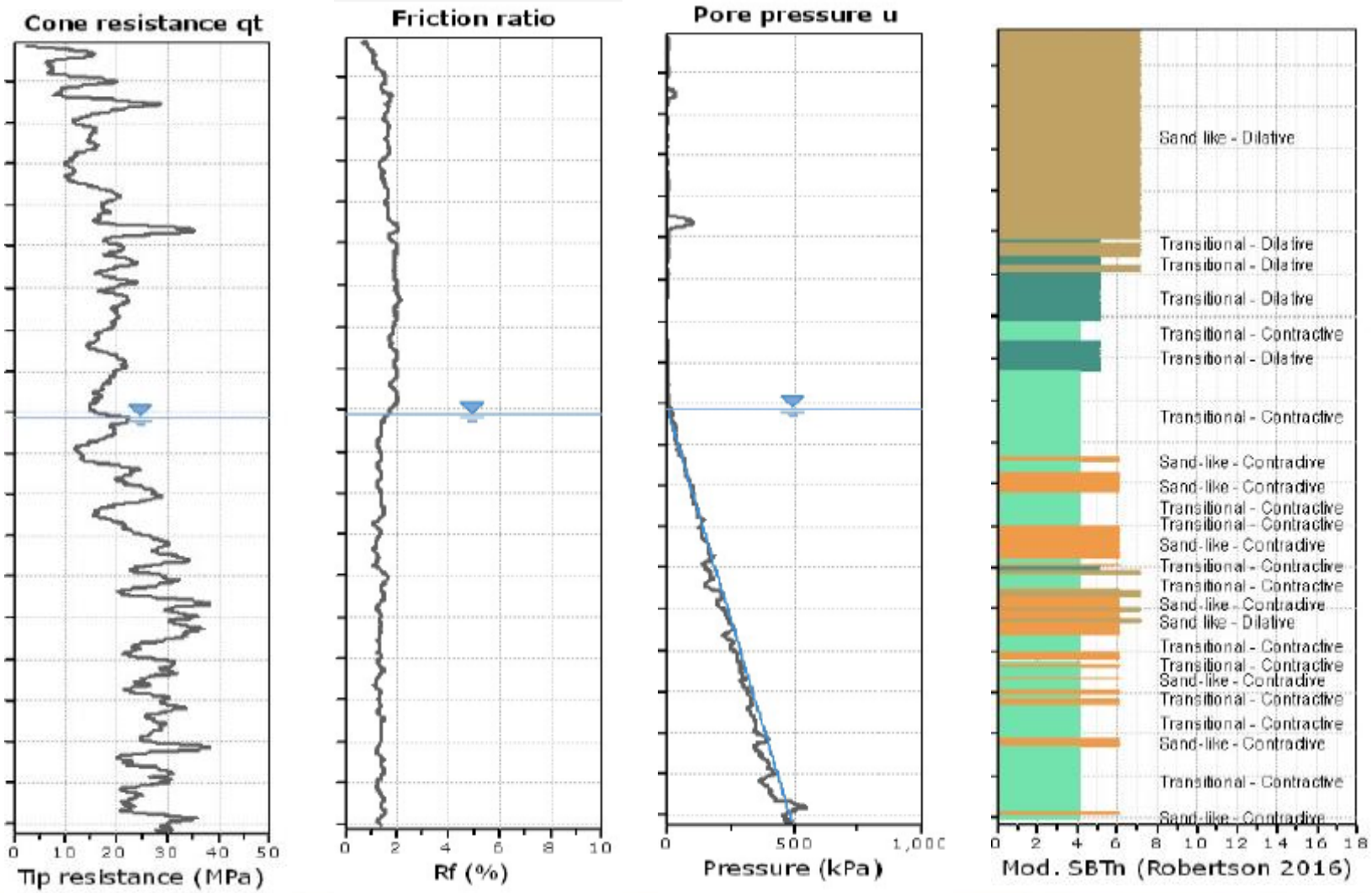
DEFINIÇÃO DAS ZONA SUSCEPTÍVEIS

Experiência Samarco:

- CPTUs de quase 100 metros de profundidade;
- Zona contrátil acima do nível de água;
- Comportamento contrátil em regiões de altos níveis de tensão (ou grandes profundidades)

DEFINIÇÃO DAS ZONA SUSCEPTÍVEIS



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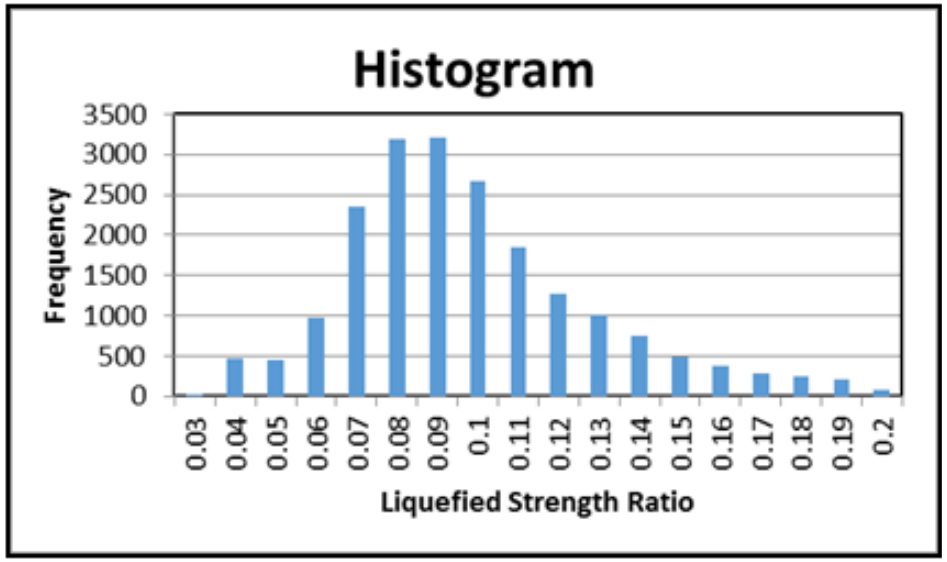
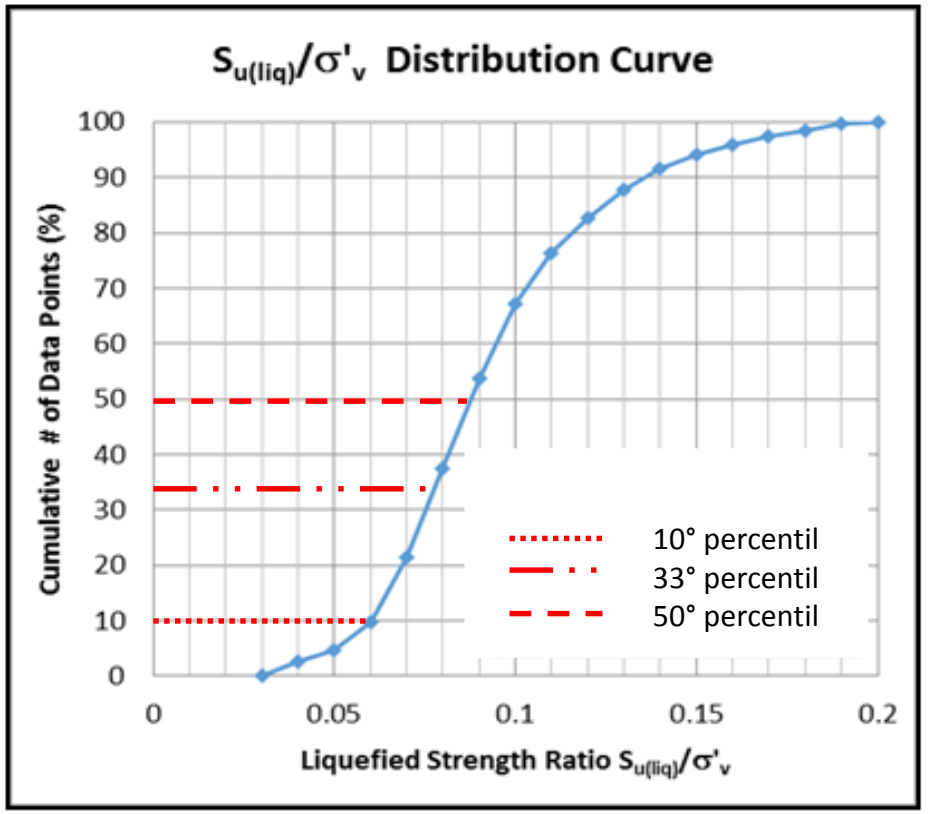
DEFINIÇÃO DAS ZONA SUSCEPTÍVEIS

Para definição da resistência liquefeita dos materiais são utilizadas as metodologias de Olson (2002) e Robertson (2010).

A Samarco realiza análises de sensibilidade utilizando os percentis de 10%, 33% e 50%.

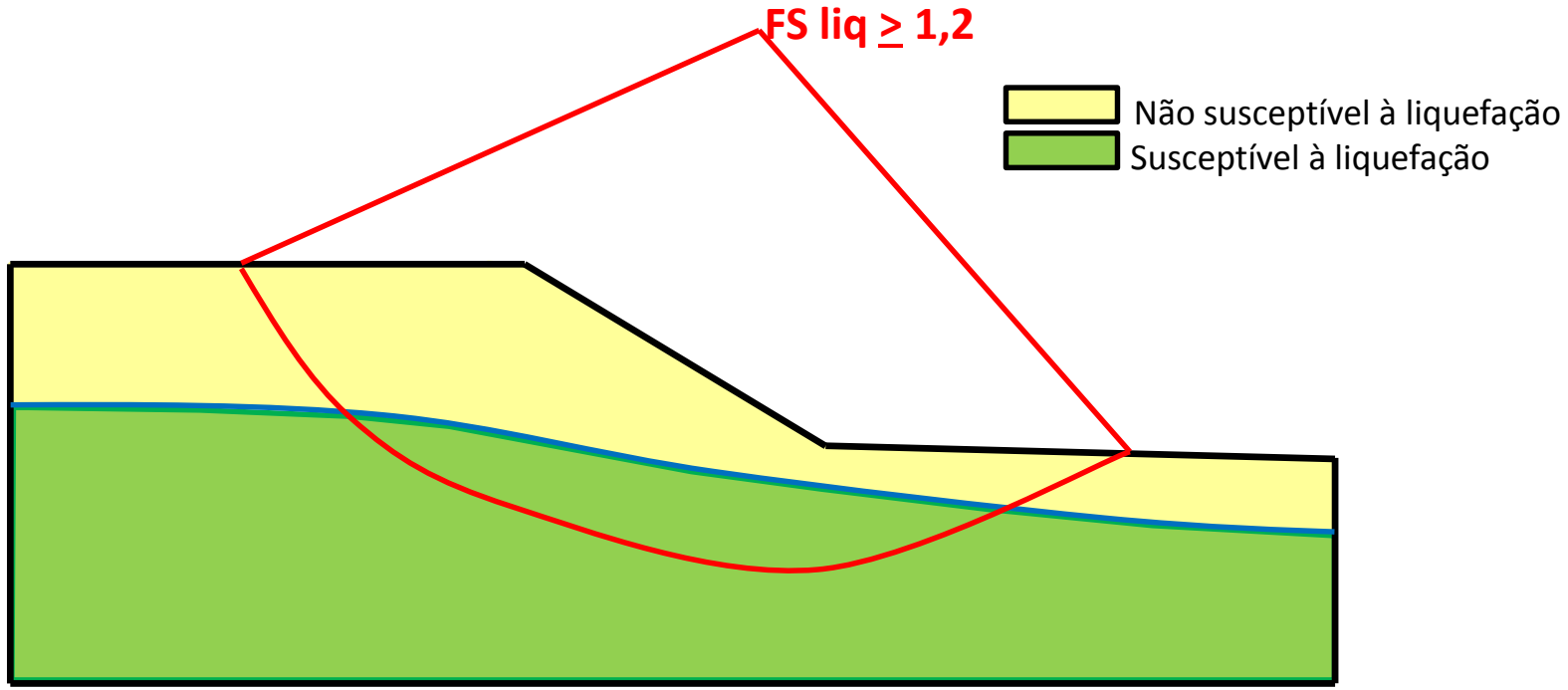




CONDIÇÕES ANALISADAS

NÍVEL DE ÁGUA

1. Combinação dos dados atuais do monitoramento e das investigações (SPT e CPTU);
2. PMP-Precipitação máxima provavel;
3. Nível freático crítico definido a partir do histórico dos intrumentos e das camadas susceptíveis à liquefação acima do N.A. atual, PMP;
4. Colmatação parcial do sistema de drenagem interno (avaliação da margem de segurança e para o descomissionamento das estruturas)



CONCLUSÕES

Verificação da Estabilidade à Liquefação

- Avaliação da susceptibilidade à liquefação (Robertson e Olson)
- Estratigrafia de acordo com resultados de CPT
- Nível d´água definido através de instrumentos e CPT
- Verificação de eventual zona contrátil acima do N.A.
- Análise de estabilidade com parâmetros de resistência liquefeita associados ao 10° percentil (com análise de sensibilidade para os percentis 33 e 50)
- Análises circulares e planares, rasas e profundas
- Atendimento aos critérios de projeto estabelecidos pela ABNT e CDA
- FS mínimo > 1.2 (pós-liquefação c/ NA medido nos instrumentos e no CPT)
- FS mínimo > 1.1 (considerando a zona contrátil acima do NA e sismo)

Seminário – ”Avanços Tecnológicos para a Gestão de Barragens de Mineração”

13 de dezembro de 2017

100.000 employees

7 continents
+ than 150 countries

No. 343

Fortune 500

$19.5bi

US Dollar in 2015

#1

World's Largest
Engineering Company

Industry Leading Tailings Expertise

More than 300 tailings projects completed worldwide

- Delivering engineering and environmental solutions in designing, monitoring and managing tailings and waste products
- No other high-risk geotechnical structure offers more competing objectives and challenges than mine tailings embankments

Representative Services

- Design: Geotechnical, Civil, Infrastructure
- Construction
- Stewardship
- Water Management
- Training
- Emergency Preparedness
- Risk Management

Sample Project Experience

Tailings Stewardship Program and Training

Client: Confidential Client, the Americas

Developed and implemented a tailings stewardship program for a large copper and molybdenum company.It successfully identified potential risks and reduced overall O&M costs. The program also included the implementation of training for operators and engineers for the TSFs, and introduced design, construction, and management components of TSFs. The client saw a reduction in liabilities and a standardized approach to the operation of tailings facilities across all operations. The program continues to grow and expand, and minimize the long-term risks associated with the tailings storage.

Andina Tailings Stability and Non-Conventional Tailings Disposal Options

Client: CODELCO Chile, Saladillo Chile

Completed an engineering evaluation of tailings discharge and management operations and TSF stability, and a prefeasibility evaluation of alternatives for non-conventional tailings disposal at the Andina Mine in the Andes Mountains to determine if non-conventional tailings disposal methods may be feasible. Reviewed worldwide, non-conventional tailings technologies and their environmental impacts including filtered, thickened tailings and dry tailings; contacted mines and suppliers to identify those with relevant experience; and identified equipment currently used.

Tailings and Water Stewardship Program

Client: Coeur Mining, Bolivia, Mexico, and AK

Developed a stewardship program with management at Coeur Mining in 2012. The program was implemented at the operating facilities with TSF and water dams in Bolivia, Mexico, and Alaska. The program consisted of developing a baseline of guidelines for managing the tailings. The guidelines stipulated specific operational requirements, documentation, training, and updates. A team from Coeur and AECOM conducted site visits to the facilities and met with staff to understand ongoing risks and operational management, procedures, and risk challenges.

Tailings Dam Operation, Maintenance, and Monitoring

Client: Confidential Client, AZ, CO, and NM

Provide ongoing services for monitoring the O&M of existing TSFs in Arizona, Colorado, and New Mexico. Includes monthly and quarterly site visits to review operational procedures, train personnel, inspect and read instrumentation, and provide recommendations for ongoing site activities.

Filtered Tailings Evaluations

Client: Confidential Client, AZ

Developed a conceptual level design for a new filtered TSF (dry stack) at a high production (greater than 100,000 tons per day) copper mine in southern Arizona. This proposed filtered TSF would have a storage capacity of over six billion tons of tailing. Work performed included tailing rheology and pilot-scale thickener testing, a trade-off study to evaluate optimum thickener underflow/filter feed solids concentrations, development of a conceptual infiltration model to estimate foundation seepage, and the development of conceptual designs for the filtered TSF. These conceptual designs included the TSF facility layout, thickener and filter plant layout and equipment selection, conceptual conveyor infrastructure, surface water controls, and other appurtenant facilities. Designs were used to develop a Class 5 estimate of CAPEX, sustaining capital, and OPEX costs.

Tailings Basin Design and Construction

Client: Confidential Client, Minnesota

Providing design and construction services for a tailings basin at the taconite open pit mine and pellet operation. The dam design consists of a phased construction procedure of upstream dike construction to an ultimate elevation capable of storing 35 years of tailings waste. AECOM evaluated the siting, probable tailings deposition, dike construction volumes and probable construction costs, as well as geotechnical aspects of the options.

AECOM

Sample Project Experience

Twelve Abandoned Bolivian Mine Facilities Environmental Audit/Impact Assessment

Client: COMIBOL Corporación Minera de Bolivia and World Bank, Bolivia

Completion of Environmental Audits and Impact Assessments for 12 abandoned surfaces and underground mine facilities considered for privatization or reclamation/closure under Bolivia's mining-sector capitalization and restructuring program. The facilities included open pits, open shafts and portals, tailings and waste rock piles, and venting gases and mine drainage. Activities included site investigations, mapping, sampling, reclamation, and remediation design.

Confidential Mine Risk Assessment

Client: Confidential Client, NM

Provided geotechnical investigation, evaluation, design, and construction oversight services in support of developing a close-out plan for a mine in New Mexico. AECOM evaluated mine rock pile stability, erosion and runoff conditions and designed and constructed several earthen structures (e.g., water control dams, cutoff walls, piping, and earthen covers). Performed a subsidence risk assessment to evaluate risk associated with underground mining. The assessment included comprehensive review of all identified risks associated with this project, including groundwater, surface water, landslide potentials, and impact to lives and environment.

Emergency Action Plan

Client: Confidential Client, Operating properties in AZ, NM, and CO

Developed more than 30 EAPs for both tailings and water dams in the Southwest. This included performing hydrology, estimating dam breach conditioning, and modeling flood inundation. EAPs included procedures for notification chart and emergency response, as well as flood inundation maps. Also involved in the implementation of tabletop activities, which present the information associated with the plans to stakeholders.

North Tailings Impoundment Studies and Engineering

Client: Rio Tinto Kennecott Copper, Utah

AECOM supported Rio Tinto Kennecott Copper in extending the North Tailings Impoundment life. Conducted studies and detailed engineering in support of the north impoundment completion embankment raise as well as modifications to the single point whole tailings discharge and cyclone tailings delivery systems. The projects included embankments and pipeline support berms, additional tailings delivery overland pipelines, drop boxes, upset condition provisions, modifying the cyclone and choke stations, interconnecting pipe systems, and embankment elevations modifications. Study and engineering activities for the tailing system consisted of final feasibility and detailed engineering for the process; hydraulic flow and transient analyses of pipelines and computational fluid dynamics modeling of pump feed sumps; mechanical, piping, structural, electrical, and instrumentation and controls system. Study and engineering activities for the elevation modifications consisted of civil, geotechnical and structural conceptual through detailed engineering. Extended tailings impoundment capacity up to an additional 6 years.

TSF Conceptual-Design

Client: Camino Rojo Mine, Zacatecas, Mexico

Developed conceptual-level designs for a TSF at the proposed greenfield Camino Rojo mine in northeastern Zacatecas, Mexico. Four methods of construction were evaluated including a rockfill embankment, cyclone underflow embankment, dry stack, and a tailings and waste rock co-disposal facility. Developed a conceptual-level facility design and cost estimate for each method. The evaluations for each method included a high-level siting study and design of major components, such as the embankment, underdrain systems, tailing delivery and deposition system, reclaim water system, and power distribution. The results of the conceptual-level designs were used to evaluate the most cost effective construction method.

AECOM

Summary

- Since April 2016 a team of international specialists with significant experience in response to natural and mining disasters from AECOM has conducted monthly Independent Dam Safety and Stability Audit on behalf of the Ministério Público de Minas Gerias
  - Christina Winckler, John Bove, Claudius Maranhão and Diego Gomez – geotechnical;
  - Casey Robertson, John Sikora and Ned Andrews – hydrology, hydraulics, sediment transport and river mechanics;
  - Monica Menezes – geology;
  - Vicente Mello – risk management and planning
  - Tat Ebihara and Ray Rinkle – environment restoration;
  - Richard Davidson, Ed Toms and Bill Bow – overall QA/QC;

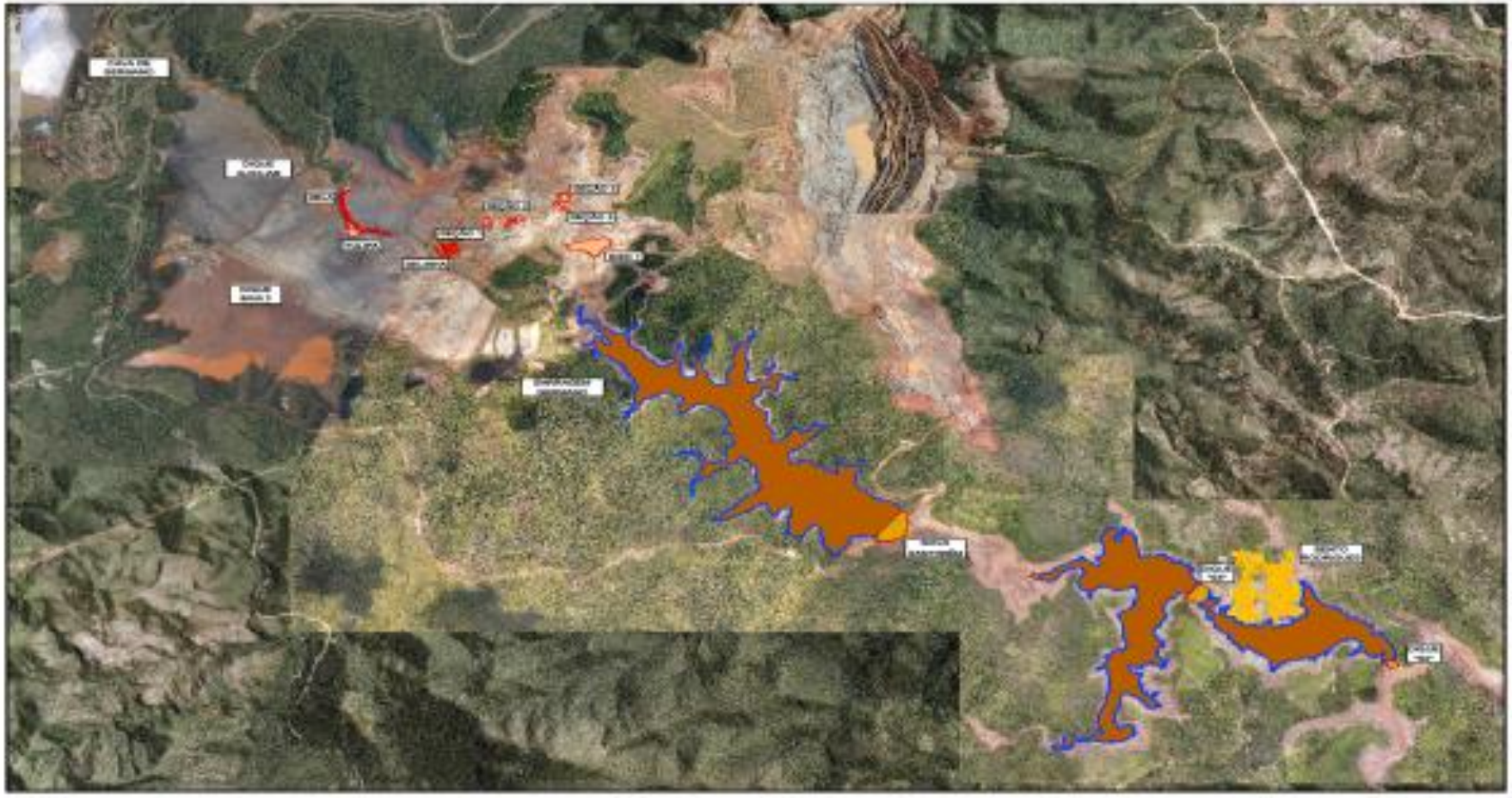
The monthly audit encompass

- Field visit to inspect all structures;
- Meetings with the designers responsible for the structures:
  - Germano dam;
  - New Santarém dam;
  - Sela, Tulipa and Selinha dikes;
  - S3 and S4 dikes;
  - Water management system.
- Meetings with the Samarco’s engineering, construction, monitoring and operations teams;
- Presentation to the Ministério Público de Minas Gerais.

Since the start of the Independent Audit

- AECOM has being on the Germano Complex site more than 20 times;
- We have received and reviewed around 5,000 documents;
- Submitted 28 audits reports:
  - Germano Complex;
  - Eixo 1 dam;
  - Candonga;
  - Tailings Management Plan;
  - S4 dike.

Germano Complex – Tailings Dam Management System



Germano Complex – Tailings Dam Management System

- Reinforce and recuperate remaining structures:
  - Germano main dam;
  - Sela, Tulipa and Selinha dikes;
  - S3 dike.
- Build new structures:
  - New Santarém dam;
  - S4 dike.
- Separate water from tailings:
  - Change the drainage to avoid water going into the Fundão Valley;
  - Bay 3 water pumping system.

Germano Main Dam – Upper slope

Germano main dam – toe

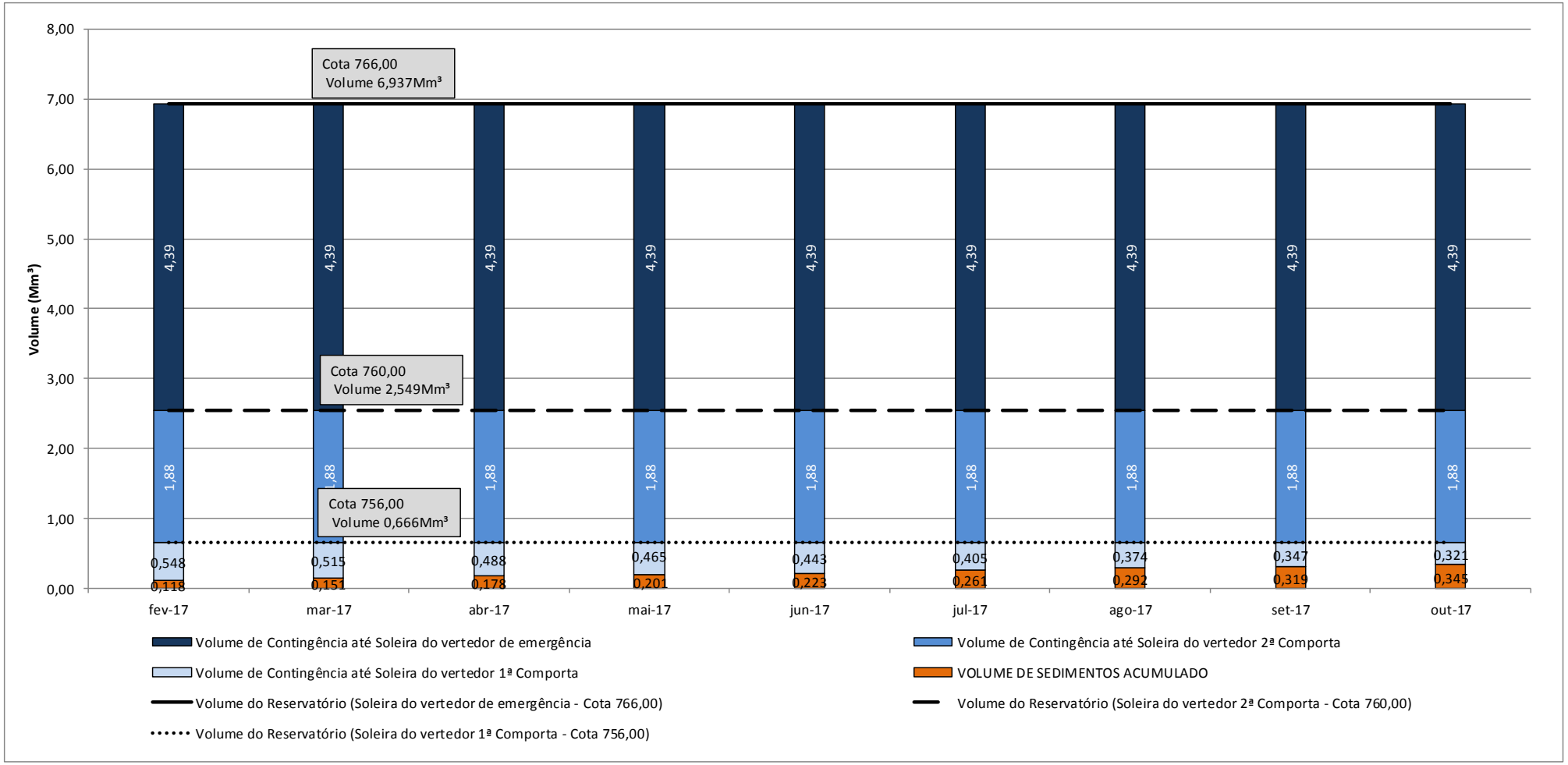
Sela and Tulipa dikes

Selinha Dike

New Santarem Dam

New Santarem Dam

Bathymetric Survey – New Santarem



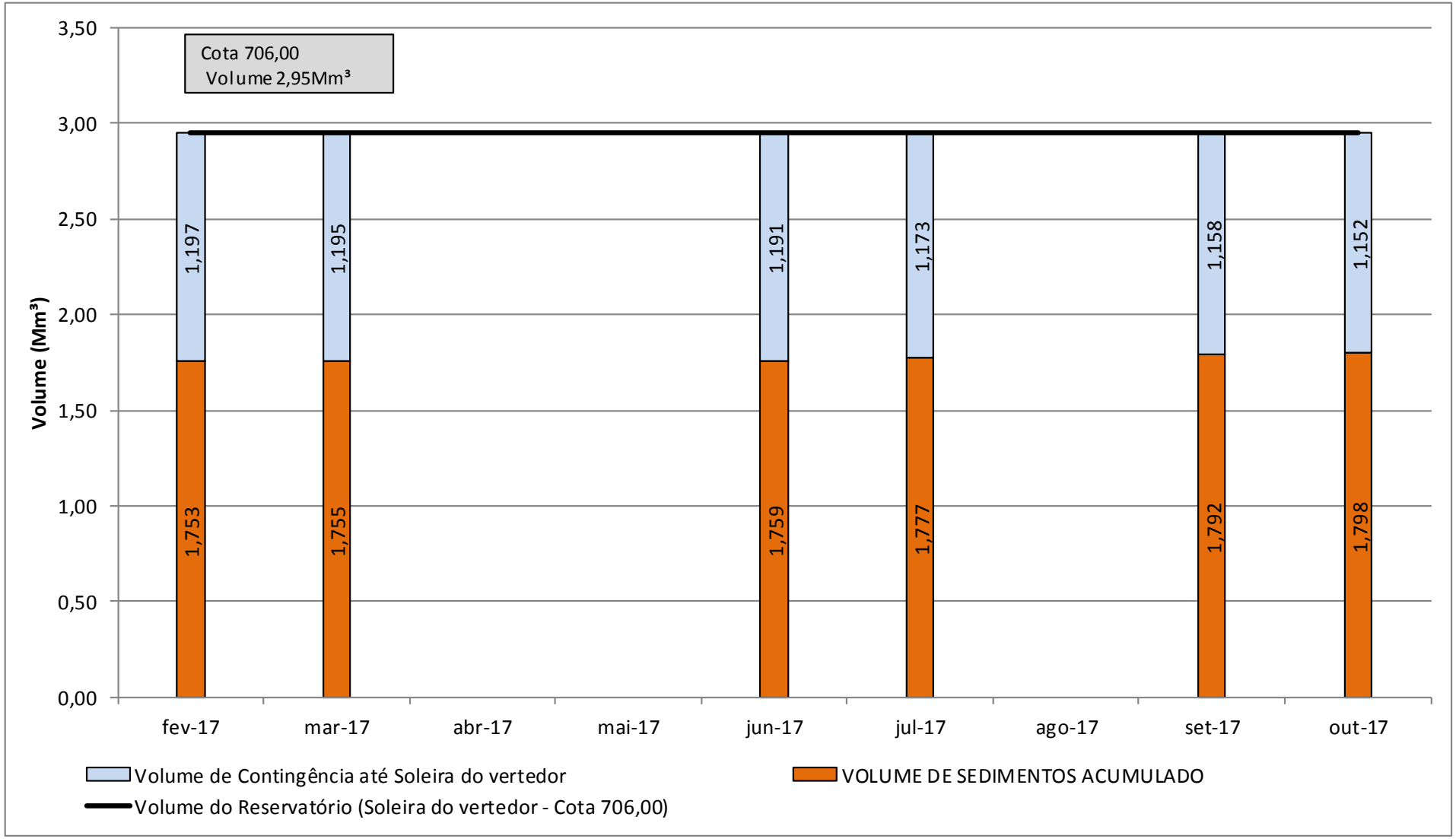
Entre 20/09 e 31/10 assoreamento aproximado de 26.000 m³.

Volume total assoreado de 345.000 m³.

Crest of Dike S3

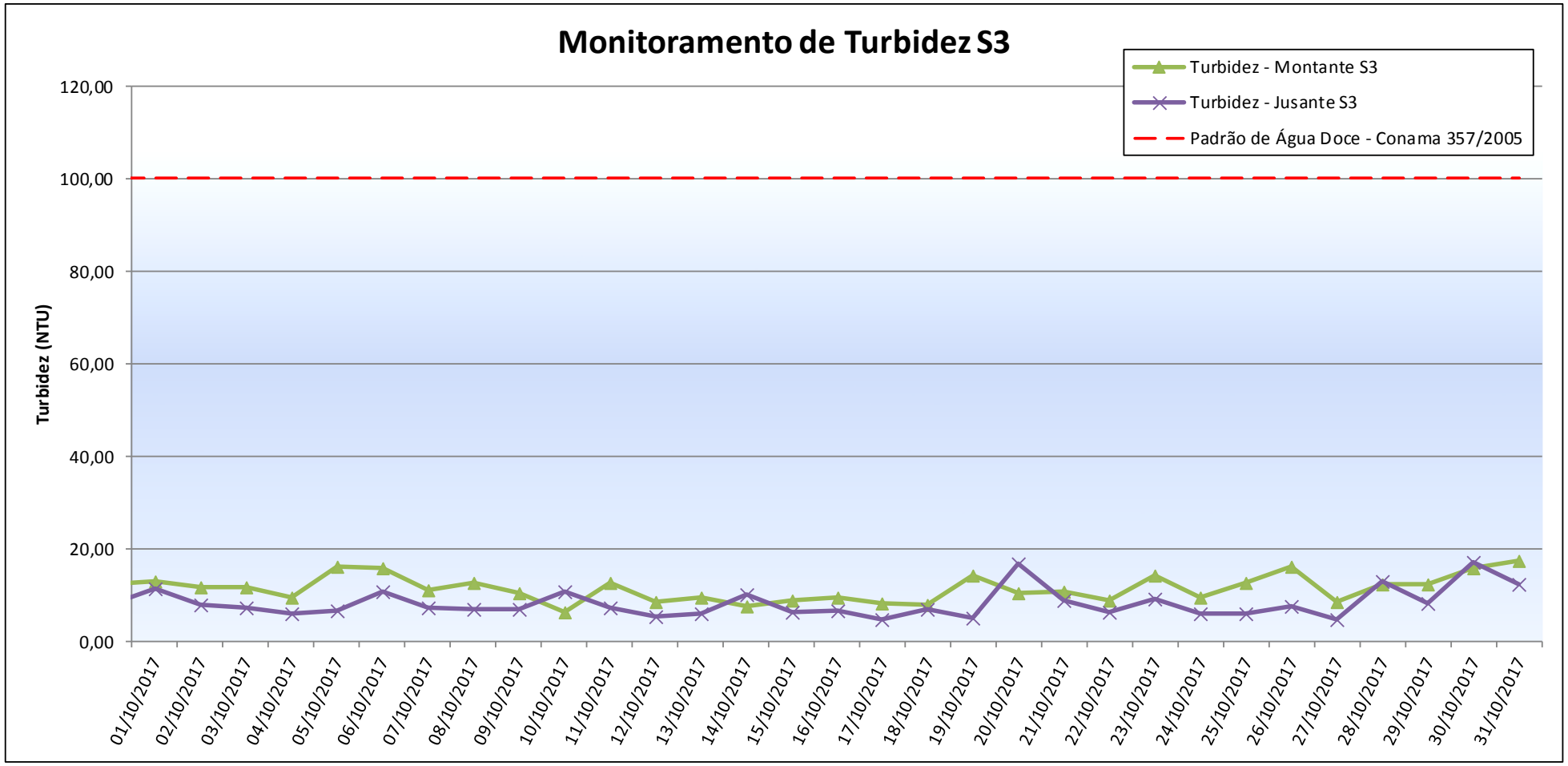
Water quality – crest of Dike S3, November 19th

Bathymetric Survey, S3



Evolução do assoreamento da ordem de 6.000 m³ entre setembro e outubro/17.

Turbidity Measurements, S3



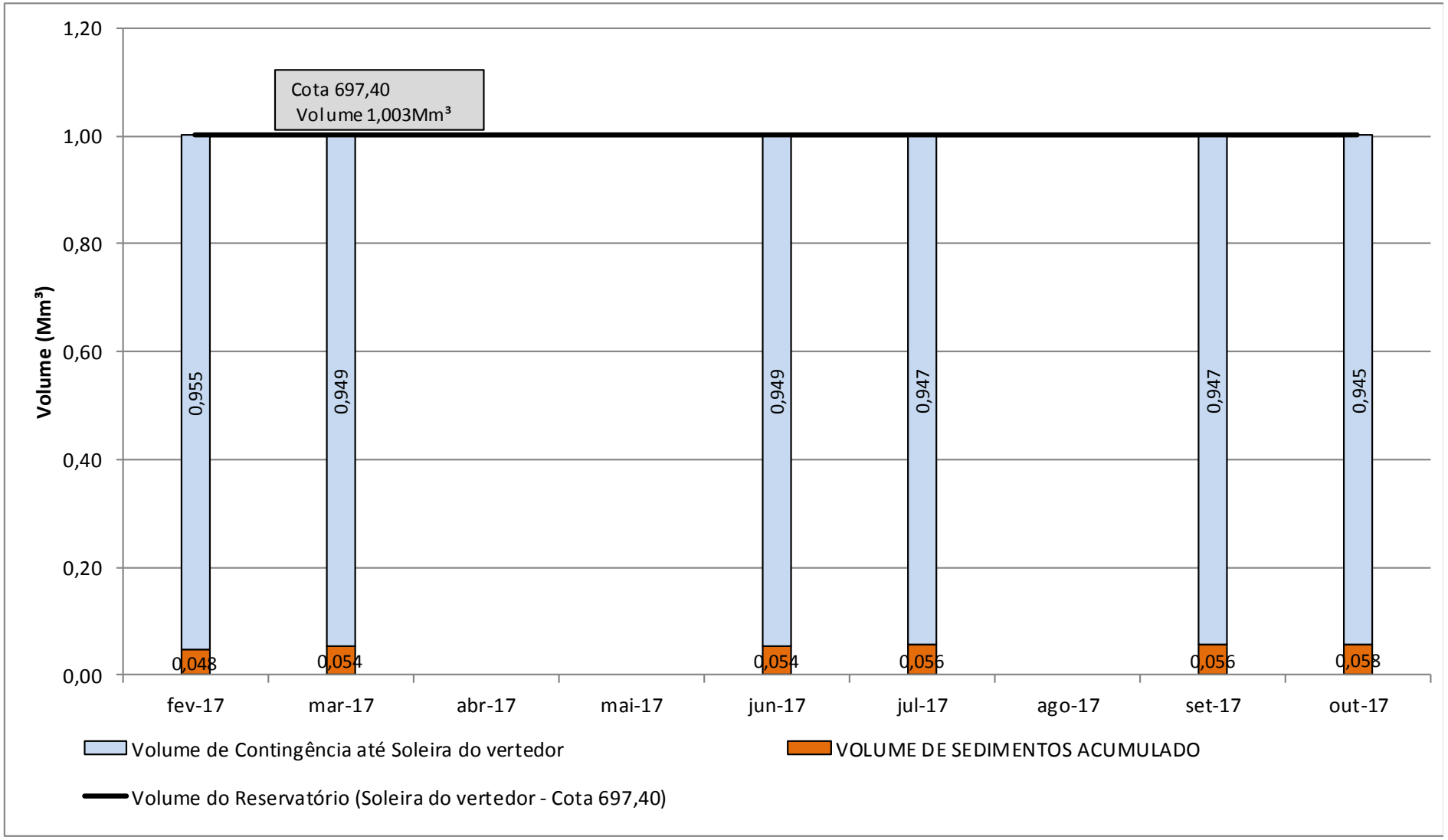
Dike S4

Confluence of Santarem creek and Gualaxo do Norte

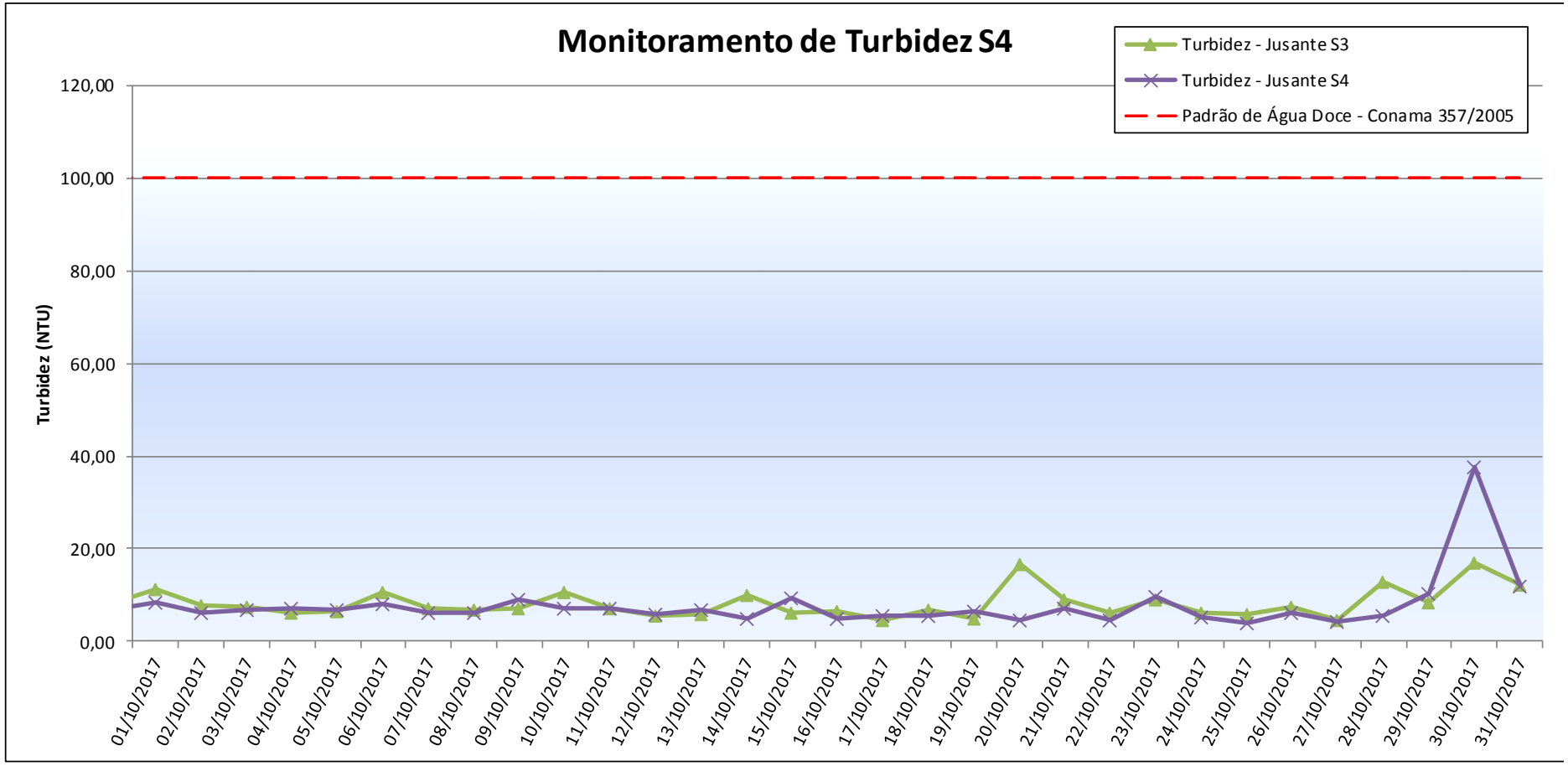
January 11th after
22 mm of rain

November 19th
after 39 mm of rain

Bathymetric Survey, S4



Turbidity Measurements, S4

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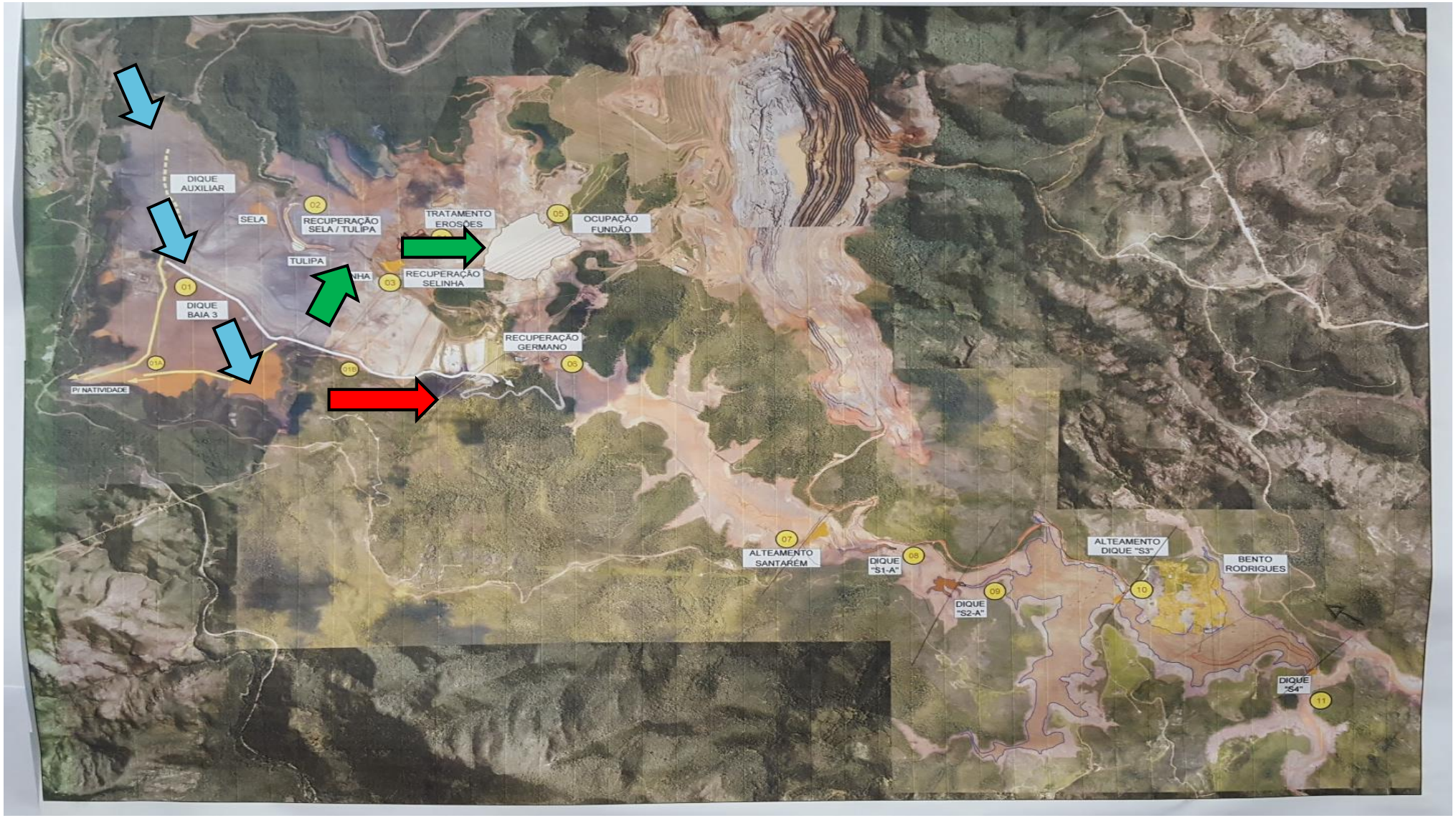
Water Diversion and Management System



Pump station of Baia 3 Dike

Conclusion remarks

- Factors of Safety:
  - Since November 2016 the factors of safety for the structures have been above 1.5 (for the long term drained loading condition):
    - Germano main dam;
    - Sela, Tulipa and Selinha dikes;
    - Santarém dam.
- Sediment management:
  - The bathymetric surveys on New Santarém, S3 and S4 minor sediment transport
- Water quality:
  - The turbidity measurements at S3 and S4 show good water quality

Obrigado

Formal Scope from the MPMG

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M-1037299927

Autos nº 6132918-29.2015.8.13.0024
Autores: MINISTÉRIO PÚBLICO DO ESTADO DE MINAS GERAIS e ESTADO DE MINAS GERAIS
Réus: SAMARCO MINERAÇÃO S/A e CONSÓRCIO CANDONGA

O **MINISTÉRIO PÚBLICO DO ESTADO DE MINAS GERAIS e ESTADO DE MINAS GERAIS** vem, em cumprimento à cláusula 6, parágrafo segundo do termo de acordo judicial celebrado em 06/02/2016 apresentar à **SAMARCO MINERAÇÃO S/A** o escopo da auditoria técnica independente para acompanhar e fiscalizar as medidas de reparo e reforço das estruturas de diques e barragens remanescentes do Complexo de Germano:

- **Inspeção dos locais**, avaliando cada dique e barragem, sua fundação, dispositivos de descarga, reservatório, áreas imediatamente a jusante, instrumentação e as vias de acesso.
- **Verificação dos projetos, da construção, dos reparos e reforços**, com suficiente detalhamento, para poder

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certificar se os maciços, estruturas extravasoras e taludes do reservatório satisfazem todos os requisitos de segurança atualmente aplicáveis. Deve-se avaliar, também, se as premissas de projeto estão sendo respeitadas, na medida em que as condições atuais das barragens no nível de "como construída", são registradas.

- **Conferência da documentação das estruturas**, avaliando se a documentação existente atende ao previsto no Plano de Segurança de Barragens (Lei 12.334/ 2010 e Portaria DNPM No 416) e nas Deliberações Normativas do COPAM (DNs 62/2002 e 87/2005), além de ser suficiente para orientar, em todos os aspectos, os procedimentos seguros de operação.
- **Verificação da capacidade dos sistemas extravasores**, assegurando que as estruturas estão aptas a descarregar seguramente as vazões de projeto e de forma adequada, incluindo as bordas livres previstas em projeto. Identificar para quais tempos de recorrência eles estão dimensionados.
- **Análise da estabilidade e adequação estrutural**: em relação aos aspectos que envolvem percolação de água pelo maciço, recalques, escorregamentos e erosão de todas as partes dos barramentos, incluindo-se suas fundações, bem como, quaisquer barreiras naturais sob condições de carregamentos, normais e extremos. Identificar os Fatores

de Segurança mínimos das barragens, quanto à estabilidade geotécnica.

- **Verificação da susceptibilidade à liquefação, dos materiais que compõem o maciço e a fundação**. Em caso de identificar a susceptibilidade à liquefação, realizar a análise de estabilidade, definindo o Fator de Segurança em relação a este fenômeno e estabelecer as condições para manutenção da segurança da barragem.
- **Avaliação das condições nas quais as estruturas se encontram**, em todos os aspectos necessários para a manutenção da segurança, principalmente naqueles previstos no Manual de Operação de cada barragem (por exemplo: as cotas das superfícies da lama e dos rejeitos granulares - níveis dos reservatórios; o comprimento da praia a montante do barramento e a borda livre operacional).
- **Verificação do estado de conservação das instalações necessárias à segurança da barragem**, inclusive sua instrumentação, de acordo com os requisitos de manutenção definidos no Manual de Operação de cada estrutura.
- **Análise dos resultados do monitoramento**, avaliando se os métodos e a frequência de observação e monitoramento são adequados e suficientes para se detectar qualquer condição de anomalia ou instabilidade em função do tempo. Observar se os dados de monitoramento foram

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regularmente analisados e usados e se não apontam qualquer condição potencialmente insegura na barragem, relativa aos níveis d'água e dos taludes do reservatório.

- **Atualização das premissas adotadas para eventos extremos**, considerando enchentes e sismos para os quais as barragens estão projetadas e levando-se em conta qualquer evento extremo que possa ter ocorrido desde a implantação das barragens.
- **Avaliação do Plano de Ação Emergencial existente**, verificando se existe um nível apropriado de preparação para emergência, e se estes preparativos estão adequadamente documentados.
- **Comparação com auditorias anteriores**: revendo relatórios anteriores de auditoria de segurança, a fim de se determinar sua concordância com as boas práticas de engenharia.
- **Análise dos possíveis Modos de Falhas de cada estrutura** e riscos relacionados aos modos de falhas;
- **Recomendações** dos auditores para mitigar riscos, acompanhado de 'cronograma para implantação das medidas recomendadas.
- **Registro de restrições operacionais**, caso sejam necessárias.
- Outras observações e análises que os auditores entenderem convenientes

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A partir do recebimento da presente manifestação pela SAMARCO MINERAÇÃO S/A, o MINISTÉRIO PÚBLICO aguarda o prazo máximo de 15 (quinze) dias para que a COMPROMISSÁRIA apresente uma empresa independente e com notório reconhecimento para a realização da auditoria técnica, nos termos da cláusula 6, paragrafo primeiro, do termo de Acordo.

Belo Horizonte, 14 de março de 2016.

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