THE INTERNATIONAL ENERGY AGENCY TECHNOLOGY COLLABORATION PROGRAMME ON HYDROPOWER

IEA Hydropower

Joint ANNEX IX and XII Workshop
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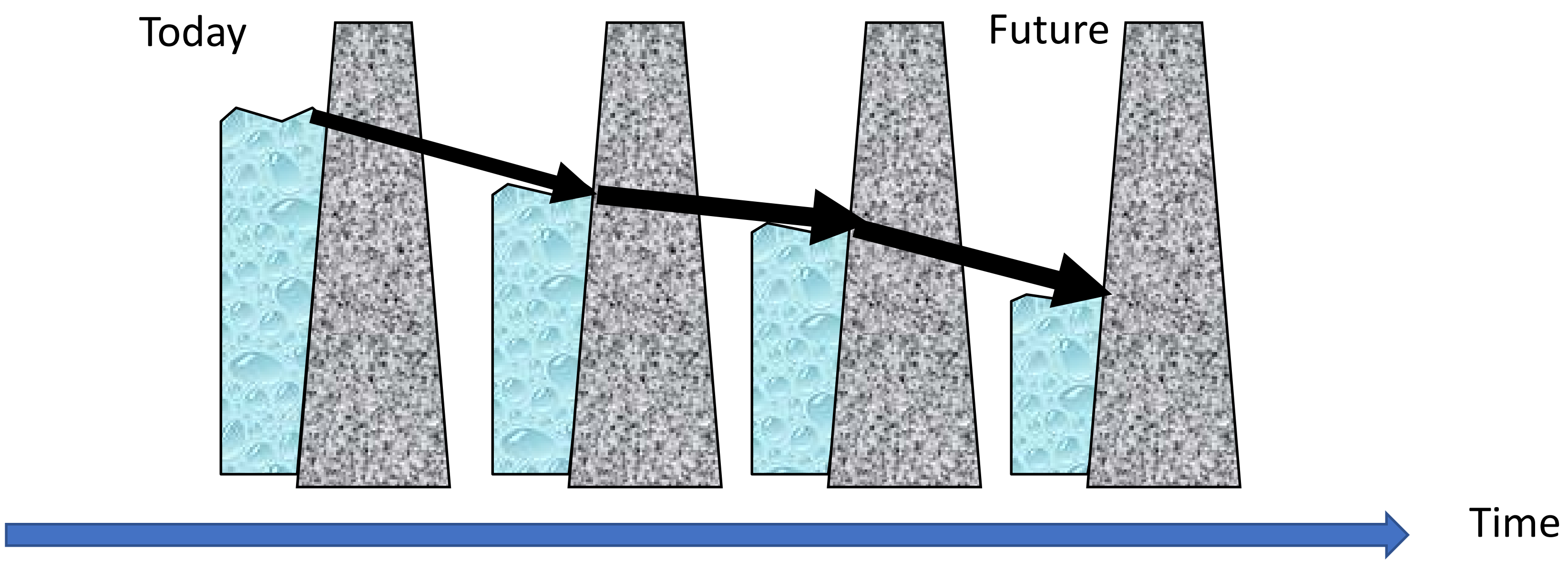
Hydropower Services and Climate Change: Adaptation, Resilience and Valuation of Climate Change Services

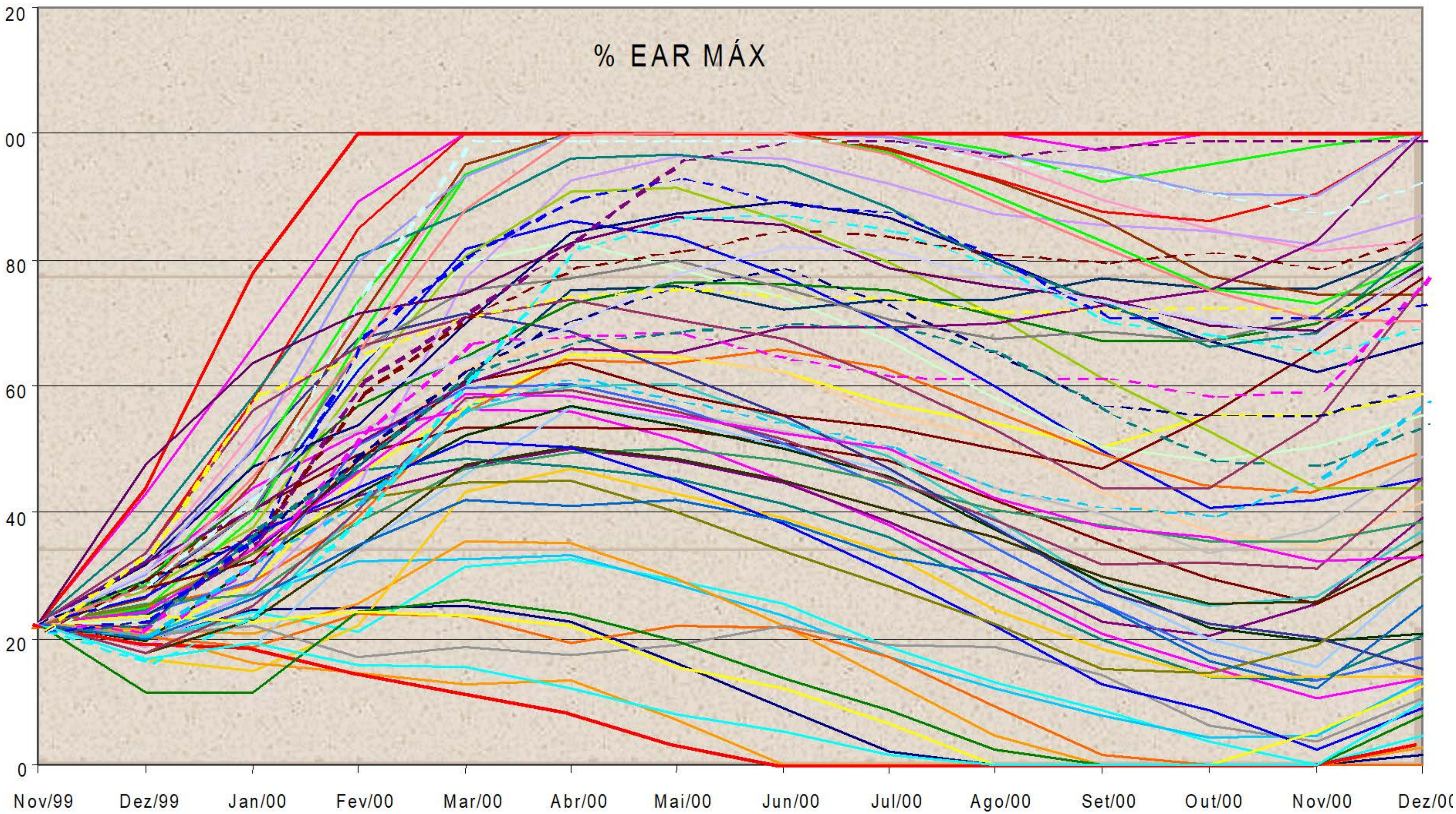
JERSON KELMAN
COPPE-UFRJ

In countries that most of the electricity is generated by hydro plants, hydrological uncertainty is a relevant issue



Future water storage depends on present storage, future water inflow and the <u>decision</u> about how much thermoelectricity could be substituted by hydroelectricity

Hydrological uncertainty

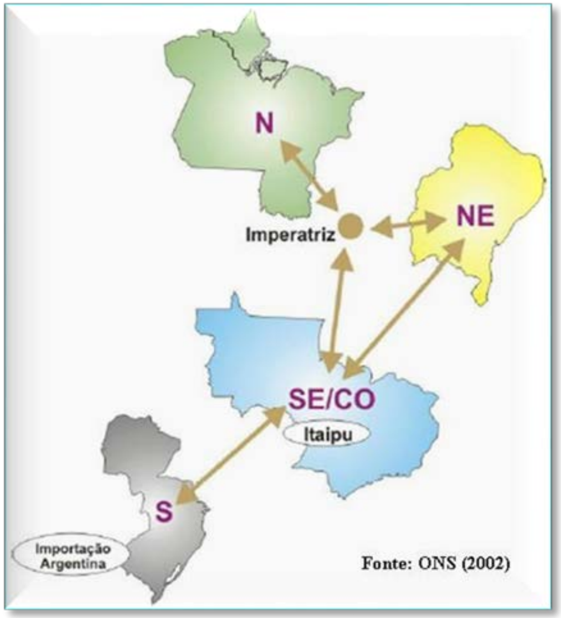


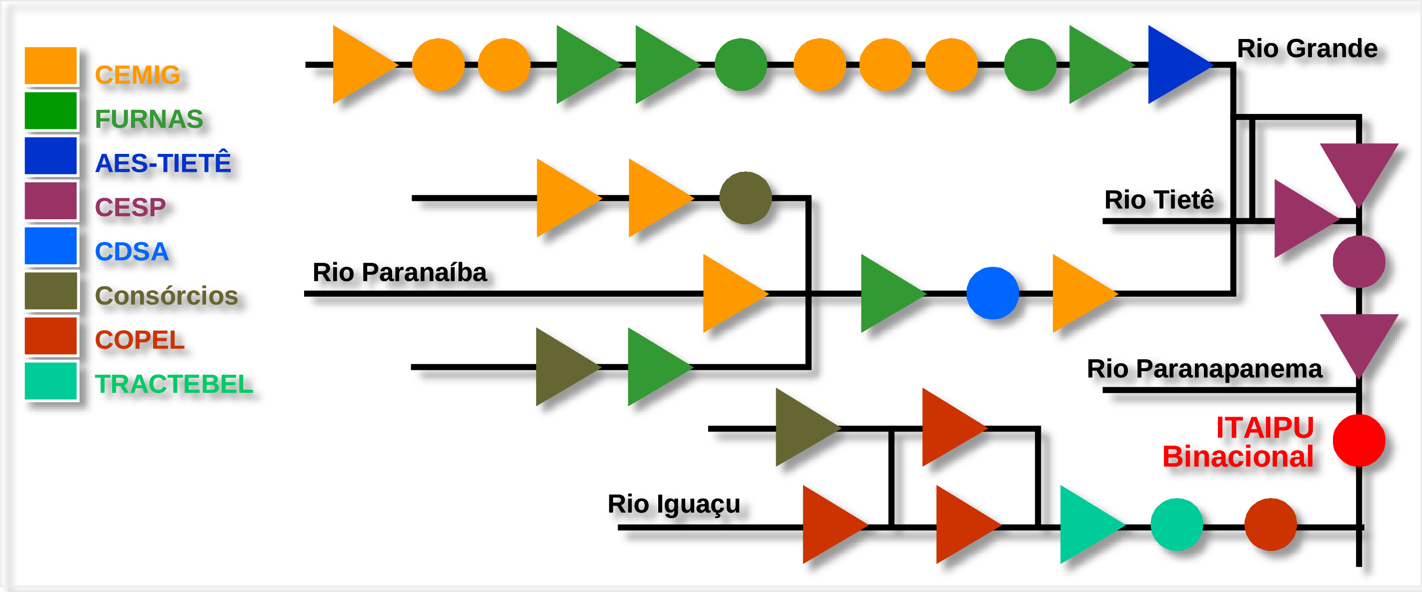
Centralized dispatch

In order to take advantage of hydrological diversity, energy is transported through long distances

Power plants in the same river basin are own by different companies

Power plants share a generation pool. Energy allocated to each plant is proportional do the “reliable energy” (delta demand resulting from the inclusion of the plant in the pool)





OPERAÇÃO DE UM RESERVATÓRIO PARA CONTROLE DE CHEIAS[1]

POR

J.Kelman[2,3], J.Damazio[2], M.V.F.Pereira[2], J.P.Costa[4]

RESUMO -- Este trabalho tem como objetivo fornecer a vazão defluente mínima, função do nível de armazenamento do reservatório, que garanta um risco pequeno para a ocorrência de uma situação de emergência. Entende-se por situação de emergência aquela em que a vazão defluente já é suficientemente elevada para causar danos a jusante (pontes, cidades, etc.). A metodologia adotada determina também o volume de espera para amortecimento de cheias. Previsões de vazões e a operação simultânea de diversos reservatórios não são levados em consideração: estes temas serão abordados em próximos artigos.

INTRODUÇÃO

A regra de operação de um reservatório, isto é, a decisão quanto à vazão defluente, depende de um grande número de fatores: mercado, armazenamento nos outros reservatórios, afluências previstas, etc.. Esta decisão deve naturalmente ser viável, isto é, pertencer a um conjunto definido pelas restrições impostas por razões econômicas, físicas ou ligadas à segurança. O objetivo deste trabalho é estabelecer restrições simples sobre a vazão defluente em função do volume do reservatório de forma a exercer um efeito moderador sobre as cheias.

Definições

Sejam

h - duração da estação de cheias (dias)

$v(t)$ - volume (m^3) armazenado no reservatório no dia t ($t = 1,2, \ldots h$); sem perda de generalidade adota-se um volume morto igual a zero.

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[1]Este artigo resulta das atividades de pesquisa do projeto 7139 - CEPEL, que recebe o apoio do DEOP - ELETROBRÁS

[2]Pesquisador do Centro de Pesquisas de Energia Elétrica (CEPEL)

[3]Professor visitante da Coordenação dos Programas de Pós-Graduação em Engenharia da Universidade Federal do Rio de Janeiro (COPPE/UFRJ)

[4]Aluno do Programa de Engenharia Civil da COPPE/UFRJ. Professor colaborador do CESET - PR.

R.Hidrol.Rec.Hídricos, 2(2):139-160, jul./dez.1980

International Symposium on Real-Time Operation of Hydrosystems, Waterloo, Ontario, Canada, June 24-26, 1981

(4)

FLOOD CONTROL RESTRICTIONS FOR A HYDROELECTRIC PLANT

Jerson Kelman, Jorge M. Damazio, Mário V.F. Pereira, Joari P. da Costa
CEPEL-Centro de Pesquisas de Energia Elétrica
Cidade Universitária - Ilha do Fundão
P.O. Box 2754 - Rio de Janeiro - RJ
Brazil

SYNOPSIS

This paper presents a methodology to impose bounds on the yield of one reservoir in order to keep flood risk below a pre-established level. This is accomplished by an efficient backward recursion scheme which mimics the real time operation of the reservoir. Synthetic traces are used to take the streamflow stochasticity into account.

The performance of the methodology is evaluated through the case study of the Três Marias power plant, which reservoir can be used to protect a city located 150 km downstream. Flood control bounds were calculated for different hypothesis regarding forecasted maximum release, ranging from no information to perfect information.

INTRODUCTION

The operation objectives of a reservoir system primarily designed to meet conservative purposes may change with time. A typical example arose when the operating rules of the brazilian hydroelectric system, originally designed to optimize power production, were reevaluated in order to take flood control constraints into account.

The methodology described in this paper provides daily bounds on the yields of one reservoir as a function of its stored volume. These bounds ensure that the probability of causing downstream damage is kept below a pre-established acceptable level. Downstream damage is said to occur whenever the maximum safe release is violated. This usually happens when the reservoir reaches the maximum volume for normal operation (v_M) and dam-safety procedures override any flood control restriction (Kelman et al., 1980). Another critical situation may take place if a sizeable part of the total flow at the site to be protected comes from tributaries joining the main river downstream to the dam. In this case the daily maximum release is the difference between the actual maximum flow at the site and the uncontrolled flow. In other words, the reservoir maximum yield depends on a random variable whose probability distribution will be estimated according to the forecasting capability. Forecast errors in this real time decision process may lead to "optimistic" maximum releases at the reservoir and cause downstream damage even when the reservoir is not full.

Flood control restrictions may prevent the reservoir from filling up

When deciding about a new infrastructure project…

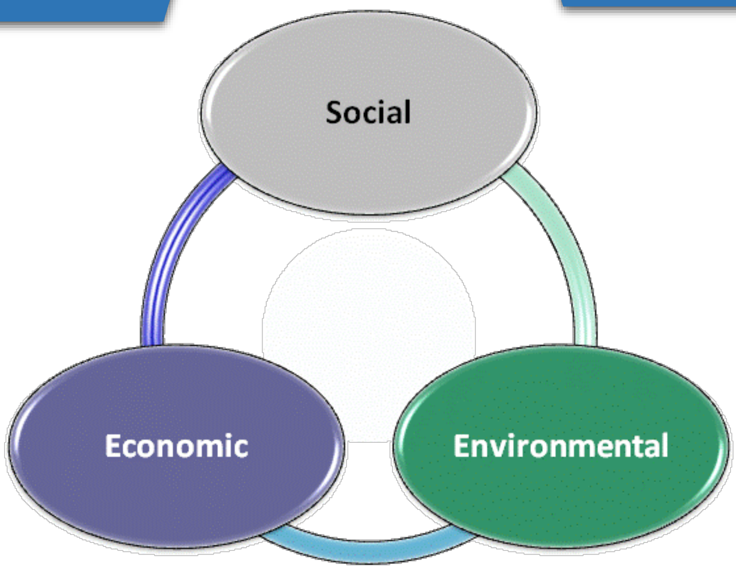
What happens if the plant is built?

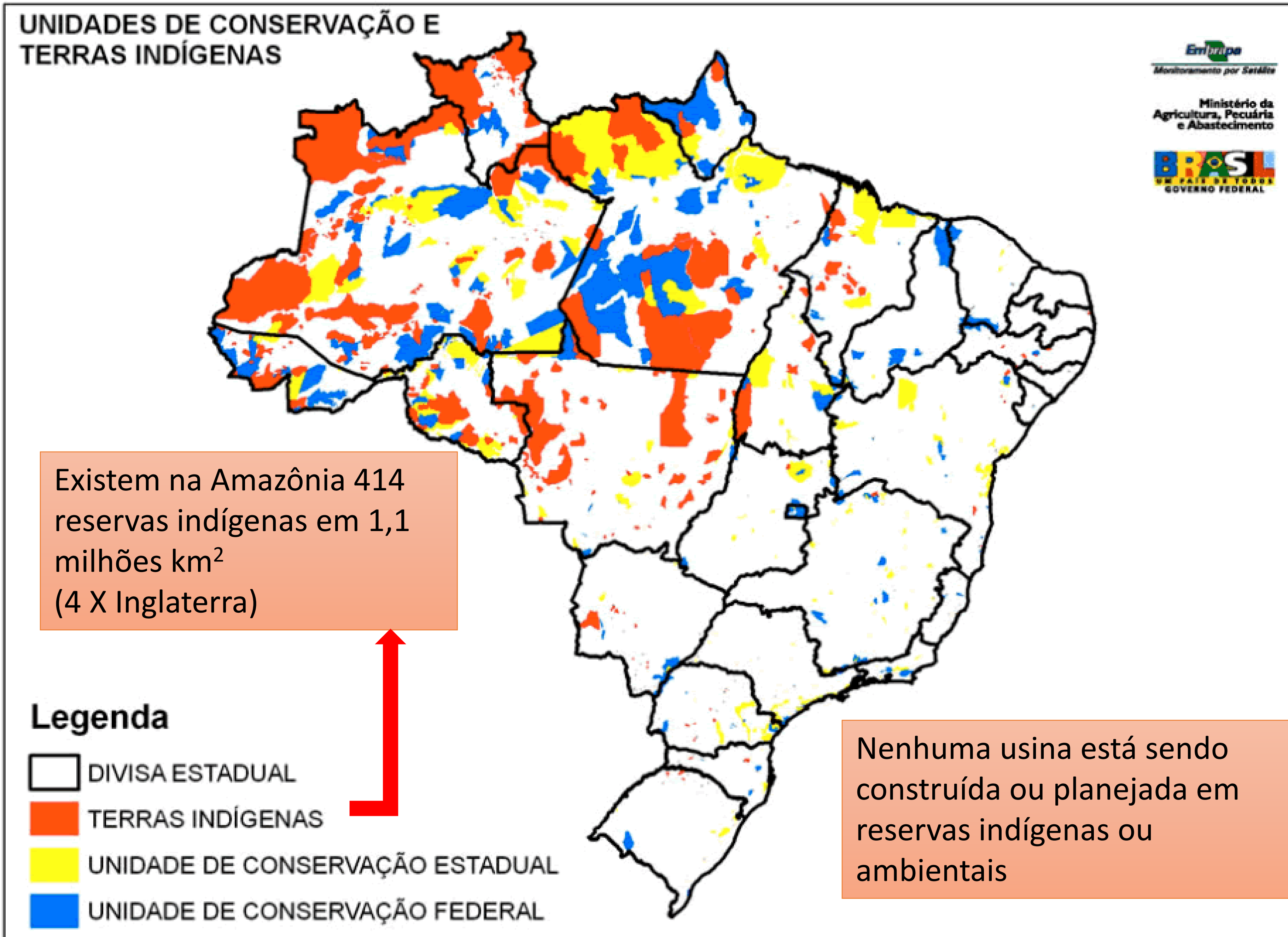
What happens if the plant isn´t built?

Local impacts

X

Global impacts

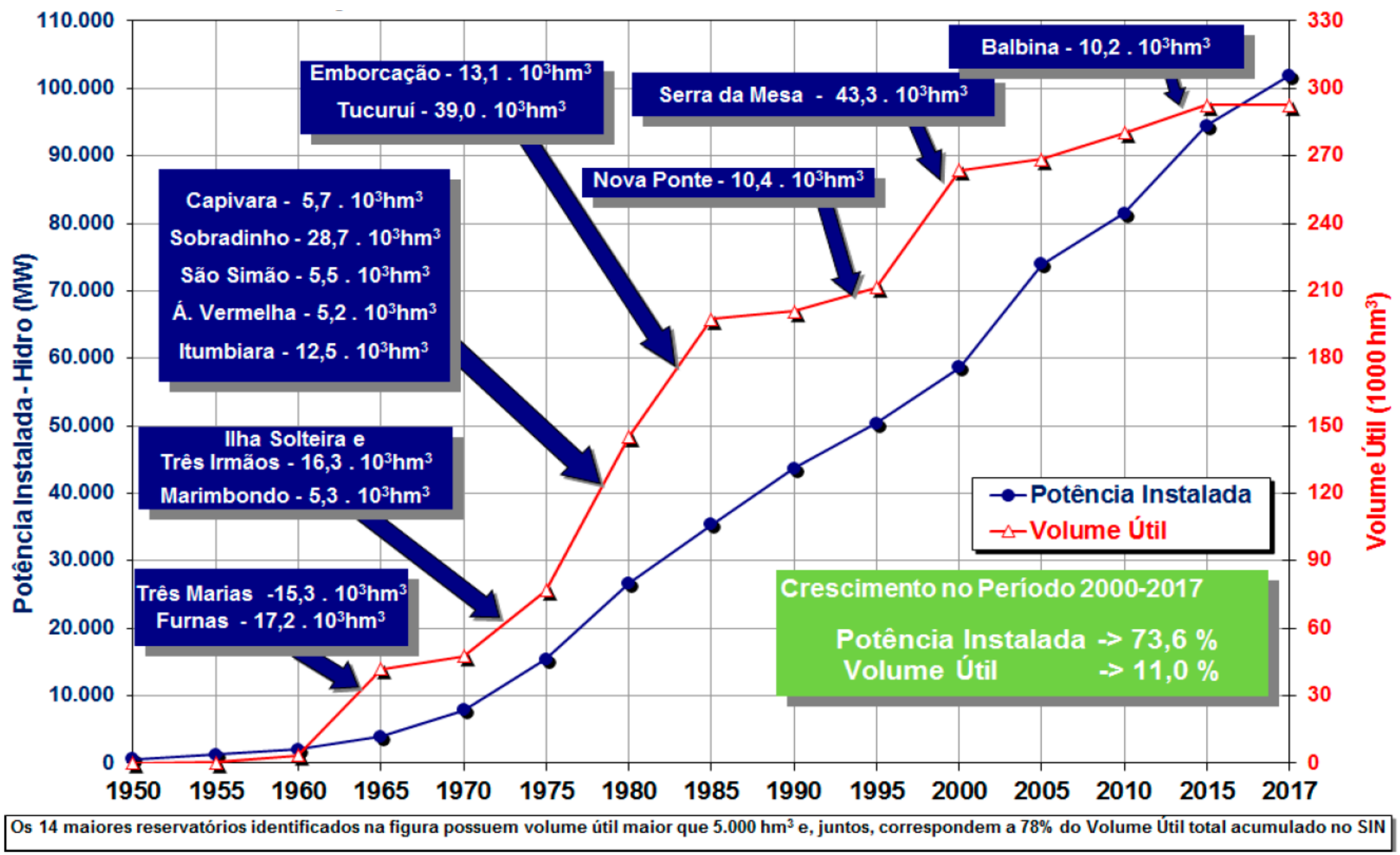




Existem na Amazônia 414 reservas indígenas em 1,1 milhões km^2
(4 X Inglaterra)

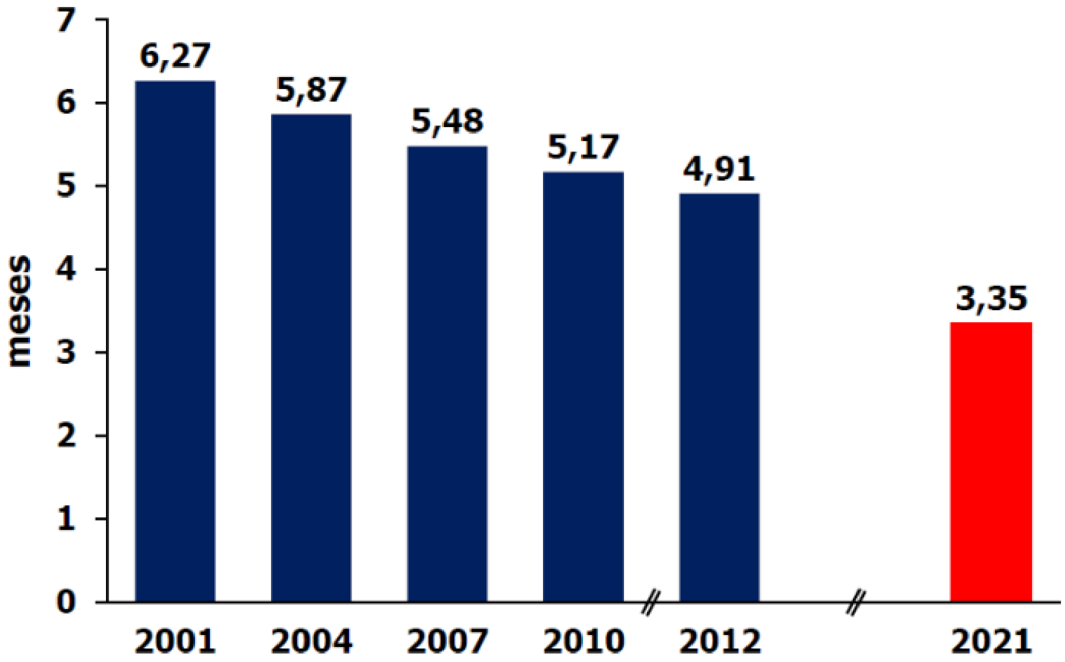
Nenhuma usina está sendo construída ou planejada em reservas indígenas ou ambientais

Capacidade de reservação



Fonte: PSR.

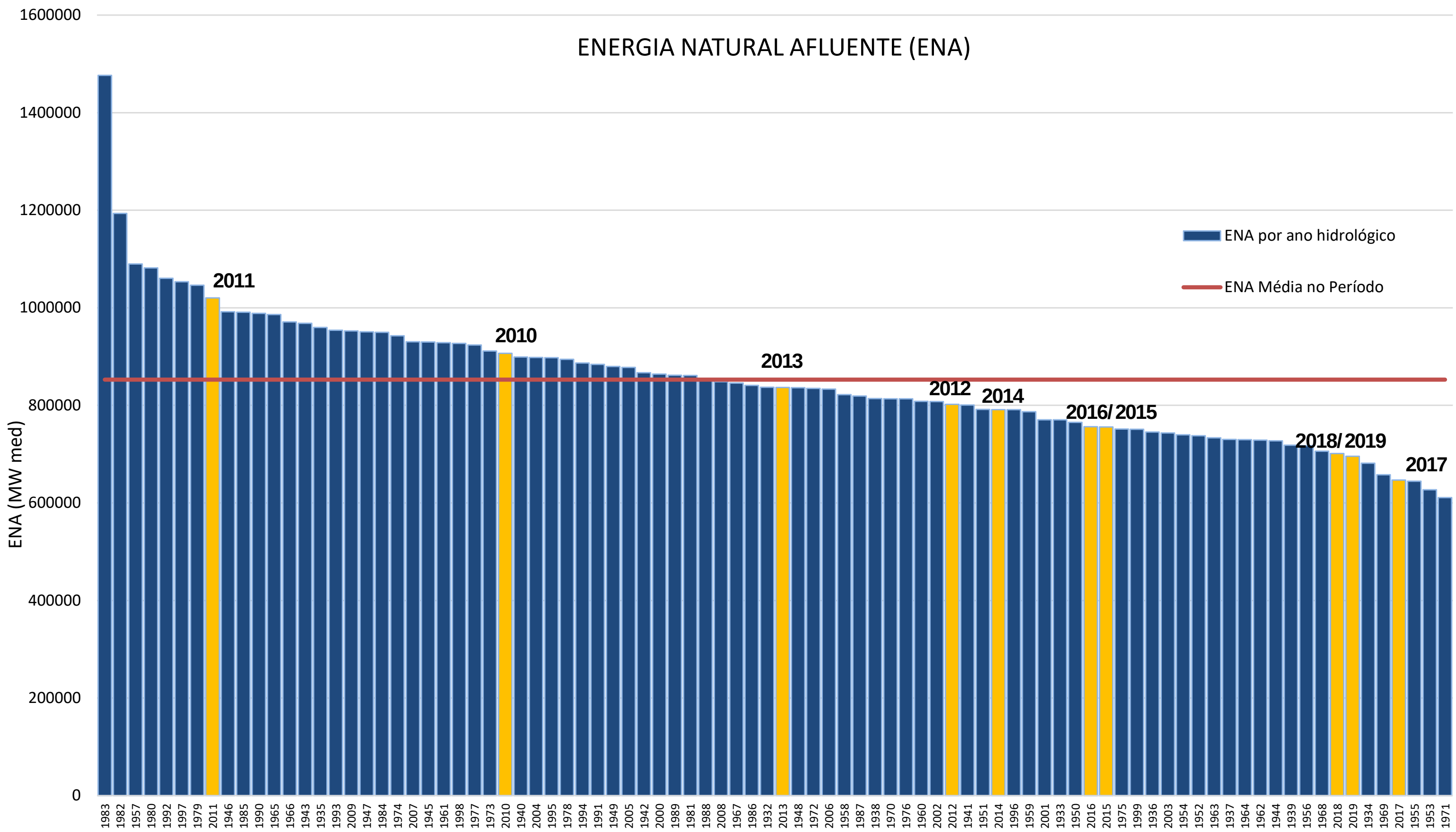
Evolução da Capacidade de Regularização no SIN



Tempo para esvaziar os reservatórios se nenhuma afluência chegasse às usinas e nenhuma térmica, eólica e solar gerassem. Mostra-se o declínio na capacidade de regularização

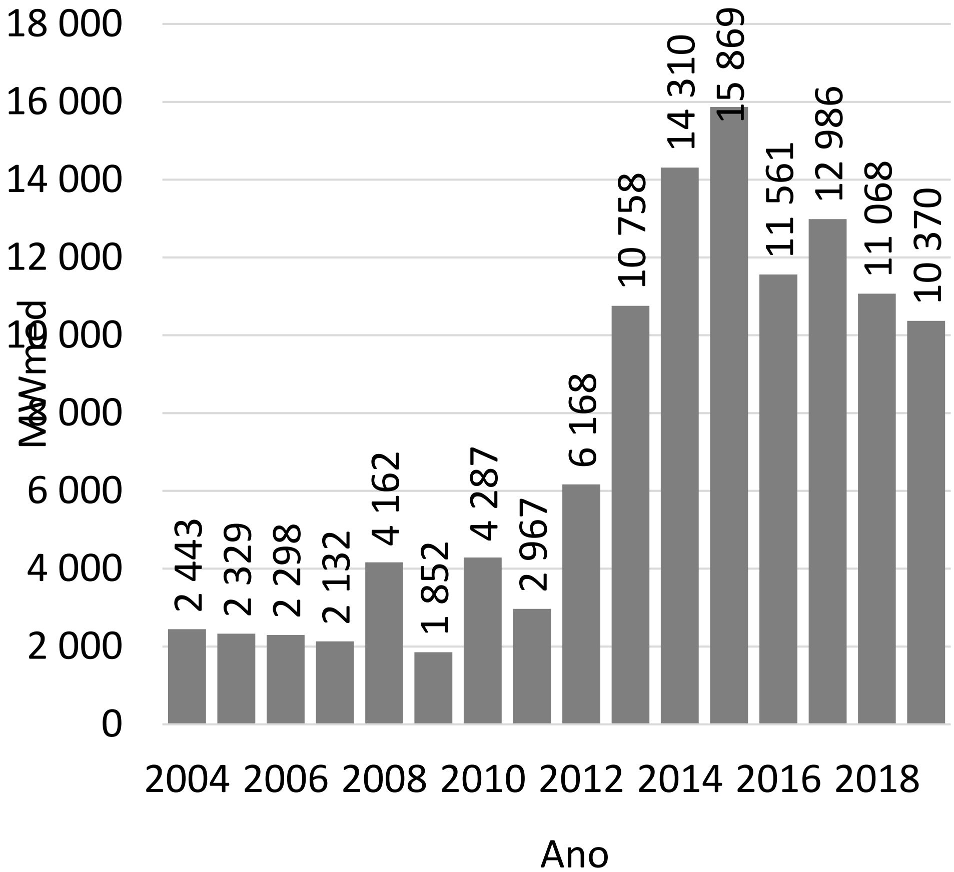
Fonte: FIRJAN a partir de dados do ONS e EPE.

Quão Crítica é Crise dos Últimos Anos?

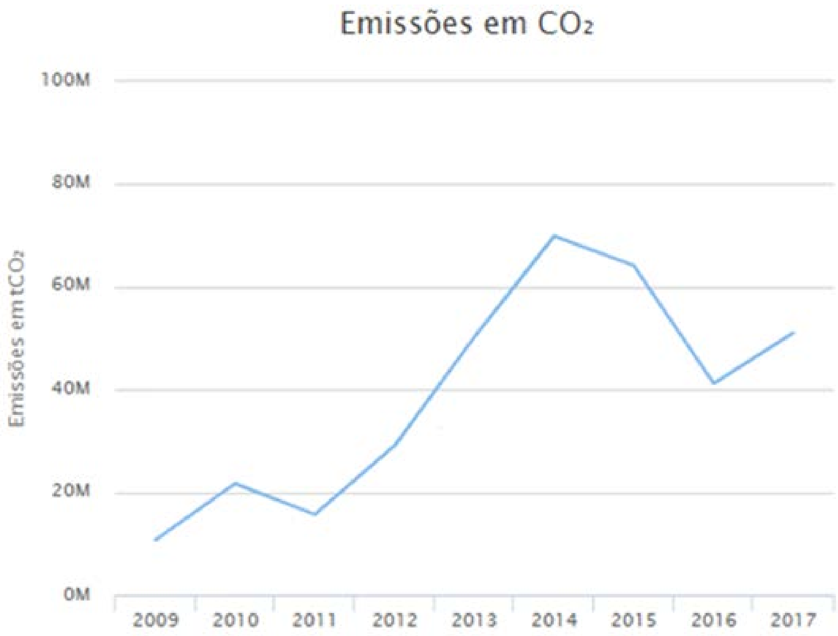


Fonte: dados do ONS.

Despacho Termelétrico

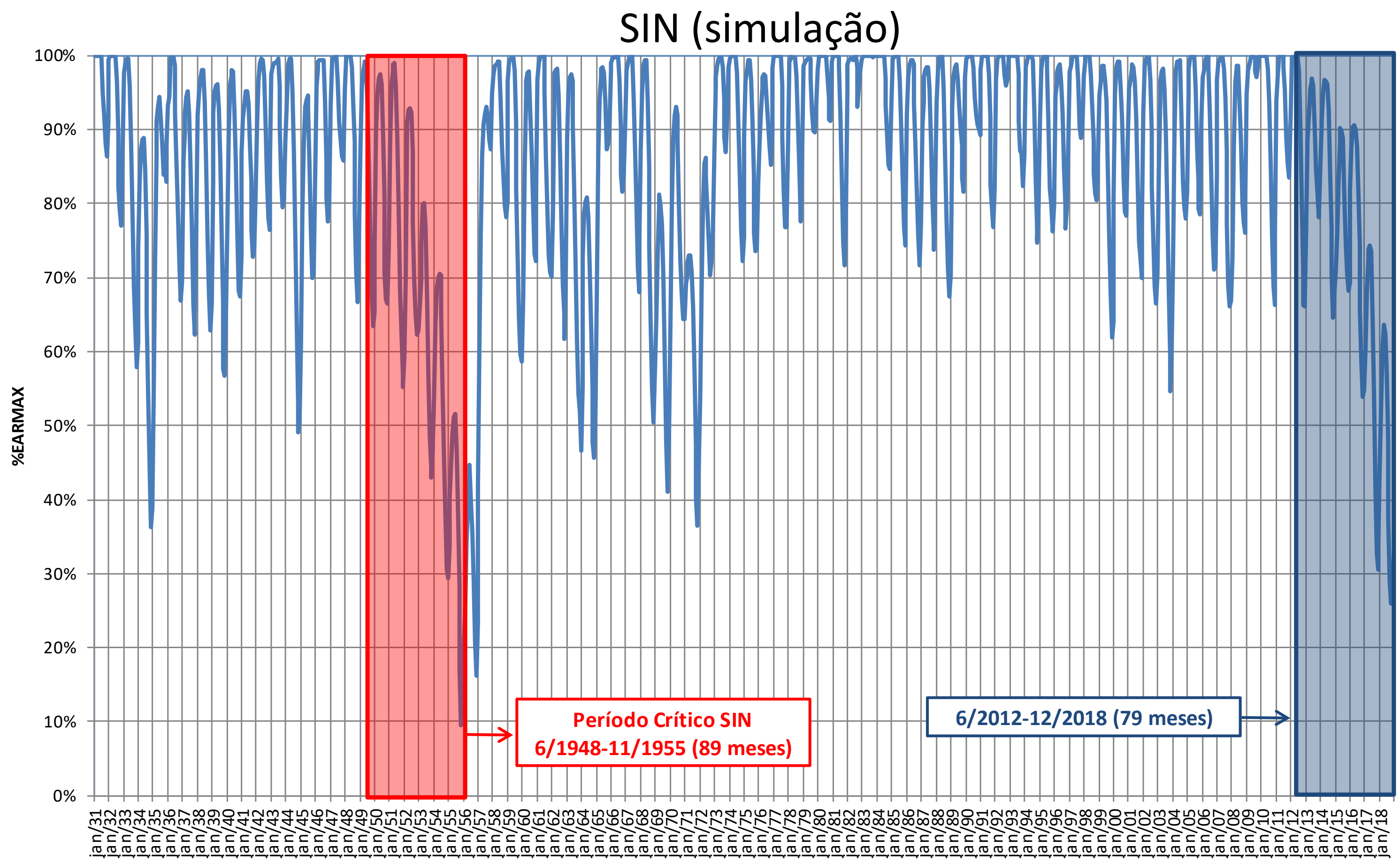


Fonte: ONS.



Fonte: http://monitoreletrico.seeg.eco.br/

Nível dos Reservatórios (1931 a 2018)



Fonte: ONS, PEN 2019

PALAVRA FINAL Jerson Kelman

É possível fazer prognósticos sobre o futuro observando o passado?

Todos sabem que as vazões afluentes às usinas hidroelétricas que foram observadas no passado não ocorrerão de forma idêntica no futuro. Mas, se o processo estocástico "utilizado" pela Natureza for estacionário, as estatísticas – por exemplo, as médias – do futuro serão próximas às do passado. A hipótese de estacionariedade é o pilar prin-

sive nas regiões onde haverá aumento da precipitação, devido ao aumento da evapotranspiração, por sua vez causada pelo aumento da temperatura. Segundo o estudo, a vazão média para o período de 2011 a 2040, quando comparada ao período de 1961 a 1990, diminuirá cerca de 20% na bacia do rio Paraná e de 30% na bacia do rio São

ção das curvas cota x área x volume e cota x m3/s x MW dos principais reservatórios e usinas do SIN.

Segundo, não basta considerar as previsões de mudança climática nos cenários futuros de afluência às usinas. É preciso considerar também os efeitos da mudança de uso do solo (não incluída no estudo da FBDS), que, de acor-

Usina	1931-1992	1993-2012	Δ
Itaipu	9789 m^3/s	11817 m^3/s	+ 20%
Sobradinho	2814 m^3/s	2161 m^3/s	- 23%

Climate change: a challenge to decision-makers in managing Brazilian hydro systems

A. Livino, Harvard University, Brazil
J. Briscoe, E. Lee and P. Moorcroft, Harvard University, USA
J. Kelman, Federal University of Rio de Janeiro, Brazil

The study described here aims to contribute to the investigation of impacts of climate and land-use changes on the hydrological cycle in Brazil. It explores how the climate and vegetation models can be used credibly in conjunction with hydrological models to investigate the impacts of climate change on the hydrological cycle. The paper describes work done in the Paraná river basin, and ongoing work in the Tapajós river basin.

Brazilian electric power generation is dominated by hydropower, which accounts for more than 80 per cent of production. Altogether, Brazil is building or planning more than 33 GW of new hydropower capacity in the next 10 years, most of it (around 75 per cent) in the Amazon. An important historical challenge to the operational planning of the Brazilian interconnected electrical system has been the stabilization of energy supply, as a result of the seasonal and annual uncertainty of hydro resources.

The present study, investigating the impacts of climate and land-use changes on the hydrological cycle, will provide new insights for two reasons. First, the hydrological model uses more realistic runoffs, precipitation and evapotranspiration, which are generated from a biosphere model coupled with a regional climate model, thus incorporating land-use change and climate change into the assessment of future water resources for hydropower planning in Brazil. Second, the work promotes cutting-edge research and interaction among scientists, engineers, and also decision-makers who are participating from the beginning of this study, and may influence the presentation of the results and the most sensitive variables to be analysed.

The Paraná basin was chosen primarily to address the valid concerns of practitioners that few, if any, of the plethora of climate models are credible, because they make no effort to explain important features of Brazilian hydrology. In this case, the test was to see whether the results of the models would be able to explain 'the Paraná paradox', namely a large secular increase in flows of the Paraná river in recent decades.

The Tapajos basin was chosen because there are major plans for development of this currently undeveloped basin in the coming decades. Plans include hydropower, but also navigation, which is vital for a cheaper and more environmentally friendly export of grains.

1. Background

Climate change studies and assessment of changes in land use are often used as the basis for generating scenarios, which can assist in decision making in various sectors. However, practitioners show justified scepticism about these studies, since the results vary so widely and there are seldom efforts to show that the models can reproduce known hydrological features.

Many studies have been conducted to estimate and analyse the hydrological impacts of climate change and the changes in land use. There is great interest in this type of study in Brazil because:

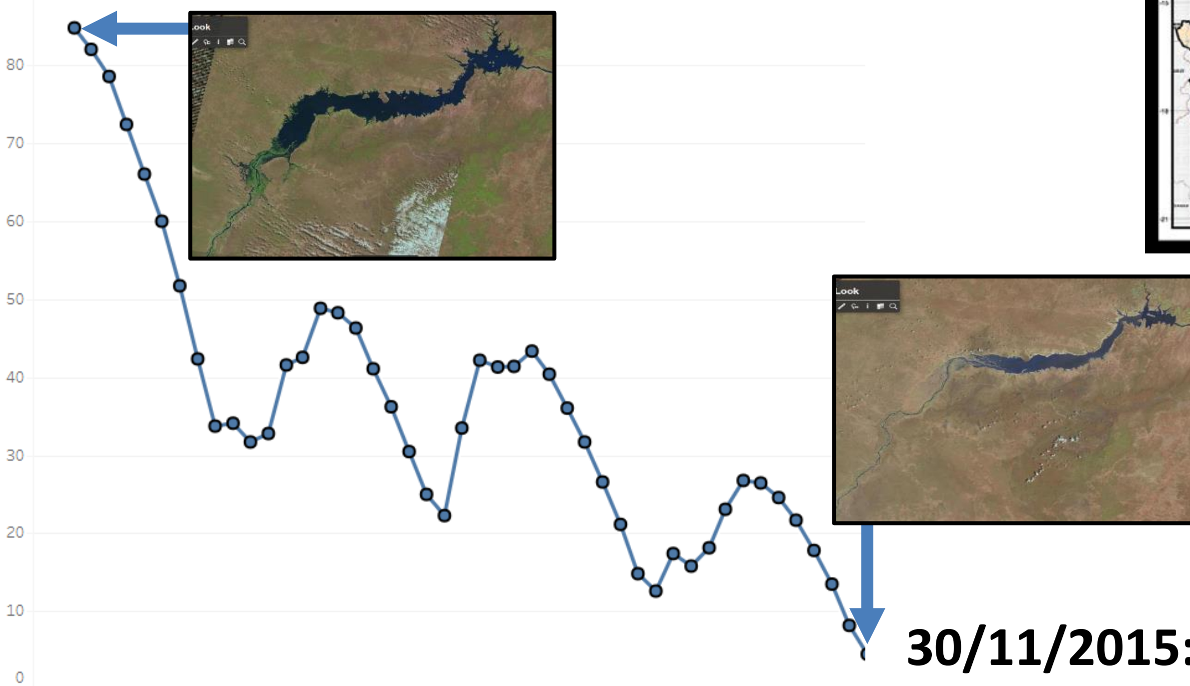
- more than 80 per cent of the electric energy is produced by hydroelectric plants;
- hydropower will retain a dominant role in the foreseeable future, despite the fact that most new plants will be built in the Amazon; and,
- most of the new plants will not have regulating reservoirs as a result of environmental constraints and the flatness of the terrain, which means that the energy output will be more dependent on the flow of the river, which in turn is directly linked to rainfall and soil characteristics and vegetation of the watershed*.

Studies of climate change and its influence on the hydrological cycle suffer from a mismatch between the spatial scales characteristic of each model type. Global climate models (GCM) usually work in the range of 1 × 1 (approximately 120 × 120 km) and seek to represent the processes and relationships between the atmosphere, the vegetation and the soil. On the other hand, hydrological models are traditionally used to represent and simulate the processes of runoff generation and their propagation in the drainage network in the catchment area. Most of these models consider only the processes of the land phase of the hydrological cycle, using rainfall as input data. They usually work on scales of 5 × 5 km. An advantage in the use of a regional climate model (RCM, such as BRAMS – Brazilian Regional Atmospheric Model) is that the current resolution (a scale of a few rather than hundreds of kilometres) enables them to capture the heterogeneity of the processes that influence the generation of the flow in the river basin scale without the need for disaggregation (downscaling). Both types of model, climate and hydrological, represent, with different levels of accuracy, the interaction soil × climate × vegetation. To use them jointly, it is necessary to deal with the redundant representations. In this context, this study sought to investigate the best hydrological models to contribute to the assessment of impacts in river flows, using as input the results of atmospheric models and vegetation.

*In other words, the future powerplants will tend to be run-of-the-river, the same as those recently built or being built on the Madeira river (Jirau and Santo Antonio), Xingu river (Belo Monte), and Teles Pires river (Teles Pires and Colider).

San Francisco River Basin

01/02/2012: **85%**



30/11/2015: **5%**

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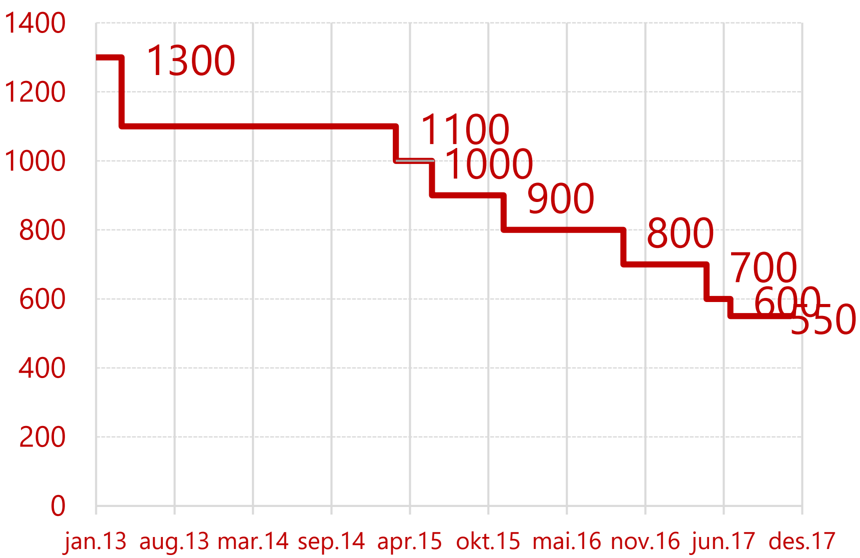
Histórico dos resultados do MRE

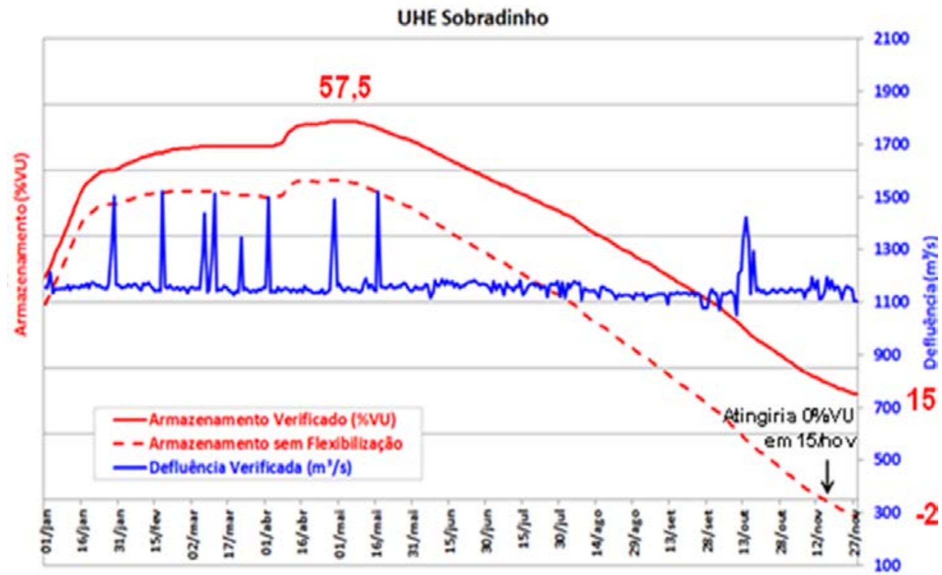
Impactos financeiros representativos nos últimos anos

Sobradinho Reservoir

Minimum outflow (m³/s)

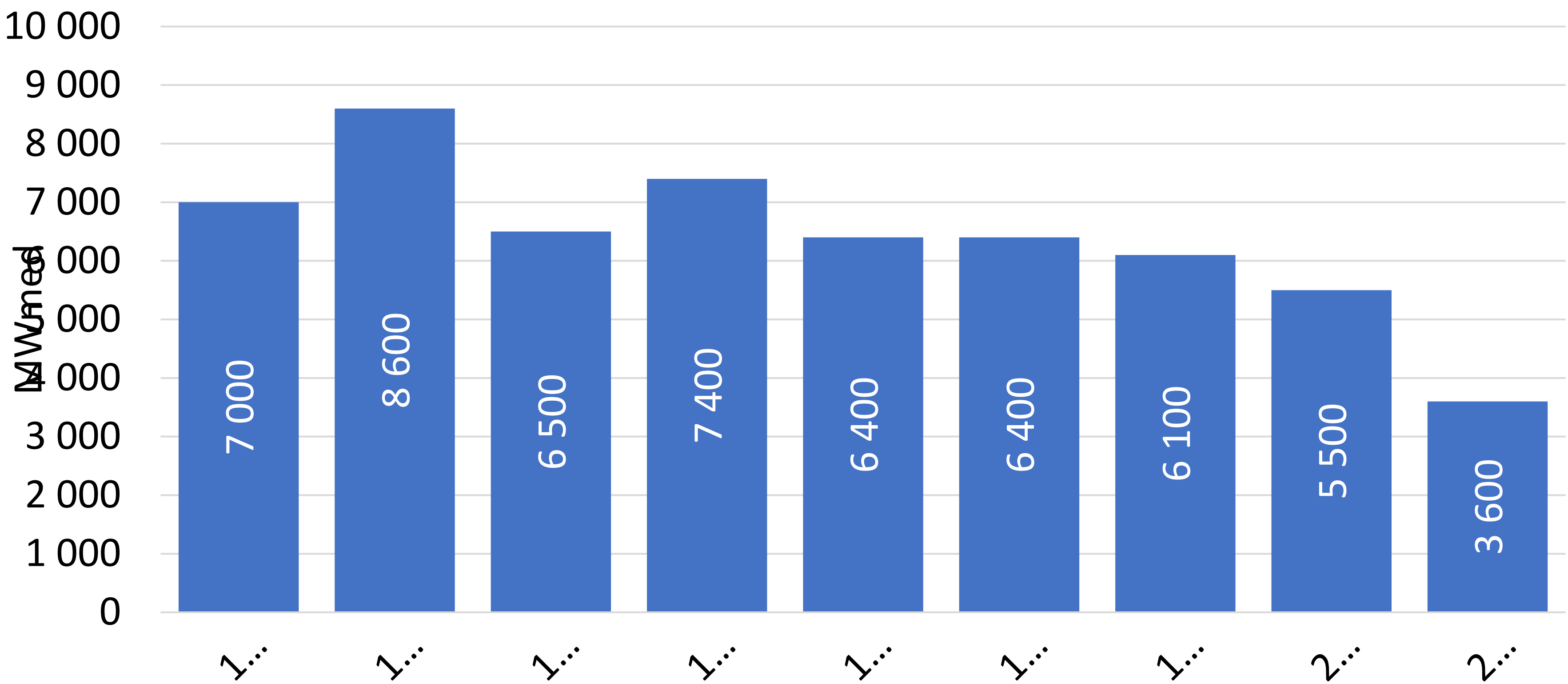


Storage evolution (2014)




LEVANTAMENTO DA AGRICULTURA IRRIGADA
Embrapa
ANA
AGÊNCIA NACIONAL DE ÁGUAS

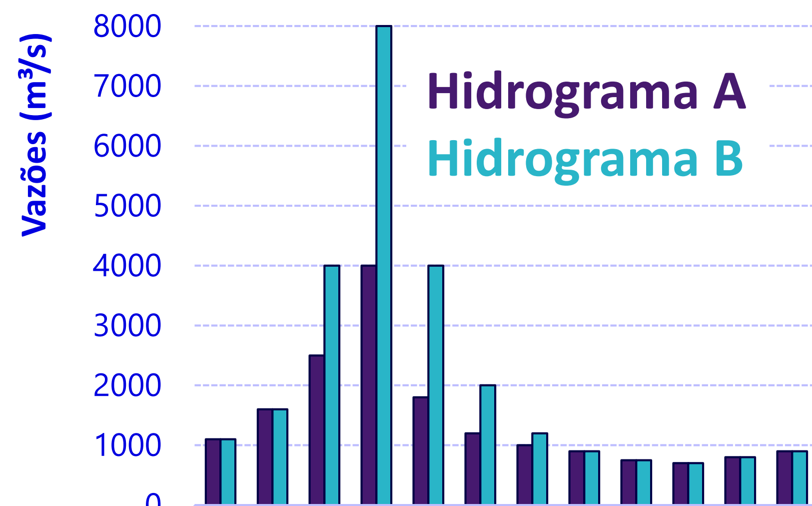
Redução da Energia Firme no Rio São Francisco



Fonte: Kelman, Jerson e Rafael. Energia firme da região Nordeste. Editora Brasil Energia, 2019.

Vazão ambiental da UHE Belo Monte

Belo Monte: uso de hidrogramas ambientais “*de consenso*” no rio Xingu



	Jan	Fev	Mar	Abr	Mai	Jun	Jul	Ago	Set	Out	Nov	Dez
o	1100	1600	2500	4000	1800	1200	1000	900	750	700	800	900
o seg	1100	1600	4000	8000	4000	2000	1200	900	750	700	800	900

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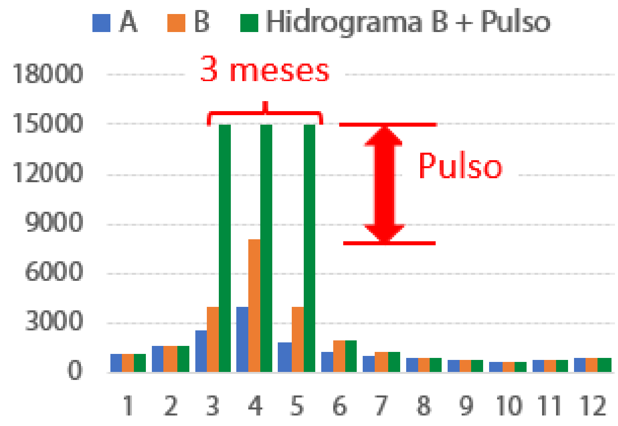
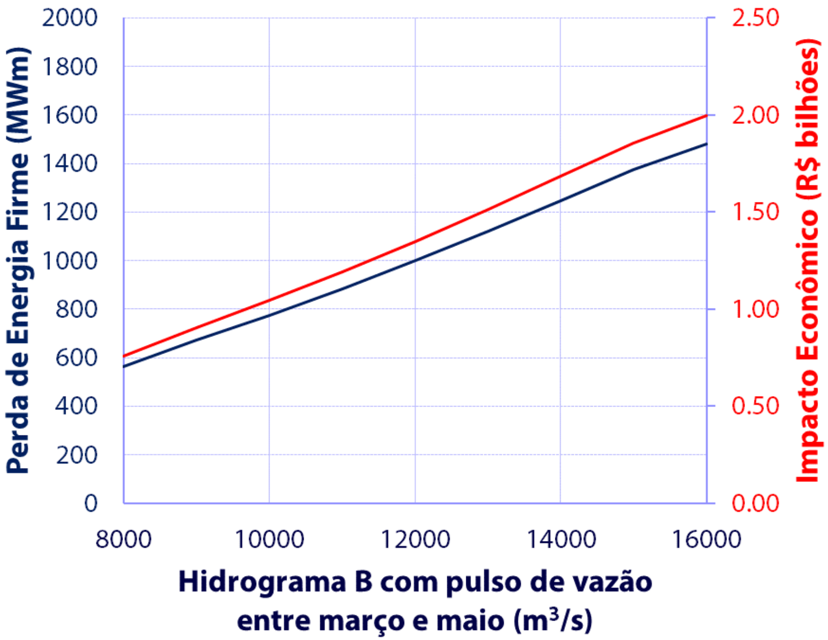
Vazão ambiental da UHE Belo Monte

Recomendação do MP

O próprio EIA-Rima, no Prognostico Global, aponta que seriam necessários pelo menos 15.000 m3/s para que ocorra um pulso de inundação expressivo, e que precisaria, ainda, ser mantido por pelo menos três meses durante o ano. A princípio, com o rio Xingu atingindo essa descarga de água, tanto em termos de volume de vazão quanto de tempo de inundação, os processos ecológicos seriam assegurados [...].





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Impacto econômico

O impacto econômico do hidrograma sugerido (**cerca de R$ 2 bilhões / ano**) equivale ao custo da construção de moradias para uma população igual a um Maracanã lotado **por ano***.

* R$ 2 bilhões / R$ 100 mil/moradia x 4 pessoas / moradia = 80 mil pessoas.

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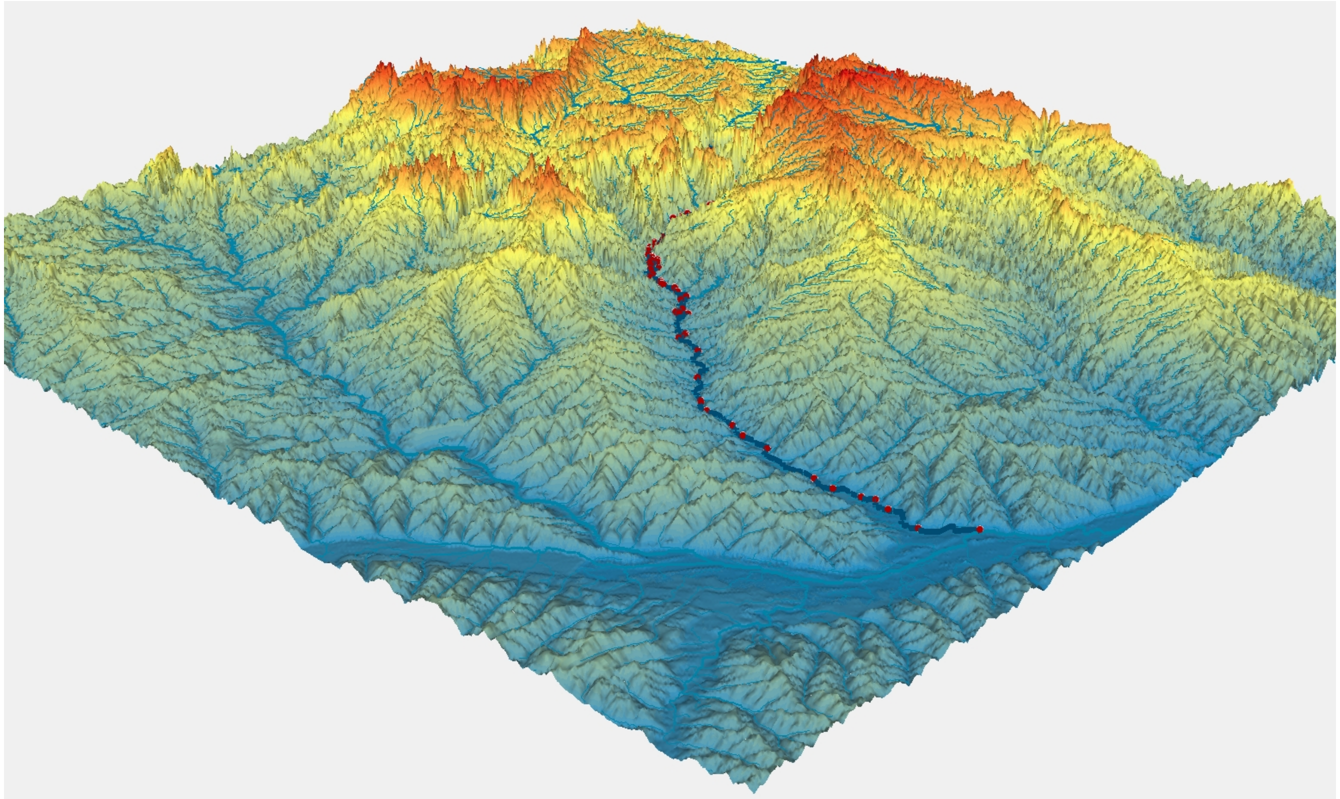
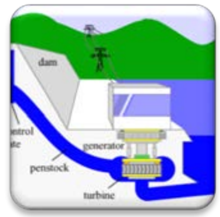
MDE – Visão 3D



Hera (PSR)



$$\text{Max } F(x)$$
sujeito a:
$$A(x) \le b$$

SIG

- Rede de Drenagem
- Locais Candidatos
- Curvas cota-área-volume
- Regionalização das

Orçamento

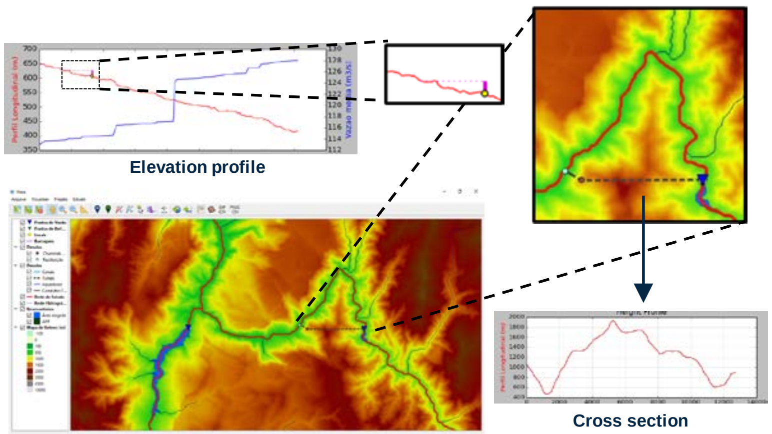
- Dimensionamento das estruturas
- Interface CAD para cálculo de volumes

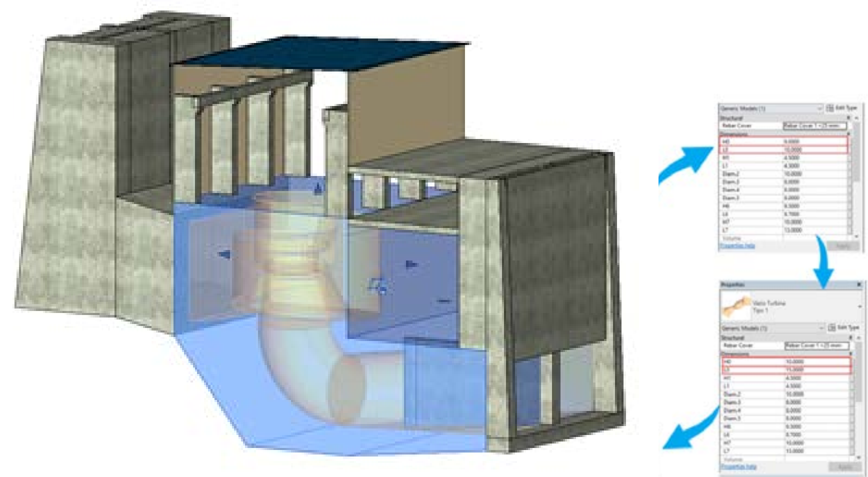
HERA (Otimização)

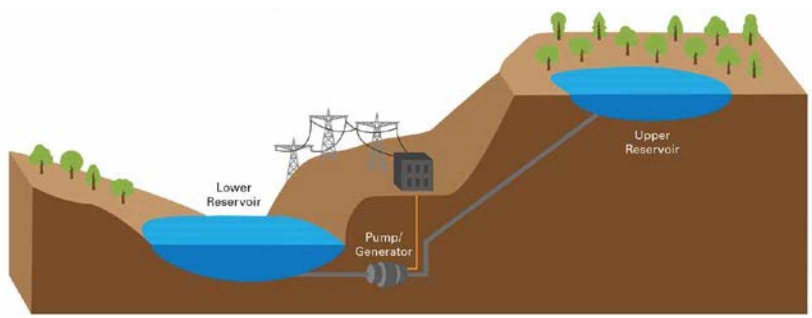
- Análise de Custo x Benefício
- Alternativas de quedas

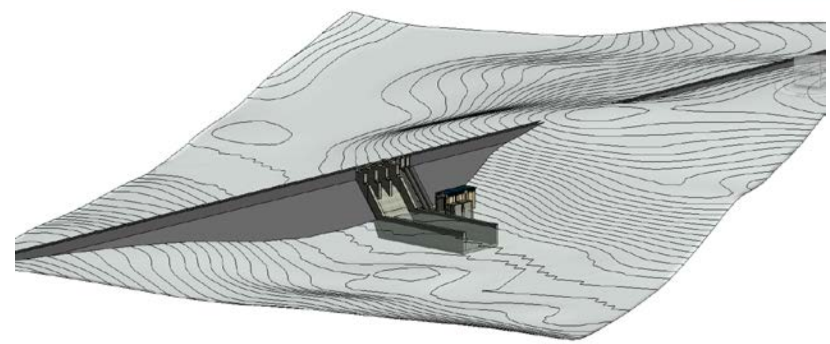
Resultados

HERA Model



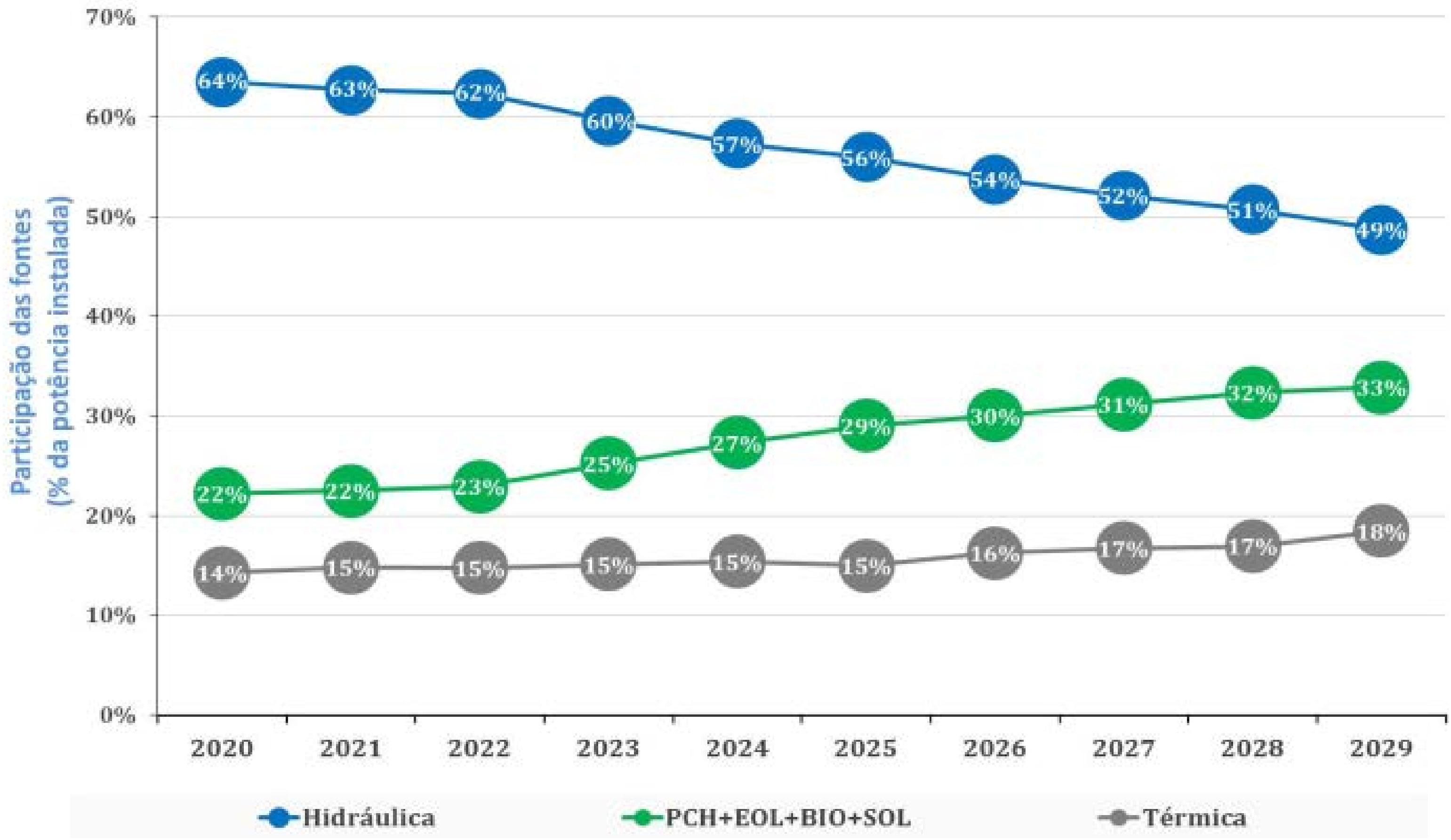






Developed by PSR
Case studies in cooperation with TNC

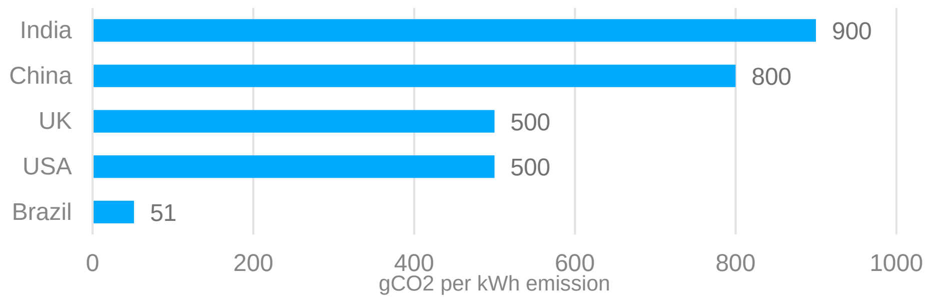
Redução da Capacidade Hidrelétrica de 64% para 49%



Fonte: EPE, PDE 2029.

Greenhouse Gas Emissions*

- Unit GHG emission factors (tCO2/MWh) of each power plant are multiplied by the corresponding electricity production from SDDP (MWh)
- Given the strong penetration of renewables, end-of-horizon electricity matrix remains very “clean”
  - Emissions per unit of electricity consumption: **51 gCO_2 per kWh**
  - Emission per unit of electricity consumption in Brazil is one tenth of the world average



* results from co-optimization run