



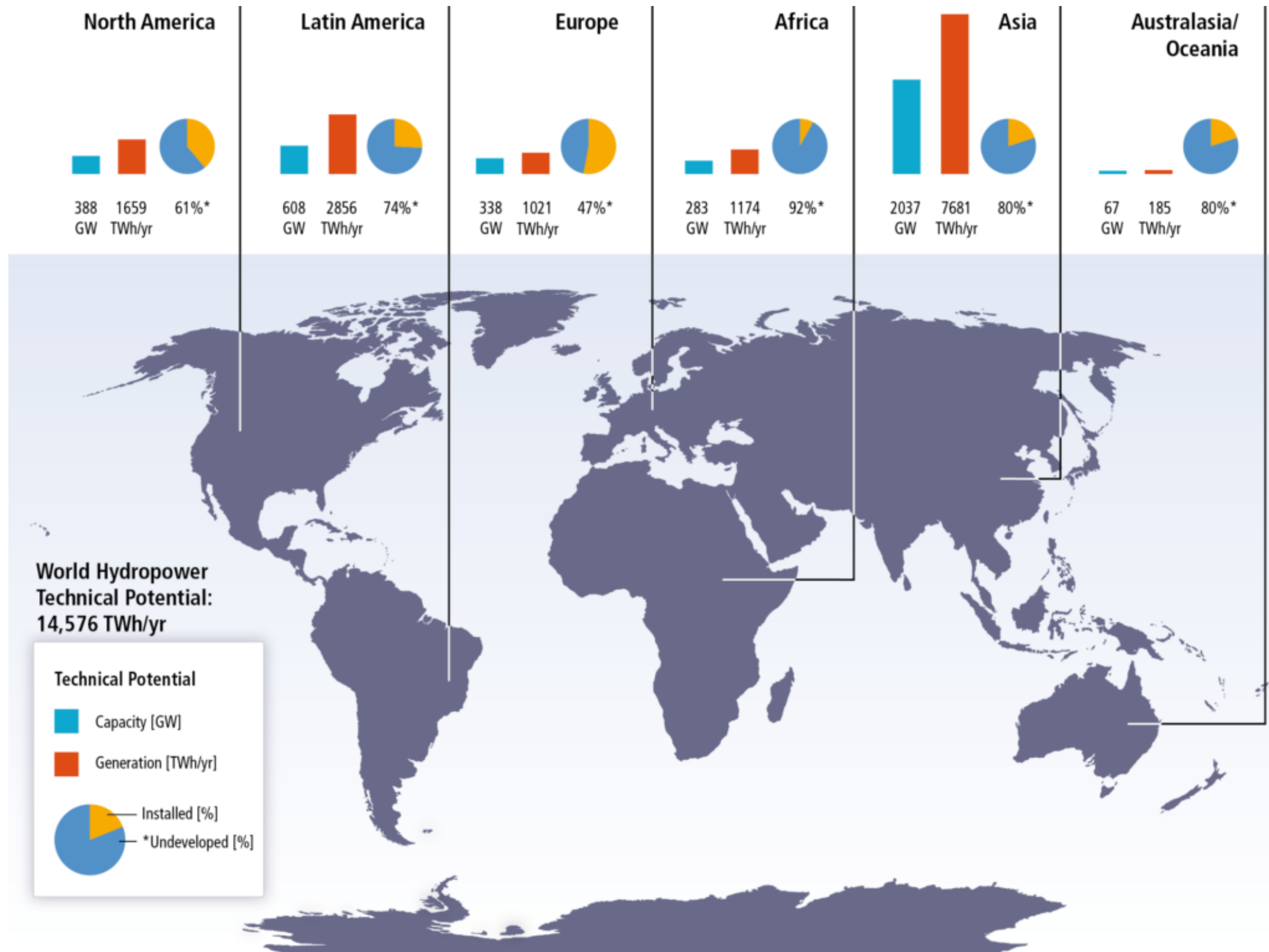
Potencial de usinas hidrelétricas reversíveis no Brasil

Comitê Permanente de Energia
Academia Nacional de Engenharia

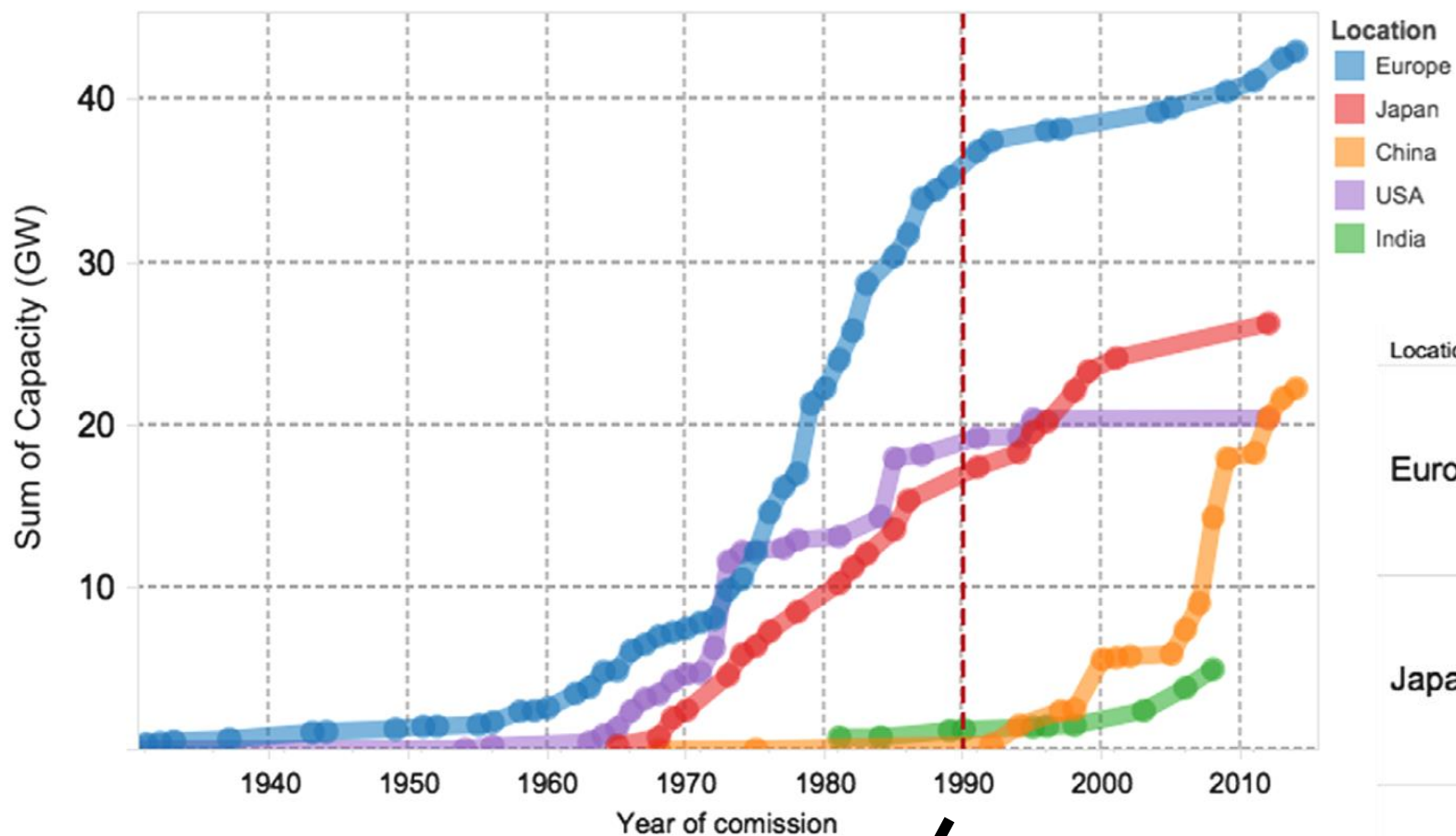
Julian Hunt

Porto Alegre, 16/09/2021

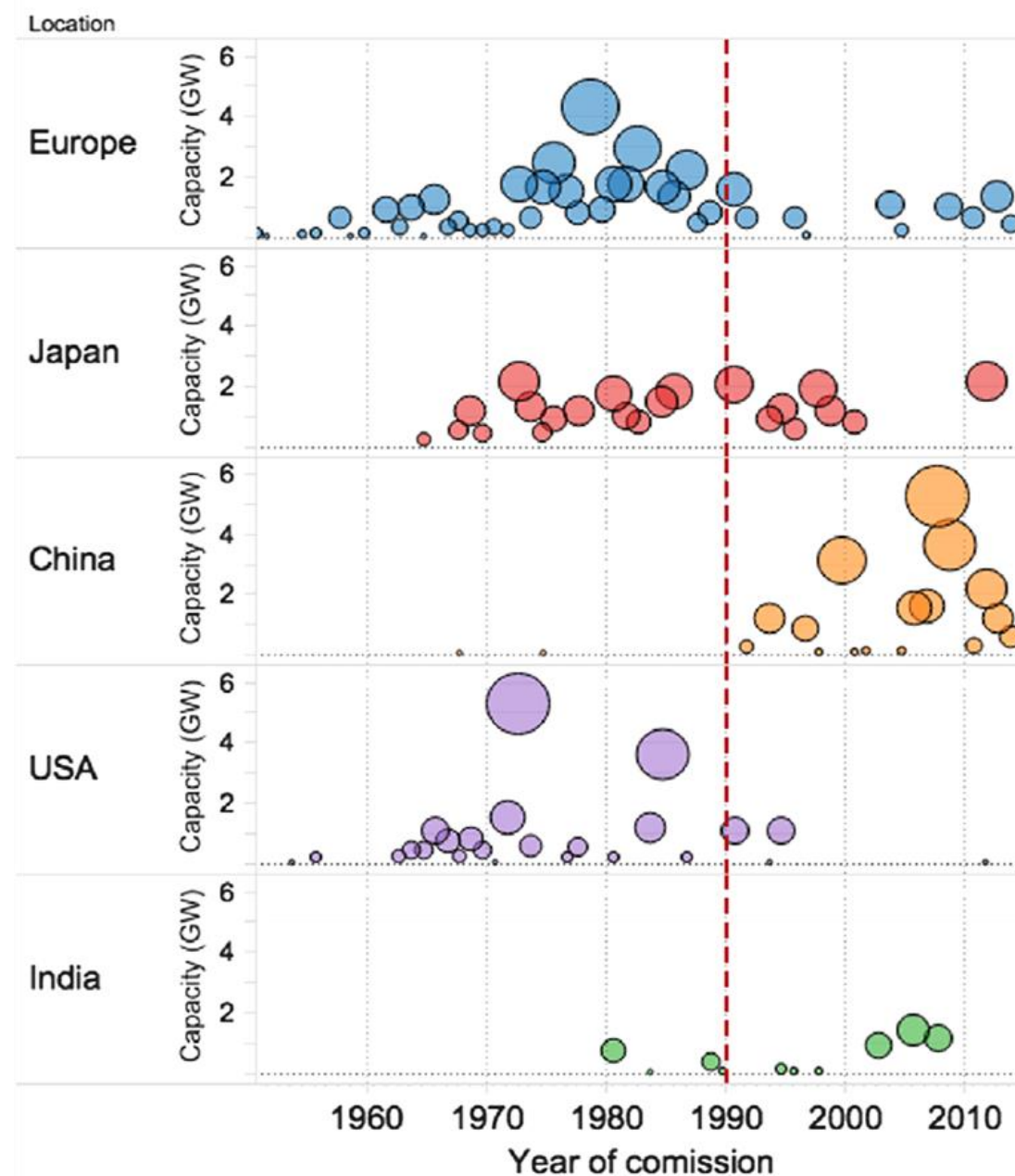
Visão internacional de hidrelétricas: Faça o que eu digo não faça o que eu faço



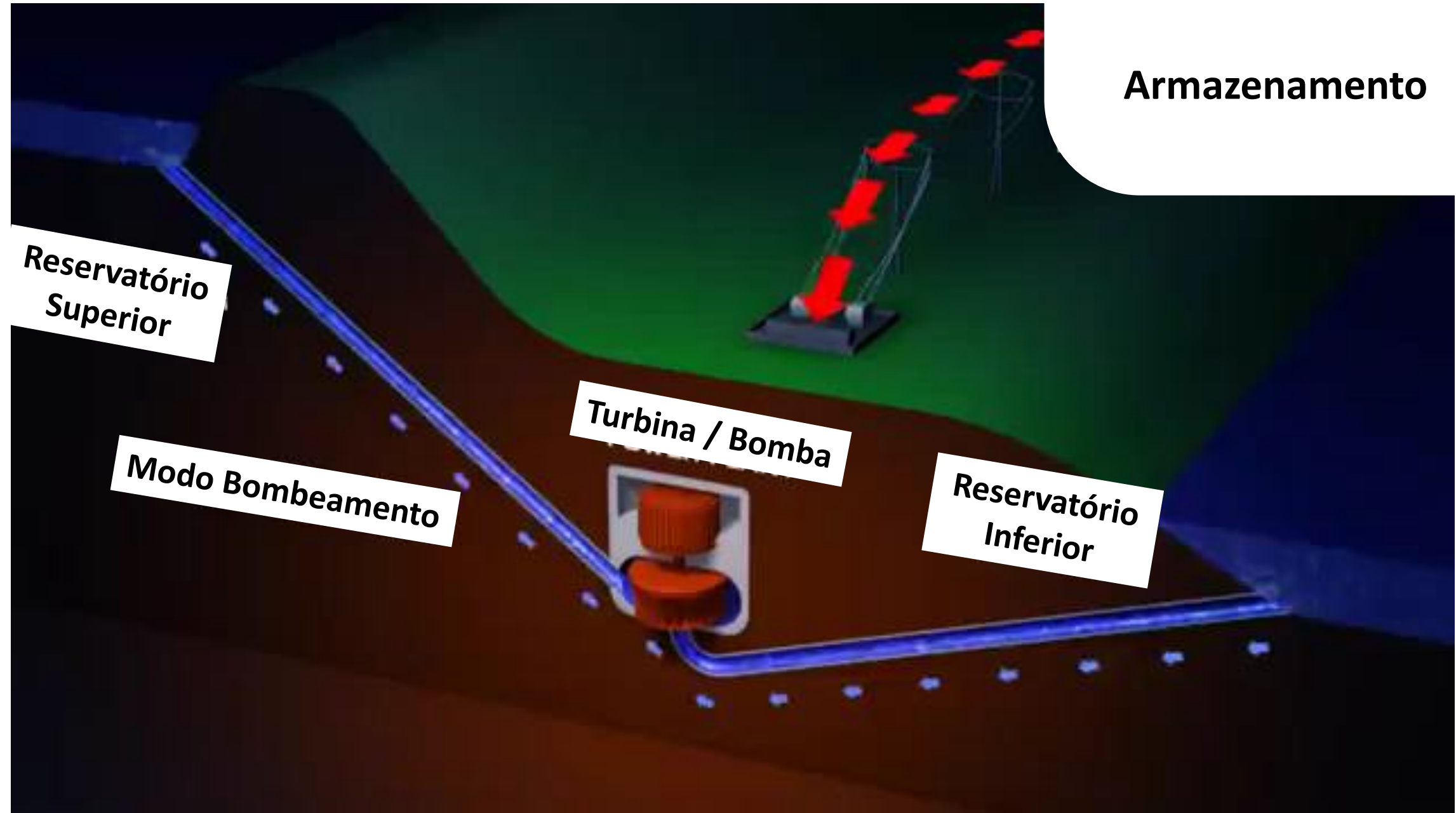
Histórico de construção de UHR no mundo



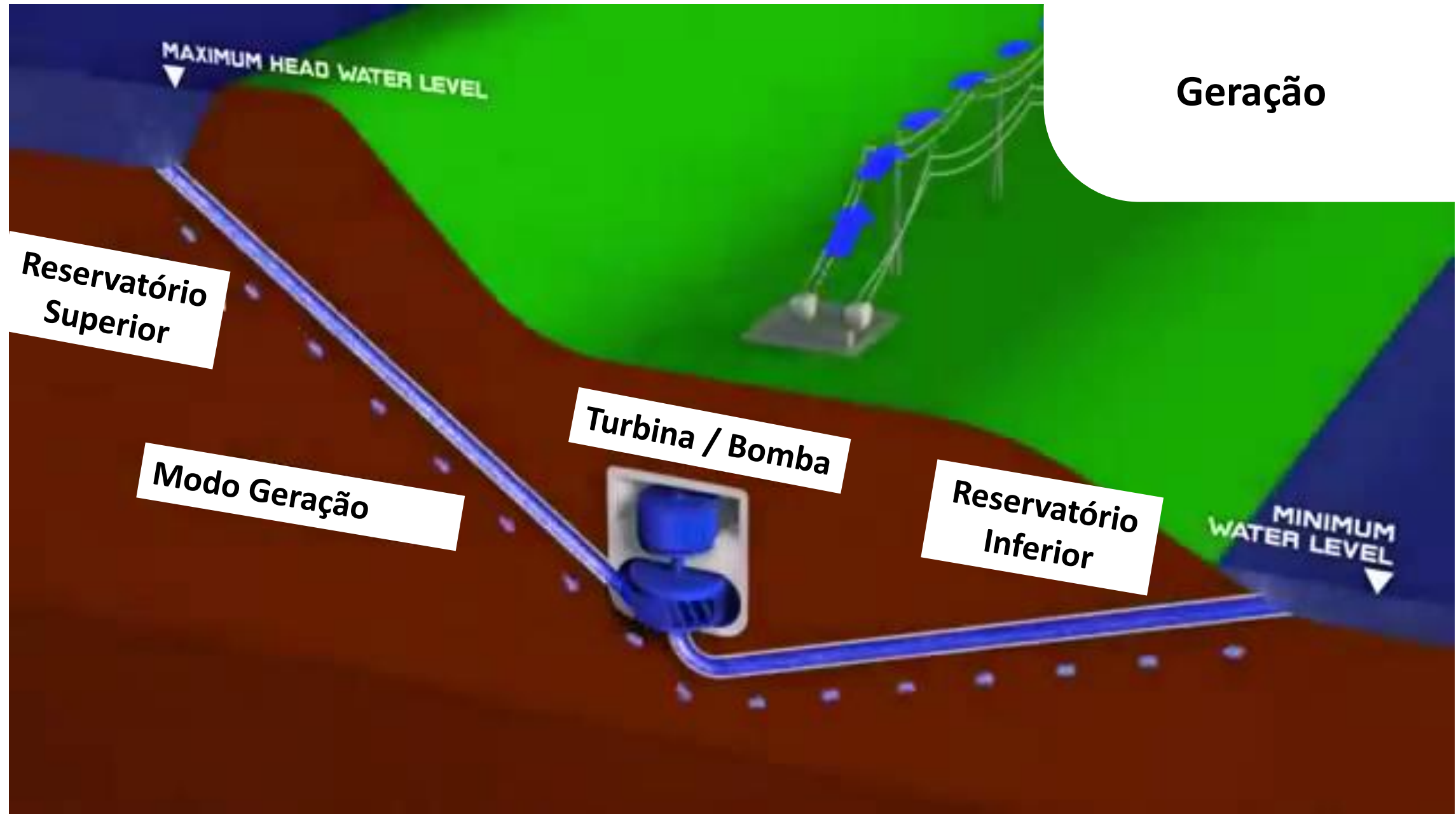
O que aconteceu em 1990?



Usina Hidrelétrica Reversível (Armazenamento)



Usina Hidrelétrica Reversível (Geração)



UHR Horária

Energy
MWh



Power
GW

PHS Type	Operation Mode	Occasions when the PHS type operates
Pluri-annual Pumped-Storage (PAPHS)	Pump	Annual surplus in hydroelectric generation [22].
		Annual fuel prices cheaper than average.
		Lower than average annual electricity demand [32].
	Generation	Annual deficit in hydroelectric generation [22].
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Seasonal Pumped-Storage (SPHS)	Pump	Rainy seasons or ice melting seasons, with high hydropower generation [33].
		Summer, with high solar power generation [23].
		Windy seasons, with high wind power generation [34,35].
		Low demand season, when electricity demand reduces.
	Generation	Dry period or freezing winters, with low hydropower generation [33].
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Weekly Pumped-Storage (WPHS)	Pump	During the weekends, when power demand reduces [36].
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Daily Pumped-Storage (DPHS)	Pump	Night, when electricity demand reduces [37].
		Day, when there is solar power generation [38].
	Generation	Day, when electricity demand increases [37].
		Night, when there is no solar power generation [38].
Hourly Pumped-Storage (HPHS)	Pump & Generation	Ancillary services: frequency control, remove harmonics in the grid, provide backup power in case of disturbances in supply.

UHR Diária

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MWh



Power
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Potencial de UHR Diária do Brasil

Para mais detalhes, veja o site abaixo:
<https://www.projetouhr.com.br/>
101 views

2,15 - 2,18 B R\$/GW

All items

2,07 - 2,15 B R\$/GW

All items

1,85 - 2,07 B R\$/GW

All items

Túneis (2,15 - 2,18 B R\$/MWh)

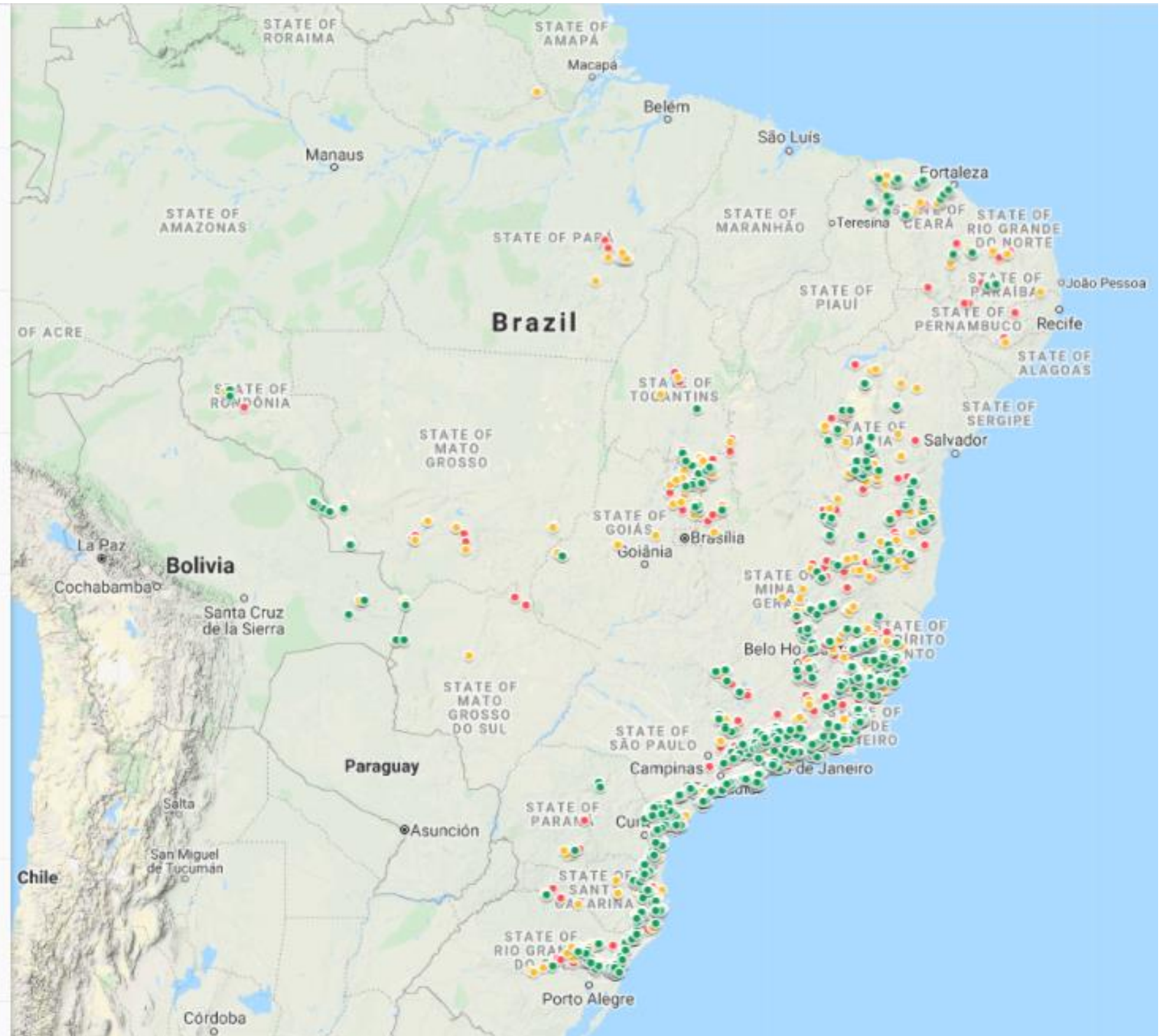
All items

Túneis (2,07 - 2,15 B R\$)

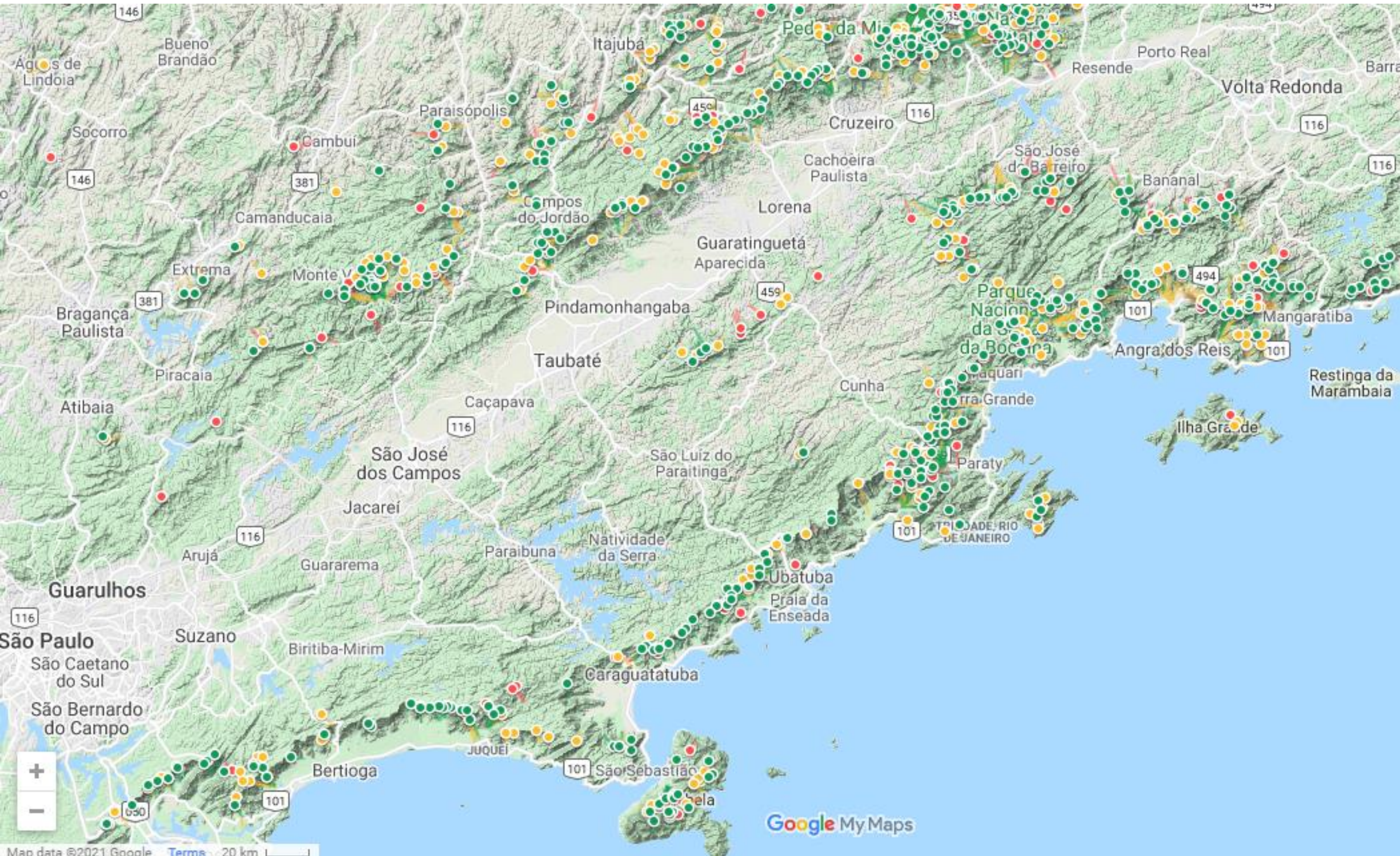
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Túneis (1,85 - 2,07 B R\$)

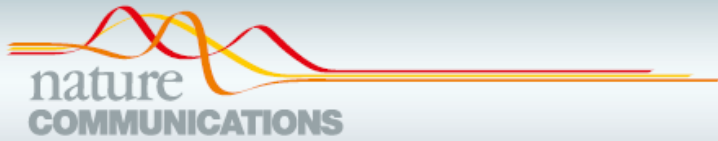
All items



Potencial de UHR Diária do Brasil



Modelo de mapeamento de UHR no Brasil



ARTICLE

<https://doi.org/10.1038/s41467-020-14555-y>

OPEN

Global resource potential of seasonal pumped hydropower storage for energy and water storage

Julian D. Hunt¹, Edward Byers¹, Yoshihide Wada¹, Simon Parkinson^{1,2}, David E.H.J. Gernaat^{3,4}, Simon Langan¹, Detlef P. van Vuuren^{3,4} & Keywan Riahi¹

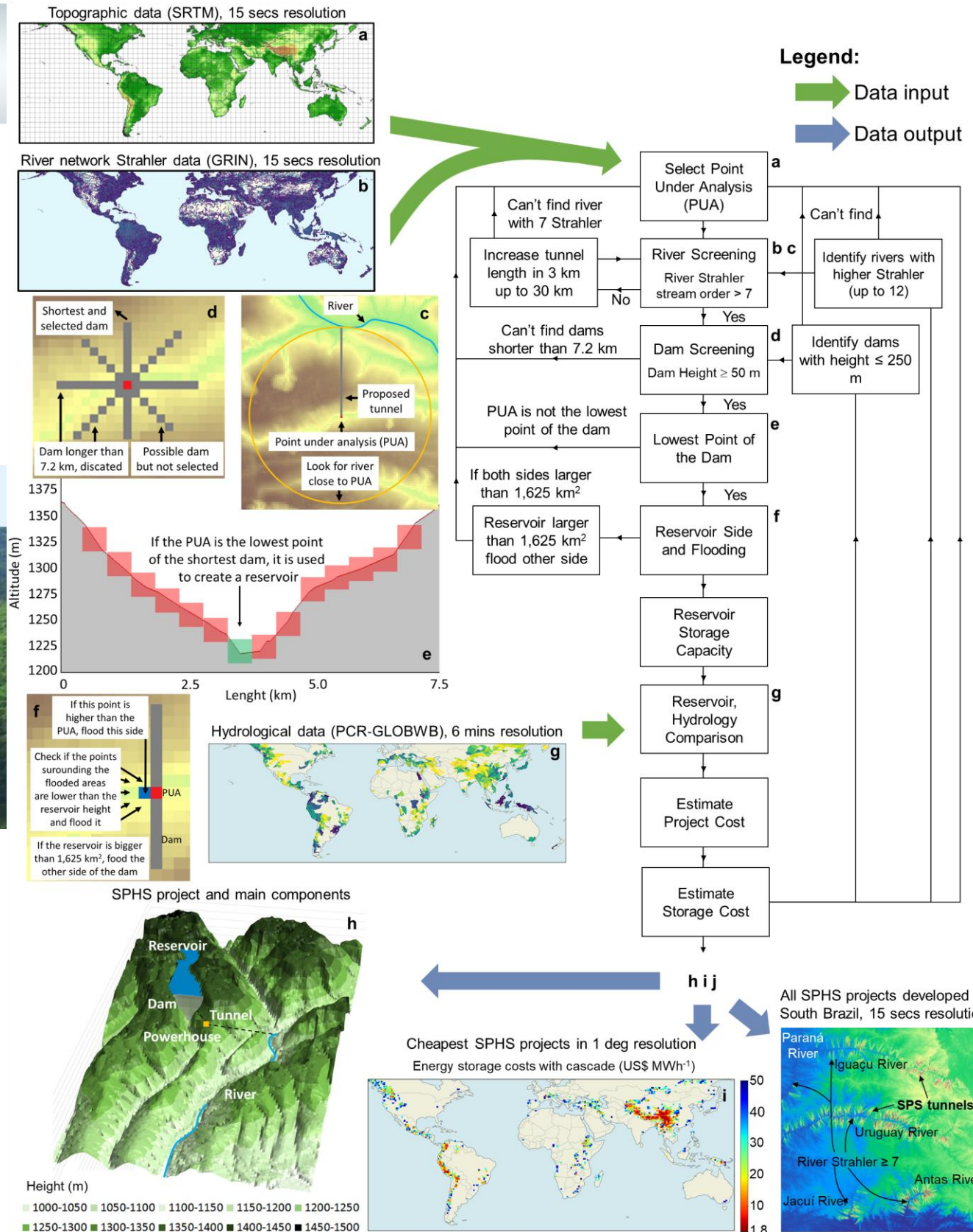
Check for updates

GESEL INÍCIO SOBRE O PROJETO NOTÍCIAS MATERIAL DE REFERÊNCIA RESULTADOS MAPAS UHR

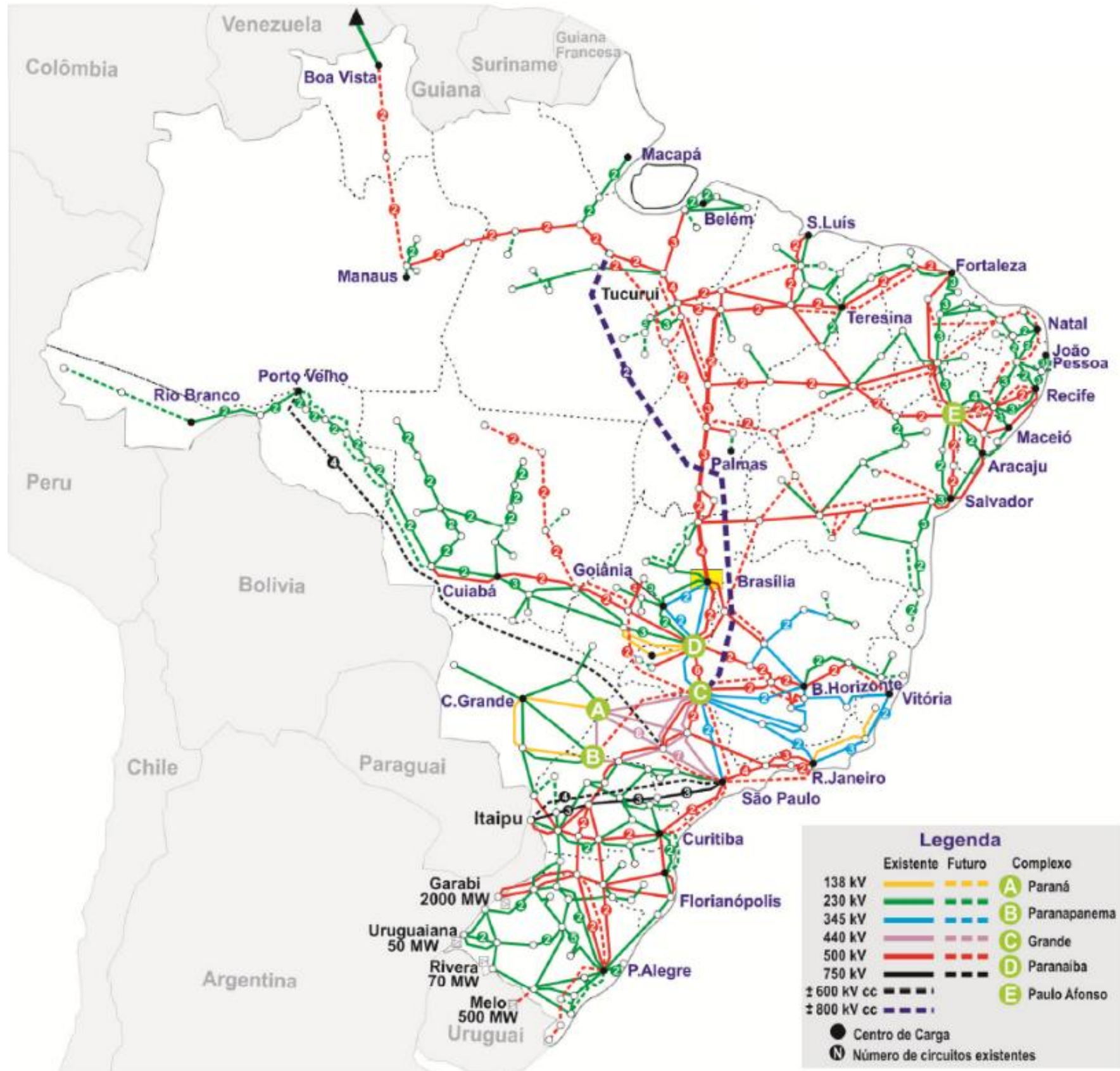
Viabilidade das Usinas Reversíveis no Sistema Interligado Nacional



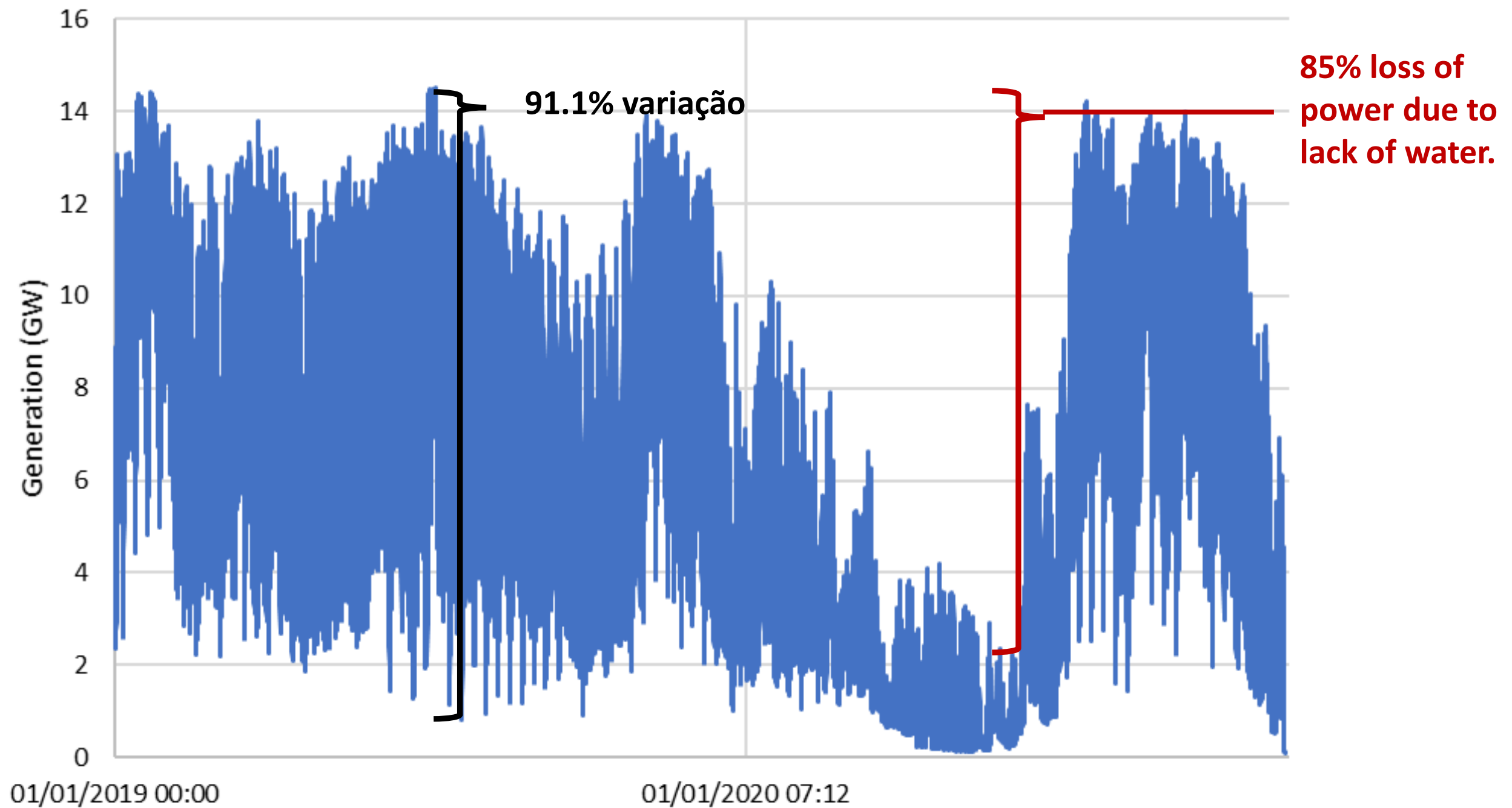
STATE GRID
BRAZIL HOLDING S.A.
国家电网巴西控股公司



UHR Diárias - Otimização de Transmissão no SIN



UHR vs Hidrelétricas para Potência



UHR Semanal

Energy
MWh



Power
GW

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UHR Semanal – Otimização da transmissão de geração eólica no Nordeste



UHR Sazonal

Energy
MWh



Power
GW

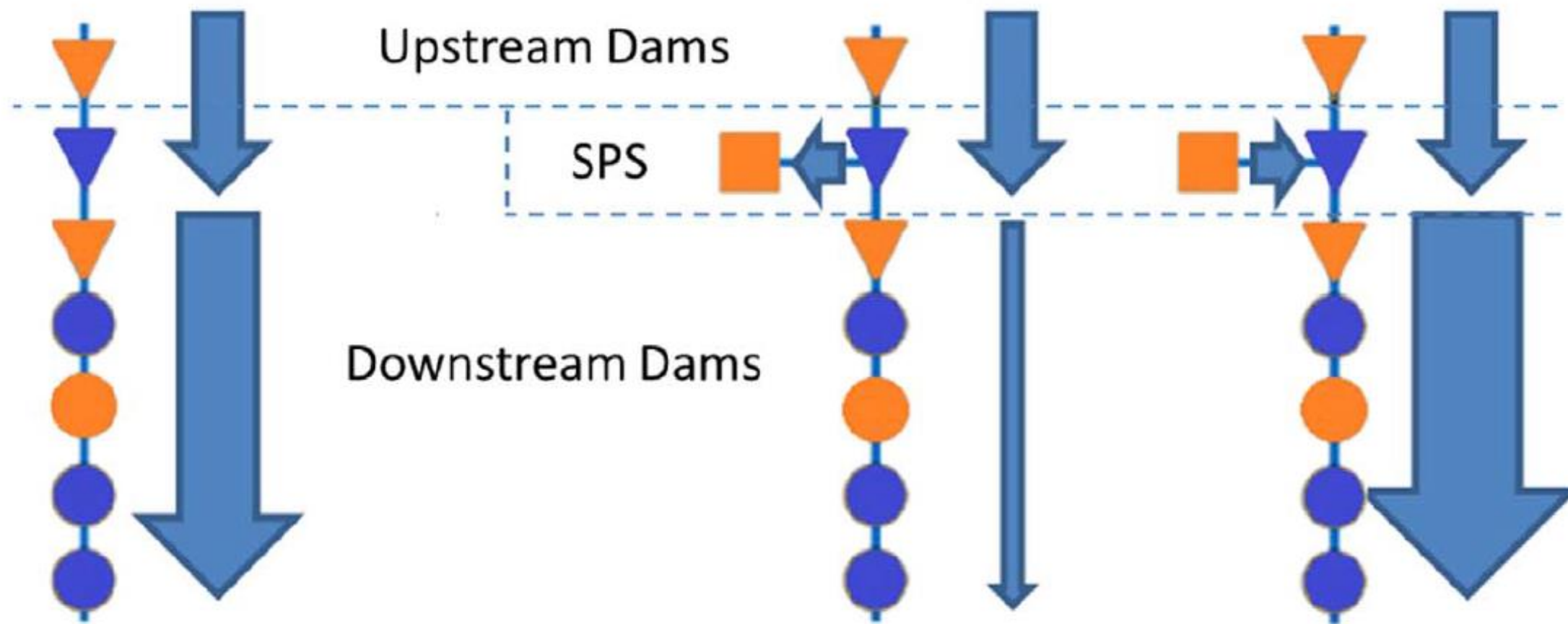
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UHR Sazonal




Convencional Cascade

Cascade with SPS Storing

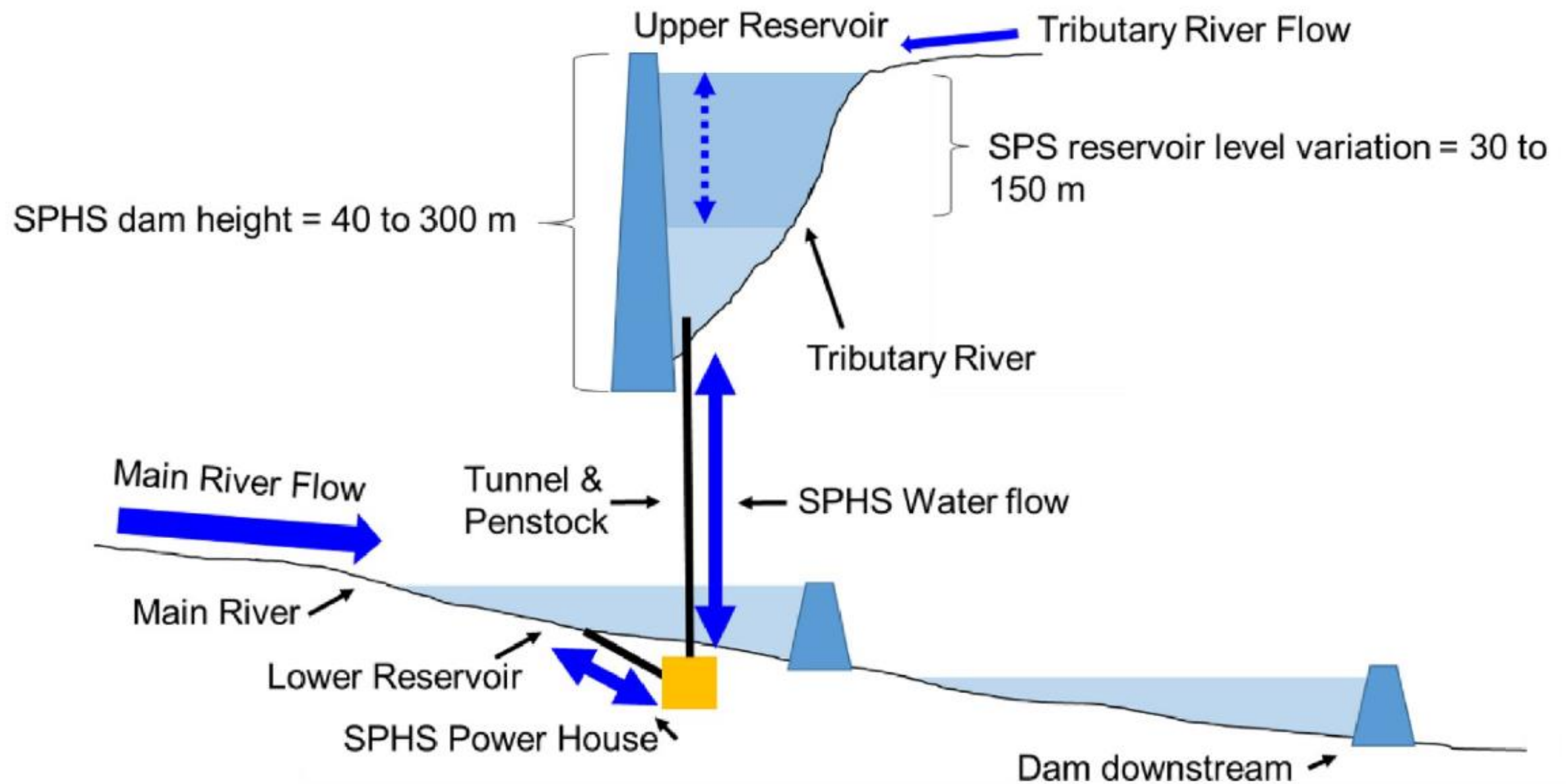
Cascade with SPS Generating



-  Water Flow
-  Existing Reservoir Dam
-  Existing Run-of-the-River Dam

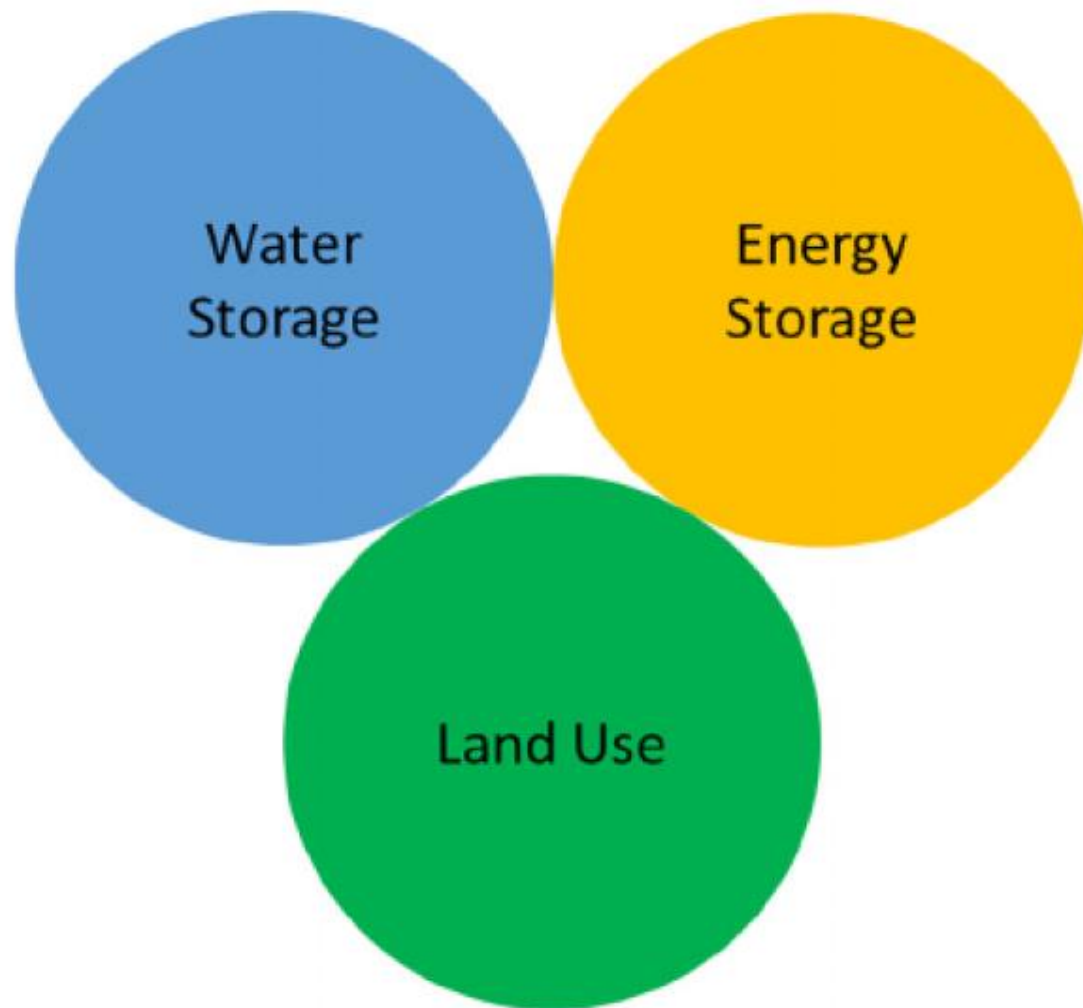
-  Proposed SPS Dam
-  Proposed Reservoir Dam
-  Proposed Run-of-the-River Dam

UHR Sazonal

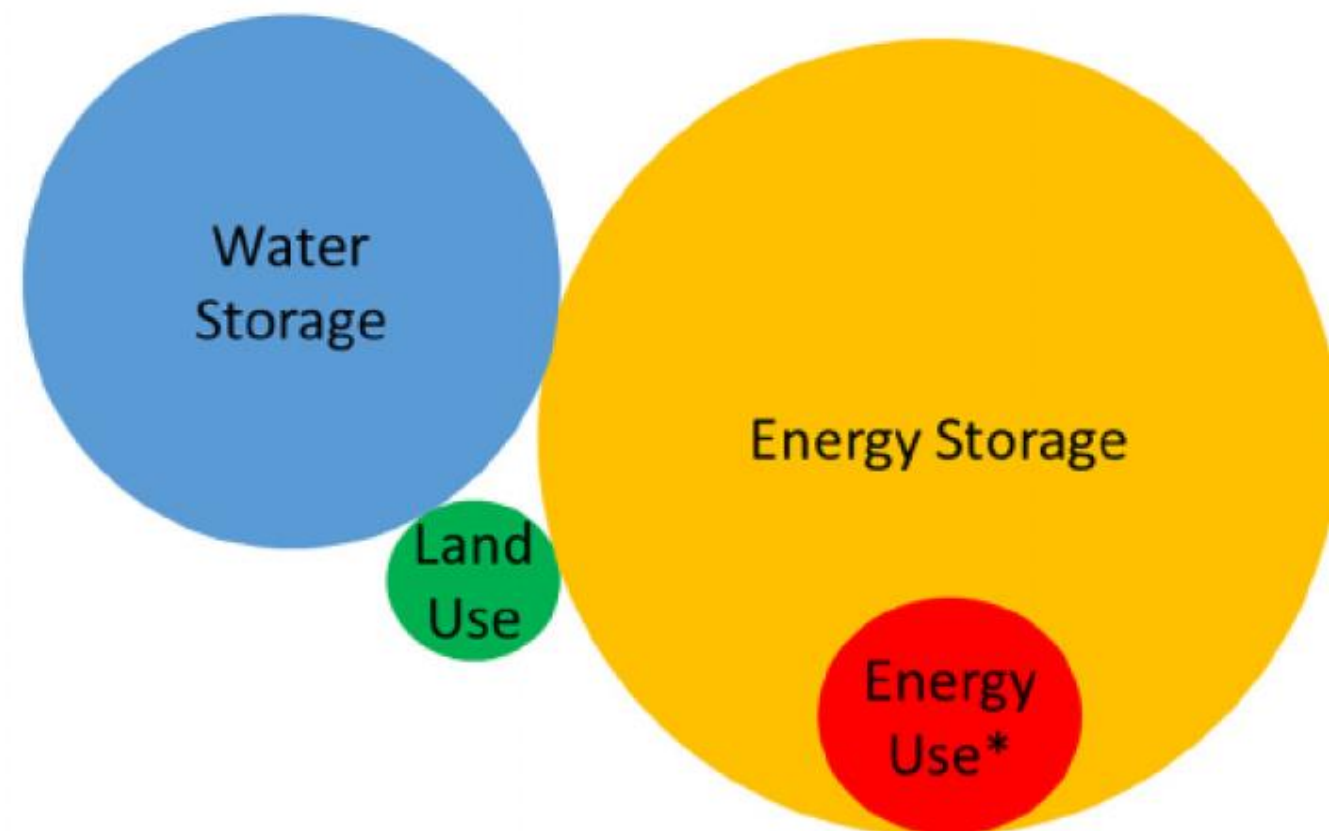


UHR Sazonal

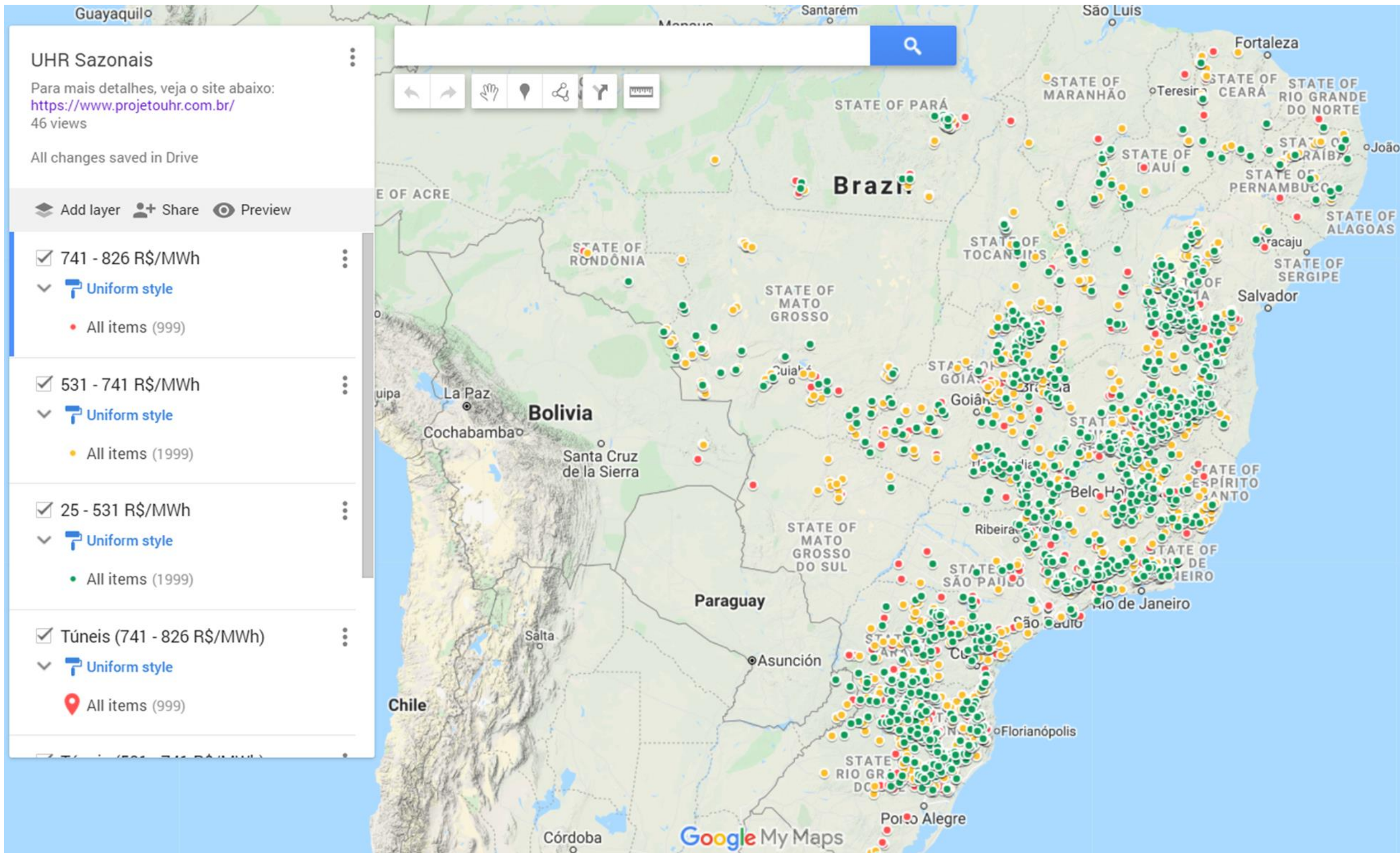
Conventional Reservoir Dams



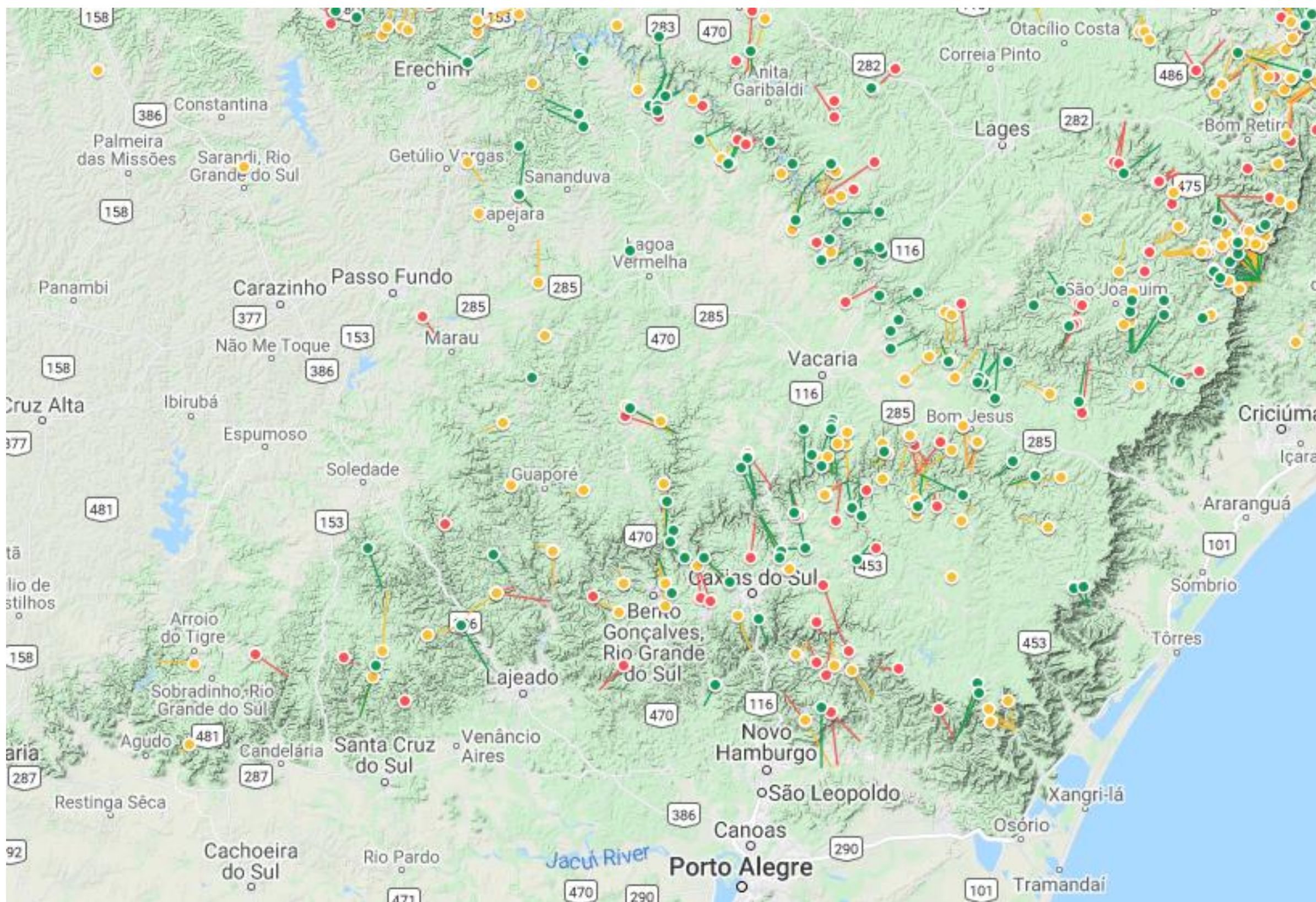
Seasonal Pumped-Storage



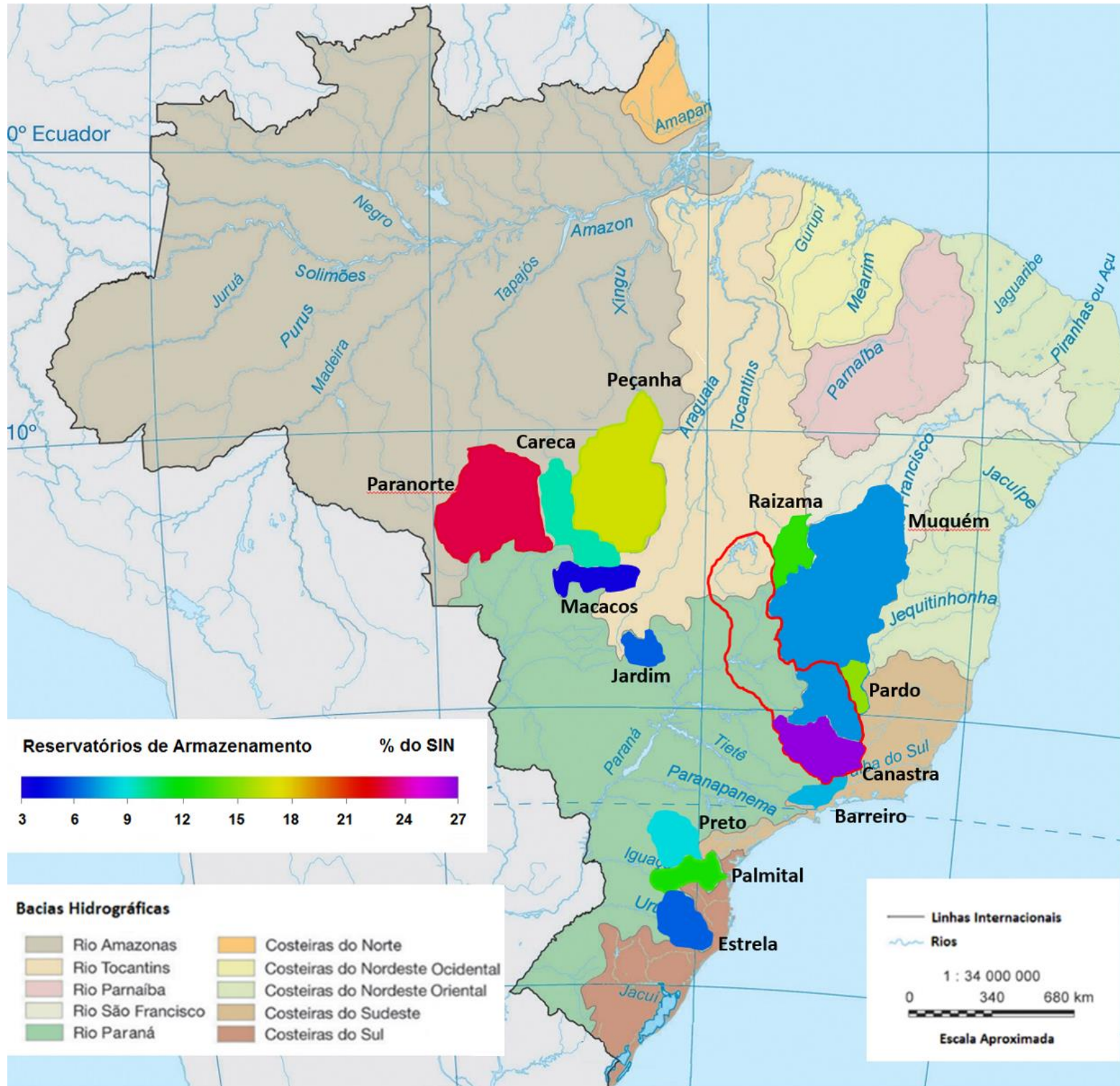
Potencial de UHR Sazonais



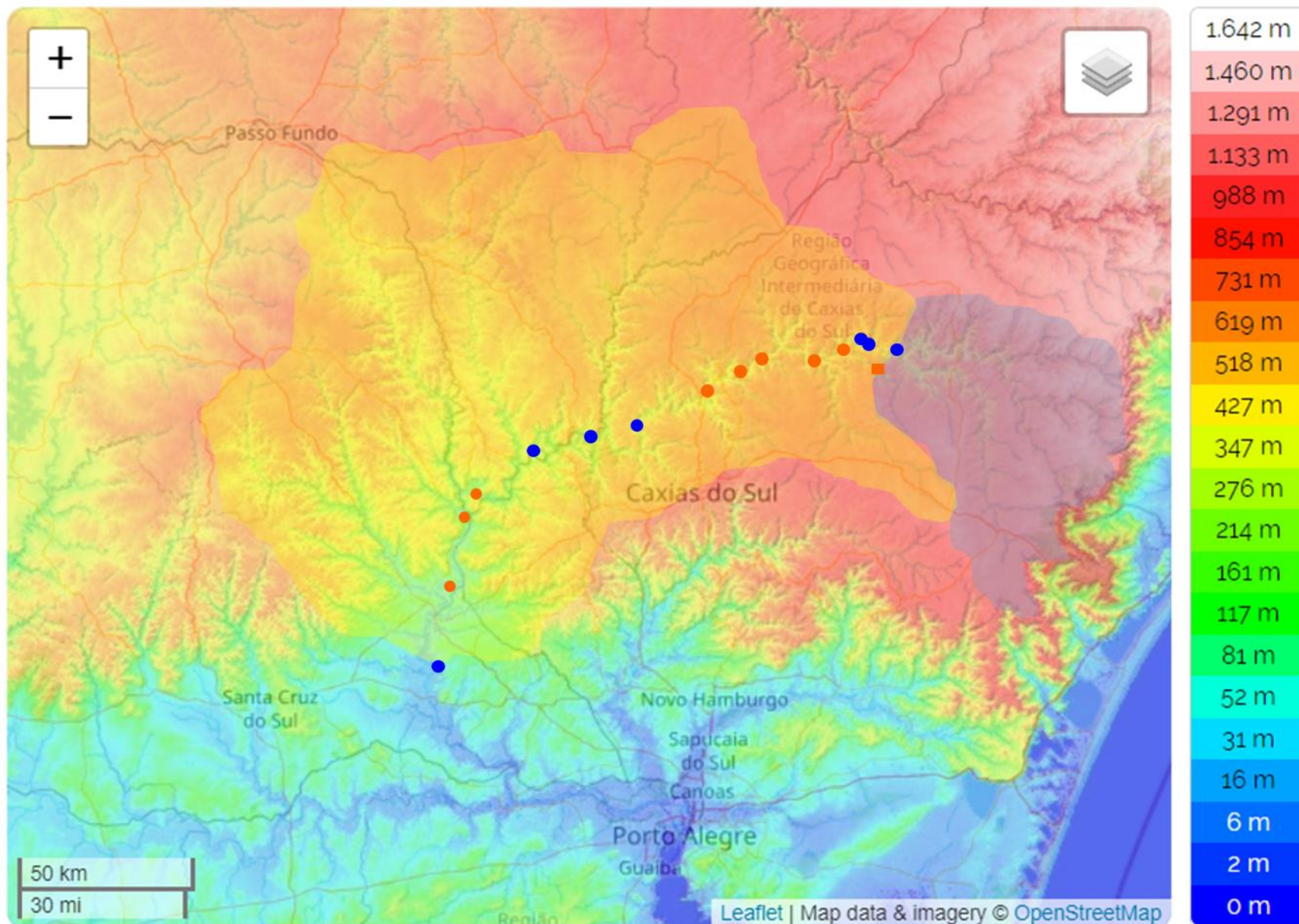
Potencial de UHR Sazonais



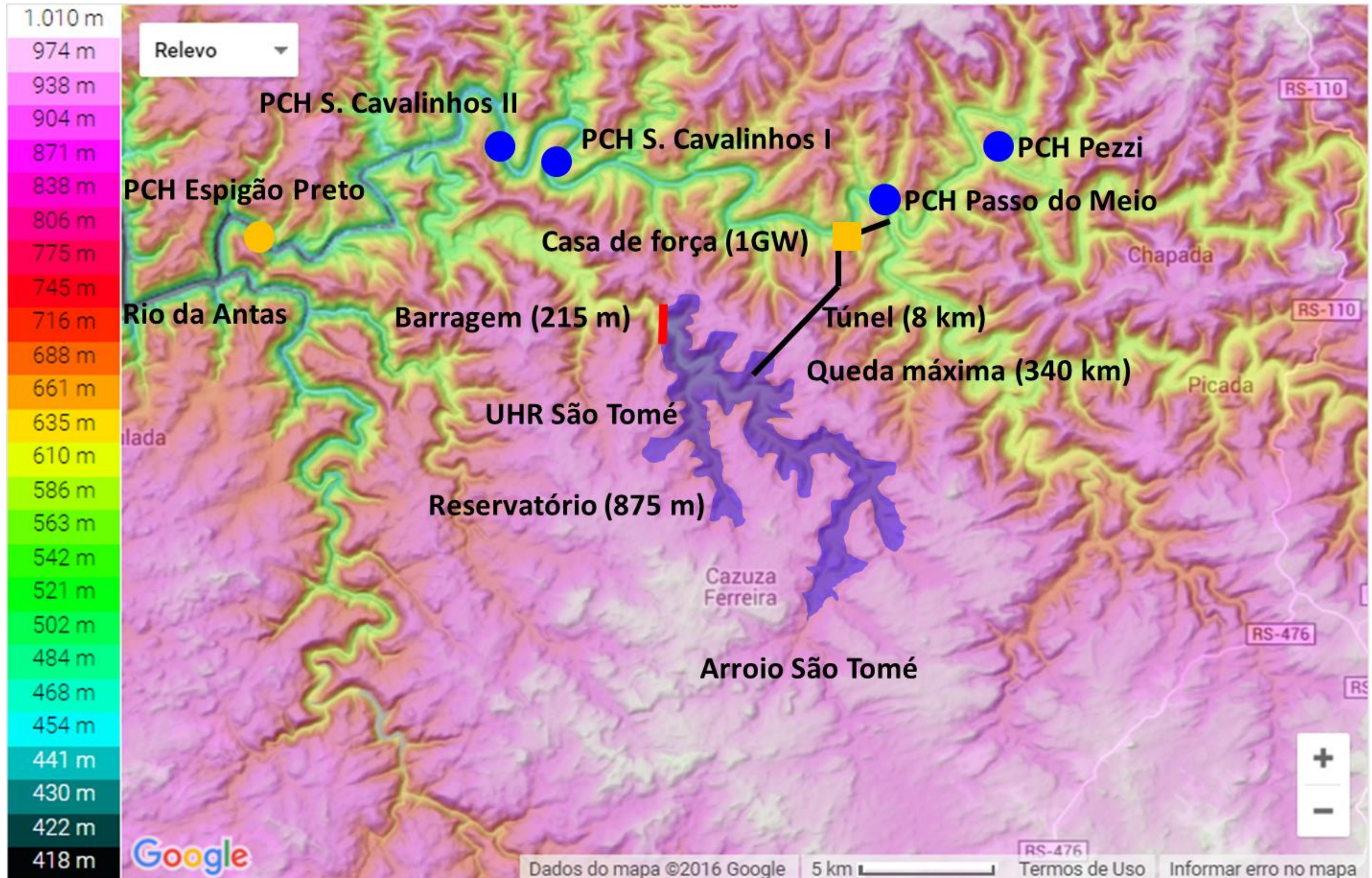
Projetos de UHR Sazonais



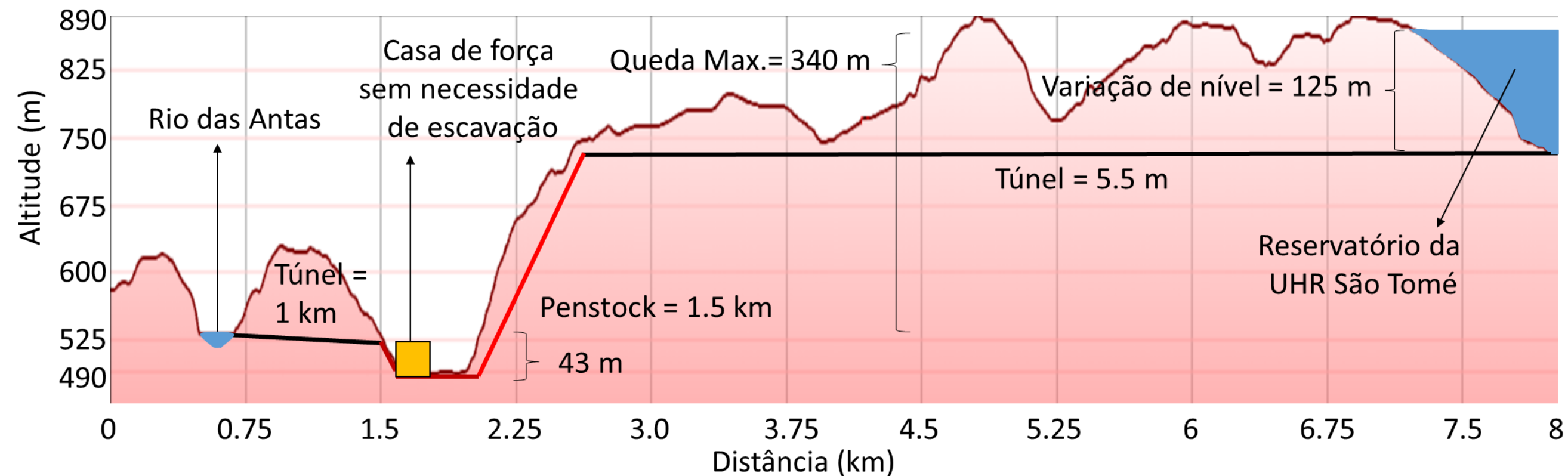
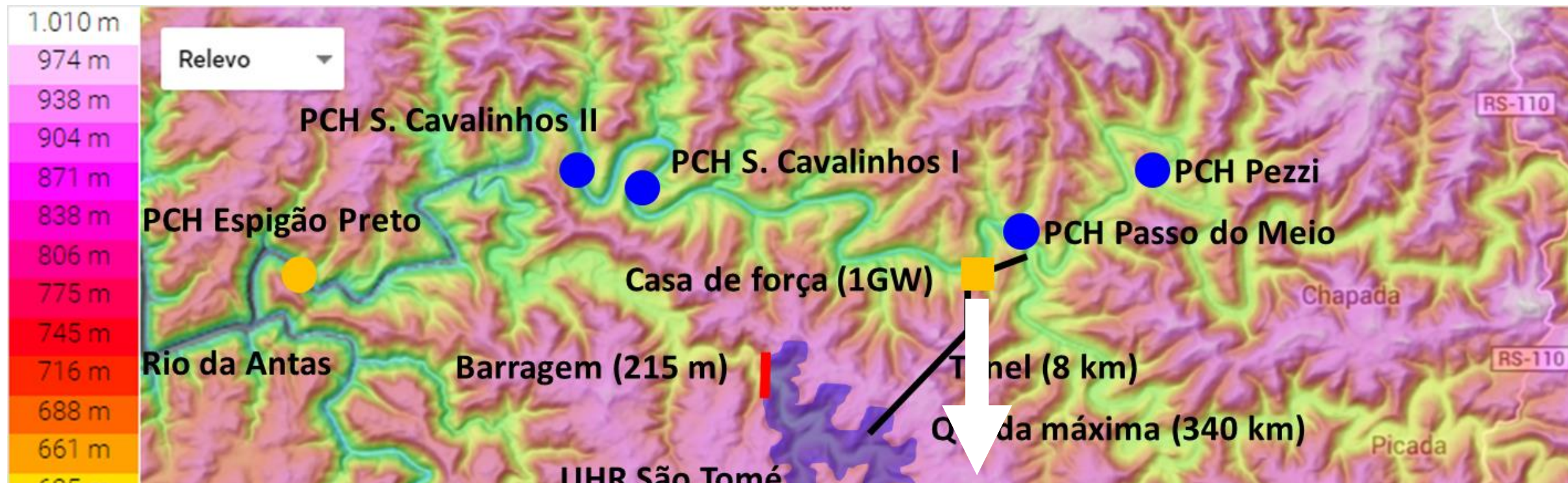
Seasonal PHS



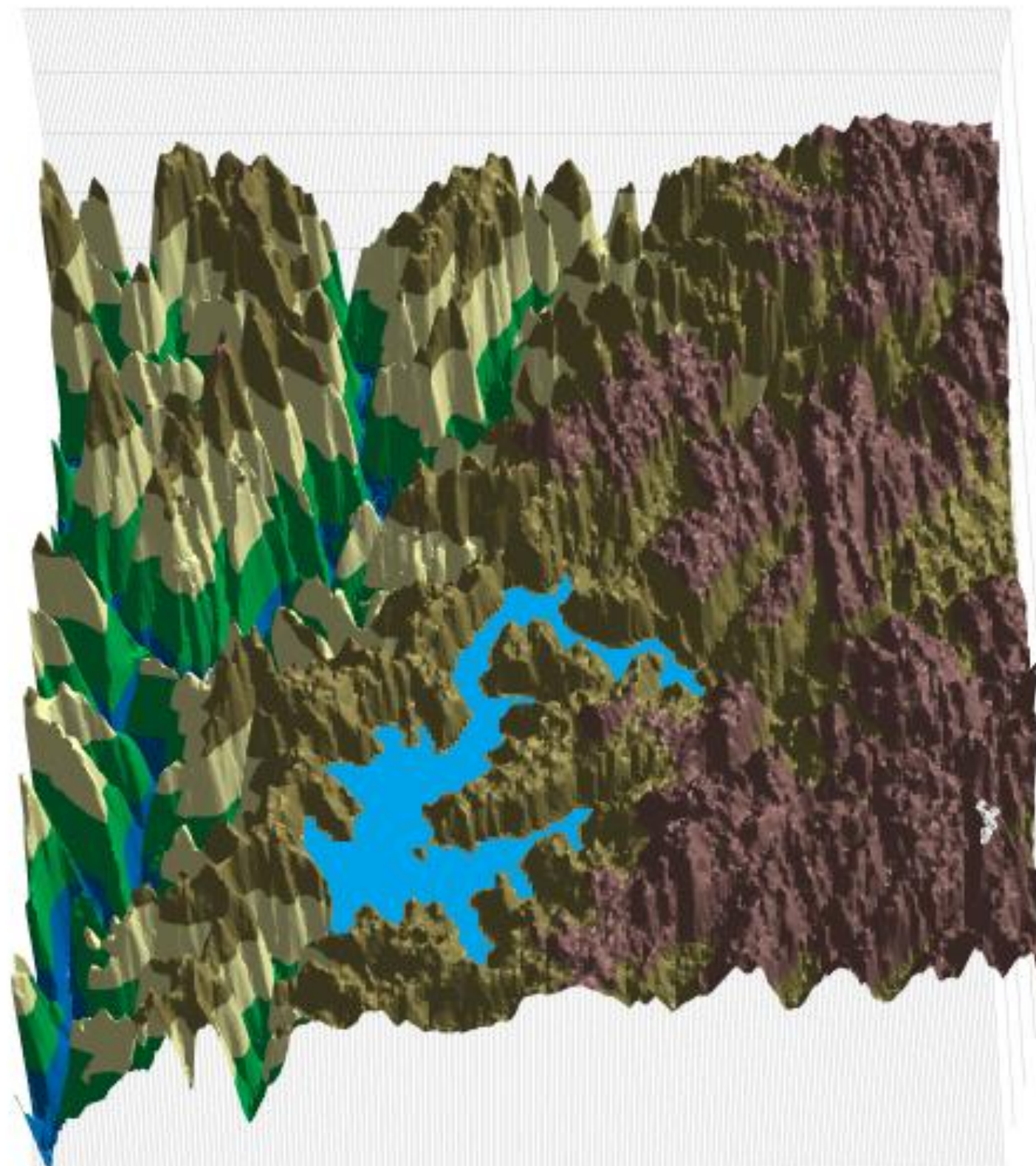
Seasonal PHS



Seasonal PHS

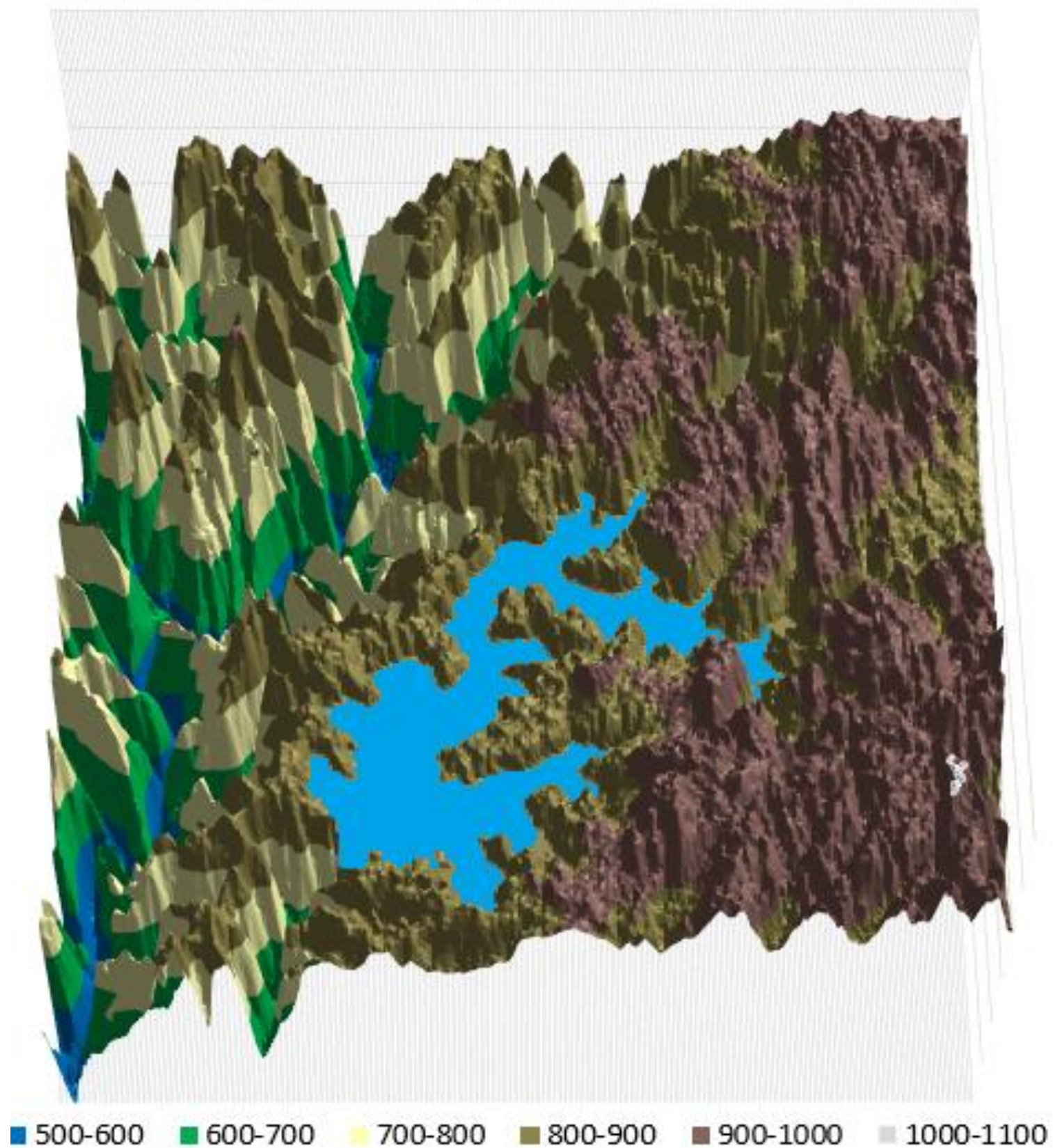


UHRS São Tomé 800 metros

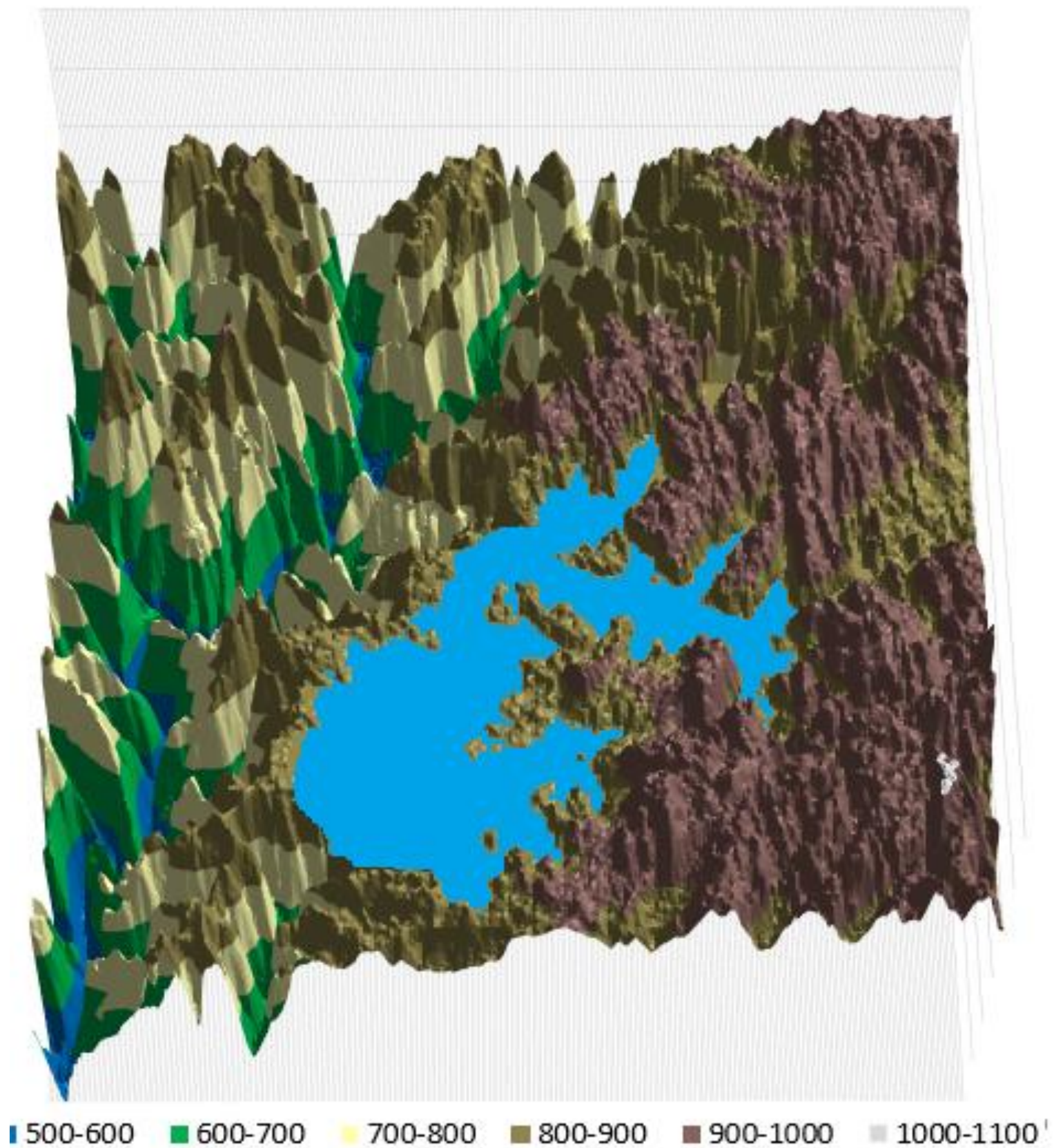


■ 500-600 ■ 600-700 ■ 700-800 ■ 800-900 ■ 900-1000 ■ 1000-1100

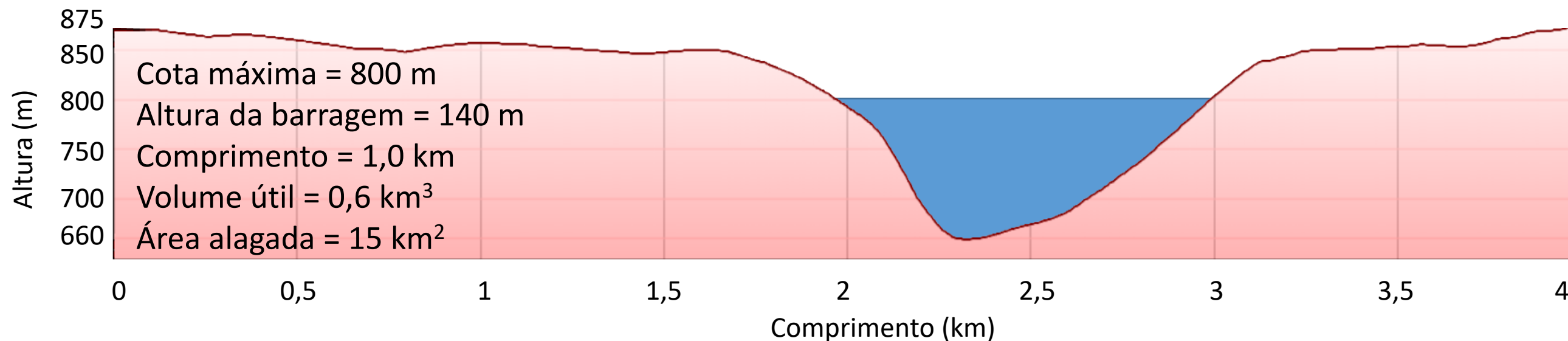
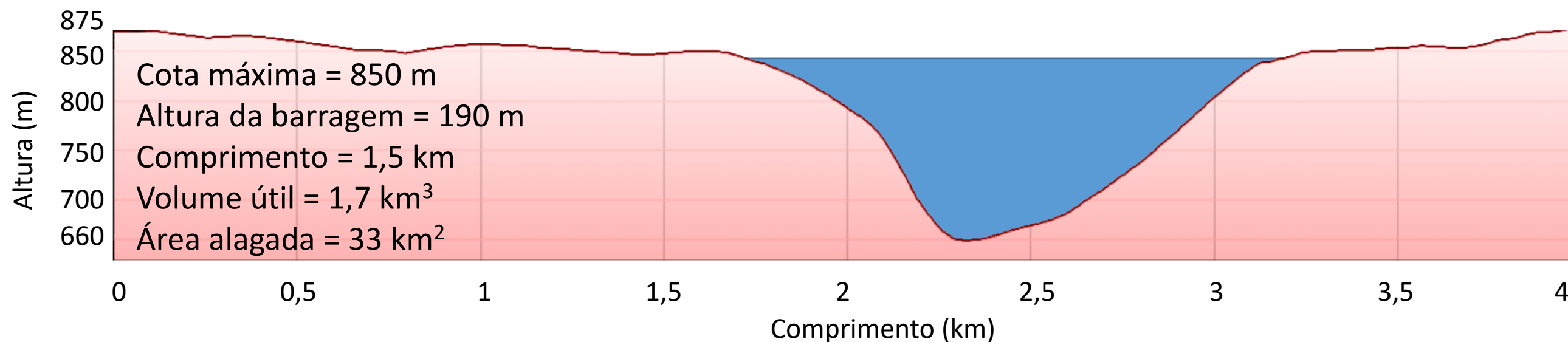
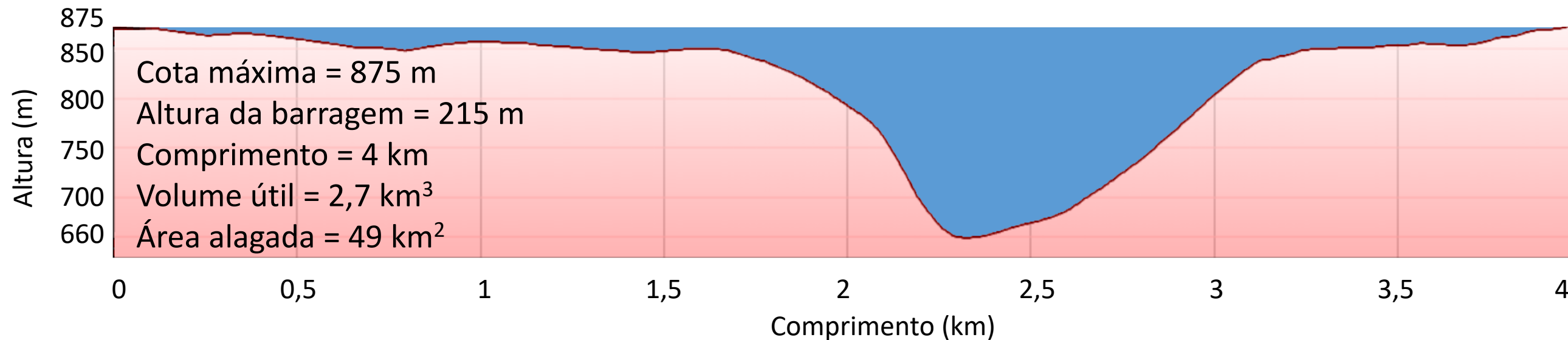
UHRS São Tomé 850 metros



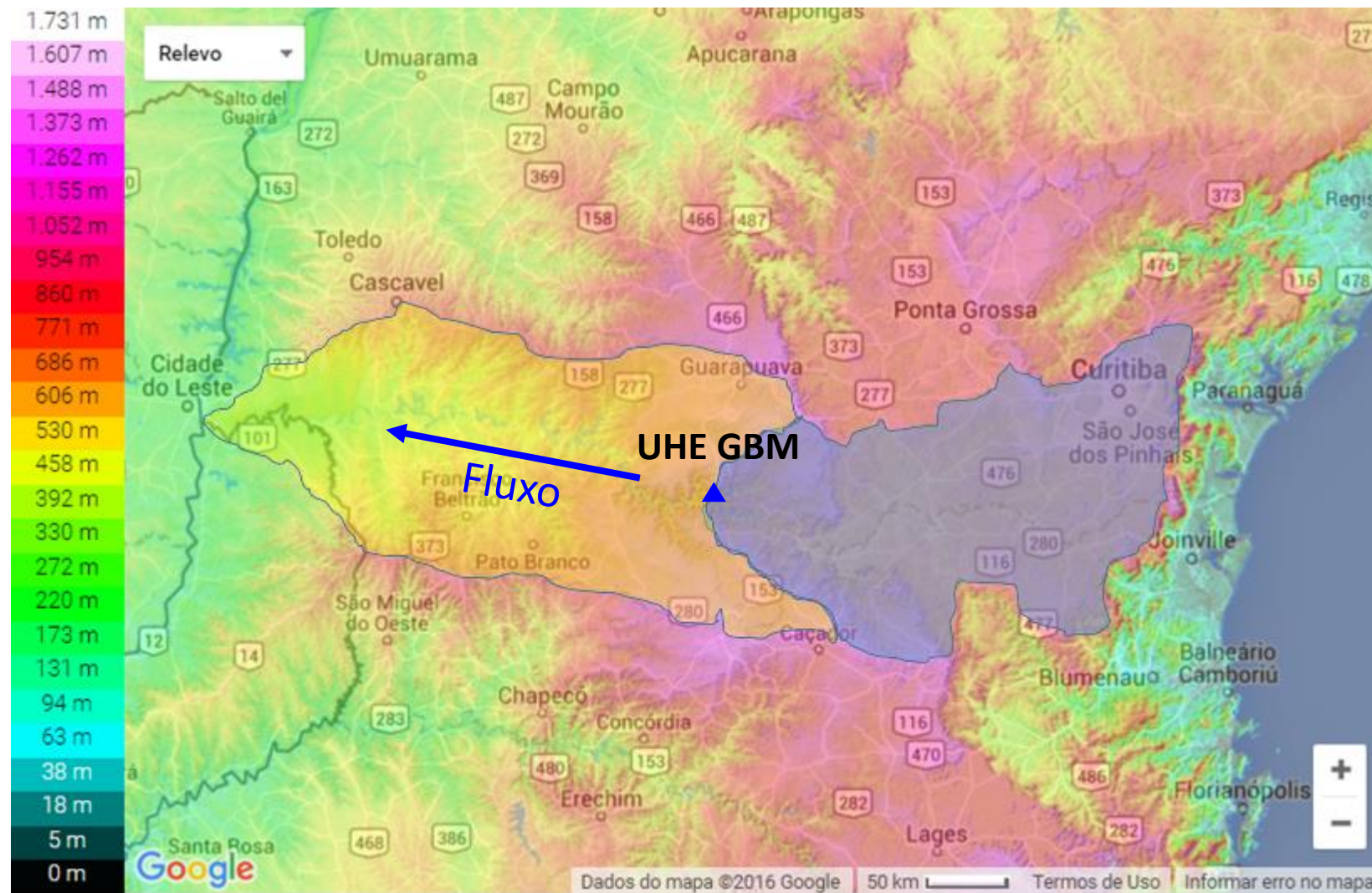
UHRS São Tomé 875 metros



Diferentes Alturas de Barragem



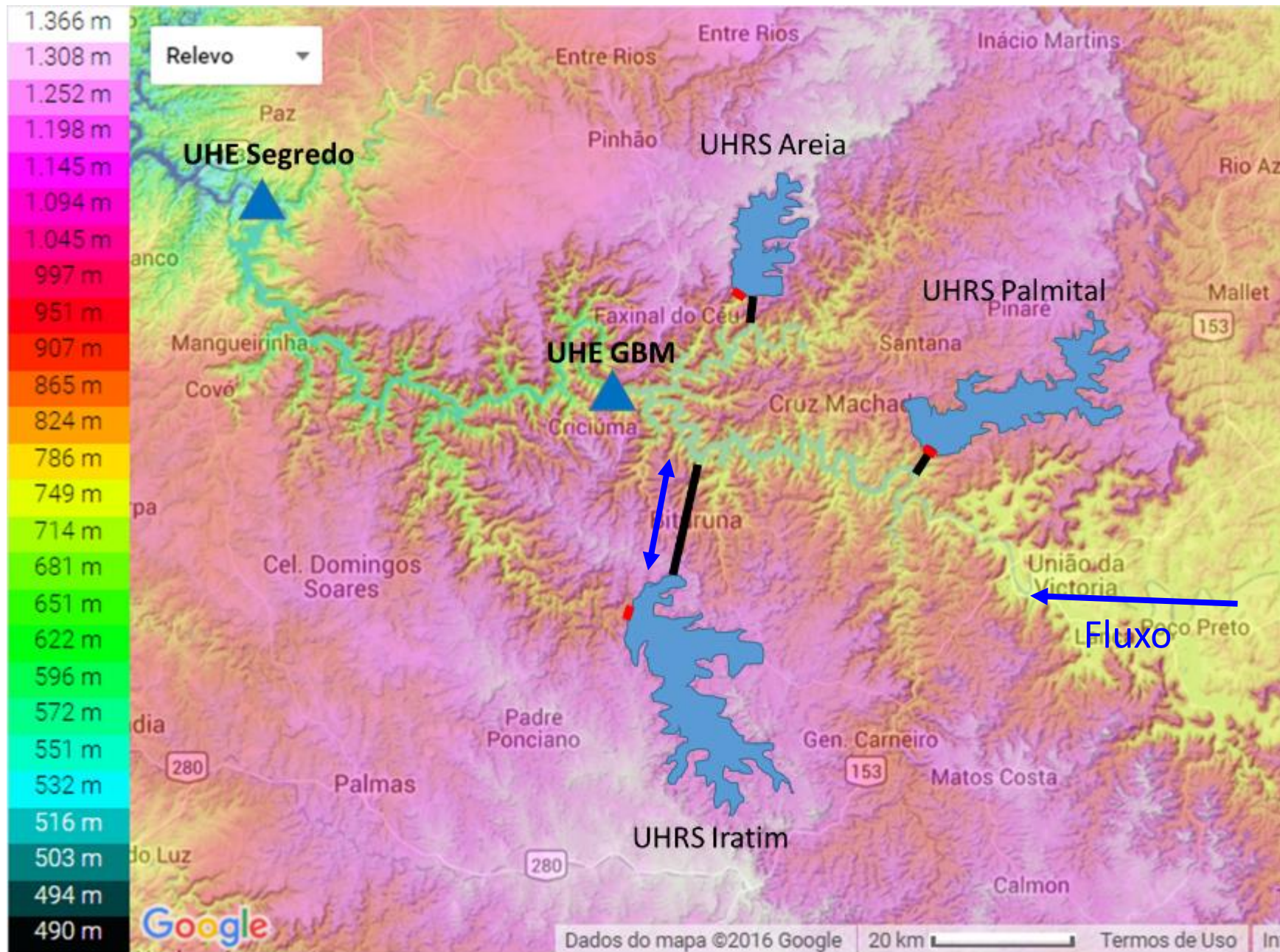
UHR Sazonal no Rio Iguaçu







Área de Captação da UHE GBM

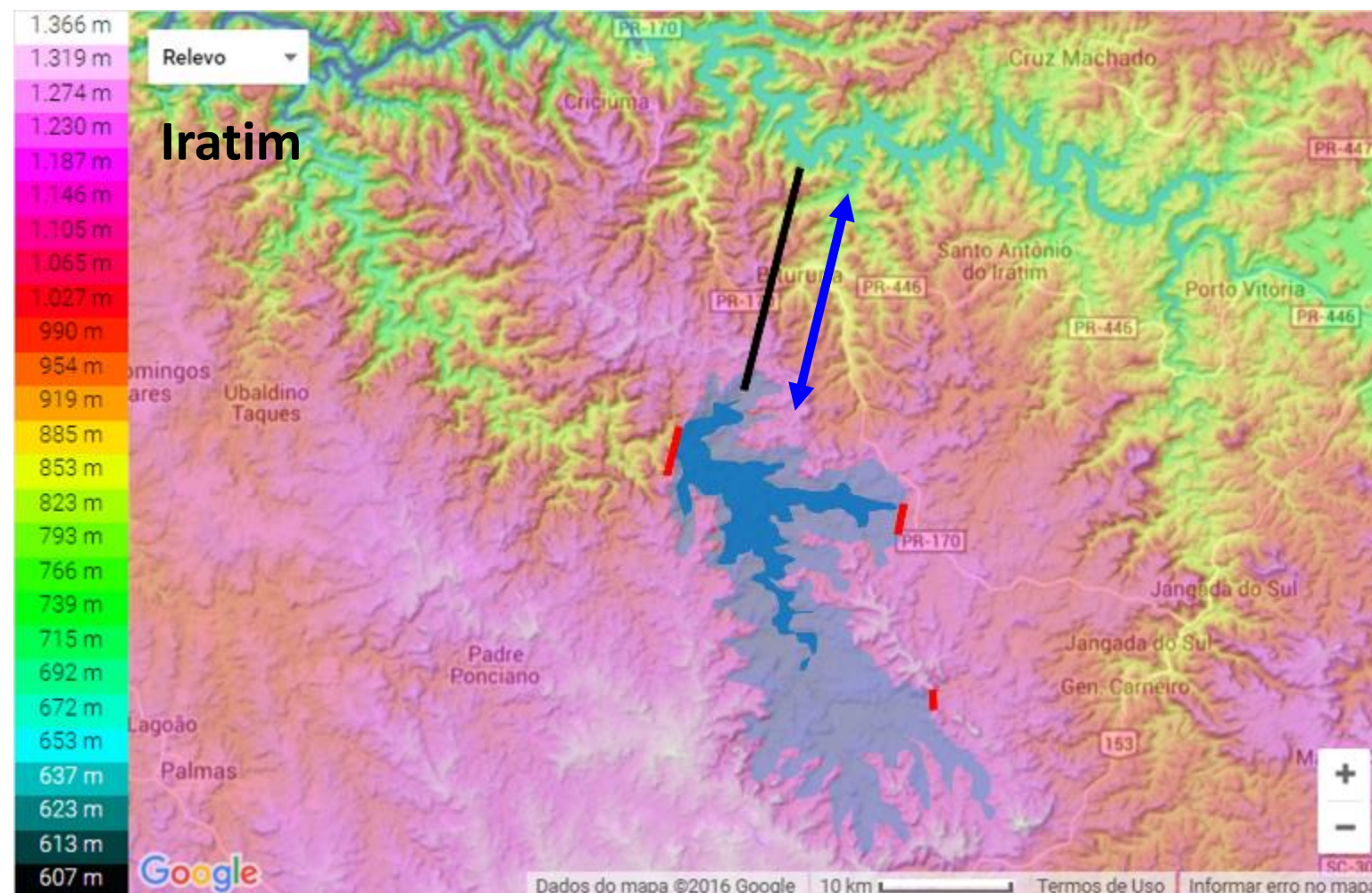
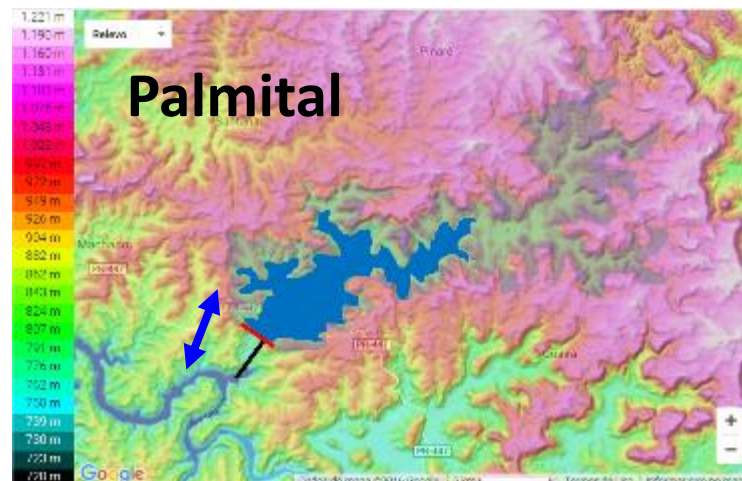
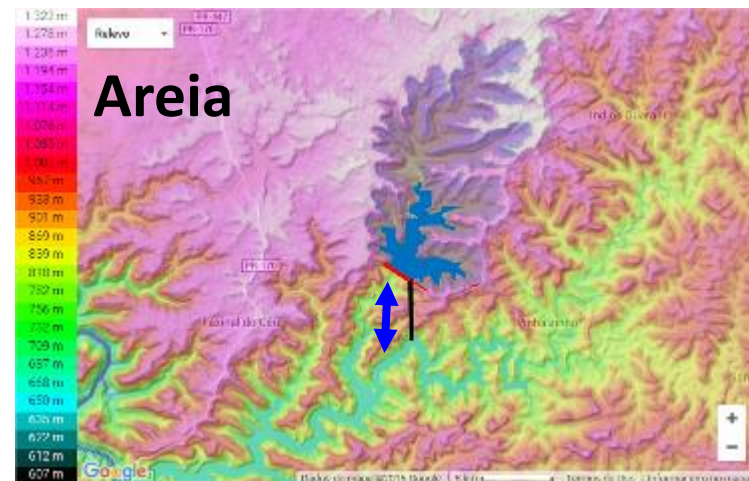
Área de Captação do Rio Iguaçu a Jusante da UHE GBM

UHR Sazonal no Rio Iguaçu



-  Cota Máxima das UHRs propostas
-  Tubulações
-  Barragens
-  UHEs

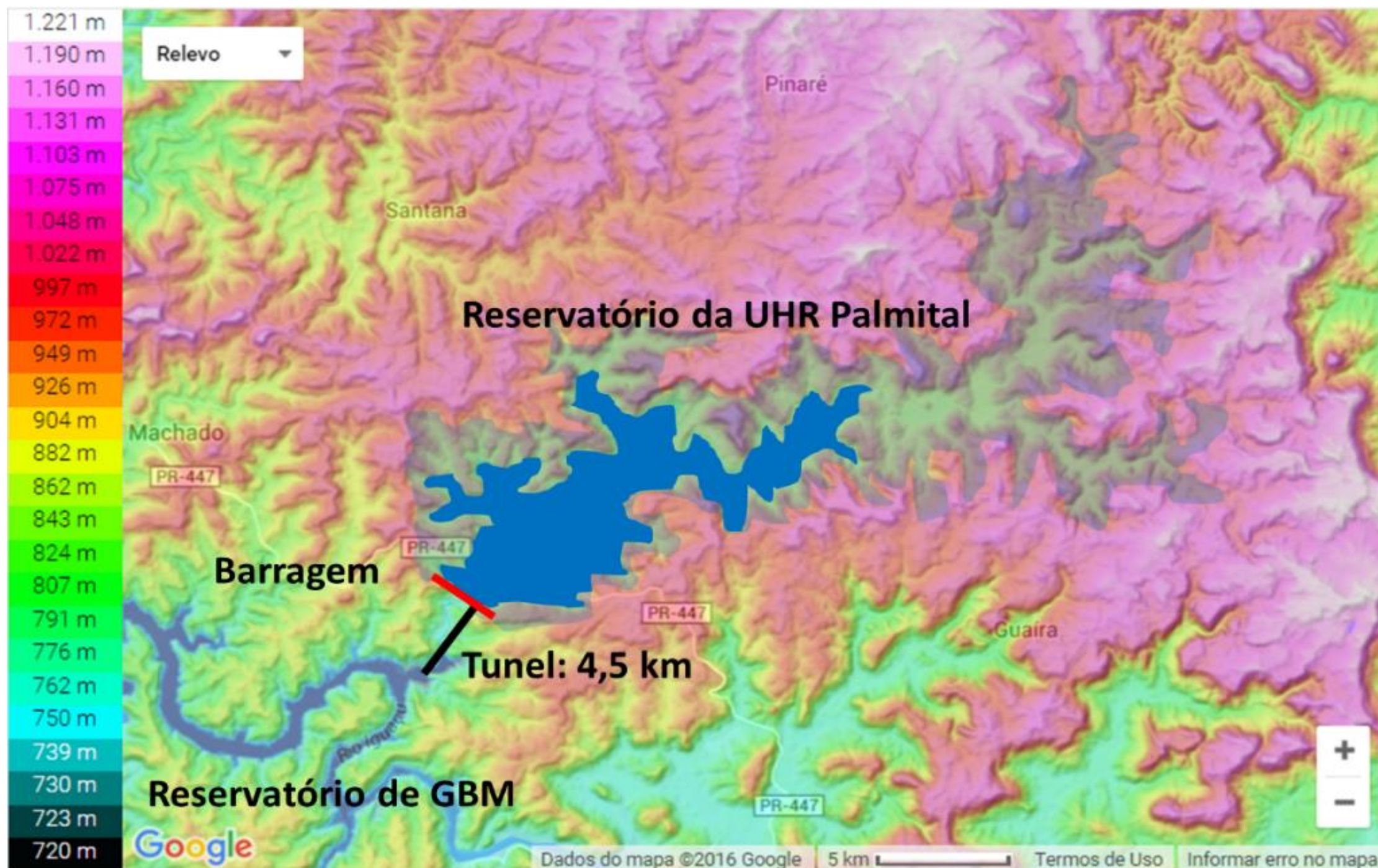
UHR Sazonal no Rio Iguaçu



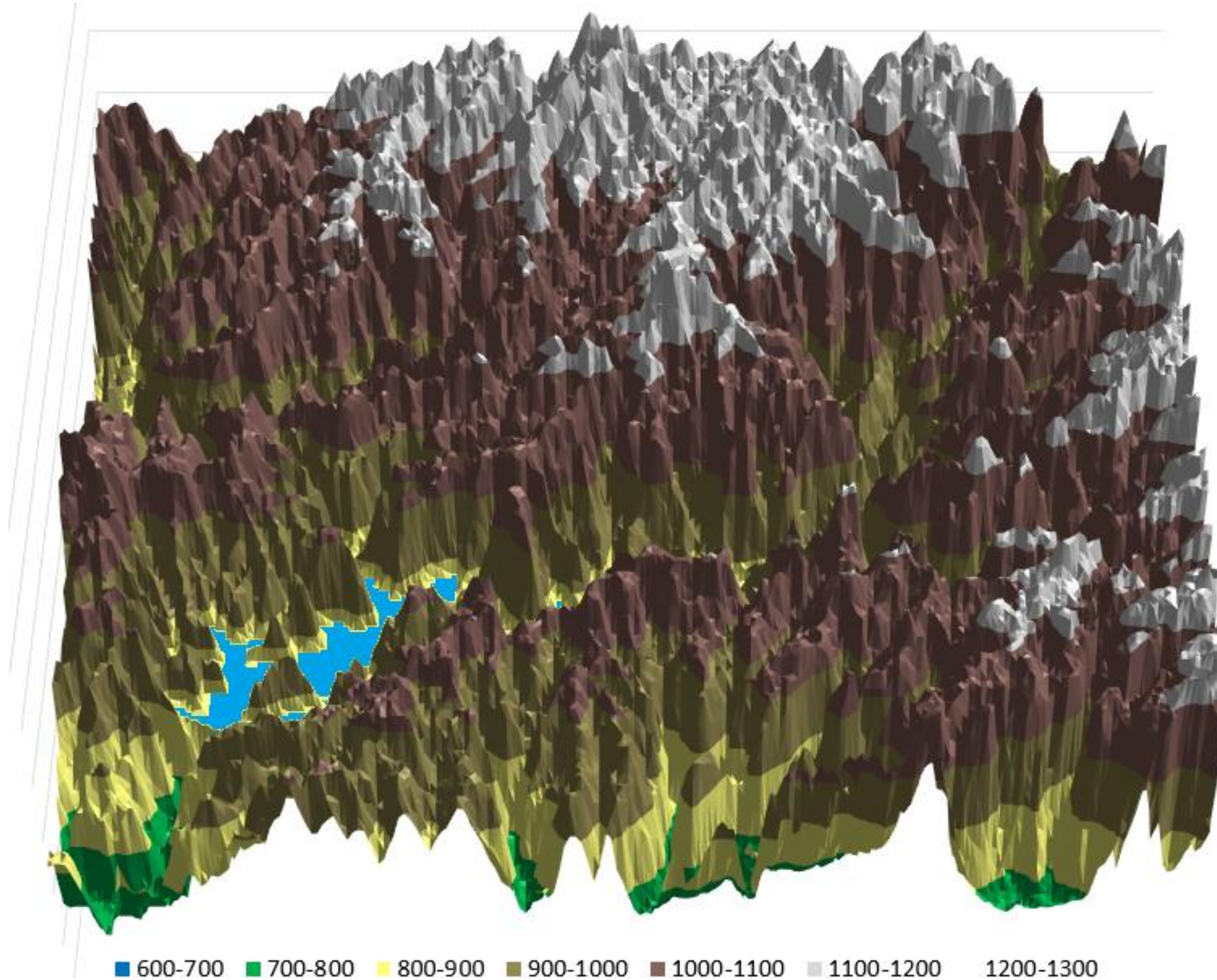
	Areia	Palmital	Iratim
Cotas Máxima / Mínima (m)	1.100 / 900	1.000 / 850	1.150 / 1,050
Variação de Cota (m)	200	150	100
Queda das UHE a Jusante (m)	480	480	480
Altura Max. da Barragem (m)	300	220	250
Comp. da Barragem (km)	3	2,5	5
Tubulação (m)	4,5	4	17
Volume Útil (hm ³)	8.700	13.700	14.400
Área Alagada (km ²)	92	177	241
Área de Drenagem (km ²)	30.100	30.100	30.100
Vazão de Bombeamento (m ³ /s)	551,7	868,8	913,2
Armazenamento (GWmed / % SIN)	23,1 / 7,9	33,1 / 11,4	42,7 / 14,7
Eficiência Sistêmica (%)	104,1	110,9	97
Potência para Ciclo Anual (GW)	2,2	2,7	4,7

* Armazenamento total do SIN = 292 GWmed

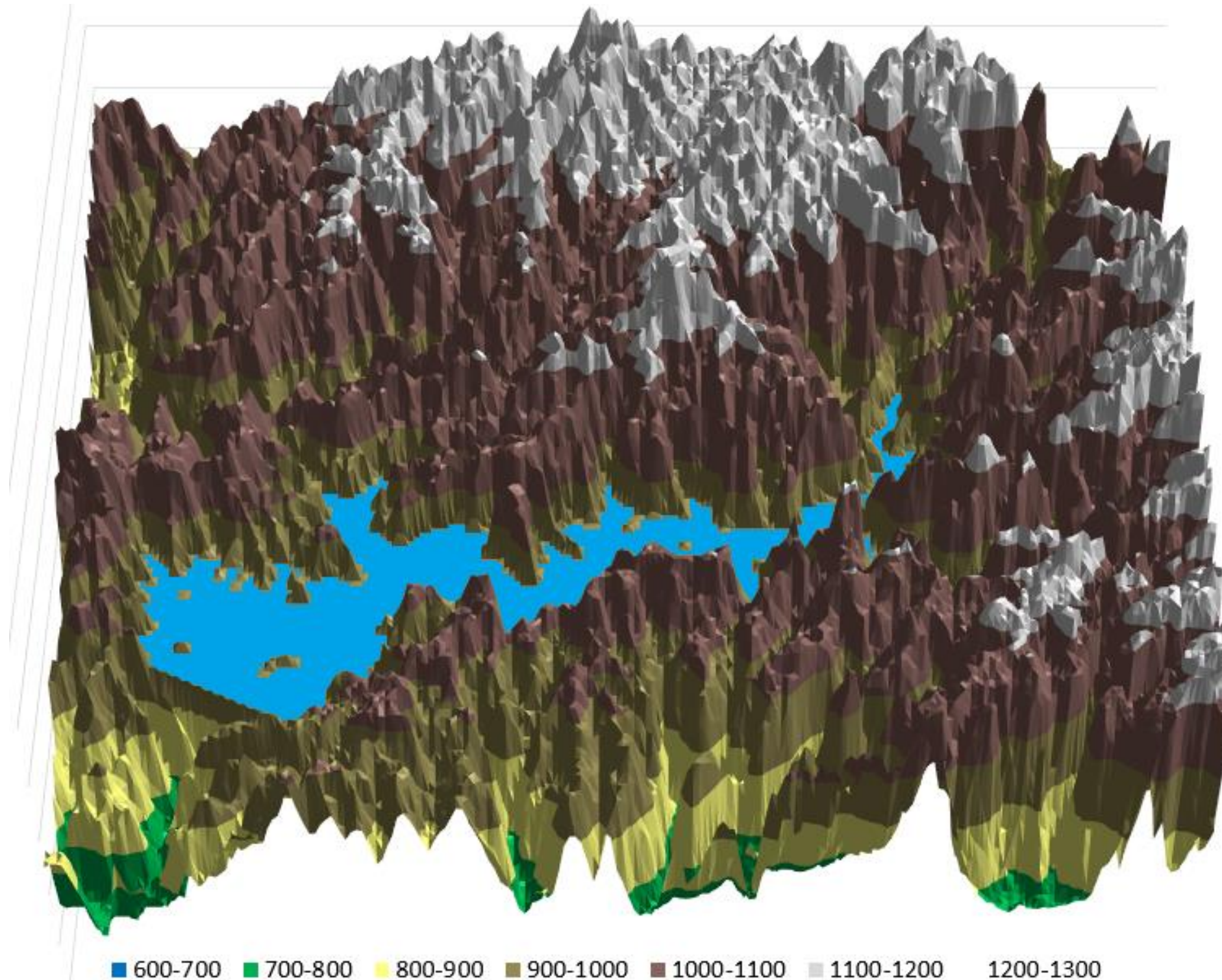
UHRS Palmital no Rio Iguaçu



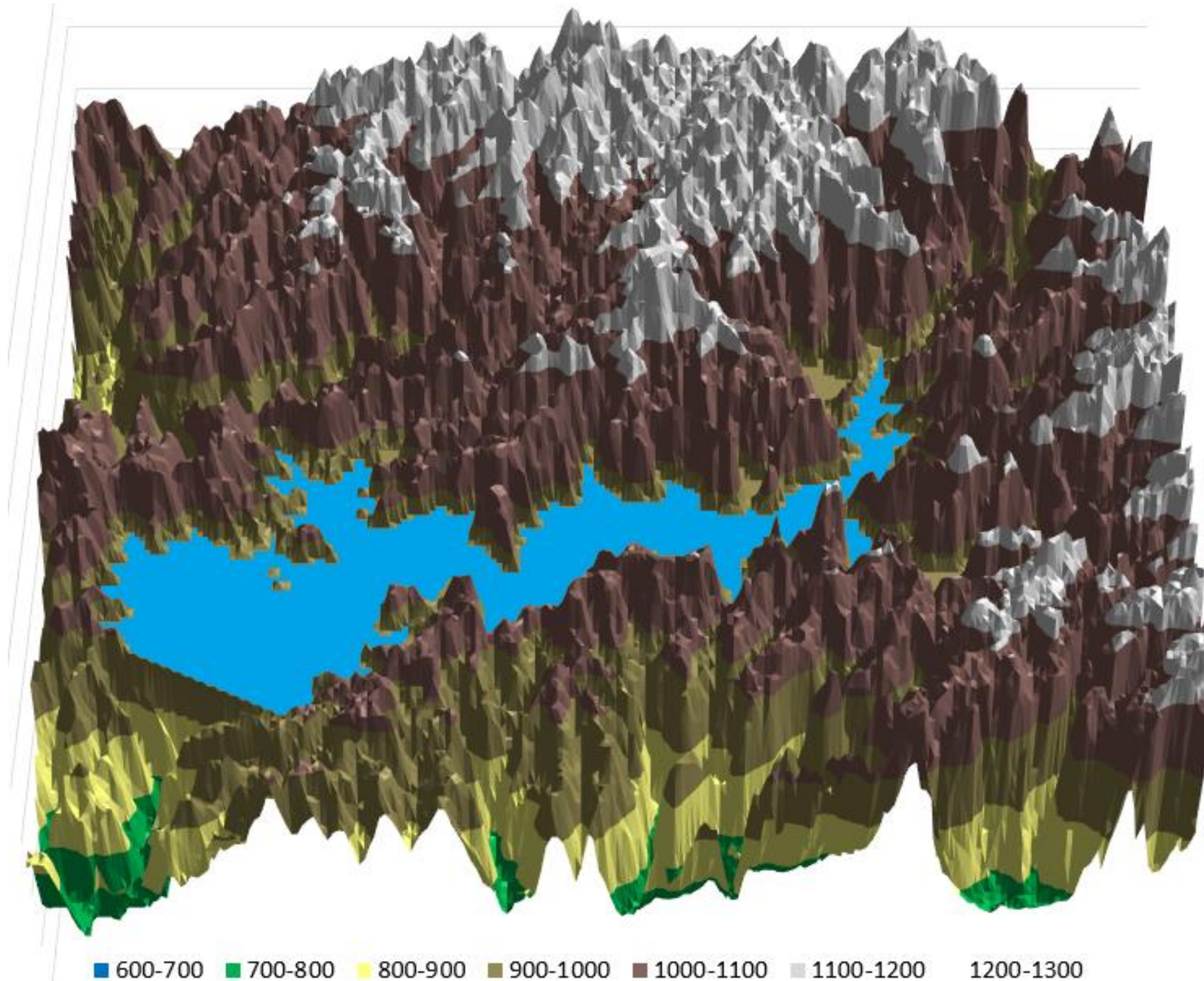
UHRS Palmital 880 metros



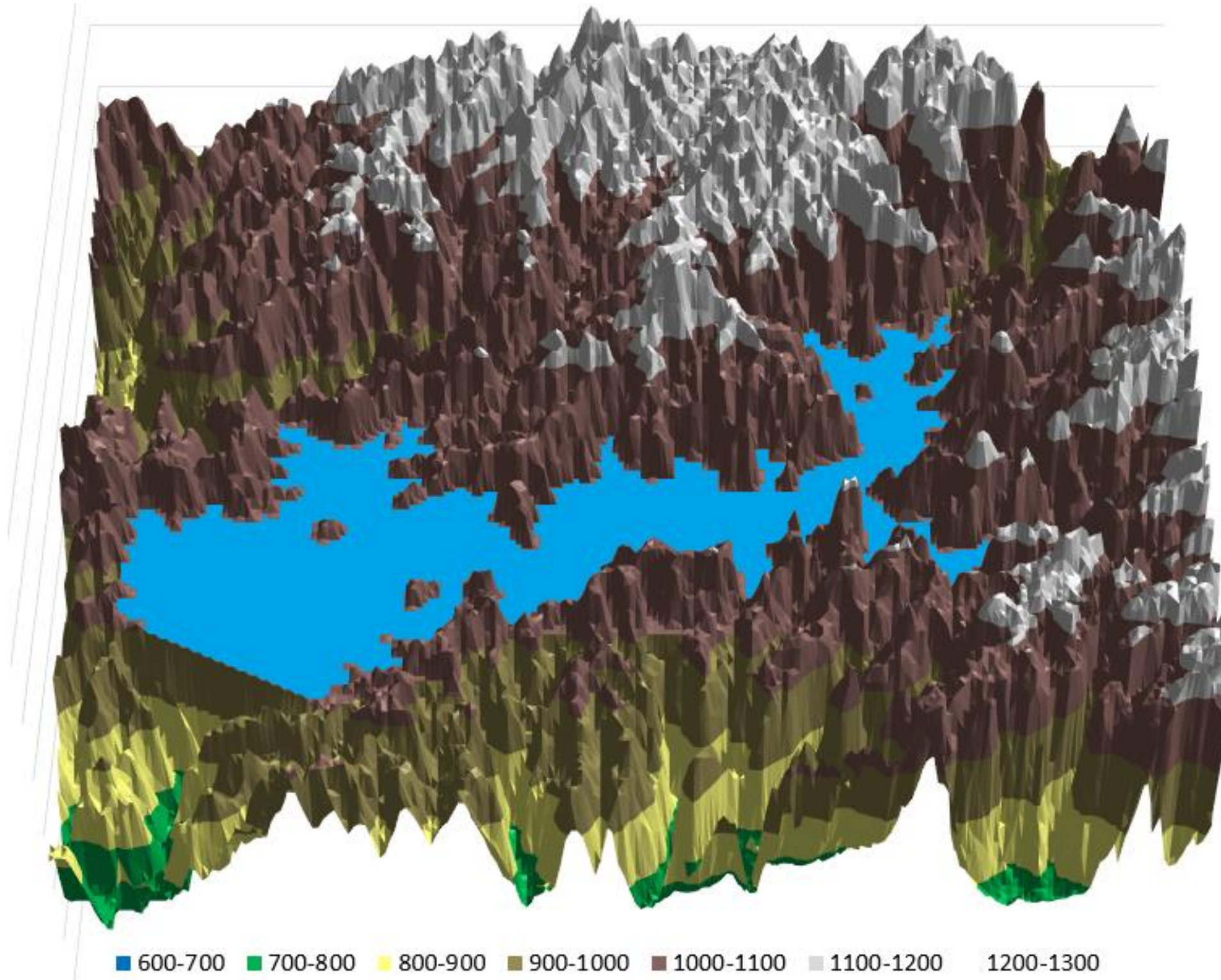
UHRS Palmital 950 metros



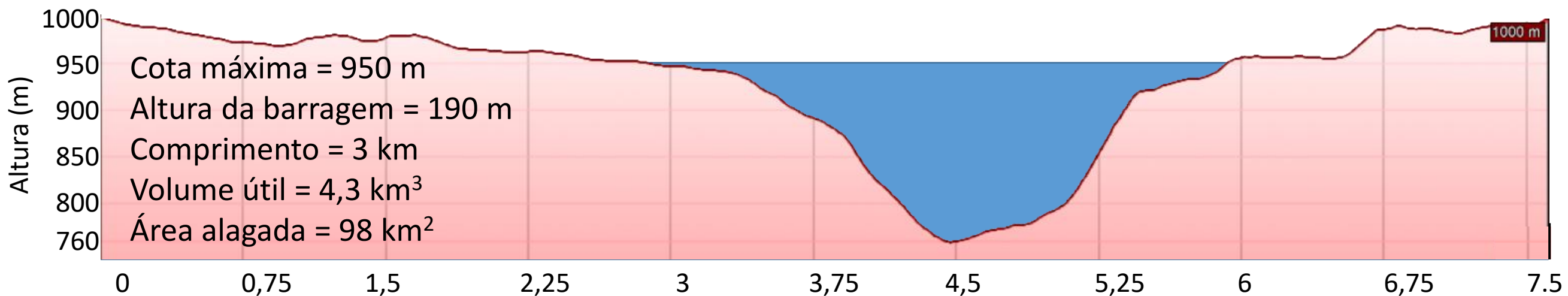
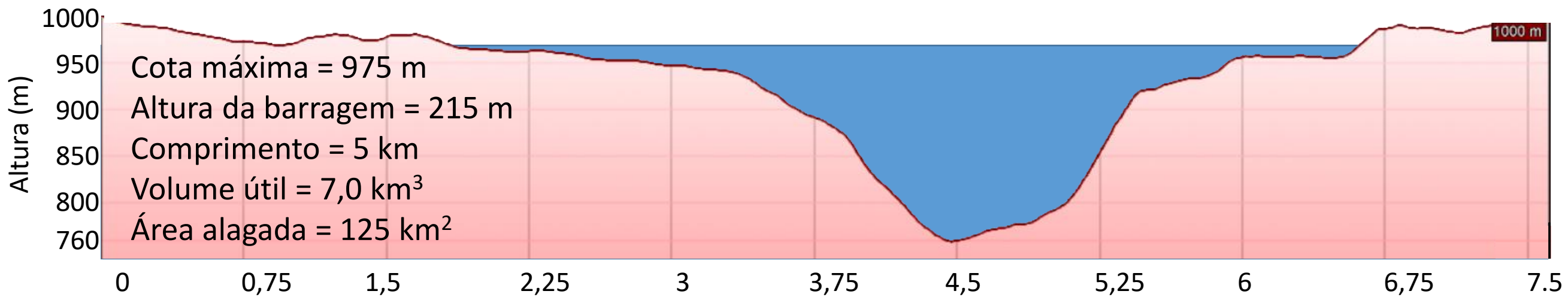
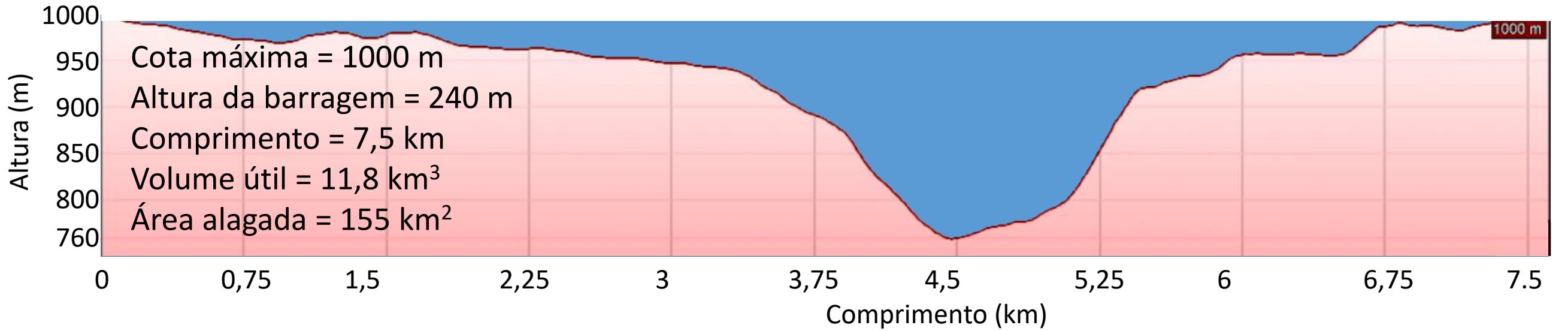
UHRS Palmital 975 metros



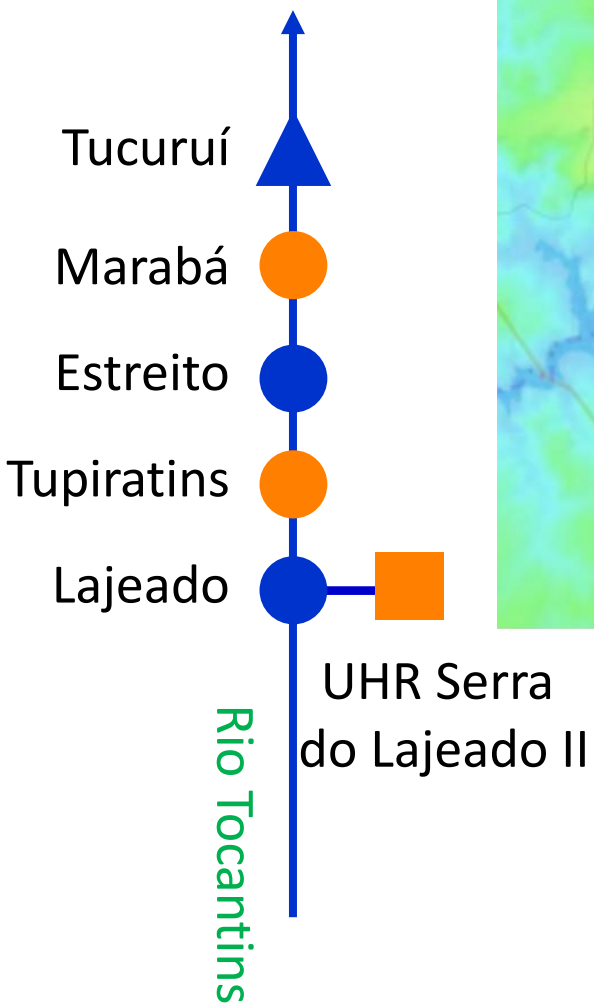
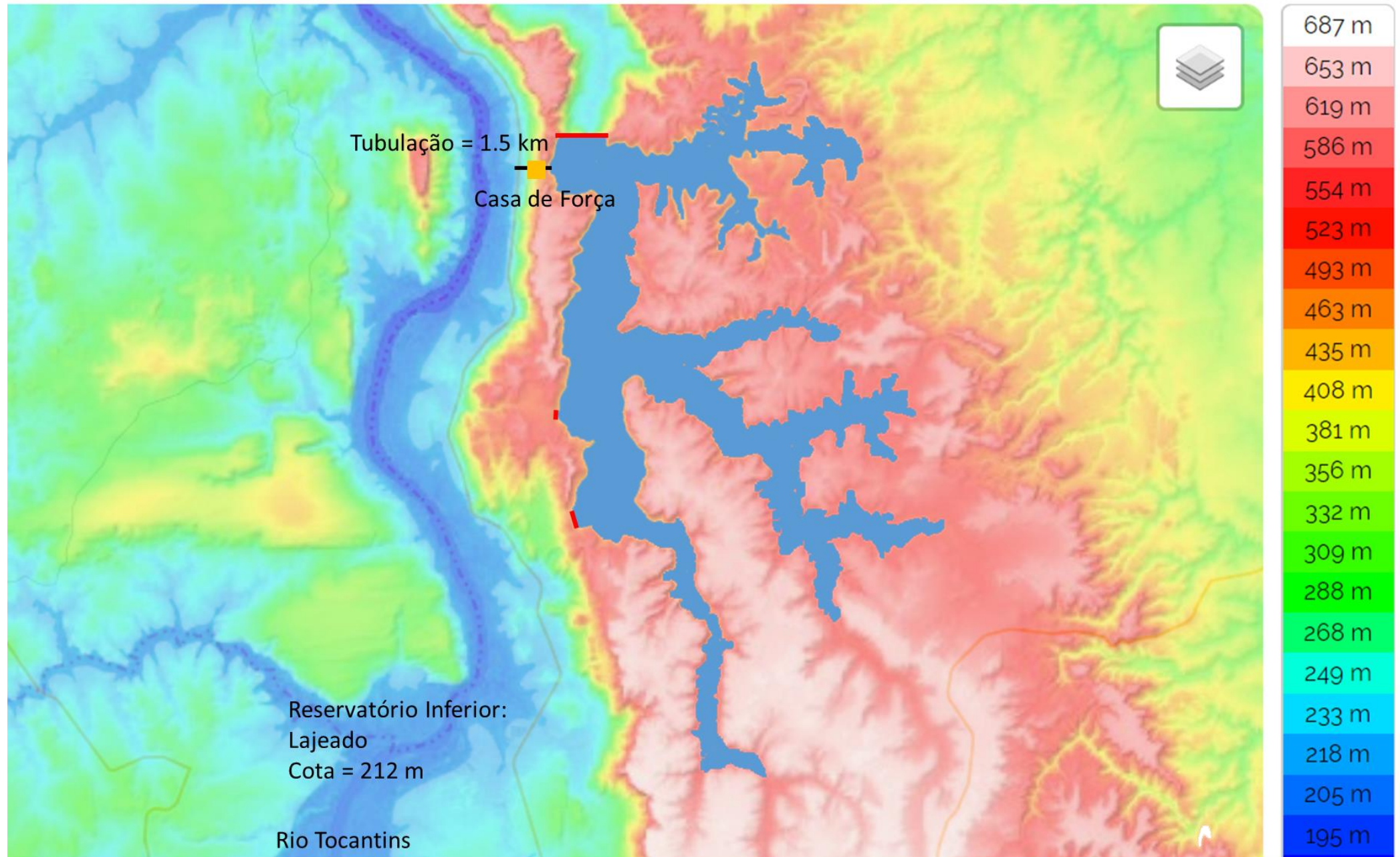
UHRS Palmital 1000 metros



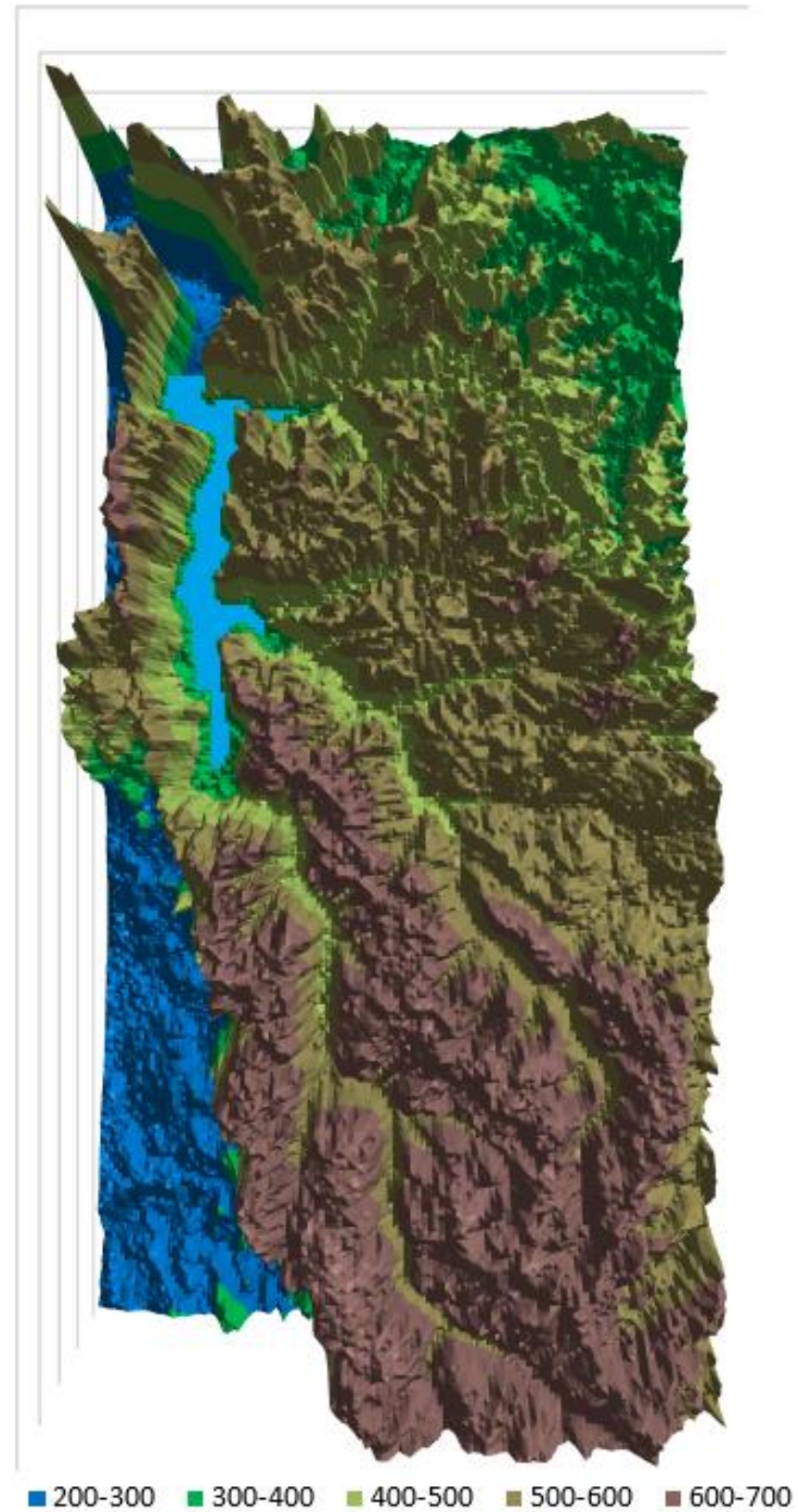
Diferentes Alturas para a Barragem da UHR Palmital



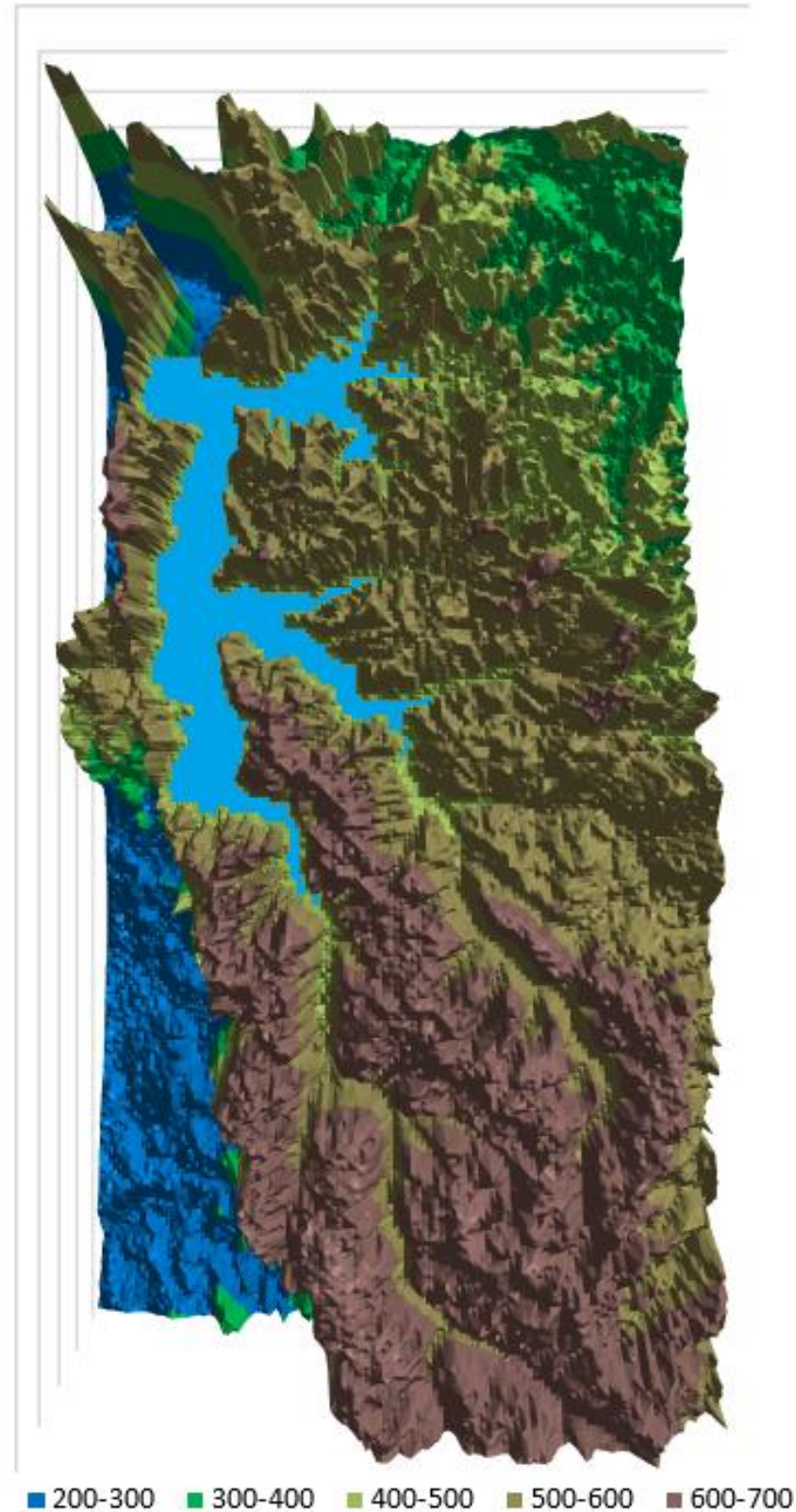
UHR Serra do Lajeado no Rio Tocantins



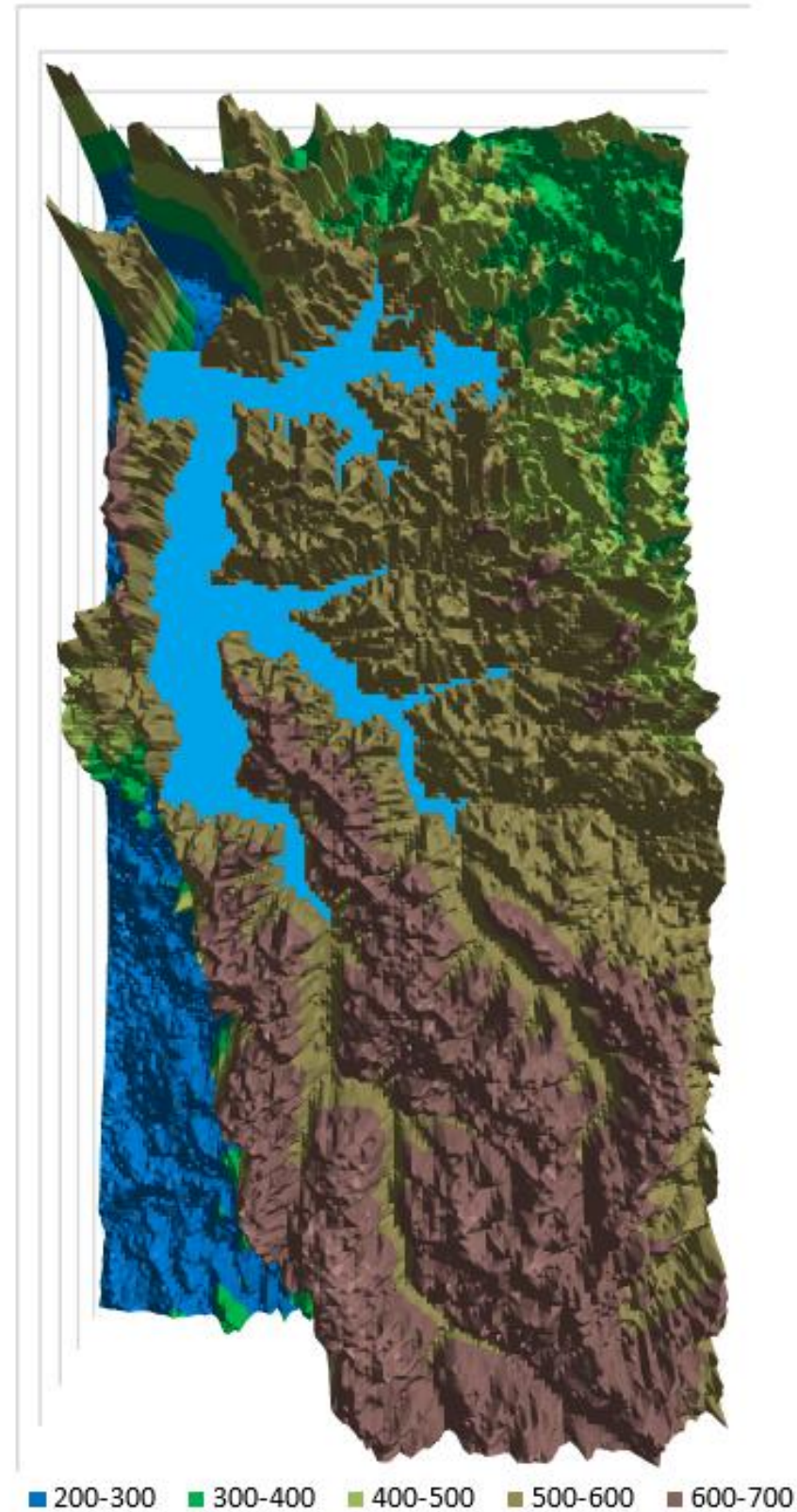
UHR Serra do Lajeado 390 metros



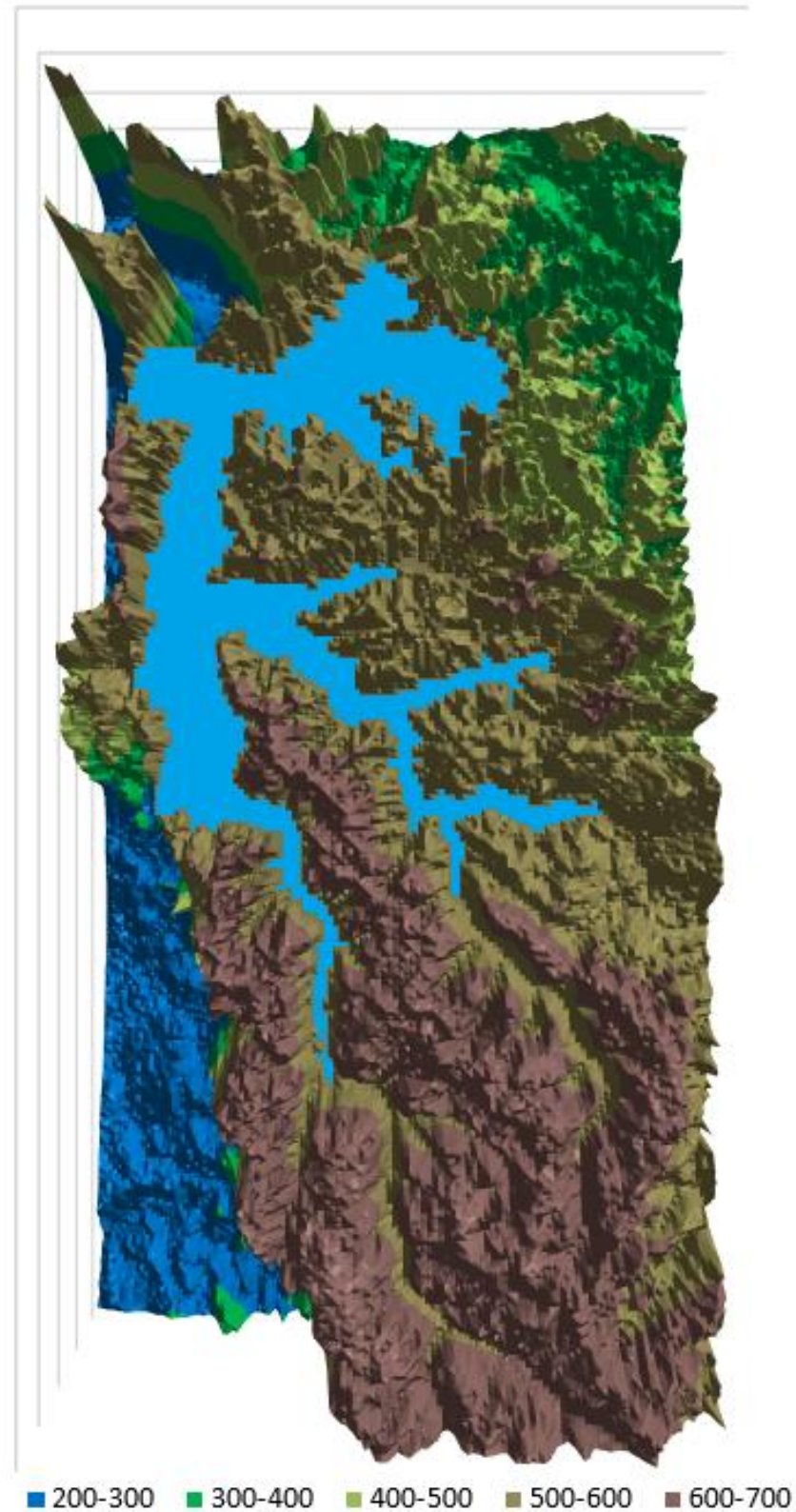
UHR Serra do Lajeado 475 metros



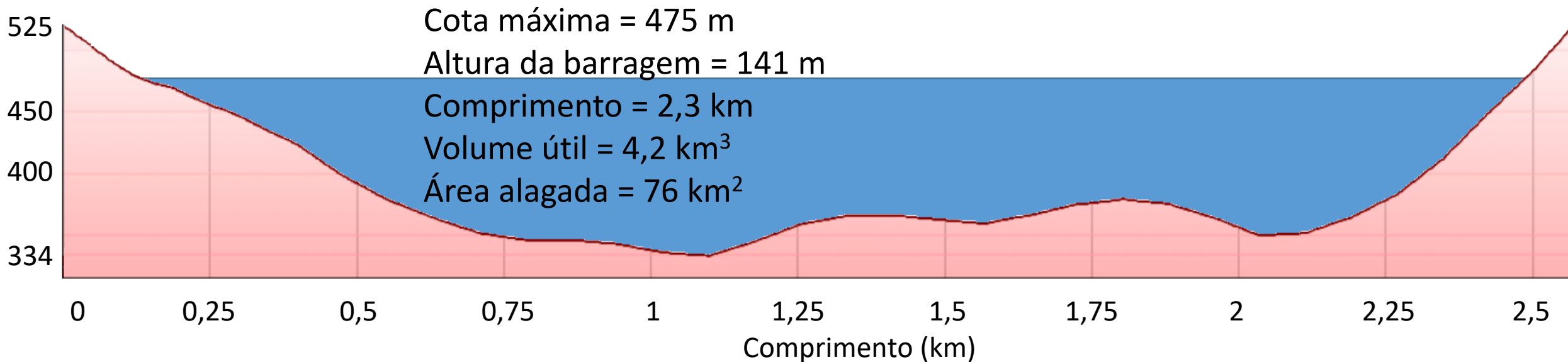
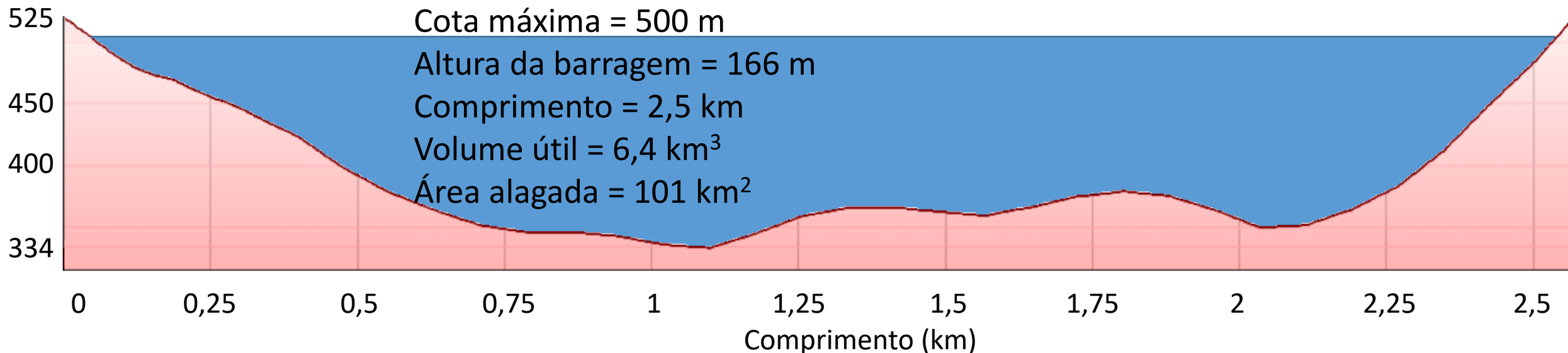
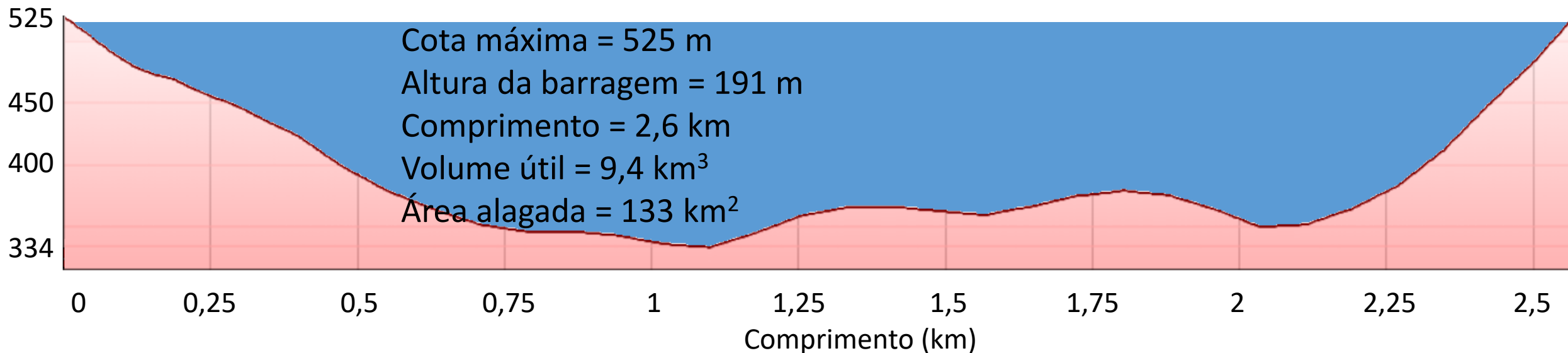
UHR Serra do Lajeado 500 metros



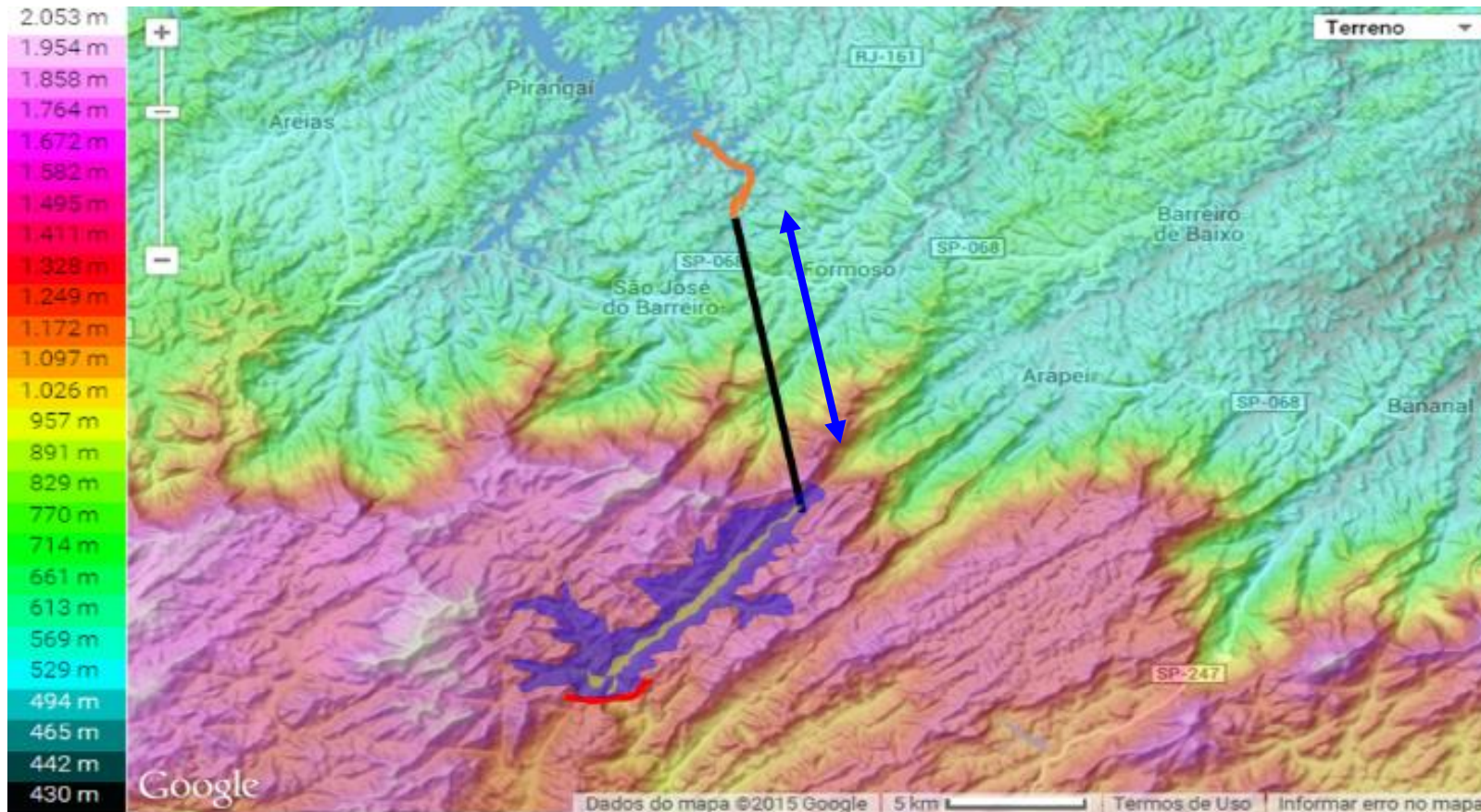
UHR Serra do Lajeado 525 metros



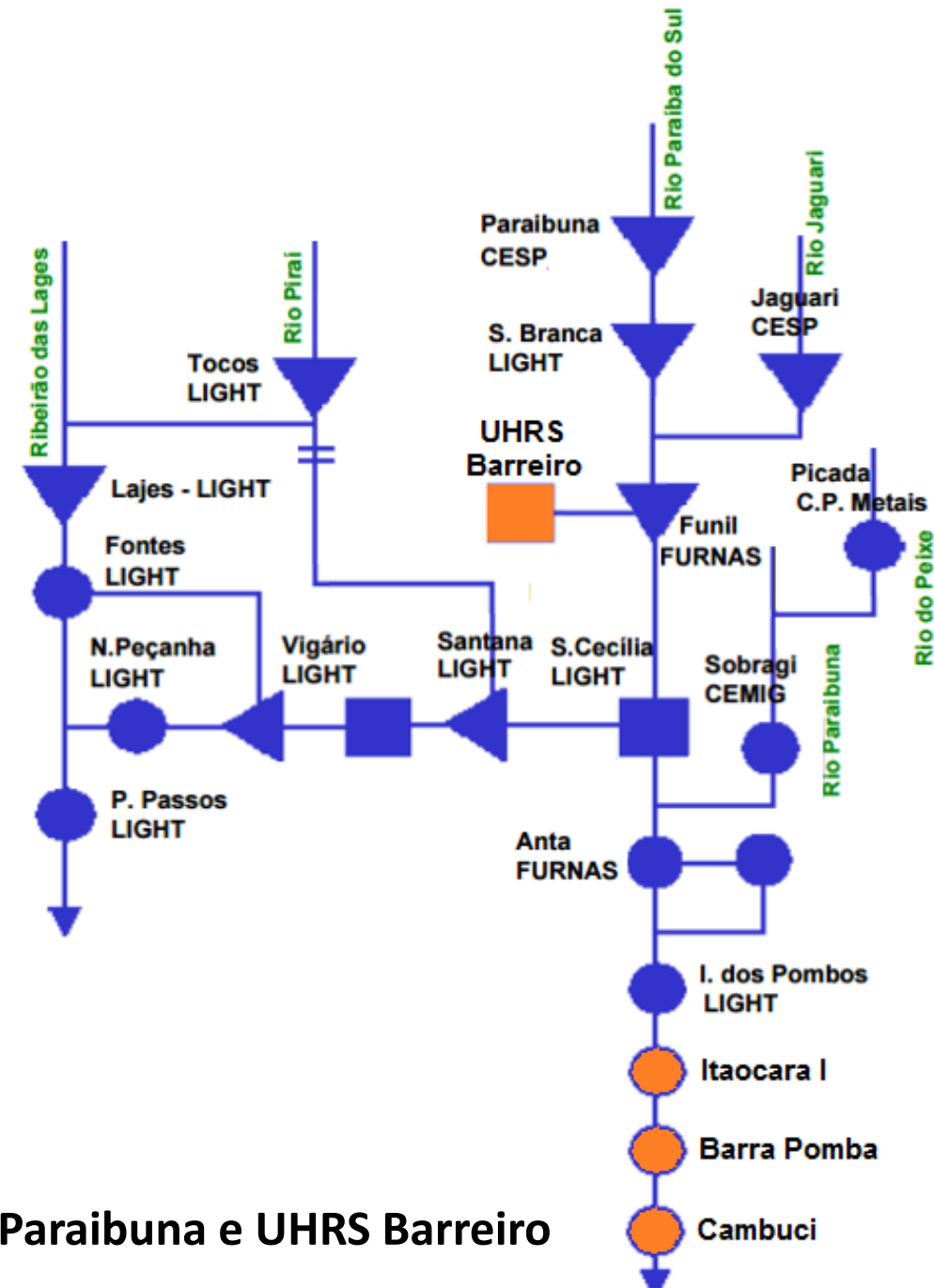
Diferentes Alturas de Barragem



Rio Paraíba do Sul: UHRS Barreiro



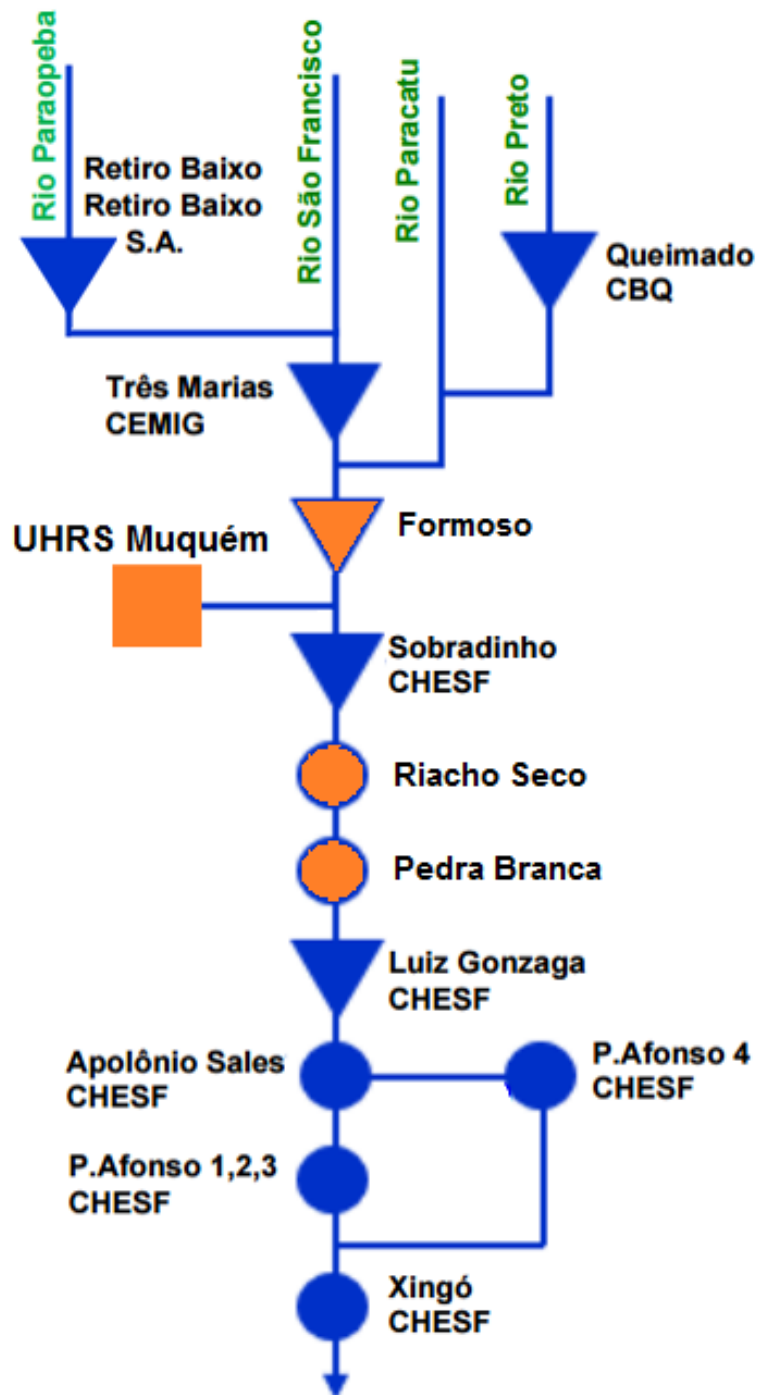
- Barragem (260 metros)
- Tubulação (12 km)
- Canal (5 km)
- Cota Máxima (1450 metros)
- Cota Mínima (1200 metros)
- Cota de Funil (460 metros)



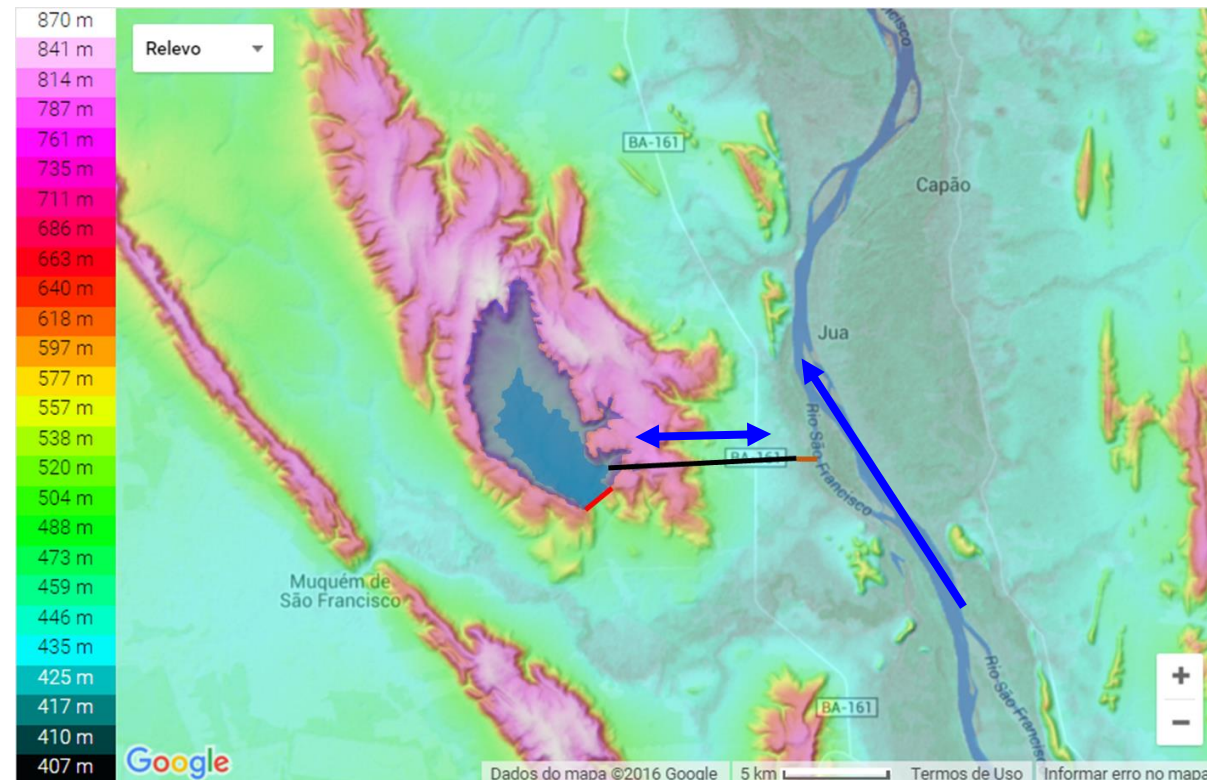
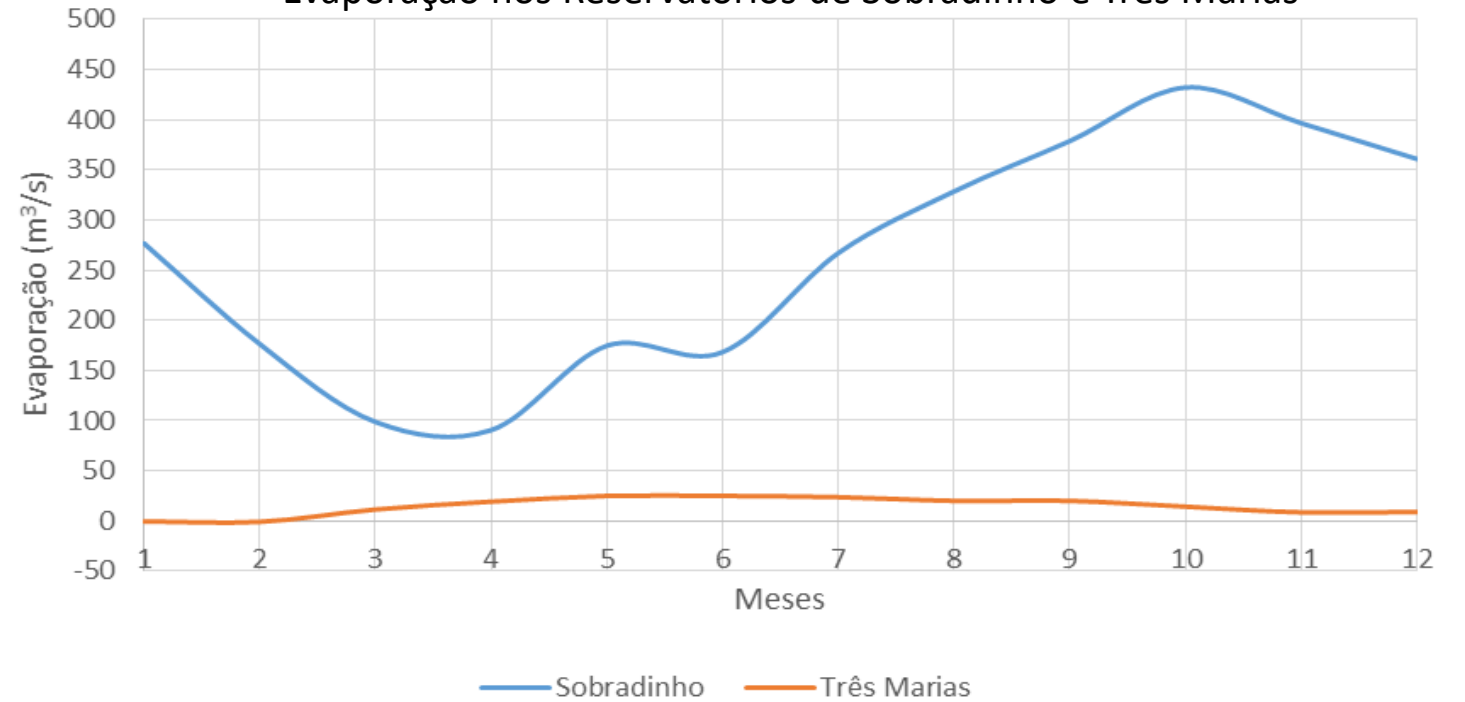
Comparativo entre Armazenamento Hídrico da UHE Paraibuna e UHRS Barreiro

Usina	Volume Útil (hm ³)	Área Alagada (km ²)	Índice (Gwmed/km ²)	Armaz. (GWmed/%)	Área de Drenagem (km ²)	Eficiência (%)
UHRS Barreiro	4.000	29	0,548 (22)	15,9 / 5,5	13.400	89%
UHE Paraibuna	2.636	177	0,025 (1)	4,45 / 1,5	4.350	100%

Rio São Francisco: UHRS Muquém



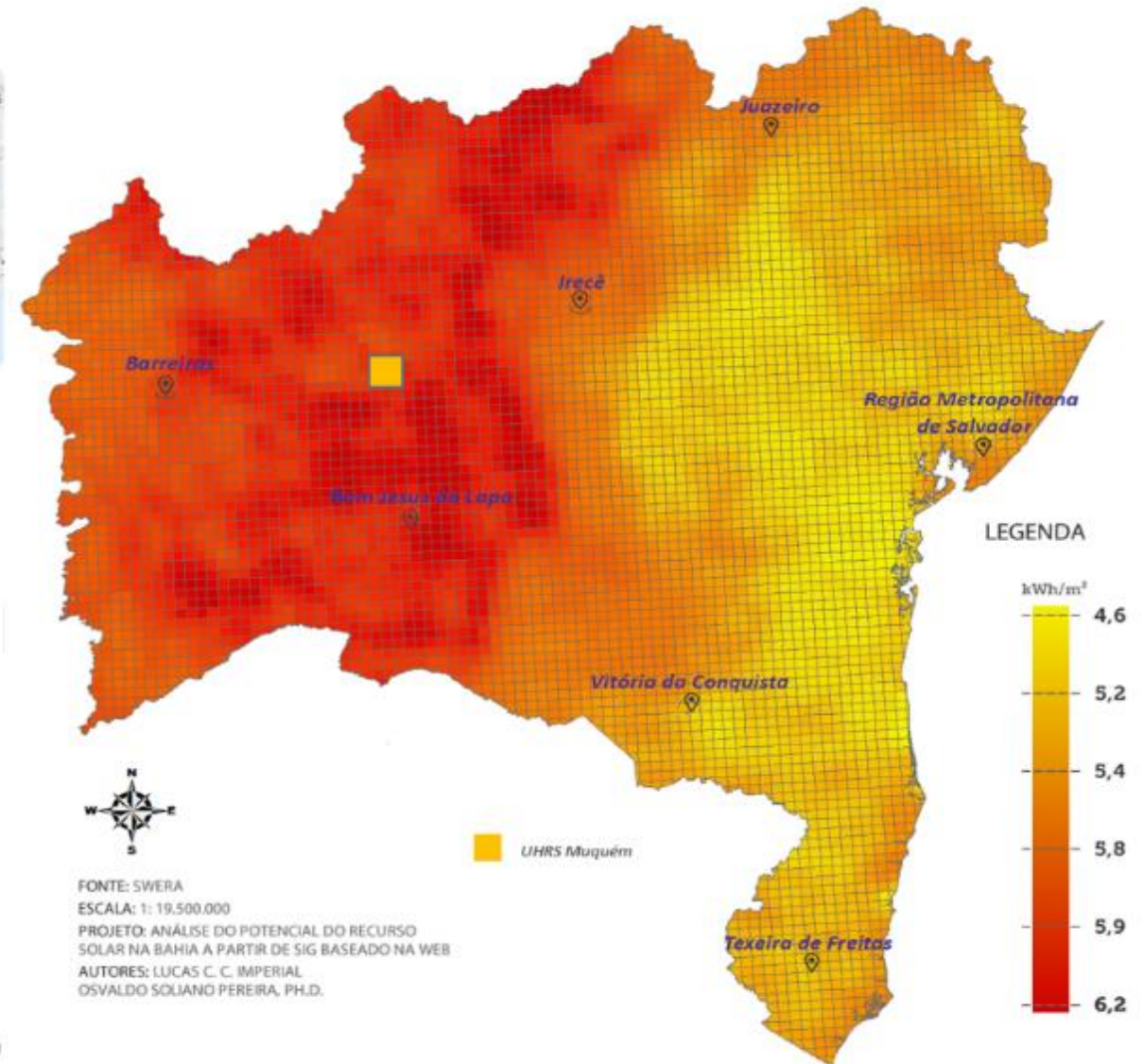
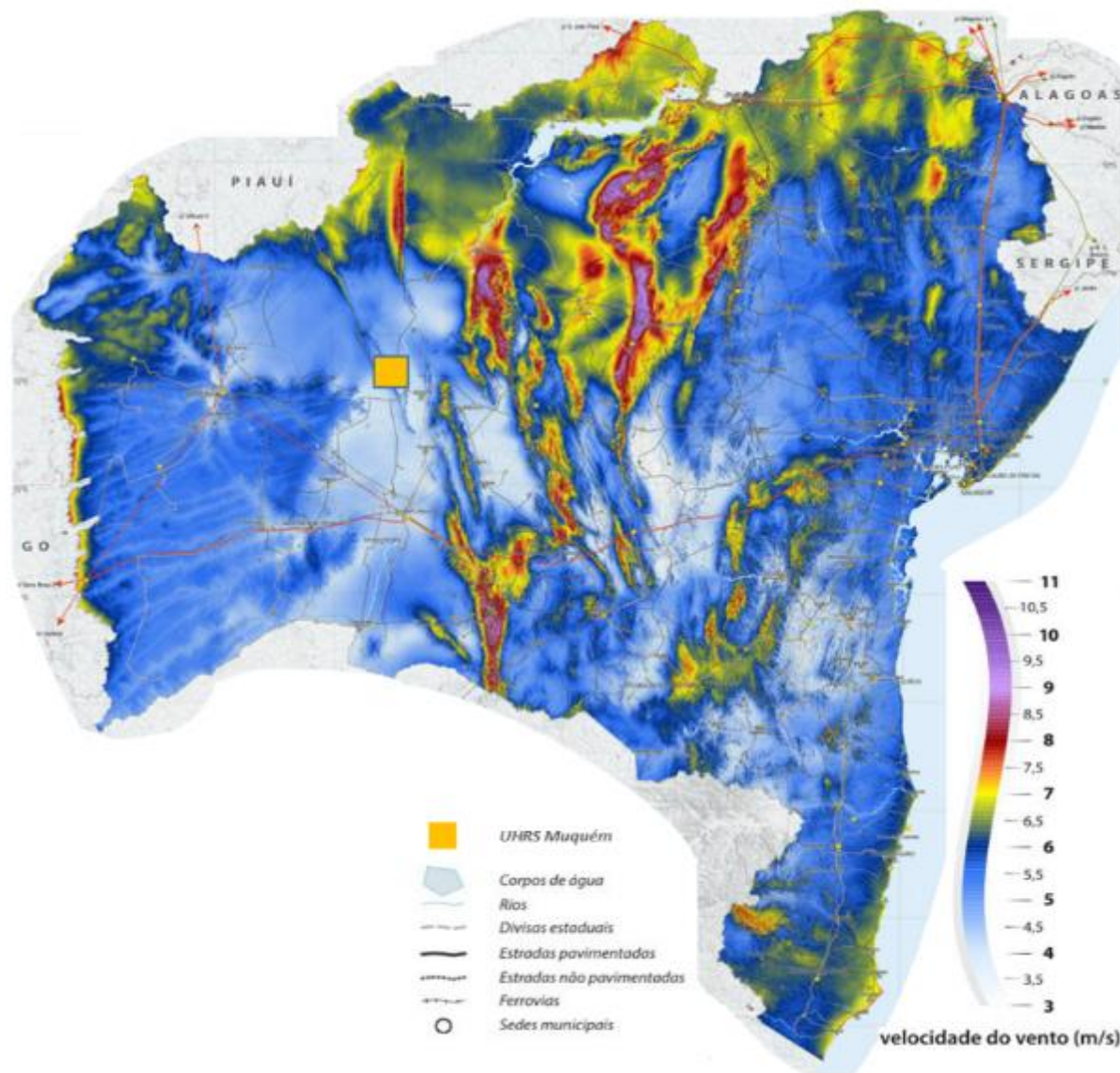
Evaporação nos Reservatórios de Sobradinho e Três Marias



- Barragem (230 m; 2 km)
- Tubulação (9 km)
- Canal (1 km)
- Cota Máxima (700 m)
- Cota Mínima (550 m)
- Cota do Rio S.F. (411 m)

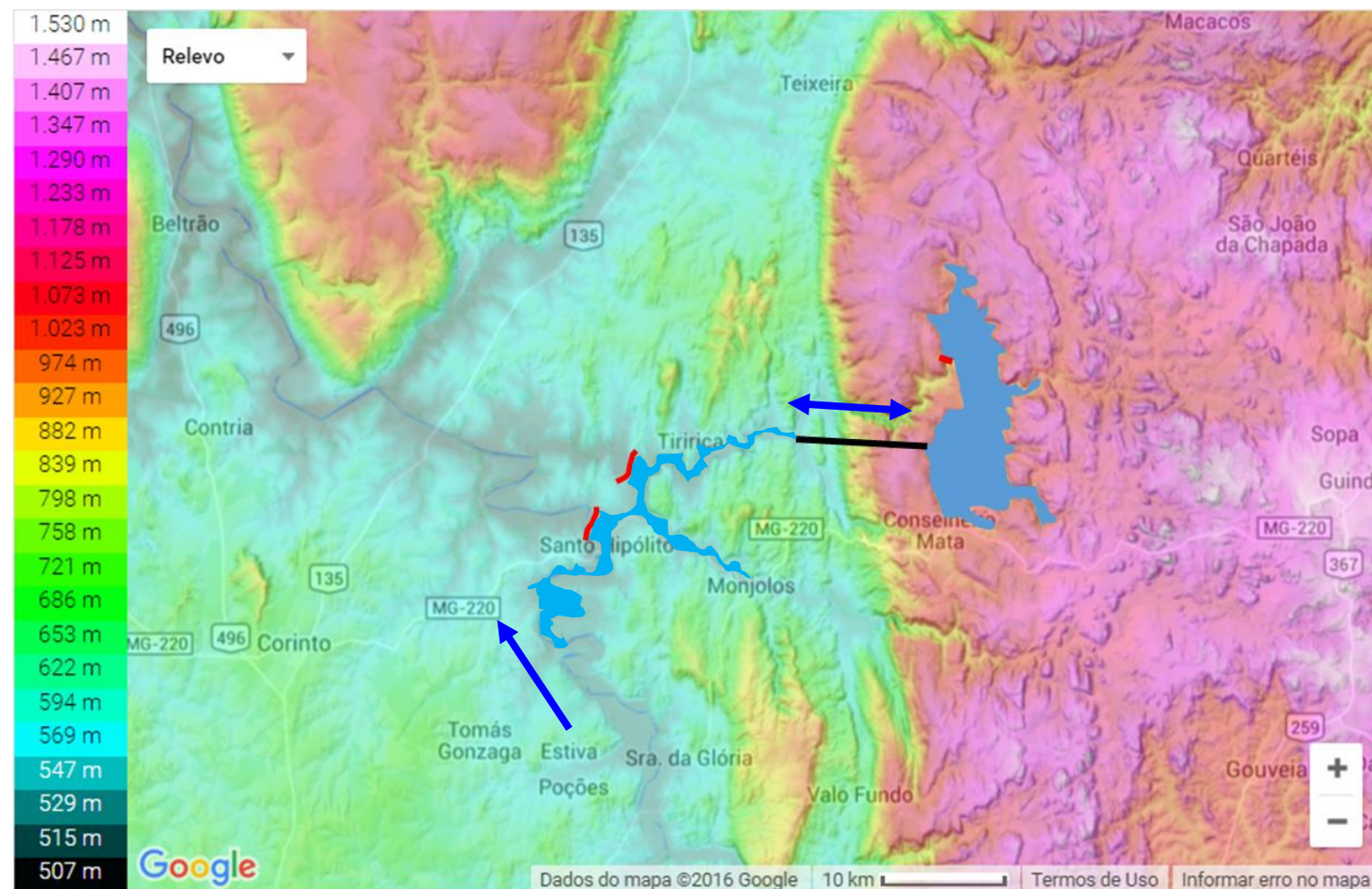
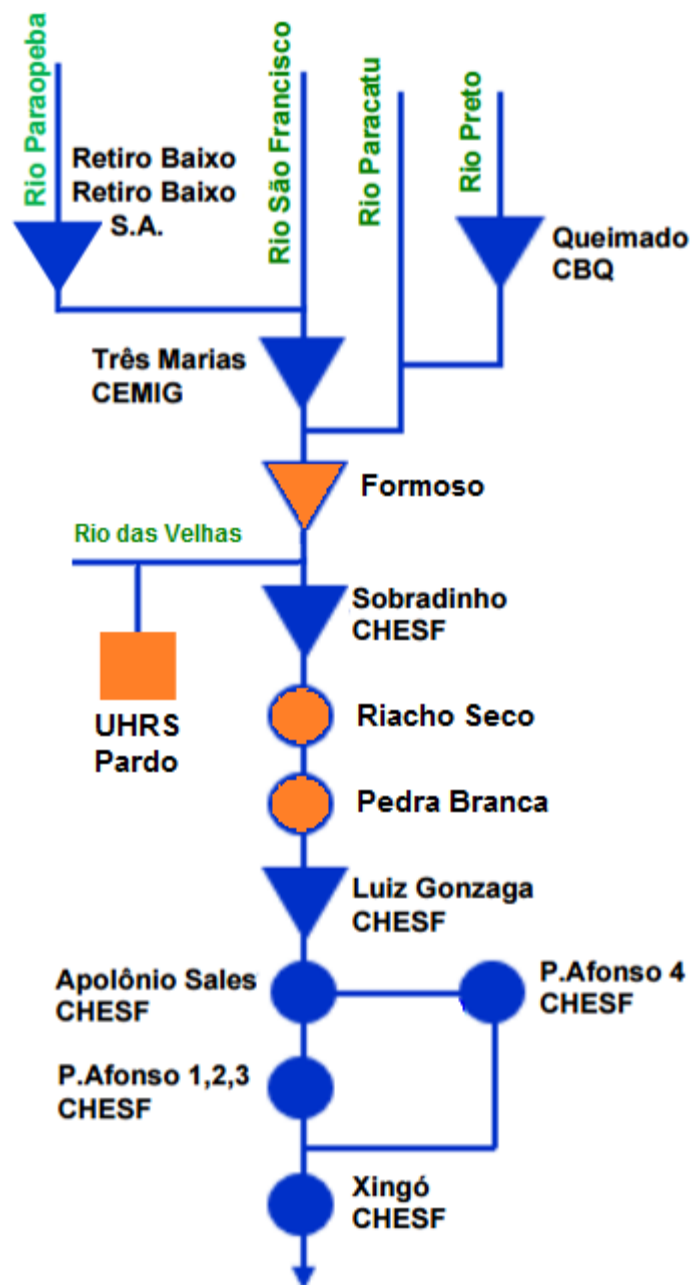
Rio São Francisco: UHRS Muquém

- Redução da Intermitência da geração da geração eólica e solar.



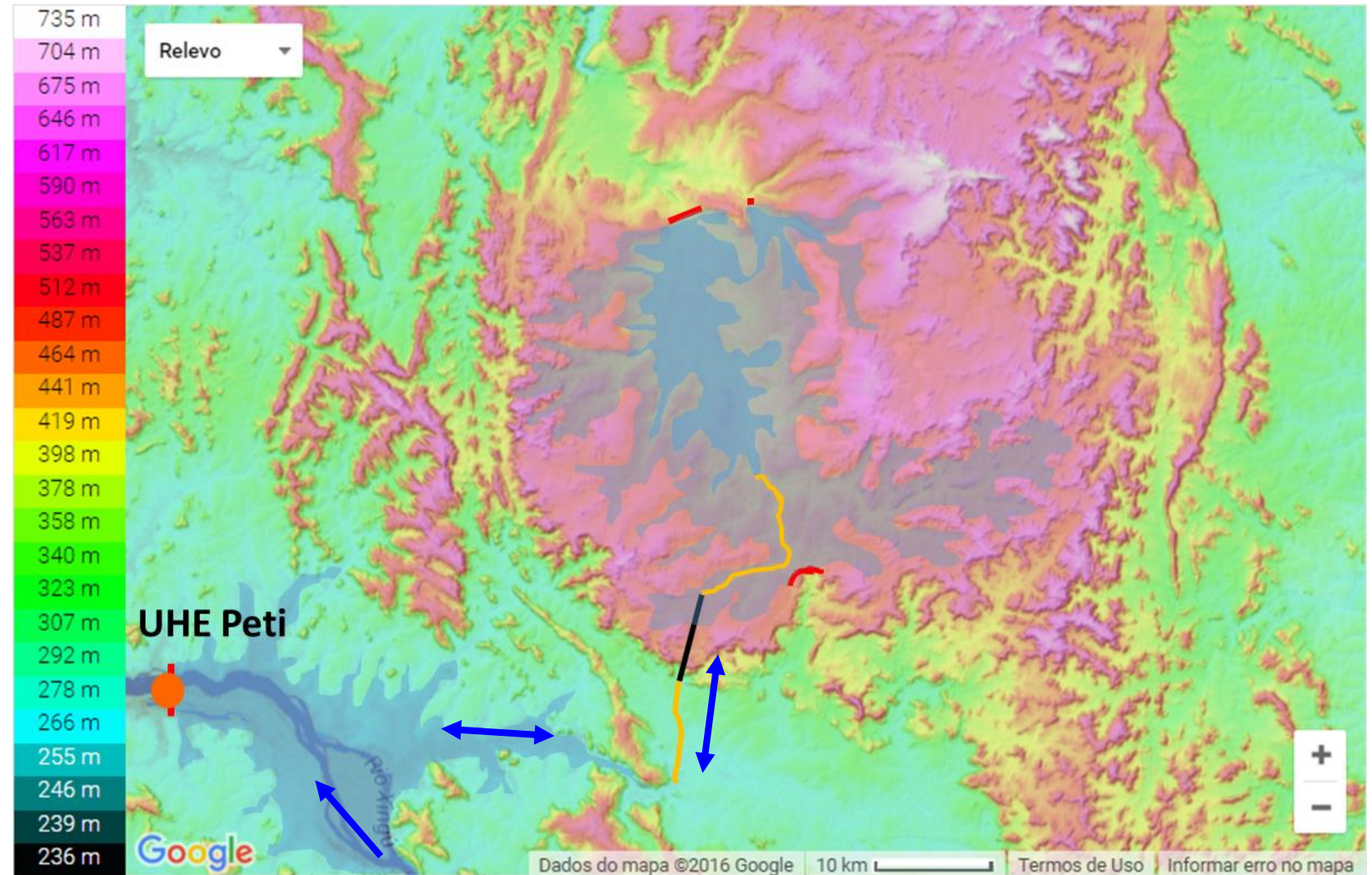
Usina	Volume Útil (hm ³)	Área Alagada (km ²)	Índice (Gwmed /km ²)	Barragem (m)	Tubo (km)	Cota (m) Mínima/Máxima	Cota Inferior (m)	Armaz. (GWmed/% do SIN)	Área de Drenagem (km ²)	Eficiência (%)
UHRS Muquém	7.800	52	0,27 (11)	230	9	550 / 700	411	13,9 / 4,8	326.000	95%

Rio das Velhas/Bacia S. Francisco: UHRS Pardo

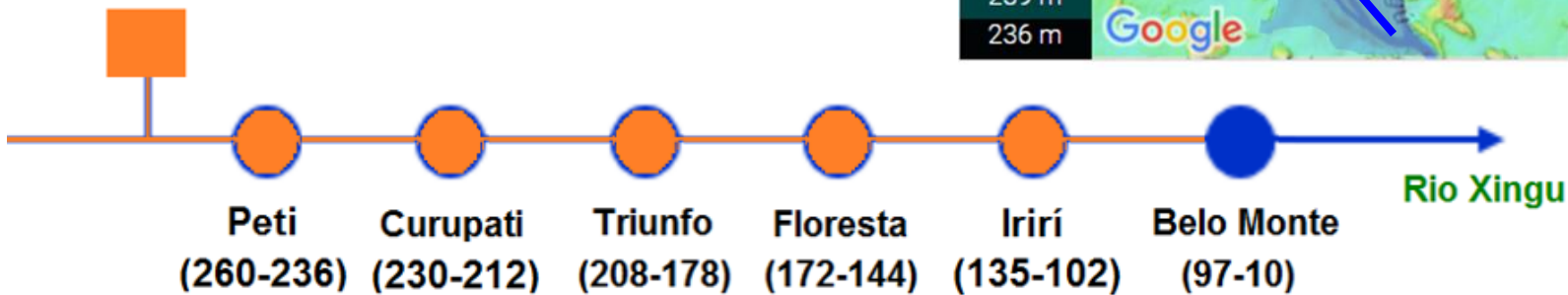


Usina	Volume Útil (hm ³)	Área Alagada (km ²)	Índice (Gwmed/km ²)	Barragem (m)	Tubo (km)	Cota (m) Mínima/Máxima	Cota Inferior (m)	Armazenamento (GWmed/% do SIN)	Área de Drenagem (km ²)	Eficiência (%)
UHRS Pardo	16.500	150	0,283 (11)	175	10	950/1100	540	42,5 / 14,5	19.000	92%

Rio Xingu: UHRS Peçanha

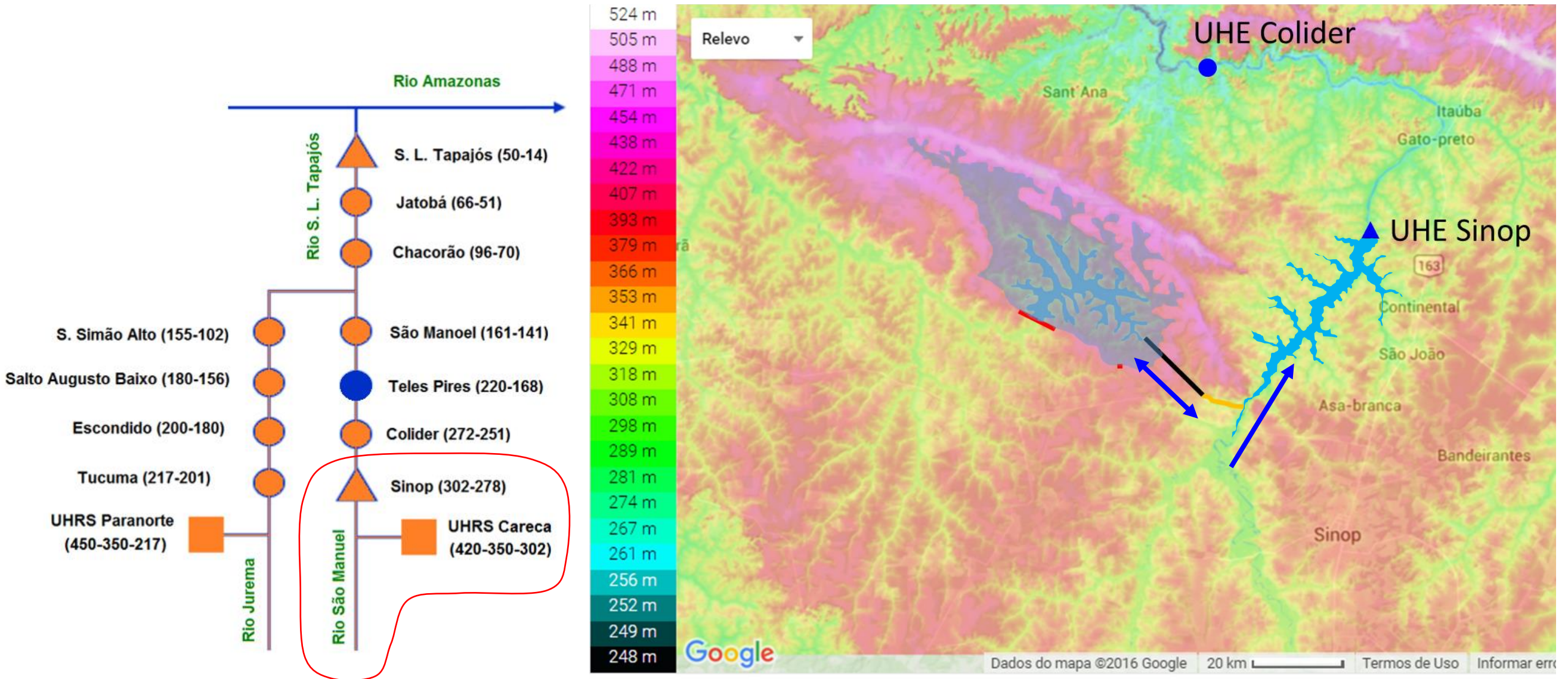


UHRS Peçanha (530-440)



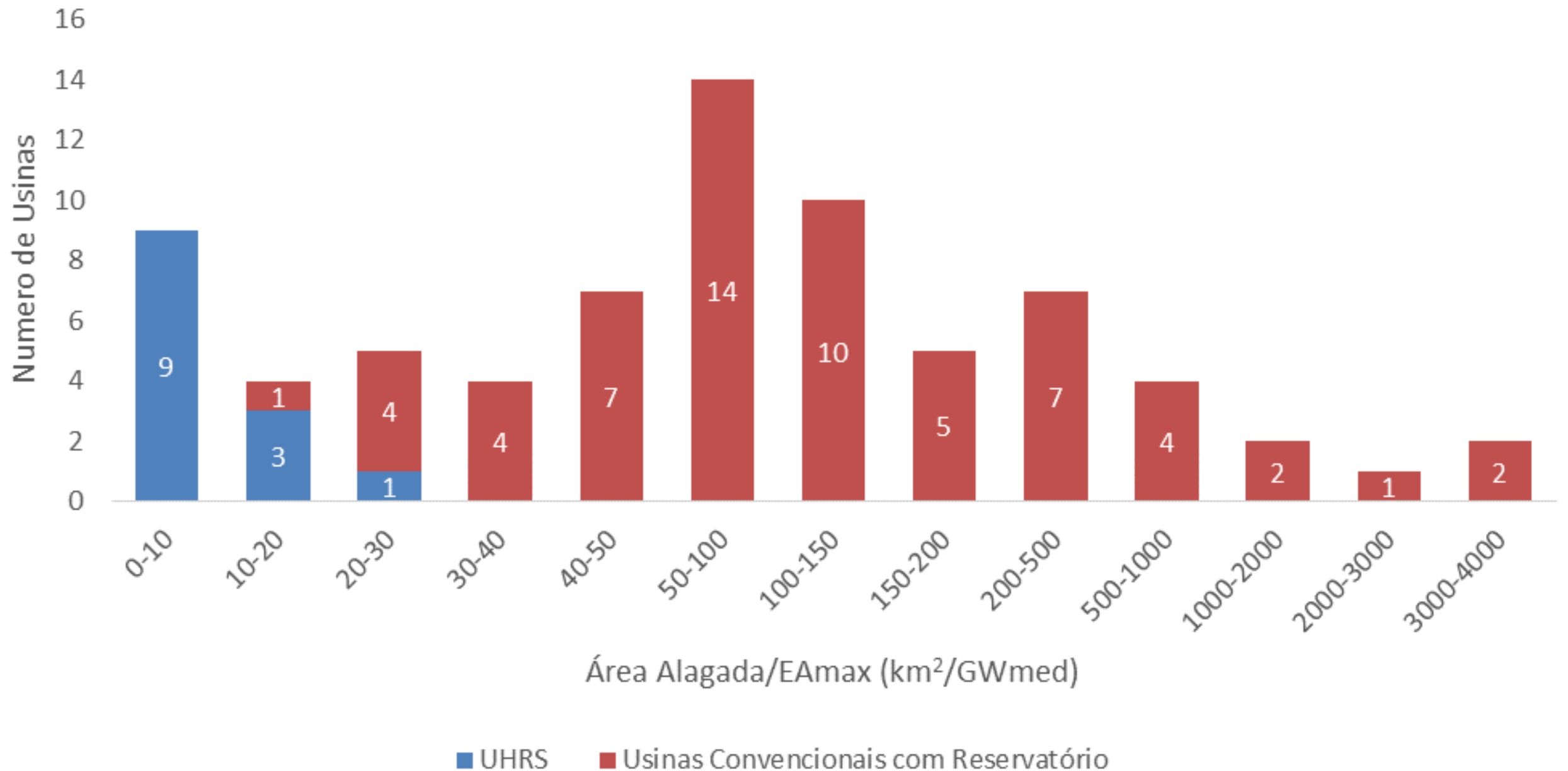
Usina	Volume Útil (hm ³)	Área Alagada (km ²)	Índice (Gwmed /km ²)	Barragem (m)	Tubo (km)	Cota (m) Mínima/Máxima	Cota Inferior (m)	Vazão de Bombeamento (m ³ /s)	Armaz. (GWmed/% do SIN)	Área de Drenagem (km ²)	Eficiência (%)
UHRS Xingu	36.400	615	0,077 (3)	122	9	440 / 530	260	2314,8	47,2 / 16,6	169.000	129%

Rio Teles Pires: UHRS Careca

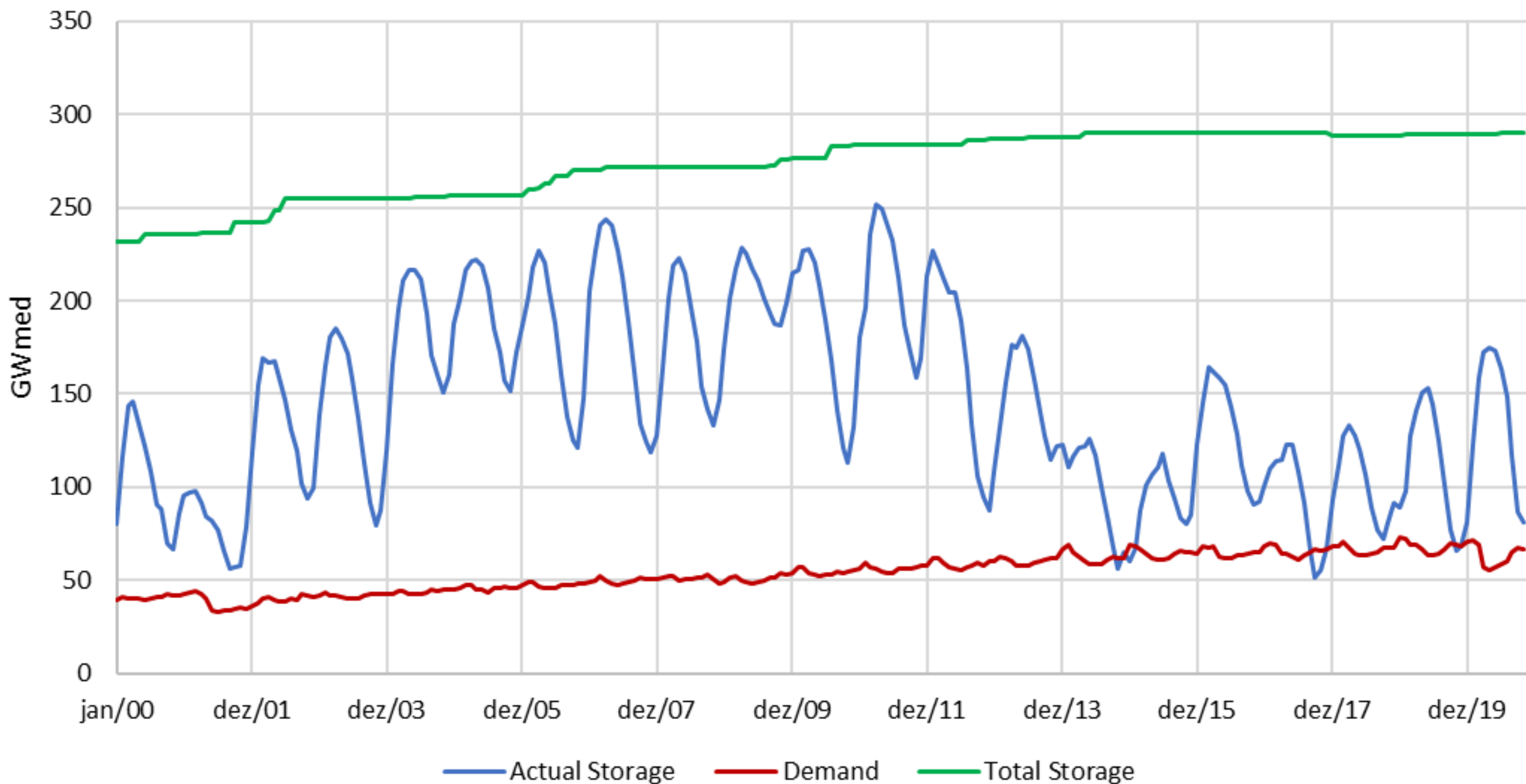


Usina	Volume Útil (hm ³)	Área Alagada (km ²)	Índice (Gwmed /km ²)	Barragem (m)	Tubo (km)	Cota (m) Mínima/Máxima	Cota Inferior (m)	Vazão de Bombeamento (m ³ /s)	Armaz. (GWmed/% do SIN)	Área de Drenagem (km ²)	Eficiência (%)
UHRS Careca	21.390	508	0,045 (2)	102	17	350 / 420	302/292	1.368,8	22,7 / 7,8	37.400	125%

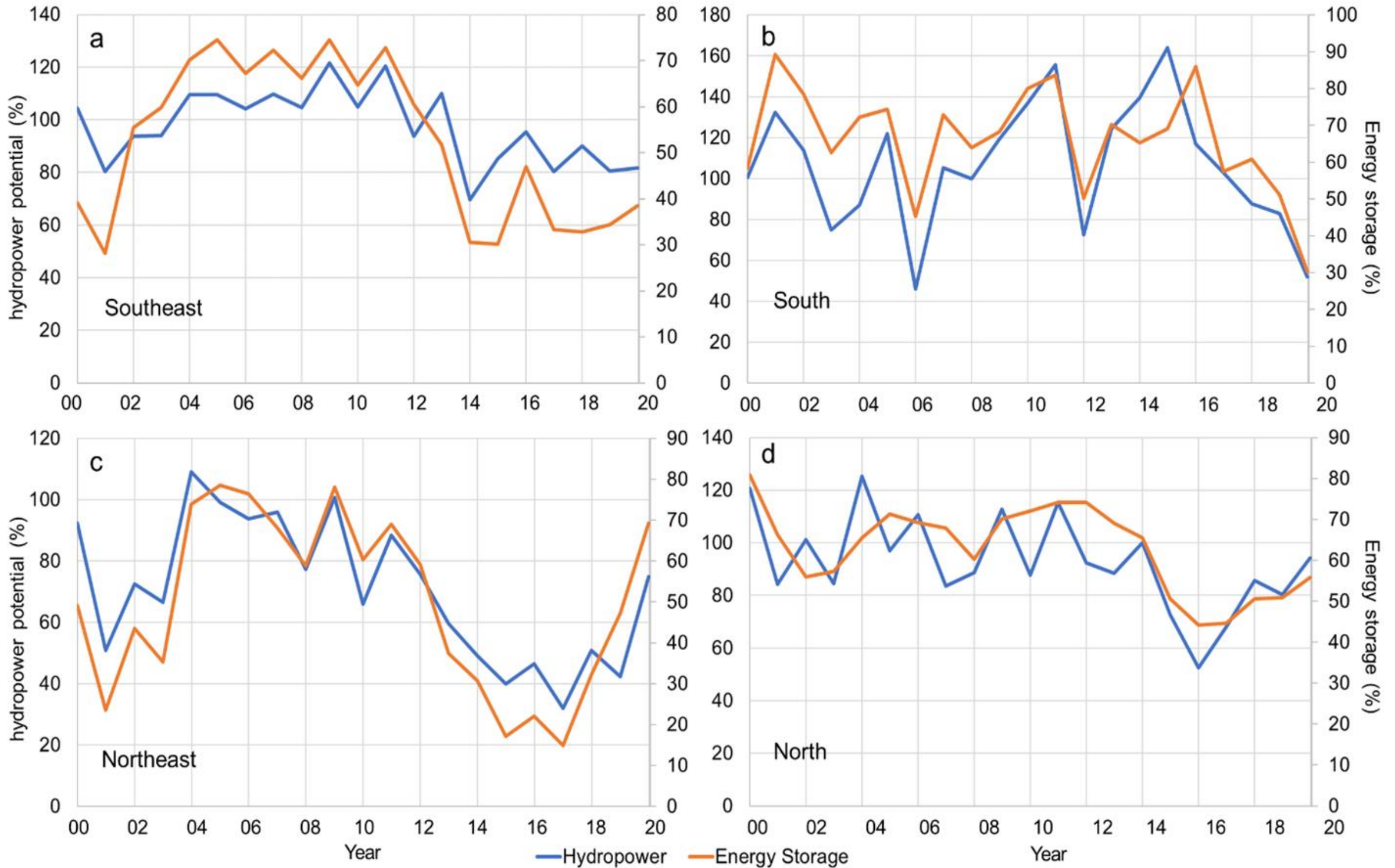
UHR Sazonal: Área Alagada



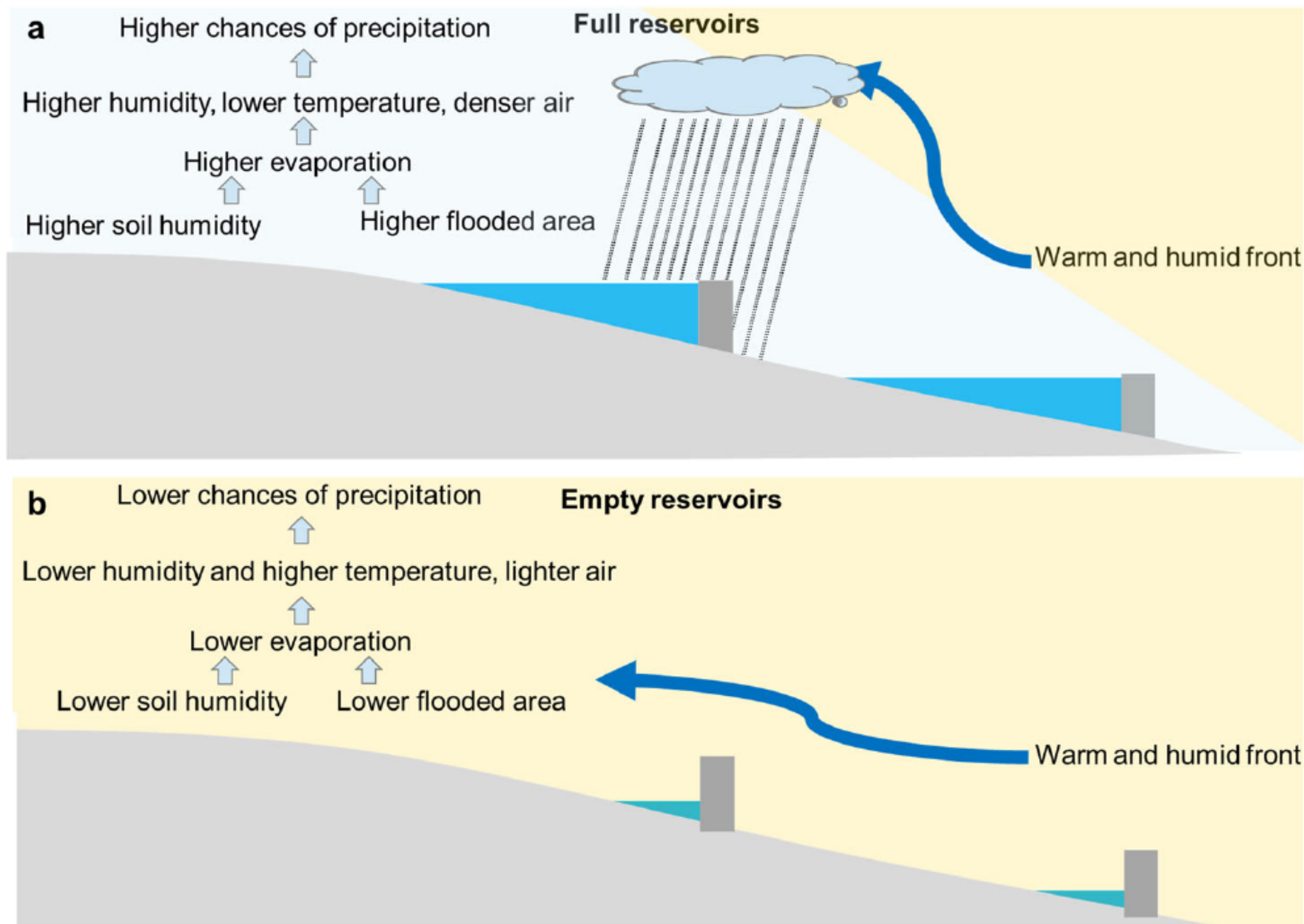
UHR Sazonal: Porque mais reservatório?



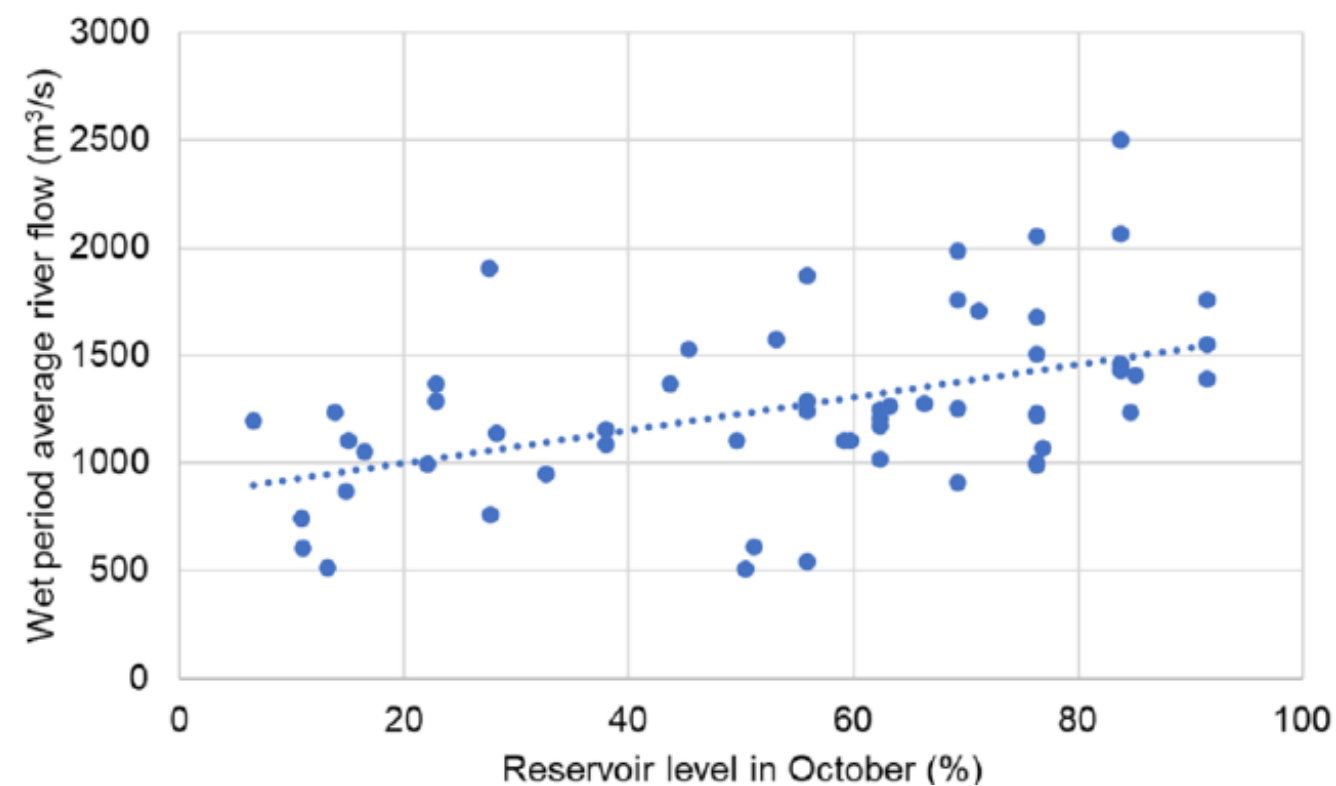
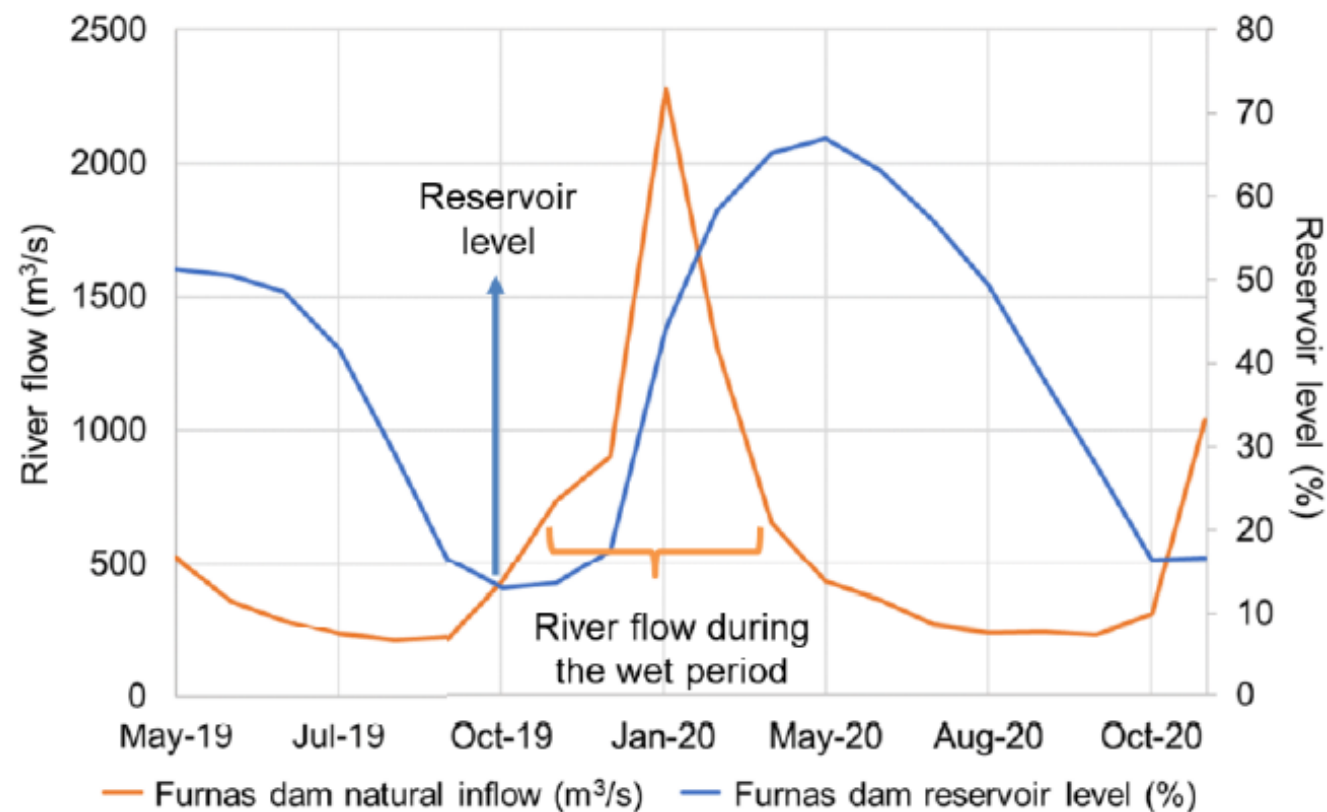
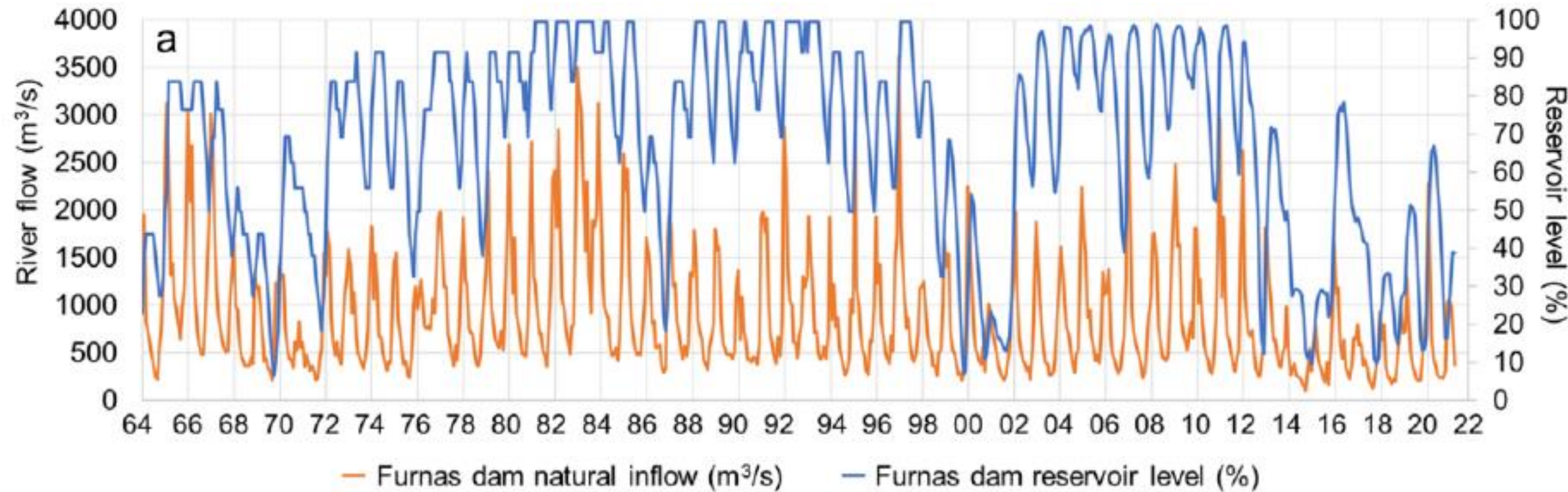
UHR Sazonal: ENA vs Armazenamento Energético



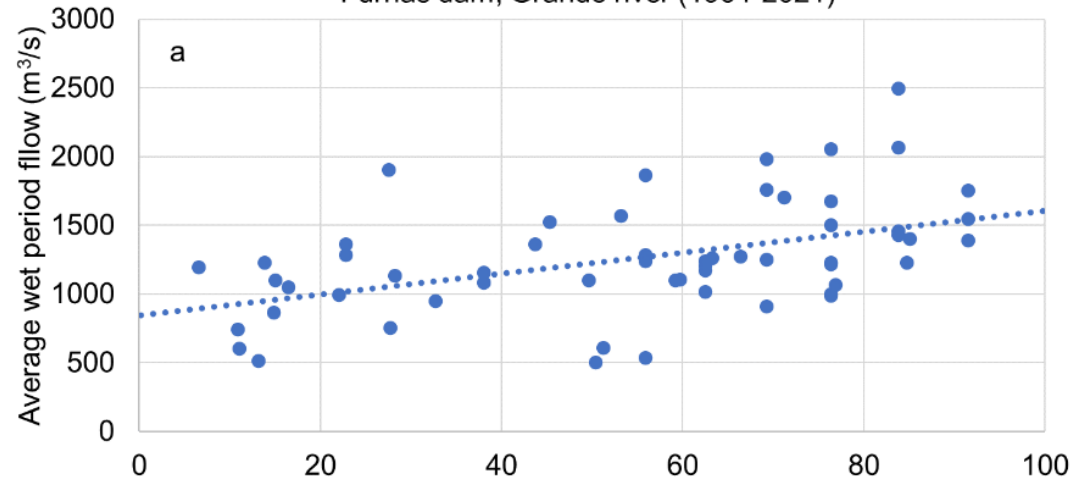
UHR Sazonal: ENA vs Armazenamento Energético



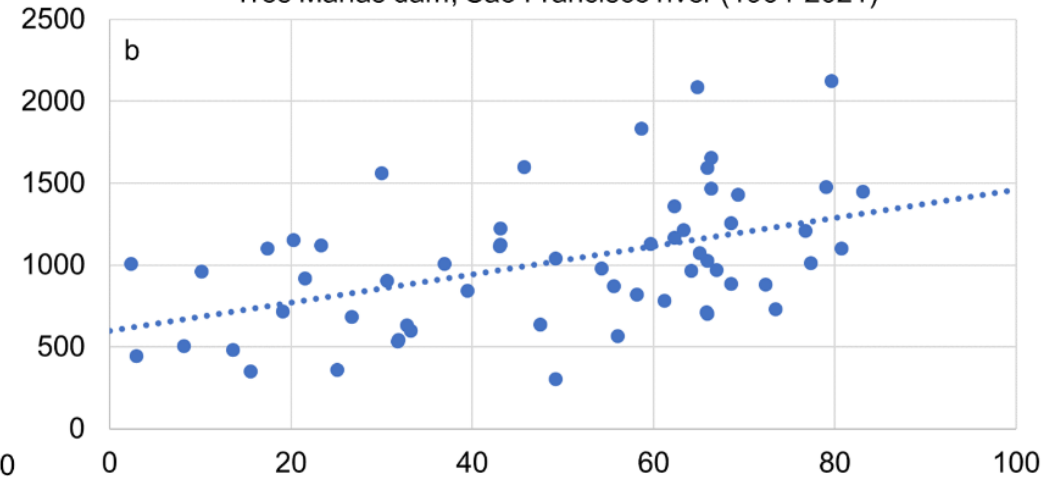
UHR Sazonal: ENA vs Armazenamento Energético



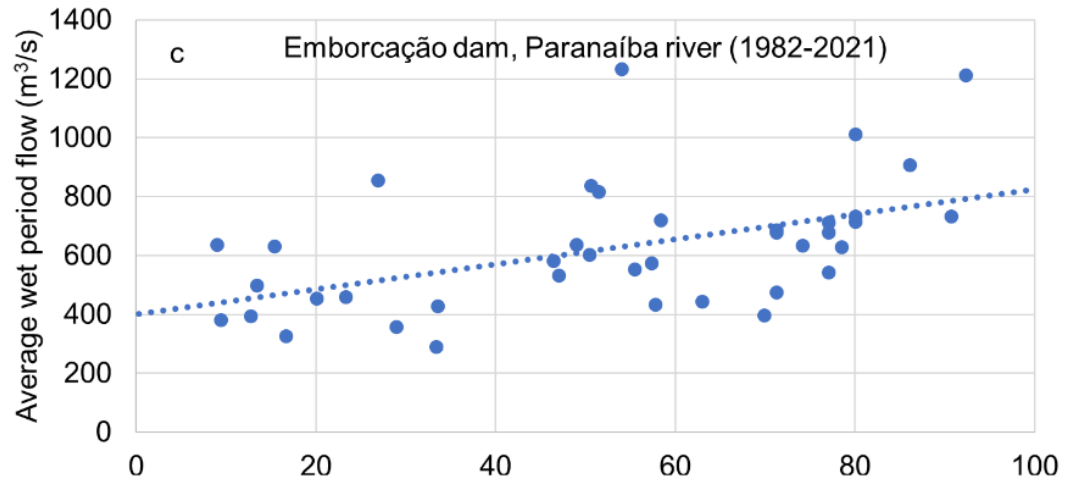
Furnas dam, Grande river (1964-2021)



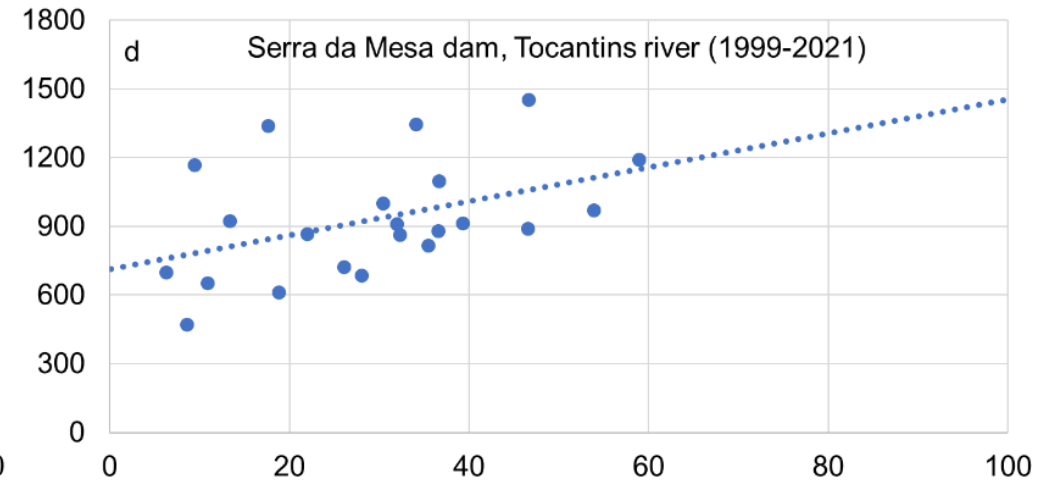
Três Marias dam, São Francisco river (1964-2021)



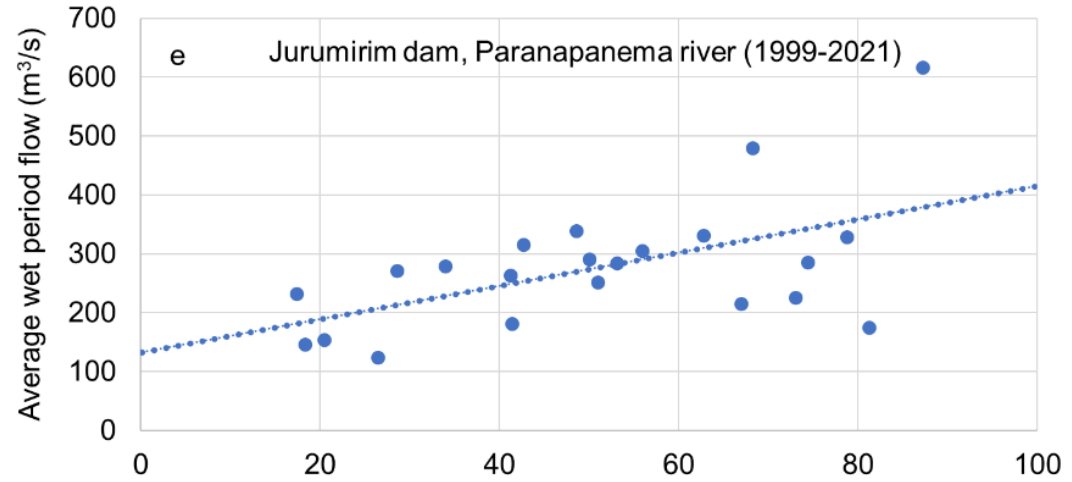
Emborcação dam, Paranaíba river (1982-2021)



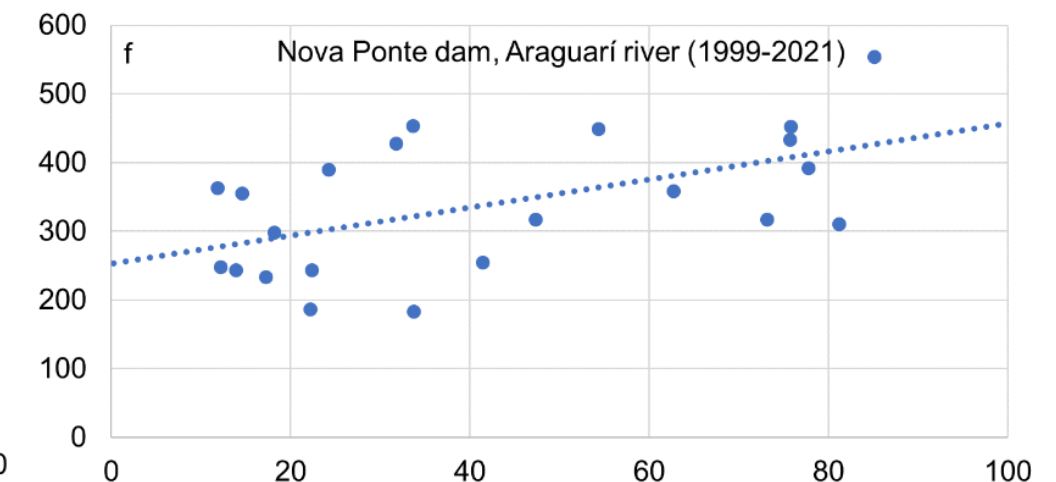
Serra da Mesa dam, Tocantins river (1999-2021)



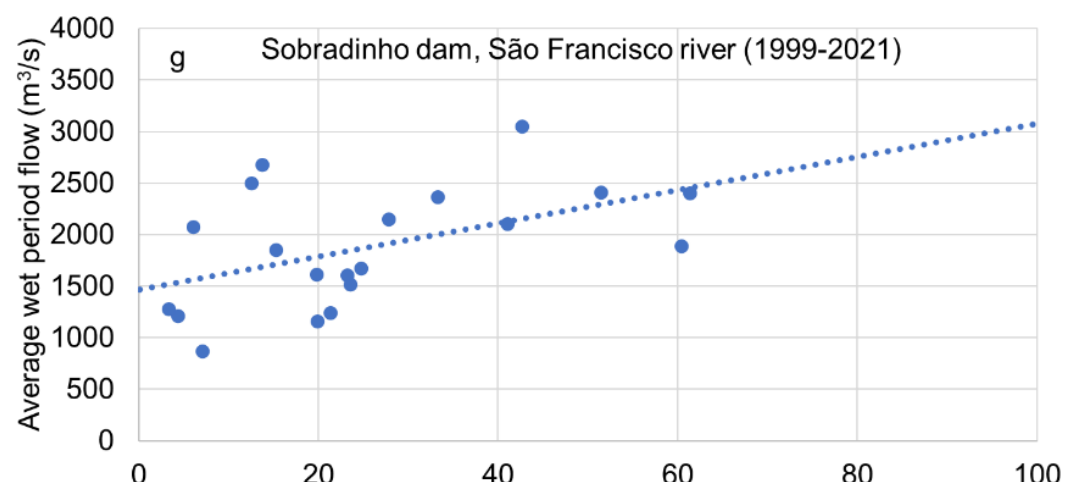
Jurumirim dam, Paranapanema river (1999-2021)



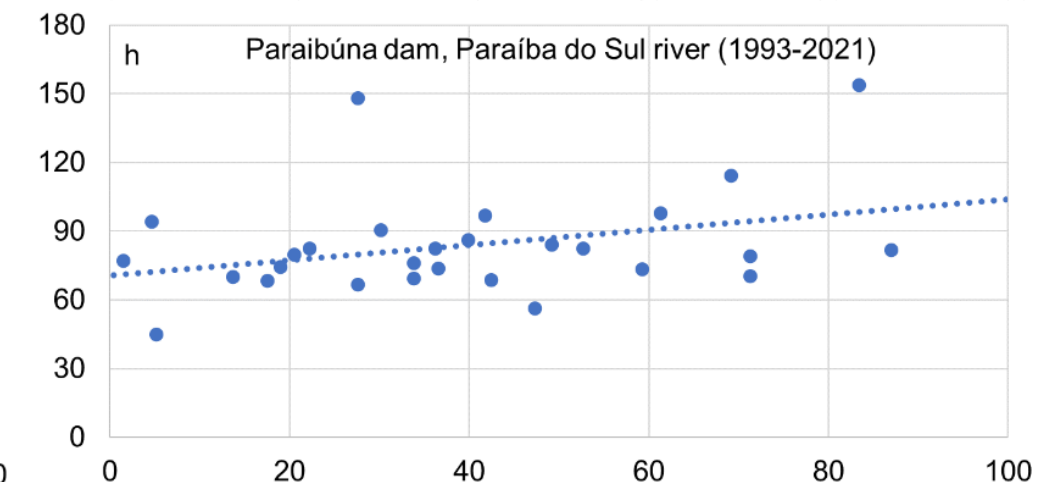
Nova Ponte dam, Araguaí river (1999-2021)



Sobradinho dam, São Francisco river (1999-2021)



Paraibúna dam, Paraíba do Sul river (1993-2021)



UHR Sazonal: ENA vs Armazenamento Energético

Dams	Generation head, including dams downstream (m)	Increase in cascade generation (GW)	Reservoir storage capacity (GWm)	Increase in generation / storage capacity	Reservoir filling order
Jurumirim	385.30	0.96	4.2	0.229	1
Três Marias	357.1	2.72	18.6	0.146	2
Sobradinho	306.9	4.36	30.0	0.145	3
Furnas	610.25	4.11	35.8	0.115	4
Emborcação	510.15	1.91	22.7	0.084	5
Nova Ponte	641.65	1.15	22.7	0.051	6
Serra da Mesa	323.4	2.11	47.6	0.044	7
Paraibuna	336.7	0.09	3.0	0.030	8
Total	-	17.41	184.6	-	-

UHR Pluri-annual

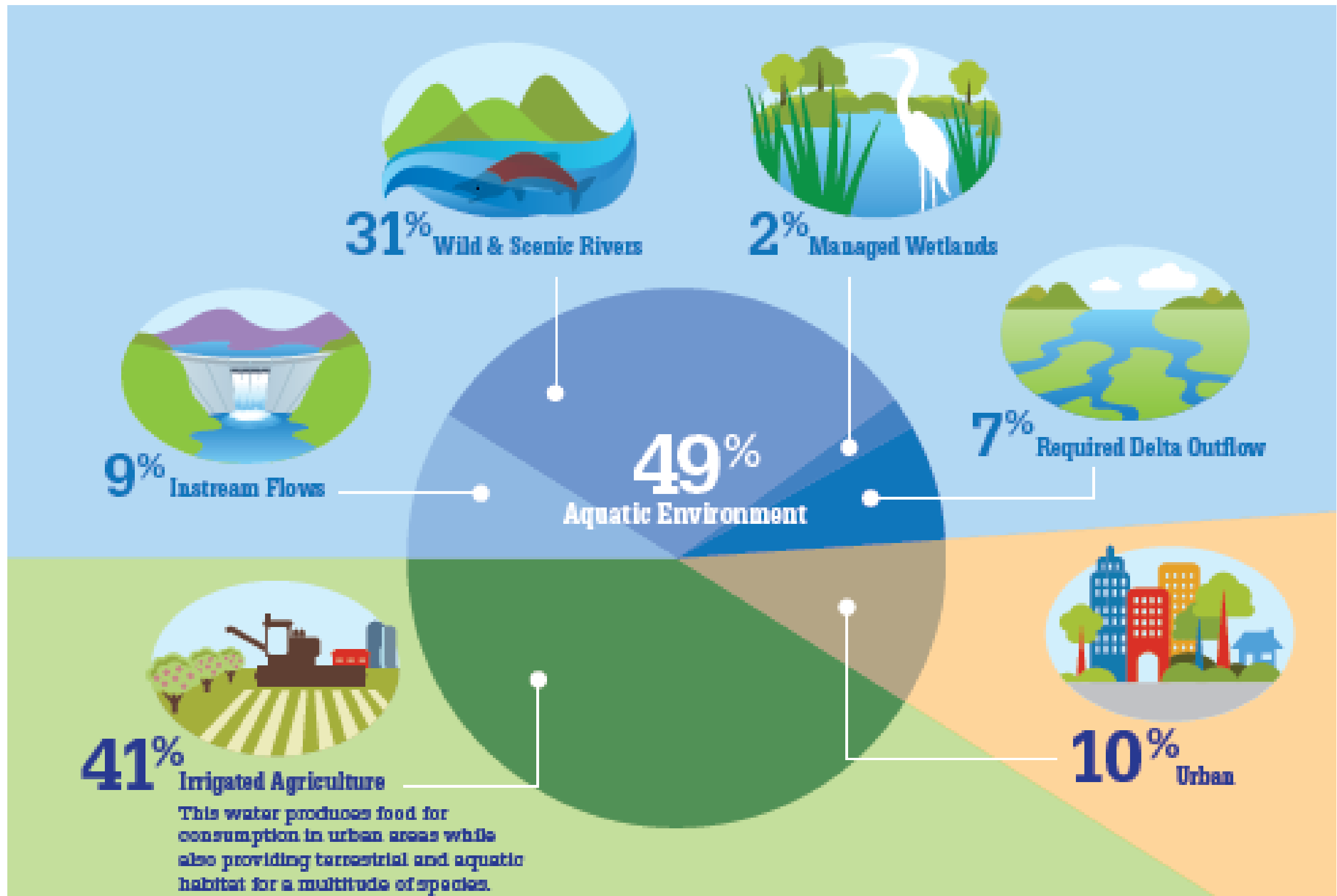
Energy
MWh



Power
GW

PHS Type	Operation Mode	Occasions when the PHS type operates
Pluri-annual Pumped-Storage (PAPHS)	Pump	Annual surplus in hydroelectric generation [22].
		Annual fuel prices cheaper than average.
		Lower than average annual electricity demand [32].
	Generation	Annual deficit in hydroelectric generation [22].
		Annual fuel prices more expensive than average.
		Higher than average annual electricity demand [32].
Seasonal Pumped-Storage (SPHS)	Pump	Rainy seasons or ice melting seasons, with high hydropower generation [33].
		Summer, with high solar power generation [23].
		Windy seasons, with high wind power generation [34,35].
		Low demand season, when electricity demand reduces.
	Generation	Dry period or freezing winters, with low hydropower generation [33].
		Winter, with low solar power generation [23].
		Not windy seasons, with low wind power generation [34,35].
		High demand season, when electricity demand increases.
Weekly Pumped-Storage (WPHS)	Pump	During the weekends, when power demand reduces [36].
		Windy days, with high wind power generation [35].
		Sunny days, with high solar power generation [4].
	Generation	During weekdays, when power demand increases [36].
		Not windy days, with low wind power generation [35].
		Cloudy days, with low solar power generation [4].
Daily Pumped-Storage (DPHS)	Pump	Night, when electricity demand reduces [37].
		Day, when there is solar power generation [38].
	Generation	Day, when electricity demand increases [37].
		Night, when there is no solar power generation [38].
Hourly Pumped-Storage (HPHS)	Pump & Generation	Ancillary services: frequency control, remove harmonics in the grid, provide backup power in case of disturbances in supply.

UHR Plurianual: Múltiplo Usos da Água



UHR Plurianual: Segurança Energética



Henry Hub Prices 2019-01-01 to 2021-01-06



Obrigado!

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