Cost Optimization of Water Resources in Pernambuco, Brazil: Valuing Future Infrastructure and Climate Forecasts

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INTRODUCTION AND AIM OF STUDY

- Droughts are projected to intensify in semi-arid regions (Jiménez Cisneros, et. al., 2014), causing stress to the water supply.
- Optimal management of water resources and minimizing cost of water supply is vital to reduce strain on society and economy with limited water availability.
- Precipitation and streamflow forecasts permit adaptation of water strategies, and are slowly becoming a part of the policy making process (Lemos et. al., 2002).
- The first objective of the research is to evaluate the resiliency and cost associated with providing water to municipalities with current infrastructure, where deficit are met through trucks, and comparing it with future infrastructure, where a new source of water supply – Rio São Francisco – will cover some of the deficit.
- The second objective of the study is to evaluate the value of climate information by using streamflow scenarios using climate information, and comparing it with a fixed release policy derived from historical data.

PERNAMBUCO

- Second largest population in Northeast, seventh largest in Brazil (Lopez-Calva et. al., 2014).
- Urban population at 81% in 2010 (IBGE, 2010).
- Population is expected to rise by 7.5% from 2016 to 2030 (IBGE, 2010).
- Both tropical, and semi-arid climate.
- Precipitation ranges from 400 mm/year to 2350 mm/year with majority of the rainfall falling in the Eastern region (SRHE, 2016).

CHALLENGES FOR PERNAMBUCO

- Droughts are expected to rise, and between 2071-2100, the precipitation is estimated to reduce by 60% (Marengo, et. al., 2007).
- Total annual water demand from Capibaribe River Basin is expected to grow by 23% from 2010 to 2025 (SRHE, 2010).
- Total water demand from the Jucazinho system in Capibaribe River is expected to rise by 34% from 2010 to 2025 driven by urban demand (SRHE, 2010).

JUCAZINHO SYSTEM

- One of the largest reservoirs in the state at 327 million m^3 of max capacity.
- Receives water from the Capibaribe River
- At zero capacity as of January 26, 2017

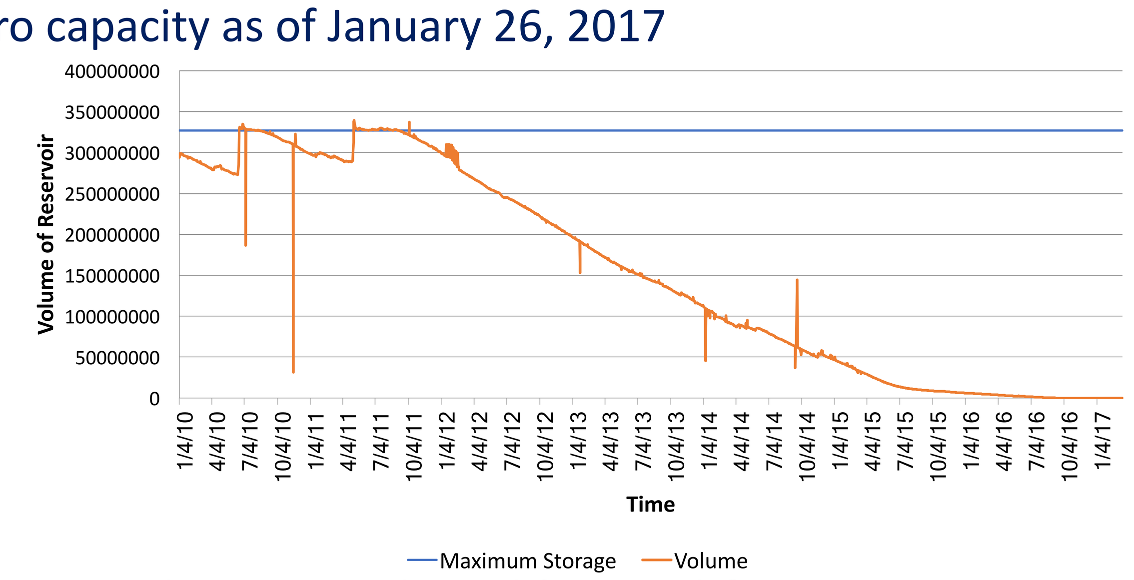

Figure 1: Storage in Jucazinho reservoir from 2010 to 2017

- Jucazinho system is a 5 reservoir system providing water to 19 municipalities.
  - Three other reservoirs (Eng. Gercino Pontes, Machado, Poço Fundo) are in Capibaribe River, and one reservoir, Prata, is in the Una river.

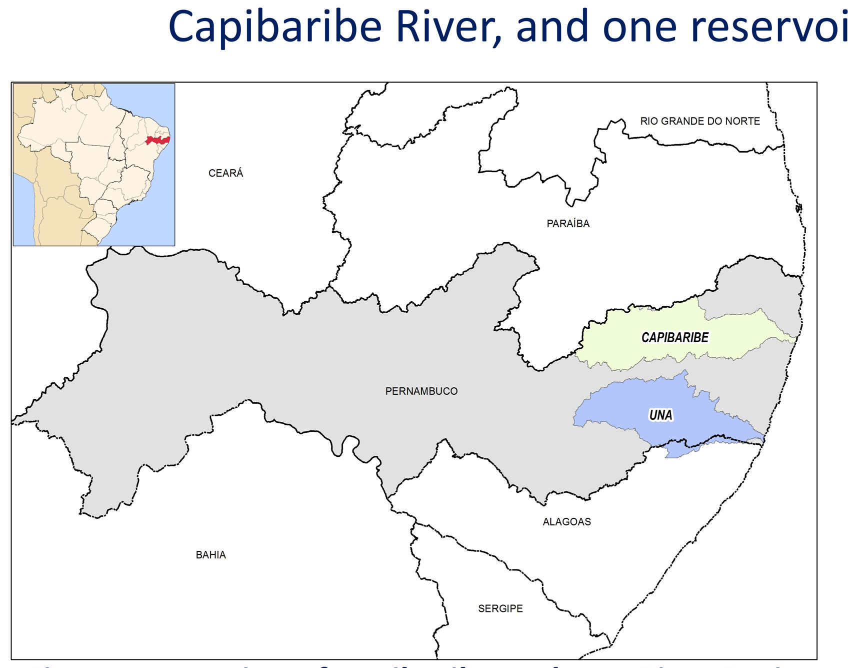

Figure 2: Location of Capibaribe and Una River Basin

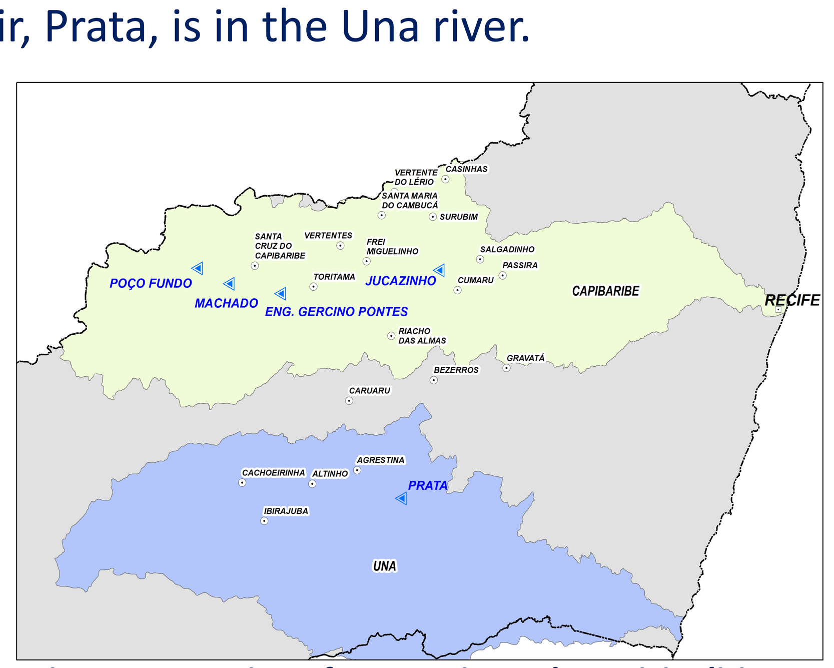

Figure 3: Location of Reservoirs and Municipalities

MODEL FORMULATION

- The objective function seeks to reduce the cost of water supply, including deficit.

$$min_Q \sum_{t=1}^{T}\left\{\sum_{r=1}^{R}\sum_{m=1}^{M} c_{rm}Q_{rmt} + \sum_{k=1}^{IMP}\sum_{m=1}^{M} c_{km}^{IMP}\,Q_{kmt}^{IMP} + \frac{1}{S}\sum_{r=1}^{R}\sum_{s=1}^{S}\pi F_{rts}\right\}$$

- Q_{rmt} is the water from reservoir r to municipality m
- c_{rm} is the cost of supply from reservoir r to municipality m
- Q_{kmt}^{IMP} is the imported water from transporter k to municipality m
- c_{km}^{IMP} is the associated cost
- F_{rts} is the deficit
- π is the cost of deficit

Demand constraint: $\sum_{r=1}^{R} Q_{rmt} + \sum_{k=1}^{IMP} Q_{kmt}^{IMP} \geq D_{mt}$

- D_{mt} is the demand

Reservoir Capacity Constraint: $SC_r^{min} \leq S_{rts} \leq SC_r^{max}$

Reservoir Releases Constraint: $PC_r^{min} \leq P_{rt} \leq PC_r^{max}$

Reservoir Balance: $S_{rts} = S_{r(t-1)s} + I_{rts} - \sum_{m=1}^{M} Q_{mrt} - P_{rt} + \sum P_{r*t} - L_{rts} + F_{rts}$

- S_{rts} is the volume of water stored in reservoir r at time t in climate scenario s
- I_{rts} the inflow
- P_{rt} the volume released from the reservoir r to the downstream river reach,
- $\sum P_{r*t}$ are incoming inflows from upstream reservoirs r*
- L_{rts} the losses
- F_{rts} is added to the reservoir mass balance to reflect the failure at the reservoir level and is simulated over all scenarios

MODEL SETUP

- The total time period T is taken as 25 years at a twelve month planning period.
- The study considers 5 import trucks, providing water at the rate of 600 m^3/month.
  - Most expensive source of water supply (more than 7 times the cost of water supply from reservoirs).
- In the future, Rio São Francisco will supply water to cover some of the deficit.

STREAMFLOW SETUP – THREE TEST CASES

- To evaluate resiliency of the current and future infrastructure, and the value of climate forecast, the study takes three test cases.
- The first case uses perfect information about the future to assess the resiliency of current and future infrastructure.
- The second case assesses the value of climate information by computing streamflow forecasts using K-nearest neighbors, and compares it with the third case of deriving a fixed policy from historical data.

RESULTS

	PERFECT FORECAST		FIXED POLICY		CLIMATE FORECAST	
	Current Infrastructure	Future Infrastructure	Current Infrastructure	Future Infrastructure	Current Infrastructure	Future Infrastructure
	Million R$					
Jucazinho	16.997	11.677	36.185	25.333	19.457	16.263
Machado	0.121	0.117	0.010	0.010	0.085	0.080
Eng Gercino Pontes	2.477	2.430	1.435	1.435	2.738	2.629
Poço Fundo	0.730	0.635	5.001	5.001	0.602	0.478
Prata	49.455	46.606	15.156	13.775	4.221	38.921
Rio São Francisco	NA	12.342	NA	26.252	NA	12.540
Failure	67.08	8.81	131.36	44.39	90.15	42.05
Total Cost of Supply	69.780	73.807	57.787	71.806	27.103	70.911
Total Cost with Failure	136.86	82.617	189.147	116.196	117.253	112.961

Table 1: Average annual cost (million R$) of water supply with 3 streamflow cases, current and future infrastructure

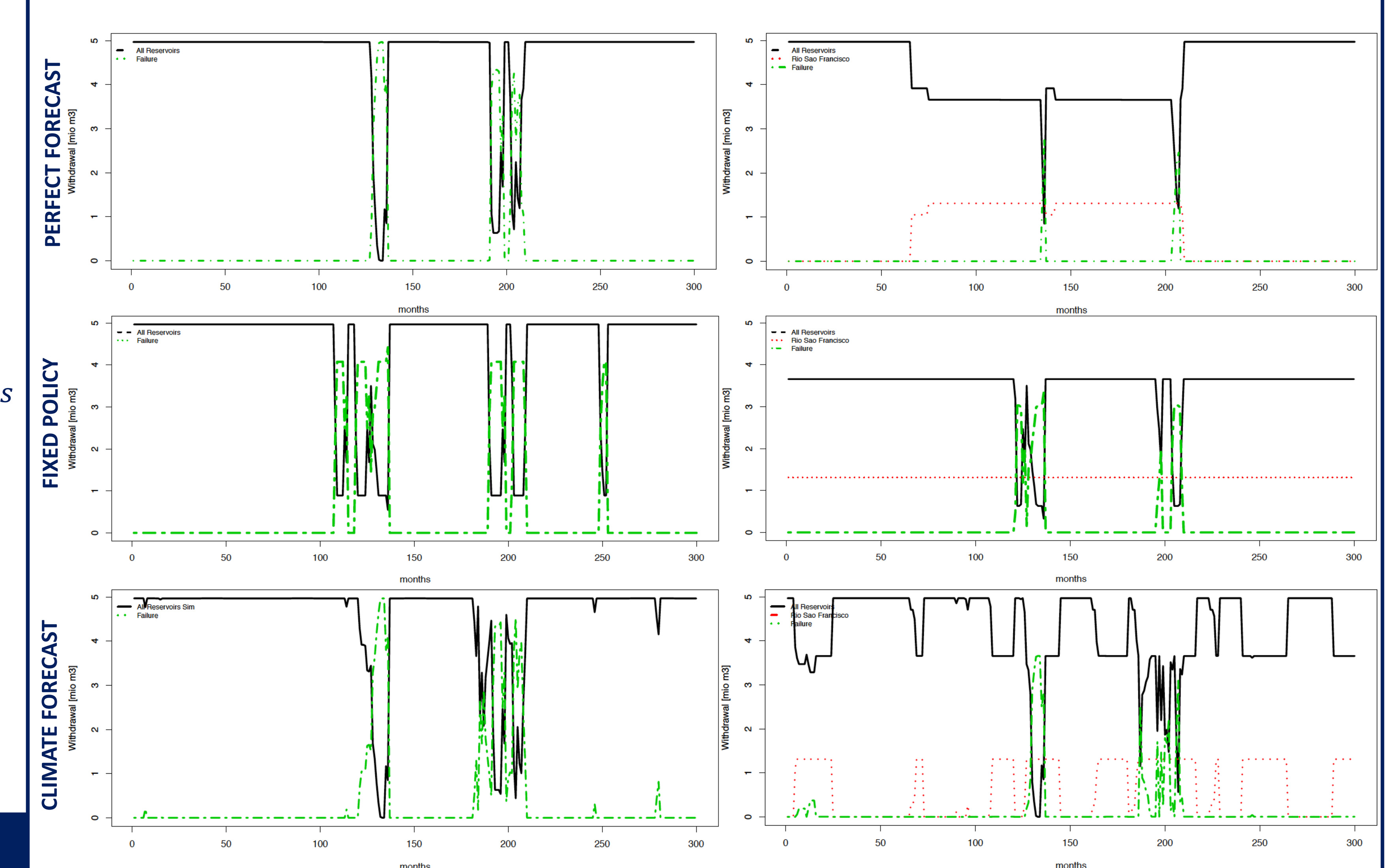

Figure 4: Withdrawal from reservoirs, Rio São Francisco, and failure to provide water

- Even with future infrastructure, one cannot avoid failure.
- Use of climate information can reduce cost of failure significantly as compared to a fixed release policy.
  - With current infrastructure, failure cost reduces by ~R$41 million,
  - With future infrastructure, failure cost reduces to ~R$2 million.
- Cost of water supply from Rio São Francisco is higher than that from reservoirs, during fixed policy, supply from Rio São Francisco leads to higher costs.
- Droughts lasting more than a year result in failure during perfect forecast.
- Fixed release policy in the case of future infrastructure always relies on use of Rio São Francisco to provide water, which also increases the cost of water supply.

CONCLUSION

- Climate forecasts help reduce failure significantly.
- Infrastructure still needs improvement, and during extreme and prolonged droughts, the state needs to harness additional means beyond Rio São Francisco.

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REFERENCES

Jiménez Cisneros, B.E., T. Oki, N.W. Arnell, G. Benito, J.G. Cogley, P. Döll, T. Jiang, and S.S. Mwakalila, (2014) Freshwater resources. In: Climate Change 2014: Impacts,Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 229-269.

Lopez-Calva, L. F., Rodella, A., Sharman, M.A. (2014), Equity for Sustained Growth: Pernambuco Equity Assessment. The World Bank.

Marengo JA, Ambrizzi T, Alves L, Nobre C, Pisnitchenko I. (2007) Atlas de cenários climáticos futuros State para o Brasil (versão 1.0). Ministério do Meio Ambiente, Cachoeira Paulista, 124.

Neto, A.R., Scott, C.A., Lima, E.A., Montenegro, S.M.G.L., Cirilo, J.A. (2014), Infrastructure sufficiency in meeting water demand under climate-induced socio-hydrological transition in the urbanizing Capibaribe River basin – Brazil. Hydrololgy and Earth System Sciences, 18, 3449–3459, 2014. doi:10.5194/hess-18-3449-2014

IBGE (2016), Diretoria de Pesquisas, Coordenação de Trabalho e Rendimento, Pesquisa Nacional por Amostra de Domicílios Contínua. Censo Demográfico 2010.

SRHE (2010) Pernambuco: Plano Hidroambiental da Bacia Hidrográfica do Rio Capibaribe, Tomo II – Cenários Tendenciais e Sustentáveis, Secretariat of Water and Energy Resources – Secretaria de Recursos Hidricos, Governo de Pernambuco, SRHE, Recife, 190 pp., 2010.

SRHE (2016) Atlas de Bacias hidrográficas: Precipitação Pluviométrica Média Annual Mapa de Situação. Laboratório de Meteorologia de Pernambuco – LAMEPE. Secretaria de Recursos Hidricos, Governo de Pernambuco.