Planning for Drought in Megacities:
A Case Study of the Recent São Paulo, Brazil Drought

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1. Abstract

This study discusses the challenges encountered by São Paulo, Brazil in coping with the 2013-2015 drought and explores the benefits of collaboratively developed drought management plans. As a result of rapid urbanization, high population growth rates, and record low streamflows, the São Paulo water supply reached its lowest storage level in history in 2015. The public was not informed of the severity of the drought nor the measures that were being taken to reduce the impacts. The occurrence of this drought and the ensuing social unrest highlight the need for a collaboratively developed drought management plan in São Paulo. This study uses a simulation model of the Cantareira System, the largest reservoir system supplying water to the metropolitan region, to evaluate how stressed the system is at meeting current and future demands, to develop alternative drought management plans, and to assess these plans. A set of system performance metrics was used to explore trade-offs and identify promising plans. Opportunities to include stakeholders in the development of plans are identified throughout the study. The analysis demonstrates how a drought plan increases the resiliency of Sao Paulo's water supply and its ability to weather future unknowns in demand and supply.

2. Background Information

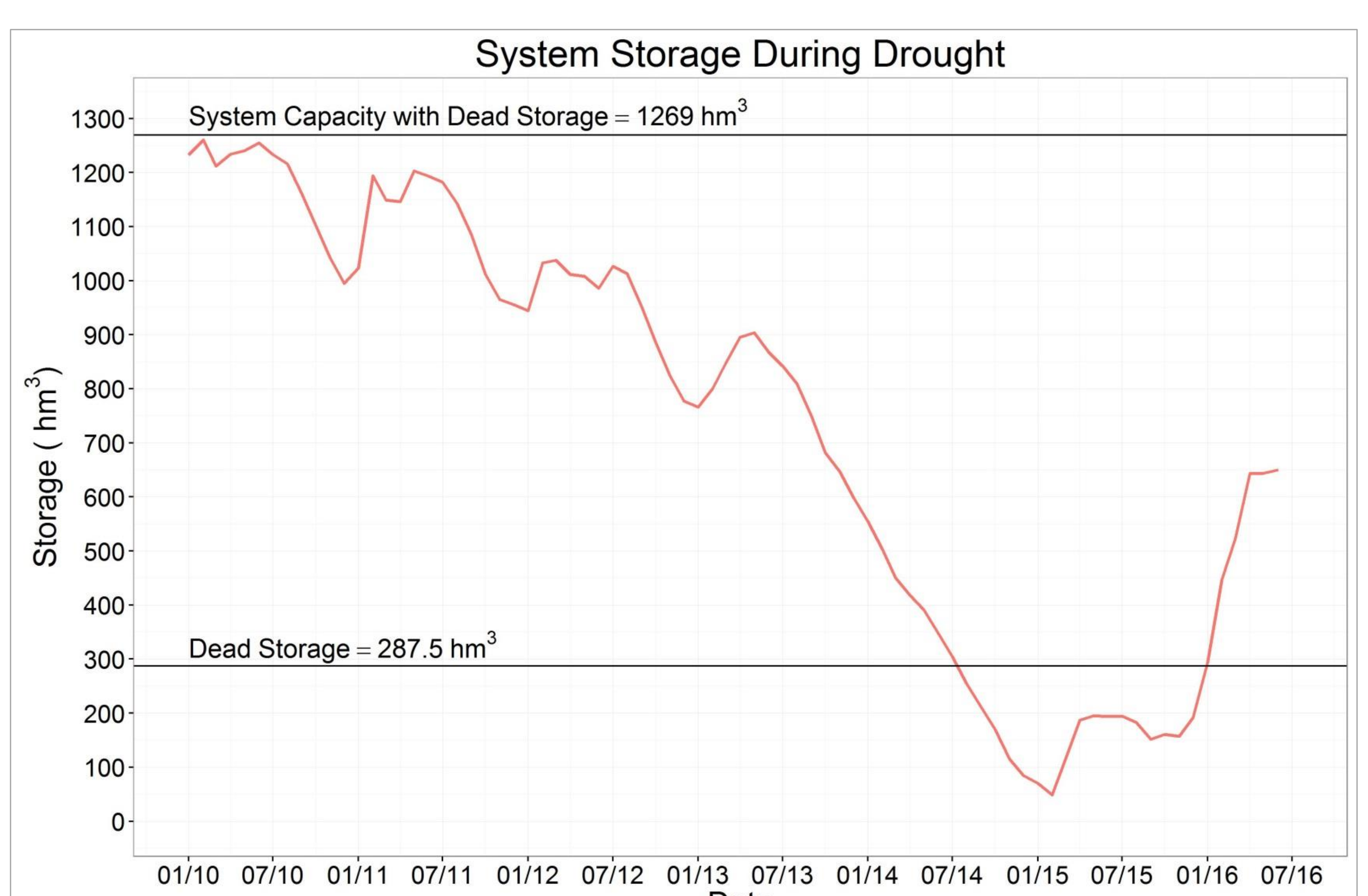
Cantareira System:

- Comprised of five reservoirs
- Capacity of 982 hm^3 without dead storage, 1,269 hm^3 with dead storage
- Demand to the city is 33 m^3/s, downstream demand is 5 m^3/s
- Supplies water to 15 million people

São Paulo Drought:

- Lowest inflows and system storage recorded in 84 years
- Portions of the population without water for days or in some cases weeks

Photo Credit: Mídia NINJA/ContaDagua.org

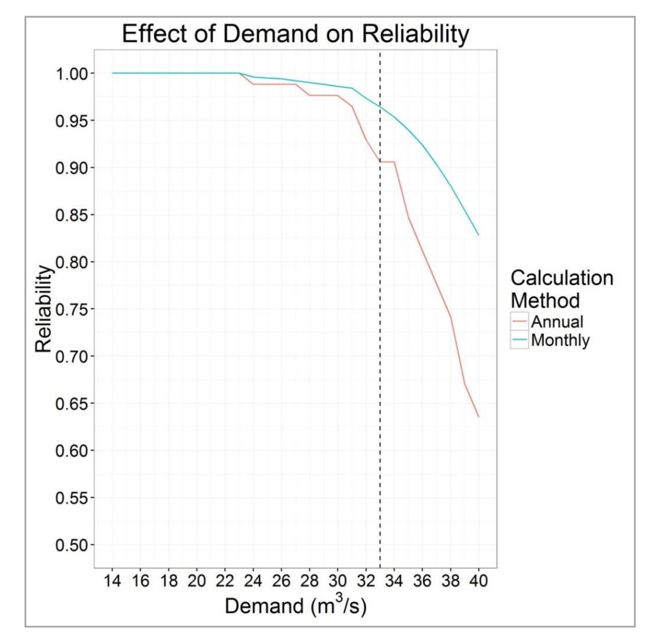


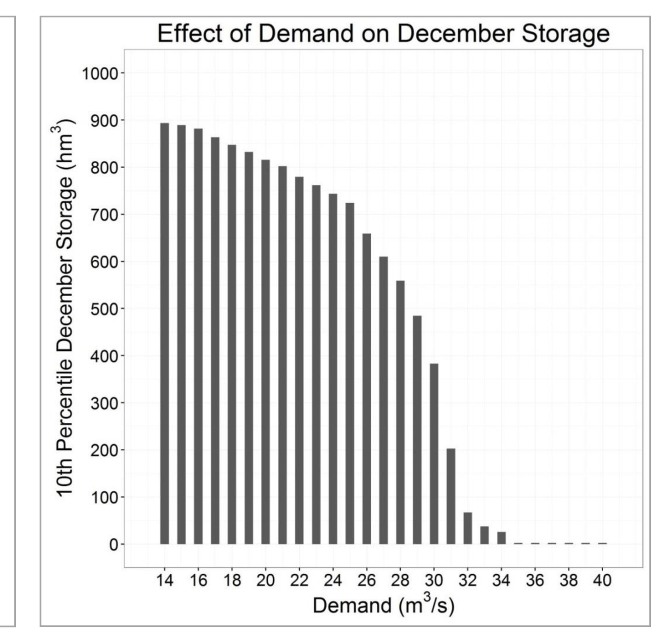
3. Research Questions

1. Can the Cantareira system reliably meet the current demand and future needs?
2. Could alternative, collaboratively developed drought plans have improved system performance during the drought?
3. How can we evaluate these drought plans?

4. System Vulnerability Assessment

- System safe yield is 23 m^3/s, as compared to the current 33 m^3/s demand.
- At the current demand, the system is expected to fail about once in every 10 years.
- A robust drought plan is needed for the system.
- The public should be informed of the risks to the system to help them better understand the need for management actions.





Demand	33 m^3/s	37 m^3/s	40 m^3/s
Annual Reliability	0.91	0.78	0.64
Monthly Reliability	0.96	0.90	0.83

5. Drought Plan Development

Drought Plan components:

Indicator: *observation that describes the state of the system*

- Days of supply remaining (DSR) considers the current storage and a three month forecast of inflow and demand

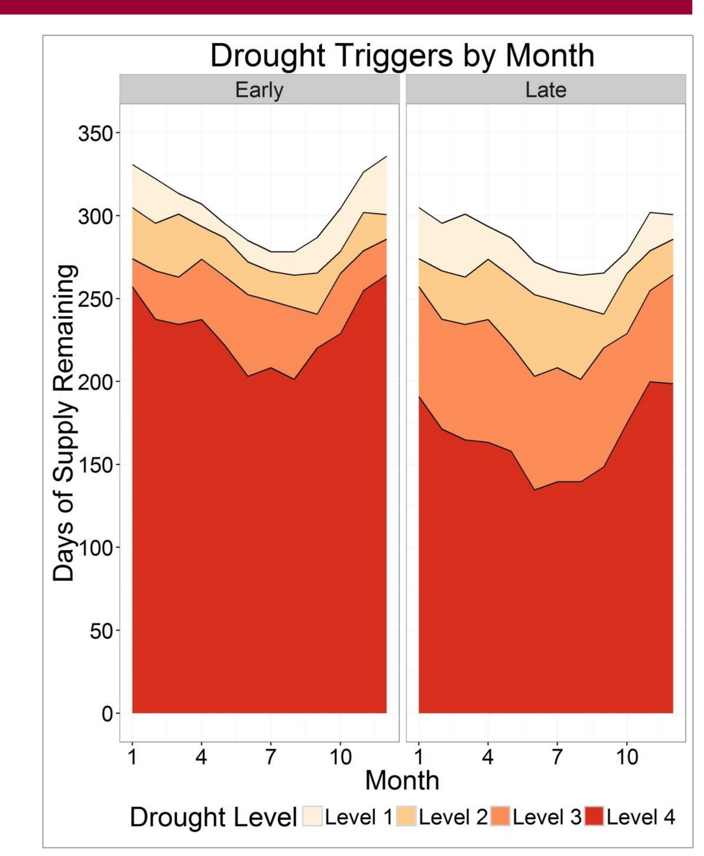
$$DSR(i) = \left\{\frac{S(i) + [(\sum_1^3 I(i+1)) - (\sum_1^3 D(i+1))]}{D(i)}\right\}$$

Triggers: *predefined value of a drought indicator that initiates a drought response*

- Four decreasing percentiles of DSR (see right)

Management Actions: *steps that can be taken to increase water supply or decrease water demands*

- Demand reductions that become increasingly severe with increasing drought level



Ten drought plans were developed to explore the trade-offs between triggering drought response actions early or late and between initiating severe or mild sets of demand restrictions.

Drought Plan	1	2	3	4	5	6	7	8	9	10
Restriction Severity	Very Mild	Mild	Moderate	Severe	Very Severe	Very Mild	Mild	Moderate	Severe	Very Severe
Trigger	Late	Late	Late	Late	Late	Early	Early	Early	Early	Early

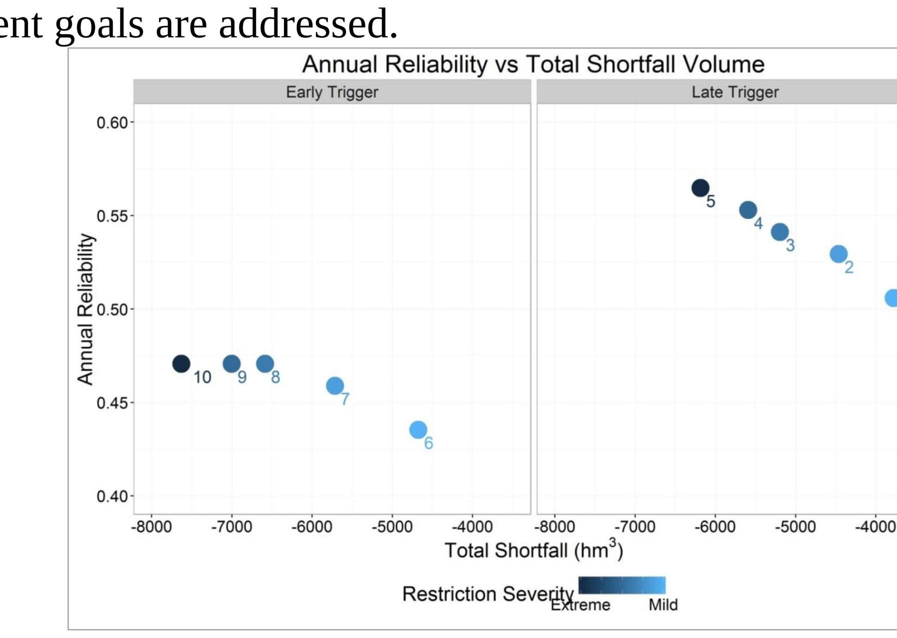
*Drought plan components should be collaboratively developed with stakeholders. In their absence, the above components are used to illustrate what these may look like.

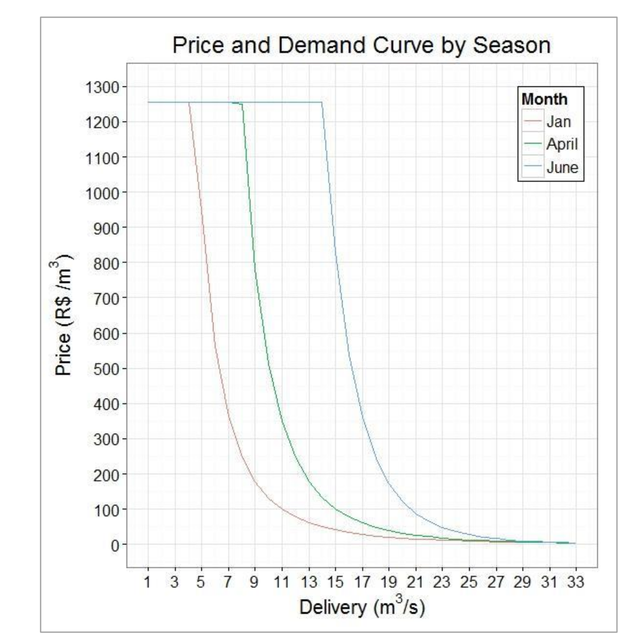
6. Drought Plan Assessment

Performance metrics should be identified by all stakeholders to ensure the broad range of management goals are addressed.

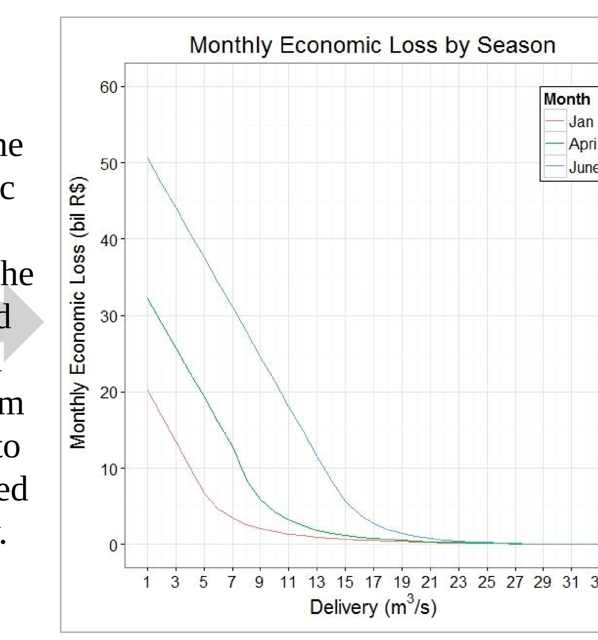
In this model, performance metrics include:

- Annual reliability (%)
- Shortfall volume (hm^3)
- Economic loss ($)
- 10th percentile December storage (hm^3)

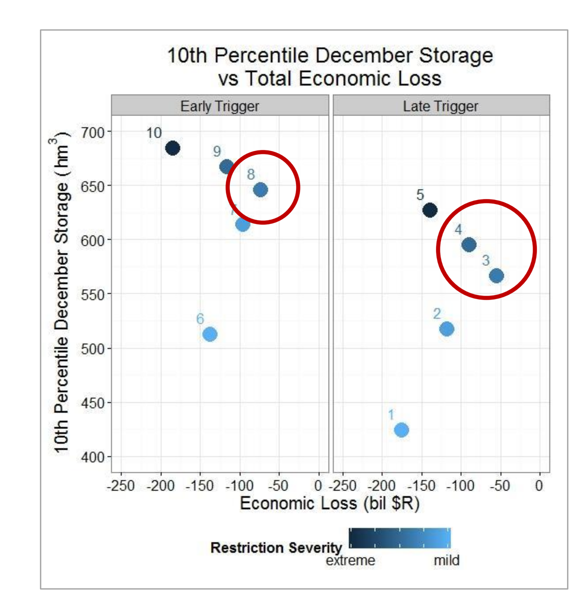


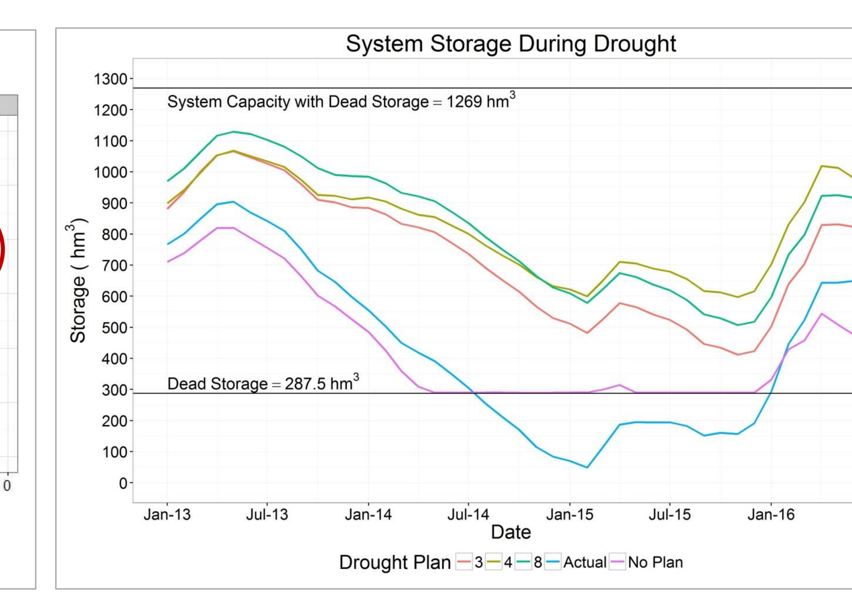


To find the economic loss, integrate the price and demand curve from 33 m3/s to the reduced delivery.



The identification of promising drought plans requires the engagement of stakeholders. However, for illustrative purposes, it is suggested that plans 3, 4, and 8 appear promising as they minimize economic losses and maintain acceptable storage levels during even the worst drought (see below).





7. Conclusions & Future Work

- The **Cantareira system is stressed** at the current demand and increasingly stressed at higher demands.
- **Trade-offs** exist between highly conservative and highly risky plans.
- Promising drought plans can be found by comparing **performance metrics.**
- Calculating the **economic losses** associated with reduced deliveries may be helpful in balancing the frequency and severity of restrictions.
- **Exploring trade-offs with stakeholders** would allow them to understand risks and be more accepting of management responses to the drought.
- The **robustness of drought plans** must be tested to analyze plan performance with the consideration of **climate change** impacts.