Problem Formulation for Assessment of TBW System

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1 Summary

The purpose of this document is to clarify the metrics by which TBW modeling results will be assessed. Section 2 contains mathematical descriptions of each potential performance metric as well as references to the exact variables reported by the AMPL model used for calculation. Section 3 describes the metrics of supply and demand used during exploratory modeling.

2 Performance Metrics of Interest

2.1 Level of Service

The calculation for level of service (LoS) is given in detail in Appendix 8A of the Long-Term Master Water Plan (LTMWP), Section 5.1. One note is that LoS should be carefully defined to be different than **reliability**. Level of service is described both as: (a) the fraction of days in a given realization when the system is in a "satisfactory" state; and (b) the policy p that determines whether or not a particular realization is reliable. For example, if the calculated LoS for a realization is x, where $x > p$, then the particular realization is satisfactory for a level of service policy level p. Reliability is then calculated as the fraction of realizations within a simulation of the system for which $x > p$ is true. This implies that as the policy LoS p declines, reliability of the system increases. Below we describe how to quantify level of service for each *realization* rather than an entire simulation, and are not concerned immediately with setting a policy LoS p level. Our method for calculating the LoS in the subsections that follow can be found in our GitHub repository file **performance_metrics.py**, function calc_LOS().

2.1.1 For CWUP Only

Measuring level of service for the LTMWP was done based on violations of the Consolidated Well Use Permit (CWUP), or more specifically when slack variables were used to loosen the permitted capacity during modeling in order to meet regional demands. In each realization, violations of the CWUP are reported based on the **wup_mavg_pos[CWUP]** variable from the csv output files returned from AMPL, reported in any day of violation across the realization (with $N_d = 7,304$ days). Where this value V_{CWUP} is greater than zero, a violation of the permit has occurred. As such, we track level of service for a particular realization of a simulation via the following formulas:

$$v_d = \begin{cases} 1 & \text{if} \quad V_{CWUP} > 0 \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

where v_d is the binary indicator of whether day d sees a violation of CWUP. Following from this, we calculate the level of service LoS_r for realization r to be:

$$LoS_r = \frac{\sum_{day=1}^{day=N_d} v_{day}}{N_d} \tag{2}$$

2.1.2 For all relevant Slack Variables

Following the same methodology as in section 2.1.1 above, we also calculate level of service based on all possible groundwater and surface water violations of: (1) CWUP (V_{CWUP}, tracked as **wup_mavg_pos[CWUP]**); (2) Brandon Urban Dispersed wellfields (V_{BUD}, **wup_mavg_pos[BUD]**)); (3) South-Central Hillsborough wellfields (V_{SCH}, **wup_mavg_pos[SCH]**); (4) Tampa Bypass Canal (V_{TBC}, **ngw_slack[TBC]**); (5) Alafia intake (V_{ALA}, **ngw_slack[ALA]**). LoS_r is calculated in an identical method to Equation 2 above, but v_d is calculated via the following adjustment:

$$v_d = \begin{cases} 1 & \text{if} \quad \exists\, V_{loc} > 0 \quad \forall\, loc \in [CWUP, BUD, SCH, TBC, ALA] \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

2.2 Environmental Sustainability

To track sustainable use of regional groundwater supply, the regional model records "target offset" variables that indicate whether pumping, combined with groundwater recharge efforts, have resulted in an unsustainable drop in the groundwater table. Specifically, a target offset value is recorded if the water level at a given monitoring well (*monitoring wells or water supply wells used to determine this?*) fall below a designated height. Those offsets are summed across all wells and reported as a daily total for the region. To assess a given realization's ability to meet groundwater targets, **we take the greatest 30-day average of daily total regional offsets** to represent the environmental sustainability of groundwater use by TBW. See the function calc_environmental_burden() of performance_metrics.py for Python code to calculate this quantity.

This is calculating using the daily target offset totals TO_d (variable tg_offset in the .log output files from AMPL). First, the 30-day (monthly) moving average of TO_d is calculated across a realization r, and the representative environmental sustainability performance metric ES_r for the realization is taken as the maximum value in that set of monthly moving averages of daily target offset.

2.3 Short-Term Vulnerability

Level of service and reliability can speak to the frequency of supply shortage events, but not to their severity. Vulnerability can be measured by tracking: (1) the number of "unmanageable days" where demand is greater than supply; (2) the severity of shortage over the course of unmanageable days (specifically, events of two weeks or more consecutive days of shortage); (3) the average duration of unmanageable events. The calculation of these metrics is also given in Appendix 8A of the LTMWP. Our calculations (which are different in some ways from those in the LTMWP as explained below) for these metrics can be found in the find_failure_periods() function of performance_metrics.py.

2.3.1 Unmanageable Events

Our calculation of unmanageable days differs slightly from the calculation described in the LTMWP. For a given realization r, we define the management state of a given day d as M_d, which is assigned a value in a similar manner to Equation 3 above:

$$M_d = \begin{cases} 1 & \text{if } V_l > 0 \quad \exists\, l \in [CWUP, BUD, SCH, TBC, ALA] \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

For our calculations, an unmanageable *event* would occur given 15-or-more consecutive days where $M_d = 1$, where at least one system slack variable is triggered each day. A single unmanageable event can last anywhere from 15 to 364 days. Each unmanageable event is added to the tally UE_r for the realization, counting how often they occur. Similarly, the duration of each event is added to the vector UD_r, and the magnitude (the sum of violations V_l across each location l for every day of the event) UM_r of each event as well.

The severity of shortages can be then be quantified based on (a) the frequency of unmanageable events or (b) the 95th percentile worst event in each realization by duration or by magnitude. Frequency f_r is calculated as:

$$f_r = \frac{\sum UE_r}{N_d} \tag{5}$$

to represent the fraction of days that were unmanageable. Aside from that, we can quantify shortage severity SS_r in terms of extremes:

$$SS_r = Pr[X \leq x] \geq 0.95 \tag{6}$$

where X can be either UD_r or UM_r and x is the 95th percentile event in terms of either duration or magnitude.

2.3.2 Cost of Conservation Implementation

As a next step to some of the work we have started here, it would make sense to translate unmanageable event duration or magnitude into costs of drought mitigation. A simple way would be to transform the magnitude of shortages (in terms of millions of gallons of water that would need to be conserved) into the reduction in revenue for TBW based on the Uniform Rate in the given year of simulation. We are open to suggestions as to what financial metrics related to short-term mitigation are most important to planning for TBW - our work in the Triangle has used short-term mitigation worst-case costs (i.e. 99th percentile drought event cost) along with use restriction frequency as measures of shortage severity and financial risk.

2.4 Cost

Each simulation (development concept) of the model follows different infrastructure and operational plans, making it essential to track costs as they develop across realizations.

Our initial assessment of cost as a performance metric represents only the **sum of capital costs incurred**, infrastructure construction but not operational expenses for each realization.

2.4.1 Capital Costs

Based on cost tables in Appendix 15A of the LTMWP, we summed infrastructure costs for projects in each realization based on the development concept used for the particular model simulation done (i.e. for model simulation 80, the capital costs of expanding the desalination facility were included). Because these values do not change between realizations for a single model simulation/concept, the calculation is simply an sum of total capital costs given in the report and is not detailed here. Future adjustments to this calculation, should we incorporate demand growth to each stochastic realization and triggering mechanisms for sequencing of projects, would be a method for present-valuing infrastructure costs. Our calculations are separately shown in calc_cost() of performance_metrics.py.

2.4.2 Operating Costs

Finally, though we did not include it in our recent presentation, future quantification of realization costs should include some consideration of operational/variable costs due to new infrastructure projects. This would also capture changes to operational policy that capital costs may not (i.e. holding desalination production at a fixed level vs. status-quo operation).

3 Measures of Supply and Demand

For the LTMWP, TBW created 1,000 combinations of future supply and demand scenarios which were narrowed to 334 realizations using Latin Hypercube Sampling (LHS). Each realization represents a stationary 20 year time series of regional demands and inflows.

3.1 Average Annual Demand

Average annual demand for each realization remains stationary for the 20 year period. Performance across 20 year simulations for each value of average annual demand were used to infer the effects of regional demand growth on the performance metrics described in Section 2.

3.2 Average annual inflow

The average annual inflow at the Tampa Bay Bypass Canal (TBC in the model) was used as a proxy for the system inflow.

3.3 SSI6: A measure of drought

While average annual inflow was used to create realization, average annual inflow may not be an informative metric on system performance as years with high inflows during we periods may mask droughts during dry periods. To examine the region's vulnerability to drought conditions, we used a measure of drought known as the Standardized Streamflow

Indicator (SSI) [2, 1]. To calculate SSI, the daily inflows are assumed to be lognormally distributed, for day t and inflow Q_t:

$$Y_t = lnQ_t$$

This timeseries is then standardized:

$$Z_t = \frac{Y_t - \hat{\mu}_Y}{\hat{\sigma}_Y}$$

SSI_6 represents the 6-month moving average of Z_t.

We define **drought events as instances within a realization when** $SSI_6 < 0$ **continuously for at least 3 months and** $SSI_6 < -1$ **at least once during that interval**.

SSI_6 was used to measure the maximum length, severity and frequency of droughts in each realization.

References

[1] Jonathan D. Herman, Harrison B. Zeff, Jonathan R. Lamontagne, Patrick M. Reed, and Gregory W. Characklis. Synthetic Drought Scenario Generation to Support Bottom-Up Water Supply Vulnerability Assessments. *Journal of Water Resources Planning and Management*, 142(11):04016050, November 2016.

[2] Thomas B McKee, Nolan J Doesken, John Kleist, et al. The relationship of drought frequency and duration to time scales. In *Proceedings of the 8th Conference on Applied Climatology*, volume 17, pages 179–183.