Memorandum

From: Daniel Obenour, PhD, NC State University

To: Forrest Westall, PE, UNRBA

Date: 6 Oct 2020

Re: Falls Lake "WARMF Lake" Model Segmentation

Background:

Some water quality models represent waterbodies as a series of continuously stirred tank reactors (CSTRs). Reservoir segments are well represented using CSTRs when the segments are isolated from each other (e.g., due to constrictions) and when the rate of diffusive transport greatly exceeds the rate of advective transport within each segment (i.e., Peclet <0.1; Chapra, 2008). Waterbodies can also be represented as plug flow reactors (PFRs), particularly when advective transport greatly exceeds diffusive transport (i.e., Pelcet >10, as in some streams). In practice, a PFR can be represented by a large number of CSTRs in series. A comparison of contaminant decay in a waterbody treated alternatively as a PFR versus a series of 5 CSTRs is shown below. Note that the PFR representation results in greater contaminant reduction, all else being equal, highlighting a substantive difference between these two approaches.

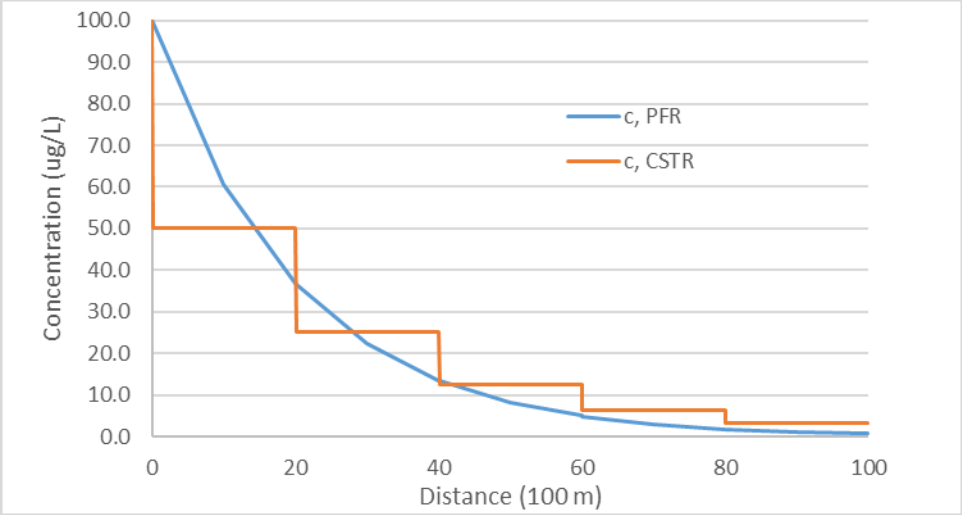

Figure 1: Concentration profile for a waterbody modeled as a PFR versus a series of 5 CSTRs. In both cases, the hypothetical substance is assumed to decay at a rate of 0.05/100 m.

The morphology of Falls Lake suggests potential modeling representations. The upstream portion of Falls Lake (above Creedmor Road) can be divided into wide segments separated by obvious constrictions (e.g., at road causeways), such that a CSTR representation appears appropriate for these segments (this could be verified mathematically). The downstream portion of Falls Lake (i.e., below Creedmor Road) is relatively narrow, such that advective transport may exceed diffusive transport, indicating a PFR (or large number of CSTRs in series) representation may be more appropriate. However, if nutrient

concentrations do not vary as much in the lower segments, using a smaller number of CSTRs may not lead to appreciable model error.

Discussion items:

1. Add additional segment to the lake model, splitting the current segment that extends from I-85 to the Rolling View pinch point. (Agree or Disagree)

   Since the proposed split would presumably occur at the Cheek Road causeway, which is a major constriction point, adding an additional segment will improve the mechanistic realism of the model

2. Perform calibration to data at the downstream end of each segment, instead of the segment average. (Agree or Disagree)

   In reality, reservoirs do not behave as perfect CSTRs or PFRs, but rather somewhere in between. Thus, both calibration approaches represent a compromise. Calibrating to segment mean/midpoints is more consistent with the mathematical representation of the reservoir as a series of CSTRs, as proposed by "WARMF Lake". Calibrating to segment mean/midpoints would be more critical if the flow can reverse (as in Jordan Lake). On the other hand, given a consistent flow direction (as in Falls Lake), calibration to segment end points can result in (slightly) more accurate loading inputs to downstream segments. Given the small changes in observed concentrations (e.g., nutrients) among adjacent segments (based on the currently proposed segmentation), either approach is expected to be a workable representation of the system.

References:

Chapra, S. C. (2008). Surface water-quality modeling. Waveland press.