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Supplementary Information for

Management Transition to the Great Lakes Nearshore: Insights from Hydrodynamic Modeling

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Supplementary Information

Examining Application of a Solely Far-Field Model

Waters available for receipt of an effluent discharge are categorized as being near-field or far-field environments. The region proximate to an outfall where turbulent mixing occurs due to effluent momentum and buoyancy is referred to as the near-field (also zone of initial dilution [1], and initial mixing region [2]). Waters beyond the near-field, where effluent momentum and buoyancy are attenuated and mixing and transport are dominated by ambient wave and current action, are termed the far-field. It is readily apparent that WWTP effluent plumes (Figure 11), especially those of the larger point sources, may extend not only well beyond the near-field but well into the far-field, the appropriate focus for protection in nearshore regulatory applications. Because of the different space and time scales in the near-field and far-field with respect to transport processes, it is impossible for a single model to fully characterize the detailed dynamics of both environments. A common way to address the issue is to use separate near-field (e.g., initial mixing zone) and far-field (e.g., 3D circulation) models. However, issues arise as the interaction between the far-field and near-field is not resolved in this approach. Near-field models often fail to accommodate spatiotemporal variability in the ambient flow and water quality conditions adjacent to the near-field, assuming that the plume mixes with clean ambient water, i.e., experiences no constituent return from the far-field [3]. On the other hand, far-field models cannot fully capture the near-field dynamics resulting from momentum imparted by diffusers, although performance may be improved by increasing the near-field model grid resolution within the computational domain of the far-field.

In applying FVCOM to the phosphorus–*Cladophora* dynamic, the phosphorus load (flow rate × concentration) is added to the water column in the form of a flux to ensure conservation of mass of the water and effluent constituents. In this study, our interest is not the fine structure of the near-field plume, where phosphorus concentrations are high enough to be growth-saturating and the alga is insensitive to spatiotemporal variations [4]. Rather, our focus is on plume patterns at the far-field scale where concentrations are lower and variations in phosphorus concentration occur over an ecologically meaningful range. It is variation at this spatial scale that mediates the juxtaposition of the POC footprint with algal habitat. Although resolution of near-field dynamics is not our intent from a phosphorus management perspective, it serves our interest in testing the limits of the model to ask to what extent a far-field model alone (i.e., FVCOM in this case) can predict plume dimensions without directly resolving near-field dynamics. Studies in Massachusetts Bay [5,6] demonstrated that a 3D circulation model (e.g., ECOMsi) can predict the initial dilution of plumes in the near-field quite well, while successfully simulating the far-field effluent plume pattern. Several mechanisms explaining why a far-field model may perform well in capturing near-field phenomena and successfully represent the impact of the near-field on far-field conditions (when the near-field processes are not fully resolved) are explored by Zhang and Adams [3]. Their results show that, under weak ambient current conditions, the flow in the near-field produced by plume entrainment (resolvable only by near-field models) is similar to that caused by density exchange (resolvable by far-field models). Moreover, in cases with strong ambient mixing conditions, near-field properties are governed by the magnitude of crossflow passing over the diffuser, a feature well simulated by far-field models [7–9]. In addition, ambient water column stratification resolved by a far-field model may provide a density ceiling that can easily trap a rising plume, even if near-field entrainment dynamics are not represented explicitly.

Sensitivity analyses were conducted to examine the impact of unresolved near-field dynamics on simulation of the far-field (plume dimensions). A near-field model, CORMIX3, was first run to identify the near-field dimensions of the Duffin Creek WWTP outfall for two mixing scenarios: well-mixed and stratified ambient conditions. The resulting CORMIX3 near-field dimensions, 90–150 m, are equivalent to the model cell size (~100 m) at the outfall in our FVCOM model configuration. We then examined the sensitivity of model-predicted far-field conditions (plume dimensions) for the two mixing scenarios. A comparison of model results for the two cases shows that near-field dynamics play an insignificant role in mediating far-field behavior, as near-field dynamics are of primary importance to initial mixing. The spatial distribution of the plume is very similar for the two cases with an average difference over the majority of the domain of <3 μg NO_3-N·L^{-1} (<1%; Figure S2). Although neither case serves to resolve true near-field dynamics, the results suggest that model-predicted plume dimensions at the far-field scale are robust and insensitive to the representation of initial plume mixing, at least over the simulation period considered here. This provides us with further confidence that near-field dynamics are not significant at our scale of interest.

Furthermore, we compared simulated and observed vertical nitrate profiles for stations at six selected transects (Figure S3). The results demonstrate that model predictions and field observations agree well in both vertical pattern and magnitude at all stations on transects that are located between the study site’s three WWTPs. This reinforces the conclusion that the model captures the plume pattern in the far-field well, which is the primary interest of this research. The vertical profiles closest to WWTPs vary markedly with depth. The model captures most of the patterns near the Highland Creek and Corbett Creek WWTPs as well. However, the model captures less of the vertical variation in the two transects closest to the Duffin Creek WWTP, as near-field dynamics are not directly resolved in our model. It must be noted that, if the research focus is on the near-field itself, those dynamics must be carefully incorporated into the system. The best approach for this would be to utilize a two-way online coupled near-field/far-field model, in which the far-field model provides real-time ambient mixing conditions to drive the near-field model, and the near-field model provides the real-time initial mixing conditions to the far-field model at each step in the model simulation.

Supplemental Figures

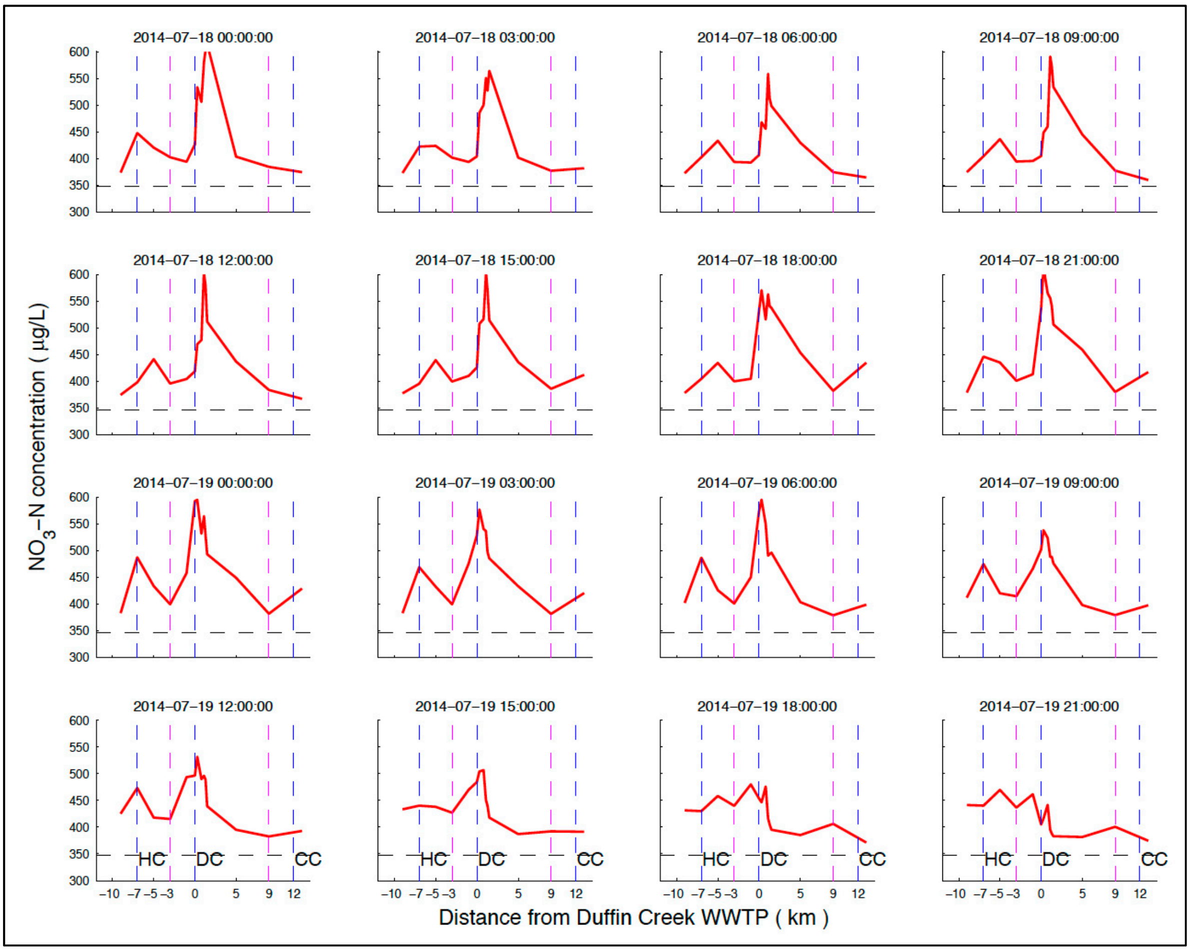

Figure S1. Model-simulated transect-mean NO_3-N concentrations averaged at 3-h intervals. Labels for the blue dashed lines (HC, DC, CC) indicate the locations of the Highland Creek, Duffin Creek, and Corbett Creek WWTPs. The pink dashed lines indicate the edge of the potential influence area (alongshore extent) of the Duffin Creek WWTP plume. The black dashed line indicates the baseline (offshore) concentration.

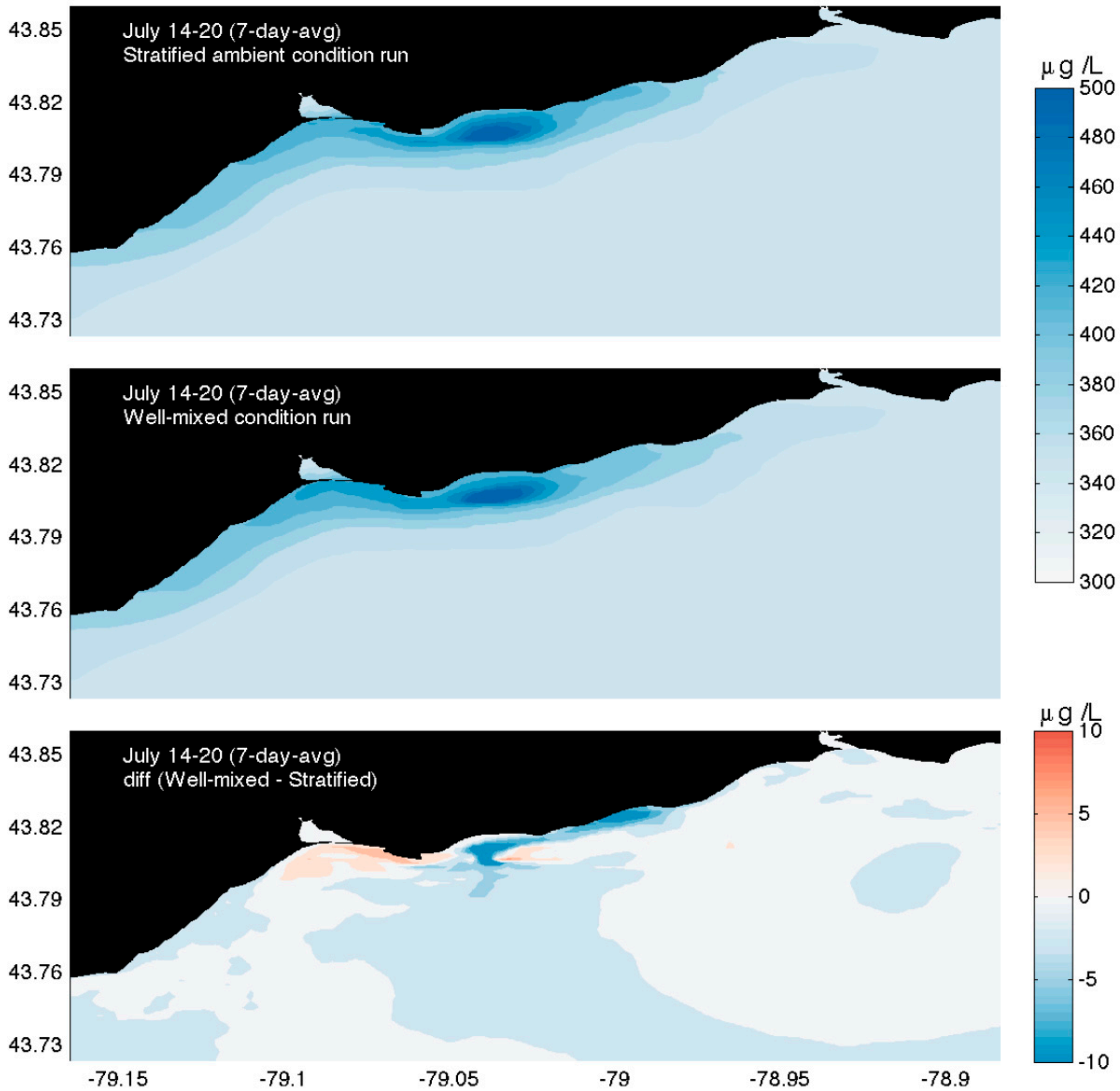

Figure S2. Model simulations of NO_3-N concentration illustrating the position of the Duffin Creek WWTP plume for the stratified (upper panel) and well-mixed (middle panel) conditions at the initial mixing zone and the difference between the two simulations (lower panel).

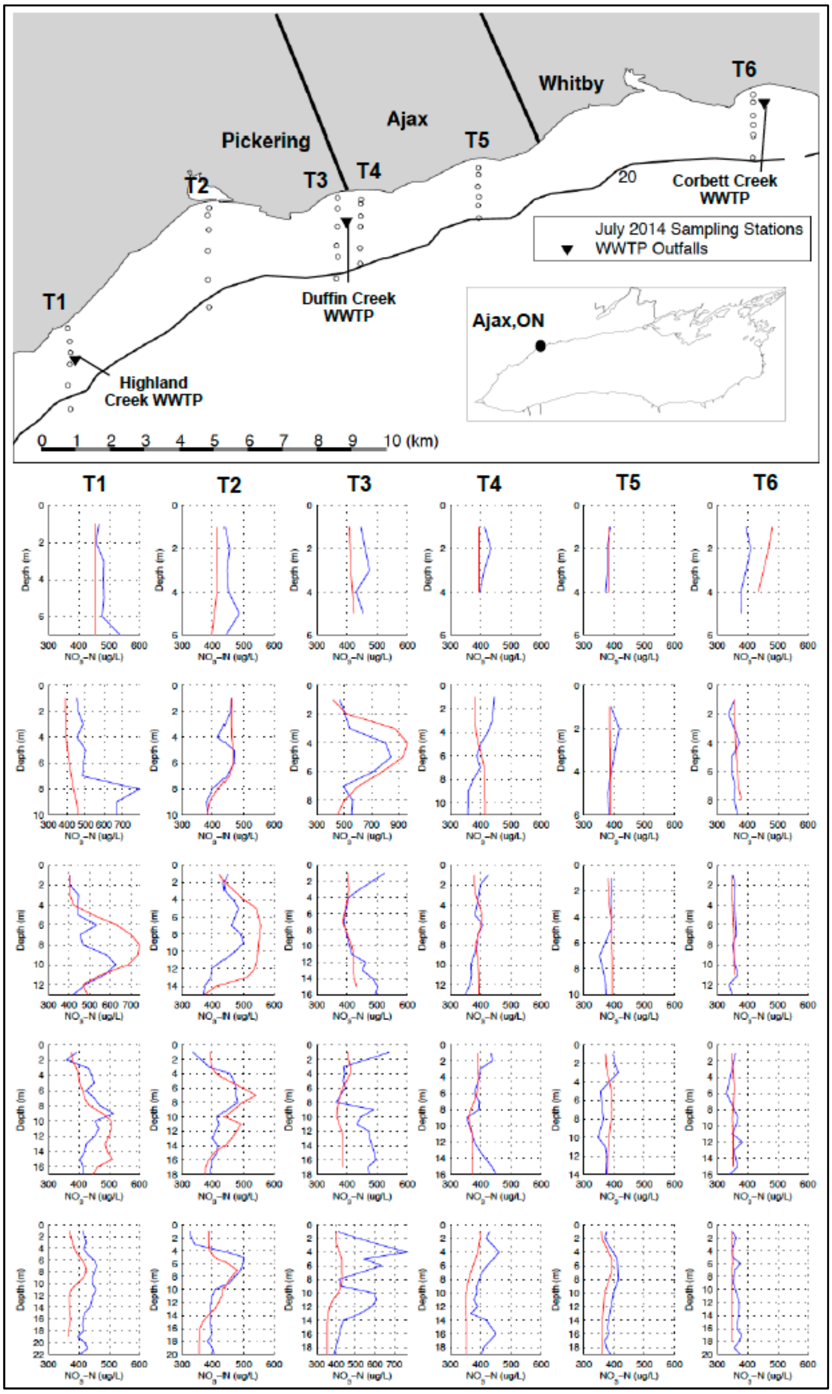

Figure S3. Simulated (red) and observed (blue) vertical nitrate profiles for six transects (T1–T6) offshore of Ajax, Ontario (ON) in July 2014. Upper panel: T1, T3, T4, and T6 are the transects closest to WWTPs; T2 and T5 are transects between WWTPs. Lower panel: Vertical profiles are presented from the most nearshore sampling station (top) to the most offshore sampling station (bottom). The shallowest depth of sampling (<2 m) at each sampling station is not shown, as no vertical variability was shown in either observations or model results due to the shallowness of the water. Model predictions agree well with observations at all stations on transects T2 and T5 in both vertical pattern and magnitude. This reinforces that the model captures the plume pattern in the far-field well, which is the primary interest of this research. The model captures most of the patterns in T1 (near the Highland Creek WWTP; except T1 station 2) and T6 (near the Corbett Creek WWTP; except T6 station 1). The model captures less of this vertical variation in transects T4 and T5 (the two transects closest to the Duffin Creek WWTP) as near-field dynamics are not directly resolved in the model.

Supplemental References

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