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Daily Detroit river total phosphorus loads to Lake Erie from water treatment plant turbidity

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ABSTRACT

The Great Lakes Water Quality Agreement established the western and central basin of Lake Erie total phosphorus (TP) target of 6000 metric tons per year. Models that develop load-response curves showed that daily loads and annual loads of the Detroit River are important. Direct measurements near the river mouth are difficult due to Lake Erie seiches and surface oscillations. Therefore, an alternative approach for estimating daily loads is needed. We show that existing turbidity-TP relationships can be applied to water treatment plant (WTP) turbidity to develop daily load estimates by those responsible for routine monitoring. We show how turbidity measured at WTP are comparable to those measured in the river. WTP uses an existing infrastructure that is of high temporal resolution, so agencies charged with determining loads may use this network. By using daily water flux and the WTP-based observations, daily TP concentration estimates and loads are applied upstream near Belle Isle and downstream near Fighting Island. By adding the respective loads to the river, we obtain daily TP flux estimates to Lake Erie. Due to well known turbidity gradients, the Windsor WTP needs an adjustment to better reflect turbidity in the entire river. After adjusting, the summed daily rates to Lake Erie from both stations are comparable each other and to other rates. We also show the 2019–2024 annual averages are approximately 15 % greater than that estimated by the Environmental Protection Agency (EPA) and Environment and Climate Change Canada (ECCC). These daily and annual load estimates can be useful augmentations of more traditional monitoring efforts that provide only annual loads.

1. Introduction

The Great Lakes Water Quality Agreement (GLWQA, 2016) established Lake Erie western and central basin total phosphorus (TP) target load of 6000 metric tons per year, anticipating returning the extent of central basin hypoxia to that of the 1990s and early 2000s. Scavia et al. (2024), using a statistical model developed for central basin hypoxia extending back to 1959, showed that there is a trade-off among fisheries in terms of TP load and hypoxic area. However, the 6000 metric tons per year is currently the target. While Canada and U.S. agencies focus monitoring on primary tributaries of interest and many of the important rivers are monitored at least daily, the Detroit River is not. Lake Erie process models need daily estimates of these loads to the lake. For example, the process models used to develop the load-response curves supporting the targets, as well as other efforts, have had to assume daily loads from the river, and showed that both daily and annual loads of the Detroit River are key drivers of central basin hypoxia (e.g., Bocaniov et al., 2016, 2019; Lam et al., 2008; Rucinski et al., 2010, 2016; Rowe et al., 2023; Scavia et al., 2016; Zhang et al., 2016). Thus, accurate estimates, including daily estimates, from the Detroit River are particularly important for modeling and for setting targets for central basin hypoxia.

Direct measurements of TP near the Detroit River mouth are difficult due to complicated flow distributions around islands and Lake Erie seiches and surface oscillations that influence pollutant transport and nutrient loading (Derecki and Quinn, 1990; Jackson, 2016; Quinn, 1988; Scavia and Calappi, 2023). Due to these challenges, most Detroit River load estimates have been based on summing loads to the St. Clair/ Detroit River system (e.g., Dolan and Chapra, 2012; EPA/ECCC, 2025; Maccoux et al., 2016; Scavia et al., 2019). However, this approach is complicated by uncertainties in the Lake Huron load and by load modulation by Lake St. Clair (Bocaniov et al., 2019; Burniston et al., 2018; Scavia, 2023, Scavia et al., 2019, 2020, 2022). This summing process also produces only annual loads.

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Burniston et al. (2009, 2018) and Totten and Duris (2019) provide more robust load estimates by making far more routine measurements in river transects upstream of Lake Erie's influence. Replicating those approaches for the daily estimates is likely challenging programmatically, logistically, and financially. While state, provincial, and federal agencies are looking to implement new, more rigorous monitoring programs (EPA/ECCC, 2025), we offer a method to develop two daily estimates of the load from the Detroit River to Lake Erie, both based on applying water treatment plant (WTP) daily turbidity observations to the established TP-turbidity relationships at their respective locations to determine a load.

Strong predictive relationships between phosphorus and turbidity suggest turbidity could be used as a surrogate for direct P measurements. For example, Robertson et al. (2018) showed strong relationships between turbidity and TP in Great Lakes tributaries, and Howell et al. (2014) showed strong TP-turbidity relationships in data from Lake Huron's nearshore. Scavia et al. (2022) assembled data from Lake Huron and the St. Clair River to develop relationships for the St. Clair River system. They used these relationships to estimate daily TP concentrations at the Point Edward and Marysville water treatment plant intakes and estimated the load from Lake Huron.

Herein, we use a similar approach with two different regressions to determine daily and annual TP flux from the upstream portion of the Detroit River (around Belle Isle) and a downstream section of the river (near Fighting Island). By adding the respective loads to the river downstream of those estimates, we obtain and compare TP flux estimates to Lake Erie. It is important to note that, on its own, the upstream regression and daily discharge at Fort Wayne describes the TP efflux from Lake St. Clair. The total Lake Erie load requires the addition of inputs below this point in the river. Similarly, the downstream regression describes total TP flux in the Detroit River up to the WTP intake near the head of Fighting Island; additional inputs below this point must be added to estimate the load to Lake Erie.

2. Methods

Daily average turbidity at the Windsor WTP was provided by the treatment plant staff as daily values of raw water intakes from 1 January 2001 to 31 December 2024 (Fig. 1). Daily average turbidity at the Water Works Park, SW Detroit, and Wyandotte WTP raw water intakes were provided through Environmental Consulting & Technology, Inc. (Grosse Pointe, Michigan) as part of the WQData Live program.

Michigan Department of Energy, Great Lakes, and Environment (EGLE) collected two types of TP and turbidity (NTU) data. One type was data collected from long-term monitoring sites, and the other data was collected from multiple locations across a transect (all on the U.S. side of the international border); these samples were collected on a line to include the long-term sample location and were only collected for a few years and used to assess cross-channel gradients in TP. All samples were provided by EGLE staff for long-term stations A and F, and for the transects in U.S. waters, A through F, in recent years (Fig. 1). Ministry of Environment, Conservation, and Parks (MECP) TP and turbidity data near the river intakes of the Windsor and Amherstburg plants were downloaded from https://tinyurl.com/3y5bv4jk on 15 December 2024. TP and turbidity data from the Trenton Channel are from Totten and Duris (2019) and across the connecting channel near there by Burniston et al. (2018). United States Geological Survey (USGS) recent cross-channel transects of integrated TP data from Ralph Wilson Park, Fort Wayne, and just south of the Rouge River were taken from https://www.waterqualitydata.us/ on 15 December 2024.

New TP data and flux measurements were sampled at transects on both sides of Belle Isle, a full river transect at Fort Wayne, and on transects on both sides of Fighting Island. Transect samples were collected at five points across the channel, spaced so that each point

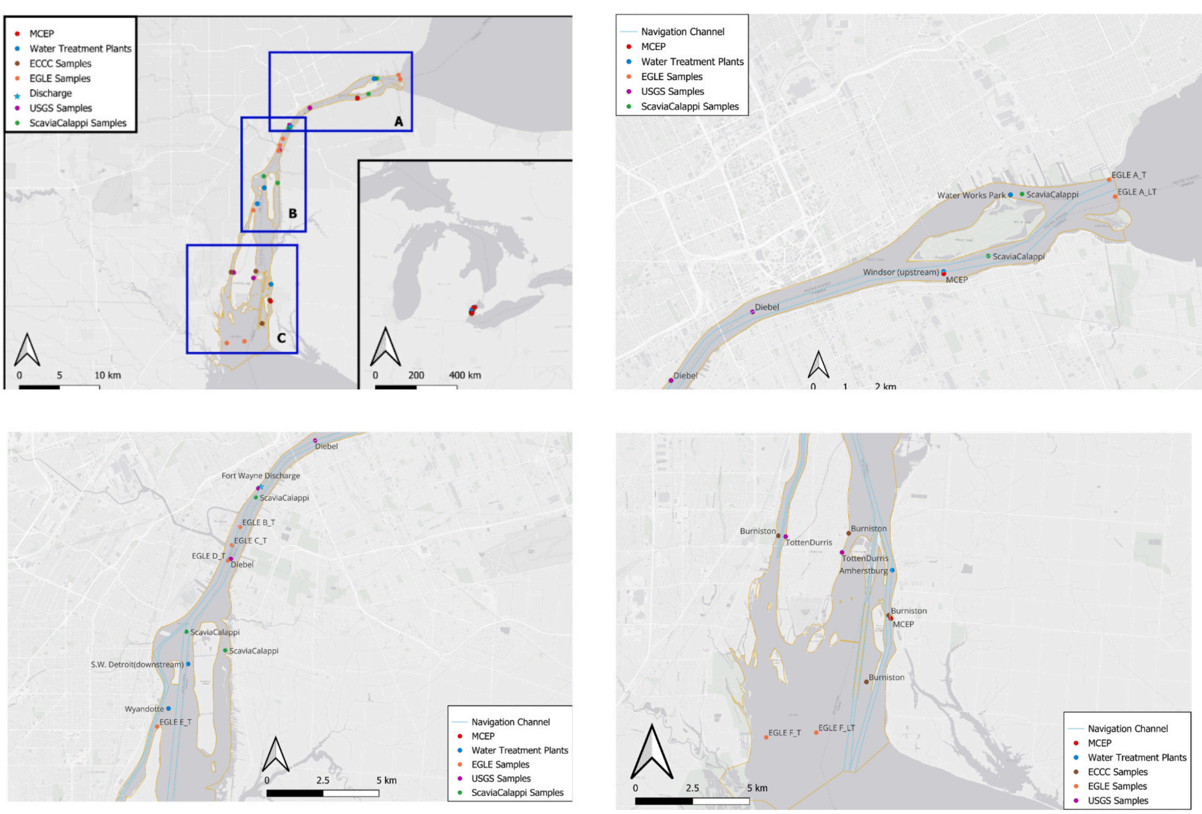

Fig. 1. Locations of domain of the study sampling by EGLE (Michigan Energy, Great Lakes, and Environment), ECCC (Environment and Climate Change Canada), USGS (United States Geological Survey), MECP (Ministry of Environment, Conservation, and Parks), and this work plus the general location of the water treatment plant intakes.

represented an equal fraction (20 %) of the discharge through the transect. Discrete samples were processed for TP after digestion by the National Center for Water Quality Research laboratory (https://ncwqr.org/) at Heidelberg University using standard techniques for low phosphorus concentration.

USGS (M. Diebel, pers. comm.) took 92 samples representing a single date. On each date, the transect was sampled at five points and spaced as described above. The five samples were then combined into a single composite sample for laboratory analysis. The annual load estimates were made with WRTDS-K (https://tinyurl.com/37b77x9a).

Daily water discharge at Fort Wayne was determined by USGS, and values were retrieved for 1 January 2008–31 December 2024 at the station from https://tinyurl.com/yvaanbk2 on 14 March 2025.

TP-turbidity relationships – Even though the datasets were collected over different time periods and in different locations along the Detroit River, we compared the turbidity-TP relationships in the river for temporal, seasonal, and geographic differences. We categorized the datasets into different locations along the Detroit River, different seasons based on the month of data collection, different time periods, and by country. We used analysis of covariance to examine differences in the slopes and intercepts of simple linear regressions between log-normalized turbidity and TP. US and Canada regressions were significantly different for slope but not for intercept. Geography (location along the connecting channel) had different intercepts but not slopes. Seasons (Winter/Spring vs Summer/Fall) and time (1998–2006, 2007–2016, 2017–2023) had both different slopes and intercepts.

None of these regressions produced more statistically significant fits than the ones below. For statistical and logistical reasons, we settled on two regression equations, one for the upstream portion and one for the downstream section representing the TP in the Detroit River up to that point. For the upstream section around Belle Isle, the TP-turbidity regression (n = 321, Electronic Supplementary Material (ESM) Fig. S1) was based on river TP and river turbidity from MECP and the long-term EGLE A (see below) station:

$$\mathrm{Log}_{10}\,(\mathrm{TP}) = 0.571{*}\mathrm{Log}_{10}\,(\mathrm{NTU}) - 2.279\ (R^2 = 0.60)$$

where TP is mg/l and NTU represents turbidity in NTU units.

For the downstream Detroit River TP, regression (n = 568, ESM Fig. S1), we used river TP and river turbidity from all EGLE stations except station F that may be influenced by Lake Erie, the MECP data, and Totten and Duris (2019) for the Trenton Channel:

$$\mathrm{Log}_{10}\,(\mathrm{TP}) = 0.498{*}\mathrm{Log}_{10}\,(\mathrm{NTU}) - 2.182\ (R^2 = 0.52)$$

It is important to note these relationships were developed with turbidity measurements in the river co-located in space and time with TP measurements. We used these regressions with WTP turbidity to estimate the daily river TP concentrations. When multiplied by flow from the USGS gauge at Fort Wayne, we calculated TP flux at that location.

Loads to the river below the upstream and downstream stations — We use the methods outlined in Scavia et al. (2019) and show that the contribution added to the river below each of the two sections was small but not insignificant (ESM Table S1). For the update, we conducted a Generalized Additive Model (GAM) analysis of Lake St. Clair outlet TP concentration times the annual discharge at Fort Wayne and WRTDS (Weighted Regressions on Time, Discharge, and Season) on the Rouge River. We updated the other non-point sources of TP based on the updated unit estimates of the Rouge and Thames rivers. The Great Lakes Water Authority (GLWA) point-source data are also shown in ESM Table S1; the 2022–2024 values used were the average of 2019 to 2021.

3. Results

Partitioning of flow around the islands is important for determining to what extent the TP sample locations largely represent the same water as the WTP intakes where turbidity is measured. The percentage of flux that goes along the navigation channel side of the islands shows that the navigation channel location is important.

Flux around Belle Isle – The US Army Corps of Engineers collected discharge measurements at several locations on the Detroit River six times between 2008 and 2013. On either side of Belle Isle, these averaged 76 % and 24 %, for the navigation and non-navigation sides of the island, respectively (Fig. 2). The percentage of water on the side of the island with the navigation channel is similar to the proportion, 74 %, reported by Holtschlag and Koschik (2002).

EGLE long-term Station A vs flow near Belle Isle – To determine if the long-term EGLE sampling site at the top of the Detroit River, A (Fig. 3), was representative of waters flowing down the navigation or non-navigation side of Belle Isle, we used the steady-state model of the St. Clair and Detroit rivers (Calappi et al., 2024). The model was run with typical conditions, and the dividing streamline was traced (Fig. 3). Additional model runs were examined to determine if a moderate wind from the north-northwest and the south-southeast at 10 m/s was enough to shift which side of Belle Isle best represented the long-term sample location. Additionally, discharges ± 15 % of the average discharges were also evaluated; the flow distribution around Belle Isle remained similar. While more extreme wind and discharge events do occur, this captures realistic, frequently occurring conditions. The range of discharges examined covers 78 % of the period of record (1900–2023). While the wind conditions are not the most extreme, they are from directions perpendicular to the discharge and are expected to maximize deflection of the streamlines. From this analysis, the long-term site, EGLE A, represents the flow on the navigation side of Belle Isle.

Discharge measured at Fort Wayne — The effect of changes in discharge as measured at Fort Wayne varies both daily and annually (Fig. 4). The lowest values are due to ice buildup and blockage on the river. It is important to recognize this variation when calculating loads because it varies as much as 67 % (e.g., 4500 to 7500 m^3/s) annually during this time. For example, even if TP remained constant at the 2013 concentration, the load would be higher in 2019 due to the difference in discharge alone. The summation approach does not explicitly consider this variation. There is also considerable variability from day to day (Fig. 4) that must be considered when estimating daily loads.

Turbidity at WTP intakes and in the river – To demonstrate that WTP turbidity was similar to that measured in the river, we compared those values with the river measurements. Using the log plot to emphasize lower values, a substantial difference was found between that measured by the Windsor plant and that measured in the river by EGLE and MECP. We then multiplied the Windsor values by 0.3, and they lined up with what was measured in the river (Fig. 5 top). It is not clear why the turbidity at the WTP intake was higher than in the river, but it may be that the cross-stream gradients observed in that area are a driving factor. The MECP data are taken in the river near the intake, and the EGLE A values are taken closer to the outlet of Lake St. Clair. Both the original and the reduced values are shown in Fig. 5. The reduced values matched observations of turbidity and TP (see below) in the river better. While the river measurements on both sides of Belle Isle were well represented by the WTP, the samples missed many of the higher values at the WTP

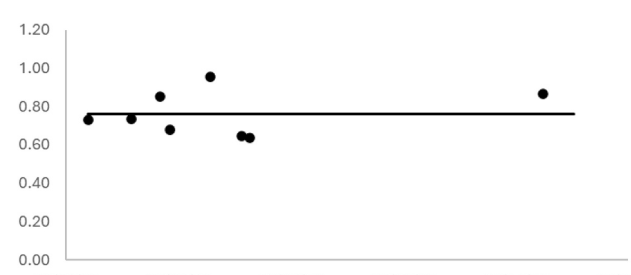

Fig. 2. Measured percent of total discharge on the commercial navigation channel side of Belle Isle and Fighting Island.

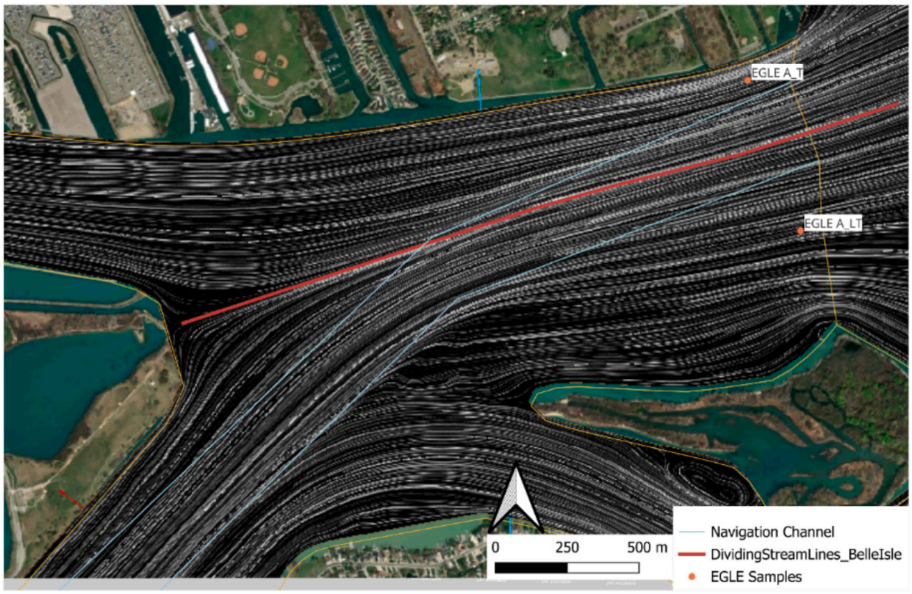

Fig. 3. Streamlines around Belle Isle are in white. The streamline dividing the flow around the island is shown in red. The background streamlines represent the no wind case. The shipping channel is shown in blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

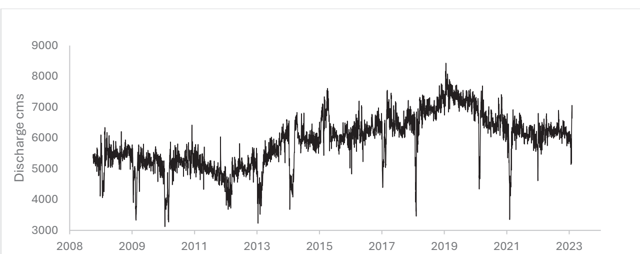

Fig. 4. Detroit River discharge as measured at Fort Wayne – USGS gauge 04165710.

(Fig. 5) as was found in the St. Clair River (Scavia et al., 2022).

We compared the SW Detroit WTP turbidity with that measured by EGLE means at transect B, C, D, and E. There are not as many turbidity measurements in this section, but they were consistent with the WTP measurements, as well as those measured earlier by Totten and Duris (2019) (Fig. 5).

TP concentrations calculated from the WTPs and measured in the river – The WTP turbidity at the downstream station and the adjusted WTP turbidity from the upstream station, along with the regression conversions, were used to calculate the WTP-turbidity regression-based TP concentrations. The WTP-turbidity estimates of TP are compared to the MECP, EGLE A (long-term), and our estimates of the transect means on the navigation channel side of Belle Isle. Based on the few measurements on the non-navigation channel side of the island (Fig. 5), we assumed the concentration to be half of the concentration on the navigation channel side. The annual TP load changed little if we assumed that concentrations were equal.

The correlation and RMSE (root mean square error) between TP estimated at the WTP and measurements in the river on the same day were 0.54 and 0.006 mg/l (each day, n = 174) and 0.49 and 0.008 mg/l (averaged over the month, n = 100) for upstream station. The values for the downstream station were 0.50 and 0.005 mg/l (n = 110) and 0.56 and 0.004 mg/l (n = 47). The correlation coefficient values are relatively low in part because the WTP estimates are averaged over the day, but the river samples were taken at discrete times. There could be substantial variability during the day. The river samples may also miss higher values found in the WTP estimates as reported by Scavia et al. (2022) for the St. Clair River. So, we also looked at the daily trends over time in both the WTP estimates and those found in the river.

These river measurements and WTP-based estimates were compared, and, in all cases, we found regression-based estimates of TP to be good matches with the transect mean river estimates (Fig. 6). While a fair amount of the river sampling did not match the higher values calculated from the WTP, like in the St. Clair River (Scavia et al., 2022), there was general agreement. The higher turbidity (Fig. 5a) and thus TP (Fig. 6a) values and variability in the upstream section are likely due to the plumes from the Thames River and its proximity to the head of the Detroit River. These plumes usually pass through the navigation channel on the south side of Belle Isle.

For the downstream regression, we used average turbidity at the SW Detroit and the Wyandotte plants and only SW Detroit when only it exists. At times when no data were available (4 % of the time), we used the average of before and after the SW Detroit gap. We compared the WTP-turbidity regression estimates for the downstream section with transect means taken in the vicinity of the intakes (EGLE mean for C, D, E; USGS composites below the Rouge). There was good alignment of the WTP-turbidity TP regression estimates and those measured in the river (Fig. 6c). TP values reported by Burniston et al. (2018) and Totton and Duris (2019) were similar to those measured in subsequent years. They reported 0.011 ± 0.009 mg/l in 2013–2014 and 0.017 ± 0.007 mg/l in 2015, respectively.

TP load estimates – Multiple loads to Lake Erie were computed and compared. Loads were computed by multiplying the WTP-regression-estimated daily TP concentration by the daily discharge from the USGS station (Fig. 4) and separately adding the TP flux contributed to the river downstream of those estimates. The average total contribution of load to the river (2008–2024) below the upstream section is the last column in ESM Table S1 divided by the number of days in the year (assuming they are evenly distributed over time). For the downstream section, we only added 20 % of that load to the river because US and Canadian sources below the downstream section is less than below the upstream section. The estimated daily loads for 2019–2024 (Fig. 7, ESM Table S1) show that the northern section and the southern section, with respective loads added to the river below the sections, are similar. As expected, the monthly loads have less variability and are also included in ESM Table S1 and ESM Fig. S2.

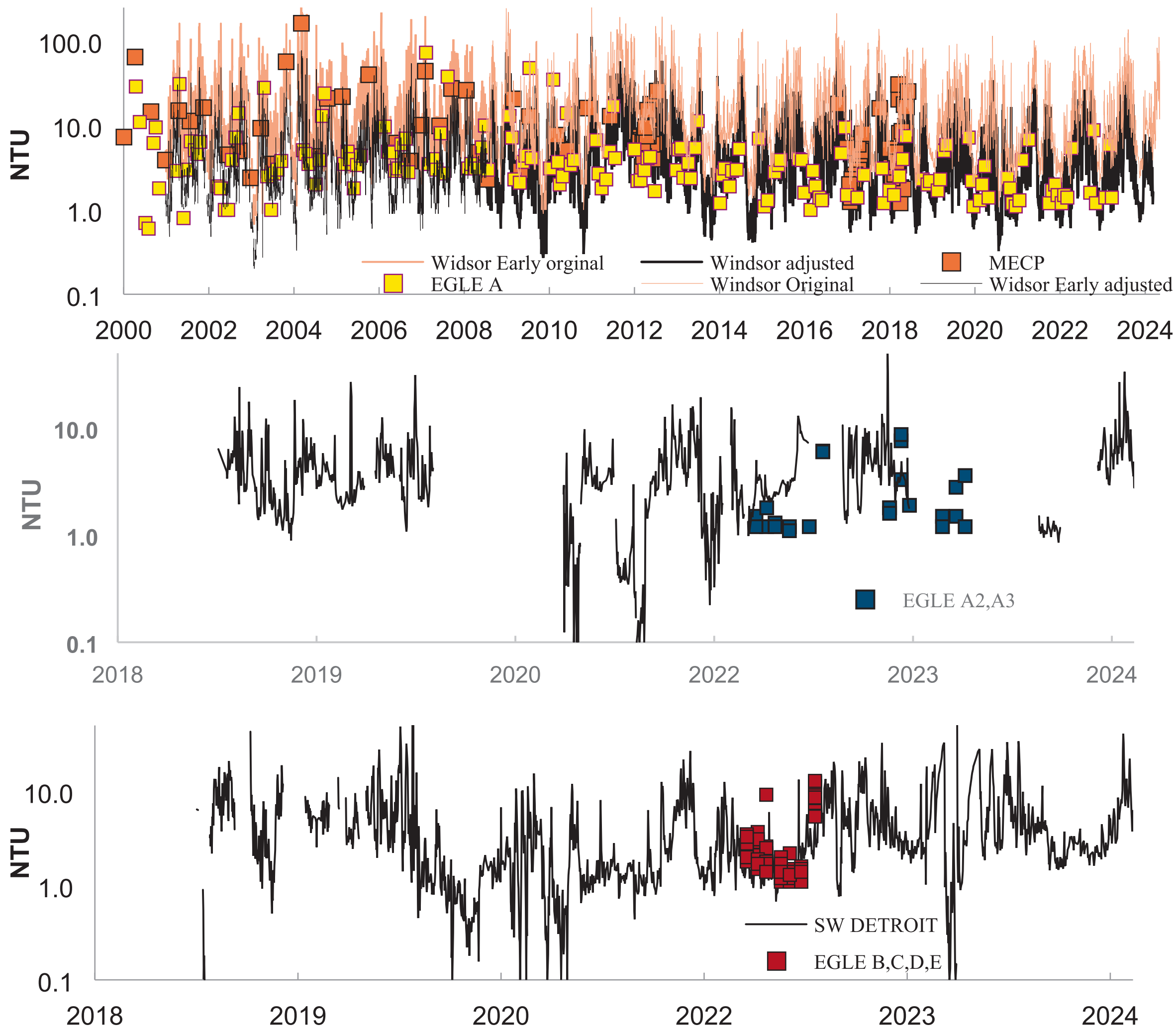

Fig. 5. East of Belle Isle, Windsor plant (top), West of Belle Isle, Water Works Plant (middle), SW Detroit plant (bottom).

To compare those loads with previously estimated annual loads, we summed the daily loads for each year (Fig. 8) from the upstream and downstream sections. We compared those estimates with annual loads estimated by summing the loads including Lake St. Clair (Scavia et al., 2019; Scavia et al., 2022) and with preliminary values determined from a transect below River Rouge by USGS (Diebel pers. comm.). The USGS loads were plotted with the 90 % prediction intervals with the same added load to the river below the transect. The estimates of WTP-turbidity regression from the upstream and downstream sections are similar to each other and to both independent estimates, and they are about 15 % higher than that estimated by the Environmental Protection Agency (EPA) and Environment and Climate Change Canada (ECCC) (EPA/ECCC, 2025) (Fig. 8, Fig. 9).

4. Discussion

The discrepancy from EPA and ECCC estimates is most likely due to the original estimation methods underestimating the contribution from Lake Huron (Scavia et al., 2020, 2022; Scavia, 2023) and by not including the retention by Lake St. Clair (Bocaniov et al., 2019; Scavia et al., 2019). This discrepancy with the Lake Huron load has been recognized by the agencies (Annex 4 Adaptive Management Task Team, 2023), but the effect of Lake St. Clair has apparently not been sufficiently recognized. This latter effect could reduce the impact of underestimating the load from Lake Huron.

The annual TP loads of the Detroit and Maumee rivers have been roughly equal and together contribute about 90 % of the load to the western basin and 54 % to the whole lake (EPA/ECCC, 2025; Maccoux et al., 2016; Scavia et al., 2016). The two loads have drawn significant policy attention and thus our correction and augmentation of traditional estimates of the Detroit River is important. Adjusting the load to Lake Erie with up-to-date estimates of the Lake Huron load and the effect of Lake St. Clair may impact the annual load, and Lake Erie process models require daily loads. While the agencies are looking to increase the sampling of the Detroit River (EPA/ECCC, 2025), it will still be a challenge to obtain sufficient data to directly quantify daily rates.

Scavia and Calappi (2023) suggested that more accurate load estimates that drive those models, develop mass balances, set load reduction targets, and track progress over time, require better estimates of the Detroit River TP load and assess the sources and processing of those loads. They included establishing a transect at Fort Wayne and/or on either side of Belle Isle and evaluating TP-turbidity relationships to replace or augment TP sampling. We found that using adjusted Windsor, SW Detroit, and Wyandotte WTP turbidity, appropriate TP-turbidity relationships, and the additional load to the river below the upstream and downstream stations provided daily and monthly load estimates (Fig. 7, ESM Table S1).

For allocating load source reductions, in addition to more accurate estimates of the Lake Huron load (Scavia, 2023), they also suggested sampling at the head of the St. Clair River near Port Huron at least

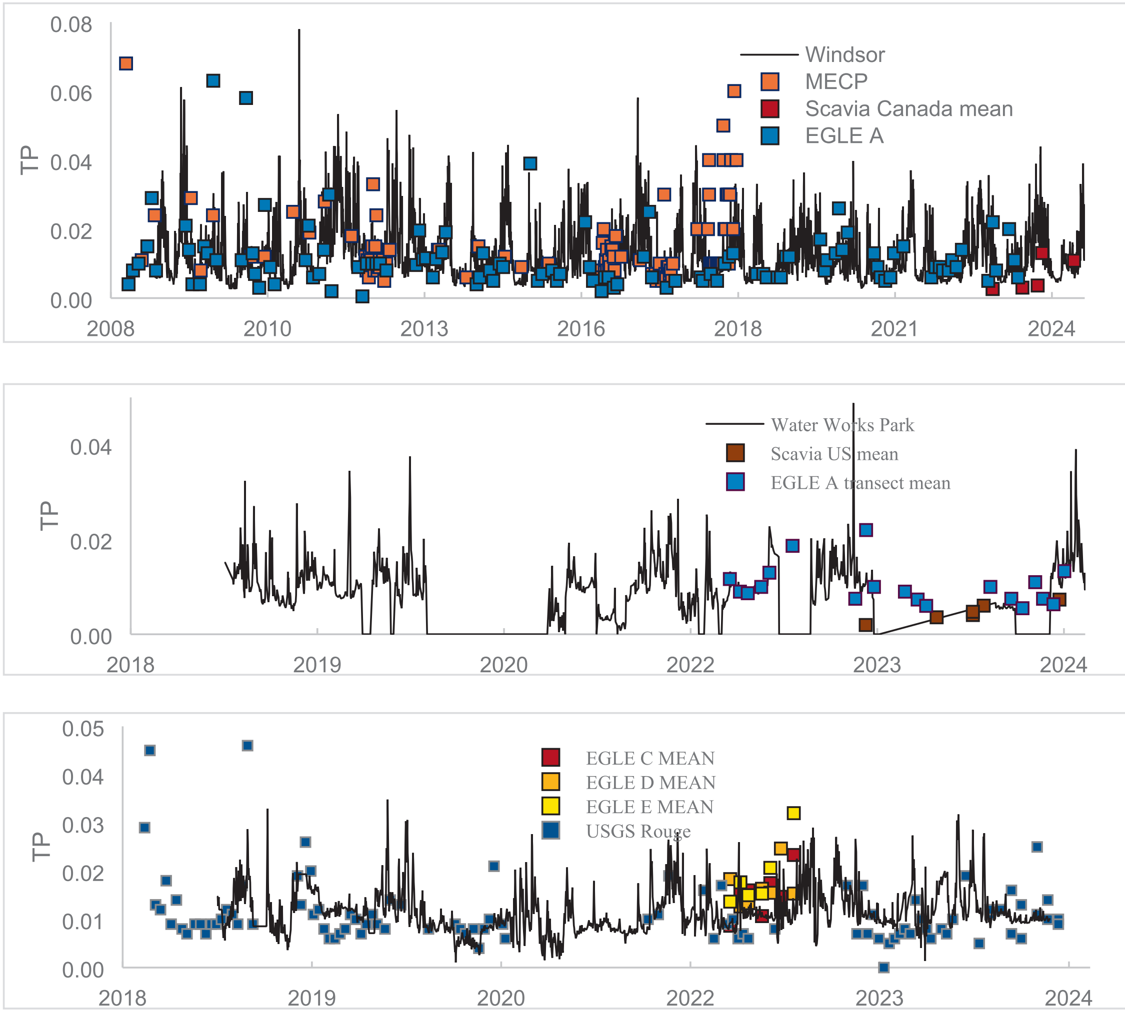

Fig. 6. Regression-based TP estimates and sampled river concentrations. Top (a) – east of Belle Isle, (b) middle – west of Belle Isle, (c) bottom – near Fighting Island.

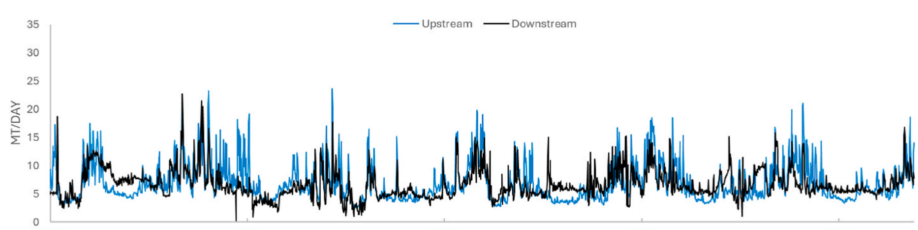

Fig. 7. Total load of the Detroit River to Lake Erie from the northern and southern sections.

weekly and augmenting that with daily turbidity measurements. While the load to Lake St. Clair is dominated by the St. Clair River (and thus Lake Huron), load reductions from the Thames River appear to be more impactful than those from the Sydenham and Clinton rivers (Bocaniov et al., 2019), and we found that they seem to be monitored primarily by measurements and flow down the navigation channel side of Belle Isle (see. Fig. 3 and Fig. 6a).

4.1. Limitations and next steps

While the WTP-regression estimates provided daily rates and the annual rates that matched those determined by updates of Scavia et al. (2019) and the preliminary USGS estimates, there are ways to enhance monitoring and improve methods. The upstream section is easier to measure because there are fewer pathways to monitor. We recommend monitoring at both sections (Fig. 7, Fig. 8), but if resources are limited, we suggest the southern transect because its daily flux may be more representative of the loads to Lake Erie because it varies less and it requires fewer loads to the river to compute the total load to Lake Erie.

Another recommendation we propose is to improve the regressions proposed here, which had R^2 values of 0.52 and 0.62. While observations were combined from several sources (n = 521 and 368) and they resulted in rather low prediction errors (ESM Fig. S1), the percent explained was low. Having significant observations at the two transects will likely reduce the uncertainty and increase the strength of the regressions.

It was also proposed by Scavia and Calappi (2023) that the potential effect of lateral variable may not be captured well enough by the WTP intakes. This is particularly true at the upstream station. While we did not have sufficient detail at the intakes to make that determination,

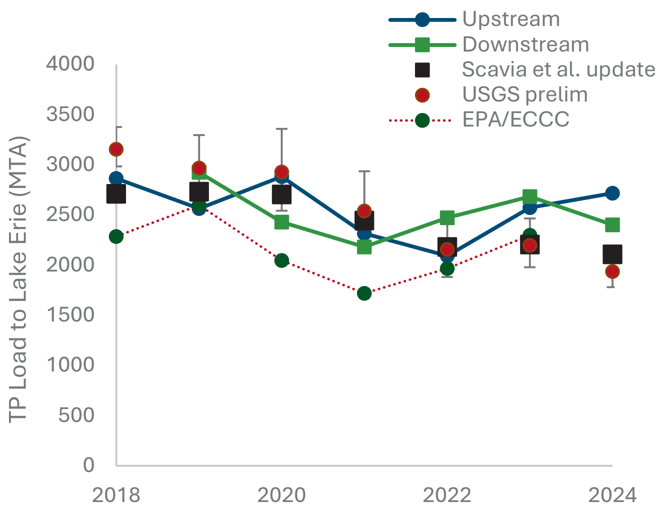

Fig. 8. Annual load estimates (metric tons (MT)/year) from the northern and southern regions from this paper and those based on methods in Scavia et al. (2019) and from USGS (Diebel, pers. comm.) and EPA/ECCC.

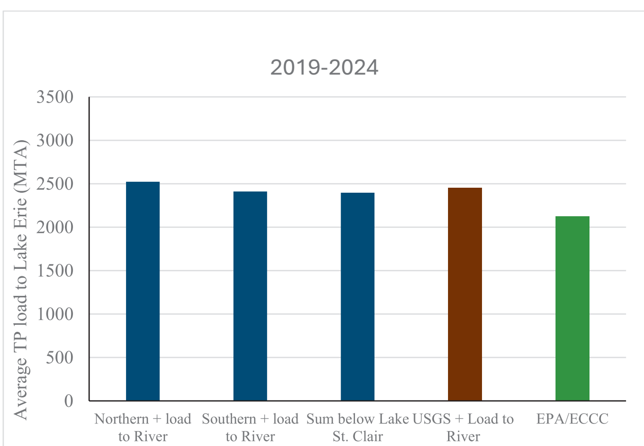

Fig. 9. Annual load estimate (MT/year) from WTP estimation, the summation based on Scavia et al. (2019), the USGS loads to Lake Erie, and the EPA/ECCC estimates.

transects of turbidity or TP would be beneficial. It may be important for the agencies to establish continuous monitors of turbidity at the sampling locations because it may not be possible to rely on the WTPs alone. Comparing daily rates with those determined with other methods will be important. That would also likely require sampling more frequently than is done now, but in the short term it may be important.

Updating the Detroit River load can lead directly to updates of Lake Erie mass balances but is only the first step in a reassessment of the goals, targets, and approaches. The next step would be to compare response curves from models calibrated to the new loads with those used to guide the current targets. Scavia and Calappi (2023) also pointed out that increased temporal resolution of the Detroit River loads could not only provide improved estimates for the process models but also provide new insights into the drivers of harmful algal blooms and hypoxia. If the new models result in substantially different response curves, it could lead to assessment of the impacts of different sources on hypoxia (e.g., western and central basin tributaries versus the Detroit River). Given the scale and scope of the binational load reduction plan, these next steps will not be trivial, requiring substantial time and resources. However, the GLWQA calls for routine reassessments and adaptive management as new information becomes available, and this should allow windows of time for adjustments if needed.

CRediT authorship contribution statement

Donald Scavia: Formal analysis, Conceptualization. **Timothy J. Calappi:** Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jglr.2025.102701.

References

Annex 4 Adaptive Management Task Team. 2023. *Binational Adaptive Management Evaluation for Lake Erie (2017-2021)*. Available at binational.net.

Bocaniov, S.A., Leon, L.F., Rao, Y.R., Schwab, D.J., Scavia, D., 2016. Simulating the effect of nutrient reduction on hypoxia in a large lake (Lake Erie, USA-Canada) with a three-dimensional lake model. J. Great Lakes Res. 42, 1228–1240.

Bocaniov, S.A., Van Cappellen, P., Scavia, D., 2019. On the role of a large shallow lake (Lake St. Clair, USA-Canada) in modulating phosphorus loads to Lake Erie. Water Resources Res. 55, 10548–10564.

Burniston, D., Dove, A., Backus, S., Thompson, A., 2018. Nutrient concentrations and loadings in the St. Clair River - Detroit River Great Lakes Interconnecting Channel. J. Great Lakes Res. 44, 398–411.

Burniston, D.A., McCrea, R., Klawunn, P., Ellison, R., Thompson, A., Bruxer, J., 2009. Detroit river phosphorus loading determination. Environment Canada, Water Quality Monitoring and Surveillance Office (locator No. WQMS09-006, Contribution No. 09–757).

Calappi, T.J., Waddell, J.M., McClerren, M.A., Gronewold, A.D., McNinch, J.E., Selegean, J.P., 2024. Evaluation of repeat bathymetric surveys on water surface elevations on the Saint Clair River. J. Great Lakes Res. 50, 102403.

Derecki, J.A., Quinn, F.H., 1990. Comparison of measured and simulated flows during the 15 December 1987 Detroit River flow reversal. J. Great Lakes Res. 16, 426–435.

Dolan, D.M., Chapra, S.C., 2012. Great Lakes total phosphorus revisited: 1. Loading analysis and update (1994-2008). J. Great Lakes Res. 38, 730–740.

EPA/ECCC 2025.(C. Buelo and J. Salerno, pers. comm., https://www.blueaccounting.org/metric/central-lake-erie-basin-hypoxia/#Explore, https://ouvert.canada.ca/data/dataset/ab57cc97-4a1f-4682-a15a-087007476ad6).

GLWQA (Great Lakes Water Quality Agreement). 2016. The United States and Canada adopt phosphorus load reduction targets to combat Lake Erie algal blooms. https://binational.net/2016/02/22/finalptargets-ciblesfinalesdep/. [accessed 25 February 2016].

Holtschlag, D.J., Koschik, J.A., 2002. Flow distribution of selected branches of St. Clair and Detroit Rivers. J. Great Lakes Res. 28, 379–395.

Howell, E.T., Barton, D.R., Fietsch, C.L., Kaltenecker, G., 2014. Fine-scale nutrient enrichment and water quality on the rural shores of Southeast Lake Huron. J. Great Lakes Res. 40, 126–140.

Jackson, P.R., 2016. Seiche-induced unsteady flows in the Huron-Erie Corridor: Spectral analysis of oscillations in stage and discharge in the St. Clair and Detroit Rivers. In: Constantinescu, G., Garcia, M., Hanes, D. (Eds.), River Flows 2016. CRC Press, London, pp. 235–241.

Lam, D., Schertzer, W., McCrimmon, R., Charlton, M., Millard, S., 2008. Modeling phosphorus and dissolved oxygen conditions pre- and post-Dreissena arrival in Lake Erie. In: Munawar, M., Heath, R.T. (Eds.), Checking the Pulse of Lake Erie. Aquatic Ecosystem Health and Management Society, Burlington, Ontario, pp. 97–122.

Maccoux, M.J., Dove, A., Backus, S.M., Dolan, D.M., 2016. Total and soluble reactive phosphorus loadings to Lake Erie: a detailed accounting by year, basin, country, and tributary. J. Great Lakes Res. 42, 1151–1165.

Quinn, F.H., 1988. Detroit River flow reversals. J. Great Lakes Res. 14, 383–387.

Robertson, D.M., Hubbard, L.E., Lorenze, D.L., Sullivan, D.J., 2018. A surrogate regression approach for computing continuous loads for the tributary nutrient and sediment monitoring program on the Great Lakes. J. Great Lakes Res. 44, 26–42.

Rowe, M.D., Valipour, R., Redder, T.M., 2023. Intercomparison of three spatially-resolved, process-based Lake Erie hypoxia models. J. Great Lakes Res. 49, 933–1003.

Rucinski, D., DePinto, J., Beletsky, D., Scavia, D., 2016. Modeling hypoxia in the Central Basin of Lake Erie under potential phosphorus load reduction scenarios. J. Great. Lakes Res. 42, 1206–1211.

Rucinski, D.K., Beletsky, D., DePinto, J.V., Schwab, D.J., Scavia, D., 2010. A simple 1-dimensional, climate based dissolved oxygen model for the central basin of Lake Erie. J. Great Lakes Res. 36, 465–476.

Scavia, D., Ludsin, S.A., Han, M., Johnson, L.T., Michalak, A.M., Obenour, D.R., Wang, Y.-C., Zhao, G., Zhou, Y., 2024. Water quality-fisheries tradeoffs in a changing climate underscore the need for adaptive ecosystem-based management. Proc. Nat. Acad. Sci. USA 121, e2322595121.

Scavia, D., Calappi, T.J., 2023. Detroit River load estimation; the need for a new monitoring approach. J. Great Lakes Res. 49, 941–948.

Scavia, D., 2023. Updated phosphorus loads from Lake Huron and the Detroit River: implications. J. Great Lakes Res. 49, 422–428.

Scavia, D., Anderson, E.A., Dove, A., Hill, B., Long, C.M., Wang, Y.-C., 2020. Lake Huron's phosphorus contributions to the St. Clair-Detroit River Great Lakes Connecting Channel. Environ. Sci. Tech. 54, 5550–5559.

Scavia, D., Bocaniov, S.A., Dagnew, A., Long, C.M., Wang, Y.-C., 2019. St. Clair-Detroit River system: phosphorus mass balance and implications for Lake Erie load reduction, monitoring, and climate change. J. Great Lakes Res. 45, 40–49.

Scavia, D., Calappi, T.J., Godwin, C.M., Hill, B., Veliz, M., Wang, Y.-C., 2022. Wind-driven sediment resuspension in the world's fourth-largest lake contributes a substantial phosphorus load to the eleventh largest lake. Environ. Sci. Technol. 56, 11061–11070.

Scavia, D., DePinto, J.V., Bertani, I., 2016. A Multi-model approach to evaluating target phosphorus loads for Lake Erie. J. Great Lakes Res. 42, 1139–1150.

Totten, A.R., Duris, J.W., 2019. Spatial distribution of nutrients, chloride, and suspended sediment concentrations and loads determined by using different sampling methods in a cross section of the Trenton Channel of the Detroit River, Michigan, November 2014–November 2015. In: U.S. Geological Survey Scientific Investigations Report 2018–5141. https://doi.org/10.3133/sir20185141.

Zhang, H., Boegman, L., Scavia, D., Culver, D.A., 2016. Spatial distributions of external and internal phosphorus loads in Lake Erie and their impacts on phytoplankton and water quality. J Great Lakes Res. 42, 1212–1227.