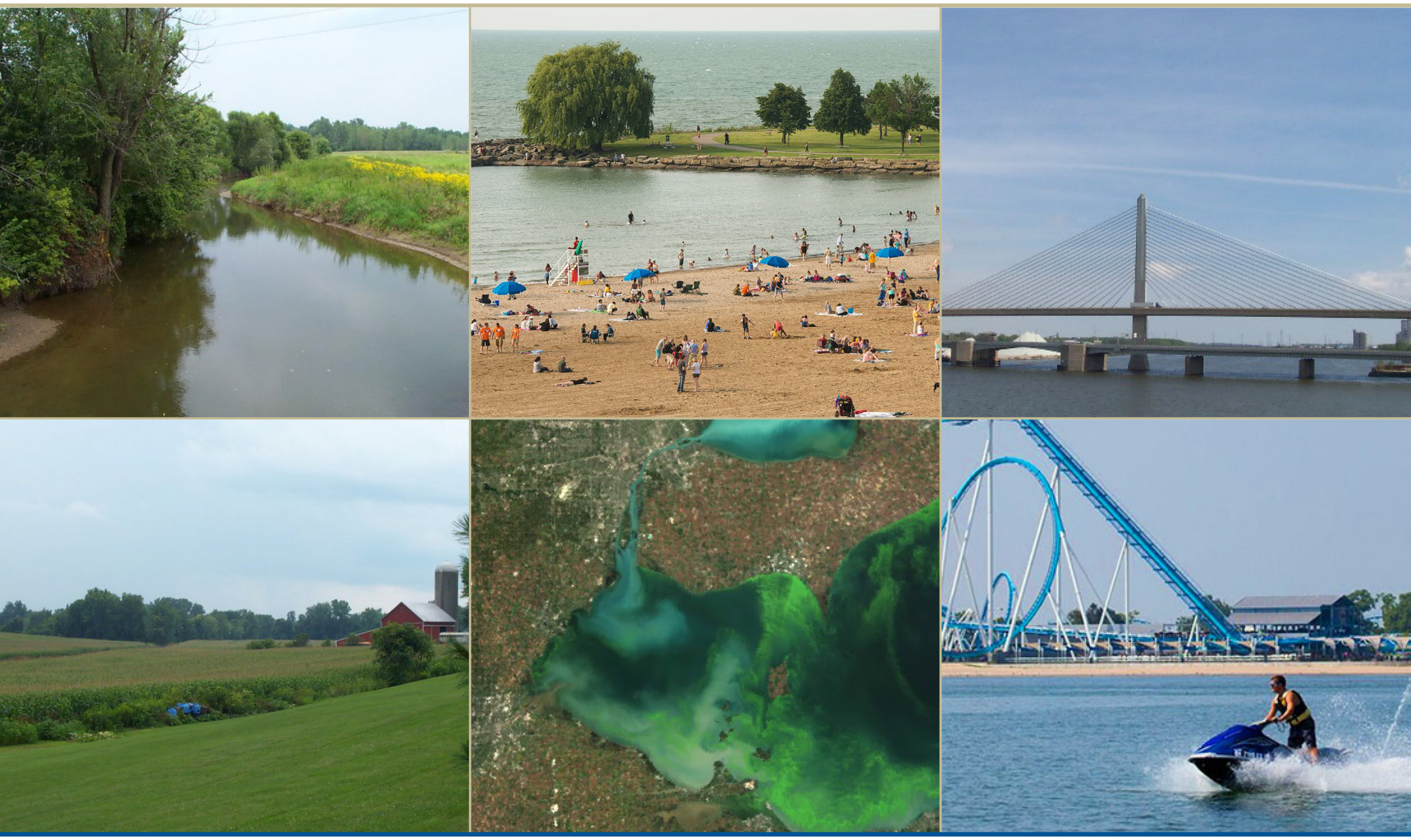
**U.S. Environmental Protection Agency**
Indiana Department of Environmental Management
Michigan Department of Environmental Quality
Ohio Environmental Protection Agency

**Final Draft**

# Methodology for Connecting Annex 4 Water Quality Targets with TMDLs in the Maumee River Basin



TETRA TECH

**Task Order No. EP-B175-00001**
August 9, 2018

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# Methodology for Connecting Annex 4 Water Quality Targets with TMDLs in the Maumee River Basin

## FINAL DRAFT

Task Order No. EP-B175-00001
August 9, 2018

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# EXECUTIVE SUMMARY

Recent work under the U.S.-Canada Great Lakes Water Quality Agreement (GLWQA) – Annex 4 led to the establishment of binational phosphorus load reduction targets for the Western and Central basins of Lake Erie, with an emphasis on reducing phosphorus contributions from the Maumee River Basin (MRB) as it is the key driver of summer harmful algal blooms (HABs). A Work Group was created to evaluate the potential impacts of the U.S. Clean Water Act total maximum daily load (TMDL) program on the Annex 4 load reduction targets. The Work Group was composed of staff from Indiana (Indiana Department of Environmental Management [IDEM]), Michigan (Michigan Department of Environmental Quality), Ohio (Ohio Environmental Protection Agency), the U.S. Environmental Protection Agency, and Tetra Tech.

The Work Group developed a methodology to allocate the Annex 4 total phosphorus (TP) and soluble reactive phosphorus (SRP[1]) load targets to each of the tributaries to the Maumee River. A primary reason for developing these upstream load targets is so Annex 4 load targets can be compared to TMDLs that were or are being developed for the tributaries of the Maumee River. Key outcomes from the project include the following:

<u>Allocation of Annex 4 spring and annual TP and SRP absolute load targets from Waterville, Ohio to HUC-8 watersheds throughout the MRB</u>

- The Annex 4 TMDL Methodology (A4TM) devised a strategy to assign Annex 4 TP and SRP absolute load targets to individual HUC-8s within the MRB. This distribution of Annex 4 spring and annual TP and SRP absolute load targets from Waterville, Ohio[2] had not been completed prior to this project effort and set baseline load targets for TP and SRP at each HUC-8 outlet in the MRB (See Table ES-1).
- The extrapolation of Annex 4 spring and annual absolute load targets from Waterville to individual HUC-8 outlets was based on flow to best align with Annex 4 goals (i.e., meeting flow weighted mean concentration targets) and to capture year-to-year changes in flow conditions driven by precipitation and climate changes in the MRB.

<u>Approach to allocate Annex 4 spring and annual TP and SRP targets to smaller subwatersheds (i.e., HUC-12 scale subwatersheds)</u>

- Additionally, the A4TM presents an approach to further estimate TP and SRP loading to smaller watershed scales (i.e., HUC-12 scale) in select subwatersheds of the MRB. The A4TM explains how one could assign TP and SRP loading, based on HUC-8 Annex 4 Translated Targets, to smaller upstream watersheds (e.g., HUC-12s) within individual HUC-8 watersheds.
- The calculative process for estimating HUC-12 TP and SRP Translated Targets employs a similar approach as the HUC-8 process and is based on the flow contribution of the individual HUC-12 subwatersheds. Flow estimates on these smaller scales can rely on either watershed modeled flow values (e.g., from SWAT) or extrapolations from observed flow data.

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[1] Agencies report both dissolved reactive phosphorus (DRP) and soluble reactive phosphorus (SRP) in the Maumee River basin and the Annex 4 report refers to both forms of the nutrient. For the purposes of this report they are considered the same and are presented primarily as SRP for consistency.

[2] Waterville, Ohio is the most downstream monitoring location where the Maumee River's loading to Lake Erie can be measured and subsequently is the location of the Great Lakes Water Quality Agreement's (GLWQA) TP and SRP targets.

Table ES-1. HUC-8 watershed targets

| Target | St. Joseph | St. Mary's | Upper Maumee | Tiffin | Auglaize | Blanchard | Lower Maumee [a] | Maumee River at Waterville |
|---|---|---|---|---|---|---|---|---|
| Spring TP | 137 | 121 | 58 | 87 | 239[b] | 104 | 114 | 860[c] |
| Spring SRP | 30 | 26 | 12[d] | 19 | 52 | 22[d] | 25 | 186[c] |
| WY TP | 373[e] | 326 | 146 | 221 | 655 | 294 | 273 | 2,288[f] |

*Notes*

Loads are metric tons of TP or SRP per spring or water year (WY).

a. Portion of the Lower Maumee watershed upstream of the U.S. Geological Survey gage on the Maumee River at Waterville (04183500).

b. The Auglaize was rounded up to 239 MT TP (from 238.48 MT TP) to ensure that the summation of HUC-8 watershed loads is exactly 860 MT TP.

c. These targets were set in *Recommended Phosphorus Loading Targets for Lake Erie* (GLWQA 2015).

d. The Upper Maumee was rounded down to 12 MT SRP (from 12.56 MT SRP) and the Blanchard was rounded down to 22 MT SRP (from 22.51 MT SRP) to ensure that the summation of HUC-8 watershed loads is exactly 186 MT SRP.

e. The St. Joseph was rounded up to 373 MT TP (from 372.49 MT TP) to ensure that the summation of HUC-8 watershed loads is exactly 2,288 MT TP.

f. This target was set in the draft *U.S. Action Plan for Lake Erie. Commitments and strategy for phosphorus reduction* (U.S. EPA 2017).

### Comparison of TMDL endpoints to Annex 4 targets at the HUC-8 and HUC-12 scales

- The A4TM also explored how one could compare TMDL endpoints to the Annex 4 Translated TP Targets at the HUC-8 and HUC-12 scales. This comparison focused on TMDL efforts in the St. Joseph River Watershed (SJRW) and the Tiffin River Watershed (TRW).
- The HUC-8 TMDL to Annex 4 comparison focused on extrapolating spring and annual TP loads, consistent with the TMDLs, to the outlet of the SJRW and TRW. These values were contrasted against the Annex 4 HUC-8 Translated TP Targets.
- The HUC-12 TMDL to Annex 4 comparison relied on translating TMDL goals on the HUC-12 scale via ‘Hypothetical TMDL target loads’ and contrasting those TP values against the Annex 4 HUC-12 Translated TP Targets.
- The results of this comparison demonstrated that Hypothetical TP TMDL target loads in certain watersheds attain the Annex 4 Translated TP Targets, but we cannot assume that watershed TP TMDLs, where they exist or are under development, will always meet Annex 4 targets. (*Note:* No state has SRP targets to protect aquatic life, therefore, there are no SRP impairments in Indiana, Michigan and Ohio and no SRP TMDLs).
- In Indiana, the Hypothetical TP TMDLs met the Annex 4 Translated TP Targets 41 to 73 percent of the time in the SJRW.
- In Ohio, the Hypothetical TP TMDLs for the SJRW and TRW met the A4 Translated TP Targets 100 percent of the time.
- Hypothetical TP TMDL target to Annex 4 Translated TP Target comparisons are influenced in part by the TP concentration target values which informed the calculation of hypothetical TP TMDL targets relative to the Annex 4 0.23 mg/L Flow Weighted Mean Concentration (FWMC) target. The individual state TP concentration target values were set based on state input and discussions among members of the *Annex*

*4 Methodology Work Group*. The hypothetical state TP TMDL targets are: IN – 0.30 mg/L for TP; MI – NA[3] for TP; and OH – 0.08 to 0.17 mg/L TP (depending on size of watershed).

- The A4TM analyses also show that there are HUC-12s in the SJRW and TRW contributing nutrients at levels above Annex 4 Translated TP Targets but these HUC-12s do not have nutrient impaired segments and no future plans for local nutrient TMDL development.
- TMDLs for nutrient impaired segments generally meet Annex 4 goals, but for overall water quality improvement in the MRB either there needs to be more TMDLs developed (i.e., more listed segments) or other implementation alternatives employed to encourage water quality improvement.

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[3] The Work Group did not calculate hypothetical TP TMDLs for Michigan subwatersheds in the SJRW and the TRW because Michigan employs a site-specific process to set TP targets for TP TMDL development. Michigan has not completed a site-specific TP criteria exercise in the SJRW or the TRW because no segments are listed as impaired for nutrient-related impairments.

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# ACRONYMS/ABBREVIATIONS

| Acronyms/Abbreviations | Definition |
|---|---|
| ALU | aquatic life use |
| BMP | best management practice |
| FWMC | flow-weighted mean concentration |
| GLWQA | U.S.-Canada Great Lakes Water Quality Agreement |
| HAB | harmful algal bloom |
| HUC | hydrologic unit code |
| IDEM | Indiana Department of Environmental Management |
| MDEQ | Michigan Department of Environmental Quality |
| NCWQR | National Center for Water Quality Research, Heidelberg University |
| NPS | nonpoint source |
| Ohio EPA | Ohio Environmental Protection Agency |
| PS | point source |
| SJRW | St. Joseph River watershed |
| SRP | soluble reactive phosphorus |
| SWAT | Soil and Water Assessment Tool |
| TMDL | total maximum daily load |
| TP | total phosphorus |
| TRW | Tiffin River watershed |
| U.S. EPA | U.S. Environmental Protection Agency |
| USGS | U.S. Geological Survey (U.S. Department of the Interior) |
| WY | water year |

| Units of measure | Definition |
|---|---|
| cfs | cubic foot per second |
| mg/L | milligrams per liter |
| MT | metric tons (1,000 kilograms) |

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# 1.0 INTRODUCTION

Binational phosphorus load reduction targets for the Western and Central basins of Lake Erie were established following recent work by Annex 4 of the Great Lakes Water Quality Agreement. These targets emphasize reducing phosphorus contributions from the Maumee River basin (MRB) because the Maumee River is the key driver of summer harmful algal blooms (HABs). An *Annex 4 Methodology Work Group* was created to evaluate the potential impacts of the U.S. Clean Water Act total maximum daily load (TMDL) program on the Annex 4 load reduction targets. The Work Group was composed of staff from Indiana (Indiana Department of Environmental Management [IDEM]), Michigan (Michigan Department of Environmental Quality [MDEQ]), Ohio (Ohio Environmental Protection Agency [Ohio EPA]), the U.S. Environmental Protection Agency (U.S. EPA), and Tetra Tech, Inc. (Tetra Tech).

The Work Group developed a methodology to allocate the Annex 4 total phosphorus (TP) and soluble reactive phosphorus (SRP[4]) load targets to each of the tributaries to the Maumee River. A primary reason for developing these upstream load targets is so Annex 4 load targets can be compared to TMDLs that were or are being developed for the tributaries of the Maumee River. The methodology describes how to derive Annex 4-specific upstream tributary loading targets at various watershed scales. The methodology describes how TP and SRP load targets were identified at the outlet points of the large tributary subwatersheds (e.g., the confluence of the St. Joseph River and St. Mary's River in Fort Wayne, Indiana, or the confluence of the Tiffin River and Maumee River near Defiance, Ohio). The methodology then describes a recommended approach to investigate tributary TP and SRP loading targets for locations within a large tributary subwatershed above its pour point; for example, conducting TP and SRP analyses for the tributaries to the St. Joseph River[5].

The methodology was tested with the St. Joseph River watershed (SJRW)[6] and Tiffin River watershed (TRW)[7] (Figure 1), which are hydrologic units (i.e., watersheds) identified by an eight-digit hydrologic unit code (HUC-8). The protocols are flexible enough that the methodology can be replicated in other locations. Specifically, this methodology describes the minimum data needs for future state, local, or federal partners to recreate this analysis in other subwatersheds, either within the MRB or other Lake Erie tributary watersheds. The methodology protocols explain how best to use these resources.

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[4] Agencies report both dissolved reactive phosphorus (DRP) and soluble reactive phosphorus (SRP) in the Maumee River basin and the Annex 4 report refers to both forms of the nutrient. For the purposes of this report they are considered the same and are presented primarily as SRP for consistency.

[5] SRP, in part, may be released by the decay of organic materials and not be loaded from a watershed. If decay was the major source of SRP, then it would not be valid to project (or distribute) those loads up into the watersheds. However, decay of organic material has not been identified as a significant source of SRP within the Maumee River watershed. Thus, it appears to be acceptable to project SRP targets up into the watershed.

[6] The SJRW is in northwestern Ohio, south central Michigan and northeast Indiana. The watershed is approximately 1,085 square miles and forms the main stem of the Maumee River when it joins the St. Mary's River in Fort Wayne, Indiana.

[7] The TRW is in northwestern Ohio and southeastern Michigan. The watershed is approximately 778 square miles. The Tiffin River joins the Maumee River main stem near Defiance, Ohio.

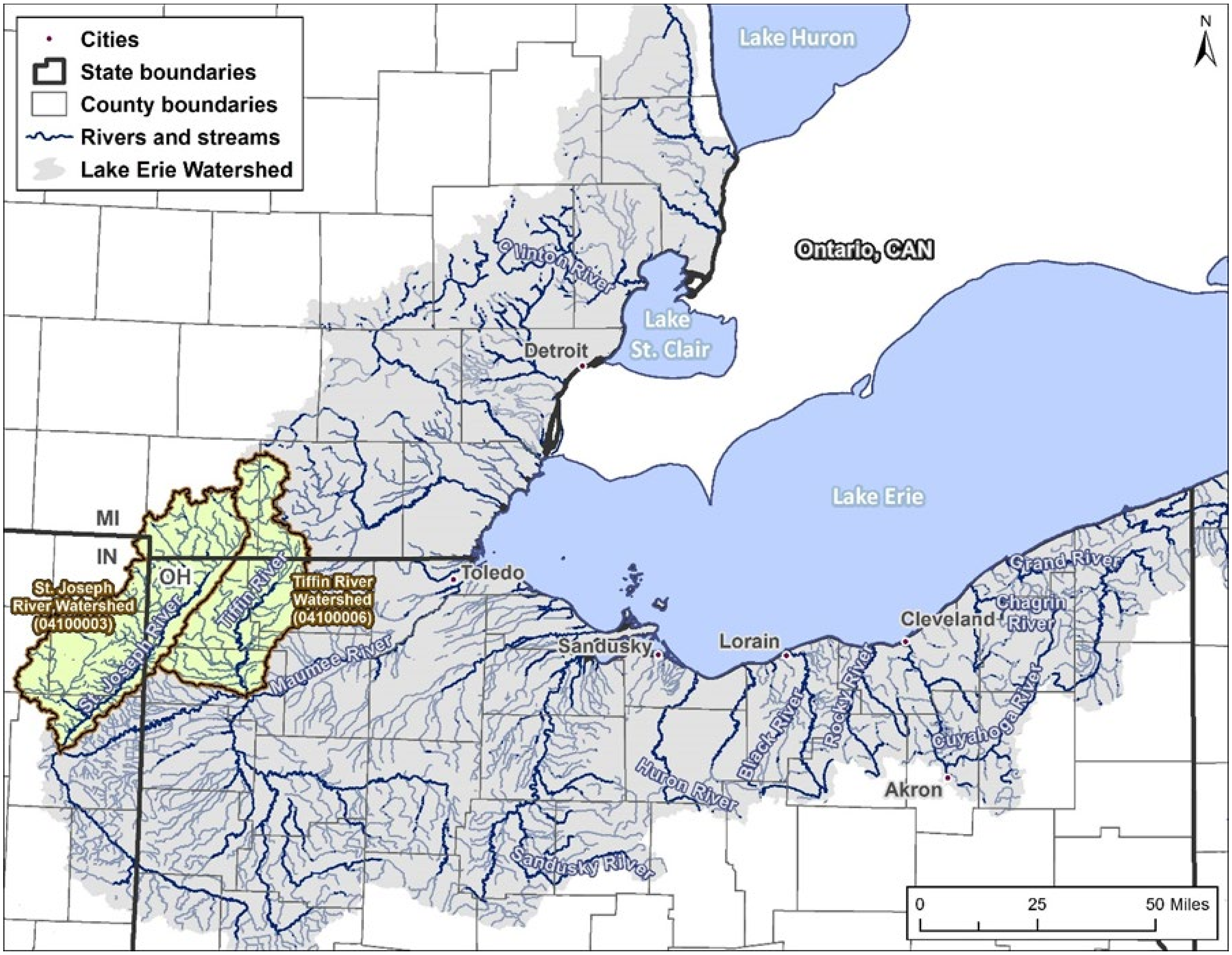

Figure 1. St. Joseph River watershed and Tiffin River watershed within the Lake Erie basin.

## 1.1 BACKGROUND

Since the 1990s, Lake Erie has been experiencing increasing algal growth, resulting in increased impairment of water quality, as well as increased impairment of the use and enjoyment of the tremendous natural resource that is Lake Erie (U.S. EPA 2015). While algae occur naturally in freshwater systems, too much algal growth can lead to dense algal blooms. Nuisance algal blooms can deplete dissolved oxygen, interfere with natural food webs, and clog water intakes. Some blooms produce algal toxins called microcystin that threaten human and animal life; such blooms are referred to as HABs. HABs can result in health warnings at beaches for both contact and ingestion. HABs and nuisance algal blooms in Lake Erie have increased over the past decade (GLWQA 2015). The blooms threaten drinking water quality and human and animal health if the water is ingested, increase costs associated with treatment needs, and occasionally force closures of treatment plants.

Algal growth requires nutrients such as phosphorus and nitrogen, and increased nutrient loading can exacerbate algal blooms. Recent work completed by Annex 4 of the GLWQA concludes that inputs of phosphorus are more significant than those of nitrogen in impacting Lake Erie. While phosphorus is an essential nutrient for aquatic life, elevated concentrations of phosphorus can lead to nuisance algal blooms that negatively impact aquatic life and recreation (swimming, boating, fishing, etc.). Algal decomposition depletes dissolved oxygen in the water column, and in extreme cases can create hypoxic conditions, which stress benthic macroinvertebrates and fish.

Excluding the Detroit River, the Maumee River is the largest tributary to Lake Erie and its watershed encompasses more than 6,500 square miles in Indiana, Michigan, and Ohio. Most of the MRB is in Ohio, approximately 5,000 square miles. Watersheds of the MRB contribute flow and pollutant loading to the main stem of the Maumee River, which enters the Western Basin of Lake Erie in the city of Toledo, Ohio. The GLWQA Task Team concluded that nonpoint source runoff from the Maumee River during the spring period is the best predictor of cyanobacteria bloom severity in Lake Erie. This conclusion was reached based upon the work of the modeling Sub-Team and loading data provided by the National Center for Water Quality Research (NCWQR) at Heidelberg University in Tiffin, Ohio. The influence of the Maumee River is due to its high concentrations and large loading of phosphorus coupled with the fact it discharges to the shallow western basin of Lake Erie.

### 1.1.1 Lake Erie Annex 4 Targets

Recent work by Annex 4 of the GLWQA led to the establishment of binational phosphorus load reduction targets for the Western and Central basins of Lake Erie, with an emphasis on reducing phosphorus contributions from the Maumee River as it is the key driver of summer HABs. Notably, 35 percent of the annual TP loading to Lake Erie is from Western basin tributary watersheds (Maccoux et al. 2016). Indiana, Ohio, and Michigan have agreed to reduce phosphorus loads from the Maumee River by 40 percent from a 2008 baseline.

The Annex 4 phosphorus reduction targets for Lake Erie are as follows (GLWQA 2015; U.S. EPA 2015):

- **To minimize the extent of hypoxic zones in the waters of the Central Basin of Lake Erie:** A 40 percent reduction in annual total phosphorus entering the western and central basins of Lake Erie—from the United States and from Canada—to achieve an annual load of 6,000 metric tons to the Central Basin. This amounts to a reduction from the United States and Canada of 3,316 metric tons and 212 metric tons respectively.
- **To maintain algal species consistent with healthy aquatic ecosystems in the nearshore waters of the Western and Central basins of Lake Erie:** A 40 percent reduction in spring (March 1 through July 31) total and soluble reactive phosphorus loads from the following watersheds where algae is a localized problem: in Canada, Thames River and Leamington tributaries; and in the United States, Maumee River, River Raisin, Portage River, Toussaint Creek, Sandusky River and Huron River.
- **To maintain cyanobacteria biomass at levels that do not produce concentrations of toxins that pose a threat to human or ecosystem health in the waters of the Western Basin of Lake Erie:** A 40 percent reduction in spring (March 1 through July 31) total and soluble reactive phosphorus loads from the Maumee River in the United States.

These targets were formally adopted by the United States and Canada in February 2016. Each of the affected States (Indiana, Ohio, and Michigan) have developed domestic action plans[8] that describe how the 40 percent reduction goals will be met. U.S. EPA anticipates that development, revision, and implementation of phosphorus TMDLs will also play a part in these implementation efforts.

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[8] Indiana's Domestic Action Plan (http://www.in.gov/isda/files/Lake%20Erie%20Domestic%20Action%20Plan%20_Final.pdf, February 2018), Michigan's Domestic Action Plan (http://www.michigan.gov/documents/deq/DAP__FINAL_2-28-18_616672_7.pdf, February 2018), Ohio's Domestic Action Plan (http://lakeerie.ohio.gov/Portals/0/Ohio%20DAP/DAP%201-0%20Final%20for%20USEPA%202018-02-07.pdf, February 2018) and U.S. EPA Domestic Action Plan (https://www.epa.gov/sites/production/files/2018-03/documents/us_dap_final_march_1.pdf, March 2018)

## 1.1.2 Types of Load Targets

The Annex 4 load targets can be expressed in a variety of ways:

- **Loads:** A measure of mass that passes a point over a given time. Common units for this measure include pounds per day and metric tons (MT; 1,000 kilograms) per year.
- **Unit area loads:** A measure of mass per area that passes a point over a given time. Common units for this measure include pounds per acre per day or tons per square mile per year.
- **Flow-Weighted Mean Concentration (FWMC):** Total load divided by total flow that passes a point over a given time. This measure is essentially an arithmetic mean concentration that is weighted by flow. The common unit for this measure is milligrams per liter; however, this is a load-based target, not an ambient concentration target.

The Work Group evaluated each of these different types of load targets, but eventually focused primarily on discussing loads to allow for a more direct comparison to TMDLs.

## 1.1.3 Maumee River Annex 4 Targets

To reduce HABs in the Western Basin of Lake Erie, Annex 4 set absolute load targets for the Maumee River at Waterville and, using the year 2008 as a baseline, determined the percent reduction and FWMC necessary to achieve the absolute target:

- **Absolute load targets:** Spring (March 1 through July 31) load targets of 860 MT TP and 186 MT SRP from the Maumee River at Waterville, which should reduce HABs in nine of 10 years.
    - “To achieve a bloom no greater than that observed in 2004 or 2012, 90% of the time, the Task Team recommends a total phosphorus spring load of 860 metric tons and a dissolved phosphorus load of 186 metric tons from the Maumee River” (GLWQA 2015, p. 31).
- **Percent reduction target:** 40 percent reduction of spring TP and SRP loads (GLWQA 2015) and 40 percent reduction of annual TP loads (U.S.EPA 2015).
    - “The 860 metric ton target is approximately a 40% reduction from the 2008 spring load of 1400 metric tons for TP and 310 metric tons of SRP” (GLWQA 2015, p. 31).
    - The annual TP load target for the Maumee River is 2,287 MT in the *U.S. Action Plan for Lake Erie* (U.S. EPA 2017, p. 14).
- **FWMC target:** Spring targets of 0.23 milligrams per liter (mg/L) TP and 0.05 mg/L SRP.
    - “the 2008-target load corresponds to a Flow Weighted Mean Concentration (FWMC) of 0.23 mg/L TP and 0.05 mg/L of SRP. Because discharge varies considerably from year to year, and because the discharge of the Maumee River was so large in 2008 that it has only been exceeded about 10% of the time in the last 20+ years, the Task Team expects that achieving a FWMC of 0.23 mg/L for TP and 0.05 mg/L for SRP will result in phosphorus loads below the targets (860 and 186 metric tons) 90% of the time (9 years out of 10), if precipitation patterns do not change” (GLWQA 2015, p. 31)

As discussed in Section 1.1.2, unit area load is a common metric used to evaluate pollutant loading. Annex 4 did not determine unit area load targets. However, unit area load targets can be calculated. The Maumee River at Waterville drains an area of 6,330 square miles. The Annex 4 load targets would then yield unit area load targets of 0.468 pounds per acre for spring TP[9] and 0.10 pounds per acre for spring SRP.[10]

Annex 4 did not translate the load targets to site-specific targets for upstream tributaries of the Maumee River at Waterville. One of the primary objectives of this project was to develop a methodology to calculate load targets for the watersheds that are tributary to the Maumee River at Waterville.

## 1.2 METHODOLOGY FRAMEWORK

Annex 4 load targets were developed for the Maumee River at Waterville (GLWQA 2015; U.S. EPA 2015) and a methodology is needed to translate these targets to finer scale subwatersheds. Practices to reduce phosphorus loading to the Maumee River watershed will be implemented at small scales (e.g., HUC-10 and HUC-12 subwatersheds or smaller) and TMDLs are typically developed for similar scales. To measure progress with implementation practices and to determine if TMDLs and their necessary reductions are protective of Annex 4 targets, the Annex 4 load targets must be translated to the equivalent scales.

A methodology is necessary to develop upstream tributary targets consistent with Annex 4 that apply to upstream watersheds in the Maumee River. This methodology was developed into a three-step framework:

- **Identify Annex 4 targets at the HUC-8 scale:** Annex 4 TP and SRP targets are set for the Maumee River at Waterville. To develop upstream tributary TP and SRP targets, the Waterville targets must be distributed to the tributary HUC-8 watersheds (Figure 2). The approach for doing so is described in Section 2.1.
- **Develop a methodology to translate HUC-8 scale targets to smaller spatial scales:** After the Annex 4 targets for Waterville are calculated for the tributary HUC-8 watersheds, the HUC-8 targets need to be translated to smaller scales and compared to estimates of existing loads. The approach for doing so is described in Section 2.2.
- **Compare HUC-8 and Small-Scale Annex 4 Translated Targets to TMDL Targets Loads:** Targets developed as part of the TMDL process focus upon in-stream impairments and not the far-field effects upon downstream waterbodies (e.g., Lake Erie). For the SJRW and TRW, TMDL cumulative spring and annual target loads developed at small scales (i.e., HUC-12 scale and smaller) were evaluated with Annex 4 translated targets developed for the respective watersheds. These comparisons are presented in Section 3.0, along with a discussion about what they mean for implementation.

Existing loads can be estimated and compared with Annex 4 translated targets and TMDL target loads. In many cases, existing loads are not published and will need to be estimated using available data. Techniques to estimate existing loads are presented in Appendix A.

Finally, in addition to developing the three-step framework, the Work Group considered how the allocation and implementation phases of a TMDL project might relate to Annex 4. This information is presented in Section 4.0.

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[9] The 860 MT TP per spring load target yields unit area load target of 0.468 pounds per acre per spring.

[10] The 186 MT SRP per spring load target yields unit area load targets 0.101 pounds per acre per spring.

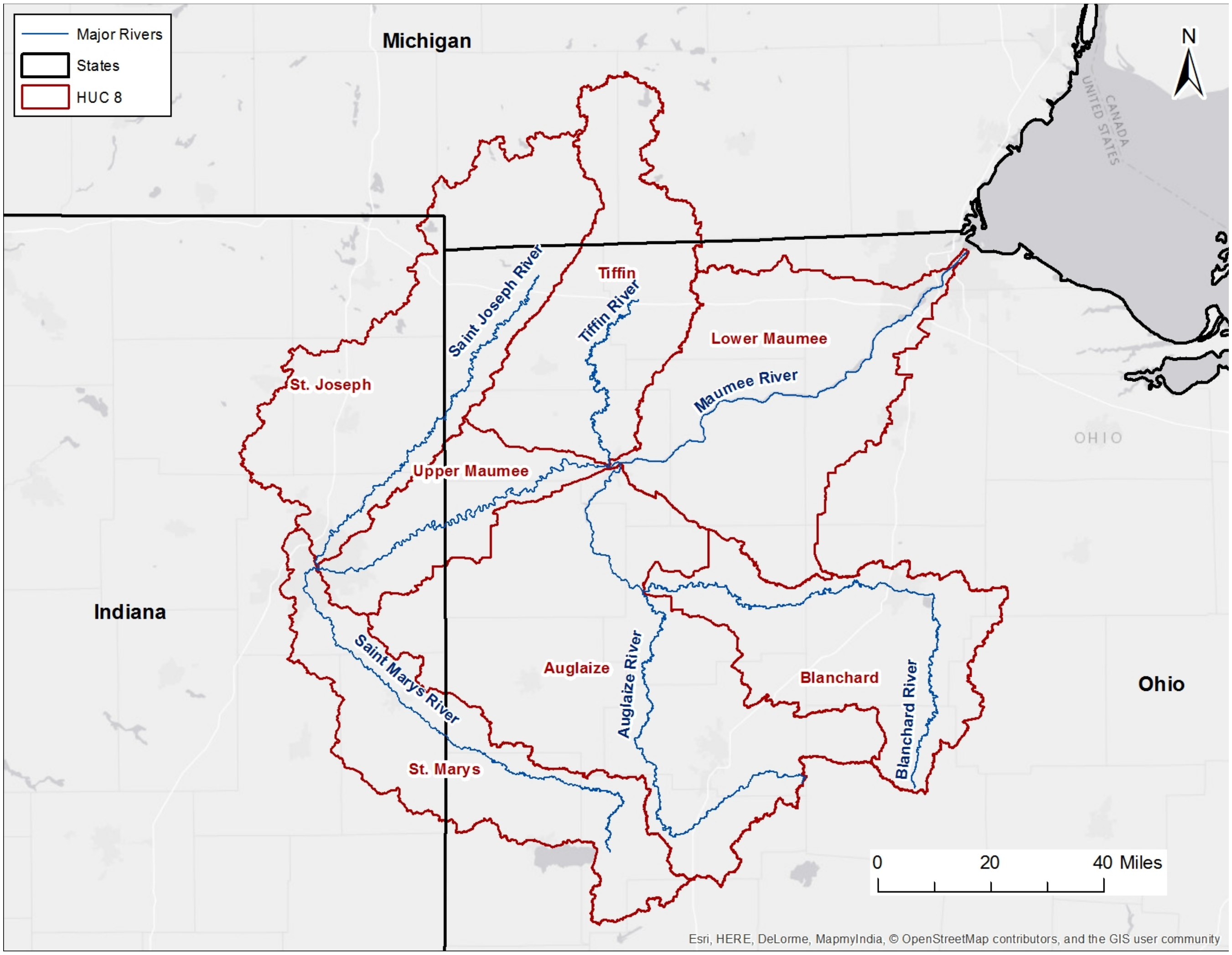

Figure 2. Major tributary (HUC-8) watersheds to the Maumee River at Waterville.

## 1.3 NOMENCLATURE

***Annex 4 targets*** refers to the spring TP and SRP and annual TP load targets for the Maumee River at Waterville. More specific terms include the phosphorus species (TP or SRP) and period (spring or annual); for example, *Annex 4 spring TP target*. Annex 4 targets are published by GLWQA (2015) and U.S.EPA (2017).

***Annex 4 translated targets*** refers to the spring TP and SRP and annual TP load targets for HUC-8 watersheds and finer scale subwatersheds within the MRB. More specific terms include the watershed or subwatershed name, phosphorus species, and period; for example, *SJRW Annex 4 translated spring TP target*. Annex 4 translated targets were developed using the methodology described herein and are published in this report.

***TMDL target loads*** refers to TP TMDLs that were converted to total (cumulative) spring or annual target loads and vary from year to year because flow varies from year to year. These TP TMDLs are either approved by U.S. EPA Region 5 (e.g., the St. Joseph River Watershed Indiana TMDLs (2017)) or are in the process of being developed by Ohio EPA (e.g., the St. Joseph River Watershed Ohio TMDLs, the Tiffin River Watershed (OH) TMDLs). More specific terms include the watershed or subwatershed name and period; for example, *SJRW TMDL annual target loads*. TMDL target loads are published in this report. While some TMDLs have already been published, they were not previously reported in the format of total spring or annual load.

***Hypothetical TMDL target loads*** refers to hypothetical TP TMDLs that were developed for all HUC-12 subwatersheds in the SJRW and TRW (regardless of listed impairments) and then converted to total (cumulative) spring or annual target loads and vary from year to year because flow varies from year to year. These hypothetical TP TMDLs were not developed by IDEM, Michigan DEQ, or Ohio EPA and are not considered actual TMDLs; they were calculated to support the analyses of this project. More specific terms include the watershed name (SJRW or TRW) and period (spring or annual); for example, *SJRW hypothetical TMDL spring target loads*. Hypothetical TMDL target loads are published in this report but are not to be considered TMDLs as defined by the CWA.

***Existing loads* and *existing conditions loads*** refer to TP loads that were estimated for locations in the SJRW or TRW. Existing loads were estimated using one of three methods:

- ***Simulated existing loads*** were estimated using a Soil and Water Assessment Tool (SWAT) model
- ***LOADEST existing loads*** were estimated using Purdue University's LOADEST web interface (see Appendix A for a discussion of LOADEST) and weekly or monthly monitoring data
- ***Integrated existing loads*** were estimated using daily or sub-daily monitoring data collected by the National Center for Water Quality Research or the U.S. Geological Survey

These existing loads are presented as total (cumulative) spring or annual loads to facilitate comparison with Annex 4 translated TP targets. Existing loads are published in this report. While some existing loads have already been published, some have not previously been published in the format of total spring or annual load.

# 2.0 METHODOLOGY TO DETERMINE ANNEX 4 TARGETS FOR THE HUC-8 AND FINER SCALES

This section of the document explains the methodology for determining Annex 4 targets at the HUC-8 and HUC-12 scales and presents the Annex 4 translated targets for the HUC-8 scale. The methodology consists of the following three-step framework:

- **Identify loading targets at the HUC-8 scale:** Annex 4 TP and SRP targets were set by the GLWQA only for the Maumee River at Waterville[11] (GLWQA 2015). To develop upstream tributary TP and SRP targets within the MRB, the Waterville targets must be distributed to the tributary HUC-8 watersheds[12]. The Work Group evaluated a variety of potential approaches and eventually decided to apportion the Waterville load targets based on the relative flow contribution of each HUC-8 watershed. Each tributary HUC-8 watershed receives an Annex 4 translated load target that is apportioned using a ratio of the HUC-8 watershed's total spring and total annual flows (water years 2002 through 2016) compared to the total spring and total annual flows of the Maumee River at Waterville. This step of the methodology has been completed and the results are presented herein for each of the HUC-8 watersheds that are tributary to the Maumee River (Table ES-1).
- **Translate HUC-8 scale targets to smaller spatial scales:** After the Annex 4 translated load targets are calculated for the tributary HUC-8 watersheds, the HUC-8 load targets need to be translated to smaller scales. The Work Group recommends that the same flow-based approach used to derive the HUC-8 Annex 4 load targets be used for the smaller spatial scales. The approach for doing so is presented within this methodology, and the results are shown for the SJRW and TRW (Section 3, Appendices C and D). The Work Group considered modifying the smaller scale Annex 4 translated targets to account for assimilative capacity (i.e., phosphorus losses in transit), but ultimately decided against doing so because little attenuation is expected to occur during the spring high flow periods when most of the loading occurs. For example, the U.S. Geological Survey (USGS) Great Lakes SPARROW phosphorus attenuation model predicts no net loss for Lake Erie tributaries during high flow periods (Robertson and Saad 2011).
- **Compare TMDLs to Annex 4 Translated Targets:** Once Annex 4 translated targets have been derived, they can be compared to target loads associated with TMDLs. Hypothetical TMDL cumulative spring and annual target loads were developed for all HUC-8 watersheds and HUC-12 subwatersheds in the SJRW and TRW, regardless of whether streams in those locations are listed for a cause of impairment that requires a TP TMDL. In this report, for the SJRW and TRW, hypothetical TMDL cumulative spring and annual target loads[13] were developed at the various scales and are compared with the Annex 4 target loads.

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[11] Waterville is the most downstream monitoring location where the river's loading to the lake can be measured.

[12] The Work Group noted in developing the methodology that it is somewhat misleading to develop a single target load for each HUC-8 and HUC-12 because multiple combinations of loads across the 250+ HUC-12 tributary subwatersheds can be distributed to achieve the targets for the Maumee River at Waterville (i.e., many-to-one issue).

[13] TMDLs are developed to meet daily concentration targets and are expressed as daily loads. The "TMDL target loads" referenced in this document are calculated as the cumulative spring or annual total of all the daily loads. See Section 1.3 for further discussion of terminology.

The Annex 4 translated targets and TMDL target loads can also be compared to estimated existing loads, and recommendations on how to best calculate existing loads for different quantities of flow and phosphorus data are presented in this document.

## 2.1 DETERMINATION OF HUC-8 SCALE TARGETS

A primary objective of this project is to develop TP and SRP load targets for the HUC-8 scale watersheds based upon the Annex 4 targets for the Maumee River at Waterville. Six HUC-8 watersheds drain to the Maumee River at Waterville, which is located within the Lower Maumee HUC-8 watershed (Figure 2; Table 1).

Several methods to distribute the Maumee River at Waterville targets to the tributary HUC-8 watersheds were explored. For this project, with an emphasis upon preventing HABs, HUC-8 scale target derivation focused upon spring target loads. The process for identifying spring load targets for the HUC-8 watersheds was then applied to the annual load target for the Maumee River at Waterville to determine the annual load targets for the HUC-8 watersheds.

Table 1. HUC-8 watersheds that drain to the Maumee River at Waterville

| HUC-8 | HUC-8 name | Drainage area (sq. mi.) | Relative area [a] | 2002-2016 total spring flow (ac-ft) | Relative flow [a] |
|---|---|---|---|---|---|
| 04100003 | St. Joseph | 1,094 | 17% | 6,112,986 | 16% |
| 04100004 | St. Mary's | 793 | 13% | 5,397,349 | 14% |
| 04100005 | Upper Maumee | 387 | 6% | 2,590,783 | 7% |
| 04100006 | Tiffin | 778 | 12% | 3,900,787 | 10% |
| 04100007 | Auglaize | 1,666 | 26% | 10,654,726 | 28% |
| 04100008 | Blanchard | 772 | 12% | 4,646,687 | 12% |
| 04100009 | Lower Maumee<br>(above Waterville)<br>(at Waterville) | 1,078<br>840<br>6,330 | --<br>13%<br>100% | --<br>5,113,761<br>38,417,018 | --<br>13%<br>100% |

*Note a:* The area and flow relative to the Maumee River at Waterville.

### 2.1.1 Potential Methods to Develop Load Targets

Annex 4 set spring load targets for the Maumee River at Waterville (860 MT TP and 186 MT SRP; GLWQA 2015). To achieve these targets, spring loads must be reduced 40 percent from 2008 baseline conditions. State regulatory agencies and watershed stakeholders indicated that universally applying a 40 percent reduction to all tributaries of the Maumee River at Waterville is unfair because it ignores differences in how the various tributaries contribute to the phosphorus loading problem. Tributary watersheds that contribute insignificant loads would require the same reductions as watersheds that contribute disproportionately large loads. Thus, a different method was necessary to select TP and SRP load targets for each HUC-8 watershed. Three options were identified:

- **Drainage area-based:** Each tributary HUC-8 watershed would receive a load target based upon its drainage area relative to the drainage area of the Maumee River at Waterville. For example, if a tributary HUC-8 watershed drained 10 percent of the area draining to Waterville, it would receive 10 percent of the Annex 4 target for Waterville.

- **Flow-based:** Each tributary HUC-8 watershed would receive a load target based upon a specified flow measure (e.g., total spring 2008 flow) relative to the same specified flow measure of the Maumee River at Waterville. For example, if a tributary HUC-8 watershed contributes 10 percent of the total spring flow at Waterville, it would receive 10 percent of the Annex 4 target for Waterville.
- **Load-based:** Each tributary HUC-8 watershed would receive a load target based upon a specified load measure (e.g., total spring 2008 load) relative to the same specified load measure of the Maumee River at Waterville. For example, if a tributary HUC-8 watershed contributed 10 percent of the total spring 2008 load measured at Waterville, it would receive 10 percent of the Annex 4 target for Waterville.

  Another load-based option would be to distribute the FWMC targets. FWMCs are an expression of load, but normalized to flow. The FWMC targets from the Maumee at Waterville could therefore be applied to the pour point of all the HUC-8 watersheds. This approach is functionally like the flow-based distribution of load targets. However, a summation of the HUC-8 outlet allowable loads will not sum to 860 MT TP and 186 MT SRP unless spring 2008 flow is used to calculate loads. Alternatively, relative amounts of existing loads could be used to calculate FWMC targets for each HUC-8 watershed that jointly achieve the FWMC target for the Maumee River at Waterville.

### Example: St. Joseph River Watershed

Each of these methods is applied to the SJRW for spring TP as an example.

- **Drainage area-based:** The SJRW (1,085 sq. mi.) is 17 percent of the Maumee River watershed at Waterville (6,330 sq. mi.). The SJRW allowable load could be specified as 17% X 860 MT = 147 MT.
- **Flow-based:** From 2002 through 2016, the SJRW's total spring flow (20,135 cfs) was 16 percent of the spring flow in the Maumee River at Waterville (126,592 cfs). The SJRW allowable load could be specified as 16% X 860 MT = 137 MT.
- **Load-based:** Based on Soil and Water Assessment Tool modeling, the SJRW's spring 2008 load (105 MT) was 7.5 percent of the spring 2008 load in the Maumee River at Waterville (1,400 MT; GLWQA 2015). The SJRW allowable load could be specified as 7% X 860 MT = 64.5 MT.

Each of these methods has advantages and disadvantages. The drainage area distribution method is easy to apply because this watershed characteristic is static. However, drainage area distribution assumes a uniform unit area load across all tributary subwatersheds. Unit area loads are not likely uniform due to both natural factors (e.g., weather patterns, soil types, slopes) and anthropogenic factors (e.g., point source discharges and different land use practices, such as urban development with storm sewers and agricultural development with tile drains).

The flow distribution method is also easy to apply, and partially accounts for differences in land use and point source discharges between watersheds by factoring in their impact on flows. To ensure that the specified flow measure is representative of the range of flow conditions, a long-term total or average could be used (e.g., 2002-2016 total spring flow) rather than the flow from a single year, which might be biased based on weather patterns for that year.

The load distribution method is more difficult to apply because spring loads need to be calculated at the outlets for tributary HUC-8 watersheds and very limited data are available for some outlets. This method also assumes all watersheds need some level of reduction, and could end up setting targets that are too low or unachievable. On the other hand, the load-based approach automatically accounts for existing differences in land use and point source discharges between HUC-8 watersheds and assigns the largest load reductions to the areas with the greatest loads.

The Work Group discussed each of these potential methods and eventually decided to use the flow distribution method. The Work Group also recommended continuing to explore potential modifications to this approach, such as factoring in the impacts of land use or other factors (see section 5.2.5 for additional information).

### 2.1.2 Development of HUC-8 Scale Spring Load Targets

Various iterations of the three general approaches described in Section 2.1.1 were evaluated and a flow-based distribution method was selected by the Work Group (Appendix B). The flow-based distribution method uses spring and annual total flows for WYs 2002 through 2016 for each HUC-8 watershed and the Maumee River at Waterville to develop ratios. The load targets for the Maumee River at Waterville were then apportioned to the HUC-8 watersheds using the flow ratio. Flows for the HUC-8 watershed outlets were estimated using daily average flow data from continuously recording U.S. Geological Survey (USGS) gages and flow estimation techniques (e.g., drainage area ratio). Refer to Appendix A for discussions of flow estimation techniques, and refer to Appendix B for discussions of flow estimations for each HUC-8 watershed that drains to the Maumee River at Waterville.

The spring load targets for the Maumee River at Waterville are 860 MT TP and 186 MT SRP. The spring TP and spring SRP target for each HUC-8 watershed were calculated using the total 2002-2016 spring flows at the Maumee River at Waterville and the HUC-8 watershed outlets. The total spring flows, distribution ratios, and spring targets are presented in Table 2.

Table 2. Annex 4 translated spring targets for the HUC-8 watersheds

| HUC-8 | HUC-8 name | 2002-2016 total spring flow (ac-ft) | Relative flow [a] | Translated spring TP target (MT) [b] | Translated spring SRP target (MT) [b] |
|---|---|---|---|---|---|
| 04100003 | St. Joseph | 6,112,986 | 15.91% | 137 | 30 |
| 04100004 | St. Mary's | 5,397,349 | 14.05% | 121 | 26 |
| 04100005 | Upper Maumee | 2,590,783 | 6.75% | 58 | 12 |
| 04100006 | Tiffin | 3,900,787 | 10.15% | 87 | 19 |
| 04100007 | Auglaize | 10,654,726 | 27.73% | 239 | 52 |
| 04100008 | Blanchard | 4,646,687 | 12.10% | 104 | 22 |
| 04100009 | Lower Maumee<br>(above Waterville)<br>(at Waterville) | --<br>5,113,761<br>38,417,018 | --<br>13.31%<br>100% | --<br>114<br>860 | --<br>25<br>186 |

*Notes*

Refer to Appendix B for information regarding flow estimation, target load calculation, and rounding.

a. The flow relative to the Maumee River at Waterville. Relative flows are rounded to the nearest one-hundredth of a percentage point.

b. Targets are rounded to the neared MT.

### 2.1.3 Development of HUC-8 Scale Annual Load Targets

Annex 4 also set a target of a 40 percent reduction of annual TP loads for tributaries in the Western and Central basins (GLWQA 2015). Annex 4 published spring load targets for the Maumee River at Waterville (860 MT TP and 186 MT SRP) but did not publish annual load targets. U.S. EPA identified the annual TP load target for the Maumee River as 2,287 MT in the *U.S. Action Plan for Lake Erie* (U.S. EPA 2017, p. 14).

To translate this target to the HUC-8 watersheds, the same method for determining HUC-8 scale spring load targets was applied to determine HUC-8 scale annual load targets. The total annual flows, distribution ratios, and targets are presented in Table 3. Refer to Appendix B for flow estimations for each WY and for discussions of tributary target load calculations.

Table 3. Annex 4 translated annual targets for the HUC-8 watersheds

| HUC-8 | HUC-8 name | 2002-2016 total annual flow (ac-ft) | Relative flow [a] | Translated annual TP target (MT) |
|---|---|---|---|---|
| 04100003 | St. Joseph | 11,497,599 | 16.28% | 373 |
| 04100004 | St. Mary's | 10,051,241 | 14.23% | 326 |
| 04100005 | Upper Maumee | 4,508,108 | 6.39% | 146 |
| 04100006 | Tiffin | 6,832,408 | 9.68% | 221 |
| 04100007 | Auglaize | 20,201,419 | 28.61% | 655 |
| 04100008 | Blanchard | 9,082,418 | 12.86% | 294 |
| 04100009 | Lower Maumee<br>(above Waterville)<br>(at Waterville) | --<br>8,439,185<br>70,612,338 | --<br>11.95%<br>100% | --<br>273<br>2,288 |

*Notes*

Refer to Appendix B for information regarding flow estimation, target load calculation, and rounding.

a. The flow relative to the Maumee River at Waterville. Relative flows are rounded to the nearest one-hundredth of a percentage point.

b. Targets are rounded to the neared MT.

## 2.2 TRANSLATE HUC-8 SCALE TARGETS TO FINER SCALE WATERSHEDS

Another objective of this project is to develop the methodology for setting TP and SRP load targets for finer scale subwatersheds that is consistent with the methodology to set HUC-8 scale watershed targets and is based upon the Annex 4 targets for the Maumee River at Waterville. The Work Group initially struggled with this objective because translation of the Annex 4 targets for the Maumee River at Waterville to upstream tributary watersheds is a many-to-one problem (i.e., multiple combinations of loads across the tributary watersheds can be distributed to achieve the Annex 4 targets for the Maumee River at Waterville). While this is also true for the six HUC-8 watersheds in the MRB, it becomes an even more significant issue for the more than 250 HUC-10 and HUC-12 subwatersheds. The Work Group ultimately moved forward with developing an approach to setting the finer scale targets, but readers should keep this issue in mind and be aware that other potential load targets exist for the subwatersheds that will still meet the goals of Annex 4.

### 2.2.1 Target-Setting Methodology

The same method for determining HUC-8 scale targets was applied to determine finer scale load targets that are consistent with the Annex 4 targets. As with the HUC-8 scale target-setting method, a flow-based distribution method is recommended for setting targets for HUC-10 and HUC-12 subwatersheds. The only significant difference is that the finer scale target-setting methodology must rely on available flow datasets for the specific HUC-10 and HUC-12 subwatersheds of interest, which may require a distribution of spring and annual flows from periods other than the WYs 2002-2016 period used for the HUC-8 watershed target-setting.

### 2.2.2 Available Flow Data

USGS maintains continuously recording flow gages in each of the HUC-8 watersheds in the MRB. However, no such data are available for the majority of HUC-10 and HUC-12 subwatersheds in the MRB.

Potential flow monitoring datasets may be available from state or local government agencies, colleges and universities, and other local organizations. Flow modeling datasets may be available from similar government entities and private organizations. For example, a SWAT model was developed for the SJRW, which provides continuous flow data for calendar years 2004-2014 for all the HUC-10 and HUC-12 outlets in the SJRW; refer to Section 3.1 for a discussion of HUC-12 subwatershed target-setting for the SJRW.

Continuous flow data may also be estimated using available flow monitoring or modeling data; refer to Appendix A for a presentation of flow-estimation techniques. For example, the drainage area ratio method was used to estimate HUC-12 subwatershed flows for the TRW; refer to Section 3.1 for a discussion of HUC-12 subwatershed target-setting for the SJRW.

### 2.2.3 Losses in Transit

The Work Group considered modifying the smaller scale Annex 4 targets to account for assimilative capacity (i.e., losses in transit). For example, if only a portion of the load derived in an upstream HUC-12 is ultimately delivered to the HUC-8 outlet, then the load that is not delivered could be subtracted from the upstream Annex 4 translated target.

USGS has developed an approach for estimating phosphorus attenuation for its SPARROW modeling (Robertson and Saad 2011) where attenuation, or loss, is estimated as a function of travel time and an exponent that varies by flow. However, SPARROW predicts no net loss for higher flow ranges, which is when much of the spring and annual phosphorus load is delivered to Lake Erie. Based on this as well as studies completed by Ohio EPA that suggest that tributaries within the Maumee River are conduits for upstream nutrient loads to be delivered downstream to Lake Erie (Ohio EPA 2014), the Work Group decided to not factor attenuation into the HUC-12 target setting process.

# 3.0 CASE STUDIES: SJRW AND TRW

TMDLs are being developed to address impaired streams in the SJRW (HUC 04100003) and TRW (HUC 04100006) to satisfy requirements of the Clean Water Act. These watersheds are tributary to the Maumee River that is a major source of nutrients to the Western Basin of Lake Erie and the subject of reduction targets developed as part of Annex 4 of the GLWQA. TMDLs have been or are being developed using states' water quality standards and targets to address in-stream impairments, while Annex 4 load targets were developed to reduce HABs, hypoxia, and biotoxins, and to maintain a healthy aquatic ecosystem and trophic states in Lake Erie. The objective of this project is to develop a methodology to determine Annex 4 load targets at the HUC-8 scale and then translate the HUC-8 scale targets to finer scales. The methodology was developed and then tested with the SJRW and TRW.

This section presents the application of the target setting methodology to the SJRW (Section 3.1) and TRW (Section 3.2) and compares the TMDLs (recalculated as cumulative spring and annual target loads) with the Annex 4 translated targets.

## 3.1 ST. JOSEPH RIVER WATERSHED

TMDLs were developed by IDEM (2017) and are being developed by Ohio EPA in accordance with stream impairments discussed in the Biological and Water Quality Study of the St. Joseph River Basin (Ohio EPA, 2015a), Annex 4 targets were translated to the SJRW and HUC-12 subwatersheds as part of this study (Section 3.1.1), and the TMDLs were evaluated with Annex 4 translated targets (Section 3.1.3).

### 3.1.1 Annex 4 Target Translation

Annex 4 translated targets for each of the 45 HUC-12 subwatersheds in the SJRW were calculated using the same flow-weighting methodology for the HUC-8 watersheds, as presented in Section 2.0 and Appendix B. Data exploration, flow estimations, and load calculations for the SJRW are presented in Appendix C.

#### 3.1.1.1 Available Flow Datasets

Flow monitoring data in the SJRW are available for four continuously recording, long-term USGS gages and one short-term Ohio EPA level logger.

A SWAT model was developed to support TMDL development using USGS and Ohio EPA flow data and TP data collected by IDEM, Ohio EPA, and the city of Fort Wayne (IDEM 2017; Ohio EPA 2015a). The SWAT model simulated flow at all HUC-12 subwatershed outlets throughout the SJRW; the model also simulates flow at many other locations, including all the TMDL sites, IDEM fixed stations, key Ohio EPA monitoring sites, and state borders.

#### 3.1.1.2 Determination of Target Loads Consistent with Annex 4 Goals

Since a SWAT model was developed for the SJRW at a sufficiently fine-scale, the SWAT model was used to develop the hydrology for the HUC-12 scale required for the methodology described in Section 2.2. As the SWAT model was developed for calendar years 2004 through 2014, the Annex 4 translated annual TP targets for the HUC-12 subwatersheds were calculated using the total WYs 2005-2014 annual total flows, while the Annex 4 translated spring TP and SRP targets were calculated using the 2004-2014 spring total flows (Section C-2). The Annex 4 translated targets are presented in Table C-4 in Appendix C.

## 3.1.2 TMDLs

TP, total suspended solids, and *Escherichia coli* TMDLs were developed for the St. Joseph River and its tributaries in Indiana using a load duration curve approach. TMDLs for the portion of the St. Joseph River in Ohio are being developed using a load duration curve approach based upon state targets. Flow estimates for both the Indiana and Ohio TMDLs were simulated with the SWAT model (IDEM 2017). In Ohio, two TP TMDLs are being developed to address nutrient impairments preliminarily using a daily TP target of 0.1 mg/L for wading-sized streams (Ohio EPA 1999). In Indiana, eight TP TMDLs were developed to address nutrient, biotic community, and dissolved oxygen impairments using a daily TP target of 0.3 mg/L.

### 3.1.2.1 Determination of TMDL Target Loads

Loads representing TMDLs were estimated using total spring flows and total WY flows for each of the 10 HUC-12 subwatersheds with established TP TMDLs from IDEM (2017) and in subwatersheds where Ohio EPA is in the preliminary process of developing TP TMDLs. Please refer to the footnotes in Table C-5 and Table C-6 for a listing of the subwatersheds where TMDLs were or are being developed.

Annex 4 targets are for the total spring load and total annual load. To compare the TMDLs with Annex 4 translated targets, the TMDLs were recalculated as total spring load and total annual loads (i.e., daily TMDLs were summed across the spring and across the full water year); these recalculated TMDLs are referred to as *TMDL spring target loads* and *TMDL annual target loads*.

Note that the TMDLs for these 10 HUC-12 subwatersheds were not all set at the outlet of the subwatershed; some were set within the subwatershed and therefore technically do not cover the entire drainage area. For the purposes of this report, however, only the TMDL loads at the outlet are presented.

### 3.1.2.2 Determination of Hypothetical TMDL Target Loads

Hypothetical TMDL target loads were calculated for each of the 45 HUC-12 subwatersheds by multiplying the total spring flows and total WY flows by the TMDL targets, which vary by state (see example below).

**Example: Annual Hypothetical TMDL TP target for Eagle Creek in 2005 (*03 03)**

Eagle Creek target = (TMDL TP Target) * (Eagle Creek Annual Flow in 2005)

Eagle Creek target = (0.30 mg/L TP) * (average daily flow of 10.1 cfs)

Eagle Creek target = 2.7 MT TP

These are referred to as *hypothetical TMDL target loads* because most of the HUC-12 subwatersheds are not listed as impaired and thus actual TP TMDLs were not developed. Loads representing hypothetical TMDLs for all 45 HUC-12s for the springs of 2004 through 2014 are presented in Table C-5, and loads representing hypothetical TMDLs for all 45 HUC-12s for WYs 2005 through 2014 are presented in Table C-6. For the 10 HUC-12 subwatersheds with approved TMDLs, the hypothetical TMDL target loads are exactly equal to the TMDL target loads discussed in Section 3.1.2.1.

## 3.1.3 Comparison of TMDLs and Annex 4 Targets

Target loads representing Annex 4 targets, approved TMDLs, and hypothetical TMDLs were evaluated.

### 3.1.3.1 HUC-8 Scale Comparison

Annex 4 translated targets for the SJRW that were determined using the Maumee River at Waterville targets (Section 2.0 and Appendix B); and the SJRW Annex 4 translated targets are:

- **Annual:** 373 MT TP
- **Spring:** 137 MT TP and 30 MT SRP

The Annex 4 translated TP targets for the SJRW HUC-8 outlet were compared with the TP TMDL at the SJRW outlet; the TP TMDL was re-calculated as total spring loads and total annual loads to allow for the comparison. As is shown in Figure 3, the TP TMDL annual target loads are protective of the Annex 4 translated TP annual target in 8 of 10 years. However, the TP spring target loads are only protective of the Annex 4 translated TP spring target in 5 of 11 springs (Figure 4).

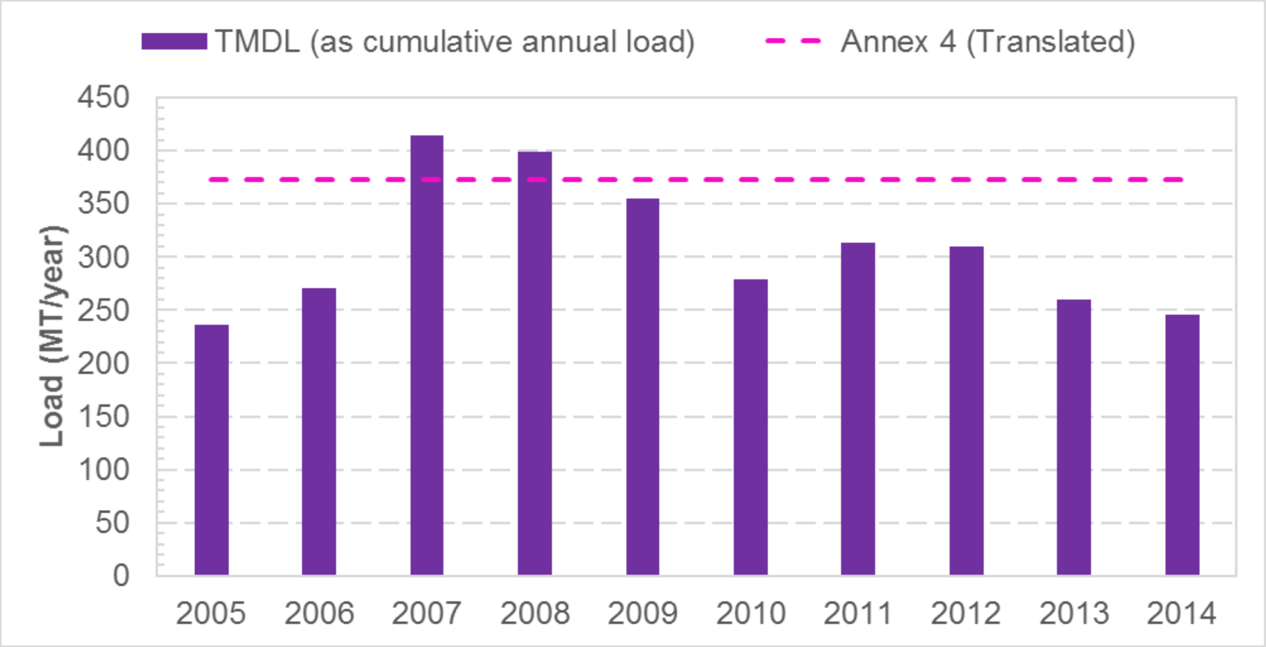

Figure 3. Annual TP target loads at the outlet of the SJRW.

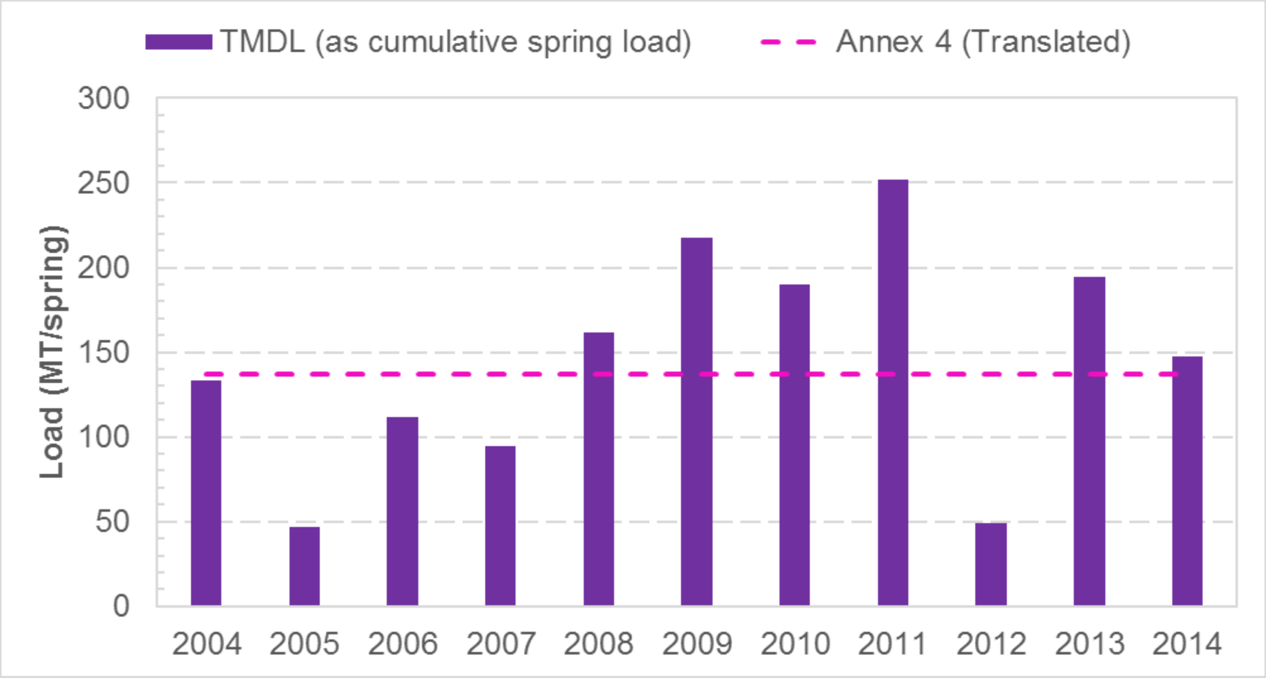

Figure 4. Spring TP target loads at the outlet of the SJRW.

### 3.1.3.2 HUC-12 Scale Comparison: Annex 4 Translated Targets and All Subwatersheds with Hypothetical TMDLs

A hypothetical TMDL condition was developed where TMDLs were assumed to be developed for all 45 HUC-12 subwatersheds in the SJRW[14]. For each HUC-12 subwatershed, each total spring flow and total WY flow was multiplied by the appropriate state TP target to estimate hypothetical TMDL spring and annual TP target loads. The Indiana TP target is 0.30 mg/L and the Ohio TP targets typically vary from 0.08 mg/L to 0.17 mg/L depending on the size of the watershed. Michigan does not currently have numeric phosphorus TMDL targets for the SJRW and the TRW, therefore, the headwater portions of these watersheds within the State of Michigan did not complete the hypothetical TP exercise.

The hypothetical TMDL target loads were then compared with Annex 4 translated targets (Section C-3).

- **Spring:** For the spring loads, there are a total of 495 different hypothetical TMDL target loads (45 HUC-12 subwatersheds multiplied by 11 springs). Of these 495 target loads, 333 or 67 percent hypothetical TMDL target loads are less than (i.e., protective of) the Annex 4 translated targets.
- **Water Year:** For the annual loads, there are a total of 450 different hypothetical TMDL target loads (45 HUC-12 subwatersheds multiplied by 10 years). Of these 450 target loads, 383 or 77 percent TMDL target loads are less than (i.e., protective of) the Annex 4 translated targets.

Generally, Annex 4 translated targets were more restrictive in wetter springs and WYs, and hypothetical TMDL target loads were more restrictive in drier springs and WYs (Section C-3). These results reflect the nature of the hypothetical TMDLs, which are concentration-based and vary with flow condition (e.g., higher flows yield larger TMDLs).

## 3.1.4 Comparison of Existing Loads to Annex 4 Translated Targets

Existing loads in the SJRW were estimated using the SWAT model and then compared with Annex 4 translated targets.

### 3.1.4.1 Available Phosphorus Data

TP monitoring data in the SJRW are available at monitoring sites sampled by IDEM, the Michigan Department of Environmental Quality, Ohio EPA, the city of Fort Wayne, Allen County (Indiana), and the St. Joseph River Watershed Initiative. Data frequency and quality vary by site. SRP data are limited to a few sites sampled by Ohio EPA and Allen County Soil and Water Conservation District (SWCD).

A SWAT model was developed to support TMDL development using USGS and Ohio EPA flow data and TP data collected by IDEM, Ohio EPA, and the city of Fort Wayne (IDEM 2017). The SWAT model simulated flow and TP load at all HUC-12 subwatershed outlets throughout the SJRW; the model also simulates flow and TP at many other locations, including all the TMDL sites, IDEM fixed stations, key Ohio EPA monitoring sites, state borders. The SWAT model was not calibrated for SRP because the TMDLs were for TP and because of the lack of available data with which to compare model output.

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[14] IDEM (2017) developed 8 TP TMDLs at HUC-12 outlets that addressed 7 segments impaired by nutrients, 18 segments with impaired biotic communities, and 2 segments impaired by dissolved oxygen. Ohio EPA is developing 2 TP TMDLs at sites impaired by nutrients within 2 HUC-12 subwatersheds.

### 3.1.4.2 Exploration of Methods to Estimate Existing Loads

SWAT and LOADEST were both explored to estimate existing loads for key locations in the SJRW (Appendix C); refer to Appendix A for a discussion of LOADEST and other load estimation techniques. IDEM provided LOADEST results for IDEM fixed stations for WYs 2008-2015. Tetra Tech used LOADEST to estimate loads for WYs 2002-2016 for IDEM fixed stations, an Ohio EPA sentinel site, and city of Fort Wayne sampling sites. The LOADEST results provided by IDEM were compared with LOADEST results calculated by Tetra Tech and the results from Tetra Tech's SWAT model.

Results generally indicated that SWAT simulated smaller TP loads than most of the LOADEST simulations and that TP loads varied considerably between LOADEST simulations (likely due to the frequency of TP data available from IDEM, Ohio EPA, and the city of Fort Wayne). An evaluation of the same input data at a single site using each of the nine regression models contained within LOADEST also yielded loads that varied considerably by model selection (Appendix C, Section C-4).

For setting HUC-12 subwatershed targets, the SWAT model was selected to estimate flow and loads because the model yields output at all 45 HUC-12 subwatershed targets, whereas LOADEST yields results in only a few locations.

### 3.1.4.3 HUC-8 Scale Comparison

The Annex 4 translated targets for the SJRW that were determined using the Maumee River at Waterville targets (Section 2.0 and Appendix B); these targets are:

- **Annual:** 373 MT TP
- **Spring:** 137 MT TP and 30 MT SRP

The Annex 4 translated TP targets for the SJRW HUC-8 outlet were compared with simulated existing loads (i.e., SWAT model results) for the SJRW outlet. As is shown in Figure 5 and Figure 6, the simulated existing loads are always below the Annex 4 translated TP targets.

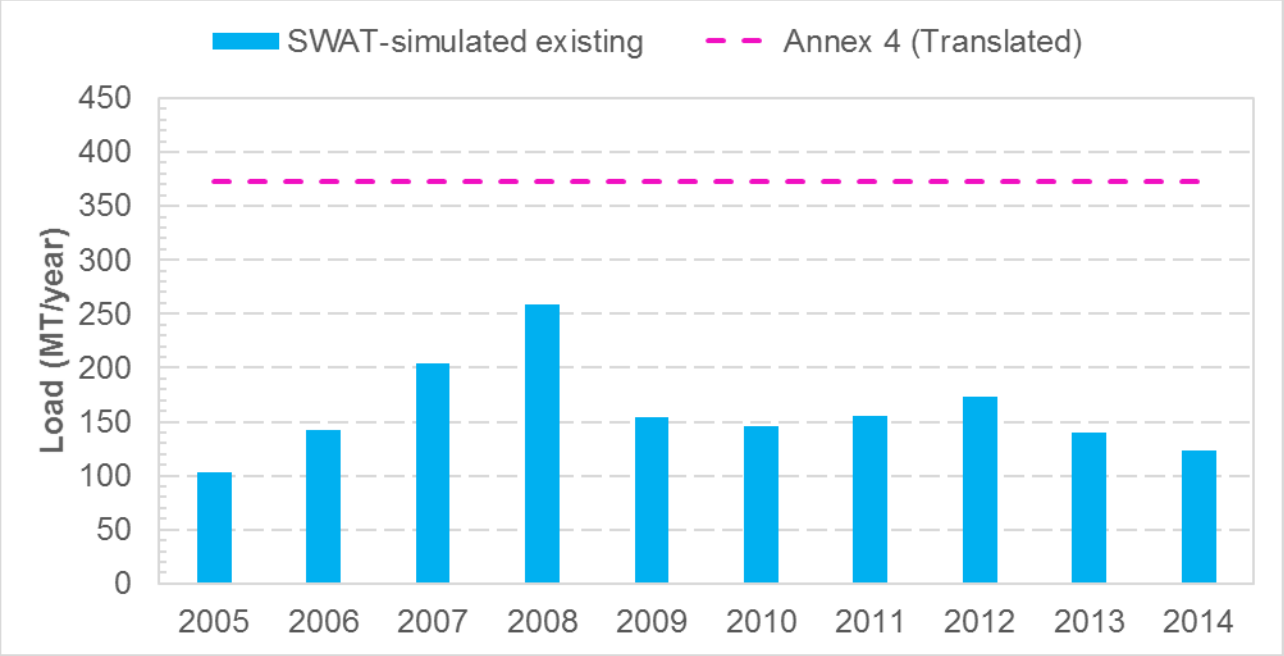

Figure 5. Simulated existing annual loads and the Annex 4 translated target at the outlet of the SJRW.

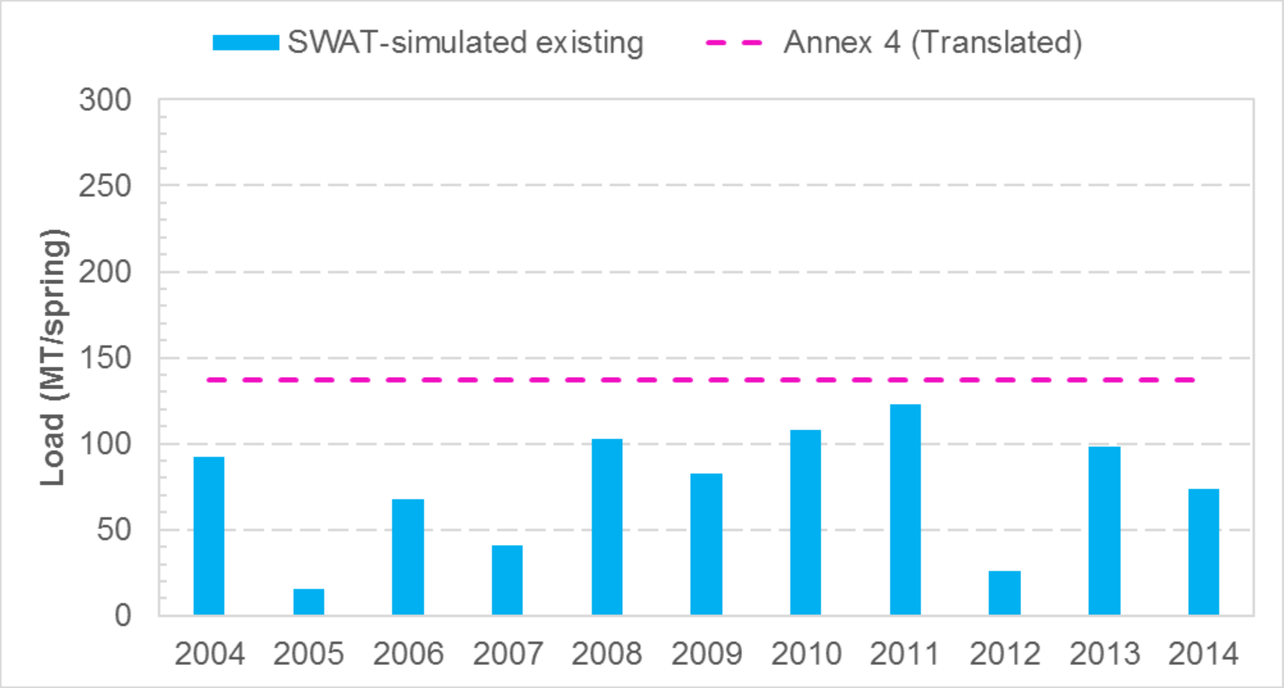

Figure 6. Simulated existing spring loads and the Annex 4 translated target at the outlet of the SJRW.

Grab samples from IDEM fixed stations in the lower St. Joseph River indicate that TP concentrations infrequently exceed the TMDL target (0.30 mg/L). The TP TMDL was developed to address the few occasions that TP concentrations exceed the target, which only occurs in the highest flow conditions (0th to 20th duration interval). For example, the 113 TP samples at IDEM fixed station LEJ100-0003 from March 2004 through October 2014 ranged from 0.03 to 0.57 mg/L, with an average of 0.13 mg/L and a median of 0.11 mg/L. About 85 percent of samples were less than 0.20 mg/L. Hence, the cumulative existing loads for the spring and WY are well below the Annex 4 translated target.

### 3.1.4.4 HUC-12 Scale Comparison

SWAT-simulated existing TP loads were summed by HUC-12 subwatershed for each spring and WY and compared with the Annex 4 translated TP targets (Appendix C, Section C-4.4). The only WY to exceed the Annex 4 translated annual TP target was WY 2008 in *West Branch Fish Creek* (HUC 04100003 04 01).

Of the 45 HUC-12 subwatersheds in the SJRW, simulated existing loads never exceeded the Annex 4 translated spring TP target in 23 subwatersheds. Of the 22 subwatersheds with an exceedance of the Annex 4 translated spring TP target, only one to three springs exceeded. Exceedances most often occurred in the springs of 2008 (eight subwatersheds), 2011 (13 subwatersheds), and 2013 (6 subwatersheds). Exceedances in the springs of 2004, 2008, and 2010 only occurred in the SJRW upstream of the confluence of Fish Creek (including the Fish Creek subwatershed). In summary, most HUC-12 subwatersheds within the SJRW are usually below the Annex 4 translated targets; please refer to Appendix C for an identification of those subwatersheds that are not.

## 3.2 TIFFIN RIVER WATERSHED

TMDLs for the TRW are being developed by Ohio EPA in accordance with stream impairments discussed in the Biological and Water Quality Study of the Tiffin River and Select Tributaries (Ohio EPA, 2015b. Annex 4 targets were translated to each of the TRW HUC-12 subwatersheds as part of this effort. The TMDLs and necessary reductions were evaluated with Annex 4 translated targets (Appendix D).

## 3.2.1 Annex 4 Target Translation

Annex 4 translated targets for each of the 26 HUC-12 subwatersheds in the TRW were calculated using the same flow-weighting methodology as for the HUC-8 watersheds, as presented in Section 2 and Appendix B.

### 3.2.1.1 Available Flow Datasets

Flow monitoring data in the TRW are available from four continuous recording USGS gages. Three of these have daily stream discharge information that cover the period examined as part of the methodology development (i.e., 2001 to 2016). These locations are Bean Creek at Powers, Tiffin River at Stryker, and Lost Creek tributary near Farmer. The fourth gage (Tiffin River near Evansport) was installed in October 2013. Flow estimates were also developed by Ohio EPA from measurements on key tributaries during their 2012 to 2014 water quality survey of the TRW. These HUC-12 watersheds include Beaver Creek, Brush Creek, Lick Creek, and Mud Creek.

A Tiffin River Soil & Water Assessment Tool (TR-SWAT) model was developed for the TRW using USGS and NCWQR data (LimnoTech 2013). The TR-SWAT model simulated flow, total suspended solids, TP, SRP, and total nitrogen for the period 2001 to 2011. The TR-SWAT model delineated the 26 TRW HUC-12 subwatersheds into 907 catchments with an average area of 540 acres.

### 3.2.1.2 Determination of Target Loads Consistent with Annex 4 Goals

Flow estimates for the entire TRW described in Appendix D were used as the starting point to describe HUC-12 scale target loads consistent with Annex 4 goals. Annual and spring discharge volumes at the TRW outlet were estimated by record extension through regression and flow distribution by drainage area ratio. Based on the same technique and other USGS gages in the TRW, spring and annual discharge volumes were estimated for the HUC-12 subwatersheds. Values at each gage location were distributed to individual HUC-12 subwatersheds by drainage area ratio (Appendix D).

## 3.2.2 TMDLs

TP and *Escherichia coli* TMDLs are being developed for the TRW and its tributaries. These TMDLs are being developed using the load duration curve method based upon Ohio EPA targets for each parameter and estimated flows derived from a drainage area weighting approach. TP TMDLs are being developed within seven HUC-12 subwatersheds to address nutrient impairments using a target of 0.08 mg/L for headwater streams and 0.10 mg/L for wading-sized streams (Ohio EPA 1999).

### 3.2.2.1 Determination of TMDL Target Loads

Loads representing TMDLs were estimated using total spring flows and total WY flows for each of the seven HUC-12 subwatersheds where Ohio EPA is developing TP TMDLs. The same approach was used for the TRW TMDLs as used for the SJRW TMDLs (see section 3.1.2.1). Please refer to the footnotes in Table D-3 and Table D-4 for a listing of the subwatersheds where TMDLs are being developed. Note that the TMDLs for these HUC-12 subwatersheds were not all set at the outlet of the subwatershed; some will be set within the subwatershed and therefore technically do not cover the entire drainage area. For the purposes of this report, however, only the TMDL loads at the outlet are presented.

### 3.2.2.2 Determination of Hypothetical TMDL Target Loads

Hypothetical TMDL target loads were calculated for each of the 26 HUC-12 subwatersheds by multiplying the total spring flows and total WY flows by the TMDL targets. These are referred to as hypothetical TMDL target loads because most of the HUC-12 subwatersheds are not listed as impaired and thus actual TP TMDLs were not developed. Loads representing hypothetical TMDLs for all 26 HUC-12s for the springs of 2008 through 2016 are presented in Table D-7 and loads representing hypothetical TMDLs for all 26 HUC-12s for WYs 2008 through 2016 are presented in Table D-8. As previously noted, TP TMDLs are being developed within seven HUC-12 subwatersheds to address nutrient impairments. These seven HUC-12 subwatersheds are identified in Table D-7 and Table D-8, but note that the actual TMDLs are for stream reaches within the subwatersheds and were not developed at the subwatershed outlet.

## 3.2.3 Comparison of TMDLs and Annex 4 Targets

Target loads representing Annex 4 targets and hypothetical TMDLs were evaluated.

### 3.2.3.1 HUC-8 Scale Comparison

The Annex 4 translated targets for the TRW that were determined using the Maumee River at Waterville targets (Section 2 and Appendix B) are:

- **Annual:** 221 MT TP
- **Spring:** 87 MT TP and 19 MT SRP

The Annex 4 translated TP targets for the TRW HUC-8 outlet were compared with the hypothetical TP TMDL at the TRW outlet; the TP TMDL was re-calculated as total spring loads and total annual loads to allow for the comparison. As is shown in Figure 7, the TP TMDL annual target loads are protective of the Annex 4 translated TP annual target in all 15 years. The TP spring target loads are also protective of the Annex 4 translated TP spring target in all 15 springs (Figure 8).

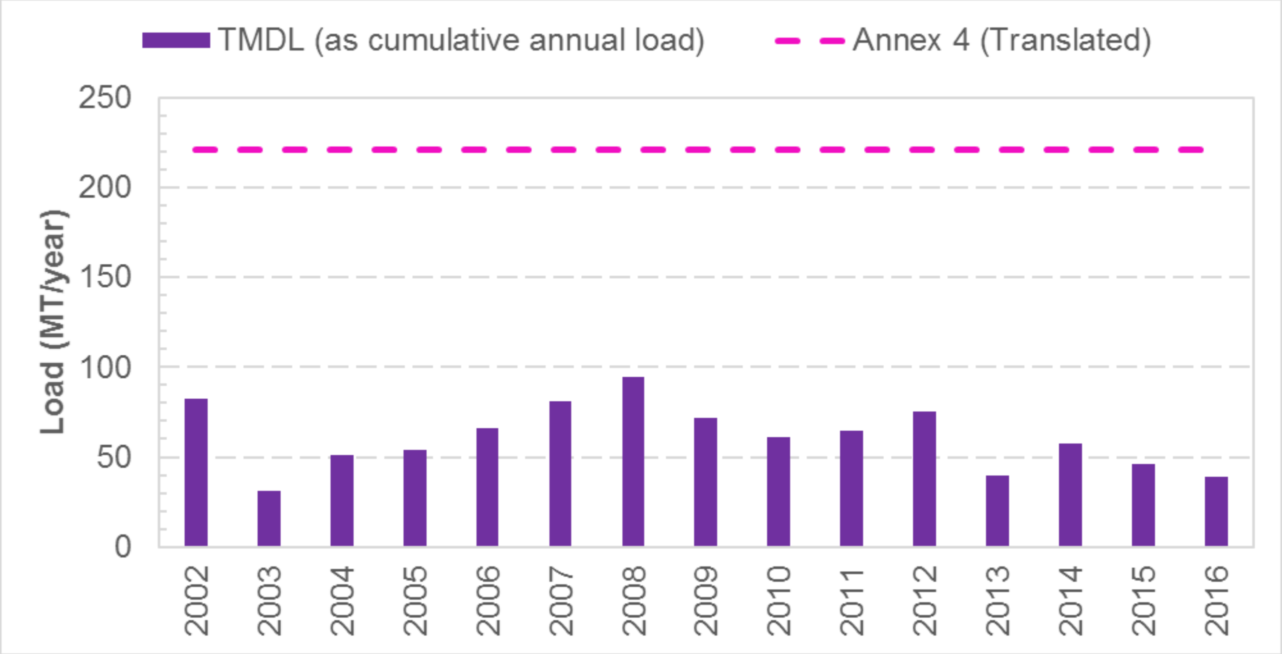

Figure 7. Annual TP hypothetical target loads at the outlet of the TRW.

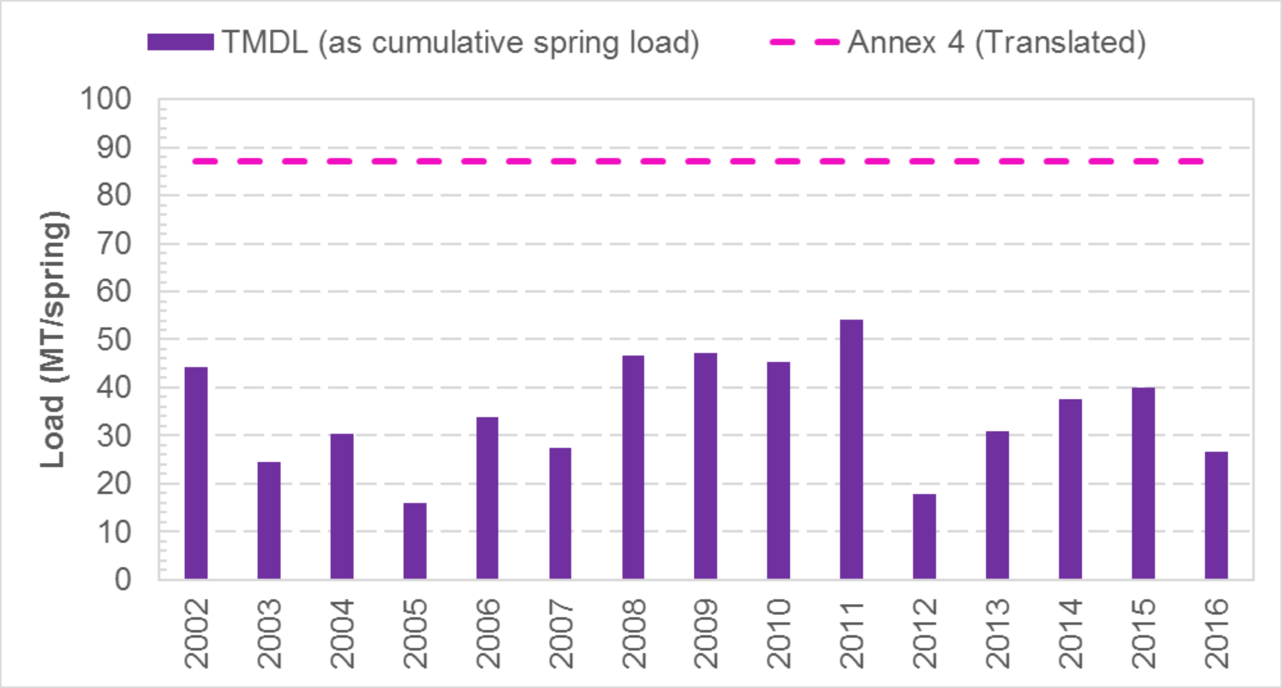

Figure 8. Spring TP hypothetical target loads at the outlet of the TRW.

#### 3.2.3.2 HUC-12 Scale Comparison: Annex 4 Translated Targets and All Subwatersheds with Hypothetical TMDLs

A hypothetical TMDL condition was developed where TMDLs were assumed to be developed for all 26 HUC-12 subwatersheds in the TRW[15]. For each HUC-12 subwatershed, each total spring flow and total WY flow was multiplied by the appropriate state TP target to estimate hypothetical TMDL spring and annual TP target loads. The Ohio TP targets are 0.08 mg/L for headwater streams and 0.10 mg/L for wading-sized streams. Michigan does not currently have numeric phosphorus TMDL targets for the SJRW and the TRW; therefore, the headwater portions of these watersheds within the State of Michigan did not complete the hypothetical TP exercise.

The hypothetical TMDL target loads were then compared with Annex 4 translated targets (Section D-3). The hypothetical TMDL spring and annual loads were always less than the Annex 4 translated spring and annual targets, respectively.

### 3.2.4 Comparison of Existing Loads to Annex 4 Translated Targets

Existing loads in the TRW were estimated using the available sampling data and then compared with Annex 4 translated targets. Existing loads in the TRW are also available from the SWAT model of the watershed (LimnoTech 2013) but were only accessible to Tetra Tech as an annual average load for the entire 2001 to 2014 simulation period. They are therefore not directly comparable to the Annex 4 translated targets, which must be evaluated on a spring-by-spring and year-by-year basis.

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[15] Ohio EPA is developing 9 TP TMDLs at sites impaired by nutrient enrichment within 7 HUC-12 subwatersheds.

### 3.2.4.1 Available Phosphorus Data

TP and SRP monitoring data in the TRW are available at sites sampled by Ohio EPA, the Michigan Department of Environmental Quality (MDEQ), USGS, and the NCWQR. Data frequency and quality vary by site. Ohio EPA routinely samples two fixed station ambient sites (Bean Creek at Powers, Tiffin River at Stryker) and conducted a water quality survey from 2012 to 2014 at multiple locations across Ohio's portion of the TRW. MDEQ supported 2016 to 2017 water quality sampling at several sites in Michigan's portion of the Bean Creek watershed. USGS initiated routine monitoring in 2014 at one location in the TRW (Tiffin River at Evansport). Finally, NCWQR operates water quality monitoring two stations in the TRW: Tiffin River at Stryker and Lost Creek tributary near Farmer.

### 3.2.4.2 Methods to Estimate Existing Loads

Existing loads were estimated using (1) GCLAS for the Tiffin River at Evansport, (2) numeric integration of daily TP concentration data from NCWQR for the Tiffin River near Stryker and for a tributary of Lost Creek (numeric integration), and (3) annual average loads from a SWAT model. None of these methods provide estimates for all 26 HUC-12 subwatersheds in the TRW. Therefore, existing loads for each HUC-12 subwatershed were also estimated using drainage area relationships between each HUC-12 subwatershed and the Tiffin River near Stryker (Appendix D, Section D-4.0)

### 3.2.4.3 HUC-8 Scale Comparison

Estimated spring and annual TP loads for the TRW outlet were estimated because there are no sampling stations at the TRW outlet. Daily TP loads were estimated for the Tiffin River near Stryker using daily TP concentration data from NCWQR and daily average flow data from USGS. Spring and annual TP loads were estimated via numeric integration of daily TP loads for springs and WYs 2008 through 2016. These estimated spring and annual TP loads for the Tiffin River near Stryker were then up-weighted via the drainage area ratio method to estimate existing TP loads for the TRW outlet. Based on the data for Stryker, it is likely that the loads at the HUC-8 outlet exceed the Annex 4 translated targets in most years (Figure 9 and Figure 10).

### 3.2.4.4 HUC-12 Scale Comparison

As discussed in Section 3.2.4, the SWAT model output accessible to Tetra Tech cannot be used to compare existing loads for each HUC-12 to the Annex 4 translated targets. Instead, the estimated existing spring and annual TP loads for the TRW outlet were distributed to each of the 26 HUC-12 watersheds in the TRW using the drainage area ratio method (Appendix D, Section D-4.2). Estimated existing TP loads in all HUC-12 subwatersheds exceed the Annex 4 translated TP targets in every spring except the springs of 2012 and 2016, which is expected since the estimated existing loads for the TRW outlet exceed in every spring except the springs of 2012 and 2016. Similarly, estimated annual TP loads exceed in every HUC-12 subwatershed in WYs 2009, 2010, 2011, 2012, and 2014. In summary, many HUC-12 subwatersheds within the TRW frequently exceed the Annex 4 translated targets; please refer to Appendix D for additional information.

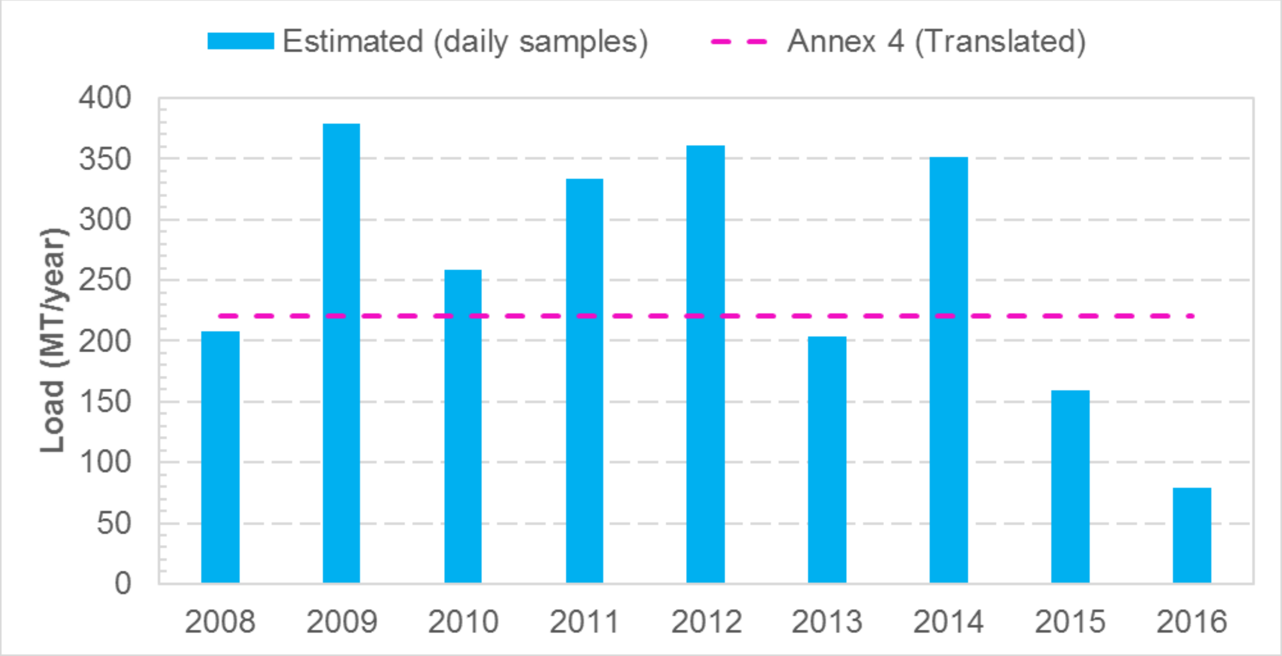

Figure 9. Estimated existing annual TP loads and the Annex 4 translated annual TP target at the TRW outlet.

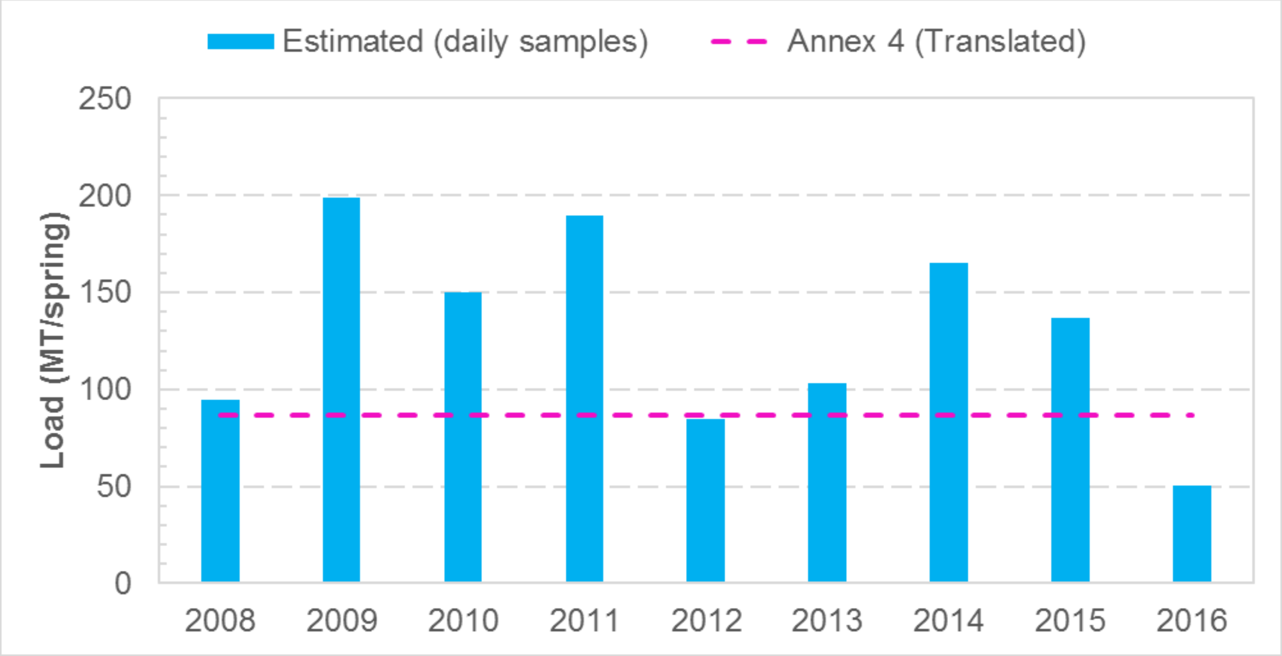

Figure 10. Estimated existing spring TP loads and the Annex 4 translated spring TP target at the TRW outlet.

# 4.0 ALLOCATION AND IMPLEMENTATION ISSUES

This section of the document addresses how the allocation and implementation phases of a TMDL project might relate to Annex 4.

## 4.1 ALLOCATION ISSUES

Unlike a TMDL, there is no regulatory requirement to develop the Annex 4 loads into wasteload allocations, load allocations, or a margin of safety. In general, however, any attempt to allocate the Annex 4 loads should be consistent with the approach used for TMDLs:

- The overall allocation between point source (PS) and nonpoint source (NPS) should reflect the magnitude of the source, where possible. For example, if most of the TP load is determined to be from NPS than most of the corresponding load reduction will also need to come from NPS.
- The allocation between PS and NPS should be based on an equitable allocation of pollution control responsibilities, if the allocation will achieve the necessary reductions. States should consider several factors including technical and programmatic feasibility, cost-effectiveness, relative source contributions, and the degree of certainty of implementation (akin to the “reasonable assurances” associated with TMDL allocations).
- Although an allocation for future growth is not required for either TMDLs or Annex 4, States should consider including future growth in Annex 4 allocations and document their decisions. The documentation should clearly explain to sources the implications of the growth allocation decision, especially if there is no allocation for growth.

States should also consider the potential implications of climate change and other future changes when implementing both TMDLs and Annex 4. Climate change may result in different weather patterns which in turn will result in different phosphorus loads and impacts within Lake Erie. There may also be future changes in management practices, such as the installation of even more drain tiles, or an increase in agricultural production to produce more food or ethanol.

## 4.2 IMPLEMENTATION ISSUES

The Work Group did not focus on implementation issues because there are already many ongoing efforts to address implementation of the Annex 4 targets. However, the Work Group offers the following general recommendations as Annex 4 implementation relates to TMDL implementation:

- Implementers of both TMDLs and Annex 4 should consult with each state’s domestic action plan, local watershed action plans, and state agency officials to obtain information about the highest priority best management practices (BMPs) and locations. There is consensus that nutrient management through the 4Rs (Right source, Right rate, Right time, Right place) is a high priority BMP, but a significant amount of research is ongoing regarding various other BMPs.
- Generally, the same types of BMPs that are needed to address the Annex 4 load reductions are needed to implement TMDLs. Since SRP is a key driver of the Lake Erie HAB problem, however, BMPs that address TP but not SRP should be given less priority. For example, grassed water ways are an effective means of reducing gully erosion and the associated TP loss but do little for SRP. Furthermore, recent studies suggest that some erosion control measures may increase SRP loads. For example, the increases in SRP loads between the 1990s and the 2010s has been attributed to, in part, phosphorus stratification in the soils associated with the adoption of no-till production in this region (Baker et.al. 2017).

- Because Annex 4 is focused on reducing far-field phosphorus loading to Lake Erie (and Maumee Bay), BMPs can be placed at any upstream location. For example, large wetland complexes along the lower Maumee River might be effective at reducing loads delivered to the bay and lake, even though they will not address upstream impairments that are the focus of TMDLs.
- Also, as previously mentioned, some subwatersheds important from an Annex 4 perspective are not the subject of TMDLs because their streams have not been listed as impaired for nutrients. These subwatersheds still need to be included for implementation to reach the Annex 4 goals.
- Although this methodology identifies an approach to establish Annex 4 translated targets for each of the 250+ HUC-12 subwatersheds in the MRB, it may be very difficult to implement BMPs at that level of precision. Instead, decision makers may wish to explore the development of an explicit prioritization approach (a path that the Work Group briefly discussed), or other alternatives, such as focusing on loads at the HUC-8 scale and using a free-market, trading approach to achieving the needed HUC-12 scale reductions, with point source permits (and potentially agricultural cost share funds) as the leverage. A trading framework could work well for Annex 4, since it is the total spring and annual load of TP and SRP that is of greatest concern for Lake Erie water quality issues. Some issues that often hamper other trading frameworks (e.g., avoidance of pollutant hot spots) will therefore not be as great a concern because the focus is on reducing the net loading to the lake.
- The Work Group identified a variety of information gaps that should be addressed. These include the following:
    - A lack of SRP data (e.g., within the SJRW).
    - No water quality standards for SRP and therefore no TMDLs developed for this pollutant.
    - Improved quality of site-specific information on issues that affect phosphorus loads within specific subwatersheds (e.g., manure application locations, livestock facilities, areas where riparian buffers affect loading).
    - Improvements within SWAT and potentially other models to address key factors governing TP and especially SRP loading in the Lake Erie basin, such as the impacts of reduced tillage agriculture, soil macropores, and extensive tiling.
    - New and simpler tools to estimate flow at ungaged locations.
- The Work Group also recommends that implementers continue to reach out and work with a variety of stakeholders, such as producers and landowners; nongovernmental organizations such as universities and conservation districts; private sector entities such as agricultural crop advisors; wastewater treatment facilities; and local governments.

# 5.0 RESULTS AND CONCLUSIONS

This section of the document summarizes some of the most important results from this project and provides some concluding thoughts and potential next steps.

## 5.1 SUMMARY OF RESULTS

The results of applying the methodology to the SJRW and TRW are summarized in Table 4 and important takeaways include the following:

- For the SJRW, the TMDL target TP loads are less than the Annex 4 TP targets and therefore would be protective of meeting the goals of Annex 4 in most years at most locations. The instances where the TMDL target TP loads are not protective of the Annex 4 TP targets occur in years when the spring or annual flow within each HUC-8 is greater than the average flow (water years 2002 through 2016) used to set the HUC-8 target.
- For the TRW, the TMDL target TP loads are always less than the Annex 4 translated TP targets and therefore are always protective of meeting the Annex 4 goals. The TRW TMDL target TP loads are more protective than the SJRW TMDL target loads because the TP concentrations used in Ohio to develop the hypothetical TMDLs (i.e., 0.08 mg/L to 0.17 mg/L) are significantly less than the TP concentration used in Indiana (0.30 mg/L).
- Estimating existing loads for comparison to the Annex 4 translated targets and TMDL target loads is another essential step that must be performed to prioritize implementation activities. The methodology explored this issue and provides recommendations for how to estimate existing loads given different quantities of data. The results from applying the methodology to the SJRW and TRW revealed the following:
    - Simulated existing spring and annual TP loads for the outlet of the SJRW (from a SWAT model) were always less than the Annex 4 translated TP targets. The SJRW therefore does not appear to be a priority watershed from an Annex 4 perspective for TP. However, implementation still needs to occur for the following reasons: (1) to meet the approved TMDLs; (2) because simulated existing TP loads from some HUC-12s within the SJRW sometimes exceed their Annex 4 translated TP targets; and (3) because there is still the potential that the existing SRP loads exceed the Annex 4 translated SRP targets.
    - An analysis of how existing SRP loads in the SJRW compare to the Annex 4 translated SRP targets at the HUC-8 and HUC-12 scales could not be performed because of a lack of available SRP monitoring data. It is the Work Group's understanding that USGS is now collecting SRP data at the Fort Wayne gage; this effort should continue. Additionally, the Work Group recommends that several sampling sites in the SJRW (e.g., Cedar Creek) begin collecting SRP data to allow for a better evaluation within the next few years.
    - In the TRW at Evansport (which only drains 72 percent of the TRW), estimated spring TP loads (from daily USGS sampling data) are slightly below the Annex 4 translated spring TP target. It is therefore very likely that the load at the HUC-8 outlet farther downstream exceeds the Annex 4 translated spring TP target because of the additional drainage of 215 square miles that includes a mix of agricultural and forested lands. Furthermore, the estimated spring SRP loads at Evansport are already above the Annex 4 translated spring SRP target and are likely even larger at the HUC-8 outlet. Therefore, the TRW should be considered a higher priority Annex 4 watershed for implementation efforts/activities than the SJRW.

Table 4. Summary of results for applying the methodology to evaluate hypothetical TMDLs in the SJRW and TRW

| Watershed | Location | Frequency that TMDL target load is less than Annex 4 translated target | | Comments |
|---|---|---|---|---|
| | | TP Spring | TP Annual | |
| SJRW[16] | HUC-8 Outlet | 45% (5 out of 11 years) | 80% (8 out of 10 years) | TP TMDL developed for the outlet of the SJRW |
| | HUC-12 Outlets | 67% (333 out of 495 HUC/year combinations) | 85% (383 out of 450 HUC/year combinations) | TP TMDLs developed for 8 out of 45 HUC-12s |
| TRW[17] | HUC-8 Outlet | 100% (15 out of 15 years) | 100% (15 out of 15 years) | No TP TMDL developed for the outlet of the TRW |
| | HUC-12 Outlets | 100% (390 out of 390 HUC/year combinations) | 100% (390 out of 390 HUC/year combinations) | TP TMDLs developed for segments in 7 out of 26 HUC-12s |

## 5.2 CONCLUSIONS

This section of the document provides some concluding thoughts on the reasons for the results, implications, and potential next steps

### 5.2.1 Absolute Annex 4 Targets and Variable TMDL Target Loads

Because the origins of the Annex 4 targets and TMDLs are different, the expression of the loads is also different. The Annex 4 targets are based on protecting water quality in Lake Erie and are set as absolute spring loads and absolute annual loads, regardless of flow or weather conditions. In contrast, TMDLs are based on meeting instream water quality standards and are developed using concentration-based targets multiplied by flow. Because flow varies by year, the allowable spring and annual load based on TMDLs also vary by year. As demonstrated for the SJRW TMDLs, this means that TMDLs are therefore protective of the Annex 4 in some years but not others (see Section 3.1.3).

TMDLs also vary by state because the concentrations used to develop them are not the same. The following bullets describe the concentration-based targets used by each state to develop TMDLs. Indiana, Michigan, and Ohio do not have numeric criteria for aquatic life use (ALU) impairments caused by nutrients. Each state uses different nutrient targets based upon different methodologies.

- The Michigan Department of Environmental Quality uses a site-specific approach to identify nutrient TMDL targets based on Michigan's narrative criteria. This methodology includes an evaluation of relevant data that describe the relationship between designated uses and nutrients. Michigan implements site-specific targets through National Pollutant Discharge Elimination System permits and TMDLs.

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[16] SJRW flow estimates are made using output from the SWAT model for the period 1/1/2004 to 12/31/2014.

[17] TRW flow estimates are made using data from USGS gages over the period 10/1/2001 to 9/30/2016.

- In Ohio, TMDL targets are selected on the basis of evaluating reference stream data published in a technical report titled *Association between Nutrients, Habitat, and the Aquatic Biota in Ohio Rivers and Streams* (Ohio EPA 1999). The document identifies ranges of concentrations for nitrogen and TP based on observed concentrations at all sampled ecoregional reference sites. Those reference stream concentrations were used as TMDL targets and are shown in Table 5. These targets were derived using grab samples from the biocriteria sampling period of June 15 to October 15. The targets were developed based on the relationship between median TP concentrations and fish and macroinvertebrate community health index scores but are typically implemented in TMDLs as daily not-to-exceed values.

Table 5. Ohio’s statewide-suggested TP targets (mg/L) for the protection of aquatic life

| Stream class | Watershed size ($mi^2$) | Beneficial use | | |
|---|---|---|---|---|
| | | EWH | WWH | MWH |
| Headwaters | < 20 | 0.05 | 0.08 | 0.34 |
| Wading | 20 - 200 | 0.05 | 0.10 | 0.28 |
| Small river | 200 - 1,000 | 0.10 | 0.17 | 0.25 |
| Large river | > 1,000 | 0.15 [a] | 0.30 | 0.32 |

*Source:* Ohio EPA 1999

*Notes:*

EWH = exceptional warmwater habitat; mg/L = milligrams per liter; MWH = modified warmwater habitat; WWH = warmwater habitat.

Statewide total phosphorus recommendations were generated by Ohio EPA (1999) with ANOVA analyses of statewide pooled data.

a. Assumes a nitrogen:phosphorus ratio that is greater than or equal to 10:1.

- In Indiana, the nutrient TMDL target is typically 0.30 mg/L TP. IDEM uses the TP target values, along with pH, dissolved oxygen, nitrate plus nitrite, and algal information, to determine ALU support for rivers and streams. Typically, if two or more of the targets are exceeded during the same sampling event, then the ALU is impaired and nutrients are considered a cause of impairment. TP TMDLs are then developed by applying the 0.30 mg/L target to identify a maximum daily load.

Additionally, because TMDLs are based on meeting daily concentration limits, it is not always easy to make direct comparisons to the Annex 4 translated targets, which are set to cumulative spring and annual loads. For example, the existing spring TP load for the outlet of the SJRW is less than the TMDL target spring TP load, implying that no reductions are needed. However, the TMDL report (IDEM 2017) does, in fact, recommended reductions that vary from 0 to 69 percent depending on flow zone because certain days exceed the daily TMDL TP concentration target.

### 5.2.2 Many Waterbodies Not Listed as Impaired for TP

TMDLs are typically developed only for waterbody segments that are not meeting states’ water quality standards. The assessment of stream segments in Indiana, Michigan, and Ohio[18] usually only consider conditions within the assessed waterbody and focus upon in-stream water quality standards. Far-field impacts upon Lake Erie are not considered when making listing decisions for the streams. Instead, each state typically assesses the biological condition of a stream or river segment to determine if the fish and macroinvertebrate communities meet

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[18] Assessment units in Ohio are subwatersheds delineated by a 12-digit hydrologic unit code, referred to as Watershed Assessment Units (WAUs). Ohio also designated Lake Erie Assessment Units (LEAUs) and Large River Assessment Units (LRAUs).

established biological criteria[19]. If the biological criteria are not met, the stream is considered impaired and then a cause of impairment is determined (e.g., siltation, habitat alterations, nutrients). Allowable loads of phosphorus are then only calculated when nutrients (and specifically phosphorus) are determined to be one of the primary causes of impairment.

Based on a preliminary review of the impairment status of streams in the MRB, it appears that many streams are not considered impaired for a cause of impairment that would require a TP TMDL. For example, TP TMDLs were only developed or are being developed for 10 of 45 HUC-12s in the SJRW and 7 of 26 HUC-12s in the TRW and the TRW TMDLs only address approximately 16 of the entire TRW drainage area. Additionally, most large river assessment units in Ohio meet their biocriteria and Ohio EPA (2014) believes that they are essentially conduits for upstream nutrient loads to be delivered downstream to Lake Erie. The following large river assessment units are in full attainment of their ALUs:

- Auglaize River from Ottawa River to mouth (04100007 90 01)
- Blanchard River from Dukes Run to mouth (04100008 90 01)
- Maumee River from Indiana-Ohio border to Tiffin (04100005 90 01)
- Tiffin River from Brush Creek to mouth (04100006 90 01)

### 5.2.3 No Waterbodies Listed as Impaired for SRP

Similarly, none of the three states have identified SRP targets to protect near-field biological conditions and therefore no SRP TMDLs have been developed within the MRB. This methodology explains how to derive Annex 4 spring and annual SRP load targets for each HUC-8 and HUC-12, but they cannot be compared to SRP TMDL target loads because the states are only developing TP TMDLs. It could be argued that SRP should be more of a focus than TP because increases in SRP have been more strongly linked to the worsening HAB problem (GLWQA 2015).

### 5.2.4 Seasonal Differences Between Annex 4 and TMDLs

As previously described, the impairment condition of streams within the Maumee River watershed is based on biological sampling that typically occurs between June 15 and October 15. This differs from the Annex 4 critical period, which is March 1 to July 31. Despite this difference, TMDL loads were found to be protective of Annex 4 loads in most situations.

Another similar consideration is that nutrient enrichment is frequently considered a low-flow phenomenon in streams, often closely linked to point sources. In these specific circumstances, stream TMDLs can result in allocations for specific critical conditions that do not address the total loading concerns of Annex 4. For example, the Ottawa River near Lima, Ohio has a TP TMDL that targets a low-flow critical condition. To the extent that these types of TMDLs only target low-flow sources of TP, they are less likely to achieve the total load reductions that are needed for Annex 4.

### 5.2.5 Potential Enhancements to Methodology

The Work Group considered factoring in the impacts of land use in setting the Annex 4 HUC-8 and HUC-12 targets but was unable to finalize an approach. Land use, including the impact of high concentrations of human and animal populations, could have a substantial impact on the loading potential from HUC12s, so future efforts

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[19] Michigan will also assess against other parameters such as dissolved oxygen and or excessive plant communities (based on narrative criteria) within the stream reach.

that capture these differences could refine this methodology to ensure that reasonable targets are set for each HUC-12 subwatershed.

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# APPENDIX A. FLOW AND LOAD ESTIMATION TECHNIQUES

## CONTENT

## FIGURES

## ACRONYMS/ABBREVIATIONS

| Acronyms/Abbreviations | Definition |
|---|---|
| NCWQR | National Center for Water Quality Research (Heidelberg University) |
| NWIS | National Water Information System |
| USGS | U.S. Geological Survey (U.S. Department of the Interior) |
| WRTDS | Weighted Regressions on Time, Discharge, and Season |

# A-1.0 FLOW

Many load estimation techniques require a daily time series of flow that is used to develop a relationship between load (or flux) and flow. The U.S. Geological Survey (USGS) maintains a national network of continuously recording streamflow gages and various entities have also developed hydrology models for watersheds across the nation; such data can be used to construct a daily time series at the location of interest (hereafter, *location*). If a daily time series of flow at the *location* is not available, then flow will need to be estimated. A time series of streamflow can be estimated through several techniques based upon the availability of streamflow data at the *location*, in the *watershed*, or in adjacent, hydrologically similar watersheds (Section A-2.3).

## A-1.1 FLOW DATA ACQUISITION

USGS is the most common source of publicly available flow data. However, other entities also collect streamflow data, including additional federal agencies, state agencies, and local government agencies.

### A-1.1.1 U.S. Geological Survey

USGS maintains the National Water Information System (NWIS; https://waterdata.usgs.gov/nwis) that reports flow and water quality data from 1.5 million locations across the United States (USGS 2017). “Nationally, USGS surface-water data includes more than 850,000 station years of time-series data that describe stream levels, streamflow (discharge), reservoir and lake levels, surface-water quality, and rainfall” (USGS 2017).

Several long-term USGS gages are in the Maumee River watershed. Gages on major rivers are summarized in Appendix B.

### A-1.1.2 Other Sources

Additional organizations maintain smaller networks of flow gages; most such networks are limited to a few locations and can be short-term gages. For example, Ohio EPA deploys short-term level loggers (and calculates flows) at key sites during their watershed studies.

## A-1.2 POTENTIAL FLOW ESTIMATION TECHNIQUES

Techniques to estimate streamflow statistics at ungaged sites across the United States are widely published (e.g., Bisese 1995; Glatfelter 1984; Hirsch 1979, 1982; Koltun 2003; Koltun and Whitehead 2002; Over et al. 2014). However, such techniques to estimate streamflow statistics (e.g., 25th percentile flow, mean annual flow, peak-flow at a 2-year recurrence interval) are not relevant here because daily flows need to be paired with phosphorus concentrations from grab samples.

The following three techniques were selected based upon their ease of use and ability to rely upon streamflow data published by USGS. Additional techniques are also available (e.g., rainfall-runoff model) but may be more difficult to use and require additional datasets. It should also be noted that none of these methods account for changes in climate or land use over time, which may be a key factor impacting Lake Erie loading issues into the future.

### A-1.2.1 Drainage Area Ratio

The drainage area ratio method can be used to estimate the flow at an ungaged site using the flow record at a gaged sited. The flow record at the gaged site is multiplied by the ratio of contributing areas to the ungaged site and the gaged site to calculate the flow record at the ungaged site. “The method is easy to use, requires little data, does not require any development, and, many times, is the only method available because regional statistics or precipitation-runoff models have not been developed” (Emerson et al. 2005, p.1).

When the drainage area ratio method is used, “great care needs to be taken in the selection of the” gaged site (Over et al. 2014, p. 14). This flow estimation technique assumes that the ratio of flows at an ungaged site and gaged site is the same as the ratio of drainage areas (Hirsch 1979) and that factors that control hydrology do not vary significantly spatially (i.e., the factors that control hydrology are spatially uniform). "This method is most commonly applied when the index gaging station is on the same stream as the ungaged site because the accuracy of the method depends on the proximity of the two, on similarities in drainage area and on other physical and climatic characteristics of their drainage basin" (Ries III and Friesz 2000, p. 14). The method does not account for regulation, point sources, and water withdrawals.

As the drainage area ratio approaches unity, the confidence in the method increases. The recommended ratio between ungaged location and gaged site is 50 to 150 percent for rural, unregulated streams in Ohio (Koltun 2003; Koltun and Whitehead 2003), Indiana (Glatfelter 1984), and other states (e.g., Virginia [Bisese 1995]). Ries III and Friesz (2000, p. 14) found that different ranges of ratios have been recommended in several studies but none of the studies "provided any scientific basis" for the use of their recommendations. Ries III and Friesz (2000, p. 25) conducted a study of drainage area ratios for Massachusetts streams and concluded that the appropriate range of ratios to apply the drainage area ratio method in Massachusetts was 30 to 150 percent.

### A-1.2.2 Record Extension through Regression

"One approach to developing a time series of streamflow ... is to extend an existing gage record in time by exploiting the interstation correlation between the station of interest and some nearby (long-term) base station" (Hirsch 1982, p. 1081). A regression can be developed with the independent variable as the gage with a longer period of record (i.e., the base station) and the dependent variable is the site with a limited streamflow record (i.e., the station of interest); this regression is then used to estimate streamflow at the site with a limited streamflow record (Nielsen 1999). The gage with a longer period of record must be selected as described by Nielsen (1999, p. 5):

> The long-term index station used in the record extension must satisfy several criteria, including that it be unregulated, have a portion of its period of record coincident with that at the short-term station, and have a substantially longer period of record than the short-term station. In addition, the concurrent daily streamflows for the short and long-term stations must plot linearly in log space and be highly correlated.

Several regression methods have been explored by USGS, including linear regression, logarithmic regression, regression plus independent noise, and maintenance of variance-extension (Hirsch 1982). In an evaluation of linear and log regressions, Hirsch (1979) found that both regressions resulted in flow time series with less variability than real flow time series (also known as variance reduction). Regressions tend to poorly fit very low flow data and overestimate such flows (Hirsch 1979, 1982). Maintenance of variance-extension and related techniques are often used in lieu of simple linear regressions that "will always underestimate the occurrence of extreme events" (Nielsen 1999, p. 4).

The streamflow record extension by regression techniques assumes that factors that control hydrology have not changed between the period-of-interest and the other time period with flow data (i.e., the factors that control hydrology are constant over time). "It is possible, however, that although a strong correlation exists between the two stations for the entire period of concurrent record, correlations might be weaker for individual months. If so, this could cause considerable error in the estimates of streamflow for those months" (Nielsen 1999, p. 5).

Generally, flow estimation for an ungaged site using gaged sites in the same watershed yields a flow record with greater confidence than using gaged sites in nearby, hydrologically similar watersheds. Similarly, gages sites closer in proximity to the ungaged sites will yield better flow estimates than gaged sites farther from the ungaged location.

### A-1.2.3 Interpolation

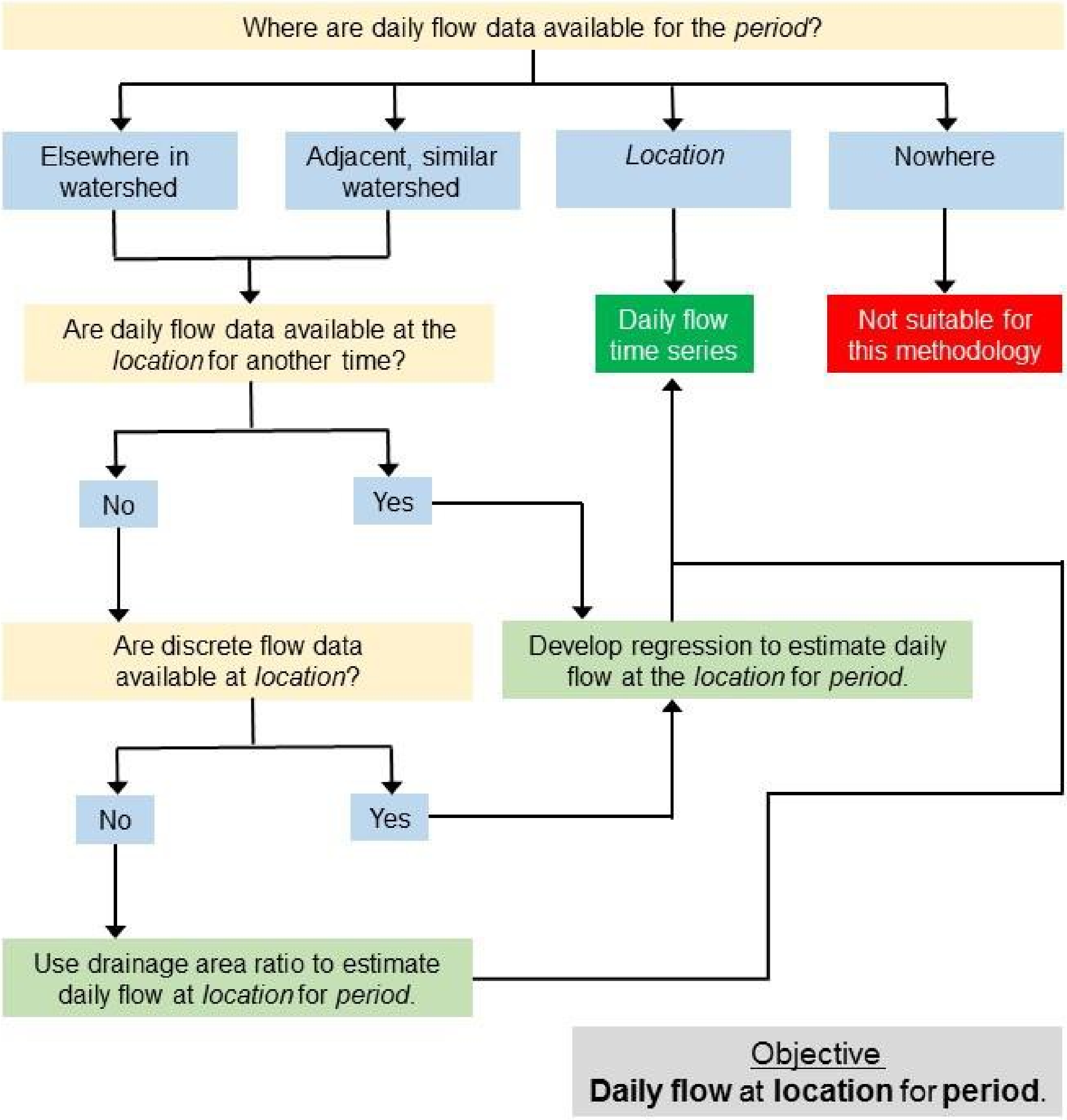
If a flow dataset is weekly or sub-weekly, but not daily, linear interpolation can be used to estimate the daily flow time series. Linear interpolation uses a simple, linear regression to predict the missing points between two known points. In this project's context, a linear regression would be used with weekly or sub-weekly data to estimate the missing days' flows.

Linear interpolation to fill data gaps assumes a linear relationship between two points. This assumption may be valid when the two points are close in time. As the time between observed data increases, the likelihood that the missing points between observed data are linear decreases. For the context of this project, gap-filling single days will yield a more accurate flow for the single day than gap-filling several days in a row because natural variation in flow is typically not linear. If significant precipitation occurred during the gap period and was not evident in the observed data before and after the gap, then the linear interpolation would be significantly inaccurate.

## A-1.3 SELECTION OF A FLOW ESTIMATION TECHNIQUE

To estimate annual or seasonal load, a daily flow record is often necessary. Daily flow records are reported for certain USGS gages and certain state agencies' monitoring sites. Daily flow is also the output of several watershed models (e.g., Soil and Watershed Assessment Tool, Load Simulation Program in C++). Note that daily simulated flow typically has considerably more uncertainty that continuously monitored flow.

The following subsections and Figure A-1 provide a methodology for developing a daily flow time series for the *location* for the time period-of-interest (hereafter, *period*) in each watershed.



*Notes*

Daily flow data are daily or sub-daily flow that is monitored or modeled. *Location* is the location-of-interest where load will be evaluated. *Period* is the time period-of-interest when load will be evaluated at the location.

A watershed is assumed to be spatially, hydrologically uniform.

An adjacent, similar watershed must be hydrologically similar to the watershed that contains the location.

Figure A-1. Flow chart for estimating a daily flow time series.

### A-1.3.1 What *daily flow* data are available for the *period*?

The first step is to identify flow datasets and determine what flow records has been developed for the location, elsewhere in the watershed, or in a nearby, hydrologically similar watershed. If only discrete flow datasets were identified, then a daily flow record cannot be estimated. Flow data will need to be monitored or simulated through hydrologic modeling.

- ***Daily flow* data for the *location* during the *period*:** If *daily flow* data are identified at the *location* for the *period*, then proceed to Section A-2.3 to develop phosphorus load estimates.
- ***Daily flow* data for elsewhere in the *watershed* during the *period*:** If *daily flow* data are identified for one or more sites within the *watershed* for the *period*, then a daily flow record can be estimated for the *location*. Proceed to Section A-1.3.2.
- ***Daily flow* data for in an adjacent, hydrologically similar watershed during the *period*:** If *daily flow* data are identified for one or more sites within an adjacent, hydrologically similar watershed for the *period*, then a daily flow record can be estimated for the *location*. Proceed to Section A-1.3.2.
- **No flow data for the *location*, elsewhere in the *watershed*, or in an adjacent hydrologically similar watershed:** If no *daily flow* data were identified, then a daily flow record cannot be estimated. Flow data will need to be monitored or simulated through hydrologic modeling.

### A-1.3.2 Are *daily flow* data available at the *location* for another time?

- **Yes:** If *daily flow* data are available for the *period* at one or more sites in the *watershed* or an adjacent, hydrologically similar watershed and *daily flow* data are available at the *location* for another time period, then a daily flow time series can be estimated for the *location* if the daily flow records at the other sites and *location* span a concurrent time period. A regression can be developed with the daily flow at the other sites as the independent variable and daily flow at the location as the dependent variable. Regressions can be linear or logarithmic (i.e., logarithmic of both variables). After the regression is developed for the other time period, it can be applied to the daily flow at the other sites for the *period* to estimate daily flow at the *location* for the *period*. Refer to Section A-1.2.2 for a discussion of the regression techniques to extend flow records.

  After developing the flow time series using the regression method, proceed to Section A-2.3 to develop phosphorus load estimates.
- **No:** If *daily flow* data are not available at the *location* for another time period that is concurrent with the period of record for the *daily flow* data for the other sites in the watershed, then proceed to Section A-1.3.3.

### A-1.3.3 Are discrete flow data available at the *location*?

- **Yes:** If *daily flow* data are available for the *period* at one or more sites in the watershed (upstream or downstream of the location of interest) and discrete flow data are available at the *location* (for the *period* or another time), then a daily flow record can be estimated for the *location* if the daily flow records at the other sites in the watershed and discrete flow data at the *location* span a concurrent time period. A regression can be developed with the daily flow at the other sites in the watershed as the independent variable and discrete flow at the location as the dependent variable. After the regression is developed, it can be applied to the daily flow at the other sites in the watershed for the period to estimate daily flow time series at the *location* for the *period*. Refer to Section A-1.2.2 for a discussion of the regression techniques to estimate flows.

  After developing the flow time series using the regression method, proceed to Section A-2.3 to develop phosphorus load estimates.

- **No:** When no daily or discrete flow data are available for the *location* but *daily flow* data for the *period* are available at another site in the *watershed* or a nearby, hydrologically similar watershed, the drainage area ratio method can be used to estimate flow at the ungaged location. The daily flow record is multiplied by the ratio of the drainage areas of the ungaged *location* and gaged site to estimate daily flow at the ungaged *location*. Refer to Section A-1.2.1 for a discussion of the drainage area ratio method.

  After developing the flow time series using the drainage area-ratio method, proceed to Section A-2.3 to develop phosphorus load estimates.

# A-2.0 PHOSPHORUS

Watershed phosphorus load is necessary to evaluate the watershed's impact upon Lake Erie and to assess the watershed with respect to the goals of Annex 4. While phosphorus load is published for some locations, often phosphorus loading must be estimated with limited phosphorus concentration data.

Load at a *location* can be estimated using available flow and pollutant concentration data. Several load estimation techniques rely upon the relationship between daily streamflow and pollutant load or flux. This section presents sources of phosphorus data (Section A-2.1), potential load estimation techniques (Section A-2.2), discusses the benefits of stratification (Section A-2.2.5), briefly compares these techniques (Section A-2.2.6), and presents procedures to estimate TP and SRP loads based upon available flow data (Section A-2.3).

## A-2.1 PHOSPHORUS DATA ACQUISITION

Phosphorus data can be obtained from several organizations. Many regulatory agencies collect water quality samples that are evaluated for phosphorus species[1]. Government agencies and private organizations have also developed water quality models that simulate phosphorus species.

Data reasonableness, representativeness, and resolution are important considerations during data acquisition and preliminary assessment. Additionally, certain entities have specific data credibility rules and policies that must be considered when obtained data.

### A-2.1.1 U.S. Geological Survey

USGS publishes water quality data, in addition to flow data, in NWIS[2] and the water quality portal[3]. Such data include grab samples collected at hundreds of sites across the nation and also includes more frequent sampling at USGS-maintained autosamplers at certain gages. USGS also published phosphorus loads calculated at certain gages.

### A-2.1.2 U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency publishes water quality data in the STOrage and RETrieval Database (STORET) and the water quality portal. These data are collected by numerous entities, including federal, state, and local government agencies.

### A-2.1.3 State Regulatory Agencies

State regulatory agencies sample state waters as part of various programs, including state total maximum daily load programs and state National Pollutant Discharge Elimination System programs. These data are often publicly available through agency websites or upon request. For example, in the St. Joseph River watershed, the Indiana Department of Environmental Management maintains a fixed station network that is often sampled monthly during non-frozen conditions.

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[1] Refer to Appendix C for a discussion of the various species of phosphorus.

[2] NWIS can be accessed at https://waterdata.usgs.gov/nwis.

[3] The water quality portal can be accessed at https://www.waterqualitydata.us/.

### A-2.1.4 Other Organizations

Local government agencies, colleges and universities, and private organizations also collect water quality samples. Data collected by government agencies is often publicly available. Citizen-led watershed groups also often collect water quality data. Such data may be collected by volunteers.

In the Lake Erie basin, the National Center for Water Quality Research (NCWQR) at Heidelberg University maintains a network of autosamplers on certain tributaries of Lake Erie. Data are collected at regular intervals and are also collected during precipitation events. NCWQR data are published online and were used as part of the basis for developing the Annex 4 targets.

## A-2.2 POTENTIAL LOAD ESTIMATION TECHNIQUES

Techniques to estimate loads using daily flow time series at sites across the United States are widely published (e.g., Baun 1982, Haggard et al. 2003, Preston et al. 1989, Richards 1998). Four general techniques are presented herein: averaging (Section A-2.2.1), numeric integration (Section A-2.2.2), ratio estimator (Section A-2.2.3), and regression (Section A-2.2.4). All four of these techniques can be improved by stratification, which is discussed in Section A-2.2.5.

As with the streamflow estimation techniques, the following four techniques were selected based upon their ease of use. Additional techniques are also available (e.g., GCLAS[4]) but may be more difficult to use and require additional datasets or expertise.

### A-2.2.1 Averaging

Various averaging techniques use observed concentration and flow data to estimate loads by averaging the concentration or flow data. Richards (1998, p. 29) describes the averaging approach as follows:

> The simplest approach involves multiplying the average concentration for some period of time by the mean daily flow for each day in the time period to obtain a succession of estimated daily (unit loads). Another approach involves multiplying the average observed concentration by the average flow based on all days of the years to obtain an “average” daily load, which is then converted to the total load.

Richards (1998, p. 29) found that “[g]enerally, the averaging approaches tend to be biased if concentration is correlated with flow: the calculated load is too low if the correlation is positive and too high if the correlation is negative.” The bias increases as the averaging period increases (Tennakoon et al nd). For example, Richards (1998, p. 34) declared that an annual load derived from four quarterly average loads will have more bias than an annual load estimated from 12 monthly average loads.

### A-2.2.2 Numeric Integration

The numeric integration technique sums the following quantity across a specified period (e.g., season, year): concentration multiplied by flow multiplied by time interval between sampling events. The time interval between sample events may be different. This technique requires that all major runoff events be captured and “is only satisfactory if the sampling frequency is high - often on the order of 100 samples per year or more” (U.S. EPA 2013, p. 9).

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[4] The Graphical Constituent Loading Analysis System (GCLAS) estimates daily loads using daily time series of concentration and flow. “GCLAS computes loads as a function of an equal-interval streamflow time series and an equal- or unequal-interval time series of constituent concentrations” (Koltun et al. 2006, p. 1). GCLAS incorporates interactive, visual assessments that are subjective. Anecdotal information indicates that USGS vets GCLAS results with multiple senior hydrologists.

The numeric integration technique “assumes that sampling during high flow periods is frequent enough that the sampled fluxes (concentrations and flows) closely match the continuous pattern of the actual fluxes, and in particular that the peak flux for each storm is not too badly underestimated” (Richards 1998, p. 37).

### A-2.2.3 Ratio Estimator

Ratio estimator techniques use observed concentration and daily flow to estimate loads by calculating observed loads, weighting them by their relative flow, and then converting to a load of the specified period (e.g., annual, seasonal). Richards (1998, p. 29) described ratio estimators as follows:

> Ratio estimators determine the average daily load for the days with concentration observations, adjust it proportionally by reference to some parameter which is more thoroughly sampled (ideally each day), and then calculate the total load by multiplying the adjusted daily load by 365.

“Ratio estimators assume that there is a positive linear relationship between dependent and independent variables which passes through the origin” (Richards 1998, p. 58). In the context of this report, the method assumes a positive linear relationship between phosphorus concentration (dependent variable) and daily flow (independent variable).

A common ratio estimator used to estimate pollutant loads is the Beale Ratio Estimator (U.S. EPA 2013). Walker (1999, p. 2-7) describes it as follows: “The factor was developed by Beale (1962) and applied in a load estimation method developed by the International Join Commission (IJC) (1977), as described by Bodo and Unny (1983, 1984).” The Beale Ratio Estimator is included in several computer packages including Method 3 of FLUX (Walker 1999) and Auto-Beale. U.S. EPA (2011, p. 11) describes FLUX as follows:

FLUX is an interactive program designed to estimate the loadings of nutrients or other water quality components passing a tributary sampling station over a given period of time. Data requirements include (a) grab-sample nutrient concentrations, typically measured at a weekly to monthly frequency for a period of at least 1 year, (b) corresponding flow measurements (instantaneous or daily mean values), and (c) a complete flow record (mean daily flows) for the period of interest. Using six calculation techniques, FLUX maps the flow/concentration relationship developed from the sample record onto the entire flow record to calculate total mass discharge and associated error statistics. An option to stratify the data into groups based upon flow, date, and/or season is also included.

### A-2.2.4 Regression

A regression is a statistical relationship between a dependent variable and one or more independent variables. Regressions can be used to predict the value of a dependent variable when the value(s) of the independent variable(s) is known. In the context of this report, a regression can be developed with the independent variable as daily flow and the dependent variable as phosphorus concentration or load. Thus, the relationship between daily flow and phosphorus concentration is used to estimate missing daily concentrations (Haggard et al. 2003, p. 188).

Haggard et al. (2003 p. 191) found that the “importance of storm events in nutrient transport and annual loads is substantial in streams and rivers.” Richards (1998) also emphasizes the need to capture storm events since they contribute considerable loads. Focusing upon storm events is also a key issue for this report because the Annex 4 targets focus on the spring period (March 1 through July 31) that includes snowmelt, spring rain storms, and higher flows conditions (relative to drier conditions and low flows during the late summer and early fall).

Regressions of environmental parameters are often log-transformed because the environmental parameters are log-normally distributed (Richards 1998). Loads estimated by regressions in logarithmic space are not useful until retransformed into real space. Retransformation bias is a common problem with log-regressions (Cohn et al. 1989, Richards 1998). Cohn et al. (1989, p. 941) found that retransformation bias “may lead to underestimation of constituent loads by as much as 50 [percent].”

Richards (nd, p. 34) found that "regression approaches can perform well if the relationship between flow and concentration is sufficiently well-defined, linear throughout a range of flows, and constant throughout the year." The regression method assumes a strong, positive relationship between daily flow and phosphorus concentration. Furthermore, the factors that control the relationship between daily flow and phosphorus concentration are assumed to have not changed between the period and the other time period with flow data (i.e., the relationship between flow and phosphorus is constant over time).

Several regression techniques have been developed:

- FLUX (Walker 1999; methods 4, 5, and 6)
- Loads Tool (Tennakoon et al. nd)
- LOADEST (Runkel et al. 2004)
- Weighted Regressions on Time, Discharge, and Season (WRTDS) (Hirsch et al. 2010)

Computer programs such as FLUX and LOADEST allow a user to either select a specific regression equation or allow the program to select the regression model with the best fit. The selection of regression equation is important because the load results for the same calibration dataset (e.g., observed concentrations and flows) can yield very different load estimates between regression equations.

An evaluation of regression equations in LOADEST using the same calibration dataset for the SJRW yielded total spring loads that varied between 5 and 22 percent. This evaluation is presented in Appendix G.

FLUX and LOADEST are the most frequently cited computer programs used to estimate pollutant loads using regression techniques. IDEM is presently using a version[5] of LOADEST to support the development of Indiana's domestic action plan.

"LOAD ESTimator (LOADEST) is a FORTRAN program for estimating constituent loads in streams and rivers" (Runkel et al. 2004, p. 1). It has 11 pre-defined regression equations that include variables for streamflow and time; a user may manually select one of the regressions, allow LOADEST to select the best of 9 of the pre-defined regression equations, or may input the user's own regression equation; Appendix A presents a preliminary evaluation of the differences in results for the various regression models. The coefficients are calculated using three methods that correct for retransformation bias:

- Maximum Likelihood Estimations
- Adjusted Maximum Likelihood Estimations
- Least Absolute Deviation

Maximum Likelihood Estimations and Adjusted Maximum Likelihood Estimations assume regression residuals are normally distributed with constant variance, whereas Least Absolute Deviation does not. LOADEST uses Adjusted Maximum Likelihood Estimations to develop 95 percent confidence intervals.

The goal of the WRTDS approach is to increase the amount of information that can be extracted from rich water-quality datasets. The method is formulated to allow for maximum flexibility in representations of the long-term trend, seasonal components, and discharge-related components of the behavior of the water-quality variable of interest. The method employs the use of weighted regressions of concentrations on time, discharge, and season. The WRTDS model considers concentration to be a product of four components and it simultaneously decomposes the record into these four components: trend, seasonality, discharge, and a random component. WRTDS is designed to be used on datasets with the following characteristics:

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[5] *Web-based Load Calculation using LOADEST*. v. 2012. https://engineering.purdue.edu/mapserve/LOADEST/.

- The number of samples collected at the sampling site is more than 200.
- The period of sample collection is at least 20 years.
- There exists a complete record of daily discharge values for the site over the entire period being analyzed.
- All sample analyses are above the laboratory limit of detection (no ‘‘less than values’’).
- The samples should be representative of the entire cross-section of the river.
- At the sampling point, the river should not be so ‘‘flashy’’ that the discharge at the time of sampling is likely to be vastly different from the daily average discharge.

### A-2.2.5 Stratification

Several load estimation techniques can be improved by stratification, which is the division of a dataset into separate subpopulations for analysis. Baun (1982, p. 4) describes stratification as follows:

> The purpose of stratification is to gain a better knowledge of a population by grouping it into subpopulations, or strata, of similar characteristics. By examining subpopulations as a unit, a better estimate of the population as a whole can be made. ... Division of a population into strata is done in a way that will minimize the concentration variation within each stratum while maximizing the variation between strata.

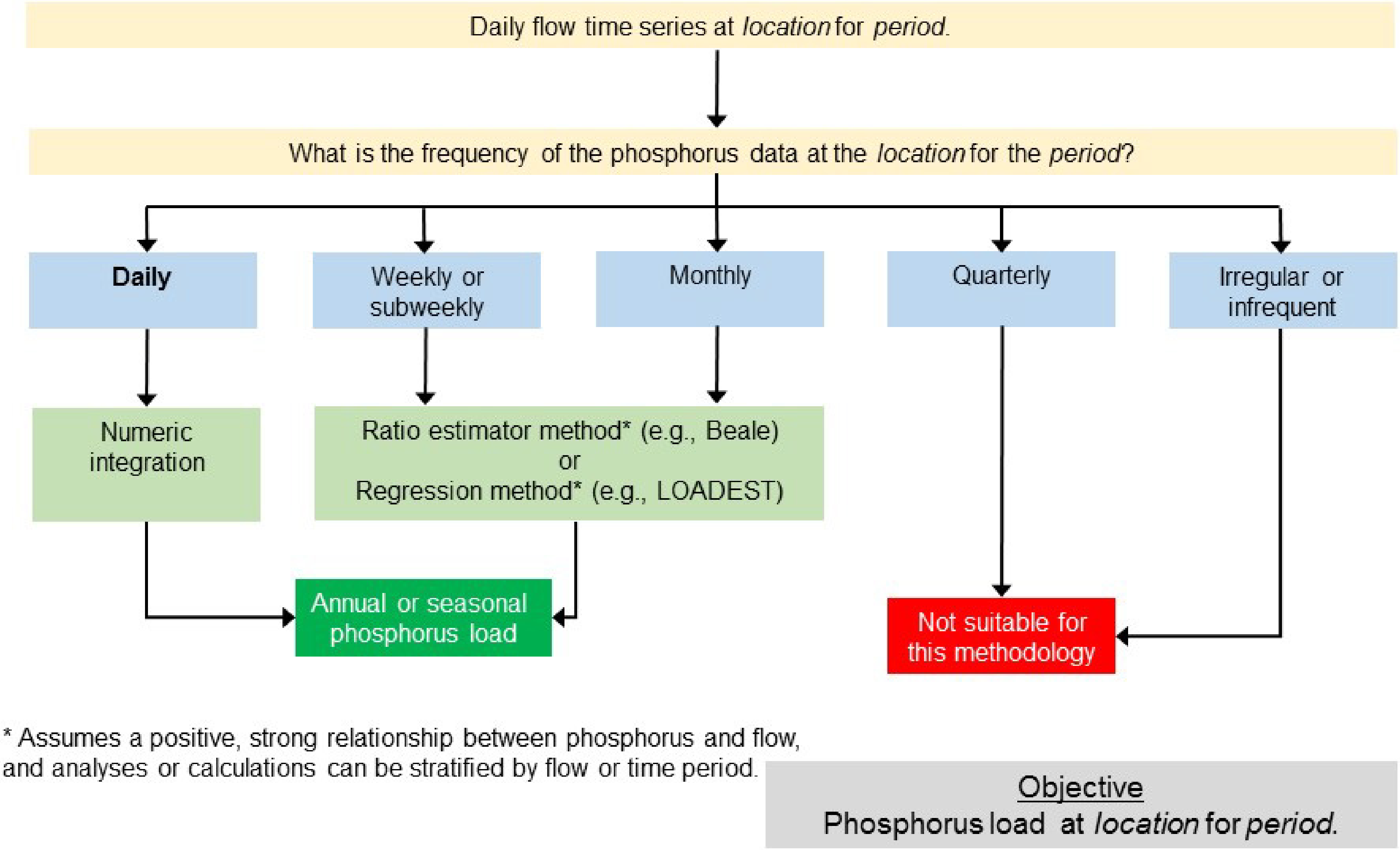
With regards to water quality data, the stratification could be by season (e.g., summer), time range (with different responses after a given date), or flow condition (e.g., high and flow ranges). Preston et al. (1992) found that that load estimation error (for averaging, ratio estimator, and regression techniques) increased as flow variability increased. A stratification by flow condition could be used to decrease load estimation error. In the case of a regression estimation techniques, separate regressions would be developed for each stratum. Several studies found that the Beale Ratio Estimator technique was improved considerably using stratification (Preston et al., 1989, 1992, Richards 1998).

### A-2.2.6 Comparison of Load Estimation Techniques

Numeric integration (also known as mass accumulation) is the most accurate approach to estimate loads “if sufficient data are collected to describe the changes in water quality,” which requires high-frequency sampling that includes storm events (Haggard et al. 2003, p. 187). In an evaluation of techniques using averaging, regressions, and ratios, Preston et al. (1989, p. 1388) found that no single estimation technique “was clearly superior for all test cases” and reported that “[r]egression estimators can provide the lowest estimate error when relationships between flow and concentration are strong and consistent.” In a similar evaluation of averaging, ratio estimator, and regression techniques using rivers and streams in the Lake Erie basin to study the effects of flow variability on load estimation techniques, Preston et al. (1992, p. 414) also found that no single technique was best under all conditions. Richards (1998, p. 34) found that “ratio approaches performed better than regression approaches, and both performed better than averaging approaches.” Preston et al. (1989 p. 1388) also concluded that ratio estimators were better than regression techniques depending on the “strength, type, and consistency of the flow-concentration relationship.” Generally, averaging, ratio estimator, and regression techniques were improved by including high flow phosphorus sampling and stratifying by flow condition (Haggard et al. 2003, Preston et al. 1989, 1992, Richards 1998).

## A-2.3 SELECTION OF A LOAD ESTIMATION TECHNIQUE

To estimate annual or seasonal load, flow data are necessary (refer back to Section A-1.3 for discussion of flow estimation). The following subsections and Figure A-2 provide a methodology for developing an annual or seasonal loads for the *location* for the *period* in a given watershed.



* Assumes a positive, strong relationship between phosphorus and flow, and analyses or calculations can be stratified by flow or time period.

Figure A-2. Flow chart for estimating an annual or seasonal phosphorus load.

### A-2.3.1 Flow Data

The first step is to identify phosphorus datasets and determine what phosphorus records has been developed for the *location.*[6] The load estimation also requires flow data. The phosphorus load estimation technique is dependent upon the frequency and representativeness of the flow data and the relationship of phosphorus to flow. For example, few phosphorous samples that are collected across all flow conditions, including many high-flow samples, can yield better load estimates than more frequent phosphorus samples collected under only certain flow conditions (e.g., only summer low-flows).

If a daily flow time series at the *location* for the *period* was developed following the methodology presented in Section A-1.3, then proceed to Section A-2.3.2. If only discrete flow data for the location during the period are available, then a daily phosphorus record cannot be estimated. Flow data will need to be monitored or simulated through hydrologic modeling.

### A-2.3.2 What is the frequency of the phosphorus data at the *location* for the *period*?

- **Daily:** If phosphorus data are daily[7], then daily phosphorus loads should be calculated using the daily phosphorus concentrations and daily flow data. The daily loads can then be summed annually or seasonally to determine the annual or seasonal load. Refer to Section A-2.2.2 for a discussion of numeric integration.
- **Weekly or sub-weekly:** If phosphorus data are weekly or sub-weekly, then phosphorus loads should be estimated using a ratio estimator (e.g., Beale ratio estimator) or a regression technique (e.g. LOADEST). The ultimate selection of a load estimation technique will depend upon the phosphorus-flow relationship. Refer to Section A-2.2.3 for a discussion of using ratio estimators to estimate loads and to Section A-2.2.4 for a discussion of using regressions to estimate loads.
- **Monthly:** If phosphorus data are monthly, then phosphorus loads should be estimated using a ratio estimator (e.g., Beale ratio estimator) or a regression technique (e.g., LOADEST). The ultimate selection of a load estimation technique will depend upon the phosphorus-flow relationship. Refer to Section A-2.2.3 for a discussion of using ratio estimators to estimate loads and to Section A-2.2.4 for a discussion of using regressions to estimate loads.
- **Quarterly:** If phosphorus data are quarterly, then a daily phosphorus record cannot be estimated. Phosphorus data will need to be monitored or simulated through water quality modeling or other approaches (see Section A-2.4).
- **Irregular or infrequent:** If phosphorus data were collected on an irregular schedule or were collected infrequently, then a daily phosphorus record cannot be estimated. Phosphorus data will need to be monitored or simulated through water quality modeling or other approaches (see Section A-2.4).

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[6] If no phosphorus concentration data were identified at the *location*, then annual or seasonal phosphorus load cannot be estimated. Phosphorus data will need to be monitored or simulated through water quality modeling.

[7] If sub-daily phosphorus concentration data are available, a daily concentration can be calculated by averaging sub-daily concentrations. If corresponding sub-daily flow data are available, sub-daily loads could be calculated and summed to determine daily loads.

## A-2.4 MODELING AND OTHER APPROACHES

A number of Soil and Waters Assessment Tool (SWAT) models have been developed for the Maumee and tributary watersheds and are another potential source of estimating current HUC-10 and HUC-12 loads. For example, Scavia et al. (2016) used a multi-model and ensemble modeling approach to evaluate which portions of the Maumee River watershed contribute the highest phosphorus loads, and the potential for reducing those loads via various implementation options. Models integrate the distribution of land use types, management practices, soil characteristics, slopes, and other factors. A well-calibrated model thus provides an estimate of the relative magnitude of phosphorus loading as a function of these risk factors. Models have many other advantages, including the ability to predict future changes in loads as a result of land use changes, climate changes, or the adoption of best management practices (BMPs).

Modeling efforts in the Maumee River basin should continue to focus on incorporating site-specific information (e.g., manure application locations, livestock facilities, areas where riparian buffers affect loading) that is critical to the accurate estimation of nutrient loads but is sometimes obscured when using assumptions based on county-wide data. There also needs to be a continued emphasis on improving the ability of models to simulate some of the key factors governing TP and especially SRP loading in the Lake Erie basin, such as the impacts of reduced tillage agriculture, soil macropores, and extensive tiling.

Another approach to estimating existing HUC-12 subwatershed loads is to start with estimates of observed loads at stations with robust flow and water quality and extrapolate those to elsewhere. The extrapolations can be performed relatively simply (e.g., apportion to upstream subwatersheds based on drainage area) or via added complexity (e.g., use of multiple locations with observed loads or factoring in watershed characteristics such as land use, soil types, or extent of key nutrient sources such as livestock). There are already various ongoing efforts along these lines, such as the *Western Lake Erie Basin Special Study* being conducted by NRCS. Continuing research needs to be conducted to see which of these approaches works best.

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# APPENDIX B. DEVELOPMENT OF HUC-8 FLOW ESTIMATES

## TABLES

## FIGURES

## ACRONYMS/ABBREVIATIONS

| Acronyms/Abbreviations | Definition |
|---|---|
| FWMC | flow weighted mean concentration |
| HUC | hydrologic unit code |
| SRP | soluble reactive phosphorus |
| TP | total phosphorus |
| USGS | U.S. Geological Survey (U.S. Department of the Interior) |
| WY | water year |

| Unit of measure | Definition |
|---|---|
| ac-ft | acre-feet |
| cfs | cubic feet per second |
| mg/L | milligrams per liter |
| MT | metric ton (1,000 kilograms) |
| sq. mi. | square mile |

# B-1.0 DEVELOPMENT OF HUC-8 WATERSHED FLOWS

To determine total phosphorus (TP) and soluble reactive phosphorus (SRP) targets for the watersheds delineated by eight-digit hydrologic unit codes (HUC-8) that are tributary to the Maumee River at Waterville, daily flow time series were needed to calculate loads and evaluate methods. This section of Appendix B presents the development of flow time series for each HUC-8 watershed.

For each of the six HUC-8 watersheds, flow data (in cubic feet per second [cfs]) were obtained from the U.S. Geological Survey's (USGS) National Water Information System. Flow estimation techniques were needed to (1) estimate flows during temporal data gaps at certain gages and (2) to estimate flows at HUC-8 watershed outlets because gages are situated upstream of the watershed outlets. The estimation techniques for each HUC-8 watershed are presented in the following subsections and summarized in Table B-1. The total spring and annual flows for each HUC-8 watershed are presented in Section B-2.0. Refer to Appendix B for a summary of available flow data in the Maumee River watershed and refer to Appendix A for a discussion of flow estimation techniques.

Table B-1. Flow estimation techniques for the HUC-8 watersheds

| HUC-8 | HUC-8 name | Area (sq. mi.) | Estimation techniques |
|---|---|---|---|
| 04100003 | St. Joseph | 1,094 | Record extension via regression<br>Extrapolation via drainage area ratio |
| 04100004 | St. Mary's | 793 | Extrapolation via drainage area ratio |
| 04100005 | Upper Maumee | 387 | Record extension via regression<br>Flow distribution via drainage area ratio |
| 04100006 | Tiffin | 778 | Record extension via regression<br>Flow distribution via drainage area ratio |
| 04100007 | Auglaize | 1,666 | Record extension via regression<br>Flow distribution via drainage area ratio |
| 04100008 | Blanchard | 772 | Record extension via regression<br>Extrapolation via drainage area ratio |
| 04100009 | Lower Maumee [a] | 840 [a] | Difference between gages<br>Flow distribution via drainage area ratio |

*Note a:* Portion of the Lower Maumee watershed upstream of the USGS gage on the Maumee River at Waterville (04183500).

## B-1.1 ST. JOSEPH (HUC 04100003)

Flow at the outlet of the St. Joseph River watershed was estimated through regression and drainage area ratio techniques. USGS maintains gages on the St. Joseph River near Fort Wayne, Indiana (04180500; 1,060 square miles [sq. mi.]) and at Newville, Indiana (04178000; 610 sq. mi.). The gage near Fort Wayne reported daily average flow data from October 1, 2001 through August 7, 2016, while the gage at Newville reported daily average flow data for water years (WY) 2002 through 2016.

A regression (Figure B-1) was developed to estimate daily average flows at the gage near Fort Wayne for August 8th through September 30th of WY 2016.

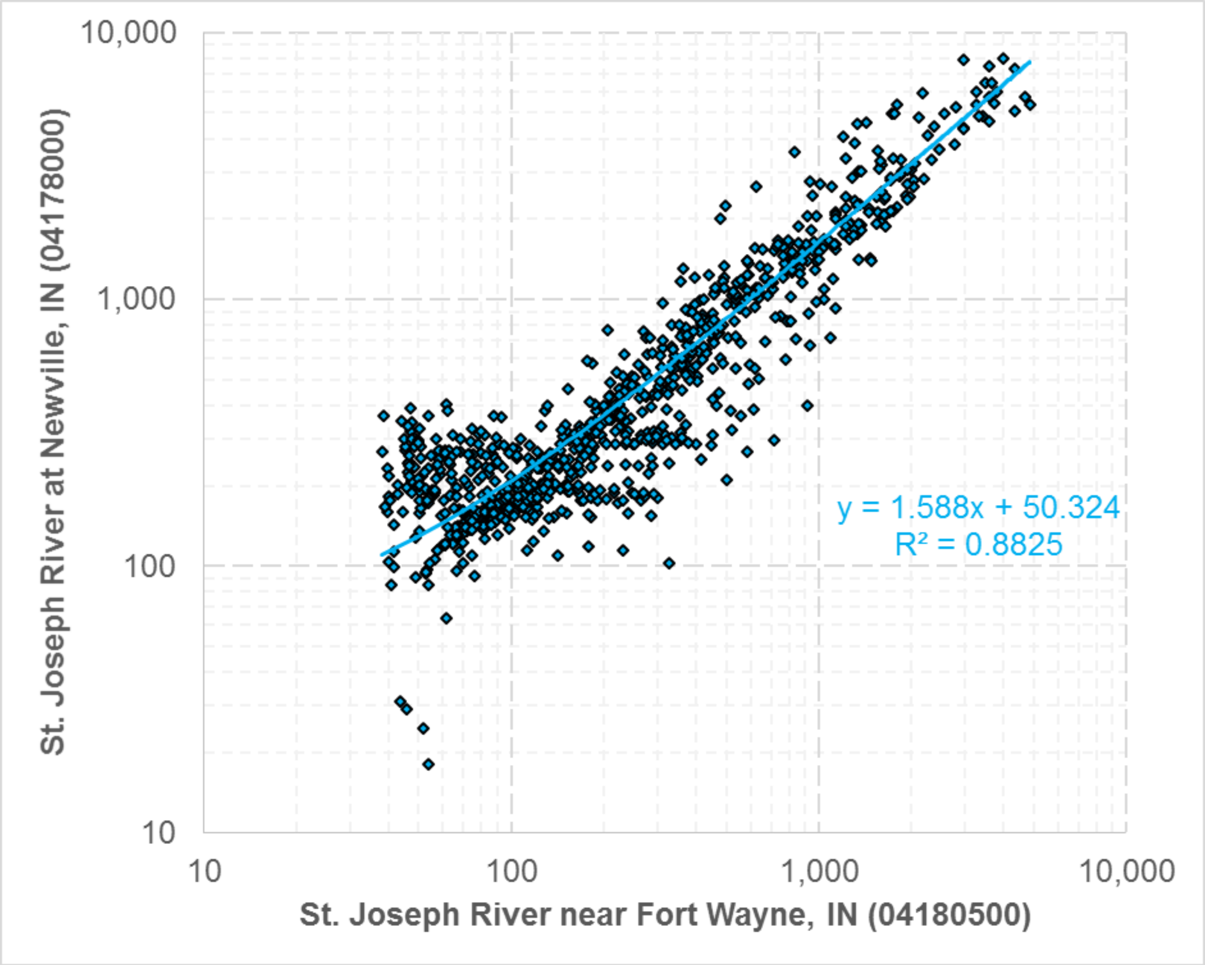

Figure B-1. Regression of flow (cfs) for two USGS gages for the St. Joseph River.

The St. Joseph River at the mouth is 1,094 sq. mi. and the drainage to the gage near Fort Wayne is 1,060 sq. mi. The ratio of drainage areas was used to extrapolate flow from the gage to the HUC-8 watershed outlet.

## B-1.2 ST. MARY’S (HUC 04100004)

Flow at the outlet of the St. Mary’s River watershed was estimated through the drainage area ratio technique. USGS maintains a gage on the St. Mary’s River near Fort Wayne, Indiana (04182000; 762 sq. mi.) The St. Mary’s River at the mouth is 793 sq. mi. The ratio of drainage areas was used to extrapolate flow from the gage to the HUC-8 watershed outlet.

## B-1.3 UPPER MAUMEE (HUC 04100005)

Flow at the outlet of the Upper Maumee River watershed was estimated by record extension through regression and flow distribution by drainage area ratio. USGS maintains gages on the Maumee River at New Haven, Indiana (04183000; 1,967 sq. mi.), at Antwerp, Ohio (04183500; 2,129 sq. mi.), and near Defiance (04192500; 5,545 sq. mi.). The gages at New Haven and near Defiance reported daily average flow data for WY 2002 through 2016, while the gage at Antwerp reported daily average flow data from March 2, 2014 through WY 2016.

Regressions were developed to estimate daily average flows at Antwerp for WY 2002 through March 1, 2014. The regression using the gage at New Haven ($R^2$ = 0.98; Figure B-2) was deemed better than the regression using the gage near Defiance ($R^2$ = 0.93).

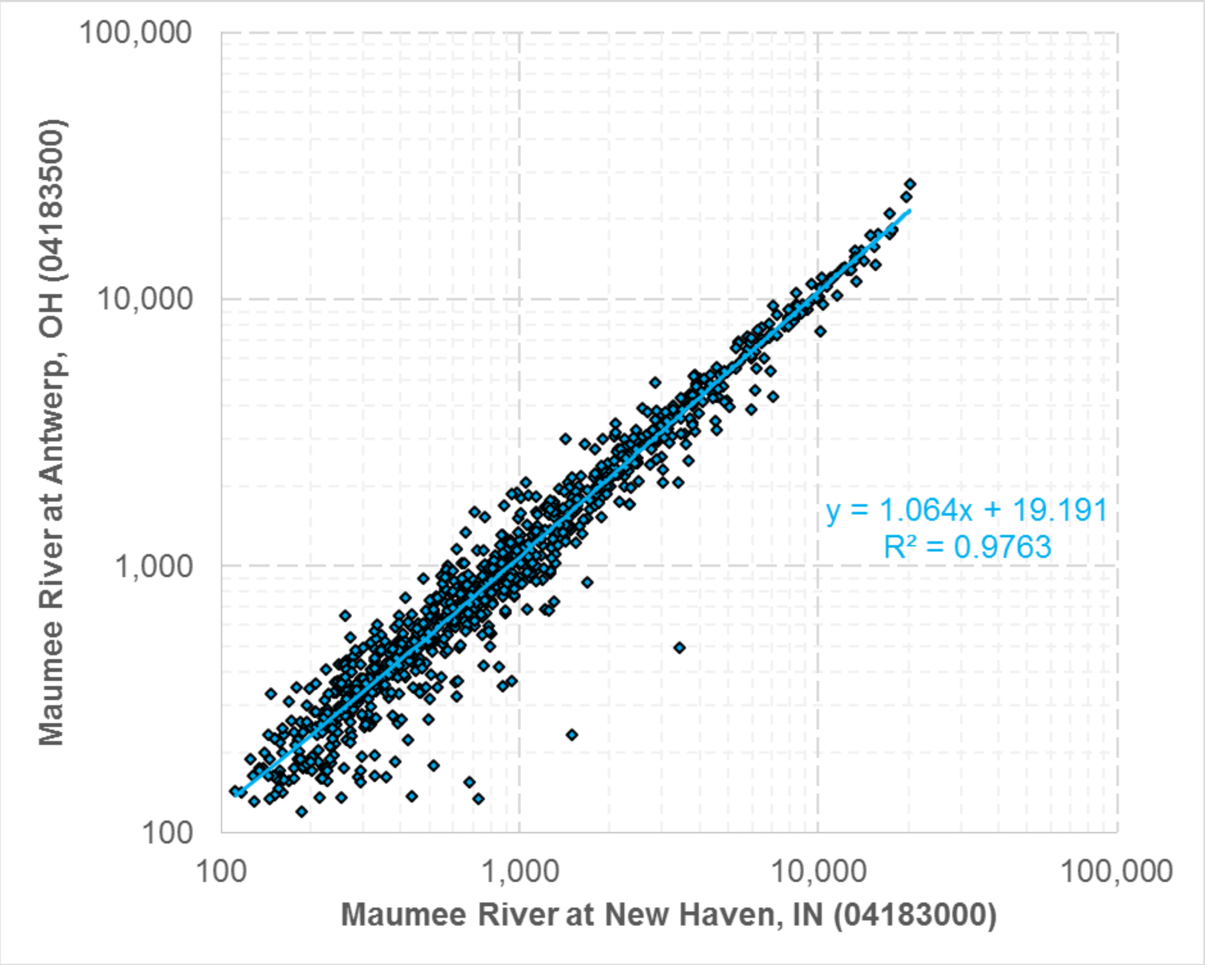

Figure B-2. Regression of flow (cfs) for two USGS gages on the Upper Maumee River.

The Upper Maumee River at the HUC-8 watershed outlet is 2,274 sq. mi. and the drainage to the gage at Antwerp is 2,129 sq. mi. Flow for the 145 sq. mi. below the gage at Antwerp was estimated using the gage near Defiance. Flows for the Maumee River at Antwerp, Tiffin River near Evansport (Section C-1.4), and Auglaize River near Defiance (Section C-1.6) watersheds were summed and subtracted from flows measured in the Maumee River near Defiance. The differential was then distributed to the Upper Maumee River, Tiffin River, and Auglaize River watersheds (and a small portion of the Lower Maumee River watershed upstream of Waterville) via drainage area ratio. For example, in the spring of 2002, the differential was 7,992 acre-feet (ac-ft) and 2,166 ac-ft were distributed to the Upper Maumee River watershed: 7,992 ac-ft * (145 sq. mi. / 535 sq. mi.) = 2,166 ac-ft.

## B-1.4 TIFFIN (HUC 04100006)

Flow at the outlet of the Tiffin River watershed was estimated by record extension through regression and flow distribution by drainage area ratio. USGS maintains gages on the Tiffin River near Evansport, Ohio (04185318; 563 sq. mi.), Tiffin River at Stryker, Ohio (04185000; 410 sq. mi.), and the Maumee River near Defiance, Ohio (04192500; 5,545 sq. mi.). The gage on the Tiffin River near Evansport reported daily average flow data for WY 2014 through 2016, while the gage on the Tiffin River at Stryker reported daily average flow data for WY 2002 through 2016.

A regression (Figure B-3) was developed to estimate daily average flows at the gage on the Tiffin River near Evansport for WY 2002 through 2013.

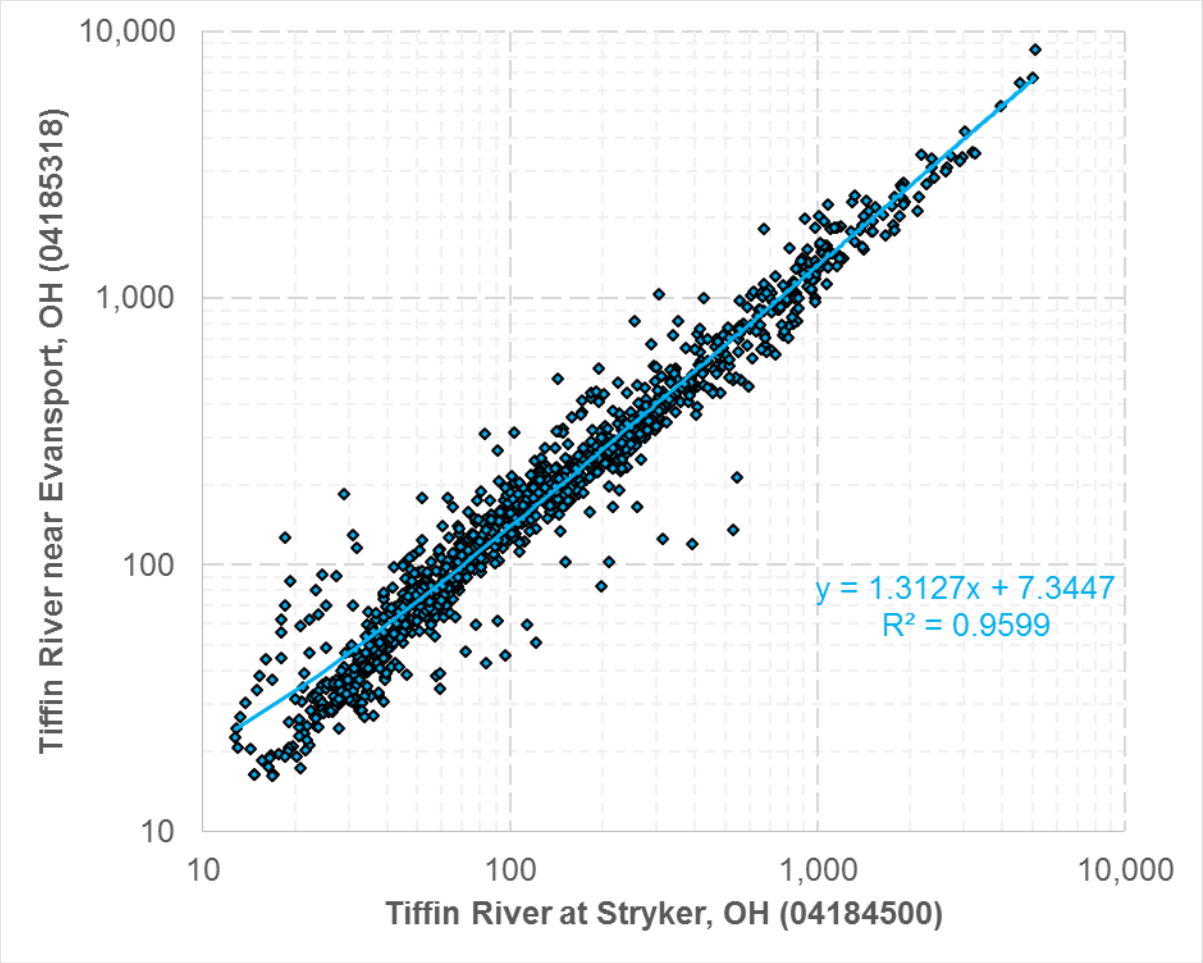

Figure B-3. Regression of flow (cfs) for two USGS gages on the Tiffin River.

The Tiffin River at the mouth is 778 sq. mi. and the drainage to the gage near Evansport is 563 sq. mi. Flow for the 215 sq. mi. below the gage on the Tiffin River near Evansport was estimated using the gage on the Maumee near Defiance. Flows for the Maumee River at Antwerp (Section C-1.3), Tiffin River near Evansport, and Auglaize River near Defiance (Section C-1.6) watersheds were summed and subtracted from flows measured in the Maumee River near Defiance. The differential was then distributed to the Upper Maumee River, Tiffin River, and Auglaize River watersheds (and a small portion of the Lower Maumee River watershed upstream of Waterville) via drainage area ratio. For example, in the spring of 2002, the differential was 7,992 ac-ft and 3,212 ac-ft were distributed to the Tiffin River watershed: 7,992 ac-ft * (215 sq. mi. / 535 sq. mi.) = 3,212 ac-ft.

## B-1.5 BLANCHARD (HUC 04100007)

Flow at the outlet of the Blanchard River watershed was estimated by record extension through regression and by drainage area ratio. USGS maintains gages on the Blanchard River near Findlay, Ohio (04189000; 346 sq. mi.), the Blanchard River at Ottawa (04189260; 628 sq. mi.), and the Auglaize River near Defiance, Ohio (04190500; 2,318 sq. mi.). The gage on the Blanchard River at Ottawa reported daily average flow data for WY 2010 through 2016, while the gages on the Blanchard River near Findlay and Auglaize River near Defiance reported daily average flow data for WY 2002 through 2016.

Regressions were developed to estimate daily average flows for the Blanchard River at Ottawa for WY 2002 through 2009. The regression using the gage on the Auglaize River near Defiance ($R^2 = 0.85$; Figure B-4) was deemed better than the regression with the gage on the Blanchard River near Findlay ($R^2 = 0.77$)

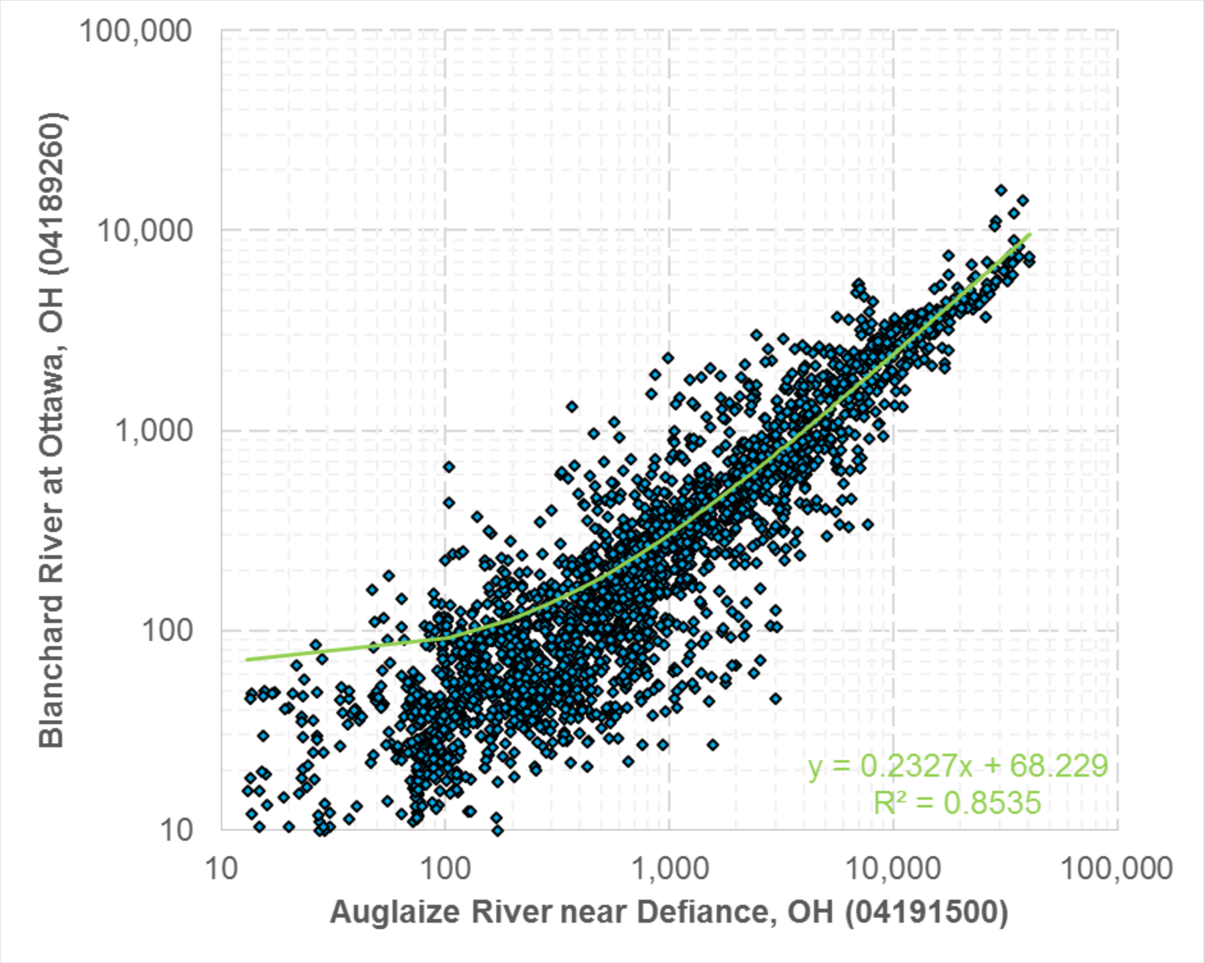

Figure B-4. Regression of flow (cfs) for USGS gages on the Blanchard and Auglaize rivers.

The Blanchard River at the mouth is 772 sq. mi. and the drainage to the gage at Ottawa is 628 sq. mi. The ratio of drainage areas was used to extrapolate flow from the gage to the HUC-8 watershed outlet.

## B-1.6 AUGLAIZE (HUC 04100008)

Flow at the outlet of the Auglaize River watershed was estimated through the flow distribution by drainage area ratio technique. USGS maintains a gage on the Auglaize River near Defiance, Ohio (04191500; 2,318 sq. mi.) and on the Maumee River near Defiance, Ohio (04192500; 5,545 sq. mi.). Both gages reported daily average flow from WY 2002 through 2016.

The Auglaize River at the mouth is 2,438 sq. mi. and the drainage to the gage on the Auglaize River near Defiance is 2,318 sq. mi. Flow for the 120 sq. mi. below the gage on the Auglaize River near Defiance was estimated using the gage on the Maumee near Defiance. Flows for the Maumee River at Antwerp (Section C-1.3), Tiffin River near Evansport (Section C-1.4), and Auglaize River near Defiance watersheds were summed and subtracted from flows measured in the Maumee River near Defiance. The differential was then distributed to the Upper Maumee River, Tiffin River, and Auglaize River watersheds (and a small portion of the Lower Maumee River watershed upstream of Waterville) via drainage area ratio. For example, in the spring of 2002, the differential was 7,992 ac-ft and 3,212 ac-ft were distributed to the Auglaize River watershed: 7,992 ac-ft * (120 sq. mi. / 535 sq. mi.) = 1,793 ac-ft.

## B-1.7 LOWER MAUMEE (HUC 04100009)

Flow for the Lower Maumee River watershed upstream of Waterville was estimated through the difference between gages on the Maumee River and via the flow distribution by drainage area ratio technique. USGS maintains gages on the Maumee River near Defiance, Ohio (04192500; 5,545 sq. mi.) at Waterville, Ohio (04193500; 6,330 sq. mi.). Both gages reported daily average flow from WY 2002 through 2016.

Flow for the Lower Maumee River HUC-8 watershed between the gages near Defiance and at Waterville was calculated by subtracting the flow monitored near Defiance from the flow monitored at Waterville.

Flow for the Lower Maumee River HUC-8 watershed above Defiance (55 sq. mi.) was estimated through a flow distribution by drainage area ratio using the flows monitored at the gage near Defiance. The Lower Maumee River HUC-8 watershed upstream of Waterville is 840 sq. mi. is. Flows for the Maumee River at Antwerp (Section C-1.3), Tiffin River near Evansport (Section C-1.4), and Auglaize River near Defiance (Section C-1.6) watersheds were summed and subtracted from flows measured in the Maumee River near Defiance. The differential was then distributed to the Upper Maumee River, Tiffin River, and Auglaize River watersheds and the 55 sq. mi. of the Lower Maumee River watershed via drainage area ratio. For example, in the spring of 2002, the differential was 7,992 ac-ft and 822 ac-ft were distributed to the Lower Maumee River watershed upstream of Waterville: 7,992 ac-ft * (55 sq. mi. / 535 sq. mi.) = 822 ac-ft.

# B-2.0 SPRING AND ANNUAL FLOWS

Daily average flows were summed for each spring (Table B-2) and each WY (Table B-3). The sums for each HUC-8 watershed were then divided by the sum for the Maumee River at Waterville to determine the relative flow[1] that each HUC-8 watershed contributes to the Maumee River at Waterville.

Evaluation of total spring and total annual flow represented as inches of flow per watershed (i.e., unit area flow depth) indicates considerable year-to-year variation to total spring and total annual flows (Figure B-5 and Figure B-6, respectively). Additionally, patterns with total spring flow often were not consistent with total annual flow. For example, total spring flow was at its lowest in all eight HUC-8 watersheds in the years 2005 and 2012 (Figure B-5), while total annual flow was not at its lowest in any HUC-8 watershed in the years 2005 and 2012 (Figure B-6).

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[1] Relative flow was rounded to the nearest hundredth of a percentage point (i.e., nearest ten-thousandth). Relative flow for the Maumee River was rounded up a hundredth of a percentage point (instead of to the nearest hundredth of a percentage point) to ensure that the HUC-8 watersheds' relative flows summed exactly to 100 percent.

Table B-2. Total spring flow (ac-ft per spring)

| Year | St. Joseph | St. Mary's | Upper Maumee | Tiffin | Auglaize | Blanchard | Lower Maumee [a] | Maumee River at Waterville |
|---|---|---|---|---|---|---|---|---|
| 2002 | 466,843 | 277,289 | 157,378 | 277,940 | 522,609 | 243,623 | 332,844 | 2,278,526 |
| 2003 | 368,292 | 702,191 | 220,506 | 166,447 | 1,100,694 | 473,635 | 301,696 | 3,333,461 |
| 2004 | 422,370 | 278,615 | 153,134 | 236,939 | 724,446 | 313,730 | 189,000 | 2,318,233 |
| 2005 | 178,095 | 146,057 | 62,243 | 95,897 | 309,195 | 159,135 | 162,322 | 1,112,943 |
| 2006 | 346,188 | 228,096 | 95,755 | 226,970 | 401,697 | 191,397 | 283,434 | 1,773,537 |
| 2007 | 315,101 | 322,872 | 174,493 | 221,403 | 522,801 | 231,381 | 148,864 | 1,936,915 |
| 2008 | 448,215 | 407,324 | 128,687 | 293,093 | 958,312 | 414,816 | 394,961 | 3,045,408 |
| 2009 | 626,760 | 331,533 | 188,149 | 334,447 | 625,810 | 273,494 | 323,652 | 2,703,846 |
| 2010 | 532,416 | 381,149 | 211,426 | 349,839 | 659,991 | 305,445 | 488,677 | 2,928,942 |
| 2011 | 640,199 | 562,817 | 261,118 | 423,379 | 1,177,662 | 552,547 | 514,594 | 4,132,316 |
| 2012 | 185,433 | 90,367 | 50,835 | 128,560 | 176,639 | 95,224 | 115,088 | 842,147 |
| 2013 | 462,504 | 322,178 | 185,145 | 228,287 | 655,611 | 372,217 | 482,984 | 2,708,926 |
| 2014 | 457,954 | 355,781 | 184,597 | 314,384 | 780,564 | 280,626 | 443,084 | 2,816,991 |
| 2015 | 402,479 | 762,758 | 339,627 | 355,996 | 1,516,695 | 488,928 | 630,492 | 4,496,975 |
| 2016 | 260,136 | 228,321 | 177,691 | 247,207 | 522,000 | 250,487 | 302,069 | 1,987,912 |
| **Total** | **6,112,986** | **5,397,349** | **2,590,783** | **3,900,787** | **10,654,726** | **4,646,687** | **5,113,761** | **38,417,078** |
| **Ratio [b]** | **15.91%** | **14.05%** | **6.75%[c]** | **10.15%** | **27.73%** | **12.10%** | **13.31%** | **100%** |

*Notes*

a. Portion of the Lower Maumee watershed upstream of the USGS gage on the Maumee River at Waterville (04183500).

b. Ratios are rounded to the nearest hundredth of a percentage point (i.e., nearest ten-thousandth).

c. The Upper Maumee was rounded up to 6.75 percent (from 6.744 percent) to ensure that the summation of HUC-8 watershed ratios is exactly 100 percent.

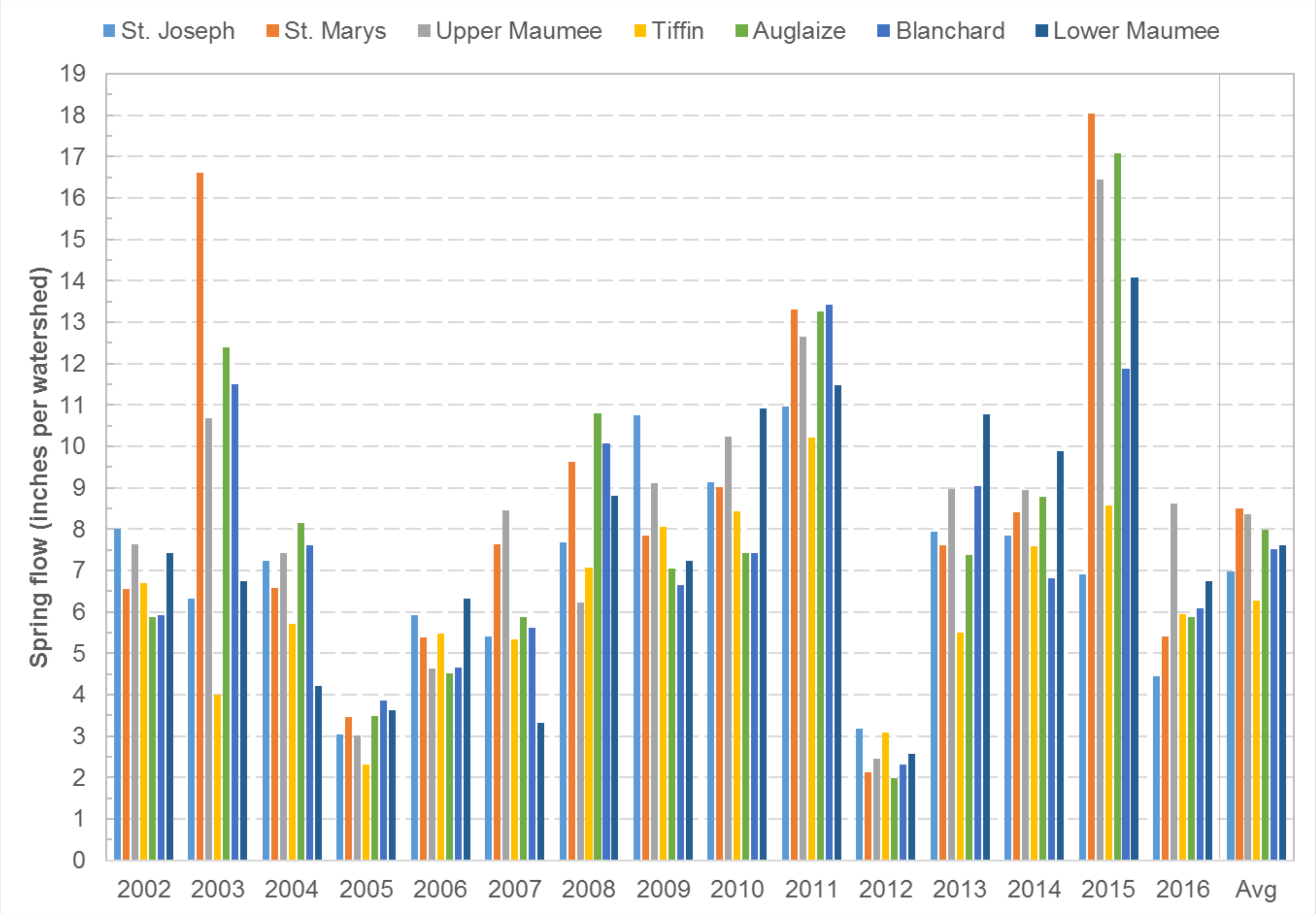


Figure B-5. Total spring flow for each HUC-8 watershed in the Maumee River basin.

Table B-3. Total WY flow (ac-ft per WY)

| Year | St. Joseph | St. Mary's | Upper Maumee | Tiffin | Auglaize | Blanchard | Lower Maumee [a] | Maumee River at Waterville |
|---|---|---|---|---|---|---|---|---|
| 2002 | 986,984 | 599,197 | 361,222 | 558,962 | 1,101,732 | 517,759 | 702,785 | 4,828,641 |
| 2003 | 573,239 | 975,510 | 306,452 | 227,260 | 1,492,729 | 675,854 | 421,274 | 4,672,318 |
| 2004 | 742,599 | 644,493 | 275,701 | 398,578 | 1,364,463 | 613,011 | 370,213 | 4,409,058 |
| 2005 | 732,687 | 696,584 | 277,430 | 419,978 | 1,509,690 | 669,720 | 441,793 | 4,747,882 |
| 2006 | 715,339 | 540,353 | 235,397 | 469,110 | 1,086,979 | 505,041 | 622,107 | 4,174,326 |
| 2007 | 964,228 | 807,806 | 431,942 | 591,663 | 1,793,329 | 779,379 | 718,989 | 6,087,334 |
| 2008 | 1,094,444 | 853,339 | 368,823 | 650,665 | 1,943,547 | 845,036 | 749,571 | 6,505,424 |
| 2009 | 970,189 | 538,435 | 259,869 | 452,792 | 1,028,102 | 490,033 | 374,304 | 4,113,725 |
| 2010 | 795,834 | 476,966 | 282,275 | 451,578 | 827,914 | 335,943 | 597,335 | 3,767,845 |
| 2011 | 764,251 | 711,937 | 303,647 | 488,544 | 1,409,143 | 735,891 | 635,427 | 5,048,840 |
| 2012 | 875,420 | 591,251 | 232,438 | 553,751 | 1,407,925 | 670,194 | 504,268 | 4,835,247 |
| 2013 | 572,703 | 574,667 | 240,968 | 283,139 | 1,139,301 | 634,094 | 630,158 | 4,075,029 |
| 2014 | 696,916 | 647,590 | 239,623 | 488,210 | 1,385,769 | 637,303 | 645,122 | 4,740,534 |
| 2015 | 542,548 | 949,029 | 425,991 | 436,469 | 1,797,575 | 565,252 | 670,259 | 5,387,123 |
| 2016 | 470,177 | 444,084 | 266,332 | 361,709 | 913,220 | 407,908 | 355,581 | 3,219,011 |
| **Total** | **11,497,559** | **10,051,241** | **4,508,108** | **6,832,408** | **20,201,419** | **9,082,418** | **8,439,185** | **70,612,338** |
| **Ratio [b]** | **16.28%** | **14.23%** | **6.39%[c]** | **9.68%** | **28.61%** | **12.86%** | **11.95%** | **100%** |

*Notes*

a. Portion of the Lower Maumee watershed upstream of the USGS gage on the Maumee River at Waterville (04183500).

b. Ratios are rounded to the nearest hundredth of a percentage point (i.e., nearest ten-thousandth).

c. The Upper Maumee was rounded up to 6.39 percent (from 6.384 percent) to ensure that the summation of HUC-8 watershed ratios is exactly 100 percent.

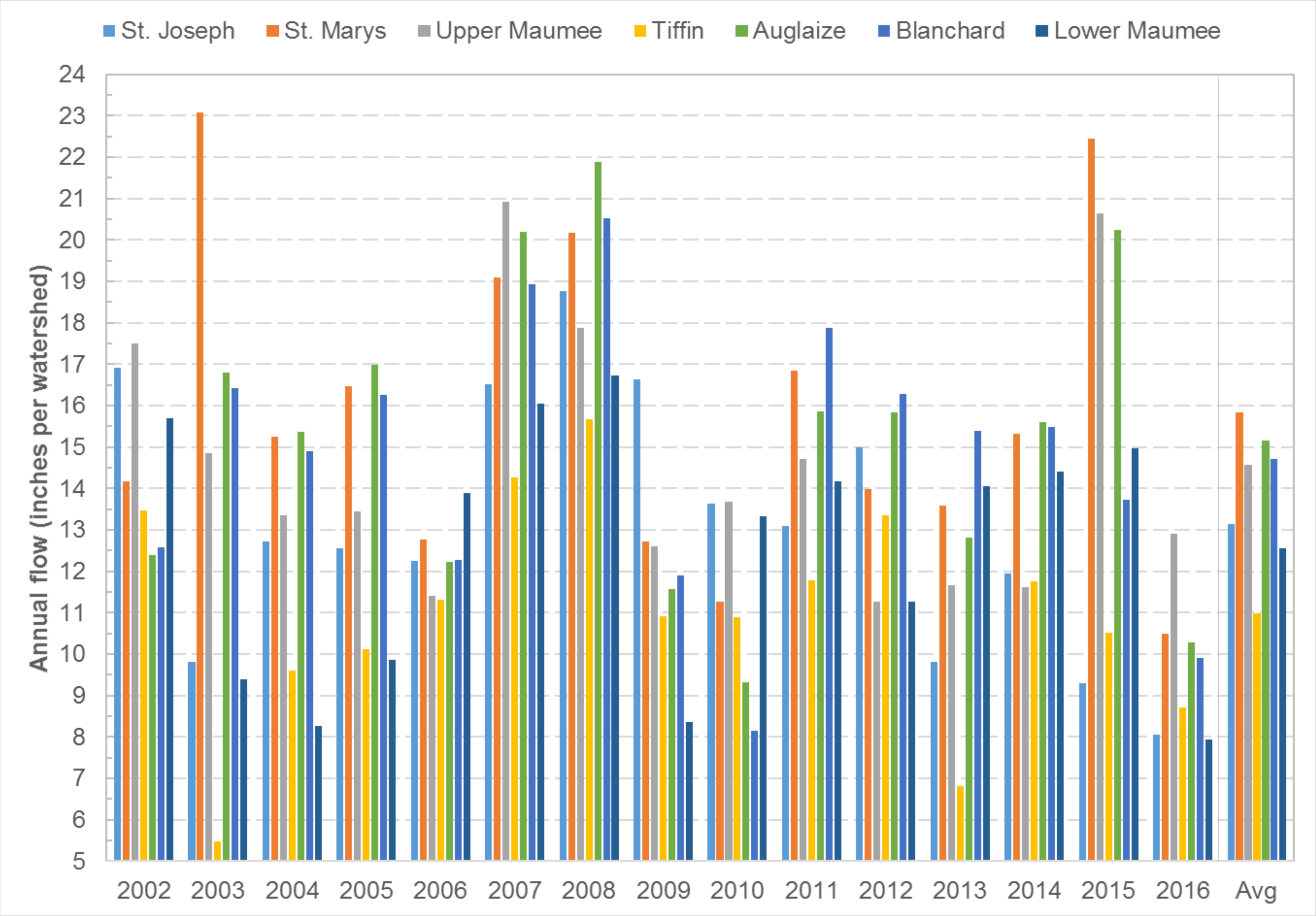


Figure B-6. Total annual flow for each HUC-8 watershed in the Maumee River basin.

# APPENDIX C. ST. JOSEPH RIVER WATERSHED EVALUATIONS

## CONTENT

## TABLES

# FIGURES

# ACRONYMS

| Acronyms/Abbreviations | Definition |
|---|---|
| CY | calendar year |
| FW | city of Fort Wayne (Indiana) |
| IDEM | Indiana Department of Environmental Management |
| Ohio EPA | Ohio Environmental Protection Agency |
| SJR | St. Joseph River |
| SJRW | St. Joseph River watershed |
| SJRWI | St. Joseph River Watershed Initiative |
| SRP | soluble reactive phosphorus |
| SWAT | Soil and Water Assessment Tool |
| TMDL | total maximum daily load |
| TP | total phosphorus |
| USGS | U.S. Geological Survey (U.S. Department of the Interior) |
| WY | water year |

| Unit of measure | Definition |
|---|---|
| ac-ft | acre-feet |
| mg/L | milligram per liter |
| MT | metric ton (1,000 kilograms) |
| MT/spring | metric ton per spring (March 1st through July 31st) |
| MT/WY | metric ton per water year (October 1st through September 30th) |

# C-1.0 AVAILABLE DATA

Daily flow data at four active gages are reported by U.S. Geological Survey (USGS; Table C-1 and Figure C-1) in the St. Joseph River watershed (SJRW). Additionally, the Ohio Environmental Protection Agency (Ohio EPA) previously operated a single level logger on the West Branch St. Joseph River (Indiana Department of Environmental Management [IDEM] 2017 and Ohio EPA from December 2012 through December 2014. Instantaneous flows were monitored by various entities but too few data are available for any meaningful analysis. Finally, a Soil and Water Assessment Tool (SWAT) model was developed to support total maximum daily load (TMDL) development; the model was calibrated using daily flow reported by USGS and Ohio EPA (IDEM 2017). For the data exploration, only daily flow reported by USGS were used with LOADEST to estimate TP loads.

Table C-1. Flow monitoring gages in the SJRW

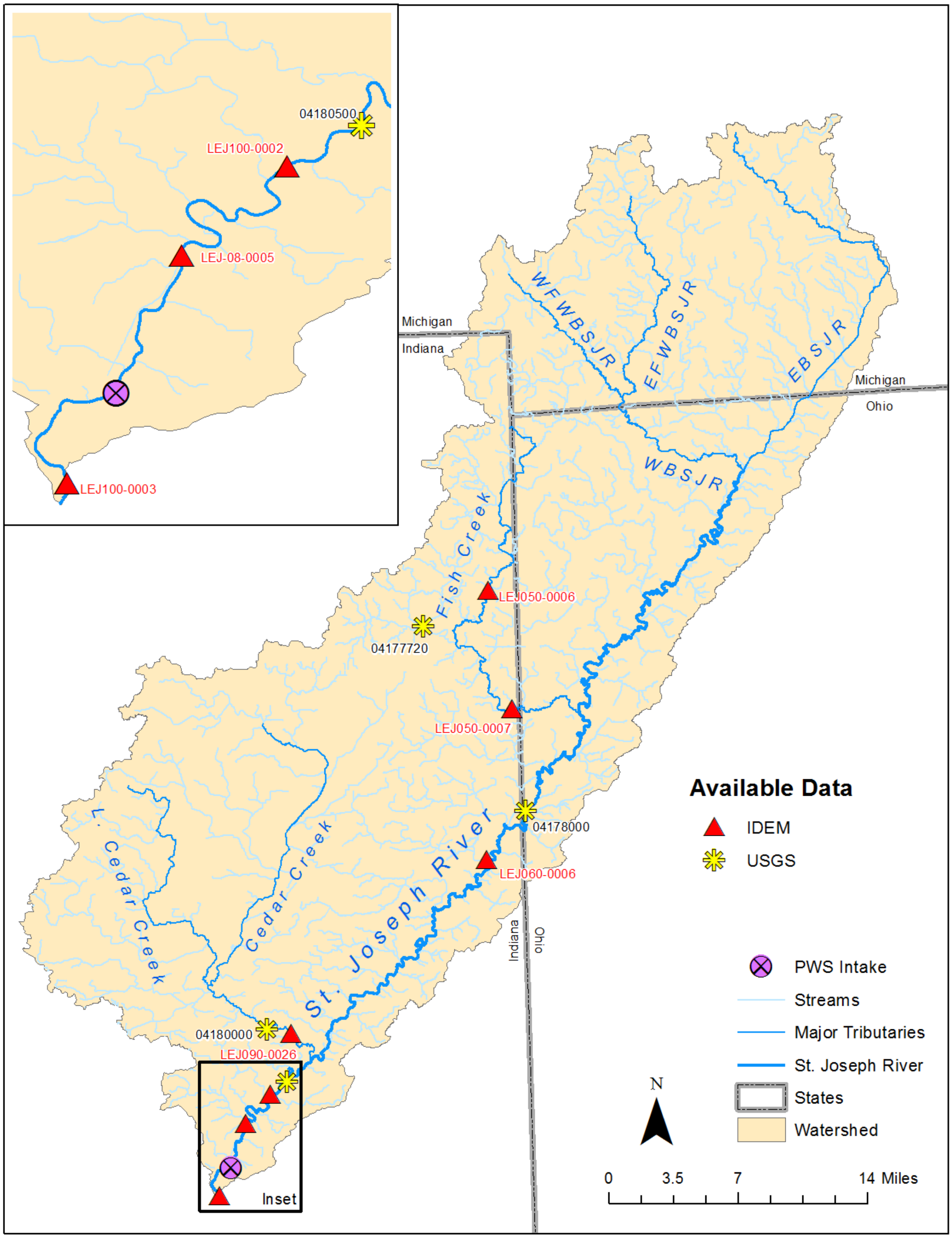
| Gage ID | Gage name | Drainage area (square miles) | Period of record (water years) |
|---|---|---|---|
| 04177500 | St Joseph River near Blakeslee OH | 394 | 1926 - 1932 |
| **04177720** | **Fish Creek at Hamilton, IN** | 37.5 | 1970 - present |
| 04177810 | Fish Creek near Artic, IN | 98 | 1988 - 2007 |
| 04179500 | Cedar Creek at Auburn, IN | 87.3 | 1944 - 1973 |
| **04178000** | **St. Joseph River near Newville, IN** | 610 | 1946 - present |
| 04178500 | St. Joseph River at Hursh, IN | 734 | 1951 - 1953 |
| 04179000 | St. Joseph River at Cedarville, IN | 763 | 1900<br>1931 - 1932<br>1955 - 1982 |
| **04180000** | **Cedar Creek near Cedarville, IN** | 270 | 1947 - present |
| **04180500** | **St. Joseph River near Fort Wayne, IN** | 1,060 | 1941 - 1955<br>1984 – present |
| P08S21 [a] | West Branch St. Joseph River at Township Road 12 | 109 | 2012-2015 [b] |

*Notes*

**Bolded** gages are active through the entire project evaluation period (WYs 2002 through 2016).

a. Ohio EPA monitoring site P08S21 is the West Branch St. Joseph River at Township Road 11.5. The level logger was installed 0.6 mile downstream of monitoring site P08S21.

b. The Ohio EPA level logger was operated from December 2012 through December 2014.



*Note:* Ohio EPA sentinel site 510220 and SJRWI site 163 are co-located with USGS gage 04178000. City of Fort Wayne sites on Hursh Road, Mayhew Road, and Tennessee Avenue are col-located with IDEM fixed stations LEJ090-0026, LEJ100-0002, and LEJ100-0003, respectively.

Figure C-1. Key flow and TP monitoring sites in the SJRW.

Total phosphorus (TP) concentration datasets are available from IDEM, Ohio EPA, the city of Fort Wayne, and the St. Joseph River Watershed Initiative (SJRWI; Table C-2 and Figure C-1). However, dissolved reactive phosphorus and soluble reactive phosphorus (SRP) concentration data are extremely limited in the SJRW.

TP load was estimated by IDEM using Purdue University's LOADEST web-interface. Tetra Tech also used Purdue University's LOADEST web-interface to estimate TP loads at IDEM fixed stations, an Ohio EPA sentinel site, and city of Fort Wayne sample sites. Finally, TP load was simulated by a SWAT model during TMDL development (IDEM 2017).

Table C-2. TP monitoring sites in the SJRW

| Location | Sampling entity | Site ID |
|---|---|---|
| Fish Creek | IDEM | LEJ050-0007 |
| SJR near Ohio-Indiana border | IDEM | LEJ060-0006 |
| | SJRWI | 163 |
| | Ohio EPA | 510220 |
| Cedar Creek | FW | Hursh |
| | IDEM | LEJ090-0026 |
| | SJRWI | 100 |
| SJR at Mayhew Road | FW | Mayhew |
| | IDEM | LEJ100-0002 |
| SJR at Tennessee Avenue | FW | Tennessee |
| | IDEM | LEJ100-0003 |

# C-2.0 DEVELOPMENT OF ANNEX 4 TRANSLATED TARGETS

Targets consistent with the goals of Annex 4 were developed for each HUC-12 subwatershed in the SJRW following the same methodology that targets were developed for the SJRW HUC-8 watershed.

## C-2.1 SUMMARY OF SJRW HUC-8 WATERSHED TARGET DEVELOPMENT

As discussed in Section 2 of the main report, targets for the SJRW were calculated by distributing the Annex 4 targets for the Maumee River at Waterville to the tributary HUC-8 watersheds using a flow-weighting of the WY 2002 through 2016 total spring and total WY flows. Total spring flow in the SJRW is 15.91 percent of the total spring flow measured in the Maumee River at Waterville. With spring targets at Waterville of 860 MT TP and 186 MT SRP (Great Lakes Water Quality Agreement 2015), the Annex 4 translated spring targets for the SJRW are 137 MT TP and 30 MT SRP. Total annual/WY flow in the SJRW is 16.28 percent of the total annual flow measured at Waterville. The annual Waterville target of 2,288 MT TP (U.S. Environmental Protection Agency 2017) yields an Annex 4 translated annual target for the SJRW of 373 MT TP.

## C-2.2 DEVELOPMENT OF SJRW HUC-12 SUBWATERSHED TARGETS

The Annex 4 translated targets for the SJRW HUC-8 watershed were distributed to the SJRW HUC-12 subwatersheds using a flow- weighting approach in the exact same manner that the Annex 4 targets for the Maumee River at Waterville were distributed to the tributary HUC-8 watersheds using a flow-weighting approach. The Work Group evaluated several potential target-setting methods (i.e., area-, flow-, and load-based) and selected the flow-based approach as the fairest and most appropriate approach, given the available data.

### C-2.2.1 Development of Flow-Weighting

Flows time series were developed using the SWAT model for 104 model subbasins. To calculate flow for each HUC-12 subwatershed, simulated in-stream flows were summed for each spring and each WY during the model simulation period (2004-2014). For headwaters HUC-12 subwatersheds (with no upstream tributary subwatersheds), to determine the relative flow contribution for each subwatershed, the simulated in-stream flow for the reach terminating at the outlet of each subwatershed was summed for each spring and WY. For subwatersheds with upstream tributary subwatersheds, the simulated in-stream flow for the reach terminating at the outlet of the specific subwatershed was reduced by the simulated in-stream flow for each reach terminating at the outlet at each upstream tributary subwatershed.

The flow-weighting for each of 45 HUC-12 subwatersheds in the SJRW is presented in Table C-3. For this methodology, the relative flow was rounded to the nearest one-hundredth of a percentage point (i.e., to the nearest ten-thousandth). To ensure that the relative flows summed to exactly 100 percent, the flow for the most downstream HUC-12 subwatershed was slightly increased or decreased, as appropriate.

Table C-3. Relative flow for each HUC-12 subwatershed in the SJRW

| HUC-12 | HUC-12 name | Area (sq. mi.) | Annual flow | | Spring flow | |
|---|---|---|---|---|---|---|
| | | | Total flow (ac-ft) [a] | Relative flow [b] | Total flow (ac-ft) [a] | Relative flow [b] |
| 01 01 | Pittsford Millpond-EBSJR | 27.5 | 210,060 | 2.60% | 127,146 | 2.85% |
| 01 02 | Anderson Drain-EBSJR | 23.1 | 167,077 | 2.07% | 98,674 | 2.21% |
| 01 03 | Laird Creek | 16.1 | 117,226 | 1.44% | 66,933 | 1.50% |
| 01 04 | Bird Creek-EBSJR | 29.6 | 205,385 | 2.55% | 114,388 | 2.56% |
| 01 05 | Silver Creek | 27.1 | 199,975 | 2.46% | 114,954 | 2.58% |
| 01 06 | Clear Fork-EBSJR | 49.9 | 369,076 | 4.58% | 205,823 | 4.61% |
| 02 01 | Cambia Millpond-EFWBSJR | 26.6 | 196,921 | 2.42% | 113,519 | 2.54% |
| 02 02 | EFWBSJR | 22.0 | 161,382 | 1.99% | 91,608 | 2.05% |
| 02 03 | WFWBSJR | 49.5 | 371,328 | 4.60% | 214,402 | 4.81% |
| 02 04 | West Branch SJR | 16.2 | 119,026 | 1.48% | 66,679 | 1.49% |
| 03 01 | Nettle Creek | 36.4 | 268,921 | 3.34% | 151,280 | 3.39% |
| 03 02 | Cogswell Cemetery-SJR | 9.7 | 72,341 | 0.90% | 40,926 | 0.92% |
| 03 03 | Eagle Creek | 34.9 | 255,337 | 3.20% | 139,547 | 3.13% |
| 03 04 | Village of Montpelier-SJR | 20.8 | 165,871 | 2.09% | 96,029 | 2.15% |
| 03 05 | Bear Creek | 24.4 | 176,114 | 2.23% | 92,785 | 2.08% |
| 03 06 | West Buffalo Cemetery-SJR | 13.7 | 94,571 | 1.20% | 54,070 | 1.21% |
| 04 01 | West Branch Fish Creek | 15.6 | 116,513 | 1.46% | 63,681 | 1.43% |
| 04 02 | Headwaters Fish Creek | 13.8 | 98,776 | 1.23% | 53,839 | 1.21% |
| 04 03 | Hamilton Lake | 16.5 | 126,770 | 1.59% | 67,409 | 1.51% |
| 04 04 | Hiram Sweet Ditch | 22.3 | 169,772 | 2.13% | 92,500 | 2.07% |
| 04 05 | Town of Alvarado-Fish Creek | 16.0 | 115,068 | 1.44% | 61,345 | 1.38% |
| 04 06 | Cornell Ditch-Fish Creek | 24.7 | 176,540 | 2.22% | 96,827 | 2.17% |
| 05 01 | Bluff Run-SJR | 23.7 | 174,723 | 2.21% | 94,376 | 2.12% |
| 05 02 | Big Run | 30.2 | 234,872 | 2.96% | 129,787 | 2.91% |
| 05 03 | Russell Run-SJR | 18.0 | 120,888 | 1.52% | 69,664 | 1.56% |
| 05 04 | Buck Creek | 18.2 | 135,575 | 1.70% | 76,161 | 1.71% |
| 05 05 | Willow Run-SJR | 16.4 | 108,170 | 1.36% | 57,680 | 1.29% |
| 05 06 | Sol Shank Ditch-SJR | 27.2 | 193,145 | 2.42% | 106,724 | 2.39% |
| 06 01 | Cedar Lake-Cedar Creek | 28.9 | 195,660 | 2.48% | 108,673 | 2.44% |
| 06 02 | Dibbling Ditch-Cedar Creek | 27.1 | 198,388 | 2.50% | 110,462 | 2.48% |
| 06 03 | Matson Ditch | 17.5 | 126,846 | 1.60% | 70,793 | 1.59% |

| HUC-12 | HUC-12 name | Area (sq. mi.) | Annual flow | | Spring flow | |
|---|---|---|---|---|---|---|
| | | | Total flow (ac-ft) [a] | Relative flow [b] | Total flow (ac-ft) [a] | Relative flow [b] |
| 06 04 | Smith Ditch-Cedar Creek | 19.0 | 166,323 | 2.10% | 95,228 | 2.13% |
| 07 01 | Headwaters John Diehl Ditch | 20.4 | 144,253 | 1.84% | 81,983 | 1.84% |
| 07 02 | Peckhart Ditch-John Diehl Ditch | 18.7 | 138,424 | 1.74% | 77,509 | 1.74% |
| 07 03 | Sycamore Creek-Little Cedar Creek | 24.7 | 176,406 | 2.25% | 98,357 | 2.20% |
| 07 04 | Black Creek | 24.6 | 174,258 | 2.23% | 98,925 | 2.22% |
| 07 05 | King Lake-Little Cedar Creek | 23.5 | 156,337 | 1.99% | 85,442 | 1.92% |
| 07 06 | Willow Creek | 32.2 | 233,678 | 2.98% | 130,343 | 2.92% |
| 07 07 | Dosch Ditch-Cedar Creek | 36.7 | 277,471 | 3.51% | 157,296 | 3.53% |
| 08 01 | Hursey Ditches-Bear Creek | 27.3 | 198,068 | 2.50% | 110,938 | 2.49% |
| 08 02 | Metcalf Ditch-SJR | 33.6 | 229,868 | 2.90% | 128,315 | 2.88% |
| 08 03 | Swartz Carnahan Ditch-SJR | 19.8 | 135,720 | 1.72% | 75,414 | 1.69% |
| 08 04 | Cedarville Reservoir-SJR | 20.2 | 144,348 | 1.83% | 78,052 | 1.75% |
| 08 05 | Ely Run-SJR | 28.4 | 208,586 | 2.67% | 115,387 | 2.59% |
| 08 06 | Becketts Run-SJR | 20.5 | 138,490[c] | 1.77% [d] | 79,493[c] | 1.76% [d] |

*Notes*

EBSJR = East Branch St. Joseph River; EFWBSJR = East Fork West Branch St. Joseph River; WFWBSJR = West Fork West Branch St. Joseph River; SJR = St. Joseph River.

a. The total annual (CY) or total spring (March 1st through July 31st) flow of the HUC-12 subwatershed across CYs 2004 through 2014.

b. The total annual or total spring flow of the HUC-12 subwatershed relative to the total annual or total spring flow at the outlet of the SJRW.

c. The *Becketts Run-SJR* subwatershed is represented by flow for reach #3, instead of reach #1 at the HUC-12 subwatershed outlet, because the reaches below are affected by the city of Fort Wayne's public water withdrawal. The city's wastewater treatment plant discharges to the Maumee River in Fort Wayne just below the confluence of the St. Joseph River and St. Mary's River. Since a similar volume of water is returned, the lowest reaches in the St. Joseph River are ignored for the purposes of flow-weighting and target distribution. Accounting for negative flows (due to withdrawals) would overly complicate the methodology with no appreciable benefit to target development.

d. The relative flow for *Becketts Run-SJR* was rounded to allow for the summation of relative flows to be exactly 100.00 percent.

## C-2.2.2 Development of Targets

The Annex 4 translated targets for the SJRW HUC-8 watershed were distributed to the 45 HUC-12 subwatersheds using the flow-weighting discussed in Section C-2.2.1 (see example below).

**Example: Annual TP target for Eagle Creek (*03 03)**

Eagle Creek target = (Annex 4 translated target for SJRW) * (Eagle Creek flow-weighting)

Eagle Creek target = (373 MT TP) * (3.21%)

Eagle Creek target = 12.0 MT TP

For this methodology, the Annex 4 translated TP targets was rounded to the nearest one-tenth of a MT, while the SRP targets were rounded to the nearest one-hundredth of a MT (Table C-4). To ensure that the relative loads summed to the Annex 4 translated targets for the SJRW outlet, the loads for the most downstream HUC-12 subwatershed (*Becketts Run-St. Joseph River*) were slightly increased or decreased, as appropriate.

Table C-4. Annex 4 translated targets for HUC-12 subwatersheds

| HUC-12 | HUC-12 name | Translated annual TP target (MT/WY) | Translated spring TP target (MT/spring) | Translated spring SRP target (MT/spring) |
|---|---|---|---|---|
| 01 01 | Pittsford Millpond-EBSJR | 9.7 | 3.9 | 0.86 |
| 01 02 | Anderson Drain-EBSJR | 7.7 | 3.0 | 0.66 |
| 01 03 | Laird Creek | 5.4 | 2.1 | 0.45 |
| 01 04 | Bird Creek-EBSJR | 9.5 | 3.5 | 0.77 |
| 01 05 | Silver Creek | 9.2 | 3.5 | 0.77 |
| 01 06 | Clear Fork-EBSJR | 17.1 | 6.3 | 1.38 |
| 02 01 | Cambia Millpond-EFWBSJR | 9.0 | 3.5 | 0.76 |
| 02 02 | EFWBSJR | 7.4 | 2.8 | 0.62 |
| 02 03 | WFWBSJR | 17.2 | 6.6 | 1.44 |
| 02 04 | West Branch SJR | 5.5 | 2.0 | 0.45 |
| 03 01 | Nettle Creek | 12.5 | 4.6 | 1.02 |
| 03 02 | Cogswell Cemetery-SJR | 3.4 | 1.3 | 0.28 |
| 03 03 | Eagle Creek | 11.9 | 4.3 | 0.94 |
| 03 04 | Village of Montpelier-SJR | 7.8 | 2.9 | 0.65 |
| 03 05 | Bear Creek | 8.3 | 2.8 | 0.62 |
| 03 06 | West Buffalo Cemetery-SJR | 4.5 | 1.7 | 0.36 |
| 04 01 | West Branch Fish Creek | 5.4 | 2.0 | 0.43 |
| 04 02 | Headwaters Fish Creek | 4.6 | 1.7 | 0.36 |
| 04 03 | Hamilton Lake | 5.9 | 2.1 | 0.45 |
| 04 04 | Hiram Sweet Ditch | 7.9 | 2.8 | 0.62 |
| 04 05 | Town of Alvarado-Fish Creek | 5.4 | 1.9 | 0.41 |

| HUC-12 | HUC-12 name | Translated annual TP target (MT/WY) | Translated spring TP target (MT/spring) | Translated spring SRP target (MT/spring) |
|---|---|---|---|---|
| 04 06 | Cornell Ditch-Fish Creek | 8.3 | 3.0 | 0.65 |
| 05 01 | Bluff Run-SJR | 8.2 | 2.9 | 0.64 |
| 05 02 | Big Run | 11.0 | 4.0 | 0.87 |
| 05 03 | Russell Run-SJR | 5.7 | 2.1 | 0.47 |
| 05 04 | Buck Creek | 6.3 | 2.3 | 0.51 |
| 05 05 | Willow Run-SJR | 5.1 | 1.8 | 0.39 |
| 05 06 | Sol Shank Ditch-SJR | 9.0 | 3.3 | 0.72 |
| 06 01 | Cedar Lake-Cedar Creek | 9.3 | 3.3 | 0.73 |
| 06 02 | Dibbling Ditch-Cedar Creek | 9.3 | 3.4 | 0.74 |
| 06 03 | Matson Ditch | 6.0 | 2.2 | 0.48 |
| 06 04 | Smith Ditch-Cedar Creek | 7.8 | 2.9 | 0.64 |
| 07 01 | Headwaters John Diehl Ditch | 6.9 | 2.5 | 0.55 |
| 07 02 | Peckhart Ditch-John Diehl Ditch | 6.5 | 2.4 | 0.52 |
| 07 03 | Sycamore Creek-Little Cedar Creek | 8.4 | 3.0 | 0.66 |
| 07 04 | Black Creek | 8.3 | 3.0 | 0.67 |
| 07 05 | King Lake-Little Cedar Creek | 7.4 | 2.6 | 0.58 |
| 07 06 | Willow Creek | 11.1 | 4.0 | 0.88 |
| 07 07 | Dosch Ditch-Cedar Creek | 13.1 | 4.8 | 1.06 |
| 08 01 | Hursey Ditches-Bear Creek | 9.3 | 3.4 | 0.75 |
| 08 02 | Metcalf Ditch-SJR | 10.8 | 3.9 | 0.86 |
| 08 03 | Swartz Carnahan Ditch-SJR | 6.4 | 2.3 | 0.51 |
| 08 04 | Cedarville Reservoir-SJR | 6.8 | 2.4 | 0.53 |
| 08 05 | Ely Run-SJR | 10.0 | 3.5 | 0.78 |
| 08 06 | Becketts Run-SJR | 6.7 [a] | 2.7 [a] | 0.51 [a] |

*Notes*

EBSJR = East Branch St. Joseph River; EFWBSJR = East Fork West Branch St. Joseph River; WFWBSJR = West Fork West Branch St. Joseph River; SJR = St. Joseph River.

a. The *Becketts Run-SJR* TP targets were rounded to allow for the summation of HUC-12 subwatershed targets to be exactly 373.0 MT TP (annual), 137.0 MT TP (spring), and 30.0 MT SRP (spring).

# C-3.0 EVALUATION OF ANNEX 4 TRANSLATED TARGETS WITH TMDLS

Annex 4 translated TP targets developed for the SJRW's HUC-12 subwatersheds were compared with hypothetical TMDL target loads developed for all 45 subwatersheds in the SJRW. SRP was not evaluated because SRP TMDLs were not developed.

## C-3.1 HYPOTHETICAL TMDL CONDITIONS

To calculate hypothetical TMDL target loads for each HUC-12 subwatershed, simulated in-stream flows were summed for each spring and each WY during the model simulation period (2004-2014) and multiplied by the appropriate TMDL target. The TP TMDL target for Indiana was 0.30 mg/L, and was applied to all model subbasins within Indiana. The TP TMDL target for Ohio was 0.08 mg/L for headwaters-sized streams and 0.10 mg/L for wading-sized streams; these targets were applied to the model subbasins within Ohio.

For headwaters subwatersheds (with no upstream tributary subwatersheds), the calculated in-stream hypothetical TMDL target loads for the reach terminating at the outlet of each subwatershed was summed for each spring and WY. For subwatersheds with upstream tributary subwatersheds, the calculated in-stream hypothetical TMDL target loads were adjusted to account for the upstream tributary subwatersheds.

Hypothetical TP TMDL target loads were not calculated for two subwatersheds that crossed the Michigan-Ohio state border (*Clear Fork-East Branch St. Joseph River* [*01 06] and *West Branch St. Joseph River* [*02 04]) and two subwatersheds that cross the Ohio-Indiana state border (*Cornell Ditch-Fish Creek* [*04 06] and *Willow Run-St. Joseph River* [*05 05]). Because these subwatershed cross state borders, the accounting for upstream, tributary watersheds results in target load differentials that represent the differences in TMDL targets, not the target loads contributed within the specified subwatershed. As such, the results have no meaning within the framework of this analysis.

The spring and annual TP target loads representing hypothetical TMDLs for each of the 45 HUC-12 subwatersheds in the SJRW are presented in Table C-5 and Table C-6, respectively. For this methodology, the TP target loads were rounded to the nearest one-tenth of a MT. In both tables, cells with bolded values mean that hypothetical TMDL target loads exceed the Annex 4 translated targets.

## C-3.2 HYPOTHETICAL TMDLS SPRING TARGET LOADS

Hypothetical TMDL spring target loads exceed Annex 4 translated spring targets in 7 of 11 springs in 20 to 23 of 45 HUC-12 subwatersheds (Table C-5):

- 2004 (20)
- 2008 (23)
- 2009 (23)
- 2010 (23)
- 2011 (23)
- 2013 (23)
- 2014 (21)

Spring loads representing hypothetical conditions do not exceed the Annex 4 target loads in the three most upstream HUC-10 subwatersheds: *East Branch St. Joseph River*, *West Branch St. Joseph River*, and *Nettle Creek-St. Joseph River*. Such loads regularly exceed Annex 4 loads in the aforementioned years throughout the other five HUC-10 subwatersheds, which are mostly in Indiana and thus use a higher TMDL target.

Table C-5. SJRW HUC-12 subwatershed hypothetical TMDL spring TP target loads (MT/spring)

| HUC-12 | HUC-12 name | T | ‘04 | ‘05 | ‘06 | ‘07 | ‘08 | ‘09 | ‘10 | ‘11 | ‘12 | ‘13 | ‘14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 01 | Pittsford Millpond-East Branch St. Joseph River | *no hypothetical TMDLs developed for Michigan HUC-12s* | | | | | | | | | | | |
| 01 02 | Anderson Drain-East Branch St. Joseph River | | | | | | | | | | | | |
| 01 03 | Laird Creek | | | | | | | | | | | | |
| 01 04 | Bird Creek-East Branch St. Joseph River | | | | | | | | | | | | |
| 01 05 | Silver Creek | | | | | | | | | | | | |
| 01 06 | Clear Fork-East Branch St. Joseph River | 6.3 | *see text preceding table* | | | | | | | | | | |
| 02 01 | Cambia Millpond-EFWBSJR | *no hypothetical TMDLs developed for Michigan HUC-12s* | | | | | | | | | | | |
| 02 02 | EFWBSJR | | | | | | | | | | | | |
| 02 03 | WFWBSJR | | | | | | | | | | | | |
| 02 04 | West Branch St. Joseph River [a] | 2.0 | *see text preceding table* | | | | | | | | | | |
| 03 01 | Nettle Creek | 4.6 | 1.3 | 0.6 | 1.5 | 1.1 | 2.1 | 2.4 | 2.2 | 3.1 | 0.7 | 2.2 | 1.5 |
| 03 02 | Cogswell Cemetery-St. Joseph River | 1.3 | 0.4 | 0.1 | 0.5 | 0.3 | 0.6 | 0.7 | 0.6 | 0.9 | 0.2 | 0.5 | 0.4 |
| 03 03 | Eagle Creek [a] | 4.3 | 1.2 | 0.6 | 1.2 | 1.1 | 1.9 | 2.2 | 2.0 | 3.0 | 0.6 | 2.1 | 1.5 |
| 03 04 | Village of Montpelier-St. Joseph River | 2.9 | 0.8 | 0.4 | 0.9 | 0.7 | 1.3 | 1.6 | 1.4 | 2.1 | 0.6 | 1.1 | 1.0 |
| 03 05 | Bear Creek | 2.8 | 0.7 | 0.2 | 0.6 | 0.5 | 0.9 | 1.3 | 1.1 | 1.6 | 0.3 | 1.1 | 0.9 |
| 03 06 | West Buffalo Cemetery-St. Joseph River | 1.7 | 0.4 | 0.2 | 0.4 | 0.3 | 0.7 | 1.1 | 0.8 | 1.1 | 0.3 | 0.7 | 0.7 |
| 04 01 | West Branch Fish Creek | 2.0 | **2.2** | 0.8 | 1.7 | 1.5 | **2.4** | **3.0** | **2.6** | **3.5** | 0.8 | **3.1** | 2.0 |
| 04 02 | Headwaters Fish Creek | 1.7 | 1.7 | 0.7 | 1.6 | 1.2 | **2.0** | **2.6** | **2.2** | **3.1** | 0.6 | **2.5** | 1.7 |
| 04 03 | Hamilton Lake | 2.1 | **2.2** | 0.8 | 1.8 | 1.4 | **2.3** | **3.2** | **2.7** | **4.0** | 0.8 | **3.2** | **2.5** |
| 04 04 | Hiram Sweet Ditch | 2.8 | **3.1** | 1.1 | 2.5 | 1.9 | **3.0** | **4.5** | **3.7** | **5.3** | 0.9 | **4.8** | **3.4** |
| 04 05 | Town of Alvarado-Fish Creek [b] | 1.9 | 1.8 | 0.7 | 1.4 | 1.4 | **2.1** | **3.1** | **2.6** | **3.8** | 0.8 | **2.8** | **2.3** |
| 04 06 | Cornell Ditch-Fish Creek [b] | 3.0 | *see text preceding table* | | | | | | | | | | |
| 05 01 | Bluff Run- St. Joseph River | 2.9 | 1.0 | 0.4 | 0.9 | 0.8 | 1.4 | 2.0 | 1.7 | 2.4 | 0.6 | 1.6 | 1.4 |
| 05 02 | Big Run | 4.0 | 1.3 | 0.5 | 1.0 | 0.9 | 1.6 | 2.4 | 1.8 | 2.5 | 0.4 | 2.1 | 1.5 |
| 05 03 | Russell Run-St. Joseph River | 2.1 | 0.6 | 0.2 | 0.5 | 0.4 | 1.0 | 1.5 | 0.9 | 1.4 | 0.3 | 1.0 | 0.9 |

| HUC-12 | HUC-12 name | T | ‘04 | ‘05 | ‘06 | ‘07 | ‘08 | ‘09 | ‘10 | ‘11 | ‘12 | ‘13 | ‘14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 05 04 | Buck Creek | 2.3 | **2.5** | 0.8 | 1.8 | 1.4 | **3.0** | **4.3** | **3.2** | **4.3** | 0.5 | **3.7** | **2.6** |
| 05 05 | Willow Run-St. Joseph River | 1.8 | *see text preceding table* | | | | | | | | | | |
| 05 06 | Sol Shank Ditch-St. Joseph River | 3.3 | **3.4** | 1.2 | 2.6 | 2.1 | **4.2** | **5.8** | **4.7** | **5.9** | 0.8 | 5.3 | **3.5** |
| 06 01 | Cedar Lake-Cedar Creek [b] | 3.3 | **3.4** | 1.3 | 2.6 | 2.3 | **3.6** | **6.0** | **4.4** | **6.0** | 0.9 | 5.4 | **4.4** |
| 06 02 | Dibbling Ditch-Cedar Creek [b] | 3.4 | **3.8** | 1.4 | 2.5 | 2.3 | **3.6** | **5.8** | **4.7** | **5.8** | 0.9 | 6.1 | **4.0** |
| 06 03 | Matson Ditch [b] | 2.2 | **2.4** | 0.9 | 1.6 | 1.5 | **2.4** | **3.7** | **3.0** | **3.9** | 0.5 | 3.7 | **2.6** |
| 06 04 | Smith Ditch-Cedar Creek | 2.9 | **3.3** | 1.5 | 2.4 | 2.2 | **3.5** | **5.2** | **4.1** | **4.7** | 0.9 | 4.2 | **3.2** |
| 07 01 | Headwaters John Diehl Ditch | 2.5 | 2.5 | 1.0 | 1.8 | 1.9 | **2.7** | **4.7** | **3.3** | **4.4** | 0.9 | 3.7 | **3.5** |
| 07 02 | Peckhart Ditch-John Diehl Ditch [b] | 2.4 | **2.7** | 1.0 | 1.7 | 1.7 | **2.7** | **4.5** | **3.4** | **4.0** | 0.6 | 3.6 | **2.7** |
| 07 03 | Sycamore Creek-Little Cedar Creek | 3.0 | 3.0 | 1.2 | 2.2 | 2.6 | **3.2** | **5.5** | **3.8** | **5.2** | 1.1 | 4.2 | **4.3** |
| 07 04 | Black Creek | 3.0 | **3.2** | 1.1 | 2.5 | 2.5 | **3.2** | **5.2** | **3.9** | **5.0** | 1.1 | 4.6 | **4.3** |
| 07 05 | King Lake-Little Cedar Creek | 2.6 | **2.7** | 1.1 | 1.8 | 2.3 | **2.8** | **5.0** | **3.4** | **4.6** | 0.8 | 3.4 | **3.7** |
| 07 06 | Willow Creek | 4.0 | **4.2** | 1.4 | 3.2 | 3.4 | **4.1** | **6.6** | **5.4** | **6.9** | 1.2 | 6.5 | **5.4** |
| 07 07 | Dosch Ditch-Cedar Creek [b] | 4.8 | **5.6** | 2.0 | 3.7 | 4.0 | **5.2** | **8.3** | **7.0** | **8.1** | 1.3 | 7.2 | **6.1** |
| 08 01 | Hursey Ditches-Bear Creek | 3.4 | **3.9** | 1.2 | 2.7 | 2.3 | **4.0** | **5.8** | **5.0** | **6.0** | 0.8 | 5.5 | **3.9** |
| 08 02 | Metcalf Ditch-St. Joseph River | 3.9 | **4.7** | 1.5 | 3.0 | 2.5 | **4.6** | **6.5** | **5.2** | **7.2** | 1.0 | 7.0 | **4.5** |
| 08 03 | Swartz Carnahan Ditch-St. Joseph River | 2.3 | **2.9** | 0.9 | 1.6 | 1.7 | **2.5** | **3.7** | **3.2** | **4.1** | 0.4 | 4.0 | **2.8** |
| 08 04 | Cedarville Reservoir-St. Joseph River | 2.4 | **2.9** | 0.9 | 1.5 | 2.1 | **2.5** | **3.8** | **3.3** | **4.2** | 0.6 | 4.2 | **3.0** |
| 08 05 | Ely Run-St. Joseph River | 3.5 | **4.2** | 1.3 | 2.4 | 3.5 | **3.9** | **5.4** | **4.6** | **5.8** | 0.8 | 6.1 | **4.7** |
| 08 06 | Becketts Run-St. Joseph River [b] | 2.7 | **3.0** | 1.0 | 1.7 | 2.4 | **2.8** | **3.6** | **3.1** | **3.8** | 0.7 | 4.1 | **3.2** |

*Notes*

EFWBSJR = East Fork West Branch St. Joseph River; T = Annex 4 translated spring total phosphorus target; WFWBSJR = West Fork West Branch St. Joseph River.

**Bolded blue** values exceed the Annex 4 translated targets.

a. Ohio EPA is developing a TP TMDL at one site impaired by nutrient enrichment in each of these two HUC-12 subwatershed (Ohio EPA, 2015)

b. IDEM (2017) developed a TP TMDL at the outlet or within each of these 8 HUC-12 subwatersheds to address segments impaired by nutrients, with impaired biotic communities, or impaired by dissolved oxygen.

## C-3.3 HYPOTHETICAL TMDL ANNUAL TARGET LOADS

Hypothetical TMDL annual target loads exceed Annex 4 translated annual target loads in 3 of 10 WYs in 18 or 23 of 45 HUC-12 subwatersheds (Table C-6):

- 2008 (23)
- 2009 (23)
- 2010 (18)

Annual loads representing hypothetical TMDL conditions do not exceed the Annex 4 translated targets in the three most upstream HUC-10 subwatersheds: *East Branch St. Joseph River*, *West Branch St. Joseph River*, and *Nettle Creek-St. Joseph River*. Hypothetical TMDL annual target loads regularly exceed Annex 4 translated annual targets in the aforementioned years throughout the other five HUC-10 subwatersheds, which are mostly in Indiana.

Table C-6. SJRW HUC-12 subwatershed hypothetical TMDL annual TP target loads (MT/WY)

| HUC-12 | HUC-12 name | T | ‘05 | ‘06 | ‘07 | ‘08 | ‘09 | ‘10 | ‘11 | ‘12 | ‘13 | ‘14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 01 | Pittsford Millpond-EBSJR | *no hypothetical TMDLs developed for Michigan HUC-12s* | | | | | | | | | | |
| 01 02 | Anderson Drain-EBSJR | | | | | | | | | | | |
| 01 03 | Laird Creek | | | | | | | | | | | |
| 01 04 | Bird Creek-EBSJR | | | | | | | | | | | |
| 01 05 | Silver Creek | | | | | | | | | | | |
| 01 06 | Clear Fork-EBSJR | 17.3 | *see text preceding table* | | | | | | | | | |
| 02 01 | Cambia Millpond-EFWBSJR | *no hypothetical TMDLs developed for Michigan HUC-12s* | | | | | | | | | | |
| 02 02 | EFWBSJR | | | | | | | | | | | |
| 02 03 | WFWBSJR | | | | | | | | | | | |
| 02 04 | West Branch St. Joseph River [a] | 5.6 | *see text preceding table* | | | | | | | | | |
| 03 01 | Nettle Creek | 12.6 | 2.8 | 3.5 | 4.5 | 4.6 | 3.9 | 3.3 | 3.9 | 3.8 | 3.0 | 2.5 |
| 03 02 | Cogswell Cemetery-St. Joseph River | 3.4 | 0.7 | 1.1 | 1.2 | 1.3 | 1.1 | 0.9 | 1.1 | 0.9 | 0.6 | 0.7 |
| 03 03 | Eagle Creek [a] | 12.0 | 2.7 | 3.0 | 4.7 | 4.3 | 3.7 | 3.1 | 3.8 | 3.5 | 2.7 | 2.7 |
| 03 04 | Village of Montpelier-St. Joseph River | 7.8 | 1.6 | 2.3 | 3.0 | 2.7 | 2.5 | 2.2 | 2.4 | 2.3 | 1.5 | 1.9 |
| 03 05 | Bear Creek | 8.2 | 1.4 | 1.6 | 2.8 | 2.3 | 2.1 | 1.7 | 2.1 | 1.9 | 1.5 | 1.7 |
| 03 06 | West Buffalo Cemetery-St. Joseph River | 4.4 | 1.0 | 1.2 | 1.8 | 1.5 | 1.4 | 1.1 | 1.4 | 1.3 | 0.9 | 1.2 |
| 04 01 | West Branch Fish Creek | 5.4 | 3.9 | 4.0 | **6.4** | **5.9** | 5.0 | 4.2 | 4.9 | 4.8 | 4.1 | 3.6 |
| 04 02 | Headwaters Fish Creek | 4.6 | 3.4 | 3.7 | **5.2** | **4.9** | 4.2 | 3.6 | 4.1 | 4.1 | 3.4 | 2.9 |
| 04 03 | Hamilton Lake | 5.9 | 3.9 | 4.6 | **7.1** | **6.5** | 5.7 | 4.3 | 5.5 | 5.0 | 4.3 | 4.1 |
| 04 04 | Hiram Sweet Ditch | 7.9 | 5.2 | 6.2 | **9.2** | **8.6** | 7.9 | 5.8 | 7.1 | 6.7 | 6.2 | 5.6 |
| 04 05 | Town of Alvarado-Fish Creek [b] | 5.4 | 3.6 | 3.9 | **6.6** | **5.9** | 5.2 | 4.2 | 4.8 | 4.9 | 3.7 | 3.6 |
| 04 06 | Cornell Ditch-Fish Creek [b] | 8.3 | *see text preceding table* | | | | | | | | | |
| 05 01 | Bluff Run- St. Joseph River | 8.2 | 2.1 | 2.5 | 4.0 | 3.3 | 3.2 | 2.5 | 3.1 | 3.0 | 2.2 | 2.4 |
| 05 02 | Big Run | 11.0 | 2.4 | 2.7 | 4.1 | 3.9 | 3.7 | 2.8 | 3.3 | 3.1 | 2.8 | 2.7 |
| 05 03 | Russell Run-St. Joseph River | 5.7 | 1.2 | 1.4 | 2.2 | 2.1 | 1.9 | 1.4 | 1.8 | 1.7 | 1.3 | 1.3 |

| HUC-12 | HUC-12 name | T | ‘05 | ‘06 | ‘07 | ‘08 | ‘09 | ‘10 | ‘11 | ‘12 | ‘13 | ‘14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 05 04 | Buck Creek | 6.3 | 4.2 | 4.7 | **7.2** | **7.1** | **6.6** | 4.8 | 5.5 | 5.2 | 4.9 | 4.4 |
| 05 05 | Willow Run-St. Joseph River | 5.1 | *see text preceding table* | | | | | | | | | |
| 05 06 | Sol Shank Ditch-St. Joseph River | 9.1 | 6.1 | 6.5 | **10.2** | **10.2** | **9.4** | 7.1 | 7.8 | 7.2 | 7.0 | 6.2 |
| 06 01 | Cedar Lake-Cedar Creek [b] | 9.2 | 6.4 | 5.9 | **10.1** | **10.7** | **9.9** | 7.0 | 7.5 | 8.0 | 7.0 | 7.0 |
| 06 02 | Dibbling Ditch-Cedar Creek [b] | 9.3 | 6.3 | 6.3 | **10.3** | **10.3** | **9.9** | 7.2 | 7.8 | 7.6 | 7.8 | 6.7 |
| 06 03 | Matson Ditch [b] | 5.9 | 4.1 | 4.3 | **6.7** | **6.5** | **6.3** | 4.5 | 5.1 | 4.8 | 4.8 | 4.2 |
| 06 04 | Smith Ditch-Cedar Creek | 7.8 | 5.6 | 5.7 | **8.6** | **8.7** | **8.4** | 6.3 | 6.5 | 6.1 | 5.8 | 5.6 |
| 07 01 | Headwaters John Diehl Ditch | 6.8 | 4.8 | 4.2 | **7.9** | **7.7** | **7.5** | 5.1 | 5.5 | 5.9 | 4.8 | 5.5 |
| 07 02 | Peckhart Ditch-John Diehl Ditch [b] | 6.5 | 4.5 | 4.3 | **7.5** | **7.5** | **7.2** | 5.2 | 5.2 | 5.2 | 4.7 | 4.6 |
| 07 03 | Sycamore Creek-Little Cedar Creek | 8.2 | 6.0 | 5.3 | **10.1** | **9.4** | **9.0** | 6.1 | 6.6 | 7.2 | 5.7 | 7.0 |
| 07 04 | Black Creek | 8.2 | 5.6 | 5.7 | **9.6** | **9.4** | **8.7** | 6.2 | 6.2 | 7.0 | 6.2 | 7.1 |
| 07 05 | King Lake-Little Cedar Creek | 7.3 | 5.4 | 4.7 | **9.4** | **8.4** | **8.0** | 5.3 | 5.9 | 6.2 | 4.7 | 6.0 |
| 07 06 | Willow Creek | 10.9 | 7.6 | 7.8 | **12.5** | **12.6** | **11.6** | 8.2 | 8.4 | 8.9 | 9.0 | 9.1 |
| 07 07 | Dosch Ditch-Cedar Creek [b] | 13.0 | 9.3 | 9.3 | **15.2** | **14.6** | **13.9** | 10.2 | 9.9 | 10.4 | 9.8 | 9.9 |
| 08 01 | Hursey Ditches-Bear Creek | 9.3 | 6.3 | 6.7 | **10.8** | **10.4** | **9.8** | 7.3 | 7.5 | 7.3 | 7.2 | 6.7 |
| 08 02 | Metcalf Ditch-St. Joseph River | 10.8 | 7.7 | 7.4 | **12.4** | **12.2** | **10.9** | 8.2 | 8.8 | 9.0 | 8.7 | 7.8 |
| 08 03 | Swartz Carnahan Ditch-St. Joseph River | 6.3 | 4.7 | 4.2 | **7.3** | **7.0** | **6.6** | 4.8 | 5.2 | 5.1 | 5.3 | 5.0 |
| 08 04 | Cedarville Reservoir-St. Joseph River | 6.8 | 5.0 | 4.4 | **7.9** | **7.5** | **7.1** | 5.1 | 5.3 | 5.5 | 5.7 | 5.4 |
| 08 05 | Ely Run-St. Joseph River | 9.8 | 6.9 | 6.7 | **11.7** | **10.7** | **10.4** | 7.1 | 7.6 | 7.4 | 8.6 | 8.3 |
| 08 06 | Becketts Run-St. Joseph River [b] | 6.4 | 2.0 | 2.7 | 3.7 | 3.6 | 2.8 | 3.1 | 2.8 | 3.0 | 2.3 | 5.7 |

*Notes*

EBSJR = East Branch St. Joseph River; EFWBSJR = East Fork West Branch St. Joseph River; T = Annex 4 translated annual total phosphorus target; WFWBSJR = West Fork West Branch St. Joseph River.

**Bolded blue** values exceed the Annex 4 translated targets.

a. Ohio EPA is developing a TP TMDL at one site impaired by nutrient enrichment in each of these two HUC-12 subwatersheds (Ohio EPA, 2015).

b. IDEM (2017) developed a TP TMDL at the outlet or within each of these 8 HUC-12 subwatersheds to address segments impaired by nutrients, with impaired biotic communities, or impaired by dissolved oxygen.

# C-4.0 ESTIMATION OF EXISTING LOADS

TP concentration and load datasets are available from multiple entities in the SJRW. However, dissolved reactive phosphorus and SRP concentration data are extremely limited in the SJRW. The TP datasets were evaluated to determine which dataset(s) may be suitable for estimating existing loads for the SJRW at the HUC-8 outlet and HUC-12 outlets.

## C-4.1 COMPARISON OF LOAD ESTIMATIONS

TP loads were estimated using Purdue University's LOADEST web-interface or simulated in the SWAT model.

- **LOADEST by IDEM:** To support development of Indiana's domestic action plan, IDEM estimated TP loads using Purdue University's LOADEST web-interface for several fixed stations in the SJRW, St. Mary's River watershed, and Upper Maumee HUC8 watershed. IDEM ran Purdue University's LOADEST web-interface using fixed station data from 2008 through early 2016 and allowed LOADEST to select the best regression model.
- **LOADEST by Tetra Tech:** Tetra Tech also ran Purdue University's LOADEST web-interface to estimate loads for additional IDEM fixed station data (WYs 2002-2016) and data collected by Ohio EPA, the city of Fort Wayne, and SJRWI. LOADEST was run using TP data from WYs 2002-2016 and flow data from the period of record for the appropriate gage. Non-detects were set to one-half of the detection limit. LOADEST was allowed to select the best regression model.
- **SWAT Model by Tetra Tech:** TP was simulated in Tetra Tech's SWAT model for CYs 2004 through 2014; the model was calibrated using TP data from IDEM, Ohio EPA, and the city of Fort Wayne. Refer to Appendix D of the TMDL report (IDEM 2017) for the SWAT model report.

Annual and spring (March 1 through July 31) total loads and FWMCs were evaluated at several key locations. Only the spring results are presented herein.

**LOADEST**

"LOAD ESTimator (LOADEST) is a FORTRAN program for estimating constituent loads in streams and rivers" (Runkel et al. 2004, p. 1). It has 11 pre-defined regression equations that include variables for streamflow and time; a user may manually select one of the regressions, allow LOADEST to select the best of 9 of the pre-defined regression equations, or may input the user's own regression equation.

In this appendix, the term "LOADEST" is used to refer to Purdue University's LOADEST web-interface.

### C-4.1.1 Fish Creek at County Road 79

Three sets of load estimations are available for Fish Creek at county road 79:

- LOADEST results (regression model #8) for LEJ050-0007 (January 2008 - March 2016) provided by IDEM
- LOADEST results (regression model #8) for LEJ050-0007 (WYs 2002-2016)
- SWAT model results for subbasin 49 (CYs 2004-2014)

Daily flows from gage 04177720 were used for both LOADEST analyses. The gage drains an area that is considerably smaller than the drainage area of the IDEM fixed station. For the purposes of this evaluation, the daily flow at the gage is deemed acceptable, with the caveat that these loads are thus underestimated.

Results for complete WYs are presented in Figure C-2 and Figure C-3. Generally, the two sets of LOADEST results are similar. The SWAT model simulates considerably larger loads in WYs 2004 and 2008 and a considerably smaller load in WY 2009. FWMC results are similar. Only in WY 2015 do LOADEST results exceed the 0.23 mg/L FWMC target (Figure C-3).

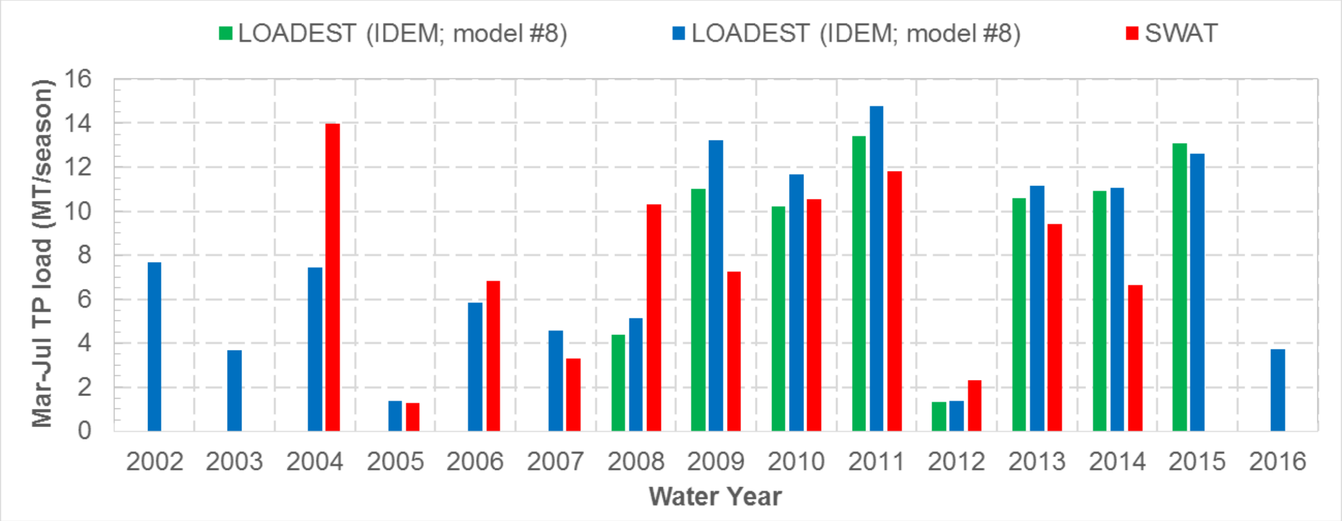
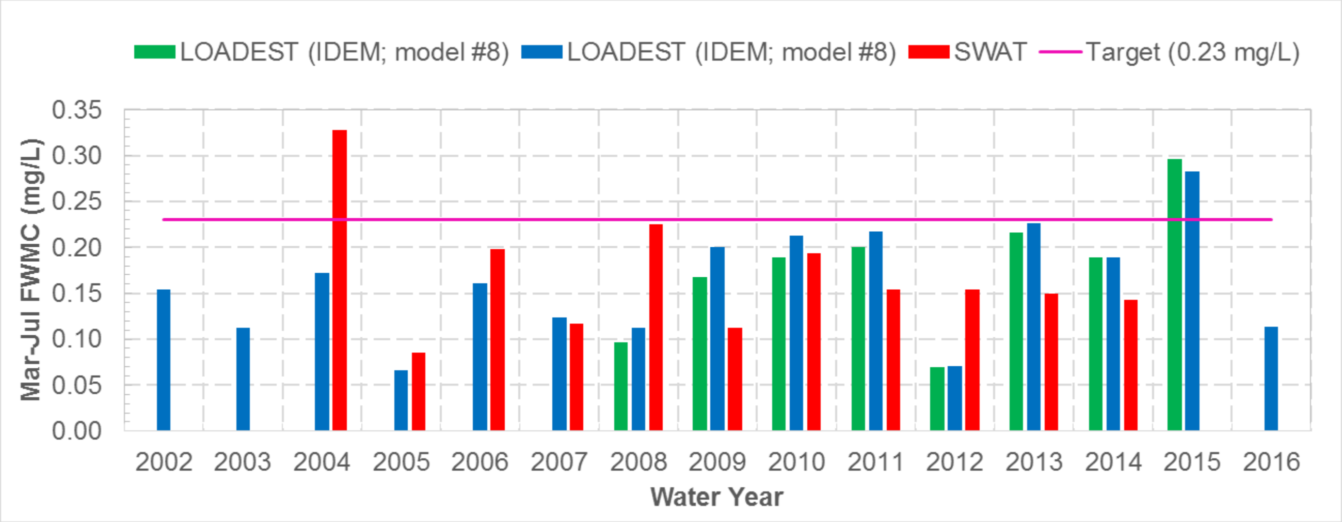


Figure C-2. Total spring load estimation results for Fish Creek at county road 79.



*Note:* The FWMC target of 0.23 mg/L for the Maumee River at Waterville is shown for comparison purposes.

Figure C-3. Spring FWMC results for Fish Creek at county road 79.

## C-4.1.2 St. Joseph River near the Ohio-Indiana State Line

Five sets of load estimations are available for the St. Joseph River (SJR) near the Ohio-Indiana state line:

- LOADEST results (regression model #7) for IDEM fixed station LEJ060-0006 (January 2008 - March 2016) provided by IDEM
- LOADEST results (regression model #6) for IDEM fixed station LEJ060-0006 (WYs 2002-2016)
- LOADEST results (regression model #4) for Ohio EPA site 510220 (November 2005 - September 2016)
- LOADEST results (regression model #6) for SJRWI site 163 (April 2015 - September 2016)
- SWAT model results for subbasin 43 (CYs 2004-2014)

Daily flows from gage 04180000 were used for each LOADEST analysis. Ohio EPA site 510220 and SJRWI site 163 are co-located with the USGS gage. IDEM fixed station LEJ060-0006 is 6.09 river miles downstream of the gage; only minor tributaries discharge between the gage and IDEM fixed station. Therefore, flow at the USGS gage is assumed representative of flow at the IDEM fixed station.

Results for complete WYs are presented in Figure C-4 and Figure C-5. Generally, the LOADEST results provided by IDEM yield smaller loads than the LOADEST results from this project. LOADEST results for Ohio EPA and SJRWI data are similar and yield smaller loads than the two sets of LOADEST results for IDEM fixed station data. The SWAT model simulates loads that are more similar to the LOADEST results for Ohio EPA and SJRWI data. FWMC results are similar. LOADEST results for the IDEM fixed station data exceed the 0.23 mg/L FWMC target during several WYs, whereas the SWAT results only exceed once (Figure C-5).

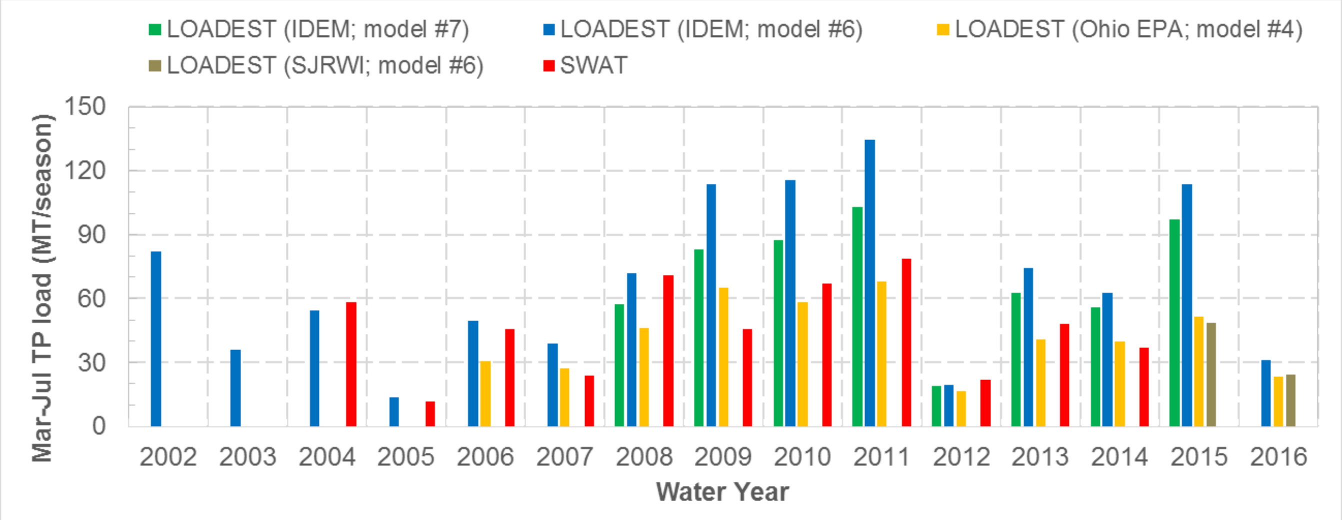
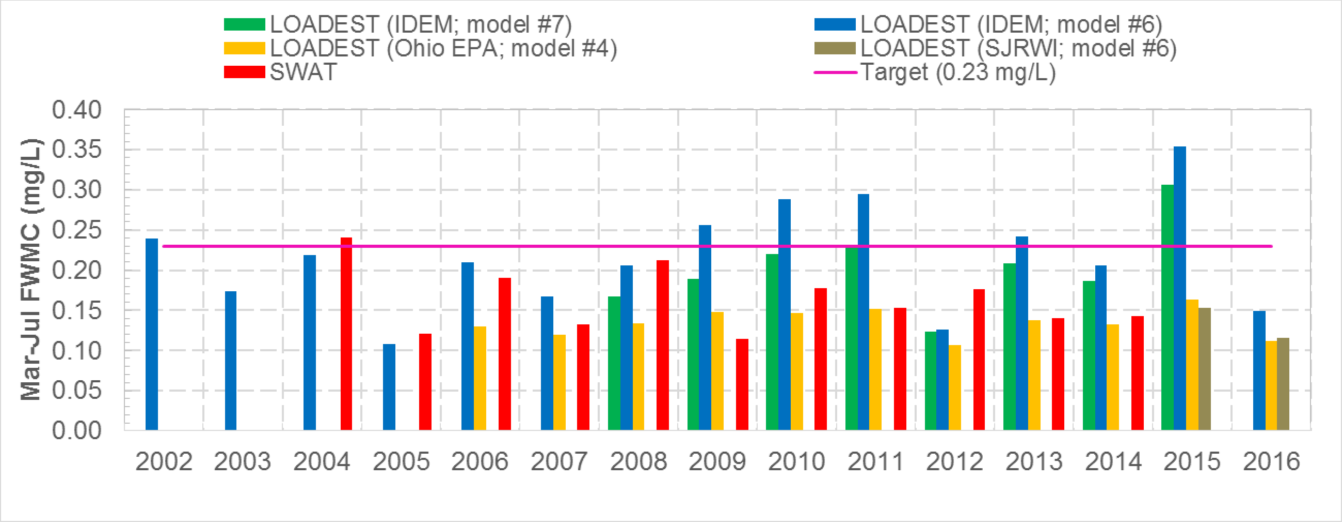


Figure C-4. Total spring load estimation results for the SJR near the Ohio-Indiana state line.



*Note:* The FWMC target of 0.23 mg/L for the Maumee River at Waterville is shown for comparison purposes.

Figure C-5. Spring FWMC results for the SJR near the Ohio-Indiana state line.

## C-4.1.3 Cedar Creek at Tonkel Road or Hursh Road

Five sets of load estimations are available for Cedar Creek at Tonkel Road or Hursh Road:

- LOADEST results (regression model #6) for IDEM fixed station LEJ090-0026 (January 2008 - March 2016) provided by IDEM
- LOADEST results (regression model #8) for IDEM fixed station LEJ090-0026 (WYs 2002-2016)
- LOADEST results (regression model #7) for SJRWI site 100 (April 2002 - October 2014)
- LOADEST results (regression model #1) for the city of Fort Wayne site at Hursh Road (January 2012 - September 2016)
- SWAT model results for subbasin 9 (CYs 2004-2014)

Daily flows from gage 04180000 were used for each LOADEST analysis. IDEM fixed station LEJ090-0026 and SJRWI site 100 are co-located with the USGS gage. The gage is at Tonkel Road but flows are assumed representative of flow at Hursh Road.

Results for complete WYs are presented in Figure C-6 and Figure C-7. Generally, the LOADEST results provided by IDEM yield larger loads than the LOADEST results from this project. LOADEST results for SJRWI data yield loads between the two sets of LOADEST results for IDEM fixed station data. Results for the city of Fort Wayne data are considerably smaller than the other three sets of LOADEST results. The SWAT model simulates loads that are smaller than all the LOADEST results except for the Fort Wayne results. FWMC results are similar. LOADEST results for the IDEM fixed station data exceed the 0.23 FWMC target in several WYs, while SJRWRI data exceed the target during most WYs (Figure C-7).

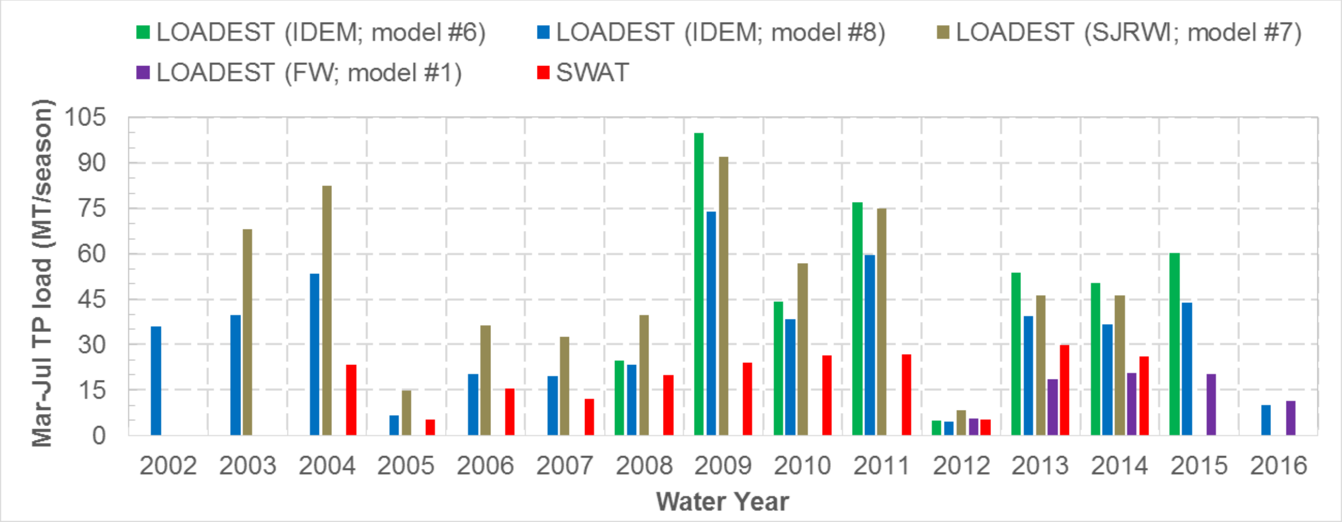
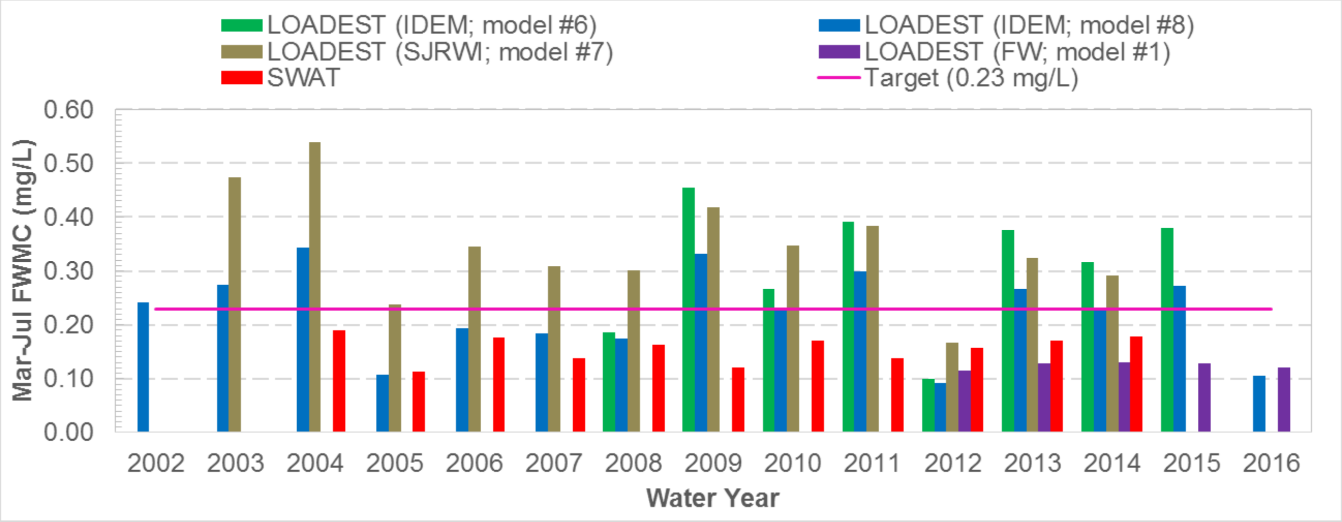


Figure C-6. Total spring load estimation results for Cedar Creek at Tonkel Road or Hursh Road.



*Note:* The FWMC target of 0.23 mg/L for the Maumee River at Waterville is shown for comparison purposes.

Figure C-7. Spring FWMC results for Cedar Creek at Tonkel Road or Hursh Road.

### C-4.1.4 St. Joseph River at Mayhew Road

Four sets of load estimations are available for the SJR at Mayhew Road:

- LOADEST results (regression model #9) for IDEM fixed station LEJ100-0002 (February 2008 - March 2011) provided by IDEM
- LOADEST results (regression model #6) for IDEM fixed station LEJ100-0002 (WYs 2002-2011)
- LOADEST results (regression model #9) for the city of Fort Wayne site at Mayhew Road (WYs 2002-2016)
- SWAT model results for subbasin 5 (CYs 2004-2014)

Daily flows from gage 04180500 were used for each LOADEST analysis.

Results for complete WYs are presented in Figure C-8 and Figure C-9. Generally, the LOADEST results yield larger loads that the SWAT results. LOADEST results occasionally exceed the 0.23 FWMC target. Due to limited overlap between datasets, few visual observations can be determined with the spring total load and spring FWMC results.

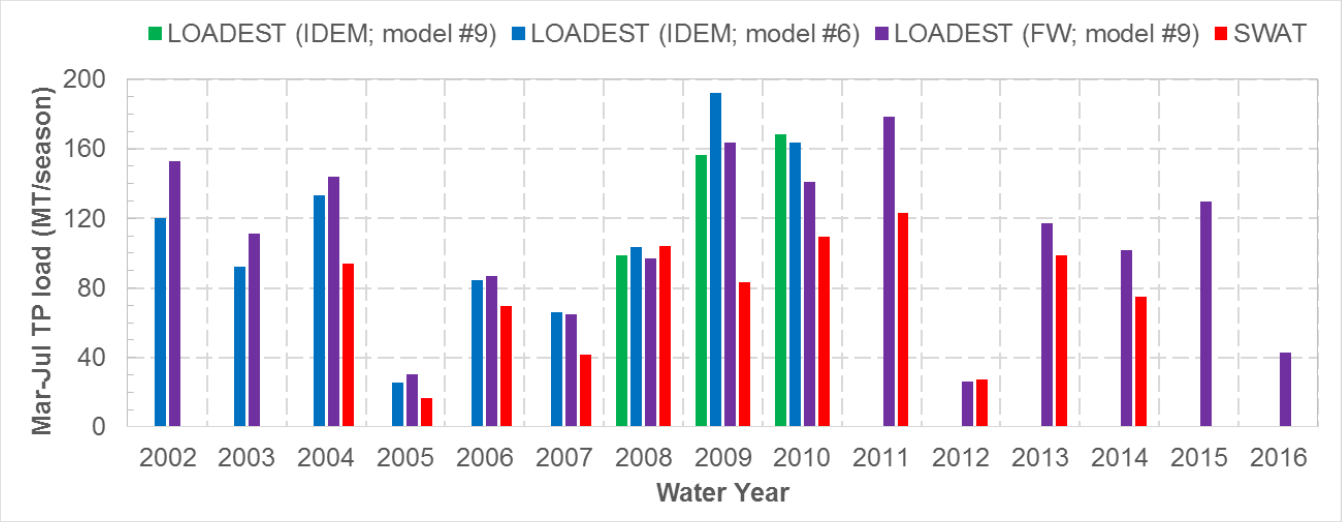
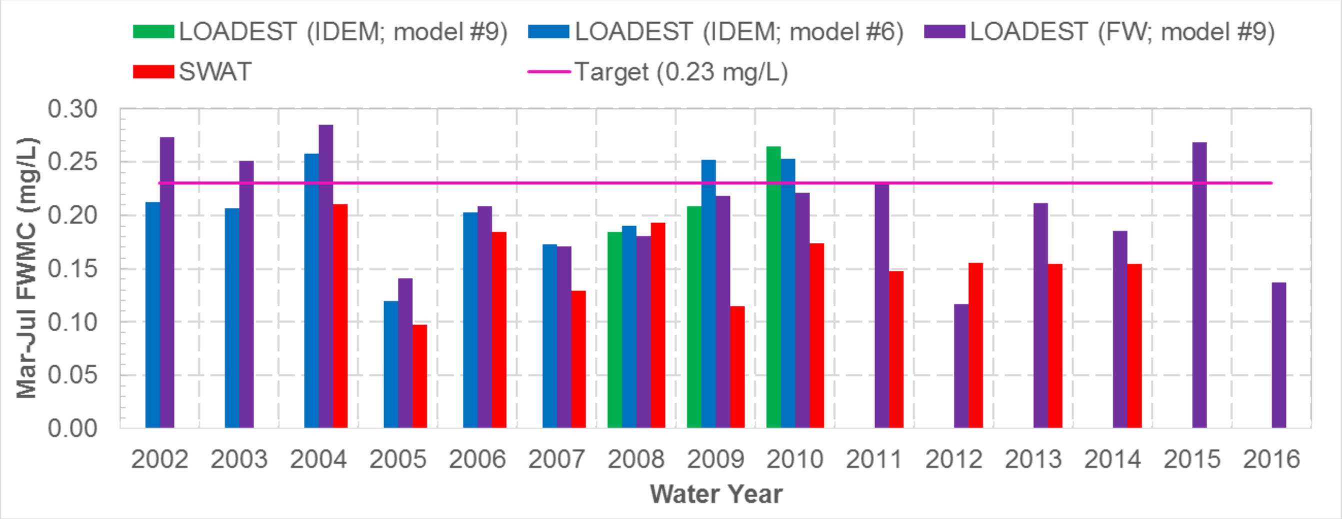


Figure C-8. Total spring load estimation results for the SJR at Mayhew Road.



*Note:* The FWMC target of 0.23 mg/L for the Maumee River at Waterville is shown for comparison purposes.

Figure C-9. Spring FWMC results for the SJR at Mayhew Road.

## C-4.1.5 St. Joseph River at Tennessee Avenue

Four sets of load estimations are available for the SJR at Tennessee Avenue:

- LOADEST results (regression model #8) for IDEM fixed station LEJ100-0003 (February 2008 - September 2015) provided by IDEM
- LOADEST results (regression model #6) for IDEM fixed station LEJ100-0003 (WYs 2002-2015)
- LOADEST results (regression model #4) for the city of Fort Wayne site at Tennessee Avenue (WYs 2002-2015)
- SWAT model results for subbasin 1 (CYs 2004-2014)

Daily flows from gage 04180500 were used for each LOADEST analysis. Gage flows are not representative of the flow at Tennessee Avenue because the city of Forty Wayne's public drinking water supply intake is upstream of Tennessee Avenue (between the sampling sites and the gage).

Results for complete WYs are presented in Figure C-10 and Figure C-11, except for the Fort Wayne results. For reasons unknown, the LOADEST results for Fort Wayne data yield loads more than twice as large as the results for the IDEM fixed stations[1]. Generally, the LOADEST results yield larger spring total loads and spring FWMCs that the SWAT results. LOADEST results occasionally exceed the 0.23 FWMC target (Figure C-11).

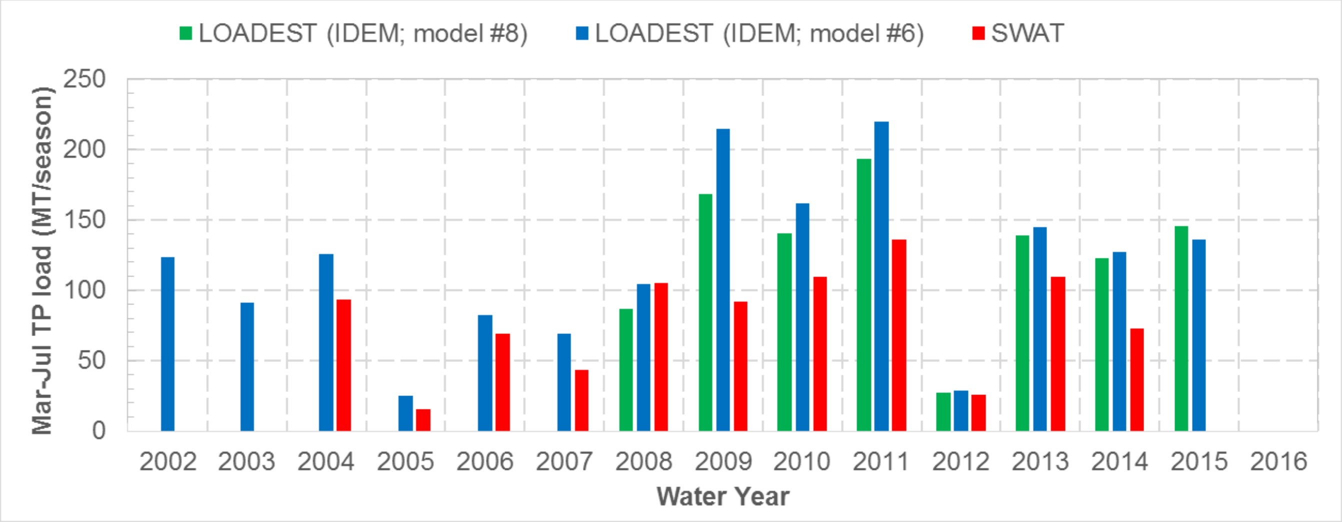


Figure C-10. Total spring load estimation results for the SJR at Tennessee Avenue.

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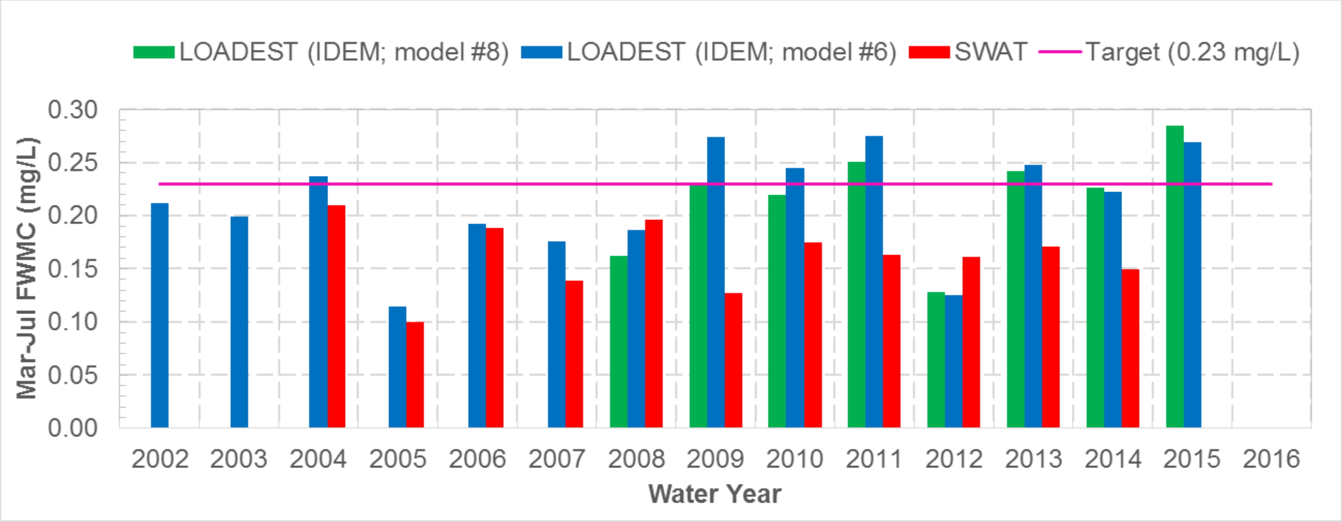
[1] LOADEST was re-run on the city of Fort Wayne's Tennessee Avenue dataset twice: once with the removal of an outlier and once more with non-detections removed. Both sets of LOADEST results yielded even larger loads.



*Note:* The FWMC target of 0.23 mg/L for the Maumee River at Waterville is shown for comparison purposes.

Figure C-11. Spring FWMC results for the SJR at Tennessee Avenue.

## C-4.2 EVALUATION OF LOADEST MODELS

An evaluation of LOADEST was conducted to determine the relative differences between spring (March 1 through July 31) loads estimated using the various regression models in the program. Generally, different regression models yield different load estimates that vary between one another from 5 to 22 percent.

Purdue University's web-based version of LOADEST[2] was used for this analysis. Both flow and TP datasets were manually inserted into the web-based interface. The flow data for WYs 2002 through 2016[3] were obtained for the USGS gage on the St. Joseph River near Fort Wayne, Indiana (04180500); daily average flow data were downloaded from the National Water Information System[4]. TP data were obtained for IDEM's fixed station on the St. Joseph River at Tennessee Avenue in Fort Wayne (LEJ100-0003 and STJ0.5). IDEM provided the TP data, which were 158 records[5] from all months of the year. IDEM TP data were collected across the ranges of flows monitored at the USGS gage (Figure C-12); thus, the TP data should be representative of all flow conditions.

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[2] *Web-based Load Calculation using LOADEST*. v. 2012. https://engineering.purdue.edu/mapserve/LOADEST/.

[3] Due to the need for a new rating curve, USGS has only published approved data through August 7, 2016. LOADEST regression analyses were conducted across the full period of record when both flow and TP data were available. Since no flows were available after August 7, 2016, the regressions excluded flow and TP data from after that date.

[4] *USGS Water Data for Indiana*. https://waterdata.usgs.gov/in/nwis/nwis.

[5] The dataset included one non-detect, with a detection threshold of 0.03 milligrams per liter (mg/L). The single non-detected was reduced to one-half of the detection threshold (0.015 mg/L).

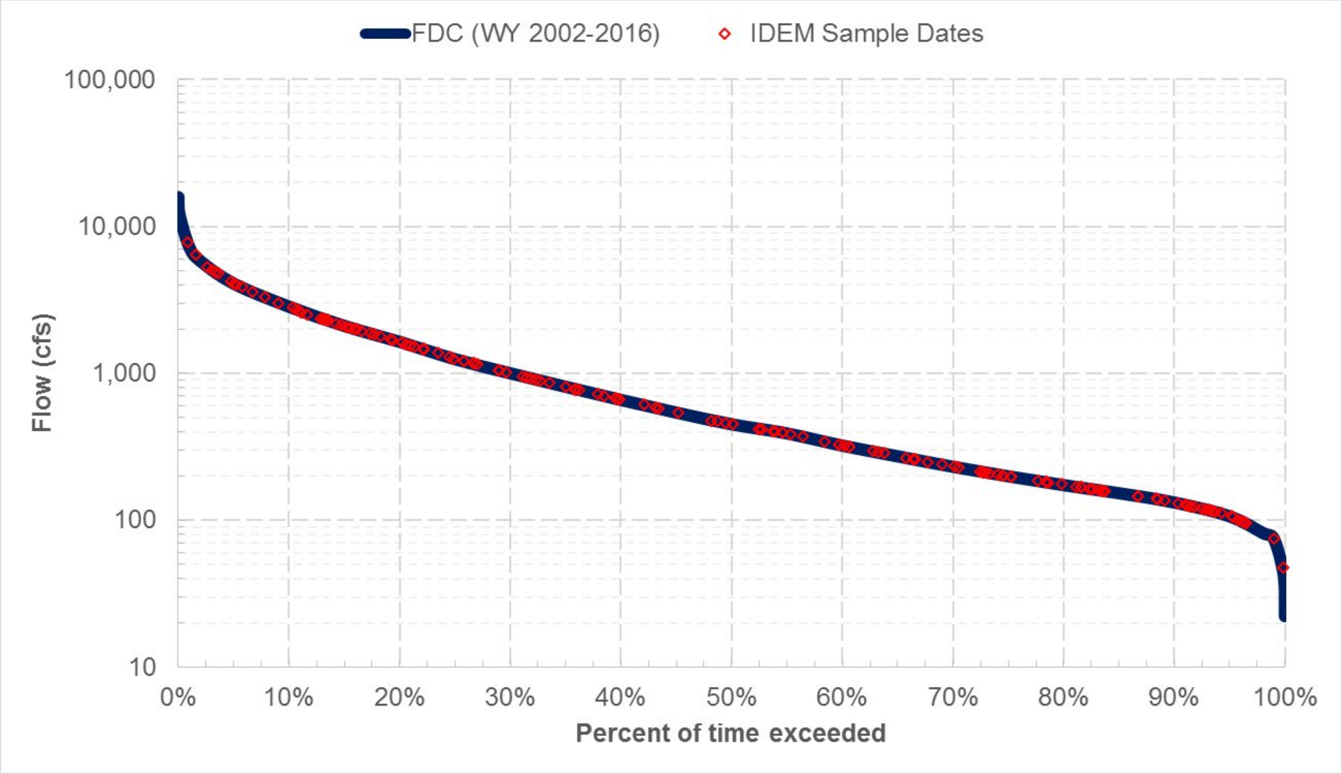

Figure C-12. Flow conditions monitored at the USGS gage and for TP sample collected at the IDEM fixed station.

The USGS gage and IDEM fixed station are not co-located and are about 10 river miles apart. Within this span is the city of Fort Wayne's intake for their public drinking water supply. The withdrawal was not accounted for during this preliminary evaluation; thus, the loads are likely overestimates. However, lack of consideration for the withdrawal should not affect the objective of this preliminary evaluation, which is to compare loading results among regression models. Since all regression models used the same flow time series (which does not account for the withdrawal) the relationship between loads from different models should not be affected.

The web-based version of LOADEST allows users to select which regression model to use or to allow LOADEST to select the best regression model[6]. For this evaluation, the regression model was selected manually and each of the nine regression models was run using the same input flow and TP datasets. LOADEST would have selected regression model #6 as the best regression model.

LOADEST adjusted maximum likelihood estimation results were evaluated and synthesized for analyses of spring total loads and FWMCs. The total spring load for each WY (MT per season) was calculated by summing the LOADEST-estimated loads for each month (pounds per month) and converting to appropriate units of measure. The spring FWMC for each WY (mg/L) was calculated by dividing the sum of the LOADEST-estimated daily loads (pounds per day) by the sum of daily flows cubic feet per second and converting to appropriate units of measure.

Total spring loads varied considerably from WY to WY (Figure C-13), which reflects inter-annual variation in streamflow. Spring FWMCs show similar variation (Figure C-14). Variation between regression model results during the same WY reflect the differences of the regression models.

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[6] LOADEST selects the best regression model based upon the Akaike information criterion (Runkel 2004).

The percent difference[7] between regression model results ranges from 5 to 22 percent, with a median percent difference of 11 percent. These results are consistent with the literature presented in Appendix A: the relationship between flow and phosphorus is critical to the accuracy of the regression estimates. LOADEST selected regression model #6 is the best. Without daily TP data, it is not possible to determine which regression model yields the most accurate results.

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[7] For the percent difference calculation, the regression model yielding the smallest load per WY is defined as the minimum, while the regression model yielding the largest load per WY is defined as the maximum. The percent difference is calculated as the quantity of the maximum minus the minimum divided by the quantity of the maximum plus the minimum.

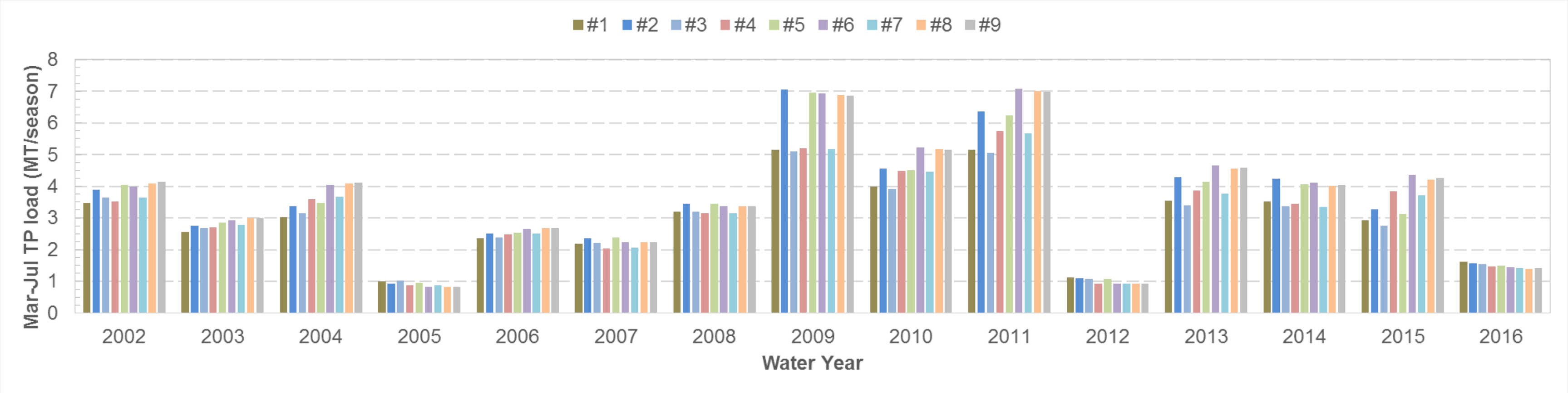
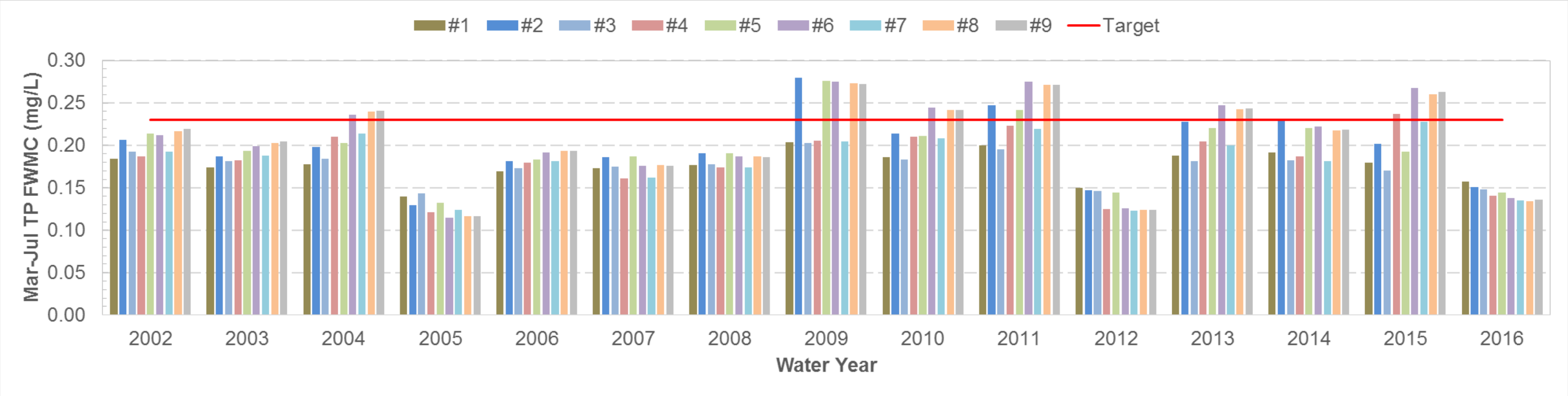


Figure C-13. Spring TP loads at the outlet of the SJRW for WYs 2002-2016.



*Note:* The flow-weighted mean concentration target of 0.23 mg/L for the Maumee River at Waterville is shown for comparison purposes.

Figure C-14. Spring TP flow weighted mean concentrations at the outlet of the SJRW for WYs 2002-2016.

## C-4.3 SELECTION OF APPROACH FOR ESTIMATING EXISTING LOADS

Loads simulated in SWAT tended to be smaller, and sometimes considerably smaller, than loads estimated using LOADEST. The primary objective of the SWAT model was to simulate flow at ungaged sites to support development of TMDLs through the load duration curve framework (IDEM 2017). During the TMDL project, more time and resources were expended on the hydrological calibration than the TP calibration.

The evaluation tends to indicate that LOADEST results for key stations may be the most suitable loading dataset to determine existing loads at key sites in the SJRW. However, LOADEST results can only be generated at a few sites with sufficient data. Only the SWAT model results can provide the necessary data to evaluate existing loads and allowable loads consistent with Annex 4 for every HUC-12 subwatershed in the SJRW.

## C-4.4 EVALUATION OF ANNEX 4 TRANSLATED TARGETS WITH SIMULATED EXISTING LOADS

TP time series were developed using the SWAT model for 104 model subbasins. To calculate existing TP load for each HUC-12 subwatershed, simulated in-stream TP loads were summed for each spring and each WY during the model simulation period (2004-2014). For headwaters subwatersheds (with no upstream tributary HUC-12 subwatersheds), the simulated in-stream TP load for the reach terminating at the outlet of each subwatershed was summed for each spring and WY. For subwatersheds with upstream tributary subwatersheds, the simulated in-stream TP load for the reach terminating at the outlet of the specific subwatershed was reduced by the simulated in-stream TP load for each reach terminating at the outlet at each upstream tributary subwatershed.

The simulated existing TP loads for the spring and WY for each of the 45 HUC-12 subwatersheds in the SJRW are presented in Table C-7 and Table C-8, respectively. For this methodology, the existing TP loads were rounded to the nearest one-tenth of a MT. In both tables, cells with bolded values mean that simulated existing TP loads exceed the Annex 4 translated targets.

Simulated existing loads exceed Annex 4 translated spring targets in 7 of 11 springs in 3 to 13 of 45 HUC-12 subwatersheds (Table C-7):

- 2004 (3)
- 2008 (9)
- 2009 (1)
- 2010 (3)
- 2011 (13)
- 2013 (6)
- 2014 (3)

Simulated existing spring TP loads that exceeded in 2013 and 2014 were primarily in Indiana, while the exceedances were primarily in Ohio in the other five years.

Simulated existing annual TP loads exceed Annex 4 translated annual targets in one HUC-12 subwatershed: *West Branch Fish Creek* (*04 01) in 2008 (Table C-8).

Table C-7. SJRW HUC-12 subwatershed simulated existing spring TP loads (MT/spring)

| HUC-12 | HUC-12 name | T | ‘04 | ‘05 | ‘06 | ‘07 | ‘08 | ‘09 | ‘10 | ‘11 | ‘12 | ‘13 | ‘14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 01 | Pittsford Millpond-East Branch St. Joseph River | 3.9 | 2.4 | 0.4 | 1.9 | 0.7 | 2.7 | 1.6 | 3.1 | 2.3 | 0.9 | 1.4 | 0.9 |
| 01 02 | Anderson Drain-East Branch St. Joseph River | 3.0 | 2.3 | 0.4 | 2.2 | 0.9 | 3.0 | 1.5 | 2.4 | 2.6 | 0.8 | 1.4 | 0.9 |
| 01 03 | Laird Creek | 2.1 | 1.9 | 0.2 | 1.6 | 0.7 | **2.4** | 1.2 | 2.0 | **2.5** | 0.7 | 1.0 | 0.7 |
| 01 04 | Bird Creek-East Branch St. Joseph River | 3.5 | 2.4 | 0.5 | 2.5 | 1.2 | **3.9** | 1.8 | 2.9 | 3.4 | 1.0 | 1.7 | 1.4 |
| 01 05 | Silver Creek | 3.5 | 3.0 | 0.3 | 2.3 | 1.0 | **3.9** | 2.1 | 3.1 | **3.6** | 1.4 | 1.5 | 1.1 |
| 01 06 | Clear Fork-East Branch St. Joseph River | 6.3 | 4.0 | 0.9 | 4.0 | 1.9 | **6.4** | 3.4 | 5.2 | **6.6** | 1.8 | 3.5 | 2.5 |
| 02 01 | Cambia Millpond-EFWBSJR | 3.5 | 1.7 | 0.3 | 1.5 | 0.9 | 2.4 | 1.6 | 2.8 | 2.7 | 0.9 | 1.5 | 1.0 |
| 02 02 | EFWBSJR | 2.8 | 1.7 | 0.2 | 1.5 | 0.7 | 2.6 | 1.3 | 2.3 | **3.1** | 0.8 | 1.3 | 0.9 |
| 02 03 | WFWBSJR | 6.6 | 4.1 | 0.8 | 3.3 | 1.5 | 6.0 | 3.6 | 5.3 | 5.8 | 1.5 | 3.9 | 2.4 |
| 02 04 | West Branch St. Joseph River [b] | 2.0 | 1.3 | 0.2 | 1.4 | 0.6 | **2.2** | 1.0 | 1.6 | **2.1** | 0.4 | 1.1 | 0.8 |
| 03 01 | Nettle Creek | 4.6 | 3.5 | 0.9 | 3.0 | 1.5 | **5.0** | 2.8 | 4.1 | **5.4** | 1.4 | 3.1 | 2.1 |
| 03 02 | Cogswell Cemetery-St. Joseph River | 1.3 | 0.4 | 0.1 | 0.7 | 0.3 | 0.9 | 0.5 | 0.8 | 1.2 | 0.2 | 0.4 | 0.4 |
| 03 03 | Eagle Creek [b] | 4.3 | 3.6 | 0.8 | 2.9 | 1.5 | **4.7** | 2.6 | **4.5** | **5.8** | 1.1 | 3.4 | 2.4 |
| 03 04 | Village of Montpelier-St. Joseph River | 2.9 | 1.7 | 1.2 | 2.5 | 1.9 | 2.5 | 1.9 | 2.3 | **3.1** | 1.7 | 1.3 | 2.0 |
| 03 05 | Bear Creek | 2.8 | 2.1 | 0.6 | 1.6 | 1.2 | 2.3 | 2.2 | **2.9** | **3.6** | 0.9 | 2.3 | 2.1 |
| 03 06 | West Buffalo Cemetery-St. Joseph River | 1.7 | 0.6 | 0.1 | 0.5 | 0.3 | 0.5 | 0.8 | 1.0 | 1.3 | 0.5 | 0.5 | 0.9 |
| 04 01 | West Branch Fish Creek | 2.0 | **3.8** | 0.3 | 1.2 | 0.7 | **2.6** | 1.5 | 1.7 | 1.9 | 0.4 | 1.9 | 1.0 |
| 04 02 | Headwaters Fish Creek | 1.7 | 1.6 | 0.2 | 1.1 | 0.4 | 1.7 | 0.8 | 1.4 | 1.5 | 0.3 | 1.1 | 0.7 |
| 04 03 | Hamilton Lake | 2.1 | **2.7** | 0.2 | 1.2 | 0.6 | 1.6 | 1.3 | 1.8 | 2.0 | 0.4 | 1.8 | 1.2 |
| 04 04 | Hiram Sweet Ditch | 2.8 | **3.2** | 0.4 | 1.7 | 0.8 | 1.9 | 1.7 | 2.4 | 2.6 | 0.5 | 2.4 | 1.8 |
| 04 05 | Town of Alvarado-Fish Creek [c] | 1.9 | 1.4 | 0.1 | 0.9 | 0.5 | 1.2 | 0.9 | 1.6 | 1.9 | 0.4 | 1.1 | 0.9 |
| 04 06 | Cornell Ditch-Fish Creek [c] | 3.0 | 1.9 | 0.2 | 1.3 | 0.7 | 2.2 | 1.7 | 2.8 | **3.2** | 0.5 | 2.0 | 1.8 |
| 05 01 | Bluff Run- St. Joseph River | 2.9 | 2.8 | 1.7 | 2.5 | 1.9 | 3.4 | 3.2 | 3.8 | **4.3** | 2.3 | **3.2** | **3.1** |
| 05 02 | Big Run | 4.0 | 3.0 | 0.6 | 1.9 | 1.2 | 3.3 | 3.1 | 3.8 | **4.5** | 0.8 | 3.9 | 2.5 |

| HUC-12 | HUC-12 name | T | '04 | '05 | '06 | '07 | '08 | '09 | '10 | '11 | '12 | '13 | '14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 05 03 | Russell Run-St. Joseph River | 2.1 | 0.7 | 0.1 | 0.4 | 0.4 | 1.2 | 1.2 | 0.9 | 1.1 | 0.4 | 0.8 | 1.1 |
| 05 04 | Buck Creek | 2.3 | 1.5 | 0.3 | 1.1 | 0.7 | 2.0 | 1.8 | 2.1 | **2.5** | 0.3 | **2.6** | 1.5 |
| 05 05 | Willow Run-St. Joseph River | 1.8 | 0.7 | 0.2 | 0.5 | 0.4 | 1.2 | 1.0 | 1.2 | 1.5 | 0.1 | 1.5 | 0.9 |
| 05 06 | Sol Shank Ditch-St. Joseph River | 3.3 | 1.6 | 0.4 | 1.6 | 1.0 | 2.4 | 2.2 | 2.6 | 2.6 | 0.5 | 3.0 | 1.8 |
| 06 01 | Cedar Lake-Cedar Creek [c] | 3.3 | 2.8 | 0.4 | 1.6 | 0.9 | 2.2 | 2.4 | 2.8 | 2.6 | 0.5 | 2.8 | 2.7 |
| 06 02 | Dibbling Ditch-Cedar Creek [c] | 3.4 | 2.9 | 0.5 | 1.7 | 1.0 | 2.2 | 2.9 | 3.2 | 3.0 | 0.5 | **3.5** | 2.5 |
| 06 03 | Matson Ditch [c] | 2.2 | 1.5 | 0.3 | 1.0 | 0.6 | 1.2 | 1.3 | 1.8 | 1.7 | 0.2 | 1.7 | 1.4 |
| 06 04 | Smith Ditch-Cedar Creek | 2.9 | 1.6 | 0.7 | 1.4 | 1.1 | 1.7 | 1.9 | 2.1 | 2.1 | 0.5 | 2.0 | 1.9 |
| 07 01 | Headwaters John Diehl Ditch | 2.5 | 1.5 | 0.3 | 1.0 | 0.8 | 1.4 | 1.6 | 1.8 | 1.9 | 0.4 | 2.1 | 1.9 |
| 07 02 | Peckhart Ditch-John Diehl Ditch [c] | 2.4 | 1.5 | 0.4 | 1.1 | 0.9 | 1.6 | 1.9 | 2.0 | 2.1 | 0.3 | 2.4 | 1.6 |
| 07 03 | Sycamore Creek-Little Cedar Creek | 3.0 | 2.0 | 0.6 | 1.5 | 1.5 | 1.9 | 2.5 | 2.4 | 2.6 | 0.7 | 2.8 | **3.1** |
| 07 04 | Black Creek | 3.0 | 2.1 | 0.4 | 1.6 | 1.3 | 1.9 | 2.3 | 2.4 | 2.5 | 0.7 | **3.2** | **3.1** |
| 07 05 | King Lake-Little Cedar Creek | 2.6 | 1.7 | 0.6 | 1.1 | 1.2 | 1.4 | 2.2 | 1.7 | 2.2 | 0.3 | 1.7 | 2.1 |
| 07 06 | Willow Creek | 4.0 | 2.8 | 0.5 | 2.0 | 1.5 | 2.1 | 2.6 | 3.0 | 3.3 | 0.5 | 4.1 | 3.3 |
| 07 07 | Dosch Ditch-Cedar Creek [c] | 4.8 | 2.9 | 0.6 | 1.5 | 1.5 | 2.2 | 2.5 | 3.0 | 2.8 | 0.6 | 3.2 | 2.5 |
| 08 01 | Hursey Ditches-Bear Creek | 3.4 | 1.9 | 0.4 | 1.7 | 1.1 | 2.4 | 2.4 | 2.8 | 2.7 | 0.4 | 3.3 | 2.3 |
| 08 02 | Metcalf Ditch-St. Joseph River | 3.9 | 2.7 | 0.5 | 1.7 | 1.1 | 2.4 | 2.6 | 3.2 | 3.9 | 0.5 | **4.9** | 2.2 |
| 08 03 | Swartz Carnahan Ditch-St. Joseph River | 2.3 | 1.7 | 0.3 | 0.8 | 0.7 | 1.1 | 1.3 | 1.7 | 1.7 | 0.2 | 2.1 | 1.3 |
| 08 04 | Cedarville Reservoir-St. Joseph River | 2.4 | 1.3 | --[a] | 0.6 | --[a] | 1.1 | 1.2 | 1.7 | 2.0 | --[a] | 2.0 | 1.3 |
| 08 05 | Ely Run-St. Joseph River | 3.5 | 1.7 | 0.4 | 1.0 | 1.3 | 1.5 | 1.7 | 1.8 | 2.2 | 0.3 | 2.3 | 1.8 |
| 08 06 | Becketts Run-St. Joseph River [c] | 2.7 | 0.8 | 0.3 | 0.5 | 0.8 | 0.9 | 1.1 | 1.0 | 1.1 | 0.3 | 1.2 | 0.9 |

*Notes*

EFWBSJR = East Fork West Branch St. Joseph River; T = Annex 4 spring total phosphorus target; WFWBSJR = West Fork West Branch St. Joseph River.

Bolded blue values exceed the Annex 4 target loads.

a. A negative load was calculated, possibly due to settling in the Cedarville Reservoir.

b. Ohio EPA is developing a TP TMDL at one site impaired by nutrient enrichment in each of these two HUC-12 subwatersheds (Ohio EPA, 2015).

c. IDEM (2017) developed a TP TMDL at the outlet or within each of these 8 HUC-12 subwatersheds to address segments impaired by nutrients, with impaired biotic communities, or impaired by dissolved oxygen.

Table C-8. SJRW HUC-12 subwatershed simulated existing annual TP loads (MT/WY)

| HUC-12 | HUC-12 name | T | ‘05 | ‘06 | ‘07 | ‘08 | ‘09 | ‘10 | ‘11 | ‘12 | ‘13 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 01 | Pittsford Millpond-East Branch St. Joseph River | 9.8 | 1.9 | 3.0 | 4.0 | 6.4 | 3.1 | 3.8 | 2.8 | 4.1 | 2.4 |
| 01 02 | Anderson Drain-East Branch St. Joseph River | 7.8 | 1.9 | 3.7 | 4.3 | 5.7 | 2.8 | 2.9 | 3.2 | 3.8 | 2.4 |
| 01 03 | Laird Creek | 5.5 | 1.6 | 2.8 | 3.3 | 5.1 | 2.4 | 2.5 | 3.0 | 3.5 | 1.8 |
| 01 04 | Bird Creek-East Branch St. Joseph River | 9.6 | 2.6 | 4.5 | 5.5 | 7.7 | 3.5 | 3.7 | 4.4 | 5.0 | 2.9 |
| 01 05 | Silver Creek | 9.4 | 2.2 | 3.9 | 4.8 | 8.3 | 4.0 | 3.8 | 4.4 | 5.7 | 2.6 |
| 01 06 | Clear Fork-East Branch St. Joseph River | 17.3 | 4.5 | 7.4 | 8.5 | 13.0 | 6.5 | 7.1 | 8.5 | 8.4 | 5.7 |
| 02 01 | Cambia Millpond-EFWBSJR | 9.2 | 1.8 | 2.9 | 4.2 | 6.1 | 3.0 | 3.5 | 3.3 | 4.1 | 2.6 |
| 02 02 | EFWBSJR | 7.6 | 1.6 | 2.8 | 3.6 | 5.3 | 2.4 | 2.9 | 3.6 | 3.9 | 2.1 |
| 02 03 | WFWBSJR | 17.4 | 4.2 | 6.1 | 8.1 | 12.9 | 6.5 | 6.8 | 7.1 | 8.6 | 5.8 |
| 02 04 | West Branch St. Joseph River [b] | 5.6 | 1.3 | 2.3 | 2.6 | 4.4 | 1.9 | 2.1 | 2.6 | 2.6 | 1.5 |
| 03 01 | Nettle Creek | 12.6 | 3.9 | 5.6 | 7.0 | 10.6 | 5.2 | 5.5 | 6.8 | 7.1 | 4.6 |
| 03 02 | Cogswell Cemetery-St. Joseph River | 3.4 | 0.6 | 1.3 | 1.3 | 1.6 | 0.8 | 1.1 | 1.4 | 1.1 | 0.6 |
| 03 03 | Eagle Creek [b] | 12 | 3.8 | 5.5 | 8.3 | 11.6 | 5.1 | 5.9 | 7.2 | 7.3 | 4.7 |
| 03 04 | Village of Montpelier-St. Joseph River | 7.8 | 4.1 | 5.7 | 5.9 | 5.4 | 4.0 | 4.3 | 4.8 | 4.5 | 2.7 |
| 03 05 | Bear Creek | 8.2 | 3.0 | 3.8 | 5.9 | 6.4 | 4.1 | 4.0 | 4.8 | 4.7 | 3.5 |
| 03 06 | West Buffalo Cemetery-St. Joseph River | 4.4 | 0.8 | 1.4 | 2.0 | 1.4 | 0.9 | 1.3 | 1.7 | 1.9 | 0.7 |
| 04 01 | West Branch Fish Creek | 5.4 | 1.8 | 2.1 | 3.5 | 6.2 | 2.9 | 2.2 | 2.6 | 3.2 | 2.6 |
| 04 02 | Headwaters Fish Creek | 4.6 | 1.1 | 1.8 | 2.5 | 4.0 | 1.7 | 1.8 | 2.0 | 2.4 | 1.4 |
| 04 03 | Hamilton Lake | 5.9 | 1.7 | 2.3 | 3.7 | 5.4 | 2.8 | 2.4 | 2.8 | 3.1 | 2.6 |
| 04 04 | Hiram Sweet Ditch | 7.9 | 2.2 | 3.3 | 4.6 | 6.2 | 3.6 | 3.1 | 3.5 | 4.0 | 3.2 |
| 04 05 | Town of Alvarado-Fish Creek [c] | 5.4 | 1.1 | 1.8 | 3.1 | 3.9 | 1.9 | 2.0 | 2.4 | 2.8 | 1.5 |
| 04 06 | Cornell Ditch-Fish Creek [c] | 8.3 | 1.8 | 3.0 | 4.6 | 5.3 | 3.0 | 3.5 | 4.0 | 4.4 | 2.7 |
| 05 01 | Bluff Run- St. Joseph River | 8.2 | 5.5 | 6.2 | 8.1 | 8.2 | 6.8 | 6.6 | 7.2 | 7.6 | 6.0 |
| 05 02 | Big Run | 11 | 3.6 | 4.6 | 6.5 | 8.1 | 5.1 | 5.3 | 6.0 | 5.9 | 5.6 |

| HUC-12 | HUC-12 name | T | ‘05 | ‘06 | ‘07 | ‘08 | ‘09 | ‘10 | ‘11 | ‘12 | ‘13 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 05 03 | Russell Run-St. Joseph River | 5.7 | 1.1 | 1.4 | 2.2 | 2.3 | 1.3 | 1.3 | 1.7 | 1.8 | 1.2 |
| 05 04 | Buck Creek | 6.3 | 2.3 | 2.8 | 4.2 | 5.2 | 3.1 | 2.8 | 3.1 | 3.0 | 3.6 |
| 05 05 | Willow Run-St. Joseph River | 5.1 | 1.4 | 1.5 | 2.7 | 3.1 | 1.7 | 1.7 | 1.9 | 1.9 | 2.0 |
| 05 06 | Sol Shank Ditch-St. Joseph River | 9.1 | 3.0 | 3.6 | 5.1 | 6.0 | 4.2 | 3.8 | 3.7 | 3.8 | 4.3 |
| 06 01 | Cedar Lake-Cedar Creek [c] | 9.2 | 2.7 | 3.1 | 4.8 | 7.5 | 4.7 | 3.9 | 3.4 | 4.7 | 3.9 |
| 06 02 | Dibbling Ditch-Cedar Creek [c] | 9.3 | 3.2 | 3.8 | 5.7 | 7.0 | 5.1 | 4.3 | 4.1 | 4.3 | 4.8 |
| 06 03 | Matson Ditch [c] | 5.9 | 1.6 | 2.1 | 3.2 | 3.7 | 2.5 | 2.4 | 2.3 | 2.5 | 2.3 |
| 06 04 | Smith Ditch-Cedar Creek | 7.8 | 2.6 | 3.0 | 4.0 | 4.4 | 3.4 | 3.0 | 3.1 | 2.9 | 2.9 |
| 07 01 | Headwaters John Diehl Ditch | 6.8 | 2.1 | 2.2 | 4.0 | 4.5 | 3.3 | 2.4 | 2.5 | 3.1 | 3.0 |
| 07 02 | Peckhart Ditch-John Diehl Ditch [c] | 6.5 | 2.3 | 2.7 | 4.0 | 4.5 | 3.3 | 2.8 | 2.8 | 2.7 | 3.4 |
| 07 03 | Sycamore Creek-Little Cedar Creek | 8.2 | 3.5 | 3.5 | 6.1 | 6.3 | 4.6 | 3.5 | 3.5 | 4.3 | 3.9 |
| 07 04 | Black Creek | 8.2 | 3.3 | 3.5 | 5.8 | 6.4 | 4.4 | 3.5 | 3.2 | 4.4 | 4.6 |
| 07 05 | King Lake-Little Cedar Creek | 7.3 | 2.7 | 2.7 | 4.6 | 4.6 | 3.6 | 2.4 | 2.9 | 3.1 | 2.5 |
| 07 06 | Willow Creek | 10.9 | 3.8 | 4.6 | 6.6 | 7.6 | 5.5 | 4.2 | 4.1 | 5.1 | 6.0 |
| 07 07 | Dosch Ditch-Cedar Creek [c] | 13 | 3.5 | 3.8 | 5.8 | 6.8 | 5.0 | 4.2 | 3.7 | 4.5 | 4.6 |
| 08 01 | Hursey Ditches-Bear Creek | 9.3 | 3.2 | 3.9 | 5.9 | 6.4 | 4.6 | 3.8 | 3.6 | 4.3 | 4.8 |
| 08 02 | Metcalf Ditch-St. Joseph River | 10.8 | 3.4 | 3.9 | 6.6 | 6.9 | 4.9 | 4.5 | 5.1 | 5.1 | 6.2 |
| 08 03 | Swartz Carnahan Ditch-St. Joseph River | 6.3 | 1.9 | 2.1 | 3.3 | 3.9 | 2.6 | 2.2 | 2.2 | 2.6 | 3.0 |
| 08 04 | Cedarville Reservoir-St. Joseph River | 6.8 | --[a] | 1.8 | 2.2 | 3.8 | 2.5 | 2.2 | --[a] | --[a] | 0.1 |
| 08 05 | Ely Run-St. Joseph River | 9.8 | 2.3 | 2.7 | 4.5 | 4.3 | 3.6 | 2.7 | 2.9 | 3.2 | 3.4 |
| 08 06 | Becketts Run-St. Joseph River [c] | 6.4 | 1.2 | 1.4 | 2.3 | 2.0 | 2.0 | 1.6 | 1.5 | 1.5 | 1.7 |

*Notes*

EFWBSJR = East Fork West Branch St. Joseph River; T = Annex 4 annual total phosphorus target; WFWBSJR = West Fork West Branch St. Joseph River.

**Bolded blue** values exceed the Annex 4 target loads.

a. A negative load was calculated, possibly due to settling in the Cedarville Reservoir.

a. Ohio EPA is developing a TP TMDL at one site impaired by nutrient enrichment in each of these two HUC-12 subwatersheds (Ohio EPA, 2015).

c. IDEM (2017) developed a TP TMDL at the outlet or within each of these 8 HUC-12 subwatersheds to address segments impaired by nutrients, with impaired biotic communities, or impaired by dissolved oxygen.

# C-5.0 KEY FINDINGS

The evaluations of Annex 4 translated targets, simulated existing loads, and hypothetical TMDL target loads (i.e., hypothetical TMDLs developed for all subwatersheds) for the SJRW HUC-12 subwatersheds generally indicate that hypothetical TMDL target loads are more protective than Annex 4 translated targets in drier years, and Annex 4 translated targets are more protective than hypothetical TMDL target loads in wetter years.

## C-5.1 DIFFERENCES WITH THE ALLOWABLE LOADS

Annex 4 translated targets for the SJRW HUC-12 subwatersheds are static, maximum allowable loads, while hypothetical TMDL target loads (assuming hypothetical TMDLs were developed for all 45 HUC-12 subwatersheds) are dynamic because TMDLs are concentration-based and vary with flow. Generally, in drier springs and drier WYs, the hypothetical TMDL target loads are more stringent (i.e., smaller allowable loads) than Annex 4 translated targets. For example, refer to the drier springs of 2005, 2006, and 2007 in Table C-5 and drier WYs 2005, 2006, and 2009-2014 in Table C-6.

Because hypothetical TMDL target loads vary by flow, wetter years yield larger loads. The baseline year for Annex 4 (WY 2008) in the SJRW was a wet year and had a wet spring. As shown in Table C-5 and Table C-6, hypothetical TMDL target loads in WY 2008 are larger than the Annex 4 translated targets in the spring and WY.

## C-5.2 DIFFERENCES WITH TMDLS

IDEM (2017) developed six TP TMDLs in Indiana and Ohio EPA (2015) is developing two TP TMDLs in Ohio to address in-stream impairments of biological communities. Most HUC-12 subwatersheds whose simulated existing spring or annual TP loads exceed the respective Annex 4 translated TP targets do not have TMDLs. Thus, implementing TMDLs (to address both the TMDLs and Annex 4 translated targets) will not address the clear majority of subwatersheds in the SJRW (including those whose existing loads exceed the Annex 4 translated targets) because no TMDLs were developed.

Simulated existing spring loads most often exceeded Annex 4 translated spring targets in the springs of 2008, 2011, and 2013 (Section C-4.4); simulated existing WY loads exceeded Annex 4 translated WY targets in only one HUC-12 subwatershed in one WY (Section C-4.4). In the springs of 2008 and 2011, of the subwatersheds whose simulated existing spring loads exceed the Annex 4 translated spring targets (primarily in Ohio and Michigan), only two subwatersheds are expected to receive TP TMDLs: *West Branch St. Joseph River* (*02 04) and *Eagle Creek* (*03 03). In 2013, of the six Indiana subwatersheds whose simulated existing spring loads exceed the Annex 4 translated spring targets, only one subwatershed received a TMDL (IDEM 2017): *Dibbling Ditch-Cedar Creek* (*06 02).

# C-6.0 REFERENCES

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# APPENDIX D. TIFFIN RIVER WATERSHED EVALUATIONS

## CONTENT

## TABLES

# ACROMYMNS

| Acronyms/Abbreviations | Definition |
|---|---|
| MDEQ | Michigan Department of Environmental Quality |
| Ohio EPA | Ohio Environmental Protection Agency |
| SRP | soluble reactive phosphorus |
| TMDL | total maximum daily load |
| TP | total phosphorus |
| TR-SWAT | Tiffin River Soil and Water Assessment Tool |
| TRW | Tiffin River watershed |
| USGS | U.S. Geological Survey (U.S. Department of the Interior) |
| WY | water year |

| Unit of measure | Definition |
|---|---|
| ac-ft | acre-feet |
| mg/L | milligram per liter |
| MT | metric ton (1,000 kilograms) |
| MT/spring | metric ton per spring (March 1st through July 31st) |
| MT/y | metric ton per year |

# D-1.0 AVAILABLE DATA

Flow monitoring data in the Tiffin River watershed (TRW) are available from four continuous recording U.S. Geological Survey (USGS) gages. Three of these have daily stream discharge information that cover the period examined as part of the Methodology development (i.e., water years [WY] 2002 – 2016). These locations are:

- Bean Creek at Powers
- Tiffin River at Stryker
- Lost Creek tributary near Farmer.

The fourth gage (Tiffin River near Evansport) was installed in October 2013. Flow estimates were also developed by the Ohio Environmental Protection Agency (Ohio EPA) from measurements on key tributaries during their 2012 – 2014 water quality survey of the TRW.

Total phosphorus (TP) and soluble reactive phosphorus (SRP) monitoring data in the TRW are available at sites sampled by Ohio EPA, the Michigan Department of Environmental Quality (MDEQ), the USGS, and the National Center for Water Quality Research (NCWQR). Data frequency and quality vary by site.

- Ohio EPA routinely samples two fixed station ambient sites (Bean Creek at Powers, Tiffin River at Stryker). Ohio EPA also conducted a water quality survey from 2012 to 2014 at multiple locations across their portion of the TRW.
- MDEQ supported 2016 - 2017 water quality sampling at several sites in their portion of the Bean Creek watershed.
- USGS initiated routine monitoring in 2014 at one location in the TRW (Tiffin River at Evansport).
- NCWQR operates two water quality monitoring stations in the TRW: Tiffin River at Stryker and Lost Creek tributary near Farmer.

A Tiffin River Soil & Water Assessment Tool (TR-SWAT) model was developed for the TRW using USGS and NCWQR data (LimnoTech 2013). The TR-SWAT model simulated flow, total suspended solids (TSS), TP, SRP, and total nitrogen (TN) for the period 2001 – 2011. The TR-SWAT model delineated the 26 TRW HUC-12 subwatersheds into 907 catchments with an average area of 540 acres.

# D-2.0 DEVELOPMENT OF ANNEX 4 TRANSLATED TARGETS

Targets consistent with the goals of Annex 4 were developed for each HUC-12 subwatershed in the TRW following the same methodology that targets were developed for the TRW HUC-8 watershed.

## D-2.1 SUMMARY OF TRW HUC-8 WATERSHED TARGET DEVELOPMENT

As discussed in Section 2 of the main report, targets for the TRW were calculated by distributing the Annex 4 targets for the Maumee River at Waterville to the tributary HUC-8 watersheds using a flow-weighting of the WY 2002 through 2016 total spring and total WY flows. Total spring flow in the TRW is 10.15 percent of the total spring flow measured in the Maumee River at Waterville. With spring targets at Waterville of 860 MT TP and 186 MT SRP (Great Lakes Water Quality Agreement 2015), the TRW spring targets are 87 MT TP and 19 MT SRP. Total annual/WY flow in the TRW is 9.68 percent of the total annual flow measured at Waterville. The annual Waterville target of 2,288 MT TP (U.S. Environmental Protection Agency 2017) yields a TRW annual target of 221 MT TP.

## D-2.2 DEVELOPMENT OF TRW HUC-12 SUBWATERSHED TARGETS

The TRW HUC-8 watershed target loads were distributed to the TRW HUC-12 subwatersheds using a flow-weighting approach in the exact same manner that the Annex 4 targets for the Maumee River at Waterville were distributed to the tributary HUC-8 watersheds using a flow-weighting approach. The Work Group evaluated several potential target-setting methods (i.e., area-, flow-, and load-based) and selected the flow-based approach as the fairest and most appropriate approach, given the available data.

### D-2.2.1 Development of Flow-Weighting

Unit area flows were estimated for each subwatershed for each spring and WY using the unit area flow of a nearby USGS gage. Spring and WY unit area flows for each subwatershed were multiplied by the drainage area of each subwatershed to determine the total (cumulative) spring and annual flows. The flow-weighting was calculated by dividing the total (cumulative) annual flows from all 15 WYs for each subwatershed by the total 15-WY flow of the TRW. The flow-weighting for each of 26 HUC-12 subwatersheds in the TRW is presented in Table D-1.

Table D-1. Relative flow for each HUC-12 subwatershed in the TRW

| HUC-12 | HUC-12 name | Area (sq. mi.) | Annual flow | | Spring flow | |
|---|---|---|---|---|---|---|
| | | | Total flow (ac-ft) | Relative flow [a] | Total flow (ac-ft) | Relative flow [a] |
| 01 01 | Bowen Drain-Bean Creek | 17.8 | 12,815 | 2.40% | 7,178 | 2.38% |
| 01 02 | Branch Creek-Bean Creek | 26.9 | 19,333 | 3.62% | 10,829 | 3.60% |
| 01 03 | Round Creek-Bean Creek | 18.5 | 13,324 | 2.49% | 7,463 | 2.48% |
| 01 04 | Saint Joseph Creek-Bean Creek | 31.4 | 22,574 | 4.22% | 12,645 | 4.20% |
| 01 05 | Lime Creek | 42.6 | 30,695 | 5.74% | 17,193 | 5.71% |
| 01 06 | Covell Drain-Bean Creek | 46.4 | 33,409 | 6.25% | 18,714 | 6.22% |
| 02 01 | Silver Creek-Bean Creek | 21.6 | 15,539 | 2.91% | 8,704 | 2.89% |
| 02 02 | Deer Creek-Bean Creek | 31.7 | 21,436 | 4.01% | 12,092 | 4.02% |
| 02 03 | Old Bean Creek | 33.3 | 22,510 | 4.21% | 12,698 | 4.22% |
| 02 04 | Mill Creek | 40.7 | 27,504 | 5.14% | 15,515 | 5.15% |
| 02 05 | Stag Run-Bean Creek | 14.4 | 9,760 | 1.83% | 5,506 | 1.83% |
| 03 01 | Bates Creek-Tiffin River | 29.2 | 19,784 | 3.70% | 11,160 | 3.71% |
| 03 02 | Leatherwood Creek | 17.3 | 11,712 | 2.19% | 6,607 | 2.19% |
| 03 03 | Flat Run-Tiffin River | 33.1 | 22,411 | 4.19% | 12,642 | 4.20% |
| 04 01 | Upper Lick Creek | 27.9 | 18,898 | 3.53% | 10,661 | 3.54% |
| 04 02 | Middle Lick Creek | 30.8 | 20,848 | 3.90% | 11,760 | 3.91% |
| 04 03 | Prairie Creek | 29.7 | 20,124 | 3.76% | 11,352 | 3.77% |
| 04 04 | Lower Lick Creek | 17.4 | 11,749 | 2.20% | 6,627 | 2.20% |
| 05 01 | Beaver Creek | 45.1 | 30,480 | 5.70% | 17,194 | 5.71% |
| 05 02 | Brush Creek | 65.9 | 44,600 | 8.34% | 25,159 | 8.36% |
| 05 03 | Village of Stryker-Tiffin River | 25.2 | 17,057 | 3.19% | 9,622 | 3.20% |
| 05 04 | Coon Creek-Tiffin River | 30.2 | 20,415 | 3.82% | 11,516 | 3.83% |
| 06 01 | Lost Creek | 32.3 | 21,834 | 4.08% | 12,316 | 4.09% |
| 06 02 | Mud Creek | 26.6 | 17,971 | 3.36% | 10,137 | 3.37% |
| 06 03 | Webb Run | 20.4 | 13,779 | 2.58% | 7,773 | 2.58% |
| 06 04 | Buckskin Creek-Tiffin River | 20.9 | 14,164 | 2.65% | 7,990 | 2.65% |

*Notes*

a. The total annual or total spring flow of the HUC-12 subwatershed relative to the total annual or total spring flow at the outlet of the TRW.

## D-2.2.2 Development of Targets

The TRW HUC-8 watershed load targets were distributed to the 26 HUC-12 subwatersheds using the flow-weighting discussed in Section D-2.2.1. For this methodology, the targets were rounded to the nearest one-tenth of a MT (Table D-2).

Table D-2. HUC-12 subwatershed targets

| HUC-12 | HUC-12 name | Annual TP (MT/WY) | Spring TP (MT/spring) | Spring SRP (MT/spring) |
|---|---|---|---|---|
| 01 01 | Bowen Drain-Bean Creek | 5.3 | 2.1 | 0.5 |
| 01 02 | Branch Creek-Bean Creek | 8.0 | 3.1 | 0.7 |
| 01 03 | Round Creek-Bean Creek | 5.5 | 2.2 | 0.5 |
| 01 04 | Saint Joseph Creek-Bean Creek | 9.3 | 3.7 | 0.8 |
| 01 05 | Lime Creek | 12.7 | 5.0 | 1.1 |
| 01 06 | Covell Drain-Bean Creek | 13.8 | 5.4 | 1.2 |
| 02 01 | Silver Creek-Bean Creek | 6.4 | 2.5 | 0.5 |
| 02 02 | Deer Creek-Bean Creek | 8.9 | 3.5 | 0.8 |
| 02 03 | Old Bean Creek | 9.3 | 3.7 | 0.8 |
| 02 04 | Mill Creek | 11.4 | 4.5 | 1.0 |
| 02 05 | Stag Run-Bean Creek | 4.0 | 1.6 | 0.3 |
| 03 01 | Bates Creek-Tiffin River | 8.2 | 3.2 | 0.7 |
| 03 02 | Leatherwood Creek | 4.8 | 1.9 | 0.4 |
| 03 03 | Flat Run-Tiffin River | 9.3 | 3.7 | 0.8 |
| 04 01 | Upper Lick Creek | 7.8 | 3.1 | 0.7 |
| 04 02 | Middle Lick Creek | 8.6 | 3.4 | 0.7 |
| 04 03 | Prairie Creek | 8.3 | 3.3 | 0.7 |
| 04 04 | Lower Lick Creek | 4.9 | 1.9 | 0.4 |
| 05 01 | Beaver Creek | 12.6 | 5.0 | 1.1 |
| 05 02 | Brush Creek | 18.4 | 7.3 | 1.6 |
| 05 03 | Village of Stryker-Tiffin River | 7.0 | 2.8 | 0.6 |
| 05 04 | Coon Creek-Tiffin River | 8.4 | 3.3 | 0.7 |
| 06 01 | Lost Creek | 9.0 | 3.6 | 0.8 |
| 06 02 | Mud Creek | 7.4 | 2.9 | 0.6 |
| 06 03 | Webb Run | 5.7 | 2.2 | 0.5 |
| 06 04 | Buckskin Creek-Tiffin River | 5.9 | 2.3 | 0.5 |

# D-3.0 EVALUATION OF ANNEX 4 TRANSLATED TARGETS WITH TMDLS

Annex 4 translated TP targets developed for the TRW's HUC-12 subwatersheds were compared with hypothetical total maximum daily load (TMDL) target loads developed for all 26 subwatersheds in the TRW. SRP was not evaluated because there is no TMDL target for SRP.

## D-3.1 HYPOTHETICAL TMDL CONDITIONS

To calculate hypothetical TMDL target loads for each HUC-12 subwatershed, estimated unit area flows for each spring and each WY (2002-2016) were multiplied by the subwatershed area and appropriate TMDL target. The TP TMDL target for Ohio is 0.08 milligrams per liter (mg/L) for headwaters-sized streams, 0.10 mg/L for wading-sized streams, and 0.17 mg/L for small rivers; these targets were applied to the subwatersheds within Ohio.

The spring and annual TP target loads representing hypothetical TMDLs for each of the 26 HUC-12 subwatersheds in the TRW are presented in Table D-3 and Table D-4, respectively. For this methodology, the TP target loads were rounded to the nearest one-hundredth of a MT.

## D-3.2 TOTAL PHOSPHORUS TARGETS

Hypothetical TMDL target loads never exceed the Annex 4 translated spring targets (Table D-3) or annual targets (Table D-4) in any of the 26 HUC-12 subwatersheds in the TRW. The hypothetical TMDL target loads are frequently less than half of the Annex 4 translated spring targets.

Table D-1. HUC-12 subwatershed hypothetical TMDL spring TP target loads (MT/spring)

| HUC-12 | HUC-12 name | T | ‘02 | ‘03 | ‘04 | ‘05 | ‘06 | ‘07 | ‘08 | ‘09 | ‘10 | ‘11 | ‘12 | ‘13 | ‘14 | ‘15 | ‘16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 01 | Bowen Drain-Bean Creek | *no hypothetical TMDLs developed for Michigan HUC-12s* | | | | | | | | | | | | | | | |
| 01 02 | Branch Creek-Bean Creek | | | | | | | | | | | | | | | | |
| 01 03 | Round Creek-Bean Creek | | | | | | | | | | | | | | | | |
| 01 04 | Saint Joseph Creek-Bean Creek | | | | | | | | | | | | | | | | |
| 01 05 | Lime Creek | | | | | | | | | | | | | | | | |
| 01 06 | Covell Drain-Bean Creek | | | | | | | | | | | | | | | | |
| 02 01 | Silver Creek-Bean Creek | 2.5 | 1.69 | 0.93 | 1.35 | 0.78 | 1.45 | 1.36 | 2.30 | 2.27 | 2.09 | 2.35 | 0.85 | 1.39 | 1.91 | 1.78 | 1.14 |
| 02 02 | Deer Creek-Bean Creek [a] | 3.5 | 2.87 | 1.61 | 1.92 | 0.98 | 2.15 | 1.68 | 2.87 | 2.93 | 2.84 | 3.44 | 1.10 | 1.95 | 2.30 | 2.52 | 1.70 |
| 02 03 | Old Bean Creek | 3.7 | 1.77 | 0.99 | 1.19 | 0.61 | 1.33 | 1.04 | 1.77 | 1.81 | 1.75 | 2.13 | 0.68 | 1.20 | 1.42 | 1.55 | 1.05 |
| 02 04 | Mill Creek [a] | 4.5 | 2.17 | 1.21 | 1.45 | 0.74 | 1.62 | 1.27 | 2.17 | 2.21 | 2.14 | 2.60 | 0.83 | 1.47 | 1.73 | 1.90 | 1.28 |
| 02 05 | Stag Run-Bean Creek | 1.6 | 1.31 | 0.73 | 0.87 | 0.45 | 0.98 | 0.77 | 1.31 | 1.33 | 1.29 | 1.57 | 0.50 | 0.89 | 1.05 | 1.15 | 0.77 |
| 03 01 | Bates Creek-Tiffin River | 3.2 | 2.65 | 1.48 | 1.77 | 0.90 | 1.98 | 1.55 | 2.65 | 2.70 | 2.62 | 3.18 | 1.02 | 1.80 | 2.12 | 2.32 | 1.57 |
| 03 02 | Leatherwood Creek | 1.9 | 0.92 | 0.52 | 0.62 | 0.31 | 0.69 | 0.54 | 0.92 | 0.94 | 0.91 | 1.11 | 0.35 | 0.63 | 0.74 | 0.81 | 0.55 |
| 03 03 | Flat Run-Tiffin River | 3.7 | 3.00 | 1.68 | 2.01 | 1.02 | 2.25 | 1.76 | 3.00 | 3.06 | 2.97 | 3.60 | 1.15 | 2.04 | 2.40 | 2.63 | 1.78 |
| 04 01 | Upper Lick Creek [a] | 3.1 | 1.49 | 0.83 | 1.00 | 0.51 | 1.11 | 0.87 | 1.49 | 1.52 | 1.47 | 1.78 | 0.57 | 1.01 | 1.19 | 1.31 | 0.88 |
| 04 02 | Middle Lick Creek [a] | 3.4 | 1.64 | 0.92 | 1.10 | 0.56 | 1.23 | 0.96 | 1.64 | 1.67 | 1.63 | 1.97 | 0.63 | 1.11 | 1.31 | 1.44 | 0.97 |
| 04 03 | Prairie Creek [a] | 3.3 | 1.59 | 0.89 | 1.06 | 0.54 | 1.19 | 0.93 | 1.59 | 1.62 | 1.57 | 1.90 | 0.61 | 1.08 | 1.27 | 1.39 | 0.94 |
| 04 04 | Lower Lick Creek | 1.9 | 0.93 | 0.52 | 0.62 | 0.32 | 0.69 | 0.54 | 0.93 | 0.94 | 0.92 | 1.11 | 0.35 | 0.63 | 0.74 | 0.81 | 0.55 |
| 05 01 | Beaver Creek | 5.0 | 2.40 | 1.34 | 1.61 | 0.82 | 1.80 | 1.41 | 2.40 | 2.45 | 2.38 | 2.88 | 0.92 | 1.63 | 1.92 | 2.10 | 1.42 |
| 05 02 | Brush Creek [a] | 7.3 | 3.52 | 1.97 | 2.35 | 1.20 | 2.63 | 2.06 | 3.52 | 3.58 | 3.48 | 4.21 | 1.35 | 2.38 | 2.81 | 3.08 | 2.08 |
| 05 03 | Village of Stryker-Tiffin River | 2.8 | 2.29 | 1.28 | 1.53 | 0.78 | 1.71 | 1.34 | 2.29 | 2.33 | 2.26 | 2.74 | 0.88 | 1.55 | 1.83 | 2.00 | 1.35 |
| 05 04 | Coon Creek-Tiffin River | 3.3 | 2.74 | 1.53 | 1.83 | 0.93 | 2.05 | 1.60 | 2.74 | 2.79 | 2.71 | 3.28 | 1.05 | 1.86 | 2.19 | 2.40 | 1.62 |
| 06 01 | Lost Creek | 3.6 | 1.72 | 0.96 | 1.15 | 0.59 | 1.29 | 1.01 | 1.72 | 1.75 | 1.70 | 2.06 | 0.66 | 1.17 | 1.38 | 1.51 | 1.02 |

| HUC-12 | HUC-12 name | T | ‘02 | ‘03 | ‘04 | ‘05 | ‘06 | ‘07 | ‘08 | ‘09 | ‘10 | ‘11 | ‘12 | ‘13 | ‘14 | ‘15 | ‘16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 06 02 | Mud Creek [a] | 2.9 | 1.42 | 0.79 | 0.95 | 0.48 | 1.06 | 0.83 | 1.42 | 1.44 | 1.40 | 1.70 | 0.54 | 0.96 | 1.13 | 1.24 | 0.84 |
| 06 03 | Webb Run | 2.2 | 1.09 | 0.61 | 0.73 | 0.37 | 0.81 | 0.64 | 1.09 | 1.11 | 1.07 | 1.30 | 0.42 | 0.74 | 0.87 | 0.95 | 0.64 |
| 06 04 | Buckskin Creek-Tiffin River | 2.3 | 1.90 | 1.06 | 1.27 | 0.65 | 1.42 | 1.11 | 1.90 | 1.93 | 1.88 | 2.27 | 0.73 | 1.29 | 1.52 | 1.66 | 1.12 |

*Note*

T = Annex 4 translated spring total phosphorus target.

a. Ohio EPA is developing one or two TMDLs at sites impaired by nutrient enrichment in these seven HUC-12 subwatersheds (Ohio EPA, 2015).

Table D-2. HUC-12 subwatershed hypothetical TMDL annual TP target loads (MT/y)

| HUC-12 | HUC-12 name | T | ‘02 | ‘03 | ‘04 | ‘05 | ‘06 | ‘07 | ‘08 | ‘09 | ‘10 | ‘11 | ‘12 | ‘13 | ‘14 | ‘15 | ‘16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 01 | Bowen Drain-Bean Creek | *no hypothetical TMDLs developed for Michigan HUC-12s* | | | | | | | | | | | | | | | |
| 01 02 | Branch Creek-Bean Creek | | | | | | | | | | | | | | | | |
| 01 03 | Round Creek-Bean Creek | | | | | | | | | | | | | | | | |
| 01 04 | Saint Joseph Creek-Bean Creek | | | | | | | | | | | | | | | | |
| 01 05 | Lime Creek | | | | | | | | | | | | | | | | |
| 01 06 | Covell Drain-Bean Creek | | | | | | | | | | | | | | | | |
| 02 01 | Silver Creek-Bean Creek | 6.4 | 3.02 | 1.26 | 2.31 | 2.38 | 2.97 | 3.85 | 4.47 | 3.61 | 2.93 | 2.92 | 3.39 | 1.81 | 2.89 | 2.12 | 1.71 |
| 02 02 | Deer Creek-Bean Creek [a] | 8.9 | 5.42 | 1.99 | 3.24 | 3.41 | 4.15 | 5.03 | 5.88 | 4.38 | 3.77 | 4.08 | 4.73 | 2.50 | 3.50 | 2.88 | 2.46 |
| 02 03 | Old Bean Creek | 9.3 | 3.35 | 1.23 | 2.00 | 2.11 | 2.56 | 3.11 | 3.63 | 2.71 | 2.33 | 2.52 | 2.92 | 1.54 | 2.16 | 1.78 | 1.52 |
| 02 04 | Mill Creek [a] | 11.4 | 4.09 | 1.50 | 2.44 | 2.57 | 3.13 | 3.80 | 4.44 | 3.31 | 2.84 | 3.08 | 3.57 | 1.89 | 2.64 | 2.17 | 1.86 |
| 02 05 | Stag Run-Bean Creek | 4.0 | 2.47 | 0.91 | 1.47 | 1.55 | 1.89 | 2.29 | 2.68 | 1.99 | 1.72 | 1.86 | 2.16 | 1.14 | 1.59 | 1.31 | 1.12 |
| 03 01 | Bates Creek-Tiffin River | 8.2 | 5.00 | 1.84 | 2.99 | 3.15 | 3.83 | 4.64 | 5.43 | 4.04 | 3.48 | 3.77 | 4.37 | 2.31 | 3.23 | 2.66 | 2.27 |
| 03 02 | Leatherwood Creek | 4.8 | 1.74 | 0.64 | 1.04 | 1.10 | 1.33 | 1.62 | 1.89 | 1.41 | 1.21 | 1.31 | 1.52 | 0.80 | 1.13 | 0.93 | 0.79 |
| 03 03 | Flat Run-Tiffin River | 9.3 | 5.66 | 2.08 | 3.38 | 3.57 | 4.34 | 5.26 | 6.15 | 4.58 | 3.94 | 4.27 | 4.95 | 2.61 | 3.66 | 3.01 | 2.57 |
| 04 01 | Upper Lick Creek [a] | 7.8 | 2.81 | 1.03 | 1.68 | 1.77 | 2.15 | 2.61 | 3.05 | 2.27 | 1.95 | 2.12 | 2.46 | 1.30 | 1.82 | 1.49 | 1.28 |
| 04 02 | Middle Lick Creek [a] | 8.6 | 3.10 | 1.14 | 1.85 | 1.95 | 2.37 | 2.88 | 3.36 | 2.51 | 2.16 | 2.34 | 2.71 | 1.43 | 2.00 | 1.65 | 1.41 |

| HUC-12 | HUC-12 name | T | ‘02 | ‘03 | ‘04 | ‘05 | ‘06 | ‘07 | ‘08 | ‘09 | ‘10 | ‘11 | ‘12 | ‘13 | ‘14 | ‘15 | ‘16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 04 03 | Prairie Creek [a] | 8.3 | 2.99 | 1.10 | 1.79 | 1.88 | 2.29 | 2.78 | 3.25 | 2.42 | 2.08 | 2.25 | 2.61 | 1.38 | 1.93 | 1.59 | 1.36 |
| 04 04 | Lower Lick Creek | 4.9 | 1.75 | 0.64 | 1.04 | 1.10 | 1.34 | 1.62 | 1.90 | 1.41 | 1.21 | 1.32 | 1.53 | 0.81 | 1.13 | 0.93 | 0.79 |
| 05 01 | Beaver Creek | 12.6 | 4.53 | 1.67 | 2.71 | 2.85 | 3.47 | 4.21 | 4.92 | 3.66 | 3.15 | 3.41 | 3.96 | 2.09 | 2.93 | 2.41 | 2.06 |
| 05 02 | Brush Creek [a] | 18.4 | 6.63 | 2.44 | 3.96 | 4.18 | 5.08 | 6.16 | 7.20 | 5.36 | 4.61 | 5.00 | 5.79 | 3.06 | 4.29 | 3.52 | 3.01 |
| 05 03 | Village of Stryker-Tiffin River | 7.0 | 4.31 | 1.59 | 2.58 | 2.71 | 3.30 | 4.00 | 4.68 | 3.49 | 3.00 | 3.25 | 3.77 | 1.99 | 2.79 | 2.29 | 1.96 |
| 05 04 | Coon Creek-Tiffin River | 8.4 | 5.16 | 1.90 | 3.08 | 3.25 | 3.95 | 4.79 | 5.60 | 4.17 | 3.59 | 3.89 | 4.51 | 2.38 | 3.34 | 2.74 | 2.34 |
| 06 01 | Lost Creek | 9.0 | 3.24 | 1.19 | 1.94 | 2.04 | 2.49 | 3.01 | 3.52 | 2.63 | 2.26 | 2.45 | 2.84 | 1.50 | 2.10 | 1.73 | 1.47 |
| 06 02 | Mud Creek [a] | 7.4 | 2.67 | 0.98 | 1.60 | 1.68 | 2.05 | 2.48 | 2.90 | 2.16 | 1.86 | 2.01 | 2.33 | 1.23 | 1.73 | 1.42 | 1.21 |
| 06 03 | Webb Run | 5.7 | 2.05 | 0.75 | 1.22 | 1.29 | 1.57 | 1.90 | 2.22 | 1.66 | 1.42 | 1.54 | 1.79 | 0.95 | 1.32 | 1.09 | 0.93 |
| 06 04 | Buckskin Creek-Tiffin River | 5.9 | 3.58 | 1.32 | 2.14 | 2.25 | 2.74 | 3.32 | 3.89 | 2.90 | 2.49 | 2.70 | 3.13 | 1.65 | 2.31 | 1.90 | 1.63 |

*Note:* T = Annex 4 translated annual total phosphorus target.

a. Ohio EPA is developing one or two TMDLs at sites impaired by nutrient enrichment in these seven HUC-12 subwatersheds (Ohio EPA, 2015).

# D-4.0 ESTIMATION OF EXISTING LOADS

TP and SRP concentration and load datasets are available from multiple entities in the TRW. The datasets were evaluated to determine which dataset(s) may be suitable for estimating existing loads for the TRW at the HUC-8 outlet and HUC-12 outlets.

## D-4.1 COMPARISON OF LOAD ESTIMATIONS

Although existing loads in the TRW are available from the SWAT model of the watershed (LimnoTech 2013). these loads were only accessible to Tetra Tech as an annual average load by catchment for the entire 2001 to 2014 time period. They are therefore not directly comparable to the Annex 4 targets, which must be evaluated on a spring-by-spring and year-by-year basis. Because of this limitation, a relatively simplified approach was made to estimate existing loads at each HUC-12 subwatershed. Loads for each HUC-12 subwatershed were estimated using a drainage area ratio relationship and loads estimate for the Tiffin River at Stryker. The following steps were used:

1. **Estimate TP loads for the Tiffin River near Stryker:** Daily TP loads were calculated using TP concentrations from NCWQR and flows from USGS for the Tiffin River at Stryker. Daily TP loads were integrated to estimate spring and annual TP loads (Table D-5).

Table D-5. Estimated existing TP loads for the Tiffin River near Stryker

| Period | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|
| Spring (MT/spring) | 50 | 105 | 79 | 100 | 45 | 54 | 87 | 72 | 27 |
| Annual (MT/y) | 110 | 200 | 137 | 176 | 191 | 108 | 186 | 84 | 42 |

2. **Estimate TP loads for the Tiffin River at the TRW outlet:** A drainage area ratio was used to estimate the spring and annual TP loads for the Tiffin River at the TRW outlet (777 square miles) using the estimated spring and annual TP loads for the Tiffin River near Stryker (410 square miles).

Table D-6. Estimated existing spring TP loads for the Tiffin River near Stryker and TRW outlet

| Location | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|
| Spring (MT/spring) | 95 | 199 | 150 | 190 | 85 | 103 | 165 | 137 | 50 |
| Annual (MT/y) | 208 | 379 | 259 | 333 | 361 | 204 | 352 | 159 | 79 |

3. **Estimate TP loads for the TRW HUC-12 subwatersheds:** Drainage area ratios were used to estimate spring and annual TP loads for the HUC-12 subwatersheds using the estimate spring and annual TP loads for the Tiffin River at the TRW outlet. Drainage areas of the HUC-12 subwatersheds are presented in Table D-1.

## D-4.2 EVALUATION OF ANNEX 4 TRANSLATED TARGETS WITH ESTIMATED EXISTING LOADS

The estimated existing spring and annual TP loads for each of the 26 HUC-12 subwatersheds in the TRW are presented in Table D-7 and Table D-8, respectively. In both tables, cells with bolded values mean that estimated existing TP loads exceed the Annex 4 translated TP targets.

Estimated existing TP loads in all HUC-12 subwatersheds exceed the Annex 4 translated TP targets in every spring except the springs of 2012 and 2016, which is expected since the estimated existing loads for the TRW outlet exceed in every spring except the springs of 2012 and 2016. Similarly, estimated annual TP loads exceed in every HUC-12 subwatershed in WYs 2009, 2010, 2011, 2012, and 2014. Due to the drainage area weighting methodology, when the estimated existing load for the TRW HUC-8 watershed exceeds its Annex 4 translated targets, all the estimated existing loads for the HUC-12subwatersheds will exceed their Annex 4 translated targets.

Table D-7. TRW HUC-12 subwatershed estimated existing spring TP loads (MT/spring)

| HUC-12 | HUC-12 name | T | '08 | '09 | '10 | '11 | '12 | '13 | '14 | '15 | '16 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 01 | Bowen Drain-Bean Creek | 2.1 | 2.17 | 4.56 | 3.44 | 4.35 | 1.95 | 2.36 | 3.79 | 3.14 | 1.15 |
| 01 02 | Branch Creek-Bean Creek | 3.1 | 3.27 | 6.87 | 5.19 | 6.56 | 2.94 | 3.56 | 5.71 | 4.73 | 1.74 |
| 01 03 | Round Creek-Bean Creek | 2.2 | 2.26 | 4.74 | 3.58 | 4.52 | 2.02 | 2.45 | 3.94 | 3.26 | 1.20 |
| 01 04 | Saint Joseph Creek-Bean Creek | 3.7 | 3.82 | 8.03 | 6.06 | 7.65 | 3.43 | 4.15 | 6.67 | 5.52 | 2.03 |
| 01 05 | Lime Creek | 5.0 | 5.20 | 10.91 | 8.24 | 10.41 | 4.66 | 5.65 | 9.07 | 7.51 | 2.76 |
| 01 06 | Covell Drain-Bean Creek | 5.4 | 5.66 | 11.88 | 8.97 | 11.33 | 5.07 | 6.15 | 9.87 | 8.17 | 3.01 |
| 02 01 | Silver Creek-Bean Creek | 2.5 | 2.63 | 5.52 | 4.17 | 5.27 | 2.36 | 2.86 | 4.59 | 3.80 | 1.40 |
| 02 02 | Deer Creek-Bean Creek [a] | 3.5 | 3.86 | 8.11 | 6.12 | 7.73 | 3.46 | 4.20 | 6.74 | 5.58 | 2.05 |
| 02 03 | Old Bean Creek | 3.7 | 4.06 | 8.52 | 6.43 | 8.12 | 3.64 | 4.41 | 7.08 | 5.86 | 2.16 |
| 02 04 | Mill Creek [a] | 4.5 | 4.96 | 10.41 | 7.85 | 9.92 | 4.44 | 5.38 | 8.65 | 7.16 | 2.64 |
| 02 05 | Stag Run-Bean Creek | 1.6 | 1.76 | 3.69 | 2.79 | 3.52 | 1.58 | 1.91 | 3.07 | 2.54 | 0.94 |
| 03 01 | Bates Creek-Tiffin River | 3.2 | 3.57 | 7.48 | 5.65 | 7.14 | 3.20 | 3.87 | 6.22 | 5.15 | 1.90 |
| 03 02 | Leatherwood Creek | 1.9 | 2.11 | 4.43 | 3.34 | 4.23 | 1.89 | 2.29 | 3.68 | 3.05 | 1.12 |
| 03 03 | Flat Run-Tiffin River | 3.7 | 4.04 | 8.48 | 6.40 | 8.09 | 3.62 | 4.39 | 7.04 | 5.83 | 2.15 |
| 04 01 | Upper Lick Creek [a] | 3.1 | 3.41 | 7.15 | 5.40 | 6.82 | 3.05 | 3.70 | 5.94 | 4.92 | 1.81 |
| 04 02 | Middle Lick Creek [a] | 3.4 | 3.76 | 7.89 | 5.95 | 7.52 | 3.37 | 4.08 | 6.55 | 5.43 | 2.00 |
| 04 03 | Prairie Creek [a] | 3.3 | 3.63 | 7.61 | 5.75 | 7.26 | 3.25 | 3.94 | 6.33 | 5.24 | 1.93 |
| 04 04 | Lower Lick Creek | 1.9 | 2.12 | 4.44 | 3.35 | 4.24 | 1.90 | 2.30 | 3.69 | 3.06 | 1.13 |
| 05 01 | Beaver Creek | 5.0 | 5.49 | 11.53 | 8.70 | 11.00 | 4.92 | 5.97 | 9.58 | 7.94 | 2.92 |
| 05 02 | Brush Creek [a] | 7.3 | 8.04 | 16.87 | 12.74 | 16.09 | 7.21 | 8.73 | 14.02 | 11.61 | 4.27 |
| 05 03 | Village of Stryker-Tiffin River | 2.8 | 3.07 | 6.45 | 4.87 | 6.15 | 2.76 | 3.34 | 5.36 | 4.44 | 1.63 |
| 05 04 | Coon Creek-Tiffin River | 3.3 | 3.68 | 7.72 | 5.83 | 7.37 | 3.30 | 4.00 | 6.42 | 5.32 | 1.96 |
| 06 01 | Lost Creek | 3.6 | 3.93 | 8.26 | 6.23 | 7.88 | 3.53 | 4.27 | 6.86 | 5.68 | 2.09 |
| 06 02 | Mud Creek [a] | 2.9 | 3.24 | 6.80 | 5.13 | 6.48 | 2.90 | 3.52 | 5.65 | 4.68 | 1.72 |

| HUC-12 | HUC-12 name | T | ‘08 | ‘09 | ‘10 | ‘11 | ‘12 | ‘13 | ‘14 | ‘15 | ‘16 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 06 03 | Webb Run | 2.2 | **2.48** | **5.21** | **3.93** | **4.97** | 2.23 | **2.70** | **4.33** | **3.59** | 1.32 |
| 06 04 | Buckskin Creek-Tiffin River | 2.3 | **2.55** | **5.36** | **4.04** | **5.11** | 2.29 | **2.77** | **4.45** | **3.69** | 1.36 |

*Notes*

T = Annex 4 spring total phosphorus target.

**Bolded blue** values exceed the Annex 4 target loads.

a. Ohio EPA is developing one or two TMDLs at sites impaired by nutrient enrichment in these seven HUC-12 subwatersheds (Ohio EPA, 2015).

Table D-8. TRW HUC-12 subwatershed estimated existing annual TP loads (MT/y)

| HUC-12 | HUC-12 name | T | ‘08 | ‘09 | ‘10 | ‘11 | ‘12 | ‘13 | ‘14 | ‘15 | ‘16 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 01 | Bowen Drain-Bean Creek | 5.3 | 4.76 | **8.68** | **5.93** | **7.64** | **8.28** | 4.67 | **8.06** | 3.65 | 4.76 |
| 01 02 | Branch Creek-Bean Creek | 8.0 | 7.17 | **13.10** | **8.95** | **11.52** | **12.48** | 7.05 | **12.16** | 5.51 | 7.17 |
| 01 03 | Round Creek-Bean Creek | 5.5 | 4.94 | **9.03** | **6.17** | **7.94** | **8.60** | 4.86 | **8.38** | 3.80 | 4.94 |
| 01 04 | Saint Joseph Creek-Bean Creek | 9.3 | 8.38 | **15.29** | **10.45** | **13.45** | **14.58** | 8.23 | **14.19** | 6.43 | 8.38 |
| 01 05 | Lime Creek | 12.7 | 11.39 | **20.79** | **14.21** | **18.29** | **19.82** | 11.19 | **19.30** | 8.75 | 11.39 |
| 01 06 | Covell Drain-Bean Creek | 13.8 | 12.40 | **22.63** | **15.46** | **19.91** | **21.57** | 12.18 | **21.01** | 9.52 | 12.40 |
| 02 01 | Silver Creek-Bean Creek | 6.4 | 5.77 | **10.53** | **7.19** | **9.26** | **10.03** | 5.67 | **9.77** | 4.43 | 5.77 |
| 02 02 | Deer Creek-Bean Creek [a] | 8.9 | 8.46 | **15.45** | **10.56** | **13.59** | **14.73** | 8.32 | **14.34** | 6.50 | 8.46 |
| 02 03 | Old Bean Creek | 9.3 | 8.89 | **16.23** | **11.09** | **14.27** | **15.47** | 8.73 | **15.06** | 6.83 | 8.89 |
| 02 04 | Mill Creek [a] | 11.4 | 10.86 | **19.82** | **13.55** | **17.44** | **18.90** | 10.67 | **18.40** | 8.34 | 10.86 |
| 02 05 | Stag Run-Bean Creek | 4.0 | 3.85 | **7.04** | **4.81** | **6.19** | **6.71** | 3.79 | **6.53** | 2.96 | 3.85 |
| 03 01 | Bates Creek-Tiffin River | 8.2 | 7.81 | **14.26** | **9.74** | **12.54** | **13.59** | 7.68 | **13.24** | 6.00 | 7.81 |
| 03 02 | Leatherwood Creek | 4.8 | 4.62 | **8.44** | **5.77** | **7.43** | **8.05** | 4.54 | **7.84** | 3.55 | 4.62 |
| 03 03 | Flat Run-Tiffin River | 9.3 | 8.85 | **16.15** | **11.04** | **14.21** | **15.40** | 8.69 | **14.99** | 6.80 | 8.85 |
| 04 01 | Upper Lick Creek [a] | 7.8 | 7.46 | **13.62** | **9.31** | **11.98** | **12.99** | 7.33 | **12.64** | 5.73 | 7.46 |
| 04 02 | Middle Lick Creek [a] | 8.6 | 8.23 | **15.03** | **10.27** | **13.22** | **14.32** | 8.09 | **13.95** | 6.32 | 8.23 |
| 04 03 | Prairie Creek [a] | 8.3 | 7.95 | **14.51** | **9.91** | **12.76** | **13.83** | 7.81 | **13.46** | 6.10 | 7.95 |
| 04 04 | Lower Lick Creek | 4.9 | 4.64 | **8.47** | **5.79** | **7.45** | **8.07** | 4.56 | **7.86** | 3.56 | 4.64 |

| HUC-12 | HUC-12 name | T | ‘08 | ‘09 | ‘10 | ‘11 | ‘12 | ‘13 | ‘14 | ‘15 | ‘16 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 05 01 | Beaver Creek | 12.6 | 12.04 | **21.97** | **15.01** | **19.33** | **20.94** | 11.83 | **20.39** | 9.24 | 12.04 |
| 05 02 | Brush Creek [a] | 18.4 | 17.61 | **32.15** | **21.97** | **28.28** | **30.64** | 17.30 | **29.84** | 13.53 | 17.61 |
| 05 03 | Village of Stryker-Tiffin River | 7.0 | 6.74 | **12.30** | **8.40** | **10.82** | **11.72** | 6.62 | **11.41** | 5.17 | 6.74 |
| 05 04 | Coon Creek-Tiffin River | 8.4 | 8.06 | **14.72** | **10.05** | **12.94** | **14.03** | 7.92 | **13.66** | 6.19 | 8.06 |
| 06 01 | Lost Creek | 9.0 | 8.62 | **15.74** | **10.75** | **13.84** | **15.00** | 8.47 | **14.61** | 6.62 | 8.62 |
| 06 02 | Mud Creek [a] | 7.4 | 7.10 | **12.95** | **8.85** | **11.39** | **12.35** | 6.97 | **12.02** | 5.45 | 7.10 |
| 06 03 | Webb Run | 5.7 | 5.44 | **9.93** | **6.79** | **8.74** | **9.47** | 5.35 | **9.22** | 4.18 | 5.44 |
| 06 04 | Buckskin Creek-Tiffin River | 5.9 | 5.59 | **10.21** | **6.98** | **8.98** | **9.73** | 5.50 | **9.48** | 4.30 | 5.59 |

*Notes*

T = Annex 4 spring total phosphorus target.

**Bolded blue** values exceed the Annex 4 target loads.

a. Ohio EPA is developing one or two TMDLs at sites impaired by nutrient enrichment in these seven HUC-12 subwatersheds (Ohio EPA, 2015).

# D-5.0 KEY FINDINGS

The evaluations of Annex 4 translated targets, existing conditions loads, and hypothetical TMDL conditions target loads (i.e., hypothetical TMDLs developed for all subwatersheds) for the TRW HUC-12 subwatersheds indicate that hypothetical TMDL target loads are more protective than Annex 4 translated targets. However, Ohio EPA (2015) plans to develop TP TMDLs for only 7 HUC-12 subwatersheds in Ohio to address in-stream impairments of biological communities. Therefore, most HUC-12 subwatersheds in the TRW will not have TMDLs. Thus, implementing TMDLs (to address both the TMDLs and Annex 4 translated targets) will not address the majority of subwatersheds in the TRW (including those whose existing loads exceed the Annex 4 translated targets) because no TMDLs were developed.

# D-6.0 REFERENCES

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