

Regional Water Planning Study Appendix A Data and Methodology

Wabash Headwaters Region

Jacobs Engineering Group Inc.

Report to Indiana Finance Authority



Jacobs

January 2025

Acronyms and Abbreviations

°F	degree(s) Fahrenheit
BFI	baseflow index
CAFO	concentrated animal feeding operation
CFO	confined feeding operation
cfs	cubic foot (feet) per second
CPI	Consumer Price Index
EPA	U.S. Environmental Protection Agency
GPCD	gallon(s) per capita per day
ID	identification
IDEM	Indiana Department of Environmental Management
IDNR	Indiana Department of Natural Resources
MG	million gallon(s)
MGD	million gallon(s) per day
MHI	median household income
mi ²	square mile(s)
N/A	not available
NAD	National Address Database
NPDES	National Pollutant Discharge Elimination System
PART	streamflow partitioning (hydrograph separation)
STATS Indiana	statistical data source maintained by the Indiana Business Research Center at Indiana University's Kelley School of Business
SWWF	Significant Water Withdrawal Facility
U.S.	United States
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

Contents

Acronyms and Abbreviations	i
A1 Introduction	A1-1
A2 Data Sources	A2-1
A3 Sub-basin Delineation.....	A3-1
A4 Water Demand Methodology.....	A4-1
A4.1 Significant Water Withdrawal Facility and Monthly Report of Operations	A4-1
A4.2 Rural Use and Livestock Operations	A4-1
A4.3 Spatiotemporal Resolution and Distribution.....	A4-4
A4.4 Self-Supplied Residential Water Demand: Population and Water Demand Estimation.....	A4-2
A4.5 Explanatory Variables	A4-3
A4.6 Water Demand Regression Model Metrics	A4-4
A5 Water Supply Methodology.....	A5-1
A5.1 Natural Streamflow.....	A5-4
A5.2 Natural Baseflow	A5-6
A5.3 Minimum Instream Flow Requirements	A5-10
A5.4 Net Return Flows	A5-10
A5.5 Net Reservoir Releases.....	A5-11
A6 References	A6-1

Tables

Table A2-1. Wabash Headwaters Region Study Area Regional Water Planning Study Data Sources	A2-1
Table A3-1. Sub-basin Delineation and Associated Gauging Stations for Wabash Headwaters Region	A3-1
Table A4-1. Indiana Department of Environmental Management Confined Feeding Operations Animal Requirements.....	A4-3
Table A4-2. Constructed Farm Size Categories for Historical Linear Regression	A4-3
Table A4-3. Sub-basin Breakdown of Animal Types per County and Farm Size	A4-1
Table A4-4. Animal Categories and Associated Gallons per Capita per Day.....	A4-3
Table A4-5. Key Metrics Used to Evaluate the Public Water System Model Performance	A4-5
Table A5-1. Monthly Fraction of Extraction Returning to the System for Historical and Future Net Return Flows Estimations.....	A5-11

Figures

Figure A3-1. Delineated Sub-basins for the Wabash Headwaters Region.....A3-2

Figure A4-1. Rural Water Use Historical Time Series for the Wabash Headwaters RegionA4-2

Figure A4-2. Feeding Operations (CFOs and CAFOs) in the Wabash Headwaters Region.....A4-1

Figure A4-3. Feeding Operations (CFOs and CAFOs) Total Water Consumption per Sub-basinA4-1

Figure A4-4. Spatiotemporal MethodologyA4-2

Figure A4-5. Historical and Projected Population for the 10-County Study Area in the Wabash
Headwaters RegionA4-3

Figure A5-1. USGS Streamflow Gauges Used to Estimate Streamflow at Sub-basin 10 OutletA5-5

Figure A5-2. Annual Streamflow Volumes for Gauges Upstream and Downstream of Sub-basin 10 Outlet
Used to Estimate Streamflow at Sub-basin 10 Outlet.....A5-6

Figure A5-3. Example Hydrograph Separation on Daily Data from Techniques Available in the USGS
Hydrologic ToolboxA5-7

Figure A5-4. Comparison of Baseflow Index for Multiple Methodologies 2007 through 2022 Based upon
USGS Gauge Data and Estimated Discharge at Sub-basin 10A5-8

Figure A5-5. Baseflow Index Versus Drainage Area at USGS Streamflow Gauges for 2007
through 2022A5-9

Figure A5-6. Comparison of Baseflow Index, USGS Measured Streamflow, and Natural Streamflow for
Each Sub-basin in the Study AreaA5-9

A1 Introduction

This appendix includes the information and methodologies used for the water demand and water supply analyses. First, data sources (Section A2) are listed aiming to provide a quick reference for the input data required for the implementation of the methodologies in the event of further refinement or study update. Second, the delineation of the sub-basins (Section A3) in the Wabash Headwaters Region study area is described. This information is key for the analysis, as all results are presented at the sub-basin level. Third, the water demand methodology (Section A5) and water supply (availability) methodology (Section A5) are presented. In the case of the water demand, the methodology is presented by key steps in the approach; in the case of the water supply, the methodology is explained by each component of the equations used for the evaluation of available water supply.

A2 Data Sources

This section summarizes the data sources used to develop the water demand and water supply monthly time series for the supply availability analysis. Table A2-1 lists and describes the data sources and indicates how each was used in the analysis.

Table A2-1. Wabash Headwaters Region Study Area Regional Water Planning Study Data Sources

Source	Description	Application	Reference
SWWF database	<p>Monthly extraction data by water use sector from January 1985 through December 2022 representing total extraction by water use for all facilities; water users include the following:</p> <ul style="list-style-type: none"> • Public utility water suppliers • Industrial users • Agricultural and turf irrigation • Energy production • Rural uses such as large CAFO farms • Miscellaneous category 	<ul style="list-style-type: none"> • Proxy for historical demand time series • Demand model development • Sub-basin extractions for water supply availability 	IDNR SWWF Data
IDEM CFO- and CAFO-issued permits	<ul style="list-style-type: none"> • 2022 dataset 	<ul style="list-style-type: none"> • Small CAFO demand estimation • CAFO extractions by sub-basin for water supply availability 	IDEM Animal Farms: Pending and Issued CFO Permits
USDA Census of Agriculture	<ul style="list-style-type: none"> • 2007, 2012, 2017, and 2022 agriculture data for each study area county in Indiana and Ohio 		National Agricultural Statistics Service 2022 Census of Agriculture - Volume 1, Chapter 2: County Level Data
County Census Counts: STATS Indiana	<ul style="list-style-type: none"> • Historical population data from 1990 to 2020 • Future population projections from 2020 to 2050 	<ul style="list-style-type: none"> • Demand model development for explanatory variable use 	County Census Counts: STATS Indiana Projections Topic Page: STATS Indiana
National Oceanic and Atmospheric Administration	<ul style="list-style-type: none"> • Historical temperature and precipitation climate data 	<ul style="list-style-type: none"> • Demand model development for explanatory variable use 	Climate at a Glance County Time Series National Centers for Environmental Information
Federal Reserve Bank	<ul style="list-style-type: none"> • County MHI for 1989 through 2022 	<ul style="list-style-type: none"> • Demand model development for explanatory variable use • Future MHI development using linear regression method for each county 	Federal Reserve Economic Data

Source	Description	Application	Reference
STATS Indiana	County-adjusted CPI for 1989 through 2022	<ul style="list-style-type: none"> • Demand model development for explanatory variable use • Future MHI development using linear regression method for each county 	STATS Indiana
NPDES	Return flow data by users from 2007 through 2022	<ul style="list-style-type: none"> • Estimation of historical return flows for public utilities, industrial, energy, and miscellaneous water users • Estimation of historical fractions of consumptive use 	EPA NPDES (2024)
United States Army Corps of Engineers – Chicago District	Historical reservoir inflows and outflows in cfs from 2007 through 2022 in 6-hour increments for Huntington, Salamonie, and Mississinewa Lake Dams	<ul style="list-style-type: none"> • Estimation of historical and projected net reservoir releases 	N/A at website; provided directly by United States Army Corps of Engineers – Chicago District
USGS National Water Information System	Historical daily streamflow in cfs from river gauges at nine locations from different available periods (refer to Table A3-1).	<ul style="list-style-type: none"> • Location of gauges for sub-basin delineation • Natural streamflow estimation • Instream flow requirement estimation using statistics from 1990 through 2020 	USGS Water Data for the Nation

CAFO = concentrated animal feeding operation
CFO = confined feeding operation
cfs = cubic foot (feet) per second
CPI = Consumer Price Index
EPA = U.S. Environmental Protection Agency
IDEM = Indiana Department of Environmental Management
IDNR = Indiana Department of Natural Resources
MHI = median household income
N/A = not available
NPDES = National Pollutant Discharge Elimination System
SWWF = Significant Water Withdrawal Facility
USDA = U.S. Department of Agriculture
USGS = U.S. Geological Survey

A3 Sub-basin Delineation

The Wabash Headwaters Region was subdivided into individual areas, called sub-basins, which represent the drainage area associated with individual USGS streamflow gauging stations. Ten sub-basins were delineated using the USGS StreamStats v4.24.0 online tool (Ries et al., 2017) in the Wabash Headwaters Region. Table A3-1 shows each sub-basin’s associated USGS streamflow gauge at its outlet, the primary waterway, the drainage area that makes up the Wabash Headwaters Region, and the period for which streamflow data are available. Figure A3-1 shows a map of the sub-basins and their associated flow gauges.

Table A3-1. Sub-basin Delineation and Associated Gauging Stations for Wabash Headwaters Region

Sub-basin ID	Sub-basin Name	USGS Station Number at Outlet	Waterway	Available Period	Drainage Area (mi ²)
1	Mississinewa-Marion	03326500	Mississinewa River at Marion, Indiana	October 01, 1987, through May 07, 2024	682
2	Salamonie-Warren	03324300	Salamonie River Near Warren, Indiana	October 01, 1987, through May 07, 2024	425
3	Wabash-Linn Grove	03322900	Wabash River at Linn Grove, Indiana	October 01, 1987, through May 07, 2024	453
4	Little-Huntington	03324000	Little River near Huntington, Indiana	April 01, 1944, through May 06, 2024	263
5	Wabash-Wabash	03325000	Wabash River at Wabash, Indiana	October 01, 1989, through May 07, 2024	1,768
6	Wabash-Peru	03327500	Wabash River at Peru, Indiana	October 01, 1987, through May 07, 2024	2,686
7	Eel-North Manchester	03328000	Eel River at North Manchester, Indiana	October 01, 1987, through May 07, 2024	417
8	Wabash-Logansport	03329000	Wabash River at Logansport, Indiana	November 02, 1987, through May 07, 2024	3,779
9	Deer Creek-Delphi	03329700	Deer Creek near Delphi, Indiana	October 01, 1987, through May 07, 2024	274
10	Wabash-Ungauged	Ungauged watershed	Wabash River upstream of Tippecanoe River	N/A	343
TOTAL					11,090

ID = identification
mi² = square mile(s)

The sub-basins were delineated to produce smaller, more manageable areas defined by measured streamflow data, topographic features, and hydrological flow paths that include upstream-to-downstream fluxes. These subareas facilitate detailed and localized analysis of the water demands and resources as well to assess the broader regional water availability. Because different areas in a watershed can have varying hydrological characteristics, the smaller sub-basins will capture streamflow, infiltration, and groundwater recharge more accurately; they also provide a targeted water framework for planning based on more localized impacts to land use, climate, and socioeconomical changes that are important for water demand forecasting.

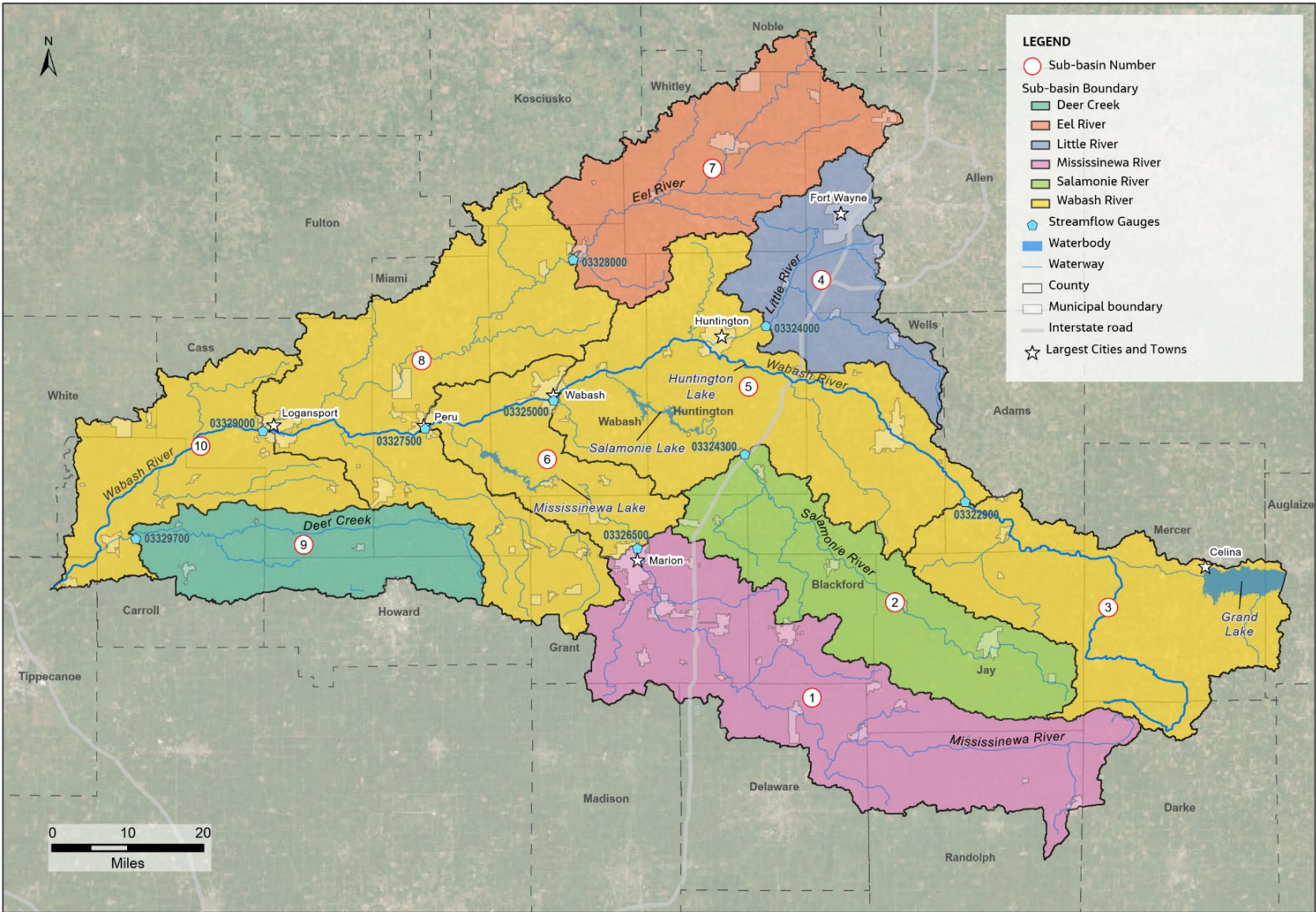


Figure A3-1. Delineated Sub-basins for the Wabash Headwaters Region

A4 Water Demand Methodology

Water demand forecasting relies on various data to predict future water use accurately. This section describes the Wabash Headwaters Region’s historical and future water demand methodology and data processing used for this study. Similar methodology was previously used for other regions in Indiana (Letsinger and Gustin, 2024; IFA, 2021). The water demand analysis aims to characterize water use and the factors that influence this use to predict future water needs. This process is important to ensure effective water resource management and support future planning. The key components for this analysis included historical water use, socioeconomic factors, and climate and weather data. Each component and how they were summarized and/or derived are described in this section.

A4.1 Significant Water Withdrawal Facility and Monthly Report of Operations

Monthly historical water-use and location data were collected from the IDNR SWWF for the period of 1980 through 2022 to examine historical water-use for the utilities in the study area (IDNR, 2024). Monthly Report of Operations documents were collected from the IDEM Virtual File Cabinet (IDEM, 2023) and detail the daily records submitted by utilities monitoring the volume of water processed by treatment plants. The reports were valuable for understanding peak flows and adding missing data that were not captured in the SWWF database. The data recorded for the water demand analyses between the years of 1985 through 2022 provide valuable information that improves the understanding of historical water-use, which ultimately leads to better future water demand projections.

The historical data on water use were supplemented with corresponding data on explanatory variables for each major use sector. The explanatory variables included data on population served, housing, employment, climate, power generation, rural use, and irrigation for the major use sectors. The major use sectors in this section include the following:

- Public supply (also referred to as public water utilities) serves residential and nonresidential customers (commercial and industrial).
- Industry includes process water, cooling water, mineral extraction, and quarry dewatering.
- Energy production includes power generation and thermoelectric cooling.
- Irrigation includes agricultural fields and golf courses.
- Rural use includes livestock and aquaculture.
- Miscellaneous includes fire protection, construction, pollution abatement and other activities with a temporary nature.
- Self-supplied includes residential.

A4.2 Rural Use and Livestock Operations

A historical time series for the livestock sector was created for each sub-basin from 2007 through 2022 using Indiana’s livestock classification categories of CAFOs and CFOs. The historical water use for each sub-basin in the watershed was determined by comparing USDA historical Census of Agriculture data with the Pending and Issued CFO Permits database (IDEM, 2024). Figure A4-1 displays the historical time

series for Sub-basins 1 through 10, where water use data for all CAFOs and CFOs in a given sub-basin in the study area have been combined.

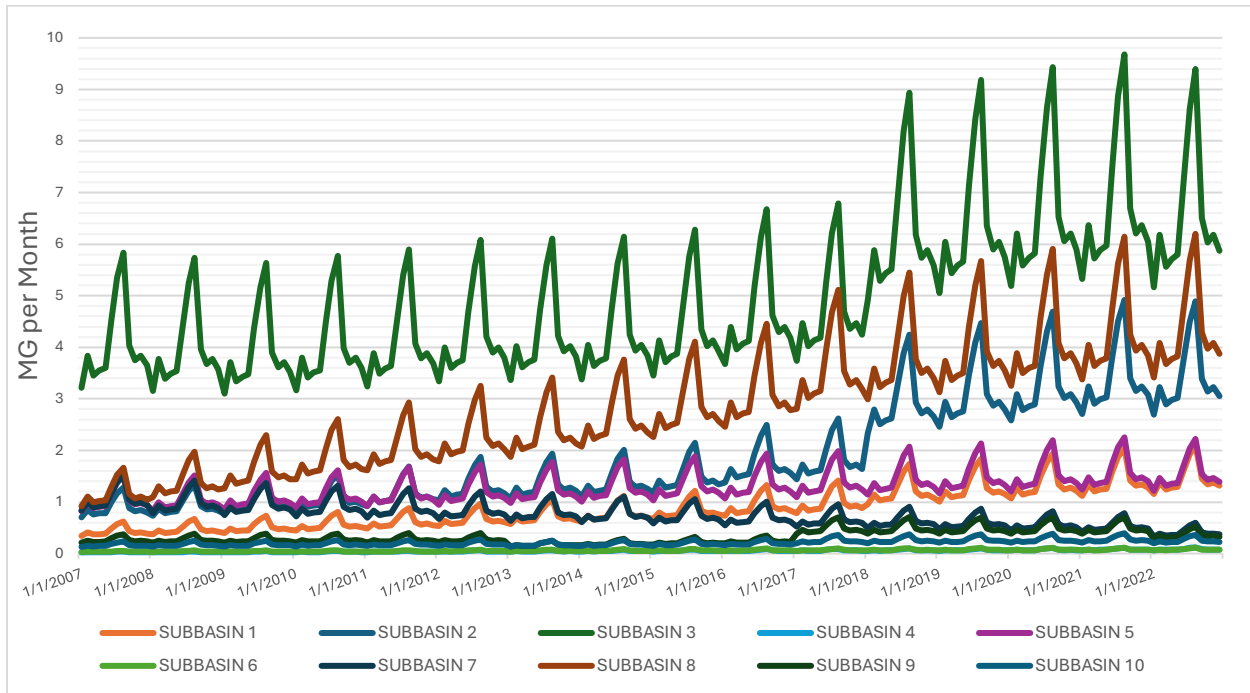


Figure A4-1. Rural Water Use Historical Time Series for the Wabash Headwaters Region

MG = million gallons(s)

The USDA Census of Agriculture displays animal count and farm count by county and state for every 5 years (USDA, 2024). Each has the previous census data for context, so the 2007, 2012, 2017, and 2022 censuses were used for analysis of the years 2007, 2012, 2017, and 2022 for each county in the study area in both Indiana and Ohio. Each animal in the census has a different farm size categorization (defined in USDA reports as “inventory category”) and subcategories, which differ from Indiana’s confined feeding definitions. The Indiana definition threshold for CFO and CAFO farms are presented in Table A4-1. The USDA data analysis procedure was completed for the three Ohio counties per Indiana feeding operation definitions, as CFO and CAFO data are not available for Ohio.

Using the defined animal count requirements for Indiana CFOs and CAFOs (displayed in Table A4-1), three categories were created to reorganize USDA data by animal types: (1) cattle and calves, (2) hogs and pigs, and (3) poultry. The maximum sheep and lamb USDA inventory category of 1,000 animals or more did not display sufficient animal counts to be accurately incorporated into the analysis. Equines (horses) were quantified as a total amount per county rather than animal count per farmland area, so these data were also excluded. Neither animal had significant animal count presented in the USDA census data, so the numbers are considered negligible for this analysis.

Table A4-1. Indiana Department of Environmental Management Confined Feeding Operations Animal Requirements

Farm Size	Cattle	Swine or Sheep	Poultry	Horses
CFO	300+	600+	30,000+	500
CAFO	700 dairy, 1,000 veal, or 1,000 cattle	2,500 swine, or 10,000 sheep/lambs	30,000 hens, 55,000 turkeys, 5,000 ducks, or 125,000 broilers	500

Source: IDEM, n.d.

Notes:

For a farm to be considered a CFO or CAFO, it must meet at least one (not all) minimum quantity in this table.

All values are in units of animal count per feeding operation.

Values for swine, hen, and ducks are minimum requirements per IDEM definitions. Different manure handling systems have different minimum requirements.

Horses must be in confinement.

The USDA Census of Agriculture has a significantly wider pool of farmers than the CFO and CAFO classification, so animal counts are assumed to directly correlate. To ensure consistent and controlled data between USDA datasets, IDEM feeding requirements, and the 2022-specific CFO and CAFO farm dataset, subcategories for each animal category were omitted when developing the three categories. Inventory categories smaller than minimums in the IDEM categories were not included. Because poultry has numerous subcategories described in the IDEM requirements and USDA census, poultry farms were not differentiated for CFO and CAFO farms to keep animal counts consistent. The poultry USDA subcategories differed between total animal count and animal count per farm size between turkeys, layers, and broilers, so the total quantity ensures all counts are incorporated. Table A4-2 displays the farm size categories for the three animal types.

Table A4-2. Constructed Farm Size Categories for Historical Linear Regression

Farm Size	Cattle and Calves	Pigs and Hogs	Poultry
CFO	200 to 499	500 to 999	Total
CAFO	500+	1,000+	Total

Note: All values are in units of animal count per feeding operation and not split by IDEM subcategories

Source: USDA, 2024.

Using the animal categories described in Table A4-2, CFO and CAFO animal counts for the four USDA census data points (2007, 2012, 2017, and 2022) were compiled per county in the watershed planning region and select surrounding counties, and a linear regression was performed. Ohio counties only used data from 2017 and 2022 for the linear regression. Some counties with only one operator had their animal count data withheld (marked “D” instead of a numeric value in the census report) for some census years, requiring estimation. For inventories smaller than the IDNR CFO definition, a minimum animal count was assumed. For inventories meeting CFO definitions, maximum animal count was assumed. These assumed values were then multiplied by the number of farms in the specified inventory category to provide a numeric animal count replacement for counties whose data were withheld; this process was repeated until the total animal count for all other inventory categories could be subtracted from total animal count for specified year to achieve missing CFO and CAFO values. This estimation was checked by comparing the resultant value with an inventory category to ensure the number is within the category range. This was not conducted for 2022 values, because those quantities came directly from the IDEM-issued permits dataset (IDEM, 2024). Figure A4-2 displays 2022 CFOs and CAFOs by animal type and size, respectively.

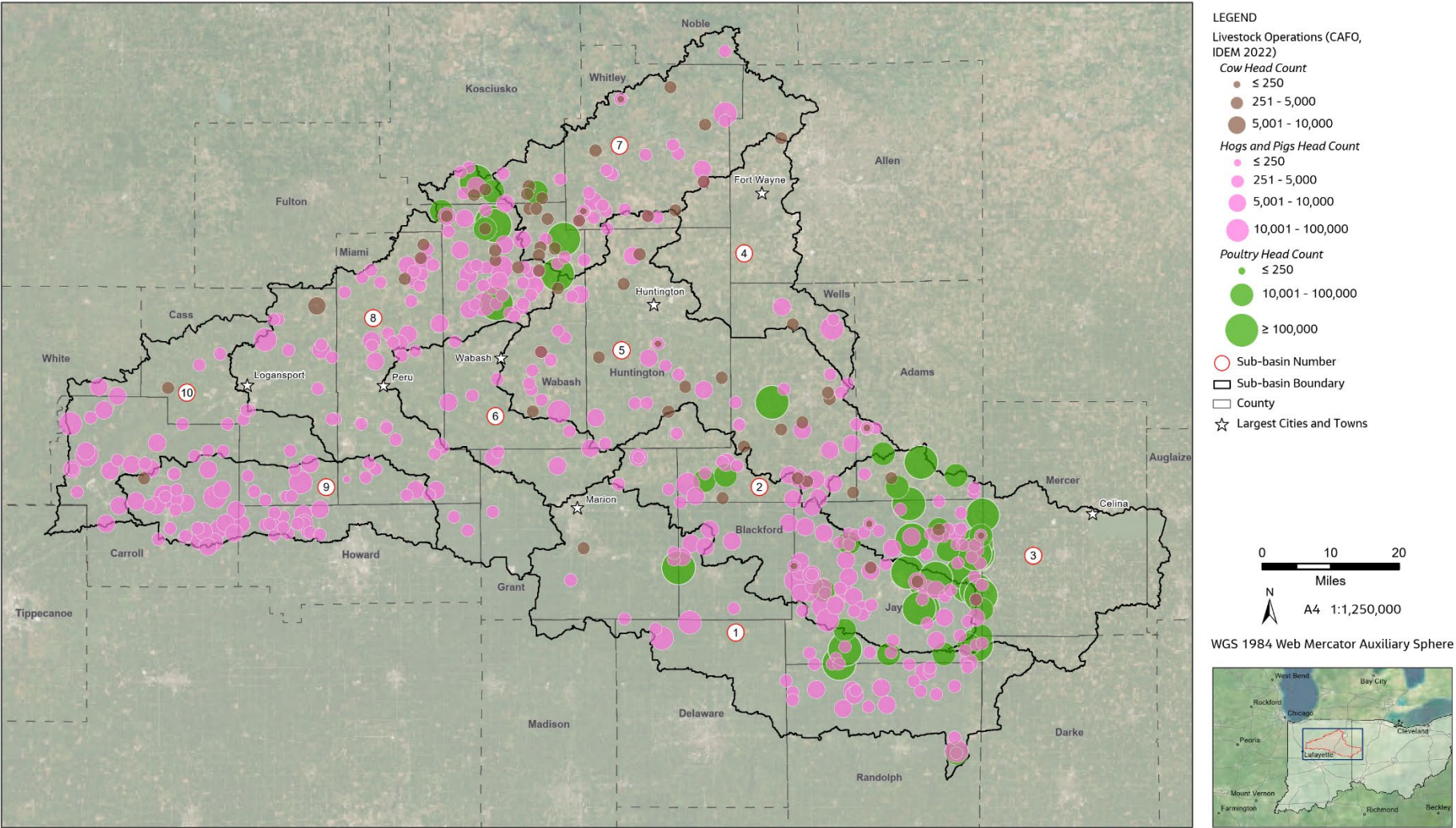


Figure A4-2. Feeding Operations (CFOs and CAFOs) in the Wabash Headwaters Region

The types and quantities of animals raised in each county is variable, so the farm size categories are not applicable everywhere. The IDEM 2022 dataset provides the types of animals in specific CFOs and CAFOs, which can then be considered over the county and sub-basin level for the feeding operation type. A linear regression was developed for every animal type present in the CFOs and/or CAFOs for a given county. If only CFOs or CAFOs for a given animal type were present in the IDEM 2022 dataset, then a linear regression for only that farm size was produced. For example, the IDEM 2022 dataset showed pigs and poultry present in Blackford County, so a linear regression for cattle was not performed. As pigs and hogs are present in CFOs and CAFOs in Blackford County, a linear regression was performed for each. In Carroll County, only CFOs were present for cattle and calves in the IDEM 2022 dataset (IDEM, n.d.), so a linear regression for CAFOs with cattle and calves was not performed for Carroll County.

Each linear regression was developed using the USDA values and estimates for the four datapoints (years), and this was done separately for CFOs and CAFOs for a given animal category. For example, the linear regression for Pigs and Hogs for Blackford County consisted of one graph, with two lines (linear regressions) for CFOs and CAFOs, respectively. From each linear regression, the equation was then used to create a continuous time series from 2007 to 2022. Outliers and discrepancies were dealt with by corrective measures to ensure consistent data across datasets and calculations. Some counties had periods without any head count for a given animal type, which was calculated as negative values in the regression, so a zero replaced that negative value. Other counties and animal types had drastic jumps in reported head counts, which could not be accurately depicted through a singular linear regression, so multiple linear regressions were performed for specific segments of time (for example, 2007 to 2012 as a single segment) to match the known values from the USDA data.

The linear regression resulted in a compilation of each county's total head count for CFOs and/or CAFOs per animal type. To project a historical time series for each of the 10 sub-basins in the planning region, each county's data were split by the proportional head count of each sub-basin in an Indiana county from the 2022 IDEM dataset. The head count per sub-basin in the county was divided by the total head count for each animal type and farm size to develop a sub-basin factor, using the IDEM 2022 dataset (IDEM, n.d.); this was performed for all 10 sub-basins and for the proportion of farms outside of the planning region for county-focused reporting and historical time series. The sub-basin factors for each county are displayed in Table A4-3.

Table A4-3. Sub-basin Breakdown of Animal Types per County and Farm Size

County	Sub-basin	Cattle and Calves (%)		Hogs and Pigs (%)		Poultry (%)	
		CAFO	CFO	CAFO	CFO	CAFO	CFO
Adams ^a	3	100	--	--	48	--	91
	5	--	100	--	52	--	9
Allen ^a	7	--	100	--	--	--	--
Blackford	1	--	--	61	100	100	--
	2	--	--	39	--	--	--
Carroll	9	--	25	34	21	--	--
	10	--	--	23	28	--	--
	Outside	--	75	44	52	--	--

County	Sub-basin	Cattle and Calves (%)		Hogs and Pigs (%)		Poultry (%)	
		CAFO	CFO	CAFO	CFO	CAFO	CFO
Cass	8	84	--	33	32	--	--
	9	--	--	34	38	--	--
	10	16	--	7	30	--	--
	Outside	--	--	26	--	--	--
Delaware ^a	1	--	--	100	--	--	--
Grant	1	100	--	14	39	--	--
	2	--	--	35	26	--	--
	6	--	--	51	14	--	--
	8	--	--	--	21	--	--
Huntington	2	--	--	14	--	--	--
	5	100	100	86	100	--	--
Jay	1	5	--	7	21	3	9
	2	51	46	72	33	39	38
	3	44	54	21	46	58	53
Miami	6	--	--	3	5	--	--
	8	--	--	80	64	--	--
	9	--	98	5	16	--	--
	Outside	--	2	12	15	--	--
Noble ^a	7	--	--	--	100	--	--
Randolph ^a	1	--	--	100	100	--	100
Wabash	5	39	21	14	23	--	--
	6	--	--	3	9	--	--
	7	39	29	8	10	26	
	8	22	50	75	58	74	100
Wells	2	9	--	40	--	--	100
	3	20	--	5	--	--	--
	4	--	34	15	16	--	--
	5	71	66	31	76	100	--
	Outside	--	--	9	8	--	--
Whitley	5	--	12	9	3	--	--
	7	100	85	61	93	--	100
	Outside	--	3	30	4	100	--

^a Located in the watershed but outside the study area.

Note: The "outside" category refers to farms in the county outside of the study area.

-- = Not available or accessible data

The sub-basin factors (percentages) displayed in Table A4-3 were then multiplied by the USDA-derived total headcount of the same animal type and farm size to calculate the headcount in the sub-basins for a given county and outside the planning region, as applicable. The proportional head counts were organized by the 10 sub-basins to help approximate water use. Estimates for the three Ohio counties (Auglaize, Darke, and Mercer) could not use the IDEM dataset to develop sub-basin proportions. For the

portion in Ohio, the acreage of rural land in the county (subtracting all public supply service areas) was divided by the total acreage of the respective sub-basin to get a proportion of land for agricultural use in that county in each sub-basin and assumed for livestock to calculate a conservative estimate. The water consumption was then applied to this acreage factor to use as the sub-basin factor for linear regression.

The three developed animal types are too general to accurately relate animal head count to water use and cannot be used alone. Animal age, intended livestock use, and production rates are some factors impacting each animal’s water consumption. Cattle, for example, requires varying water amounts depending on if they are dairy calves, heifers, milking cows, or dry beef cattle. Swine water consumption depends on the finished weight of the animal. Furthermore, the number of swine or cattle per gallons of water does not increase proportionately, so an approximation based on animal count per 5 MG of water was used for a conservative estimation. Gallons per capita per day (GPCD) was then calculated for swine and cattle as displayed in Table A4-4.

For poultry, GPCD is calculated based on the rate of production and age, and it is separated into layers (and then pullets and hens) and broilers. The average amount of water (at 69.8 degrees Fahrenheit [°F]) per 1,000 birds was calculated for layer pullets 4, 12, and 18 weeks of age and laying hens at production rates of 50%, and 90%, respectively (Ezenwankwo, 2021). Similarly, the average water intake (at 68°F) per 1,000 mixed-sex broilers was calculated for broilers 1 to 8 weeks of age. The water amounts were then converted to GPCD and displayed in Table A4-4.

Table A4-4. Animal Categories and Associated Gallons per Capita per Day

Animal Types	Livestock Intended Use	Water Consumption Factor (GPCD)
Cattle and Calves	Calves ^a	2.73
	Heifers ^a	6.63
	Milking Cows	30.44
	Dry Cows ^a	15.02
Pigs and Hogs	Nursery	0.40
	Grow to Finish (50–280 pounds)	1.05
	Wean to Finish (15–280 pounds)	0.82
	Sow Breed to Wean	2.71
Poultry	Layers (pullets)	0.04
	Layers (hens)	0.06
	Broilers ^a	0.07

^a Calves includes boars, heifers include sheep, dry cows include horses, and broilers include ducks and turkeys for the purpose of relating datasets in this analysis

Notes:

Cattle and Calves and Pigs and Hogs water consumption requirements source: Fedrow, 2019.

Poultry water consumption requirements source: Ezenwankwo, 2021.

The IDEM dataset includes livestock divided by the various intended usages outlined in Table A4-4 so the calculated water consumption factors could be seamlessly applied to these head counts to calculate the water usage rate. The animals without independent categories (such as sheep, ducks, and horses) present in the dataset (IDEM, 2024) were assigned water consumption factors similar in size and water use assumptions as noted in Table A4-4. The livestock by intended use GPCDs values were then totaled into the three developed animal types and organized by county and farm size. However, a weighted average water consumption rate was needed to sort between CAFO and CFO for each animal type in each county and apply to the historical USDA-derived animal head counts. The weighted average was

calculated by dividing the total water consumption rate (gallons per day) by the total head count for each animal type and farm size in each county. These rates are slightly different than the standard water consumption factors listed in Table A4-4, as they account for local variance, but all were within a 5% margin of error of the standard factors. As the Ohio county data were not specific to animal stages and intended uses, an average GPCD was used for cattle, calves, pigs, and hogs, and the layer's (hens) GPCD was used for poultry.

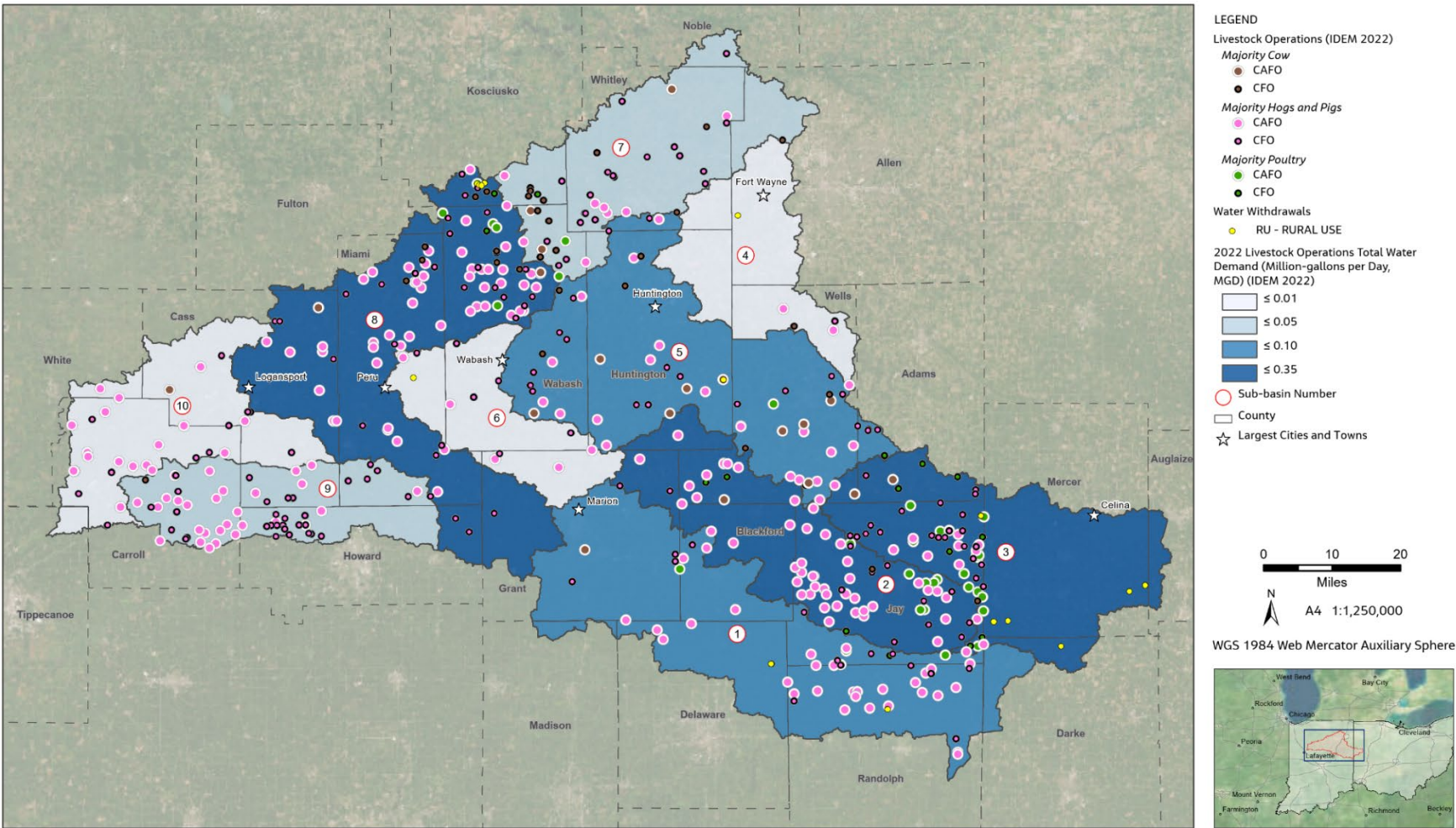
Each weighted water consumption rate was then applied to the calculated head count of the same county, farm size, and animal type for a given sub-basin for every year in the time series. For example, the weighted water consumption rate for Blackford County pigs and hogs in CFOs was applied to the Blackford County pigs and hogs in CFOs head count in Sub-basins 1 and 2 separately, calculating the proportional water-use to be used in independent time series plots. This process was repeated for all the animal types per farm sizes per county in each sub-basin and added together resulting in a grand total water consumption rate, from 2007 to 2022, for each sub-basin. However, this total does not account for seasonal water use variation, as agriculture and livestock production are cyclical and not linear throughout the year.

The USGS developed livestock water withdrawals (in million gallons per day [MGD]) for each month as a percentage of the annual withdrawal (Shaffer, 2009). The withdrawals are considered monthly averages derived from aggregated data and unique to each state. The USGS monthly percentage for Indiana was applied to the combined water consumption rate for each month of the year respectively, for years 2007 to 2022. This data was converted to million gallons per month and plotted as the final combined CFO and CAFO water consumption historical time series. Figure A4-3 displays the 2022 CAFOs and CFO locations with water consumption by sub-basin.

This process was repeated in a similar way for the county-focused analysis, with the only difference being the USDA-derived head count extracted for compilation and plotting. For the county analysis, each time series utilized the total head count in a county, instead of the proportioned sub-basin head count, to apply the weighted water consumption. This was completed for all the counties in the study area including Blackford, Carroll, Cass, Grant, Huntington, Jay, Miami, Wabash, Wells, and Whitley counties. Demands for specific counties that lie partially in the study area (but not completely) were analyzed by others conducting a similar study for the North Central Region (Adams, Allen, Delaware, Noble, and Randolph counties). These data were added to the sub-basin-focused analysis but not included in the county-focused analysis. Some counties have feeding operations outside of the water study area and have two historical time series showing the total water consumption in the county and the water consumption outside of the region but still in the county. The latter extracted the USDA-derived head counts proportioned in the "outside" sub-basin category, and this was completed for Carroll, Cass, Miami, Wells, and Whitley counties.

A4.3 Spatiotemporal Resolution and Distribution

Spatiotemporal methodology involves analyzing data across space and time. This approach was helpful to this study because it allowed for the visualization of population data, as well as economic and climate variables. Resolution of all input data (as described previously) were originally supplied on a county level. To use the water demand information for the water availability analysis, aggregating and disaggregating water demands by sub-basin rather than by county was important. Information for all users, including public utilities and their associated water service areas, was recalculated using geospatial tools to spatially allocate a sub-basin identifier. Figure A4-4 shows an example of how the designation was achieved using a spatiotemporal method.



Data Sources: IN Gov (2024), TIGER (2024), JACOBS (2024), Imagery Sources: ESRI Online Imagery Services
\\lausyd0vs01\GISProj\US_Wabash\AApps\Wabash_Mapping_v3.aprx\EEKM100_Wabash_F019b_CAFD_v05 | Date: 28/11/2024

Figure A4-3. Feeding Operations (CFOs and CAFOs) Total Water Consumption per Sub-basin

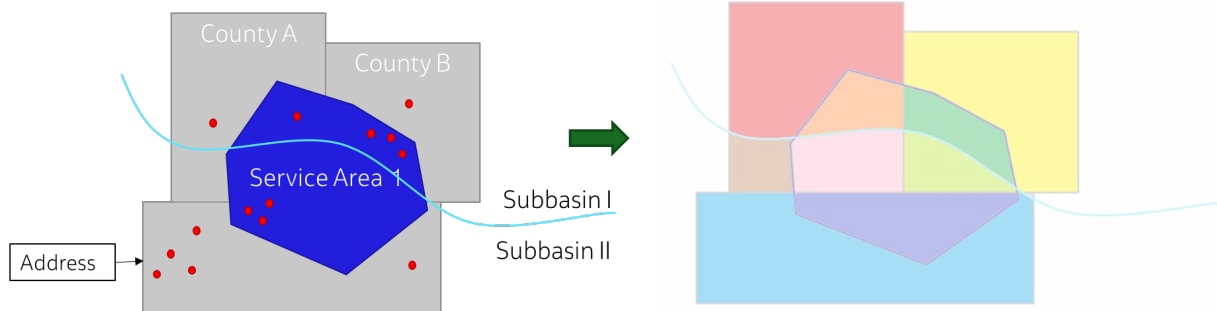


Figure A4-4. Spatiotemporal Methodology

The explanatory variables used during the modeling process were also disaggregated using this spatiotemporal method.

$$population_{servicearea} = \sum_i \frac{\# \text{ addresses in service area in county }_i}{\# \text{ addresses in county }_i} * population_{county_i} \quad (1)$$

$$climate_inputs_{servicearea} = \sum_i \frac{\text{area of service area in county }_i}{\text{area service area}} * climate_inputs_{county_i} \quad (2)$$

$$economical_inputs_{servicearea} = \sum_i \frac{\# \text{ addresses in service area in county }_i}{\# \text{ addresses in service area}} * economical_inputs_{county_i} \quad (3)$$

A4.4 Self-Supplied Residential Water Demand: Population and Water Demand Estimation

A spatial overlay was conducted to generate a set of polygons that represent the unique intersections of sub-basins, counties, and service areas. This overlay allows for reassociation and reaggregation of spatial data. The next step was to use address points for Indiana (U.S. Department of Transportation National Address Database [NAD]) (DOT 2024) and identify the number of address points in each overlapping region (polygon) such as Service Area 1, which falls into County A, and Sub-basin 1. Each unique polygon formed by the overlay is assigned address counts. The number of addresses per polygon was further revised to show only the residential addresses using the Property Class Code identifier. Any addresses outside public service areas were assigned to the relevant intersection polygons. Population distribution was determined by address counts to accurately account for density.

After determining the self-supplied residential population for 2022, the estimated public-supplied population was compared to the population served by a series of municipalities, as reported in their water audits (IFA, 2024), to determine if the approach was accurate. Once the estimates were reviewed and corrected, the spatial analysis method was applied to the historical time series and the population projections found in the County Census Counts: STATS Indiana (STATS Indiana, 2024) database. Analyzing the historical time series and population data in Indiana provides a better understanding of internal migration and population fluctuations in the area. This plays a role in how to locate current self-supplied residents and how to project which areas will likely continue using self-supplied water.

Finally, self-supplied residential water demand was calculated using the average of 76 GPCD in Indiana and 75 GPCD in Ohio (Dieter et al., 2018, Table 6). Approximately 25% of the total Indiana population relies on self-supplied domestic water use. Self-supplied domestic water withdrawals in Indiana come from ground water and totals about 127 MGD (Dieter et al., 2018).

A4.5 Explanatory Variables

When forecasting water demand, explanatory variables (such as population, climate, and economic factors) typically are considered to understand water use patterns. Model testing included model selection and explanatory variable selection. Separate water demand models were developed for most individual users, excluding agricultural irrigation, enabling us to fine-tune each model to suit specific user needs.

The regression analyses used for most of the facilities relied on explanatory variables to guide future growth and demand. Different combinations of population, precipitation, temperature (for example, average, minimum, maximum), Palmer Drought Severity Index, CPI, and MHI, including actual and inflation adjusted, were tested as input variables to the prediction models, but only a few variables were used consistently. Temperature, population, precipitation, MHI, and adjusted CPI were the variables mostly used for public water utilities while temperature, precipitation, and adjusted CPI were used for industrial users.

A4.5.1 Population

Historical population data from 1990 to 2020 were obtained from STATS Indiana (STATS Indiana, n.d.). Future population projections 2020 through 2050 were also obtained from STATS Indiana (STATS Indiana, 2024). Figure A4-5 presents the total historical and projected population for the 10 counties (Blackford, Carroll, Cass, Grant, Huntington, Jay, Miami, Wabash, Wells, and Whitley counties) in the study area as published by STATS Indiana (STATS Indiana, 2024, n.d.).

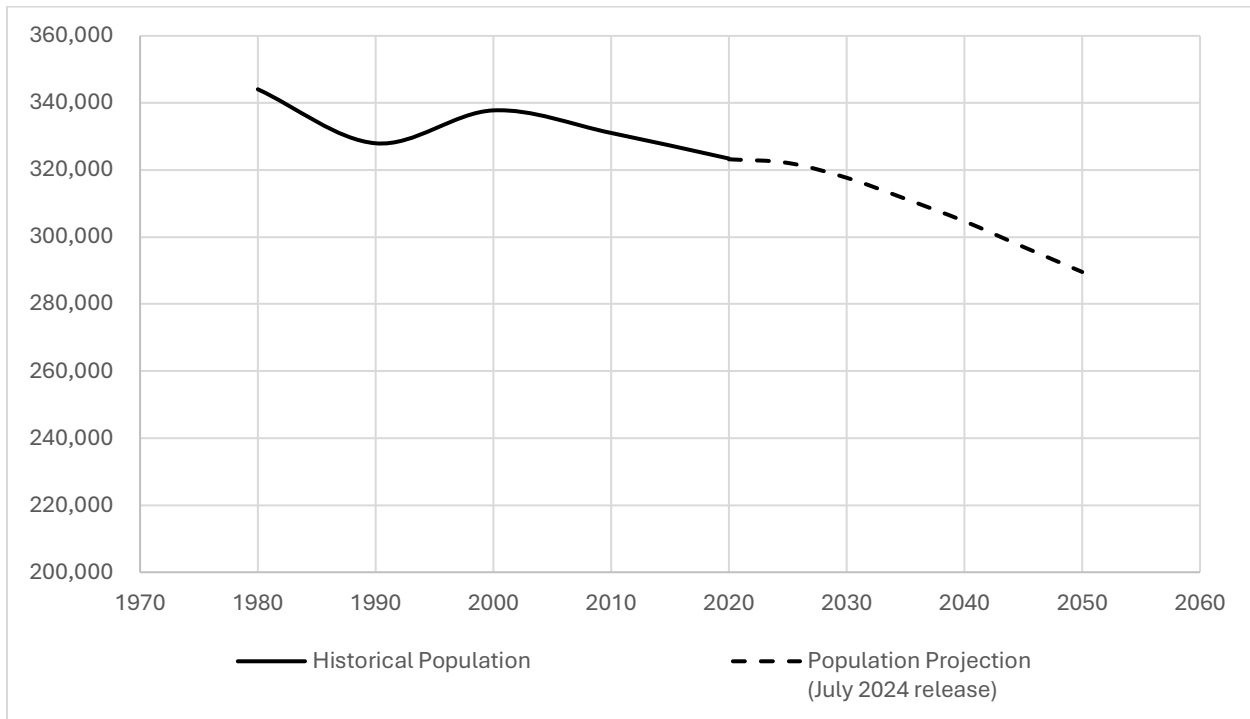


Figure A4-5. Historical and Projected Population for the 10-County Study Area in the Wabash Headwaters Region

The census data and projections show a decrease in growth for most of the counties in the region. The only county that shows a modest increase in population is Wells County with an expected 6% increase in

population between 2020 and 2050. Population projections from 2050 through 2070 were forecasted based on annual data using autoregressive integrated moving averages.

A4.5.2 Climate

Historical climate data, temperature (°F), and precipitation (millimeters) were obtained from National Oceanic and Atmospheric Administration’s website (NOAA, n.d.). Future climate data were obtained from existing climate models described in Appendix B.

A4.5.3 Median Household Income

Historical MHI was obtained from the Federal Reserve Bank (fred.stlouisfed.org). Future MHI was extrapolated from historical data using linear regression method for each county.

A4.5.4 Adjusted Consumer Price Index

Historical CPI was obtained from Stats Indiana (STATS Indiana, n.d.). Future CPI was calculated by calculating the average historical growth rate (year-over-year growth ratio over the historical period). Future values were extrapolated using this value for every county. CPI was then adjusted for inflation by extending the inflation data using the average historical inflation from 1980 to 2022, calculating the cumulative inflation, and finally adjusting the CPI using the ratio of the cumulative inflation at a given time compared to January 2022.

The following is how the adjusted CPI was calculated:

Step 1: Calculate Year-over-Year Change Ratio.

$$Ratio_t = \frac{Variable_t}{Variable_{t-1}}$$

Step 2: Determine Average Growth Rate of the historical data.

$$Average\ Ratio = \frac{1}{n} \sum_{t-1}^n Ratio_t$$

Step 3: Extrapolate Future Values.

$$Variable_{t+k} = Variable_t \times (Average\ Ratio)^k$$

Step 4: Extend the inflation data using the average historical inflation from 1980 (3.342% annual or 0.2743% monthly).

Step 5: Calculating the cumulative inflation.

$$Cumulative\ Inflation_t = \left(\prod_{i=0}^t \left(1 + \frac{Inflation_i}{100} \right) \right) - 1$$

Step 6: Adjusting CPI based on cumulative inflation and Jan 2022.

$$Adjusted\ CPI_t = CPI_t \times \frac{Cumulative\ Inflation_{2022/01}}{Cumulative\ Inflation_t}$$

A4.6 Water Demand Regression Model Metrics

Table A4-5 summarizes the coefficient metrics for the public water systems. These key metrics are used to evaluate the performance of the regression model and the variables performance used to forecast demand.

Table A4-5. Key Metrics Used to Evaluate the Public Water System Model Performance

User	R-Squared (Train) ^a	F-Statistic ^b	F-Statistic p-Value ^c	Root Mean Square Error ^d	Akaike Information Criterion ^e	Bayesian Information Criterion ^f
Blackford County						
City of Dunkirk	0.009	1.27	0.283940	3,394,717	13,437	13,453
Hartford City Water Works	0.024	0.91	0.473635	2,752,409	6,251	6,270
Carroll County						
Delphi Water Works	0.051	5.40	0.000306	4,903,466	13,739	13,759
Flora Utilities	0.492	97.60	0.000000	769,959	12,228	12,248
Town of Camden	0.054	3.19	0.014244	307,885	6,420	6,437
Cass County						
Logansport Municipal Water Department	0.323	43.76	0.000000	28,819,802	13,845	13,865
Town of Galveston	0.224	38.89	0.000000	420,921	11,733	11,749
Town of Walton	0.197	5.60	0.000449	402,204	2,760	2,773
Grant County						
Gas City Municipal Water Department	0.505	69.84	0.000000	2,227,755	11,173	11,196
Jonesboro Water Works	0.070	6.69	0.000034	922,984	10,921	10,941
Marion Water Works	0.796	285.01	0.000000	18,924,731	13,534	13,558
Swayzee Water Utilities	0.308	40.37	0.000000	551,847	8,089	8,104
Town of Fairmount	0.112	5.14	0.000635	1,436,925	5,251	5,266
Town of Van Buren	0.179	6.55	0.000015	215,381	4,286	4,304
Huntington County						
City of Huntington	0.031	2.95	0.020098	15,681,069	13,356	13,376
Norwood Regional Water and Sewer District	0.038	2.07	0.131597	519,007	3,155	3,163
Town of Andrews	0.013	1.25	0.288525	748,013	5,745	5,754
Town of Warren	0.042	5.86	0.000633	503,316	11,879	11,895
Jay County						
City of Portland	0.151	13.45	0.000000	2,891,704	12,528	12,551
Town of Redkey	0.021	3.80	0.023329	1,047,656	10,978	10,989
Miami County						
Town of Bunker Hill	0.004	0.17	0.913218	253,370	3,667	3,679

User	R-Squared (Train) ^a	F-Statistic ^b	F-Statistic p-Value ^c	Root Mean Square Error ^d	Akaike Information Criterion ^e	Bayesian Information Criterion ^f
Wabash County						
Indiana American - Somerset	0.592	89.74	0.000000	59,387	6,265	6,283
Indiana American - Wabash	0.649	153.07	0.000000	8,344,625	11,673	11,692
Lagro Municipal Water Utility	0.120	3.09	0.019498	315,245	2,713	2,726
Roann Water Works	0.197	15.05	0.000000	262,857	8,685	8,707
Town of North Manchester	0.133	5.81	0.000222	2,039,131	4,985	5,001
Wells County						
Markle Water Works	0.037	3.84	0.004454	848,425	12,307	12,327
Ossian Municipal Water Department	0.334	31.49	0.000000	707,919	5,725	5,738
Whitley County						
Columbia City Municipal Utility	0.401	37.38	0.000000	2,948,282	7,450	7,467
Town of Churubusco	0.406	66.56	0.000000	989,354	12,037	12,057
Town of South Whitley	0.830	655.29	0.000000	706,038	12,155	12,171

^a R-Squared (Train) is also known as the coefficient of determination and measures the proportion of the variance in the dependent variable that is predictable from the independent variables.

^b F-Statistic is used in regression analysis and analysis of variance to determine whether the means between two or more groups are significantly different.

^c F-Statistic p-Value helps to determine whether the observed relationships in the data are statistically significant.

^d Root Mean Square Error is used to evaluate the accuracy of a regression model by measuring the average magnitude of the errors between predicted values and actual values.

^e Akaike Information Criterion is used to compare the fit of different regression models and in model selection by balancing the goodness of fit and model complexity.

^f Bayesian Information Criterion is used for model selection among a set of candidate models and it helps to balance the goodness of fit and model complexity, like the AIC, but with a stronger deduction for the number of parameters.

A5 Water Supply Methodology

This section describes the Wabash Headwaters Region’s historical and future water availability methodology used for this study. This methodology was used in previous hydrologic studies in Indiana (Letsinger and Gustin, 2024; IFA, 2021). The water availability analysis aims to characterize monthly water availability based on local hydrology, stream hydraulics, instream flow requirements, flood control reservoir operations, and anthropogenic uses of water as defined by the water demand methodology defined in previous Section A4. The water availability analysis is a watershed-based inventory of current (2007 through 2022) and future (2023 through 2070) water availability to support ongoing and future water resources planning and management efforts in the region. The watersheds used in the analysis correspond to the sub-basins delineated and described in Section A3.

Historical measured data and analytical techniques were used to characterize, quantify, and evaluate components of water availability for each sub-basin in the Wabash Headwaters Region. Three metrics are used for this analysis: (1) water availability, (2) excess water availability, and (3) cumulative water availability. The first two metrics are estimated at the sub-basin level and the last term at the sub-basin level but accounting for the effect of upstream sub-basins. The following provides a brief description of these metrics.

Water availability is characterized as the net natural baseflow remaining in the net stream after instream flow requirements are met and the sub-basin reservoir operations are accounted for. The sub-basin’s water availability is an estimate of reliable supplies that are available while ensuring net minimum instream flow requirements and flood control factors are prioritized. Monthly water availability is quantified using net¹ terms to perform the water availability assessment at the sub-basin level using Equation 1:

$$\text{Water availability} = \text{net natural baseflow} - \text{net minimum instream flow requirement} + \text{sub-basin net reservoir release (1)}$$

Where:

Net natural baseflow = Total groundwater contributions to streamflow within the sub-basin; estimated based on natural streamflow; these contributions are estimated as portion of natural streamflow, which is streamflow that would be measured if anthropogenic (man-made) effects of surface-water and groundwater withdrawals and wastewater return flows were removed.

Net minimum instream flow requirement = streamflow required to remain in the sub-basin stream to support ecological function of the stream

Sub-basin² net reservoir release = difference between reservoir outflows and reservoir inflows to characterize whether the reservoir in the sub-basin is storing or releasing water downstream

Excess water availability is quantified to evaluate the water supply remaining after consumptive water uses are considered. The nonconsumptive proportion of water use factors in the portion of the surface water and groundwater withdrawals that is returned to the system. The excess water availability

¹ In sub-basins without upstream sub-basins, net natural baseflow, net minimum instream flow requirement, sub-basin net reservoir releases and sub-basin net return flows are the same as the corresponding cumulative terms.

² “Sub-basin” word is added to the term to differentiate between the net reservoir releases calculated for the sub-basin versus the cumulative net reservoir releases that include the net reservoir releases from upstream sub-basins.

provides an evaluation of whether supplies are sufficient to meet water use demands within a sub-basin. Monthly excess water availability is quantified for each sub-basin using Equation 2:

$$\text{Excess Water Availability} = \text{water availability} - \text{withdrawals} + \text{return Flows} \quad (2)$$

Where:

Withdrawals = total surface water and groundwater extracted to meet water use demands in the sub-basin

Return flows = total return flows discharged back to streams within the sub-basin; this is how the nonconsumptive portion of water used in the sub-basin is integrated back into the water availability analysis

The difference between *withdrawals* and *return flows* is also known as *net return flows*. Since the *withdrawals* and *return flows* correspond to those taking place at the sub-basin level, the water availability and excess water availability metrics are estimated at the sub-basin level. If excess water availability is a negative value, the sub-basin water resources likely are being strained, and a closer look should be taken to evaluate potential water shortages. If the excess water availability is positive, expansion of water use in the sub-basin could occur. Positive and negative excess water availability can occur on a seasonal basis in a given year depending on climate and hydrology. Thus, the evaluation of excess water availability is transient, and whether water shortage or excess water occurs will depend on seasonal and annual conditions. While excess water availability can occur in any sub-basin, the hydraulic connectivity of sub-basins must be recognized to account for upstream excess water availability where water in excess in upstream sub-basins could be made available to downstream sub-basins. Therefore, an additional metric called the **Cumulative excess water availability** is quantified to account for regional water availability in the study area. It is estimated same as *excess water availability* but using the cumulative terms: cumulative natural baseflow, cumulative minimum instream flow requirements, cumulative withdrawals, and cumulative return flows. This metric is especially important for the water supply assessment of the downstream study area, the North Central Indiana region.

For the water availability and excess water availability, the components used in the water balance are calculated at the sub-basin level to reflect conditions in the sub-basin. These components follow:

- Net natural baseflow
- Net instream flows
- Sub-basin extractions
- Sub-basin return flows
- Sub-basin net reservoir releases

“Sub-basin” word is added to the term to differentiate between the net reservoir releases calculated for the sub-basin versus the cumulative net reservoir releases that include the net reservoir releases from upstream sub-basins. For the cumulative excess water availability, all cumulative water availability components are used. The historical water availability assessment included the following steps for each sub-basin:

1. Evaluate historical data associated with each sub-basin in the study area. Based on the availability of data, January 2007 through December 2022 data were selected to represent and quantify historical water availability. Ultimately, this period was selected because of reporting of return flow data starting in January 2007 from the EPA’s NPDES (2024).
2. Estimate *sub-basin withdrawals* and *cumulative withdrawals*. For the water supply methodology, the total extractions are equivalent to the demand (withdrawals) estimated following the

methodology described in Section A4, Water Demand Methodology, which includes historical and estimated withdrawals not included in the SWWF database. The *cumulative withdrawals* are estimating adding to the sub-basin withdrawals the corresponding upstream sub-basins.

3. Estimate *sub-basin net reservoir releases* and *cumulative net reservoir releases* for flood control reservoirs. This is estimated as the difference between reservoir outflows and reservoir inflows: Positive (+) values represent a net release of water from the reservoir to the stream; negative (-) values represent a net storage of water in the reservoir. The cumulative net reservoir releases is estimated by adding the corresponding upstream sub-basin net reservoir releases.
4. Estimate the *sub-basin return flows* and *cumulative return flows*. The return flows are extracted water returned to system after use and treatment, as necessary. It is estimated based on the NPDES monitoring data (EPA, 2024) and fractions of consumptive use associated with various water uses. The *cumulative return flows* is estimated by adding the corresponding upstream sub-basin return flows.
5. Estimate *cumulative natural streamflow*. The natural streamflow is the streamflow that would occur naturally based on hydrologic conditions without human influence (for example, streamflow in absence of reservoir storage, or diversions from streams). The cumulative natural streamflow is estimated by removing cumulative extractions, cumulative return flows, and cumulative reservoir influences (volumes) from measured streamflow data at USGS gauging stations. The difference between extractions and return flows is also referred as net return flows or consumptive use. As pre-processing step, daily timeseries for the anthropogenic related terms were developed because the measure streamflow data available on a daily timesteps.
6. Estimate *cumulative natural baseflow*. The natural baseflow is the groundwater contributions to streamflow. In this study, it is estimated based on natural streamflow estimates (from previous step) using the USGS HYSEP-Slide program.
7. Estimate *minimum instream flow requirement*. The minimum instream flow required is the streamflow required to remain in the stream to support ecological function of the stream. It is estimated based on measured streamflow data at USGS gauging stations.
8. Estimate *net natural baseflow* and *net minimum instream flow requirements* at the sub-basin level. The initial estimates of natural baseflow and instream flow requirements reflect cumulative values because the approach uses measured streamflow at USGS gauges, which incorporates all upstream flows. In this step, the net natural baseflow and instream flows are estimated by subtracting the downstream cumulative flow from the cumulative flow at the next upstream sub-basin. The sum of the sub-basin net baseflow and instream flows are equal to the cumulative values at the outlet of the most downstream sub-basin.
9. Estimate two water supply metrics by sub-basin described above:
 - a. *Water availability*. The water availability indicates the amount of water that is available in sub-basin for human consumption after instream flow and human management influence is considered. It is estimated as the baseflow minus instream flow plus net reservoir release (refer to Equation 1).
 - b. *Excess water availability*. The sub-basin (local) excess water availability provides an evaluation of whether supplies are sufficient to meet water use demands in a sub-basin. It is estimates as the water supply remaining after consumptive use (extractions minus return flows). The consumptive use is considered to acknowledge there is a portion of the surface water and groundwater withdrawals that is returned to the system.

10. Estimate *cumulative water availability* at each sub-basin. The cumulative excess water availability accounts for upstream excess water availability where water in excess in upstream sub-basins could be made available to downstream sub-basins. For this metric, all cumulative water availability components are used. In sub-basin 10, the most downstream sub-basin (see Appendix A3), its cumulative excess water availability represents the regional excess water availability, and it is used for the North Central Region's water availability study.

The following subsections provide additional methodology details for each individual term used in the evaluation of historical and future water supply metrics indicating the difference in historical and future analysis and, if applicable, additional pre-process steps required for their estimation. For all these terms, except from the natural streamflow, the components were estimated as a sub-basin term as well as a cumulative term.

A5.1 Natural Streamflow

The starting point for the historical natural streamflow estimation at each sub-basin is the measured streamflow at selected measuring points or gauges (refer to Table A3-1). The methodology for the projected (future) sub-basin streamflow is described in Appendix B as part of the integration of climate change into the future scenario. For this term, only the cumulative value was required.

The development of a synthesized streamflow timeseries for sub-basin 10 was conducted as a pre-process for the estimation of the natural streamflow. A streamflow measuring device at the outlet of sub-basin 10 is absent. An approach was devised using USGS streamflow gauges upstream and downstream of the Sub-basin 10 outlet to characterize streamflow at the outlet of Sub-basin 10. This approach is described below.

The streamflow gauges at the outlet of Sub-basin 8, Wabash-Logansport, and Sub-basin 9, Deer Creek-Delphi, were used to characterize the volumes of water flowing into Sub-basin 10, while three gauges including Tippecanoe River near Delphi, Indiana, Wildcat Creek near Lafayette, Indiana, and Wabash River at Lafayette, Indiana, were used to characterize streamflow downstream of the Sub-basin 10 outlet. Figure A5-1 shows a map of the five USGS streamflow gauges used to calculate streamflow at the outlet of Sub-basin 10. Also shown on Figure A5-1 is the drainage area that contributes runoff flow to the Wabash River's streamflow at Lafayette USGS gauge that is downstream of the Sub-basin 10 outlet and the two other downstream gauges (Tippecanoe near Delphi and Wildcat Creek near Lafayette).

The first step in estimating streamflow at the outlet of Sub-basin 10 was to calculate the net accretions and depletions, or gains and losses of streamflow, between the two upstream gauges (Sub-basins 8 and 9) and the three downstream gauges (Tippecanoe River near Delphi, Wildcat Creek near Lafayette, and Wabash River at Lafayette). Daily gains and losses were estimated by subtracting total downstream flows from the total upstream flows. The resulting time series reflects a series of positive and negative values indicating gains and losses between the upstream and downstream gauges. The daily gains and losses were then scaled by the fraction of the contributing area that coincides with Sub-basin 10 over the total contributing area at the Wabash River at Lafayette streamflow gauge. While there could be spatial variability associated with gains and losses between the upstream and downstream gauges, scaling the gains and losses according to area was deemed adequate for the purposes of the water availability. The scaled gains and losses were then added to the Sub-basin 8 and 9 daily streamflow to acquire streamflow at the outlet of Sub-basin 10.

Figure A5-2 shows annual streamflow volumes at the two upstream streamflow gauges and three downstream gauges, the estimated gains and losses between the upstream and downstream

gauges, and the estimated streamflow at the Sub-basin 10 outlet. The estimated streamflow at Sub-basin 10 is generally greater than the sum of streamflow at the Sub-basin 8 and 9 gauges, indicating there is generally a gain in streamflow in Sub-basin 10 on an annual basis. The sum of Sub-basins 8 and 9, Wildcat Creek near Lafayette, Tippecanoe River near Delphi, and the gains and losses add up to the streamflow of the Wabash River at Lafayette.

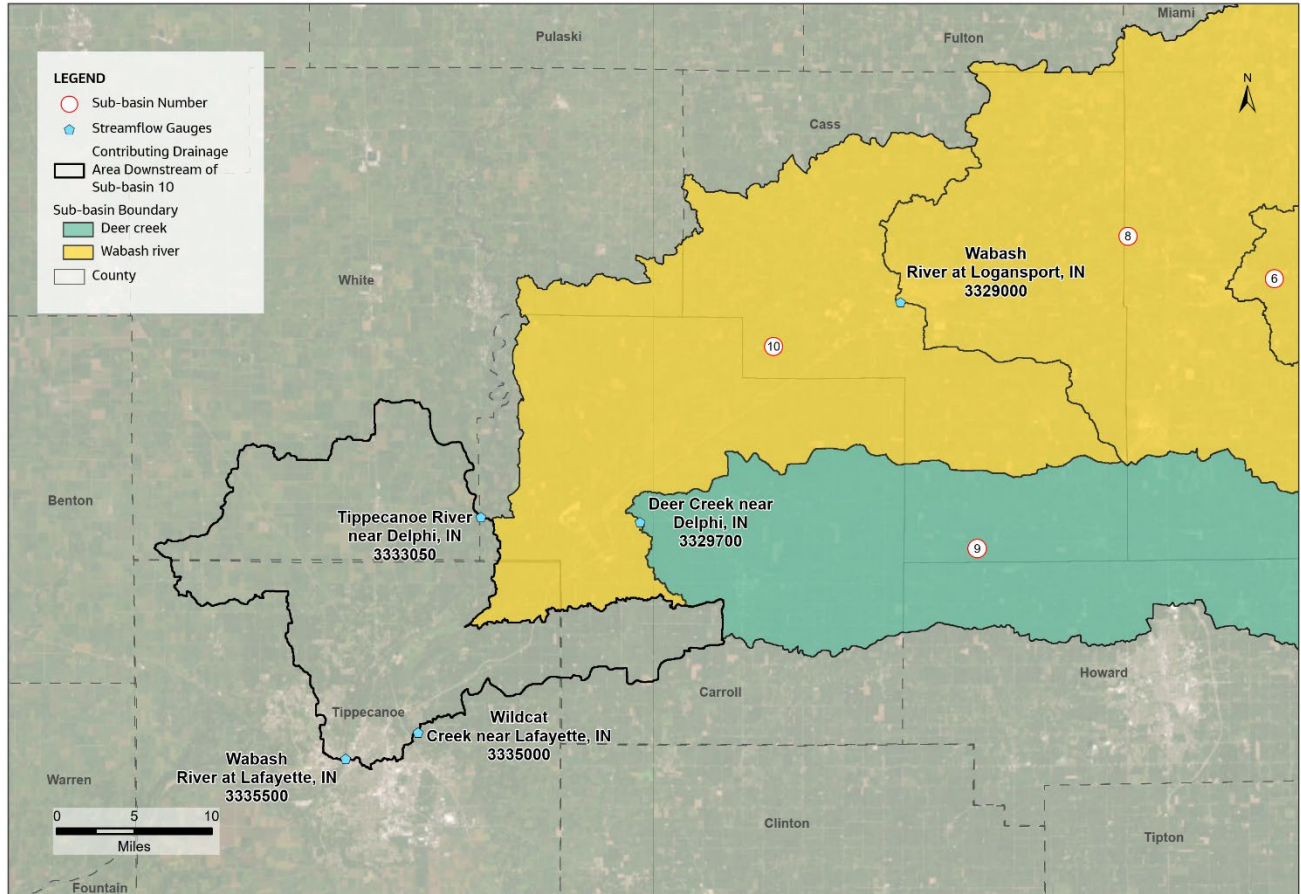


Figure A5-1. USGS Streamflow Gauges Used to Estimate Streamflow at Sub-basin 10 Outlet

Note: Measured streamflow from streamflow gauges upstream and downstream of Sub-basin 10 were used to estimate measured streamflow at the outlet of Sub-basin 10.

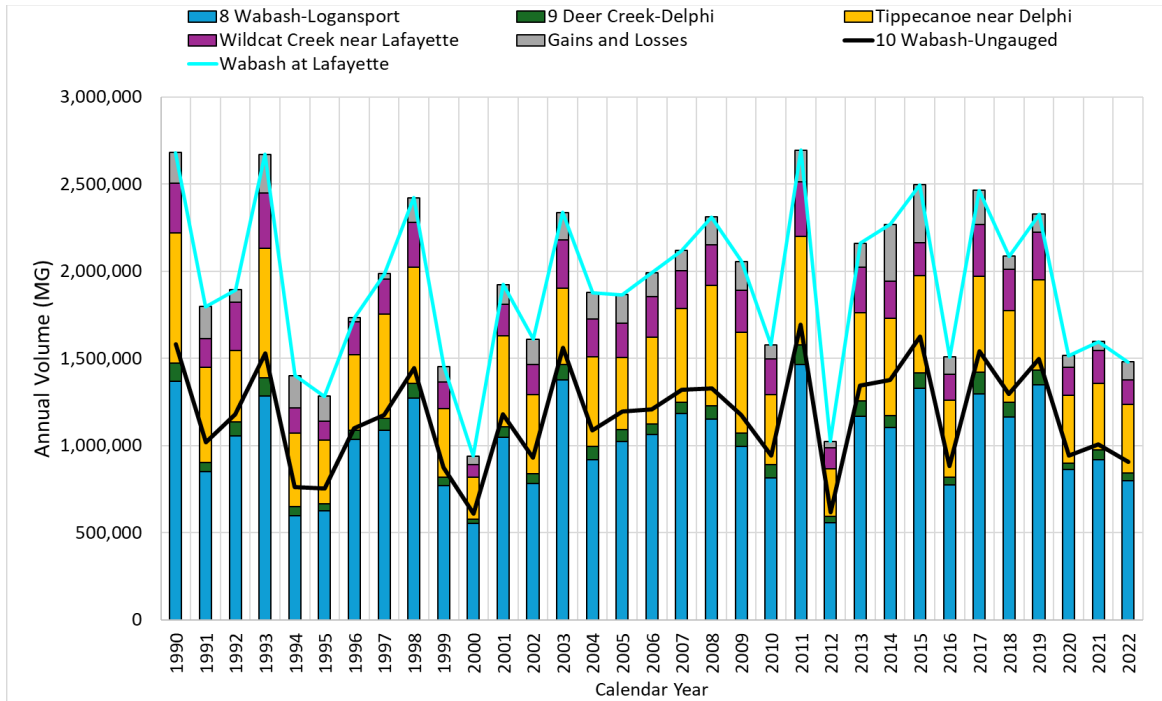


Figure A5-2. Annual Streamflow Volumes for Gauges Upstream and Downstream of Sub-basin 10 Outlet Used to Estimate Streamflow at Sub-basin 10 Outlet

Note: Gains and losses between the upstream and downstream streamflow gauges were quantified by taking the difference between the upstream and downstream gauges. The sum of all terms shown as bars equate to measured streamflow at Wabash at Lafayette to indicate all measured streamflows have been accounted for in estimating measured streamflow at the outlet of Sub-basin 10.

A5.2 Natural Baseflow

The historical and future *cumulative natural baseflow* was estimated based on historical and future natural streamflow estimates, respectively, using the USGS HYSEP-Slide program (Sloto and Crouse, 1996) to conduct a hydrograph separation. The initial estimates of natural baseflow reflect cumulative values because the approach uses measured streamflow at USGS gauges, which incorporates all upstream flows. The *net natural baseflow* is estimated by subtracting the downstream cumulative flow from the cumulative flow at the next upstream sub-basin.

Hydrograph separation is the computational process of dividing a stream hydrograph into baseflow and surface runoff components and is a common technique used in water resource investigations. Baseflow is generally recognized as the groundwater discharge component of streamflow. Hydrograph separation relies on assumptions that result in a simplification of the complex routing within the portion of the water cycle connecting precipitation with streamflow, with intermediary components such as overland flow, recharge to groundwater from precipitation and snowmelt, and groundwater discharge to streams. These processes may occur on different time scales in different areas in a single basin.

There are several techniques available for hydrograph separation. Most methods are graphical in nature, relying on different algorithms to separate the baseflow and surface runoff components. This includes the streamflow partitioning (hydrograph separation) (PART) method (Rutledge, 1998, 2007), the method utilized in the water supply evaluation of the Central Indiana and Southeast-Central Indiana

regional water studies (IFA, 2021; Letsinger and Gustin, 2024). The USGS Hydrologic Toolbox (Barlow et al., 2017) incorporates several baseflow separation methods, including PART in a user-friendly interface. The other methods incorporated into the Toolbox include the following:

- **HYSEP (3 versions)**—The HYSEP Fixed Interval, Local Minimum, and Sliding Interval methods originally developed by Pettyjohn and Henning (1979) and implemented in the HYSEP software by Sloto and Crouse (1996).
- **Baseflow Index (BFI) (2 versions)**—The BFI method Standard and Modified methods originally developed by the Institute of Hydrology (1980a, 1980b) and implemented in a computer program by Wahl and Wahl (1995).
- **DF-Two Param (TwoPRDF) and BFLOW**—The two-parameter digital filter developed by Eckhardt (2005) and later implemented in a computer program described by Eckhardt (2008).

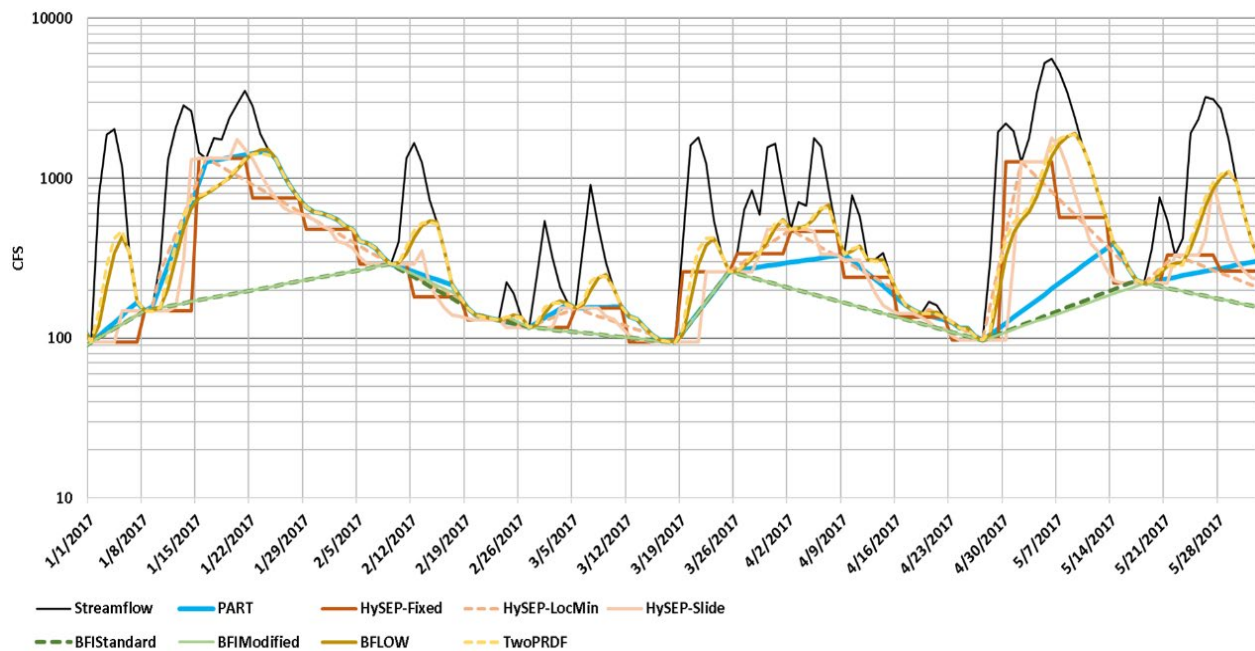


Figure A5-3. Example Hydrograph Separation on Daily Data from Techniques Available in the USGS Hydrologic Toolbox

Note: Each technique uses a different approach to estimate baseflow from the measured streamflow hydrographs. HYSEP-Slide was deemed most adequate for use in this study for its ability to replicate consistent results across all sub-basins.

Figure A5-3 provides an example of baseflow separation results on a portion of a hydrograph. Most processes connect, to some extent, dips in the hydrograph, with varying extension of baseflow up into larger flow portions of the hydrograph. In general, those implementing any of these techniques are cautioned against using daily baseflow results and are encouraged to use yearly or longer durations for evaluation.

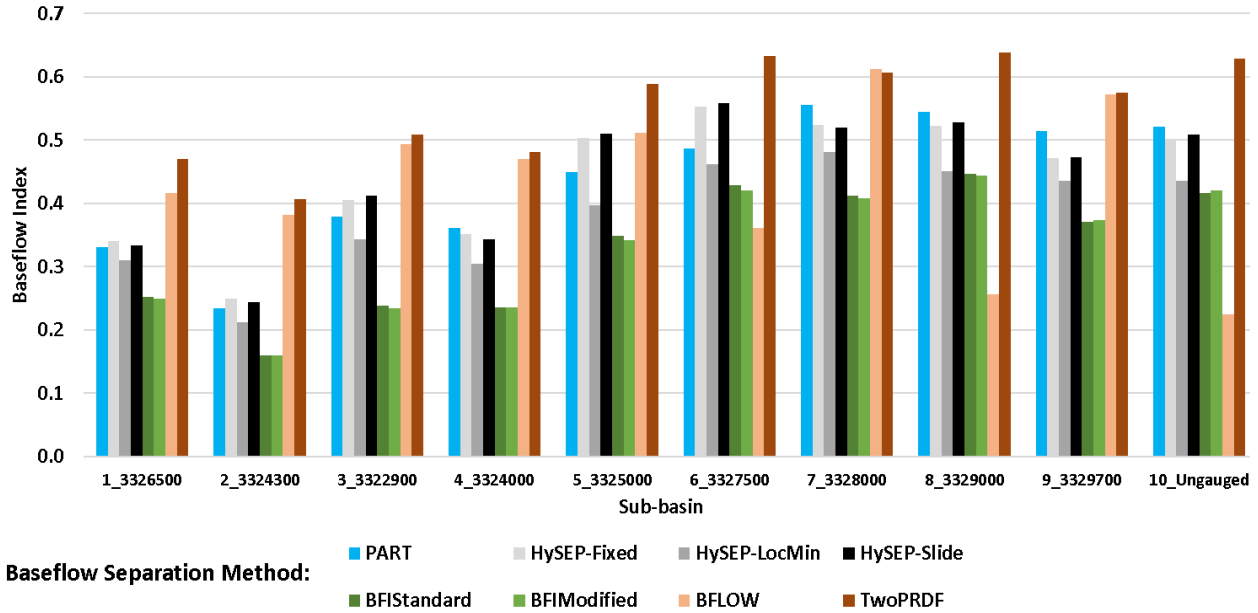


Figure A5-4. Comparison of Baseflow Index for Multiple Methodologies 2007 through 2022 Based upon USGS Gauge Data and Estimated Discharge at Sub-basin 10

Note: The BFI varies across baseflow separation techniques and sub-basins.

Often the relationship between baseflow and streamflow is summarized as the BFI, the ratio of total computed baseflow divided by the total computed streamflow, for a given period. Figure A5-4 provides a comparison of the BFI for the described methodologies. The range is wide, with the BFI methods typically low and the two-parameter digital filter method typically high. The PART results are typically in the middle, as are the HYSEP methods.

After review of the methodologies and comparisons between basins, HYSEP-Slide was chosen as the hydrograph separation method for use in this study. The PART method tended to generate inconsistent baseflow estimates between basins for the same discharge event, leading to problematic interpretation of results, and the HYSEP-Slide method generated reasonable results with good consistency between sub-basins.

Following the computation of the natural streamflow, natural baseflow was estimated for each basin using the HYSEP-Slide methodology. Figure A5-5 plots the computed BFI against the drainage area. Variability is high for the smaller basins (less than 1,000 mi²; ranging between 0.25 and 0.52) and is consistently above 0.5 for the larger basins. The BFI was also computed for the natural streamflow (measured streamflow adjusted to represent natural runoff), with data shown on Figure A5-6. The largest differences between USGS gauge data and the natural streamflow is the reduction in the BFI in the larger Sub-basins. Sub-basins 5 and 6 contain reservoirs, and the delayed flow from stored water may have been interpreted as baseflow prior to the adjustments made in the generation of natural streamflow. These effects are propagated downgradient into Sub-basins 9 and 10, and the result is a gradual increase in BFI in the downstream direction for the Wabash River.

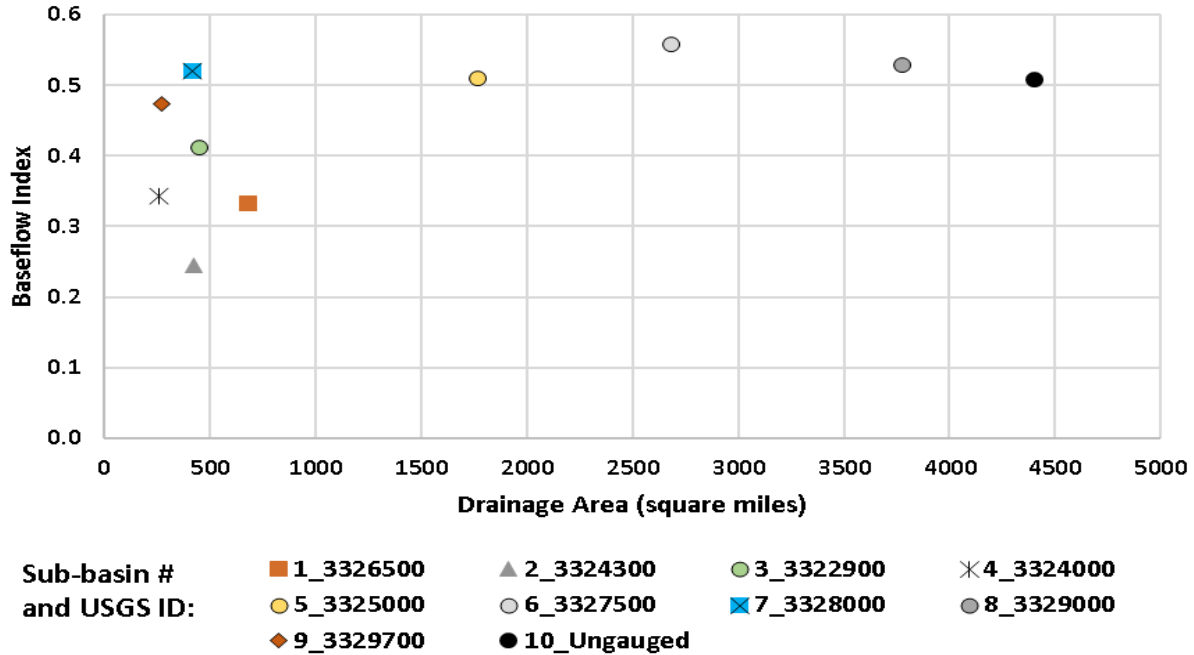


Figure A5-5. Baseflow Index Versus Drainage Area at USGS Streamflow Gauges for 2007 through 2022

Note: The BFI is relatively stable as the drainage area increases beyond 1,000 mi².

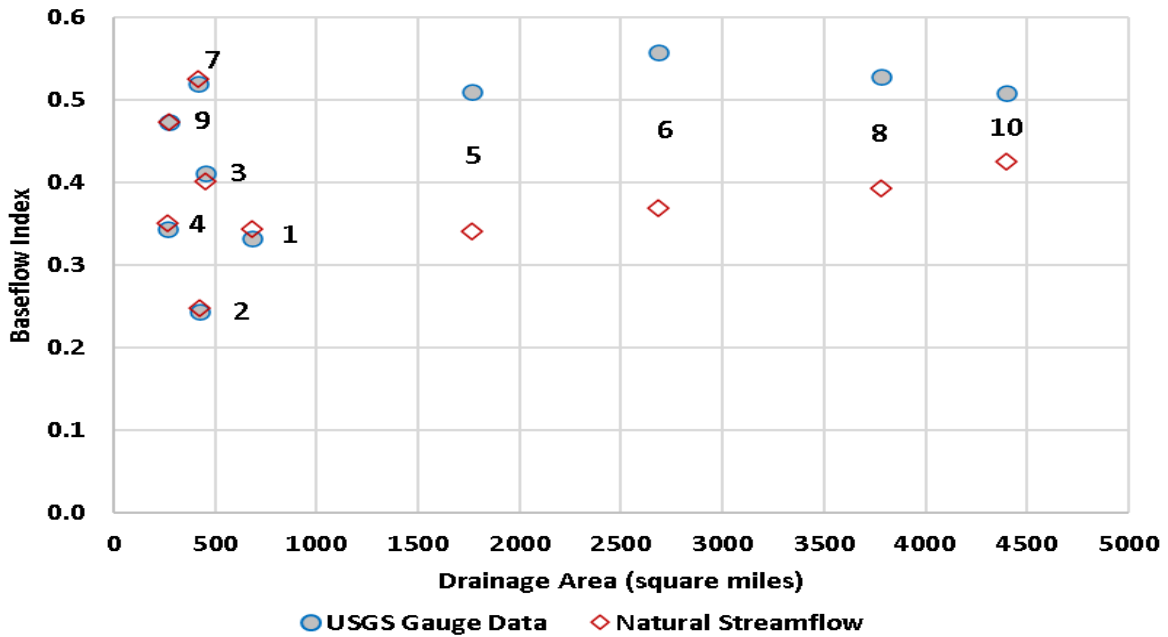


Figure A5-6. Comparison of Baseflow Index, USGS Measured Streamflow, and Natural Streamflow for Each Sub-basin in the Study Area

Notes: The difference in the BFI between the USGS-measured streamflow and the natural streamflow increases as the drainage area increases.

Labels indicate sub-basin number.

A5.3 Minimum Instream Flow Requirements

Historical *Cumulative minimum instream flow requirements* are quantified to establish minimum amount of streamflow that must remain in the stream to support riverine ecosystem health, recreational use, and water quality. The future *cumulative minimum instream flow requirements are assumed to remain the same as historical*. Two metrics are used to determine the instream flows:

- 7Q10, defined as the lowest 7-day average flow in a stream that occurs once every 10 years. The IDNR recommends this as the minimum value during low-flow periods (IDNR, 2015).
- Q90, defined as the minimum flow that is present 90% of the time in a stream. On average, flows will be lower than this value 10% of the time.

The instream flow metrics were computed on actual streamflow data (not the natural streamflow calculated for this study) for the period 1990 through 2020. Because no regulatory statutes define the determination of minimum instream flows, a similar protocol used by the Central Indiana Water Study (IFA, 2021) is implemented herein, where the annual Q90 is used to specify minimum flow during winter and spring months (December through May), when streamflow is typically higher, and the 7Q10 during summer and fall months (June through November), when streamflow is typically lower.

The flow rates defined by these metrics vary depending upon the size of the stream and watershed, the hydrology of the watershed, geology, and water use patterns. Typically, as streamflow rates increase in a downstream direction, so will the instream flow requirements.

The *net minimum instream flow requirements* are estimated for the water availability estimate at the sub-basin level. The initial estimate's instream flow requirements reflect cumulative values because the approach uses measured streamflow at USGS gauges, which incorporates all upstream flows. The net instream flows are estimated by subtracting the downstream cumulative flow from the cumulative flow at the next upstream sub-basin. The sum of all sub-basins' net instream flows requirements are equivalent to the cumulative values at the outlet of the most downstream sub-basin, which is Sub-basin 10. Appendix D provides the cumulative and net instream flow requirements for the sub-basins in the study area.

A5.4 Net Return Flows

Sub-basin net return flow approach included an assumed monthly fix fraction for irrigation, livestock operations, and self-supplied residential for the historical as well as the future projections as indicated in Table A5-1: for the self-supplied residential, a monthly pattern of return flow fractions is applied across all years; and, for the rural users and livestock operations, a constant 20% is assumed.

For the industry, public supply, energy production, and rural use water users, the historical *sub-basin return flows* were estimated based on the NPDES monitoring data that corresponds to flows from external outflows in conduit or through treatment plant. A filter for outliers that deviated by four times from the mean of the time series was employed, and runoff from treatment plants with capacity greater than 1 MGD was removed. The future *sub-basin net return flows* for users with NPDES were estimated based on the proportion of non-consumptive water returned to each sub-basin at rates based on historical monthly water use trends were developed for those users with NPDES, their estimated consumptive use fractions were assumed the same as historical.

Table A5-1. Monthly Fraction of Extraction Returning to the System for Historical and Future Net Return Flows Estimations

Month	Self-Supplied Residential	Irrigation and Livestock Operations
January	1.00	0.20
February	1.00	0.20
March	0.98	0.20
April	0.98	0.20
May	0.98	0.20
June	0.81	0.20
July	0.81	0.20
August	0.81	0.20
September	0.93	0.20
October	0.93	0.20
November	0.93	0.20
December	1.00	0.20

Source: Shaffer, 2009.

The *cumulative return flows* are estimated by adding the corresponding upstream *sub-basin return flows*. The cumulative term is used for the estimation of *cumulative natural streamflow* and the *cumulative excess water availability*.

A5.5 Net Reservoir Releases

Sub-basin net reservoir releases are estimated for reservoirs with flood control purposes. Historical *Sub-basin net reservoir releases* are calculated as the differences between measured inflows and outflows from reservoirs. Future *Sub-basin net reservoir releases* are repeated into the future using a climate-based year-type indexing approach as described in Appendix B as part of the integration of climate change into the future scenario. Reservoir operations are assumed to be consistent with historical operations.

Only three reservoirs are used for flood control purposes in the study area located in two sub-basins:

- Sub-basin 5: J. Roush Lake Dam (Huntington) and Salamonie Lake Dam
- Sub-basin 6: Mississinewa Lake Dam

The *cumulative net reservoir releases* are estimated by adding the corresponding upstream sub-basin net reservoir releases. The cumulative term is used for the estimation of *cumulative natural streamflow* and the *cumulative excess water availability*.

A6 References

- Barlow, P. M., W. L. Cunningham, T. Zhai, and Mark Gray. 2017. *The Groundwater Toolbox: A Graphical and Mapping Interface for Analysis of Hydrologic Data*. U.S. Geological Survey Software Release, Groundwater Toolbox Version 1.3.1. May 26. <http://dx.doi.org/10.5066/F7R78C9G>.
- Dieter, C. A., M. A. Maupin, R. R. Caldwell, M. A. Harris, T. I. Ivahnenko, J. K. Lovelace, N. L. Barber, and K. S. Linsey. 2018. *Estimated Use of Water in the United States in 2015*. U.S. Geological Survey Water Availability and Use Science Program Circular 1441. Supersedes USGS Open-File Report 201701131. <https://pubs.usgs.gov/publication/cir1441>.
- Eckhardt, K. 2005. "How to construct recursive digital filters for baseflow separation." *Hydrological Processes*. Volume 19, Number 2. pp. 507-515. <https://doi.org/10.1002/hyp.5675>.
- Eckhardt, K. 2008. "A comparison of baseflow indices, which were calculated with seven different baseflow separation methods." *Journal of Hydrology*. Volume 352, Number 1-2. pp. 168-173. <https://doi.org/10.1016/j.jhydrol.2008.01.005>.
- Ezenwankwo, Samuel. 2021. "Water Consumption Rate for Layers and Broilers For Optimal Output." Poultry Farm Guide. <https://www.poultryfarmguide.com/blog/water-requirement-for-layers-and-broilers/>.
- Fedrow, Dara M. 2019. Water Use in Confined Animal Feeding Operations (CAFOs) In Minnesota: Who's Keeping Track? Master of Science Thesis, Environmental Studies, University of Montana. <https://scholarworks.umt.edu/etd/11365/>.
- Indiana Department of Environmental Management (IDEM). 2023. *Virtual Filing Cabinet Month Report of Operations*. [IDEM: Legal Counsel: Virtual File Cabinet](https://www.in.gov/idem/legal-counsel/virtual-file-cabinet/).
- Indiana Department of Environmental Management (IDEM). 2024. Pending and Issued CFO Permits. Accessed September 2024. <https://www.in.gov/idem/cfo/resources/pending-and-issued-cfo-permits>
- Indiana Department of Natural Resources (IDNR). 2015. *Indiana's Water Shortage Plan*. March 20. IDNR, Division of Water. <https://www.in.gov/iurc/files/DNR-March-2015-Indianas-Water-Shortage-Plan.pdf>.
- Indiana Department of Natural Resources (IDNR). 2024. "Significant Water Withdrawal Facility Data 1985-2022." Accessed June 2024. <https://www.in.gov/dnr/water/water-availability-use-rights/significant-water-withdrawal-facility-data/>.
- Indiana Finance Authority (IFA). 2021. *Central Indiana Water Study Phase III: Water Availability*. IFA Regional Water Study Program. <https://www.in.gov/ifa/files/Central Indiana Water Availability Report.pdf>.
- Indiana Finance Authority (IFA). 2024. "2022 Legislative Report – Appendix B – Complued dataset." Water Loss Audits. Accessed October 28, 2024. <https://www.in.gov/ifa/water-loss-audits/#tab-831700-6-Additional Documents>.
- Institute of Hydrology. 1980a. Low Flow Studies: Research Report. Report 1. Unpublished. Wallingford, United Kingdom. January. <https://nora.nerc.ac.uk/id/eprint/9093/>.

- Institute of Hydrology. 1980b. Low Flow Studies: Catchment Characteristic Estimation Manual. Report 3. Unpublished. Wallingford, United Kingdom. <https://nora.nerc.ac.uk/id/eprint/9098/>.
- Letsinger, S. L. and A. R. Gustin. 2024. Regional Water Study: Water Demand and Availability in the Driftwood, Flatrock-Haw, and Upper East Fork White River Watersheds. Indiana Finance Authority Award 079396-00002B.
- Nation Oceanic Atmospheric Administration (NOAA). 2024. Climate at a glance: County time series. NOAA National Centers for Environmental Information. Accessed June 21, 2024. <https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/county>.
- Pettyjohn, W. A. and R. Henning, 1979. *Preliminary estimate of ground-water recharge rates, related streamflow and water quality in Ohio*. Ohio State University Water Resources Center, Project Completion Report Number 552.
- Ries, K. G.III, J. K. Newson, M. J. Smith, J. D. Guthrie, P. A. Steeves, T. L. Haluska, K. R. Kolb, R. F. Thompson, R. D. Santoro, and H. W. Vraga. 2017. *StreamStats, Version 4*. U.S. Geological Survey Fact Sheet 2017-3046. Supersedes USGS Fact Sheet 2008–3067. October. <https://doi.org/10.3133/fs20173046>.
- Rutledge, A. T. 1998. Computer programs for describing the recession of ground-water discharge and for estimating mean ground-water recharge and discharge from streamflow records—Update. U.S. Geological Survey Water Resources Investigations Report 98–4148. <https://pubs.usgs.gov/publication/wri984148>.
- Rutledge, A. T. 2007. *Program User Guide for PART*. Distributed with PART hydrograph separation analysis software. U.S. Geological Survey. <http://water.usgs.gov/ogw/part/>.
- Shaffer, K. H. 2009. Variations in withdrawal, return flow, and consumptive use of water in Ohio and Indiana, with selected data from Wisconsin, 1999–2004. U.S. Geological Survey Scientific Investigations Report 2009–5096. September. <https://pubs.usgs.gov/sir/2009/5096/>.
- Sloto, R. A. and M. Y. Crouse. 1996. *HYSEP—A computer program for streamflow hydrograph separation and analysis*. U.S. Geological Survey Water Resources Investigations Report 96–4040. <http://pubs.er.usgs.gov/publication/wri964040>.
- STATS Indiana. n.d. www.stats.indiana.edu. Accessed January 2, 2025. <https://www.stats.indiana.edu/>.
- STATS Indiana. 2024. “Population Projections.” July. <https://www.stats.indiana.edu/topic/projections.asp>.
- U. S. Environmental Protection Agency (EPA). 2024. NPDES Monitoring Data Download. Enforcement and Compliance History Online (ECHO). Accessed June 2024. <https://echo.epa.gov/trends/loading-tool/get-data/monitoring-data-download>.
- U.S. Department of Agriculture (USDA). 2024. “Chapter 2, County Data.” *2022 Census of Agriculture, Indiana State and County Data*. AC-22-A-51. USDA National Agricultural Statistics Service. February. https://www.nass.usda.gov/Publications/AgCensus/2022/Full_Report/Volume_1_Chapter_2_County_Level/Indiana/.

- U.S. Department of Transportation (DOT). n.d. National Address Database (NAD). Release 12.
<https://www.transportation.gov/mission/open/gis/national-address-database/national-address-database-nad-disclaimer>. Accessed May 16, 2024.
- Wahl, K. L. and T. L. Wahl. 1995. "Determining the flow of Comal Springs at New Braunfels, Texas."
Proceedings of Texas Water 95. American Society of Civil Engineers. San Antonio, Texas: Texas
Water 95. August 16 and 17. pp. 77-86.