North Central Indiana Regional Water Study

Wabash River – Granville Bridge (IFA, 2024a)

Prepared By:

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North Central Indiana Regional Water Study

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Executive Summary

Study Purpose: The North Central Indiana Regional Water Study (Study) estimated historical and 50-year future water demand and water supply availability. The Study Area encompassed all or portions of 15 counties within the upper Wabash River watershed, including Boone, Clinton, Fountain, Fulton, Howard, Kosciusko, Montgomery, Parke, Pulaski, Tippecanoe, Tipton, Vermillion, Vigo, Warren, and White (**Figure ES-1**).

Study Approach: The water availability estimates presented in this Study are based on data-driven analyses following a methodology similar to that used in previous regional water studies in Indiana, with some refinement. Water availability was calculated as baseflow in a stream or river not allocated to a defined use or purpose, also referred to as excess water in the system. Calculations were conducted, and results are presented, for 16 hydrologic subbasins of the upper Wabash River watershed. Stakeholders throughout the Study Area provided important input to the Study on topics such as future demand assumptions and estimates of water withdrawals and return flows.

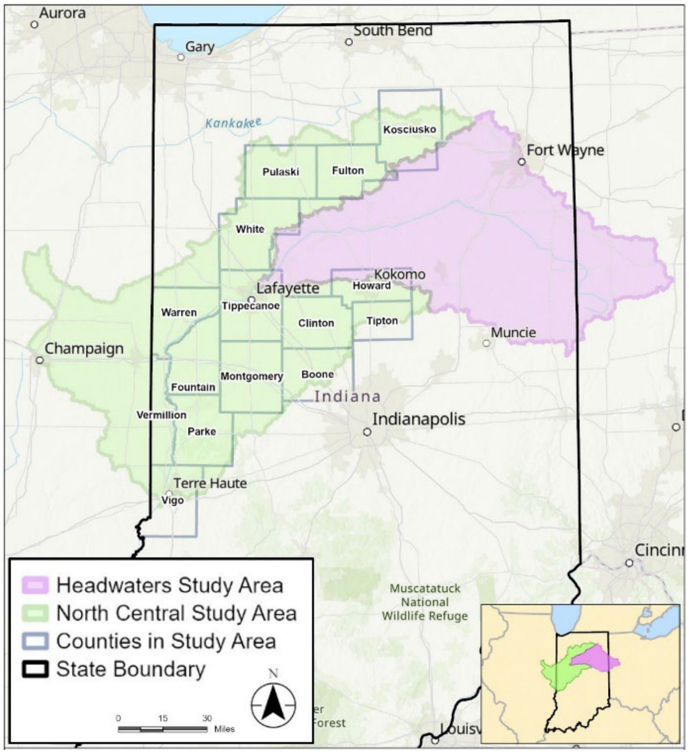

Figure ES-1. North Central Indiana Regional Water Study Area

Regional Setting: North Central Indiana contains a diverse range of hydrology, geology, population centers, land and water uses that vary geographically and with time. The region generally consists of agricultural land surrounding moderately sized population centers, including Lafayette, the tenth largest city in Indiana. The 2022 Study Area population was estimated to be 710,000 in Indiana and 215,000 in Illinois. Much of the Study Area overlies the Mahomet (Teays) Bedrock Valley. The Wabash River, which has the largest watershed of any river in the state, runs through the heart of the Study Area. The Wabash River itself supports most surface water withdrawals within the region, including two energy facilities. The remaining water withdrawals in the region are predominantly from groundwater wells.

Water Demand: Historical water withdrawals within the 15-county Study Area were primarily characterized using monthly water use data by sector from the IDNR Significant Water Withdrawal Facility database. In 2022, total water withdrawals were 789 million gallons per day (MGD). Cooling water for energy production dominates current water withdrawals, and most (~99%) of that water withdrawn is returned to the river (i.e., non-consumptive use). Public supply is the second largest water use sector. Historical water withdrawals peaked in 2006 (**Figure ES-2**). Demand has been dominated by energy production water use in Subbasins 12 and 15. In 2016, one coal energy plant in Subbasin 15 (light pink) went offline; another coal energy plant in Subbasin 12 (light blue) is scheduled to go offline in 2028.

The 2070 Study Area-wide projected water demand is 260 MGD. The 2070 projected demand is similarly distributed between public supply (78 MGD, or 30 percent of total, an increase from 70 MGD in 2022), irrigation (70 MGD, 27 percent of total, an increase from 42 MGD in 2022), industrial (66 MGD, 25 percent of total, an increase from 37 MGD in 2022), and other water use sectors (**Figure ES-2**). Public supply water demand is projected to increase, but slightly less than industrial and irrigation water demands, due in part to declining population forecasts in some of the subbasins.

The past 15 years have shown a decrease in surface water withdrawals and an increase in groundwater withdrawals. Since 2007, annual surface water withdrawals have decreased 50%, from around 1,250 MGD to less than 650 MGD. Over that same period, groundwater withdrawals have varied from year to year, but in total have increased 6%, from just over 110 MGD to just under 120 MGD. Surface water withdrawal reductions are largely due to decreased river withdrawals for use as cooling water in coal-based electricity generating facilities, while increases in groundwater withdrawals are primarily attributed to increased irrigation. Historically, public supply, industrial use, and irrigation in the Study Area have all been sourced primarily from groundwater.

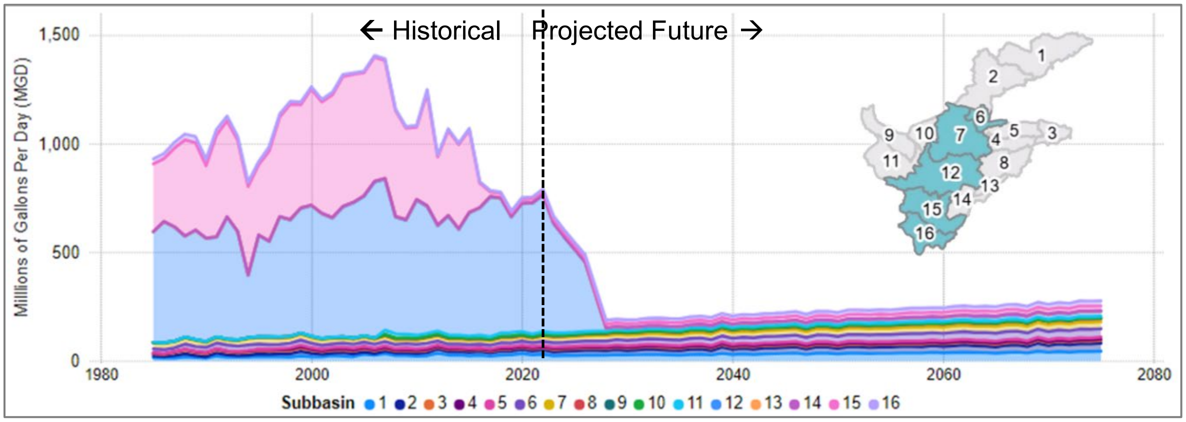

Figure ES-2. Historical (1985 to 2022) and Future Projected (2023 to 2072) Annual Water Demand in the North Central Indiana Study Area, by Subbasin, with Subbasin Inset Map (Wabash mainstem subbasins in blue)

Historical Water Availability: Historical water supply exceeds historical water demand in most locations and most seasons, but may be approaching a condition of total water allocation and limited excess during particularly dry seasons. Historically, there has been sufficient water for human and ecological needs in most locations and most seasons. Variations in natural baseflow are the main driver of cumulative excess water availability, and there is a strong seasonal variation across subbasins that is largely influenced by geology. Spring typically has had highest availability due to higher natural baseflow, followed by winter. During these wetter seasons, precipitation and snowmelt recharge into local aquifers, driving groundwater levels higher and producing higher baseflow. Fall is generally the most limiting season, followed by summer, due to low streamflow, low natural baseflow (the portion of streamflow that is from groundwater discharge and not surface runoff), and higher water withdrawals. During dry seasons, stored groundwater is discharged back into river systems as aquifer levels decline.

Projected Future Water Availability: Projected future water availability in the Study Area will likely differ from recent history because of projected future water demands and the effects of climate change.

Notably, fall cumulative excess water availability is projected to continue to decrease in the future, regardless of whether additional climate change is factored into the analysis. On a seasonal average basis, future cumulative excess water availability remains positive across all subbasins, indicating that there is enough water in those conditions. Seasonal variability similar to that observed historically is projected in the future, with cumulative excess water availability highest in the spring, relatively similar in the winter and summer, and lowest in the fall at all subbasins.

Fall cumulative excess water availability is likely to decrease, with all subbasins showing a 5% to 34% decrease (**Figure ES-3**), primarily due to lower estimated fall baseflow under future conditions. Future water availability is projected to remain varied across the Study Area, with subbasins along the Wabash River exhibiting greater cumulative excess water availability than tributary subbasins. Future fall cumulative excess water availability in the Wabash River subbasins will be even more reliant on baseflow and upstream reservoir releases from the Wabash River Headwaters region.

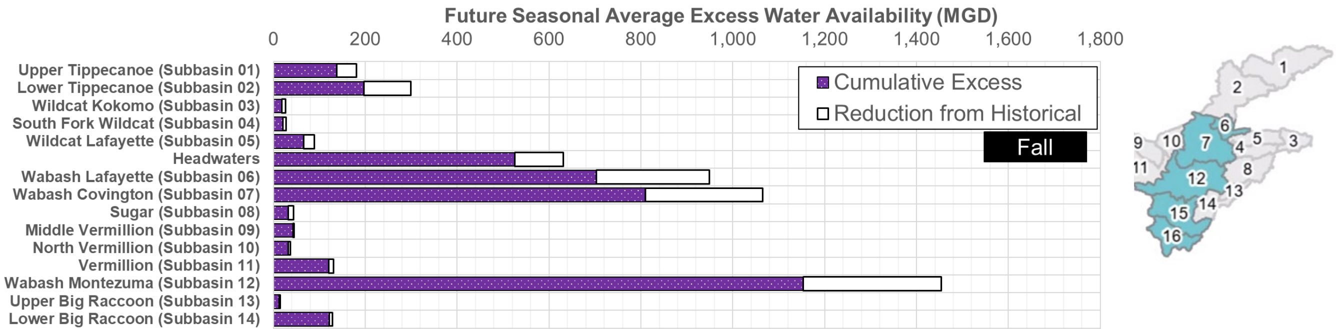

Figure ES-3. Projected Future Fall Season Cumulative Excess Water Availability by Subbasin

Figure ES-4 compares historical and projected future fall cumulative excess water availability at representative “typical” (median), “dry year,” and “drought” conditions. Median fall cumulative excess water availability in most subbasins will likely decrease, with upper tributary subbasins (01-05) showing the largest reduction. In many subbasins, particularly the Tippecanoe River (Subbasins 01-02), Wildcat Creek (03-05), and portions of the Wabash mainstem (07), the projected reductions are expected to be more pronounced in drought years.

In most future years, seasons, and across subbasins, future supplies nearly always exceed future demands (including instream flows), leaving positive cumulative excess water availability. Similar to the historical period analysis, water supply is projected to remain abundant during most years and seasons. Under future dry conditions, current supply-demand imbalances are likely to get worse. Future fall water availability is likely to be substantially reduced relative to historical conditions, consistently by 15%-30% across the Study Area subbasins. Future seasonal variability in water availability is projected to increase. Future conditions in spring are anticipated to be wetter, while conditions in the fall are anticipated to be drier. This creates greater seasonal imbalances, resulting in larger annual flow volumes but also more stress on the water system anticipated in the fall. Lastly, upstream reservoirs are projected to more frequently contribute the majority of future cumulative excess water availability during the fall season along the mainstem of the Wabash River.

Water Resource Risks, Opportunities, and Recommendations: With recent increasing drivers for economic development, Indiana is rapidly approaching a crossroads in water management. While multiple risks could threaten water availability and suitability into the future, numerous opportunities exist to more effectively manage and protect the region's finite water resources.

Risks: Water supply utilities and providers across Indiana and around the country are continuously managing multiple existing and potential future risks. This Study focused on water availability and the suitability of available water for use. Five specific related risks and uncertainties – climate change, water quantity, water quality, the difficulty in predicting future conditions, and local impacts of additional water development – are identified and described in the Study report.

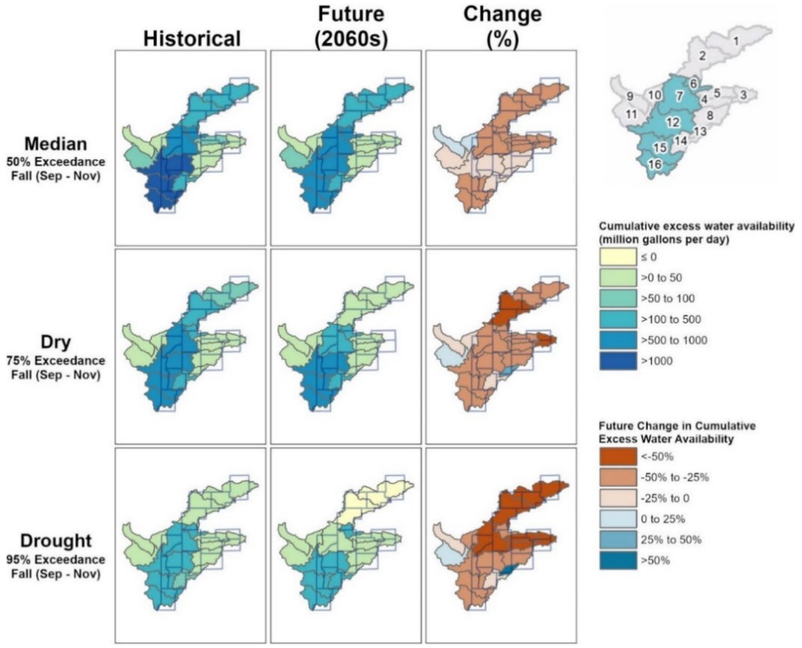

Figure ES-4. Changes Between Historical and Projected Future Fall Cumulative Excess Water Availability for Median (50%), Dry (75%), and Drought (95%) Conditions

Opportunities and Recommendations: The North Central Indiana region is not yet coming up against the 'hard boundary' of simply not enough available, affordable, reliable water supply to meet projected demand. This Study, however, identified some current and projected future localized limitations (i.e., within certain subbasins) and annual and seasonal variability limitations on water availability that merit consideration. Accordingly, nine potential approaches are recommended that can individually and/or collectively contribute toward an increase in future available water supply to maintain or strengthen the people, environment, productivity, and economy of North Central Indiana. This includes strategies to:

- enhance the supply of surface water and/or groundwater, including recommendations (1) groundwater exploration and development; (2) reservoir storage reallocation; (3) increased or expanded water storage; and (4) alternative water supplies.
- decrease the demand for water, including recommendation (5) water conservation and water use efficiency.
- better understand and manage water as a limited resource, including recommendations (6) data collection, monitoring networks, and modeling; (7) communication, coordination, and education; (8) water policy and practice; and (9) recommended follow-on analyses.

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Abbreviations

°F	degrees Fahrenheit
303(d)	Section 303(d) of the Clean Water Act
7Q10	lowest 7-day average flow that occurs every 10 years (on average)
ACS	American Community Survey
ASR	Aquifer Storage and Recovery
BG	billion gallons
CAFO	Concentrated Animal Feeding Operation, larger regulated livestock operation
CESM1-CAM5	Community Earth System Model Community Atmosphere Model 5.0, a future climate model
CFO	Confined Feeding Operation, smaller regulated livestock operation
cfs	cubic feet per second
CSO	Combined Sewer Overflow
CWA	cumulative water availability
DSAC	Dam Safety Action Classification
ECHO	U.S. EPA Environmental Compliance History Online
EIA	U.S. Department of Energy, Energy Information Administration
EP	energy production (water-use sector)
EPA	U.S. Environmental Protection Agency
FSMP	Fixed Station Monitoring Program
GCM	Global Climate Model
gpm	gallons per minute
GWMN	Groundwater Monitoring Network
IC	Indiana Code
IDEM	Indiana Department of Environmental Management
IDNR	Indiana Department of Natural Resources
IFA	Indiana Finance Authority

IN	industrial (water-use sector)
INCCIA	Indiana Climate Change Impacts Assessment
IR	irrigation (water-use sector)
IWRRC	Indiana Water Resources Research Center
MCL	Maximum Concentration Limit
MG	million gallons
MGD	million gallons per day
mg/L	milligrams per liter
MWh	megawatt hour
MI	miscellaneous (water-use sector)
MRLC	Multi-Resolution Land Characteristics
NBF	initial natural baseflow
NFS	non-federal sponsor
NID	National Inventory of Dams
NPDES	National Pollutant Discharge Elimination System
PER	Preliminary Engineering Report
PFAS	per- and polyfluoroalkyl substances
PS	public supply (water-use sector)
PWS	public water supplies
Q80	minimum daily flow that is present 80% of the time (i.e., stream flow has only been that level or below 20% of the time)
Q90	minimum daily flow that is present 90% of the time (i.e., stream flow has only been that level or below 10% of the time)
RCP	Representative Concentration Pathway, refers to greenhouse gas concentrations in future climate model scenarios
Study	North Central Indiana Regional Water Study
SWWF	Significant Water Withdrawal Facility (high-capacity water pumping)
TDS	Total Dissolved Solids, a water quality metric
TSS	Total Suspended Solids, a water quality metric
USACE	U.S. Army Corps of Engineers

USGS	U.S. Geological Survey
VIC	Variable Infiltration Capacity model
WQMS	Water Quality Monitoring Strategy
WWTP	Wastewater Treatment Plant

Glossary

7Q10	The lowest 7-day average flow that occurs (on average) once every 10 years. In this Study, the 7Q10 low flow was used as a minimum instream flow.
Anticline	An arch of stratified rock in which the layers bend downward in opposite directions from the crest.
Alluvial (aquifer)	Unconsolidated geologic sediment of any grain size deposited by a river, stream, or creek. In Indiana, “alluvium” is often used to distinguish modern finer-grained riverine sediment from coarser-grained glacially derived outwash sediment.
Anthropogenic	Man-made or influenced by humans. Anthropogenic refers to interventions by humans, such as water withdrawals from aquifers and streams, wastewater returns, land use, land-cover modifications, and sources of contamination.
Aquifer	Subsurface water-bearing layer of geologic sediment or rock that facilitate the flow of groundwater.
Baseflow	The part of a flowing water body that represents the stream-adjacent groundwater surface and is not associated with runoff.
Baseline scenario	The foundational reference that outlines the most likely situation and outcome to occur.
Basin (watershed)	The contributing land area that drains water, such as rainfall or snowmelt, to a basin outlet. Also called a drainage basin or catchment.
Bedrock	Any lithified geologic material that remains intact and in place where it was deposited.
Capture	Pumping an extraction well “captures” water in a zone around the well. Extraction wells can be used to remove contaminated groundwater for treatment and further disposal
Change factor	A number reflecting the future proportional change in monthly stream flow simulated by a hydrologic model that incorporates future temperature, precipitation, and/or other meteorological input data.
Conjunctive use	Coordinated use of surface water and groundwater.
Consumptive use	The percent of water withdrawals that are not returned to waterways. For example, irrigation water is estimated to have an 80 percent consumptive use rate, meaning the plant transpires 80 percent of the applied irrigation water, and 20 percent of the irrigation water either runs off or percolates into the groundwater.
Critical habitat	Specific geographic areas essential to the conservation of a listed threatened or endangered species.

Dewatering	The removal of surface water or groundwater by pumping to facilitate excavations for construction or mining.
Discharge	Streamflow volume, usually measured in cubic feet per second (cfs).
Evapotranspiration	The removal of water from the earth's surface and vegetation through the processes of evaporation and transpiration.
Excess water availability	The portion of water availability in a stream (at the subbasin outlet) that could be used to support additional surface water or groundwater withdrawals without impacting instream flows or existing surface water and net groundwater withdrawals.
First order subbasin	A subbasin that does not receive flow any upstream subbasin(s). These are typically located on tributaries to larger rivers.
Glacial till (till)	An often thick, poorly sorted, clay-rich, unconsolidated geologic deposit that is created by the movement of a glacier.
Groundwater	Water that occurs beneath the land surface and fills the pore spaces of the alluvium, soil, or rock formation in which it is situated. It excludes soil moisture, which refers to water held by capillary action in the upper unsaturated zones of soil or rock.
Groundwater recharge	The amount of water that is added to a groundwater aquifer through the process of infiltration.
Headwaters	The most up-gradient, or first-order, tributary watersheds contributing water and sediment downstream to the stream network. The term "Headwaters" in this report specifically refers to the subbasins of the upper Wabash River Watershed that were analyzed in a related study (Jacobs, 2025).
Hydrograph	A graph showing streamflow (y-axis) over time (x-axis), reflecting streamflow from the area upstream of the measurement point.
HYSEP	A software tool for separating and analyzing streamflow hydrographs into baseflow (groundwater) and precipitation (runoff) components.
Instream flow	Instream flows are minimum stream flows required to support the ecological health of the stream, recreational use, and water quality.
Moraines	Ridges or mounds of glacial origin that consist of intermixed clay, silt, sand, gravel, cobbles, and boulders.
Natural baseflow	The groundwater contribution of streamflow that is discharged from aquifers to streams. Streams can have gaining (groundwater contribution to the stream) or losing (water loss from the stream bed to recharge groundwater) reaches. Natural baseflow is an estimate of the groundwater discharge contribution to a stream reach without considering anthropogenic (man-made) interventions such as water withdrawals or wastewater-return flows.

Natural streamflow	The streamflow that would be measured if anthropogenic (man-made) effects of surface-water and groundwater withdrawals and wastewater return flows were removed.
Observation well	A subsurface borehole (groundwater well) that, instead of pumping, is used to observe and monitor the water table elevation.
Outstanding Resource Waters	A component of the federal Clean Water Act that allows states to identify pristine waterways that constitute an outstanding state resource due to their exceptional water quality, statewide ecological importance, and/or unique recreational value.
Outwash	Geologic sediment deposited by meltwater from a receding glacier; in Indiana, modern rivers and streams often follow meltwater channels.
Public Water System	Water utilities that distribute water from either surface water or groundwater sources. A PWS can be a community system that serves a large population, or a system such as a school that has their own water well(s). Also represented as “PS” in this report, referring to the Public Supply water-use sector.
Reservoir reallocation	The process of changing how, and for what purpose, water is stored and released in a reservoir.
Return flow	Discharge to surface waters from facilities permitted by the NPDES program, such as wastewater treatment plants. Also refers to estimated non-consumptive flows that return to the hydrologic system through diffuse infiltration and subsurface migration.
Runoff	Precipitation that is unable to infiltrate into a groundwater aquifer and instead flows along the earth’s surface.
Streamflow	Streamflow discharge, usually measured in cubic feet per second (cfs)
Stream gage	Equipment to measure streamflow at a given location where a flowing body of water is confined to a known geometry (such as a channel) to facilitate the measurement of flow volume and other flow statistics.
Subbasin	A smaller drainage area within a larger river basin or watershed, such as the drainage area for a tributary to a larger river system.
Surface water	Water flowing and stored in streams, lakes, and reservoirs. In Indiana, surface water bodies are fresh (non-saline) water.
Unconfined aquifers	An aquifer that does not flow beneath an impermeable geologic layer and is free to flow in accordance with gravity. Sometimes called “water table aquifer” in shallow wells.
Unconsolidated	Geologic material (such as sediment, alluvium, soil, and till) that has not gone through the process of lithification.
Water availability	The portion of natural baseflow in a stream (at the subbasin outlet) remaining after accounting for instream flow requirements in the subbasin.

Water budget	An accounting method of estimating the net sum movement of water into and out of a hydrologic system through precipitation, evapotranspiration, recharge, diversions, return flows, and runoff.
Water demand	The amount of water required for different purposes and in different water use sectors, such as for residential, industrial, and public water supplies. Historical water demand is often quantified by water withdrawal (water use) volumes.
Watershed (basin)	The contributing land area that drains water, such as rainfall or snowmelt, to a basin outlet. Also called a drainage basin or catchment.

Acknowledgements

This report was made possible through funding from the Indiana Finance Authority, with valuable guidance from James McGoff, Chief Operating Officer and Director of Environmental Programs, and Sarah Hudson, Technical Assistance and Outreach Manager, Water Programs.

Sincere gratitude is extended to Dr. Sally Letsinger, Technical Advisor to the Indiana Finance Authority's Water Programs and Senior Research Scientist in the Department of Geography at Indiana University. Her unwavering guidance, valuable insights, and sense of humor were instrumental in keeping the project on track and contributing to its success.

The following individuals served on the North Central Indiana Water Study Advisory Committee and provided valuable information and guidance throughout the project.

- Mark Basch, Indiana Department of Natural Resources
- Jeffrey Frey, United States Geological Survey
- Anne Catherine Hazlett, Purdue University
- Jill Hoffmann, White River Alliance
- David Knipe, Indiana Department of Natural Resources
- Randy Kron, Indiana Farm Bureau
- David Lampe, United States Geological Survey
- Garth Lindner, Indiana Department of Natural Resources
- Allison Mann, Indiana Department of Natural Resources
- Ryan Mueller, Indiana Department of Natural Resources
- Moumita Mukherjee, Indiana Department of Natural Resources
- Alexander Powers, Indiana Department of Environmental Management
- Caitlin Smith, Indiana Farm Bureau
- Andy Tauer, Indiana Farm Bureau
- Christian Walker, Indiana Department of Environmental Management

The following stakeholders in the watershed region provided information instrumental to demand forecasting. Local insights on current conditions and growth trends facilitated development of a more accurate projection of future water demand.

- Abbie Smith, City of Tipton
- Amanda Heber, Vermillion County Economic Development Coalition
- Andy Tauer, Indiana Farm Bureau
- Caitlin Sheets, Greater Kokomo Economic Development Alliance
- Chase Thompson, Frankfort Water Works
- Cheryl Morphew, Crawfordsville Economic Development
- Cyndi Todd, Partnership Parke County
- Daniel Sympson, Duke Energy Corporation
- Erik Orstead, Eli Lilly
- Kara Dewlen, Warren County Local Economic Development Organization
- Karen McLean, Northern Indiana Public Service Company
- Kari Britto, Indiana American Water
- Kristin Clary, Greencastle/Putnam County Development Center
- Laurie Robertson-Hardwick, City of Greencastle
- Lori Dukes, Greater Kokomo Economic Development Alliance
- Matt Hobbs, Indiana American Water
- Mayor Lynda Dunbar, City of Greencastle
- Michael Ladd, Fulton County Economic Development
- Michael Smallwood, Duke Energy Corporation
- Molly Whitehead, Boone County Economic Development
- Paul Moses, Greater Lafayette Commerce
- Randy Strasser, White County Economic Development
- Richard Miller, Indiana American Water
- Ryan Ottinger, City of Lebanon
- Shan Sheridan, Clinton County Chamber of Commerce and Economic Development

- Steve Moore, Lafayette Water Works
- Steve Witt, Terre Haute Economic Development Corporation
- Tom Klein, Montgomery County

Last but not least, additional data was provided by Professor Keith Cherkauer of the Purdue University Agricultural and Biological Engineering Department, the Louisville District of the U.S. Army Corps of Engineers, and the Illinois State Water Survey, a division of the Prairie Research Institute at the University of Illinois.

1.0 Introduction

1.1 Authorization and Purpose

Pursuant to Indiana Code (IC) 5-1.2-11.5 (https://iga.in.gov/laws/2024/ic/titles/5#5-1.2-11.5) and the State of Indiana's Water Infrastructure Task Force Final Report (dated November 9, 2018), the Indiana Finance Authority (IFA) began in 2017 to systematically undertake a series of regional studies to identify water infrastructure needs and solutions, and to identify efficiencies that may be gained through regional partnerships and improved sharing of resources.

In November 2023, Governor Holcomb asked the IFA to conduct a regional water study in the north central region of the state, generally comprised of the upper Wabash River Watershed. IFA staff expanded the study area to include the hydrologically connected headwaters of the upper Wabash River Watershed.

The purpose of this North Central Indiana Regional Water Study (Study) is to examine and provide an assessment of the historical and projected future 50-year water demand and water supply availability for the watersheds primarily located in and contributing to Boone, Clinton, Fountain, Fulton, Howard, Kosciusko, Montgomery, Parke, Pulaski, Tippecanoe, Tipton, Vermillion, Vigo, Warren, and White Counties, as shown in Figure 1-1. A separate Regional Water Study was concurrently conducted for IFA in the Headwaters[1] of the upper Wabash River Watershed (Wabash Headwaters Regional Water Study; Jacobs, 2025), also shown in Figure 1-1. A portion of the North Central Indiana study area (Study Area) is located in Illinois. For an accurate estimate of future water availability within the Wabash River Watershed, all water budget components, including both supply and demand of water in the Illinois portion of the basin, were included in the Study. However, the Risks, Opportunities, and Recommendations (Chapter 9) are focused on Indiana alone.

Water resources and water demand are unique to each region of Indiana. With the completion of this North Central Indiana Regional Water Study and the Wabash Headwaters Regional Water Study, the IFA has now completed 5 of the 10 regional water studies planned statewide (Figure 1-2). The report on the I-74 corridor (Driftwood, Flatrock-Haw, and Upper East Fork White River Watersheds) south and east of Indianapolis was the most recent prior study, completed in February 2024. The IFA believes that these studies, once combined, will better enable future statewide water resources planning.

Note that this Study is a new independent analysis of demand for and availability of groundwater and surface water in the region; no such study has previously been completed for the Wabash River Basin in Indiana. While portions of this Study Area overlap with portions of the Central Indiana Water Study (INTERA, 2021a), this Study is not a continuation of any water-related investigations previously conducted in the region. Study objectives are described further in Section 1.2.

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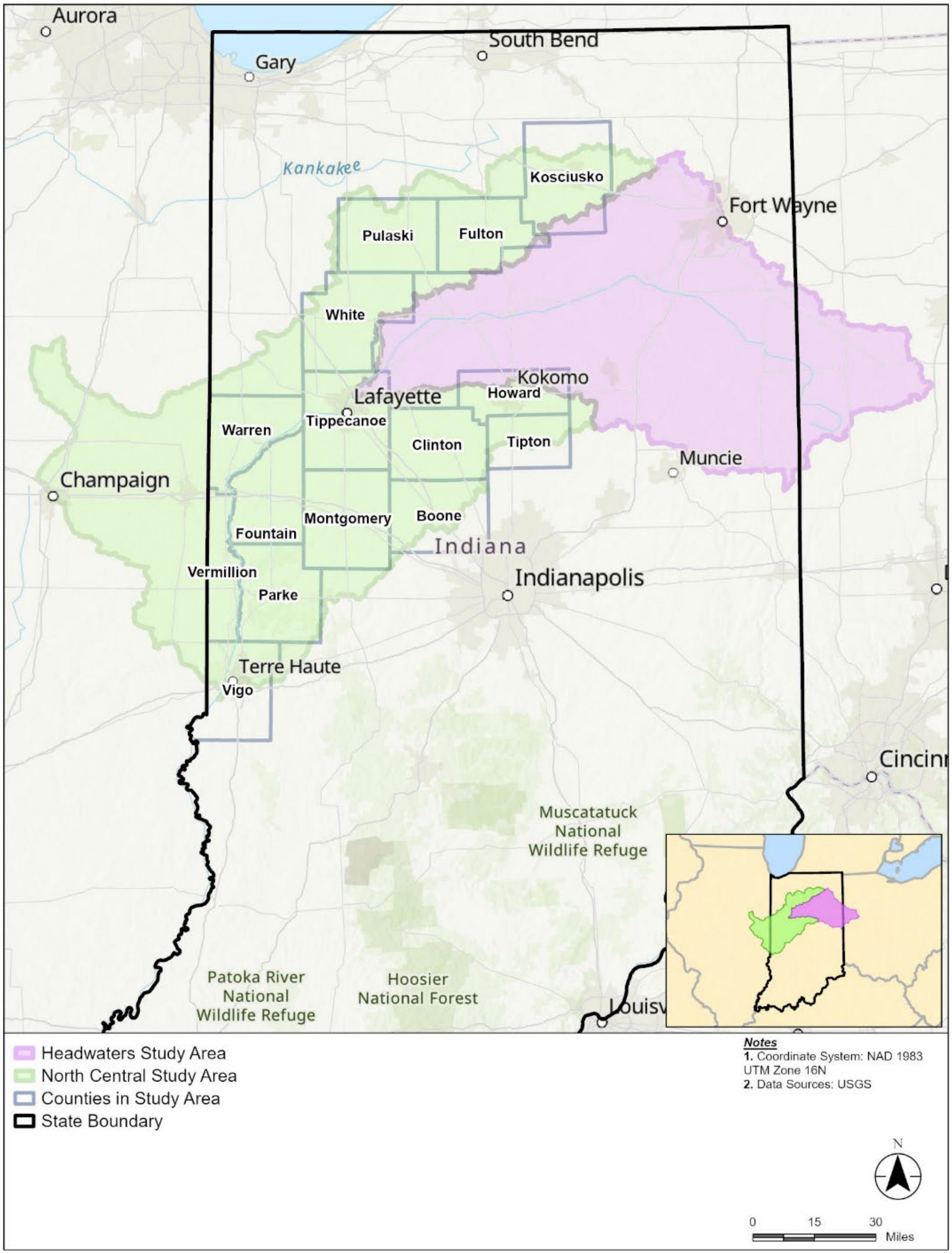
[1] The term “Headwaters” in this report refers to the subbasins of the upper Wabash River Watershed that were analyzed in a related study (Jacobs, 2025).



Notes
1. Coordinate System: NAD 1983 UTM Zone 16N
2. Data Sources: USGS

Figure 1-1. Study Areas and Study County Boundaries

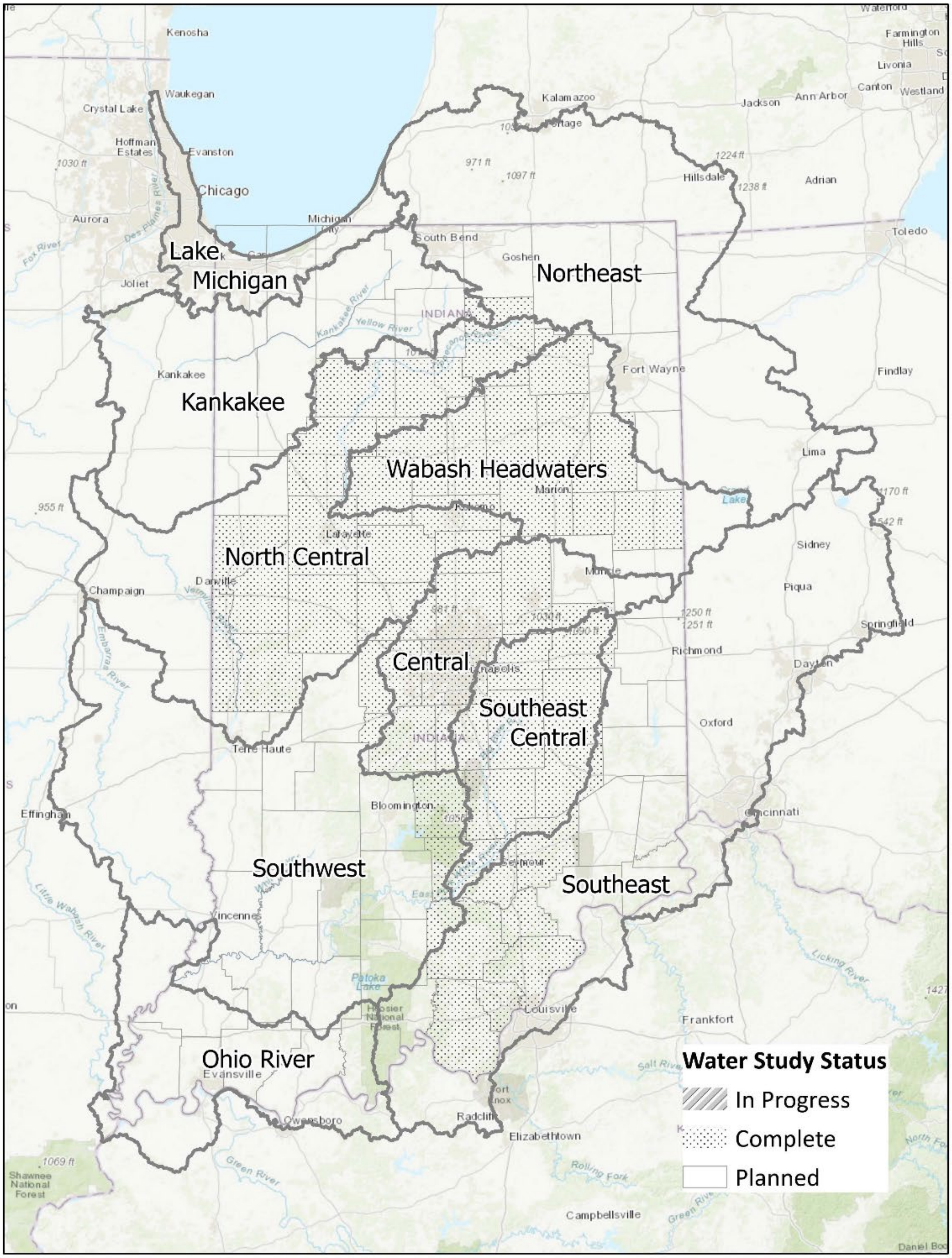


Figure 1-2. Indiana Regional Water Study Regions and Study Completion Status (IFA 2024b)

1.2 Study Objectives

The primary goal of the Study is to improve the understanding of groundwater and surface water demand and water availability throughout the Study Area, both historically and 50 years into the future. Objectives of the Study include:

- **Build Upon Current Knowledge:** Assemble and process water resources data within the North Central Indiana region, identify data gaps, and recommend upgrades to the monitoring networks to address data gaps.
- **Collaborate Across Many Partners:** Consult with utilities, industry, and county representatives to better understand current and future water demands and growth plans, and to establish productive partnerships among water resources agencies and other regional water interests to incorporate the best available science and data into the analysis.
- **Evaluate Historical Water Demand:** Quantify recent historical water demands by sector and source and evaluate major growth drivers for historical water resources development.
- **Evaluate Available Water Supply Information:** Assess streamflow records, reservoir operations, and instream flows, and investigate surface water and groundwater interactions.
- **Quantify Historical Water Availability:** Build a representation of regional water resources based on water budgets and geology consistent with other regional water studies to quantify historical water supply availability and investigate potential regional water supply limitations and/or surpluses.
- **Project Future Water Availability:** Forecast future water demands and streamflow over the next 50 years, incorporating water conservation, population, economic growth, and historical droughts, then use the same water resources system representation to quantify future water availability and investigate potential regional water supply limitations and/or surpluses.
- **Develop Recommendations:** Analyze historical and future trends in water availability, identify risks and opportunities for future water resources development, consider ideas to address future needs, identify key topics for further analysis surrounding water supply and demand issues, and communicate findings to local and state officials.

The North Central Indiana Regional Water Study provides a data-driven foundation for collaborative decision making on shared water needs, challenges, and opportunities (Project Vision from IFA, 2024c).

The water availability estimates presented in this Study rely on data-driven, formulaic analyses following a methodology similar to that used in previous regional water studies in Indiana, with some refinement. The data used in this Study are primarily from publicly available, authoritative sources, including:

- Federal (e.g., U.S. Geological Survey (USGS), U.S. Census Bureau, U.S. Environmental Protection Agency (EPA))

- State (e.g., Indiana Department of Natural Resources (IDNR), Indiana Department of Environmental Management (IDEM))
- University (e.g., Purdue University, Indiana University)
- Regional (e.g., Economic Development authorities)
- Local (e.g., water utilities, industry)

Based on the availability of data and public records maintained by these sources, the period of analysis for historical water availability (including water demand) was limited to 2007-2022. This Study also relies on data developed as part of the Wabash Headwaters Regional Water Study, which was conducted concurrently by others. In developing water availability estimates, the Stantec Study team coordinated regarding input datasets from the Wabash Headwaters Regional Water Study, but did not independently assess the veracity of all information provided.

This Study seeks to identify regions of excess historical and projected future water availability and regions where a water supply deficit may exist, but does not seek to specifically identify or evaluate solutions to address such excesses and/or deficits. It is important to note that this is not intended to be a full water planning study (i.e., which would include identification and analysis of actionable water management strategies). However, some suggested recommendations, opportunities, and possible next steps are offered.

1.3 Report Outline

This report is organized as follows:

- Chapter 1-Introduction (this section)
- Chapter 2-Regional Setting
- Chapter 3-Regional Water Study Approach
- Chapter 4-Baseline Water Demand Estimate
- Chapter 5-Baseline Water Budget Component Estimates
- Chapter 6-Historical Water Availability
- Chapter 7-Future Water Availability
- Chapter 8-Water Quality
- Chapter 9-Water Resource Risks, Opportunities, and Recommendations
- Chapter 10-References

Also included are a number of supporting Appendices:

- Appendix A-Additional Geologic and Hydrogeologic Background Information
- Appendix B-Data Collection, Pre-Processing, and Analysis for Water Budget Components: Availability and Supply
- Appendix C-Baseflow Separation Approach
- Appendix D-Historical and Future Water Demand Methodology and Future Water Demand by County
- Appendix E-Historical and Projected Future Water Demand by Subbasin
- Appendix F-Development of Future Baseline Data
- Appendix G-Historical Water Availability by Subbasin
- Appendix H-Future Baseline Water Availability by Subbasin
- Appendix I-Future Alternative Scenarios and Water Availability Assessment Results
- Appendix J-Water Quality
- Appendix K- Historical and Projected Future Water Demand Summaries by County

2.0 Regional Setting

North Central Indiana contains a diverse range of hydrology, geology, population centers, and water uses that vary geographically and with time. The region generally consists of agricultural land surrounding moderately sized population centers, including Lafayette, the tenth largest city in Indiana. The majority of the Study Areas sits within the Tipton Till Plain, a flat to gently rolling surface that contains variably thick sand and gravel lenses, and overlies the ancient Mahomet (Teays) Bedrock Valley that contains the productive Mahomet (Teays) Aquifer. The Wabash River, which has the largest watershed of any river in the state, runs through the heart of the Study Area and accumulates streamflow due in part to the inflow from several major tributaries.

The Wabash River itself supports most surface water withdrawals within the region by magnitude, including two energy facilities. The remaining water withdrawals in the region are predominantly through groundwater wells that draw from a range of unconsolidated aquifers, including intra-till, near-surface sand plains, and glacial outwash deposits along and beneath most waterways in the Study Area, as well as the Mahomet (Teays) Aquifer. The path of the Wabash River, the location of population centers, the ebb and flow of agricultural and industrial water use, and proximity to the Mahomet (Teays) Aquifer shape much of the current regional water resources setting. This Chapter provides additional background for the major regional factors that influence water resources in the Study Area.

2.1 Climate

2.1.1 OVERVIEW

Indiana has a humid continental climate and experiences four distinct seasons: cold snowy winters, wet springs characterized by thunderstorms, high temperatures and humidity in the summer, and cool dry conditions in the fall season. Indiana’s climate is influenced by its continental location, sitting at a convergence point between warm, moist air transported from the Gulf of Mexico and continental polar air brought southward by the jet stream from central and western Canada (Scheeringa, 2011). The interaction between these contrasting air masses promotes the development of low-pressure systems that generally move eastward and bring abundant rainfall. These systems frequently pass north of the state in midsummer, leaving relatively drier and warmer conditions. Due to the seasonality of precipitation, snowfall and snowmelt, surface runoff, baseflow, and groundwater recharge are highest in the winter and spring and lower in the summer and fall. Seasonal and spatial variations in temperature and precipitation patterns across the state are evident (Figures 2-1 and 2-2), with warmer temperatures and higher precipitation totals from north to south. The Study Area is large enough to capture these statewide patterns in temperature and precipitation.

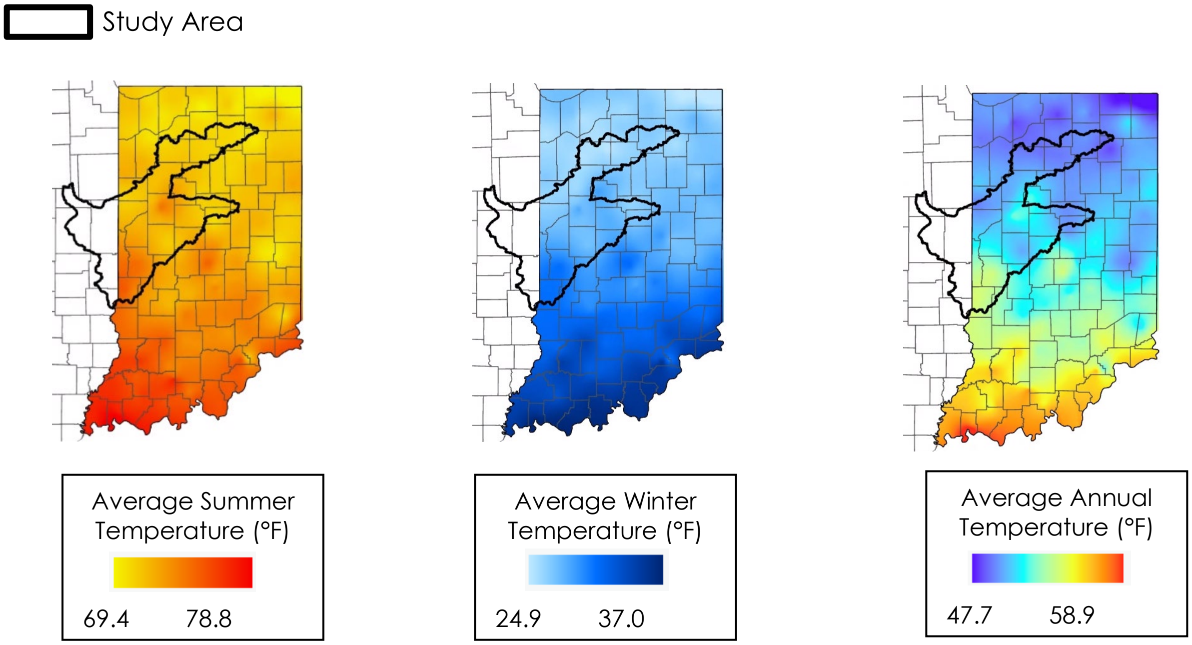
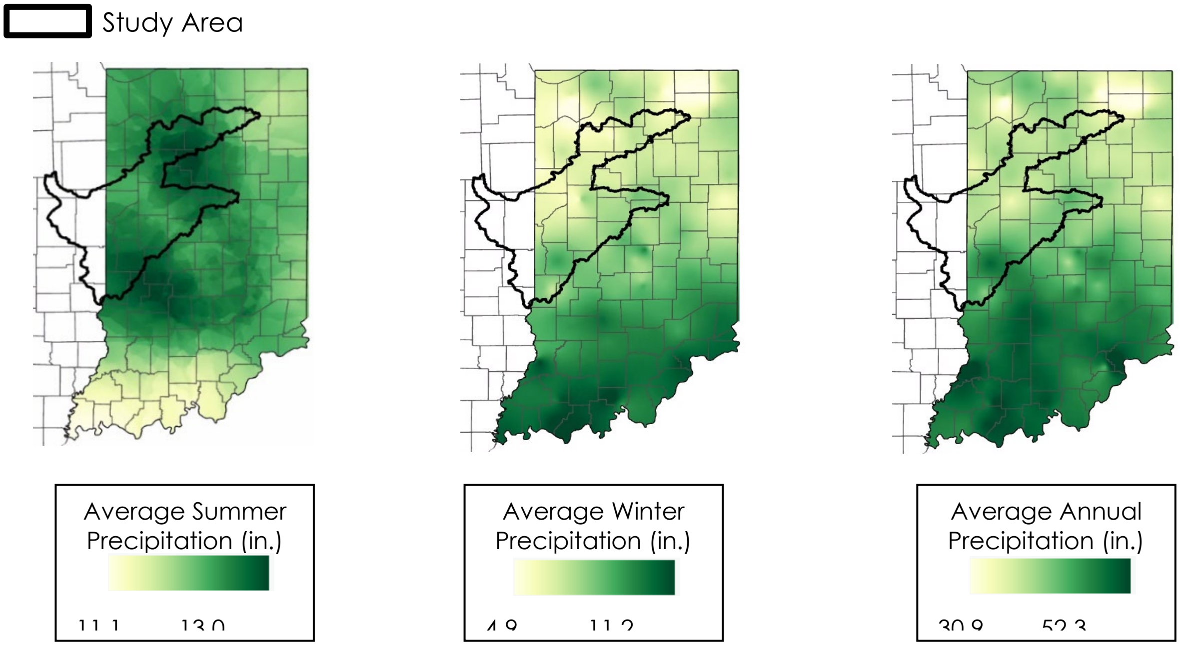


Figure 2-1. Statewide Temperature Averages 1981-2020



Note: Data is from 1981 through 2020 and collected from NOAA, NCDC, and NCEI (Waggoner, 2022). Statewide averages were created from 124 observation stations across Indiana.

Figure 2-2. Statewide Precipitation Averages 1981-2020

Monthly average air temperature, precipitation, and snowfall variables from 1991-2020 near Lafayette (NWS, 2024a) provide an overview of generalized seasonal climate trends in the Study Area (Figure 2-3).

This area of Indiana sees a fluctuation in air temperature throughout the year, from an average daily minimum of around 20 degrees Fahrenheit (°F) in January to an average daily maximum greater than 80°F in July. Snowfall occurs from November through April, typically peaking in January and February, while precipitation falls year-round, peaking in the late spring from April through July as air temperatures rise. Due in part to the seasonal transition from snowfall to rainfall and warming air temperatures in the spring, the region can experience periodic flood events. Recent flooding in 2013 and 2018 drove many rivers across the Study Area and the state into flood stages due to melting snow cover combined with high intensity rainfall delivered over a short period (NWS, 2013; NWS, 2018).

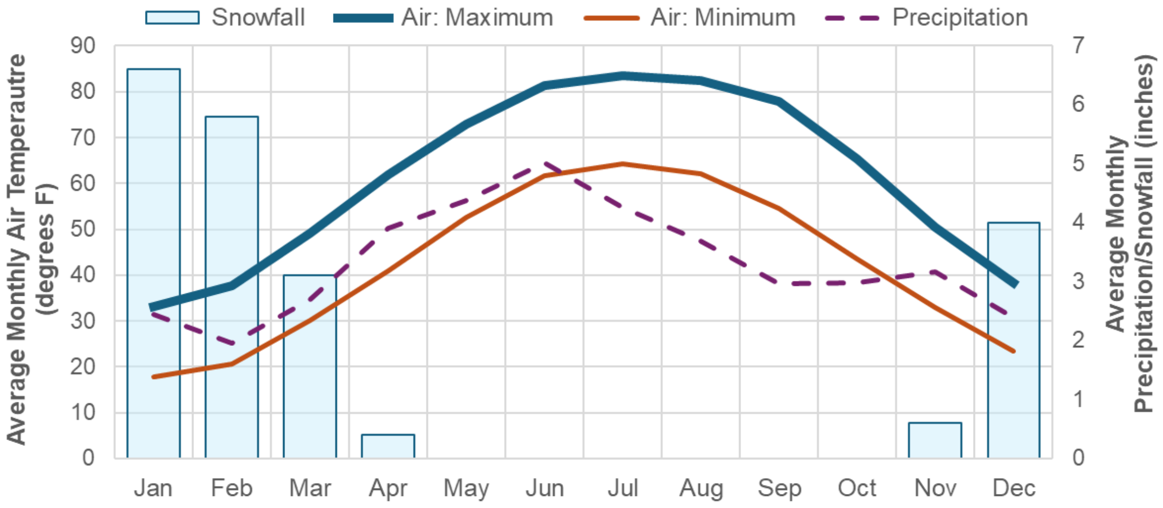


Figure 2-3. Average Monthly Climate Variables Near Lafayette, Indiana from 1991-2020

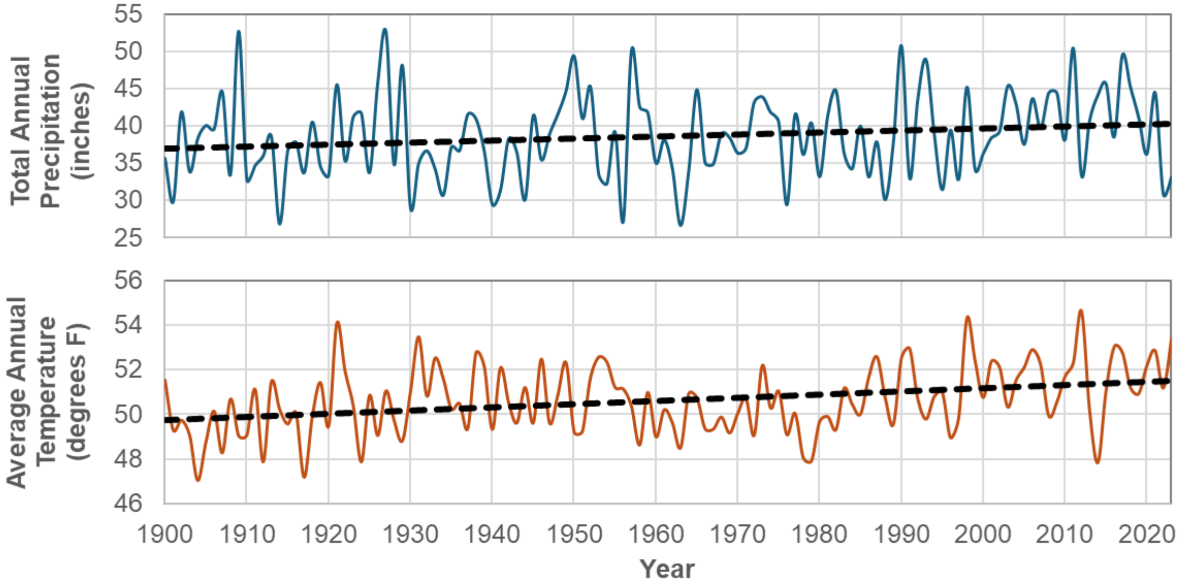
2.1.2 TRENDS

Recent studies analyzing Indiana climate data over the past several decades to hundred years (i.e., 1895) have noted trends related to precipitation, daily air temperatures, extreme events, and drought (Widhalm et al., 2018a; Widhalm et al., 2018b; Cherkauer et al., 2021).

- **Precipitation:** Overall, precipitation across Indiana has increased 5.6 inches annually since 1895, but the trends vary both annually and seasonally. Annually, the southern part of the state experienced the largest increase in precipitation. Seasonally, precipitation has increased in spring, summer, and fall across the state, though the spatial patterns differ by season. Winter precipitation shows modest increases in the central and northern regions (Widhalm et al., 2018a, Widhalm et al. 2018b). These trends are consistent with observed data for Tippecanoe County, which has seen total annual precipitation increases of approximately 2 inches since 1900 (Figure 2-4) (NWS, 2024b).

- **Temperature:** Statewide, annual average temperature has increased 1.2°F (0.1°F per decade) since 1895, with the largest amount of warming occurring in spring (0.2°F per decade). Since 1960, all four seasons have experienced a faster rate of temperature increase, with winter showing the most significant rise at 0.7°F per decade (Widhalm et al., 2018a, Widhalm et al., 2018b). These trends are consistent with observed data for Tippecanoe County, which has seen average annual temperature increases of approximately 1.8 °F since 1900 (Figure 2-4) (NWS, 2024b).

- **Climate variability and extremes:** An increasing trend in extreme events related to precipitation and drought has been documented in many studies. Historical records indicate that the number of extreme precipitation days have increased by 0.2 days per decade from 1900 to 2016, or there have been over 2 days per year of additional extreme precipitation since 1900, many of these more intense than historical events (Widhalm et al., 2018a, Widhalm et al., 2018b). A recent study also found wetter extremes have increased at a larger rate than dry extremes, and the transition from wet extremes to dry extremes is occurring more quickly (Ford et al., 2021). This is consistent with results of other studies (Otkin et al., 2018) that have noted an increase in frequency of ‘‘flash’’ droughts. Similar to what was experienced in Indiana in 2012, precipitation deficits are compounded by elevated atmospheric evaporative demand, resulting in a rapid depletion of soil moisture and resultant moisture stress to crops and native vegetation, and a rapid onset of dry conditions.



Note: Data is from NWS (2024b) Climate at a Glance for Tippecanoe County, Indiana. Black dashed lines represent the trend over the entire historical period.

Figure 2-4. Historical Precipitation and Temperature and Trends for Tippecanoe County

2.2 Hydrology

Hydrology in Indiana is heavily influenced by its underlying geology, climate, and topography, making it an important area of study for water resource management, environmental conservation, and flood mitigation efforts.

2.2.1 OVERVIEW

The Wabash River, Indiana's largest river and a key water supply component of the Study Area, starts in the northeast corner of the state and flows southwest then south, collecting runoff over an area of 32,910 square miles (including contributions from the White River and tributaries in Illinois) before discharging into the Ohio River. The Wabash River ranks 15th in average discharge among U.S. rivers, serving as a critical water source for agriculture, industry, and communities along its course (Martin et al., 2016).

A watershed is an area of land that drains runoff via streams and rivers to a common outlet. Watersheds exist at many scales and are hierarchical, with smaller watersheds (subbasins) nested within larger ones. The Wabash Watershed (also referred to as the Wabash River Watershed) as delineated by the USGS[2] is the largest relevant watershed for this Study, draining 20,747 square miles into the Wabash River as it winds through Indiana (Figure 2-5). The upper portion of the Wabash Watershed contains the headwaters of the Wabash River and major tributaries including the Eel River, Salamonie River, and Mississinewa River. These waterways drain 4,447 square miles and are collectively referred to as the Headwaters Study Area or Headwaters in this report. The middle portion of the Wabash Watershed is the focus of this Study and is referred to as the North Central Indiana Study Area, or simply the Study Area. The Study Area drains 8,320 square miles and consists of six smaller USGS watersheds, four of which contain major tributaries to the Wabash River: the Tippecanoe Watershed, containing the Tippecanoe River; the Wildcat Watershed, containing Wildcat Creek; the Vermilion Watershed, containing the Vermilion River; and the Sugar Creek Watershed, containing Sugar Creek. The remaining two watersheds, the Middle Wabash-Little Vermilion and Middle Wabash-Busseron, each contain a segment of the Wabash River.

Streamflow in the Study Area is highly variable on an annual and seasonal basis. Table 2-1 presents the total flow volumes in billion gallons (BG) for the study period of 2007-2022 at USGS stream gage 03335500 Wabash River at Lafayette, IN, broken down by seasonal periods: winter/spring (December-May) and summer/fall (June- November) (see Figure B-1 for a map of gage locations). The flow volumes illustrate both interannual and intra-annual variability in streamflow. Winter/spring flow volumes range from 822 BG in 2012 to 1,973 BG in 2011, while summer/fall volumes vary from 203 BG in 2012 to 1,562 BG in 2015, indicating notable differences in streamflow between the wetter and drier seasons. Total annual flow volumes also exhibit considerable variability, ranging from 1,024 BG in 2012 to 2,695 BG in 2011. The historical rank associated with each year highlights the relative position of that year within the period of record, allowing for a comparison of extreme high (wet) or low flow (dry) years. The year 2012 (a drought year) is the driest in the study period with a rank of 16, while 2011 is the wettest year, ranked 1.

Much of the intra-annual variability in seasonal flow volumes is driven by precipitation and geology. In the winter and spring, groundwater recharge is at a mazimum, the ground is saturated, and runoff from storm events occurs as overland flow. In the summer and fall, precipitation is reduced and streamflow is sustained primarily from storred groundwater in aquifers discharging back into streams. This dynamic is illustrated in Figure 2-6 using USGS streamflow and groundwater elevation data near Lafayette for the dry year of 2012. Wet season storm events increase groundwater levels through recharge, while dry season flow is sustained from groundwater discharge (via reductions in groundwater elevation).

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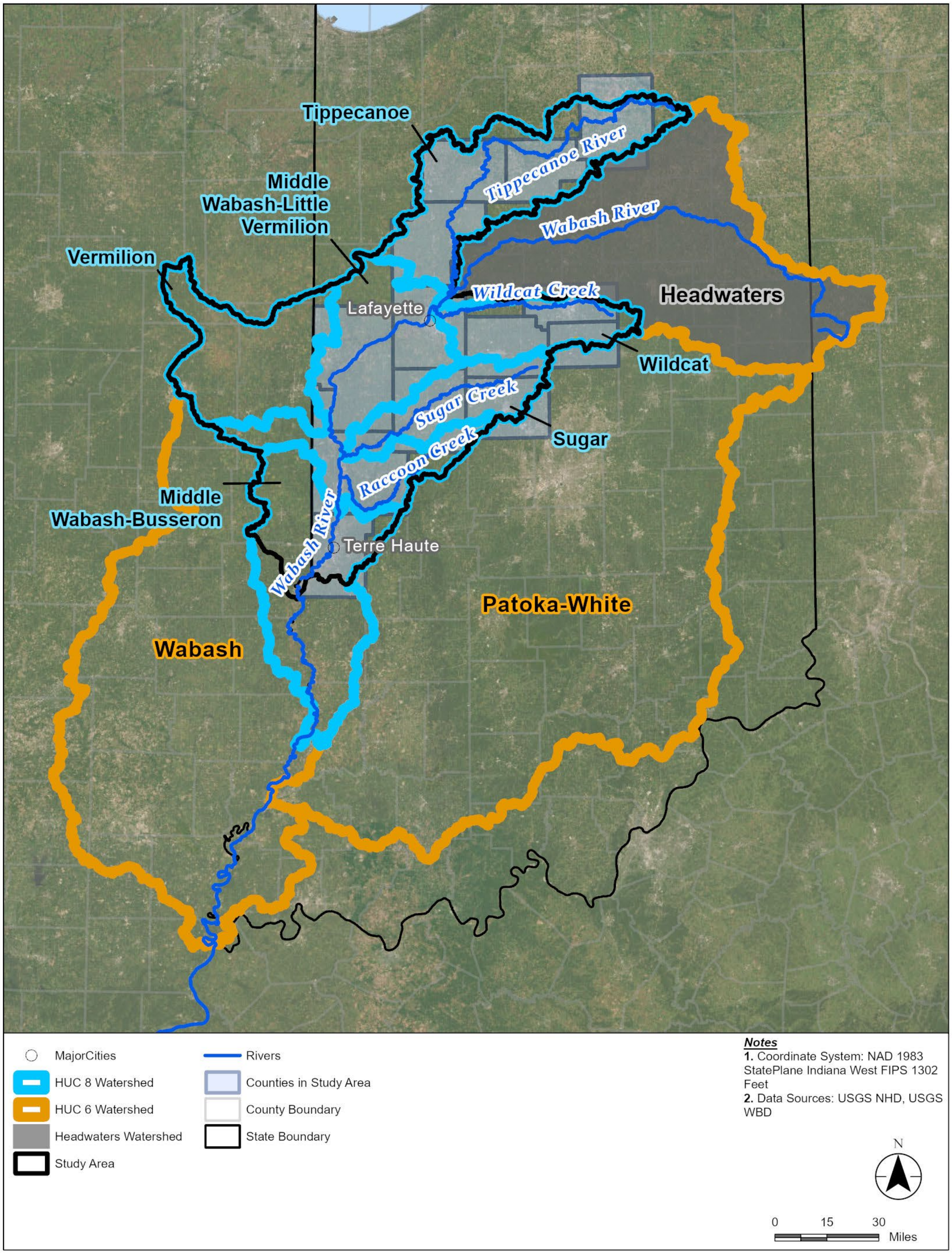
[2] The Wabash Watershed is defined by USGS Hydrologic Unit Code 051201



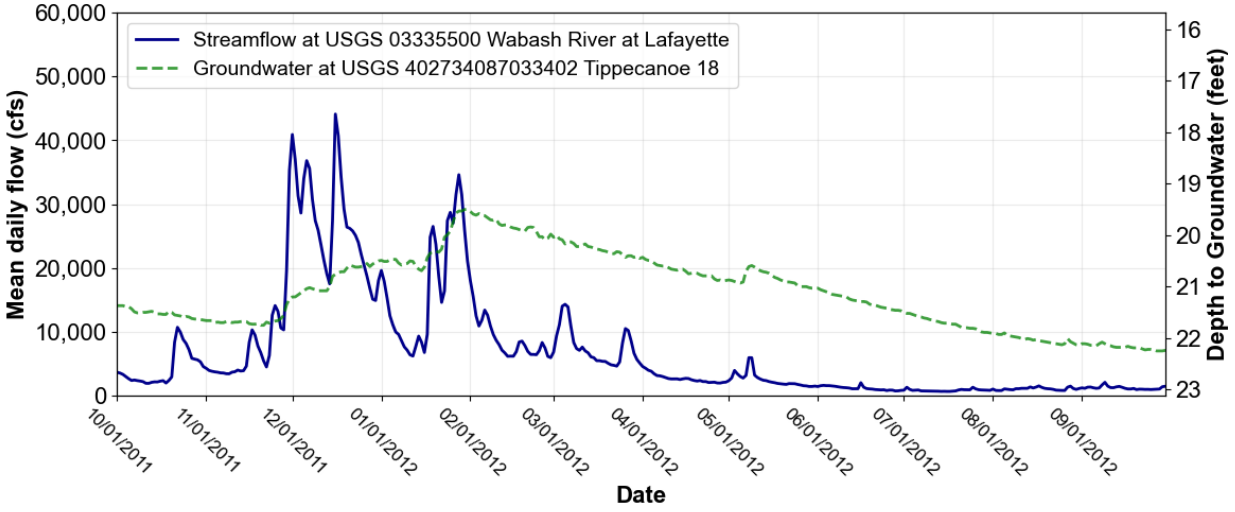
Note: The Wabash Watershed and Patoka-White Watershed both contribute to the total drainage area of the Wabash River.

Figure 2-5. Wabash Watershed and Smaller Watersheds Within the Study Area

Table 2-1. Total Seasonal and Annual Flow Volumes and Ranking for USGS 03335500 Wabash River at Lafayette, IN (2007-2022)

Year	Total Winter/Spring Flow Volume (BG)	Total Summer/Fall Flow Volume (BG)	Total Flow Volume (BG)	Study Period Rank
2007	1,751	368	2,119	8
2008	1,852	460	2,312	5
2009	1,639	417	2,056	10
2010	924	655	1,579	12
2011	1,973	722	2,695	1
2012	822	203	1,024	16
2013	1,489	670	2,159	7
2014	1,495	774	2,269	6
2015	935	1,562	2,497	2
2016	1,049	459	1,509	14
2017	1,435	1,029	2,464	3
2018	1,217	868	2,085	9
2019	1,697	631	2,328	4
2020	1,213	304	1,517	13
2021	913	684	1,597	11
2022	1,183	297	1,480	15

Key:
BG = billion gallons
USGS = U.S. Geological Survey



Note: USGS 402734087033402 is a groundwater well located approximately 4 miles north of the Wabash River on State Road 26, and was completed in "Sand and gravel aquifers (glaciated regions)" based on the National Aquifer Code and "Outwash" based on the local aquifer code. This groundwater monitoring location near Lafayette, IN, and is taken to be generally representative of groundwater elevations in the floodplain connected aquifer near Lafayette, IN.

Figure 2-6. Streamflow and Groundwater Elevation in the Study Area for 2012

To convey variation in daily streamflow throughout the Study Area, daily streamflow records from the Tippecanoe River and the Wabash River were plotted and analyzed. Figure 2-7 presents daily streamflow values for five selected years—2011, 2015, 2021, 2022, and 2012—representing a range of hydrological conditions, including wet (2011 and 2015), average (2021), below average (2022), and dry/drought (2012) years for USGS 03333050 Tippecanoe River near Delphi near the outlet of the Tippecanoe River. Streamflow patterns for the wet years, 2011 and 2015, exhibit higher flows throughout the year, with notable peaks from late April to the end of August, reflecting significant precipitation and runoff events. In contrast, the dry and below-average years, 2012 and 2022, show much lower flows overall, with reduced variability and minimal peak flow events. The average year, 2021, is between these extremes, displaying moderate flow patterns with occasional peaks that, with the exception of a few events, are generally less pronounced than in wet years. These variations in daily streamflow clearly illustrate the hydrologic response to differing climatic conditions, where wet years are characterized by frequent and intense flow events, and dry years exhibit more stable, lower flows. The maximum and minimum daily streamflow values for these years range from 7,029 cubic feet per second (cfs) in 2012 (dry/drought year) to 16,098 cfs in 2015 (wet year) and from 158 cfs in 2012 to 479 cfs in 2015, highlighting the significant impact of annual precipitation on streamflow dynamics. Monthly average streamflow from 2007 to 2022 ranges from 868 cfs (561 million gallons per day (MGD)) in September to 3,382 cfs (2,186 MGD) in March as shown in Figure 2-8. The annual average streamflow for this period varies from 1,142 cfs (738 MGD) in 2012 to 2,924 cfs (1,890 MGD) in 2008.

There is a significant increase in streamflow downstream along the Wabash River through the Study Area. Near the upstream end of the Study Area at Lafayette, IN, the Wabash River has an average daily flow rate of 8,390 cfs (5,423 MGD), while at the downstream end of the Study Area near Terre Haute, IN, the average daily flow rate nearly doubles to 14,568 cfs (9,416 MGD).[3] To highlight the interannual variability near the downstream extent of the Study Area, Figure 2-9 shows daily streamflow for five selected years—2011, 2015, 2021, 2022, and 2012—at USGS 03341500 Wabash River at Terre Haute. Wet years, such as 2011 and 2015, have consistently higher flows with clear peaks from late April to August, similar to patterns observed in the Tippecanoe River near Delphi. However, the magnitude of peak flows is significantly higher at Terre Haute, reflecting the cumulative effect of upstream contributions and the larger drainage area. In contrast, dry and below-average years like 2012 and 2022 show much lower, more stable flows with fewer peak events, mirroring the reduced variability seen in the Tippecanoe River but on a larger scale. The average year, 2021, also shows moderate flows with occasional peaks, aligning with trends in the Tippecanoe River but slightly more pronounced variability due to the larger drainage area. The data highlights how streamflow varies in response to different climate conditions, with wet years showing more frequent and intense flows, and dry years having lower, more stable flows. Maximum daily streamflow ranges from 43,994 cfs in 2012 (dry year) to 97,986 cfs in 2015 (wet year), while minimum flows range from 1,300 cfs in 2012 to 3,210 cfs in 2015, showing the clear impact of annual precipitation on streamflow. Monthly average streamflow from 2007 to 2022 ranges from 4,294 cfs (2,776 MGD) in September to 22,885 cfs (14,793 MGD) in March as shown in Figure 2-10.

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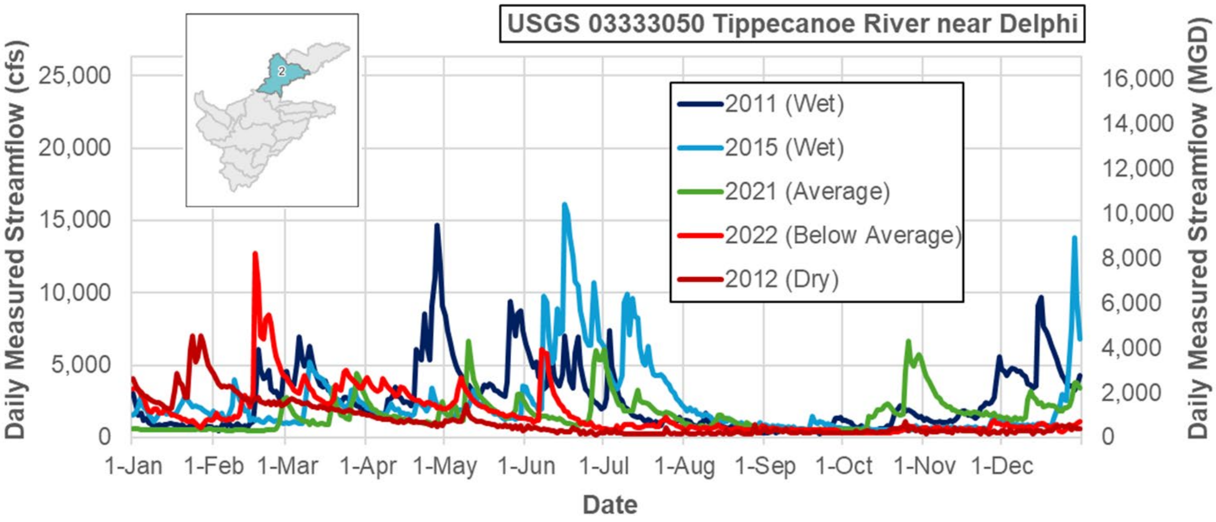
[3] Based on daily streamflow measured at USGS 03335500 Wabash River at Lafayette and USGS 03341500 Wabash River at Terre Haute, respectively, over the period from 2007 to 2022.



Note: The inset map on the top plot highlights Subbasin 02. USGS 03333050 is located at the outlet of this Subbasin.

Figure 2-7. Daily Streamflow Hydrographs at USGS 03333050, Tippecanoe River near Delphi, for Five Years (2011, 2012, 2015, 2021, and 2022), Highlighting the Variability in Flow Across Wet, Average, Below Average, And Dry Hydrological Conditions

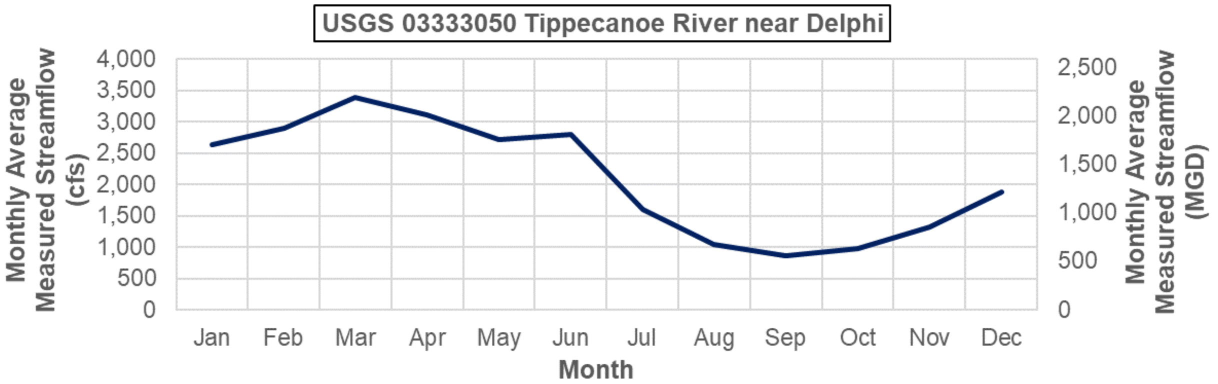
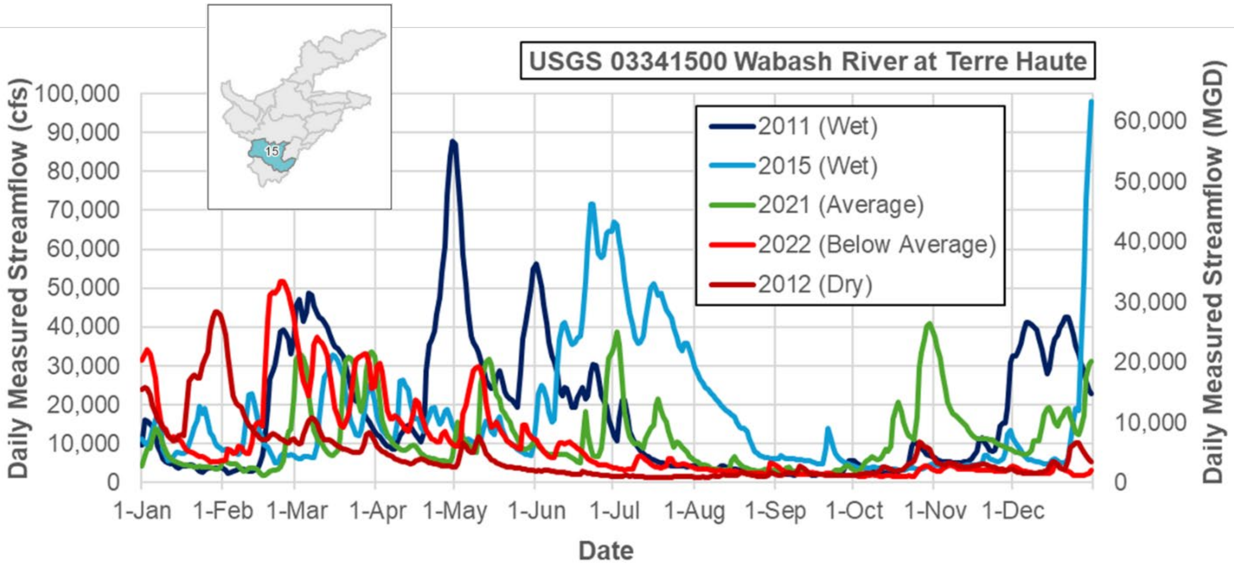


Figure 2-8. The Hydrograph of Monthly Average Measured Streamflow at U.S. Geological Survey 03333050 Tippecanoe River near Delphi (2007-2022)



Note: The inset map on the top plot highlights Subbasin 15. USGS 03341500 is located at the outlet of this Subbasin.

Figure 2-9. Daily Streamflow Hydrographs at U.S. Geological Survey 03341500 Wabash River at Terre Haute, for Five Years (2011, 2012, 2015, 2021, and 2022), Highlighting the Variability in Flow Across Wet, Average, Below Average, And Dry Hydrological Conditions

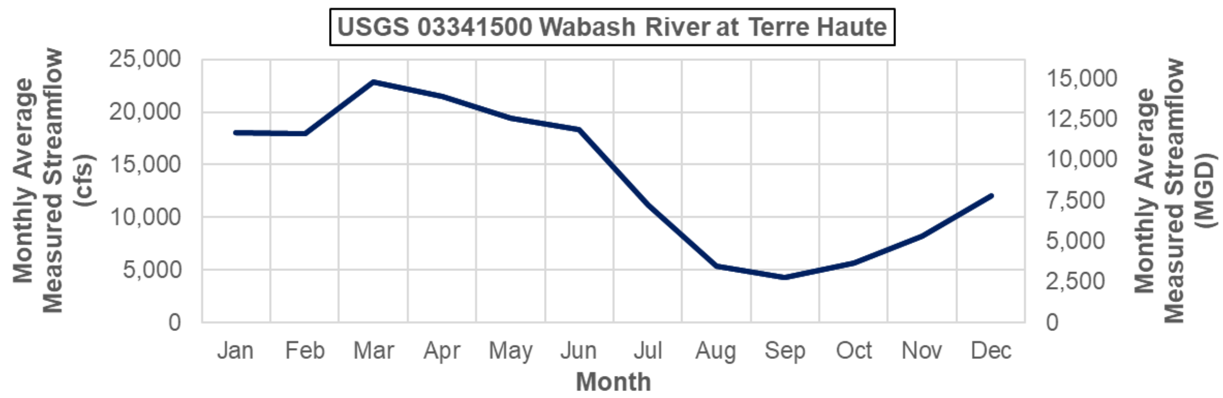


Figure 2-10. The Hydrograph of Monthly Average Measured Streamflow at U.S. Geological Survey 03341500 Wabash River at Terre Haute (2007-2022)

2.2.2 TRENDS

Some recent studies have analyzed trends in Indiana streamflow to determine if flow volumes are generally increasing, decreasing, or remaining relatively stable (e.g., Ficklin et al., 2018; Cherkauer et al., 2021). These studies generally indicate streamflow is increasing on an annual basis, in line with precipitation increases. A trend analysis of river flows and groundwater levels for a previous Indiana regional water study also confirmed annual increases over the last 30 years, with most of the increase observed in the winter and spring (Letsinger and Gustin, 2024). Consistent with wet season increases in wet season streamflow, a statewide water balance study (Letsinger et al., 2021) showed annual groundwater recharge is increasing across all seasons for the period of 2000-2019 relative to 1980-1999, that groundwater recharge is shifting to occur more in the winter than in the spring, and that recharge increased most in near-stream aquifers (i.e., outwash aquifers) as a result of more intense and episodic storm events.

To analyze seasonal trends in the Study Area, a daily time series from fifteen USGS stream gages and two USGS groundwater elevation sensors was gathered from 1990-2022 (see Figure B-1 for a map of gage locations). A Mann-Kendall Test[4] was calculated on each total seasonal flow volume or average groundwater elevation (winter = December through February, spring = March through May, summer = June through August, fall = September through November) to determine the signal (i.e., direction of change over time) and the signal strength (whether the signal is statistically significant or not). A recent 30-year time period was selected, the minimum required for a climate period analysis, to capture relatively recent trends in climate, water withdrawals, and reservoir operations. The majority of USGS gages show an increasing flow volume signal in the past 30 years in the winter and spring, and a decreasing flow volume signal in the summer and fall, though no gage or season had a statistically significant signal strength (Table 2-2). Both groundwater elevation sensors showed that groundwater elevations are generally increasing, but not with any statistical significance.

Table 2-2. Mann Kendall Analysis on U.S. Geological Survey Gages from 1990-2022

	Mann Kendall Slope and Significance[1] for Seasonal Flow Volumes or Depth to Groundwater[2]			
U.S. Geological Survey Gage (Subbasin)	**Winter**	**Spring**	**Summer**	**Fall**
03331753 Tippecanoe River at Winamac, IN (01) [2]	-	+	+	+
03333050 Tippecanoe River near Delphi, IN (02)	-	-	-	-
402734087033402 Tippecanoe 18 (groundwater elevation)	+	+	+	+
03333700 Wildcat Creek at Kokomo, IN (03)	-	+	-	-
03334500 South Fork Wildcat Creek near Lafayette, IN (04)	+	+	-	-
03335000 Wildcat Creek near Lafayette, IN (05)	+	+	-	-
03335500 Wabash River at Lafayette, IN (06)	-	+	-	-
03336000 Wabash River at Covington, IN (07)	+	+	-	-
03339500 Sugar Creek at Crawfordsville, IN (08)	+	+	-	+
03336645 Middle Fork Vermilion River above Oakwood, IL (09)	+	+	+	-
03338780 North Fork Vermilion River near Bismarck, IL (10)	-	-	-	-
03339000 Vermilion River near Danville, IL (11)	+	-	-	-
03340500 Wabash River at Montezuma, IN (12)	+	+	-	-
03340800 Big Raccoon Creek near Fincastle, IN (13)	+	+	+	+
03341300 Big Raccoon Creek at Coxville, IN (14) [3]	+	+	+	+
03341500 Wabash River at Terre Haute, IN (15)	+	+	-	-
392820087242601 Vigo 7 (groundwater elevation)	+	+	+	+

Note: [1] One "+" sign equals increasing and one "-" sign equals decreasing but not statistically significant at a 90% significance level.
[2] For groundwater, one "-" sign indicates lower groundwater elevations or increasing depth to groundwater, while one "+" sign indicates increasing groundwater elevations or decreasing depth to groundwater.
[3] Streamflow records for USGS 03331753 and U.S. Geological Survey 03341300 started in 2001 and 1992, respectively.

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[4] A Mann-Kendall test is used to statistically assess if there is a consistently increasing or decreasing trend in a variable over time, whether that trend is linear or not.

Both the streamflow volume and groundwater elevation trend analysis are consistent with recent studies throughout Indiana analyzing a similar study period (Letsinger et al., 2021; Letsinger and Gustin, 2024), with trends toward higher streamflow volumes in the winter/spring, lower volumes in the summer/fall, and higher groundwater elevations. Of note, Letsinger et al. (2021) also observed potential groundwater recharge is responsive to seasonal shifts in precipitation (shifting slightly from spring to winter) and is more likely to be concentrated in near-stream/river aquifers because the intensification of runoff events is causing more rapid runoff of precipitation, which reduces the opportunity for infiltration of rainwater on upland areas and slopes. The trend analysis suggests the outwash aquifers along the Wabash River (and the subbasins along the Wabash River assessed in this study) are likely to see ongoing aquifer replenishment with the increase in spring/winter precipitation, streamflow, and recharge.

An additional trend analysis was conducted to see how streamflow volumes in recent history compare to the full 100-year period of record. Annual calendar year flow volume from 2007-2022 was compared to the available 100-year (1924-2023) flow record for USGS 03335500 Wabash River at Lafayette, IN, to quantify streamflow variation over time (Figure 2-11). Average flow volumes were also compared for the each season: winter (December through February), spring (March through May), summer (June through August), and fall (September through November). In general, the Study period contains more high flow years, including 10 of the wettest 21 years out of the past 100 years. The remaining six years all rank in the lower half of the full historical record, including the drought year of 2012. Since 2007, more than three of every five annual winter and spring seasons rank in the top 50% of all recorded years, a shift towards wetter winters that is consistent with the documented increases in annual precipitation and precipitation extremes described above. Six of the recent fall seasons rank in the bottom 50% of all recorded years, showing a slightly broader distribution than wet seasons and a more represenative sample of recorded history. These seasonal summaries highlight the intra- and inter-annual variability in the region, where, for example, one of the wettest years (2011) can be followed by one of the driest years (2012). There are also inverted years in recent history with relatively dry winter/spring seasons and relatively wet summer/fall seasons. In 2021, winter flow volumes were in the lowest 15% of recorded history, and were similar in magnitude to fall flow volumes, which were in the top 10% of fall flow volumes in recorded history. When combined for the entire year, 2021 flow volume was slightly below the historical average.

While the Study Period contains a range of wet and dry years, it is weighted towards wetter years, reflecting the recent increasing trends in streamflow and precipitation discussed above. In particular, relatively wetter winter and spring seasons are respresented in the Study Period, but drought periods are represented less frequently relative to the past 100 years. As noted above, Indiana has seen measurable seasonal shifts in precipitation and streamflow over the past 30 years and increases in precipitation and temperature over the past 100 years, and using the most recent 16-year period as a reference for a historical and future water availability analysis is appropriate. As discussed further in Section 3.3.3, the effects of future climate change on streamflow are accounted for in the water availability study, assuming current climatic and hydrologic trends continue into the future. A limitation of this study is the frequency of future drought periods cannot be predicted with any certainty, and thus the potential effects of an increased frequency or duration of drought periods relative to the recent historical period are not considered. This could be the subject of future analysis.

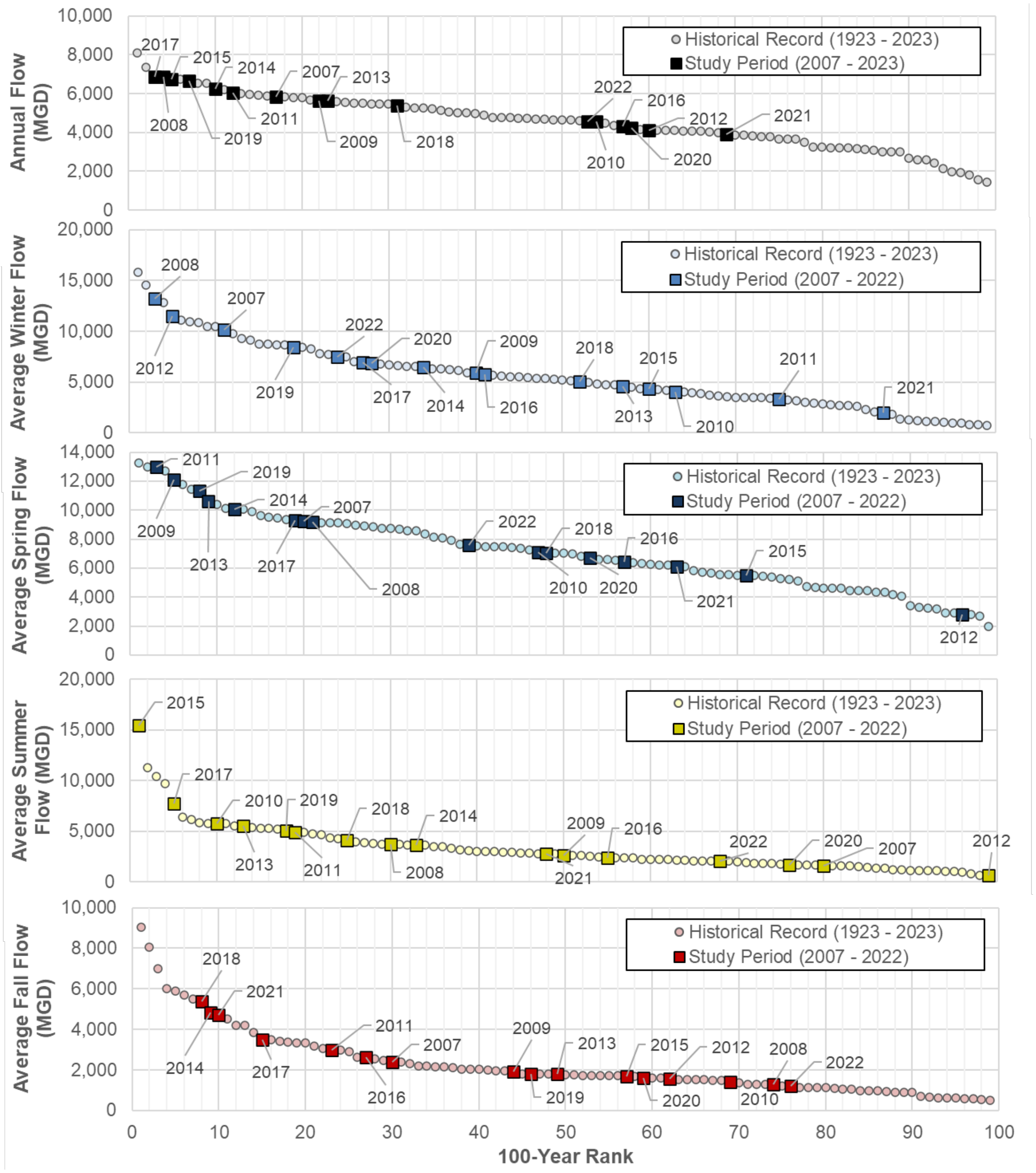


Figure 2-11. Ranking of Annual (top), Winter (second), Spring (third), Summer (fourth), and Fall (bottom) Wabash River Flow Volume at U.S. Geological Survey 03335500 Near Lafayette, IN

2.3 Geology and Hydrogeology

The geology in North Central Indiana features unconsolidated glacial deposits that overlie sedimentary bedrock. These unconsolidated deposits and bedrock units host important aquifers that supply water for domestic, municipal, irrigation, and industrial use. An aquifer is the portion of a mappable geologic unit that contains sufficiently saturated permeable material to yield useable quantities of groundwater to wells and springs. The hydrogeologic conditions associated with the Study Area are thoroughly presented in the Hydrogeologic Atlas of Aquifers of Indiana (Fenelon et al., 1994), and IDNR Aquifer Systems Mapping (IDNR, 2011).

2.3.1 GEOLOGY

The unconsolidated deposits in the Study Area were placed during several glacial events, and the underlying sedimentary bedrock occurs structurally as a broad anticline (Cincinnati Arch) with a slight plunge to the northwest (Gray and Letsinger, 2011; IGSa, 2024). Sediment size, the extent of sediment sorting, thickness, depth below land surface, and lateral extent are significant geologic variables of these unconsolidated deposits. The general grain size distribution of the unconsolidated deposits is illustrated in Appendix A. With regard to the bedrock, sedimentary rock type, burial depth, thickness, lateral extent, fracturing, and the type of overlying unconsolidated deposits are significant geologic variables. These geologic features affect the ability of the unconsolidated deposits and sedimentary bedrock to convey groundwater to wells and springs.

Unconsolidated deposits consist of uncemented geologic materials (sediments) that were deposited across the Study Area by Quaternary continental glaciers, wind, and water. These deposits typically include glacial moraines, till, and outwash that are characterized by their land surface expressions. Moraines are ridges or mounds that consist of intermixed clay, silt, sand, gravel, cobbles, and boulders, while till consists of clay and silt intermixed with irregularly sized sand, gravel, cobbles, and boulders below a relatively flat land surface (i.e., a till plain). Outwash consists of sorted sand and gravel deposits from glacial meltwater streams typically associated with the Wabash, Tippecanoe, and other rivers. Recognizing the aquifers within these deposits, the IDNR (2011) identified the aquifer units that are presented in Figure 2-12. Within the upper Wabash River basin, outwash, till, and moraines dominate. Within the middle and lower Wabash River basins, outwash is predominantly present along the Wabash River and its tributaries while till predominates beyond the river floodplains.

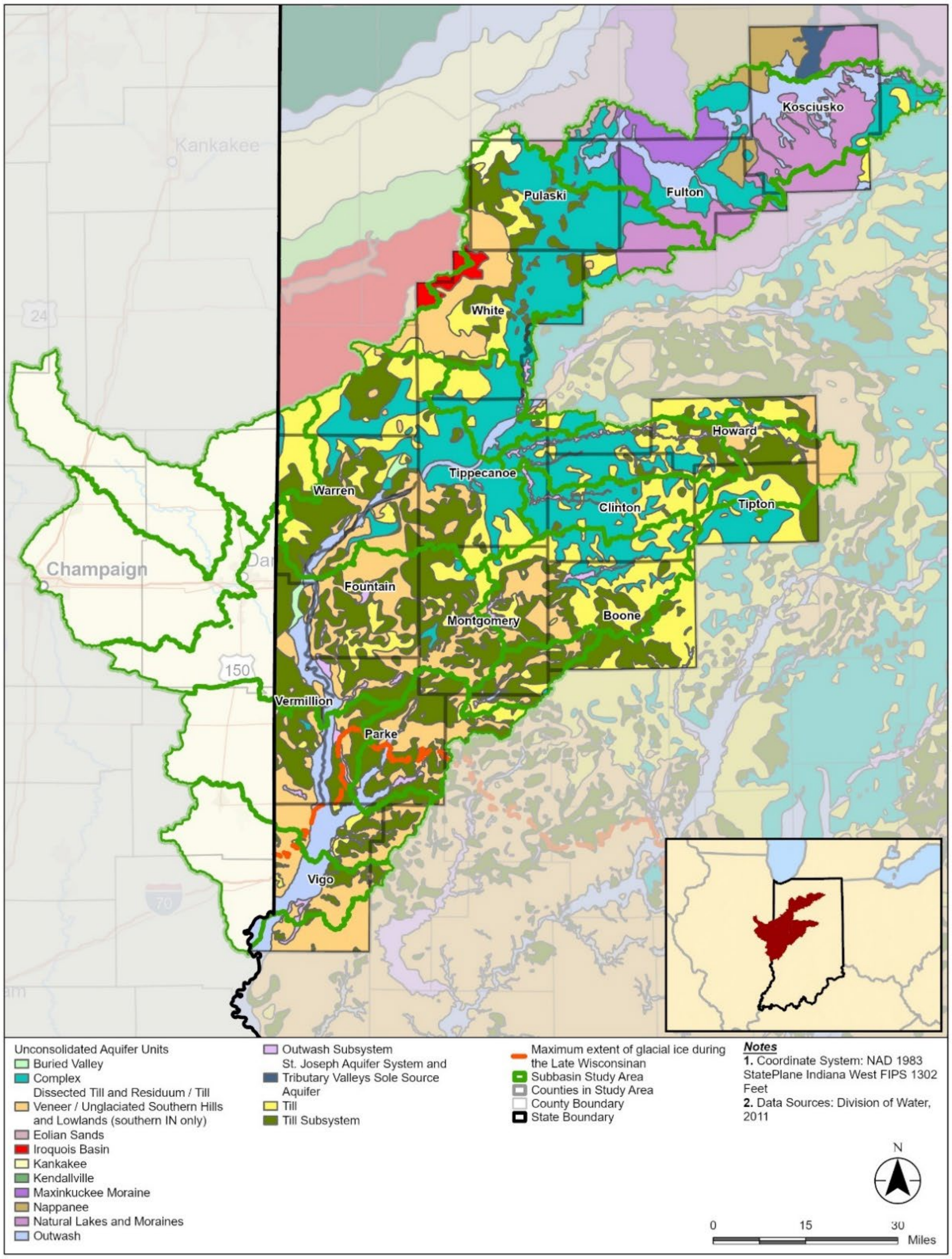


Figure 2-12. Aquifer Units Associated with the Unconsolidated Deposits of the North Central Indiana Study Area. The units shown in this figure were composited from IDNR mapping. Aquifer system maps from IDNR (2011) that were prepared for each county provide detailed information on the general location and extent, composition, thickness, and groundwater production for each named aquifer system at a local level. While these maps illustrate aquifer system locations, many individual aquifers (such as intratill aquifers) have not been mapped.

The geological characteristics, composition, and thickness of the unconsolidated deposits vary across the counties within the Study Area. Land surface and bedrock topography maps are included in Appendix A along with an unconsolidated deposit thickness map to illustrate the location and thickness of the deposits across the Study Area. Based on IDNR's (2011) aquifer system mapping of the unconsolidated deposits, the following presents the basic geologic characteristics of the unconsolidated deposits by region and deposit type:

- Within the upper Wabash River basin (Kosciusko, Pulaski, Fulton, White, Tippecanoe, Clinton, Tipton, and Howard counties), the outwash is composed of sand and gravel that ranges from 18 to up to 118 feet thick, with a total unconsolidated deposit thickness of 50 to 150 feet. The outwash may lie at land surface or be covered by 5 to 45 feet of silt, sandy clay, or clay. Some of the sand and gravel deposits may include clay, sandy clay, or gravelly clay. Till adjacent to the outwash contains single or multiple intratill sand and gravel layers. While the overall thickness of the till ranges from 50 to over 400 feet, the intratill sand and gravel units generally range from 5 to 50 feet thick. These tills are identified as complex because they have multiple lenses of sand and gravel interbedded with till and/or outwash deposits. In Fulton and Kosciusko counties, moraines exist that include localized 15- to 50-foot-thick sand and gravel deposits. The total thickness of these units can be over 325 feet.

- Within the middle and lower Wabash River basins (Vigo, Parke, Vermillion, Warren, Fountain, Montgomery, and Boone counties), the outwash is composed of thick deposits of sands and gravels that are capped by a layer of clay, sandy clay, or silt in some areas. The sand and gravel deposits range from 25 to 130 feet thick, whereas the overall unconsolidated sediment package ranges from 40 to 160 feet thick. Till adjacent to the outwash in this area can reach up to 150 feet thick and contain thin, discontinuous sand and gravel deposits that range from 2 to 20 feet thick.

The main preglacial river valley in north central Indiana was the Mahomet (Teays) Bedrock Valley which drained the northern half of the state. The buried valley traverses Indiana from east to west. As shown on the bedrock topographic surface maps in Appendix A, this feature is a deeply incised valley in the sedimentary bedrock surface. Geologic cross sections J through O of the valley, presented in Appendix A, highlight the locations of glacially deposited sand and gravel within the valley in different parts of the Study Area. This valley contains thick glacial deposits relative to the adjacent unconsolidated sediments outside of the valley, and it is an important aquifer. In the Study Area, the buried bedrock valley extends across Warren, Tippecanoe, White, Clinton and Boone counties. Unconsolidated deposits within the valley range from between 200 to 425 feet thick, with an average thickness of 300 feet (Bruns and Steen, 2003). The unconsolidated deposits in the valley vary in thickness, continuity, and grain size.

Sedimentary rocks form the bedrock geology within Indiana (IGWS, 2024c). These sedimentary rocks consist of consolidated and cemented sand, silt, clay, lime, and coal that have been changed to stone. The rock types associated with each sedimentary unit vary due to the type of material that was deposited when the rocks were formed. A stratigraphic column that highlights rock type, unit thickness and general location in the state is included in Appendix A. The bedrock lithologies of the Pennsylvanian McLeansboro, Carbondale, and Raccoon Creek groups are predominantly sandstone and shale with minor limestone and coal. The Mississippian Blue River and Sanders Groups are composed of limestone and dolomite that include gypsum and anhydrite with minor sandstone. The Mississippian Borden Group, New Albany Shale, Coldwater Shale, Ellsworth Shale, and Antrim Shale are primarily composed of shale, mudstone, and siltstone with minor limestone. The Silurian and Devonian Carbonates of the Muscatatuck, New Harmony, and Bainbridge/Salina Groups are predominantly composed of limestone and dolomite with minor shale. Recognizing the aquifers within these sedimentary rocks, the IDNR (2011) identified the aquifer units that are presented in Figure 2-13, derived from mapping by Gray et al. (1987). The sedimentary rocks were uplifted along the Cincinnati Arch and were tilted westward toward the state line. The depth to and elevation of the bedrock below the unconsolidated deposits vary depending on past glaciation, erosion, and the incised Mahomet (Teays) Bedrock Valley, as shown on the bedrock topographic surfaces in Appendix A.

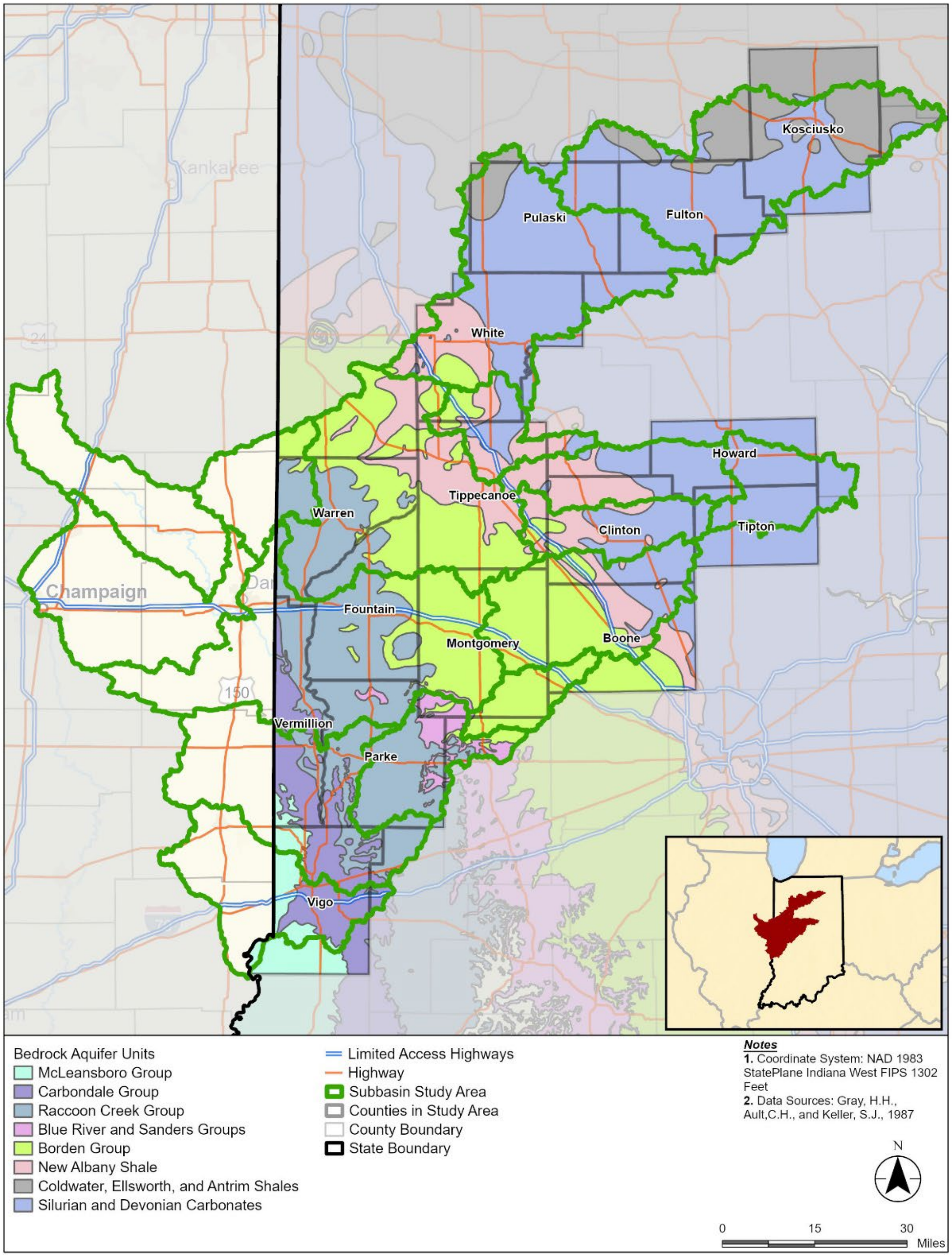


Figure 2-13. Aquifer Units Associated with the Sedimentary Bedrock of the North Central Indiana Study Area. Aquifer system maps from IDNR (2011) that were prepared for each county provide detailed information on the general location and extent, composition, thickness, and groundwater production for each named bedrock aquifer unit at a local level.

2.3.2 HYDROGEOLOGY

The hydrogeology of the Study Area features unconsolidated aquifers in glacial deposits that may be connected to surface waters, and bedrock aquifers that yield groundwater from a variety of rock types. The hydrogeology and potential yield of the individual aquifers depend upon how the aquifer receives recharge, the rock type(s) of the aquifers, the permeability and preferred flowpaths within the aquifer, groundwater flow directions, and whether the aquifer is connected to rivers and streams (baseflow). Hydrogeology documents the occurrence, distribution, and movement of water below the Earth's surface (Ravier and Buoncristiani, 2018). Within the Study Area, there are four types of aquifers in the unconsolidated deposits: surficial sand and gravel (alluvial, outwash, and moraines), buried sand and gravel (outwash, complex till, and moraines), discontinuous buried sand and gravel (till), and sand and gravel aquifers in deep bedrock valleys (alluvial and outwash). There are also four types of aquifers in the bedrock: complexly interbedded sandstone, shale, limestone, and coal (various units); sandstone (McLeansboro, Carbondale, and Raccoon Creek Groups); Silurian-Devonian limestones (Muscatatuck, New Harmony, and Bainbridge/Salina Groups), and an upper weathered bedrock zone (Borden Group) (Fenelon et al., 1994).

2.3.2.1 Unconsolidated Aquifers

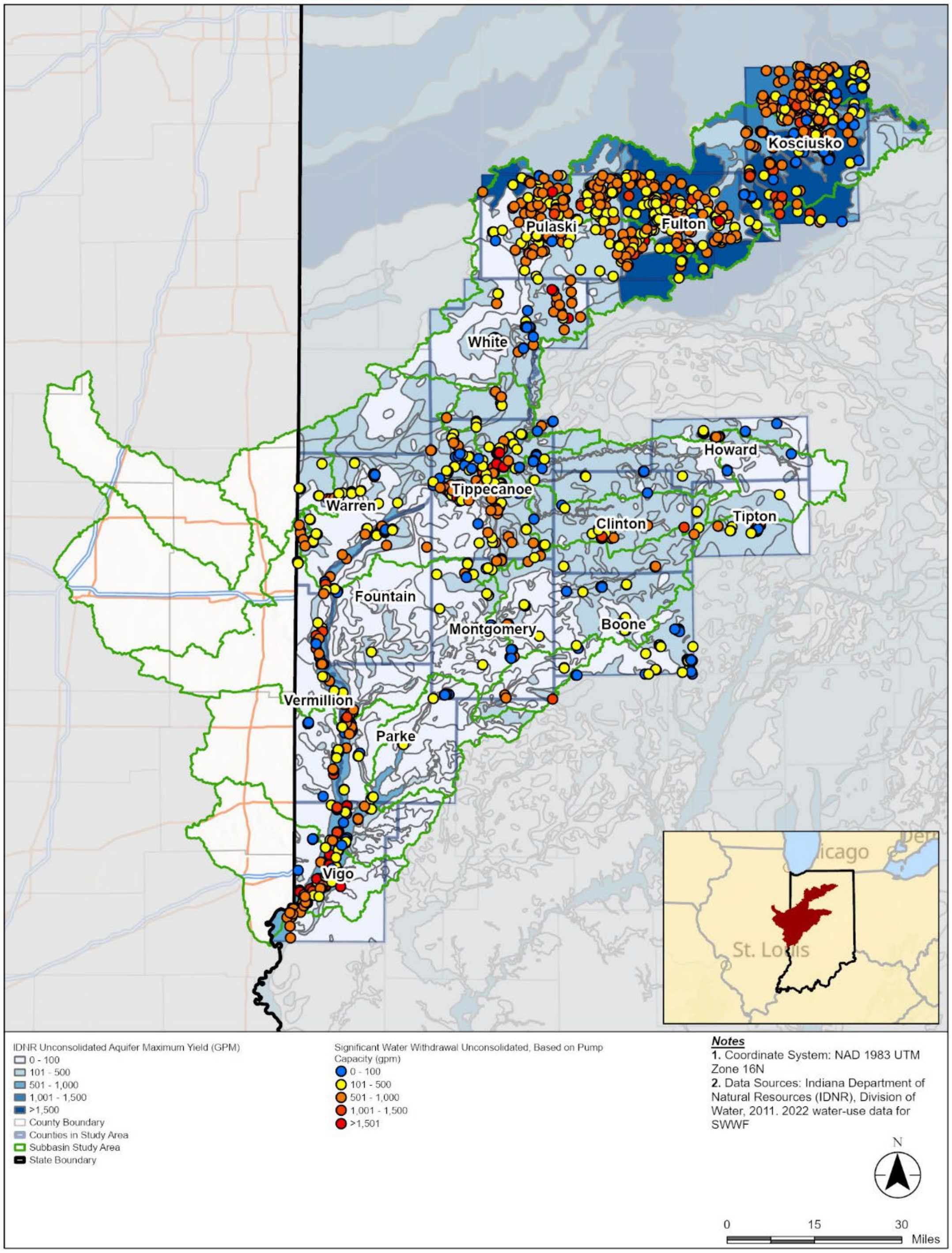
Unconsolidated aquifers provide approximately 92% of all groundwater used in this part of Indiana. The distribution of the unconsolidated aquifer units throughout the Study Area is shown in Figure 2-12. Estimated maximum yields associated with the unconsolidated aquifers are shown in Figure 2-14 along with the locations of Significant Water Withdrawal Facilities (SWWF). High-capacity wells that obtain groundwater from unconsolidated aquifers can be found within outwash deposits along the Wabash River; complex glacial till deposits through Pulaski, White, Tippecanoe, and Clinton Counties; and moraines and outwash deposits in Fulton and Kosciusko Counties. The permeability and potential maximum yield of the unconsolidated deposits are shown on the figures in Appendix A.

The aquifer characteristics and groundwater production rates from the unconsolidated deposits vary across the counties within the Study Area. Table 2-3 presents a summary of the relative permeability and yield of the different aquifer types by location within the Wabash River basin.

Table 2-3. Relative Permeability and Yield Range of the Unconsolidated Aquifers[1]

Wabash River Basin Area	Deposit Type	Relative Permeability	Thickness (ft)	Yield Range (gpm)	Remarks
Upper	Outwash	High	35-150	75-2,250	Kosciusko, Fulton, Pulaski Counties
Upper	Moraines	High	15-30	50-1,450	Kosciusko and Fulton Counties
Upper	Complex Till	High	10-50	60-2,000	Multiple intratill sand and gravel deposits
Upper	Till	Low to High		70-1,300	Contains discontinuous sand and gravel beds
Middle	Outwash	High	10-112	50-2,500	Warren, Fountain, Vermillion, and Parke Counties
Middle	Till	Low to High		10-1,000	Higher yield where discontinuous intratill sand and gravel present
Lower	Outwash	High	25-60	50-8,333	Vigo County

Note:
[1] Tills within the upper Wabash River basin that do not have significant sand and gravel interbeds generally have low permeability, and therefore, few wells are completed within these units. Similarly, tills within the middle and lower Wabash River basin often have low permeability with groundwater yields of less than 20 gpm in the middle and 10 gpm in the lower basin.



Notes
1. Coordinate System: NAD 1983 UTM Zone 16N
2. Data Sources: Indiana Department of Natural Resources (IDNR), Division of Water, 2011. 2022 water-use data for SWWF

Figure 2-14. Estimated Maximum Yield and Significant Water Withdrawal Facilities (SWWF) Associated with the Unconsolidated Aquifers. Notice the alignment of these facilities with the outwash, till (complex), and moraine aquifer units presented in Figure 2-12. This figure also illustrates where groundwater exploration opportunities exist relative to existing development.

The Mahomet (Teays) Bedrock Valley in White, Tippecanoe, and Warren Counties consists of 250- to 400-foot-thick unconsolidated deposits that can provide significant groundwater resources. The location, contour, and depth of this valley are highlighted in Appendix A. The deeper portions of the bedrock valleys are filled with thick sand and gravel deposits, but few wells are completed in the deepest parts of the valley. The sand and gravel deposits within this valley are highly permeable and yield between 85 and 3,000 gpm to individual wells. Areas with high yield aquifer units are focused in the southeast corner of White County and northeastern Tippecanoe County.

The Indiana Department of Natural Resources and the U.S. Geological Survey have collected groundwater level data in Indiana since 1935. The state's observation well network currently consists of 35 wells located throughout the state. In addition to these wells, the Indiana Department of Natural Resources also monitors some wells through the Voluntary Groundwater Level Monitoring Program. The program incorporates privately owned wells to complement the network of existing monitoring stations used to track groundwater elevations throughout Indiana. The program is a collaboration between the IDNR Division of Water and the USGS. Based on USGS (2024a) records, 13 wells in the Study Area have had more than 10 water level measurements recorded, and illustrate the water level history of unconsolidated aquifers across the area. Hydrographs for the 13 observation wells are included in Appendix A along with a map that illustrates the locations of these wells in the Study Area.

Water level records for observation wells completed in the unconsolidated aquifers indicate that groundwater levels have remained relatively stable in this part of the state since monitoring began in 1967. In Kosciusko County, three observation wells (KO-10, KO-11, and KO-12) have noted a water level decline of a few feet between 2016 and 2024. Similarly, in Fulton County, one observation well (FU-7) has recorded an overall water level decline of approximately 3 feet between 1967 and 2024 and exhibited wider swings in water levels in more recent years. In Pulaski County, water levels in one observation well (PU-7) have fluctuated, but annual peak levels remain similar between 1967 and 2024. In Tippecanoe County, observation wells TC-17 and TC-18 indicate water levels fluctuated approximately 10 feet between 1989 and 2024, but since 2018 have declined approximately three feet. In Clinton, Boone, and Parke Counties, the story is similar. Each of these counties has only one or two observation wells. BO-17 recorded a six-foot water decline associated with the 2012 drought but as of 2024, is within four feet of its 1986 initial measurements. In Montgomery County, observation well MY 7 has exhibited an approximately 15-foot decline in water levels between 1967 and 2024. In contrast, water levels in Vigo County at VI-7 have risen 10 feet between 1970 and 2024. Even though they have declined 5 feet since 2018, water levels are still higher now than they were in 1970.

2.3.2.2 Bedrock Aquifers

Sedimentary rock types and characteristics strongly influence the bedrock aquifers, water availability, and the amount of groundwater each aquifer will yield. The Significant Water Withdrawal Facilities (SWWF) are shown in Figure 2-15 in relation to the bedrock aquifer units. Bedrock aquifers in the Study Area that include high-capacity wells include the Silurian and Devonian Carbonate Aquifer and the Pennsylvanian Raccoon Creek Group. As shown in Figure 2-15, the highest yielding bedrock aquifer wells are mostly located in the northeast portion of the Study Area where the Silurian and Devonian Carbonate Aquifer underlies the unconsolidated aquifers.

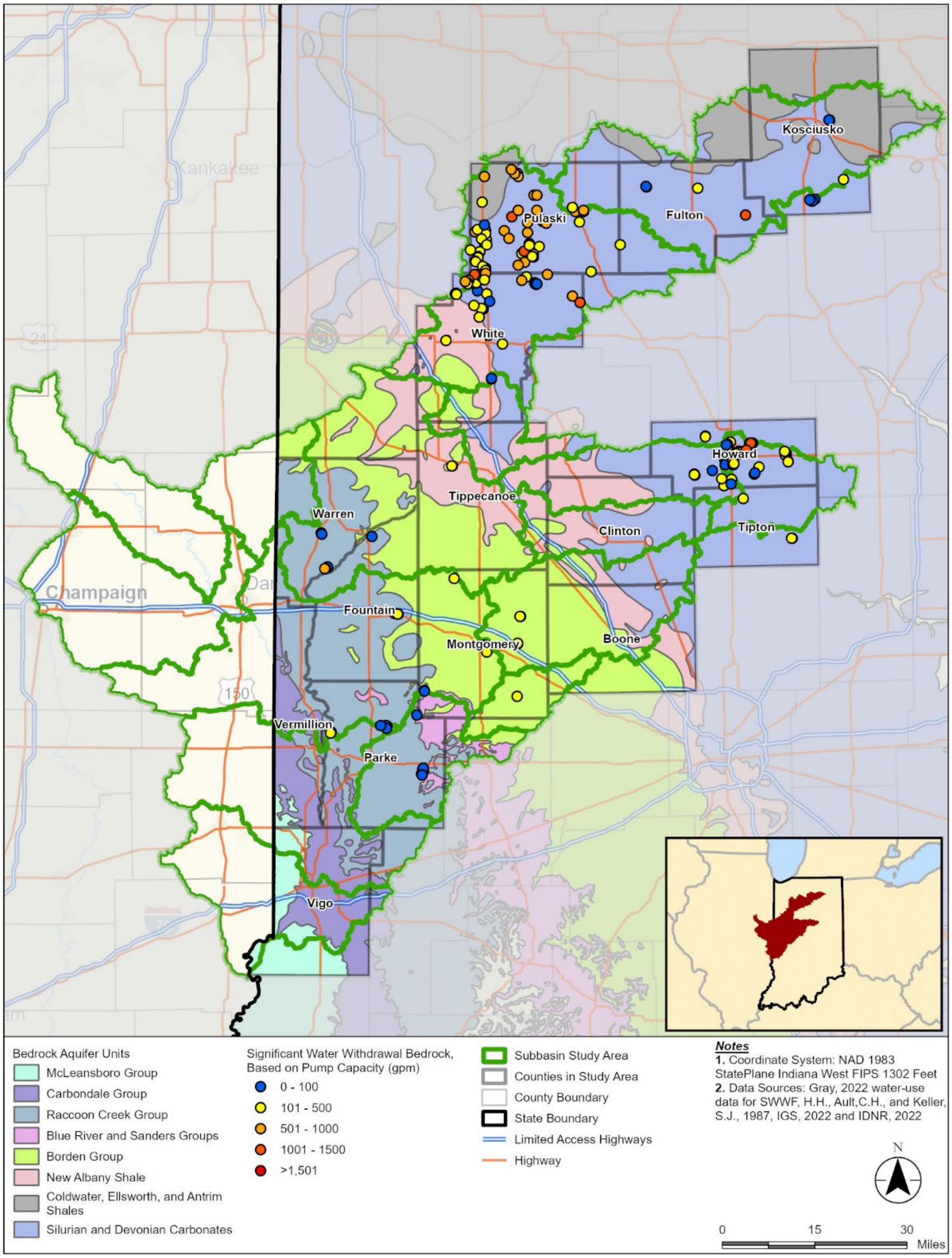


Figure 2-15. Significant Water Withdrawal Facilities (SWWF) Associated with the Bedrock Aquifer Units

The various sedimentary rocks identified by IDNR (2011) as bedrock aquifer units have variable water yielding capabilities. The Silurian and Devonian Carbonate Aquifer can be highly permeable and productive, range from 275 to 900 feet thick, and yield between 15 and 1,400 gpm to individual wells. Carbonate aquifers underlie about one-half of Indiana and are the most productive of the bedrock aquifers (Fenelon et al., 1994). The overlying Mississippian New Albany, Coldwater, Ellsworth, and Antrim Shales have limited permeability and generally do not yield significant quantities of groundwater to wells, only being used for limited domestic purposes. There are domestic wells completed in this unit with yields less than 20 gpm, but many dry holes have been reported in some counties. The Mississippian Borden Group is not very permeable unless fractured, and well yields are typically limited to less than 20 gpm. Many dry holes have also reportedly been encountered in this unit. A few 25 to 225 gpm yielding wells have been completed in some counties in the upper weathered Borden Group bedrock. The Mississippian Blue River and Sanders Group Aquifers are relatively permeable and yield between 2 and 60 gpm to wells, although higher yields have been reported in isolated areas. The Pennsylvanian McLeansboro, Carbondale, and Raccoon Creek Groups are relatively permeable where thicker sandstone beds are present, and yield between 50 and 250 gpm to individual wells in some areas. Typical well yields are generally less than 30 gpm, and some dry holes have been reported.

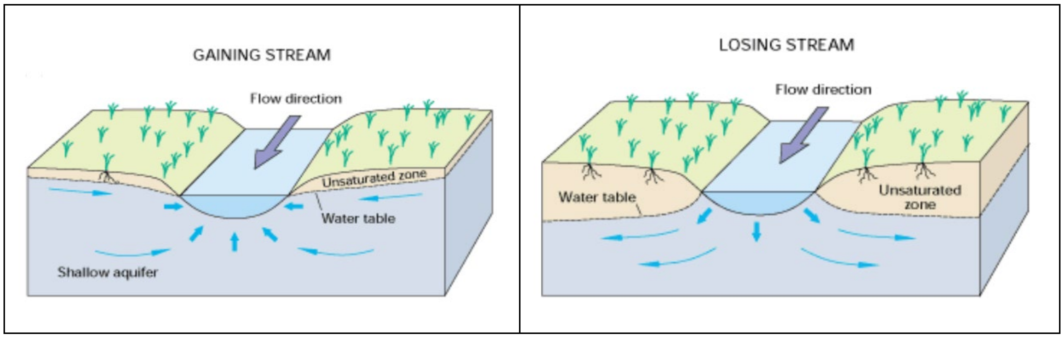
Few continuous water level records for the bedrock aquifers exist, and noticeably absent are any continuous water-level measurements for the Silurian and Devonian Carbonate Aquifer within the counties of the Study Area, in spite of its high usage in Pulaski, White, and Howard Counties. Based on USGS (2024a) records, only one bedrock well in the Study Area has had more than 10 water level measurements recorded. A hydrograph for this observation well is included in Appendix A, along with a map that illustrates the location of this well in the Study Area. This observation well, PA-6, is completed to a depth of 155 feet in Parke County and yields groundwater level information between 1967 and 2024 in the Pennsylvanian Raccoon Creek Group Aquifer. Over the period of record, water levels have fluctuated approximately six feet.

2.3.2.3 Recharge

Recharge is a hydrologic process where water moves from rivers or the land surface into aquifers. Near surface recharge rates have been estimated from multiple regression analyses for Indiana. Groundwater recharge data used in the multiple regression analysis were derived from calculations of groundwater baseflow and surface-water runoff for 279 streams in Indiana that represent both the glaciated portion of Indiana in the northern two-thirds of the state and the unglaciated southern third (Letsinger, 2015). A statewide water-balance yielded a statewide average annual groundwater recharge rate of 6 inches per year (Letsinger et al., 2021). In southern Indiana, recharge rates can be as little as 1 inch per year, while in other areas of Indiana, recharge rates can reach 14 inches per year. Appendix A includes a figure illustrating recharge rates across the Study Area, indicating that the highest recharge rates exist near streams and outwash aquifers in Kosciusko, Fulton, Pulaski, Tippecanoe, and Vigo Counties. Some areas in the Study Area receive little recharge, typically within till and intertill deposits. Recharge varies seasonally, with lower recharge during the dry season and increased recharge during wet conditions. The seasonal effects on recharge may affect the dynamics of water availability (Letsinger et al., 2021).

2.3.2.4 Baseflow

Baseflow is the groundwater portion of streamflow that sustains the stream between precipitation events. Baseflow is important for sustaining human centers of population and ecosystems. Baseflow is derived from unconsolidated and/or bedrock aquifer water storage near surface valley soils and riparian zones. Water percolates to groundwater and then flows to a body of water (Ward and Trimble, 2003). Streams interact with groundwater in three ways. Streams gain water from inflow of groundwater through the streambed (gaining stream, Figure 2-16), they lose water to groundwater by outflow through the streambed (losing stream, Figure 2-16), or they do both, gaining in some reaches and losing in other reaches or periods of time. For groundwater to discharge into a stream channel as baseflow, the elevation of the water table in the vicinity of the stream must be higher than the elevation of the stream-water surface (Winter et al., 1998). The volume and rate of water moving as baseflow can be affected by macropores, micropores, and other fractured conditions in the soil and shallow geomorphic features. Infiltration to recharge subsurface storage increases baseflow. Evapotranspiration reduces baseflow because trees absorb water from subsurface soils and bedrock (Bierman, 2014).



Source Winter et al. (1998).

Figure 2-16. Conceptual Diagrams of Gaining and Losing Streams from Baseflow

The baseflow contribution to streamflow in a river or creek is highly seasonal and event driven. As discussed in more detail in Section 5.6 and Appendix C, the baseflow portion of streamflow can be quantified using a baseflow separation mathematical method. An example of measured daily streamflow and the estimated baseflow contribution is shown in Figure 2-17 for USGS 03335500 Wabash River at Lafayette as a daily hydrograph for a dry year (2012, top) and a wet year (2015, bottom), along with groundwater elevations from a nearby well completed in soil and gravel, USGS 402734087033402. The fluctuating high flow component of a measured streamflow hydrograph comes from surface runoff from storm events, while the steady, consistent low flow component consists of baseflow. During storm or rain on snow events (e.g., December 2011), baseflow is elevated, but constitutes a smaller portion of total flow. Groundwater recharge occurs during these months, as evidenced by rising groundwater elevations. During dry months or seasons (e.g., March 2012 through October 2012), and in between storm events, baseflow is the primary component of total flow. Throughout much of Indiana, there is little to no groundwater recharge from the start of the growing season through early fall, when evapotranspiration is high and plants, trees, and crops are consuming any precipitation that is received before it has an opportunity to recharge. Therefore, any baseflow in the streams in the summer and fall is primarily from groundwater storage (i.e., recharge received in earlier seasons or years) discharging to the stream, as evidenced by falling groundwater elevations.

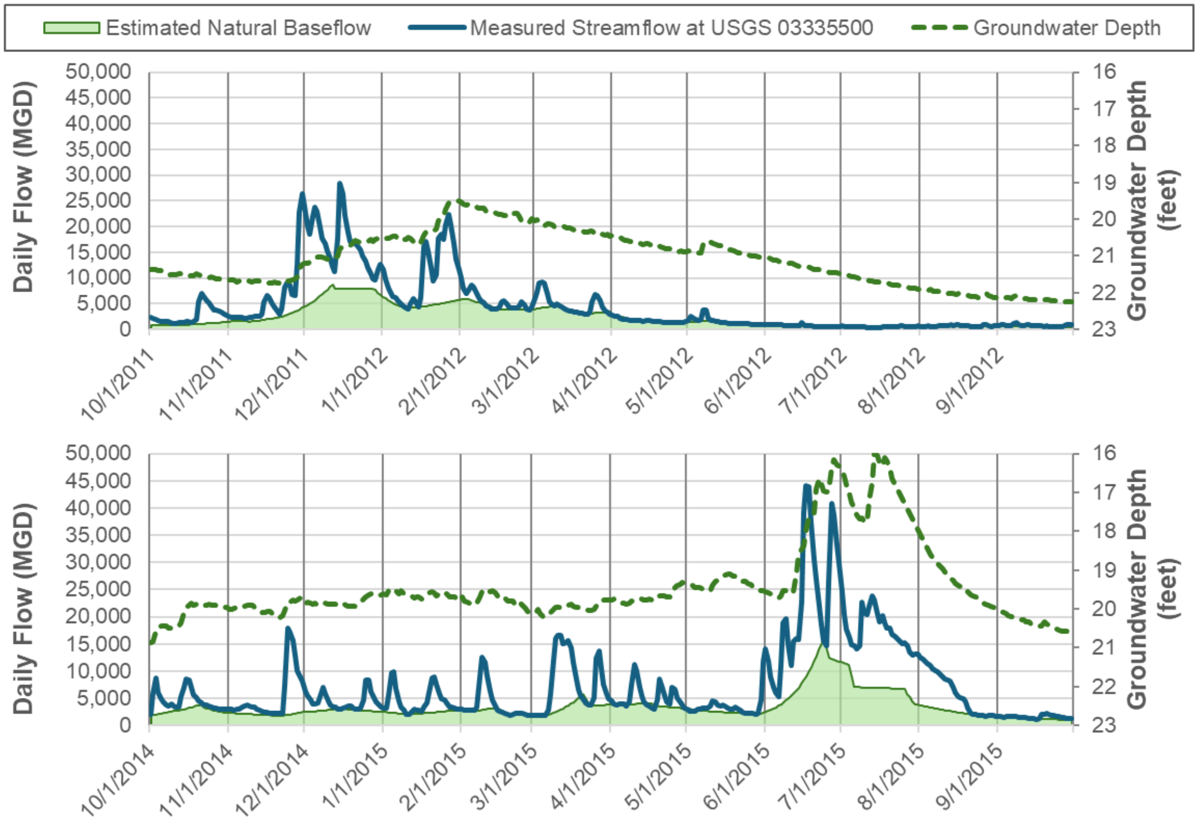


Figure 2-17. Measured Streamflow and Estimated Baseflow at USGS 03335500 Wabash River at Lafayette, IN and Groundwater Elevation at USGS 402734087033402 for a Relatively Dry Year (2012, top) and a Relatively Wet Year (2015, bottom)

2.4 Population Centers

The Study Area predominantly features agricultural lands interspersed with large cities and smaller towns fueled by the region's main industries of manufacturing, agriculture, education, and energy production). In 2022, the population of the Study Area subbasins is estimated to be 710,000 in Indiana and 215,000 in Illinois

Located near the center of the Wabash watershed, the largest metropolitan statistical area (MSA) is Lafayette, home to 224,515 people, with 70,650 living within the City of Lafayette. Other major urban centers in the Study Area include Kokomo, Terre Haute, Lebanon, Warsaw, Crawfordsville, and Frankfort (Table 2-4). The basin is relatively sparsely populated. As an indication of the rural nature of the basin, the largest city, Lafayette, is home to 1% of the state's total population of 6.8 million. The population density (people per square mile) in nearly every city in the Study Area is more than the statewide average of 190 people per square mile. Table 2-5 lists selected major public utilities within the Study Area and identifies the primary populations served by each facility.

Table 2-4. Cities, 2023 Population and Population Density of the Study Area

City/Town Name	2023 Population	Square Miles	People per Square Mile
Indiana (statewide)	6,833,037	35,826	190
Lafayette	70,650	29.4	2,409
Kokomo	59,375	36.7	1,622
Terre Haute	58,491	34.2	1,713
Lebanon	17,575	15.5	1,115
Warsaw	16,592	13.4	1,229
Crawfordsville	16,408	9.7	1,684
Frankfort	15,536	8.1	1,972
Rochester	6,244	4.6	1,356
Monticello	5,504	3.5	1,568
Tipton	5,255	2.6	2,021
Winona Lake	5,073	2.8	1,813
Clinton	4,814	2.3	2,096
Syracuse	3,232	2.0	1,541
Attica	3,221	1.8	1,703
Covington	3,112	1.3	2,338
Winamac	2,445	1.4	1,816
West Terre Haute	2,073	0.8	2,580
Veedersburg	2,066	3.0	649
Greentown	2,005	1.3	1,565
Battle Ground	1,989	1.0	2,073
Liberty	1,958	0.9	2,317
Milford	1,955	1.5	1,175
Williamsport	1,921	1.3	1,421
Shadeland	1,811	27.1	77
Monon	1,764	0.9	1,960
Brookston	1,703	0.7	2,344
Rossville	1,601	0.5	3,498
Fairview Park	1,426	0.9	1,548
Russiaville	1,374	0.9	1,499
Mulberry	1,266	0.5	2,564
Ladoga	1,149	0.5	2,298
Thorntown	1,115	0.6	1,865
Akron	1,061	0.5	2,124
Dayton	1,049	1.1	999
Seelyville	1,052	0.9	1,008
North Webster	886	0.8	1,203

Source: ACS 2023 5-Year Population Estimates, 2020 U.S. Gazetteer Files

Table 2-5. Major Public Water Utilities in the Study Area

Utility Name	Principal City Served	Principal City Population	County	Primary Water Source
City of Lafayette Water Works	Lafayette	70,650	Tippecanoe	Groundwater
Indiana-American Water Co Inc	Lafayette	70,650	Tippecanoe	Groundwater
Indiana-American Water Co Inc	Kokomo	59,375	Howard	Groundwater and Surface water
Indiana-American Water Co Inc	Terre Haute	58,491	Vigo	Groundwater
Indiana-American Water Co Inc	West Lafayette	44,802	Tippecanoe	Groundwater
Lebanon Utilities	Lebanon	17,575	Boone	Groundwater
Indiana-American Water Co Inc	Warsaw	16,592	Kosciusko	Groundwater
Indiana-American Water Co Inc	Crawfordsville	16,408	Montgomery	Groundwater
City of Frankfort	Frankfort	15,536	Clinton	Groundwater
Rochester Water Department	Rochester	6,244	Fulton	Groundwater
Monticello Municipal Utility	Monticello	5,504	White	Groundwater
Tipton Municipal Utilities	Tipton	5,255	Tipton	Groundwater
Clinton Township Water Company Incorporated	Clinton	4,814	Vermillion	Groundwater
Clinton Water Utility	Clinton	4,814	Vermillion	Groundwater
City of Attica	Attica	3,221	Fountain	Groundwater
Town of Rockville	Rockville	2,551	Parke	Groundwater
Town of Winamac	Winamac	2,445	Pulaski	Groundwater
West Terre Haute Water Works	West Terre Haute	2,073	Vigo	Groundwater
Town of Veedersburg	Veedersburg	2,066	Fountain	Groundwater
Town of Wolcott	Wolcott	1,044	White	Groundwater
Town of Linden	Linden	526	Montgomery	Groundwater

Source: ACS 2023 5-Year Population Estimates, SWWF Database

Note: This is not a comprehensive list of all public utilities in the Wabash Watershed. These facilities were identified as having the largest annual water withdrawal rates in the region (SWWF Database) as well as highlighting the major public water suppliers to the larger population centers in the Study Area.

2.4.1 SOCIOECONOMIC CHARACTERISTICS

Though the Wabash Watershed is predominantly rural, it is home to a diverse mix of economic and industry activity. Much of the land in the region is allocated to cultivated crops, such as corn and soybeans (MRLC, 2019) and as a result, the Study Area's economy is strongly supported by the agricultural sector. Additionally, the region is home to several large educational institutions, such as Purdue University and Indiana State University. As of 2023, the largest sector in the Study Area by employment is education, followed by manufacturing and retail trade (U.S. Census Bureau, 2023).

Table 2-6[5] compares selected socioeconomic characteristics in the Study Area to the State of Indiana, as of 2023. Across the board, the Study Area metrics are slightly below statewide metrics. The Study Area's unemployment rate and poverty rate, 4.4% and 12.6%, respectively, fall with a percent of statewide values of 4.3% and 12.2%, respectively. Labor force participation rate, which represents the percentage of the working-age population that is employed or actively seeking employment, is 64% for the state of Indiana while the Study Area's labor force participation rate is slightly lower at 61.4%. Median household income in the Study Area, $67,552, is less than 4% below the statewide median household income of $70,051. However, home values in the Study Area are almost 20% lower than the median home value in Indiana. This is representative of the rural nature of the Study Area and the lower home values associated with less developed rural areas (Bauchaud, 2022).

Table 2-6. Selected Socioeconomic Characteristics in Study Area, Indiana

	Labor Force Participation Rate	Unemployment Rate	Median Household Income	Poverty Rate	Median Home Value
Study Area	61.4%	4.4%	$67,552	12.6%	$168,367
Indiana	64.0%	4.3%	$70,051	12.2%	$201,600

Source: U.S. Census Bureau, 2023

2.5 Water Withdrawals

Water withdrawals within the 15-county Study Area of North Central Indiana are primarily characterized using data from the Significant Water Withdrawal Facility (SWWF) database (IDNR, 2023) where a facility is defined as "the water withdrawal facilities of a person that, in the aggregate from all sources and by all methods, has the capability of withdrawing more than 100,000 gallons of groundwater, surface water, or ground and surface water combined in one (1) day" (IDNR, 2023). Data obtained for this Study included a monthly withdrawal time series for all SWWF facilities in the Study Area from 1985 to 2022, with each withdrawal characterized by source (surface water intake or groundwater well) and one of six water use sectors:

- public supply (public water supply and drinking water/sanitary facilities)
- irrigation (agricultural irrigation, golf course irrigation)

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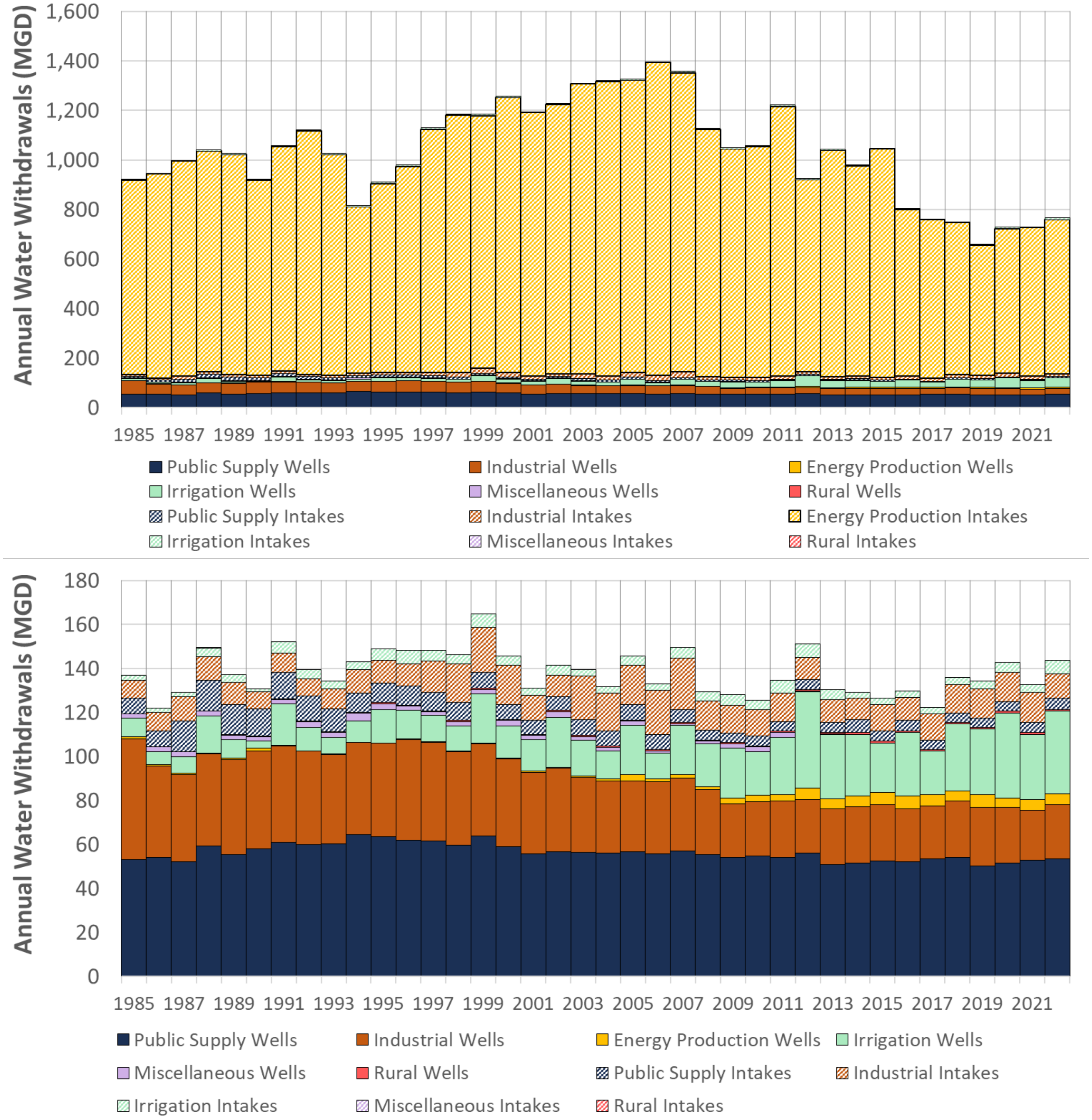
[5] Values listed for the Study Area are an average of county-level data collected for all Indiana counties in encompassed by the Study Area. It should be noted that county-level socioeconomic data for the counties in Illinois partially encompassed by the Study Area are excluded from the values in the table.

- industrial (process water, cooling water, mineral extraction except coal, quarry dewatering, waste assimilation)
- energy production (power generation, cooling water, coal mining, geothermal, oil recovery)
- rural (livestock, aquaculture)
- miscellaneous (fire protection, amusement parks, construction dewatering, dust control, pollution abatement, hydrostatic testing, recreational field drainage)

Additional information on SWWF data processing is provided in Appendix B.

The distribution of water withdrawals by sector and source from 1985 to 2022 is shown with and without energy production withdrawals from surface water intakes in Figure 2-18. This distinction is necessary since energy production at two electricity generating facilities on the Wabash River amounts to a significant magnitude of total water withdrawals, most of which are not consumed but are returned to the stream, and inclusion of these values does not allow for a clear analysis of water withdrawal trends. However, withdrawals for energy production peaked around 2006 and have since declined steadily due in part to the closure of a coal-fired power generating station (in Vigo County) in 2016. Other water withdrawal trends include:

- Public supply represents the largest portion of total withdrawals (excluding energy production), and is sourced primarily from groundwater, with both trends remaining consistent since 1985. Public supply surface water withdrawals have been reduced by about 50% since 1985.
- Industrial water withdrawals historically represented a large portion of total withdrawals (excluding energy production) but have trended downward since 1985. These are primarily sourced from groundwater, though total industrial withdrawals from surface water intakes have increased since 1985.
- Irrigation surpassed industrial water use around 2011 to become the second largest groundwater withdrawal sector behind public supply (excluding energy production). Average annual irrigation withdrawals from groundwater have tripled from 1985-1994 to 2013-2022.
- Energy production withdrawals of groundwater have increased steadily since 2005.
- Miscellaneous and rural withdrawals from wells and intakes make up a small portion of total withdrawals.



Note: All sectors (top) and excluding energy production withdrawals from surface water intakes (bottom). Data for Public Supply Wells, Industrial Wells, Energy Production Wells, Irrigation Wells, Miscellaneous Wells, Rural Wells, Public Supply Intakes, Industrial Intakes, Irrigation Intakes, Miscellaneous obtained from the Indiana Significant Water Withdrawal Facility database (IDNR, 2023).

Key:
Intakes = surface water intakes
MGD = million gallons per day
Wells = groundwater wells

Figure 2-18. Significant Water Withdrawals in North Central Indiana by Source and Sector from 1985 to 2022

One prominent trend observed in the data over the past 15 years is a decrease in surface water withdrawals and an increase in groundwater withdrawals (Figure 2-19). Since 2007, annual surface water withdrawals have decreased 50%, from around 1,250 MGD to less than 650 MGD. Over that same period, groundwater withdrawals have varied from year to year, but in total have increased 6%, from just over 110 MGD to just under 120 MGD. Surface water withdrawal reductions are largely due to decreased river withdrawals for use as cooling water in coal-based electricity generating facilities, while increases in groundwater withdrawals are primarily attributed to increased irrigation. A notable increase in groundwater withdrawals was observed in 2012, when the region experienced a significant drought with prolonged high summer air temperatures and low relative total annual precipitation. The lack of precipitation during the agricultural growing season likely caused increased groundwater withdrawals.

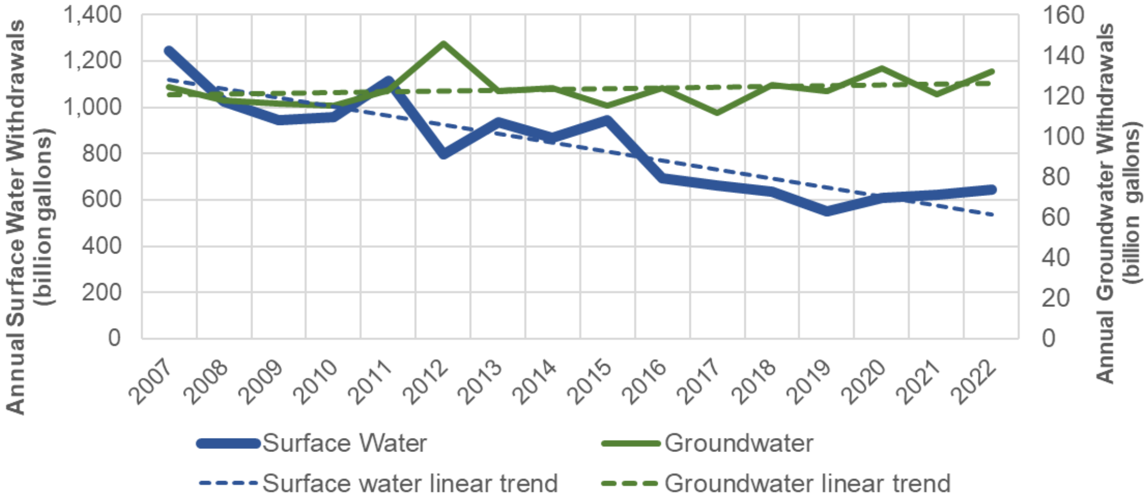


Figure 2-19. Trend in Annual Surface Water and Groundwater Withdrawal Volumes by Source Since 2007 in the Study Area

A level of seasonality is also apparent in monthly water withdrawals for certain water use sectors. As shown within Figure 2-20, public supply and industrial withdrawals are relatively stable throughout the year, with slight increases in the summer months for public supply due to increased water demand for landscape irrigation at homes and businesses. Irrigation withdrawals show the highest level of seasonality. Water withdrawals peak in summer months that correspond to high temperatures, high evapotranspiration, and the greatest water demand for agricultural crops like soybeans and corn.

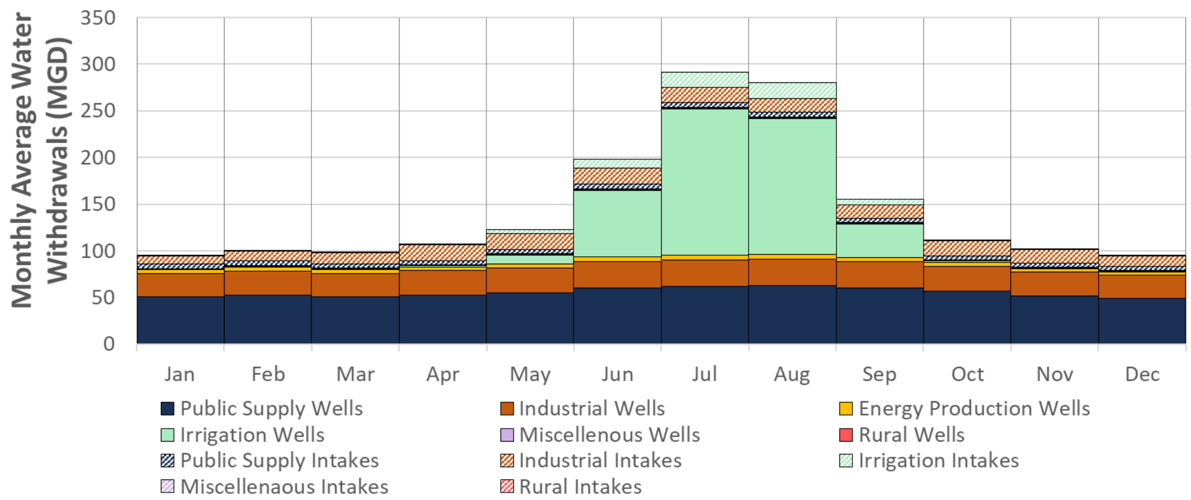
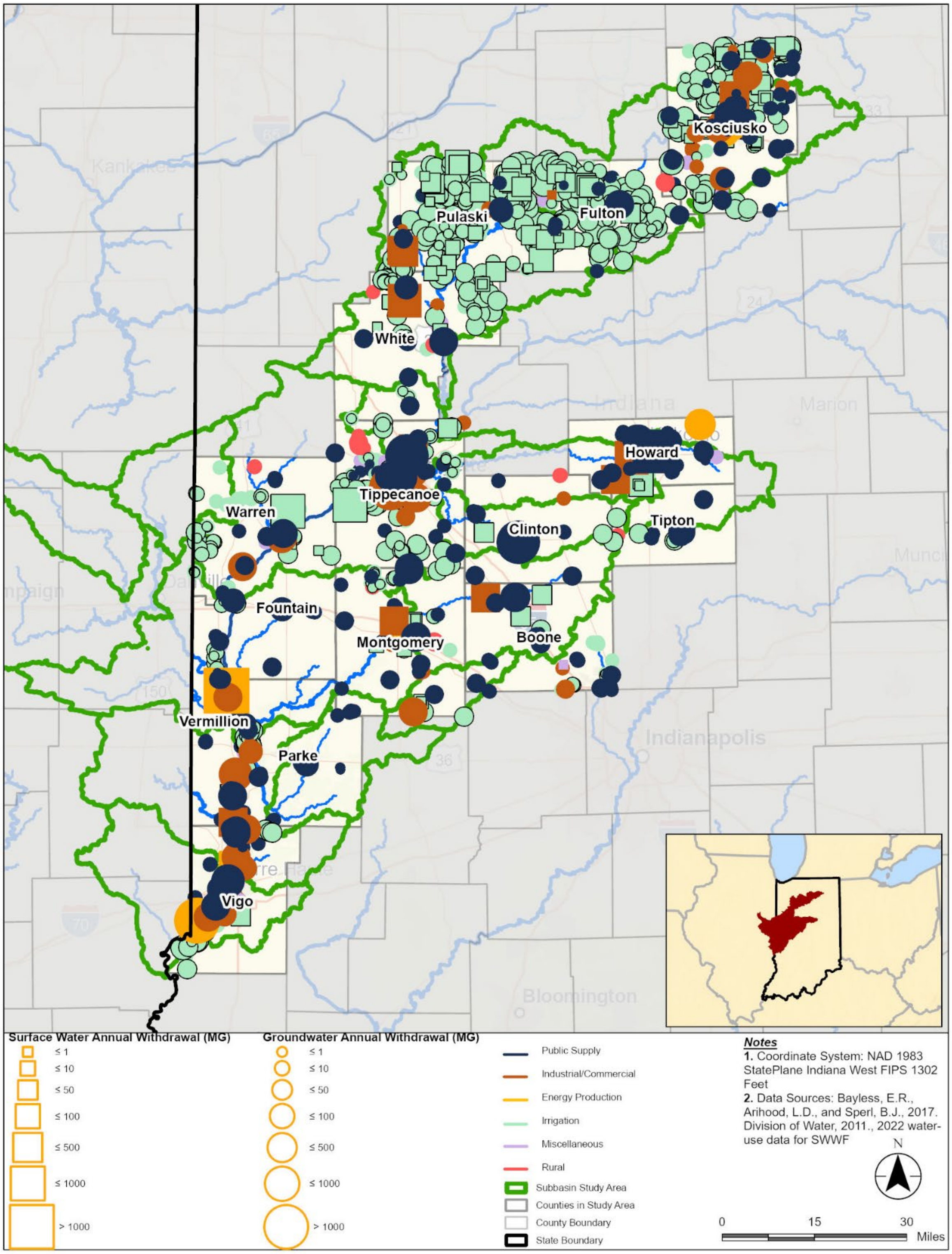


Figure 2-20. Monthly Average Water Withdrawals in the Study Area from 1985-2022 by Water Use Sector and Source (Excluding Energy Production from Surface Water Intakes)

The spatial distribution of water withdrawals shows several trends that reflect the hydrologic, geologic, and population characteristics of the Study Area (Figure 2-21). Irrigation withdrawals from groundwater are prominent in the northern counties of Kosciusko, Fulton, and Pulaski, while large public supply withdrawals are also predominantly from groundwater and clustered around major population centers. In the southern portion of the Study Area, withdrawals for all sectors tend to be from groundwater and tend to be adjacent to the Wabash River.

A review of 2022 total water withdrawals by source, sector, and county provides additional insight into regional water relationships (Figure 2-22). Water withdrawals are sourced from both surface water and groundwater; though surface water withdrawals are much larger in magnitude, used in primarily one sector at two locations, and the use is primarily non-consumptive. The majority of surface water withdrawals belong to the energy production sector in Vermillion County, while a smaller portion of surface water withdrawals support industrial use, and no surface water is used for public supply. Public water supply withdrawals occur in all counties, with the greatest withdrawals supporting larger population centers in Tippecanoe County (Lafayette) and Vigo County (Terre Haute). Tippecanoe County also supports the largest industrial withdrawals. Withdrawals for agricultural irrigation occur mainly in Fulton, Pulaski, and Kosciusko Counties, which accounted for 85% of total irrigation withdrawals in 2022. Rural and miscellaneous withdrawals are relatively small in the Study Area. The majority of withdrawals were concentrated in Vermillion, Tippecanoe, Kosciusko, Pulaski, and Vigo Counties, while the combined withdrawals from White, Parke, Warren, Fountain, Montgomery, Tipton, and Clinton Counties represented only 17% of total annual withdrawals in 2022 across the Study Area (excluding surface water withdrawals for energy production).



Note: Based on data for 2022.

Figure 2-21. Significant Water Withdrawal Facilities Within North Central Indiana Study Area

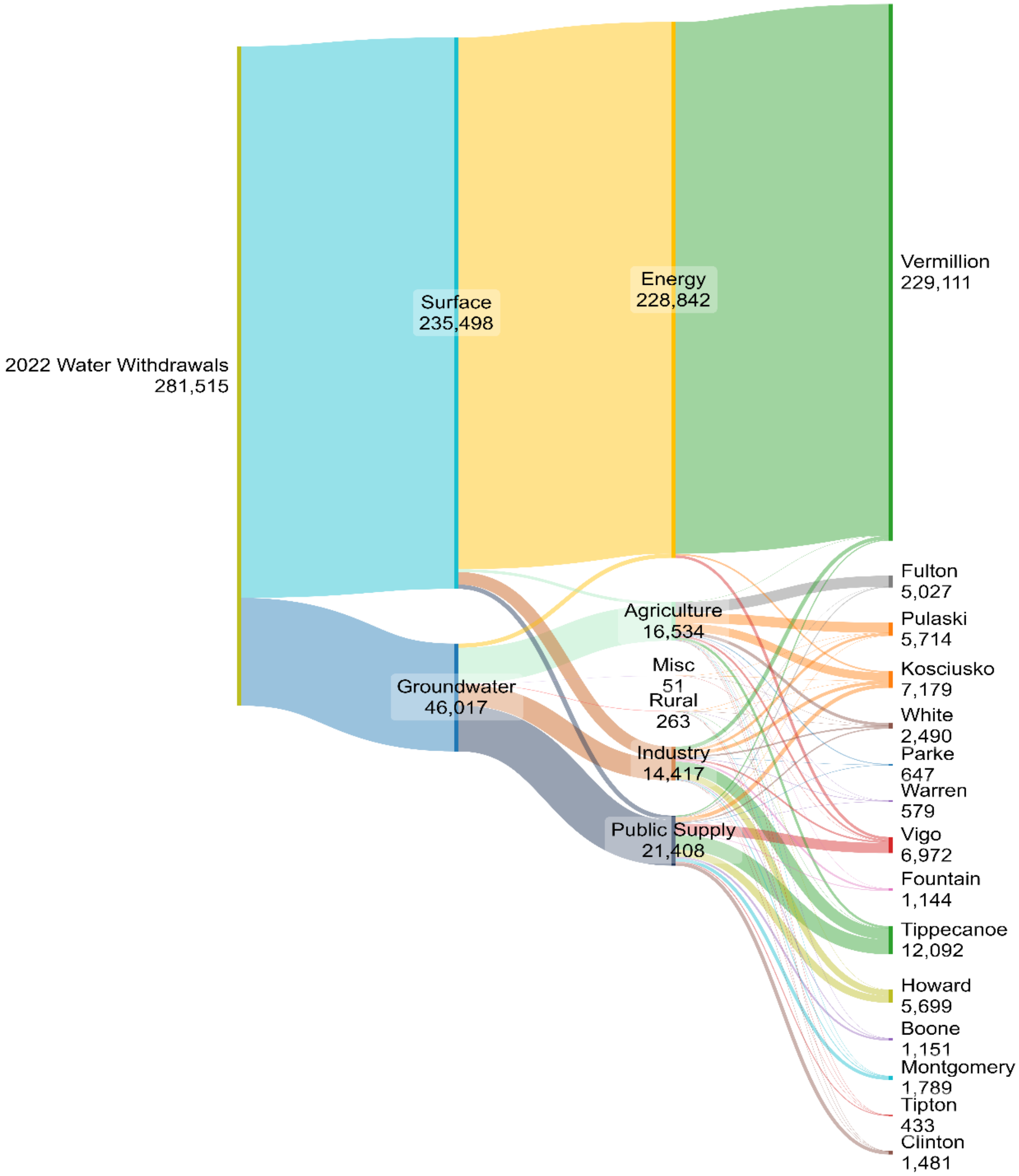


Figure 2-22. North Central Indiana Study Area Total Annual Water Withdrawals (million gallons) in 2022 by Source, Sector, and County

Of the total 2022 withdrawal volume, 235,000 MG (84%) came from surface water intakes, and approximately 46,000 million gallons (MG) (14%) came from groundwater wells. Aquifer units defined by IDNR were mapped to SWWF facility locations and well depths, and aquifer units were assigned to each withdrawal volume from 2022 to better understand the distribution of groundwater withdrawals from unconsolidated and bedrock aquifers (Figure 2-23). 42,000 MG (92%) of groundwater withdrawals came from surficial aquifer units, or unconsolidated aquifers, while 3,500 MG (8%) came from bedrock aquifers. However, several counties rely heavily on bedrock aquifers to provide a significant percentage of their groundwater use, including Howard (73%), White (54%), Warren (51%), and Pulaski (29%). Howard, Pulaski, and White Counties rely on the Silurian-Devonian Carbonate Aquifer, while Warren County uses water from the Borden Group Aquifer.

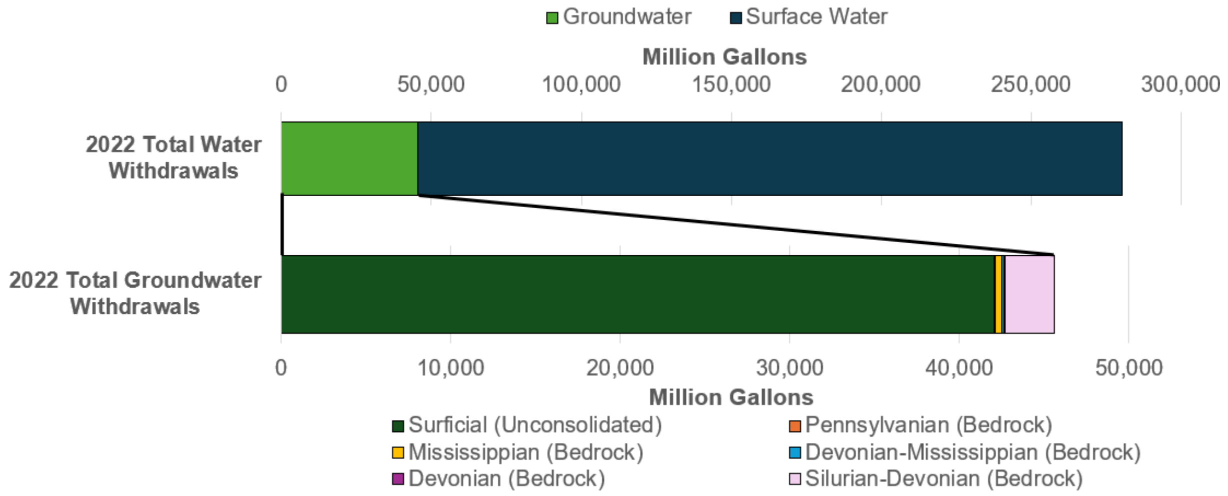


Figure 2-23. North Central Indiana Study Area Total Annual Water Withdrawals (million gallons) in 2022 by Source and Aquifer Unit

Several known withdrawal sectors are not accounted for in the SWWF database due to the size of their individual withdrawals not meeting the minimum criteria for registration, even though collectively they withdraw a notable annual volume of water. These sectors include withdrawals for self-supplied residential domestic uses and Concentrated Animal Feeding Operations (CAFO). In addition, Illinois has a separate water withdrawal program for some water use sectors. Additional information on data collection and demand estimates for these categories is provided in Appendix B. The total 2022 withdrawal volume estimated for each of these sources is shown in Table 2-7. Together they totaled 10,000 MG, or about 4% of the 2022 withdrawal volume reported in the SWWF.

Table 2-7. Other Sector Estimated Withdrawals in the Study Area for 2022

Sector	2022 Estimated Withdrawal Volume (Million Gallons)
Concentrated Animal Feeding Operations (Indiana)	415
Self-Supplied Residential (Indiana)	3,415
Concentrated Animal Feeding Operations (Illinois)	41
Self-Supplied Residential (Illinois)	535
Irrigation (Illinois)	762
Public Supply (Illinois)	4,685
Industrial and Commercial (Illinois)	378
TOTAL	**10,231**

2.6 Dams

Dam data for the North Central Indiana and Wabash Headwaters Study Areas were downloaded from the United States Army Corps of Engineers (USACE) publicly available National Inventory of Dams (NID) database. There were 191 dams identified within these limits, shown in Figure 2-24. Dams are symbolized by their relative normal storage volume, defined in the NID as “the total storage space in a reservoir below the normal retention level, including dead and inactive storage and excluding any flood control or surcharge storage.” Dam normal storage volume is categorized as less than 1,000 acre-feet, between 1,000 and 15,000 acre-feet, and greater than 15,000 acre-feet.

The number of dams classified by the dam’s primary purpose and normal storage capacity are classified in Table 2-8. Most dams in the Study Area have normal storage of less than 1,000 acre-feet. Dams of this size were assumed to have minimal impact on this Study, and therefore, were not considered for additional analysis. Most dams have recreation or flood risk reduction as a primary purpose. On-stream dams with normal storage areas greater than 15,000 acre-feet were most likely to have the largest impacts on water availability and were generally of greater interest. Flood control dams were also of greater interest, as they most likely have the largest impact on natural streamflow.

Table 2-8. Summary of Dams in the Study Area and Primary Purpose

Dam Primary Purpose	**Number of Dams per Normal Storage Category (acre-feet)**			
	<1,000	**1,000 - 15,000**	**>15,000**	**Total**
Debris Control	2			2
Fire Protection, Stock, or Small Fish Pond	1			1
Fish and Wildlife Pond	2			2
Flood Risk Reduction	21	3	4	28
Other	5	1		6
Recreation	123	9	2	134
Tailings	3			3
Water Supply	4	1		5
N/A	9	1		10
Total	**170**	**15**	**6**	**191**

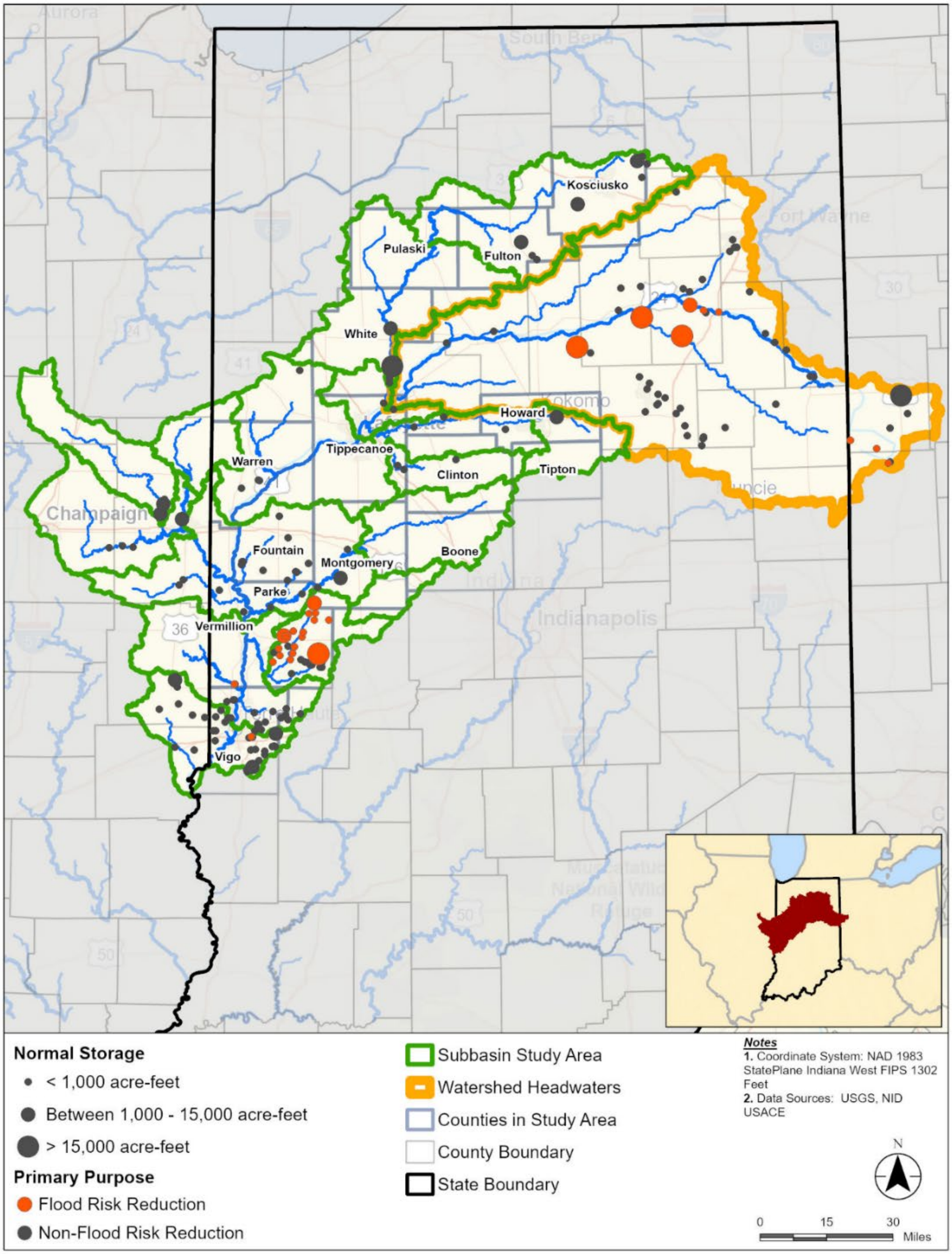


Figure 2-24. Regional Overview of Dam Locations and Relative Normal Storage

3.0 Regional Water Study Approach

The general approach to quantify water availability in the Study Area includes calculation of a water budget for subbasins, or spatial units that represent a unique drainage area. A water budget accounts for flow into and out of a subbasin, quantifying how flow is allocated for different uses and purposes. Water availability is a term used to describe flow that is not allocated to a defined use or purpose, and is also referred to as excess water in the system. A regional data driven analysis framework was adopted from previous Indiana regional water studies (INTERA, 2021a; Letsinger and Gustin, 2024) to calculate water budget components and evaluate historical and future water availability within the Study Area subbasins.

3.1 Historical Water Availability Analysis Framework

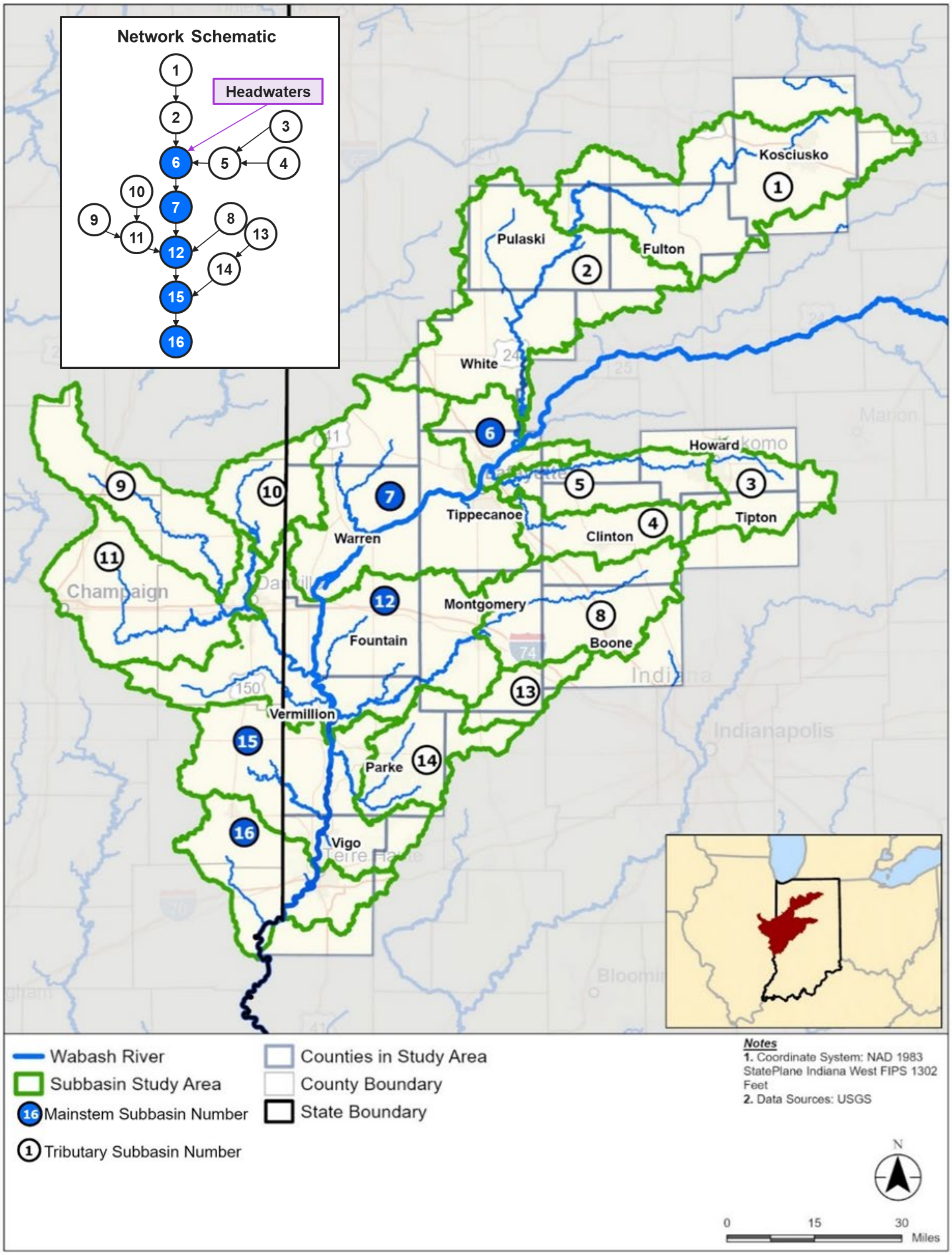
The 15-county North Central Indiana Study Area and portions of Illinois were organized into subbasins based on the locations of continuous daily flow measurements available from USGS stream gaging stations from 2007 to 2022 (Figure 3-1 and Table 3-1). Appendix B provides additional information on stream gage selection and subbasin delineation. Water availability is quantified using subbasin hydrologic boundaries rather than political or administrative boundaries like counties. A subbasin delineates the spatial limit of surface water that flows to a single downstream outlet location and is a logical spatial unit to analyze the cumulative effects of withdrawals on streamflow in a river network. Defining the downstream boundary of each subbasin at a USGS stream gaging station ensures the water availability analysis is based on measured data. Choosing this boundary for a spatial unit requires disaggregation of county, state, and census level data to the subbasin scale, as defined further in Chapter 4.

A subbasin is distinct from a watershed, though both represent an area of land that drains to a common outlet. The subbasins defined in this Study are smaller scale hydrologic boundaries that may receive inflow from one or more upstream subbasins. A watershed is the entire land area that flows to a common outlet, which may include multiple upstream subbasins that flow into one another. The arrows depicted in Figure 3-1 indicate the direction of flow from one subbasin to the next, and the total subbasins that constitute the entire watershed upstream of each subbasin outlet are listed in Table 3-1.

Water availability is defined and evaluated using two separate but related metrics:

- ***Water Availability***: the portion of natural baseflow remaining in a stream (at the subbasin outlet) after instream flow requirements in the subbasin are accounted for. Natural baseflow is an estimate of the natural groundwater discharge to the stream that would occur in the watershed in the absence of groundwater withdrawals and return flows. Instream flows are minimum stream flows required to support the ecological health of the stream, recreational use, and water quality. Water availability may be supplemented by flows released from reservoir storage.

- ***Excess Water Availability:*** the portion of water availability that could be used to support additional surface water or groundwater withdrawals without impacting instream flows or existing surface water and groundwater net withdrawals (net water withdrawals are the amount of water withdrawn minus the amount of withdrawn water returned to the stream).



Notes
1. Coordinate System: NAD 1983 StatePlane Indiana West FIPS 1302 Feet
2. Data Sources: USGS

Figure 3-1. Regional Water Availability Subbasin and County Boundaries

Table 3-1. Description of Subbasins in Study Area

Subbasin ID	Subbasin Name	Subbasin Area (sq. mi.)	Watershed Area (sq. mi.)	Upstream Subbasin(s) in Watershed	USGS Station at Outlet	Station Name
1	Upper Tippecanoe	942	942		03331753	Tippecanoe River at Winamac, IN
2	Lower Tippecanoe	927	1,869	1	03333050	Tippecanoe River near Delphi, IN
3	Wildcat Kokomo	242	242		03333700	Wildcat Creek at Kokomo, IN
4	South Fork Wildcat	243	243		03334500	South Fork Wildcat Creek near Lafayette, IN
5	Wildcat Lafayette	309	794	3, 4	03335000	Wildcat Creek near Lafayette, IN
6	Wabash Lafayette	205	7,267	1-5 + Headwaters	03335500	Wabash River at Lafayette, IN
7	Wabash Covington	951	8,218	1-6 + Headwaters	03336000	Wabash River at Covington, IN
8	Sugar	512	512		03339500	Sugar Creek at Crawfordsville, IN
9	Middle Vermilion	432	432		03336645	Middle Fork Vermilion River above Oakwood, IL
10	North Vermilion	262	262		03338780	North Fork Vermilion River near Bismarck, IL
11	Vermilion	596	1,290	9, 10	03339000	Vermilion River near Danville, IL
12	Wabash Montezuma	1,098	11,118	1-11 + Headwaters	03340500	Wabash River at Montezuma, IN
13	Upper Big Raccoon	139	139		03340800	Big Raccoon Creek near Fincastle, IN
14	Lower Big Raccoon	309	448	13	03341300	Big Raccoon Creek at Coxville, IN
15	Wabash Terre Haute	699	12,265	1-14 + Headwaters	03341500	Wabash River at Terre Haute, IN
16	Wabash Vigo	454	12,719	1-15 + Headwaters	Synthetic[1]	-

Note:

[1] A synthetic hydrology was developed for Subbasin 16 to represent the downstream boundary of the Study Area, which is ungaged. Additional details are provided in Appendix B.1.

[2] Headwaters refers to the watershed upstream of and draining into Subbasin 06 that was evaluated through a separate analysis (Jacobs, 2025)

Key:
IL = Illinois
IN = Indiana
sq. mi. = square mile

Water Availability and ***Excess Water Availability*** are calculated at both the subbasin (i.e., local) and watershed (i.e., regional) scale. When calculated at the watershed scale, these metrics are defined as ***Cumulative Water Availability*** and ***Cumulative Excess Water Availability***, and they account for the cumulative effects of all water budget components from all upstream subbasins that have an influence on streamflow at the individual subbasin outlet. These metrics most closely represent the water available at a subbasin outlet, which could include flow contributions from the upper watershed. At the subbasin scale, ***Water Availability*** and ***Excess Water Availability*** are calculated using the net natural baseflow, water withdrawals, return flows, net instream flow, and net reservoir storage generated within an individual subbasin. These metrics are helpful for relating withdrawals to streamflow and baseflow generated within each subbasin, independent of contributions from the upper watershed.

The general process for calculating cumulative water budget components, cumulative excess water availability, and excess water availability is briefly described below. The order of calculation operation description described cumulative water budget components first, which are then used to estimate excess water availability. This description differs slightly from other regional water studies (e.g., INTERA 2021b), but the method is the same.

3.1.1 CUMULATIVE WATER BUDGET COMPONENT CALCULATION

Calculation of water availability requires quantification of five primary water budget components:

- Natural Baseflow
- Instream Flow
- Reservoir Operations
- Water Withdrawals
- Return Flows

All components of the historical water budget were collected or derived from publicly available data. The general process for calculating water budget components is shown in Figure 3-2 and described below. Details on data collection, pre-processing, and analysis are provided in Appendix B. Data collection was limited to a recent historical period of 2007-2022 because publicly available data on return flows are only available from the EPA Enforcement and Compliance History Online (ECHO) database starting in 2007.

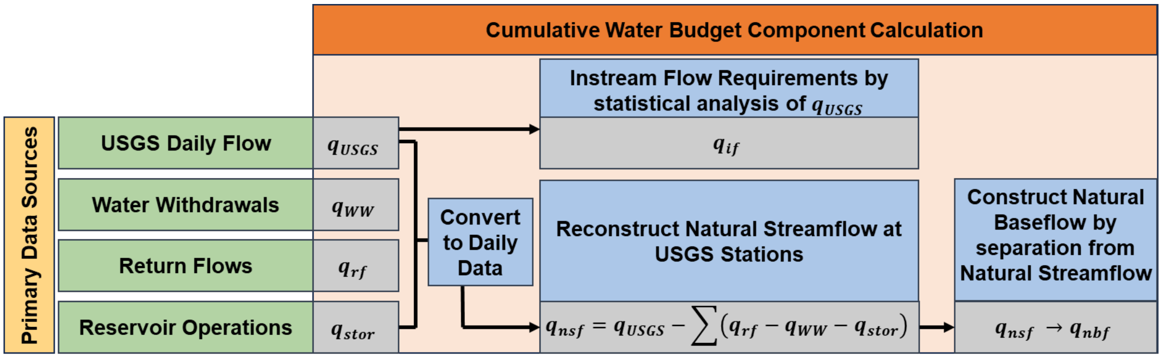


Figure 3-2. General Process for Calculating Cumulative Water Budget Components

Cumulative water budget components were calculated following this sequence:

- **Measured Streamflow (q_{USGS}):** Collect historical USGS daily stream flow for all gages at subbasin outlets and synthesize data to fill missing dates.

- **Instream Flow (q_{if}):** Calculate instream flow requirements at each USGS gage consistent with previous regional water studies (e.g., Letsinger and Gustin, 2024). From December through May (winter and spring seasons), instream flow is defined using a Q90 metric, a value that indicates the minimum daily streamflow level that is exceeded 90% of the time. From June through November (summer and fall seasons, when low flows typically occur), instream flow is defined using a 7Q10 metric, or the lowest 7-day average flow that occurs (on average) once every 10 years. A full description of the calculation is provided in Section 5.2.

- **Reservoir Operations (q_{stor}):** Obtain operational records for major reservoirs and calculate or estimate daily changes in storage. The operations of three major reservoirs in the North Central Indiana Study Area were included in the analysis, with the majority of reservoir storage being generated by the Cecil M. Harden Dam in Subbasin 13 (Upper Big Raccoon). Significant reservoir storage effects are also attributed to the Headwaters Study Area, which contains several large flood control reservoirs. Additional information is provided in Section 5.3 and Appendix B.6.

- **Water Withdrawals (q_{ww}):** Collect water withdrawal data available within the Study Area and estimate daily water withdrawals from all surface water intakes and groundwater wells. Water withdrawals were quantified for the following six water use sectors using data reported the SWWF database (IDNR, 2023) and data provided by the Illinois Water Inventory Program through the Illinois State Water Survey (IWIP, 2024): public supply, energy production, industrial and commercial, irrigation, miscellaneous, and rural. Water withdrawals from CAFOs and self-supplied residential sectors were estimated from available data as described in Chapter 4. Additional information is provided in Appendix B.2 and Appendix B.3.

- **Return Flows (q_{rf}):** Estimate daily return flows for all water withdrawal sectors. The ECHO database was used to quantify monthly return flows from regulated National Pollutant Discharge Elimination System (NPDES) discharge points, which were converted to daily return flow data. These returns were assumed to represent major return flows from SWWFs in the public supply, energy production, industrial and commercial, miscellaneous, and rural sectors. Return flows for CAFOs, irrigation, and self-supplied residential uses were estimated using a return flow factor multiplied by daily withdrawals. Additional information is provided in Appendix B.4 and Appendix B.5.

- **Natural Streamflow (q_{nsf}):** Convert daily measured historical streamflow to daily natural streamflow by subtracting all daily upstream return flows, adding all daily upstream withdrawals, and adding the difference between all upstream reservoir releases and all upstream reservoir increases in storage (a reservoir increase in storage indicated streamflow was captured, generating a positive q_{stor}, while a reservoir release from storage indicates stored streamflow was released, generating a negative q_{stor}). This step removes anthropogenic influences on measured streamflow by adding back all water withdrawn or stored upstream and subtracting all water discharged upstream.

- **Natural Baseflow (q_{nbf}):** Apply a baseflow separation algorithm to the reconstructed natural streamflow time series to estimate a natural baseflow time series at the watershed outlet. Additional details on the baseflow separation methodology are provided in Appendix C.

3.1.2 CUMULATIVE EXCESS WATER AVAILABILITY

Cumulative excess water availability was calculated using the following sequence as shown in Figure 3-3.

- ***Cumulative Water Availability*** **(q_{CWA}):** Subtract daily instream flow from daily natural baseflow, then add back operations for all upstream reservoirs (reservoir releases are added back to increase water availability, while increases in reservoir storage are subtracted to decrease water availability). Summarize results by averaging daily results across four seasons: Winter (December through February), Spring (March through May), Summer (June through August), and Fall (September through November).

- ***Cumulative Excess Water Availability*** **(q_{CEA}):** Add daily net returns (withdrawals minus returns) from all locations within the watershed. Calculate seasonal averages.

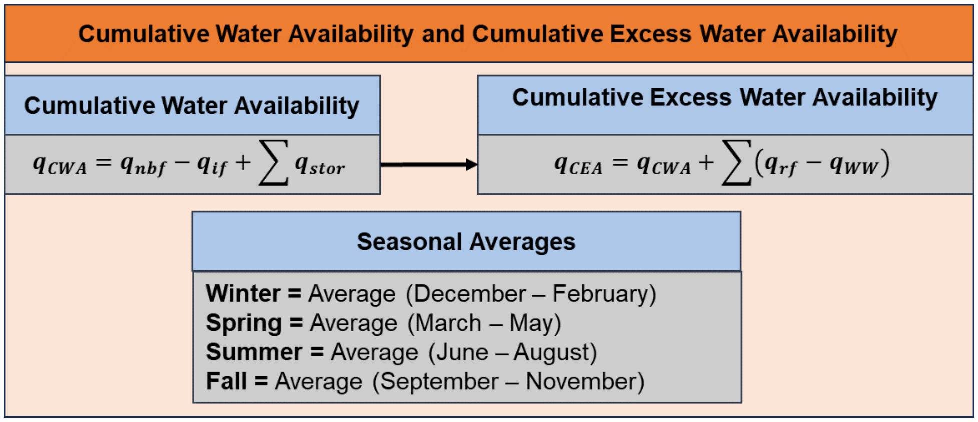


Figure 3-3. General Process for Calculating Cumulative Water Availability and Cumulative Excess Water Availability

A graphical example of the historical cumulative water availability calculation process is shown in Figure 3-4 for Subbasin 06, Wabash Lafayette. Outputs are presented on a monthly average basis as an annual hydrograph. On the top left plot, measured streamflow is converted to cumulative natural streamflow by adding all upstream withdrawals, subtracting all upstream return flows, and incorporating the effects of all upstream reservoirs. The dashed natural streamflow line is higher than measured streamflow in the spring and lower than measured streamflow in the fall, reflecting the removal of the cumulative anthropogenic effects of upstream reservoir inflow stored and the subsequent release of stored water, respectively. The baseflow separation algorithm produces a cumulative natural baseflow that reflects only groundwater baseflow, removing the effects of storm flow. On the top right plot, cumulative natural baseflow is retained as a green line. Cumulative water availability is the blue portion of natural baseflow that is in excess of cumulative instream flows. Cumulative water availability can be decreased or increased by reservoir storage or reservoir releases, respectively. The months of August through November are the most critical for cumulative water availability due to low natural baseflow. The bottom plot retains cumulative water availability as a blue line, and shows how cumulative net returns can decrease cumulative water availability to produce cumulative excess water availability. In this case, cumulative net returns are small relative to natural baseflow and occur primarily in late summer.

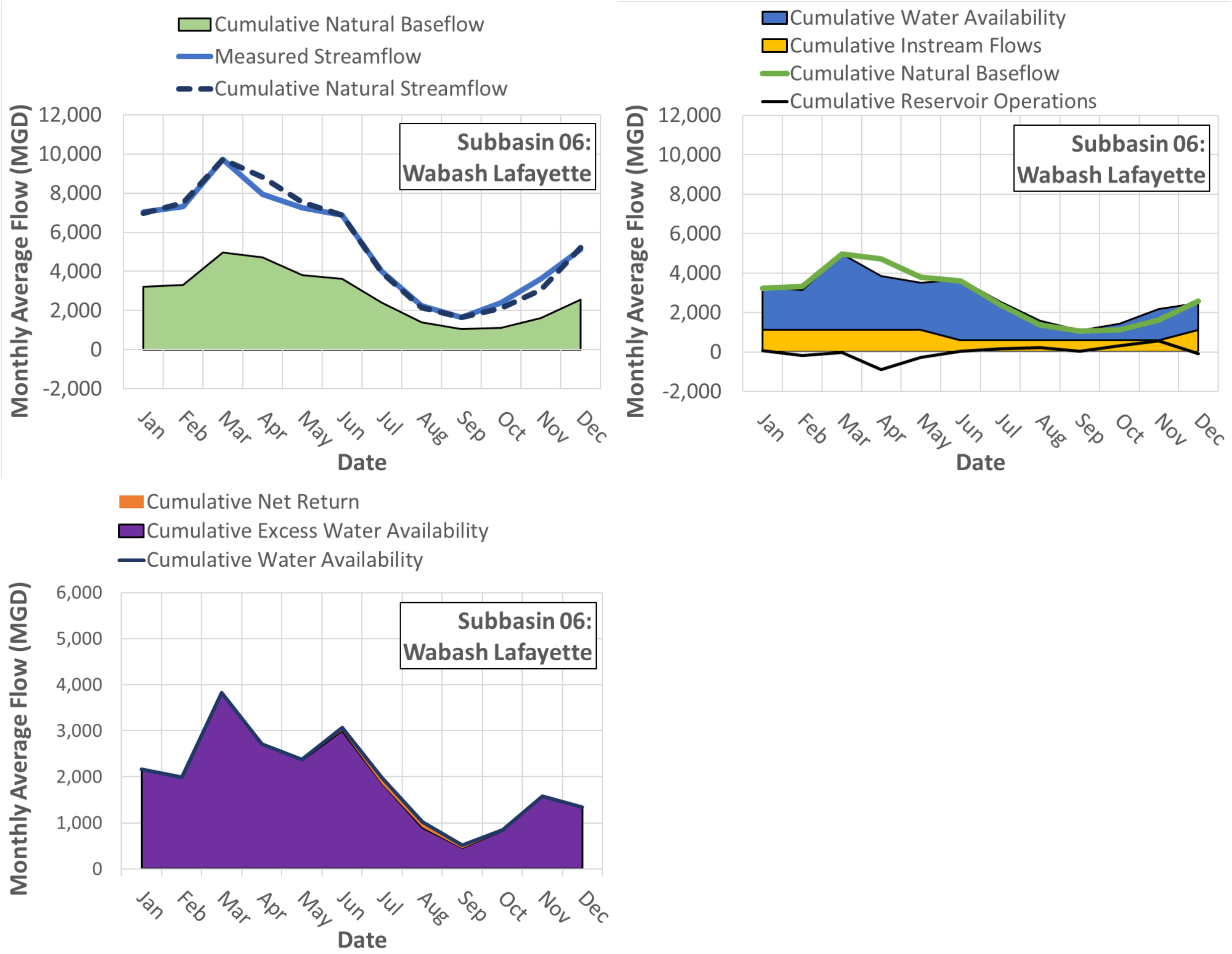


Figure 3-4. Graphical Examples of Cumulative Excess Water Availability Results

3.1.3 EXCESS WATER AVAILABILITY

Excess water availability was calculated using the following sequence as shown in **Error! Reference source not found.**:

- Calculate net water budget components within a subbasin (Q_{nbf}, Q_{if}, Q_{ww}, Q_{rf}, Q_{stor}) by subtracting the cumulative water budget component from all upstream connected subbasins. For example, to calculate net water budget components for Subbasin 06, cumulative water budget components from Subbasin 02, 05, and the Headwaters would be subtracted from the Subbasin 06 cumulative water budget components. This step provided an estimate of the water budget component generated strictly within the subbasin and excluding all upstream contributions.

- ***Water Availability (Q_{WA}):*** Subtract daily net instream flow from daily net natural baseflow, then add back the net reservoir releases. Calculate seasonal averages.

- ***Excess Water Availability (Q_{EA}):*** Add daily net returns (net withdrawals minus net returns) within the subbasin. Calculate seasonal averages.

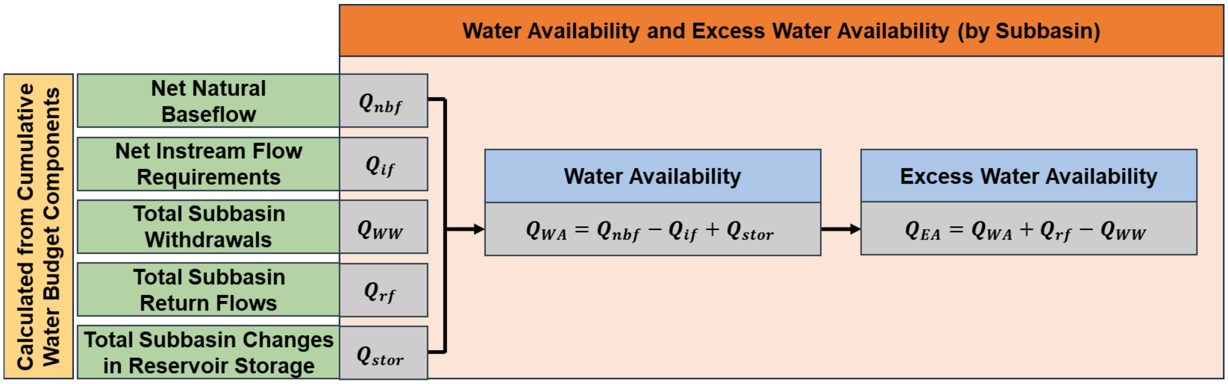


Figure 3-5. General Process for Calculating Water Availability and Excess Water Availability

3.2 Future Water Availability Analysis Framework

The same subbasin delineation and general analytical framework used to quantify historical water availability were implemented to estimate future water availability over a 50-year planning horizon, from 2023-2072. Future cumulative water budget components were estimated using future projected natural baseflow, water withdrawals, and return flows.

The general process steps for estimating future cumulative water budget components are described briefly below, with corresponding steps numbered in Figure 3-6. Additional details on climate change assumptions and Study approach are provided in Section 3.3.

1. Use each year from the historical time series of daily natural streamflow from 2007-2022 to represent a year within the future period of 2023-2072, repeating some historical years multiple times. The sequence of future years was selected to be similar to the sequence of future years developed for the Indiana Climate Change Impacts Assessment (INCCIA) (Cherkauer et al., 2021), since many climate change assumptions from the INCCIA were used in this Study.

2. For each daily natural streamflow time series from 2023-2072, multiply daily streamflow by a climate change factor that varies by month, future period, and subbasin. The change factor is a number that generally ranges from 0.5 to 1.5, reflecting the future change in monthly stream flow simulated by a hydrologic model that incorporated future temperature, precipitation, and other meteorological input data from the INCCIA study. Additional details are provided in Appendix F.

3. Apply a baseflow separation algorithm to the future natural streamflow time series to estimate future natural baseflow at the watershed outlet for each subbasin.

4. Estimate future monthly water withdrawals for each demand sector by subbasin, as described in Chapter 4. Projections for some demand sectors were developed using simulated future air temperature and precipitation data generated for the INCCIA study and averaged at the county level.

5. Estimate return flows for each demand sector by subbasin. A regression equation was developed for each subbasin for the public supply, industrial and commercial, and energy production sectors that estimated historical return flows as a function of historical withdrawals. For the future period, future withdrawals were used as an input to the regression equation to estimate future return flows. Additional details are provided in Appendix F. Return flows for CAFOs, irrigation, and self-supplied residential uses were estimated using the same return flow factor as the historical period, multiplied by monthly average withdrawals.

6. Assume instream flow requirements and monthly average reservoir operations for the future period year are the same as the representative historical year.

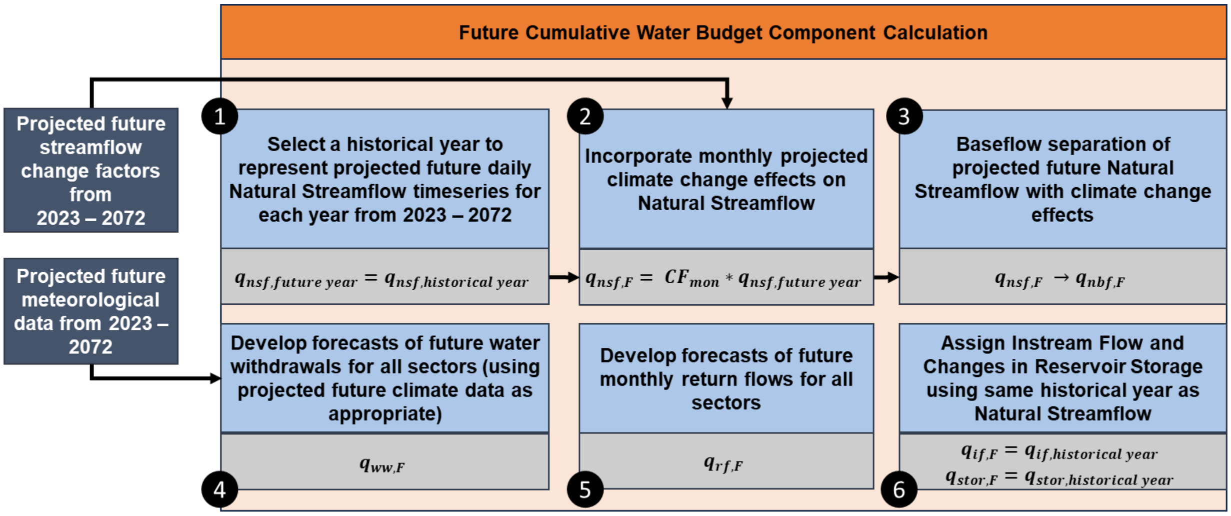


Figure 3-6. General Process for Calculating Future Cumulative Water Budget Components

The same general framework for the historical period for calculating local and regional water availability was applied to the future period (see Figure 3-3).

3.3 Defining a Future Baseline Scenario

A singular future baseline scenario was developed based on estimated trends in population, economic development, and climate over the next 50 years. The Baseline scenario of water demand bases the future forecast not only on historical trends, estimated future demographics (e.g., population and income), and estimated future climate factors, but also bases the forecast on known foreseeable future industrial and agricultural (i.e., irrigation) and agricultural development plans. Refer to Chapter 4 for additional discussion about the Baseline scenario. Trends were defined based on feedback from surveys and interviews with interested parties throughout the Study Area, as well as on a review of published reports, studies, and press releases relevant to local water demands and climate change.

3.3.1 PARTICIPANTS/STAKEHOLDER INPUT

Future demand assumptions and estimates were informed by input from stakeholders throughout the Study Area. Twenty-two entities were interviewed representing 14 economic development departments, four water utilities, three large water consumers and the Indiana Farm Bureau. In addition, a survey of economic development director, water utility directors and water utility operators, was conducted with 15 respondents. Of those surveyed, five had a water plan, eight anticipated needing additional future water service capacity, and three anticipated a decrease in demand. Most did not currently employ water conservation to address water scarcity; however, three have water conservation ordinances.

The following themes emerged from the stakeholder conversations:

- Different counties have different growth aspirations, from content with status quo to aggressive growth.
- Concerns about water availability range from no concerns to immediate water needs.
- Water concerns within a county can differ greatly depending on existing infrastructure, growth areas.
- Industrial growth anticipated in food processing, electric vehicle battery and supporting manufacturing, semiconductor advanced packaging and assembly, and existing growth or maintenance in mining.
- Power generation is shifting from coal, but water needs remain high and remain generally in their current locations.
- Water quality concerns are top of mind for locations with current water quality issues.
- Economic development is often concentrated in the largest city within the county or along a highway corridor.
- With limited local supply (and without interbasin transfers), development in some areas has been halted.
- Lack of infrastructure or aging/ failing infrastructure in some rural communities is financially constraining, and thus is stalling growth.
- Many see lack of housing as a contributing reason for lack of growth.
- Moving water within county boundaries to growth areas is politically acceptable.
- Carbon sequestration concerns exist regarding future water quality.
- Trends point toward an increase in agricultural irrigation use.

3.3.2 MAJOR DEMAND ASSUMPTIONS

Future baseline demand was developed using water demand forecasting methods described further in Chapter 4. Forecasts were modified for some sectors and in some subbasins based on major planned changes in water use. In some cases, projected changes in future water withdrawals resulted in a step change, where withdrawals increased or decreased drastically within a single year (e.g., retirement of a coal plant that was withdrawing surface water for energy production would decrease water withdrawals, while a planned manufacturing facility coming online would increase water withdrawals). Major demand assumptions for the future baseline scenario are summarized in Table 3-2.

Table 3-2. Major Demand Assumptions in the Future Baseline Scenario

Sector	Assumption
Energy Production	Coal energy generating unit on the Wabash River (Subbasin 12) is retired in 2028. This results in a large change in surface withdrawal volume, but since consumptive use is estimated at 1% of withdrawals, and 99% of withdrawals are returned to the Wabash River, the retirement would not significantly alter net returns (withdrawals minus return flows) or excess water availability.
Energy Production	Future energy capacity by technology is based on statewide projections in Purdue University's "Indiana Electricity Projections: The 2023 Forecast." Purdue's report included projections through 2041, so the assumed growth rate by technology type from 2042-2072 was the average growth rate, by technology, from the 2023-2041 forecast.
Industrial Use	General industrial growth based on time trends and interviews with economic development departments in counties seeking to grow.
Public Supply	Increase in residential development forecast in Boone, Tippecanoe, and Howard Counties based on planned housing developments in these counties.
Irrigation	Time trends since 1985 indicate significant increases in irrigation withdrawals, particularly in areas with sandy soils (Kosciusko County, Marshall County, Fulton County). Based on these time trends and interviews with industry experts, irrigation withdrawals are forecasted to continue increasing.

3.3.3 CLIMATE CHANGE ASSUMPTIONS

The potential effects of future climate change on air temperature, precipitation, and streamflow were estimated using data developed for the INCCIA by Cherkauer et al. (2021). The INCCIA was an assessment by scientists and decision makers across Indiana that quantified and described how a changing climate affects state and local interests. To analyze future climate change, the study (Cherkauer et al., 2021) relied on statistically downscaled climate data (e.g., air temperature and precipitation) from six global climate models (GCM) that best represented climate processes over the midwestern United States (Byun and Hamlet, 2018; Byun et al., 2019). For each GCM, two emissions scenarios were analyzed: a medium emissions scenario (representative concentration pathway (RCP) 4.5) and a high emissions scenario (RCP 8.5). Downscaled climate data was used to drive simulations of surface hydrology using the Variable Infiltration Capacity (VIC) large-scale hydrology model. This model was calibrated to local Indiana conditions and used to simulate hydrologic fluxes and storage based on historical and future climate data. Model outputs included future precipitation and air temperature and their effects on streamflow over a simulation period that spanned from 2011-2100.

Data from the INCCIA study was provided to the project team (Cherkauer, K. personal communication, 2024) for analysis. The data provided included historical and future simulated daily precipitation and air temperature at gridded locations throughout Indiana, and historical and future simulated daily streamflow at select USGS gage locations throughout Indiana. All variables were provided as a time series for four 30-year periods: historical (1984-2013), Period 1 (2011-2040), Period 2 (2041-2070), and Period 3 (2071-2100). To align with the 50-year assessment period for the North Central Indiana Regional Water Study, only Period 1 and Period 2 time series were analyzed.

All available GCMs and emissions scenarios were reviewed to assess their effects on air temperature, precipitation, and streamflow. Each GCM produced distinct results, ranging from 5% to 25% increases in annual precipitation and 3 to 8 degrees Celsius increases in annual average temperature by the 2080s for the RCP 8.5 emissions scenarios, with slightly less warming and precipitation increases for the RCP 4.5 emissions scenarios (Byun and Hamlet, 2018). The differences between the two emissions scenarios through Period 2 centered around the 2050s, however, were relatively minor, with greater differences across GCMs than across emissions scenarios. The GCM Community Earth System Model Community Atmosphere Model 5.0 (CESM1-CAM5) represented the central tendency, or the median of changes, in temperature and precipitation across all GCMs, so it was selected to represent future climate change conditions. To be consistent with other Indiana regional planning studies (Letsinger and Gustin, 2024) and to be conservative from a future water availability perspective, an RCP 8.5 emissions scenario was selected as the future Baseline climate scenario.

A summary of changes in average monthly precipitation, maximum air temperature, and streamflow due to future climate change as simulated by CESM1-CAM5 RCP 8.5 at select locations is shown in Figure 3-7, Figure 3-8, and Figure 3-9, respectively. Trends include the following:

- Maximum monthly air temperatures are predicted to increase in all months, with greater increases in the fall, winter, and summer than in the spring, and are predicted to increase more in Period 2 (2041 to 2070) than in Period 1 (to 2040) relative to historical conditions. The increases by future period are generally consistent across locations.
- Monthly average precipitation is predicted to increase, with large relative increases in the late winter, spring, and early summer. Counties in the southern portion of the Study Area (Boone County and Vigo County) are predicted to have drier relative fall seasons in the future than counties in the northern portion of the Study Area (Kosciusko County and Tippecanoe County), which are predicted to have relatively more precipitation in nearly all months.
- The combined effects of increases in temperature and precipitation result in similar changes to streamflow across gages throughout the river network and across different drainage areas. Winter and spring generally show more streamflow in the future relative to historical conditions, while late summer and fall generally show reduced streamflow of around 10% relative to historical conditions.

Future meteorological and streamflow data from Cherkauer et al. (2021) were used to support development of future water demand estimates and future natural streamflow, respectively. For demand estimates, a time series of future monthly average meteorological data from 2023-2072 was developed for each county and subbasin, based on the gridded data point closest to the county or subbasin center. These variables were used as an input for estimating future water demands, as described further in Section 4.1. To represent future streamflow, a sequence of annual historical natural streamflow time series was assembled, where a selected year from 2007-2022 was used to represent each year from 2023-2072. To represent the effects of climate change on future streamflow, average monthly future natural streamflow was scaled (i.e., increased or decreased) in each month by a climate factor based on the amount of change represented in the VIC model. Additional detail on future streamflow sequencing and change factor application is provided in Section 5.3.

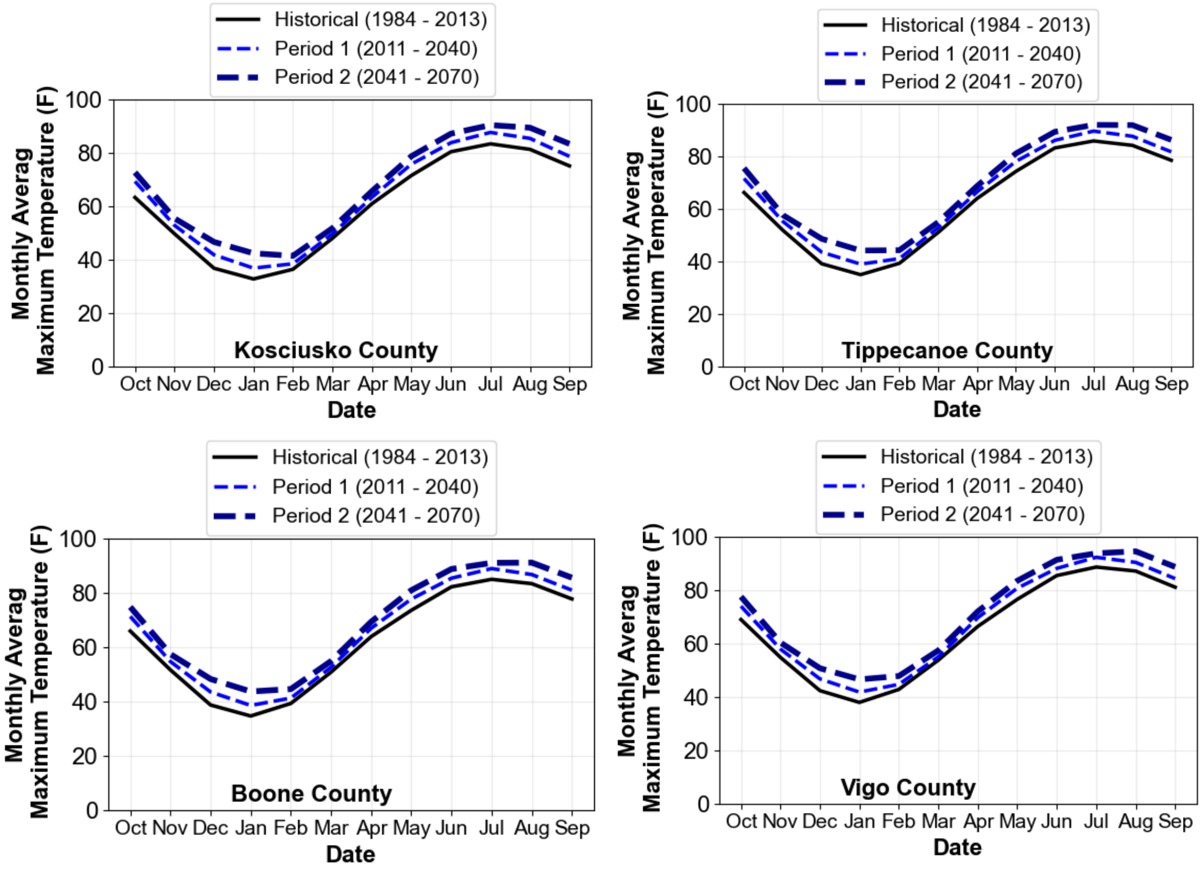


Figure 3-7. Simulated Maximum Average Monthly Temperature for Historical and Future Periods by County

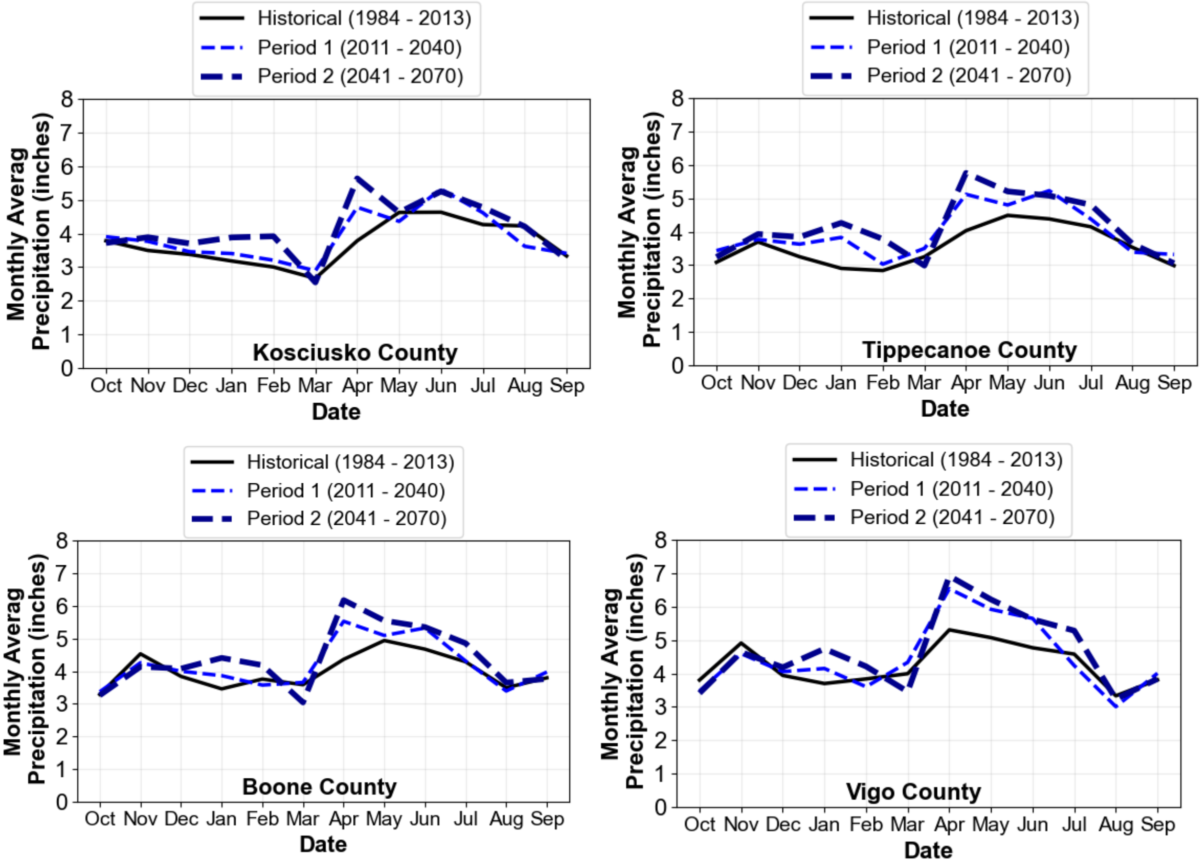


Figure 3-8. Simulated Total Average Monthly Precipitation for Historical and Future Periods by County

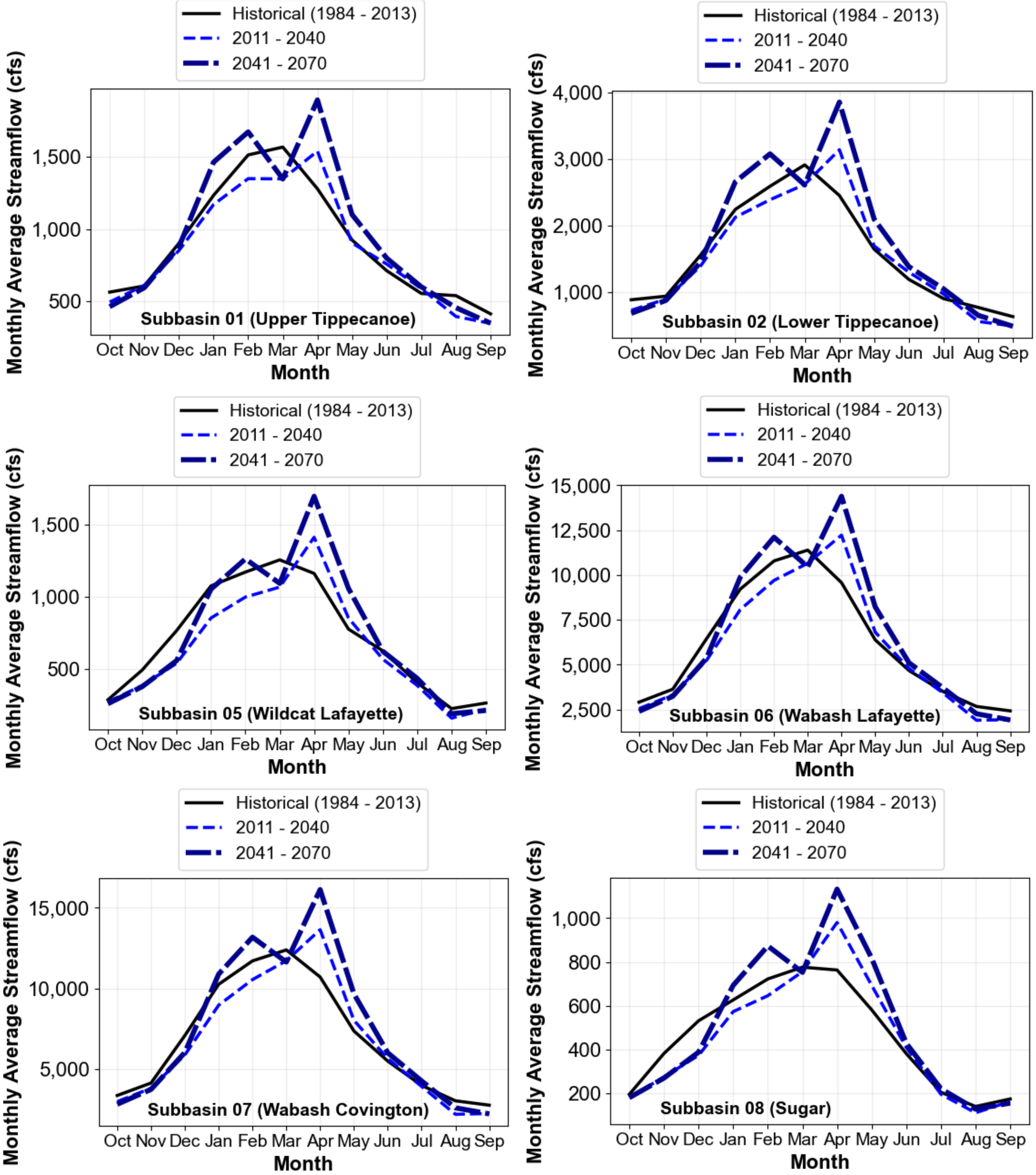


Figure 3-9. Simulated Monthly Average Streamflow for Historical and Future Periods by Subbasin Location

3.4 Simplifying Assumptions for Water Availability Estimates

The approach for quantifying water availability generally follows the steps outlined in previous regional water studies (e.g., INTERA, 2021a). The approach implements the following simplifying assumptions as a tradeoff to enable quantification of complex physical processes.

- **Stream depletions caused by groundwater withdrawals occur instantaneously.** Any change in aquifer storage related to groundwater withdrawals is neglected when calculating natural streamflow, and as a result, any groundwater withdrawal is assumed to instantaneously deplete streamflow at an equivalent magnitude. This is a reasonable approximation in this region, where most groundwater withdrawals occur within the outwash and alluvial connected aquifers located adjacent to major rivers. In actuality, groundwater withdrawals create pumping-induced flow (leakage) into adjacent aquifers that would deplete streamflow over time, and streamflow depletions would lag groundwater withdrawals in time. Because results of this Study are summarized on a seasonal basis over three months, and because over 90% of groundwater withdrawal volume is from unconfined aquifers (Section 2.3), this time lag is not considered significant.
- **Groundwater storage is neglected as a source of excess water availability**. Groundwater storage in aquifers changes in response to recharge and withdrawals through pumping. Most wells in the region are tapped into alluvial connected aquifers, while only 10% pump from deep aquifers that are recharged solely through deep percolation (Section 2.3). The water availability method assumes these deeper aquifers are not sources of water availability since their recharge dynamics and storage capacities are complex and not easily quantified or integrated into the water availability assessment. Any water available from deep aquifers should be quantified in a separate study that quantifies recharge, withdrawals, and sustainable yield. Water available from deep aquifers would be additive to the water availability quantified in this Study, which is from streamflow and floodplain-connected aquifers.
- **Variable runoff from storm flows is neglected as a source of excess water availability unless captured and released from existing reservoirs**. The water availability methodology uses natural baseflow as an estimate of total available groundwater supply, and all water availability metrics are calculated using natural baseflow or existing reservoir releases as the source of water supply. These metrics quantify the minimum continuous baseflow available for future water resources development. It is possible future water demands may be seasonal, not continuous, and flexible to withdraw in times of stormflow. These types of demands would require a more refined analysis than the one applied in this Study to quantify water availability.
- **The travel time, evaporation, and groundwater depletion of reservoir releases are neglected when calculating natural streamflow and water availability**. Within the Wabash River basin, the travel time from when a flood control reservoir in the Headwaters region releases flow until it is measured at a stream gage in Terre Haute can be on the order of several days. Conversely, the time from when upstream reservoirs start to store storm flows to when the storm flow peak is recorded downstream is on the order of several days. This travel time is neglected

when calculating natural streamflow; and as a result, days of calculated negative natural streamflow occur in the analysis during conditions when reservoir inflow occurs upstream before a peak flow has occurred downstream. Days with calculated negative natural streamflow were set to 0 in the analysis. Similarly, when historical reservoir releases are added back to natural baseflow to quantify water availability, the evaporative and recharge losses that occur between the reservoir outlet and any downstream point are not calculated. Reported water availability due to these assumptions may be slightly higher than if these losses were accounted for.

3.5 Presentation of Results

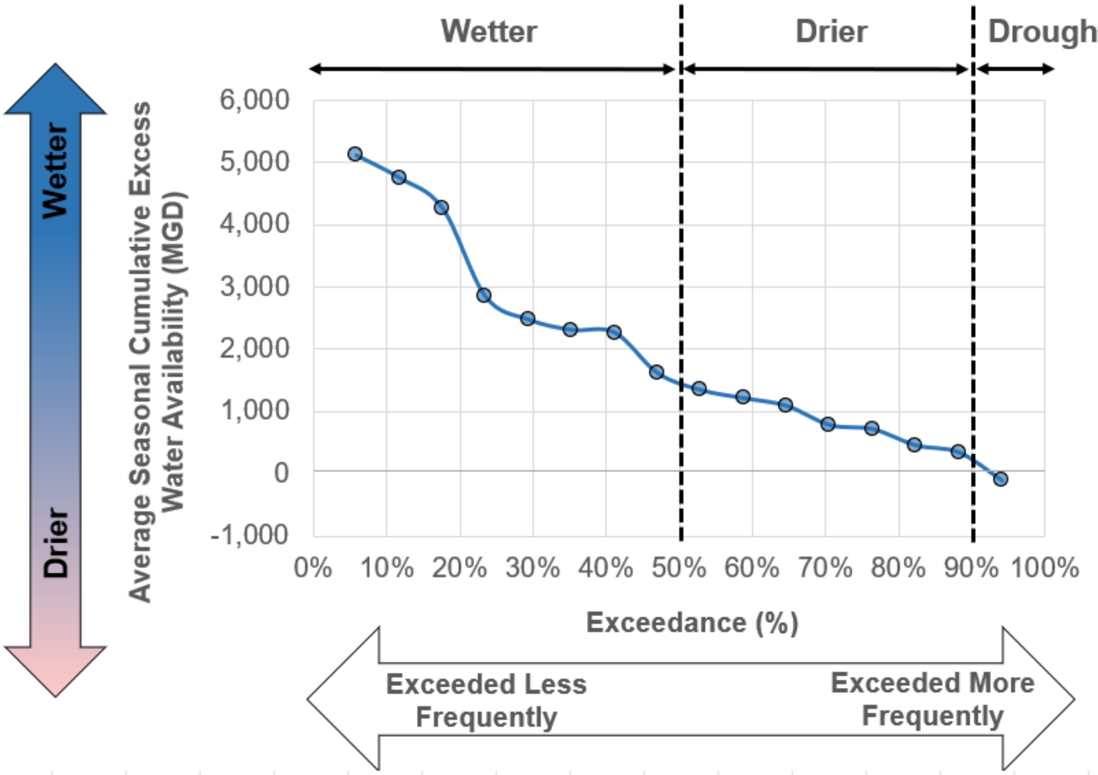
Study results are presented in a variety of ways to highlight the variability in water budget components across the subbasins, across time through multiple years, and throughout an individual year.

3.5.1 EXCEEDANCE CURVE

An exceedance curve is a graphical representation showing the probability that a particular value, such as cumulative excess water availability, will be equaled or exceeded during a defined period of time. In the field of hydrology, these curves are commonly used to quantify the frequency at which a given metric of water-related events are exceeded, such as river discharge or cumulative excess water availability above a threshold value. An annotated example of an exceedance curve is shown in Figure 3-10. The x-axis of the exceedance curve represents the exceedance probability as a percentage, while the y-axis shows the value of interest. Every marker on the plot aligns with an exceedance value on the x-axis and a value on the y-axis. For example, a value of 5,000 MGD at the 10% exceedance indicates that this amount of cumulative excess water availability is equaled or exceeded 10% of the time during the analysis period. This frequency of exceedance is low (or rare), indicating it is not often exceeded. This exceedance value is typically associated with wet periods or high flow events. In contrast, a value of -100 MGD at the 95% exceedance indicates the that this amount of cumulative excess water availability is equaled or exceeded 95% of the time during the analysis period. This frequency of exceedance is high (or common), indicating it is often exceeded, but may not be exceeded during very dry or drought conditions.

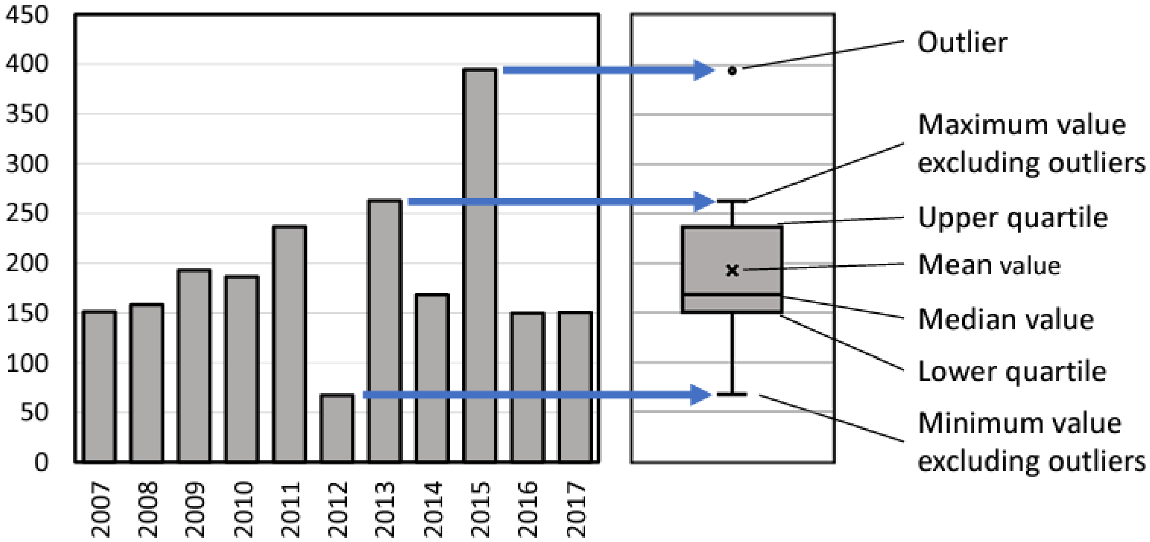
3.5.2 BOX AND WHISKER PLOT

A box and whisker plot (or box plot) is a graphical representation of the distribution of a data set using quartiles, mean values, median values, and outliers. An annotated example box and whisker plot is shown in Figure 3-11. The box is bounded by the lower quartile and upper quartile, with the median shown as a horizontal line between the two quartiles and the mean shown with an *X*. The top “whisker” extends vertically from the box and ends at the maximum value, excluding outliers (outliers are data that exceed 1.5 times the quartile range at either end of the box). The bottom whisker extends vertically from the bottom of the box and ends at the minimum value, excluding outliers. All outliers are shown as individual dots. A box and whisker plot shows the distribution of data for, as an example, the components of a water budget within a time series. They provide a concise overview of the value of the majority of data and are useful when comparing distributions between water budget components or other datasets.



Note: The x-axis of the exceedance curve represents the exceedance probability as a percentage, while the y-axis shows the value of interest. Every marker on the plot aligns with an exceedance value on the x-axis and a value on the y-axis.

Figure 3-10. Example Exceedance Curve

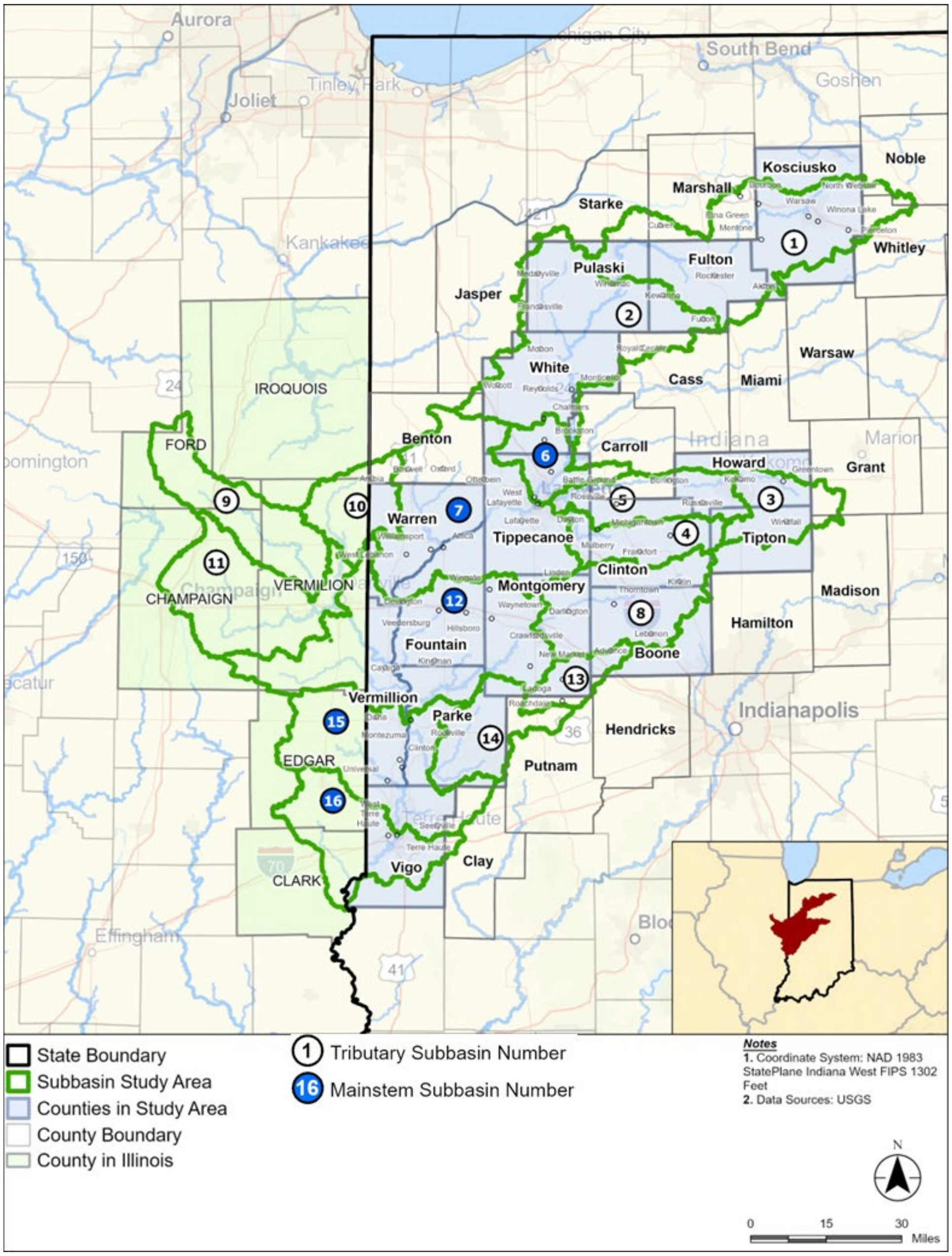


Note: The annual time series on the left is represented as a single box and whisker plot on the right, illustrating outliers, minimum and maximum values, and quartile values.

Figure 3-11. Example Box and Whisker Plot (from INTERA, 2021b)

4.0 Water Demand Estimates

The North Central Indiana Regional Water Study is focused on understanding water demand 50 years into the future in the 16 subbasins of the Study Area (Figure 4-1). While water utilities are a primary focus of the study, the analysis includes water use in all water use sectors to ensure an integrated understanding of water demand and availability in the region.



Notes
1. Coordinate System: NAD 1983 StatePlane Indiana West FIPS 1302 Feet
2. Data Sources: USGS

Figure 4-1. Study Area, Subbasin Boundaries, County Boundaries, Major Cities and Towns

4.1 Overview

In 2022, total water withdrawals in the North Central Indiana Study Area were 789 MGD. By comparison, water withdrawals reported in the Central Indiana Water-Supply Needs report (INTERA, 2020) were 384 MGD in 2018 or approximately 50% of the North Central Indiana Study Area. Additionally, water withdrawals in the Driftwood, Flatrock-Haw, and Upper East Fork White River (I-74 Corridor) Study Area (Letsinger and Gustin, 2024) were reported to be 74 MGD in 2020, slightly less than 10% of the North Central Indiana Study Area (Table 4-1).

Table 4-1. Comparison of Current Water Demand Across Three Indiana Regional Water Study Areas, by Water Use Sector (MGD)

Water Use Sector *and of total*	**Current (c)**			**Projected Future (2070)**		
	North Central Indiana	**Central Indiana (a) (c)**	**Driftwood, Flatrock-Haw & Upper East Fork White (b)**	**North Central Indiana**	**Central Indiana (a)**	**Driftwood, Flatrock-Haw & Upper East Fork White (b)**
Public Supply	71	199	44	78	250	68
% total	*9%*	*52%*	*59%*	*30%*	*50%*	*70%*
Agricultural (d)	43	12	15	70	19	17
% total	*5%*	*3%*	*21%*	*27%*	*4%*	*18%*
Industrial	36	83	8	65	95	7
% total	*5%*	*22%*	*11%*	*25%*	*19%*	*7%*
Energy Production	627	58	0	35	87	0
% total	*79%*	*15%*	*0%*	*13%*	*18%*	*0%*
Domestic (e)	12	32	7	12	45	5
% total	*2%*	*8%*	*9%*	*5%*	*9%*	*5%*
Total	**789**	**384**	**74**	**260**	**496**	**97**

Sources: (a) INTERA, 2020, (b) Letsinger and Gustin, 2024.

Notes: (c) the Central Indiana Study did not report 2022 water demand as the report was completed in 2020, therefore 2018 was the most current water demand available. (d) For comparison purposes, water demand of the North Central Indiana water use sectors CAFO and CFO and Irrigation were added together and reported in the Agricultural sector; and (e) the water use sectors Self-Supplied, Rural and Miscellaneous were added together and reported in the Domestic Water Use Sector.

Where public supply (PS) water withdrawals were the dominant water use sector in the Central Indiana and I-74 Corridor study areas, energy production (EP) dominates current water withdrawals in the North Central Indiana Study Area. The EP withdrawals were driven by a coal energy plant, where the water is withdrawn for cooling.

In the late 2020s, it is assumed that the coal energy plant in the North Central Indiana Study Area will transition to natural gas. The 2070 Study Area-wide projected water demand is 260 MGD, down from 2020’s level of 789 MGD. Overall, by 2070 the North Central Indiana Study Area projected demand is similarly distributed between PS (30% of total), irrigation (IR) (27% of total), and industrial (IN) (25% of total) water use sectors. This is in comparison to Central Indiana and the I-74 Corridor study areas, which are both dominated by PS use. Reflecting the demographics of the respective study areas, in the Central

Indiana Study Area IN water use is the second largest demand sector whereas in the I-74 Corridor study IR is the second largest demand sector.

A closer look at water withdrawals in the North Central Indiana Study Area shows the regional difference in water use sector types and withdrawals (Figure 4-2). The 2022 EP withdrawals were driven by the coal energy plant, occurred in Wabash Montezuma (Subbasin 12 in Vermillion County) where withdrawals were 627 MGD (79% of total). The withdrawals in Subbasin 12 were significantly more than other subbasins, which withdrew between 0.79 MGD (subbasin 14, Lower Big Racoon) and just over 30 MGD (subbasin 1, Upper Tippecanoe) (Figure 4-2).

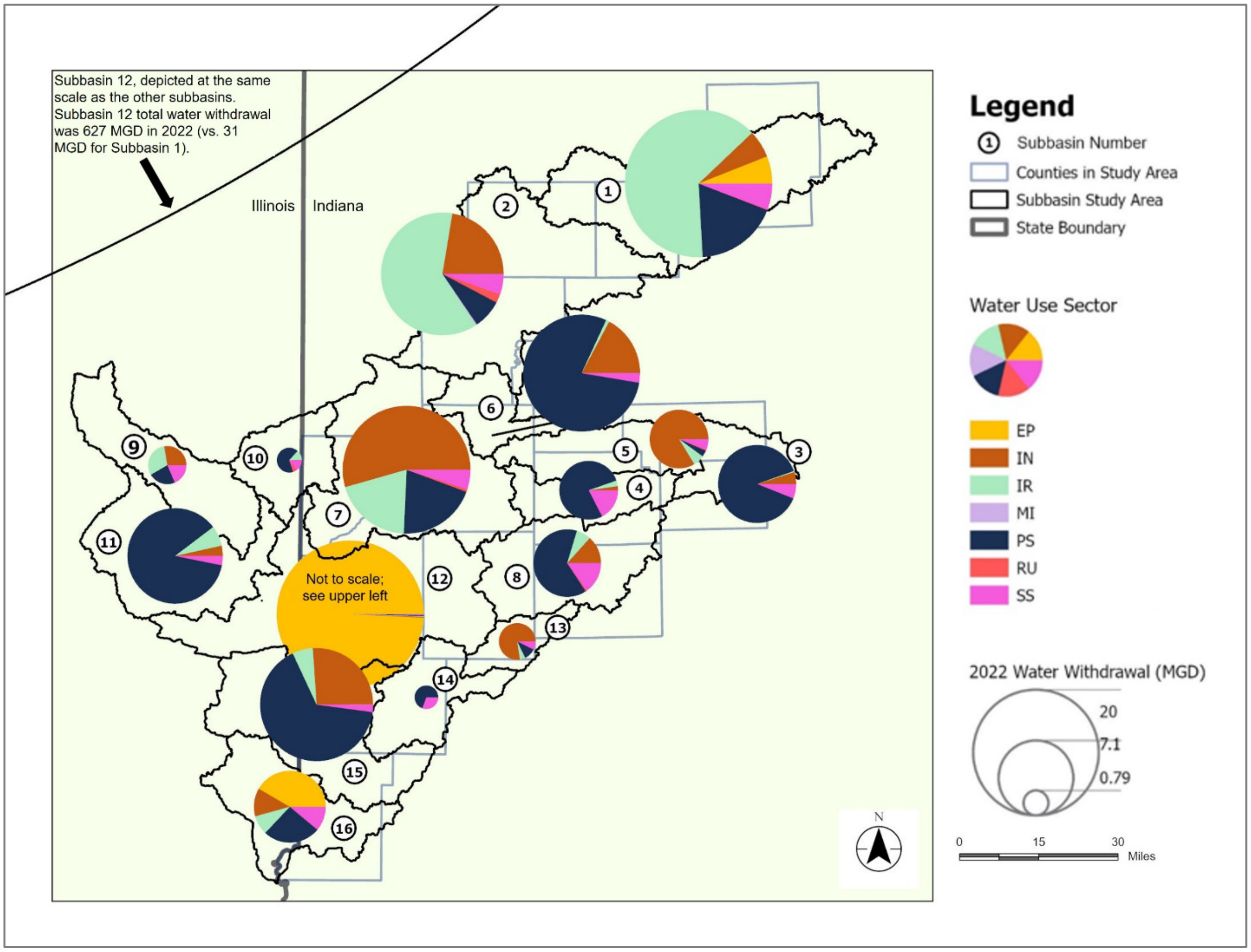


Figure 4-2. Water Withdrawals by Subbasin and Water Use Sector, 2022

Excluding water withdrawals for EP, public supply (PS) was the largest single water sector, concentrated in the relatively more populated regions in Wildcat Kokomo (Subbasin 03), South Fork Wildcat (Subbasin 04 in Clinton County), Wabash Layfette (Subbasin 06), Sugar (Subbasin 08 in Boone County), and Wabash Terra Haute (Subbasin 15). Irrigation (IR) withdrawals constituted the third largest water use sector in the Study Area, concentrated primarily in the agricultural and rural Upper Tippecanoe (Subbasin 01) and Lower Tippecanoe (Subbasin 02 in Kosciusko, Fulton, Pulaski, and White counties) and totaling

42 MGD Study Area-wide. Industrial (IN) water use, concentrated in Wabash Covington (Subbasin 07 in Tippecanoe and Warren counties) withdrew a total of 27 MGD.

By 2070 the total Study Area water withdrawals are projected to decline to 260 MGD, down from 789 MGD in 2022. The PS water use sector still comprises the largest single water use sector, projected to withdraw a total of 78 MGD (representing 30% of total), and the primary use is still roughly in the same geographic regions as in 2022 (Figure 4-3). Total Study Area IR withdrawals are projected to increase from 42 MGD in 2022 to 70 MGD (representing 27% of total) in 2070, as growers continue to invest in irrigation equipment, a trend observed since data collection began in the mid-1980s. Total IN withdrawals are projected to increase from 37 MGD in 2022 to 66 MGD (representing 25% of total) by 2070, driven in part by expansion and/or development in the pharmaceutical industry, manufacturing (including electric vehicle battery plants and supporting industries), food processing, and agribusiness.

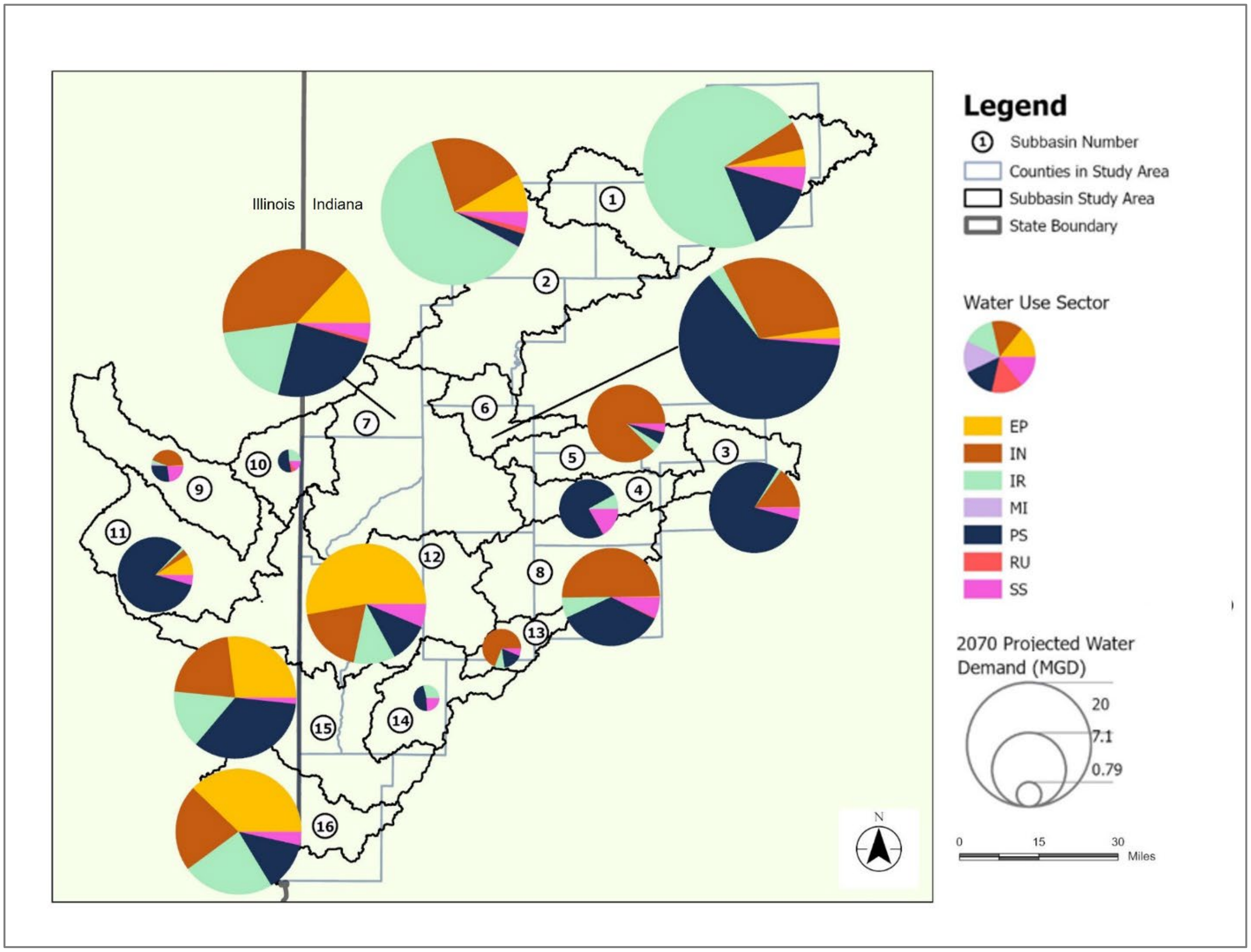


Figure 4-3. Projected Water Demand by Subbasin and Water Use Sector, 2070

4.2 Baseline Water Demand Projection Approach

This section of the study describes the Baseline future water demand projections in more detail. Future development plans, and subsequent water demand, can contain a degree of speculation. To minimize any speculation, the Baseline future water demand projection includes industrial and public water supply development that has been publicly announced with estimated dates for opening and/or expanding facilities. Future projections also incorporate historical trends, estimated future demographics (e.g., population and income), and estimated future climate factors. Utilizing the Baseline approach to future water demand projections provides decision makers the ability to include other, potentially more speculative, regional development plans in future planning efforts. See Appendix I for assumptions regarding other scenarios separate from the Baseline scenario.

Water demand projecting provides the basis for making operational, tactical, and strategic decisions for water utilities and water resource planning agencies (Gardiner and Herrington, 1990; Billings and Jones, 2008). Projections for operational and tactical decisions are aimed at short-term demand estimation, like peak day and peak hour demand. These decisions affect how resource managers operate treatment plants and wells to meet short-term demand. Projections for strategic decisions are aimed at predicting water demand years in the future to develop new water sources and/or expand existing treatment capacity (Donkor et.al., 2014). The methods used to project demand are selected based on the type of decision to be informed and the future projection horizon. Note that throughout this document the terms water demand and water withdrawals are used interchangeably.

Determining the planning horizon, the projection periodicity (e.g., annual, monthly, peak day, peak hour) and the water use sector informs which projection method is appropriate to utilize for water demand projections. Variables that are considered influential in determining long-term future water demand projections can include socio-economic variables as well as various types of weather-related variables. However, not all water use types will be influenced by the same variables.

In general, for long-term water demand, the literature suggests that appropriate drivers of demand include the following (Wang et.al., 2009; Wu and Zhou, 2010):

- Historical demand
- Time
- Population
- Measures of wealth, such as gross domestic product or median household income
- Weather variables such as temperature, precipitation, and evapotranspiration

The long-term water demand projection for this Study estimates monthly demand over a 50-year period, from 2023 to 2072, for 16 subbasins that encompass the Study Area (see Figure 4-1). In addition to the temporal and geographic scale, the Study estimates demand for the following eight water use sectors:

- Public Supply (PS), representing water served to cities and towns from a public or private water utility and schools, or other public entities, that have their own water wells to meet their individual institutional demand
- Irrigation (IR), representing water used in the production of crops
- Industrial (IN), representing dedicated, industry-owned wells and surface water intakes, used for industrial production. Note that this water demand does not account for industries historically served by public water suppliers
- Energy Production (EP), representing water used in the production of energy
- Self-supplied (SS), representing individual residential well owners supplied by on-site wells for domestic use
- Confined Feeding Operations (CFO) and CAFOs, representing large scale livestock facilities
- Rural (RU), representing a variety of rural users, but not rural residential users. Examples include Purdue University Physical Facilities, and several agricultural limited liability corporations. Note it appears that some very large CAFOs' water withdrawals may be reported in this category in the SWWF database
- Miscellaneous (MI), representing a variety of uses including fire departments, country clubs, amusement parks

The eight water use sectors, the source of the historical water demand, and the determinants of water demand (historical and projected future) are listed in Table 4-2. Although historical use played an important role in determining future water demand, history alone does not accurately project potential future use, particularly for water use sectors that are impacted by economic development decisions and industries undergoing changes in operational practices.

For example, average annual historical IR demand increased from 1985 to 2022, on average by approximately 3% per year.[6] Understanding whether this observed time trend of increasing average annual irrigation withdrawals would continue in the future requires more than an understanding of the past. Therefore, experts in the field were also consulted to inform the future projections. For agriculture this information was obtained by interviewing experts from the Indiana Farm Bureau, economic development directors, and Agricultural Extension specialists at Purdue University. The consensus from the experts was that average annual irrigation will continue to trend upwards as growers are able to invest in irrigation equipment in response to continued and future drought years and to maintain or improve crop yield. Additionally, actual future annual demands may spike in periods of drought, the timing of which are not possible to predict. Therefore, the region could experience spikes in future annual demand of IR water, rather than the steady rate of increase predicted in this analysis.

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[6] Irrigation water withdrawals were also observed to increase in drought years (2012, 2020, and 2022) as would be expected.

Economic development directors and utility managers also provided insights into future plans for IN and PS water use sectors. Therefore, the determinants of future water withdrawal by water use sector, listed in Table 4-2, include information gleaned from area experts. For detailed descriptions of the methods and determinants used to estimate future water demand for each water use sector, with detail of per-county estimates, see Appendix D.

Table 4-2. Water Demand Projection Method, Demand Driver Category, By Water Use Sector

Water Use Sector	Historical Use (a)	Projection Method	Demand Driver Category		
			Trend Variable	Seasonality	Climate Change
PS	SWWF	Regression and Time Trends	Year and information obtained from interviews with County economic development directors and utility directors[2] MHI, Population	Monthly	Evapo-transpiration
IR	SWWF	Regression	Historical annual water withdrawals and interviews with regional experts at the Indiana Farm Bureau, Purdue Agricultural Extension and economic development directors[2]	Monthly	Evapo-transpiration
IN	SWWF	Modified time trend	Based on time trends and interviews with county economic development directors and utility managers[2]	NA	NA
EP	SWWF[1]	Modeled imbedded water demand by energy type	Long-term future energy demand obtained from Purdue University's "Indiana Electricity Projections: The 2023 Forecast." (Purdue, 2023). Short term estimates of energy production by use type obtained from interviews with Duke Energy[2]	NA	NA
SS	Modeled using per capita water demand and rural household address database		Future population	NA	NA
CAFOs & CFOs[3]	Modeled animal water requirement by animal type, extended to number and density of current and estimated future of CAFOs		Historical time trend	Historical	NA
RU	SWWF	Time trend	Year	NA	NA
MI	SWWF	Time trend	Year	NA	NA

Notes: 1) Indiana SWWF database used for all counties located within Indiana. Historical water withdrawals for Illinois were obtained from the Illinois State Water Inventory Program (ISWS). 2) For information obtained during various interviews see Section 3.5, Participants, Stakeholder Input. 3) The terms CFO and CAFO relate to the size of the Combined Feeding Operation. All farms with at least 300 cattle, 600 swine or sheep, 30,000 poultry, or 500 horses in confinement are CFOs. A CAFO designation is strictly a size designation in Indiana, where CAFOs confine a larger number of animals than CFOs (IDEM, 2022b).

Key:
CAFO = Concentrated Animal Feeding Operation
CFO = Confined Feeding Operation
EP = energy production
IN = industrial
IR = irrigation
MHI = median household income
MI = miscellaneous
NA = not applicable
PS = public supply
RU = rural use
SS = self-supplied residential
SWWF = Significant Water Withdrawal Facility

4.3 Water Demand by Subbasin

The geographic units for the water demand projections, by necessity, must be at a subbasin scale to align with the hydrologically based water availability methodology being used here (see Figure 4-1). However, much of the data that determines water demand is collected and reported by political boundaries (e.g., population, median household income, temperature, and precipitation). Unfortunately, political boundaries, e.g., cities, counties, and states and even water service territories, do not always align with hydrologic subbasin boundaries. Additionally, most of the activity that drives future water demand is managed at the county or city level (e.g., local economic development agencies, industries, water utilities). Therefore, the future water demand was initially projected at the county level (by water use sector) and then disaggregated and/or aggregated into subbasins (Table 4-3). Furthermore, the counties that were all or nearly all located within the Study Area are referred to in this analysis as Study Area Counties. There were a few other counties that were partially located within the subbasins and reported withdrawals within Study Area subbasins, however at far lower volumes than withdrawals in the Study Area Counites. These counites, with minimum withdrawals within the subbasins, are referred to as Supplemental Counites in this analysis. See Appendix D for a detailed description of the development of the county-level future water use projections.

What follows is a discussion of the water demand projections for the entire North Central Indiana Study Area, summarized over all subbasins. For a detailed description of historical and the projected future water demands summarized for each individual subbasin, see Appendix E.

Table 4-3. Study Area Subbasins, Waterways and County/State (a)

Sub-basin ID	Subbasin Name	Waterway	County (all or part)	
			Study Area	Supplemental
01	Upper Tippecanoe	Tippecanoe River	Kosciusko, Fulton, Pulaski	Noble, Whitley, Marshall, Starke
02	Lower Tippecanoe	Tippecanoe River	Fulton, Pulaski, White	Benton, Cass, Carroll, Fulton, Jasper, Starke
03	Wildcat Kokomo	Wildcat Creek	Howard, Tipton	Grant
04	South Fork Wildcat	South Fork Wildcat Creek	Clinton, Tippecanoe, Tipton	None
05	Wildcat Lafayette	Wildcat Creek	Tipton, Howard, Tippecanoe	Carroll
06	Wabash Lafayette	Wabash River (Lafayette)	Tippecanoe, White	Carroll
07	Wabash Covington	Wabash River (Covington)	Tippecanoe, Tipton, Montgomery, Warren, Fountain, White	Benton
08	Sugar	Sugar Creek	Boone, Clinton, Tipton, Tippecanoe, Montgomery	None
09	Middle Vermilion	Middle Fork Vermilion River	None	Illinois (a)
10	North Vermilion	North Fork Vermilion River	Warren	Benton, Illinois (a)
11	Vermilion	Vermilion River	None	Illinois (a)
12	Wabash Montezuma	Wabash River (Montezuma)	Fountain, Montgomery, Parke, Vermillion, Warren	Illinois (a)
13	Upper Big Raccoon	Big Raccoon Creek	Boone, Montgomery, Putnam	Clay, Putnam
14	Lower Big Raccoon	Big Raccoon Creek	Montgomery, Parke	Putnam
15	Wabash Terre Haute	Wabash River (Terre Haute)	Parke, Vermillion, Vigo	Illinois (a),
16	Wabash Vigo	Wabash River (Vigo)	Vigo	Clay, Illinois (a),

Notes: (a) The future demand for Illinois was not organized by county. Rather the Illinois counites of Champaign, Clark, Edgar, Ford, Iroquois, Livingston, and Vermilion are reported as “Illinois.”

Historical water demand in the Study Area has been dominated by EP water use in Wabash Montezuma (Subbasin 12, specifically Vermillion County) and Wabash Terre Haute, (Subbasin 15, specifically Vigo County) (Figure 4-4). In 2018, one coal energy plant, located in Subbasin 15 (shaded light pink in Figure 4-4), went offline; another coal energy plant, located in Subbasin 12 (shaded light blue in Figure 4-4), is scheduled to go offline in 2028. At the peak of energy water demand for those two coal plants in 2006, the water withdrawals driven by EP demand in Subbasin 12 and Subbasin 15 drove the total water withdrawals for the Study Area to just over 1,400 MGD.

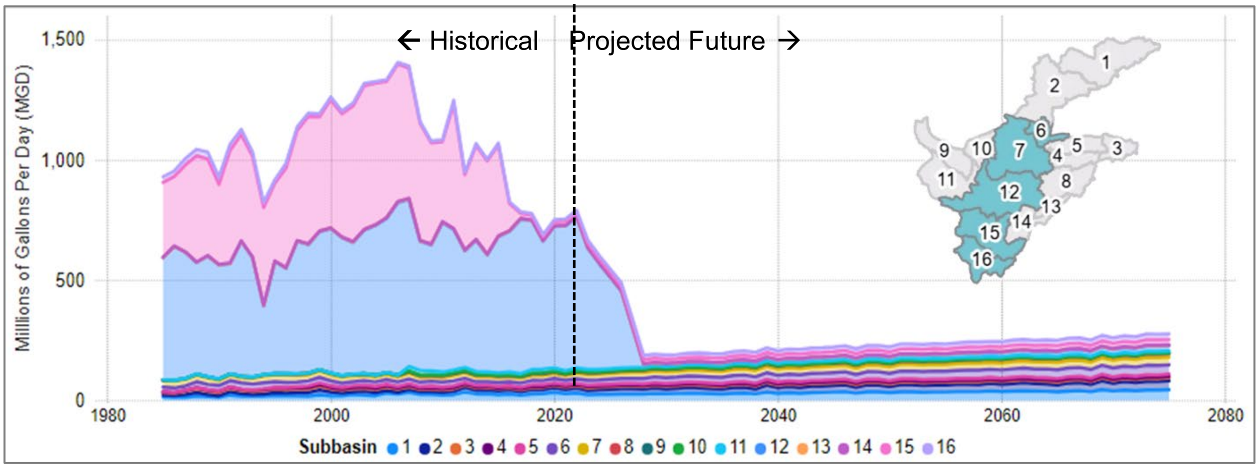


Figure 4-4. Historical (1985 to 2022) and Projected Future (2023 to 2072) Annual Water Demand in the North Central Indiana Study Area, by Subbasin

The same volume of water withdrawal data as shown in Figure 4-4 is replicated in Figure 4-5, displayed by water use sector instead of subbasin. Energy production (shaded gold in Figure 4-5) water withdrawals comprise the majority of water withdrawals in the Study Area (Figure 4-5).

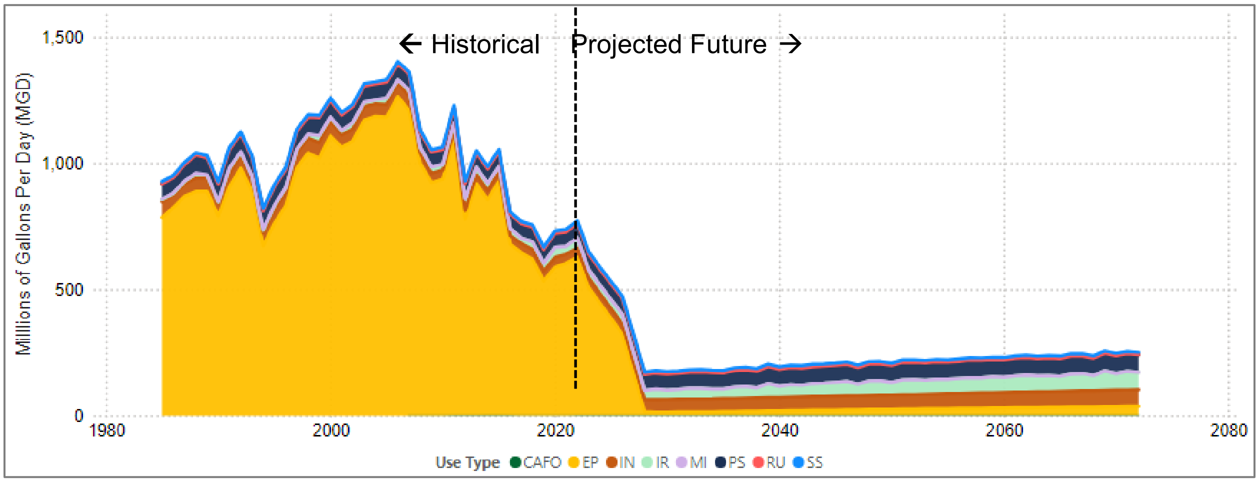


Figure 4-5. Historical (1985 to 2022) and Projected Future (2023 to 2072) Annual Water Demand in the North Central Indiana Study Area, by Water Use Sector

Going forward, the details of the projected future water demand are easier to understand by excluding the historical EP water withdrawals from Figure 4-4 and Figure 4-5. Figure 4-6 presents the same information as Figure 4-4, but excludes EP withdrawals. In general, water withdrawals have increased between 1985 and 2022. Note that not all subbasins cover the same geographic area (e.g., are the same size), serve a similar population base, or support the same industries and economic sectors.

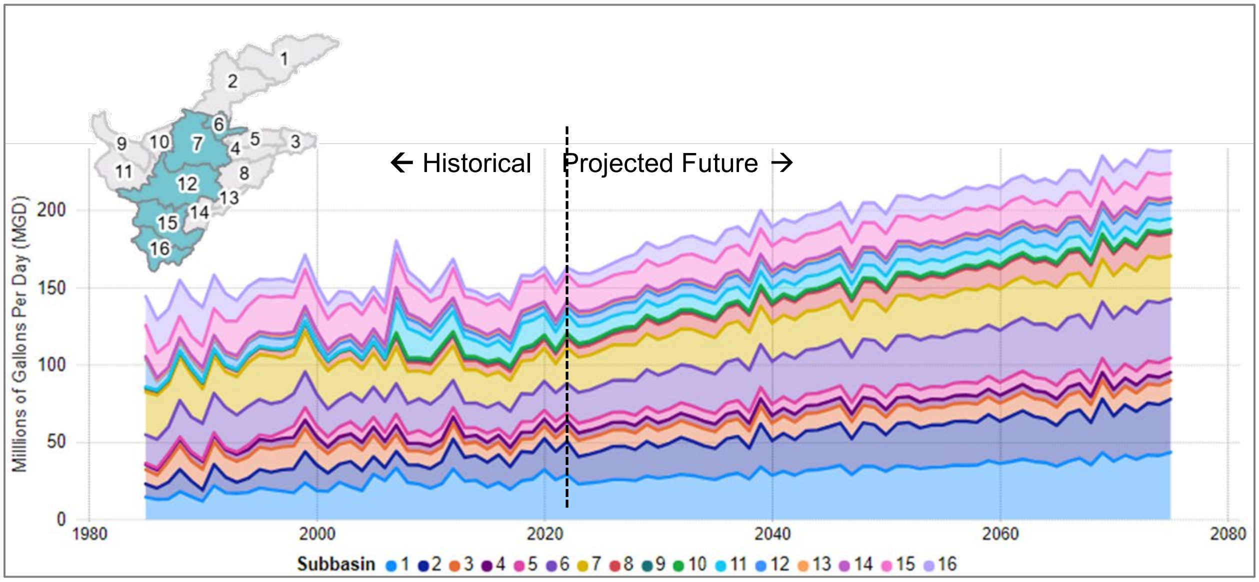


Figure 4-6. Historical (1985 to 2022) and Projected Future (2023 to 2072) Annual Water Demand in the North Central Indiana Study Area, by Subbasin, Excluding Water Demand for Energy Production

In the future, water use for energy production is projected to continue, but not projected to be the largest water use sector in the Study Area. The three largest water use sectors in the future within all subbasins are projected to be IN, IR, and PS (Figure 4-7). In general, future projections for both IN and IR water demand sectors are estimated to increase over time. Public supply water demand is projected to increase, but slightly less than IN and IR water demands, due in part to declining population forecasts in some of the subbasins. For a detailed explanation of the methods and results of future projections by water use sectors, as well as the tabular data used to develop Figure 4-5 and Figure 4-7, see Appendix D.

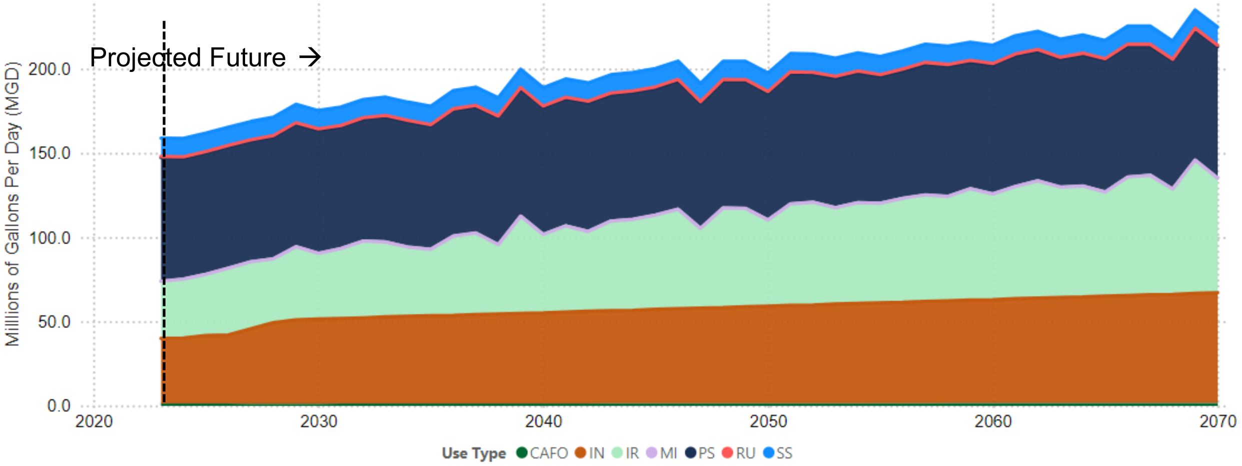


Figure 4-7. Future Projected (2023 to 2070) Annual Water Demand by Water Use Sector in North Central Indiana Study Area, All Subbasins, Excluding Water Demand for Energy Production

Figure 4-8 and Figure 4-9 are another form of graphical representation to show how water use changes in both place of use and sector of use over time. Figure 4-8 shows historical water use in 2022 where:

- Total Study Area water use is 789 MGD
- Top four water use sectors ranked by withdrawal volume:
  - EP (627 MGD, or 80% of total)
  - PS (71 MGD, or 8% of total)
  - IR (42 MGD, or 5% of total)
  - IN (37 MGD, or 5% of total)
- Top four subbasins ranked by withdrawal volume:
  - Wabash Montezuma (Subbasin 12) – 698 MGD, or 88% of total
  - Upper Tippecanoe (Subbasin 01) – 31 MGD, or 4% of total
  - Wabash Covington (Subbasin 07) – 23 MGD, or 3% of total
  - Lower Tippecanoe (Subbasin 02) – 21 MGD or 3% of total

Figure 4-9 shows how water use is projected to change by 2070:

- Total Study Area water use is projected to be 260 MGD, down from 789 MGD
- Top four water use sectors ranked by withdrawal volume:
  - PS (78 MGD, or 30% of total) up from 71 MGD in 2022
  - IR (70 MGD, or 27% of total) up from 42 MGD in 2022
  - IN (62 MGD or, 24% of total), up from 37 MGD in 2022
  - EP (35 MGD, or, 14% of total down from 627 MGD in 2022
- Top four subbasins ranked by withdrawal volume:
  - Upper Tippecanoe (Subbasin 01) – 31 MGD, or 16% of total
  - Wabash Layfette (Subbasin 06) – 39 MGD, or 15% of total
  - Lower Tippecanoe (Subbasin 02) – 32 MGD, or 13% of total
  - Wabash Covington (Subbasin 07) – 32 MGD, or 13% of total

In summary, Figures 4-8 and 4-9 show the following changes in water use sector over the 50-year planning horizon:

- EP (using coal) was the largest water use sector in 2022 in Wabash Montezuma (Subbasin 12) and Wabash Vigo (Subbasin 16).
- PS, IR and IN water withdraws are all projected to increase over the study period, with IN and IR having the largest% increases, however all three water use sectors represent a similar% of total demand in the Study Area (between 24% (IR) and 30% (PS)). The top four subbasins are also using nearly the same percentage of water in the Study Area, between 13% (Lower Tippecanoe Subbasin 02 and Wabash Covington Subbasin 07) and 16% (Upper Tippecanoe Subbasin 01).

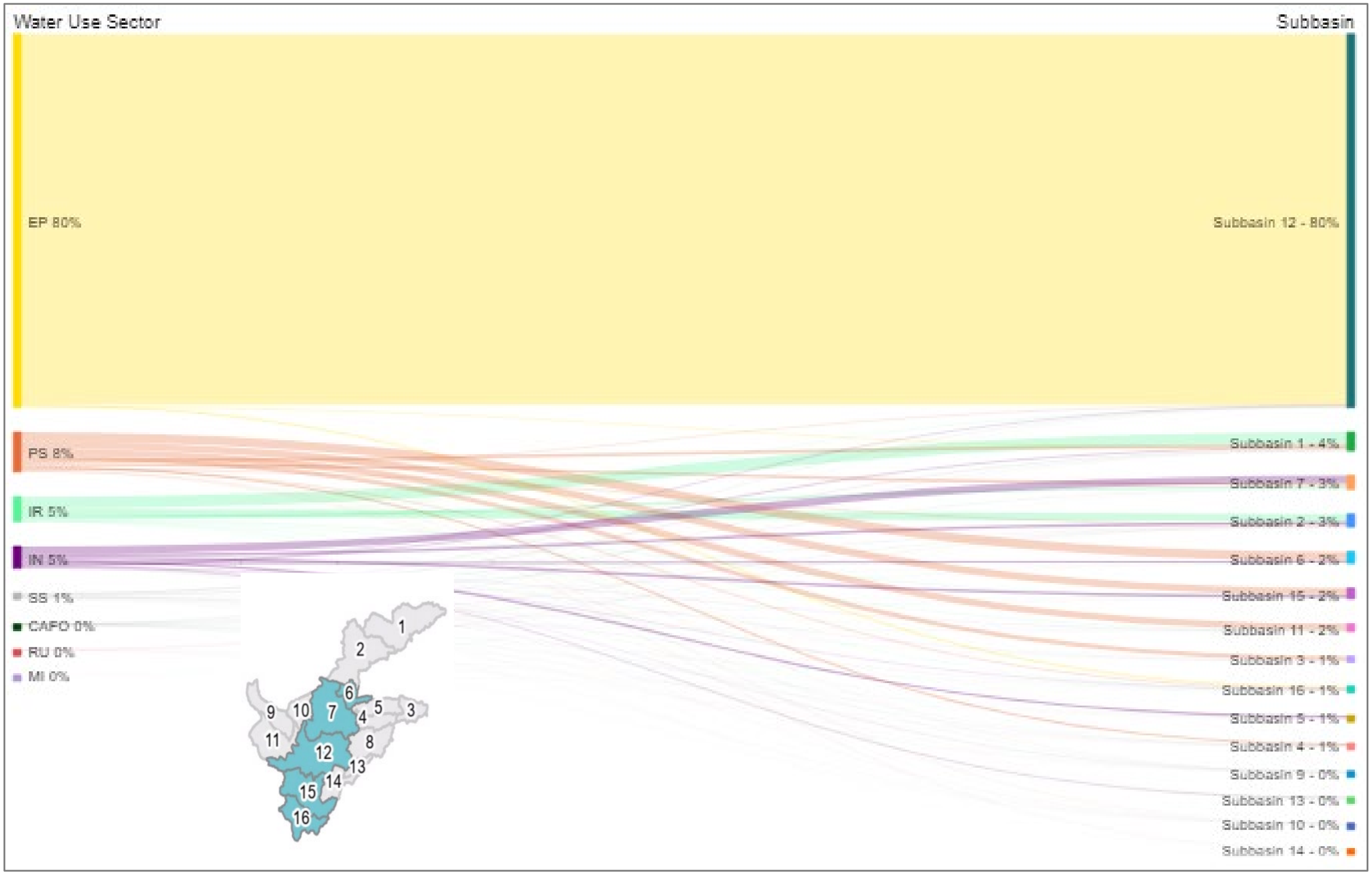


Figure 4-8. Water Withdrawals by Use Sector and Subbasin, as 2022 Percent of Total

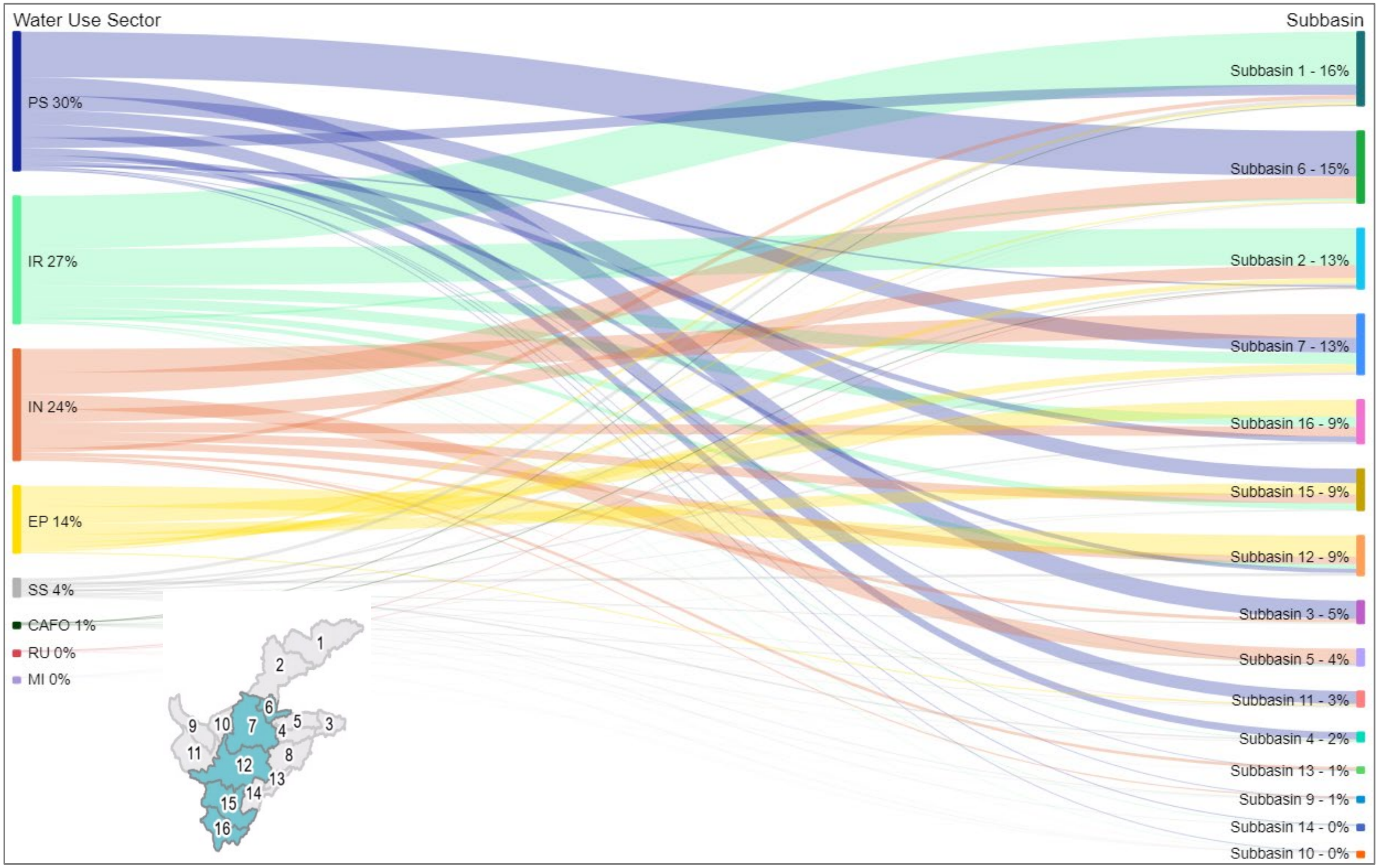


Figure 4-9. Water Withdrawals by Use Sector and Subbasin, 2070, as Percent of Total

Tabular data summarizing the information presented in Figures 4-4 through 4-9 is presented in Table 4-4, providing the average annual withdrawals and future projected water demand for 10-year periods from 1985 to 2070. Note that the initial period (1985 to 1992) is averaged over eight years. Additionally, Table 4-4 shows the average annual change in water withdrawals for each period.

Collectively, Upper Tippecanoe (Subbasin 01) and Lower Tippecanoe (Subbasin 02) have historically withdrawn approximately 25 MGD (1985 to 1992) and are estimated to continue to withdrawal an annual average of 25 MGD to 79 MGD (2063 to 2072). The dominant water use sector in these two subbasins is IR and IN (primarily mining, printing, and food processing). Average annual historical growth in water withdrawals in these two subbasins has been up to 3%. Future increases in water withdrawals are estimated to continue at a constant 1% per year, and irrigation and industrial demands are projected to increase.

Wabash Lafayette (Subbasin 06) and Wabash Covington (Subbasin 07) have historically withdrawn an annual average of approximately 40 MGD, which is projected to increase to a combined annual average of 68 MGD during the 2063 to 2072 timeframe. The dominant historical water use sectors are PS (serving the cities of Lafayette, West Lafayette, Linden, Attica, and Purdue University) and IN (manufacturing, agri-processing, and mining). Historically there was a slight annual average decline in water use due to the economic downturn during the period that includes the 2007 to 2009 recession. Industrial growth in the Lafayette/West Lafayette area is projected to expand. Population growth will also likely be spurred by growth in industry.

Wabash Terre Haute (Subbasin 15) and Wabash Vigo (Subbasin 16) had an annual average withdrawal of 36 MGD during the 1985 to 1992 period, falling to 22 MGD during the 2013 to 2022 period. The decline in water use was primarily seen in the IN (primarily mining, manufacturing, and agribusiness) and public supply water use sectors, due to declining population.

See Appendix D for a detailed description of the methods used to estimate each of the water use sectors by county. See Appendix E for a detailed description of individual subbasin projections, including tabular data detailing historical and future water availability within subbasins in the Study Area by year and month in five-year increments.

Table 4-4. Ten Year Average Annual Water Demand by Subbasin, Historical (1985 to 2022) and Projected Future (2023 to 2075), MGD, and Average Annual Change, Excluding Coal-Based Energy Production

Subbasin	Historical Use (MGD) (a)				Projected Future				
	1985 to 1992 (a)	1993 to 2002	2003 to 2012 (b)	2013 to 2022	2023 to 2032	2033 to 2042	2043 to 2052	2053 to 2062	2063 to 2075
Subbasin 1, Upper Tippecanoe	15.5	19.3	24.9	25.2	26.6	29.6	34.1	36.8	39.5
Avg Annual Percent Change	*NA*	*3%*	*3%*	*0%*	*1%*	*1%*	*1%*	*1%*	*1%*
Subbasin 2, Lower Tippecanoe	10.3	12.9	13.0	17.6	20.3	22.1	25.9	28.4	30.5
Avg Annual Percent Change	*NA*	*3%*	*0%*	*3%*	*1%*	*1%*	*2%*	*1%*	*1%*
Subbasin 3, Wildcat Kokomo	12.6	14.0	11.1	8.4	10.7	11.1	11.3	11.6	11.9
Avg Annual Percent Change	*NA*	*1%*	*-2%*	*-3%*	*2%*	*0%*	*0%*	*0%*	*0%*
Subbasin 4, South Fork Wildcat	4.2	5.0	5.0	4.5	4.9	5.0	5.1	5.1	5.2
Avg Annual Percent Change	*NA*	*2%*	*0%*	*-1%*	*1%*	*0%*	*0%*	*0%*	*0%*
Subbasin 5, Wildcat Lafayette	1.2	4.9	6.9	5.8	6.5	7.1	7.7	8.3	8.9
Avg Annual Percent Change	*NA*	*20%*	*3%*	*-2%*	*1%*	*1%*	*1%*	*1%*	*1%*
Subbasin 6, Wabash Lafayette	21.9	21.3	19.7	17.5	22.2	27.2	30.4	33.8	36.9
Avg Annual Percent Change	*NA*	*0%*	*-1%*	*-1%*	*2%*	*2%*	*1%*	*1%*	*1%*
Subbasin 7, Wabash Covington	26.1	26.6	21.4	21.0	24.3	26.1	27.8	29.6	31.3
Avg Annual Percent Change	*NA*	*0%*	*-2%*	*0%*	*1%*	*1%*	*1%*	*1%*	*1%*
Subbasin 8, Sugar	3.1	5.1	6.2	6.0	8.3	10.9	11.9	13.0	13.9
Avg Annual Percent Change	*NA*	*7%*	*2%*	*0%*	*3%*	*3%*	*1%*	*1%*	*1%*
Subbasin 9, Middle Vermilion	NA	NA	1.1	1.9	1.7	1.6	1.6	1.6	1.5
Avg Annual Percent Change	*NA*	*0%*	*11%*	*6%*	*-1%*	*0%*	*0%*	*0%*	*0%*
Subbasin 10, North Vermilion	0.2	0.2	0.8	1.0	0.8	0.8	0.8	0.8	0.8
Avg Annual Percent Change	*NA*	*0%*	*18%*	*3%*	*-3%*	*0%*	*0%*	*0%*	*0%*
Subbasin 11, Vermilion	NA	NA	9.5	12.4	10.3	9.6	9.2	8.8	8.4
Avg Annual Percent Change	*NA*	*NA*	*NA*	*3%*	*-2%*	*-1%*	*0%*	*0%*	*0%*
Subbasin 12, Wabash Montezuma	7.8	6.1	5.3	4.8	6.7	12.3	15.1	17.7	20.3

Subbasin	Historical Use (MGD) (a)				Projected Future				
	1985 to 1992 (a)	1993 to 2002	2003 to 2012 (b)	2013 to 2022	2023 to 2032	2033 to 2042	2043 to 2052	2053 to 2062	2063 to 2075
Avg Annual Percent Change	*NA*	*-3%*	*-1%*	*-1%*	*3%*	*6%*	*2%*	*2%*	*1%*
Subbasin 13, Upper Big Raccoon	0.7	1.8	2.5	2.1	2.1	2.2	2.2	2.2	2.2
Avg Annual Percent Change	*NA*	*13%*	*4%*	*-2%*	*0%*	*0%*	*0%*	*0%*	*0%*
Subbasin 14, Lower Big Raccoon	1.2	1.1	0.9	0.9	1.0	1.0	1.0	1.0	1.0
Avg Annual Percent Change	*NA*	*-1%*	*-1%*	*0%*	*1%*	*0%*	*0%*	*0%*	*0%*
Subbasin 15, Wabash Terre Haute	16.1	22.4	18.8	18.2	17.2	17.9	19.1	20.3	21.4
Avg Annual Percent Change	*NA*	*4%*	*-2%*	*0%*	*-1%*	*0%*	*1%*	*1%*	*1%*
Subbasin 16, Wabash Vigo	22.0	10.6	7.2	4.5	14.4	15.6	16.9	18.3	19.6
Avg Annual Percent Change	*NA*	*-9%*	*-4%*	*-5%*	*12%*	*1%*	*1%*	*1%*	*1%*
Total	143.6	152.1	154.4	151.9	167.4	183.2	197.1	208.7	219.4
Avg Annual Percent Change	*NA*	*1%*	*0%*	*0%*	*1%*	*1%*	*1%*	*1%*	*0%*

Note:
(a) 1985 to 1992 is averaged over eight years, the remaining periods are averaged over 10 years.
Key:
MGD = million gallons per day
NA = Not Applicable

Despite the relatively high demand for water withdrawals for coal-based energy production, the consumptive water use of coal-based energy production is very low. The vast majority of water withdrawn to operate the coal plants is returned to the subbasin, estimated at 99% of withdrawals (Meldrum et al., 2013). Therefore, despite the relatively large volume of energy withdrawals from 1985 to 2028, the consumptive use during that period was relatively low (Figure 4-9).

It is easier to see the change in consumptive use projected into the future when excluding energy withdrawals from the historical period (Figure 4-10). In 1985 when withdrawals were reported to be 934 MGD, consumptive use is estimated to have been 39 MGD or 4% of withdrawals. This relatively low consumptive use is due to the fact that the EP withdraws are nearly all returned to the subbasin, having been used to cool machinery, then treated then returned. By 2070, when withdrawals are projected to be 260 MGD, consumptive use is projected to be 81 MGD, or 31% of withdrawals. The increase in consumptive use is driven in large part by the increase in irrigation withdrawals during that period, as irrigation is estimated to have an 80% consumptive rate due to plant transpiration of the water into the atmosphere. Other water uses, such as PS, with an estimated consumptive use of 20%, and IN, with an estimated consumptive use rate of 10%, also have a higher consumptive rate than coal-fired energy production. The future projections show that the consumptive rate of water withdrawals is anticipated to continue increasing as withdrawals for irrigation, public supply, and industrial withdrawals increase.

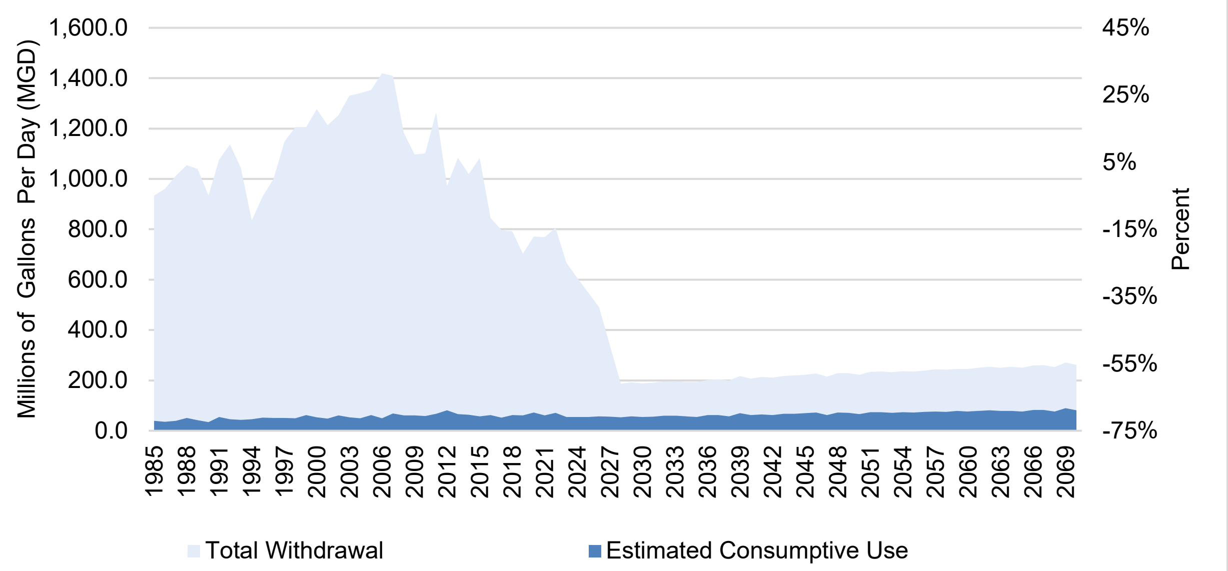


Figure 4-10. Historical Annual (1985-2022) and Projected Future (2023-2070) Water Withdrawals and Consumptive Use in North Central Indiana Study Area, All Subbasins, Millions of Gallons Per Day

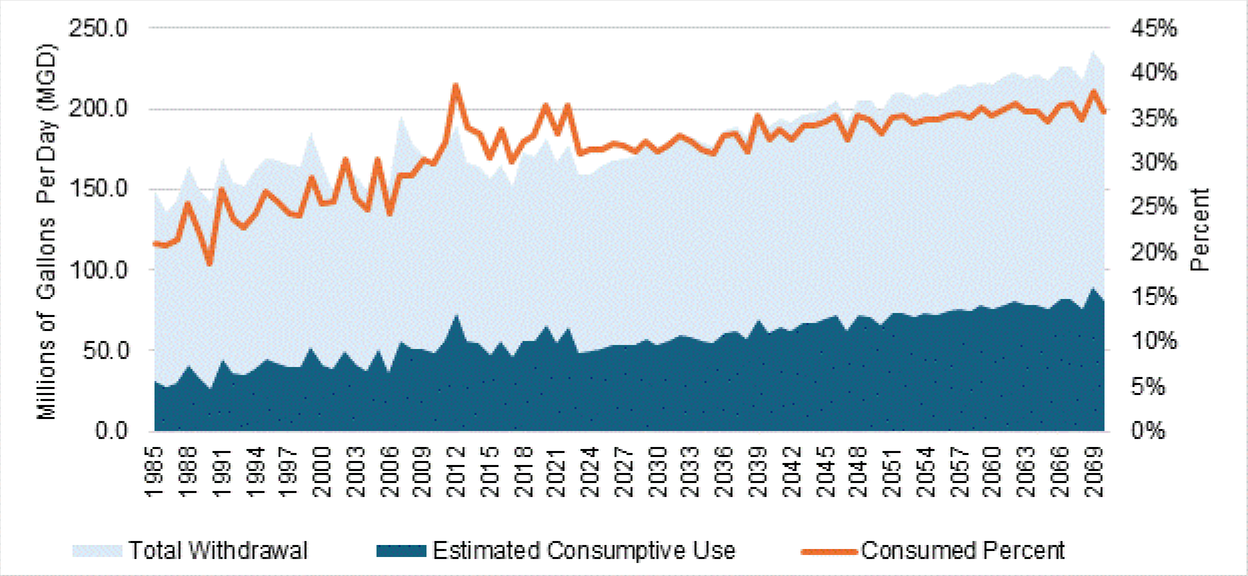
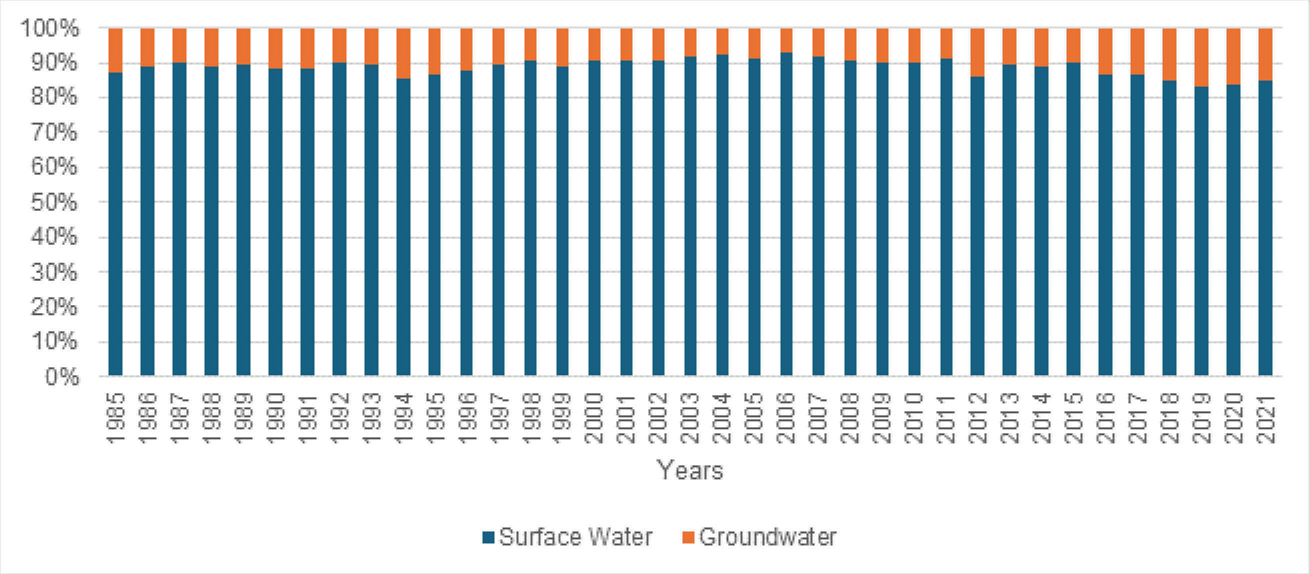


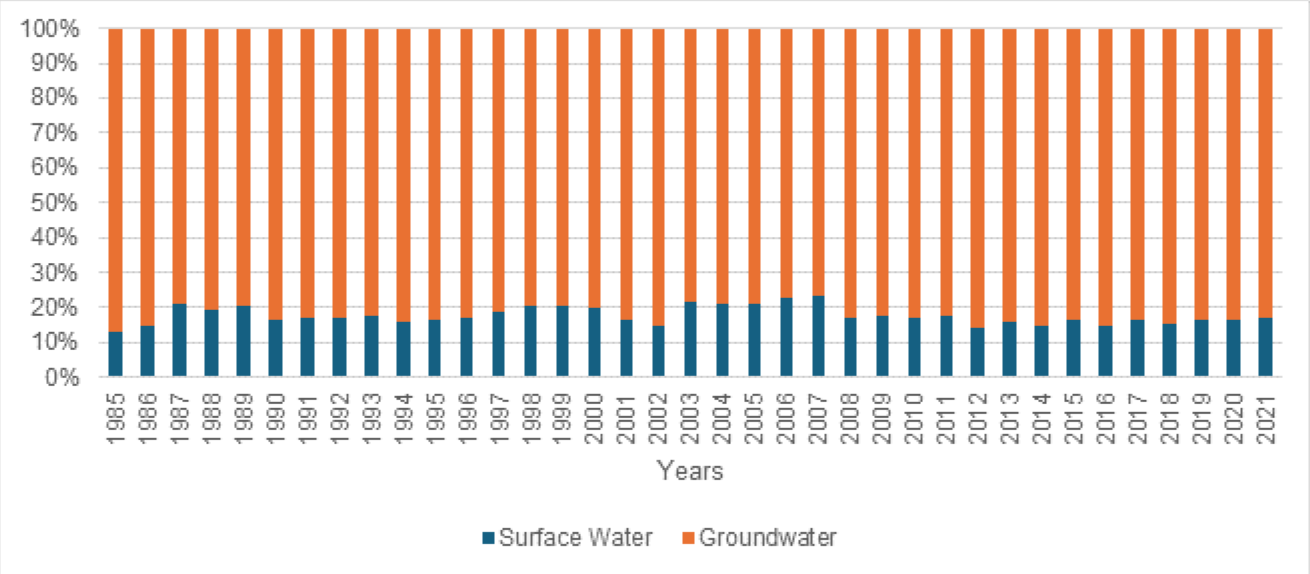
Figure 4-11. Historical Annual (1985-2022) and Projected Future (2023-2070) Water Withdrawals and Consumptive Use in North Central Indiana Study Area, Excluding Energy Withdrawals, Millions of Gallons Per Day

Historical and future projections of water withdrawals have been presented by subbasin and water use sector, and their consumptive use has been addressed, but the projected future demand presented in this Study does not estimate or project the specific source of supply to meet that demand (See Chapter 7, Future Water Availability). However, the historical source of water withdrawals, either surface water or groundwater, is known. Surface water is characterized as water diverted from a river or stream, whereas groundwater is water supply pumped from a well. The primary use of surface water in the subregion has been diversions for EP required to operate coal powered energy plants (Figure 4-11). When energy production withdrawals from surface water are exclude from total historical withdrawals, the primary source of water use for all other uses has been groundwater (Figure 4-12).



Source: Substantial Water Withdrawal Facility data 1985 to 2022 (INDR, 2023)

Figure 4-11. Historical Annual Water Withdrawals by Source in North Central Indiana Study Area, All Subbasins, Percent of Total



Source: Substantial Water Withdrawal Facility data 1985 to 2022 (INDR, 2023)

Figure 4-12. Historical Annual Water Demand by Source Sector in North Central Indiana Study Area, Excluding Energy Withdrawals, All Subbasins, Percent of Total

4.4 Average and Peak Monthly Demand Considerations

Long-term water demand projections, such as those in this North Central Indiana Regional Water Study, are used as strategic planning tools and frequently focus on average usage, either monthly or annual. Over a 50-year planning horizon, consideration should also be given to potential changes in not only average volumes of water demand but also the usage pattern over a year, particularly if changes in climate shift the peak usage periods (e.g., from mid-summer months to early fall months). These monthly averages and monthly usage patterns provide useful information for long-term planning.

Peak usage, or maximum day or monthly demand, is equally as important to inform operational and tactical decisions for water utilities and frequently inform utility or facility-level infrastructure or operational/management decisions. For example, an industrial facility may invest in on-site water storage to manage facility-level peaks in water demand. Or resource managers may consider whether standard operating procedures such as the cycling or filling of water tower storage, flushing hydrants, schedule to fill backup utility reservoir storage are adequate for future conditions. Therefore, reporting on changes in the magnitude of monthly peaks may also provide insights into the strategic planning process.

What follows is a summary of the monthly average, monthly usage pattern, and the monthly peaks for water demand. The summaries present averages and peaks over a 5-year period of time. Detail is also provided for the PS, IN, IR, and EP water use sectors.

4.4.1 ALL WATER USER SECTORS, MONTHLY AVERAGE AND PEAK VOLUMES, ALL SUBBASINS

The **historical maximum average monthly withdrawal** across all subbasins and water use sectors of 1,652.8 MGD occurred in August during the 2001 to 2005 period of time (Table 4-5).[7] This volume was driven by the EP water use, where two coal plants were in production in Wabash Montezuma (Subbasin 12) and Wabash Terre Haute (Subbasin 15). Following the scheduled retirement of the last coal energy plants in 2028, **average monthly use** is projected to range between 155.4 MGD, in January of the 2031 to 2035 period, to 515.6 MGD in July of the 2066 to 2070 period.

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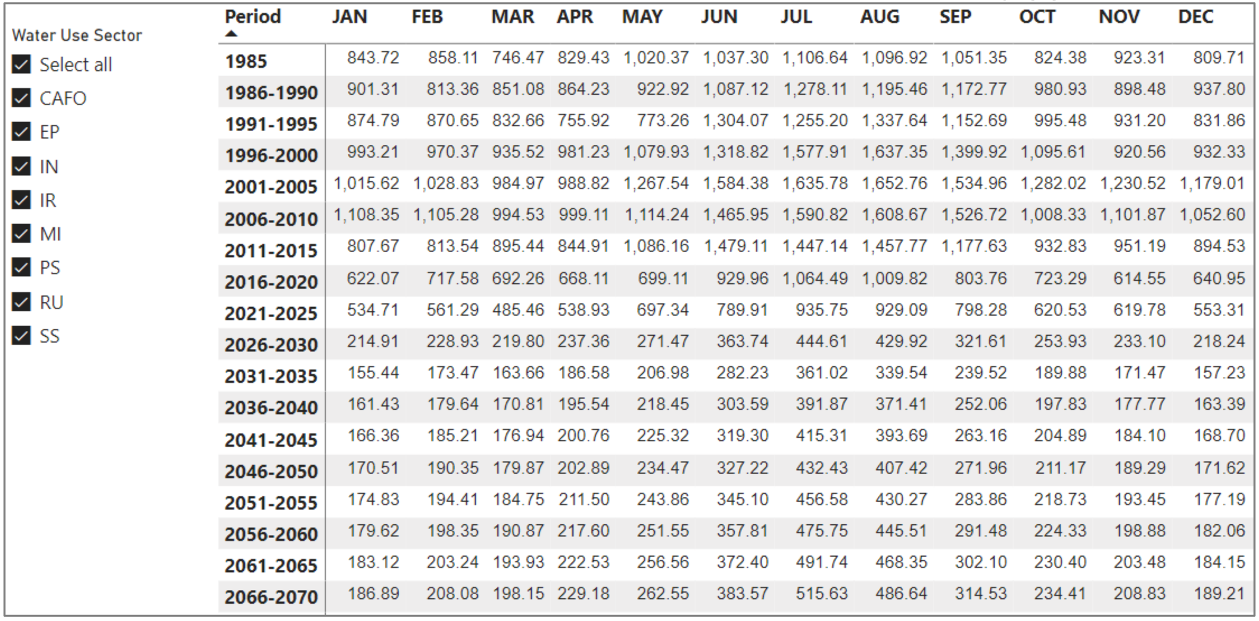
[7] To see the importance of comparing the average monthly withdrawal volumes to the average annual withdrawal volumes, consider that the maximum average annual withdrawal shown in Figure 4-3 is just under 1,500 MGD whereas the maximum average monthly volume is 1,657.28 MGD.

Table 4-5. Average Historical and Projected Future Monthly Water Demand by 5-Year Period, All Water Use Sectors, All Subbasins, Millions of Gallons per Day (a)



Water Use Sector
☑ Select all
☑ CAFO
☑ EP
☑ IN
☑ IR
☑ MI
☑ PS
☑ RU
☑ SS

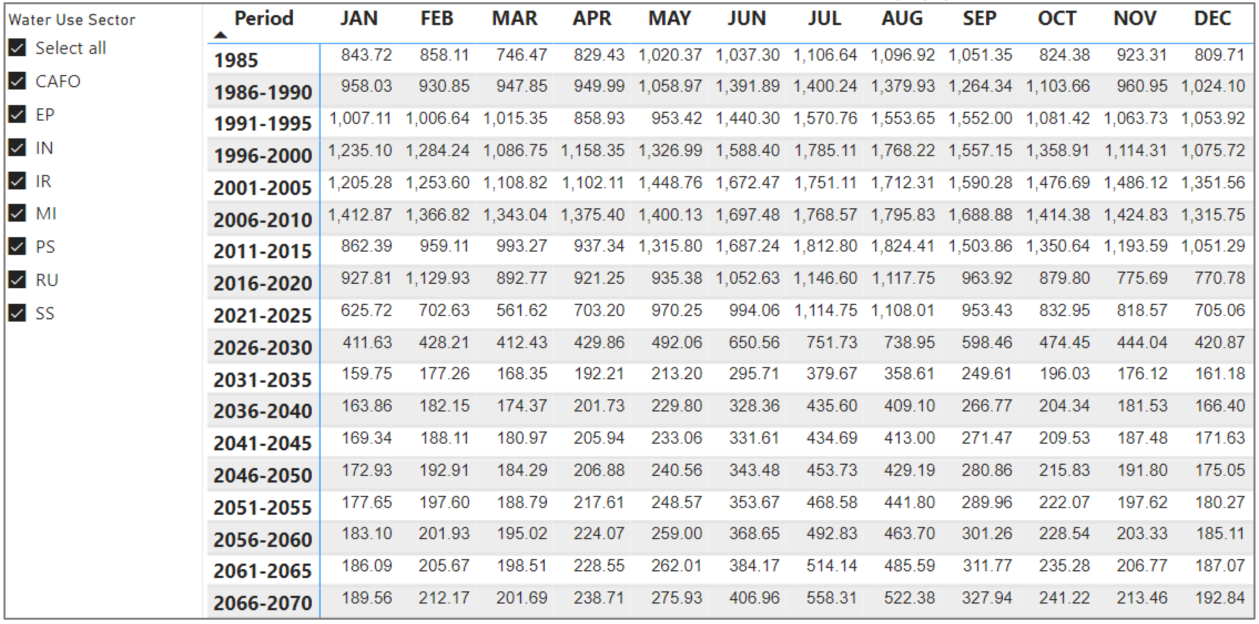
Period	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	843.72	858.11	746.47	829.43	1,020.37	1,037.30	1,106.64	1,096.92	1,051.35	824.38	923.31	809.71
1986-1990	901.31	813.36	851.08	864.23	922.92	1,087.12	1,278.11	1,195.46	1,172.77	980.93	898.48	937.80
1991-1995	874.79	870.65	832.66	755.92	773.26	1,304.07	1,255.20	1,337.64	1,152.69	995.48	931.20	831.86
1996-2000	993.21	970.37	935.52	981.23	1,079.93	1,318.82	1,577.91	1,637.35	1,399.92	1,095.61	920.56	932.33
2001-2005	1,015.62	1,028.83	984.97	988.82	1,267.54	1,584.38	1,635.78	1,652.76	1,534.96	1,282.02	1,230.52	1,179.01
2006-2010	1,108.35	1,105.28	994.53	999.11	1,114.24	1,465.95	1,590.82	1,608.67	1,526.72	1,008.33	1,101.87	1,052.60
2011-2015	807.67	813.54	895.44	844.91	1,086.16	1,479.11	1,447.14	1,457.77	1,177.63	932.83	951.19	894.53
2016-2020	622.07	717.58	692.26	668.11	699.11	929.96	1,064.49	1,009.82	803.76	723.29	614.55	640.95
2021-2025	534.71	561.29	485.46	538.93	697.34	789.91	935.75	929.09	798.28	620.53	619.78	553.31
2026-2030	214.91	228.93	219.80	237.36	271.47	363.74	444.61	429.92	321.61	253.93	233.10	218.24
2031-2035	155.44	173.47	163.66	186.58	206.98	282.23	361.02	339.54	239.52	189.88	171.47	157.23
2036-2040	161.43	179.64	170.81	195.54	218.45	303.59	391.87	371.41	252.06	197.83	177.77	163.39
2041-2045	166.36	185.21	176.94	200.76	225.32	319.30	415.31	393.69	263.16	204.89	184.10	168.70
2046-2050	170.51	190.35	179.87	202.89	234.47	327.22	432.43	407.42	271.96	211.17	189.29	171.62
2051-2055	174.83	194.41	184.75	211.50	243.86	345.10	456.58	430.27	283.86	218.73	193.45	177.19
2056-2060	179.62	198.35	190.87	217.60	251.55	357.81	475.75	445.51	291.48	224.33	198.88	182.06
2061-2065	183.12	203.24	193.93	222.53	256.56	372.40	491.74	468.35	302.10	230.40	203.48	184.15
2066-2070	186.89	208.08	198.15	229.18	262.55	383.57	515.63	486.64	314.53	234.41	208.83	189.21

Note: (a) Historical water withdrawals for Illinois subbasins were not available prior to 2007.

In contrast to the average monthly volumes shown in Table 4-5, the **historical maximum peak monthly withdrawal** across all subbasins and water use sectors of 1,824.4 MGD occurred in August during the 2011 to 2015 period of time (Table 4-6). The average monthly withdrawal for the same time period was 1,457.8 (Table 4-5) a difference of 366.6, or 25% above the average volume for the same time. A peak during the 2011 to 2015 time period was driven in part by a peak in irrigation use during the 2012 drought (see Appendix D for more information about historical irrigation demands). This difference in the average and the peak five-year monthly averages highlights the importance of reporting both average and peak volumes.

The peak volume was also driven by the EP water use, where two coal plants were in production in Wabash Montezuma (Subbasin 12) and Wabash Terre Haute (Subbasin 15). Following the retirement of the last coal energy plants in 2028, **peak monthly use** is projected to range between 159.8 MGD in January of the 2031 to 2035 period) and 558.3 MGD in July of the 2066 to 2070 period. In general, the maximum peak volumes range between 110% and approximately 140% of maximum average volumes.

Table 4-6. Peak Historical and Projected Future Monthly Water Demand by 5-Year Period, All Water Use Sectors, All Subbasins, Millions of Gallons per Day (a)



Water Use Sector
☑ Select all
☑ CAFO
☑ EP
☑ IN
☑ IR
☑ MI
☑ PS
☑ RU
☑ SS

Period	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	843.72	858.11	746.47	829.43	1,020.37	1,037.30	1,106.64	1,096.92	1,051.35	824.38	923.31	809.71
1986-1990	958.03	930.85	947.85	949.99	1,058.97	1,391.89	1,400.24	1,379.93	1,264.34	1,103.66	960.95	1,024.10
1991-1995	1,007.11	1,006.64	1,015.35	858.93	953.42	1,440.30	1,570.76	1,553.65	1,552.00	1,081.42	1,063.73	1,053.92
1996-2000	1,235.10	1,284.24	1,086.75	1,158.35	1,326.99	1,588.40	1,785.11	1,768.22	1,557.15	1,358.91	1,114.31	1,075.72
2001-2005	1,205.28	1,253.60	1,108.82	1,102.11	1,448.76	1,672.47	1,751.11	1,712.31	1,590.28	1,476.69	1,486.12	1,351.56
2006-2010	1,412.87	1,366.82	1,343.04	1,375.40	1,400.13	1,697.48	1,768.57	1,795.83	1,688.88	1,414.38	1,424.83	1,315.75
2011-2015	862.39	959.11	993.27	937.34	1,315.80	1,687.24	1,812.80	1,824.41	1,503.86	1,350.64	1,193.59	1,051.29
2016-2020	927.81	1,129.93	892.77	921.25	935.38	1,052.63	1,146.60	1,117.75	963.92	879.80	775.69	770.78
2021-2025	625.72	702.63	561.62	703.20	970.25	994.06	1,114.75	1,108.01	953.43	832.95	818.57	705.06
2026-2030	411.63	428.21	412.43	429.86	492.06	650.56	751.73	738.95	598.46	474.45	444.04	420.87
2031-2035	159.75	177.26	168.35	192.21	213.20	295.71	379.67	358.61	249.61	196.03	176.12	161.18
2036-2040	163.86	182.15	174.37	201.73	229.80	328.36	435.60	409.10	266.77	204.34	181.53	166.40
2041-2045	169.34	188.11	180.97	205.94	233.06	331.61	434.69	413.00	271.47	209.53	187.48	171.63
2046-2050	172.93	192.91	184.29	206.88	240.56	343.48	453.73	429.19	280.86	215.83	191.80	175.05
2051-2055	177.65	197.60	188.79	217.61	248.57	353.67	468.58	441.80	289.96	222.07	197.62	180.27
2056-2060	183.10	201.93	195.02	224.07	259.00	368.65	492.83	463.70	301.26	228.54	203.33	185.11
2061-2065	186.09	205.67	198.51	228.55	262.01	384.17	514.14	485.59	311.77	235.28	206.77	187.07
2066-2070	189.56	212.17	201.69	238.71	275.93	406.96	558.31	522.38	327.94	241.22	213.46	192.84

Note: (a) Historical water withdrawals for Illinois subbasins are not available prior to 2007.

4.4.2 PUBLIC SUPPLY (PS) WATER USE SECTOR, MONTHLY AVERAGE AND PEAK VOLUMES, ALL SUBBASINS

Average monthly historical water demand for PS water use sector increased over the period 1985 to the 2006 to 2010 time period. In 1985 withdrawals ranged from the mid- to high-50s in MGD to the low-70s in MGD (Table 4-6). By the 2006 to 2010 time period, the five-year monthly average PS water withdrawals peaked in August at 82.42 MGD. Since the 2006 to 2010 time period, monthly average withdrawals generally decline until the 2031-2035 period when the peak monthly volume is projected to return to volumes seen during the 2006- 2010 time period. The maximum average monthly PS withdrawal is projected to occur in June of the 2066 to 2070 time period, at 89.2 MGD.

The fact that future projected average volumes in the period 2036 to 2040 are close in magnitude to the historic volumes reported in the period 2006 to 2010 should not be interpreted to mean that the existing water supply infrastructure and distribution systems can serve future demand, at least up to 2040. Future projected PS demand is not necessarily occurring in the in the same counties/cities as historical demand, as population is projected to increase in some subbasins and decrease in others. Additionally, water supply professionals and economic development directors in some regions mentioned a need to invest in aging water systems infrastructure, or in some cases, develop additional, reliable high quality water supplies.

Peak monthly water demand for the PS water use sector has historically ranged between the mid-60s in MGD to a high of the mid-90s in MGD with the peak high volume occurring in June, July, and August (Table 4-8). Historically peak factors range (calculated by dividing the monthly peak values by the average peak values for the same month) between 0.9 and 1.15 of average monthly water withdrawals, with the highest peaks in June (top panel of Figure 4-13). In the future, the monthly peaks increase slightly, to a June high of 1.2 (bottom panel of Figure 4-13), indicating that water utility operations may require study for both long-term average annual water demand increases but also short-term planning assessment of operations.

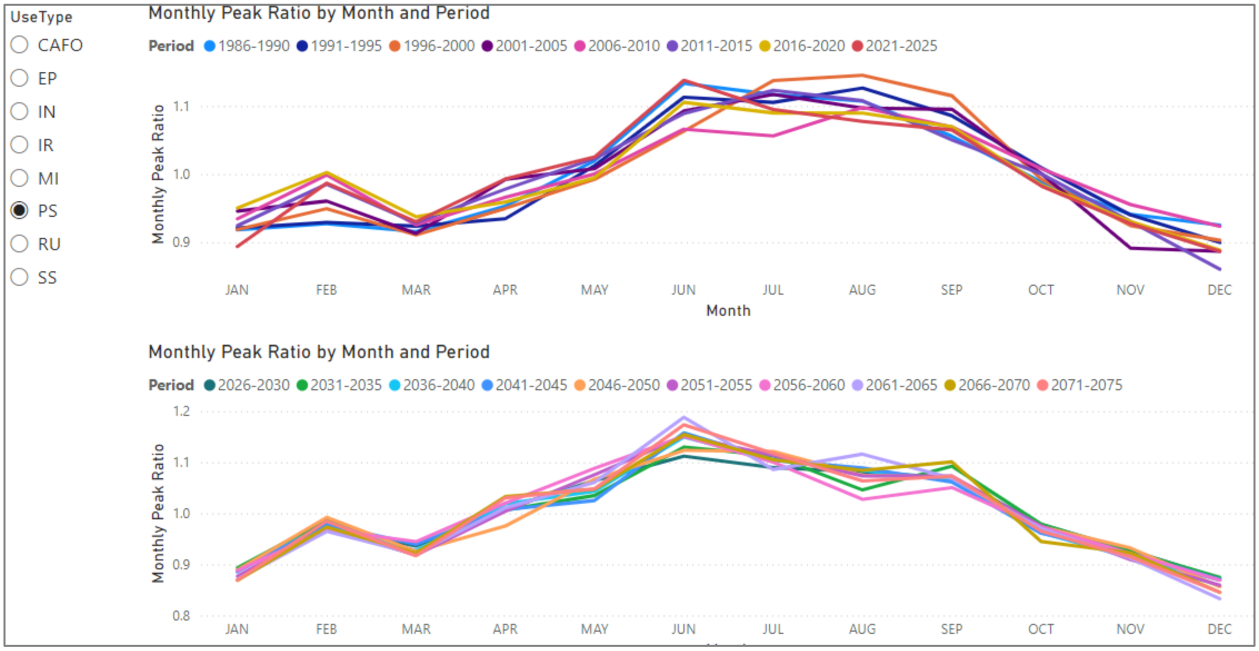
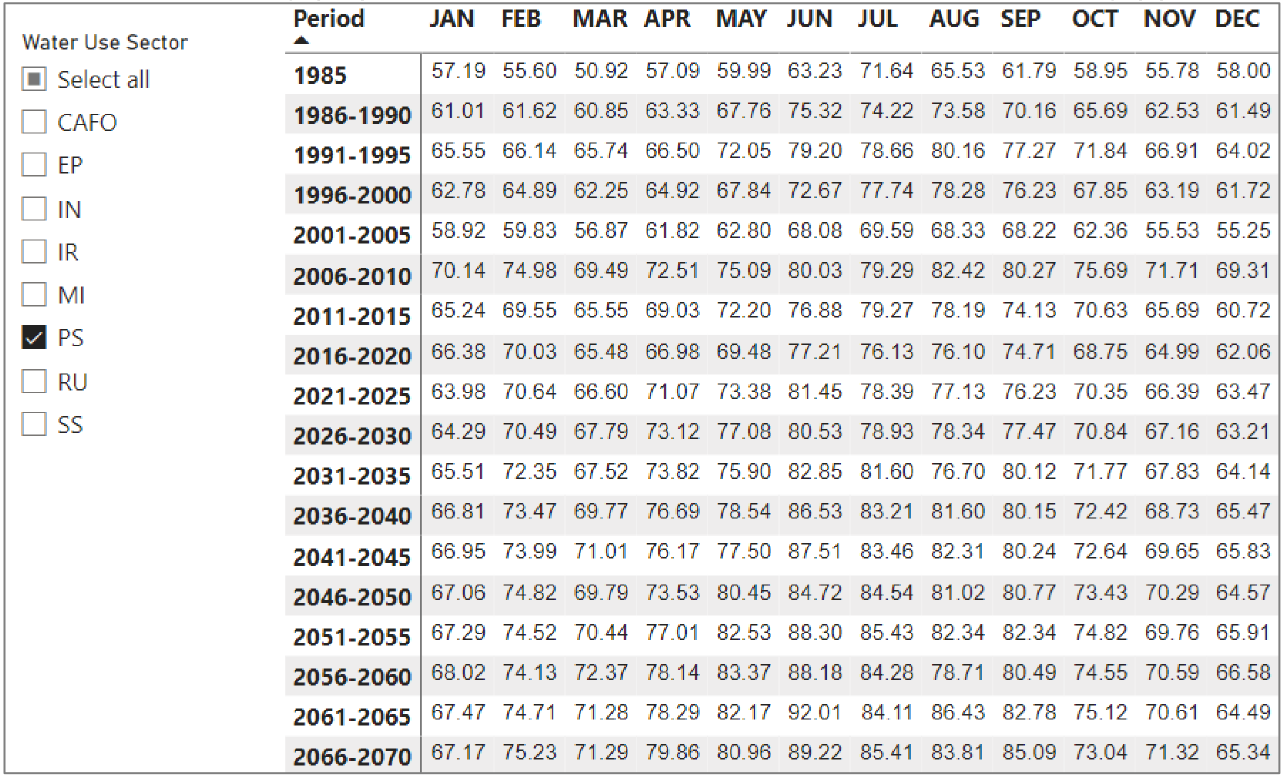


Figure 4-13. Historical Monthly Peak Factors, Historical (1985-2025) and Projected Future (2026-2075), Public Supply

The monthly usage pattern can best be seen by calculating **indexed monthly water usage ratios**. The index is calculated by dividing the average monthly usage by the average annual usage for the same time period, representing the **magnitude of the monthly average usage compared to the annual average for that time period**. A value of 1 means monthly usage is equal to the average annual usage over the year. Values greater than 1 occur in months with usage is greater than 1/12th of the annual average usage. The data can help suggest whether there are trends in the peak months. Table 4-9 illustrates these trends by providing a detailed view of monthly indexed water usage ratios across multiple historical and projected periods, emphasizing distinct seasonal patterns and shifts in usage intensity. The data consistently shows that water withdrawals peak during the summer months of June, July, and August, driven by increased demand for outdoor watering and other seasonal activities. The darkest shades on the heat map highlight the most water-intensive months within each period.

Table 4-7. Average Historical and Projected Future Monthly Water Demand by 5-Year Period, Public Supply (PS) Water Use, All Subbasins, Millions of Gallons per Day (a)



Water Use Sector
▣ Select all
☐ CAFO
☐ EP
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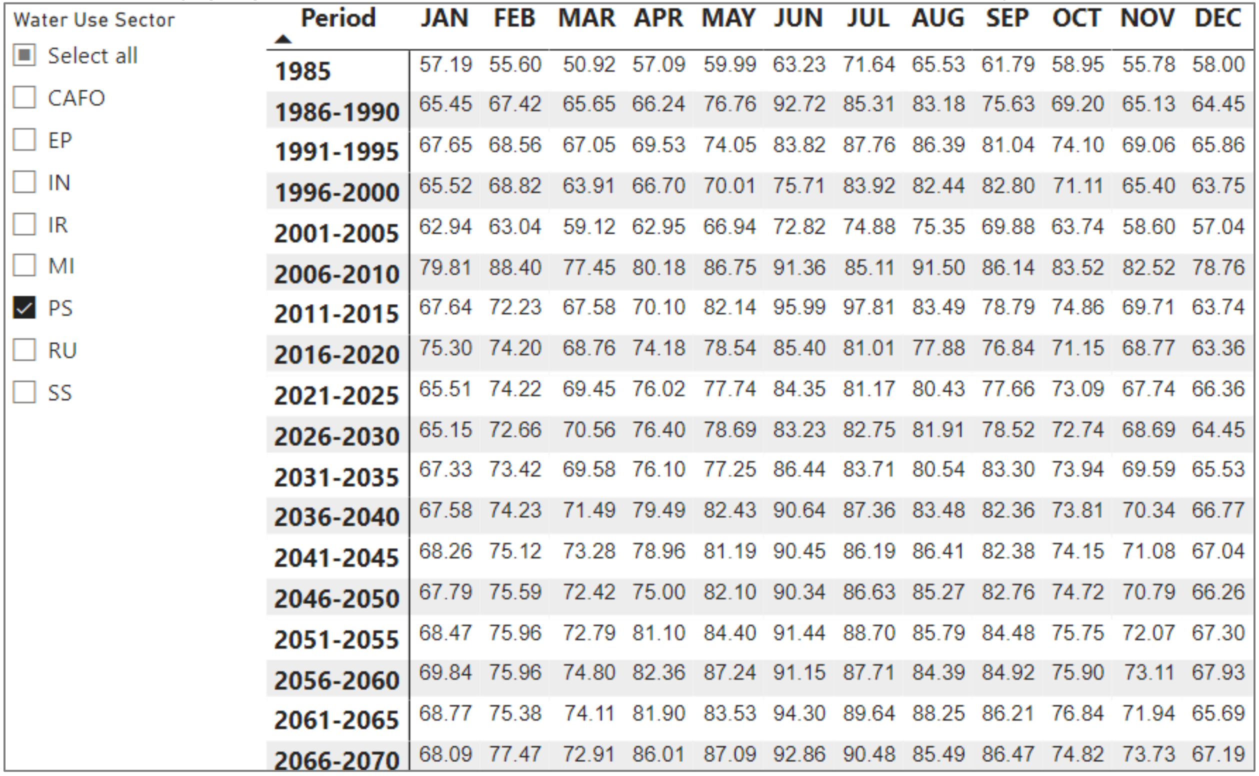
☐ IR
☐ MI
☑ PS
☐ RU
☐ SS

Period ▲	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	57.19	55.60	50.92	57.09	59.99	63.23	71.64	65.53	61.79	58.95	55.78	58.00
1986-1990	61.01	61.62	60.85	63.33	67.76	75.32	74.22	73.58	70.16	65.69	62.53	61.49
1991-1995	65.55	66.14	65.74	66.50	72.05	79.20	78.66	80.16	77.27	71.84	66.91	64.02
1996-2000	62.78	64.89	62.25	64.92	67.84	72.67	77.74	78.28	76.23	67.85	63.19	61.72
2001-2005	58.92	59.83	56.87	61.82	62.80	68.08	69.59	68.33	68.22	62.36	55.53	55.25
2006-2010	70.14	74.98	69.49	72.51	75.09	80.03	79.29	82.42	80.27	75.69	71.71	69.31
2011-2015	65.24	69.55	65.55	69.03	72.20	76.88	79.27	78.19	74.13	70.63	65.69	60.72
2016-2020	66.38	70.03	65.48	66.98	69.48	77.21	76.13	76.10	74.71	68.75	64.99	62.06
2021-2025	63.98	70.64	66.60	71.07	73.38	81.45	78.39	77.13	76.23	70.35	66.39	63.47
2026-2030	64.29	70.49	67.79	73.12	77.08	80.53	78.93	78.34	77.47	70.84	67.16	63.21
2031-2035	65.51	72.35	67.52	73.82	75.90	82.85	81.60	76.70	80.12	71.77	67.83	64.14
2036-2040	66.81	73.47	69.77	76.69	78.54	86.53	83.21	81.60	80.15	72.42	68.73	65.47
2041-2045	66.95	73.99	71.01	76.17	77.50	87.51	83.46	82.31	80.24	72.64	69.65	65.83
2046-2050	67.06	74.82	69.79	73.53	80.45	84.72	84.54	81.02	80.77	73.43	70.29	64.57
2051-2055	67.29	74.52	70.44	77.01	82.53	88.30	85.43	82.34	82.34	74.82	69.76	65.91
2056-2060	68.02	74.13	72.37	78.14	83.37	88.18	84.28	78.71	80.49	74.55	70.59	66.58
2061-2065	67.47	74.71	71.28	78.29	82.17	92.01	84.11	86.43	82.78	75.12	70.61	64.49
2066-2070	67.17	75.23	71.29	79.86	80.96	89.22	85.41	83.81	85.09	73.04	71.32	65.34

Note: (a) Historical water withdrawals for Illinois subbasins are not available prior to 2007.

Table 4-8. Peak Historical and Projected Future Monthly Water Demand by 5-Year Period, Public Supply (PS) Water Use, All Subbasins, Millions of Gallons per Day



Water Use Sector
☒ Select all
☐ CAFO
☐ EP
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☐ MI
☑ PS
☐ RU
☐ SS

Period	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	57.19	55.60	50.92	57.09	59.99	63.23	71.64	65.53	61.79	58.95	55.78	58.00
1986-1990	65.45	67.42	65.65	66.24	76.76	92.72	85.31	83.18	75.63	69.20	65.13	64.45
1991-1995	67.65	68.56	67.05	69.53	74.05	83.82	87.76	86.39	81.04	74.10	69.06	65.86
1996-2000	65.52	68.82	63.91	66.70	70.01	75.71	83.92	82.44	82.80	71.11	65.40	63.75
2001-2005	62.94	63.04	59.12	62.95	66.94	72.82	74.88	75.35	69.88	63.74	58.60	57.04
2006-2010	79.81	88.40	77.45	80.18	86.75	91.36	85.11	91.50	86.14	83.52	82.52	78.76
2011-2015	67.64	72.23	67.58	70.10	82.14	95.99	97.81	83.49	78.79	74.86	69.71	63.74
2016-2020	75.30	74.20	68.76	74.18	78.54	85.40	81.01	77.88	76.84	71.15	68.77	63.36
2021-2025	65.51	74.22	69.45	76.02	77.74	84.35	81.17	80.43	77.66	73.09	67.74	66.36
2026-2030	65.15	72.66	70.56	76.40	78.69	83.23	82.75	81.91	78.52	72.74	68.69	64.45
2031-2035	67.33	73.42	69.58	76.10	77.25	86.44	83.71	80.54	83.30	73.94	69.59	65.53
2036-2040	67.58	74.23	71.49	79.49	82.43	90.64	87.36	83.48	82.36	73.81	70.34	66.77
2041-2045	68.26	75.12	73.28	78.96	81.19	90.45	86.19	86.41	82.38	74.15	71.08	67.04
2046-2050	67.79	75.59	72.42	75.00	82.10	90.34	86.63	85.27	82.76	74.72	70.79	66.26
2051-2055	68.47	75.96	72.79	81.10	84.40	91.44	88.70	85.79	84.48	75.75	72.07	67.30
2056-2060	69.84	75.96	74.80	82.36	87.24	91.15	87.71	84.39	84.92	75.90	73.11	67.93
2061-2065	68.77	75.38	74.11	81.90	83.53	94.30	89.64	88.25	86.21	76.84	71.94	65.69
2066-2070	68.09	77.47	72.91	86.01	87.09	92.86	90.48	85.49	86.47	74.82	73.73	67.19

Note: (a) Historical water withdrawals for Illinois subbasins are not available prior to 2007.

Table 4-9. Indexed Historical and Projected Future Monthly Average Water Demand by 5-Year Period, Public Supply (PS) Water Use, All Subbasins, Index Value

Period	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.96	0.93	0.85	0.96	1.01	1.06	1.20	1.10	1.04	0.99	0.94	0.97
1986-1990	0.92	0.93	0.92	0.95	1.02	1.13	1.12	1.11	1.06	0.99	0.94	0.93
1991-1995	0.92	0.93	0.92	0.93	1.01	1.11	1.10	1.13	1.09	1.01	0.94	0.90
1996-2000	0.92	0.95	0.91	0.95	0.99	1.06	1.14	1.15	1.11	0.99	0.92	0.90
2001-2005	0.95	0.96	0.91	0.99	1.01	1.09	1.12	1.10	1.10	1.00	0.89	0.89
2006-2010	0.93	1.00	0.93	0.97	1.00	1.07	1.06	1.10	1.07	1.01	0.96	0.92
2011-2015	0.92	0.99	0.93	0.98	1.02	1.09	1.12	1.11	1.05	1.00	0.93	0.86
2016-2020	0.95	1.00	0.94	0.96	0.99	**1.10**	1.09	1.09	1.07	0.98	0.93	0.89
2021-2025	0.90	0.98	0.93	0.99	1.02	1.13	1.10	1.09	1.07	0.98	0.93	0.89
2026-2030	0.90	0.97	0.94	1.01	1.06	1.12	1.10	1.08	1.06	0.97	0.92	0.88
2031-2035	0.89	0.98	0.93	1.01	1.04	1.12	1.11	1.07	1.07	0.98	0.93	0.88
2036-2040	0.89	0.98	0.94	1.01	1.05	1.13	1.11	1.08	1.06	0.96	0.92	0.87
2041-2045	0.89	0.98	0.94	1.01	1.04	1.13	1.11	1.08	1.06	0.97	0.92	0.87
2046-2050	0.89	0.98	0.93	1.00	1.05	1.13	1.11	1.07	1.06	0.97	0.92	0.88
2051-2055	0.88	0.97	0.93	1.01	1.07	1.14	1.10	1.08	1.06	0.97	0.92	0.87
2056-2060	0.89	0.97	0.94	1.01	1.06	1.14	1.11	1.06	1.06	0.97	0.92	0.87
2061-2065	0.88	0.97	0.92	1.02	1.06	1.15	1.10	1.09	1.07	0.96	0.92	0.87
2066-2070	0.88	0.97	0.93	1.02	1.05	1.14	1.10	1.07	1.07	0.96	0.92	0.87

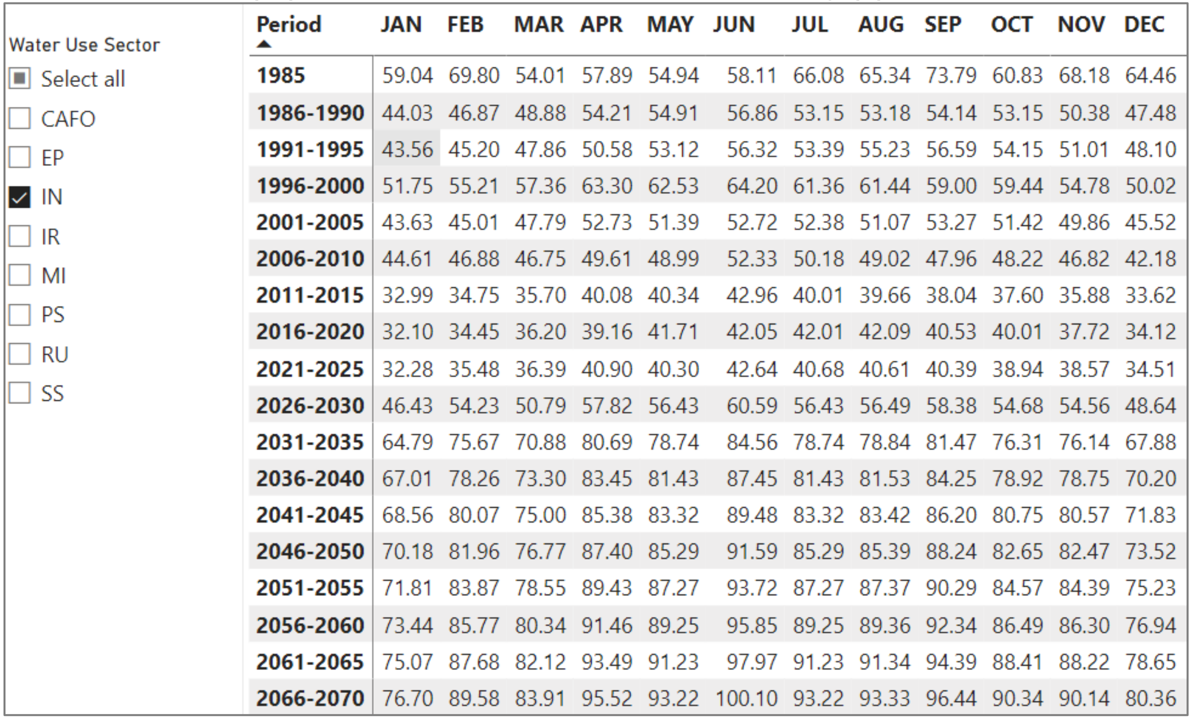
4.4.3 INDUSTRIAL (IN) WATER USE SECTOR, MONTHLY AVERAGE AND PEAK VOLUMES, ALL SUBBASINS

Average monthly water demand for IN water use sector was as high as 73.79 MGD in September of 1985, declining to a low of 32.10 by January of 2016 to 2020 (Table 4-10). The projected future industrial demand increases in every month for every 5-year period during the planning periods. By the end of the planning horizon average monthly demand is projected to be between 76.70 MGD (January) and 100.10 MGD (June).

Peak monthly water demand for IN water use sector is generally 10% to 30% higher than average monthly withdrawals, both for historical and future (Table 4-11).

The monthly usage pattern can best be seen by calculating indexed monthly water usage ratios. The index is calculated by dividing the average monthly usage by the average annual usage, showing the magnitude of the monthly average usage compared to the annual average for that time period. Table 4-11 illustrates these trends by providing a detailed view of monthly indexed water usage ratios across multiple historical and projected periods. Industrial water use patterns show less seasonal variability than PS or IR water use sectors. The data shows that water withdrawals are higher April through September and less through the winter months. Since much of the IN water demand is for mining, the reduction in winter water demand is driven by the winter weather curtailing mining operations.

Table 4-10. Average Historical and Projected Future Monthly Water Demand by 5-Year Period, Industrial (IN) Water Use, Millions of Gallons per Day (a)

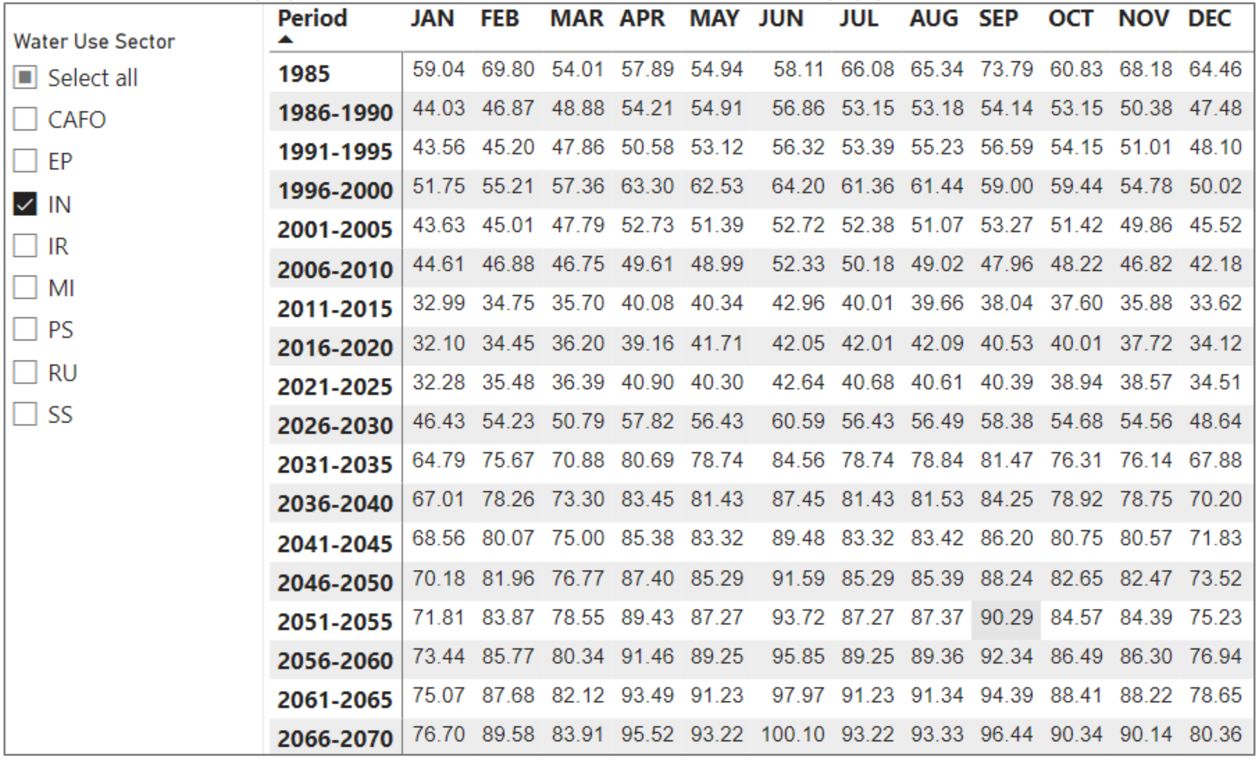


Water Use Sector
- ▣ Select all
- ☐ CAFO
- ☐ EP
- ☑ IN
- ☐ IR
- ☐ MI
- ☐ PS
- ☐ RU
- ☐ SS

Period ▲	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	59.04	69.80	54.01	57.89	54.94	58.11	66.08	65.34	73.79	60.83	68.18	64.46
1986-1990	44.03	46.87	48.88	54.21	54.91	56.86	53.15	53.18	54.14	53.15	50.38	47.48
1991-1995	43.56	45.20	47.86	50.58	53.12	56.32	53.39	55.23	56.59	54.15	51.01	48.10
1996-2000	51.75	55.21	57.36	63.30	62.53	64.20	61.36	61.44	59.00	59.44	54.78	50.02
2001-2005	43.63	45.01	47.79	52.73	51.39	52.72	52.38	51.07	53.27	51.42	49.86	45.52
2006-2010	44.61	46.88	46.75	49.61	48.99	52.33	50.18	49.02	47.96	48.22	46.82	42.18
2011-2015	32.99	34.75	35.70	40.08	40.34	42.96	40.01	39.66	38.04	37.60	35.88	33.62
2016-2020	32.10	34.45	36.20	39.16	41.71	42.05	42.01	42.09	40.53	40.01	37.72	34.12
2021-2025	32.28	35.48	36.39	40.90	40.30	42.64	40.68	40.61	40.39	38.94	38.57	34.51
2026-2030	46.43	54.23	50.79	57.82	56.43	60.59	56.43	56.49	58.38	54.68	54.56	48.64
2031-2035	64.79	75.67	70.88	80.69	78.74	84.56	78.74	78.84	81.47	76.31	76.14	67.88
2036-2040	67.01	78.26	73.30	83.45	81.43	87.45	81.43	81.53	84.25	78.92	78.75	70.20
2041-2045	68.56	80.07	75.00	85.38	83.32	89.48	83.32	83.42	86.20	80.75	80.57	71.83
2046-2050	70.18	81.96	76.77	87.40	85.29	91.59	85.29	85.39	88.24	82.65	82.47	73.52
2051-2055	71.81	83.87	78.55	89.43	87.27	93.72	87.27	87.37	90.29	84.57	84.39	75.23
2056-2060	73.44	85.77	80.34	91.46	89.25	95.85	89.25	89.36	92.34	86.49	86.30	76.94
2061-2065	75.07	87.68	82.12	93.49	91.23	97.97	91.23	91.34	94.39	88.41	88.22	78.65
2066-2070	76.70	89.58	83.91	95.52	93.22	100.10	93.22	93.33	96.44	90.34	90.14	80.36

Note: (a) Historical water withdrawals for Illinois subbasins are not available prior to 2007.

Table 4-11. Peak Historical and Projected Future Monthly Water Demand by 5-Year Period, Industrial (IN) Water Use, Millions of Gallons per Day (a)

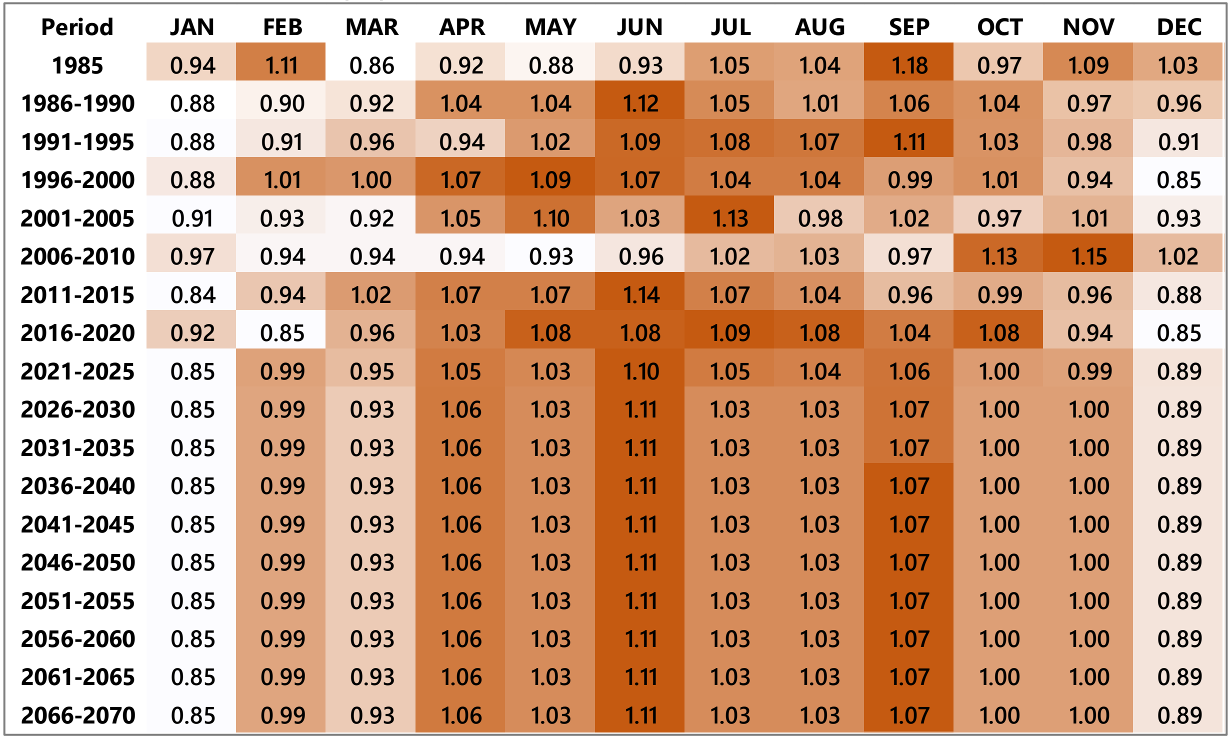


Water Use Sector
- ■ Select all
- ☐ CAFO
- ☐ EP
- ☑ IN
- ☐ IR
- ☐ MI
- ☐ PS
- ☐ RU
- ☐ SS

Period ▲	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	59.04	69.80	54.01	57.89	54.94	58.11	66.08	65.34	73.79	60.83	68.18	64.46
1986-1990	44.03	46.87	48.88	54.21	54.91	56.86	53.15	53.18	54.14	53.15	50.38	47.48
1991-1995	43.56	45.20	47.86	50.58	53.12	56.32	53.39	55.23	56.59	54.15	51.01	48.10
1996-2000	51.75	55.21	57.36	63.30	62.53	64.20	61.36	61.44	59.00	59.44	54.78	50.02
2001-2005	43.63	45.01	47.79	52.73	51.39	52.72	52.38	51.07	53.27	51.42	49.86	45.52
2006-2010	44.61	46.88	46.75	49.61	48.99	52.33	50.18	49.02	47.96	48.22	46.82	42.18
2011-2015	32.99	34.75	35.70	40.08	40.34	42.96	40.01	39.66	38.04	37.60	35.88	33.62
2016-2020	32.10	34.45	36.20	39.16	41.71	42.05	42.01	42.09	40.53	40.01	37.72	34.12
2021-2025	32.28	35.48	36.39	40.90	40.30	42.64	40.68	40.61	40.39	38.94	38.57	34.51
2026-2030	46.43	54.23	50.79	57.82	56.43	60.59	56.43	56.49	58.38	54.68	54.56	48.64
2031-2035	64.79	75.67	70.88	80.69	78.74	84.56	78.74	78.84	81.47	76.31	76.14	67.88
2036-2040	67.01	78.26	73.30	83.45	81.43	87.45	81.43	81.53	84.25	78.92	78.75	70.20
2041-2045	68.56	80.07	75.00	85.38	83.32	89.48	83.32	83.42	86.20	80.75	80.57	71.83
2046-2050	70.18	81.96	76.77	87.40	85.29	91.59	85.29	85.39	88.24	82.65	82.47	73.52
2051-2055	71.81	83.87	78.55	89.43	87.27	93.72	87.27	87.37	90.29	84.57	84.39	75.23
2056-2060	73.44	85.77	80.34	91.46	89.25	95.85	89.25	89.36	92.34	86.49	86.30	76.94
2061-2065	75.07	87.68	82.12	93.49	91.23	97.97	91.23	91.34	94.39	88.41	88.22	78.65
2066-2070	76.70	89.58	83.91	95.52	93.22	100.10	93.22	93.33	96.44	90.34	90.14	80.36

Note: (a) Historical water withdrawals for Illinois subbasins are not available prior to 2007.

Table 4-11. Indexed Historical and Projected Future Monthly Average Water Demand by 5-Year Period, Industrial (IN) Water Use, All Subbasins, Index Value



Period	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.94	1.11	0.86	0.92	0.88	0.93	1.05	1.04	1.18	0.97	1.09	1.03
1986-1990	0.88	0.90	0.92	1.04	1.04	1.12	1.05	1.01	1.06	1.04	0.97	0.96
1991-1995	0.88	0.91	0.96	0.94	1.02	1.09	1.08	1.07	1.11	1.03	0.98	0.91
1996-2000	0.88	1.01	1.00	1.07	1.09	1.07	1.04	1.04	0.99	1.01	0.94	0.85
2001-2005	0.91	0.93	0.92	1.05	1.10	1.03	1.13	0.98	1.02	0.97	1.01	0.93
2006-2010	0.97	0.94	0.94	0.94	0.93	0.96	1.02	1.03	0.97	1.13	1.15	1.02
2011-2015	0.84	0.94	1.02	1.07	1.07	1.14	1.07	1.04	0.96	0.99	0.96	0.88
2016-2020	0.92	0.85	0.96	1.03	1.08	1.08	1.09	1.08	1.04	1.08	0.94	0.85
2021-2025	0.85	0.99	0.95	1.05	1.03	1.10	1.05	1.04	1.06	1.00	0.99	0.89
2026-2030	0.85	0.99	0.93	1.06	1.03	1.11	1.03	1.03	1.07	1.00	1.00	0.89
2031-2035	0.85	0.99	0.93	1.06	1.03	1.11	1.03	1.03	1.07	1.00	1.00	0.89
2036-2040	0.85	0.99	0.93	1.06	1.03	1.11	1.03	1.03	1.07	1.00	1.00	0.89
2041-2045	0.85	0.99	0.93	1.06	1.03	1.11	1.03	1.03	1.07	1.00	1.00	0.89
2046-2050	0.85	0.99	0.93	1.06	1.03	1.11	1.03	1.03	1.07	1.00	1.00	0.89
2051-2055	0.85	0.99	0.93	1.06	1.03	1.11	1.03	1.03	1.07	1.00	1.00	0.89
2056-2060	0.85	0.99	0.93	1.06	1.03	1.11	1.03	1.03	1.07	1.00	1.00	0.89
2061-2065	0.85	0.99	0.93	1.06	1.03	1.11	1.03	1.03	1.07	1.00	1.00	0.89
2066-2070	0.85	0.99	0.93	1.06	1.03	1.11	1.03	1.03	1.07	1.00	1.00	0.89

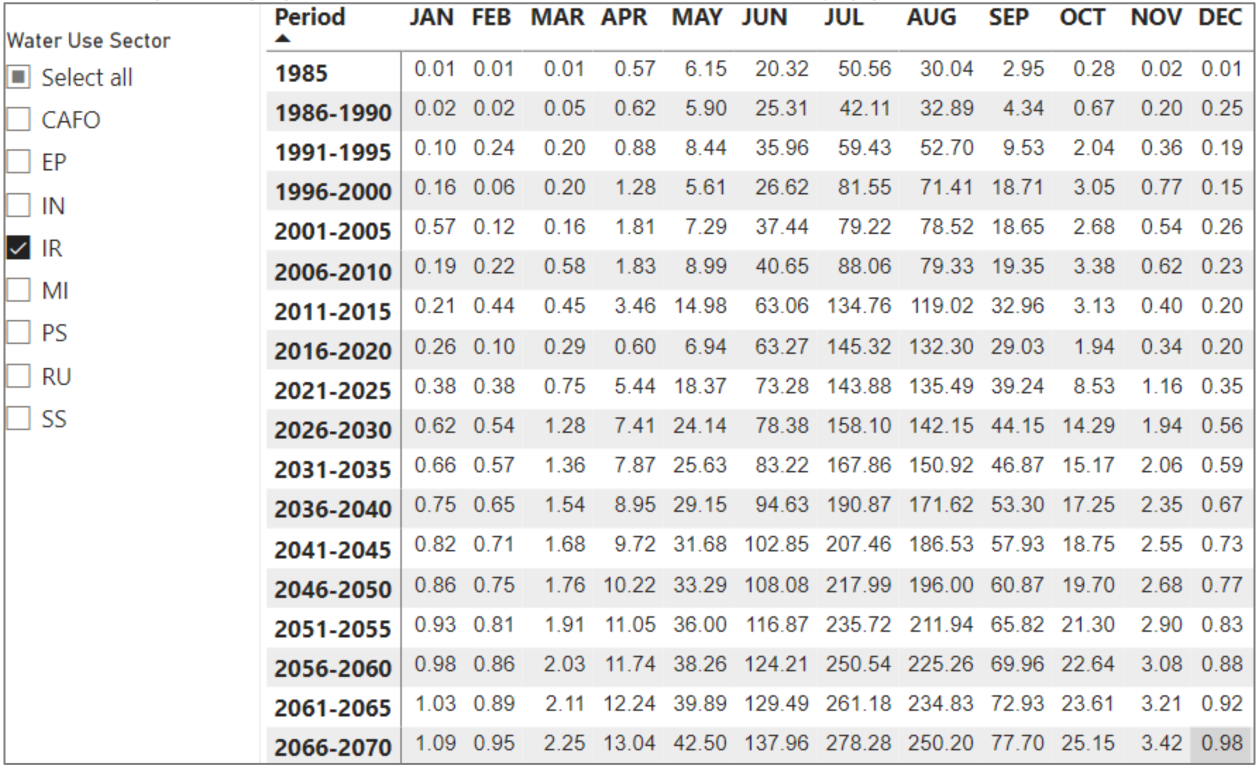
4.4.4 IRRIGATION (IR) WATER USE, MONTHLY AVERAGE AND PEAK VOLUMES, ALL SUBBASINS

Average monthly water demand for IR water use sector is concentrated in the summer months of June, July, and August. The average monthly volumes show a steady increase from 1985, with a historical high of 145.32 MGD in August in the period between 2016 and 2020 (Table 4-12). Irrigation water withdrawals are projected to continue increasing to a high of 278.28 MGD in July of the period 2066 to 2070.

Peak monthly water demand for IR water use sector is generally 5% to 13% higher than average monthly withdrawals, both for historical and future (Table 4-13).

The monthly usage pattern can best be seen by calculating indexed monthly water usage ratios, showing the magnitude of the monthly average usage compared to the annual average for that time period. Table 4-14 illustrates these trends by providing a detailed view of monthly indexed water usage ratios across multiple historical and projected periods. Irrigation water use patterns show seasonal variability, with use concentrated during the growing season in June, July, and August.

Table 4-12. Average Historical and Projected Future Monthly Water Demand by 5-Year Period, Irrigation (IR) Water Use, Millions of Gallons per Day (a)



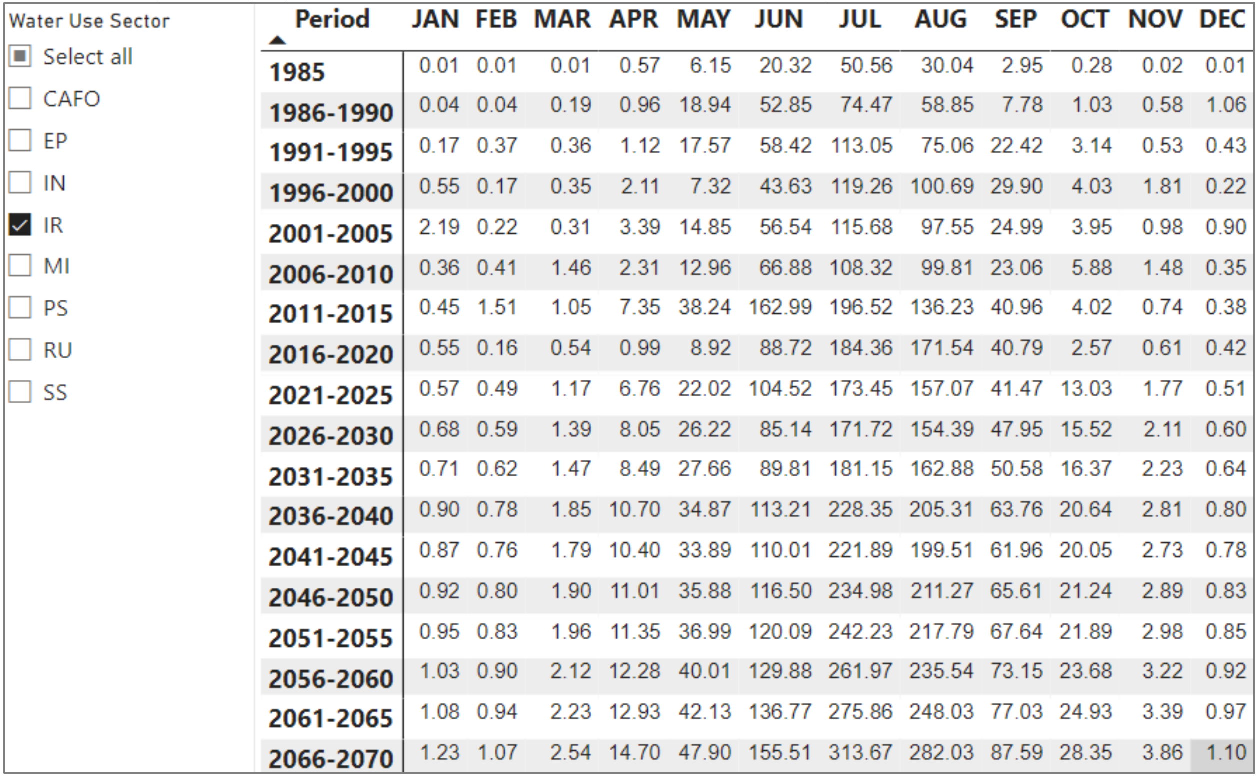
Water Use Sector

- ▣ Select all
- ☐ CAFO
- ☐ EP
- ☐ IN
- ☑ IR
- ☐ MI
- ☐ PS
- ☐ RU
- ☐ SS

Period ▲	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.01	0.01	0.01	0.57	6.15	20.32	50.56	30.04	2.95	0.28	0.02	0.01
1986-1990	0.02	0.02	0.05	0.62	5.90	25.31	42.11	32.89	4.34	0.67	0.20	0.25
1991-1995	0.10	0.24	0.20	0.88	8.44	35.96	59.43	52.70	9.53	2.04	0.36	0.19
1996-2000	0.16	0.06	0.20	1.28	5.61	26.62	81.55	71.41	18.71	3.05	0.77	0.15
2001-2005	0.57	0.12	0.16	1.81	7.29	37.44	79.22	78.52	18.65	2.68	0.54	0.26
2006-2010	0.19	0.22	0.58	1.83	8.99	40.65	88.06	79.33	19.35	3.38	0.62	0.23
2011-2015	0.21	0.44	0.45	3.46	14.98	63.06	134.76	119.02	32.96	3.13	0.40	0.20
2016-2020	0.26	0.10	0.29	0.60	6.94	63.27	145.32	132.30	29.03	1.94	0.34	0.20
2021-2025	0.38	0.38	0.75	5.44	18.37	73.28	143.88	135.49	39.24	8.53	1.16	0.35
2026-2030	0.62	0.54	1.28	7.41	24.14	78.38	158.10	142.15	44.15	14.29	1.94	0.56
2031-2035	0.66	0.57	1.36	7.87	25.63	83.22	167.86	150.92	46.87	15.17	2.06	0.59
2036-2040	0.75	0.65	1.54	8.95	29.15	94.63	190.87	171.62	53.30	17.25	2.35	0.67
2041-2045	0.82	0.71	1.68	9.72	31.68	102.85	207.46	186.53	57.93	18.75	2.55	0.73
2046-2050	0.86	0.75	1.76	10.22	33.29	108.08	217.99	196.00	60.87	19.70	2.68	0.77
2051-2055	0.93	0.81	1.91	11.05	36.00	116.87	235.72	211.94	65.82	21.30	2.90	0.83
2056-2060	0.98	0.86	2.03	11.74	38.26	124.21	250.54	225.26	69.96	22.64	3.08	0.88
2061-2065	1.03	0.89	2.11	12.24	39.89	129.49	261.18	234.83	72.93	23.61	3.21	0.92
2066-2070	1.09	0.95	2.25	13.04	42.50	137.96	278.28	250.20	77.70	25.15	3.42	0.98

Note: (a) Historical water withdrawals for Illinois subbasins are not available prior to 2007.

Table 4-13. Peak Historical and Projected Future Monthly Water Demand by 5-Year Period, Irrigation (IR) Water Use, Millions of Gallons per Day



Water Use Sector

- ▣ Select all
- ☐ CAFO
- ☐ EP
- ☐ IN
- ☑ IR
- ☐ MI
- ☐ PS
- ☐ RU
- ☐ SS

Period ▲	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.01	0.01	0.01	0.57	6.15	20.32	50.56	30.04	2.95	0.28	0.02	0.01
1986-1990	0.04	0.04	0.19	0.96	18.94	52.85	74.47	58.85	7.78	1.03	0.58	1.06
1991-1995	0.17	0.37	0.36	1.12	17.57	58.42	113.05	75.06	22.42	3.14	0.53	0.43
1996-2000	0.55	0.17	0.35	2.11	7.32	43.63	119.26	100.69	29.90	4.03	1.81	0.22
2001-2005	2.19	0.22	0.31	3.39	14.85	56.54	115.68	97.55	24.99	3.95	0.98	0.90
2006-2010	0.36	0.41	1.46	2.31	12.96	66.88	108.32	99.81	23.06	5.88	1.48	0.35
2011-2015	0.45	1.51	1.05	7.35	38.24	162.99	196.52	136.23	40.96	4.02	0.74	0.38
2016-2020	0.55	0.16	0.54	0.99	8.92	88.72	184.36	171.54	40.79	2.57	0.61	0.42
2021-2025	0.57	0.49	1.17	6.76	22.02	104.52	173.45	157.07	41.47	13.03	1.77	0.51
2026-2030	0.68	0.59	1.39	8.05	26.22	85.14	171.72	154.39	47.95	15.52	2.11	0.60
2031-2035	0.71	0.62	1.47	8.49	27.66	89.81	181.15	162.88	50.58	16.37	2.23	0.64
2036-2040	0.90	0.78	1.85	10.70	34.87	113.21	228.35	205.31	63.76	20.64	2.81	0.80
2041-2045	0.87	0.76	1.79	10.40	33.89	110.01	221.89	199.51	61.96	20.05	2.73	0.78
2046-2050	0.92	0.80	1.90	11.01	35.88	116.50	234.98	211.27	65.61	21.24	2.89	0.83
2051-2055	0.95	0.83	1.96	11.35	36.99	120.09	242.23	217.79	67.64	21.89	2.98	0.85
2056-2060	1.03	0.90	2.12	12.28	40.01	129.88	261.97	235.54	73.15	23.68	3.22	0.92
2061-2065	1.08	0.94	2.23	12.93	42.13	136.77	275.86	248.03	77.03	24.93	3.39	0.97
2066-2070	1.23	1.07	2.54	14.70	47.90	155.51	313.67	282.03	87.59	28.35	3.86	1.10

Table 4-14. Indexed Historical and Projected Future Monthly Average Water Demand by 5-Year Period, Irrigation (IR) Water Use, All Subbasins, Index Value

Period	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.00	0.00	0.00	0.06	0.68	2.18	5.47	3.24	0.33	0.03	0.00	0.00
1986-1990	0.00	0.00	0.01	0.06	0.62	2.69	4.53	3.52	0.46	0.07	0.02	0.02
1991-1995	0.01	0.02	0.01	0.06	0.56	2.46	4.34	3.75	0.63	0.10	0.02	0.01
1996-2000	0.01	0.01	0.01	0.07	0.58	2.48	4.71	4.15	1.05	0.11	0.04	0.03
2001-2005	0.03	0.01	0.01	0.09	0.67	2.53	4.21	4.19	0.96	0.09	0.03	0.02
2006-2010	0.01	0.01	0.03	0.09	0.63	1.99	4.36	3.94	0.97	0.06	0.03	0.01
2011-2015	0.01	0.01	0.01	0.11	0.47	2.03	4.35	3.84	1.06	0.04	0.01	0.01
2016-2020	0.01	0.01	0.01	0.15	0.19	**1.98**	4.53	4.20	0.97	0.05	0.01	0.03
2021-2025	0.01	0.02	0.03	0.15	0.52	2.05	4.33	3.81	1.11	0.05	0.03	0.05
2026-2030	0.02	0.01	0.03	0.19	0.61	1.99	4.01	3.60	1.12	0.06	0.05	0.05
2031-2035	0.02	0.01	0.03	0.19	0.61	1.99	4.01	3.60	1.12	0.06	0.05	0.05
2036-2040	0.02	0.01	0.03	0.19	0.61	1.99	4.01	3.60	1.12	0.06	0.05	0.05
2041-2045	0.02	0.01	0.03	0.19	0.61	1.99	4.01	3.60	1.12	0.06	0.05	0.05
2046-2050	0.02	0.01	0.03	0.19	0.61	1.99	4.01	3.60	1.12	0.06	0.05	0.05
2051-2055	0.02	0.02	0.03	0.19	0.61	1.99	4.01	3.60	1.12	0.06	0.05	0.05
2056-2060	0.02	0.02	0.03	0.19	0.61	1.99	4.01	3.60	1.12	0.06	0.05	0.05
2061-2065	0.02	0.02	0.03	0.19	0.61	1.99	4.01	3.60	1.12	0.06	0.05	0.05
2066-2070	0.02	0.02	0.03	0.19	0.61	1.99	4.01	3.60	1.12	0.06	0.05	0.05

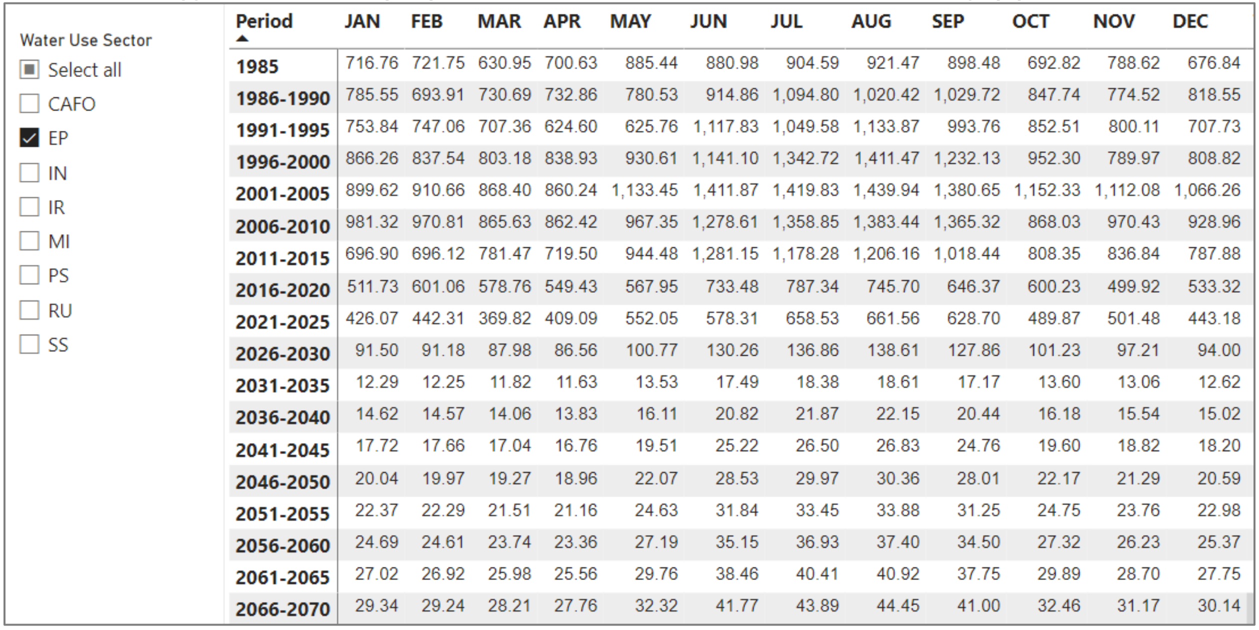
4.4.5 ENERGY PRODUCTION (EP) WATER USE, MONTHLY AVERAGE AND PEAK VOLUMES, ALL SUBBASINS

Historical average monthly water demand for EP water use sector have ranged from 511.7 MGD in January during the 2021 to 2025 time period, to over 1,400 MGD during the summer months in 2001 to 2005 (Table 4-15). This volume supported the coal power plants located in subbasin 12, Wabash Montezuma and subbasin 16, Wabash Vigo. In the period 2026 to 2030, when the second of the two coal plants is slated to close, the water use declines to ranges between 11.8 MGD in April of the time period 2031 to 2035 to a high of nearly 44.4 MGD in August of the period 2066 to 2070.

Peak monthly water demand for EP water use sector is generally 3% to 30% higher than average monthly withdrawals, both for historical and future projected (Table 4-16).

The monthly usage pattern shows that peak months are May through September.

Table 4-15. Average Historical and Projected Future Monthly Water Demand by 5-Year Period, Energy Production (EP) Water Use, Millions of Gallons per Day (a)

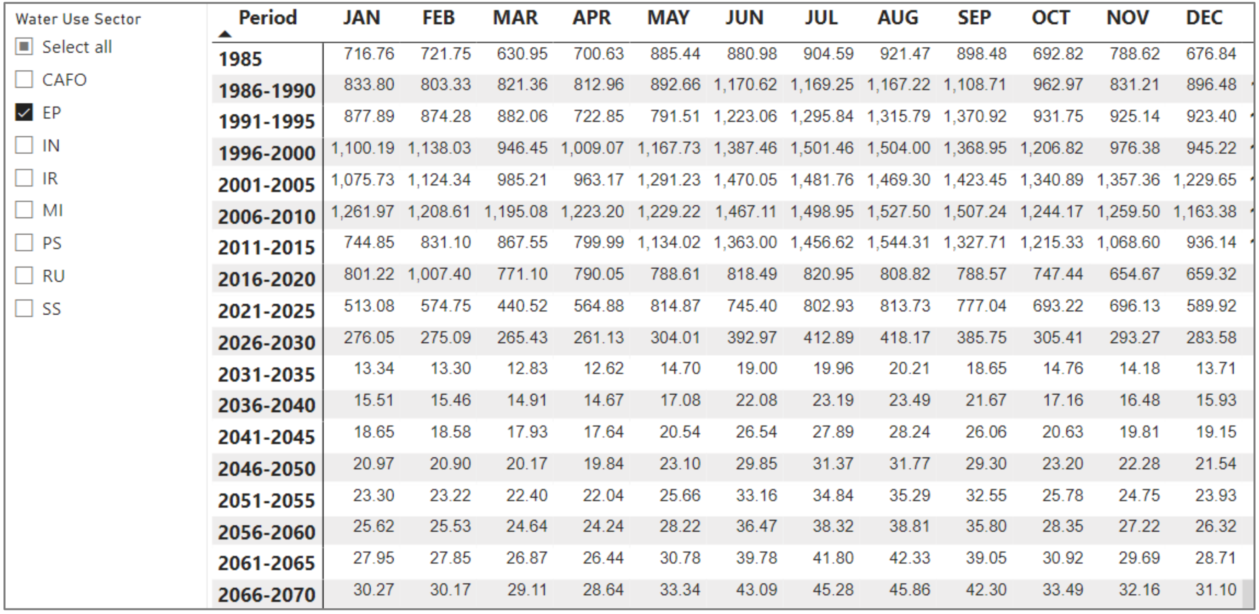


Water Use Sector
▣ Select all
☐ CAFO
☑ EP
☐ IN
☐ IR
☐ MI
☐ PS
☐ RU
☐ SS

Period	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	716.76	721.75	630.95	700.63	885.44	880.98	904.59	921.47	898.48	692.82	788.62	676.84
1986-1990	785.55	693.91	730.69	732.86	780.53	914.86	1,094.80	1,020.42	1,029.72	847.74	774.52	818.55
1991-1995	753.84	747.06	707.36	624.60	625.76	1,117.83	1,049.58	1,133.87	993.76	852.51	800.11	707.73
1996-2000	866.26	837.54	803.18	838.93	930.61	1,141.10	1,342.72	1,411.47	1,232.13	952.30	789.97	808.82
2001-2005	899.62	910.66	868.40	860.24	1,133.45	1,411.87	1,419.83	1,439.94	1,380.65	1,152.33	1,112.08	1,066.26
2006-2010	981.32	970.81	865.63	862.42	967.35	1,278.61	1,358.85	1,383.44	1,365.32	868.03	970.43	928.96
2011-2015	696.90	696.12	781.47	719.50	944.48	1,281.15	1,178.28	1,206.16	1,018.44	808.35	836.84	787.88
2016-2020	511.73	601.06	578.76	549.43	567.95	733.48	787.34	745.70	646.37	600.23	499.92	533.32
2021-2025	426.07	442.31	369.82	409.09	552.05	578.31	658.53	661.56	628.70	489.87	501.48	443.18
2026-2030	91.50	91.18	87.98	86.56	100.77	130.26	136.86	138.61	127.86	101.23	97.21	94.00
2031-2035	12.29	12.25	11.82	11.63	13.53	17.49	18.38	18.61	17.17	13.60	13.06	12.62
2036-2040	14.62	14.57	14.06	13.83	16.11	20.82	21.87	22.15	20.44	16.18	15.54	15.02
2041-2045	17.72	17.66	17.04	16.76	19.51	25.22	26.50	26.83	24.76	19.60	18.82	18.20
2046-2050	20.04	19.97	19.27	18.96	22.07	28.53	29.97	30.36	28.01	22.17	21.29	20.59
2051-2055	22.37	22.29	21.51	21.16	24.63	31.84	33.45	33.88	31.25	24.75	23.76	22.98
2056-2060	24.69	24.61	23.74	23.36	27.19	35.15	36.93	37.40	34.50	27.32	26.23	25.37
2061-2065	27.02	26.92	25.98	25.56	29.76	38.46	40.41	40.92	37.75	29.89	28.70	27.75
2066-2070	29.34	29.24	28.21	27.76	32.32	41.77	43.89	44.45	41.00	32.46	31.17	30.14

Note: (a) Historical water withdrawals for Illinois subbasins are not available prior to 2007.

Table 4-16. Peak Historical and Projected Future Monthly Water Demand by 5-Year Period, Energy Production (EP) Water Use, Millions of Gallons per Day



Water Use Sector
▣ Select all
☐ CAFO
☑ EP
☐ IN
☐ IR
☐ MI
☐ PS
☐ RU
☐ SS

Period	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	716.76	721.75	630.95	700.63	885.44	880.98	904.59	921.47	898.48	692.82	788.62	676.84
1986-1990	833.80	803.33	821.36	812.96	892.66	1,170.62	1,169.25	1,167.22	1,108.71	962.97	831.21	896.48
1991-1995	877.89	874.28	882.06	722.85	791.51	1,223.06	1,295.84	1,315.79	1,370.92	931.75	925.14	923.40
1996-2000	1,100.19	1,138.03	946.45	1,009.07	1,167.73	1,387.46	1,501.46	1,504.00	1,368.95	1,206.82	976.38	945.22
2001-2005	1,075.73	1,124.34	985.21	963.17	1,291.23	1,470.05	1,481.76	1,469.30	1,423.45	1,340.89	1,357.36	1,229.65
2006-2010	1,261.97	1,208.61	1,195.08	1,223.20	1,229.22	1,467.11	1,498.95	1,527.50	1,507.24	1,244.17	1,259.50	1,163.38
2011-2015	744.85	831.10	867.55	799.99	1,134.02	1,363.00	1,456.62	1,544.31	1,327.71	1,215.33	1,068.60	936.14
2016-2020	801.22	1,007.40	771.10	790.05	788.61	818.49	820.95	808.82	788.57	747.44	654.67	659.32
2021-2025	513.08	574.75	440.52	564.88	814.87	745.40	802.93	813.73	777.04	693.22	696.13	589.92
2026-2030	276.05	275.09	265.43	261.13	304.01	392.97	412.89	418.17	385.75	305.41	293.27	283.58
2031-2035	13.34	13.30	12.83	12.62	14.70	19.00	19.96	20.21	18.65	14.76	14.18	13.71
2036-2040	15.51	15.46	14.91	14.67	17.08	22.08	23.19	23.49	21.67	17.16	16.48	15.93
2041-2045	18.65	18.58	17.93	17.64	20.54	26.54	27.89	28.24	26.06	20.63	19.81	19.15
2046-2050	20.97	20.90	20.17	19.84	23.10	29.85	31.37	31.77	29.30	23.20	22.28	21.54
2051-2055	23.30	23.22	22.40	22.04	25.66	33.16	34.84	35.29	32.55	25.78	24.75	23.93
2056-2060	25.62	25.53	24.64	24.24	28.22	36.47	38.32	38.81	35.80	28.35	27.22	26.32
2061-2065	27.95	27.85	26.87	26.44	30.78	39.78	41.80	42.33	39.05	30.92	29.69	28.71
2066-2070	30.27	30.17	29.11	28.64	33.34	43.09	45.28	45.86	42.30	33.49	32.16	31.10

4.5 Daily Peaking Factors

In addition to monthly peaking factors, utility managers also are concerned about daily peaks in water usage. The daily peaking factor is calculated as the ratio of the daily peak water use by the average daily water use. The hydraulic models used to design water utility systems utilize these peak values in their system designs

Daily peaks can be caused by a variety of factors. Typical daily demand patterns frequently have two peaks, one early in the morning and another peak of lower intensity corresponding with dinner time (Gato-Trinidad, 2014). Peaking factor is important in water and wastewater system design and operation – it is used to design water treatment processes and water distribution systems which operate efficiently, safely, and cost-effectively, and to ensure adequate system reliability across a range of anticipated water demand conditions (Swamee and Sharma, 2008). Projecting daily peaks can also be useful in optimizing water-system-level pumping schedules in order to minimize energy costs (Jentgen, 2007) and the methods used to project hourly demand frequently utilize artificial neural networks (Bougadis, 2005).

Utilities within the Study Area have reported daily peaks in their Preliminary Engineering Reports (PERs) for water distribution system and treatment improvements. The cities of Frankfort, Lebanon, Kokomo, and Warsaw released PERs with an examination of treatment and supply improvements, with review of peaking factors. The peaking factors inform infrastructure decisions as peaking factors are based upon daily flow rates throughout the water system or plant. Such decisions include water and wastewater treatment plant design, and distribution system design and storage requirements – to meet water demand, to ensure sufficient water pressure, and to maintain appropriate water residence/travel times within the distribution pipes (Swamee and Sharma, 2008). Below is a summary of information obtained from the PERs.

- The Frankfort Water Works (Wessler Engineering, 2020) presented a review of water system improvements in response to various new developments. A variable peaking factor dependent on the water sector utilizing flow was present. Industrial users had a peaking factor of 1.2, while residential users had a peaking factor of 1.6.
- Lebanon Utilities Distribution System and Treatment Improvements (Butler Fairman and Seufert, 2021) provided a 20-year future overview of flow based on previous historical estimates to aid future improvements, with a future daily peaking factor estimated at 2.5.
- The Kokomo Wastewater Treatment Plant (WWTP) investigated a Peak Excess Flow Treatment Facility Project (Lochmueller Group, 2020), with an overview of 2017, 2018, and 2019 flow values, yielding a peaking factor of 1.78, 1.29, and 1.69 respectively.
- Warsaw's Wastewater Treatment Plant Expansion (Wessler Engineering, 2018) determined peaking factors based upon an increase in average design flow, with a peaking factor of 3 for combined domestic and industrial uses.

5.0 Baseline Water Budget Component Estimates

A time series for each water budget component of each subbasin was developed for the recent historical period (2007 to 2022) and the future planning horizon (2023 to 2072). A description of the analysis framework was provided in Chapter 3, and a description of the water demand water budget components and water demand results was provided in Chapter 4. This Chapter describes development of historical and future time series for all other water budget components, providing more detail to the individual framework components described in Section 3.1.1.

5.1 Measured Streamflow

Measured streamflow reflects observed conditions, including flow from natural and anthropogenic processes. Daily average streamflow measurements at USGS streamflow gage stations were used to quantify the historical total runoff from the upstream watershed, including surface runoff, baseflow, return flows of the non-consumptive portion of water withdrawals, and reservoir releases (see Figure B-1 for a map of gage locations). Return flows and reservoir releases reflect anthropogenic increases in total runoff, while their counterparts – the consumptive portion of water withdrawals and inflow captured to storage in reservoirs – reflect anthropogenic decreases to total runoff.

5.1.1 HISTORICAL

Historical streamflow at each subbasin was represented using measured USGS gage data as shown in Table 3-1 and described further in Appendix B.1.

5.1.2 FUTURE

Future measured streamflow is not a component of the future water budget. As described in Section 5.5, the water budget relies on future natural streamflow derived from historical natural streamflow.

5.2 Instream Flow

For the purposes of this Study, instream flows[8] are defined as the minimum amount of natural baseflow that should be left in a stream to support the ecological health of the stream, recreational use, and water quality. Instream flows are not available to be withdrawn or contribute to estimates of water availability.

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[8] The Indiana Natural Resources Commission is authorized to determine and establish minimum instream flows based on Indiana Code 14-25-7-14. The statute does not explicitly define minimum instream flows for river systems, but suggests that when values are established, they should be based on the varying low flow characteristics of streams and the importance of instream and withdrawal uses. Instream uses means any use of water that uses surface water in place, including commercial and recreational navigation, hydroelectric power generation, waste assimilation, fish and wildlife habitat, general recreation, and maintenance of environmental and aesthetic values.

5.2.1 HISTORICAL

Indiana’s Water Shortage Plan (IDNR, 2015) provides some background on minimum instream flow values in Indiana. Historically, the streamflow equivalent to the 7Q10 (lowest seven-day average flow having a 10-year recurrence interval) is considered the absolute minimum instream flow. This metric is critical to protecting water quality and is used as a factor in determining the level of treatment required for discharges into the State’s rivers and streams. Recognizing that it is desirable to protect the 7Q10 flow to maintain water quality in addition to other instream uses, the Water Shortage Plan recommends initiating reductions to water withdrawals during drought conditions before flow decline to the 7Q10, typically when the Q80 (the daily average flow that is exceeded 80% of the time) is met. For the months of May through October, the Q80 is a trigger to initiate a local action process to protect aquatic and riparian habitat, which could include monitoring of water withdrawals, voluntary reduction of water withdrawals, or development of local or regional policies that reflect public preferences regarding water use priorities.

Consistent with recent regional water studies in Indiana (INTERA, 2021a), this Study uses both a 7Q10 metric and a Q90 metric (the daily average flow that is exceeded 90% of the time) to define minimum instream flows within each subbasin. The 7Q10 is used to define minimum instream flow values, consistent with the Water Shortage Plan, during the typically drier months of June through November. The Q90 is used to define minimum instream flow values during the typically wetter months of December through May. There is no guidance in the Water Shortage Plan for defining minimum instream flows outside of shortage conditions and outside of the drier summer months – the Q90 metric is often used as a presumptive standard for environmental flow protection when instream flow values are not defined (Gleeson and Richter, 2018).

To calculate 7Q10 and Q90 for each subbasin, the measured USGS gage daily flow data was collected from 1990 to 2020 (or shorter if the full record was not available), a period that reflects recent climate and streamflow trends (Blum et al., 2019) and is consistent with other regional water studies (Letsinger and Gustin, 2024). Table 5-1 presents the 7Q10 and Q90 values for each subbasin, along with the assessment periods used to calculate the values. As shown, instream flow values vary widely by subbasin across the Study Area, from a 7Q10 value of 1 MGD (2 cfs) and Q90 value of 3 MGD (5 cfs) at Subbasin 13, up to 1,034 MGD (1,600 cfs) for 7Q10 and 1,939 MGD (3,000 cfs) for Q90 at Subbasin 16 (furthest downstream in the Study Area).

Table 5-1. Instream Flow Values by Subbasin

Subbasin	USGS gage	Assessment Period	7Q10 (cfs)	7Q10 (MGD)	Q90 (cfs)	Q90 (MGD)
01	03331753 Tippecanoe River at Winamac, IN	2001-2020	181	117	289	187
02	03333050 Tippecanoe River near Delphi, IN	1990-2020	297	192	500	323
03	03333700 Wildcat Creek at Kokomo, IN	1990-2020	14	9	25	16
04	03334500 South Fork Wildcat Creek near Lafayette, IN	1990-2020	23	15	39	25
05	03335000 Wildcat Creek near Lafayette, IN	1990-2020	71	46	127	82
06	03335500 Wabash River at Lafayette, IN	1990-2020	908	587	1,761	1,138
07	03336000 Wabash River at Covington, IN	1990-2020	1,137	735	2,050	1,325
08	03339500 Sugar Creek at Crawfordsville, IN	1990-2020	14	9	34	22
09	03336645 Middle Fork Vermilion River above Oakwood, IL	1990-2020	5	3	17	11
10	03338780 North Fork Vermilion River near Bismarck, IL	1990-2020	5	3	19	12
11	03339000 Vermillion River near Danville, IL	1990-2020	32	21	80	52
12	03340500 Wabash River at Montezuma, IN	1990-2020	1,213	784	2,400	1,551
13	03340800 Big Raccoon Creek near Fincastle, IN	1990-2020	2	1	5	3
14	03341300 Big Raccoon Creek at Coxville, IN	1990-2020	39	25	63	41
15	03341500 Wabash River at Terre Haute, IN	1990-2020	1,433	926	2,810	1,816
16	Synthetic[1] (Wabash at Vigo, IN)	1990-2020	1,600	1,034	3,000	1,939

Note:
[1] A synthetic hydrology was developed for Subbasin 16 to represent the downstream boundary of the Study Area. Additional details are provided in Appendix B.1.
Key:
cfs = cubic feet per second
MGD= million gallons per day
USGS= U.S. Geological Survey

5.2.2 FUTURE

The same instream flow values were used for historical and future periods.

5.3 Reservoir Operations

Upstream dam and reservoir operations have the potential to increase or decrease the measured streamflow at a downstream location. When inflow is captured for storage, downstream measured streamflow is decreased relative to flows that would have occurred absent the reservoir. Conversely, when dams release water from storage, downstream measured streamflow is increased relative to a condition without dam releases.

5.3.1 HISTORICAL

Major dams in the Study Area were identified and screened based on storage capacity as identified in the NID – those with less than 1,000 acre-feet of normal storage were excluded from further analysis, as they do not have significant storage capacity to influence regional water availability. Initially, 16 reservoirs were identified and further analyzed based on storage capacity, the primary purpose of the dam, and data availability. As described in Appendix B.6, only three dams were identified that either (1) were capable and authorized to store large peak flows, or (2) were required to release minimum flows to augment low flows downstream of the dam during dry months. These dams, along with influential dams from the Headwaters region, are shown in Table 5-2.

Table 5-2. Dams Included in Water Budget Calculations

Dam	Waterway	Subbasin	Primary Purpose	Maximum Storage Capacity (acre-feet)
Cecil M. Harden Dam	Big Raccoon Creek	14	Flood Risk Reduction	132,800
Oakdale Dam	Tippecanoe River	02	Recreation	24,752
Lake Vermilion Dam	Vermilion River	11	Water Supply	15,352
Mississinewa Dam	Mississinewa River	Headwaters	Flood Risk Reduction	368,400
J. Edward Roush Dam	Wabash River	Headwaters	Flood Risk Reduction	153,100
Salamonie Dam	Salamonie River	Headwaters	Flood Risk Reduction	263,600

Daily operational data is publicly available only for Cecil M. Harden Dam from the USACE Louisville District (USACE, 2024). Estimates of daily dam operations were developed for Oakdale Dam and Lake Vermilion Dam based on a review of publicly available streamflow data and information provided by personal communication with dam owners. The effects of these dams were analyzed by calculating a daily change in reservoir storage as daily reservoir releases (outflows) minus daily capture (inflows), then averaging the values on a monthly basis. A positive value indicates outflows exceeded inflows, and the reservoir was releasing stored water. A negative value indicates inflows exceeded outflows, and the reservoir was accumulating water. Mean monthly changes in reservoir storage are shown in Figure 5-1. In general, the flood control reservoirs (Cecil M. Harden Dam and the three Headwaters Dams) have the largest flow effect, while the Vermilion Dam and Oakdale Dam have a relatively small flow effect. During the months of July through November, the flood control reservoirs typically release stored water in advance of flood season, which results in a net decrease in flood control reservoir storage. During the months of February through May, the flood control reservoirs show net increases in reservoir storage due to capture of snowmelt and of peak flows during storm events.

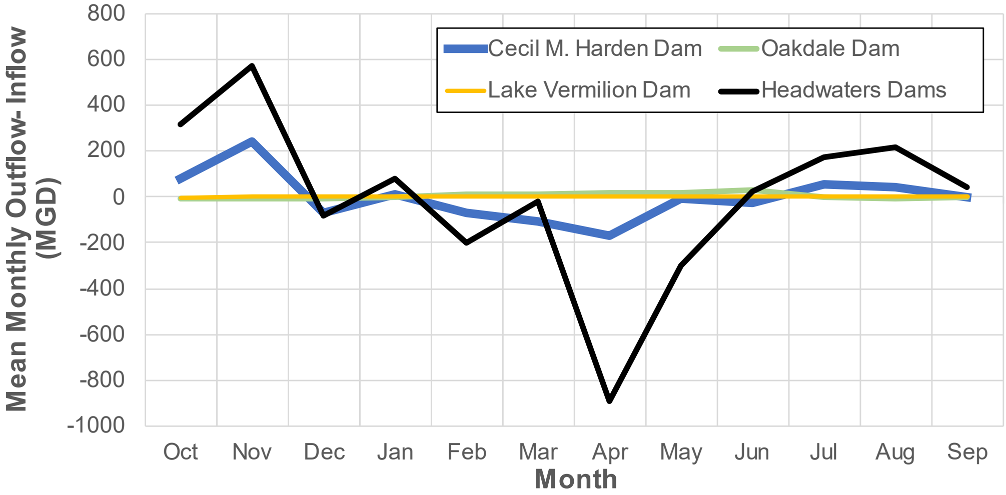


Figure 5-1. Mean Monthly Changes in Reservoir Storage from 2007-2022 for Major Reservoirs in the Study Area

5.3.2 FUTURE

Future reservoir operations were assumed to mimic historical reservoir operations. As described in Section 5.5, the future time period of 2023-2072 was created by resequencing the years from 2007-2022. For each future year, the historical reservoir operations from 2007-2022 were preserved.

5.4 Return Flows

Return flows represent the non-consumptive portion of water withdrawals that are returned back to the stream or percolated as groundwater.

5.4.1 HISTORICAL

The basis of historical return flows for the public supply, energy production, and industrial and commercial water sectors were records of discharge monitoring reports regulated under the NPDES program and tracked in the ECHO database (EPA, 2020). A full description of the method to develop return flows is in Appendix B.4 and Appendix B.5. In total, 365 discharge points were identified in the Study Area, including both Indiana and Illinois. Data retrieved from ECHO included monthly, quarterly, or annual average discharges from regulated facilities for the period 2007-2022. Return flow locations were cross checked with the IDEM database of NPDES returns to correct any erroneous return flow locations. Each return flow was designated as energy production, public supply, or industrial and commercial based on the facility description. Quarterly or annual values were disaggregated to daily estimates, and outlier data were removed from the dataset by comparing to historical trends and checking for corroborating increases in downstream flow gages.

Major return flows in the North Central Indiana region include cooling water discharge from energy producers, wastewater treatment plant effluent, discharges from industrial facilities, and dewatering discharge from mines and construction sites. There was no simple way to identify return flows that were associated with rural or miscellaneous water use sectors as identified in the SWWF – explicit return flows were not calculated for these sectors.

To quality check the return flow data against water withdrawal data, a time series of monthly withdrawals from the SWWF database was compared against a time series of monthly reported return flows for public water supply systems, energy producers, and industrial and commercial entities. To the extent possible, identifying data from the SWWF was matched to identifying data from ECHO, and additional documentation from public utilities was reviewed to clarify differences in facility name and other factors that may create a mismatch between withdrawals and return flows (e.g., when industrial withdrawals are sent to a public water treatment plant, the withdrawals are classified as industrial and commercial but the return flows are classified as public supply). Return flow volumes for the energy production and industrial and commercial sectors were generally consistent with withdrawal volumes. The main exception was for large coal energy generation facilities, which generally reported higher monthly return flow volumes through ECHO than withdrawal volumes through SWWF. This discrepancy could be due to measurement uncertainty or other factors related to on-site water use. To more accurately reflect the consumptive use proportion, return flows from all coal facilities were adjusted to be 99% of the monthly water withdrawal volumes (based on consumptive use estimated from Meldrum et al. 2013 and Shaffer and Runkle, 2007).

As observed in other regional water studies (Wiener et al. 2020; INTERA, 2021a), monthly return flows from many wastewater treatment plants significantly exceeded the monthly water withdrawals from associated water utilities, particularly during wetter periods. This factor was attributed to the reporting of combined sewer overflow (CSO) data to the ECHO database. A CSO is a system that transports sewage and urban runoff together. During a storm event, heavy rainfall produces runoff that increases the reported discharge from a CSO. This reported flow reflects both sewage water, the non-consumptive return flows of water previously withdrawn, and storm runoff, which represents instantaneous streamflow generated within the subbasin. For the purposes of this water availability Study, inclusion of storm runoff would artificially increase return flows, since it does not reflect a true return of water withdrawn. In addition, the runoff component of CSO return flow is a natural contribution to measured streamflow downstream. Subtracting this value from measured streamflow to produce natural streamflow would artificially decrease natural streamflow and could produce lower natural baseflow. An initial analysis indicated up to 35% of annual return flow volumes from wastewater treatment plants in the Study Area could be comprised of storm runoff. This volume was substantial enough to warrant an adjustment to large, reported return flows.

A method was formulated to remove the storm flow component of WWTP return flows by comparing water withdrawals, return flows, and measured streamflow at gages downstream of the withdrawal and return flow locations. For each of the major 10 WWTPs, a SWWF dataset was compiled that reflects the assumed water withdrawals associated with the WWTP. The monthly data for WWTPs and SWWFs was plotted from 2007-2022 and compared to measured streamflow downstream. Time periods were identified with minimum annual return flows, which generally correlated with periods of minimal streamflow, when storm runoff was contributing minimally to return flow. A ratio was calculated for this period that reflected the non-consumptive portion of the SWWF withdrawal, which was taken to be the actual return flow of withdrawn water at that discharge point. The lowest ratio (i.e., highest consumptive use) throughout the historical period was applied to the time series of monthly withdrawals to generate adjusted monthly return flow volumes. An example of original data and adjusted data for one paired SWWF and WWTP combination is shown in Figure 5-2.

In total, 12 WWTP return flow time series were adjusted from the NPDES reported value, reducing the return flows from these facilities from 23 BG per year (reported) to 15 BG per year, an adjustment of 35%. When compared to average annual water withdrawals in the Study Area of approximately 16.5 BG per year, the adjusted return flows reflect a consumptive use factor of about 10%, which is a typical consumptive use factor for public supplies. Most of the adjustments for these WWTP return flows occurred in the wetter months (Figure 5-3).

For all other water sectors, return flows were estimated consistent with other regional water studies (Letsinger and Gustin, 2024) as shown in Table 5-3.

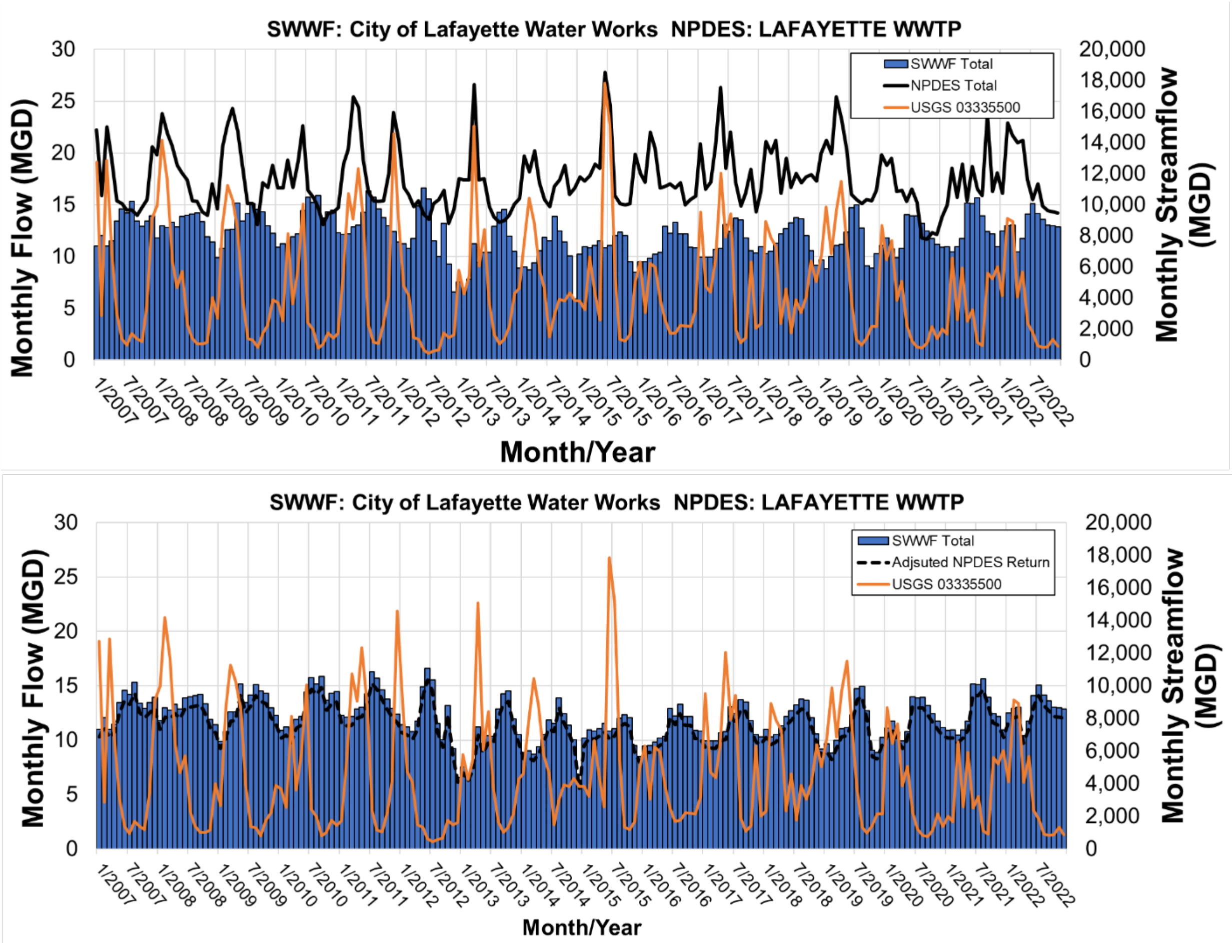


Figure 5-2. Monthly Water Withdrawals and Return Flows (left axis) and Measured Monthly Streamflow (right axis), for a Paired Public Water Supply Withdrawal and Wastewater Treatment Plant

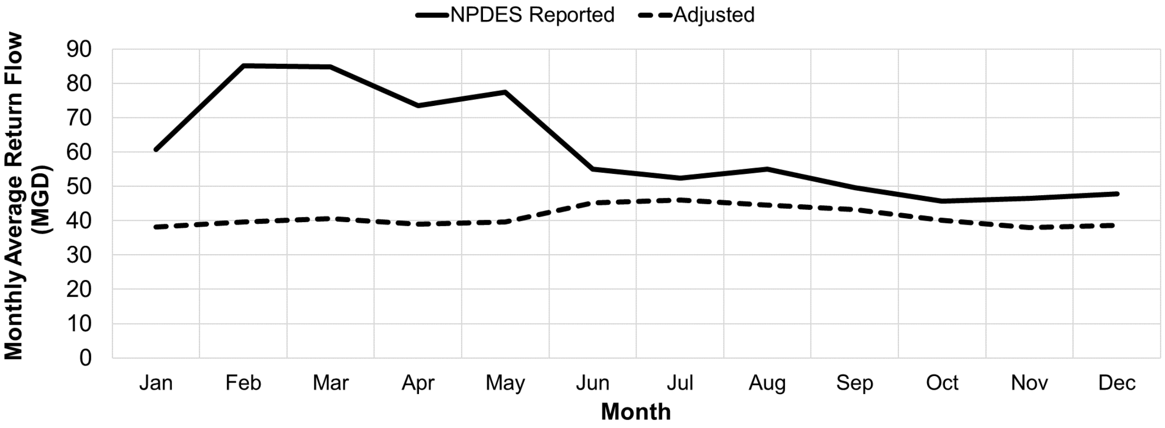


Figure 5-3. Reported NPDES Return Flows and Adjusted Return Flows for the Twelve Largest Wastewater Treatment Plans in the Study Area

Table 5-3. Historical Return Flow Estimates for Irrigation, CAFOs, and Self-Supplied Residential

Sector	Return Flow Assumption
Irrigation	80% of irrigation withdrawals are considered consumptive, either taken up by crops and livestock or lost through evapotranspiration, consistent with regional estimates of crop demand (Shaffer, 2009; Shaffer and Runkle, 2007). The remaining 20% is assumed to be return flow that first infiltrates into the earth and eventually returns to the stream as baseflow. To simplify the assessment, these return flows are assumed to occur instantaneously. The potential impact of agriculture drainage tiles are not accounted for in irrigation return flows, though Indiana has the highest percentage of cropland with drainage tiles in the country (Frankenberger and Kladivko, n.d.). Future updates to the water availability method could evaluate whether the effect of drainage tiles supports the assumption of instantaneous irrigation return flow, or whether infiltration and runoff processes cause meaningful delays or losses that should be accounted for.
CFO/CAFO	80% of livestock withdrawals are considered consumptive for animal related operations, consistent with regional estimates for median consumption at livestock farms (Shaffer, 2009). The remaining 20% is assumed to be return flow that first infiltrates into the earth and eventually returns to the stream as baseflow. To simplify the assessment, these return flows are assumed to occur instantaneously.
Self-Supplied Residential Domestic	Seasonal return flow estimates are based on regional consumptive used factors for self-supplied residential use (Shaffer, 2009), and are estimates as a percentage of withdrawals by season that are returned instantaneously: 100% in winter, 98% in spring, 81% in the summer, and 93% in the fall.

Key:
CAFO = Concentrated Animal Feeding Operation
CFO = Confined Feeding Operation

5.4.2 FUTURE

Linear regressions were used to develop future return flows for public supply and industrial and commercial use sectors for each subbasin. Equations were developed based on regression over the full year or on a seasonal basis, developing best fit coefficients between historical withdrawals and return flows by subbasin. Additional details are provided in Appendix F.

For energy production sectors, the near-term energy source in the Study Area is coal. Based on data from the U.S. Department of Energy, Energy Information Administration, the major regional coal plants have a consumptive use factor of 1%, meaning 99% of water withdrawals are returned back to a waterway. This same 1% consumptive use factor was used until coal was projected to be phased out under the future baseline scenario. Future water withdrawals for energy production were estimated using energy generation growth by energy generation technology as reported in Indiana Electricity Projections (Phillips et al., 2023) (additional information is provided in Appendix D.2). Future water withdrawal volumes were estimated based on future energy demand, generation mix, and withdrawal intensity by energy generation source. For each energy generation technology, a consumptive use factor was defined, and the remaining portion of withdrawals were assumed to be return flows (Table 5-4).

Table 5-4. Future Return Flow Estimates by Energy Generation Technology

Generation Type	Withdrawal Intensity (gallon/MWh)	Return Flows (% of withdrawals)	Source
Open Loop Cooling	43.006	99%	EIA data average for Indiana
Flat Panel Photovoltaic (PV)	0.006	0%	Meldrum et al. (2013)
Onshore Wind	0.001	0%	Meldrum et al. (2013)
Combined Cycle Cooling Tower	0.731	31%	EIA data average for Indiana
Combustion Turbine: Gas	0.43	88%	Meldrum et al. (2013)

Key:
EIA = U.S. Department of Energy, Energy Information Administration
MWh = megawatt hour

For all other sectors, future return flows were estimated using the approach defined in Table 5-3.

5.5 Natural Streamflow

Natural streamflow is defined as the daily average flow at a USGS streamflow gage station that would occur if there were no anthropogenic effects (i.e., water withdrawals, return flows, and reservoir storage) occurring in the watershed. Evaluation of the natural streamflow at each USGS stream gage station coupled with separation of natural streamflow into natural baseflow and natural stormflow are the basis of the water availability analysis framework.

5.5.1 HISTORICAL

As shown graphically in Figure 3-4**Error! Reference source not found.**, historical daily natural streamflow was calculated by subtracting daily return flows, adding daily withdrawals, and adding daily net changes in reservoir storage summed over the entire watershed upstream of the USGS station to the daily measured streamflow at the USGS station.

5.5.2 FUTURE

Although the INCCIA study produced future daily streamflow data, the model outputs exhibit systematic biases from individual GCMs. This challenge is fairly common and is resolved by bias-correcting model outputs. In this Study, bias-corrected future daily natural streamflow was calculated in two steps: hydrologic sequencing and hydrologic change factor application.

Hydrologic sequencing: A sequence of future streamflow years was developed using future streamflow data from the INCCIA. The INCCIA used a climate period analysis, where climate change was modeled by scaling a baseline historical condition, with every year of the simulation was scaled in a way that represents the climate change signal centered around a future 30-year climate period. For example, the INCCIA used a historical 30-year period of 1984-2013. To produce data for a future 30-year period of 2011-2040, the 1984-2013 temperature and precipitation time series was scaled by the effects of climate change. Daily values from the historical period were multiplied by a factor that increased or decreased their magnitude in a way that was statistically consistent with the change in temperature and precipitation simulated by the GCM. The historical dataset was repeated into the future, but with a change in temperature and precipitation relative to the baseline historical condition.

To rectify the difference between the historical period of this Study (2007-2022) and the INCCIA (1984-2013), an analysis was conducted to select years from 2007-2022 that best matched the seasonal streamflow volume of the years 1984-2006. Winter/spring and summer/fall flow volumes were totaled, and the years that most closely matched both seasons (i.e., “wet” and “dry”) were identified for each gage. The years that most frequently matched across all 26 gages of the combined North Central Indiana and Headwaters Study Areas were selected as representative. The final hydrologic sequence is shown in Table 5-5. Two representative exceedance curves of measured streamflow and the resequenced flow (Figure 5-4) show the range of flows in the INCCIA period are generally well represented using flows from 2007-2022.

Table 5-5. Future Streamflow Hydrologic Sequence

Actual Historical Year	Representative Year	Future Year(s)	Actual Historical Year	Representative Year	Future Year(s)
1984	2020	2041, 2071	1999	2012	2026, 2056
1985	2013	2042, 2072	2000	2021	2027, 2057
1986	2014	2043	2001	2021	2028, 2058
1987	2021	2044	2002	2022	2029, 2059
1988	2012	2045	2003	2015	2030, 2060
1989	2021	2046	2004	2010	2031, 2061
1990	2018	2047	2005	2007	2032, 2062
1991	2007	2048	2006	2010	2033, 2063
1992	2018	2049	2007	2007	2034, 2064
1993	2017	2050	2008	2008	2035, 2065
1994	2016	2051	2009	2009	2036, 2066
1995	2021	2052	2010	2010	2037, 2067
1996	2021	2023, 2053	2011	2011	2038, 2068
1997	2011	2024, 2054	2012	2012	2039, 2069
1998	2018	2025, 2055	2013	2013	2040, 2070

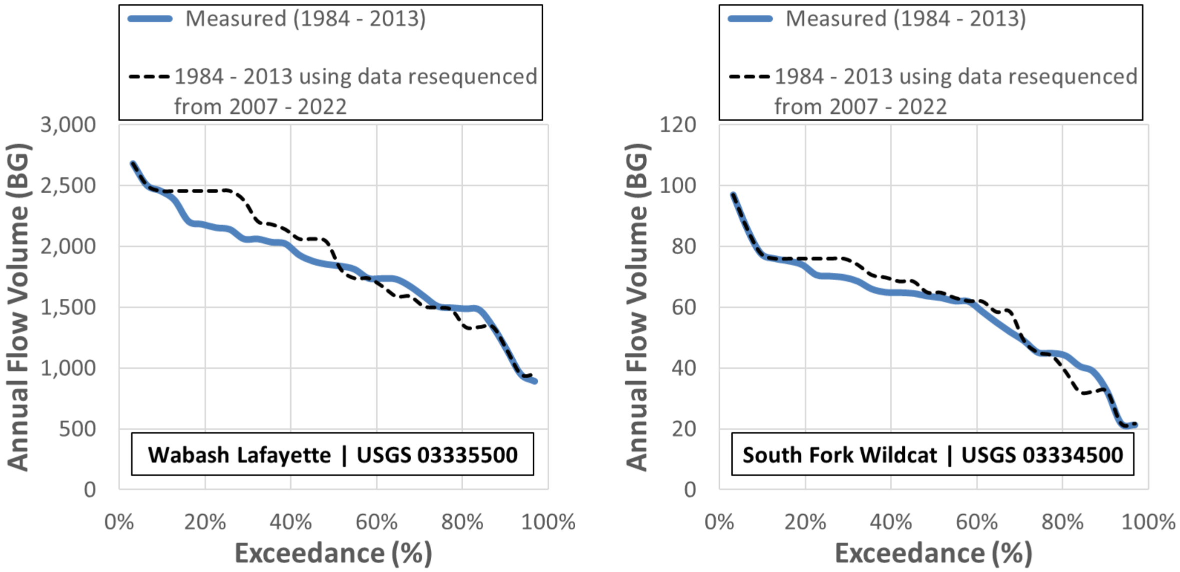
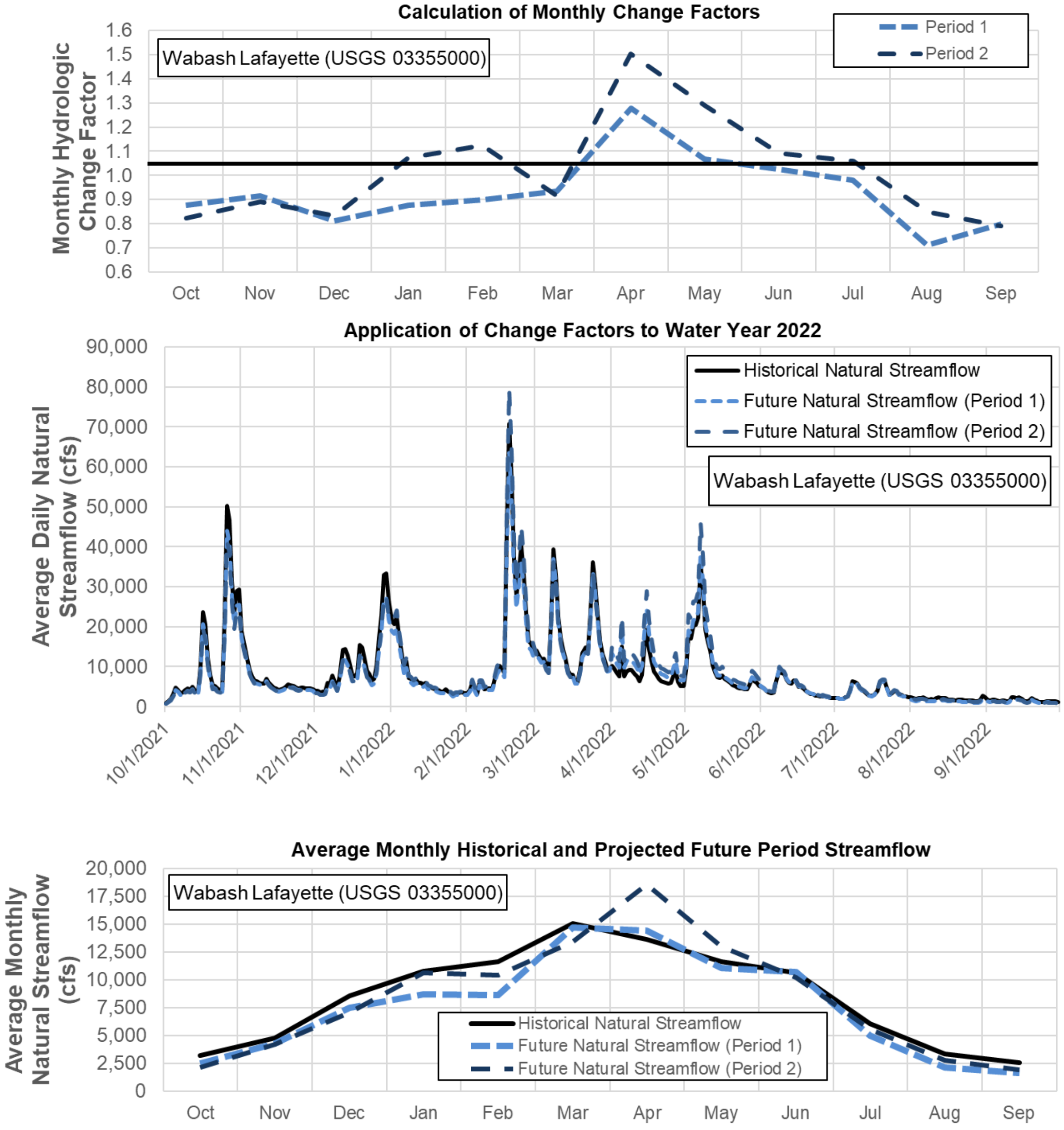


Figure 5-4. Representative Exceedance Curves of Measured Historical Streamflow and Resequenced Data

Hydrologic change factor application: Each year of future streamflow was adjusted using a set of monthly hydrologic change factors. The adjustment process is similar to the Delta Method, a climate change analysis technique that adds the difference between simulated future and historical climate data to the actual historical climate data to create a statistically bias-corrected model (Navarro-Racines et al., 2020). A change factor represents the change in future streamflow predicted by a hydrologic model, relative to the historical streamflow predicted by a hydrologic model. A monthly change factor typically ranges between 0.5 and 1.5, and when applied to historical measured streamflow it produces an estimate of how future climate change could impact the magnitude of historical measured streamflow. Change factors less than one would reduce streamflow-volume estimates, while change factors greater than one would increase streamflow-volume estimates. The hydrologic change factor approach has been applied widely in other regions, including to estimate future effects of streamflow and groundwater interactions under different climate conditions (CA DWR, 2018).

In the INCCIA study (Cherkauer et al., 2021), historical streamflow was simulated using a hydrologic model that used historical air temperatures and precipitation, among other variables, as inputs. The same model was used to simulate future streamflow, but the historical air temperature and precipitation time series were scaled by the effects of future climate change centered around three future periods: 2011-2040 (Period 1), 2041-2070 (Period 2), and 2071-2100 (Period 3). Historical and future streamflow data for all three periods of the INCCIA study was provided to the project team for most USGS stream gages that aligned with subbasin outlets. To develop a monthly change factor for each USGS gage, monthly average future simulated flow was calculated for each period and divided by the monthly average historical flow. A set of twelve change factors was calculated for each period and each gage. Daily natural streamflow in each future year was multiplied (i.e., scaled) by the change factor for the relevant period, with change factors switching to Period 2 for all years after 2040. This process is illustrated in Figure 5-5.



Note: Generation of Change Factor (top), Application of Change Factor to Specific Year (middle), and Average for Future Periods Compared to Historical (bottom). Period 1 = 2011-2040 and Period 2 = 2041-2070 as defined in Cherkauer et al. (2021).

Figure 5-5. Climate Change Factor Example for USGS 03355000 (Wabash Lafayette)

5.6 Natural Baseflow

Natural baseflow originates from the portion of precipitation that infiltrates in the ground, recharging the underlying aquifer, and consists of the natural groundwater discharge to a stream that would occur in the watershed in the absence of groundwater withdrawals and return flows. Natural baseflow estimates for a watershed are obtained using a method called baseflow separation. Baseflow separation partitions a natural streamflow hydrograph into a baseflow component and a stormflow component. The stormflow component is comprised of short-duration storm-based runoff, while the baseflow component is the longer duration discharge of groundwater into a stream.

The IFA regional water availability methodology (INTERA, 2021a) defines natural baseflow as the basis of water availability modeling. In previous regional water availability studies for Indiana (INTERA, 2021a; Letsinger and Gustin, 2024), baseflow separation was completed using the USGS computer program PART (Rutledge, 1998). As described in Appendix C, this method produced inconsistencies in baseflow volumes when applied to the natural streamflow in the Study Area. A sensitivity analysis was conducted on 16 baseflow separation methods, and the HYSEP Sliding Interval method (Sloto and Crouse, 1996) was selected for implementation. This method is available to implement in the USGS Groundwater Toolbox (Barlow et al., 2015), contains default parameters that do not require calibration, can be consistently applied across the Study Area, and produces comparable total baseflow volumes to the PART method across the Study Area.

5.6.1 HISTORICAL

The natural streamflow time series for each subbasin was used as input to the USGS Groundwater Toolbox using the HYSEP Sliding Interval baseflow separation method to develop a baseflow time series. An example year of baseflow separation from natural streamflow at Wabash Lafayette (Subbasin 06) is shown in Figure 5-6, and average monthly values over the historical simulation period are shown in Figure 5-7.

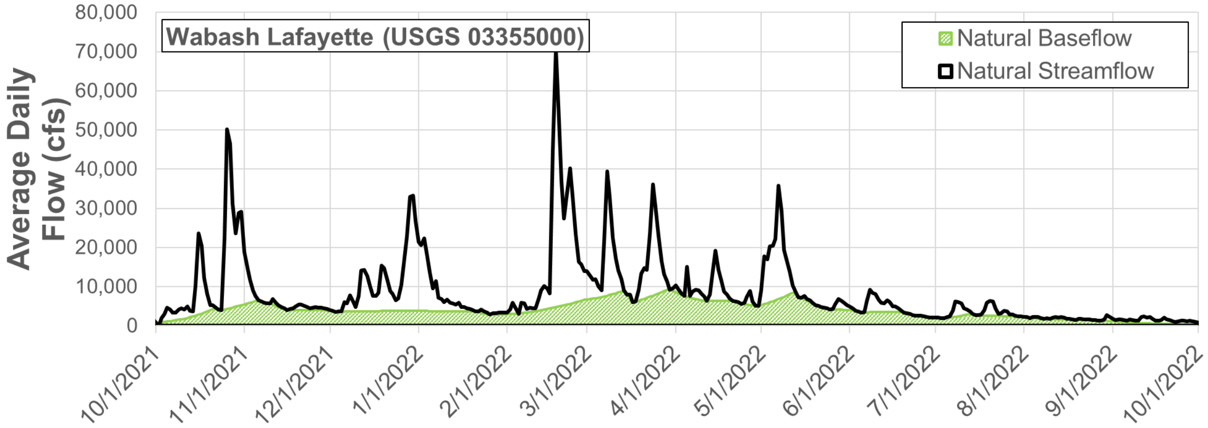


Figure 5-6. Baseflow Separation Example for Wabash Lafayette in Water Year 2022

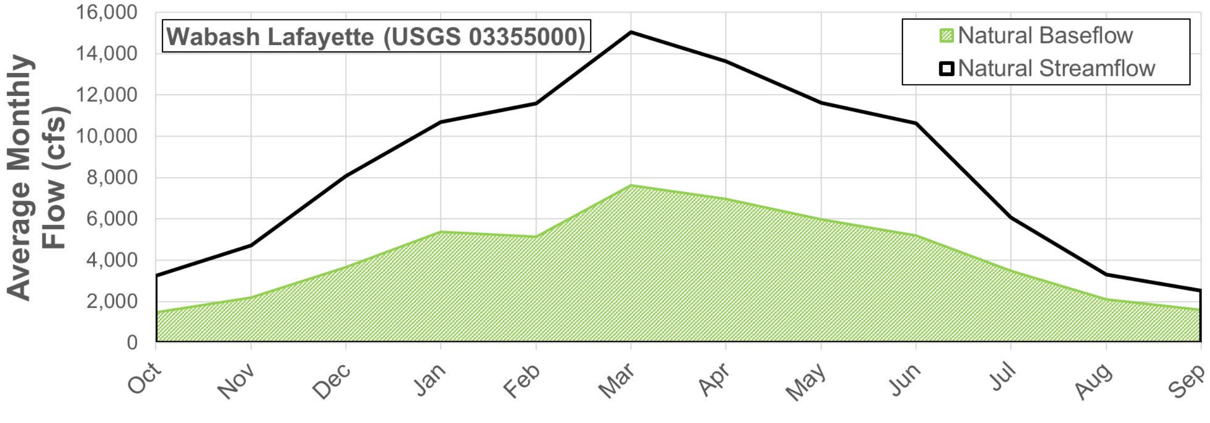


Figure 5-7. Baseflow Separation Example for Wabash Lafayette for the Historical Simulation Period showing estimated groundwater and runoff components of streamflow

5.6.2 FUTURE

The same method for baseflow separation was applied to both historical and future natural streamflow. The time series of future natural streamflow was used as input to the USGS Groundwater Toolbox, and the HYSEP Sliding Interval baseflow separation method was used to develop a future baseflow time series for each subbasin.

6.0 Historical Water Availability Results

This Chapter provides a summary of recent historical water availability from 2007-2022 using a variety of metrics, figures, and plots. Additional details on water availability for individual subbasins can be found in Appendix G.

6.1 Water Availability Summary

Historical season-averaged subbasin excess water availability (local) and cumulative excess water availability (regional) are shown in Figure 6-1. These plots show data for each subbasin in a row with two horizontal bars: the first bar shows subbasin excess water availability, or the water availability generated within each subbasin, while the second bar shows cumulative excess water availability upstream, or the water availability accumulated from all upstream subbasins. Each subbasin has a value for the first bar, subbasin excess, but only those with an upstream subbasin will have the second bar, cumulative excess upstream. The sum of both bars indicates the total cumulative excess water availability for that subbasin. For example, the first bar for Lower Tippecanoe (02)[9] indicates the water availability generated within Lower Tippecanoe (02), while the second bar indicates the water availability generated in Upper Tippecanoe (01) that accumulates at the outlet of Lower Tippecanoe (02) as it flows downstream. The combined total of both bars is the total value of cumulative excess water availability at Lower Tippecanoe (02).

Results indicate strong seasonality, with water availability highest in the spring, relatively similar in the winter and summer, and lowest in the fall at all subbasins. Wet season water availability is driven primarily by high natural baseflow, with subbasins that have larger drainage areas producing greater within-subbasin excess availability, and subbasins located further downstream having greater cumulative excess availability. Fall water availability is sustained primarily from Tippecanoe River baseflow, Headwaters baseflow and reservoir releases, and Wabash River baseflow. Water availability is also spatially varied, with subbasins along the Wabash River (Headwaters, 06, 07, 12, 15, and 16) exhibiting greater cumulative water availability than tributary subbasins.

Average seasonal subbasin excess water availability is generally positive in all subbasins, but Wabash Lafayette (06) shows negative average excess water availability in the winter and fall. This subbasin is somewhat unique for this Study, in that it is the second smallest subbasin by drainage area but contains the confluence of three major river systems: the Tippecanoe River, Wildcat Creek, and the Wabash River headwaters. Though these three river systems contribute a high volume of natural baseflow to the subbasin, little natural baseflow is generated within the small drainage area of Wabash Lafayette (06). Because the subbasin itself contains the majority of the water withdrawals for Lafayette and many return flows are discharged downstream into Wabash Covington (07), subbasin excess water availability is very low, and sometimes negative.

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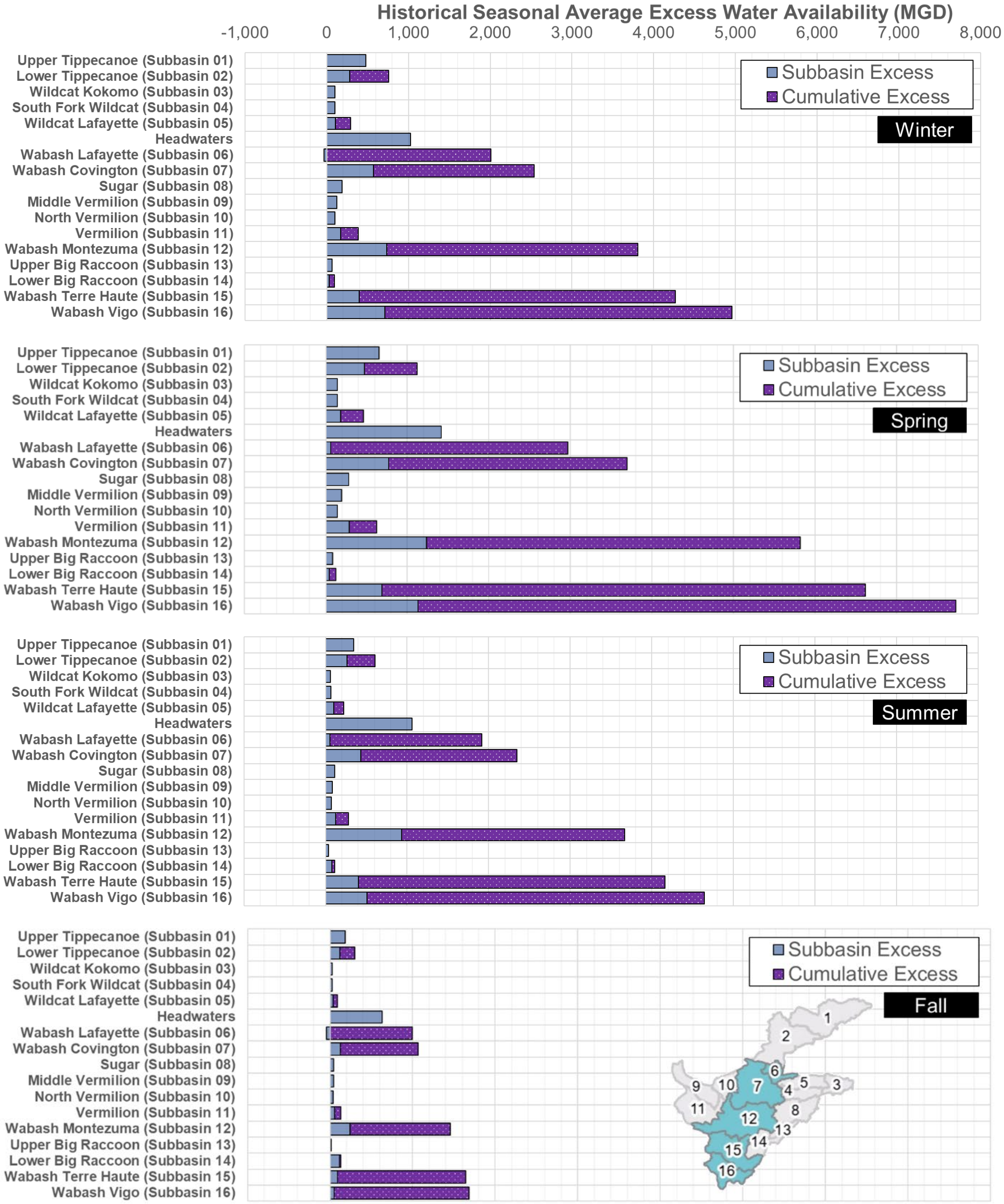
[9] For the presentation of results in Chapters 6 and 7, each subbasin will generally be referred to by subbasin name followed by the subbasin number in parenthesis, e.g., Wabash Lafayette (06). At times, groups of subbasins may be referred to in parenthesis, e.g., subbasins along the Wabash River (Headwaters, 06, 07, 12, 15, and 16).



Note: Cumulative excess water availability includes the sum of the bars labeled Subbasin Excess and Cumulative Excess. Headwaters shown as subbasin excess though it includes all subbasins in the Headwaters region. Mainstem Wabash River subbasins include Headwaters, 06, 07, 12, 15, and 16.

Figure 6-1. Historical Subbasin and Cumulative Excess Water Availability by Subbasin and Season

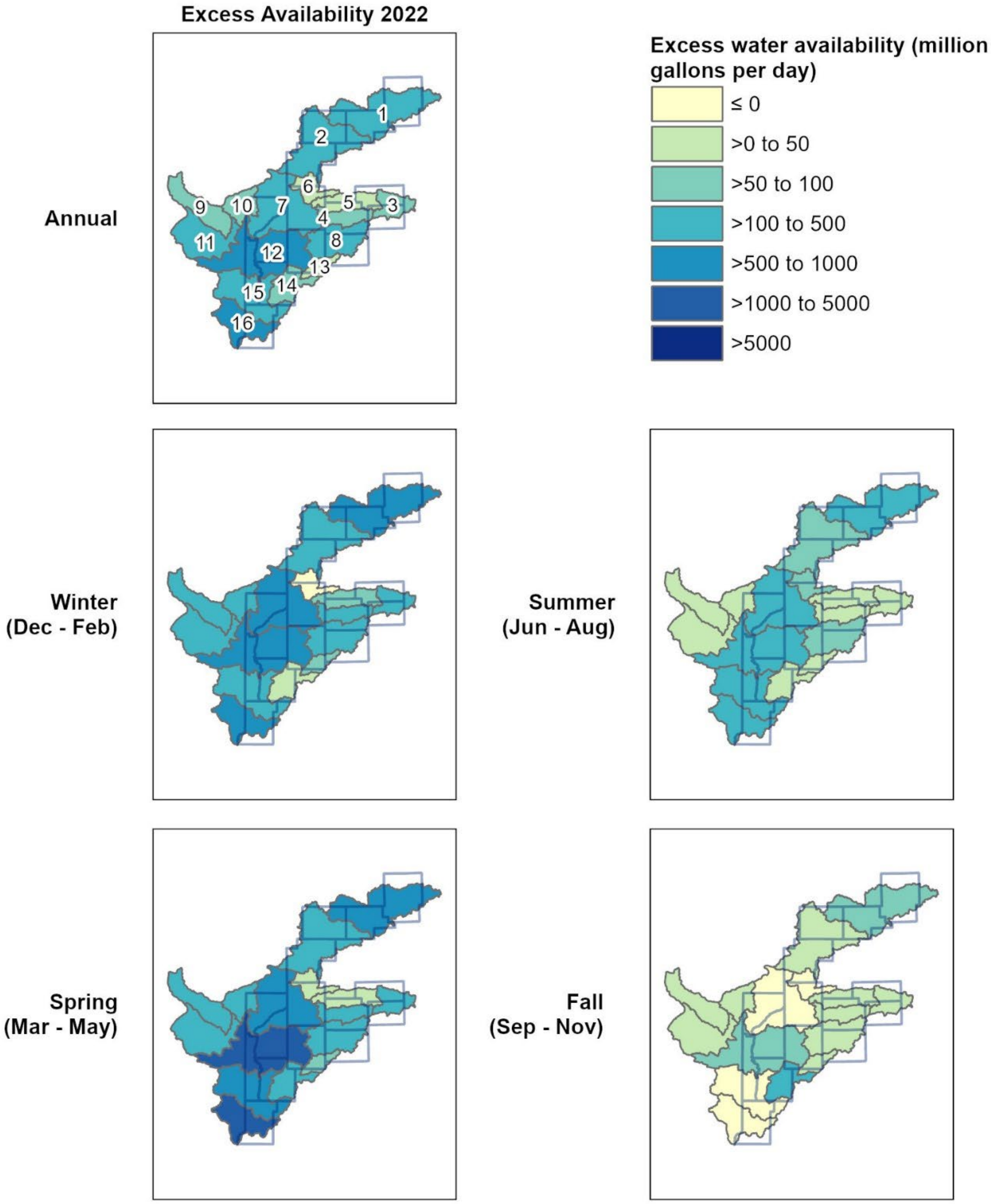
6.2 2022 Spatial Summary

A spatial summary of excess water availability (local) and cumulative excess water availability (regional) is shown in Figure 6-2 and Figure 6-3, respectively, on both an annual and seasonal scale for 2022. The year 2022 was selected to provide a snapshot example of water availability for a year in recent history, though as shown in later sections, water availability differs substantially by year.

For 2022, annual average excess water availability ranged from 7 MGD in Wabash Lafayette (06) to 600 MGD in Wabash Montezuma (12), demonstrating significant variability across subbasins. Spring 2022 showed the highest excess water availability due to high natural baseflow, followed by winter, then summer. The Tippecanoe River (Subbasins 01, 02) and mainstem Wabash River Subbasins (07, 12, 15) generally followed similar trends, generating higher subbasin excess water availability than other subbasins on smaller tributaries. Fall showed the lowest excess water availability due to low natural baseflow. This trend was particularly evident in subbasins along the Wabash River, where all subbasins, except for Wabash Montezuma (12), showed negative values during fall 2022. These negative values indicate natural baseflow generated within the subbasin boundary was generally less than the net instream flow requirement of the subbasin, an occurrence that was not observed in the tributary subbasins.

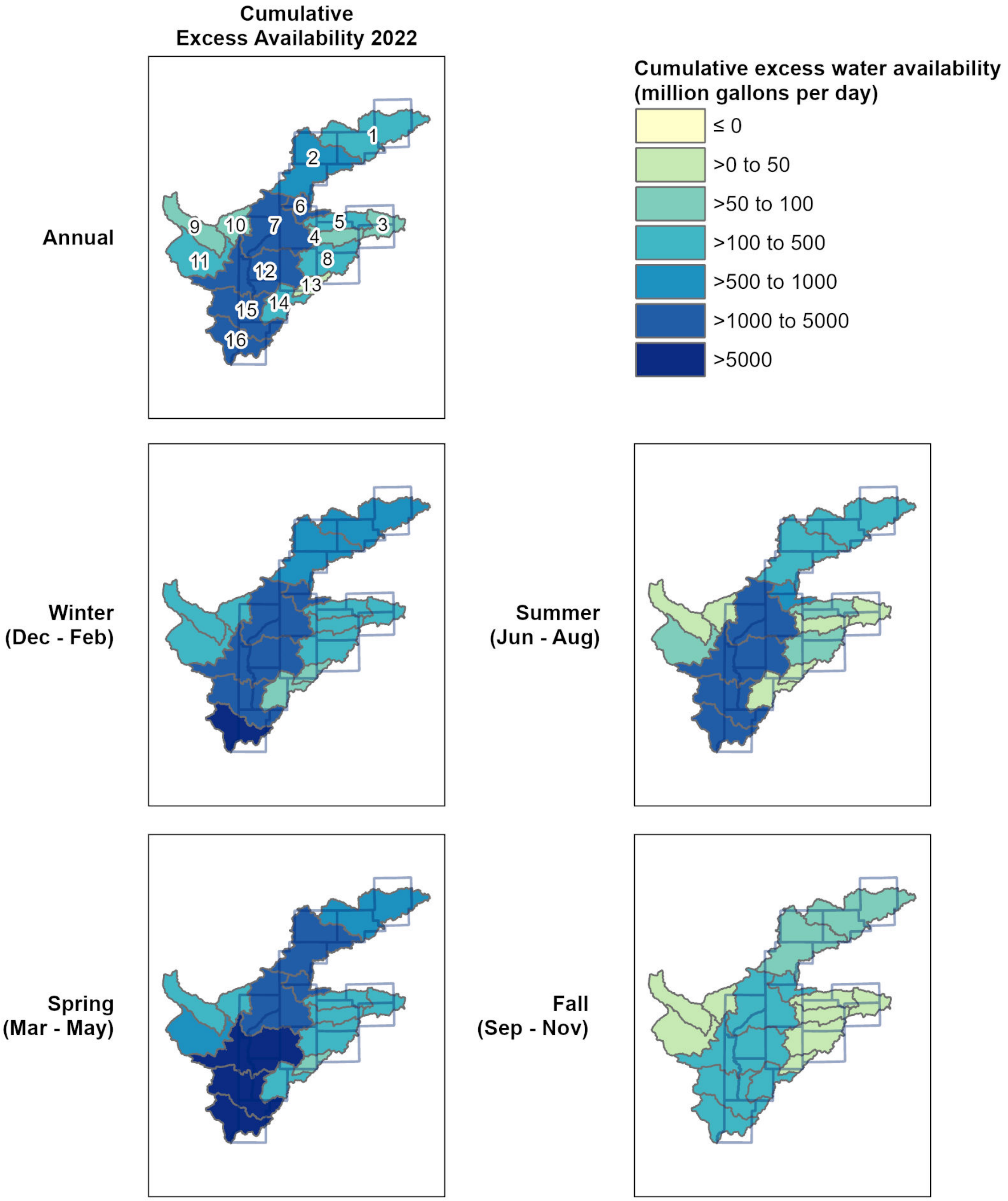
Annual and seasonal average cumulative excess water availability for 2022 is shown in Figure 6-3. Variations in cumulative excess water availability occur from upstream to downstream on the Wabash River and along tributaries, with downstream subbasins generally exhibiting higher levels of availability than upstream subbasins. Subbasins along the Tippecanoe River (01, 02) in the upper portion of the Study Area tend to demonstrate higher cumulative excess water availability than subbasins along Sugar Creek (08), Wildcat Creek (03, 04, 05), Big Raccoon Creek (13, 14), and the Vermilion River (08, 09, 10). Contrary to excess water availability results, there are no subbasins with negative cumulative excess water availability in 2022, either annually or seasonally.

In analyzing water availability in the Study Area, it is essential to distinguish between excess water availability and cumulative excess water availability, as they reflect different hydrologic scales. Excess water availability highlights localized water surpluses or shortages within a subbasin, helping identify subbasins that may face higher relative water stress. Cumulative excess water availability accounts for water contributions from upstream subbasins, representing the cumulative water resources available as water flows downstream. This metric provides a broader perspective on water availability across a watershed, considering inputs from interconnected subbasins upstream. When viewed together, these metrics highlight which subbasins generally withdraw more water than they generate, and which subbasins rely on flow contributions from upstream watersheds to support current and future proposed water resources development.



Note: The year 2022 was selected to provide a snapshot example of water availability for a year in recent history. Water availability differs substantially by year.

Figure 6-2. 2022 Average Excess Water Availability by Subbasin and Season



Note: The year 2022 was selected to provide a snapshot example of water availability for a year in recent history. Water availability differs substantially by year.

Figure 6-3. 2022 Average Cumulative Excess Water Availability by Subbasin and Season

6.3 Summary of Cumulative Excess Water Availability Components

The major water budget components of cumulative excess water availability are shown as box and whisker plots (see Section 3.5.2) for Lower Tippecanoe Subbasin 02 (Figure 6-4), Wabash Lafayette Subbasin 06 (Figure 6-5), and Sugar Subbasin 08 (Figure 6-6). These three subbasins are selected to demonstrate representative results for a tributary watershed with no substantial upstream reservoir influences (Subbasin 02), a mainstem Wabash River watershed with greater relative upstream reservoir influences (Subbasin 06), and a first order tributary subbasin (Subbasin 08). Box and whisker plots of components of cumulative excess water availability for all subbasins are provided in Appendix G.

For Lower Tippecanoe (02), shown in Figure 6-4, natural baseflow is the water budget component with the greatest difference across seasons. Median winter and spring natural baseflow vary from 1,000 MGD to 1,500 MGD, respectively, while summer and fall natural baseflow vary from 750 MGD to 500 MGD, respectively. Return flows and water withdrawals are substantially less than natural baseflow in all seasons, with the summer season showing the largest relative magnitude of water withdrawals due primarily to upstream irrigation. Net reservoir releases are also a relatively small contribution to the water budget, as they only reflect the contributions of the Oakdale Dam, which operates primarily in a run-of-river mode with no flood control storage.

Instream flow is defined as a singular value for winter/spring seasons based on the Q90 metric, and a separate singular value for the summer/fall seasons based on the 7Q10 metric. Since these values do not change throughout the historical analysis period, these lines remain constant in each season and represent the largest demand value within the water budget. Cumulative water availability represents natural baseflow minus instream flow and reservoir operations. For this subbasin, cumulative water availability variability is essentially natural baseflow minus instream flow, meaning variability in natural baseflow is the primary driver of cumulative water availability. Cumulative excess water availability represents cumulative water availability minus withdrawals plus return flows. Due to the relatively small magnitude of withdrawals and return flows compared to natural baseflow, cumulative excess water availability is similar to cumulative water availability, with a range that varies seasonally based on natural baseflow and instream flow values.

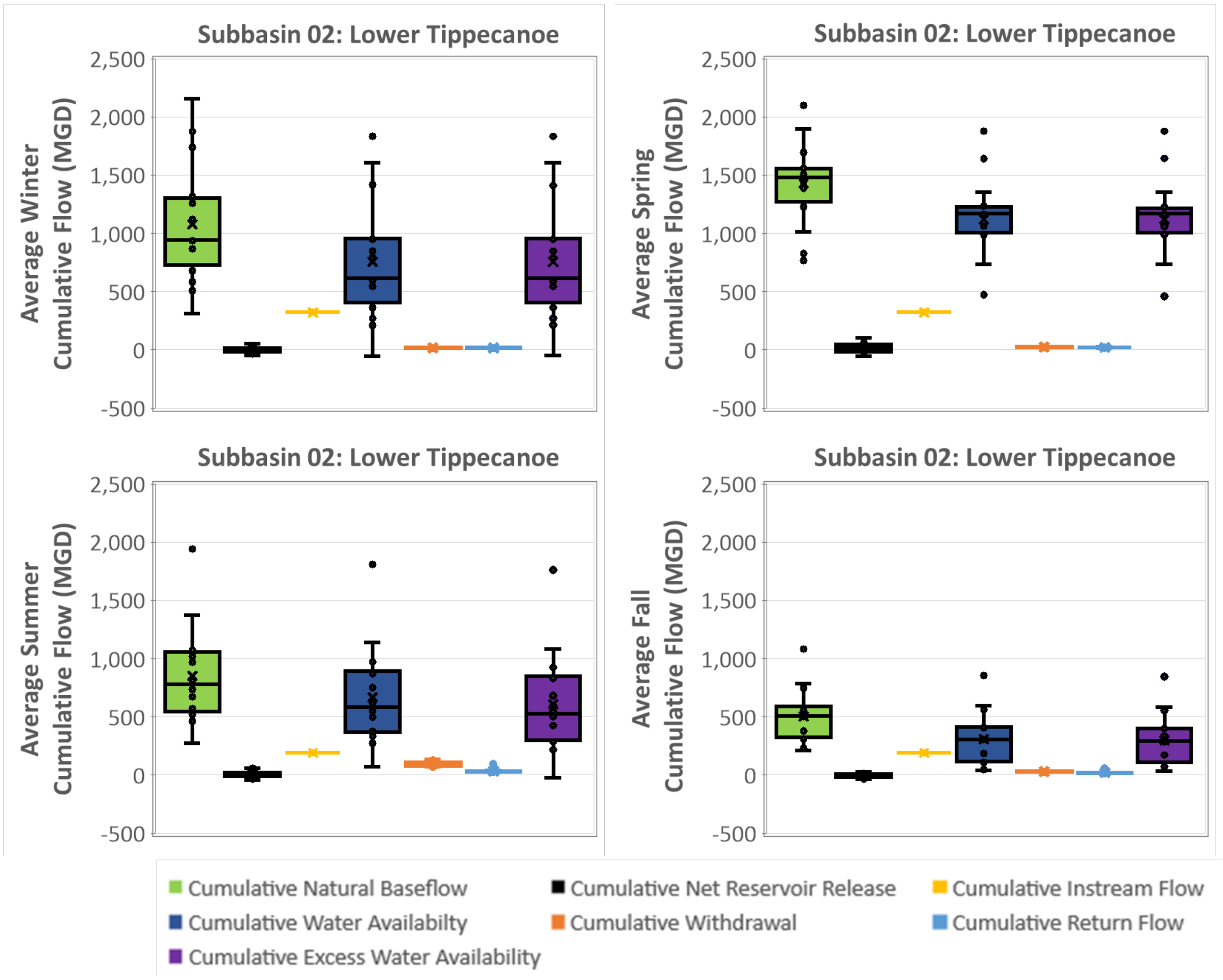


Figure 6-4. Box Plots of Historical Seasonal Cumulative Excess Water Availability Components for Lower Tippecanoe (Subbasin 02)

For Wabash Lafayette (06), shown in Figure 6-5, natural baseflow is also the water budget component with the greatest difference across seasons. This subbasin receives natural baseflow from the Tippecanoe River, upper Wabash River, and Wildcat Creek, and is highly sensitive to these contributions. Median winter and spring natural baseflow varies from 2,500 MGD to 4,200 MGD, respectively, while summer and fall natural baseflow varies from 2,000 MGD to 1,000 MGD, respectively. Return flows and water withdrawals are also substantially less than natural baseflow in all seasons, with the summer season showing the largest relative magnitude of water withdrawals. Despite this subbasin containing most of the city of Lafayette and associated water withdrawals, total consumptive water use has a small effect on water availability and cumulative excess water availability in all seasons. The influence of reservoir operations is most prominent in the winter and fall. In the winter, upstream flood control reservoirs in the Wabash Headwaters Study Area are filling, reducing downstream flow and water availability. Spring reservoir operations and instream flow are the largest water budget components that reduce cumulative water availability by about 1,500 MGD. In the fall, these flood control reservoirs are releasing stored stormwater to create reservoir storage capacity for the next wet season. These fall releases counter the effects of low natural baseflow and instream flow, helping to increase cumulative water availability. These effects are examined more closely in Section 6.6.

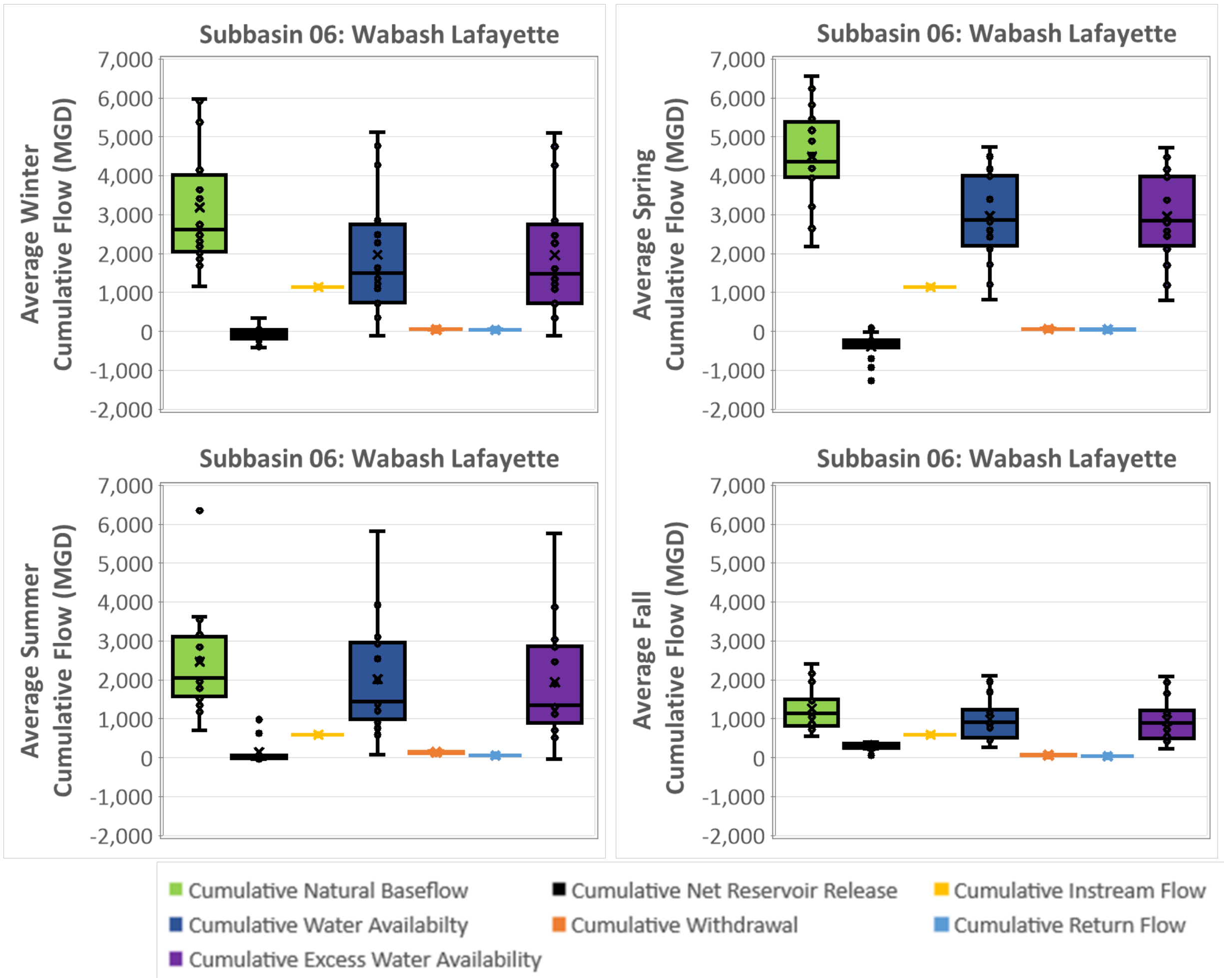


Figure 6-5. Box Plots of Historical Seasonal Cumulative Excess Water Availability Components for Wabash Lafayette (Subbasin 06)

For Sugar (08), a first-order subbasin with no contributions from upstream subbasins, Figure 6-6 shows that natural baseflow is also the water budget component with the greatest difference across seasons. Median winter and spring natural baseflow varies from 160 MGD to 300 MGD, respectively, while summer and fall natural baseflow varies from 100 MGD to 50 MGD, respectively. Summer and fall baseflow reductions compared to the wetter seasons are more pronounced than Lower Tippecanoe and Wabash Lafayette, reflecting the bedrock geology of Sugar Creek that limits seasonal recharge and dry season baseflow contributions. Return flows and water withdrawals are also substantially less than natural baseflow in all seasons. There are no reservoir operations in the subbasin, so there is no reservoir effect on water availability. Fall is the most limiting season for cumulative excess water availability, with values ranging from 20 MGD in the lower quartile of the historical period to 50 MGD in the upper quartile of the historical period. These values are consistent with the cumulative excess water availability estimates developed for this subbasin in previous regional water studies (INTERA, 2021a).

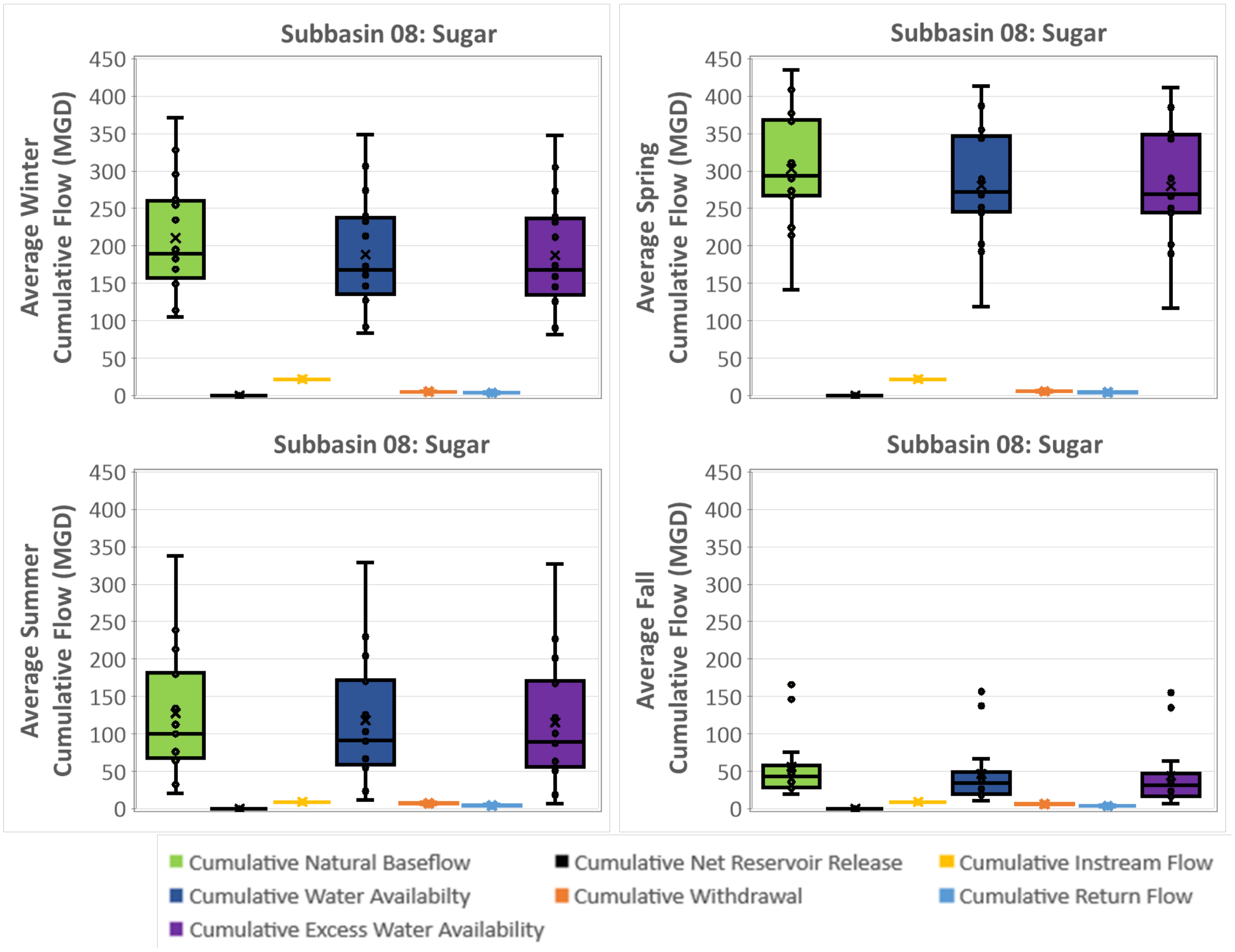
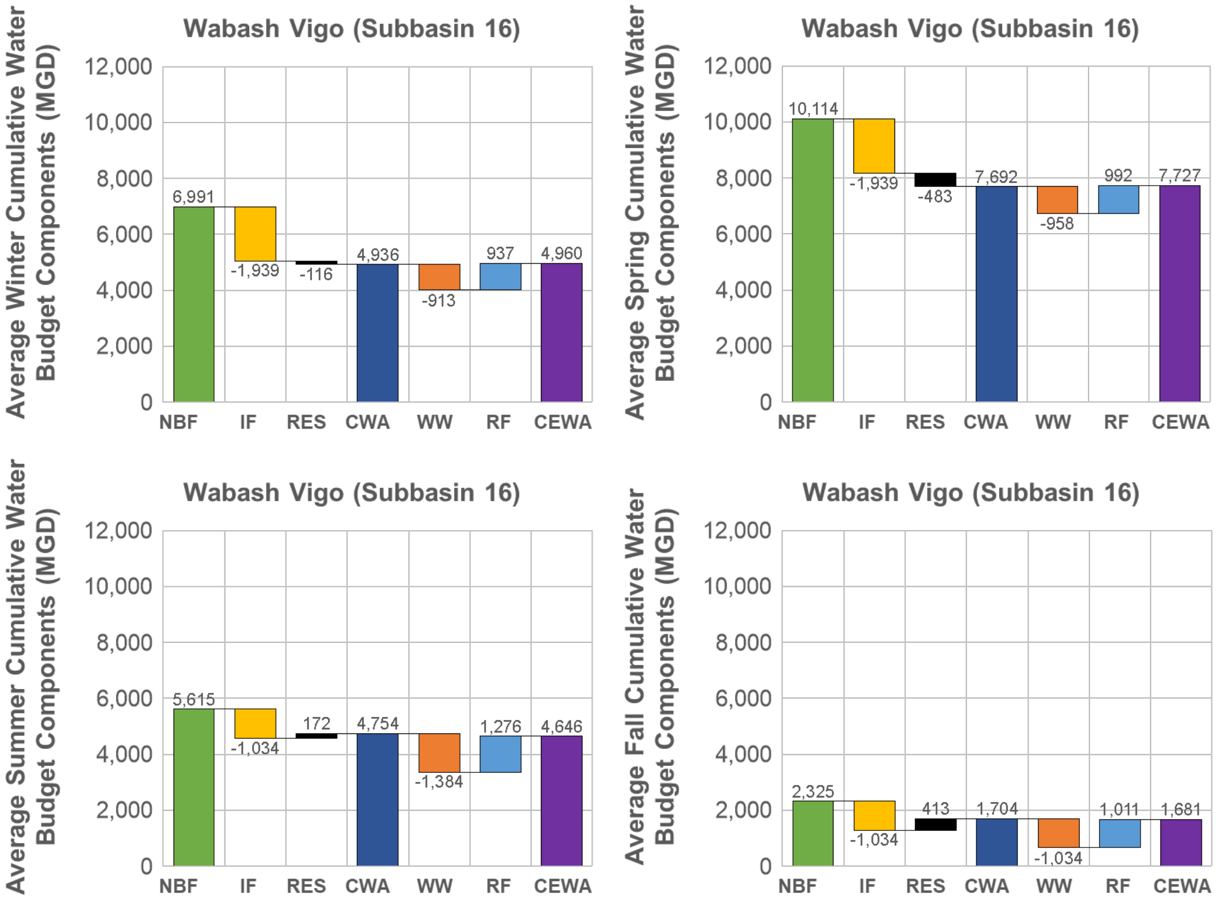


Figure 6-6. Box Plots of Historical Seasonal Cumulative Excess Water Availability Components for Sugar (Subbasin 08)

A concise view of average cumulative water budget components in the Study Area for each season is gained by analyzing the most downstream subbasin, Wabash Vigo (16). The plots shown in Figure 6-7 are read from left to right, with the initial natural baseflow (NBF) value indicating the primary water supply. The next two bars represent instream flow and net reservoir operations, which are subtracted from NBF to generate cumulative water availability (CWA). Water withdrawals (WW) are then subtracted from cumulative water availability, and return flows are added, to produce cumulative excess water availability.

Across winter, spring, and summer, average cumulative water availability exceeds water withdrawals, indicating average historical water supply is at least double the volume of average water demands after accounting for instream flows and upstream reservoir operation. During fall, water withdrawals are 58% of cumulative water availability, indicating more than half of the average water supply available, after accounting for instream flows and upstream reservoir operation, is withdrawn to meet water demands. Across all seasons, however, consumptive use of water is relatively low. The highest rate of consumptive use is in the summer, when about 6% of water withdrawals are consumed and 94% of water withdrawals by volume are returned to the stream.

Throughout the year, cumulative excess water availability as a percentage of natural baseflow is relatively stable, ranging from a minimum value of 71% in the winter to a maximum value of 83% in the summer. Large variations in average cumulative excess water availability magnitude across seasons (from a minimum value of 1,681 MGD in the fall to a maximum of 7,727 MGD in the spring) are primarily attributable to large variations in natural baseflow magnitude. The largest supply side water budget component across all seasons is instream flow, which is highest in winter/spring and lowest in summer/fall. Even though water withdrawals exceed instream flow magnitude in the summer and is equivalent in magnitude in the fall, much of the water withdrawals is returned to the system as return flow, and the consumptive use of water withdrawals is relatively small compared to the instream flow magnitude. In the fall, reservoir operations provide 413 MGD, which offsets the instream flow component of the water budget and increases overall cumulative excess water availability by about 33% were reservoir operations to be absent.



Key:
CEWA = cumulative excess water availability
CWA = cumulative water availability
IF = instream flow
NBF = natural baseflow
RES = net reservoir operation
RF = return flow
WW = water withdrawal

Figure 6-7. Historical Seasonal Cumulative Water Budget Components for Subbasin 16

6.4 Cumulative Excess Water Availability Data Summary

Seasonal cumulative excess water availability across all 16 subbasins from 2007 to 2022 for winter, spring, summer, and fall are shown in Table 6-1 through Table 6-4, respectively. These tables highlight seasonal and spatial variability, emphasizing that water availability is largely driven by natural hydrologic patterns and human influences. Key trends observed in the data include:

- Similar to Figure 6-3, the winter and spring seasons exhibit higher cumulative excess water availability due to higher natural baseflow, whereas summer and fall show relatively lower cumulative excess water availability due to lower natural baseflow and higher water withdrawals.
- Cumulative excess water availability varies by an order of magnitude at most subbasins, even within the same seasonal period. For example, the minimum and maximum winter cumulative excess water availability at Wabash Vigo (15) is 284 MGD in 2021 and 9,957 MGD in 2007, respectively. This variation is driven almost entirely by differences in natural baseflow, which are largely a function of geology, recharge potential, and climate, both in the current season and in the preceding seasons that set the antecedent conditions.
- Subbasins along the Wabash River mainstem (06, 07, 12, 15, 16) consistently show the highest cumulative excess water availability across all seasons, reflecting their larger drainage areas, high relative natural baseflow, and water contributions from their upstream subbasins.
- Low and even negative cumulative excess water availability is observed in certain subbasins during the winter and summer seasons. The effects of individual years with particularly dry or drought conditions on cumulative excess water availability are observed more easily for the winter of 2021 and the summer of 2012. In both seasons, relatively low amounts of precipitation and storm events led to minimum seasonal natural baseflow values in the 16-year recent historical analysis period. In both seasons, negative cumulative excess water availability was calculated along the upper subbasins of the Wabash River. At these locations, seasonal natural baseflow was lower than minimum instream flow values.
- Low and even negative cumulative water availability is also observed multiple times during the winter season in Lower Big Raccoon (14). This subbasin is downstream of the Cecil M. Harden Lake, which stores large amounts of natural streamflow during the winter season. Negative cumulative excess water availability is produced downstream in years when the amount of water stored is greater than downstream natural baseflow minus instream flows.

Table 6-1. Winter Historical Cumulative Excess Water Availability (MGD)

Subbasin	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Upper Tippecanoe (01)	826	1,135	400	382	89	996	126	291	303	339	524	497	608	591	32	539
Lower Tippecanoe (02)	1,409	1,833	632	549	272	1,609	214	362	592	555	848	602	951	960	-45	791
Wildcat Kokomo (03)	181	153	70	67	68	193	93	67	79	61	89	79	147	85	32	129
South Fork Wildcat (04)	177	117	68	89	81	163	81	63	96	89	104	85	117	84	40	128
Wildcat Lafayette (05)	496	404	194	285	166	631	220	131	278	247	344	156	514	258	73	317
Wabash Lafayette (06)	4,743	4,253	1,057	1,219	322	5,119	756	460	1,603	1,344	2,319	854	2,870	2,491	-102	2,286
Wabash Covington (07)	6,605	5,135	1,616	1,651	618	6,198	1,018	351	1,860	2,007	2,917	1,337	3,651	2,915	-45	2,763
Sugar (08)	305	212	149	177	130	347	159	90	126	161	174	145	239	232	82	273
Middle Vermilion (09)	205	155	132	146	80	81	74	37	102	223	140	97	174	153	19	139
North Vermilion (10)	159	109	75	89	65	85	67	27	82	153	129	111	164	120	30	131
Vermilion (11)	722	490	390	480	234	304	240	79	304	672	491	254	667	400	22	433
Wabash Montezuma (12)	9,074	7,784	2,362	2,902	1,219	8,498	1,894	616	2,787	3,458	4,202	1,852	5,389	4,570	27	4,295
Upper Big Raccoon (13)	109	73	64	61	45	97	57	53	71	63	61	47	87	84	37	75
Lower Big Raccoon (14)	265	89	30	150	-81	239	49	-25	137	198	139	-10	57	122	81	97
Wabash Terre Haute (15)	9,951	8,528	2,779	3,363	1,394	9,344	1,864	758	3,191	4,344	4,656	1,824	6,019	5,141	302	4,841
Wabash Vigo (16)	11,750	10,312	3,516	3,751	1,378	10,772	2,163	1,034	3,462	5,134	5,220	1,856	6,977	6,097	382	5,553

Notes:
Winter values are calculated as the average cumulative excess water availability from December through February.
Cells are colored consistent with the color scale in Figure 6-2.
Key:
MGD = million gallons per day

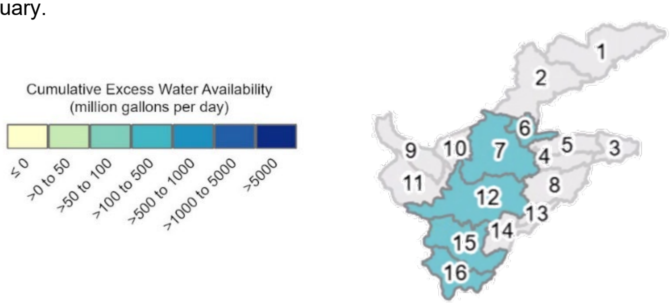
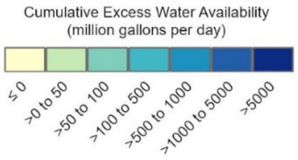


Table 6-2. Spring Historical Cumulative Excess Water Availability (MGD)

Subbasin	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Upper Tippecanoe (01)	675	817	1,120	514	905	272	597	702	345	580	690	758	821	661	275	738
Lower Tippecanoe (02)	1,225	1,177	1,879	992	1,645	461	1,164	1,087	734	1,061	1,192	1,199	1,352	1,098	480	1,191
Wildcat Kokomo (03)	147	159	216	124	204	45	191	132	106	122	193	92	199	105	107	166
South Fork Wildcat (04)	150	155	171	136	228	51	177	133	125	107	198	107	173	126	109	131
Wildcat Lafayette (05)	462	436	577	392	642	142	647	395	811	351	612	328	721	311	262	331
Wabash Lafayette (06)	3,424	3,960	4,486	2,591	4,737	774	3,419	4,008	1,696	2,676	2,140	2,928	4,198	2,467	1,206	2,819
Wabash Covington (07)	4,442	5,057	6,026	3,282	5,679	1,098	4,379	3,592	2,155	3,382	2,945	3,544	5,333	3,047	1,708	3,456
Sugar (08)	270	269	354	290	412	116	343	202	244	290	350	246	385	266	190	250
Middle Vermilion (09)	164	198	285	207	295	54	229	136	148	181	220	154	288	241	129	210
North Vermilion (10)	133	112	160	130	184	46	179	90	117	156	201	142	193	180	131	167
Vermilion (11)	563	696	854	668	879	172	779	388	446	591	713	628	820	634	445	685
Wabash Montezuma (12)	6,774	7,288	8,837	5,391	8,661	1,703	7,160	5,309	3,527	5,220	5,346	5,299	8,227	5,155	3,310	5,903
Upper Big Raccoon (13)	83	110	119	79	134	38	92	68	77	78	97	74	101	70	60	87
Lower Big Raccoon (14)	169	118	153	81	341	19	175	138	41	121	25	114	161	98	57	206
Wabash Terre Haute (15)	7,456	8,826	10,252	5,631	10,103	1,845	7,745	6,034	4,603	5,741	6,132	6,377	9,120	5,647	3,675	6,616
Wabash Vigo (16)	8,830	10,440	12,339	6,502	11,751	2,154	9,019	6,850	4,767	6,350	7,506	7,676	10,593	6,442	4,379	8,027

Notes:
Spring values are calculated as the average cumulative excess water availability from March through May.
Cells are colored consistent with the color scale in Figure 6-2.
Key:
MGD = million gallons per day



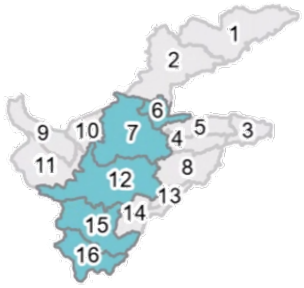


Table 6-3. Summer Historical Cumulative Excess Water Availability (MGD)

Subbasin	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Upper Tippecanoe (01)	158	349	347	316	496	0	641	226	839	174	553	209	473	198	326	191
Lower Tippecanoe (02)	218	595	501	834	925	-20	1,081	454	1,763	300	855	424	682	298	548	290
Wildcat Kokomo (03)	8	89	33	111	72	10	78	44	138	24	90	53	65	30	57	32
South Fork Wildcat (04)	16	75	72	92	86	8	42	37	186	52	106	31	88	44	62	26
Wildcat Lafayette (05)	51	293	181	441	265	21	213	115	759	135	310	140	288	101	156	64
Wabash Lafayette (06)	453	1,849	1,259	3,005	2,842	-90	2,444	1,321	5,756	1,102	3,868	1,354	2,840	684	1,162	793
Wabash Covington (07)	572	2,386	1,634	3,891	3,428	-45	2,770	1,372	7,384	1,285	4,667	1,629	3,352	836	1,372	989
Sugar (08)	19	201	101	227	122	7	87	69	327	91	172	54	167	63	87	51
Middle Vermilion (09)	21	130	68	145	66	6	77	105	219	63	44	58	74	89	134	33
North Vermilion (10)	16	75	50	108	55	5	68	84	173	61	96	83	96	72	115	41
Vermilion (11)	84	420	260	551	249	18	261	360	683	241	174	237	264	243	350	94
Wabash Montezuma (12)	858	3,841	2,932	6,238	4,665	127	3,938	2,607	12,250	2,005	6,204	2,463	4,799	1,805	2,570	1,392
Upper Big Raccoon (13)	4	117	28	48	30	2	20	17	107	18	35	32	43	17	32	14
Lower Big Raccoon (14)	14	262	203	160	109	-4	84	54	256	65	120	46	153	110	109	44
Wabash Terre Haute (15)	998	4,987	3,492	6,610	5,401	109	4,231	3,115	14,061	2,511	6,535	2,813	5,210	2,149	2,739	1,609
Wabash Vigo (16)	990	5,730	3,966	7,342	6,134	180	5,176	3,317	15,506	2,627	7,244	3,025	5,744	2,417	3,146	1,790

Notes:
Summer values are calculated as the average cumulative excess water availability from June through August.
Cells are colored consistent with the color scale in Figure 6-2.
Key:
MGD = million gallons per day

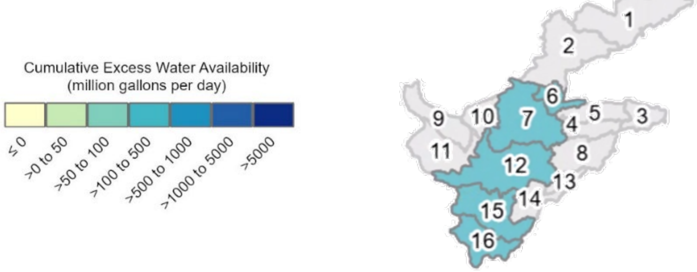
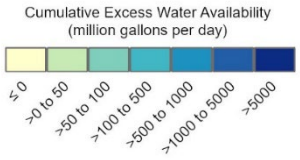
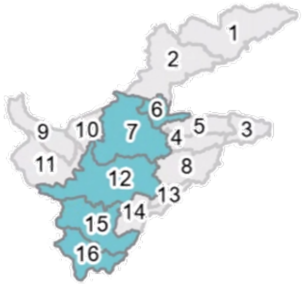


Table 6-4. Fall Historical Cumulative Excess Water Availability (MGD)

Subbasin	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Upper Tippecanoe (01)	149	120	255	48	269	23	103	294	117	211	271	299	230	32	423	57
Lower Tippecanoe (02)	289	180	301	107	338	34	110	847	173	400	403	556	305	72	583	97
Wildcat Kokomo (03)	14	5	10	3	13	50	10	42	7	7	27	121	9	25	76	3
South Fork Wildcat (04)	13	12	21	11	25	20	9	59	16	20	36	81	13	17	74	6
Wildcat Lafayette (05)	44	30	86	29	76	90	26	195	49	56	95	339	46	60	198	10
Wabash Lafayette (06)	704	393	906	437	940	469	773	2,075	838	1,229	1,134	1,947	908	538	1,667	226
Wabash Covington (07)	756	616	1,086	509	1,076	495	707	2,357	1,073	1,341	1,337	2,245	980	491	1,850	134
Sugar (08)	16	17	48	18	35	37	16	39	24	45	64	155	28	24	135	7
Middle Vermilion (09)	12	52	128	9	5	31	4	95	67	61	34	75	13	8	121	14
North Vermilion (10)	11	16	48	9	3	25	3	71	78	57	58	84	18	16	85	8
Vermilion (11)	36	103	378	23	24	101	19	247	203	231	94	265	34	22	290	34
Wabash Montezuma (12)	1,045	823	2,018	699	1,374	739	766	3,077	1,164	1,770	1,672	3,337	1,148	597	2,785	255
Upper Big Raccoon (13)	2	3	22	1	13	8	8	23	6	29	6	60	9	7	38	1
Lower Big Raccoon (14)	109	122	160	99	83	55	113	118	123	151	102	246	134	149	184	111
Wabash Terre Haute (15)	1,158	1,077	2,100	606	1,284	758	834	3,486	1,809	2,108	1,740	3,884	1,392	714	2,976	322
Wabash Vigo (16)	1,155	999	2,247	623	1,214	673	907	3,641	1,667	2,138	1,838	4,058	1,366	749	3,309	311

Notes:
Fall values are calculated as the average cumulative excess water availability from September through November.
Cells are colored consistent with the color scale in Figure 6-2.
Key:
MGD = million gallons per day





6.5 Cumulative Excess Water Availability Exceedance

Exceedance curves of historical average seasonal cumulative excess water availability are shown in Figure 6-8 through Figure 6-11. These figures contain the same data as Table 6-1 through Table 6-4, but the data is reordered from largest to smallest value by season. Exceedance curves allow for the analysis of how often certain values were met or exceeded during a given period and a quantification of cumulative excess water availability under a range of hydrologic conditions, including median, dry, and drought periods. For example, the cumulative excess water availability that occurs with a 50% exceedance would be expected to occur or be exceeded at least one in every two years into the future. Conversely, the cumulative excess water availability that occurs with a 95% exceedance would be exceeded in 19 of 20 years, or in all but drought conditions. In terms of water resources management, these values are useful in supporting planning decisions around how much new water resources development could be supported in future median and dry conditions.

Exceedance curves of historical average seasonal cumulative excess water availability exhibit a consistent seasonal pattern across all 16 subbasins. In general, the curves for the different seasons—winter, spring, summer, and fall—follow a distinct order. The spring curve consistently appears at the top due to higher precipitation, higher snowmelt driven runoff, and low evapotranspiration in early spring. The winter and summer curves are sequentially lower than spring, while the fall curve remains at the bottom of the chart, when drier conditions, lower natural baseflow, increased evapotranspiration, and higher soil moisture deficits produce the most limiting season for water availability. This pattern is uniform across all subbasins. The magnitude of the difference between spring and fall availability is notable, with spring values being at least three times higher than fall values at the 50% exceedance probability.

While cumulative excess water availability in most subbasins follows the same general seasonal pattern, subbasins along the Wabash River (Subbasins 06, 07, 12, 15, and 16) exhibit slight deviations. The highest cumulative excess water availability value is observed in the summer of 2015, when late season storms produced relatively high amounts of sustained runoff and natural baseflow. Additionally, cumulative excess water availability for winter and spring is nearly identical between the 0% and 20% exceedance probability. Beyond 20%, the summer and winter curves tend to align closely with each other. From 80% to 100% exceedance probability (low availability values), the curves for summer, fall, and winter converge to almost identical values, indicating a similar minimum cumulative excess water availability across these seasons. These deviations suggest unique hydrological behavior in the Wabash River subbasins, influenced by localized geologic, climatic, geomorphological, and anthropogenic factors.

Subbasin 14 also exhibits deviations from the typical patterns observed in the other subbasins-the winter season has the lowest cumulative excess water availability and fall has the highest. This anomaly is attributed primarily to the influence of reservoir releases and storages from Cecil M. Harden Reservoir, which regulates downstream flow and moderates cumulative excess water availability across seasons, particularly in fall, contributing to these unique exceedance curve patterns.

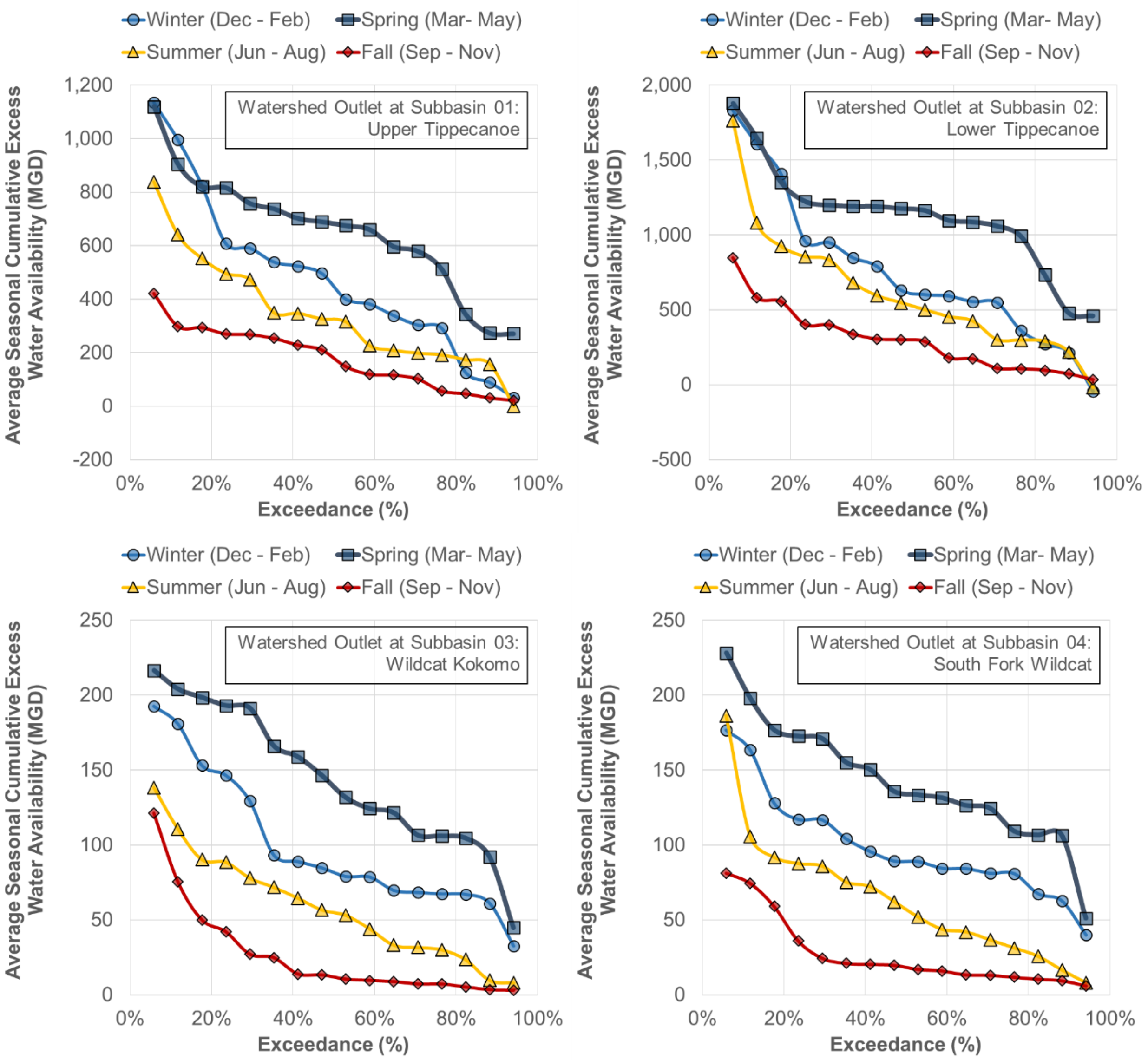


Figure 6-8. Exceedance Curves of Historical Average Seasonal Cumulative Excess Water Availability by Watershed Outlet from 2007-2022 for Upper Tippecanoe (top left, Subbasin 01), Lower Tippecanoe (top right, Subbasin 02), Wildcat Kokomo (bottom left, Subbasin 03), and South Fork Wildcat (bottom right, Subbasin 04)

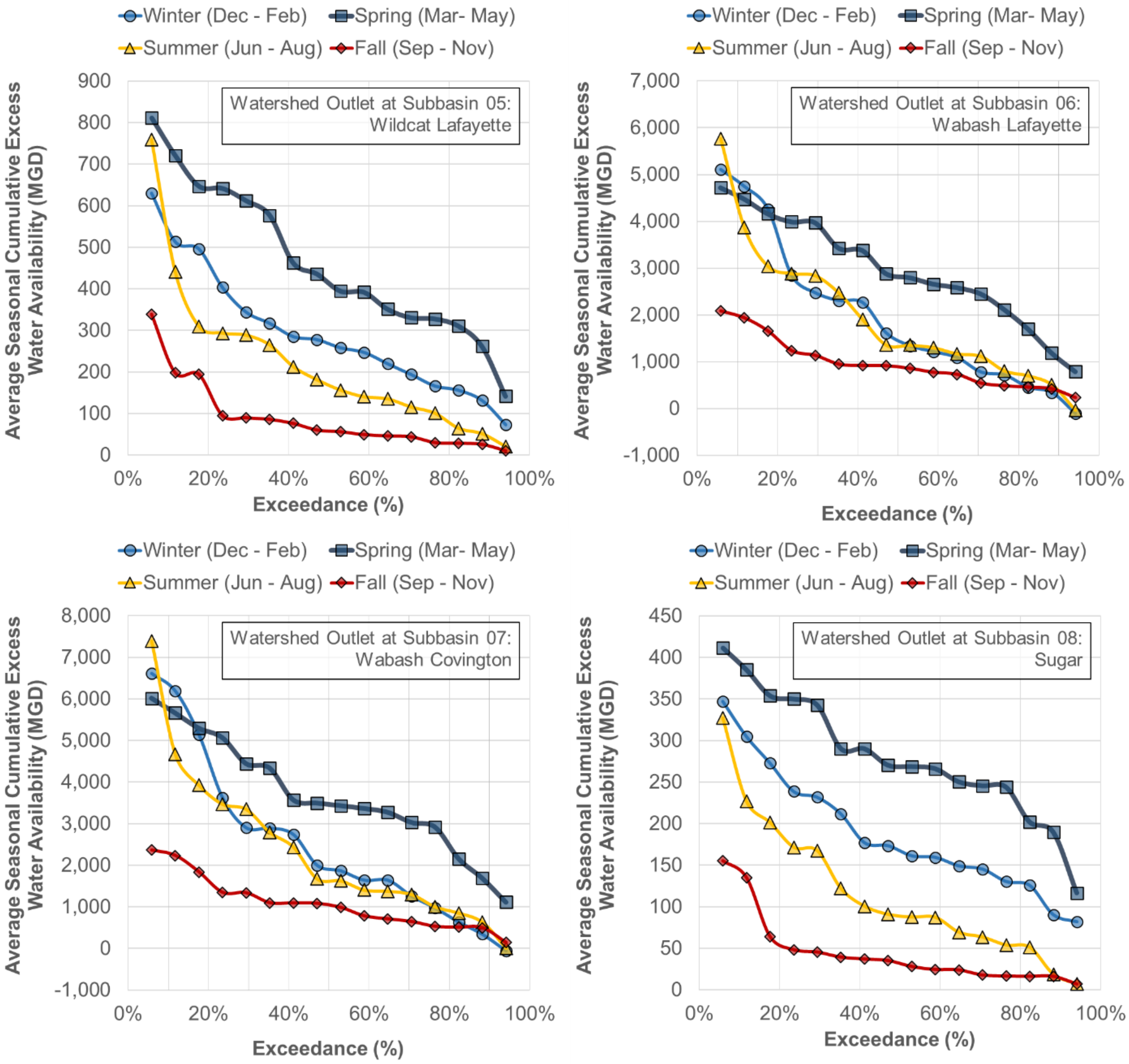


Figure 6-9. Exceedance Curves of Historical Average Seasonal Cumulative Excess Water Availability by Watershed Outlet from 2007-2022 for Wildcat Lafayette (top left, Subbasin 05), Wabash Lafayette (top right, Subbasin 06), Wabash Covington (bottom left, Subbasin 07), and Sugar (bottom right, Subbasin 08)

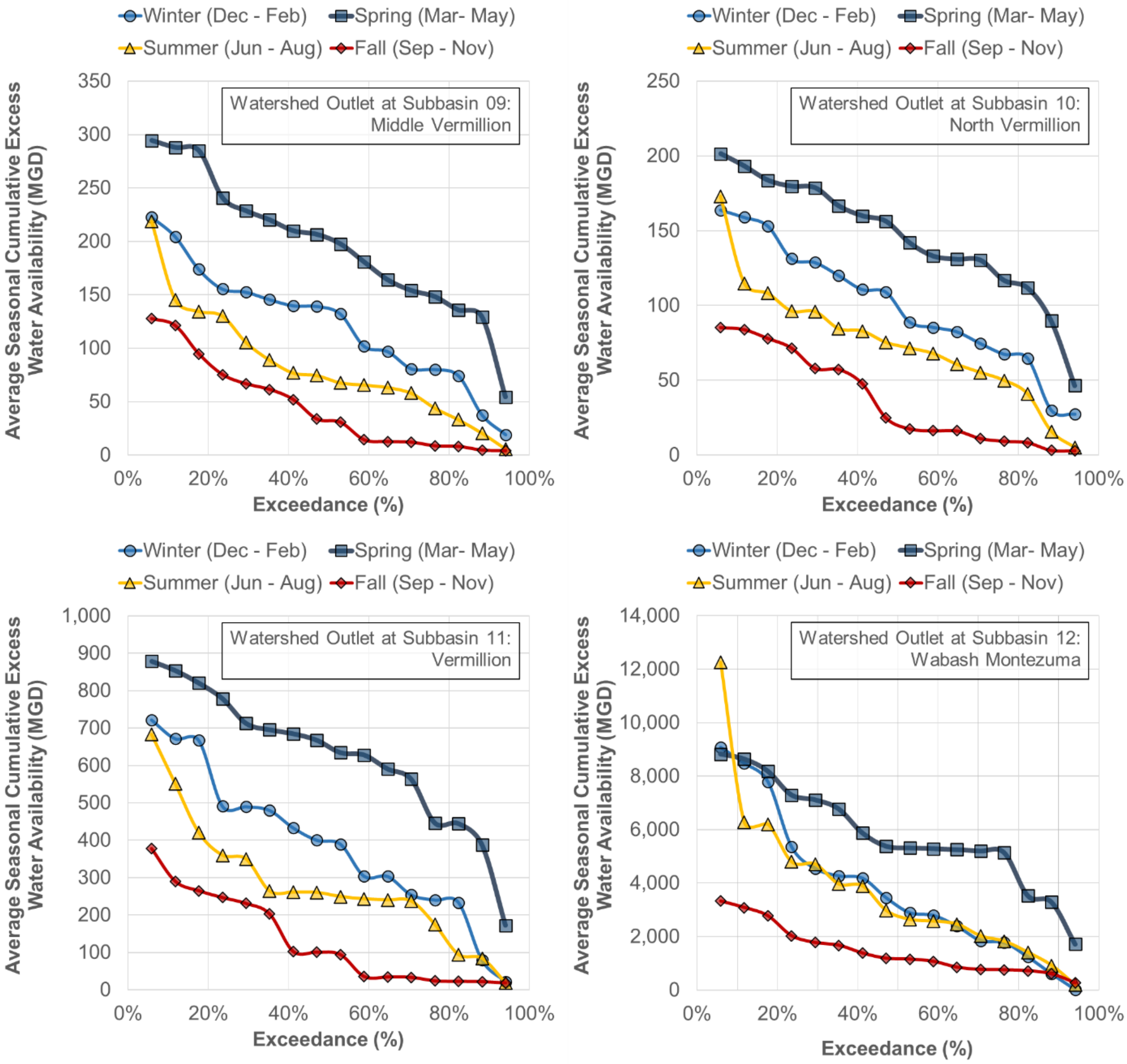


Figure 6-10. Exceedance Curves of Historical Average Seasonal Cumulative Excess Water Availability by Watershed Outlet from 2007-2022 for Middle Vermilion (top left, Subbasin 09), North Vermilion (top right, Subbasin 10), Vermilion (bottom left, Subbasin 11), and Wabash Montezuma (bottom right, Subbasin 12)

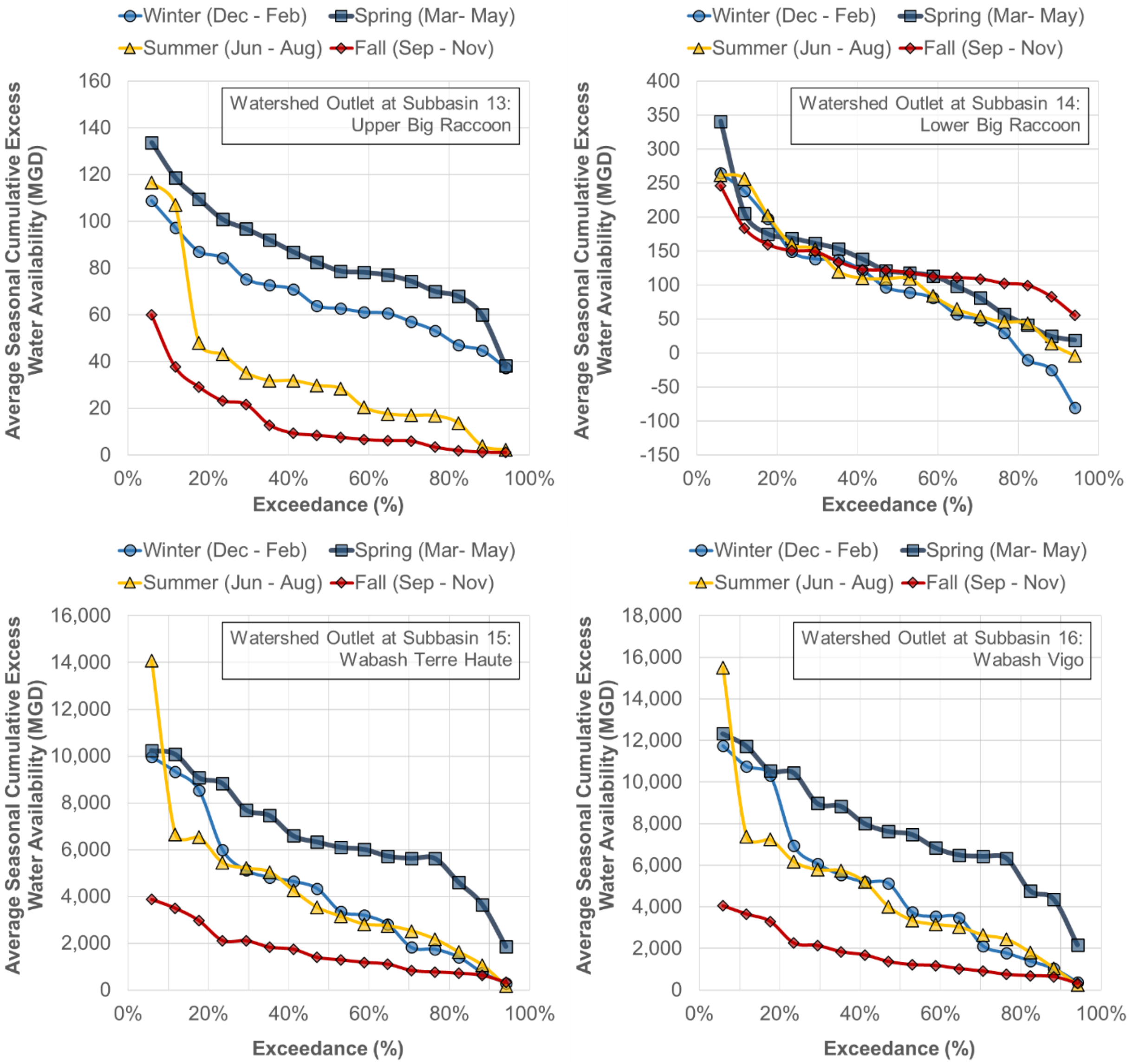


Figure 6-11. Exceedance Curves of Historical Average Seasonal Cumulative Excess Water Availability by Watershed Outlet from 2007-2022 for Upper Big Raccoon (top left, Subbasin 13), Lower Big Raccoon (top right, Subbasin 14), Wabash Terre Haute (bottom left, Subbasin 15), and Wabash Vigo (bottom right, Subbasin 16)

6.6 Effects of Upstream Reservoir Releases

In this section, the primary components of cumulative excess water availability—natural baseflow, net reservoir releases, instream flow, and net return flow (withdrawals minus return flows)—are analyzed longitudinally to provide additional insights into water availability dynamics along the Wabash River. This longitudinal representation is shown for the most critical water availability months, fall and summer, for a relatively dry year (2022) and a relatively wet year (2017) in Figure 6-12.

During a relatively dry fall (2022), cumulative excess water availability along the Wabash River is almost entirely sustained by reservoir releases (Figure 6-12). In this season, the instream flow and historical net return flows exceeded the available natural baseflow, indicating cumulative excess water availability consists entirely of managed water releases from upstream reservoirs. Conversely, during a relatively wet fall (2017), natural baseflow becomes the dominant component, accounting for about 80% of cumulative excess water availability, with reservoir releases accounting for 20%. This variation of results for the fall season across wet and dry years demonstrates the interplay between natural hydrological processes and reservoir operations, and how they have historically influenced cumulative excess water availability.

Similarly, Figure 6-13 illustrates longitudinal cumulative excess water availability along the Wabash River for Summer 2022 (a relatively dry year) and Summer 2017 (a relatively wet year). During the dry summer of 2022, natural baseflow remains the primary source of water availability, despite minimal net reservoir releases. The cumulative excess water availability is driven by baseflow as instream flow and historical net return flows are lower than the available natural baseflow. In contrast, during the wetter summer of 2017, net reservoir releases significantly increase, and the additional releases constitute about 25% of cumulative excess water availability at Wabash Lafayette (06). This percentage decreases to about 14% at Wabash Vigo (16) indicating the increase in natural baseflow in the downstream direction along the Wabash River can reduce the proportion of cumulative excess water availability comprised of reservoir releases.

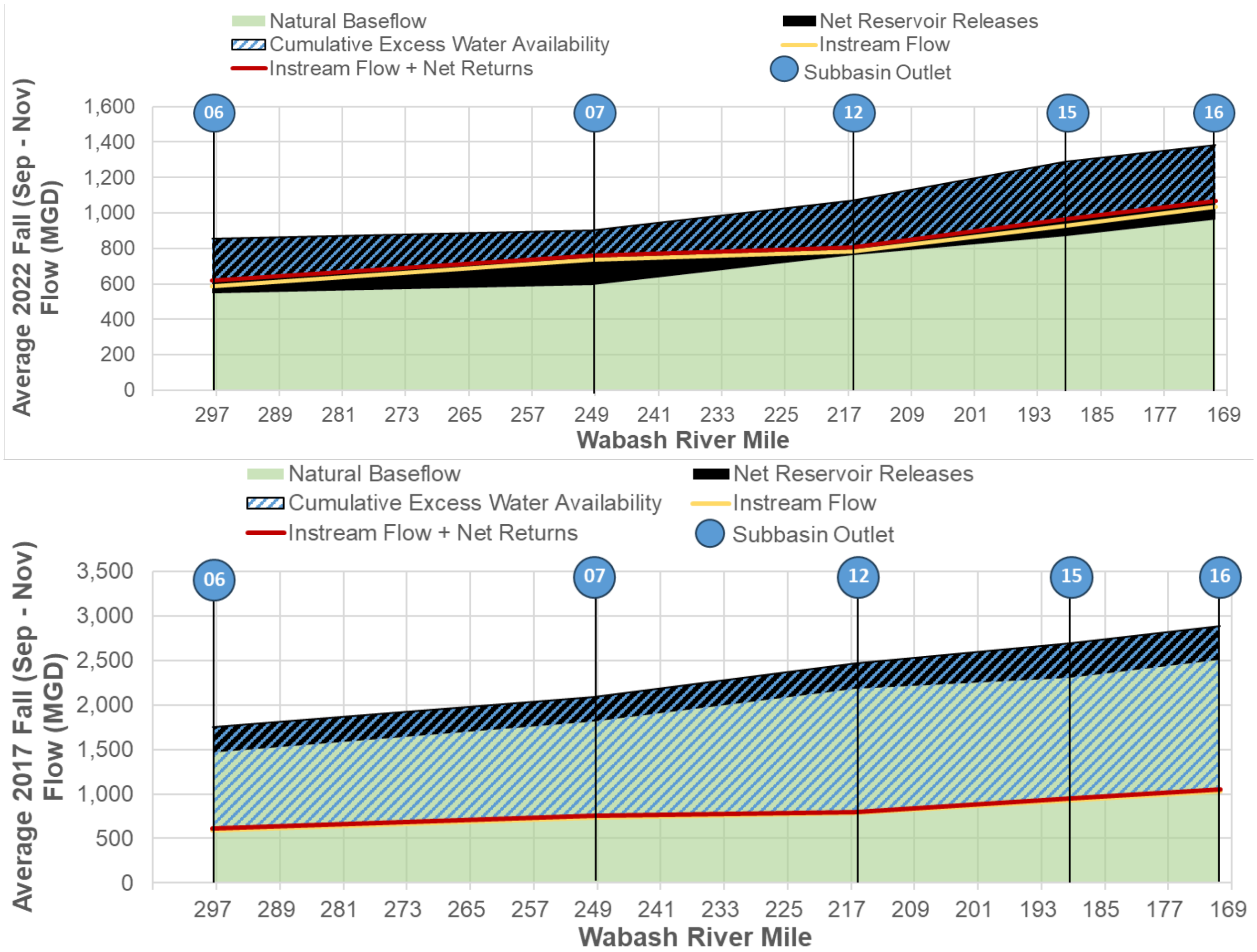


Figure 6-12. Longitudinal Cumulative Excess Water Availability Along the Wabash River for a Relatively Dry Year Fall 2022 (top) and a Relatively Wet Year Fall 2017 (bottom)

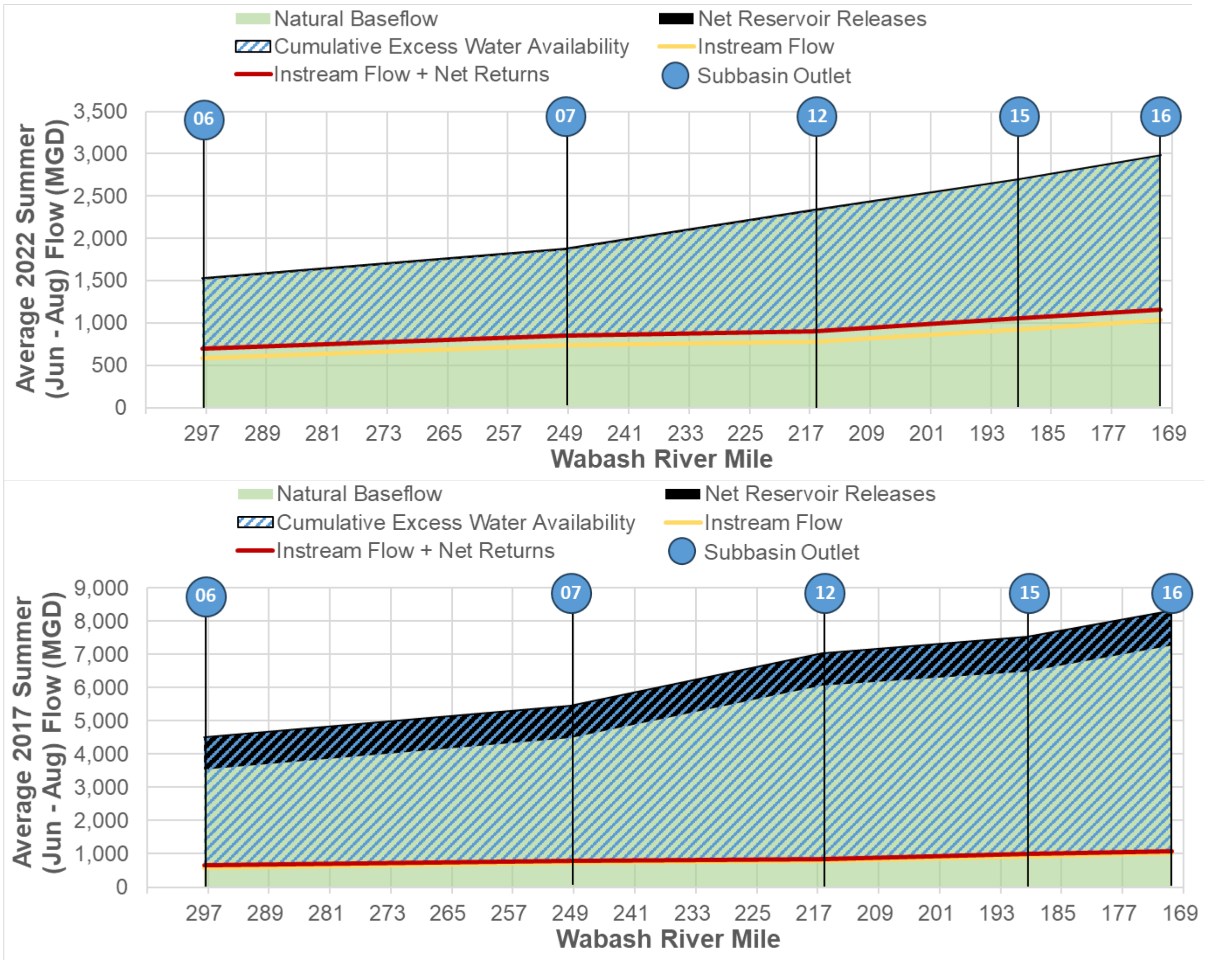


Figure 6-13. Longitudinal Cumulative Excess Water Availability Along the Wabash River for a Relatively Dry Year Summer 2022 (top) and a Relatively Wet Year Summer 2017 (bottom)

The portion of fall cumulative excess water availability provided by upstream reservoir releases at Wabash Lafayette (06) is shown as the top plot in Figure 6-14, and the bottom plot shows the percentage of cumulative excess water availability comprised of reservoir releases for all Wabash River subbasins. Fall reservoir releases are predominantly from dams in the Headwaters, and are relatively stable year-to-year, with less annual variation than natural baseflow. Stable reservoir releases are a product of reservoir storage capacity and hydrology – reservoirs in the Headwaters generally fill to capacity during the wet season, hold a stable pool during the summer, then release stored storm flows during the fall to create storage capacity for the next wet season. These results indicate fall reservoir releases in the upstream headwaters provide essential contributions to cumulative excess water availability along the mainstem Wabash River, especially in drier fall seasons when natural baseflow is relatively low. On average, upstream reservoir releases comprise approximately 40% of cumulative excess water availability at all subbasins along the Wabash River, though that percentage can range from about 10% in wetter fall seasons (e.g., 2011, 2014, 2018) to around 75% in drier fall seasons (e.g., 2010, 2020) to the more recent 100% - 200% seen in the driest fall in the historical availability period, 2022, when a portion of reservoir releases provided all cumulative excess water availability and met the instream flow water budget component.

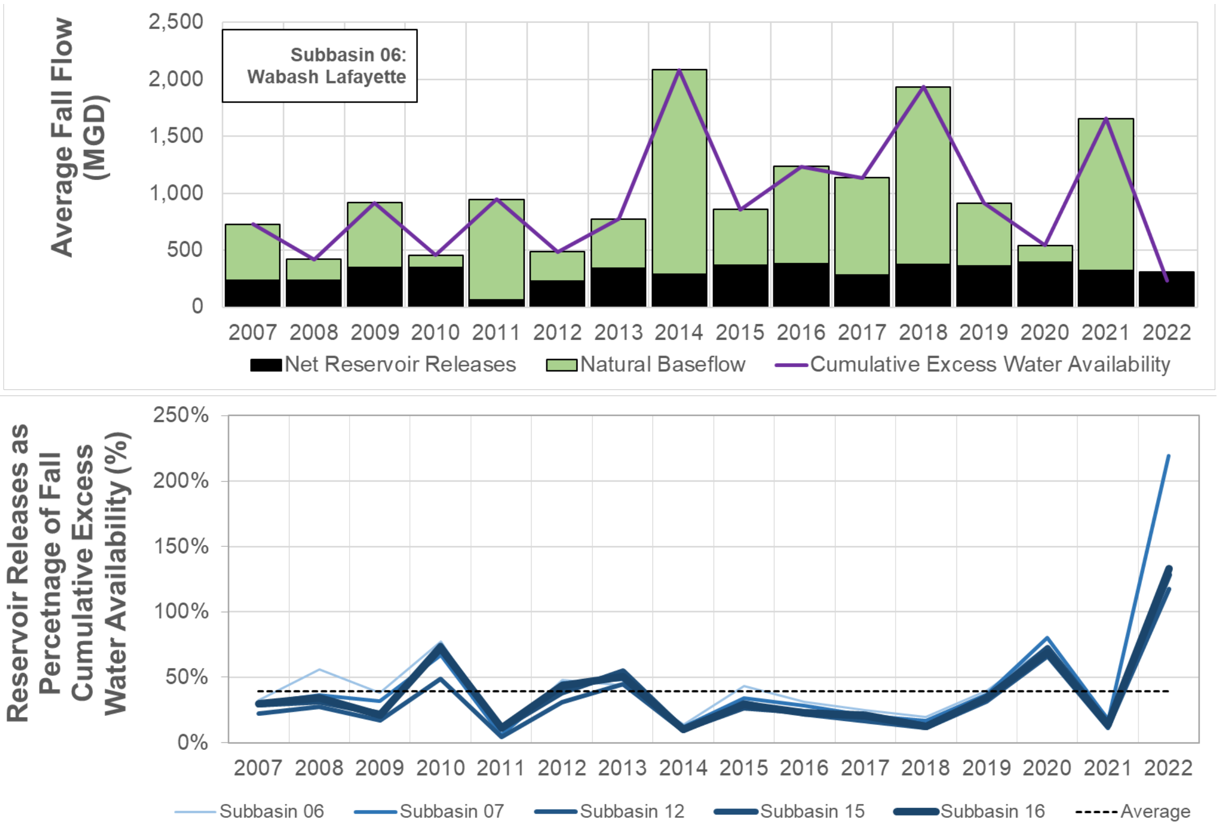


Figure 6-14. Reservoir Release Contribution to Fall Cumulative Excess Water Availability

6.7 Historical Water Availability Key Findings

Key findings from the analysis of recent historical water availability highlight several important implications for water resource management in the region.

Historical water supply exceeds historical water demand in most locations and most seasons: Historical cumulative excess water availability was generally high across all subbasins, typically greater than water demands except during the driest summer and winter. These results indicate water supply is abundant during most years and seasons **but may be approaching a condition of total water allocation and limited excess during dry seasons.**

Variations in natural baseflow are the main driver of cumulative excess water availability: Seasonal and inter-annual fluctuations in natural baseflow closely align with changes in excess and cumulative excess water availability, indicating natural hydrological processes are the main driver of regional water availability. This relationship suggests future changes in precipitation, snowfall, and land use will have a direct effect on water availability.

Cumulative water availability and cumulative excess water availability increase from upstream to downstream: A clear pattern emerges showing increasing cumulative excess water availability from upstream to downstream subbasins. Downstream subbasins generally exhibit higher levels of cumulative excess water availability, indicating natural baseflow and reservoir releases from upstream subbasins contribute meaningfully to water availability in the downstream subbasins of the watershed. Excess water availability for individual subbasins shows more spatial variability, with some relatively larger subbasins on tributaries generating greater excess water availability than relatively smaller subbasins on the mainstem Wabash River.

Strong seasonal variation in cumulative excess water availability across subbasins: Cumulative excess water availability is typically highest in the spring season, followed by winter, summer, and fall. Fall is generally the most limiting season for cumulative excess water availability due to low streamflow and low natural baseflow throughout the Study Area. Some drier summer and winter seasons in the historical period produce the lowest natural baseflow values, however, and result in low or negative cumulative excess water availability along the mainstem Wabash River. Fall reservoir releases from the upstream Headwaters help support positive fall cumulative excess water availability along the mainstem Wabash River. Fall releases from a flood control reservoir in Lower Big Raccoon (14) result in a different trend of seasonal water availability, with the fall season exhibiting the highest seasonal cumulative water availability for that subbasin. These results suggest localized hydrological behaviors, influenced by factors such as climate variability, hydrogeology, human interventions, and reservoir operations, contribute to the complexity of water availability dynamics in these regions.

Negative cumulative excess water availability occurs in some seasons: Notably, several subbasins, including Lower Tippecanoe (02), Wabash Lafayette (06), and Lower Big Raccoon (14), experience periods of negative cumulative excess water availability, observed during the historical period in the winter and summer seasons. When these periods occur, instream flow needs and water withdrawals are in excess of natural baseflow, return flows, and reservoir releases, meaning a water availability deficit exists and any new water withdrawals would further increase the water availability deficit. These deficits highlight areas with supply-demand imbalances that may face water stress during periods of low natural baseflow.

Different seasons in the historical period limit water availability in different ways: While fall is typically the most limiting season for cumulative excess water availability, the summer of 2012 was identified as the most constrained season across the entire historical timeframe analyzed. During this summer, a regional drought characterized by record high temperatures increased water demand, while record low seasonal precipitation, low snowfall in the preceding winter, and streamflow limited natural baseflow. This particular year underscores the importance of accounting for intra-annual and interannual variability, especially during extreme drought conditions that can exacerbate water scarcity.

Cumulative excess water availability during the most limiting season is heavily supported by upstream reservoir releases: Methodology for this Study assumes that cumulative natural baseflow, which is largely sourced from drawing down aquifers during the fall when no aquifer recharge is occurring, is the water budget supply component that is first allocated to meet instream flow needs, next followed by upstream reservoir releases, if present. This assumption is made because none of the upstream reservoirs have a release requirement to provide minimum flows for the mainstem of the Wabash River (i.e., there is no federal authorization for this particular purpose). Under this assumption, cumulative excess water availability along the Wabash River is largely comprised of managed reservoir releases in the Headwaters region during the (relatively dry) fall season. Throughout the entire historical Study period, excluding 2022, upstream reservoir releases made up anywhere from 10% to 75% of fall cumulative excess water availability along the mainstem Wabash River, with an average of 41%. In 2022, instream flow and historical net return flows exceeded natural baseflow for the only time in the historical analysis period, meaning upstream reservoir releases supported some portion of instream flows and water withdrawals, while serving as the sole source of cumulative excess water availability. This particular year, and the long-term average trend of reservoir releases supporting some level of cumulative excess water availability along Wabash River subbasins, highlights the importance of upstream water management on downstream water availability during critically dry seasons.

7.0 Future Water Availability Results

A relative comparison between future and historical water availability is provided in this Chapter to show differences in water availability due to projected future water demands and the effects of climate change on meteorological and streamflow variables. Future results in this Chapter are summarized using statistics from 16 representative future years between 2043 and 2072, which generally includes future years centered around the 2060s. The future 16 representative years include one future year corresponding to each year of the recent historical period,[10] 2007-2022 (see Section 5.5.2 for details on future years). These 16 representative future years were used to allow a more directly statistical comparison to the 16-year recent historical period. By selecting these years, the comparative analysis of water budget components explicitly reflects future baseline scenario assumptions, including projected climate change effects on natural baseflow and future projected water demands, return flows, and reservoir releases. Additional details on future water availability are provided in Appendix H.

7.1 Future Water Availability Summary

Future season-averaged subbasin excess water availability and cumulative excess water availability are shown in Figure 7-1. Similar to Figure 6-1, these figures show data for each subbasin in a row with two horizontal bars: the first bar shows subbasin water excess availability, or the water availability generated within each subbasin, while the second bar shows cumulative excess water availability, or the water availability accumulated from all upstream subbasins. Each subbasin has a value for the first bar, subbasin excess, but only those with an upstream subbasin will have the second bar, cumulative excess upstream. The sum of both bars indicates the total cumulative excess water availability for that subbasin.

On a seasonal average basis, cumulative excess water availability remains positive across all subbasins, indicating future available supply is in excess of future projected demands. Similar seasonal variability is observed in future water availability, with availability highest in the spring, relatively similar in the winter and summer, and lowest in the fall at all subbasins. Wet season water availability is driven by high natural baseflow, which is projected to increase in the spring for future conditions relative to historical conditions. Winter and summer availability are projected to remain relatively similar to historical conditions, while fall availability will likely be reduced relative to historical conditions. These reductions are described further in the next section, but are primarily due to lower estimated fall baseflow under future conditions. Water availability remains spatially varied, with subbasins along the Wabash River mainstem (Headwaters, 06, 07, 12, 15, and 16) exhibiting greater cumulative water availability than tributary subbasins. Future fall water availability on the Wabash River subbasins is projected to be even more reliant on excess flow from the Headwaters, as described in Section 7.4.

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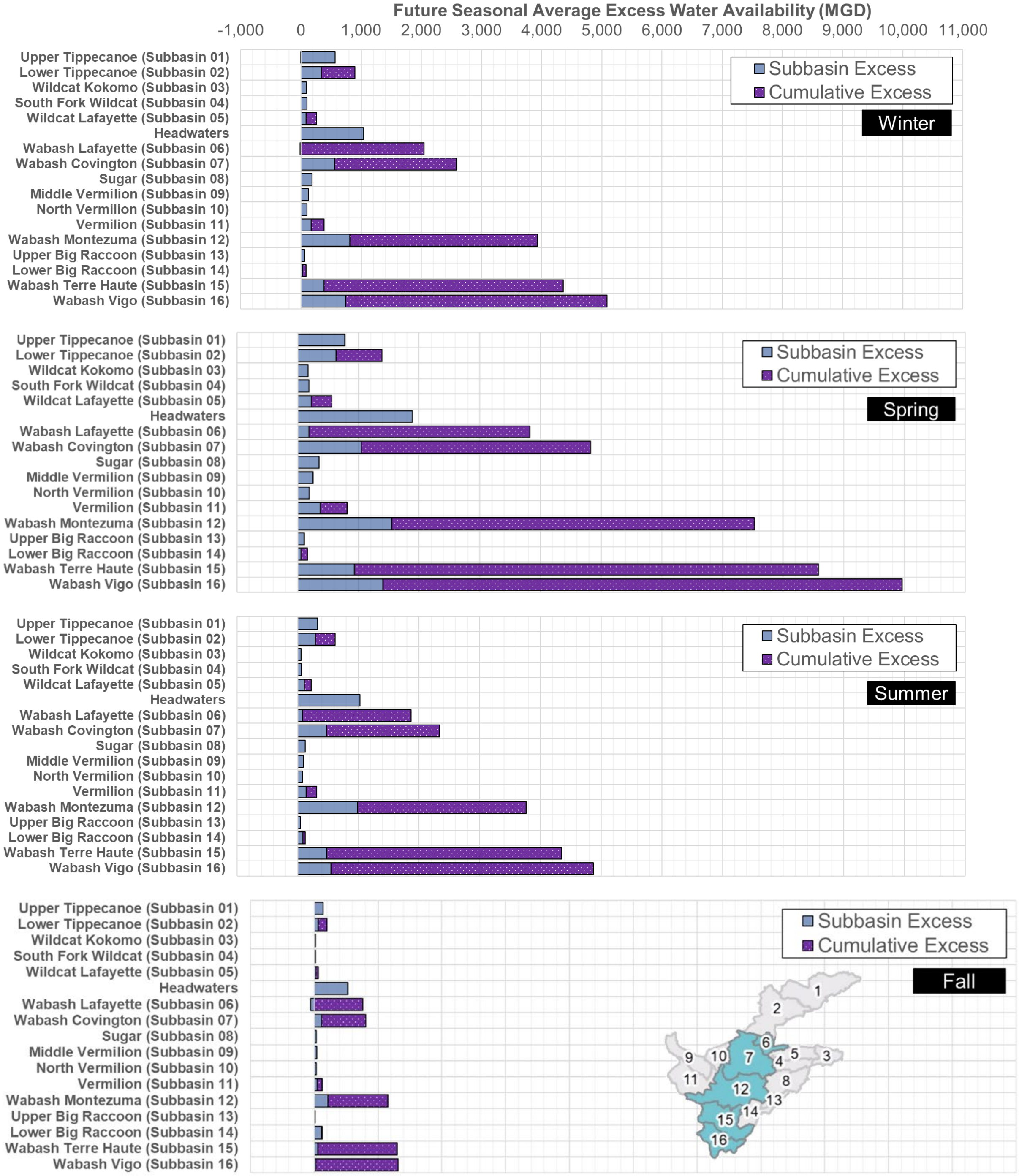
[10] The future year, with corresponding historical year in parentheses, included: 2064 (2007), 2065 (2008), 2066 (2009), 2067 (2010), 2068 (2011), 2069 (2012), 2070 (2013), 2043 (2014), 2060 (2015), 2051 (2016), 2050 (2017), 2055 (2018), 2065 (2019, replaced with 2008), 2071 (2020), 2057 (2021), 2059 (2022). Note that 2008 was used twice since 2019 was not represented in the future sequence.



Note: Cumulative excess water availability includes the sum of the bars labeled Subbasin Excess and Cumulative Excess. Headwaters shown as subbasin excess though it includes all subbasins in the Headwaters region. Mainstem Wabash River subbasins include Headwaters, 06, 07, 12, 15, and 16.

Figure 7-1. Future Subbasin and Cumulative Excess Water Availability by Subbasin and Season

7.2 Projected Changes in Future Water Availability

An overview of changes in excess water availability and cumulative excess water availability are provided separately in this section. A spatial overview of historical and future excess water availability is shown in Figure 7-2. The figure also includes the percentage change between future and historical values. In many subbasins, future water availability is in the same range for plotting purposes as historical water availability and may show as the same color, even though the percentage change may indicate more or less water availability. A numerical comparison between historical and future excess water availability shown in the spatial plots indicates large seasonal differences across all subbasins (Table 7-1 and Table 7-2). The following observations are provided for each season:

- **Winter**: Winter subbasin excess water availability is projected to generally increase by 18% along the Tippecanoe River subbasins (01, 02) due to higher projected streamflow and baseflow relative to historical conditions. These are also subbasins with higher relative recharge rates due to the geology that is largely comprised of outwash, till, and moraines, so higher relative baseflow would be anticipated with increases in future precipitation. Some smaller tributary subbasins on the eastern portion of the watershed show -2% to -19% reductions in future winter water availability (03, 04, 05, 13, 14). These subbasins are underlaid by more bedrock-dominant geology, where future projected baseflow changes are relatively less sensitive to future changes in precipitation. Wabash Lafayette (06) is the only subbasin with average negative subbasin excess availability. This is predominantly due to the small drainage area of the subbasin that was delineated specifically for this Study. A relatively small amount of net natural baseflow is generated in this small drainage area compared to the relatively high water demands of the Lafayette population center.
- **Spring**: Spring excess water availability is projected to increase by at least 16% in all subbasins, the most of all seasons, due to higher projected baseflow relative to historical conditions.
- **Summer**: Summer subbasin excess water availability is projected to decrease minimally for the Headwaters and smaller first order subbasins (01, 03, 04) primarily due to higher projected water demands in excess of increases in summer baseflows. Conversely, summer water availability increases from 6% to 33% for all subbasins downstream of Wabash Lafayette (06) primarily due to higher projected summer baseflow that exceeds increases in consumptive demand.
- **Fall**: All subbasins show projected reduced subbasins excess water availability of -4% to -52% relative to historical conditions, driven primarily by decreases in future fall baseflow. Subbasins on the Tippecanoe River and Wildcat Creek (01 through 05) generally show the largest reduction in future excess water availability relative to historical conditions, as these subbasins had the largest projected change in future fall streamflow in the INCCIA study (Cherkauer et al., 2021). The results are consistent with the INCCIA study, which estimated monthly flows in future summer and fall seasons would be lower than historical values, and also consistent with trends presented in Section 2.2.2. These subbasins also had relatively large increases in fall water withdrawals relative to historical conditions, contributing to the decline in projected subbasin excess

availability. The negative average excess water availability in Wabash Lafayette (06) is projected to become more negative in the future due to lower baseflow and higher demand.

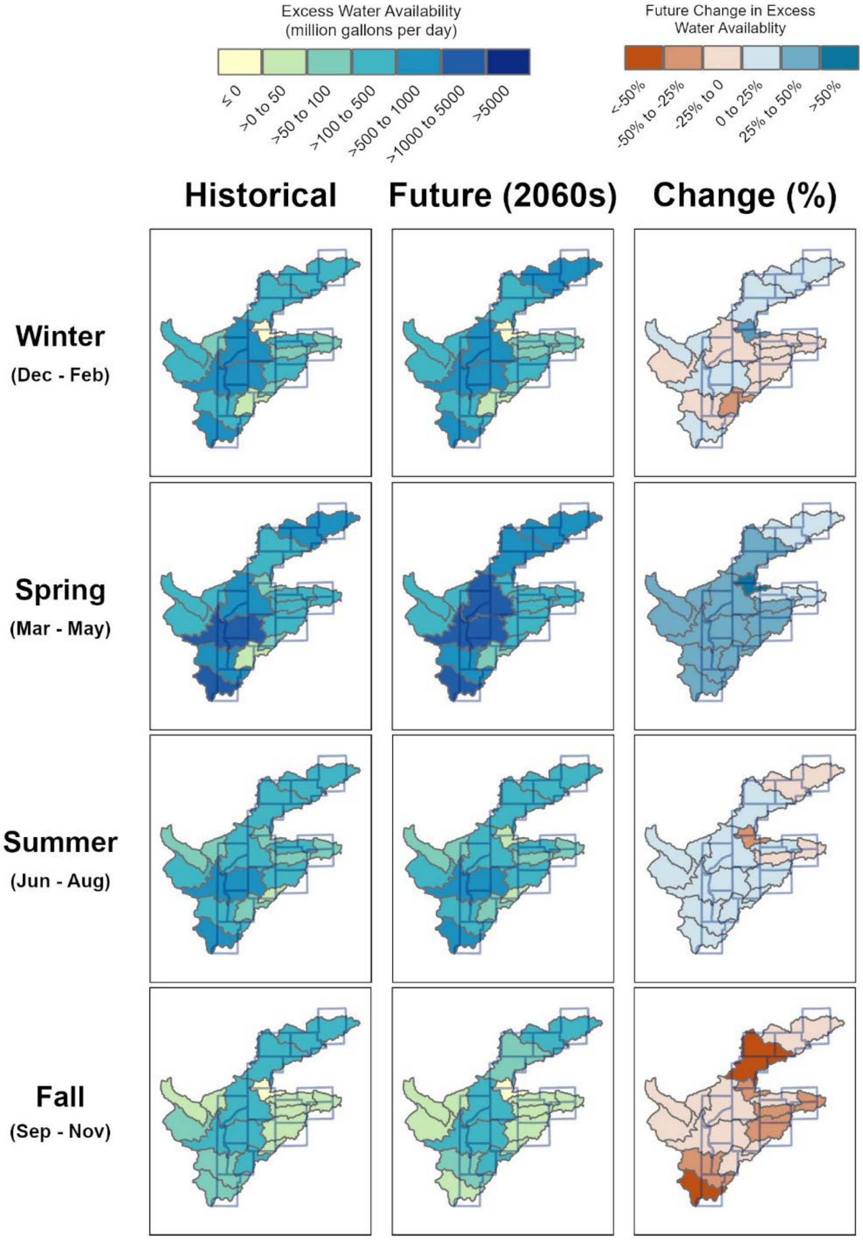


Figure 7-2. Overview of Historical (2007-2022) and Future (2060s) Excess Water Availability, and the Percentage Change over Time, by Subbasin and Season

Table 7-1. Historical and Future Winter and Spring Excess Water Availability

Subbasin	Winter Excess			Spring Excess		
	Historical (MGD)	Future (MGD)	% Change	Historical (MGD)	Future (MGD)	% Change
Upper Tippecanoe (01)	480	567	18%	654	773	18%
Lower Tippecanoe (02)	281	336	20%	472	631	34%
Wildcat Kokomo (03)	100	91	-8%	144	167	16%
South Fork Wildcat (04)	99	96	-2%	142	184	29%
Wildcat Lafayette (05)	108	87	-19%	185	221	19%
Headwaters	1,026	1,039	1%	1,414	1,891	34%
Wabash Lafayette (06)	-32	-16	50%	62	186	200%
Wabash Covington (07)	571	561	-2%	768	1,051	37%
Sugar (08)	188	187	-1%	280	352	26%
Middle Vermilion (09)	122	126	3%	196	255	30%
North Vermilion (10)	100	103	3%	145	189	30%
Vermilion (11)	171	166	-3%	287	377	32%
Wabash Montezuma (12)	733	815	11%	1,235	1,550	26%
Upper Big Raccoon (13)	68	64	-6%	85	107	26%
Lower Big Raccoon (14)	31	21	-32%	42	53	27%
Wabash Terre Haute (15)	395	382	-3%	690	932	35%
Wabash Vigo (16)	710	741	4%	1,132	1,407	24%

Key: MGD = million gallons per day

Table 7-2. Historical and Future Summer and Fall Excess Water Availability

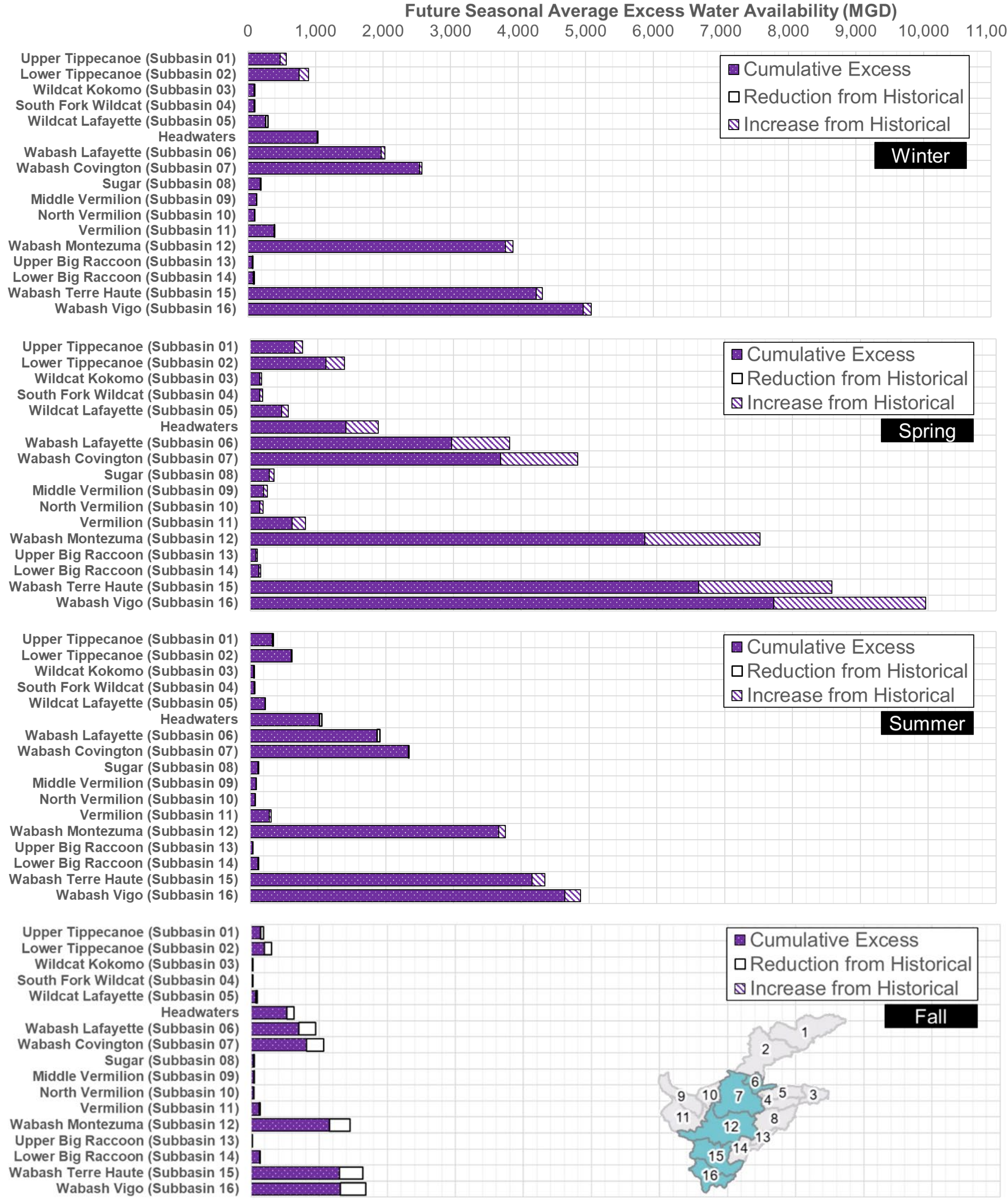
Subbasin	Summer Excess			Fall Excess		
	Historical (MGD)	Future (MGD)	% Change	Historical (MGD)	Future (MGD)	% Change
Upper Tippecanoe (01)	343	330	-4%	181	138	-24%
Lower Tippecanoe (02)	266	290	9%	119	59	-50%
Wildcat Kokomo (03)	58	57	-3%	26	19	-29%
South Fork Wildcat (04)	64	62	-3%	27	20	-26%
Wildcat Lafayette (05)	102	105	4%	38	29	-25%
Headwaters	1,060	1,024	-3%	631	525	-17%
Wabash Lafayette (06)	58	77	33%	-46	-59	-29%
Wabash Covington (07)	435	471	8%	126	114	-9%
Sugar (08)	115	127	10%	44	33	-26%
Middle Vermilion (09)	83	95	14%	45	42	-7%
North Vermilion (10)	75	79	6%	37	32	-12%
Vermilion (11)	124	142	14%	53	49	-7%
Wabash Montezuma (12)	934	991	6%	242	215	-11%
Upper Big Raccoon (13)	35	44	26%	15	12	-18%
Lower Big Raccoon (14)	78	84	7%	115	110	-4%
Wabash Terre Haute (15)	403	483	20%	91	59	-35%
Wabash Vigo (16)	507	551	9%	52	25	-52%

Key: MGD = million gallons per day

Changes in future season-averaged cumulative excess water availability relative to historical values are shown in Figure 7-2, and a spatial overview of historical and future cumulative excess water availability is shown in Figure 7-4. This figure also includes the percentage change between future and historical values. In many cases, future cumulative excess water availability is in the same range for plotting purposes as historical cumulative excess water availability and may show as the same color, even though the percentage change may indicate more or less water availability. Similar to projected subbasin excess availability results, large seasonal differences in projected cumulative excess water availability are observed across all subbasins (Table 7-3 and Table 7-4). The following observations are provided for each season:

- **Winter**: Winter cumulative excess water availability is projected to generally increase by 18% along the Tippecanoe River subbasins (01, 02) and 2% to 3% along the mainstem Wabash River mainstem subbasins (06, 07, 12, 15, 16) due to higher projected streamflow and baseflow relative to historical conditions. Most of the cumulative flow volume on the mainstem Wabash River is sourced from the Tippecanoe River subbasins (01, 02). Some smaller tributary subbasins on the eastern portion of the watershed show -2% to -15% reductions in future winter water availability (03, 04, 05, 13, 14).
- **Spring**: Spring cumulative excess water availability is projected to increase by 16% to 34%, the most of all seasons for all subbasins, due to higher projected streamflow and baseflow relative to historical conditions. Percentage increases are slightly higher on average for subbasins downstream of Wabash Lafayette (06).
- **Summer**: Summer cumulative excess water availability is projected to decrease from 0% to -5% for almost all subbasins upstream of Wabash Covington (07) primarily due to higher projected water demands in excess of increases in summer baseflows. Conversely, summer water availability increases from 3% to 26% for most subbasins downstream of Wabash Lafayette (06) primarily due to higher simulated cumulative baseflow that exceeds increases in consumptive demand.
- **Fall**: The reductions in fall subbasin excess water availability in all subbasins shown in Table 7-2 translates to large reductions in cumulative excess water availability in all subbasins. Fall cumulative excess water availability is reduced -5% to -34% relative to historical conditions, driven primarily by decreases in future fall baseflow. The results are consistent with the INCCIA study, which estimated monthly flows in future summer and fall seasons would be lower than historical values, and also consistent with trends presented in Section 2.2.2.

The Headwaters and Lower Big Raccoon (14) subbasins reflect a smaller range of projected changes in fall cumulative excess water availability in the future relative to historical conditions for Indiana subbasins. Both subbasins have at least one large flood control reservoir that stores winter flows and makes stored water releases primarily in the fall season. Reductions in future fall availability at these subbasins due to lower natural baseflow are somewhat mitigated by reservoir releases (this is assessed further in Section 7.4).



Note: Headwaters shown as subbasin excess, though it includes all subbasins in the Headwaters region. Mainstem Wabash River subbasins include Headwaters, 06, 07, 12, 15, and 16.

Figure 7-3. Change from Historical to Future Cumulative Excess Water Availability by Subbasin and Season

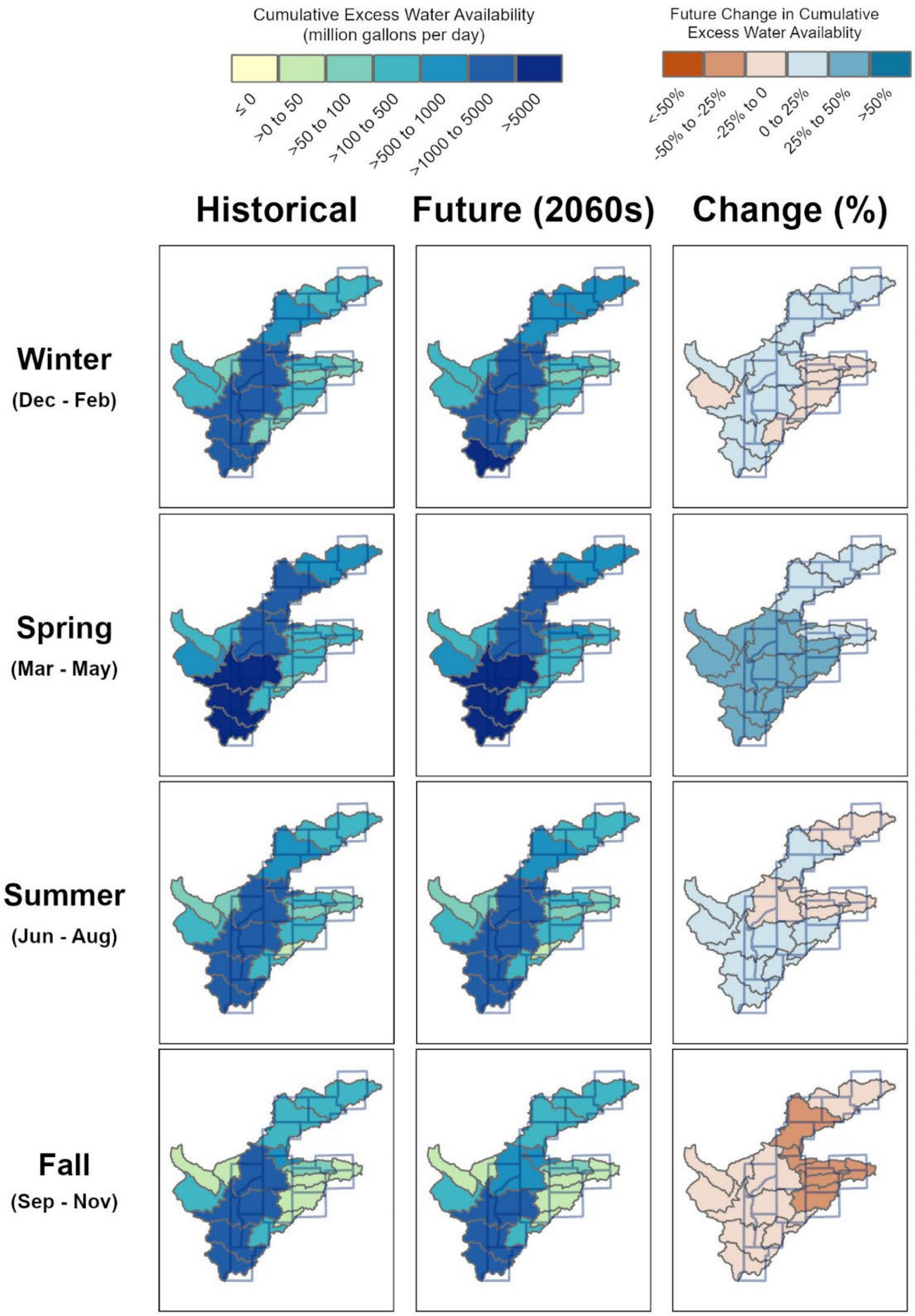


Figure 7-4. Overview of Historical (2007-2022) and Future (2060s) Cumulative Excess Water Availability, and the Percentage Change over Time, by Subbasin and Season

Table 7-3. Historical and Future Winter and Spring Cumulative Excess Water Availability

Subbasin	Winter Cumulative Excess			Spring Cumulative Excess		
	Historical (MGD)	Future (MGD)	% Change	Historical (MGD)	Future (MGD)	% Change
Upper Tippecanoe (01)	480	567	18%	654	773	18%
Lower Tippecanoe (02)	758	899	19%	1,121	1,391	24%
Wildcat Kokomo (03)	100	91	-8%	144	167	16%
South Fork Wildcat (04)	99	96	-2%	142	184	29%
Wildcat Lafayette (05)	295	263	-11%	464	561	21%
Headwaters	1,026	1,039	1%	1,414	1,891	34%
Wabash Lafayette (06)	1,975	2,026	3%	2,971	3,826	29%
Wabash Covington (07)	2,537	2,579	2%	3,695	4,829	31%
Sugar (08)	188	187	-1%	280	352	26%
Middle Vermilion (09)	122	126	3%	196	255	30%
North Vermilion (10)	100	103	3%	145	189	30%
Vermilion (11)	386	386	0%	623	814	31%
Wabash Montezuma (12)	3,808	3,927	3%	5,819	7,523	29%
Upper Big Raccoon (13)	68	64	-6%	85	107	26%
Lower Big Raccoon (14)	96	82	-15%	126	159	26%
Wabash Terre Haute (15)	4,269	4,356	2%	6,613	8,581	30%
Wabash Vigo (16)	4,960	5,082	2%	7,727	9,964	29%

Key: MGD = million gallons per day

Table 7-4. Historical and Future Summer and Fall Cumulative Excess Water Availability

Subbasin	Summer Cumulative Excess			Fall Cumulative Excess		
	Historical (MGD)	Future (MGD)	% Change	Historical (MGD)	Future (MGD)	% Change
Upper Tippecanoe (01)	343	330	-4%	181	138	-24%
Lower Tippecanoe (02)	609	619	2%	300	197	-34%
Wildcat Kokomo (03)	58	57	-3%	26	19	-29%
South Fork Wildcat (04)	64	62	-3%	27	20	-26%
Wildcat Lafayette (05)	221	221	0%	89	66	-27%
Headwaters	1,060	1,024	-3%	631	525	-17%
Wabash Lafayette (06)	1,915	1,870	-2%	949	703	-26%
Wabash Covington (07)	2,345	2,337	0%	1,066	810	-24%
Sugar (08)	115	127	10%	44	33	-26%
Middle Vermilion (09)	83	95	14%	45	42	-7%
North Vermilion (10)	75	79	6%	37	32	-12%
Vermilion (11)	281	314	12%	131	120	-8%
Wabash Montezuma (12)	3,668	3,762	3%	1,454	1,153	-21%
Upper Big Raccoon (13)	35	44	26%	15	12	-18%
Lower Big Raccoon (14)	112	126	13%	129	122	-5%
Wabash Terre Haute (15)	4,161	4,349	5%	1,640	1,301	-21%
Wabash Vigo (16)	4,646	4,873	5%	1,681	1,315	-22%

Key: MGD = million gallons per day

Interpretation of the average change by season is supported by horizontal bar charts that show how each component of the water budget contributed to a projected change in excess water availability and cumulative excess water availability (Figure 7-5 through Figure 7-8). The top plot shows water budget components for each subbasin (i.e., local), while the bottom plot shows cumulative (i.e., regional) water budget components. Both charts include changes in natural baseflow, reservoir operations, and consumptive demand (withdrawals minus returns). Instream flow is not included because the value did not change between historical and future analyses, so it has a value of 0 (zero) in all seasons.

Each horizontal bar in Figure 7-5 through Figure 7-8 corresponds to a subbasin, with positive values to the right and negative values to the left relative to the 0 value on the x-axis. Positive values indicate a change in that water budget component led to projected increased water availability (e.g., higher future baseflow, reduced future consumptive demand, or higher future net reservoir releases). Negative values indicate a change in that water budget component led to projected decreased water availability (e.g., lower future baseflow, increased future consumptive demand, or lower future net reservoir releases). The positive and negative values are combined to calculate the total change in water availability for each subbasin.

For example, in Figure 7-5, Wabash Vigo (16) saw a projected increase of 122 MGD in winter cumulative excess water availability, which results predominantly from a projected 90 MGD increase in average natural baseflow from Upper Tippecanoe (01) and Lower Tippecanoe (02) that was offset by projected reductions in baseflow in the Headwaters, Wabash Lafayette (06), and Wabash Covington (07). The increase was also supported by a projected 50 MGD increase in reservoir releases from the Headwaters. These increases were offset by an increase in consumptive demand of 18 MGD, which came primarily from Subbasins 02, 06, 11, and 16.

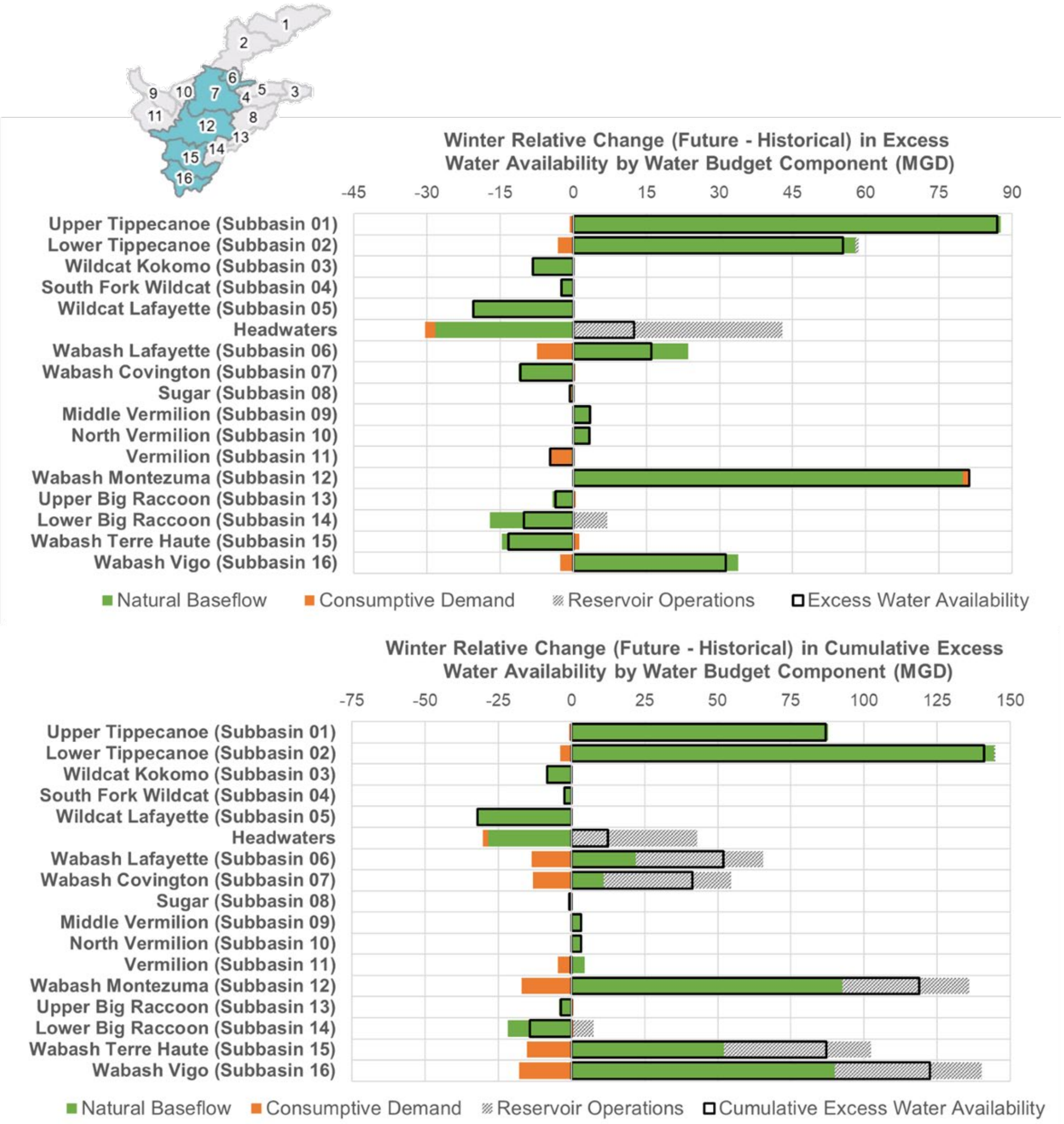
The dominant trend observed across seasons and subbasins is that changes in future projected baseflow relative to historical baseflow are the primary driver of changes in future water availability. Future baseflow changes are primarily driven by projected changes in climate, including higher precipitation in the winter and spring, which increase baseflow; and lower precipitation combined with higher air temperatures in the summer and fall, which lower baseflow. Changes in subbasin (local) and cumulative (regional) projected future excess water availability are highly seasonal, influenced by the geographic area of baseflow change and to some extent the geographic area of demand change. The following seasonal narrative summaries describe the changes shown in Figure 7-5 through Figure 7-8.

Winter: Baseflow changes are distributed differently throughout the Study Area, with baseflow increases projected in Upper Tippecanoe (01), Lower Tippecanoe (02), Wabash Montezuma (12), and Wabash Terre Haute (15) subbasins. All other subbasins show lower future winter baseflow that reduces subbasin excess water availability. In particular, the Headwaters and Wildcat Creek Subbasins (03, 04, 05) located further east see the largest decreases in winter baseflow. Projected increases in winter consumptive demand are observed primarily in subbasins with larger population centers and projected population growth (Wabash Lafayette, Vermilion, Wabash Vigo). The cumulative effects of these changes are that cumulative excess water availability increases along the Wabash River mainstem from 45 MGD at Wabash Lafayette (06) to 120 MGD at Wabash Vigo (16), with much of the cumulative increase coming from Tippecanoe River baseflow.

Spring: Relatively higher spring precipitation is projected to increase streamflow uniformly throughout the Study Area, resulting in increased natural baseflow that is simulated to offset projected consumptive demand increases in every subbasin. Cumulative consumptive demand increases are anticipated to be less than 5% of the total cumulative natural baseflow increases, and cumulative excess water availability is projected to increase by 30 MGD in the smallest tributary subbasins and from 900 MGD to 2,400 MGD in the Wabash River mainstem Subbasins 06, 07, 12, 15, and 16.

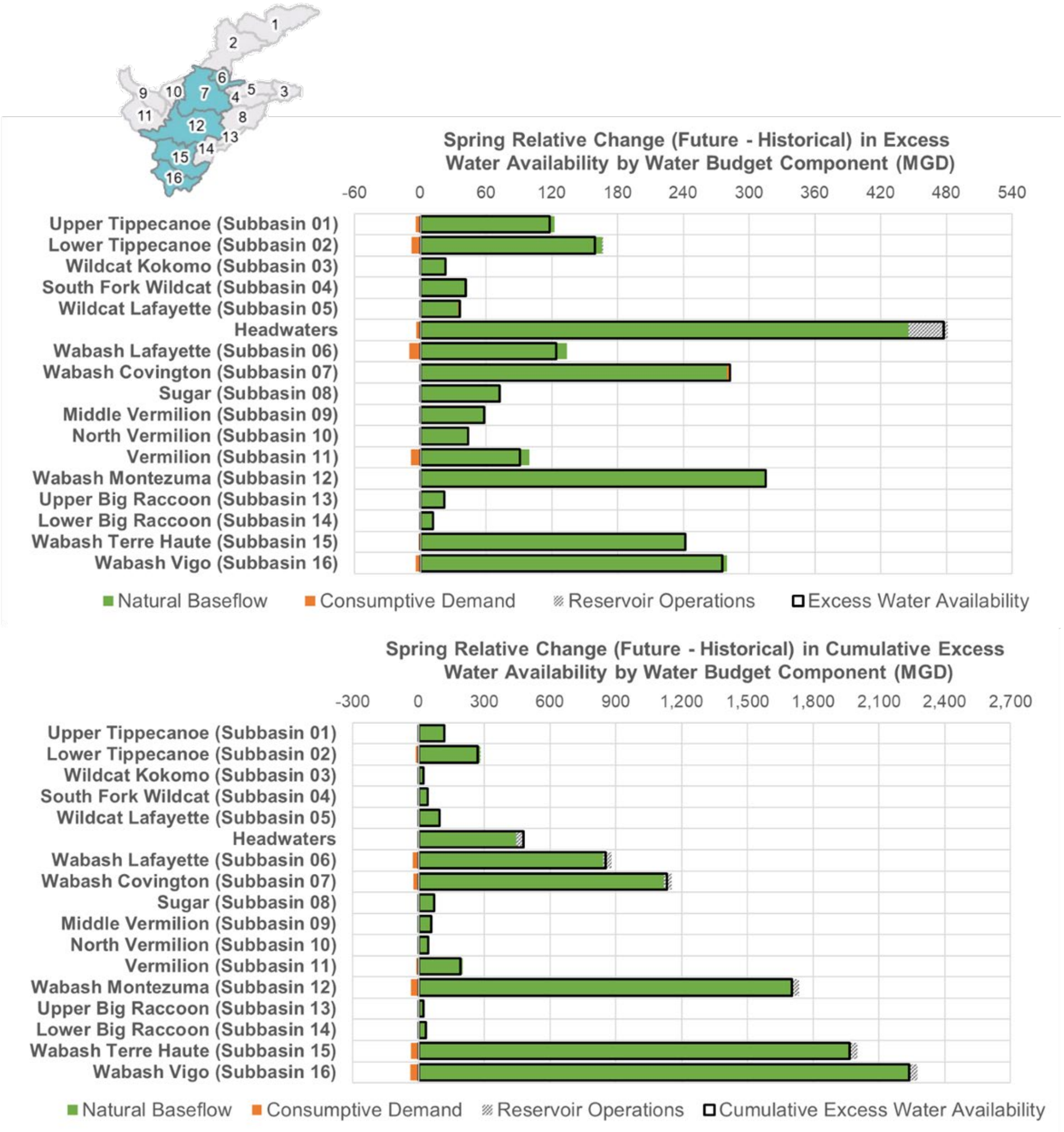
Summer: A combination of baseflow increases and consumptive demand increases are observed in the forecasts in most subbasins during the summer. The largest summer consumptive demand increases are projected to occur in the Tippecanoe River Subbasins (01, 02) primarily due to increased forecasted irrigation demand. In Upper Tippecanoe (01), demand increases offset any baseflow increases, leading to decreased subbasin excess water availability. Reductions in summer excess water availability are also expected in Wabash Lafayette (06); which combined with lower summer baseflows, could decrease subbasin excess water availability by 15 MGD. All other subbasins show an increase in summer subbasin natural baseflow. The Headwaters shows a reduction in reservoir releases; because future reservoir releases were not explicitly forecast, only repeated from historical years; this is not necessarily a modeled outcome, only the result of differences in averaging. Primarily due to increased consumptive demand that offsets baseflow increases, summer cumulative excess water availability is generally projected to decrease by up to 50 MGD in the subbasins upstream (01 to 06) of Wabash Covington (07). All subbasins further downstream along the Wabash River mainstem and contributing tributaries show increased summer cumulative excess water availability due to higher natural baseflow offsetting the consumptive demand projected to occur in subbasins upstream of Wabash Covington (07).

Fall: Lower natural baseflow is related to reductions in subbasin excess water availability in each subbasin during the fall. In subbasins with projected increased consumptive demand, the reduction to water availability is compounded even further. Some subbasins are forecasted to slightly decrease consumptive use, notably where large surface water withdrawals are no longer operational during the future period (Wabash Montezuma and Wabash Terre Haute). While the total volume of water withdrawn to support energy production was historically large, only 1% of withdrawals went to consumptive use; and thus, future changes in consumptive use are relatively small. In all subbasins where increased consumptive demand is expected to occur, on a cumulative basis, baseflow reductions exceed increased consumptive demand by at least one order of magnitude moving downstream. Total reductions in fall cumulative excess water availability along the mainstem Wabash River could range from 200 MGD to 400 MGD, upstream to downstream.



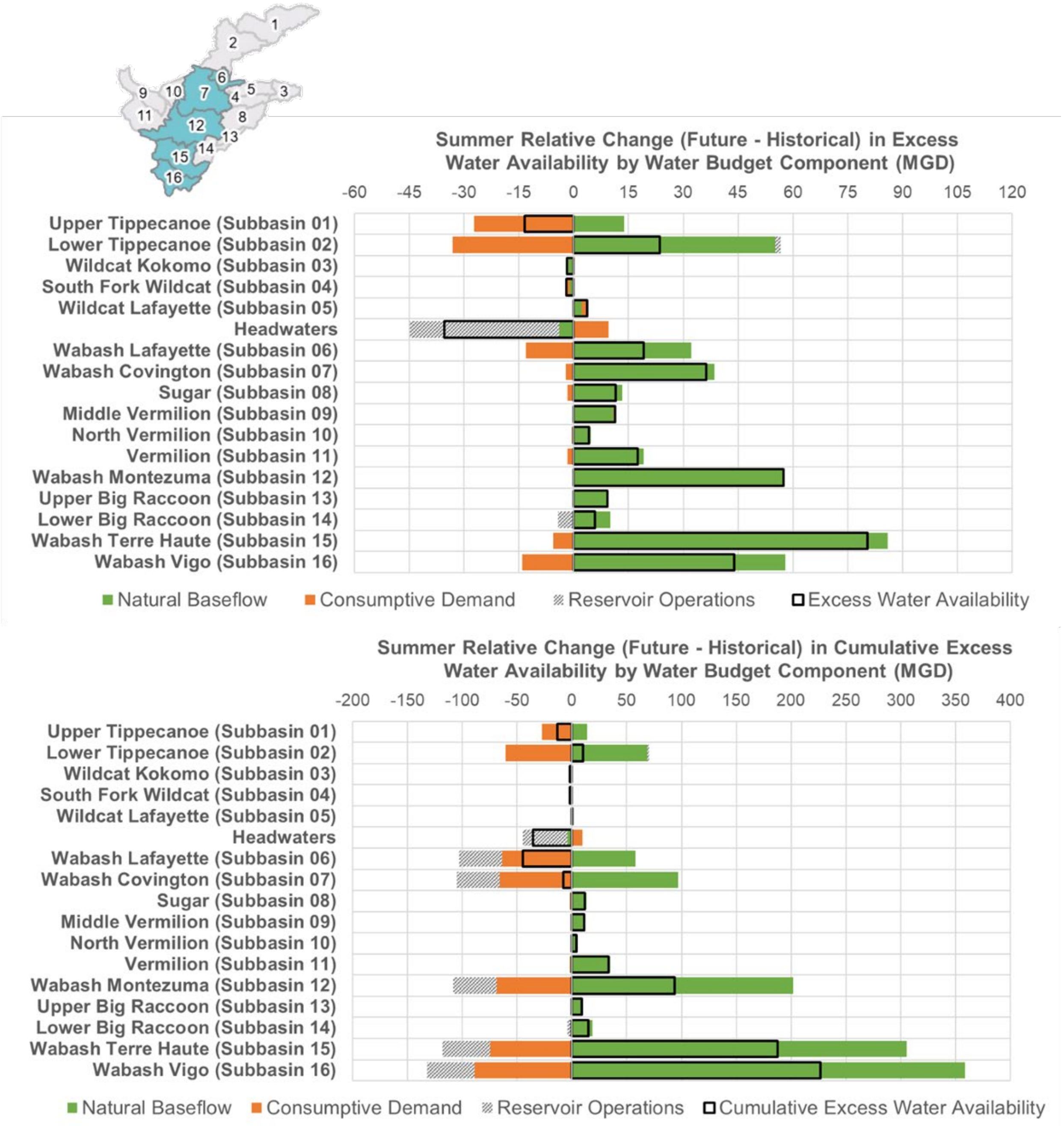
Note: Bars with positive values (to the right of the 0 value on the x-axis) indicate the water budget component has contributed to an increase in water availability into the future relative to historical conditions (e.g., increased baseflow, decreased consumptive demand/increased return flow, or increased reservoir releases). Bars with negative values (to the left of the 0 value on the x-axis) indicate the water budget component has contributed to a decrease in water availability into the future relative to historical conditions (e.g., reduced baseflow, increased consumptive demand/decreased return flow, or decreased reservoir releases). The sum of positive and negative bars for each subbasin in the top plot will equal the total seasonal change in subbasin excess water availability from Table 7-1. The sum of positive and negative bars for each subbasin in the bottom plot will equal the total seasonal change in cumulative excess water availability from Table 7-3.

Figure 7-5. Relative Difference Between Average Future and Historical Winter Water Budget Components; Subbasin (top) and Cumulative (bottom)



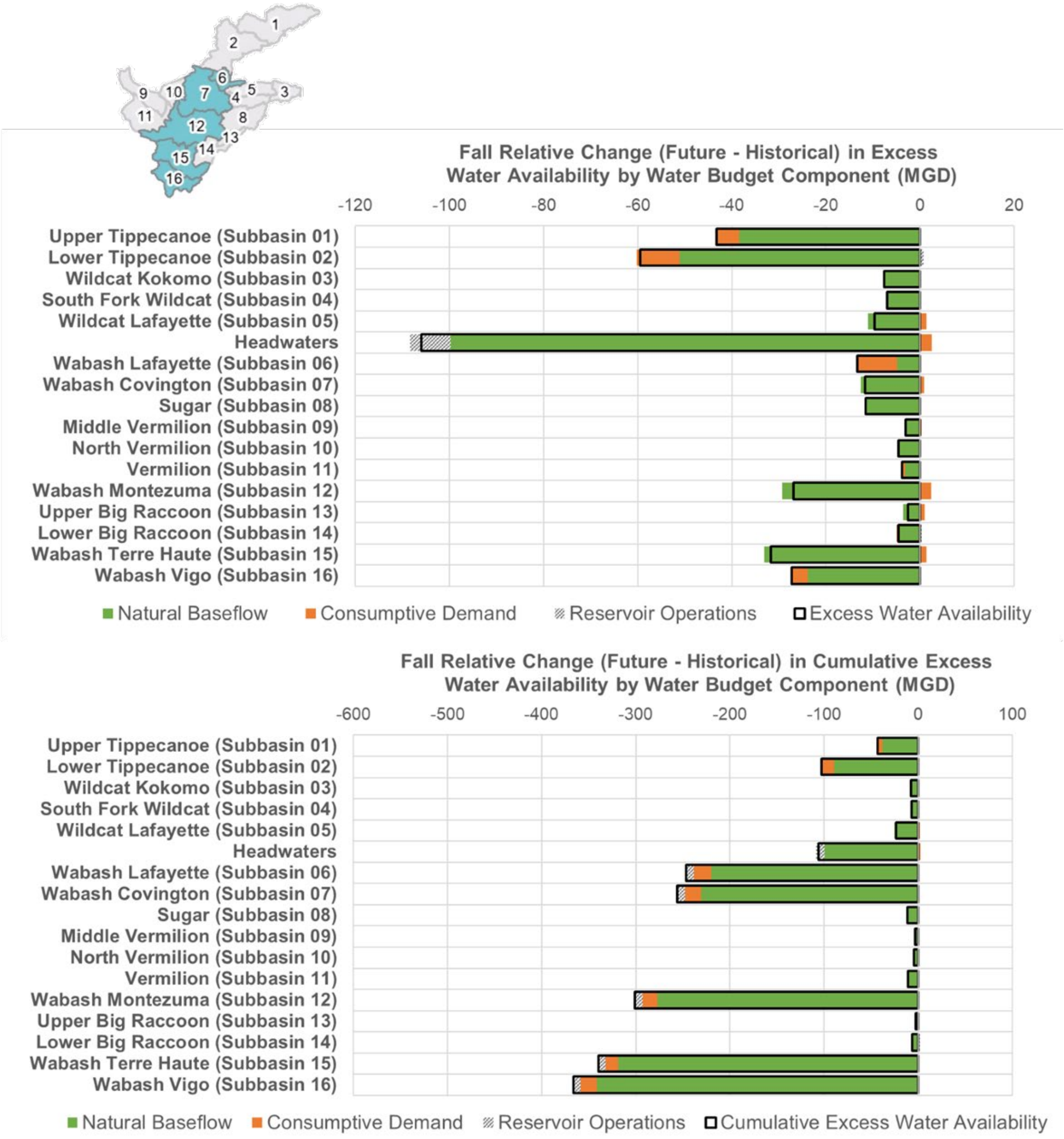
Note: Bars with positive values (to the right of the 0 value on the x-axis) indicate the water budget component has contributed to an increase in water availability into the future relative to historical conditions (e.g., increased baseflow, decreased consumptive demand/increased return flow, or increased reservoir releases). Bars with negative values (to the left of the 0 value on the x-axis) indicate the water budget component has contributed to a decrease in water availability into the future relative to historical conditions (e.g., reduced baseflow, increased consumptive demand/decreased return flow, or decreased reservoir releases). The sum of positive and negative bars for each subbasin in the top plot will equal the total seasonal change in subbasin excess water availability from Table 7-1. The sum of positive and negative bars for each subbasin in the bottom plot will equal the total seasonal change in cumulative excess water availability from Table 7-3.

Figure 7-6. Relative Difference Between Average Future and Historical Spring Water Budget Components; Subbasin (top) and Cumulative (bottom)



Note: Bars with positive values (to the right of the 0 value on the x-axis) indicate the water budget component has contributed to an increase in water availability into the future relative to historical conditions (e.g., increased baseflow, decreased consumptive demand/increased return flow, or increased reservoir releases). Bars with negative values (to the left of the 0 value on the x-axis) indicate the water budget component has contributed to a decrease in water availability into the future relative to historical conditions (e.g., reduced baseflow, increased consumptive demand/decreased return flow, or decreased reservoir releases). The sum of positive and negative bars for each subbasin in the top plot will equal the total seasonal change in subbasin excess water availability from Table 7-2. The sum of positive and negative bars for each subbasin in the bottom plot will equal the total seasonal change in cumulative excess water availability from Table 7-4.

Figure 7-7. Relative Difference Between Average Future and Historical Summer Water Budget Components; Subbasin (top) and Cumulative (bottom)



Note: Bars with positive values (to the right of the 0 value on the x-axis) indicate the water budget component has contributed to an increase in water availability into the future relative to historical conditions (e.g., increased baseflow, decreased consumptive demand/increased return flow, or increased reservoir releases). Bars with negative values (to the left of the 0 value on the x-axis) indicate the water budget component has contributed to a decrease in water availability into the future relative to historical conditions (e.g., reduced baseflow, increased consumptive demand/decreased return flow, or decreased reservoir releases). The sum of positive and negative bars for each subbasin in the top plot will equal the total seasonal change in subbasin excess water availability from Table 7-2. The sum of positive and negative bars for each subbasin in the bottom plot will equal the total seasonal change in cumulative excess water availability from Table 7-4.

Figure 7-8. Relative Difference Between Average Future and Historical Fall Water Budget Components; Subbasin (top) and Cumulative (bottom)

7.3 Projected Changes in Future Exceedance Values

Previous sections focused on average seasonal changes in future water availability relative to historical water availability. These changes are useful in analyzing changes around a typical condition. Changes in exceedance curves are useful in showing how future cumulative excess water availability may change around median and extreme values, both wet and dry extremes. Exceedance curves of future seasonal cumulative excess water availability for representative subbasins are shown on the graphs in Figure 7-9 and Figure 7-10. The historical exceedance curves for the same subbasin and season are also plotted on the graphs for reference. Additional exceedance plots for all subbasins are provided in Appendix H.

- **Winter**: The Upper Tippecanoe (01) future winter cumulative excess water availability increase is concentrated at exceedance intervals less than 40%, indicating future wet winters may contain more extreme events and higher streamflow than historical wet winters. However, the median future winter may not change significantly from historical conditions. The driest historical winter flow conditions in the Wabash Lafayette (06) (95% exceedance) resulted in negative cumulative excess water availability, and this condition would also be expected in the future (i.e., increases in future winter baseflow are not expected to improve the worst-case future winter conditions).

- **Spring**: Similar trends in future spring exceedance curves are observed across all representative subbasins. Increases in projected spring availability are observed at all exceedance intervals, indicating future spring cumulative excess water availability is anticipated to be higher than historical conditions in all hydrologic year types, including median, dry, and drought conditions.

- **Summer**: Summer exceedance curves are very similar across historical and future periods, indicating cumulative excess water availability in future wet, dry, and drought summers would be similar to historical conditions. Similar to winter, the driest (i.e., drought) summer on the Wabash Lafayette (06) (95% exceedance) is expected to have negative cumulative excess water availability in the future, similar to historical conditions.

- **Fall**: Fall is forecast to produce the largest reduction in exceedance values at all subbasins, when future cumulative excess water availability is reduced at nearly every exceedance interval. At most subbasins, all exceedance intervals are projected to drop 15% to 30%, meaning all future fall periods are simulated to be drier than historical conditions. In Upper Tippecanoe (01), drought conditions (90% - 95% exceedance) shift from having a small amount of positive cumulative excess water availability to having negative excess water availability, meaning water demands could reduce natural baseflow below the minimum instream flow. In several subbasins, the historical 50% exceedance value is similar to the future 20% - 30% exceedance value. One way to interpret this is the fall historical water availability that was generally exceeded every other year may only be exceeded once every 4 to 5 years in the future. Similarly, the 50% exceedance value of future cumulative excess water availability is similar to the 75% - 85% exceedance value of historical cumulative excess water availability. The median (usual) future fall water availability could be similar to what was considered a historically dry fall in the past.

To highlight spatial changes in future fall seasons, Figure 7-11 compares historical and future fall cumulative excess water availability at the 50%, 75%, and 95% exceedance interval. These maps highlight similar trends discussed above, including a reduction in median (50% exceedance) fall cumulative excess water availability in all subbasins, with upper tributary Subbasins (01 through 05) showing the largest reduction in future availability relative to historical conditions.

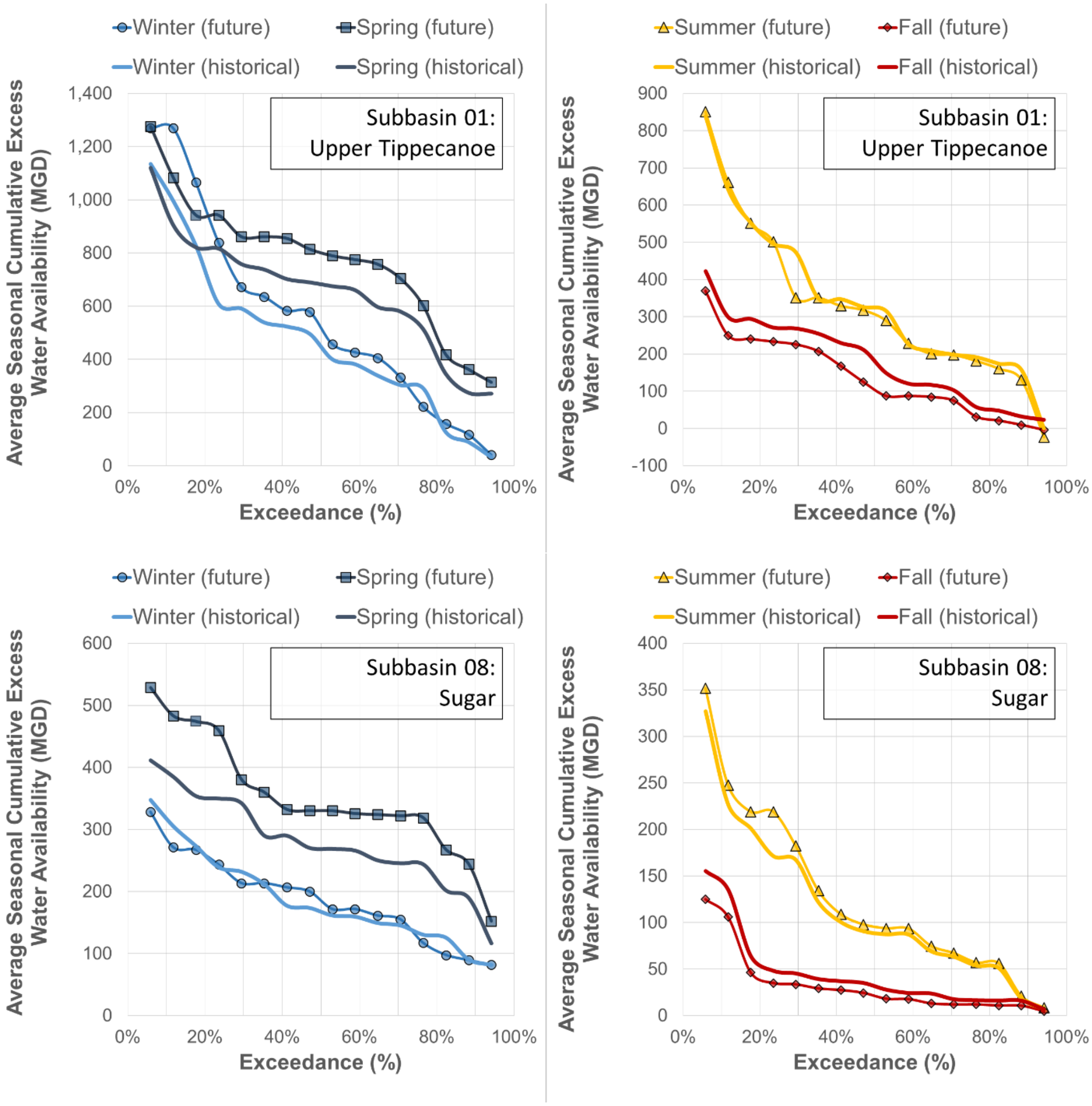


Figure 7-9. Historical and Future Cumulative Excess Water Availability Exceedance Curves for Relatively Small First Order Subbasins (Upper Tippecanoe and Sugar)

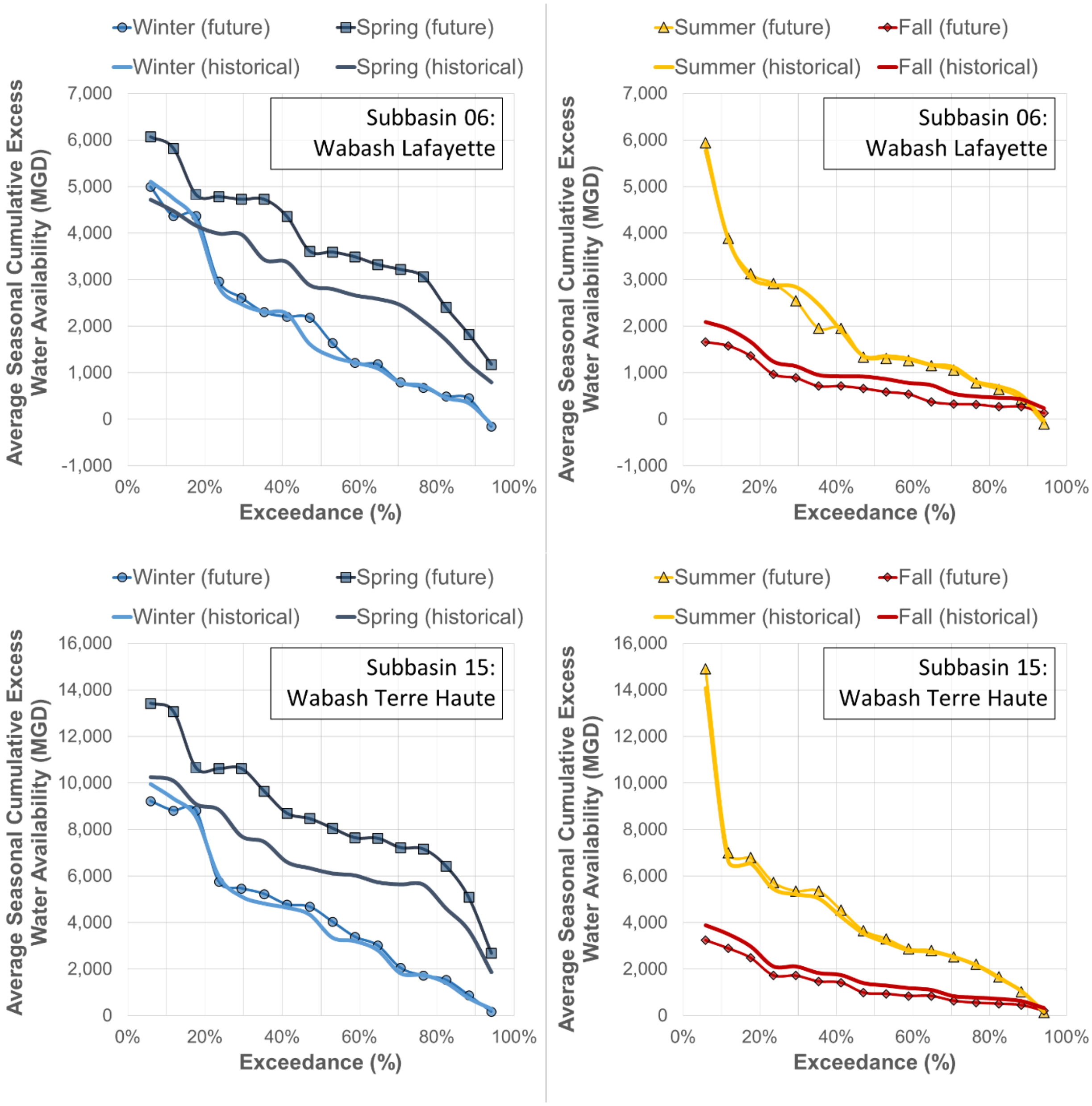


Figure 7-10. Historical and Future Cumulative Excess Water Availability Exceedance Curves for Relatively Large Wabash River Subbasins (Lafayette and Terre Haute)

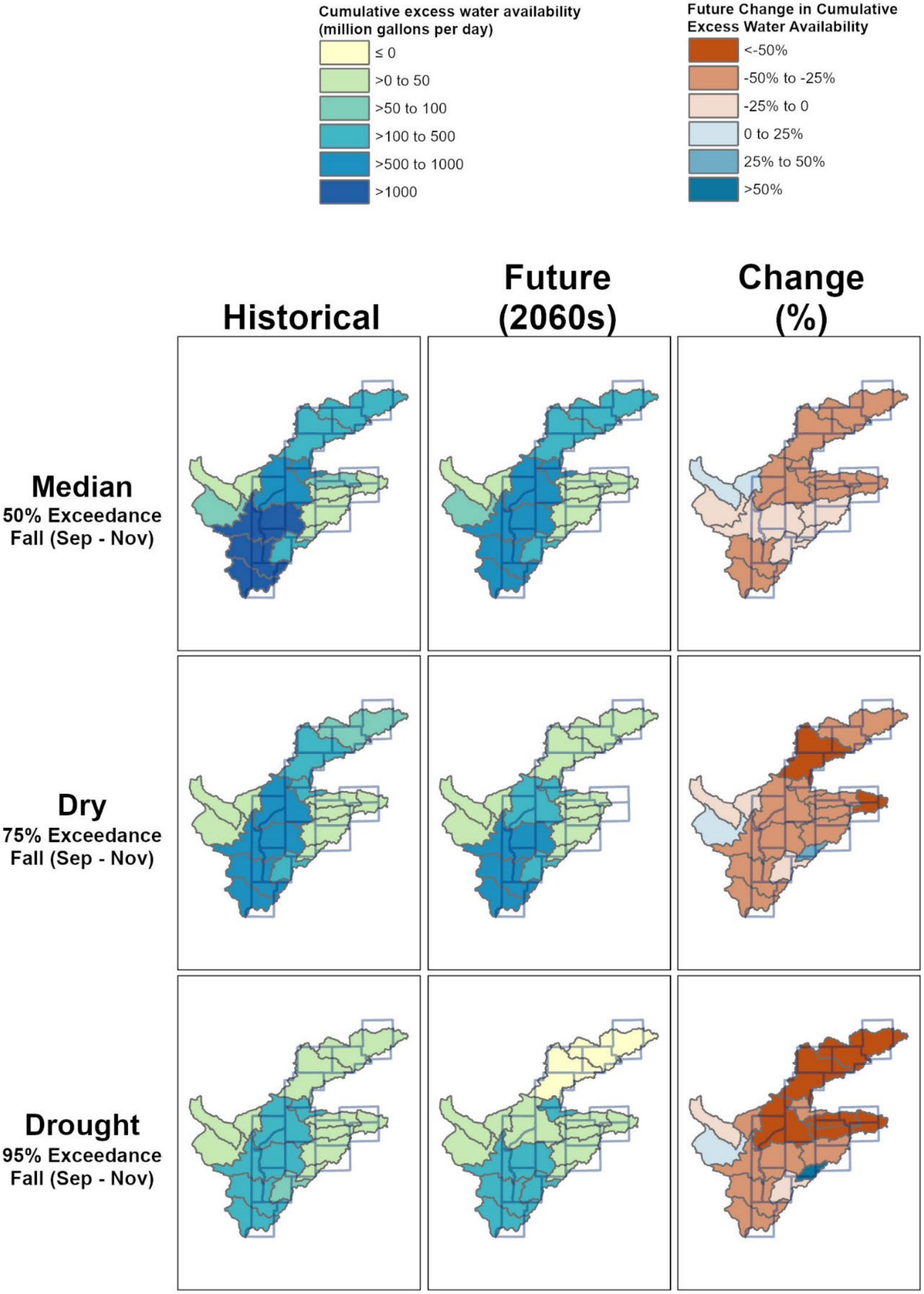


Figure 7-11. Changes Between Historical and Projected Future Fall Cumulative Excess Water Availability for Median (50%), Dry (75%), and Drought (95%) Conditions

7.4 Upstream Reservoir Effects on Future Water Availability

As described in previous sections, lower projected baseflow in future fall seasons is the primary factor in reductions in fall cumulative excess water availability. The magnitude of future fall reservoir releases is not anticipated to change substantially, since summer and winter pool elevations are not expected to change, and these elevations dictate the total volume of water released in the fall. As a result, reservoir releases are expected to constitute a larger share of cumulative excess water availability in the future than during historical periods. An example of this trend is shown in Figure 7-12 for the Wabash Lafayette Subbasin (06), though the same trends are observed for all Wabash River subbasins. Reservoir releases comprised approximately 42% of fall cumulative excess water availability during the historical period and are expected to contribute approximately 52% of fall cumulative excess water availability during the future period.

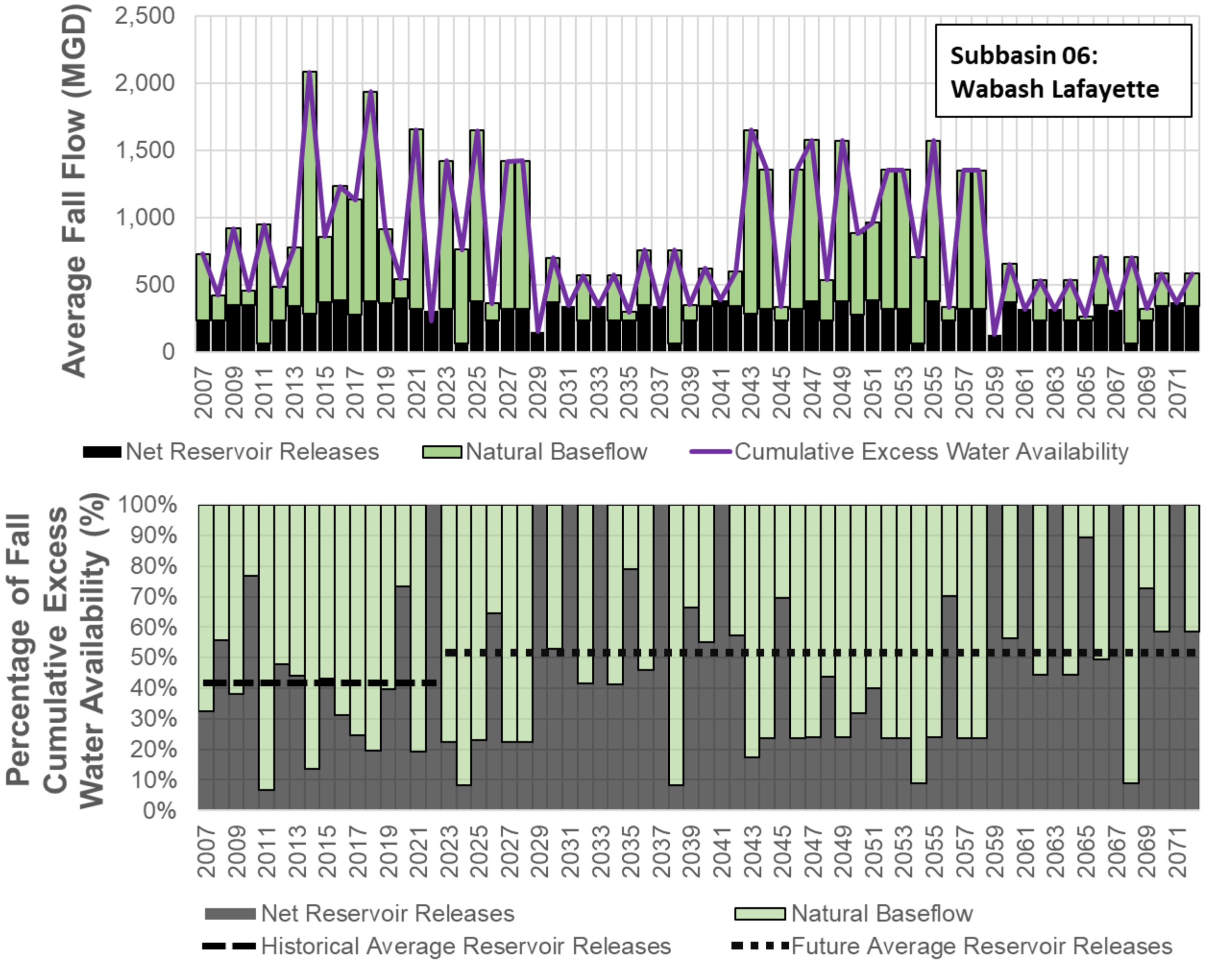


Figure 7-12. Supply Components of Fall Cumulative Excess Water Availability under Historical and Future Periods. Magnitude (top) and Percentage Values (bottom)

7.5 Future Water Availability Key Findings

The analysis of future water availability highlighted some notable trends with important considerations for regional water management.

In most future years, seasons, and across subbasins, future supplies nearly always exceed future demands (including instream flows), leaving positive cumulative (i.e., regional) excess water availability. Similar to the historical period analysis, water supply is projected to remain abundant during most years and seasons. Projected increases in wet season natural baseflow suggest water supply abundance in winter and spring seasons may increase in the future, but this is contrasted by projected recurrent low natural baseflow and demand increases during the fall. An important implication is that the wet season may become more condensed, producing higher flows but over shorter durations, consistent with recent documented increases in precipitation intensity observed over the Midwest (Cherkauer et al. 2021).

Under future dry conditions, current supply-demand imbalances get worse. Future fall water availability is likely to be substantially reduced relative to historical conditions, consistently by 15%-30% across the Study Area subbasins. These reductions are predominantly due to projected changes in climate and the resultant effects on streamflow, and to a lesser extent due to projected increased consumptive demands. However, the combined effect of these two changes is most pronounced in the fall, which is historically the most limiting season for water availability in the region. Future winter and summer periods with drought conditions (i.e., 95% exceedance values) will continue to experience negative cumulative excess water availability due to low baseflow and increased demand. The future period saw only a 0.3% increase in seasons with projected negative cumulative excess water availability, however, indicating water supply is nearly always available to meet demands, though in reduced quantities. These reductions may have implications for instream flows, water quality, and the reliable water supply or yield that could be expected under the most limiting future conditions (95% exceedance).

Future intra-annual variations in water availability increase. Future conditions in spring are anticipated to be wetter, while conditions in the fall are anticipated to be drier. This creates greater intra-annual variability, with more flow volume anticipated per year but also less flow volume and more stress on the water system anticipated in the fall.

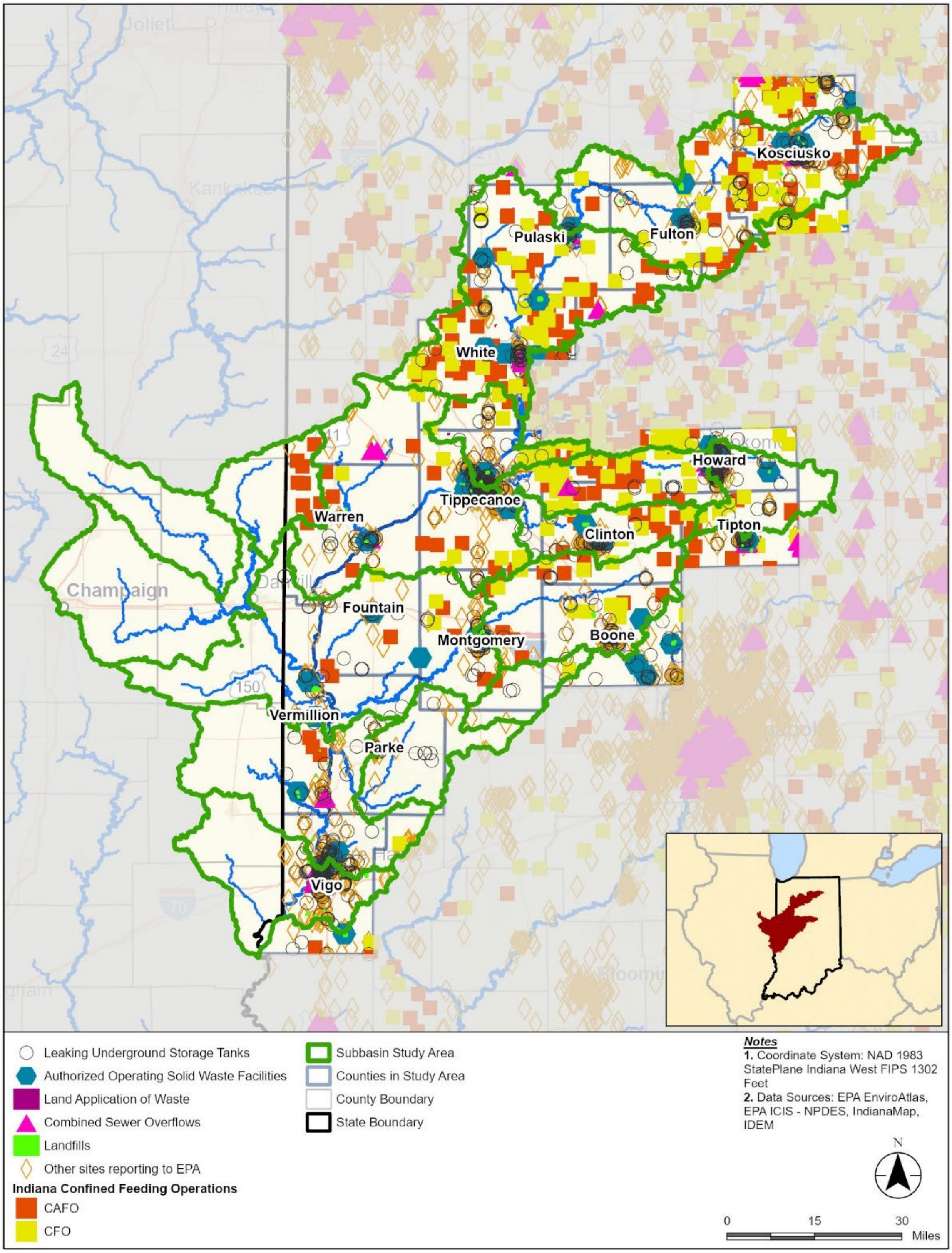
Releases from upstream reservoirs are projected to comprise the majority of future cumulative excess water availability during the seasonally low flow fall season along the mainstem of the Wabash River. Because projected future fall baseflow is anticipated to be reduced relative to historical conditions and projected future upstream fall reservoir releases are projected to remain relatively stable, future fall cumulative excess water availability is likely to become increasingly dependent on upstream reservoir releases. Reservoir releases are estimated to provide 52% of future fall cumulative excess water availability, an increase over the 42% estimated historically.

8.0 Water Quality

Water quality contamination is a well-documented concern in central Indiana due to point and non-point sources, such as land use or regulated facilities, in addition to naturally occurring contaminants in subsurface geologic materials (e.g., Banaszak, 1987; Risch et al., 2014; Letsinger, 2017; IDEM, 2023; Letsinger and Gustin, 2024). Figure 8-1 presents potential sources of surface and groundwater contamination in the Study Area; additional sources for consideration are highlighted in Appendix J. The Study Area subsurface and aquifer system presents a moderate to high risk of near-surface aquifer contamination, and underlying geologic materials are a known source of naturally occurring arsenic (Letsinger, 2015; Letsinger, 2017). Iron and manganese also naturally occur in groundwater. Geological and hydrological considerations are discussed in more detail in Section 2.3.

Specific examples of pervasive origins of source water contamination have been highlighted by targeted state or federal regulation and include Combined Sewer Overflows (CSOs), CAFOs, nutrients from agricultural runoff, and industry such as historical electric generating stations. Combined Sewer Overflows are a known threat to water quality in the state as documented by numerous recent water quality studies and IDEM (Risch et al., 2014; IDEM, 2023). The data in **Error! Reference source not found.** 8-1 document that the upper Study Area is densely populated with operating or retired CFOs. CFOs are regulated by IDEM under the Confined Feeding Control Law which is focused on regulating CFOs to protect water quality. CFOs and “Land Application of Waste” facilities (also shown in Figure 8-1) are significant sources of nutrients, fertilizers, and pesticides which can be impactful to adjacent/underlying aquifers and groundwater as well as surface water runoff. Nutrient concentrations in surface and groundwaters are discussed in additional detail below.

The following sections provide a summary of recent groundwater and surface water data collected in the state and the spatial distribution of contaminants and receptors of concern/interest. Temporal trends for specific contaminants and emerging contaminants are also highlighted in the Study Area for consideration and impact on current and future water supplies.



Notes
1. Coordinate System: NAD 1983 StatePlane Indiana West FIPS 1302 Feet
2. Data Sources: EPA EnviroAtlas, EPA ICIS - NPDES, IndianaMap, IDEM

Notes: data west of Indiana state line has been excluded.
"Other Sites reporting to EPA" include: EPA Superfund sites, RCRA Hazardous Waste Sites, Permitted Water Dischargers (NPDES), Toxic Release Inventory (TRI).

Figure 8-1. Known Sources of Surface and Groundwater Contamination in Indiana

8.1 History, Trends, and Emerging Contaminants

Since 1957, IDEM has collected surface water quality data through the Fixed Station Monitoring Program (FSMP). The program is still active and has been adopted in the IDEM Water Quality Monitoring Strategy (WQMS), which is updated every four years. The Surface Water Quality Monitoring Strategy was developed in the 1990s to assess water quality in streams, lakes, and rivers through organized data collection and to satisfy the requirements of the Clean Water Act. As of 2022, there were 168 surface water sites across Indiana where water samples are collected monthly for laboratory analysis of several water chemistry parameters.

In conjunction, groundwater monitoring via IDEM's Groundwater Monitoring Network (GWMN) was established in 2008 to determine baseline groundwater quality across the state through random sampling of residential drinking water wells, better understand the regional groundwater and surface water nexus, and establish protocol for protecting source water and drinking water (IDEM, 2022a). From 2008 through 2021, over 3,000 samples were collected from unique sites across the state including from 240 public water supplies (PWS) and over 1,200 private groundwater wells. These samples were analyzed for general chemistry, nitrate/ammonia, metals, VOCs, SVOCs, degraded pesticides, and fungicides. The GWMN identified arsenic as the primary concern to drinking water quality in Indiana, and sampling results showed that arsenic concentrations are highly variable across relatively short distances. The project has become more focused on specific areas of the state where there are known arsenic issues.

IDEM's WQMS program has resulted in a robust overview highlighting trends in Indiana waterways and groundwater for recent history. The program has been useful in implementing a successful protocol for Section 303(d) of the Clean Water Act (303(d)) listed impaired waterways. The 303(d) list is used to prioritize the establishment of total maximum daily loads and has also helped to identify emerging water quality issues in source waters, such as per- and poly-fluoroalkyl (PFAS), and emerging trends in basin-wide ground- and surface-water quality conditions. The Indiana Water Resources Research Center, among others, is leading research on emerging contaminants in Indiana waters that may be a threat to environmental and human health (IWRRC).

Emerging contaminants in Indiana, not limited to the Study Area, may include:

- Micro-plastics (i.e., plastic particles <5 millimeters in size)
- Pharmaceuticals
- Trihalomethanes
- PFAS
- Cyanobacteria (blue-green algae)

As of 2024, the majority of these contaminants were not federally regulated for human health in surface water bodies or drinking water, and limited field data from monitoring sites exist in the Study Area and regionally. Micro-plastics, PFAS, and Cyanobacteria are currently the most well-studied for the North Central Indiana Study Area.

8.1.1 MICRO-PLASTICS

Research specific to Indiana rivers and surface water in the Great Lakes region has recently been published on micro-plastics (IWRRC 2018; Fuschi et al., 2022; Conrad et al., 2023). Micro-plastics can potentially harm aquatic organisms, though the human implications are not fully known. Micro-plastics have been found in all tested watersheds, and concentrations did not vary significantly with surrounding land use (Conrad et al., 2023). The sources, pathways and transport of micro-plastics are still poorly understood but are an emerging public health concern.

8.1.2 CYANOBACTERIA

Cyanobacteria, also known as blue-green algae, occur naturally in a wide range of water bodies throughout Indiana and the United States. Blue-green algae presence has surged in freshwater bodies in Indiana in recent decades due to the influx of nutrients in the waterways and hotter average temperatures. Not all species are toxic; however, if cyanotoxins are present in high concentrations, waterways can be rendered unsafe for contact by humans and animals. In 2022, IDEM developed a surveillance program for swimmable lakes and reservoirs that includes sampling at 21 swimming areas. One water body within the Study Area is included in the monitoring program: Raccoon Lake in Vermillion County (IDEM, 2023).

8.1.3 PFAS

In 2021, IDEM began PFAS monitoring at Community Public Water Systems throughout the state to understand the existence of PFAS in the state water supply and evaluate the effectiveness of conventional drinking water treatment. For this Study, the PFAS data from Indiana surface and groundwater collected by IDEM (2021-2024) and EPA (2023 and 2024) at PWSs were analyzed for detection, regulatory exceedance, and spatial distribution in the Study Area (EPA, 2024b; IDEM, 2024). 98 total samples were taken in the Study Area and considered in this analysis (Figure J-5 in Appendix J) and PFAS were only detected in 10 samples, each of which were below the current guidance level for human health. Of the PFAS constituents sampled by EPA and IDEM, currently five have a regulatory standard (Maximum Contaminant Level, MCL) developed by the EPA for human health protection in treated drinking water (Table 8-1).

Table 8-1. Final EPA National Primary Drinking Water Regulations-PFAS MCL-April 26, 2024

Parameter	Maximum Contaminant Level Goal (MCLG)	Maximum Contaminant Level (MCL)
PFOA	0	4 ppt
PFOS	0	4 ppt
PFNA	10 ppt	10 ppt
PFHxS	10 ppt	10 ppt
GenX (HFPO-DA)	10 ppt	10 ppt
Mixture of 2 or more: GenX, PFBS, PFNA, PFHxS	Hazard Index (HI) of 1	HI of 1

8.2 Study Area Surface Water Quality

In 2023, IDEM published a 10-year trend analysis based on the FSMP data from 2011-2020, which supplements a previous 10-year trend analysis performed by the USGS with FSMP data from 2000-2010 (Risch et al., 2014; IDEM, 2023). Twenty-three sampling sites from middle and upper Wabash River basins were utilized in the IDEM analysis, and the results are summarized in Table 8-2 below. The following constituents were found to exceed regulatory guidance levels in one or more samples over the 10-year period: Nitrate, Chloride, and total dissolved solids (TDS). However, the majority of sampled constituents in the watershed (2011-2020) were found to have either decreased at individual sites or remained constant (no statistically significant change) compared to the previous decade.

Table 8-2. 2011 -2020 IDEM Stream Water Quality Trend Summary-Percent Change in Annual Median Concentration (IDEM 2023)

Constituents		**River Basin**	
		Upper Wabash	**Middle Wabash**
Nutrients	Nitrate	No significant changes	No significant changes
	Organic Nitrogen	Significant **increase** at 5 sites (25-49%)	Significant **decrease** at 2 sites (-5 & -25%)
	Total Phosphorus	Significant **increase** at 5 sites (25-125%)	Significant **decrease** at 3 sites (about -25%)
	TSS	Significant **increase** at 4 sites (30-125%) Significant **decrease** at 2 sites	Significant **increase** at 2 sites (50 and 80%)
Ions	Chloride	Significant **increase** at 4 sites (15-35%) Significant **decrease** at 2 sites (-10 & -20%)	Significant **decrease** at 3 sites (-12-15%)
	Sulfate	Significant **decrease** at 6 sites	Significant **decrease** at 9 sites
	Hardness	Significant de**crease** at 2 sites (-11%)	Significant **increase** at 2 sites (<11%)
	TDS	Significant **increase** at 1 site	Significant **increase** at 3 sites
Metals	Lead	Significant **increase** at 3 sites (<50%) Significant **decrease** at 5 sites (<-50%)	Significant **increase** at 1 site (<50%)
	Iron	Significant **increase** at 4 sites (25 to 150%) Significant **decrease** at 2 sites	Significant **increase** at 1 site (<50%)
	Copper	Significant **decrease** at 1 site	Significant **increase** at 1 site Significant **decrease** at 1 site
	Zinc	Significant **increase** at 6 sites (50 - 200%) Significant **decrease** at 5 sites (-10%)	Significant **increase** at 1 site Significant **decrease** at 1 site

Key:
IDEM = Indiana Department of Environmental Management
TDS = total dissolved solids
TSS = total suspended solids

An additional overview of surface water impairment in the Study Area is provided by the current federal 303(d) listing of impaired waterways; a figure and table summarizing each impaired stream section and corresponding impairment in the Study Area, per analysis of 2024 EPA ATTAINS data, are included in Appendix J (EPA 2024c). The primary 303(d) impairments in the Study Area are due to one or more of the following constituents: ammonia, biological integrity, chloride, cyanide (free), dissolved oxygen, *E. coli*, mercury in fish tissue, nutrients, polychlorinated biphenyls (PCBs) in fish tissue, and phosphorus (total). The number of 303(d) impaired NHD waterways in the Study Area is as follows per constituent: ammonia (7), biological integrity (181), chloride (3), cyanide (1), dissolved oxygen (45), E. Coli (726), nutrients (81), phosphorus (10), PCBs in fish tissue (262), and mercury in fish tissue (17).

Figure J-2 in Appendix J highlights potentially sensitive receiving waters and habitats in the Study Area within Indiana. The Study Area includes eighteen distinct stream segments or waterways on the Indiana Outstanding Rivers and Streams list (also referred to as Outstanding State Resources Waters) and two Critical Habitat zones for the Rabbitsfoot (*Quadrula clyndrica*) mussel species.

8.3 Study Area Groundwater Quality

IDEM has collected groundwater samples as part of a GWMN to determine the quality of groundwater in the state's aquifers, identify and expand monitoring in contaminated areas, and improve water quality monitoring. From 2008 to 2021, over 3,000 samples have been collected from 240 public water supplies and over 1,200 private residential drinking water wells (IDEM, 2024a). In addition, groundwater quality in Indiana has been investigated by federal government agencies (USGS), academic institutions (e.g., Indiana University), and some voluntary organizations (e.g., Indiana Water Monitoring Council). Water quality data from these agencies were compiled and are presented along with U.S. Environmental Protection Agency primary drinking water standards (MCLs) or secondary standards and aquifer type (unconsolidated or bedrock) in the analysis described below.

Groundwater quality within the Study Area varies by constituent and location. The following constituents considered include organic chemicals, total dissolved solids (TDS), arsenic, chloride, iron, manganese, nitrate as nitrogen, and sulfate. As shown in Figure 8-2, TDS concentrations frequently exceed the secondary drinking water standard of 500 milligrams per liter (mg/L) in Vigo and Montgomery Counties in both unconsolidated and bedrock aquifers, but there is limited data in other counties from which to make overall assessments. As shown in Figure 8-3, chloride concentrations are generally less than the 250 mg/L secondary standard in both unconsolidated and bedrock aquifers across the area, but there are some exceedances in Vigo and Fountain Counties. Organic chemicals (herbicides and pesticides) have been detected above MCLs across the Study Area as shown in Figure 8-4. Arsenic concentrations in unconsolidated and bedrock aquifers exceed drinking water standards in some samples in almost all the counties as shown in Figure 8-5. Nitrate as nitrogen is typically found above drinking water standards in Vigo, Tippecanoe, and Kosciusko Counties as shown in Figure 8-6. Contaminant concentration maps for other analytes are included in Appendix J. Sulfate concentrations are generally less than 250 mg/L and exhibit a similar pattern to chloride as shown in Figure J-8 in Appendix J. Iron and manganese concentrations indicate that iron typically exceeds the secondary drinking water standard across the Study Area, whereas manganese is more likely to exceed secondary standards in Vigo and Montgomery Counties (Figures J-6 and J-7 in Appendix J).

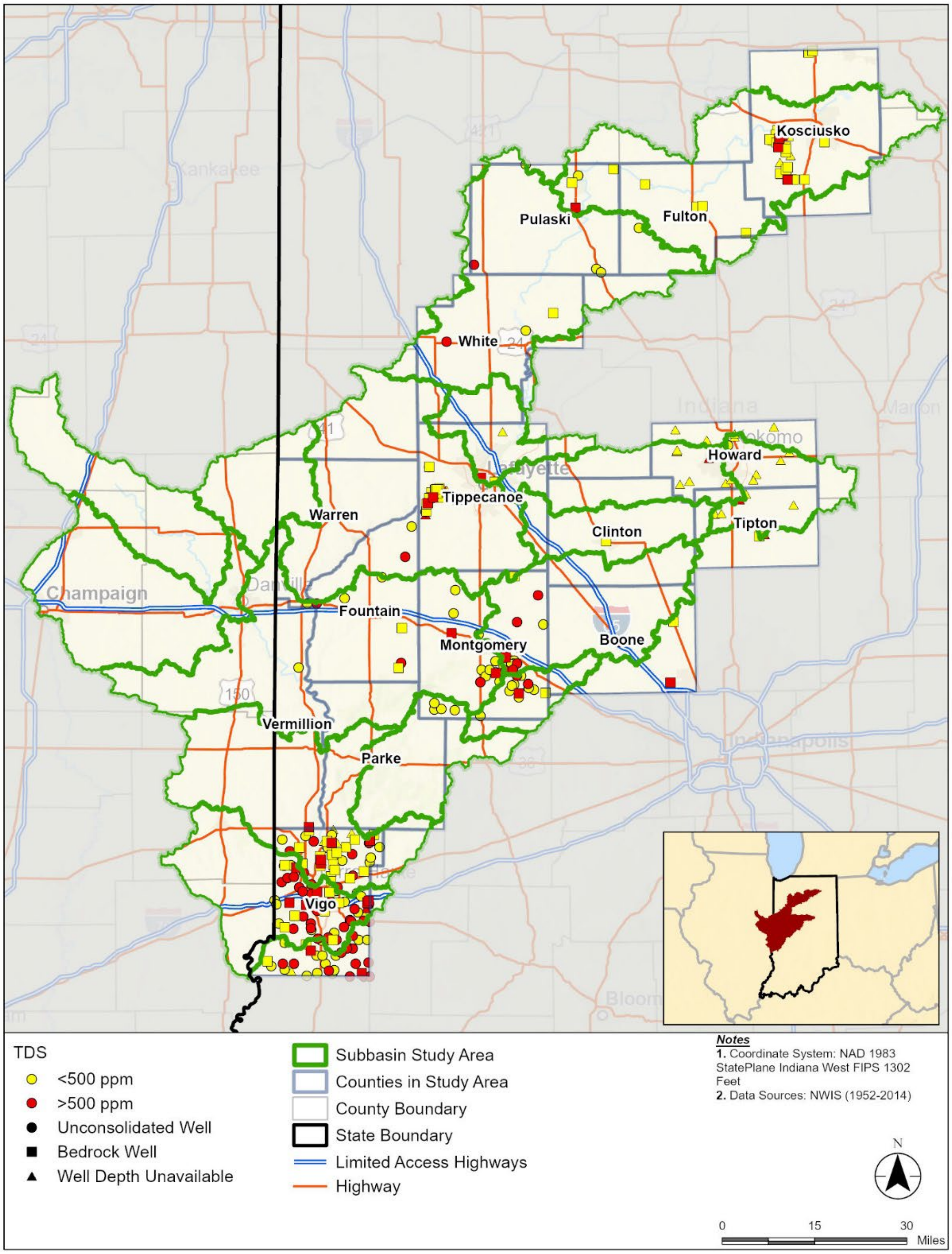


Figure 8-2. Total Dissolved Solids Concentrations Within the Unconsolidated and Bedrock Aquifers Relative to Secondary Drinking Water Standard (Depicted as Generalized Locations). Data sourced from USGS, 2024a. Analytical results vary by study and dates collected.

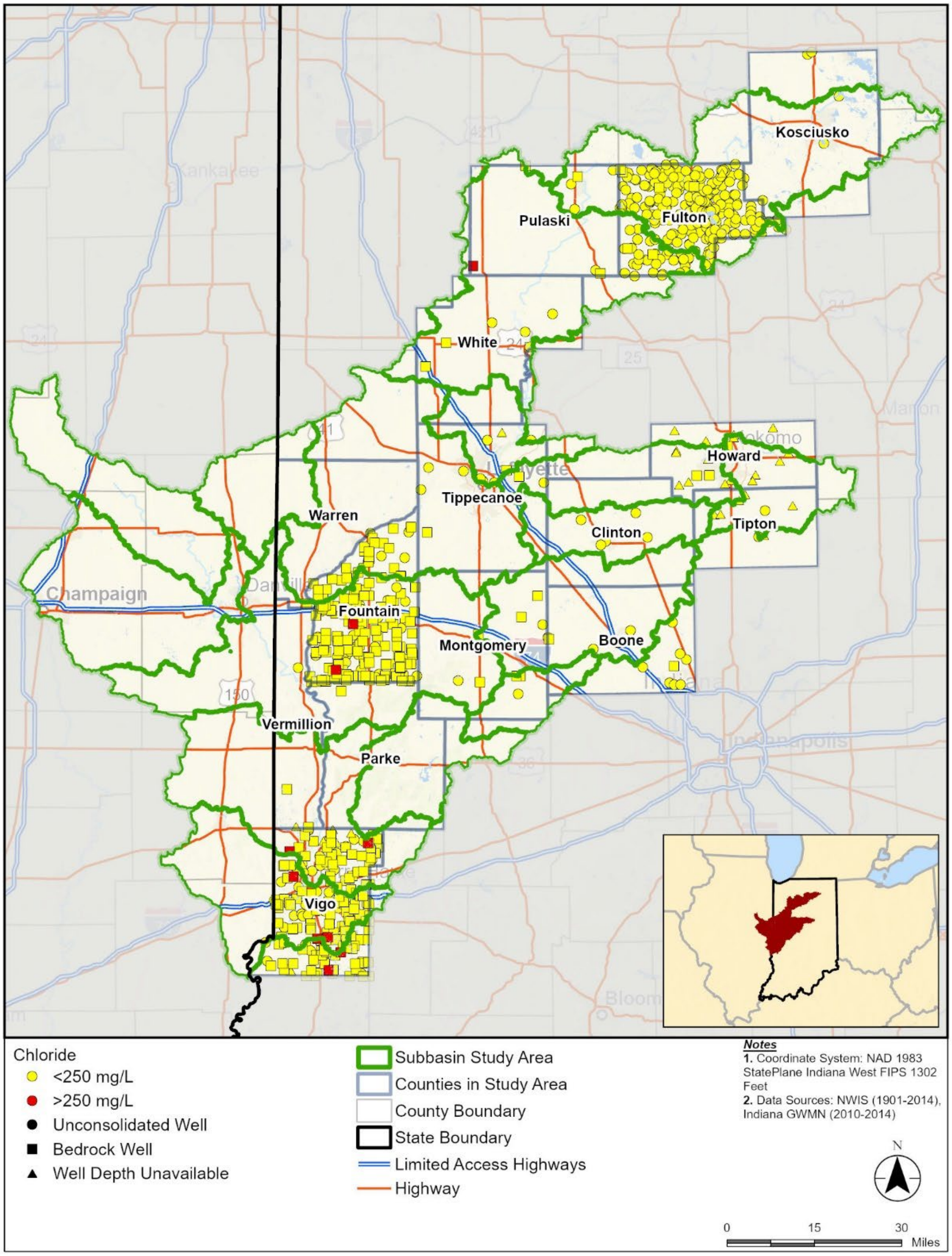


Figure 8-3. Chloride Concentrations within the Unconsolidated and Bedrock Aquifers Relative to Secondary Drinking Water Standard (Depicted as Generalized Locations). Data sourced from IDEM, 2024a and USGS, 2024a. Analytical results vary by study and dates collected.

The currently available data reveal an incomplete picture of water quality conditions in the Study Area. Figure 8-3 Figures 8-2 through Figure 8-6 highlight the dramatic differences in the distribution of sampled well locations. While Vigo, Fountain, and Fulton Counties are blanketed in sample locations, the remaining counties are relatively sparsely covered. Similar sample distribution trends exist for iron, manganese, and sulfate, which are included in Appendix J. Increased density of sampling points across all counties is needed to better assess overall water quality conditions with regard to particular analytes.

Details on the specific contaminants that exceed primary drinking water standards (MCL) are as follows:

- Organic compounds include herbicides and pesticides that are expected to cause adverse impacts on the environment or to human health. As shown in Figure 8-4, clusters of organic compound MCL exceedances have been observed to the west of Lafayette in Tippecanoe County and west and southwest of Warsaw in Kosciusko County. Samples that exceeded MCLs have been noted in all counties within the Study Area. The specific organic compounds that were detected above their respective MCLs include: 1,2-Dibromo-3-chloropropane, Alachlor, Atrazine, Chlordane, Di(2-ethylhexyl) phthalate, Dichloromethane, Simazine, and Toxaphene. A majority of these compounds are associated with runoff leaching from farming practices, herbicides, pesticides, and discharge from factories. The potential health effects from long term exposure of these observed chemicals are increased risk of cancer, cardiovascular system, and reproductive problems (EPA, 2024a). Organic compounds that exceed MCLs are presented in Table J-2, Appendix J along with their county and specific location.

- Arsenic is a regulated metal in public drinking water. As shown in Figure 8-5, arsenic is present in both the unconsolidated and bedrock aquifers across most of the Study Area. Health effects associated with arsenic exposure can include skin damage or problems with circulatory systems and may have an increased risk of contracting cancer (EPA, 2024a). Contamination from arsenic may be associated with erosion of natural deposits (Letsinger, 2017), runoff from orchards, and glass and electronics production wastes.

- Nitrate as Nitrogen contaminants is regulated under MCL standards in public drinking water. As shown in Figure 8-6, nitrate has primarily been detected above primary drinking water standard levels in Vigo, Kosciusko, and Tippecanoe Counties. Contamination from nitrate is associated with runoff from fertilizer use, leaking from septic tanks, sewage, and erosion of natural deposits. Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die (EPA, 2024a).

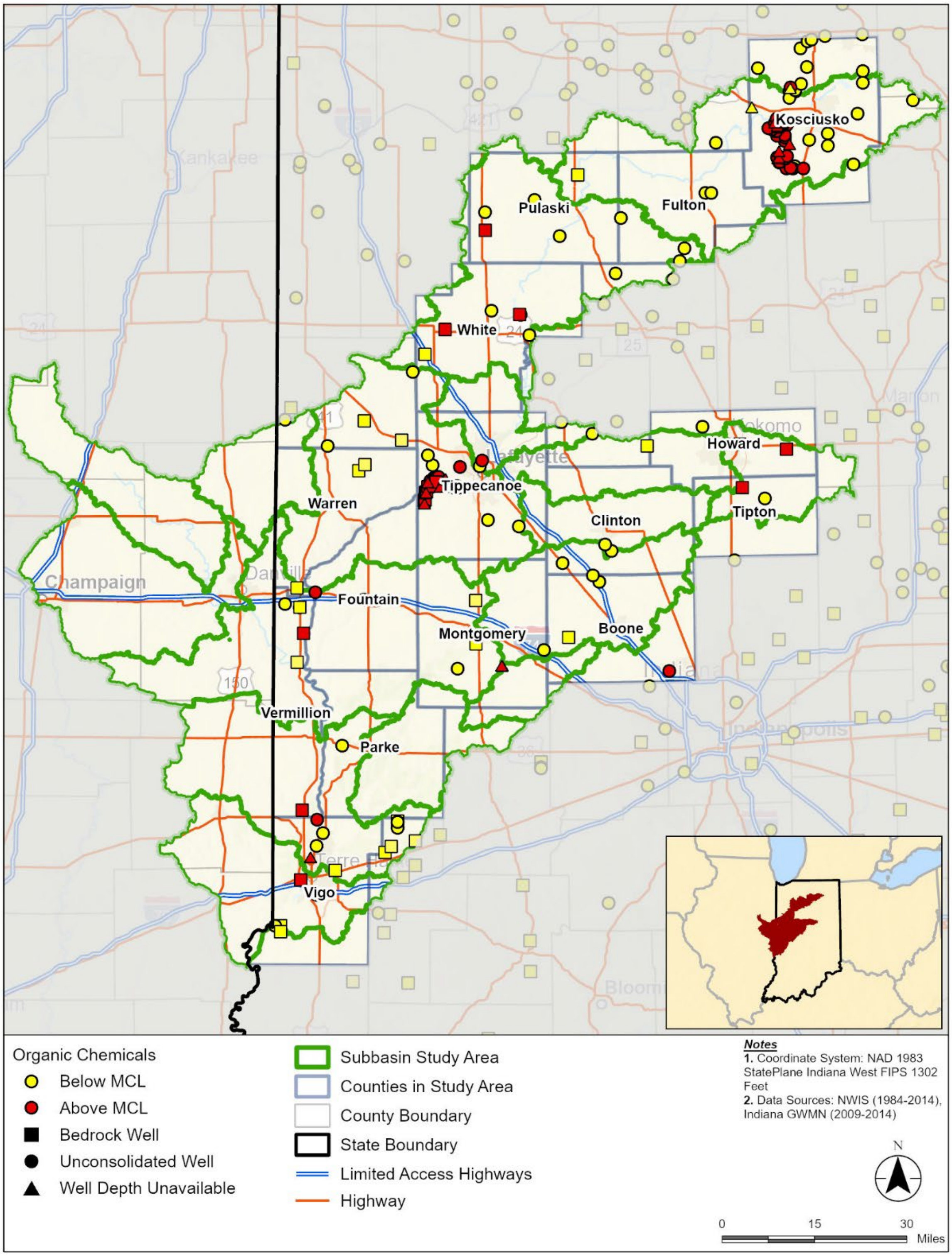


Figure 8-4. Organic Chemical Concentrations within the Unconsolidated and Bedrock Aquifers of the Study Area (Depicted as Generalized Locations). Data sourced from IDEM, 2024a and USGS, 2024a. Analytical results vary by study and dates collected.

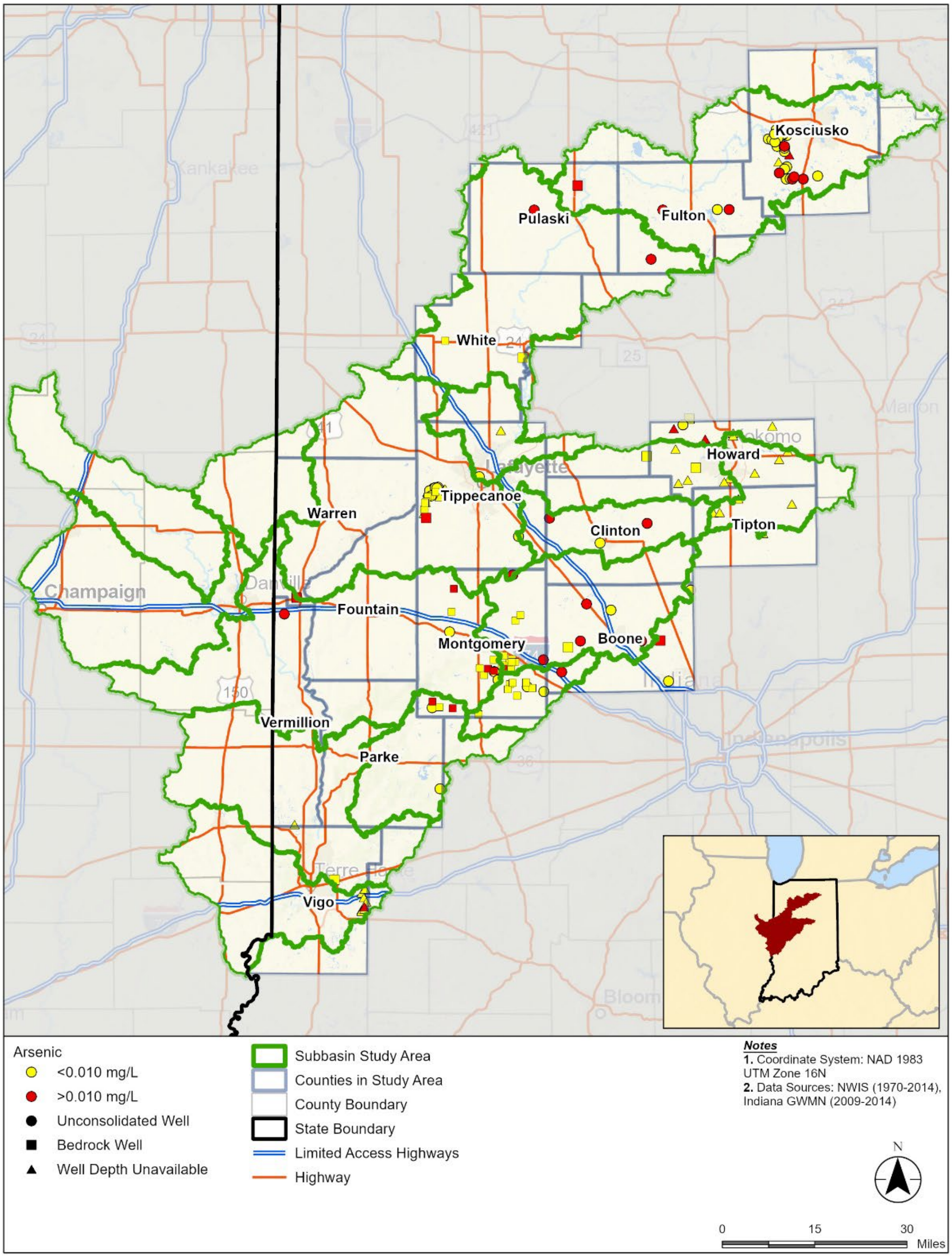
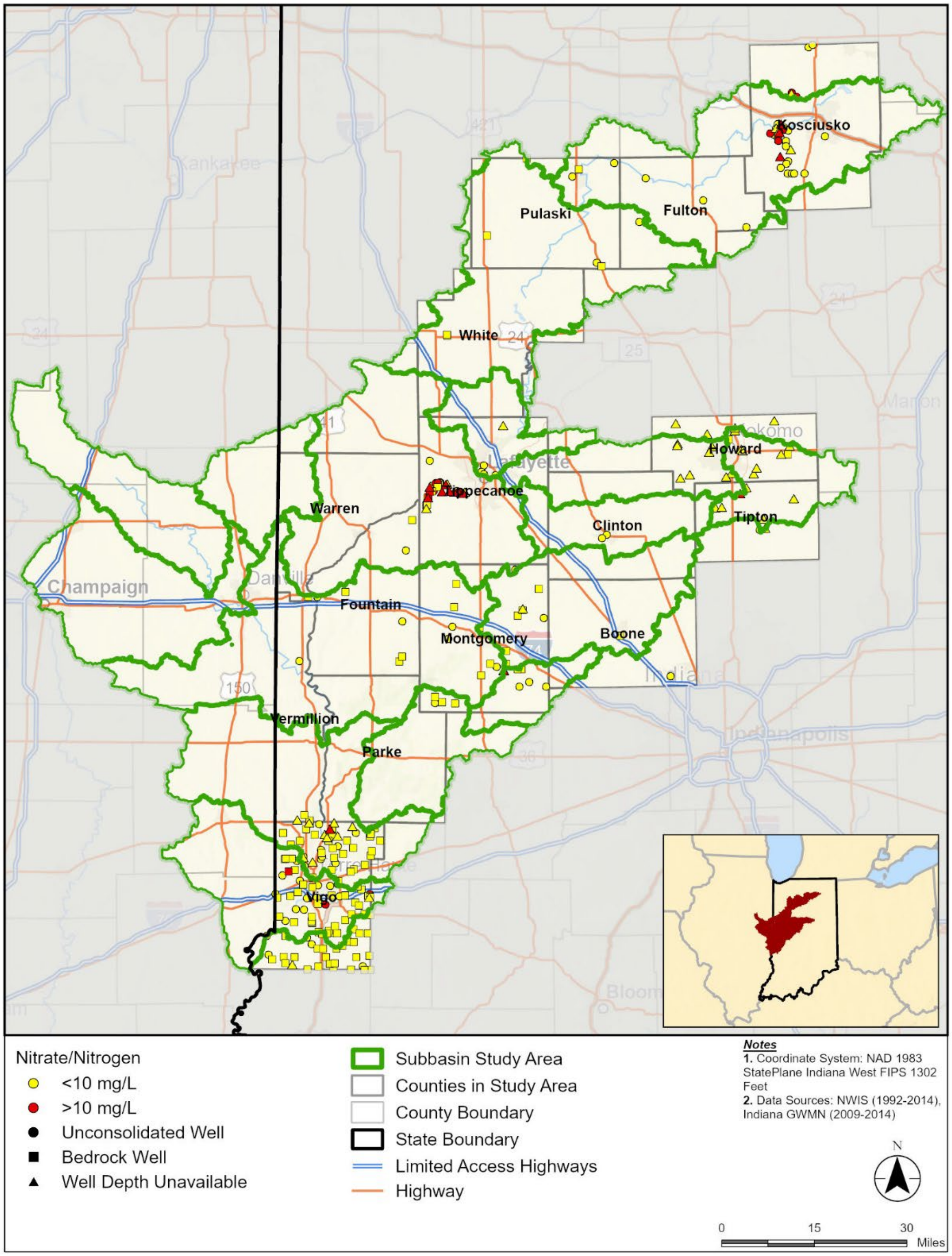


Figure 8-5. Arsenic Concentrations Within the Unconsolidated and Bedrock Aquifers within the Study Area (Depicted as Generalized Locations). Data sourced from IDEM, 2024a and USGS, 2024a. Analytical results vary by study and dates collected.



Notes
1. Coordinate System: NAD 1983 StatePlane Indiana West FIPS 1302 Feet
2. Data Sources: NWIS (1992-2014), Indiana GWMN (2009-2014)

Figure 8-6. Nitrate as Nitrogen Concentrations within the Unconsolidated and Bedrock Aquifers Within the Study Area (Depicted as Generalized Locations). Data sourced from IDEM, 2024a and USGS, 2024a. Analytical results vary by study and dates collected.

While the USGS, EPA, and IDEM have developed a robust water quality data set, it appears there are a few areas in which the data set could be improved, as follows:

1. Continue to work with other state and federal agencies, landowners, and county agencies to increase the density and breadth of water quality sampling. One of the gaps identified in this Study was the variability in the spatial distribution of groundwater quality results between counties. Fountain, Fulton, Vigo, and some of Montgomery appear to have a broader distribution of groundwater quality results. In contrast, other counties appear to have limited or sparse characterization of their aquifer groundwater quality, including Boone, Clinton, Howard, Kosciusko, Parke, Pulaski, Tipton, Vermillion, Warren, and White.
2. Work with local water well drilling contractors to obtain basic water quality data on newly completed wells or older wells when the pumps are replaced. Partnering with county health departments to acquire or share information may also be an option. Basic water quality data should include pH, electrical conductivity or TDS, and iron. It could also include sampling for arsenic, chloride, sulfate, manganese, and nitrate as nitrogen. Such testing or sampling could be completed once the well has been developed and before it is put back in operation.
3. Acquire additional analyses of organic chemicals to further assess the extent and depth of these contaminants. The prevalence and concentrations of these chemicals are not necessarily surprising, but deserve further investigation to protect public health.

9.0 Water Resource Risks, Opportunities, and Recommendations

With recent increasing drivers for economic development, Indiana is rapidly approaching a crossroads in water management. This Study shows that, under most conditions, there is sufficient water available in the North Central Indiana region to meet projected demands, now and over the next half century. While multiple risks could threaten water availability and suitability into the future, numerous opportunities exist to more effectively manage and protect the region’s finite water resources. This Chapter summarizes the key water resources risks in the Study Area and then outlines opportunities and recommendations for more holistic integrated water resources management.

9.1 Risks

Water supply utilities and providers across Indiana and around the country are continuously managing multiple existing and potential future risks. Notably, aging infrastructure, a changing climate, a dynamic regulatory environment, legacy and emerging contaminants, an aging workforce, and affordability are mentioned time and again as concerns in water industry surveys. This Study focused on water availability and the suitability of available water for use.

Five specific related risks and uncertainties (climate change, water quantity, water quality, the difficulty in predicting future conditions, and local impacts of additional water development) are identified and described in this section.

9.1.1 THE EFFECTS OF CLIMATE CHANGE

The future effects of climate change within the Study Area are uncertain, and future projections of precipitation, air temperature, and other climate variables vary substantially across different models. There is evidence that air temperatures and wet season precipitation have been increasing over the past 100 years (Section 2.1.2), and that as a result, hydrologic regimes are shifting with more flow in the wet season and less in the dry (Section 2.2.2). Because future air temperatures, precipitation, and streamflow cannot be predicted with certainty, there is a high likelihood that future climate change will not conform exactly to the trends analyzed in this Study. A reasonable approach was implemented in this Study to illustrate potential future climate risks on water resources.

This Study used a conservative approach to estimate future water availability through selecting a high emission, central tendency future climate change scenario (Section 3.3.3) that projected increased air temperatures (i.e., increased future climate-sensitive water demands) and decreased natural baseflow during the drier fall season (i.e., decreased water supply). There remain additional potential secondary effects from climate change that are not quantified in this Study. These include, for example, increased power demand for industrial and residential cooling, which could increase water demands, and more rapid development of irrigation wells to meet increased crop demand due to increasing rates of evapotranspiration.

There is a risk, from a planning perspective, that future climate change could be significant and result in greater demands or reductions in baseflow than assumed in this Study (i.e., future conditions could be worse than the projections used in this Study). The conservative emissions scenario was selected to increase confidence that future water availability quantified in this Study is not overestimated. There is also a risk, however, that future climate change is not as significant as predicted, and planning for water availability could be considered overly conservative if there is little change in future conditions relative to the present. To quantify this possible future, an additional future scenario was developed that assumed a stationary (non-changing) climate. In this additional scenario, projected increases in future air temperature and decreases in future baseflow due to climate change were removed, and historical values were repeated into the future using the same year sequencing as the future baseline (see Section 5.5.2). Summary results are provided in Appendix I. The results show that the most critical season for water availability, the fall, still shows reduced cumulative excess water availability relative to historical conditions of 3% to 5% across most subbasins due to projected increases in water demand that are not climate dependent (e.g., due to projected population or industrial growth). **An important conclusion from this future scenario analysis is that fall cumulative (i.e., regional) excess water availability is projected to continue to decrease in the future, regardless of whether additional climate change is factored into the analysis.**

Increased projected streamflow in the winter, spring, and early summer due to climate change also increases water availability and could provide a potential opportunity for future water management strategies. Currently, reservoir storage capacity in the Headwaters and the North Central Indiana region is allocated primarily towards flood risk reduction, and there is limited off-channel surface water storage or groundwater banking. If more flow is available during the winter months in the future, water availability will increase, leading to more opportunities to capture and store streamflow for potential use during a drier season or year. Some recommendations related to this opportunity are provided in Section 9.2.

9.1.2 WATER QUANTITY

The quantity of available water is highly variable, and insufficient water availability during some conditions in certain subbasins is a key water resources risk. The overarching limitations influencing future water availability risk are:

- Spatial variability (i.e., future water availability, or lack thereof, in certain subbasins)
- Seasonal variability (e.g., high projected future demand, coupled with low projected future baseflow in fall and summer seasons)
- Interannual variability (e.g., future water availability in relatively drier and drought years versus in wetter years).

With the development of additional supplies to meet future water demands, there is always the possibility that the water sources may not be able to provide the desired water supply. This is particularly true when developing groundwater supplies, as their successful development depends upon many factors related to the location where the water supply is required. Productive aquifers do not exist everywhere within the

Study Area. Section 9.2.1 identifies recommended areas for groundwater exploration to mitigate the risk of insufficient groundwater supply.

9.1.3 WATER QUALITY

As presented in Chapter 8, both groundwater and surface water quality were analyzed as part of this Study, with the intent being to better understand the ‘suitability’ of available water resources to be developed for use. Based on this review, it was found the groundwater in the Study Area is impaired by organic compounds, arsenic, and nitrate as nitrogen. Data from several wells across the Study Area show that these contaminants exceed their primary drinking water standard (MCL). Due to the elevated concentrations of these contaminants in some areas, there is a risk that existing or future water supplies may be adversely affected and require water treatment to continue to use or develop additional water supplies, along with associated cost increases to use the water. While industrial or agricultural development of groundwater with these water quality conditions may not be an issue, use of groundwater for public water supply will require treatment to reduce these constituents to protect public health, if primary drinking water standards are exceeded, before it can be legally served through its water system to its customers, and water quality monitoring will be required to assure the treatment system is protecting public health by maintaining reduced contaminant levels. This applies to groundwater obtained from both unconsolidated and bedrock aquifers.

From a water quality perspective, the development of additional groundwater supplies from within this Study Area should include the following evaluations to assess the need for any water treatment to meet water use requirements as part of a groundwater exploration and development effort:

- An initial assessment of the susceptibility of the unconsolidated or bedrock aquifer being considered to contamination based on land use, potential sources of contamination, hydrogeologic conditions, and recharge characteristics.
- Sampling of the potential water supply based on the intended use of the water.
    - For agricultural purposes, water sampling should include a major cation and anion analysis in addition to nutrients, herbicides, and pesticides.
    - For municipal purposes, water sampling should include a major ion analysis in addition to all EPA regulated drinking water contaminants plus perfluorooctanoic acid and PFAS.
- For industrial purposes, water sampling should include a major ion analysis plus those parameters relevant to the industrial process.
- Analysis of the sample results is needed to determine whether or not treatment is necessary and determine the appropriate water quality treatment, if required.
- A monitoring program would be required to determine if and how source water quality changes and the effectiveness of any treatment process to meet required or desired water quality standards.

Development of future water supplies from surface water in the Study Area may also require site-specific sampling and monitoring to fully understand localized treatment needs. The majority of the Study Area contains stream segments with one or more Clean Water Act Section 303(d) listed impairments, such as *E. coli*, nutrients, and chloride, which are constituents commonly treated with conventional water treatment technology for water supply across the U.S. Trends in IDEM surface water sampling data indicate that nitrate, chloride, and TDS regularly exceed regulatory standards in the Study Area. IDEM's robust surface water sampling program and trend tracking helps to assess the effectiveness of pollution prevention protocols or regulations in place and can help isolate emerging point sources of contamination and identify their spatial relationships to locations of projected future excess water availability.

Emerging contaminants such as PFAS and micro-plastics found in the Study Area and surface water bodies in various parts of the state could introduce the need for new or advanced treatment technology in the future as these contaminants are better understood and more robust regulatory standards are developed.

9.1.4 DIFFICULTY IN PREDICTING FUTURE CONDITIONS

Based on the availability of public data used for the water availability model, and to remain consistent with similar regional water studies in Indiana, the water availability analysis for this Study was conducted using a recent 16-year historical period of 2007-2022. This 16-year period is somewhat short of the 30-year standard used for representative climate conditions (e.g., NCEI 2024; WMO 2021). As reviewed in Section 2.2.2, measurable seasonal shifts in precipitation and streamflow have been observed in Indiana over the past 30 years, and these shifts are well represented in the most recent 16-year period. With respect to the frequency of extreme events like flooding and droughts, however, a 16-year period is a short period of record that may not contain flood or drought severity or duration that could be expected in the future. A limitation of this Study is that the frequency of future drought periods cannot be predicted with any certainty, and thus the potential effects of an increased frequency or duration of drought periods relative to the recent historical period are not considered in the quantification or analysis of water availability. This could be the subject of future study.

Underrepresenting the frequency of historical dry seasons in a water availability analysis increases the risk that water availability determinations could be made presuming more water is available more frequently in the future than may actually occur. For example, the winter of 2021 was a historically dry winter, within the top 20% driest winters of the past 100 years. The water availability analysis results for winter 2021 indicated negative cumulative excess availability along the upper Wabash River, primarily because natural baseflow dropped below the instream flow value. The winter of 2021 was only repeated once (see Table 5.5) in the future period analysis summarized in Chapter 7. If the frequency of similar dry periods were to increase in the future (for example, if dry fall periods extend into early winter, and spring precipitation and snowmelt are delayed until late spring more frequently), winters may become a season that limits excess water availability more frequently with winter streamflow more frequently approaching the Q90 value. This type of qualitative analysis may be useful as a supplement to the quantitative results of this Study when considering future water resource development opportunities.

9.1.5 LOCAL IMPACTS OF ADDITIONAL WATER DEVELOPMENT

The preceding four risks pertain to water availability and the suitability of available water for use. It is also important to note that the development of additional water supplies may introduce additional risk. In recognition of the hydrologic interconnectedness of groundwater and surface water in the Study Area, this risk includes the potential for adverse impacts to streamflow and to existing water users. Impacts to streamflow could affect instream flows, impact aquatic ecosystems, and could affect downstream water users. Impacts to existing water users could also occur through the development of additional groundwater in areas where a high level of use is already present.

The development of additional groundwater resources from both unconsolidated and bedrock aquifers has the potential to affect streamflow. Both the unconsolidated and bedrock aquifers are potentially connected to the streams and provide the baseflow of the surface water resources. Due to this hydrologic connection, the potential for impact to streamflow increases as the distance between the stream and groundwater development decreases either horizontally or vertically. A recent Purdue University doctoral dissertation (Jame, 2023) discussed the phenomenon of subsurface and surface hydrology and the potential impacts it could cause for the increased utilization of water withdrawals. The dissertation summarized similar findings within the balance of subsurface and surface resources. Development of either deep groundwater resources near a stream or aquifers far away from the stream would be expected to have the least potential for adverse impact.

Additional development of unconsolidated or bedrock aquifers in areas where significant use is already present has the potential to stress existing resources and adversely impact existing users (e.g., through lowering the local water table). Indiana has not identified any Restricted Use Areas to date, but state statutes are in place to curtail additional development if and when adverse impacts are identified (IC 14-25-4).

9.2 Opportunities and Recommendations

Some communities in the arid Western U.S. are coming up against the ‘hard boundary’ of simply not enough available, affordable, reliable water supply to meet projected demand. While this is not the case in the North Central Indiana region, this Study identified some current and projected future localized limitations (i.e., within certain subbasins), seasonal limitations, and both interannual and intra-annual variability limitations on water availability that merit consideration and attention.

Accordingly, nine potential approaches are recommended that can individually and/or collectively contribute toward an increase in future available water supply to maintain or strengthen the people, environment, productivity, and economy of North Central Indiana. This includes strategies to:

- Enhance the supply of surface water and/or groundwater (recommendations 1-4)
- Decrease the demand for water (recommendation 5)
- Better understand and manage water as a limited resource (recommendations 6-9)

Included are strategies for water users, water providers, and local/regional and state entities. Note that these recommendations are listed in order of the above categories, not by priority.

9.2.1 GROUNDWATER EXPLORATION AND DEVELOPMENT (1)

Water availability in this Study was quantified primarily using natural baseflow within a creek or river, but opportunities exist to further develop groundwater through water supply wells that directly connect to aquifers. Groundwater exploration areas that could potentially support the future completion of new water supply wells were identified, as described below, for both unconsolidated and bedrock aquifers. These areas appear to have a better chance of success than other areas in the region based on rock type and the productivity and density of existing high-capacity wells. The viability of these areas as potential groundwater sources would require further characterization of quantity, water quality, and potential impacts to existing neighboring well owners.

Groundwater exploration of the unconsolidated and bedrock aquifers should precede development to validate available groundwater quantity and quality, and to assess potential impacts to surface water resources. Due to the uncertainty of individual well yields and water quality even where productive aquifers are targeted, the development of groundwater is never certain. Advancing development without first confirming the availability and reliability of the needed water supply puts the entire development at risk. Developing groundwater supplies in anticipation of increased demand is the proper way to minimize the risk of insufficient supply in relation to growing water demand.

Unconsolidated aquifers: Within the unconsolidated aquifers, groundwater exploration areas were identified that include outwash, moraines, and complex till. Figure 9-1 highlights recommended groundwater exploration areas associated with the unconsolidated aquifers along with potential yields for individual wells. These areas were identified from existing high-capacity wells, unconsolidated aquifer type and thickness, and existing well density. Unconsolidated aquifers with high-capacity pumping rates ranging from 70 to 2,600 gpm were used along with coarse-grained stratified sediment types to indicate potential development areas. IDNR Aquifer Systems Mapping and unconsolidated aquifer maximum yield maps were also used to assist in identifying these areas. Based on the difference between the saturated unconsolidated aquifer thickness and depths of existing wells, it appears there are areas within the unconsolidated aquifers where deeper wells could be installed to extract presently undeveloped groundwater resources. Figure 9-1 also highlights some locations where a high density of existing wells indicates the aquifers in that area have high concentrated utilization (which likely has implications for future well siting, spacing, and potential yield).

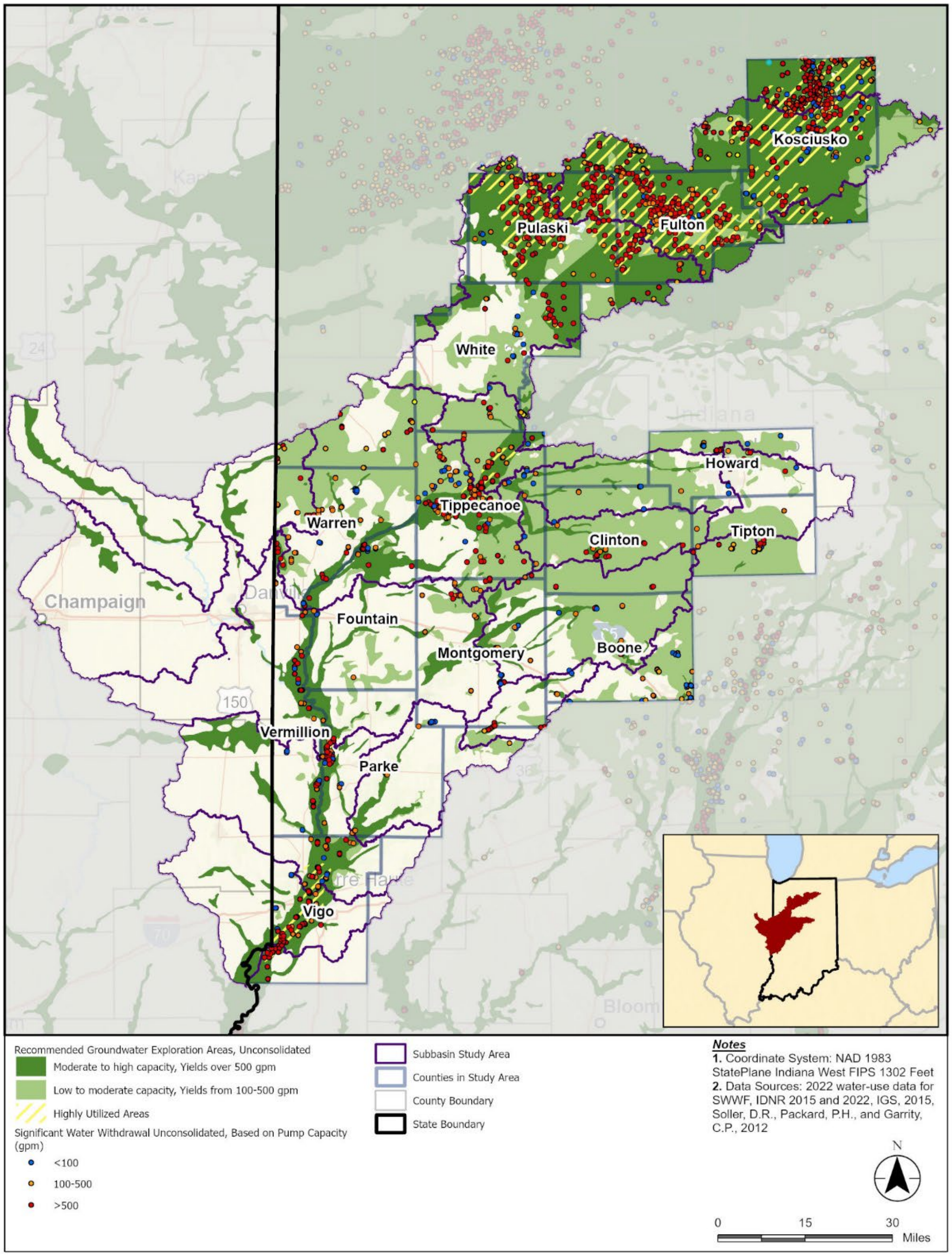
The unconsolidated aquifers that lie within the Mahomet (Teays) Bedrock Valley are of particular interest given their well yields and relatively low level of existing groundwater resource development. As shown in Figure 9-1, unconsolidated aquifers suitable for development may exist within Warren, Tippecanoe, Boone, Clinton, White, and Tipton Counties, and have not been as extensively developed as the unconsolidated aquifers in Pulaski, Fulton, and Kosciusko Counties. The northern central portion of Boone County appears to have better development prospects within that county. The unconsolidated aquifers within the valleys include discontinuous sand and gravel (Iroquois/Tipton Till) and multiple intratill sand and gravel layers (Iroquois/Tipton Complex; Kankakee/Iroquois Complex) that yield between 75 and

3,000 gpm. Outside of areas near Lafayette, these aquifers have not been extensively developed in Warren, Tippecanoe (southeast of Lafayette), White, Clinton, Boone, and Tipton Counties, and could provide significant groundwater resources if proven viable through hydrogeologic exploration. INTERA's (2023) exploration of the unconsolidated aquifers in the Mahomet (Teays) Bedrock Valley in southwestern Clinton County demonstrated the viability of developing additional groundwater supplies, indicating that it may be possible to develop up to 2 MGD from various sites. Other pre-glacial bedrock valleys that are associated with thick unconsolidated deposits and could be further explored exist within Pulaski, Fulton, and Kosciusko Counties, and narrower valleys within Warren and Vermillion Counties.

INTERA (2024) recently completed a hydrogeologic exploration of the unconsolidated aquifers at three sites along the Wabash River southwest of Lafayette in Tippecanoe County. This project explored the possibility of developing a large water supply in North Central Indiana using collector wells. The planned collector wells along the river would utilize riverbank filtration (RBF) to sustain high yields and provide quality source water. By design, an RBF well induces recharge of river water through the riverbed sediments. Three test production wells were completed along with 26 monitoring wells to evaluate the feasibility of developing a potential groundwater supply source from the sand and gravel deposits within the floodplain of the Wabash River overlying the Mahomet (Teays) Aquifer. Based on the testing, it was estimated that up to 57 MGD could be developed using collector wells at these locations.

Bedrock aquifers: Within the bedrock aquifers, groundwater exploration areas were identified within the Silurian and Devonian Carbonate Aquifer, the Raccoon Creek Group, and the Blue River and Sanders Group. Figure 9-2 highlights recommended exploration areas associated with the bedrock aquifers. These particular aquifers were selected for exploration on the basis of existing high-capacity wells and rock type. Bedrock aquifers with high-capacity wells yielding 70 gpm or more were strong drivers of areas considered for groundwater exploration. These aquifer units were further filtered to identify areas where high-capacity wells overlapped with dolomite, limestone, and sandstone rock types. The results of this screening are shown in Figure 9-2Figure 9-2. Areas with high existing well density are identified as highly utilized areas. While the Raccoon Creek Group has been included for exploration in the southwestern part of the Study Area, the groundwater development potential will depend upon the rock type present, aquifer permeability and water quality considerations. Although it is a reported source for a number of high-capacity wells, the Borden Group was not included as a recommended exploration area because it is primarily composed of low permeability siltstone and shale.

Surface waters should be evaluated and monitored for potential impacts during groundwater exploration activities. Beyond monitoring for impacts, planning for future groundwater development (especially of shallow groundwater resources) near a stream should recognize and quantify the potential for reduced water availability in that stream. It is important to recognize and quantify the surface water-groundwater interaction.



Notes
1. Coordinate System: NAD 1983 StatePlane Indiana West FIPS 1302 Feet
2. Data Sources: 2022 water-use data for SWWF, IDNR 2015 and 2022, IGS, 2015, Soller, D.R., Packard, P.H., and Garrity, C.P., 2012

Figure 9-1. Groundwater Exploration Areas Recommended for the Unconsolidated Aquifers Within North Central Indiana

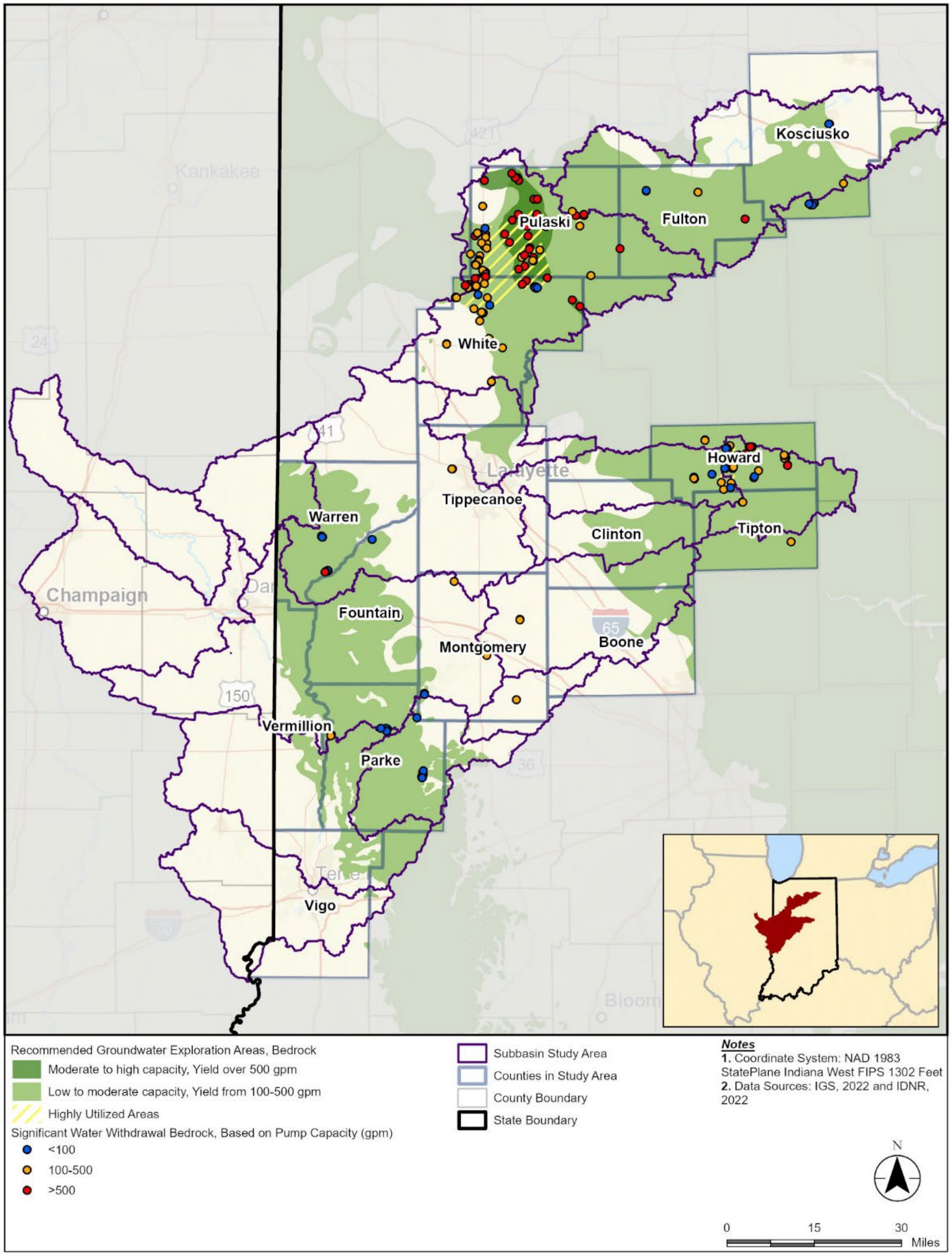


Figure 9-2. Groundwater Exploration Areas Recommended for the Bedrock Aquifers Within North Central Indiana

Key opportunities considered for groundwater development include:

- Unconsolidated aquifers that could be explored for additional groundwater supplies exist within outwash, moraines, and complex till across the Study Area as shown in Figure 9-1.
- Unconsolidated aquifers within the Mahomet (Teays) Bedrock Valley should be explored to determine whether they can provide groundwater of sufficient quantity and quality in close proximity to proposed developments. The opportunity to develop these resources lies within multiple counties across the Study Area.
- The Silurian and Devonian Carbonate Aquifer has the potential to supply additional groundwater resources for developments within multiple counties as shown in Figure 9-2. A few counties rely on the productivity of this aquifer to provide the majority of their groundwater resources.
- The Raccoon Creek Group Aquifer may be able to supply additional groundwater resources where saturated sandstone is present within the area identified in Figure 9-2.

9.2.2 RESERVOIR STORAGE REALLOCATION (2)

Water availability in subbasins along the Wabash River could be increased by increasing the volume of water provided by upstream reservoir operations. Since USACE is not currently undertaking many new reservoir construction projects, the most practical way to increase water storage in USACE reservoirs is by reallocating a portion of existing storage capacity. Reallocation refers to the process of reassessing and redistributing the usage of storage capacity within an existing reservoir to an alternative or higher-priority use.

USACE flood risk reduction reservoirs typically serve multiple purposes and contain three main water storage zones, or "pools": the flood control pool, the conservation pool, and the inactive (or sediment) pool. The flood control pool is usually kept empty to allow for the storage of runoff during periods of high inflow. The conservation pool is designated for more specific purposes, such as hydropower, navigation, water supply, water quality management, or irrigation. Recreation is also typically used as part of the conservation pool, often the top portion. The inactive or sediment pool, while technically usable, is generally not relied upon for meeting downstream water demands. This pool is primarily reserved for maintaining hydropower head or for storing sediment that accumulates over time, or is the reservoir capacity below the lowest outlet. It is important to note that USACE policy prohibits reallocating flood control pool storage to other uses, such as water supply, if a dam has a Dam Safety Action Classification (DSAC) rating of 1, 2, or 3. However, reallocating storage from the conservation pool (below the normal pool level) is possible for dams with a DSAC rating of 3.

There are four major flood risk reduction reservoirs within the Study Area operated by the USACE: Cecil M. Harden, Salamonie, Mississinewa, and J. Edward Roush. These reservoirs are also authorized for other purposes, including water quality, recreation, and fish and wildlife. None of these reservoirs has an authorized water supply purpose, so all of these reservoirs have the technical potential to reallocate existing conservation storage space for water supply but would need to have reallocation studies authorized to be studied formally by USACE. The water supply reallocation process generally consists of a study performed in two phases: reconnaissance and feasibility. The reconnaissance study, which is fully funded at the Federal level, assesses whether a feasibility study is necessary and if Congressional approval is required for reallocation. If the reconnaissance study determines that a feasibility study is warranted, a more detailed feasibility study is conducted. This study is funded equally by the USACE and the non-federal sponsor (NFS). This entire process can take several years to complete.

Nine completed and ongoing reservoir reallocation studies conducted by USACE were reviewed to provide additional context on how technical potential for water supply reallocation has been converted into actual water supply storage. Across these studies, a range from 1% to 35% of the total net conservation pool was being evaluated for reallocation to water supply storage. As a conservative estimate based solely on the documented USACE reallocation studies available and without considering other limiting factors, the current Study assumed potential for reallocating 10% of the conservation pool of all four major USACE reservoirs for water supply.

Time series data on flow and reservoir operating elevations from 2007 to 2022, along with pool elevations and storage volumes, were obtained from USACE online resources. Publicly available water control manuals and time series plots were also used to identify critical reservoir operating periods and maintain consistent assumptions across all reservoirs. Net conservation pool volumes were obtained from water control manuals when available; otherwise, they were estimated based on elevation and available pool acreage. The Study assumed the winter pool period to be from December to the end of March, with reservoir filling occurring in April to reach the summer pool in May. The summer pool ranges from May through September, followed by a drawdown from October through November. These operating periods were similar across all the dams studied. Storage below the winter pool elevation was considered inactive storage.

As an estimate of potential new water supply, 10% of the net conservation pool for each reservoir was assumed to be reallocated to water supply. This was achieved for analytical purposes by lowering the current winter pool elevation to allow for additional water supply storage. This additional storage was assumed to be released during the drawdown period (October to November) to increase water availability in the fall, the period with historically the lowest water availability. The reallocated volume was assessed as a release in addition to historical releases of the 2007-2022 period. A schematic example of the pool levels and potential operational changes for the reservoirs is shown in Figure 9-3. With the additional release corresponding to the reallocated storage, the drawdown in November and December is assumed to occur at a steeper rate, as reflected in the rapid lowering of the summer pool (in red) compared to current drawdown (in blue). However, storage would be recovered by May of the next year to maintain the summer pool elevation.

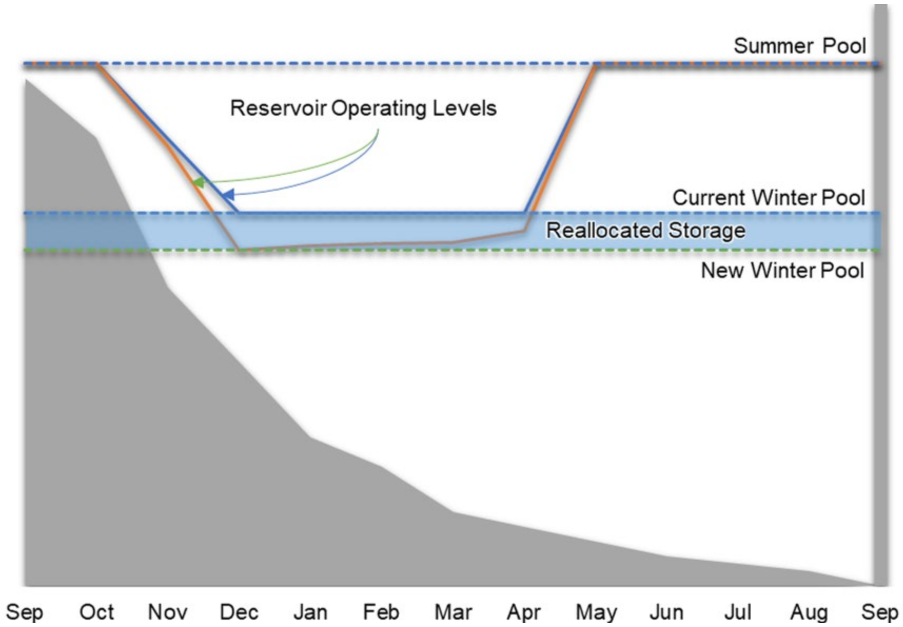


Figure 9-3. Assumed Reallocated Storage and Reservoir Operational Changes

The potential reallocation volumes and releases from each reservoir are summarized in Table 9-1. Approximately 76 MGD of additional flow could be added to the Wabash River mainstem from all the dams combined in the Study Area from October through November, with 57 MGD coming from reservoirs in the Headwaters and 19 MGD coming from Cecil M. Harden Lake. Historical net release data for each dam indicate that, even if the reservoirs were to be drawn down lower by the end of November, they would all still refill to the summer pool elevation by the beginning of the following May. In other words, each reservoir spilled a volume from December through May that was at least equivalent to the volume of reallocated storage. This reallocation strategy does not impact the summer or flood pool elevations, but is dependent on the availability of inactive storage below the winter pool, which in turn is influenced by the sedimentation rate. According to the water control manuals for Salamonie Lake and Cecil M. Harden Lake, the sedimentation rate does not currently pose a significant issue for utility or operation, nor is it expected to in the near future.

Table 9-1. Summary of Historical Minimum Release and Potential Reallocation Volume and Reallocation Release Rates

Dam	DSAC Rating	Net Conservation Pool (MG)	Reallocation Volume (10% of Net Active Pool) (MG) [1]	Reallocated Release Over Drawdown Period (Oct to Nov) (MGD) [2]	Historical Minimum Winter Release (MGD) [3]
Salamonie	4	14,070	1,407	**23**	14
Mississinewa	4	18,166	1,817	**30**	22
J. Edward Roush	3	2,737	274	**4**	16
Cecil M. Harden	3	11,454	1,145	**19**	13
Combined			**4,643**	**76**	**65**

Notes: [1] Reallocation is assumed from inactive storage.
[2] Reallocated release is the flow that could be released downstream in addition to the current minimum release.
[3] Historical minimum winter release represents minimum required regulated downstream release.
Key: DSAC = Dam Safety Action Classification; MG = million gallons; MGD = million gallons per day

9.2.3 INCREASED OR EXPANDED WATER STORAGE (3)

Expanding existing or developing new water storage capacity can be used to address both water supply and system operational limitations. Traditionally in relatively wet regions not subject to dry periods or drought, a utility may only have the capability to store the equivalent volume of one day or multiple days of water demand. This storage is typically intended to bridge system operation disruptions (i.e., temporary water treatment and/or water distribution system outages). In relatively dry regions of the western U.S., particularly those subject to variable climatic conditions, it is more common to maintain larger storage volumes to store wet period excess flows for later use in dry periods. In some cases, months or even years of water demand can be met entirely from storage. Three key strategies to enhance water storage capacity in the Study Area are described in this section, as well as a fourth ‘integration’ strategy.

Conjunctive use of groundwater and surface water: Water providers in the region may consider implementing a conjunctive use approach to water management, similar to that employed for Indianapolis. Conjunctive use refers to the combined use of surface and groundwater resources to meet water demands throughout the watershed ideally across both space and time. The current approach to quantify regional water availability in Indiana focuses primarily on baseflow, or groundwater discharged to a waterway, as a water supply source. This approach generally aligns with the mechanics of most major surface and groundwater withdrawal facilities, which extract surface water and groundwater that are fully hydraulically connected to surface waterways. However, regional water management generally does not include long-term groundwater storage in aquifers. During shortage periods for hydraulically connected groundwater and surface water users, for example, groundwater stored in aquifers could be (but is currently not) used to make up the deficit. This approach is not necessarily available everywhere in the watershed, but where suitable unconsolidated or bedrock aquifers are available adjacent to surface water resources, this approach could be used as a mitigation strategy during water short periods. Review of the hydrographs for the observation wells seem to suggest that the aquifers have not been overly developed or stressed to date and could support such an approach.

Note that there can be technical and/or regulatory challenges associated with implementing conjunctive use, such as the need for more advanced infrastructure (e.g., treatment and/or conveyance) to manage alternating between groundwater and surface water sources. Developing an integrated groundwater and surface water management plan could help to provide sustainable development.

Local surface storage: The water balance methodology used in this Study focused on the baseflow component of the hydrograph. Another strategy to enhance excess water availability would be to develop new water storage facilities to better capture peak flows, particularly spring season runoff, for use in drier seasons and perhaps even drier years. This could include the development of new on- or off-channel (a.k.a., “upland”) active reservoir storage, enlargement of existing reservoirs, repurposing of legacy gravel pits or other surface or subsurface mines, and/or the acquisition of existing storage facilities.

The first step in identifying and developing such storage options would be to conduct a water storage investigation to identify, evaluate, and screen potential surface water storage facility alternatives. Criteria to be included in such an assessment could include:

- Hydrology / Water Availability

- Physical Features / Geology
- Environmental / Permitting / Mitigation
- Socio-economic / Land Use / Zoning
- Environmental / Social Justice
- Site / Civil / Infrastructure
- Engineering / Construction
- Compatibility with Long-Range Planning and Economic Development
- Proximity to water demand centers and/or existing water distribution infrastructure

Subsurface storage, such as through Aquifer Storage and Recovery (ASR): ASR is the injection and storage of clean, potable water into an aquifer for subsequent recovery (via pumping) and then use. ASR can be envisioned as a water ‘savings account’ – making deposits during wet periods (such as by diversion from rivers or reservoirs) and storing for ‘withdrawals’ to provide water supply during dry periods.

In addition to the evaluation and screening criteria described above, aquifers being considered for ASR implementation would need hydrogeologic and geochemical investigations to determine if the formation is suitable to receive and store water and if there are water quality considerations that may impact the receiving aquifer and/or the injected/stored water. Relatedly, analysis needs to be undertaken to assess the availability of sufficient water for storage. While ASR is a potentially more complicated approach to water storage, it can typically offer the benefits of reduced environmental impact (e.g., as compared to on-channel dams) and also reduced loss of stored water (e.g., generally less water ‘leaks’ out of the ASR stored water ‘bubble’ than would evaporate off of a similarly sized above-ground reservoir).

Integrated water management planning: The development of a watershed-wide integrated water management plan that combines conjunctive use, local surface storage, and ASR could help to optimize water resources. Further, it would be beneficial to include provisions for adaptive management to adjust strategies in the future in response to changing hydrologic and/or socio-economic conditions.

9.2.4 ALTERNATIVE WATER SUPPLIES (4)

Just as is often recommended for sound financial investment planning, sound water resource planning increasingly includes efforts to diversify the portfolio of water supply sources, sometime to include ‘alternative’ or less-commonly used water supply strategies. Such diversification can increase water system reliability and resilience, both to known and sometimes even to unknown (or lesser understood) risks. Two strategies commonly and/or increasingly employed for water supply diversification in areas of the U.S. with increasing water availability limitations are described below.

Water Reuse: Water reuse (a.k.a., water reclamation or water recycling) typically is defined as including the necessary advanced water treatment and re-supply infrastructure to beneficially reuse water, often for purposes such as agriculture and irrigation (e.g., golf courses or lawn watering), potable water supply (through direct or indirect reuse), groundwater replenishment, industrial process input (e.g., cooling water), and/or environmental restoration.

Given the acceleration of industrial development in Indiana, including high-water demanding entities, reuse regulations should be pursued to allow highest and best use, reuse, and recycling of available water resources. There are limitations to fresh water supplies throughout the Study Area, and encouraging advancement and technological investment to eliminate single-use water demands in industries that result in losses to the watershed can create efficiencies of water conveyance and conservation. As industries push to meet corporate sustainability goals for water stewardship, providing opportunities to reuse treated municipal effluent or industrial process water to offset potable water demands of non-contact cooling or irrigation can provide a win-win for industries and the utilities serving them. By creating a framework for water recycling in the State of Indiana, withdrawals from existing watersheds can be stabilized and water can be beneficially reused throughout its lifecycle: raw water, potable water, municipal/industrial wastewater, and treated effluent.

Regional collaboration, including water conveyance: Some regions have found that considering and managing water as a more regional resource, as opposed to a predominantly local resource, can similarly increase water system reliability and resilience. Regional collaboration includes enhanced communication and coordination among water entities, described further in Section 9.2.6 below.

Regional collaboration can also include shared capital and/or reoccurring investment in new water management strategies that serve multiple entities at a regional scale. This could take the form of increased emergency interconnections between water utilities (as a means to share and thus reduce system risk). It could also take the form of annexation of currently served and/or new growth areas into the service area of existing nearby utilities who are well-situated with their existing or planned infrastructure to better accommodate growth (and in some cases, who might be better equipped to take on new water supply challenges, such as providing the water treatment which may be necessary under the recent PFAS rule). Lastly, regional collaboration could include strategies to develop shared water diversions, groundwater development, and/or water storage facilities, which can then often benefit from an economy of scale and a shared investment burden. This could also include strategies to develop new or upgraded pipelines and associated conveyance facilities (e.g., pump stations, booster stations, interties) to move water, either continuously or in times of need, from areas experiencing a surplus of water availability to areas of unmet need.

9.2.5 WATER CONSERVATION AND WATER USE EFFICIENCY (5)

In many communities, the ‘low hanging fruit’ when it comes to water resource planning and management is conserving the limited water supply that has already been developed and using existing water resources more efficiently. In comparative analysis of water management strategies, enhanced water conservation and water use efficiency often shows the greatest cost effectiveness (i.e., return on investment). Water conservation can be achieved passively, such as through ongoing improvements in the efficiency of water fixtures and appliances, or through residential densification, as denser development include less outdoor space to be watered. Water conservation can also be enhanced through such means as investment, regulations, requirements, and education.

Enhanced water conservation and water use efficiency could include:

- Enhanced utility leak detection and more aggressive capital improvement planning schedules to identify and replace aging and failing water distribution system infrastructure (thus minimizing the volume of non-revenue generating water that is ‘lost’ through leakage or seepage). Note that funding support and technical assistance can be of great benefit here, especially for smaller utilities (who typically have more limited resources).

  Note that water utilities in Indiana are required to submit validated water loss audits every even-numbered year to the IFA, who is then required by IC 8-1-30.8 to complete a biennial legislative report that summarizes the compiled audit data (IFA, 2024d).

  The 2024 audit included data from 446 PWSs, collectively serving over 4.9 million Hoosiers. From the survey, the median water loss (as a percentage by volume of water supplied) was 19%, with the 25th and 75th percentile water losses spanning a range of 10 to 30%. In total, the statewide annual cost of this ‘non-revenue water’ was nearly $200 million in 2024 (IFA, 2024e).

- Programs to minimize irrigated public spaces, such as reducing turf grass adjacent to municipal buildings or in roadway medians.

- Incentives for residential water conservation and water use efficiency improvements, addressing end-use water demand both inside and outside of the home.

- From discussions with the agricultural community in Indiana, it is clear that significant efforts are underway to improve crop yields, crop resilience, and crop water use efficiency. As irrigated agriculture is an important current and projected consumer of water in the Study Area, these efforts should be applauded, emphasized, and supported by water providers and state entities where practicable.

- Industrial water use efficiency for industrial water users to optimize on-site processes. For example, industries could be encouraged to adopt or enhance existing water cycling systems.

- Stormwater management: develop stormwater management practices that reduce runoff and provide supplemental water supplies.

- Analysis of water rate billing structures and the implementation of increasing block structure pricing, whereby the rate charged per unit of water increases as the volume of consumption increases. In other words, customers often are charged a low rate in the first ‘block’, typically designed to align with customary indoor domestic water use adjusted by dwelling size, then are increasingly charged more per gallon for additional increments of water used. This approach has been implemented across much of the western U.S.

Enhanced water conservation and water use efficiency often requires and includes enhanced public education and outreach, and can also benefit from enhanced coordination amongst water providers.

9.2.6 DATA COLLECTION, MONITORING NETWORKS, AND MODELING (6)

Review of the surface water and groundwater data for North Central Indiana has led to the discovery of a number of data gaps, particularly related to groundwater quantity and quality. Filling these data gaps would be helpful in fostering additional understanding of the water resources of the area.

These data gaps and suggested improvements include the following:

- Groundwater level monitoring data for both the unconsolidated and bedrock aquifers is limited.
  - Thirteen observation wells are currently used to monitor groundwater levels in the unconsolidated aquifers within the Study Area, and only a few of these have long-term datasets.
    - Increase the number of water level observation wells to five per county and distribute them across the different aquifer types that are more utilized within each county.
    - Where the Wabash River or its tributaries are present in a county, include two observation wells near the watercourse – one upstream and one downstream.
  - One well is currently used to monitor water levels in the bedrock aquifers within the Study Area.
    - Increase the number of water level observation wells to two per county and distribute them between the bedrock aquifers utilized.
- Groundwater quality monitoring is lacking or deficient within certain counties.
  - Water quality monitoring in Vigo, Fountain, and Fulton Counties historically has been generally spatially widespread and of sufficient detail to identify issues; this should be continued.
  - Increase the sampling and distribution of water quality samples collected in the other counties within the Study Area.
- Refine data reporting to the EPA under NPDES to better distinguish between combined sewer overflows and treated effluent discharge. For many facilities, these flows are reported as a singular dataset, making it difficult to determine how much reported NPDES discharge was from treated effluent and how much was from stormwater.
- While analyses are underway in certain regions, the State of Indiana lacks a comprehensive scientific understanding of subsurface water resources, including information pertaining to aquifer extents, dimensions, and hydrogeologic parameters, aquifer capacity, water levels, aquifer recharge, and maximum sustainable groundwater yield. Scientific studies to better understand the

State's aquifers (as distinct from aquifer types or aquifer systems) would enable more accurate analysis of current and future groundwater availability.

- Similarly, investments are underway in certain regions of the State to develop or enhance existing simulation models of regional water systems in order to assess the impacts of proposed water supply development projects and to test scenarios of water extraction, water storage, and water discharge. These efforts should be expanded to encompass regions of particular interest and/or regions of particular projected future water availability limitations and to better capture the dynamics of the coupled groundwater-surface water hydrologic system.

9.2.7 COMMUNICATION, COORDINATION, AND EDUCATION (7)

As a particular resource becomes more limited in a region, public awareness, understanding, and appreciation of that resource inherently increases. This trend is currently being experienced in parts of Indiana regarding water resources. There are steps that can be taken by water suppliers as well as regional and state entities to facilitate, enhance, and support the public's water resources literacy, and there are also benefits for water resource management from increased public awareness and increased collaboration. Example recommendations regarding strategies for communication, education, and outreach include the following:

- Promote and increase awareness of existing state-wide resources (such as existing infrastructure, plans, regulations, goals, and data).
- Develop and maintain websites where the public can monitor reservoir levels, stream levels, aquifer levels, precipitation totals, and drought forecasts.
- Collaborate with and support existing water utility and other communications campaigns on water conservation.
- Provide public education materials for teachers to utilize in their classrooms.
- Encourage local media coverage of water conservation issues and the importance of water conservation, especially during dry years.
- Provide water conservation information to the public at State and municipal buildings and other public places.
- Make information on water conservation available on State of Indiana and municipal websites and include links to information on water conservation.
- Tailor messages to resonate with water users and specific industries (e.g., by recognizing the values and needs of the target audience).
- Expand and/or modify existing academic and agricultural extension programs to further advance the topics of water conservation and water use efficiency.

- Partner with EPA Water Sense and participate in the EPA Water Sense sponsored “Fix a Leak Week.”
- Make water provider staff available to give presentations and/or workshops on the importance of water conservation and ways to save water to local organizations, schools, and civic groups.
- Develop and communicate clear and consistent public messaging on drought stages (e.g., recommended or required limitations on water usage, reduction goals, and the value of reductions).
- Increased communication and collaboration among water suppliers regarding drought contingency planning (e.g., alignment on the timing of drought declarations, the definition of drought stages, and even on voluntary and mandatory drought water use requirements).
- Create platforms, incentives, and forums for water suppliers and other entities involved in water management (e.g., academic researchers, stakeholder groups, large water users) to share best practices and lessons learned; to share and review monitoring data and to standardize data collection and reporting; to present and review water resource development plans; and to identify, discuss, and develop strategies to help mitigate potential adverse impacts from new water supply development.

9.2.8 WATER POLICY AND PRACTICE (8)

It is commendable that IFA has chosen to fund and conduct regional water availability studies, and that IFA is seeking to build on these studies where needed to help advance the water management discussion in Indiana. As such, the IFA is positioned to advance additional legislative policy and water management practice efforts. Beyond items already mentioned in other sections, specific recommendations to this end include:

- Promote statewide legislation to determine, establish, and protect environmental flows.
- Establish and maintain regional water planning groups that include representation from across water sectors and water stakeholders.
- Continue to work toward implementing statewide water planning, to include future water supply and water demand analysis to support estimates of future water availability, and also identification and analysis of water management strategies conducted using consistent methodology statewide and updated on a periodic basis (e.g., 5- or 10-year intervals).

9.2.9 RECOMMENDED FOLLOW-ON ANALYSES (9)

The following additional work is recommended to build upon the work completed through this Study. These additional analyses would be valuable to help reduce risk, increase the potential for success of future projects, and protect existing water users.

- Require a site-specific groundwater exploration study to support water supply development for proposed large groundwater withdrawal facilities. This approach should consist of at least the following steps:
  - Review the available geologic and hydrogeologic data within an approximately five-mile radius of the proposed project site and identify locations and details of neighboring significant water withdrawal facilities and domestic wells.
  - Develop a groundwater exploration plan that identifies the target aquifer(s), the amount of water proposed for development, proposed drilling depths through the respective aquifer(s), test well locations and well design, observation well locations and design, well completion and development strategies, and step and constant rate aquifer testing durations and monitoring plan including neighboring wells, surface waters, and springs as appropriate. The plan should also include water quality sampling of the potential water supply based on the intended use of the water.
  - Complete test and observation wells, and perform aquifer testing with monitoring of existing surface water and groundwater resources, and water quality sampling, as warranted.
  - Prepare a groundwater exploration report that details the findings of the well drilling, reveals the aquifer testing results, monitoring results, production rates, and permeability associated with the tested aquifer(s), water quality, and includes at least analytical modeling of the proposed production well or wellfield layout to assess potential impacts of the proposed water supply production on neighboring users.
- Consider acquiring airborne geophysics to better define hydrogeologic conditions of unconsolidated aquifers and supplement existing hydrogeologic data.
- Address the identified data collection, monitoring networks, and modeling data gaps.
- Consider additional studies of historic and paleohistoric drought in Indiana, including analysis of the frequency, duration, and intensity of past drought episodes, and also analysis of whether these drought characteristics are stationary or non-stationary in time. Such studies can leverage recorded observations and indices (such as the Palmer Hydrologic Drought Index, the Palmer Drought Severity Index, streamflow, groundwater level, air temperature, and/or precipitation records) as well as reconstructed climate records from paleoclimate studies (such as isotopic analysis from lake sediments and/or tree ring data). These studies would enable a better understanding of the characteristics of past drought periods and could provide insight on the potential impacts of an increased frequency or duration of future droughts.
- Since large water supply projects can take years (or even decades) to implement, it would be prudent for water providers and large water users, along with other stakeholders, to continue to undertake the next steps necessary to plan, evaluate, design, and permit water supply projects which might become necessary to meet future needs.

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APPENDIX A

Additional Geologic and Hydrogeologic Background Information

APPENDIX B

Data Collection, Pre-Processing, and Analysis for Water Budget Components: Availability and Supply

APPENDIX C

Baseflow Separation Approach

APPENDIX D

Historical and Future Water Demand Methodology and Future Water Demand by County

APPENDIX E

Historical and Projected Future Water Demand by Subbasin

APPENDIX F

Development of Future Baseline Data

APPENDIX G

Historical Water Availability by Subbasin

APPENDIX H

Future Baseline Water Availability by Subbasin

APPENDIX I

Future Alternative Scenarios and Water Availability Assessment Results

APPENDIX J

Water Quality

APPENDIX K

Historical and Projected Future Water Demand Summaries by County