Regional Water Study

Water Demand and Availability in the Driftwood, Flatrock-Haw, and Upper East Fork White River Watersheds

Sally L. Letsinger, Ph.D.
sletsing@indiana.edu

Andrew R. Gustin
angustin@iu.edu

Indiana University, Department of Geography

Report to Indiana Finance Authority

Award # 079396-00002B

February 2024

INDIANA UNIVERSITY
BLOOMINGTON

Acknowledgements

This research was funded by the Indiana Finance Authority (Award #079396-00002B) and was supported in part by Lilly Endowment, Inc., through its support for the Indiana University Pervasive Technology Institute and high-performance computing resources at Indiana University. Thanks to Kara Gealy (Indiana University) for providing research support to this project.

We would like to express our gratitude for the participation of:

- Indiana Department of Natural Resources, Division of Water
- Indiana Department of Environmental Management
- United States Geological Survey
- Indiana University

Citation

Letsinger, S.L., and Gustin, A.R., 2024. Regional water study: Water Demand and Availability in the Driftwood, Flatrock-Haw, and Upper East Fork White River Watersheds; Report to Indiana Finance Authority, Award 079396-00002B, 106 p.

List of Acronyms

ACRONYM	TERM
7Q2	Lowest 7-day average flow that occurs every 2 years (a measure of typical seasonal lows)
7Q10	Lowest 7-day average flow that occurs every 10 years (on average)
AET	Actual evapotranspiration
CAFO	Concentrated Animal Feeding Operation
CEG	Citizens' Energy Group
CFO	Confined Feeding Operation
CFS	Cubic feet per second (stream discharge)
CPI	Consumer Price Index
DOT	Department of Transportation
DWV	Drinking Water Viewer (utility database)
DWW	Drinking Water Watch (utility database)
EIA	Energy Information Administration
EP	Energy Production (water-use sector)
EPA	U.S. Environmental Protection Agency
GPM	Gallons per minute
GW	Groundwater
GWR	Groundwater recharge
HUC	Hydrologic Unit Code
IBRC	Indiana Business Research Center
IDEM	Indiana Department of Environmental Management
IDNR	Indiana Department of Natural Resources
IFA	Indiana Finance Authority
IGWS	Indiana Geological and Water Survey
IN	Industrial (water-use sector)
IPCC	Intergovernmental Panel on Climate Change
IR	Irrigation (water-use sector)
IRR	Irrigation
ISDA	Indiana State Department of Agriculture
IU	Indiana University
IURC	Indiana Utility Regulatory Commission

IWRRC	Indiana Waters Resource Research Center
LULC	Land use and land cover
MG	Million gallons
MGD	Millions of gallons per day
MI	Miscellaneous (water-use sector)
MK	Mann-Kendall trend test
MRO	Monthly Report of Operations (for public utilities)
NAD	National Address Database
NASS	National Agricultural Statistics Service
NCDC	National Climate Data Center
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System (EPA)
PART	Hydrograph separation (groundwater baseflow-estimation) method
PDSI	Palmer Drought Severity Index
PET	Potential evapotranspiration
PS	Public Supply (water-use sector)
PWS	Public Water System
Q90	Minimum flow that is present 90% of the time
RU	Rural Use (water-use sector)
SEN	Theil–Sen estimator of slope
SSP	Shared Socioeconomic Pathways (population model)
SS-Res	Self-supplied residential (domestic) water
SWB2	Soil Water Balance model, v2
SWWF	Significant Water Withdrawal Facility (high-capacity water pumping)
TDS	Total dissolved solids (low = fresh water; high = brackish water)
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VFC	Virtual Filing Cabinet (IDEM)

Executive Summary

In this study, estimates of water demand were made for the Southeast-Central Indiana region for the next 50 years for the public supply sector. This was accomplished using a multiple regression-based approach to develop county-level models and project future water demand based on economic variables for baseline (minimum water demand) growth, and climate variables for estimates of seasonal water use.

A watershed-based water inventory was developed for use in an analysis of current and future water availability. In addition to projections of future public-water-supply demand, future water use was projected for other water-use sectors (e.g., irrigation, industrial, animal agriculture, and self-supplied residential) using less rigorous methods than that for public supplies.

A surface water-balance model was developed for both current (1985-2021, based on observations) and future (2021-2075, driven by global climate model outputs) conditions so that likely future seasonal variability could be represented for planning purposes.

Current and future water-availability analyses were conducted to assess not only the spatial distribution of water resources in the study area, but to also evaluate the impact of the human element on current and anticipated future withdrawals and returns to the water cycle. Current and potential future limitations in available water are also identified and presented in the report.

Total future water demand in the Southeast-Central Region is estimated to be 30% (23 MGD) more than current withdrawals (2020). Demand for public water supplies is the largest fraction of this increase. From water utility planning documents, many water service-area expansions are planned to serve a larger population that is currently self-supplied. At least three counties expect additional industrial or rural-sector (i.e., concentrated animal feeding operations) demand to be met by public supplies.

The dominant source water used to meet all water-use sector demands is groundwater. The Southeast-Central Indiana region is located in a transitional geologic terrane that straddles the boundary of the last glacial maximum. Aquifer resources to the north of this boundary are more accessible and higher yielding than those to the south. Further, glacial outwash aquifers line and underlie many of the streams and rivers in the region, providing water to public water utilities and cultivated crop irrigators adjacent to the river corridors.

Highlights:

Current and future water demand in the Southeast-Central Indiana region is dominated by public-water supply sector use

The region is characterized by rural land uses

Groundwater is the dominant water source in the region

Current water demand in the region is 74 MGD

Future water demand in the region is estimated to be 97 MGD

Public water utilities are estimated to experience a 56% increase in water demand in the next 50 years (44 MGD to 68 MGD)

Changes in climate are causing shifts in timing and distribution of precipitation and aquifer recharge

River flow volumes are increasing (winter/spring) as are most water levels in groundwater observation wells

Seasonality of demand and availability is becoming more pronounced (dry summers)

Public water utilities and irrigators might need to invest in storage options to meet future dry-season demand

Only two surface-water intakes are used for municipal water supplies, and both of those are supplemented by additional means (either groundwater wells or emergency purchase agreements with other utilities) to ensure a reliable supply during the summer. Therefore, with more than 25 additional MGD in demand forecast for public water supplies, most of this supply will be withdrawn from the outwash aquifer that underlies the major streams and rivers in the region. Between 30 and 90% of additional peak demand (from 1 MGD up to 23 MGD, depending on the customer base within the counties) in the dry summer months is projected by 2070.

The region is characterized by acute seasonality in the water cycle, meaning that annual totals of precipitation, runoff, and aquifer recharge dominate inputs to the water cycle in the winter and spring, while natural (i.e., evaporation, vegetation transpiration) and anthropogenic (i.e., water withdrawals) outputs exceed inputs to the water cycle in the summer and fall.

Unlike other regions in the state (e.g., Central Indiana, Indianapolis), the water-use sectors in the Southeast-Central Indiana region are highly consumptive, so that only a fraction of water withdrawn from aquifers is returned to the water cycle by man-made uses. For example, the largest water-use sector in the Central Indiana region is energy production, which is non-consumptive. In the Southeast-Central Indiana region, the largest-water use sectors are the public supply and agricultural sectors, which are highly consumptive. Although some portion of public supply water is returned for reuse, there are non-revenue water losses and water provided to other consumptive-use sectors (e.g., industrial, animal agriculture) by utilities in the Southeast-Central Indiana region. Because of this, the consistent receipt of precipitation is critical to regional water sustainability. Back-to-back drought years could be problematic for water-utility operations.

Trend analyses of river flows and groundwater levels for most monitoring points in the study area show annual increases over the last 30 years. Once again, however, seasonal trend results point to the bulk of this increase occurring in the winter and spring. Much of winter and spring river flows run off downstream, but increases in groundwater levels suggest that additional water is being retained in the subsurface. Data from observation wells and stream gages show a high degree of hydrologic connection of surface and groundwater resources, with implications for surface contamination of aquifers and limited natural drought resilience in some hydrogeologic settings.

Changes in climate conditions include increased temperature, precipitation, and atmospheric thirst (potential evapotranspiration), causing some areas of the region to experience water deficits in the summer and fall of most years. Wastewater returns offset some of the increased summer withdrawals, but additional storage might be needed to meet future summer and fall demand by public water utilities and irrigators.

Citation: Letsinger, S.L., and Gustin, A.R., 2024. Regional water study: Water Demand and Availability in the Driftwood, Flatrock-Haw, and Upper East Fork White River Watersheds; Report to Indiana Finance Authority, Award 079396-00002B, 106 p.

Table of Contents

List of Figures

List of Sidebars

List of Tables

Water Demand and Availability in the Driftwood, Flatrock-Haw, and Upper East Fork White River Watersheds

Introduction

The fundamental objective of this report is to assess historical and future public water utility use, with water withdrawals serving as a proxy for demand. Using the water demand data compilation and forecasts, we incorporate them into an assessment of historical and future water availability. It is important to emphasize that while our primary lens focuses on water utilities, to accomplish this evaluation necessitates a broader perspective on all water-use sectors. This comprehensive approach ensures an integrated understanding of water demand and availability in the region.

Central to this approach is understanding all the factors that concurrently influence water demand and availability. The region has its own unique characteristics, which are very different from the urban metropolitan region to the west. In the Southeast-Central Indiana region, the largest water-use sector is public water supply. Rural and agricultural land uses dominate the private sector water uses, and public water utilities support a wide range of water-use sectors. The physiography and geologic history of the region govern the distribution of groundwater aquifers, the primary water source in the study area. Economic growth drives baseline demand, while the effects of climate influence seasonal peak demands and strain utility operations.

However, the intersection of water demand and availability is not solely defined by these driving forces. Aspects of natural and anthropogenic water quality are linked to its consequent usability – possibly limiting availability. Further, water conservation and the pursuit of efficiency are potential pathways to balance demand sustainably. Throughout this report, the interaction of these factors will be highlighted, shedding light on their collective influence and interdependence.

The focus of this study lies within Southeast-Central Indiana, encompassing three 8-digit Hydrologic Unit Code (NHD, https://www.usgs.gov/national-hydrography/national-hydrography-dataset) watersheds (Figure 1): the Driftwood (05120204; 1165 sq mi), the Flatrock-Haw (05120205; 600 sq mi), and the Upper East Fork White River (05120206; 800 sq mi).

The Southeast-Central Indiana region is typified by a wide range of transitional and gradational landscapes. The western edge of the region is highly urbanized with Indianapolis, Greenwood, Franklin, and Columbus development modifying the land cover and hydrology. Northern, eastern, and southern portions of the region are rural, dotted with small communities and development along transportation corridors, such as I-74, I-65, US 40, and US 52. Cultivated crops dominate the land use and land cover away from the urban areas. Dairy cows, pigs, and poultry are raised in some of the highest densities in the state in Concentrated Animal Feeding Operations (CAFOs), and these operations are regulated along with other industrial and commercial facilities.

Study Objectives

This study is an analysis of water-resource use, demand, and availability from 1985 through 2075 in eight Central Indiana counties (Figure 1): Bartholomew, Decatur, Hancock, Henry, Jackson, Johnson, Rush, and Shelby. The primary objective is to identify key trends and challenges concerning water availability and demand in the region for public water utilities.

The various analyses presented in this report span different time periods, each dictated by the datasets employed:

1. **Water Demand Analysis (Historical):** This analysis leverages water-use data sourced from the Indiana Department of Natural Resources, Division of Water, Significant Water Withdrawal Facility (SWWF) database. The period covered by this database spans from 1985 to 2021.
2. **Water Demand Analysis (Future):** For projecting public utility future water demand, the report looks ahead to the years 2022 through 2075. The projections are rooted in a variety of estimates and model outputs, each detailed in their respective sections later in the report.
3. **Climate-Driven Water Balance Analysis:** Both the future water demand and availability analyses are underpinned by water-balance model output, which is discussed in additional detail later in the report. This model is influenced by variables from a CMIP5 global climate model (CanESM2; Chylek et al., 2011). The timeframe for this climate-driven analysis overlaps a historical water-balance model based on observations (1985-2021; Letsinger et al., 2021) and extends it from 2022 to 2075.
4. **Water Availability Analysis (Historical):** The foundation for this analysis is a subbasin water inventory including water withdrawals as well as data on water returned to the basins by utilities, industrial users, and select animal operations. This information is available through the NPDES (U.S. EPA, ECHO database). This dataset starts in 2007 and extends through 2021.
5. **Water Availability Analysis (Future):** The future scope for the water-availability analysis covers the period of 2022 through 2075, consistent with the future water-demand analysis timeframe.
6. **Factors that Affect Water Availability:** Risks and threats to the water supply including water quality concerns are discussed. Finally, opportunities for water conservation in several water-use sectors are reviewed.

The report begins with a brief overview of the characteristics that define the region and follows with presentation of the water demand and availability analyses as outlined above.

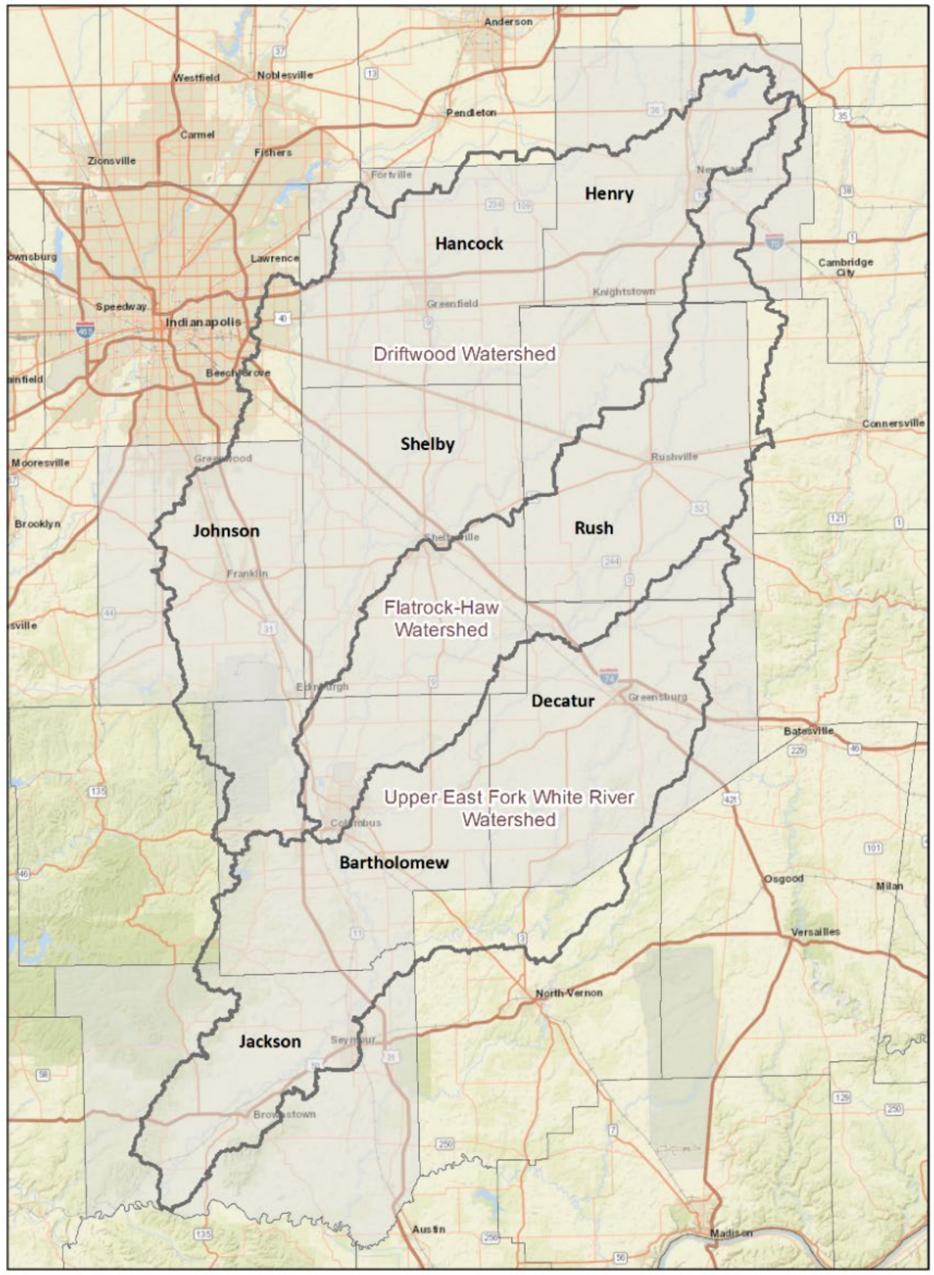


Figure 1. Extent of Southeast-Central Indiana Region considered in this study. The three watersheds include the Driftwood, Flatrock-Haw, and Upper East Fork White River. These watersheds encompass portions of Henry, Hancock, Rush, Shelby, Johnson, Decatur, Bartholomew, and Jackson Counties. Interstate-74 is the primary transportation route through the study area, extending from Indianapolis to the northwest through Shelby, Rush, and Decatur Counties to the southeast.

Regional Overview

Population Centers

The study area predominantly features agricultural lands interspersed with urban centers. The southeastern corner of Indianapolis, along the western edge of the Driftwood watershed, represents the largest urban area, housing a significant portion of its 887,642 residents. Notably, an estimated 70,000 people from the city reside within the study area (US Census, 2020, and Census Cartographic Boundaries).

The urban sprawl from Indianapolis reaches beyond the city limits, extending to towns like Greenwood and Fortville. Other major urban hubs within or predominantly in the study area include Columbus, Franklin, Greenfield, Greensburg, Seymour, and Shelbyville, among others. In addition, the region hosts numerous smaller towns and villages (Table 1).

Table 1. Population centers in Southeast-Central Indiana.

NAME	2020 pop	Sq miles	people/sq mi
Bargersville	9,560	18.7	511
Brownstown	3,025	1.6	1,887
Carthage	918	0.6	1,577
Clifford	205	0.1	2,330
Columbus	50,474	28.0	1,802
Cordry-Sweetwater Lakes	1,274	3.4	376
Cumberland	5,954	2.4	2,492
Edinburgh	4,435	3.1	1,412
Elizabethtown	406	0.3	1,556
Fortville	4,784	2.9	1,647
Franklin	25,313	13.0	1,945
Glenwood	245	0.2	1,392
Greenfield	23,448	13.7	1,713
Greensburg	12,312	9.3	1,322
Greenwood	63,830	27.9	2,287
Hartsville	317	0.3	975
Hope	2,099	0.9	2,212
Indianapolis city (balance)	887,642	368.0	2,412
Knightstown	2,140	1.0	2,054
Lewisville	337	0.3	1,311
Medora	635	0.3	1,918
Milroy	650	0.7	982
Morristown	1,205	2.5	480
Mount Summit	342	0.2	1,810
New Castle	17,396	7.4	2,358
New Palestine	2,743	1.7	1,576
New Whiteland	5,589	1.5	3,787
North Vernon	6,563	7.8	838
Prince's Lakes	1,372	1.5	903
Rushville	6,208	3.1	2,007
Scipio	308	1.2	264
Seymour	21,563	12.0	1,802
Shelbyville	20,067	11.6	1,723
Shirley	819	0.3	2,360
Spiceland	958	0.5	1,893
St. Paul	968	0.3	3,237
Taylorsville	512	1.1	481
Trafalgar	1,422	2.6	539
Vallonia	292	0.8	383
Waldron	805	1.3	641
Westport	1,393	1.3	1,046
Whiteland	4,599	4.6	999

Public Water Utilities

Forty-one public water utilities are located in the Southeast-Central Indiana region and vary widely in the area, population, and water-use sectors that they serve (Table 2). The water source for these utilities is dominantly groundwater, and the service-area (Figure 2) sizes range in extent largely based on whether self-supplied water from aquifers or surface-water intakes are well distributed and accessible. There are many examples of utility collaboration in the region, with some utilities purchasing water from other public water utilities on a regular or emergency basis.

Water-service areas vary by population served, but also vary based on the water availability owing to the distribution of geologic materials and proximity of residences and businesses to productive aquifers or to surface-water sources. Throughout this report, the importance of the last glacial boundary on the distribution of water-bearing sediments (aquifers) to water availability is emphasized. The water-service areas in the transitional zone around and south of the glacial boundary are larger because self-supplied water is not as available as to the north.

Table 2. Public water utilities in the Southeast-Central Indiana region. The utilities vary widely in the area and population they serve.

Utility Name	area sq mi	Pop Served	Density (people/sq mi)	Towns/places served by utility	Source/ *Purchased/ +Both
Anderson Township RSD	1	900	891	Milroy	GW
Bargersville Water Department	44	31,425	720	Bargersville, Providence	GW
Brown County Water Utility	292	13,882	48	Brown County	GW+
Carthage Town	1	1,000	1,858	Carthage	GW
Citizens Energy Group Water	596	836,630	1,403	Indianapolis, New Palestine	GW/SW
Columbus Municipal Utility	29	48,438	1,681	Columbus	GW
Cordry-Sweetwater Conservancy District	4	3,425	895	Cordry-Sweetwater Lakes	GW*
Decatur County Rural Water	88	3,440	39	Decatur County	GW/SW*
Eastern Bartholomew Water	163	13,547	83	Clifford, Elizabethtown, Hartsville, Taylorsville	GW+
Edinburgh Water Utility	3	4,480	1,468	Edinburgh	GW+
Fortville Water Works	4	6,940	1,786	Fortville	GW
Glenwood Water Works	0	305	1,311	Glenwood	GW
Greenfield Water Utility	15	23,000	1,586	Greenfield	GW
Greensburg Municipal Water Works	9	11,250	1,255	Greensburg	GW/SW
Hoosier Youth Challenge Academy	0	262	1,259	Facility	GW
Hope Water Department	1	2,113	1,924	Hope	GW*
Indiana American - Johnson County	36	80,518	2,233	Franklin, Greenwood, New Whiteland	GW
Indiana American - Seymour	13	19,160	1,528	Seymour	GW
Indiana American - Shelbyville	9	17,095	1,853	Shelbyville	GW+
Jackson County Water Utility	325	13,667	42	Brownstown, Vallonia	GW+
Jennings Water Inc	158	7,812	50	Tannersville, Butlerville	GW+

Utility Name	area sq mi	Pop Served	Density (people/sq mi)	Towns/places served by utility	Source/ *Purchased/ +Both
Knightstown Water Utility	1	2,182	1,743	Knightstown	GW
Lewisville Water Works	0	392	863	Lewisville	GW
Medora Water Department	0	873	2,508	Medora	GW+
Morristown Water Department	1	1,218	868	Morristown	GW
Mount Summit Water Utility	0	400	1,943	Mount Summit	GW
New Castle Water Works	10	19,880	1,935	New Castle	GW
NineStar Connect	0	66	353	Hancock County	GW+
NineStar GEM	8	1,500	179	Cumberland / Hancock County	GW
North Vernon Water Department	8	6,500	796	North Vernon	SW
Prince’s Lakes Water & Sewage Utility	36	4,095	114	Prince's Lakes, Nineveh	GW
Rushville City Utility	3	6,800	2,074	Rushville	GW
Shirley Municipal Water	0	960	2,658	Shirley	GW
Southwestern Bartholomew	61	8,652	141	Ogilville, Bethany	GW*
Spiceland Municipal Water Utility	1	969	648	Spiceland	GW+
St. Paul Municipal Water	0	1,096	3,274	St. Paul	GW
Sugar Creek Utilities - Riley Village (NineStar)	0	137	512	Hancock County	GW
Trafalgar Water Department	1	1,277	1,317	Trafalgar	GW*
Waldron Conservancy District	0	800	2,631	Waldron	GW
Westport Water Company	1	1,598	1,094	Westport	SW+
Whiteland Water Works	3	5,045	1,692	Whiteland	GW*

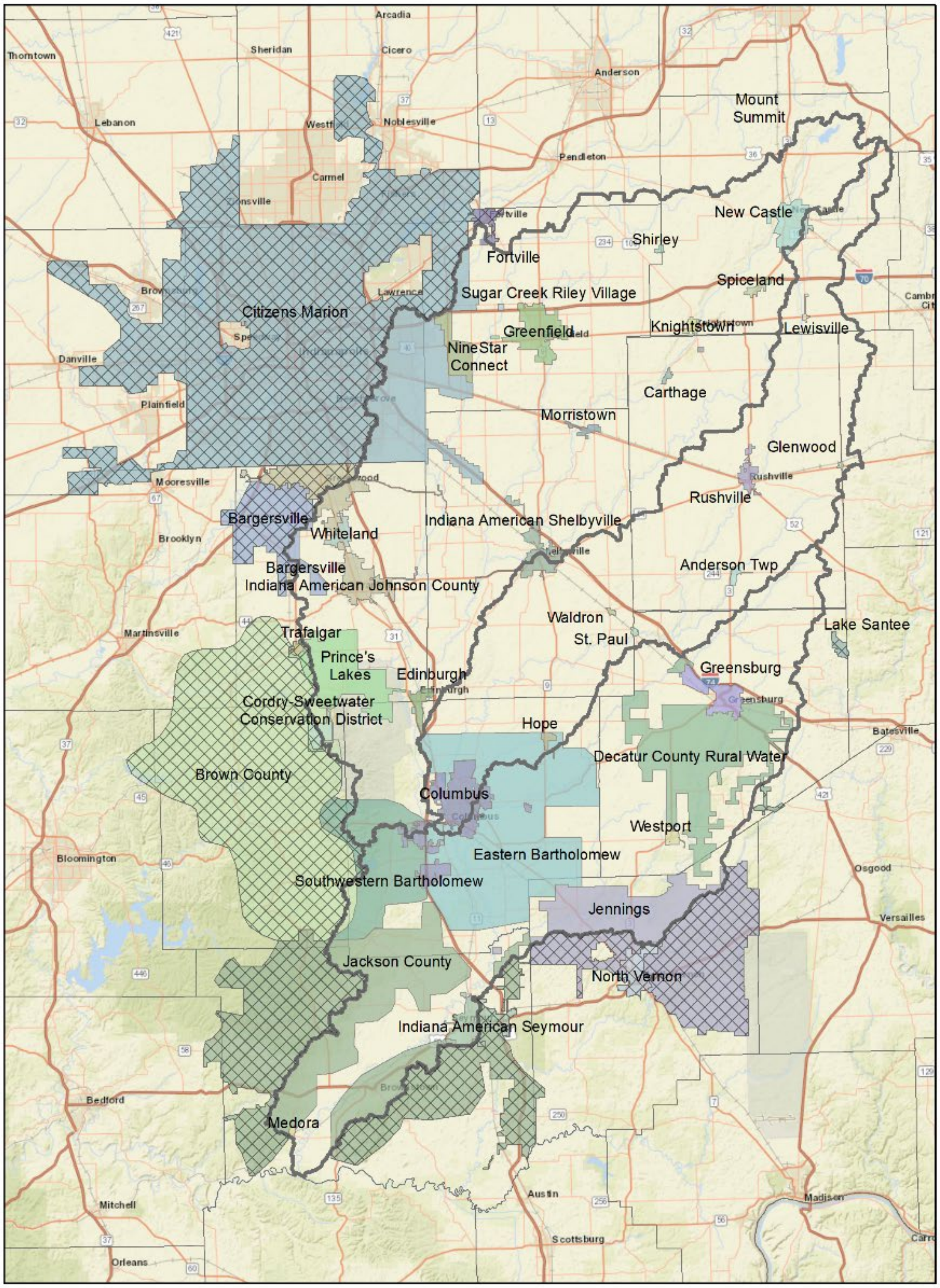


Figure 2. Community public water systems (utilities) in and around the South-Central Indiana Region. Most are supplied by groundwater. Several communities share water resources through regular or emergency purchase agreements. Many of these utilities straddle the study watersheds and were considered if most of their service area is contained within the watershed boundaries. Examples where most of the service area is outside include Brown County Water Utility and Jennings Water, Inc. The service areas were updated from an original dataset from the IURC (2014).

There are several water-use sectors in the region. The public-water use sector is not only the largest component of water use, but utilities also support many of the sectors that are often self-supplied in other parts of the state (e.g., industrial and animal agriculture). Additional information on these sectors, including estimates of current and future demand, are presented later in the report (see Water Demand Forecasts – Public Water Utilities). Figure 3 shows the locations of the largest water users in the region.

Industry

A number of industries are present within the study area, including a variety of manufacturing operations, quarries, and retail businesses. Stone quarries and sand and gravel operations dominate this sector. For non-mining (e.g., manufacturing) industrial water use, there are more public-supply industrial facilities than self-supplied.

Quarries

There are several crushed limestone and sand/gravel aggregate quarries in the region, with major quarrying operations occurring in the central portions of the study area. Shelby Materials is one of the sand and gravel operations, with plants to the north of Shelbyville and Edinburgh. Other quarry operations include New Point Stone Company in St. Paul, Rush County Stone Company near Milroy, Heritage Aggregates southeast of Columbus, and US Aggregates and Ward Stone LLC, both north of Hope.

Cultivated Crops and Animal Agriculture

Many of the farms that grow cultivated crops in the portion of the study area located between Edinburgh and Seymour (along the Driftwood and East Fork White Rivers) irrigate their fields during the growing season using groundwater wells. There are also hundreds of Animal Feeding Operations (CFOs, CAFOs) where pigs, chickens, dairy cows, and other livestock are raised (IDEM, 2022).

Power Generation

Although energy production is a dominant water-use sector in Indiana, there is only one energy production power plant, located in the northern reaches of the study area and operated by Duke Energy (Henry County Peak Plant). Historically there were several other coal-fired power generation plants in the study area that used a significant amount of cooling water, but the majority of these plants have either closed or transitioned to less-water-intensive power generation such as natural gas or renewable energy (EIA, 2022).

CFO vs CAFO

Farms in Indiana that exceed specific thresholds for the number of confined livestock are regulated under the Confined Feeding Control Law (IDEM, 2023). Whether a farm is considered a Confined Feeding Operation (CFO) or a Concentrated Animal Feeding Operation (CAFO) depends on the size of the farm. CAFOs are subject to additional permitting requirements under Indiana law. Both types of operations are referred to as CAFOs throughout this report.

CFO

A Confined Feeding Operation is any farm that has more than 300 cattle, 600 pigs or sheep, 30,000 poultry (chickens, turkeys, or ducks), or 500 horses.

CAFO

A Concentrated Animal Feeding Operation follows the US EPA definition of a 'large CAFO' which is a farm with more than 700 dairy cows, 1,000 beef cattle, 2,500 adult pigs, 10,000 adolescent swine, 500 horses, 10,000 sheep, 55,000 turkeys, or between 30,000 and 125,000 chickens (depending on the type of chicken and manure handling system employed).

Before being approved, CFOs and CAFOs are subject to a permitting process and inspections of associated buildings and manure storage structures. IDEM regulates nutrient management, storm water runoff from manure applied to fields, setback distances, and facility design.

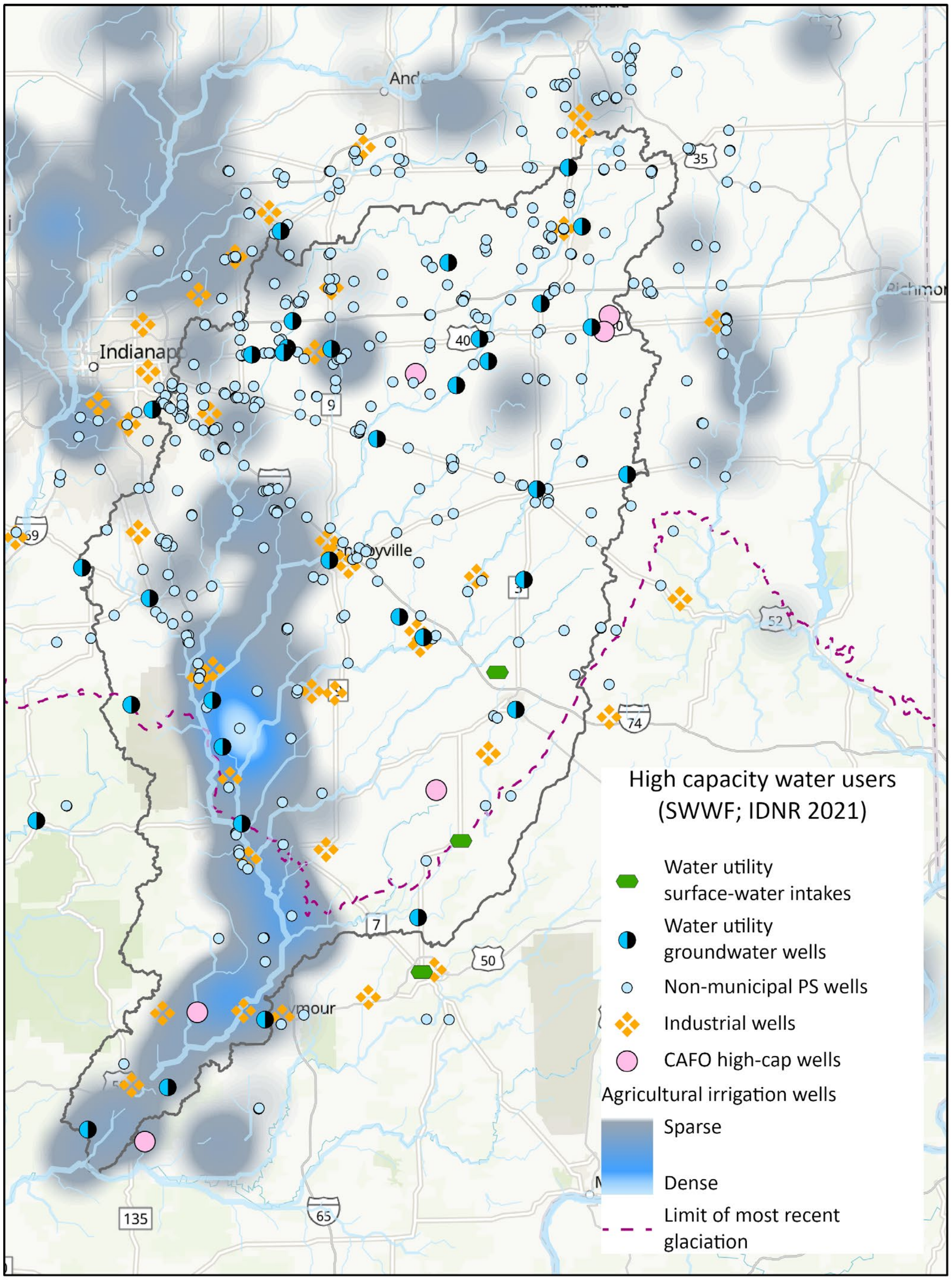


Figure 3. High-capacity water users (also called “significant water withdrawal facilities”) in and around the Southeast-Central Indiana region. Irrigation withdrawals along the East Fork White River are shown as a density heat map so that other uses can also be reviewed. Water utility well and intake locations have been generalized. Indiana Department of Natural Resources (IDNR) Significant Water Withdrawal Facilities (SWWF) database (2021).

Land Cover / Use

The watersheds that comprise the study area are heavily dominated by agriculture. According to the 2021 National Land Cover Database (NLCD, 2021), nearly 73% of the study area is covered by either cultivated crops (~67%), or hay pastures (~6%), with another 14% having forested tree cover, and only around 11% having some level of urban development. Corn and soybeans are by far the most commonly cultivated crop in the area (NASS, 2021).

Climate

Indiana has a humid continental climate trending towards humid subtropical near the southern border of the state, and future projections under a range of climate-change scenarios include warming temperatures and increased, but seasonally redistributed, precipitation (Brettschneider, 2014; Widhalm et al., 2018; IPCC AR6 2021).

A dominant aspect of the Southeast-Central Indiana region is the seasonality of the climate. With climate change, the region is experiencing not only increasing temperatures (both during the day and night), but also increasing precipitation. Some areas are experiencing decreasing winter snowcover; which can, in turn, decrease groundwater recharge in upland areas distant from stream and river corridors. However, on the whole, the area is experiencing increasing precipitation. Because of the seasonality of the climate and also of the land use (i.e., dramatic differences in vegetation biomass because of cultivated crop agriculture), surface-water discharges, groundwater recharge, and groundwater baseflow (the portion of stream discharge contributed by groundwater) are highest in the winter and spring, and much lower in the summer and fall.

Rapid shifts between abundant moisture and drought conditions (flash drought; Lesinger and Tian, 2022) are becoming more common, causing challenges for public water utilities and agricultural producers that depend on consistent water availability (both in aquifers and soil moisture) to meet their missions (Fowler et al., 2022). The lowest natural seasonal water availability coincides with the highest water withdrawals from all water-use sectors. Understanding the factors that influence water demand and availability, as well as the historical and likely future ranges - *and timing* - of demand and availability are necessary to strategically plan for sustainable and resilient water utilities.

Temperature

The central portion of Indiana sees a notable fluctuation in temperature throughout the year. The average low and high temperatures for Indianapolis (used here as a proxy for the northern part of the study area) during 1990-2020 ranged from 20.9 °F in January to 85.2 °F in July. The annual average low temperature is 44.6 °F and the annual average high temperature is 62.9 °F (NWS, 2023). Even more extreme high average temperatures can be seen in the southern portion of the study area, such as Jackson County.

Precipitation

The midwestern United States is generally considered to be a fairly 'wet' part of the country, and the study area is no exception to this. The average annual rainfall for Indianapolis in the northwestern portion of the study area is nearly 44 inches, occurring mainly during the first half of the year. Indianapolis receives around 26 inches of snow annually on average, mostly occurring in December, January, February, and March. Although this area receives a significant amount of precipitation during part of the year, there is a history of seasonal droughts that tend to occur during the late summer and early fall months. While seasonal droughts do not happen every year, some major droughts of record (Figure 36) occurred during the latter parts of 1999 and 2012, among other years.

Flooding

Rivers, especially in the lower parts of the watersheds, have the capacity to experience periodic flood events. The intensity of these floods is enhanced by the significant amount of agricultural ground cover, which often include buried tile drains to increase drainage, resulting in increased runoff. The more extreme intensity and duration of precipitation events in recent years also contributes to increased runoff and increased annual groundwater recharge in lowland aquifers (Letsinger and Balberg, 2021). A notable flood in the recent past occurred in 2008 and affected portions of Columbus, Edinburgh, and Franklin (Morlock et al., 2008).

Geology

Unconsolidated Deposits

The boundary of the last glacial maximum (Pleistocene Wisconsin glaciation, Gray and Letsinger, 2011) crosses the southern third of the region, with unconsolidated glacial deposits to the north of the boundary and shallow bedrock with thin soil cover to the south. The region exhibits deposits from glaciation during both the recent Wisconsin glaciation and earlier glacial events (Gray and Letsinger, 2011).

The dominant unconsolidated deposit at the surface is clay-rich glacial till of the Huron-Erie Lobe, known locally as the Trafalgar Formation (IGS, 1989). Major river valleys contain silt, sand, and gravel alluvium as well as stratified drift deposits from glacial outwash. Additionally, the region has isolated, discontinuous sand and gravel lenses deposited on the till during the retreat of the Wisconsin glaciation.

The glacial deposits thin near the margins of the glacial limit, so counties such as Decatur do not exhibit the thick deposits mapped in the northern parts of the study area.

Bedrock

The subsurface in the study region features a succession of sedimentary rocks. Notable among these are the Muscatatuck Group, Borden Group, New Albany Shale, Louisville Limestone, Whitewater Formation, and Pleasant Mills Formation, with other minor constituents as documented by USGS Mineral Resources Data (MRData). These formations span ages from the Ordovician to the Mississippian period. Bedrock outcrops can occasionally be observed along the peripheries of watersheds, predominantly to the southwest, and in certain riverbeds. Karst development in limestones south and southwest of the study watersheds have modified the landscape to which the study area drains, with sinkholes and springs commonplace.

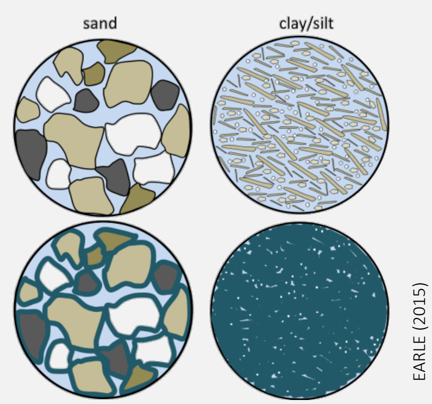
There is a regional geologic uplift structure known as the Cincinnati Arch located east of the study area (Figure 4, Collinson, et al., 1988; Nelson, 1995). This structure is comprised of Ordovician-aged sedimentary rocks that are nearest to the surface along the arch axis. To the west of the arch and underlying the study area, these Ordovician units dip downward and toward the Illinois Basin, becoming increasingly buried beneath Silurian and Devonian rocks.

Glacial Outwash Aquifers

Much of the groundwater pumped in the study area is drawn from aquifers located in glacial outwash deposits. These deposits are created when meltwater from a glacier concentrates coarse-grained sediment in a drainage corridor.

Modern rivers like the Flatrock, Driftwood, and White River tend to follow the same drainage networks created by the glaciers, though their current flow volumes are far less than they were during glacial recession.

Sand and gravel outwash generally has a porosity of around 30% and can yield 20-50 GPM for domestic wells and up to 1000 GPM for high-capacity wells (IDNR, 2011). The actual porosity and yield will vary depending on the sorting, compaction, grain size, angularity, and thickness of the sediment.



Outwash aquifers often do not have an impermeable clay layer protecting the groundwater, meaning they can be more susceptible to contamination from surface activities and are less resilient to drought conditions than confined aquifers.

In the northeastern portions of the study area there are thousands of exploratory wells that penetrate through the shallower Muscatatuck and Bainbridge Groups and into the underlying Ordovician rocks to access natural gas in the Trenton Limestone Formation. Over 1,300 natural gas wells are located in the study area, with most are within Decatur, Rush, and Shelby Counties (Figure 5). The wells have an average total depth of 912 feet, with individual well depths ranging from 395 to 1,800 feet.

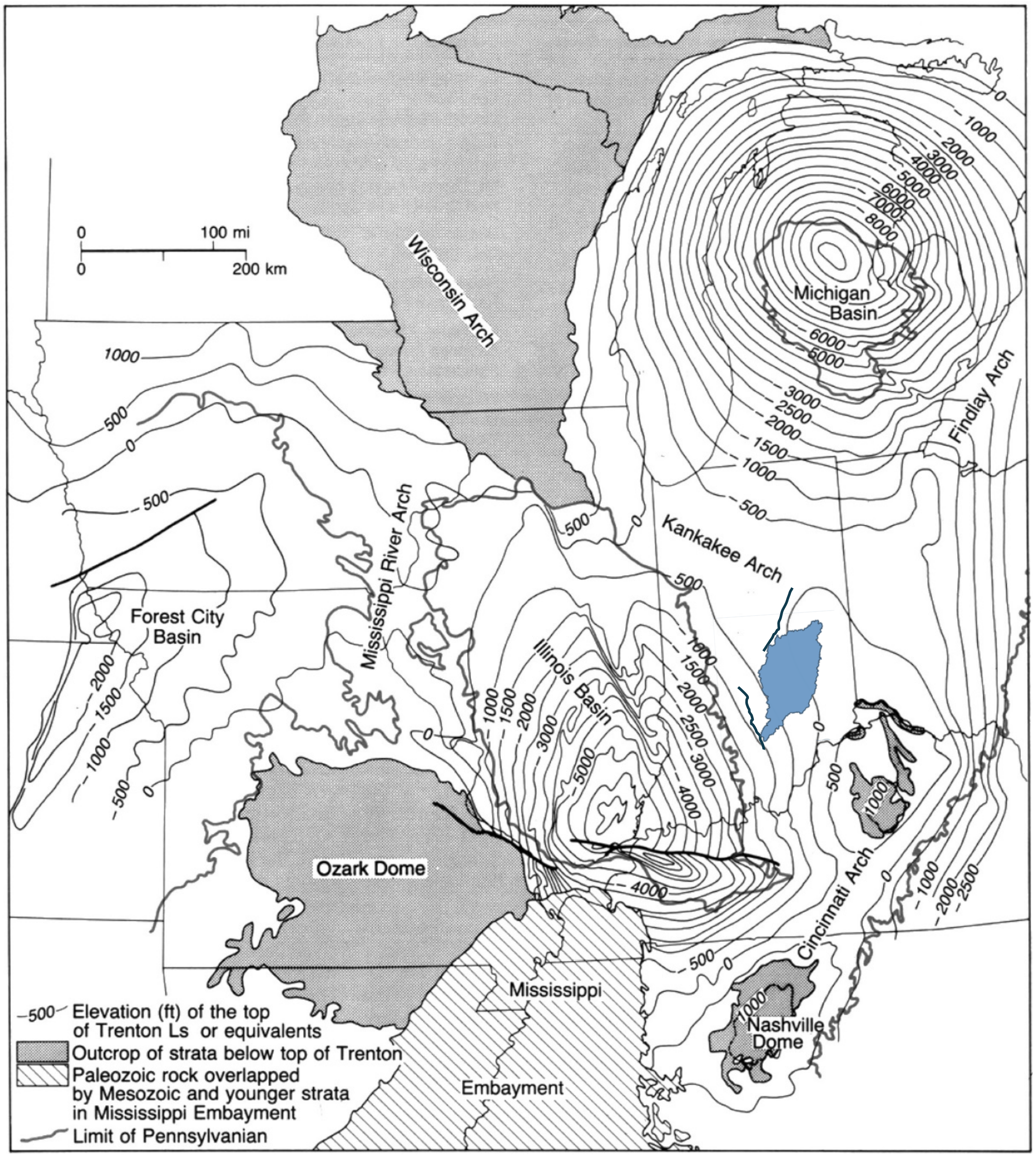


Figure 4. Map showing major structural features (faults, folds, domes, and basins) that control the exposure and depth of bedrock units in the Midwest U.S. The Southeast-Central Indiana region (watershed) boundary is also shown. The Cincinnati Arch to the east-southeast of the study area, and the Kankakee Arch to the north-northwest of the study area, are high-elevation subsurface features that control the direction and angle of bedrock strata in Indiana. Modified from Nelson (1995) and Collinson, et al. (1988).

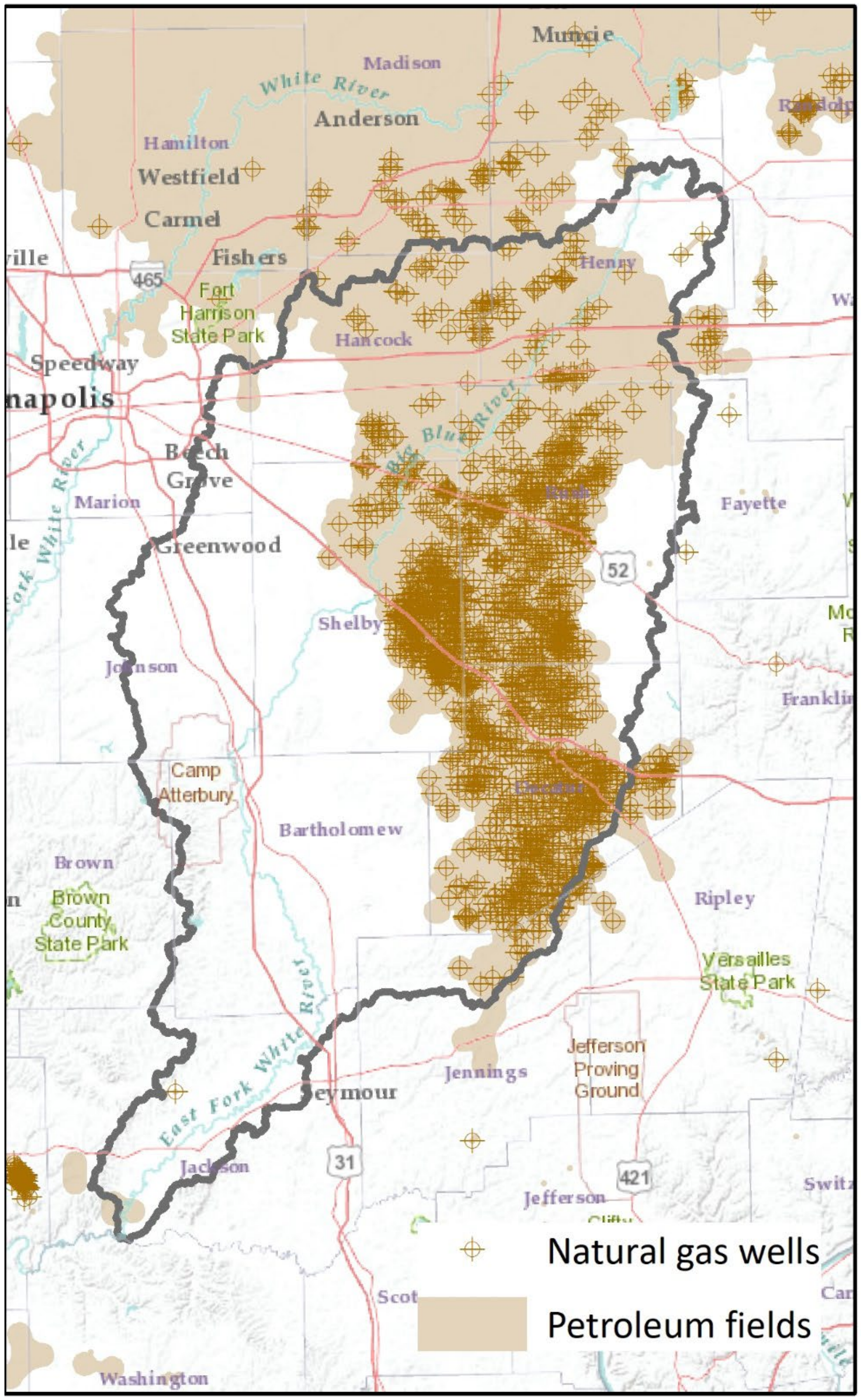


Figure 5. Over 1400 wells extract natural gas from the Trenton Limestone in the study area (Keller, 1998; Indiana Geological Survey, 2015). The Trenton Limestone lies far below where groundwater wells obtain water from bedrock aquifers.

Historical Water Sources

Rivers

The study area encompasses a network of waterways, including branches of the White River, the Flatrock River, the Big Blue River, Haw Creek, Sugar Creek, and other minor tributaries as detailed by the USGS National Hydrography Dataset (NHD). Originating predominantly from the northeast, these waterways traverse the region and converge into the East Fork of the White River. This river is a significant tributary to the White River, which subsequently flows into the Wabash River. Reaches of the Big Blue River, Driftwood River, Flatrock River, and East Fork of the White River have some of the most mobile channel-migration rates of streams in Indiana (Robinson, 2013).

Aquifers

The study area is underlain by three principal aquifer types: near-surface unconsolidated glacial outwash deposits, intratill sand and gravel aquifers (often of limited extent), and bedrock aquifers. The distribution, storage, and usage of these aquifers are closely tied to the Wisconsin glacial limit, which bisects the study region. To the north of this boundary, the primary water sources are the higher-yielding unconsolidated glacial deposits, accommodating the needs of municipalities and numerous self-supplied residential wells. In contrast, to the south of the glacial limit, bedrock aquifers dominate. However, the generally lower yields of bedrock aquifers have influenced water-supply strategies. Specifically, utility water service areas in the north tend to be more compact and localized, centered around communities, whereas in the south, they are expansive—often spanning entire counties—to ensure water distribution to the rural population with fewer options for self-supplied residential water.

The unconsolidated and bedrock aquifers supply the water accessed for all water-use sectors in the region. Surface-water (streams, rivers, and impoundments) are used at much lower rates than in the Southeast-Central Indiana region. The groundwater stored in aquifers is recharged with water received from precipitation (rain or snow) that infiltrates into the subsurface after other elements of the water cycle are met. The depth, geometry, and grain size govern the storage characteristics of each aquifer, as do groundwater withdrawals from those aquifers or adjacent aquifers to which they are hydrologically connected.

Outwash Aquifers

Hydrogeologically important glacial outwash deposits line and underly most of the streams and rivers in the study area, providing abundant water resources for both public water supply and irrigation. These outwash deposits generally have a yield of 20-50 GPM for domestic wells and up to 1000 GPM for high-capacity production wells (IDNR, 2011). The lack of a confining clay layer protecting these outwash deposits make them more susceptible to contamination from surface activities and less resilient to drought conditions than buried intratill aquifers.

Intratill Aquifers

Many of the aquifers that are serving as water sources for public-water-supply utilities and self-served users in the study area are buried sand and gravel deposits, many of which are discontinuous (Soller et al., 2012). In the Southeast-Central Indiana region, these are described by the IDNR as “intratill” aquifers (IDNR, 2011), meaning they are composed of coarser sediment deposited between two layers of clay-rich glacial till. They tend to be relatively thin (~5-20 ft; IDNR, 2011) and located away from the main river valleys. Often these intratill aquifers are noted as being locally or regionally discontinuous, suggesting that they are not connected to the outwash valleys and groundwater drainage networks in the region.

Unlike outwash aquifers, intratill aquifers are covered by a layer of clay which can protect the aquifer from pollution, but also limits the rate at which precipitation can infiltrate as recharge. There are some utilities in the study area with wells experiencing drawdown and silting due to overpumping (according to various Preliminary Engineering Reports). The thickness of the overlying confining clay layer is highly variable and can range from just a few feet to more than 100 feet (IGS, 2002). Many of the discontinuous intratill aquifers are along the flanks and upper reaches of subbasins in the study area, and wells drilled into this sediment typically only have the capacity to yield 10 GPM (IDNR, 2011).

Bedrock Aquifers

Portions of the study area utilize wells that tap into bedrock aquifers as their primary water source. This is generally the case when outwash and intratill aquifers are not locally available, or when fractured bedrock such as limestone (or sometimes shale or siltstone) exists close to the surface. These shallow bedrock aquifers are very limited in yield, and communities that access these aquifers generally need additional water sources (e.g., river water) and storage options. Deeper bedrock aquifers in the Silurian-Devonian Carbonate Aquifer System have the potential for further exploration, but are not currently widely utilized as a water source.

Water demand

In water-utility operations, most planning is done to support baseline (minimum annual) water use centered around demand in units of Million Gallons per Day (MGD). Infrastructure design (source water, distribution, and treatment) needs to support both baseline water usage for a wide range of customer needs, but also peak demands (maximum daily use) that occur regularly (i.e., more water usage during warm seasons) and under more unexpected emergency conditions (e.g., fire response).

On an aggregated basis, the study area uses a total of 74 MGD, with the public supply sector dominating the use of water in the region (43.5 MGD in 2020). Irrigation is a seasonal water use and accesses water from groundwater aquifers, whereas industrial uses pump more surface water and operate year around. Figure 6 presents the total water demand for all sectors in the Southeast-Central Indiana region. Embedded within the public-supply sector numbers is additional water supplied for industrial and rural (CAFO) uses. Most water used in this region is consumptive, which will be discussed in additional detail later in the report.

Shown for comparison in Figure 6 is the estimated future water demand for all sectors in 2070. As a preview of the public-sector demand results, Table 3 presents the average and maximum daily public water supply (utility) withdrawals in MGD for 2020 (observed) and 2070 (projected). Details of the future demand forecast are presented later in the report.

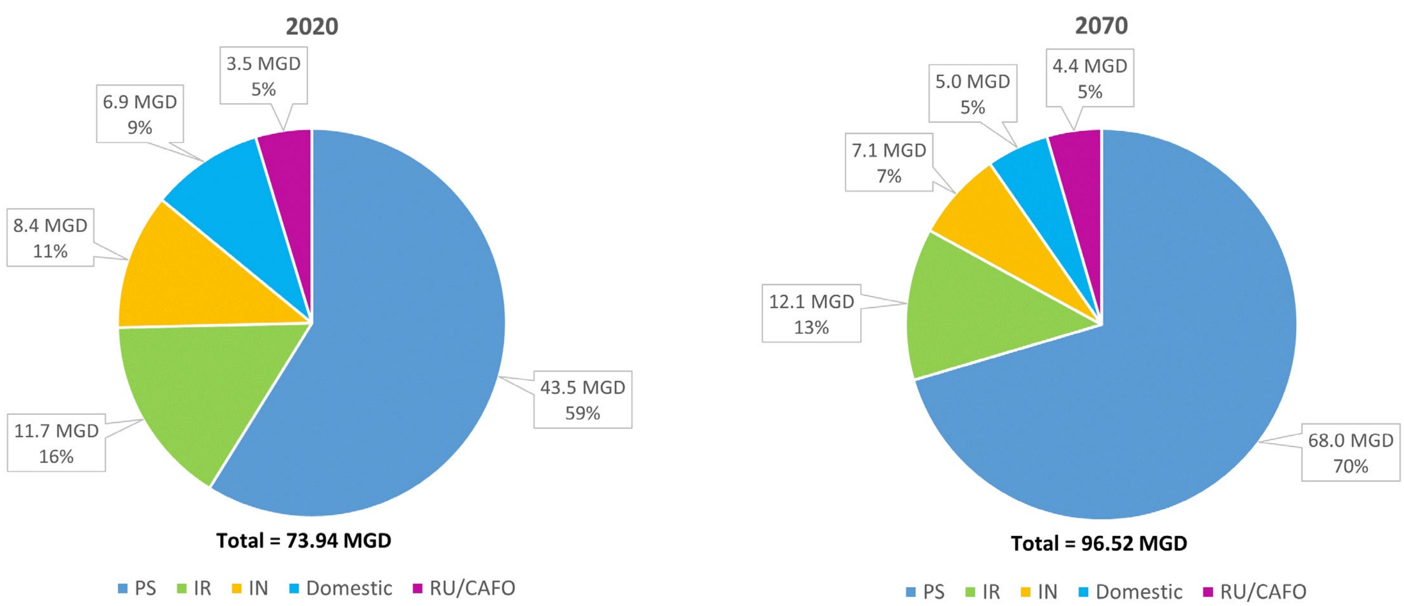


Figure 6. Reported and estimated water withdrawals in 2020 totaled 73.94 MGD, dominated by public water utility demand. In the 2070 projection, the dominant demand is again in the public-supply sector. The projection, which totals 96.52 MGD, includes additional residential customers in expanded public water utility service areas, as well as estimated increases in publicly-supplied industrial uses in Bartholomew, Decatur, and Jackson Counties as indicated in their Preliminary Engineering Reports. A commensurate decline in the self-supplied residential ("Domestic") population is shown. Irrigation demand is projected to increase under warmer summers assuming the same agricultural area is irrigated in the future. Using estimates from county planning documents, most industrial and livestock (CAFO) operations are projected to stay at similar water-use rates for this forecast, increasing at a rate of 5% per 20 years (0.25%/year). Monthly industrial demand was based on 2017 to 2021 data, a period in which some reported industrial water withdrawals declined (or ceased); therefore, the total 2070 industrial demand shows a possible decline.

Table 3. Average and maximum daily public water supply (utility) withdrawals in MGD for 2020 (observed) and 2070 (projected).

County	2020 PS Withdrawals MGD (Ave day)	2070 PS Withdrawals MGD (Ave day)	Diff MGD (Ave day)	% Diff	2020 PS Withdrawals MGD (Max day)	2070 PS Withdrawals MGD (Max day)	Diff MGD (Ave day)	% Diff
Bartholomew	9.0	19.0	+10.0	111%	11.8	23.1	+11.3	96%
Decatur	2.6	5.2	+2.6	100%	2.8	5.5	+2.7	96%
Hancock	3.6	5.4	+1.8	50%	4.5	5.9	+1.4	31%
Henry	2.6	3.5	+0.9	35%	2.8	3.6	+0.8	29%
Jackson	3.8	5.4	+1.6	42%	4.4	5.9	+1.5	34%
Johnson	12.8	22.3	+9.5	74%	15.3	28.9	+13.6	89%
Rush	0.8	0.9	+0.1	13%	0.9	0.9	0	0%
Shelby	3.6	6.7	+3.1	86%	4.3	6.9	+2.6	61%

Historical Water Use

In this study, historical water demand for municipal water utilities was assessed through the examination of monthly water-withdrawals reported in the Indiana Department of Natural Resources, Division of Water, Significant Water Withdrawal Facility (SWWF) database covering withdrawals spanning from 1985-2021. Although water demand is closely related to water withdrawals, there are times when pumping alone is insufficient to describe demand. A limited number of years of additional data were incorporated into the demand analysis from the Indiana Department of Environmental Management, Drinking Water Branch, archive of Monthly Report of Operations (MRO) documents submitted by utilities each month. These reports record daily volumes of water processed by treatment plants. The number of MRO records that could be used was limited by their format in the reporting and archive platform; the reports are scanned images of handwritten and typed forms, and extracting data from them is a manual process. Each utility usually submits a separate report for each treatment plant, so extracting the data for even a single utility is a laborious process.

The data recorded in MROs and the SWWF database often align quite well with one another (aggregated at monthly intervals); but the granularity of the daily data in the MRO documents are valuable for understanding peak flows, as well as often providing information on water flows related to pumping from storage or operational maintenance. MRO data was accessed specifically for drought years when utility water-withdrawal records from the SWWF recorded a decline in source-water pumping during the summer or known drought events. There are a number of reasons that declines occur when actual "demand" is highest. Summer demand experienced by water utilities is usually highest because of seasonal outdoor water-use such as residential lawn and garden irrigation. If a drought episode is severe enough, lawns can go dormant, or garden losses might negate the need to irrigate. Water-use restrictions (voluntary or mandatory) can also cause a reduction in demand. However, there are cases where the source water, such as river flow, is inadequate for pumping and the utility must switch to another source, or to withdrawing from storage.

The figures and tables below present the current water demand in the Southeast-Central Indiana region in a variety of ways to illustrate the water sources, water-use sectors, locations, and even the seasonality of water use. Figure 7 is a Sankey diagram showing the flow of water from source to end use. The two parts of a Sankey diagram are nodes that can be thought of as bars in a traditional bar chart where the height of the bar is the magnitude of the value, in this case water volume in millions of gallons (MG). Connecting the nodes are links, which can be used to trace the flow of water from the source to the use to visualize the proportions of water. The key above Figure 7 guides the interpretation of the figure, and it can be used as a guide in the subsequent Sankey diagrams that present additional details of the water demand. Figure 7 shows surface and groundwater sources use by water-use sectors including:

- public utility water suppliers (PS)
- industrial users (IN)
- agricultural and turf irrigation (IR)
- energy production (EP)
- rural uses such as large CAFO farms (RU)

The right side of the figure shows the county withdrawals. Tracing the flows, the figure illustrates the dominant use of groundwater as a water source, the large proportion of public water utility extractions, a smaller proportion of industrial, irrigation, and rural water uses, and which counties extract the most water. The counties are displayed in "flow order" meaning that they are arranged from north-to-south as the water flows through the stream network and groundwater-flow gradients in the region. Counties along the Driftwood and East Fork White Rivers utilize the most water (Shelby, Bartholomew, and Jackson Counties).

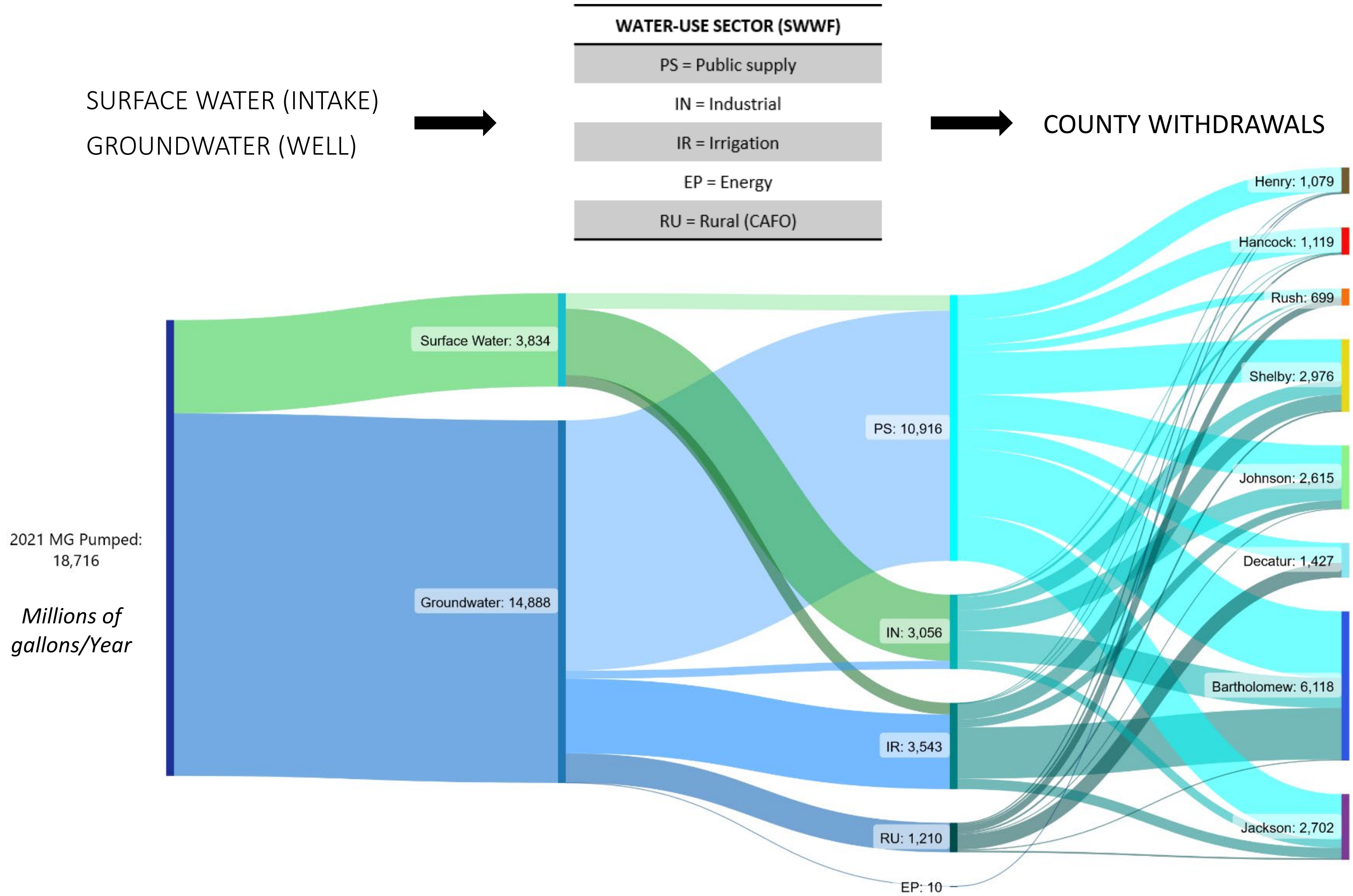


Figure 7. This figure is a Sankey diagram showing annual sector water use in counties by water source. Counties are shown in "flow order" meaning that they are arranged north-to-south as water flows through the Southeast-Central Indiana region. A key above the diagram guides the use of the diagram, tracing water sources to the left, through their water-use sectors, to locations of withdrawals (counties). Indiana Department of Natural Resources (IDNR) Significant Water Withdrawal Facilities (SWWF) database (2021)

Figure 8 is a more detailed and complex presentation of the same data presented in Figure 7, showing additional aquifer types used by the different water types and largely governed by the spatial distribution of aquifer materials and the proximity of communities, businesses, and farms to the water resources. Although maps of geologic materials will be presented later in the report, the diagram shows that the northern counties (Henry, Hancock, Rush) do not have access to the high-yielding glacial outwash aquifers that are located in the western and southern portions of the region. Communities in these three counties utilize buried sand and gravel aquifers of varying depths, thicknesses, and extents.

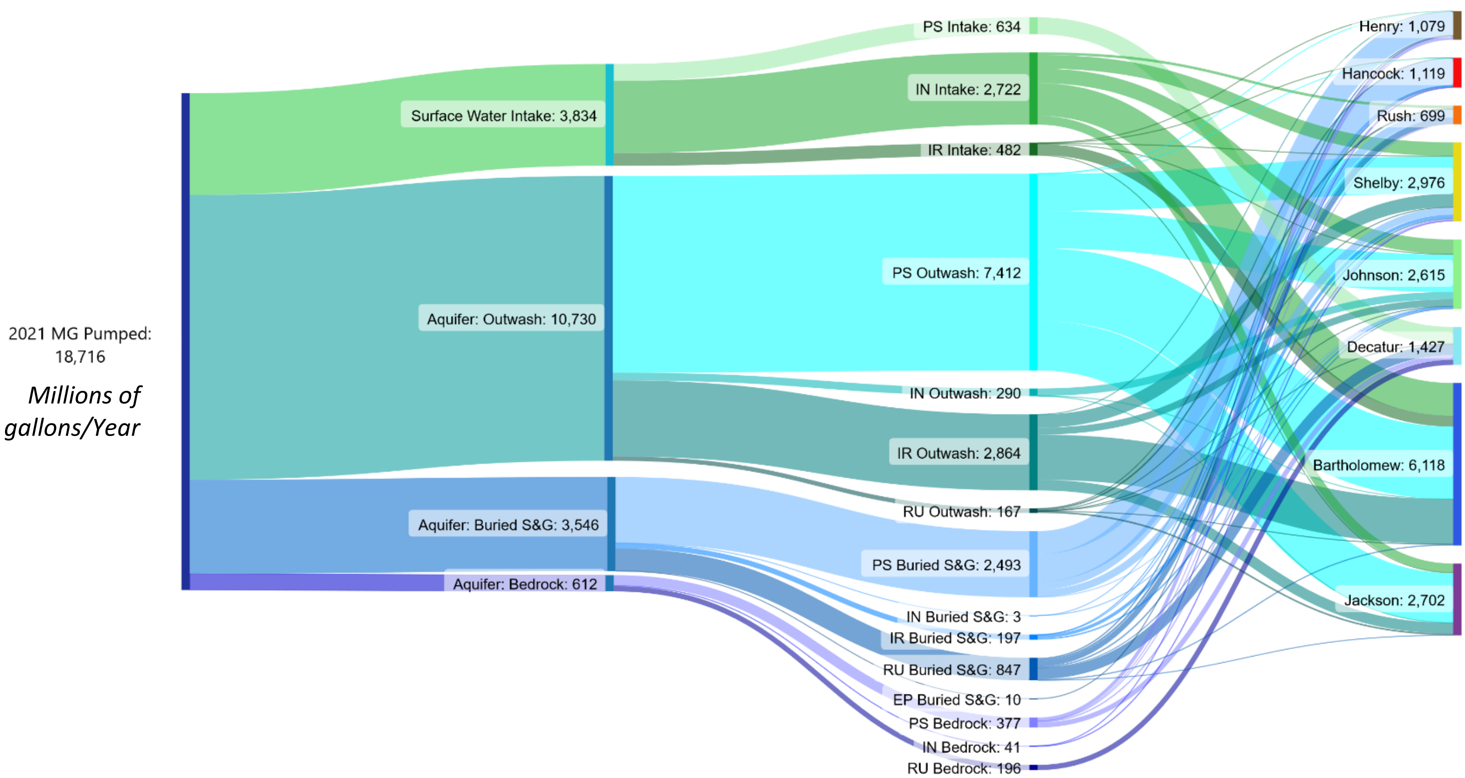


Figure 8. This figure is a Sankey diagram showing source water by intake or specific aquifer type, annual sector water use, and the location of the water use (county). Counties are shown in “flow order” meaning that they are arranged north-to-south as water flows through the Southeast-Central Indiana region. Indiana Department of Natural Resources (IDNR) Significant Water Withdrawal Facilities (SWWF) database (2021).

Public Water Supply

Looking in detail at the public water supply sector, a traditional bar chart (Figure 9) presents the source water used by the public water utilities in each county, with groundwater dominating the supply. Decatur County uses a blend of low-yielding bedrock aquifers along with surface-water intakes to meet their demand.

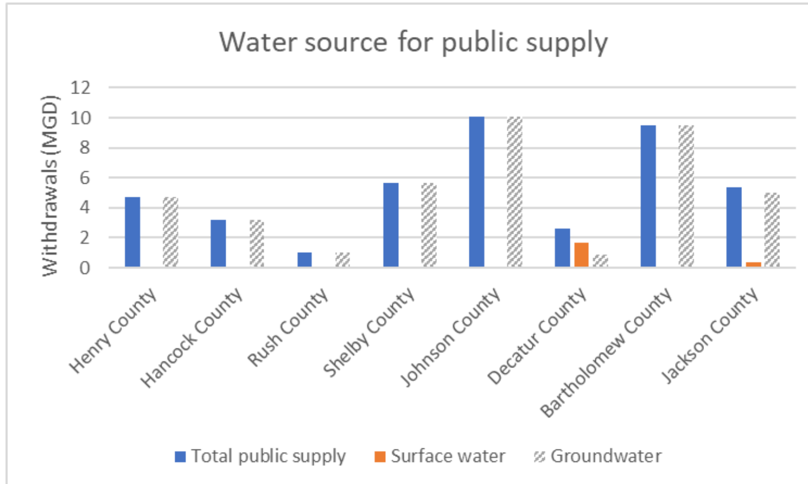


Figure 9. Groundwater is the dominant public water supply source in the Southeast-Central Indiana region. Only communities without access to high-yielding groundwater aquifers utilize surface water (streams, rivers) for public supply.

Figure 10 is a Sankey diagram that presents water use for the public supply sector along with the self-supplied residential ("domestic") sector and the proportion of the public utility demand in each season. The public utilities supply industrial and agricultural (livestock) water sectors in addition to residential users, so their year-around baseline (minimum) demand is fairly consistent across seasons. Additional information on peak demands is presented in Table 4 and Appendix D.

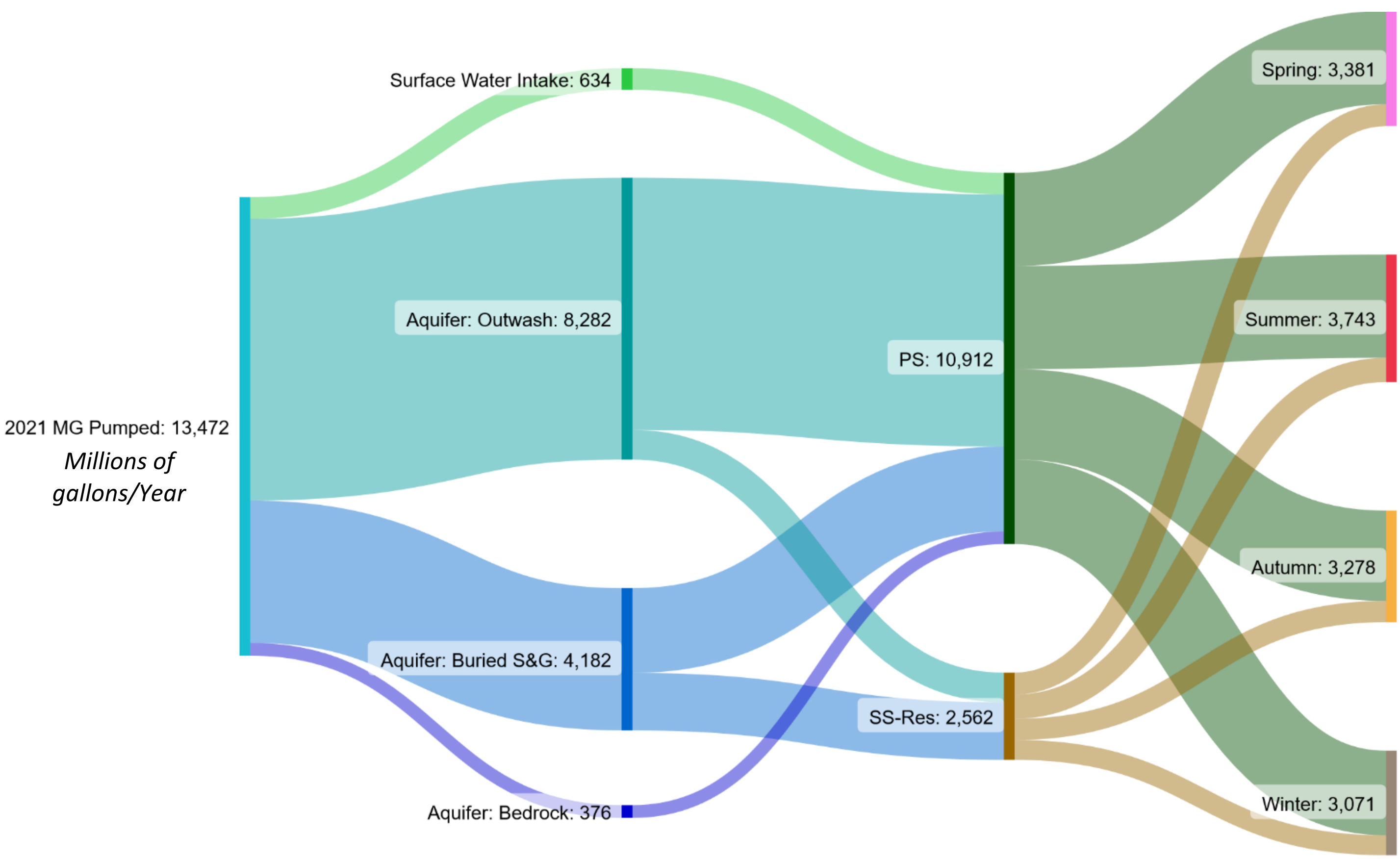


Figure 10. Sankey diagram showing the breakdown of source-water used for public supply (PS) and self-supplied residential (SS-Res) uses in the Southeast-Central Indiana region. The right side of the diagram shows the seasonal proportion of public and private water supplies, with an increase in water demand, as expected, in the summer (22% more than the baseline winter demand in 2021).

Table 4. Sampling of public-utility water withdrawal minimum and maximum demand (peaks) during daily operations as reported in data compiled from 2010, 2012, 2021, and 2022 from Monthly Reports of Operations (MROs) submitted to the Indiana Department of Environmental Management (IDEM) each month by water utilities. See Appendix D for monthly demand and peaking factors from the IDNR SWWF database (historical water use) and future public-supply demand models.

		LOWEST Daily Min Demand MGD	HIGHEST Daily Min Demand MGD	LOWEST Daily Max Demand (PEAK) MGD	HIGHEST Daily Max Demand (PEAK) MGD
	Bartholomew	1.40	1.74	1.61	2.22
	Decatur	1.22	1.53	1.82	3.38
	Hancock	1.34	1.69	1.34	3.77
DAILY	Henry	1.18	1.41	1.39	3.78
	Jackson	1.19	1.27	1.97	6.79
	Johnson	1.20	1.31	1.59	2.59
	Rush	1.21	1.51	2.41	3.18
	Shelby	1.18	1.32	1.56	2.89

Self-Supplied Residential (Domestic) Water Supply

Figure 11 presents the self-supplied residential ("domestic") water demand in the region. The smaller municipal public supply service areas to the north of the region are met with larger populations of residential water users providing their own water, almost exclusively through private groundwater wells (Table 5). Dieter et al. (2018) presents data reflecting that a small portion of rural residences obtain their water through public-supply deliveries, presumably because the hydrogeologic setting was insufficient to provide the needed quantities of water. Henry, Hancock, Rush, and Shelby Counties have significant proportions of self-supplied residential water users (Table 5 and Figure 11). Appendix A gives in-depth detail on the methods of estimating water use in this sector.

Table 5. Estimates of self-supplied residential water users are derived from the National Address Database (US DOT, NAD) point analysis by comparing to utility service areas to approximate the number of households. This number was multiplied by the average person per household in the county based on Census Tract data to estimate the number of people who remain unserved in each county. This number was then subtracted from county population to approximate the public-utility supplied residential population. See Appendix A for additional details on methodology.

County	County population (2020)	Public-supplied population	Estimated self-supplied residential population	2020 self-supplied residential water use (MGD)	% Self-supplied residential
Bartholomew	82,208	76,885	5,323	0.40	6%
Decatur	26,472	19,107	7,365	0.56	28%
Hancock	79,840	37,409	42,431	3.22	53%
Henry	48,914	27,965	20,949	1.59	43%
Jackson	46,428	36,863	9,565	0.72	21%
Johnson	161,765	14,7817	13,948	1.0	9%
Rush	16,752	7,361	9,391	0.71	56%
Shelby	45,055	22,968	22,087	1.68	49%
TOTAL	**507,434**	**376,375**	**131,059**	**9.96**	**26%**

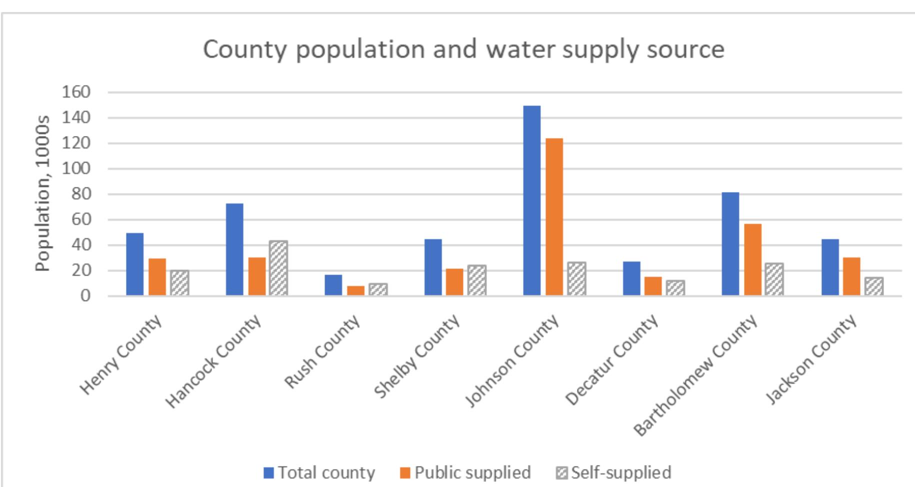


Figure 11. Proportion of each county (from north-to-south in the study area) supplied by public and self-supplied water sources.

Irrigation Water Supply

Figure 12 is a Sankey diagram that is specific to the irrigation water-use sector in the region. The sector is dominated by cultivated crop irrigation from the outwash aquifers along the Big Blue, Driftwood and East Fork White Rivers (Shelby, Bartholomew, and Jackson Counties), and that water is extracted almost exclusively during the dry summer and fall seasons. A smaller proportion of turf irrigation (i.e., golf courses, school athletic fields, common areas of suburban neighborhoods) occurs in the region and utilizes surface water intakes.

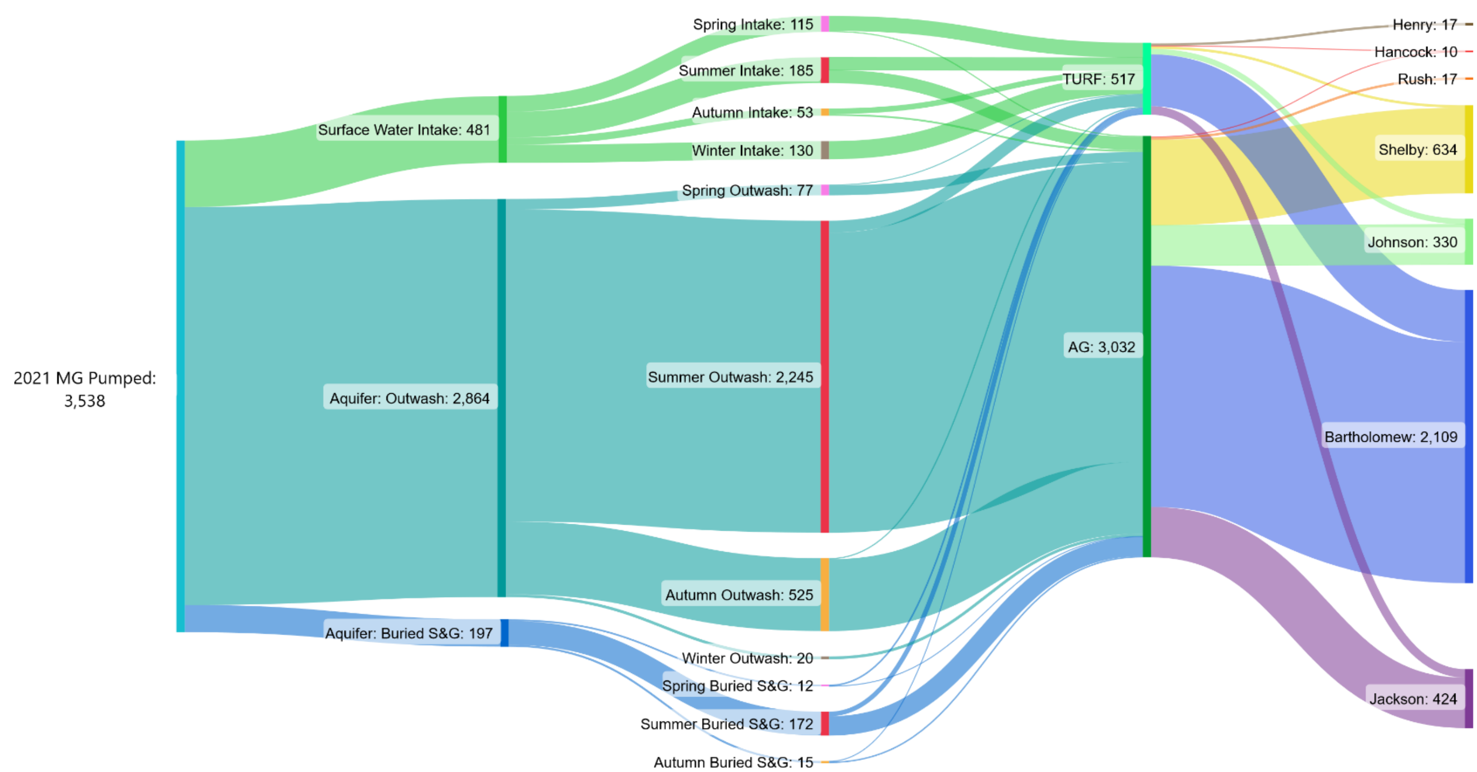


Figure 12. Sankey diagram showing the water sources (unconsolidated aquifers; there are no irrigation wells that draw from bedrock aquifers in the study area), dominance of summer and autumn irrigation in both agricultural (cultivated crops) and turf (golf courses and other non-agricultural) sectors, and the counties where the irrigation is occurring. In most cases, agricultural irrigators access aquifer resources directly beneath the fields that they irrigate. Because continuous aquifers do not extend uniformly throughout the Southeast-Central Indiana region, irrigated crops are often clustered along streams and rivers that are underlain by prolific glacial outwash aquifers (see Figure 29). There were no registered irrigation facilities in Decatur County in 2021.

Water Demand Forecasts – Public Water Utilities

This report focuses on municipal water utilities at the county scale, so demand forecasts were conducted by aggregating water withdrawals (as supplemented by reported water-treatment volumes when needed) for utilities in each of the eight counties in the Southeast-Central Indiana region.

Figure 13 through Figure 18 present many of the data sources important to the water-demand analysis.

Water-service areas (Figure 2), county boundaries, and hydrological features do not align neatly; therefore, for the water-demand portion of this study, the water-service area for each utility defined its county assignment.

The historical water use was tabulated for all of the municipal water utilities (and some larger facilities) and was used as the basis for forecasting future water withdrawals. Future water withdrawals were, in most cases, projected using a multiple regression analysis.

Figure 13. Map showing the regional study area. Additional detail can be seen in **Figure 1**.

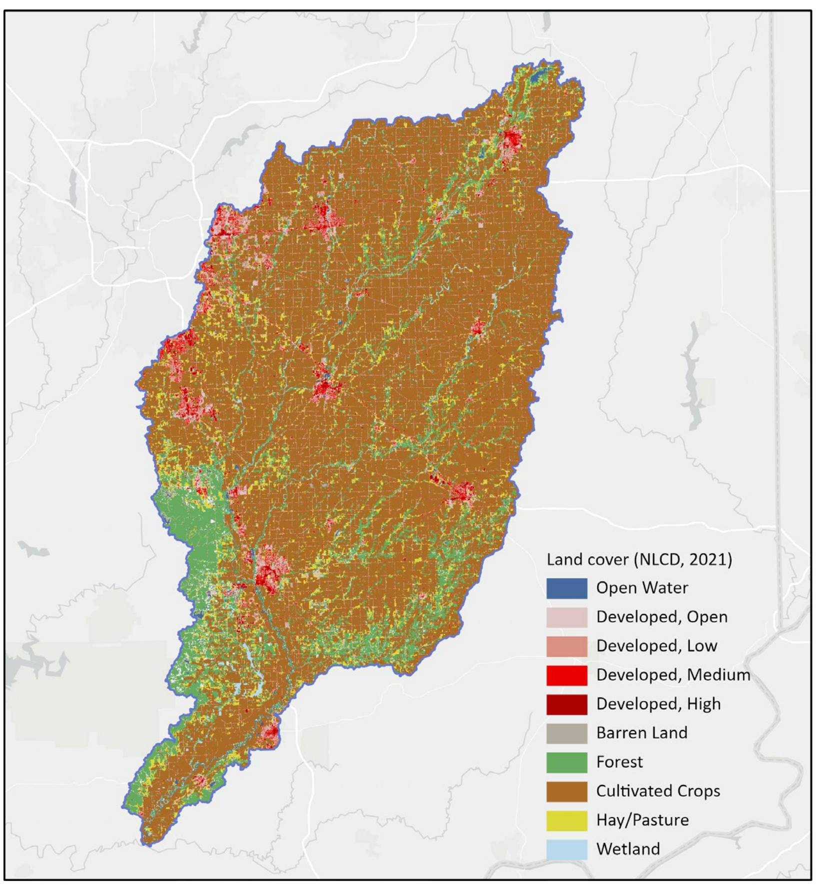


Figure 14. Map showing the land use and land cover in the study area. The region is dominated by agricultural land uses (i.e., cultivated crops). Urban ("developed") land uses characterize the eastern extent of the Indianapolis metropolitan region, as well as the municipal areas of the cities and towns in the region. Southern portions of the region are forested. Data from the National Land Cover Dataset (USGS NLCD, 2021).

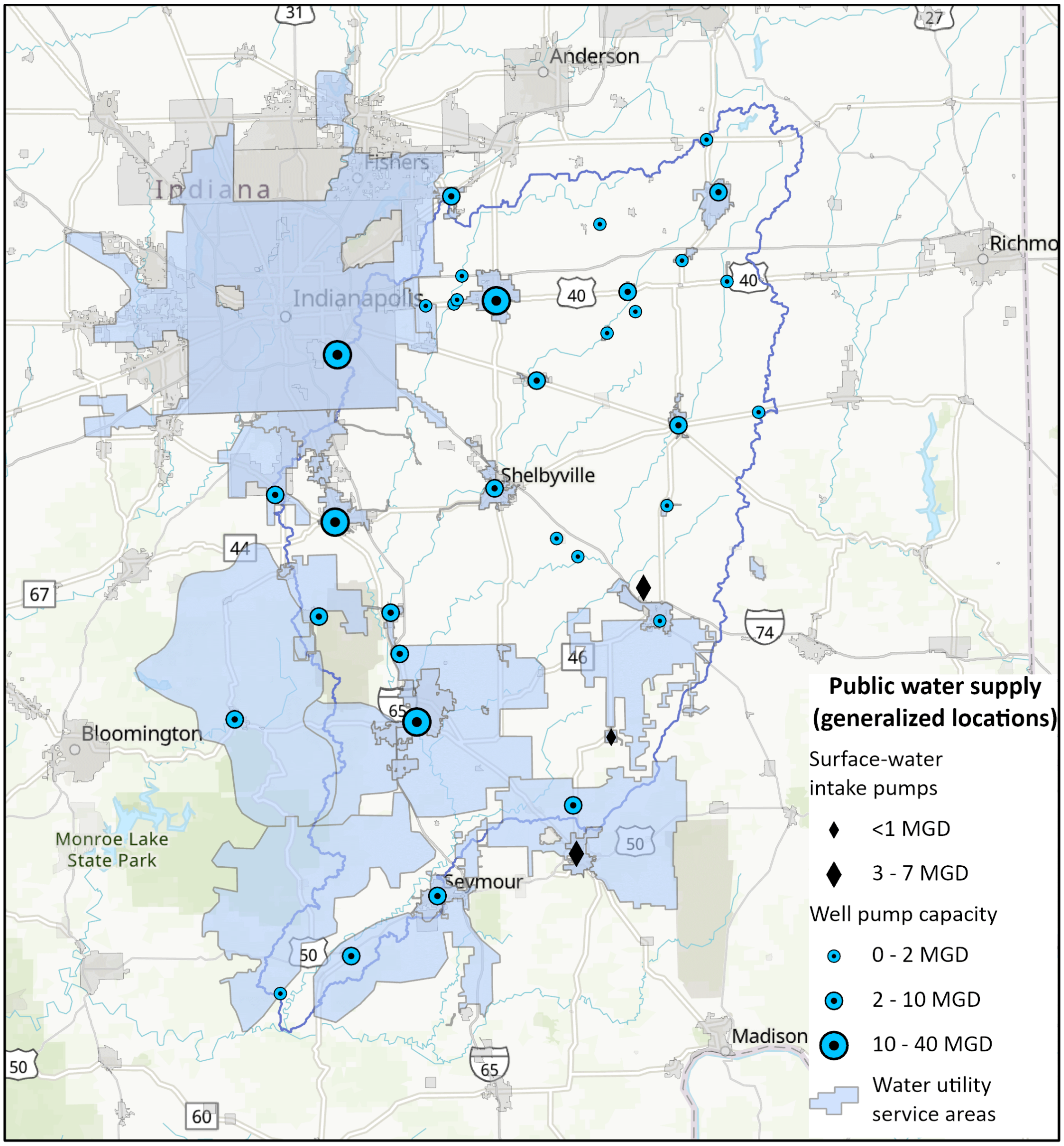


Figure 15. Public water utility service areas (updated from IURC, 2014) are shown along with generalized locations of well fields (IDNR SWWF, 2021). The size of the point is scaled by the total pump capacity of the utility, showing the locations of larger and smaller utilities. The pumping capacity of utilities is related to the population served (and in this region, other sectors such as industrial and agricultural sector customers), but can be limited by the yield of the type of aquifer that underlies the service area. Pump capacities for surface-water intakes in the study area range between 0.5 and 7.2 MGD.

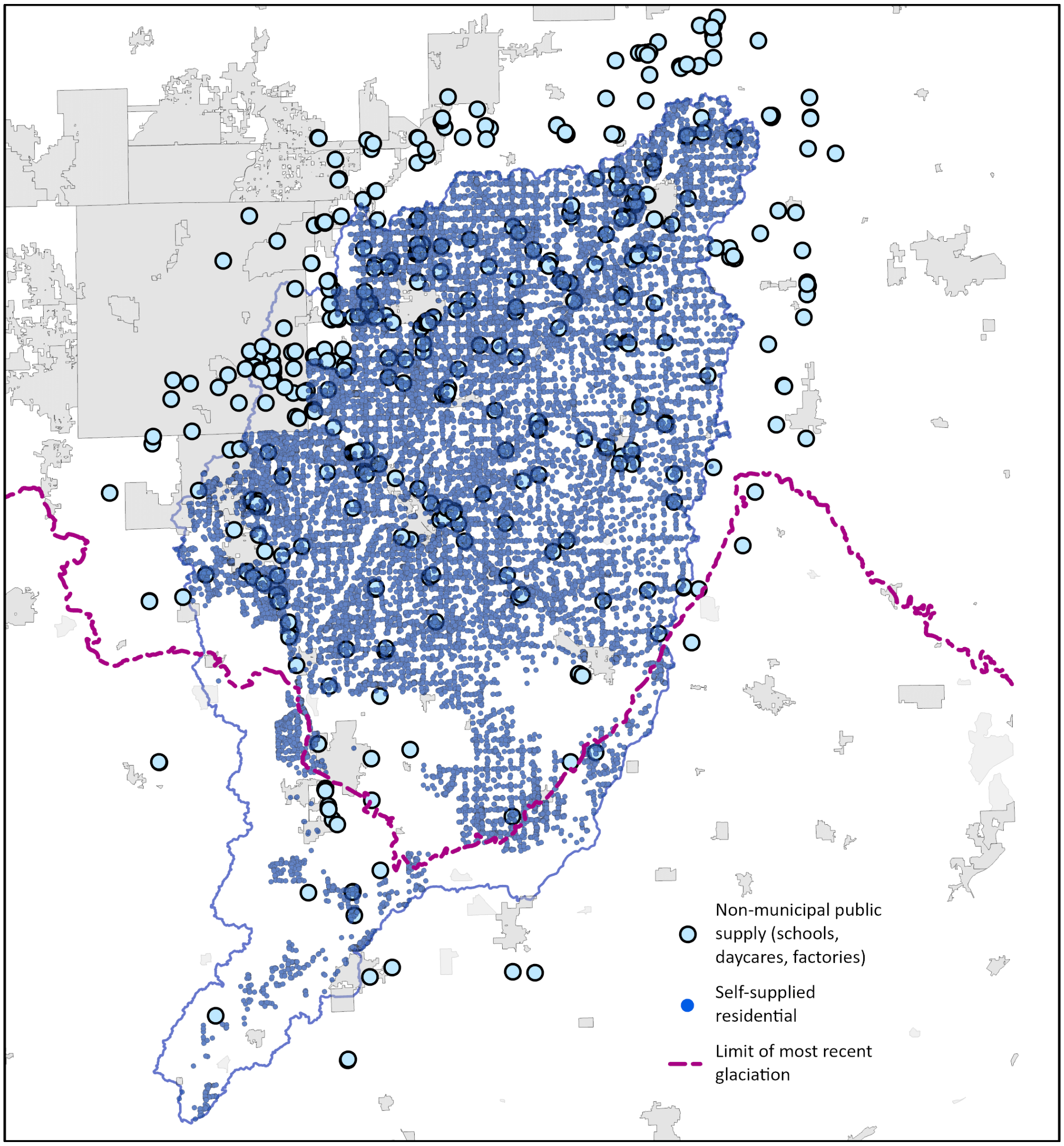


Figure 16. This map shows non-municipal (non-utility) water supplies. Non-utility public supplies, such as schools, daycares, and factories (IDNR SWWF, 2021) and self-supplied residential ("domestic") well locations (proxy used: National Address Database; USDOT, 2023) are shown. Note the lack of self-supplied water wells near and south of the glacial boundary where unconsolidated deposits are thin and aquifers have poor or insufficient yields.

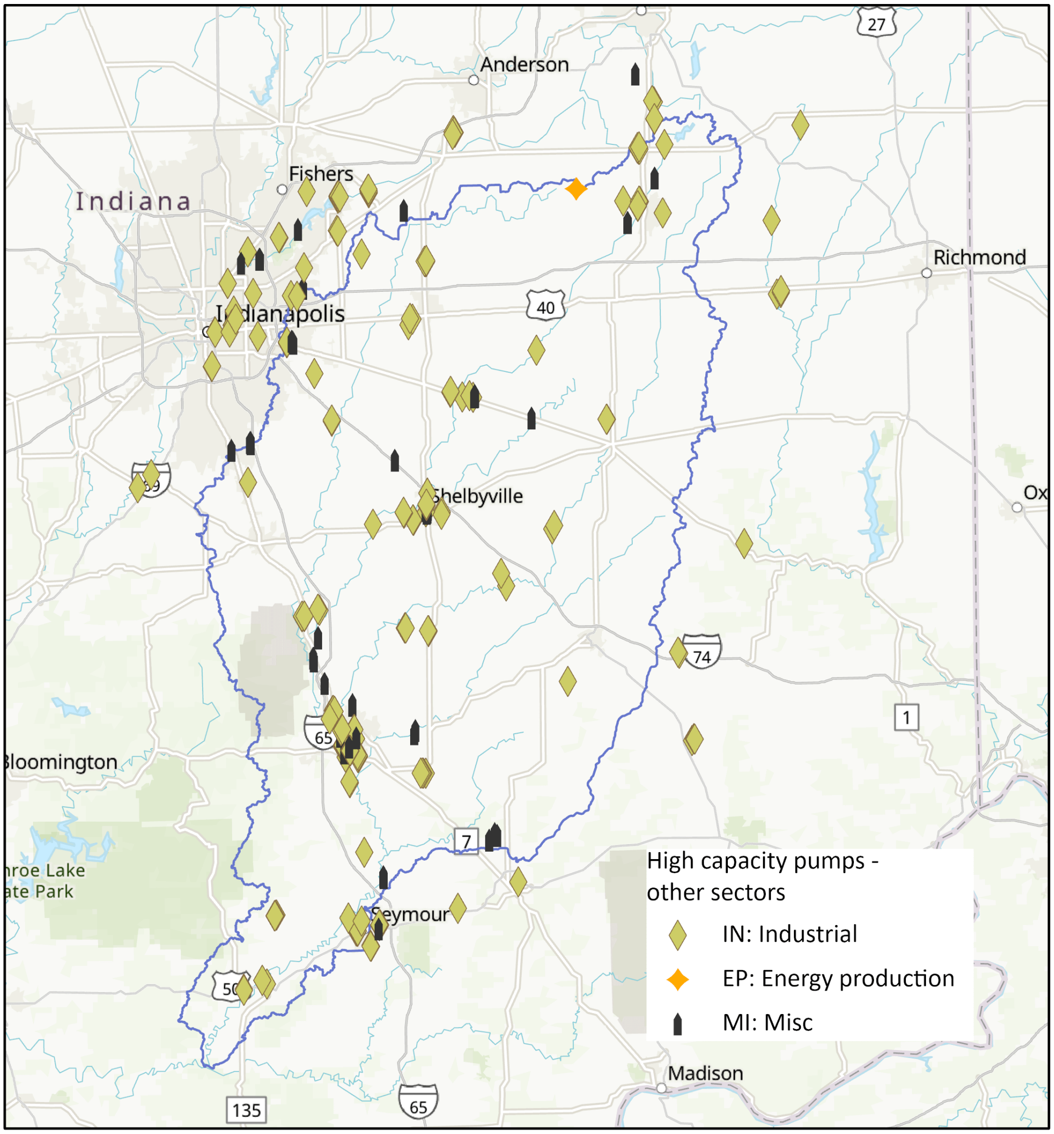


Figure 17. This map shows the distribution of self-supplied industrial, energy production, and miscellaneous water-use sectors in and around the study area (IDNR SWWF, 2021).

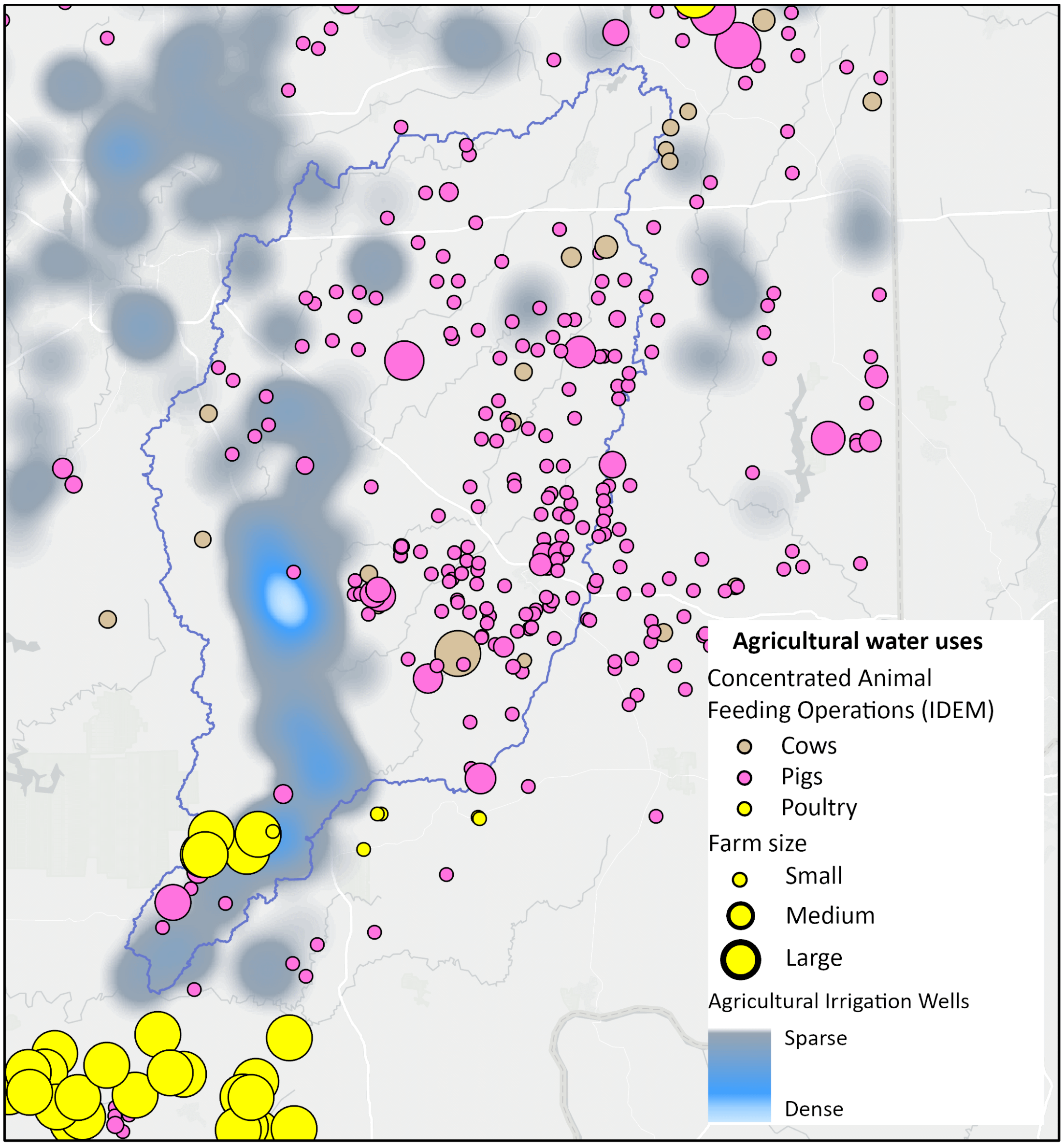


Figure 18. This map shows the water withdrawals from the agricultural sector. There are a large number of irrigation wells, shown in a heatmap format to illustrate sparse and dense areas of irrigation. The highest density of irrigation wells is in Bartholomew County, and wells withdraw water from near-surface glacial outwash aquifers along and under the East Fork of the White River. Also shown on this map are the locations of concentrated animal feeding operations (CAFOs) in the area. Operations housing dairy cows, pigs, and poultry (dominantly laying hens/egg farms) make Southeast-Central Indiana one of the highest-density livestock regions in the state.

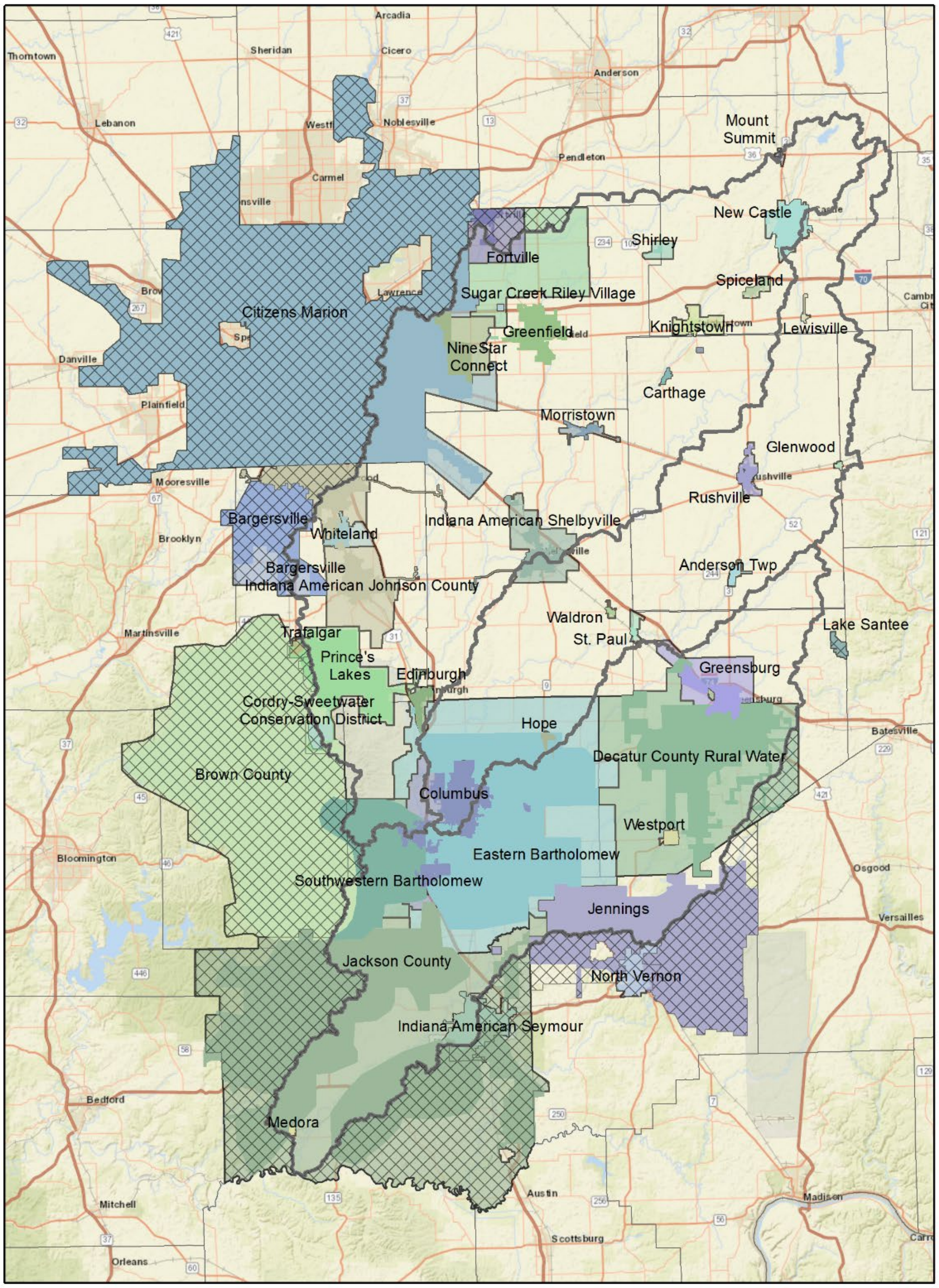


Figure 19. Future water utility service areas as projected by individual utilities or counties and reported in water planning documents, such as Preliminary Engineering Reports or county water plans. The current service area is shown in the background (darker solid fill; see Figure 2), so the reader can evaluate the extent of projected future public water distribution. The current service areas are also shown in Figure 2. See Appendix A for population projections in each county.

Multiple regression analyses rely on identifying statistically significant explanatory variables that describe the behavior of the dependent variable, which in this case was county-level public-utility water withdrawals. Methods described by Kiefer et al. (2013) and Maidment and Miaou (1985) provided guidance on possible drivers of a general trend for water-utility demand, as well as emphasis on describing seasonal demand fluctuations more tied to weather and climate variables. The variables used in attempting to decode the historical water-use patterns (model development) also need to be used in future projections (model application). Therefore, much consideration was given to the variables most likely to provide insights into not only general trends of future water use, but also the possible ranges of seasonal variability that drive peak demand and that utilities should consider for planning purposes.

Existing literature (Dziegielewski et al., 2002; Dziegielewski and Baumann, 2011; IFA, 2021; Kiefer et al., 2013; Maidment and Miaou, 1985) has pointed to trends in economic variables as consistent with general trends and fluctuations in baseline (i.e., non-seasonal or minimum) water demand. Following this guidance, for most of the public water supply models, a per capita monthly income (U.S. Bureau of Economic Analysis, Personal Income and Employment by Major Component [CAINC4]) corrected for inflation using the Consumer Price Index (U.S. Bureau of Labor Statistics, Consumer Price Index) defined the baseline trend. To forecast the baseline demand, a linear trend of the economic variable (per capita income) was extrapolated into the future. This linear trend accounted for the anticipated variations in baseline water demand attributed to economic growth, thereby providing insights into the overall trajectory of water utilization.

Most seasonal variability in regression or elasticity models developed for water utilities is focused on temperature and precipitation. Early attempts at describing the seasonal variability using only temperature and precipitation within multiple regression models were not successful. Therefore, additional climate variables were added to the model test variables, based on the knowledge that seasonal water demand is driven by outdoor water use, which is driven by an integrated concept known as atmospheric thirst.

Atmospheric thirst is potential evapotranspiration (PET), which is the amount of evaporation and plant transpiration that would occur if there was sufficient water to evaporate or transpire. Put another way, high temperatures and dry air can hold more moisture than cooler temperatures and humid air. If potential evapotranspiration values are high, the atmosphere can be thought of as “thirsty.” There is a difference, however, between potential (capacity) and actual (availability) evapotranspiration (AET). The difference between the two values can signal a water deficit (if AET is less than PET; Stephenson, 2003; Albano et al., 2022). Therefore, outdoor water use is likely more related to potential evapotranspiration than it is to temperature or precipitation alone. The details of the methods of preparing these variables for development and application of the water demand models is presented in the section .

Appendix C summarizes the regression model statistics and metrics used to project future water demand. The relative significance of the explanatory economic and climate variables differed across counties, as did their statistical significance. The section of the report entitled Public Water Utility Demand Results presents summaries of the demand models for each county (see also Table 6 and Table 7 for historical and future average public-supply demand, and Table 8 and Table 9 for historical and future peak public-supply demand).

In the eight counties for which models were developed, two demonstrated insensitivity to climate variables in characterizing seasonal demand variability. Due to challenges in creating models that fully captured water demand behavior in Henry and Rush counties, a generalized trend was chosen for their future water-use projections. The water-demand data could either reflect genuine trends or arise from artifacts of reporting of water use by utilities. This could stem from staff changes or inconsistent reporting practices. Given that these counties are predominantly rural with a high percentage of self-supplied water use, water utilities in these areas might not encounter a high level of summer outdoor water demand. In contrast, other counties, like Hancock, despite having a high proportion of self-supplied residential populations, exhibited strong correlations of climate variables with their seasonal water demand.

MORE INFORMATION

Soil Water Balance Model

To prepare variables of PET and AET (and measures of water deficits) for the regression model development and the use of those models to extend estimates of seasonal (i.e., peak) water demand into the future, the USGS Soil Water Balance Model v2 (SWB2; USGS; Westenbroek et al., 2018) was used to calculate a spatially continuous daily surface water-balance model for the region. The water balance for the historical observations (1985-2021; Letsinger et al., 2021) was extended in a new modeling effort for this study from 2022 to 2075. Estimates of future temperature, precipitation, and land use were needed to extend the model into the future. The global earth-surface climate model CanESM2 (Chylek et al., 2011) downscaled for regional application by Abatzoglou and Brown (2012) was used as the source of the future climate variables, while a modified version of the National Landcover Dataset (USGS NLCD, 2016; Letsinger et al., 2021) that incorporated future land-use changes as described in county and utility planning documents (see Figure 19 for mapped future water service areas) was used to describe the land cover.

While global climate models offer forecasts of temperature and precipitation spanning decades into the future, precipitation projections appear less verifiable compared to those for temperature. A common approach in utilizing outputs from global circulation models is the use of ensembles. These are averages derived from a collection of climate model outputs aimed at replicating historical statistics, such as mean temperature or precipitation levels.

However, while average values can provide insight into regional climate, achieving a statistical average similar to observed data can be accomplished in two distinct ways. The first method involves values that hover closely around the average, which when aggregated, converge to the statistical average. On the other hand, the alternative method is characterized by significant highs and lows that effectively offset each other, resulting in an average akin to observed values. In our study, delineating future climate variability was paramount to assisting water utilities in their peak demand planning.

When evaluating model ensembles for this project, despite their strength in representing mean states, we found that they fell short in capturing the true variability and extremes of known climatic events (e.g., the droughts of 1988 and 2012). These events, which may occur outside of historical norms, are critical for utilities to anticipate and plan for. While we acknowledge that relying on a single model, such as CanESM2, has its inherent limitations and may not capture the full breadth of possible futures, our intent is to provide a more detailed perspective on potential climatic extremes and variability (Mehan et al., 2019).

Further, we chose only one future scenario in the CanESM2 model suite, that of the high emission RCP8.5 (representative concentration pathway). This scenario in future climate models was intended to represent a very high baseline emission scenario representing "worst-case" conditions. Since these models have been tested and validated over the last decade, the high-emission scenario has been found to be consistent with the progression of climate change that we are currently observing (Knutti et al., 2010; Hausfather, 2019; IPCC, 2012, 2022; Ribes et al., 2021). Although how climate change will play out in the future is still unknown, this scenario is consistent with the observed conditions in the Southeast-Central Indiana region and is thought to be the best approach to preview likely future climate conditions.

Baseline versus Seasonal Demand Projections

Figure 20 illustrates the integration of a generalized baseline (minimum) water-demand trend informed by economic explanatory variables, along with the seasonal (peak) water demand driven by climate variables, into a comprehensive multiple regression model. In this case, the example is from Hancock County, Indiana, and the baseline (or minimum) water-demand trend is described by inflation-adjusted personal per capita income. When the baseline trend is removed, the seasonal water demand can be inspected (see Figure 20b).

A multiple regression model, by design, seeks to establish a linear trend using historical demand as a reference. Not every fluctuation in water withdrawal data will find representation within this model. Instead, the approach aims to offer insights into the foundational demand that water utilities might anticipate, alongside potential seasonal variability due to changing climate conditions that will drive peak demand. This example from Hancock County indicates that, based on historical consumption patterns, the projected baseline demand influenced by economic factors shows an increasing trend. The seasonal component of the model suggests that future seasonal variability is likely to mirror past seasonal minimums and peaks.

Inspection of the seasonal component of the model (Figure 20) offers a valuable perspective on how water demand might react to anticipated climatic shifts. Some consecutive years project baseline (i.e., minimum) demand values that appear elevated, suggesting a response to potential prolonged periods of arid conditions beyond typically observed annual seasonal variations. In the Hancock County water-demand model example, there is a gradually increasing trend in the seasonal water demand likely due to climate change (increasing temperatures and decreasing summer/fall precipitation in many years). The model forecasts that there will be an average demand increase of 0.1 MGD more in 2075 than 2023 due to climate change. Year-to-year seasonal demand variability is projected to continue to be responsive to prevailing weather conditions.

Many utilities that rely on groundwater aquifers have storage capacities equivalent to that of the one-day average water consumption for that utility. In contrast, those dependent on surface water maintain some reservoir storage to counteract potential low-flow scenarios. Several utility planning documents indicate a vulnerability to multi-year water-supply challenges stemming from extended droughts. Given the pronounced seasonal demand fluctuations observed in "normal" years within the region, and the possibility of back-to-back drought years under future temperature and precipitation scenarios, a reevaluation of both current and projected storage capacities by many utilities might prove necessary to address potential water supply challenges.

The model results shown in Figure 20 for Hancock County are summarized (along with the other counties in the study area) in Table 6 and Table 7 for historical and future average public-supply demand, and Table 8 and Table 9 for historical and future peak public-supply demand.

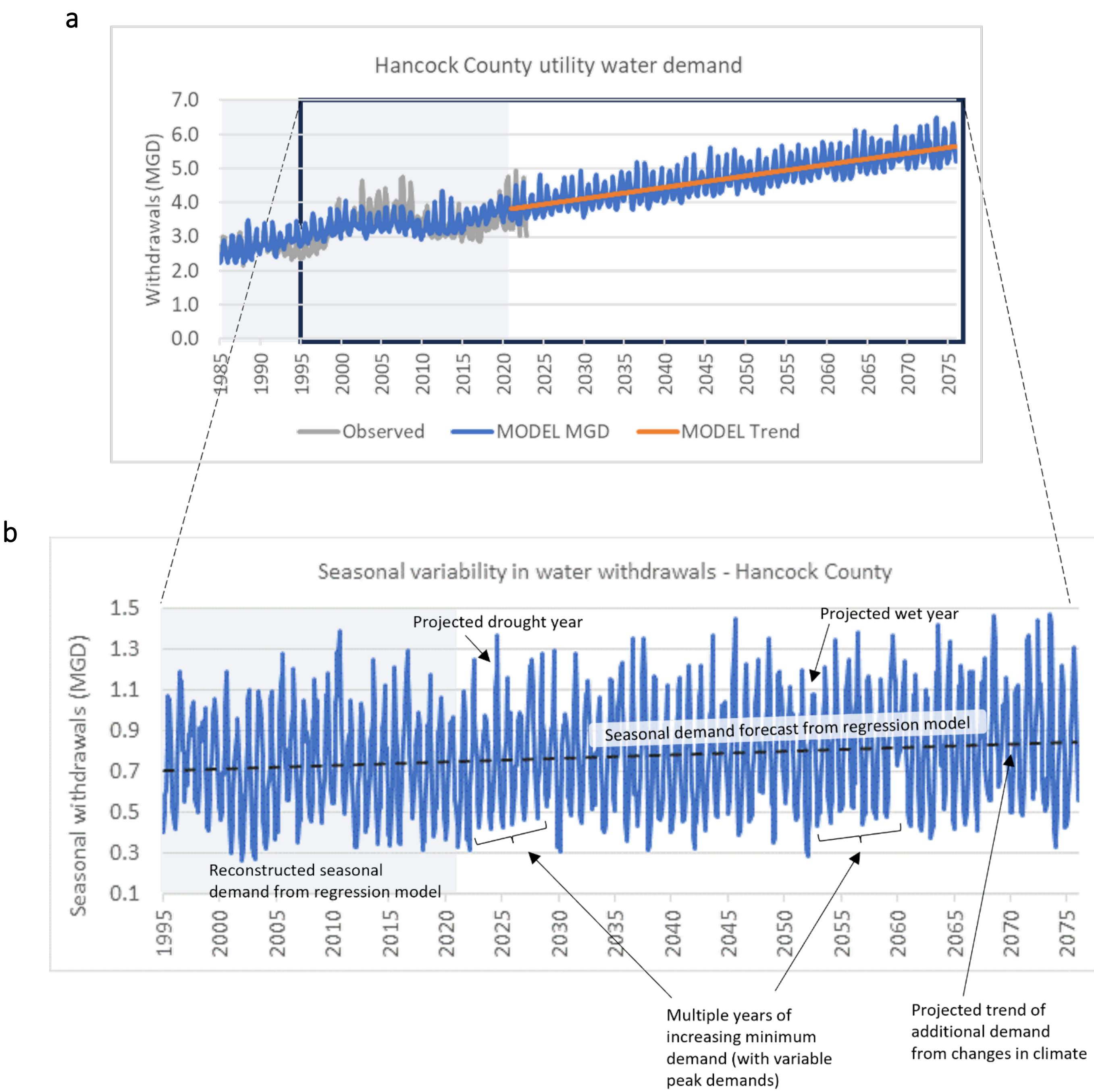


Figure 20. Example of public water utility demand model that attempts to capture the baseline (minimum) trend (usually based on economic variables) as well as the potential future seasonal variability (based on climate variables). Because the demand data are blended from multiple utilities in each county, the models are intended to capture the overall trend and reflect seasonal variability. A perfect model fit was not expected, nor obtained. The top panel shows the observed data (gray) upon which the model was based, along with the modeled water demand (blue). The bottom panel is a closer look at the range of seasonal variability that can be expected in the future because of temperature, precipitation, and atmospheric thirst. See Table 6 and Table 7 for historical and future (projected) average public-supply demand, and Table 8 and Table 9 for historical and future (projected) seasonal maximum (peak) public-supply demand.

Public Water Utility Demand Results

Table 6 and Table 7 present the county level historical and future demand projections for average expected day demand and Table 8 and Table 9 present the historical and future maximum day demand. Table 3 above presented percentage changes for demand in 2020 and projected for 2070, and Figure 21 below shows the results mapped by county. Please refer to Appendix D for county-level monthly average and maximum (peak) demand for 5-year increments between 1985 and 2075.

Public water utilities are estimated to experience a 56% increase in water demand in the next 50 years (44 MGD to 68 MGD). Between 30 and 90% of additional peak demand (from 1 MGD up to 23 MGD, depending on the customer base within the counties) in the dry summer months is projected by 2070.

Table 6. County-level average public utility water demand in MGD for 5-year increments between 1985-2020.

From SWWF	AVE PS DEMAND							
County	1985	1990	1995	2000	2005	2010	2015	2020
Bartholomew	6.7	9.6	12.4	12.4	12.4	8.1	10.4	9.0
Decatur	1.9	2.2	2.4	2.4	3.1	3.2	2.6	2.6
Hancock	2.7	2.8	2.6	3.4	3.8	3.5	3.2	3.8
Henry	3.4	3.1	3.4	3.4	3.5	2.6	3.0	2.6
Jackson	3.2	3.3	4.0	4.9	4.0	3.7	4.3	3.8
Johnson	6.9	8.3	11.9	12.0	14.9	14.1	12.0	12.8
Rush	1.0	1.1	1.1	1.1	1.0	1.3	1.1	0.8
Shelby	2.3	2.4	3.4	3.9	4.0	3.4	3.7	3.8

Table 7. County-level average (future) public utility water demand in MGD for 5-year increments between 2025-2075.

From models	AVE PS DEMAND										
County	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075
Bartholomew	11.7	11.7	12.7	13.0	14.4	14.5	15.6	16.6	18.1	19.0	19.9
Decatur	3.2	3.4	3.6	3.9	4.1	4.3	4.5	4.8	5.0	5.2	5.4
Hancock	4.0	4.1	4.4	4.4	4.7	4.8	5.0	5.2	5.3	5.4	5.6
Henry	2.7	2.8	2.9	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6
Jackson	4.4	4.5	4.5	4.7	4.8	4.9	5.0	5.1	5.3	5.3	5.4
Johnson	14.2	15.1	15.5	16.8	18.2	18.1	18.9	20.0	21.5	22.2	22.4
Rush	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.8
Shelby	4.5	4.8	4.9	5.2	5.4	5.6	5.8	6.1	6.4	6.6	6.8

Table 8. County-level maximum public utility water demand in MGD for 5-year increments between 1985-2020.

From SWWF	MAX PS DEMAND						
County	1985	1990	1995	2000	2005	2010	2015	2020
Bartholomew	8.2	11.8	15.6	14.8	14.2	13.5	14.8	11.8
Decatur	2.4	2.8	2.8	2.9	3.7	3.6	2.9	2.8
Hancock	3.0	3.2	3.0	3.8	4.4	3.9	3.5	4.8
Henry	3.9	3.5	4.3	3.8	3.9	3.1	3.3	2.8
Jackson	3.4	3.9	4.6	5.2	4.7	4.3	5.2	4.4
Johnson	7.7	9.9	14.4	14.5	17.7	19.8	14.0	15.3
Rush	1.2	1.2	1.2	1.2	1.0	1.5	1.2	0.9
Shelby	2.5	2.5	3.8	4.2	4.4	3.6	4.0	4.5

Table 9. County-level maximum (future) public utility water demand in MGD for 5-year increments between 2025-2075.

From models	MAX PS DEMAND										
County	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075
Bartholomew	16.3	15.3	16.0	16.1	20.4	18.3	18.3	19.3	21.9	23.1	23.2
Decatur	3.6	3.7	3.9	4.1	4.6	4.6	4.8	5.0	5.4	5.5	5.7
Hancock	4.5	4.5	4.9	4.9	5.6	5.2	5.5	5.7	5.9	5.9	6.3
Henry	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.5	3.6
Jackson	5.1	4.9	4.8	5.1	5.6	5.5	5.4	5.5	5.9	5.9	5.7
Johnson	21.2	19.3	19.4	21.3	27.6	22.6	22.4	23.2	26.1	28.9	26.4
Rush	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.8
Shelby	5.0	5.0	5.0	5.4	5.8	5.9	6.1	6.4	6.8	6.9	7.0

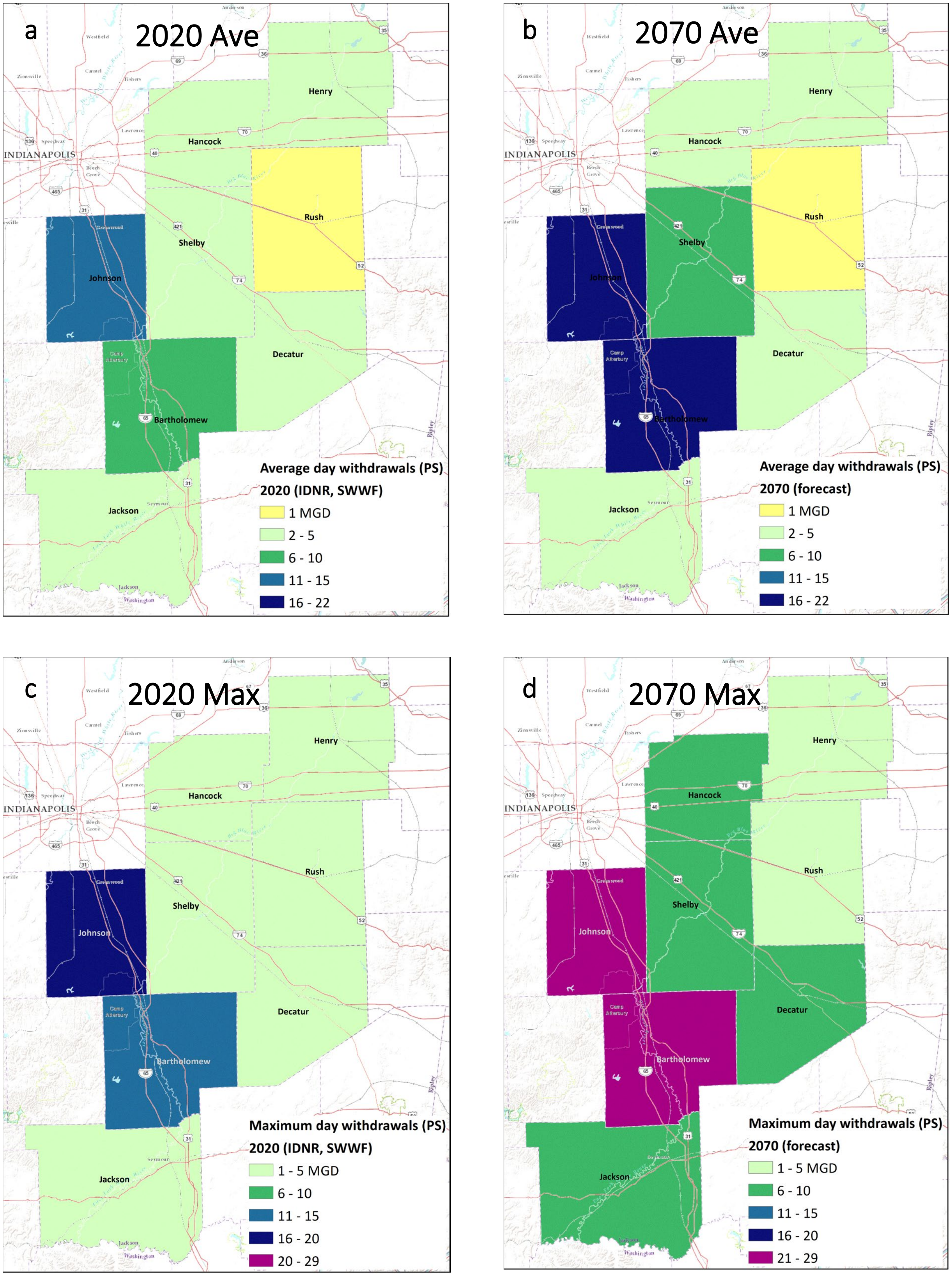


Figure 21. County-level average (observed, 2020) and future (projected, 2070) public utility average water demand (top) and maximum day withdrawals (bottom).

Water Availability

The following part of the report involves water availability, which includes the physiographic, hydrogeological, and climatic factors that characterize water resources in this region. A comprehensive analysis of water availability includes not only natural features, but requires an inventory of anthropogenic (man-made) withdrawals and wastewater returns to the regional water cycle. Discussions of water-conservation practices, water quality, and other risks and threats to the shared water resource are also included.

Indiana has a surprisingly diverse set of hydrogeologic environments that govern the distribution of aquifer resources in the subsurface. Therefore, conditions at the surface can have a variety of effects, some of which will be felt immediately, and some of which might not be of concern for decades or centuries.

The structure of this section of the report begins with an overview of the natural characteristics of the water cycle including the geologic framework as well as current and future climate. Examples of seasonality and relevant hydrologic trends (flow-regime changes) are included.

Integrating anthropogenic factors into the discussion, overviews are provided for current and future irrigation, animal agriculture, self-supplied residential, and mining and non-mining industrial water uses.

The mechanics of the water availability approach closely follow IFA (2021) and include the preparation of an anthropogenic inventory of water withdrawals (outflows) and returns (inflows) from non-consumptive or partially non-consumptive uses. As mentioned previously, the availability assessment is a spatially distributed analysis, which is based on natural and anthropogenic water flows throughout the stream network, organized by sub-watersheds or subbasins.

Just as in the water demand analysis, the extension of the water availability model based on historical data was extended into the future using projected water-withdrawal and return flows along with simulated natural baseflows matched to future climate variability. The details of the approach are presented along with the results of the current and future excess water availability analysis.

Following the results of the location-specific water availability analyses, other factors that can hinder sustainable and resilient water supply and distribution are discussed including water conservation, water quality, and other risk factors.

Factors Influencing Water Availability

All regional aquifers, including glacial outwash, till, buried sand and gravel, and bedrock, are interconnected with surface waters. Aquifer recharge eventually discharges to a stream or river. The distribution of geologic materials controls the distribution and types of aquifers, which are varied and complex in the Southeast-Central Indiana region. A brief overview of the geologic history will be given, followed by an overview of factors that control the amount and timing of water available in the aquifers and streams used for water supply.

Figure 22 presents a regional map of the generalized surficial geology for the Midwest states in the U.S. The Southeast-Central Indiana region lies at the southern extent of the Pleistocene glaciation, and the glacial deposits containing valuable aquifer materials thin near this glacial limit.

Figure 23 shows both unconsolidated and bedrock aquifer system types mapped in Indiana by the U.S. Geological Survey (Fenelon et al., 1994).

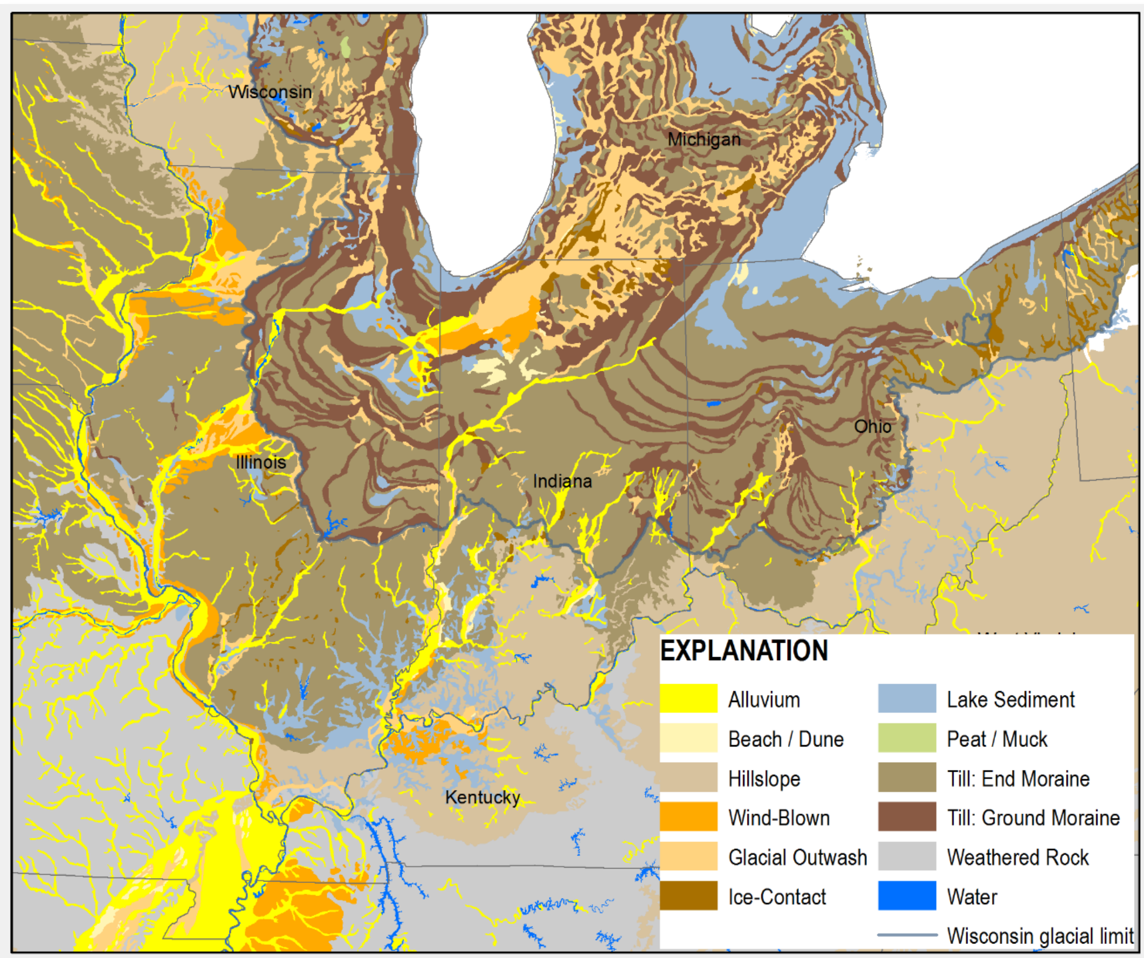


Figure 22. Generalized surficial geology for the Midwest U.S. states. The surface materials are dominated by Pleistocene continental glacial deposits that originated from the Great Lakes basins to the north. Underlying the surface unconsolidated (not yet cemented into rock) materials are sedimentary bedrock deposits of limestone, sandstone, and shale. The local geological setting is an important factor in how water is distributed or stored across the landscape. Modified from Fullerton et al., 2003.

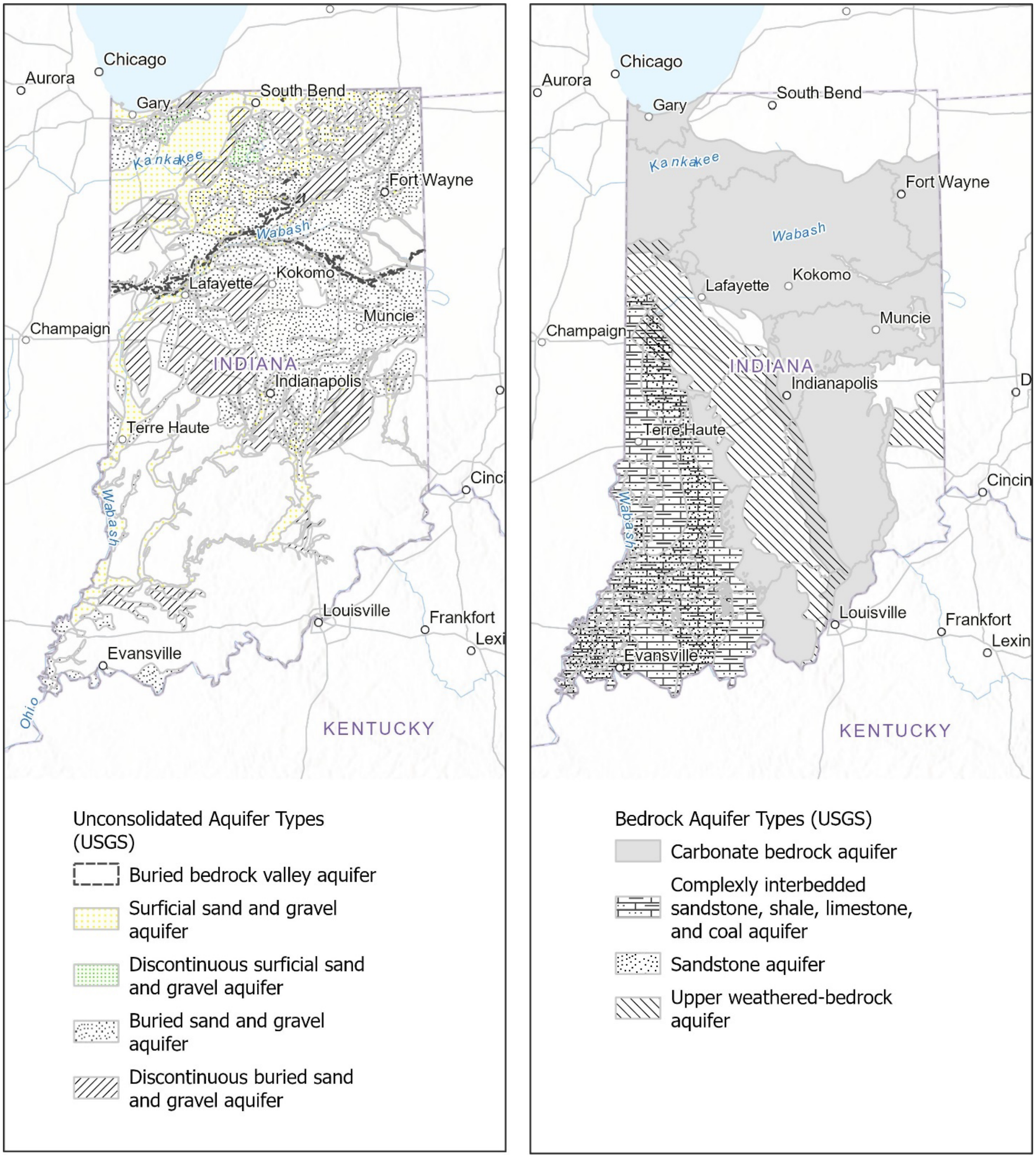


Figure 23. Aquifer system types mapped in Indiana by the U.S. Geological Survey (Fenelon et al., 1994). In the left panel are mapped unlithified, or unconsolidated, aquifer types. These aquifer systems are water-laden sediments deposited during geologically recent times from continental glaciation that originated from the north. In the Southeast-Central Indiana region, **"intratill" aquifers** dominate the buried discontinuous aquifer types. In the right panel are mapped generalized bedrock aquifer systems in Indiana. These aquifer systems underlie the glacial deposits and consist of nearly flat-lying sedimentary deposits of limestone, sandstone, and shale. Although these bedrock types are described as aquifers, the depth, yield, and quality are extremely site-specific.

Although most of the water withdrawn in the Southeast-Central Indiana region is obtained from unconsolidated aquifer systems (glacial outwash deposits or discontinuous intratill sand and gravel) or low-yielding shallow bedrock aquifers, there are deeper bedrock aquifers in the Silurian-Devonian Carbonate Aquifer System (Figure 24, Figure 25) that could be explored. Figure 24 shows the mapped hydrostratigraphic units in Indiana above which have been found to have fresh (potable, not saline) water. The stratigraphic column in Figure 25 shows the sequence of rock units (oldest at the bottom, youngest at the top) in the Southeast-Central Indiana Region. Most wells developed in this aquifer system yield less than 100 GPM, but yields around 500 GPM are possible in some areas (see Figure 28 and Figure 31).

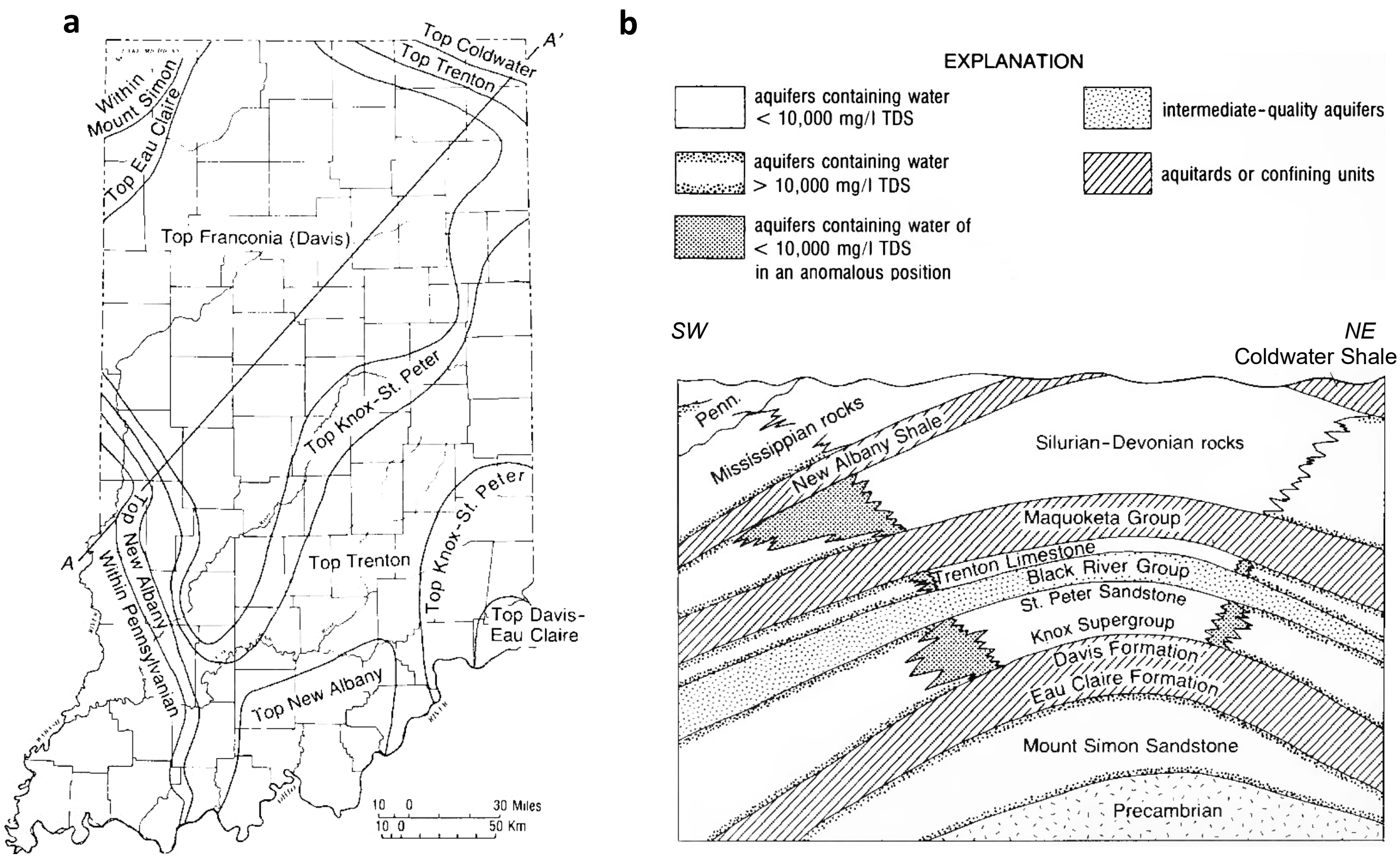


Figure 24. The map on the left (a) shows the hydrostratigraphic units in the state of Indiana that delineate fresh (potable, low total dissolved solids [TDS]) water from brackish (briny, saline, high total dissolved solids [TDS]) water. The figure on the right (b) is a cross-section (side view of the subsurface) view of the bedrock stratigraphy in Indiana along the Cincinnati and Kankakee Arches (see Figure 4). The fresh water in the Southeast-Central Indiana region can be found above the Trenton Limestone (see the stratigraphic column in Figure 25) according to Rupp and Pennington (1987). The Maquoketa Group is a confining unit that separates the gas-bearing Trenton Limestone from the Silurian-Devonian Carbonate Aquifer System. Although not currently widely used as an aquifer source in the study area, the Silurian-Devonian Carbonate Aquifer System shown in (b) is a possible option for future groundwater exploration. Figures from Rupp and Pennington (1987).

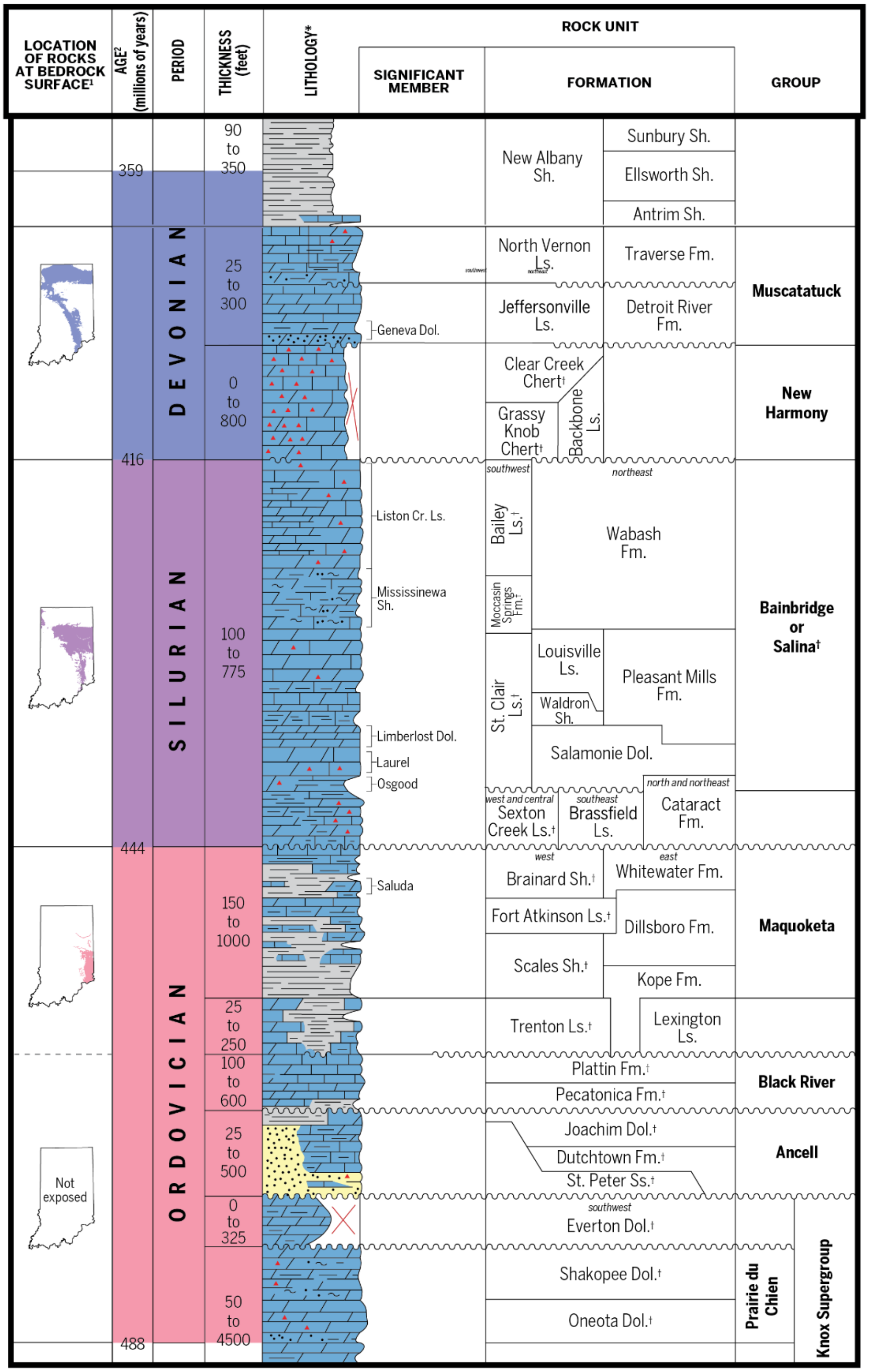


Figure 25. This diagram is a portion of the stratigraphic column representing bedrock units in the Southeast-Central Indiana region with the oldest units shown at the bottom of the diagram (also the deepest, or farthest below ground surface) and the youngest units shown at the top (closest to the surface). The discussion above notes that the Silurian-Devonian Carbonate (i.e., limestones and dolostones) Aquifer System contains some freshwater resources, but wells developed in that aquifer system do not typically produce high yields. Modified from Thompson et al., 2016.

Figure 26 and Figure 27 present a series of maps showing the geologic factors from the ground surface down to the bedrock surface that describe the unconsolidated sediment stack and the distribution of aquifer materials. The hydrology and geologic context of the surface and groundwater resources interact with climate and anthropogenic factors to distribute the water in four dimensions (the three spatial dimensions as well as throughout the years and seasons).

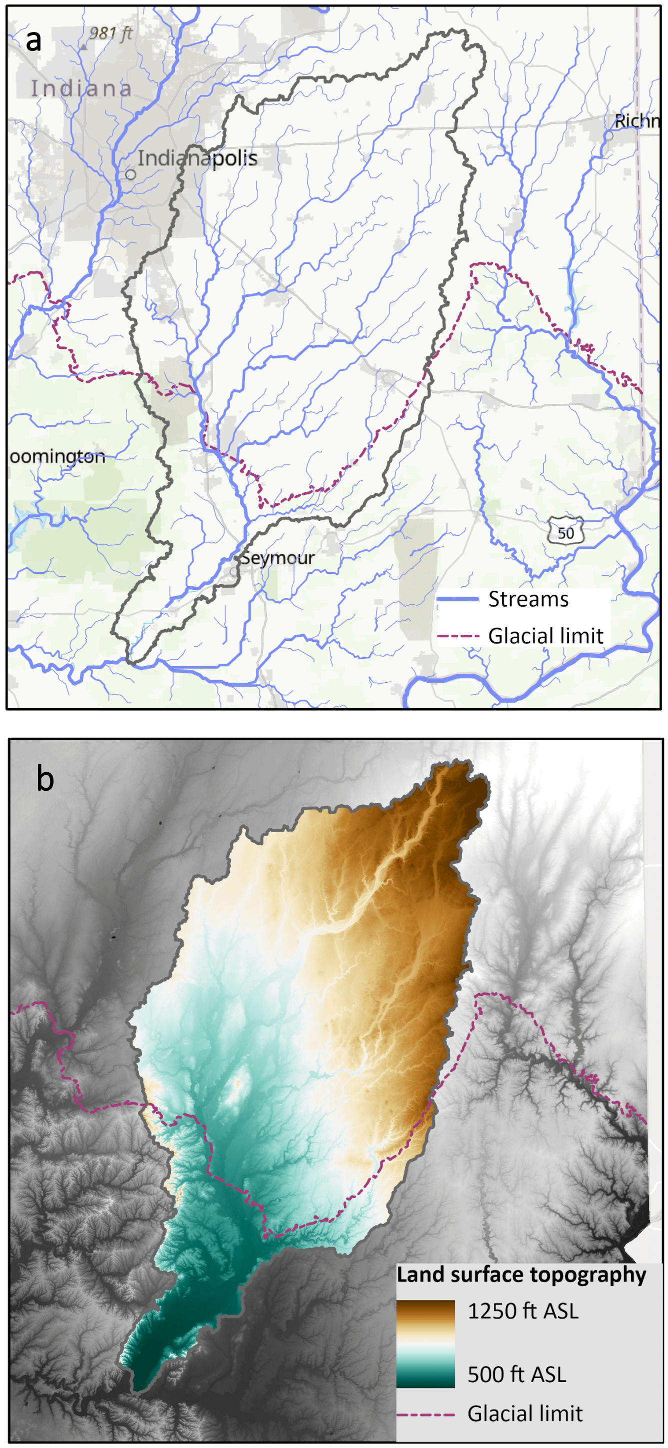


Figure 26. The top map (a) shows the streamflow network through the study area. All streams and tributaries flow to the southwest and join the East Fork of the White River. The bottom map (b) shows the land-surface topography, dropping 750 ft in elevation from north to south (Naylor et al, 2015).

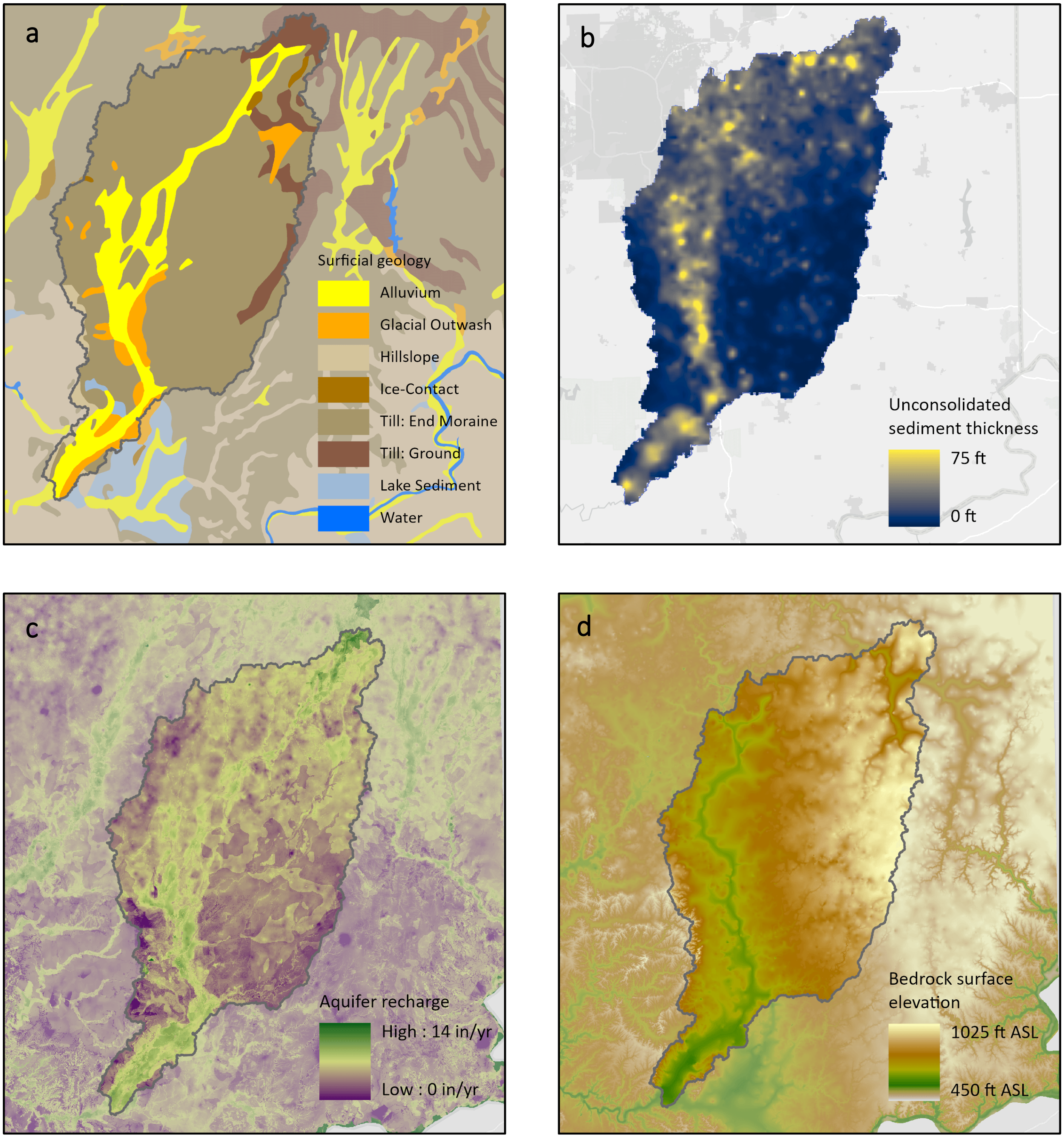


Figure 27. The images above describe the unconsolidated sediment stack and the distribution of aquifer materials. Data sources include surficial geology by Fullerton et al., 2003 (a); coarse unconsolidated sediment thickness by Bayless et al., 2017 (b); near-surface annual aquifer recharge rates by Letsinger, 2015b (c); and bedrock-surface elevation by Naylor et al., 2016 (d).

Figure 28 through Figure 32 present several data sources that illustrate the variability in aquifer types and yield throughout the region. Locations of high-capacity wells that extract groundwater from unconsolidated and bedrock aquifers (Figure 28) are shown along with maps of expected aquifer yields from unconsolidated aquifers (Figure 29), data sources that reflect areas of low water productivity (Figure 30), maps of high-capacity bedrock wells and aquifer systems (Figure 31), and areas of potential future availability based on aquifer type and historical yields (Figure 32).

Expected residential well yields

There are estimated to be more than 9,000 domestic residential wells within the study area. Of these, there are 7,680 **unconsolidated** water wells in the study area (IDNR water well record database) and 1,525 are finished in coarse-grained stratified sediment (valley outwash deposits) with an average depth of 70 feet. There are 6,155 unconsolidated wells in the study area that are not terminated in valley outwash deposits, and these wells have an average depth of 90 feet suggesting that valley outwash deposits tend to be shallower than buried upland intratill aquifers.

Nearly 2,800 wells in the study area access **bedrock** aquifers (~30%). Of these, approximately 1,350 are located inside of existing utility service areas, making it unlikely that they are currently being utilized as a primary residential water source. Only 1,337 of the ~2,800 bedrock wells have non-zero pump test data to indicate how productive the well and aquifer are. When considering only wells with pump test data, the average pump rate is around 15 GPM (many are much less). The average depth of bedrock wells with pump test data is around 114 feet, but depths can reach as much as 480 feet.

Expected high-capacity well yields

There are a total of 431 high-capacity (IDNR SWWF, 2021) wells in the study area from 151 unique facilities listed as being finished in **unconsolidated sand and gravel aquifers**. A large proportion of these wells obtain their water from alluvial or glacial outwash aquifers. The wells range in depth from 20 to 350 ft, with an average of 100 ft (median of 90 ft).

These wells collectively produced around 13.4 billion gallons of water in 2021, with an average facility pumping capacity of around 96 million gallons per year and an average individual well pumping capacity of around 31 million gallons per year. The pump rate for individual wells ranges from 12 GPM to 2400 GPM, with an average value of around 665 GPM.

There are twelve high-capacity (IDNR SWWF, 2021) wells within the study area that acquire their water from **bedrock aquifer sources**. These facilities have groundwater wells that terminate in limestone or dolostone aquifers. Only around 3% of the water pumped by SWWFs in 2021 was procured from these bedrock wells. The users range from public utilities like Greensburg, Spiceland, Knightstown, and St. Paul, to various industrial facilities including gravel and stone quarries, a dairy farm, and a wood veneer company.

Collectively, these twelve facilities pumped around 650 million gallons of water in 2021, with an average value of around 50 million gallons. The average pump capacity of all bedrock wells utilized by the facilities is around 200 GPM, with individual values ranging from 90 GPM up to 510 GPM.

The majority of SWWF wells in the study area that are finished in bedrock are relatively shallow (~50-100 feet), though there are a few which are drilled beyond 200 feet to make it through the glacial drift overburden to fractured bedrock. Decatur, Shelby, and Hancock counties combined have two-thirds of the SWWF bedrock wells in the study area, with Henry, Rush, and Johnson counties each having at least one facility.

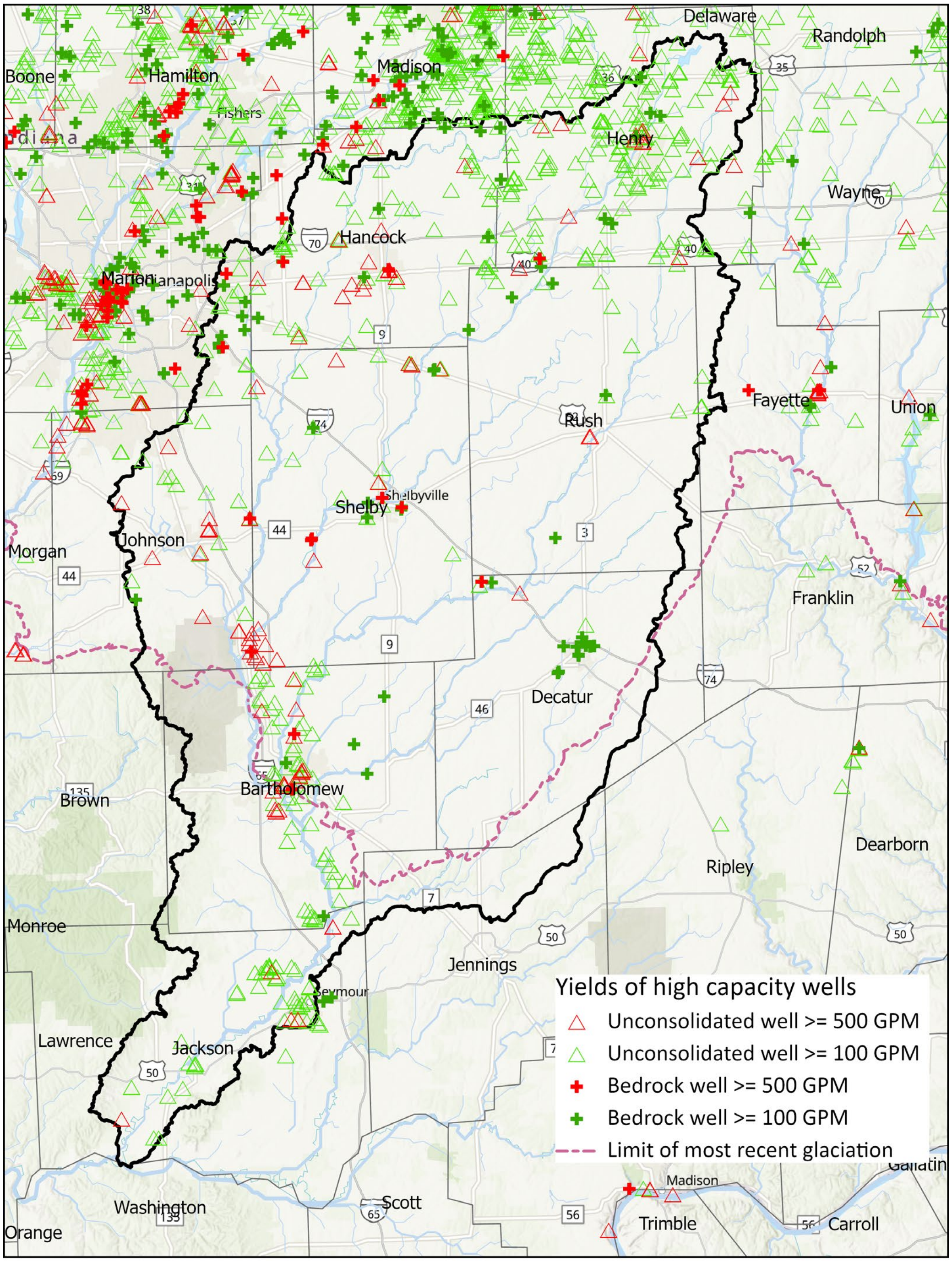


Figure 28. High-capacity wells extract from unconsolidated and bedrock aquifers, with yields typically less than 500 GPM. Data are from the IDNR 2021 Significant Water Withdrawal Facility (SWWF) Database and the IDNR water well record database. Map format and symbology are based on Bayless et al., 2017, for ease of comparison with their Figure 5K (which presents these data for the entire state of Indiana).

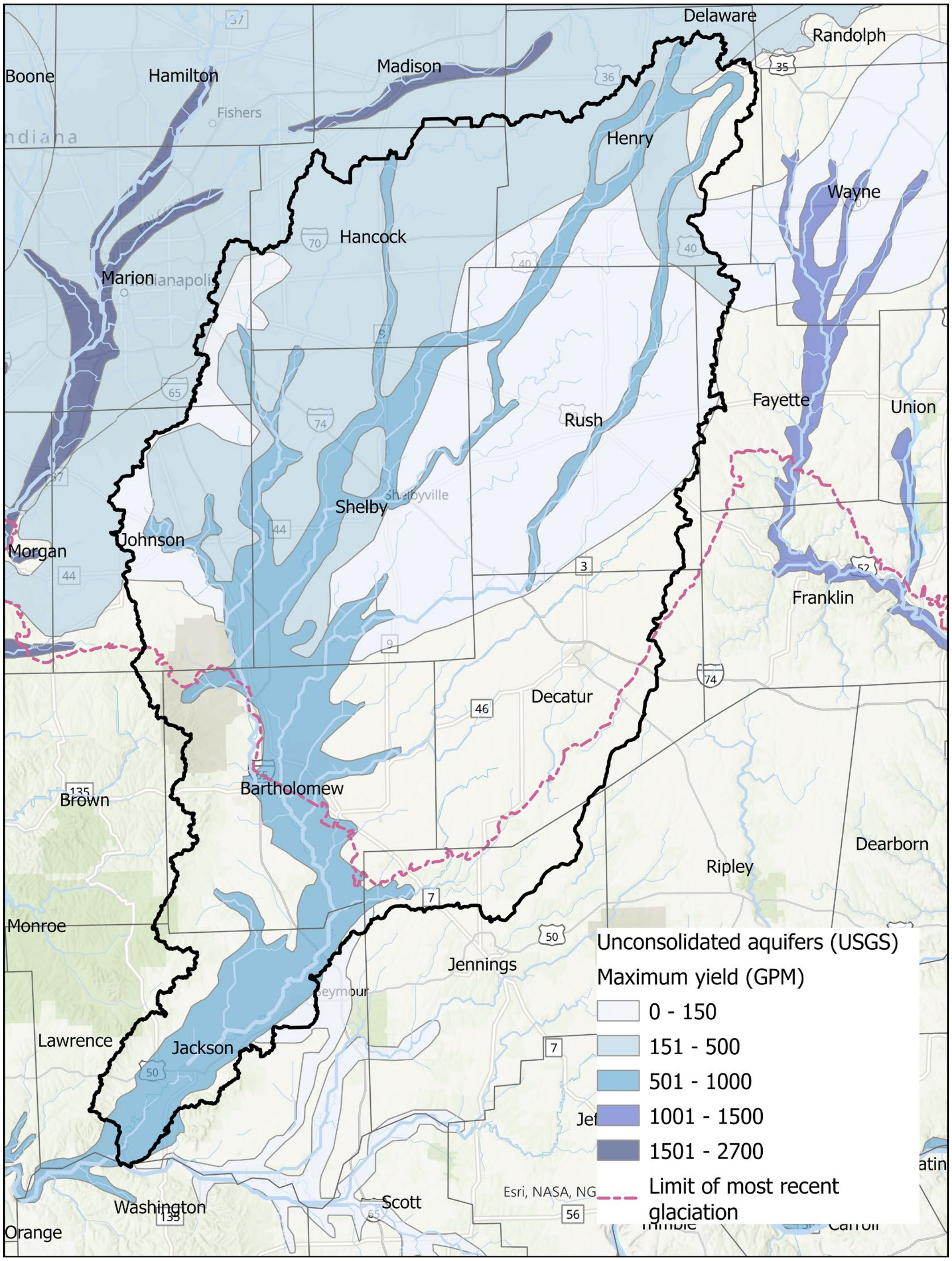


Figure 29. On average, unconsolidated aquifers have maximum yields of 1000 GPM from outwash aquifers, less than other outwash systems to the west and east. Map units are from Soller et al. (2012).

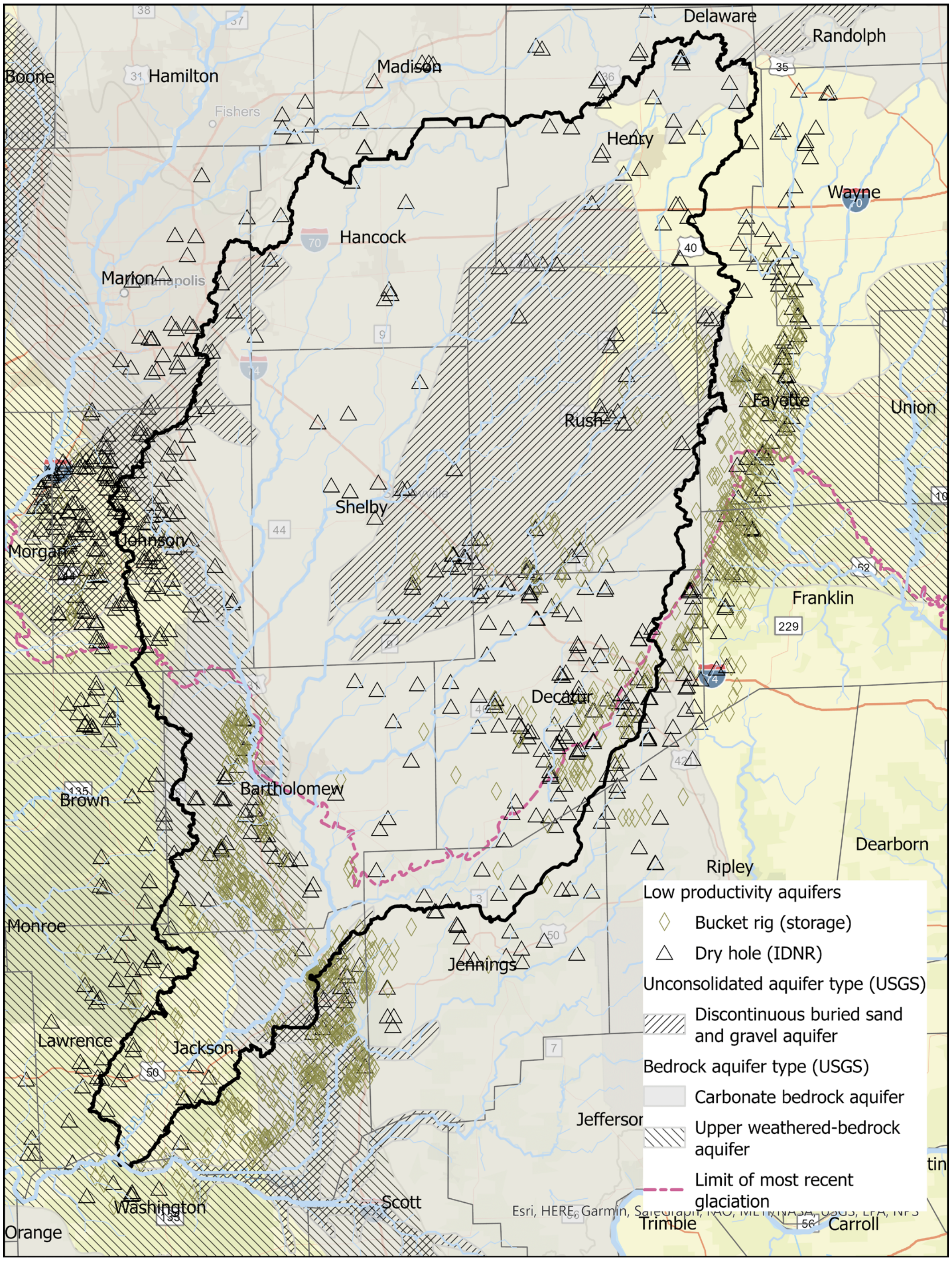


Figure 30. Low productivity aquifers (Maquoketa Group to the east, New Albany Shale and Borden Group to the west), accessed primarily by residential water-users, are common around the periphery of the basin. Shown on this map along with the distribution of aquifer types are locations of shallow low-productivity wells ("bucket rig wells" used to collect groundwater from low-yielding aquifers and store it for later use) and locations where dry holes (well attempts that did not encounter water) were recorded in water well records. The discontinuous buried sand and gravel aquifers in this region are intratill (within glacial till) aquifers. Data from IDNR water well record database; Soller et al., 2012.

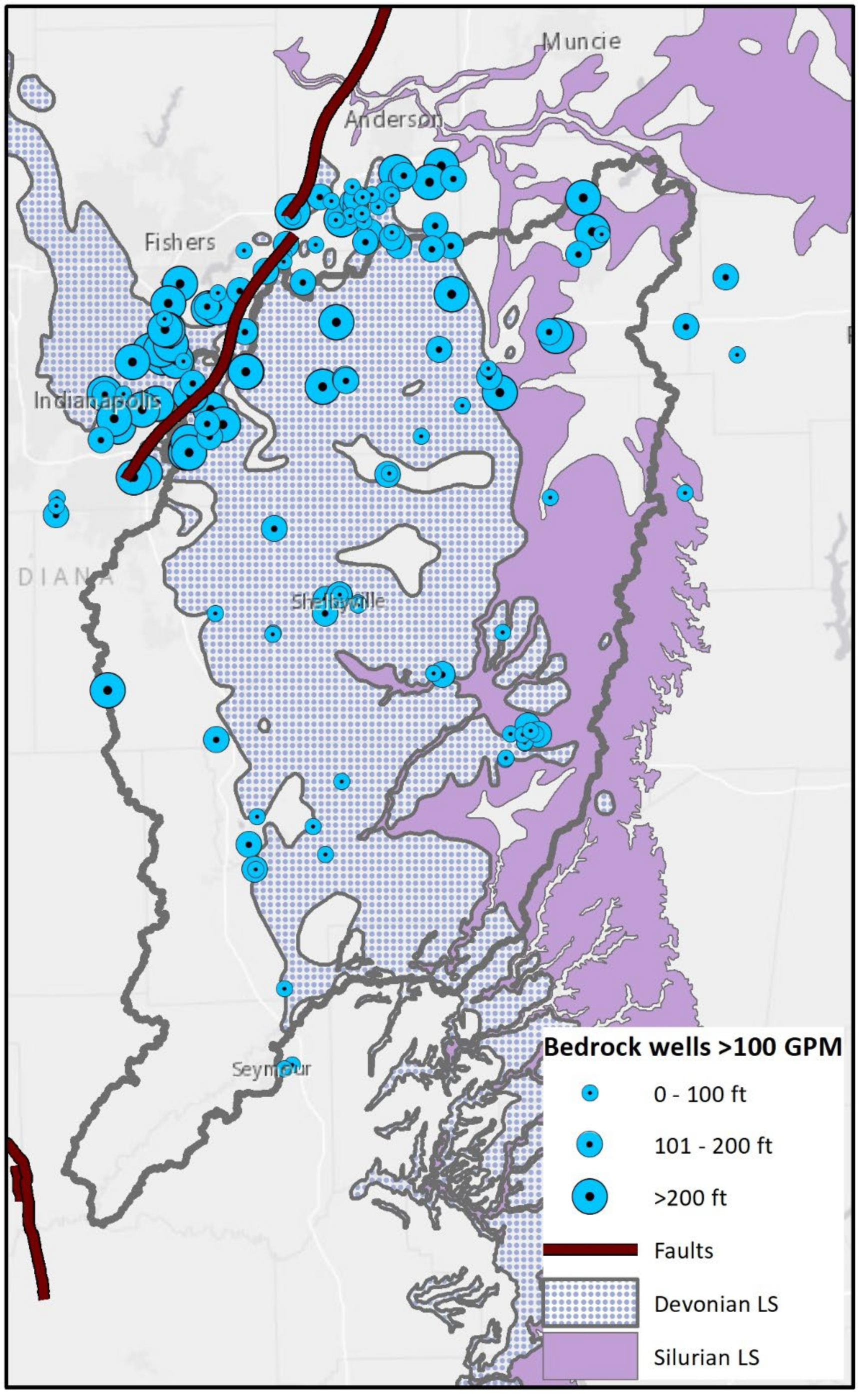


Figure 31. Range of depths of high-capacity wells producing from bedrock aquifers in the study area (IDNR SWWF, 2021). The near-surface expression of the Silurian-Devonian Carbonate Aquifer System is also shown for reference (map units from Gray et al., 1987). Refer to Figure 28 for the range of aquifer yields from these wells (90-500 GPM in the Southeast-Central Indiana Region). Note the high-capacity wells clustered around the Fortville Fault (just outside of the study area to the northwest, or upper left of the map). There is likely greater water potential around the complex geologic structure of that faulted area than in other portions of the bedrock aquifers of the study area.

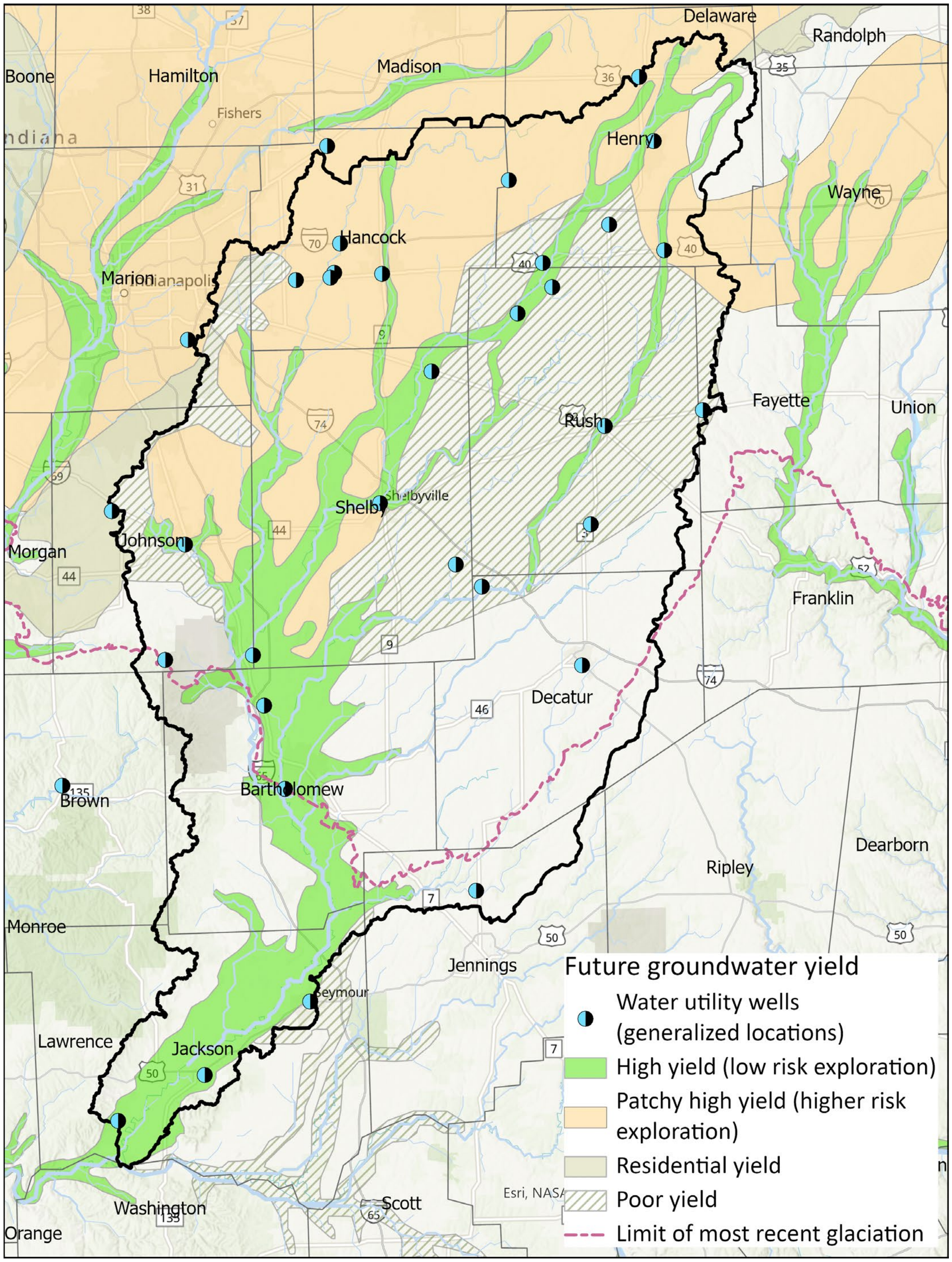


Figure 32. Map showing the range of aquifer yields to consider in future exploration of water supplies. Map units are from Soller et al., 2012.

Water Sources and Trends

The Indiana Water Cycle

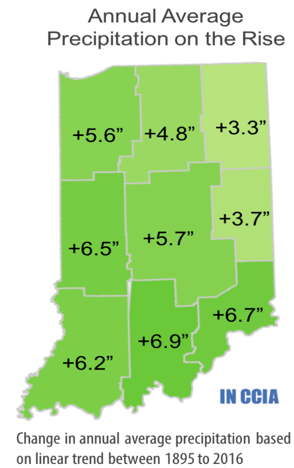
Previous work in Indiana (Widhalm et al., 2018; and Hamlet et al., 2019) has noted increasing statewide trends in precipitation, temperature, growing season, and snow cover from 1900 to (near) present (Figure 33). Ford et al. (2021) note trends in the standardized precipitation index (SPI) from 1951 to 2019 for the Midwest U.S. Purdue University (Profs. Cherkauer and Bowling) have tracked increasing and decreasing long-term trends in surface and groundwater levels (https://www.agry.purdue.edu/indiana-water).

Water resources are affected by seasonality, especially in a state like Indiana that experiences four distinct seasons. During dry conditions, high water-use demand for a number of water sectors could be met with declining aquifer levels responding to an insufficient amount of groundwater recharge.

The north-to-south precipitation gradient has been intensifying in recent years, with precipitation increases concentrated in southern and central Indiana (Figure 33). The pattern of increasing stream flows and groundwater levels from southwest to northeast in the state is a common pattern in many of the trends, likely a result of increasing precipitation along the Ohio River Valley. More about these trends will be presented later in the report.

Those familiar with the concept of water balance usually think of the natural water cycle; however, the volume of water (pools) and how it moves (fluxes) is much more complex (see: the new Water Cycle Diagram by the U.S. Geological Survey at https://www.usgs.gov/special-topics/water-science-school/science/water-cycle).

Along with increasing precipitation, Indiana is also experiencing increasing temperatures (Figure 34), including increasing minimum temperatures and nighttime lows. Drought occurs with a combination of low precipitation and high seasonal temperatures, which affect many pools of water from the atmosphere to the soil, streams, and aquifers. The Palmer Drought Severity Index (Figure 35) is a metric that can be used to classify the severity of drought conditions. Although drought can affect entire regions, the specific characteristics of each locality will define the "drought of record" and the severity of the impact (see Figure 36).



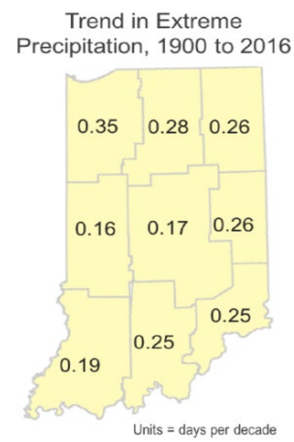
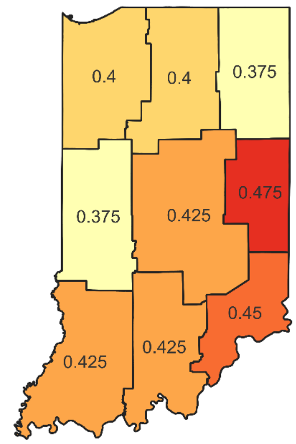


Figure 33. Increasing temperature and precipitation trends are expected to continue and accelerate in the future. Projections suggest that annual statewide temperatures will increase by 5 to 6°F by mid-century and 6 to 10°F by late-century, with no additional growing season precipitation. This is likely to cause increased water demand and water stress. Figure from Widhalm et al., 2018.

Figure 34. This map reflects the annual average temperature trend (degrees F) for Indiana from 1960-2016 (NOAA Climate At A Glance Database, https://www.ncdc.noaa.gov/cag). The Central and Southeast-Central Indiana regions are showing steadily increasing temperatures. The largest increases are in the winter and spring, although summer and fall temperatures are also increasing. Increasing temperatures in the winter can affect whether precipitation is received as snow or rain, which could thereby influence winter infiltration in areas that do not receive runoff (i.e., upland regions) and rely on slow water infiltration to recharge aquifers.



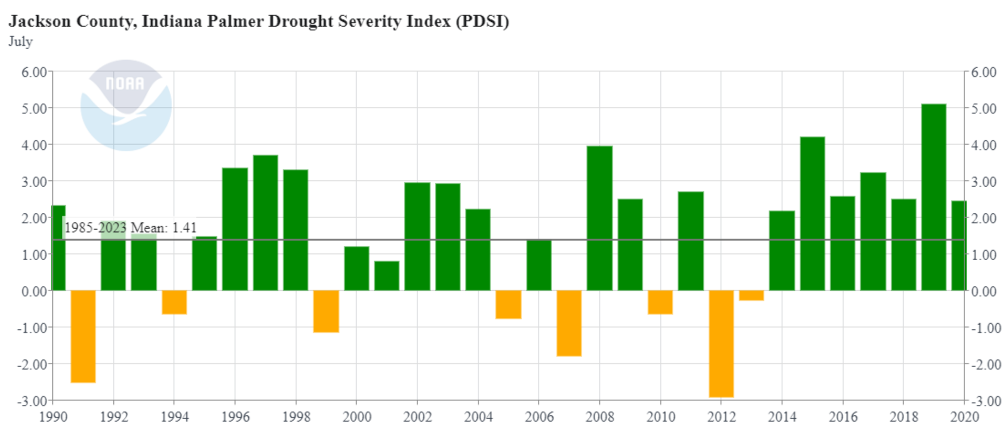


Figure 35. July Palmer Drought Severity Index (PDSI) for Jackson County in Southeast-Central Indiana. Wet years outnumber dry years from 1990-2020, although the intensity of dry events can affect conditions during the following year. https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/county/time-series/IN-081/pdsi/1/7/1990-2020

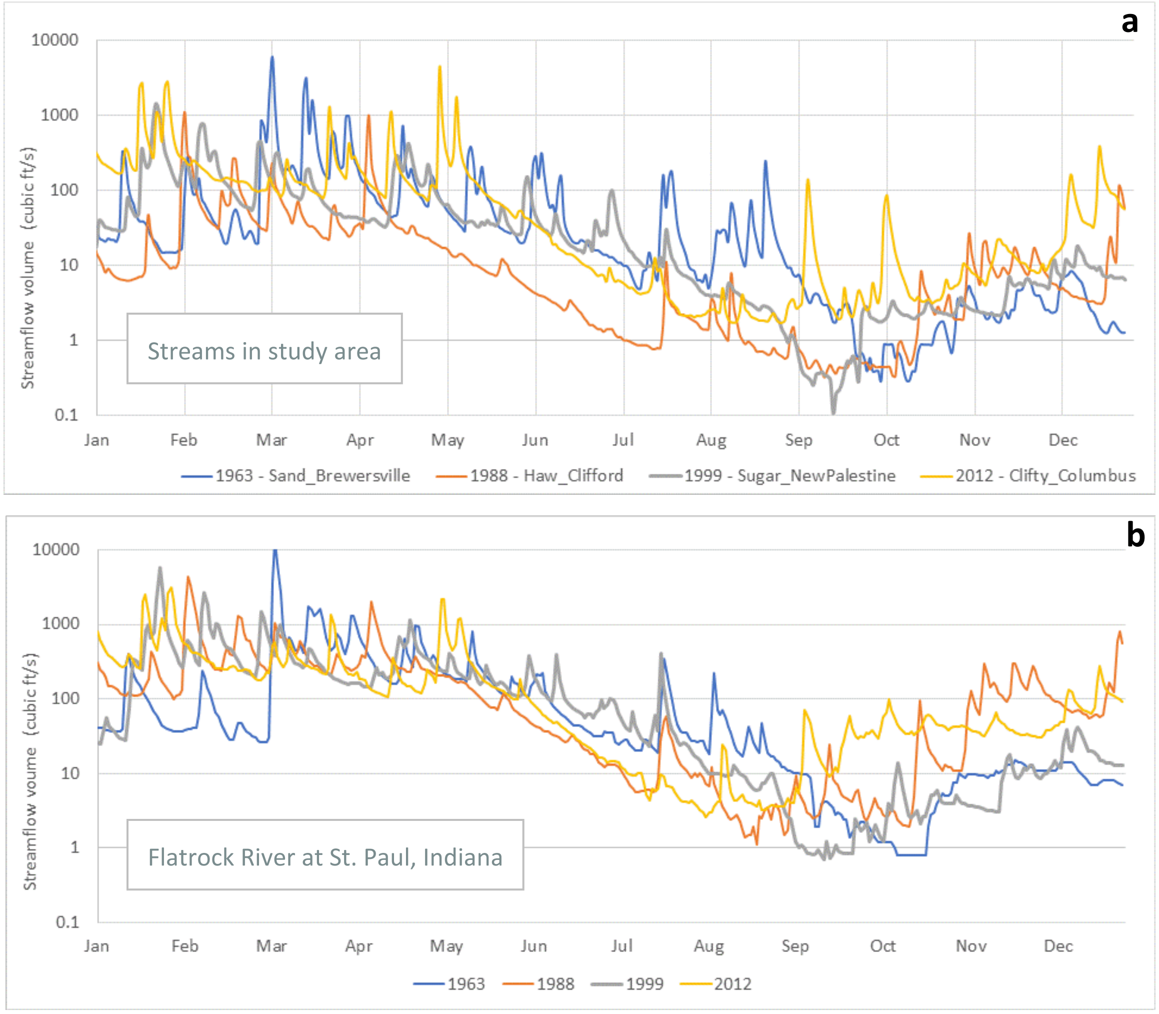
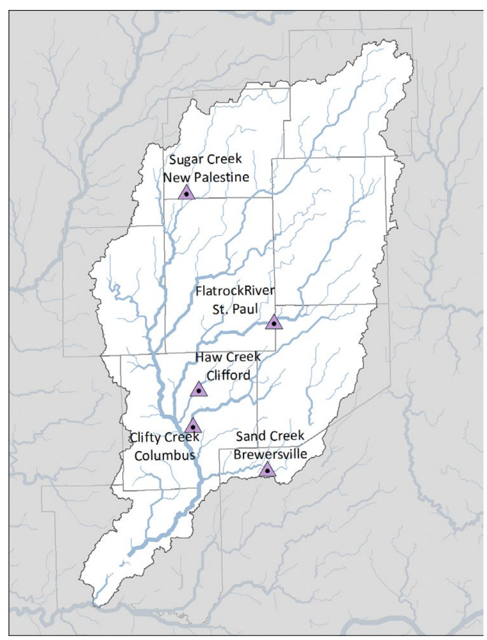


Figure 36. Streams and rivers of different sizes, drainage areas, stream orders, and connectivity to groundwater have different levels of drought resilience. Therefore, one "Drought of Record" does not apply to every stream in the same way, even if they are in close geographic proximity. The upper graph (a) shows the droughts of records for four stream gages in the study area, all of which reached their lowest flow in different years (the x-axis shows the months of those respective years). The lower graph (b) shows the flow in one river – Flatrock River at St. Paul, Indiana, for the same drought years as the streams shown in (a). The drought of record for the Flatrock River at St. Paul was 1999; upstream of this gage, there was a 120-day drought of record, including three weeks of zero flow. Sugar Creek at New Palestine experienced similar conditions; however, other streams did not experience their lowest flows in 1999.



Instream Flows

Healthy ecosystems require minimum amounts of water to thrive. The amount of water for these uses is referred to as minimum "instream flows" (see sidebar).

Although there are recommendations for minimum instream flows by the IDNR Water Shortage Plan (i.e., the 7Q10 statistic; IDNR, 2015, Section VII. B1, B2) to maintain ecological stream functions, assessment of excess availability of water is not limited by any current regulatory statute. In this study, following the practice used in the Central Indiana Water Study (IFA, 2021; Phase III: Water Availability, Chapter 2, Section 2.9), the annual Q90 is used as a default value for instream flow in the winter and spring, and the 7Q10 is used in the seasonally dry summer and fall (using 1992-2022 streamflow data; Blum et al., 2019). Excess availability is calculated only after these flows are set aside, and should regulatory guidance increase the instream flow requirements, there would be a commensurate decrease in calculated excess water availability.

Instream Flows

A minimum amount of water flow is required in streams and rivers to support aquatic life and preserve water quality. There are two main statistical metrics for determining how much flow is necessary to accomplish this:

7Q10

7Q10 is defined as the lowest 7-day average flow in a stream that occurs once every ten years. The Indiana Department of Natural Resources recommends this metric as the minimum standard to maintain during low-flow periods through water use reductions (IDNR, 2015.)

Q90

Q90 is the minimum amount of flow that is present 90% of the time in a given stream. In other words, flow levels should only be lower than the Q90 levels 10% of the time.

Both of these statistical metrics are based on the "normal" streamflow data to which discharges are compared (usually a 30-year period, see Blum et al., 2019). The flow volumes required to achieve these standards will vary greatly depending on the size of the stream, the local geology, and the area of the contributing watershed.

Annual and Seasonal Hydrologic Trends

Figure 37 is a schematic cross-section showing subsurface flow paths for infiltrated water. Shallow aquifers are replenished by modern rainwater (or snowmelt) on short time scales (monthly/annual/decades) because rates of flow are faster and flow paths are usually shorter because the water remains close (in distance and depth) to where it originated. Regional flow can originate from much farther away, and water flowing to discharge areas (such as river valleys) often travels deeper in the subsurface and at slower flow rates (decades to centuries). https://www.usgs.gov/special-topics/water-science-school/science/groundwater-photo-gallery

A statewide water-balance study (Letsinger et al., 2021) showed that the statewide average annual groundwater recharge rate is about 6 inches per year, but it is not uniformly distributed – some areas receive very little recharge (1 inch per year in southern Indiana), while others receive more than 14 inches per year. Trend analyses (Letsinger et al., 2021) show that recharge is increasing most in near-stream aquifers (e.g., outwash aquifers) as a result of intensified and episodic stormwater runoff.

In the last 20 years, recharge has shifted slightly from spring to winter. Although some upland aquifers (sand and gravel lenses in glacial till in Central Indiana) could experience declining water levels owing to lower rates of groundwater recharge over time, groundwater-level trends for the observation wells in the study area are currently showing annually rising water levels (statistical significance varies, see Appendix F). However, there are several wells that show seasonal (dry-season) declines on the western and southern edges of the study area in Shelby, Bartholomew, and Jackson Counties. The seasonality could have effects on water supplies (Fowler et al., 2022) and ecosystems (Tavernia et al., 2013).

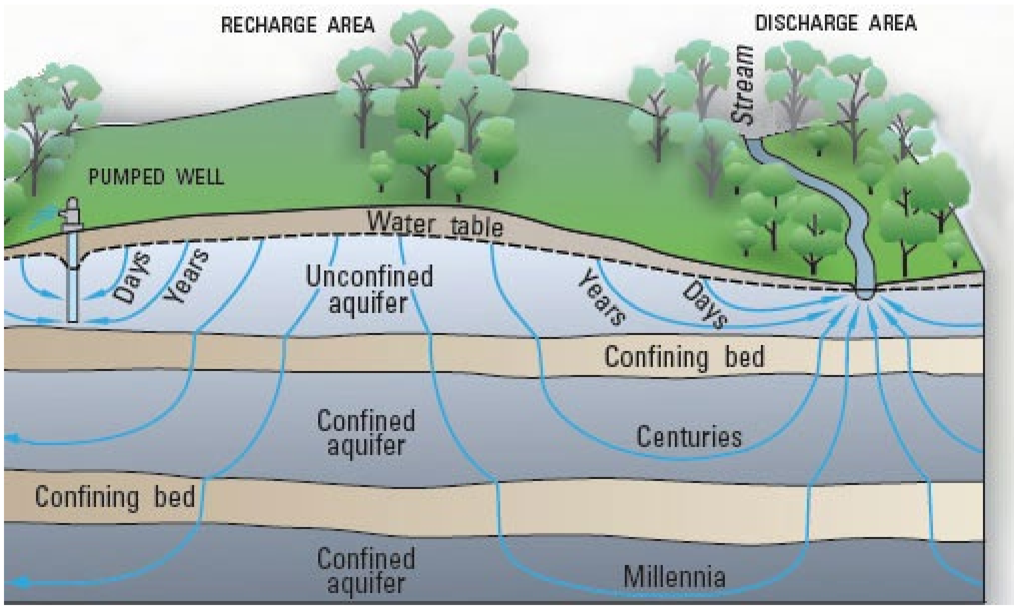
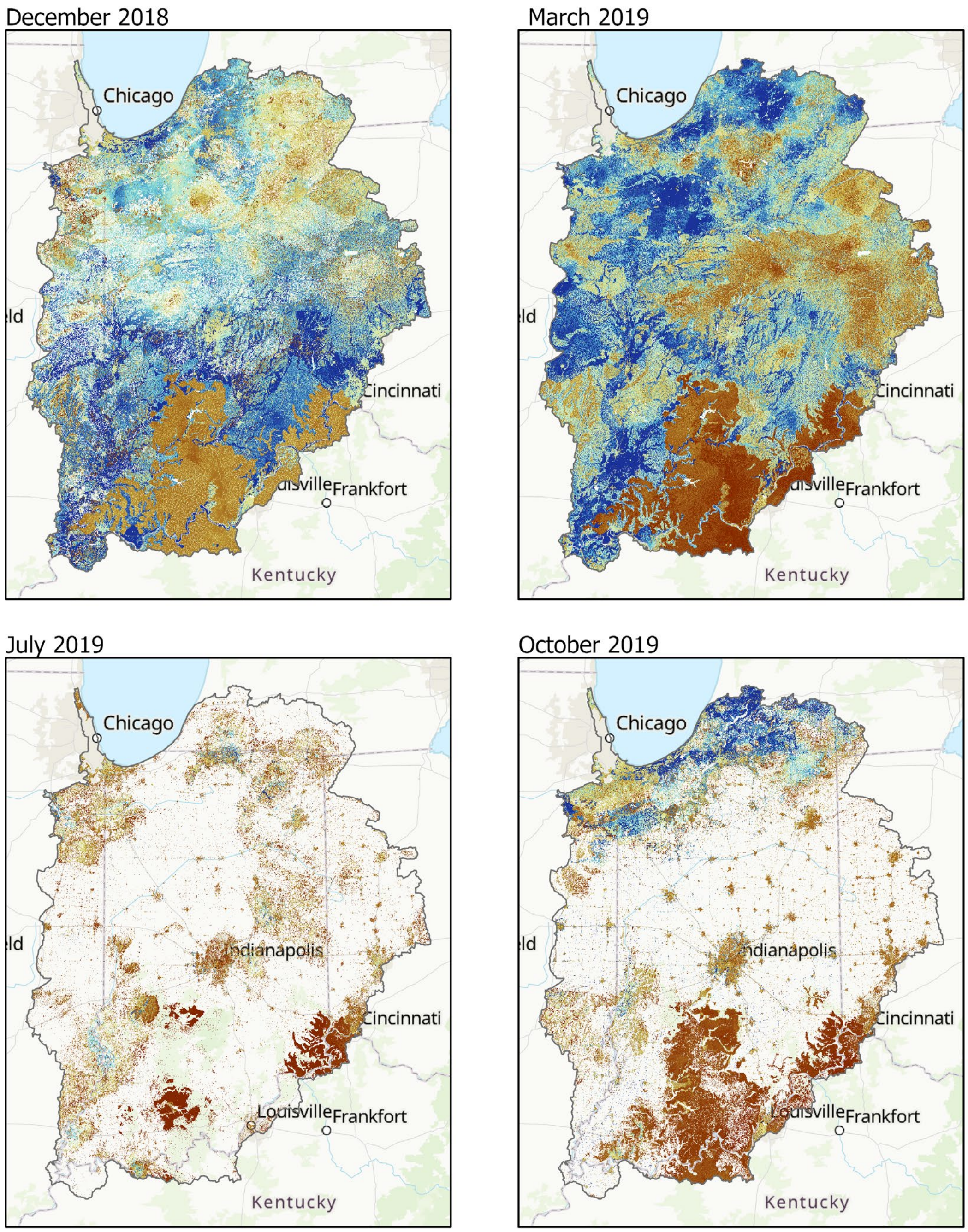


Figure 37. Schematic cross-section showing subsurface flow paths for infiltrated water. Shallow aquifers are replenished by modern rainwater (or snowmelt) on short time scales (monthly/annual/decades) because rates of flow are faster and flow paths are usually shorter as the water remains close (in distance and depth) to where it originated. Regional flow can originate from much farther away, and water flowing to discharge areas (such as river valleys) often travels deeper in the subsurface and at slower flow rates (decades to centuries). https://www.usgs.gov/special-topics/water-science-school/science/groundwater-photo-gallery

Figure 38 shows an example of how annual groundwater recharge is distributed through the seasons in the state, with winter (December panel) and spring (March panel) showing the highest rates of net infiltration. The geologic materials and land uses (such as urban impervious surfaces) ultimately control rates of infiltration. Near-surface glacial till (i.e., fine-grained) deposits more resistant to water migration into the subsurface than are coarser grained deposits such as alluvium (river sediment) and glacial outwash deposits. Summer (July panel) and fall (October panel) show that virtually no potential aquifer recharge is received in many areas of the state, including the Southeast-Central Indiana region. Stored groundwater is responsible, therefore, for groundwater baseflow contributions in the summer and fall for many stream and river systems in the state.

Water availability is inherently linked to the dynamics of aquifer recharge and storage, particularly as it relates to seasonal fluctuations. Drawing water from groundwater storage to augment water availability during low-flow scenarios is not always feasible. While the study area is characterized by high transmissivity aquifers such as outwash deposits, alluvial deposits, and buried sand and gravel lenses, significant flow rates are predominantly restricted to these formations. Other formations, like bedrock, exhibit minimal groundwater transmission, with till transmitting even less. Therefore, water withdrawals for public supplies and irrigation are mostly confined to outwash and alluvium close to streams. However, focusing the majority of pumping in these regions presents the danger of risking stream depletion.



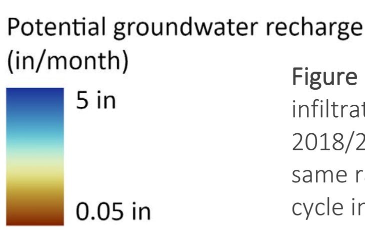


Figure 38. Monthly potential groundwater recharge (net infiltration, inches/month) snapshots for four months (winter of 2018/2019 to fall of 2019). These maps, all scaled across the same range for comparison, show the dynamic seasonal water cycle in the Midwest U.S. (Letsinger et al., 2021).

NOTE: the color ramp range starts at 0.05 in/month instead of zero (which is white or transparent on these maps), so that the non-zero recharge rates can be seen on the summer (July) and fall (October) maps.

Figure 39 presents a compilation of long-term surface water discharge (consistent with Ficklin et al., 2018), and groundwater-level trends in the study area. The hydrology of the state is tied closely to the geology of the state, so the glacial maximum boundary (limit of glacial advance from the north) is also shown. North of this boundary, aquifers derived from glacial material deposits are common; south of the boundary, where bedrock is very shallow, groundwater resources are limited. The north-to-south precipitation gradient has been intensifying in recent years, with precipitation increases concentrated in south and central Indiana. The pattern of increasing stream flows and groundwater levels from southwest to northeast in the state is likely a result of increasing precipitation trends along the Ohio River Valley. Not all streams and rivers in the state are experiencing increasing flow.

Figure 40 presents river discharge data for USGS gage 03365500, East Fork White River at Seymour, Indiana, to illustrate the historical frequency of low-flow events experienced in the river from 1930 to present, as evaluated using the 7Q10 low-flow statistic (based on 1992-2022 normal flows). Low-flow conditions are less severe and less frequent in recent years than in the past, reflecting runoff and baseflow from upstream catchments. Given the widespread increases in stream flows and groundwater levels throughout the region, this likely reflects climate-driven increases in precipitation rather than solely factors such as urbanization or land management practices.

Given the fluctuations (currently increasing in the winter) in stream flows in the region with commensurate changes in what is considered to be "low flow," it is important that state and federal agencies establish consistent methodologies or guidance for instream flows. It is recommended that IDNR regularly update these metrics, especially in the face of changing climate and hydrological patterns. This would ensure that water resource management remains adaptive and responsive to current and future challenges.

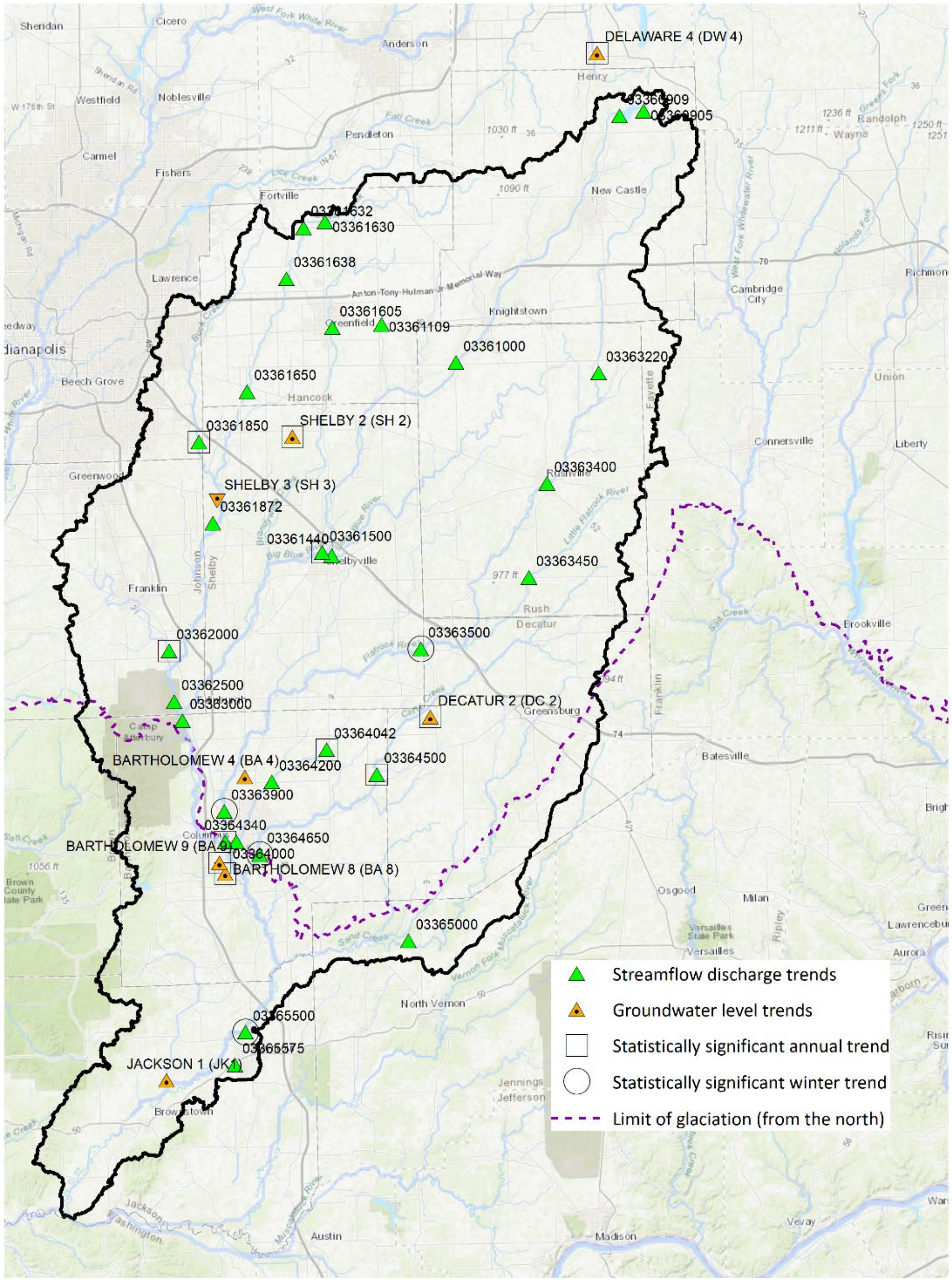


Figure 39. Compilation of long-term annual surface water discharge (consistent with Ficklin et al., 2018) and groundwater-level trends in the study area. With the exception of groundwater levels in the Shelby 3 (SH 3; note inverted symbol) observation well, all annual streamflow and groundwater-level trends are increasing (1992-2022). Please see Appendix F, Tables F7 and F9 for results of the streamflow and groundwater-level trend calculations. The hydrology of the state is tied closely to the geology of the state, so the glacial maximum boundary (limit of glacial advance from the north) is also shown.

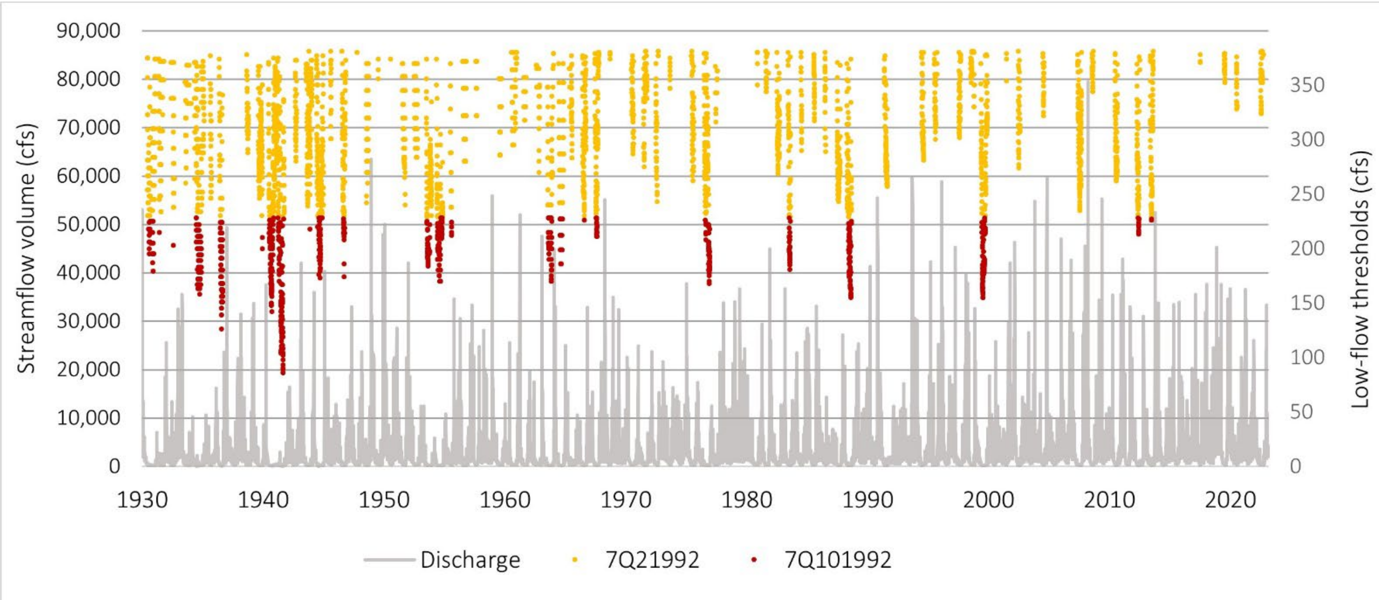


Figure 40. This graph presents river discharge data for USGS gage 03365500, East Fork White River at Seymour, Indiana, to illustrate the historical frequency of low flow events experienced in the river from 1930 to present, as evaluated using the 7Q10 low-flow statistic (based on 1992-2022 normal flows). The red data series show when the river was at or below the 7Q10 threshold, representing times when the river flow was lower than recommended levels for ecosystem health (usually associated with drought conditions). The yellow data series is the 7Q2 discharge threshold, which represents a more common seasonal low flow. Low-flow conditions are less severe and less frequent in recent years than in the past, reflecting runoff and baseflow from upstream catchments. Given the widespread increases in stream or river flows and groundwater levels throughout the region, this likely reflects climate-driven increases in precipitation rather than solely factors such as urbanization or land management practices.

Water Availability Forecasts – by Subbasin

Watershed-based Water Inventories

A major component of this study was the application of a water-availability model for the Southeast-Central Indiana region from 2007-2021. The approach closely follows that developed in the Central Indiana Water Study (IFA, 2021; Phase III: Water Availability, Chapter 2), which was intended to provide a basis for investigating the natural variability in hydrologic conditions. Although this project has public supply water demand and availability as its focus, water availability involves a resource shared by many water-use sectors. Therefore, the availability model necessarily included historical and future projections of water demand in all sectors, as well as an accounting of water returns to the system from the non-consumptive portion of water withdrawn.

Water Demand Forecasts – Other Sectors

The detailed exploration of historical water and future public water utility demand was presented above. A related water-availability analysis requires a comprehensive perspective on water usage in all sectors. This entails not merely an assessment of current water withdrawals but also forecasting of future requirements, leading to a complete water inventory. While the initial demand analysis was undertaken at the county scale, transitioning to hydrologic boundaries – specifically watersheds delineated at the HUC10 scale (USGS, NHD) – allows a detailed, localized insight into water dynamics. This granular approach ensures a seamless integration of demand and availability analyses, based on a comprehensive water-balance inventory (see Appendix E).

Beyond public utilities, this analysis extends to other water-use sectors, including irrigation, livestock (specifically CAFOs), industrial processes, and self-supplied residential demands. Each sector exhibits unique water consumption patterns and trends, warranting sector-specific projection methodologies.

Crop Irrigation Trends

Warmer overnight temperatures during critical parts of the growing season (i.e., July) in Indiana have been linked to reduced corn yields over the last decade (Hayhoe et al., 2009; Bowling et al., 2018). Warming temperatures and tenuous plant-available water in the summer months can be disastrous for crops if flash droughts develop and starve growing crops at critical times (Pendergrass et al., 2020; Iglesias et al., 2022).

Irrigation can amend crop water requirements, but usually cannot be applied in sufficient amounts during persistent drought conditions to salvage crops. Irrigation from water wells can draw down groundwater levels and increase soil water evaporation and plant evapotranspiration by bringing water to the ground surface, especially during the hot summer months (Qing et al., 2023). These interacting processes in the water cycle are expected to

Consumptive Water Use

Water use can be divided into two main types – consumptive or non-consumptive - depending on whether or not the water is ultimately returned to the local groundwater system.

Most residential water use is considered non-consumptive, though a slight seasonal component (2% in spring, 19% in summer, 7% in fall) related to outdoor water use during the growing season is considered consumptive. The remaining water treated in septic systems and wastewater treatment plants is then reintroduced into the local environment through outflows and infiltration.

In the agricultural sector, the majority of water usage (~80%) is considered consumptive as the water is taken up by crops and livestock, or lost through transpiration and evaporation. The remaining 20% of water used in agriculture is assumed to infiltrate into the earth and eventually return to the groundwater system.

Water used in energy production for cooling and in industrial processing is generally considered non-consumptive.

intensify as temperatures continue to increase (Hayhoe et al., 2009; Rosa et al., 2020; Douville et al., 2021; Haqiqi et al, 2021).

Figure 41 summarizes the proportion of groundwater (wells) to surface-water (intakes) irrigation pumping from 1985-2021 in the Southeast-Central Indiana region. The graph shows a trend that has increased dramatically over the last 20 years. Groundwater has always dominated the groundwater/surface water irrigation ratio in this region; however, surface-water withdrawals for irrigation have been steady for most of the reporting period (1985-2021) while groundwater-use has continued to increase. Because of increased precipitation in the planting and early growing season, future water-balance models (see SWB2) project that agricultural irrigation demand could increase relative to current extraction rates along near-river aquifers, so even without expansion into areas not currently irrigated, warmer summers under future climate conditions will increase crop-water requirements. Appendix F has additional details of the future irrigation water demand forecasting methods.

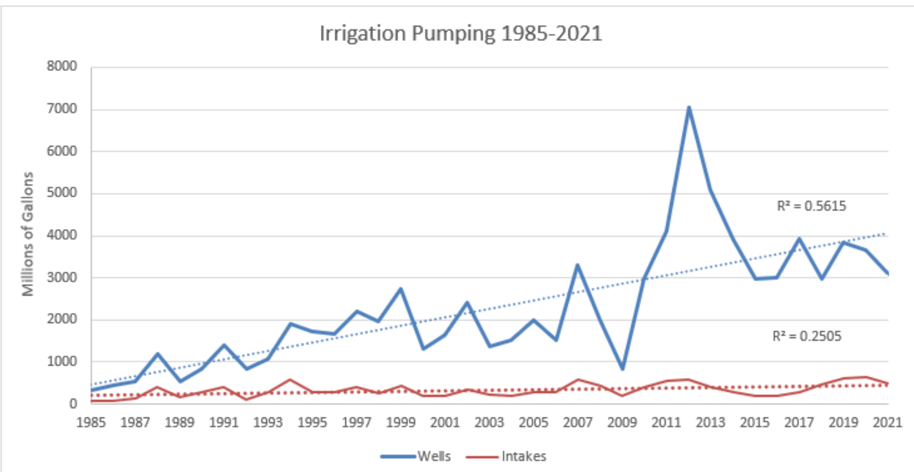


Figure 41. This graph summarizes the proportion of groundwater (wells) to surface-water (intakes) irrigation pumping from 1985-2021 in the Southeast-Central Indiana region. The graph illustrates total annual withdrawals for irrigation, showing dips and peaks based on the moisture availability that year. These data are from the Indiana Department of Natural Resources, Division of Water, Significant Water Withdrawal Facility (SWWF) database.

Rural – Concentrated Animal Feeding Operations

Figure 42, Figure 43, and Figure 44 below show the historical growth of concentrated and confined livestock facilities in Indiana since the 1970s. The Southeast-Central Indiana region has some of the highest densities of hog, poultry, and dairy operations in the state, with most of the farms in Decatur, Rush, Shelby, and Jackson Counties. Although the number of regulated farms has declined in recent years, the number of animals in many facilities has increased. See Appendix A for methods used to estimate water usage for facilities not reporting water use to the IDNR SWWF database. In 2021, CAFOs reporting water use recorded in the IDNR SWWF database summed to around 228 MG, and the aggregate total of water used by CAFOs not required to report water usage in 2021 was 1,278 MG. There are CAFOs in Jackson County that report water use, but also have water-use supplied by public water utilities, so the data describing total water use in this sector is fragmented. The “non-SWWF” facilities are distributed around the entire region, whereas the few SWWF-reporting CAFOs are located in just a few of the subbasins.

Similarly, wastewater returns from CAFOs require estimates. “Non-discharging” CAFOs do not need to report wastewater volumes through the NPDES. Most facilities stopped reporting after a 2008 federal appeals court ruling, and Indiana implemented their rule changes in response in 2012.

For the future demand projections, the overall growth in the CAFO sector was based on a rate of 5% per 20 years (from county planning documents). Future seasonal CAFO water demand was simulated based on reported 2017-2021 withdrawals.

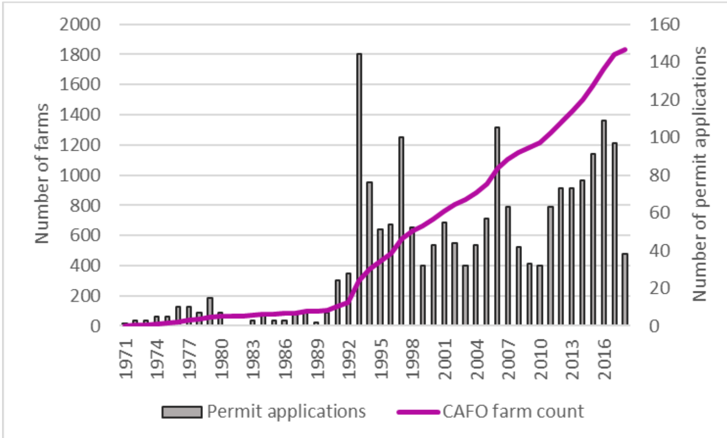


Figure 42. Number of CFO/CAFO permit applications and cumulative CAFO farm count in Indiana. The Southeast-Central Indiana region has some of the highest densities of hog, poultry, and dairy operations in the state, with most of the farms in Decatur, Rush, Shelby, and Jackson Counties (IDEM; see Appendix A).

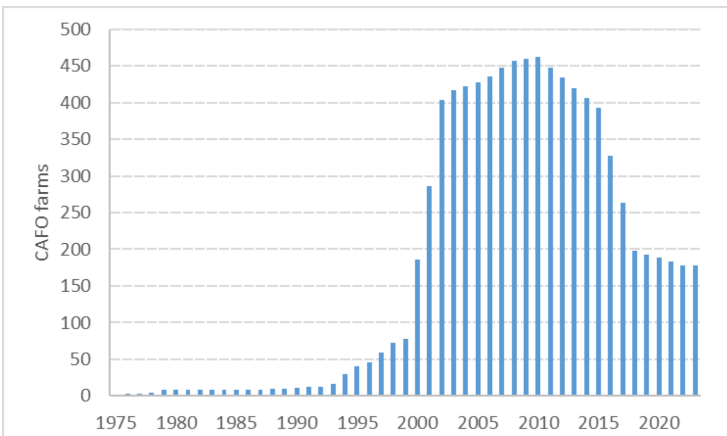


Figure 43. Number of CAFO farms in the Southeast-Central Indiana region from 1980 to 2022. Although the number of regulated farms has declined in recent years, the number of animals in many facilities has increased (see Appendix A).

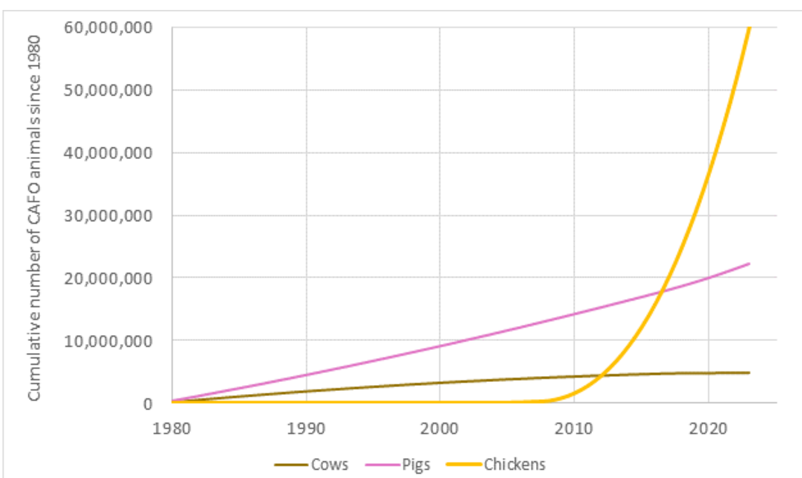


Figure 44. Cumulative number of CAFO animals in Southeast-Central Indiana by animal type (see Appendix A).

Commercial and Industrial

Mining (quarries, aggregate, sand and gravel pits, asphalt, concrete, etc.) dominate the self-supplied Industrial water-use sector with 2,726 MG of mining use from 14 facilities (13 reporting water use in 2021) compared to 324.5 MG of non-mining use in 2021 from 6 facilities (4 reporting use in 2021). Many more non-mining industrial uses are supported by public water utilities (~1700 MG in 2021) than are self-supplied. The spatial distribution of water sources (i.e., aquifers) or proximity to streams or rivers governs where water uses can be self-supplied. Wastewater returns are reported through the NPDES and were used exclusively to represent mining and non-mining industrial returns. For the future demand projections, the overall growth in the industrial sector was based on a rate of 5% per 20 years (from county planning documents). Future seasonal Industrial water demand was simulated based on reported 2017-2021 withdrawals.

Domestic Self-Supplied Water

Estimates from 2015 for domestic self-supplied population and water use are provided in Dieter et al. (2018), but updated estimates are provided here because the self-supplied residential population is a sizeable fraction of demand in the Southeast-Central Indiana region. To estimate the self-supplied residential population in the study area, a refined version (agricultural residences added) of the National Address Database (US DOT, NAD) dataset was processed to identify and classify all residential addresses. These address points were compared to known utility service areas (Figure 2) and points falling outside of all service areas were selected ("unserved" population). The unserved residential addresses were linked to their respective counties, and the average number of people per household in each subbasin was calculated using 2020 Census Tract data (U.S. Census, S1101 dataset). Finally, the number of unserved residential addresses in each subbasin were multiplied by the average number of people per household in that county to arrive at an unserved residential population estimation, which was used for the estimate of self-supplied residential ("domestic") water users. See Appendix A for in-depth details of the estimation process.

Historical Water Availability Assessment

This part of the study seeks to comprehensively evaluate the sustainability of flows within subbasins located in the Southeast-Central Indiana region, with a particular emphasis on understanding the interplay between inherent natural dynamics and human-driven modifications. This analysis encompassed a total of 21 HUC10 subbasins (Figure 45, and Appendix F) that fall within a broader 3-HUC8 region. The temporal frame of our dataset spanned from 2007 through 2075.

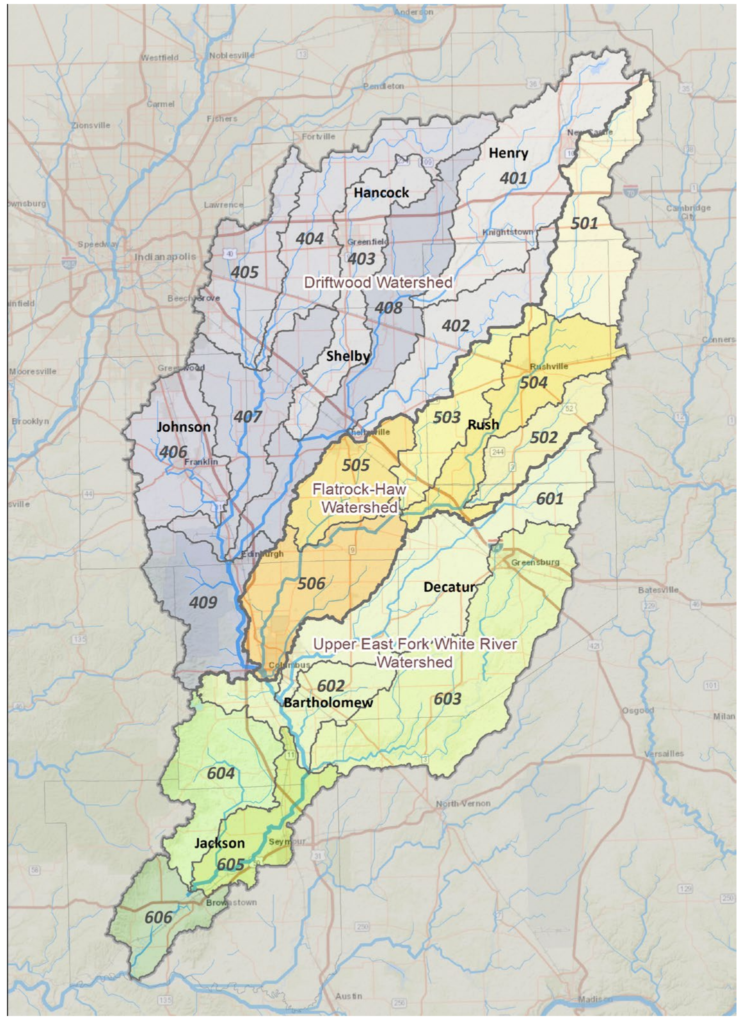


Figure 45. 10-digit hydrologic unit codes used in the water availability analysis. Subbasin codes for water utilities can be found in Tables G1 and G2 in Appendix G.

The mechanics of the water availability approach closely follow IFA (2021; Phase III: Water Availability, Chapter 2) and included the preparation of an anthropogenic inventory of water withdrawals (outflows) and returns (inflows) from non-consumptive or partially non-consumptive uses (Figure 46, see Appendix E). The public water utility future demand forecasts (Water Demand Forecasts – Public Water Utilities; Table 6, Table 7, Table 8, and Table 9) were used in this analysis, along with water-demand projections for the other water-use sectors described above. The public-supply demand models were re-apportioned from county-level totals into their respective subbasins. Because the public-supply water sector dominates the water withdrawals in this region, the locations of withdrawals greatly affect the water balance in those subbasins (Table 10 and Table 11; Figure 47 and Figure 48; see Appendix G).

As mentioned previously, the availability assessment is a spatially distributed analysis, which is based on natural and anthropogenic water flows throughout the stream network, organized by sub-watersheds or subbasins (see Appendix F). The analysis employed the IFA (2021; Phase III: Water Availability, Chapter 2) concept of "**natural streamflow**" and "**natural baseflow**" to understand the spatial distribution of hydrogeological processes in the study area.

Natural streamflow is the streamflow that would be measured if anthropogenic (man-made) effects of surface-water and groundwater withdrawals and wastewater return flows were removed. Natural baseflow is the groundwater portion of streamflow from the water exchange between aquifers and 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) influences such as water withdrawals or wastewater-return flows.

To estimate excess water availability in each subbasin, the natural baseflow was compared to net returns (wastewater returns minus water withdrawals) and instream-flow requirements. A positive value represents excess water availability after other requirements have been met, whereas a negative value represents a water deficit. Appendix F provides additional details on the historical and future excess water availability assessment. This portion of the report (Water Availability Assessment) will focus on the results and implications of the analysis.

The calculations were conducted for each subbasin and produced annual totals, as well as seasonal (winter/spring/summer/fall) estimates of excess water availability. As throughout this report, the combination of acute seasonality of precipitation, aquifer recharge, and water demand along with the dominance of consumptive water uses in the region results in seasonal water deficits that could become commonplace as the climate warms.

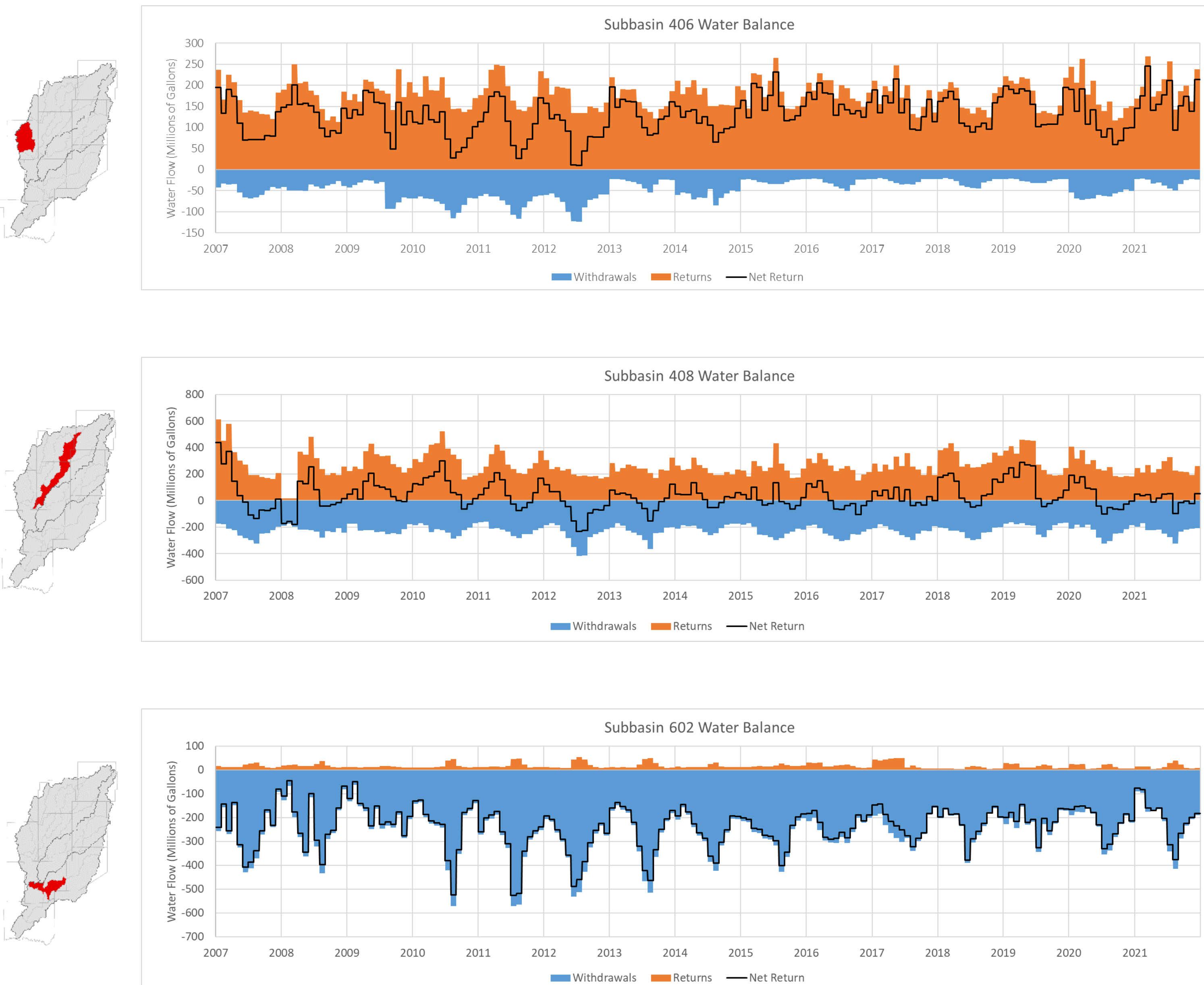


Figure 46. Three examples of anthropogenic water balances for HUC10 subbasins in the Southeast-Central Indiana region. The graphs show examples of subbasins where non-consumptive water returns (e.g., NPDES wastewater returns; portions of residential, irrigation, and CAFO water use) exceed the volumes withdrawn (Subbasin 406, top); have equivalent returns and withdrawals, although exhibiting seasonality (Subbasin 408, middle); and where irrigation and public supply withdrawals exceed man-made discharges/returns (Subbasin 602, bottom).

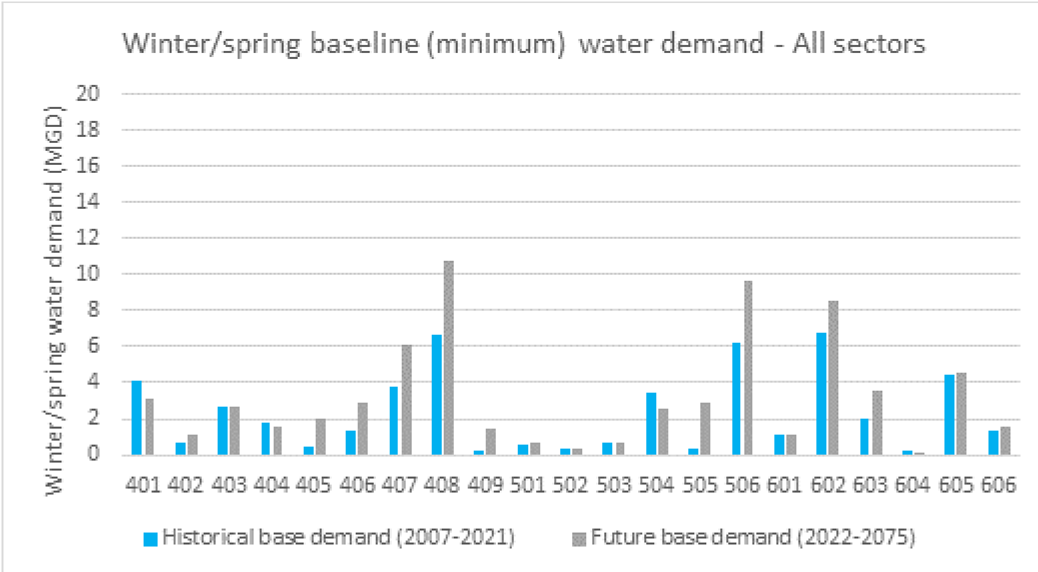
Table 10. Water withdrawals and wastewater returns for the Southeast-Central Indiana region (Driftwood, Flatrock/Haw, and East Fork White River Watersheds) for 2021. This table is patterned after a table in Wiener et al. (2016) that tabulated withdrawals and wastewater returns (referred to as “discharges”) for subbasins in the Wabash River Basin in Indiana in 2007.

2021 Inventory MGD	EP		IN		IR		MI		PS		RU		Estimated (GW)		Measured	Estimated			Rtrn/
HUC10*	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	Self-Supplied	CAFOs	Discharges NPDES	Returns CAFO/SS/IR	Total Withdrawals	Total Returns	With Ratio
0512020**401**	0	0	0	0	0.027	0.017	0	0.004	0	2.711	0	0	0.846	0.096	5.974	0.815	3.702	6.789	1.8
0512020**402**	0	0	0	0.107	0	0.017	0	3E-05	0	0	0	0	0.284	0.091	0	0.285	0.498	0.285	0.6
0512020**403**	0	0	0	0.003	0.003	0.264	0	0	0	2.047	0	0	0.548	0.094	3.463	0.582	2.959	4.046	1.4
0512020**404**	0	0.027	0	0	0	0	0	0	0	0.785	0	0	0.976	0.079	0.432	0.924	1.867	1.356	0.7
0512020**405**	0	0	0.307	0	0.081	0.092	0	0	0	0.002	0	0	0.230	0	1.891	0.248	0.711	2.140	3.0
0512020**406**	0	0	0	0.004	0.002	0.235	0	0	0	0.032	0	0	0.701	0.040	5.836	0.707	1.012	6.543	6.5
0512020**407**	0	0	0	0.755	0.034	1.225	0	0	0	3.499	0	0	0.541	0.083	0.260	0.772	6.137	1.032	0.2
0512020**408**	0	0	1.51	0	0	0.448	0	0	0	4.915	0	0.016	0.653	0.115	7.253	0.720	7.656	7.973	1.0
0512020**409**	0	0	0	0	0.054	0.492	0	0.091	0	0	0	0	0.157	0	1.459	0.255	0.794	1.715	2.2
0512020**501**	0	0	0	0	0	0	0	0	0	0.033	0	0.025	0.259	0.263	0.236	0.294	0.580	0.530	0.9
0512020**502**	0	0	0	0	0	0	0	0	0	0.044	0	0	0.093	0.115	0.063	0.109	0.252	0.172	0.7
0512020**503**	0	0	0.208	0	0	0	0	0	0	0.063	0	0	0.163	0.172	0.404	0.186	0.607	0.590	1.0
0512020**504**	0	0	0.332	0	0	0	0	0	1.607	0.911	0	0	0.265	0.222	2.250	0.290	3.337	2.541	0.8
0512020**505**	0	0	0	0	0	0.061	0	0.182	0	0.007	0	0	0.326	0.011	0.194	0.317	0.587	0.512	0.9
0512020**506**	0	0	2.012	2E-04	1.087	3.004	0.006	0	0	3.784	0	0	0.355	0.135	8.986	1.175	10.382	10.161	1.0
0512020**601**	0	0	0	0	0.006	0.137	0	0	0	0	0	0	0.152	1.077	0.040	0.386	1.372	0.426	0.3
0512020**602**	0	0	2.483	0.01	0.027	0.852	0	0	0	3.698	0	0	0.018	0	0.298	0.193	7.088	0.490	0.1
0512020**603**	0	0	0	0	0	0.002	0	0	0.129	0.501	0	0.535	0.297	0.249	4.612	0.326	1.712	4.938	2.9
0512020**604**	0	0	0	0.027	0	0	0	0	0	0	0	0	0.033	0.080	0.055	0.047	0.140	0.102	0.7
0512020**605**	0	0	0.792	0	0.024	1.324	0	0	0	3.777	0	0.004	0.103	0.504	4.714	0.466	6.528	5.179	0.8
0512020**606**	0	0	0.117	0	0.04	0.28	0	0	0	1.337	0	0	0.016	0.075	0.418	0.093	1.864	0.512	0.3
SW Total	0.00		7.76		1.38		0.01		1.74		0.00						10.89		
GW Total		0.03		0.90		8.45		0.28		28.15		0.58					48.90		
All Total	0.03		8.66		9.83		0.28		29.88		0.58		7.02	3.50	48.84	9.19	59.79	58.03	1.3**

* Driftwood Watershed, HUC10 – 400 subbasins
Flatrock/Haw Watershed, HUC10 – 500 subbasins
East Fork White River Watershed, HUC10 – 600 subbasins
** average wastewater return/withdrawal ratio of all subbasins

Table 11. Subbasin comparison of historical baseline (minimum demand in winter/spring) and peak (maximum, summer/fall) water demand in MGD (all sectors) for 2007-2021 to projected future baseline and peak demand for 2022-2075. Maps and tables in Appendix G provide a cross-reference to identify the HUC10 subbasin locations for sources and service areas of public water supply utilities. See Appendix D for county-level historical and projected future monthly peaking factors. See Figure 45 for an index map showing the locations of the subbasins referenced in the table.

SUBBASIN	Historical Baseline (MGD)	Historical Peak (MGD)	Future Baseline (MGD)	Future Peak (MGD)	Change in Baseline (MGD)	Change in Peak (MGD)
401	4.06	4.38	3.07	3.3	-0.99	-1.08
402	0.64	0.75	1.16	1.29	0.52	0.54
403	2.71	3.44	2.69	3.22	-0.01	-0.23
404	1.77	1.87	1.61	1.75	-0.16	-0.12
405	0.47	0.9	1.98	2.51	1.51	1.61
406	1.39	1.71	2.88	3.57	1.49	1.86
407	3.82	6.01	6.1	8.88	2.28	2.88
408	6.67	8.39	10.75	13.55	4.07	5.16
409	0.22	1.67	1.45	3.1	1.23	1.43
501	0.57	0.65	0.69	0.75	0.12	0.11
502	0.37	0.43	0.29	0.32	-0.08	-0.11
503	0.71	0.76	0.7	0.75	-0.01	-0.01
504	3.42	3.46	2.59	2.48	-0.83	-0.98
505	0.36	0.52	2.92	3.19	2.56	2.66
506	6.24	15.06	9.65	19.32	3.41	4.26
601	1.09	1.9	1.12	1.81	0.03	-0.09
602	6.75	9.82	8.51	11.22	1.76	1.40
603	2.02	2.45	3.59	4.03	1.56	1.58
604	0.2	0.24	0.12	0.13	-0.09	-0.11
605	4.43	8.58	4.55	8.21	0.12	-0.37
606	1.39	2.24	1.52	2.47	0.13	0.23
DRIFTWOOD	2.42	3.24	3.52	4.58	1.11	1.34
FLATROCK-HAW	1.95	3.48	2.81	4.47	0.86	0.99
UPPER EAST FORK WHITE	2.65	4.2	3.23	4.64	0.59	0.44
TOTAL: PATOKA-WHITE	2.35	3.58	3.24	4.56	0.89	0.98



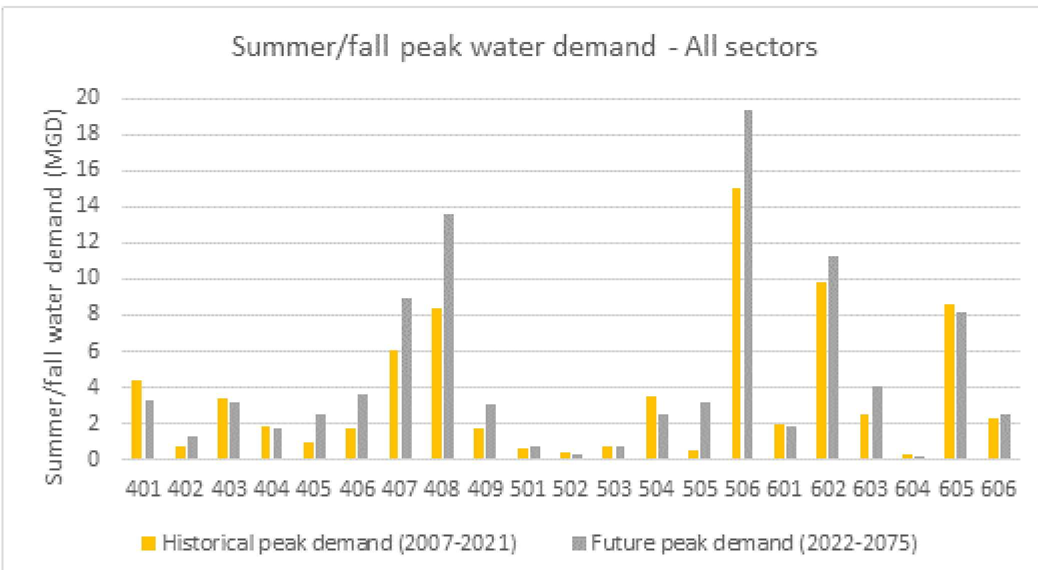
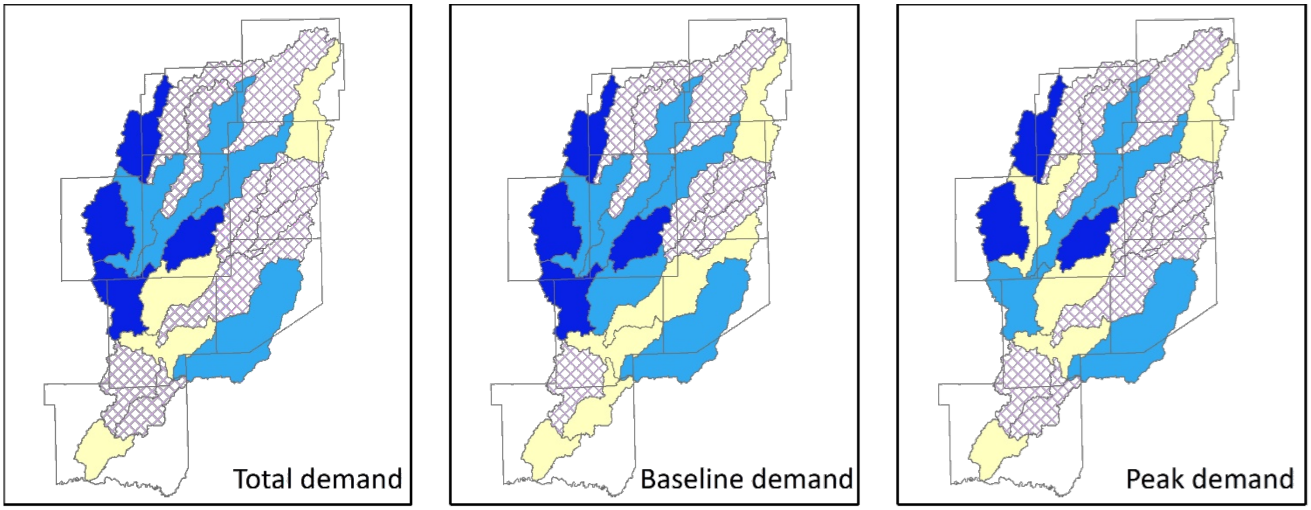


Figure 47. Subbasin-level comparison of historical (2007-2021) and future (2022-2075) daily baseline (minimum) and peak (maximum) water demand with all water-use sectors aggregated.



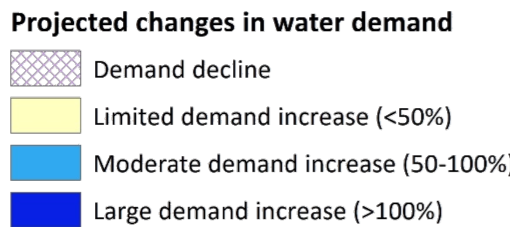


Figure 48. Mapped projected changes in total (left), baseline (minimum; middle graph), and peak (maximum, right graph) demand between 2020 and 2070. Large percentage increases are projected for the western, central, and eastern edges of the Southeast-Central Indiana region. Some demand declines are projected for some of the rural areas of the region. See Figure 45 and Appendix G for index maps and tables of the subbasins.

Future Water Availability Forecast

Following IFA (2021) the natural baseflows calculated for the 2007-2021 period were used in estimates of future water availability from 2022-2075. Appendix F provides the details of how projections of future climate and future water balance in the Southeast-Central Indiana region were used to classify each of the years to assign a realistic natural baseflow and match the projections that drove the future public utility water demand projections. Doing this best represents the interaction of natural and anthropogenic variables likely to occur in different climate conditions and should provide insight into conditions that might strain public water utilities in the future.

This section focuses on the results and implications of the future water availability forecast for the 21 HUC10 subbasins in the Southeast-Central Indiana region. Most years have dramatic seasonal variations in water availability, with most recharge, baseflow, and streamflow occurring in the winter (Dec-Jan-Feb) and spring (Mar-Apr-May). Very little recharge occurs in the summer (Jun-Jul-Aug) and fall (Sep-Oct-Nov), and baseflow during those seasons represents contributions from stored groundwater. Table 12 presents a summary of the summer future excess water availability (MG) calculated for each subbasin. Negative values represent insufficient water supply. Appendix G includes results presented for each season in tabular form.

Table 12. Table of summer historical and projected future excess water availability (MG) in the Southeast-Central Indiana region for each HUC10 subbasin. See Figure 45 for an index map showing the location of the subbasins in this table. See Appendix G for excess water availability results for each season in tabular form.

Subbasin	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075
401	48.17	50.83	6.40	-2.56	50.03	6.85	10.59	6.73	36.03	6.24	36.15	-4.55	-4.43	36.33
402	56.31	8.93	17.25	2.88	55.36	12.67	16.53	12.39	41.81	12.50	42.02	0.96	0.80	42.07
403	59.09	62.21	18.27	6.27	58.73	15.01	19.08	14.93	44.34	14.34	44.09	3.23	3.21	43.87
404	56.09	59.08	17.28	3.46	56.09	12.73	16.79	12.60	42.41	12.56	42.33	1.32	1.29	42.23
405	35.55	44.81	16.44	2.33	34.32	14.55	14.57	14.20	22.98	14.09	22.48	0.04	0.37	22.36
406	41.17	113.14	29.14	9.08	40.04	34.62	26.60	33.41	37.74	33.16	37.53	3.10	2.98	37.15
407	73.61	46.33	45.86	-4.31	70.22	64.78	44.82	59.82	80.40	63.60	79.87	-18.11	-18.14	79.68
408	255.93	305.57	118.63	29.75	246.25	113.08	115.46	109.93	218.52	110.88	217.11	3.64	3.43	218.09
409	33.24	36.99	79.25	47.90	32.53	138.51	77.95	139.08	179.77	137.99	179.32	10.65	10.77	179.10
501	34.15	10.53	15.11	2.31	34.11	14.85	14.99	14.84	23.35	14.84	23.34	0.95	0.96	23.34
502	57.05	10.03	17.74	4.49	57.15	13.87	17.96	13.89	43.67	13.87	43.68	2.72	2.69	43.68
503	56.80	10.60	18.00	4.64	57.27	14.01	18.13	14.05	43.80	14.01	43.85	2.88	2.82	43.82
504	125.11	187.15	68.89	14.68	126.39	64.00	69.63	64.20	125.56	63.76	125.55	6.24	6.35	124.85
505	34.64	11.22	15.77	0.67	32.41	13.23	13.15	12.73	21.29	12.81	21.16	-1.51	-1.57	20.83
506	-8.25	-5.65	93.17	77.90	5.08	154.08	85.56	144.21	201.55	154.49	204.42	32.41	33.03	205.94
601	63.00	101.88	30.81	3.78	68.97	29.29	30.95	29.50	57.52	28.95	57.49	1.42	1.55	57.71
602	45.95	84.77	20.25	-1.39	58.20	23.55	23.58	18.74	46.00	23.10	45.99	-5.79	-5.02	46.61
603	6.70	18.36	15.88	17.98	4.05	-0.50	12.00	-1.48	-0.94	-1.67	-1.17	0.59	0.42	-3.33
604	34.05	10.46	15.05	-1.36	30.52	11.06	11.07	10.08	19.03	10.30	18.51	-4.48	-4.60	17.71
605	259.06	260.13	106.30	-50.75	373.30	195.03	111.98	191.77	43.36	194.45	45.36	-51.01	-52.24	44.84
606	120.64	124.71	94.77	24.02	137.99	121.92	95.31	120.92	130.79	122.03	130.97	-2.09	-1.89	130.84

Because large tables of data are useful for reference, but less intuitive for data synthesis and interpretation, a range of maps (Figure 49 and Figure 50) and figures (Figure 51, Figure 52, and Figure 53) were developed to present the data in a format that demonstrates the importance of the seasonality of climate and demand in the resultant excess water availability in the Southeast-Central Indiana region. The captions contain additional discussion.

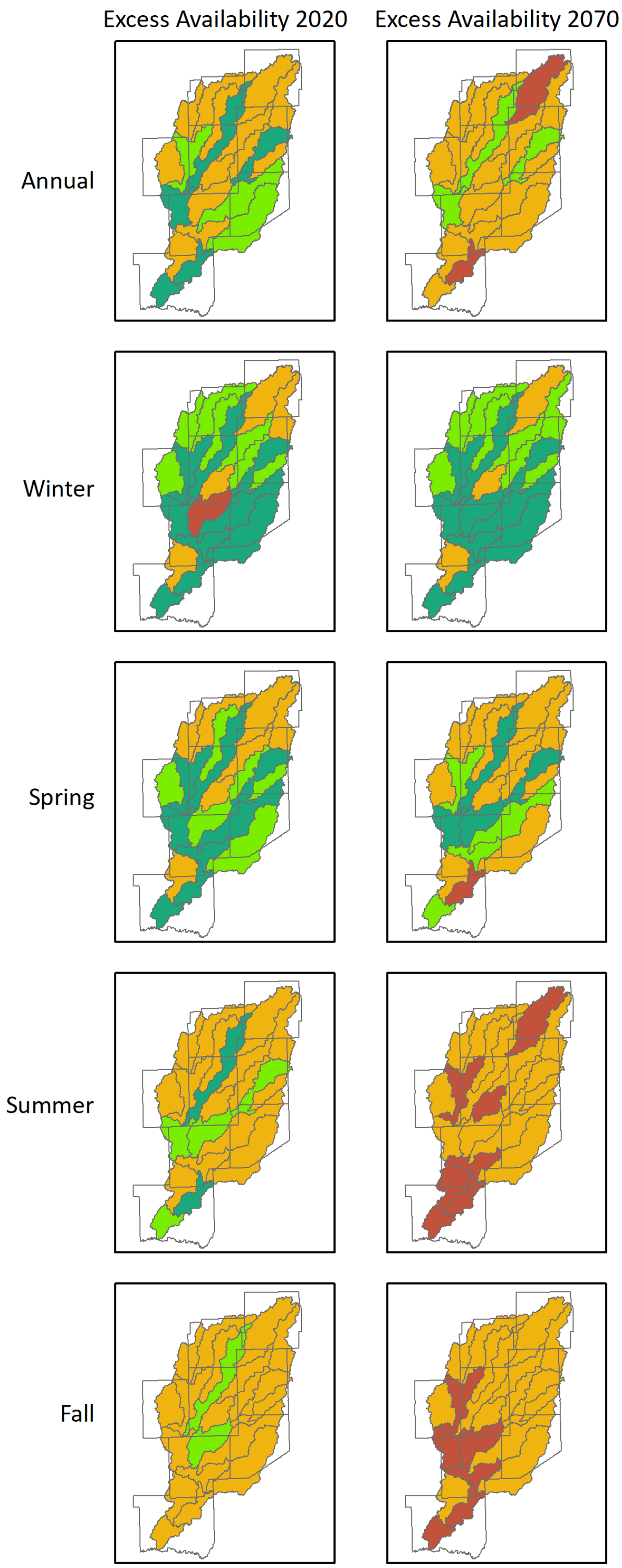


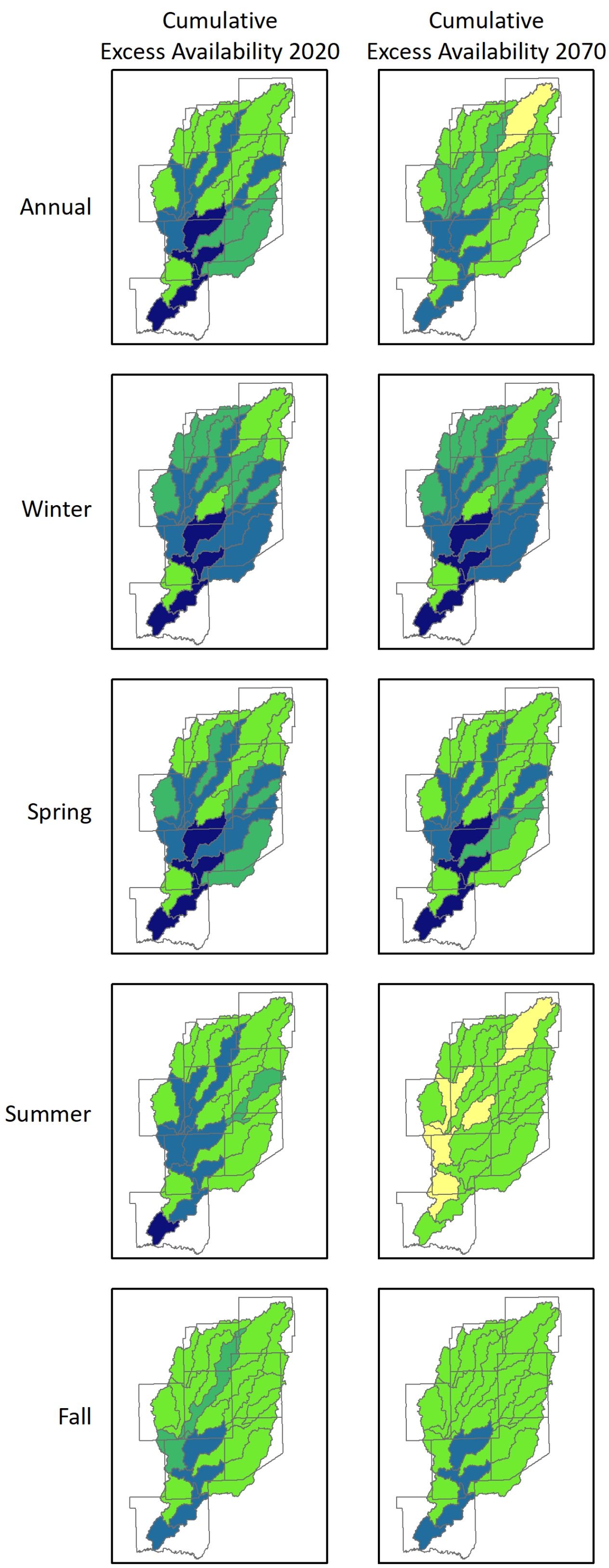
Figure 49. Maps showing examples of historical (2020) and future (2070) excess water availability for the HUC10 subbasins in the Southeast-Central Indiana region. See Figure 45 and Appendix F & G for index maps and tables of the subbasins.

This analysis includes both natural (rain, evaporation, soil and plant water uptake, recharge) and anthropogenic (man-made; water withdrawals and returns) factors, and also allows for seasonal instream flows before a final calculation of excess water availability.

The maps show snapshots of recent (2020) and projected future (2070) future excess water availability in the subbasins in the study area. As other elements of this analysis have shown, there is strong seasonality to the annual water cycle in this region, with winter and spring having a larger buffer of excess water after withdrawals and instream-flow needs than is experienced during summer and fall each year.

Further, the projected future conditions show the potential for many of the subbasins to experience more extreme water deficits or low excess water availability for a longer fraction of the year.

These snapshots only show examples of conditions that could occur with projected future climate conditions and water use. The 2070 example does not represent persistent or average conditions. Please see Figure 51, Figure 52, and Figure 53 for presentation of the variability of possible future water-availability conditions in the watershed.



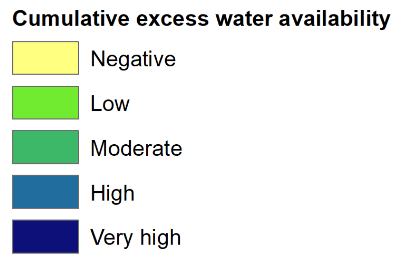
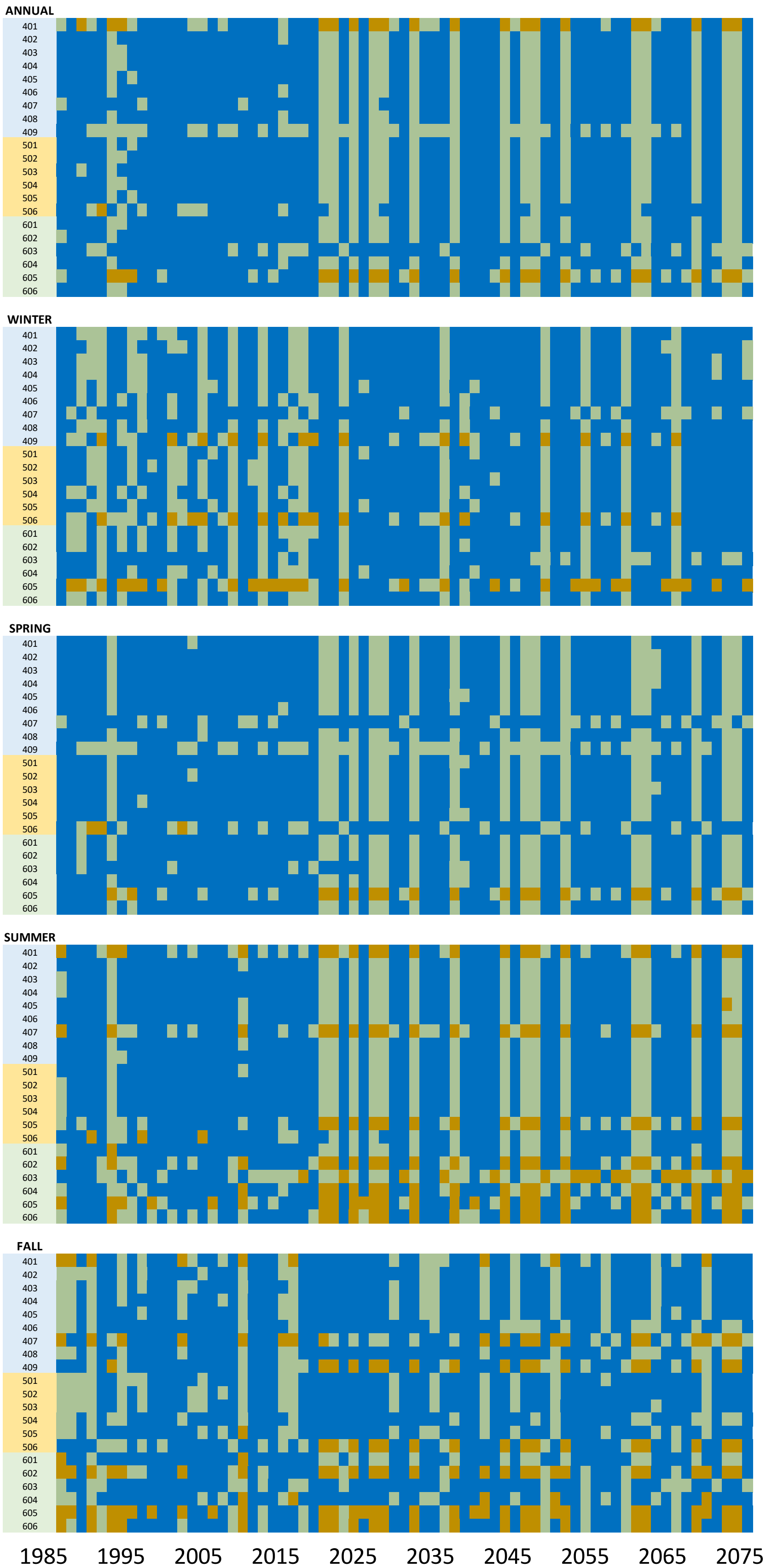


Figure 50. Maps showing examples of historical (2020) and future (2070) cumulative excess water availability for the HUC10 subbasins in the Southeast-Central Indiana region. See Figure 45 and Appendix F & G for index maps and tables of the subbasins.

The maps show snapshots of recent (2020) and projected future (2070) future cumulative excess water availability in the subbasins in the study area.

Cumulative excess water availability incorporates the receipt of water from upstream basins throughout the stream network, generally additive moving downstream. Because this analysis incorporates man-made water withdrawals and wastewater returns, in addition to instream ecological water needs, there are some subbasins in some seasons (e.g., summer) that experience negative (deficit) cumulative excess water availability. This means there is insufficient water remaining to meet all of the needs for that season (shown in yellow).

These snapshots only show examples of conditions that could occur with projected future climate conditions and water use. The 2070 example does not represent persistent or average conditions. Figure 52 presents every month of projected cumulative excess water availability for all subbasins in the study area, showing the full range of expected future conditions.



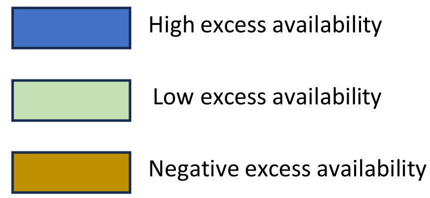


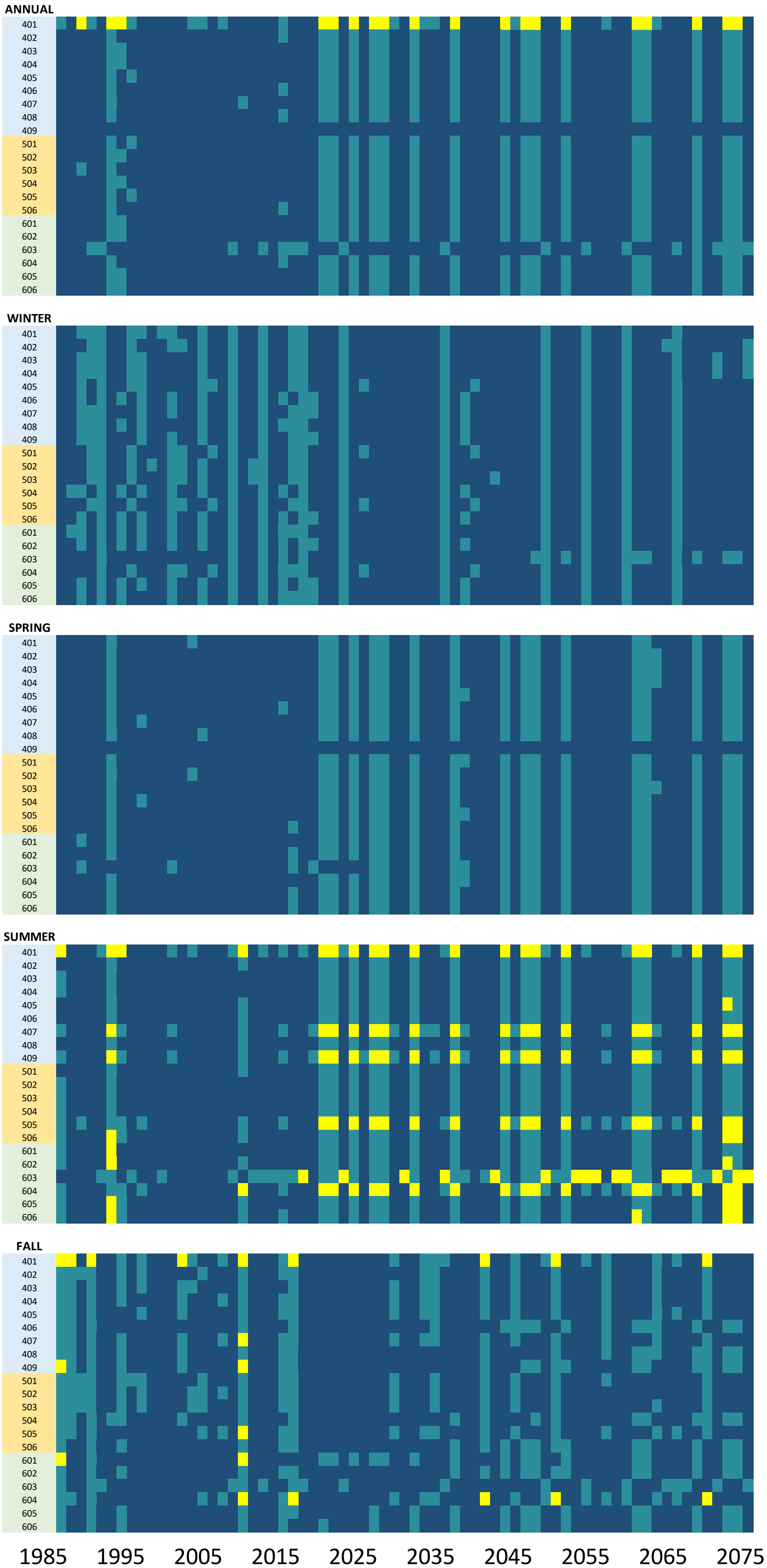
Figure 51. These classified colorbar plots show the historical (1985-2021) and future (2022-2075) excess water availability for the HUC10 subbasins in the Southeast-Central Indiana region for the average annual water balance (top) and seasonal water balances (winter, spring, summer, and fall).

The spatial scale is on the y-axis, with the subbasins (see Figure 45 or Appendix F & G for their locations) listed in upstream-downstream order. The time scale is on the x-axis, with historical (observed) conditions to the left and future (forecast) conditions to the right.

The vertical striping shows that all (or most) basins respond to conditions in the same way in some years (e.g., a wet year or a dry year).

The seasonal plots show that the natural and anthropogenic (man-made) inputs and outputs to the water cycle are strongly seasonal, with most of the water availability occurring in the winter and spring (blue/green). Summer and fall have strong natural reductions in precipitation and therefore declines in aquifer recharge and groundwater baseflow in streams, and during the same time water withdrawals are highest. The lack of any excess water availability in some of the subbasins is shown in brown.

Of concern in the future are concurrent years with water-availability deficits; however, the future annual projections shows that the system (as envisioned in this study) largely recovers each year. This suggests adequate water will be available in total, but storage in some subbasins might need to be increased to cover the summer and fall deficits.



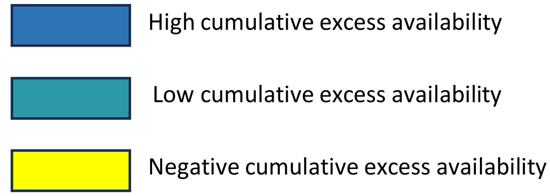


Figure 52. These classified colorbar plots show the historical (1985-2021) and future (2022-2075) cumulative excess water availability for the HUC10 subbasins in the Southeast-Central Indiana region for the average annual water balance (top) and seasonal water balances (winter, spring, summer, and fall).

The spatial scale is on the y-axis, with the subbasins (see Figure 45 or Appendix F & G for their locations) listed in upstream-downstream order. The time scale is on the x-axis, with historical (observed) conditions to the left and future (forecast) conditions to the right.

Cumulative excess water availability incorporates the receipt of water from upstream basins throughout the stream network, generally additive moving downstream. Because this analysis incorporates man-made water withdrawals and wastewater returns, in addition to instream ecological water needs, there are some subbasins in some seasons that experience negative (deficit) cumulative excess water availability. This means there is insufficient water remaining to meet all of the needs for that season (shown in yellow).

The vertical striping shows that all (or most) basins respond to conditions in the same way in some years (e.g., a wet year or a dry year). Drought years routinely produce low cumulative excess water availability throughout the entire stream network, even in the wet (winter, spring) seasons. Very dry summers and falls can also influence the water balance for the following winters. But throughout the next 50 years, most subbasins are projected to recover from dry seasons as precipitation and groundwater recharge are received over the following non-growing seasons.

Figure 53. These classified colorbar plots show the historical (1985-2021) and future (2022-2075) balance between annual and seasonal aquifer recharge (recall Fig. 37, 38) and anthropogenic (man-made) water withdrawals (pumping) for all of the HUC10 subbasins in the Southeast-Central Indiana region for each year (top) and seasons (winter, spring, summer, and fall).

The spatial scale is on the y-axis, with the subbasins (see Figure 45 or Appendix F & G) listed in upstream-downstream order. The time scale is on the x-axis, with historical (observed) conditions to the left and future (forecast) conditions to the right.

These plots can be used to further understand the strong seasonal partitioning of when water is received and withdrawn, and how much water remains for potential future uses.

In these plots, green colors represent the remainder of annual or seasonal aquifer recharge after withdrawals are made in each subbasin. Because very little recharge occurs in this region in the summer and fall, and seasonal peak (maximum) water withdrawals also occur during these seasons, many subbasins do not have sustainable summer and fall withdrawal rates when compared to the timing of recharge.

Excess water availability is also a factor of: (1) groundwater baseflow contributions to summer and fall streamflow (i.e., aquifer storage), and (2) man-made water returns to the local water cycle offset withdrawals in some subbasins in many seasons. The local natural subbasin characteristics combined with water-use sectors and behaviors make each subbasin unique.

The results below refer to the subbasins in Figure 45. Refer to Tables G1 and G2 in Appendix G for the subbasin assignments for water utility sources and returns.

Driftwood River Watershed (HUC10 “400” Subbasins)

Shelby, Johnson, and Bartholomew Counties are among the fastest growing regions in the study area in terms of water demand. Johnson County is projected to experience some reductions in spring water availability; however, the water availability forecast for Bartholomew County projects abundant future winter availability, adequate spring availability, and dramatic seasonal deficits in future summer and fall water availability. Minimal population growth and therefore small increases in withdrawals for public supply are expected in Henry and Rush Counties

The Driftwood River Watershed drainage system is characterized by large water withdrawals, large return flows, and large seasonal variability in natural baseflow. Negative excess annual and summer availability are forecast periodically (but frequently) for subbasin 401. This includes the Big Blue River upstream from the stream gaging station at Carthage (USGS 03361000) and the city of New Castle. In addition to Carthage and New Castle, the other towns that source their water from this basin are Knightstown, Mount Summit, and Spiceland.

Lower excess annual and negative summer and fall water availability are forecast in 2070 for subbasin 407 along Sugar Creek. Subbasins 407 and 409 are also projected to experience a decline in future summer cumulative excess water availability. This includes the observation wells of Shelby 2 (USGS 393943085490901) and Shelby 3 (USGS 393522085555401), and the gaging station of Sugar Creek near Edinburgh (USGS 03362500). No major towns exist in this basin, and Indiana American – Johnson County is the only utility that sources their water from this basin. Indiana American – Johnson County has wastewater returns located upstream (subbasin 406) of their water withdrawals (subbasin 407).

Flatrock River – Haw Creek Watershed (HUC10 “500” Subbasins)

Part of Shelby and Bartholomew Counties lie in the Flatrock-Haw watershed and have some of the highest anticipated future demands in the study area (subbasins 505, 506).

The winter availability forecast in subbasin 501 along the upper reaches of the Flatrock River remains within similar ranges as past variability. Lewisville is the only utility who sources their water from this subbasin. Lower excess annual and negative summer and fall availability are forecast in 2070 for subbasin 505, as is summer cumulative excess water availability. This includes Lewis Creek in the southern portion of the subbasin and the East Fork of Salt Creek along the western edge. The city of Shelbyville and the town of Prescott are the two main population centers in this basin, and there are no utilities who source their water from subbasin 505.

Higher winter availability is forecast in subbasin 506 along Haw Creek and the Flatrock River, including the City of Columbus and the towns of Taylorsville and Hope. The observation well Bartholomew 4 (USGS 391627085534401) and the gaging stations along Haw Creek at Hope and near Clifford (USGS 03364200), as well as the gaging station on the Flatrock River at Columbus (USGS 03363900) and the East Fork of the White River at Columbus (USGS 03364000) are within this subbasin. Subbasin 506 is the water source for Eastern Bartholomew and is one of two source basins for the City of Columbus.

Upper East Fork White River Watershed (HUC10 “600” Subbasins)

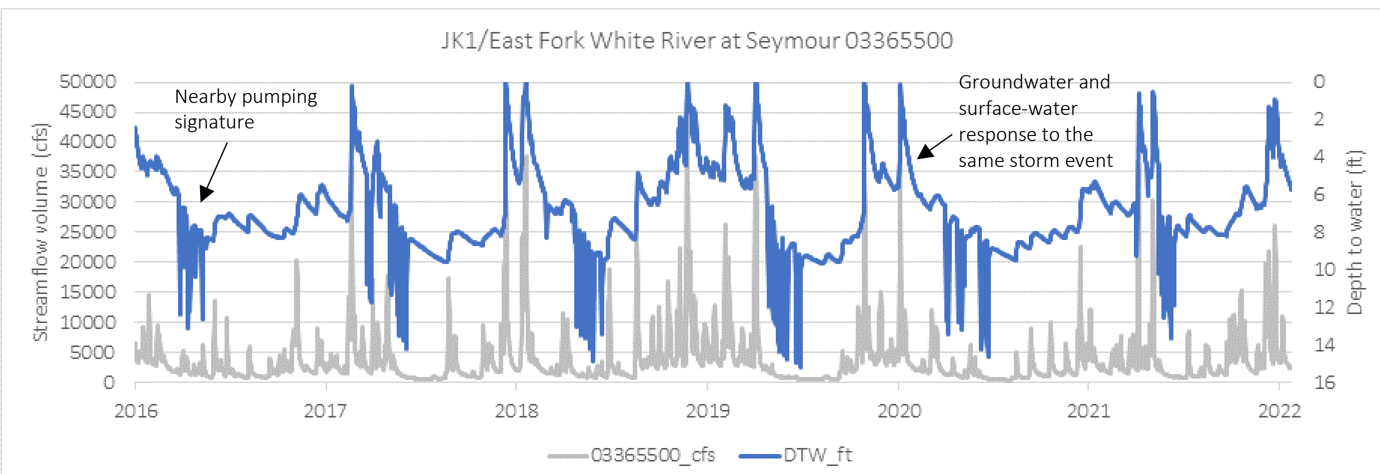
Decatur County joins counties in the Driftwood watershed as among the fastest growing regions in terms of water demand. The Upper East Fork White River and tributaries drainage system is characterized by large water withdrawals from public water supplies and agricultural irrigation, small return flows, and large seasonal variability in natural baseflow. In the period 2007-2021, excess water availability was very low in each subbasin, and has become negative in two downstream subbasins. The negative values are due to periods of extremely low to zero natural baseflow, in addition to excessive anthropogenic effects (withdrawals and returns).

Lower excess annual and negative summer and fall availability are forecast in 2070 for subbasin 601. This includes the towns of Adams, Milford, Hartsville, and part of the city of Columbus. Clifty Creek is the main drainage, with observation well Decatur 2 (USGS 392022085371801) and stream gaging stations on Clifty Creek at Hartsville (USGS 03364500) and near Columbus (USGS 03364650). This subbasin serves as one of two water sources for the city of Greensburg and contains the Honda Manufacturing Plant.

The city of Columbus has wastewater returns (subbasin 506) upstream of the water withdrawals from subbasin 602. Lower summer availability is forecast in subbasin 604 (for both excess and cumulative excess water availability) along White Creek and Cooley Creek. There are no major towns in this basin, and no utilities source water from this subbasin.

Lower excess annual and negative summer and fall availability are also forecast in subbasin 605 along the East Fork White River near the stream gaging station at Seymour (USGS 03365500) and observation well Jackson 1 (JK1; USGS 385542086005601). Indiana American – Seymour sources their water from this basin as well as Jennings Water. The towns of Jonesville and Reddington are also within this basin. This observation well monitors groundwater levels in the glacial outwash aquifer. The correspondence of peaks in the observation-well hydrograph (showing water-table rises) to stream-discharge peaks reflects connectivity between the surface and groundwater systems in this area (Figure 54). The immediate response of the groundwater table to storm events suggests an unconfined system with little lag between receipt of precipitation and aquifer recharge. The clusters of dips in the groundwater-level hydrograph record nearby irrigation pumping in the summer, which is pulling water from the same aquifer as the observation well.

Lower annual, summer, and fall availability are forecast in subbasin 606 along the East Fork of the White River downstream from observation well Jackson 1 (USGS 385542086005601). The towns of Brownstown, Medora, and Vallonia are in this subbasin and both Jackson County utility and Medora source their water from this subbasin.



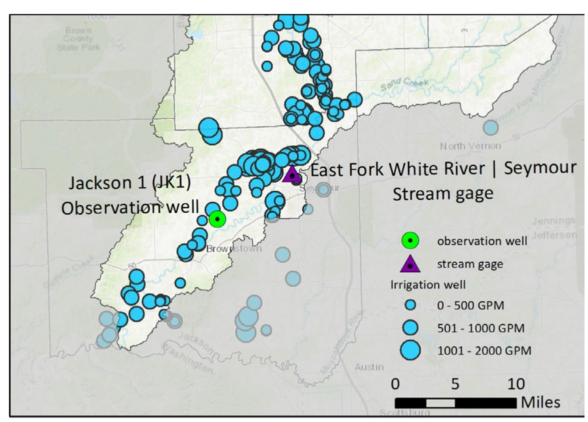


Figure 54. This plot shows hydrograph data for groundwater levels (blue, depth to water [DTW, ft] on right axis) and streamflow volume (discharge) data (gray, streamflow volume [cubic feet per second] on left axis). The monitoring locations are shown on the map to the right.

Risks to the water supply

Utilities in the Southeast-Central Indiana region confront multiple challenges, from water source vulnerabilities and regulatory requirements to revenue and affordability constraints. Addressing these can bolster the robustness and resilience of utilities, positioning communities to grow intentionally, strategically, and sustainably.

Risks to the water supply range from natural or intrinsic factors such as low-productivity aquifers or seasonality of aquifer recharge or river discharge to threats from man-made activities. There are many of these including aging infrastructure, insufficient or non-resilient water distribution system designs, operation and compliance, and endangerment of the shared water resource by overpumping or contamination of surface water and groundwater aquifers. Affordability is a topic not covered in this report in any detail, but barriers to affordable clean water supplies for consumers is as problematic as insufficient rates, highlighting the need to ensure that water utilities can maintain, adapt, and grow as necessary to support their communities. A water utility professional lamented at the recent Indiana Water Summit (Indianapolis, August 10, 2023; https://thewhiteriveralliance.org/programs/water-summit/past-water-summits/2023-indiana-water-summit) that cost-saving measures by homeowners or businesses through passive (water-saving appliances) or active (behavioral changes) practices do not benefit the water utility in the same way because the infrastructure, operation, and maintenance of the supply, treatment, and distribution system has to be completely functional from source to use no matter the amount of water going through the pipe. That was an important reminder that public water utility investments benefit all customers and appropriate operational revenue structures are integral to a safe and sustainable water supply into the future.

Table 13 lists risks to the water supply or distribution for each county in this study. The factors considered include:

Source Water Vulnerability: Utility/utilities in the county identified as having potential vulnerabilities related to intrinsic properties such as aquifer type or extent (Figure 56; Figure 57), surface water with limited baseflow contributions from groundwater, or surface or groundwater contamination (natural or man-made; Figure 58).

Seasonally Limited Supplies: The water availability analysis shows risks to the water supply from the integrated inquiry into water withdrawals, extractions, and seasonality of natural flows. It highlights issues regarding spatial separation of withdrawals versus returns and how the local hydrology can be affected. It also identifies subbasins where summer and fall water withdrawals for public supplies and irrigation greatly exceed seasonal recharge and stored groundwater contributions to baseflow. Locations that are susceptible to drought conditions are included in this category.

Infrastructure limitations: Public water utilities can have capacity constraints through either source water (i.e., accessed by wells or intakes), treatment facilities, insufficient storage, or underdeveloped / aging distribution networks. Details in Preliminary Engineering Reports (when available) can reveal limitations in one or more factors, and if at least one utility in a county had such limitations, it was noted.

Compliance: Utility/utilities in the county identified as having regulatory compliance challenges indicated by having received multiple notifications of regulatory violations or having been subject to enforcement action in the last five years (U.S. EPA, ECHO database). For this assessment, risks to water quality were included, whereas administrative violations were not.

Affordability: Utility/utilities in the county identified as having affordability challenges to consumers. Included in this assessment was the rate of water, the amount of non-revenue water lost to leaks (>20%), and whether or not combined sewer overflows (CSOs) were present in the county as an indicator of likely costly future infrastructure-investment needs. Water rates greater than $50 for 5000 gallons/month (>150% of state average) were used as the cutoff for consumer affordability concerns (see:

https://www.in.gov/iurc/files/IURC-2022-Water-Billing-Survey-Final.pdf). Note that rates were unavailable for some utilities in the study area.

Outside threats:

Each county has unique factors that provide challenges to public water utility operations. “Outside threats” highlight risks to the utility from factors such as:

- Ongoing water quality concerns from land use or regulated facilities
- Non-sustainable pumping (e.g., irrigation), especially during the summer
- Likelihood of climate impacts owing to excessive heat or infrastructure threats from flooding

Table 13 shows that a significant portion of the Southeast-Central Indiana region is grappling with a wide variety of risks and challenges to offering sustainable and resilient public water supplies. Some solution options might include more utility-to-utility collaboration (e.g., purchase agreements, shared resources), accessing external funding for infrastructure investments to bolster facilities and distribution while shielding the customer base from rate increases, or possibly regionalization of utility water supplies (see IFA, 2018).

Table 13. Risks and challenges to the water supply, aggregated by county. Not all utilities, aquifers, or streams exhibit the same level of risk in each county. In the table below, “Y” indicates that one or more utilities are currently or expected to encounter challenges in one or more areas, whereas “N” indicates that no utilities in the county are facing such challenges.

Counties	Source: Supply or WQ (current)	Seasonal supply limitations (future)	Infrastructure limitations* (current)	Compliance (recent)	Affordability (current)	Outside threats (current/future)
Bartholomew	Y	Y	Y	Y	Y	WQ, Irrigation, Climate
Decatur	Y	Y	Y	Y	N	WQ, Climate
Hancock	N	N	Y	Y	N	WQ
Henry	Y	Y	Y	Y	Y	WQ, Climate
Jackson	N	Y	Y	N	Y	WQ, Irrigation, Climate
Johnson	N	Y	Y	Y	Y	WQ, Climate
Rush	N	N	N	Y	Y	WQ
Shelby	Y	Y	Data gaps	N	N	WQ, Climate

* wells, treatment, distribution/leaks, inadequate storage

Climate Risks

Climate change presents a formidable challenge to water supply, especially with its impact on precipitation patterns. Data presented in this report have shown that on an annual basis, precipitation is increasing, river flows are increasing, and groundwater levels are increasing. Yet, simultaneously, extreme weather events are cause for alarm for water supply management. Intense storms are capable of causing flash floods, jeopardizing water quality and damaging infrastructure. In contrast, severe droughts decrease available water sources and amplify competition for this critical resource.

Historical data and future projections presented in this report have also highlighted seasonality of water availability that introduce another layer of complexity. Water demand (as measured by withdrawals) demonstrates substantial variation across seasons, occasionally pressing the limits of water utilities during peak demand. Seasonal inconsistencies also have implications for agricultural irrigation and ecosystem health.

Streams and rivers of different sizes, flows, and geologic settings have unique combinations of factors that lead to low-flow conditions and stream depletion, and extreme weather events are reflected differently in each setting (see). Aquatic ecosystems and water quality are adversely affected by such conditions.

Figure 55 shows projected future (2050) risk of extreme heat and precipitation from climate modeling utilized by the Environmental Resilience Institute (Hoosier Resilience Index [HRI], see https://hri.eri.iu.edu/climate-vulnerability/index.html). Although the Southeast-Central Indiana region is not extensive, there are still characteristics that vary across the area. How these areas will experience the effects of climate change (such as increasing temperatures and intense rainfall) will also differ depending on their unique factors. The HRI forecasts that effects from extreme precipitation are likely to affect Hancock County to the north as well as Bartholomew and Jackson Counties to the south. Impacts from extreme heat are also projected to affect Bartholomew and Jackson Counties. The geologic setting of the southern counties near the glacial boundary is characterized by thin soils and few aquifers away from the river corridor. The lack of these materials for water retention and storage makes that portion of the region less naturally resilient to extreme or persistent perturbations to the water cycle.

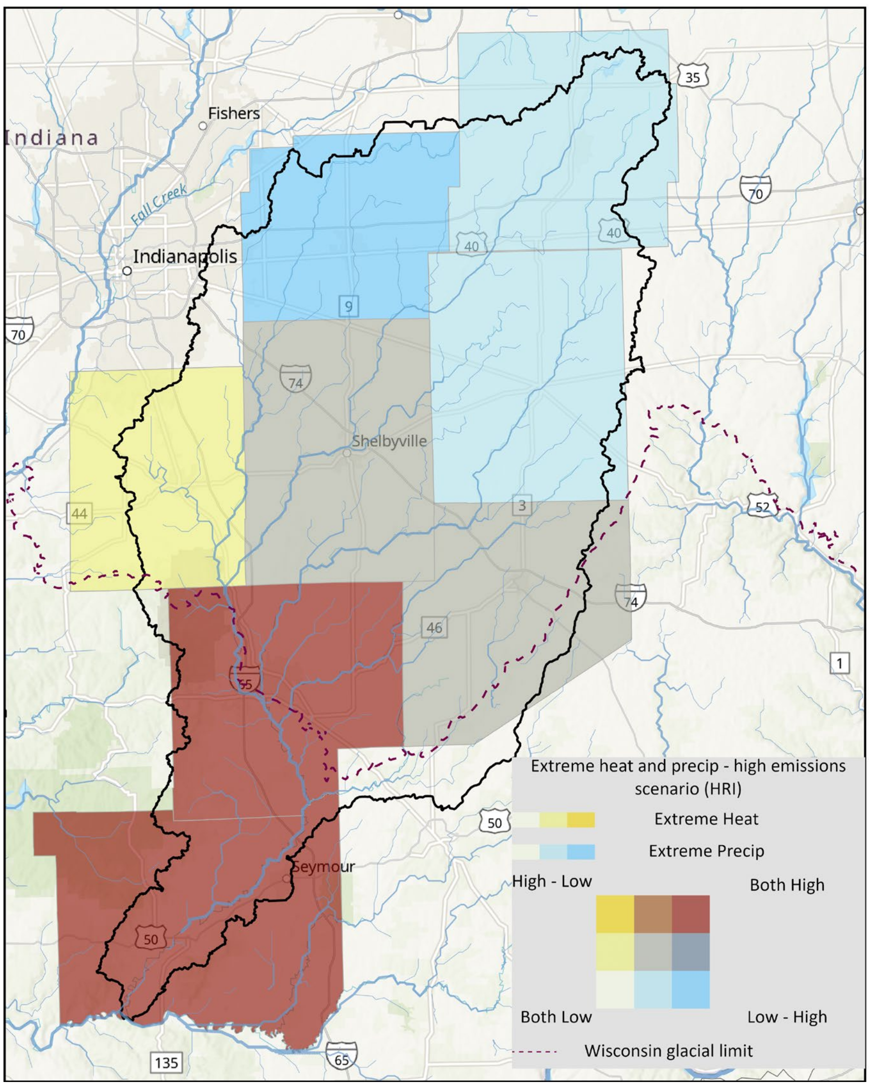


Figure 55. Projected future (2050) risk of extreme heat and precipitation from climate modeling utilized by the Environmental Resilience Institute (Hoosier Resilience Index, see https://hri.eri.iu.edu/climate-vulnerability/index.html). Although the Southeast-Central Indiana region is not extensive, there are still characteristics that vary across the area. How these areas will experience the effects of climate change (such as increasing temperatures and intense rainfall) will also differ depending on their unique factors.

Water Quality

Water quality is a pervasive threat to the region through point sources such as underground storage tanks and industrial discharges to nonpoint sources including nutrients from agricultural runoff and residential septic systems. Some of the geologic materials in the subsurface have naturally occurring ("geogenic") levels of contaminants such as arsenic, although the three-dimensional spatial distribution is heterogeneous and does not affect all water supplies (Letsinger, 2017). Furthermore, emerging contaminants, like per- and polyfluoroalkyl substances (PFAS), are a growing concern for both water availability and quality. Increased runoff from shifts in precipitation intensity can pose additional water quality threats to surface waters and riverside aquifers, such as the glacial outwash aquifers in the Southeast-Central Indiana region. Figure 57 shows the mapped near-surface aquifer sensitivity risk throughout the region, alongside a map showing the distribution of factors that can enhance (e.g., agricultural drainage tiles) or encounter contamination (e.g., outwash aquifers, wetlands).

Because some public water utilities in the region support industrial (and sometimes CAFO) water demand at an equal or greater level than self-supplied industrial facilities in those counties, the water utilities also usually have the challenge of processing industrial wastewater along with the rest of the waste from the regular customer population. Treating industrial wastewater adds expense and risk to the utility and could expose the surrounding community to contaminant residue present in municipal biosolids that are land applied across the region. Such hazards have been identified in other regions in the Midwest US (https://www.michigan.gov/egle/about/organization/water-resources/biosolids).

The Indiana Department of Environmental Management (IDEM) has found evidence of PFAS in some of the public water supplies throughout the state (https://www.in.gov/idem/resources/nonrule-policies/per-and-polyfluoroalkyl-substances-pfas). The chemicals are used in hundreds of types of products and industries.

An overview of surface water quality in the region is provided by the current federal 303(d) listing of impaired waterways (https://www.in.gov/idem/nps/watershed-assessment/water-quality-assessments-and-reporting/section-303d-list-of-impaired-waters), which shows most major rivers and streams in the region to be impaired by a large range of bacterial, biological, and chemical parameters (most of which are from surface migration). Surface-water quality in the past has been impacted by combined sewer overflows. The IDEM Groundwater Section monitors groundwater quality through ongoing sampling in their monitoring network (https://www.in.gov/idem/cleanwater/information-about/groundwater-monitoring-and-source-water-protection/statewide-groundwater-monitoring-network).

Figure 58 is an inventory of known ground- and surface-water contamination (natural and anthropogenic) along with locations of regulated facilities. A large area of the Southeast-Central Indiana region has multiple threats to water quality. With so many water utilities reliant on a single water source (aquifer or river), contamination is a primary threat to a sustainable water supply into the future.

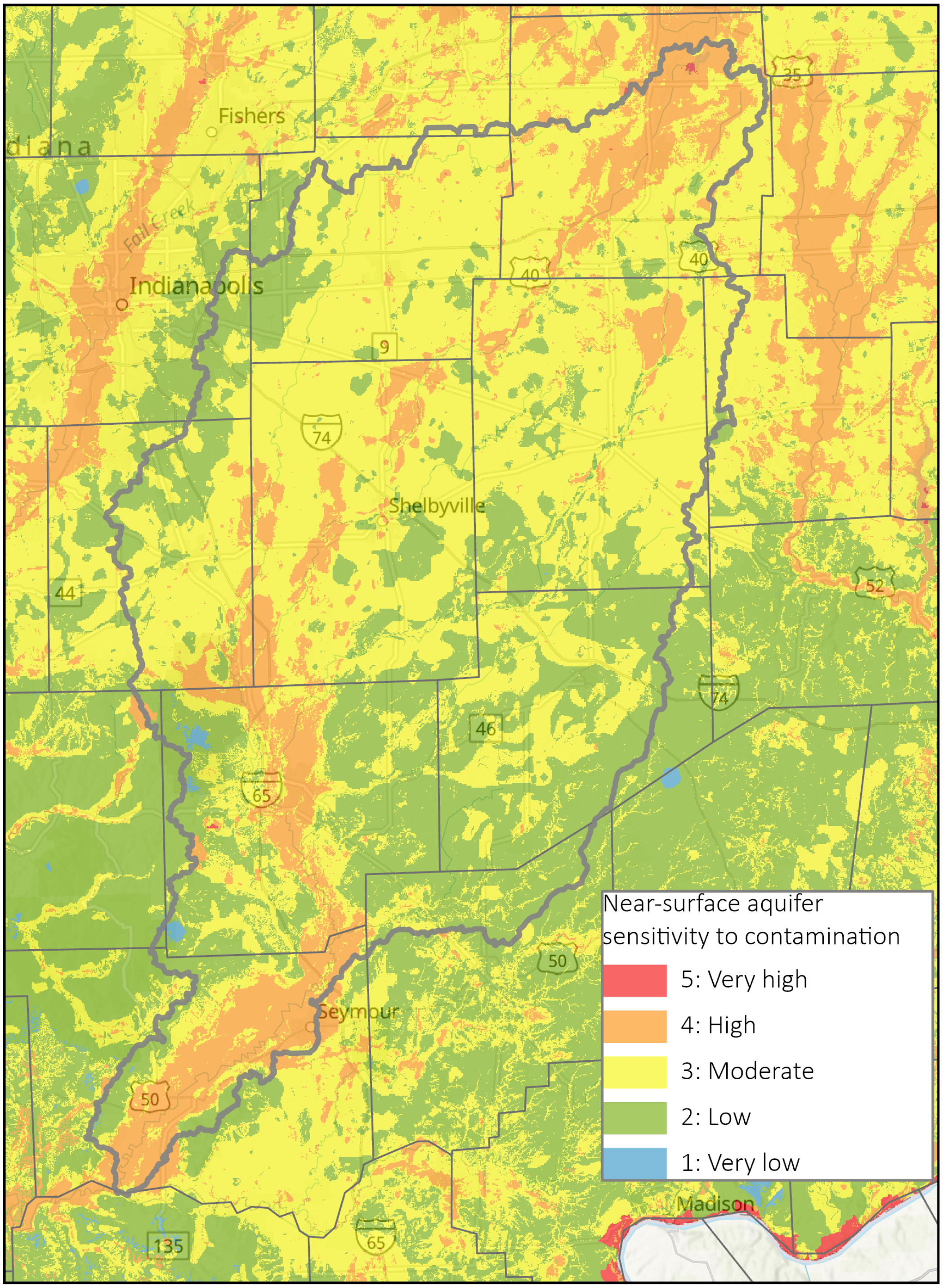


Figure 56. This map shows near-surface aquifer sensitivity to contamination (Letsinger, 2015b). Aquifer sensitivity is the likelihood of contamination owing to site-specific characteristics that control the rate at which water can enter and flow through aquifers. It is a function of the intrinsic properties of geologic materials, land use and land cover, surface topography, and watershed characteristics. On this map, highly sensitive aquifer settings are located adjacent to (and under) the surface-water drainages (streams, rivers) where coarse geologic materials (stream and glacial outwash deposits) are located. The low sensitivity classification in the southern part of the study area is more a result of the lack of aquifers than any inherent conditions that could prevent contaminant migration into the subsurface.

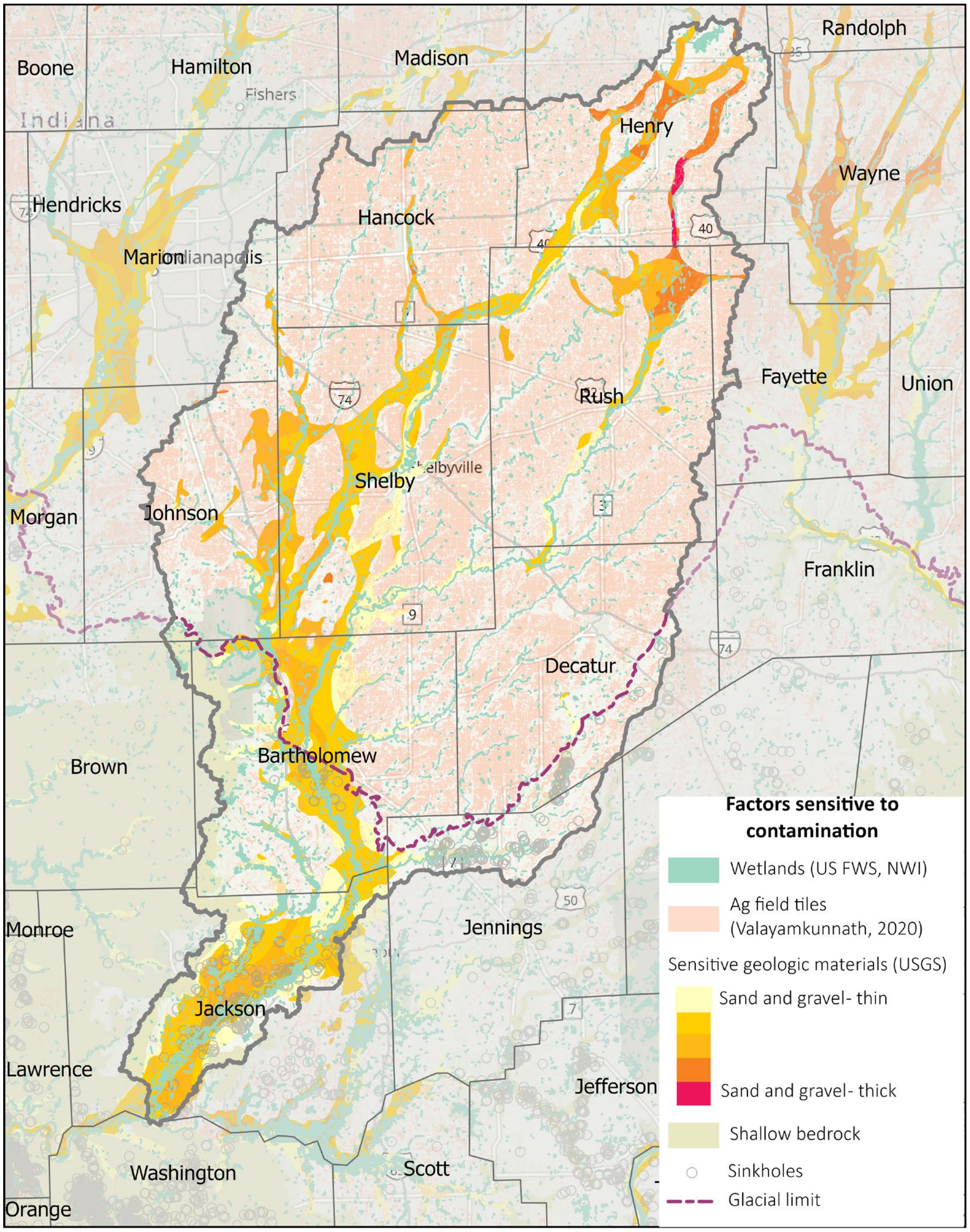


Figure 57. Examples of geological and land-use factors enhancing sensitivity or susceptibility to contamination. Coarse-grained geologic materials, such as stream and glacial outwash deposits, in addition to shallow bedrock, can have intrinsic sensitivity to contamination (Soller et al., 2012; see Figure 56). Agricultural field tiles (Valayamkunnath et al., 2020), used to drain land intended for cultivating crops (e.g., corn, soybeans) can create efficient pathways for nutrients to be distributed throughout watersheds. Similarly, sinkholes (to the south of the study area) can receive and deliver contaminated water through enlarged fractures and karst conduits (Letsinger, 2011). Wetlands (US FWS, NWI) are sensitive ecological environments that have diverse vegetation and fauna that can be negatively impacted by contamination.

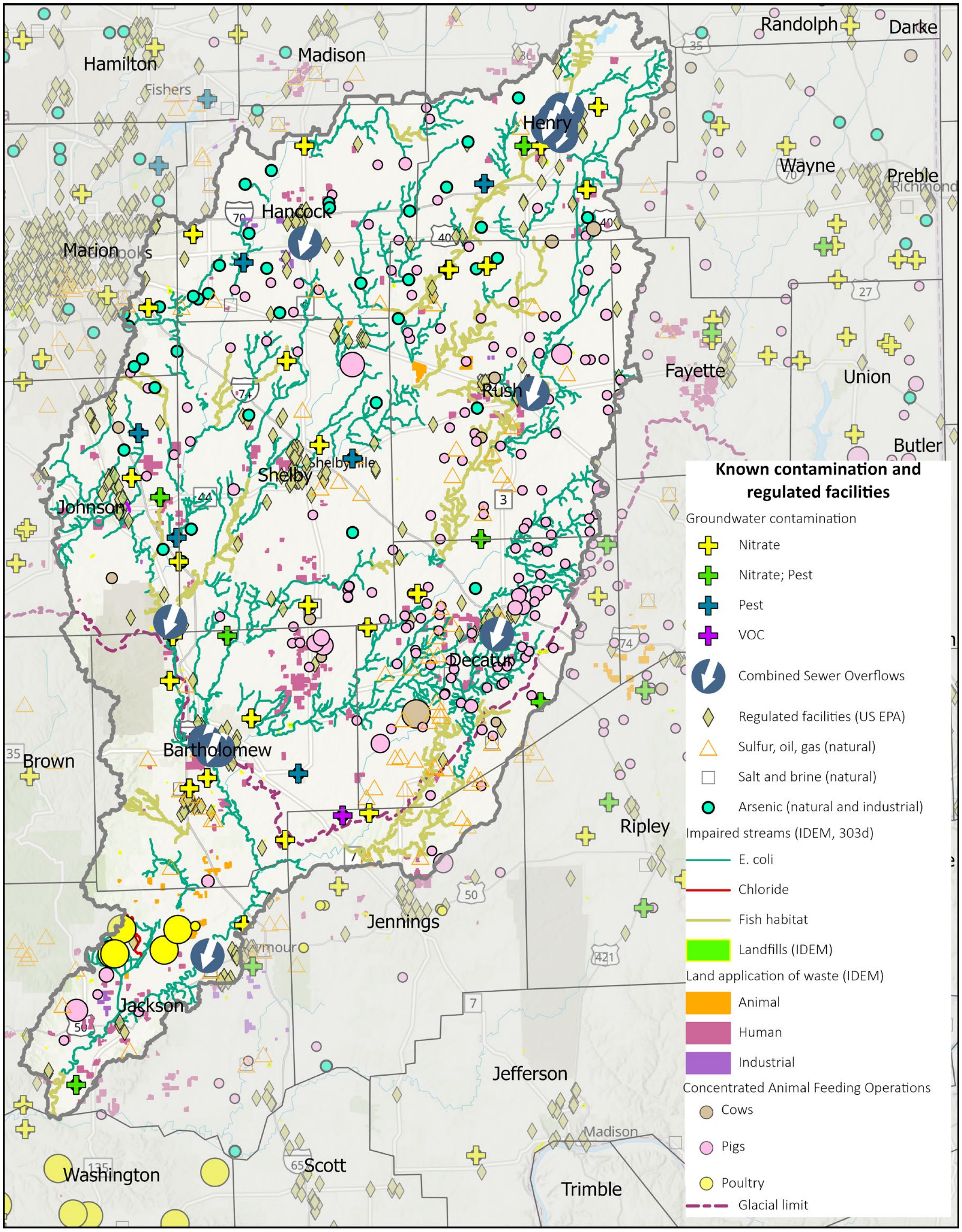


Figure 58. Compilation of known ground- and surface-water contamination (natural and anthropogenic) along with locations of regulated facilities. A large area of the Southeast-Central Indiana region has multiple threats to water quality. With so many water utilities reliant on a single water source (aquifer or river), contamination is a primary threat to a sustainable water supply into the future. Data from the Indiana Department of Environmental Management.

Water Conservation

Public Water Utilities

Supply limitations at water utilities can arise from a variety of factors, often stemming from both source availability and operational constraints. Actual source limitations, such as low streamflow, slowly recharging aquifers, and overpumping by multiple users sharing an aquifer, can result in diminished water resources. The phenomenon of well interference and water-table drawdown further compounds these limitations, leading to reduced well yields and lowered water levels in aquifers. Concurrently, operational factors such as insufficient wastewater treatment capacity and limited storage capacity can contribute to supply vulnerabilities.

Mitigating these limitations requires a multifaceted approach. To address source-based limitations, sustainable water management practices are crucial, including equitable allocation of water resources and implementing measures to prevent over-extraction. Moreover, focusing on aquifer recharge and maintaining healthy streamflow regimes can bolster available water supplies.

Regarding storage recommendations, recent guidance suggests that water utilities should maintain an adequate storage buffer to bridge supply gaps caused by increased demand or unforeseen disruptions. The recommended storage amount can vary based on local conditions, system characteristics, and the severity of potential supply interruptions. While there might not be a universally defined "recommended" amount of storage, some guidelines suggest that utilities should aim for storage capacities that extend beyond immediate demand needs, providing a cushion during emergencies, repairs, or temporary source shortages.

In the study area, most of the utilities that source groundwater rely on storage equivalent to the average demand of a single day. Surface-water utilities, of which there are few, rely on impoundments that can provide emergency water supplies for a few days. These narrow margins underscore the vulnerability of these systems to sudden disruptions. To enhance resilience, utilities may consider increasing storage capacities to withstand prolonged supply interruptions, particularly in the face of climate-related uncertainties and natural or man-made disasters. While regulatory requirements might stipulate a minimum storage volume, exceeding these mandates can enhance the ability of utilities to manage crises and maintain service continuity.

Because water is a shared resource, potential conservation methods by all water-use sectors can help curtail demand. These strategies span from voluntary actions undertaken by individuals, businesses, and farmers to mandatory restrictions imposed by local governments or utilities.

Residential Water Consumption

Per Capita Demand

Using only withdrawal data from public utilities, it is difficult to parse out residential usage from industrial usage, and the additional non-person consumption causes some utilities that supply a high proportion of their water to support industrial uses to have their calculated per capita demand far above the 76 gallons per day (GPD) estimated by Kindler and Russell (1984) and Dieter et al. (2018). This value is widely used for self-supplied residential rates of water use. However, data from utilities that are almost entirely residential have per capita use that ranges from 41 GPD to 80 GPD (Figure 59, left side). East Bay Municipal Utilities District (1991) found a similar value to the low end of the range (45 GPD) in northern California. In general, developed countries use more water than developing countries, and the United States has higher rates of consumption than other developed countries (Gleick, 1996). The United States is not a monolith, and use varies across the country, with arid regions requiring more water than humid regions (Gleick, 1996; DeOreo et al., 2016; Mayer, 2016). DeOreo et al. (2016) found that per capita average water use across the United States decreased 15% from 69 GPD per person in 1999 to 59 GPD in 2016.

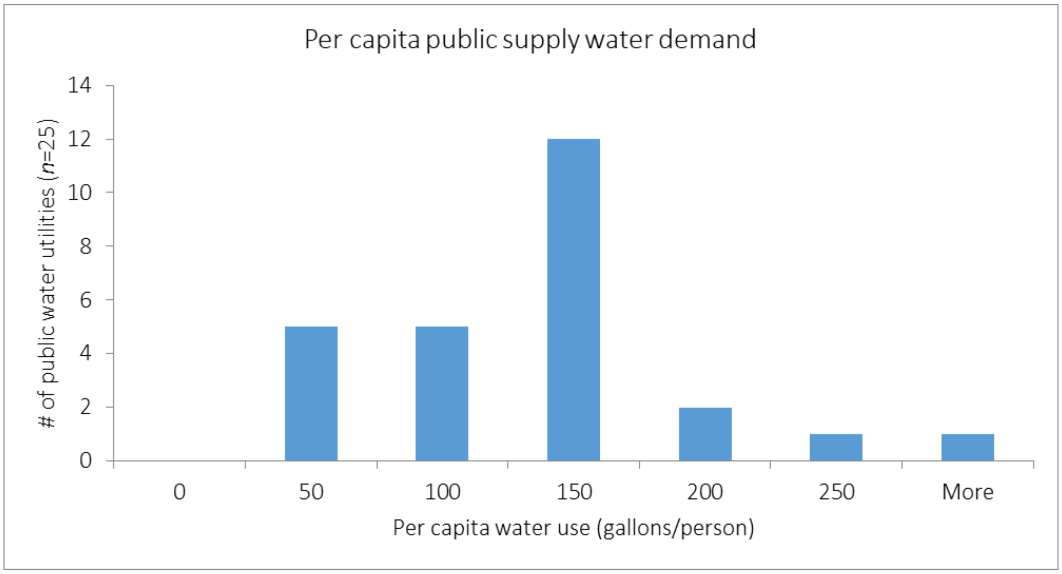


Figure 59. Per capita water use for 25 public water supply utilities in the Southeast-Central Indiana region. In general, rural water utilities with a dominantly residential customer population have lowest per capita rates. Higher rates reflect a high proportion of non-revenue water losses (leaks), or represent non-residential uses (e.g., industrial or CAFOs).

Finley and Basu (2020) and DeOreo et al. (2016) have noted that per capita water use is declining. In the Southeast-Central Indiana region, there is insufficient data to quantify this; however, there has been widespread adoption of residential water conservation efforts aimed at reducing water usage in households through behavioral changes (Dietz et al., 2009), technology adoption, and policy measures. DeOreo et al., (2016) found a 22% decrease in average annual household water use across the country. The adoption of water-saving technologies has played a significant role in promoting water conservation at the residential level. Some common water-saving technologies and practices include:

Water conservation, in both urban and rural settings, has emerged as a fundamental practice to ensure sustainable water resources for future generations. Several techniques and technologies have been instrumental in driving this positive change.

Among the most widely adopted are low-flow fixtures. These fixtures, including toilets, faucets, and showerheads, are designed to use less water, achieving efficiency without compromising functionality. Their adoption in modern households helps families reduce water consumption and, by extension, utility bills. A study by Olmstead in 2014 revealed that households with low-flow toilets consumed 20% less water than those without. Similarly, the water savings attributed to low-flow showerheads was pegged at 9%. The advancement of water/energy-saving appliances further underlines the commitment to conservation. For instance, Energy Star-rated washing machines and dishwashers are not only energy efficient but also consume considerably less water.

DeOreo et al. (2016) noted that eventual full adoption of water-saving fixtures and appliances could lower indoor household water use to below 40 gallons per capita per day across the United States. They explain that further reductions are anticipated even in the absence of consumers actively swapping out their fixtures or appliances; as when these items break or wear out, the replacements will be more efficient. Therefore, a water-efficiency plateau should not be a concern for some time to come.

Utilities can assist with residential water conservation (or waste reduction) by providing automated metering to identify persistent customer-side water leakage (DeOreo et al., 2016). There are many variables that contribute to indoor water use patterns, such as the age of fixtures and appliances, and the age of housing stock. Utilities should determine appropriate efficiency targets for their own service area based on local factors.

Outdoor Water Use Impact on Public Supply Utilities

For households aiming to further their conservation efforts, onsite reuse of water, or **graywater recycling,** offers an innovative solution (DeOreo et al., 2016). By capturing wastewater from household sources like sinks and washing machines, treating it, and then reusing it for non-potable purposes, these systems redefine the traditional understanding of waste. Parallel to this, **rainwater harvesting** offers an avenue for households to lessen their dependence on municipal water supplies. By collecting and storing rainwater, it becomes a valuable resource for various outdoor purposes, particularly landscaping.

Outdoor water use in the residential sector is a significant source of demand during hot summer months and times of drought. In suburban areas that are governed by homeowner's associations, there may even an implied or stated expectation to maintain a well-manicured and appealing lawn. Part of the domestic water use for any utility goes toward irrigation for watering gardens and grass, either manually or with automated sprinkler systems. For optimal growing conditions, it is estimated that turfgrass lawns in Indiana require between 1 and 1.5 inches of water each week, depending on local climate and soil conditions (Throssel and Reicher, 1998).

Smart irrigation systems represent another leap forward, especially for areas with significant outdoor water usage. By harnessing data on current weather conditions and soil moisture levels, these systems can automatically adjust water output, ensuring plants receive just the right amount of moisture while eliminating wasteful excess that traditional systems might produce. Landscape plant selection can provide passive drought-tolerant water conservation strategies. In the humid Midwest US, a blend of strategies for many "greenspaces" might result in a little less green. Hayden et al. (2015) and Doll et al. (2023a, 2023b) have found that a blend of native drought-resistant plants, xeriscaping, and typical lawn components is optimal to balance water conservation and landscape appeal.

Most utilities have a mixture of industrial, commercial, and residential usage, casting some uncertainty on the exact magnitude of residential contribution to the annual summer usage spikes. However, it seems reasonable to assume that the majority of variance from baseline demand during the summer is caused by residential irrigation. Working with this assumption, the amount of water that could theoretically be conserved during drought periods through mandatory lawn watering restrictions can be estimated by subtracting the minimum monthly usage from the maximum (peak) summer usage. In the drought year of 2012, peaking factors ranged from around 1.3x to nearly 2x baseline usage for the utilities that are not known to provide significant amounts of water for irrigation (Figure 60). A typical peaking factor during a non-drought year is usually closer to 1.1 - 1.3x baseline usage (see Appendix D). The assumption that residential usage drives the majority of seasonal peak demand is further validated through water use reported by a utility whose water customer base is almost entirely residential (97%) and that saw a peaking factor of nearly 1.9x during June of 2012.

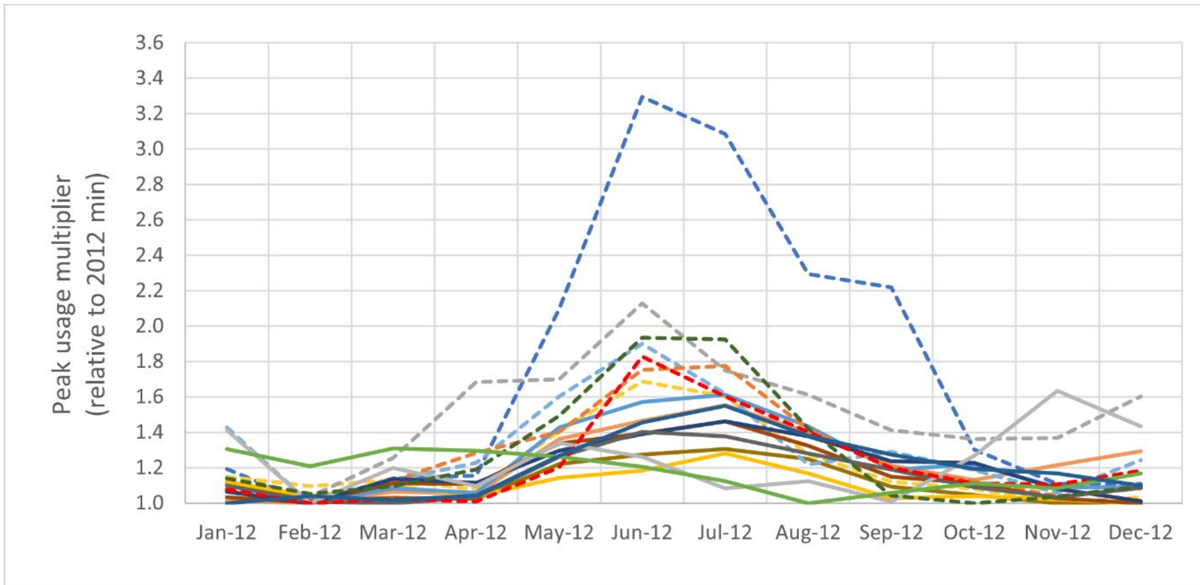


Figure 60. Peak usage multipliers for summer water demand experienced by utilities within the study area during the 2012 drought. Y-Axis shows peak usage multipliers *relative to the annual 2012 minimum demand for each utility* (SWWF, 2021). The 2012 minimum demand is set at 1 for each utility (usually occurring in February), so that the maximum peak is indicated as a factor or multiplier of the minimum, allowing utilities of different sizes to be compared. Utilities with the highest summer peaks are shown as dashed lines. Recall that some public-supply utilities in the Southeast-Central Indiana region serve customers in the industrial or agricultural sectors, in addition to residences and businesses in their service areas.

While having green lawns may be aesthetically satisfying, maintaining a lush yard is not critical, and during water shortages many municipalities have imposed water conservation requirements. For example, during the severe drought of 2012, Citizens Energy Group (CEG) put into place mandatory water conservation measures for their Indianapolis service area. These included bans on watering turfgrass, washing vehicles or sidewalks, and filling pools, as well as limitations on how water can be applied to flowers and gardens (Franklin Township Informer, 2012). Even as recently as June of 2023, CEG encouraged their customers to conserve water during the abnormally dry early summer (Indianapolis Star, 2023).

During the 2012 water-restriction mandates, data from CEG (CEG, 2013) suggest voluntary and mandatory lawn watering bans reduced demand by about 14% and 31%, respectively (estimated at around 32 MGD and 75 MGD of reduced demand during the summer of 2012). This signifies that while seasonal water-demand spikes are inevitable, conservation efforts can substantially mitigate water demand, especially for large utilities with a large residential population. On the contrary, smaller utilities like Rushville do not display the same demand patterns, making the impact of conservation efforts there potentially less pronounced.

Finley and Basu (2020) examined water-demand response to permanent water-use restrictions compared to threshold-driven limits in several Canadian cities with different climate regimes (humid and semiarid). They found that average demands were largely unaffected by permanent restrictions, but cities with strict limits on outdoor water use have seen a reduction in variability of daily demands and decline in peak demands (smaller surges).

While the effectiveness of conservation measures varies depending on numerous factors such as total irrigated area, type of soil, type of vegetation, and temperature fluctuations, the data suggest that mandatory bans on lawn watering could curtail peak demand by 20-30% during summer months for certain utilities. As climate conditions evolve, intensifying droughts and temperatures, the push for utilities to adopt conservation strategies will be ever more pressing. Lawn watering restrictions, among other measures, can serve as a pragmatic approach to counteract water demand during critical supply shortages.

Agricultural Conservation

A significant sector where water conservation can be impactful is agriculture, particularly in crop cultivation. Tactics to mitigate water demand during the summer months include altering irrigation methods and soil treatment prior to planting. The careful combination of these methods can notably reduce irrigation water requirements.

Irrigation Techniques

The choice of irrigation techniques plays a pivotal role in efficient water use. The choice largely depends on the scale of the farm and the extent of land under irrigation. Drip irrigation is an efficient and promising irrigation technique for smaller farms; however, it is cost-prohibitive when scaling up to large farms (Chu, 2017; van der Kooji, 2013). For larger farms, the techniques of center pivot irrigation and tile drain gates are the most cost-effective and commonly used irrigation methods. Center pivot irrigation focuses on distributing irrigation water from a central point. The technology involves intentionally choosing when and where to irrigate based on soil moisture, crop needs, and time of day, and the systems can use directional, low-pressure nozzles to prevent unnecessary excess irrigation (The Groundwater Foundation).

A water conservation option for large scale farms with tile drains is to install a tile drain gate at the outflow. These work by controlling the rate of discharge from drain tiles during the growing season, allowing the water to have more time to be taken up by the roots. According to the USDA website Farmers.gov, these structures can reduce water flow by 20-40%, reduce released nitrogen by up to 40%, and have the potential to increase yields by up to 10% in dry years.

Agricultural Soil Conservation

Another technique for reducing water usage in agriculture is through soil conservation. This can be divided into two main approaches – tilling methods and the planting of cover crops. According to the Indiana State Department of Agriculture (ISDA) Conservation Transect Survey, the vast majority (~80%) of corn and soybean fields in the study area are not tilled after harvest (ISDA, 2023), indicating that this method of water conservation is already being widely implemented and thus has limited potential for reducing future demand. If 5 inches per year of water savings is assumed by no-till methods and applied to the remaining 20% of fields in the study area that currently till their lands after harvest (around 54,000 acres; NASS/USDA, 2021), there is the potential for an additional 1,450 million gallons per season of demand reduction. This is roughly equivalent to the amount of water pumped during the summer and fall by Columbus Water Utility.

Cover crop planting works similarly to no-till methods in that it protects the soil from erosion and can add nutrients (UC Davis, Sustainable Agriculture Research and Education Program, 2017). Cover crops are generally not planted as cash crops but are grown in addition to them and enhance the quality of cash crops that are subsequently grown. Their root structures act to encourage water infiltration, leading to further reductions in erosion and an overall reduced need for irrigation.

According to Sustainable Agriculture Research and Education (SARE, Forgey, 2010), it is possible to plant cover crops in fields that are also implementing no-till methods. This can enhance the quality of the soil and increase corn yields by up to 20 bushels per acre. However, with no-till practices, farmers may have to explore other methods for clearing cover crops such as allowing livestock to graze before planting cash crops. In drought years, cover crops may actually consume some of the soil moisture that would be used for cash crops, actually increasing the need for more irrigation (Forgey, 2010). Currently within the study area, only around 14% of agricultural fields are planted with living cover crops (ISDA, 2023). This suggests that benefits to soil quality and stability could be obtained by a more widespread adoption of cover crop planting, and possibly some benefits to soil moisture could be seen during years with typical precipitation.

Conclusions

Historical and future public utility water demand for the next 50 years were presented in this report. Historical and future excess water availability for subbasins within the Southeast-Central Indiana region were calculated following methods developed and presented in IFA (2021).

The Southeast-Central Indiana region has unique hydrogeological and land-use characteristics that govern demand and availability and make it distinctly different from surrounding regions. Public water utilities are the dominant water-use sector, and the rural character of the region is further expressed in a disaggregated mosaic of self-supplied water uses.

The IDNR SWWF water-use database (2021) was a critical data resource for the analyses presented in this report. Even more granular (detailed) water-use data are available in the IDEM Virtual File Cabinet records of utility Monthly Reports of Operation (MRO); however, very little of the MRO data could be used because it is not in a digital format (the records are scanned paper records). Development of an MRO submission process for utilities that ingested the reports into a database would vastly improve the ability to understand public water utility operations and employ the data for planning purposes.

Natural (climate) and anthropogenic (withdrawals and returns, additional development, service-area expansions) factors combined with the seasonality of the regional water balance will continue to stress water resources in the summer and fall (Tavernia et al., 2013). Some acute drought periods might extend over sequential years of water stresses in the future (Fowler et al., 2022). Annual excess water availability is likely to be sufficient during most years, but to ensure sufficient supply during times of peak demand, additional storage by public water utilities and irrigators (Rosa et al., 2020) might be necessary.

Minimum instream flows are not defined by statute in Indiana. Current guidance (IDNR, 2015) relies on non-stationary metrics such as the 7Q10 and Q80 (or Q90, IFA, 2021; Phase III: Water Availability, Chapter 2, Section 2.9), which are currently increasing in many streams and rivers in Indiana (although the 7Q10 in some smaller streams is zero). The objective of establishing minimum flows is to maintain a supportive environment for a healthy riparian ecosystem. However, the amount of water needed for that purpose is not clear.

For water availability to be assessed with all demands considered (i.e., human, vegetation, ecosystems, soils, atmosphere), instream-flow guidance is currently insufficient to accurately estimate or project excess water availability for many planning purposes. Possible solutions include (1) developing a complex assessment of minimum flows appropriate to the characteristics of each ecosystem (time consuming and difficult to regulate), or (2) establishing a frequent review of recommended metrics (e.g., every 5 years).

References:

Abatzoglou J.T. and Brown T.J., 2012, A comparison of statistical downscaling methods suited for wildfire applications, *International Journal of Climatology*, 32, pp. 772-780. https://developers.google.com/earth-engine/datasets/catalog/IDAHO_EPSCOR_MACAv2_METDATA [Accessed, 1 August 2023].

Albano, C.M., Abatzoglou, J.T., McEvoy, D.J., Huntington, J.L., Morton, C.G., Dettinger, M.D. and Ott, T.J., 2022, A multidataset assessment of climatic drivers and uncertainties of recent trends in evaporative demand across the continental United States. *Journal of Hydrometeorology*, 23(4), pp.505-519.

Ali, R., McFarlane, D., Varma, S., Dawes, W., Emelyanova, I., Hodgson, G. and Charles, S., 2012, Potential climate change impacts on groundwater resources of south-western Australia. *Journal of Hydrology*,475, p.456-472.

Ault, C. H., Becker, L. E., Droste, J. B., Keller, S. J., and Shaver, R. H., 1992, Map of Indiana showing thickness of Silurian rocks and location of reefs: Indiana Geological Survey Miscellaneous Map 54, scale 1:500,000. Available at https://igws.indiana.edu/bookstore/details.cfm?Pub_Num=MM54 [Accessed, 1 August 2023].

Bayless, E.R., Arihood, L.D., Reeves, H.W., Sperl, B.J.S., Qi, S.L., Stipe, V.E., and Bunch, A.R., 2017, Maps and grids of hydrogeologic information created from standardized water-well drillers' records of the glaciated United States: U.S. Geological Survey Scientific Investigations Report 2015–5105, 34 p., https://doi.org/10.3133/sir20155105.

Beckett, J.L., and Oltjen, J.W., 1993, Estimation of the water requirements for beef production in the United States: *J. Animal Science*, v. 71, pp. 818-826.

Blum, A.G., Archfield, S.A., Hirsch, R.M., Vogel, R.M., Kiang, J.E. and Dudley, R.W., 2019, Updating estimates of low-streamflow statistics to account for possible trends. *Hydrological Sciences Journal*, v. 64, no. 12, pp.1404-1414., https://doi.org/10.1080/02626667.2019.1655148

Bogart, S., 2023, SankeyMATIC [Used for generation of Sankey Diagrams], https://www.sankeymatic.com

Bowling, L.C., Widhalm, M., Cherkauer, K.A., Beckerman, J., Brouder, S., Buzan, J., Doering, O., Dukes, J., Ebner, P., Frankenburger, J., Gramig, B., Kladivko, E.J., Lee, C., Volenec, J., and Weil, C., 2018, Indiana's Agriculture in a Changing Climate: A Report from the Indiana Climate Change Impacts Assessment: Agriculture Reports. Paper 1. http://dx.doi.org/10.5703/1288284316778 [Accessed, 1 August 2023].

Brettschneider, B., 2014, Intra-annual Climate Variability: https://us-climate.blogspot.com/2014/12/intra-annual-climate-variability.html [Accessed, 1 August 2023].

Burger, A.M., Bleuer, N.K., Forsyth, J.L., Gooding, A.M., Gray, H.H., Hill, J.R., Johnson, G.H., Keller, S.J., Lineback, J.A., Nicoll, R.S., Schneider, A.F., Wayne, W.J., and Wier, C.E., digital compilation by Gustin, A.R., 2013. BEDROCK_GEOLOGY_RGM_250K_IN: Bedrock geology of Indiana, from the Regional Geologic Map Series of the Indiana Geological Survey (Indiana Geological Survey, 1:250,000, Polygon Shapefile) https://www.indianamap.org/datasets/INMap::regional-bedrock-geology-1250000/about

Calvin, K., Bond-Lamberty, B., Clarke, L., Edmonds, J., Eom, J., Hartin, C., Kim, S., Kyle, P., Link, R., Moss, R. and McJeon, H., 2017, The SSP4 [Shared Socioeconomic Pathway]: A world of deepening inequality. *Global Environmental Change*, *42*, pp.284-296. https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about#v2

Citizens Energy Group (CEG), 2013, Drought Management Plan, Archived at: https://web.archive.org/web/20140704125610/https://www.citizensenergygroup.com/pdf/Drought-Management-Plan.pdf [Accessed, 1 August 2023].

Chen, L. and Ford, T.W., 2022, Future changes in the transitions of monthly-to-seasonal precipitation extremes over the Midwest in Coupled Model Intercomparison Project Phase 6 models: *Intl Journal of Climatology*, pp 255-274. https://rmets.onlinelibrary.wiley.com/doi/epdf/10.1002/joc.7756

Cherkauer, K.A., Bowling, L.C., Byun, K., Chaubey, I., Chin, N., Ficklin, D.L., Hamlet, A.F., Kines, S.J., Lee, C.I., Neupane, R., Pignotti, G.W., Rahman, S., Singh, S., Femeena, P.V., and Williamson, T.N., 2021. Climate change impacts and strategies for adaptation for water resource management in Indiana. *Climatic Change* 165, 21. https://doi.org/10.1007/s10584-021-02979-4

Chu, J., 2017, New Design Cut Costs, Energy Needs for Drip Irrigation, Bringing the Systems Within Reach for More Farmers, MIT News, https://news.mit.edu/2017/design-cuts-costs-energy-drip-irrigation-0420 [Accessed, 1 August 2023].

Chylek, P., Li, J., Dubey, M.K., Wang, M. and Lesins, G.J.A.C., 2011. Observed and model simulated 20th century Arctic temperature variability: Canadian earth system model CanESM2. *Atmospheric Chemistry and Physics Discussions*, *11*(8), pp.22893-22907.

Collinson, C., Sargent, M.L, and Jennings, J.R., 1988, Illinois Basin Region, in Sedimentary Cover – North American Craton, U.S., The Geology of North America, Volume D-2: The Geological Society of America, pp. 383-426.

Condon, L.E., Atchley, A.L. and Maxwell, R.M., 2020, Evapotranspiration depletes groundwater under warming over the contiguous United States. *Nature Communications*, 11(1), p.873.

Cullens, F., 2013, Water use for heat abatement [Cattle cooling usage estimations], Michigan State University Extension https://www.canr.msu.edu/news/water_use_for_heat_abatement [Accessed, 1 August 2023].

DeOreo, W.B., Mayer, P.W., Dziegielewski, B. and Kiefer, J., 2016. Residential end uses of water, version 2. Water Research Foundation https://www.waterrf.org/research/projects/residential-end-uses-water-version-2 [Accessed, 1 August 2023].

Dieter, C.A., Maupin, M.A., Caldwell, R.R., Harris, M.A., Ivahnenko, T.I., Lovelace, J.K., Barber, N.L., and Linsey, K.S., 2018, Estimated use of water in the United States in 2015: U.S. Geological Survey Circular 1441, 65 p., https://doi.org/10.3133/cir1441. [Supersedes USGS Open-File Report 2017–1131.]

Dietz, T., Gardner, G.T., Gilligan, J., Stern, P.C. and Vandenbergh, M.P., 2009, Household actions can provide a behavioral wedge to rapidly reduce US carbon emissions. *Proceedings of the National Academy of Sciences*, 106(44), pp. 18452-18456.

Doll, C.A., Burton, M.P., Pannell, D.J., and Rollins, C.L., 2023a, Are greenspaces too green? Landscape preferences and water use in urban parks. *Ecological Economics*, 211, 107896. https://doi.org/10.1016/j.ecolecon.2023.107896

Doll, C.A., Pannell, D.J., and Burton, M.P., 2023b, Economic evaluation of alternative urban park designs that conserve irrigation water: https://www.econclaire.com/s/ClaireDoll_Study3.pdf [Accessed, 1 August 2023].

Douville, H., Raghavan, K., Renwick, J., Allan, R.P., Arias, P.A., Barlow, M., Cerezo-Mota, R., Cherchi, A., Gan, T.Y., Gergis, J. and Jiang, D., 2021. *Water cycle changes*. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, *Cambridge University Press*, pp. 1055–1210 https://doi.org/10.1017/9781009157896.010

Droste, J.B., and Shaver, R.H., 1986, Bainbridge Group, *in*: Shaver, R. H., Ault, C. H., Burger, A. M., Carr, D. D., Droste, J. B., Eggert, D. L., Gray, H. H., Harper, D. , Hasenmueller, N. R., Hasenmueller, W. A., Horowitz, A. S., Hutchison, H. C., Keith, B. , Keller, S. J., Patton, J. B., Rexroad, C. B., Wier, C. E. 1986, Compendium of Paleozoic rock-unit stratigraphy in Indiana--a revision: Indiana Geological Survey Bulletin 59, 203 p., available at: https://igws.indiana.edu/compendium/bainbridge-group [pp. 9-10; accessed October 22, 2023]

Droste, J.B., and Shaver, R.H., 1986, Muscacatuck Group, *in*: Shaver, R. H., Ault, C. H., Burger, A. M., Carr, D. D., Droste, J. B., Eggert, D. L., Gray, H. H., Harper, D. , Hasenmueller, N. R., Hasenmueller, W. A., Horowitz, A. S., Hutchison, H. C., Keith, B. , Keller, S. J., Patton, J. B., Rexroad, C. B., Wier, C. E. 1986, Compendium of Paleozoic rock-unit stratigraphy in Indiana--a revision: Indiana Geological Survey Bulletin 59, 203 p., available at: https://igws.indiana.edu/compendium/muscatatuck-group [pp. 99-100; accessed October 22, 2023]

Dziegielewski, B. and Baumann, D.D., 2011. Predicting future demands for water, *Elsevier*, pp. 163-187

Dziegielewski, B., Sharma, S., Yang, X., Bik, T., Margono, H. and Sa, R., 2002, Predictive models of water use: An analytical bibliography. *Prepared for the United States Geological Survey. Southern Illinois University at Carbondale.*

Earle, S., 2015, Physical Geology. Victoria, B.C.: BC campus. Retrieved from https://opentextbc.ca/geology/ [Accessed, 1 August 2023].

East Bay Municipal Utilities District, 1991, Urban Water Management Plan, East Bay Municipal Utilities District, Oakland, CA, USA.

Environmental Resilience Institute, Hoosier Resilience Index https://hri.eri.iu.edu/climate-vulnerability/index.html [Accessed, 1 August 2023].

Ezenwankwo, S., 2021, Water Consumption Rate for Layers and Broilers for Optimal Output, Poultry Farm Guide https://www.poultryfarmguide.com/blog/water-requirement-for-layers-and-broilers/ [Accessed, 1 August 2023].

Fedrow, D.M., 2019, Water use in confined animal feeding operations (CAFOs) in Minnesota-Who's Keeping Track: Graduate Student Theses, Dissertations, & Professional Papers. 11365. https://scholarworks.umt.edu/etd/11365 [Accessed, 1 August 2023].

Fenelon, J.M., Bobay, K.E., Greeman, T.K., Hoover, M.E., Cohen, D.A., Fowler, K.K., Woodfield, M.C., and Durbin, J.M., 1994, Hydrogeologic atlas of aquifers in Indiana: U.S. Geological Survey Water-Resources Investigations Report 1992–4142, 197 p., https://pubs.er.usgs.gov/publication/wri924142.

Ficklin D.L., Abatzoglou, J.T., Robeson, S.M., Null, S.E., and Knouft J.H., 2018. Natural and managed watersheds show similar responses to recent climate change. *Proceedings of the National Academy of Sciences* 115 (34): 8553–8557 DOI: https://doi.org/10.1073/pnas.1801026115

Ficklin, D.L., Maxwell, J.T., Letsinger, S.L., and Gholizadeh, H., 2015. A climatic deconstruction of recent drought trends in the United States. Environ. Res. Lett. 10, 044009. https://doi.org/10.1088/1748-9326/10/4/044009

Ford, T.W., Chen, L. and Schoof, J.T., 2021. Variability and Transitions in Precipitation Extremes in the Midwest United States. Journal of Hydrometeorology, vol. 22, no. 3, pp.533-545.

Forgey, D., 2010, Adding Cover Crops to a No-Till System, Sustainable Agriculture Research and Education (SARE) https://www.sare.org/resources/adding-cover-crops-to-a-no-till-system/ [Accessed, 1 August 2023].

Fowler, K.K., 1991, Description and effects of 1988 drought on ground-water levels, streamflow, and reservoir levels in Indiana: U.S. Geological Survey Water Resources Investigation Report 91-4100, 91 p.

Fowler, K., Peel, M., Saft, M., Nathan, R., Horne, A., Wilby, R., McCutcheon, C. and Peterson, T., 2022, Hydrological shifts threaten water resources. *Water Resources Research*, 58(8), p.e2021WR031210.

Franklin Township Informer (Indianapolis, IN), "Mandatory Water Ban frequently asked questions." sec. News, 25 July 2012, p. 8. NewsBank: Access World News, Historical and Current, [Accessed, 1 August 2023].

Fullerton, D.S., Bush, C.A., and Pennell, J.N., 2003. Map of Surficial Deposits and Materials in the Eastern and Central United States (East of 102˚ West Longitude). United States Geological Survey 46.

Gleick, P.H., 1996, Basic water requirements for human activities: Meeting basic needs, *Water International*, v. 21, pp. 83-92.

Gray, H.H., 1989, Quaternary Geologic Map of Indiana (Miscellaneous Map 49), Indiana Geological Survey (IGS) https://igws.indiana.edu/IGSDigitalDownload.cfm?sud=1&iud=379 [Accessed, 1 August 2023].

Gray, H.H., 2000, Physiographic divisions of Indiana: Indiana Geological Survey Special Report 61, 15 p., 2 fig., 1 pl.

Gray, H.H., Ault, C.H., and Keller, S J., 1987, Bedrock geologic map of Indiana: Indiana Geological Survey Miscellaneous Map 48, scale 1:500,000.

Gray, H.H. and Letsinger, S.L., 2011, A History of Glacial Boundaries in Indiana https://scholarworks.iu.edu/dspace/bitstream/handle/2022/27246/SR71_A1b.pdf [Accessed, 1 August 2023].

Guthrie, T., 2011, Water needs of pigs: Michigan State University Extension https://www.canr.msu.edu/news/water_needs_of_pigs [Accessed, 1 August 2023].

Hamed, K. H., 2009, Exact distribution of the Mann-Kendall trend test statistic for persistent data, *Journal of Hydrology*. p: 86–94.

Hamlet, A.F., Byun, K., Robeson, S.M., Widhalm, M., and Baldwin, M., 2020. Impacts of climate change on the state of Indiana: ensemble future projections based on statistical downscaling. *Climatic Change* 163, 1881–1895. https://doi.org/10.1007/s10584-018-2309-9

Haqiqi, I., Grogan, D.S., Hertel, T.W., and Schlenker, W., 2021. Quantifying the impacts of compound extremes on agriculture. *Hydrology and Earth System Sciences*, 25(2), pp.551-564.

Hausfather, Z., 2019, Explainer: The high-emissions 'RCP8.5' global warming scenario, Carbon Brief Ltd., https://www.carbonbrief.org/explainer-the-high-emissions-rcp8-5-global-warming-scenario/ [Accessed, 1 August 2023].

Hayden, L., Cadenasso, M.L., Haver, D., and Oki, L.R., 2015, Residential landscape aesthetics and water conservation best management practices: Homeowner perceptions and preferences. *Landscape and Urban Planning*, Volume 144, Pages 1-9, ISSN 0169-2046, https://doi.org/10.1016/j.landurbplan.2015.08.003.

Hayhoe, K., VanDorn, J., Naik, V., and Wuebbles, D., 2009, Climate change in the Midwest. Confronting climate change in the US Midwest. *Union of concerned scientists*. Archived at: https://web.archive.org/web/20121031225913/https://www.ucsusa.org/assets/documents/global_warming/midwest-climate-impacts.pdf [Accessed, 1 August 2023].

Iglesias, V., Travis, W.R. and Balch, J.K., 2022, Recent droughts in the United States are among the fastest-developing of the last seven decades. *Weather and Climate Extremes*, 37, p.100491.

Indiana Department of Environmental Management (IDEM), 2023, Combined Sewer Outfall (CSO) https://www.in.gov/idem/cleanwater/information-about/combined-sewer-overflow-cso-program/indiana-cso-outfall-map/ [Accessed, 1 August 2023].

Indiana Department of Environmental Management (IDEM), 2023, About Confined Feeding Operations and Concentrated Animal Feeding Operations, https://www.in.gov/idem/cfo/about-confined-feeding-operations-and-concentrated-animal-feeding-operations [Accessed, 1 August 2023].

Indiana Department of Environmental Management (IDEM), 2023, Drinking Water Watch (DWW) https://myweb.in.gov/IDEM/DWW/index.jsp [Accessed, 1 August 2023].

Indiana Department of Environmental Management (IDEM), 2023, Drinking Water Viewer (DWV) https://indwv.gecsws.com [Accessed, 1 August 2023].

Indiana Department of Environmental Management (IDEM), 2023, Virtual Filing Cabinet (VFC) Monthly Report of Operations (MRO) https://ecm.idem.in.gov/cs/idcplg?IdcService=GET_DOC_PAGE&Action=GetTemplatePage&Page=HOME_PAGE [Accessed, 1 August 2023].

Indiana Department of Environmental Management (IDEM), 2023, Pending and Issued CFO Permits https://www.in.gov/idem/cfo/resources/pending-and-issued-cfo-permits/ [Accessed, 1 August 2023].

Indiana Department of Natural Resources (IDNR), 2011a, Unconsolidated Aquifer Systems of Indiana https://maps.indiana.edu/metadata/Hydrology/Aquifer_Systems_Unconsolidated_IDNR.html [Accessed, 1 August 2023].

Indiana Department of Natural Resources (IDNR), 2011b, Bedrock Aquifer Systems in Indiana https://maps.indiana.edu/metadata/Hydrology/Aquifer_Systems_Bedrock_IDNR.html [Accessed, 1 August 2023].

Indiana Department of Natural Resources (IDNR), 2015, Indiana's Water Shortage Plan https://secure.in.gov/iurc/files/DNR-March-2015-Indianas-Water-Shortage-Plan.pdf [Accessed, 1 August 2023].

Indiana Department of Natural Resources (IDNR), 2021, Significant Water Withdrawal Facility (SWWF) Database https://www.in.gov/dnr/water/water-availability-use-rights/significant-water-withdrawal-facility-data/ [Accessed, 1 August 2023].

Indiana Department of Natural Resources (IDNR), 2021, Water Well Record Database https://www.in.gov/dnr/water/ground-water-wells/water-well-record-database/ [Accessed, 1 August 2023].

Indiana Finance Authority (IFA), 2015, Evaluation of Water Utility Planning in Indiana: a survey of best practices, challenges, and needs. Senate Bill 474. Report to Indiana State Legislature. https://www.in.gov/ifa/files/IFA-2015_Water_Report.pdf [Accessed, 1 August 2023].

Indiana Finance Authority (IFA), 2018, Southeastern Indiana Regional Water Supply: Feasibility and cost analysis. Technical report, Indiana Finance Authority. https://www.in.gov/ifa/files/IFA-Final-Southeast-Regional-Supply-Report-1-12-2018.pdf [Accessed, 1 August 2023].

Indiana Finance Authority (IFA), 2020, Central Indiana Water Demand, Report to Indiana Finance Authority, Regional Water Studies Program. 166 p. https://www.in.gov/ifa/files/Central-Indiana-Water-Forecast-Report_2.pdf [Accessed, 1 August 2023].

Indiana Finance Authority (IFA), 2021, Central Indiana Water Study. Report to Indiana Finance Authority, Regional Water Studies Program. 363 p. https://www.in.gov/ifa/files/Central%20Indiana%20Water%20Availability%20Report.pdf [Accessed, 1 August 2023].

Indiana Geological Survey (IGS, now IGWS), 2002, Surficial Clay Thickness Points (Point Shapefile) https://www.indianamap.org/datasets/INMap::surficial-clay-thickness-points/about

Indiana Geological Survey (IGS, now IGWS), 2015a, PETROLEUM_WELLS_IGS_IN.SHP: Petroleum Well Locations in Indiana (Indiana Geological Survey, 1:24,000, Point Shapefile), 20150108, https://maps.indiana.edu/metadata/Geology/Petroleum_Wells.html

Indiana Geological Survey (IGS, now IGWS), 2015b, Surficial Unconsolidated Thickness Contours (Polyline Shapefile) https://www.indianamap.org/datasets/INMap::surficial-unconsolidated-thickness-contours/about

Indiana Water Resources Research Center (IWRRC), 2019, The State of Indiana Waters. Available at: https://iwrrc.org/indiana-water [Accessed, 8 June 2023].

Indianapolis Star (Indianapolis, IN), June 7, 2023, "Hot, dry weather in Central Indiana leads to water conservation warning." https://www.indystar.com/story/news/local/2023/06/07/indianapolis-weather-drought-water-conservation-warning-when-water-lawns/70297156007/ [Accessed, 1 August 2023].

Intergovernmental Panel on Climate Change (IPCC) AR6, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. *Cambridge University Press*. In Press.

Intergovernmental Panel on Climate Change (IPCC)., 2022, Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II Contribution to the IPCC Sixth Assessment Report (eds. H.-O. Pörtner, Ed.). *Cambridge University Press*.

Indiana State Department of Agriculture (ISDA), 2023 https://www.in.gov/isda/divisions/soil-conservation/conservation-transect/ [Accessed, 1 August 2023].

Indiana Utility Regulatory Commission (IURC), 2022, Water Rates https://www.in.gov/iurc/files/IURC-2022-Water-Billing-Survey-Final.pdf [Accessed, 1 August 2023].

Indiana Utility Regulatory Commission (IURC), 2014, 2014 Water Utility Resource Report, https://www.in.gov/iurc/files/IURC-2014-Water-Utility-Resource-Report.pdf [Accessed, 1 August 2023].

Keller, S. J., 1998, Underground storage of natural gas in Indiana: Indiana Geological Survey Special Report 59, 77 p., 10 figs. doi: 10.5967/k372-ar53, also available at: https://scholarworks.iu.edu/dspace/handle/2022/27229 [Accessed, 1 October 2023].

Kendall, M.G. and J.D. Gibbons, 1990. *Rank correlation methods*, fifth ed., Griffin, London.

Kiefer, J., Clayton, J.M., Dziegielewski, B. and Henderson, J., 2013. Changes in water use under regional climate change scenarios. *Water Research Foundation*, 398 p.

Kiefer, J.C., and Krentz, L.R., 2018, Information needs for water demand planning and management: *Journal AWWA*, v. 110, no. 3, pp. 50-57.

Kindler, J., and Russell, C.S., eds., 1984, Modeling Water Demands, *Academic Press Inc*., Toronto, ON, Canada.

Kinghorn, M., 2012, Indiana's Population Projections, 2010 to 2050, Indiana Business Research Center (IBRC) http://www.ibrc.indiana.edu/ibr/2012/spring/article1.html [Accessed, 1 August 2023].

Kinghorn, M., 2018, Methodology for Indiana State and County Population Projections, 2015 to 2050, Indiana Business Research Center, Kelly School of Business, Indiana University https://www.stats.indiana.edu/about/pop_proj_15-50.asp [Accessed, 1 August 2023].

Klopatek, S.C., and Oltjen, J.W., 2022, How advances in animal efficiency and management have affected beef cattle's water intensity in the United States: 1991 compared to 2019: *J of Animal Science*, v. 100, pp. 1-13. https://doi.org/10.1093/jas/skac297

Knutti, R., Furrer, R., Tebaldi, C., Cermak, J. and Meehl, G.A., 2010. Challenges in combining projections from multiple climate models. *Journal of Climate*, 23(10), pp.2739-2758.

Konrad, C.P., 2022, BFS—A non-linear, state-space model for baseflow separation and prediction U.S. Geological Survey Scientific Investigations Report 2022–5114, 24 p., https://doi.org/10.3133/sir20225114

Kundzewicz, Z.W., Mata, L.J., Arnell, N.W., Döll, P., Jimenez, B., Miller, K., Oki, T., Şen, Z. and Shiklomanov, I., 2008. The implications of projected climate change for freshwater resources and their management. *Hydrological sciences journal*, *53*(1), pp.3-10.

LaTour, J.K., 1993, Contribution of return flows to streamflow in selected stream reaches in Illinois, 1988-1989: U.S. Geological Survey Water Resources Investigation Report 93-4089, 35 p.

Lesinger, K. and Tian, D., 2022, Trends, Variability, and Drivers of Flash Droughts in the Contiguous United States: *Water Resources Research*, 58, e2022WR032186. https://doi.org/10.1029/2022WR032186

Letsinger, S.L., 2011, SINKHOLE_INVENTORY_IN_KY_2011: Sinkhole inventory for southern Indiana and northern Kentucky (Indiana Geological Survey, Point Shapefile) https://maps.indiana.edu/metadata/Hydrology/Karst_Sinkhole_Inventory_2011.html [Accessed, 1 August 2023].

Letsinger, S. L., 2015a, Map of Indiana showing near-surface aquifer recharge: Indiana Geological Survey Miscellaneous Map 92, scale 1:500,000.

Letsinger, S.L., 2015b, Relationship of groundwater recharge rates to aquifer sensitivity to contamination in shallow aquifers in Indiana using multiple regression analysis: report to Indiana Department of Environmental Management, Contract ARN A305-2-52, 32 p.

Letsinger, S.L., 2017, Geological investigations of the distribution of arsenic in groundwater: report to Indiana Department of Environmental Management, Contract ARN A305-6-190, 132 p.

Letsinger, S.L., 2018, Spatial distribution of significant water withdrawal facilities (SWWF) in Indiana. Report to Indiana Finance Authority, 108 p.

Letsinger and Balberg, 2021, Implications to aquifer storage from climate-driven shifts in water-balance partitioning: Indiana, Midwest USA https://ui.adsabs.harvard.edu/abs/2021AGUFM.H45D1211L/abstract [Accessed, 1 August 2023].

Letsinger, S.L., Balberg, A., and Gustin, A.R., 2021a, Implications to aquifer storage from shifts in timing of water-balance partitioning: Indiana, United States: Report to the Indiana Department of Environmental Management, Award #41486, 90 p.

Letsinger, S.L., Balberg, A., Hanna, E., Hiatt, E.K., 2021b. Geohydrology: Watershed Hydrology, in: Encyclopedia of Geology. *Elsevier*, p. 442–456. https://doi.org/10.1016/B978-0-12-409548-9.12389-9

Liang, Y., Tabler, G.T., and Dridi, S., 2020, Sprinkler Technology Improves Broiler Production Sustainability: From Stress Alleviation to Water Usage Conservation: A Mini Review [Poultry cooling usage estimates], *National Library of Medicine, National Center for Biotechnology Information* https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7536280/ [Accessed, 1 August 2023].

Maidment, D.R., and Miaou, S-P., 1985, Transfer function models of daily urban water use: *Water Resources Research*, v. 21, no, 4, pp. 425-432.

Mann, H.B., 1945. Nonparametric tests against trend, *Econometrica*, Vol. 13, p. 245–259.

Martin, G.R., Fowler, K.K., and Arihood, L.D., 2016, Estimating selected low-flow frequency statistics and harmonic-mean flows for ungaged, unregulated streams in Indiana: U.S. Geological Survey Scientific Investigations Report 2016-5102, 45 p., http://dx.doi.org/10.3133/sir20165102

May, J., n.d., Estimating water usage on Michigan swine farms: Michigan State University Extension, 3 p. https://www.canr.msu.edu/uploads/235/67987/lyndon/Water_Use_for_Swine_Farms.doc [Accessed, 1 August 2023].

Mayer, P. W., 2016, Water Research Foundation Study Documents Water Conservation Potential and More Efficiency in Households. *Journal AWWA*, 108(10), pp. 31-40.

Meehan, M., Stokka, G., and Mostrom, M., 2021, Livestock Water Requirements, *North Dakota State University* https://www.ag.ndsu.edu/publications/livestock/livestock-water-requirements [Accessed, 1 August 2023].

Mehan, S., Gitau, M.W., and Flanagan, D.C., 2019, Reliable future climatic projections for sustainable hydro-meteorological assessments in the Western Lake Erie Basin: *Water*, v. 11, no. 3, https://www.mdpi.com/2073-4441/11/3/581 [Accessed, 1 August 2023].

Mehan, S., Aggarwal, R., Gitau, M.W., Flanagan, D.C., Wallace, C.W. and Frankenberger, J.R., 2019. Assessment of hydrology and nutrient losses in a changing climate in a subsurface-drained watershed. *Science of the Total Environment*, 688, pp.1236-1251.

Morlock, S.E., Menke, C.D., Arvin, D.V., and Kim, M.H., 2008, Flood of June 7–9, 2008, in central and southern Indiana: U.S. Geological Survey Open File Report 2008–1322, 15 p., 3 app. https://pubs.usgs.gov/of/2008/1322/ [Accessed, 1 August 2023].

National Oceanic and Atmospheric Administration (NOAA), CONUS Climate Divisions, National Centers for Environmental Information (Decadal Temperature Change figure), https://www.ncei.noaa.gov/access/monitoring/dyk/us-climate-divisions [Accessed, 1 August 2023].

National Weather Service, 2023, https://www.weather.gov/ind/localcli [Accessed, 1 August 2023].

Naylor, S., Johnson, M., and Schumacher, J., 2015, SURFACE_DEM_100M_IGS_IN.RST: Ground Surface Elevation DEM of Indiana (Indiana Geological Survey, tif file, 100m resolution)

Naylor, S., Schumacher, J., and Sperl, B. J., 2016a, Map showing elevation of the bedrock surface in Indiana: Indiana Geological Survey Miscellaneous Map 94A, scale 1:500,000.

Naylor, S., Schumacher, J., and Sperl, B. J., 2016b, Map showing thickness of unconsolidated deposits in Indiana: Indiana Geological Survey Miscellaneous Map 95A, scale 1:500,000.

Nelson, W.J., 1995, Structural Features in Illinois: Bulletin 100 of the Illinois State Water Survey, 144 p. http://library.isgs.illinois.edu/Pubs/pdfs/bulletins/bul100.pdf [Accessed, 30 August 2023].

Norberg, O.S., 2010, Strip tillage for high-residue irrigated cropping systems, Oregon State University Extension Service, 1-8

Olmstead, S.M. and Stavins, R.N., 2009. Comparing price and nonprice approaches to urban water conservation. *Water Resources Research*, 45(4).

Partridge, T., Winter, J., Kendall, A., Basso, B., Pei, L. and Hyndman, D., 2023, Irrigation benefits outweigh costs in more US croplands by mid-century. *Communications Earth & Environment*, 4(1), p.274. https://doi.org/10.1038/s43247-023-00889-0

Pendergrass, A.G., Meehl, G.A., Pulwarty, R. et al., 2020. Flash droughts present a new challenge for subseasonal-to-seasonal prediction. *Nature Climate Change*, vol 10, p. 191–199. https://doi.org/10.1038/s41558-020-0709-0

Pesti, G.M., Amato, S.V., and Minear, L.R., 1984, Water consumption of broiler chickens under commercial conditions: *Poultry Science*, v. 64, pp. 803-808.

Qing, Y., Wang, S., Yang, Z.L. and Gentine, P., 2023, Soil moisture− atmosphere feedbacks have triggered the shifts from drought to pluvial conditions since 1980. *Communications Earth & Environment*, 4(1), p.254. https://doi.org/10.1038/s43247-023-00922-2

Regional District of Nanaimo, 2019, Livestock Water Use [cleaning usage estimates], Archived at: https://web.archive.org/web/20190320152826/https://rdnwaterbudget.ca/awdm/livestock-water-use/ [Accessed, 1 August 2023].

Riahi, K., Van Vuuren, D.P., Kriegler, E., Edmonds, J., O'Neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O. and Lutz, W., 2017, The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change*, *42*, pp.153-168.

Ribes, A., Qasmi, S., and Gillett, N.P., 2021, Making climate projections conditional on historical observations: *Science Advances*, v.7, eabc0671. https://www.science.org/doi/10.1126/sciadv.abc0671

Robbins, P.R., Carson, E.E., Wheaton, R.Z., and Mannering, J.V., 1977, Irrigation of Field Crops in Indiana, Purdue University Cooperative Extension Service, ID-119.

Robinson, B.A., 2013, Recent (circa 1998 to 2011) channel-migration rates of selected streams in Indiana. US Department of the Interior, US Geological Survey Scientific Investigations Report 2013–5168, 14 p. https://pubs.usgs.gov/sir/2013/5168/pdf/sir2013-5168.pdf

Rosa, L., Chiarelli, D.D., Sangiorgio, M., Beltran-Peña, A.A., Rulli, M.C., D'Odorico, P. and Fung, I., 2020, Potential for sustainable irrigation expansion in a 3 C warmer climate. Proceedings of the National Academy of Sciences, 117(47), pp. 29526-29534.

Rupp, J.A. and Pennington, D., 1987, January. Determination of the 10,000 mg/1 TDS surface within the bedrock aquifers of Indiana. In Proceedings of the Indiana Academy of Science (Vol. 97, pp. 383-390).

Rutledge, A.T., 1998, Computer programs for describing the recession of ground-water discharge and for estimating mean ground-water recharge and discharge from streamflow records--update: U.S. Geological Survey Water-Resources Investigations Report 98-4148, 43 p.

Shaffer, K.H., 2009, Variations in withdrawal, return flow, and consumptive use of water in Ohio and Indiana, with selected data from Wisconsin, 1999–2004: U.S. Geological Survey Scientific Investigations Report 2009–5096, 93 p. https://pubs.usgs.gov/sir/2009/5096/pdf/sir20095096.pdf; https://www.usgs.gov/publications/consumptive-water-use-great-lakes-basin [Accessed, 1 August 2023].

Soller, D.R., Packard, P.H., and Garrity, C.P., 2012, Database for USGS Map I-1970, Map showing the thickness and character of Quaternary sediments in the glaciated United States east of the Rocky Mountains: U.S. Geological Survey Data Series 656, available at https://pubs.usgs.gov/ds/656 [Accessed, 1 August 2023].

Stephenson, N., 2003, Actual evapotranspiration and deficit: biologically meaningful correlates of vegetation distribution across spatial scales: *J. of Biogeography*, v. 25, p. 855-870. https://doi.org/10.1046/j.1365-2699.1998.00233.x

Strand Associates, Inc., 2018, Bargersville Water Utility Master Plan https://bargersville.in.gov/Document%20Center/Services/Utilities/Water/2018.Bargersville.WSMP_.FINAL_.102518.pdf [Accessed, 1 August 2023].

Tavernia, B.G., Nelson, M.D., Caldwell, P. and Sun, G., 2013, Water stress projections for the northeastern and midwestern United States in 2060: Anthropogenic and ecological consequences. *JAWRA Journal of the American Water Resources Association*, 49(4), pp.938-952.

The Groundwater Foundation, Center Pivots https://groundwater.org/center-pivots/ [Accessed, 1 August 2023].

Thompson, Todd Alan; Sowder, Kimberly; Johnson, Matthew R., 2016 - Generalized stratigraphic column of Indiana Bedrock. Indiana Geological & Water Survey, https://igws.indiana.edu/IGNIS/GeneralizedStratigraphicColumn.pdf - https://scholarworks.iu.edu/dspace/handle/2022/27682 [Accessed, 1 August 2023].

Thornthwaite, C.R., and Mather, J.R., 1955, The water balance: Centerton, N.J., Drexel Institute of Technology-Laboratory of Climatology, *Publications in Climatology*, 104 p.

Thornthwaite, C.R., and Mather, J.R., 1957, Instructions and tables for computing potential evapotranspiration and the water balance: Drexel Institute of Technology-Laboratory of Climatology, *Publications in Climatology*, v. 10, no. 3, p. 185–311.

Thornton, M.M., R. Shrestha, Y. Wei, P.E. Thornton, S-C. Kao, and B.E. Wilson, 2022, Daymet: Daily Surface Weather Data on a 1-km Grid for North America, Version 4 R1. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/2129

Throssell, C. and Reicher, Z., 1998, Irrigation Practices for Home lawns, Purdue Turfgrass Science Program, Department of Agronomy, https://www.extension.purdue.edu/extmedia/ay/ay-7-w.pdf [Accessed, 1 August 2023].

Trost, J.J., Roth, J.L., Westenbroek, S.M., and Reeves, H.W., 2018, Simulation of Potential Groundwater Recharge for the Glacial Aquifer System East of the Rocky Mountains, 1980–2011, using the Soil-Water-Balance Model. US Geological Survey Scientific Investigations Report 2018–5080, 49 pp.

UC Sustainable Agriculture Research and Education Program, 2017, "Cover Crops." What is Sustainable Agriculture? *UC Division of Agriculture and Natural Resources.* https://sarep.ucdavis.edu/sustainable-ag/cover-crops [Accessed, 1 August 2023].

U.S. Army Corps of Engineers, Ohio River Basin study, https://www.lrh.usace.army.mil/Portals/38/docs/orba/USACE%20Ohio%20River%20Basin%20CC%20Report_MAY%202017.pdf [Accessed, 1 August 2023].

U.S. Bureau of Economic Analysis, Personal Income and Employment by Major Component [CAINC4], retrieved from https://apps.bea.gov/regiona, June 12, 2023.

U.S. Bureau of Labor Statistics, Consumer Price Index for All Urban Consumers: All Items in Midwest [CUUR0200SA0], retrieved from FRED, Federal Reserve Bank of St. Louis; https://fred.stlouisfed.org/series/CUUR0200SA0, June 12, 2023.

U.S. Census, Census Cartographic Boundaries, https://www.census.gov/geographies/mapping-files/time-series/geo/cartographic-boundary.html [Accessed, 1 August 2023].

U.S. Census, 2020 Population, https://data.census.gov/ [Accessed, 1 August 2023].

U.S. Census Average People Per Household, Dataset S1101, https://data.census.gov/table?q=households&g=050XX00US18005$1400000,18013$1400000,18031$1400000,18059$1400000,18065$1400000,18071$1400000,18079$1400000,18081$1400000,18097$1400000,18139$1400000,18145$1400000&tid=ACSST5Y2021.S1101&moe=false [Accessed, 1 August 2023].

U.S. Census, 2016, TIGER/Line Indiana Current Places, [used for population centers list], http://www2.census.gov/geo/tiger/TIGER2016/PLACE/tl_2016_18_place.zip [Accessed, 1 August 2023].

U.S. Department of Agriculture (USDA), Farmers.gov, Water, https://www.farmers.gov/conservation/concerns-tool/water [Accessed, 1 August 2023].

U.S. Department of Agriculture (USDA), National Agricultural Statistics Service (NASS), 2021, 2021 Indiana Cropland Data Layer, https://www.nass.usda.gov/Research_and_Science/Cropland/metadata/metadata_in21.htm [Accessed, 1 August 2023].

U.S. Department of Transportation (DOT) National Address Database (NAD) Release 12, Archived at https://web.archive.org/web/20230122025439/https://www.transportation.gov/mission/open/gis/national-address-database/national-address-database-nad-disclaimer [Accessed, 1 August 2023].

U.S. Energy Information Administration (EIA), 2022, Indiana State Profile and Energy Estimates https://www.eia.gov/state/analysis.php?sid=IN [Accessed, 1 August 2023].

U.S. Environmental Protection Agency (EPA) HUC10, 2009, Generalized 10-digit Hydrologic Unit Boundaries of the United States http://watersgeo.epa.gov/ArcGIS/rest/services/OW/WBD_NAD83/MapServer [Accessed, 1 August 2023].

U.S. Environmental Protection Agency (EPA) NPDES, National Pollutant Discharge Elimination System, via the Enforcement and Compliance History Online (ECHO) database https://echo.epa.gov/trends/loading-tool/get-data/monitoring-data-download [Accessed, 1 August 2023].

U.S. Environmental Protection Agency (EPA) SDWIS Safe Drinking Water Information System https://www.epa.gov/ground-water-and-drinking-water/safe-drinking-water-information-system-sdwis-federal-reporting [Accessed, 1 August 2023].

U.S. Fish and Wildlife Service (FWS) National Wetlands Inventory (NWI) https://www.fws.gov/program/national-wetlands-inventory [Accessed, 1 August 2023].

U.S. Geological Survey (USGS) National Hydrology Dataset (NHD) https://www.usgs.gov/national-hydrography/national-hydrography-dataset [Accessed, 1 August 2023].

U.S. Geological Survey (USGS) NLCD, 2021, National Land Cover Database (CONUS) https://www.mrlc.gov/data/nlcd-2021-land-cover-conus [Accessed, 1 August 2023].

U.S. Geological Survey (USGS), National Water Information System (NWIS), https://www.usgs.gov/tools/national-water-information-system-nwis-mapper [Accessed, 1 August 2023].

U.S. Geological Survey (USGS) Mineral Resource Data (MRData), Geologic Units by County https://mrdata.usgs.gov/geology/state/state.php?state=IN [Accessed, 1 August 2023].

Valayamkunnath, P., Barlage, M., Chen, F., et al., 2020, Mapping of 30-meter resolution tile-drained croplands using a geospatial modeling approach. *Sci Data* 7, 257. https://doi.org/10.1038/s41597-020-00596-x

van der Kooij, S., Zwarteveen, M., Boesweld, H., and Kuper, M., 2013, The Efficiency of Drip Irrigation Unpacked, *Agricultural Water Management*, 123, 103-110

Ward, D., and McKague, K., 2007, Water requirements for livestock, Fact Sheet, Ontario Ministry of Agricultural Food and Rural Affairs. AGDEX 716/400

Weerasooriya, R.R., Liyanage, L.P.K., Rathnappriya, R.H.K., 2012, Industrial water conservation by water footprint and sustainable development goals: a review. *Environ Dev Sustain* 23, 12661–12709 https://doi.org/10.1007/s10668-020-01184-0

Westenbroek, S.M., Kelson, V.A., Dripps, W.R., Hunt, R.J., and Bradbury, K.R., 2010, SWB—A modified Thornthwaite-Mather Soil-Water- Balance code for estimating groundwater recharge: U.S. Geological Survey Techniques and Methods 6–A31, https://pubs.usgs.gov/tm/tm6-a31/ [Accessed, 10 December 2022].

Westenbroek, S.M., Engott, J.A., Kelson, V.A., and Hunt, R.J., 2018, SWB Version 2.0—A soil-water-balance code for estimating net infiltration and other water-budget components. USGS Numbered Series 6-A59. U.S. Geological Survey, Reston, VA. Available at: http://pubs.er.usgs.gov/publication/tm6A59 [Accessed, 10 December 2022].

Widhalm, M., Robeson, S., Hall, B., Baldwin, M., and Coleman, J., 2018, Indiana's Climate Trends: A Resource for the Indiana Climate Change Impacts Assessment, Indiana Climate Change Impacts Assessment (IN CCIA). Purdue University, West Lafayette, Indiana. https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1001&context=climatetr [Accessed, 1 August 2023].

Wiener, M.J., Jafvert, C.T. and Nies, L.F., 2016. The assessment of water use and reuse through reported data: A US case study. *Science of the Total Environment*, 539, pp.70-77. https://doi.org/10.1016/j.scitotenv.2015.08.114

Williams, T., Bauer, B., Carter, C., Keto, D., Kelley, W., and Vardiman, J., 2017, Using No-Till to Minimize Extreme Weather Impacts. MP-131.2. Jan 2017. University of Wyoming. https://www.wyoextension.org/publications/html/MP131-2

Glossary

Term	Definition
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. Most NPDES discharges are permitted based on a 7Q10 low flow for adequate dilution.
Actual evapotranspiration	A measure of the amount of water that the earth surface and vegetation lose due to evaporation and transpiration.
Alluvium	Unconsolidated geologic sediment of any grain size deposited by a river, stream, or creek.
Anthropogenic	Man-made, or influenced by man. In this report, 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	Subterranean voids, generally as bedrock fractures or interstitial voids in sand and gravel alluvium, 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.
Basin (watershed)	The contributing land area that drains water, such as rainfall or snowmelt, to a basin outlet, or pour point. Also called a drainage basin or catchment.
Bedrock	Any lithified geologic material that remains intact and in place where it was deposited.
Biome	A biome is suite of vegetation and fauna that establishes in a certain location as a result of climatic (e.g., temperature, precipitation) and morphogenetic or topoclimatic factors.
Confined (aquifer)	An aquifer that flows beneath an impermeable geologic layer, allowing water pressure to build. Sometimes called "artesian" aquifer.
Continuous corn	The agricultural experiment of growing a monoculture of corn in the same field for multiple successive years rather than rotating crops.
Crop rotation	The agricultural technique of changing the specific crop that is planted in a given field from year to year to reduce nutrient depletion.

Discharge	Streamflow volume, usually measured in cubic feet per second (cfs) or cubic meters per second (cms). See stream discharge
Evapotranspiration	The removal of water from the earth's surface and vegetation through the processes of evaporation and transpiration.
Excess water availability	Water available for beneficial uses after other needs and demands are met, such as water withdrawals and ecosystem needs
Glacial till (till)	An often thick, poorly sorted, clay-rich, unconsolidated geologic deposit that is created by the movement of a glacier.
Headwaters	The most up-gradient, or first-order, tributary watersheds contributing water and sediment downstream to the stream network.
Hydrograph	A graph showing stream discharge (y-axis) over time (x-axis), reflecting runoff from the area upstream of the measurement point.
Hyporheic flow	The area of a watershed adjacent to and below a stream channel where active exchange of surface water into subsurface sediments, mixing with near-surface groundwater, and then back to surface flow occurs.
Induced recharge	A hydrologic condition where the level of the underground water table in an area is lower than the level of a nearby surface drainage, causing the groundwater to be recharged from the drainage.
Indiana Department of Environmental Management	IDEM, Ground Water Section, maintains the Indiana Groundwater Quality Monitoring Network
Indiana Finance Authority	Funding agency for this study
Indiana University	IU, provided expertise and research infrastructure for this study.
Instream flow	Minimum instream flow is a lower limit on streamflow that is used as a drought-response threshold. Guidance on minimum instream flows are intended to ensure a supportive hydrologic environment for riparian ecosystems.
Interflow	Shallow subsurface flow down gradient along a hillslope.
Irrigation well	Water well that extracts groundwater from an aquifer for the purpose of amending the available water for plant, often crops or turf, growth.
Mann-Kendall trend test	A statistical test used to assess temporal datasets for increasing or decreasing trends as well as statistical significance of the trend. The Mann-Kendall test does not assess the magnitude of change. See Sen slope.
Natural baseflow	Discharge from aquifers to streams. Baseflow is the groundwater contribution of streamflow. 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.
Net Infiltration	The theoretical amount of water that could be added to a groundwater aquifer through the process of infiltration after other components are satisfied. “net_infiltration” is the variable name in SWB2 for potential groundwater recharge.
Observation well	A subsurface borehole (groundwater well) that, instead of pumping, is used to observe and monitor the water-table elevation.
Outwash	The geologic alluvium deposited by meltwater from a receding glacier.
Peaking factor	Ratio of maximum water demand to the average demand, such as peak daily demand to average daily demand.
Peak use multiplier	Ratio of maximum water demand to the minimum demand. Similar to peaking factor, but maximum demand is relative to minimum demand (not average demand).
Potential evapotranspiration	The theoretical maximum amount of water that could be suspended in the atmosphere, assuming the surface water available for evaporation and transpiration is not limited.
Potential groundwater recharge	The theoretical amount of water that could be added to a groundwater aquifer through the process of infiltration after other components are satisfied. “net_infiltration” is the variable name in SWB2 for potential groundwater recharge.
Public Water System	PWS, 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 non-community non-transient (NCNT) system such as a school that has their own water well(s). PWS are subject to the LCR.
Recharge (groundwater recharge)	The amount of water that is added to a groundwater aquifer through the process of infiltration.
Runoff	Precipitation that is unable to infiltrate into a groundwater aquifer and instead flows along the earth’s surface.
Sankey diagram	A Sankey diagram is a data-visualization tool to illustrate flow from one set of values to another.

Sen slope	Theil–Sen estimator of slope used along with the Mann-Kendall trend test to calculate the magnitude of trends in the long-term temporal data.
Streamflow volume	Streamflow discharge, usually measured in cubic feet per second (cfs) or cubic meters per second (cms)
Stream discharge	Streamflow volume, usually measured in cubic feet per second (cfs) or cubic meters per second (cms)
Stream gage	A location where a flowing body of water is confined to a known geometry to facilitate the estimation of flow volume.
Subwatershed	A smaller portion of a larger watershed, defined as the region up-slope from or above a given point that directs rainwater toward that point as drainage.
Surface water	Locations where there is an uninhibited interface between water and the atmosphere, either due to the water table being exposed at the earth's surface or because of water flowing over an impermeable surface.
Till (glacial till)	An often thick, poorly sorted, clay-rich, unconsolidated geologic deposit that is created by the movement of a glacier.
Unconfined (aquifer)	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 budget	An accounting method of calculating the net sum movement of water into and out of a hydrologic system through precipitation, evapotranspiration, recharge, and runoff.
Water cycle	The conceptual model that describes the closed-loop system of water – from water vapor in the atmosphere to precipitation, then through or across the surface as infiltrated groundwater or runoff (respectively), and back into the atmosphere as water vapor by the processes of evaporation and transpiration.
Water demand	The amount of water required for different purposes and in different water-use sectors, such as for residential, institutional, industrial, and public water supplies. Demand is often quantified by water-withdrawal volumes.
Watershed (basin)	The contributing land area that drains water, such as rainfall or snowmelt, to a basin outlet, or pour point. Also called a drainage basin or catchment.

APPENDICES

Appendix A. Data Sources and Processing for Water Demand and Availability Analyses

Data sources and processing

1. Water Demand Analysis
2. Water Availability Analysis

Water Demand Analysis Data Processing

Data Sources

Significant Water Withdrawal Facilities (SWWF)

The Indiana database of Significant Water Withdrawal Facilities (SWWFs) current to 2021 was obtained on a statewide scale from https://www.in.gov/dnr/water/files/IN-SWWF.zip

The database is a Microsoft Access database file that represents a collection of facilities across the state that have the capacity to withdraw more than 100,000 gallons of water per day from surface and/or groundwater sources. The database has been maintained since 1985 and contains mostly complete records going back to this date.

Data are included from all counties, requiring subsequent filtering and processing to select specific points based on their sector or their location in either a given county of interest (for county-wide analyses) or within a sub-basin contained within the study area (for HUC10 Basin analyses). More on this in the Data Processing section below.

All pumping locations include monthly withdrawal data in gallons. The database classifies facilities into six primary water-use sectors, defined as:

- public utility water suppliers (PS),
- industrial users (IN),
- agricultural and turf irrigation (IR),
- energy production (EP),
- rural uses such as large CAFO farms (RU), and
- miscellaneous category (MI). Points from the miscellaneous category were not included in all analyses.

Monthly Report of Operations (MRO)

Public utilities in Indiana are required to keep track of the amount of water that they treat every day and submit that information each month to the Indiana Department of Environmental Management as a Monthly Report of Operations (MRO) form. These forms are publicly available through the IDEM's Virtual Filing Cabinet (VFC) search function at https://vfc.idem.in.gov/.

The forms that are accessible in the VFC database are not digitized, but rather are PDF scans that often contain handwritten treatment information. The data includes daily measures of Alkalinity, pH, Hardness, and other measures of water quality, in addition to the total amount of water treated. The forms also have a monthly summary with the total amount of water treated, along with the minimum, maximum, and average day for that month. MRO data can go back to the 1990s for some utilities, but the database is incomplete and there are often months or entire years missing.

When available, MRO data were downloaded for the years of 2010, 2012, 2021, and 2022 for all of the utilities in the study area using their associated PWSID reference numbers (usually multiple records each month for each facility representing separate treatment points). Supplemental MRO data were also obtained for select time periods when the SWWF database was either missing data or had values that seemed anomalous, as a way of validating or gap-filling.

Utilities that purchase water from other utilities are still required to report the amount of water that enters their system. This means that MRO data can be used to understand the relative amount of water being provided by utilities that do not pump their own water and are therefore not in the SWWF database.

Confined Animal Feeding Operations (CAFO)

Confined Feeding Operations (CFOs) and larger-scale Confined Animal Feeding Operations (CAFOs) are required to register with the Indiana Department of Environmental Management if they raise more than a set threshold of animals each year. A list of active CFO and CAFO farms in Indiana derived from the partial lists located at

https://www.in.gov/idem/cfo/resources/pending-and-issued-cfo-permits/

was obtained through the Indiana Department of Environmental Management for the years of 2022, 2018, and 2015. The 2022 and 2018 data have detailed counts of the number and type of animal on each farm, whereas the 2015 data only provides data on the number of farms and no specific information on the animals.

National Address Database (NAD)

The National Address Database (NAD) is a database of points representing different types of addresses across the country (Residential, Commercial, Industrial, etc.). The database is created and managed by the US Department of Transportation and was downloaded from:

https://www.transportation.gov/mission/open/gis/national-address-database/national-address-database-nad-disclaimer

The version of the database downloaded and analyzed for this project is 'Release 12', which is archived at https://web.archive.org/web/20230122025439/https://www.transportation.gov/mission/open/gis/national-address-database/national-address-database-nad-disclaimer

Parcel Data

As part of the process of analyzing the NAD dataset, we used the Property Class Codes field in a statewide parcel dataset to visualize land use and further highlight locations that may need additional address points. The parcel data from 2019 was obtained from

https://maps.indiana.edu/download/Reference/Land_Parcels_County_IGIO.zip

Parcel data were not used directly in this project, but rather used as a backdrop while processing the NAD data in order to more quickly identify relevant locations that were omitted in the NAD.

Population Models

Census & Indiana Business Research Center

Population estimates for 2020 and population forecasts for 2015-2050 were obtained using the US Census Bureau P1 dataset (https://data.census.gov/table?g=040XX00US04&tid=DECENNIALDHC2020.P1) and Indiana Business Research Center (IBRC) population projections (https://www.stats.indiana.edu/about/pop_proj_15-50.asp), respectively. The latter implements a cohort-component method that considers 2015 Census data and projects this forward by applying county-specific mortality, migration, and fertility rates.

Shared Socioeconomic Pathways (SSP)

The Shared Socioeconomic Pathways (SSPs) are a set of five standardized storylines developed by an international team under the guidance of the Intergovernmental Panel on Climate Change (IPCC). They are designed to explore the potential impacts of different future development pathways on greenhouse gas emissions and climate change. The SSPs provide a common framework for researchers to assess the implications of different socioeconomic and technological scenarios for climate change, and to compare the results of different studies.

More information on the models can be found at https://tntcat.iiasa.ac.at/SspDb/dsd. After an analysis of the five SSP pathways, we determined that SSP4 most closely matched the population growth projections through the year 2050 from the Indiana Business Research Center (IBRC). Accordingly, this model was used to extend these population projections beyond 2050. The SSP4 model represents a world where there is rapid economic development and technological change, but it favors middle- and high-income groups, leading to a further fragmentation of society and increased inequality.

Data Processing

Significant Water Withdrawal Facilities (SWWF)

The version of the database used in this study was from 2021. Most of the locations of the facilities and sources are generalized or incorrect, so accurate locations determined in an earlier study (Letsinger, 2018) were joined to the sources that were in both datasets using the [lngSiteLcn] field. Locations of new facilities and sources used the IDNR-assigned locations. All of the water-use sectors were further subdivided into sub-sectors as follows:

PS – Municipal, non-municipal

IN – Mining (quarries, aggregate, asphalt), non-mining industrial (e.g., manufacturing)

EP – Community (utilities), onsite (single user/facility)

IR – Agricultural, turf (golf courses or other irrigation such as schools, businesses, or homeowner's associations)

RU – CAFO, Aquaculture

MI – not subdivided

Because the study was dominantly focused on the public supply (PS) sector, a review of the community or municipal PS facility reports was undertaken; and important omissions were reported to IDNR, who followed up in a timely manner to obtain the reports for missing years.

Some elements of the study that relied on SWWF reports by large utilities that provide water to multiple communities (e.g., Indiana-American) were unable to be thoroughly completed because of the lack of location-specific water-use data for communities (e.g., Shelbyville). We made the decision to parse the water-use data based on proportion of the population in the service area that was in the Southeast-Central Indiana region. Because we do not know how non-residential water use is distributed throughout a large and complex service area (even if we know the locations of industrial or commercial facilities), our estimates could be misallocated.

A careful examination and processing of the SWWF database revealed a number of mistakes that had to be manually corrected. This includes the misallocation of use sectors (e.g., apartment complexes with no power generation facilities being listed as EP, power plants that do not provide drinking water being listed as PS, etc.) as well as several water usage values that were seemingly mis-entered. The latter case was most often skewed by an order of magnitude (i.e., gallons vs tens of gallons), but occasionally off by a factor of 1000. These cases were identified based on anomalous spikes or dips in the data compared to the baseline usage of a given facility. In some cases, data were unavailable for a facility for a month, or sometimes even for an entire year. In these cases, data from an adjacent month or year was copied over to approximate the usage during the span of missing data.

Public Supply Sector

The Public Supply sector in the SWWF database provides values for the amount of water pumped by each utility. In order to estimate the daily PS water demand for a given county, we had to carefully consider the service areas and water sources of the utilities, as some service areas cross county boundaries and some utilities pump water from a different county than they serve.

For utilities that predominantly serve one county but have a small amount of service area that extends into an adjacent county, the demand was allocated to the primary county. When a utility mainly serves one county but has a water source in an adjacent county, MRO data were used to determine the amount of water originating from the water treatment plant in the adjacent county. This demand is applied to the county where the water is being supplied rather than the county where it is being sourced.

In a few cases, a utility purchases water from another utility that is located in a different county. Whenever this is true, MRO data were again used to determine the amount of water being sold by the selling utility and that demand was applied to the purchasing county where the water is being supplied.

Monthly Report of Operations (MRO)

The MRO data are provided as a scanned PDF, meaning that the monthly treatment amounts had to be manually digitized by examining and transcribing each form. Sometimes the forms contain typed data, but often the numbers are handwritten can be difficult to read. Furthermore, the data are supposed to be submitted in units of ‘thousands of gallons’, but this is not always the case for each utility. Care was taken to check the amount being reported against SWWF data to ensure that they were the same order of magnitude. In some cases, inconsistencies with relative magnitudes were identified and the data were adjusted to the proper units.

Once processed, the total gallons treated during the month were used to supplement missing or anomalous SWWF data to create a more complete timeline of water usage by the utilities in the study area. The minimum and maximum daily treatment values were also used to understand what peak daily demand looks like for each utility. This is one of the reasons that MRO data were obtained for the drought year of 2012, as an indication of what demand extremes a specific utility may need to be prepared for during future droughts.

Population Projections

We considered each of the SSP models and compared them to projected population trends through the year 2050 from StatsIndiana (http://www.stats.indiana.edu/topic/projections.asp). After an analysis of the different models, we determined that SSP4 seemed to represent the shape of the most probable growth scenario for this region. While the general population trend for SSP4 was consistent with IBRC projections, the actual population numbers did not always align with the current population as taken from recent data (see Population Models section above).

To account for this discrepancy and create a model for future population growth that aligns with current population numbers, we applied a simple multiplier to the SSP4 data in order to shift the 2020 values from the model to match the Census data on a county basis. In some cases, the SSP4 model values were shifted up and in other cases they were shifted down. More rural counties typically were shifted down (i.e., declining populations), while more urban counties with higher populations needed to be shifted up to match the actual 2021 population. The shift multipliers used ranged from 0.58 to 1.28, with an average multiplier value across the eight relevant counties of 0.92. The projections were revisited and adjusted ("tweaked") after data were released regarding population changes from mortality owing to the 2019-2020 COVID pandemic and accelerated migration patterns resulting from the "Great Resignation."

Table showing the County population-growth projections for each decade averaged for each 5-year period.

County	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075
Barth.	84,612	87,015	88,712	90,408	91,408	92,407	93,048	93,689	93,911	94,133	93,630
Decatur	27,082	27,691	27,653	27,614	27,335	27,055	26,699	26,344	25,907	25,470	24,873
Hancock	83,959	88,077	90,177	92,276	93,680	95,083	96,099	97,115	97,672	98,229	97,994
Henry	49,430	49,946	50,547	51,147	51,336	51,524	51,529	51,535	51,345	51,154	50,594
Jackson	46,762	47,095	47,553	48,010	48,081	48,151	48,057	47,963	47,684	47,404	46,794
Johnson	175,331	188,896	193,402	197,907	200,931	203,955	206,146	208,338	209,546	210,754	210,278
Rush	16,770	16,787	16,854	16,922	16,839	16,756	16,629	16,502	16,315	16,129	15,833
Shelby	45,384	45,712	46,253	46,794	46,960	47,125	47,123	47,121	46,934	46,748	46,220

Concentrated Animal Feeding Operations (CAFO)

Due to the 'snapshot' status of CAFO data in Indiana, we processed the available data to establish some general temporal trends on water usage. For the 2018 and 2022 data snapshots included accurate counts of the type and number of animals on each farm; therefore, it was possible to establish an estimate of how much water is used annually based on known values of water usage associated with different animal species. These estimations take into account water consumption (and wasted water meant for consumption), water usage for cooling during summer months, and water usage for cleaning manure from living quarters.

Once the total amount of annual water usage was summed for each farm inside the study area during 2018 and 2022, the totals from all the farms in each subbasin were summed together and plotted against the number of farms in that basin. This was used to establish a linear trend relating the number of farms in a subbasin to the amount of water usage, allowing an average 'water use per CAFO farm' to be established. The linear trend worked out to be around 19,949 gallons per day per farm, on average, with an R^2 value of 0.74.

The next step was to take this value of 19,949 gallons per farm per day, and apply it to the farm counts from the 2015 data to estimate how much water might have been used in 2015. Using this method, we developed estimates of CAFO water use in the study area for 2022, 2018, and 2015. For the years between these years, a linear transform was used to connect the 2015 values to 2018, and the 2018 values to 2022. However, to calculate water balance for the region before 2015, we needed to estimate how much water was used by CAFOs in the more distant past.

The CAFO data have a number of fields that indicate whenever a given farm initially applied for a CAFO permit and when it was approved. Using this information, it was possible to take the counts of farms from 2015 and project them back in time to approximately when their business originated (or came under the regulatory umbrella of IDEM) and thus how many farms existed during any given year in the past.

To estimate the amount of water usage in the past was not as simple as multiplying the number of farms in a year by the water usage amount of 19,949 gallons per farm per day (although that was the starting point). This is because the number of animals on a farm is known to decrease moving back in time. That is to say, in more recent years there has been a trend of fewer, larger farms compared to the past; especially for farms that raise poultry and pork. This trend on a statewide level can be extrapolated by looking at species specific animal counts from the 5-year USDA Agricultural Census. The most recent 2017 dataset and other years going back to 1987 was obtained from https://www.nass.usda.gov/Publications/AgCensus/

Although some data are unavailable (proprietary), like the chicken counts from Jackson County (an egg-producing and poultry-farm-heavy county), we were able to use chicken and pig counts from other counties in the study area to establish a trend of the number of chickens and pigs per farm in the past. These trends were projected backwards in order to determine the percentage of 2015 animal counts in the past.

Then, this percentage multiplier was applied to the estimated water usage (based on the number of farms and the 19,949 gallons per farm per day value above). The percentage multiplier based on chicken populations was used in the chicken-dominated basins of 604 and 605, whereas the percentage multiplier based on pig populations was used in the pig-dominated basins of 401, 402, 403, 404, 407, 408, 501, 502, 503, 504, 506, 601, 603, and 606. Finally, the (dairy) cattle-dominated basins (405, 406, 409, 505, and 602) are assumed to have steady populations of cattle moving backwards in time and so no percentage multiplier was used and the 19,949 gallons per farm per day was applied directly to the number of farms during a given year in the past.

Ultimately, we needed monthly estimates of CAFO water usage to compare to other monthly data like SWWF and NPDES water returns. To this point, the daily estimates had been extrapolated into annual estimates, but this did not take into account the seasonal water usage on animal farms. To get at this, we used data from a 2009 USGS publication on water usage: Shaffer, 2009; https://pubs.usgs.gov/sir/2009/5096/pdf/sir20095096.pdf)

On page 48 of Shaffer (2009), Figure 22 gives a percentage of annual withdrawals for each month related to livestock water withdrawals in Indiana, ranging from 6.6% in January to 12% in August. These percentage values were multiplied by the annual sum for a given year to allocate water usage on a monthly basis and account for seasonal variation. The resultant dataset is a monthly estimation for CAFO water usage in each subbasin in the study area going back to 1985 that considers farm counts, average water usage per farm (based on animal counts), and seasonal variations in water use throughout the year.

National Address Database (NAD)

It was determined that while the National Address Database has robust representation of the locations of standard residential houses, commercial businesses, and industrial locations, it does not specify those farm (agriculture) addresses also have rural residential houses versus those that are only related to agriculture. Additionally, it often assigns a single point to apartment complexes with multiple units. Because of this, it was necessary to manually examine the points in the database and the land encompassed by the study area using recent aerial photos. When appropriate, additional residential address points were added to capture unrepresented residential households.

Self-Supplied Residential

The main purpose for processing and enhancing the NAD dataset was in order to determine the locations of residential households in the study area so that we could approximate how many of these households are served by public water utilities and how many are self-supplied. Once the NAD was processed and all unrepresented residential households were added, we compared the dataset to polygon vector files representing our best interpretation of Water Utility Service Area boundaries based on a number of sources (most commonly maps of service areas from Preliminary Engineering Reports, but sometimes based on town administrative boundaries). By comparing the NAD file to the Water Utility Service Areas, we were able to establish the number of households that are within the service area of each utility, as well as the number of households that are outside of all utility service areas and are thus considered 'self-supplied'.

Knowing the number of households, we were able to indirectly produce population estimations for a given utility, as well as estimations of the number of people currently self-supplied. To approximate the average number of people per household, Census Tract data from the 2021 S1101 dataset were used (https://data.census.gov/table?tid=ACSST1Y2019.S1101). The average number of people per household for the tracts in the study area were joined to a GIS shapefile representing the spatial area of the tract. These polygons were then converted into a raster data set with a cell size of 250 meters, with each cell containing the value representing the average number of people per household in that tract. Then zonal statistics were extracted on each subbasin in the study area and an average number of people per household in each subbasin was estimated accordingly.

Using the estimate of the number of people in each subbasin that are self-supplied, we approximated how much water is used by self-supplied residences by multiplying the self-supplied population in each subbasin by the average amount of daily per-capita water use as defined by 2015 USGS data specific to Indiana (Dieter et al, 2018). This value is estimated to be around 76 gallons per day per person, so an annual estimate of water usage in this sector for 2021 was achieved by multiplying 76 by the number of people, and then multiplying this by 365 days.

However, we also needed to estimate the amount of self-supplied water usage in the past for purposes of water balance. To approximate this, we calculated the trend of population growth on a county-level for the major counties within the study area. Summed census data for the counties of interest from 1990, 2000, 2010, and 2018-2022 were plotted and a linear trendline was established that represented the average rate of population growth within the study area.

To extrapolate the amount of self-supplied water usage in the past, it was assumed that the number of self-supplied residences increased at the same rate as population increased in the study area. Based on the trendline, it is estimated that population has increased at a rate of around 11.2% per decade, 1.2% per year, and 0.0935% per month. The amount of self-served water usage in the past was then estimated by reducing the 2021 annual estimation by 0.0935% each month moving backwards from December of 2021.

Aquifers

To determine the source aquifer for self-supplied users such as rural residential households and CAFOs not in the SWWF database, we used a surficial geology layer obtained from a USGS publication on the quaternary sediments of the glaciated United States (Soller et al., 2012; https://pubs.usgs.gov/ds/656/). The feature representing surficial outwash aquifers was isolated and a 500-meter buffer was applied to the feature in order to represent the marginal extents of the outwash deposit that extend underground beyond the surface deposit. Any points that intersected with this buffered outwash feature were assumed to be obtaining their water from outwash aquifers. Any self-supplied points beyond the extent of the buffered outwash feature were assumed to be using a buried (confined) sand and gravel aquifer as their water source. The number of bedrock aquifer wells is limited and are generally associated with larger PS and IN users (to the north of the glacial limit) and low-productivity residential wells (along and to the south of the glacial limit), so for depicting withdrawals from aquifers for residential users (e.g., in Sankey diagrams) we assumed that no self-supplied users are tapping into bedrock aquifers.

Water Availability Analysis Data Processing

The water demand data compilation described above was utilized in the water-availability analysis in a subbasin-level inventory of withdrawals and returns. Please see Appendix E for a graphical presentation of the time series of withdrawals and returns for each subbasin. Appendix F contains details of the excess availability model that utilized these data compilations, and includes maps of the HUC10 subbasins referenced in this document.

Data Sources

Significant Water Withdrawal Facilities (SWWF)

The Indiana database of Significant Water Withdrawal Facilities (SWWFs) current to 2021 was obtained on a statewide scale from https://www.in.gov/dnr/water/files/IN-SWWF.zip.

This dataset has been discussed extensively above and is included here to represent the demand portion of the HUC10 subbasin water inventory that was conducted for the excess water availability assessment.

National Pollutant Discharge Elimination System (NPDES)

Estimates of the amount of non-consumptive or partially consumptive wastewater being returned as stream discharge in the different subbasins from Water Treatment Plants and some Industrial facilities were obtained through the USEPA's NPDES database (National Pollutant Discharge Elimination System), downloaded from

https://echo.epa.gov/trends/loading-tool/get-data/monitoring-data-download

The locations of NPDES discharges inside the study area and their associated EPA lookup reference numbers were derived from the NPDES Pipe Location shapefile obtained from

https://maps.indiana.edu/download/Environment/Waste_Water_NPDES_Pipe_Locations.zip

Data Processing

National Pollutant Discharge Elimination System (NPDES)

Like the SWWF database, there were some inconsistencies within the NPDES return data that could be identified as probable errors created when entering data (often by one order of magnitude). When these were identified and were deemed to be convincingly anomalous, the data were corrected to reflect adjacent months.

In addition to this, some facilities (most often industrial facilities or quarries) report their return flow data every 3 or 6 months rather than monthly. In these cases, the data were converted back to average monthly values based on the number of days in each applicable month.

Significant Water Withdrawal Facility (SWWF) Return Flows

The majority of the water pumped by SWWF locations is presumed to be returned by way of NPDES discharges, most often after flowing through a wastewater treatment plant. The major industrial facilities that are not connected to a municipal sewer system also report their discharges through the NPDES.

The sector of Irrigation is the only sector included within SWWF demand that needs to have return flows estimated. Because irrigation water is applied to the land surface; although irrigation is a highly consumptive water sector, some amount of water will inevitably infiltrate into the soil and be returned to groundwater. We are assuming that 80% of irrigation water is consumed by plants, meaning that 20% is returned to the ground (Table 24, Shaffer, 2009).

Concentrated Animal Feeding Operation (CAFO) Return Flows

We assume that self-supplied CAFOs in the study area consume about 80% of the water that they pump, and that 20% is returned to the ground through infiltration. These numbers are supported by Shaffer (2009), which indicates that the median consumption for livestock farms in Ohio is 76%. Since Indiana tends to have slightly more seasonal variability (more extreme summer usage) than Ohio according to data used in this study, a slightly higher consumptive value of 80% and a return value of 20% was employed.

Self-Supplied Residential Return Flows

In order to estimate how much water pumped by self-supplied residential users is consumptive, we again referenced the 2009 USGS water usage report (Shaffer, 2009; https://pubs.usgs.gov/sir/2009/5096/pdf/sir20095096.pdf). Table 15 in this report approximates the amount of consumptive use in the Public Supply sector in Indiana. While these values are not directly related to self-supplied residential, it is assumed that both self-supplied residential and publicly supplied residential users will have similar usage patterns.

The table assumes that there is no consumptive use in the winter (everything is returned), and estimates an average of 2% consumption in the spring, 19% consumption in the summer (for watering lawns, etc.), and 7% consumption in the autumn. This suggests that 100% of water pumped for self-supplied residential use is returned in the winter, 98% is returned in the spring, 81% is returned in the summer, and 93% is returned in the autumn. These seasonal values were applied to water seasons (Dec-Feb = winter, Mar-May = spring, Jun-Aug = summer, Sep-Nov = fall).

Appendix B. Utility Sankey Diagram

Utility Sankey Diagram

B1. Sankey diagram showing public utility pumping proportions and water source.

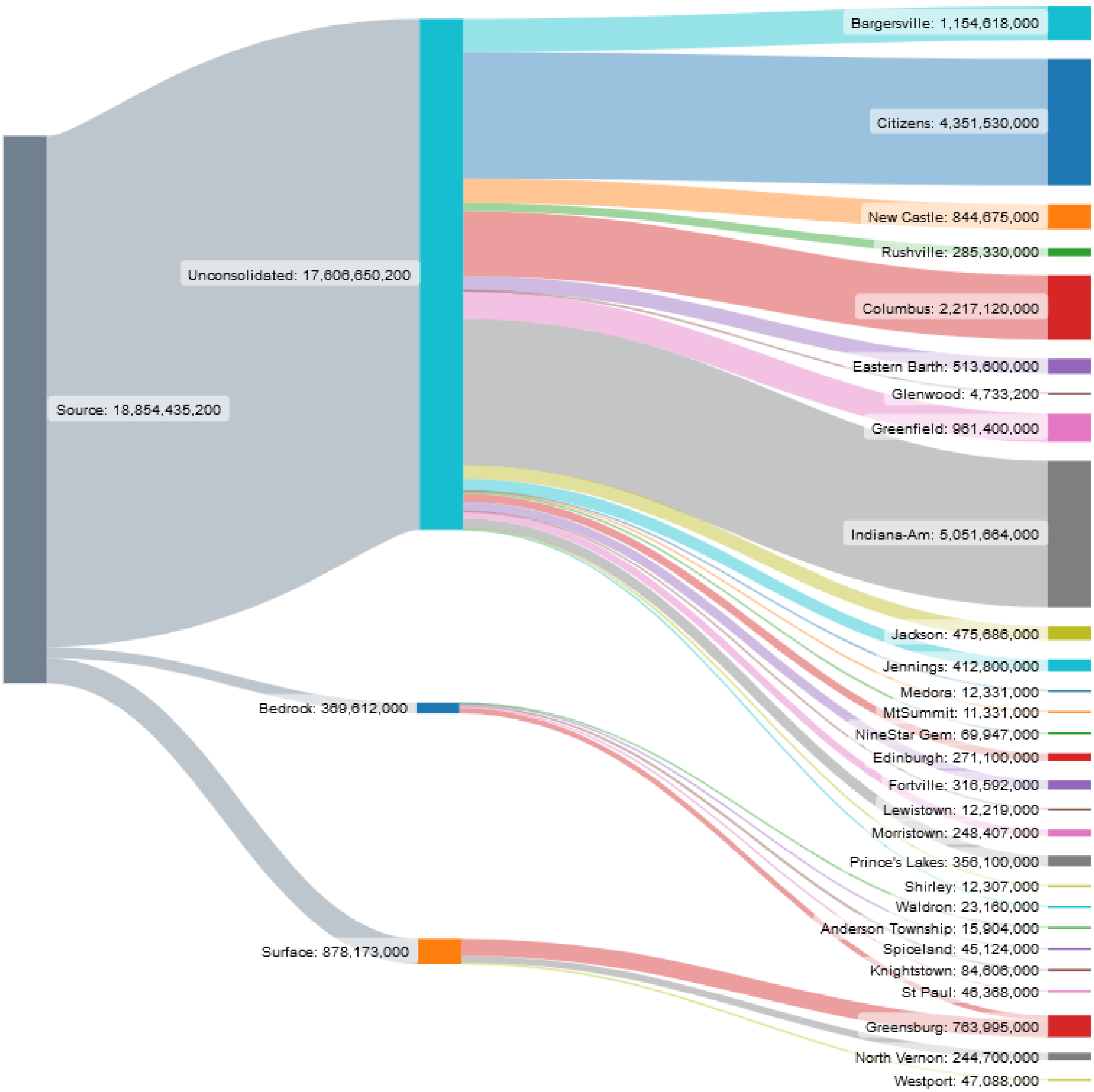


Figure B1: Sankey diagram showing the source aquifer and water usage (gallons) from 2021 for the public utilities in the study area.

Appendix C. Water Demand Regression Model Results

Table C1. Regression statistics based on historical public water utility demand (aggregated by county) and applied to future (predicted) variables representing economic growth and climate variables.

Table C1. Regression statistics based on historical public water utility demand (aggregated by county) and applied to future (predicted) variables representing economic growth and climate variables.

COUNTY	MODEL	VARIABLES	SIGNIF	COEFF	R^2	F
Bartholomew	Linear multiple regression	MaxTemp	< 0.001	0.0436	0.48	75.5
		PET-AET	< 0.001	0.4786		
		IRR	< 0.001	5.0643		
		population	< 0.001	-0.0003		
DECATUR	Regression discontinuity design	MaxTemp	< 0.001	4.3E-03	0.53	117.6
	Linear multiple regression	PET - AET	< 0.001	0.07		
		Per capita personal income	< 0.001	2.4E-03		
HANCOCK	Linear multiple regression	Precip (12 month moving average)	< 0.001	0.15	0.63	138.8
		AveTemp	< 0.001	0.01		
		PET-AET	< 0.001	0.13		
		IRR	< 0.001	4.85		
		Per capita personal income	< 0.001	1.6E-03		
HENRY	Trend only					
	-2.8E-05*MMYYYY + 3.92					
JACKSON	Linear multiple regression - seasonal	PET-AET	< 0.001	0.16	0.46	178.6
	Base level trend	MaxTemp	< 0.001	3.9E-03		
JOHNSON	Linear multiple regression	MaxTemp	< 0.001	0.03	0.72	266.1
		PET-AET	< 0.001	0.81		
		IRR	< 0.001	39.40		
		Per capita personal income	< 0.001	0.01		
RUSH	Trend only					
	-8.5E-06*MMYYYY + 1.39					
SHELBY	Linear multiple regression	Precip (12 month moving average)	< 0.01	-0.08	0.63	176.3
		MaxTemp	< 0.001	0.01		
		PET-AET	< 0.001	0.06		
		Per capita personal income	< 0.001	2.9E-03		

Appendix D. Historical and Future Peaking Factors

Historical and Future Peaking Factors

Peaking factors were calculated using monthly water-use data as a proxy for water demand. Data source was Indiana Department of Natural Resources, Division of Water, Significant Water Withdrawal Database (IDNR, 2021).

Maximum monthly peaking factor = annual average demand/maximum monthly demand

Table D1: Bartholomew County historical and future peaking factors.

Year	Average Annual Demand (MGD)	Maximum Month Demand (MGD)	Minimum Month Demand (MGD)	Max Monthly Peaking Factor	Min Monthly Peaking Factor
1985	6.69	8.18	5.88	1.22	0.88
1990	9.57	11.76	8.32	1.23	0.87
1995	12.43	15.63	10.57	1.26	0.85
2000	12.36	14.78	10.90	1.20	0.88
2005	12.42	14.21	8.65	1.14	0.70
2010	8.15	13.45	5.60	1.65	0.69
2015	10.37	14.76	8.47	1.42	0.82
2020	9.03	11.82	7.06	1.31	0.78
2025	11.69	16.26	9.58	1.39	0.82
2030	11.73	15.34	9.33	1.31	0.80
2035	12.68	15.96	10.67	1.26	0.84
2040	12.97	16.08	10.62	1.24	0.82
2045	14.42	20.45	11.59	1.42	0.80
2050	14.46	18.31	12.18	1.27	0.84
2055	15.57	18.34	13.48	1.18	0.87
2060	16.56	19.25	14.41	1.16	0.87
2065	18.14	21.95	15.34	1.21	0.85
2070	19.00	23.07	16.36	1.21	0.86
2075	19.89	23.23	17.72	1.17	0.89

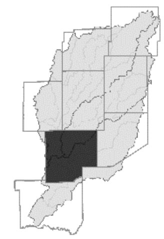
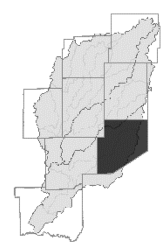


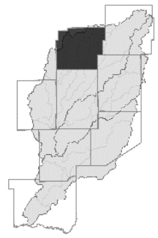
Table D2: Decatur County historical and future peaking factors.

Year	Average Annual Demand (MGD)	Maximum Month Demand (MGD)	Minimum Month Demand (MGD)	Max Monthly Peaking Factor	Min Monthly Peaking Factor
1985	1.87	2.36	1.55	1.26	0.83
1990	2.21	2.76	1.87	1.25	0.85
1995	2.44	2.81	2.04	1.15	0.83
2000	2.37	2.86	1.63	1.21	0.69
2005	3.10	3.69	2.59	1.19	0.84
2010	3.24	3.63	3.00	1.12	0.92
2015	2.60	3.56	2.37	1.37	0.91
2020	2.57	2.75	2.18	1.07	0.85
2025	3.19	3.63	2.98	1.14	0.94
2030	3.42	3.67	3.19	1.07	0.93
2035	3.62	3.85	3.46	1.07	0.96
2040	3.86	4.12	3.67	1.07	0.95
2045	4.12	4.57	3.87	1.11	0.94
2050	4.31	4.56	4.11	1.06	0.95



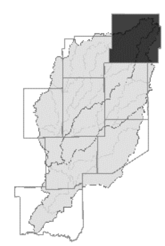
2055	4.49	4.77	4.32	1.06	0.96
2060	4.77	5.04	4.59	1.06	0.96
2065	5.03	5.36	4.79	1.07	0.95
2070	5.21	5.52	4.99	1.06	0.96
2075	5.44	5.67	5.24	1.04	0.96

Table D3: Hancock County historical and future peaking factors.



Year	Average Annual Demand (MGD)	Maximum Month Demand (MGD)	Minimum Month Demand (MGD)	Max Monthly Peaking Factor	Min Monthly Peaking Factor
1985	2.69	3.00	2.48	1.11	0.92
1990	2.84	3.16	2.56	1.11	0.90
1995	2.61	3.00	2.38	1.15	0.91
2000	3.35	3.79	3.10	1.13	0.93
2005	3.81	4.42	3.32	1.16	0.87
2010	3.48	3.91	3.05	1.12	0.88
2015	3.23	4.92	2.96	1.52	0.92
2020	3.61	4.49	3.21	1.24	0.84
2025	3.95	4.50	3.63	1.14	0.92
2030	4.07	4.53	3.65	1.11	0.90
2035	4.42	4.86	3.82	1.10	0.86
2040	4.43	4.94	4.03	1.12	0.91
2045	4.68	5.62	4.22	1.20	0.90
2050	4.77	5.22	4.45	1.09	0.93
2055	5.01	5.48	4.63	1.09	0.92
2060	5.20	5.72	4.75	1.10	0.91
2065	5.27	5.89	4.86	1.12	0.92
2070	5.41	5.94	4.99	1.10	0.92
2075	5.64	6.31	5.22	1.12	0.93

Table D4: Henry County historical and future peaking factors.



Year	Average Annual Demand (MGD)	Maximum Month Demand (MGD)	Minimum Month Demand (MGD)	Max Monthly Peaking Factor	Min Monthly Peaking Factor
1985	3.37	3.90	2.82	1.16	0.84
1990	3.14	3.46	2.76	1.10	0.88
1995	3.44	4.29	3.05	1.24	0.88
2000	3.44	3.84	3.09	1.11	0.90
2005	3.48	3.93	3.07	1.13	0.88
2010	2.58	3.13	1.83	1.21	0.71
2015	2.98	3.26	2.51	1.09	0.84
2020	2.59	2.76	2.42	1.07	0.94

Table D5: Jackson County historical and future peaking factors.

Year	Average Annual Demand (MGD)	Maximum Month Demand (MGD)	Minimum Month Demand (MGD)	Max Monthly Peaking Factor	Min Monthly Peaking Factor
1985	3.18	3.38	2.88	0.94	0.91
1990	3.27	3.95	2.81	1.21	0.86
1995	4.01	4.57	3.71	1.14	0.93
2000	4.88	5.24	4.44	1.07	0.91
2005	3.99	4.67	3.59	1.17	0.90
2010	3.73	4.31	3.31	1.15	0.89
2015	4.27	5.24	3.45	1.23	0.81
2020	3.82	4.38	3.30	1.15	0.87
2025	4.41	5.14	4.11	1.17	0.93
2030	4.51	4.89	4.19	1.08	0.93
2035	4.41	5.14	4.11	1.17	0.93
2040	4.52	4.89	4.22	1.08	0.93
2045	4.44	5.14	4.11	1.16	0.93
2050	4.51	4.89	4.22	1.08	0.93
2055	4.41	4.72	4.11	1.07	0.93
2060	4.51	5.08	4.22	1.13	0.94
2065	4.43	4.82	4.11	1.09	0.93
2070	4.53	5.15	4.22	1.14	0.93
2075	4.42	4.82	4.11	1.09	0.93

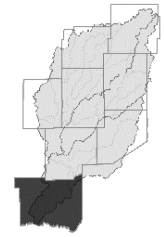


Table D6: Johnson County historical and future peaking factors.

Year	Average Annual Demand (MGD)	Maximum Month Demand (MGD)	Minimum Month Demand (MGD)	Max Monthly Peaking Factor	Min Monthly Peaking Factor
1985	6.93	7.67	6.38	1.11	0.92
1990	8.34	9.86	7.30	1.18	0.88
1995	11.86	14.42	10.26	1.22	0.87
2000	11.96	14.52	10.74	1.21	0.90
2005	14.89	17.69	11.89	1.19	0.80
2010	14.14	19.75	11.26	1.40	0.80
2015	12.00	18.74	10.80	1.56	0.90
2020	12.75	15.33	10.91	1.20	0.86
2025	14.22	21.18	12.18	1.49	0.86
2030	15.11	19.34	12.77	1.28	0.84
2035	15.54	19.36	13.79	1.25	0.89
2040	16.77	21.29	14.59	1.27	0.87
2045	18.21	27.64	15.24	1.52	0.84
2050	18.13	22.63	16.13	1.25	0.89
2055	18.86	22.41	17.02	1.19	0.90
2060	20.04	23.18	18.06	1.16	0.90
2065	21.46	26.05	18.73	1.21	0.87
2070	22.25	28.86	19.46	1.30	0.87
2075	22.39	26.37	20.41	1.18	0.91

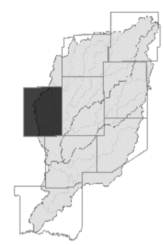
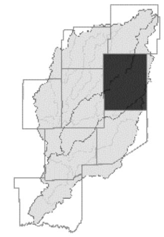
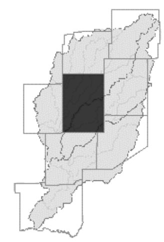


Table D7: Rush County historical and future peaking factors.



Year	Average Annual Demand (MGD)	Maximum Month Demand (MGD)	Minimum Month Demand (MGD)	Max Monthly Peaking Factor	Min Monthly Peaking Factor
1985	0.97	1.20	0.75	1.24	0.77
1990	1.12	1.17	1.05	1.05	0.94
1995	1.12	1.19	1.06	1.06	0.95
2000	1.14	1.21	1.05	1.06	0.92
2005	0.98	1.03	0.89	1.06	0.91
2010	1.28	1.49	1.11	1.16	0.87
2015	1.08	1.40	1.02	1.30	0.94
2020	0.79	0.89	0.67	1.12	0.85

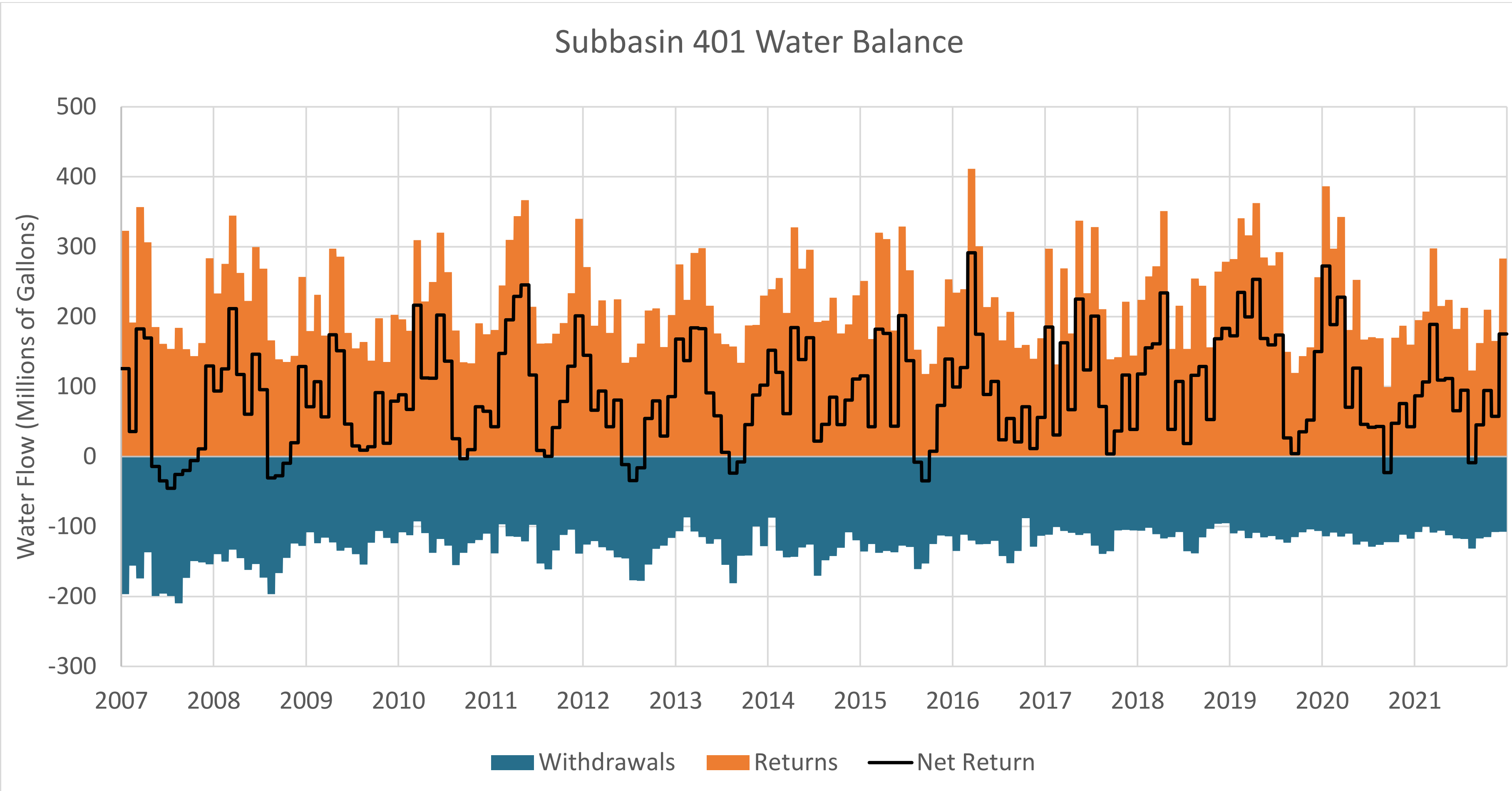
Table D8: Shelby County historical and future peaking factors.



Year	Average Annual Demand (MGD)	Maximum Month Demand (MGD)	Minimum Month Demand (MGD)	Max Monthly Peaking Factor	Min Monthly Peaking Factor
1985	2.33	2.49	2.21	1.07	0.95
1990	2.36	2.51	2.23	1.06	0.94
1995	3.40	3.77	3.19	1.11	0.94
2000	3.92	4.17	3.56	1.07	0.91
2005	4.01	4.44	3.66	1.11	0.91
2010	3.40	3.62	2.86	1.06	0.84
2015	3.68	5.41	3.29	1.47	0.89
2020	3.63	4.34	2.64	1.20	0.70
2025	4.53	4.96	4.28	1.09	0.94
2030	4.79	5.02	4.57	1.05	0.95
2035	4.85	5.02	4.65	1.04	0.96
2040	5.25	5.44	4.99	1.04	0.95
2045	5.42	5.80	5.09	1.07	0.94
2050	5.64	5.94	5.35	1.05	0.95
2055	5.81	6.06	5.59	1.04	0.96
2060	6.10	6.39	5.81	1.05	0.95
2065	6.44	6.77	6.17	1.05	0.96
2070	6.65	6.94	6.35	1.04	0.96
2075	6.81	7.01	6.63	1.03	0.97

Appendix E. Water Balance Graphs

Water Balance Graphs



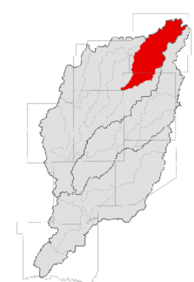


Figure E1: Historical water withdrawals and returns from subbasin 401.

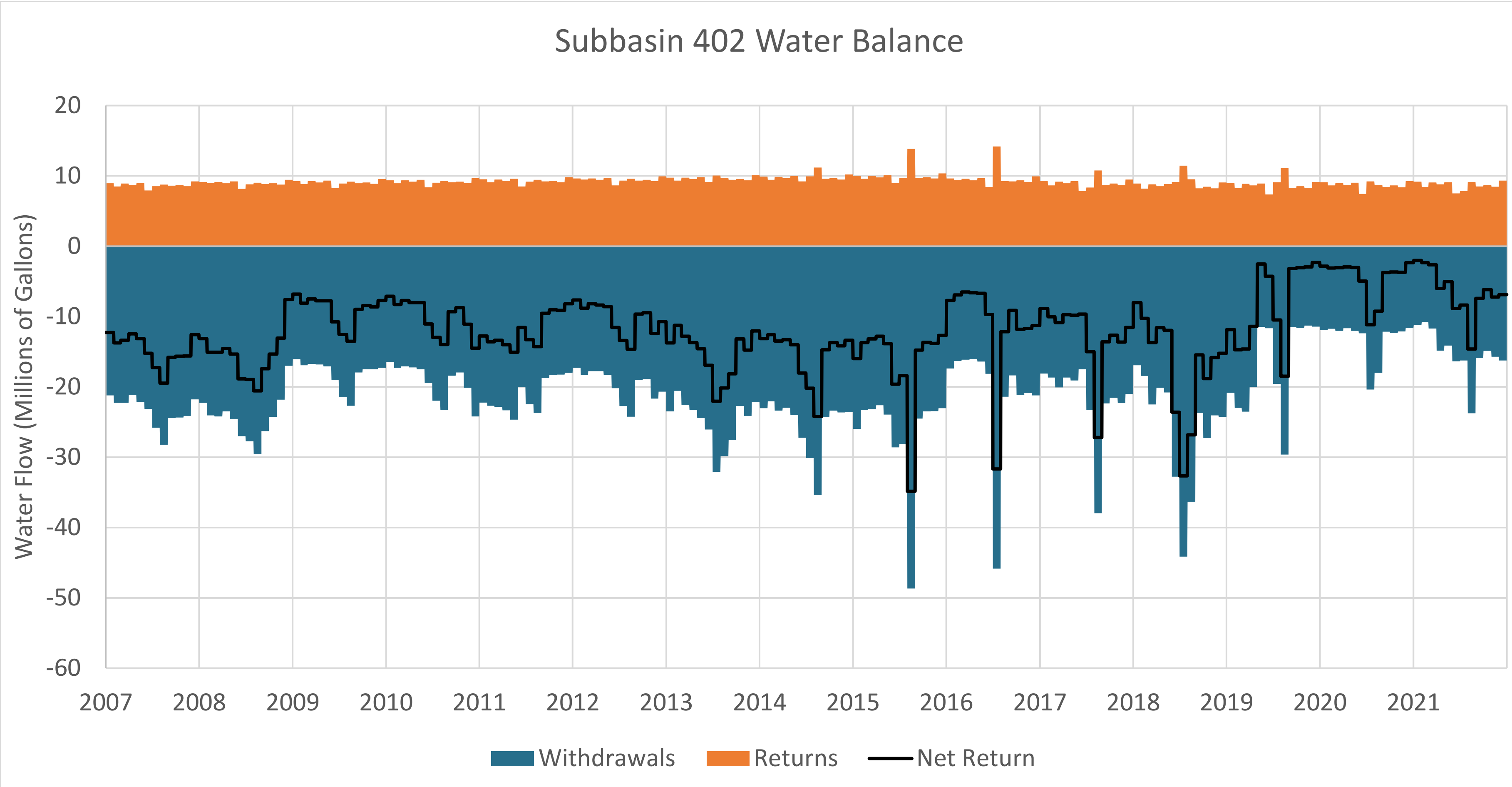
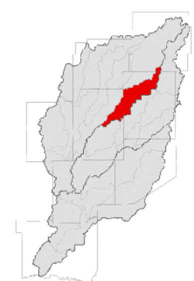


Figure E2: Historical water withdrawals and returns from subbasin 402.



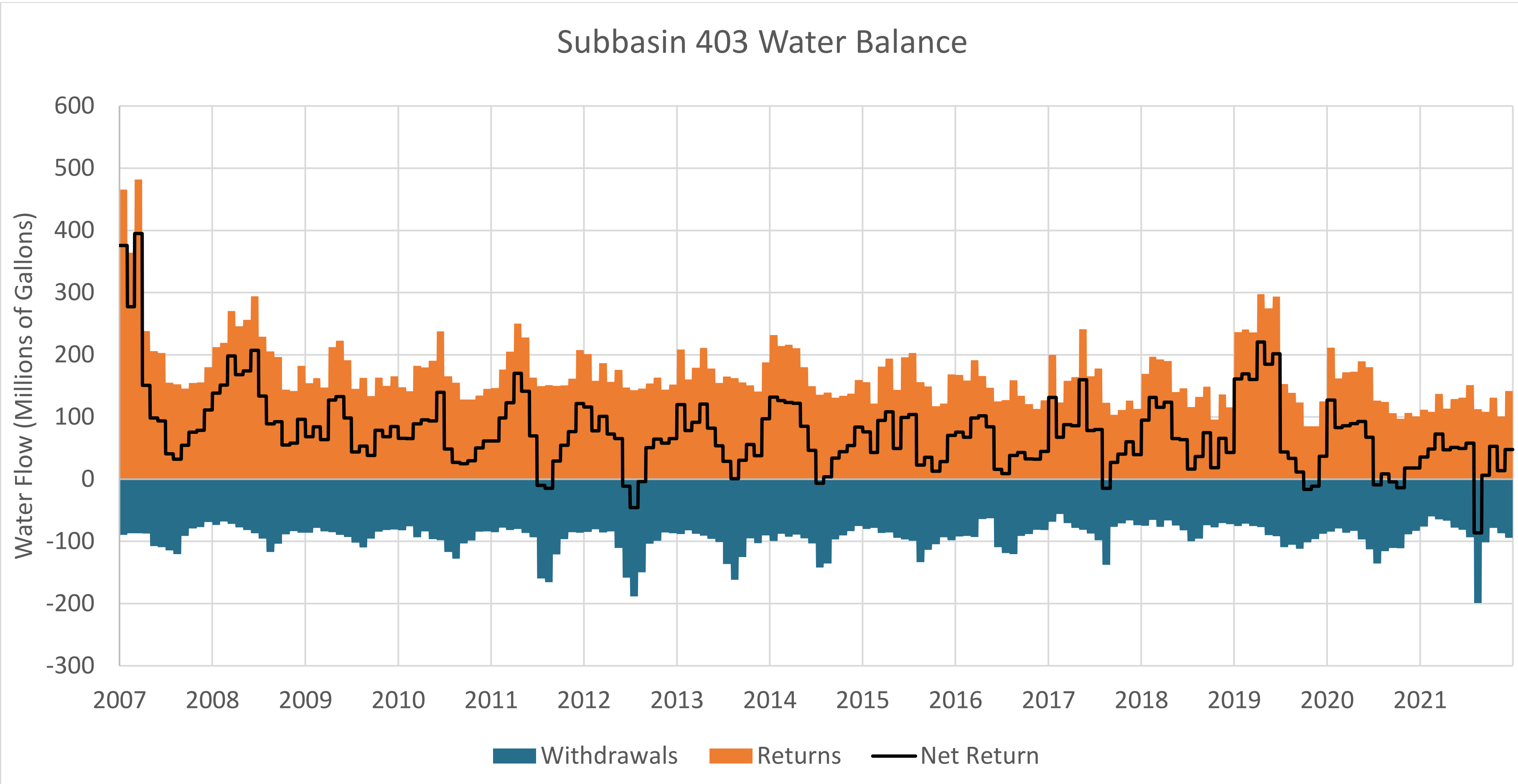
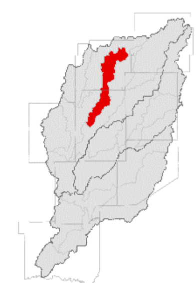


Figure E3: Historical water withdrawals and returns from subbasin 403.



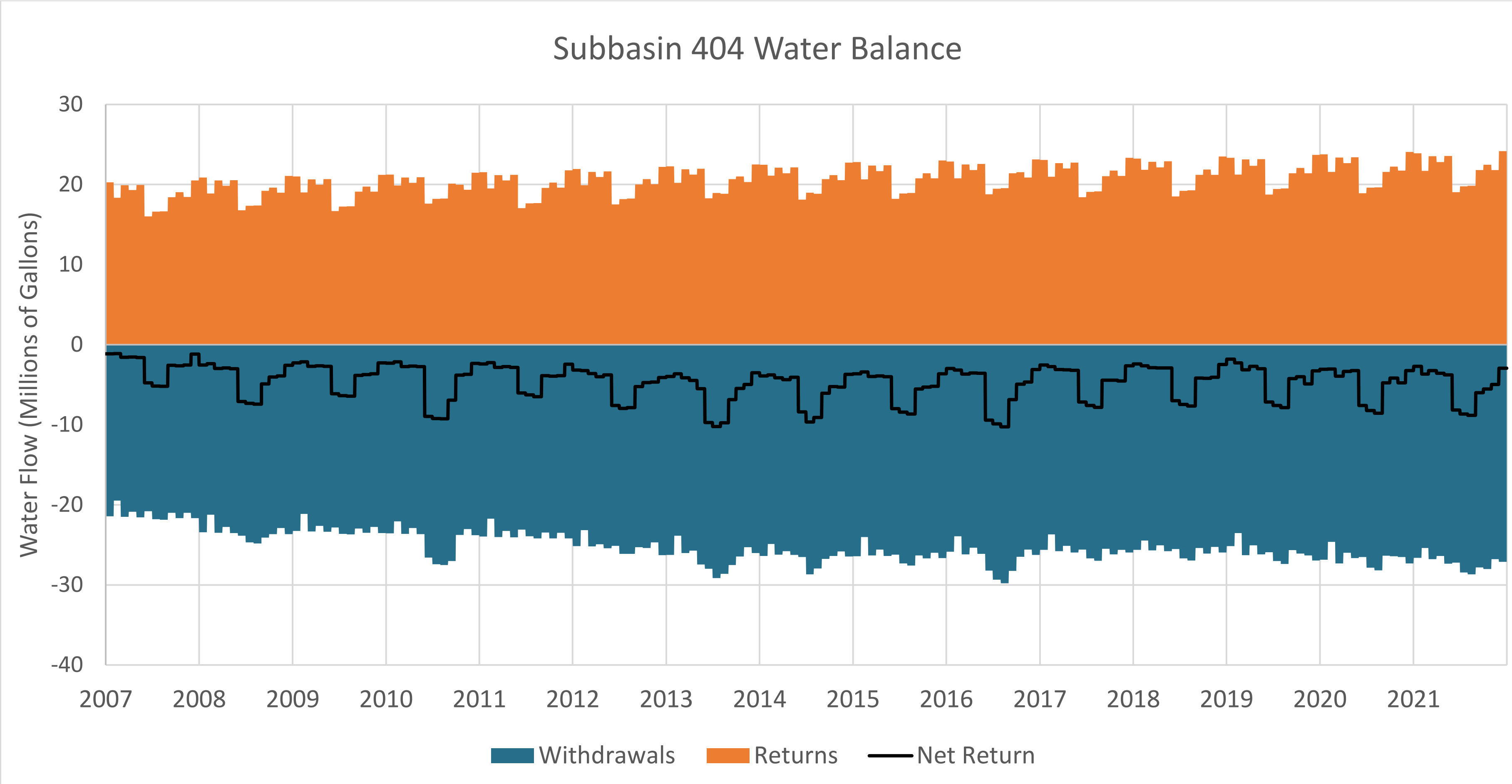
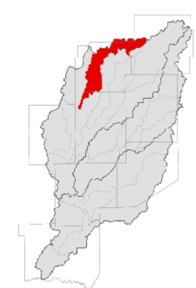


Figure E4: Historical water withdrawals and returns from subbasin 404.



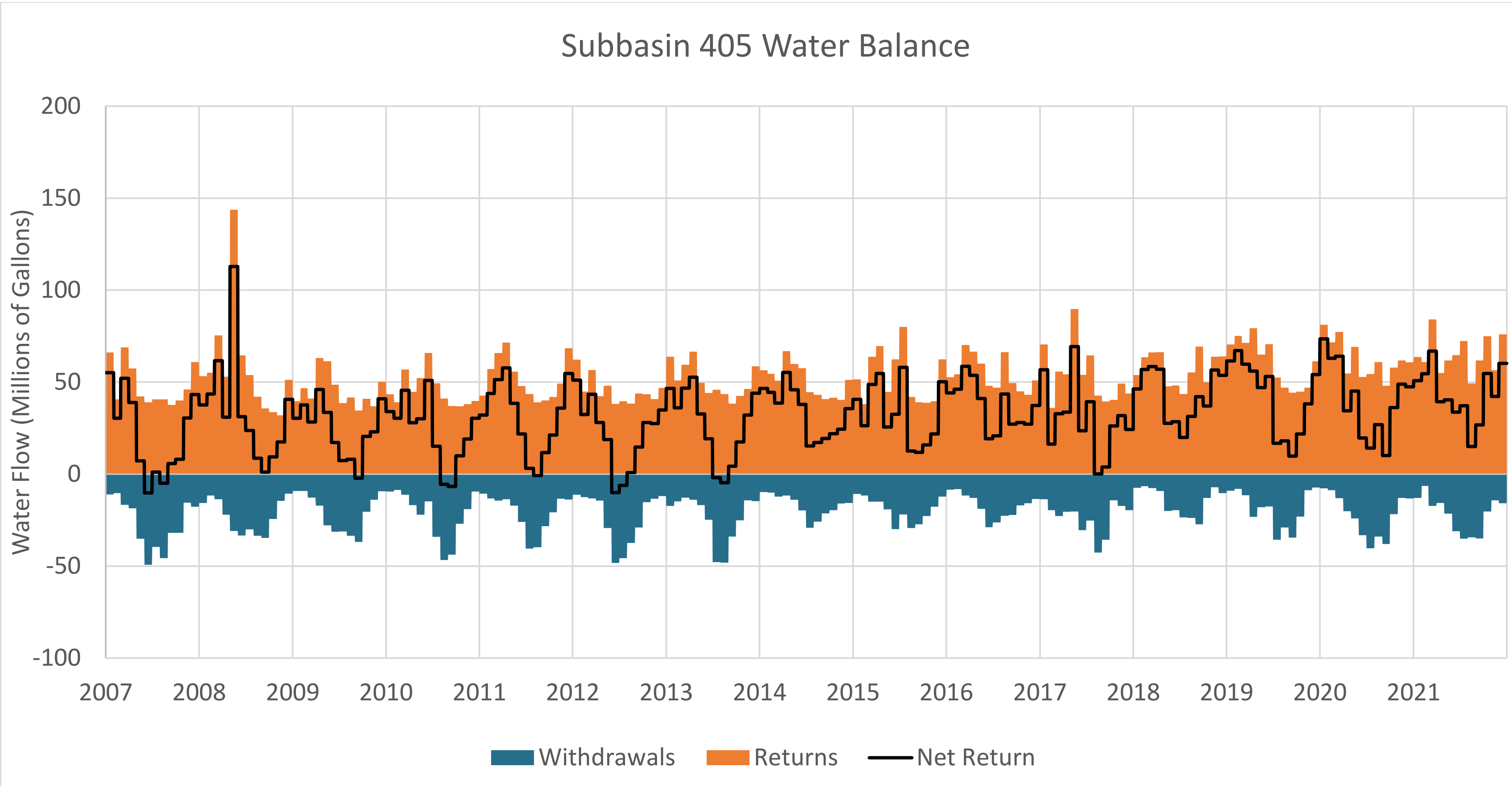
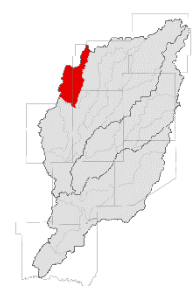


Figure E5: Historical water withdrawals and returns from subbasin 405.



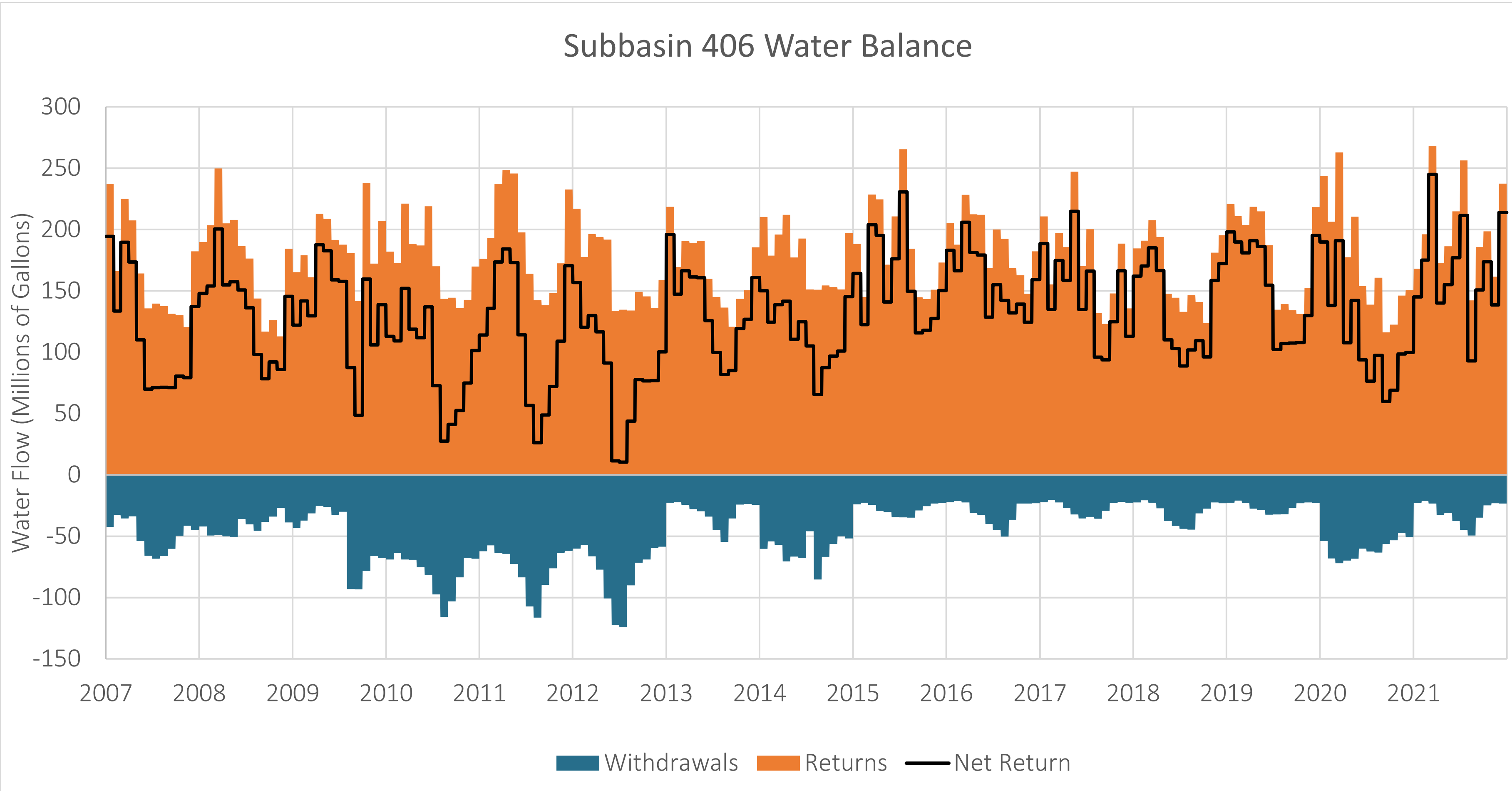
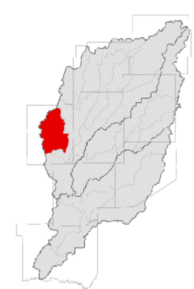


Figure E6: Historical water withdrawals and returns from subbasin 406.



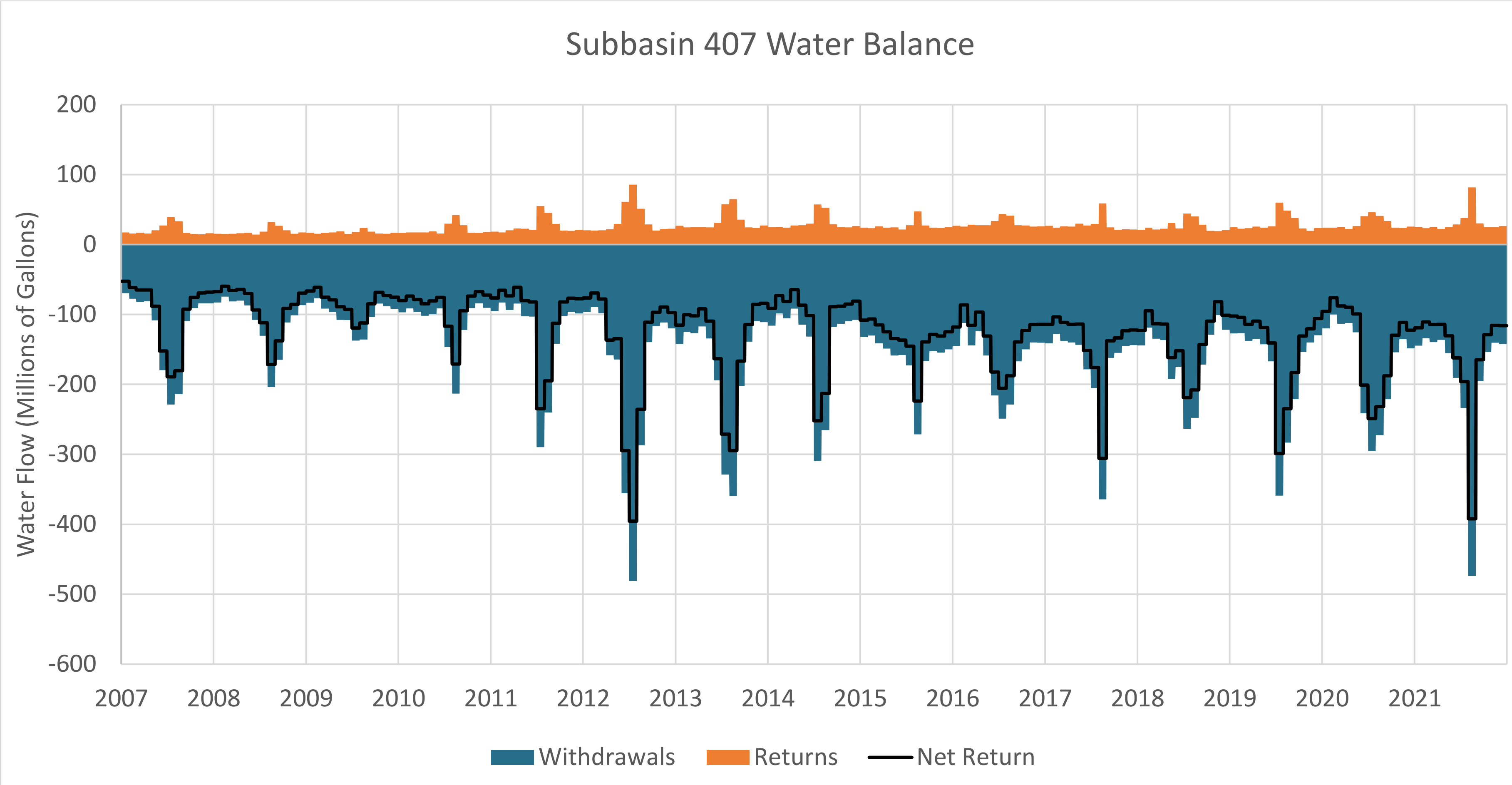
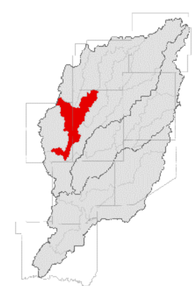


Figure E7: Historical water withdrawals and returns from subbasin 407.



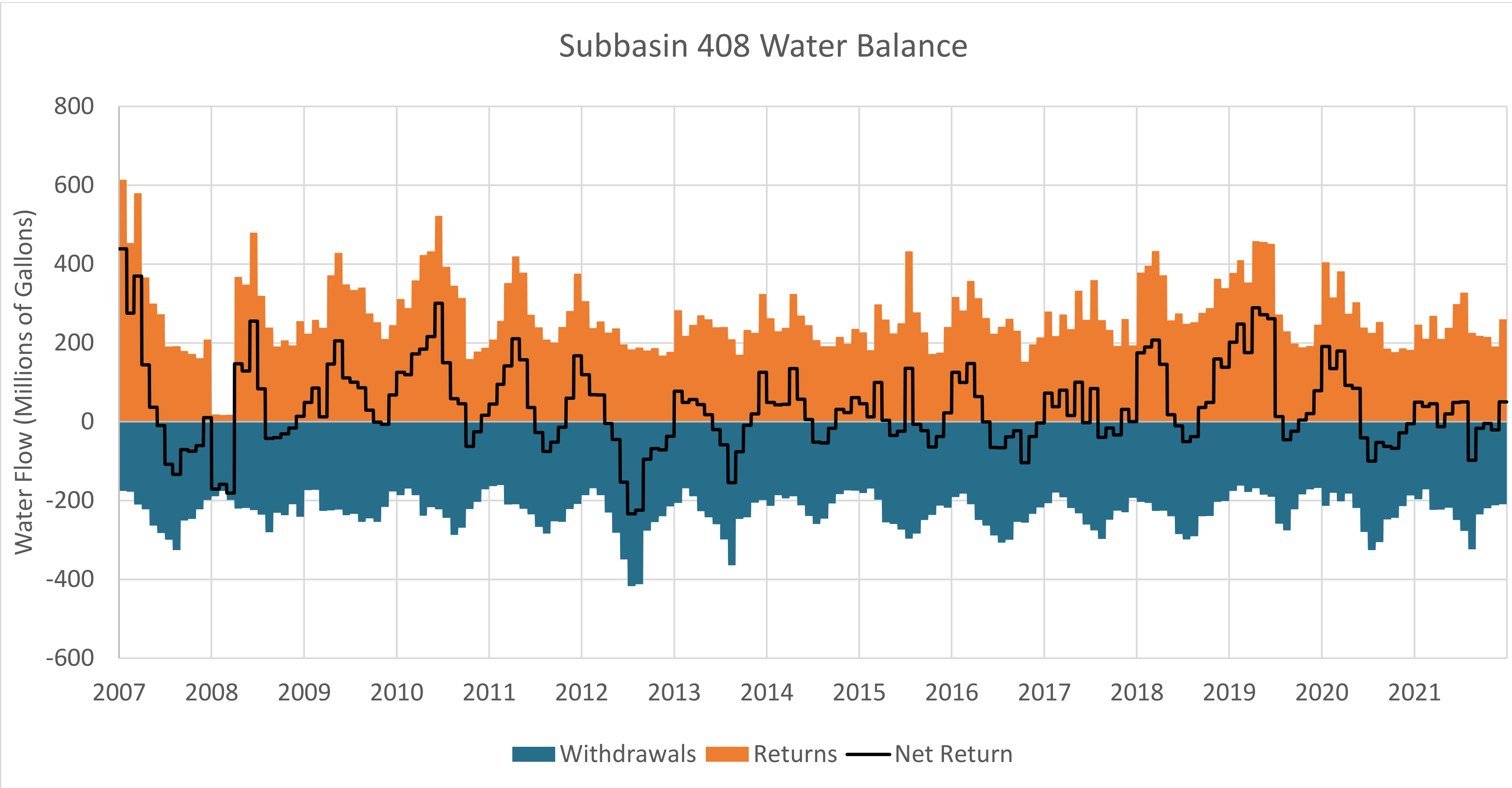
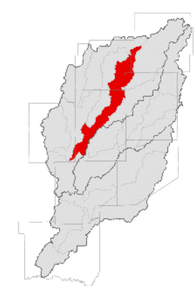


Figure E8: Historical water withdrawals and returns from subbasin 408.



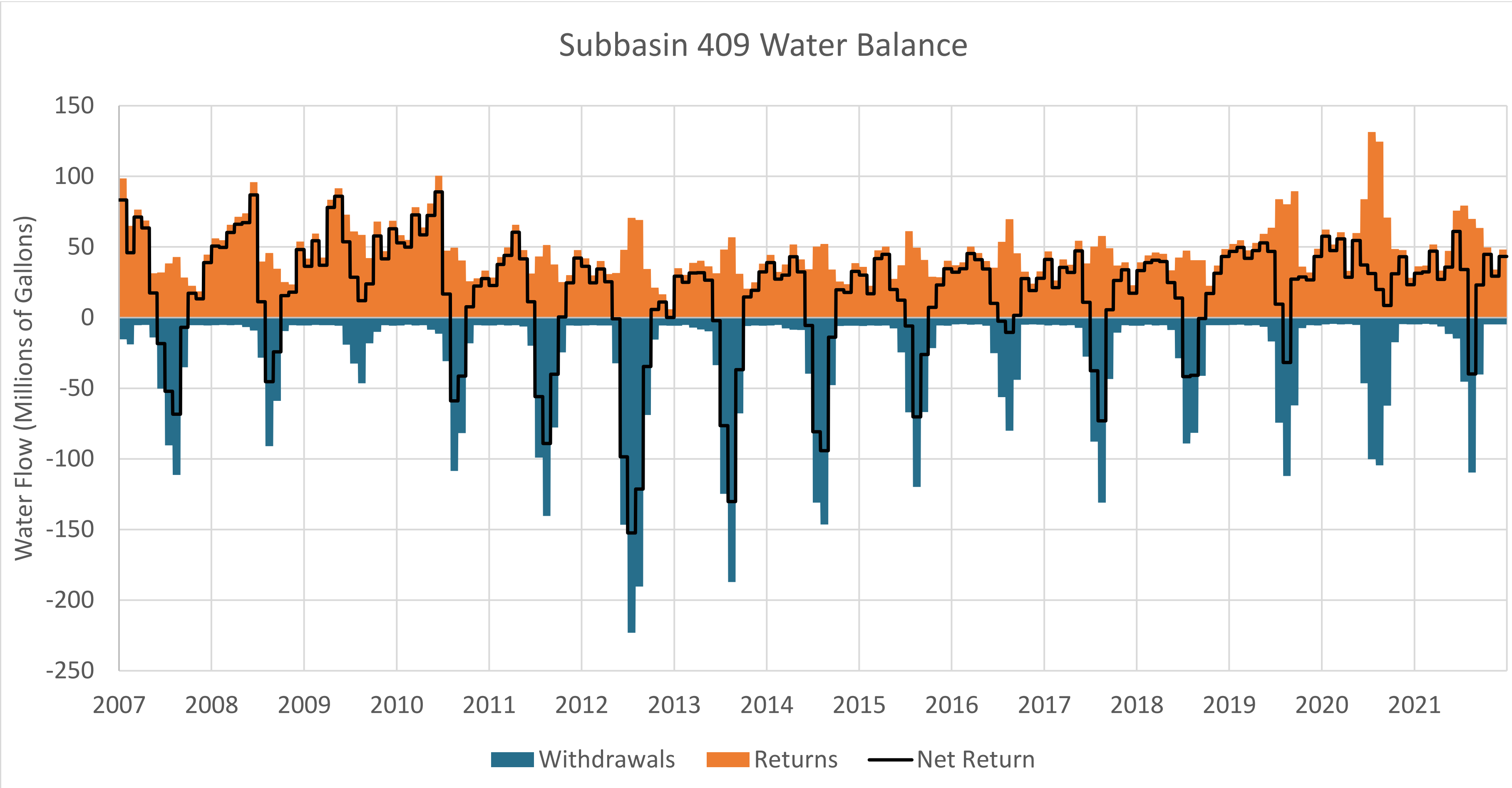
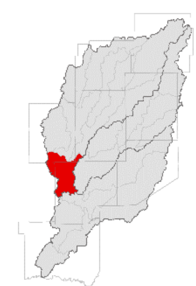


Figure E9: Historical water withdrawals and returns from subbasin 409.



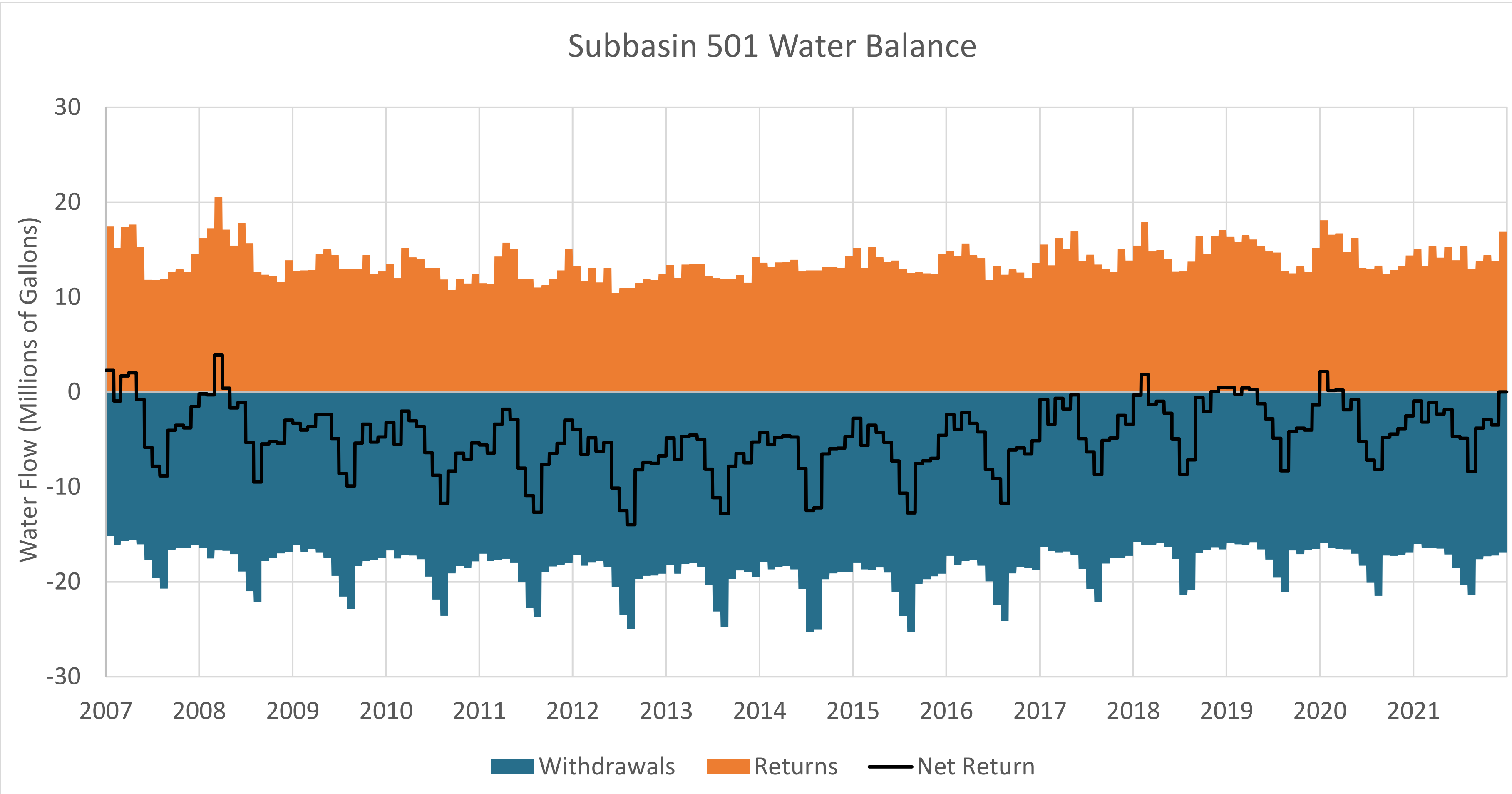
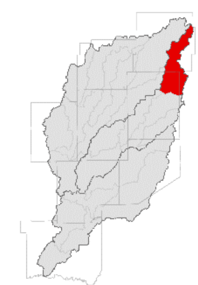


Figure E10: Historical water withdrawals and returns from subbasin 501.



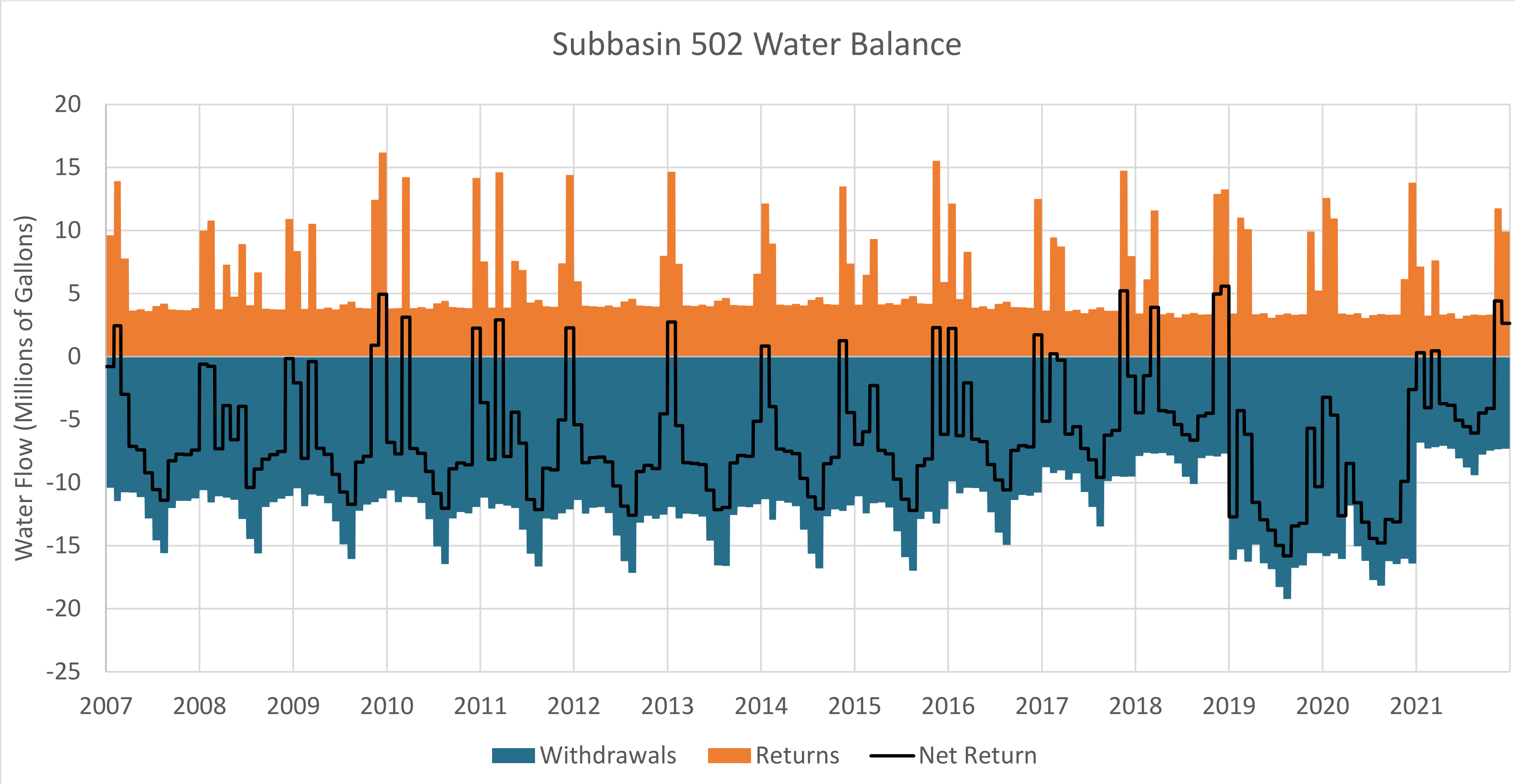
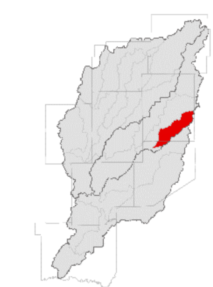


Figure E11: Historical water withdrawals and returns from subbasin 502.



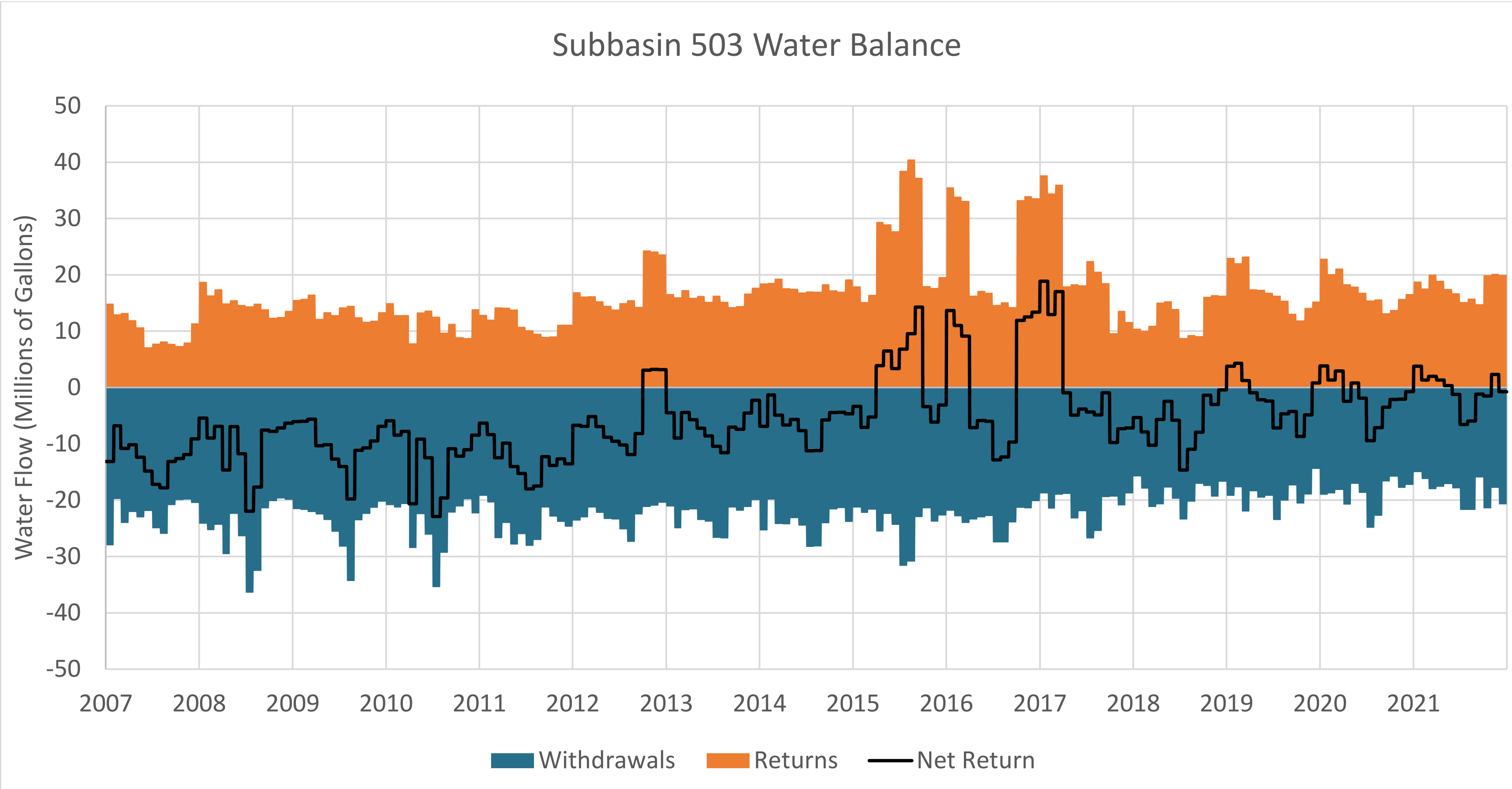
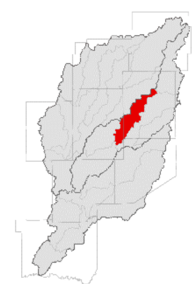


Figure E12: Historical water withdrawals and returns from subbasin 503.



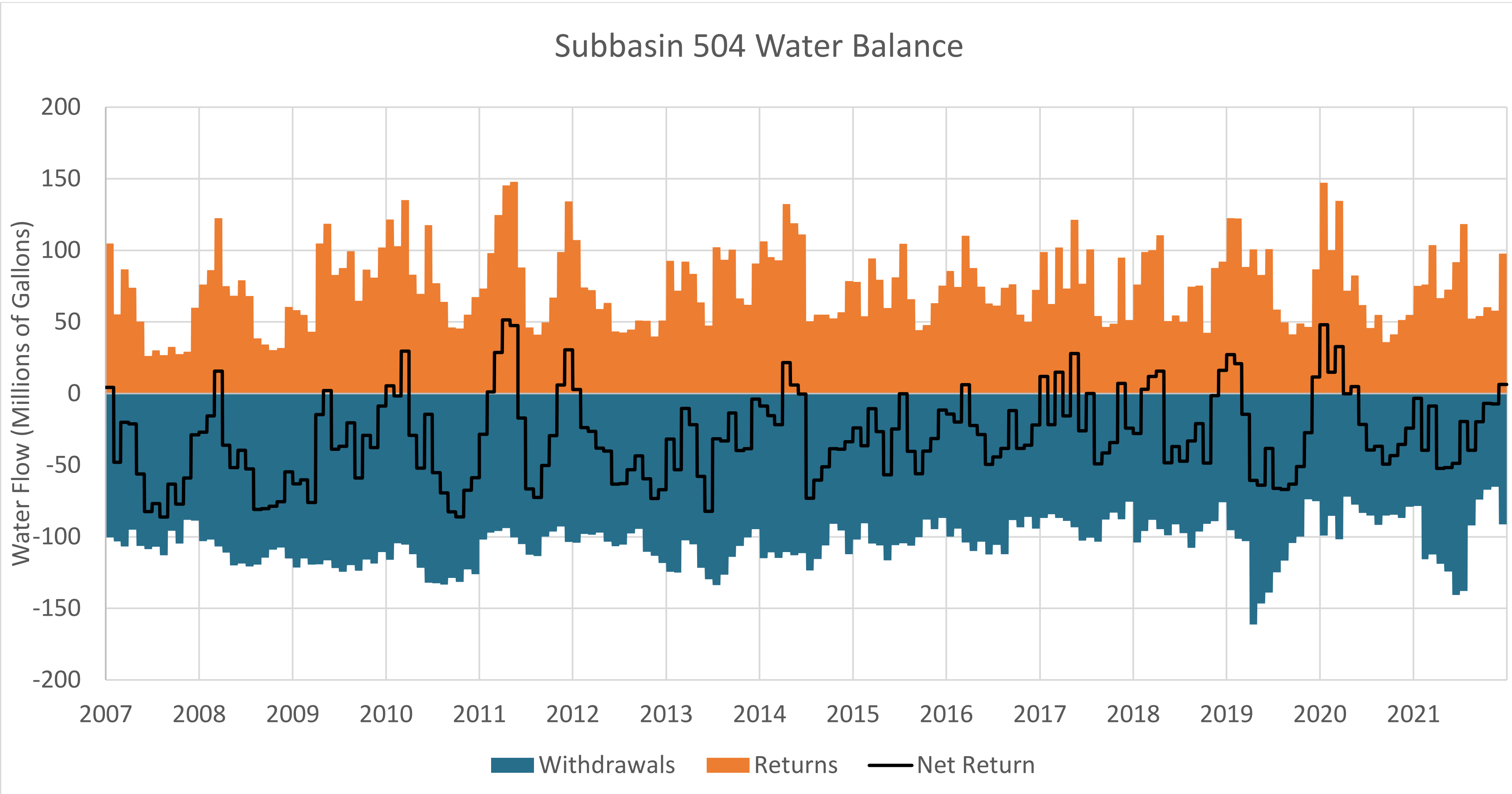
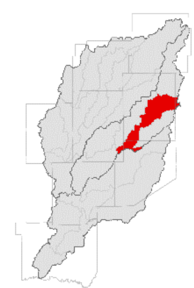


Figure E13: Historical water withdrawals and returns from subbasin 504.



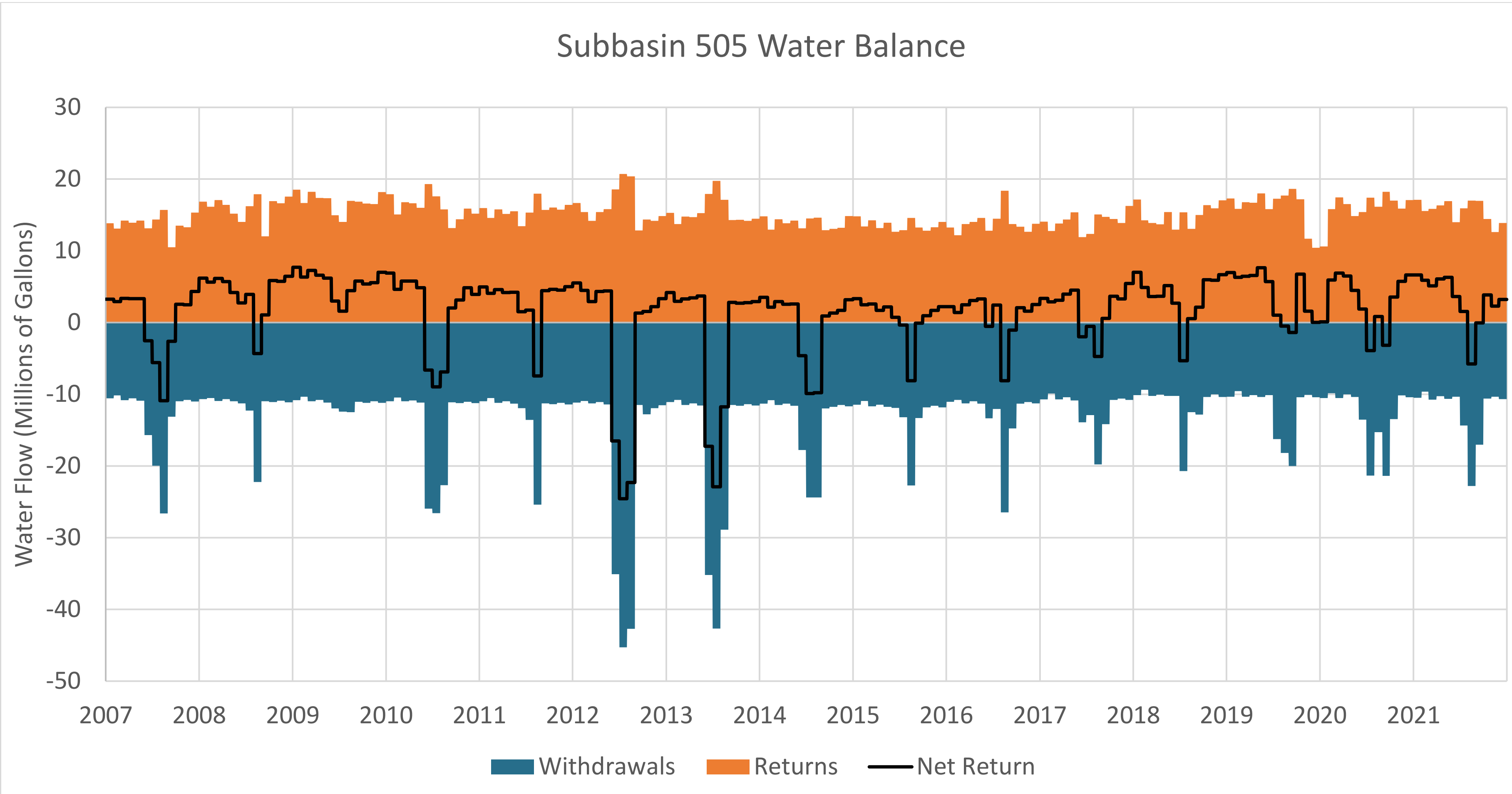
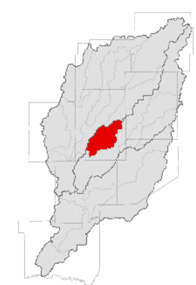


Figure E14: Historical water withdrawals and returns from subbasin 505.



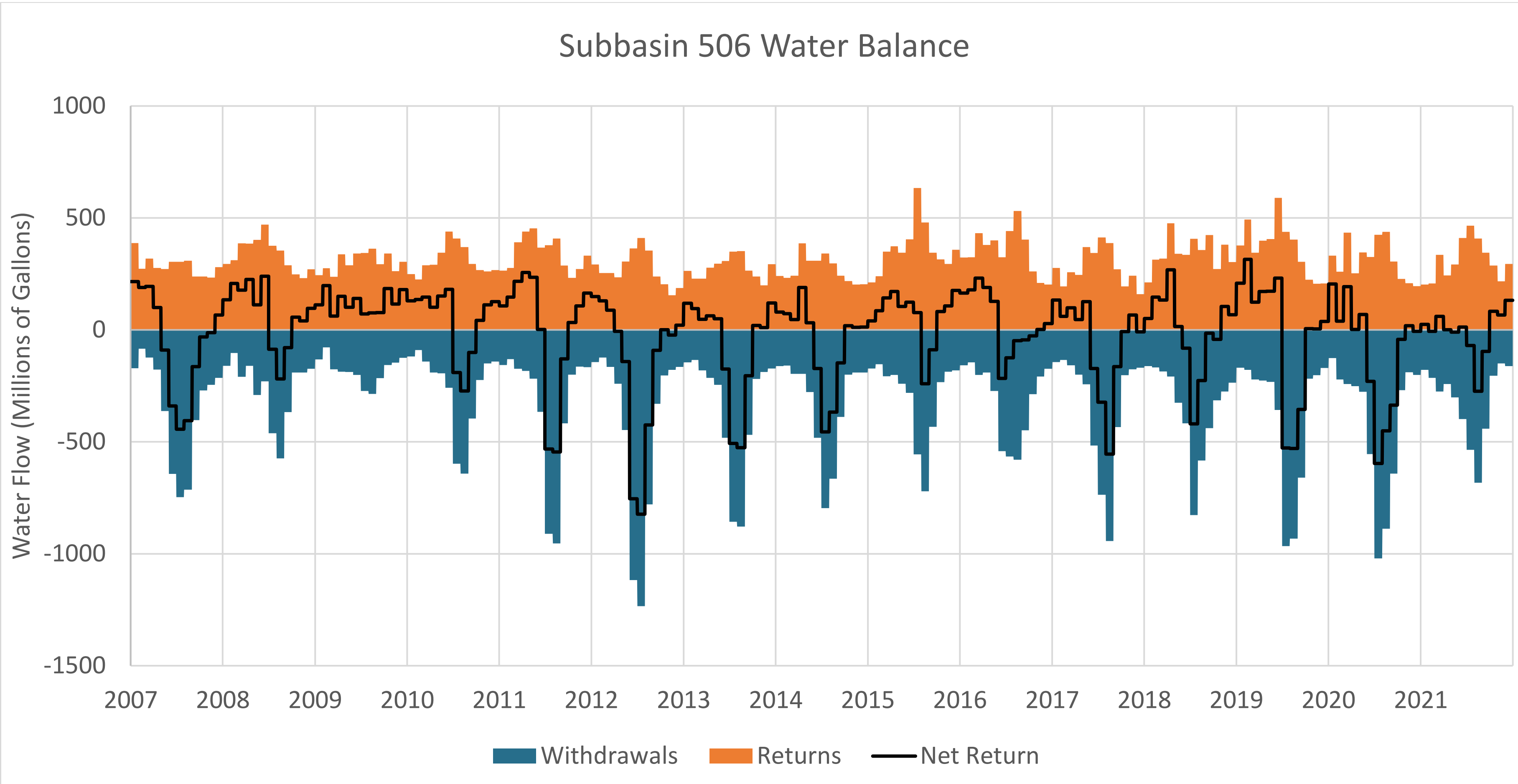
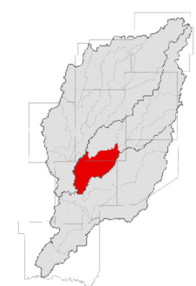


Figure E15: Historical water withdrawals and returns from subbasin 506.



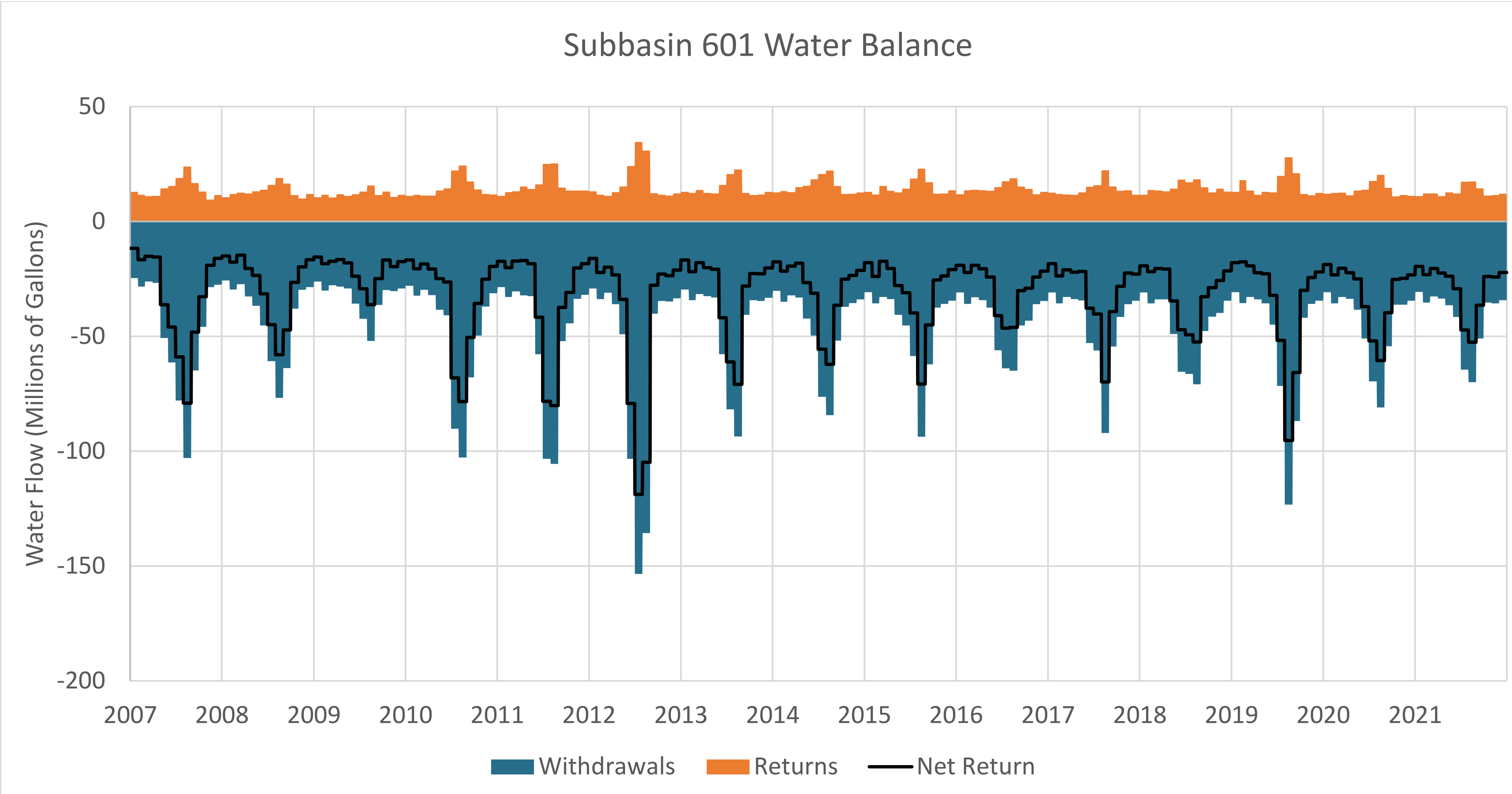
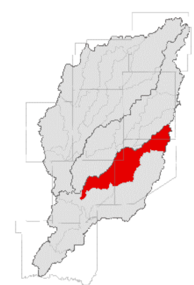


Figure E16: Historical water withdrawals and returns from subbasin 601.



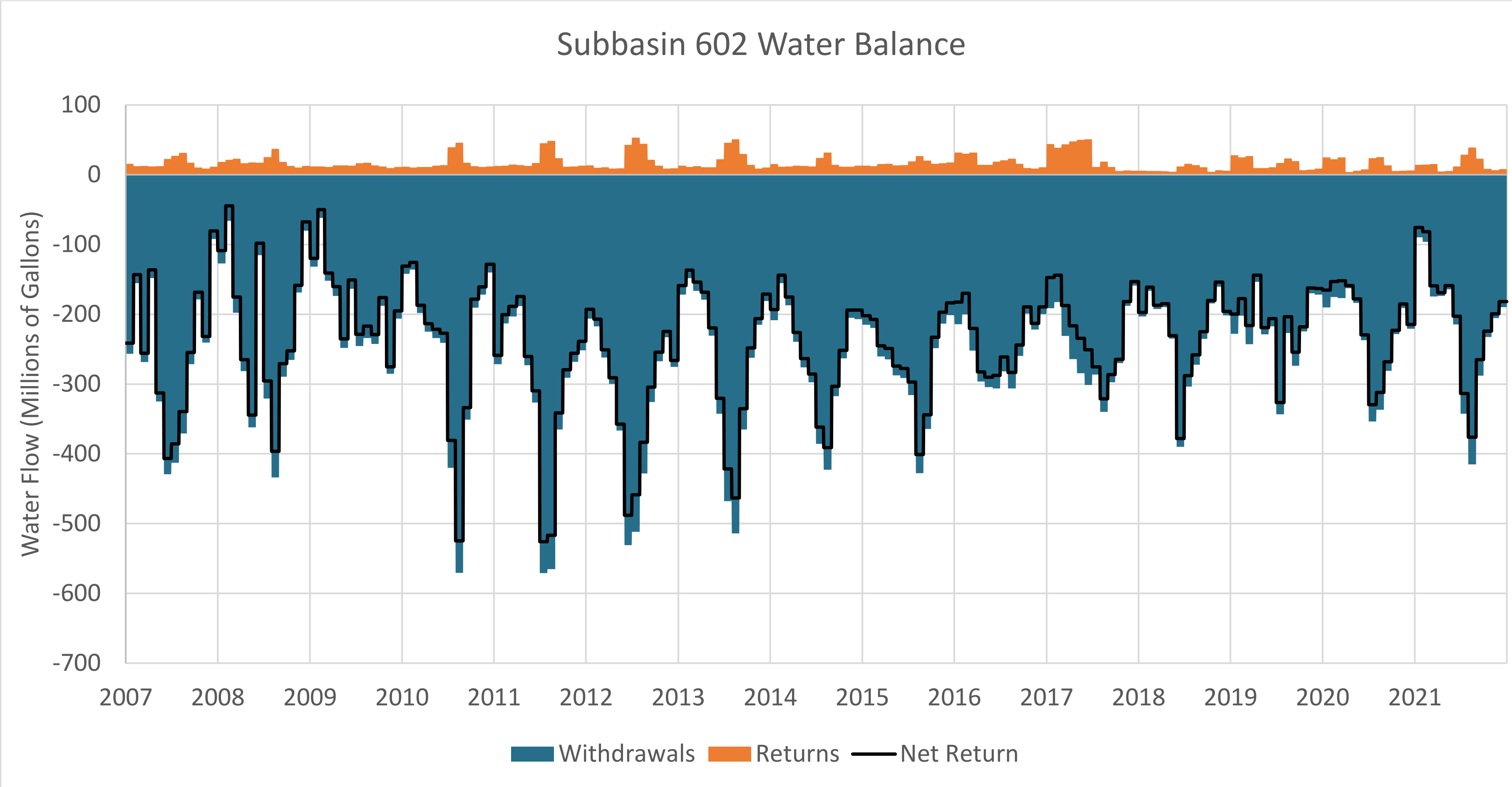
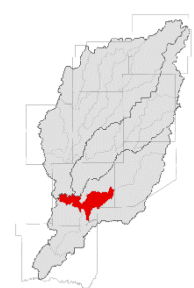


Figure E17: Historical water withdrawals and returns from subbasin 602.



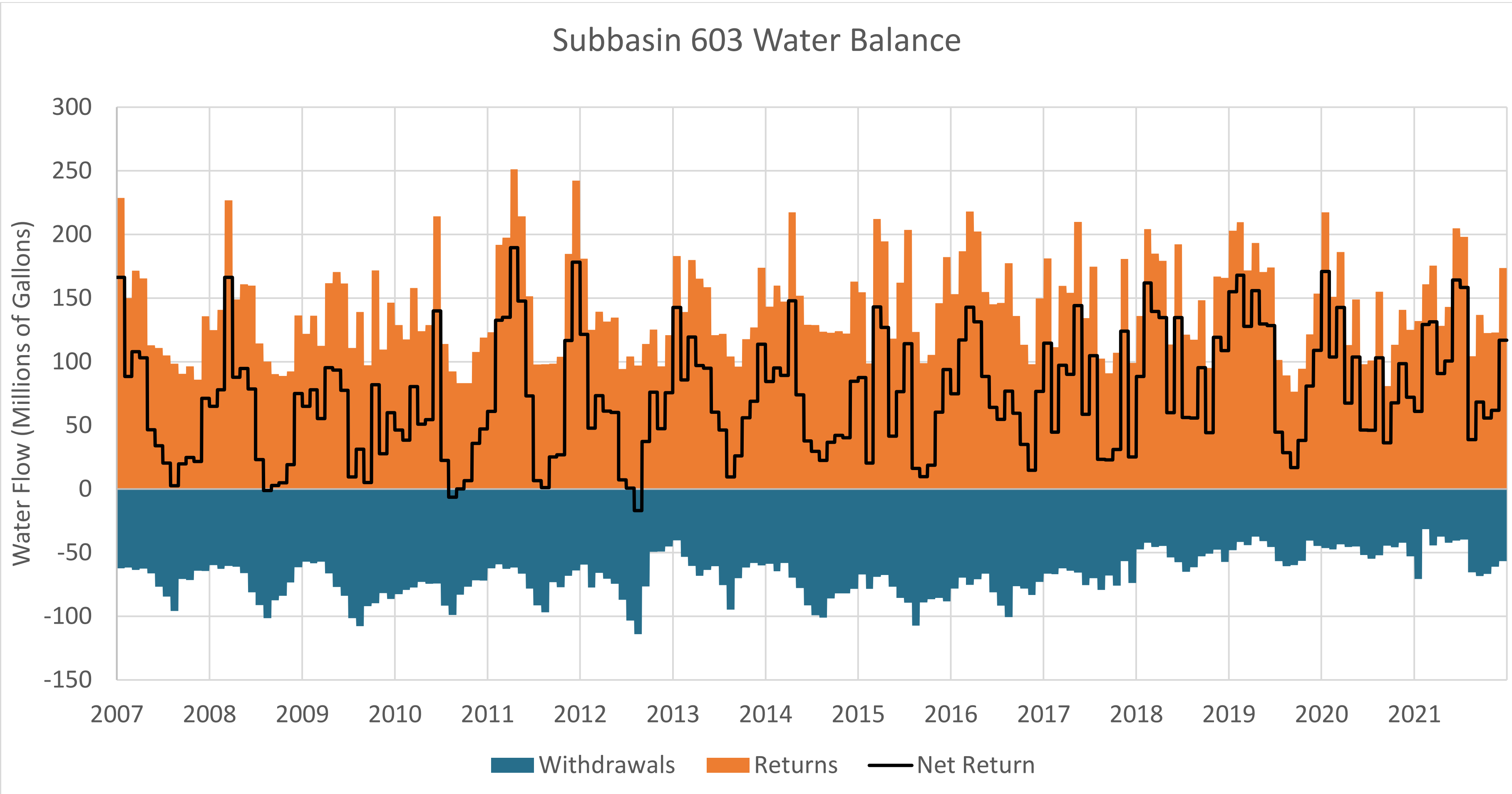
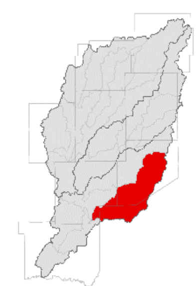


Figure E18: Historical water withdrawals and returns from subbasin 603.



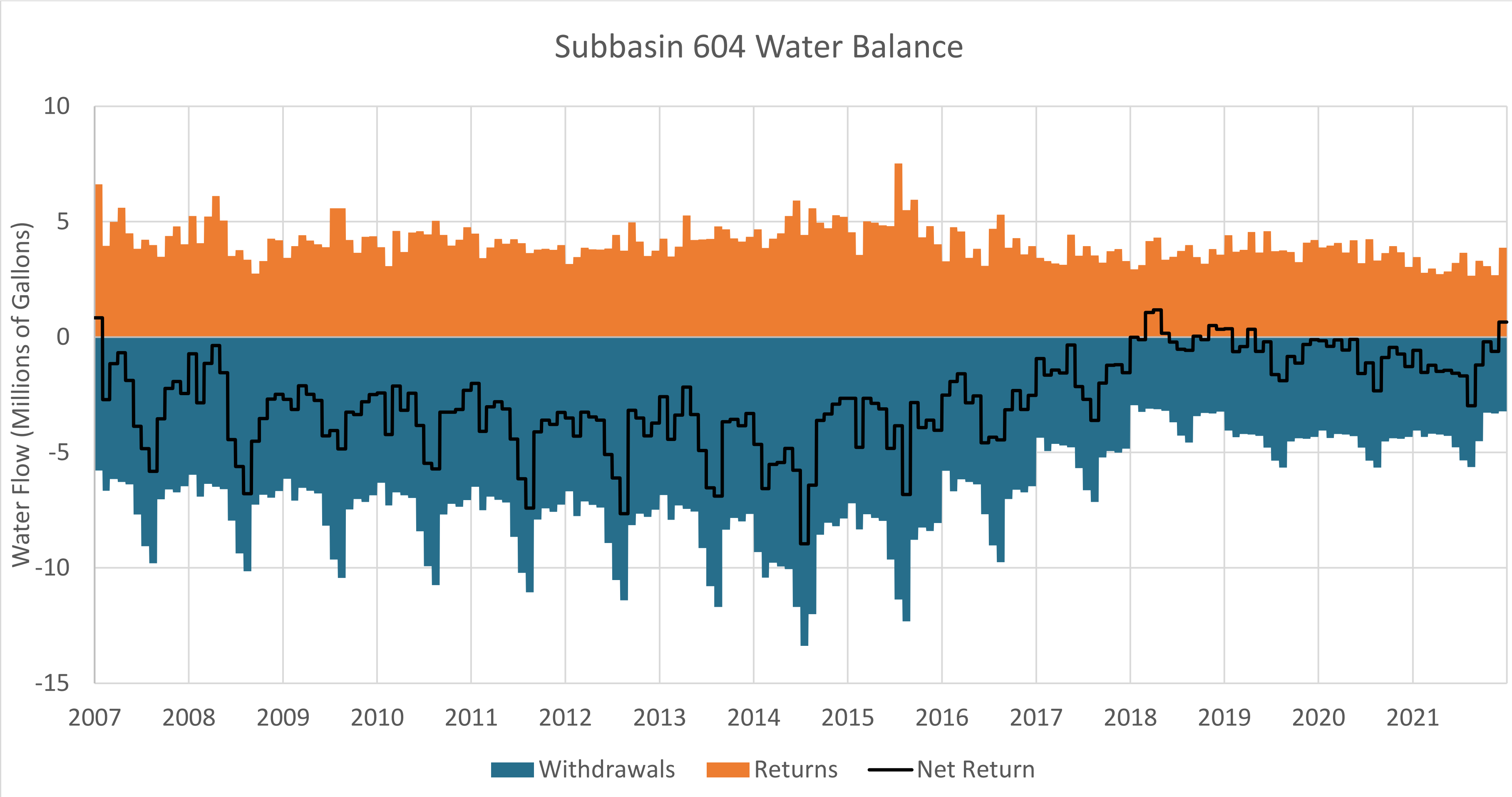
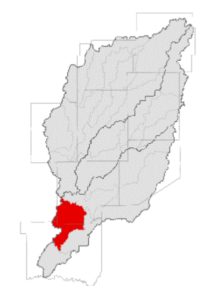


Figure E19: Historical water withdrawals and returns from subbasin 604.



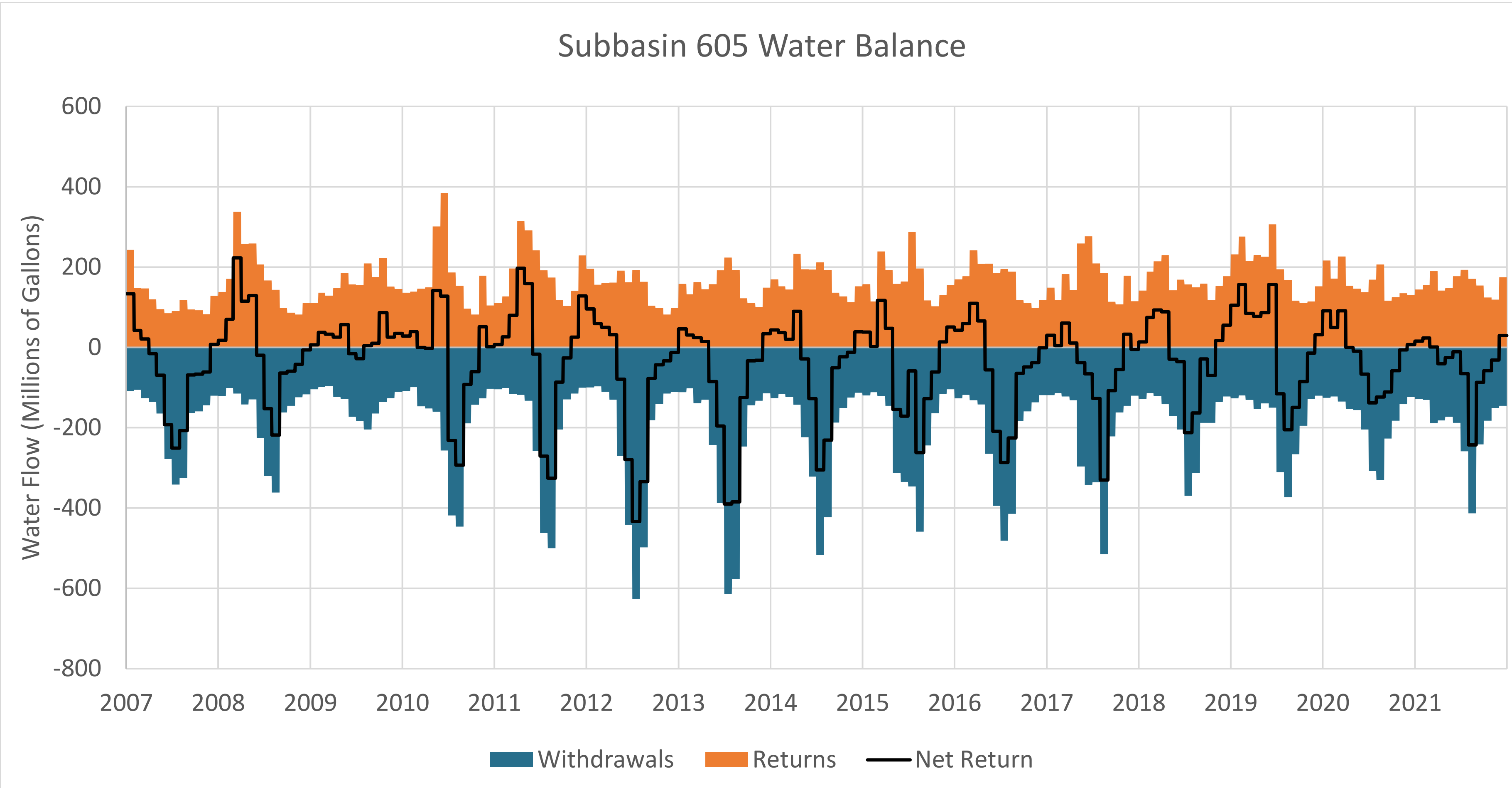
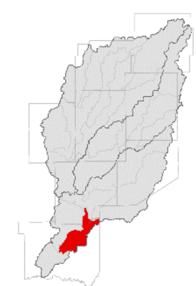


Figure E20: Historical water withdrawals and returns from subbasin 605.



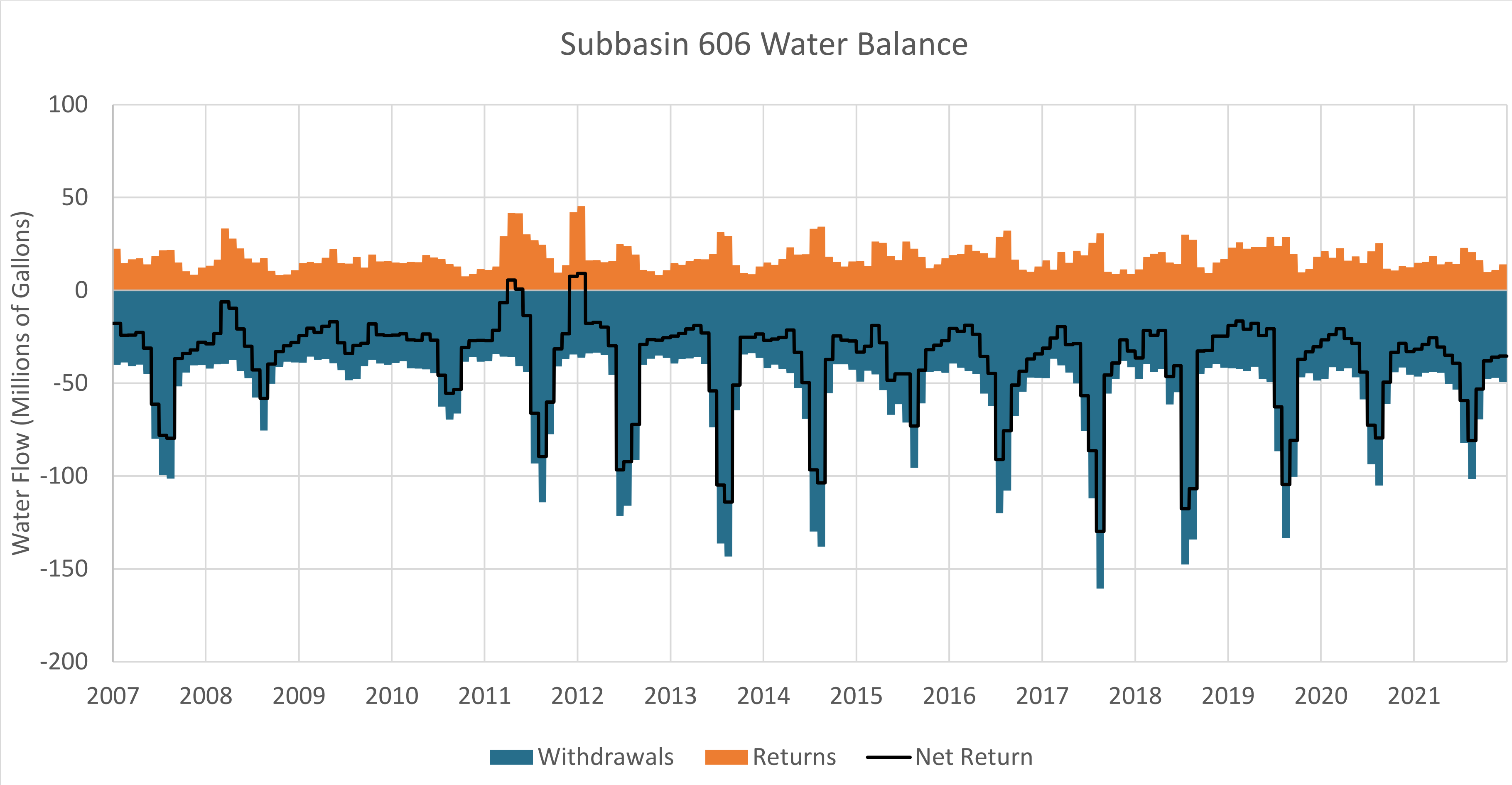
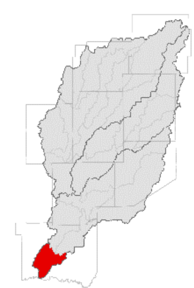


Figure E21: Historical water withdrawals and returns from subbasin 606.



Appendix F. Water Availability Model Setup

F1. Index map of study area showing the locations of subbasins, observation wells, and stream gaging stations.
F2. Figure showing schematic representation of HUC10 subbasin flow network.
F3. Table showing HUC10 subbasin network characteristics.
F4. Table showing US Geological Survey stream gages located in the study area.
F5. Table showing hydrograph partitioning metrics.
F6. Table showing low- and high-flow statistics for study area stream gages.
F7. Table showing annual and seasonal trend statistics for stream gage discharges.
F8. Table of observation wells in and around the Southeast-Central Indiana Region.
F9. Table of annual and seasonal trend statistics for groundwater-level observation wells.

Note

See Appendix G: Excess Water Availability Results for the results from the historical and future water excess water availability analysis described here.

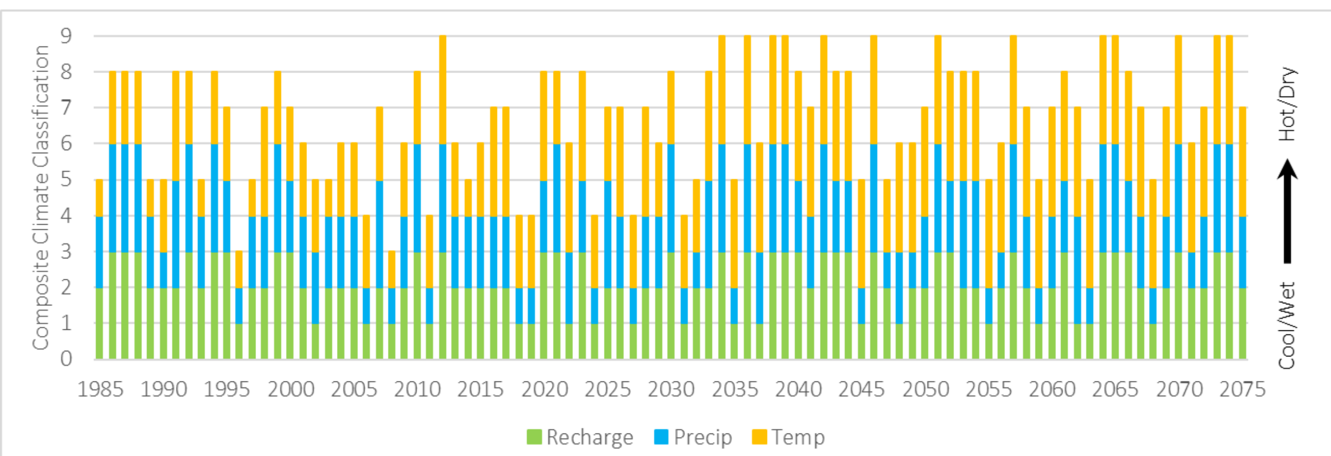
Future excess water availability calculations were based on:

1. Estimates or projections of future demand in all sectors. Projections of future public-supply demand are covered extensively in the report, but projections were made for:
    a. Public supply (including residential, industrial, CAFO, and some irrigation)
        i. Based on multiple regression models (see Appendix C and report narrative), using climate-driven (CanESM2) SWB2 model output variables for future climate variables (such as PET-AET) used in public-water utility demand forecasts.
        ii. Future economic variables (such as per capita income) were based on historical trends.
    b. Self-supplied residential use
        i. Residential water use is discussed in Appendix A.
        ii. Future residential water use was based on utility planning documents, especially future service areas. Most utility and county planning documents were for water-service area expansions to be in place by ~2040. A conservative timeline of 2050 was used to simulate conversion of self-supplied residential to public supply.
        iii. Per subbasin, the current and future residential users were determined, and a constant monthly rate of "conversion" was calculated to transfer the self-supplied residential water use to public supply from 2022 through 2050. The number of self-supplied residential water users were maintained at the 2050 rate through 2070. The counties with high numbers of self-supplied residential water users did not have increasing populations projections, so new rural developments were not simulated.
    c. Self-supplied CAFO use
        i. Based on utility and county planning documents, a 5% per 20 years rate of CAFO water-use increase was applied for this sector.
        ii. Reported water use from 2017-2021 was used to simulate seasonal variability for this sector, with the monthly rate of water-use increase applied monthly.
        iii. Reported water use for the CAFO (RU = rural) sector ceased in several subbasins in 2020-2021, and future CAFO water use for those subbasins declined in the demand forecast as a result.
    d. Irrigation
        i. Future water use in the irrigation sector was based on the climate-driven (CanESM2) water balance model (SWB2) developed for this project.
        ii. Existing irrigation locations were specified in the model, along with annual versions of land cover maps, including crop type (based on historical NASS crop-type mapping), used as input for the water-balance forecast. The crop type is used by the model to simulate plant root development throughout the growing season, simulating crop-water demand on a daily time step.
        iii. SWB2 model output for irrigation water demand (units = inches/day) were aggregated to monthly water demand (inches/month) by subbasin.
        iv. The monthly irrigation water demand per subbasin was averaged for the historical period of 2000-2020 (May-June-July-August-September). The reported monthly water use (IDNR SWWF) from 2000-2020 was also averaged per subbasin (MGD).
        v. The irrigation water-use forecast per month per subbasin was based on the proportion of the SWB2 estimate of crop water demand compared to the historical average and a multiplier was used to calculate an estimated amount of irrigation water use (MGD) based on whether the climate demand (i.e., hotter, drier, cooler, wetter) was higher or lower than the historical average.
    e. Self-supplied industrial (including mining/quarries)
        i. Based on utility and county planning documents, a 5% per 20 years rate of industrial water-use increase was applied for this sector.

    ii. Reported water use from 2017-2021 was used to simulate seasonal variability for this sector, with the monthly rate of water-use increase applied monthly.
    iii. Reported water use for the Industrial (IN) sector ceased in several subbasins in 2020-2021, and future water use for those subbasins declined in the demand forecast as a result.

2. The future public sector demand models were conducted at the county scale (Appendix C), but the excess availability and cumulative excess availability models were conducted at the HUC10 subbasin scale (National Hydrography Dataset). See Figures F1, F2, and Table F3 for schematics and characteristics of the subbasin network.
3. To validate results and provide context to the historical and future excess water availability calculations and forecasts, a range of data and calculations were compiled to describe:
    a. Streamflow
        i. Stream gages – Table F4
        ii. Streamflow hydrograph partitioning statistics from Konrad (2022) – Table F5
        iii. Low- and high-flow statistics calculated for the stream gages used in the excess water availability analysis for seasonal instream flows (7Q10, Q90) – Table F6
        iv. Annual and seasonal Mann-Kendall trend statistics for stream discharge at USGS stream gages in the Southeast-Central Indiana region – Table F7
    b. Groundwater
        i. Observation wells – Table F8
        ii. Annual and seasonal Mann-Kendall trend statistics for groundwater level (depth-to-water) at USGS observation wells in the Southeast-Central Indiana region – Table F9
4. Demand projections were allocated to each HUC10 subbasin using the proportion of the utility service areas from each county that were in each basin. The US Department of Transportation National Address Database (Release 12) address points were used to allocate the proportion of the demand within service areas to each HUC10 subbasin (see Appendix A for NAD data processing steps). In many cases for the highest water-use public supplies in the Southeast-Central Indiana region, it is not clear which supply wells (i.e., data from the IDNR SWWF) are providing water to which parts of their complex service areas (e.g., Indiana-American); therefore, service-area allocations were chosen over the IFA (2021) approach of allocating demand back to point locations (i.e., pumps).
5. Details of how future returns from self-supplied and NPDES-reporting facilities were handled can be found in Appendix A.
6. Estimates of natural baseflow were calculated following the methods developed and presented in IFA (2021; Phase III: Water Availability, Chapter 2) to:
    a. extract natural streamflow from 15 years of daily US Geological Survey stream gage discharge observations (2007-2021) by adding back withdrawn (pumped) water from all water-use sectors in the watershed (see Table F3 for subbasin contributions/assignments to specific stream gages) and subtracting water returned to the local water cycle through non-consumptive or partially consumptive water uses. This process combined the daily stream discharge data with the monthly water inventory (withdrawals and returns), as described in IFA (2021; Phase III: Water Availability, Chapter 2).
    b. Employing the PART streamflow partitioning (hydrograph separation) method by Rutledge (1998) on the modified daily discharge data for each stream gage to produce annual and monthly estimates of baseflow in inches. The output was converted to MGD using the watershed area, and annual and seasonal natural baseflow was retained for the next part of the analysis. Climate dynamics important to the Indiana water cycle are closely related to distinct seasonal cycles, and calendar (financial or reporting) quarters tend to obscure what could otherwise be strong data signals.
    c. Seasons in this study are defined as:
        i. Winter: Dec-Jan-Feb (where December is from the previous calendar year)
        ii. Spring: Mar-Apr-May
        iii. Summer: Jun-Jul-Aug
        iv. Fall/autumn: Sep-Oct-Nov

7. Again, following the methods and example established by IFA (2021; Phase III: Water Availability, Chapter 2, Section 2.9), the natural baseflow was used as the basis for each subbasin-level calculation of excess water availability by a systematic accounting of withdrawals, returns, and seasonal instream flows (Winter/Spring = Q90; Summer/Fall = 7Q10 using streamflow from 1992-2022; Blum et al., 2019) on an annual and seasonal basis. Positive remainders indicate excess water availability, whereas negative remainders indicate negative water availability. The seasonal breakdown can reveal the strong signals in natural or anthropogenic factors influencing the annual totals (see Appendix G).
8. Estimates of future natural baseflow and water availability
    a. For each year and season, the 15 years of natural baseflows calculated as described above (and closely following IFA, 2021; Phase III: Water Availability, Chapter 2) were used to represent the future annual and seasonal variability of streamflow in each subbasin.
    b. Rather than repeating the cycle of hydrographs in the same historical order in which they occurred, each year was assigned a climate classification, so that an appropriate hydrograph could be assigned that might better match climate-based demand projections.
    c. Metrics, such as the Palmer Drought Severity Index (PDSI), were used to understand how extreme conditions (such as the 1988, 1999, 2012 droughts, and the 1992 and 2008 floods) affected hydrographs to establish thresholds for classification.
    d. A three-variable classification was developed based on temperature, precipitation, and potential groundwater recharge.
    e. Future climate model output variables (average and max temperature, precipitation, and net infiltration (recharge)) from SWB2 modeling were used to classify each year of the future time series according to whether the climate forecasts simulated:
        i. cool/normal/or hot temperatures
        ii. wet/normal/dry precipitation projection
        iii. high/normal/dry recharge forecast based on net infiltration (recognizing the low annual recharge in this region typically signals a dry summer and/or fall
    f. The figure below shows that climate projections forecast much more persistently warm conditions starting in the 2030s; therefore, hydrographs that reflect the forecast climate projections were used. Because the future public-utility withdrawals were based on the same climate projections and because the public-water supply sector is the dominant water user in this region, it is important to match the future demand projections with the future water availability projections.



9. Each subbasin has different characteristics, so empirical data related to specific subbasins was used to assign historical natural baseflows. Every attempt was made to assign hydrographs from the same subbasin for the future baseflow conditions for each year, but if an example (previously observed "design" baseflow) hydrograph was not available for the climate classification, a hydrograph in a basin with the same stream order and groundwater/surface water connection status (i.e., connected, isolated, mixed) was assigned instead.

10. After the annual and seasonal baseflow datasets for each of the 21 subbasins were compiled, and the future demand and return projections for each subbasin were compiled, the same approach used in IFA (2021; Phase III: Water Availability, Chapter 2) and Item #7 above, was used to calculate the excess water availability for each year and each season.
11. The same approach used in IFA (2021; Phase III: Water Availability, Chapter 2) was used to calculate the cumulative excess water availability for each year and each season. This entailed summing the excess water availability (Item #10 above) for each subbasin in the stream network from upstream to downstream. This quantity accounts for water received from upstream basins and represents the cumulative water available in excess of man-made and ecological (as defined by minimum instream flows) needs.
12. Appendix G contains tables summarizing the historical (2007-2021) and future (2022-2075) projected water-availability results for each subbasin in 5-year increments.

References:

Blum, A.G., Archfield, S.A., Hirsch, R.M., Vogel, R.M., Kiang, J.E. and Dudley, R.W., 2019, Updating estimates of low-streamflow statistics to account for possible trends. Hydrological Sciences Journal, v. 64, no. 12, pp.1404-1414., https://doi.org/10.1080/02626667.2019.1655148

Fowler, K.K., 1991, Description and effects of 1988 drought on ground-water levels, streamflow, and reservoir levels in Indiana: U.S. Geological Survey Water Resources Investigation Report 91-4100, 91 p.

Indiana Department of Natural Resources (IDNR), 2021, Significant Water Withdrawal Facility (SWWF) Database https://www.in.gov/dnr/water/files/wa-2021WUSummary.pdf

Indiana Finance Authority (IFA), 2021, Central Indiana Water Study. Report to Indiana Finance Authority, Regional Water Studies Program. 363 p. https://www.in.gov/ifa/files/Central%20Indiana%20Water%20Availability%20Report.pdf

Letsinger, S.L., Balberg, A., and Gustin, A.R., 2021a, Implications to aquifer storage from shifts in timing of water-balance partitioning: Indiana, United States: Report to the Indiana Department of Environmental Management, Award #41486, 90 p.

Morlock, S.E., Menke, C.D., Arvin, D.V., and Kim, M.H., 2008, Flood of June 7–9, 2008, in central and southern Indiana: U.S. Geological Survey Open File Report 2008–1322, 15 p., 3 app. https://pubs.usgs.gov/of/2008/1322/

Rutledge, A.T., 1998, Computer programs for describing the recession of ground-water discharge and for estimating mean ground-water recharge and discharge from streamflow records--update: U.S. Geological Survey Water-Resources Investigations Report 98-4148, 43 p.

U.S. Department of Transportation, National Address Database (NAD) Release 12 – Archived at https://web.archive.org/web/20230122025439/https://www.transportation.gov/mission/open/gis/national-address-database/national-address-database-nad-disclaimer

U.S. Geological Survey (USGS) NHD – National Hydrology Dataset - https://www.usgs.gov/national-hydrography/national-hydrography-dataset

U.S. Geological Survey (USGS) NIWS – National Water Information System - https://www.usgs.gov/tools/national-water-information-system-nwis-mapper

Westenbroek, S.M.; Engott, J.A; Kelson, V.A; Hunt, R.J., 2018. SWB Version 2.0—A soil-water-balance code for estimating net infiltration and other water-budget components. USGS Numbered Series 6-A59. U.S. Geological Survey, Reston, VA. Available at: http://pubs.er.usgs.gov/publication/tm6A59

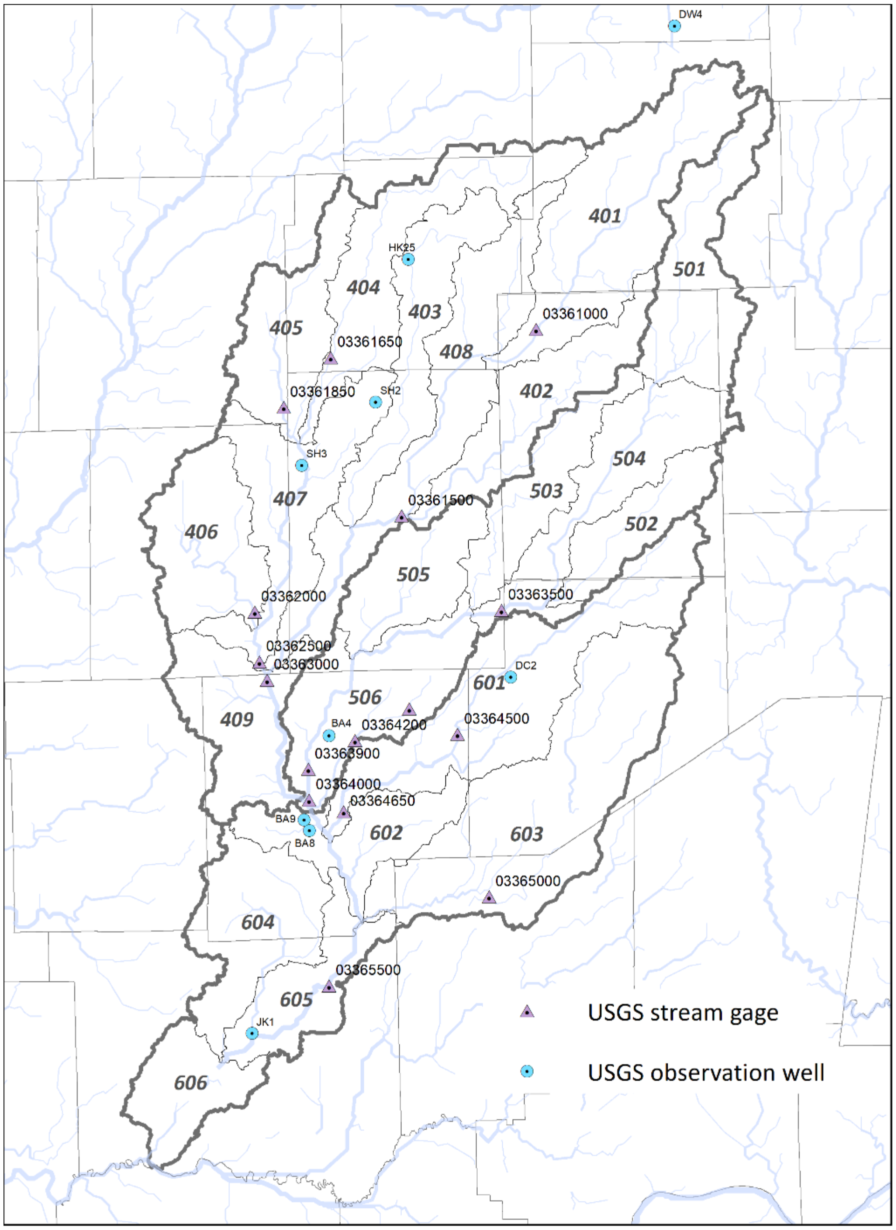


Figure F1. Index map of the Southeast-Central Indiana region showing the study watersheds with their component HUC10 subbasins. Additional data used in the analysis included streamflow discharge from stream and river and water-level observation wells gages (U.S. Geological Survey). Additional details about the subbasins and streamflow network are available in Table F3.

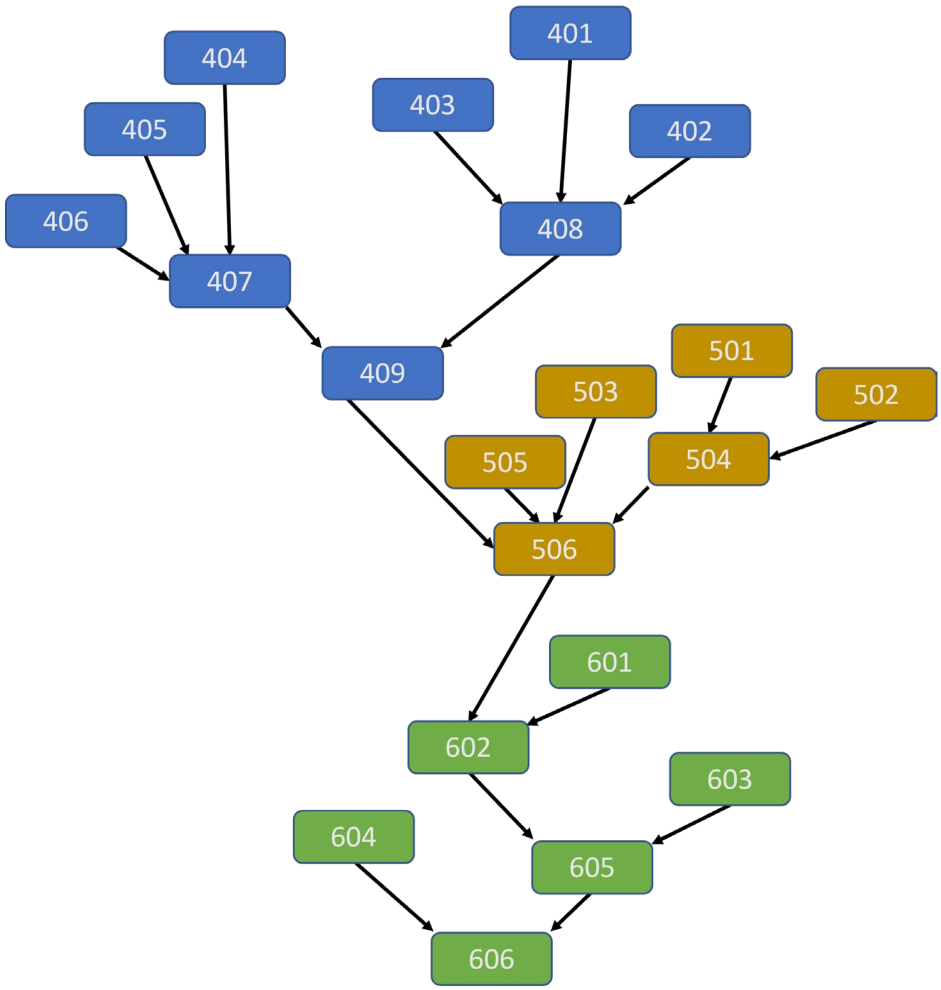


Figure F2. Schematic of HUC10 subbasin flow network.

Table F3. HUC10 subbasin network characteristics for excess water availability analysis.

Driftwood

	Sub-Basin ID	USGS gages	Sub-Basin Area	Inclusive Sub-Basin Area	Sub-Basin gage	Receives Sub-Basins *Compound basin	Total Upstream DA
HUC10			Sq mi	Sq mi			Sq mi
0512020401	401	Big Blue River at Carthage	196.5	196.5	03361000		184
0512020402	402		104.7	104.7			
0512020403	403		106.6	106.6			
0512020404	404	Sugar Creek at New Palestine	132.4	132.4	03361650		93.9
0512020405	405	Buck Creek at Acton	100.9	100.9	03361850		78.8
0512020406	406	Youngs Creek near Edinburgh	108.6	108.6	03362000		107
0512020407	407	Sugar Creek near Edinburgh	132.8	474.7	03362500	404, 405, 406	474
0512020408	408	Big Blue River at Shelbyville	175.4	583.3	03361500	401, 402, 403	421
0512020409	409	Driftwood River near Edinburgh	107.0	1164.9	03363000	407*, 408*	1060
		DRAINS TO 506					

Flatrock-Haw

	Sub-Basin ID	USGS gages	Sub-Basin Area	Inclusive Sub-Basin Area	Sub-Basin gage	Receives Sub-Basins *Compound basin	Total Upstream DA
HUC10			Sq mi	Sq mi			Sq mi
0512020501	501		122.8	122.8			
0512020502	502		63.3	63.3			
0512020503	503		79.93	79.9			
0512020504	504	Flatrock River at St. Paul	119.4	305.4	03363500	501, 502	303
0512020505	505		81.5	81.5			
0512020506	506	Haw Creek at Hope	131.0		03364042		17.9
0512020506	506	Haw Creek near Clifford	131.0		03364200		47.5
0512020506	506	Flatrock River at Columbus	131.0		03363900		534
0512020506	506	East Fork White River at Columbus	131	1762.692	03364000	503, 505, 504*, 409*	1707
		DRAINS TO 602					

Upper East Fork White River

	Sub-Basin ID	USGS gages	Sub-Basin Area	Inclusive Sub-Basin Area	Sub-Basin gage	Receives Sub-Basins *Compound basin	Total Upstream DA
HUC10			Sq mi	Sq mi			Sq mi
0512020601	601	Clifty Creek at Hartsville	205.6	205.6	03364500		91.4
0512020601	601	Clifty Creek near Columbus	205.6	205.6	03364650		202
0512020602	602	No gage	84.7	2053.0		601, 506*	
0512020603	603	Sand Creek near Brewersville	259.0	259.0	03365000		155
0512020604	604		116.0417	116.0			
0512020605	605	East Fork White River at Seymour	77.79062	2389.7	03365500	602*, 603	2341
0512020606	606		68.38022	2574.2		604, 605*	

Table F4. US Geological Survey stream gages located in the study area.

HUC08 Code	USGS Gaging Station	Drainage Area (Square Miles)
05120204 Driftwood	03361000 Big Blue River at Carthage	184
	03361650 Sugar Creek at New Palestine	93.9
	03361850 Buck Creek at Acton	78.8
	03362000 Youngs Creek near Edinburgh	107
	03362500 Sugar Creek near Edinburgh	474
	03361500 Big Blue River at Shelbyville	421
	03363000 Driftwood River near Edinburgh	1060
05120205 Flatrock-Haw	03363500 Flatrock River at St. Paul	303
	03364042 Haw Creek at Hope	17.9
	03364200 Haw Creek near Clifford	47.5
	03363900 Flatrock River at Columbus	534
	03364000 East Fork White River at Columbus	1707
05120206 Upper East Fork White	03364500 Clifty Creek near Hartsville	91.4
	03364650 Clifty Creek near Columbus	202
	03365000 Sand Creek near Brewersville	155
	03365500 East Fork White River at Seymour	2341

Table F5. Hydrograph partitioning metrics from USGS Scientific Investigations Report 2022-5114 (Konrad, 2022).

Gage	Name	Q mean (cfs)	Baseflow Fraction	Surface Flow Fraction	Direct Runoff Fraction	Error
03361000	Big Blue River at Carthage	212	0.478	0.165	0.205	0.04
03361500	Big Blue River at Shelbyville	545	0.434	0.361	0.012	0.06
03361650	Sugar Creek at New Palestine	114	0.051	0.66	0.014	0.15
03361850	Buck Creek at Acton	105	0.042	0.523	0.007	0.15
03362000	Youngs Creek near Edinburgh	141	0.325	0.354	0.034	0.10
03362500	Sugar Creek near Edinburgh	588	0.387	0.408	0.027	0.08
03363000	Driftwood River near Edinburgh	1,360	0.427	0.25	0.17	0.05
03363500	Flatrock River at St. Paul	382	0.361	0.42	0.02	0.08
03363900	Flatrock River at Columbus	663	0.416	0.373	0.037	0.08
03364000	East Fork White River at Columbus	2,181	0.451	0.17	0.198	0.05
03364042	Haw Creek at Hope	23	0.011	0.527	0	0.14
03364200	Haw Creek near Clifford	58	0.026	0.443	0.071	0.16
03364500	Clifty Creek at Hartsville	117	0.347	0.445	0	0.02
03364650	Clifty Creek near Columbus	302	0.053	0.341	0.417	0.14
03365000	Sand Creek near Brewersville	170	0.258	0.598	0	0.08
03365500	East Fork White River at Seymour	3,148	0.439	0.145	0.198	0.06

Table F6. Low- and high-flow statistics calculated for the stream gages used in the excess water availability analysis. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years. This value was used to represent minimum instream flows during the summer and fall in this study. The Q90 is the stream discharge at which it is equal to or higher 90% of the time. These values were used to represent minimum instream flows during the winter and spring months. The values below are given in cubic feet per second, for comparison to average stream flow (see Table F5). The 7Q10 and Q90 are relative to the baseline time period of the data. A series of 7Q10 values were calculated to demonstrate the increasing flows in the Southeast-Central Indiana Region in most of the streams and rivers. Two calculations of Q90 are also included. The baseline time period of 1992-2022 was used in this study to represent the current condition of the study area (see Blum et al., 2019). See the report narrative for implications of the choice of baseline in the water-availability analysis.

		PERIOD OF RECORD		7Q10	7Q10	7Q10	7Q10	7Q10	Q90	Q90
Gage	Name	Start date	End date	POR*	1967-1997	1987-2017	1992-2022	2000-2023	POR*	1992-2022
03361000	Big Blue River at Carthage	1950	2004	28.7	32.7	33.1**	---	---	50.8	59.8
03361500	Big Blue River at Shelbyville	1943	2023	43.6	49.7	51.5	53.2	56.7	78.8	94.9
03361650	Sugar Creek at New Palestine	1967	2023	2.4	2.4	2.0	1.9	3.1	8.8	8.4
03361850	Buck Creek at Acton	1967	2023	1.5	1.5	1.3	1.22	1.3	6.2	6.8
03362000	Youngs Creek near Edinburgh	1942	2023	1.7	2.3	2.2	2.3	2.1	5.4	9.1
03362500	Sugar Creek near Edinburgh	1943	2023	20.8	23.8	21.4	21.9	22.6	49.9	61.5
03363000	Driftwood River near Edinburgh	1941	2023	95.0	107.7**	102.5**	108.5**	108.5	167.0	239.0**
03363500	Flatrock River at St. Paul	1930	2023	2.6	4.0	3.1	3.4	4.2	16.0	20.0
03363900	Flatrock River at Columbus	1967	2023	28.0	28.0	26.2	26.8	29.5	61.9	63.0
03364000	East Fork White River at Columbus	1948	2023	138.5	153.1	147.8	149.6	180.7	269.0	308.0
03364042	Haw Creek at Hope	2010	2023	0.0	---	---	---	---	0.6	---
03364200	Haw Creek near Clifford	1967	2023	0.7	0.7	0.7	0.8	0.8	2.4	2.8
03364500	Clifty Creek at Hartsville	1948	2023	0.0	0.0	0.0	0.0	0.0	0.9	1.5
03364650	Clifty Creek near Columbus	2006	2023	2.32	---	---	---	---	7.6	---
03365000	Sand Creek near Brewersville	1948	1986	0.03	1.1	---	---	---	3.5	---
03365500	East Fork White River at Seymour	1927	2023	181.5	213.2	219.0	228.3	247.72	317.0	418.0

*Period of record

**Short time series; incomplete calculation

--- Some calculations could not be completed because of an insufficiently short or incomplete dataset

Table F7. Annual and seasonal trend statistics for stream discharge at USGS stream gages in the Southeast-Central Indiana region. Several of the gages show increasing flows during the winter, some of which are significant enough to influence the annual trend.

MK = Mann-Kendall trend test (non-parametric). The MK statistic indicates the direction of the trend (positive is increasing; negative is decreasing). The test statistic also allows an assessment of the statistical significance (see symbols next to the values; a lower number represents greater significance and no symbol indicates that the result is not significant). **Sen** = Sen-Thiel slope estimator (also known as "Sen's slope"), which indicates the strength of the trend determined in the Mann-Kendall trend analysis (a higher slope indicates a stronger trend).

Gage	Name	MK Annual	Sen Annual	MK Winter	Sen Winter	MK Spring	Sen Spring	MK Summer	Sen Summer	MK Fall	Sen Fall
03361000	Big Blue River at Carthage[1]	0.3	64.9	-0.1	-39.8	-1.2	-381.8	0.2	93.0	0.1	7.3
03361500	Big Blue River at Shelbyville	1.8+	6.8	2.5*	14.3	1.5	7.9	0.5	3.4	0.2	0.9
03361650	Sugar Creek at New Palestine	1.1	0.7	1.9+	2.2	1.0	1.6	0.0	0.1	0.4	0.2
03361850	Buck Creek at Acton	2.1*	1.6	2.5*	2.7	1.1	1.8	0.8	0.9	0.2	0.2
03362000	Youngs Creek near Edinburgh	2.4*	2.3	2.5*	4.6	1.9+	3.2	0.6	0.7	0.4	0.3
03362500	Sugar Creek near Edinburgh	1.7	6.2	1.8	12.8	1.2	8.6	0.2	1.5	0.1	0.4
03363000	Driftwood River near Edinburgh[1]	---	---	---	---	---	---	---	---	---	---
03363500	Flatrock River at St. Paul	1.6	3.2	2.2*	9.6	1.2	4.0	0.2	0.4	0.3	0.4
03363900	Flatrock River at Columbus	1.6	7.0	2.4*	16.9	0.7	6.0	0.4	2.8	0.3	0.5
03364000	East Fork White River at Columbus	2.3*	35.5	2.0*	50.6	1.3	33.6	1.2	32.0	0.4	4.4
03364042	Haw Creek at Hope	1.3*	1.2	0.8	1.3	-0.1	-0.2	2.0*	1.7	2.3*	1.0
03364200	Haw Creek near Clifford	0.7	2.3	0.8	3.5	-0.3	-2.9	1.6	4.8	2.4*	3.9
03364500	Clifty Creek at Hartsville	2.2*	1.8	2.7	4.3	0.7	1.1	0.3	0.2	0.6	0.3
03364650	Clifty Creek near Columbus	0.0	1.3	-0.6**	-4.5	0.0	-0.4	0.8	8.1	1.5	4.9
03365000	Sand Creek near Brewersville[1]	---	---	---	---	---	---	---	---	---	---
03365500	East Fork White River at Seymour	1.3	27.6	1.8+	71.3	1.1	34.4	0.3	9.7	0.4	3.3

[1] short or incomplete time series, limited data

Significance: + 0.1; * 0.05; ** 0.01, *** 0.001

Table F8. Observation wells in and around the Southeast-Central Indiana Region.

County	IDNR Ref No	USGS Site ID	Well Name	Well Depth (ft)	SWL (ft)	Aquifer	Confined
Bartholomew	121660	391627085534401	BA4	93	23	Unconsolidated	N
Bartholomew	212665	390950085553501	BA8	55	22	Unconsolidated	Y
Bartholomew	121689	391035085560401	BA9	115	15	Unconsolidated	Y
Decatur	121714	392022085371801	DC2	47	4	Bedrock	Y
Delaware	21674	400541085213701	DW4	91	47	Unconsolidated	Y
Hancock	169083	394940085460101	HK25	76	30	Unconsolidated	Y
Jackson	410085	385542086005601	JK1	60	14	Unconsolidated	N
Johnson	190505	393616086134502	JO10	104	13	Unconsolidated	N
Shelby	121609	393943085490901	SH2	150	28	Unconsolidated	N
Shelby	190711	393522085555401	SH3	107	2	Unconsolidated	Y

Table F9. Annual and seasonal trend statistics for groundwater-level observation wells in and around the Southeast-Central Indiana region in flow order (north-to-south). The trend is calculated for depth-to-water, so a negative trend indicates rising water levels.

MK = Mann-Kendall trend test (non-parametric). The MK statistic indicates the direction of the trend (positive is increasing; negative is decreasing). The test statistic also allows an assessment of the statistical significance (see symbols next to the values; a lower number represents greater significance and no symbol indicates that the result is not significant). **Sen** = Sen-Thiel slope estimator (also known as “Sen’s slope”), which indicates the strength of the trend determined in the Mann-Kendall trend analysis (a higher slope indicates a stronger trend).

Site ID	Well	MK Annual	Sen Annual	MK Winter	Sen Winter	MK Spring	Sen Spring	MK Summer	Sen Summer	MK Fall	Sen Fall
391627085534401	**BA4**	-0.65	-0.02	-1.05	-0.02	-1.21	-0.04	-0.14	0.00	0.24	0.01
390950085553501	**BA8**	-2.35*	-0.15	-2.51**	-0.15	-1.58	-0.11	-0.59	-0.06	-2.75	-0.14*
391035085560401	**BA9**	-4.24***	-0.44	-4.77***	-0.48	-2.97**	-0.46	-2.74**	-0.37	-3.91***	-0.51
392022085371801	**DC2**	-1.73+	-0.02	-3.20**	-0.05	-0.57	-0.01	-0.75	-0.01	-0.34	-0.01
400541085213701	**DW4**	-5.61***	-0.04	-4.56***	-0.04	-4.32***	-0.05	-3.68***	-0.04	-3.88***	-0.04
394940085460101	**HK25**[1]	---	---	---	---	---	---	---	---	---	---
385542086005601	JK1[1]		-0.07		-0.53		0.29		-0.23		0.07
393616086134502	**JO10**	Not calculated		---	---	---	---	---	---	---	---
393943085490901	**SH2**	-1.67+	-0.02	-1.87+	-0.04	-0.97	-0.02	-0.32	-0.01	0.20	0.01
393522085555401	**SH3**[1]		0.34		0.04		0.24		0.53		0.79

[1] short or incomplete time series, limited data
Significance: + 0.1; * 0.05; ** 0.01, *** 0.001

Appendix G. Excess Water Availability Results

Excess Water Availability Results

G1. Table of water utilities linked to subbasin index.

G2. Reference table of public water supply water sources and wastewater returns.

G3. Table of annual excess availability results.

G4. Table of winter excess availability results.

G5. Table of spring excess availability results.

G6. Table of summer excess availability results.

G7. Table of fall excess availability results.

G8. Table of annual cumulative excess availability results.

G9. Table of winter cumulative excess availability results.

G10. Table of spring cumulative excess availability results.

G11. Table of summer cumulative excess availability results.

G12. Table of fall cumulative excess availability results.

Note

See Appendix F: Water Availability Model Setup for the methods used to develop the results below, as well as index maps and tables that can be used to identify the location of subbasins referenced in the excess water availability results.

Table G1. Subbasin water sources and subbasins served by different utilities in the study area.

Utility Name	Subbasin Source(s)	Subbasin(s) Served
Anderson Township	502	502
Bargersville	West of 406	406
Brown County	West of 409	604
Carthage	401	401
Citizens Energy Group	West of 406 & 407	404, 405, 407
Columbus	506, 602	409, 506, 601, 602, 604
Cordry-Sweetwater	See Prince's Lakes	409
Decatur County	See Greensburg	601, 603
Eastern Bartholomew	506	506, 601, 602, 603, 604
Edinburgh	408	408, 409
Fortville	North of 405	405
Glenwood	504	504
Greenfield	403	403, 404
Greensburg	601, 603	601, 603
Hoosier Youth Challenge Academy	401	401
Hope	See E. Bartholomew	506, 601
Indiana American - Johnson County	407	406, 407
Indiana American - Seymour	605	605
Indiana American - Shelbyville	408	402, 403, 408, 505
Jackson County	606	604, 605, 606
Jennings Water	605	603
Knightstown	401	401
Lewisville	501	501
Medora	606	606
Morristown	408	408
Mount Summit	401	401
New Castle	401	401, 501
NineStar Connect	404	403, 404, 405
NineStar GEM	404, 405	404, 405
NineStar Sugar Creek	404	404
North Vernon	South of 603	603
NineStar Philadelphia	404	404
Prince’s Lakes	408	406, 407, 409
Rushville	504	504
Shirley	408	408
Southwestern Bartholomew	See Columbus	409, 602, 604
Spiceland	401	401
St. Paul	504	504
Trafalgar	See Prince's Lakes	406
Waldron	503	503
Westport	603	603
Whiteland	See IA Johnson	408

Table G2. Reference table of locations of public water supply water sources and wastewater returns. The water inventory of withdrawals and returns conducted for the water availability part of this study revealed imbalances in the anthropogenic influences on the subbasin-level. For example, note that Columbus has two wellfields, one of which is down-basin (subbasin 602) of the wastewater discharge locations (subbasin 506). Similarly, Indiana American – Johnson County withdraws water from subbasin 407, and the discharge from the service areas that purchase from that utility are located upgradient in Subbasin 406.

Subbasin	Wellfield	Wastewater Treatment Plant
401	Carthage, HYCA, Knightstown, Mt. Summit, New Castle, Spiceland	Carthage, Kennard, Knightstown, New Castle, Summit Springs RWD
402	N/A	N/A
403	Greenfield	Cumberland Southern, Greenfield
404	NineStar Connect, NineStar GEM, NineStar Sugar Creek, NineStar Philadelphia	Maxwell Intermediate School, New Palestine, Philly Estates
405	NineStar GEM	Cumberland, Eastway Apartments, GEM Utilities, Indianapolis KOA Campground, McDonalds #11963, The Hope Center Indy, Indy Municipal Storm Sewer System
406	N/A	Franklin, New Whiteland, Whiteland
407	Indian American - Johnson	Clark Elementary School
408	Edinburgh, Indiana American - Shelbyville, Prince's Lakes, Shirley	Edinburgh, Morristown, Shelbyville, Shirley
409	N/A	Prince's Lakes
501	Lewisville	Mooreland Environmental Control Center, South Henry RWD
502	Anderson Township	Anderson Township
503	Waldron	Western Rush Co
504	Glenwood, Rushville, St. Paul	Glenwood, Rushville, St. Paul
505	N/A	N/A
506	Columbus, Eastern Bartholomew	Columbus, Hope
601	Greensburg	Hartsville
602	Columbus	Elizabethtown
603	Greensburg, Westport	Greensburg, Westport
604	N/A	Lakeview Villages
605	Indiana American - Seymour, Jennings	Seymour
606	Jackson, Medora	Brownstown, Medora

Table G3: Annual excess availability forecast results for HUC10 subbasins in the study area.

Subbasin	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075
401	7.91	11.60	2.78	9.82	10.28	18.98	4.36	18.66	11.71	18.43	11.73	-2.86	-2.63	12.08
402	35.80	26.77	30.55	34.83	35.04	44.17	29.90	44.16	37.08	44.03	37.33	22.50	22.22	37.12
403	38.35	42.03	32.29	38.28	38.57	47.06	32.59	46.75	39.69	46.28	39.45	24.79	24.71	39.28
404	35.88	39.75	30.88	35.55	35.98	44.77	30.42	44.67	37.86	44.58	37.79	23.03	22.99	37.70
405	26.09	28.04	29.74	24.95	24.89	37.59	27.43	37.24	27.94	37.04	27.54	17.20	17.37	27.43
406	37.43	64.67	47.60	37.82	36.45	61.93	44.54	60.79	52.41	60.24	52.12	24.12	24.06	51.82
407	41.07	17.96	86.19	14.14	38.94	93.58	84.67	91.44	39.12	92.57	38.21	28.16	28.40	37.84
408	169.09	177.46	173.69	162.32	162.84	240.58	168.58	237.97	174.54	238.17	173.37	91.50	91.24	173.72
409	67.82	108.58	104.07	127.87	66.44	77.37	102.20	77.31	170.41	76.80	170.13	74.12	74.14	169.98
501	24.06	23.29	27.27	24.12	24.01	37.10	27.11	37.09	27.69	37.09	27.69	17.35	17.36	27.68
502	37.38	28.56	31.82	36.98	37.46	46.37	32.04	46.38	39.61	46.38	39.61	24.88	24.87	39.63
503	37.19	28.83	32.12	37.07	37.54	46.45	32.14	46.47	39.69	46.46	39.72	24.98	24.95	39.72
504	109.75	105.41	116.32	104.50	110.83	171.75	116.40	172.01	128.01	171.49	127.94	68.17	68.06	127.48
505	25.35	24.57	28.48	23.27	23.04	36.13	25.96	35.83	26.36	35.70	26.17	15.65	15.55	25.83
506	3.39	31.31	14.55	125.65	42.15	60.26	69.93	57.33	175.44	60.78	176.35	41.22	41.28	176.60
601	62.96	79.32	76.59	56.06	73.90	90.57	76.62	90.61	71.13	90.40	71.08	42.70	42.76	71.19
602	31.00	40.87	43.10	27.99	46.02	42.61	45.84	39.99	36.36	42.18	35.82	20.70	21.56	35.98
603	22.34	39.20	56.20	29.15	20.30	21.53	51.84	20.77	28.25	20.35	27.89	27.56	27.42	25.73
604	23.70	22.94	26.90	20.78	20.66	33.49	23.37	33.00	23.59	32.72	23.03	12.30	12.12	22.21
605	185.57	123.99	148.62	47.91	301.89	232.23	150.13	231.50	45.32	232.01	45.85	-29.86	-30.17	45.74
606	81.61	86.64	104.54	67.09	98.20	117.52	104.75	117.13	85.54	117.52	85.48	36.25	36.34	85.35

Table G4: Winter excess availability forecast results for HUC10 subbasins in the study area.

Subbasin	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075
401	0.76	13.07	30.65	64.24	5.73	5.93	30.97	5.56	18.15	5.46	18.19	34.91	35.22	18.39
402	30.68	45.33	56.63	88.76	30.11	30.46	56.02	30.80	43.24	30.32	43.39	60.02	59.77	42.87
403	33.34	45.14	59.44	92.39	33.79	33.89	58.99	33.47	45.87	33.12	45.66	62.37	62.28	45.53
404	30.76	42.61	57.00	89.43	30.99	31.39	56.61	31.30	43.91	31.19	43.82	60.50	60.46	43.76
405	36.44	28.32	50.97	58.22	35.05	27.59	48.32	27.26	42.36	27.09	42.28	51.17	51.14	42.12
406	55.17	45.61	88.34	108.60	53.92	37.28	84.03	36.12	70.13	35.52	69.89	79.98	79.85	69.55
407	49.49	25.89	156.92	105.58	48.07	57.71	155.21	56.51	55.59	56.75	54.88	131.50	131.73	54.58
408	165.73	165.15	310.57	443.43	161.37	70.95	303.98	69.16	193.52	68.55	192.89	335.78	335.16	191.92
409	254.48	221.85	172.91	413.55	252.45	-10.59	170.74	-10.87	331.52	-11.09	331.35	277.53	277.41	331.05
501	34.09	36.38	47.85	57.07	34.03	26.86	47.63	26.86	42.12	26.86	42.11	51.09	51.09	42.11
502	32.31	47.10	58.00	90.78	32.34	32.97	58.22	32.94	45.58	32.98	45.68	62.30	62.25	45.67
503	32.18	47.12	58.26	90.79	32.39	32.94	58.19	32.95	45.64	32.95	45.65	62.32	62.31	45.65
504	148.58	68.00	201.49	289.91	148.56	61.89	200.44	62.00	162.88	61.62	162.81	268.75	268.44	162.70
505	35.48	37.66	48.94	56.36	33.18	25.97	46.55	25.76	40.90	25.54	40.71	49.52	49.43	40.33
506	205.18	160.69	-54.22	465.76	286.32	-56.55	106.82	-56.51	372.14	-56.29	372.44	273.18	273.54	372.68
601	99.85	79.47	141.08	169.94	61.91	64.72	141.07	64.61	95.06	64.70	95.05	156.07	156.09	95.12
602	88.24	66.58	123.48	149.23	52.30	54.74	126.26	54.01	82.28	54.24	82.82	137.46	137.13	81.98
603	154.49	199.47	307.05	184.33	152.71	132.16	301.95	131.38	189.57	130.86	189.02	152.16	152.03	186.78
604	33.69	35.97	47.38	54.17	31.10	23.66	44.26	23.30	38.40	22.92	37.90	46.58	46.31	37.08
605	74.50	-68.24	150.63	336.56	-68.84	-25.05	148.99	-25.02	-68.80	-25.02	-68.81	161.19	161.23	-68.81
606	114.81	91.04	183.84	259.20	55.94	18.02	184.01	17.82	97.61	17.99	97.41	189.25	189.29	97.32

Table G5: Spring excess availability forecast results for HUC10 subbasins in the study area.

Subbasin	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075
401	41.16	35.09	21.11	47.88	43.64	83.94	23.34	83.54	39.71	83.38	39.80	9.77	9.90	39.95
402	68.91	56.49	49.20	72.57	68.19	108.73	48.57	108.82	64.88	108.59	65.15	34.89	34.59	64.82
403	72.19	66.24	52.21	76.07	71.74	111.75	51.32	111.35	67.47	111.01	67.27	37.10	37.03	67.10
404	68.99	63.31	49.69	73.29	69.13	109.45	49.12	109.36	65.65	109.25	65.58	35.41	35.38	65.50
405	46.88	40.75	46.72	55.86	45.46	84.41	44.15	84.20	45.94	83.91	45.45	22.84	23.04	45.34
406	73.89	85.51	84.41	68.91	72.15	136.99	80.71	135.86	82.40	135.27	82.19	41.16	41.10	81.85
407	88.59	18.63	148.94	41.29	86.99	211.71	146.49	210.63	53.08	210.71	52.04	76.25	76.80	51.86
408	332.99	251.96	286.11	365.83	324.68	608.63	278.48	605.67	261.56	606.20	260.69	168.26	168.31	260.89
409	115.29	250.86	217.81	247.46	112.69	156.34	215.56	156.05	269.89	155.83	269.70	156.66	156.61	269.43
501	44.63	49.21	44.10	54.96	44.52	84.06	43.91	84.05	45.71	84.06	45.70	23.01	23.02	45.70
502	70.52	58.22	50.42	74.60	70.54	110.98	50.60	110.96	67.35	110.98	67.28	37.17	37.20	67.35
503	70.23	58.46	50.79	74.72	70.64	111.10	50.79	111.09	67.45	111.11	67.47	37.31	37.30	67.48
504	229.27	139.52	205.05	222.55	229.85	405.12	204.32	405.97	203.80	404.85	203.54	123.60	123.55	202.61
505	45.93	50.45	45.35	54.17	43.58	83.14	42.75	82.89	44.40	82.67	44.22	21.36	21.28	43.89
506	-32.04	172.21	87.81	299.09	83.03	55.17	171.80	55.36	288.41	55.41	287.92	153.53	153.91	288.56
601	125.80	120.44	131.87	103.64	103.15	194.11	131.86	194.07	120.41	194.08	120.30	73.87	73.85	120.42
602	106.42	101.31	115.72	89.18	87.89	167.28	117.93	165.25	104.83	166.76	104.43	61.65	62.97	104.41
603	35.61	68.03	80.33	37.18	33.08	37.31	75.60	36.72	45.49	36.23	45.14	34.12	34.03	43.08
604	44.19	48.81	43.67	51.70	41.23	80.52	40.20	80.20	41.65	79.75	41.14	18.00	17.92	40.31
605	400.57	165.29	156.75	231.15	112.43	555.91	156.34	556.09	52.33	555.94	52.37	-21.07	-21.16	52.28
606	161.77	137.03	162.39	155.94	121.89	268.17	162.45	268.03	111.84	268.19	111.70	81.35	81.47	111.61

Table G6: Summer excess availability forecast results for HUC10 subbasins in the study area.

Subbasin	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075
401	48.17	50.83	6.40	-2.56	50.03	6.85	10.59	6.73	36.03	6.24	36.15	-4.55	-4.43	36.33
402	56.31	8.93	17.25	2.88	55.36	12.67	16.53	12.39	41.81	12.50	42.02	0.96	0.80	42.07
403	59.09	62.21	18.27	6.27	58.73	15.01	19.08	14.93	44.34	14.34	44.09	3.23	3.21	43.87
404	56.09	59.08	17.28	3.46	56.09	12.73	16.79	12.60	42.41	12.56	42.33	1.32	1.29	42.23
405	35.55	44.81	16.44	2.33	34.32	14.55	14.57	14.20	22.98	14.09	22.48	0.04	0.37	22.36
406	41.17	113.14	29.14	9.08	40.04	34.62	26.60	33.41	37.74	33.16	37.53	3.10	2.98	37.15
407	73.61	46.33	45.86	-4.31	70.22	64.78	44.82	59.82	80.40	63.60	79.87	-18.11	-18.14	79.68
408	255.93	305.57	118.63	29.75	246.25	113.08	115.46	109.93	218.52	110.88	217.11	3.64	3.43	218.09
409	33.24	36.99	79.25	47.90	32.53	138.51	77.95	139.08	179.77	137.99	179.32	10.65	10.77	179.10
501	34.15	10.53	15.11	2.31	34.11	14.85	14.99	14.84	23.35	14.84	23.34	0.95	0.96	23.34
502	57.05	10.03	17.74	4.49	57.15	13.87	17.96	13.89	43.67	13.87	43.68	2.72	2.69	43.68
503	56.80	10.60	18.00	4.64	57.27	14.01	18.13	14.05	43.80	14.01	43.85	2.88	2.82	43.82
504	125.11	187.15	68.89	14.68	126.39	64.00	69.63	64.20	125.56	63.76	125.55	6.24	6.35	124.85
505	34.64	11.22	15.77	0.67	32.41	13.23	13.15	12.73	21.29	12.81	21.16	-1.51	-1.57	20.83
506	-8.25	-5.65	93.17	77.90	5.08	154.08	85.56	144.21	201.55	154.49	204.42	32.41	33.03	205.94
601	63.00	101.88	30.81	3.78	68.97	29.29	30.95	29.50	57.52	28.95	57.49	1.42	1.55	57.71
602	45.95	84.77	20.25	-1.39	58.20	23.55	23.58	18.74	46.00	23.10	45.99	-5.79	-5.02	46.61
603	6.70	18.36	15.88	17.98	4.05	-0.50	12.00	-1.48	-0.94	-1.67	-1.17	0.59	0.42	-3.33
604	34.05	10.46	15.05	-1.36	30.52	11.06	11.07	10.08	19.03	10.30	18.51	-4.48	-4.60	17.71
605	259.06	260.13	106.30	-50.75	373.30	195.03	111.98	191.77	43.36	194.45	45.36	-51.01	-52.24	44.84
606	120.64	124.71	94.77	24.02	137.99	121.92	95.31	120.92	130.79	122.03	130.97	-2.09	-1.89	130.84

Table G7: Fall excess availability forecast results for HUC10 subbasins in the study area.

Subbasin	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075
401	-2.95	2.05	2.05	-3.22	-2.77	2.92	1.64	2.53	5.96	2.36	5.77	14.90	15.30	6.68
402	2.35	6.69	7.75	1.72	1.54	8.08	7.13	7.88	10.92	7.96	11.30	20.12	19.73	11.23
403	3.82	8.71	7.87	5.01	5.04	10.85	9.58	10.48	13.59	9.92	13.29	22.45	22.32	13.14
404	2.27	7.73	7.76	2.20	2.30	8.33	7.37	8.23	11.57	8.11	11.50	20.45	20.40	11.38
405	3.23	7.00	10.52	1.34	2.47	9.86	8.36	9.34	14.23	9.11	13.69	16.61	16.81	13.66
406	6.93	21.11	13.92	7.84	7.10	14.80	12.23	13.74	39.30	13.01	38.79	11.60	11.66	38.64
407	-1.43	10.45	8.30	-11.54	-3.52	21.48	7.41	20.17	5.05	20.59	3.69	-1.61	-1.36	2.89
408	22.28	55.94	51.55	3.48	19.61	74.66	48.52	72.11	104.88	72.05	103.12	46.95	46.70	104.30
409	22.07	41.29	48.26	28.19	21.90	28.34	46.50	28.12	68.82	27.61	68.53	-11.50	-11.41	68.74
501	2.30	8.49	8.89	1.24	2.31	9.85	8.78	9.84	14.52	9.84	14.51	17.38	17.38	14.51
502	3.06	7.67	8.15	3.07	3.24	9.31	8.38	9.35	12.75	9.31	12.69	21.72	21.72	12.72
503	2.97	7.88	8.46	3.14	3.28	9.40	8.50	9.43	12.79	9.41	12.81	21.81	21.76	12.83
504	1.02	28.25	15.51	3.19	3.52	57.40	16.86	57.30	66.32	57.15	66.41	13.73	13.51	66.27
505	3.10	9.20	9.54	-0.18	0.75	8.25	7.07	7.99	12.60	7.83	12.35	15.09	14.93	12.02
506	53.95	36.55	79.60	63.16	52.16	49.59	77.86	47.51	102.91	50.77	103.85	-7.43	-8.54	102.45
601	1.09	18.64	16.76	-0.54	34.91	11.69	16.78	11.79	32.99	11.39	32.92	0.89	0.98	32.97
602	-5.19	8.46	9.31	-3.77	32.56	8.21	11.97	5.27	27.60	7.91	25.30	-4.60	-2.92	26.19
603	1.65	25.25	24.13	4.59	0.47	2.34	20.43	1.66	5.88	1.15	5.54	7.72	7.55	3.37
604	2.21	8.39	8.78	-1.84	-0.85	6.40	5.25	6.09	10.65	5.56	9.95	12.57	12.32	9.10
605	-37.22	32.17	17.37	-50.49	458.71	5.17	19.75	5.29	92.24	4.81	92.31	-31.10	-31.08	92.48
606	-1.75	26.15	36.47	-5.04	74.25	22.05	36.51	21.84	53.07	21.96	52.99	-8.21	-8.22	52.80

Table G8: Annual cumulative excess availability forecast results for select HUC10 subbasins in the study area.

Subbasin	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075
401	7.91	11.60	2.78	9.82	10.28	18.98	4.36	12.15	11.71	18.43	11.73	-2.86	-2.63	12.08
402	35.80	26.77	30.55	34.83	35.04	44.17	29.90	37.43	37.08	44.03	37.33	22.50	22.22	37.12
403	38.35	42.03	32.29	38.28	38.57	47.06	32.59	40.19	39.69	46.28	39.45	24.79	24.71	39.28
404	35.88	39.75	30.88	35.55	35.98	44.77	30.42	38.01	37.86	44.58	37.79	23.03	22.99	37.70
405	26.09	28.04	29.74	24.95	24.89	37.59	27.43	28.03	27.94	37.04	27.54	17.20	17.37	27.43
406	37.43	64.67	47.60	37.82	36.45	61.93	44.54	53.27	52.41	60.24	52.12	24.12	24.06	51.82
407	140.47	150.42	194.40	112.47	136.26	237.87	187.05	157.69	157.34	234.43	155.65	92.50	92.83	154.79
408	169.09	177.46	173.69	162.32	162.84	240.58	168.58	175.69	174.54	238.17	173.37	91.50	91.24	173.72
409	277.98	304.00	363.94	304.33	268.22	411.52	355.45	384.92	384.06	407.54	381.71	193.78	193.78	381.54
501	24.06	23.29	27.27	24.12	24.01	37.10	27.11	27.69	27.69	37.09	27.69	17.35	17.36	27.68
502	37.38	28.56	31.82	36.98	37.46	46.37	32.04	39.62	39.61	46.38	39.61	24.88	24.87	39.63
503	37.19	28.83	32.12	37.07	37.54	46.45	32.14	39.72	39.69	46.46	39.72	24.98	24.95	39.72
504	109.75	105.41	116.32	104.50	110.83	171.75	116.40	128.21	128.01	171.49	127.94	68.17	68.06	127.48
505	25.35	24.57	28.48	23.27	23.04	36.13	25.96	26.51	26.36	35.70	26.17	15.65	15.55	25.83
506	509.49	590.18	627.95	537.84	490.61	744.92	616.19	675.16	674.47	738.47	673.90	351.22	353.04	674.15
601	62.96	79.32	76.59	56.06	73.90	90.57	76.62	71.12	71.13	90.40	71.08	42.70	42.76	71.19
602	572.46	669.50	704.54	593.90	564.51	835.49	692.82	746.27	745.59	828.87	744.98	393.92	395.80	745.34
603	22.34	39.20	56.20	29.15	20.30	21.53	51.84	28.81	28.25	20.35	27.89	27.56	27.42	25.73
604	23.70	22.94	26.90	20.78	20.66	33.49	23.37	23.88	23.59	32.72	23.03	12.30	12.12	22.21
605	594.80	708.71	760.75	623.05	584.81	857.02	744.66	775.08	773.85	849.21	772.87	421.48	423.23	771.07
606	700.11	818.28	892.18	710.92	703.68	1008.04	872.77	884.39	882.98	999.45	881.38	470.04	471.68	878.63

Table G9: Winter cumulative excess availability forecast results for select HUC10 subbasins in the study area.

Subbasin	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075
401	0.76	13.07	30.65	64.24	5.73	5.93	30.97	5.56	18.15	5.46	18.19	34.91	35.22	18.39
402	30.68	45.33	56.63	88.76	30.11	30.46	56.02	30.80	43.24	30.32	43.39	60.02	59.77	42.87
403	33.34	45.14	59.44	92.39	33.79	33.89	58.99	33.47	45.87	33.12	45.66	62.37	62.28	45.53
404	30.76	42.61	57.00	89.43	30.99	31.39	56.61	31.30	43.91	31.19	43.82	60.50	60.46	43.76
405	36.44	28.32	50.97	58.22	35.05	27.59	48.32	27.26	42.36	27.09	42.28	51.17	51.14	42.12
406	55.17	45.61	88.34	108.60	53.92	37.28	84.03	36.12	70.13	35.52	69.89	79.98	79.85	69.55
407	171.86	142.44	353.23	361.82	168.03	153.98	344.17	151.19	211.99	150.55	210.88	323.16	323.18	210.01
408	165.73	165.15	310.57	443.43	161.37	70.95	303.98	69.16	193.52	68.55	192.89	335.78	335.16	191.92
409	215.22	191.04	467.49	549.00	209.43	128.66	459.19	125.67	249.11	125.30	247.77	467.29	466.89	246.50
501	34.09	36.38	47.85	57.07	34.03	26.86	47.63	26.86	42.12	26.86	42.11	51.09	51.09	42.11
502	32.31	47.10	58.00	90.78	32.34	32.97	58.22	32.94	45.58	32.98	45.68	62.30	62.25	45.67
503	32.18	47.12	58.26	90.79	32.39	32.94	58.19	32.95	45.64	32.95	45.65	62.32	62.31	45.65
504	148.58	68.00	201.49	289.91	148.56	61.89	200.44	62.00	162.88	61.62	162.81	268.75	268.44	162.70
505	35.48	37.66	48.94	56.36	33.18	25.97	46.55	25.76	40.90	25.54	40.71	49.52	49.43	40.33
506	801.85	712.70	1144.87	1632.09	785.26	325.00	1103.20	319.57	994.84	317.64	994.44	1263.56	1263.28	991.97
601	99.85	79.47	141.08	169.94	61.91	64.72	141.07	64.61	95.06	64.70	95.05	156.07	156.09	95.12
602	901.70	792.17	1285.95	1802.03	847.17	389.72	1244.27	384.18	1089.90	382.35	1089.50	1419.63	1419.38	1087.08
603	154.49	199.47	307.05	184.33	152.71	132.16	301.95	131.38	189.57	130.86	189.02	152.16	152.03	186.78
604	33.69	35.97	47.38	54.17	31.10	23.66	44.26	23.30	38.40	22.92	37.90	46.58	46.31	37.08
605	1056.19	991.65	1593.00	1986.36	999.88	521.87	1546.21	515.56	1279.47	513.20	1278.52	1571.79	1571.40	1273.87
606	1204.69	1118.66	1824.22	2299.72	1086.92	563.56	1774.48	556.68	1415.48	554.11	1413.83	1807.62	1807.00	1408.26

Table G10: Spring cumulative excess availability forecast results for select HUC10 subbasins in the study area.

Subbasin	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075
401	41.16	35.09	21.11	47.88	43.64	83.94	23.34	83.54	39.71	83.38	39.80	9.77	9.90	39.95
402	68.91	56.49	49.20	72.57	68.19	108.73	48.57	108.82	64.88	108.59	65.15	34.89	34.59	64.82
403	72.19	66.24	52.21	76.07	71.74	111.75	51.32	111.35	67.47	111.01	67.27	37.10	37.03	67.10
404	68.99	63.31	49.69	73.29	69.13	109.45	49.12	109.36	65.65	109.25	65.58	35.41	35.38	65.50
405	46.88	40.75	46.72	55.86	45.46	84.41	44.15	84.20	45.94	83.91	45.45	22.84	23.04	45.34
406	73.89	85.51	84.41	68.91	72.15	136.99	80.71	135.86	82.40	135.27	82.19	41.16	41.10	81.85
407	278.35	208.19	329.76	239.35	273.74	542.56	320.47	540.05	247.08	539.15	245.25	175.65	176.32	244.54
408	332.99	251.96	286.11	365.83	324.68	608.63	278.48	605.67	261.56	606.20	260.69	168.26	168.31	260.89
409	421.58	270.59	435.04	407.12	411.67	820.34	424.97	816.30	314.64	816.92	312.73	244.50	245.11	312.75
501	44.63	49.21	44.10	54.96	44.52	84.06	43.91	84.05	45.71	84.06	45.70	23.01	23.02	45.70
502	70.52	58.22	50.42	74.60	70.54	110.98	50.60	110.96	67.35	110.98	67.28	37.17	37.20	67.35
503	70.23	58.46	50.79	74.72	70.64	111.10	50.79	111.09	67.45	111.11	67.47	37.31	37.30	67.48
504	229.27	139.52	205.05	222.55	229.85	405.12	204.32	405.97	203.80	404.85	203.54	123.60	123.55	202.61
505	45.93	50.45	45.35	54.17	43.58	83.14	42.75	82.89	44.40	82.67	44.22	21.36	21.28	43.89
506	978.13	960.37	1120.14	1143.30	955.67	1750.04	1094.51	1745.06	1048.60	1743.86	1044.92	680.82	682.12	1044.47
601	125.80	120.44	131.87	103.64	103.15	194.11	131.86	194.07	120.41	194.08	120.30	73.87	73.85	120.42
602	1103.93	1080.81	1252.01	1246.94	1058.82	1944.15	1226.37	1939.13	1169.01	1937.95	1165.22	754.69	755.97	1164.89
603	35.61	68.03	80.33	37.18	33.08	37.31	75.60	36.72	45.49	36.23	45.14	34.12	34.03	43.08
604	44.19	48.81	43.67	51.70	41.23	80.52	40.20	80.20	41.65	79.75	41.14	18.00	17.92	40.31
605	1139.54	1148.84	1332.34	1284.12	1091.90	1981.46	1301.97	1975.85	1214.50	1974.18	1210.36	788.81	790.00	1207.97
606	1345.51	1334.68	1538.41	1491.76	1255.01	2330.15	1504.63	2324.07	1367.99	2322.12	1363.20	888.16	889.39	1359.89

Table G11: Summer cumulative excess availability forecast results for select HUC10 subbasins in the study area.

Subbasin	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075
401	48.17	50.83	6.40	-2.56	50.03	6.85	10.59	6.73	36.03	6.24	36.15	-4.55	-4.43	36.33
402	56.31	8.93	17.25	2.88	55.36	12.67	16.53	12.39	41.81	12.50	42.02	0.96	0.80	42.07
403	59.09	62.21	18.27	6.27	58.73	15.01	19.08	14.93	44.34	14.34	44.09	3.23	3.21	43.87
404	56.09	59.08	17.28	3.46	56.09	12.73	16.79	12.60	42.41	12.56	42.33	1.32	1.29	42.23
405	35.55	44.81	16.44	2.33	34.32	14.55	14.57	14.20	22.98	14.09	22.48	0.04	0.37	22.36
406	41.17	113.14	29.14	9.08	40.04	34.62	26.60	33.41	37.74	33.16	37.53	3.10	2.98	37.15
407	206.42	263.36	108.72	10.56	200.67	126.68	102.78	120.02	183.53	123.41	182.21	-13.65	-13.51	181.43
408	255.93	305.57	118.63	29.75	246.25	113.08	115.46	109.93	218.52	110.88	217.11	3.64	3.43	218.09
409	329.54	351.90	164.49	25.44	316.46	177.86	160.28	169.74	298.92	174.49	296.98	-14.47	-14.72	297.78
501	34.15	10.53	15.11	2.31	34.11	14.85	14.99	14.84	23.35	14.84	23.34	0.95	0.96	23.34
502	57.05	10.03	17.74	4.49	57.15	13.87	17.96	13.89	43.67	13.87	43.68	2.72	2.69	43.68
503	56.80	10.60	18.00	4.64	57.27	14.01	18.13	14.05	43.80	14.01	43.85	2.88	2.82	43.82
504	125.11	187.15	68.89	14.68	126.39	64.00	69.63	64.20	125.56	63.76	125.55	6.24	6.35	124.85
505	34.64	11.22	15.77	0.67	32.41	13.23	13.15	12.73	21.29	12.81	21.16	-1.51	-1.57	20.83
506	713.79	901.00	403.36	118.75	646.70	511.34	404.75	496.56	780.58	505.48	784.11	6.75	13.42	787.88
601	63.00	101.88	30.81	3.78	68.97	29.29	30.95	29.50	57.52	28.95	57.49	1.42	1.55	57.71
602	776.79	1002.88	434.17	122.54	715.67	540.63	435.70	526.06	838.09	534.43	841.60	8.17	14.98	845.59
603	6.70	18.36	15.88	17.98	4.05	-0.50	12.00	-1.48	-0.94	-1.67	-1.17	0.59	0.42	-3.33
604	34.05	10.46	15.05	-1.36	30.52	11.06	11.07	10.08	19.03	10.30	18.51	-4.48	-4.60	17.71
605	783.49	1021.23	450.05	140.51	719.71	540.13	447.70	524.58	837.15	532.76	840.43	8.76	15.39	842.26
606	938.18	1156.41	559.87	163.18	888.22	673.12	554.08	655.58	986.97	665.09	989.91	2.19	8.90	990.82

Table G12: Fall cumulative excess availability forecast results for select HUC10 subbasins in the study area.

Subbasin	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075
401	-2.95	2.05	2.05	-3.22	-2.77	2.92	1.64	2.53	5.96	2.36	5.77	14.90	15.30	6.68
402	2.35	6.69	7.75	1.72	1.54	8.08	7.13	7.88	10.92	7.96	11.30	20.12	19.73	11.23
403	3.82	8.71	7.87	5.01	5.04	10.85	9.58	10.48	13.59	9.92	13.29	22.45	22.32	13.14
404	2.27	7.73	7.76	2.20	2.30	8.33	7.37	8.23	11.57	8.11	11.50	20.45	20.40	11.38
405	3.23	7.00	10.52	1.34	2.47	9.86	8.36	9.34	14.23	9.11	13.69	16.61	16.81	13.66
406	6.93	21.11	13.92	7.84	7.10	14.80	12.23	13.74	39.30	13.01	38.79	11.60	11.66	38.64
407	11.00	46.30	40.49	-0.17	8.34	54.46	35.38	51.47	70.15	50.82	67.66	47.05	47.51	66.57
408	22.28	55.94	51.55	3.48	19.61	74.66	48.52	72.11	104.88	72.05	103.12	46.95	46.70	104.30
409	20.85	66.40	59.84	-8.06	16.09	96.14	55.93	92.28	109.94	92.63	106.81	45.35	45.34	107.19
501	2.30	8.49	8.89	1.24	2.31	9.85	8.78	9.84	14.52	9.84	14.51	17.38	17.38	14.51
502	3.06	7.67	8.15	3.07	3.24	9.31	8.38	9.35	12.75	9.31	12.69	21.72	21.72	12.72
503	2.97	7.88	8.46	3.14	3.28	9.40	8.50	9.43	12.79	9.41	12.81	21.81	21.76	12.83
504	1.02	28.25	15.51	3.19	3.52	57.40	16.86	57.30	66.32	57.15	66.41	13.73	13.51	66.27
505	3.10	9.20	9.54	-0.18	0.75	8.25	7.07	7.99	12.60	7.83	12.35	15.09	14.93	12.02
506	95.45	214.99	199.93	62.25	85.97	232.62	198.16	224.50	347.67	226.20	345.94	138.24	137.86	346.10
601	1.09	18.64	16.76	-0.54	34.91	11.69	16.78	11.79	32.99	11.39	32.92	0.89	0.98	32.97
602	96.54	233.63	216.69	61.72	120.88	244.30	214.93	236.28	380.66	237.59	378.86	139.13	138.84	379.06
603	1.65	25.25	24.13	4.59	0.47	2.34	20.43	1.66	5.88	1.15	5.54	7.72	7.55	3.37
604	2.21	8.39	8.78	-1.84	-0.85	6.40	5.25	6.09	10.65	5.56	9.95	12.57	12.32	9.10
605	98.20	258.88	240.82	66.31	121.36	246.65	235.36	237.94	386.53	238.74	384.40	146.85	146.39	382.43
606	98.65	293.42	286.07	59.43	194.76	275.10	277.12	265.87	450.25	266.26	447.35	151.22	150.48	444.32