

Appendix G. Water Availability Assessment Framework and Modeling Methods

This appendix documents the spatial framework, observational context, hydrologic modeling, and post-processing methods used to develop historical and future water-availability estimates for the Southwest Indiana Regional Water Study. It is organized first for readers seeking a subbasin, streamgage, or public-water-utility reference, and then for readers seeking the technical details of the SWB2 and streamflow/baseflow calculations.

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

- G.1. Water Availability Assessment Overview
- G.2. Hydrologic Data, Observed Trends, and Managed-Flow Context
- G.3. SWB2 Model Preparation and Simulation Inputs
- G.4. Post-processing and Water-Availability Application Using an R Workflow

Appendix to:

Southwest Indiana Regional Water Study

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G.1 Water Availability Assessment Overview

The assessment follows water through four connected layers: reader navigation and subbasin assignment; observed hydrologic context; simulation of runoff and net infiltration with SWB2; and R-based conversion workflow of those outputs to the streamflow, baseflow, and water-availability terms used in the results appendix.

- Use Figure G-1 to locate the study watersheds, streamgages, and assessment subbasins.
- Use Figure G-2 to trace the upstream-to-downstream streamgage network and identify nested or confluence catchments.
- Use Table G-1 to identify river basin, streamgage, assessment subbasin, waterway, and drainage area.
- Use Table G-2 to cross-reference a public water utility with its withdrawal-source subbasin and the subbasin or subbasins served.
- Use Tables G-3 through G-7 to review the streamgage network, flow statistics, trends, and groundwater context that underpin interpretation of the modeled results.
- Use Table G-8 for reservoir screening.
- Use Section G.3 for the detailed SWB2 water-balance model preparation, climate, and land-use assumptions.
- Use Section G.4 for model calibration, R post-processing workflow, and water-availability accounting.

G.1.1 Assessment sequence and related report materials

This section is a skeleton framework of the historical and future excess water availability methods used in this study and where to find detailed information in different parts of the Appendices.

1. Estimates or projections of future demand in all sectors are covered extensively in Appendix A.
2. Details of how future returns from self-supplied and NPDES-reporting facilities were handled can be found in Appendix A.
3. Demand or return projections were allocated to each USGS streamgage subbasin based on the point location of the water supply or withdrawal source or the point location of the wastewater return (Table G-2).
4. 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 G-3
 - ii. Streamflow hydrograph partitioning statistics from Konrad (2022) – Table G-4
 - 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 G-5
 - iv. Annual and seasonal Mann-Kendall trend statistics for stream discharge at USGS stream gages in the Southwest Indiana region – Table G-6
 - b. Groundwater
 - i. Annual and seasonal Mann-Kendall trend statistics for groundwater level (depth-to-water) at USGS observation wells in the Southwest Indiana region – Table G-7
5. Estimates of natural streamflow were calculated following the methods developed and presented in IFA (2021; Phase III: Water Availability, Chapter 2) to extract natural streamflow from 17 years of daily US Geological Survey streamgage discharge observations (2007-2021) by adding back withdrawn (pumped) water from all water-use sectors in the watershed (see Table G-2 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).
6. See Section G.4.7 of this Appendix for detailed information on the two alternative methods used to estimate natural baseflow for the water availability calculations.
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 H).

8. Estimates of future natural baseflow and water availability relied on the framework established for two different methods of estimating natural baseflow and water availability (see Sections G.4.7.1 and G.4.7.2 of this Appendix), but were forced with a future climate model.
9. See Section G.3 of this Appendix for information on future climate model selection and input data representing future conditions using the USGS Water Balance Model SWB2 (Westenbroek et al., 2018).
10. After the annual and seasonal baseflow datasets and the future demand and return projections for each of the 21 subbasins were compiled, the same approach used in IFA (2021; Phase III: Water Availability, Chapter 2) and Item #8 above was used to calculate the excess water availability for each year and season.
11. Appendix H contains tables summarizing the historical (2007-2024) and future (2025-2075) projected water-availability results for each subbasin in 5-year increments.

G.1.2 Seasonal definitions

- **Winter:** December-February; December is assigned to the following analysis year.
- **Spring:** March-May.
- **Summer:** June-August.
- **Fall:** September-November.

G.1.3 Study subbasins and streamgage network

Table G-1. List of subbasins used as spatial containers for water availability calculations in this study. The subbasins are the catchments or subwatershed areas between streamflow monitoring stations. They can be identified by the USGS Gage ID number or by the project Subbasin ID.

River Basin	USGS Gage ID	Subbasin	Waterway	Area (mi ²)
Patoka	USGS-03375500	1	Patoka River at Jasper, IN	262
Patoka	USGS-03376300	2	Patoka River at Winslow, IN	340
Patoka	USGS-03376500	3	Patoka River at Princeton, IN	219
East Fork White	USGS-03371500	4	East Fork White River near Bedford, IN	1469
East Fork White	USGS-03372500	5	Salt Creek near Harrodsburg, IN	432
East Fork White	USGS-03373500	6	East Fork White River near Shoals, IN	642
White	USGS-03359000	7	Mill Creek near Manhattan, IN	293
White	USGS-03360000	8	Eel River at Bowling Green, IN	537
White	USGS-03360500	9	White River at Newberry, IN	1412
White	USGS-03374000	10	White River at Petersburg, IN	1500
White	USGS-03374100	11	White River at Hazelton, IN	179
Wabash	USGS-03341500	0	Wabash River at Terre Haute, IN	696
Wabash	USGS-03342000	12	Wabash River at Riverton, IN	899
Wabash	USGS-03342500	13	Busseron Creek near Carlisle, IN	228
Wabash	USGS-03343010	14	Wabash River at Vincennes, IN	341
Wabash	USGS-03345500	15	Embarras River at Ste. Marie, IL	1510
Wabash	USGS-03346500	16	Embarras River at Lawrenceville, IL	816
Wabash	USGS-03377500	17	Wabash River at Mt. Carmel, IL	446
Wabash	USGS-03378000	18	Bonpass Creek at Browns, IL	228
Wabash	USGS-03378500	19	Wabash River at New Harmony, IN	396
Wabash	Ungauged	20	Lower Wabash River	450



Figure G-1. Index map of the Southwest Indiana region showing the study watersheds, assessment subbasins, and USGS streamgages. The subbasin label is the associated streamgage identifier.

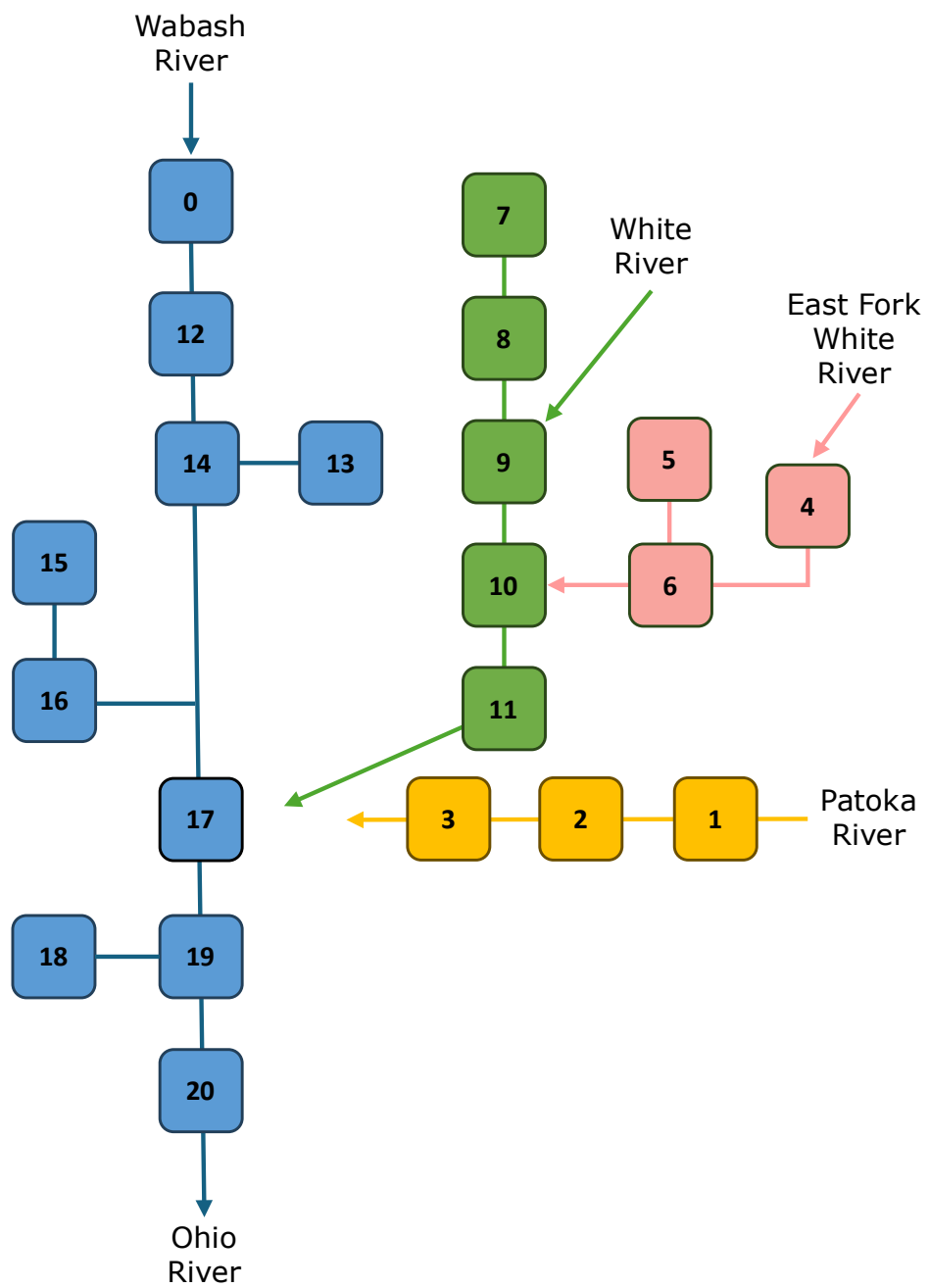


Figure G-2. Schematic of Southwest Indiana subbasin flow network based on USGS streamgage locations.

Table G-2. Public water-utility and assessment-subbasin cross-reference, with each utility, its withdrawal-source subbasin, and the subbasin or subbasins served.

Utility Name	Subbasin Source(s)	Subbasin(s) Served
Alfordsville Water Utility	See Dubois	03374000
B&B Water Project, Inc.	See Bloomington	03360500, 03372500
Bainbridge Water Works	03360000	03360000
BBP Water Corporation	03360500	03360500, 03360000
Bedford City Utilities	03373500	03373500
Bicknell Municipal Utilities	03374000	03374000
Big Walnut Water Company	See Greencastle	03360000
Birdseye Water System	See Patoka Lake	03376300, 03375500
Bloomington Utilities, City Of	03372500	03373500, 03360500, 03372500
Brazil City Water Works	03360000	03360500, 03341500, 03360000
Brown County Water Utility	03360500	03372500, 03360500
Bruceville Water Utility	See Knox Co.	03343010
Burnt Pines Water Association	See N. Vernon	03371500
Campbellsburg Water Works	03374000	03371500, 03374000
Carbon Water Corporation	See Brazil	03341500
Carlisle Water Department	03343010	03342500, 03343010
Cataract Lake Water Corporation	03360000	03359000, 03360000
Center Point Water Works	See Brazil	03360500, 03360000
Clay City Water Works	03360500	03360500
Clinton Township Water Company	03341500	03341500
Clinton Water Utility	03341500	03341500
Cloverdale, Town of	03359000	03359000, 03360000
Crane Water Works	See Eastern Heights	03374000
Crothersville Utilities	03371500	03371500
Cynthiana Water Works	See German Twp.	03378500, Lower Wabash
Dana Water Works	03341500	03341500
Daviess County Rural Water	See Loogootee	03374000
Decker Water Works	03374100	03374100
Dubois Water Utilities	See Patoka Lake	03374000, 03375500, 03376300
Duff Water Corporation	See Patoka Lake	03376300
Dugger Utilities	See Linton	03342500, 03374000
Dupont Water Company	See Madison	03371500
East Fork Water	03374000	03374000, 03373500
East Lawrence Water Authority	See Bedford	03373500, 03371500
East Monroe Water Corporation	See Bloomington	03372500
Eastern Heights Utilities	03360500	03360500, 03373500
Edwardsport Water Utility	03374000	03374000
Ellettsville Water Works	See Bloomington	03360500
Ellis Water Company, Inc.	See Linton	03374000, 03360500, 03342500
Elnora Water Works	03374000	03374000
Fairview Park Water Utilities	03341500	03341500
Fayette Township Water Association	03341500	03341500

Utility Name	Subbasin Source(s)	Subbasin(s) Served
FCI & FPC Terre Haute	03342000	03342000
Ferdinand Water Department	See Patoka Lake	03376300
Fillmore Water Utility	See Greencastle	03360000
Francisco Water Department	See Pike-Gibson	03376500
Freelandville Water Association	03343010	03343010, 03374000
German Township Water District Inc.	See Evansville	Lower Wabash, 03378500
Gosport Water Utility	03360500	03360500
Greencastle Department Of Water	03360000	03360000
Hayden Water Association	See Jennings	03371500
Hazelton Water Department	03377500	03374100, 03377500
Hillsdale Water Corporation	Upstream of 03341500	03341500
Holton Community Water Corp.	See Hoosier Hills	03371500
Huntingburg Municipal Water	03376300	03376300
Hymera Water Works	See Jasonville	03342500
Indiana American- Farmersburg	See IA Terre Haute	03342000, 03342500
Indiana American- Mecca	03341500	03341500
Indiana American- Merom	03342000	03342000
Indiana American- Sullivan	03343010	03342500, 03342000, 03343010
Indiana American- Terre Haute	03341500, 03342000	03342000, 03341500
Ireland Utilities, Inc	See Jasper, Patoka Lake	03376300, 03374000
Jackson County Water	03371500	03371500, 03372500, 03373500
Jackson County Water- Reddington	See IA Seymour	03371500
Jamestown Municipal Water Works	03360000	03360000
Jasonville Utilities	03360500	03360500, 03342500
Jasper Municipal Water Utility	03376300	03376300, 03374000
Jennings Northwest Regional Utility	See Jennings	03371500
Jennings Water, Inc.	Upstream of 03371500	03371500
Kent Water Company	East of 03371500	03371500
Knightsville Water Works	See Brazil	03360000
Knox County Water, Inc.	See Vincennes, Edwardsport	03374000, 03343010, 03374100
Linton Municipal Water Utility	03374000	03374000
Loogootee Water Works	03374000	03374000
Lyford Water Works	03341500	03341500
Lyons Water Utility	03374000	03374000
Martinsville Water Utility	03360500	03360500
Medora Water Department	03371500	03371500
Mitchell Water Department	03373500	03373500, 03371500
Monroe City Water Utilities	03374100	03374000, 03374100
Montezuma Municipal Utility	03341500	03341500
Montgomery Water Dept	03374000	03374000
Morgan County Rural Water Company	03360500	03360500, 03359000
Morgantown Water Utility	03360500	03360500
Natural Public Supply, Inc.	03371500	03371500

Utility Name	Subbasin Source(s)	Subbasin(s) Served
Naval Support Activities Crane	03374000, 03373500	03374000, 03373500
Newberry Water Utility	03374000	03374000, 03360500
North Lawrence Water Authority	03373500	03373500, 03372500
North Salem Water Corporation	03360000	03360000
North Vernon Water Department	03371500	03371500
Oakland City Water Department	03376500	03376500
Oaktown Water Works	03343010	03343010
Odon Water Utilities, Inc.	03374000	03374000
Oolitic Water Works	See Bedford	03373500
Orleans Water Works	See Patoka Lake	03374000, 03373500
Otwell Water Corporation #1	03374000	03374000, 03376300
Otwell Water Corporation #2	03374000	03374000, 03374100
Owensville Water Works	03378500	03378500
Painted Hills Utility Company	03360500	03360500
Paoli Water Department	See Patoka Lake	03374000
Paragon Water Works	03360500	03360500
Patoka Lake Regional Water	03375500	03374000, 03375500, 03376300, 03373500, 03371500
Patoka Water & Electric	03377500	03377500
Paxton Water Corporation	03343010	03342500, 03342000, 03343010
Petersburg Water Company	03374100	03374100, 03374000, 03376300
Pike Gibson Water, Inc.	See Patoka Lake, Petersburg	03376500, 03376300, 03374100, 03374000, 03377500
Pleasantville Water Company	See Linton	03374000, 03342500, 03343010
Poseyville Municipal Water	03378500	03378500, Lower Wabash
Princeton Water Dept	03377500	03378500, 03377500, 03376500
Putnamville Correctional Facility	See Reelsville	03360000
Reelsville Water Company	03360000	03360000
RHS Water Corporation	See Bloomington	03372500, 03373500
Salt Creek Services, Inc.	03372500	03372500
Sandborn Water Department	03374000	03374000
Scottsburg Water Department	03371500	03371500
Seelyville Water Works	03341500	03341500, 03342000
Shady Side Water Corporation	See Bloomington	03372500
Shelburn Water Utilities	03342000	03342000, 03342500
Shoals Water Company	03374000	03373500, 03374000
Sisters of Providence	03342000	03342000
South 43 Water Association, Inc.	See Greencastle	03360000
South Lawrence Utilities	03373500	03373500, 03374000
Southern Monroe Water, Incorporated	See Bloomington	03373500, 03372500
Southwestern Bartholomew	See Columbus	03371500, 03372500
Springs Valley Regional Water District	See Patoka Lake	03374000
Spurgeon Water Works	See Patoka Lake	03376500
St. Anthony Water Utility	See Patoka Lake	03376300

Utility Name	Subbasin Source(s)	Subbasin(s) Served
St. Bernice Water Corp	See Clinton Twp.	03341500
St. Henry Water Corporation	See Patoka Lake	03376300
Staunton Municipal Water	03341500	03341500, 03360500
Stucker Fork Water Utility	03371500, East of 03371500	03371500
Sullivan-Vigo Rural Water Corp	See IA Terre Haute	03342000, 03360500, 03342500
Switz City Waterworks	See Linton	03360500, 03374000
Town of Lizton Water Utility	See Citizens	03360000
Town of Nashville Water Utility	See Brown County, E. Monroe	03372500, 03360500
Town of New Harmony	03378500	Lower Wabash, 03378500
Universal Water Works	03341500	03341500
Van Bibber Lake Conservancy District	03360000	03360000
Van Buren Water, Inc.	See Bloomington	03373500, 03360500
Vernon Water Department	See North Vernon	03371500
Vincennes Water Utilities	03377500	03377500, 03343010
Washington Twp Water Corp. of Monroe Co.	See Bloomington	03360500
Washington Water Works	03374000	03374000
West Terre Haute Water	03342000	03342000
Wheatland Water Works	03374000	03374000
Wilfred Water Corporation	See Hymera	03342500
Winslow Water Works	See Pike-Gibson	03376300, 03376500

G.2 Hydrologic Data, Observed Trends, and Managed-Flow Context

G.2.1 Streamgage subbasin network

Table G-3. USGS streamgage subbasin network characteristics used in the water-availability assessment.

PATOKA RIVER BASIN						
Subbasin ID	HUC08	Gage	USGS gages	Subbasin Area (square mi)	Upstream Subbasin ID	Total Upstream Drainage Area (square mi)
1	05120209	03375500	PATOKA RIVER AT JASPER, IN	262		262
2	05120209	03376300	PATOKA RIVER AT WINSLOW, IN	340	1	602
3	05120209	03376500	PATOKA RIVER NEAR PRINCETON, IN	219	2*	822
DRAINS TO 03377500 (SWI 17)						
EAST FORK WHITE RIVER BASIN						
Subbasin ID	HUC08	Gage	USGS gages	Subbasin Area (square mi)	Upstream Subbasin ID	Total Upstream Drainage Area (square mi)
FROM I74 #605	05120206	03365500	EAST FORK WHITE RIVER AT SEYMOUR, IN			2341
4	05120207	03371500	EAST FORK WHITE RIVER NEAR BEDFORD, IN	1469	I74 605*	3858
5	05120208	03372500	SALT CREEK NEAR HARRODSBURG, IN	432		432
6	05120208	03373500	EAST FORK WHITE RIVER NEAR SHOALS, IN	642	4*, 5	4933
DRAINS TO 03374000 (SWI 10)						
WHITE RIVER BASIN						
Subbasin ID	HUC08	Gage	USGS gages	Subbasin Area (square mi)	Upstream Subbasin ID	Total Upstream Drainage Area (square mi)
FROM CIWS #13	05120201	03354000	WHITE RIVER AT CENTERTON, IN			2444
7	05120203	03359000	MILL CREEK NEAR MANHATTAN IN	293		293
8	05120203	03360000	EEL RIVER AT BOWLING GREEN, IN	535	7	830
9	05120202	03360500	WHITE RIVER AT NEWBERRY, IN	1412	7, 8*, CIWS 13*	4687
10	05120208	03374000	WHITE RIVER AT PETERSBURG, IN	1500	9*	11118
11	05120202	03374100 (03374000)*	WHITE RIVER AT HAZELTON, IN	179	10*	11296
DRAINS TO 03377500 (SWI 17)						

WABASH RIVER BASIN						
Subbasin ID	HUC08	Gage	USGS gages	Subbasin Area (square mi)	Upstream Subbasin ID	Total Upstream Drainage Area (square mi)
0 (FROM NCI #15)	05120111	03341500	WABASH RIVER AT TERRE HAUTE, IN			12265
12	05120111	03342000	WABASH RIVER AT RIVERTON, IN	899	NCI 15*	13201
13	05120111	03342500	BUSSEYON CREEK NEAR CARLISLE, IN	228		228
14	05120111	03343010 (03343000)*	WABASH RIVER AT MEMORIAL BRG AT VINCENNES, IN	341	12*, 13	13769
15	05120112	03345500	EMBARRAS RIVER AT STE. MARIE, IL	1510		1510
16	05120112	03346500 (03345500)*	EMBARRAS RIVER AT LAWRENCEVILLE, IL	816	15	2326
17	05120113	03377500	WABASH RIVER AT MT CARMEL, IL	446	16*, 14*	28659
18	05120113	03378000	BONPAS CREEK AT BROWNS, IL	228		228
19	05120113	03378500	WABASH RIVER AT NEW HARMONY, IN	396	18, 17*	29282
20	05120113	Ungauged	LOWER WABASH RIVER, IN	450	19	29732
DRAINS TO Ohio River						

KEY:

FIRST ORDER first order tributary
ID* draining ↑stream subbasins
17 confluence catchment

Key definitions: “first order” identifies a first-order tributary; an asterisk identifies a subbasin receiving drainage from upstream assessment subbasins; and a confluence catchment combines two or more modeled branches.

G.2.2 Hydrograph partitioning and flow benchmarks

Published hydrograph-partitioning metrics were used as independent context for the relative contributions of baseflow, surface flow, and direct runoff. They were not treated as error-free calibration targets. Low- and high-flow statistics were calculated for a common 1993-2022 baseline to support seasonal instream-flow thresholds and interpretation of the model outputs.

Table G-4. Hydrograph-partitioning metrics reported by Konrad (2022) for selected USGS streamgages. The published baseline period is 1981-2020; Qmean is mean streamflow and the component fractions may vary through time.

Gage	Subbasin ID	Name	Q mean (cfs)	Baseflow Fraction	Surface Flow Fraction	Direct Runoff Fraction	Error
03375500	1	Patoka River at Jasper, IN	394	0.2	0.1	0.4	0.1
03376300	2	Patoka River at Winslow, IN	911	0.2	0.2	0.1	0.2
03376500	3	Patoka River at Princeton, IN	1193	0.3	0.2	0.0	0.2
03371500	4	East Fork White River near Bedford, IN	5212	0.3	0.4	0.1	0.1
03372500	5	Salt Creek near Harrodsburg, IN	no analysis				
03373500	6	East Fork White River near Shoals, IN	6667	0.4	0.4	0.0	0.1
03359000	7	Mill Creek near Manhattan, IN	364	0.1	0.0	0.4	0.1
03360000	8	Eel River at Bowling Green, IN	1050	0.3	0.3	0.0	0.1
03360500	9	White River at Newberry, IN	5923	0.5	0.2	0.1	0.1
03374000	10	White River at Petersburg, IN	14672	0.5	0.0	0.2	0.1
03374100	11	White River at Hazelton, IN	16374	0.6	0.1	0.1	0.1
03341500	0	Wabash River at Terre Haute, IN	13089	0.6	0.1	0.1	0.1
03342000	12	Wabash River at Riverton, IN	14519	0.4	0.4	0.0	0.1
03342500	13	Busseron Creek near Carlisle, IN	264	0.3	0.3	0.0	0.1
03343010	14	Wabash River at Vincennes, IN	16323	0.6	0.1	0.0	0.1
03345500	15	Embarras River at Ste. Marie, IL	1499	0.3	0.2	0.2	0.1
03346500	16	Embarras River at Lawrenceville, IL	2696	0.3	0.2	0.0	0.1
03377500	17	Wabash River at Mt. Carmel, IL	33643	0.6	0.1	0.1	0.1
03378000	18	Bonpass Creek at Browns, IL	281	0.1	0.5	0.0	0.1
03378500	19	Wabash River at New Harmony, IN	38081	0.6	0.1	0.0	0.1

Table G-5. Low- and high-flow statistics for streamgages used in the water-availability assessment, 1993-2022. The 7Q10 is the annual minimum 7-day mean flow with a 10-year recurrence interval and was used for Summer and Fall thresholds. Q90 is the discharge equaled or exceeded 90 percent of the time and was used for Winter and Spring thresholds. Values are in cubic feet per second.

PATOKA RIVER BASIN				1993-2022	1993-2022		
Gage	Subbasin ID	USGS gages	Period of Record	Q_90 (MGD)	Q_7,10 (MGD)	Q mean (MGD)	Q mean (CFS)
03375500	1	PATOKA RIVER AT JASPER, IN	1992-2025	24.9	9.1	266.5	412.4
03376300	2	PATOKA RIVER AT WINSLOW, IND.	1992-2025	48.0	14.3	616.9	954.5
03376500	3	PATOKA RIVER NEAR PRINCETON, IND.	1992-2025	70.2	22.2	804.1	1244.2
EAST FORK WHITE RIVER BASIN				1993-2022	1993-2022		
Gage	Subbasin ID	USGS gages	Period of Record	Q_90 (MGD)	Q_7,10 (MGD)	Q mean (MGD)	Q mean (CFS)
03365500	FROM I74 #605	EAST FORK WHITE RIVER AT SEYMOUR, IN	Complete	270.2	145.5	2172.9	3361.9
03371500	4	EAST FORK WHITE RIVER NEAR BEDFORD, IN	1992-2025	391.0	201.2	3607.2	5581.1
03372500	5	SALT CREEK NEAR HARRODSBURG, IN	1992-2001	35.5	31.2	367.4	568.5
03373500	6	EAST FORK WHITE RIVER NEAR SHOALS, IN	1992-2025	492.9	238.7	4613.1	7137.5
WHITE RIVER BASIN				1993-2022	1993-2022		
Gage	Subbasin ID	USGS gages	Period of Record	Q_90 (MGD)	Q_7,10 (MGD)	Q mean (MGD)	Q mean (CFS)
03354000	FROM CIWS #13	WHITE RIVER AT CENTERTON, IN	Complete	358.4	209.7	2019.5	3124.6
03359000	7	MILL CREEK NEAR MANHATTAN IND.	1992-2002	12.9	9.7	244.7	378.6
03360000	8	EEL RIVER AT BOWLING GREEN, IN	1992-2025	54.2	21.9	695.4	1076.0
03360500	9	WHITE RIVER AT NEWBERRY, IND.	1992-2025	590.1	313.1	3989.1	6172.1
03374000	10	WHITE RIVER AT PETERSBURG, IN	1992-2025	1415.4	715.9	9944.5	15386.4
03374100 (03374000)*	11	WHITE RIVER AT HAZELTON, IN	2010-2025#	1564.1	801.1	10531.9	16295.2

WABASH RIVER BASIN				1993-2022	1993-2022		
Gage	Subbasin ID	USGS gages	Period of Record	Q_90 (MGD)	Q_7,10 (MGD)	Q mean (MGD)	Q mean (CFS)
03341500	0 (FROM NCI #15)	WABASH RIVER AT TERRE HAUTE, IND.	Complete	1803.2	946.7	8566.2	13253.8
03342000	12	WABASH RIVER AT RIVERTON, IN	1992-2025	2023.0	1123.9	9579.0	14820.9
03342500	13	BUSSEY CREEK NEAR CARLISLE, IN	Missing data	9.1	2.7	186.6	288.7
03343010 (03343000)*	14	WABASH RIVER AT MEMORIAL BRIDGE AT VINCENNES, IN	2009-2025#	2242.7	1339.9	10072.7	15584.7
03345500	15	EMBARRAS RIVER AT STE. MARIE, IL	1992-2025	36.0	14.3	1007.7	1559.2
03346500 (03345500)*	16	EMBARRAS RIVER AT LAWRENCEVILLE, IL	2002-2025#	64.5	25.4	1733.7	2682.4
03377500	17	WABASH RIVER AT MT CARMEL, IL	1992-2025	4091.2	2351.5	22486.3	34791.4
03378000	18	BONPAS CREEK AT BROWNS, IL	1992-2025	0.2	0.1	192.3	297.5
03378500	19	WABASH RIVER AT NEW HARMONY, IN	2010-2025#	4558.5	2516.8	24104.5	37295.2
Lower Wabash	20	Ungauged	2010-2025#	4628.5	2555.5	No gage	No gage

gap fill with synthetic hydrograph

G.2.3 Streamflow trends

Seasonal and annual Mann-Kendall tests and Sen-Theil slopes were calculated to identify changes in the observed streamflow record. These trends provide an empirical check on the assumption that a single historical baseline is stationary. They also help distinguish broad climatic shifts from gage-specific changes associated with regulation, return flows, diversions, or other local controls.

Table G-6. Seasonal and period-of-record trend statistics for streamflow at USGS streamgages in the Southwest Indiana region, 1993-2022. Several gages show increasing March flows that influence Spring and annual trends.

Mann Kendall Slope and Significance for Seasonal
Stream Flow Volumes

Gage ID	Subbasin ID	Location	Winter	Spring	Summer	Fall	Total Period
USGS-03375500	1	PATOKA RIVER AT JASPER, IN	+	+	+	+	+++
USGS-03376300	2	PATOKA RIVER AT WINSLOW, IND.	+	+	+	+	+++
USGS-03376500	3	PATOKA RIVER NEAR PRINCETON, IND.	+	+	+	+	+++
USGS-03371500	4	EAST FORK WHITE RIVER NEAR BEDFORD, IN	+	+	+	+	++
USGS-03373500	6	EAST FORK WHITE RIVER NEAR SHOALS, IN	+	+	+	+	++
USGS-03360000	8	EEL RIVER AT BOWLING GREEN, IN	+	+	-	+	+
USGS-03360500	9	WHITE RIVER AT NEWBERRY, IND.	+	+	+	+	+++
USGS-03374000	10	WHITE RIVER AT PETERSBURG, IN	+	+	+	+	+++
USGS-03341500	0	WABASH RIVER AT TERRE HAUTE, IN	+	+	-	-	N/A
USGS-03342000	12	WABASH RIVER AT RIVERTON, IN	+	+	-	+	+
USGS-03345500	15	EMBARRAS RIVER AT STE. MARIE, IL	+	+	+	+	+++
USGS-03346500	16	EMBARRAS RIVER AT LAWRENCEVILLE, IL	+	+	+	+	+++
USGS-03377500	17	WABASH RIVER AT MT CARMEL, IL	+	+	+	+	++
USGS-03378000	18	BONPAS CREEK AT BROWNS, IL	+	Ø	+	+	+++

Note: "+" sign indicates an increasing trend in discharge, while "-" sign indicates a decreasing trend in discharge.

"Ø" indicates little to no change in discharge. Cells highlighted in blue indicate statistically significant results

+ = 90% confidence level, ++ = 95% confidence level, +++ = 99% confidence level

Notes: MK = Mann-Kendall trend test; Sen = Theil-Sen slope. Trend direction and statistical confidence are shown in the table key. Superscript 1 identifies a short, incomplete, or otherwise limited record. Flow statistics for Wabash River at Terre Haute, Indiana, were calculated by Stantec, 2024; no annual trend metrics were provided.

G.2.4 Groundwater-level trends

Groundwater observation wells in and near the study region were evaluated by aquifer setting and season. The trend results provide independent context for interpreting modeled net infiltration and groundwater-supported streamflow. A positive trend in Table G-7 indicates a rising water-table elevation; it does not directly quantify recharge or aquifer storage change.

Table G-7. Annual and seasonal Mann-Kendall trend statistics for groundwater-level observation wells in and near the Southwest Indiana region.

USGS Location ID	Subbasin ID	Aquifer Type	Aquifer Depth (ft)	Site Name	Time Period	Winter	Spring	Summer	Fall	Total Period
382323086044501	outside (1)	Bedrock	93	HARRISON 8	1986-2024	↑	↓	↑	↑	↑
383659086545901	10	Bedrock	143	MARTIN 5	1984-2010	↑↑↑	↑↑↑	↑↑↑	↑↑↑	↑↑↑
385542086005601	I74-605	Unconsolidated	60	JACKSON 1	2016-2024	↓	↓	↓	↓	↓↓↓
392612086230001	CI-13	Unconsolidated	126	MORGAN 5	2016-2024	↑	↑	↑	∅	∅
393619087043001	NCI-15	Bedrock	155	PARKE 6	1984-2024	↓	↓	↓	↓	↓↓↓
392820087242601	12	Unconsolidated	70	VIGO 7	1984-2024	↑↑	↑↑↑	↑↑	↑↑	↑↑↑
383247087361001	17	Unconsolidated	53	KNOX 7	1984-2010	↑	↑	↑	↓	↑
383247087361001	17	Unconsolidated	53	KNOX 7	2015-2024	↓	∅	↓	↓↓	↓↓↓
384951087202501	14	Bedrock	137	KNOX 8	1989-2024	↓	↓↓	↓	↑	↓↓↓
380758087551001	19	Unconsolidated	58	POSEY 3	1984-2024	↑	↑	↑	↑	∅
380626087344401	outside (20)	Bedrock	70	VANDERBURGH 7	1986-2024	↑	↑	↑	↑	↑

Note: "↓" sign indicates falling/decreasing water levels, while "↑" sign indicates rising water levels.

"∅" indicates little to no change in water level. Cells highlighted in blue indicate statistically significant results

↑ = 90% confidence level, ↑↑ = 95% confidence level, ↑↑↑ = 99% confidence level

G.2.5 Dams, reservoirs, and managed-flow screening

Numerous dams and impoundments exist within the Southwest Indiana study area. Three U.S. Army Corps of Engineers reservoirs—Cagles Mill Lake, Monroe Lake, and Patoka Lake—were represented explicitly in the signed cumulative reservoir-operations term (Qstor). These large multipurpose projects are operated for flood-risk reduction and other authorized purposes, substantially alter downstream flow timing, and have sufficiently consistent daily pool and outflow records to support a monthly operations reconstruction.

The National Inventory of Dams was spatially filtered to identify other structures within the study area having reported normal storage greater than 1,000 acre-ft (Table G-8). The inventory includes recreational lakes, municipal water-supply reservoirs, conservancy-district impoundments, cooling-water reservoirs, flood-control structures, and other local-purpose facilities. Their operating records, outlet behavior, diversions, evaporation, and return pathways generally were not available at the temporal and spatial resolution needed for separate Qstor reconstruction.

These unmodeled facilities were not assumed to be hydrologically absent or negligible. Their effects may remain embedded in observed streamflow and may contribute to apparent storage, release, travel-time, or trend signals that cannot be isolated by the available data. The historical natural-streamflow calculation procedure removes only the documented withdrawals, returns, transfers, and reservoir operations represented explicitly in the accounting. Accordingly, Qstor represents the best-documented dominant regional reservoir operations, not the cumulative influence of every dam or other hydrologic modification.

Table G-8. Dams and reservoirs within the Southwest Indiana study area having reported normal storage greater than 1,000 acre-ft in the U.S. Army Corps of Engineers National Inventory of Dams. Shaded rows identify the three reservoirs represented explicitly in Qstor (reservoir storage).

Dam or reservoir	Owner	NID ID	Normal storage (acre-ft)	Primary purpose	Reported spillway type
Amy Lake Dam	AMY FAMILY PARTNERSHIP	IN04018	1,211	Recreation	None
Beaver Creek Lake Dam	JASPER MUNICIPAL WATER UTILITY	IN00022	2,550	Water Supply	Uncontrolled
Bradford Woods Lake Dam	INDIANA UNIVERSITY, BRADFORD WOODS	IN00047	1,162	Recreation	Uncontrolled
Cagles Mill Dam	USACE - Louisville District	IN03002	27,112	Flood Risk Reduction	Uncontrolled
Chinook Mine Dam No. 17	SUNDANCE LAND AND CATTLE C O.	IN03910	1,553	Other	None
Country Squire Lake Dam	Not reported	IN00495	1,065	Recreation	Uncontrolled
Delaney Creek Dam No. 5	DELANEY CREEK CONSERVANCY DISTRICT	IN00660	1,155	Flood Risk Reduction	None
Gibson Generating Plant Dam	DUKE ENERGY LLC	IN00464	29,000	Other	Uncontrolled
Glendale Reservoir	INDIANA DEPARTMENT OF NATURAL RESOURCES	IN00081	20,400	Recreation	None
Grandview Lake Dam	GRANDVIEW LOT OWNERS ASSOCIATION INCORPORATED	IN00017	9,235	Water Supply	Uncontrolled

Dam or reservoir	Owner	NID ID	Normal storage (acre-ft)	Primary purpose	Reported spillway type
Greenwood Lake Dam	DOD USN	IN03007	12,780	Flood Risk Reduction	Uncontrolled
Griffy Reservoir Dam	Steve Glasgow	IN00359	1,280	Recreation	Uncontrolled
Hardy Lake Dam	Not reported	IN00413	12,000	Not reported	None
Heritage Lake Dam	CLEAR CREEK CONSERVANCY DISTRICT	IN00222	5,000	Not reported	Uncontrolled
Hoosier Energy Reservoir Dam	HOOSIER ENERGY RURAL ELECTRIC COOPERATIVE, INC	IN00523	13,800	Water Supply	Uncontrolled
Huntingburg City Lake Dam	HUNTINGBURG MUNICIPAL WATER UTILITY	IN00121	2,000	Not reported	Uncontrolled
Ken Ray	Aaron Chandler	IN00060	1,670	Recreation	None
Kickapoo Lake Dam	DEPARTMENT OF NATURAL RESOURCES	IN00446	3,303	Flood Risk Reduction	None
Lake & Forest Club Dam	LAKE AND FOREST CLUB INCORPORATED	IN00046	2,000	Recreation	Uncontrolled
Lake Lemon Dam	Bob Madden	IN00010	13,300	Water Supply	Uncontrolled
Lake Sullivan Dam Busseron No. K-1	SULLIVAN CO. PARK & RECREATION DIST.	IN00154	4,936	Flood Risk Reduction	None
Lamb Lake Dam	THOMAS JOHNSON	IN00338	1,600	Recreation	Uncontrolled
Lamb Lake Estates Dam	LAMB LAKE LOT OWNERS ASSOCIATION	IN00133	7,250	Water Supply	Uncontrolled
Little Walnut Creek Conservancy District Structure #4	LITTLE WALNUT CREEK CONSERVANCY DISTRICT	IN00497	5,900	Flood Risk Reduction	Uncontrolled
Lutheran Lake Dam	LUTHERAN RESORT ASSOCIATION, INCORPORATED	IN00162	1,040	Recreation	None
Monroe Dam	USACE - Louisville District	IN03001	182,250	Flood Risk Reduction	Uncontrolled
Moss Dam	US FISH AND WILDLIFE SERVICE	IN03492	2,689	Fish and Wildlife Pond	Uncontrolled
Old Timbers Lake	Jefferson Proving Ground	IN03556	2,252	Fish and Wildlife Pond	Uncontrolled
Paint Mill Lake Dam	PAINT MILL LAKE ASSOCIATION, INC	IN00433	1,304	Recreation	None
Painted Hills Lake Dam	Not reported	IN00197	1,914	Recreation	Uncontrolled

Dam or reservoir	Owner	NID ID	Normal storage (acre-ft)	Primary purpose	Reported spillway type
Patoka Lake Dam	USACE – Louisville District	IN03018	167,290	Flood Risk Reduction	Uncontrolled
Patton Park Lake Dam	PATTON PARK INCORPORATED	IN00371	1,001	Recreation	Uncontrolled
Prides Creek Lake Dam	PRIDES CREEK CONSERVANCY DISTRICT	IN00188	1,129	Flood Risk Reduction	Uncontrolled
Shakamak Lake Dam	Paul Sipples	IN00420	1,860	Recreation	None
Springs Valley Lake (F7)	USDA FS	IN00076	1,690	Fish and Wildlife Pond	Controlled
Sweetwater Lake Dam	CORDRY SWEETWATER CONSERVANCY DISTRICT	IN00025	9,500	Recreation	Uncontrolled
Twin-Rush Creek Dam No. 1	TWIN RUSH CREEK CONSERVANCY DISTRICT	IN00820	1,951	Water Supply	Uncontrolled
Twin-Rush Creek Dam No. 2	CITY OF SALEM	IN00153	3,050	Water Supply	Uncontrolled
West Boggs Creek Structure No. 1	DAVIESS MARTIN COUNTY JOINT PARKS AND RECREATION BOARD	IN00213	8,148	Flood Risk Reduction	Uncontrolled
Williams Dam (In-Channel)	Indiana Department of Natural Resources	IN00805	5,333	Former Hydroelectric Recreation	Uncontrolled
Yellowwood Lake Dam	DEPARTMENT OF NATURAL RESOURCES	IN00270	1,777	Recreation	Uncontrolled



Figure G-3. Map showing location of several utility public-water-supply reservoirs in the Southwest Indiana region.

G.3 SWB2 Model Preparation and Simulation Inputs

G.3.1 Model purpose and application

The U.S. Geological Survey Soil-Water-Balance model, version 2 (SWB2; Westenbroek et al., 2018), was used to simulate the spatially distributed daily water balance. Historical data development and calibration initially used a 1980-2024 dataset. As final modeling decisions became more certain, the historical production run was established for January 1, 2005 through December 31, 2024 (2005-2007 was included for model spin-up, intending the model to be used for analysis from 2007 through 2024). The future model run simulated the water balance from January 1, 2020 through December 31, 2075, providing an overlap period for comparing the forcing and water-balance behavior before the projection years. The principal outputs used by the study were surface runoff, actual evapotranspiration, soil-water storage, and net infiltration (potential groundwater recharge). Runoff and net infiltration were subsequently transformed into monthly natural streamflow and effective groundwater-discharge estimates using the post-processing framework documented in Sections G.4.1-G.4.10. Climate-derived water-balance variables were also summarized for the public-water-supply and irrigation water-demand projection analyses.

SWB2 combines daily precipitation and minimum and maximum temperature with gridded topography, soil properties, impervious cover, and annually varying land use. At each model cell, water is partitioned among bucket interception, snow accumulation and melt, runoff, evapotranspiration, soil-water storage, irrigation where enabled, and downward movement below the modeled root zone. The conceptual water balance can be written as:

$$N_t = P_{eff,t} + I_t - R_t - AET_t - \Delta S_t \text{ (G-1)}$$

where $N(t)$ is net infiltration below the modeled root zone (potential groundwater recharge, used in this study as a recharge proxy), $P_{eff,t}$ is effective precipitation; $I(t)$ is simulated irrigation; $R(t)$ is direct surface runoff; $AET(t)$ is actual evapotranspiration; and $\Delta S(t)$ is the change in root-zone soil-water storage. SWB2 performs the calculations internally at a daily time step and also represents antecedent soil moisture, frozen or snow-covered conditions, and land-use-specific lookup values.

The model grid resolution was 250 m. The model domain covered the full hydrologic extent of Indiana to the HUC-8 level, which includes all of Indiana, and portions of Illinois, Michigan, Ohio, and Kentucky. Daily outputs were accumulated to monthly and annual volumes or depths and summarized by streamgage catchment as required by the study analyses. All historical and future inputs were aligned to the same grid, projection, cell origin, land-use codes, and daily calendar before model execution.

G.3.2 Static and slowly varying physical inputs

G.3.2.1 Topography, drainage, and karst representation

Flow direction for runoff and downgradient interflow was derived using the D8 method from a 100-m digital elevation model (DEM). Sink filling and flow-path enforcement were reviewed separately in the Mitchell Plateau karst region because closed depressions and disrupted surface drainage represent real sinkholes and conduit capture rather than elevation artifacts. The DEM was modified through an iterative process that involved editing elevation contours in a polyline version of the terrain data and enforcing the flow paths as identified by karst-basin mapping conducted for this study. The tool Topo-To-Raster in ArcGIS Pro Spatial Analyst Toolbox was used to regenerate the elevation raster. Each iteration involved re-deriving the flow network from each tributary drainage until the mapped primary (subsurface) flow path was represented correctly. Some mapped karst basins had too strongly developed surface-flow geomorphic expression to override in this way. The terrain data (DEM) were not modified for these basins as it was clear that the existing terrain captures surface runoff in addition to

the known subsurface flow (hybrid flow). HUC12 flow routing was adjusted for these basins, but the topographic data were not modified. The modified terrain DEM was resampled to the 250-m SWB2 grid, and the D8 flow-direction assignment was conducted on the final terrain dataset used as input to SWB2. The statewide flow network therefore incorporates the study's karst-basin interpretation in the terrain dataset. The HUC12 dataset (Blodgett, 2022) used for flow-routing as described in Section G.4. was also modified for 17 watersheds (including five classified as "disconnected basins") in the karst basins of southern Indiana to assign the TOHUC routing to the correct downstream (or conduit-pirated) watershed.

G.3.2.2 Hydrologic soil group and available water capacity

Hydrologic soil groups were obtained from STATSGO. The standard A, B, C, D, A/D, B/D, and C/D groups were supplemented with water, urban, and thin-soil classes. The thin-soil class represents the shallow-bedrock portion of southern Indiana where unconsolidated aquifer storage is limited and runoff generation to downgradient areas remains hydrologically important. Mined-land representation was explicitly included in the soils data using the HSG B classification to represent secondary porosity of mined and reclaimed lands.

Available water capacity was derived from STATSGO. The selected historical run used the AWC150_in/ft grid. SWB2 combines the gridded available-water-capacity value with the rooting depth assigned to the applicable land-use class to determine maximum modeled soil-water storage:

$$S_{max,x,y} = AWC_x \times Z_{r,LU(x,y)} \quad (G-2)$$

where $S_{max,x,y}$ is maximum root-zone soil-water storage at cell x in year y , $AWC(x)$ is the applicable gridded available-water-capacity value, and $Z_{r,LU(x,y)}$ is the dynamic rooting depth for that year's land-use or crop class.

G.3.3 Historical climate and initial conditions

Historical daily precipitation and minimum and maximum temperature were obtained from Daymet and read directly from annual NetCDF files. Precipitation was converted from millimeters to inches with a scale factor of 0.03937008. Maximum and minimum temperature were converted from degrees Celsius to degrees Fahrenheit using a scale factor of 1.8 and an offset of 32.0. Missing precipitation values at or below -9999 were set to zero, while missing temperature values were replaced with the applicable mean. Precipitation was the primary atmospheric water input; temperature controlled the rain-snow partition, snowmelt, Hargreaves evapotranspiration, and growing-degree-day calculations.

Both the historical and future models use the same gridded initial conditions: Climate Prediction Center January mean soil moisture and Daymet January 1980 snow-water equivalent. The initial continuous frozen-ground index was 100, with an upper limit of 83 and an effective lower limit of 56.

G.3.4 Historical annual land cover and irrigation status

G.3.4.1 Annual land-cover construction

A custom annual land-use raster was developed for each historical model year. This component was retained but updated from the preceding Indiana study (Letsinger et al., 2021) because neither NLCD nor the Cropland Data Layer (CDL) alone distinguishes all of the hydrologic and land-management conditions required by SWB2. The annual raster was assembled in the following order:

1. National Land Cover Dataset annual layers were used for:
 - a. 1985-1991 (USGS 2024)
 - b. 1992-2005 (USGS "Historical" dataset; Sohl and Sayler, 2008; Sohl et al., 2014, 2018)
 - c. 2006-2023 (USGS 2024)
 - d. 2024 (USGS 2025)
 - e. 1985 (USGS 2024) was repeated for 1980-1984, used for model spin-up

2. NLCD classes were simplified to a modified Anderson Level II grouping and resampled from 30 m to the 250-m model grid using majority resampling.
3. The cultivated-crop class in the simplified NLCD was used as a mask within which crop identity could be assigned.
4. Annual NASS CDL data were aligned to the model grid and simplified to corn, soybeans, other crops, fallow or idle cropland, and pasture/hay/wheat. Double crops were assigned to the first crop. Crop trees were grouped with forest, and water or aquaculture retained the water treatment.
5. For years preceding statewide CDL availability, the 2001 and 2002 crop layers were alternated within the NLCD crop mask to provide a spatially variable crop-rotation proxy.
6. The annual irrigation mask was imposed after crop identity. Only eligible crop or turf cells received irrigated land-use codes; forest, developed land, wetlands, open water, barren land, and other noneligible cover within a buffered irrigation footprint retained their original classification.

This hierarchy preserved annual NLCD land-cover change, crop-specific rooting and growing-season behavior, and the distinction between irrigated and rainfed agricultural cells without allowing an irrigation buffer to overwrite an incompatible land cover.

G.3.4.2 Irrigation-location reconstruction

Historical irrigation extent combined three sources: Indiana Department of Natural Resources Significant Water Withdrawal Facility (SWWF) registrations, LANID irrigated-land mapping, and visually mapped center-pivot locations that were not represented by either source. SWWF facilities were screened to groundwater sources and classified as agricultural/crop irrigation or turf irrigation. The historical mask used active facilities with pumping capacity of at least 70 gal/min (100,800 gal/day). Agricultural locations were represented by the implemented 400-m radius GIS buffer (raster representation is about 0.2 sq miles to conservatively approximate a center-pivot irrigation system) and turf locations by a 360-m radius approximating 100 acres. Overlapping buffers were merged rather than counted additively.

LANID annual irrigation (annual from 1997 – 2017, Xie and Lark 2021, Xie et al., 2021; 2018-2020, Martin et al., 2024) mapping was resampled to the 250-m grid. More than 3,000 visually mapped center-pivot points were compared with registered sites and LANID parcels; 682 nonoverlapping locations were retained and introduced in batches into the annual masks for 2000-2017. The combined mapping was intended to reduce underrepresentation of Indiana irrigation while remaining conservative: adjoining cropland was not automatically pulled into a buffer, and noncrop cover was not reclassified as irrigated.

Irrigation: The irrigated land-use code identifies where SWB2 is permitted to add water under its irrigation rule; it is not a prescribed withdrawal volume. A fixed irrigated footprint can therefore produce different simulated irrigation amounts among years as precipitation, temperature, crop type, and soil-water deficit change.

G.3.4.3 Combined SWB2 land-use classes

Table G-9. Combined SWB2 Indiana land-use classes and their hydrologic or management distinctions.

Code	SWB2 Indiana class	Hydrologic or management distinction
1	Open water	Persistent surface water
2	Developed	Built and impervious-dominated land
3	Barren	Barren, mined, or mechanically disturbed cover
4	Forest	Deciduous, evergreen, and mixed forest

Code	SWB2 Indiana class	Hydrologic or management distinction
5	Shrubland	Shrub/scrub and related cover
7	Wetlands	Woody and herbaceous wetlands
8 / 21	Urban grass / irrigated turf	Separates rainfed developed open space from managed turf
61 / 62	Irrigated / rainfed corn	Crop-specific and irrigation-specific lookup values
63 / 64	Irrigated / rainfed soybeans	Crop-specific and irrigation-specific lookup values
65 / 66	Irrigated / rainfed other crops	Other annual and specialty crops
67	Fallow or idle cropland	Cultivated footprint without an active crop class
68 / 69	Irrigated / rainfed pasture, hay, or wheat	Perennial grass and small-grain grouping
99	Unassigned	No supported Indiana SWB2 class

G.3.5 Land-use lookup tables and differentiating settings

Each combined land-use class linked to lookup values for runoff curve number by hydrologic soil group, rooting depth, maximum infiltration, planting and growing-season timing, crop coefficients, and irrigation amount and triggering schedule. These lookups control the hydrologic difference among cover classes even when climate and soil inputs are identical.

Table G-10. Historical and future model selections and input controls used in SWB2.

Component	Historical control	Future control / comparison note
Grid / period	1,680 × 2,136 cells; 250 m; NAD83 UTM Zone 16; daily; 2005-2024	Same grid; daily; 2020-2075
Interception	BUCKET; fractional-canopy-cover grid inactive; evaporation-to-rainFall ratio grid active	BUCKET
Evapotranspiration	HARGREAVES	HARGREAVES
Runoff	CURVE_NUMBER	CURVE_NUMBER
Soil moisture	FAO-56_TWO_STAGE	FAO-56_TWO_STAGE
Precipitation	GRIDDED Daymet	GRIDDED NorESM2-LM LOCA2
Growing degree day	BASKERVILLE_EMIN	BASKERVILLE_EMIN
Fog / direct recharge	NONE / NONE	NONE / NONE
Flow routing	D8; revised karst flow-direction grid	D8; revised karst flow-direction grid
Irrigation	FAO-56; eligibility embedded in annual land-use grid; separate irrigation-mask directive inactive	Same method; eligibility embedded in future land-use grid
Rooting depth / crop coefficient	DYNAMIC / FAO-56	DYNAMIC / FAO-56

Component	Historical control	Future control / comparison note
Hydrologic soil groups	Ten-class HSG grid with explicit surface coal mine representation	Ten-class HSG grid with explicit surface coal mine representation
Available water capacity	AWC 150cm (gridded) in/ft	AWC 150cm (gridded) in/ft
Land-use lookup	Landuse_LU_deepersoy_20260709	Landuse_LU_deepersoy_20260709
Irrigation lookup	Irrigation_LU_fieldcapacityIRR_20260709	Irrigation_LU_fieldcapacityIRR_20260709
Impervious cover	Static 2016-derived percentage grid	Static 2016-derived percentage grid
Run provenance	Model 13; swb2_HUC12_IN_20052024_250m_awc150_origirr_fieldcap_soyrootdepth_20260710.ctl	swb2_Future_NorESM2_LM_19802075_250m_20260717.ctl; active period 2020-2075

G.3.5.1 Crop, rooting-depth, and irrigation parameters

A lookup table governs the treatment of crop and irrigation parameters. Corn and soybeans were not treated as interchangeable crops. They used different basal crop-coefficient sequences, plant heights, planting dates, and root-zone depths. Corn used the deepest agricultural root zone; soybeans (“soy”) retained a shallower but crop-specific profile. Irrigated and rainfed versions of a crop shared crop growth, runoff, infiltration, and rooting parameters, but only the irrigated code permitted an application event.

Table G-11. Implemented crop, rooting-depth, crop-coefficient, and irrigation parameters by SWB2 land-use class.

Codes / class	Planting; Kcb ini/mid/end	Root depth, HSG A/B/C/D (ft)	Implemented irrigation rule
8 / 21 - turf	Apr. 29; 0.80 / 0.85 / 0.85	0.60 / 0.50 / 0.50 / 0.50	Code 21: Jun. 15-Sep. 1; 0.5 in/event; MAD 0.55; efficiency 1.00
61 / 62 - corn	Apr. 27; 1.20 / 0.60 / 2.50*	6.00 / 5.50 / 5.00 / 4.00	Code 61: Jun. 15-Sep. 1; 0.5 in/event; MAD 0.55; efficiency 0.90
63 / 64 - soybeans	Apr. 30; 0.20 / 1.15 / 0.50	3.00 / 3.00 / 2.75 / 2.50	Code 63: Jun. 15-Sep. 1; 0.5 in/event; MAD 0.55; efficiency 0.90
65 / 66 - other crops	May 10; 0.70 / 1.05 / 0.95	3.00 / 3.00 / 2.75 / 2.50	Code 65: Jun. 15-Sep. 1; 0.5 in/event; MAD 0.55; efficiency 0.90
68 / 69 – pasture/hay/wheat	Mar. 20; 0.40 / 0.85 / 0.85	4.01 / 3.29 / 3.29 / 3.29	Code 68: Jun. 15-Sep. 1; 0.5 in/event; MAD 0.55; efficiency 0.88

*out of normal range for Kcb end for corn

For every irrigated class, the future lookup assigns all simulated irrigation to groundwater and uses the application scheme identified in the file as field_capacity_original (this option uses irrigation to restore soil moisture completely to field capacity, any inefficiently applied irrigation water is added directly back into the soil-moisture reservoir). The lookup-table depletion fraction and maximum allowable depletion are both 0.55 for the

irrigated crop and turf classes. The 0.5-inch application amount is an event depth, not a fixed monthly application amount; SWB2 applies it only when the FAO-56 soil-water condition and the lookup timing permit irrigation. Application efficiencies are 1.00 for turf, 0.90 for corn, soybeans, and other crops, and 0.88 for pasture/hay. Rainfed companion codes have zero application amount and an application scheme of none.

The land-use lookup table also supplies the hydrologic-soil-group-specific curve numbers and maximum net-infiltration limits. For most undeveloped classes, the maximum net-infiltration sequence for HSG A, B, C, D, A/D, B/D, and C/D is 4.00, 1.00, 0.24, 0.12, 3.00, 0.24, and 0.12 inches per day, respectively. Developed land uses 0.12 inch per day across those seven groups. Curve numbers and special water, urban, and thin-soil treatments remain class-specific in the lookup table and were not reduced to a single statewide calibration value.

G.3.6 Historical SWB2 model selection

Candidate historical SWB2 configurations were screened by comparing basin-aggregated runoff and net infiltration with natural streamflow components and with independent recharge or baseflow estimates. The purpose of this comparison was to identify structural bias and select defensible SWB2 inputs and lookup settings. The separate transformation of runoff and net infiltration, including the conceptual groundwater reservoir, seasonal scaling coefficient (α), calibration objective, and sensitivity analysis, is documented in Sections G.4.1-G.4.10.

The selected SWB2 configuration produced lower groundwater-supported flow than PART hydrograph-separation estimates (Rutledge, 1998) at many gages. Comparisons with published baseflow-index estimates (Wolock, 2003; Letsinger et al., 2021a; Konrad, 2022) suggested that PART often represented the wetter end of the plausible range, whereas the SWB2-based framework represented a drier planning case. The study retained this contrast to bracket water-availability results rather than tuning the landscape model to reproduce a single hydrograph-separation method.

Model-selection interpretation also accounted for departures from a natural local water balance (or incompletely filtered natural streamflow hydrograph). Large mainstem basins integrate tributary timing and floodplain storage; reservoirs convert low-flow behavior into an operating signal; municipal withdrawals and wastewater returns can dominate the human portion of the water balance; and karst conduits can transfer recharge across surface-water divides. These locations were used as cumulative checks but were not allowed to dictate SWB2 settings that degraded less-regulated catchments.

G.3.7 Future climate forcing

G.3.7.1 Climate Model Selection

The future SWB2 run used daily precipitation and minimum and maximum temperature from the NorESM2-LM global Earth-system model under SSP2-4.5, statistically downscaled with LOCA2 (Seland et al., 2020; Pierce et al., 2014, 2023). The realization r1i1p1f1 and the 1/16-degree LOCA2 product were used. NorESM2-LM is the lower-resolution configuration of the Norwegian Earth System Model. SSP2-4.5 combines a middle-of-the-road socioeconomic pathway with intermediate radiative forcing.

A single internally coherent model realization was selected rather than averaging daily values across an ensemble. This choice preserves the sequencing and covariance of temperature, precipitation, drought, and extreme events that drive soil-water deficits and seasonal recharge. A climate-model ensemble average can describe central climate tendencies but can dampen the persistence and magnitude of individual droughts or wet periods, which is of interest in water-resources planning applications. The tradeoff is that NorESM2-LM represents only one plausible trajectory and does not span the full range of climate-model uncertainty.

G.3.7.2 NorESM2-LM SSP2-4.5 Application to Indiana Climate

Rather than selecting a probabilistic ensemble center climate model (often referred to as the “central tendency” model), NorESM2-LM was selected for the representation of seasonality that is increasingly familiar to residents of Indiana. When applied to the land surface of the Midwest U.S., the NorESM2-LM model under the SSP2-4.5 scenario projects distinct regional hydroclimatic shifts. For a landlocked, agriculturally intensive state like Indiana, the model simulates a pronounced amplification of seasonal precipitation variability. Rather than a uniform increase in rainfall, the model outlines a future characterized by a wet-to-dry seasonal asymmetry. Under this intermediate forcing pathway, Indiana is projected to experience intensified wet extremes during the winter and spring months. Conversely, the summer convective season transitions toward a more volatile state. While short-term, heavy downpours still occur, they are increasingly interspersed with longer dry spells and elevated risk of summer agricultural drought. This translates to a higher frequency of rapid, monthly-to-seasonal transitions—essentially swinging between excessive soil moisture during spring planting and acute water stress during the peak summer growing season. This shift has already been seen and documented in the Midwest US and the state (Akisanola et al, 2024; Bowling et al., 2018; Chen and Ford, 2023; Cherkauer et al., 2023; Indiana State Climate Office, 2025; Letsinger et al., 2021; NOAA, 2022; and Widhalm et al., 2018). Therefore, this model was selected to reflect the hydrological regime in Indiana under climate stress, rather than select a model purely based on statistical criteria.

G.3.7.3 NorESM2-LM SSP2-4.5 Model Characteristics

The model is considered to be on the lower-sensitivity side of the CMIP6 model range (Seland et al., 2020), while SSP2-4.5 remains an intermediate pathway (IPCC, 2021). This combination avoided both a minimal-change case and the high-sensitivity tail (worst-case scenario) while retaining a climate trajectory capable of testing seasonal water stress (“stress test”) through 2075.

The NorESM2-LM model combined with the SSP2-4.5 scenario represents a highly controlled climate projection framework designed to evaluate the physical impacts of a moderate warming future. In terms of a warming trajectory, the Norwegian Earth System Model (NorESM2-LM) simulates a long-term global temperature increase of approximately 2.2°C by the 2090s relative to the pre-industrial baseline. Given that today's actual global temperatures have already risen by roughly 1.5°C above pre-industrial levels (NOAA, 2022), the model projects an additional net warming of approximately 0.7°C to 0.8°C across the coming decades.

While the model forces a trajectory of gradual physical climate change, the non-climate framework of this study remains strictly controlled under the “Middle of the Road” SSP2 pathway through the use of SSP2 landuse/landcover and population projections. This means that while atmospheric temperature and direct meteorological variables dynamically shift, other critical societal and structural boundary conditions—such as regional demographics, urbanization trends, general economic growth trajectories, and baseline technological development—are held constant to historical patterns. Isolating the scenario variables in this manner ensures that any observed impacts or vulnerabilities identified within this study are directly attributable to the specific physical climate forcing of the SSP2-4.5 pathway rather than shifting socioeconomic assumptions.

The historical 2020-2024 overlap in the future model should not be expected to reproduce the Daymet calendar sequence of weather events. It provides a continuity and bias-screening interval between two internally consistent model executions. The model scenario therefore supplies one physically ordered sequence, with uncertainties stated explicitly.

LOCA2 precipitation (pr), maximum temperature (tasmax), and minimum temperature (tasmin) were subset to 2020-2075 and the model domain. The source grid was geographic longitude-latitude referenced to WGS84. Precipitation was converted from kilograms per square meter per second, equivalent to millimeters per second, to inches per day with a scale factor of 3,401.574803. Temperature was converted from Kelvin to degrees Fahrenheit using a scale factor of 1.8 and an offset of -459.67. Values at or above 1.0×10^{30} were treated as

missing; missing precipitation was assigned zero and missing temperature the applicable mean. SWB2 performed the grid-to-grid spatial access using the projection definitions in the control file. Leap days were retained within the daily 2020-2075 execution. Because LOCA2 is a downscaled and bias-corrected product, no additional adjustment was conducted.

G.3.8 Future land use and crop rotation

G.3.8.1 External broad-cover projections

Future land cover was based on the U.S. Geological Survey Forecasting Scenarios of Land-Use Change (FORE-SCE) product for 2020-2075 (Sohl and Saylor, 2008; Sohl et al., 2014, 2018). Scenario B2 was selected because it represents moderate population growth, intermediate economic development, and comparatively diverse technological change. The 250-m annual product provides an external, reproducible basis for the spatial pattern of developed-land expansion, cropland conversion, forest change, mining or disturbance, and other broad transitions.

The FORE-SCE B2 scenario derives from the older SRES scenario family and is not formally equivalent to SSP2-4.5. The two were paired because their moderate narratives are broadly consistent, not because they represent an exact emissions or socioeconomic crosswalk. The study used FORE-SCE as a relative spatial land-conversion trajectory and retained Indiana-specific agricultural detail rather than interpreting the scenario as a literal county-level population forecast.

Table G-12. Reclassification of FORE-SCE land-cover classes and Indiana agricultural treatment for the future SWB2 run.

FORE-SCE source class(es)	Reclassified SWB2 class	Indiana agricultural treatment
Water	1 - Open water	No crop overlay
Developed	2 - Developed	Projected conversion overrides former crop/irrigation status
Mechanically disturbed, mining, barren	3 - Barren	No crop overlay
Deciduous, evergreen, mixed forest	4 - Forest	No crop overlay
Shrubland	5 - Shrubland	No crop overlay
Herbaceous and woody wetland	7 - Wetlands	No crop overlay
Grassland; hay/pasture	69 - Rainfed pasture/hay/wheat	Retained as the applicable agricultural grass class
Cropland	62 - Corn proxy before overlay	Replaced by the year-specific Indiana crop/irrigation proxy
Perennial ice/snow	99 - Unassigned	No supported Indiana class

G.3.8.2 Indiana crop and irrigation overlay

FORE-SCE was not used directly to assign Indiana crop species or irrigation because its broad classes do not reproduce field-scale corn-soybean rotation, continuous-corn or continuous-soy areas, or the observed distribution of irrigated fields and turf. Within cells that remained agricultural in a given FORE-SCE year, a four-year 2020-2023 stack of CDL crop identity and irrigation status was repeated through 2075. Thus 2024 reused the 2020 agricultural layer, 2025 reused 2021, and so forth. Repeating the observed sequence preserved

realistic crop rotation, regional heterogeneity, and parcels with repeated corn or soybean production while avoiding an unsupported attempt to forecast the crop planted on each field decades in advance.

The future irrigated extent was held to the 2020-2023 baseline cycle; no independent expansion of irrigated acreage was imposed. Irrigation status was retained only where the contemporaneous FORE-SCE layer remained agricultural. A projected conversion to developed, forest, wetland, barren, or another nonagricultural class removed the crop and irrigation overlay. Conversely, the method did not create any new irrigated parcels merely because FORE-SCE retained or added cropland.

Holding irrigated extent constant does not hold future irrigation volume constant. SWB2 continued to calculate soil-water deficit daily from future climate, soil storage, crop timing, and the irrigation lookup. Consequently, a baseline irrigated cell could require more or less applied water in different future years, while a rainfed cell continued to respond only to precipitation, temperature, snowmelt, runoff, evapotranspiration, and soil storage.

G.3.9 Historical-to-future consistency and quality assurance

The historical and corrected future controls use the same grid, flow-direction and HSG rasters, AWC150 grid, impervious-cover grid, interception input, initial soil-moisture and snow grids, corn/soy and land-use parameterization, and the same SWB2 process methods. In both controls, timing is governed by the dynamic rooting-depth, FAO-56 crop-coefficient, and lookup-table settings. The intended time-varying changes are therefore concentrated in the replacement of Daymet (historical climate) and annual historical land use with NorESM2-LM LOCA2 climate and the FORE-SCE future landuse.

G.3.10 SWB2 interpretation and limitations

SWB2 estimates potential recharge as water moving below the modeled root zone; it does not simulate saturated groundwater flow, travel time through an aquifer, pumping capture, or discharge to a particular stream reach. Net infiltration is therefore interpreted as a spatially and temporally distributed recharge (proxy) input rather than as an instantaneous one-to-one prediction of observed baseflow. This distinction is especially important in karst terrain, large alluvial basins, and regulated or return-flow-dominated watersheds.

The future results represent one coherent climate and land-use scenario, not a probability distribution; another global model or scenario could produce a different trajectory. FORE-SCE B2 supplies a consistent external pattern of broad land conversion, while the repeated 2020-2023 agricultural sequence assumes that recent crop rotations and irrigated extent remain a reasonable (and familiar) management baseline. The method supports regional comparison and long-range planning and should be updated as improved irrigation mapping and land-development projections become available. Additional climate model scenarios can be run easily with the existing framework to assess a range of possible hydrological futures for Indiana.

G.4 Post-processing and Water-Availability Application Using an R Workflow

G.4.1 Purpose and scope

The Indiana regional water-availability method requires monthly estimates of natural streamflow and baseflow to calculate local excess water availability (Qea) and cumulative excess water availability (Qcea) (IFA, 2021). For the historical period, natural streamflow was reconstructed from U.S. Geological Survey (USGS) gage records by accounting for modeled withdrawals, return flows, and reservoir operations. Equivalent observations do not exist for future conditions. A post-processing framework was therefore developed to translate SWB2 runoff and net infiltration into continuous monthly streamflow and baseflow estimates under both historical and projected climate forcing.

SWB2 simulates landscape water-balance components but does not route channel flow or simulate saturated groundwater flow to a stream outlet. The post-processing framework represents two pathways: accumulated runoff is treated as the rapid, same-month contribution to streamflow, and accumulated net infiltration is treated as a recharge proxy entering a conceptual linear groundwater reservoir. Discharge from that reservoir represents the delayed groundwater contribution to streamflow. The framework is a simple bucket accounting model designed for regional monthly analysis; it is not a distributed groundwater-flow or hydraulic-routing model.

G.4.2 Processing of hydrologic variables from SWB2

G.4.2.1 Temporal aggregation and units

Daily runoff and net-infiltration rasters from the 250-m SWB2 grid were accumulated to monthly depths (all SWB2 outputs are in inches). The historical SWB2 execution spans 2005-2024, and the future execution spans 2020-2075, as documented in Sections G.3.1-G.3.9. The streamflow framework used the months required for calibration, overlap evaluation, and projection. Monthly aggregation is consistent with the regional water-use and water-availability accounting (IDNR SWWF, and NPDES) and reduces the importance of within-month timing that cannot be resolved from reported monthly withdrawals and returns.

For hydrologic component x (runoff, RO, or net infiltration, NI), monthly mean or area-weighted depth was converted to a HUC12 (Blodgett, 2022) volume as:

$$V_{h,t}^x = d_{h,t}^x \times A_h \times 17.3787 \quad (\text{G-3})$$

where $V(x,h,t)$ is the local monthly volume in million gallons (MG), $d(x,h,t)$ is the corresponding depth in inches, $A(h)$ is HUC12 area in square miles, and 17.3787 is the conversion from one inch over one square mile to MG. If raster-cell volumes rather than zonal mean depths were summed in the production workflow, Equation G-3 is algebraically equivalent provided that partial cells and NoData areas were handled consistently.

G.4.2.2 HUC12 aggregation and upstream network

Local monthly runoff and net-infiltration volumes were summarized for each HUC12 in the study domain. The Blodgett (2022) version of the HUC12 watershed boundary dataset was used to align, if needed, with the recently published USGS National Water Availability Assessment (NWAA; Miller et al., 2024; Stets et al., 2025; USGS, 2025). Downstream connectivity was defined from the TOHUC field in the Watershed Boundary Dataset. For each outlet HUC12, a recursive upstream search identified the full set of contributing HUC12s, including the outlet watershed itself. Accumulated monthly volume was then calculated as:

$$V_{h,t}^{x,acc} = \sum V_{j,t}^{x,local}, j \in U(h) \quad (G-4)$$

where $V(x,acc,h,t)$ is accumulated runoff or net-infiltration volume at outlet h , $V(x,local,j,t)$ is the locally generated volume in contributing HUC12 j , and $U(h)$ is the set of all HUC12s draining to h . The network accumulation preserves mass within the represented domain but does not impose a separate channel travel-time or floodplain-storage function. At a monthly time step, all accumulated runoff is therefore available to the outlet during the month in which SWB2 generated it.

G.4.3 Historical natural streamflow target

Calibration used monthly natural streamflow (Q_{nsf}), not unadjusted gage flow. Consistent with the study-wide sign convention, the historical target was reconstructed as:

$$Q_{nsf,g,t} = Q_{usgs,g,t} + Q_{ww,g,t} - Q_{rf,g,t} - Q_{stor,g,t} \quad (G-5)$$

where $Q(usgs)$ is observed gage volume; $Q(ww)$ is upstream withdrawal; $Q(rf)$ is upstream return flow; and $Q(stor)$ is the signed reservoir-operation term, positive for net release and negative for net storage. Thus withdrawals are added back, returns are removed, and managed releases are removed from observed flow. The exact spatial accumulation and monthly routing of Q_{ww} , Q_{rf} , and Q_{stor} are documented in the demand, return-flow, reservoir, and Central Indiana boundary-condition sections of the technical appendix.

The natural streamflow approach reduces known anthropogenic effects but does not create a perfectly natural record. Unreported withdrawals, uncertain discharge routing, interbasin transfers, reservoir evaporation or spill, travel-time differences, and operational data gaps remain sources of error. These data gaps become progressively more important the further downstream that flows are accumulated. The term natural streamflow is therefore used here in preference to observed natural streamflow.

G.4.4 Conceptual groundwater reservoir

G.4.4.1 Model structure and equations

At each calibrated assessment location g , accumulated runoff was treated as immediate streamflow. Accumulated net infiltration was multiplied by a season-specific scaling coefficient and added to a conceptual groundwater reservoir. Baseflow released at the beginning of month t was calculated from stored water as:

$$Q_{bf,g,t} = k_g S_{g,t} \quad (G-6)$$

where $Q(bf,g,t)$ is simulated baseflow volume (MG), $S(g,t)$ is conceptual groundwater storage at the beginning of the month (MG), and $k(g)$ is the dimensionless monthly recession coefficient. Total simulated streamflow was:

$$Q_{sim,g,t} = V_{g,t}^{RO,acc} + Q_{bf,g,t} \quad (G-7)$$

where $Q(sim,g,t)$ is simulated monthly streamflow and $V(RO,acc,g,t)$ is accumulated SWB2 runoff volume. Following release of baseflow, storage was advanced one month as:

$$S_{g,t+1} = (1 - k_g)S_{g,t} + \alpha_{g,t} V_{g,t}^{NI,acc} \quad (G-8)$$

where $V(NI,acc,g,t)$ is accumulated SWB2 net-infiltration volume and $\alpha(g,t)$ is the season-specific net-infiltration scaling coefficient. Under this ordering, newly added net infiltration cannot contribute to baseflow until the following monthly time step. The seasonal coefficient was assigned as:

$$\alpha_{g,t} = \alpha_g^{wet} \text{ for Dec - May; } \alpha_{g,t} = \alpha_g^{dry} \text{ for Jun - Nov} \quad (G-9)$$

Wet-season months were December-May (corresponding to Winter and Spring in the study) and dry-season months were June-November (corresponding to Summer and Fall in the study). These seasons apply only to

the reservoir scaling coefficient and should not be assumed to match seasonal definitions used in the return-flow or other sector analyses.

Scaling-coefficient interpretation: Alpha (α) is the net-infiltration scaling coefficient used throughout the application framework. It is calibrated as independent gage-specific wet- and dry-season values. The production calibration constrained alpha to the interval 0-2; a separate upper-bound sensitivity run relaxed the ceiling to 4 (which was not reached). Alpha is an empirical scaling coefficient, not a physical fraction, and should not be interpreted as measured recharge efficiency.

G.4.4.2 State initialization and mass-balance implications

Conceptual groundwater storage must be initialized before the first evaluated month. Storage was initialized to zero, after which storage evolved sequentially. Because a zero initial condition can suppress early simulated baseflow, the production workflow used the 2005-2006 portion of the historical SWB2 run as model spin-up, with analysis of outputs starting in December 2006.

G.4.5 Calibration and parameter estimation

G.4.5.1 Calibration locations and parameter set

The reservoir model was calibrated independently at 23 selected USGS gage locations in the Southwest Indiana study area (20 gages in the SWI region, plus three upstream gages from upstream river basins studied in other regional water studies). Independent calibration allowed recession and net-infiltration scaling to reflect catchment-scale differences in geology, soil storage, karst, alluvial exchange, regulation, drainage area, and uncertainty in the natural target. For each gage, the working parameter set consisted of $k(g)$, $\alpha(\text{wet},g)$, and $\alpha(\text{dry},g)$, with the bounds defined as:

$$0.001 \leq k_g \leq 1.0; \quad 0.0 \leq \alpha_g^{\text{wet}}, \alpha_g^{\text{dry}} \leq 2.0 \quad (\text{G-10})$$

These are numerical calibration bounds, not independently measured physical ranges. Values of alpha greater than 1.0 indicate that unscaled SWB2 net infiltration was insufficient to reproduce the groundwater-supported portion of the natural hydrograph under this model structure; they may also compensate for domain omissions, scale mismatch, runoff partitioning, or incomplete natural-streamflow calculation errors. A separate sensitivity calibration relaxed the upper bound from 2 to 4 to test whether the production ceiling constrained the solution; this sensitivity case was not adopted as the primary model.

G.4.5.2 Optimization objective

The bounded parameter optimization used the limited-memory Broyden-Fletcher-Goldfarb-Shanno algorithm with bounds (L-BFGS-B; Byrd et al., 1995). Candidate parameter sets were evaluated by simulating the complete monthly series and comparing Qsim with Qnsf. The objective balanced overall hydrograph agreement, lower-flow behavior, and total volume:

$$\text{Score} = KGE + 0.5(\text{LogNSE}) - 2|\text{Bias}| \quad (\text{G-11})$$

where KGE is Kling-Gupta Efficiency (Gupta et al., 2009; Kling et al., 2012), LogNSE is Nash-Sutcliffe Efficiency calculated in logarithmic flow space (Nash and Sutcliffe, 1970), and Bias is relative volumetric bias. Because L-BFGS-B minimizes an objective function, the negative of the score was supplied to the optimizer. KGE represents correlation, variability, and mean-flow agreement; LogNSE increases the influence of low and moderate flows; and the absolute-bias penalty discourages solutions that reproduce timing while misrepresenting total volume.

G.4.6 Model evaluation and selection

Performance was evaluated by comparing simulated and natural monthly streamflow at the calibration gages. Reported diagnostics included KGE, LogNSE, relative bias, the composite score, and Pearson correlation. Because the model supports regional monthly water-availability assessment, evaluation emphasized seasonal timing, low-flow persistence, recession behavior, and volumetric consistency rather than daily flood peaks or event-scale travel time.

Simulated groundwater discharge was also compared diagnostically with baseflow estimated using the PART hydrograph-separation method (Rutledge, 1998). PART was used as an independent reasonableness check, not as an error-free calibration target. Hydrograph separation is sensitive to record length, basin area, regulation, tributary integration, and the assumption that streamflow recession can be partitioned cleanly into surface and groundwater components. Final model selection therefore prioritized performance against Qnsf while interpreting PART comparisons alongside basin setting and known management effects.

The resulting Qbf is the simulated effective groundwater discharge under the conceptual model. It is not identical to SWB2 net infiltration, aquifer recharge measured in the field, or a uniquely observed baseflow series. This terminology is especially important in karst terrain, large alluvial reaches, reservoir-regulated basins, and catchments dominated by wastewater returns or interbasin transfers.

G.4.7 Historical and future application

After calibration and evaluation, the selected parameter set for each assessment location was held constant and applied to the corresponding historical and future SWB2 runoff and net-infiltration series. The future application therefore changes climate and land-cover forcing as documented in Sections G.3.7-G.3.9 while retaining the calibrated post-processing structure. This assumes that the effective recession and net-infiltration-to-streamflow relationships remain stationary through 2075. The assumption is appropriate for a controlled scenario comparison but does not represent future changes in aquifer properties, channel geometry, drainage infrastructure, groundwater pumping capture, reservoir operations, or interbasin transfer.

The framework produced monthly Qsim and Qbf at the modeled assessment locations. These natural hydrologic terms were subsequently combined with projected Qww, Qrf, and Qstor in the regional water-availability calculations to estimate future Qea and Qcea. Anthropogenic projections were not inserted into SWB2 runoff or net infiltration; they were maintained as separate accounting terms so that climate-land-cover response and human water management could be evaluated transparently.

G.4.7.1 Excess Water Availability

The historical and future water availability assessment evaluates the quantity of water remaining after accounting for natural hydrologic processes, anthropogenic (human) water use, reservoir operations, and environmental flow (habitat) requirements. The objectives of the assessment are to identify subbasins where current water demands represent a substantial proportion of available water, establish a historical baseline for comparison with future conditions, and identify locations where future water availability may become constrained.

The assessment was conducted for 21 USGS streamgage-defined subbasins within the Southwest Indiana study area, encompassing the Patoka, East Fork White, White, and Wabash River systems before their confluence with the Ohio River (Figure G-1). Monthly water-balance calculations span from 2007 through 2075 and are summarized as annual and seasonal (Winter, Spring, Summer, and Fall) averages. To reduce the influence of individual wet and dry years, historical and future conditions are presented as five-year centered averages (2018–2022, center year 2020; 2048–2052, center-year 2050; and 2068–2072, center year 2070).

The water availability methodology follows the conceptual framework developed for previous Indiana regional water studies (IFA, 2021; Phase III: Water Availability, Chapter 2) and incorporates both natural hydrologic processes and anthropogenic influences within a spatially distributed, subbasin-scale water balance. Anthropogenic components include reported water withdrawals (Q_{ww}), regulated and estimated return flows (Q_{rf}), and reservoir operations (Q_{stor}). Net returns (Q_{nret}) are calculated as the difference between return flows and withdrawals ($Q_{rf} - Q_{ww}$), where positive values represent a net addition of water to the stream system (i.e., more returns than withdrawals) and negative values represent a net depletion (i.e., more withdrawals than returns). Reservoir operations are represented as the net effect of reservoir releases and storage (reservoir outflow minus inflow), where positive values indicate a net release of water to downstream reaches.

Natural streamflow represents the streamflow that would occur in the absence of human influences. Historical natural streamflow was estimated by removing the cumulative effects of net returns and reservoir operations from observed USGS streamflow:

$$Q_{nsf} = Q_{USGS} - Q_{nret,accum} - Q_{stor,accum}$$

where Q_{USGS} is observed streamflow, $Q_{nret,accum}$ represents accumulated upstream net returns, and $Q_{stor,accum}$ represents accumulated upstream reservoir effects.

Natural baseflow, representing the groundwater contribution to streamflow, was estimated using the calibrated Soil-Water-Balance (SWB2, Westenbroek et al., 2018) model. The simulated net infiltration (potential groundwater recharge) output from the SWB2 model was converted to a monthly baseflow proxy using a calibrated linear reservoir model. Simulated streamflow was then calculated by combining the SWB2 modeled runoff and the baseflow proxy. Model parameters were calibrated at monthly time steps against the natural streamflow derived from observed streamflow at USGS streamgages throughout the study area, producing a spatially consistent representation of both the magnitude and timing of natural streamflow and baseflow contributions (IFA, 2021). The calibrated model was subsequently driven using downscaled climate projections (NorESM2-LM SSP2-4.5) to estimate future natural hydrologic conditions.

Alternative historical and future water availability estimates based on the PART/BFI (see below) baseflow methodology are presented to provide additional context regarding uncertainty associated with baseflow estimation.

Water availability was evaluated at both the local subbasin scale and the cumulative river basin scale. Local excess water availability represents the amount of water available within an individual subbasin after accounting for natural baseflow, net returns, reservoir operations, and instream-flow (habitat) requirements. Positive values indicate that water remains available after satisfying human and habitat water needs, whereas negative values indicate that the calculated water balance is insufficient to satisfy all modeled requirements during the specified period.

The conceptual water-balance equation used to estimate local excess water availability (Q_{ea}) is:

$$Q_{ea} = Q_{nbf} + Q_{nret} + Q_{stor} - Q_{if}$$

where Q_{nbf} is natural baseflow, Q_{nret} is net returns, Q_{stor} is the net effect of reservoir operations, and Q_{if} is the instream-flow requirement. Cumulative excess water availability (Q_{cea}) is calculated using the same accounting framework after incorporating accumulated upstream contributions of natural baseflow, net returns, and reservoir operations.

Historical and future results are presented using maps, regional summaries, and subbasin-scale analyses to illustrate both the spatial distribution of water availability and the relative importance of locally generated versus upstream-contributed water resources. Complete annual and seasonal results for Q_{ea} and Q_{cea} for all subbasins, together with the companion PART/BFI (see below) analysis, are provided in Appendix H.

Figure G-4 presents the historical annual net return flow for the Southwest Indiana region, whereas Figure G-5 shows seasonal historical and future net returns for the region. The significance of the sign of Qnet is provided in each figure caption.

Figure G-6 presents the historical annual accumulated reservoir (Qstor) flow for the Southwest Indiana region, whereas Figure G-7 shows seasonal historical and future accumulated Qstor for the region. The significance of the sign of Qstor is also provided in each figure caption.

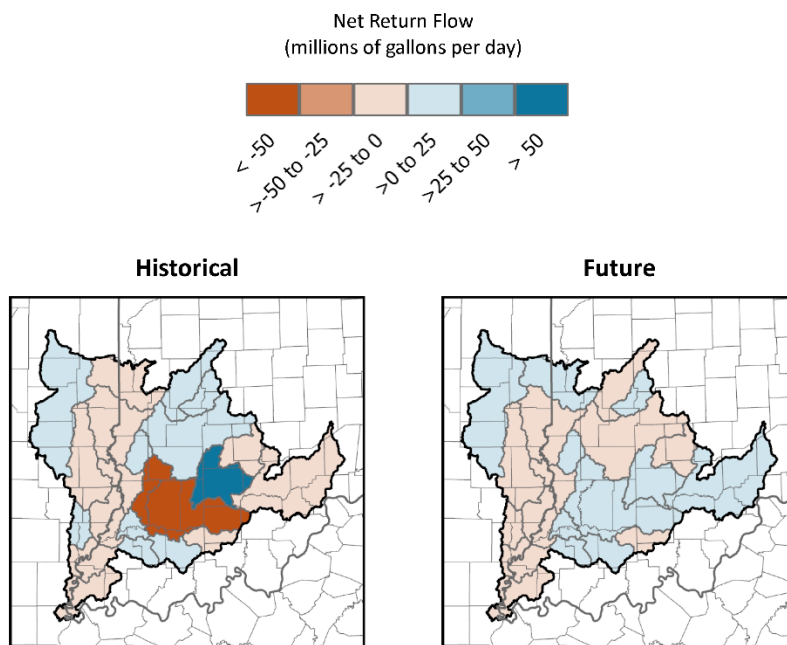


Figure G-4. Southwest Indiana subbasin-averaged annual net return flow in millions of gallons per day (MGD) for the Historical (2020) and Future (2025-2075) analysis periods. Net returns are calculated as $Q_{net} = Q_{rf} - Q_{ww}$ (returns minus withdrawals). Therefore, a negative net return indicates more withdrawals than returns on an annual basis in a subbasin, whereas a positive net return represents more returns than withdrawals. Lighter colors represent more-balanced withdrawal/return water management in that subbasin.

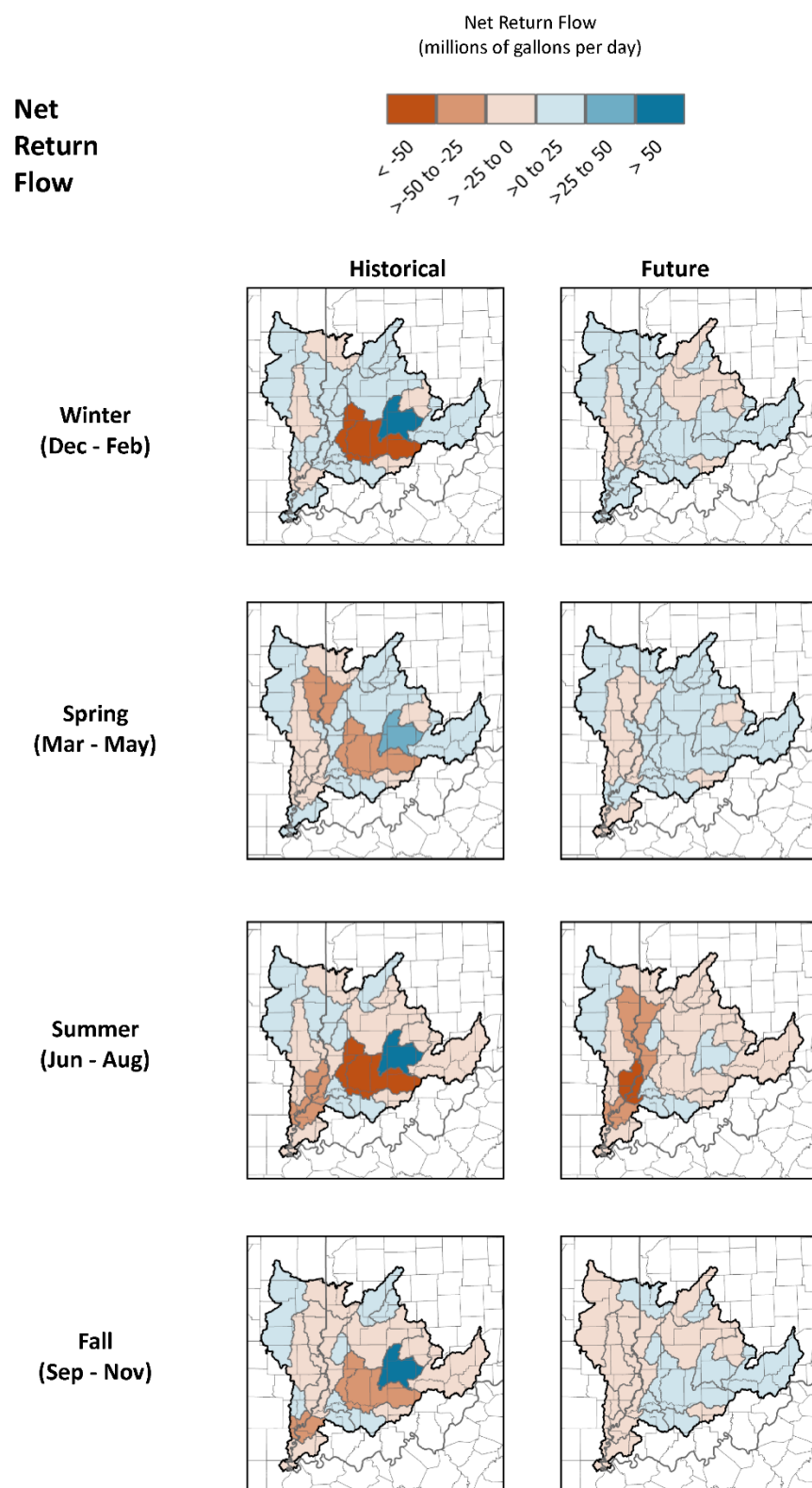


Figure G-5. Southwest Indiana subbasin-averaged seasonal net return flow in millions of gallons per day (MGD) for the Historical (2020) and Future (2025-2075) analysis periods. Net returns are calculated as $Q_{net} = Q_{rf} - Q_{ww}$ (returns minus withdrawals). Therefore, a negative net return indicates more withdrawals than returns on a seasonal basis in a subbasin, whereas a positive net returns represents more returns than withdrawals. Lighter colors represent more-balanced withdrawal/return water management in that subbasin.

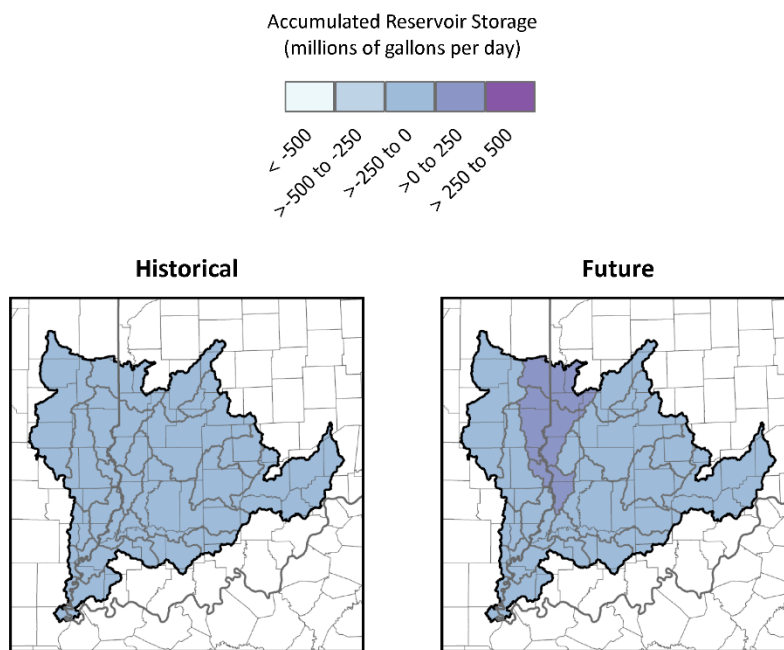


Figure G-6. Southwest Indiana subbasin-averaged seasonal accumulated reservoir storage (Q_{stor}) flow in millions of gallons per day (MGD) for the Historical (2020) and Future (2025-2075) analysis periods. Negative values represent water stored, or retained, in the reservoir, whereas positive values represent water released from the reservoir.

Accumulated Reservoir Storage

Accumulated Reservoir Storage
(millions of gallons per day)

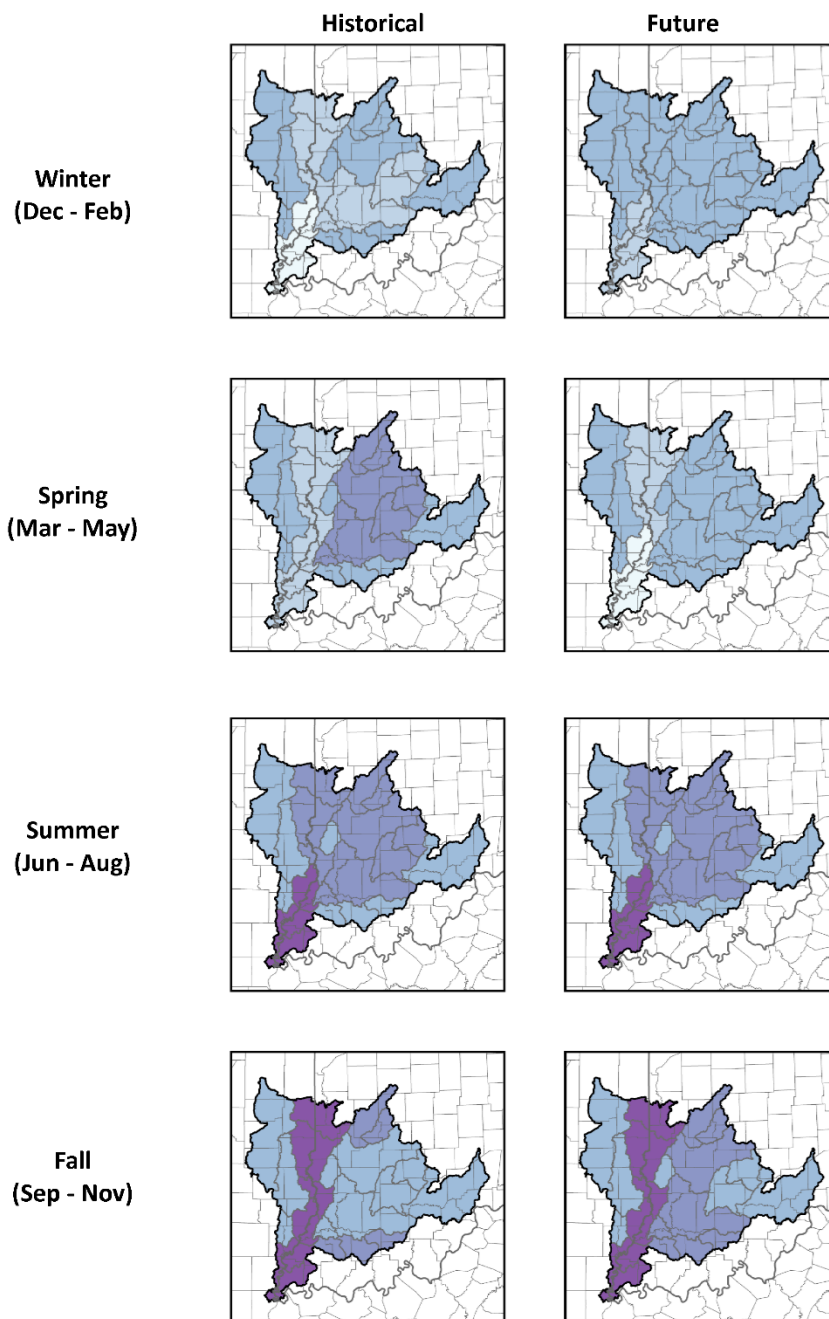
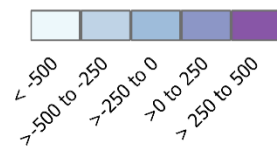


Figure G-7. Southwest Indiana subbasin-averaged seasonal accumulated reservoir storage (Qstor) flow in millions of gallons per day (MGD) for the Historical (2020) and Future (2025-2075) analysis periods. Negative values represent water stored, or retained, in the reservoir, whereas positive values represent water released from the reservoir. Regulated reservoirs usually have specified minimum release volumes to maintain instream flows during the dry season, so the largest positive Qstor values are shown in the Summer and Fall.

G.4.7.2 PART/BFI Method

An alternative baseflow-estimation approach was developed to evaluate the sensitivity of water-availability results to the representation of natural groundwater contributions. Historical natural baseflow estimated using the USGS PART hydrograph-separation method was used to calculate a monthly Baseflow Index (BFI) at each assessment location. BFI represents the proportion of natural streamflow attributed to baseflow and was calculated as the ratio of PART-derived natural baseflow to natural streamflow. A BFI of 0.60, for example, indicates that approximately 60 percent of the natural streamflow represented during that period was estimated to originate as baseflow. Because the groundwater contribution to streamflow varies through time, BFI was evaluated separately by season rather than treated as a single fixed property of each watershed. This method uses metrics of the hydrologic behavior of the historical streamflow data for the last 19 years during wet seasons and dry seasons and assumes those metrics will be constant into the future (for the next 50 years). That assumption should be valid if the hydrologic conditions over the last 19 years are within the same range as the next 50 years.

Historical relationships between BFI and natural streamflow were developed independently for each gage and season using monthly data from December 2006 through December 2024 (Figure G-4). Natural streamflow volumes were first normalized by drainage area and expressed as inches per month to provide a consistent measure of streamflow magnitude among assessment locations. For each gage and season, a linear regression model was then fit relating the historical PART-derived BFI to the natural logarithm of monthly natural-streamflow depth. These gage- and season-specific regression relationships characterize how the proportion of natural streamflow attributed to baseflow varied with streamflow magnitude during the historical period.

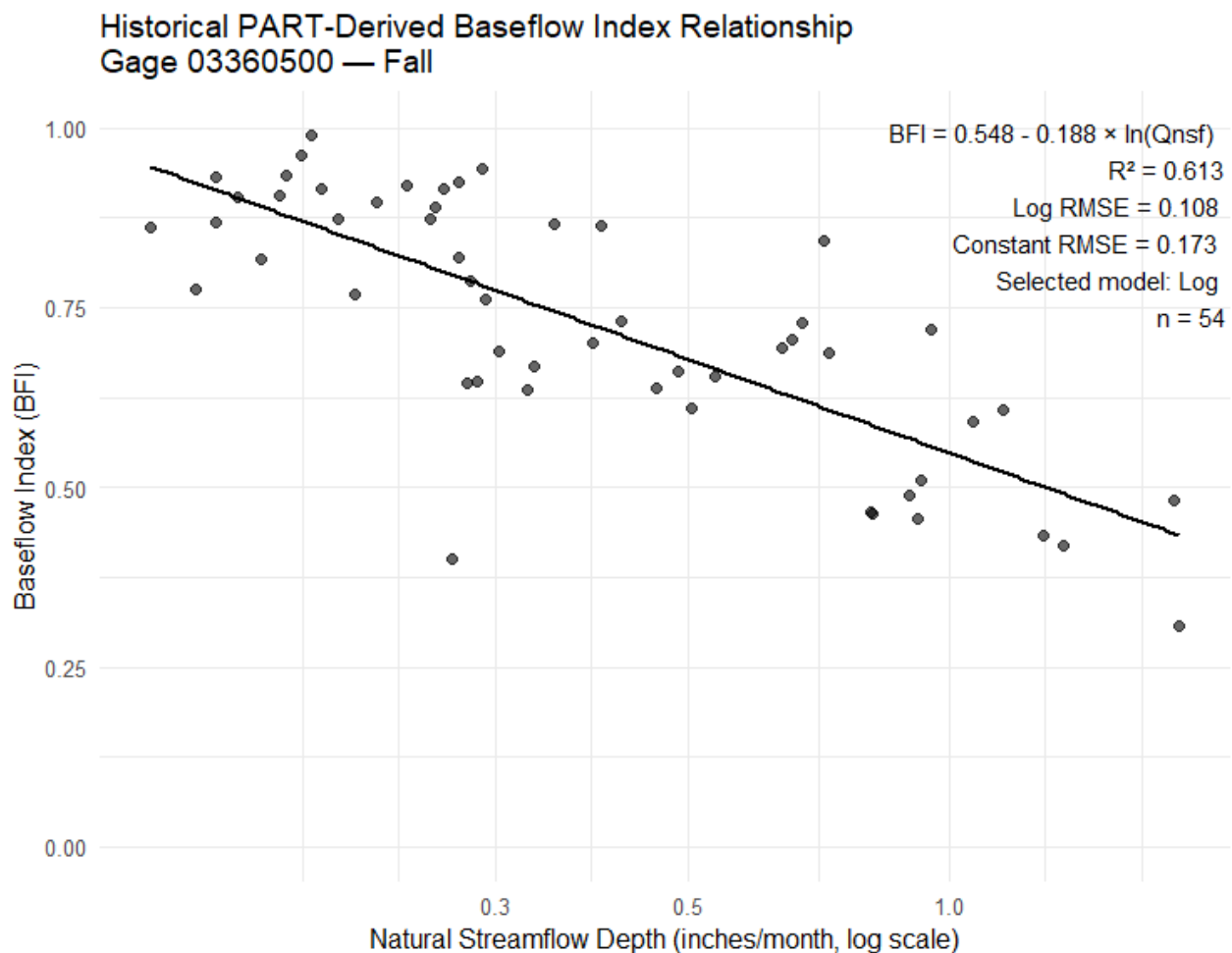


Figure G-8. Example relationship used in the development of the PART/BFI method for estimating future natural baseflow, shown for the White River at Newberry (Subbasin 9, Gage 03360500) during Fall. Historical monthly natural baseflow was estimated using the USGS PART hydrograph-separation method, and the baseflow index (BFI) was calculated as the ratio of PART-derived natural baseflow to natural streamflow. Natural streamflow was converted to watershed-equivalent depth (inches) to normalize for drainage area, and historical BFI was related to the natural logarithm of normalized natural streamflow. Points represent individual historical Fall months from the December 2006 through November 2024 analysis period, and the fitted line and equation illustrate the empirical relationship evaluated for this gage-season combination. For future conditions, natural streamflow derived from the SWB2 simulation was the known hydrologic input. The historical relationship between the BFI and normalized natural streamflow was then applied to the future natural-streamflow series to estimate the portion of that flow attributable to natural baseflow. Estimated baseflow fractions were constrained between 0 and 1 where extrapolation of the historical relationship produced values outside physically meaningful bounds. This approach provides a “PART-derived” estimate of future natural baseflow without applying the PART hydrograph-separation method directly to the projected streamflow series.

The historical regression relationships (Table G-13) were subsequently applied to projected monthly natural streamflow to estimate the future natural-baseflow component. Future SWB2-simulated natural streamflow was converted to drainage-area-normalized depth using the same procedure applied to the historical data and entered into the corresponding gage- and season-specific regression equation. The resulting relationship provided an estimate of the fraction of projected natural streamflow attributable to baseflow for each future month. Because extrapolation beyond the range of historical streamflow conditions could occasionally produce estimated fractions outside the physically meaningful range, values were constrained between 0 and 1. Future natural baseflow was then calculated by applying this estimated baseflow fraction to the projected natural-streamflow volume. Thus, the future analysis used SWB2-simulated natural streamflow as the projected

hydrologic input while using relationships derived from historical PART results to estimate its natural-baseflow component.

The resulting future baseflow estimates are referred to as the PART/BFI method because PART itself cannot be directly applied to an unobserved future streamflow record. Instead, the approach transfers the historical relationship between PART-derived baseflow fractions and hydrologic conditions to SWB2-projected future natural streamflow. The method therefore provides an alternative representation of future natural baseflow while retaining the projected hydrologic variability represented by SWB2 (see Figure G-9). These baseflow estimates were subsequently incorporated into the same water-availability accounting framework used for the primary SWB2 method, allowing differences in calculated local and cumulative excess water availability to be evaluated as sensitivity to the representation of natural baseflow.

Table G-13. Gage- and season-specific regression coefficients used in the PART/BFI method to estimate future natural baseflow for the Southwest Indiana Water Availability Study. For each assessment location and season (Winter, Spring, Summer, and Fall), the slope and intercept were derived from linear regression of the historical PART-derived baseflow index (BFI; natural baseflow divided by natural streamflow) against the natural logarithm of drainage-area-normalized natural streamflow depth (inches per month). The resulting relationships were applied to future SWB2-simulated natural streamflow to estimate the fraction of projected natural streamflow attributable to baseflow. Estimated baseflow fractions were constrained between 0 and 1, and the resulting fraction was applied to projected natural-streamflow volume to calculate future natural baseflow. The regression takes the form $BFI = \text{Intercept} + \text{Slope} \times \ln(Q_{nsf})$, where Q_{nsf} is drainage-area-normalized natural streamflow in inches per month. Subbasin ID, streamgage identification number, and waterway are provided for each assessment location.

Subbasin ID	Gage ID	Waterway	Season	slope	intercept
1	03375500	Patoka River at Jasper, IN	Winter	-0.059	0.212
1	03375500	Patoka River at Jasper, IN	Spring	-0.063	0.263
1	03375500	Patoka River at Jasper, IN	Summer	-0.030	0.153
1	03375500	Patoka River at Jasper, IN	Fall	-0.104	0.139
2	03376300	Patoka River at Winslow, IN	Winter	0.059	0.432
2	03376300	Patoka River at Winslow, IN	Spring	0.044	0.449
2	03376300	Patoka River at Winslow, IN	Summer	0.005	0.283
2	03376300	Patoka River at Winslow, IN	Fall	0.008	0.312
3	03376500	Patoka River at Princeton, IN	Winter	0.120	0.479
3	03376500	Patoka River at Princeton, IN	Spring	0.057	0.548
3	03376500	Patoka River at Princeton, IN	Summer	0.001	0.359
3	03376500	Patoka River at Princeton, IN	Fall	-0.017	0.298
4	03371500	East Fork White River near Bedford, IN	Winter	-0.147	0.616
4	03371500	East Fork White River near Bedford, IN	Spring	-0.221	0.752
4	03371500	East Fork White River near Bedford, IN	Summer	-0.201	0.654
4	03371500	East Fork White River near Bedford, IN	Fall	-0.196	0.534
5	03372500	Salt Creek near Harrodsburg, IN	Winter	-0.051	0.242
5	03372500	Salt Creek near Harrodsburg, IN	Spring	-0.055	0.302
5	03372500	Salt Creek near Harrodsburg, IN	Summer	-0.135	0.167
5	03372500	Salt Creek near Harrodsburg, IN	Fall	-0.193	0.085
6	03373500	East Fork White River near Shoals, IN	Winter	-0.140	0.562
6	03373500	East Fork White River near Shoals, IN	Spring	-0.191	0.709
6	03373500	East Fork White River near Shoals, IN	Summer	-0.202	0.592
6	03373500	East Fork White River near Shoals, IN	Fall	-0.167	0.477
7	03359000	Mill Creek near Manhattan, IN	Winter	-0.155	0.460
7	03359000	Mill Creek near Manhattan, IN	Spring	-0.192	0.622
7	03359000	Mill Creek near Manhattan, IN	Summer	0.006	0.396
7	03359000	Mill Creek near Manhattan, IN	Fall	0.034	0.295
8	03360000	Eel River at Bowling Green, IN	Winter	-0.178	0.512
8	03360000	Eel River at Bowling Green, IN	Spring	-0.203	0.621

Subbasin ID	Gage ID	Waterway	Season	slope	intercept
8	03360000	Eel River at Bowling Green, IN	Summer	-0.125	0.412
8	03360000	Eel River at Bowling Green, IN	Fall	-0.098	0.381
9	03360500	White River at Newberry, IN	Winter	-0.188	0.619
9	03360500	White River at Newberry, IN	Spring	-0.253	0.757
9	03360500	White River at Newberry, IN	Summer	-0.206	0.608
9	03360500	White River at Newberry, IN	Fall	-0.188	0.548
10	03374000	White River at Petersburg, IN	Winter	-0.144	0.619
10	03374000	White River at Petersburg, IN	Spring	-0.240	0.809
10	03374000	White River at Petersburg, IN	Summer	-0.209	0.665
10	03374000	White River at Petersburg, IN	Fall	-0.172	0.577
11	03374100	White River at Hazelton, IN	Winter	-0.154	0.632
11	03374100	White River at Hazelton, IN	Spring	-0.253	0.835
11	03374100	White River at Hazelton, IN	Summer	-0.197	0.682
11	03374100	White River at Hazelton, IN	Fall	-0.171	0.583
0	03341500	Wabash River at Terre Haute, IN	Winter	-0.081	0.619
0	03341500	Wabash River at Terre Haute, IN	Spring	-0.188	0.770
0	03341500	Wabash River at Terre Haute, IN	Summer	-0.134	0.676
0	03341500	Wabash River at Terre Haute, IN	Fall	-0.057	0.566
12	03342000	Wabash River at Riverton, IN	Winter	-0.076	0.599
12	03342000	Wabash River at Riverton, IN	Spring	-0.167	0.757
12	03342000	Wabash River at Riverton, IN	Summer	-0.114	0.711
12	03342000	Wabash River at Riverton, IN	Fall	-0.064	0.591
13	03342500	Busseron Creek near Carlisle, IN	Winter	-0.090	0.550
13	03342500	Busseron Creek near Carlisle, IN	Spring	-0.125	0.630
13	03342500	Busseron Creek near Carlisle, IN	Summer	-0.095	0.478
13	03342500	Busseron Creek near Carlisle, IN	Fall	-0.046	0.443
14	03343010	Wabash River at Vincennes, IN	Winter	-0.099	0.613
14	03343010	Wabash River at Vincennes, IN	Spring	-0.175	0.776
14	03343010	Wabash River at Vincennes, IN	Summer	-0.126	0.698
14	03343010	Wabash River at Vincennes, IN	Fall	-0.076	0.594
15	03345500	Embarras River at Ste. Marie, IL	Winter	-0.109	0.514
15	03345500	Embarras River at Ste. Marie, IL	Spring	-0.205	0.678
15	03345500	Embarras River at Ste. Marie, IL	Summer	-0.141	0.507
15	03345500	Embarras River at Ste. Marie, IL	Fall	-0.148	0.346
16	03346500	Embarras River at Lawrenceville, IL	Winter	-0.073	0.497
16	03346500	Embarras River at Lawrenceville, IL	Spring	-0.122	0.631
16	03346500	Embarras River at Lawrenceville, IL	Summer	-0.139	0.493
16	03346500	Embarras River at Lawrenceville, IL	Fall	-0.170	0.278
17	03377500	Wabash River at Mt. Carmel, IL	Winter	-0.136	0.621
17	03377500	Wabash River at Mt. Carmel, IL	Spring	-0.191	0.763
17	03377500	Wabash River at Mt. Carmel, IL	Summer	-0.132	0.674
17	03377500	Wabash River at Mt. Carmel, IL	Fall	-0.135	0.573
18	03378000	Bonpass Creek at Browns, IL	Winter	-0.062	0.274
18	03378000	Bonpass Creek at Browns, IL	Spring	-0.054	0.299
18	03378000	Bonpass Creek at Browns, IL	Summer	-0.057	0.113
18	03378000	Bonpass Creek at Browns, IL	Fall	-0.080	0.066
19	03378500	Wabash River at New Harmony, IN	Winter	-0.124	0.627
19	03378500	Wabash River at New Harmony, IN	Spring	-0.170	0.775
19	03378500	Wabash River at New Harmony, IN	Summer	-0.134	0.700
19	03378500	Wabash River at New Harmony, IN	Fall	-0.170	0.551
20	Ungauged	Lower Wabash River	Winter	-0.124	0.627
20	Ungauged	Lower Wabash River	Spring	-0.170	0.774
20	Ungauged	Lower Wabash River	Summer	-0.133	0.701
20	Ungauged	Lower Wabash River	Fall	-0.171	0.551

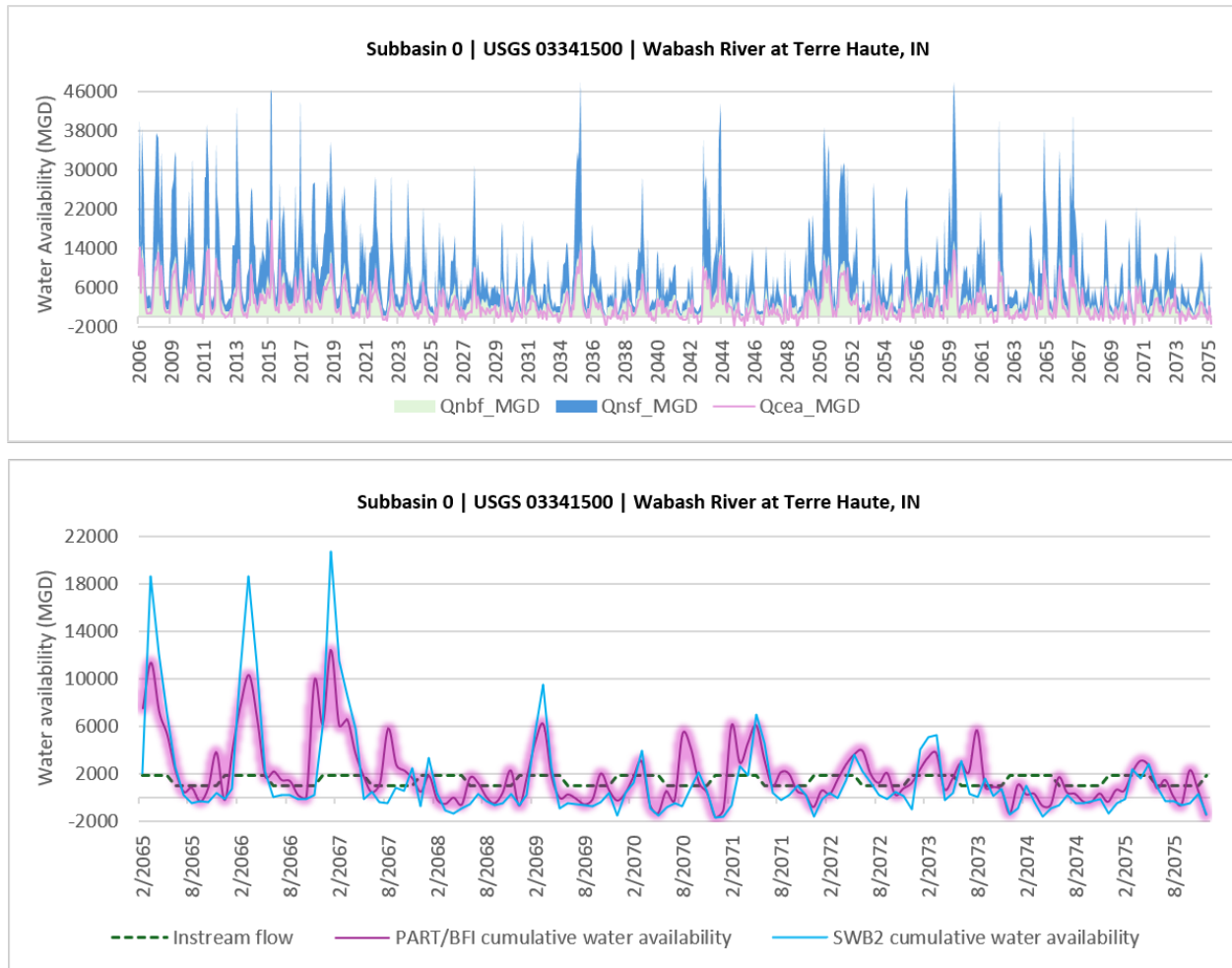


Figure G-9. Example of the full Historical (2007-2024) and Future (2025-2075) cumulative excess water availability (Qcea) time series for an example subbasin in the Southwest Indiana study area (Subbasin 0, 03341500, Wabash River at Terre Haute, Indiana), top graph. The derived components natural streamflow (Qnsf) and natural baseflow (Qnbf) are shown so availability volumes can be compared to total water flow in the river (converted to units of MGD). The bottom graph compares the Qcea time series (2/2065 to 10/2075) as calculated by the two methods (SWB2 and PART/BFI) to derive estimates of natural baseflow (Qnbf), which is the volume that underpins the water availability estimates.

G.4.8 Notation Glossary

Table G-14. Governing notation for the SWB2 streamflow and baseflow post-processing framework.

Symbol	Meaning and use
RO / NI	SWB2 runoff / net infiltration; depth before zonal conversion and volume after conversion is stated explicitly
Qusgs	Observed monthly USGS streamflow volume
Qnsf	Monthly natural streamflow target reconstructed from gage flow and anthropogenic terms
Qsim	Monthly streamflow simulated from accumulated runoff plus conceptual-reservoir discharge
Qbf	Simulated effective groundwater-discharge or baseflow component
S	Conceptual groundwater storage carried between monthly time steps
k_g	Monthly groundwater recession coefficient calibrated for assessment location g
α	Net-infiltration scaling coefficient calibrated as separate wet- and dry-season values for each gage
Qww / Qrf / Qstor	Withdrawal / return-flow / signed reservoir-operation terms used in calculating natural streamflow and scenario accounting

G.4.9 Interpretation and limitations

The post-processing framework provides a consistent bridge between spatially distributed SWB2 water-balance outputs and the monthly streamflow and baseflow terms required by the regional assessment. Its strengths are transparent mass accounting, limited parameterization, preservation of monthly antecedent storage, and direct application to a common historical-future framework. Its principal limitations arise from the assumption of same-month runoff delivery, a single linear groundwater store at each calibrated outlet, stationary future calibration parameters, incomplete representation of cross-boundary drainage and karst transfer, and uncertainty in the natural calibration target.

Results should therefore be interpreted as scenario-based monthly hydrologic inputs appropriate to regional comparison, not as forecasts of daily discharge or simulations of aquifer heads, channel hydraulics, reservoir operations, or individual groundwater flow paths. The separate reporting of accumulated runoff, net infiltration, simulated baseflow, natural streamflow, and anthropogenic terms allows users to identify which component controls a result and where future refinements would have the greatest value.

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