Regional Water Planning Study Appendix B Integration of Future Climate in Demand and Supply Projections

Wabash Headwaters Region

Jacobs Engineering Group Inc.

Report to Indiana Finance Authority

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Acronyms and Abbreviations

°C	degree(s) Celsius
°F	degree(s) Fahrenheit
CAFO	concentrated animal feeding operation
CESM1-CAM5	Community Earth System Model Version 1 Community Atmosphere Model Version 5
CFO	confined feeding operation
CO_2	carbon dioxide
CPI	consumer price index
GCM	global circulation model
GFDL-CM3	National Oceanic and Atmospheric Association Geophysical Fluid Dynamics Laboratory Climate Model Version 3
$gtCO_2$	gigaton(s) carbon dioxide
MGD	million gallon(s) per day
MHI	median household income
N/A	not applicable
RCP	representative concentration pathway
study, the	Wabash Headwaters Region Regional Water Study
study area	Wabash Headwaters Region study area
U.S.	United States
USGS	U.S. Geological Survey
VIC	variable infiltration capacity

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B1 Climate Projections Used in Study

B1.1 Available Climate Change Datasets

To evaluate future water use demands and water availability within the Wabash Headwaters Region study area (study area), future projections were developed to account for potential changes in climate and hydrology. Climate and hydrology datasets representing projected climate and hydrologic conditions were developed as part of a study that evaluated potential impacts of climate change on the state of Indiana (Cherkauer, 2021;Hamlet et al., 2019). As part of the study, climate projections from 10 global circulation models (GCMs) were analyzed for two separate representative concentration pathways (RCPs): RCP4.5 and RCP 8.5.

The GCMs simulate the physics of the climate capturing the flows of air and water in the atmosphere and/or the oceans, as well as the transfer of heat. These models conduct climate projections in three dimensions, incorporating many kilometers of height in the atmosphere or depth of the oceans in dozens of model layers. The RCP provide plausible descriptions of the future, based on socio-economic scenarios of how global society grows and develops. There are four pathways scientists use across the globe as inputs for climate models to generate projections of climate change impacts and assess the effects of different emission scenarios: RPC2.6, RPC4.5, RPC6.0 and RPC8.5. The number represents the amount of energy that warms the Earth, the higher the number is, the higher the carbon emissions are. The 10 models included in the study are listed as follows:

- Community Earth System Model Version 1 Community Atmosphere Model Version 5 (CESM1-CAM5)
- National Oceanic and Atmospheric Administration Geophysical Fluid Dynamics Laboratory Climate Model Version 3 (GFDL-CM3)
- National Oceanic and Atmospheric Administration Geophysical Fluid Dynamics Laboratory Earth System Model Modular Ocean Model Version 4.1
- First Institute of Oceanography Earth System Model
- Hadley Centre Global Environment Model Version 2 Atmosphere-Ocean
- Hadley Centre Global Environment Model Version 2 Carbon Cycle
- Community Climate System Model Version 4
- Community Climate System Model Climate Model
- Hadley Centre Global Environment Model Version 2 Earth System Model
- Model for Interdisciplinary Research on Climate Version 5

The model names indicate the names of the institutions that developed the models, along with the model type (earth system, ocean, atmosphere-ocean, carbon cycle). Datasets from the Indiana climate change study (Hamlet et al., 2019) are available for public use and include projected changes in precipitation, temperature, and streamflow at U.S. Geological Survey (USGS) gauging stations throughout the state of Indiana for the 10 GCMs and 2 RCPs. Projected climate and streamflow datasets for this study were developed using a climate period analysis, which entails scaling precipitation and temperature for a selected historical period by projected changes in precipitation and temperature as defined by a GCM. The Hamlet study selected the 1984 through 2013 period for the basis of their climate period analysis. Precipitation and temperature for this period were then adjusted to reflect precipitation and temperature conditions for three future 30-year periods. The three climate periods were defined as follows:

- Period 1: 2011 through 2040
- Period 2: 2041 through 2070
- Period 3: 2071 through 2100

As part of the Hamlet study, a variable infiltration capacity (VIC) model was developed for Indiana and used to evaluate historical and future streamflow conditions throughout the state. The VIC model provides the capability of using the projected climate datasets as input to the model to produce routed streamflow at select locations, in this case streamflow as generated at each USGS gauging station.

B1.2 Selection of Climate Projections

A selection process was conducted to decide on one GCM and one RCP from Hamlet et al. (2019) for use as the baseline future projection to evaluate future water demand and water availability. The selection of the RCP was based on a reasonably likely scenario following the historical trend of carbon emissions. As can be observed in Figure B1-1, the actual emissions from 1959 through 2017 trend is closest to RCP8.5 pathway (the highest of the four). The selection of the GCM focused primarily on projected changes in streamflow patterns because streamflow is a key driver of the historical water availability for the study area. In addition to the baseline scenario, three other models were selected to conduct additional demand scenarios and gain a better understanding of the impact of climate change on future water demands. Figure B1-2 presents annual streamflow volumes at the Sub-basin 9 Deer Creek-Delphi gauge as an example used to characterize annual variability across the 10 GCMs and 2 RCPs evaluated.

Based on evaluation of projected streamflow conditions, the GCMs selected for the water demand and water availability analysis are as follows:

For the baseline, climate data and streamflow data were extracted from the CESM1-CAM5-RCP8.5 model, which was developed by the National Center for Atmospheric Research. This model was used to project study's baseline climate conditions assuming high greenhouse gas emissions. Under the RCP 8.5 scenario, Indiana is expected to experience significant warming, with average temperature rising 7 degrees Fahrenheit (°F) by the end of the century. Precipitation changes would be expected to include more intense rainfall events and seasonal shifts (Byun and Hamlet, 2018; Byun, n.d.). These changes could impact user sectors such as irrigation and public water utilities.

- Climate models used for alternative demand predictions are as follows:
  - **CESM1-CAM5-RCP 4.5 (cool/wet):** This model was used for Cooler Demand projections under moderate greenhouse gas emissions. The RCP 4.5 is considered a stabilization scenario where greenhouse gas emissions peak in 2040 and then decline, leading to a stabilization of the radiative forcing at 4.5 watts (W)/square meter by 2100. The model projects moderate warming with temperatures increasing by 2 to 3 degrees Celsius (°C) by the end of the century. Changes in precipitation patterns are expected to include intense rainfall events and precipitation in winter and spring (Byun and Hamlet, 2018; Byun, n.d.).
  - **GFDL-CM3-RCP 8.5 (hot/wet):** This model was developed by the Geophysical Fluid Dynamics Laboratory. The RCP 8.5 high-emission scenario projects significant changes in climate due to increasing greenhouse gas concentrations. Indiana is expected to experience substantial warming, with average temperatures rising significantly by the end of the century. This could lead to hotter summers and mild winters. Changes in precipitation patterns are also expected

with more intense rainfall and shift in seasonal precipitation. Intensity and frequency of extreme events would be expected to increase.

- **HadGEM-2AO-RCP 4.5 (hot/dry):** This model was developed by the UK Met Office. It is part of the Hadley Centre Global Environment Model family and includes an atmospheric, ocean, and sea ice model. The RCP 4.5 assumed moderate changes in temperature and precipitation but provides different responses than the CESM1-CAM5-RCP 4.5 scenario due to its unique processes. Also, its higher resolution may provide more detailed regional climate projections.

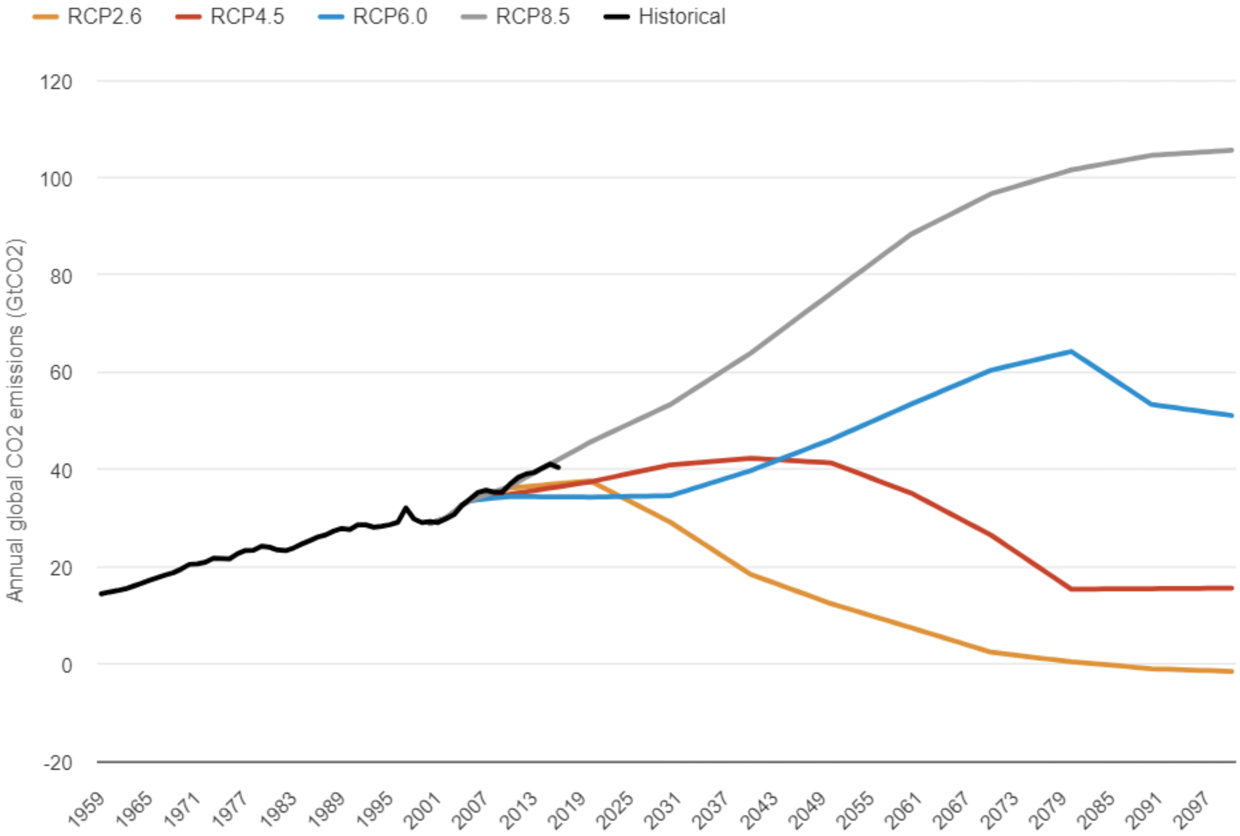


Figure B1-1. Global Carbon Emissions and Scenarios for the 21st Century

CO_2 = carbon dioxide
$gtCO_2$ = gigatons carbon dioxide

Source: from Analysis: Just four years left of the 1.5C carbon budget - Carbon Brief article (McSweeney and Pearce, 2017). *The figures uses historical data from* Global Carbon Project *from the Analysis and data | European Environment Agency's home page and scenarios from Potsdam Institute for Climate Impact Research, plotted by Carbon Brief.*

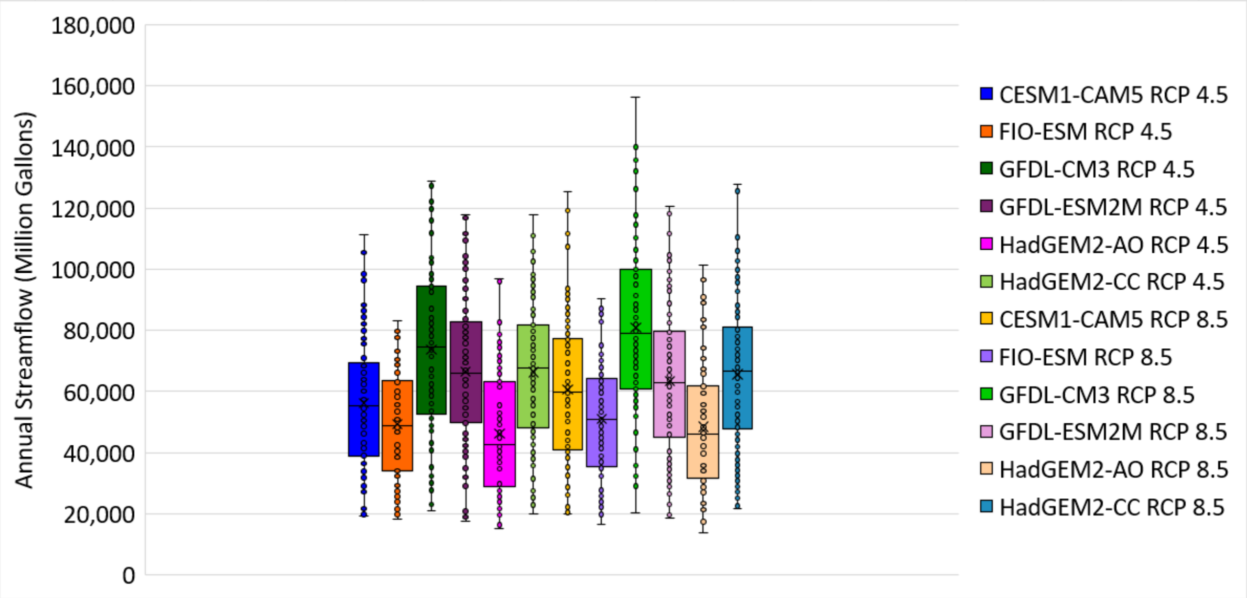


Figure B1-2. Annual Streamflow Volume for 10 Global Circulation Models and 2 Representative Concentration Pathways at Sub-basin 9 (Deer Creek-Delphi) Streamflow Gauge

B2 Incorporation of Baseline Climate Projections

B2.1 Future Water Demand

The climate explanatory variables of temperature and precipitation were included in the demand forecast for energy production, industrial, irrigation (including agriculture and golf courses), and public supply sectors. These variables provide insight into the influence of climate factors on water demand. Table B2-1 and Table B2-2 show the percent of users in each sub-basin with maximum temperature or precipitation, respectively, as an explanatory variable. Temperature and precipitation are explanatory variables for some users.

Table B2-1. Percent of Users in Each Sector with Maximum Temperature as an Explanatory Variable

Sub-basin Number and Name	Energy Production	Industrial	Irrigation	Public Supply
1 Mississinewa-Marion	N/A	50	100	93
2 Salamonie-Warren	100	100	100	71
3 Wabash-Linn Grove	N/A	50	50	75
4 Little-Huntington	N/A	67	100	75
5 Wabash-Wabash	N/A	83	75	67
6 Wabash-Peru	N/A	100	100	100
7 Eel-North Manchester	N/A	100	75	71
8 Wabash-Logansport	N/A	79	100	80
9 Deer Creek-Delphi	N/A	100	100	83
10 Wabash-Ungauged	N/A	83	100	67

N/A = not applicable

Table B2-2. Percent of Users in Each Sector with Precipitation as an Explanatory Variable

Sub-basin Number and Name	Energy Production	Industrial	Irrigation	Public Supply
1 Mississinewa-Marion	N/A	50	66	93
2 Salamonie-Warren	100	100	100	71
3 Wabash-Linn Grove	N/A	50	50	75
4 Little-Huntington	N/A	33	100	75
5 Wabash-Wabash	N/A	83	75	67
6 Wabash-Peru	N/A	100	100	100
7 Eel-North Manchester	N/A	100	75	71
8 Wabash-Logansport	N/A	67	100	80
9 Deer Creek-Delphi	N/A	100	100	83
10 Wabash-Ungauged	N/A	83	100	67

The only energy production user in the watershed (Montpelier Generating Station LLC) has temperature, precipitation, median household income (MHI), and inflation adjusted Consumer Price Index (CPI) as its explanatory variables.

Industrial uses are influenced by temperature, precipitation, population, and inflation adjusted CPI as explanatory variables for their future projections. However, their water use is rarely influenced by MHI. Ohio industrial demand, along with seven other users in Indiana were projected using either a trendline or a constant value projecting the average consumption of the last few years.

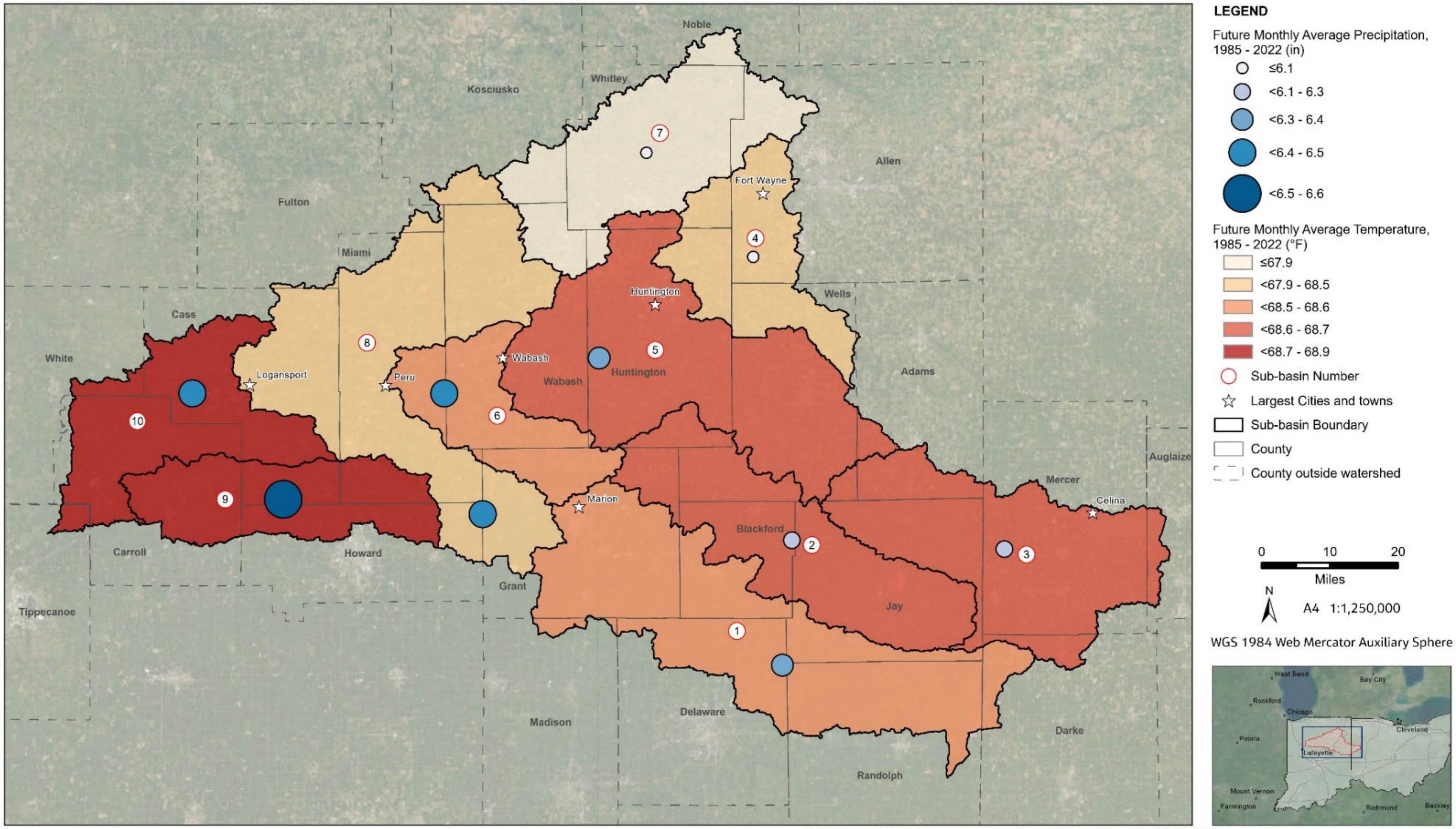
Use in the irrigation sector were modeled considering their annual peak water demand and using maximum temperature and average precipitation as the explanatory variables. The only exceptions were two golf courses in Sub-basins 5 and 7, as well as the irrigation demand forecast for the Ohio portion of the watershed. These users were projected as a linear trend into the future.

Like industrial uses, the majority of public supply water demand is influenced by temperature, precipitation, population, and inflation adjusted CPI as the explanatory variables. Approximately half of individual public water suppliers' demand is influenced by MHI as well. The main exceptions are small users, such as schools, manufactured housing, Ohio demand, and other small public utilities without an assigned service area. These smaller users were modeled using a trend analysis. The only large public supplier modeled using trend analysis was Peru Utilities, which consists of Peru Utilities Board, City of Peru Utilities, and Grissom Air Reserve Base facilities.

Five out of eight miscellaneous users are influenced by temperature and precipitation, and these variables were used to forecast future water demand. Water demand forecasts for the rest used either simple trendline or the average consumption of the last few years as a constant value. Rural water use was modeled using trend projections of monthly data that reflect the seasonality observed in historical demand.

Water demand time series forecasts for self-supplied concentrated animal feeding operation (CAFO) and confined feeding operation (CFO), as well as self-supplied residential water users, were develop using animal and human population data and per capita water use. Because these were already synthetic curves, their forecast did not use any explanatory variables.

Figure B2-1 shows the projected (2022 to 2100) monthly average precipitation and temperature by sub-basin. Figures B2-2 and B2-3 show the seasonal average maximum temperature and precipitation for 2022 and the projected baseline 2070. They also show a heat map with the difference in maximum temperature and precipitation to assess how much change in those two climate factors may be expected in the 50-year period.



Data Sources: CEC North American Atlas (2024),IN Gov (2024), TIGER (2024), USGS (2021), JACOBS (2024); Imagery Sources: ESRI Online Imagery Services
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Figure B2-1. Future Precipitation and Temperature per Sub-basin from 2022 to 2100

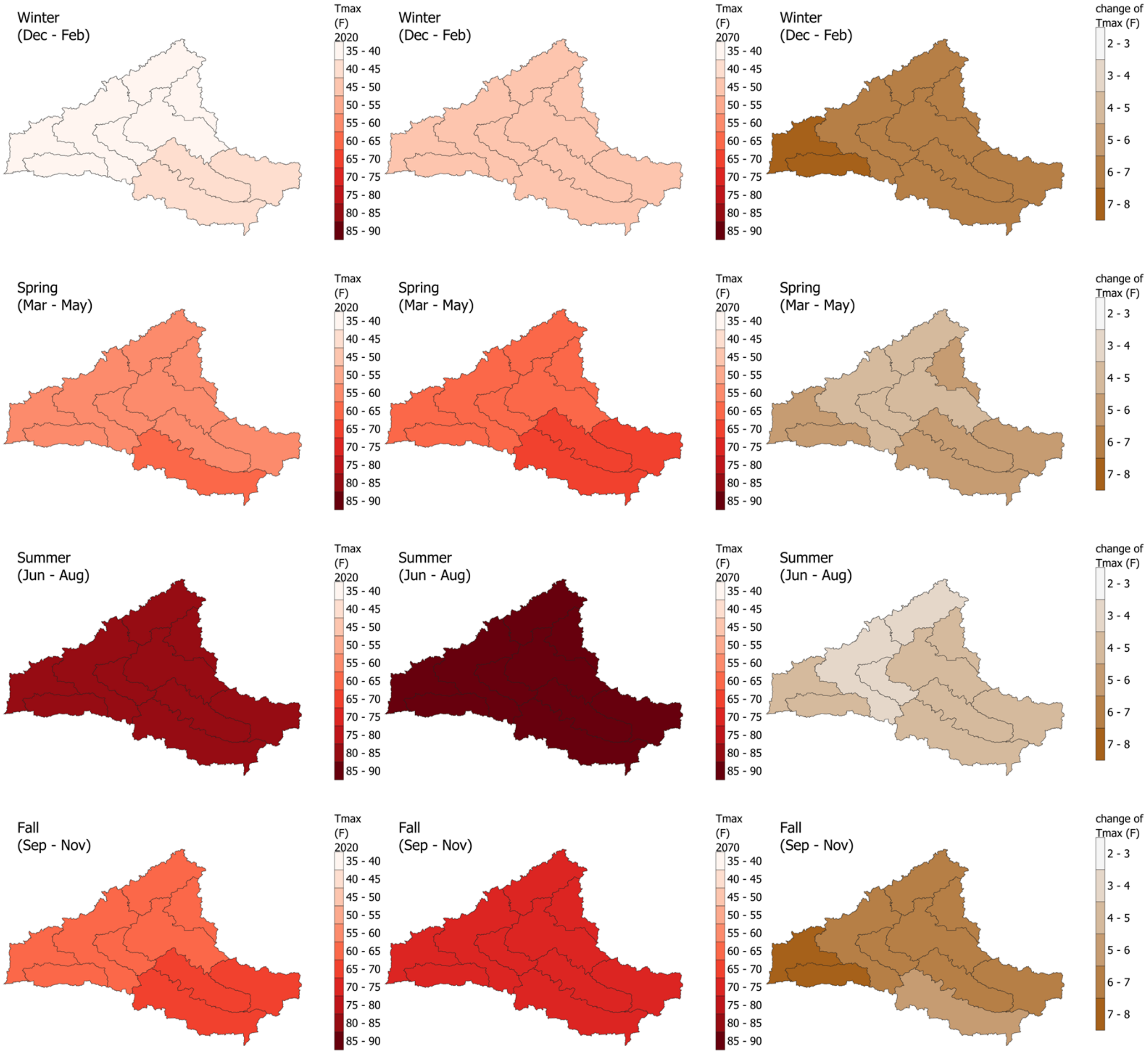

Figure B2-2. Seasonal Average Daily Maximum Temperature (Fahrenheit) for Baseline Scenario (2020, 2070, and Expected Change in Maximum Temperature Between the 2 Years)

Daily maximum temperature in the study area ranges from 35 to 90°F, with highest temperatures registered in the summer and lowest temperatures in the winter. From 2020 to 2070, the daily maximum temperature is expected to increase 2 to 8°F. Even though the increase in temperature is seen in all four seasons, the biggest increases are projected to occur in the winter and fall. Historical data (2020) shows larger differences between seasons, while in the future (2070) the differences become smaller. Current temperatures (2020) show two distinct areas in the southwest portion of the watershed where higher temperatures have been registered. This seems to occur in all seasons except summer where the temperature distribution appears to reach the same maximum temperatures across the entire watershed. Future projections (2070) show maximum temperature will not vary as much between sub-basins. Only in the spring might higher temperatures occur in the southwest region. The downstream end of the watershed (Sub-basins 9 and 10) is expected to experience the greatest increase in temperature over the forecasting period.

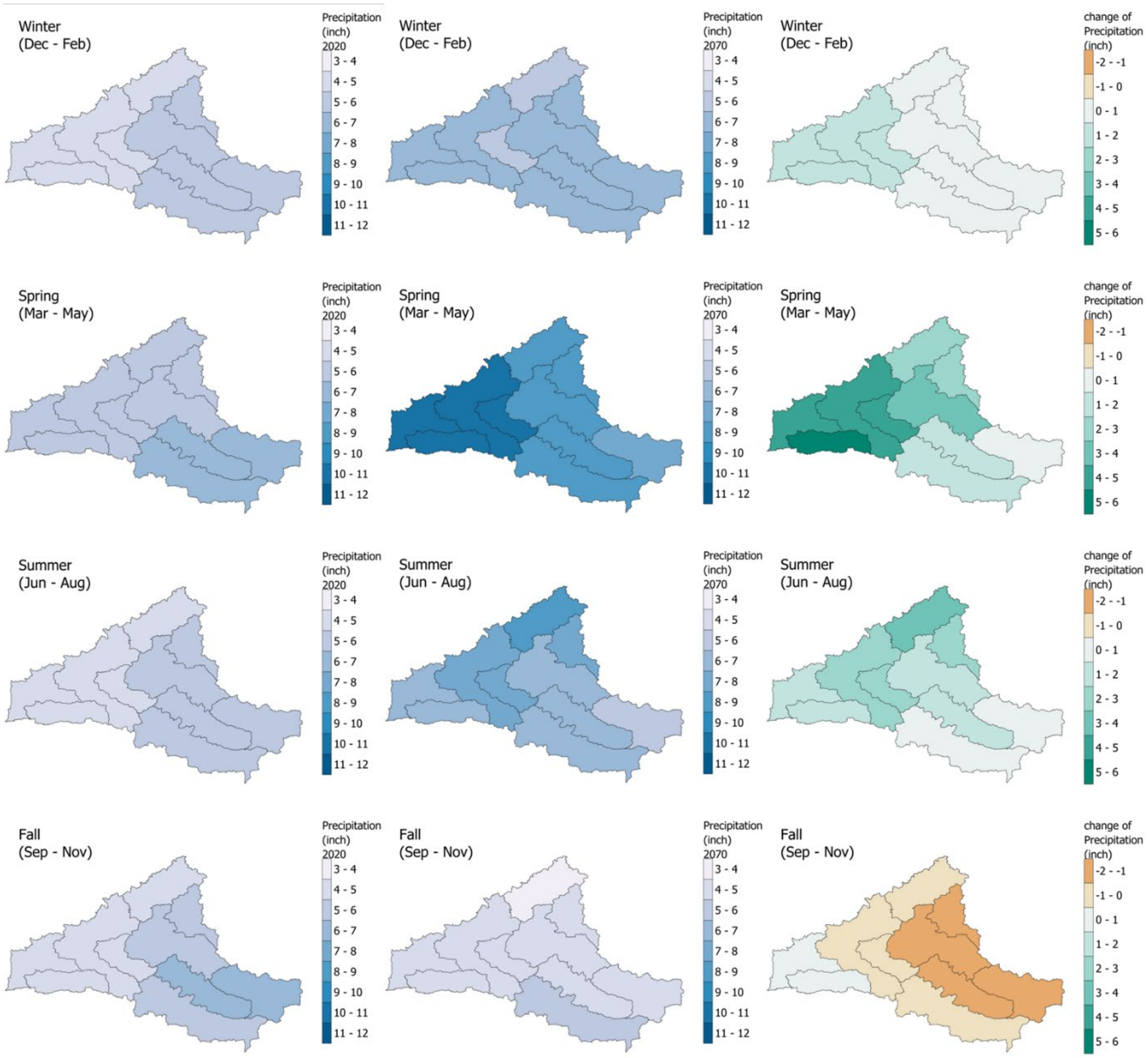

Figure B2-3. Seasonal Average Monthly Precipitation (inches) for Baseline Scenario (2020, 2070, and Expected Change in Precipitation Between the 2 Years)

Monthly precipitation in the study area ranges from 3 to 7 inches for the historical period (2020) and it is projected to increase to 3 to 12 inches by 2070. The largest increase will be observed in spring, followed by summer and winter. In fall, precipitation is projected to decrease by 1 to 2 inches across the watershed. Overall, future precipitation will increase and show higher seasonal variations. Currently (2020), higher precipitation is recorded in the headwaters of the watershed (Sub-basin 3). In the future (2070), increased precipitation (6 to 7 inches) would be distributed across the watershed during the winter and fall. In the spring, heavy precipitation is expected in the downstream part of the watershed (Sub-basins 6, 8, 9, and 10).

B2.2 Future Water Supply

The following sections describe in detail how each of the water availability components were projected forward to reflect conditions in the selected future baseline scenario.

B2.2.1 Return Flows

Projected future return flows were estimated by applying monthly fractions to the projected water demands on a sub-basin and water use sector basis. Irrigation and CAFOs water use categories used a 20% uniform fraction to characterize historical return flows. The same assumption was used to estimate projected future return flows associated with irrigation and CAFOs water uses. Similarly, return flows associated with self-supplied residential water use were estimated using monthly factors ranging from 81% in June through August, 93% in September through November, 98% in March through May, and 100% in December through February (Shaffer, 2009). Projected future return flows for self-supplied residential use used the same monthly factors as was used to estimate historical return flows.

For other water use categories, including public supply, energy, industrial, rural, and miscellaneous, an analysis was performed to develop monthly return flow fractions by comparing monthly historical extractions to return flows to estimate typical fractions of consumptive use for each sub-basin and water use sector. Table B2-3 presents the monthly public supply return flow fractions for each sub-basin. Table B2-4 presents the monthly industrial return flow fractions for each sub-basin.

Table B2-3. Public Supply Return Flow Fractions

Sub-basin Number and Name	January	February	March	April	May	June	July	August	September	October	November	December
1 Mississinewa-Marion	0.57	0.68	0.78	0.95	0.94	1.07	0.98	0.83	0.65	0.55	0.52	0.51
2 Salamonie-Warren	1.65	1.78	1.92	2.09	2.04	2.34	2.16	1.90	1.86	1.65	1.52	1.58
3 Wabash-Linn Grove	1.44	1.55	1.93	1.90	2.21	2.82	2.55	1.95	1.94	1.33	1.18	1.22
4 Little-Huntington	1.35	1.63	1.90	2.00	2.06	2.26	2.00	1.75	1.36	1.24	1.14	1.19
5 Wabash-Wabash	0.47	0.50	0.51	0.52	0.51	0.56	0.56	0.55	0.49	0.46	0.49	0.49
6 Wabash-Peru	0.90	0.97	1.07	1.02	1.04	1.26	1.17	1.16	1.01	0.92	0.90	0.89
7 Eel-North Manchester	1.18	1.37	1.53	1.49	1.53	1.65	1.84	1.51	1.29	0.98	1.05	1.03
8 Wabash-Logansport	5.35	5.93	6.49	7.17	7.57	9.11	8.97	8.63	7.72	7.00	5.81	5.23
9 Deer Creek-Delphi	1.32	1.46	1.81	2.16	2.18	2.63	2.69	2.38	2.15	1.63	1.30	1.20
10 Wabash-Ungauged	1.28	1.35	1.42	1.54	1.58	1.68	1.75	1.59	1.48	1.40	1.28	1.21

Table B2-4. Industrial Water Supply Return Flow Fractions

Sub-basin Number and Name	January	February	March	April	May	June	July	August	September	October	November	December
1 Mississinewa-Marion	1.00	0.96	0.95	0.99	0.92	0.99	0.98	0.98	1.00	0.94	0.97	0.96
2 Salamonie-Warren	0.70	0.68	0.65	1.08	0.96	1.00	0.67	0.71	0.76	0.59	0.57	0.60
3 Wabash-Linn Grove	0.96	1.19	0.87	1.22	1.09	1.10	1.24	1.04	1.09	1.14	0.91	0.90
4 Little-Huntington	0.32	0.31	0.32	0.43	0.42	0.41	0.42	0.45	0.41	0.33	0.31	0.33
5 Wabash-Wabash	0.70	0.74	0.75	0.92	0.95	1.04	0.80	0.81	0.82	0.61	0.61	0.70
6 Wabash-Peru	1.19	1.64	1.78	1.11	1.09	1.09	1.35	1.16	1.08	1.04	1.01	0.94
7 Eel-North Manchester	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8 Wabash-Logansport	0.94	0.97	0.91	1.04	1.13	1.31	0.86	0.89	1.12	0.81	0.89	0.96
9 Deer Creek-Delphi	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10 Wabash-Ungauged	0.53	0.54	0.57	0.63	0.70	0.73	0.73	0.66	0.60	0.51	0.52	0.56

N/A = not applicable; this sub-basin does not include industrial water use

B2.2.2 Natural Streamflow

The following sections describe the approach used to develop future projections of natural streamflow for use in evaluating future water availability. The approach described herein includes mapping historical estimates of natural streamflow into the future using a streamflow index, and application of monthly streamflow change factors to scale future streamflow in response to potential changes in climate.

Streamflow Index Approach

To characterize natural streamflow for the future, a streamflow index approach was used to identify years within the study's historical period (2007 through 2022) with similar hydrology to the historical years (1984 through 2013) used in the climate period analysis implemented for the state of Indiana (Hamlet et al., 2019) that is being leveraged for this study. Annual winter and spring streamflow volumes and summer and fall streamflow volumes were quantified at USGS gauges for the historical study period (2007 through 2022) and the historical climate period (1984 through 2013). Because the two periods overlap between 2007 and 2013, the need for a streamflow index is required only for the historical climate period from 1984 through 2006. The selection of USGS streamflow gauges used in the development of the streamflow index was expanded beyond the streamflow gauges in the study area to include streamflow gauges that cover the area of the North Central Indiana Study. These studies were conducted in parallel tracks, and this approach was developed in close coordination. The intent with expanding the streamflow gauge network for use in characterizing hydrology is to capture potential spatial variability in climate and hydrologic response to ensure the index approach captures streamflow dynamics in combined water supply studies areas of Wabash Headwaters and North Central Indiana Studies (Jacobs, 2025; Stantec, 2025 in progress). Figure B2-4 shows a map of the streamflow gauges included in the streamflow index approach.

After quantifying the annual winter and spring streamflow volume and summer and fall streamflow volume at each gauge for the two historical periods, each historical year in the climate period analysis was assigned a year from the historical water availability period that had the closest seasonal streamflow volumes as the climate period year. Figure B2-5 shows an example of this process for Sub-basin 7 (Eel-North Manchester), where streamflow volumes for the two seasons are plotted for the historical and climate periods for comparison of seasonal flow volumes. Examples of how the historical period years are mapped to the climate period years are highlighted in the red boxes within Figure B2-5. This approach was applied across all gauges previously mentioned. The final set of years used in the streamflow index were developed based on the historical period years that had the highest number of occurrences across all gauges; therefore, years were selected that tended to closely represent hydrologic conditions across the region.

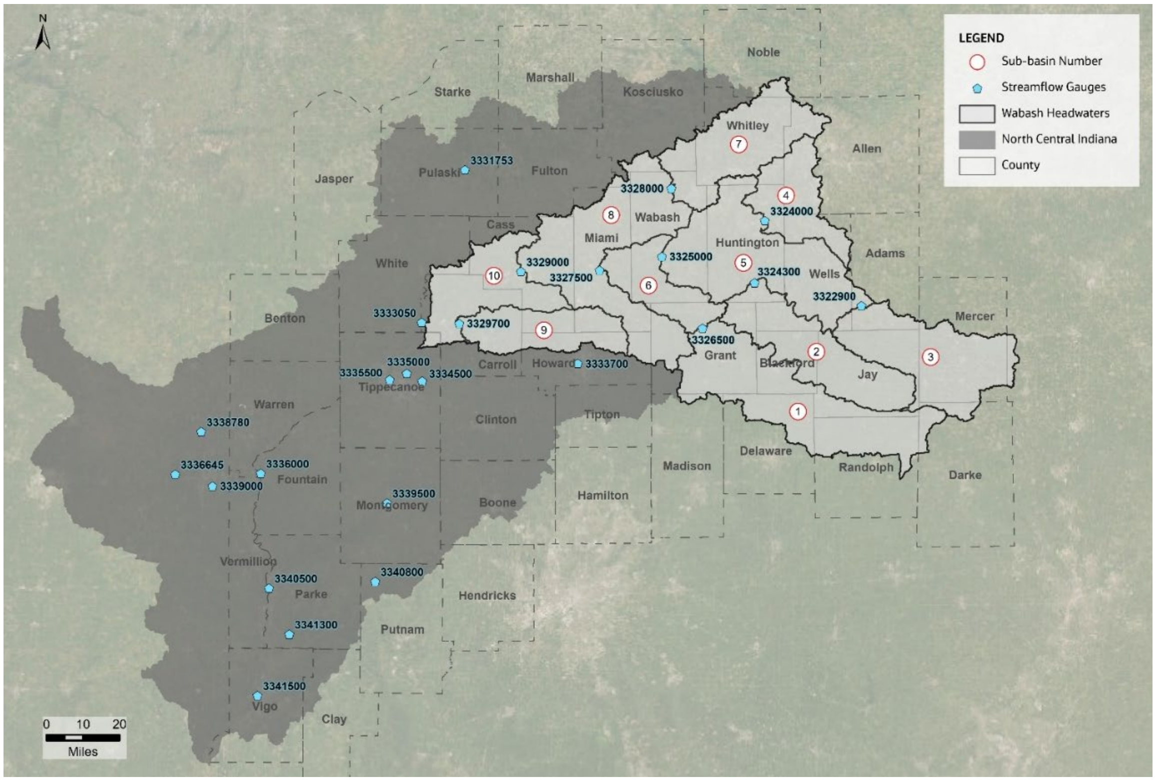

Figure B2-4. U.S. Geological Survey Streamflow Gauging Stations Included in Streamflow Index Development

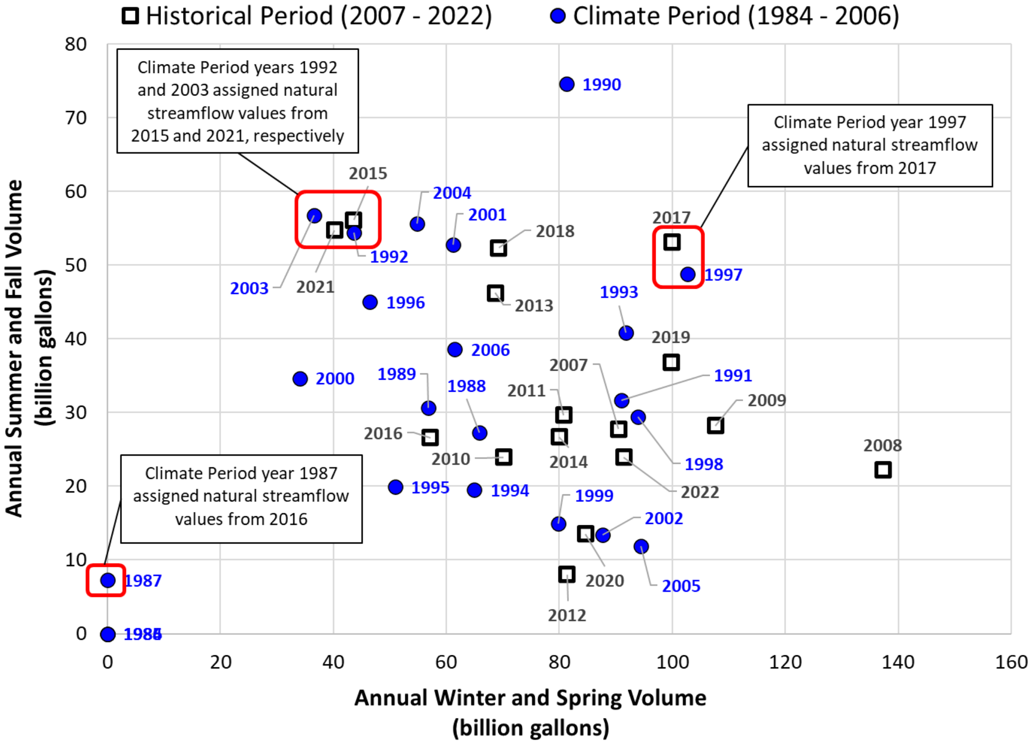

Figure B2-5. Example of Relating Seasonal Streamflow Volumes between Historical and Climate Periods for Sub-basin 7, Eel-North Manchester

Table B2-5 shows the relationship among historical climate period years, streamflow index years, and how they map to future years for the three climate periods.

Table B2-5. Climate Period Years and Related Streamflow Index Years and Their Relationship to Future Years for Each Climate Period

Historical Climate Period Years	Streamflow Index Years	Future Years Period 1 (2011 through 2040)	Future Years Period 2 (2041 through 2070)	Future Year Period 4 (2071 through 2100)
1984	2020	N/A	2041	2071
1985	2013	N/A	2042	2072
1986	2014	N/A	2043	2073
1987	2021	N/A	2044	2074
1988	2012	N/A	2045	2075
1989	2021	N/A	2046	N/A
1990	2018	N/A	2047	N/A
1991	2007	N/A	2048	N/A
1992	2018	N/A	2049	N/A
1993	2017	N/A	2050	N/A
1994	2016	N/A	2051	N/A
1995	2021	N/A	2052	N/A
1996	2021	2023	2053	N/A
1997	2011	2024	2054	N/A
1998	2018	2025	2055	N/A
1999	2012	2026	2056	N/A
2000	2021	2027	2057	N/A
2001	2021	2028	2058	N/A
2002	2022	2029	2059	N/A
2003	2015	2030	2060	N/A
2004	2010	2031	2061	N/A
2005	2007	2032	2062	N/A
2006	2010	2033	2063	N/A
2007	2007	2034	2064	N/A
2008	2008	2035	2065	N/A
2009	2009	2036	2066	N/A
2010	2010	2037	2067	N/A
2011	2011	2038	2068	N/A
2012	2012	2039	2069	N/A
2013	2013	2040	2070	N/A

Monthly Streamflow Change Factors

VIC simulated streamflow datasets for historical and baseline future scenarios were obtained for each of the USGS gauging stations in the study area (Hamlet et al., 2019). Because the future streamflow datasets are based on modeled values, any potential model biases must be isolated and removed when evaluating the potential changes in streamflow due to projected changes in climate. To evaluate changes in streamflow due to climate change, monthly streamflow change factors were calculated for each USGS gauge by first calculating the average monthly historical and future streamflow and second, dividing the future monthly average streamflow by the historical monthly average streamflow for each of the three climate periods. Comparing future modeled streamflow to historical modeled streamflow in this manner reduces any potential VIC model bias on streamflow dynamics by isolating the change in streamflow resulting from changes in climate.

The monthly streamflow factors can then be applied to the historical natural streamflow developed for the water availability study to scale monthly streamflow to reflect projected changes in climate. Figure B2-6 through Figure B2-8 show monthly change factors for all sub-basins in the study area for each climate period. In addition, the monthly change factors are shown in Tables B2-6 through Table B2-8 for the 2011 through 2040, 2041 through 2070, and 2071 through 2100 climate periods, respectively. When the monthly streamflow change factor is greater than 1.0, streamflow is projected to increase in that month in the future, and when the monthly streamflow change factor is less than 1.0, streamflow is projected to decrease in that month in the future. Monthly streamflow change factors are applied according to the climate period that is represented by the monthly streamflow factor. For example, years between 2041 and 2070 are scaled based on the Period 2 monthly streamflow change factors. In general, during Climate Period 1, streamflow is projected to decrease during winter months (December through February), increase in spring months (March through May), and decrease in summer (June through August) and fall months (September through November). Streamflow under Climate Period 2 generally is projected to increase during winter and spring and decrease during summer and fall months. Similarly, streamflow under Climate Period 3 generally is projected to increase during winter and spring and decrease during summer and fall months. Through time projected increases and decreases in streamflow tends to increase. For example, Climate Period 2 shows larger increases during winter than Climate Period 1, and Climate Period 3 shows larger increases during winter than Climate Period 2. Similarly, Climate Period 3 shows the largest decreases in fall streamflow.

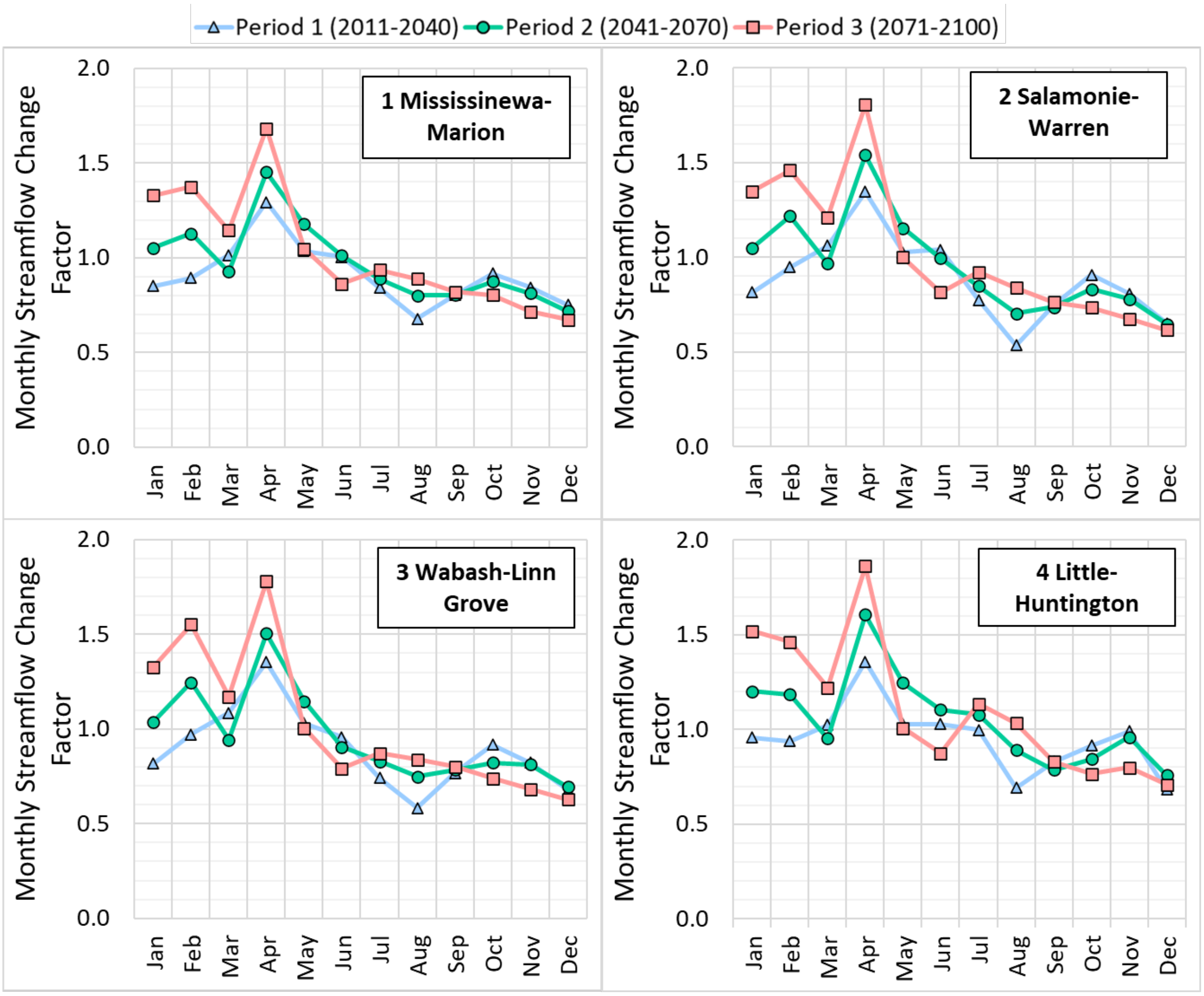

Figure B2-6. Monthly Streamflow Change Factors for Sub-basins 1 through 4 for Each Climate Period

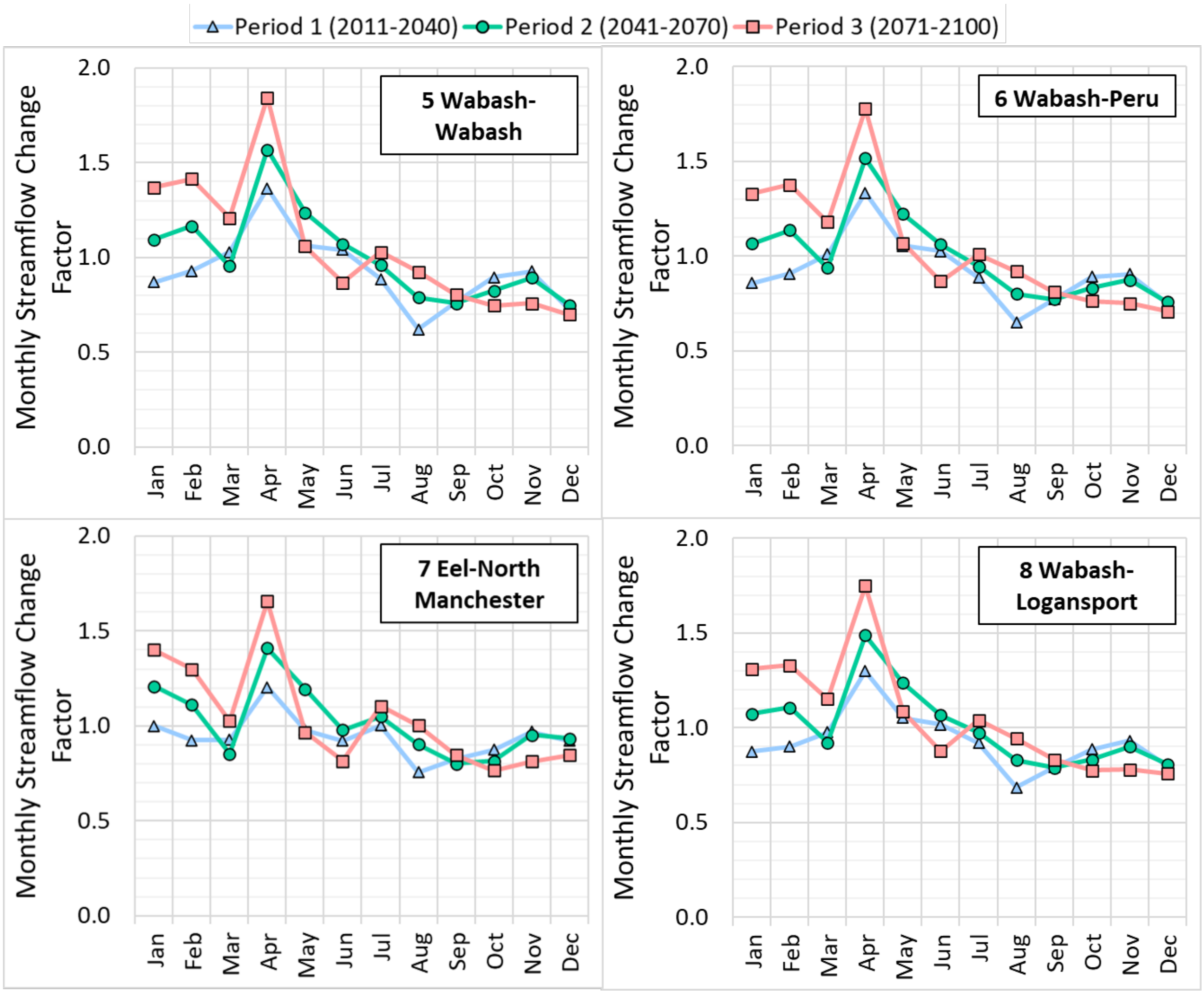

Figure B2-7. Monthly Streamflow Change Factors for Sub-basins 5 through 8 for Each Climate Period

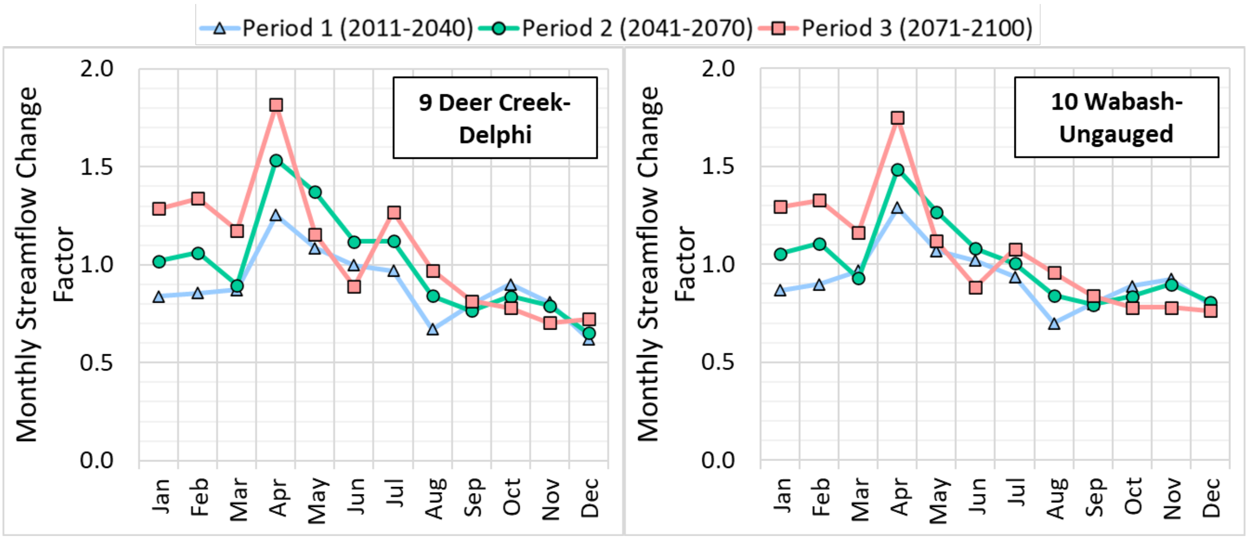

Figure B2-8. Monthly Streamflow Change Factors for Sub-basins 9 and 10 for Each Climate Period

Table B2-6. Period 1 (2011 through 2040) Monthly Streamflow Change Factors

Sub-basin Number and Name	January	February	March	April	May	June	July	August	September	October	November	December
1 Mississinewa-Marion	0.85	0.89	1.02	1.29	1.04	1.00	0.84	0.68	0.80	0.92	0.84	0.75
2 Salamonie-Warren	0.82	0.95	1.06	1.35	1.03	1.04	0.77	0.54	0.75	0.91	0.81	0.65
3 Wabash-Linn Grove	0.82	0.97	1.09	1.35	1.03	0.96	0.74	0.58	0.77	0.92	0.82	0.68
4 Little-Huntington	0.96	0.94	1.02	1.36	1.03	1.03	1.00	0.69	0.83	0.91	0.99	0.68
5 Wabash-Wabash	0.87	0.93	1.03	1.36	1.06	1.04	0.89	0.62	0.77	0.90	0.93	0.73
6 Wabash-Peru	0.86	0.91	1.01	1.33	1.05	1.03	0.89	0.65	0.77	0.89	0.91	0.75
7 Eel-North Manchester	1.00	0.92	0.93	1.20	0.98	0.92	1.00	0.76	0.82	0.87	0.97	0.92
8 Wabash-Logansport	0.88	0.90	0.98	1.30	1.05	1.02	0.92	0.69	0.79	0.89	0.93	0.80
9 Deer Creek-Delphi	0.84	0.85	0.87	1.25	1.09	1.00	0.97	0.67	0.80	0.90	0.81	0.62
10 Wabash-Ungauged	0.87	0.90	0.97	1.29	1.07	1.02	0.94	0.70	0.80	0.89	0.93	0.80

Table B2-7. Period 2 (2041 through 2070) Monthly Streamflow Change Factors

Sub-basin Number and Name	January	February	March	April	May	June	July	August	September	October	November	December
1 Mississinewa-Marion	1.05	1.13	0.93	1.45	1.18	1.01	0.89	0.80	0.80	0.87	0.81	0.72
2 Salamonie-Warren	1.05	1.22	0.97	1.54	1.15	0.99	0.85	0.70	0.74	0.83	0.78	0.65
3 Wabash-Linn Grove	1.04	1.25	0.94	1.51	1.15	0.91	0.83	0.75	0.78	0.82	0.81	0.69
4 Little-Huntington	1.20	1.18	0.95	1.61	1.25	1.10	1.08	0.89	0.79	0.84	0.96	0.76
5 Wabash-Wabash	1.09	1.17	0.95	1.57	1.24	1.07	0.96	0.79	0.76	0.83	0.89	0.75
6 Wabash-Peru	1.07	1.14	0.94	1.52	1.22	1.06	0.95	0.80	0.77	0.83	0.87	0.76
7 Eel-North Manchester	1.21	1.11	0.85	1.41	1.19	0.98	1.05	0.90	0.80	0.82	0.95	0.93
8 Wabash-Logansport	1.07	1.11	0.92	1.49	1.24	1.07	0.98	0.83	0.79	0.83	0.90	0.81
9 Deer Creek-Delphi	1.02	1.06	0.90	1.54	1.37	1.12	1.12	0.84	0.77	0.84	0.79	0.65
10 Wabash-Ungauged	1.05	1.11	0.93	1.49	1.27	1.08	1.00	0.84	0.79	0.84	0.90	0.81

Table B2-8. Period 3 (2071 through 2100) Monthly Streamflow Change Factors

Sub-basin Number and Name	January	February	March	April	May	June	July	August	September	October	November	December
1 Mississinewa-Marion	1.33	1.35	1.33	1.52	1.37	1.33	1.40	1.31	1.29	1.29	1.33	1.35
2 Salamonie-Warren	1.37	1.46	1.55	1.46	1.42	1.38	1.30	1.33	1.34	1.33	1.37	1.46
3 Wabash-Linn Grove	1.15	1.21	1.17	1.22	1.21	1.18	1.03	1.15	1.18	1.16	1.15	1.21
4 Little-Huntington	1.68	1.81	1.78	1.86	1.84	1.78	1.66	1.75	1.82	1.75	1.68	1.81
5 Wabash-Wabash	1.05	1.00	1.01	1.01	1.06	1.07	0.97	1.08	1.16	1.12	1.05	1.00
6 Wabash-Peru	0.86	0.82	0.79	0.88	0.87	0.87	0.82	0.88	0.89	0.89	0.86	0.82
7 Eel-North Manchester	0.94	0.92	0.87	1.14	1.03	1.01	1.10	1.04	1.27	1.08	0.94	0.92
8 Wabash-Logansport	0.89	0.84	0.84	1.03	0.92	0.92	1.00	0.94	0.97	0.96	0.89	0.84
9 Deer Creek-Delphi	0.82	0.76	0.80	0.83	0.80	0.81	0.85	0.83	0.82	0.84	0.82	0.76
10 Wabash-Ungauged	0.80	0.73	0.74	0.76	0.75	0.76	0.76	0.77	0.78	0.78	0.80	0.73

B2.2.3 Reservoir Releases

Given the complexity of reservoir operating rules, forecasting how these may be operated under projected future conditions was not within the scope of this project; therefore, limited assumptions were made in reflecting future reservoir operations to account for their influence on water supply dynamics in the future. Projected future reservoir releases are assumed to operate in the same manner as they were operated in during the historical period. This assumption reflects stationarity conditions with no change in the magnitude or timing of reservoir storage, and releases do not account for potential changes in streamflow resulting from future climate change.

The streamflow index approach previously described for the development of natural streamflow was applied for the development of future net reservoir releases. This approach essentially repeats historical net reservoir releases into the future based on hydrologic conditions for a given year. Historical net reservoir releases were repeated on a calendar year basis to reflect seasonal changes in reservoir storage.

B2.2.4 Natural Baseflow

Natural baseflow for the future period was developed by running the projected natural streamflow times series for each sub-basin through the HYSEP-Slide utility that was used to estimate natural baseflow for the historical period.

B2.2.5 Instream Flows

Instream flow requirements are assumed to remain consistent with historical instream flow requirements.

B3 Demand Scenarios Under Variation of Climate Conditions

To investigate the effect of climate factors on future water demand, three additional models were used to develop future water demand forecasts for the study area. These modes are described in Section B1.2.

Figure B3-1 and Figure B3-2 summarize the results of the baseline scenario for two future years, 2025 (immediate future) and 2070 (long-term future). The figures also compare the demands between the baseline and the three additional climate scenarios. The results are shown as percent change from the baseline to highlight the increases and decreases in demand under different climate conditions. In 2025, the baseline scenario shows daily water demands range from 2 to 18 million gallons per day (MGD) (Figure B3-1). Generally, Sub-basin 2 shows the lowest water demand in the watershed. Sub-basins 7 and 9 show somewhat lower demand than other sub-basins. Sub-basins 1 and 10 show higher demands though all seasons. Sub-basins 5, 6, and 8 have strong seasonality showing higher demand in summer but lower demand in other seasons. The lowest water demands for these sub-basins are observed in the winter. In 2070, water demand is expected to decrease in downstream sub-basins and increase in upstream sub-basins. However, the seasonality of each sub-basin is similar to 2025, showing a higher demand in summer and lower demand in winter.

Compared to the baseline, other climate scenarios in 2025 show slight changes from -2 to 1%. The differences are broader in 2070 and range from -4 to 2%. The cool/wet scenario derived from the same GCM model as the baseline has similar effects on water demand as the baseline. This indicates the cooler temperature does not affect water demand forecasting significantly. The other two scenarios were derived from different GCM models and show different seasonal pattern to the baseline. The hot/wet scenario resulted in higher water demands in the spring and fall but less water demands in winter and summer. The hot/dry scenario required more water in summer and fall and less water in winter and spring.

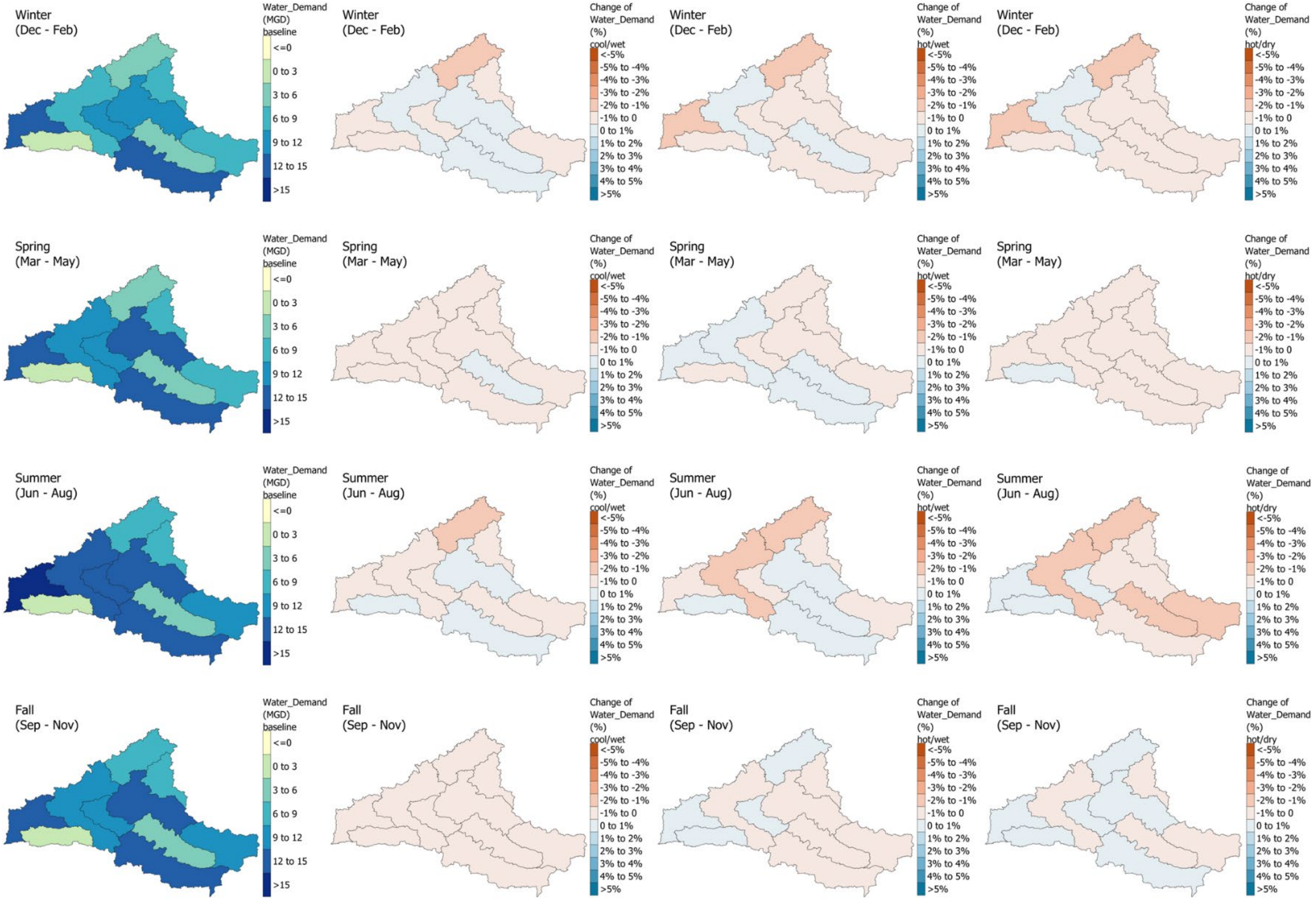

Figure B3-1. Seasonal Average Water Demand (MGD) per Sub-basin for Baseline Scenario and Corresponding Changes (percentage) from Cool/Wet, Hot/Wet, and Hot/Dry Scenarios in 2025

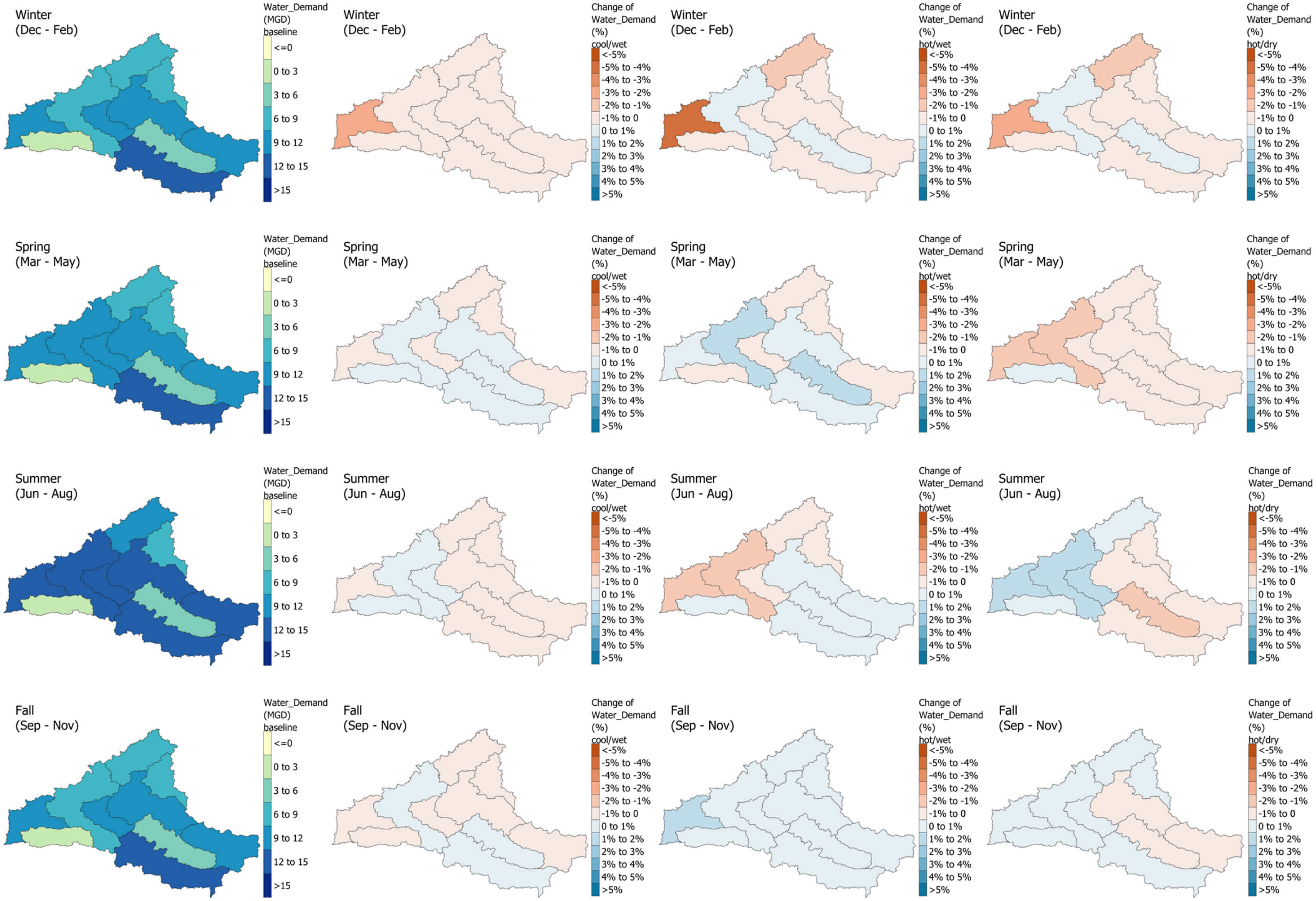

Figure B3-2. Seasonal Average Water Demand (MGD) per Sub-basins for Baseline Scenario and Corresponding Changes (percentage) from Cool/Wet, Hot/Wet, and Hot/Dry Scenarios in 2070

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