TECHNICAL MEMORANDUM

TO:	Lei Yang, P.E., Chief Professional Engineer, Natural System and Restoration, Southwest Florida Water Management District Gabe I. Herrick, Lead Environmental Scientist, Natural System and Restoration, Southwest Florida Water Management District
FROM:	Hua Zhang, P.G., Senior Professional Geologist, Natural System and Restoration, Southwest Florida Water Management District
DATE:	May 7, 2024
SUBJECT:	Reconstruction of baseline flows for the upper Peace River based on Peace River Integrated Model 2 (PRIM2)

1. Introduction

The Upper Peace River (UPR) basin is an approximately 826 square miles river watershed located in Polk County and northern Hardee County, or the drainage area upstream of the USGS 02295637 Peace River at US 17 at Zolfo Springs, FL gage. The headwater of the Peace River originated from the confluence of Saddle Creek (which drains Lake Hancock and its watershed) and the Peace Creek Canal (which drains the Lake Alfred and Winter Haven areas). The upper segment of the Peace River is a 36-mile reach bounded by USGS gauge 02294650 at Bartow and USGS gauge 02295637 at Zolfo Springs (Figure 1).

Much of the upper Peace River basin has been impacted by phosphate mining, agriculture, and population growth over the last century. Surface and groundwater withdrawals have caused long-term decline in river discharge and ground-water level (Lewelling et al., 1998; Basso, 2003; Metz and Lewelling, 2009). The increasing groundwater withdraw from 1930s to 1970s caused long-term decline in the potentiometric surfaces of the Hawthorn Aquifer System (HAS) and the Upper Floridan Aquifer (UFA). As a result, Kissengen Spring flow gradually declined from about 15~20 million gallons per day (mgd) during the 1930s until it ceased completely in the 1950s (Peek, 1951). Decline in the potentiometric surfaces directly affects the streamflow by causing decreases in or cessation of spring flows into the stream and flow losses from the stream into sinkholes, and indirectly by increasing the potential for downward leakage from the river into the underlying aquifer system.

Assessment of water use impacts on stream discharge was essential for reevaluation of minimum flows for the UPR. The purpose of this study is to reconstruct a baseline river flow that characterizes hydrologic conditions expected in the absence of water use impacts. To accomplish this, the numerical model simulation using Peace River Integrated Model version 2 (PRIM2) was used in combination with historical water use estimates to quantify the impact of historical groundwater withdrawal on the upper Peace River flows.

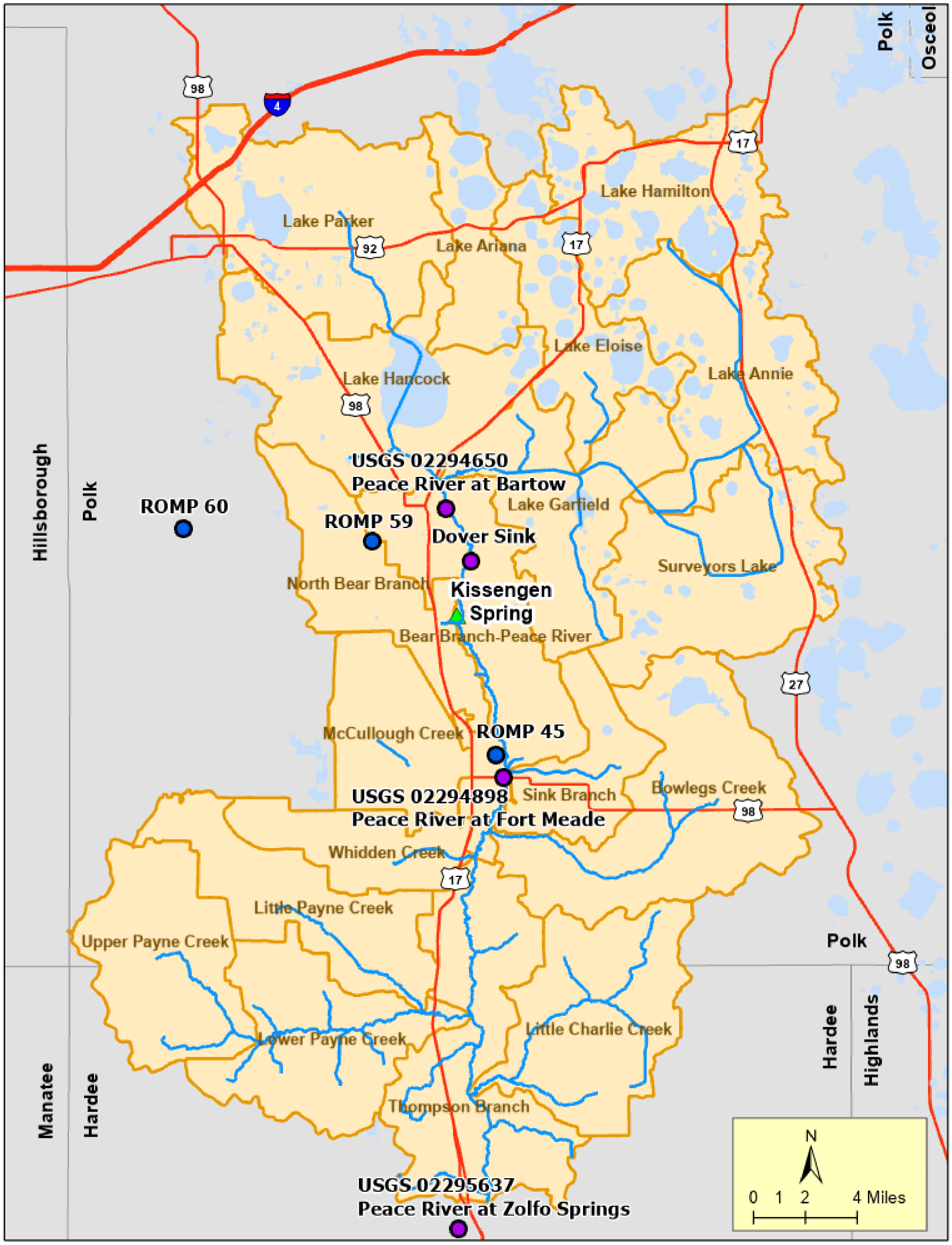

Figure 1 Map of the upper Peace River basin and tributaries and major surface water and groundwater monitoring site locations.

2. Hydrogeologic Conditions

2.1 Physiography

The upper Peace River basin primarily resides within the Central Ridge Highlands, characterized by ridges and elevated uplands. The basin exhibits a north-to-south physiographic transition, evolving from an upland, internally-drained Central Lake District to a poorly-drained Southwestern Flatwoods District (Lewelling et al., 1998). Land surface elevation varies considerably, exceeding 200 ft NGVD along the northeastern Lake Wales Ridge and dipping to around 100 ft NGVD in central Hardee County (Figure 2). Local features significantly influencing the hydrologic system include the Bartow Embayment and Bone Valley Uplands. The Bartow Embayment represents an internally-drained, localized erosional basin partially infilled with phosphate-rich siliciclastic deposits (Lewelling et al., 1998). The Peace River originates from the western Lakeland Ridges and eastern Lake Wales Ridge flanking the Embayment. These ridges are characterized by high surface, closed basin lakes and sinkholes, deep water tables and lack of surface drainage features. Southward from Homeland to Zolfo Springs lies the Bone Valley Uplands, characterized by land surface elevations typically exceeding 130 ft NGVD (Brooks, 1981). This region is dominated by pine flatwoods, wetlands, and lakes occupying a poorly-drained plateau. Notably, extensive phosphate mining activities have significantly altered the natural drainage patterns within this region.

2.2 Hydrogeology

The Peace River basin is underlain by a three-tiered aquifer system: the Surficial Aquifer (SA), the Hawthorn Aquifer System (HAS), and the Floridan Aquifer System (FAS). Detailed descriptions of stratigraphic and hydrogeologic units in this region are presented in Figure 3.

Surficial Aquifer System

The Surficial Aquifer (SA) is the uppermost, unconfined layer of the basin's aquifer system. Its depth varies from a few feet to exceeding 100 feet in sandhill ridges. Composed of unconsolidated quartz sand, silt, and progressively more clay with depth, these deposits originated from undifferentiated sediments laid down during the Holocene and Pleistocene epochs. The water table in the northern basin closely reflects the topography, mirroring the land surface near rivers, wetlands, streams, and lakes. In higher elevation areas, the water table typically resides 5 to 10 feet below the surface, with seasonal fluctuations of a few feet, generally lowest in spring and highest in late summer. Notably, the Lake Wales Ridge can have a water table depth of 50 to 100 feet. Due to its limited yield, the surficial aquifer supplies relatively small water quantities in the upper Peace River basin and is primarily used for domestic purposes or lawn irrigation.

Hawthorn Aquifer System

Underlying the SA is the confined Hawthorn Aquifer System (HAS), also known as the Intermediate Aquifer System (IAS). The HAS comprises thin, interbedded limestones, sands, and phosphatic clays within geologic formations of the Hawthorn Group (Figure 3 Generalized correlation chart for stratigraphic and hydrogeologic units in the upper Peace River basin.Figure 3). It is relatively thin in the upper Peace River basin and thickens southward. Notably, the uppermost confining bed beneath the SA may be absent in the basin's extreme north, where the water-producing zone of the HAS is often missing. Spechler and Kroening (2007) depicted the absence of the HAS in Saddle Creek and Peace Creek north of the Lakeland-Winter Haven line. The top of the HAS varies in elevation, ranging from over 100 feet above sea level in central Polk County to exceeding 100 feet below sea level in Highlands County. The HAS thickens progressively southward within the basin and includes both water-bearing and confining units.

Where present, the HAS exhibits a significantly lower permeability (2 to 3 orders of magnitude) compared to the underlying Upper Floridan Aquifer (UFA) and is often classified as a semi-confining unit. The HAS typically consists of an upper confining unit of clayey sand, shell, and marl, underlain by a lower confining unit of sandy clay and clayey sand. Sandwiched between these confining units are one or two permeable zones separated by another confining unit. The upper permeable zone is the upper Arcadia Aquifer formerly known as PZ2 or Zone 2. The second zone is the lower Arcadia aquifer formerly known as PZ3 or Zone 3 (Knochenmus, 2004; Spechler and Kroening, 2007; LaRoche and Horstman, 2023). Within the Peace River basin, the transmissivity of the HAS ranges from 1 to 8,800 ft^2/day for Zone 2 and from 200 to 43,000 ft^2/day for Zone 3 (Knochenmus, 2004).

Floridan Aquifer System

The deepest confined aquifer is the Floridan aquifer, comprised of limestone and dolostone formations. It is further subdivided into the Upper Floridan Aquifer (UFA) and the Lower Floridan Aquifer (LFA), separated by the Middle Confining Unit (MCU). A confining unit of clays and dolomitic limestones from the lower Arcadia Formation of the Hawthorn Group separates the UFA from the HAS. The top of the UFA dips southward, ranging from near sea level elevation in central Polk County to exceeding 1,000 feet below NAVD88 in southern Charlotte County (Knochenmus, 2004). The hydrogeologic units within the UFA include the Upper Production Zone (UPZ) (Basso, 2002), corresponding to the Suwannee Limestone, the semi-confining Ocala Limestone, and the Lower Production Zone (LPZ) of the Avon Park Formation. Notably, the UFA exhibits high permeability along specific horizons and serves as the primary water supply source for the basin, contributing approximately 85 to 90% of all groundwater. Lateral ground-water flow within the Upper Floridan aquifer moves west-southwest from center of the Green Swamp Potentiometric High toward the Gulf Coast. Based on aquifer testing data from the Southwest Florida Water Management District (SWFWMD), transmissivity values for the UFA in the Peace River basin range from 30,000 to 300,000 ft^2/day, with reported leakance values between 10^{-3} and 10^{-5} per day (d^{-1}). The lower boundary of the UFA is the MCU.

2.3 Groundwater level

Ground-water flow patterns are determined by hydraulic gradients and the differences in head potential between the aquifers. The potentiometric surfaces of the Upper Floridan aquifer for predevelopment (Figure 4), 1975 (Figure 5), and 2020 (Figure 6) clearly illustrate the historical change of the groundwater level in the upper Peace River basin. Drawdown maps created by calculating the difference in potentiometric surfaces between May 1975 (Mills and Laughlin, 1976) and pre-development (Johnston et al., 1980) illustrated the extensive decline of the groundwater level as much as 50 ft (Figure 7). Furthermore, the drawdown map (Figure 8) and rebound map (Figure 9) of May 2020 (Data provided by the Florida Department of Environmental Protection, Florida Geological Survey, 2023) illustrated that there was a significant recovery of groundwater resources between May 1975 and May 2020. Review of the hydrographs for the groundwater monitoring wells at ROMP 60 (Figure 10), 59

(Figure 11 and Figure 12) , and 45 (Figure 13 and Figure 14) indicate that a sharp decline in the ground-water level occurs from 1960 to 1980 and a gradual recovery of groundwater level from 1980s to present. The UFA potentiometric-surface map and hydrographs indicates a 30 to 40 ft rise in aquifer water levels since the 1975 levels, but groundwater levels remain as much as 30 ft below the pre-development conditions.

2.4 Groundwater and surface water interaction

With the lowering of potentiometric surfaces, the upper Peace River from Bartow to Fort Meade reversed from receiving groundwater discharge prior to the 1950s to a groundwater recharge area over time. Dissolution of limestone and dolomite rocks underlying upper Peace River channel created numerous karst features such as fractures, crevasses, and sinkholes, which connect the Peace River to Hawthorn and Upper Floridan aquifers. When the river water level is higher than groundwater, the karst features allow downward flow of water from the river to underlying aquifers (Lewelling et al., 1998; Basso, 2003; Knochenmus, 2004; Metz and Lewelling, 2009). Discharge measurements conducted by Metz and Lewelling (2009) along the upper Peace River indicate 2 to 16 cfs of streamflow lost through the Dover Sink, which is the most influential karst feature on the channel of the upper Peace River.

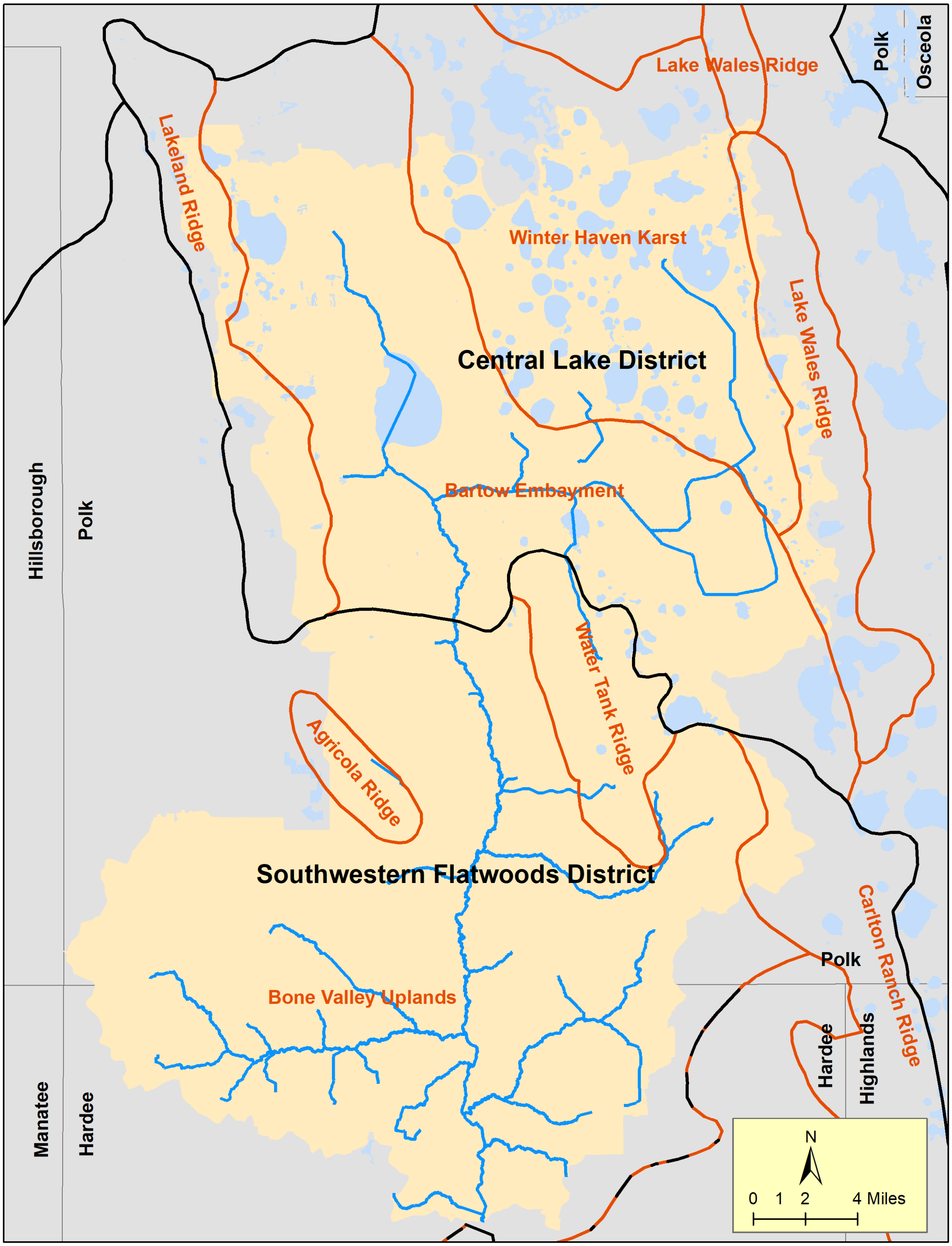

Figure 2. Physiographic division and subdivision of the upper Peace River basin.

<table>
<tr><th>Series</th><th colspan="2">Stratigraphic Unit</th><th colspan="2">Hydrogeologic Unit</th><th>Lithology</th></tr>
<tr><td>Holocene to Pliocene</td><td colspan="2">Undifferentiated Surficial Deposits</td><td colspan="2">Surficial Aquifer</td><td>Sand, silty sand, clayey sand, peat, and shell</td></tr>
<tr><td rowspan="6">Miocene</td><td rowspan="7">Hawthorn Group</td><td rowspan="3">Bone Valley Member
Peace River Formation</td><td>Confining Unit</td><td rowspan="7">Hawthorn Aquifer System</td><td rowspan="4">Predominantly phosphatic clay, gray to green to brown, plastic, ductile, minor sand, phosphatic gravel, residual limestone and dolostone</td></tr>
<tr><td>PZ 2</td></tr>
<tr><td rowspan="2">Confining Unit</td></tr>
<tr><td>Arcadia Formation</td></tr>
<tr><td rowspan="3">Tampa or Nocatee Member</td><td>PZ 3</td><td rowspan="3">Limestone, gray to tan, sandy, soft, clayey, minor sand, phosphatic. Chert found locally</td></tr>
<tr><td rowspan="2">Confining Unit</td></tr>
<tr><td rowspan="2">Oligocene</td></tr>
<tr><td colspan="2">Suwannee Limestone</td><td>Upper Permeable Zone</td><td rowspan="3">Upper Floridan Aquifer</td><td>Limestone,cream to tan, sandy, vuggy, fossiliferous</td></tr>
<tr><td rowspan="3">Eocene</td><td colspan="2">Ocala Limestone</td><td>Semi-Confining Unit</td><td>Limestone,white to tan, friable to micritic, fine-grained, soft, abundant foraminifera</td></tr>
<tr><td colspan="2" rowspan="2">Avon Park Formation</td><td>Lower Permeable Zone</td><td rowspan="2">Limestone and dolomite. Limestone is tan, recrystallized. Dolomite is brown, fractured, sucrosic, hard. Peat found locally at top. Interstitial gypsum in lower part.</td></tr>
<tr><td colspan="2">Middle Confining Unit</td></tr>
</table>

Figure 3 Generalized correlation chart for stratigraphic and hydrogeologic units in the upper Peace River basin.

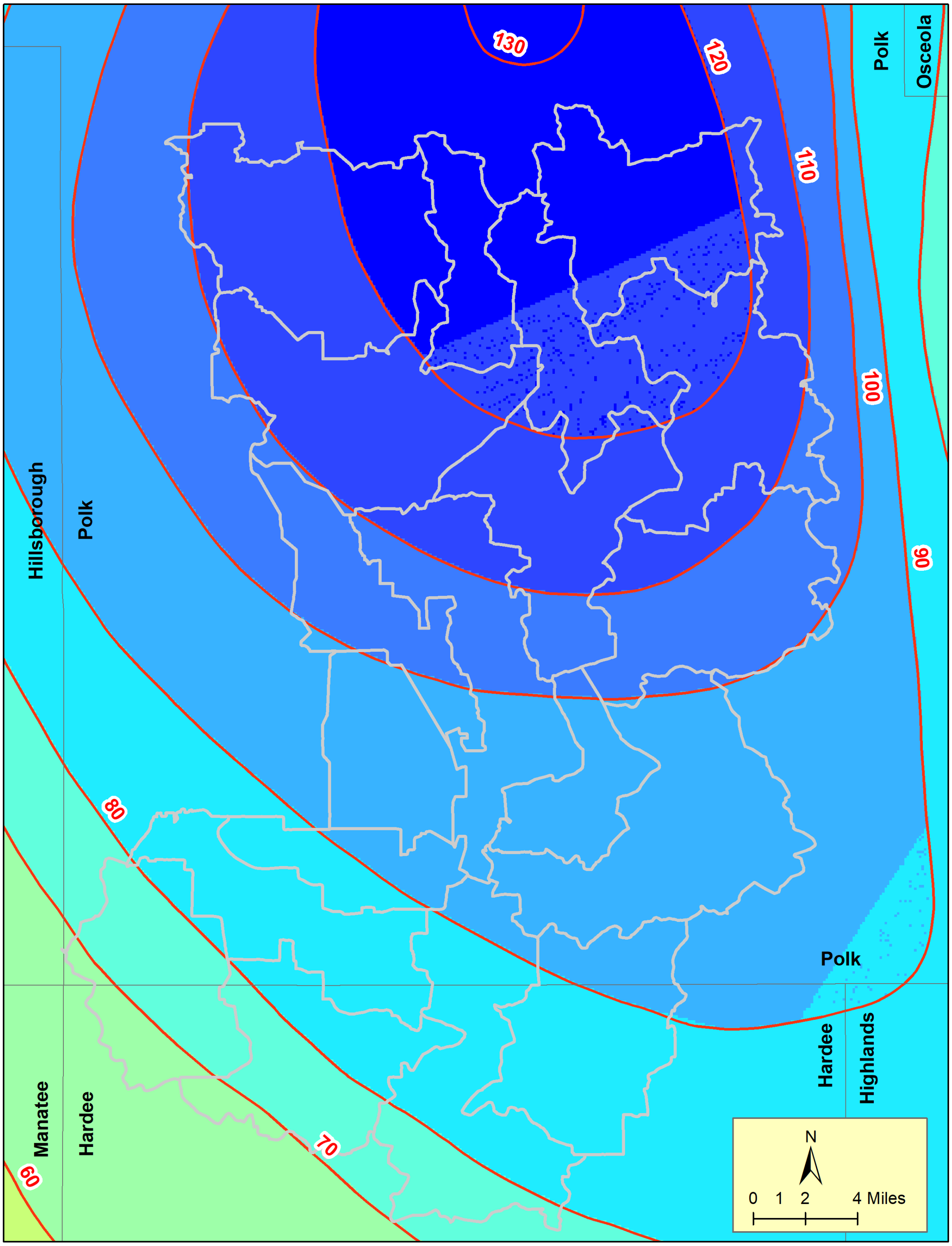

Figure 4. Pre-development Upper Floridan Aquifer Potentiometric Surface for the upper Peace River basin

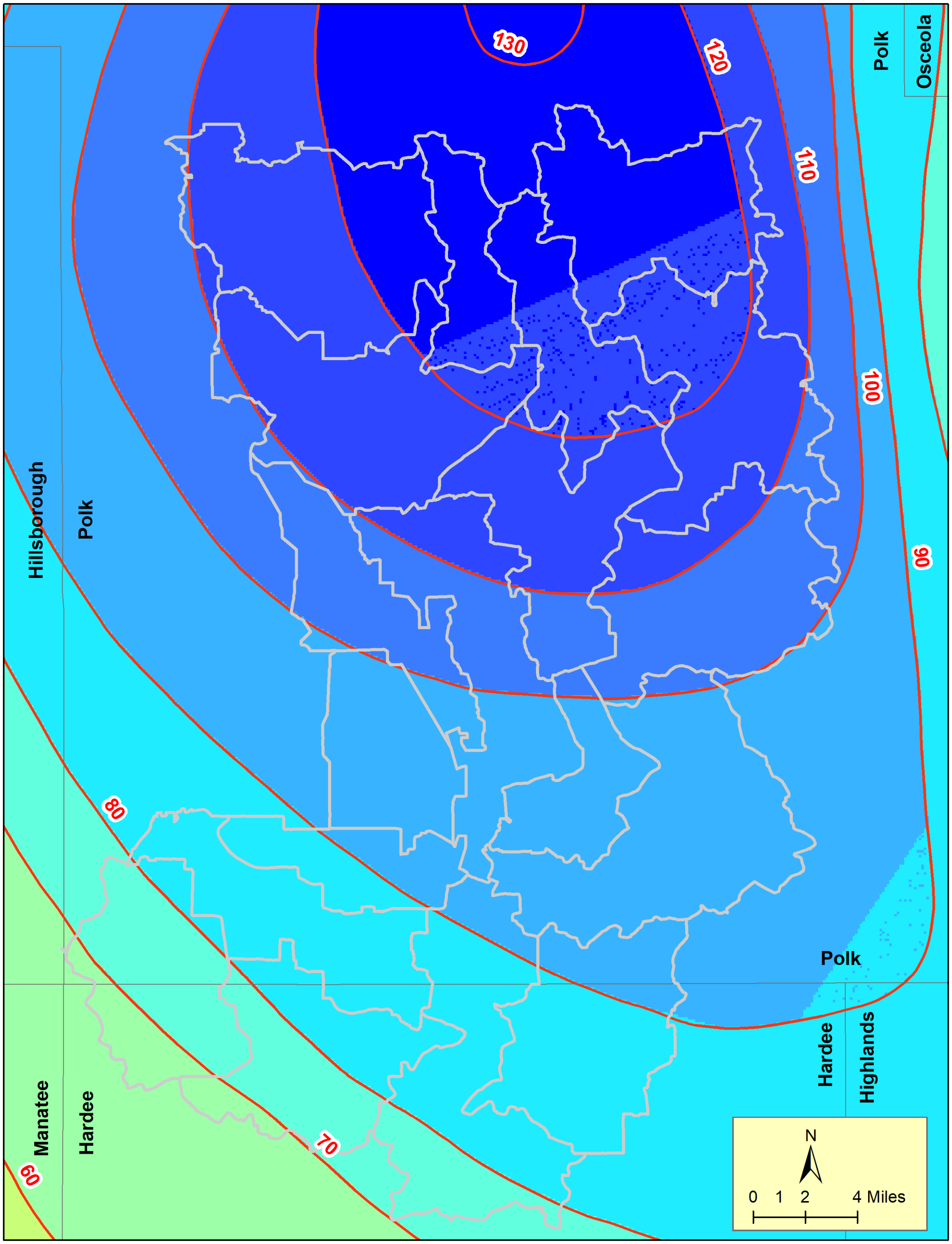

Figure 5. May 1975 Upper Floridan Aquifer Potentiometric Surface for the upper Peace River basin

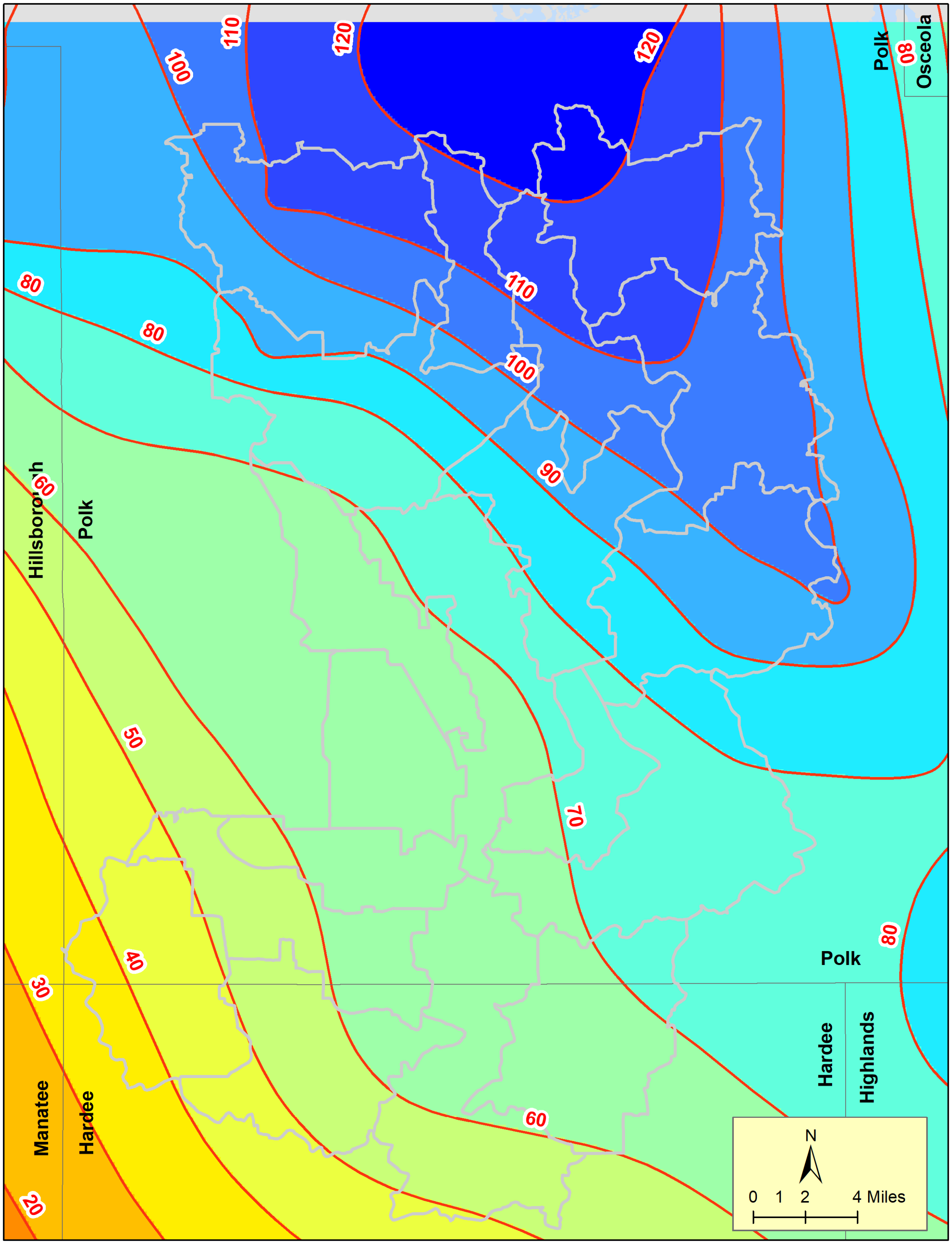

Figure 6. May 2020 Upper Floridan Aquifer Potentiometric Surface for the upper Peace River basin

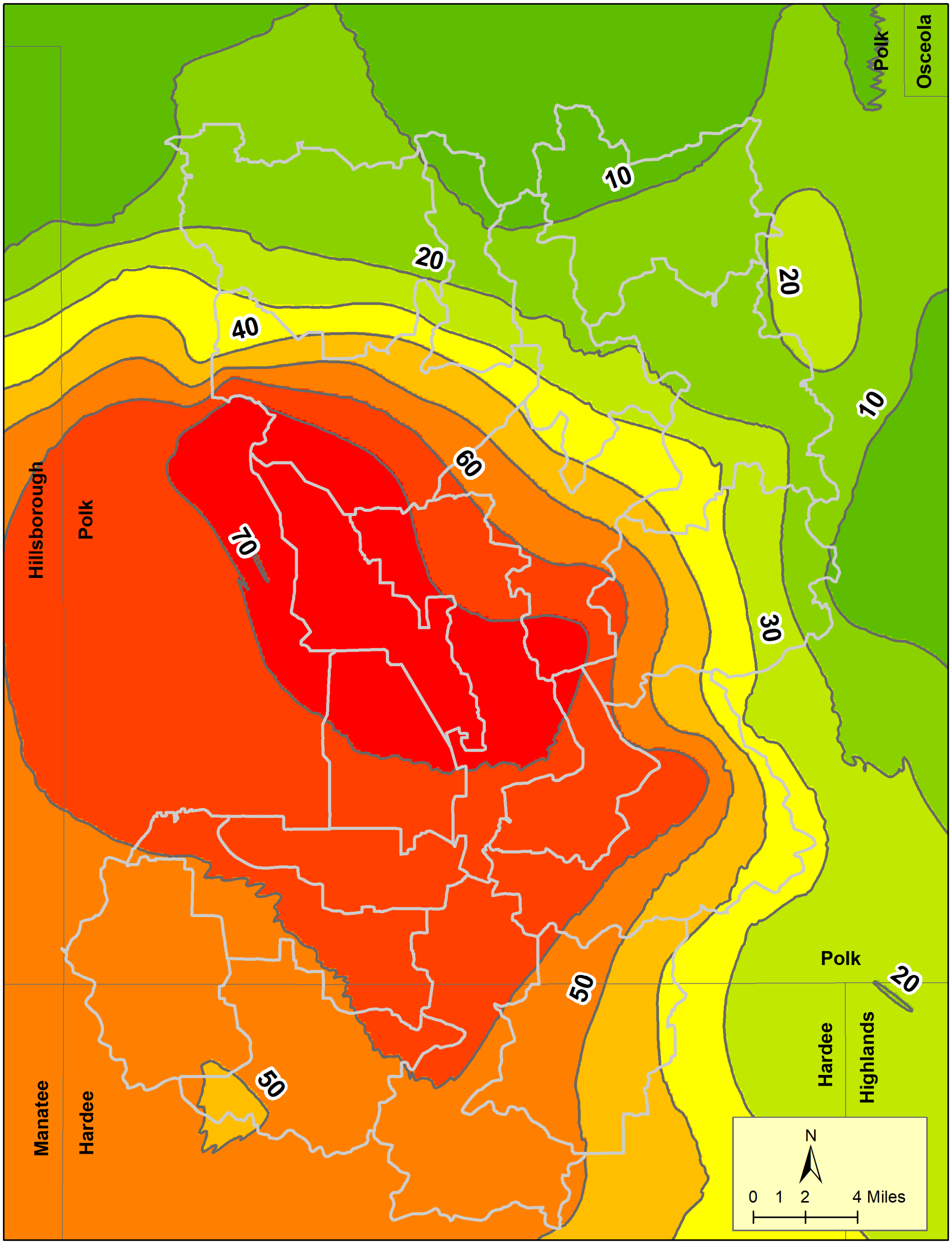

Figure 7. Calculated Upper Floridan Aquifer Drawdown (Pre-development - May 1975)

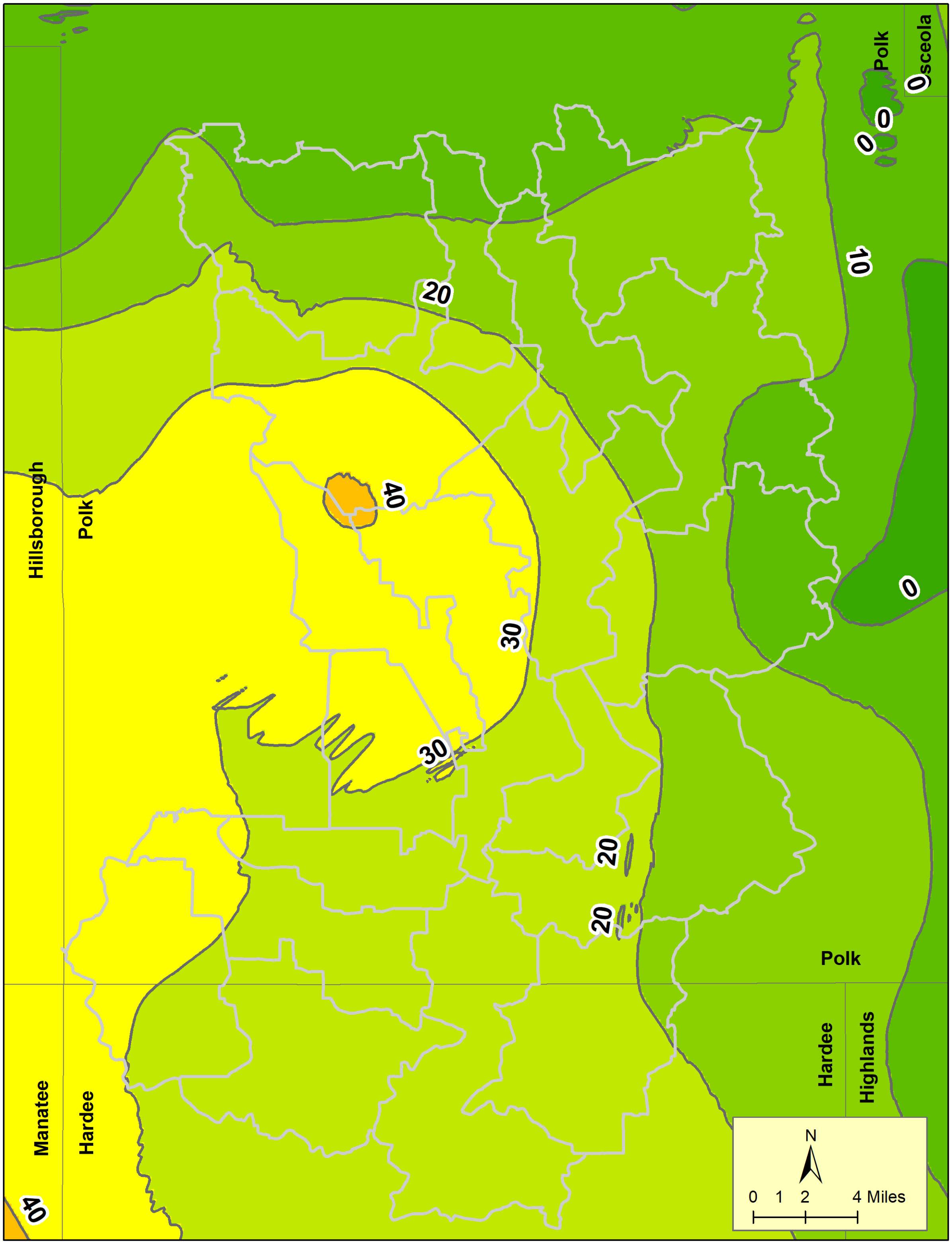

Figure 8. Calculated Upper Floridan Aquifer Drawdown (Pre-development - May 2020)

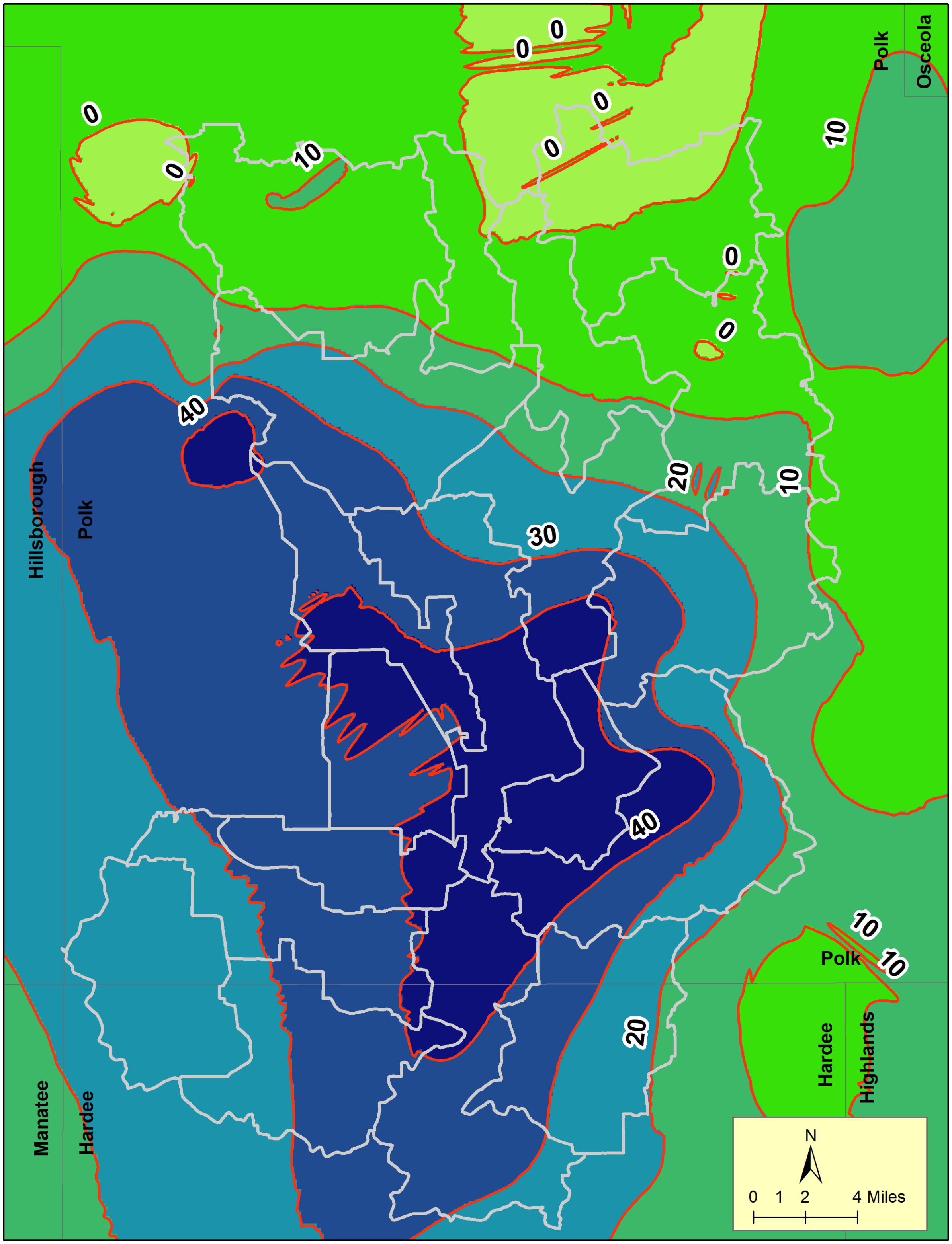

Figure 9. Calculated Upper Floridan Aquifer Rebound (May 2020 – May 1975)

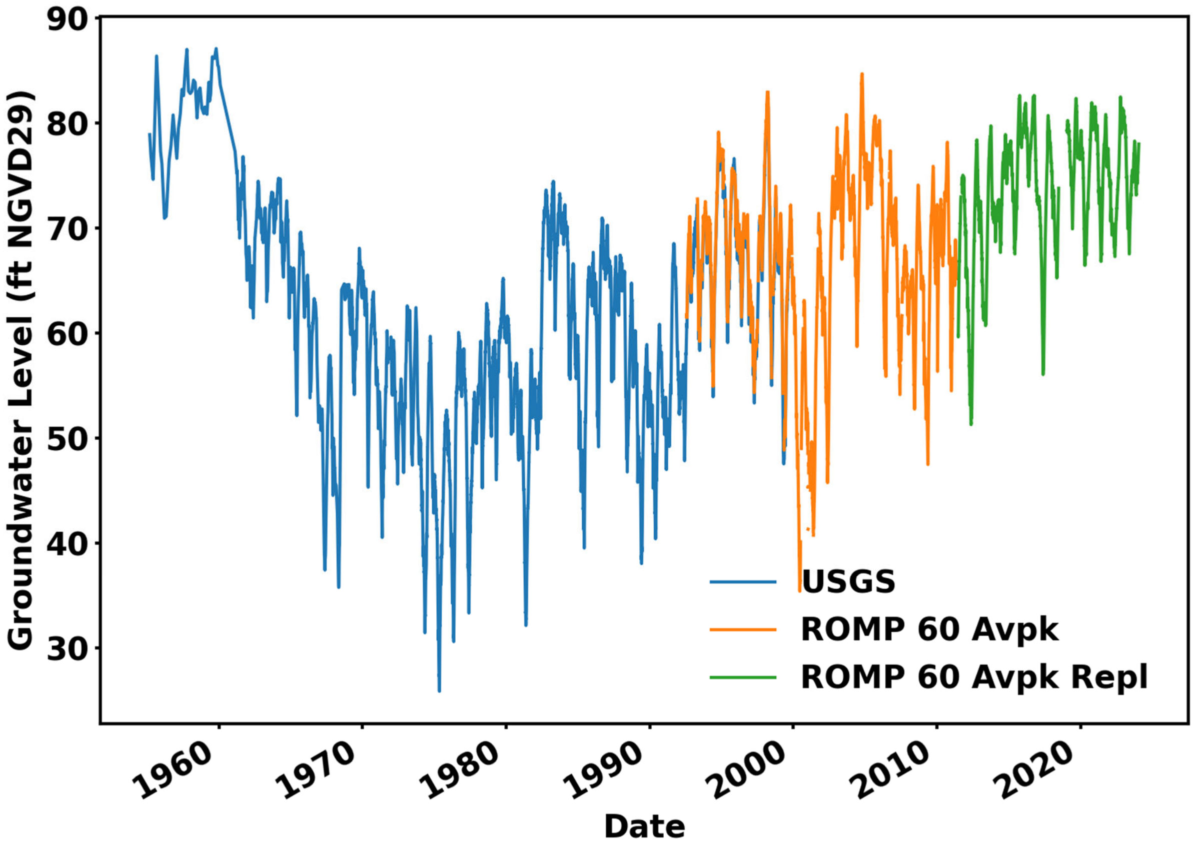

Figure 10. Upper Floridan Aquifer Groundwater level at ROMP 60. Note: ROMP 60 Avpk (SID 17974) was abandoned in 2011. Time series of ROMP 60 Avpk Repl (777757) was used in the analysis beginning year 2011.

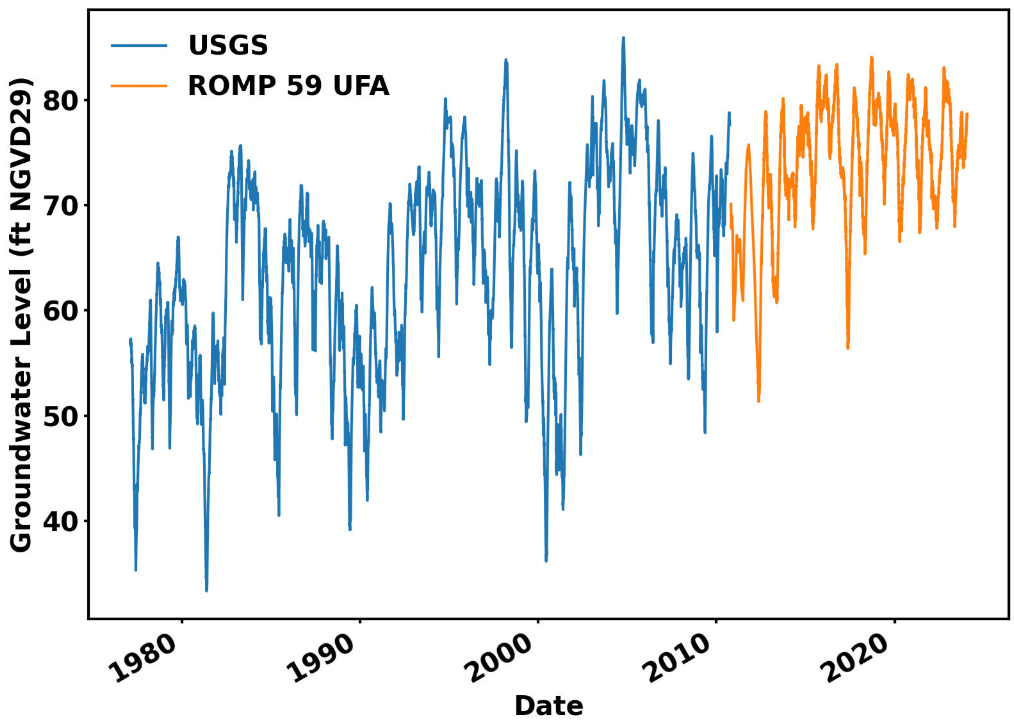

Figure 11. Upper Floridan Aquifer Groundwater level at ROMP 59.

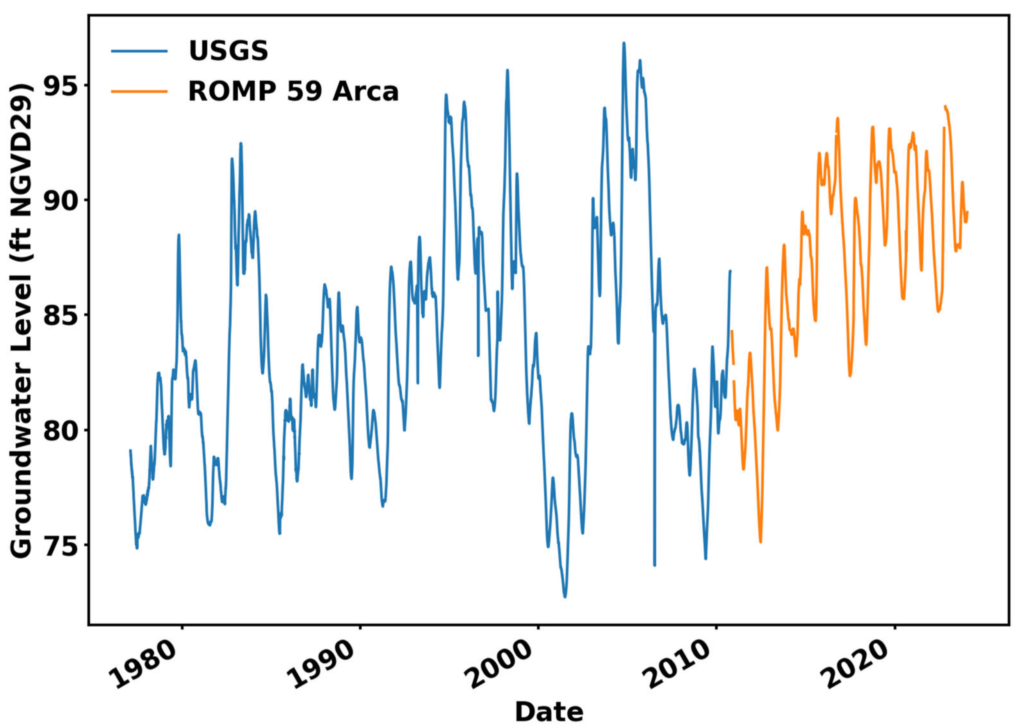

Figure 12. Hawthorn Aquifer System Groundwater level at ROMP 59.

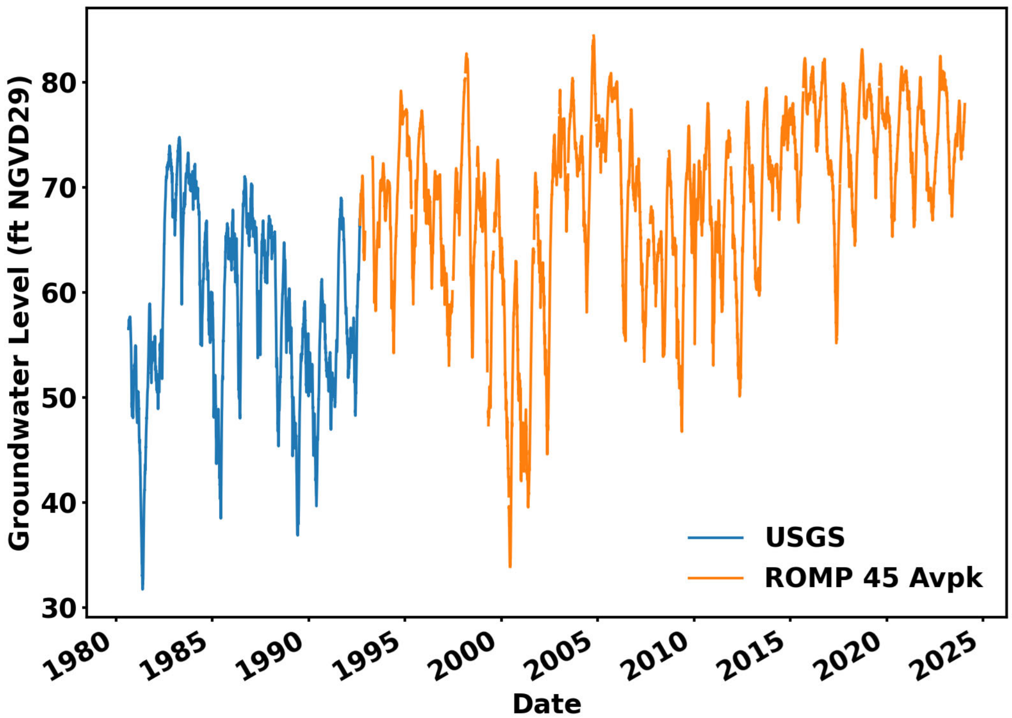

Figure 13. Upper Floridan Aquifer Groundwater level at ROMP 45.

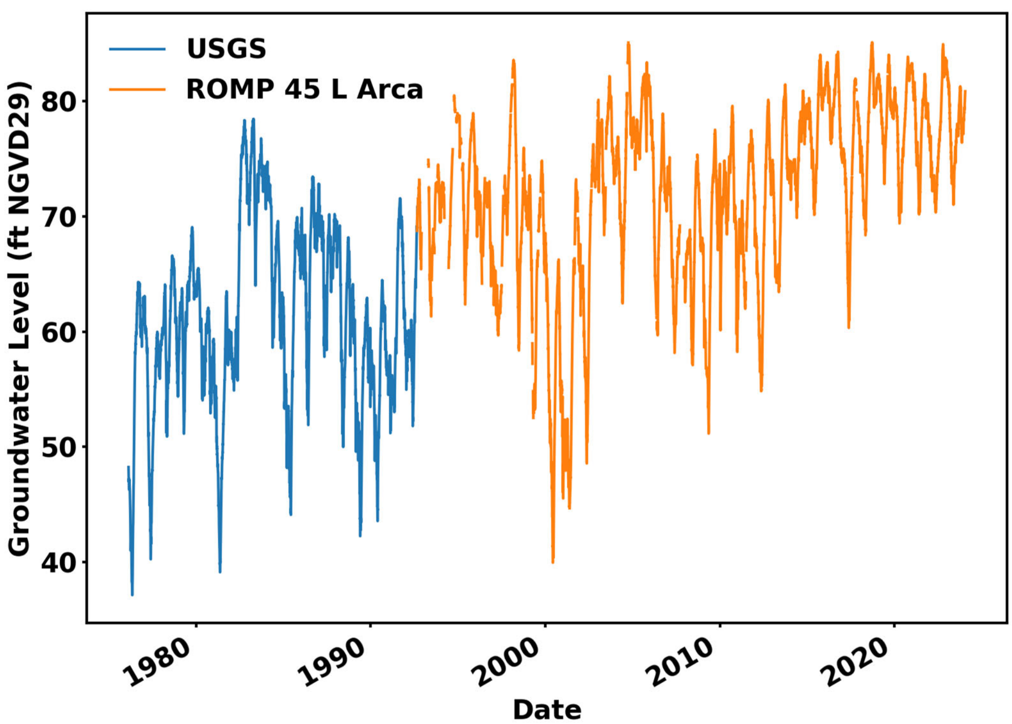

Figure 14. Hawthorn Aquifer System Groundwater level at ROMP 45.

3. Peace River Integrated Model Version 2 (PRIM2) Scenario Results

The District developed and subsequently updated the Peace River Integrated Model (PRIM) to investigate factors affecting flows in the Peace River and its tributaries. The factors include long-term rainfall variations, groundwater pumping, regulation of surface water, as well as land use and land cover changes. Detailed information on model components, required inputs, calibration and validation results, and results of simulated scenarios are documented in HydroGeoLogic, Inc. (2023).

3.1 Calibration of PRIM2 model

The Peace River Integrated Model 1 (PRIM 1) developed in 2011 (HGL, 2011) was calibrated based on daily data from 1998 to 2002 and verified using data from 1994 to 1997. The model was subsequently updated to PRIM2 and recalibrated using daily data from 2003 to 2018 (16 years) in 2023. The calibrated PRIM2 model demonstrated to accurately reproduce observed high and low patterns of streamflow, lake levels, and groundwater potentiometric elevations.

Streamflow was calibrated using observations at USGS gauges at Bartow (02294650), Fort Meade (02294898), and Zolfo Spring (02295637) along the upper Peace River. Discharge or streamflow percentiles, along with other statistical metrics demonstrates the good agreement between observed data and simulation results, which met most calibration criteria. All stream gauges were favorably replicated in terms of magnitude, temporal fluctuation, and flow percentiles. Favorable agreement between simulated streamflow losses through karst features between Bartow and Homeland and observed discharges through karst conduits from 2002 to 2006 was achieved as part of stream calibration.

3.2 Groundwater withdrawal scenarios

Two groundwater withdrawal scenarios (75% and 50% pumping off) were conducted using the calibrated PRIM2 model and model results were used for the development of unimpacted streamflows. The scenario runs were compared with the base case scenario, which represents the 100% pumping condition from 2003 through 2018. To account for regional effects of reduced groundwater pumping, the heads in the HAS and UFA along the lateral boundaries of the model were assigned as time-varying heads. Heads along these boundaries were updated based on regional groundwater models to reflect reduced pumping outside the PRIM domain. Initial conditions were identical to those in the base case. The impacts of changes in pumping were evaluated in terms of streamflow, lake levels, SA and UFA groundwater heads, and water budgets. The potentiometric head differences in response to changes in pumping are illustrated in Figure 15 for SA and Figure 16 for UFA. Fifty percent reduction in groundwater pumping increased the UFA heads throughout the entire basin. UFA heads increased by 5 feet or more for much of the central and western parts of the basin with the greatest head increase occurring along the western boundary of the basin in the area where drawdown was highest under base case pumping conditions.

3.3 Groundwater withdrawal impacts on the upper Peace River flows

Comparison of PRIM2 simulated hydrographs and flow exceedance curves under base and reduced pumping scenarios are presented for the USGS gauges at Bartow (Figure 17 and Figure 18), Fort Meade (Figure 19 and Figure 20), and Zolfo Springs (Figure 21 and Figure 22). The results show that groundwater withdrawals reduced streamflows at Bartow and Ft. Meade but increased streamflows at Zolfo Springs. In the PRIM, groundwater extraction is modeled as a transfer of water from the subsurface to the surface as return flows. Groundwater withdrawal impacts on streamflow are simulated as integrated processes including 1) surface runoff from land application of the return flow, and 2) stream water lose/gain because of aquifer level change due to groundwater withdrawal. Streamflow reductions at Bartow and Fort Meade can be attributed to the relatively high leakance between the UFA and the SA in the northern part of the upper Peace River basin, while increased streamflow at Zolfo Springs can be attributed to the much tighter confinement of the UFA in the middle Peace River basin.

The PRIM2 simulated daily flow difference between the 50% pumping scenario and the base (100% pumping) scenario was calculated and illustrated in Figure 23 for the three gauges. Because streamflow response to groundwater withdrawal has been demostrated to be relatively linear, 75% pumping scenario was not needed to develop streamflow adjustment. Averaged monthly streamflow adjustment due to groundwater withdrawal is presented in Figure 24, which was calculated by doubling the daily flow difference between the 50% pumping and 100% pumping scenarios and averaged by month over the 2003-2018 simulation period. The groundwater use caused a streamflow impact between a minimum of -0.62 cfs in May and maximum of 32.73 cfs in September at the Bartow gauge. For the Fort Meade gauge, the groundwater withdrawal resulted in stream flow change of 4.31 cfs in May to 34.78 cfs in September. In contrast, the stream flow impact was between -25.18 cfs in June and 12.22 cfs in October for the Zolfos Springs gage. The adjustment values are used in combination with the historical groundwater use data to develop the baseline or unimpacted stream flow.

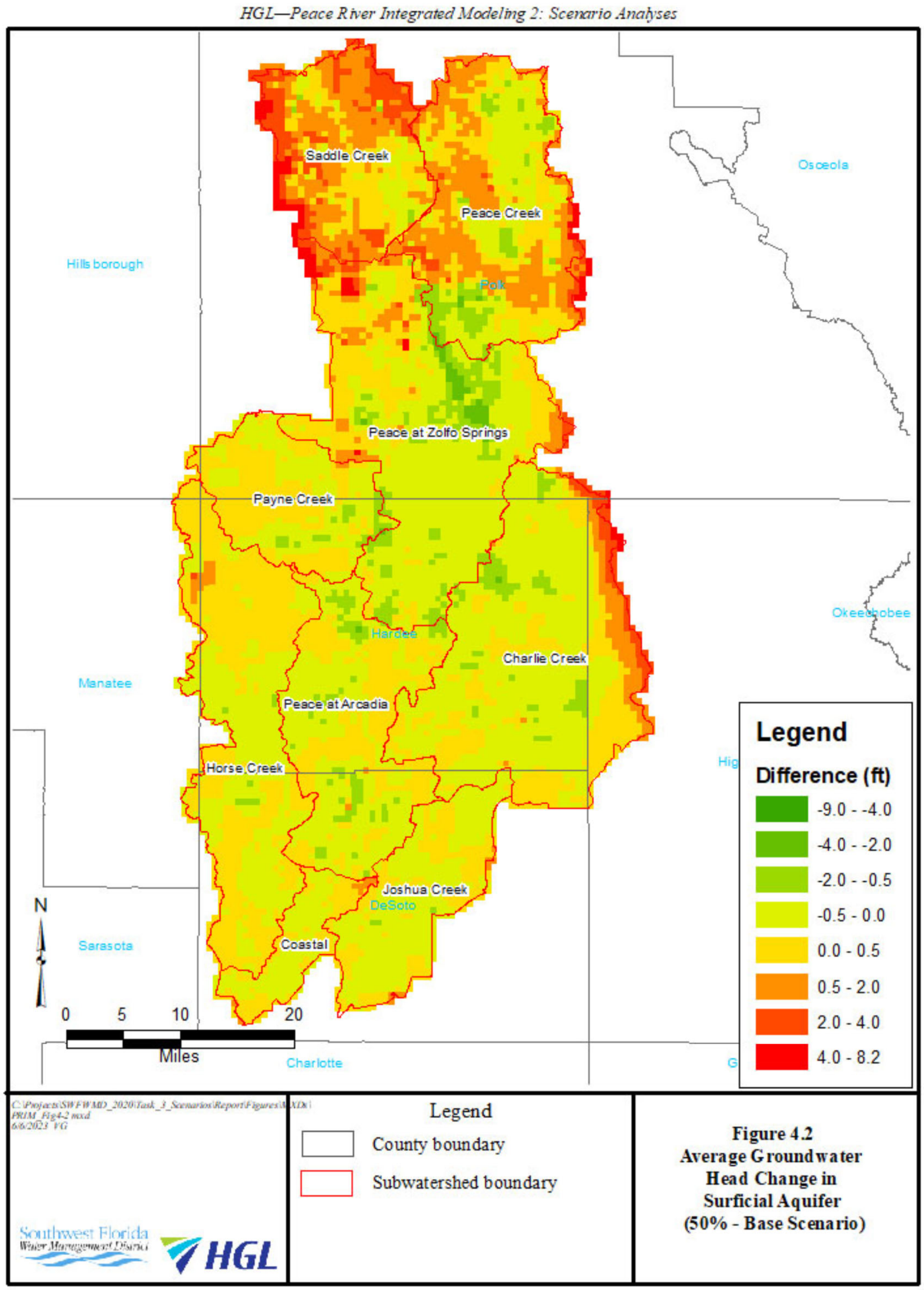

Figure 15. PRIM2 simulated Surficial Aquifer Drawdown (50% pumping scenario – 100% pumping scenario)

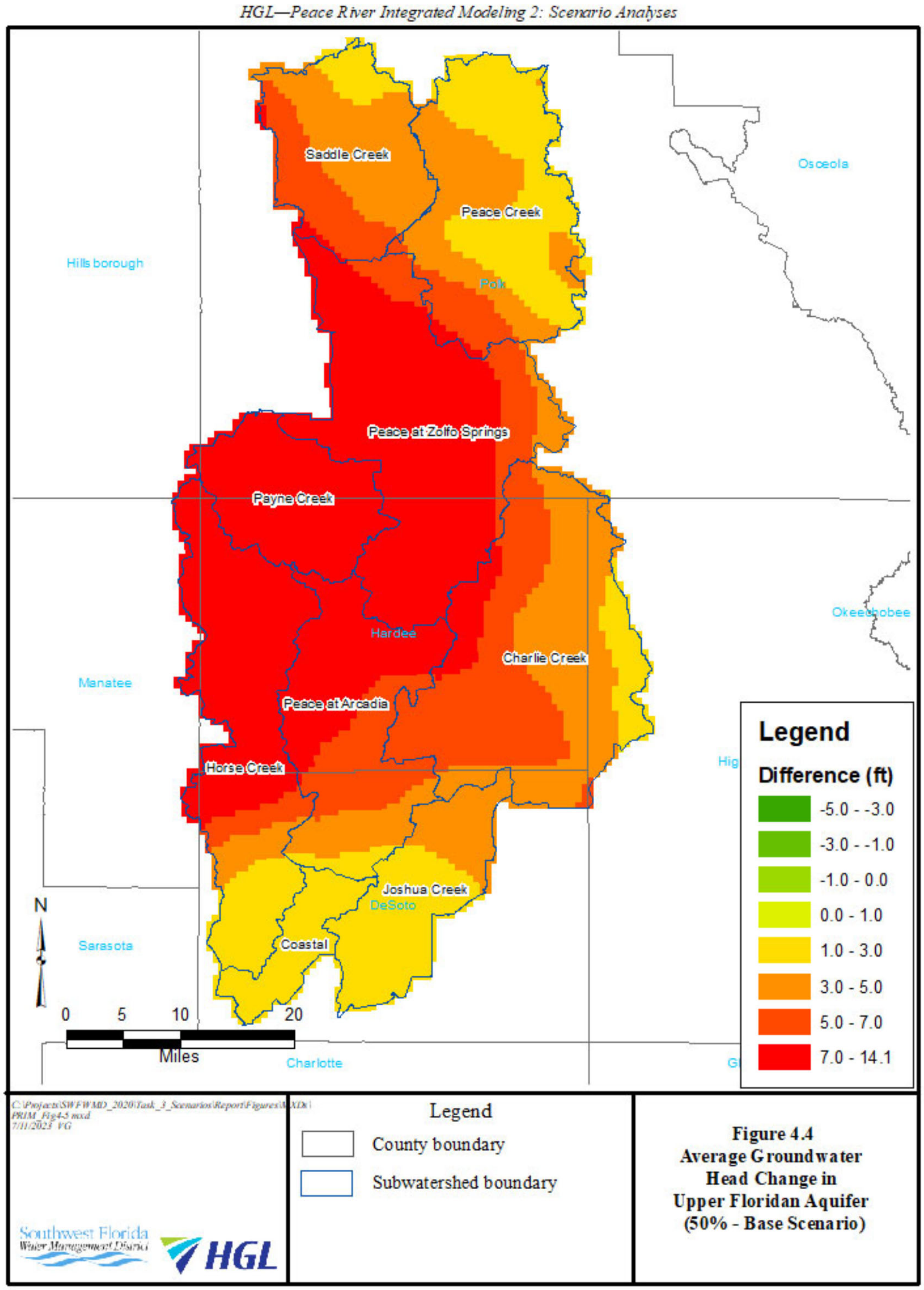

Figure 16. PRIM2 simulated Upper Floridan Aquifer Drawdown (50% pumping scenario – 100% pumping scenario)

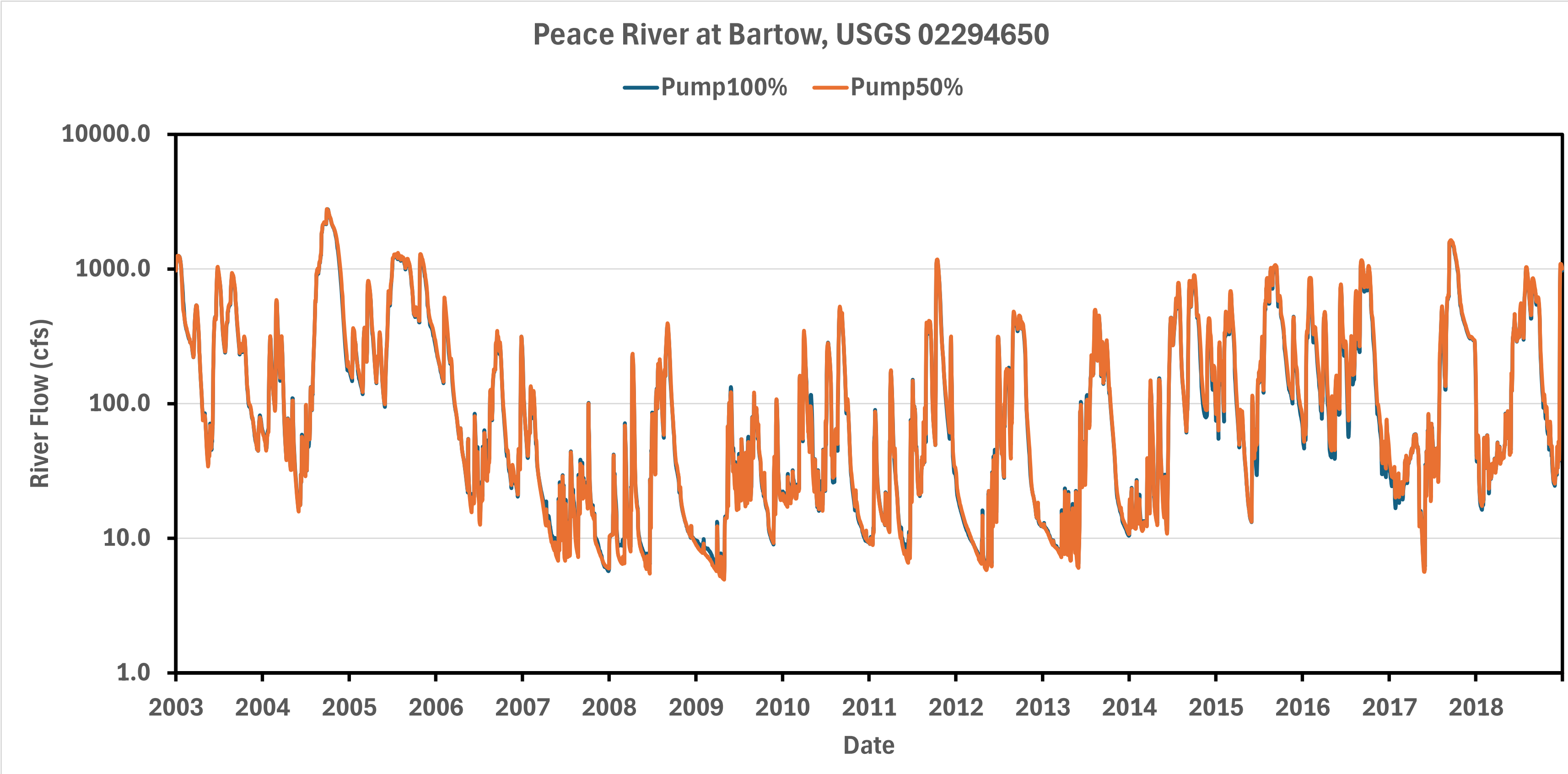

Figure 17. PRIM2 simulated stream flow at USGS 02294650 (Peace River at Bartow) under the 50% pumping scenario and 100% pumping scenario

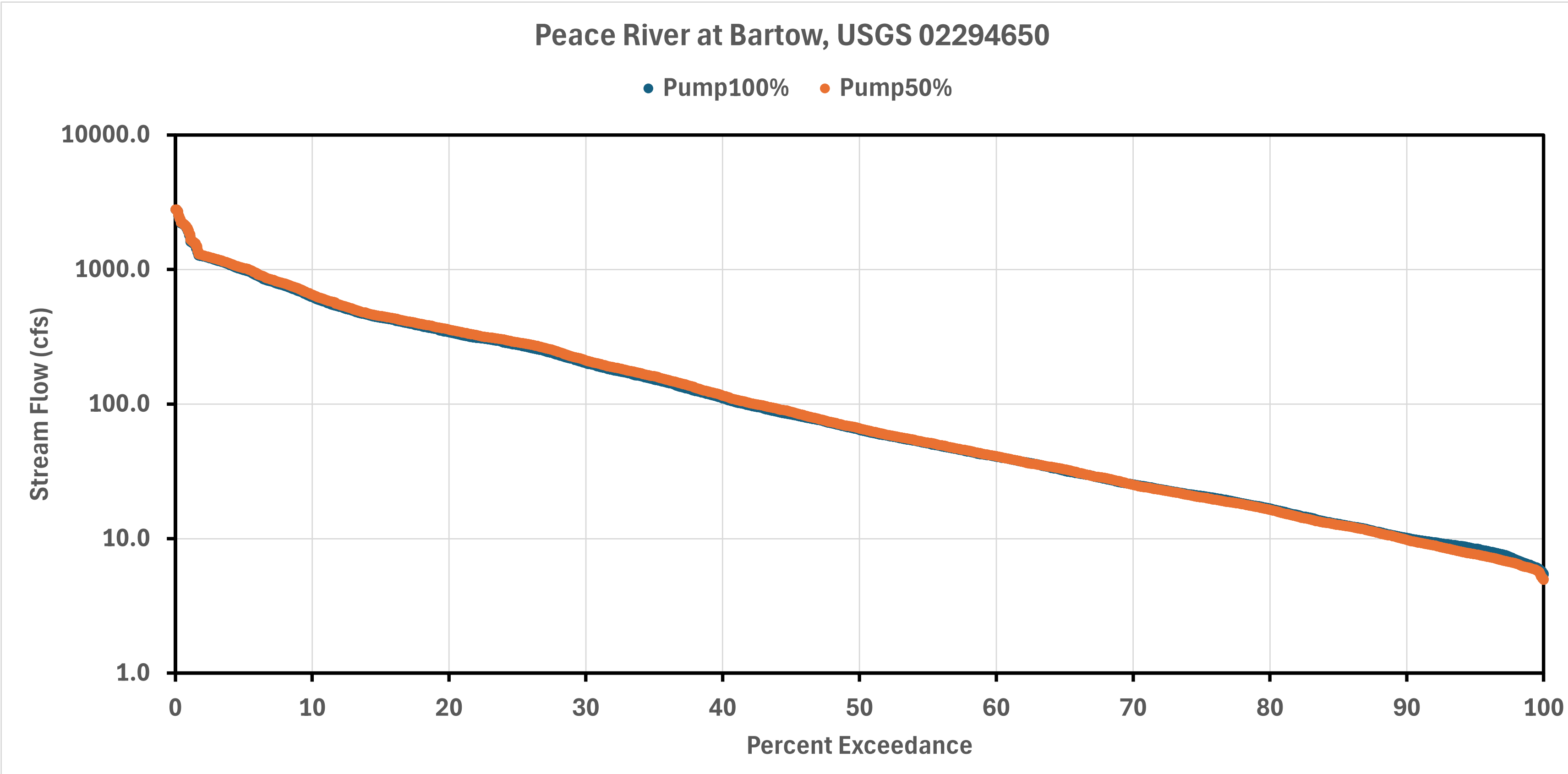

Figure 18. Flow duration curve of PRIM2 simulated stream flow at USGS 02294650 (Peace River at Bartow) under the 50% pumping scenario and 100% pumping scenario

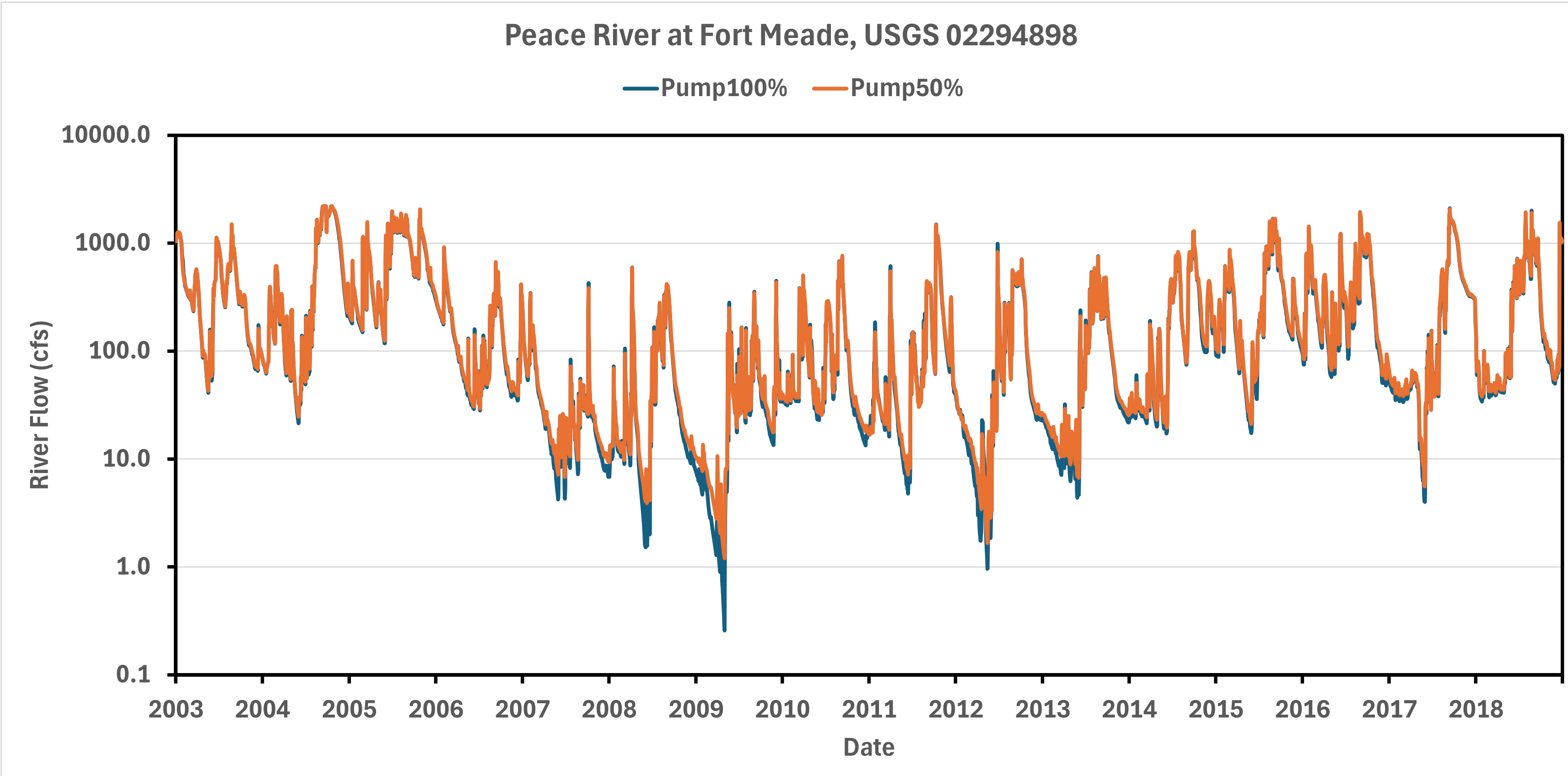

Figure 19. PRIM2 simulated stream flow at USGS 02294898 (Peace River at Fort Meade) under the 50% pumping scenario and 100% pumping scenario

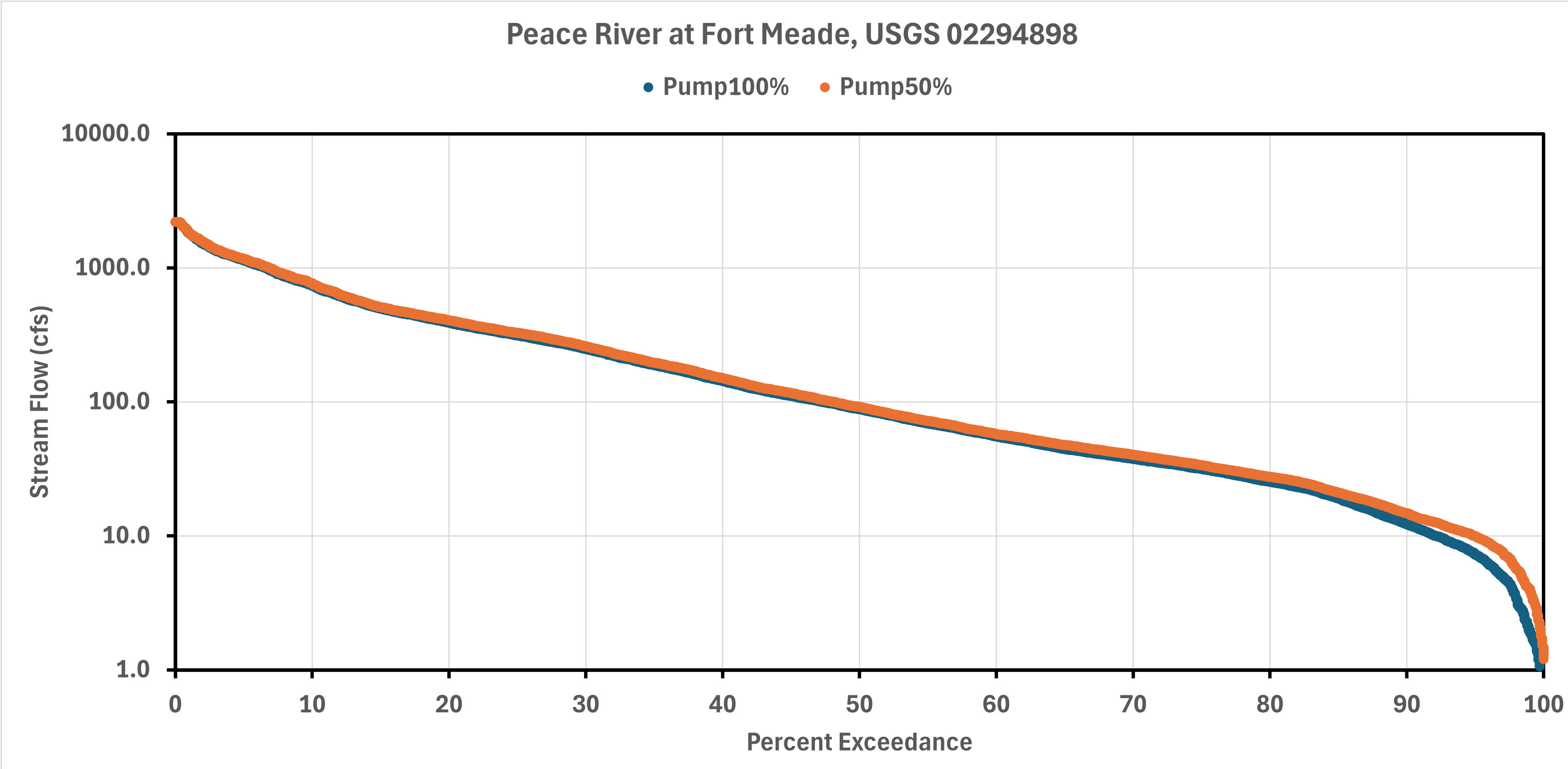

Figure 20. Flow duration curve of PRIM2 simulated stream flow at USGS 02294898 (Peace River at Fort Meade) under the 50% pumping scenario and 100% pumping scenario

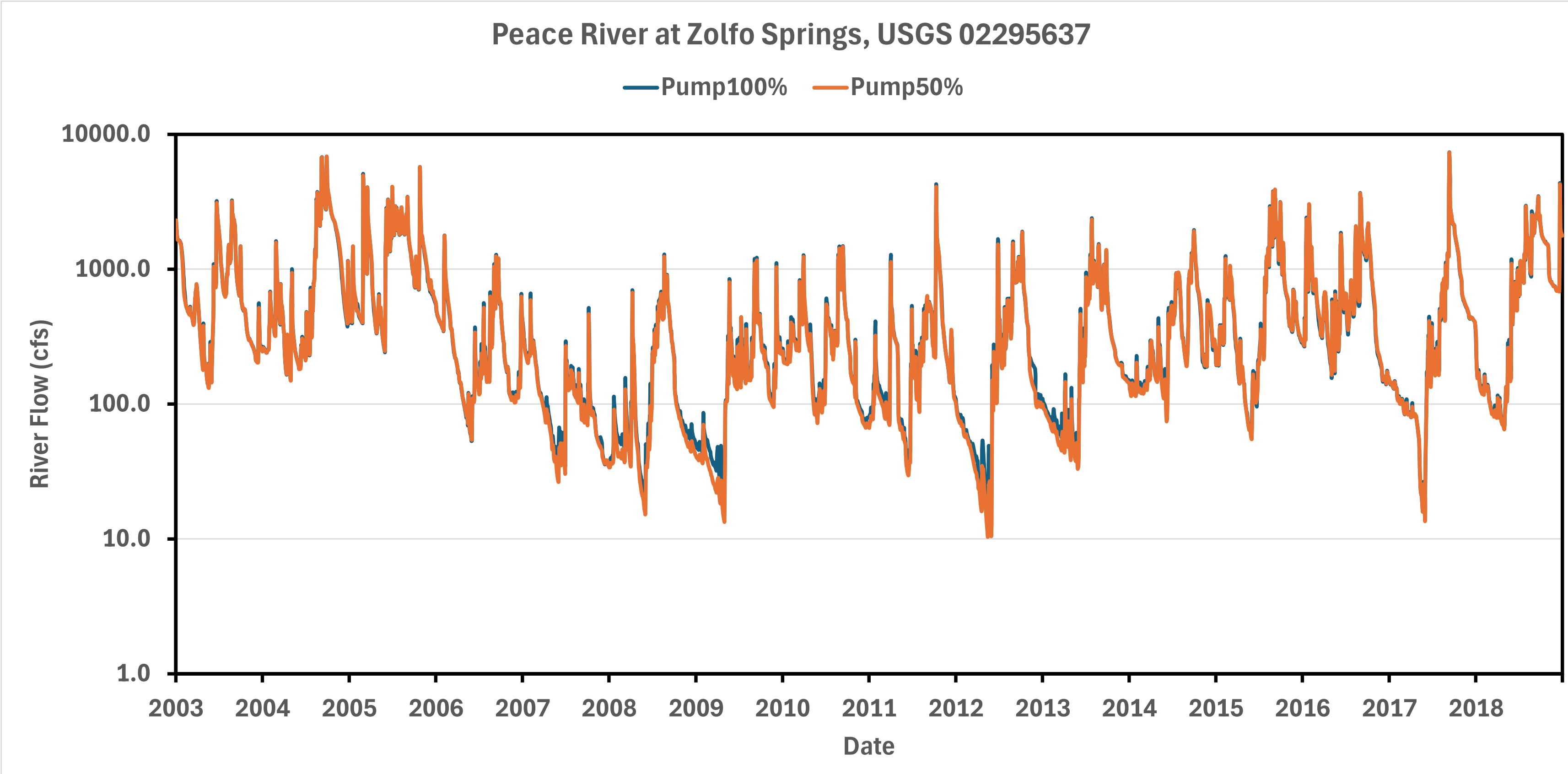

Figure 21. PRIM2 simulated stream flow at USGS 02295637 (Peace River at Zolfo Spring) under the 50% pumping scenario and 100% pumping scenario

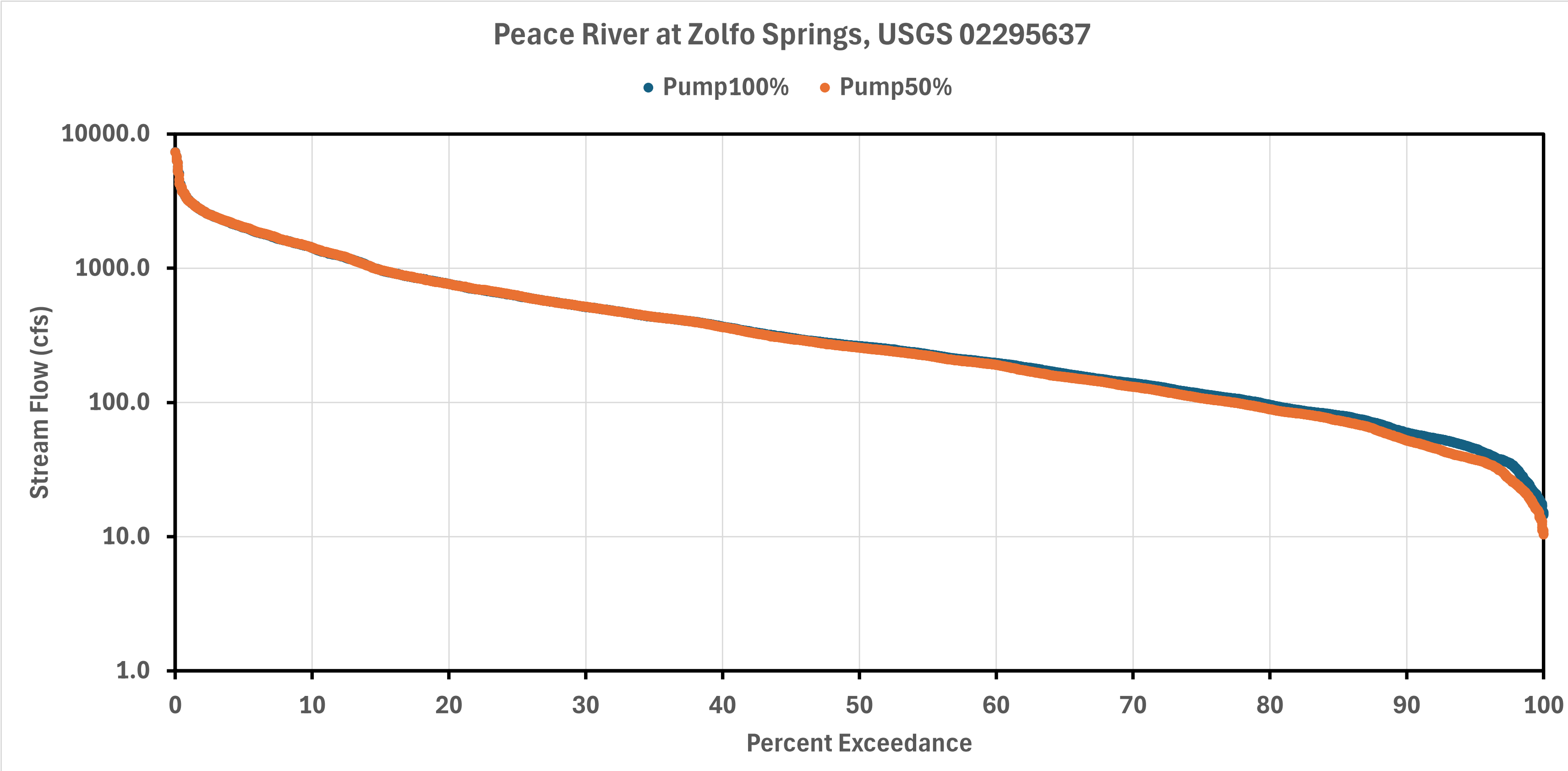

Figure 22. Flow duration curve of PRIM2 simulated stream flow at USGS 02295637 (Peace River at Zolfo Spring) under the 50% pumping scenario and 100% pumping scenario

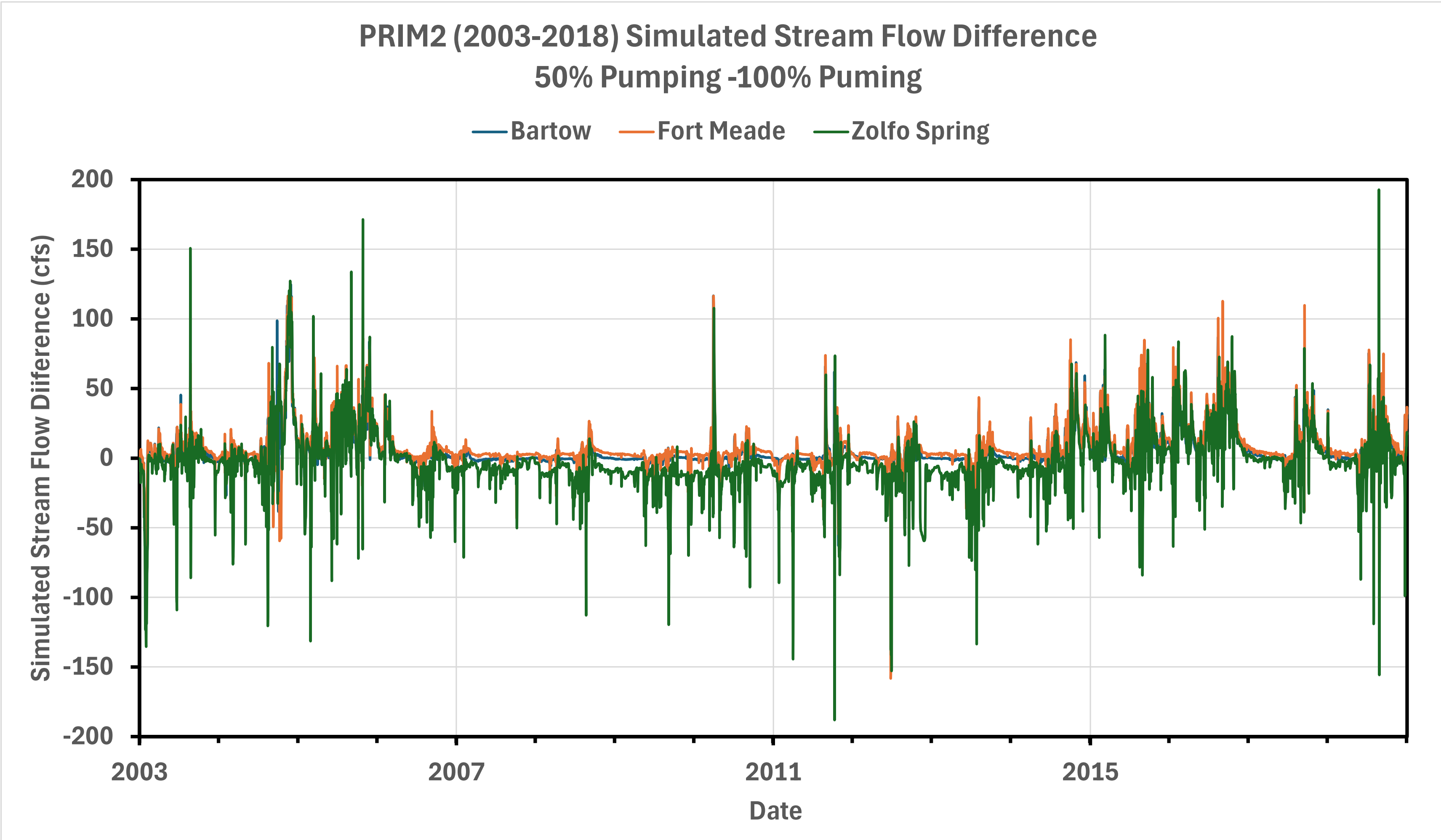

Figure 23. PRIM2 simulated stream flow difference between the 50% pumping scenario and 100% pumping scenario

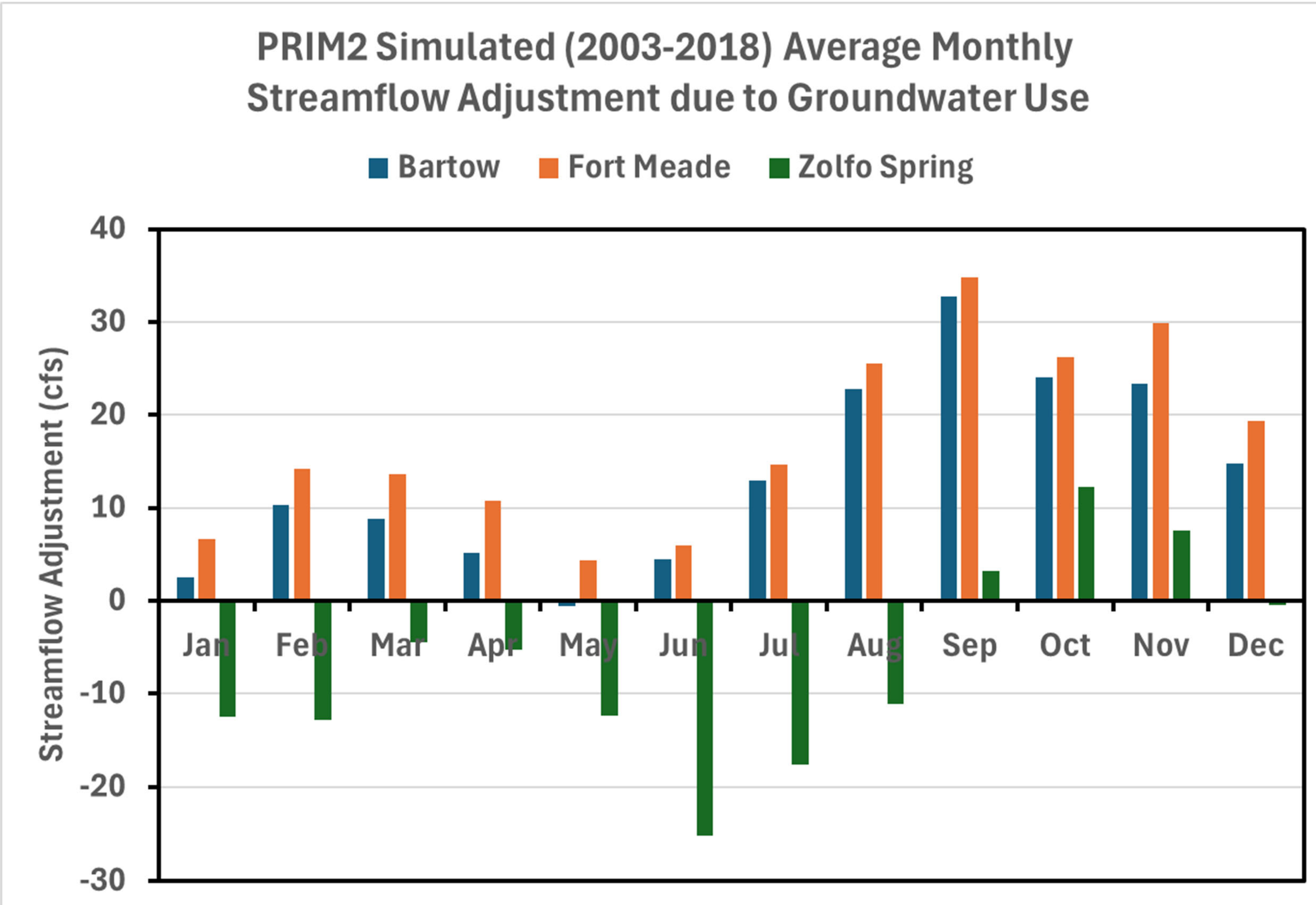

Figure 24. PRIM2 simulated monthly average stream flow adjustment due to groundwater withdrawal

4. Historical Groundwater Use

The upper Peace River basin relies heavily on groundwater for water supply. The historical trend of groundwater use has been studied using data from various sources. SWFWMD has published the annual water use report since 1983 with summarized groundwater and surface water use amount based on metered and estimated data (Ferguson and Hampton, 2022). A detailed well pumping record has been compiled annually since 1992 and stored in a database with monthly pumping records for permitted wells and estimated withdrawals of domestic self-supply (DSS) water use at 2 km grids. The historical water use data has been compiled by USGS by county and by use category in Florida between 1950 and 1990 (Marella, 1995), which provided the water withdrawals at Polk and Hardee Counties in year 1965, 1970, 1975 as well as annual data from 1977 to 1983 for use in the analysis. In addition, estimated water use from 1934 to 1965 as reported by Stewart (1966) and Kaufman (1967) was used in the construction of historical water use.

The major use of groundwater in the Peace River basin has historically been for agricultural irrigation and activities associated with the mining and processing of phosphate ore (Hammett, 1990). Distribution of active and reclaimed mining land associated with the phosphate industry is shown in Figure 25. A large fraction of the upper Peace River basin has been substantially altered by phosphate mining, which have profound impacts on the hydrological conditions in the area. Polk County also has one of the largest agricultural operations including commercial citrus groves as well as beef and dairy cattle in the state. Figure 26 shows the distribution of agricultural land in the basin. With rapid population increase in the region, numerous utilities scattered in the basin (Figure 27) has an increasing demand for public water supply. A summary of groundwater use in Polk County from 1934 to 2022 is presented in Figure 28 based on the analysis of historical records. Summarized groundwater use inside the upper Peace River basin by category from 1992 to 2022 is shown in Figure 29. A synthesized historical record of total groundwater use in the Polk County and Hardee County from 1934 to 2022 is shown in Figure 30 where the data gap was filled by linear interpolation.

Overall groundwater use increased from the 1930s to 1970s followed by a decreasing trend from the late 1970s to the 2000s. Over the last two decades, the groundwater withdrawals have been relatively stable in the upper Peace River basin. Peek (1951) estimated annual ground-water withdrawals of 22 mgd in southwest Polk County by 1940 which increased to 90 mgd by 1950. He attributed about 70 percent of the total groundwater withdrawn to phosphate mining use. Groundwater withdrawals continued to increase in Polk County reaching about 230 mgd in 1960 and over 410 mgd by 1975. Water-conserving practices in agriculture and mining have reduced Polk County groundwater use by about 100 mgd since the mid-1970s. Currently, groundwater withdrawals average between 300 and 400 mgd from Hardee and Polk Counties (Figure 30).

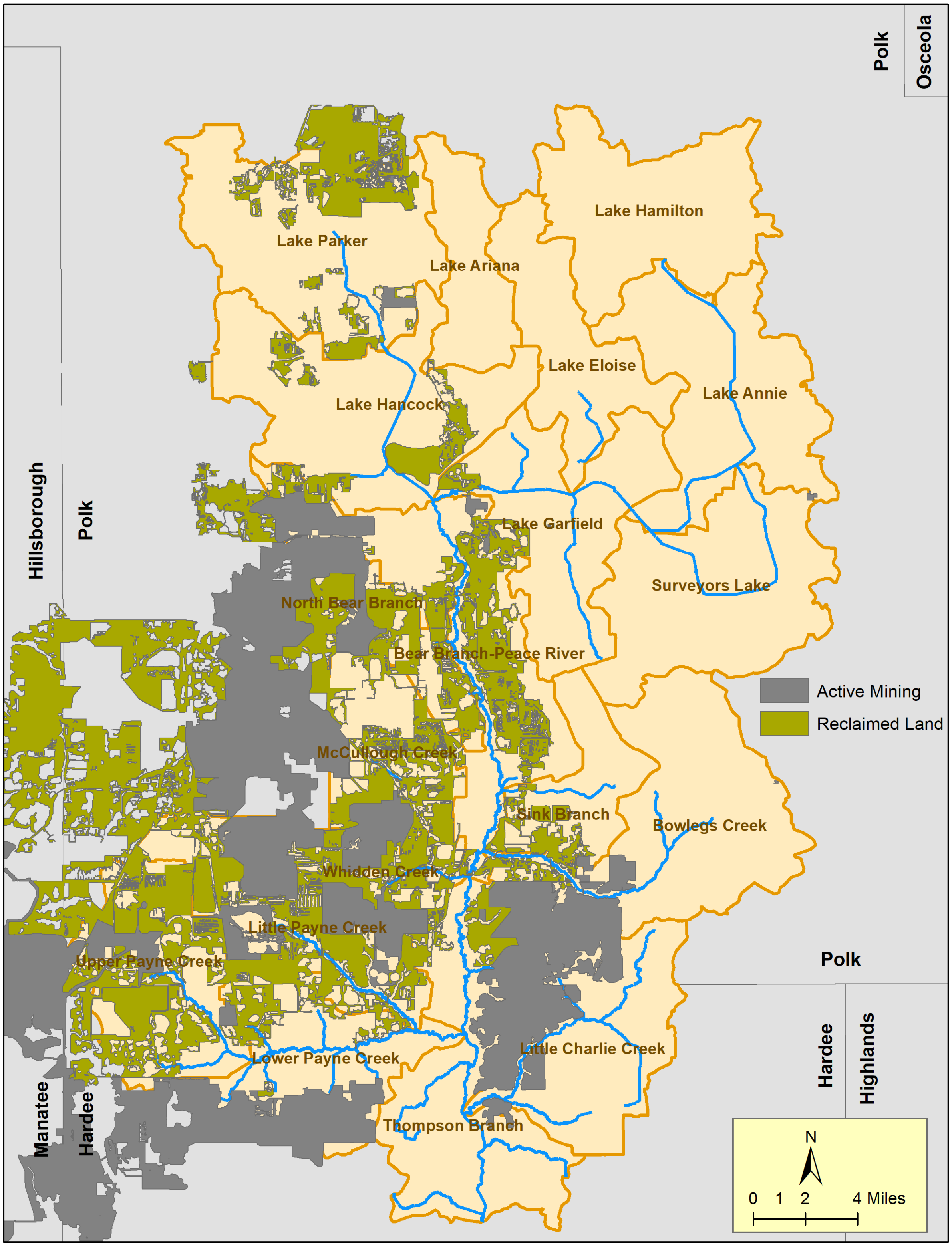

Figure 25 Distribution of the active and reclaimed mining land in the Upper Peace River basin.

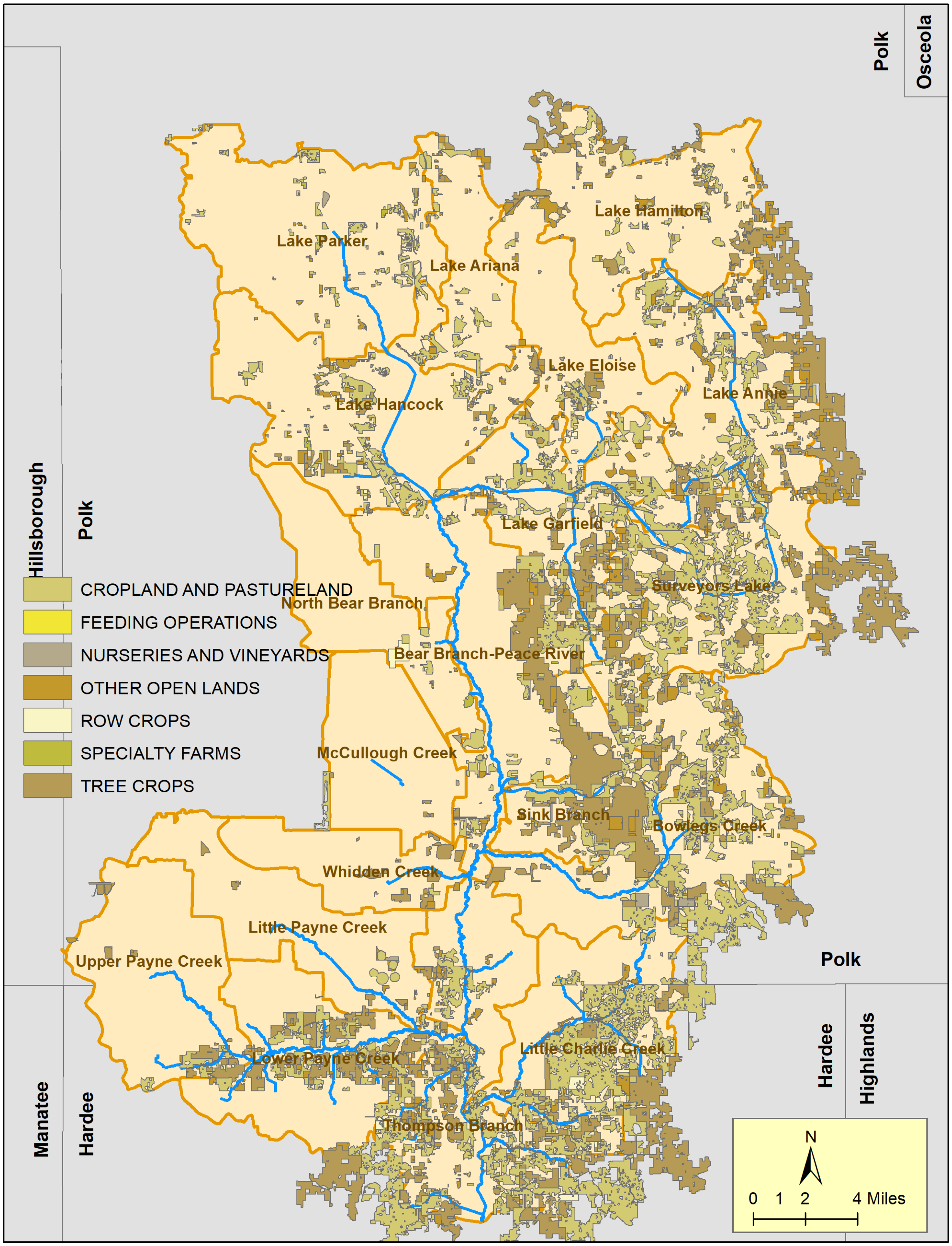

Figure 26 Distribution of agricultural land in the Upper Peace River basin.

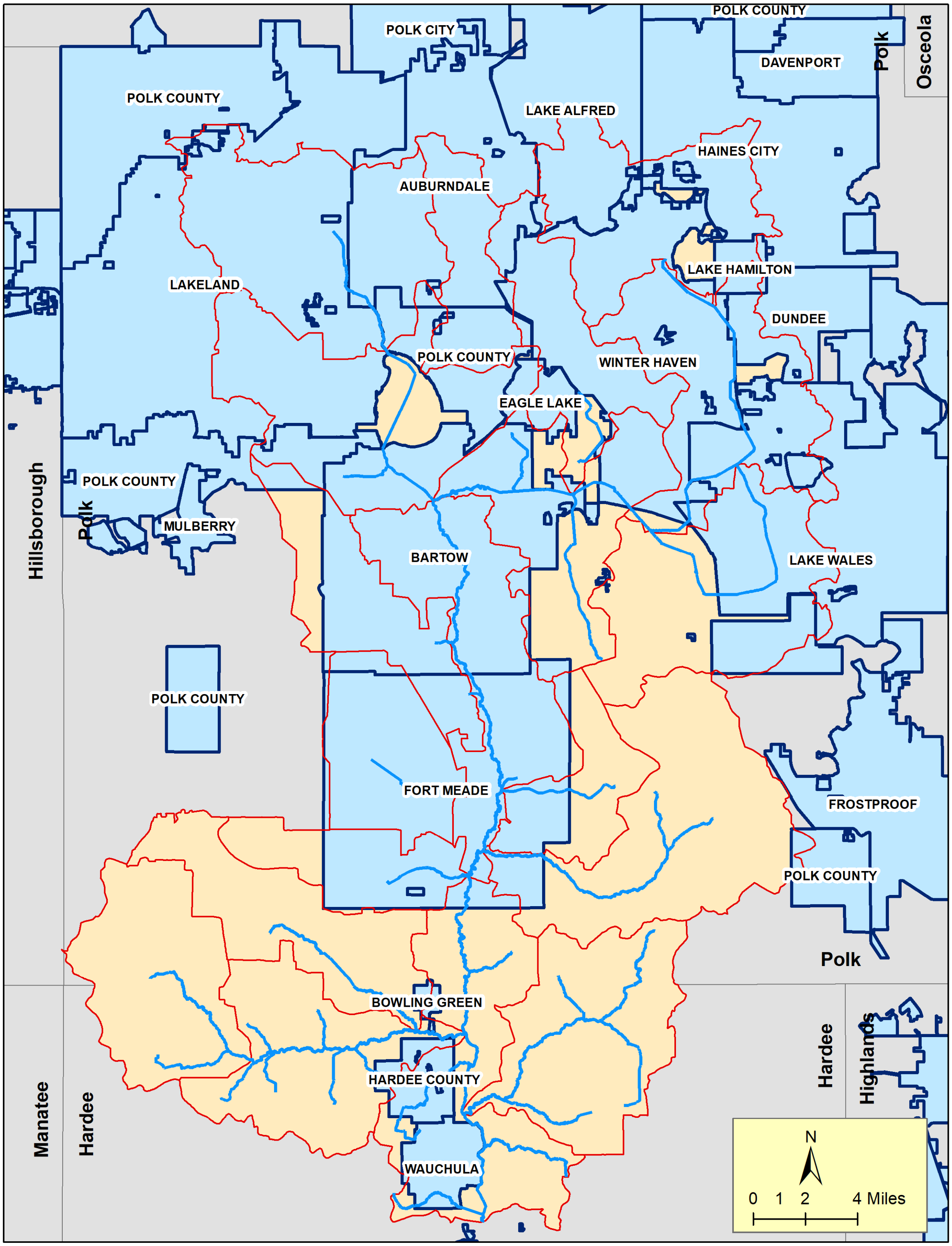

Figure 27 Distribution of public supply utility service area in the Upper Peace River basin.

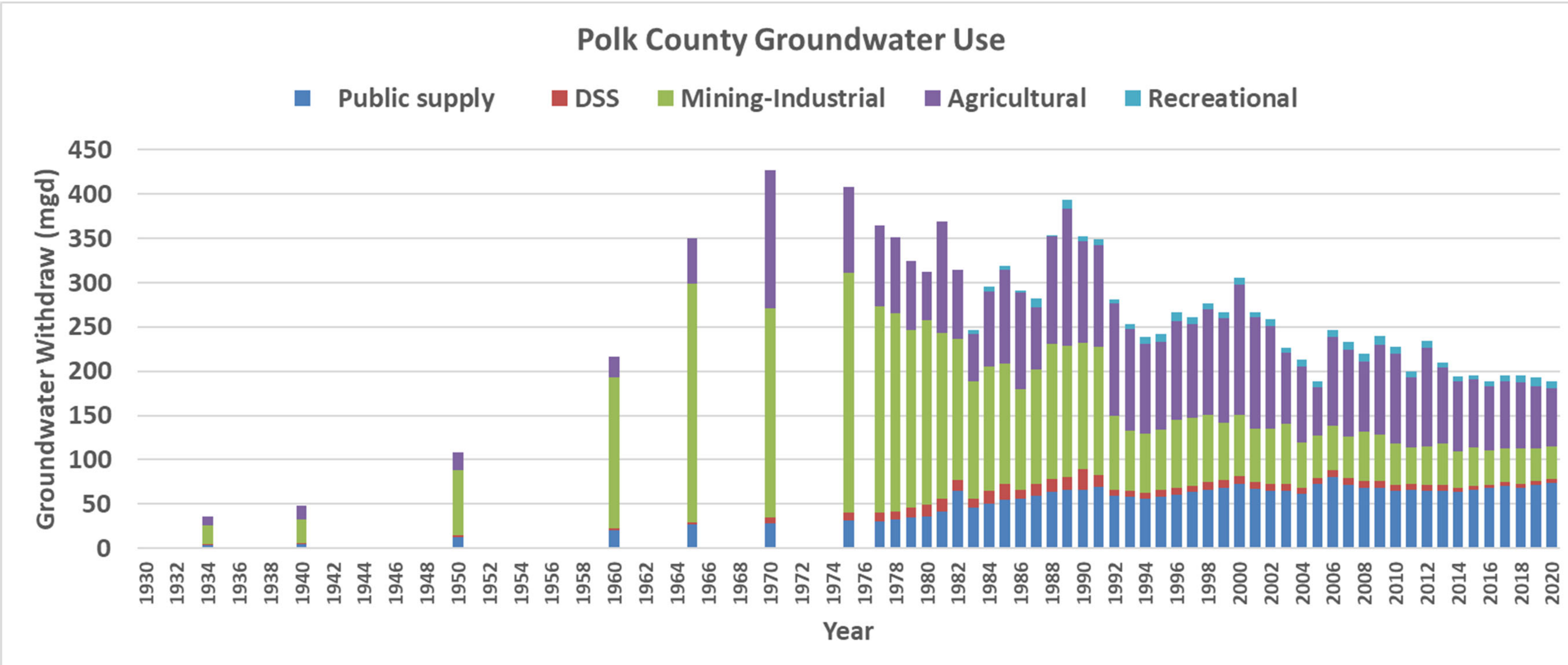

Figure 28 Historical groundwater use in the Polk County from 1930s to 2022.

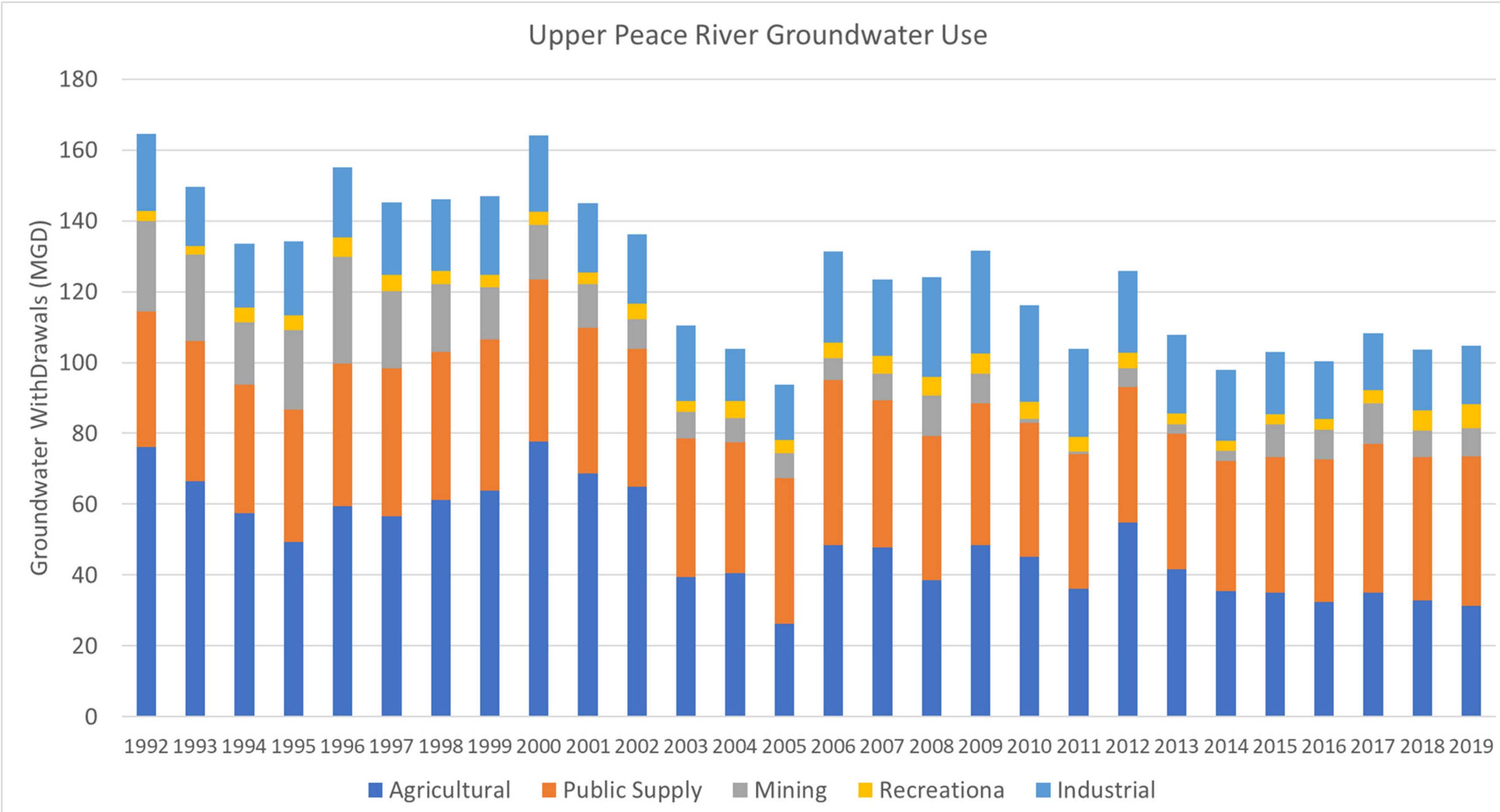

Figure 29 Groundwater use in the upper Peace River basin from 1992 to 2022.

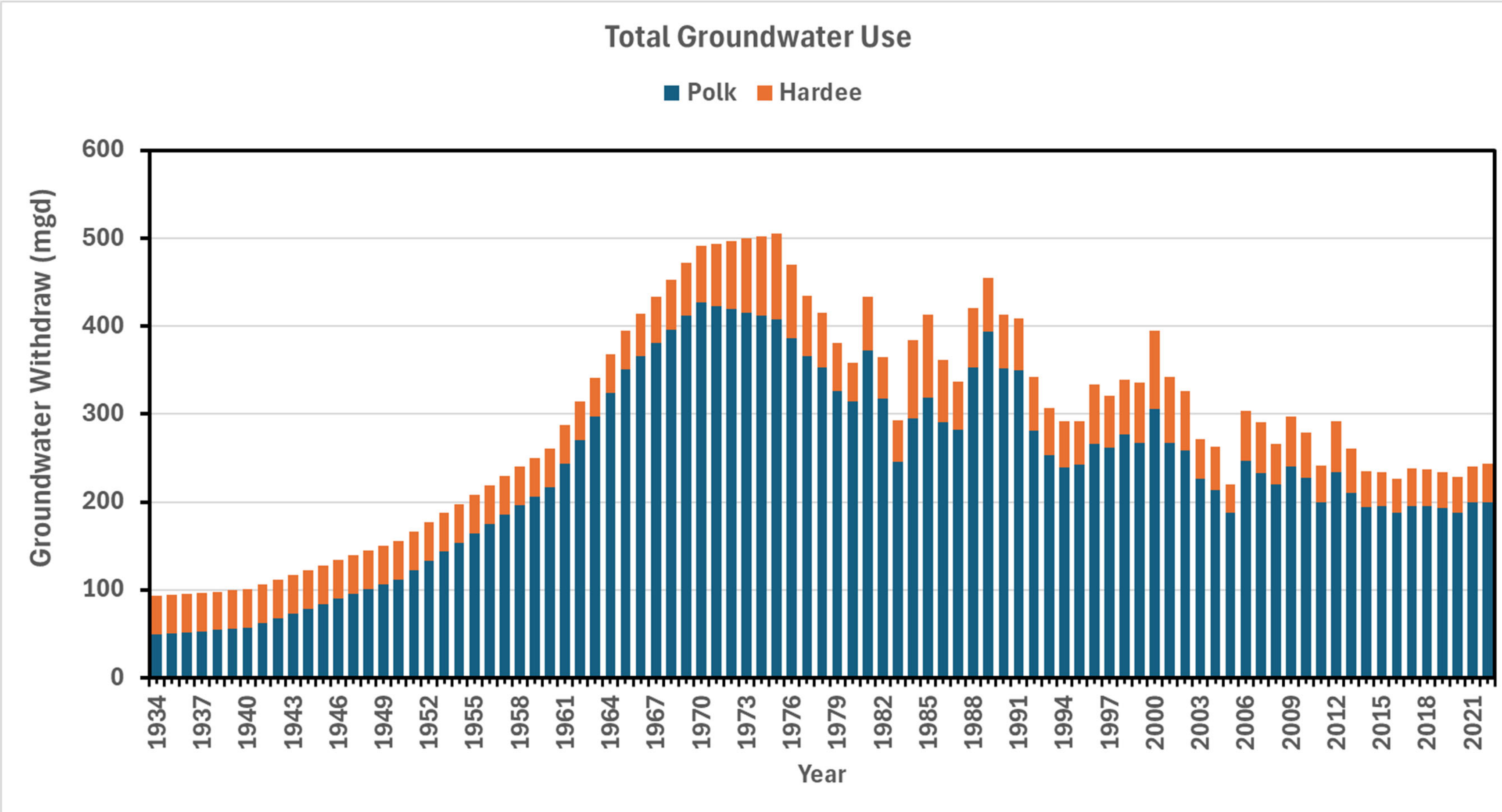

Figure 30 Gap filled annual Groundwater use in the Polk County and Hardee County from 1934 to 2022.

5. Adjustment to Upper Peace River Flow

To construct a historical record of the stream flow without impact from groundwater withdrawals, the PRIM2 simulated streamflow impacts was used in combination with the historical groundwater use data. The technical approach was developed to synthesize the streamflow adjustments from 1934 to 2022 for the Peace River gauges at Bartow, Fort Meade, and Zolfo Springs. The adjustment was then applied to the measured streamflow at the gauges to produce the baseline or unimpacted flow records.

5.1 Technical approach

The specific steps undertaken to develop upper Peace River daily baseline flows were as follows:

(1) The PRIM2 daily simulated flows (2003-2018) for both the base (100% pumping) and 50% pumping reduction scenarios were each averaged into monthly flows, and differences in flows between the two scenarios were calculated for each month.
(2) The monthly average differences in flows calculated in step 1 were multiplied by two to estimate the monthly impacts of total groundwater withdrawals on stream flows (Figure 24).
(3) The ratio of annual average total groundwater withdrawal in Polk County and Hardee County from 1934 to 2021 (Figure 30) was calculated over the average groundwater withdrawal between 2003-2018 (PRIM2 simulation period). The calculated ratio varied between a minimum of 0.361 in year 1934 to a maximum of 1.945 in year 1975.
(4) The annual groundwater withdrawal ratios were multiplied by the monthly streamflow adjustment to produce monthly time series of streamflow adjustments for each stream gauges (Figure 31).
(5) The daily gauged flows measured at the three USGS gauges (Bartow, Fort Meade, and Zolfo Springs) were corrected for the effects of groundwater withdrawals calculated for each month in step (4).

5.2 Estimated unimpacted stream flow

The simulated upper Peace River stream flow adjustment due to groundwater withdrawal is illustrated in Figure 31. At Bartow and Fort Meade gauge, the measured streamflow was adjusted up to reflect the increased leakage of river water to underlying aquifers due to the decline of groundwater potentiometric surface. In contrast, the streamflow at the Zolfo Springs gauge was subtracted to account for excess return flow.

Hydrographs and flow exceedance curves of gauge flow and adjusted baseline flow are presented for Bartow (Figure 32 and Figure 33), Fort Meade (Figure 34 and Figure 35), and Zolfo Springs (Figure 36 and Figure 37). Summary statistics (P10, P50, P60, and Mean) were given in Table 1 for gauged and baseline flows of Bartow, Fort Meade, and Zolfo Springs.

The long-term mean streamflow change due to groundwater withdrawals were 15.6, 21.6, and -6.8 cfs for Bartow, Fort Meade, and Zolfo Springs, respectively. The simulated pattern of flow change agrees with the general understanding of the groundwater – surface water interaction along the upper Peace River. Upstream of Fort Meade Gauge, the numerous karst features along the stream channel caused substantial downward discharge of stream water to the underlying aquifers (Lewelling et al., 1998; Basso, 2003; Knochenmus, 2004; Metz and Lewelling, 2009). Due to the higher confinement of Hawthorn group in the southern part of the basin, the groundwater withdrawal is returned to surface water in the form of surface runoff or irrigation. Therefore, the groundwater uses in general increased streamflow at the Zolfo Springs gauge (HGL, 2023).

Table 1 Statistics of gauged and reconstructed baseline flows of the Upper Peace River

Gauge	Statistics	Gauged Flow	Baseline Flow	Flow Change	
		cfs	cfs	cfs	%
Bartow	P10	15.0	24.3	9.3	38%
	P50	90.9	107.7	16.8	16%
	P90	584.8	599.9	15.1	3%
	Mean	217.3	232.9	15.6	7%
Fort Meade	P10	7.5	23.2	15.7	68%
	P50	79.0	103.5	24.5	24%
	P90	581.0	604.5	23.5	4%
	Mean	207.7	229.3	21.6	9%
Zolfo Springs	P10	81.5	71.5	-10.0	-14%
	P50	305.0	299.5	-5.5	-2%
	P90	1470.0	1458.8	-11.2	-1%
	Mean	613.2	606.4	-6.8	-1%

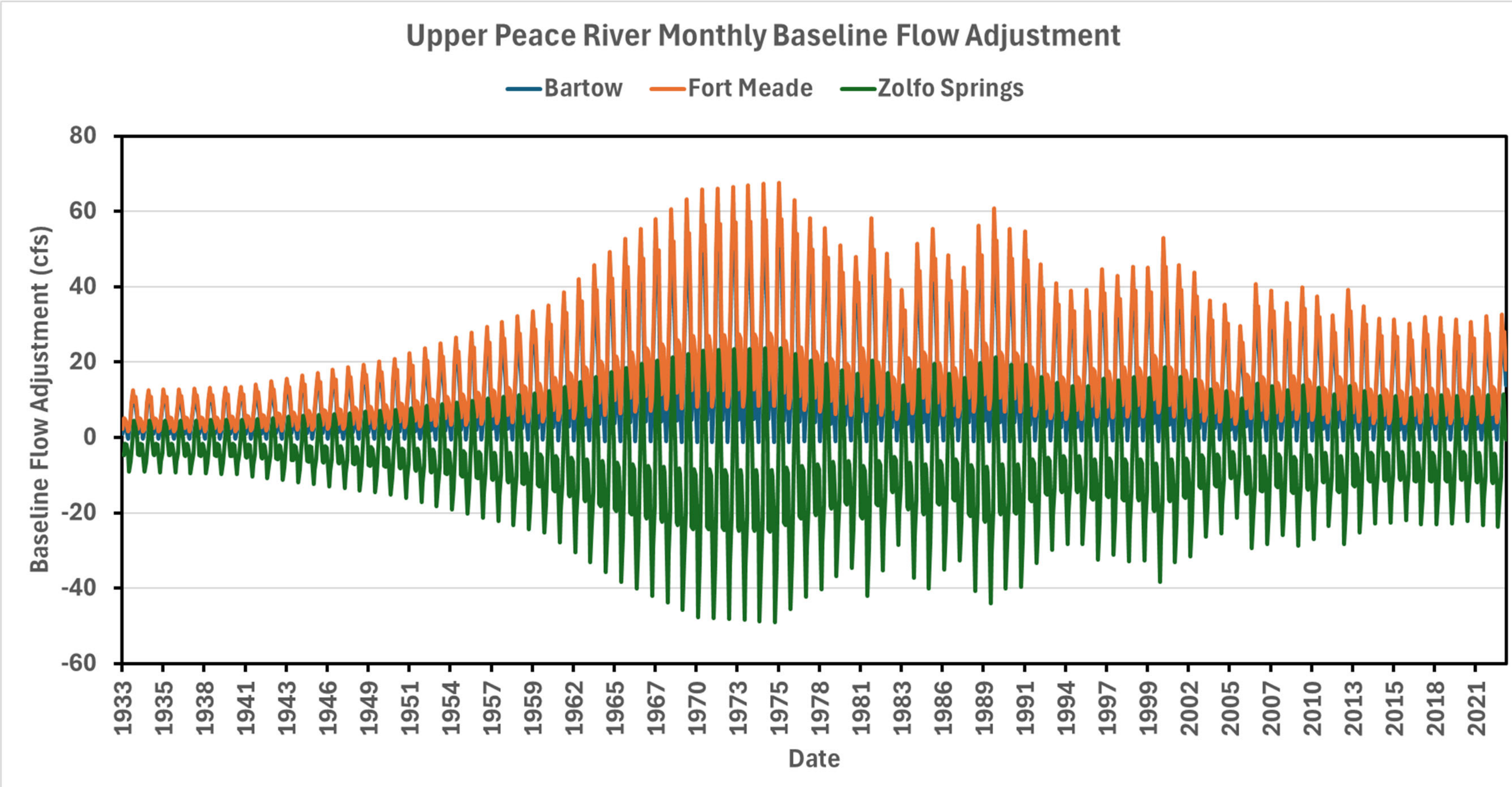

Figure 31 Baseline flow adjustment developed for the river gauges based on PRIM2 simulation and estimated groundwater withdrawal.

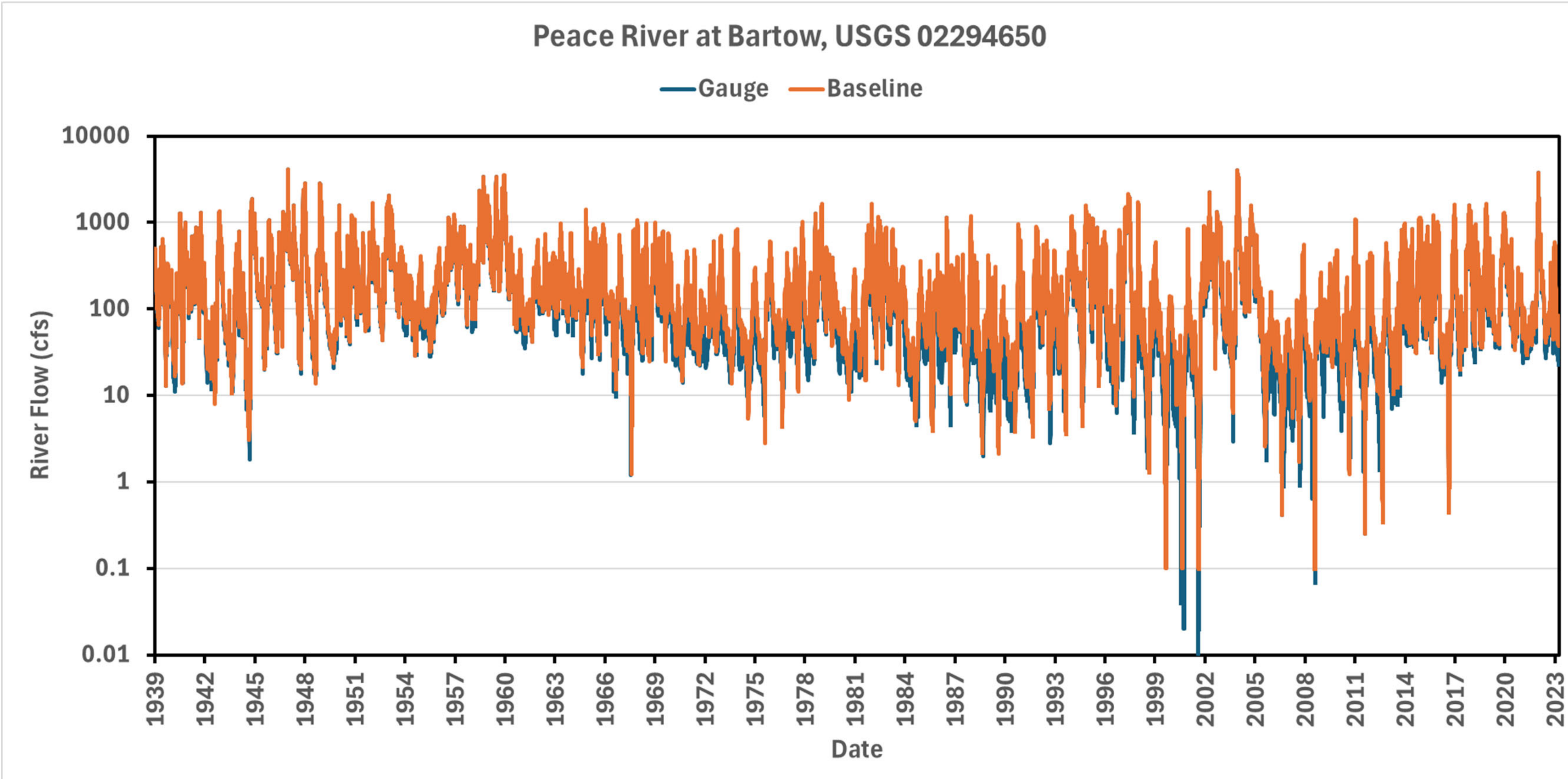

Figure 32 Comparison between gauged flow and reconstructed baseline flow of USGS 02294650 (Peace River at Bartow)

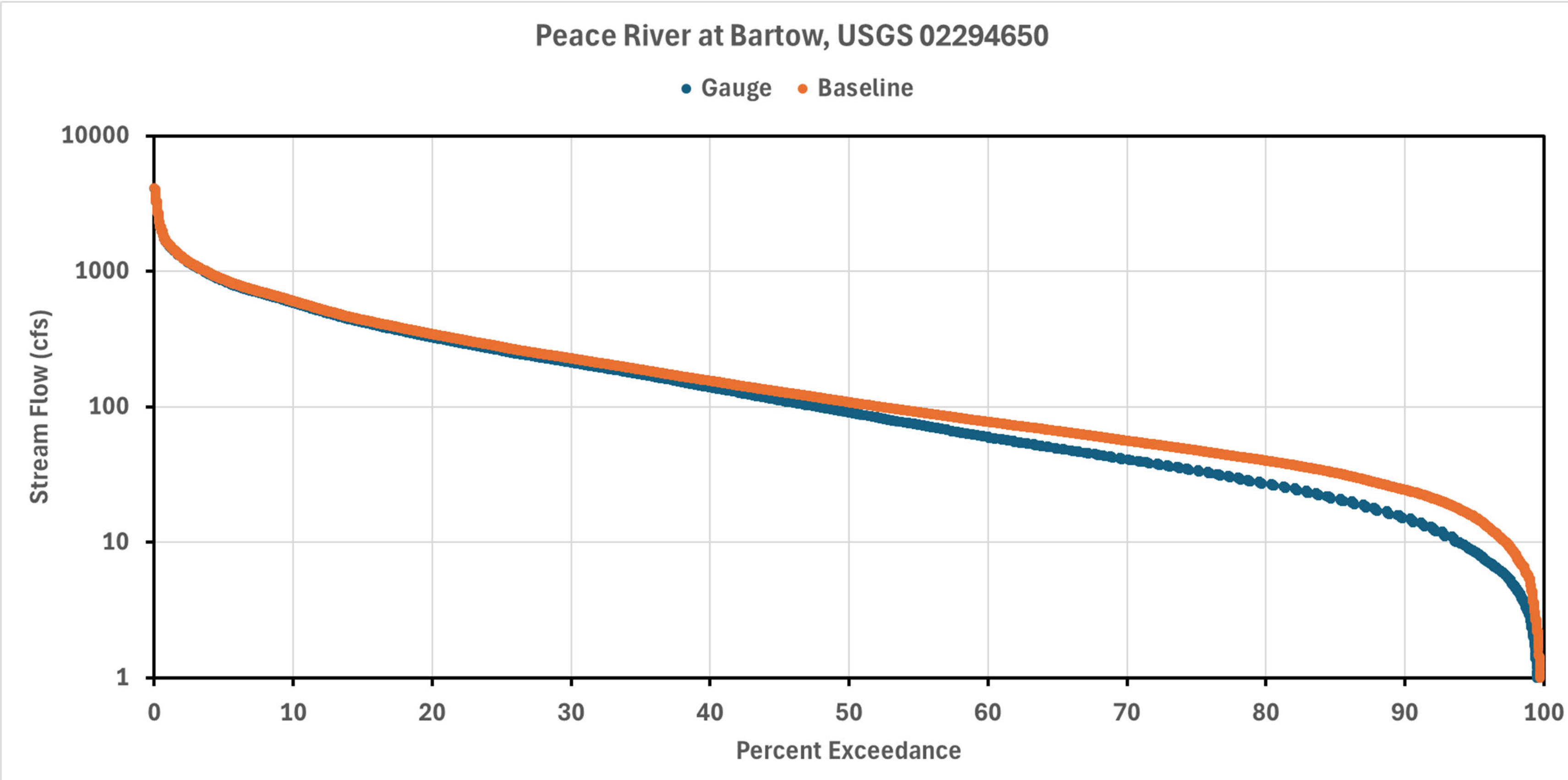

Figure 33 Flow duration curve of gauged flow and reconstructed baseline flow of USGS 02294650 (Peace River at Bartow)

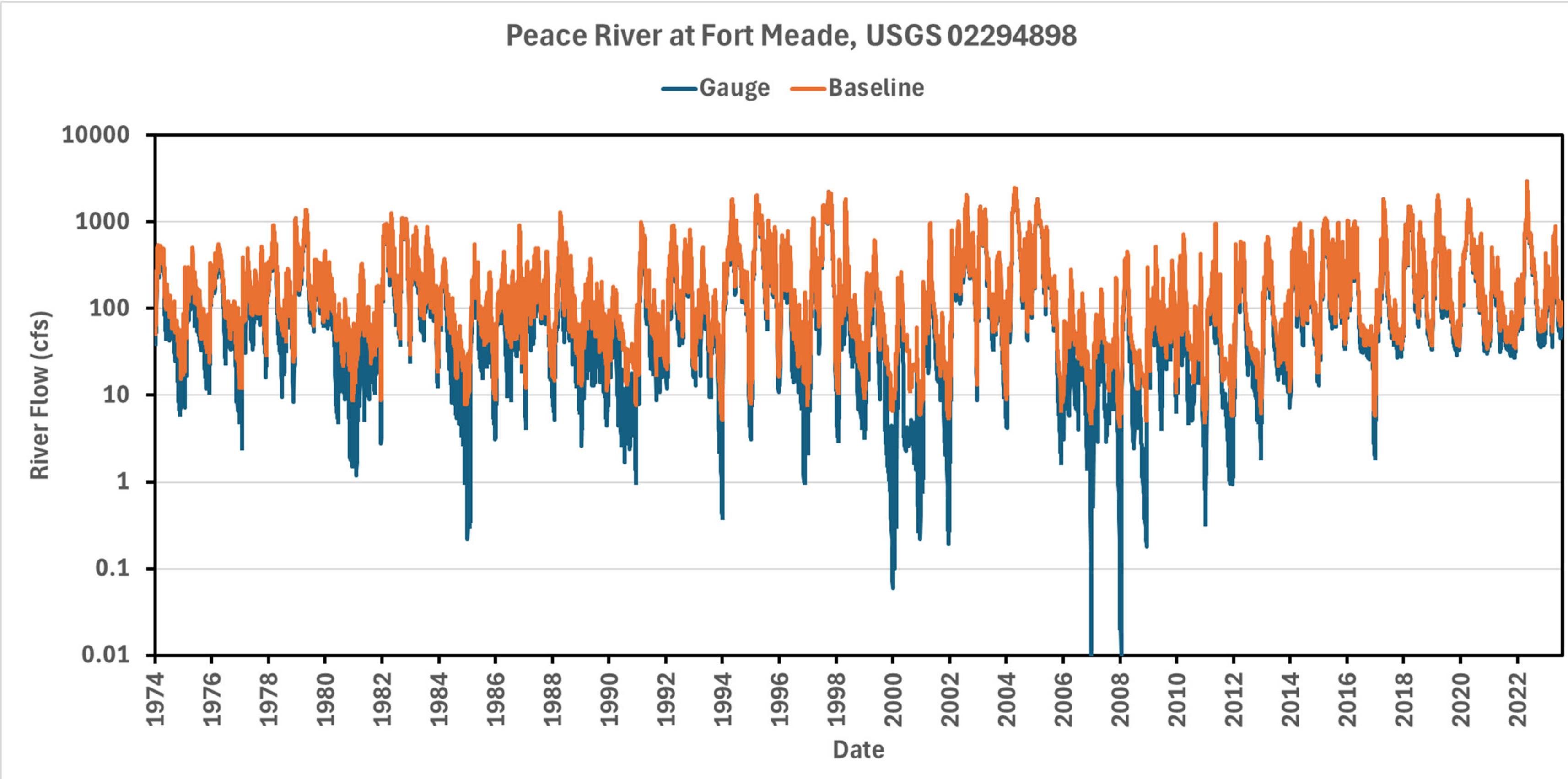

Figure 34 Comparison between gauged flow and reconstructed baseline flow of USGS 02294898 (Peace River at Fort Meade)

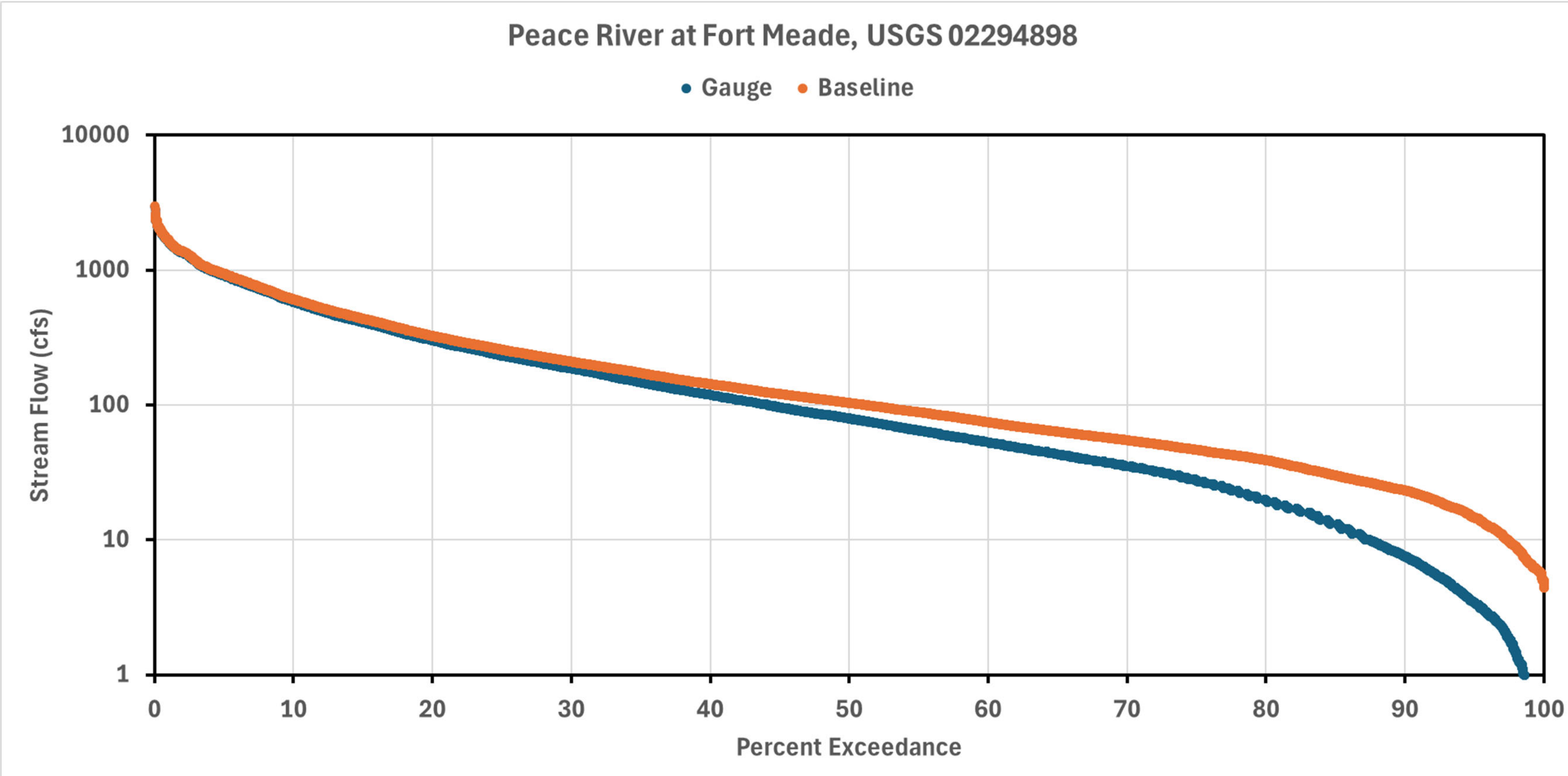

Figure 35 Flow duration curve of gauged flow and reconstructed baseline flow of USGS 02294898 (Peace River at Fort Meade)

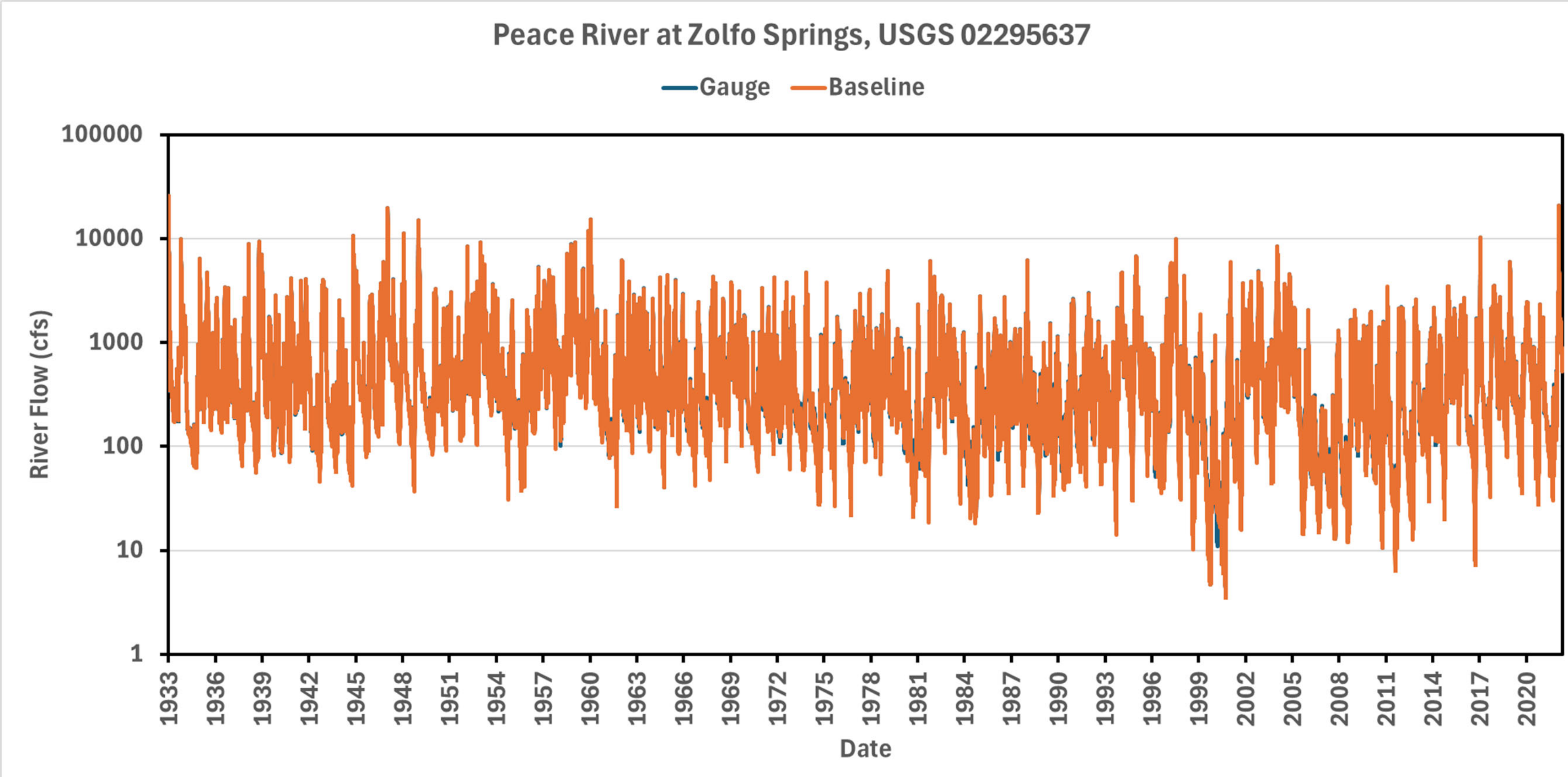

Figure 36 Comparison between gauged flow and reconstructed baseline flow of USGS 02295637 (Peace River at Zolfo Spring)

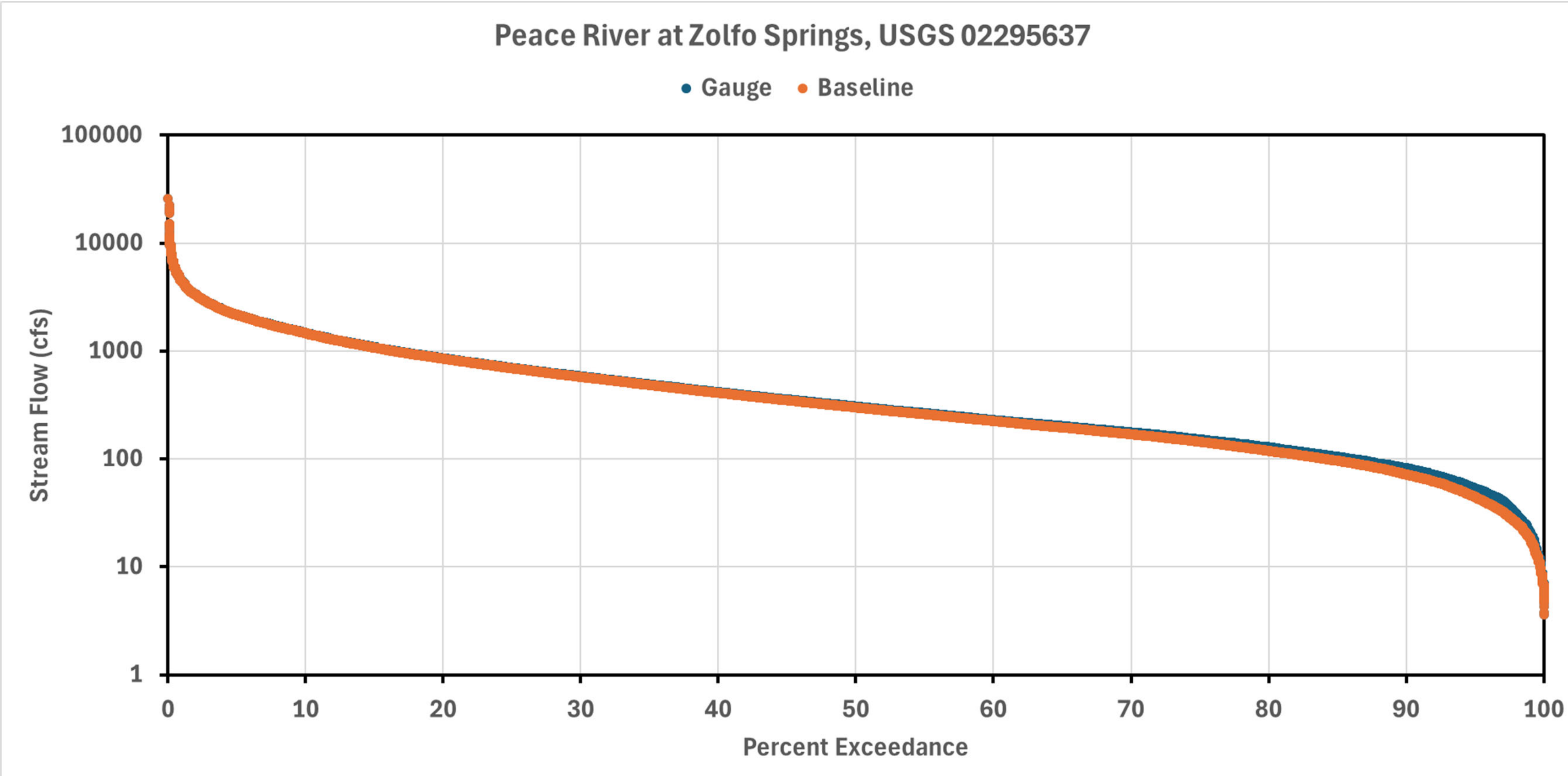

Figure 37 Flow duration curve of gauged flow and reconstructed baseline flow of USGS 02295637 (Peace River at Zolfo Spring)

6. Summary

Impacts of groundwater withdrawals on stream flow along the upper Peace River were simulated using the adjustment factor derived from the PRIM2 pumping scenario outputs and long-term groundwater use records. The baseline (unimpacted) stream flows at Bartow, Fort Meade, and Zolfo Springs were calculated for the evaluation of minimum flows. The long-term mean streamflow changes due to groundwater withdrawals were 15.6 cfs and 21.6 cfs for Bartow and Fort Meade, respectively, indicating an overall loss of streamflow to the underlying aquifer due to the decline of the potentiometric surface. In contrast, the mean streamflow change was -6.8 cfs at Zolfo Springs, which reflects the increased streamflow due to the return flow from surface runoff and irrigation.

References:

1. Basso, R.J., 2003, *Predicted change in hydrologic conditions along the Upper Peace River due to a reduction in ground-water withdrawals*. Brooksville, Southwest Florida Water Management District Report, 53 p.
2. Ferguson, J. F., Hampton, C; 2022, *Southwest Florida Water Management District, 2021 Estimated Water Use Report*. Southwest Florida Water Management District, 239 p.
3. Hammett, K.M., 1990, *Land use, water use, streamflow characteristics, and water-quality characteristics of the Charlotte Harbor inflow area, Florida*. U.S. Geological Survey Water-Supply Paper 2359-A, 64 p.
4. Hutchinson, C.B., 1978, *Appraisal of shallow ground-water resources and management alternatives in the upper Peace and eastern Alafia River basins, Florida*. U.S. Geological Survey Water-Resources Investigations Report 77-124, 57 p.
5. HydroGeoLogic, Inc. 2023. *Peace River Integrated Modeling Project 2 (PRIM 2) – Draft Report. Prepared for the Southwest Florida Water Management District*, March 2023. Brooksville, Florida.
6. Kaufman, M.I., 1967, *Hydrologic Effects of Ground-water Pumpage in the Peace and Alafia River Basins, Florida, 1934-1965*. Tallahassee, State of Florida Board of Conservation, Division of Geology. Report of Investigations No. 49, 32p.
7. Knochenmus, L.A., 2004, *Streamflow losses through karst features in the Upper Peace River hydrologic area, Polk County, Florida, May 2002 to May 2003*. U.S. Geological Survey Fact Sheet 102-03, 4 p.
8. LaRoche, J.J., and Horstman, T.M., 2023, *Hydrostratigraphic Framework of the Southwest Florida Water Management District: Technical Report of the Regional Observation and Monitor-well Program*: Brooksville, Florida, Geohydrologic Data Section, Southwest Florida Water Management District, 29 p.
9. Lewelling, B. R., Ann B. Tihansky, and Jack L. Kindinger. 1998. *Assessment of the hydraulic connection between ground water and the Peace River, west-central Florida*. US Geological Survey, Water-Resources Investigations Report 97–4211, 96p.
10. Marella, R.L.,1995, *Water-use data by category, county, and water management district in Florida, 1950-90*. U.S. Geological Survey Open-File Report 94-521, 114 p.

11. Metz, P.A., and Lewelling, B.R., 2009, *Hydrologic Conditions that Influence Streamflow Losses in a Karst Region of the Upper Peace River, Polk County, Florida*. U.S. Geological Survey Scientific Investigations Report 2009-5140, 82 p.

12. Peek, H.M., 1951, *Cessation of flow of Kissengen Spring in Polk County, Florida, in Water resource studies*. Tallahassee, Florida Geological Survey Report of Investigations 7, p. 73-82.

13. Southwest Florida Water Management District, 2002, *Upper Peace River—An analysis of minimum flows and levels*. Brooksville, 244 p.

14. Spechler, R.M., and Kroening, S.E., 2007, *Hydrology of Polk County, Florida*. U.S. Geological Survey Scientific Investigations Report 2006-5320, 114 p.

15. Stewart, H.G., Jr., 1966, *Ground-water resources of Polk County, Florida*. Tallahassee, Florida Geological Survey Report of Investigations 44, 170 p.