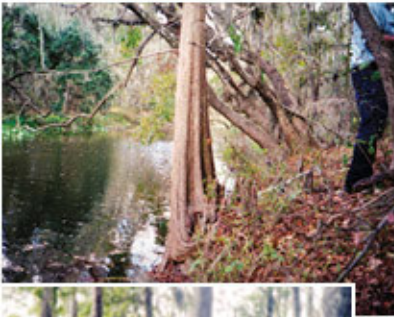


Peace River Cumulative Impact Study



**Long-Term Flow
Patterns in the
Peace River Watershed**

Previous Studies of Long-term Changes in Watershed Hydrology

- **USGS**
 - Hammett 1990 (Landuse/Streamflow)
 - Lewelling & Wylie 1993 (Mined/Reclaimed)
 - Lewelling et al. 1998 (Groundwater/Surface Water)
- **District**
 - Basso 2002 (Surface/Groundwater)
 - Basso & Schultz 2003 (Rainfall/Flow)
 - Kelly et al. 2002 (Upper River Minimum Flows)
 - Kelly et al. 2005 (Middle River Minimum Flows)
- **Coastal Environmental**
 - 1996 (Rainfall/Flow)
- **PBS&J (CHNEP)**
 - 1999 (Rainfall/Flow)
- **Ardaman & Associates**
 - Garlanger 2002 (Mining/Landuse/Flows)
- **SDI 2003** (Mining/Landuse/Flows)
- **Summary HBMP Studies**
 - Lower Peace River 1976-2004
 - Shell Creek 1991-2004



Factors Affecting River Flow

- **Land-use changes**
- **Hydrological structural alterations**
- **Groundwater withdrawals**
- **Long-term rainfall variation**

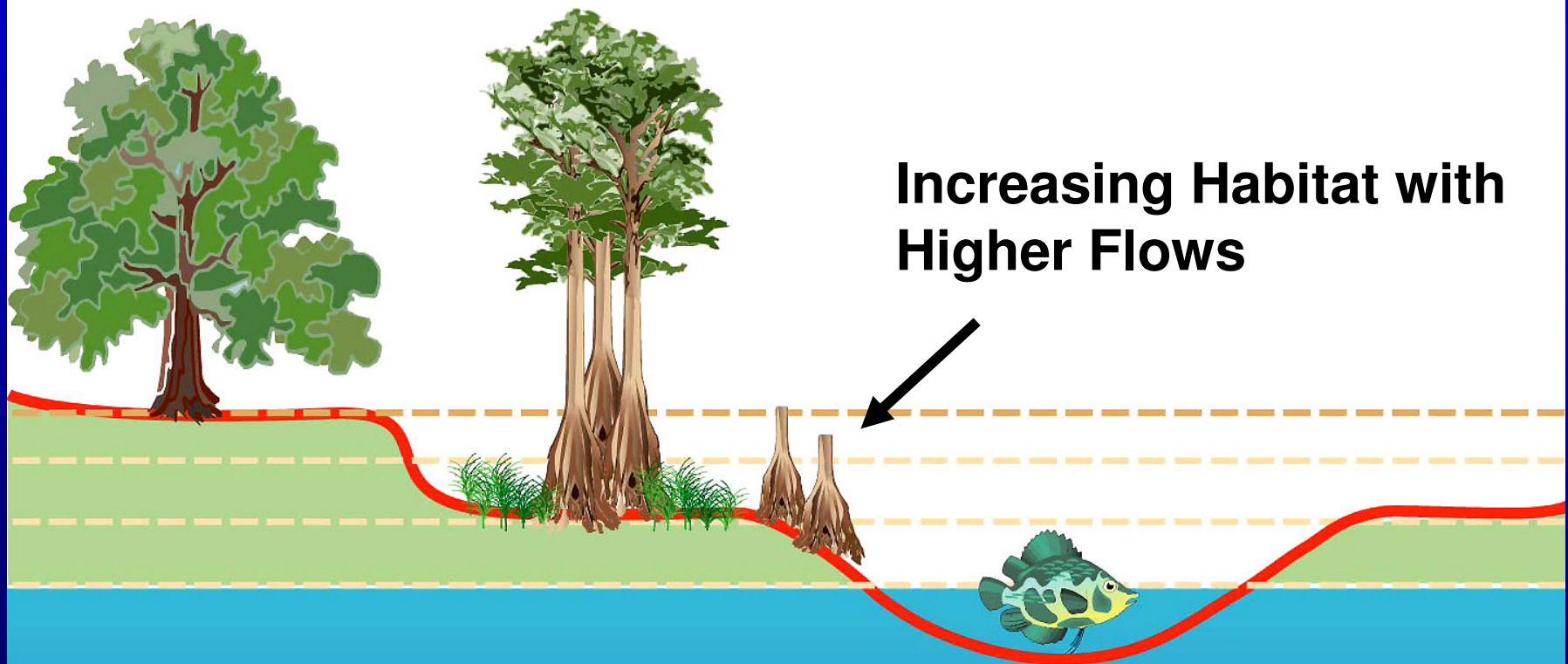


Impacts of Flow Reductions

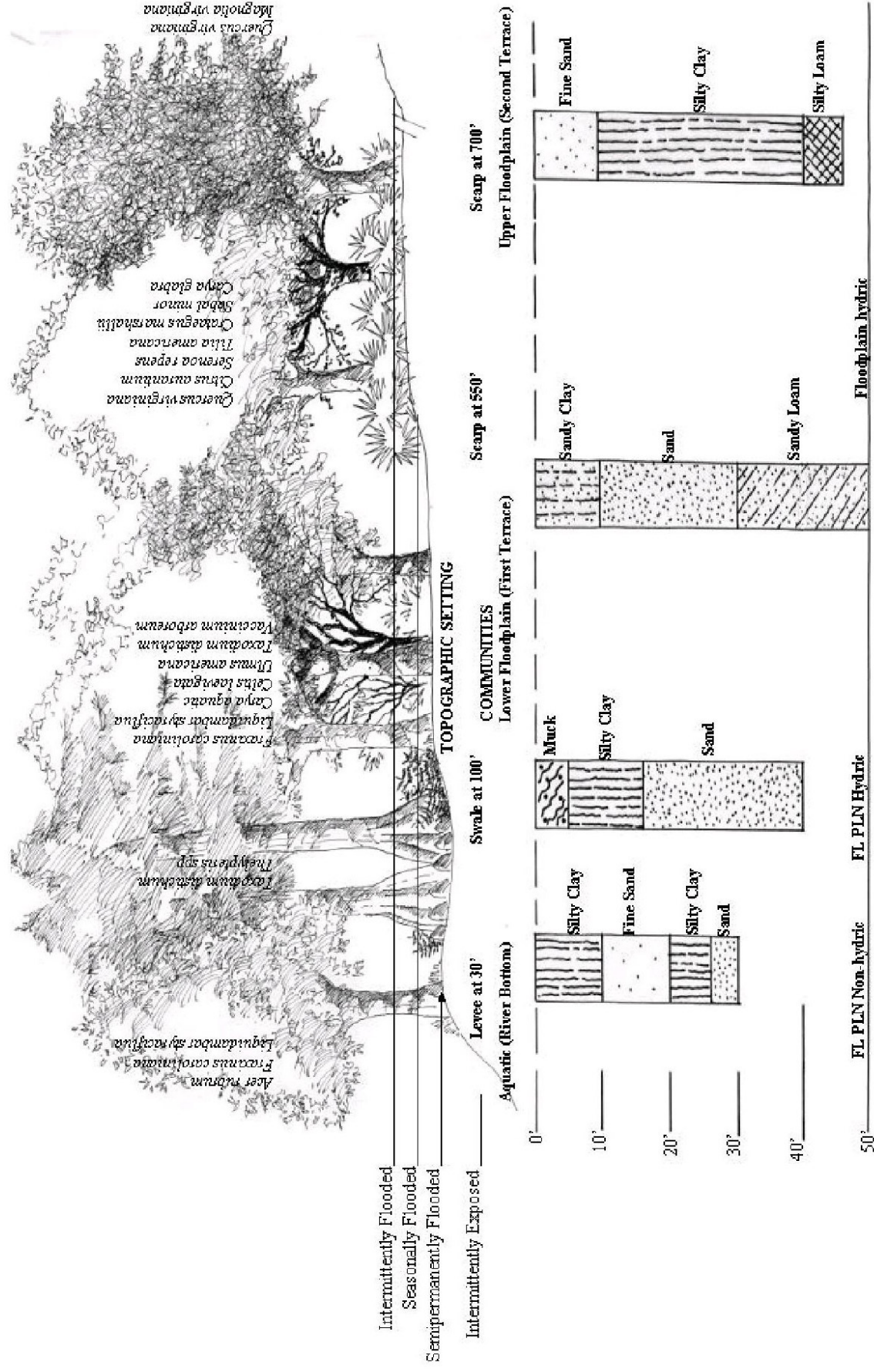
- Loss of in-stream riverine habitat
- Loss of flood-plain habitat
- Changes in flood-plain vegetation communities
- Potential decreases in public water supply
- Increased estuarine upstream movement of saltwater interface
- Decreased estuary productivity



MFL Floodplain Community Structure



A typical profile of the vegetation, hydrology, soils, and topographic gradients in the floodplain of the upper Peace River (from unpublished data collected during a study of the upper Peace River, PBS&J 2000).



MFL Soils/Vegetation Analyses

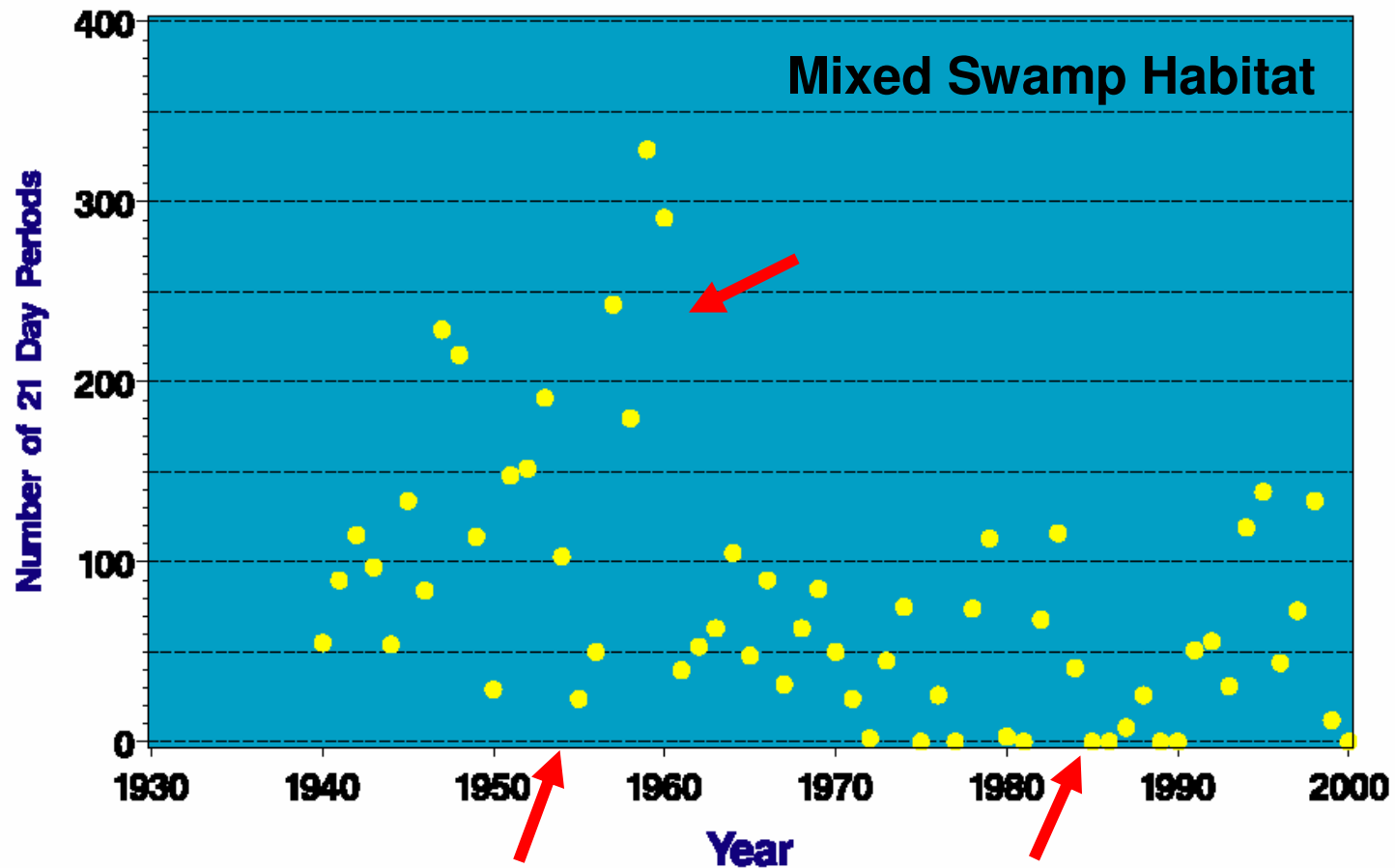


MFL Hydrologic Analyses

Transect #143 and Elevation=83.8 feet

Number of Yearly 21 Day Inundation Periods

Median Elevation for Mixed Swamp Community

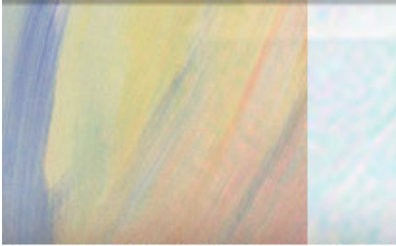


Factors Affecting River Flow

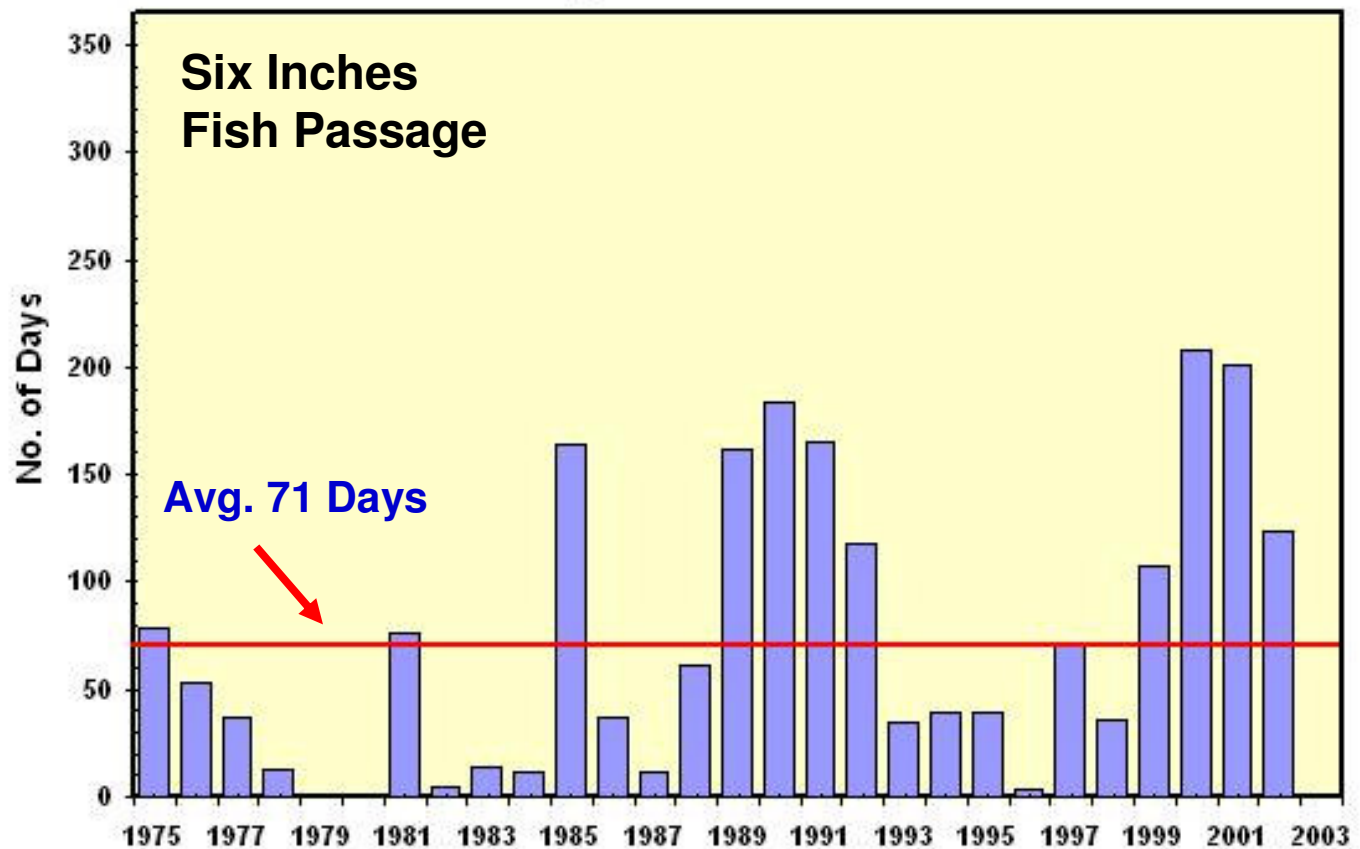
- **Groundwater Withdrawals**
- **Historical Changes in Groundwater Elevations**
- **Natural Climatic Cycles**



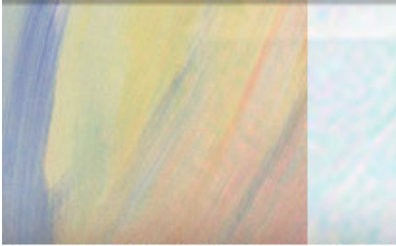
District Upper Watershed MFL



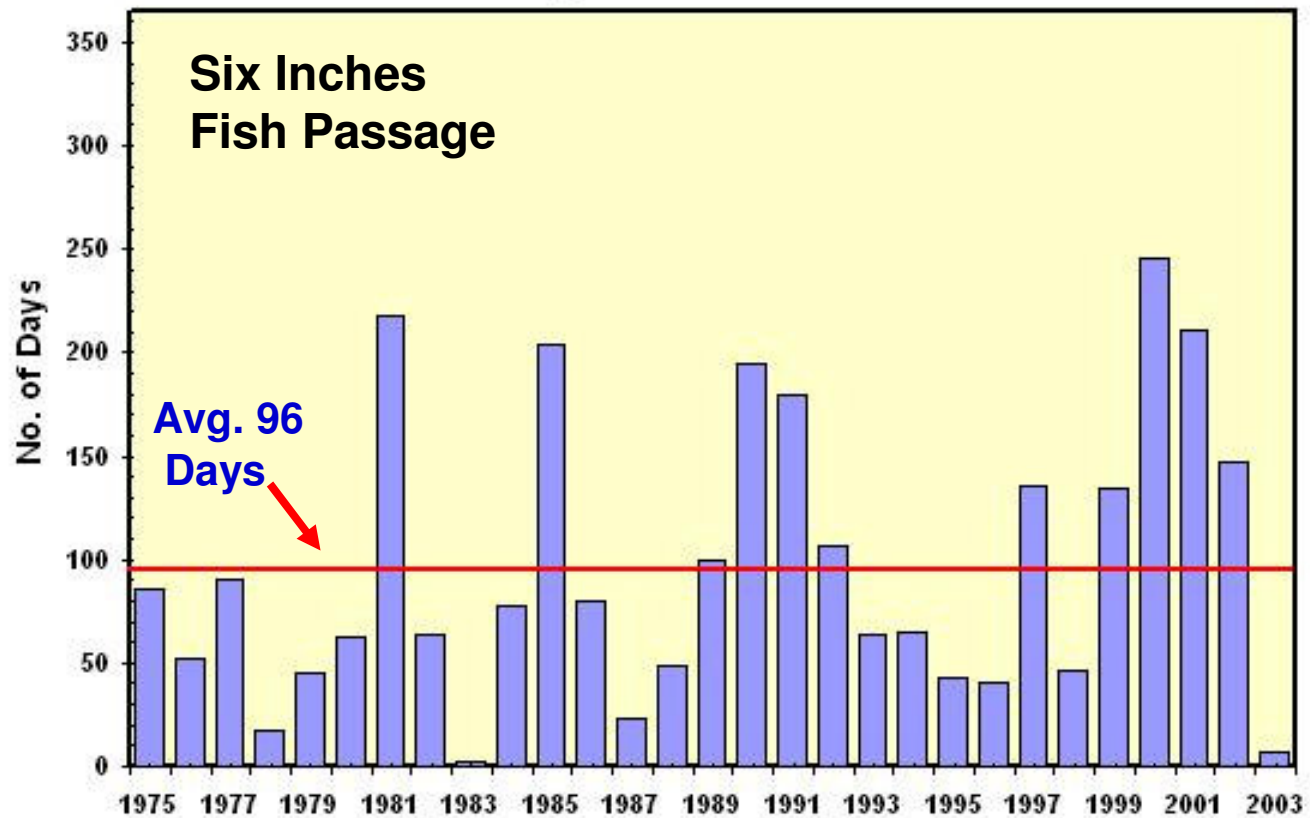
Upper Peace River - Bartow Station (1975-2003)
Days/Year MFL not met



District Upper Watershed MFL

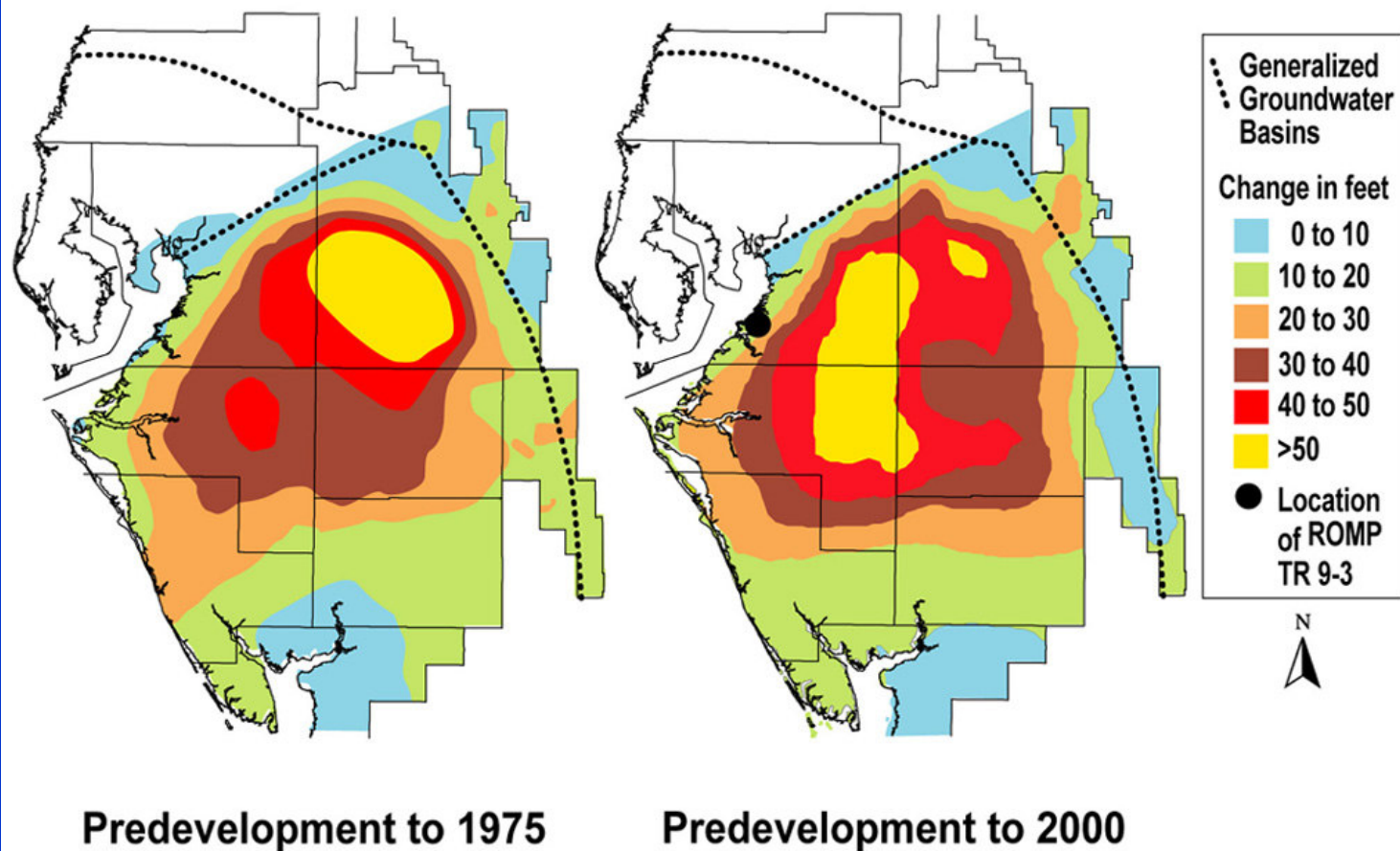


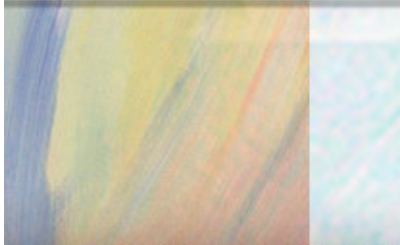
Upper Peace River - Ft Meade Station (1975-2003)
Days/Year MFL not met



Groundwater Declines

Long Term Changes in the Potentiometric Surface of the Upper Floridan Aquifer

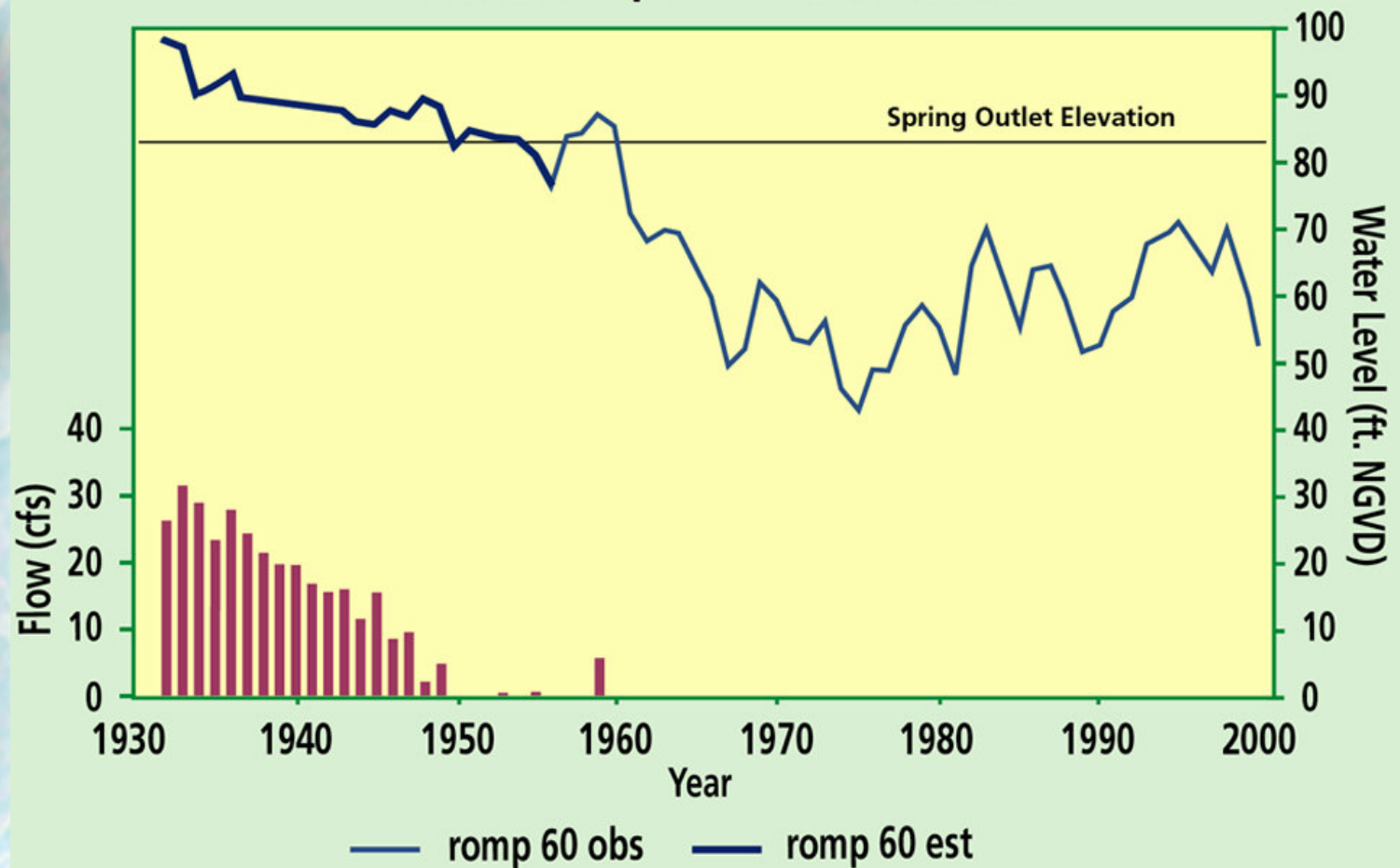




Kissengen Springs (1894) - gaining stream

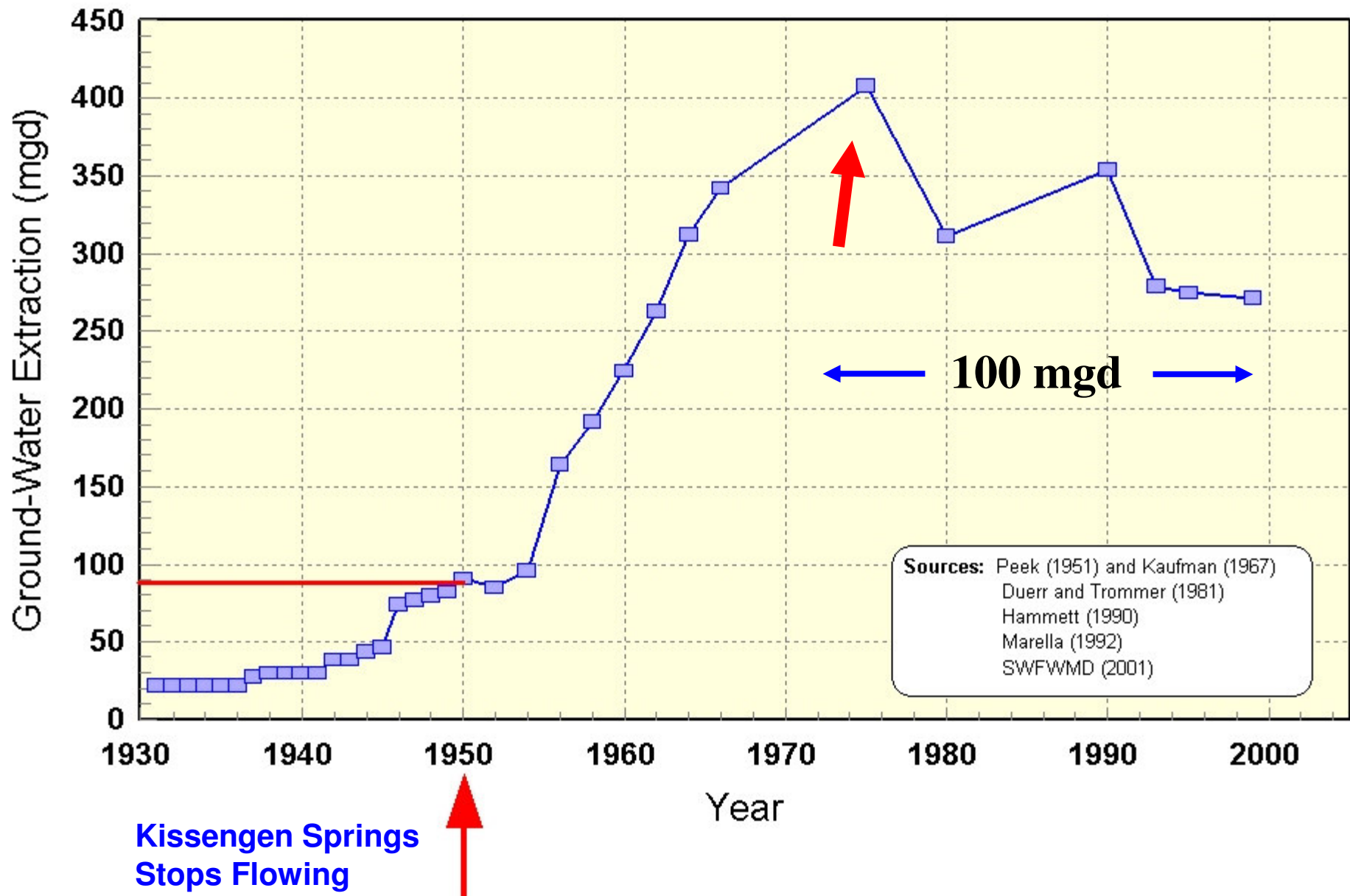
Kissengen Spring / Floridan Aquifer

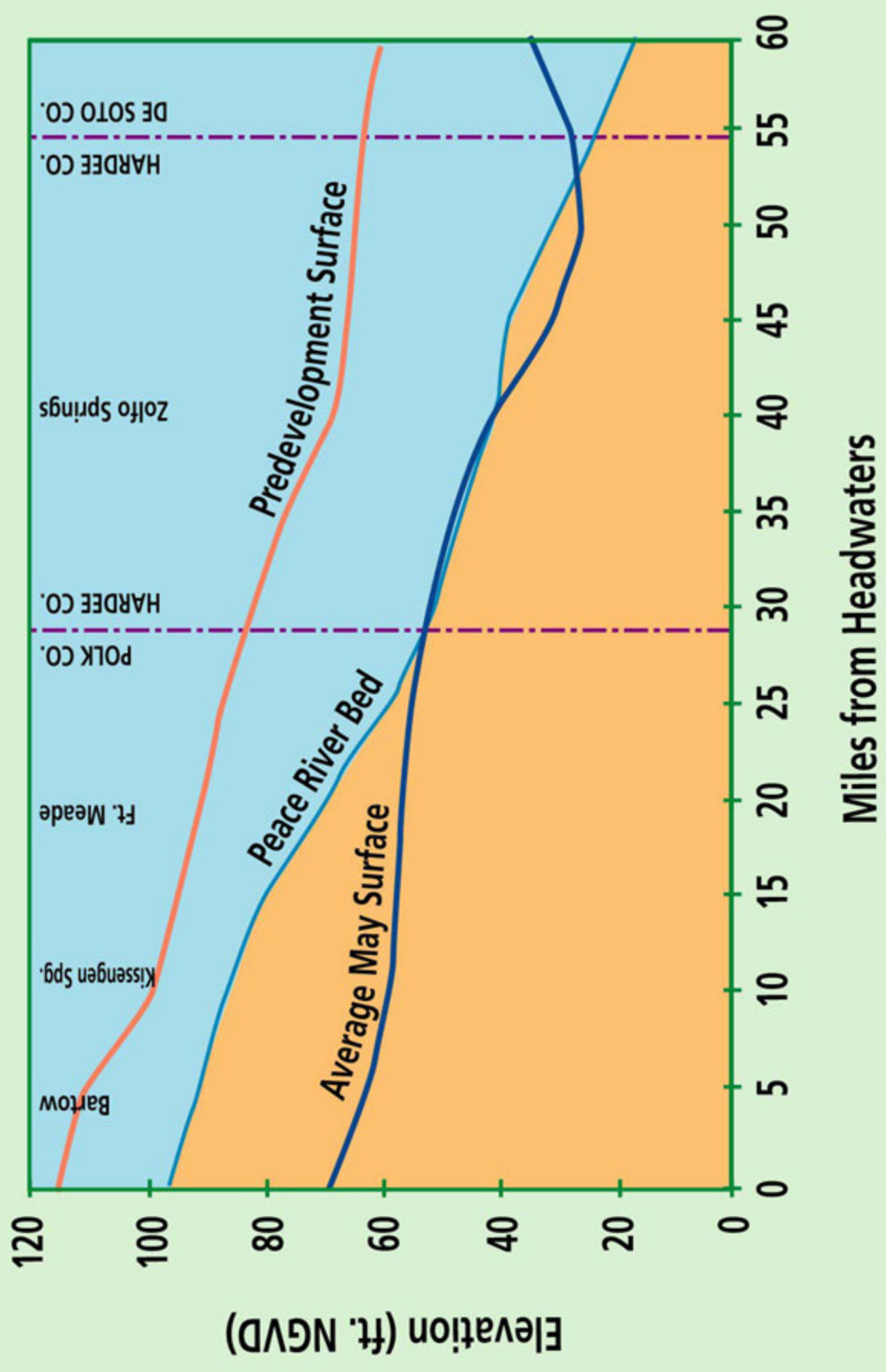
Kissengen Springflow &
Floridan Aquifer Water Levels



Polk County

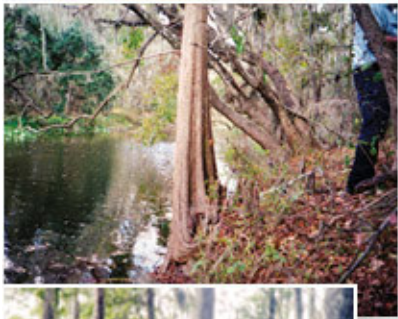
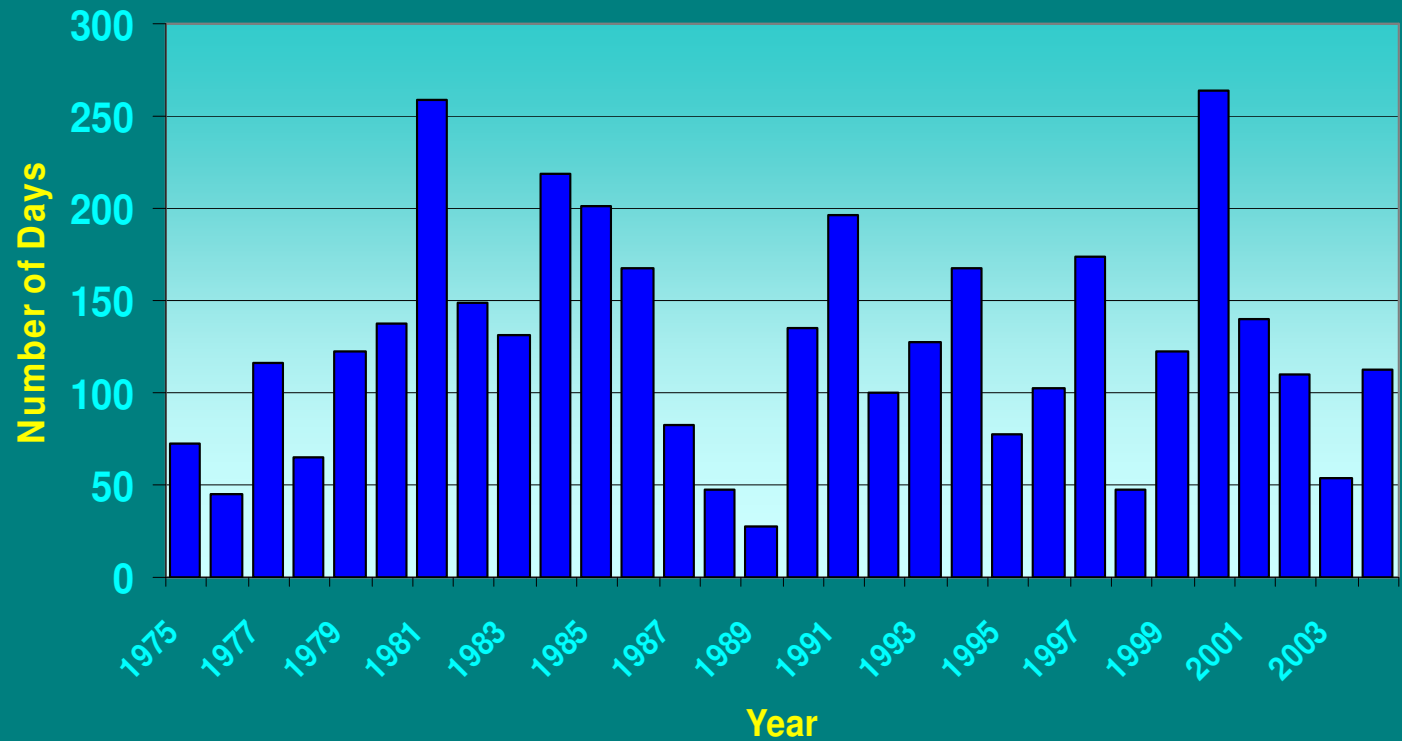
Ground-Water Withdrawal History



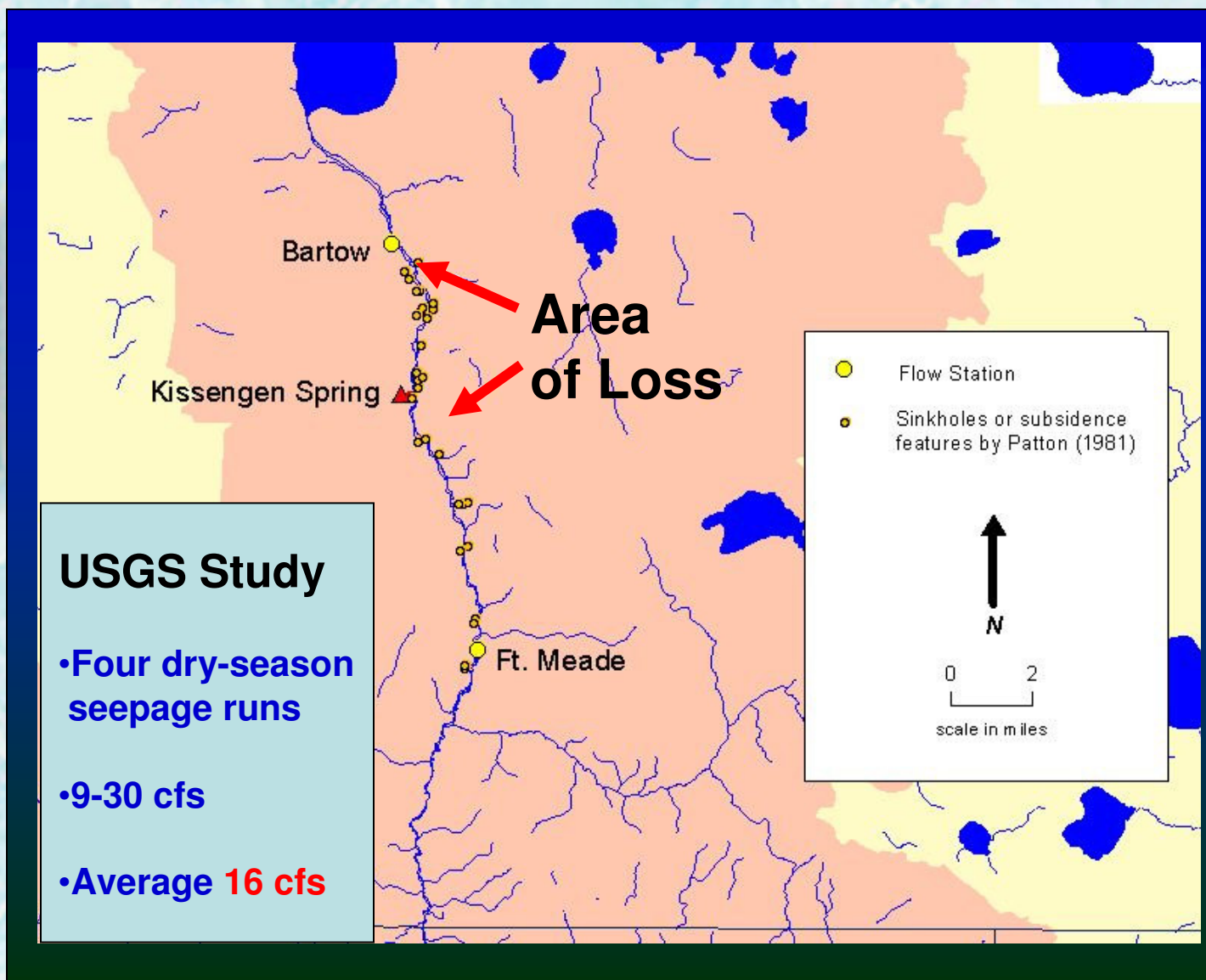
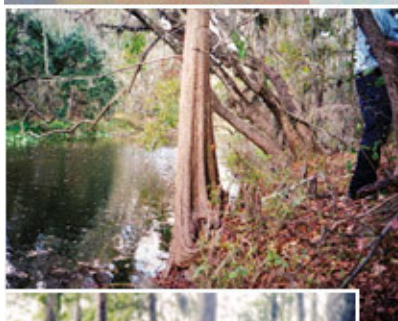


Effects of Lowered Groundwater

Number of Days Flows at
Bartow Exceed Ft. Meade

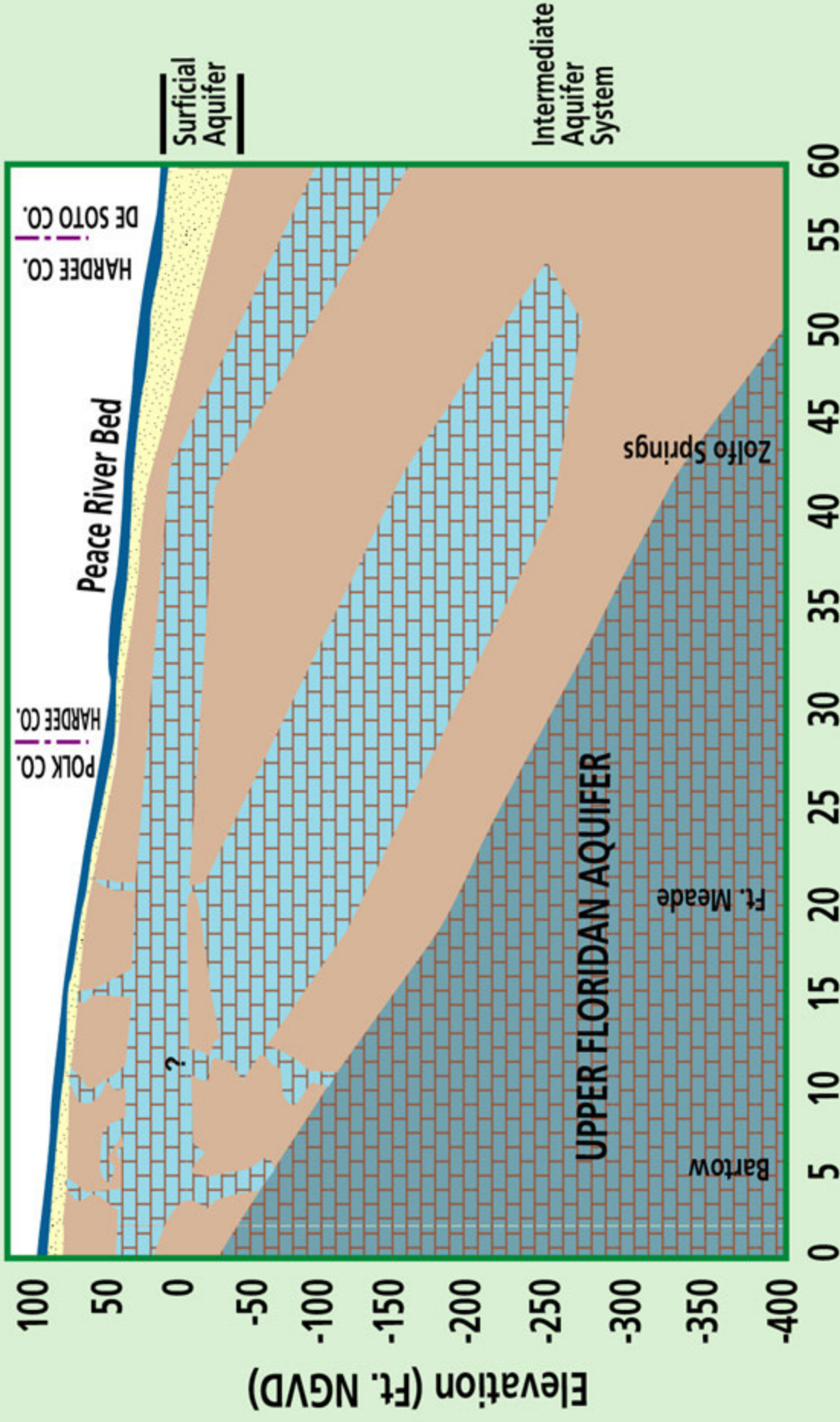


Area of Streamflow Loss

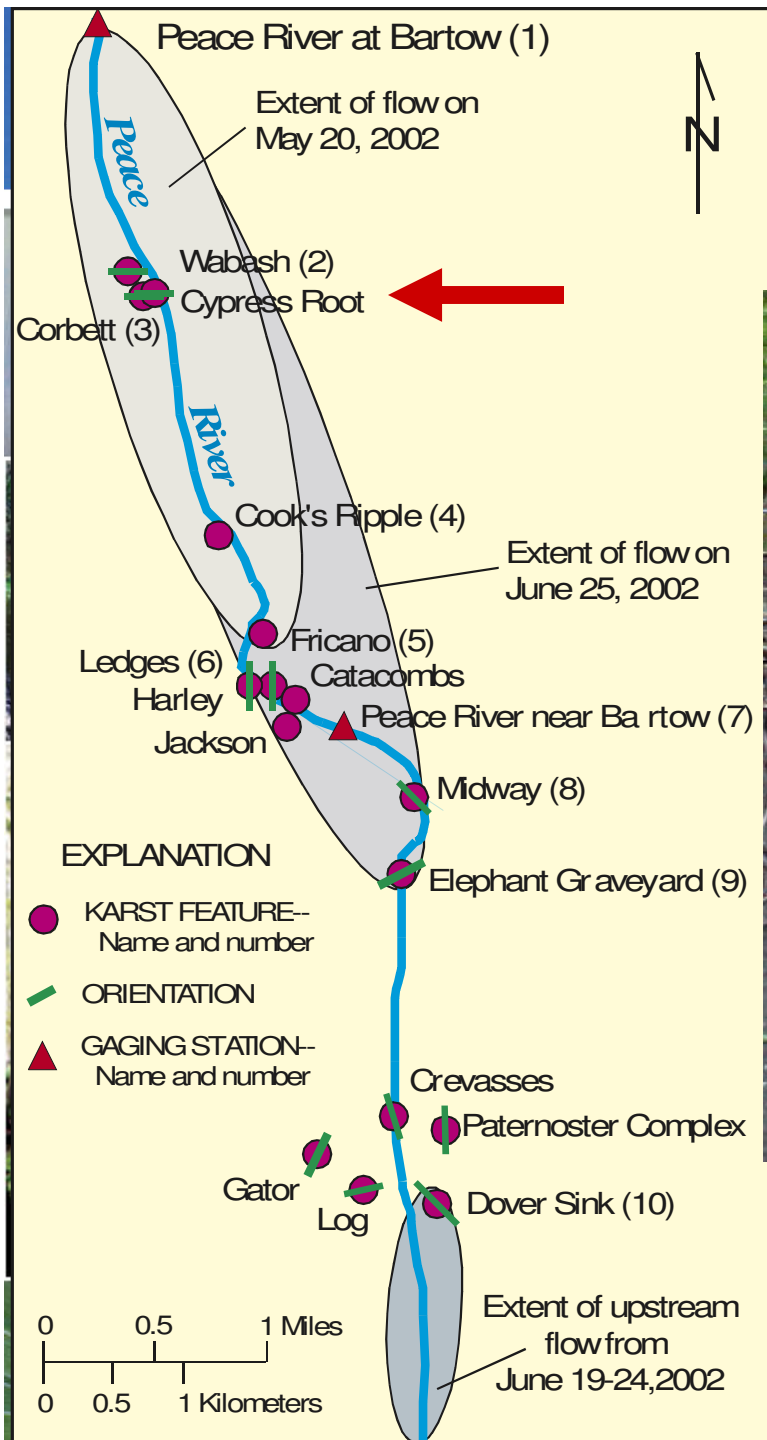


North

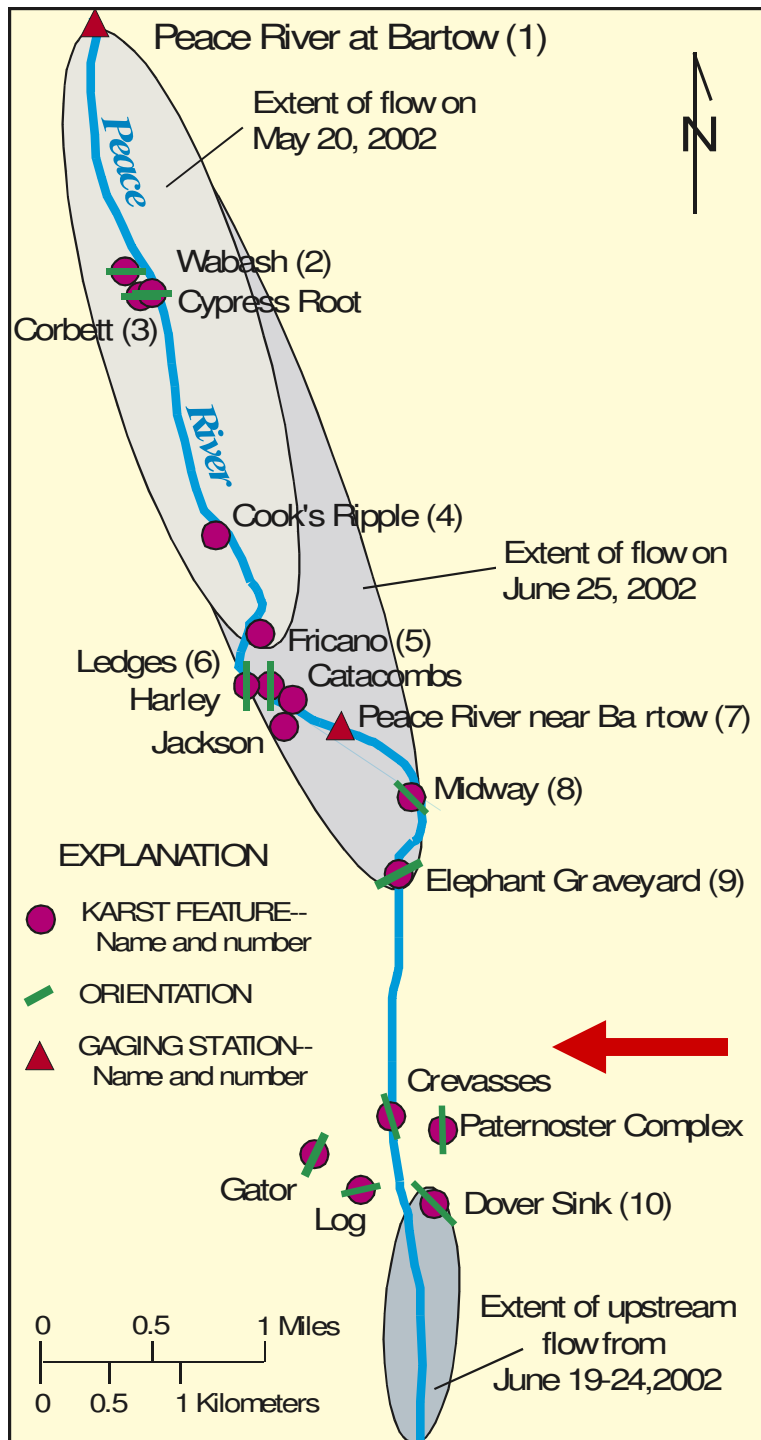
South



Miles from Headwaters



Cypress Root

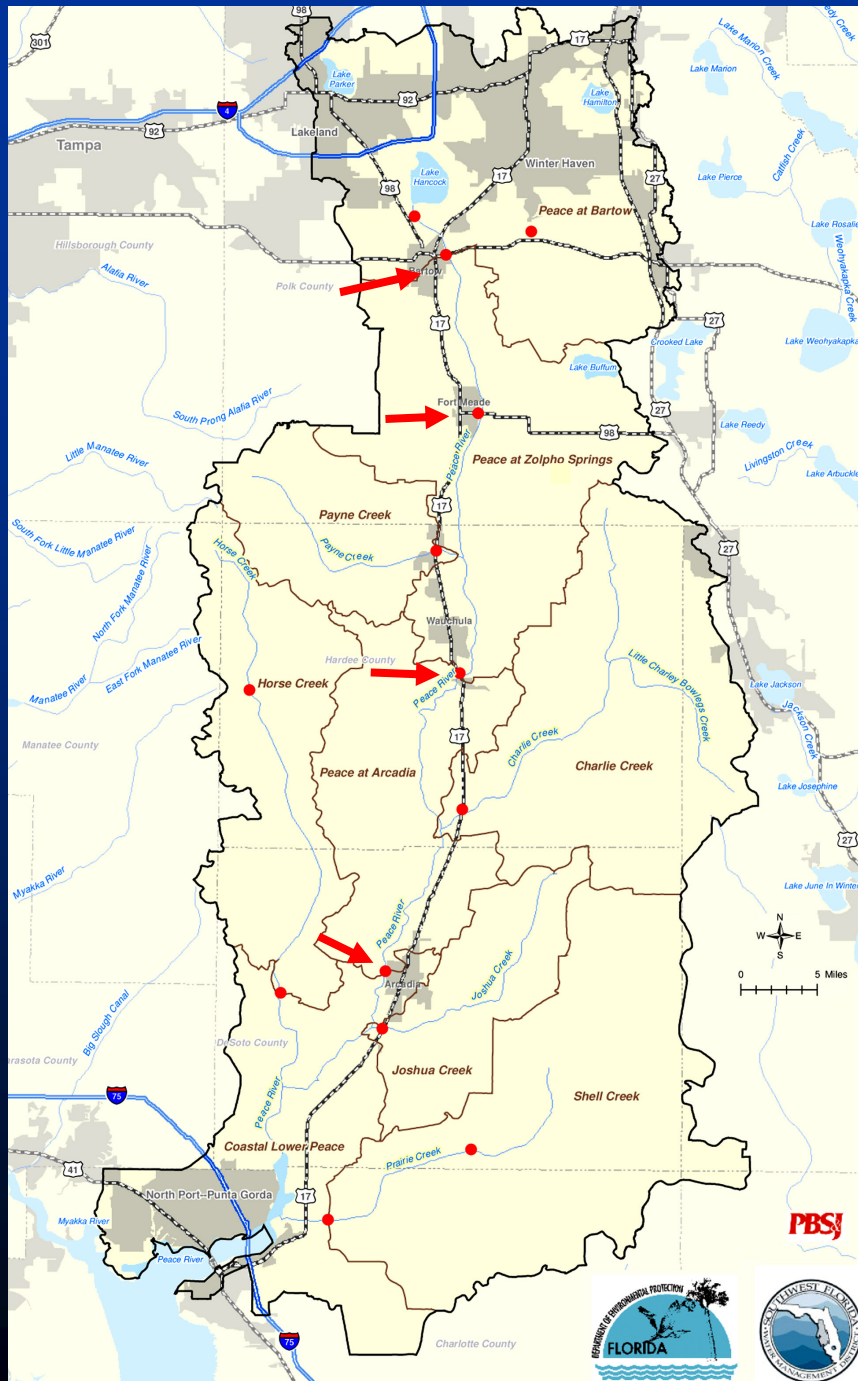


Crevasses



Primary Long-Term Watershed Gages

- Peace Creek Drainage Canal near Wahneta
- Saddle Creek at Structure P-11 Near Bartow
- Peace River at Bartow
- Peace River at Fort Meade
- Peace River at Zolfo Springs
- Payne Creek near Bowling Green
- Peace River at Zolfo Springs
- Charlie Creek near Gardner
- Peace River at Arcadia
- Joshua Creek at Nocatee
- Horse Creek near Myakka Head
- Horse Creek near Arcadia
- Prairie Creek near Fort Ogden
- Shell Creek near Punta Gorda



USGS Gages Within Study Area	Area (sq miles)	Period of Flow Record	
		Start	End
Peace River Watershed			
Peace Creek Drainage Canal Near Wahneta	162	1991	2004
Saddle Creek at Structure P-11 Near Bartow	135	1963	2004
Peace River at Bartow	390	1939	2004
Peace River at Fort Meade	480	1974	2004
Bowlegs Creek near Ft Meade	47	1964	2004
Payne Creek near Bowling Green	121	1963	2004
Peace River at Zolfo Springs	826	1933	2004
Charlie Creek near Gardner	330	1950	2004
Peace River at Arcadia	1367	1931	2004
Joshua Creek at Nocatee	132	1950	2004
Horse Creek near Myakka Head	42	1977	2004
Horse Creek near Arcadia	218	1950	2004
Prairie Creek near Fort Ogden	233	1963	2004
Shell Creek near Punta Gorda	373	1965	2004
Additional Reference Gages			
Myakka River near Sarasota	229	1936	2004
Little Manatee River near Wimauma	149	1939	2004
Withlacoochee River at Croom	570	1939	2004

Watershed Time Series Analyses

• Percentiles

- Q100 (Minimum)
- Q95 (Low Flow)
- Q90 (Low Flow)
- Q75
- Q50 (Median)
- Mean
- Q25
- Q10 (High Flow)
- Q5 (High Flow)
- Q0 (Maximum)

• Time Periods

- Period of Record
- 1979 to 1999



Selected Examples

- **USGS Gaging Locations**

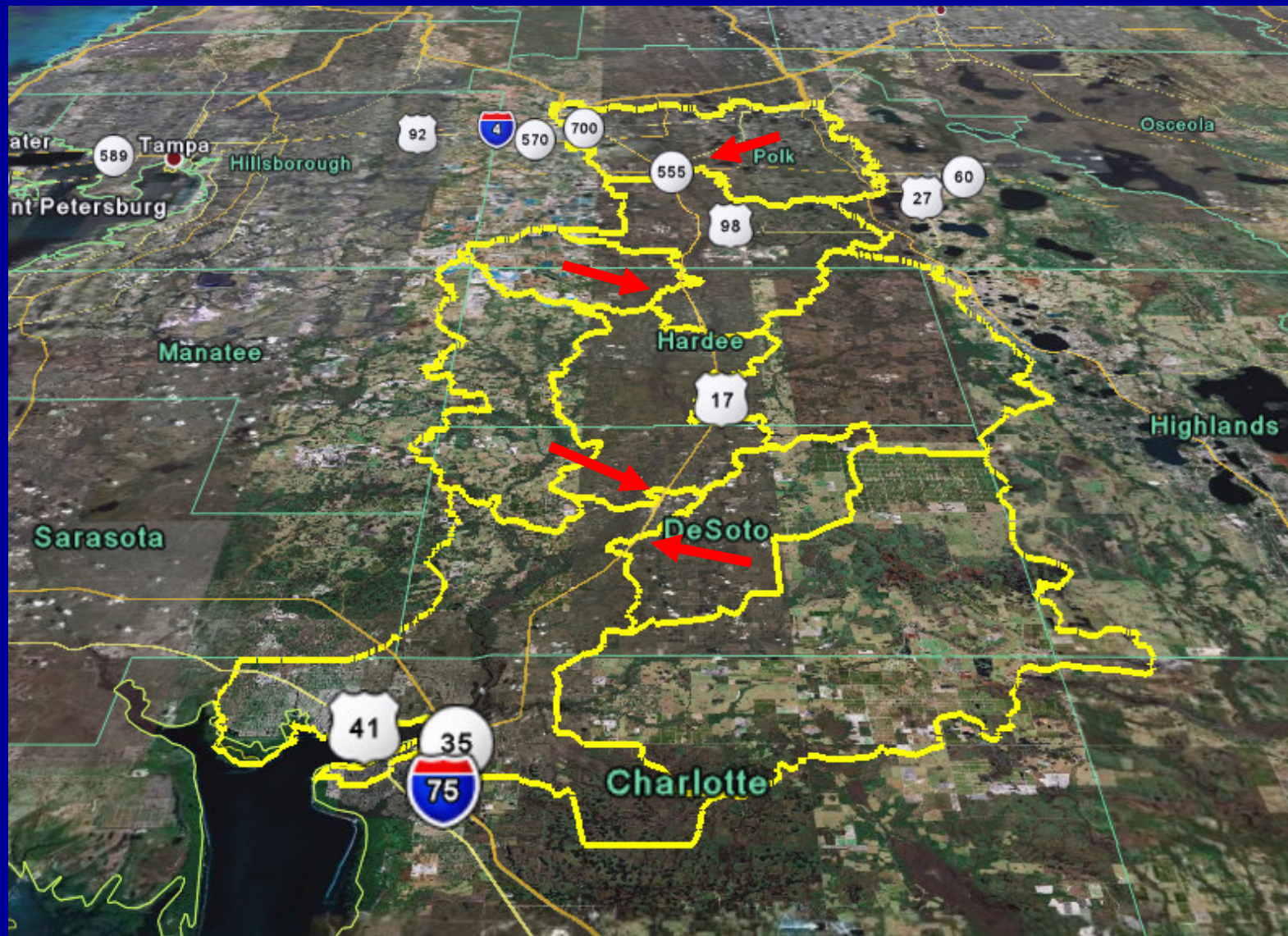
- Peace River at Bartow (upper watershed)
- Peace River at Arcadia (lower watershed)
- Payne Creek (mining)
- Joshua Creek (agriculture)

- **Flow Percentiles**

- Maximum
- Median
- Minimum



Peace River at Arcadia



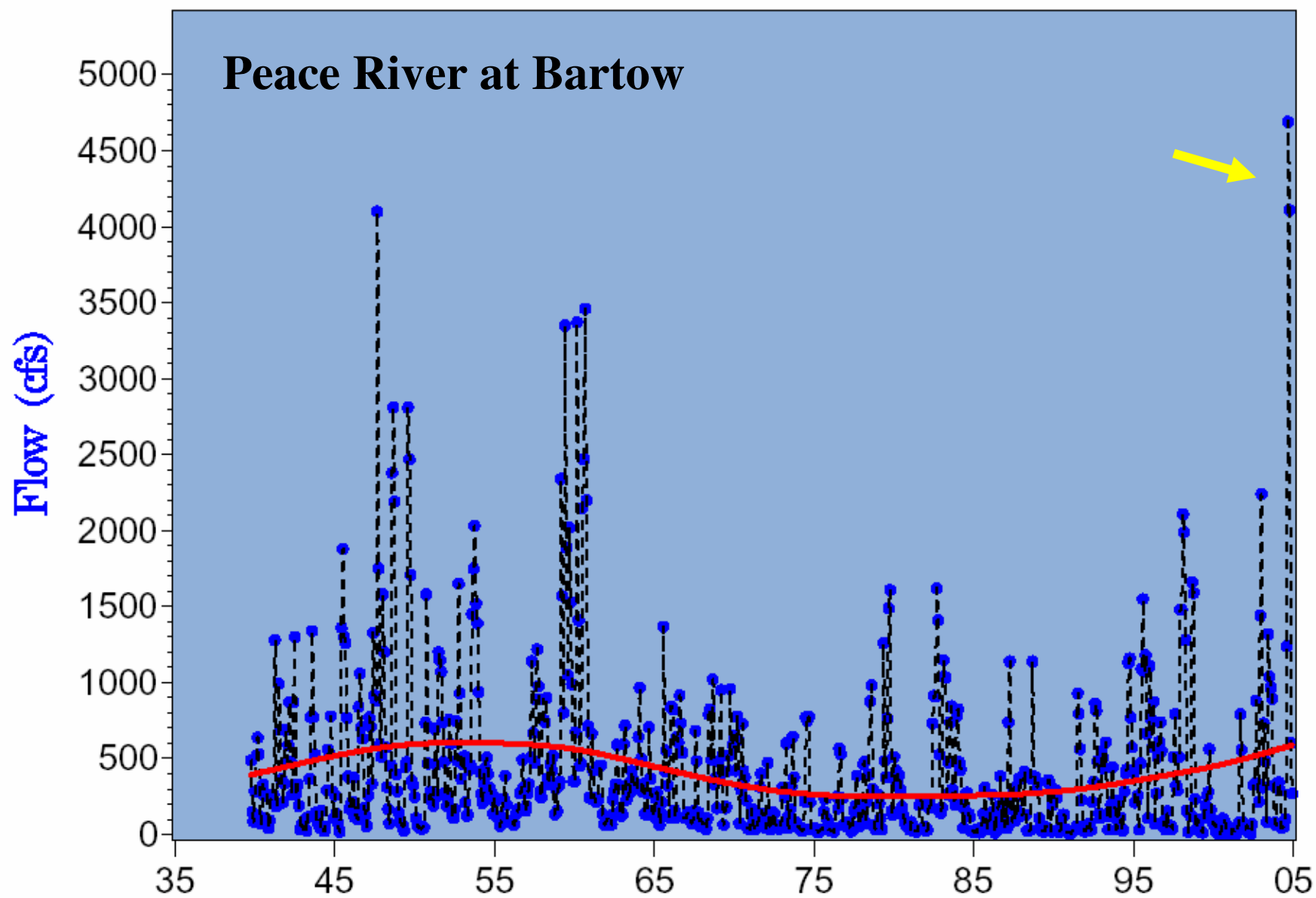


Figure D139. Monthly maximum flow at long-term Peace River at Bartow (2294650) gage (1939-2004)

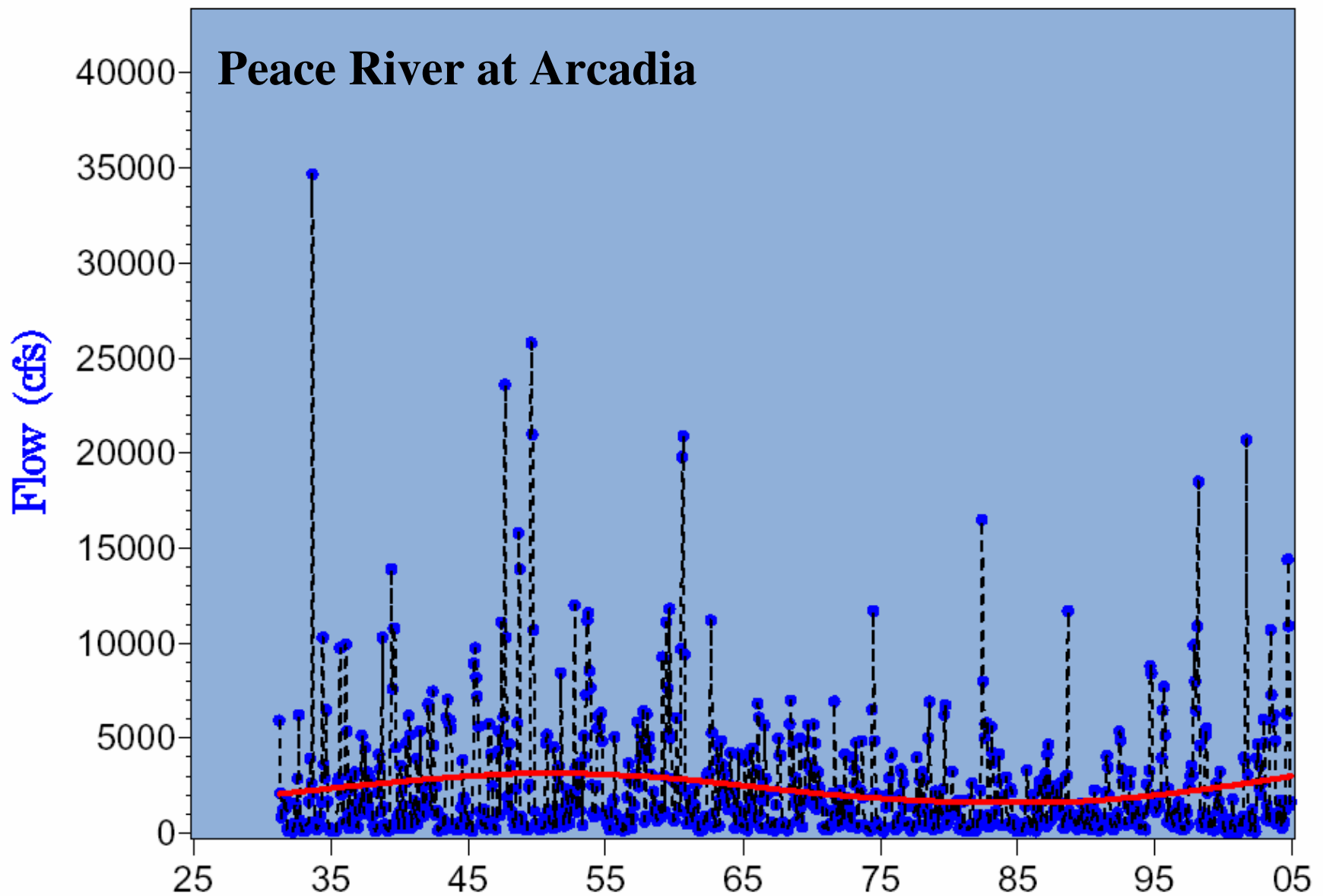


Figure D145. Monthly maximum flow at long-term Peace River at Arcadia (2296750) gage (1931-2004)

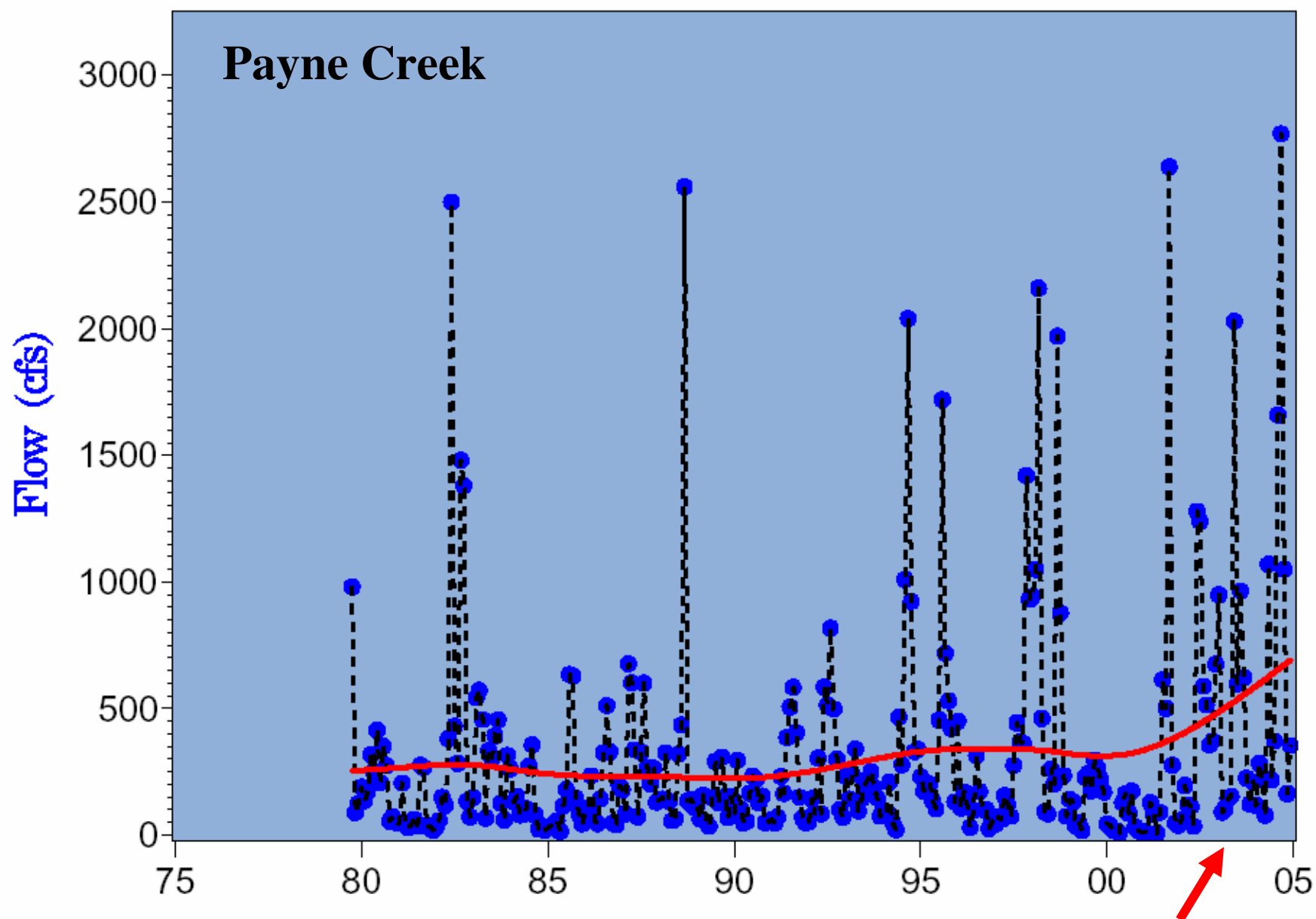


Figure D142. Monthly maximum flow at long-term Payne Creek (2295420) gage (1979-2004)

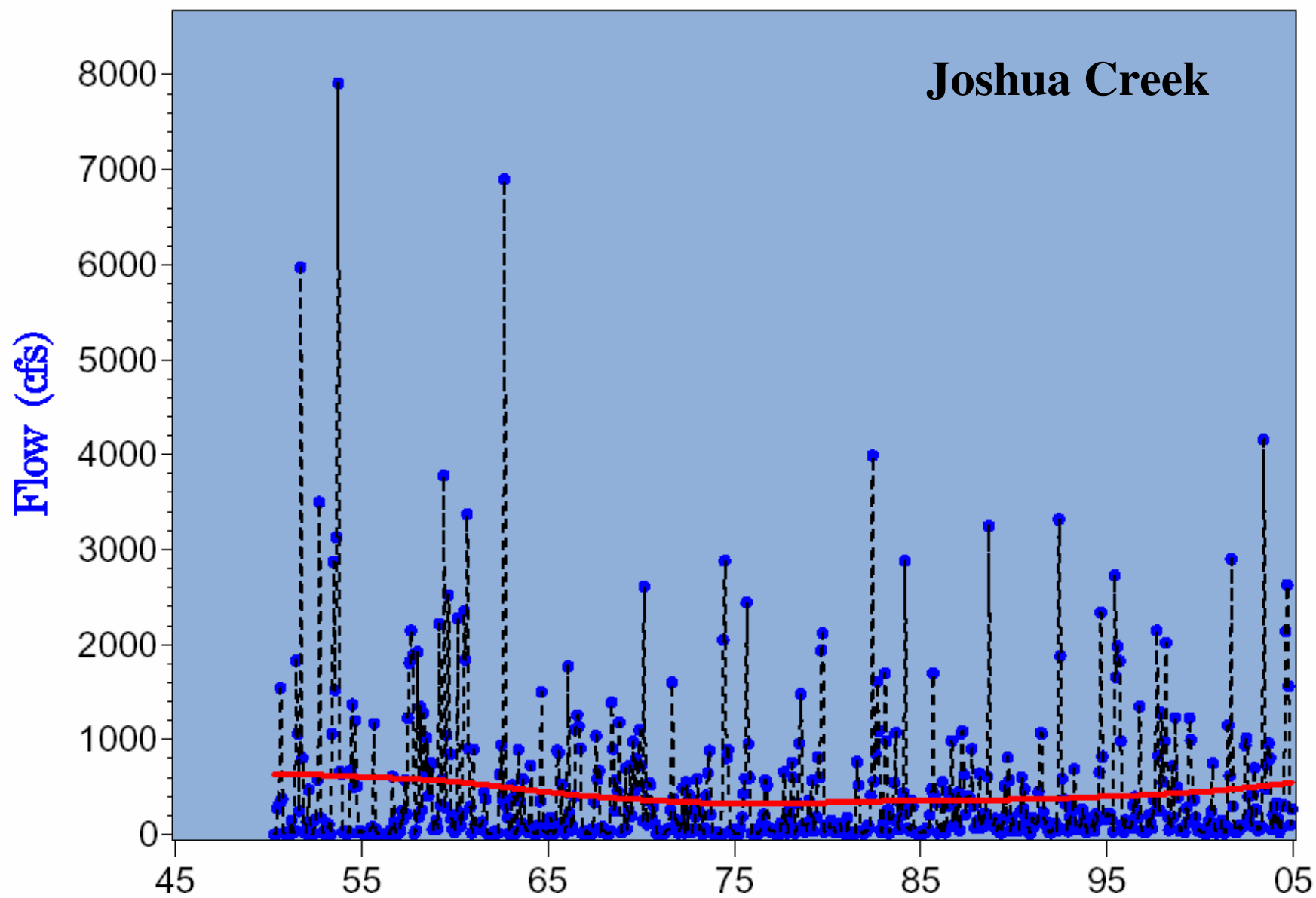


Figure D146. Monthly maximum flow at long-term Joshua Creek at Nocatee (2297100) gage (1950-2004)

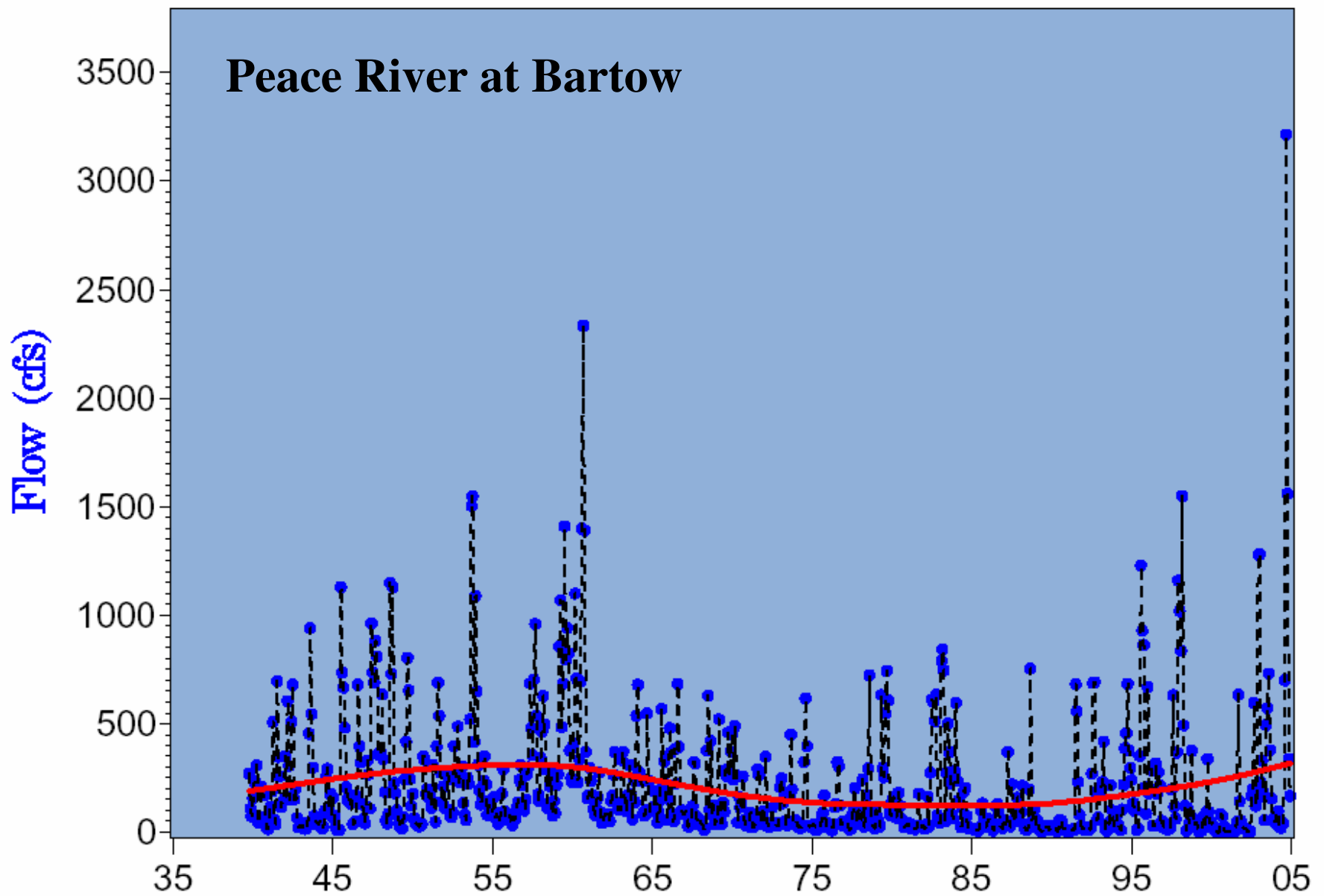


Figure D71. Monthly Q50 flow at long-term Peace River at Bartow (2294650) gage (1939-2004)

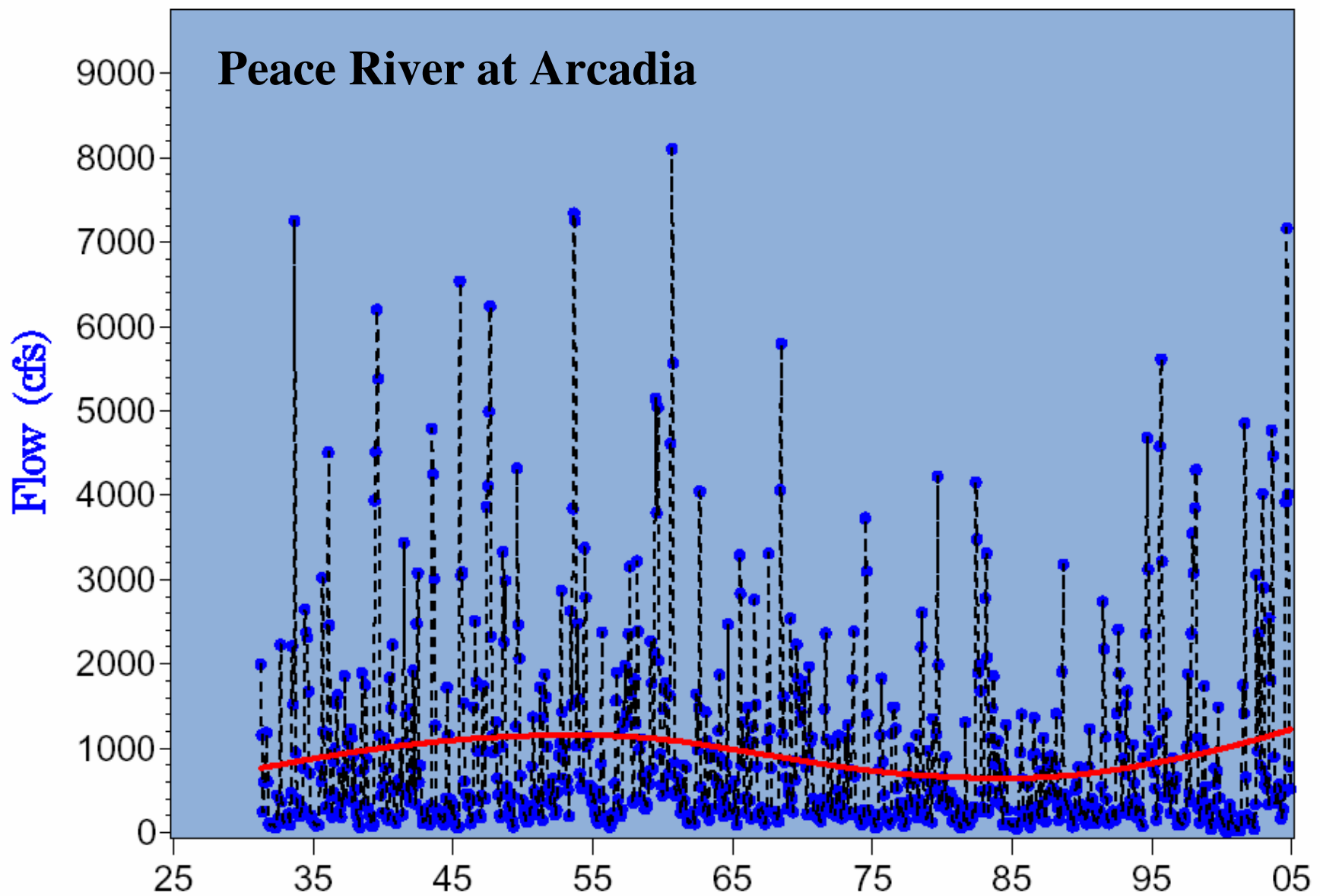


Figure D77. Monthly Q50 flow at long-term Peace River at Arcadia (2296750) gage (1931-2004)

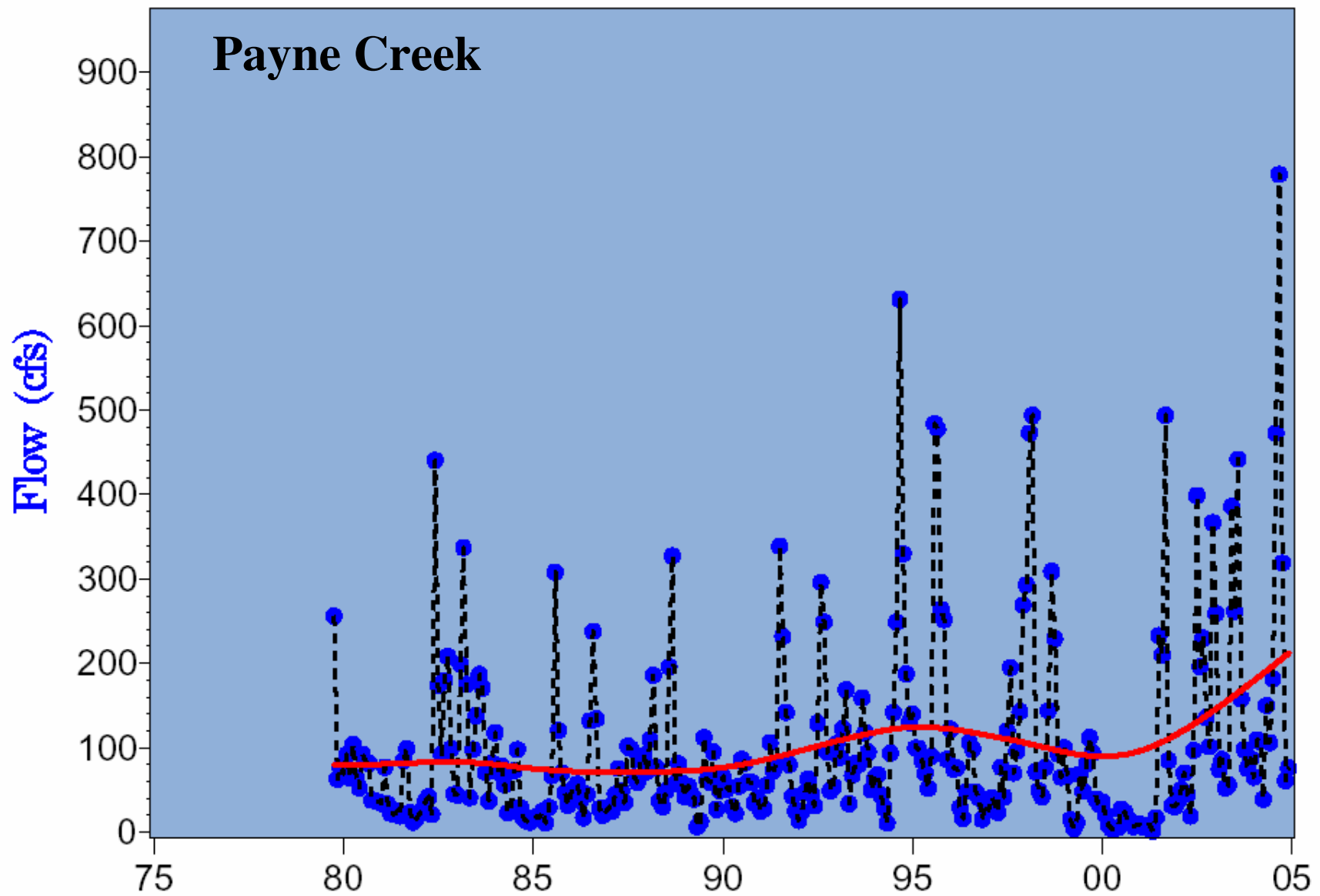


Figure D74. Monthly Q50 flow at long-term Payne Creek (2295420) gage (1979-2004)

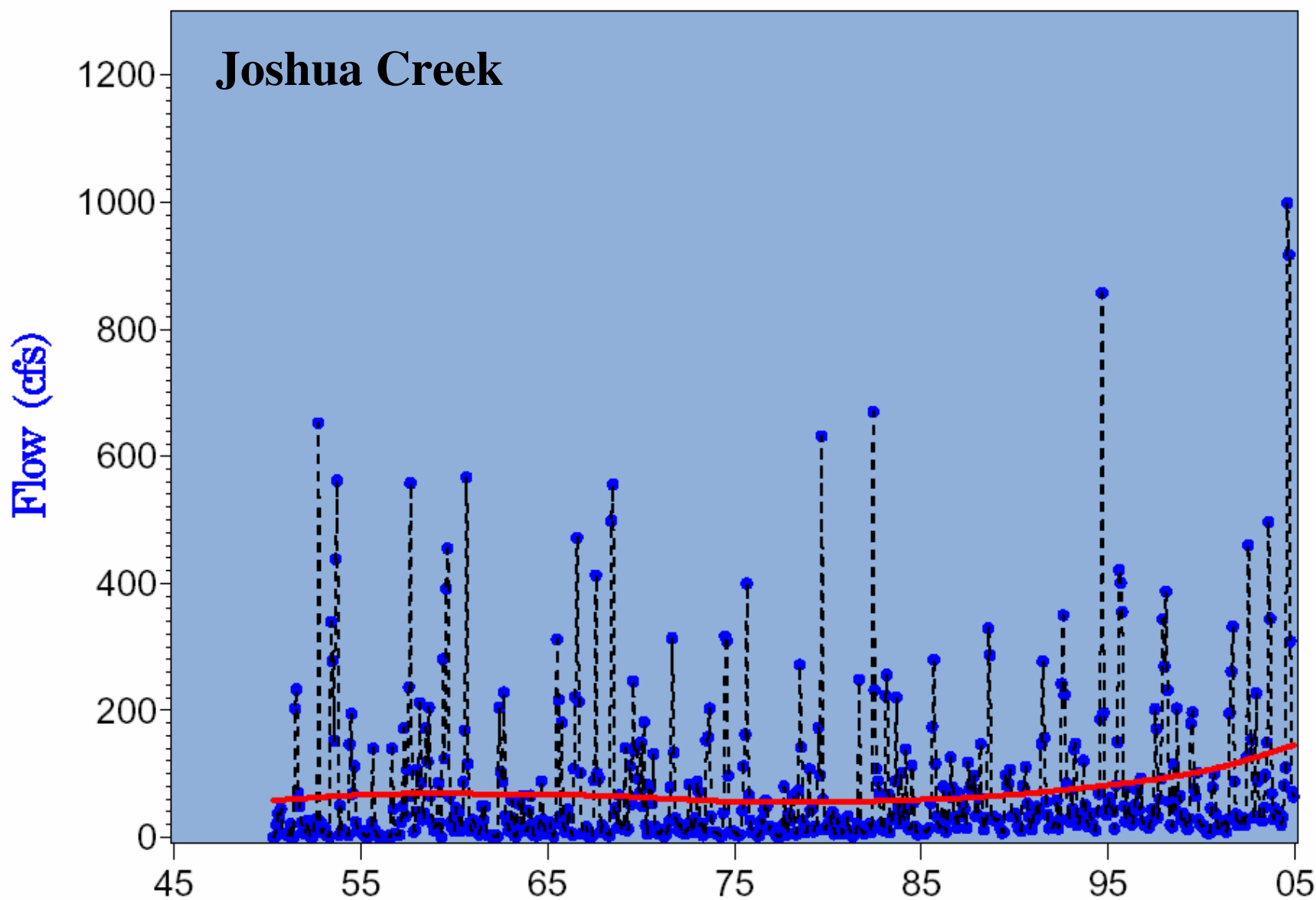


Figure D78. Monthly Q50 flow at long-term Joshua Creek at Nocatee (2297100) gage (1950-2004)

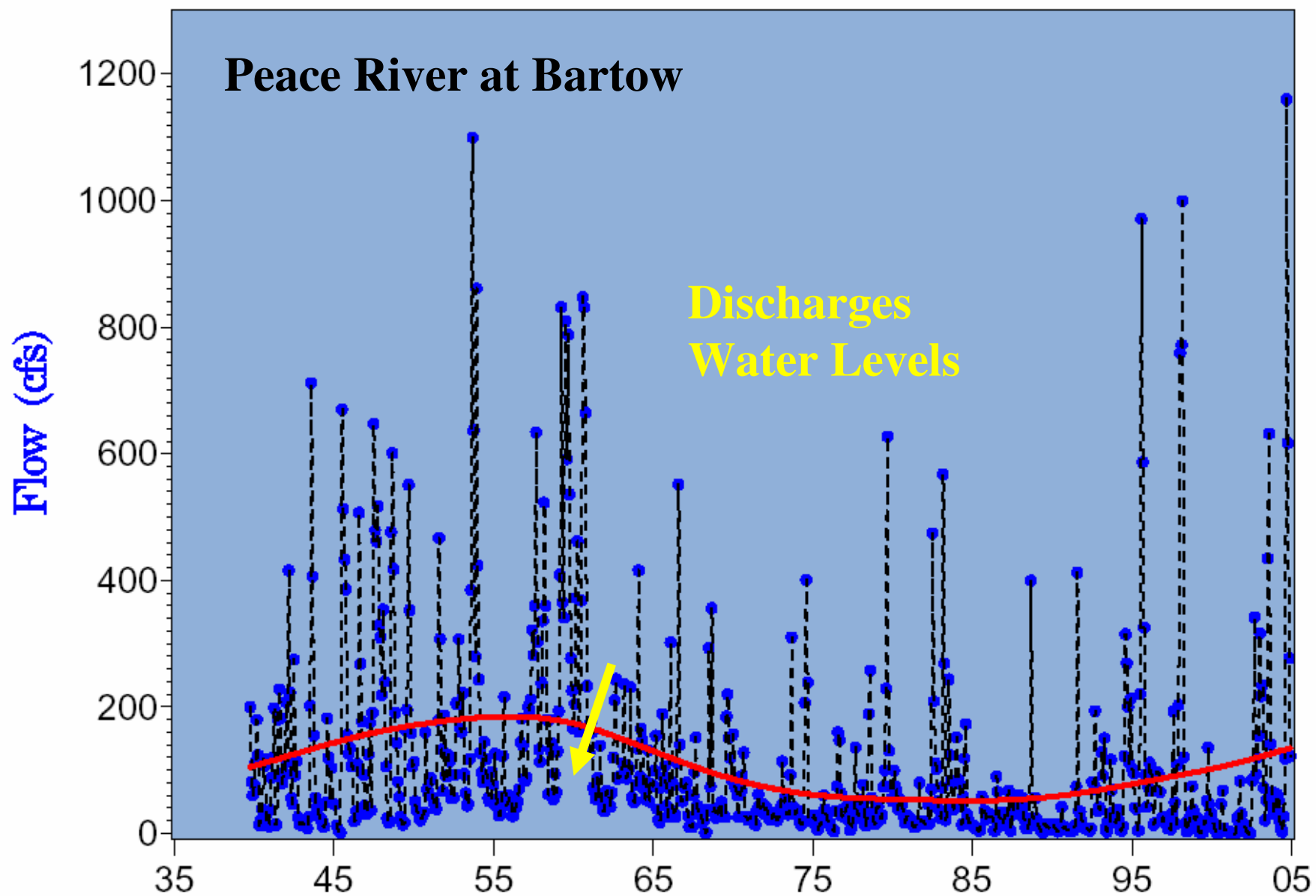


Figure D3. Monthly minimum flow at long-term Peace River at Bartow (2294650) gage (1939-2004)

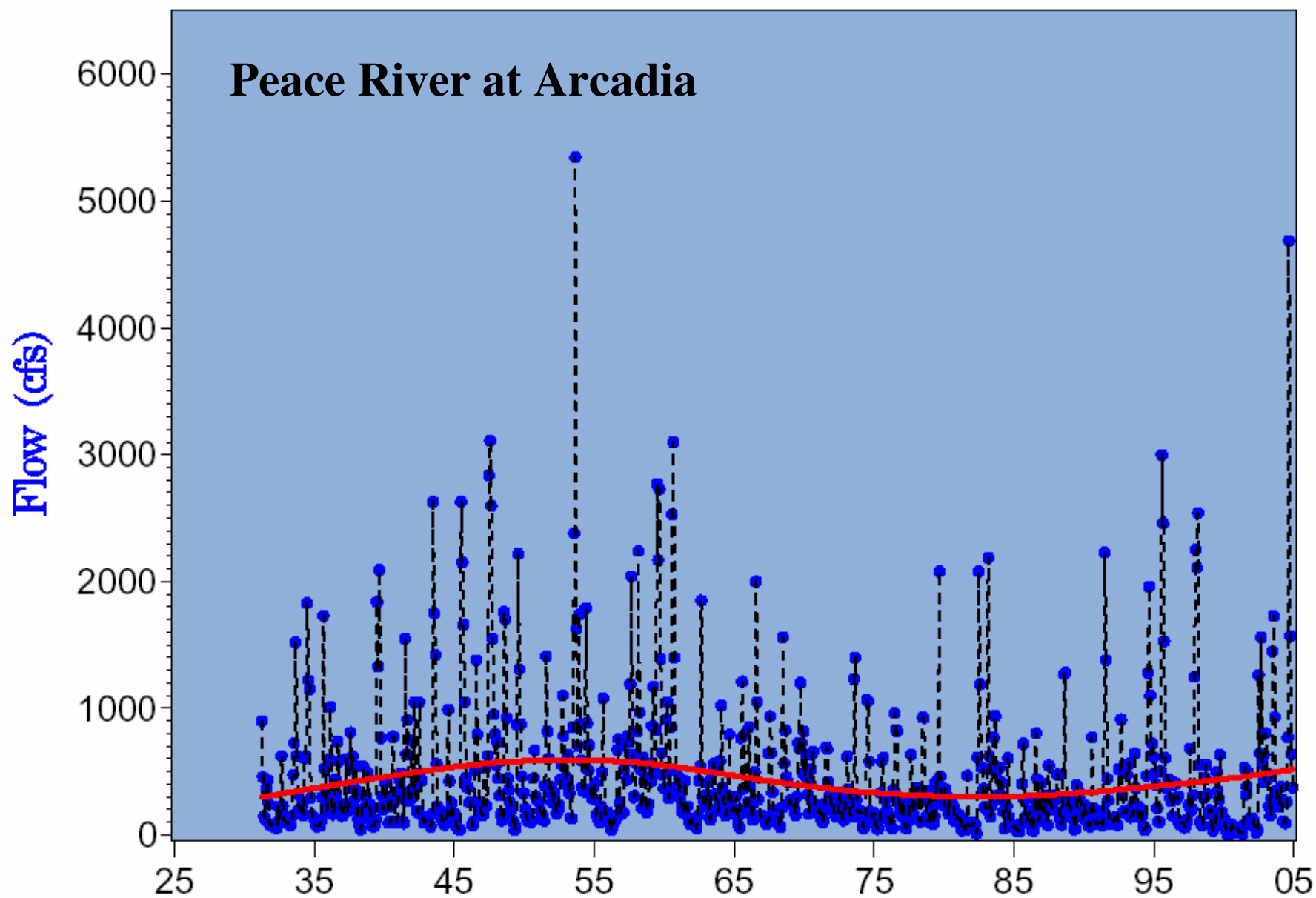


Figure D9. Monthly minimum flow at long-term Peace River at Arcadia (2296750) gage (1931-2004)

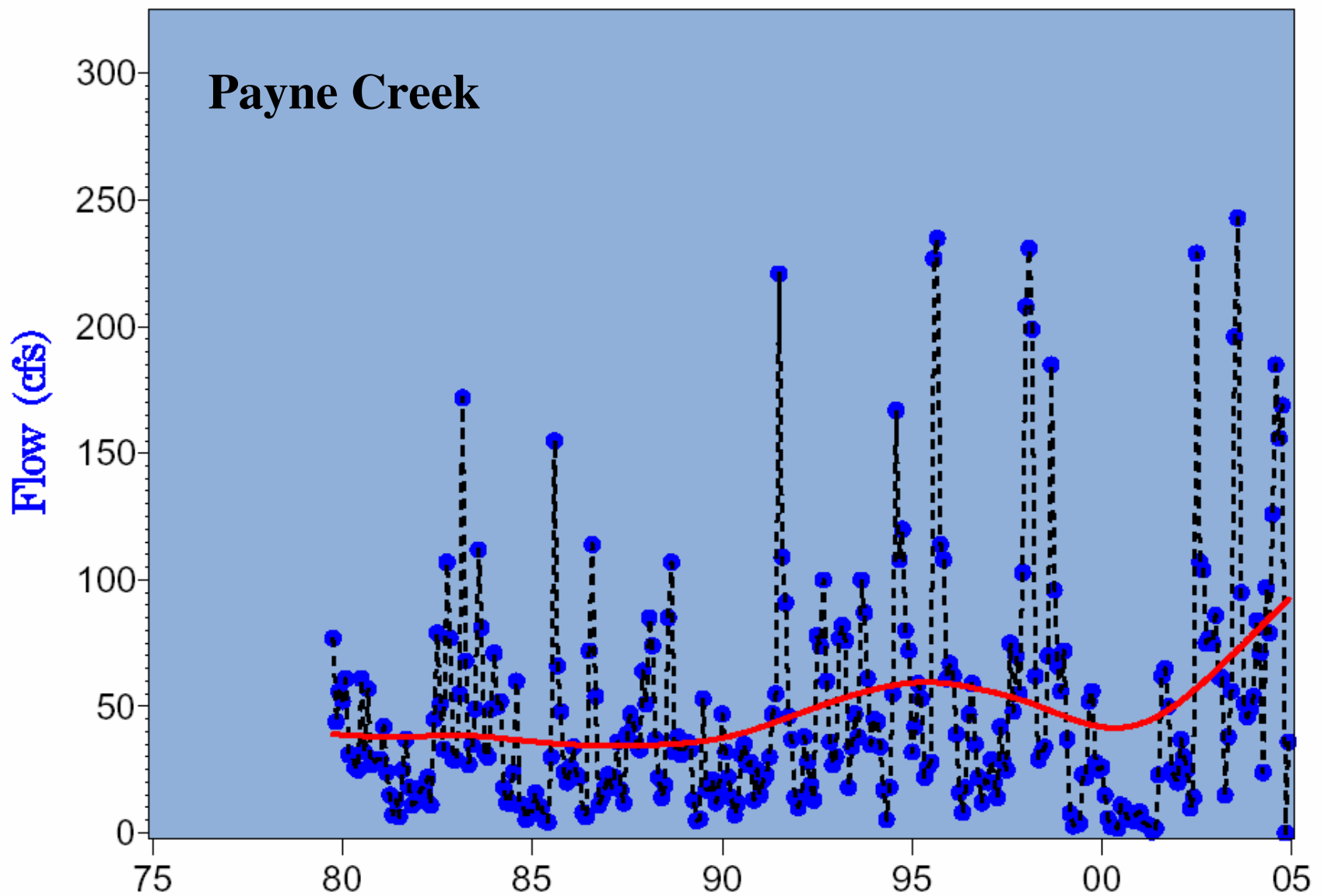


Figure D6. Monthly minimum flow at long-term Payne Creek (2295420) gage (1979-2004)

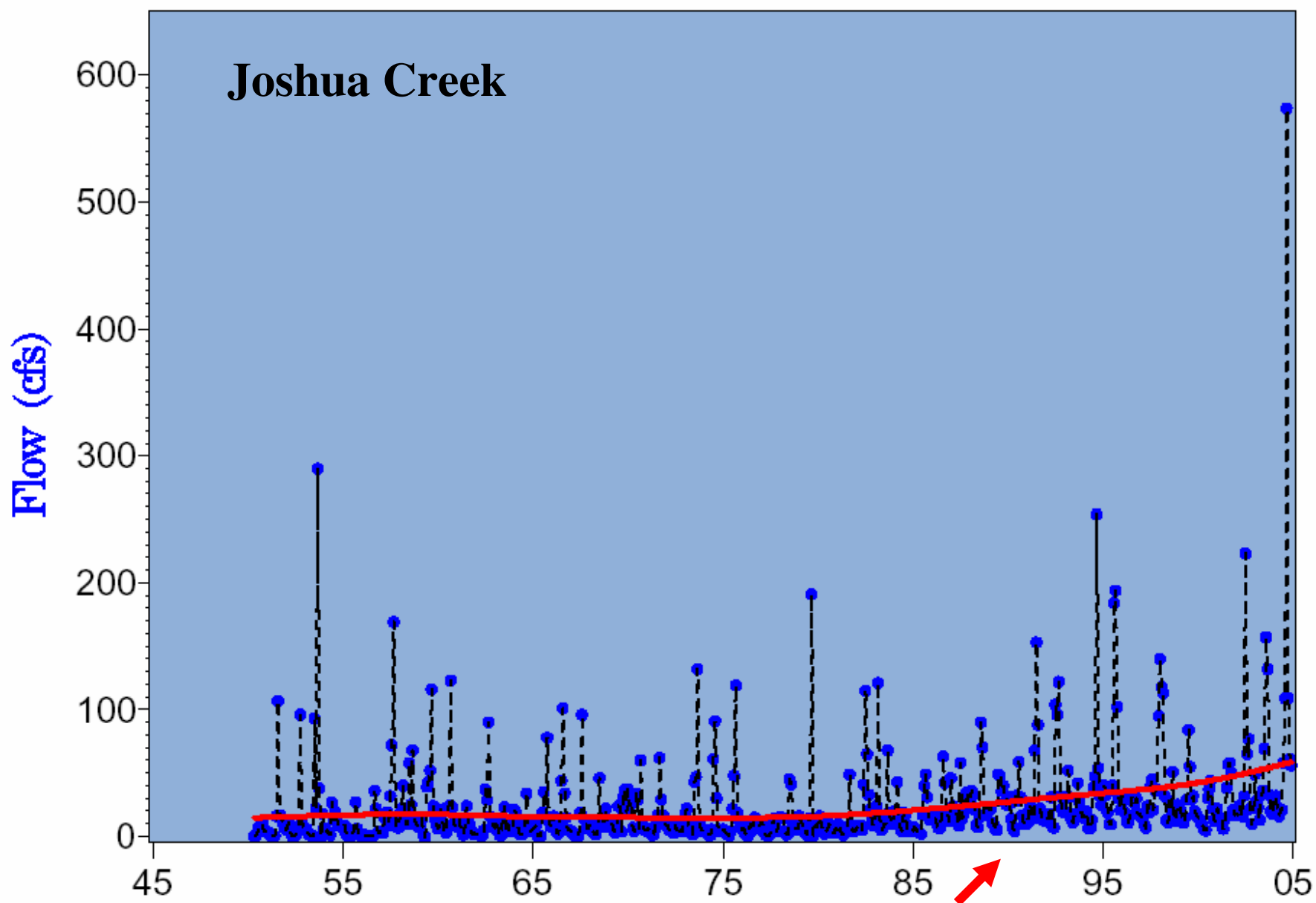


Figure D10. Monthly minimum flow at long-term Joshua Creek at Nocatee (2297100) gage (1950-2004)

Table D.12
Summary of Results of Seasonal Kendall Trend Analyses Based on Monthly Values (Period of Record – 2004)

USGS ID	Gage Identification	Time Period of Data	Maximum	Q5	Q10	Q25	Median	Q75	Q90	Q95	Minimum	Mean
Peace River Watershed												
2293987	Peace Creek Drainage Canal near Wahneta	1992										
2294491	Saddle Creek at Structure P-11 near Bartow	1964								▲	▲	
2294650	Peace River at Bartow	1940	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
2294898	Peace River at Fort Meade	1975										
2295013	Bowlegs Creek near Ft Meade	1990										
2295420	Payne Creek near Bowling Green	1980										
2295637	Peace River at Zolfo Springs	1934	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
2296500	Charlie Creek near Gardner	1951										
2296750	Peace River at Arcadia	1932										
2297100	Joshua Creek at Nocatee	1951			▲	▲	▲	▲	▲	▲	▲	▲
2297155	Horse Creek near Myakka Head	1978										
2297310	Horse Creek near Arcadia	1951										
2298123	Prairie Creek near Fort Ogden	1978				▲	▲	▲	▲	▲	▲	
2298202	Shell Creek near Punta Gorda	1965							▲	▲	▲	
Reference Watersheds												
2298830	Myakka River near Sarasota	1937	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
2300500	Little Manatee River near Wimauma	1940	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
2312500	Withlacoochee River at Croom	1940	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲

Note: Direction of arrow denotes significant increasing or decreasing trend. Red arrows are significant at $p=0.05$ level, while blue show trends significant at $p=0.10$, and blanks indicate no significant trends in Seasonal Kendall Tau test corrected for serial correlations.

Table D.13
Summary of Results of Seasonal Kendall Trend Analyses of Monthly Flow Percentiles over Different Selected Periods of Time Through 2004

USGS Gaging Site	Flow Percentile	1935	1940	1945	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995
Peace River Watershed														
Peace Creek Drainage Canal near Wahneta	Q30													
	Q50													
	Q10													
Saddle Creek at Structure P-11 near Bartow	Q30								▲			▲		
	Q50													
	Q10													
Peace River at Bartow	Q30		▼	▼	▼	▼	▼	▼						
	Q50		▼	▼	▼	▼	▼	▼						
	Q10		▼	▼	▼	▼	▼							
Peace River at Fort Meade	Q30													
	Q50													
	Q10													
Bowlegs Creek near Ft Meade	Q30													
	Q50													
	Q10													
Payne Creek near Bowling Green	Q30													
	Q50													
	Q10													
Peace River at Zolfo Springs	Q30	▼	▼	▼	▼	▼	▼	▼						
	Q50	▼	▼	▼	▼	▼	▼	▼						
	Q10	▼	▼	▼	▼	▼	▼							

Table D.13 (continued)
Summary of Results of Seasonal Kendall Trend Analyses of Monthly Flow Percentiles over Different Selected Periods of Time Through 2004

USGS Gaging Site	Flow Percentile	1935	1940	1945	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995
Selected Reference Watersheds														
Myakka River near Sarasota	Q90		▲	▲	▲	▲	▲	▲	▲					
	Q50		▲	▲	▲	▲	▲	▲	▲					
	Q10		▲	▲			▲	▲	▲	▲				
Little Manatee River near Wimauma	Q90		▲	▲	▲	▲	▲	▲	▲	▲				
	Q50		▲	▲	▲	▲	▲	▲	▲	▲				
	Q10		▲	▲			▲	▲	▲	▲				
Withlacoochee River at Croom	Q90		▲	▲	▲	▲	▲	▲						
	Q50		▲	▲	▲	▲	▲	▲						
	Q10		▲	▲	▲	▲	▲	▲						

Note: Direction of arrow denotes significant increasing or decreasing trend. Red arrows are significant at $p=0.05$ level, while blue show trends significant at $p=0.10$, and blanks indicate no significant trends in Seasonal Kendall Tau test corrected for serial correlations.

Hashed lines indicate periods prior to USGS gaging at each location.

Summary of Statistical Trends

- **Significant Declines**

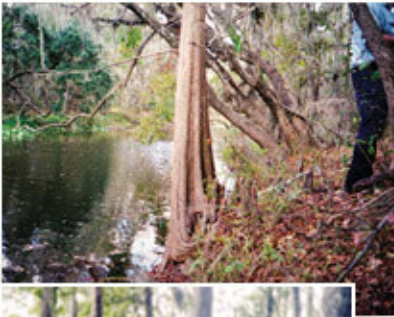
- Bartow
- Zolfo
- Arcadia

- **Significant Increases**

- **Joshua Creek**
- Horse Creek
- Prairie Creek

- **However No Significant Change Since**

- Bartow (1970)
- Zolfo (1970)
- Arcadia (1965)



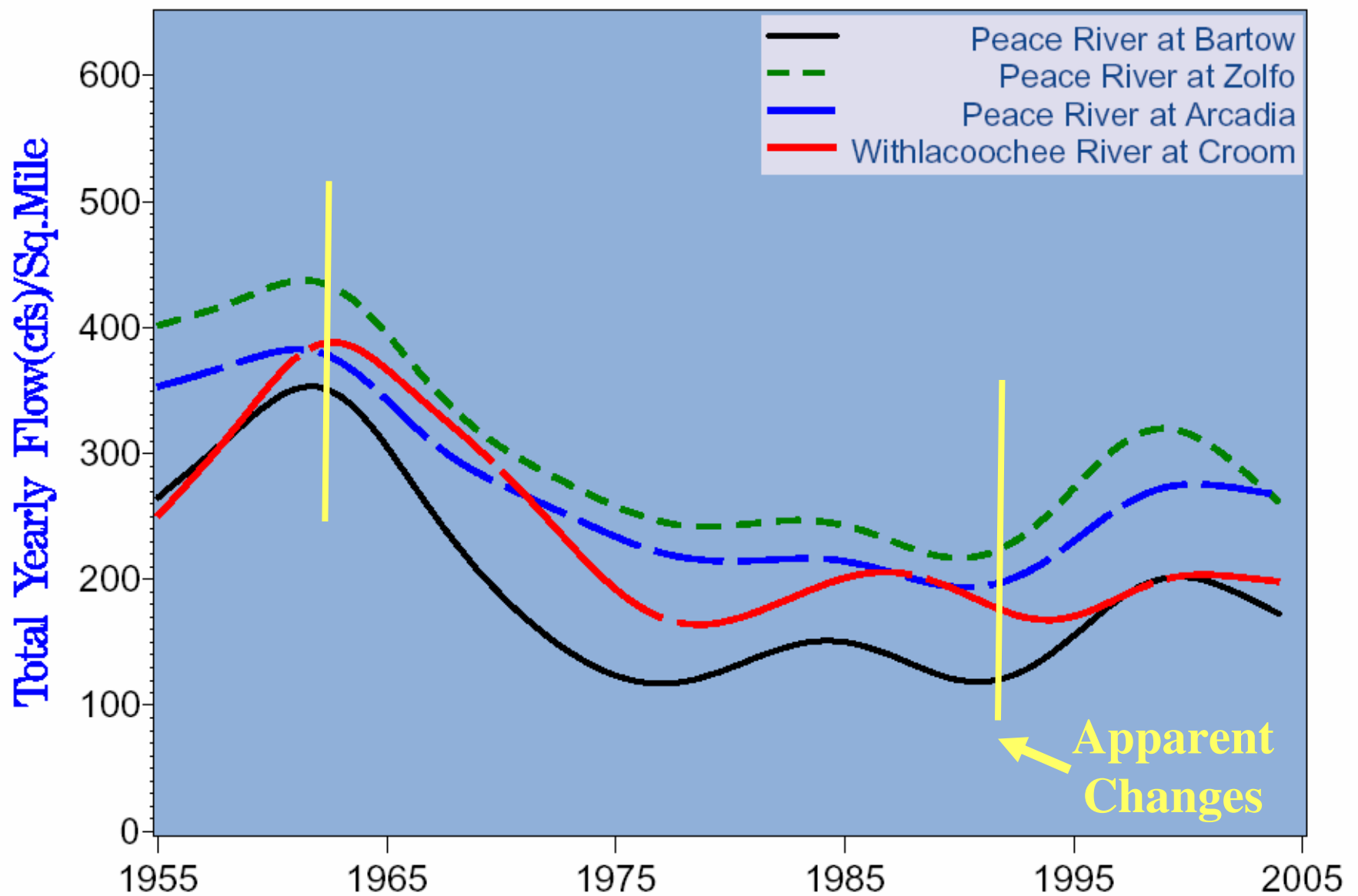


Figure D338. Five year moving averages of total yearly flows standardized to watershed area (1955-2004)

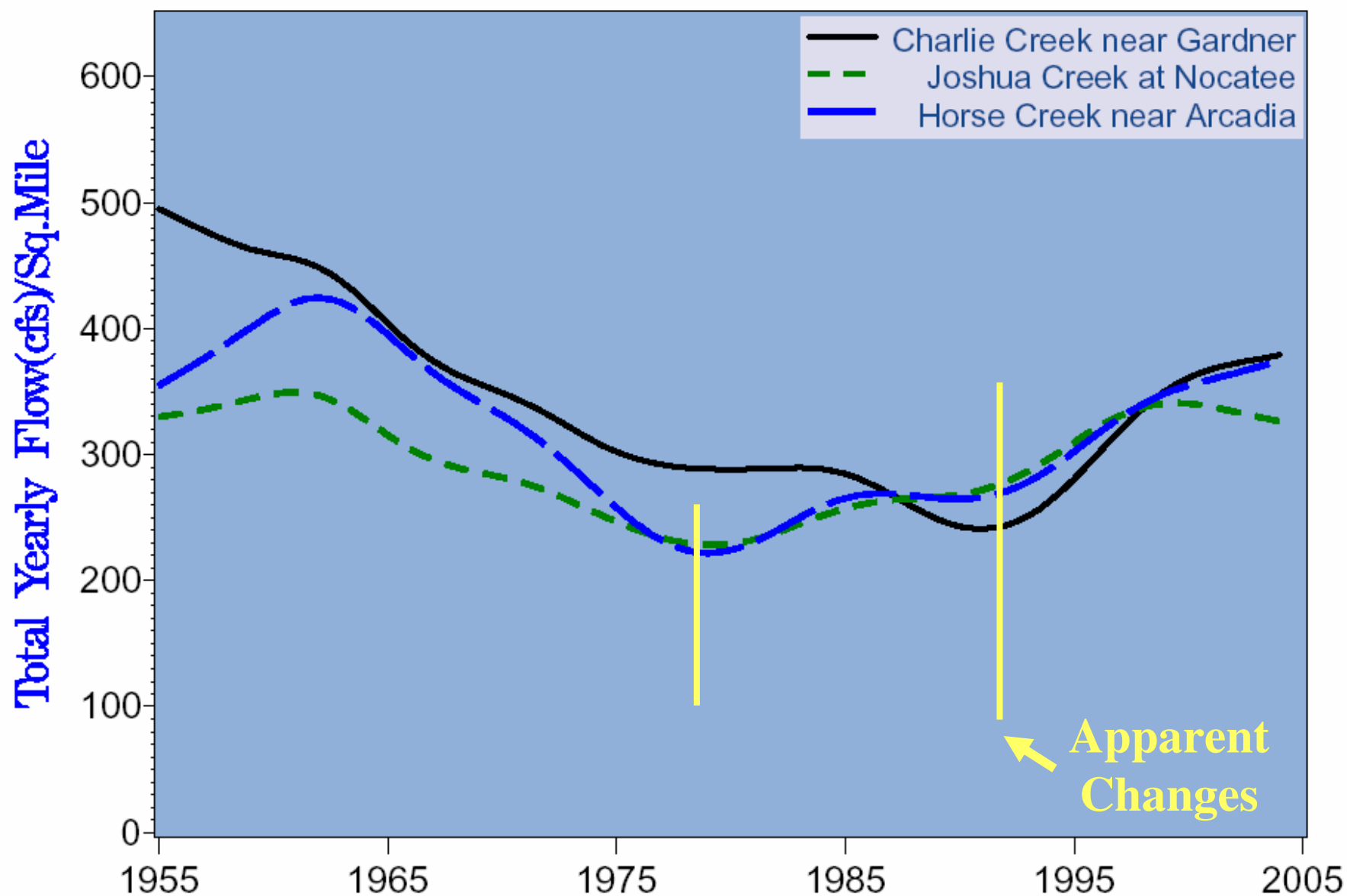
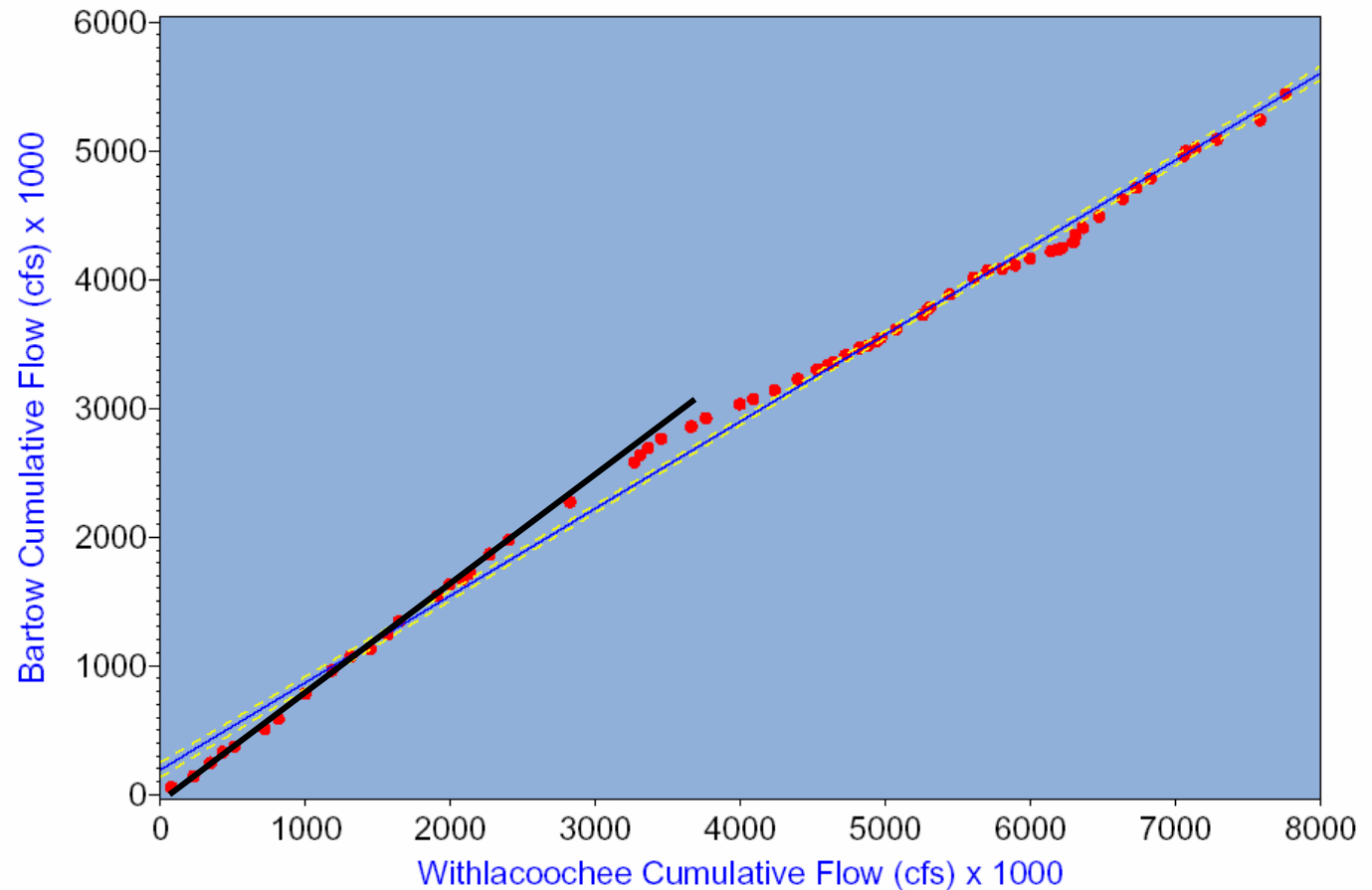
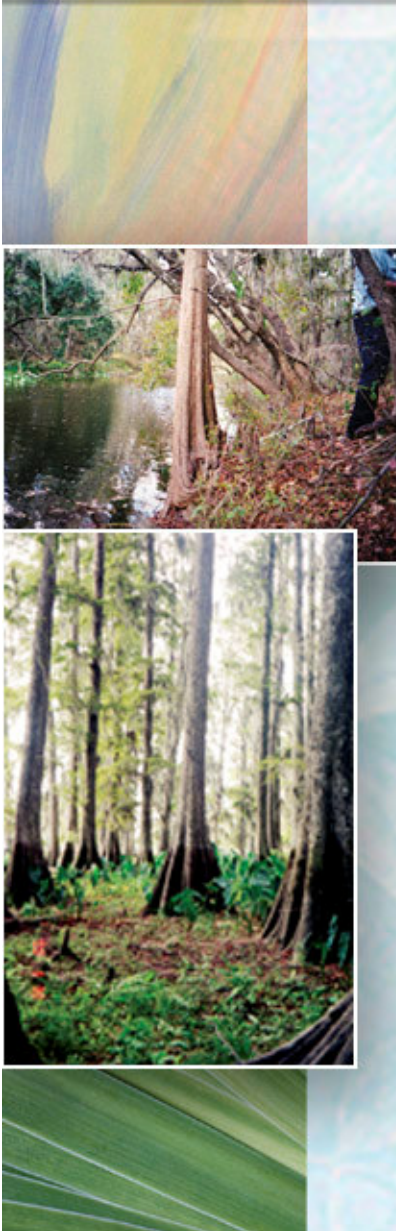


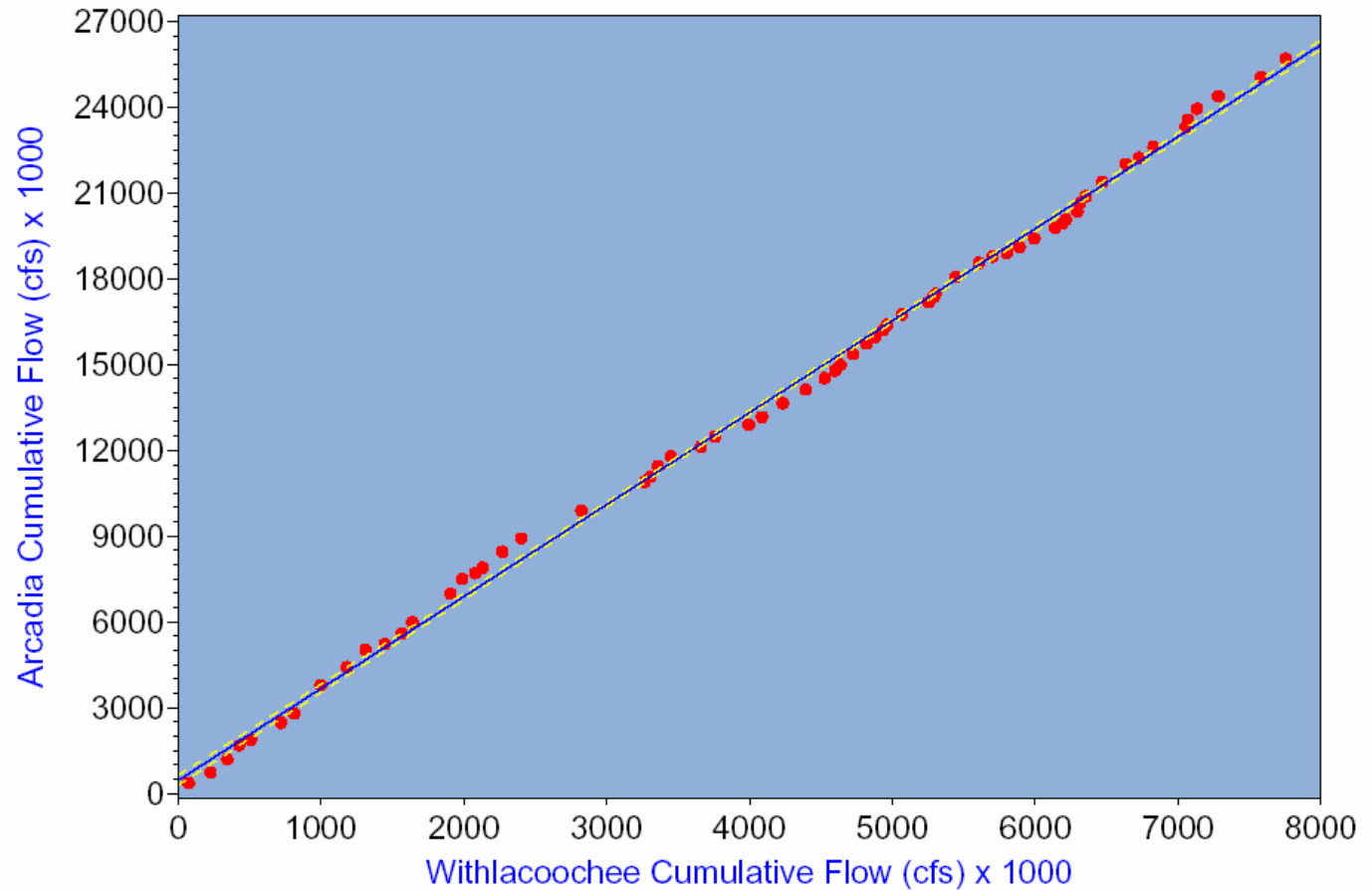
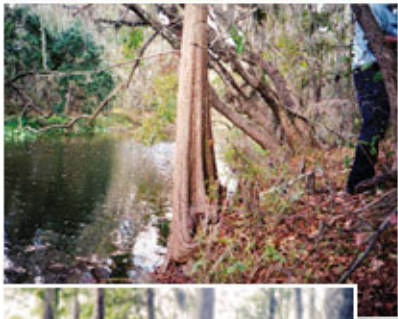
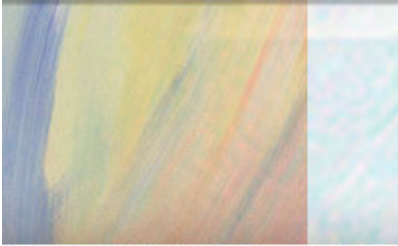
Figure D339. Five year moving averages of total yearly flows standardized to watershed area (1955-2004)

Comparisons of Peace Gages with Withlacoochee River at Croom



Withlacoochee River at Croom vs. Peace River at Bartow (1940-2004)

Comparisons of Peace Gages with Withlacoochee River at Croom



Withlacoochee River at Croom vs. Peace River at Arcadia (1940-2004)

Peace River Cumulative Impact Study



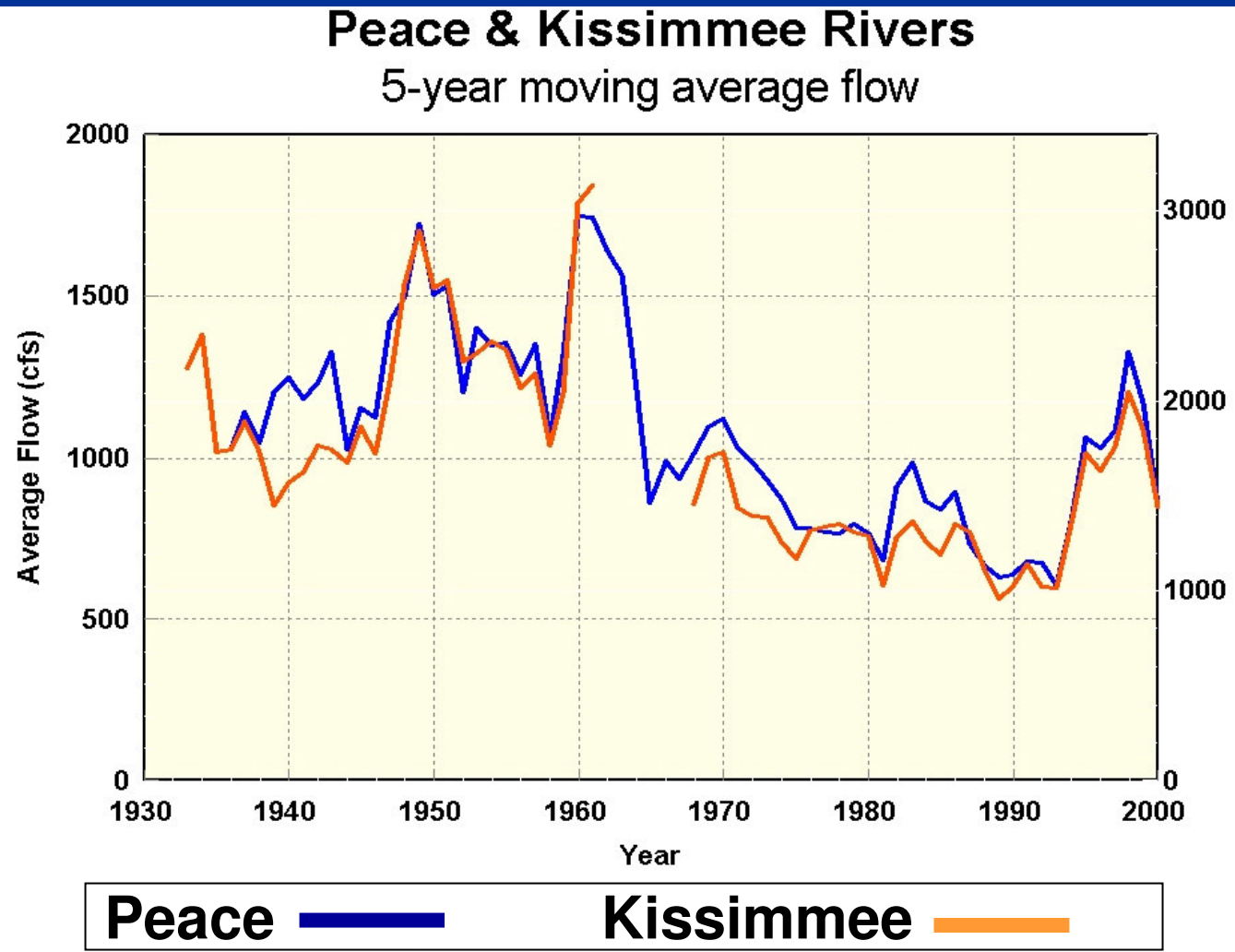
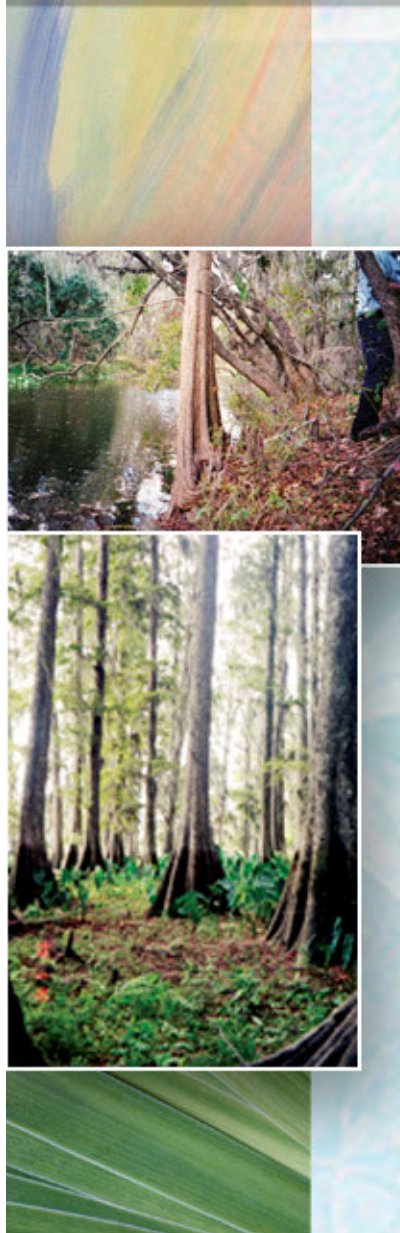
**Long-Term Rainfall
Patterns in the
Peace River Watershed**

Peace River Basin Rainfall Studies



- **Palmer and Bone (1977)**
- **Palmer and Nguyen (1986)**
- **SWFWMD Ridge II Report (1990)**
- **Coastal Environmental (1996)**
- **Enfield and others (2001)**
- **Garlanger (2002)**
- **SWFWMD (2003)**

Widespread Similar Flow Patterns



Long-Term Variation in Rainfall

Recent Rainfall/Climate Studies

*By NOAA, SFWMD, & Univ of Miami
(Enfield and Others, 2001)*

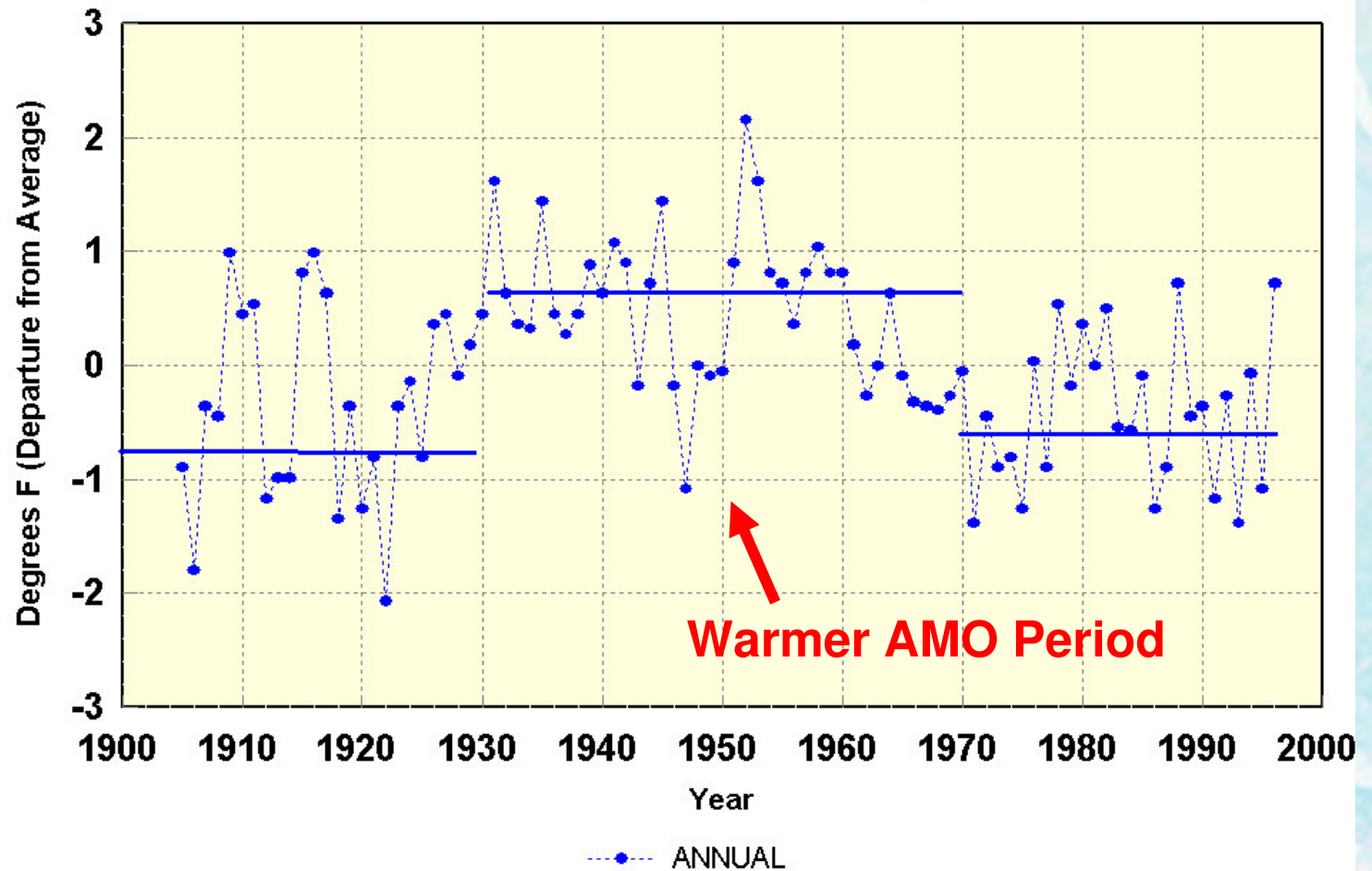
- Statistically significant differences in rainfall between the pre-1970 period versus the last 30 years
- Rainfall changes produced a 40 percent change in inflow to Lake Okeechobee
- Rainfall changes may be due to the Atlantic Multidecadal Oscillation (AMO)



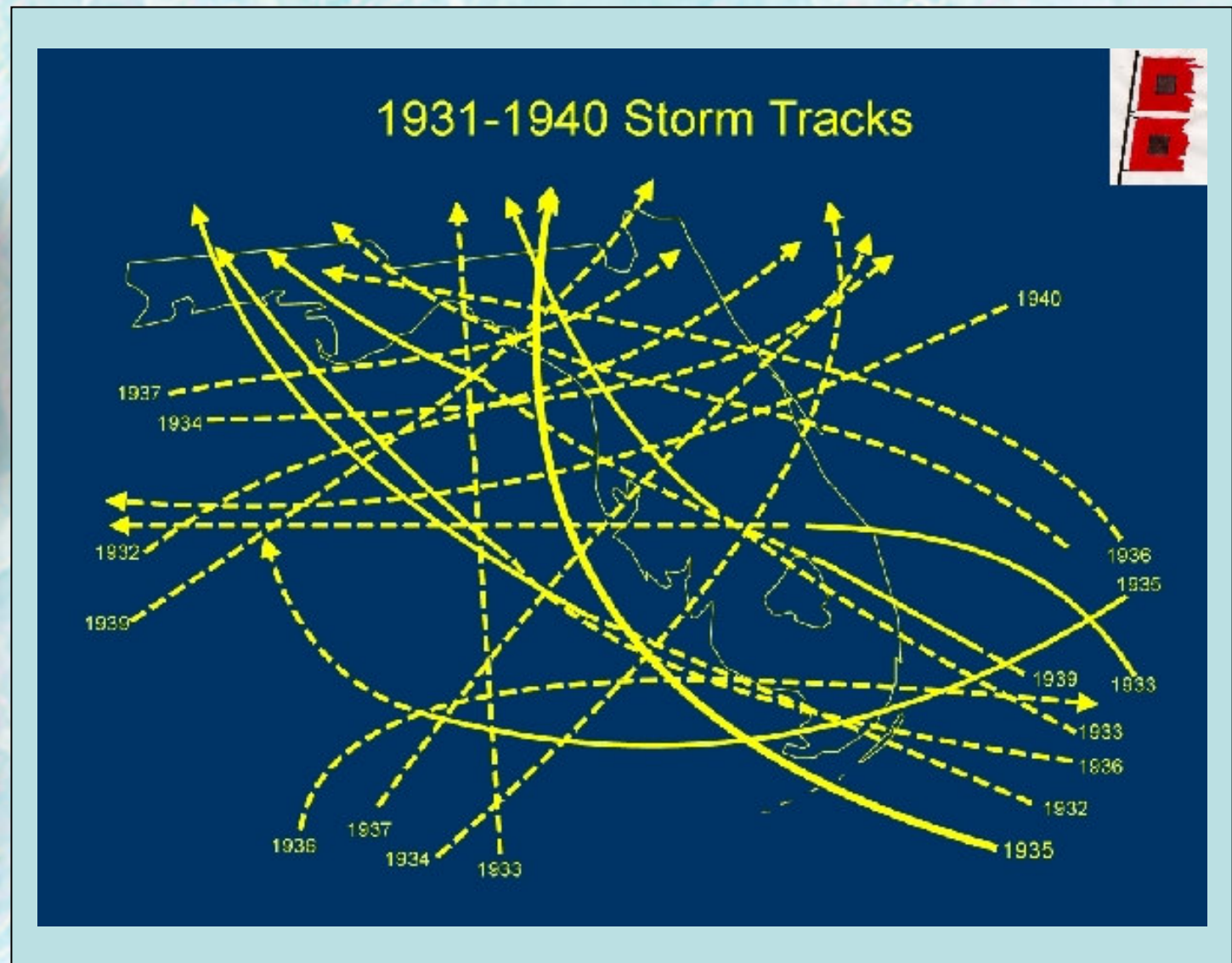
Atlantic Multidecadal Oscillation (AMO)

Atlantic Ocean Sea Surface Temperature

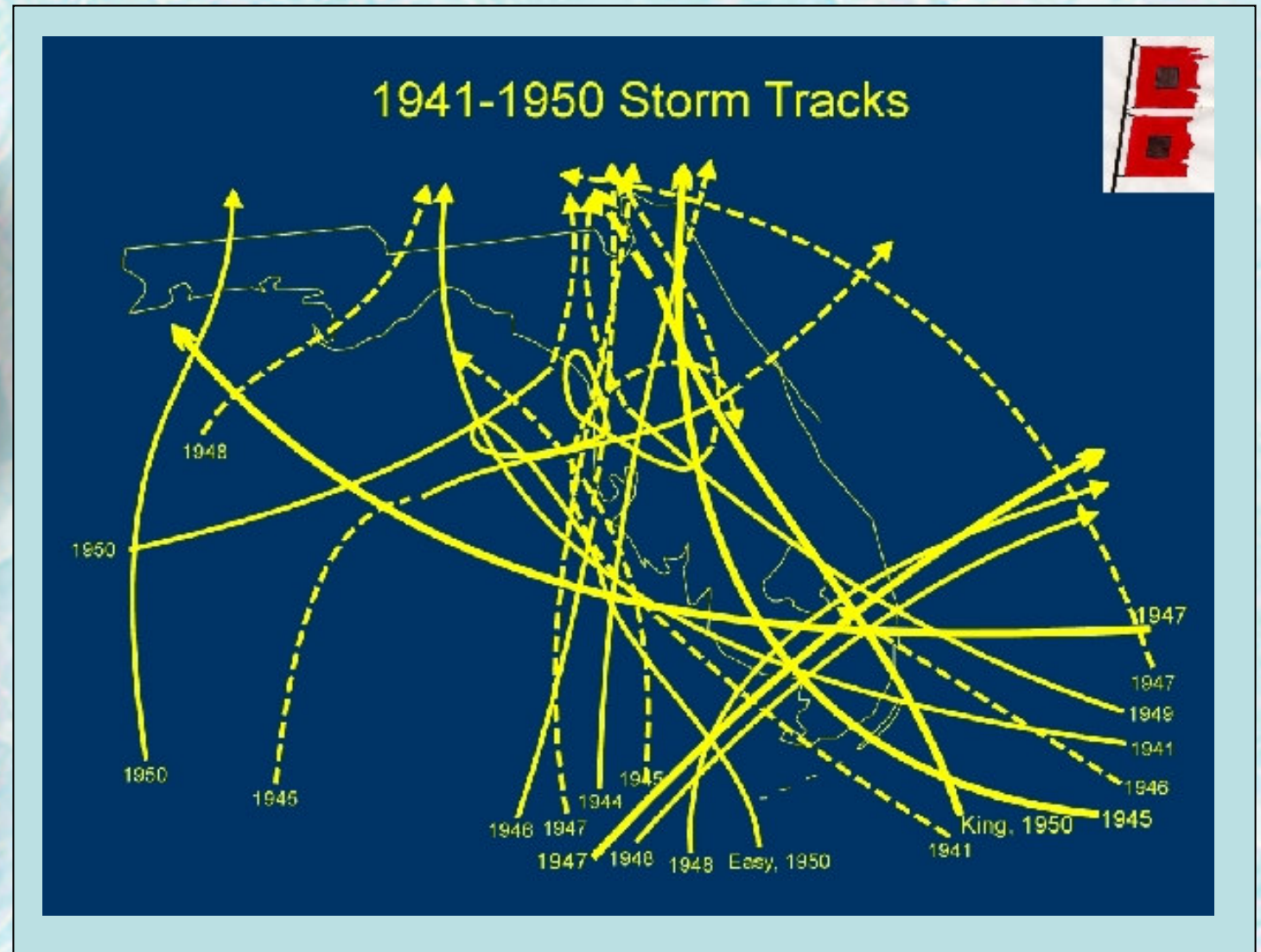
50N-60N Lat/10W-50W Long



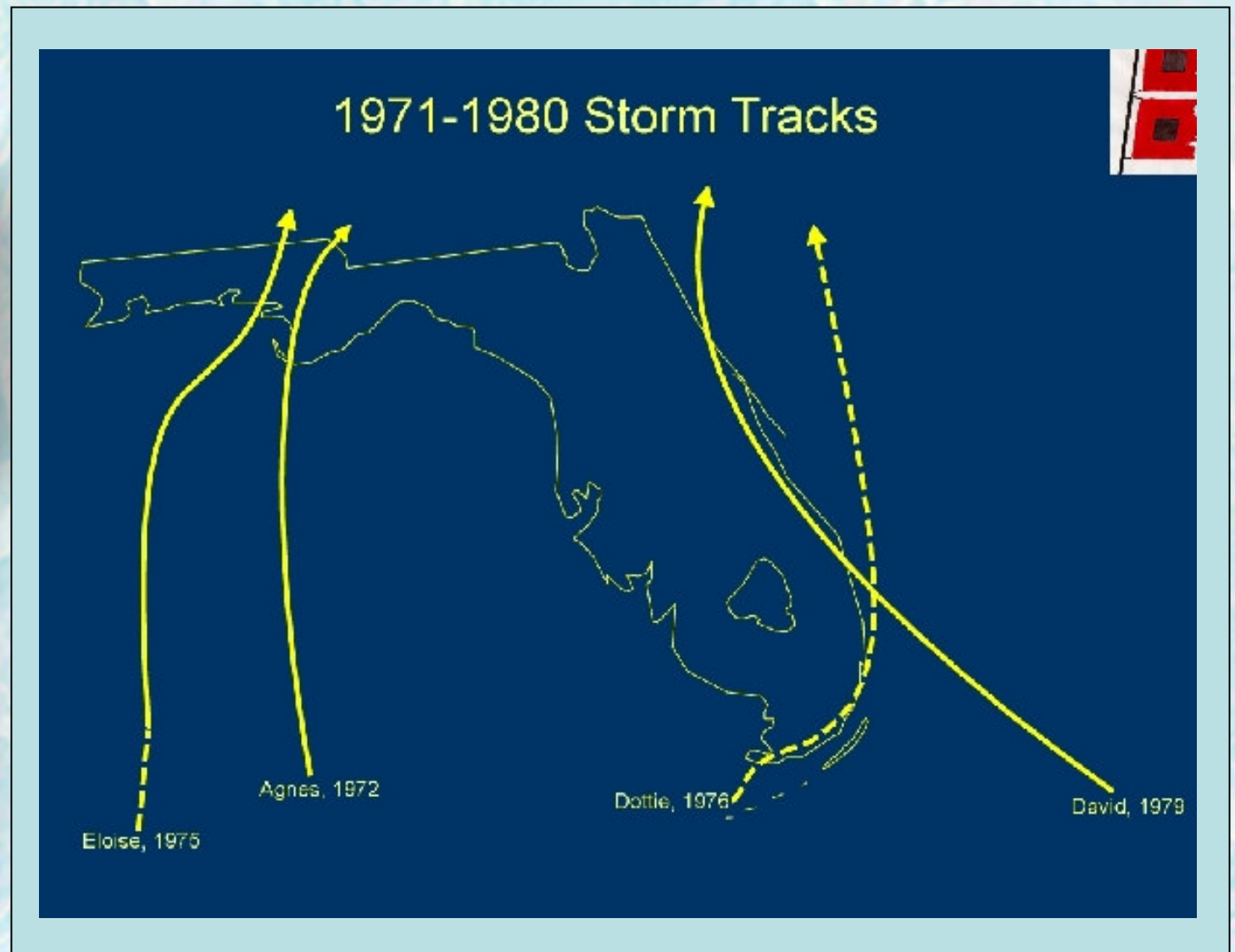
Tropical Cyclone Frequency



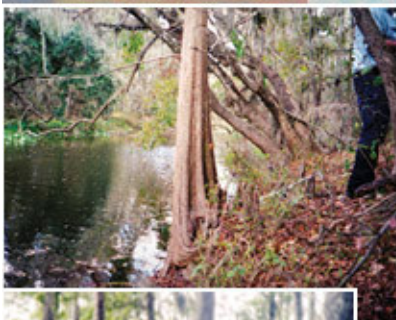
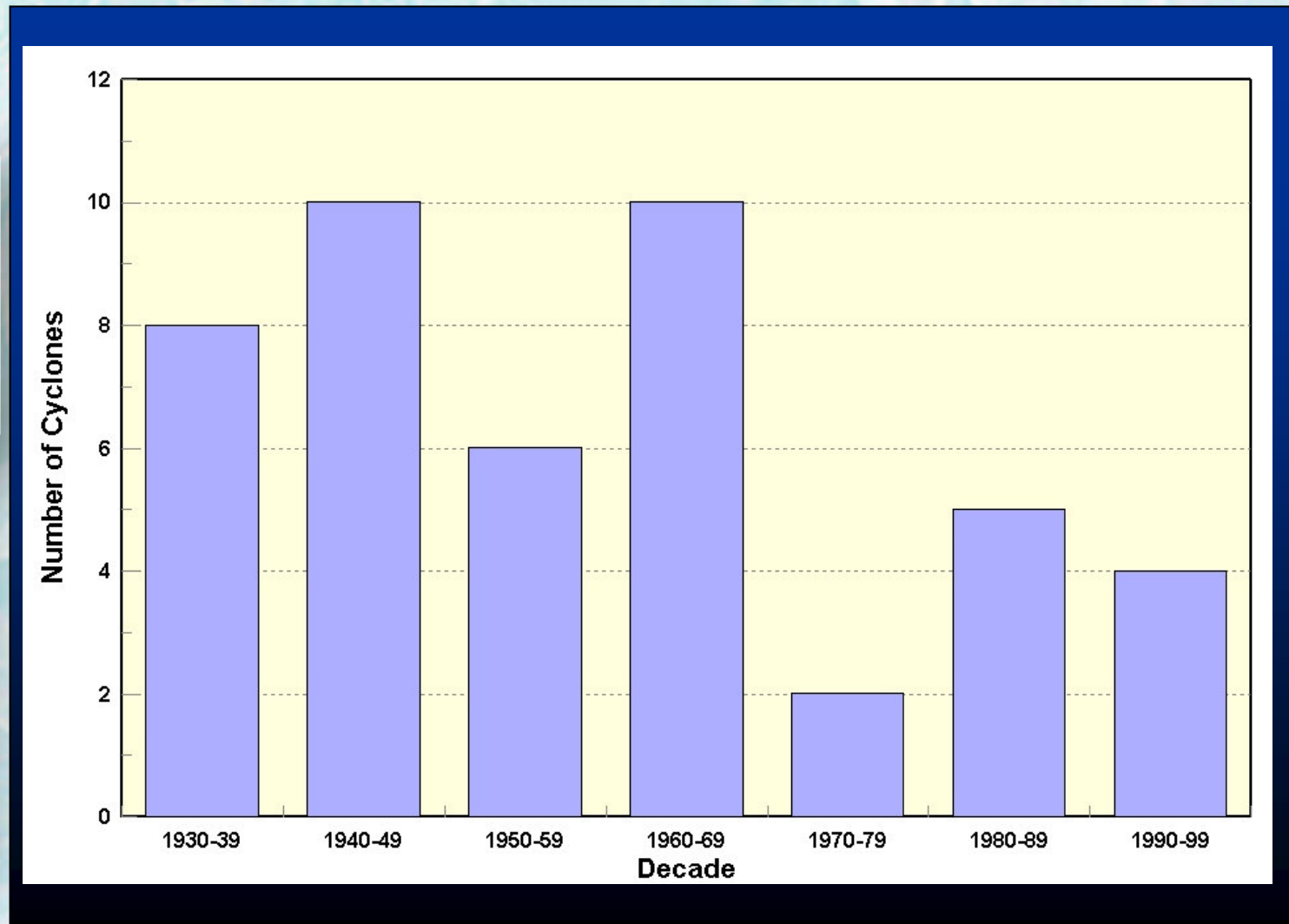
Tropical Cyclone Frequency



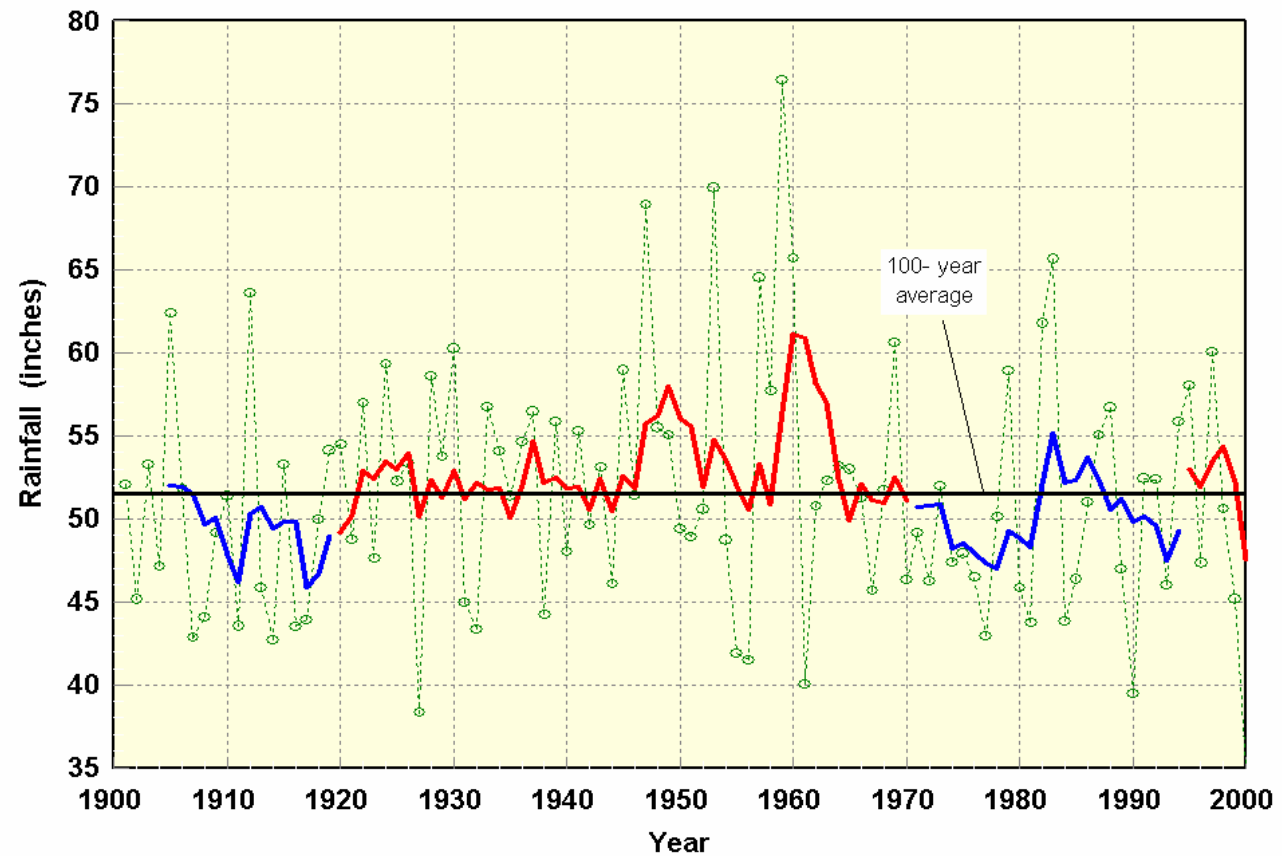
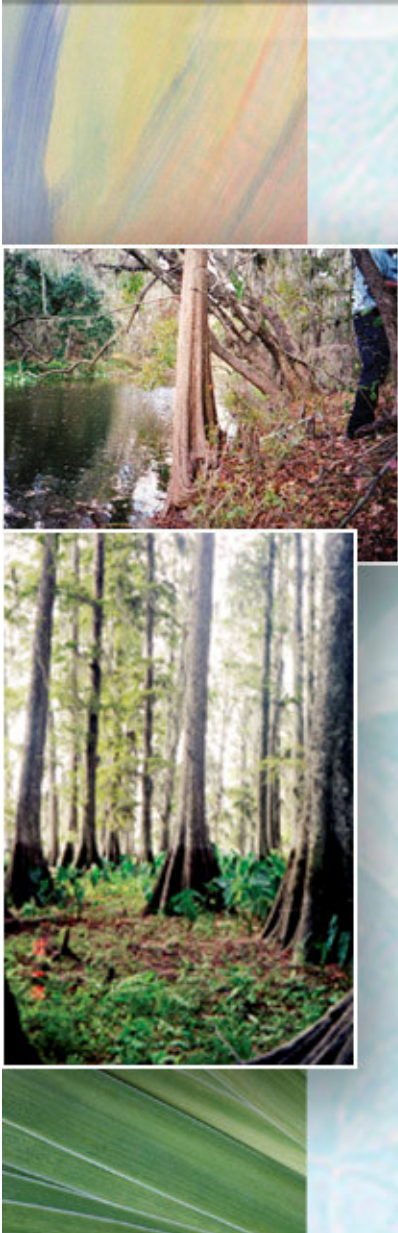
Tropical Cyclone Frequency



Tropical Systems Affecting Peace River Watershed

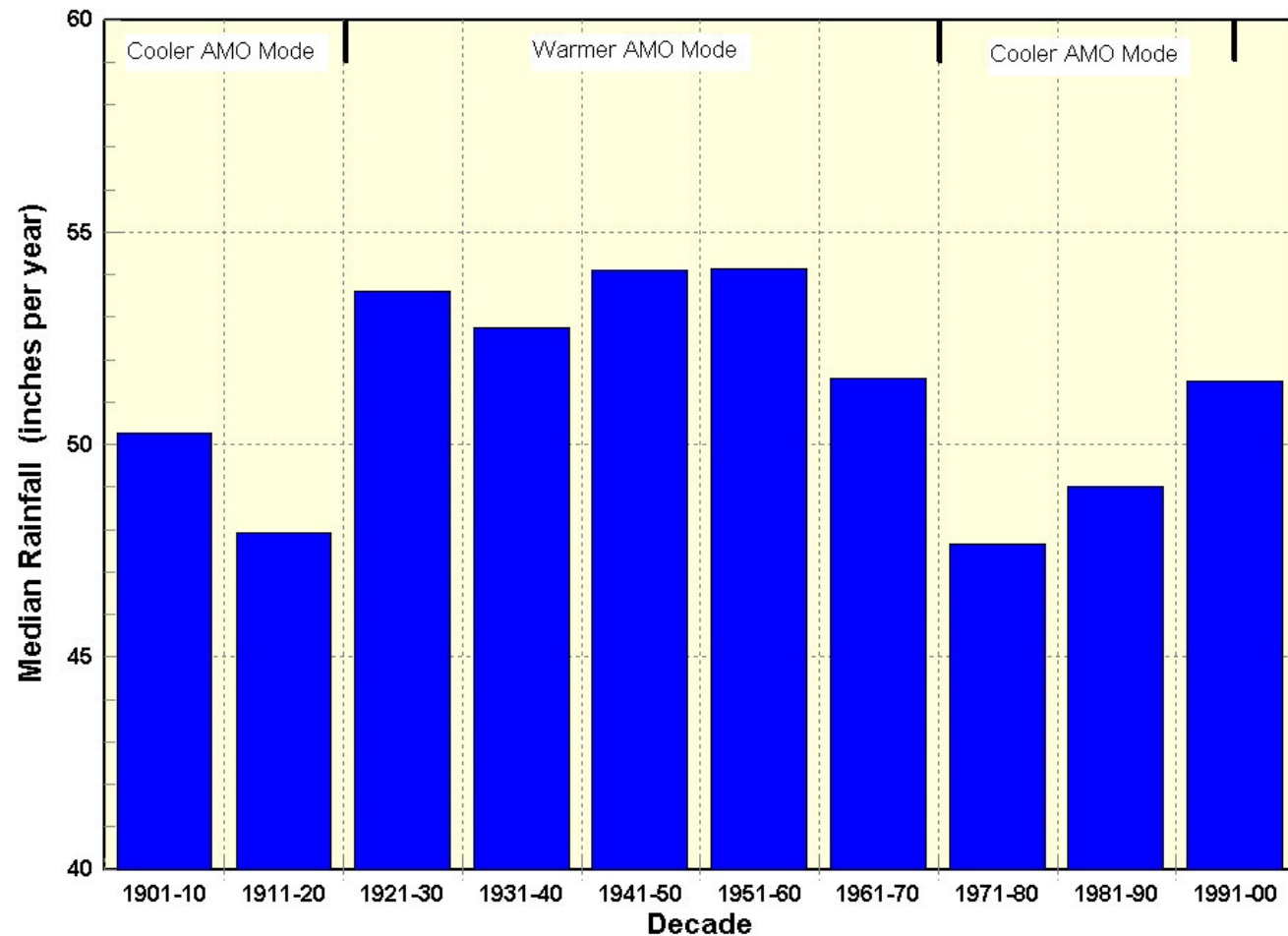


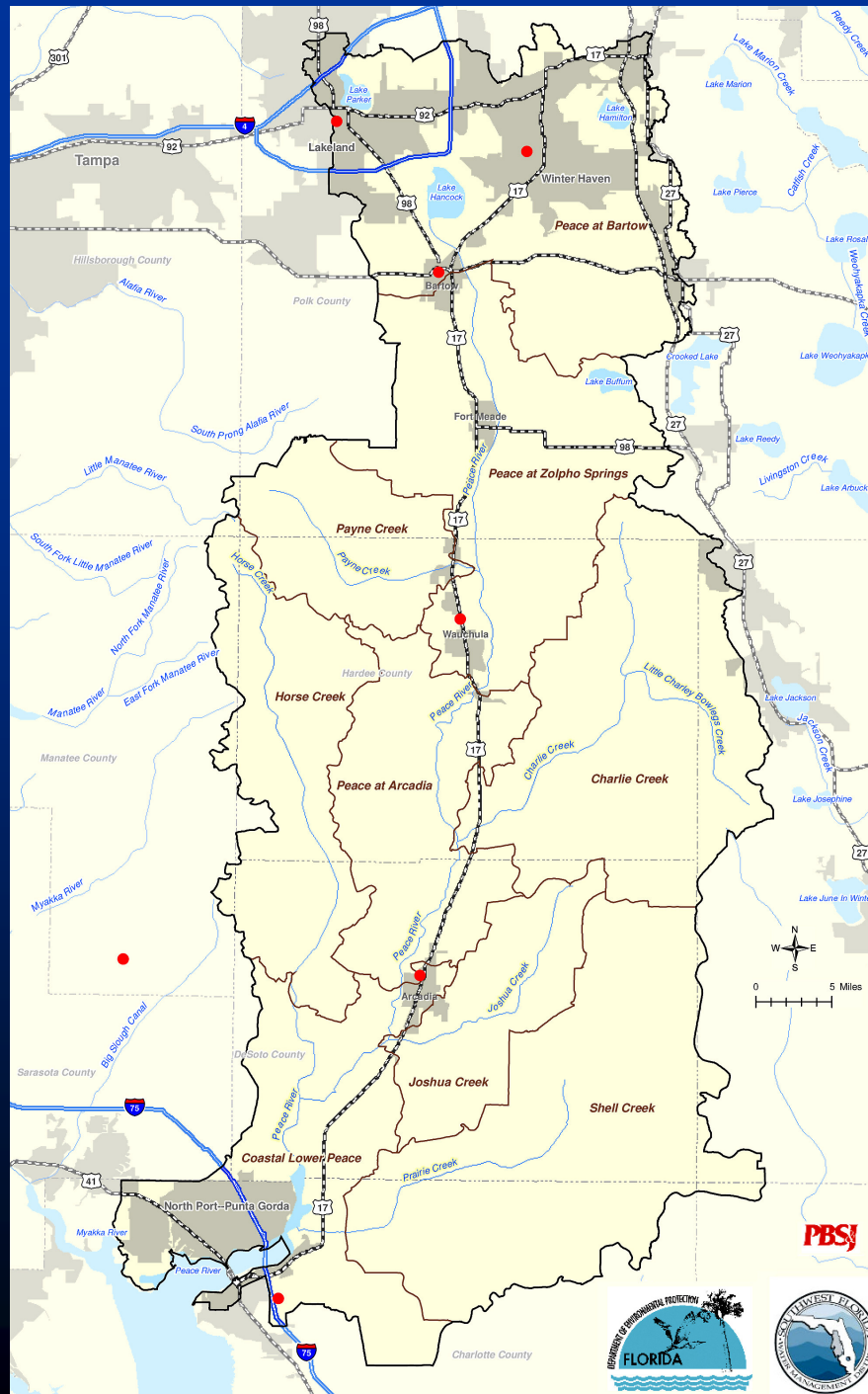
West Central Florida Rainfall



Warmer AMO **Cooler AMO**

Upper Peace River Watershed Rainfall



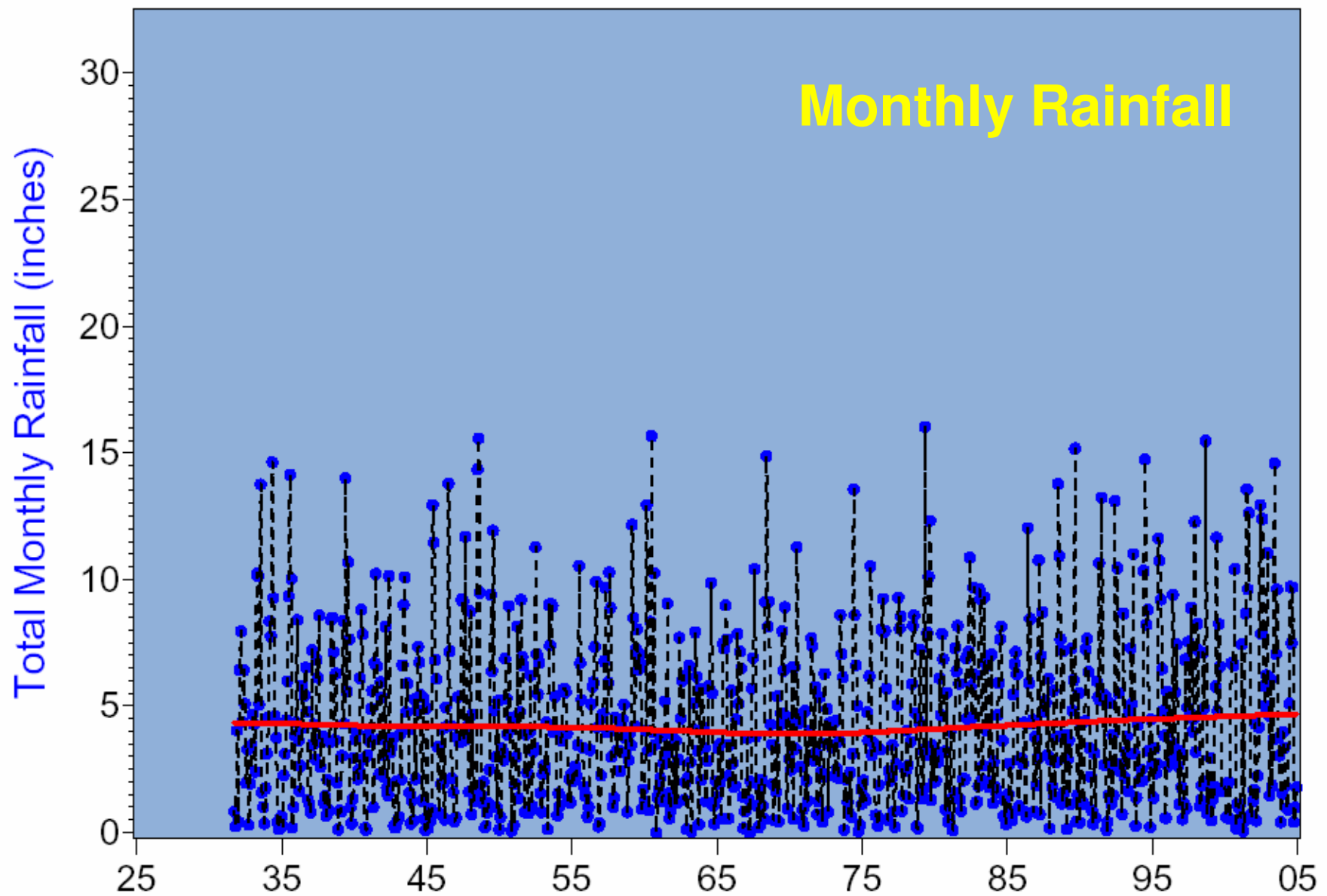


• Peace River Watershed

- Winter Haven 1941
- Lakeland 1915
- Bartow 1908
- Wauchula 1933
- Arcadia 1907
- Punta Gorda 1914

• Other Reference Gages

- Myakka 1943
- Brooksville 1901
- Bradenton 1911



Monthly rainfall at long-term Lakeland NOAA gage (District #157) 1932-2004)

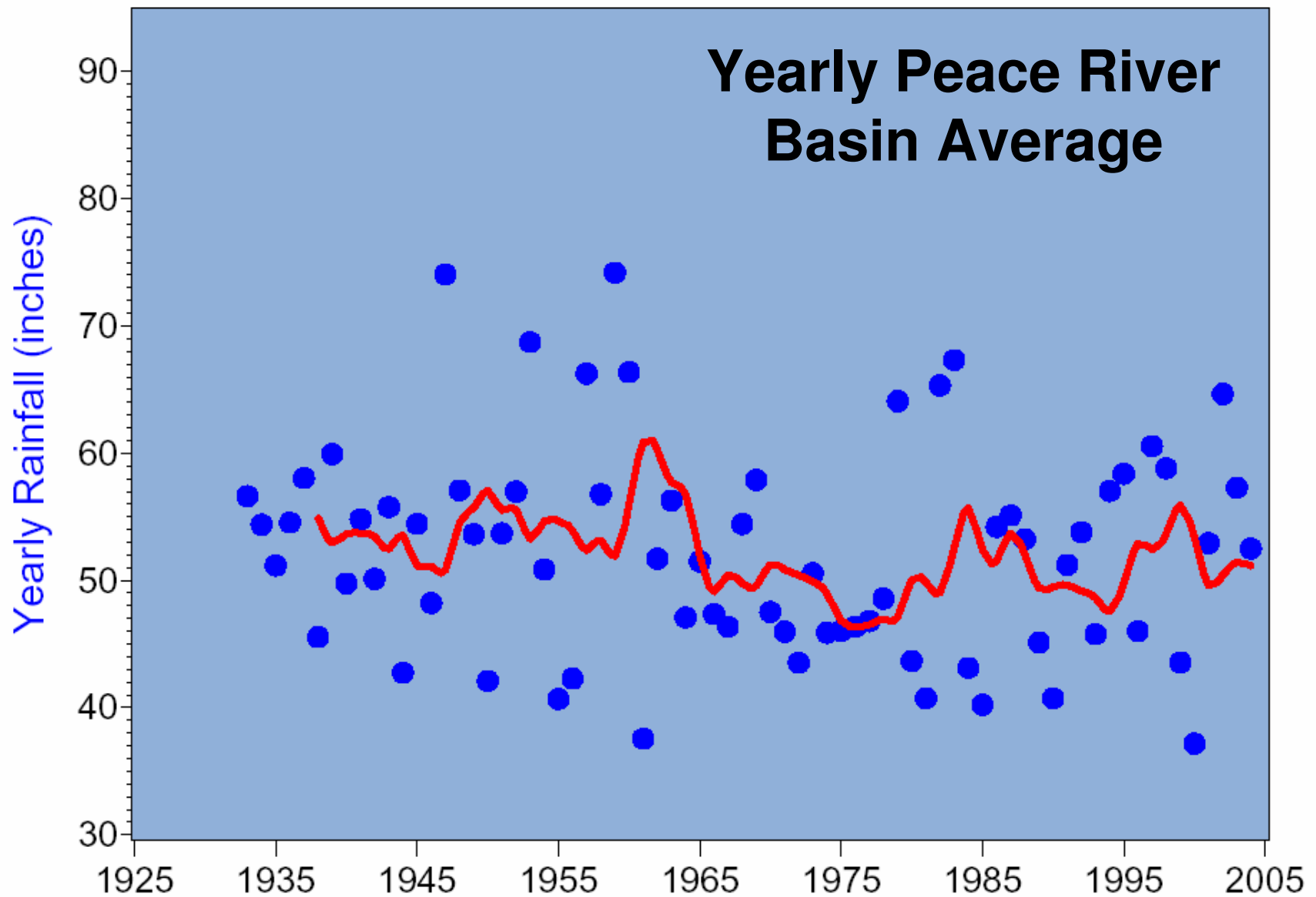


Figure D. Yearly total and 5-year moving average rainfall for the average of the four Peace River watershed basin gages

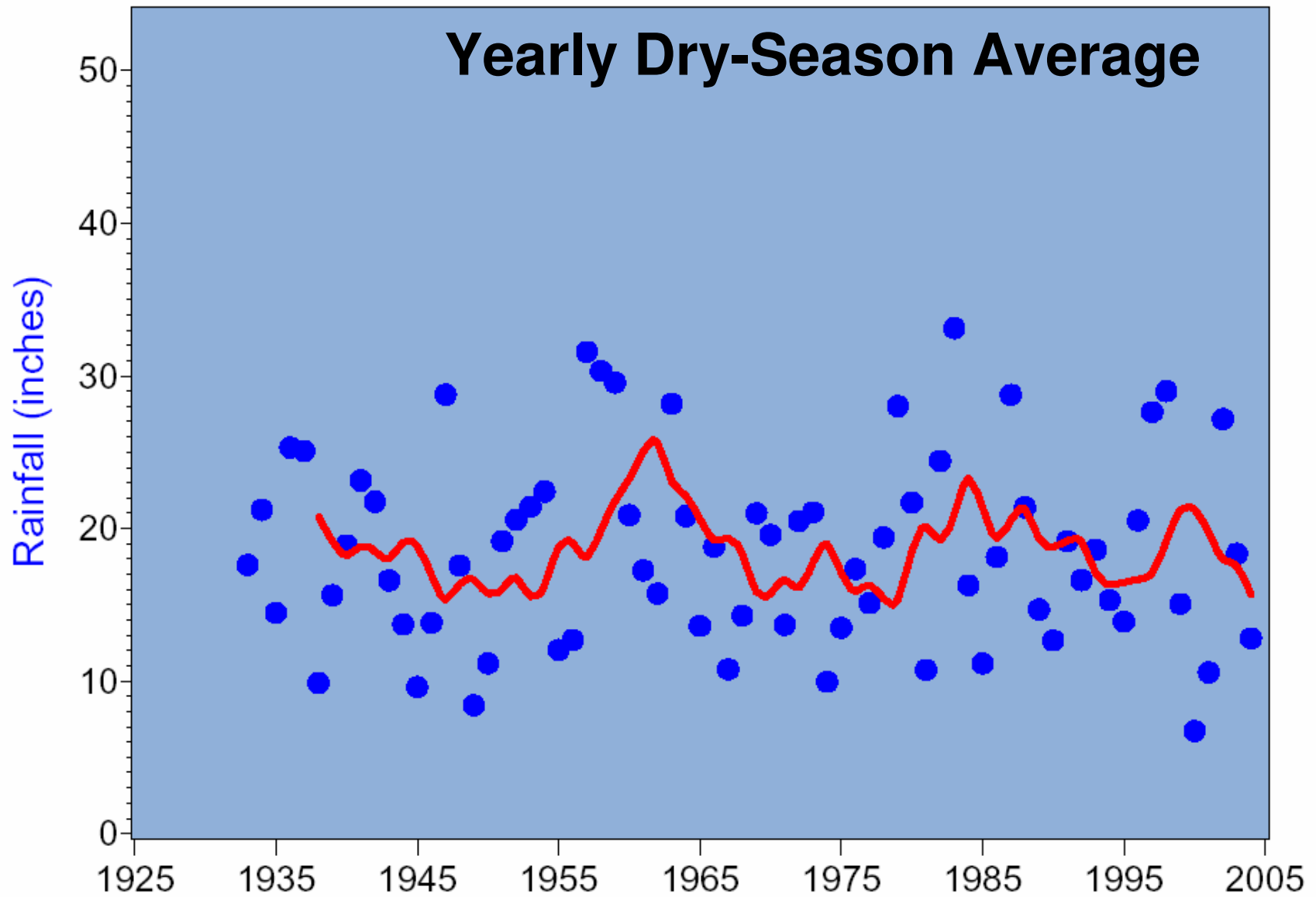


Figure D. Yearly dry-season and 5-year moving average rainfall for the average of the four Peace River watershed basin gages

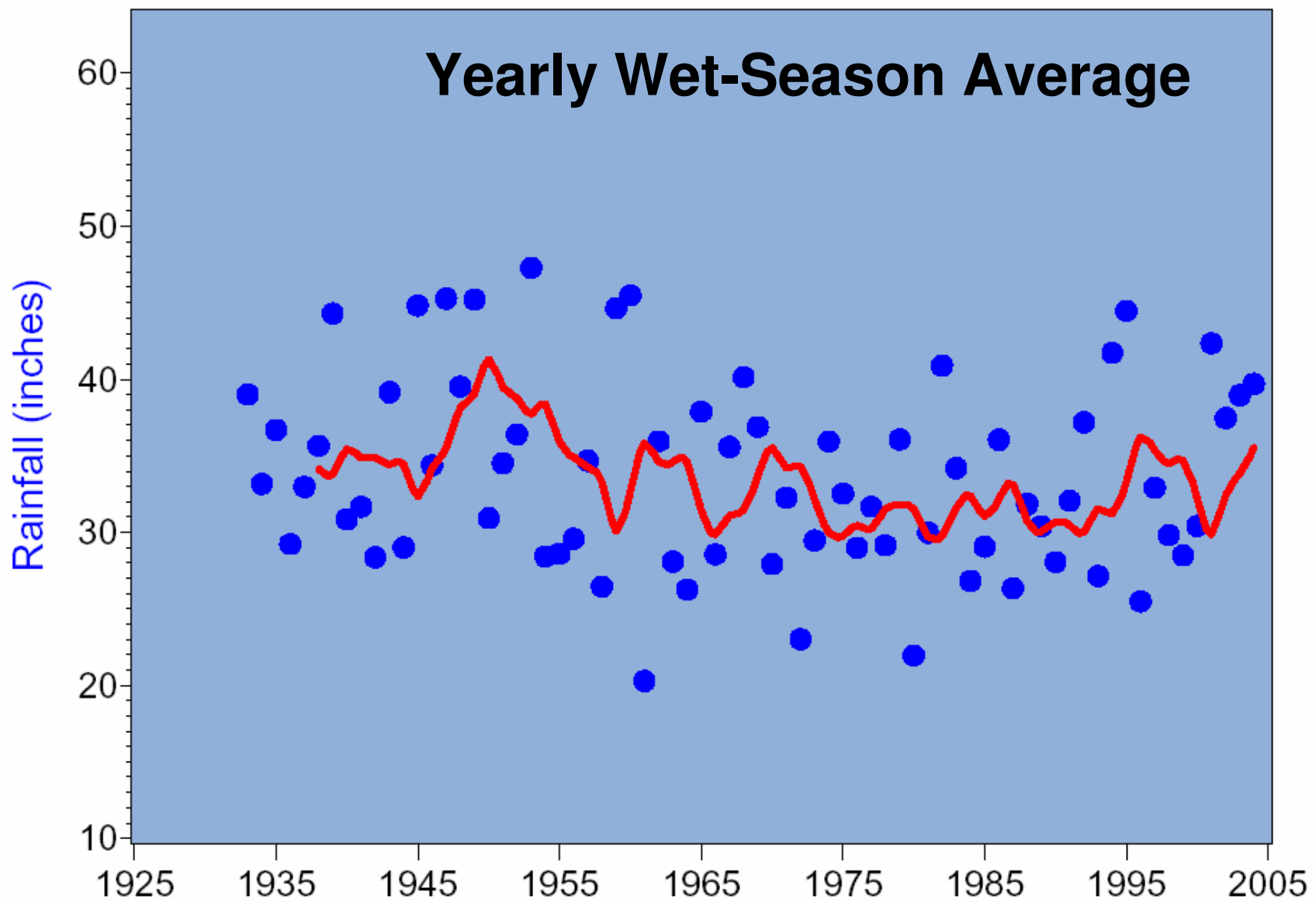


Figure D. Yearly wet-season and 5-year moving average rainfall for the average of the four Peace River watershed basin gages

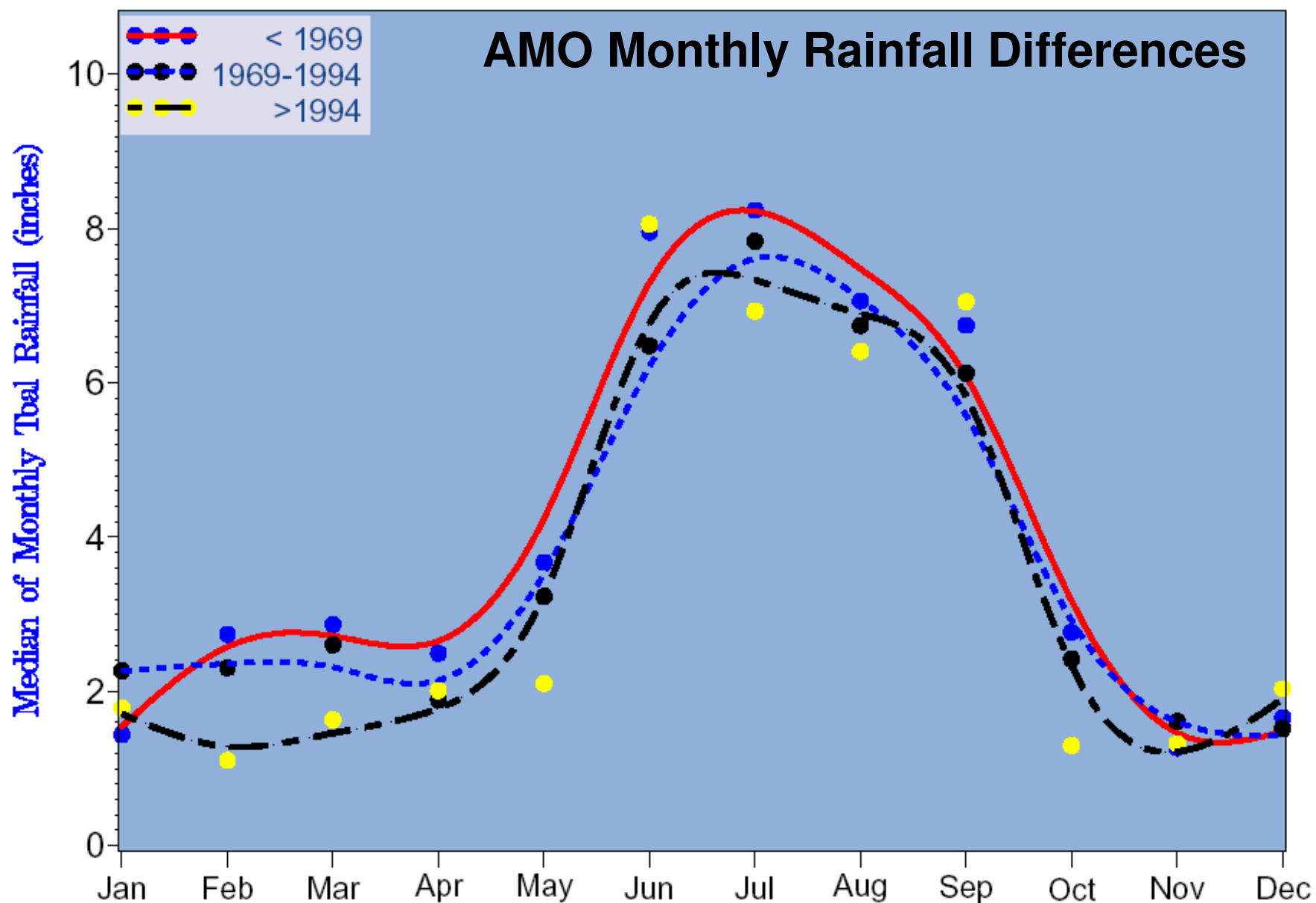


Figure D. Seasonal monthly rainfall differences among AMO periods averaged Peace Basin NOAA gage (District #89) 1932-2004)

Additional Graphical Rainfall Analyses

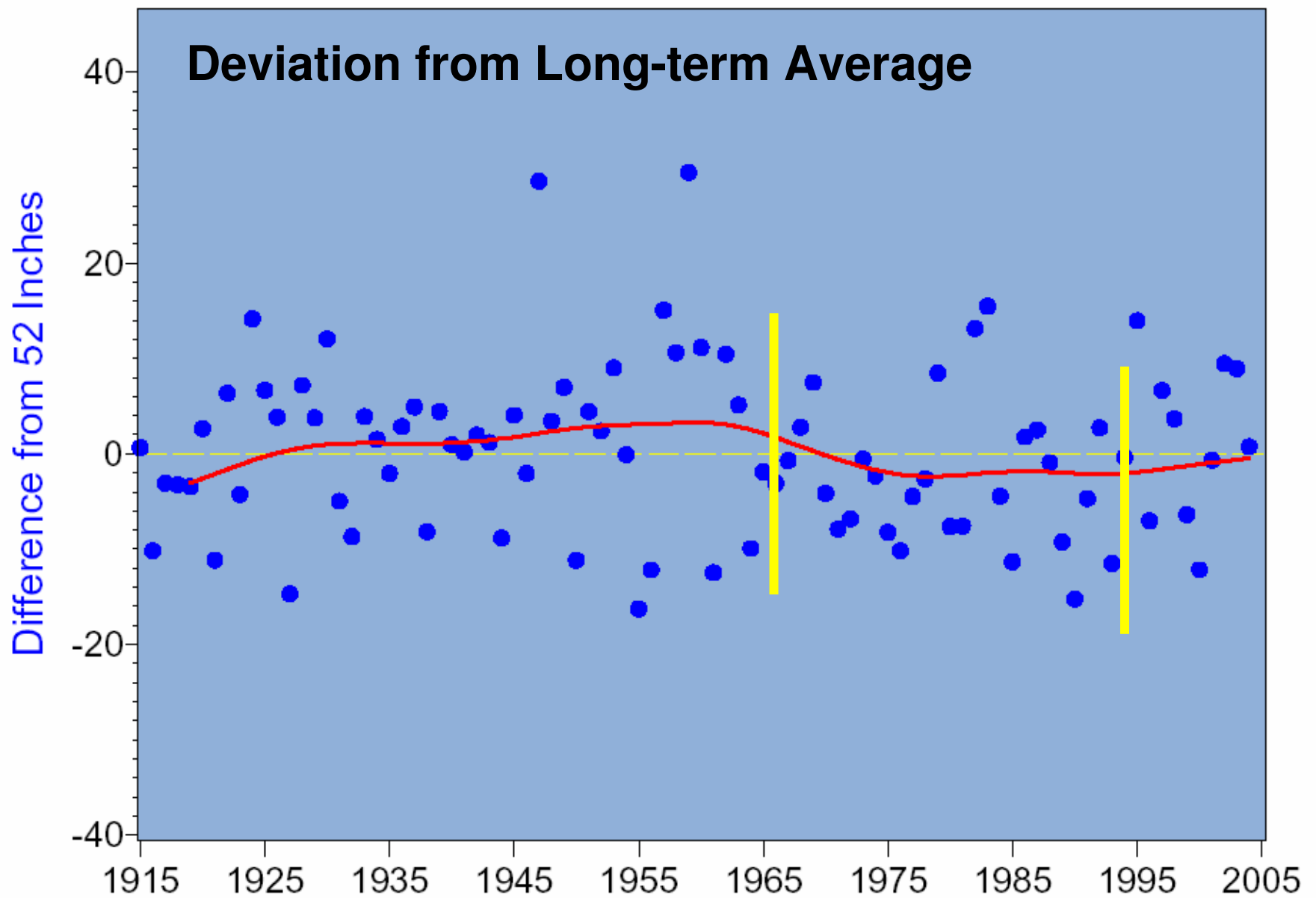
- **Annual Deviations from Long-term Averages**

- Overall
- Dry Season
- Wet Season

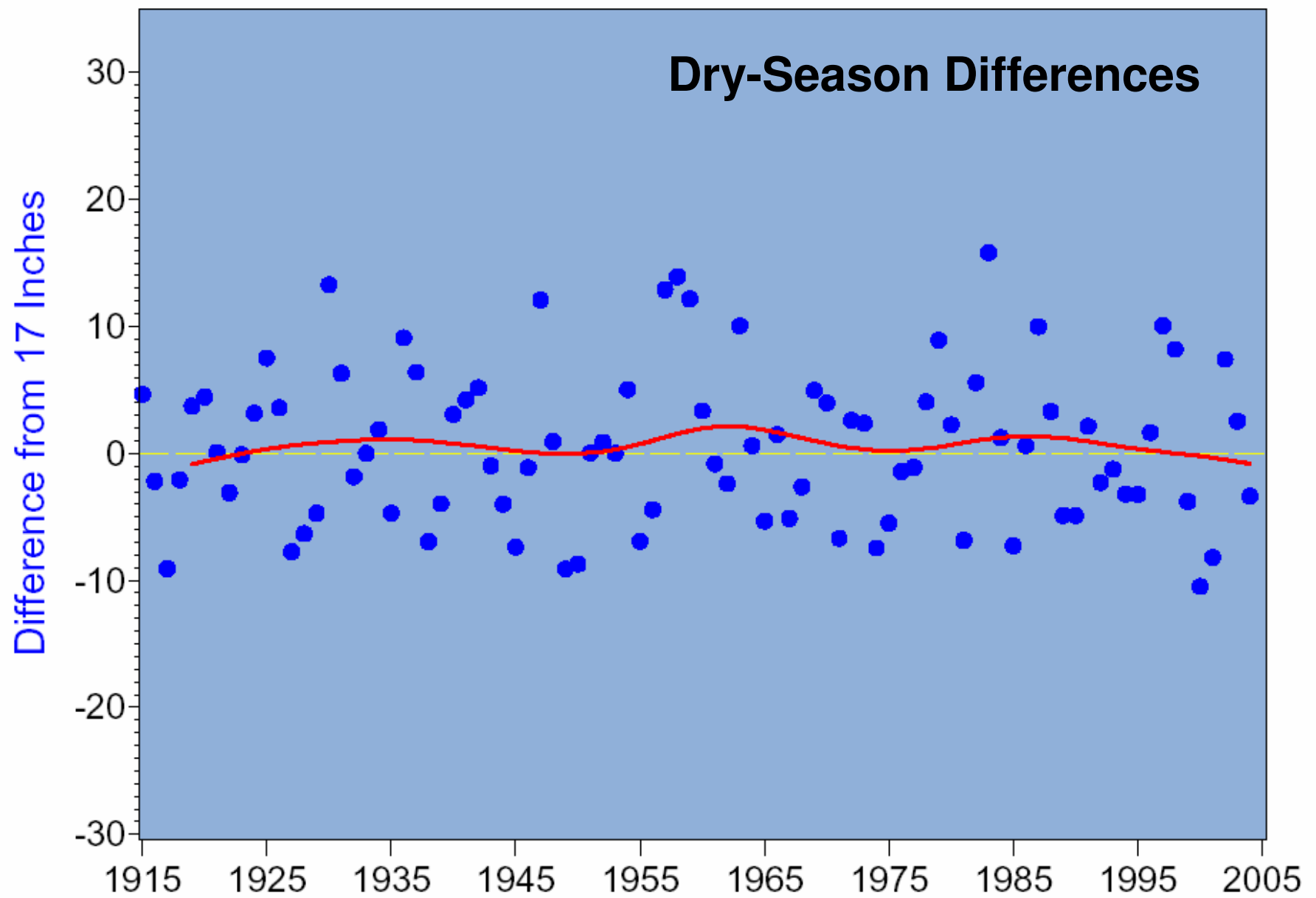
- **Comparisons to Evapotranspiration**

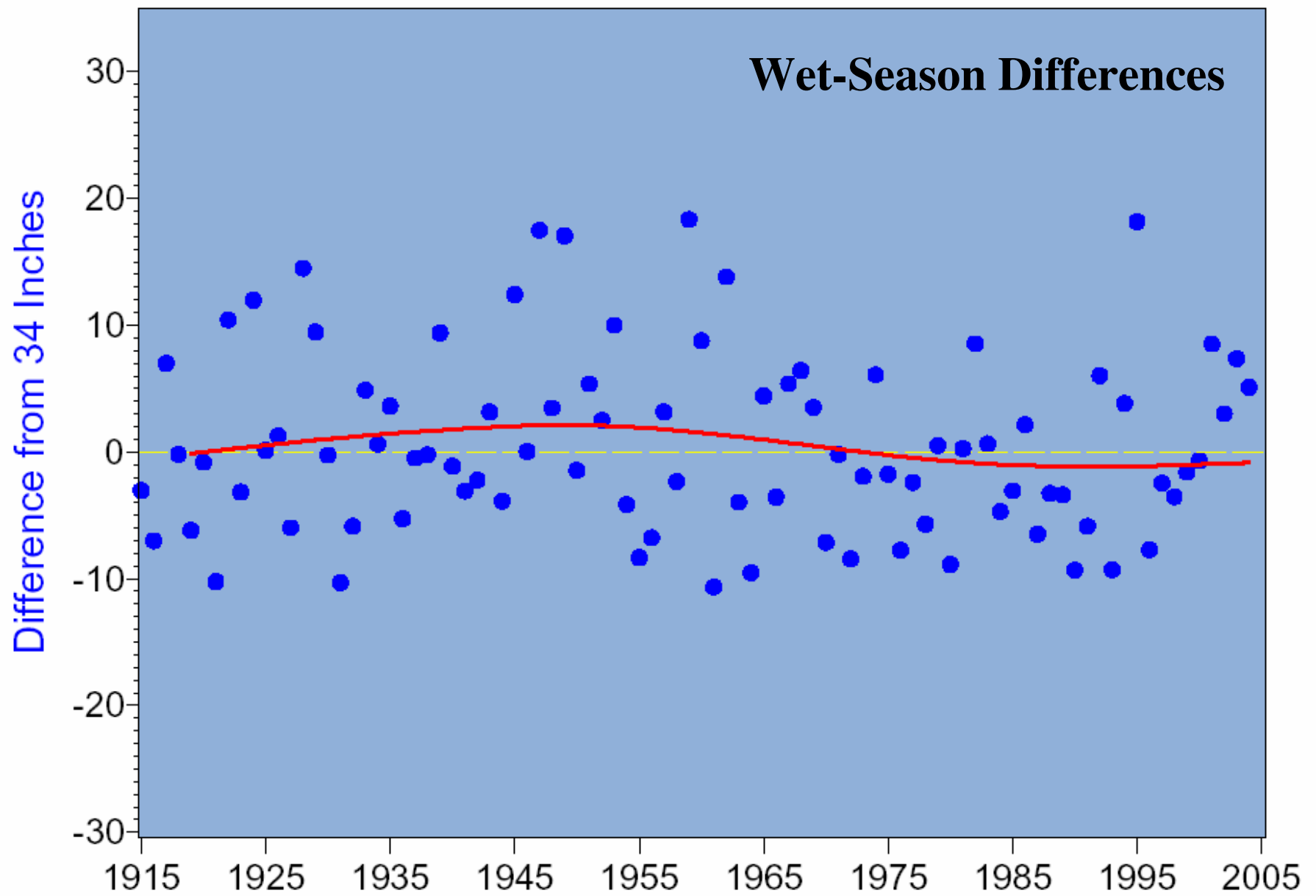
- **Long-term Accumulated Differences**





Yearly and 5-year moving average of Bartow, Arcadia and Punta Gorda average annual rainfall (1915-2004)



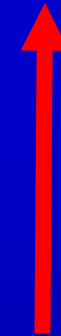
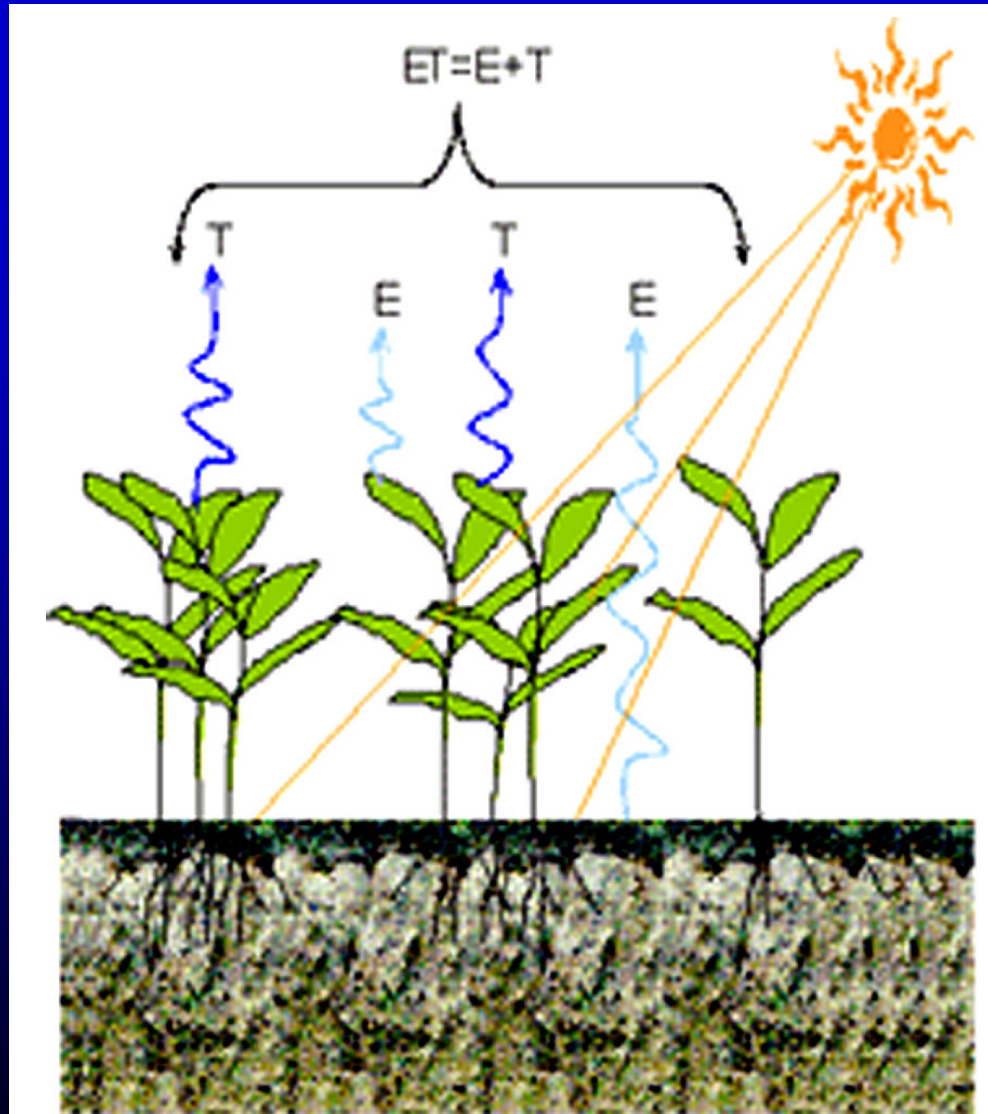


Yearly and 5-year moving average annual wet-season Bartow, Arcadia and Punta Gorda average rainfall (1915-2004)

Evapotranspiration



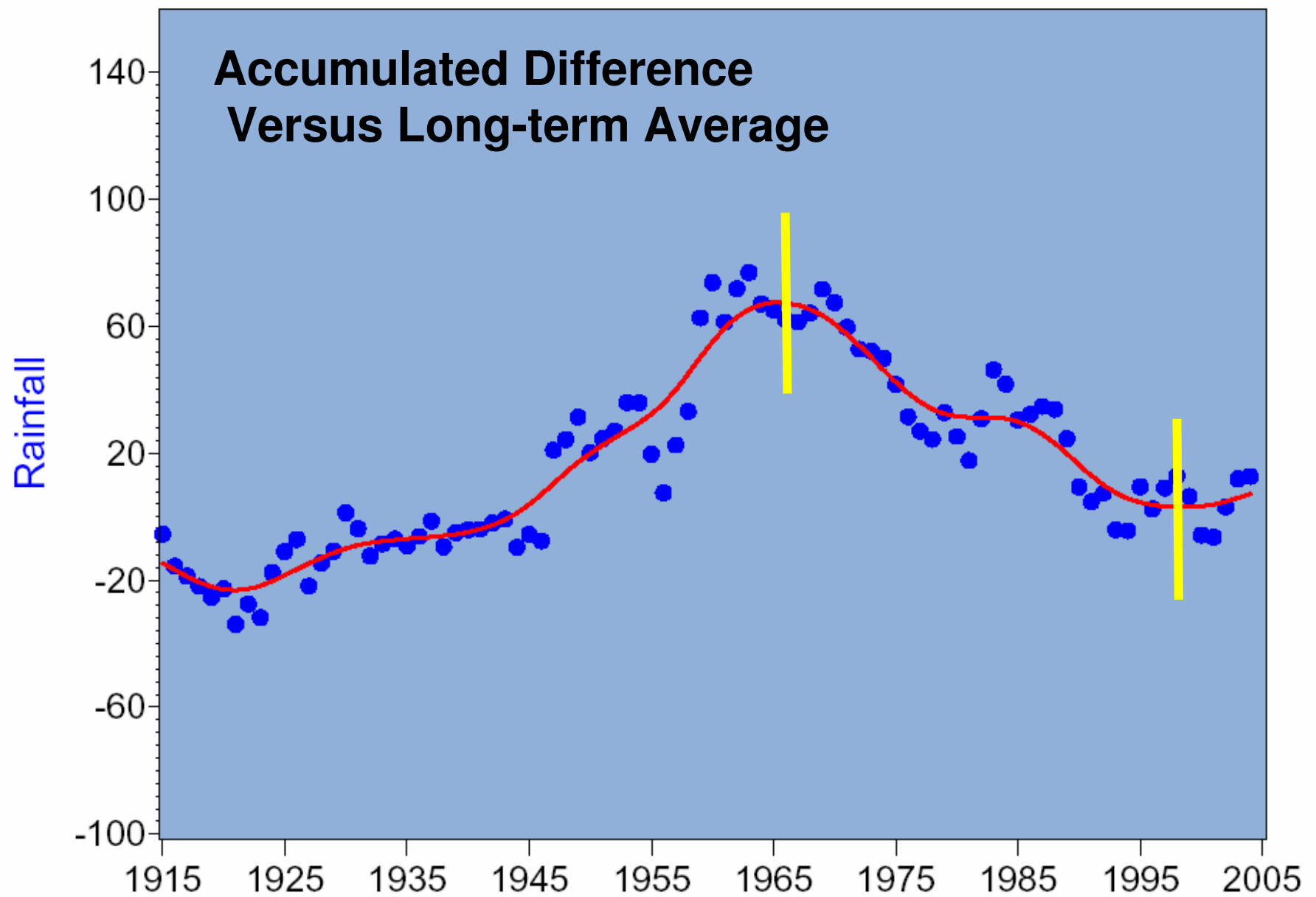
**52 Inches
Annually**



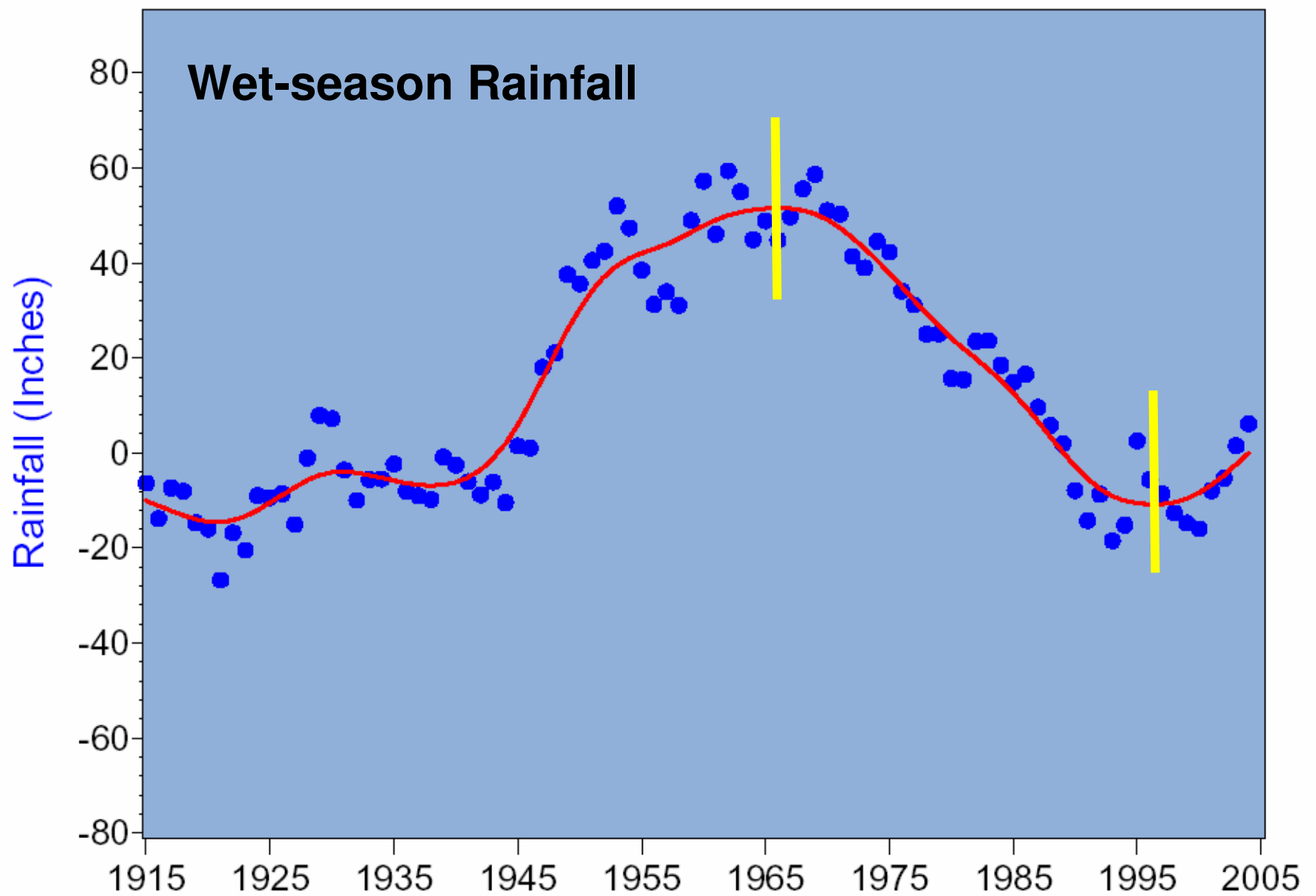
**38 Inches
Annually**

**10% change
= 5 inches**

**$5 / (52 - 38)$
= 35.7 %**



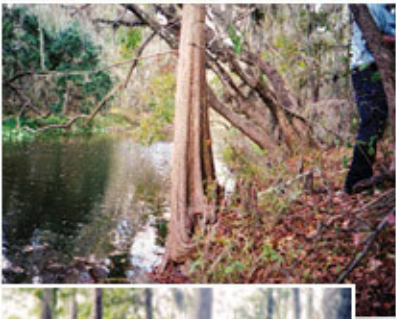
Long-term cumulative annual rainfall above 52.0 inches of Bartow, Arcadia and Punta Gorda average rainfall (1915-2004)

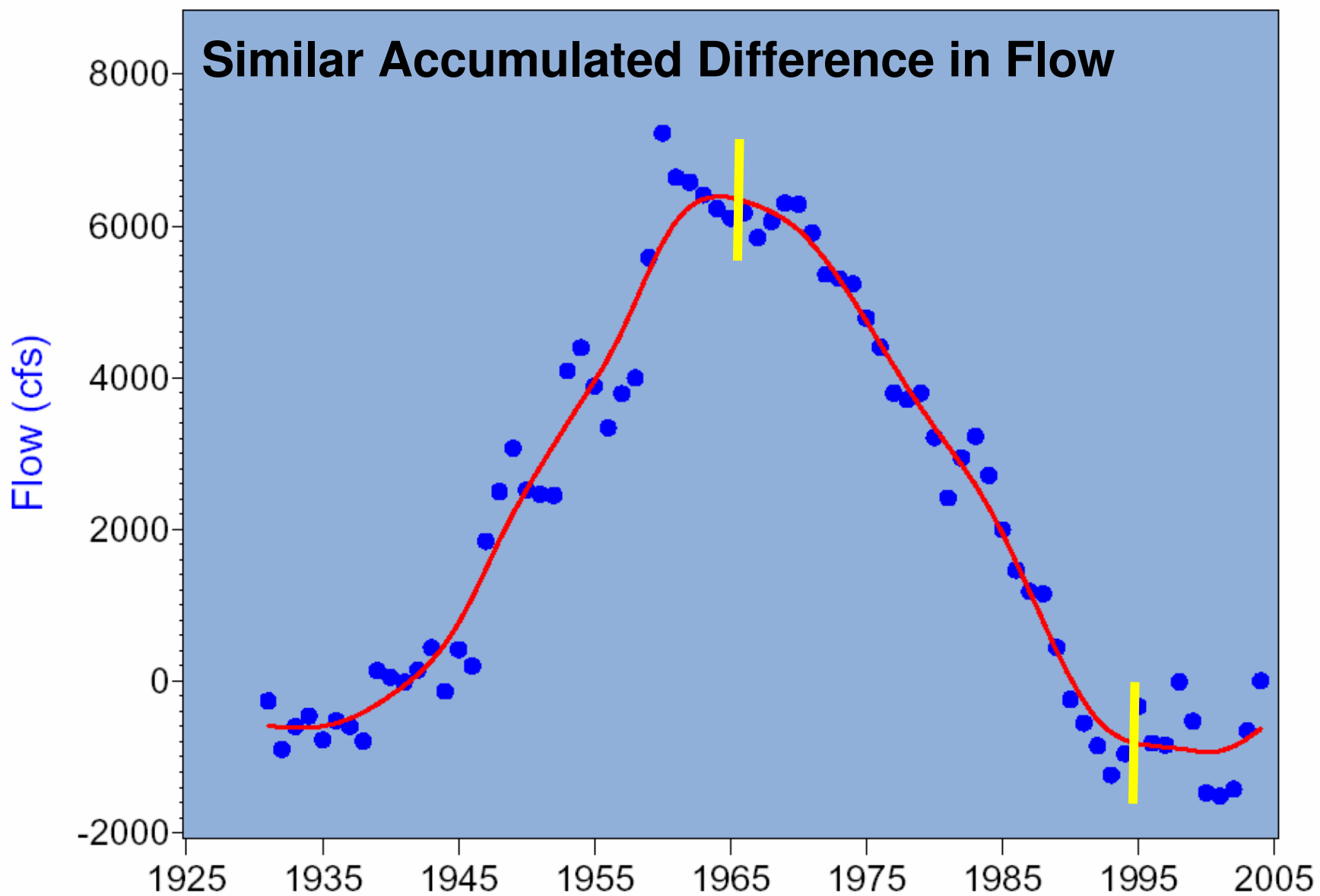


Long-term cumulative annual wet-season rainfall above 34.5 inches of Bartow, Arcadia and Punta Gorda average rainfall (1915-2004)

Flow and Rainfall Relationships

- Comparisons of Flows to Those Observed for Rainfall





Long-term cumulative Peace River at Arcadia flow over 1084 cfs (1932-2004)

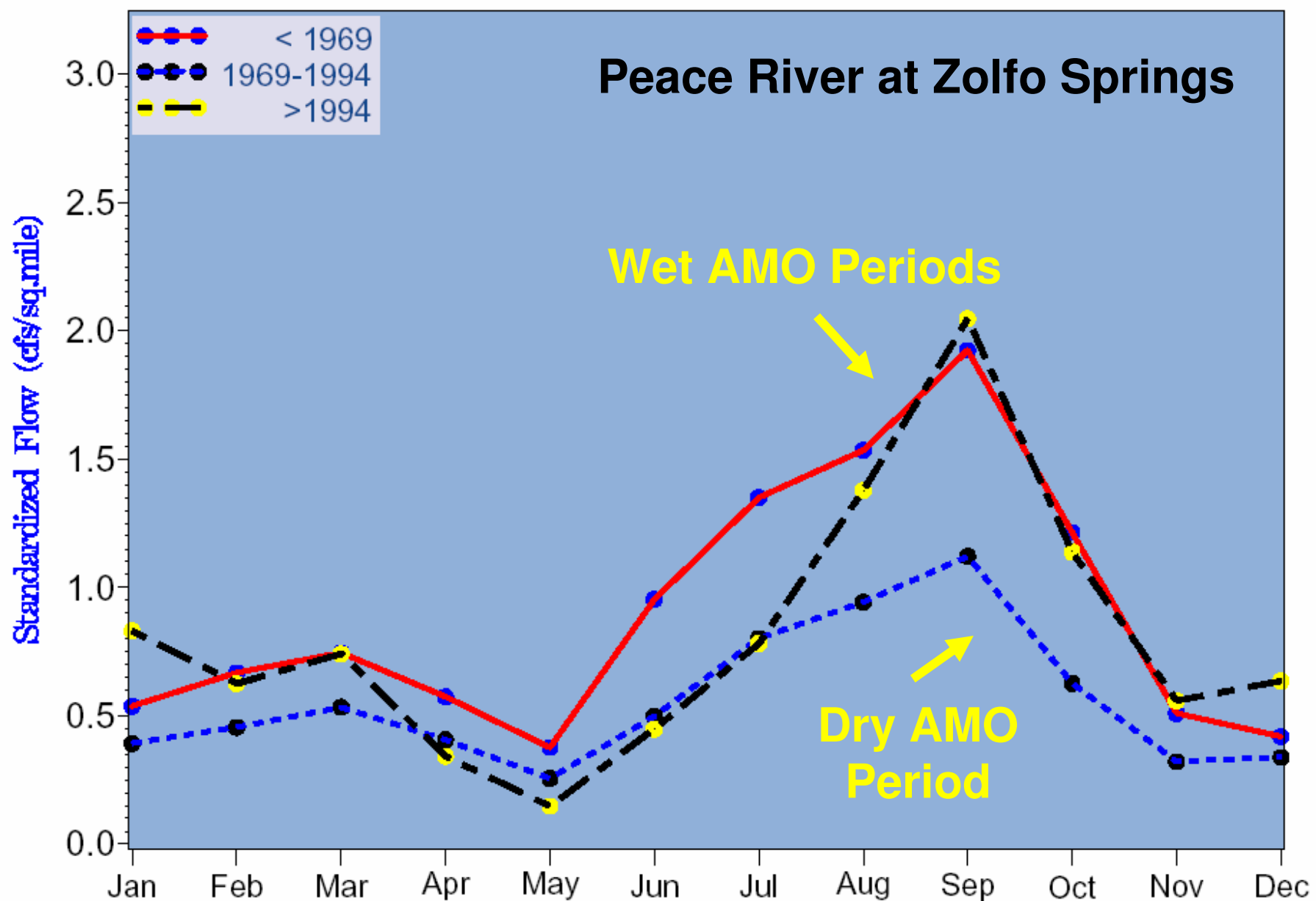


Figure D363. Seasonal differences among AMO periods of monthly mean flow at long-term Peace River at Zolfo (2295637) gage

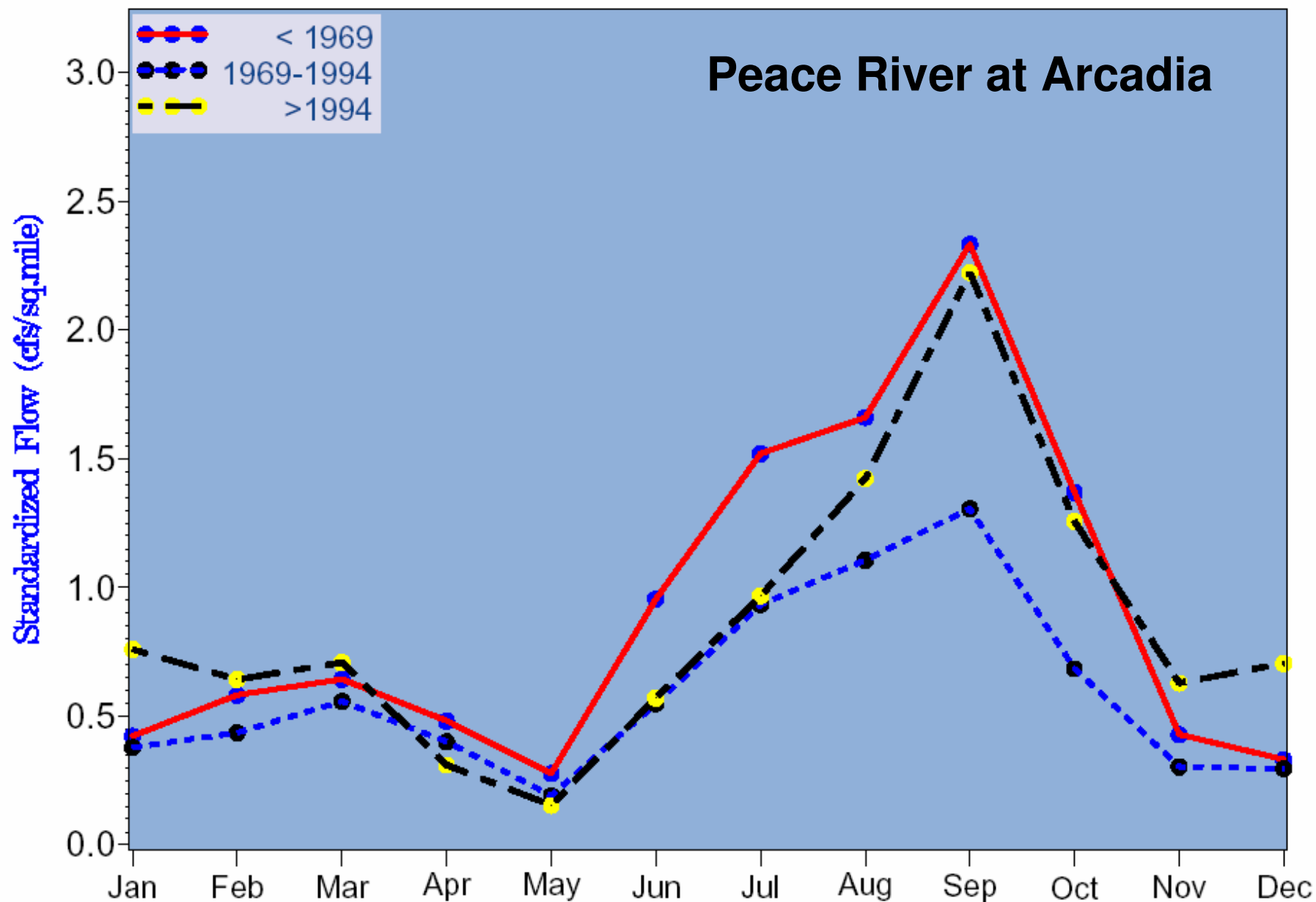


Figure D365. Seasonal differences among AMO periods of monthly mean flow at long-term Peace River at Arcadia (2296750) gage

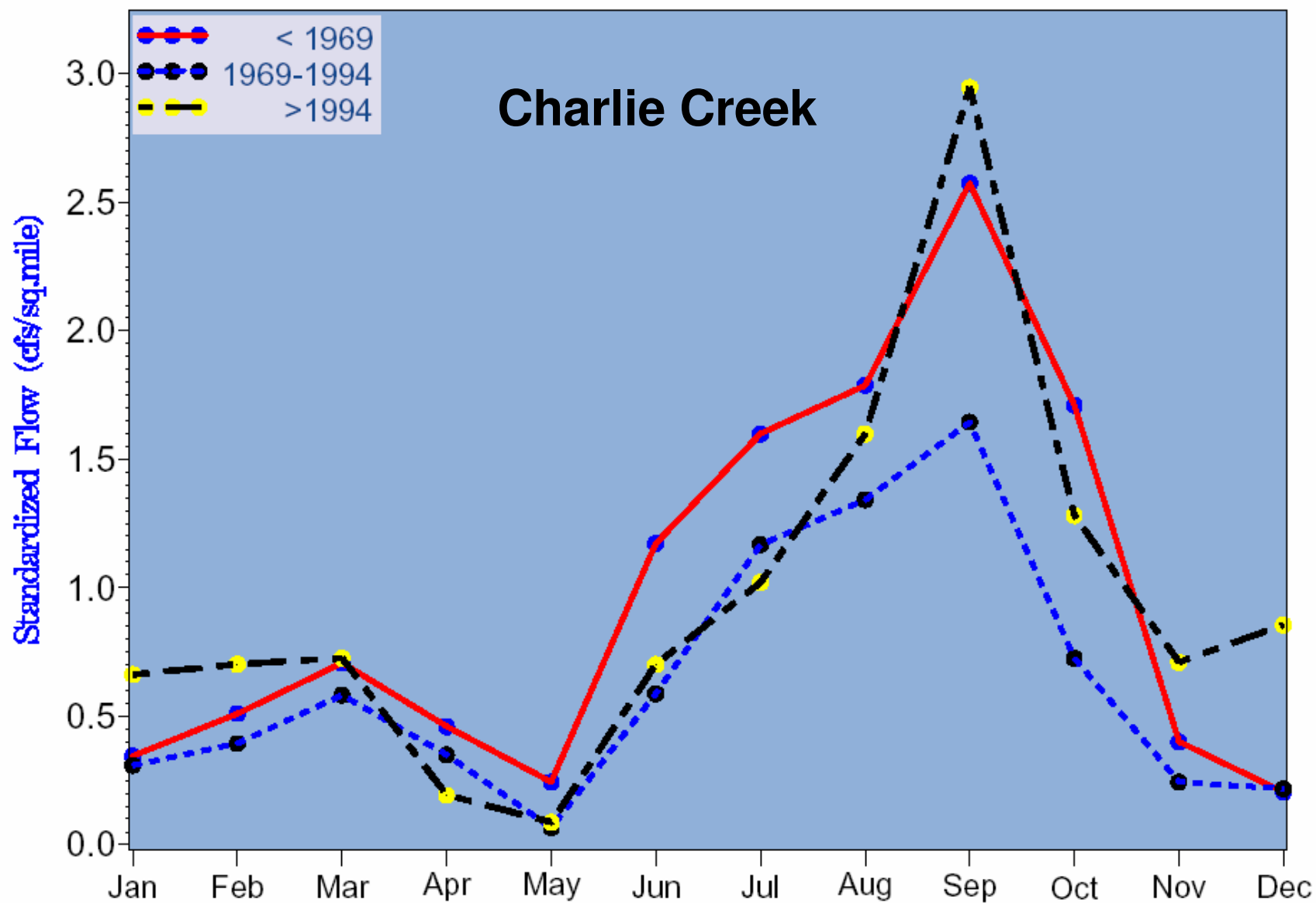


Figure D364. Seasonal differences among AMO periods of monthly mean flow at long-term Charlie Creek (2296500) gage

Withlacoochee River at Croom

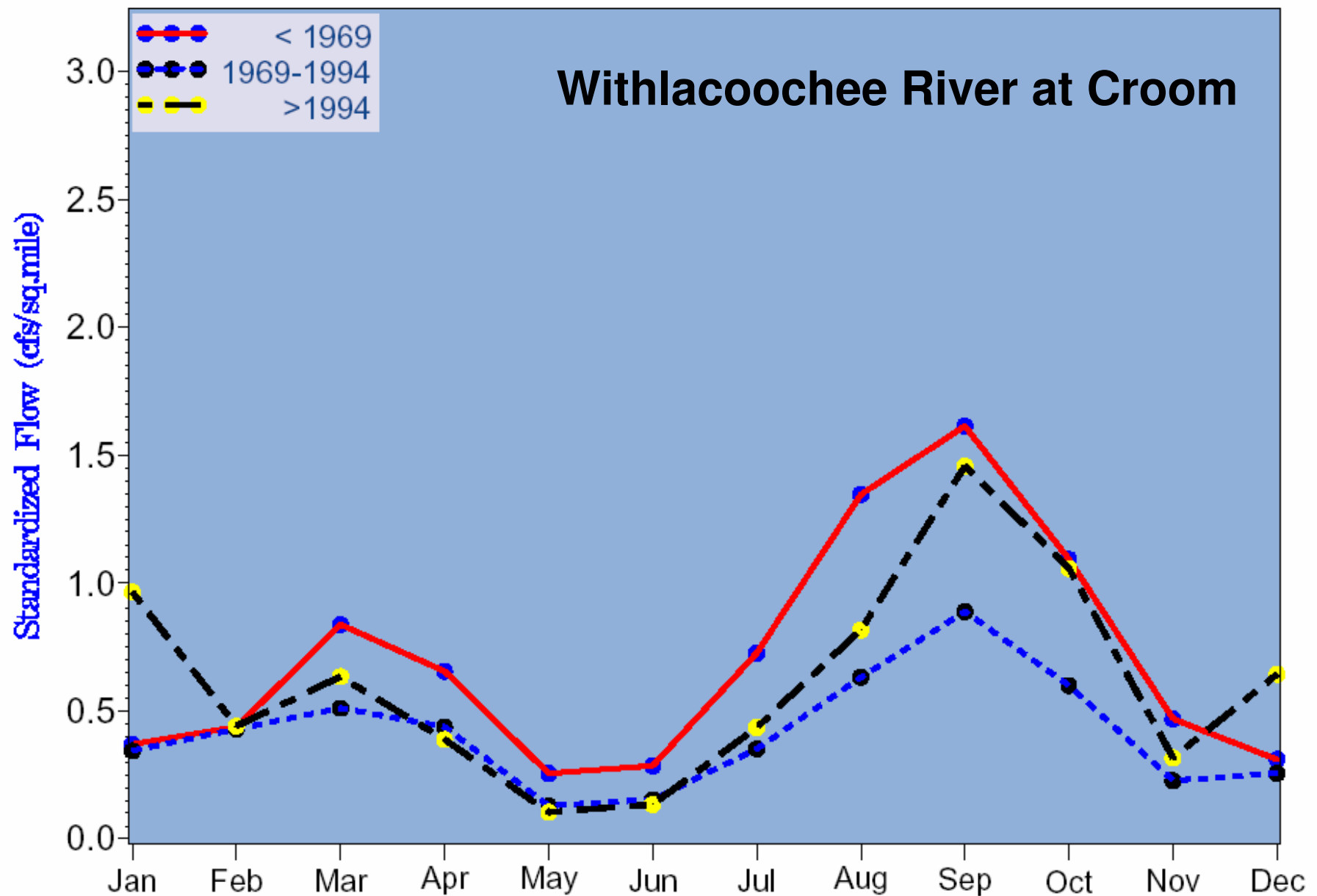
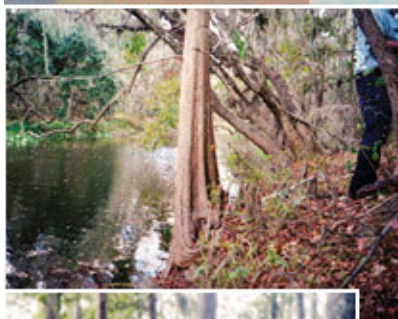


Figure D373. Seasonal differences among AMO periods of monthly mean flow at Withlacoochee River at Croom (2300500) gage

Summary & Conclusions

- There have been changes in long-term rainfall patterns in the Peace River Watershed
- These changes have been slightly less in the lower coastal watersheds
- The observed changes in rainfall (and flow) seem to be accounted for by the recently proposed AMO theory



Summary & Conclusions

- Small increases/decreases in rainfall can result in much larger changes in observed runoff (flow)
- This is especially true when as observed the changes (+/-) primarily occur during the wet-season
- A very large amount of the observed long-term variations in mean/median/higher flows can be explained by observed natural variations in rainfall (AMO)



Summary & Conclusions

- **There have been significant long-term changes in low/base flow not related to rainfall patterns**
 - **Upper watershed declines in low flows (dry-season) have been caused by loss of spring flows and declines in groundwater levels**
 - **Lower watershed subbasins (Horse, Joshua, Shell and Prairie Creeks) increases directly related to agricultural groundwater discharges during the dry-season**

