



ENGINEERING PRESENTATION ON CONSERVATION WITHIN DISTRICT

BY: HENDRIX WAI ENGINEERING, INC.

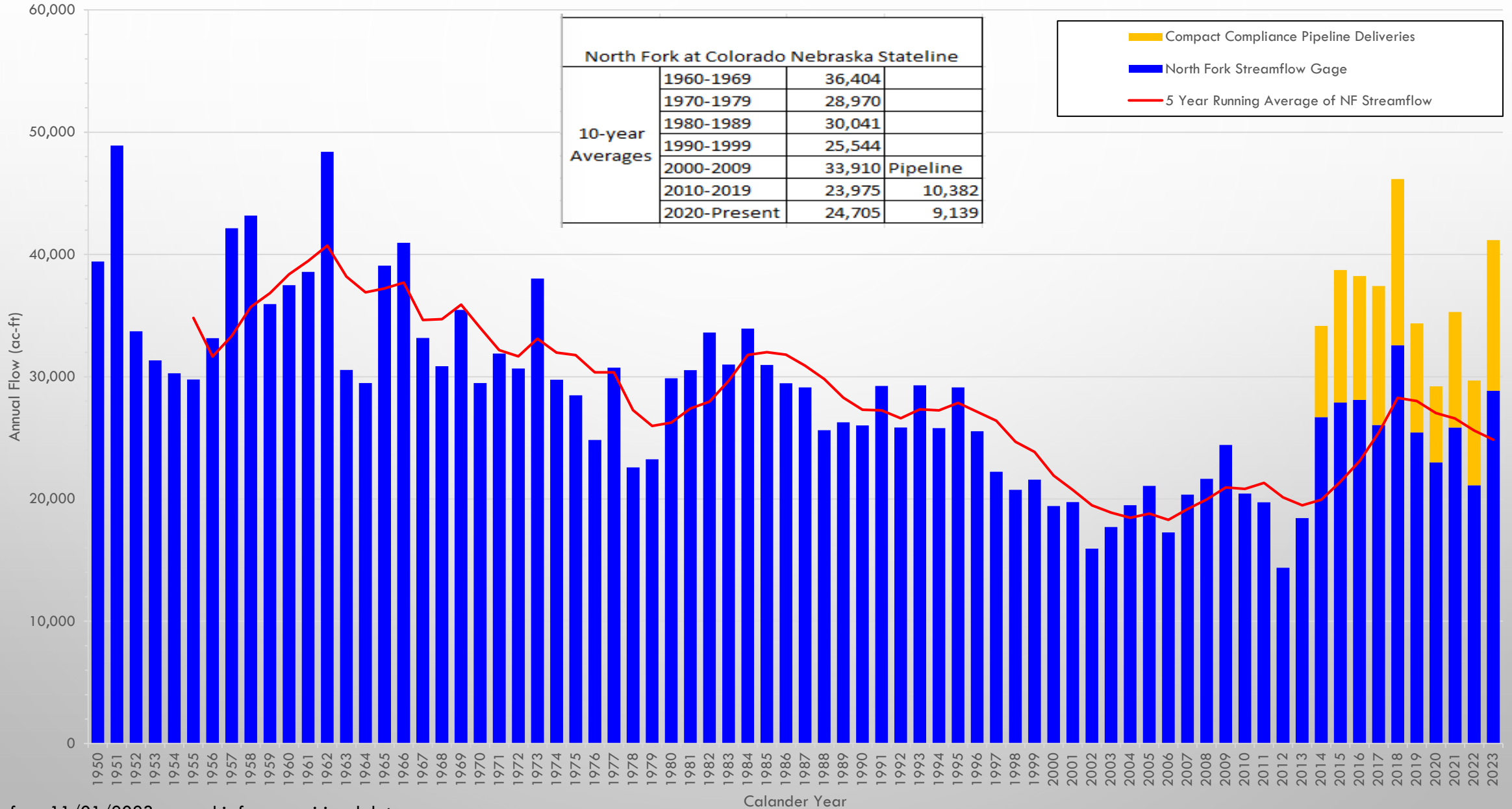
MARCH 22, 2024

TOPICS COVERED WITHIN PRESENTATION

- WHY CONSERVATION IS IMPORTANT TO THE RRWCD
- ASSUMPTIONS USED IN CONSERVATION ANALYSIS
- STUDY PERIOD
- ANNUAL PUMPING
- TRANSMISSIVITY
- AQUIFER INFLOWS
- AQUIFER OUTFLOWS
- GROUNDWATER STORAGE LOSS
- CHANGE IN GROUNDWATER LEVELS
- ESTIMATED AQUIFER CAPACITY
- RRWCD ANNUAL PUMPING WITH CONSERVATION
- CONCLUSIONS

North Fork Republican at Colorado-Nebraska Stateline

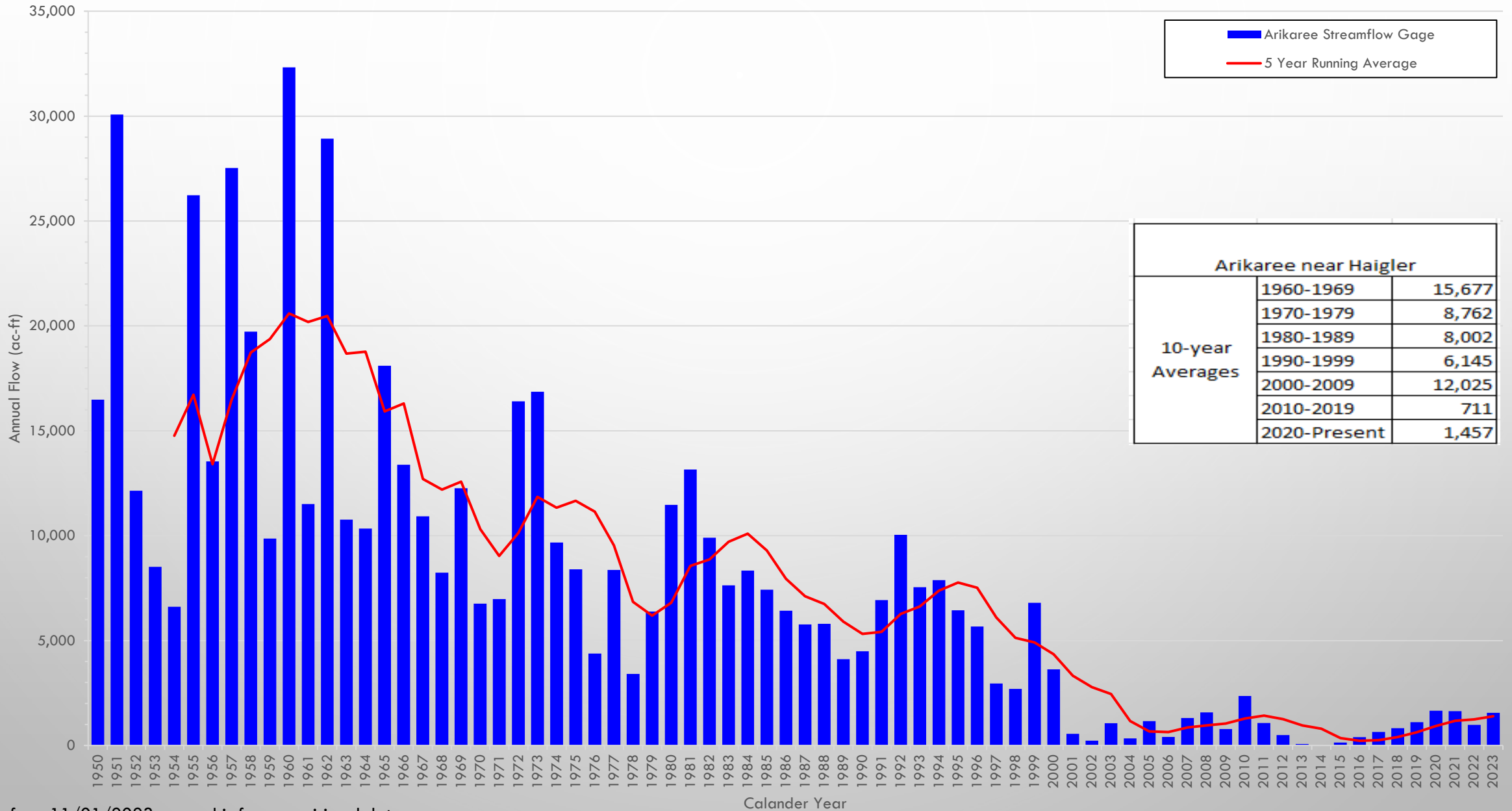
22.4% of Flow Allocated to Colorado



Note: Data from 11/01/2023 onward is from provisional data

Arikaree River at Haigler, Nebraska Gage

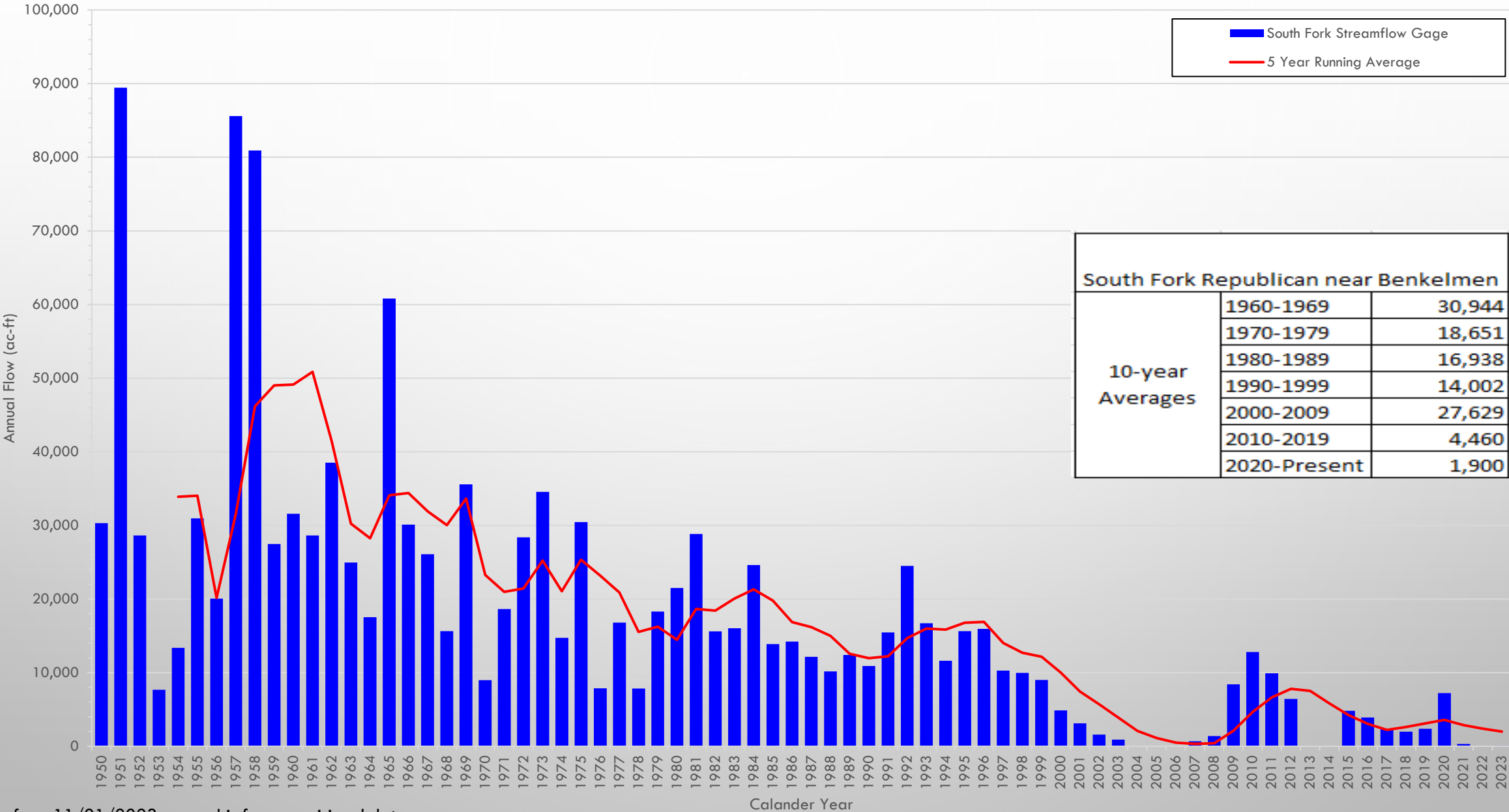
78.5% of Flow Allocated to Colorado



Note: Data from 11/01/2023 onward is from provisional data

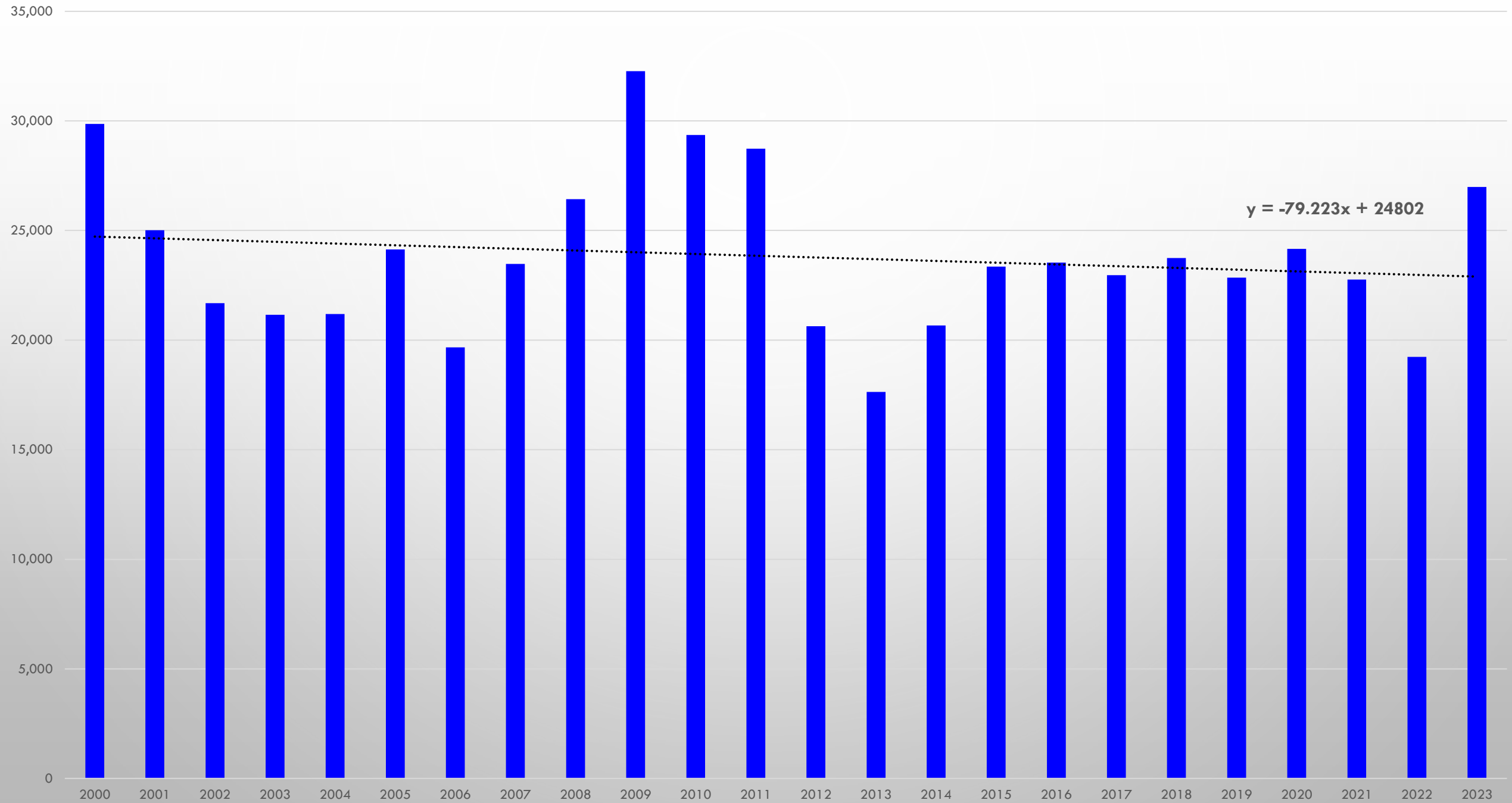
South Fork Republican near Benklman, Nebraska Gage

44.4% of Flow Allocated to Colorado



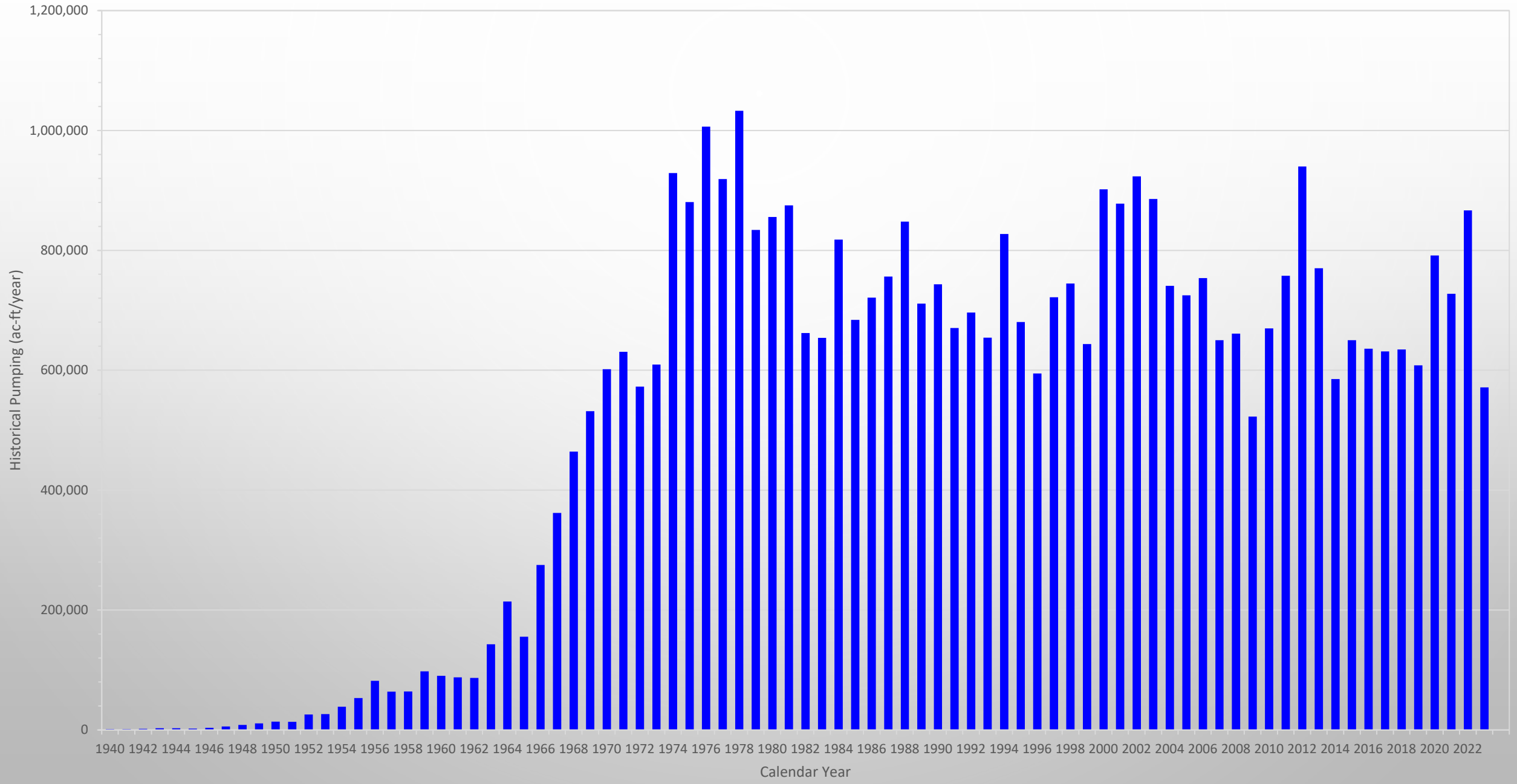
Note: Data from 11/01/2023 onward is from provisional data

Colorado's RRCA Allocation

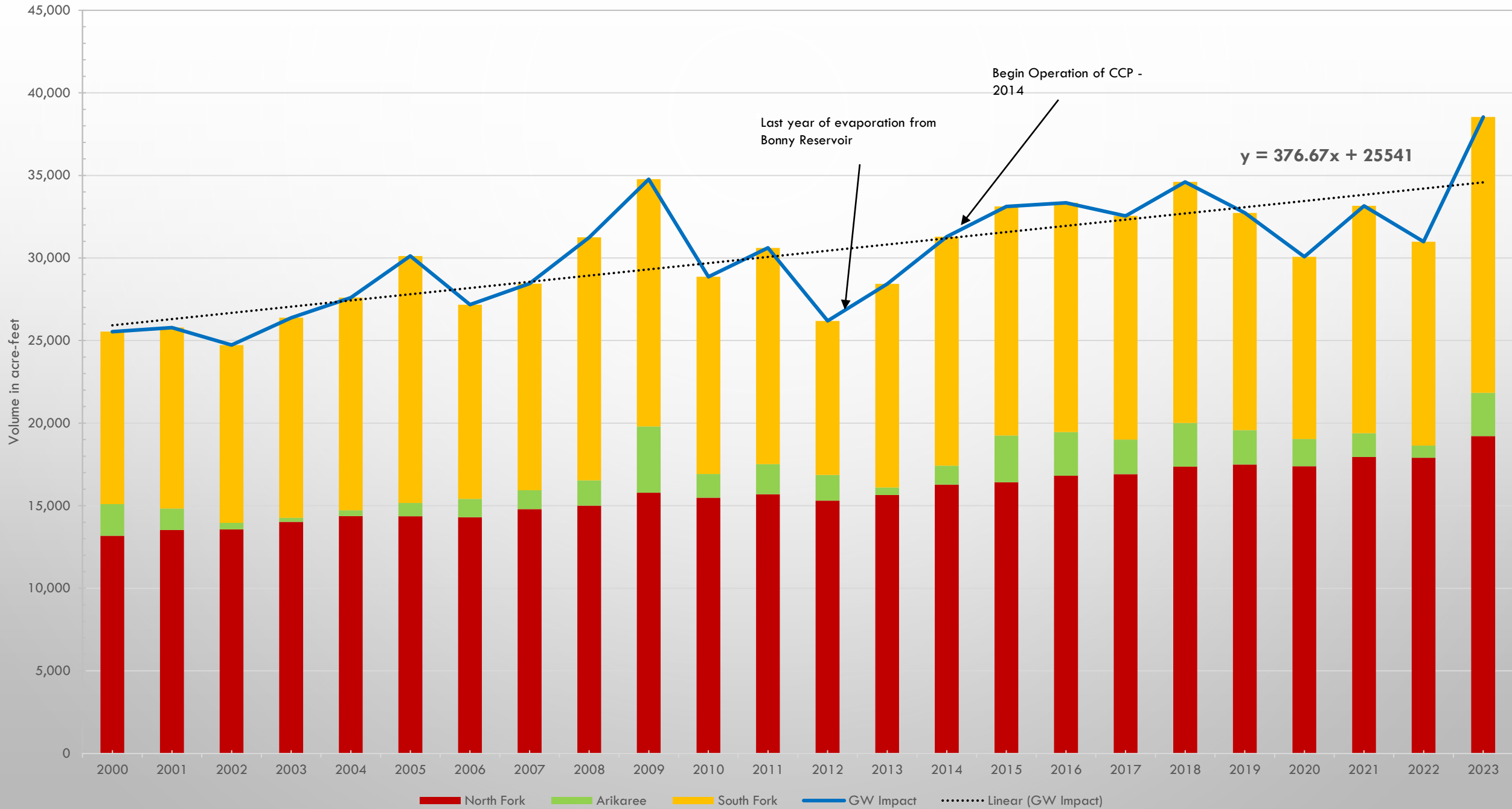


Historical Irrigation Pumping in Colorado

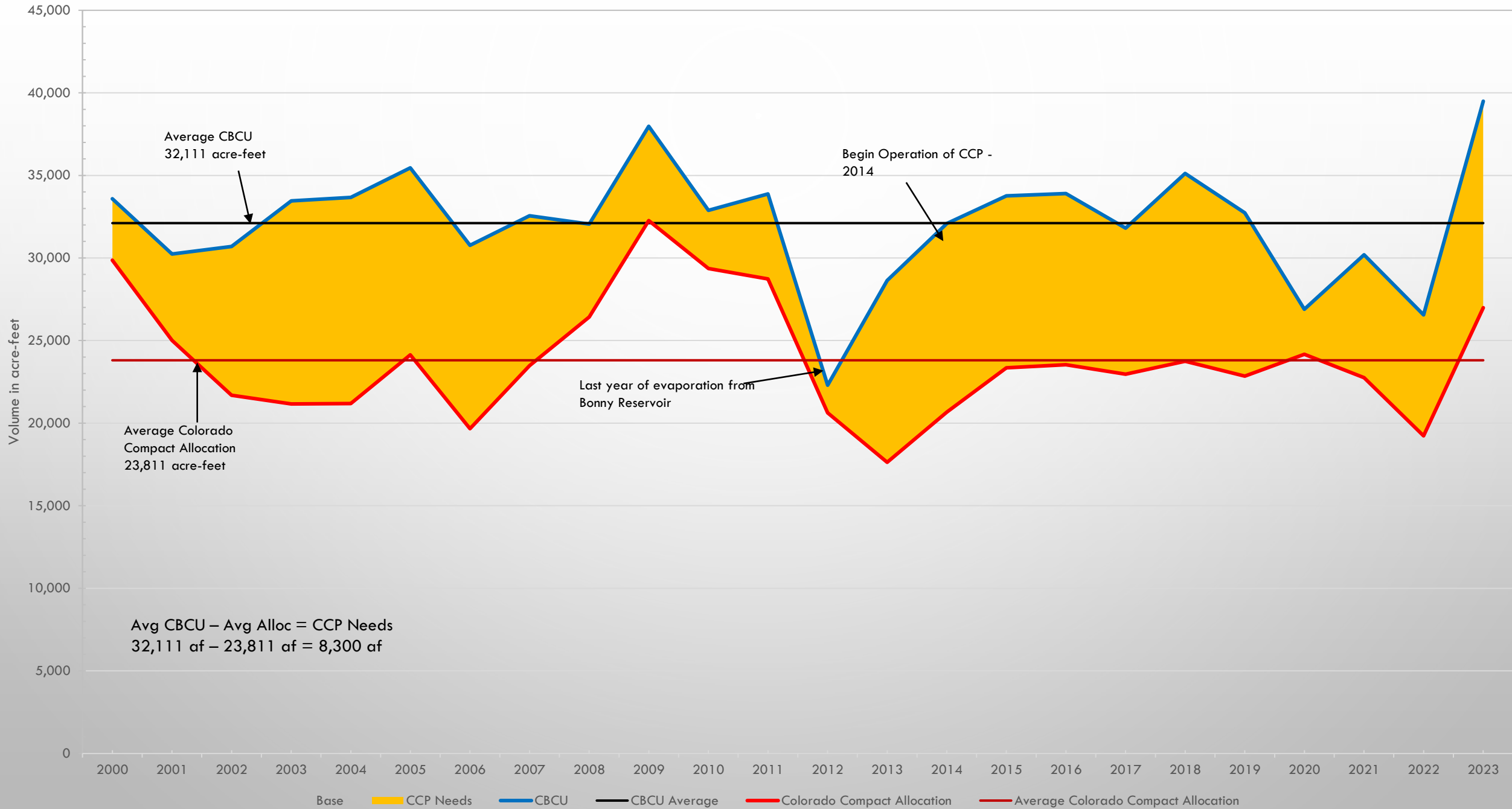
within RRCA Model Domain



Colorado's Groundwater Impacts to CBCU - 2000 to 2023

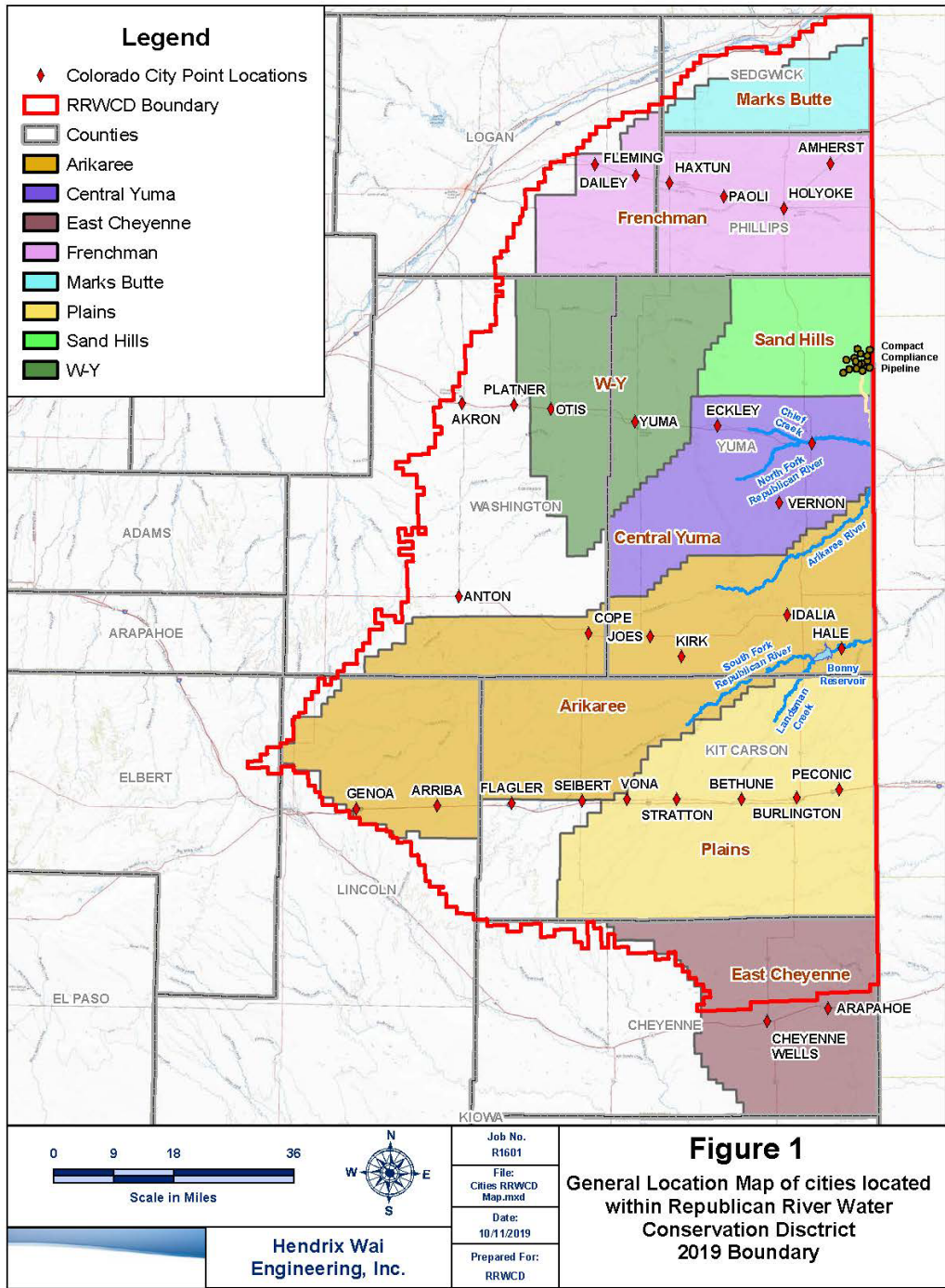


Total Computed Beneficial CU versus Colorado Allocation - 2000 to 2023



ASSUMPTIONS USED IN ANALYSIS

- ALL ASSUMPTIONS, INPUTS AND PARAMETERS THAT ARE A PART OF THE REPUBLICAN RIVER GROUNDWATER MODEL (GW MODEL).
- LIMITED OUTPUT FROM THE GW MODEL FROM 1960 TO 2021.
- INCORPORATED THE WATER BALANCE PERIOD OF 2002 TO 2021 THAT HAS BEEN USED IN PREVIOUS ANALYSES FOR THE DISTRICT.
- THE RRWCD AREA WAS 5,632,640 ACRES. INDIVIDUAL GROUNDWATER MANAGEMENT DISTRICTS OBVIOUSLY WOULD HAVE DIFFERENT AREAS.
- SPECIFIC YIELD FOR GROUNDWATER LEVELS OF 0.175 INCHES PER INCH. THIS SPECIFIC YIELD HAS BEEN USED IN PREVIOUS WATER BALANCE ANALYSES.



ACREAGES

- CALCULATED AREA USING ARCGIS SOFTWARE:
 - RRWCD
 - TOTAL ACRES WITHIN THE RRWCD – 5,632,640 ACRES
 - TOTAL ACRES IRRIGATED WITHIN THE RRWCD – 531,959 ACRES
 - ARIKAREE GWMD
 - TOTAL ACRES WITHIN ARIKAREE – 1,386,240 ACRES
 - TOTAL ACRES IRRIGATED WITHIN ARIKAREE – 75,526 ACRES
 - CENTRAL YUMA GWMD
 - TOTAL ACRES WITHIN CENTRAL YUMA – 499,840 ACRES
 - TOTAL ACRES IRRIGATED WITHIN CENTRAL YUMA – 68,156 ACRES

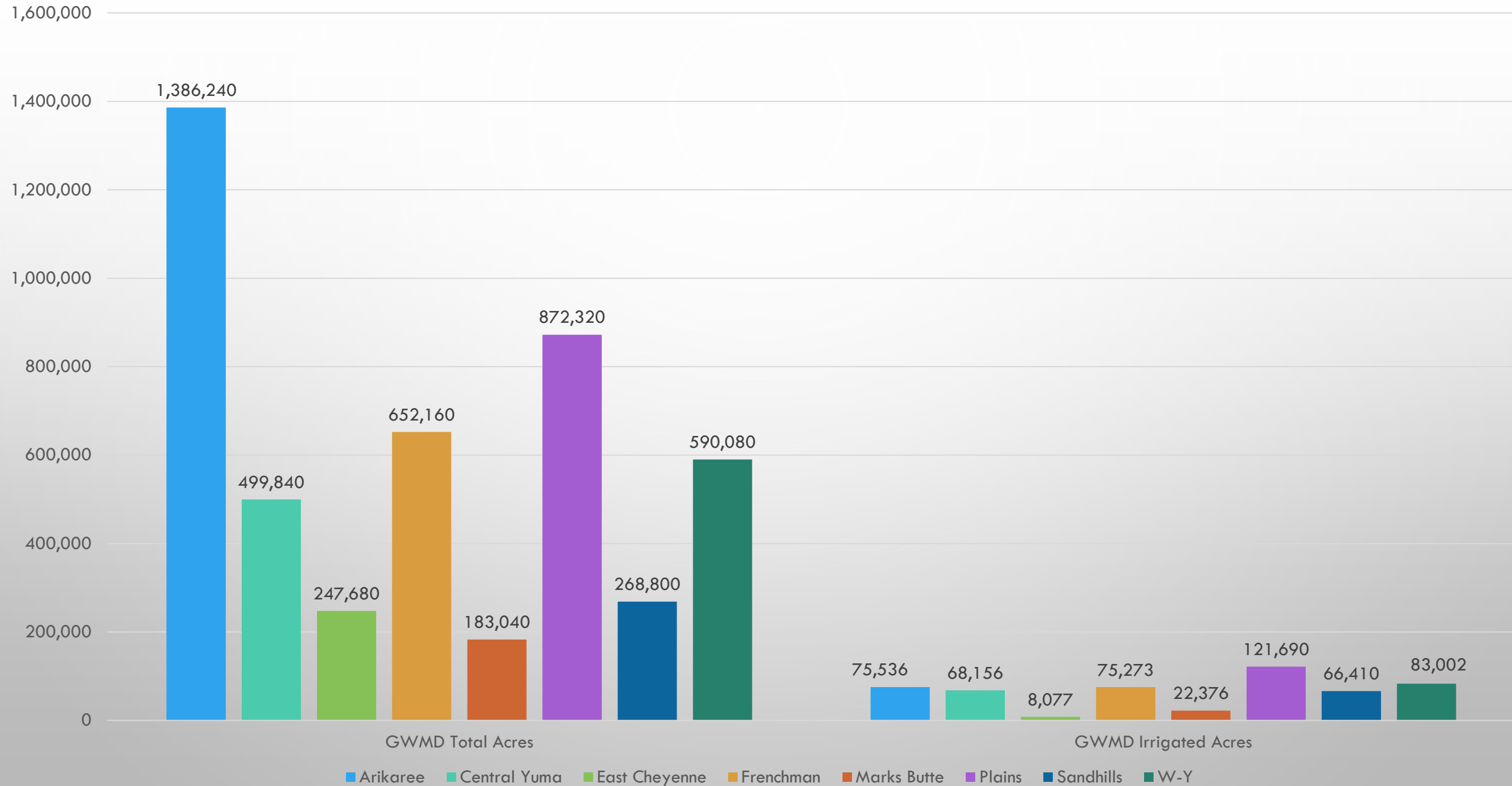
ACREAGES

- CALCULATED AREA USING ARCGIS SOFTWARE:
 - EAST CHEYENNE GWMD (WITHIN RRWCD)
 - TOTAL ACRES WITHIN E. CHEYENNE – 247,680 ACRES
 - TOTAL IRRIGATED ACRES WITHIN E. CHEYENNE – 8,077 ACRES
 - FRENCHMAN GWMD
 - TOTAL ACRES WITHIN FRENCHMAN – 652,160 ACRES
 - TOTAL IRRIGATED ACRES WITHIN FRENCHMAN – 75,273 ACRES
 - MARKS BUTTE GWMD
 - TOTAL ACRES WITHIN MARKS BUTTE – 183,040 ACRES
 - TOTAL IRRIGATED ACRES WITHIN MARKS BUTTE – 22,376 ACRES

ACREAGES

- CALCULATED AREA USING ARCGIS SOFTWARE:
 - PLAINS GWMD
 - TOTAL ACRES WITHIN PLAINS – 872,320 ACRES
 - TOTAL IRRIGATED ACRES WITHIN PLAINS – 121,690 ACRES
 - SANDHILLS GWMD
 - TOTAL ACRES WITHIN SANDHILLS – 268,800 ACRES
 - TOTAL IRRIGATED ACRES WITHIN SANDHILLS – 66,410 ACRES
 - W-Y GWMD
 - TOTAL ACRES WITHIN W-Y – 590,080 ACRES
 - TOTAL IRRIGATED ACRES WITHIN W-Y – 83,002 ACRES

GWMDs Area in Acres



STUDY PERIOD

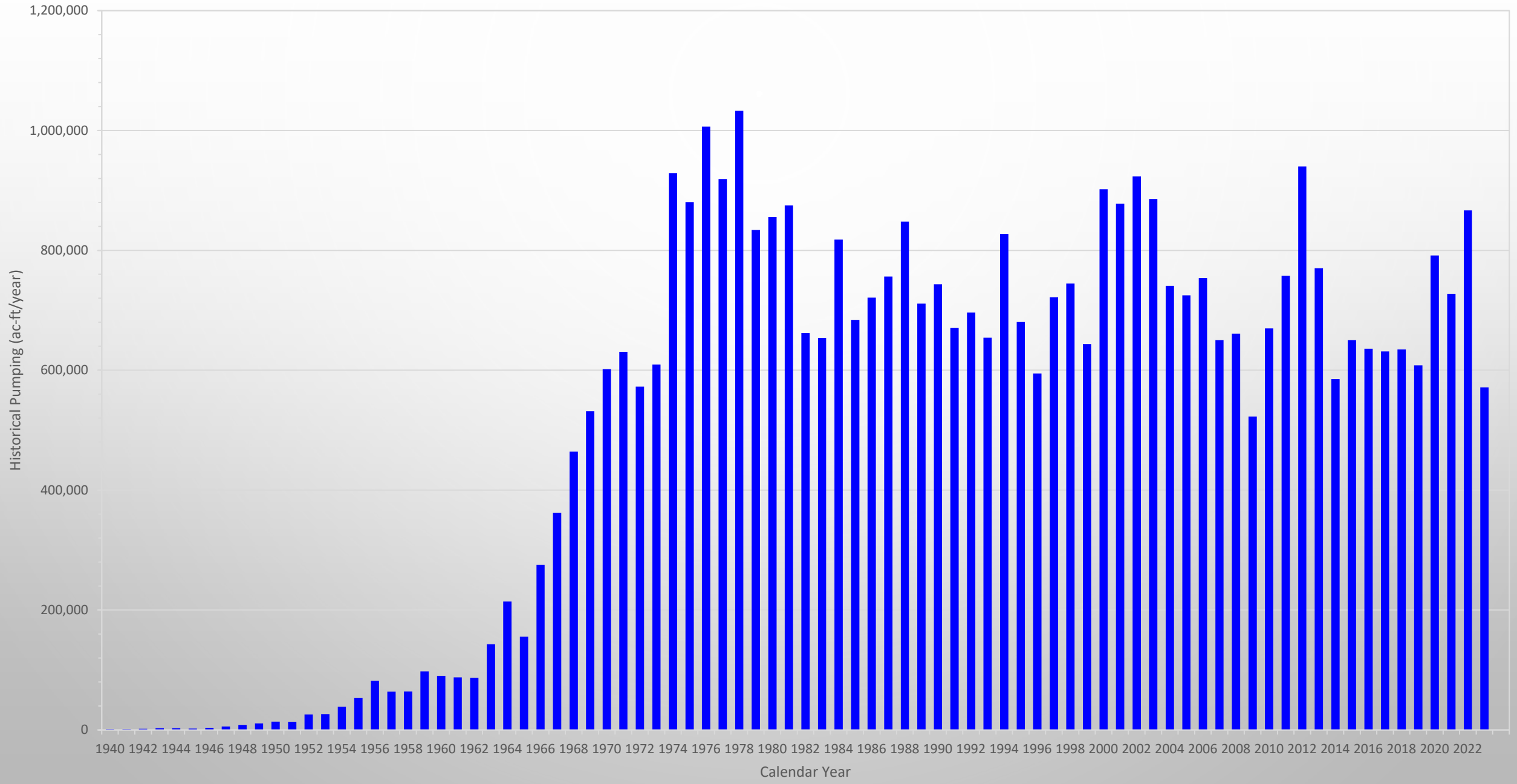
- STUDY PERIOD USED WITHIN ANALYSIS – 1960 TO 2022.
- REASONS TO THIS STUDY PERIOD:
 - 2023 GROUNDWATER MODEL RUNS ARE NOT YET FINALIZED
 - 1960 WAS THE FIRST YEAR USED IN WORK PREVIOUSLY PROVIDED TO THE DISTRICT IN THE “STATE OF THE BASIN – COMPACT COMPLIANCE AND HISTORICAL WATER BALANCE” PRESENTATION MARCH 14, 2014.
 - CONSISTENT WITH THE “WATER BALANCE BY GROUNDWATER MANAGEMENT DISTRICTS FOR 1998 TO 2017” DATED JANUARY 7, 2019.
 - CONSISTENT WITH THE “WATER BALANCE BY GROUNDWATER MANAGEMENT DISTRICTS FOR 2002 TO 2021” DATED DECEMBER 5, 2022.
- COMPARATIVE WATER BALANCE PERIOD – 2002 TO 2021

RRWCD ANNUAL PUMPING

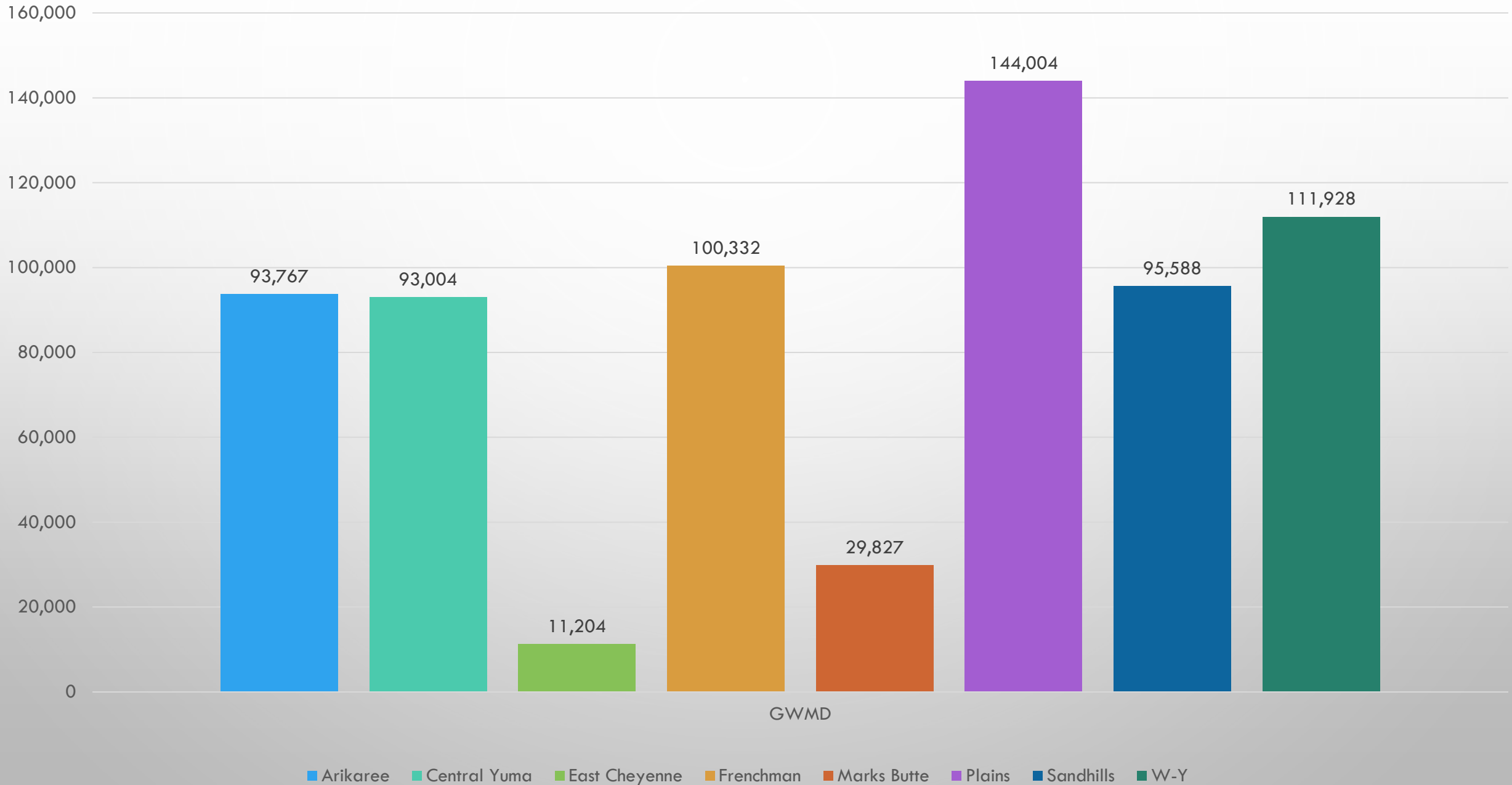
- PERIOD 1960 TO 2023
 - AVERAGE PUMPING = 663,608 ACRE-FEET
 - MAXIMUM PUMPING = 1,035,234 ACRE-FEET (1978)
- PERIOD 2004 TO 2023 (LAST 20 YEARS)
 - AVERAGE PUMPING = 694,671 ACRE-FEET
 - 15.67 INCHES PER ACRE OF APPLIED PUMPING
 - MAXIMUM PUMPING = 969,848 ACRE-FEET (2012)
 - MINIMUM PUMPING = 522,678 ACRE-FEET (2009)

Historical Irrigation Pumping in Colorado

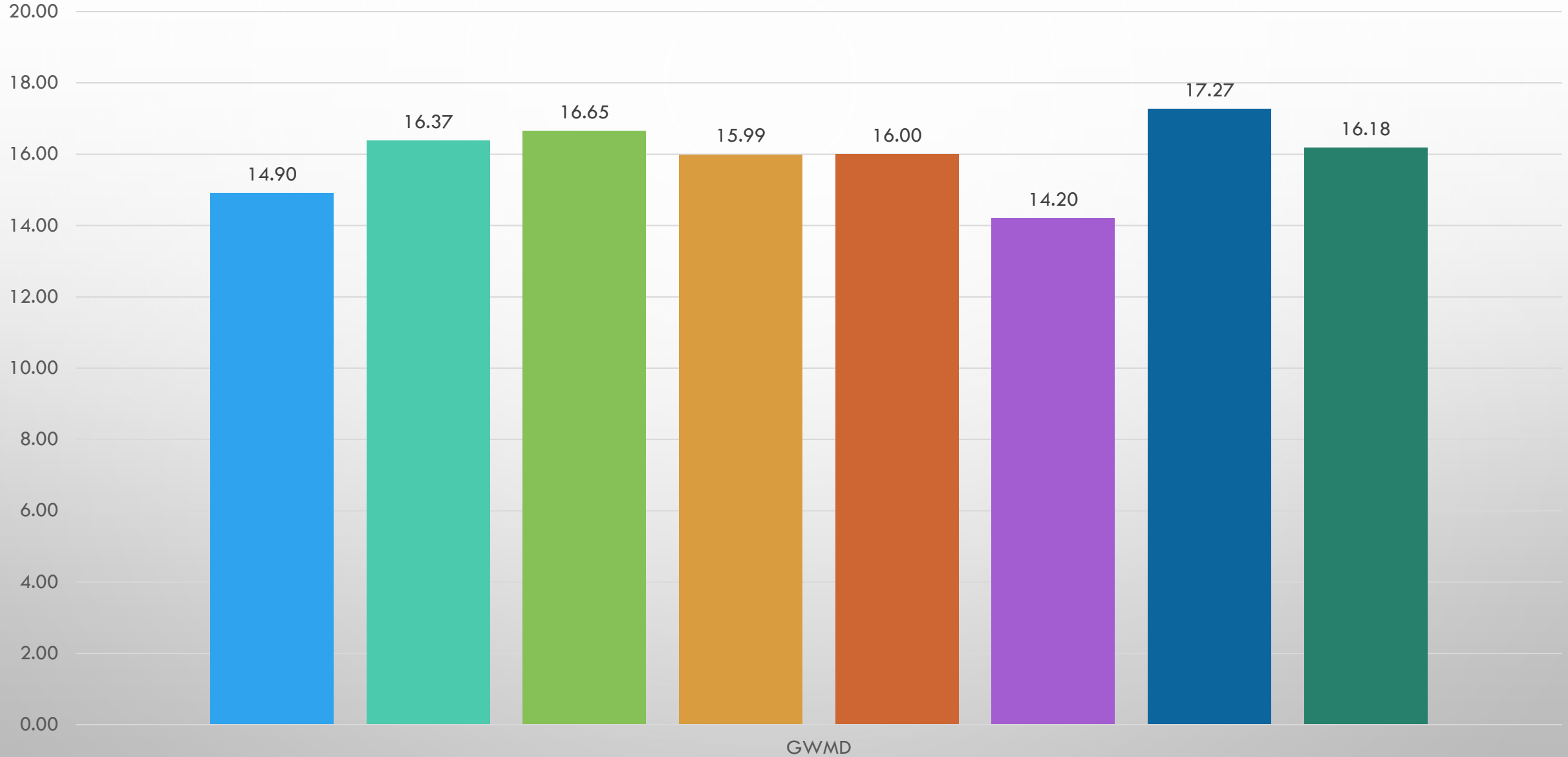
within RRCA Model Domain



Average 2004 to 2023 Pumping by GWMDs in Acre-Feet



Average 2004 to 2023 Pumping by GWMDs (Inches Applied per Acre)

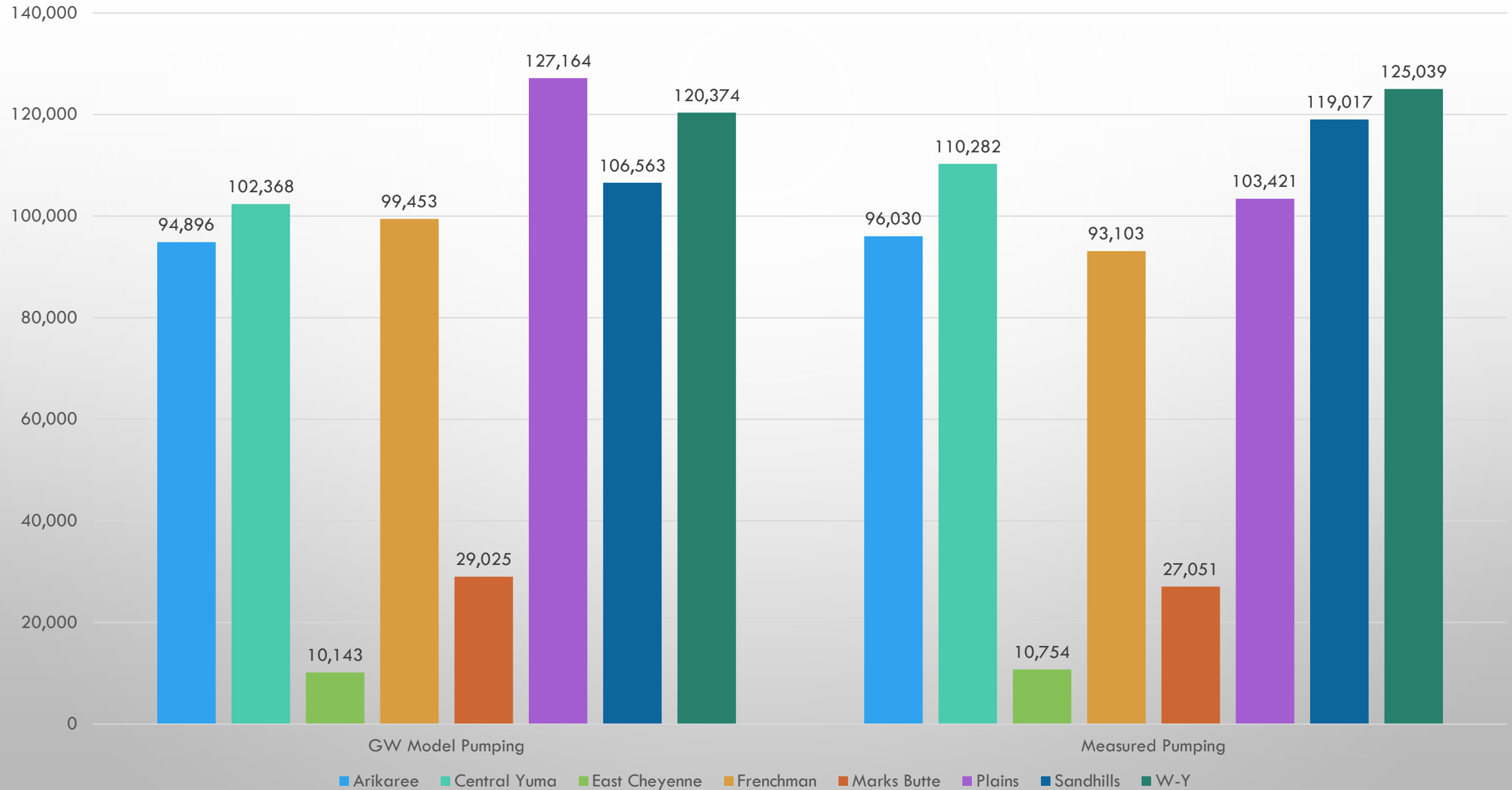


■ Arikaree ■ Central Yuma ■ East Cheyenne ■ Frenchman ■ Marks Butte ■ Plains ■ Sandhills ■ W-Y

RRWCD 2011 TO 2023 ANNUAL PUMPING

- MEASURED PUMPING – PERIOD 2011 TO 2023
 - AVERAGE PUMPING = 695,076 ACRE-FEET
 - MAXIMUM PUMPING = 921,081 ACRE-FEET (2012)
- IT SHOULD BE NOTED THAT EAST CHEYENNE GWMD MEASURED WELL PUMPING WAS UNAVAILABLE FROM 2011 TO 2015.
- GW MODEL PUMPING VS MEASURED PUMPING (DISTRICTWIDE AVERAGE) – PERIOD 2011 TO 2023
 - GW MODEL PUMPING – 705,410 ACRE-FEET
 - MEASURED PUMPING – 700,768 ACRE-FEET (THIS AVERAGE INCLUDES GW MODEL PUMPING FOR EAST CHEYENNE GWMD FOR THE MISSING YEARS)

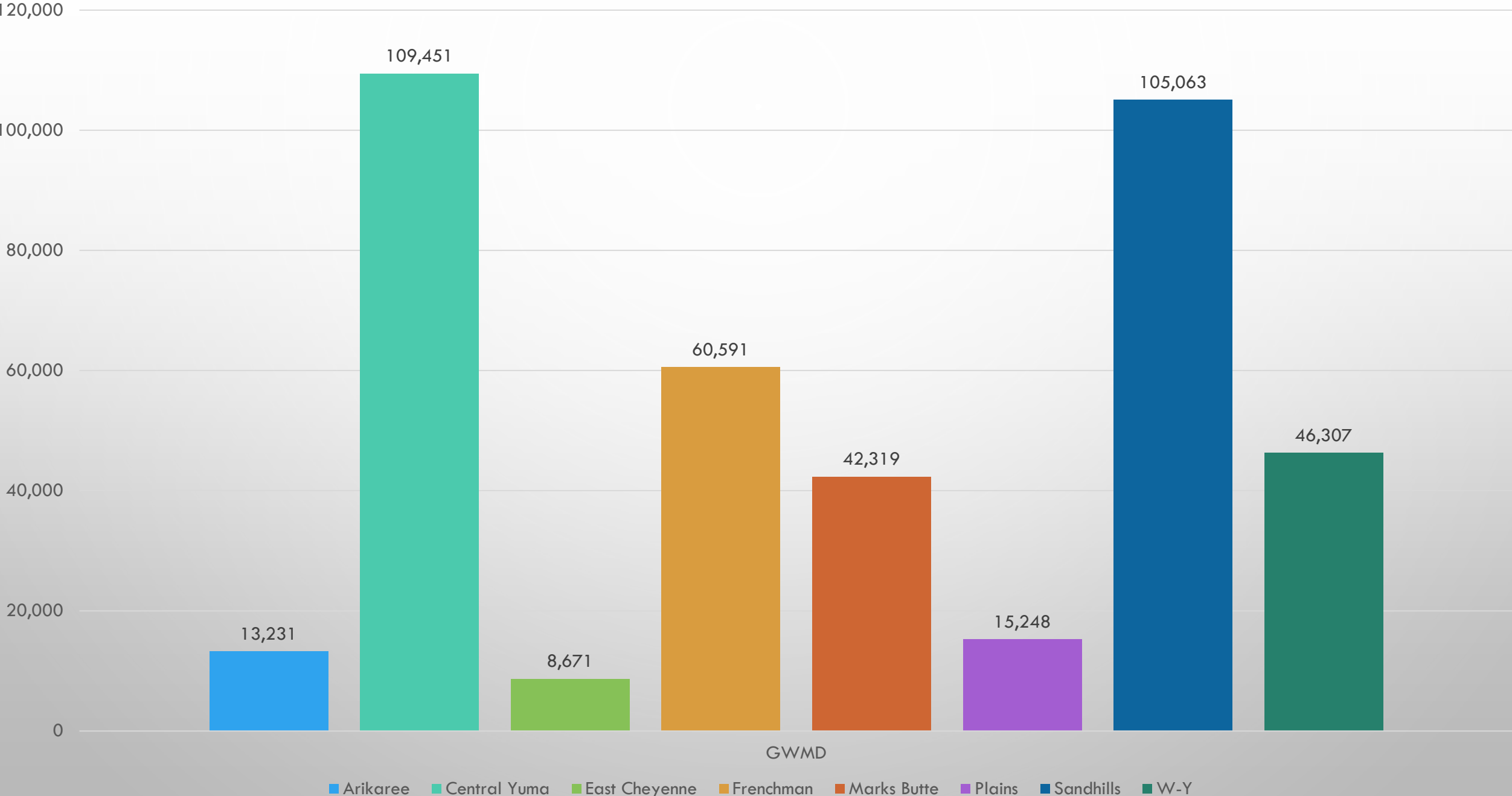
Comparison of 2011 to 2023 Pumping by GWMDs (ac-ft)



TRANSMISSIVITIES

- DEFINITION OF TRANSMISSIVITY: TRANSMISSIVITY IS AN INDEX OF THE RATE OF GROUNDWATER MOVEMENT COMMONLY REFERRED TO IN GALLONS PER DAY PER FOOT (GPD/FT).
- TRANSMISSIVITY WITHIN THE DISTRICT AND GWMDS WERE BASED ON TRANSMISSIVITIES USED WITHIN THE GW MODEL.
- WE REVIEWED VARIOUS PUMP TESTS WITHIN THE DISTRICT AND GWMDS THAT DERIVED TRANSMISSIVITIES AT WELLS WHERE PUMP TESTS WERE CONDUCTED AS AN ADDITIONAL SOURCE.
- TRANSMISSIVITY FOR A GWMD WAS BASED ON THE TRANSMISSIVITY AT THE CENTROID OF THE GWMD.
- THE DISTRICT'S AVERAGE TRANSMISSIVITY WAS CALCULATED AS THE AVERAGE OF THE TRANSMISSIVITIES AT THE CENTROID OF THE GWMDS.
- THE DISTRICT'S TRANSMISSIVITY WAS CALCULATED AS 50,110 GPD/FT.

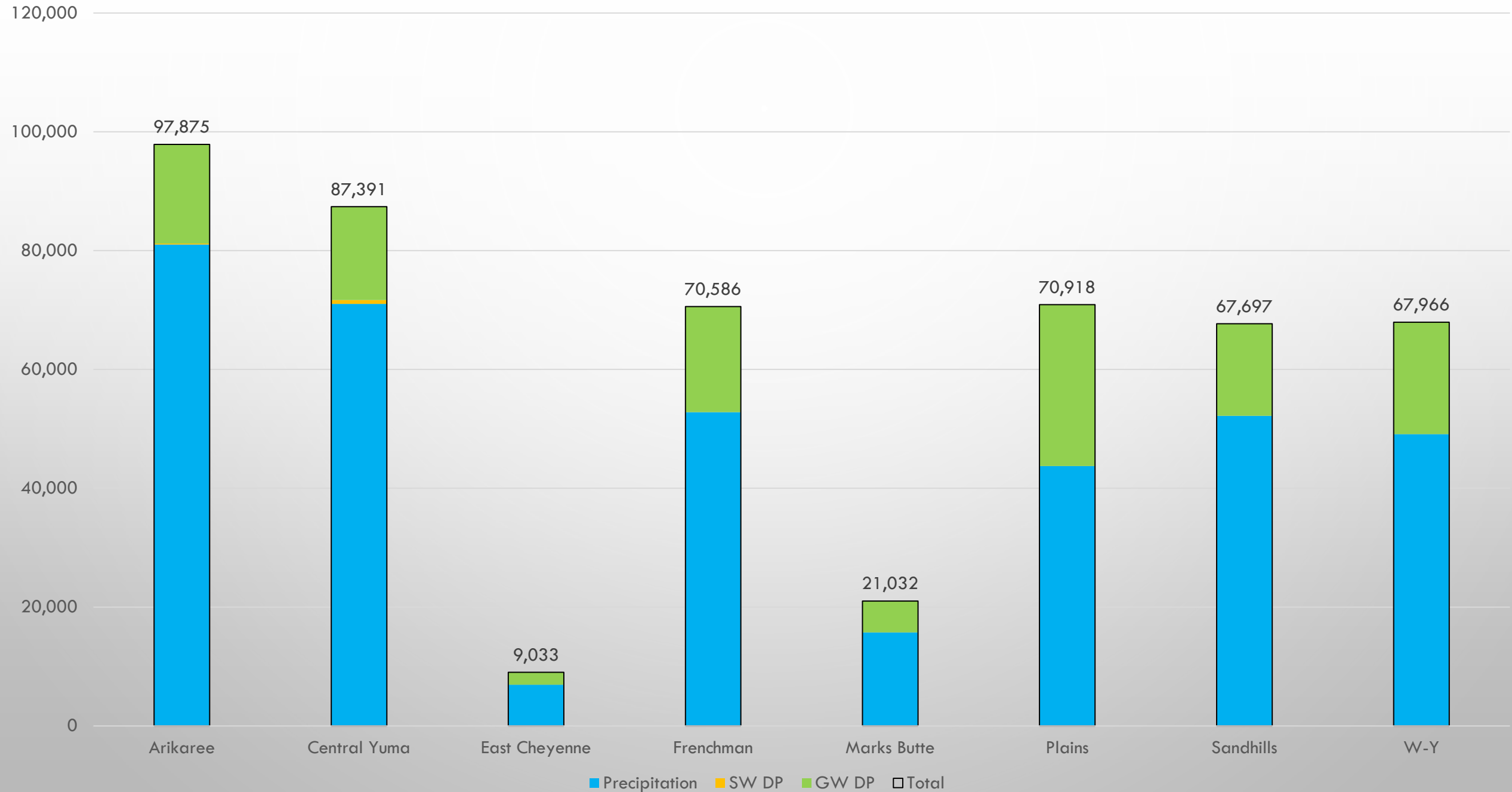
Centroid Transmissivity by GWMDs (gpd/ft)



AQUIFER INFLOWS

- PRECIPITATION
- DEEP PERCOLATION FROM IRRIGATION (WELL PUMPING AND SURFACE WATER DIVERSIONS)
 - SOME GWMDS DO NOT HAVE IRRIGATION CANAL SYSTEMS WITHIN THEIR GWMD THUS WOULD ONLY HAVE A DEEP PERCOLATION FROM WATER APPLIED TO THE FIELDS FROM WELL PUMPING.
- DEEP PERCOLATION FROM CANAL AND LATERAL LOSSES ASSOCIATED WITH IRRIGATION CANAL SYSTEMS.
 - SOME GWMDS DO NOT HAVE IRRIGATION CANAL SYSTEMS WITHIN THEIR GWMD THUS WOULD NOT HAVE ANY DEEP PERCOLATION FROM CANAL AND LATERAL LOSSES.
- IF PUMPING IS REDUCED, THEN THE AMOUNT OF INFLOW TO THE AQUIFER FROM DEEP PERCOLATION OF WATER APPLIED TO THE FIELDS WOULD ALSO BE REDUCED.
- 2002 TO 2021 AVERAGE DISTRICT AQUIFER INFLOWS – 546,627 ACRE-FEET
 - PRECIPITATION – 423,561 ACRE-FEET
 - SURFACE WATER SYSTEM DEEP PERCOLATION – 781 ACRE-FEET
 - GROUNDWATER PUMPING DEEP PERCOLATION – 122,285 ACRE-FEET

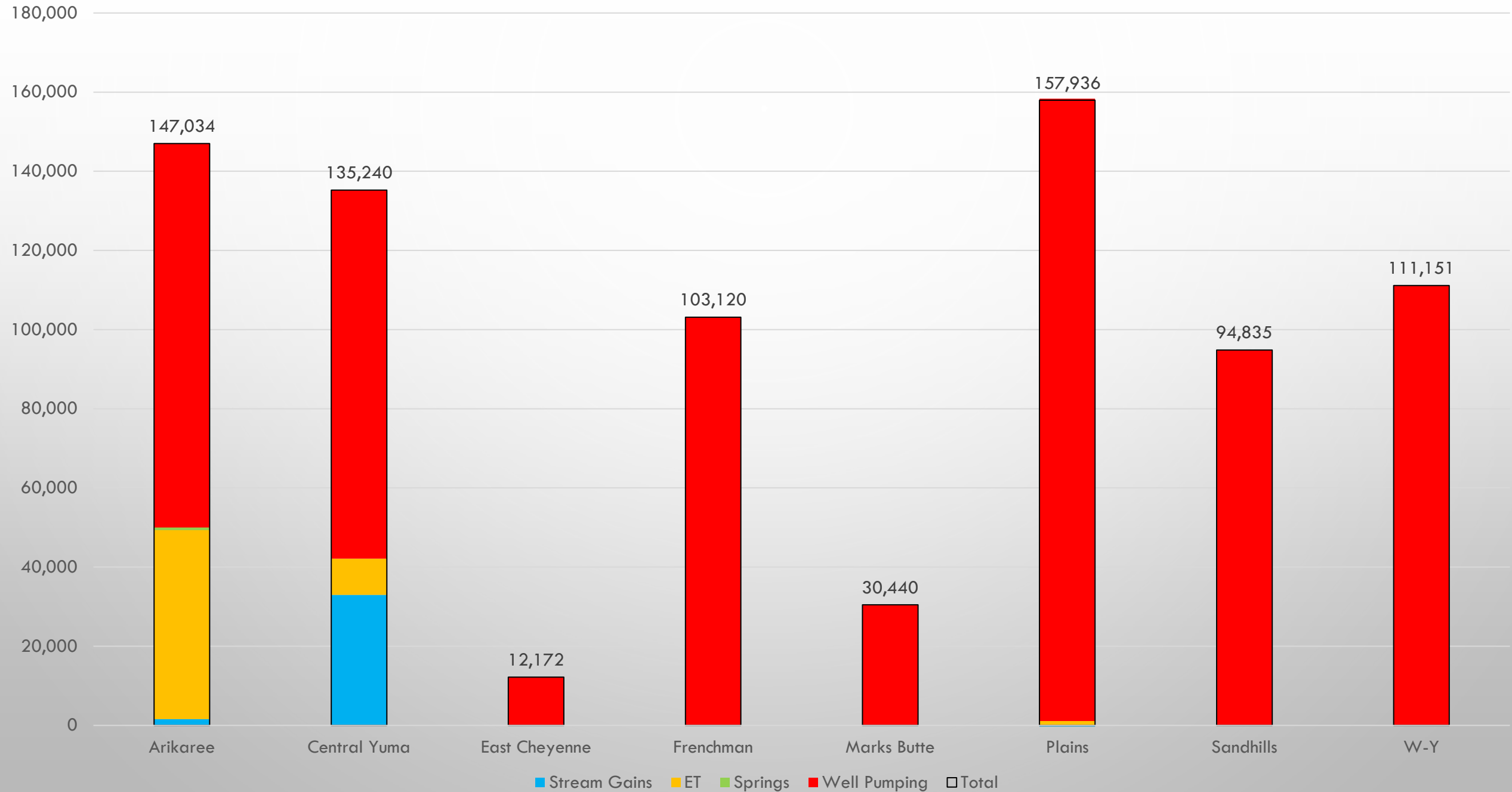
Aquifer Inflows by GWMDs (ac-ft)



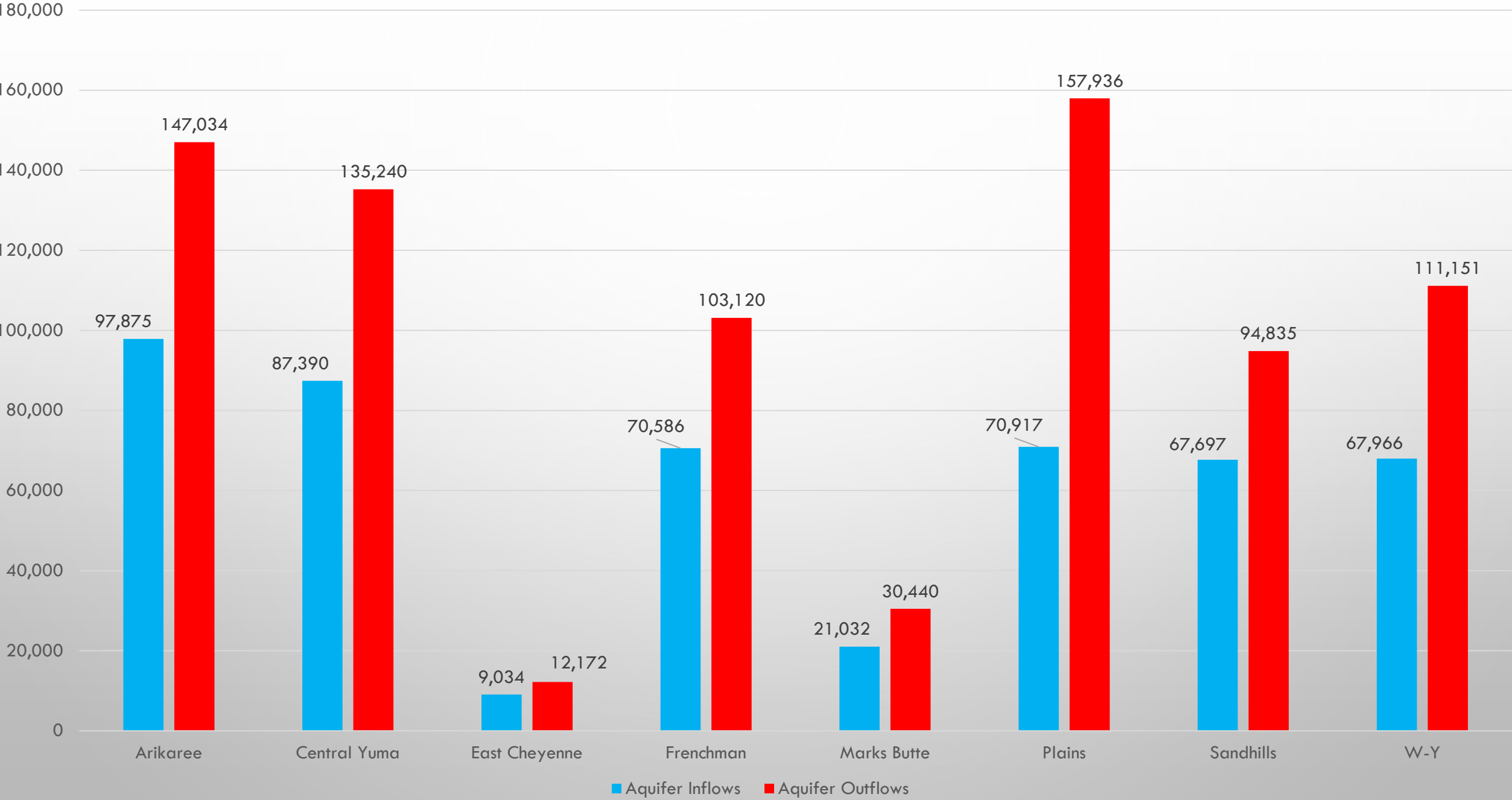
AQUIFER OUTFLOWS

- WELL PUMPING (LARGEST COMPONENT OF AQUIFER OUTFLOWS).
- GROUNDWATER TO A STREAM.
- EVAPORATION OF GROUNDWATER FROM THE SOIL.
- FLOW FROM A SPRING
- IF THE ABOVE AQUIFER OUTFLOWS EXCEED AQUIFER INFLOWS, THEN CHANGE IN AQUIFER STORAGE IS NEGATIVE.
- BOUNDARY UNDERFLOW.
 - CALCULATION OF BOUNDARY UNDERFLOW USES DARCY'S LAW ($Q=K * S * A$):
 - Q = FLOW IN AC-FT PER YEAR. (DISTRICT UNDERFLOW ESTIMATED AT 119,900 AC-FT/YR.),
 - K = HYDRAULIC CONDUCTIVITY IN FEET PER YEAR (DISTRICT K ESTIMATED AT 20,857 FT/YR.).
 - S = SLOPE OF THE HYDRAULIC GRADIENT IN FEET PER FEET (DISTRICT S ESTIMATED AT 0.00325 FT/FT).
 - A = CROSS SECTIONAL AREA THROUGH THE CENTROID IN FEET² (DISTRICT A ESTIMATED AT 1,770.8 AC).
- DIRECTION OF FLOW IS BASED ON GROUNDWATER CONTOURS BUT DOESN'T CHANGE WHERE COLORADO MUST MEET COMPACT COMPLIANCE.
- **ALL SUB DRAINAGES ARE INCLUDED IN THE COMPACT ACCOUNTING THUS ALL AREAS WITHIN THE DISTRICT PROVIDE AN IMPACT TO THE COMPACT ACCOUNTING.**

Aquifer Outflows by GWMDs (ac-ft)



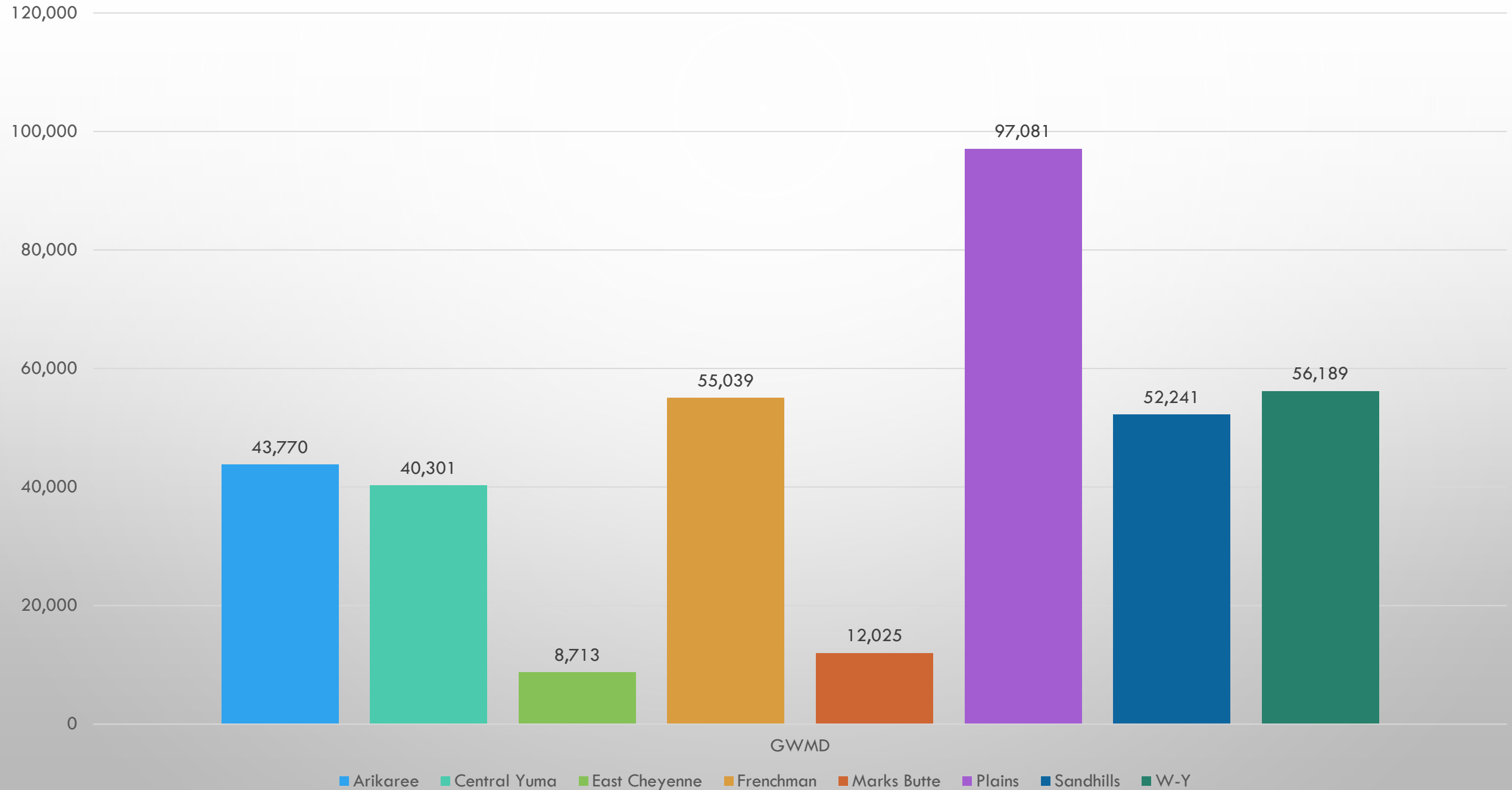
Aquifer Inflows vs. Aquifer Outflows (ac-ft)



GROUNDWATER STORAGE

- GROUNDWATER STORAGE LOSS OCCURS WHEN AQUIFER OUTFLOWS EXCEED AQUIFER INFLOWS.
 - MAXIMUM GROUNDWATER STORAGE LOSS OF 952,883 AC-FT IN 2012.
- GROUNDWATER STORAGE GAIN OCCURS WHEN AQUIFER INFLOWS EXCEED AQUIFER OUTFLOWS.
 - MAXIMUM GROUNDWATER STORAGE GAIN OF 753,798 AC-FT IN 2009.
- **THE DISTRICT FARMERS CAN ONLY CONTROL WELL PUMPING OF ALL THE INFLOW AND OUTFLOW COMPONENTS.**
- GROUNDWATER STORAGE LOSS FOR THE DISTRICT (1960 TO 2021) WAS 371,711 AC-FT.
- GROUNDWATER STORAGE LOSS FOR THE DISTRICT (2002 TO 2021) WAS 367,439 AC-FT.

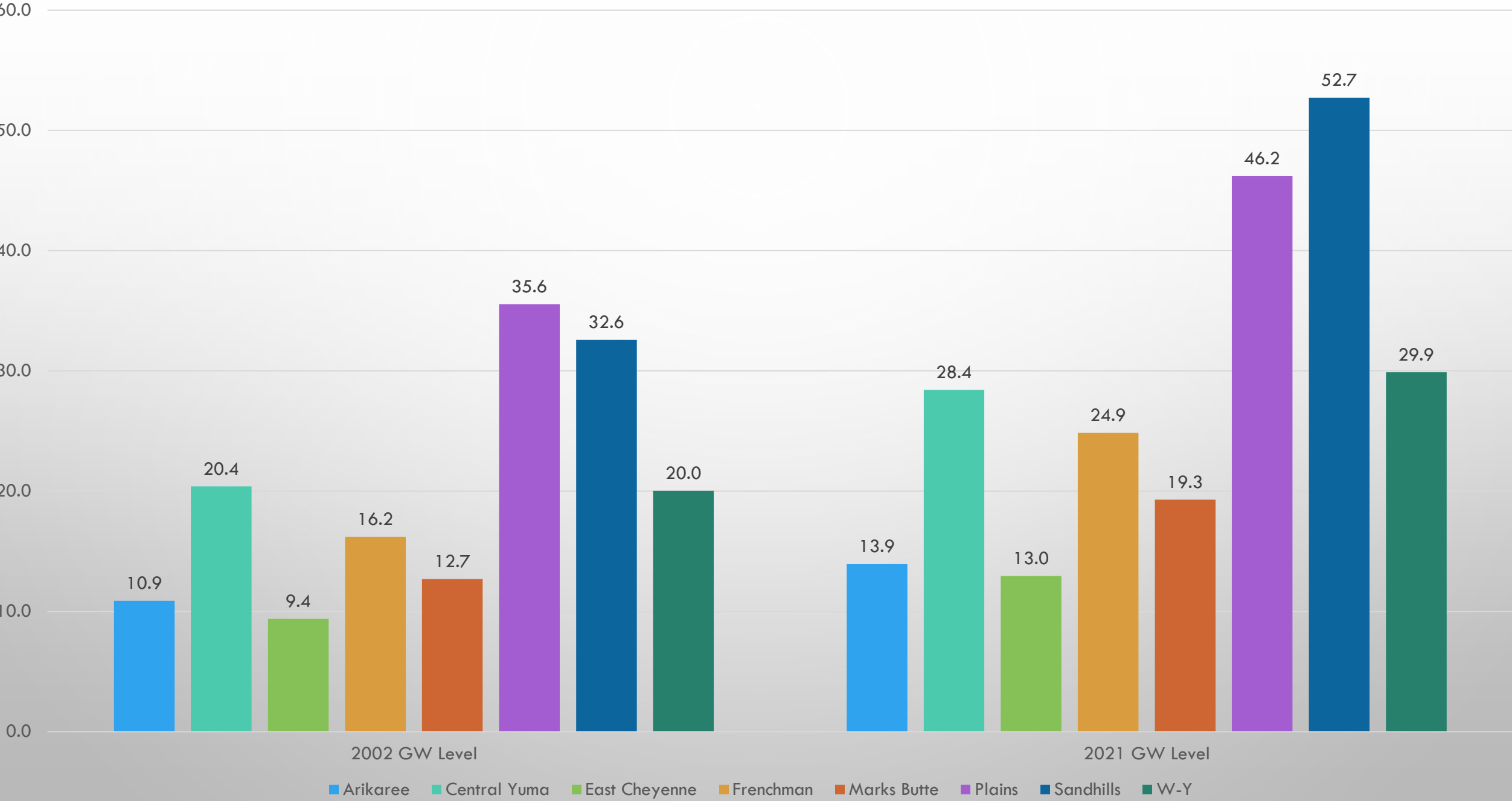
Average Ground Water Storage Loss by GWMDs (ac-ft)



GROUNDWATER LEVEL CHANGES FROM 1960

- CHANGES TO GROUNDWATER LEVELS IS THE RESULT OF CHANGES TO GROUNDWATER STORAGE.
- A GROUNDWATER STORAGE LOSS RESULTS IN A DROP IN THE GROUNDWATER LEVELS.
- A GROUNDWATER STORAGE GAIN RESULTS IN A RISE IN THE GROUNDWATER LEVELS.
- FORMULA USED TO CALCULATE A GROUNDWATER LEVEL CHANGE:
 - $(\text{CHANGE IN STORAGE} \times \text{AREA} \times \text{SPECIFIC YIELD} \times -1) + \text{PREVIOUS YEARS GROUNDWATER LEVEL}$.
- THE AVERAGE GROUNDWATER LEVEL CHANGE FOR THE DISTRICT (1960 TO 2021) WAS 11.47 FEET.
- THE AVERAGE GROUNDWATER LEVEL CHANGE FOR THE DISTRICT (2002 TO 2021) WAS 20.24 FEET.
 - GROUNDWATER LEVEL CHANGE FROM 1960 IN THE WATER BALANCE ANALYSIS IN 2002 WAS 16.82 FEET.
 - GROUNDWATER LEVEL CHANGE FROM 1960 IN THE WATER BALANCE ANALYSIS IN 2021 WAS 23.38 FEET.
 - IN THOSE 20 YEARS THE GROUNDWATER LEVEL CHANGE HAS DROPPED AN ADDITIONAL 6.56 FEET.

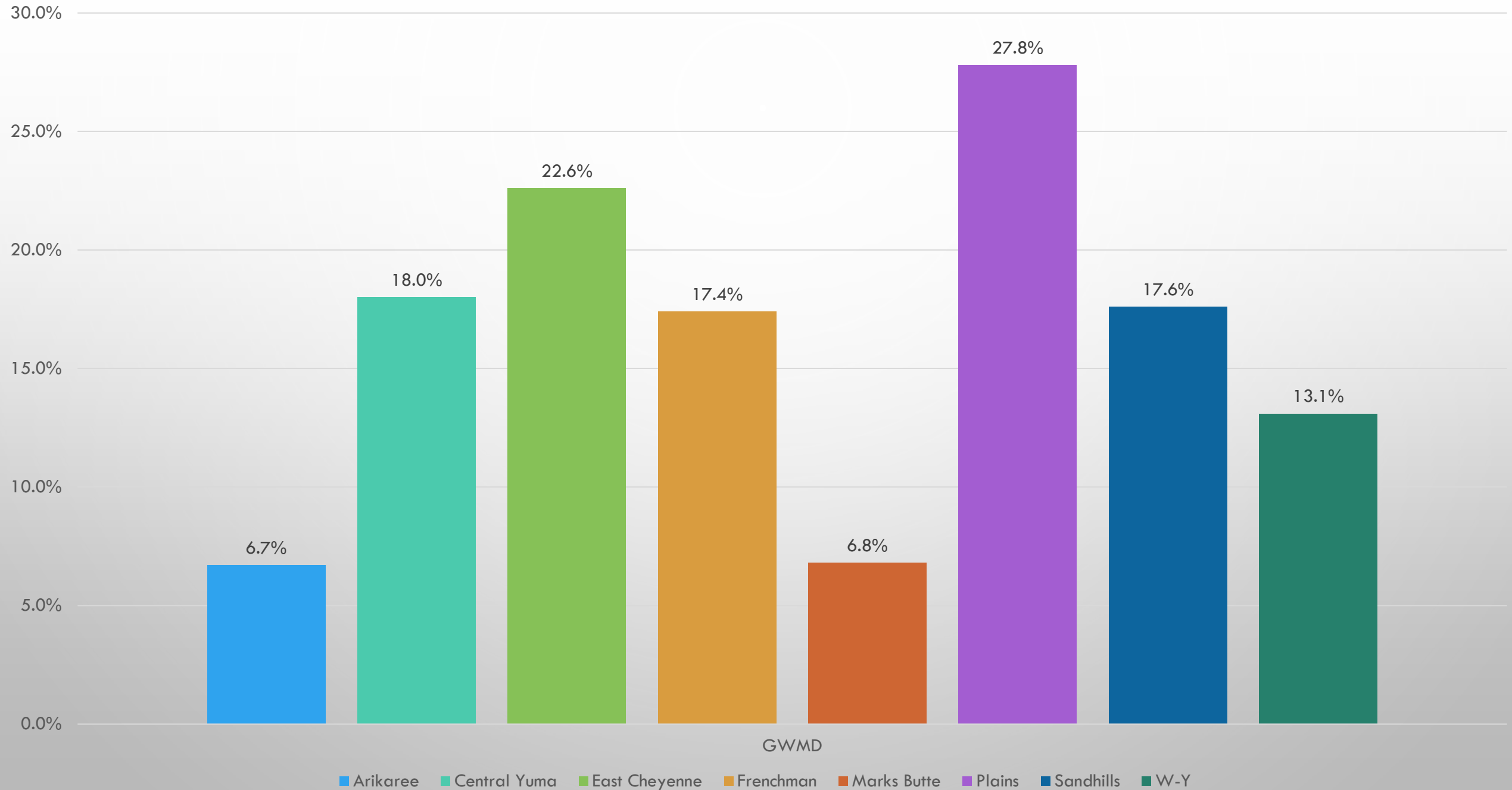
Change in Ground Water Levels from 1960 (ft)



ESTIMATED AQUIFER CAPACITY

- ESTIMATED AQUIFER CAPACITY IS BASED ON A CALCULATION USING ARCGIS SOFTWARE, THE PRE-DEVELOPMENT AQUIFER CAPACITY, AND THE 2017 VOLUME OF WATER WITHIN THE AQUIFER AS PROVIDED BY THE USGS GIS FILES.
 - THIS WAS CALCULATED AS $1 - (\text{ESTIMATED 2017 VOLUME} / \text{ESTIMATED PRE-DEVELOPMENT CAPACITY})$.
- WE CALCULATED THAT 14.5% OF THE PRE-DEVELOPMENT AQUIFER CAPACITY HAS BEEN CONSUMED AND IS NOT AVAILABLE FOR FURTHER PUMPING.
- THIS IS A VOID IN THE AQUIFER THAT CAN BE REFILLED SLOWLY WHEN AQUIFER INFLOWS EXCEED AQUIFER OUTFLOWS. HOWEVER, THE RECHARGE OF THE AQUIFER MAY TAKE THOUSANDS OF YEARS
- THERE IS OBVIOUS VARIATIONS IN LOCALIZED AQUIFER CAPACITY AND OUR ANALYSIS IS BASED ON THE ENTIRE DISTRICT OR GWMD.

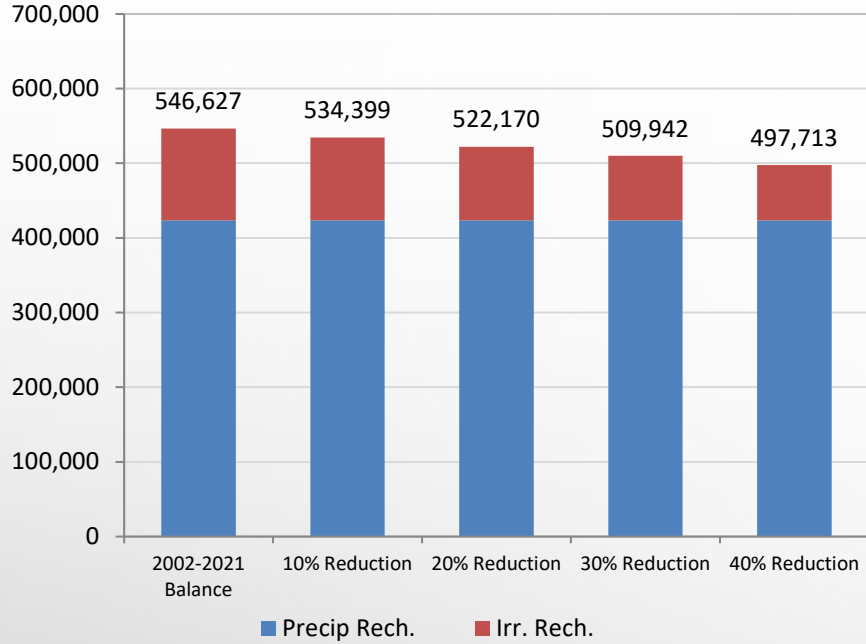
Estimated Aquifer Capacity Used by GWMDs (ac-ft)



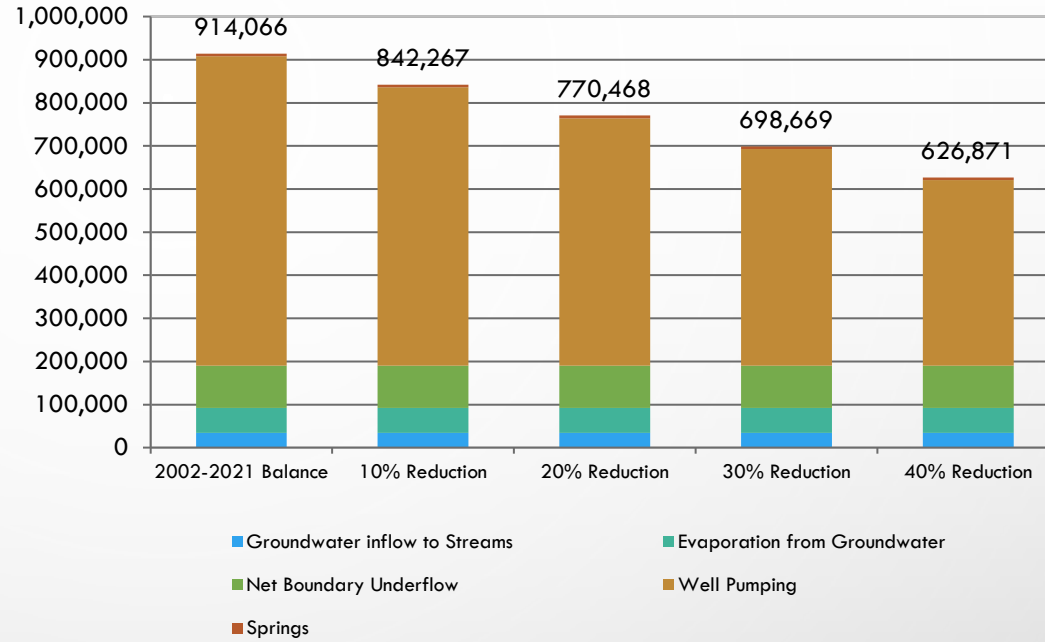
POTENTIAL IMPACTS OF CONSERVATION

- EVALUATED THE IMPACTS WITHIN THE GW MODEL OF A PUMPING REDUCTION OF 10%, 20%, 30% AND 40%.
- REDUCTION OF PUMPING RESULTS IN LESS AQUIFER INFLOWS AS IRRIGATION RECHARGE IS REDUCED.
- REDUCTION OF PUMPING RESULTS IN LESS AQUIFER OUTFLOWS AS PUMPING IS THE LARGEST COMPONENT OF AQUIFER OUTFLOWS.
- THIS RESULTS IN A DECREASE IN GROUND WATER STORAGE LOSS THUS EXTENDING THE LIFE OF THE AQUIFER.
- THE VARIOUS PUMPING REDUCTIONS WILL NOT STOP THE DROP IN GROUNDWATER LEVELS BUT WILL SLOW THE DECLINE OVER THE NEXT 60 YEARS.

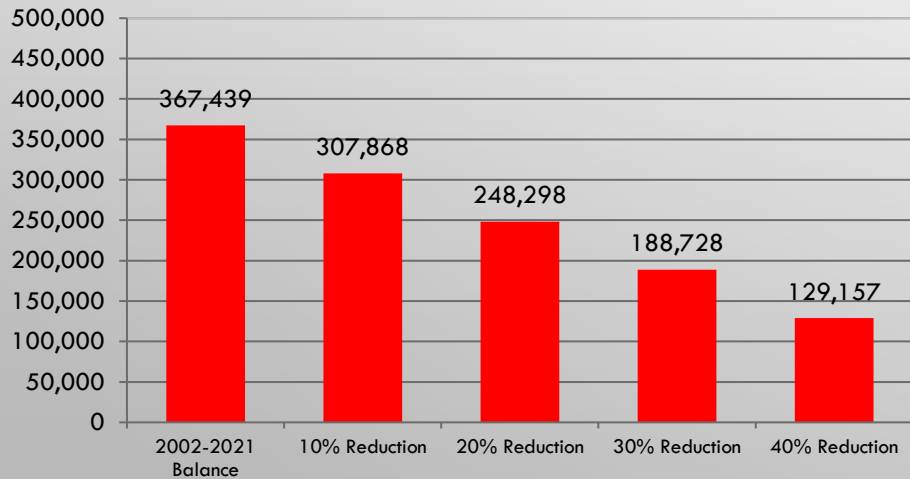
Aquifer Inflow



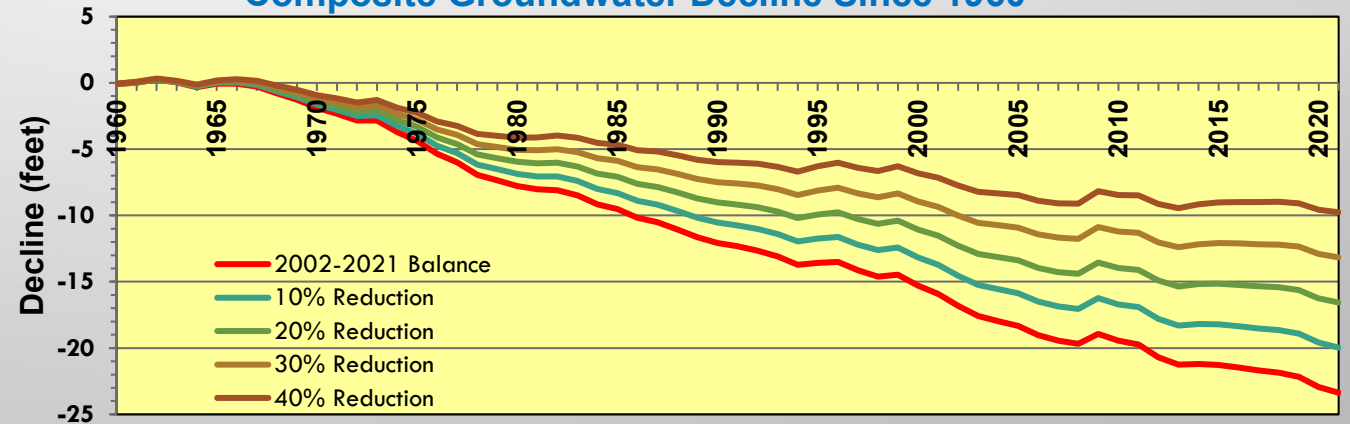
Aquifer Outflow



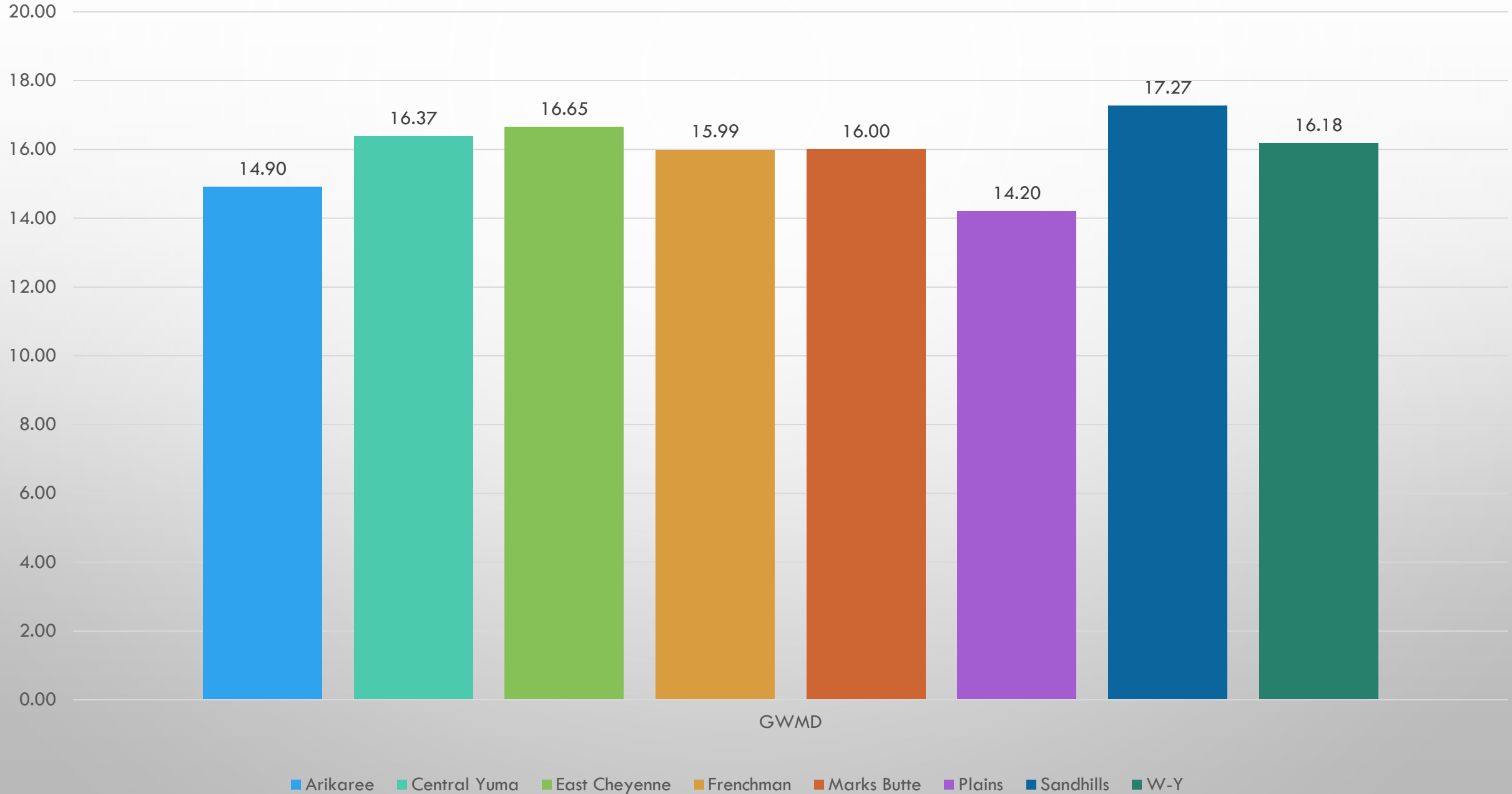
Ground Water Storage Loss



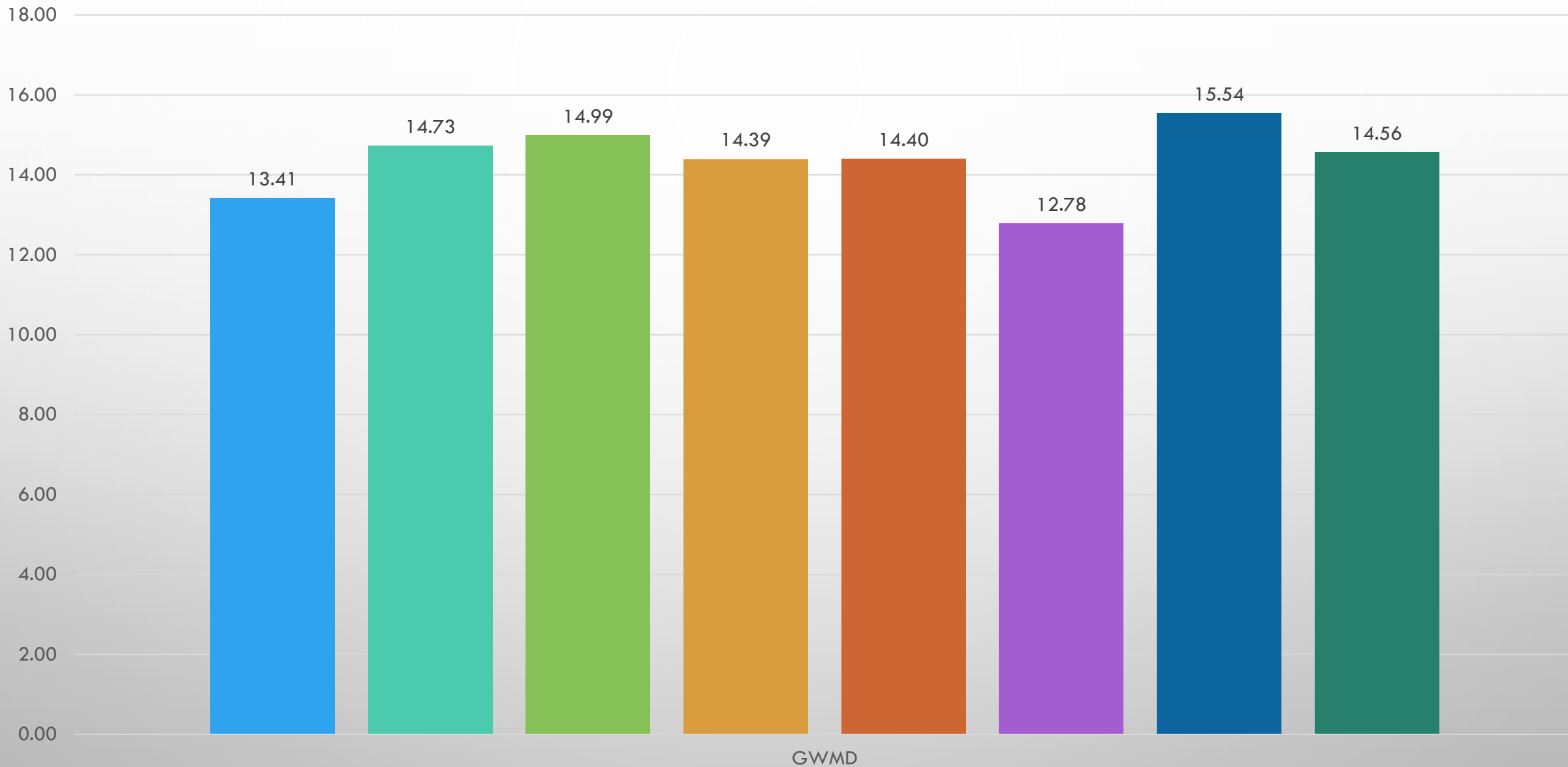
Composite Groundwater Decline Since 1960



Average 2004 to 2023 Pumping by GWMDs (Inches Applied per Acre)



Average 2002 to 2021 Pumping by GWMDs with 10% Conservation (Inches Applied per Acre)



■ Arikaree ■ Central Yuma ■ East Cheyenne ■ Frenchman ■ Marks Butte ■ Plains ■ Sandhills ■ W-Y

RRWCD ANNUAL PUMPING WITH CONSERVATION

- PERIOD 2004 TO 2023 (LAST 20 YEARS)
 - **AVERAGE PUMPING = 694,671 ACRE-FEET**
 - IRRIGATED = 531,959 ACRES
 - 15.67 INCHES PER ACRE OF APPLIED PUMPING
- 10% CONSERVATION OF PUMPING (REDUCING PUMPING BY 10%)
 - **AVERAGE PUMPING = 625,052 ACRE-FEET**
 - ASSUMES 14.10 INCHES APPLIED TO 531,959 ACRES
- 20% CONSERVATION OF PUMPING (REDUCING PUMPING BY 20%)
 - **AVERAGE PUMPING = 555,897 ACRE-FEET**
 - ASSUMES 12.54 INCHES APPLIED TO 531,959 ACRES

CONCLUSIONS

- HWE ANALYZED A 62-YEAR PERIOD FOR THE WATER BALANCE STUDIES.
- REDUCTION IN WELL PUMPING IS THE MAJOR COMPONENT TO AQUIFER OUTFLOWS THAT CAN BE MANAGED BY THE GWMDS AND LOCAL FARMERS.
- IF THERE WAS A REDUCTION OF 10% OF THE 2004 TO 2023 PUMPING FOR THE NEXT 62 YEARS, THIS WOULD BE SIGNIFICANTLY LESS WATER LEAVING THE AQUIFER.
- THERE WOULD STILL BE A DECLINE IN AQUIFER CAPACITY AND GROUNDWATER LEVELS WOULD STILL DROP; HOWEVER, THE RATE OF DECLINE WOULD BE LESS THAN AT CURRENT LEVELS.
- THE LARGER OF PUMPING REDUCTION THEN THE BIGGER THE IMPACT WOULD BE ON REDUCING GROUNDWATER STORAGE LOSSES AND DROPS IN GROUNDWATER LEVELS.
- THE CLOSER THE DISTRICT AND GWMDS CAN BRING DOWN THE AQUIFER OUTFLOWS TO THE AQUIFER INFLOWS SHOULD BE CONSIDERED.

QUESTIONS?

